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THE COMBINED SOLAR AND TIDAL INFLUENCE IN CLIMATE

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ABSTRACT

To provide an early warning indication of the CO_2 warming signal, we are searching for periodic or projectable trends in climate. The strong 20.5 year oscillation in Eastern North American January temperature found by Mock and Hibler shows evidence of a beat between waves with periods of 22.36 (22.21 to 22.55) years and 18.64 (18.45 to 18.79) years with an opposition at about 1880. These are interpreted to be the 22.279 year solar Hale magnetic cycle and the 18.61 year lunar nodal tidal cycle. The lunar nodal cycle is known to produce changes in the sea surface temperature through increased mixing of the mixed layer of the ocean. This beat note is shown to be evident in the Western High Plains drought record of Mitchell, Stockton and Meko and to provide a better fit to the drought series, especially at the beat oppositions in 1880 and 1770.

INTRODUCTION

An important part of the research into the effects of increasing CO_2 in the atmosphere is the early detection of the effect of CO_2 upon climate. Detection is important because any change in man's production of CO_2 will be slow to implement and because the response to change has a delay of perhaps a decade before it can become effective. This is a difficult problem because of the considerable natural variation of the climate with time scales of a decade or more.

It is clear that if the rhythmic and long-term trends in atmospheric temperature are ignored, the influence of CO_2 will go undetected until the year 1990 or 2000. See for example Madden and Ramanathan (1), who made such a study ignoring any trends in temperature.

Several authors have chosen a more fruitful course and have attempted to make predictions of current and future climate based upon the long temperature records with strong regular variations available from ice cores from the Greenland ice cap. See for example Dansgaard et. al. (2), Hibler and Langway (3), and Broecker (4).

Figure 1 is a reproduction from Broecker's paper and shows the temperature projection based on the Camp Century cycles. The climate projections of Dansgaard et al. and Hibler and Langway are similar. All of the projections based on ice core data illustrate the nature of the difficulty involved in detecting the CO_2 effect, as they all suggest that the temperature in the 1980s and 1990s should be low, rather like that of 1810-35 which was perhaps 0.5°C below the mean temperature of the last 200 years. The change is a result of natural processes. This unfortunate occurrence of an expected extended cool period just when the CO_2 effect should become apparent emphasizes the need to understand, if possible, any and all predictable regularities in the climate. Even if these components are not large enough to be dominant, they could reduce the range of uncertainty in the expected temperature projection and thus allow a more certain detection of the CO_2 effect.

THE BEAT EFFECT IN ATMOSPHERIC TEMPERATURE

It has long been known that at least Eastern U. S. winter temperatures showed a considerable regular variation (5). Recent analysis by Mock and Hibler (6) of January temperatures over eastern U. S. and Canada shows a strong regular oscillation in these temperatures with a mean period of 20.5 years. There is also remarkable coherence among the separate records from the 12 stations analyzed. Figure 2 is a reproduction of Figure 3a of their paper (7).

Mock and Hibler's plot has the classic form of a beat note between two regular oscillations of comparable frequencies. If we assume that a beat is involved, the two oscillations were clearly in maximum reinforcement in about 1935-40 and were in opposition in about 1880. The oscillations are approaching another opposition in the immediate future. About three peaks fall between the maximum coherence (and amplitude) and the opposition giving about 6 waves to the full beat. The actual number need not be an integer, but is obviously in the range 6 ± .5. From the characteristic shape of the opposition interval around 1880 it is clear that the shorter period (higher frequency) wave is somewhat stronger than the longer period wave and the longer period wave must have exactly one fewer cycles between oppositions. The long period wave thus completes 5 ± .5 oscillations while the short period wave completes 6 ± .5. Given the mean period of 20.5 years from Mock and Hibler's analysis, it can be shown algebraically that the two oscillations involved have periods of 22.36 (22.21 to 22.55) and 18.64 (18.45 to 18.79) years (8).

These periods are remarkably close to the solar magnetic oscillation cycle of 22.279 ± .027 years established by Dicke (9) and the lunar nodal cycle of 18.61 years (established astronomically with negligible error). Both cycles are plausibly involved with observed climate, the phase corrected solar magnetic sunspot period via a solar luminosity change with a peak to peak amplitude of 0.3% or less, [Dicke (9)], and the lunar nodal cycle (the period of rotation of the plane of the moon's orbit) through the modulation of the twice daily ocean tidal currents as explained by Loder and Garrett (10). Marine effects of the 18.6 year period lunar phenomena have been reported by Hachey and McLellan (11) and Maximov and Smirnov (12) for sea surface temperatures and by Maximov and Sleptsov-Shevlevich (13) on arctic sea ice area. Indirect evidence of changes in the temperature of the sea with the 18.6 year period are shown by the shifts in the latitude of the southern limit of wintering of herring in the North Atlantic in phase with the lunar declination cycle from Kislyakov (14). The catch of striped bass off the U.S. east coast also shows opposite phase variations at northern and southern ports indicating migration of fish populations in phase with the lunar declination [Rust and Kirk (15)]. With such marked and ubiquitous effects in the marine environment, it would be surprising if the 18.6 year lunar cycle did not show up in atmospheric records as well.

