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Surface radiation balance measurements in India during the IQSY

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ABSTRACT. Results of surface radiation balance measurements at Poona, Calcutta and Delhi during the IQSY are presented. The diurnal, seasonal and spatial variations of net radiation are discussed, with reference to solar elevation, cloudiness, albedo and surface moisture and temperature. Net radiation during day is a maximum during the clear summer months and least during cloudy monsoon and winter months. At night net radiation is negative and generally very small or zero. Marked differences are present in the magnitude and the distribution of net radiation at Poona, Calcutta and Delhi.

1. Introduction

Studies of net radiation at the earth's surface are of vital importance in understanding the general energy balance on the earth and the processes of heat and moisture exchange between the earth's surface and the atmosphere. Information on net radiation has been very scanty in the past, but recent studies during the IGY and after, have resulted in increasing the knowledge of the magnitude and variations of the net radiation at the earth's surface. Most of these have been based on computed data derived from meteorological parameters. For the Indian Ocean and its environment, Mani *et al.* (1967) have prepared monthly maps showing the spatial distribution of surface net radiation, from computed data.

Though measurements of shortwave and longwave radiation fluxes were made at different stations in India for many years, direct measurements of net radiation itself were not made in India till 1964, when continuous measurements were organised at three stations as part of the IQSY meteorological programme of observations. While the data obtained at these three stations are not representative of all the different climatic zones of the country, they give for the first time direct observational data, enabling a study of the effect of the nature of the soil surface upon the magnitude and disposition of net radiative flux, and of the amount of radiant energy available for various processes that originate at the air-earth interface.

2. Instruments and exposure

The instrumental equipment for the continuous record of net radiation, used at New Delhi and Calcutta were Funk net pyrradiometers with Cambridge thread recorders and at Poona, a Schulze net pyrradiometer with a four channel recorder. The instruments were exposed with the sensitive surfaces 1·5 metres above the ground. The soil in the observation plot at Poona is black cotton soil, that at Calcutta and at Delhi grey alluvial soil. The soil surfaces were kept clear of grass throughout the year.

The net pyrradiometer is an instrument designed to measure the net flux of radiation through a horizontal plane. Measurement of net radiation for meteorological purposes is difficult, since the instrument must be sensitive to radiation ranging from $0 \cdot 2\ \mu$ to $60\ \mu$, should respond rapidly to changes in net radiation and come to a steady state rapidly and be independent of the temperature difference between the instrument and the surroundings. The absorbing surface should be able to view the whole hemisphere and obey the cosine law. The theory and principle of the working of Funk and Schulze net pyrradiometers are discussed by Funk (1959) and Schulze (1953/1954).

3. Factors controlling net radiation

Net radiation Q is the difference between the total incoming and outgoing radiation fluxes, both shortwave and longwave and is given by $Q=R_S\downarrow - R_S\uparrow + R_L\downarrow - R_L\uparrow$, where R_S and R_L are the shortwave and longwave radiation fluxes. All fluxes towards the surface are considered to be positive and all fluxes away from the surface, negative.

$R_S\downarrow$ is the downward flux of solar radiation at the surface or global solar radiation T, which is affected mainly by cloud amount and to a smaller extent by atmospheric aerosols and atmospheric absorption. The nature of the surface itself has no direct influence on T, but has a profound influence on the reflected solar radiation $R_S\uparrow$ and, therefore, on shortwave radiation balance $(R_S\downarrow - R_S\uparrow)$.

