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Measurements of nocturnal radiation made at Dum Dum airport, Calcutta

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ABSTRACT. A report on the measurements of net outgoing long wave radiation (nocturnal radiation) and incoming long wave radiation (sky radiation) made at Dum Dum airport, Calcutta, with an Ångström Pyrgeometer for the period November 1959 to March 1962 has been presented. Values of monthly net outgoing nocturnal radiation and sky radiation expressed as percentage of black body radiation for clear sky nights have been presented in a tabular form. An empirical relation of the effect of cloud on the net outgoing radiation has been suggested. The effect of haze/dust particles on the net outgoing radiation has also been discussed.

1. Introduction

Considerable work has been done in India and abroad on the heat radiation from the night sky. In India, the major work has been done at Poona by Ramanathan and Desai (1932), Raman (1935, 1936), Ramanathan and Ramdas (1935), Ramdas *et al.* (1937, 1939) and more recently by Chacko (1951) and Mani and Chacko (1963). The purpose of the present paper is to present a report on the measurements of nocturnal radiation made at Dum Dum airport, Calcutta during the period November 1959 to March 1962. It is worthwhile to mention that the radiation measurements at Dum Dum began during the IGY, a detailed report on which appeared in a recent paper by Mani *et al.* (1962).

2. Description of the instrument

The measurements were made with an Ångström's Compensation Pyrgeometer. The instrument consists primarily of two pairs of manganin strips—one pair being plated with gold and other coated with platinum black. When the strips are exposed to the atmosphere, the dark strips get cooled more rapidly than the bright ones. By heating the dark strips electrically to the temperature of the bright strips, a measure can be obtained of the net outgoing radiation. The measurement of equivalence of temperatures is done with sensitive thermojunctions attached to the back of the strips and the heating current measured by a sensitive milliammeter.

3. Data used

The data reported in this communication are based on observations taken at Dum Dum airport with an Ångström Compensation Pyrgeometer, as described above, daily at 2030 and 2330 IST. At the time of each observation, the temperature of the air very close to the instrument, atmospheric pressure, vapour pressure, wind speed, cloud amount and types of clouds were also recorded. The results of the observations made at Dum Dum airport, Calcutta, for the period November 1959 to March 1962 are summarised and shown in Tables 1—4.

Table 1 shows the mean monthly "black body" radiation at the surface temperature (°K), net outgoing nocturnal radiation and sky radiation in gm. cal. $cm^{-2} min^{-1} K^{-4}$ at 2030 and 2330 IST for clear sky nights, while Tables 2 and 3 show the above values for overcast nights and partly cloudy nights respectively. The overcast and partly cloudy sky conditions have been taken as those occasions when the sky was covered with 7-8 oktas and less than 5 oktas of clouds (irrespective of the types of the cloud) respectively.

Next, the net outgoing radiation and sky radiation expressed as percentage of black body radiation for different months for clear sky nights have been worked out and the results shown in Table 4.

TABLE 1

Mean monthly values of night radiation in gm. cal/cm² min for clear nights

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
							1959						
(IST) 2030	a											0·624	0·581
	b											0·117	0·119
	c											0·507	0·462
2330	a											0·625	0·574
	b											0·121	0·127
	c											0·504	0·447
							1960						
2030	a	0·573	0·621	0·649	0·687	0·697	0·681	—	0·692	0·687	0·645	0·602	0·591
	b	0·123	0·115	0·110	0·098	0·084	0·068	—	0·080	0·079	0·093	0·115	0·106
	c	0·450	0·506	0·539	0·589	0·613	0·613	—	0·612	0·608	0·552	0·487	0·485
2330	a	0·558	0·598	0·630	0·675	0·687	0·670	—	0·687	0·677	0·641	0·590	0·576
	b	0·130	0·117	0·115	0·103	0·090	0·076	—	0·057	0·091	0·108	0·127	0·125
	c	0·428	0·481	0·515	0·572	0·597	0·594	—	0·630	0·586	0·533	0·463	0·451
							1961						
2030	a	0·587	0·602	0·669	0·697	0·703	—	0·680	—	—	0·651	0·608	0·567
	b	0·107	0·115	0·107	0·087	0·073	—	0·070	—	—	0·087	0·100	0·111
	c	0·480	0·487	0·562	0·610	0·630	—	0·610	—	—	0·564	0·508	0·456
2330	a	0·569	0·588	0·647	0·677	0·685	0·655	0·665	0·678	0·676	0·655	0·593	0·554
	b	0·122	0·113	0·103	0·088	0·083	0·065	0·069	0·057	0·065	0·071	0·091	0·109
	c	0·447	0·475	0·544	0·589	0·602	0·590	0·596	0·621	0·611	0·584	0·502	0·445
							1962						
2030	a	0·569	0·612	0·653									
	b	0·111	0·101	0·100									
	c	0·458	0·511	0·553									
2330	a	0·553	0·598	0·638									
	b	0·105	0·095	0·101									
	c	0·448	0·503	0·537									