THE BEAT EFFECT IN WESTERN HIGH PLAINS DROUGHT

The postulated interaction between solar magnetic and lunar nodal periods also allows a more satisfactory analysis of droughts on the U.S. Western High Plains. The careful work of Mitchell, Stockton, and Meko (16) demonstrates a strong and predictable cycle in such droughts. They show an interesting correlation between drought and solar magnetic cycles. In addition, they demonstrate a rather good correlation between the envelope of sunspot numbers (a general indicator of long term solar activity) and the intensity of drought as indicated by their Drought Area Index (DAI). Droughts are more severe when the solar activity is highest.

Figure 3, adapted from Mitchell, Stockton, and Meko's figure 2, displays drought indices derived from tree ring data for the High Plains area. I have added a set of regular time marks at the spacing of the solar magnetic cycle, 22.279 years. Note that the marks and peaks match rather well except for the time around 1860 where the waves shorten and allow the insertion of an extra wave. This, again, is the typical effect of a beat where the shorter period is more intense than the longer. Thus, the three droughts 1862, 1882 and 1900-01 do not correlate well with the solar cycle marks, the 1882 drought being well between two marks and also of smaller intensity. (The time around 1880, recall, is also the time when opposition of the solar and lunar waves is evident in Figure 2.) There are 12 full waves lying between the drought peak at 1711.4 and that at 1955.7 giving a mean drought period of 20.36 years (17). Inclusion of the latest drought at about 1976.5 changes this but little to 20.39 years (18).

An elementary algebraic analysis similar to that performed for the Eastern January air temperatures yields the periods of the two component waves. Again, there are six waves of the shorter period oscillation and five waves of the longer oscillation between the oppositions at about 1880 and 1770. Together with the gross period of 20.36 years from the figure of Mitchell, et al. (16), this yields 22.21 and 18.51 years for the two components of the drought cycles. This is in good agreement with the estimates from the January air temperatures, and the solar and lunar cycles.

The evidence reviewed here suggests the hypothesis that beat interactions between effects of the solar magnetic and lunar nodal cycles may account for a significant proportion of observed climatic variability on the decadal scale.

This hypothesis can be further explored through a simple model in which the lunar nodal cycle and the solar magnetic cycle are allowed to interact to create a single beat cycle. In the version described here, the amplitude of the lunar cycle is assumed to be constant, while the amplitude of the solar cycle is adjusted each year by the historically recorded sunspot number envelope (19), reflecting the findings of Mitchell, et al. (16). The model then has four remaining parameters: the period of each cycle, their relative amplitudes, and their relative phase. The period parameters are fixed by hard astrophysical data: the 18.61 year lunar tidal period and the 22.279 year solar magnetic period. The observed January temperature records cited earlier fix the phases in opposition at about 1880. The relative amplitude cannot be specified independently, because we have not suggested which causal interactions are involved in the postulated relationship. Instead, we adjust the amplitude of the lunar wave empirically with respect to the solar wave to provide an opposition effect similar in pattern to that shown in Figure 2 for January temperatures. This yields an amplitude for the solar wave about 2/3 that of the lunar wave at the 1880 opposition.

The beat wave resulting from this model is shown in Figure 4. The peak of each wave is marked by a vertical line. Just below these are plotted the times of maximum drought intensity from Mitchell, Stockton and Meko as shorter vertical lines. Note the rather good agreement with the peak times, including that for the extra wave that arises at the 1880 opposition. There is another opposition at about 1770 at which time the solar influence, adjusted to reflect sunspot records, was stronger than the lunar tidal curve and no extra peak was produced. In the nodal pattern, however, a wider peak spacing appears. This fits the wider spacing of the drought data maxima at 1757 and 1781.

A consequence of this beat scale is that the coming opposition that should fall near 1991 should in all probability be like that near 1770 (that is, without an extra drought inserted) since the general intensity of solar activity, as indicated in the sunspot envelope, is now much higher than it was in 1880. Thus the next High Plains drought is predicted to occur in about AD 2005, as shown in the figure. If any drought is noticeable in the interval it should be very weak and at about 1991. It must be recognized, however, that the increasing CO_2 heating may affect North American precipitation to such an extent that the High Plains droughts may no longer be recognizable among other more widespread drought conditions in these latitudes.

The beat wave of Figure 4 is rather different in shape from the filter output of Mitchell, Stockton and Meko seen in Figure 3. This is because the beat wave is entirely linear, being the sum of two sine waves, while the drought area index is highly non-linear, that is an area is either above or below the condition for drought state-1. When drought increases in an area, the count for the index may only increase if the drought area expands. This gives a considerable limitation to the amplitude range of the DAI.

