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Seasonal Oscillations of daily mean Maximum Temperature in India and neighbourhood

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ABSTRACT. The mean daily maximum temperatures of 124 selected observatories have been subjected to harmonic analysis. The annual oscillations are observed to predominate over the other harmonic oscillations. The amplitudes of annual oscillation are highest in northwest of India and least over the west coast. Half-yearly oscillation amplitudes are highest over central India more towards northern latitudes. The close proximity of the dates of onset of SW monsoon and amplitude maxima of the annual oscillations over a major part in northwest India and adjoining area is striking.

The regression coefficients of the first and second harmonic amplitude with latitude, longitude and elevation have been worked out and discussed.

1. Introduction

The predominant features of Indian rainfall as revealed by Fourier Analysis have been presented by Lettau and White (1964). Earlier, Jagannathan and Khambete (1963) had discussed the important characteristics of the seasonal oscillations of the diurnal range of temperature in India and adjoining regions. In the present paper, the mean daily maximum temperatures at 124 stations in India and adjoining regions have been subjected to harmonic analysis and study on the same lines as was done by Jagannathan (1957). The data have been taken from the *Climatological Tables of Observatories in India* (1953). The stations have been grouped into four regions and the mean values of latitude, longitude and elevation are given in Table 1 (Also see Fig. 2, dotted lines). In Region I, the stations are not so uniformly distributed, therefore, the results in this region (values of coefficients) may not be so representative.

2. Analysis

In the present study, the first five harmonic components of the variations of mean daily maximum temperature have been obtained.

$$A_t = A_0 + \sum_{n=1}^{5} A_n \cos\left(\frac{2\pi nt}{T} - \phi_n\right)$$

where,

A_t = Resultant amplitude of the wave at time t reckoned from $t = 0$ as 15 January

A_0 = Mean amplitude (Annual mean)

A_n = Amplitude of the n^{th} harmonic

ϕ_n = Phase angle of the n^{th} harmonic

T = Periodic time, *i.e.*, 12 months.

The first three harmonic components of the mean daily maximum temperature variations at Nagpur are illustrated in Fig. 1. The first and second harmonics with maximum amplitudes and their phases with dates of maxima are given in Table 2 for all the stations.

3. Discussion

3.1. *Annual oscillation*

The spatial distribution of the amplitude maxima in the annual oscillation and the corresponding dates of incidence of these maxima are shown in Figs. 2 and 3 respectively.

The amplitude of the first harmonic generally being predominant over all other harmonics, is a reflection of the main summer. It is seen from Fig. 2 that the amplitudes A are least over the coastal belts (particularly over the west coast) and gradually increase inland attaining very high values over the Kashmir area and adjoining West Pakistan and Baluchistan. It is seen from *Aviation Climatological Tables* (India met. Dep. 1944), that during summer season, except for a limited area in north India and adjoining places where the low cloud amount is less than 1/10th of the sky (shown in the inset of Fig. 3), the rest of India remains partly to fairly clouded.

The close resemblance in the run of the I.T.C.Z. (northern limit of SW monsoon), the isophase lines for 150° (*i.e.*, 15 June) and 180° (*i.e.*, 15 July), and the gradual shift of the area of least clouding from May to July is striking (shown in Fig. 3 and in its inset).

3.2. *Relationship of the amplitudes of the annual oscillations with latitude, longitude and elevation*

To examine the extent to which the amplitudes of the annual oscillation are dependent on latitude, longitude and elevation, the correlation coefficients, regression coefficients, and their standard errors along with multiple correlation coefficients are given in Tables 3(a) and 4 (a).

The origin of co-ordinates has been taken at 6°N and 65°E and mean sea level. The units for latitude and longitude are minutes and for altitude feet. Amplitudes are in °F.

