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Studies of terrestrial radiation fluxes at the ground in India

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ABSTRACT. The results of measurements of longwave effective outgoing radiation and downward fluxes at the ground at eight stations in India during 1958-1962 are presented. Maps showing the distribution month by month of the net outgoing and downward infra-red fluxes have been prepared. The net outgoing radiation is a maximum during the dry months and a minimum during the monsoon over the whole country. The downward flux is a maximum during May to September and a minimum during winter. Comparisons with values computed from radiation charts show the calculated values to be substantially higher than those observed.

1. Introduction

In practically all matters relating to energy balance and transformation within the atmosphere, terrestrial radiative fluxes are as significant as solar radiative fluxes; yet terrestrial radiation has received much less attention in the past and till very recently, even close to the earth's surface, measurements of thermal radiation were not sufficiently extensive for conclusions other than of local validity to be drawn.

Measurements of the downward longwave radiation from the atmosphere and the net outward longwave flux have been made with Angström pyrgeometers at Poona though not regularly, for many years (Ramanathan and Desai 1932, Raman 1935, Chacko 1951). The Angström pyrgeometer measures the longwave effective outgoing radiation F_{net}, as a difference between the longwave radiation flux downward from the atmosphere $F\downarrow$ and that upward from the instrument. The two components are separated by calculating the upward radiation by means of the Stefan-Boltzmann equation on the assumption that the emissivity of the blackened strips of the instrument is 1·00.

Regular daily observations with Angström pyrgeometers were started at four stations during the IGY (Mani and Chacko 1963) and are now made at ten stations in India. The instrument has its limitations. It can only be used at night when there is no precipitation and the winds are light. Precautions have to be taken to avoid the effects of temperature differences. The instrument has to be calibrated regularly. Despite various practical difficulties, regular measurements 4 times nightly have been taken at all stations since the IGY. The present paper discusses the results of observations at the ground of the longwave effective outgoing radiation and atmospheric radiation at eight stations in India from 1958—1962.

2. Observations

Measurements of the effective outgoing longwave radiation F_{net} at the ground were made at 2030, 2330, 0230 and 0530 IST on all nights when there was no rain at the time of observation. $F\downarrow$ was calculated. The values of F_{net} and $F\downarrow$ considered here refer to a period of five years from 1958—1962 for Poona and Delhi, for 3 years 1960—1962 for Calcutta, Madras, Trivandrum, Jodhpur and Nagpur and for 2 years 1961 and 1962 for Visakhapatnam. The mean monthly values of F_{net} and $F\downarrow$ at 2030 IST for the eight stations are given in Tables 1 and 2.

Trivandrum, Madras, Visakhapatnam and Calcutta are coastal stations where the diurnal variations of temperature are small and water vapour content high throughout the year. Trivandrum and Madras are situated in the southern half of the Indian peninsula while Poona, Visakhapatnam and Nagpur lie in the middle of the country. Calcutta is typical of the northeast region with its hot

TABLE 1

Mean monthly values of the net outgoing longwave radiation F_n
(Clear nights)

	Delhi	Poona	Calcutta	Madras	Trivan-drum	Nagpur	Jodhpur	Visakha-patnam
				(cal/cm²/min)				
Jan	·105	·130	·111	·097	·079	·118	·135	·104
Feb	·104	·146	·091	·101	·096	·129	·133	·102
Mar	·125	·105	·102	·009	·090	·138	·152	·093
Apr	·129	·110	·092	·092	·069	·139	·147	·071
May	·122	·120	·080	·081	·070	·131	·133	·076
Jun	·089	·121	·073	·084	·071	·104	·098	·063
Jul	·054	·080	·053	·071	·067	·053	·084	·058
Aug	·064	·076	·063	·086	·091	·071	·072	·054
Sep	·077	·083	·056	·074	·080	·075	·111	·062
Oct	·110	·109	·076	·075	·079	·107	·114	·069
Nov	·115	·119	·102	·092	·075	·114	·143	·100
Dec	·107	·121	·112	·090	·089	·115	·125	·102
Mean	·105	·110	·084	·087	·080	·108	·116	·080