The downward terrestrial radiation $R_L\downarrow$ depends on air temperature, on cloud amount and temperature, and on the water content in the atmosphere,

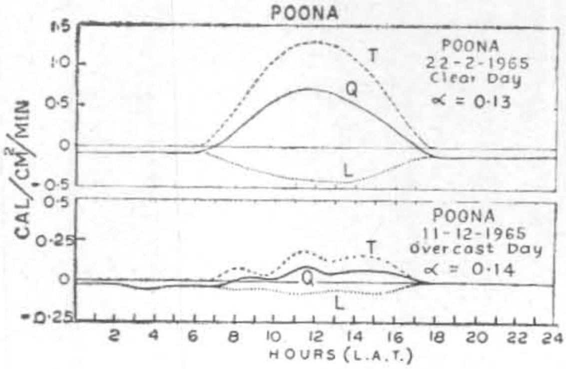

Fig. 1. Global radiation T, net radiation Q and net terrestrial radiation L at Poona

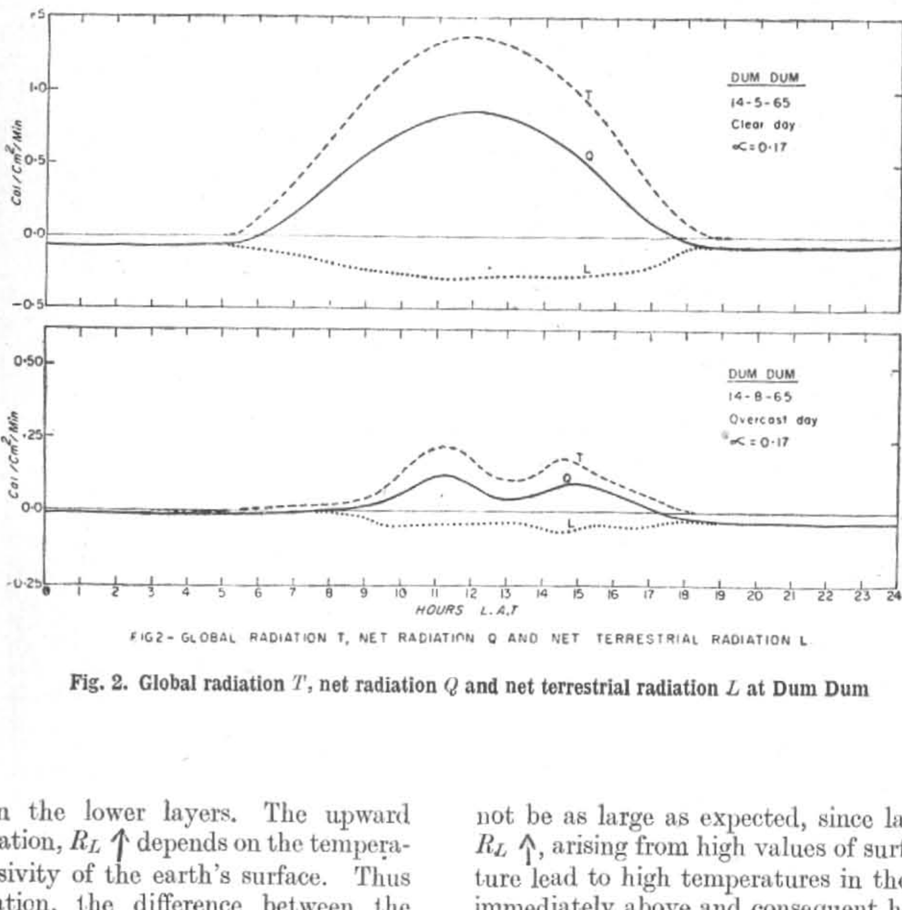

Fig. 2. Global radiation T, net radiation Q and net terrestrial radiation L at Dum Dum

particularly in the lower layers. The upward terrestrial radiation, $R_L \uparrow$ depends on the temperature and emissivity of the earth's surface. Thus the net radiation, the difference between the amount of shortwave radiation absorbed by the earth's surface ($R_S \downarrow - R_S \uparrow$) and the mount of effective outgoing longwave radiation ($R_L \uparrow - R_L \downarrow$) is a complex of interacting variables, with no clear separation of 'cause' and 'effect' (Robinson 1964). For a given regime of T, the net radiation and its variations during the day will depend on the nature of the surface, but the variations will not be as large as expected, since large values of $R_L \uparrow$, arising from high values of surface temperature lead to high temperatures in the atmosphere immediately above and consequent high values of $R_L \downarrow$.

