Diurnal and Seasonal variations of Heat-flow into soil at Waltair

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ABSTRACT. Heat-flow into the soil is evaluated indirectly from temperature profiles and measured directly by a transducer on representative days in different months. On calm and clear days, the heat conveyed in either direction (on a daily basis) is roughly of the same magnitude, but during transition months or when there are rapid upward or downward trends of temperature variation, some positive or negative carry-over to the next day is observed. Significant features of the seasonal curves are the post-monsoon peak in the downward fluxes and early summer peak in the outward fluxes. The early evening minimum in the diurnal curves has the lowest magnitude in July and has another lower value between December and January and its highest value in March. The time of occurrence in course of day of this minimum is earlier in winter than in summer with a swing-back to its winter value immediately after the withdrawal of the southwest monsoon.

The evaluation of heat-flow into the ground occupies an important place in micrometeorological investigations, for it enables the quantitative estimation of energy-disposal for various exchange processes at the earth-atmosphere interface. In this evaluation the physical properties of the soil like structure and texture, colour, surface cover, moisture content etc, play an important role. It was therefore, proposed in the present investigation to study the diurnal and seasonal heat-flow into the soil intensively both by direct as well as indirect methods. For the indirect determination of heat flux, three Negretti and Zambra mercury-in-glass bent bulb thermometers, specially designed for soil temperature measurements, were buried at 5, 15 and 30 cm below the ground and the surface temperature was measured by means of an ordinary mercury-in-glass thermometer with due precautions regarding its calibration and exposure. Observations were taken every hour continuously for 24 hours on representative days in different months. Simultaneously heat-flow into the soil was measured directly with the aid of a heat-flow transducer manufactured by the Beckman and Whitley Co., California.

The heat-flow transducer measures uniform one-dimensional heat-flow through solid media and is a thermoelectric device producing an electromotive force proportional to the amount of heat conducted through the plate perpendicular to its parallel surfaces. In the present study it was installed at a depth of 2·5 cm below the ground surface. The output of the transducer was measured on a portable millivolt indicator unit, also manufactured by Beckman and Whitley. There is also provision in the plate itself for the measurement of the transducer temperature by means of a copper-constantan thermojunction embedded at the centre of the plate. This enables correction of the transducer output corresponding to various plate temperatures.

Computations of heat-flux, q, at the soil surface from temperature distribution in the soil column were made according to the equation—

$$q = -k\rho c \left(\frac{\partial \theta}{\partial z}\right)_{z=0} \qquad (1)$$

where,

k = thermal diffusivity,

ρ = density,

c = specific heat of the soil, and

$\left(\frac{\partial \theta}{\partial z}\right)_{z=0}$ = depth variation of temperature in the soil, at the surface.

Since the direct experimental determination of the thermal constants of the soil is not easy, the thermal diffusivity, k, was derived in an indirect way by the range and lag methods suggested by Johnson and Davies (1927). In the range method, the standard conductivity equation for the fluctuation, θ', of temperature at any depth, z, has been used in the form

$$\theta' = Ae^{-bz} \sin\left(\frac{2\pi t}{T} - bz\right) \qquad (2)$$

where,

A=half the diurnal range R of temperature,

t=time of observation, reckoned from the zero reference value of temperature.

T= 24 hours and

$$b = \sqrt{\pi/Tk} \qquad (3)$$

b was deterimined from a graph drawn between $\log_e (R_1/R_2)$ and $(z_2 - z_1)$, where R_1 and R_2 are daily ranges of temperature at depths z_1 and z_2 respectively and hence k could be computed from the relation (3).

In the lag method, the lag between the times of occurrence of maximum temperature at the corresponding depths is required. The thermal diffusivity was worked out making use of the criterion that the temperature, θ, at any depth, z, becomes a maximum when

$$t = \left\{(2n+1)\frac{\pi}{2} + z\sqrt{\pi/Tk}\right\} \frac{T}{2\pi} \qquad (4)$$

where n is an integer and the other symbols have the same meaning as before. Thus the lag between the times of occurrence of maximum temperature at depths z_1 and z_2 is—

$$L = (z_2 - z_1)\frac{T}{2\pi}\sqrt{\pi/Tk} \qquad (5)$$

from which it follows

$$k = \frac{(z_2 - z_1)^2}{L^2} \times \frac{T}{4\pi} \qquad (6)$$

The relation (6) above enables us to calculate k from the observed data.

