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Studies of Nocturnal Radiation at Poona and Delhi

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1. Introduction

Measurements of nocturnal atmospheric radiation using Ångström compensation pyrgeometers were first made in 1930 at Poona by Ramanathan and Desai (1932), extended by Raman (1935, 1936) who studied its variations with time during the night and its dependence on the temperature and humidity in the lower layers of the atmosphere, and by Ramdas *et al.* (1937, 1939) who measured the hourly variation in the nocturnal radiation coming from different altitudes of the night sky using a Moll micro-thermopile. The measurements were resumed by Chacko (1951) in 1945 and continued in 1946 and 1949. Routine measurements of nocturnal radiation were introduced in July 1957 at Poona and Delhi, in connection with the implementation of a scheme of radiation measurements at a network of 14 stations in India. The results of measurements of nocturnal radiation during 1958 at Poona and Delhi are analysed, compared with the results obtained earlier and presented in the following paragraphs.

2. Method of measurement

The Ångström compensation pyrgeometer and the technique of measurement of nocturnal radiation with it are well known and have been described in detail in the earlier papers (Ramanathan and Desai 1932, Raman 1935 and Chacko 1951). If E is the outgoing long wave radiation from the black strips at temperature $T°$ A and S the incoming long wave radiation from the atmosphere, the net outgoing radiation $E{-}S$ is termed the outward terrestrial radiation or nocturnal radiation N. E the black body radiation at T is equal to σT^4 where σ is the Stefan Boltzman constant. N is directly measured with the pyrgeometer and S the sky radiation is computed from values of E and N.

Pyrgeometer observations were made at 2030 IST on all nights except when there was rain, with the Ångström pyrgeometer exposed horizontally on the roof of the radiation observatory buildings at Delhi and Poona, where a practically free exposure to the entire sky was available. A precision milliammeter was used to measure the heating current i and a high-sensitivity galvanometer to indicate the equality of temperatures of the thermocouples. The air temperature and relative humidity were measured with Assmann psychrometers. The constants of the instruments were determined at the Central Radiation Laboratory, Poona with a standard instrument and checked at the stations with a travelling standard.

3. Discussion of results

In Table 1 (a) are given the mean monthly values of the outward terrestrial radiation N and the sky radiation S for all nights of the year 1958 at Delhi along with air temperature T, water vapour pressure V.P. in mm of Hg, the ratio S/E and the blackbody radiation E. Table 1 (b) gives similar values for clear skies

TABLE 1(a)

Mean monthly values of night radiation during 1958 at New Delhi (All nights)

	No. of obsns. (*n*)	Air temp. (°A) *T*	Vapour Pressure mm of Hg (VP)	Black body radiation cal/cm²/min (*E*)	Net radiation cal/cm²/min (*N*)	Sky radiation cal/cm²/min (*S*)	Ratio *S/E*
Jan	29	289·1	12·3	0·577	0·055	0·522	0·905
Feb	28	290·5	10·7	0·588	0·059	0·529	0·900
Mar	28	295·8	13·7	0·632	0·111	0·521	0·824
Apr	30	302·0	16·5	0·687	0·117	0·570	0·830
May	31	304·5	13·5	0·710	0·124	0·586	0·825
Jun	24	308·1	23·0	0·744	0·098	0·646	0·868
Jul	25	303·1	33·3	0·697	0·052	0·645	0·925
Aug	12	302·1	35·5	0·688	0·069	0·619	0·899
Sep	24	300·7	31·5	0·675	0·059	0·616	0·912
Oct	31	295·2	21·8	0·627	0·106	0·521	0·831
Nov	29	289·3	13·6	0·579	0·129	0·450	0·777
Dec							
Year		295·4	20·5	0·656	0·089	0·567	0·863

TABLE 1(b)

Mean monthly values of night radiation at New Delhi during 1958 (Clear nights)