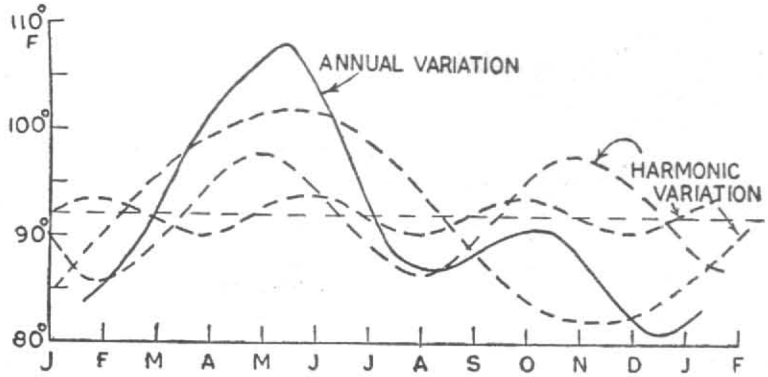

Fig. 1. Annual variations of mean daily maximum temperature and its first three harmonics at Nagpur

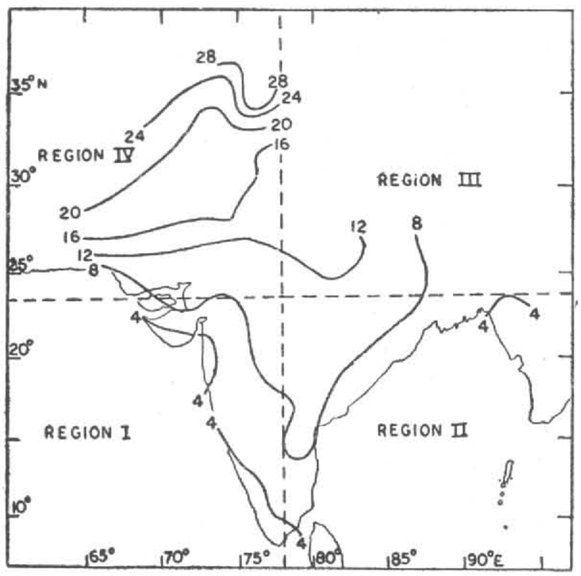

Fig. 2. Distribution of A_1 (°F) — First harmonic amplitudes in °F

TABLE 1

Region No.	Specification	Position of centroid		
		Latitude (N)	Longitude (E)	Elevation (ft)
I	29 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° 25′	73° 40′	1670
II	32 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	17° 46′	82° 00′	602
III	32 stations in northeast India (including East Pakistan) to the north of tropic of Cancer and to the east of 78°E meridian	25° 41′	85° 14′	1175
IV	31 stations in northwest India (including West Pakistan) to the north of tropic of Cancer and to the west of 78°E meridian	29° 25′	73° 29′	2589

