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## NOTES, COMMENTS, AND REMARKS

# AMPLITUDE OF SUNSPOT-DEPENDENT RADIOCARBON VARIATIONS: DATA FROM CORALS AND WINE

MORDECKAI MAGARITZ, ISRAEL CARMI, and ZIV SIRKES

Department of Isotope Research
The Weizmann Institute of Science, 76100 Rehovot, Israel

It has been suggested that the sunspot cycle modulates the production rate of radionuclides in the atmosphere and that these modulations can be traced in various parts of the earth surface system. On the basis of a theoretical analysis, Damon, Sternberg, and Radnell (1983) have concluded that the effects of the 11-yr cycle of sunspots should be observable in $^{14}C$ data provided the measurements are done at a 2 permil (sd) level. This conclusion is based on calculations using models discussed by Lingenfelter and Ramaty (1970) and by O'Brien (1979) and on the $^{14}C$ inventory modified from Damon, Lerman, and Long (1978). In this note we compare the amplitude estimate of Damon, Sternberg, and Radnell (1983), who calculated a representative peak-to-peak variation of 1.7‰ in $^{14}C$ for the sunspot cycle between 1848 and 1856, with experimental values derived from recently published data. We find the experimental value to be larger by a significant factor from the theoretical calculation.

One set of data is $^{14}C$ measurements of samples of wine grown in Tbilisi between 1909 to 1952. Burchuladze *et al* (1980) and Povinec, Burchuladze, and Pagava (1983) have found in this set of data an 11-yr cycle indirectly, by correlation with the data of sunspot numbers. The average peak-to-peak variation of $\Delta^{14}C$ in the wine samples was 8.6‰. Another set of data is the $^{14}C$ activity in growth bands of a single coral given by Druffel (1982). Figure 1 shows the data of core TRII between 1712 and 1781. Within the existing time resolution, there is an interval of 9 to 15 yr between consecutive maxima or minima in the time series, the most common value being 12 yr; the peak-to-peak variation is at least 6‰.

We applied an objective method of time series analysis to the two series of data to uncover their periodicities. Our method is objective because it does not require any *a priori* assumptions on the relationship between $^{14}C$ data and sunspot cycles. Time-series analyses of increasing sophistication have been applied to $^{14}C$ data sets to discover their characteristics. Lately, the method of Maximum Entropy Spectral Analysis (MESA) (Ulrych & Bishop, 1975) has been used to advantage in the analysis of such data. MESA has many useful characteristics, among which is the ability to identify long periods in relatively short time series. Using the data set of Suess (1978), we calculated the period of the grand trend with MESA (Carmi, Sirkes, & Magaritz, 1984) to be 13,200 yr. The same data set was used to show a correlation between the spectra of $^{14}C$ activity and the width of tree rings for periods between 100 and 2000 yr (Sonnet & Suess, 1984).

Our MESA program is based on Barrodale and Erickson (1980a, b). In

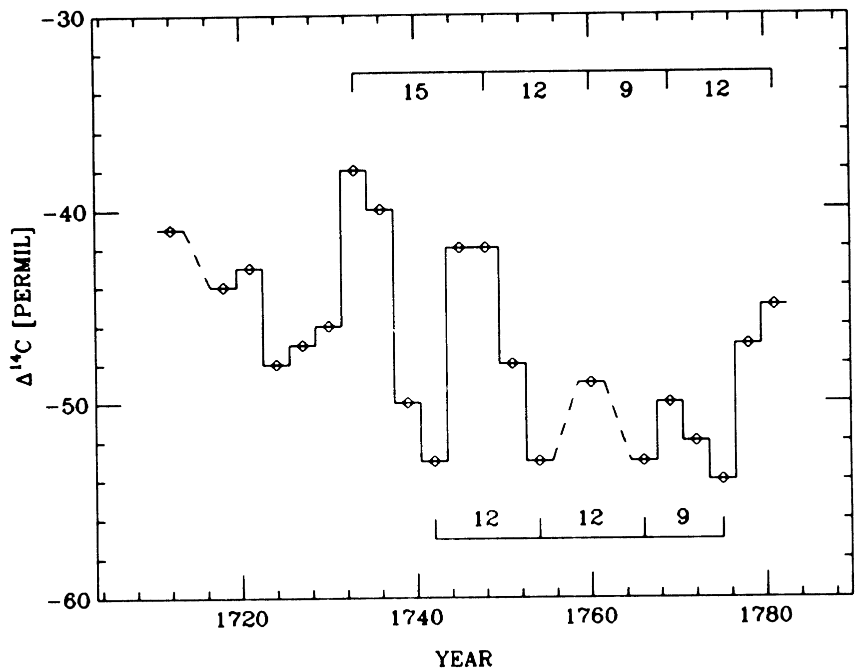


Fig 1. $^{14}$C activity in core TRII of a banded coral (Druffel, 1982)

