Geophys. J. R. astr. Soc. (1982) 69, 321–327

Evidence for 18.6-yr M_N term in Japanese air pressure and geophysical implications

Robert G. Currie* *Laboratory for Planetary Atmospheres, Goddard Space Flight Center, Greenbelt, Maryland 20771, USA*

Received 1981 June 9; in original form 1980 August 20

Summary. Evidence is found in Japanese station pressure records for the 11-yr solar cycle term and a long-period signal near 20 yr which we identify as the 18.6-yr M_N lunar nodal term in atmospheric tides. Amplitudes of the identified M_N term are highly variable with a nominal amplitude of 0.1 mb and, for the seven available stations, the term is in phase (0.0 ± 2.3 yr) with the M_N term in 30 temperature records in north-eastern North America. These results are important because of my proposal that enhanced drought conditions in the western United States on a time-scale of ~ 20 yr are neither 'recurrent' nor 'rhythmic', but rather periodic with a period 18.6 yr. And the influence of the Rocky Mountains (as well as the Tibetan Plateau) on standing atmospheric waves *vis-à-vis* precipitation is the common forcing function for the signal in temperature and drought conditions.

1 Introduction and perspective

The genesis of the present paper was work by Currie (1974) which indicated that an 11-yr solar cycle signal in surface air temperature existed only in North America. Currie (1979, fig. 4) also found unexpected evidence for the 18.6-yr lunar nodal tide M_N term in these records with mean period of 18.4 yr and amplitude 0.06°C. Evidence for both the 11-yr and 18.6-yr M_N terms in European sea-level records had also been reported (Currie 1976, 1981a).

During a final study (Currie 1981c) on North American temperature data, pressure records for North America were processed and similarly for temperature and presssure records for Europe and Australia. In no case could either a solar cycle or lunar nodal signal be substantiated. However, for records of Japan evidence for both terms in station air pressure was found as reported herein.

The results for Japanese pressure data led to a detailed investigation of the apparent M_N term (Currie 1979) in North American air temperature records. As a result, Currie (1981d) proposed that enhanced conditions of drought in the western United States on a time-scale of ~ 20 yr are neither 'recurrent' (Roberts 1975) nor 'rhythmic' (Mitchell, Stockton & Meko 1979), but rather periodic with a period of 18.6 yr. And the influence of the Rocky

---

*National Research Council Senior Resident Research Associate. Permanent mailing address: 300 Main Street, Roscoe, Texas 79545, USA.

Mountains on atmospheric tidal phenomena at epochs of maximum in the M_N tide is the common forcing function for the M_N signal in North American temperature records and the Drought Area Index (DAI) record (Mitchell *et al.* 1979) for the western United States since 1800 AD. Because of the well-established influence of large-scale orography on climate (Smith 1979), and because of the aforementioned proposal of Currie (1981d), evidence for a signal near 18.6 yr in air pressure over Japan assumes special significance because these islands are in the lee of the Tibetan Plateau. The paper will thus be confined principally to this term.

The numerical techniques employed are based on the Principle of Maximum Entropy as applied to spectrum analysis of time series (Burg 1975). Although few geophysicists are aware of it, the Principle is hardly a radical innovation as Jaynes (1979) points out: its philosophy was clearly foreshadowed by Laplace and Jeffreys; its mathematics by Maxwell, Boltzmann and Gibbs. Other noted contributors are Shannon and Jaynes. A survey of the method as applied to time series is given by Childers (1978), while more recent texts are Haykin (1979) and Robinson & Treitel (1980). It is termed the MEM (Maximum Entropy Method) or MESA (Maximum Entropy Spectrum Analysis).

2 Data and signal detection

Examination of worldwide station pressure data (Spanger & Jenne 1979) reveals two unfortunate features. First, from 1951–1960 both monthly and yearly mean values are given to 1 mb instead of 0.1 mb. Second, with few exceptions, station pressure data from 1961 to 1970 were not incorporated into the data base although subsequently, to 1977, there are data (given to 0.1 mb). Thus, the records effectively end in 1950. Twelve station pressure records extending back into the nineteenth century exist for Japan. Five of the stations could not be utilized because of extensive gaps in the data. The remaining seven stations, together with location and time span, are listed in Table 1.