The values of k for dry soil in the observatory enclosure by the above two methods have been previously determined by Subrahmanyam and Subba Rao (1957). The average value of 5.834×10^{-3} cm²/sec, as reported by them, has been used in the present work for the computation of heat fluxes.

The density, ρ, of dry soil was measured by taking a number of auger samples from different plots in the observatory enclosure and the mean value of these, 1·396 gm/cm³, was adopted in the computational work.

The soil in the observatory was sometimes found to be so dry that its specific heat could be taken as that of the dry soil itself; the value of 0·18 cal/gm. deg. was chosen for the specific heat on the basis of Kersten's work (1949) as referred to by Portman (1954); at other times the specific heat was evaluated from the general formula—

$$C = C_w W + C_s (1 - W) \qquad (7)$$

where,

C =specific heat of moist soil,

C =specific heat of water,

C_w =specific heat of dry soil and

W =fraction of water, by weight, in the moist soil.

When the soil was not perfectly dry the density was calculated from the expression—

$$\rho = \frac{\rho_d}{1 - W} \qquad (8)$$

where,

ρ = density of moist soil,

ρ_d = denisty of dry soil, and

W=fraction of water by weight in moist soil.

The moisture content of the soil was determined by taking several auger

TABLE 1

Net diurnal heat-flow (gm. cal/cm²/day)

(obtained from thermometric observations)

Date (0800 to 0800 IST)		Positive flow	Negative flow	Net flow	Ratio of —ve to +ve	State of sky and wind
Jan	27-1-60 to 28-1-60	69·0	32·4	36·6	0·47	Clear sky during day, clouding (4/10) in night at certain hours; light winds during day, calm in night
Mar	4-3-60 to 5-3-60	58·6	49·6	9·0	0·85	Clear, moderate to light winds during day; calm in night
	26-3-60 to 27-3-60	66·4	65·8	0·6	0·99	Clear, very light winds even in daytime
Apr	5-4-60 to 6-4-60	63·6	43·8	19·8	0·69	Clear, moderate winds during day but calm in night
May	28-5-59 to 29-5-59	31·4	19·4	12·0	0·62	Mostly cloudy (medium clouds), 6/10, clear sky for a short time during day, light winds
Jul	30-7-59 to 31-7-59	36·0	11·0	25·0	0·31	Overcast whole day, almost calm. Rain from 4 A.M.
Aug	29-8-59 to 30-8-59	58·8	35·8	23·0	0·61	Mostly cloudy (low and middle, 8/10), windy during day, moderate in night
Sep	25-9-59 to 26-9-59	76·4	50·6	25·8	0·66	Clear, almost calm
Nov	3-11-59 to 4-11-59	89·0	53·4	35·6	0·60	Clear, moderately windy till midnight, later calm
	30-11-59 to 1-12-59	66·4	53·4	13·0	0·80	Clear, moderate winds during day, calm in night
Dec	31-12-59 to 1-1-60	64·2	36·6	27·6	0·57	Mostly clear; medium and high clouds (2/10) in the middle part of the night

samples in the locality at different depths down to 30 cm and drying and weighing them in an automatic moisture content oven manufactured by Griffin and Tatlock Ltd., London.

Making use of the values of k, ρ and c thus obtained, the flux of heat into the soil was computed from equation (1). The curves in Fig. 1 show (*i*) the diurnal variation of computed heat flux at the soil surface and (*ii*) the heat flux at 2·5 cm below the ground as measured directly by the transducer. Positive values represent flux into the ground while negative values flux out of the soil. The transducer is always seen to indicate lower values of flux than those obtained from the temperature distribution method owing to its lower position in the ground. The times of occurrence of maximum influx and efflux are also found to be slightly out-of-phase for the same reason. Likewise the times of reversal of the flux in both cases show departures on account of the transducer's position at a lower level. Table 1 shows the net heat-flow as evaluated from temperature

