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Seasonal Oscillations of air temperature in India and neighbourhood*

P. JAGANNATHAN

Meteorological Office, Poona

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ABSTRACT. The annual and the half-yearly oscillations in the mean temperature of air at 4 feet above ground level at 167 meteorological stations in India and neighbourhood have been separated. The dependence of the components of the vectors of the different oscillations on the location of the stations have been determined. Regression equations for representing the components of the oscillations as a linear function of latitude, longitude and elevation have been derived. The fit of these representations has been found to be fairly good, the correlation between the actual and the calculated values being of the order of 0·8 to 0·9 generally. The significance of the gradients with respect to the positional co-ordinates have been discussed.

1. Introduction

It is well known that next to the availability of water, the temperature of the air governs the important phytophases of the crop like the germination of seeds etc. Most plants will grow only within narrow ranges of temperature ; and for each species and variety there is a minimum below which growth is not possible, an optimum at which growth is most rapid, and a maximum beyond which growth stops. These critical temperatures may vary from crop to crop (Lundegårdh 1931). Also, the seasonal course of air temperature is a characteristic of the location of the station and is a major factor in defining the climate as 'temperate' or 'severe', 'maritime' or 'continental' etc. A study of the annual course of air temperature is important therefore for such and other purposes. The annual march of air temperature is primarily dependent upon the variation in the amount of heat received from the sun. The daily rate of solar radiation received at any point on earth's surface depends upon the quantity of radiation that emanates from the sun, the duration of the sun's presence above the horizon and the meridian altitude of the sun. There are, however, other factors also, such as, the distribution of land and water, in the neighbourhood of the station, its elevation, the atmospheric and oceanic circulations etc, which disturb to a marked extent this picture of the annual march of temperature as determined by the sun.

2. Scope of the Study

The march of temperature of the air at any particular station is to a large extent a systematic oscillation repeating practically in a similar manner year after year. In Fig. 1 the variation of the mean temperature(see footnote on p.156) in respect of a few stations are shown graphically. These curves have certain general features common to all and certain distinguishing features peculiar to a few. For example, the temperature is lowest during the winter months and increases during the hot weather season. However, the slight variation in the course of the year at the coastal places like Cochin and Pamban distinguish themselves from the high ranges in the interior stations like Lucknow, Jacobabad etc. The highest mean temperature at places like Dras, Srinagar and Quetta occur in July-August, while at the other stations we have a double wave with the primary maximum occurring during May or June and a secondary maximum about October. The character of the variation in the air temperature during the course of the year, and the relationship between these distinguishing characters and the location of the stations form the subject matter of study in this paper.

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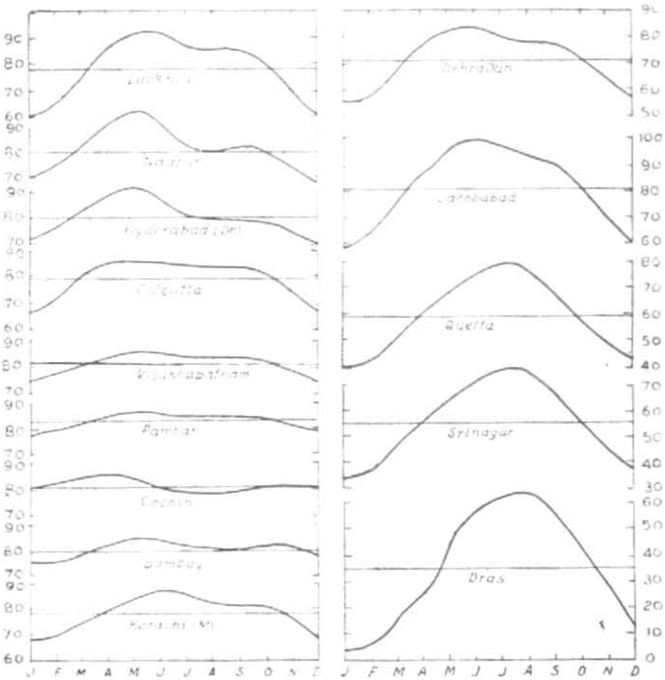

Fig. 1. Mean air temperature

For this study, the mean temperature has been taken as $\frac{1}{2}$ (mean daily maximum temperature+mean daily minimum temperature)*. The mean temperatures of air over 167 meteorological stations distributed throughout India and neighbourhood have been used as the material for analysis. The stations selected are the same as those dealt with by the author (1948) for the study of the distribution of mean temperature over India and the diurnal range of temperature over India. The actual list of stations, their latitude, longitude and elevation above sea level as well as the mean temperature during the different months are given in Tables 1 and 2 of the paper cited above. The stations have been grouped into four regions. The specification of the regions and the location of the centroid in the four regions are given in Table 1†.

3. Graduation of seasonal temperature variation

A suitable mathematical model for studying the annual oscillation of temperature appears to be a set of 'harmonics' with the fundamental period as the year. Symbolically, we aim at expressing the temperature T_t at any time of the year t in the form:

$$T_t = \overline{T} + \sum_{r=1}^{r=n} a_r \cdot \sin\left(\frac{2\pi rt}{P}+\phi_r\right) \qquad (1)$$

where,

$\overline{T}$=mean temperature over the entire period of length P (here the year)

* The temperature of air is that indicated by thermometers installed inside Stevenson Screens at a height of 4 ft above ground level.

