551.521 : 551.553.21

An estimate of Solar Radiation over India in the pre-monsoon season

M. G. GUPTA

Meteorological Office, New Delhi

(*Received 17 October 1964*)

ABSTRACT. The computations of diabatic heating over India in the pre-monsoon season, with the help of a simple formula due to Mintz (1958), indicate the gradual build up of a zone of diabatic heating over central India from March to May. These results have been checked against estimates of net radiation over India during March, April and May. For this purpose the outgoing long wave radiation was computed with the help of Elsasser's radiation diagram, the results of which agree fairly well with the measurements of long wave radiation by Tiros IV. For incoming solar radiation, mean values based on 2–6 years' data of pyrheliometer observations have been utilised. By subtracting the outgoing radiation from the sum of (*a*) the radiation observed at the surface of the earth and (*b*) the radiation absorbed by the atmosphere, an estimate of the net radiation for diabatic heating has been obtained. The values thus obtained, are generally higher than the values given by Mintz's formula. But there is fairly good agreement on the order of magnitude.

1. Introduction

In the past decade, meteorologists have tried to construct realistic models of the general circulation, which include some form of diabatic heating. The best known experiments in this direction are those of Phillips (1956) and Mintz (1958).

From the view point of model experiments, the monsoon over India poses an interesting problem because we may regard it as a perturbation on zonal flow created by intense heating over the Indian Sub-continent. However, if we are to build a theoretical model of the monsoon, we need much detailed information on the rate of diabatic heating over India.

In this paper, we present a few estimates of diabatic heating based on a simple formula due to Mintz (1958). These computations are later checked against calculations of the net radiation, that is, the difference between incoming solar radiation and outgoing long wave radiation over India.

The present study is confined to the pre-monsoon months of March, April and May. In these months, the atmosphere over India is largely free of clouds. In this period, the average number of days when the total cloud amount is more than 2-3 octas, does not exceed more than 5 per month, at any Indian station, with the only exception of Calcutta in May. To simplify the calculation therefore, our estimates are based on the assumption of clear skies.

2. Network of upper air stations and pyrheliometer observations

In Fig. 1 we show the network of upper air stations for which monthly normal values of temperature and water vapour content are available. In the same figure we have indicated the stations for which the mean incoming radiation (sky+diffuse) is available for each month. The mean radiation values are based on 2–6 years' data. They were kindly supplied to us for this investigation by Mr. P. S. Hariharan, Meteorologist, Poona.

Unfortunately, the component of diffuse radiation is only available from two stations, *viz.*, New Delhi and Poona. As we shall see later, we have to get over this deficiency by making an assumption about the fraction of the total radiation (received at the ground) which is direct.

In a few instances the location of an upper air station does not coincide exactly with a station equipped with a pyrheliometer. For example, while we can estimate the outgoing long wave radiation from the mean upper air sounding of Bombay, the incoming solar radiation can be only estimated from the pyrheliometer observations at Poona. We assume that the incoming radiation figures of Poona are also representative of Bombay. The proximity of the two stations partly justifies this assumption, but this need not be strictly true because the moisture pattern over Bombay may differ from Poona.

3. Computations with Mintz's formula

Mintz's (1958) formula expresses the difference between the net heat supplied to a column of the atmosphere from the ground and the heat lost by the column to space (Fig. 2). Let us denote the first term by Q_G and the second by Q_0 so that—

$$Q = Q_G - Q_0 \tag{3·1}$$

The second term is generally constant. This has been experimentally verified by satellite observations of the long wave radiative flux through the top of the atmosphere (Huss 1961).