TABLE 2

Mean monthly values of downward longwave radiation flux $F\downarrow$
(Clear nights)

	Delhi	Poona	Calcutta	Madras	Trivan-drum	Nagpur	Jodhpur	Visakha-patnam
				(cal/cm²/min)				
Jan	·447	·495	·486	·545	·581	·507	·456	·522
Feb	·483	·509	·521	·552	·572	·506	·492	·543
Mar	·482	·572	·557	·577	·585	·559	·517	·578
Apr	·556	·581	·596	·596	·615	·594	·568	·620
May	·603	·568	·617	·608	·599	·600	·620	·628
Jun	·649	·541	·612	·602	·593	·647	·651	·634
Jul	·656	·583	·631	·617	·595	·627	·650	·617
Aug	·636	·545	·620	·604	·560	·611	·627	·637
Sep	·640	·558	·621	·617	·584	·598	·599	·623
Oct	·525	·536	·578	·603	·574	·548	·568	·604
Nov	·469	·500	·509	·543	·586	·521	·501	·550
Dec	·442	·496	·464	·549	·572	·492	·467	·534
Mean	·549	·540	·566	·584	·585	·567	·560	·591

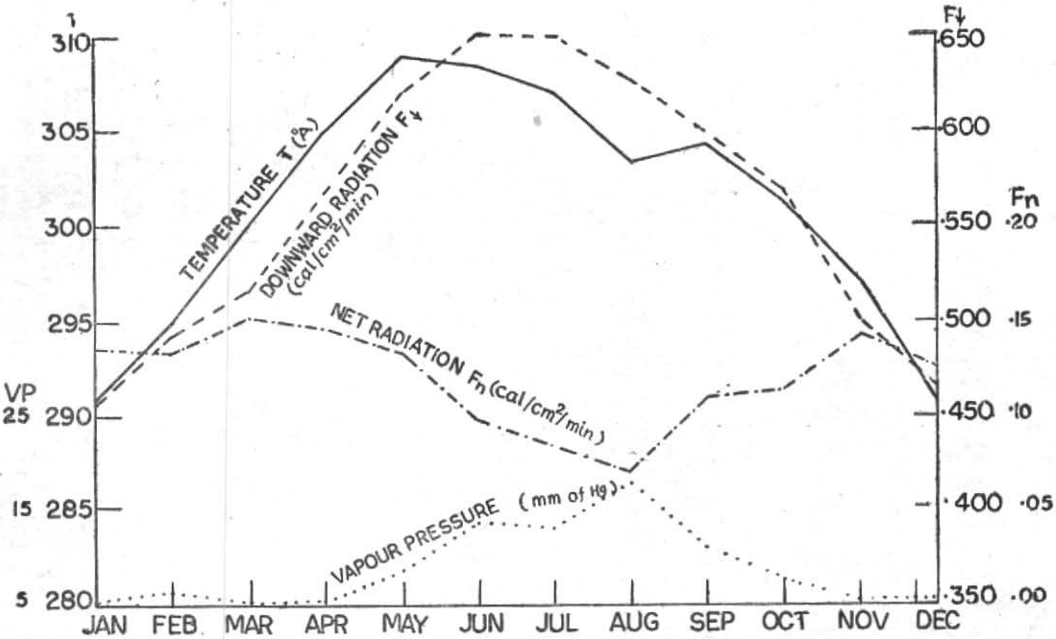

Fig. 1. Annual march of downward and net upward infra-red radiation flux, temperature and vapour pressure during clear nights at Jodhpur

humid summer followed by the monsoon and mild winter. New Delhi and Jodhpur are typical of the semi-arid zones to the north and northwest with its extreme summer and winter conditions. Madras on the east coast has climatic conditions quite different from that of the rest of the country, the northeast monsoon occurring during October and November being a special feature of this area.

