Mausam, (1993), **44**, 2, 163-166

551.508.29 : 551.525

A six level automatic soil temperature measuring system

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(*Received 8 October 1991, Modified 17 July 1992*)

सार—चार टर्मिनल वाले थर्मिस्टरों का उपयोग करते हुए एक स्वचालित मृदा ताप मापक उपकरण का विकास किया गया है। छः स्तरों अर्थात् मृदा सतह से 10 सें॰ मी॰ ऊपर, मृदा सतह तथा मृदा सतह से 10 सें॰ मी॰, 20 सें॰ मी॰, 30 सें॰ मी॰ और 60 सें॰ मी॰ नीचे से प्राप्त विभव को प्रवर्धित करके उनके विविध निर्गमों को चार्ट अभिलेखी पर अभिलेखित किया जाता है। उपकरण का क्षेत्रीय परीक्षण किया गया है और मई 1991 के दौरान लगातार प्रेक्षण लिए गए। दिन के भिन्न-भिन्न समयों के लिए तापमान रेखाचित्र आलेखित किए गए और सभी स्तरों के दैनिक परिवर्तनों पर भी विचार-विमर्श किए गए। अवमंदन की सीमा व उष्मा चालकता और मृदा उष्मा फ्लक्स का मूल्यांकन करने का प्रयास किया गया है।

ABSTRACT. An automatic soil temperature measuring equipment is developed using four terminal thermistors. The output voltages from the six levels, *i.e.*, 10 cm above soil surface, soil surface and 10 cm, 20 cm, 30 cm and 60 cm below the soil surface, are amplified and their multiplexed output is recorded on a chart recorder. The equipment is tested in the field and continuous observations are taken during May 1991. Temperature profiles for different hours of the day are plotted and diurnal variations of all levels are also discussed. An attempt is made to evaluate the damping depth and thence the thermal conductivity and soil heat flux.

Key words — Soil temperature profiles, Soil temperature variation, Soil flux.

1. Introduction

Basically, the measurement of soil temperature at different depths is very important in atmospheric boundary layer and agricultural meteorology studies. The temperature attained by the ground is a direct manifestation of equilibrium of air and ground. This equilibrium depends upon many parameters like, the incoming solar radiation, absorption of this radiation by the ground, reflection of part of this radiation back to the air above, soil conductivity, moisture content etc. It is well understood that by day, soil temperature decreases with depth. Hence, it is expected that heat flows downward into the soil by thermal conduction. At night when the soil surface is cooler, the sign of the temperature gradient is reversed, and heat may be expected to flow upwards.

The principle of conservation of energy states that all gains and losses of energy at the interface must balance. The general equation for conservation of energy is (Oke 1978, Mitsuta *et al.* 1973):

$$Q_N = Q_H + Q_E + Q_G \tag{1}$$

where, Q_N is the net all wave radiation, Q_H is the turbulent transfer of sensible heat into the atmosphere. Q_E is the contribution of latent heat of evaporation and evapotranspiration and Q_G is the transfer of heat through the ground. In the following study an attempt is made to evaluate Q_G with the help of the six level soil temperature measuring equipment.

2. Description of the measurement system

The sensor voltages at six levels, *i.e.*, 10 cm above soil surface, soil surface and 10,20,30 and 60 cm below soil surface are amplified. Their outputs are multiplexed and then sequentially compared with a reference amplifier which is so adjusted that the final differential amplifier gives zero voltage at 0°C. Thus the output voltage from the six levels and then the reference voltage are recorded in sequence on a chart recorder.

2.1. *Sensors*

The temperature sensors used are linearised bead thermistors manufactured by Yellow Springs Instrument Co., U.S.A. and having a 3.16 mm diameter. They have a sensitivity of 129.163 ohm/°C and are quite linear in the temperature range —50°C to +50°C. At 0°C they have a resistance of 13693.9 ohm and follow a temperature dependent relation given below:

$$R(t) = (-129.163)\,T + 13693.9\ \Omega \tag{2}$$

where, $R(t)$ is the resistance at T°C. The six thermistors with their linearisation resistors were calibrated in a temperature bath. All the thermistors followed the same graph with a relative maximum deviation of $\pm$ 20 ohms corresponding to $\pm$ 0.15°C.