As has already been pointed out (Jagannathan 1948), the mean temperature of air cannot be considered completely represented as the mean of the maximum and minimum temperatures. A closer examination of this problem and attempts to represent the mean temperature as a function of the mean of maximum and minimum temperatures as well as the range is in progress and will be discussed separately.

† These were not given in the previous paper and are being added here at Miss Carruther's suggestion—*vide Met. Mag.*, **79**, 934 (Apr 1950)

TABLE 1

Region No.	Specification	Position of centroid		
		Latitude (N)	Longitude (E)	Elevation (ft)
I	42 stations in the western half of the Peninsula, bounded in the north by the tropic of Cancer and in the east by 78°E meridian	17° 4′	75° 2′	1461·3
II	40 stations in the eastern half of the Peninsula, bounded in the north by the tropic of Cancer and in the west by 78°E meridian	18° 40′	83° 0′	545·6
III	45 stations in the northeast India (including Eastern Pakistan) to the north of the tropic of Cancer and to the east of 78°E meridian	25° 53′	85° 34′	953·0
IV	40 stations in the northwest India (including West Pakistan) to the north of tropic of Cancer and to the west of 78°E meridian	30° 19′	73° 24′	2903·9

$a_r \sin\left(\frac{2\pi rt}{P}+\phi_r\right)$ represents the rth harmonic of period P/r

a_r=amplitude, *i.e.*, half the range between the maximum and the minimum in the oscillation, and

ϕ_r=phase angle of the rth harmonic.

The evaluation of the components in the 'harmonics' has been made as follows—

The entire length of the period is marked out by N equal intervals of time and labelled t=0, 1, 2, .. (N—1). The observed values of the variate at these N points of time be T_0, T_1, T_2, ...$T_{(N-1)}$. We may write equation (1) above in the form

$$T_t = \overline{T} + \sum_r p_r \cos\left(\frac{2\pi rt}{N}\right) + q_r \sin\left(\frac{2\pi rt}{N}\right) \quad (2)$$

where, $p_r = a_r \sin\phi_r$ and $q_r = a_r \cos\phi_r$

If the values of T_t at the N points of time $t = 0, 1, .. N-1$ are substituted in eq. (2), we get N equations, which can be solved for the $2r$ ($<N$) constants by the method of least squares.

For a fuller discussion of the method of analysis reference may be made to Pollak (1947), where synthesis schedules for the quick calculation of the harmonic components have also been given.

The maximum in the oscillation of the rth order will occur when

$$\sin\,[(2\pi rt/N) + \phi_r] = 1, \quad (3)$$

i.e., when $(2\pi rt/N)+ \phi_r = \pi/2$ or $5\pi/2$

Similarly the minimum will occur when

$$\sin\,[(2\pi rt/N) + \phi_r] = -1 \quad (4)$$

For example the date of occurrence of the maximum in the oscillation can be calculated from the phase angle from considerations of the fact that the unit of time is a twelfth of the year = 30·4375 days and that the origin of the time axis corresponds to January 16th.

The date of maximum in the annual oscillation is given by —

$$D_x = t_x\, 30{\cdot}4375 + 16 \text{ days from 1 Jan} \quad (5)$$

and those in the half-yearly oscillation by—

$$d_x = t_x\, 30{\cdot}4375+16 \text{ and}$$
$$t_x\, 30{\cdot}4375+198{\cdot}625 \text{ days from 1 Jan} \quad (6)$$

where t_x are as obtained from eq (3) above with r = 1 and 2 respectively.

Assuming that the mean monthly air temperatures are representative of the middle

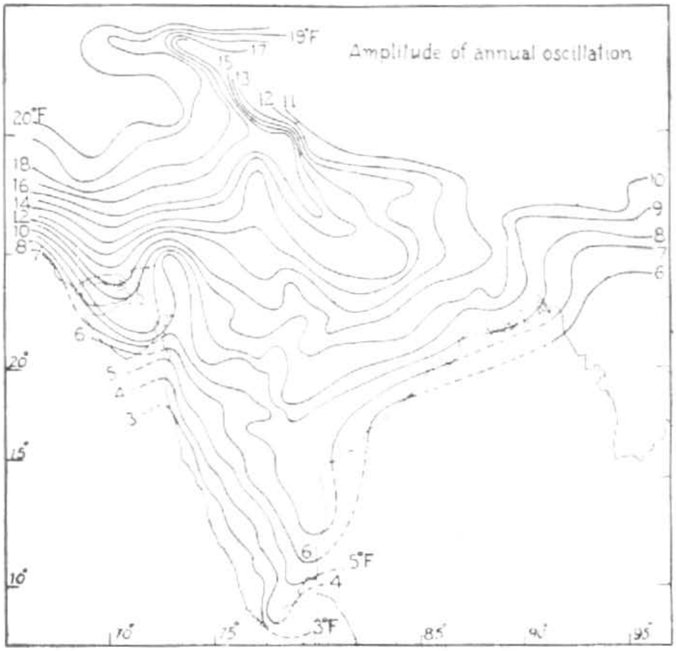

Fig. 2. Amplitude of annual oscillation of temperature (°F)

