MAUSAM, 49, 2 (April 1998), 203-210

551.521.32 (547.1)

Effective terrestrial radiant energy at the ground at Pune

V. DESIKAN and V.R. CHIVATE

Meteorological Office, Pune-411005, India

(Received 3 September 1993, Modified 4 December 1996)

सार — भू-तल के समीप के अन्य मौसम वैज्ञानिक प्राचलों में आने वाले परिवर्तनों को पृथ्वी की प्रभावी निर्गमनी विकिरण ऊर्जा नियंत्रित करती है। इस ऊर्जा के प्रत्यक्ष मापों के अभाव में अन्य विकिरण प्राचलों से मान निकाले गए हैं, जिनको पुणे में मापा जा रहा है। इस पार्थिव ऊर्जा में एक औसत दिन में 8.5 वर्ग एम. जे. एम. के अनुक्रम में कमी आती है। अधिकतम अनुक्रम अप्रैल में 12.53 वर्ग एम. जे. एम. तथा न्यूनतम अगस्त में 3.87 वर्ग एम. जे. एम. पाया गया है। यह दैनिक अधिकतम दोपहर में अथवा ठीक उसके बाद होता है। तथापि वर्ष - दर - वर्ष आने वाले परिवर्तन वर्षा के वितरण तथा हवा में नमी की मात्रा पर निर्भर करते हैं।

ABSTRACT. The effective outgoing terrestrial radiant energy controls the variations in other meteorological parameters near the ground surface. In the absence of direct measurements of this energy, the values are derived from other radiation parameters that are being measured at Pune. On an average day the loss of this terrestrial energy is of the order of 8.5 MJm^{-2}. The maximum of 12.53 MJm^{-2} is reached in April and the minimum of 3.87 MJm^{-2} during August. The daily maximum occurs at noon or just after that. Year-to-year variations however depend on the rainfall distribution and the moisture in the air.

Key words — Terrestrial radiation, Radiant exposure, Radiant energy, Pyranometer.

1. Introduction

Although solar irradiance is the primary source of all energy transactions in the earth-atmosphere system, a wide variety of interactions is largely controlled by the earth's radiance. The changes in the ambient temperature, humidity, evaporation etc. are affected by variations in this earth's radiance. Because of the low temperatures (compared to that of the sun) at which the emission takes place, the radiance occurs at wavelengths of terrestrial radiant energy. The interaction between this energy and the atmosphere, whose temperature is not significantly different, is quite complex. The net solar irradiance is available for heating, directly and indirectly, the earth and the atmosphere. The thermal radiation is one of resulting transformations of the solar irradiance after absorption by the earth's surface. The radiative heating of each successive layer of the atmosphere by this thermal radiation is equally important. One of the important effects of this thermal radiation lies on the thermodynamical aspects leading to the various changes in the atmospheric parameters, like, temperature, pressure, air flow and cloud formation. The regular and continuous measurement of the effective outgoing radiant energy is, however, difficult and carried out only at limited centres. The present paper deals with the data deduced from other regular radiation measurements being made at Pune and the variations that take place over a time.

2. Data collection

In the terrestrial region of electromagnetic spectrum, the entire environment, including the instrument itself, is emitting the radiant energy in the same wavelengths monitored. An instrument which will directly measure the terrestrial radiant energy must be insensitive to the wavelengths of solar irradiance. Most of the window materials that are suitable for such selective transmission do not, however, have sufficient hardness and are generally hygroscopic in nature, resulting in abrupt changes in the transmission characteristics of the window materials. Added to this, the window material itself participates in the energy transactions. The very few materials which are impervious to the solar irradiance and weather resistant as well as are prohibitively costly. Thus the measurement of the effective outgoing terrestrial radiation is not made on a large network scale. The measurements are again highly vitiated by the dust deposits and water deposition due to dew, fog and precipitation. It is more convenient to deduce the effective outgoing terrestrial radiation ($H_{\uparrow}^{*}$) from the measurements of global and reflected solar radiant exposures and the net total radiant

