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Measurements of Solar Radiation and Atmospheric Turbidity with Ångström Pyrheliometers at Poona and Delhi during the I.G.Y.

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ABSTRACT. The paper discusses the diurnal and seasonal variations of the Ångström turbidity coefficient at Delhi and Poona during 1958, calculated from measurements of direct solar radiation with Ångström compensated pyrheliometers and standard red glass filters. Turbidity shows a pronounced maximum during the summer months at both places and a minimum during winter, with the turbidity at Delhi being about twice that at Poona. Turbidity values are generally higher in the early morning and late evening hours than during the hotter part of the day and the values are generally higher in the early morning than in the afternoon. Variations in turbidity with altitude and latitude and in different synoptical air masses are also discussed.

1. Introduction

Measurements of the intensity of direct solar radiation at normal incidence are of fundamental importance in meteorological, climatological and geophysical studies, in the analysis of the absorption and scattering of radiation in the atmosphere and in investigations of the degree of turbidity of the atmosphere and its constituents such as dust and water vapour.

Direct solar radiation measurements with Ångström pyrheliometers have been made at Delhi since 1955 and at Poona since 1957. The present paper summarises the results of these observations during the IGY and the diurnal and seasonal variations of direct solar radiation for the entire spectrum and for selected regions. Ångström turbidity coefficients, which give a close measure of the total quantity of dust present in the atmosphere have been computed for the first time for these regions. The diurnal and seasonal variations of turbidity as well as its dependence on different synoptic air masses are discussed.

2. Method of measurement

The principle of measurement of direct solar radiation intensities at normal incidence using Ångström compensation pyrheliometers is well known (IGY Instr. Manual 1957). In operation, the absorption of heat by a thin blackened manganin strip exposed to the sun's rays is determined by measuring the electrical energy necessary to warm a similar but shielded strip to the same temperature. The equality of temperatures is measured by means of thermocouples attached to the backs of the strips and connected in opposition through a sensitive null point galvanometer. The heating current provided by a low-voltage battery and parallel pair of rheostats is measured by means of a precision milliammeter. If i is the heating current in amperes, the intensity I of direct solar radiation in cal/cm^2/min is given by $I=K.i^2$, where K is a constant for the pyrheliometer, depending on the resistance, width and absorption coefficient of the strips.

By isolating the red and infra-red regions of the spectrum, where absorption by water vapour is considerable, from the ultraviolet and visible regions, where attenuation is due mainly to scattering by air molecules and dust, a turbidity factor can be computed for the short-wave component of radiation I_k (IGY Instr. Manual 1957). I_k is given by I_t-I_r, where I_t is the total direct solar radiation measured without any filters and I_r is the red and infra-red radiation for the wavelength range 630 to 2800 $m\mu$, measured after transmission through the red filter Schott RG_2. Standard red Schott glass filters RG_2 of 1·5 mm thickness having almost 100 per cent transmission between 0·630 and 2·800 μ and with Davos correction factor DR_2 obtained from the Davos Physical Meteorological Observatory were used to isolate the shortwave radiation. If I_R is the intensity measured with filter RG_2 having a correction factor DR_2, $I_r = DR_2 . I_R$

I_k is then given by $I_t - DR_2 . I_R$ (1)

Observations of I_t and I_R were made regularly thrice a day at 0830, 1130 and 1430 IST, whenever the sun and sky within 5° of the sun were free from clouds. Instantaneous observations at 0530 and 1730 IST were also taken whenever the sun's disc was visible above the horizon. Over 450 observations were made at Delhi during 1958 and over 600 at Poona which are summarised in Tables 1 and 2. No observations were possible at Delhi during July and at Poona during July and August, as a result of monsoon clouding. The number of days when intensity measurements could be made were 175 at Delhi and 190 at Poona, the fewer days during monsoon at Poona being offset by fewer observations during winter at Delhi. More observations were possible on the whole, in the mornings than in the afternoons.

3. Atmospheric Turbidity

In the ultraviolet and visible regions of the spectrum, where attenuation is caused mainly by dry air and dust, the attenuation can be expressed as

$$I = \frac{1}{S} \int_0^\infty I_0 \; (\lambda) . \, e^{-A(\lambda)} \, .d\lambda \qquad (2)$$

where I is the radiation intensity measured with the instrument

$I_0(\lambda)$ is the solar intensity outside the atmosphere at the mean sun-earth distance Rm,

S is the reduction factor for the mean solar distance R^2/Rm^2, R being the sun-earth distance corresponding to the date,

$e^{-A(\lambda)}$ is the transmission of the whole atmosphere as a function of wavelength,

$A(\lambda) = A_R \; (\lambda) + A_D \; (\lambda)$, where $A_R \, (\lambda)$ gives the extinction in clear dry air (Rayleigh scattering) and $A_D \, (\lambda)$ the extinction by dust.