It is now assumed that the heat supplied to the column (Q_G) is proportional to the temperature

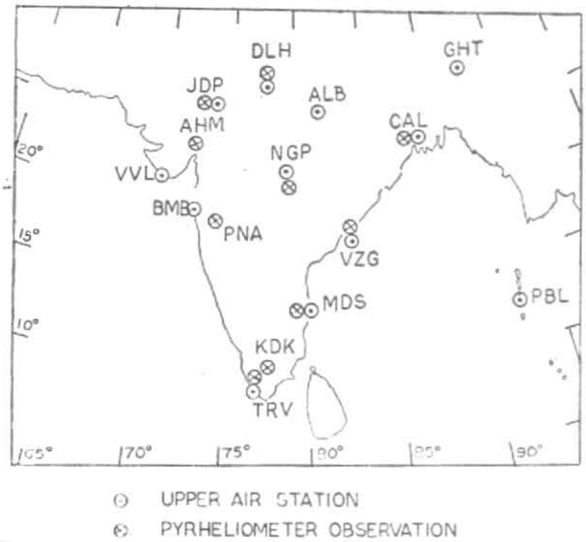

Fig. 1. Network of upper air stations and pyrheliometer observatories

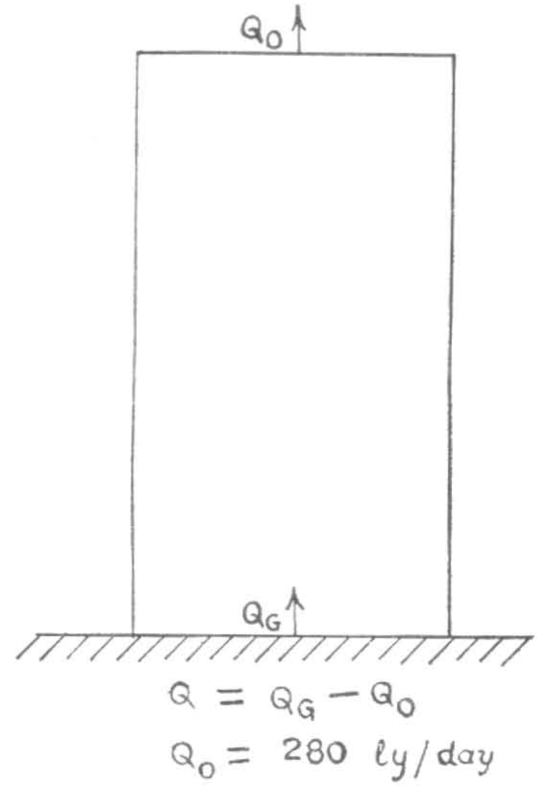

Fig. 2. Flux of heat through unit column of the atmosphere (Mintz 1958)

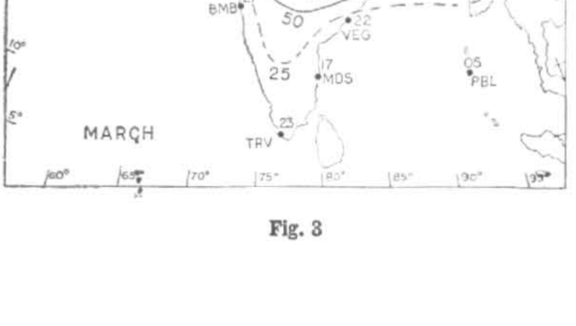

Fig. 3

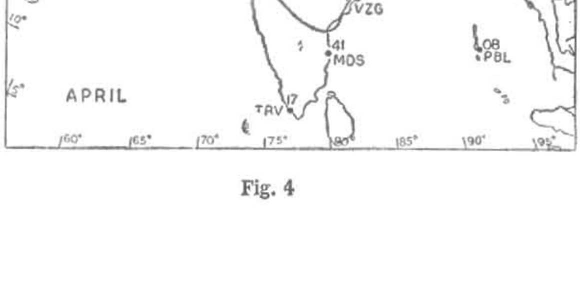

Fig. 4

Figs. 3-4. Rate of diabatic heating by Mintz's formula
(Contours indicate values in langlies per day)

difference between the ground and a representative level of the atmosphere, 500 mb. Consequently,

$$Q = Q_G - Q_0$$
$$= b\,(T_G - T_5) - Q_0 \qquad (3\cdot2)$$

where b is the constant of proportionality, and the subscripts G, 5 refer to the temperatures at the ground and at 500 mb respectively.