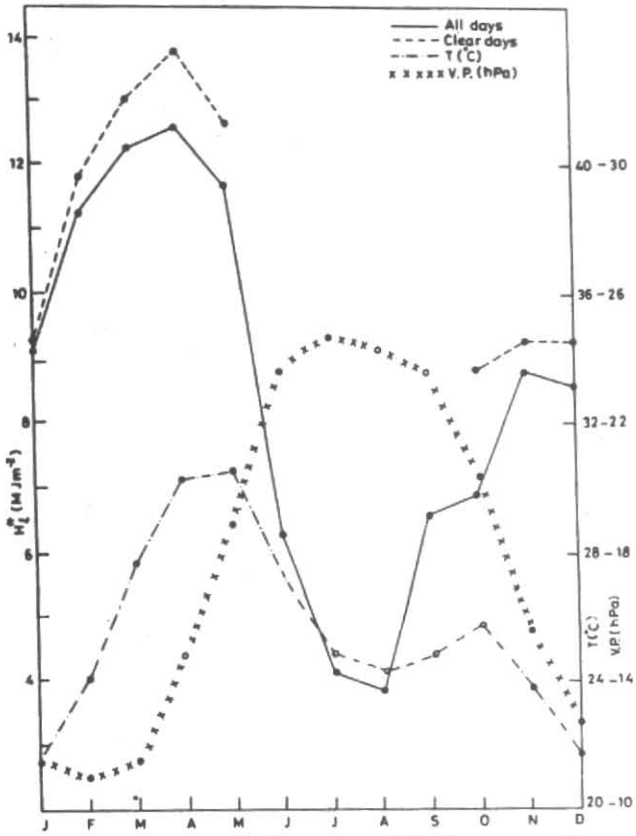

Fig.1. Annual March of effective terrestrial radiant energy at Pune

energy. The difference between the global solar radiant exposure and the reflected solar radiant exposure gives the net solar radiant exposure. The net total radiant energy is the algebraic sum of net solar radiant exposure and the effective outgoing (net) terrestrial radiant energy.

At Pune regular and continuous recordings of global and reflected radiant exposures and net total radiant energy are being carried out. The reflected pyranometer (CM-5 type) and the net pyrradiometer (Funk type) are installed on the ground at the standard height and with the same bare soil undersurfaces. The global radiant exposure is measured by a CM-5 pyranometer. The data thus deduced are for a five year period (1984-88) and the results discussed.

3. Results and discussion

In India, net terrestrial radiant energy (same as ETR) is being measured on a network scale at few stations using Angstrom pyrgeometer. These measurements are recorded as spot values at 00 h and 15 h UTC and restricted to dark hours as these pyrgeometers cannot be used during day times. As early as in 1937 Ramdas *et al.* (1937) and again Chacko (1951) during 1945-49 had made specific measurements during the night with the pyrgeometer and discussed the results. They found that the effective radiance from the earth decreases with time on a cloudless night and is attributable mainly due to the drop in the air temperature. Mani and Chacko (1963), Mani *et al.* (1965), De and Gupta (1964), Swaminathan and Desikan (1967) and Das (1987) have discussed the results in a limited way based on these data obtained with pyrgeometer.

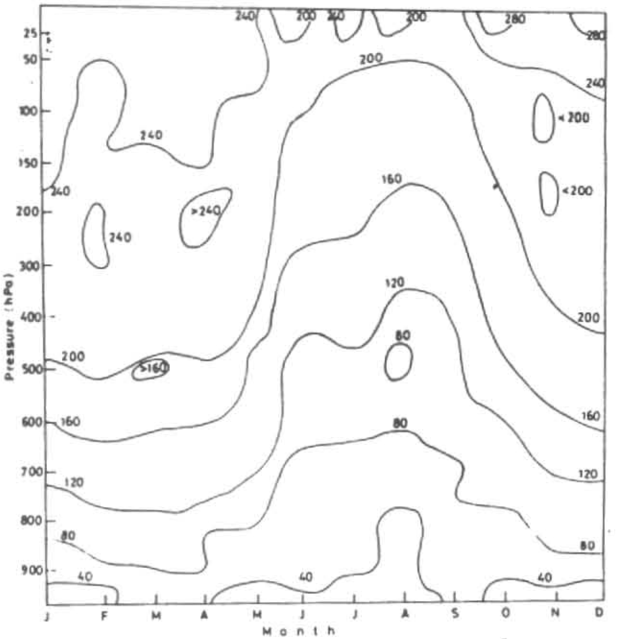

Fig.2. Mean net terrestrial radiant flux (Wm^{-2})

Kondratyev (1965, 1969) gives a detailed and delightful account of the terrestrial radiant energy on all its aspects. He, however, prefers to use computed values to the measured values as he considers that the methods for measuring the radiant energy are imperfect. The $H_{\uparrow}^{*}$ has a simple diurnal range with a maximum at noon and a minimum just before sunrise.

3.1. *Daily variations of* $H_{\uparrow}^{*}$

On an average Pune loses 8.5 MJm^{-2} in the form of outgoing terrestrial radiant energy every day while it is nearly 9.8 MJm^{-2} on a cloudless day. Fig.1 gives the annual variations in $H_{\uparrow}$ on all days and on cloudless days. The maximum is reached in April (12.53 MJm^{-2}), about 47 per cent more than the daily average. The minimum loss occurs in August (3.87 MJm^{-2}) being 54 per cent lower than the annual daily mean loss. In February $H_{\uparrow}^{*}$ increases by more than 25 per cent from 9.44 MJm^{-2} of January on cloudless days while it is 24 per cent on all days. This is due to drier air and generally cloudless conditions (more than 15 days without any cloud) which normally prevail during February.