	No. of obsns. (*n*)	Air temp. (°A) (*T*)	Vapour pressure mm of Hg (VP)	Black body radiation cal/cm²/min (*E*)	Net radiation cal/cm²/min (*N*) Mean	Max.	Min.	Sky radiation cal/cm²/min (*S*) Mean	Max.	Min.	Ratio *S/E*
Jan	15	288·5	11·8	·572	·061	·083	·041	·511	·542	·486	·893
Feb	21	290·1	10·5	·585	·061	·083	·047	·524	·552	·498	·896
Mar	18	297·3	13·5	·645	·128	·145	·102	·517	·563	·469	·801
Apr	16	301·7	16·3	·684	·127	·155	·077	·557	·616	·502	·814
May	25	304·5	13·9	·710	·129	·186	·048	·581	·676	·510	·817
Jun	16	308·7	21·9	·751	·109	·143	·073	·642	·701	·555	·855
Jul	4	305·2	31·9	·717	·062	·073	·048	·655	·671	·632	·913
Aug	4	302·0	33·7	·687	·092	·111	·059	·595	·633	·570	·866
Sep	7	301·1	30·5	·679	·080	·091	·059	·599	·642	·569	·882
Oct	22	294·9	20·6	·624	·119	·153	·078	·505	·576	·453	·810
Nov	27	289·4	13·5	·579	·129	·156	·070	·450	·584	·385	·777
Mean		298·5	19·8	·658	·100			·558			·848

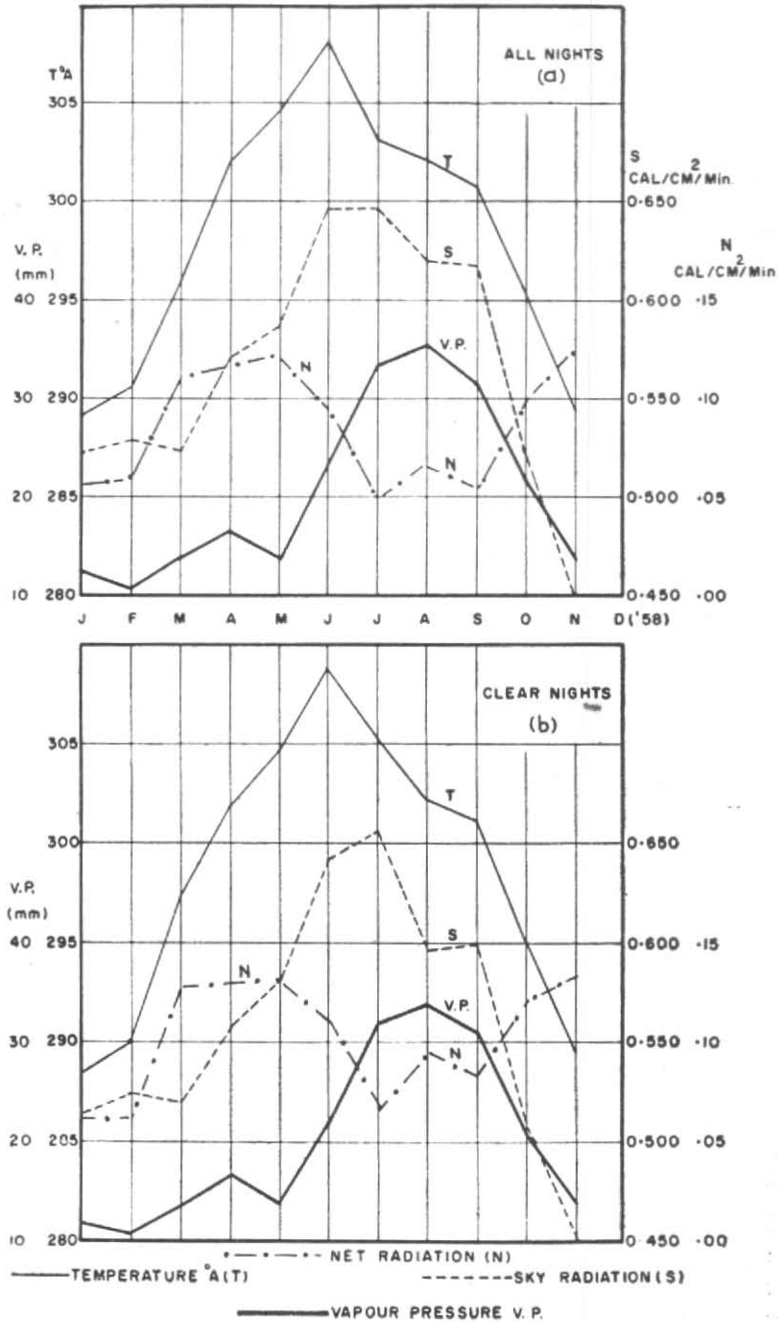

Fig. 1. Annual march of temperature, vapour pressure, sky radiation and net radiation (New Delhi)

alone at Delhi with the maximum and minimum values reached by N and S. In Figs. 1 (a) and 1 (b) are plotted the mean monthly values of sky radiation S, longwave effective outgoing radiation N, vapour pressure V.P. and air temperature T for all nights and for clear nights alone. Nights with high cloud or medium or low cloud near the horizon less than 1 octa have been taken as clear nights.