$$A_R \; (\lambda) = m \, . \, a_R \; (\lambda) \qquad (3)$$

where m is the optical air mass and $a_R \; (\lambda)$ is the extinction coefficient for Rayleigh scattering.

$$A_D \; (\lambda) = m_h \, . \, a_D \; (\lambda) \qquad (4)$$

where m_h is the relative air mass $750.m/p$; p is the pressure in mm of Hg, and $a_D \, (\lambda)$ is the extinction coefficient of the atmospheric haze. $a_R \; (\lambda)$ according to Möller (1957) is given by $0 \cdot 00897 . \lambda^{-4.09}$. $a_D \; (\lambda)$ was expressed by Ångström as $\beta . \lambda^{-\alpha}$, where α varies from 0 to 4. An average value of 1·3 derived from actual observations has been used by him as a reasonable approximation. Equation (2) is then written as

$$I_k = \frac{1}{S} \int_0^{0.630} I_0 \; (\lambda) . \, e^{-m \times 0.00897/\lambda^{4 \cdot 09}} \times$$

$$\times \, e^{-m_h \, . \beta/\lambda^{1 \cdot 3}} \, .d\lambda \qquad (5)$$

I_k is measured. $I_0 \; (\lambda)$, S and m_h are computed. β is obtained from ready made tables, giving for selected values of β, the theoretical radiation intensity at various air masses for a water-free atmosphere.

4. Discussion of Data

4.1. *Intensity of solar radiation*—Table 1 gives the mean values of the intensity of direct radiation I_t for the whole spectral region and the intensity I_r for the red, with values of solar elevation h and the corresponding optical air mass m for each month of the year 1958 for the hours of observation 0830, 1130, 1430 and 1730 IST for Delhi.

Similar values for Poona are given in Table 2. The last columns give values of atmospheric turbidity β, this is discussed in detail in the next paragraph.

In Figs. 1(a) and 1(b) are depicted the mean monthly values of intensity I against optical air masses m for Delhi and Poona. In Figs. 2 (a) and 2(b) are shown the seasonal curves of intensity *versus* air mass, for the three main seasons—winter (October—February), summer (March—June) and monsoon (July to September). In Tables 3(a) and 3(b) are given the mean seasonal and annual values of intensity of solar radiation for specified air masses from $m=0\cdot96$ to $m=4\cdot50$ and for specified values of solar height over the range 5° to 85°, for both Delhi and Poona. The number of observations on which the data are based are given in brackets below each figure. It will be noted that for the same optical air masses and solar elevations, the solar intensities are highest in winter and lowest in summer at both stations, the ratio of maximum to minimum being 2.0 for Delhi and 1·4 for Poona. The solar intensity values during monsoon at Poona are roughly of the same order as those during winter, though generally higher. At Delhi, the monsoon values generally lie halfway between the summer and winter values. On the whole, intensities at Poona are markedly higher than at Delhi throughout the year. It must be remembered of course that the solar constant itself shows a seasonal variation of about 7 per cent due to the elliptical orbit of the earth and radiation in January is stronger by 3·3 per cent and in July weaker by 3·4 per cent. The actual variations in I from January to June are, however, of the order of 1·7 at Delhi and 1·2 at Poona.

For an optical air mass of 4 (solar height 14°), the intensity at Delhi is 0·555 cal/cm²/min (mean annual value) and 0·626 cal/cm²/min at Poona. This compares with 1·033 at Brukkaros (Drummond and Wentzel 1955), 0·816 at Kew (Stagg 1950) and 0·73 at Washington (Hand and Wollaston 1952). The solar intensities at Delhi and Poona, it will be seen, are much lower. The range of intensities at these stations are given below.

Poona	0·445 to 0·745	cal/cm²/min
Delhi	0·382 to 0·697	,,
Washington	0·52 to 0·86	,,
Blue Hill	0·82 to 1·03	,,
Brukkaros	1·03 to 1·05	,,

At a solar elevation of 60°, the solar radiation intensity at Poona has an average value of 1·29 cal/cm²/min and at Delhi 1·113 cal/cm²/min. This compares with 1·50 at Brukkaros and 1·40 in Java (Boerema and Berlage 1948).

It will also be seen from Table 3 that the seasonal variation of intensity at any particular solar elevation is less pronounced for the high angles and more for the low. This is obviously the result of the greater attenuation by turbidity, of solar radiation at low solar angles.

From the instantaneous observations of solar intensity made at Poona and Delhi, the highest values observed in each month have been picked out and are given in Table 4. It will be noted that the absolute maximum value obtained at Poona is 1·540 cal/cm²/min in February and 1·470 cal/cm²/min at Delhi in May. At the times of observation the mean solar heights were 52° and 71° corresponding to air mass values of 1·20 and 1·03 respectively. This compares with the absolute maximum value of 1·622 cal/cm²/min recorded at Brukkaros in December 1928, by scientists of the solar constant observing team of the Smithsonian Institution.