The upper air net terrestrial radiation field also shows (Fig.2) that the values of $H_{\uparrow}^{*}$ in each layer are higher in February than in any other period, (Bhagwat 1990,

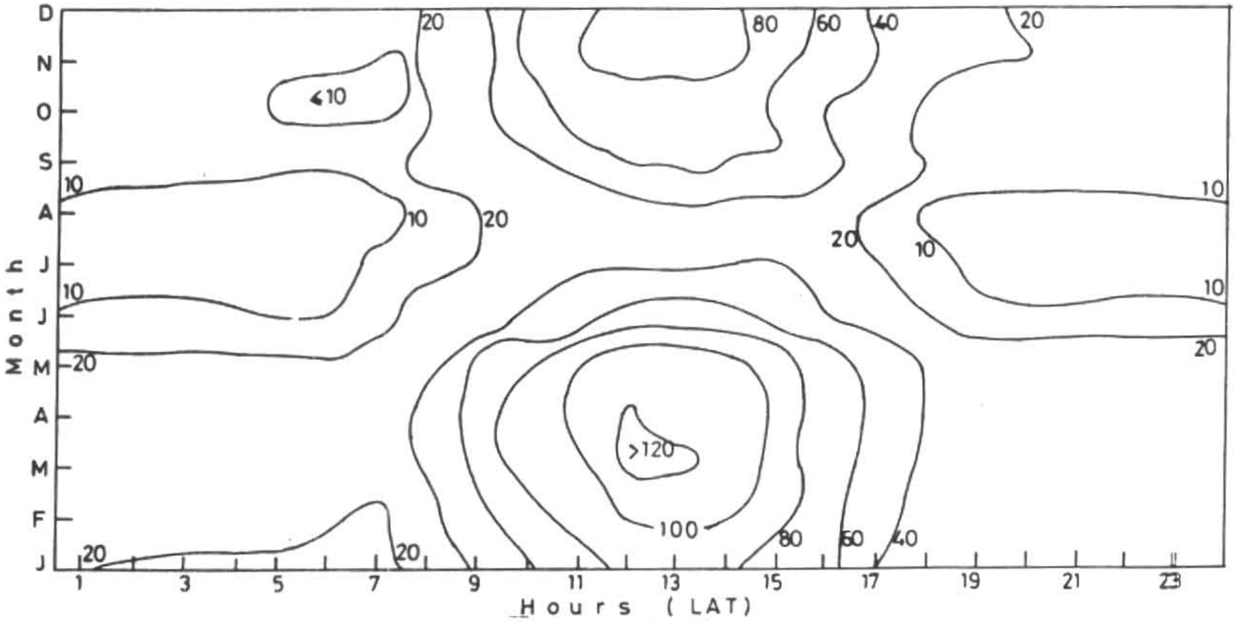

Fig.3. Isopleths of $H_{\uparrow}^{*}$, (10^{-2} Wm^{-2}) on all days at Pune

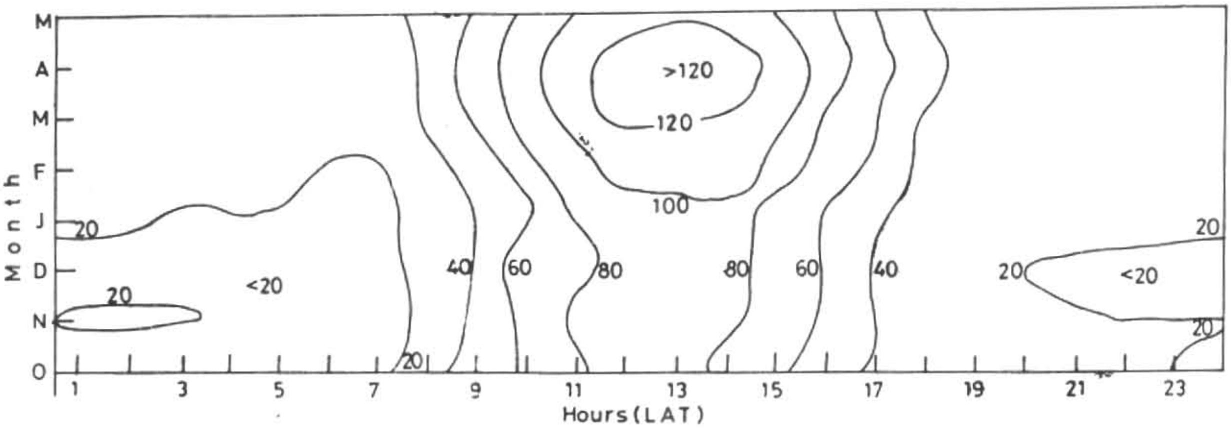

Fig.4. Isopleths of $H_{\uparrow}^{*}$ (10^{-2}Wm^{-2}) on cloudless days

Jayaraman *et al.* 1993). Despite high mean temperature in May, $H_{\uparrow}^{*}$ decreases by 7 per cent from April 12.53 MJm^{-2} mainly due to increased clouding and moisture incursion. The vapour pressure increases from 14.8 hPa in April 18.9 hPa in May. With the advent of the monsoon season $H_{\uparrow}^{*}$ drops to 6.24 MJm^{-2} in June which further falls to 3.87 MJm^{-2} in August when the daily mean temperature is around 24°C and the vapour pressure more than 24.0 hPa. A weakened monsoon activity along with reduced vapour pressure and lower cloud cover, $H_{\uparrow}^{*}$ increases to 6.60 MJm^{-2} in September.