Mitchell, Stockton and Meko also used a harmonic dial diagram to illustrate the phase correlation between the Hale magnetic sunspot cycle and the droughts. Figure 5(a) illustrates their figure. Here the time between one Hale sunspot minimum and the next (about 20-24 years) is spread uniformly around one turn of the dial and the droughts falling in this interval are plotted at an angle appropriate to their time of occurrence in this time interval. The distance from the center is proportional to the drought intensity insofar as it is indicated by the filtered Drought Area Index. The three droughts 1862, 1882, and 1900-01 can be seen to have large phase errors compared with the rest. A similar harmonic dial was prepared (Figure 5[b]) using the peak times of the beat wave (Figure 4) as the timing intervals for the dial's rotation. Here only the means of the drought peaks from the two separate filters of Mitchell, Stockton and Meko are plotted for simplicity. The plot now has no large phase errors. There is one and only one drought peak for each rotation of the dial. The purpose of this illustration is to display the improved phase distribution resulting from the beat wave timing.

These fairly strong indications of the involvement of the 18.61 year tidal modulation in the climate suggest the advisibility of looking carefully fo this period in the recently available Pacific sea surface temperature series and in any other available long time climate records. Several such records are suggested: 1) The D/H ratio of bound hydrogen in tree ring cellulose already known to show the 22 year solar cycle [Epstein and Yapp (20)]; 2) the shorter periods in the Greenland ice core records found by Hibler and Johnson (18) would benefit greatly from a filter analysis; 3) Atlantic sea surface temperature records (such as are available). The particular component of the lunar tides that is strong in the Atlantic is not the same as that of the Pacific (semi-diurnal for Atlantic and diurnal for the Pacific) [Loder and Garrett (10)]. In theory, these components should be modulated with opposite phases of the 18.61 year cycle; 4) European or North African winter temperature records, since these are affected mostly by Atlantic sea surface temperatures, whereas U.S. temperatures are affected more by Pacific surface temperatures; 5) Total U. S. water supply as reflected in mean stream flow which has recently been shown to be strongly periodic, [Langbein and Slack (21)]; and 6) A similar study of European or African total water supply.

TIDAL EFFECTS IN PRECIPITATION

If the above considerations suggest strongly that there is a tidal influence in climate, then it would be surprising if there were not an influence of the stronger 14 day cycle of the tides, even though it is briefer and has less time for its effects to accumulate. A search of the literature located a group of papers from 1962 to 1969 [Bradley, Woodbury and Brier (22); Adderly and Bowen (23); Brier and Simpson (24) and references therein] on tidal effects. These papers document a correlation of heavy precipitation with the lunar synodic (phase) month, the anomalistic (perigee) month and the tropical (declinational) month. These are supported by records from 1500 U.S. weather stations for 50 years and from 50 New Zealand stations for 24 years. These reports reinforce the conclusion that tidal currents affect sea surface temperature and hence precipitation. Brier and others have suggested that these effects may be due to the atmospheric tides. It seems more likely to me that the effects are due to the ocean tides as the oceans have much greater energy storage while the atmospheric tides are very small.

CONCLUSION

The interacting influence of a solar magnetic period of 22.3 years and a lunar tidal period of 18.6 years (as well as shorter periods) in climate is strongly suggested. These influences are best seen not as global effects but in large area winter temperatures and in droughts in large areas. From the nature of the increased tidal mixing effect on the ocean mixed layer, it would be expected that times of high tidal motion would produce colder summer sea surface temperatures, while periods of lower tidal motion would give warmer summer sea surface temperatures. The opposite phase of the effect in the Atlantic and Pacific should provide strong regional effects, but latitude zonal averaging should greatly obscure the overall effect in both temperature and precipitation. Zonal averaging will thus generally conceal these rather prominent effects. The beat between the lunar and solar influences will produce periodic oppositions at about 111 year intervals so that the oscillations will not be constant in amplitude. The effects of the opposite phase of the tidal modulation in Atlantic and Pacific should cause the oppositions to occur alternately in the climate in regions dominated by each ocean. Several sources of surface temperature and climatic records need to be examined further for evidence of the combined solar and tidal effects.

The 18.6 year, the 22.3 year and the Camp Century ice core periods were combined in appropriate proportions, producing a time series that does confirm the principal conclusions of the Broecker paper (Broecker, 1975 [4]), that the CO_2 warming effect is not yet seen because the other driving forces of the climate are producing a tendency to a cold interval at present. The intermediate and longer cycles in the climate need better confirmation, however, before a firm conclusion can be established.