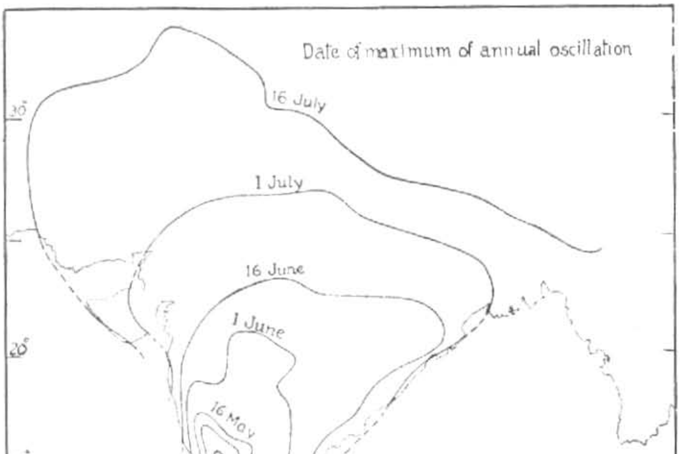

Fig. 3. Date of maximum of annual oscillation of temperature

of the months and that the 12 points of time are equally separated*, the harmonic analysis has been carried out. In Table 2 are given the mean annual temperatures and the amplitudes and phase angles for the annual and half-yearly oscillations, for the 167 stations grouped under the four regions.

4. Annual oscillation

In Figs. 2 and 3 are plotted the amplitudes of the annual oscillation of temperature and the dates of occurrence of the maximum in the annual oscillation and isopleths demarcating different levels are drawn. These figures bring out the following—

(*i*) The amplitude is lowest at barely 2-3°F on the West Coast of the Peninsula, 12-15°F along the Gangetic plains and over 20°F in the extreme northwest. Amplitudes generally increase northwards except in the sub Himalayan regions.

(*ii*) The lowest values are obtained in the coastal regions and the highest in the interior.

(*iii*) The date of occurrence of the maximum in the annual oscillation is delayed in the coastal regions as well as towards the north.

(*iv*) The peak occurs by 1 April over the west coast (south). By the middle of June, the entire Peninsula except for the east coastal regions have passed the maximum stage. By July first, the plains of North India south of the Ganges have been covered and by 15 July the northern parts of Assam and the foot of the Himalayas have attained their maximum.

5. Relationship with latitude, longitude and elevation

With a view to determine the nature of the dependence of the components of the annual oscillation on the position of the stations, the values of the amplitude and the dates of occurrence† of the maximum in the oscillation have been correlated with the latitude, longitude and elevation of the stations. The correlation coefficients are given in Table 3 (p. 164). The high correlation between the amplitude and the latitude suggests a close relationship between the two. The correlation coefficients with the longitude are small except in the case of Region III, where a steep east-to-west gradient is indicated. Further there does not appear to exist much dependence with elevation except in Regions II and IV, where a slight positive relationship is indicated. In regard to date of maximum, a high correlation with latitude in Regions I and IV, with longitude in all but IV and with elevation in II and IV have been obtained.

Table 3 indicates the relationships between the components of the oscillation with the latitude, longitude and elevation but a proper appreciation of the dependence cannot be made unless the inter-relationship between the independent variates are eliminated. Regression equations connecting the latitude, longitude and elevation with the components of the annual oscillation have been calculated and the regression coefficients, their standard errors and the multiple correlation coefficients are given in Table 4 (p. 164). For this purpose the matrix of multipliers given on page 88 of the previous paper by the author referred to have been utilised. The origin of co-ordinates has been taken at 8°N, 60°E and mean sea level. The units for latitude and longitude are minutes and that for height feet. Amplitudes are in °F and D' in months.

* This assumption, it is realised, is not quite correct but the error introduced due to the slightly unequal lengths of the months, will it is believed, not vitiate the results and conclusions arrived at here.

†The correlations were actually made with $D'=(D_x - 31\cdot2187)/m$, where D_x is the date of maximum and m is the mean length of the month in days (=30·4375)