$H_{\uparrow}^{*}$ is naturally higher on cloudless days. The highest value is recorded in April with 13.8 MJm^{-2} being lost daily. The incursion of moist winds brings down this high value by nearly 9 per cent in May.

3.2. *Diurnal variations in* $H_{\uparrow}^{*}$

Kondratyev (1969) states that $H_{\uparrow}^{*}$ has a simple diurnal variation with maximum at noon and minimum just before sunrise. There is a monotonic decrease in $H_{\uparrow}^{*}$ during the night from sunset to sunrise and he ascribes the main cause to the variations in the temperature of the radiating surface. Chacko (1951) showed from his measurements the good correspondence with the moisture content. Kondratyev (1965) states that the maximum $H_{\uparrow}^{*}$ is reached some time after mid-day. Fig.3 gives the isopleths of hourly values of $H_{\uparrow}^{*}$ on all days. It is seen that the maximum is reached around noon. March records highest hourly value of more than 1.20 MJm^{-2} around the noon. The 1.00 MJm^{-2} isopleth covers more than 3 hours during the February - May period. During the monsoon period the day time values are less than

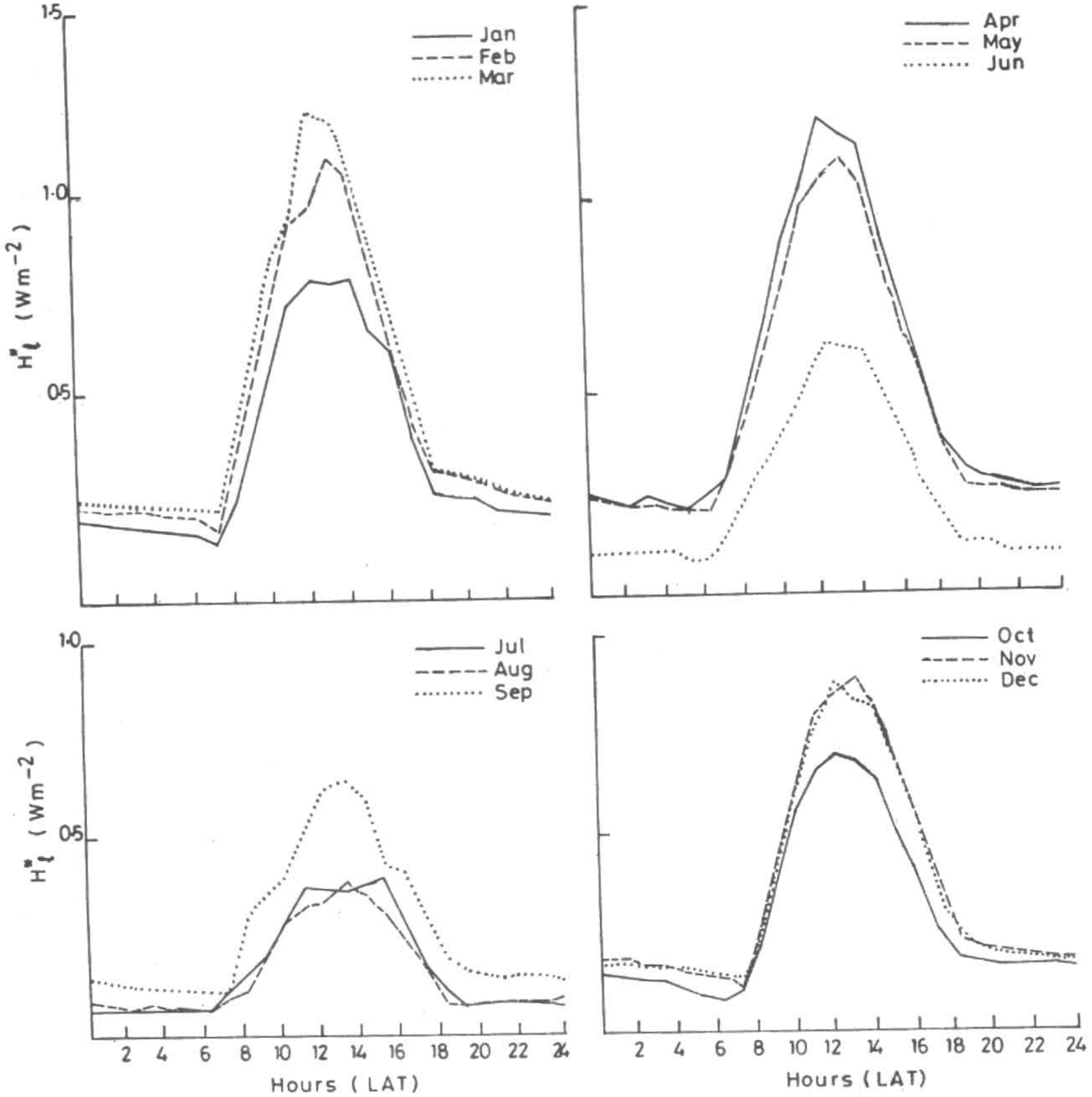

Fig.5. Diurnal variations in H_l^* on all days at Pune

400 kJm^{-2}. The entire night period during July-August records less than 100 kJm^{-2} per hour. October records less than 100 kJm^{-2} before sunrise. The winter values not even reach 1.00 MJm^{-2} even at noon time.

Fig.4 gives the isopleths of H_l^* on cloudless days. There is no cloudless day during the monsoon months June-September. The isopleth of 1.20 MJm^{-2} covers three hours between 12-14 hours during March-April. The isopleth of 1.00 MJm^{-2} encompasses more than five hours during March to May. The rate of radiative cooling somehow remains retarded in November at night time unlike October or December.

The variations in the hourly values for each month are depicted in Fig.5. Eventhough the data considered pertain to days which are not necessarily cloudless, the decreasing trend in H_l^* from nightfall to day break is clearly seen. This continues even during the monsoon period. Unlike the noon maximum for global radiant exposure, The maximum occurs generally just after the local noon. The highest noon maximum in H_l^* (1240 kJm^{-2}) Pune occurs in March and the minimum of 350 kJm^{-2} in August, being about 72 per cent lower than the March value. As soon as the monsoon weakens, the noon value increases by more than 86 per cent to 650 kJm^{-2} in September. The time of occurrence of