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7. This figure deserves some comment. Filters can produce, on their own, some complex output shapes, but only when the filter output is very small compared with the input signal. This is not the case here. A single time series result is significant but here there are 12 separate time series from independent stations across eastern North America. All the separate outputs are essentially identical, an event hardly likely to occur by chance. The beat opposition seen in the figure occurs at the same time as that seen in the western U.S. drought series analyzed below. The probability of the coincidence is also low.

8. Define 'a' as the number of oscillations between oppositions in the short period wave. 'a-1' is then the number of oscillations between oppositions in the long period wave. '$\bar{p}$' is the mean period, 'p_1' the period of the long wave component, and 'p_2' the period of the short wave component. Then since $(a-1)*p_1 = a*p_2$ and $(p_1 + p_2)/2 = \bar{p}$, it follows that $p_1 = [a/(a-0.5)]*\bar{p}$ while $p_2 = [(a-1)/(a-0.5)]*\bar{p}$. The quoted periods and their asymmetrical "confidence limits" result from using values of a = 6 - .5, and 6+.5 in these equations.

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10. The effect of the twice monthly variation of the tides is prominent in producing changes in sea surface temperature in shallow waters, and in many estuaries the water column goes from strong stratification at the neap tide to essentially complete uniformity during the spring tides each month. The effect of the 14 day tide variation on coastal water temperature is quite strong. (R. H. Herlineaux, *Fish. Res. Bd. Can. Progr. Rept. Pac. Coast Sta.*, *108*, pp. 7-9 [1957].) The change in the moon's position over the nodal cycle (± 18° to ± 28° in the sky) has a modulation effect upon tidal currents

of 10 to 15% (J. W. Loder and C. Garrett, J.G.R., 83, No. C4, p. 1967 [1978] and G. Godin, The Analysis of Tides [University of Toronto Press, 1972]). As explained by Loder and Garrett, the tidal currents move massive quantities of coastal waters over irregular bottoms twice a day, producing variable eddy diffusion which modulates the degree of mixing of the ocean mixed layer and hence the sea surface temperature.

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14. A. G. Kislyakov, reported by Maximov and Smirnov, Ref. 11.

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16. J. Murray Mitchell, Jr., C. W. Stockton, and D. M. Meko, in Solar-Terrestrial Influences on Weather and Climate, B. M. McCormac and T. A. Seliga, Eds. (Reidel Pub. Co., Holland, 1979), pp. 125-143.

17. Despite a gross period of 20.36 years, Mitchell, et al.'s Fourier analysis of the DAI series gave a period of 22 years. The 22 year component over most of the time interval is stronger than the 18.6 year period and the amplitude limiting effect of the non-linearity of the DAI enhances the ability of the Fourier transform to ignore short interferences with a moderately regular series.

18. It is interesting to note that a predominant 20 year period was found in the oxygen isotope record for 3 Greenland ice cores over a 728 year period by W. D. Hibler, III, and S.J. Johnson (Nature, 280, 481-3 [1979]). The oxygen isotope variations are related to the atmospheric temperature at the time of snowfall.

19. Following Dicke (9) the sunspot number amplitudes were increased by a factor of 1.3 from the beginning of the record until 1816 after which it was decreased linearly to 1.0 at 1837. If this correction is omitted or made as large as 2.0 there is no significant change in the results. This correction allows for the undercount in early observations due to the use of small telescopes. See K. O. Kiepenheur, The Sun (Ed. G. R. Kuiper), University of Chicago Press, 1953.

