Indian J. Met. Hydrol. Geophys. (1977), **28**, 3, 349-354

551·521 : 551·573

Measurements of radiation balance components over a water surface

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(*Received 23 November 1976*)

ABSTRACT. Results of measurement of solar and infra-red radiative fluxes in the upward and downward directions over a 20 m² evaporimeter tank are presented. The diurnal and seasonal variations of each component of the radiation balance are discussed. A numerical relation between hourly values of net radiation and global solar radiation is obtained. It is, however, found that the net radiation is greater in the afternoon than in the forenoon for a given amount of global solar radiation.

1. Introduction

A characteristic feature of global maps of net radiation at the earth's surface is the discontinuity in the isopleths over the coastal regions (Kondrat'ev 1973). The amount of net radiation over the surface of oceans, seas and lakes is significantly higher than that over adjoining land areas. This is due to differences in surface albedo and land-sea temperature contrasts. Thus for interpreting the spatial differences in net radiation, it is important to examine the relative magnitudes of the various components of radiation balance over different types of surface.

Studies of the radiation balance over water surface also have a practical application, since such information is required as an input in the estimation of evaporation from lakes and reservoirs by the energy-budget method (Gangopadhyaya 1966).

In this paper, results of measurement of solar and infra-red radiative fluxes in the upward and downward directions over a 20 m² evaporimeter tank are presented. The diurnal and seasonal variation of these parameters and of the net radiation are analysed and discussed.

2. Instrumentation

2.1. *Measurement of all-wave radiation*

The Schulze Radiation Balance Meter records the upward and downward radiative fluxes on a horizontal surface in the 0·3 to 60 μ wavelength region. The sensor essentially comprises two constantan-silver thermopiles (26 mm long, 5 mm wide, 10 mm high) which are mounted on the top and base of a solid aluminium cylinder (8 cm diameter, 4 cm height). The active junctions, located on the outside, are blackened and form the upper and lower receiving surfaces. They are protected by hemispherical polyethylene domes, and radiation shades of 30 cm diameter are provided.

The thermo-voltages generated by the upper and lower thermopiles are continuously monitored on a recorder. However, to compute the radiation fluxes from the thermo-voltages, the temperature of the inactive junctions is required to be known. For this purpose, the instrument temperature is also continuously recorded by another copper-constantan thermopile which has its active junctions inside the aluminium cylinder and inactive junctions buried 1 m below the ground surface. The temperature at this depth varies little with time and is measured with a suitable soil thermometer.

The difference between the upper and lower thermo-voltages, which is a measure of the net flux, is also recorded continuously as a separate parameter. A schematic circuit diagram of the Schulze Radiation Balance Meter is shown in Fig. 1.

2.2. *Measurement of global solar radiation*

The Moll's Solarimeter employs a constantan-manganin thermopile mounted under two concentric hemispherical glass domes on a metal base (11 cm height) which is prevented from being heated by radiation by means of a 30 cm diameter screen. The size of the sensitive surface is 12× 11 mm. The glass domes filter out long wave radiation of wavelengths longer than 4 μ and allow only the shorter wavelengths to fall on the sur-

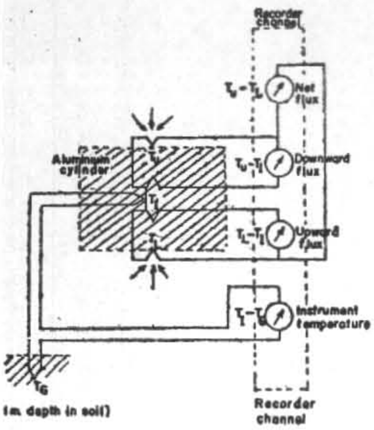

Fig. 1. Schematic diagram of Schulze radiation balance meter

face. The thermopile output is thus proportional to the global solar radiation on a horizontal surface and is continuously recorded.

2.3. *Measurement of evaporation*

The 20 m^2 evaporimeter tank is cylindrical in shape with a flat base, having diameter 5·04 m corresponding to a 20 m^2 surface area, and depth 2 m. The tank is sunk in the ground with the rim about 7·5 cm above the surface. The water level is maintained approximately at ground level. The drop in the water level due to evaporation is measured by means of a simple volumetric device which is placed within a still-well.

