

## 3.5 Soil temperature and soil heat flux

### 3.5.1 Soil temperature

The soil temperature near the earth's surface is high in the day and low at night, as a result of solar radiation. Its daily variation is sinusoidal. As the measuring depth increases, the sinusoidal daily variation decreases in amplitude and the phase shifts backwards. Because the litter layer on the ground surface of a forest tends to become thicker and its border with a soil is less clear as one goes deeper into a cold climate region, caution should be exercised in the measuring depth.

#### Types of instruments

There are three types of thermo sensors for measuring soil temperature: thermocouple, thermistor (Photo 3.5-1) and platinum resistance (Photo 3.5-2). For more details, refer to Section 3.3 “Air temperature”. Because soil has a larger time constant than air, there is no need for a sensing unit to be small. It can be made larger to make it more waterproof. This is necessary due to the high water content of soil.



Photo 3.5-1 Thermistor thermometer  
107-L, Campbell. (Photograph: courtesy  
of Climatec, Inc.)



Photo 3.5-2 Platinum resistance thermo sensor  
C-HPT-5-JM, Climatec. (Photograph: courtesy of  
Climatec, Inc.)

A thermocouple can be handmade. For soil temperature observation, T-type copper-constantan thermocouples are generally used. To create a thermocouple, compensation lead wire, consisting of a copper wire and a constantan wire, is joined at one end by means of electric welding, silver brazing or soldering. Temperature can be measured by a thermocouple together with a data logger into which a cold junction circuit is built. There are various compensation lead wires of different diameters. Those as thick as a few millimeters are strong and they easily handle the large time constant of soil. The waterproof efficiency of a thermocouple can be enhanced by putting it into a metal pipe that is one size larger than the thermocouple and then adding sealant.

A thermistor is a thermo sensor that takes advantage of the proportionality between temperature and

electric resistance of a conductive substance. Because the proportionality factor differs between substances, a thermistor and its connecting logger are usually sold as a pair.

Platinum resistors are basically either three-wire or four-wire. Being little subject to age-related changes, platinum resistors are well-suited for soil temperature sensors that are hard to replace frequently.

The radiation thermometer is another type of instrument that is often used to measure ground surface temperature (Photo 3.5-3). From the surface of any object, longwave radiation corresponding to its surface temperature is emitted. The radiation thermometer captures this longwave radiation, and converts it into temperature to indicate the surface temperature of the object. Despite its advantage of noncontact observation, its accuracy is plus or minus 2 °C, which makes it inferior in accuracy to contact sensors.



Photo 3.5-3 Radiation thermometer IR-SA, CHINO. Right: with telescope attached.

(Photograph: courtesy of CHINO CORPORATION)

### Measuring method

The shallower is the soil depth is, the greater are the time variation and vertical change of soil temperature  $T_s$  [K]. Thus, thermo sensors need to be placed densely in the shallow layer. As one installation procedure, after a hole is excavated, the thermo sensor is thrust into an undisturbed section of the soil (Photo 3.5-4) and then the hole is refilled. In another method, a narrow vertical hole is dug, into which a thermo sensor is inserted, and the hole is refilled with the same soil. In the former procedure, because the surrounding soil is disturbed, the hole has to be carefully refilled. The latter method is applied to the observation of a shallow layer because it is difficult to ensure that the sensor contacts the soil properly in a deep hole. In either case, the waterproof efficiency of sensors and cables should be taken into consideration.

One important factor in flux measurement is the temperature of heat/gas exchange surface including ground surface. A method for measuring surface temperature is explained here. To measure surface temperature, the use of a surface thermometer is most convenient and reliable. When surface temperature is measured with a contact



Photo 3.5-4 Underground section where a thermocouple thermometer (left of the stick) and a soil moisture meter (right of the stick) are embedded. (seasonal forest of Kratie, Cambodia)

thermometer, the sensor should be the smallest possible and it should be installed as close to the surface as possible. The sensing unit is usually installed such as not to be directly exposed to solar radiation.

#### **Tips!**

One is often confused about which cable is connected to which sensor after all the sensors are embedded at several depths in a place. It is convenient to attach tags with the information of measuring depth at the ground surface and to the logger junctions for maintenance.

Tips 3.5-1

#### **Tips!**

Cables can be laid in a spiral tube or resin pipe for protection against gnawing by mice and other animals.

Tips 3.5-2

#### **Tips!**

A waterproof data logger that is equipped with a thermo sensor may perform poorly as a result of condensation on the instrument base. Such malfunction can be prevented by placing silica gel inside the logger and sealing it tightly. The silica gel should be replaced occasionally.