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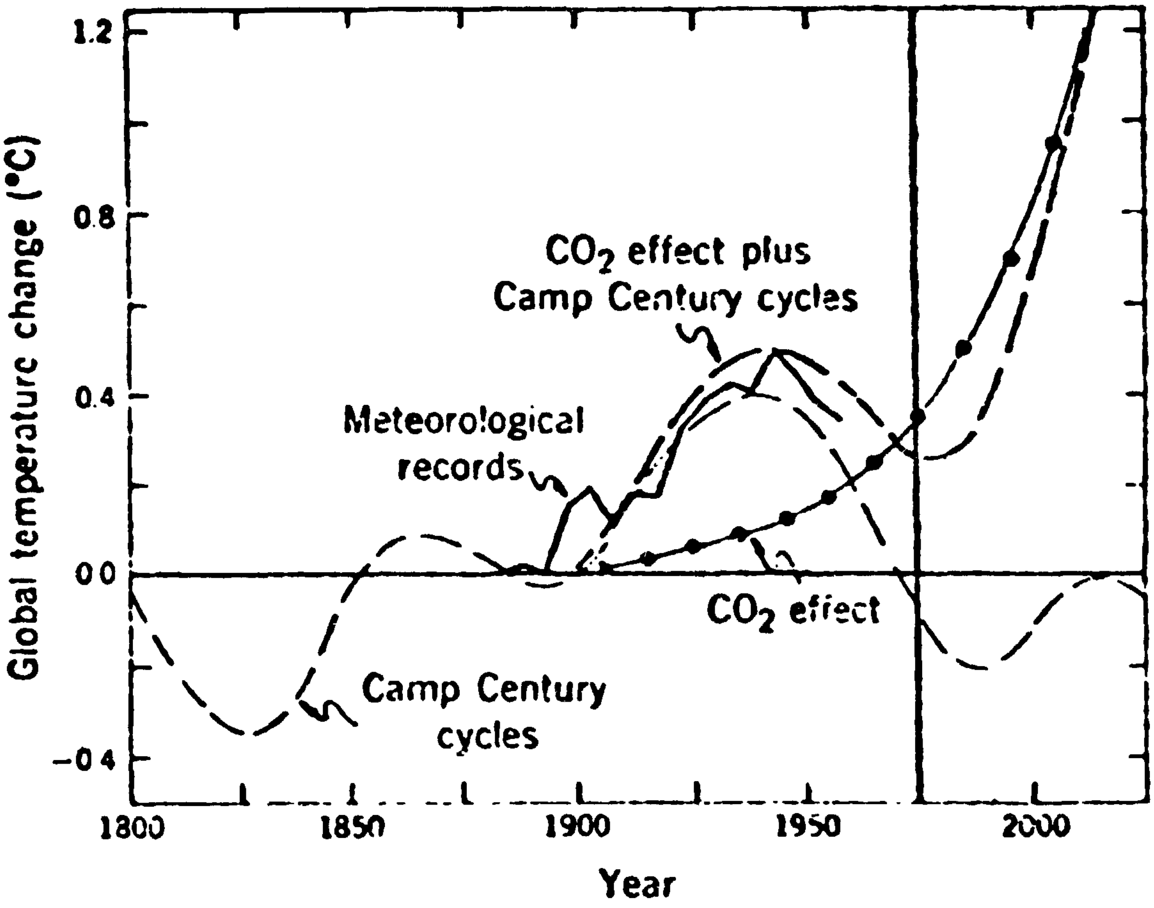

Figure 1. Broecker's temperature prediction based on the Camp Century ice core. The lower dashed curve is the ice core prediction alone. The upper dashed curve is the same prediction with the indicated CO_2 effect added.