TABLE 2

Serial No.	Station	A_0 (°F)	Annual oscillation			Half-yearly oscillation		
			A_1	ϕ	D_1	A_2	ϕ	d_1*
				REGION I				
1	Bhuj	91·1	6·8	150	15 Jun	6·6	197	24 Apr
2	Jamnagar	89·4	5·9	155	20 Jun	5·1	220	5 May
3	Rajkot	92·9	6·4	135	30 may	0·8	162	6 Apr
4	Bhavnagar	93·5	6·7	137	2 Jun	5·6	202	26 Apr
5	Veraval	85·1	0·6	243	18 Sep	2·8	223	7 May
6	Surat	91·5	3·3	92	17 Apr	4·7	196	23 Apr
7	Ahmedabad	94·5	7·7	128	23 May	6·4	207	28 Apr
8	Akola	93·3	9·7	108	3 May	6·1	199	25 Apr
9	Bombay	86·8	1·1	158	23 Jun	3·1	227	9 May
10	Indore	88·2	8·1	122	17 May	6·5	205	28 Apr
11	Mahabaleshwar	74·5	7·3	58	13 Mar	5·0	211	1 May
12	Ratnagiri	86·9	1·5	20	5 Feb	2·9	233	12 may
13	Marmagoa	84·8	1·5	26	11 Feb	2·0	276	4 Jun
14	Ahmednagar	89·7	6·9	103	28 Apr	4·9	192	21 Apr
15	Poona	89·4	6·7	79	4 Apr	5·4	190	28 Apr
16	Belgaum	84·7	7·5	63	18 Mar	4·9	183	16 Apr
17	Aurangabad	90·4	7·3	103	28 Apr	5·3	198	24 Apr
18	Bangalore	84·0	5·6	98	23 Apr	3·3	164	7 Apr
19	Mangalore	87·3	3·1	41	26 Feb	1·6	215	3 May
20	Cochin	85·5	2·9	44	29 Feb	1·1	210	1 May
21	Trivandrum	85·7	2·4	50	5 Mar	1·0	159	5 Apr
22	Mercara	76·1	6·1	50	5 Mar	3·4	171	10 Apr
23	Ootacamund	66·0	5·1	74	29 Mar	2·2	172	12 Apr
24	Kodaikanal	63·8	3·0	100	25 Apr	1·5	203	26 Apr
25	Hassan	83·8	5·7	67	23 Mar	3·8	166	8 Apr
26	Bellary	92·9	6·9	105	30 Apr	4·9	171	10 Apr
27	Amraoti	92·0	8·7	110	5 May	6·1	200	25 Apr
28	Bidar	88·6	8·1	109	4 May	4·2	195	22 Apr
29	Hoshangabad	89·8	9·1	120	15 May	6·9	206	28 Apr
				REGION II				
1	Jessore	87·6	6·9	145	10 Jun	4·4	187	18 Apr
2	Calcutta	88·5	4·7	139	4 Jun	4·3	173	12 Apr
3	Balasore	88·7	6·5	134	30 May	3·9	180	15 Apr
4	Puri	86·1	3·9	171	6 Jul	2·3	174	12 Apr
5	Cuttuck	90·9	6·2	130	25 May	4·7	179	15 Apr
6	Gopalpur	86·3	4·1	163	28 Jun	2·6	211	1 May
7	Jabalpur	88·3	9·9	132	27 May	6·7	203	26 Apr
8	Nagpur	92·1	9·9	117	12 May	5·9	204	27 Apr
9	Raipur	90·3	9·4	120	15 May	6·2	199	25 Apr
10	Chanda	92·6	9·5	113	8 May	5·8	197	24 Apr
11	Nizamabad	92·0	8·7	103	28 Apr	4·3	199	25 Apr
12	Hyderabad (Begumpet)	90·4	7·7	103	28 Apr	4·4	195	22 Apr
13	Negapatam	90·0	7·7	162	27 Jun	0·8	200	25 Apr
14	Madras	92·2	7·5	143	8 Jun	1·1	194	22 Apr
15	Cuddapah	95·3	8·1	123	18 May	2·7	166	8 Apr
16	Kurnool	93·7	7·5	107	2 May	3·6	184	17 Apr
17	Nellore	93·4	8·7	144	9 Jun	2·0	181	15 Apr
18	Masulipatam	90·1	6·9	146	11 Jun	2·1	208	30 May
19	Cocanada	89·3	6·4	128	23 May	3·1	187	18 Apr
20	Vizagapatnam	86·9	4·9	159	24 Jun	1·8	181	15 Apr
21	Pachmarhi	80·1	8·7	120	15 May	6·1	203	26 Apr

D_1=Date of maximum of annual oscillation, d_1=Date of maximum of half-yearly oscillation

* Second maximum occurs after six months

TABLE 2 (*contd*)