TABLE 2

Seasonal Oscillation of Temperature

REGION 1

Serial No.	Station	Mean temperature (°F)	First harmonics Amplitude (°F)	First harmonics Phase angle	Second harmonics Amplitude (°F)	Second harmonics Phase angle
1	Bhuj	79·8	9·4	284° 8′	4·5	257° 8′
2	Dwarka	78·7	7·7	291 18	2·7	242 49
3	Jamnagar	78·8	9·3	278 43	3·7	249 7
4	Rajkot	79·5	9·2	288 13	4·1	248 58
5	Veraval	78·1	5·4	267 10	2·5	229 30
6	Surat	80·7	6·1	293 24	3·6	256 10
7	Bhavnagar	81·4	9·2	288 42	4·1	253 33
8	Ahmedabad	82·6	8·4	291 56	4·7	247 4
9	Indore	76·1	9·9	301 0	4·6	251 21
10	Akola	80·3	9·7	319 5	4·7	258 29
11	Amravati	80·7	8·5	316 9	4·7	256 35
12	Buldhana	77·9	7·5	322 40	4·6	257 58
13	Khandwa	79·6	10·2	306 26	4·7	255 52
14	Hoshangabad	78·6	11·2	303 13	5·0	252 57
15	Bombay	80·1	3·2	277 41	2·8	230 15
16	Ratnagiri	80·2	2·1	300 26	2·5	230 6
17	Marmagao	80·3	2·5	317 24	2·2	240 26
18	Karwar	79·4	2·5	316 23	2·3	241 27
19	Malegaon	78·6	8·3	304 54	5·0	261 37
20	Ahmednagar	76·7	6·9	308 43	3·9	261 36
21	Poona	77·1	5·8	317 42	4·0	262 30
22	Sholapur	80·6	6·6	324 57	4·2	269 12
23	Bijapur	79·2	6·0	326 51	3·7	276 42
24	Belgaum	74·4	4·0	350 15	3·4	267 4
25	Aurangabad	78·4	7·1	315 51	3·5	255 39
26	Bidar	78·4	6·7	331 27	3·8	260 15
27	Gulbarga	81·0	7·6	317 32	4·0	268 58
28	Raichur	82·1	6·3	327 0	3·7	270 27
29	Chitaldrug	77·3	4·6	344 36	3·2	281 51
30	Hassari	73·0	3·5	338 3	3·1	280 4
31	Bangalore	74·5	4·5	327 30	3·0	278 18
32	Mysore	76·1	3·7	340 44	2·9	285 42
33	Mangalore	80·8	2·1	355 15	1·9	250 54
34	Kozhikode	80·5	2·1	8 4	2·1	261 55
35	Cochin	81·4	2·1	25 42	1·5	269 7
36	Trivandrum	79·9	1·9	355 4	1·4	277 35
37	Palayamkotti	85·4	4·6	296 9	1·9	291 55
38	Coimbatore	79·8	3·4	327 3	2·6	282 25
39	Bellary	82·1	6·4	320 21	3·4	281 10
40	Mercara	68·7	2·9	16 19	2·5	273 35
41	Ootacamund	57·6	2·4	318 18	2·0	268 44
42	Kodaikanal	58·7	2·8	324 55	1·5	275 2

TABLE 2 (*contd*)

REGION II

Serial No.	Station	Mean temperature (°F)	First harmonics Amplitude (°F)	First harmonics Phase angle	Second harmonics Amplitude (°F)	Second harmonics Phase angle
1	Chittagong	77·1	7·0	277° 10′	3·3	280° 27′
2	Noakhali	77·0	7·9	277 20	3·7	281 58
3	Barisal	78·1	8·2	280 57	4·0	284 19
4	Jessore	78·5	9·5	283 11	4·6	282 48
5	Calcutta	78·8	9·0	287 34	4·2	283 11
6	Sangorkola	79·4	8·3	285 56	3·9	285 10
7	Midnapur	80·2	8·3	296 20	4·4	282 7
8	Burdwan	79·2	9·4	287 30	4·5	279 39
9	Bankura	79·8	10·3	293 13	4·7	272 59
10	Krishnagar	78·6	10·2	284 16	4·6	278 47
11	Balasore	79·6	8·6	291 24	3·9	283 22
12	Puri	80·5	6·1	281 16	4·0	283 13
13	Gopalpur	79·7	6·6	284 14	2·5	290 36
14	Cuttack	81·7	8·0	301 50	4·0	283 13
15	Sambalpur	80·2	10·2	302 10	4·8	266 0
16	Purulia	79·1	10·3	292 53	4·5	273 59
17	Ranchi	74·9	10·4	296 7	4·4	265 51
18	Jabalpur	76·5	12·3	297 38	4·6	256 51
19	Seoni	76·1	10·0	305 9	4·5	258 52
20	Nagpur	80·4	10·1	309 6	4·8	258 59
21	Raipur	79·7	10·1	307 34	5·0	262 25
22	Chanda	80·7	9·6	312 1	4·8	272 30
23	Nizamabad	80·3	9·0	316 10	4·9	263 25
24	Hyderabad (Dn)	80·0	7·7	319 18	3·9	265 18
25	Hanamkonda	81·9	7·7	314 9	3·9	261 8
26	Pamban	82·6	3·3	292 32	1·4	268 47
27	Madurai	84·0	4·9	300 10	1·5	282 5
28	Nagapattinam	83·2	5·7	291 2	1·2	263 2
29	Tiruchirapalli	84·3	5·9	300 50	1·8	280 12
30	Salem	82·1	5·0	316 46	2·4	276 27
31	Cuddalore	82·7	6·4	288 44	1·4	233 16
32	Vellore	82·2	7·2	298 47	2·6	269 38
33	Madras	83·1	8·1	283 42	1·3	232 29
34	Cuddapah	85·1	7·2	315 52	4·0	272 29
35	Kurnool	82·5	7·4	318 39	3·7	269 20
36	Nellore	84·5	7·6	295 15	1·9	258 27
37	Masulipatam	82·5	6·7	293 14	2·2	251 34
38	Kakinada	82·2	6·1	298 24	3·3	255 41
39	Visakhapatnam	81·2	5·1	287 27	2·0	270 59
40	Pachmarhi	70·5	10·4	307 34	4·9	255 46