Tips 3.5-3

### 3.5.2 Soil heat flux

Soil heat flux on the ground surface represents the magnitude of heat exchange between soil and atmosphere, which is expressed in  $\text{Wm}^{-2}$ . Because soil heat flux is proportional to the temperature gradient at a given depth, it can be calculated on the basis of the vertical profile of soil temperature. However, measurement using a heat flux plate is easier and thus more common.

#### Instruments

The heat flux plate (Photos 3.5-5 and 3.5-6) operates based on the principle that the temperature difference between the two sides of a thin plate (thermal resistance plate) with a given thermal conductivity is proportional to the amount of passing heat. Heat flux is obtained by dividing the output value of a heat flux plate [mV] by a sensitivity constant [ $\text{mV}(\text{Wm}^{-2})^{-1}$ ].

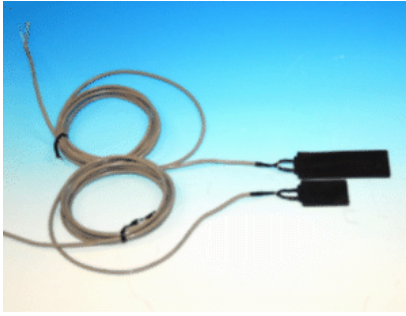


Photo 3.5-5 Heat flux plate PHF-100, PREDE.  
(Photograph: courtesy of PREDE CO., LTD.)

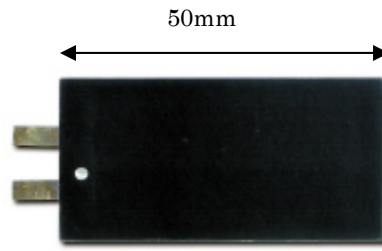


Photo 3.5-6 Heat flux plate MF-180M, EKO.  
(Photograph: courtesy of EKO INSTRUMENTS CO., LTD.)

## Measurement

A heat flux plate should be installed horizontally (Photo 3.5-7). To measure the heat flux of the ground surface, it is better to install the plate at a shallow depth, because the amount of heat stored in the soil above the heat flux plate is ignored. But if the measuring depth is too shallow, errors may occur because the plate prevents water movement and because solar radiation affects measurements. Although there is no determined practice, plates are mostly embedded 1cm to 3cm below the surface. Close contact of the plate with soil should be assured.



Photo 3.5-7 Embedded heat flux plate. (Kawagoe forest meteorology research site)

The method of calculating the heat flux on the basis of temperature change and heat capacity in each soil layer (Equation 3.5-1) is called thermal integration (Fig. 3.5-1).

$$Q = \sum_n^{i=1} Q_i + Q_b = \sum C_{v_i} \Delta z_{d_i} \Delta T_{s_i} + Q_b \quad (3.5-1)$$

Here,  $Q$ : soil heat flux [ $\text{Wm}^{-2}$ ],  $C_v$ : volume heat capacity of soil [ $\text{Jm}^{-3}\text{K}^{-1}$ ],  $z_d$ : thickness of each soil layer [m],  $T_s$ : soil temperature,  $Q_b$ : soil heat flux at the bottom of the lowest soil layer [ $\text{Wm}^{-2}$ ] and  $i$ : subscript indicating soil layer  $i$ . The volume heat capacity is strongly affected not only by soil components but also by

soil moisture. Therefore, soil moisture measurement is also required.

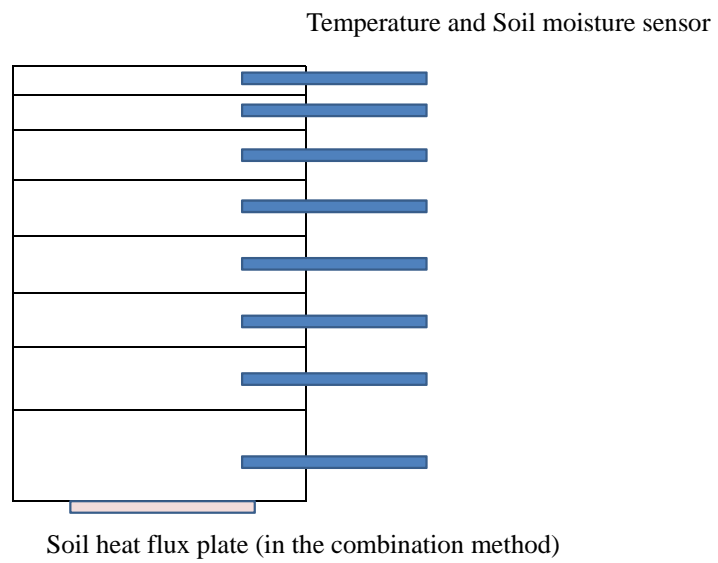


Fig. 3.5-1 Conceptual image of the temperature integration method and the combination method.