It would also appear from Table 4 that the 1·4 cal/cm²/min datum is always reached during the months October to March at Poona and during November, December, February, April and May at Delhi and an intensity of 1·3 cal/cm²/min can be expected during all the 12 months of the year at Poona and all 12 months except June and September at Delhi. The solar intensity may be as high as 1·53 cal/cm²/min at any time in November and February at Poona and 1·45 cal/cm²/min in November and May at Delhi. Even in

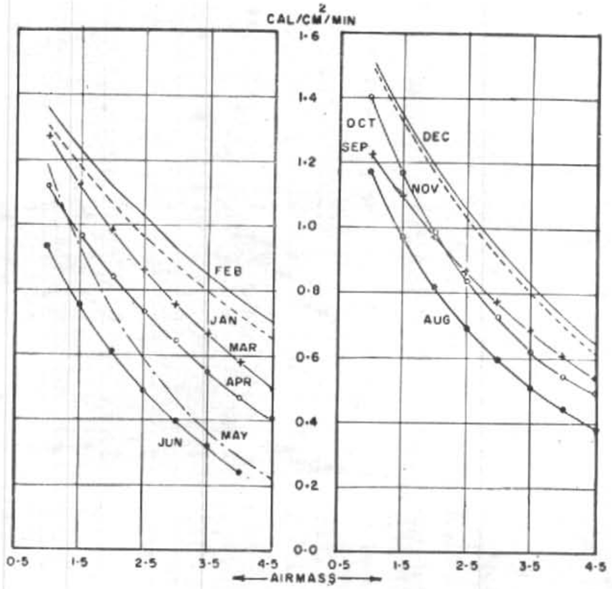

Fig. 1 (a). Intensity at various air masses, Delhi 1958

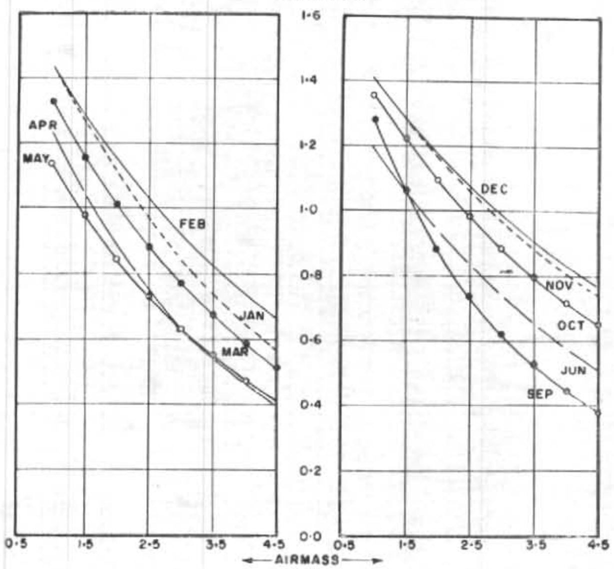

Fig. 1(b). Intensity at various air masses, Poona 1958

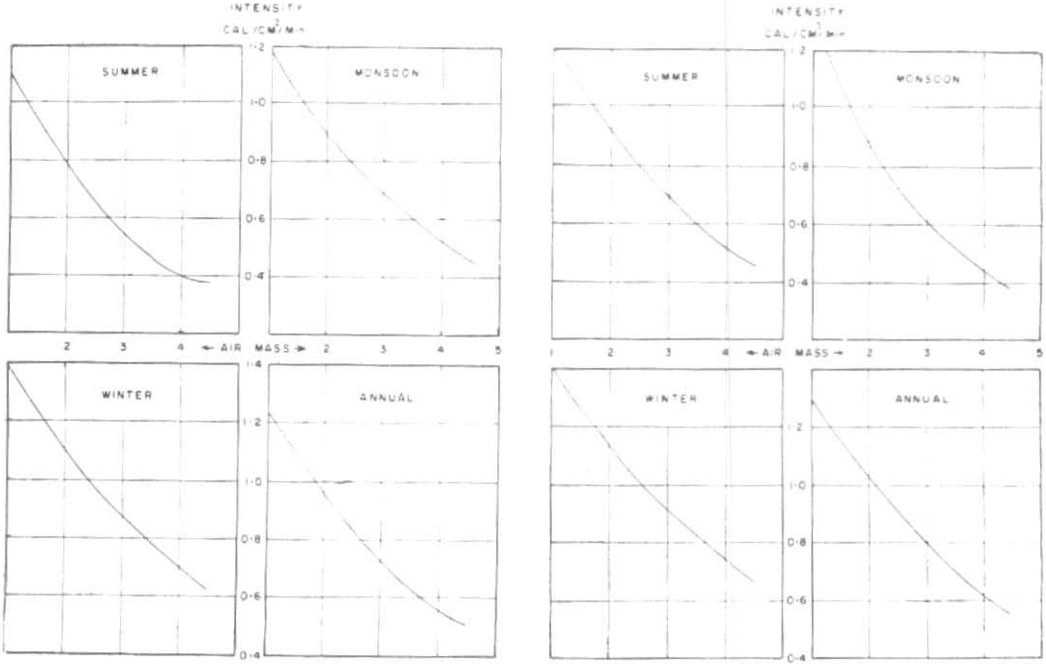

Fig. 2 (a) — **New Delhi**

Fig. 2 (b) — **Poona**

Figs. 2 (a) and 2 (b). Seasonal variation of intensity with air masses

mid-winter, when the noon sun is as low as 50° at Poona and 35° at Delhi values as high as 1·5 and 1·4 cal/cm^2/min are of frequent occurrence.

The minimum value of solar intensity observed are 0·727 cal/cm^2/min at Delhi in June and 1·064 cal/cm^2/min at Poona in May. The ratio maximum/minimum for the same air mass varies by 1·6 to 3·2 at Delhi and 1·3 to 1·8 at Poona. Variations in the radiation intensity reaching the surface of the earth arise from fluctuations in the transparency of the atmosphere and for the same air mass, the variation is a measure of the variation in the dust content of the atmosphere.

