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Fluctuations in the seasonal oscillations of temperature in India

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ABSTRACT. Statistical analysis of the time series of the mean annual temperature and characteristic parameters representing seasonal variation of temperature over 8 representative stations of India has been made. Mean annual temperature shows an increasing trend at Calcutta, Bombay, Bangalore and Allahabad and decreasing trend at Fort Cochin. Quasi-biennial oscillation is a significant feature of the temperature variation not only in the mean annual temperature but also in the amplitude of the seasonal variation of the temperature of the different parts of the country.

1. Introduction

Secular trends in the annual mean maximum and minimum temperatures over India were studied by Pramanik and Jagannathan (1954). They concluded that there is no general tendency for a systematic increase or decrease in these; however, at some of the stations some oscillatory tendency was observed. Jagannathan (1963) analysed the trend in the characteristics of seasonal variation of temperature in the arid and semi-arid regions of the globe and observed that the mean annual temperature experienced a slight decrease at practically all Indian stations during periods of maximum solar activity over those of minimum solar activity. Further, the annual range of temperature and the seasonal and semi-annual waves of temperature showed fluctuations somewhat paralleling the sunspot cycle.

In the present paper it is proposed to study the fluctuations in the different harmonic parameters representing the seasonal variation of mean temperature over India.

2. Seasonal oscillation of temperatures

Eight stations representing the different parts of the country have been studied. Table 1 gives the position of the stations and data utilized. The data are over 90 years in length except for Hyderabad for which the period is 76 years. The corrections to the mean monthly temperatures of Hyderabad due to change of site from Engineer's Office to Nizamiah Observatory in 1938 and to Begmpet Observatory from 1951 were also made as indicated in *World Weather Records* (Vol. 4, 1950-60, Asia) so as to make the data homogeneous.

Jagannathan (1957) observed that the first two harmonics account for nearly 90 per cent of the seasonal variation, except at a few stations, where higher frequency oscillations accounted for 30 to 50 per cent of the variations. In the present study, six harmonic terms were fitted to represent the seasonal variations of temperature :

$$T_t = A_0 + \sum_{r=1}^{6} a_r \sin\left(\frac{2\,\pi r t}{P} + \phi_r\right) \qquad (1)$$

where A_o is the mean annual temperature and

$$a_r \sin\left(\frac{2\,\pi r t}{P} + \phi_r\right)$$

represents the r^{th} harmonic of period P/r, a_r and ϕ_r being the amplitude and phase angle of the r^{th} harmonic and P is the fundamental period, the year.

For the stations considered in this study the harmonics above the third have been found to be generally insignificant. As such, the time series characteristics in respect of the terms upto the third only have been discussed here. The seasonal variation has been derived on the basis of the monthly values considering them as representative of the middle of the months. The slight inequality in the length of the months, it is believed, will not vitiate the conclusions derived here. The monthly mean temperature is obtained as the arithmetic average of the mean maximum and mean minimum temperatures.

3. Distribution of the characteristic parameters

The mean values of the parameters based on the entire length of the record, their variance and coefficient of variability are given in Table 2. The frequency distribution of the different parameters have been found to be nearly normal*.

*The graphs of these are not given here for want of space.

TABLE 1

Location of stations and period of data

Stations	Lat. (°N)	Long. (°E)	Elevation (m)	Period	Years
Fort Cochin	09°58′	76°14′	003	1875-1968	94
Bangalore	12°58′	77°35′	921	1875-1968	94
Madras	13°00′	80°11′	016	1875-1968	94
Hyderabad	17°27′	78°28′	545	1893-1968	76
Bombay	18°54′	72°49′	011	1878-1968	91
Nagpur	21°06′	79°03′	310	1875-1968	94
Calcutta	22°32′	88°20′	006	1878-1968	91
Allahabad	25°27′	81°44′	098	1876-1966	91

The mean annual temperature, it is seen, suffers a year-to-year variation with coefficient of variability about 1 to 2 per cent, while the harmonic components exhibit variations which are much higher; the amplitudes of the first and second harmonics experience 10 to 30 per cent while the amplitudes of the third harmonic experience a coefficient of variability of 30 to 70 per cent. Thus it is seen that the seasonal variation of temperature, which is largely a measure of the continentality, experiences considerable variations from year to year.