3. Results

3.1. *Maximum and minimum values of net outgoing and downward fluxes*

It will be seen from Table 1 that the net outgoing radiation is a maximum at Jodhpur (26° 18′N, 72° 01′E) and a minimum at Trivandrum (08° 29′N, 76° 57′E), except during the monsoon. The annual march of the net outgoing radiation and the downward flux for these two stations are plotted in Figs. 1 and 2, with values of the surface temperature and specific humidity.

The atmosphere over Jodhpur is more or less dry throughout the year except during the short monsoon season. An average of 0·116 ly/min is lost by longwave radiation from the ground during the year at Jodhpur. The net outgoing radiation is a maximum (0·150 ly/min) during the hot summer months March and April and a minimum (0·072 ly/min) during August. These large values of net outgoing radiation cause appreciable nocturnal cooling in the area during the dry months.

Trivandrum is highly humid throughout the year situated as it is in the equatorial rainfall area on the west coast of the peninsula. The temperatures are also fairly constant at about 26°C, throughout the year. The net outgoing radiation is also more or less constant throughout the year, 0·096 ly/min being the highest value in February, and 0·069 ly/min the least in April. The mean effective outgoing radiation for the whole year is only 0·080 ly/min, 69 per cent of the value for Jodhpur.

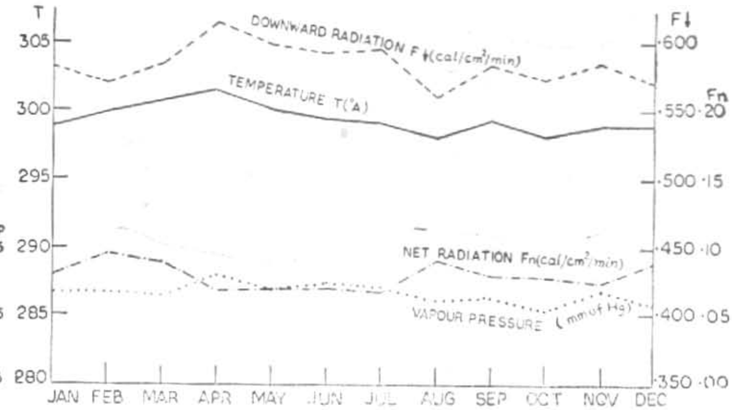

Fig. 2. Annual march of downward and net upward infra-red radiation flux, temperature and vapour pressure during clear nights at Trivandrum

The maximum downward infra-red flux over the country is at Visakhapatnam (0·591 ly/min), with Trivandrum (0·585 ly/min) and Madras (0·584 cal/cm²/min) coming next. The minimum is at Poona (0·540 ly/min).

The downward flux at Jodhpur (0·560 ly/min) shows a very large annual variation (Fig. 1) being 0·650 ly/min during June and 0·456 ly/min during January. The high values from April to September are a result of the increased temperatures and increased water vapour content during these months. Trivandrum on the other hand (Fig. 2), has a fairly constant downward flux throughout the year.

The coastal stations Calcutta, Madras, Trivandrum and Visakhapatnam are characterised by high humidities and comparatively lower yet constant temperatures throughout the year. They form a group having similar net outgoing and downward fluxes, the net outgoing radiation being on the whole less at these stations and the downward fluxes being higher than at the stations situated inland.

The inland stations with their relative dryness and a continental type of climate form a second group with higher values of net outgoing radiation and comparatively lower values of downward fluxes. The mean values are summarised below—

	Mean F_n	Mean $F\downarrow$	
Coastal stations	0·083	0·581	cal/cm²/min
Inland stations	0·110	0·554	cal/cm²/min

At all stations the net outgoing radiation is a maximum during the dry months and a minimum during the moist months of the monsoon.

The highest values of downward fluxes are observed during April to September at all stations and the lowest during December to February. This is to be expected considering the annual variations of temperature and water vapour content in the atmosphere.