3. Notation and sign convention

The radiation balance equation is expressed as

$$F_{\text{Net}} = F_{\text{Solar}\downarrow} + F_{\text{Solar}\uparrow} + F_{\text{IR}\downarrow} + F_{\text{IR}\uparrow} \tag{3·1}$$

where,

$F_{\text{Solar}\downarrow}$ = global solar radiation incident at the surface,

$F_{\text{Solar}\uparrow}$ = solar radiation reflected from the surface,

= $\alpha F_{\text{Solar}\downarrow}$, α being the surface albedo,

$F_{\text{IR}\downarrow}$ = infra-red radiation received at the surface from the atmosphere and clouds,

$F_{\text{IR}\uparrow}$ = infra-red emission from the surface.

= $\epsilon\,\sigma\,T_*^4$ where ϵ is the emissivity of the surface (=1), σ is the Stefan-Boltzmann constant and T_* is the temperature of the surface in °K,

F_{Net} = all-wave net radiation.

Fluxes in the downward direction are considered to be positive and those in the upward direction to be negative. F_{Net} is thus an algebraical sum of the four quantities on the right hand side of equation (3·1) F_{Net} is positive or negative depending upon its direction.

4. Observations and analysis of data

The Schulze Radiation Balance Meter was installed at a height of 1·5 m above the water surface of the 20 m^2 evaporimeter at the Central Agricultural Meteorological Observatory, Pune, in the year 1972. Data recorded in four representative months January, April, July and October, were considered for the purpose of the present work. Continuous records of the upward, downward and net all-wave flux were analysed. The values were first averaged over successive 15 min intervals and then summed up to get the fluxes in ly/hr. Global solar radiation $F_{\text{Solar}\downarrow}$ in ly/hr was likewise obtained with a Moll's Solarimeter installed permanently at the Observatory. $F_{\text{Solar}\uparrow}$ was evaluated as $\alpha F_{\text{Solar}\downarrow}$ after taking into account the diurnal variation of the albedo α of the water surface. By subtracting $F_{\text{Solar}\downarrow}$ and $F_{\text{Solar}\uparrow}$ from the corresponding values of downward and upward all-wave fluxes, $F_{\text{IR}\downarrow}$ and $F_{\text{IR}\uparrow}$ were computed. Monthly averages of F_{Net}, $F_{\text{Solar}\downarrow}$, $F_{\text{Solar}\uparrow}$, $F_{\text{IR}\downarrow}$ and $F_{\text{IR}\uparrow}$ for each hour of the day were then derived and are presented in the subsequent discussion.

5. Results

5.1. *Diurnal and seasonal variations*

The monthly means of the hour-to-hour flux values for the four months January, April, July and October 1972 are plotted in Figs. 2-5 respectively. As per the sign convention adopted $F_{\text{Solar}\downarrow}$ and $F_{\text{IR}\downarrow}$ are always positive while $F_{\text{Solar}\uparrow}$, and $F_{\text{IR}\uparrow}$ are at all times negative. F_{Net} is positive during the day and negative at night; but its 24-hr total remains positive.

During daytime, the global solar radiation $F_{\text{Solar}\downarrow}$ is the most dominant factor in the radiation balance. The diurnal variation of $F_{\text{Solar}\downarrow}$ averaged over the month, takes the form of a smooth, bell-shaped curve in January. In other months, however, small asymmetries are superimposed due to the fluctuations in cloud amount and type during the day. The highest value of $F_{\text{Solar}\downarrow}$