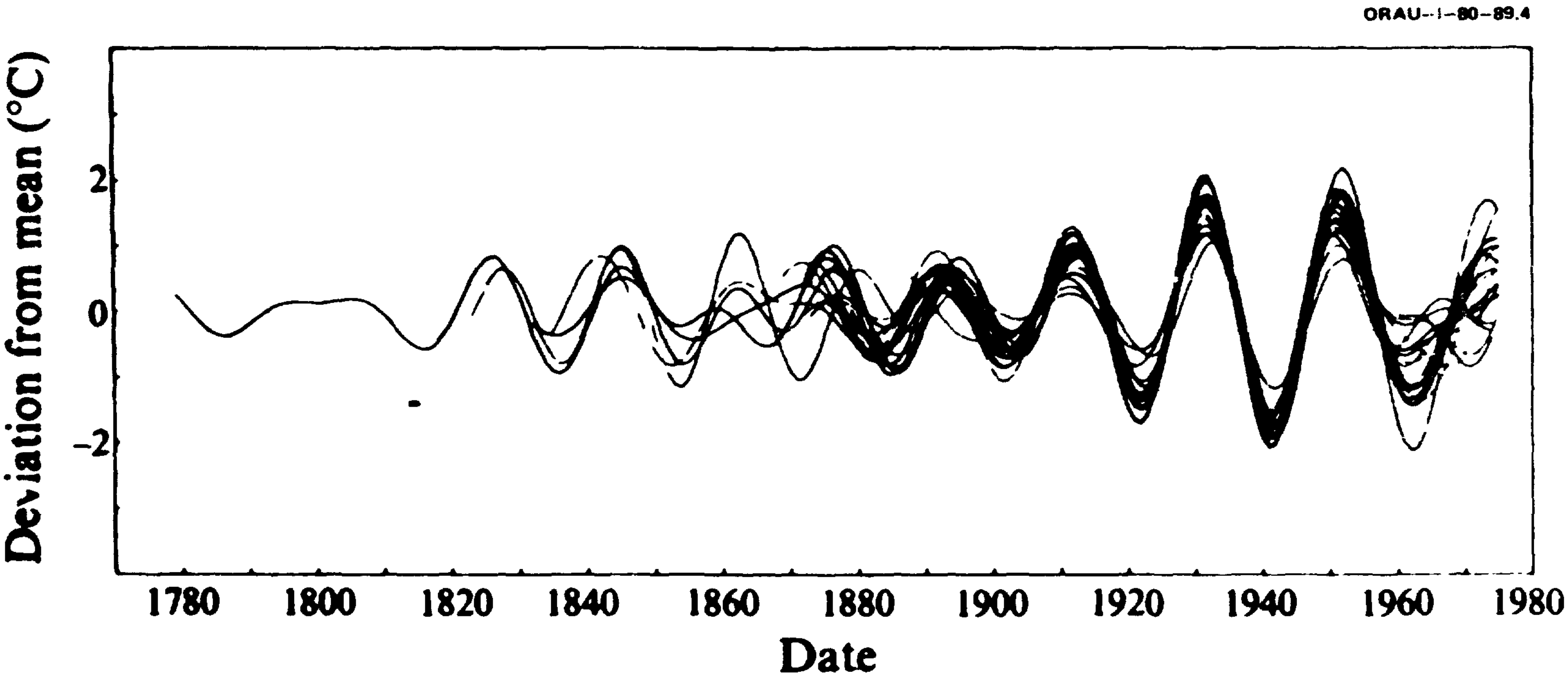

Figure 2. Mock and Hibler's superposition of 12 Eastern U.S. temperature records for January filtered through a band pass filter around 20.5 years. The separate records show remarkable coherence and strongly resemble the beat between two waves with comparable amplitudes and frequencies.

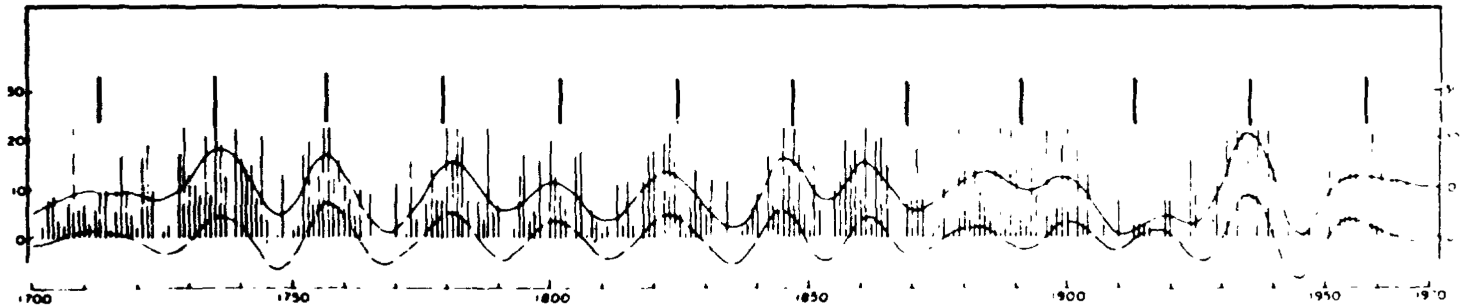

Figure 3. Drought area indices from tree ring records for the Western U.S. High Plains from Mitchell, Stockton & Meko (16). Wavy lines are their results from filtering the raw data with a band pass filter (lower) and a low pass filter (upper). The series of time marks above mark the regular phase corrected Hale magnetic sunspot cycle at 22.279 yr. intervals. Note the rapid phase shift from 1860-1900.

