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ATMOSPHERIC RADIATION AND SKY TEMPERATURES IN THAILAND

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Summary

The downward longwave atmospheric radiation flux at Chiang Mai, Ubon, Bangkok, and Songkhla at 07:00 h daily during 1969 has been calculated from surface air temperatures using Swinbank's empirical formula with a correction for cloudiness depending on cloud amounts and heights. Mean values of the radiation flux, and the frequency distribution of the fluxes, in eight 1½ month periods of the year are given. The mean fluxes lie in the range 349 to 415 Wm^{-2}. Mean effective sky temperatures, at which a blackbody emits the same flux, lie in the range 6.9 to 19.3°C. The results are consistent with measured values of atmospheric radiation under similar conditions in India.

Introduction

A knowledge of the downward longwave atmospheric radiation at the earth's surface is of interest in a number of fields, including agriculture and solar energy technology. For example, in a hot climate one would like to know how far it is possible to cool objects on the ground by radiation to the sky at night, a process governed by the intensity of downward atmospheric radiation. This radiation is difficult to measure because the instrument is at a temperature close to that of the radiation itself. Operational pyrradiometers have been available for only two decades and no data for Thailand have yet been published.

Fortunately, downward atmospheric radiation can be estimated empirically with fair accuracy from ordinary surface meteorological observations. The present paper reports the results of a study of atmospheric radiation at Chiang Mai, Ubon, Bangkok, and Songkhla made in this way. Daily meteorological observations at 07:00 zone mean time (00:00 G.M.T.) throughout the year 1969 were used[1].

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Methods

Swinbank has shown[2] that the longwave radiation flux R_0 on a horizontal surface from clear skies at night is related to the absolute screen-level air temperature T in the range 280 K to 300 K by the equation

$$R_0 = aT^6, \qquad (1)$$

where $a = 0.531 \times 10^{-12}$ $Wm^{-2}K^{-6}$. The probable error is less than 5 Wm^{-2}.

A new relationship developed by Idso and Jackson[3], which appears to be valid at any latitude and for any air temperature reached on earth, has the form

$$R_0/\sigma T^4 = 1 - c \exp(-d(273 - T)^2),$$

where σ is the Stefan-Boltzmann constant (5.672×10^{-8} W^{-2} K^{-4}), $c = 0.261$, and $d = 7.77 \times 10^{-4}$ K^{-2}. In the temperature range of interest here (280 K to 310 K) the Idso-Jackson formula gives slightly higher values of R_0 than the Swinbank formula, but the difference never exceeds the probable error 5 Wm^{-2}.

The Swinbank formula was adopted for the present study on account of its greater simplicity, but the method of use was modified slightly in the following way. Instead of substituting the screen-level temperature for T in equation (1), the highest temperature in the atmospheric layer near the surface, as given by the published RAWINSONDE data[1], was used. This modification is desirable because, whereas Swinbank's formula is based on observations made in the evening, the data used for the present study were taken in the early morning when strong temperature inversions sometimes occur. Under an inversion the appropriate temperature for estimating the downward atmospheric radiation at the surface would be that of the warm radiating layer above rather than the cooler surface temperature.

The downward atmospheric radiation from a cloudy sky is greater than that from a clear sky due to thermal radiation from the clouds. Methods of taking this effect into account have been reviewed by Geiger[4,5]. According to Angstrom and Asklof[4] the downward atmospheric radiation R is given by

$$R = R_0 + (\sigma T^4 - R_0)\, kn, \qquad (2)$$

where k is a parameter that depends on the type and height of the cloud, and n is the cloud amount on the scale n = 0 for a clear sky and n = 1 for an overcast sky. For the parameter k Meinander[4] uses 0.76 with low clouds, 0.52 with medium clouds, and 0.26 with high clouds; Philipps[4] found a dependence of k on the height H of the low cloud base (km) that can be represented by

$$k = 1 - 0.0875\, H \qquad (3)$$

in the range H = 0 to 3 km.