4·2. *Atmospheric turbidity*—Mean monthly values of Ångström's turbidity coefficient β for each hour of observation 0830, 1130, 1430 and 1730 IST for 1958 are given in Tables 1 and 2 for Delhi and Poona respectively. The annual march of β for both stations is illustrated in Fig. 3 along with similar values for Washington, Davos and Stockholm (Ångström 1930). It must be remembered that direct sun observations can be made only with relatively clear skies and represent a particular meteorological condition and strongly bias the results obtained. The frequency of observations, it will be noticed, is maximum in the forenoon hours throughout the year, even during the monsoon season.

4.2.1. *Seasonal variation of turbidity*—It will be seen from Fig. 3 (taking the curves for Poona and Delhi alone for the moment) that turbidity shows marked variations with the time of the year, has a pronounced maximum during the summer months (0·09 in June at Delhi and 0·04 in March at Poona) and a minimum during the winter months (0·02 in November at Delhi and 0·004 in October at Poona). At the minimum, the turbidity coefficient is only a tenth of its value at the maximum at Poona and about a fifth at Delhi. The mean value taking the

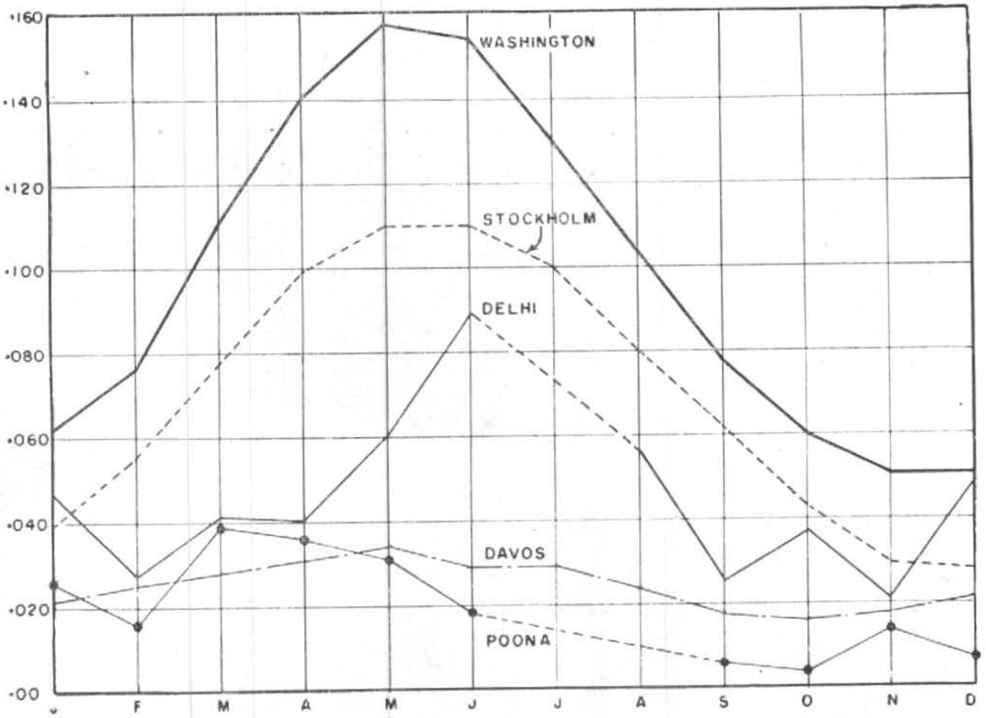

Fig. 3. Annual march of Ångström turbidity coefficient β

year as a whole, for the turbidity coefficient at Delhi (0·045) is more than twice that at Poona (0·020) throughout the year; except during the early summer months, March and April, when the coefficients are of the same order (0·04). On the whole, the atmosphere over Poona is about twice as transparent as that over Delhi almost throughout the year. This is not unexpected, since its higher elevation alone would result in a less turbid atmosphere over Poona than that over Delhi with its low elevation and proximity to the arid regions to the west.