a—black body radiation, b—net outgoing nocturnal radiation, c—incoming sky radiation

4. Discussions

It is well known that the earth's surface may be regarded as a perfect "black body". As such, the nature and intensity of its radiation depend only on the absolute temperature of its surface and are independent of the nature of the ground. But the amount of the energy which is received by the earth's surface from the atmosphere depends on the distribution of meteorological parameters in the lower layers of the atmosphere. This means that the net outgoing radiation depends on the atmospheric conditions. The measurements on the nocturnal radiation will thus throw some light on the constituents of the atmosphere, specially in the lower layers, over the station.

TABLE 2

Mean monthly values of night radiation in gm. cal/cm²/min for overcast nights

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
(IST)													
1959													
2030	a												0·609
	b												0·048
	c												0·561
2330	a												0·604
	b												0·041
	c												0·563
1960													
2030	a	0·597	—	0·631	0·665	0·675	0·686	0·680	0·683	0·672	0·658	0·637	0·605
	b	0·066	—	0·051	0·063	0·047	0·045	0·041	0·043	0·058	0·055	0·058	0·068
	c	0·531	—	0·580	0·602	0·628	0·641	0·639	0·640	0·624	0·603	0·579	0·537
2330	a	0·592	—	0·637	0·684	0·674	0·677	0·669	0·632	0·668	0·650	0·627	0·598
	b	0·069	—	0·017	0·055	0·067	0·045	0·039	0·054	0·057	0·063	0·072	0·062
	c	0·523	—	0·620	0·629	0·607	0·632	0·630	0·578	0·611	0·587	0·555	0·536
1961													
2030	a	0·621	0·611	0·660	0·689	0·686	0·680	0·678	0·676	0·670	0·653	0·622	—
	b	0·057	0·056	0·027	0·055	0·040	0·030	0·029	0·027	0·037	0·035	0·047	—
	c	0·564	0·555	0·633	0·634	0·646	0·650	0·649	0·649	0·633	0·618	0·575	—
2330	a	0·602	0·596	0·657	0·669	0·663	0·675	0·672	0·665	0·664	0·659	0·627	—
	b	0·048	0·065	0·028	0·049	0·046	0·028	0·037	0·037	0·038	0·044	0·025	—
	c	0·554	0·531	0·629	0·620	0·617	0·647	0·635	0·628	0·626	0·614	0·602	—
1962													
2030	a	—	0·641	—									
	b	—	0·087	—									
	c	—	0·554	—									
2330	a	0·576	0·611	—									
	b	0·048	0·076	—									
	c	0·528	0·535	—									

a—black body radiation, b—net outgoing nocturnal radiation, c—incoming sky radiation

4.1. *Variation of net outgoing radiation*

Fom Table 4, it is seen that the values of net outgoing radiation expressed as percentage of black body radiation for clear sky night range from 9 to 20. These values can be compared with those obtained by other workers (Sutton 1953). The percentage figures have been found to have a wide range of variation from place to place. Maurer obtained the percentage of the order of 22 per cent for observations made in Zurich, while Pernter obtained a figure as high as 49 per cent for Sonnblock. The lowest figure in our case, are during the monsoon months. These may be attributable to the presence of moisture (water vapour) in the lower layers of air,

TABLE 3

Mean monthly values of night radiation in gm. cal/cm²/min for partly cloudy nights