An alternative formula, due to Lauscher and Bolz[5] is

$$R = R_0 (1 + k'n^2),$$

where k′ has the values for different cloud types as follows: cirrus 0.04, cirrostratus 0.08, altocumulus 0.17, altostratus 0.20, cumulus 0.20, and stratus 0.24. The quadratic function of n arises from the tendency of scattered clouds to be near the horizon where their contribution to the downward atmospheric radiation is less than it would be if they were near the zenith. The Lauscher-Bolz formula generally gives values of R that are up to 3 percent less than those given by the Angstrom-Asklof formula.

In the present study the Angstrom-Asklof formula was adopted, partly so that the slightly higher values of R from this method would offset the discrepancy between the lower values of R_0 given by the Swinbank formula compared with the Idso-Jackson formula, and partly so that data on the height of the low cloud base would be utilized.

The data include the amount, the type, and the height of the base of any low clouds present, and the types of any medium or high clouds present; the amounts and heights of medium and high clouds are not given. To find R from R_0 the value of kn was first calculated for each cloud layer. In the case of the low cloud layer equation (3) was used to determine k, and the reported cloud amount gave n. No distinction was made between clouds of different type. For the medium and high cloud layers Meinander's values of k were used, and in the absence of reported medium and high cloud amounts n was arbitrarily assigned the value 0.5 when clouds were present. Again, no distinction was made between the different types of cloud in these layers. When these three values of kn had been determined, the greatest of them was used in equation (2) to calculate R. Although low clouds make an important contribution to downward atmospheric radiation, the effect of medium and high clouds is small. Consequently, the crude treatment of medium and high clouds described above does not produce large errors in the results.

Another quantity calculated in this study was the effective sky temperature T_e defined by the equation

$$R = \sigma T_e^4.$$

This temperature is of interest because it specifies the coldest point that can be reached by an object radiating heat to the sky under the prevailing atmospheric conditions.

Results

The values of downward atmospheric radiation R and the corresponding effective sky temperatures T_e at Chiang Mai, Ubon, Bangkok, and Songkhla at 07:00 zone mean time every day throughout the year 1969 were calculated from the published meteorological observations by the methods described above.

In order to study the seasonal variation of atmospheric radiation the year was divided into eight $1\frac{1}{2}$ month periods defined by standard solar declination values in conformity with the periods used in a previous solar radiation study[6]. The mean values of R and T_e at the four stations in these periods are given in Tables I and II respectively. Also, the distribution of atmospheric radiation fluxes about the mean at the four stations in each $1\frac{1}{2}$ month period was found by dividing the radiation fluxes into classes of width 25 Wm^{-2} and counting the number of occurrences in each class. The results expressed as percentage frequencies are given in Table III.

Discussion

Although, as mentioned earlier, there are no measured values of R in Thailand with which to compare the calculated values, extensive observations of downward atmospheric radiation at night have been made in India, where latitudes and climates are similar to those in Thailand. The Indian measurements suggest that the calculated values for Thailand presented in this paper are reliable.

Figure 1 shows the monthly mean values of downward atmospheric radiation during the period 1958 to 1962 at New Delhi[7] plotted as a function of monthly mean

TABLE I: MEAN DOWNWARD ATMOSPHERIC RADIATION (Wm^{-2}) AT 07:00 H.

	Chiang Mai	Ubon	Bangkok	Songkhla
Jan. 14 – Feb. 26	349	380	389	399
Feb. 27 – Apr. 12	382	390	405	404
Apr. 13 – May 28	397	407	415	400
May 29 – July 15	402	404	412	398
July 16 – Aug. 31	405	401	404	390
Sep. 1 – Oct. 15	397	398	402	397
Oct. 16 – Nov. 29	370	378	390	405
Nov. 30 – Jan. 13	349	358	371	411

TABLE II: MEAN EFFECTIVE SKY TEMPERATURE (°C) AT 07:00 H.