Values of reflected radiation $R_S \uparrow$ at Poona measured with an albedograph, give values of $R_S \uparrow$ ranging from 11—20 per cent. of global solar radiation. The surface albedo α varies with solar elevation and cloud amount during the day from 0·11—0·26 and the mean daily value during the year from 0·11—0·18, depending on solar

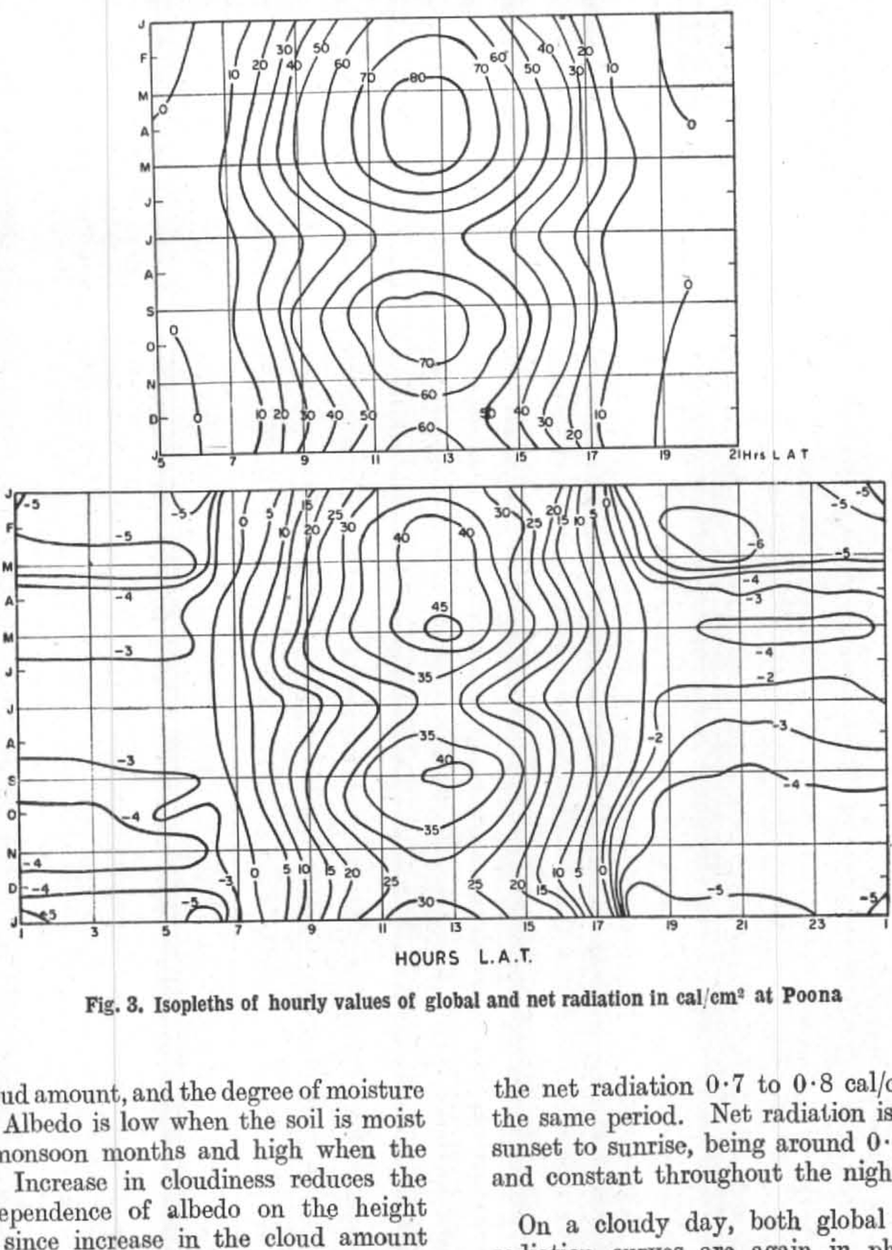

Fig. 3. Isopleths of hourly values of global and net radiation in cal/cm² at Poona