If we take the global average of (3·2), and denote the mean values—with respect to space and time—by a subscript m, we obtain—

$$Q_m = b\,(T_G - T_5)_m - Q_0 \qquad (3.3)$$

Denoting $T_G - T_5$ by $\triangle T$ we have, from (3·3),

$$b\,(\triangle T)_m = Q_0 \qquad (3\cdot4)$$

Hence,

$$Q = b\,[\triangle T - (\triangle T)_m] \qquad (3\cdot5)$$

From climatological tables we may put

$$(\triangle T)_m = 30\cdot8^\circ\mathrm{C} \qquad (3\cdot6)$$

For Q_0, Mintz considered an average value based on the computations by London (1951), Houghton (1954) and Alissow *et al.* (1956). On this basis, we have,

$$Q_0 = 280 \text{ ly/day} \qquad (3\cdot7)$$

From (3·4) we obtain—

$$b \simeq 9\cdot0 \text{ ly/day/}^\circ\mathrm{C} \qquad (3\cdot8)$$

Finally, from (3·5) we get the following expression for Q,

$$Q = 9\cdot0\,(\triangle T - 30\cdot8) \text{ langlies per day} \qquad (3\cdot9)$$

Using (3·9) we computed values of Q from monthly mean upper air soundings. The computations are shown in Figs. 3, 4 and 5.

The main features are the gradual build up of a zone of diabatic heating over central India which extends to Peninsula and northwest India towards May. The maximum rate of diabatic heating in May is of the order of 95 ly/day. This corresponds to a warming of the atmosphere by about 0·4°C/day. In the region to the northeast of India we observe a zone of cooling. The maximum cooling rate is of the same order of magnitude as the rate of diabatic heating over India.

4. Estimates of incoming radiation

Mean monthly values of the total incoming solar radiation (direct+diffuse) are available at a number of Indian stations. They are reproduced in Table 1.

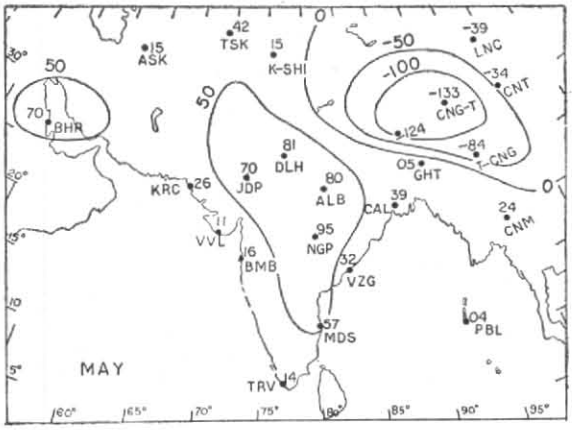

Fig. 5. Rate of diabatic heating by Mintz's formula
(Contours indicate values in langlies per day)

The two components of the total incoming radiation, direct and diffuse, are available for New Delhi and Poona. The values are shown in Table 2.

From Table 2, we computed the fraction of the total radiation that reaches the earth's surface as direct incoming radiation. This is the ratio of values in cols. II and III of Table 2. Table 3 gives us the computed values.

We have, therefore, assumed that for all stations in India, 0·70×total incoming radiation at the surface = the direct radiation reaching the ground. This implies that the remaining fraction (0·3) of the total radiation is in the form of diffuse radiation. It is difficult to state how far this assumption is valid. An examination of mean insolation figures presented by Houghton (1954) indicated that between 0°—30°N, the ratio of direct and total insolation reaching the ground is relatively constant and of the order of 0·85. Our assumption based on data from New Delhi and Poona is, therefore, of the same order of magnitude.