our procedure the length of the filter (order of autoregression) was determined by Akaike's Final Prediction Error (FPE) criterion (Ulrych & Bishop, 1975) and this, in turn, determined the maximal number of peaks in the spectrum (Jensen & Ulrych, 1973). The order of the autoregressive process for the data sets analyzed was half the number of the data points in the time series, *ie*, the maximal allowable value.

In the Tbilisi wine series, there are two duplicate values for which we used average values. We detrended the time series for the Suess effect and calculated its spectrum with MESA, using 44 data points and a filter length of 22. A period of 10.4 yr, which is quite close to that of the sunspot cycle, is very prominent in the spectrum of this time series (fig 2).

The coral core data from TRII between 1712 and 1781 are equally spaced (as is required by MESA) in 3-yr intervals, except that three data points are missing (fig 1). A data set with no gaps is required for the application of MESA, and we generated values for the missing data points by linear interpolation. Druffel (1982) interpreted the higher levels of $^{14}$C in the coral data between *ca* 1700 and 1730 as evidence for the Maunder minimum, and we detrended the data set linearly to account for this effect. Figure 3 shows the spectrum of this data set, obtained using MESA (24 data points, filter length of 12 and 7 maximum possible peaks). The peak at 11.7 yr is close to the period of the sunspot cycle, and we conclude that Druffel's (1982) data of $^{14}$C activity in banded corals contain direct evidence of the short-term cycle of sunspots.

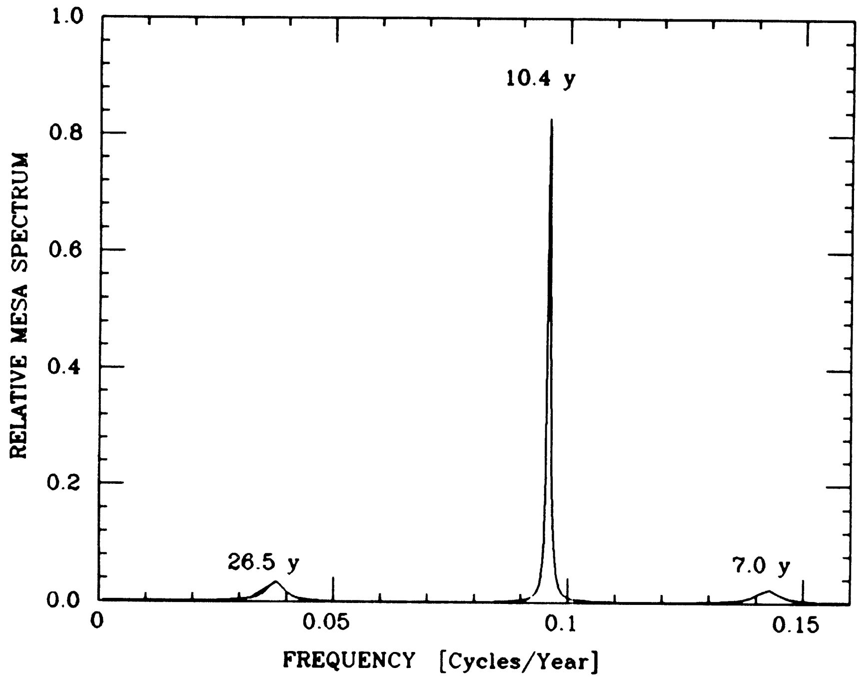


Fig 2. MESA Power Density Spectrum of $^{14}C$ activity in wines (Burchuladze *et al*, 1980)

We also attempted an analysis of a third data set (Lavrukhina & Alexeev, 1977) of $^{14}C$ activity in growth rings of a Sequoia from Crimea. The series is in half-year intervals between 1890 and 1915.5 with three data points missing. The authors claim to have found an 11-yr cycle in their series by correlation with the sunspot cycle. We applied MESA to the same series (after estimating the missing values), but were unable to identify any period remotely resembling the period of sunspots. The only explanation we can offer is that the resolution in the measurements is insufficient for MESA. This result stresses the necessity of applying objective methods of analysis on the time series.

