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A CYCLOGRAM ANALYSIS OF THE BRATISLAVA ^{14}C TREE-RING RECORD DURING THE LAST CENTURY

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ABSTRACT. Radiocarbon variations in dated tree-ring samples represent an important tool for the study of the history of solar activity and sun-earth relationships. From this point of view, an investigation of the 11-year radiocarbon cycle is very important. Our cyclogram analysis of the $\Delta^{14}C$ record in tree-ring samples during the last century has confirmed previous results obtained by conventional harmonic analysis, eg, the average amplitude of 2‰, the phase shift of 3–5 yr for different 11-yr solar cycles, and the anticorrelation dependence of $\Delta^{14}C$ on Wolf sunspot numbers. The observed shorter periodicity (ca 9 yr for $\Delta^{14}C$ compared to 10.5 yr for sunspots), may be due to extra factors in sun-earth relationships.

INTRODUCTION

The analysis of $\Delta^{14}C$ variations in annually dated tree-ring samples represents an important tool for the study of the history of solar activity and sun-earth relationships (eg, Stuiver & Quay, 1980; Povinec, Burchuladze & Pagava, 1983). Particularly interesting is the study of the 11-yr $\Delta^{14}C$ periodicity in annually dated samples (Baxter & Farmer, 1973; Damon, Long & Wallick, 1973; Povinec, 1977; Burchuladze *et al,* 1980; Fan *et al,* 1983).

The 11-yr solar cycle is the most prominent cycle observed till now in solar activity. However, short-term ^{14}C variations are difficult to observe because of the complex mechanisms of ^{14}C production by cosmic rays, ^{14}C transport from the atmosphere to the ocean and biosphere and climatic and reservoir changes. Thus, variation in the ^{14}C production rate may not give a measurable change in atmospheric ^{14}C concentration.

Spectral, correlation and harmonic analyses of $\Delta^{14}C$ values obtained from annually dated tree-ring and wine samples confirmed the existence of the 11-yr ^{14}C variations at least for 4 solar cycles (1903–1944), with the average amplitude of 2‰ for tree-ring samples and 4‰ for wine samples (Povinec, Burchuladze & Pagava, 1983; Povinec, 1987).

In this paper, we discuss results obtained by application of the cyclogram method introduced by Attolini, Cecchini and Galli (1983) on the Bratislava tree-ring ^{14}C series (Povinec, 1977) for the last century.

METHOD

The cyclogram method, different from conventional power-spectrum analysis with harmonic components integrated over time, enables us to follow the amplitude and phase variation with time for any component of given periodicity, τ. The existence of a suspected periodicity, τ, can be con-

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tinuously tested along the time series by moving a window of length, $T \geq \tau$. When the periodicity is present, the cyclogram will tend toward a level for the existence of non-random oscillations. When no periodicities are present, the cyclogram moves in a random walk. The search for characteristic periodicities was carried out by constructing cyclograms for a certain number of temporal intervals, τ.

$\Delta^{14}C$ series used in the analysis were obtained from tree rings of a lime tree *(Tilia cordata)* that grew in a non-industrialized area (48° 51′ N, 21° 10′ E), as described by Povinec (1977). The accuracy of a single measurement is equal to 3‰.

RESULTS AND DISCUSSION

Figure 1 shows input $\Delta^{14}C$ values in tree rings from 1901–1950, together with a data series after correction for the Suess effect. The sunspot record is also shown.