Results shown in Fig. 1 were obtained as follows: (1) A $2N+1$ ($N=6$) high pass filter was convolved with each series. (2) MESA amplitude spectra with prediction error filters (PEF) varying from 30 to 50 per cent record length were computed for each series, and the PEF which located the long period peak closest to 18.6 yr chosen for subsequent processing. (3) A MESA spectrum for each record was computed followed by division of the amplitude response of the high pass filter. (4) The seven spectra were averaged ensemble and standard errors, shown as bars, computed for every other spectrum estimate.

Amplitude signal-to-noise ratio (SNR) is about 2 for the 11-yr solar cycle signal and the term near 20 yr. The periods of the latter signal are listed in column 4 of Table 1, and the mean is biased away from 18.6 yr by 1.5 yr. A difficulty with the Japanese records is that

Table 1. Summary of long-period signal in surface air pressure (Japanese Islands).

	Station	Location (°.′E)		Time span	T(yr)	Pe(mb)
1	Fukuoka	33.39	130.21	1890–1960	22.3	0.02
2	Tokyo	35.40	139.45	1876–1960	20.4	0.06
3	Matsumoto	36.18	137.58	1889–1960	20.5	0.09
4	Miyako	39.38	141.59	1883–1960	20.9	0.19
5	Akita	39.44	140.45	1886–1960	20.4	0.03
6	Sapporo	43.05	141.21	1889–1960	18.8	0.14
7	Nemuro	43.22	145.36	1889–1960	17.7	0.13
		Mean			20.1	0.09
		Standard deviation (sd)			1.5	0.06
		Standard error (se)			0.6	0.02

they are not only short compared to the North American temperature records, but 10 of the data points in each record are given to only 1 mb and are therefore useless for signal detection. The difficulty in MESA of detecting the true period of a known sinusoid when record length is very short and noise levels high is well known (Chen & Stegan 1974).

For the temperature data Currie (1979) obtained a mean period of 18.4 yr and later (Currie 1981d) a period of 18.8 ± 0.9 yr. For the height of sea-level (Currie 1976) the estimate was 18.5 ± 1.1 yr. There seems to be no question that in both data sets the signal is the 18.6 yr M_N term. We identify the peak in Fig. 1 as lunar nodal but further work is needed. The data sets in Table 1 could be lengthened by 17 yr if the missing decade of data from 1961–1970 (Spanger & Jenne 1979) were incorporated into the data base; hopefully, too, the decade of data 1951–1960 given to 1 mb can be recovered to a precision of 0.1 mb.

3 Time domain analysis

The classical method of investigating the time domain behaviour of a sinusoid immersed in noise is complex demodulation. This is ineffective whenever amplitude SNR is as low as 2 because the human eye cannot discern the signal. In a series of papers Currie (1981a, b, c, d) used existing techniques to develop an innovative method.

The key element in the method is maximum entropy prediction filtering (Ulrych *et al.* 1973) followed by a conventional bandpass filter to extract the sinusoid. For short records this has not heretofore been possible. First, each record was convolved with a $2N + 1$ weight ($N = 10$) high pass filter whose amplitude response at 20 yr was 0.65. Second, since the PEF for each record models the signals and noise as composited in Fig. 1, it can be transformed into a prediction filter and used to generate data points off each end of the record. Third, a $2N + 1$ weight ($N = 40$) bandpass filter centred at 20 yr was designed. The procedure then consists of generating 40 data points off each end of the available record, convolving the bandpass filter with the extended record, and dividing each data point of the bandpassed series by 0.65 to restore true amplitude.