In the wine and in the coral series we found periodicities very similar to those of the sunspots. The two series of data were collected from completely different locations under very different climatic regimes. The Tbilisi samples were exposed to the atmosphere and grew in a temperate region; the corals grew in the tropics and below the surface of the sea. On the face of it, the corals represent a marine environment where the variations in $^{14}C$ are expected to be damped, in contradiction to the magnitude of the peak-to peak-difference observed (fig 1). However, the habitat of the corals is in very shallow water (<10m) with very high wave energy and frequent breakers; for wavelengths of a few 10s m, the mixing reaches the bottom of the sea. The corals are, therefore, in equilibrium with the atmosphere and the $^{14}C$ variations in them are undamped.

Data on sunspot numbers is available only for the last 300 yr (Eddy,

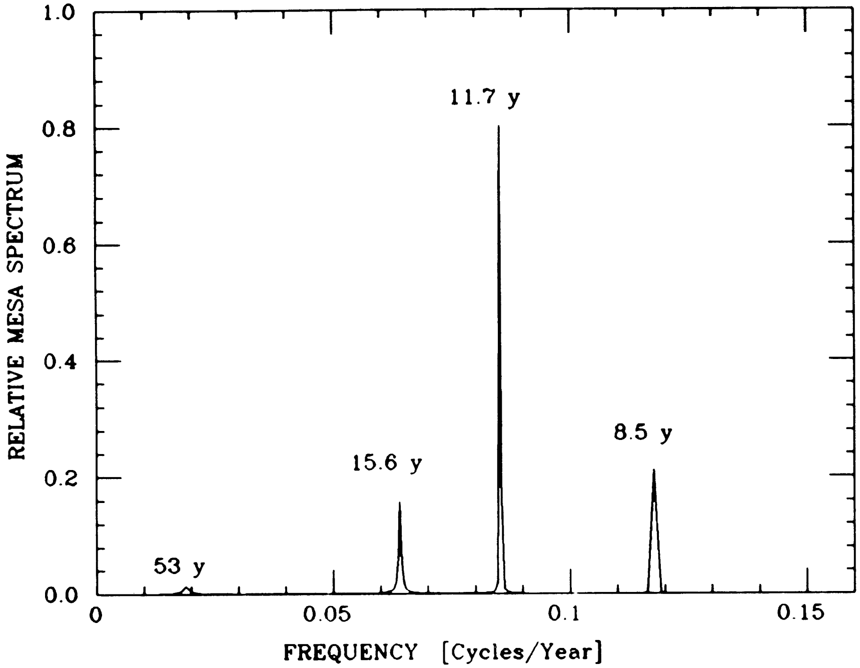


Fig 3. MESA Power Density Spectrum of the data set derived from core TRII (Druffel, 1982)

1977). The short-term 11-yr cycle of sunspot numbers is predominant in this data set and has been verified with MESA (Cohen & Lintz, 1974; Sonnet, 1982). This cycle modulates the production rate of $^{14}C$ in the stratosphere and subsequently in the atmosphere. The atmospheric modulation can be expected to be found in specimens of living organisms with well-defined annual growth phases, or in a consecutive set of discrete specimens of annual plants or organisms from the same locality. The $^{14}C$ signature implanted in such a specimen makes possible, in principle, determination of the sunspot cycle when reliable observations of sunspot numbers are not available (*ie*, before AD 1600).

In the two cases in which we have shown the 11-yr cycle to be present, the amplitude of the $^{14}C$ variation was > 4 times the value calculated theoretically by Damon, Sternberg, and Radnell (1983). The disparity should be investigated in two ways: one is by re-examining the model and the other is by the very accurate remeasuring of, eg, coral samples. The recent achievement of Suter *et al* (in press) in the very precise measurements of $^{14}C$ in large numbers of minute samples holds promise of a possible breakthrough in resolving the disparity between the theoretical calculation and the experimental data. It also opens the intriguing possibility of determining the period of sunspot cycles long before AD 1600.

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