3.2. Distribution of effective outgoing radiation over India

Fig. 3 shows the monthly distribution of the effective outgoing radiation over India. Only values for the clear nights are included. It will be seen that net infra-red radiative flux is a maximum over the semi-arid regions to the north and northwest throughout the year, except during the August months when it is a maximum in the southern half of the peninsula. It is a maximum in the north-

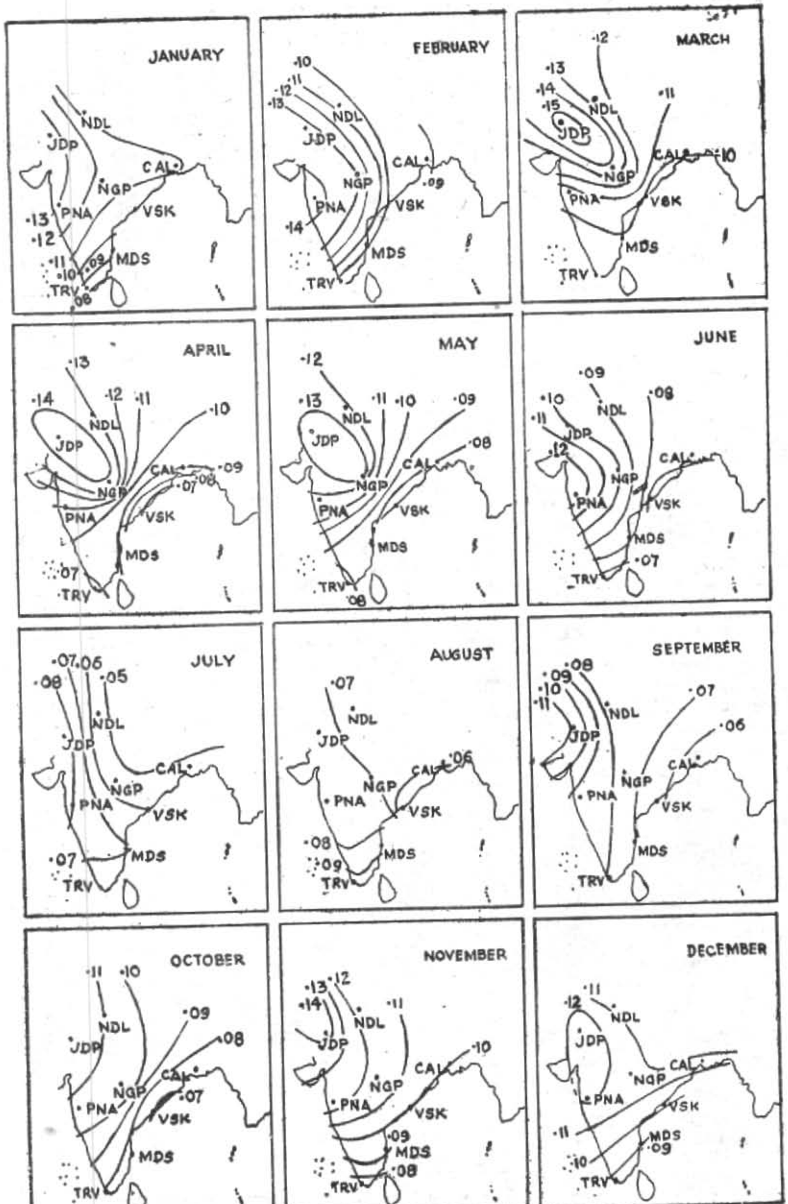

Fig. 3. Distribution of effective outgoing longwave radiation F_n (cal/cm²/min)

west from March—May and a minimum during July and August. In the southern half of the peninsula the net outgoing radiation remains fairly constant throughout the year. For the rest of the country the values are intermediate.