On the basis of the above assumption, we can estimate the total radiation absorbed by (*a*) the atmosphere and (*b*) by the earth's surface, if we know the earth's albedo. As the albedo would depend mainly on the colour of the soil, the stations for which incoming solar radiation values are available (Table 1) were divided into three categories symbolising the main soil types of the sub-continent, *viz.*, (1) grey alluvium of north India, (2) black cotton zone of the Peninsula and central India and (3) green, grass covered coastal areas. Mean values of the percentage of solar radiation absorbed by these types of the surfaces have been obtained from the values given by Ramdas (1960), and are given in Table 4. Employing these values we obtained the radiation absorbed at the surface.

TABLE 1

Mean monthly values of total incoming solar radiation (ly/day) reaching the ground

	Station	March	April	May
1.	Ahmedabad (23°04′N, 72°38′E)	571	629	659
2.	Calcutta (22°39′N, 88°27′E)	483	518	527
3.	Jodhpur (26°18′N, 73°09′E)	556	629	662
4.	Kodaikanal (10°14′N, 77°28′E)	568	516	488
5.	Madras (13°00′N, 80°11′E)	593	587	558
6.	Nagpur (21°06′N. 79°03′E)	548	583	585
7.	New Delhi (28°35′N, 77°12′E)	520	587	629
8.	Poona (18°32′N, 73°51′E)	591	612	607
9.	Trivandrum (08°29′N, 76°57′E)	574	520	430
10.	Visakhapatnam (17°43′N, 83°14′E)	576	575	586

TABLE 2

Mean direct and diffuse radiation at New Delhi and Poona in ly/day

I	II			III			IV		
Station	Total radiation at earth's surface			Direct radiation at earth's surface			Diffuse radiation at earth's surface		
	Mar	Apr	May	Mar	Apr	May	Mar	Apr	May
New Delhi	520	587	629	366	402	416	154	185	213
Poona	591	612	607	468	442	405	123	170	202

TABLE 3

Ratio of direct and total radiation

Station	Mar	Apr	May
New Delhi	·70	·68	·66
Poona	·79	·72	·67
Mean	·70		

TABLE 4

Percentage of solar radiation absorbed by surface of the earth

Station	Type of soil surface	Percentage of solar radiation absorbed
Delhi and Jodhpur	Sokrand soil (Grey, Alluvium)	59
Ahmedabad, Nagpur and Poona	Poona black cotton soil (nearly black)	84
Calcutta, Kodaikanal, Madras, Trivandrum and Visakhapatnam	Grass covered soil (green)	68

The radiation reaching the top of the atmosphere was obtained from Smithsonian Tables (1951). By subtracting from this figure the sum of the direct radiation and twice the diffuse radiation at each station, we obtained the radiation absorbed by the atmosphere. The details are given in Table 5.

Figures against row I of Table 5 are obtained by multiplying the figures in Table. 1 by $(1-\alpha)$, where α is the appropriate value of the albedo. Figures against row III are $0\cdot70\times$ values given in Table 1. The figures in row V are values in row II—[row III + 2 × row IV].

5. Outgoing long wave radiation

From the mean upper air soundings at each station, we have tried to estimate the outgoing long wave radiation at the tropopause with the help of Elsasser's diagram. The various assumptions of this diagram are well known, but for practical computations it is still recognised as a useful tool. The principal difficulty is that we have to make an assumption about the distribution of water vapour above 500 mb. In the present study it has been assumed that the moisture content decreases linearly from 500 mb to the tropopause. It is difficult to estimate the error caused by this simplification, but a few trials with more rapid rates of decrease did not indicate appreciable error. Moreover, it was found that the computations by us agreed fairly well with observations of outgoing long wave radiation over India from weather satellites. The estimate of outgoing radiation prepared with the help of Elsasser's diagram is given in Table 6.