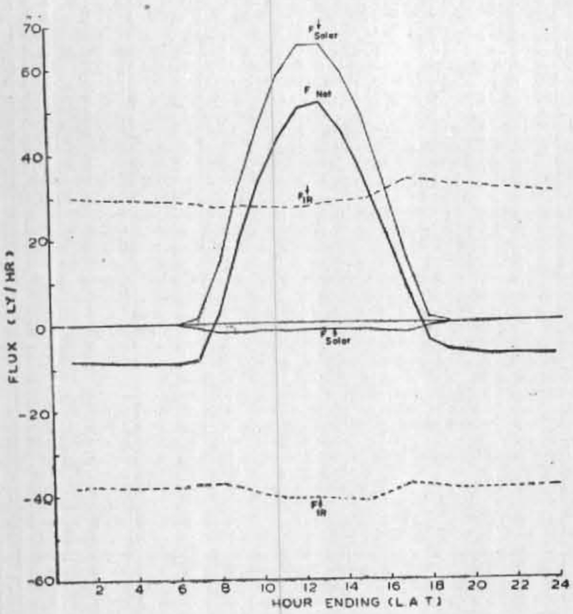

Fig. 2. Mean for January 1972

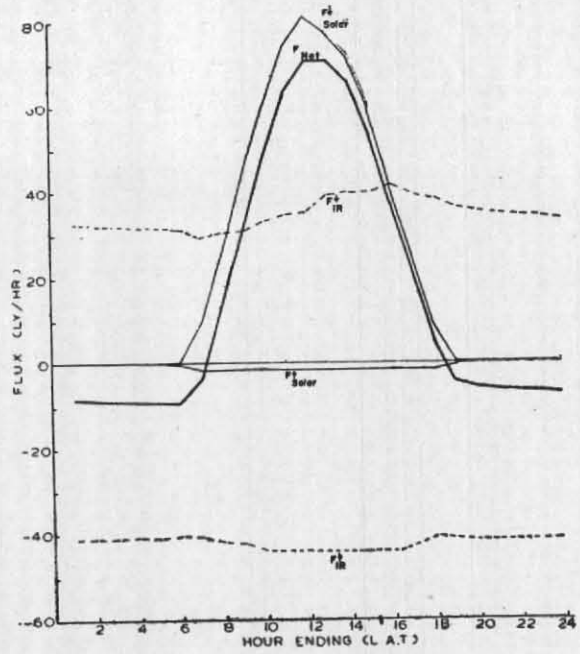

Fig. 3. Mean for April 1972

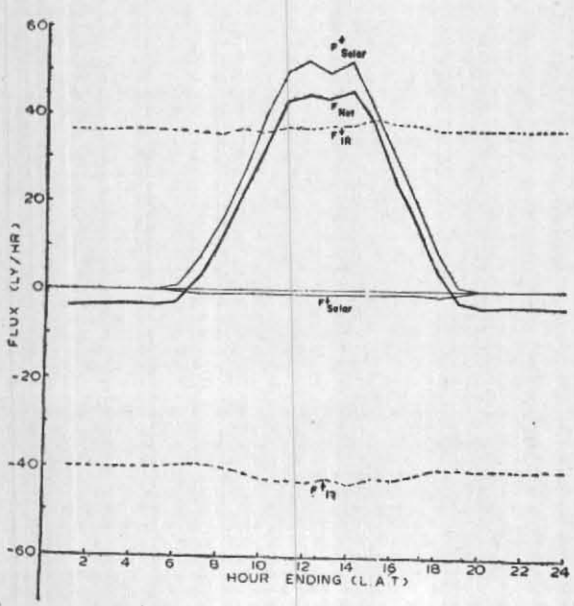

Fig. 4. Mean for July 1972

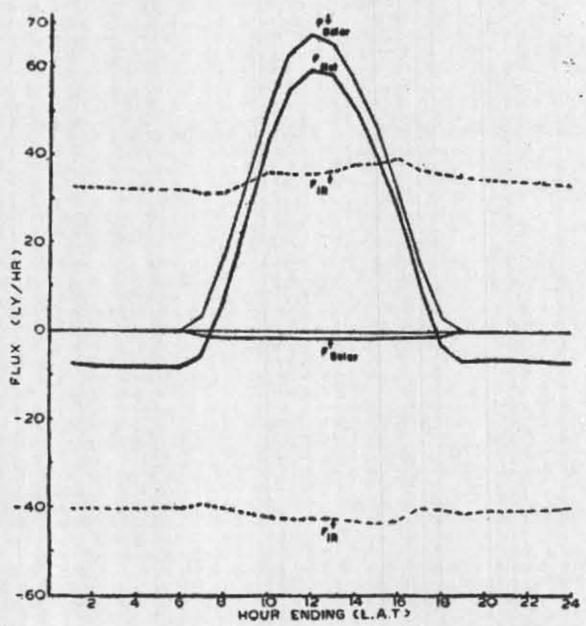

Fig. 5. Mean for October 1972

Figs. 2-5. Diurnal variation of fluxes over water

is 80·7 ly/hr during 1100-1200 LAT in April. The noontime value is lowest not in January but in July (52·2 ly/hr) because of the strong reflection taking place at the cloud tops during the monsoon season, the average daytime cloud cover being 2 oktas in January and 7 oktas in July.