(IST)		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1959													
2030	a											0·665	0·614
	b											0·069	0·094
	c											0·596	0·520
2330	a											0·645	0·599
	b											0·111	0·096
	c											0·534	0·503
1960													
2030	a	0·598	0·609	0·637	0·684	0·689	0·687	0·680	0·685	0·674	0·662	0·624	0.590
	b	0·095	0·097	0·079	0·095	0·080	0·059	0·041	0·054	0·071	0·069	0·078	0·095
	c	0·503	0·512	0·558	0·589	0·609	0·628	0·639	0·631	0·603	0·593	0·546	0·495
2330	a	0·555	0·609	0·621	0·674	0·684	0·680	0·671	0·676	0·673	0·656	0·622	0·568
	b	0·100	0·106	0·093	0·095	0·081	0·059	0·044	0·073	0·077	0·076	0·063	0·099
	c	0·455	0·503	0·528	0·579	0·603	0·621	0·627	0·603	0·596	0·580	0·559	0·469
1961													
2030	a	0·609	0·583	0·667	0·672	0·686	0·692	0·682	0·684	0·670	0·658	0·617	0·585
	b	0·090	0·069	0·069	0·082	0·046	0·051	0·049	0·043	0·051	0·068	0·083	0·096
	c	0·519	0·514	0·598	0·590	0·640	0·641	0·633	0·641	0·619	0·590	0·534	0·489
2330	a	0·583	0·597	0·655	0·659	0·659	0·668	0·670	0·676	0·667	0·653	0·604	0·566
	b	0·100	0·083	0·067	0·074	0·060	0·051	0·060	0·051	0·048	0·066	0·058	0·071
	c	0·483	0·514	0·588	0·585	0·599	0·617	0·610	0·625	0·619	0·587	0·546	0·495
1962													
2030	a	0·559	0·630	0·666									
	b	0·125	0·092	0·089									
	c	0·434	0·538	0·577									
2330	a	—	0·600	0·628									
	b	—	0·087	0·075									
	c	—	0·513	0·553									

a—black body radiation, b—net outgoing nocturnal radiation, c—incoming sky radiation

The monthly net outgoing radiation rates and the sky radiation rates on clear nights at 2030 and 2330 IST have been graphically represented in Fig. 1. It is well known that, quite often the nocturnal trend of cooling may be interrupted by mixing due to local winds of a transient character. As such, any conclusion based on radiation observations made only at 2030 and 2330 IST may not give the true picture. In order to do so, observations during the entire night are required.

TABLE 4

Net outgoing nocturnal radiation (A) and incoming sky radiation (B) expressed as percentage of black body radiation, for clear nights

	%			%	
	A	B		A	B
Jan	20	80	Jul	10	90
Feb	18	82	Aug	9	91
Mar	16	84	Sep	12	88
Apr	14	86	Oct	14	86
May	12	88	Nov	18	82
Jun	10	90	Dec	20	80

In spite of the above limitations, the following salient features came out from the two sets of observations at 2030 and 2330 IST as presented in this communication. From Fig. 1, it is seen that the net outgoing radiation rate decreased with the advance of night during February, while during March it remained the same. During the summer months (April—June) the rate increases as the night advances. In the earlier part of the monsoon (July) the rate shows slight decrease. When the monsoon is quite effective (August), the rate shows marked decrease. The rate of decrease becomes less in the later part of the monsoon (September), while in October it remains the same. During the winter months (November—January), it reverses its course, *i.e.*, there is an increase in the rate instead of decrease, the maximum rate of increase being during December.

4.2. *Variation of sky radiation*

It is well known that, if E is the outgoing long wave radiation from the black strips of the compensation pyrgeometer at temperature T°K (black body radiation) and S the incoming long wave radiation from the atmosphere (sky radiation), the net outgoing radiation N (nocturnal radiation) is equal to $E—S$. In other words, the sky radiation S is equal to $E—N$. While E is calculated from the well known Stefan Boltzman formula ($E=\sigma T^4$), N is directly measured with the compensation pyrgeometer. The values of sky radiation computed from the above values of E and N have been shown in Tables 1—3.