	Chiang Mai	Ubon	Bangkok	Songkhla
Jan. 14 – Feb. 26	6.9	12.9	14.6	16.4
Feb. 27 – Apr. 12	13.3	14.8	17.5	17.3
Apr. 13 – May 28	16.1	17.9	19.3	16.6
May 29 – July 15	17.0	17.3	18.8	16.3
July 16 – Aug. 31	17.5	16.8	17.3	14.8
Sep. 1 – Oct. 15	16.1	16.3	17.0	16.1
Oct. 16 – Nov. 29	11.0	12.6	14.8	17.5
Nov. 30 – Jan. 13	6.9	8.7	11.2	18.6

TABLE III: PERCENTAGE DISTRIBUTIONS OF ATMOSPHERIC RADIATION FLUXES

Radiation class Wm^{-2}	Jan. 14 to Feb. 26	Feb. 27 to Apr. 12	Apr. 13 to May 28	May 29 to July 15	July 16 to Aug. 31	Sep. 1 to Oct. 15	Oct. 16 to Nov. 29	Nov. 30 to Jan. 13
Chiang Mai								
285–310	0	0	0	0	0	0	0	4
310–335	11	0	0	0	0	0	3	19
335–360	65	2	0	0	0	2	29	46
360–385	21	63	14	12	16	27	46	21
385–410	3	32	65	53	31	50	15	7
410–435	0	3	21	32	53	21	7	3
435–460	0	0	0	3	0	0	0	0
Ubon								
285–310	0	0	0	0	0	0	0	0
310–335	2	2	0	0	0	0	0	10
335–360	15	2	0	0	0	0	16	50
360–385	34	34	2	0	2	21	46	30
385–410	42	48	58	72	78	55	30	10
410–435	7	12	38	21	13	21	5	0
435–460	0	2	2	7	7	3	3	0
Bangkok								
285–310	0	0	0	0	0	0	0	0
310–335	0	0	0	0	0	0	0	6
335–360	8	0	0	0	0	0	0	29
360–385	24	8	0	0	4	2	30	36
385–410	63	58	27	43	76	72	50	24
410–435	5	34	70	55	20	26	14	2
435–460	0	0	3	2	0	0	0	3
Songkhla								
285–310	0	0	0	0	0	0	0	0
310–335	0	0	0	0	0	0	0	0
335–360	0	0	0	0	0	0	0	0
360–385	26	9	2	6	22	7	12	7
385–410	43	57	82	79	78	90	51	34
410–435	29	31	16	15	0	3	29	51
435–460	2	3	0	0	0	0	8	8

surface air temperature at night. Curves giving the clear sky radiation flux according to Swinbank's formula (1) and the blackbody radiation at the surface air temperature are also shown. The points at temperatures below 22°C belong to the cool season from November to March. They lie slightly above the clear sky curve due to cloudiness caused by winter disturbances from the west. Above 28°C the points that lie on the clear sky curve belong to the hot dry season from April to June when clear skies prevail, and the remaining points midway between the clear sky curve and the blackbody curve belong to the cloudy wet season from July to September.