TABLE 5

Solar radiation absorbed by the atmosphere and the ground (ly/day)

		Ahmedabad	Calcutta	Jodhpur	Kodaikanal	Madras	Nagpur	New Delhi	Poona	Trivandrum	Visakhapatnam
I. Solar radiation absorbed at surface	Mar	480	328	328	386	403	460	307	496	390	392
	Apr	528	352	371	351	399	490	346	514	254	391
	May	554	358	391	332	379	491	371	510	292	398
II. Solar radiation at top of atmosphere	Mar	800	800	790	850	850	800	750	810	850	810
	Apr	900	900	890	880	890	900	880	900	860	900
	May	910	910	920	890	900	920	920	910	870	910
III. Direct beam at surface	Mar	400	338	389	398	415	384	364	414	402	403
	Apr	440	363	440	361	411	408	411	428	364	403
	May	461	369	463	342	391	410	440	425	301	410
IV. Diffuse at surface	Mar	171	145	167	170	178	164	156	177	172	173
	Apr	189	155	189	155	176	175	176	184	156	173
	May	198	158	199	146	167	176	189	182	129	176
V. Absorbed by atmosphere	Mar	58	172	67	112	79	88	74	42	104	61
	Apr	82	227	72	209	127	142	117	104	184	151
	May	43	225	59	256	175	158	102	121	311	148

TABLE 6

Estimate of outgoing radiation (ly/day)

Station	Mar	Apr	May
1. Ahmedabad (Veraval)	440	450	460
2. Calcutta	449	467	446
3. Jodpour	454	481	489
4. Kodaikanal (Madras)	469	458	458
5. Madras	469	458	458
6. Nagpur	454	458	501
7. New Delhi	440	470	492
8. Poona (Bombay)	467	456	463
9. Trivandrum	434	445	432
10. Visakhapatnam	431	439	442

TABLE 7

Net radiation (ly/day)

Station	Mar	Apr	May
1. Ahmedabad	98	160	137
2. Calcutta	51	112	137
3. Jodhpur	—59	— 38	— 39
4. Kodaikanal	29	102	130
5. Madras	13	68	96
6. Nagpur	94	174	148
7. New Delhi	—59	— 07	— 19
8. Poona	71	162	168
9. Trivandrum	60	93	171
10. Visakhapatnam	22	103	104