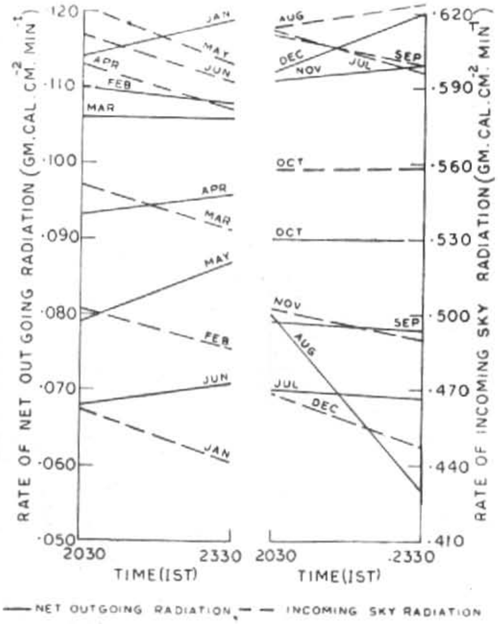

Fig. 1. Monthly net outgoing radiation and incoming sky radiation at different hours on clear nights

From Fig. 1, it is seen that on clear nights, the sky radiation increases with the advance of night during August and slightly decreases during September. During October it remains the same. From November, the sky radiation goes on decreasing with the advance of night till it reaches a minimum value in January. The rate of decrease becomes less in February. From March the rate of decrease goes on increasing till a minimum value is reached in June. In July the rate of decrease shows slight decrease. The course is reversed in August.

It is seen from Table 4 that on clear nights, the values of sky radiation expressed as percentage of black body radiaticn range between 80 and 91, being maximum in August (91 per cent) and minimum in December—January (80 per cent). During the months May to September, the percentage

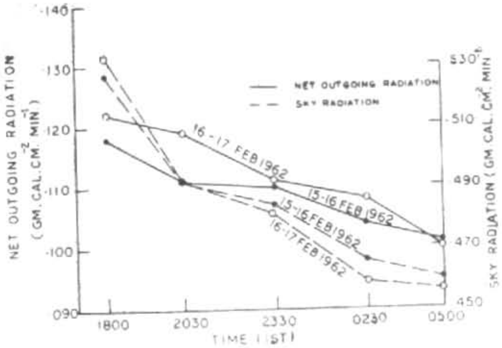

Fig. 2. Net outgoing radiation and sky radiation at different hours on clear nights of 15 16 and 16 17 Feb 1962 as measured at Dum Dum airport

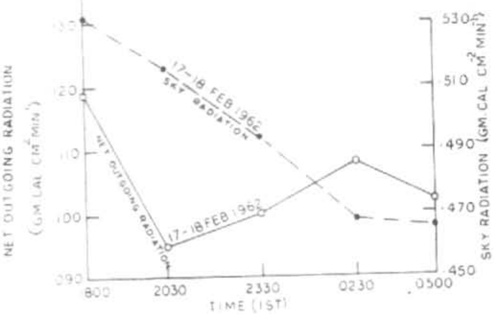

Fig. 3. Net outgoing radiation and sky radiation at different hours on the night of 17 18 Feb 1962 as measured at Dum Dum airport

figure lies above 88 per cent which is comparable to the values obtained by Mani and Chacko (1963) for radiation observations made at Delhi and Poona. They obtained the same values (88 per cent) during the months June to September at Delhi and slightly lower values (81 per cent) during June to October at Poona.

4.3. *Effect of haze/dust particles on the net outgoing radiation and sky radiation*

From the theoretical considerations, on clear nights, the net outgoing radiation after sunset should decrease gradually with the advance of night, *i.e.*, with fall of surface temperature. Ramdas *et al.* (1939) measured the variation in the nocturnal radiation from the night sky with zenith distance and with time and brought out the importance of the vertical part of the sky which has a lower effective radiating temperature than the lower parts. Raman (1936) carried out radiation measurements on some clear nights during winter at three different places at different altitudes and studied the march of radiation-loss from a horizontal surface and of the atmospheric radiation received on such a surface during the course of night. He explained his observations in terms of temperature and humidity of lower layers of the atmosphere. He observed that on clear nights, in settled weather, both the net radiation and the sky radiation decrease with time after sunset attaining a minimum value at about the time of minimum temperature. In order to find out the march of radiation-loss, some special observations were taken on some selected occasions on clear sky nights at five fixed hours. The results of the observations on two such occasions (15/16 February 1962 and 16/17 February 1962) are shown in Fig. 2. It is seen that the net outgoing radiation and sky radiation decrease with the advance of night. The results are in good agreement with those obtained by Raman.