2.2. *Probe geometry*

The cross-sectional geometry of the probe is shown in Fig. 1. The main body of the probe is made out of pieces of nylon tube with 2 cm inner diameter to accommodate the linearization resistors. Two consecutive nylon pieces are joined together with the help of an aluminium ring which has a hole for placing the thermistor. The entire length of nylon tube consists of six such joints for placing thermistors. The first level is 10 cm above soil surface and second one just touching the soil surface. The third, fourth, fifth and sixth levels are 10,20,30 and 60 cm below the soil surface. The first and second thermistors are placed away from the aluminium rings so that the first one is in free air and the second one always touches the soil surface. For the third, fourth, fifth and sixth levels care is taken that the thermistor bead just touches the outer surface of the aluminium ring. A perfect thermal contact is achieved between the thermistor and the aluminium ring with the use of silver paint. For each sensor two output wires are available and these wires run up to the top of the probe where a 16 pin connector is fixed. For six levels of observation 12 output lines are available. A 12 core cable of 50 m length is used for connecting the probe and the electronic circuitry which is kept inside the laboratory.

2.3. *Circuit design*

The complete circuit diagram is shown in Fig.2. The thermistor resistances at six levels, RT1-RT6, act as feed back resistors to six inverting amplifiers, A1-A6 (LM 324). Resistors R1 to R6 (10 kΩ) are input resistances for the inverting amplifiers. A reference voltage (—1550 mV) is generated by IC5 (LM 337) and is fed to the inputs of all the amplifiers (A1-A6). As all the thermistors are connected as feedback resistors of amplifiers A1-A6, an output voltage varying between 2046 to 1046 mV is obtained for a change in thermistor resistance 13693 to 7240 ohms corresponding to a temperature variation of 0°C to 50°C. The outputs of amplifiers A1-A6 go through the multiplexer IC3 (CD 4051) which has 8 inputs of which 1, 5, 12, 13, 14, 15 are connected and two input points 2&4 are not connected. The output of IC3 (pin No. 3) is connected to the inverting terminal of the final unity gain differential amplifier, A8, through an input resistance R9 (1 MΩ). Amplifier A7 acts as a reference amplifier whose gain is adjusted to get an output of 2046 mV. This output is directly fed through an output resistance R11 (1 MΩ) to the non-inverting terminal of the final amplifier A8. The output of A8 varies in the range 0-1000 mV for a temperature range 0°C-50°C, giving a temperature coefficient of 20 mV/°C. The output of this amplifier directly goes to the chart recorder.

IC4 (CD 4060) is used as a clock. The frequency of the clock is adjusted with R13 (2.2 MΩ), R14 (220 kΩ), C7 (0.22μF) giving a 15 second pulse. Thus all the six levels are sensed for 15 sec each. The total duration for these six measurements is 90 sec. As the multiplexing inputs 2 and 4 are not connected, a standing voltage (dummy levels) of 1.06 V appears at the output for the next 30 sec. Thus the entire sensing of six levels and two dummy levels is completed within 120 sec and thereafter the entire cycle is repeated.

3. Data analysis

The soil thermometer was exposed at Indian Institute of Tropical Meteorology (IITM), Pune campus for about a month during May 1991. The soil is black with short grass on it. Fig. 3 shows a sample analog record obtained on 7 May 1991 for about 80 minutes duration. All the six outputs are recorded one after another and the reference voltage is also clearly recorded. It may be seen that the reference voltage remains constant. This is an indication that the circuitry does not have any drift. Thus, the data reliability is high. Though the record is continuous, only half hourly values of the output are read for analysis. Referring to voltage *versus* temperature calibration graph, the temperature profiles and diurnal variations are plotted. Fig. 4 shows the diurnal variation of temperature observed on 7 May 1991 at different depths. It may be seen that the ground temperature has the highest variations : 30°C to 53.5°C. The peak occurs just before 1200 IST. Another peak is observed around 1500 IST. The soil surface temperature variations are reflected in the temperatures at 10 cm above the soil surface. The 10 cm below surface level responds to the temperature variation at the surface level with a lag and attains maximum temperature after about four and half hours. The diurnal variations at 20, 30 and 60 cm below soil surface are very small (Rosenberg *et al.* 1983).