Fig. 2(a) displays the averaged bandpassed waveform for the seven stations plotted as a continuous curve. The centroid of each solid dot is mean epoch and amplitude computed from individual waveforms, while the size of the dot and vertical bars represent the standard error (se) of epoch and magnitude, respectively. Fig. 2(b) displays the noise as a function of time and was obtained in similar fashion by centring the bandpass filter at 14 yr. More extensive discussion and further examples obtained by the method are given in Currie (1981a, b, c, d). The noise level of each record was removed to yield the signal amplitudes listed in column 5 of Table 1. The mean amplitude of 0.09 mb is only nominal because standard deviation is over half the mean reflecting an apparent amplitude gradient in latitude.

In Fig. 2(a) the epochs of maximum in pressure are nearly in phase with epochs of maximum in temperature from 30 stations in north-east North America as the following

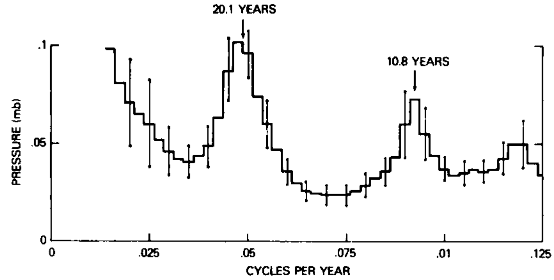

Figure 1. Average spectrum and standard error (se) bars for seven Japanese pressure records in Table 1.

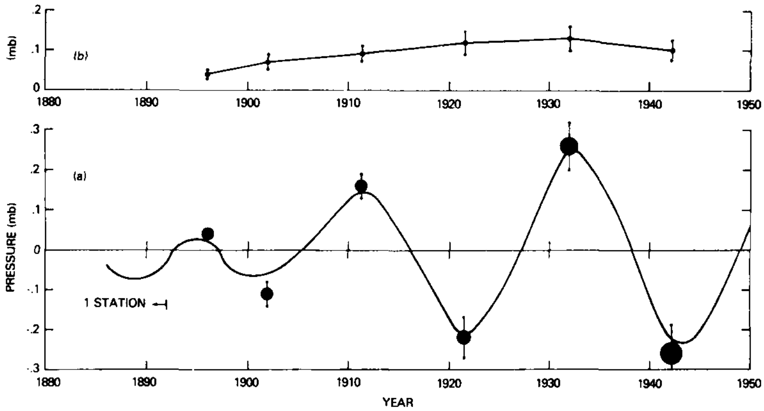

Figure 2. (a) Average waveform of long-period signal in seven pressure records, together with se in period (size of dots) and amplitude (vertical bars) at epochs of maximum–minima. (b) Estimated noise level as a function of time.

pairs show: (1896.0, 1895.9), (1911.3, 1913.8), (1932.0, 1932.6), where the second element in each pair is taken from column 2 of table 1 in Currie (1981d). Out of curiosity we changed the centre of the bandpass filter to 18.6 yr and repeated the analysis leading to Fig. 2(a). The epochs of maximum in the first element of the above pairs changed to (1896.7, 1913.5, 1932.4) yielding closer agreement.

A feature of Fig. 2 of possible importance is that both the signal plus noise waveform and the envelope of the noise have systematically increased since the end of the nineteenth century. Even when the noise level is subtracted from Fig. 2(a) the signal amplitude was increasing during the twentieth century. This is in striking contrast to the 30 temperature records in eastern North America (Currie 1981d, fig. 4a) where the signal amplitude was decreasing. And, although the solar cycle term in Fig. 1 is not treated in this paper, the same behaviour occurred for the 11 yr term in air pressure in Japan *vis-à-vis* the term in North American temperature (Currie 1981c). We cannot at present envisage an explanation for such behaviour but suggest it may turn out to be important as understanding of the dynamics of the 18.6-yr M_N atmospheric tidal wave and the circumpolar vortex of westerlies increases (see Section 6).

4 Two channel frequency domain analysis

In order to examine the phase relations further, two channel MESA (Morf *et al.* 1978; Jones 1978) was applied between each of the seven pressure records in Table 1 and the 30 temperature records in north-east North America (Currie 1981d, table A1).