Considering all the five curves in Fig. 3, it will be seen that the maximum at all five stations, so widely distributed over the globe occurs in early summer and the minimum in winter. The striking effect of the monsoon at the Indian stations is shown by the earlier fall at Poona in June and at Delhi in August, coinciding with the later arrival of the monsoon in the north. Washington is the most turbid of all the five stations, followed by Stockholm and Delhi. The actual values of turbidity as well the annual variation are smallest for the high altitude stations at Poona and Davos.

The pronounced maximum in summer and minimum in winter at all the stations and the uniformly low values of β at the high altitude stations, indicate that the cause of the variation in the dust content arises at the earth's surface and in the conditions in the lower layers of the atmosphere. It is natural that the time of maximum dust content corresponds to the time of largest temperature gradient in the lower atmosphere layers and the maximum dispersion of dust from the ground to the higher layers of the atmosphere. The effect of austausch on dust and haze in the lower layers of the atmosphere and the role played by precipitation in the removal or reduction of the dust content of the atmosphere is also well known.

4.2.2. *Diurnal variation of turbidity*—Tables 1 and 2 show that turbidity values are generally higher in the early morning and late evening hours than during the hotter part of the day. They are highest in the early morning and least during the afternoon, except at Poona during the monsoon when the diurnal variation is almost nil. The appreciable diurnal variation in summer and winter can be explained by the increase in dust content in the lower layers of the atmosphere as a result of the strong temperature inversion near the ground during the night and early morning hours and the consequent increase in dust and haze in these layers, and their modification by convection currents mixing and general turbulence during the afternoon. These variations are naturally absent during the monsoon and are maximum during the winter and least during the summer, though the absolute values are highest in summer and least in winter.

4.2.3. *Variation of turbidity with altitude and latitude*—The coefficient of turbidity varies markedly with latitude and altitude as seen from Fig. 3 and Table 5 where the turbidity coefficients for a number of stations in different parts of the world are given. It will be observed that at sea level stations turbidity varies from 0·05 to 0·12, while at high level stations it is only of the order of 0·02—0·03. The turbidity coefficient β decreases rapidly with altitude. Ångström (1930) gave the relationship as

$$\beta_h = \beta_0 \; e^{-\delta h} \tag{6}$$

Except when the atmosphere is cleansed as a result of condensation and precipitation, β depends on turbulence which raises dust from the ground and the falling speed of the dust particles which brings the dust back to the ground. Substituting the value of δ experimentally derived and expressing the height in metres he gave

$$\beta_h = \beta_{0.} \; e^{-0 \cdot 7 H \times 10^{-3}}$$

β decreases to half its value at 1000 m. β also varies with latitude and the distance of the station from the ocean areas. Equatorial oceans have the smallest turbidity and therefore a radiation climate comparatively richer in violet and ultraviolet rays. At high level stations the variation with latitude is naturally smaller.

4.2.4. *Turbidity in different air masses*—Turbidity factors for various synoptical air masses have been investigated for the American continent by Haurwitz (1934) and for Europe by Mamontova and Chromov (1933). In Stockholm, Ångström (1930) found the mean values of β for polar and tropical air to be 0·059 and 0·088 respectively and tropical maritime air to have values ranging from 0·07 to 0·12 and tropical continental air 0·10 to 0·20 respectively.

In India, the air masses have been classified into three main types (Roy 1946)—(1) the modified cold dry air over north and central India of continental polar origin, during the winter months December to February, characterized by pronounced convective stability, clear skies and good visibility, except for local mist in the morning and occasional haze in the afternoon. This air mass over the Deccan 'acquires in its travel across the country to the south tropical characteristics especially after stagnating in the anticyclonic field over tropical latitudes for some time', (2) the tropical continental air mass over western, central and north India during the summer months March to May with its source region in southwest Asia. This is the driest and hottest air over India, with marked instability associated with clear to partly clouded skies, intense insolation and turbulence leading to the development of dust raising winds and duststorms, which persist for days reducing visibility, (3) cool, highly humid and convectively indifferent equatorial maritime air over central and south India during the monsoon months June to September, characterized by mostly covered to overcast skies, frequent rain or drizzle and visibility fair to good, except in heavy rain. In the north this becomes modified as it turns west round the seasonal trough to the north. The turbidity coefficients obtained for the three main seasons and synoptic air masses for Poona and Delhi are given below—

	Poona	Delhi
Winter *Pc*	·016	·041
Summer *Tc*	·035	·059
Monsoon *Em*	·012	·041
Post monsoon	·009	·030

June has been included among the summer months at Delhi since the monsoon reaches the north later than at Poona. It will be seen that the air is clearest during and after the monsoon, after the cleansing by precipitation of the atmosphere of its dust content and during winter. The tropical continental air naturally has the maximum dust content and the monsoon and polar continental air the least.

