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# Periodicities in the time-series of the annual mean temperatures of Central England

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सार — मध्य इंग्लैंड के 1659 से 1991 तक के माध्य वार्षिक तापमान क्रमों का अधिकतम एण्ट्रॉपी स्पेक्ट्रल विश्लेषण किया गया जिससे T=7.8, 11.1, 12.5, 15, 18, 23, 32, 37, 68, 81, 109 और 203 वर्षों की उल्लेखनीय आवर्तिताओं का पता चलता है। चीन में किए गए इसी तरह के विश्लेषण से T=22, 30, 80 और 200 वर्षों की आवर्तिताओं का पता चलता है जो इससे काफी मेल खाती हैं। कुछ आवर्तिताओं के सूर्य धब्बा संख्या क्रमों में भी अच्छे मेल का पता चला है।

**ABSTRACT.** Maximum Entropy Spectral Analysis (MESA) of the annual mean temperature series for Central England for 1659-1991 indicated significant periodicities at $T$ = 7.8, 11.1, 12.5, 15, 18, 23, 32, 37, 68, 81, 109 and 203 years. These compare well with $T$ = 22, 30, 80, 200 years obtained for China. Also, a good comparison is obtained with some periodicities in the sunspot number series.

*Key words* — Temperature series, Periodicities, Peaks, Amplitude, Moving averages.

## 1. Introduction

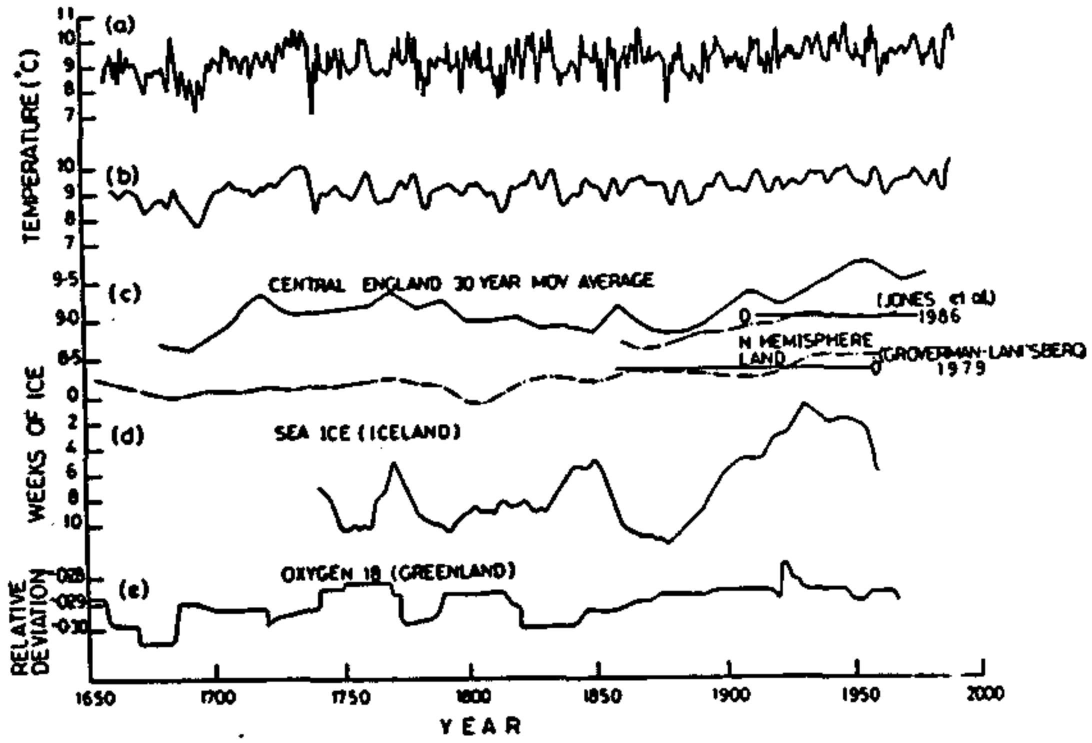
Temperature records are available at several locations all over the world for the last several decades. Scrutinizing the same in great detail, Jones *et al.* (1986 a&b) produced time-series of global and hemispheric annual mean temperatures for 1861 up-to-date. A power spectrum analysis of the same series indicated, apart from a long-term linear warming trend of 0.12 to 0.56°C/century, significant periodicities at $T$ = 5-6, 10-11, 15, 20, 28-32, and 55-80 years (Kane and Teixeira 1990). For the Mediterranean area, Metaxas *et al.* (1991) recently reported the results for the last 120 years and showed that the general pattern for this and several other areas was a sea surface temperature (SST) minimum near 1910, a double maximum in 1940 and 1965, a second minimum in 1975-80, and a rise thereafter to the present.

These series are fairly accurate and reliable from roughly 1850 onwards. However, data are available for earlier periods also. Using historical documents for China, Wang *et al.* (1991) constructed decade temperature series for the last 500 years and reported periodicities at $T$ = 200, 80, 30 and 22 years. For Central England, Manley (1974) made a very painstaking effort and produced a series from 1659 to 1973. Parker *et al.* (1992) updated the same. In this note, we report the results of a power spectrum analysis of the Central England series for 333 years (1659-1991).