TABLE 2 *(contd)*

REGION III

Serial No.	Station	Mean temperature (°F)	First harmonics Amplitude (°F)	First harmonics Phase angle	Second harmonics Amplitude (°F)	Second harmonics Phase angle
1	Dibrugarh	73·0	10·3	263° 5′	2·2	286° 49′
2	Sibsagar	73·5	12·7	265 43	1·5	309 13
3	Tezpur	75·1	10·2	265 21	2·2	299 57
4	Dhubri	70·4	8·9	271 25	3·2	290 11
5	Silchar	76·8	6·4	265 15	2·7	282 11
6	Comilla	77·4	8·0	279 5	4·0	283 42
7	Narayangunj	78·4	8·2	277 5	3·8	283 54
8	Bogra	77·2	9·7	277 37	4·1	282 53
9	Mymensingh	76·9	8·8	272 19	3·6	282 41
10	Rampurboalia	77·5	10·3	280 54	4·5	279 5
11	Faridpur	77·2	9·4	278 20	4·2	282 32
12	Behrampur	78·6	10·4	284 25	4·6	277 55
13	Malda	77·3	11·3	279 9	4·3	277 11
14	Sirajganj	76·8	9·4	277 9	4·2	282 51
15	Dinajpur	76·5	10·5	274 59	3·8	281 47
16	Rangpur	70·8	10·9	273 26	3·9	289 16
17	Jalpaiguri	75·3	10·4	255 33	3·0	278 51
18	Hazaribagh	75·2	11·2	296 10	4·7	265 16
19	Daltonganj	77·4	14·0	289 27	5·3	260 35
20	Punla	76·4	11·7	278 12	4·2	279 12
21	Bhagalpur	77·5	11·7	283 5	4·6	276 23
22	Dharbhanga	76·9	11·7	277 43	4·2	273 21
23	Motihari	75·8	12·9	278 25	4·3	273 4
24	Chapra	77·8	12·9	283 19	4·8	268 15
25	Patna	78·0	12·5	282 17	5·0	270 20
26	Gaya	79·3	12·7	290 19	5·1	267 53
27	Naya Dumka	77·8	11·1	288 26	5·0	275 37
28	Gorakhpur	77·2	13·0	280 19	3·9	270 0
29	Banaras	78·1	14·3	287 52	4·8	264 26
30	Allahabad	78·5	14·6	288 40	4·9	260 28
31	Kanpur	78·2	15·7	288 3	4·1	266 45
32	Lucknow	77·7	14·7	286 17	4·6	263 22
33	Bahrich	76·9	14·0	280 50	4·5	262 6
34	Jhansi	89·1	13·7	292 45	5·6	251 3
35	Agra	79·2	14·6	286 10	5·7	256 44
36	Mainpuri	77·9	16·0	243 3	4·6	252 31
37	Bareilly	76·1	15·3	283 2	4·3	262 53
38	Dehra Dun	71·0	13·7	281 17	3·5	252 20
39	Nowgong	77·5	14·8	291 34	4·8	255 31
40	Satna	77·0	14·1	297 6	4·8	255 35
41	Sagar	77·2	10·9	301 2	5·2	250 3
42	Darjeeling	53·5	10·7	257 31	2·1	280 7
43	Katmandu	65·9	13·0	270 26	2·4	290 31
44	Mukteswar	65·8	11·2	272 34	2·7	244 10
45	Ranikhet	60·5	11·6	277 27	3·1	249 59

TABLE 2 (*contd*)

REGION IV

Serial No.	Station	Mean temperature (°F)	First harmonics Amplitude (°F)	First harmonics Phase angle		Second harmonics Amplitude (°F)	Second harmonics Phase angle	
1	Meerut	75·8	16·1	282°	1′	3·8	259°	46′
2	Roorkee	74·3	16·2	281	41	3·6	259	0
3	Delhi	83·1	13·9	283	52	4·6	255	51
4	Sirsa	77·8	17·9	277	6	4·2	269	12
5	Patiala	75·4	17·1	278	10	5·4	258	6
6	Ambala	75·3	17·1	279	9	3·6	265	13
7	Ludhiana	75·9	18·1	277	56	3·7	257	59
8	Lahore	75·9	19·0	275	55	3·1	260	23
9	Sialkot	74·8	18·7	275	54	3·3	263	54
10	Rawalpindi	70·9	19·6	273	0	2·0	253	58
11	Khushab	76·6	20·1	273	48	2·9	260	41
12	Montgomery	77·7	20·3	274	52	3·1	256	55
13	Multan	78·8	19·5	275	23	3·3	261	12
14	Srinagar	55·2	20·4	272	33	1·1	222	24
15	Dras	35·2	30·1	257	47	0·9	251	14
16	Leh	42·5	21·7	264	49	1·6	304	53
17	Skardu	51·6	24·1	265	56	2·0	301	10
18	Gilgit	62·7	21·4	264	23	2·3	349	40
19	Peshawar	72·4	21·7	270	47	0·7	322	15
20	D.I. Khan	76·2	20·3	274	6	2·4	268	57
21	Quetta	58·9	19·1	271	52	0·6	324	46
22	Kalat	55·1	18·2	271	48	0·3	69	58
23	Pishin	59·3	20·3	274	10	1·1	123	14
24	Jacobabad	80·7	19·7	278	28	3·0	263	9
25	Hyderabad	80·8	12·9	275	2	3·7	257	59
26	Manora	77·8	6·8	273	58	2·4	241	24
27	Bikaner	80·5	17·1	279	24	4·8	256	26
28	Jodhpur	80·1	13·4	282	56	2·9	236	34
29	Jaipur	78·2	14·2	284	29	4·5	249	22
30	Ajmer	76·9	14·5	287	14	4·9	252	37
31	Kotah	81·1	12·0	291	11	4·7	253	24
32	Deesa	80·6	9·6	291	41	5·3	252	50
33	Neemuch	76·7	11·3	291	20	4·9	250	38
34	Simla	55·2	12·5	272	44	2·9	233	18
35	Chakrata	56·9	11·0	268	27	2·3	254	53
36	Murree	57·6	15·3	267	46	3·2	226	10
37	Cherat	64·6	19·0	267	55	2·5	222	0
38	Parachinar	59·1	18·9	264	55	0·9	226	42
39	Drosh	62·3	23·2	257	30	0·4	252	25
40	Mount Abu	68·9	7·5	296	3	5·1	246	13