Fig. 3 displays the composited spectra for Miyako and Nemuro *vis-à-vis* the 30 temperature records. The two phase spectra are very dissimilar except near 20 yr where mean phase is near zero and se bars smallest. For stations 1–7 of Table 1 the mean phases were 0.5, 0.2, −0.1, 0.1, −1.0, 0.8, and 2.5 yr. For those four stations (3, 4, 6, 7) displaying the strongest signal in pressure, 120 phase spectra yielded a phase difference of 0.0 yr with sd of ±2.3 yr and se of ± 0.2 yr.

5 Geophysical implications

Currie (1981d) proposed that enhanced drought conditions in the western United States since 1800 AD are neither 'recurrent' (Roberts 1975) nor 'rhythmic' (Mitchell *et al.* 1979) on

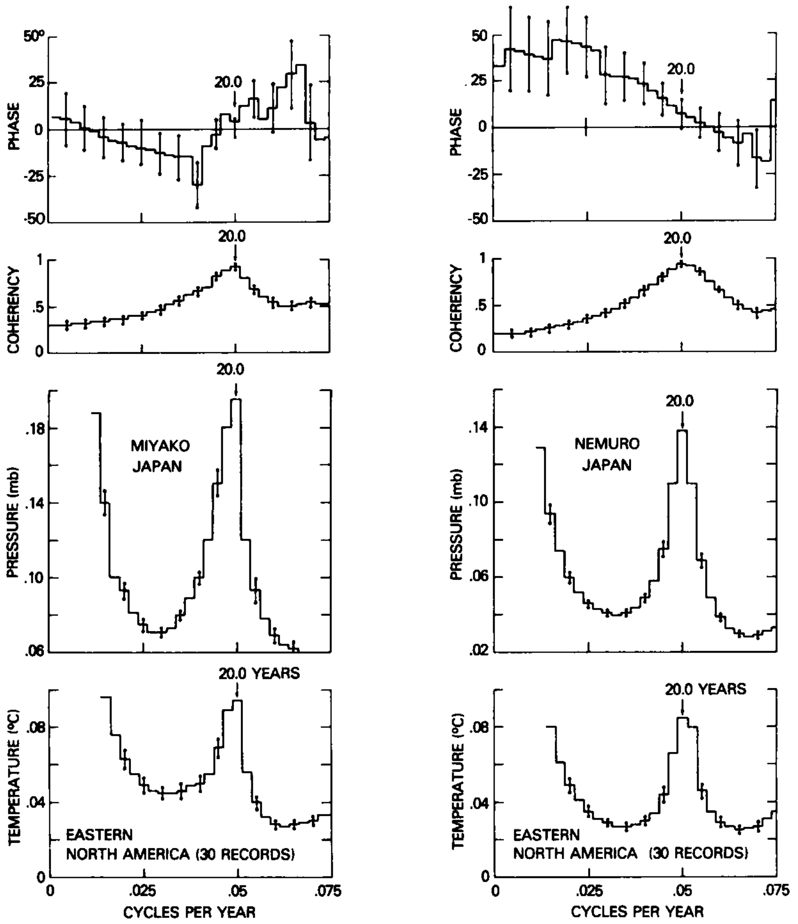

Figure 3. Average cross spectrum results, together with se bars, between Miyako pressure record and 30 temperature stations in eastern North America (see table A1 of Currie 1981d). Similarly for Nemuro.

a time-scale of ~20 yr, but are rather periodic with a period 18.6 yr. And that the influence of the Rocky Mountains on atmospheric tidal phenomena at epochs of maximum in the M_N tide is the common forcing function for the signals in the temperature records (Currie 1981d) and in the Drought Area Index (DAI) for the western United States (Mitchell *et al.* 1979). The proposal was based on three lines of evidence outlined as follows.

(1) Since 1800 AD the mean discrepancy in epoch between maxima in north-eastern North American temperature and maxima in the DAI *vis-à-vis* the maxima in the M_N tide are 0.9 and 0.1 yr, respectively. The correlations are quite good.