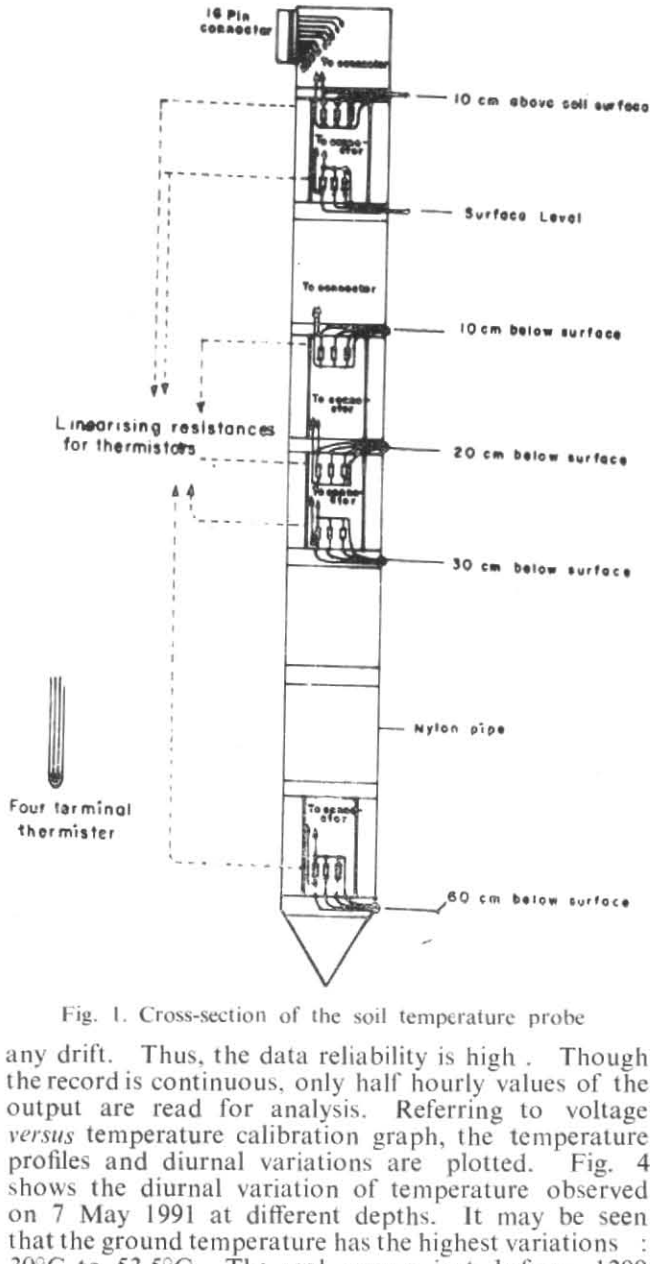


Fig. 1. Cross-section of the soil temperature probe

3.1. *Soil temperature profiles*

The above data is plotted to study the profiles at different times of the day. Fig. 5 shows the profiles for 7 May 1991 at two hourly intervals from 0600 IST to 2000 IST. It may be observed that during the early morning hours, the layer between 10 cm above the surface and 10 cm below the surface is isothermal. The maximum of soil surface temperature occurs at