TABLE 3

Correlation coefficients between the components of the annual oscillation of temperature with latitude, longitude and elevation

Component	Region	Correlation coefficient with Lat.	Long.	Elevation
a_1	I	·8490	—·2036	—·2180
	II	·8093	·2385	·4323
	III	·3980	—·7542	·0283
	IV	·7996	—·0188	·3644
D'	I	·7083	—·5768	—·2699
	II	·2114	·6284	—·5945
	III	·3523	·6355	·1360
	IV	·8370	—·1203	·6012

TABLE 5

Correlation coefficients between the components of the half-yearly oscillation of temperature with latitude, longitude and elevation

Component	Region	Correlation coefficient with Lat.	Long.	Elevation
a_2	I	·7964	—·0750	—·1454
	II	·8721	·3246	·4038
	III	—·4376	—·5375	—·0169
	IV	—·6559	·4138	—·5781
d'	I	·6137	—·6561	—·4266
	II	—·2831	—·4961	·2527
	III	·2649	·9128	·3263
	IV	—·2563	—·2990	—·0837

$d' = (d_x - 23{\cdot}6094)/15{\cdot}2187$

TABLE 4

Regression coefficients of components of annual oscillation of temperature on latitude, longitude and elevation

Component	Region	Partial regression coefficients and standard errors: Latitude R.C.	Latitude S.E.	Longitude R.C.	Longitude S.E.	Elevation R.C.	Elevation S.E.	Multiple correlation coefficient
a_1	I	·0108	·0009	·0072	·0017	·00003	·0001	·90
	II	·0087	·0011	—·0045	·0013	—·00018	·0003	·88
	III	·0068	·0077	—·0059	·0024	—·00043	·0013	·82
	IV	·0195	·0026	—·0031	·0023	—·00011	·0002	·81
D'	I	·0019	·0004	·0018	·0008	·00003	·0006	75
	II	—·0001	·0005	·0008	·0005	—·00018	·00013	·36*
	III	·0022	·0003	·0009	·0001	·00001	·00001	·87
	IV	·0011	·0001	—·0004	·0001	·00002	·00001	·88

*Insignificant at the 5 per cent level

The important features brought out by the regression coefficients are—

(*i*) Elevation has no effect on the amplitude as well as the date of occurrence of the maximum in the oscillation.

(*ii*) The amplitudes increase northwards at the rate of about 7°F for every 10° of latitude. The low insignificant value in Region III can be readily seen to be due to the peculiar nature of the orography in this region.

(*iii*) The amplitudes increase eastwards in Region I which comprise of the west coast of the Peninsula, in Regions II and III decrease eastwards and in Region IV there appears to be no dependence with longitude.

(*iv*) The date of occurrence of the maximum is delayed in Regions I, III and IV northwards and in the Regions I, II and III eastwards and in Region IV westwards.

TABLE 6

Partial regression coefficients of the components of the half-yearly oscillation on latitude, longitude and elevation

Component	Region	Partial regression coefficients (R.C.) and standard errors (S.E.) — Latitude R.C.	Latitude S.E.	Longitude R.C.	Longitude S.E.	Elevation R.C.	Elevation S.E.	Multiple correlation coefficient R
a_2	I	·0042	·0003	·0037	·0007	·000003	·00005	·90
	II	·0054	·0006	—·0024	·0007	—·00008	·0002	·91
	III	—·0085	·0009	—·0028	·0003	·00010	·00005	·89
	IV	— 0040	·0007	·0039	·0006	—·00016	·00005	·87
d'	I	·0007	·0003	—·0015	·0006	—·00004	·00005	·53*
	II	·0003	·0005	—·0012	·0006	—·00003	·00016	·50*
	III	—·0008	·0003	—·0016	·0001	·00004	·00006	·93
	IV	—·0030	·0014	—·0022	·0012	·00016	·00015	·45*

*Insignificant at the 5 per cent level

$d' = (d_x - 23{\cdot}6094)/15{\cdot}2187$

6. Half-yearly oscillation

In Figs. 4 and 5 are plotted the amplitudes and the dates of occurrence of the maxima in the half-yearly oscillation. The amplitudes of the half-yearly oscillation are much smaller in magnitude than those of the annual oscillation. The highest values of the order of 5°F are obtained in the central parts of the country between 20° and 27°N latitudes. In the extreme south of the Peninsula they are of the order of 2°F. It may also be seen that the values are smaller near the coasts and the hills. The maxima in the half-yearly waves occur towards the end of April and October in the central parts of the country between 20° and 33°N latitudes and 70° and 80°E longitudes. In the extreme south of the Peninsula they occur by the first week of April and October and in Kashmir early in March and September.