(2) A cluster of nine stations in Western Canada yields the 18.6-yr M_N term in temperature which is out of phase with the 30 stations in north-eastern North America. This is the signature of a standing tidal wave. The review of Smith (1979) and the extensive modelling results of Manabe & Terpstra (1974) establish that the influence of the large-scale orography of the Rocky Mountains and Tibetan Plateau on standing planetary-scale atmospheric waves significantly alters precipitation patterns in the north hemisphere; especially in regions to the lee of the orographies.

From the above, Currie (1981d) considered it plausible that maxima in the M_N term in temperature and in the DAI could be a result of an interaction between the Rocky Mountains and atmospheric tidal phenomena at epochs of maxima in the M_N tide. If such is indeed the case for North America, then evidence for a signal near 18.6 yr in air pressure over Japan – in the lee of the Tibetan Plateau – assumes special significance. The significance is enhanced by the phase relations discussed in Sections 3 and 4.

(3) The orbital characteristics of the Moon and Sun induce a terrestrial tide, termed lunar nodal M_N with a period of 18.613 yr, which is quite strong. In equilibrium theory the amplitude of the M_N term can be 3.6 per cent of the M_2 semi-diurnal lunar tide which is the largest of all gravitational tides. However, the M_N tide is strongly non-equilibrium because nominal amplitude in Japan is 0.1 mb, whereas the amplitude maximum in M_2 occurs over Indonesia and is only 0.08 mb (Haurwitz & Cowley 1969). Moreover, the M_N term modulates the amplitude and phase of numerous short-period tides and all of these are non-equilibrium.

A more complete discussion of the evidence is presented by Currie (1981d). Several questions were asked and will be repeated: (1) Is the modulation in amplitude and phase of shorter-period tidal constituents by M_N (Melchoir 1966) a factor in the phenomenon? (2) Why is the in-phase signal in temperature found some 25° in longitude to the lee of the Rockies, and why is there no substantive evidence for a corresponding signal in pressure anywhere in North America? (3) Why is the in-phase signal in pressure found some 30° in longitude to the lee of the Tibeta Plateau, and why is there no evidence for a corresponding signal in Japanese temperature records?

No Drought Area Index has been constructed for the environs of the Tibetan Plateau but in view of the implications of the proposal for North America – the next epoch of maximum in the M_N tide is 1991.9 AD – such a task would be worthwhile.

6 Further research

Analysis of data sets in surface air temperature and pressure for North America, Europe, Japan and Australia (see Section 1) led to results presented by Currie (1981c, d) and those herein. Earlier studies (Currie 1974, 1979) on worldwide temperature records failed to substantiate an 11-yr signal in any region but North America. However, in view of the much greater possible import of the 18.6 M_N term in atmospheric phenomena *vis-à-vis* climate, worldwide records for temperature and pressure should be re-examined.

Examination of the Spanger & Jenne (1979) data base discloses long temperature/pressure records in other regions as follows: About 49 records in USSR, 48 in India, 25 in South America, eight in the Middle East, and only five in China and Korea. These numbers are upper bounds because, undoubtedly, a significant number of the records contain gaps due either to political instability or a time-varying degree of government support.

According to Currie's (1981d) proposal, the most promising regions for detecting an 18.6-yr term in meteorological data are those in the vicinity of large-scale orography at latitudes where the circumpolar vortex of westerly winds flow. In the north hemisphere the prime regions would be China, Mongolia, Manchuria, and those portions of the USSR which abut the Tibetan Plateau; perhaps also northern India and Pakistan. But, excepting India, there are virtually no long continuous records in these environs. In the southern hemisphere the prime regions are southern Argentina and Chile. However, there is very little land mass in the lee of the Andes at such latitudes and very few stations either. The best region would be the South Atlantic Ocean some 20° to 30° in longitude to the lee of the Andes.

Acknowledgments

I am indebted to ARCO Exploration Company for allowing loan to government, to the

National Academy of Sciences–National Research Council for awarding the appointment, to Dr A. Arking of NASA for extending the invitation and to Goddard Space Flight Center for providing facilities. I thank Professor A. H. Cook for suggestions which greatly improved the presentation.