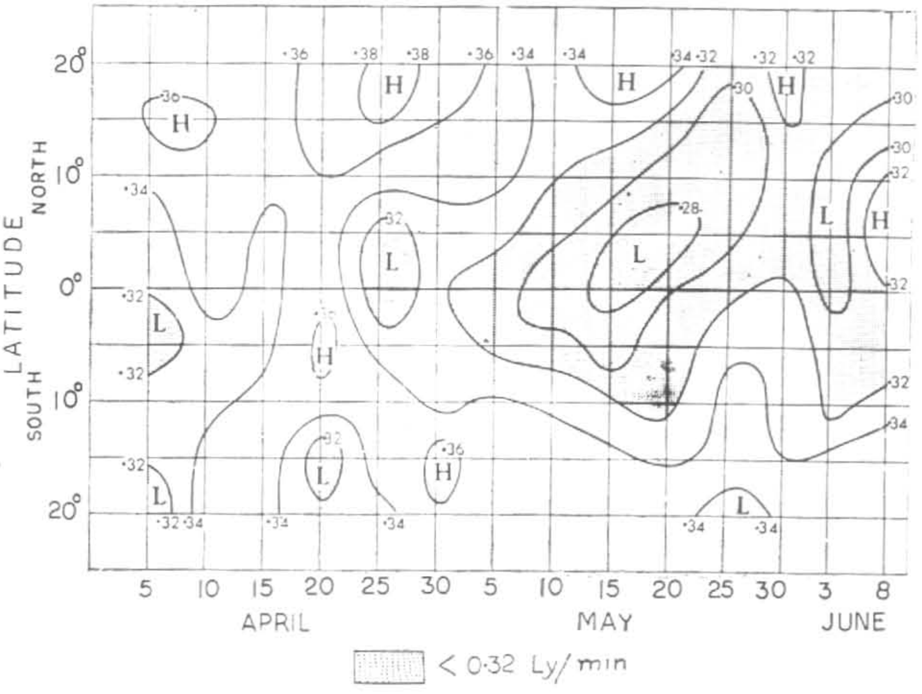

Fig. 6. Outgoing long wave radiation recorded by Tiros IV (ly/min)

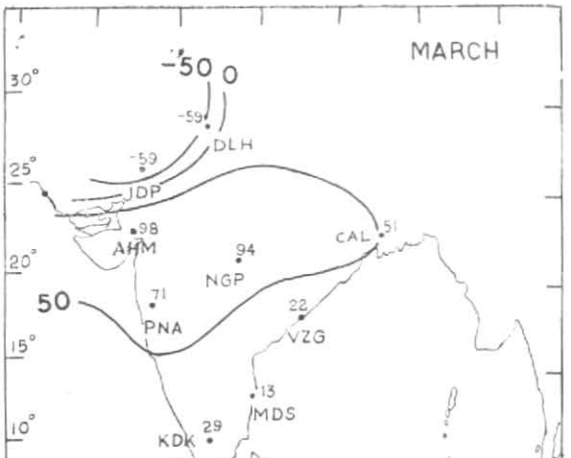

Fig. 7

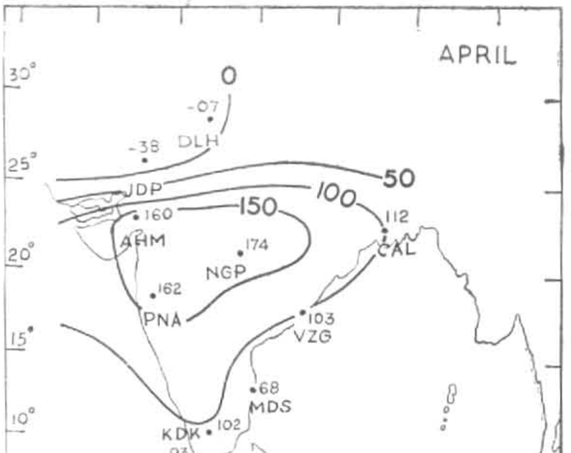

Fig. 8

Figs. 7-8. Rate of diabatic heating in langlies per day based on radiation data

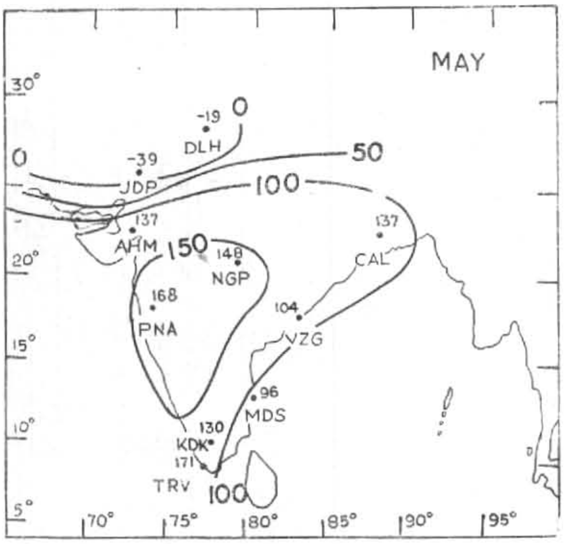

Fig. 9. Rate of diabatic heating in langlies per day based on radiation data

In Fig. 6 we reproduce the long wave radiation recorded by Tiros IV. The values shown in Fig. 6 are five-day averages for April, May and June between 50°E and 110°E, and 20°N—20°S. This diagram, was obtained through the courtesy of Mr. Krishna Rao of the United States Weather Bureau. It is rather interesting to note that the maximum long wave radiation observed by Tiros IV is of the order of 548 ly/day, while the minimum is of the order of 432 ly/day. A comparison with Table 6 shows that computations made with Elsasser's diagram yield values of the same order of magnitude.