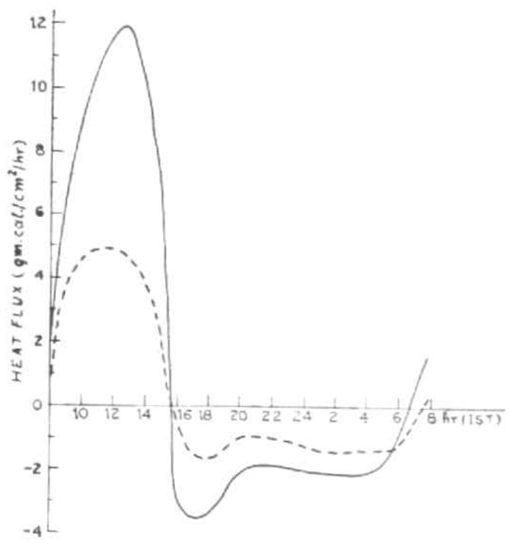

Fig. 1 (a). January 1960

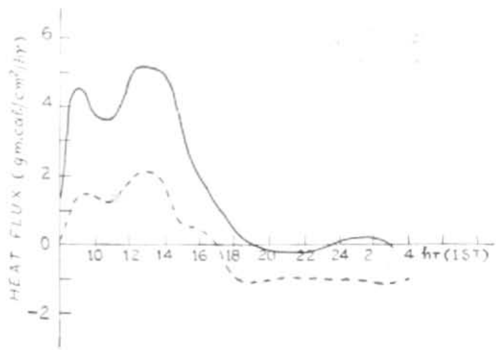

Fig. 1 (c). July 1959

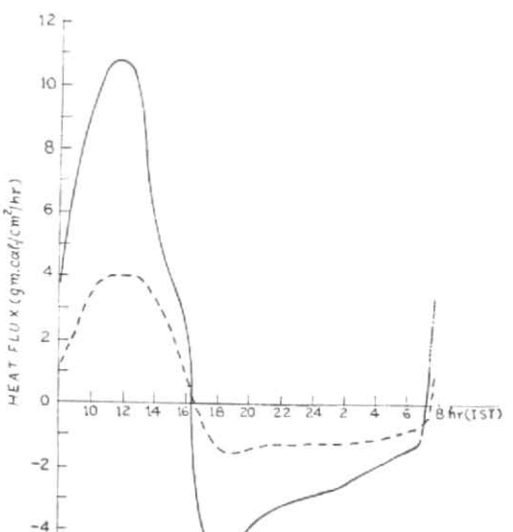

Fig. 1 (b). April 1960

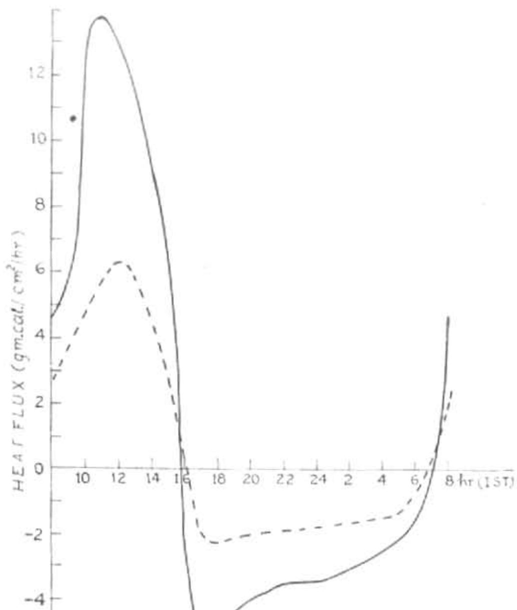

Fig. 1 (d). September 1959

Fig. 1. Diurnal heat flux into the soil at Waltair

(——— from temperature distribution, - - - - - from transducer) distribution on a daily basis in different months in relation to the general meteorological conditions prevailing during the period of observation.

It can be observed that on calm and clear days, the heat conveyed in either direction is roughly of the same order of magnitude, but during the transition months or when there are rapid upward and downward trends of temperature variation, there seems to be some positive or negative carry-over to the next day. From the table and graphs it is evident that during summer, on clear days the downward flux is larger than that either in monsoon or post-monsoon transition months. In a similar way, the outward flow of heat in winter is higher in magnitude (but less than the inward flux) particularly with clear skies than in summer or monsoon months. On cloudy days both the upward and downward fluxes are of small magnitude but the upward flux appears to be much lower.

Fig. 2 shows the curves of seasonal variation of downward and upward heat fluxes; the parallelism between the two curves is a feature of particular interest. The low values in summer and the southwest monsoon are evidently due to increased clouding which cuts down the incoming solar energy but increases the back radiation from the clouds and the humid atmosphere in the night time; the upward transport of energy is also consequently reduced. The steep rises in the positive and negative fluxes from August until October are clearly due to the gradual withdrawal of the monsoon. The highest values of outward flux are, however, found in March when the influx too shows a secondary maximum. Interestingly, this is the only period of the year when both the fluxes are almost of the same magnitude and as much energy is lost by the ground during the night as is received from above in the day-time.