We shall presently ascertain, if the entire variation has arisen as a random feature or whether any portion thereof can be ascribed to non-random components, and if so, what is the nature of the non-randomness involved. It has been recognized (WMO 1966) that the power spectrum analysis is the most appropriate tool and sufficiently flexible one, to distinguish between many different forms of non-randomness and further amenable for directly testing of their statistical significance. However, as the several tests of significance of the component powers of the spectra are based on the stationarity of the series, implying constancy of the mean as against the alternative hypothesis of trend, persistence, discontinuity or long period oscillation, the following tests of randomness are made on the series in the first instance.

4. Tests of randomness

(*i*) As the various alternatives to randomness, which are of concern in the problem of climatic fluctuations, have the common property of low frequency variation, which introduces positive serial correlation at small lags, the significance of the lag-1 correlation, r_1 is tested by the use of the one tail 95 per cent significant point of the Gaussian distribution : the test value $(r_1)_t$ is computed from:

$$(r_1)_t = \frac{-1 + t_g\sqrt{N-2}}{N-1} \qquad (2)$$

where t_g is the value of the standard deviate in the Gaussian distribution corresponding to the desired level of significance. The r_1 values are given in Table 3, along with the test values. The sample value is positive and greater than the test value for A_0 series at all the stations. Those for A_1 for Madras, A_2 for Fort Cochin and A_3 for Bombay and Nagpur are also positive and significant indicating that the series are not 'random'. Values of r_2 the serial correlation at lag-2, and r_3 that at lag-3 were then compared with r_1^2 and r_1^3 respectively to determine the existence of the Markov linear type persistence. Thus it is concluded that the mean annual temperature at Fort Cochin, Bangalore, Bombay, Nagpur, and Calcutta show considerable persistence, while at Madras, Hyderabad and Allahabad, the non-randomness is not of the persistence type. Further A_2 for Fort Cochin and A_3 for Bombay and Nagpur show persistance; while A_1 for Madras, the non-randomness is not of the persistance type. r_1 for A_2 series of Nagpur and Calcutta, of A_3 for Fort Cochin and Calcutta are negative indicating marked high frequency oscillations. They were therefore tested by the two-tailed test and all except A_3 for Calcutta were found to be significant.

TABLE 2

	A_0	A_1	A_2	A_3
	Fort Cochin			
Mean (°C)	27·24	1·13	0·82	0·24
Variance (°C)^2	0·1033	0·0559	0·0368	0·0166
Coeff. of Vari.(%)	1·2	20·9	23·3	53·7
	Bangalore			
Mean	23·75	2·47	1·62	0·29
Variance	0·1678	0·1047	0·0507	0·0194
Coeff. of Vari.	1·7	13·1	13·9	48·0
	Madras			
Mean	28·38	3·64	0·78	0·47
Variance	0·0934	0·1459	0·0795	0·0518
Coeff. of Vari.	1·1	10·5	36·1	48·5
	Hyderabad			
Mean	25·83	4·29	1·99	0·72
Variance	0·2082	0·2431	0·1199	0·1147
Coeff. of Vari.	1·8	11·5	17·4	47·0
	Bombay			
Mean	27·19	1·81	1·55	0·30
Variance	0·1538	0·1101	0·0823	0·0492
Coeff. of Vari.	1·4	18·3	18·1	73·9
	Nagpur			
Mean	26·84	5·63	2·66	1·08
Variance	0·2069	0·2553	0·1554	0·1056
Coeff. of Vari.	1·7	8·7	14·8	30·1
	Calcutta			
Mean	26·42	4·90	2·36	0·38
Variance	0·2732	0·1227	0·0808	0·0458
Coeff. of Vari.	2·0	7·4	12·4	56·3
	Allahabad			
Mean	26·03	8·15	2·75	0·85
Variance	0·2144	0·2500	0·1838	0·0976
Coeff. of Vari.	1·8	6·1	15·5	32·7

(*ii*) Mann-Kendall rank statistic has been suggested as a powerful test (Kendall and Stuart 1961), when the most likely alternative to randomness is linear or non-linear trend. The statistic τ is computed from :

$$\tau = \frac{4 \Sigma n_i}{N\,(N-1)} - 1 \qquad (3)$$

when n_i is the number of values larger than the i^{th} value in the series subsequent to its position in the time series. The test statistic $(\tau)_t$

$$(\tau)_t = \pm\, t_g \sqrt{\frac{4\,N+10}{9\,N\,(N-1)}} \qquad (4)$$

where t_g, is the value of t at the probability point in the Gaussian distribution appropriate to the two tailed test.