The albedo of a water surface is greatly dependent on the inclination of the incident radiation, ranging from zero for normal incidence to 100 per cent for parallel incidence. However, since direct solar radiation is maximum at noon and minimum near about dawn and dusk, the product of direct solar radiation and albedo remains negligibly small throughout the day. For each of the four months considered, the average hour-to-hour position of the sun was taken into account to determine the water albedo. Although these albedo values are, strictly speaking, valid in the case of direct solar radiation only, they were, as an approximation, used to obtain the reflected radiation $F_{\text{Solar}\uparrow}$ from the global solar radiation $F_{\text{Solar}\downarrow}$. As seen from Figs. 2-5, $F_{\text{Solar}\uparrow}$ makes an insignificant contribution to the radiation balance (<2 ly/hr) at any time of the day or year.

In April and October, the diurnal variation of the downward atmospheric radiation $F_{\text{IR}\downarrow}$ is characterised by a maximum between 1500 and 1700 LAT, a rapid fall upto 2000, a gradual decline upto 0700 and an increase thereafter. Nigh-time values of $F_{\text{IR}\downarrow}$ are of the order of 32 ly/hr and the diurnal range (maximum *minus* minimum) is 12·2 ly/hr in April and 8·1 ly/hr in October. In January, decrease in air temperature and moisture content in the troposphere results in an over-all decrease of $F_{\text{IR}\downarrow}$ with a diurnal range of 6·2 ly/hr. In July, with a persistent cloud cover and low cloud bases, $F_{\text{IR}\downarrow}$ remains nearly constant, around 37 ly/hr. The dependence of $F_{\text{IR}\downarrow}$ on cloudiness, water vapour content and temperature has been discussed in detail on numerical considerations in an earlier study (Kelkar *et al.* 1970).

The emission from the water surface $F_{\text{IR}\uparrow}$ is constant (about 40 ly/hr) throughout the night (1900-0500 LAT) in any month. Day-time values are higher by about 4 ly/hr but the maximum is not pronounced and is spread over a few hours' period (1000-1600 LAT). This tendency is attributable to the high heat storage capacity of water bodies.

Since $F_{\text{IR}\downarrow}$ and $F_{\text{IR}\uparrow}$ are of the same order of magnitude but of opposite sign and $F_{\text{Solar}\uparrow}$ is insignificantly small, F_{Net} very largely follows the same diurnal trend as $F_{\text{Solar}\downarrow}$ during the day. In the dark hours, however, only two factors $F_{\text{IR}\downarrow}$ and $F_{\text{IR}\uparrow}$ operate and F_{Net} is then merely the small negative difference between them. Night-time F_{Net} is approximately 6-9 ly/hr showing a very gradual fall with time. During July, however, it is about 4 ly/hr throughout the night. The cross-over from negative to positive F_{Net} takes place between 0600-0800 LAT whereas the reverse occurs between 1700-1900, the exact time depending upon the month.

5.2. *Relationship between global solar radiation and net radiation*

Numerous studies have been made on the nature of the relationship between daily totals of global solar radiation and net radiation over different types of surfaces. It is now well-known that the relationship can be generally put into the form

$$F_{\text{Net}} = a.\ F_{\text{Solar}\downarrow} - b \qquad (5\cdot1)$$

where a, b are constants, and that F_{Net} and $F_{\text{Solar}\downarrow}$ are very highly correlated (Linacre 1968). Such empirical equations serve a practical need in view of the dearth of net radiation measurements.

In the present work, the mean *hourly* values of $F_{\text{Solar}\downarrow}$ and F_{Net} over water surface were found to have a correlation coefficient of 0.99. The following regression equation was also derived:

$$F_{\text{Net}} = 0\cdot958\ F_{\text{Solar}\downarrow} - 6\cdot681 \qquad (5\cdot2)$$

where fluxes are expressed in ly/hr. A detailed examination of the relation between these two factors, however, revealed that it is influenced by the time of the day, *i.e.*, the position of the sun. Assuming that $F_{\text{Solar}\downarrow}$ incident on the water surface is the same for symmetrical positions of the sun before and after local noon, F_{Net} is almost always greater in the afternoon than in the forenoon (Figs. 6-9). For equal amounts of $F_{\text{Solar}\downarrow}$, the afternoon—forenoon differences of F_{Net} are highest (>10 ly/hr) in April and smallest in July (<1 ly/hr). These results are opposite to those of Monteith and Szeicz (1961) and Nkemdirim (1973) who measured higher net radiation over vegetated surfaces in the morning than in the afternoons for similar sun positions. This is due to the fact that over a water surface, the diurnal change of $F_{\text{IR}\uparrow}$ is small and quite symmetrical about local noon, whereas $F_{\text{IR}\uparrow}$ is maximum in the afternoon and minimum in the early morning. It is not, therefore, sufficient to derive a single regression equation between $F_{\text{Solar}\downarrow}$ and F_{Net}, but many such equations for different times of the day are needed if accurate estimation of hourly F_{Net} values are desired.