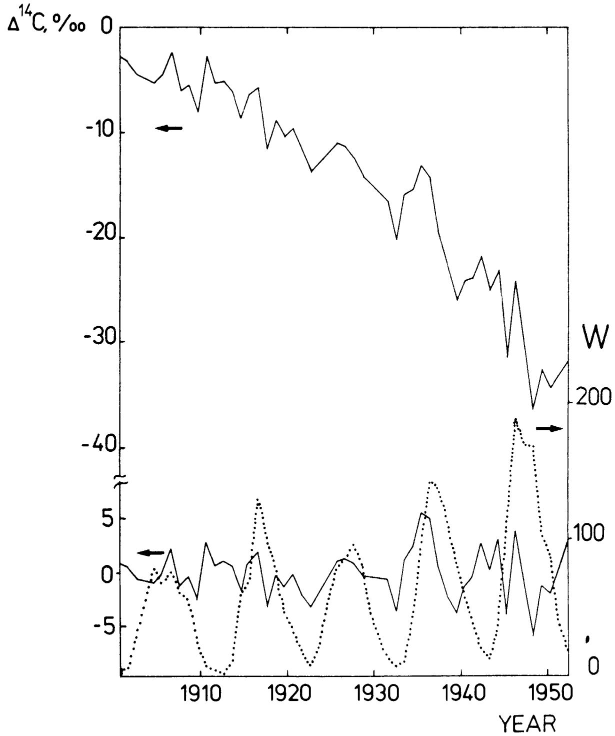

Fig 1. $\Delta^{14}C$ record in tree-ring samples for the last century (upper curve); after corrections for the Suess effect (lower curve); sunspot record is shown for comparison (dotted curve)

Figure 2 shows calculated power spectra of $\Delta^{14}C$ and sunspot series. There are peculiar periodicities as indicated by the peak appearing in the spectra. The sunspot record shows a dominant peak at 10.5 yr. In the power spectrum of the $\Delta^{14}C$ series, we can identify essentially 3 important frequency bands, 1 around the main peak at 8.8 yr that might be associated

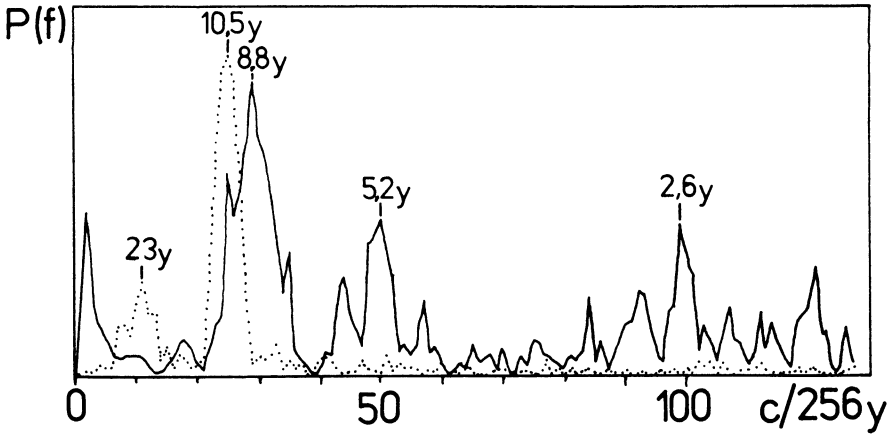

Fig 2. Power spectra from the $\Delta^{14}C$ record (solid line) and sunspot record (dotted line). In order to avoid side lobes due to the length of the record, the spectra have been obtained by computing the amplitude of the sine wave best fitted to the data reduced to the first interval.

with the peak of 10.5 yr of the sunspot series, and 2 more bands, ca 5.2 and 2.6 yr, that might be considered the 1st and 3rd harmonic of 10.5 yr. The 3 bands can be considered as pertaining to the solar signal in $\Delta^{14}C$. The discrepancy between 8.8 and 10.5 yr might be caused by a variable production rate at the minimum or decreasing phase of each sunspot cycle, or by some geophysical effect. In any case, if we consider the noise level, the frequency discrepancy might also be explained by the superposition of a noise peak with a smaller 10.5-yr peak.

The data reduction to the first interval of T=8.8 yr gives the mean wave of Figure 3A with a significance level of 6σ with respect to a random Gaussian sequence of data. The same reduction for $\Delta^{14}C$ and the time interval T=10.5 yr gives a significance level of 3σ (Fig 3B). For comparison, the same reduction for the sunspot series and T = 10.5 yr gives a significance level of 350σ (Fig 3C). Spectral analysis of peaks in the power spectrum can be used to find interesting frequency bands. However, any information concerning stability of the phase and constancy of the amplitude of a wave is lost. Part of this information can be recovered by the cyclogram analysis.

The phase and amplitude cyclograms calculated for a window, T=12 yr and for different values, τ=9 – τ=11.5 yr, are shown in Figure 4. The most stretched cyclograms are for the period, 10.5 yr for sunspot, and 9 yr for $\Delta^{14}C$, respectively.