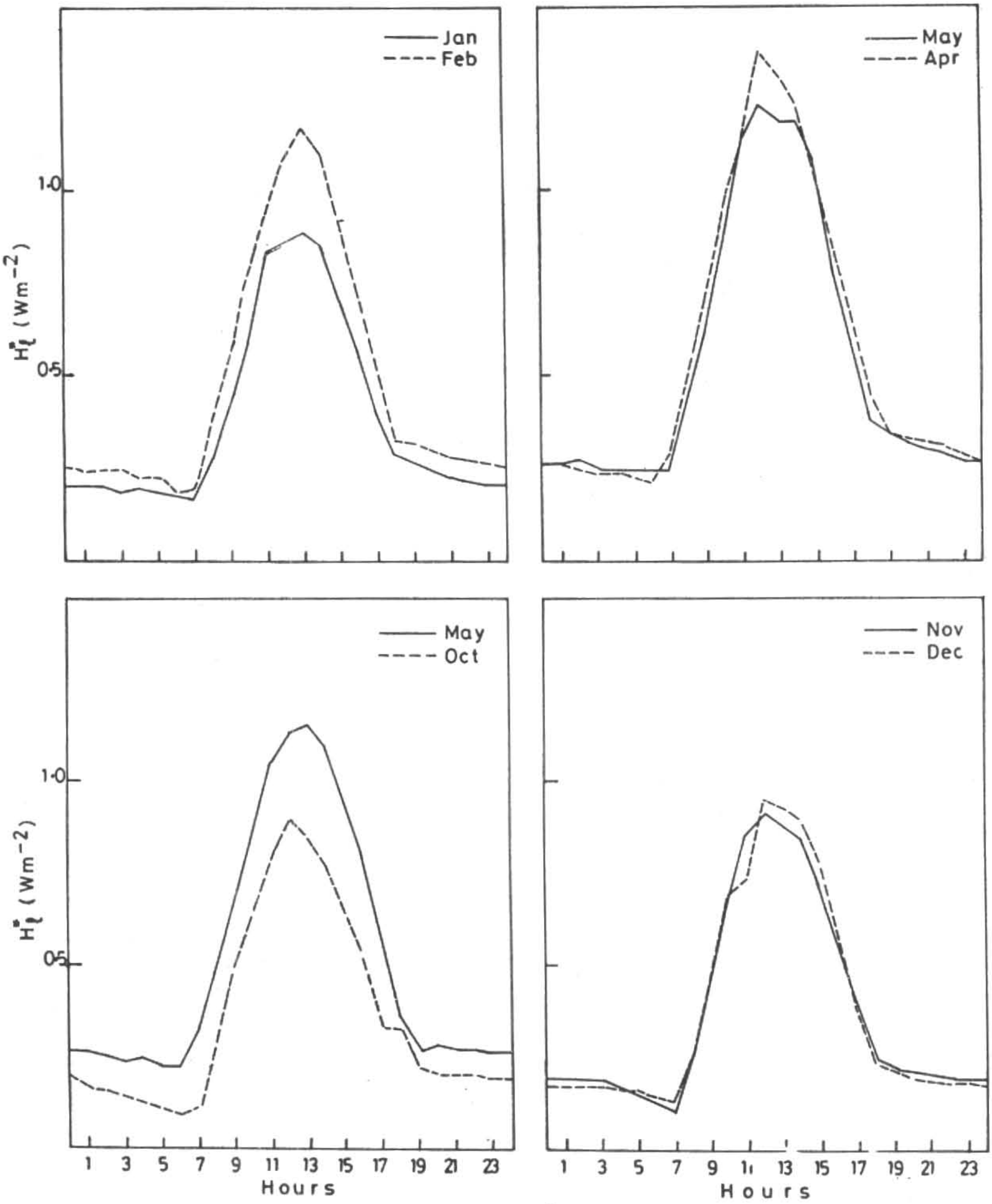

Fig.6. Diurnal variations in H_l^* on cloudless days

maximum is around noon time or slightly later, perhaps depending upon the moist conditions of the soil and other parameters like evaporation, humidity and temperature prevailing at that time (Smolen *et al.* 1989) reports that the noon hourly maximum is highest in August with 0.882 MJm^{-2} at Mlynany. The noon maximum, however, occurs during April (1370 kJm^{-2}) when cloudless sky conditions alone are considered and it is least 890 kJm^{-2} in January (Fig.6). Unlike days of all types of sky conditions, the noon maximum on a cloudfree day is generally attached at local noon. The effect of drier atmosphere in February and March is clearly seen in both Figs.5 & 6. The decreasing trend with