Table 4 gives the Mann-Kendall rank statistic and the 95 and 99 per cent values of $(\tau)_t$. The values for A_0 series of Madras, Hyderabad and Nagpur are not significant indicating that the non-randomness in these series should be attributed to causes other than trend. At the other five stations, the statistics are significant at 99 per cent level indicating the presence of trend, besides persistence recognized in the previous test. Likewise, in the A_1 series for Bangalore, Bombay and Calcutta, and in the A_2 and A_2 series for Fort Cochin, presence of trend is indicated.

(*iii*) Having ascertained that some of the series exhibit trend, we shall now test if the means have differed significantly over the years. For this purpose the series were broken into two equal halves and the significance of the difference of the means between the first and second half were tested by the Student's t-test and the magnitudes of the gradient ascertained. The difference in the means and their levels of significance are indicated in Table 5. At Calcutta, Bombay, Allahabad and Bangalore the mean annual temperature have increased for the first half to the second half, while at Fort Cochin it has decreased.

(*iv*) Thus we have seen that some of the series do exhibit trend. To lime light the nature of the trend, the series were subjected to a 'low pass filter' to supress the high frequency oscillations. The weights used were the ten ordinates of the Gaussian probability curve. The filtered series are shown by thick line in Fig. 1. It may be observed that the mean annual temperature has shown rapid rise upto about 1900 and thereafter the trend differed in the different parts of the country; Calcutta and Bombay showed a general increase while Fort Cochin showed a decrease at the other stations they are largely oscillatory.

TABLE 3

Serial corrections

Station	A_0	A_1	A_2	A_3	Test value $(r_1)_t$ at 95% level
Fort Cochin	+0·6366	—0·1192	+0·3571	—0·1794	0·1508 (—0·1717)*
Bangalore	+0·4421	—0·0505	+0·0671	+0.1119	0·1608
Madras	+0·3808	+0·1927	+0·0576	—0·0586	0·1608
Hyderabad	+0·3841	—0·0974	—0·1653	—0·0002	—0·1778
Bombay	+0·4717	+0·0347	—0·0139	+0·1729	0·1632
Nagpur	+0·2786	+0·0229	—0·1797	+0·2256	0·1608 (—0·1717)*
Calcutta	+0·7327	—0·1180	—0·1771	—0·1729	0·1632 (—0·1741)*
Allahabad	+0·4299	+0·0448	—0·0417	—0·0417	0·1632

*96% limit for 2-tailed test. These values should be used when r_1 is negative

TABLE 4

Mann Kendall Rank Test

Station	Test level of significance $(\tau)_{t*}$		Rank statistics τ†			
	99 per cent	95 per cent	A_0	A_1	A_2	A_3
Fort Cochin	0·1769	0·1372	—0·1799	—0·1339	—0·3316	—0·1404
Bangalore	0·1769	0·1372	+0·2083	—0·1546	—0·0783	—0·0141
Madras	0·1769	0·1372	+0·0410	—0·0538	—0·0061	+0·0314
Hyderabad	0·1976	0·1533	+0·0407	—0·0523	—0·0734	+0·0247
Bombay	0·1799	0·1396	+0·4483	—0·2040	+0·0748	+0·0225
Nagpur	0·1769	0·1372	—0·0168	—0·0140	—0·1132	+0·1223
Calcutta	0·1799	0·1396	+0·6488	—0·2006	—0·0168	+0·0817
Allahabad	0·1799	0·1396	+0·2833	—0·1019	+0·0307	+0·0730

$$*(\tau)_t = \pm\, t_g \sqrt{\frac{4N+10}{9N(N-1)}}, \quad \dagger\tau = \frac{4\,\Sigma\, n_i}{N(N-1)} - 1$$

TABLE 5

Difference between the means °C (M_2—M_1)