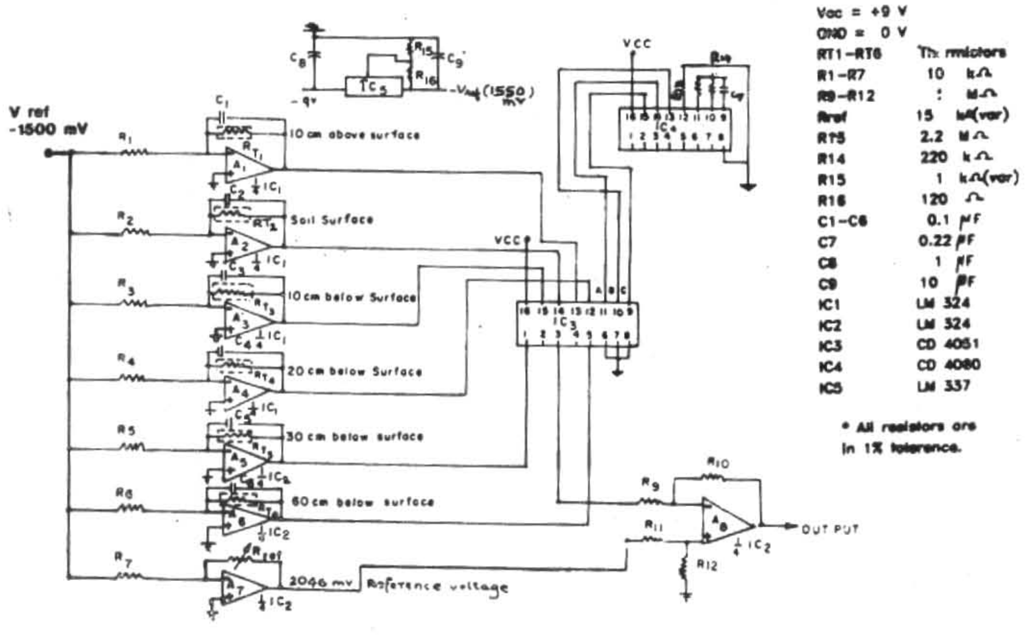


Fig. 2. Circuit diagram

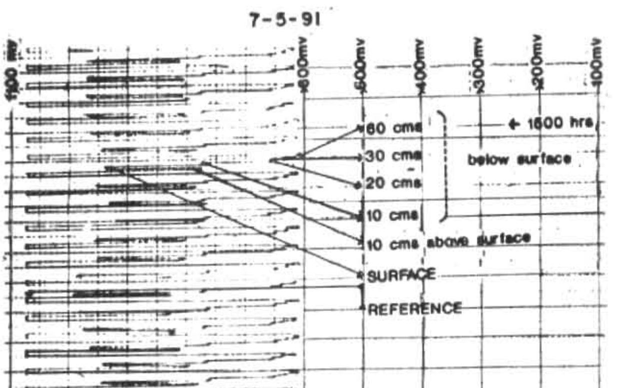


Fig. 3. Sample analog output

1200 IST and reaches a value of 51.5° C. But the air at 10 cm above the surface level follows it with lesser amplitude and reaches a maximum of 42°C. Even at 1000 IST the difference between surface level and 10 cm above the surface is 10°C. Total temperature variations at depths 10, 20, 30 and 60 cm are 8°C, 5°C, 1°C and 0.6° C respectively. As expected the variation at 60 cm is 0.6° C only. The profile shown in Fig. 5 is a typical one. In fact the profiles obtained during one month observational period are similar in nature.

3.2. *Soil heat flux*

Soil heat flux is an important parameter in the energy balance Eqn. (1). Considering the soil as a homogeneous medium, the soil heat flux Q_G (Van Wijk 1965, Fritschen & Gay 1979) is given by :