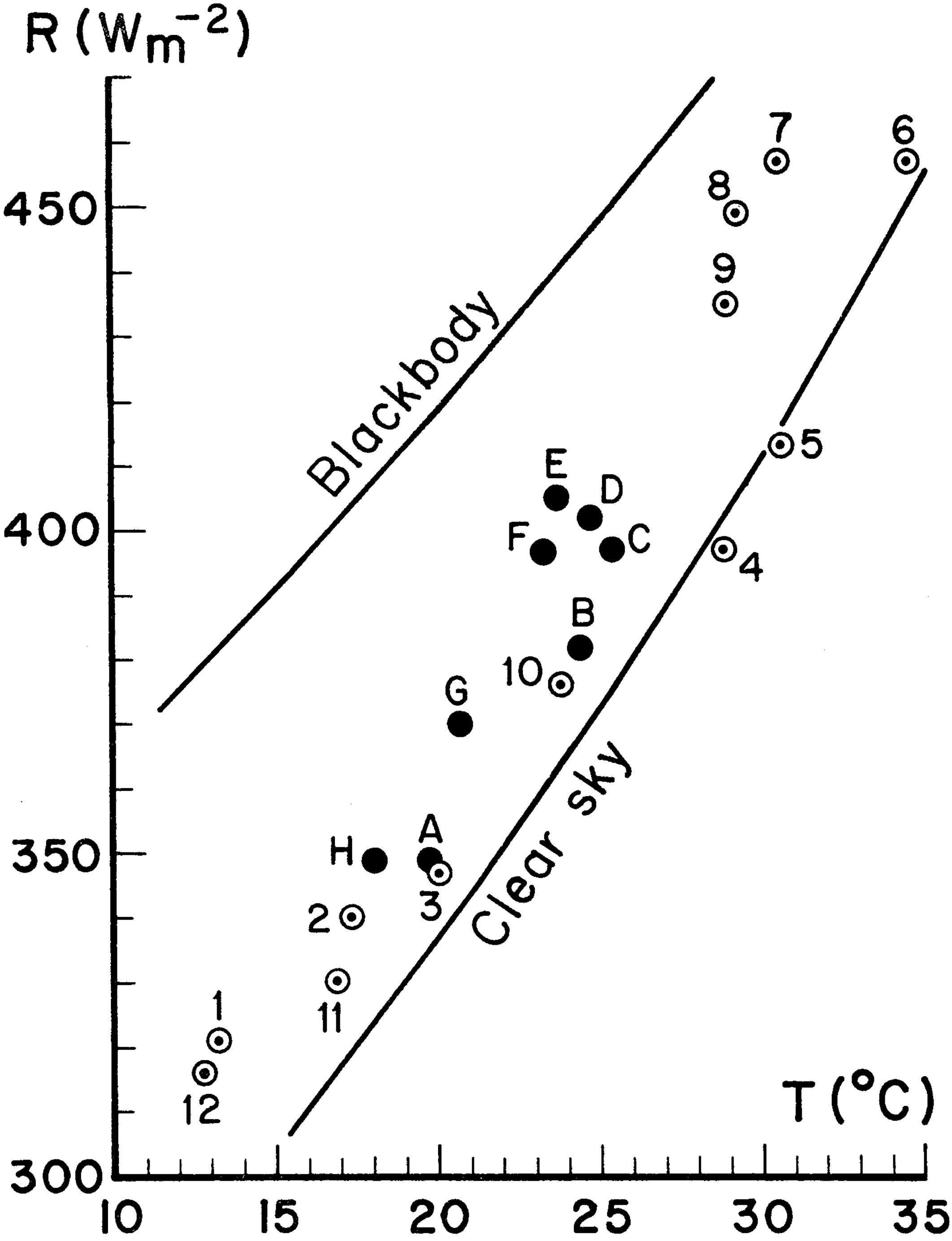

Fig. 1. Downward atmospheric radiation R versus surface air temperature T. Open circles: New Delhi, 1 = Jan., ..., 12 = Dec. Filled circles: Chiang Mai, A = Jan. 14–Feb. 26, ..., H = Nov. 30–Jan. 13.

This pattern of observed points for New Delhi has been described in detail because of its similarity to the pattern of points calculated for the eight 1½ month periods at Chiang Mai as plotted in Figure 1. The main differences between the two patterns are that the range of night temperatures is less at Chiang Mai than it is at New Delhi, and that there is no period of the year at Chiang Mai during which clouds are so scarce as to make the points lie on the clear sky curve.

Another interesting comparison is that between the observed downward atmospheric radiation fluxes at Trivandrum[8] and the fluxes calculated for Songkhla. Both of these stations are near the equator and have a maritime climate with fairly constant temperatures and atmospheric radiation fluxes throughout the year. At Trivandrum the annual mean surface air temperature at night is 26°C and the annual mean downward atmospheric radiation is 409 Wm^{-2}; at Songkhla the corresponding values are 24°C and 400 Wm^{-2} respectively. These results may be used to calculate from equation (2) average annual values for the product kn, which is a measure of the effect of clouds on downward atmospheric radiation. At Trivandrum one finds kn = 0.38, and at Songkhla kn = 0.46: the effect of clouds is nearly the same at both stations.

