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Trends and periodicities of surface air temperature of Delhi

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सार – प्रवृत्तियों और आवधिकता की खोज के लिये दिल्ली के मौसमी तथा वार्षिक सतह वायु तापमान का विश्लेषण 90 वर्ष की अवधि (1901–1990) के लिये किया गया। विश्लेषण से पता चला है कि सभी चार ऋतुओं और वार्षिक समय शृंखला का आवृत्ति वितरण सामान्य है। मानसून पूर्व और मानसूनोत्तर ऋतुओं में मारकोव रैखिक-श्रेणी प्रस्थायित्व का पता चला है। हाल ही की अवधि (1961–1990) के तापमान का औसत दीर्घ अवधि अर्थात् वार्षिक मानसून तथा मानसून पूर्व अवधि की तुलना में उल्लेखनीय रूप से कम है। मानसून तथा वार्षिक तापमान श्रेणियों में घटने की प्रवृत्ति देखी गई। निम्न पास फिल्टर विश्लेषण यह दर्शाते हैं कि प्रवृत्ति रैखिक नहीं है बल्कि दौलित है जो 10 वर्ष या इससे अधिक की अवधि के लिये है।

स्पेक्ट्रम विश्लेषण से मानसून पूर्व और मानसूनोत्तर तापमान श्रेणियों में 6.7 वर्ष के उल्लेखनीय आवर्तन का पता चलता है। शीतकाल और मानसूनोत्तर तापमान श्रेणियों में क्यू. बी. ओ. भी देखा गया।

ABSTRACT. Seasonal and annual surface air temperature of Delhi has been analysed for 90-year period (1901-1990) for finding trends and periodicities. The analysis revealed that frequency distribution of all the four seasons as well as of annual time series is normal. Markov linear-type of persistence is observed in pre and post-monsoon seasons. Recent period (1961-1990) averages of temperature are significantly lower than the long period means in respect of annual, monsoon and pre-monsoon seasons. Decreasing trend is noticed in monsoon and annual temperature time series. Low-pass filter analysis suggests that the trend is not linear but oscillatory consisting periods of 10 years or more.

The spectrum analysis indicates a significant cycle of 6.7 years in pre and post-monsoon temperature series. QBO is also observed in winter and post-monsoon temperature series.

Key words — Trend, Periodicity, Persistence, Power spectrum, Auto-correlation coefficient, Null hypothesis.

1. Introduction

Several workers (Mitchell 1963, Brinkmann 1976, Angell & Korshover 1978, Hansen *et al.* 1981, Jones *et al.* 1982 etc) have studied long-term variation in surface air temperature. Their studies indicated a warming in the northern hemisphere between 1880 and 1940 and cooling thereafter.

Very few studies appear to have been made in temperature trends in India. Secular trends in the annual mean maximum and minimum over India have been studied by Pramanik and Jagannathan (1954). Jagannathan (1963) analysed trends in the seasonal temperature of the arid and semi-arid regions of the globe which included 8 Indian stations. These studies did not reveal any systematic increase or decrease in the mean annual temperatures. However, the study of Jagannathan and Parthasarathy (1972) indicated increasing trend in the mean annual temperature at 4 stations (Calcutta, Bombay, Bangalore and Allahabad) and decreasing at Fort Cochin. Hingane *et al.* (1985) attempted to study the trend in long series of temperature data of different regions of India and the country as a whole. Recently Sarker and Thapliyal (1988) summarised climate change and variability in rainfall and temperature data for recent hundred years.

In the present study an attempt has been made to search trends and periodicities in seasonal and annual surface temperature of Delhi.

2. Data and analysis

Mean monthly temperature data for 1901-1990 have been collected for Delhi (Safdarjung).

The mean monthly temperature was calculated from daily mean temperatures.

The mean values for the four seasons, *viz.*, winter, pre-monsoon, monsoon, post-monsoon and annual temperatures have been calculated. For the winter season the data period becomes less by one year, since December of the previous year is included while computing each year's winter mean. The temperature series were then converted into temperature anomaly series, by subtracting the arithmetic mean of the corresponding series from each of its yearly values. The anomaly series thus obtained are used in low-pass filter and spectrum analysis.