5.3. *Comparison of radiation balance of water surface and bare soil*

In an earlier investigation at the Central Agricultural Meteorological Observatory, Pune (Venkataraman *et al.* 1973), net radiation in ly/day was studied over bare soil from 1964 to 1968. In order to compare these measurements with those made over water in 1972, the F_{Net} values were normalised with respect to $F_{\text{Solar}\downarrow}$ (Table 1). In all the four months January, April, July and October, the ratio $F_{\text{Net}}/F_{\text{Solar}\downarrow}$ was found to be higher over water than over bare soil. In July, for example, 44 per cent of the global solar

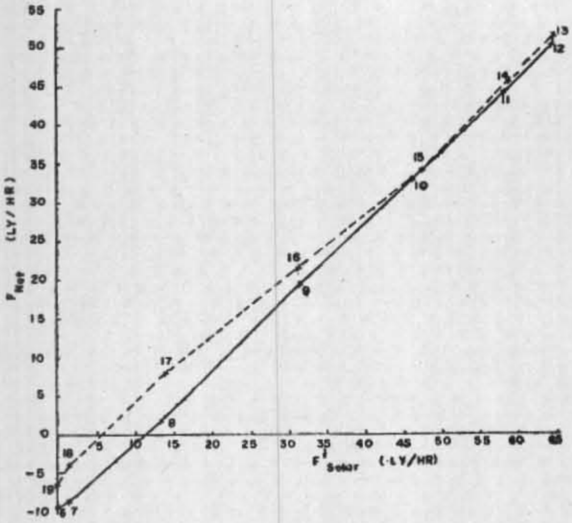

Fig. 6. Mean for January 1972

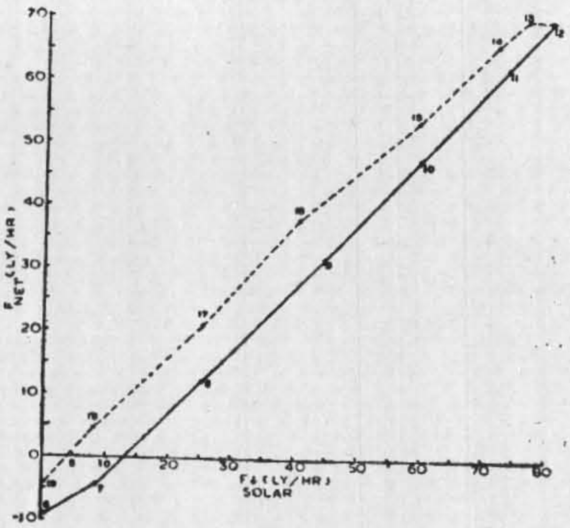

Fig. 7. Mean for April 1972

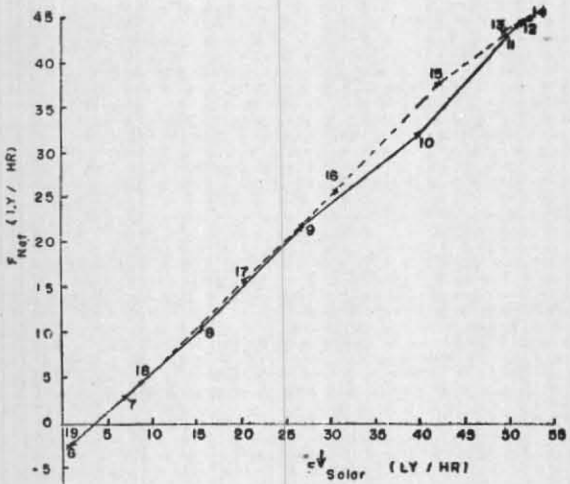

Fig. 8. Mean for July 1972

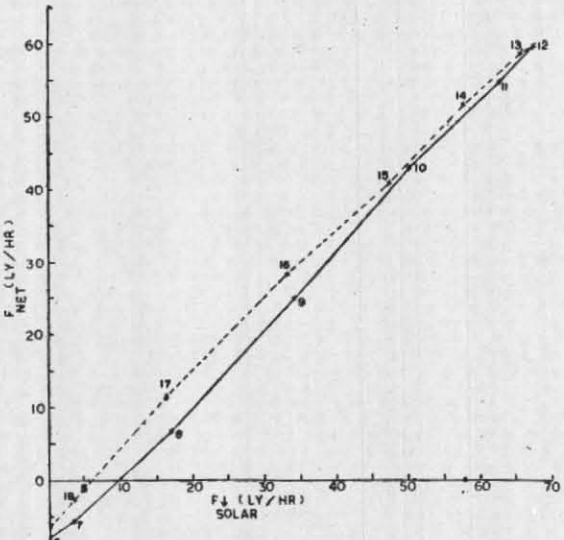

Fig. 9. Mean for October 1972

Figs. 6-9. Net radiation in relation to global solar radiation

[Superscribed numbers represent hour ending (LAT)]

radiation incident at the surface in a day is available as net radiation to the soil, but as much as 72 per cent of it becomes available to a water body.

5.4. *Latent and sensible heat fluxes*

F_{Net} is the net amount of energy available for absorption by the system and must balance the net dissipation, *i.e.*,

$$F_{Net} = L_H + S_H \qquad (5.3)$$

where L_H is the energy utilized in the process of evaporation from the waterbody and S_H is the net sensible heat flux across the air-water interface. Table 2 gives the monthly averages of evaporation E (mm/day) from the 20 m² tank. Values of L_H are computed as $L_H = L.E.$ where

TABLE 1

F_{Net} and $F_{Solar\downarrow}$ values over water surface and bare soil

Month (1972)	Pune (1972) Water surface (Present Work)			Pune (1964-68) Bare soil (Venkataraman *et al.*)		
	F_{Net}	$F_{Solar\downarrow}$ (ly/day)	$F_{Net}/F_{Solar\downarrow}$	F_{Net}	$F_{Solar\downarrow}$ (ly/day)	$F_{Net}/F_{Solar\downarrow}$
Jan	198	436	0·45	143	440	0·33