With the onset of the monsoon and the influx of moisture over the region in June, the net outgoing radiation decreases steadily across the country from the south to the north. Once the monsoon is established, net radiation is more or less uniform over the

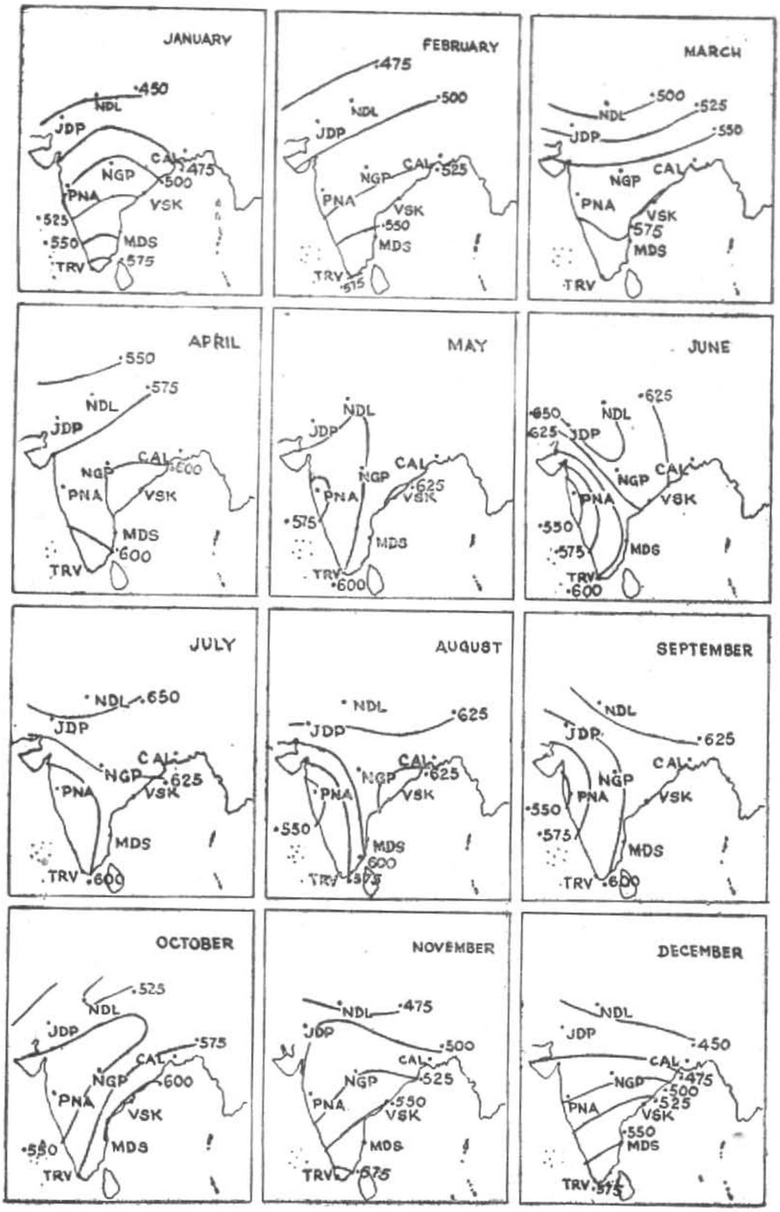

Fig. 4. Distribution of downward infra-red radiation $F\downarrow$ (cal/cm²/min)

whole country with a mean value of 0·068 ly/min for July and August. The net radiation in August in the extreme south is higher than in other months and over the rest of the country since the monsoon is least active here during these months.

The pattern changes again by September as the monsoon withdraws and the net outgoing radiation again becomes a maximum in the northwest as the winter pattern is established. The air over the extreme north is more moist in winter as a result of the

TABLE 3

Computed and observed values of net outgoing longwave radiation F_n

Station	Date	Computed	Observed
		(cal/cm²/min)	
New Delhi	3-1-62	·077	·097
	12-3-62	·071	·144
	8-5-62	·075	·126
	15-7-62	·074	·025
	24-9-62	·114	·095
	5-11-62	·078	·121
	15-4-63	·153	·132
Trivandrum	6-1-62	·112	·079
	18-3-62	·110	·071
	13-4-62	·088	·060
	4-6-62	120	·068
	23-11-62	·096	·075
	24-12-62	·103	·072
Poona	15-4-63	·109	·110
	16-4-63	·106	·110
	17-4-63	·124	·113
Ahmedabad	15-4-63	·147	·126

passage of western disturbances over the region.