Serial No.	Station	A_0 (°F)	Annual oscillation A_1	ϕ	D_1	Half-yearly oscillation A_2	ϕ	d_1*
				REGION II — *contd*				
22	Akyab	85·5	2·4	131	26 May	3·4	176	13 Apr
23	Colombo	85·3	1·4	67	22 Mar	0·5	213	2 May
24	Chaibasa	89·7	9·3	141	6 Jun	5·6	189	21 Apr
25	Gondia	90·7	9·4	117	12 May	6·2	206	28 Apr
26	Sironcha	93·1	9·0	107	2 May	4·6	199	24 Apr
27	Pendra	84·4	9·6	132	27 May	5·6	201	25 Apr
28	Jagdalpur	87·6	8·1	107	2 May	5·1	186	18 Apr
29	Madura	92·6	6·3	143	8 Jun	1·9	147	29 Mar
30	Cuddalore	88·3	7·7	161	26 Jun	0·7	220	5 May
31	Rentichintala	94·3	7·7	123	18 May	3·6	180	15 Apr
32	Calingapatam	88·3	5·3	145	10 Jun	2·4	159	5 Apr
				REGION III				
1	Dibrugarh	81·2	7·7	188	23 Jul	1·8	178	14 Apr
2	Tezpur	83·7	7·3	182	17 Jul	2·4	157	4 Apr
3	Silchar	86·1	5·2	180	15 Jul	2·3	167	9 Apr
4	Bogra	86·5	6·9	151	16 Jun	3·6	227	9 May
5	Jalpaiguri	84·6	6·6	170	5 Jul	3·3	175	13 Apr
6	Hazaribagh	84·6	10·3	133	28 May	5·8	193	21 Apr
7	Daltonganj	89·4	11·7	213	18 Aug	6·3	201	25 Apr
8	Patna	87·6	10·6	150	15 Jun	6·1	189	20 Apr
9	Gorakhpur	87·9	10·9	151	16 Jun	6·3	189	20 Apr
10	Banaras	89·6	11·9	147	12 Jun	6·7	196	23 Apr
11	Allahabad	90·1	12·3	146	13 Jun	6·3	203	26 Apr
12	Lucknow	89·7	12·5	147	12 Jun	6·2	203	26 Apr
13	Agra	90·5	12·9	157	22 Jun	7·1	204	27 Apr
14	Bareilley	87·6	12·7	157	22 Jun	6·5	199	25 Apr
15	Dehra Dun	81·4	12·3	160	25 Jun	5·6	205	27 Apr
16	Nowgong	89·7	12·4	144	9 Jun	7·2	201	25 Apr
17	Cherrapunji	63·9	5·7	182	17 Jul	2·9	175	13 Apr
18	Gauhati	84·7	7·1	100	25 Apr	1·5	203	26 Apr
19	Shillong	69·9	7·3	171	6 Jul	2·7	160	5 Apr
20	Asansol	89·7	9·3	137	2 Jun	5·8	181	15 Apr
21	Satna	88·4	11·3	140	5 Jun	6·9	204	27 Apr
22	Comilla	86·4	4·7	151	16 Jun	3·8	169	9 Apr
23	Dharbanga	86·9	8·5	153	18 Jun	5·3	185	18 Apr
24	Gaya	89·0	12·2	145	10 Jun	4·6	196	22 Apr
25	Purnea	86·7	8·0	155	20 Jun	5·0	177	13 Apr
26	Naya Dumka	87·9	9·0	142	7 Jun	5·8	183	18 Apr
27	Mainpuri	90·6	12·8	155	20 Jun	7·1	205	27 Apr
28	Saugor	87·9	9·7	132	27 May	7·7	193	21 Apr
29	Katmandu	77·7	9·8	168	3 Jul	4·0	174	12 Apr
30	Mukteshwar	62·0	10·7	172	7 Jul	3·9	208	13 Apr
31	Gonda	88·7	10·8	151	16 Jun	5·1	182	16 Apr
32	Kanpur	89·0	12·8	152	17 Jun	7·0	202	26 Apr
				REGION IV				
1	Delhi	88·8	13·8	165	30 Jun	6·6	203	26 Apr
2	Ambala	88·2	14·9	167	2 Jul	6·3	203	26 Apr
3	Ludhiana	88·1	16·7	169	4 Jul	6·2	202	26 Apr
4	Lahore	89·2	16·7	174	9 Jul	5·6	201	25 Apr
5	Sialkot	86·9	17·1	173	8 Jul	5·7	209	1 May
6	Rawalpindi	84·0	18·5	178	13 Jul	4·5	215	3 May
7	Multan	90·1	17·7	173	8 Jul	5·1	197	24 Apr