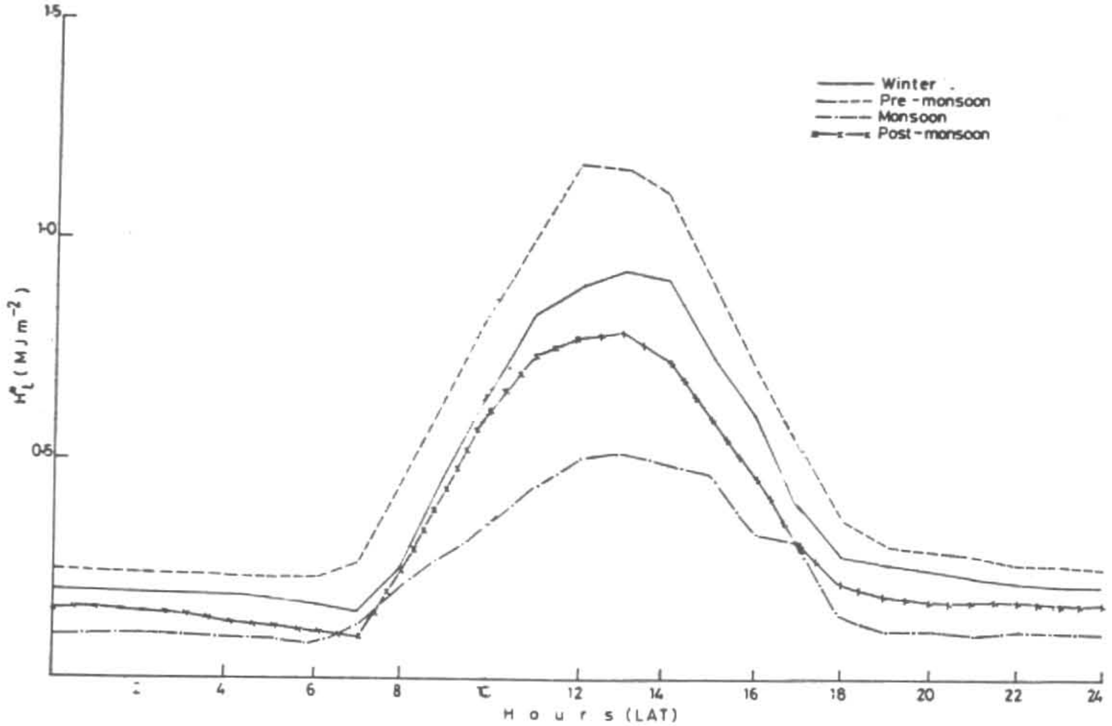

Fig.7. Seasonal diurnal variations in H_l^* on all days

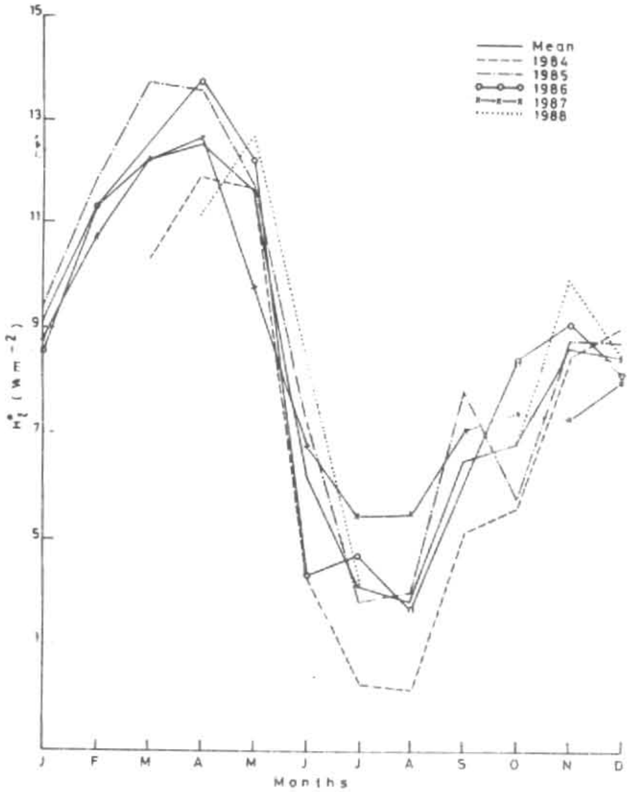

Fig.8. Year-to-year variations in H_l^* on all days at Pune

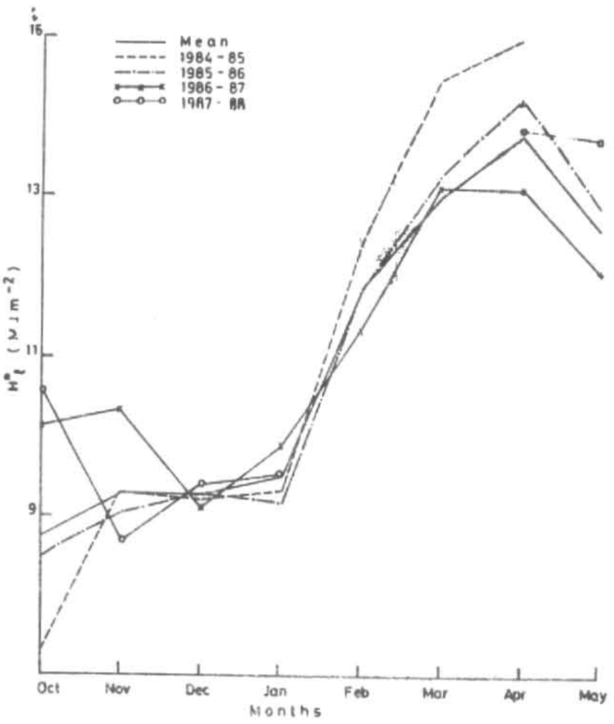

Fig.9. Year to year variations in H_l^* on cloudless days

TABLE 1
Percentage rainfall anamolies for Pune

Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Normal (mm)	1.9	0.3	3.1	17.6	34.7	102.8	186.8	106.4	127.3	91.9	37.0	4.9
1984	-100	331	-100	-66	-100	37	39	-51	45	153	-95	-100
1985	-100	-100	-100	-23	-71	-16	-30	-22	-51	87	303	-100
1986	-100	-100	-100	-100	11	153	-64	-2	-41	-99	-92	610
1987	160	178	-100	-70	271	-30	-66	119	-81	113	-72	606
1988	-100	-100	-100	222	-50	-36	68	-17	254	-100	-100	-100

time in the night values of $H_{\uparrow}^{*}$ is more prominent on cloudless days. Smolen *et al.* (1989) obtained 1.216 MJm^{-2} for noon hourly maximum in cloudless August. they conclude that cloudless is the main regulator of $H_{\uparrow}^{*}$.

3.3. *Seasonal variations in hourly values*

The hourly variations when considered for seasons as a whole, are found to be lowest during monsoon (Fig.7). The dry and cloudless conditions of the pre-monsoon season, which also receives higher solar irradiances, loses maximum $H_{\uparrow}^{*}$ both during the day and the night. The post-monsoon months lose less than those of winter because of the secondary temperature maximum and persisting moisture in the air. The noon maximum in monsoon drops to about 500 kJm^{-2} from a peak value of 1170 kJm^{-2} of the pre-monsoon period amounting to a decrease of about 57 per cent. The corresponding noon maximum in post-monsoon season is 790 kJm^{-2} and that in winter is 930 kJm^{-2}. Similarly, the morning minimum $H_{\uparrow}^{*}$ is 180 kJm^{-2} in the monsoon season and 230 kJm^{-2} during the pre-monsoon period.

3.4. *Year-to-year variations*

The mean daily values for each month very widely for $H_{\uparrow}^{*}$ field over the entire 5-year period (Fig.8). Two striking features that clearly stand out are the very low values (less than 2.3 MJm^{-2}) in July - August months during 1984 and the unusually high values of the order of 5.5 MJm^{-2} during the same period in 1987. The values during 1985, 1986 and 1988 in this period are nearly the same and of the order of the mean values. Ichiki (1988) made attempts to study the response of $H_{\uparrow}^{*}$ to various meteorological parameters and even could find some statistical relationships.