Tables 2(a) and 2(b) and Figs. 2(a) and 2(b) give corresponding values at Poona for all nights and clear nights alone, during 1958.

3.1. *Monthly and seasonal variation of sky radiation S and nocturnal radiation N*

3.1.1. *Delhi*—It will be seen from Fig. 1(a) and Table 1(a) that sky radiation at Delhi is highest during the months June to September with a mean value of 0·631 cal/cm²/min and least during October to March (0·509 cal/cm²/min). It reaches a maximum in June (0·646 cal/cm² /min), falls rapidly after September (the observed decrease in August may be ascribed to the very few observations during that month) till a minimum is reached in November (0·450 cal/cm²/min). No observations were available for December. There is a slight increase during January and February, followed by a fall in March and then a steady increase till the maximum is reached in June. The increased cloudiness and water vapour content of the atomsphere during the monsoon months and during the passage of western disturbances over Delhi in winter are responsible for the observed maxima. On cloudy nights sky radiation is mainly a function of the amount and type of cloud present.

On clear nights alone (Fig. 1b and Table 1b) the sky radiation is a maximum in July (0·655 cal/cm²/min) and a minimum in November. The highest maximum recorded during the year is 0·701 cal/cm²/min and the lowest minimum 0·385 cal/cm²/min, the mean value for the whole year being 0·558 cal/cm²/min.

During the months June to September, sky radiation S on all clear days reaches a value of about 0·88 of the black body radiation E at the surface temperature. The mean value of S/E taking the year as a whole, is 0·85 ranging from 0·78 in November to 0·91 in July.

The outgoing terrestrial radiation N is a function of the temperature and the cloud amount and water vapour content in the lower layers of the atmosphere. On a clear night, N is a function only of the temperature T and of the vapour pressure VP, *i.e.*, $N=\sigma T^4-f$ (VP). Nocturnal radiation on clear nights is least (0·062 cal/cm²/min) during the monsoon when the moisture content is high, and highest (0·129 cal/cm²/min) during the summer when the temperatures are high and the water vapour content low. The high values in October—November are to be mainly attributed to the very low humidity during these months at Delhi.

3.1.2. *Poona*—The sky radiation at Poona is a maximum during the monsoon months July to September with a mean value of 0·535 cal/cm²/min and a minimum during the winter months December to February (0·498 cal/cm²/min). It shows a small but steady increase from January (minimum 0·488 cal/cm²/min) to May, a slight fall in June, rapid increase till July when the maximum value of 0·584 cal/cm²/min is reached and a steady fall after that. The highest maximum recorded is 0·594 cal/cm²/min in May (no clear night observations were possible in July and August) and the lowest minimum 0·389 cal/cm²/min in February.

The outgoing terrestrial radiation N is least during the monsoon (·050 cal/cm²/min) and a maximum (0·154 cal/cm²/min) during the dry summer and winter months.

During the months June to October sky radiation on all clear days reaches a value of about 0·81 of the black body radiation at the surface temperature. The mean value for the year as a whole is 0·78 and the range 0·76

TABLE 2(a)

Mean monthly values of night radiation during 1958 at Poona (All nights)

	No. of obsns. (*n*)	Air temp. (°A) (*T*)	Vapour pressure mm of Hg (VP)	Black body radiation cal/cm²/min (*E*)	Net radiation cal/cm²/min (*N*)	Sky radiation cal/cm²/min (*S*)	Ratio *S/E*
Jan	31	295·5	11·8	0·629	0·141	0·488	0·776
Feb	24	299·5	10·9	0·665	0·154	0·511	0·769
Mar	31	300·2	14·8	0·671	0·150	0·521	0·776
Apr	27	300·0	18·1	0·669	0·140	0·529	0·791
May	31	299·8	24·3	0·668	0·125	0·543	0·813
Jun	25	298·1	24·4	0·652	0·114	0·538	0·825
Jul	20	296·6	24·9	0·639	0·055	0·584	0·914
Aug	20	296·1	25·4	0·635	0·050	0·585	0·921
Sep	25	295·7	23·9	0·631	0·071	0·560	0·887
Oct	27	297·8	22·8	0·650	0·106	0·544	0·837
Nov	28	296·8	17·7	0·641	0·116	0·525	0·819
Dec	31	294·9	13·9	0·624	0·130	0·494	0·792
Mean		297·6	20·2	0·648	0·113	0·535	0·827