D_1=Date of maximum of annual oscillation, d_1=Date of maximum of half-yearly oscillation,
* Second maximum occurs after six months

TABLE 2 (*contd*)

Serial No.	Station	A_0 (°F)	Annual oscillation A_1	ϕ	D_1	Half-yearly oscillation A_2	ϕ	d_1*
				REGION IV—*contd*				
8	Dras	48·2	29·5	192	27 Jul	0·9	173	12 Apr
9	Leh	54·9	23·0	186	21 Jul	2·3	159	5 Apr
10	Gilgit	72·2	24·0	182	17 Jul	1·5	133	22 Mar
11	Drosh	72·2	25·3	188	23 Jul	1·0	160	5 Apr
12	Kargil	59·3	29·7	190	25 Jul	2·5	184	17 Apr
13	Peshawar	85·0	20·1	180	15 Jul	2·5	222	6 May
14	Quetta	73·8	21·6	184	19 Jul	1·4	185	18 Apr
15	Jacobabad	95·5	18·3	171	6 Jul	5·1	201	25 Apr
16	Kalat	72·1	20·8	183	18 Jul	0·9	201	25 Apr
17	Lyallpur	88·7	17·0	181	16 Jul	4·8	202	26 Apr
18	Manora	84·1	5·7	181	16 Jul	2·9	220	5 May
19	Fortsandeman	79·7	17·7	173	8 Jul	5·1	197	24 Apr
20	Khanpur	93·6	17·2	173	8 Jul	5·0	202	26 Apr
21	Kabul	67·7	26·3	189	24 Jul	2·3	191	20 Apr
22	Sriganganagar	90·8	17·8	175	10 Jul	5·7	205	28 Apr
23	Bikaner	92·0	16·1	158	23 Jun	6·1	203	26 Apr
24	Jodhpur	91·7	11·2	160	25 Jun	6·4	205	28 Apr
25	Jaipur	89·9	12·1	160	25 Jun	6·9	206	28 Apr
26	Ajmer	88·2	9·8	152	17 Jun	6·5	204	27 Apr
27	Kotah	91·9	11·0	148	13 Jun	6·8	207	28 Apr
28	Deesa	94·4	7·3	140	5 Jun	7·1	210	1 May
29	Simla	62·4	12·5	175	10 Jun	3·7	214	2 May
30	Mt. Abu	75·8	6·7	143	8 Jun	6·3	210	1 May
31	Guna	88·9	9·9	136	1 May	6·9	211	1 May

D_1=Date of maximum of annual oscillation, d_1=Date of maximum of half-yearly oscillation,
* Second maximum occurs after six months

TABLE 3

Correlation coefficients between the amplitudes of (a) the annual oscillation A_1, (b) the half-yearly oscillation A_2, of mean daily maximum temperature with latitude, longitude and elevation

Region	Correlation coefficient with Latitude	Longitude	Elevation
	(*a*)		
I	·4242	·3081	·1878
II	·2531	—·5443	·5765
III	·2779	—·8592	—·0487
IV	·8418	—·0596	·5738
	(*b*)		
I	·6368	—·0479	—·1308
II	·8117	·0208	·6621
III	—·1089	—·8570	—·2133
IV	—·6385	·3608	—·6452