## 2. Method of analysis

Maximum Entropy Spectral Analysis (MESA) (Ulrych and Bishop 1975) was used for detecting possible peaks. Since MESA does not give power estimates correctly (Kane 1977, Kane and Trivedi 1982), MESA was used only for locating the peaks $T_k$ ($k = 1$ to $n$) and then, these were used in the expression :

$$f(t) = A_0 + \sum_{k=1}^{n} \left[ a_k \sin 2\pi \frac{t}{T_k} + b_k \cos 2\pi \frac{t}{T_k} \right] + E$$




Figs. 1(a-e). (a) Central England temperature, annual values 1659-1991, (b) Moving averages over 2 and 3 values, (c) 30-year moving averages, 10 years apart. The dashed curves show northern hemisphere land mass temperatures (Jones *et al.*, 1986a&b; Groveman and Landsberg, 1979), (d) Sea ice (Iceland), weeks of ice (Friis-Christensen and Lassen, 1991) and (e) Relative deviation of Oxygen 18 to Oxygen 16 ratio from an ice core from Camp Century, Greenland (Johnsen *et al.*, 1970)

$$= A_0 + \sum_{k=1}^{n} r_k \sin\left[2\pi \frac{t}{T_k} + \phi_k\right] + E \qquad (1)$$

where $f(t)$ is the observed time series and $E$ is Error factor. The parameters $A_0$, $(a_k, b_k)$ and their standard errors were then estimated by a standard multiple regression analysis (Bevington 1969) which gives a linear least-square fit. From these, $(r_k, \phi_k)$ and their standard errors can be calculated. Amplitudes $r_k$ exceeding $3\sigma$ (thrice the standard error) would be significant at a 99% *a priori* confidence level.

### 3. Data and results

Fig. 1 (a) shows a plot of the yearly values of the Central England series. A striking feature is a near earth Biennial Oscillation. Power spectrum analysis did reveal a strong peak at $T$ = 2.1 years, but there were many other peaks nearby. Hence, we considered this as indicative of noise, requiring elimination. For this, moving averages were calculated over two successive yearly values and then, for the series so obtained, further moving averages were calculated for three successive values [moving averages over just 2 (or 3) values were not adequate as these still had some 3 (or 2) year wiggles]. Fig. 1 (b) shows a plot of these smoothed values. Fig. 1 (c) shows a plot of 30-year moving averages, ten years apart and indicates a clear rise in the last few decades, generally attributed to greenhouse effect due to increasing levels of carbon dioxide right from the time of intense industrialization (~ 1850 onwards). Incidentally, there was a temperature drop during 1940-60, which is obviously contrary to the expected greenhouse effect. Jones *et al.* (1986b) have noted this fact and suggest as an alternative explanation a change in the Northern Hemisphere ocean circulation, a possibility supported by the modelling work of Watts (1985). Similar mechanisms might have operated during the warming from 1680 to 1710 and the cooling from 1860 to 1880. This is purely speculative. The dashed curves show Northern Hemisphere land mass temperature values (30-year moving averages) as reported by Jones *et al.* (1986a&b)

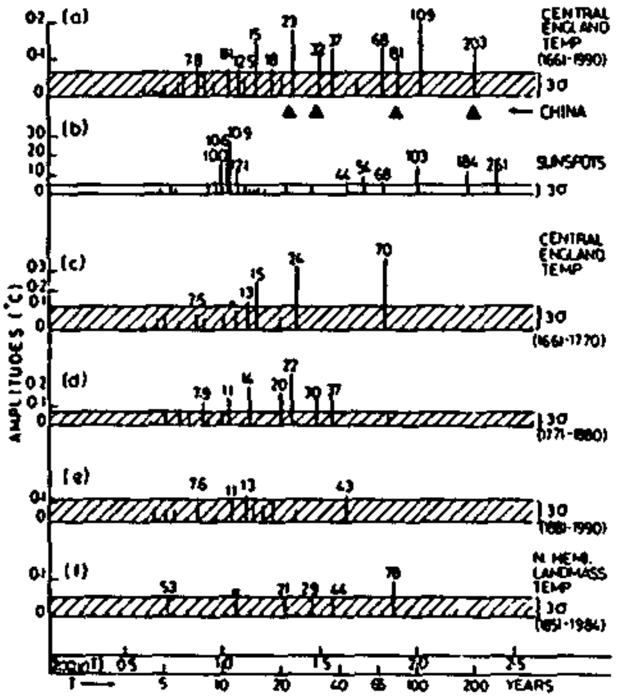
and Groveman and Landsberg (1979). The match with Central England temperature is good.