Station	A_0	A_1	A_2	A_3
Fort Cochin	—0·2861**	—0·0904	—0·1607**	—0·0874*
Bangalore	+0·3181**	—0·1471*	—0·0549	—0·0030
Madras	+0·0256	+0·0339	—0·0196	—0·0458
Hyderabad	—0·0037	—0·0147	+0·0957	+0·0747
Bombay	+0·3992**	—0·0972	—0·0147	+0·0660
Nagpur	—0·0472	+0·0268	—0·0789	+0·1713**
Calcutta	+0·7901**	—0·1736*	—0·0344	+0·0478
Allahabad	+0·3882**	—0·0980	+0·0584	+0·0867

**significant at 99% level *significant at 95% level

Thus it is apparent that the parameters representing the seasonal variation of temperature experienced oscillatory features with varying periods. It is necessary, therefore to investigate if the fluctuations observed are due to any systematic oscillation or due to any aperiodic variations and then to ascertain the frequencies of such oscillations.

5. Power spectrum analysis

The time series of the mean annual temperature and the amplitudes of the first three harmonic oscillations were subjected to power spectrum analysis on the basis of auto-correlations upto 22 lags, which is a reasonably small fraction of the total length of the record while at the the same time large enough to provide a rather good spectral resolution. In Fig. 2 are shown the spectra smoothed on the basis of 'Hanning weights (·25, ·50, 0·25)'. It can be seen that the spectra exhibit many peaks and troughs. Whether these peaks and troughs between them are only accidental due to sampling effects or whether the series indicate any significant tendency to oscillate have been determined on the basis of the sampling theory developed by Tukey (1950). The null-hypothesis for this purpose were considered in accordance with the fact whether the series revealed any persistence or not. If the persistence was of the 'Markov linear type' the appropriate red-noise spectrum and the associated 99, 95, and 90 per cent limits were calculated and the individual peaks were tested with reference to these limits. If the lag-1 correlation was significantly greater in magnitude than zero but higher lag correlation did not taper off exponentially, the spectral estimates in the first half were tested with reference to the red-noise spectra and rest against white noise. In the absence of any persistence, the spectral estimates were tested against white-noise spectrum.

Even if the spectral estimates exceeded certain specified confidence level, one cannot straightaway assert the existence of the periodicity. Out of the several periodicities exhibited in the individual spectra, the quasi-biennial oscillation (QBO) which is observed predominantly, is one of the group of cycles that is somewhat connected with the sunspot cycle and has gained considerable currency in recent years. Further the cycles corresponding to the solar cycle or some higher harmonics thereof are also observed. Since these cycles have been observed in several atmospheric phenomena even though the cause and effect relationships are still obscure, they can also be justifiably considered as probable. The other cycles, which have not been anticipated on *a priori* considerations when tested with more stringent criteria appropriate to the highest observed intensity, fall out as insignificant. The following are some of the