TABLE 2 (b)

Mean monthly values of night radiation at Poona during 1958 (Clear nights)

	Number of obsns. (*n*)	Air temp. (°A) (*T*)	Vapour pressure mm of Hg (VP)	Black body radiation cal/cm²/min (*E*)	Net radiation cal/cm²/min (*N*)			Sky radiation cal/cm²/min (*S*)			Ratio *S/E*
					Mean	Max.	Min.	Mean	Max.	Min.	
Jan	21	295·1	11·2	·626	·149	·200	·106	·477	·514	·497	·762
Feb	18	297·6	10·5	·648	·167	·244	·134	·491	·571	·389	·798
Mar	17	300·1	15·4	·669	·156	·193	·119	·513	·550	·429	·767
Apr	14	302·4	15·9	·691	·156	·210	·117	·535	·585	·488	·774
May	19	302·2	23·8	·689	·134	·198	·102	·555	·594	·502	·806
Jun	10	300·5	23·8	·673	·149	·241	·096	·524	·577	·438	·779
Jul	—	—	—	—	—	—	—	—	—	—	—
Aug	—	—	—	—	—	—	—	—	—	—	—
Sep	3	295·8	24·1	·632	·092	·152	·036	·540	·592	·486	·855
Oct	9	297·7	21·2	·649	·122	·151	·033	·527	·616	·496	·812
Nov	8	296·0	15·1	·634	·154	·168	·128	·480	·509	·462	·757
Dec	12	294·2	13·7	·619	·147	·175	·119	·472	·515	·446	·763
Mean		296·8	17·5	·653	·143			·510			·783