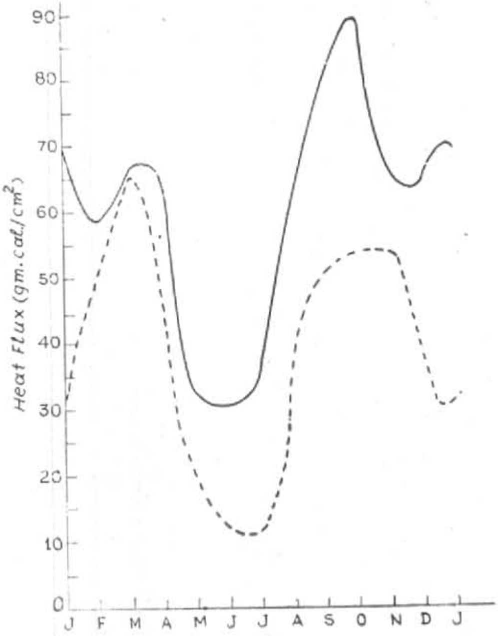

Fig. 2. Seasonal march of daily heat flux

(——— downward flux, - - - - - upward flux)

In spite of the mostly clear skies in winter months, the lower elevations of the sun at this time seem to be responsible for the smaller downward day-time fluxes while the negative fluxes too are of small magnitude, presumably due to lower surface temperatures in the nights and higher air humidities. The rapid desiccation of the soil and the atmosphere from now on coupled with rising temperatures enhances the upward flux which attains maximum values in spring. The increase in the early summer clouding and general rise in atmospheric humidity produce steady decrease in both the fluxes which have their lowest magnitudes at the peak of the southwest monsoon. The most significant features of the curves are thus the post-monsoon peak in the the downward flux and early summer peak in the outward flux.

The maximum positive fluxes in Fig. 1 around 1100 hrs on clear days are in conformity with Scheriber's data (1910—1912) for Dresden and also with the values calculated by Lettau (1949) from Haude's observations in the Gobi Desert during the

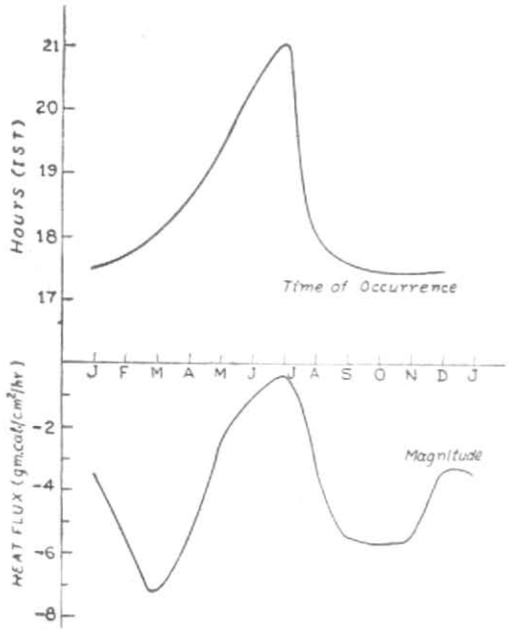

Fig. 3

Seven Hedius Expedition of 1931. The weak negative fluxes at about midnight in all the curves are more or less a characteristic feature of the diurnal curves, again supporting the values of Scheriber and Lettau.

The strong minima around 1700 hrs appear to be a seasonal feature, their magnitude and time of occurrence varying with the general climatic conditions in different seasons (Fig. 3). The magnitude curve of these early evening negative fluxes, also presented in Fig. 3, has the lowest value in July and shows a rise until the monsoon has cleared and remains steady thereafter during the winter months. From a secondary minimum between December and January it rises to another peak value in March. Likewise the time of occurrence of this minimum is also earlier in winter than in summer and swings back after the withdrawal of the southwest monsoon.

A preliminary study of the influence of soil moisture on soil heat-flows did not reveal any significant relationships. Since the moisture content of the soil affects both the heat capacity as well as the thermal conductivity of the soil, it is probable that a dynamical rather than a static analysis is required for an understanding of their mutual characteristics; further work along these lines is in progress.

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