References

Burg, J. P., 1975. Maximum entropy spectral analysis, *PhD thesis*, Stanford University, 123 pp.

Chen, W. Y. & Stegan, G. R., 1974. Experiments with maximum entropy power spectra of sinusoids, *J. geophys. Res.*, **79**, 3019–3022.

Childers, D. G., 1978. *Modern Spectrum Analysis*, IEEE Press (reprint series), New York, 334 pp.

Currie, R. G., 1974. Solar cycle signal in surface air temperature, *J. geophys. Res.*, **79**, 5657–5660.

Currie, R. G., 1976. The spectrum of sea level from 4 to 40 years, *Geophys. J. R. astr. Soc.*, **46**, 513–520.

Currie, R. G., 1979. Distribution of solar cycle signal in surface air temperature over North America, *J. geophys. Res.*, **84**, 753–761.

Currie, R. G., 1981a. Amplitude and phase of the 11-year term in sea-level: Europe, *Geophys. J. R. astr. Soc.*, **67**, 547–556.

Currie, R. G., 1981b. Solar cycle signal in Earth rotation: non-stationary behavior, *Science*, **211**, 386–389.

Currie, R. G., 1981c. Solar cycle signal in air temperature in North America: amplitude, gradient, phase, and distribution, *J. Atmos. Sci.*, **38**, 808–818.

Currie, R. G., 1981d. Evidence for 18.6 year M_N signal in temperature and drought conditions in North America since 1800 AD, *J. geophys. Res.*, **86**, 11055–11064.

Haurwitz, R. & Cowley, A. D., 1969. The lunar barometric tide, its global distribution and annual variation, *Pageoph*, **77**, 122–150.

Haykin, S. (ed.), 1979. *Nonlinear Methods of Spectral Analysis*, Topics in Applied Physics, Vol. 34, Springer-Verlag, Berlin, 247 pp.

Jaynes, E. T., 1979. Where do we stand on maximum entropy? *The Maximum Entropy Formalism*, pp. 15–118, eds Levine, R. E. & Tribus, M., MIT Press, Cambridge.

Jones, R. H., 1978. Multivariate autoregressive estimation using residuals, *Applied Time Series Analysis*, pp. 139–162, ed. Findley, D. F., Academic Press, London.

Manabe, S. & Terpstra, T. B., 1974. The effects of mountains on the general circulation of the atmosphere as identified by numerical experiments, *J. Atmos. Sci.*, **31**, 3–42.

Melchior, P., 1966. *The Earth Tides*, Pergamon Press, Oxford, 458 pp.

Mitchell Jr., J. M., Stockton, C. W. & Meko, D. M., 1979. Evidence of a 22-year rhythm of drought in the western United States related to the Hale solar cycle since the 17th century, *Solar-Terrestrial Influences on Weather and Climate*, pp. 125–144, eds McCormac, B. M. & Seliga, T. A., Reidel, Dordrecht, Holland.

Morf, M., Vieira, A., Lee, D. T. L. & Kailath, T., 1978. Recursive multi-channel maximum entropy spectral estimation, *IEEE Trans. Geosci. Electron.*, *GE-16*, 85–94.

Roberts, W. O., 1975. Relationships between solar activity and climate change, *Possible Relationships between Solar Activity and Meteorological Phenomena*, pp. 13–24, eds Bandeen, W. R. & Maran, S. P., NASA SP-366.

Robinson, E. A. & Treitel, S., 1980. *Geophysical Signal Processing*, Prentice-Hall, Englewood Cliffs, 466 pp.

Smith, R. B., 1979. The influence of mountains on the atmosphere, *Advances in Geophysics*, **21**, 87–230, Academic Press, London.

Spanger, W. M. L. & Jenne, R. L., 1979. *World Monthly Surface Station Climatology*, National Center for Atmospheric Research, Boulder, Colorado, 15 pp.

Ulrych, T. J., Smylie, D. E., Jensen, O. G. & Clarke, G. K. C., 1973. Predictive filtering and smoothing of short records by using maximum entropy, *J. geophys, Res.*, **78**, 4959–4964.