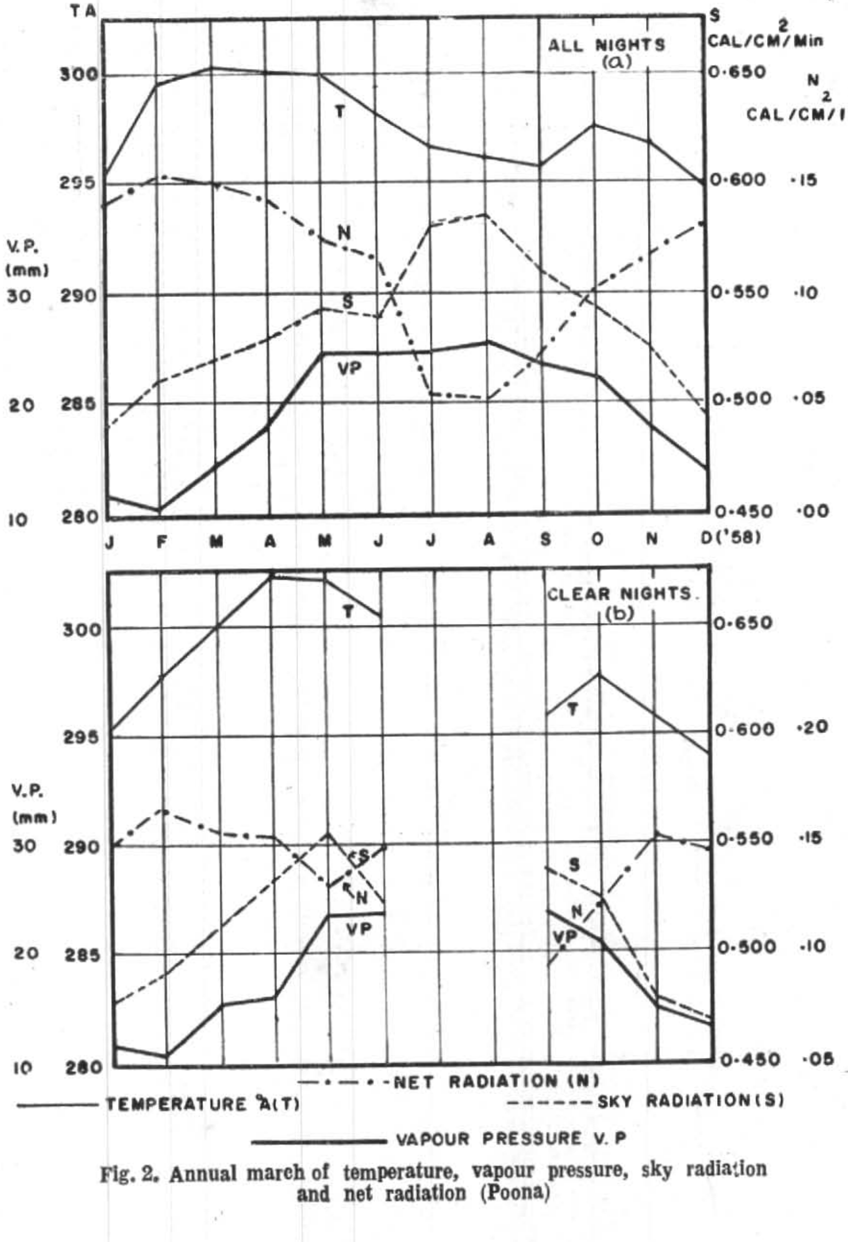

Fig. 2. Annual march of temperature, vapour pressure, sky radiation and net radiation (Poona)

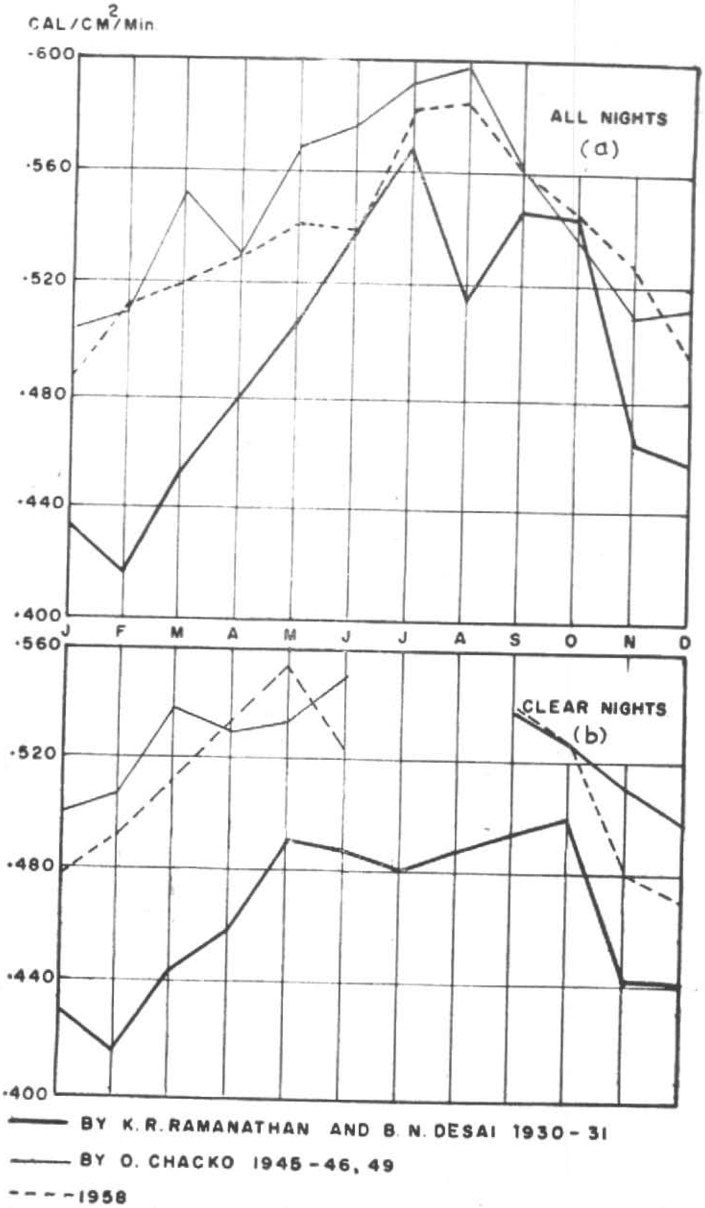

Fig. 3. Annual march of sky radiation (S) at Poona

to 0·85. This is against a value of 0·75 of the black body radiation to be expected if water vapour were the sole radiating constituent.