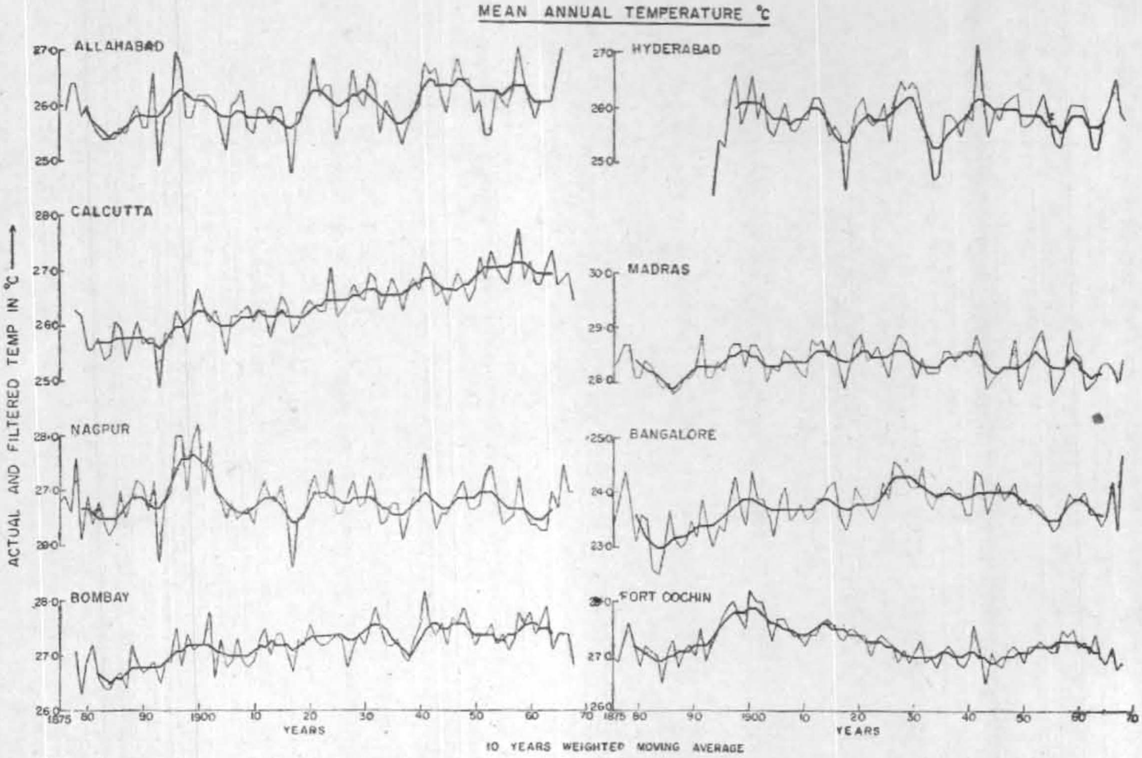

Fig. 1

(Thick curve is 10 years weighted moving average)

salient features revealed by the spectral analysis.

A_0—*Mean annual temperature*

There is a slight (significant at 90 per cent level) indication of quasi-biennial oscillation (QBO) at Fort Cochin, Bombay, and Nagpur, while at Bangalore a cycle with the range of 2·8 to 3·0 years and at Calcutta a broad hump over 2·8 to 4·2 years are observed. At Madras and Allahabad, oscillations with period longer than 17·6 years are indicated. Half sunspot cycle is indicated at Hyderabad and Madras.

A_1— *amplitude of annual oscillation*

QBO is present at all stations except Bangalore and Allahabad. Allahabad exhibits oscillation with period between 17·6 to 29·3 years, while Bombay shows very low frequency oscillation with period greater than 29·3 years.

A_2—*amplitude of half-yearly oscillation*

QBO is present in Calcutta, Nagpur, Hyderabad, Bombay and Fort Cochin. Madras exhibits low frequency oscillation with period 17·6 to 29·3 while Fort Cochin exhibits very low frequency oscillation with period length with 88 years.

A_3—*amplitude of 4-monthly oscillation*

QBO is present in Fort Cochin, Hyderabad, Bombay and Calcutta. Half sunspot cycle is present in Bangalore and Madras. Nagpur shows a low frequency oscillation with period 12·6 to 29·3.

6. Conclusion

The analysis of the long series of temperature data made here reveals :

(*i*) A general increase of mean annual temperature during the last two decades of the last century. It continued to increase subsequently at Calcutta and Bombay, while at Fort Cochin it decreased. The increase at Calcutta was of the order of 1·5° C per century while at Bombay it was about half of this amount; the decrease of mean annual temperature of Fort Cochin was of the order of 0·5°C per century.

(*ii*) At Fort Cochin and Bombay the mean annual temperature as well as all the three harmonic amplitudes exhibit QBO; at Nagpur, it is present in the mean annual temperature and amplitude of the first two harmonics, and at Calcutta and Hyderabad it is present in the amplitude of the three harmonics, and at Madras the