The amount of sea ice around Iceland is expected to be larger (smaller) when temperatures in that region are lower (higher). Fig. 1 (d) shows a plot of the amount of ice (reversed scale) as presented by Friis-Christensen and Lassen (1991). Similarly, Fig. 1(e) shows the Oxygen 18 measurements (Johnsen *et al.* 1970) from an ice core from Camp Century, Greenland, expected to reflect temperature variations, for which periodicities of 78 and 181 years were reported. There is a general, rough agreement between Figs. 1 (c&d) but not with (e).

Fig. 2 (a) shows the amplitudes of the 24 periodicities selected for a multiple regression analysis of the Central England temperature smoothed data (330 data points). As expected, the smoothing has removed periodicities below $T = 4$ years. Some periodicities are very prominent, notably $T = 203$, 109, 81, 68, 37, 32, 23, 18, 15, 12.5, 11.1 and 7.8 years. It is gratifying to note that $T = 200$, 80, 30 and 22 years (marked as full triangles) reported for temperature in China by Wang *et al.* (1991) are seen in the Central England series also. Also, the peaks at $T = 78$ and 181 years of Johnsen *et al.* (1970) are observed. It could be argued that some peaks may match by sheer chance. However, the matching peaks are significant at a 3 σ a priori level and hence coincidence probability by chance is very small, less than one peak.

The Central England series has a long-term linear trend. In Kane and Trivedi (1986), we had estimated the effects of linear trends on MESA and shown that large trends affected larger periodicities. In the present case, the spectral analysis was done on the original series, as also after correcting for a linear trend. It was noticed that all periodicities remained intact, except $T = 200$ years which changed to 199 years, indicating that distortions due to trends were negligible.

For the annual sunspot number series for 1700-1987, Kane and Trivedi (1991) presented an updated spectral analysis. Fig. 2 (b) shows the amplitudes. The triplet $T = 10.0$, 10.6 and 10.9 years forms a group of the most prominent periodicities for sunspots and these are present rather weakly (T = 11.1, 12.5 years) in the temperature series. However, some larger periodicities, *e.g.*, $T = 68$, 103, 184 years of the sunspot series match with those of the temperature series within 10%. Besides this sunspot association, no other explanation has yet been offered for the long-term temperature increases and decreases.




**Figs. 2 (a-f).** Amplitudes of the various periodicities T observed in the time-series of (a) Central England temperature 1661-1990 (330 years), (b) Sunspot number 1700-1987 (288 years), (c) Central England temperature 1661-1770 (110 years), (d) Central England temperature 1771-1880 (110 years), (e) Central England temperature 1881-1990 (110 years) and (f) Northern hemisphere landmass temperature 1851-1984 (134 years, Jones *et al.* 1986a&b). The abscissa scale is $\log_{10}$ T (years). Full triangles represent periodicities for China

The Central England temperature series does not seem to have similar characteristics all through. To check this aspect, each of the 330 point series was divided into three equal parts of 110 points and each part was subjected to MESA separately. Figs. 2 (c-e) show the amplitudes of about a dozen periodicities chosen in each part. Several periodicities are prominent in each part. The 109 year peak seen in the total series (Fig. 2a) is not seen in the three parts, mainly because the data length (110 years) is too small to detect 109 year peak. The peak at $T = 70$ years in Fig. 2(c) is also not very reliable and probably represents the linear rise during this short interval. Some of the peaks are common to all parts and hence appear in the total series also, notably $T \simeq 11$, 22 & $T = 14$. The last part refers to the recent period 1881-1990 and could be compared with the Northern Hemisphere landmass series 1851-1984 reported by Jones et. al. (1986a&b) and spectral analysed by Kane and Teixeira (1990) and shown in Fig. 2(f). The matching is not perfect, indicating that locations outside England may have slightly different characteristics.

For the Chinese series, Wang et al. (1991) reported that the periodicities 200 and 80 years contributed "most of the variance". However, when the series was recomposed using these two periodicities, the observed values in recent decades were significantly above the expected values, substantiating the idea of recent global warming. In case of Central England series, periodicities 50-205 years contributed ~ 24% variance, 20-50 years ~ 18% and 7-20 years ~ 17% (total ~ 60% variance) leaving ~ 40% as irregular, random component. Here again, observed temperatures in recent decades exceed the values expected from composed series.

## 4. Discussion

The Central England temperature series has many significant periodicities, four of which tally with the China temperature series, indicating a global characteristic. Some periodicities (though not the 11-year cycle) seem to tally with sunspot periodicities. Reid (1987, 1991) had also observed that the 11-year running means (thus, sunspot 11-year cycle eliminated) of sunspot number and the global average SST anomalies were well correlated and attempted to explain it by a variation in the sun's total irradiance (the solar "constant"). Friis-Christensen and Lassen (1991) suggested a direct influence of solar activity on global climate through the variation of the solar cycle length. Besides this possibility of relationship with sunspot numbers in the large periodicity region, no other explanation for the long-term decreases (e.g., 1710 to 1840) has yet been offered. In the present case, we have analysed the data from a very restricted portion of the globe and hence, some local effects cannot be ruled out. But the matching with China is satisfactory.

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