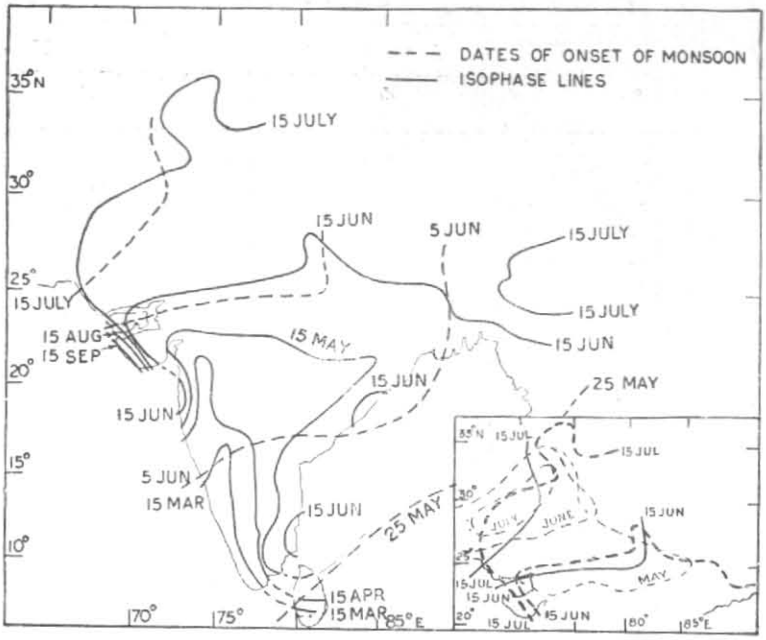

Fig. 3. First harmonic — Dates of incidence of annual maximum

Inset

1. Thin dotted lines represent areas where low clouding (in the afternoon) is 1/10 or less of the sky in the respective month indicated
2. Thick lines (continuous) represent I.T.C.Z. (northern limit of monsoon)
3. Thick dotted lines are the iso-phase curves of annual maxima (A_1) for 15 June and 15 July