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TABLE 1

Values of total I_t and red I_R radiation in cal cm^{2} min and Ångström Turbidity Coefficient β during 1958 at New Delhi

Month	No. of obsn.	h	m	I_t	I_r	β	No. of obsn.	h	m	I_t	I_r	β	Mean β
			0830 IST						1130 IST				
Jan	9	13·1	4·32	·675	·494	·073	12	38·0	1·61	1·153	·677	·035	(F.N.) ·054
Feb	13	16·8	3·41	·922	·645	·041	16	45·1	1·40	1·260	·720	·022	·031
Mar	23	24·1	2·41	·887	·530	·062	22	55·8	1·19	1·207	·614	·043	·053
Apr	21	32·3	1·80	·854	·384	·071	16	66·6	1·08	1·076	·554	·058	·065
May	15	36·5	1·64	·904	·515	·076	15	74·0	1·02	1·216	·663	·039	·057
Jun	7	37·7	1·60	·674	·365	·096	4	76·7	1·00	0·915	·478	·109	·103
Jul	—	—	—	—	—	—	—	—	—	—	—	—	—
Aug	8	31·9	1·87	·782	·440	·085	8	68·9	1·05	1·224	·598	·046	·065
Sep	4	27·8	2·10	·942	·560	·065	3	61·5	1·12	1·187	·586	·003	·034
Oct	23	24·5	2·38	·664	·583	·030	22	52·0	1·26	1·282	·681	·009	·019
Nov	24	19·5	2·64	·982	·632	·032	21	42·2	1·48	1·319	·797	·016	·024
Dec	15	14·4	3·92	·738	·548	·074	16	37·2	1·63	1·290	·807	·023	·053
			1430 IST						1730 IST				
Jan	10	32·1	1·87	1·112	·672	·036	—	—	—	—	—	—	(A.N.) ·036
Feb	14	39·1	1·57	1·202	·696	·025	1	11·3	4·93	·569	·337	·019	·022
Mar	16	47·4	1·33	1·178	·646	·030	7	13·7	4·15	·543	·265	·031	·031
Apr	11	53·5	1·22	1·066	·509	·015	6	15·3	3·69	·559	·238	·018	·017
May	11	57·3	1·16	1·075	·576	·067	3	18·3	3·08	·432	·258	·062	·065
Jun	3	61·0	1·12	0·903	·414	·067	1	19·0	2·97	·456	·250	·087	·077
Jul	—	—	—	—	—	—	—	—	—	—	—	—	—
Aug	4	56·2	1·17	1·047	·579	·068	1	17·0	3·30	·712	·427	·032	·050
Sep	—	—	—	—	—	—	1	12·5	4·41	·706	·479	·010	·010
Oct	17	38·8	1·56	1·210	·562	·002	1	6·4	8·28	·424	·312	·112	·057
Nov	22	32·3	1·84	1·214	·700	·018	—	—	—	—	—	—	·018
Dec	14	30·2	1·97	1·125	·725	·049	—	—	—	—	—	—	·049
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean β	·048	·027	·042	·041	·061	·090	—	·057	·026	·038	·022	·049	·045

TABLE 2

Values of total I_t and red I_R radiation in cal/cm²/min and Ångström Turbidity Coefficient β during 1958 at Poona