7. Relationship of the components of the half-yearly oscillation with latitude, longitude and elevation

The correlation coefficients of the components of the half-yearly oscillation with latitude, longitude and elevation are given in Table 5.

Partial regression coefficients of the components of the half-yearly oscillation on latitude, longitude and elevation, their standard errors and the multiple correlation coefficients are given in Table 6.

Here also as in the annual oscillation, the elevation has no effect on the components except in Region IV, where the amplitude decreases upwards at the rate of 0·2°F per 1000 ft. The amplitudes increase at the rate of about 3°F for every 10° latitude northwards over the Peninsula, while over North India they decrease, the decrease being of the order of 5°F in Region III and 2°F in Region IV. The amplitudes increase towards east in the western half of the country and towards west on the eastern half at the rate of about 2°F. As regards the dates of occurrence of the maximum oscillation the multiple correlation for Region III only is significant, being of the order of ·93, where the maxima occur earlier eastwards and northwards.

We have so far fitted the harmonics for the annual and the half-yearly oscillations. It would be worthwhile seeing how much of the variation in the actual pattern of the mean temperature curve have been accounted for by these two oscillations.

As the harmonics are orthogonal to each other, the variance accounted by each of the terms directly reduces the variance

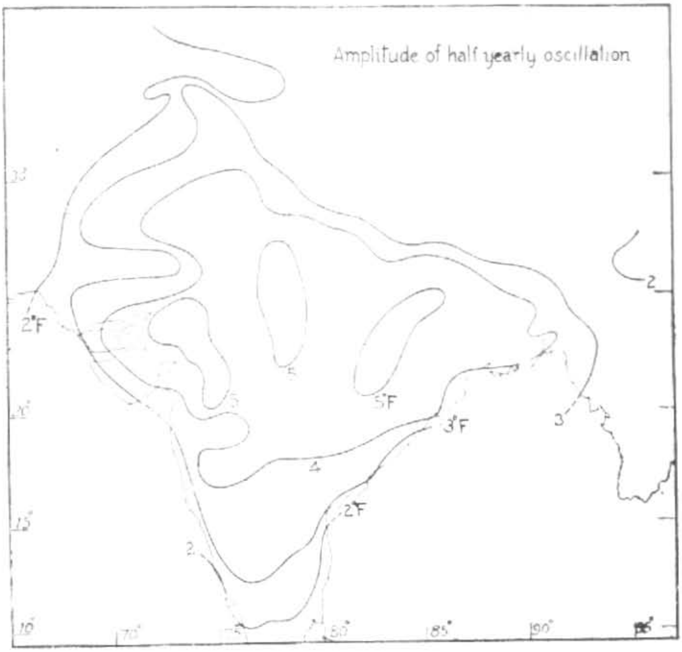

Fig. 4. Amplitude of half-yearly oscillation of temperature (°F)

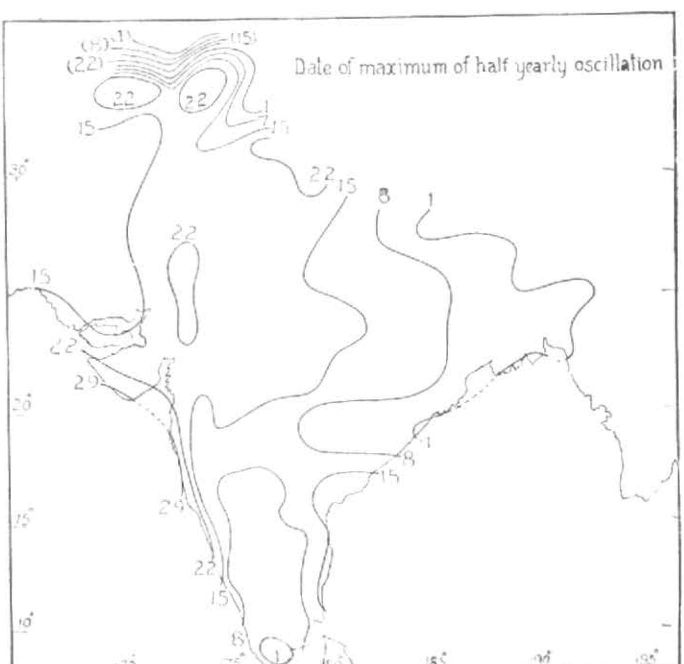

Fig. 5. Date of maximum of half-yearly oscillation of temperature

Figures (without brackets) at the end of lines refer to the date of occurrence of the maximum in the half yearly oscillation in April and October and those within brackets indicate the dates in March and September