6. Estimate of net radiation

If we subtract the outgoing radiation from the sum of (*a*) the radiation absorbed at the surface and (*b*) the radiation absorbed by the atmosphere, then an estimate is obtained of the net radiation available for diabatic heating. In substance, this amounts to forming the sum of figures against rows I and V of Table 5, and deducting the values presented in Table 6. The result of this operation is shown in Table 7.

The above values are shown in Figs. 7, 8 and 9. When we compare them with Figs. 3, 4 and 5, it is noted that over central India and Peninsula, the values are generally higher than values obtained by Mintz's formula but there is agreement on the order of magnitude. The build up of a zone of diabatic heating over central India extending to southern Peninsula in the month of May, is well marked in this case also. The supply of heat at 150 langlies per day in the months of April and May, corresponds to heating to 0·6°C per day. This appears to us to be a little on the high side.

Over northwest India, the values in Figs. 7, 8 and 9 indicate diabatic cooling which decreases from March to May. The values are contrary to the climatological belief and can be attributed to non-accounting of the heating effect by diffusion due to largeamount of suspended particles in this area, which reduces the amount of actual outgoing radiations. Investigations are in progress to estimate the role of these dust particles in the diabatic heating process.

7. Summary and conclusions

We may summarise the principal results of the study in the following manner—

(1) Computations with Mintz's formula indicate that a zone of diabatic heating gradually builds up over central India from March to May. The rate of diabatic heating is of the order of 0·4°C per day. In the region northeast of India, we find a zone of radiational cooling. The cooling rate is again of the order of 0·4°C per day.

(2) Our computations of outgoing long wave radiation with Elsasser's diagram agree fairly well with measurements of long wave radiations by Tiros IV between April and June. The maximum outgoing radiation is about 500 ly/day, while the minimum is approximately 430 ly/day.

(3) Estimates of net radiation based on pyrheliometer observations over central parts of country and Peninsula, yield values which are slightly higher than those obtained by Mintz's formula. There is, however, agreement on the order of magnitude. These estimates indicate diabatic heating at the rate of 0·6°C per day over this area.

(4) Outgoing radiations over northwest India appear to be greatly effected due to the presence of large amount of suspended dust particles.

8. Acknowledgement

The author is grateful to Dr. P. K. Das, Director of Northern Hemisphere Analysis Centre, New Delhi, for help and guidance in the preparation of this paper. The author is also thankful to Mr. P. S. Hariharan for the mean incoming radiation data of Indian stations supplied by him and also to Mr. P. Krishna Rao of the United States Weather Bureau, for the Tiros data reproduced in Fig. 6.

REFERENCES

Alissow, B. P., Drosdow, O. A. and Rubinstein, E. S.	1956	*Lehrbuch der Klimatologie*, Deutscher, Verlag der Wissenschaften, Berlin.
Houghton, H. G.	1954	*J. Met.*, **11**, p. 1.
Huss, A.	1961	Numerical studies of planetary circulations. Final Rep. No. AF19(604)-4963. Univ. California.
London, J.	1951	*Progr. Rep.*, 131.06, New York Univ.
Mintz, Y.	1958	*Bull. Res. Coun. Israel*, 7G, 2-3, 67.
Phillips, N. A.	1956	*Quart. J. R. met. Soc.*, **82**, 123.
Ramdas, L. A.	1960	Crops and Weather in India, Table 55.
Smithsonian Institution, Washington	1951	*Smithsonian Meteorological Tables*, Sixth Edition, Table 134, p. 419.