elevation, cloud amount, and the degree of moisture in the soil. Albedo is low when the soil is moist during the monsoon months and high when the soil is dry. Increase in cloudiness reduces the degree of dependence of albedo on the height of the sun, since increase in the cloud amount decreases direct solar radiation and augments diffuse sky radiation.

4. Diurnal variation of Q

The diurnal variation of net radiation Q, on cloudless and overcast days, at Poona and Dum Dum (Calcutta), is shown in Figs. 1 and 2. The albedo for Calcutta is estimated from the nature of the underlying surface as 0·17. Values of global solar radiation T and the estimated net terrestrial radiation $L=(R_L \downarrow - R_L \uparrow)$ are also given. Q is given by $T\ (1-\alpha)+L$.

On clear days, the curves for all three fluxes, T, Q and L are smooth and regular and reach a maximum about 12 noon. The total incoming solar radiation is 1·3 cal/cm²/min at noon and the net radiation 0·7 to 0·8 cal/cm²/min during the same period. Net radiation is negative from sunset to sunrise, being around 0·08 cal/cm²/min and constant throughout the night.

On a cloudy day, both global solar and net radiation curves are again in phase, but both values are very low, being about 0·15 and 0·08 cal/cm²/min respectively. At night the net radiation is almost zero. While net radiation is zero at Poona in the first half of the night, at Calcutta it is zero during the second. The effect of increasing surface temperatures during the day is noticeable in the net radiation profile, even though the sky is overcast.

5. Isopleth diagrams of T and Q

Figs. 3 and 4 are the diagrams of the hourly sums of T and Q for all months of 1965 for Poona and Calcutta. Isopleths are drawn every 5 cal/cm²/hour for positive values and 1 cal/cm²/hour, for negative values.