Table 1 gives the rainfall anomalies from the normal at Pune. There is enough indication that there is a good relationship between the changes in $H_{\uparrow}^{*}$ that occur and the rainfall occurrence at Pune during a month in rainy season, between May and October. A study of Fig.8 with Table I shows variations in $H_{\uparrow}^{*}$ and the extent of variations to be closely connected with the rainfall activity. The causal factor and the resultant could not be identified. The rainfall distribution in 1984 and 1985 and the corresponding values in $H_{\uparrow}^{*}$ show such a relationship. Rains in June and July have a corresponding decrease in $H_{\uparrow}^{*}$ in 1984. In view of deficit rainfall in June-July 1985, $H_{\uparrow}^{*}$ are relatively high. This interrelationship is more evident in the values for August-October. The rains in 1984 have corresponding low rise in $H_{\uparrow}^{*}$ during September and October in relation to the radiation fields in August. A sharp increase in $H_{\uparrow}^{*}$ in September 1985 indicates a deficit in rainfall. But in October, $H_{\uparrow}^{*}$ decreases following excess rainfall. Similar changes can also be seen during 1987 as well.

Fig.9 gives the variations in $H_{\uparrow}^{*}$ on cloudless skies alone. The values do not very much differ from each other. It can be seen that the absence of rainfall or deficiency in it corresponds to higher losses in $H_{\uparrow}^{*}$ on cloudless days. More indepth studies taking into consideration, the temperature and humidity conditions for each day, may perhaps indicate a better correspondence among $H_{\uparrow}^{*}$ and other meteorological parameter. This study is beyond the scope of this present exercise.

4. Conclusions

The effective outgoing terrestrial radiant energy $H_{\uparrow}^{*}$ is an important controlling parameter which directly affects the prevailing atmospheric conditions. The time scale and the process by which it affects the atmosphere is not exactly known. The radiative heat exchange at each layer is more complex. A variety of radiatively active gases and particulate matter that are present in the lower layers of the atmosphere have quite a contribution in affecting the thermodynamic equilibrium of each layer, thus leading to a series of reactions in the environment.

The values of $H_{\uparrow}^{*}$ are maximum during dry and warm pre-monsoon month, particularly in March and April. The minimum values are not during winter as it happens elsewhere; they are during July- August depending on the actual rainfall distribution and its intensity. The daily maximum of H_1^* occurs between 12 and 13 hours local time and the minimum just before sunrise. A steady decrease in H_1^* is noticed from sunset to sunrise only on cloudless skies. Under cloud cover, the nocturnal H_1^* varies depending on the zenith cloud cover, temperature and water vapour in the air. A study of the rainfall and the mean H_1^* indicates that they are closely related to each other. More detailed studies are to be made in this respect.

References

Bhagwat, S.P., 1990, "Vertical profile of infrared radiation over Pune", *M.Sc. Thesis*, University of Poona.

Chacko, O., 1951, "Further studies on the heat radiation from the night sky at Poona", *Indian J. Meteor. Geophys.*, **2**, 3, 190p.

Das, M.R., 1987, "Nocturnal radiation at Calcutta Airport on clean winter nights", *Mausam*, **38**, 2, 251-254.

De, A.C. and Gupta, P.K., 1964, *Indian J. Meteor. Geophys.*, **15**, 3, 439-446, University of Poona.

Ichiki, A., 1988, "Radiation measurements at Tateno and a climatological interpretation of the radiation data", *Geophys. Mag.*, **42**,3, 105-171.

Jayaraman, K., Bhagwat, S.P., and Chakravarthi, D.D., 1993, "Net terrestrial radiant flux in the vertical over Pune", *Mausam*, **44**, 175-178.

Kondratyev, K. Ya, 1965, "Radiative heat exchange in the atmosphere", Pergamon Press, London.

Kondratyev, K. Ya, 1969, "Radiation in the atmosphere", Academic Press, New York.

Mani, A. and Chacko, O., 1963, "Studies of nocturnal radiation at Poona and Delhi", *Indian J. Meteor. Geophys.*, **14** , 2, 196-204.

Mani, A., Chacko, O. and Iyer, N.V., 1965, "Studies of terrestrial radiation fluxes at the ground in India", *Indian J. Meteor. Geophys.*, **16**, 445-452.

Ramdas, L.A., Sreenivasiah, B.N. and Raman, P.K., 1937, "Variation in nocturnal radiation from the sky with zenith distance and with time during the night", *Proc. Indian Acad. Sci.*, **A5**, No. 1.3, 445-452.

Swaminathan, M.S. and Desikan, V., 1967, "A study of five years of atmospheric radiation measurements at New Delhi, *Indian J. Meteor. Geophys.*, **18**, 14, 521-526.

Smolen, F.G., Schloesser. and Slavkovsky, P., 1989, "Effects of cloudiness on long-wave radiation balance", *Contributions of Geophys. Instt. of Slovak Acad. Sci.*, **9**, 7-21.