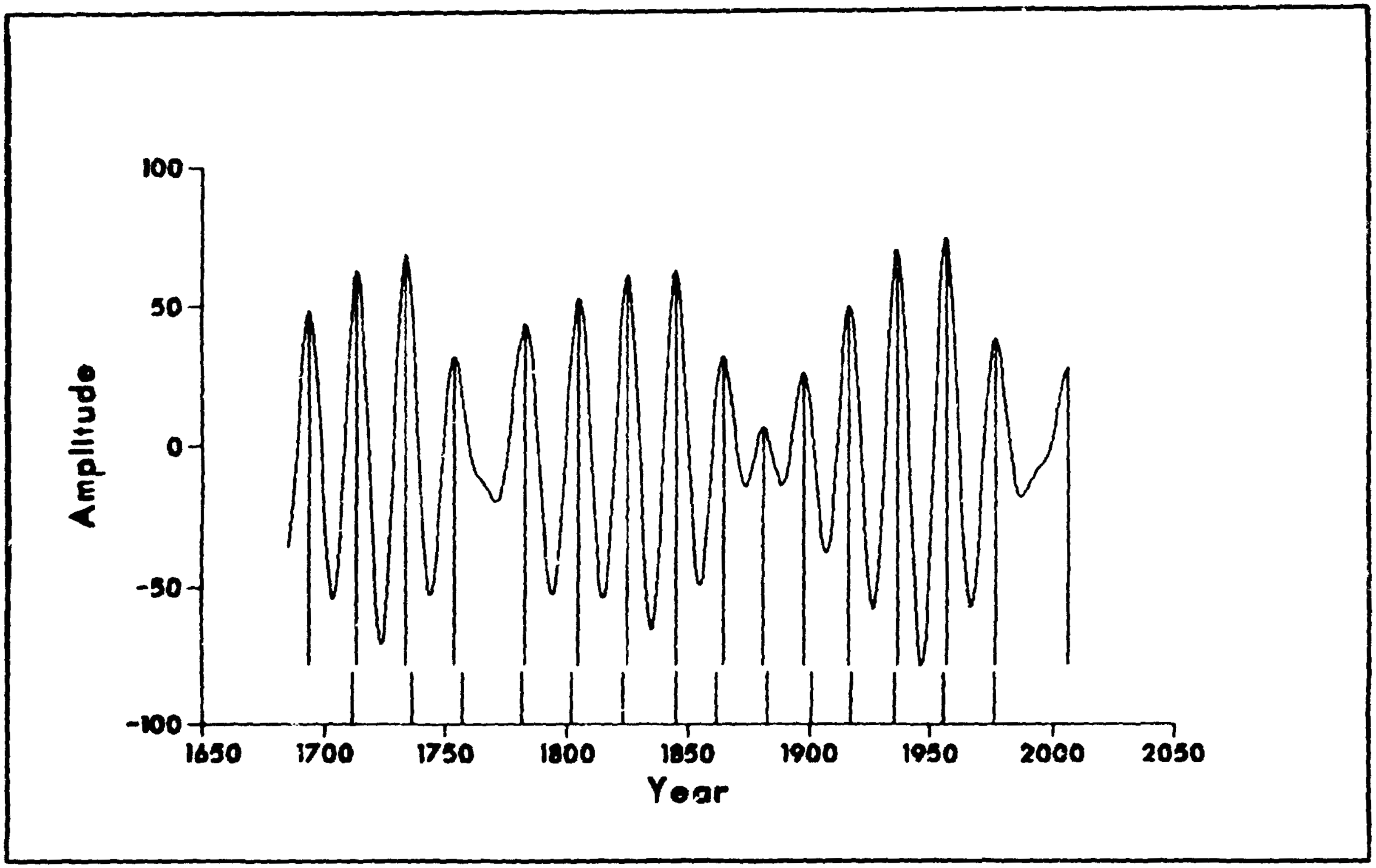

Figure 4. Beat wave between a constant 18.61 year period representing the lunar nodal tide cycle and the 22.279 year corrected Hale magnetic sunspot cycle with amplitude adjusted to fit the recorded sunspot activity. The long vertical lines mark the peaks of the beat wave, the short marks below them mark the times of maximum drought from Mitchell, Stockton and Meko.