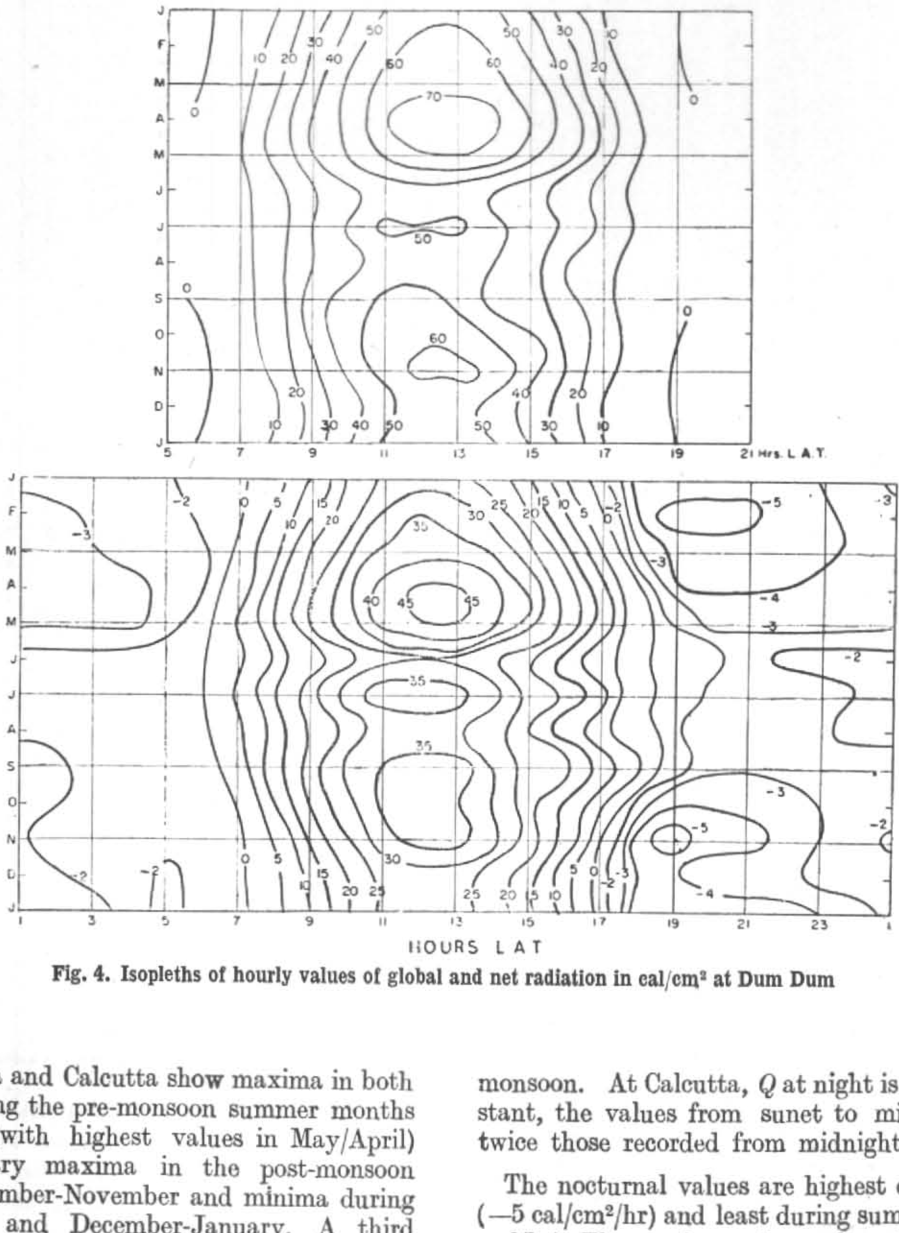

Fig. 4. Isopleths of hourly values of global and net radiation in cal/cm² at Dum Dum

Both Poona and Calcutta show maxima in both T and Q during the pre-monsoon summer months March-May (with highest values in May/April) with secondary maxima in the post-monsoon months September-November and minima during June-August and December-January. A third maximum in both T and Q occurs in July at Calcutta. The maxima in T and Q are associated with minima of cloudiness and the minimum with maximum of clouding during the monsoon months. The chief factors controlling Q are cloudiness and surface and air moisture and temperatures.

At Poona, Q remains fairly constant and negative at night, becomes zero about 45 minutes after sunrise, and after rising and reaching a maximum around noon, reaches zero again just before sunset. The symmetry of the values about noon is evident both during the winter and summer months, though this gets somewhat distorted during the monsoon. At Calcutta, Q at night is far from constant, the values from sunet to midnight being twice those recorded from midnight to sunrise.

The nocturnal values are highest during winter (—5 cal/cm²/hr) and least during summer (—2 cal/cm²/hr). The maximum day value at noon occurs in May (45 cal/cm²/day) and the minimum in December (27 cal/cm²/day). At Calcutta though the diurnal variation of net radiation is somewhat similar to that at Poona, there are obvious differences. The forenoon values are higher than the afternoon values. The early night values are also lower than the late night values.