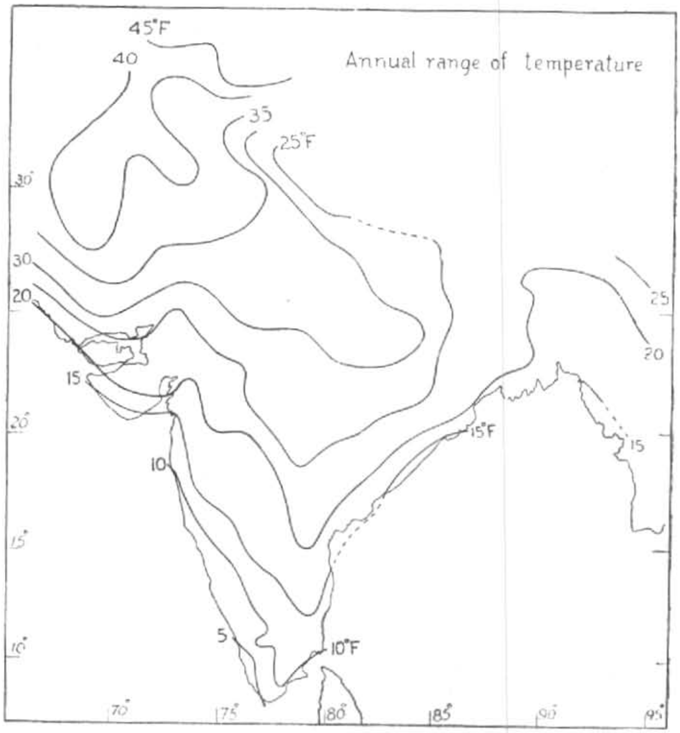

Fig. 6. Annual range of temperature

in the original series and the residual variance at any stage can be calculated by subtracting $\frac{1}{2}a^2$ from the residual variance upto that stage. Thus

$$\sigma'^2 = \sigma^2 - \tfrac{1}{2}(a_1^2 + a_2^2 + \ldots) \qquad (7)$$

where σ^2 is the variance of the twelve monthly values subjected to the analysis, a_1, a_2,....are as defined previously the amplitudes of the first, second etc harmonics and σ'^2 is the residual variance. This actually gives a criterion as to whether or not it pays to calculate further terms of the Fourier Series (Brunt 1937). The values of a_1 and a_2 are given in Table 2. The residual variances have been calculated and have been found to be generally of the order of 10 per cent of the variance in the original series, except in a few stray cases, *e.g.*, Sambalpur—50 per cent, Karachi—40 per cent, Delhi—30 per cent, where the variations in the temperature are probably further controlled by higher order harmonics and other sources of variations. It is not proposed to go into these cases in greater detail here.

8. Annual range of temperature

Before closing this discussion, it would be worthwhile examining the distribution of the 'Annual Range of Temperature', *i.e.*, the range between the highest and lowest mean temperatures of the year. In Fig. 6 are shown the isopleths of Annual Ranges*. The partial regression coefficients of the annual range of temperature on latitude, longitude and elevation are given in Table 7.

The decrease of the annual range at the rate of about a degree for 1000 ft of elevation over the Eastern Himalayas is

*It should be remembered that the amplitudes mentioned in the previous sections are half the ranges in the particular oscillation

TABLE 7

Partial regression coefficients of annual range of temperature on latitude, longitude and elevation

Region	Partial regression coefficients and standard errors						Multiple correlation coefficient
	Latitude		Longitude		Elevation		
	R.C.	S.E.	R.C.	S.E.	R.C.	S.E.	
I	·0281	·0048	·0224	·0094	—·0001	·0007	·95
II	·0276	·0021	—·0201	·0026	—·0009	·0006	·94
III	·0071	·0054	—·0147	·0016	—·0009	·0003	·83
IV	·0297	·0049	—·0048	·0044	—·0001	·0003	·75

the important feature brought out here. The range increases at the rate of about 17°F for every 10° of latitude northwards in all regions except III. The east-west gradient is about a degree for every degree of longitude eastwards over the west Peninsula and westwards over the eastern half and slightly less than a degree in Region III.

A reference to the map of the 'Forest Wealth in India' (Lorenzo 1948) reveals a striking resemblance with the pattern of annual ranges of temperature. The 'evergreens' are concentrated over the Western Ghats and to some extent over the Eastern Ghats, where the annual ranges are not more than 15°F; over the sub-Himalayan regions and over the Deccan Tableland, with ranges of 20-30°F are associated the 'Deciduous Monsoon types' and over northwest Himalayas, with higher annual ranges, the 'Mixed Himalayan'. The occurrence of the different forest types are of course further linked up with the soil, rainfall and other local factors and for a detailed study of the plant geography the combined effect of all the factors should be taken into consideration.

9. Acknowledgements

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REFERENCES

Brunt, D. 1937 *Met. Mag.*, p. 268. (also Combination of Observations, London, 1917, pp. 177-179).

Jagannathan, P. 1948 *India met. Dep. Sci. Notes*, **10**, 121 and 122.

Lorenzo, A. M. 1948 Atlas of India, Oxford Pamphlets on Indian Affairs No. 16.

Lundegårdh, H. 1931 *Environment and Plant Developmen'*, Edward Arnold and Co., London.

Pollak, L. W. 1947 *Geoph. publ., Irish met. Ser.*, Dublin.