The observations made on another cloudless night (17/18 February 1962) are quite interesting and shown in Fig. 3. At 1800 IST, the value of net outgoing radiation was 0·119 gm. cal. cm $^{-2}$ min $^{-1}$. At 2030 IST due to presence of overhead haze/dust particles, the value of net outgoing radiation was as low as 0·095 gm. cal. cm^{-2} min^{-1}. This gives an idea of the effect of haze/dust particles on the outgoing radiation, *viz.*, a reduction in its value from 0·119 to 0·095, *i.e.*, 0·024 gm. cal. cm^{-2} min^{-1}. At 2330 IST, the turbidity had lessened but the effect on the net outgoing radiation was still pronounced. At 0230 IST the sky became clear. As a result, in absence of any return of long wave radiation due to haze/dust particles the rate of net outgoing radiation increased. At 0500 IST, the rate of normal outgoing radiation was maintained. The values of sky radiation at different hours of the night are shown in Fig. 3. It is seen that the sky radiation decreased gradually from 1800 to 0230 IST. From 0230 to 0500 IST, the values of sky radiation remained almost the same, there being slight decrease in its value.

4·4. *Effect of cloud on the net outgoing radiation*

From the above discussions, it is seen that the presence of haze/dust particles appreciably affects the net outgoing radiation from the surface of the earth. The effect is more pronounced if a cloud layer is present in the lower layer of the atmosphere. The effect depends on the amount as well as the type of the clouds. It has been found that low clouds are very effective in preventing loss of heat by the surface. In fact, on extreme cases when there is a temperature inversion, the surface may actually receive more radiation from the atmosphere than it emits.

The effect of cloud on the net outgoing radiation has been studied in detail by the previous workers. Chacko (1951) while reporting the radiation observations made at Poona, noticed pronounced effect on the down-coming radiation. He noticed that even a patch of cloud at the zenith has a marked influence. According to Sutton (1953), on a clear night of low wind, the surface of the earth loses between 0·1 and 0·2 gm. cal. cm^{-2} min^{-1}. This loss is greatly reduced by low, thick cloud but is not appreciably affected by the presence of thin, high cloud. Brunt (1939) has concluded that on an average, the net loss of heat from the ground is about one-seventh of that observed with clear skies. Ångström (1928) has proposed the following empirical formula—

$$\frac{R_n}{R_0} = 1 - 0{\cdot}09\, n$$

where R_n is the net outgoing radiation when n-tenths of the sky are covered with cloud and R_0 the same observed on clear sky conditions. The above formula suffers from a serious draw back, that it does not differentiate between the low thin clouds and high thick clouds.

Keeping, however, the above limitation in view, an attempt has been made to see whether the above empirical formula holds good in respect of observations made at Dum Dum airport, Calcutta. In our case the empirical relation has come out to be

$$\frac{R_n}{R_0} = 1 - 0{\cdot}06\, n$$

irrespective of the type of the clouds. The above relation has been obtained by using data presented in Tables 1 and 2. This shows that the net outgoing radiation on overcast nights is more in tropical latitudes than that suggested by Ångström. This means that the night minimum temperature will come down considerably low. In other words, the diurnal range of temperature is more here even on overcast days. The reason may be attributed to some physical factors specially applicable to tropical latitudes, such as, structure of the clouds, temperature of the clouds etc. It is worthwhile to mention that the above value of the coefficient (*viz.* 0·06) has also been confirmed in the case of partly cloudy nights calculated from the data presented in Table 3.

While there is an unanimous agreement about the effect of clouds on the net outgoing radiation from the surface of the earth, there seems to be some confusion about the effect of suspended dust particles in the reduction of the long wave radiation loss. Veryard (1936) has observed in Peshawar that the unusually high night minimum temperatures were effected by the presence of dust haze over the station. Robinson (1947) has remarked that though the suspended particles may affect downward long wave radiation by a few per cent the effect may not be quite appreciable for most localities. In our case as already shown by the observations on 17/18 February 1962 the effect of haze/dust particles on the net outgoing radiation was appreciable.

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