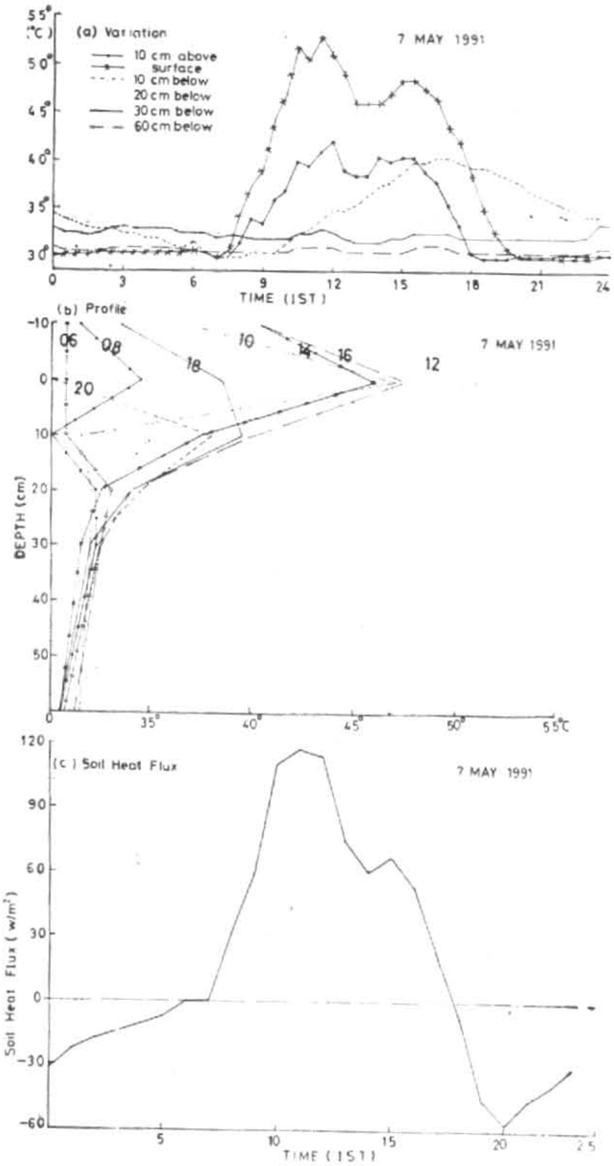
$$Q_G = -K \frac{dT}{dZ} \qquad (3)$$

where, dT/dZ is the temperature gradient and K is the thermal conductivity of the soil. K can be calculated from the following equation :

$$D = \left(\frac{2K}{c_v\, w} \right)^{\frac{1}{2}} \qquad (4)$$

where, D is the damping depth (depth at which the amplitude has decreased to the fraction $1/e$ of its value at the surface), c_v is the volumetric heat capacity and w is the radial frequency. The damping depth, D, can be evaluated by plotting the natural logarithm of the difference between maximum and minimum temperature as a function of depth Z. A straight line is obtained with a slope $-1/D$ (Van Wijk 1965). For the diurnal variation of temperature, in the present study D is evaluated to be 12.5 cm. The Eqn. (4) is applicable to a soil in which K and c_v are constant with depth. Assuming a reasonable value of $c_v = 1.25 \times 10^6$ J m^{-3} K^{-1} for dry black soil (Rosenberg *et al.* 1983), the value of K is calculated to be 7.12×10^{-1} W m^{-1} K^{-1}.

Considering soil temperatures at surface and 10 cm below the surface, the heat flux Q_G, is evaluated using Eqn. (3). The flux values are shown in Fig. 6. The positive values indicate downward flux and negative values indicate upward flux.



Figs. 4 (a-c). Diurnal variation of : (a) temperature, (b) sequence of temperature profiles, and (c) soil heat flux

4. Conclusions

The equipment is capable of estimating the soil heat flux which is an important component in the energy budget at the land surface interface. The diurnal temperature variations are maximum at the soil surface, reduce as depth increases and are negligible at 60 cm below soil surface. The 10 cm above soil surface temperature follows the surface variations but with reduced amplitude while 10 cm below soil surface temperature lags by about four and half hours. Diurnal and seasonal variations at the different depths would be useful for studying soil water content (Heilman and Moore 1980) and in forecasting models (Sutherland 1980).

Acknowledgements

The authors wish to thank Shri D. R. Sikka, Director, Indian Institute of Tropical Meteorology, Pune for his constant encouragement in the developmental work. Thanks are also due to other divisional colleagues who helped in collecting the data.

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