Month	No. of obsn.	h	m	I_t	I_r	β	No. of obsn.	h	m	I_t	I_r	β	Mean β
			0830 IST						1130 IST				
Jan	26	17·8	3·17	0·853	·562	·045	23	47·5	1·29	1·323	·733	·016	(F.N.) ·030
Feb	23	20·9	2·39	1·010	·650	·032	19	54·7	1·17	1·345	·761	·016	·024
Mar	24	25·4	2·23	0·947	·604	·056	26	65·3	1·05	1·336	·734	·024	·040
Apr	18	34·2	1·70	0·997	·596	·059	19	75·9	0·97	1·267	·644	·026	·042
May	12	34·7	1·66	0·953	·507	·029	20	85·0	0·95	1·152	·591	.019	·024
Jun	11	36·6	1·59	1·041	·573	·021	11	78·0	0·96	1·205	·642	·009	·015
Jul	—	—	—	—	—	—	—	—	—	—	—	—	—
Aug	—	—	—	—	—	—	—	—	—	—	—	—	—
Sep	5	35·6	1·64	0·936	·438	·012	1	63·5	1·06	1·250	·650	·000	·006
Oct	16	30·5	1·59	1·073	·576	·007	15	62·3	1·07	1·328	·674	·000	·003
Nov	21	25·1	2·25	1·052	·645	·029	19	52·5	1·20	1·346	·742	·006	·017
Dec	23	19·5	2·86	0·935	·569	·021	20	46·9	1·35	1·328	·712	·004	·012
			1430 IST						1730 IST				
Jan	21	41·3	1·42	1·306	·766	·010	17	11·0	3·98	·589	·436	·035	(A.N.) ·022
Feb	19	48·2	1·28	1·392	·766	·003	16	13·6	4·08	·768	·473	·014	·008
Mar	22	51·8	1·28	1·219	·688	·034	21	14·7	3·83	·634	·422	·043	·038
Apr	14	56·1	1·14	1·181	·639	·024	18	17·2	3·28	·597	·304	·037	·030
May	15	58·1	1·12	1·091	·578	·034	20	18·8	2·89	·621	·344	·041	·037
Jun	10	59·1	1·10	1·167	·625	·015	12	20·8	2·65	·802	·447	·023	·021
Jul	—	—	—	—	—	—	—	—	—	—	—	—	—
Aug	—	—	—	—	—	—	—	—	—	—	—	—	—
Sep	6	47·4	1·28	1·189	·567	·000	2	14·5	3·71	·640	·315	·011	·005
Oct	13	45·7	1·53	1·286	·666	·004	5	11·8	4·58	·734	·415	·006	·005
Nov	14	39·1	1·51	1·288	·728	·008	2	18·9	3·89	·925	·595	·015	·011
Dec	16	36·7	1·59	1·277	·713	·001	2	8·8	6·08	·740	·500	·002	·001

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean β	·026	·016	·039	·036	·031	·018	—	—	·006	·004	·014	·007	·020

TABLE 3 (a)

Mean seasonal and annual values of intensity of solar radiation (cal/cm²/min) for specified air masses during 1958

	POONA				NEW DELHI			
Air mass	Summer	Monsoon	Winter	Annual	Summer	Monsoon	Winter	Annual
0·96	1·222 (48)			1·222 (48)	1·118 (35)			
1·00	1·180 (62)	1·280 (1)	1·406 (18)	1·289 (81)	1·023 (54)	1·195 (11)	1·395* (—)	1·243 (46)
1·25	1·137 (24)	1·163 (5)	1·333 (103)	1·227 (132)	0·942 (12)	1·105 (4)	1·328 (26)	1·177 (84)
1·50	1·054 (23)	1·060 (4)	1·264 (43)	1·160 (70)	0·860 (26)	1·033 (—)	1·260 (69)	1·097 (81)
1·75	0·985 (22)	0·967 (1)	1·199 (11)	1·090 (34)	0·789 (10)	0·955 (6)	1·217 (39)	1·020 (71)
2·00	0·918 (12)	0·875 (1)	1·138 (18)	1·024 (31)	0·725 (6)	0·890 (5)	1·133 (27)	0·951 (42)
2·25	0·854 (11)	0·798* (—)	1·077 (8)	0·960 (19)	0·667 (12)	0·830* (—)	1·041 (13)	0·888 (19)
2·50	0·798 (19)	0·728* (—)	1·019 (9)	0·902 (28)	0·612 (2)	0·776* (—)	1·001 (11)	0·839 (23)
2·75	0·741 (11)	0·667* (—)	0·968 (21)	0·847 (32)	0·547 (3)	0·724* (—)	0·926 (11)	0·776 (13)
3·00	0·690 (13)	0·612* (—)	0·918 (25)	0·795 (38)	0·515 (3)	0·678* (—)	0·875 (5)	0·725 (8)
3·25	0·643 (8)	0·564* (—)	0·869 (16)	0·748 (24)	0·475 (2)	0·635 (1)	0·831 (8)	0·678 (12)
3·50	0·603 (7)	0·523* (—)	0·826 (5)	0·707 (12)	0·431 (2)	0·597* (—)	0·778 (10)	0·635 (12)
3·75	0·561 (8)	0·482* (—)	0·783 (6)	0·674 (14)	0·394 (1)	0·557* (—)	0·736 (10)	0·593 (12)
4·00	0·523 (3)	0·445* (—)	0·745 (1)	0·626 (4)	0·382 (2)	0·524* (—)	0·697 (11)	0·555 (12)
4·25	0·485 (1)	0·410* (—)	0·708 (3)	0·589 (4)	0·375* (—)	0·491* (—)	0·659 (4)	0·527 (6)
4·50	0·454 (2)	0·380* (—)	0·675 (9)	0·557 (11)	—	0·465* (—)	0·623 (4)	0·514 (4)