3.3. *Distribution of infra-red downward flux over India*

The monthly distribution of infra-red downward flux on clear nights over India is shown in Fig. 4. The downward flux is a maximum over the southern half of the peninsula and the east coast throughout the year, except during the monsoon months June to September when it is highest over north and northeast India. It is a minimum over the hot dry northwest during the winter months. This is to be expected considering the distribution of temperature and water vapour content over the country during the different seasons.

4. Comparison with computed values

In the absence of clouds, the downward flux of infra-red radiation depends mainly on the distribution of specific humidity and temperature in the atmosphere. Extensive literature on the estimation of $F\downarrow$ by empirical formulae and by radiation charts exists. The formulae involve surface parameters only while the charts take some account of the vertical distribution of temperature and humidity in the lower troposphere. The charts are to be preferred since they are based on the equation of radiative transfer and experimental results.

Using Elsasser's radiation chart and the temperature and humidity profiles from radiosonde ascents at the stations, the upward and downward and net infra-red fluxes of radiation have been calculated for a few typical nights. The observed and computed values of net outgoing radiation are given in Table 3. The computed values are generally higher than the observed values.

Wexler (1941) compared observed values in North America under winter conditions with computed values and he found the calculated values to be substantially higher than those observed. Brooks (1941) and Robinson (1950) carried out comparative calculations for some cases of their numerous observations, but used them essentially to compute a radiation diagram on an empirical basis.

Robinson (1947) found that at Kew there was nearly always an additional downward component of longwave radiation where observations were compared with estimates given by radiation charts. Good agreement was obtained only when the sky was exceptionally clear and free from high cloud. He suggested that the most important additional radiators could be thin invisible clouds, ozone and particulate matter.

5. Conclusion

The results can be briefly summarised as follows —

(1) The longwave effective outgoing radiation is less at the coastal stations which are characterised by high humidities and fairly uniform temperature than at the inland stations where the air is relatively drier. On the whole the net outgoing radiation is a maximum during the dry months and a minimum during the cloudy monsoon months.

(2) The longwave downward flux from the atmosphere is less at the inland stations than at the coastal stations. It is a maximum during April to September and a minimum during winter.

(3) During the dry summer months, the net upward radiation is a maximum over the semi-arid regions to the north and northwest and a minimum in the south. With the onset of the monsoon and influx of moisture over the area in June, the net upward radiation decreases steadily across the country from the south to the north. Once the monsoon is established, F_{net} is more or less uniform over the region. The pattern changes in September, as the monsoon withdraws and the net upward flux again becomes a maximum in the northwest and the winter pattern is re-established.

(4) The observed values of net outgoing infra-red fluxes are often much lower than those calculated from the radiation chart. The differences can be attributed to radiators other than water vapour and carbon dioxide in the atmosphere.

REFERENCES

Brooks, F. A.	1941	*Pap. Phys. Oceanogr.*, **8**, **2**.
Chacko, O.	1951	*Indian J. Met. Geophys.*, **2**, p. 190.
Mani, A. and Chacko, O.	1963	*Ibid.*, **14**, 2, p. 196.
Raman, P. K.	1935	*Proc. Indian Acad. Sci.*, **1**, p. 815.
Ramanathan, K. R. and Desai, B. N.	1932	*Beitr. Geophys.*, **35**, p. 68.
Robinson, G. D.	1950	*Quart. J. R. met. Soc.*, **76**, p. 37.
	1947	*Ibid.*, **73**, p. 127.
Wexler, H.	1941	*Mon. Weath. Rev., Suppl.*, 46.