Trends and periodicities are examined by Cramer's test, Mann-Kendall rank statistic, Gaussian low-pass

TABLE 1

Statistical parameters of seasonal and annual temperature of Delhi

Season	Mean (°C)	Std. Dev.	Coeff. of variation (%)	Chi-square value
Winter	15.7	0.75	4.8	5.644
Pre-monsoon	28.1	1.17	4.2	4.220
Monsoon	31.1	0.73	2.3	5.244
Post monsoon	23.3	0.83	3.5	6.533
Annual	25.2	0.53	2.1	8.667

filter and power spectrum analysis. The different aspects are discussed below :

2.1. *Mean and variability*

The statistical parameters such as mean, standard deviation and coefficient of variation are given in Table 1. It is interesting to note that, contrary to the general expectation, the highest temperature about 31°C is observed in monsoon season and not in pre-monsoon season when dry air prevails and skies are comparatively clear. The plausible explanation for such a result is as under :

(*i*) Monsoon current reaches Delhi towards end of June or early July; therefore, the June temperatures pertains to dry air conditions.

(*ii*) The sun is directly over tropic of cancer on 22 June and, therefore, inolation over Delhi by its proximity to the tropic of cancer is expected to be maximum in the month of June and part of July.

(*iii*) Over Delhi the number of rainy days during the entire monsoon season is only 28; the average cloud cover over Delhi during the season is about 4 oktas (India Met. Dep. 1967). The sun, therefore, does not remain cut off for long periods over Delhi and as such the temperatures are not constantly get influenced by monsoon currents.

It is further seen from the table that lowest temperature is 15.7°C in winter season and coefficient of variation varies between 4.8% (winter) and 2.1% (annual).

2.2. *Nature of frequency distribution*

For an application of statistical tests for any time series it is essential to know the nature of frequency distribution. The nature of frequency distribution of time series have been tested by chi-square test, by considering 8 equal probability class intervals. The chi-square values are also shown in Table 1. It is seen that none of the calculated chi-square values are significant. This means that all the time series can be regarded as normally distributed.

2.3. *Persistence*

The various alternatives to randomness have the common property of low-frequency variation, which introduces positive auto-correlation at small lags. Auto-correlations (r_τ) have been calculated as per WMO (1966).

$$r_\tau = C_\tau / C_o = \frac{1/(N-\tau) \sum_{i=1}^{N-\tau} (x_i - \bar{x})(x_i + \tau - \bar{x})}{1/N \sum_{i=1}^{N} (x_i - \bar{x})^2}$$

where, C_τ are the serial covariances for all lags $\tau=0$ to $\tau=m$ ($m < N$), N the number of terms of the series x_i and $\bar{x}$ the mean of all x_i in the series. Gilman *et al.* (1963) have given the methods of finding the persistence of first order, linear Markov process, which is dominant form of trend. Accordingly, the auto-correlations at lag two (r_2) and lag three (r_3) were compared with r_1^2 and r_1^3 respectively. The results are given in Table 2 with significant values suitably marked. It is seen that r is positive and significantly greater than test value (at 95% level) for all the time series except for winter season. Markov-linear type of persistence is observed in pre and post-monsoon seasons where the values of r_2 and r_3 are equal to or greater than r_1^2 and r_1^3 respectively.

3. Trend analysis

For a study of trends, the data have been examined by more than one method and discussed below :

3.1. *Comparison of short period averages with the long period means*

To Study the changes in the data with respect to time, each series was divided into three equal parts, *i.e.*, 1901-1930, 1931-1960 and 1961-1990. The averages of these sub-periods were tested against the long period means by Cramer's test and the results are given in Table 2. It is seen that recent period (1961-1990) temperature averages in respect of pre-monsoon, monsoon and annual are significantly lower than the long period means.

3.2. *Mann-Kendall rank statistic*

Table 2 also shows the Mann-Kendall rank statistic values for seasonal and annual temperature of Delhi. A significant decreasing trend is noticed in monsoon and annual temperature series. The other seasons also indicate a decreasing trend but it is not statistically significant.

3.3. *Low-pass filter*

To understand the nature of trend, the series were subjected to 'Gaussion low-pass filter' analysis. The weights used were nine ordinates (WMO 1966). The low-pass filter curves are shown in Fig. 1. A decreasing trend is noticed from year 1910 to 1935/40 in winter, monsoon and post-monsoon. Monsoon exhibits the decreasing trend from 1954 to 1980 whereas post monsoon shows an increasing trend during the same period. Annual and pre-monsoon temperature curves show a sharp decrease from 1920 till 1934 and from 1954 to 1964.