* Values by interpolation

TABLE 3 (b)

Mean seasonal and annual values of solar radiation (cal/cm²/min) for specified angles of elevation

Solar elevation (°)	POONA				NEW DELHI			
	Summer	Monsoon	Winter	Annual	Summer	Monsoon	Winter	Annual
05			0·710 (1)	0·710 (1)	0·665 (1)	—	·424 (1)	0·424 (1)
10	·525 (5)		0·708 (28)	0·677 (33)	0·475 (9)	0·709 (2)	0·884 (3)	0·775 (4)
15	0·632 (29)	0·640 (2)	0·810 (34)	0·711 (65)	0·613 (9)	0·821 (6)	0·819 (26)	0·569 (37)
20	0·743 (32)	—	0·858 (51)	0·813 (83)	0·898 (27)	—	0·977 (24)	0·769 (39)
25	0·781 (19)	—	1·012 (20)	0·880 (39)	0·955 (17)	0·716 (4)	0·991 (23)	0·967 (50)
30	0·978 (16)	0·910 (1)	1·156 (12)	1·050 (29)	0·816 (14)	—	1·103 (29)	1·008 (50)
35	0·963 (26)	0·910 (2)	1·217 (13)	1·085 (41)	0·613 (3)	—	1·250 (42)	1·035 (56)
40	1·057 (8)	1·010 (3)	1·308 (26)	1·177 (39)	1·204 (4)	—	1·228 (44)	1·052 (47)
45	1·103 (1)	1·210 (1)	1·308 (55)	1·265 (57)	1·135 (16)	—	1·265 (27)	1·252 (31)
50	1·247 (5)	1·193 (4)	1·334 (45)	1·295 (54)	1·175 (22)	1·226 (2)	1·295 (12)	1·185 (28)
55	1·164 (33)	—	1·333 (20)	1·246 (53)	1·139 (15)	1·015 (5)	1·252 (6)	1·201 (30)
60	1·220 (25)	—	1·401 (20)	1·292 (45)	1·045 (10)	1·157 (2)	1·344 (1)	1·113 (21)
65	1·223 (10)	1·250 (1)	1·275 (2)	1·244 (13)	0·963 (8)	1·163 (6)	—	1·032 (12)
70	1·220 (11)	—	—	1·267 (11)	1·026 (13)	—	—	1·029 (14)
75	1·211 (13)	—	1·310 (1)	1·211 (14)	1·213 (2)	—	—	1·026 (13)
80	1·189 (14)	—	—	1·189 (14)	—	—	—	1·213 (2)
85	1·146 (20)	—	—	1·146 (20)	—	—	—	—

TABLE 4

Highest values of *I* recorded and the corresponding air masses month by month

Month	Air mass	*I*	Solar elevation	Air mass	*I*	Solar elevation
	NEW DELHI (1958)			POONA (1958)		
Jan	1·82	1·308	33·0	1·26	1·424	49·3
Feb	1·34	1·404	47·7	1·20	1·540	52·2
Mar	1·39	1·352	45·4	1·09	1·441	60·3
Apr	1·23	1·425	64·5	0·96	1·330	78·6
May	1·03	1·470	71·0	0·95	1·292	84·9
Jun	1·01	1·188	77·1	0·97	1·305	73·9
Jul	—	—	—	—	—	—
Aug	1·04	1·344	69·7	—	—	—
Sep	1·11	1·261	62·4	1·20	1·247	63·3
Oct	1·30	1·384	50·0	1·45	1·424	51·8
Nov	1·52	1·445	40·9	1·18	1·522	54·0
Dec	1·66	1·425	36·6	1·30	1·416	48·9

TABLE 5

Serial No.	Station	Latitude	Altitude (m)	β	Authority
1	Bangkok	13°44′ N	16	0·125	Gorczynski
2	Modena	44°54′ N	51	0·100	Chistoni
3	Washington	38°54′ N	34	0·098	Abbot
4	Stockholm	59°21′ N	22	0·065	Ångström
5	Uppsala	59°51′ N	24	0·058	Westman
6	Treurenberg	79°55′ N	8	0·045	Westman
7	Delhi	28°35′ N	11	0·045	—
8	Spitzbergen	78°00′ N	..	0·045	Westman
9	Bassour	—	1160	0·031	—
10	Hump Mountain	36°08′ N	1500	0·031	Abbot
11	Davos	46°48′ N	1600	0·024	Lindholm
12	Calama	22°28′ S	2250	0·023	Abbot
13	Poona	18°32′ N	559	0·020	—
14	Mount Wilson	34°13′ N	1741	0·018	Abbot
15	Equator	0–15 N North and South	0	0·075—0·14	Gorczynski