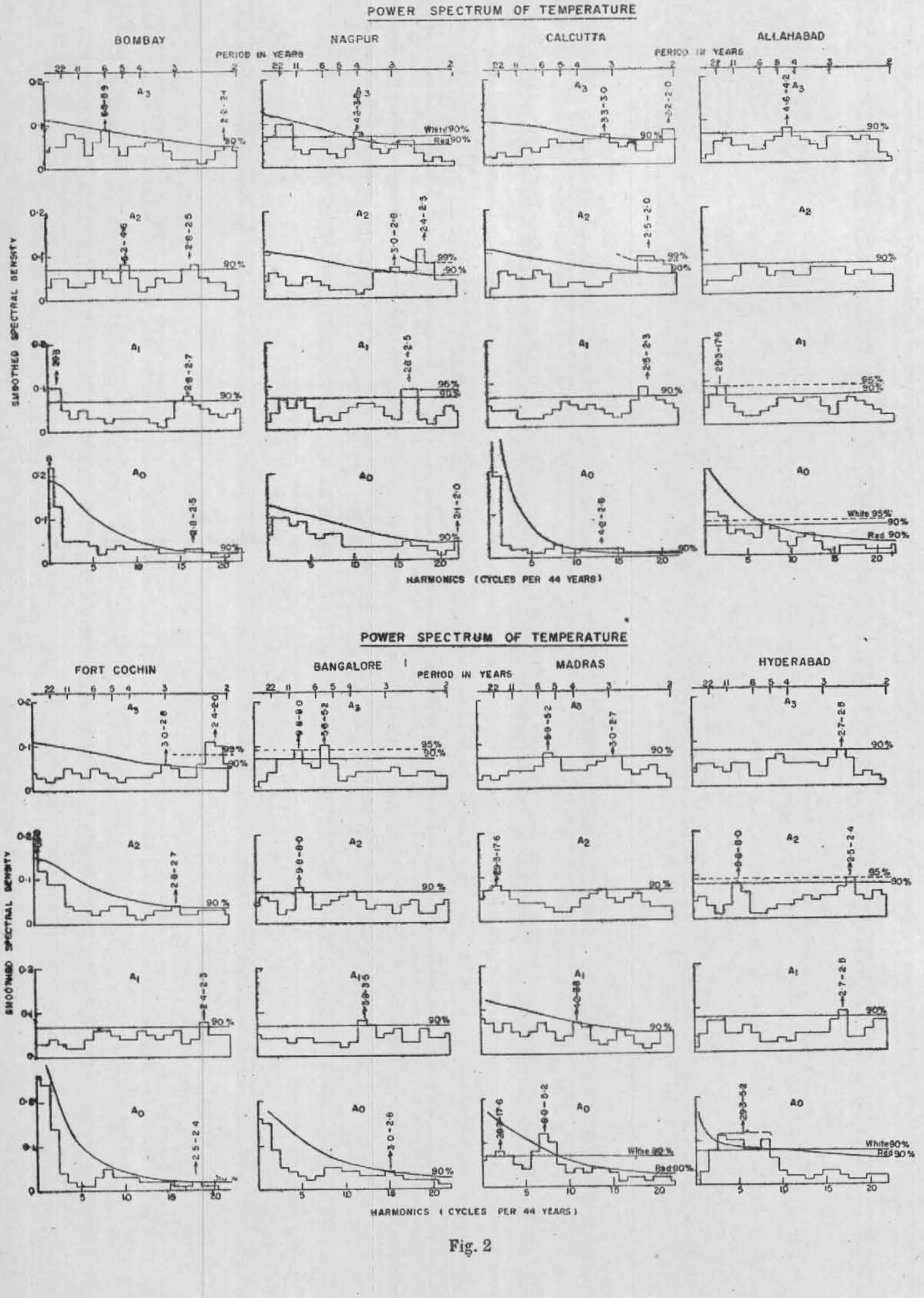
POWER SPECTRUM OF TEMPERATURE
BOMBAY
NAGPUR
CALCUTTA
ALLAHABAD
PERIOD IN YEARS
SMOOTHED SPECTRAL DENSITY
HARMONICS (CYCLES PER 44 YEARS)
POWER SPECTRUM OF TEMPERATURE
FORT COCHIN
BANGALORE
MADRAS
HYDERABAD
PERIOD IN YEARS
SMOOTHED SPECTRAL DENSITY
HARMONICS (CYCLES PER 44 YEARS)

Fig. 2

amplitude of the annual oscillation experiences QBO.

(*iii*) Thus it is seen that the QBO is a significant feature of the temperature variation not only in the mean annual temperature but also in the amplitudes of the seasonal variation of temperature in the different parts of India. Bhargava and Bansal (1969) and Koteswaram and Alvi (1969) observed in the annual/S.W. monsoon precipitation data of some south Indian stations the existence of QBO. This cycle which was originally discussed by Clayton and is often referred to as 'Southern Oscillation" has been observed in meteorological data like wind, temperature and rainfall besides indices of solar activity, ozone and geomagnetic field. The origin of the QBO has not been established with certainity, but the phenomenon is world wide and has been coherently observed in several astro-geophysical data series. It is now felt (*see* Stately 1963) that it is one of the group of cycles in the atmosphere that are somewhat connected with sunspot cycle.

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