In Fig. 3 are reproduced the values of sky radiation obtained in 1958, with those obtained in 1930-31 by Ramanathan and Desai (1932) and by Chacko (1951) in 1945, 1946 and 1949. The similarities are well marked, the maximum in June—September and the minimum in November—March. The mean values of S which are roughly the same during 1945—1949 and 1958, are however, markedly higher than those obtained during 1930-31 by Ramanathan and Desai.

3.2. *Comparison of monthly mean values of sky and nocturnal radiation at Delhi and Poona*

A comparative study of Tables 1 and 2 and Figs. 1 and 2 shows that while the variations in sky radiation received during the different seasons are roughly similar, they are more pronounced at Delhi than at Poona and taking the year as a whole, more radiation is received from the sky at Delhi than at Poona, the mean annual values being 0·567 cal/cm²/min and 0·535 cal/cm²/min respectively for all nights and 0·558 and 0·510 for clear nights alone. The annual variation in the amount of sky radiation received (0·646 to 0·450 cal/cm²/min) at Delhi is twice that at Poona (0·585 to 0·488 cal/cm²/min) and is presumably the result of the larger variations in temperature and water vapour content at Delhi. More sky radiation is received at Poona however, during October and November than at Delhi even on only clear nights, presumably as a result of the slightly higher vapour content at Poona and the slightly lower air temperature at Delhi.

The nocturnal radiation on the other hand taking the year as a whole is greater at Poona than at Delhi, the mean values for all nights being 0·113 cal/cm²/min at Poona and 0·089 at Delhi and on clear nights alone 0·143 and 0·100 respectively. The Poona value is as much as three times that at Delhi in January and February and less than that at Delhi only during November and August. The annual variation of N at Poona is 0·104 compared to 0·077 at Delhi. On the whole, more heat is lost at Poona (0·113 cal/cm²/min) by radiation than at Delhi (0·089 cal/cm²/min) over the year.

TABLE 3

Monthly mean values of sky radiation for clear nights (cal/cm² /min)

(Observed and computed using Ångström's formula)

	New Delhi		Poona	
	Observed	Computed	Observed	Computed
Jan	·511	·405	·477	·440
Feb	·524	·408	·491	·451
Mar	·517	·464	·513	·489
Apr	·557	·503	·535	·507
May	·581	·513	·555	·521
Jun	·642	·565	·524	·509
Jul	·655	·549	—	—
Aug	·595	·526	—	—
Sep	·599	·519	·540	·478
Oct	·505	·468	·527	·487
Nov	·450	·417	·480	·462
Dec			·472	·447

3.3. *Dependence of sky radiation on temperature and vapour pressure*

Ångström (Ramanathan and Ramdas 1935, Ångström 1928) expressed the dependence of the sky radiation S on water vapour pressure p at the earth's surface and air temperature T, near the instrument to be given by

$$S = \sigma T^4 \ (0 \cdot 75 - 0 \cdot 32.10^{-0 \cdot 069 p})$$

According to this semi-empirical relationship, the value of the sky radiation from a clear sky will be between 0·75 and 0·43 of that of a black body at the temperature of the atmosphere at the earth's surface. Table 3 compares the monthly means of the observed radiation at Delhi and Poona on clear nights, with the values calculated according to Ångström's formula. It will be seen that the observed values are always higher than the calculated values and the difference is more for Delhi than for Poona. This is in disagreement with the observations of Ramanathan and Desai who found good agreement between the calculated and observed average monthly value in the drier part of the year and the calculated values to be higher than the observed values only during the wet months. They ascribed it to the cloud haze often present in the atmosphere or to the imperfect applicability of the formula when the vapour pressures are high.

4. Conclusion

Results of measurements of nocturnal and sky radiation at Poona and Delhi during the IGY confirm those obtained by earlier workers at Poona, with main reference to its seasonal variations and its dependence on the temperature and water vapour content of the lower layers of the atmosphere. The sky radiation at Delhi is greater than that at Poona as a consequence of the comparatively drier atmosphere over Poona. The values of sky radiation at Poona during 1945—58 are also much higher than those observed by Ramanathan and Desai in 1930-31 and the values calculated from Ångström's formula.

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