Apr	382	575	0·66	253	610	0·41
Jul	285	396	0·72	166	380	0·44
Oct	281	458	0·61	213	501	0·43

TABLE 2

Latent and sensible heat components over water surface

Month (1972)	Evaporation from 20 m² tank E (mm/day)	L_H $(=L_E)$	F Net (ly/day)	S_H $(=F_{net}-L_H)$
Jan	3·4	198·9	198·1	—0·8
Apr	7·1	415·3	382·3	—33·0
Jul	4·4	257·4	284·6	27·2
Oct	5·0	292·5	280·6	—11·9

L is the latent heat of evaporation, *viz.*, 58·5 ly/mm at 25°C. The sensible heat exchange S_H is obtained as the difference between F_{Net} and L_H. It is seen that only during the monsoon season, S_H is positive, meaning that there is a net transport of sensible heat from water to air. In all other seasons, the sensible heat transfer is in the opposite direction. It may be mentioned, however, that in the present study, latent and sensible heat fluxes were not actually measured, nor was any exchange of heat between the sunken tank and the surrounding soil taken into account. It is further important to note that even an error of 0·1 mm/day in the measurement of evaporation E, which is not unlikely, is equivalent to an error of 5·85 ly/day in the computed value of L_H.

6. Conclusion

The study has shown that (*i*) the contribution of the reflected solar radiation to the total radiation balance of a water surface is negligibly small, (*ii*) the emission σT_*^4 from the water surface is constant, about 40 ly/hr, throughout the night in any month, (*iii*) the net flux very largely follows the diurnal trend of the global solar radiation during the daytime and (*iv*) the net flux is greater in the afternoon than in the forenoon for a given amount of global solar radiation, particularly in April.

Acknowledgements

The authors are grateful to Dr. R.P. Sarker for his interest in the study and critical review of the manuscript. They also wish to thank Shri K. Subba Rao for his useful suggestions.

Thanks are due to Shri P. S. Batar and Shri V.R. Chivate for help in the computations and to Smt. V.S. Tamhankar for typing the manuscript.

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