The question as to how closely the data for 1969 represent the average conditions in Thailand over a period of many years cannot be answered with certainty. But some indication of the likely variability of the mean values from one year to the next can be obtained by examining published data for New Delhi over the five years 1958 to 1962[7]. Here the deviations of the monthly means in individual years from the five-year monthly means are about 15 Wm^{-2} on the average, or approximately 4 percent of the mean. It seems reasonable to claim that this figure also represents the accuracy of the mean values given in Table I.

Changes in the weather cause the value of R to fluctuate from day to day. The character of these fluctuations is shown by the distributions in Table III. All the distributions are unimodal, but they have varying amounts of dispersion and skewness. As a general rule one can say that the deviations of R from the mean value in each 1½ month period are typically equal to the class width, namely 25 Wm^{-2}, or about 6 percent of the mean. One should not, however, attach too much significance to the finer details of the distributions themselves because they are derived from data for only one year.

Finally, in order to show the relationship between the effective night sky temperatures and the diurnal range of air temperatures in Thailand the annual means of the daily maximum and minimum temperatues[9] and of the calculated values of T_e are listed for each of the four stations in Table IV. Temperatures do not normally depart very far from these annual means throughout the year except in the north during the cool winter season. The effective sky temperatures T_e are typically from 15 to 20°C lower than the daily maximum air temperatures, and are about 7°C lower than the minimum air temperatures at night.

TABLE IV: ANNUAL MEAN TEMPERATURES (°C).

	Chiang Mai	Ubon	Bangkok	Songkhla
Daily max.	31.8	32.5	32.5	31.4
Daily min.	19.7	22.0	23.8	23.8
T_e (07:00 h.)	13.1	14.7	16.3	16.7

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บทคัดย่อ

การคำนวณพลังความร้อนจากอากาศเบื้องบนที่ลงมากระทบผิวโลกเป็นคลื่นยาว ที่เชียงใหม่ อุบล กรุงเทพ ฯ และสงขลา ในเวลาประมาณ 07:00 น. ทุกเช้าตลอดปี ค.ศ. 1969 นั้น ได้คำนวณจากอุณหภูมิของอากาศที่อยู่ในระดับพื้นดินเป็นสำคัญ และอาศัยกฎสังเกตของ Swinbank เป็นหลัก โดยมีการแก้ไขเปลี่ยนแปลงบ้าง ทั้งนี้ก็ขึ้นอยู่กับปริมาณและความสูงต่ำของก้อนเมฆ ในบทความนี้ได้แสดงตัวเลขจากการคำนวณผลของค่าเฉลี่ยของปริมาณการจำแนกความถี่ของพลังความร้อนจากอากาศและเบื้องบน โดยกระทำกันเป็น 8 ระยะด้วยกันตลอดช่วงเวลาหนึ่งปี แต่ละระยะนั้นใช้เวลา 1½ เดือน ผลปรากฏว่าปริมาณของพลังความร้อนโดยเฉลี่ยนั้นจะอยู่ระหว่าง 349 ถึง 415 Wm^{-2} และอุณหภูมิในท้องฟ้าเท่าที่ปรากฏโดยเฉลี่ย อันเป็นอุณหภูมิเดียวกันกับที่เทห์วัตถุสีดำจะแพร่พลังความร้อนอย่างเดียวกันออกจากตัวของมัน จะอยู่ระหว่าง 6.9 ถึง 19.3°C อนึ่งเป็นที่สังเกตว่า ผลของการคำนวณอุณหภูมิดังกล่าวตรงกันกับค่าของผลวัดของพลังความร้อนในอากาศเบื้องบนภายใต้สภาวะเดียวกันในประเทศอินเดีย