6. Daily totals of T and Q and their variation

Figs. 5 and 6 show the daily totals of T and Q for the months January and July for Poona (18°N, 74°E) and Calcutta (22°N, 88°E) for 1965, with comparative values for Tashkent (41°N, 69°E) and

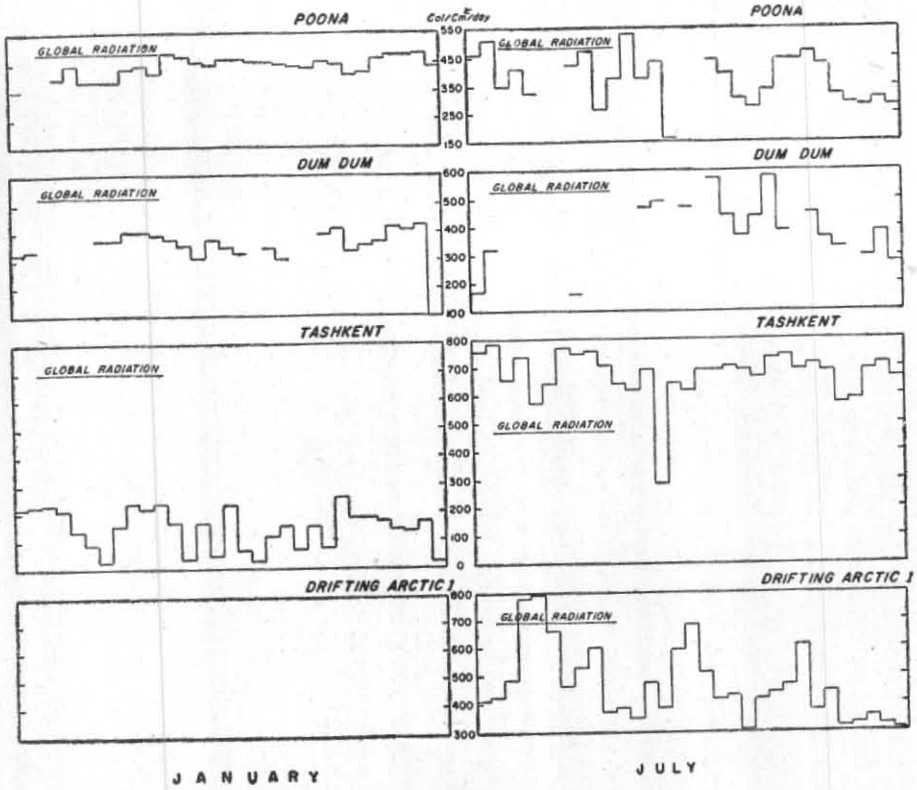

Fig. 5. Global radiation in January and July

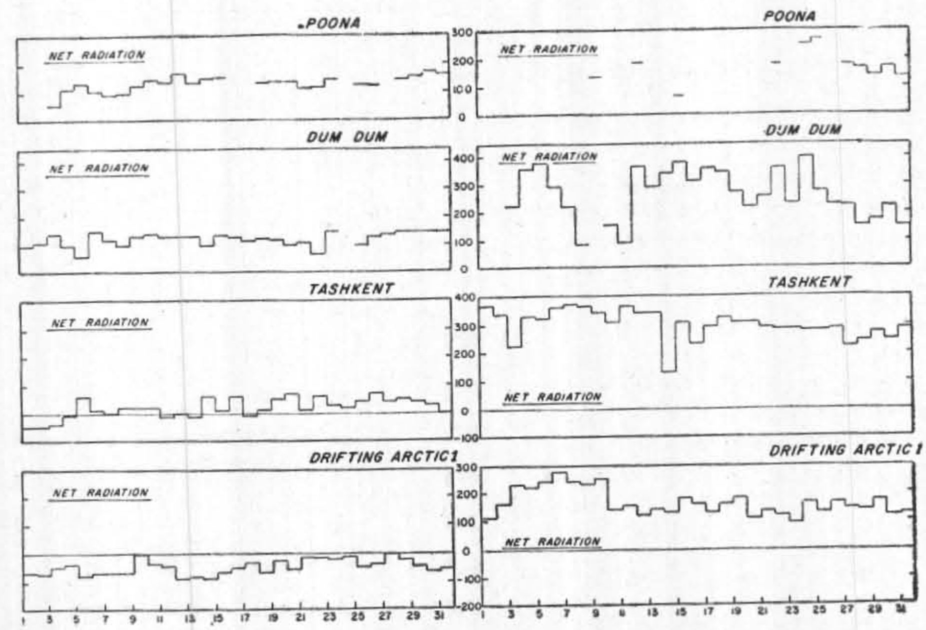

Fig. 6. Global and net radiation in January and July

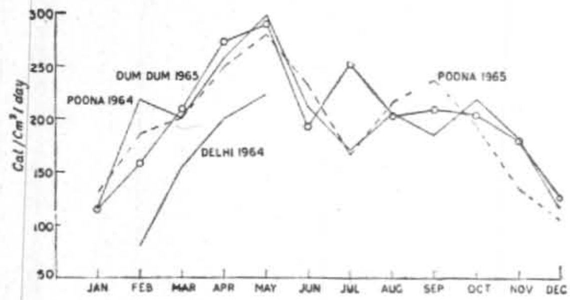

Fig. 7. Annual march of net radiation

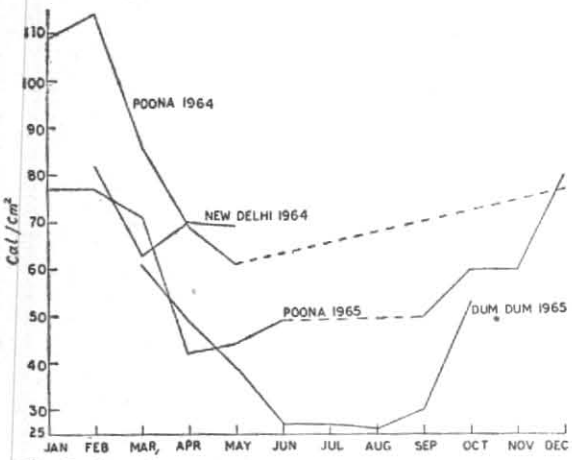

Fig. 8. Annual march of net radiation during clear nights
(Negative values of Q)

Drifting Arctic station I (84°—87½°) obtained for 1958. The climatic and latitudinal differences are clearly reflected in the nature of the day-to-day variations of the totals of T and Q. Poona and Calcutta show the expected similarities in T and Q. At Arctic station I with a snow covered surface and cloudless day, Q is negative and relatively low. When T is high as in the tropics and subtropics (Poona and Calcutta), or in summer in temperate latitudes (Tashkent), cloudless days are associated with high positive Q. Increasing cloud reduces both T and Q. In winter in temperate latitudes (Tashkent) variations of Q approximate to that at a polar station.

7. Seasonal variation of Q

The annual march of net radiation Q for Poona for the years 1964 to 1965, for Calcutta for 1965 and for Delhi for February to May 1964 are plotted in Fig. 7. The variations in net radiation at Poona and Calcutta during the different months are generally similar, with the maximum in May (about 290 cal/cm²/day) and minimum in January and December (120 cal/cm²/day). From January to May, there is a steep rise in net radiation, corresponding to a similar rise in T. Low values in March at Poona occur during both years and are genuine, caused by the large negative values of net radiation at night compared to April and May. The sharp fall in June to July is again in phase with the fall in T.

Net radiation at Delhi is appreciably lower than that at Poona and Calcutta.

The annual march of net radiation for clear nights at Poona, Calcutta and Delhi are shown in Fig. 8. Net outgoing radiation L at Calcutta is appreciably lower than that at Poona and Delhi, the values are in close agreement with effective long-wave outgoing radiation values obtained with Ångstrom pyrgeometers (Mani *et al.* 1965). The trend in the variation of the net outgoing radiation during the year is similar at Poona and Calcutta, with higher negative values in winter and lower values in the monsoon months. The 1964 values are much higher than those for 1965 throughout the year except December. The lower values at Calcutta are due to the higher humidities and comparatively lower temperatures at this station.

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