To observe the phase correlation between sunspot and ^{14}C series, we have plotted the Fourier components of sunspot series multiplied by the complex conjugate of the corresponding term of $\Delta^{14}C$, and set to 1 the amplitude of each complex vector. If there is a correlation between the two series, the geometric sum of the vectors will tend to a straight line oriented according to the phase shift of the corresponding variations. We call this a cross-cyclogram. We have, thus, pin-pointed the periodicities for T=τ=5 – T=τ=14 yr. Figure 5 shows that the cross-cyclograms are most stretched

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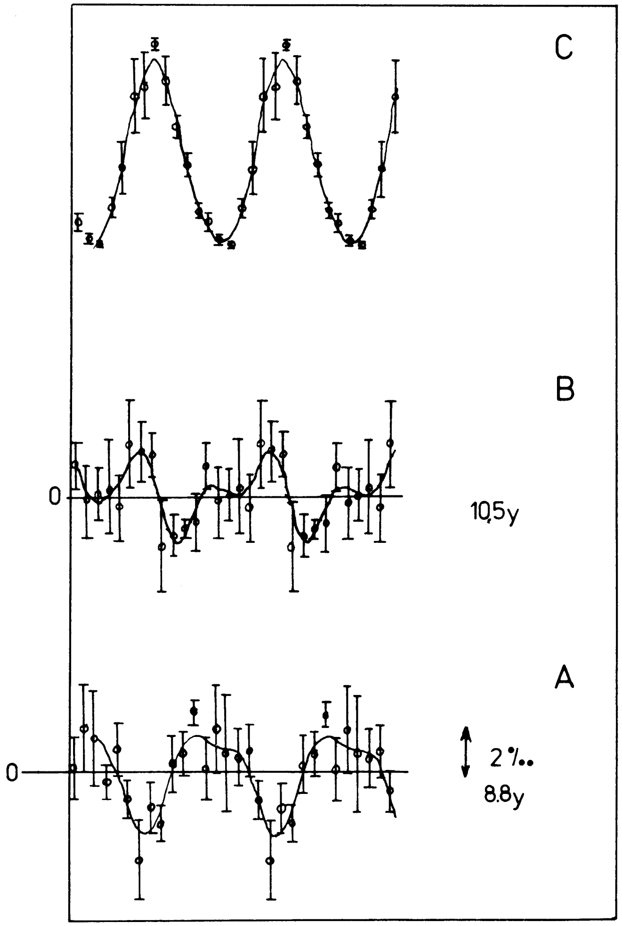

Fig 3. Input data reduction to the first interval: A. $\Delta^{14}C$ with 8.8-yr interval; B. $\Delta^{14}C$ with 10.5-yr interval; C. sunspots with 10.5-yr interval

and smooth in the band, 9–11 yr, indicating a prevailing correlation ^{14}C solar activity in the same frequency band. The most stretched and continuous cross-cyclogram is obtained for $T=\tau=10.5$ yr.

The variable phase shift of ca 3 yr may indicate a variable time-dependence of ^{14}C concentration, the maximum variation of which would correspond sometimes to the minimum of a solar activity cycle and sometimes to the final decreasing phase of each sunspot cycle.

The main results may be summarized as follows:

1) the sunspot phase and amplitude cyclograms are the most stretched for the period, 10.5 yr;

2) $\Delta^{14}C$ phase and amplitude cyclograms show a turning point at ca 1912 and are the most stretched for the period, ca 9 yr;