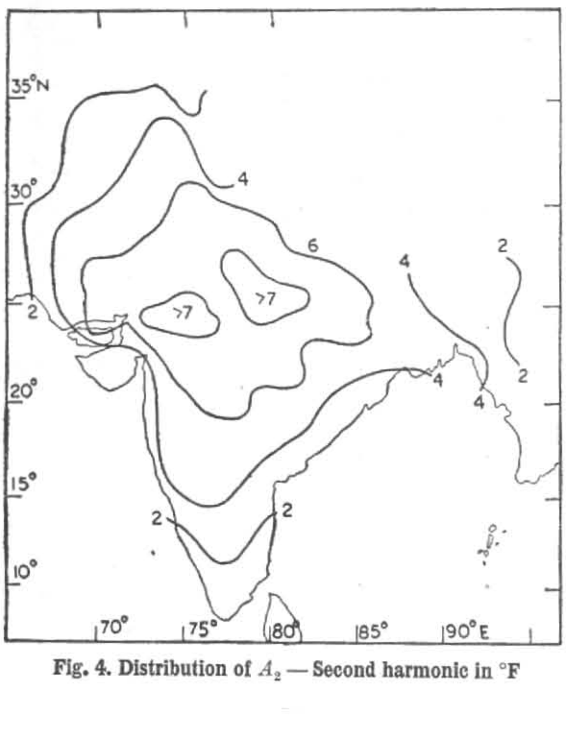

Fig. 4. Distribution of A_2 — Second harmonic in °F

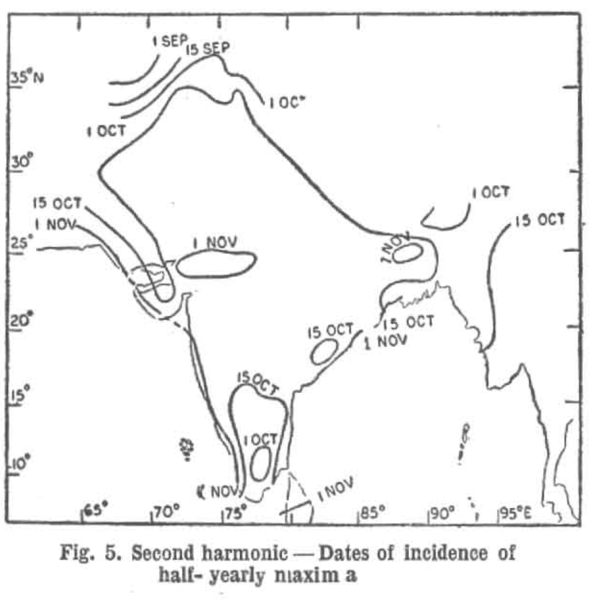

Fig. 5. Second harmonic — Dates of incidence of half- yearly maxim a

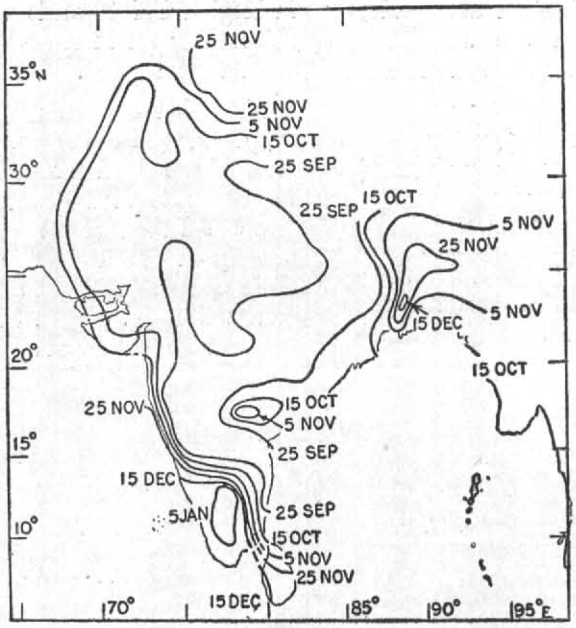

Fig. 6. Third harmonic — Dates of incidence of 4-monthly maxima

TABLE 4

Regression coefficients of the amplitudes of (a) the annual oscillation A_1, (b) the half-yearly oscillation, of mean daily maximum temperature with 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.)	
			(a)				
I	·0087	(·0010)	·0119	(·0025)	·00032	(·0002)	·83
II	·0036	(·0008)	—·0053	(·0016)	·00007	(·0001)	·79
III	·0010	(·0018)	—·0074	(·0031)	—·00002	(·0004)	·88
IV	·0255	(·0014)	—·0044	(·0029)	—·0001	(·0003)	·92
			(b)				
I	·0068	(·0001)	·0057	(·0004)	·00007	(·0002)	·89
II	·0035	(·0003)	—·0012	(·0003)	·00042	(·0003)	·87
III	—·0088	(·0007)	—·0043	(·0002)	—·00005	(·00004)	·91
IV	—·0092	(·0006)	·0065	(·0005)	—·00031	(·00006)	·90

The important features brought out by regression coefficient are —

(i) Elevation has no effect on the amplitude A,

(ii) The amplitudes increase northwards at the rate of 6°F for 10° of latitude. In Region III the value is insignificant,

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

3.3. *Half-yearly oscillation*

The amplitudes and phases of the half-yearly oscillations are shown in Figs. 4 and 5 respectively. It is seen that the maximum amplitudes occur over a limited area in central India during October and November.

3.4. *Relationship of the half-yearly amplitude with latitude, longitude and elevation*

The correlation coefficients, regression coefficients and their regression errors and multiple correlation coefficients of half-yearly amplitude A with latitude, longitude and elevation are given in Tables 3 (b) and 4 (b).

Here also, like the annual oscillation amplitude, the elevation has no effect on the amplitude except in Region IV where the amplitude decreases upwards at the rate of 0·3°F per 1000 ft. Over the Peninsula, the amplitudes increase northwards at the rate of 3°F for every 10° of latitude, while over north India they decrease at the rate of 5°F in Regions III and IV. In the western half of the Peninsula, the amplitudes increase towards east at the rate of 3°F whereas in the eastern half they increase at the rate of only 1°F towards west. There is an increase at the rate of about 2°F in Region III towards the west, while Region IV records an increase at the rate of about 4°F from west to east.

The third harmonic amplitudes are small in magnitude (all of the order of 1°F). The iso-phase lines of the third harmonic wave (Fig 6) has a well marked and narrow nodal zone in the southern parts of India, which may perhaps have some bearing on the orographic features of that region. Such nodal zones were also observed by Lettau and White (*loc. cit.*) in the third harmonic phase diagram for rainfall analysis of India.

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