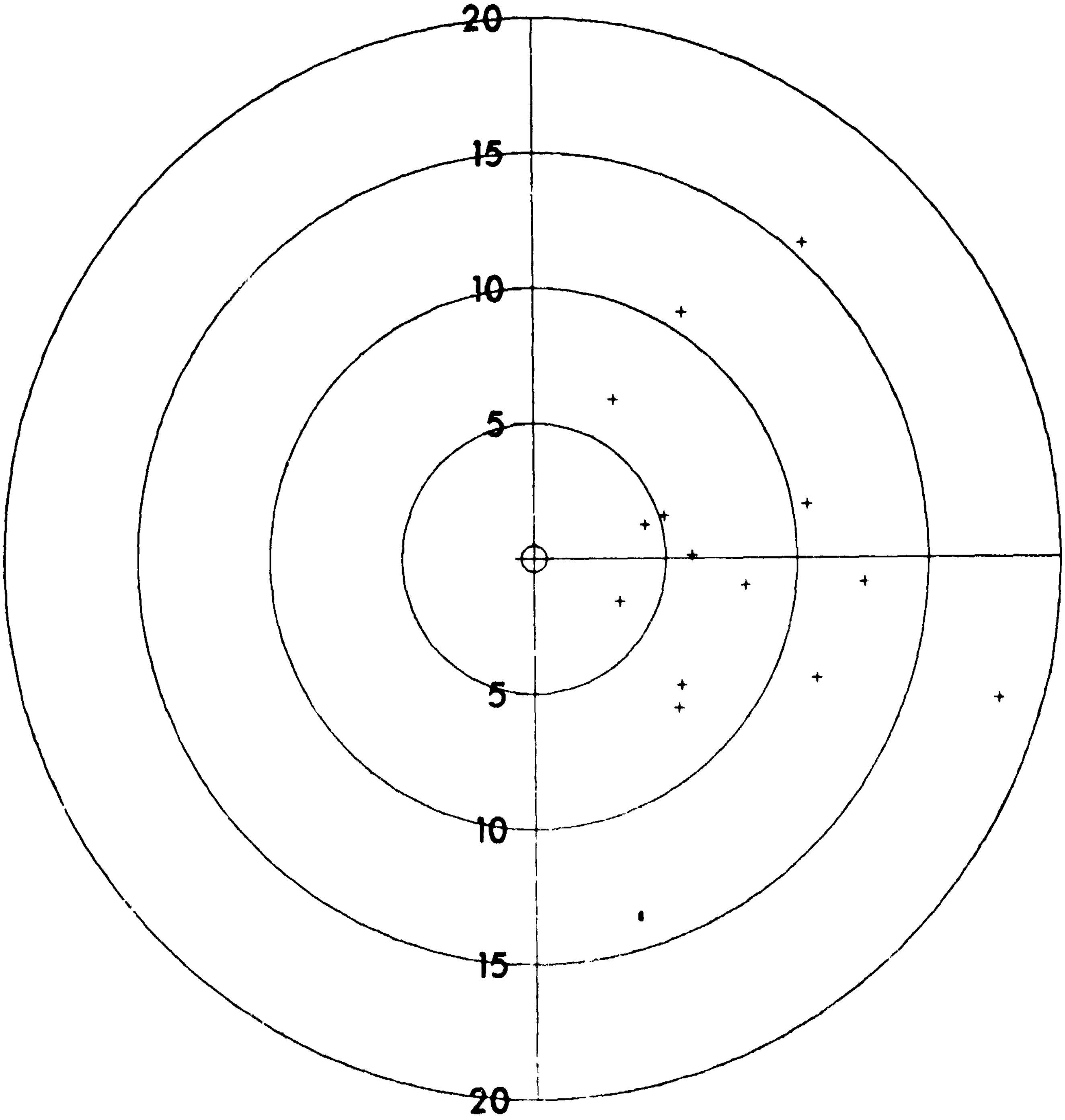

Figure 5b. Harmonic dial showing the phase relation between the solar cycle/lunar tidal cycle beat seen in Figure 4 whose peaks time the dial's rotation and the average of the drought times in Figure 5a. Note that now there are no large phase errors.

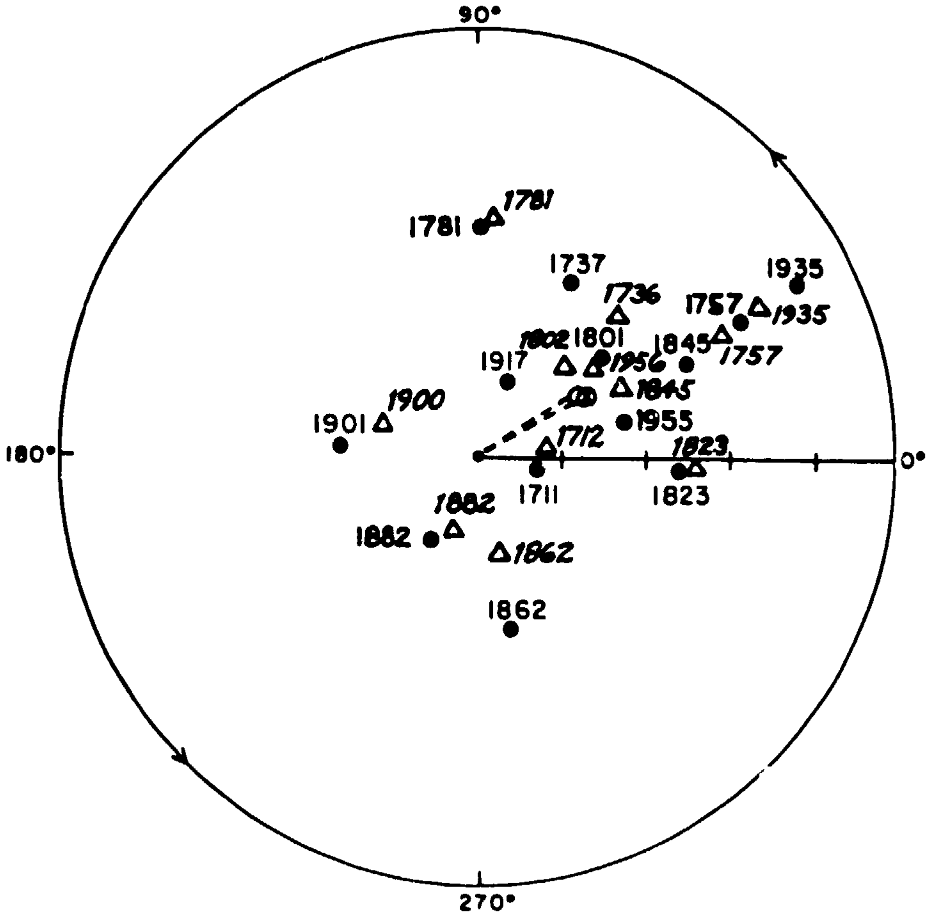

Figure 5a. Harmonic dial from Mitchell, Stockton and Meko (16) showing the phase relation between the uncorrected Hale magnetic sunspot period which times the dial's rotation and the drought area index series filtered by a band pass filter at 20.6 years (dots) and 24.3 years (triangles). Note the large phase errors at 1862, 1882, and 1900-1.