3) the cross-cyclogram vectors show the most regular behavior for the

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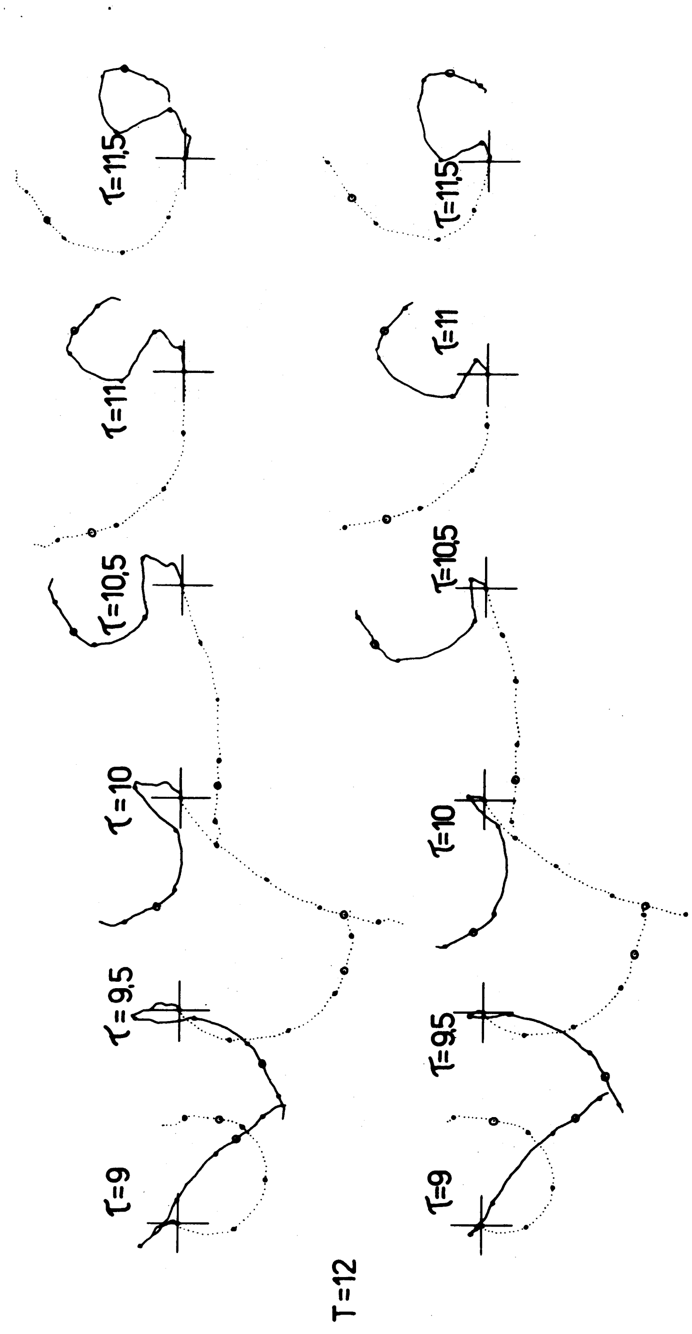

Fig 4. The phase (upper curves) and amplitude (lower curves) cyclograms calculated for a window, T=12 yr, and for different values of τ from 9–11.5 yr for the $\Delta^{14}C$ (solid line) and sunspot records (dotted line)

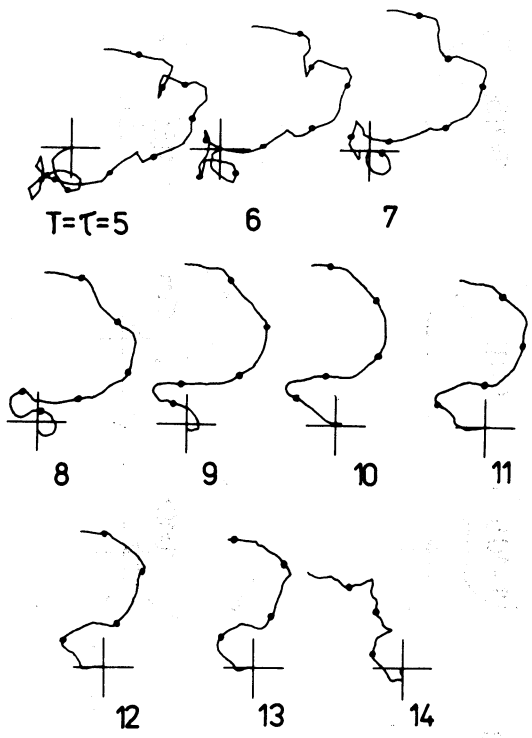

Fig 5. The cross-cyclogram analysis for T=τ=5 – T=τ=14 yr

period, 10.5 yr, with 5-yr phase shifts from 1901-1912, 2 yr from 1912-1925, 3 yr from 1925-1945 and 5 yr from 1945-1953. The mean phase shift is ca 3 yr;

4) the rms amplitude computed through the cyclogram is 2‰.

Similar results (except the larger amplitude by a factor of 2) were obtained by Galli *et al* (1987).

CONCLUSIONS

Our cyclogram analysis of the $\Delta^{14}C$ record in tree-ring samples during the last century has confirmed previous results obtained by conventional harmonic analysis, for example, average amplitude of 2‰, 3–5–yr phase shift for different solar cycles and anticorrelation dependence of $\Delta^{14}C$ on Wolf sunspot numbers. The shorter periodicity (ca 9 yr for $\Delta^{14}C$, compared to 10.5 yr for sunspots) may be due to extra factors in the sun-earth relationship.

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