4. Periodicities

For determining periodicities, if any, the data have been subjected to power spectrum analysis following the procedure of Blackman and Tukey (1958). To achieve

TABLE 2

Spectrum analysis, Mann-Kendall, Cramer's test and correlogram results of Delhi's temperature

Sea son	Mann-Kendall statistic	Cramer's test						Auto-correlation value			Significant cycles (in years)
		Average (1901-30) (°C)	t_k	Average (1931-60) (°C)	t_k	Average (1961-90) (°C)	t_k	Lag 1 (r_1)	Lag 2 (r_2)	Lag 3 (r_3)	
Winter	—0.114	15.8	1.302	15.6	—0.276	15.5	—1.020	0.125	0.026	0.016	2.5
Pre-monsoon	—0.093	28.4	1.634	28.2	0.512	27.7	—2.177*	0.170*	—0.037	0.037	6.7
Monsoon	—0.177*	31.2	1.722	31.1	0.386	30.8	—2.132*	0.211*	0.015	0.043	—
Post-monsoon	—0.016	23.5	1.503	23.0	—2.880*	23.5	1.281	0.210*	0.105	0.092	6.7, 2.6
Annual	—0.171*	25.3	1.847	25.2	0.265	25.0	—2.129*	0.253*	—0.019	0.153	—

* Significant at 95% level

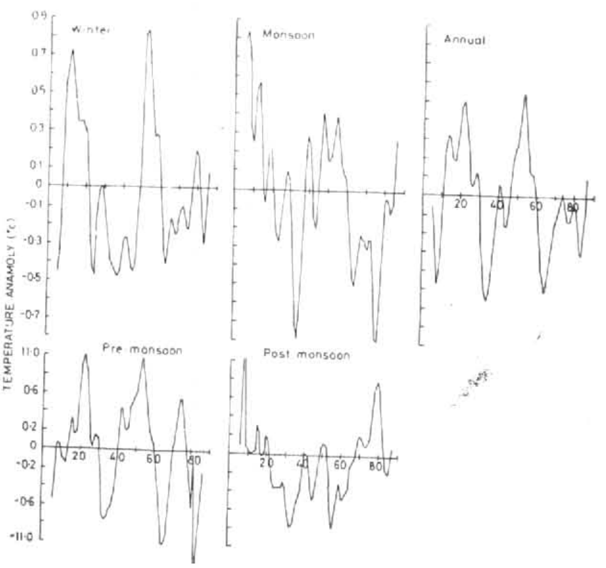

Fig. 1. Gaussian low pass filter curves of surface air temperature anomalies of Delhi (1901-1990)

satisfactory resolution in the spectrum, a maximum lag limit 30, has been chosen. Pre and post-monsoon series exhibit Markov linear-type persistence. The spectral estimates were computed and tested against red-noise spectrum for these two series. If the lag one auto-correlation coefficient (r_1) in respect of monsoon and annual temperature series are positive and significantly greater than the test value (at 95% level) but the higher lag correlation coefficients do not taper off exponentially, the spectral estimates in first half were tested with reference to the red-noise spectrum and the rest against white noise spectrum. Winter temperature series did not exhibit any persistence and therefore the spectral estimates were tested against white-noise spectrum. It is observed (Table 2) that there is a cycle of 6.7 years in the temperature of pre and post monsoon seasons and quasi-biennial oscillation in winter and post-monsoon seasons.

5. Conclusions

(*i*) Monsoon season is the warmest and winter is the coldest.

(*ii*) Seasonal and annual air temperature series are normally distributed.

(*iii*) Markov linear-type of persistence is observed in pre and post monsoon temperature series.

(*iv*) Recent period (1961-1990) temperature averages of monsoon, annual and pre-monsoon are significantly lower than the long period means.

(*v*) A significant decreasing trend in monsoon and annual temperatures is observed.

(*vi*) The power spectrum analysis shows significant cycles of 6.7 years in pre and post-monsoon temperature series and a QBO in winter and post monsoon temperatures.

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