INSTRUCTION MANUAL

Model HFP01
Soil Heat Flux Plate

Revision: 7/12

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Model HFP01 Soil Heat Flux Plate

1. Introduction

The HFP01 outputs a voltage signal that is proportional to the heat flux of the surrounding medium (usually soil). It is typically used for energy-balance or Bowen-ratio flux systems. At least two sensors are required for each site to provide spatial averaging. Sites with heterogeneous media may require additional sensors.

Before installing the HFP01, please study

- Section 2, *Cautionary Statements*
- Section 3, *Initial Inspection*

The installation procedure is provided in Section 6.

2. Cautionary Statements

- Care should be taken when opening the shipping package to not damage or cut the cable jacket. If damage to the cable is suspected, consult with a Campbell Scientific applications engineer.

- Although the HFP01 is rugged, it should be handled as a precision scientific instrument.

3. Initial Inspection

- Upon receipt of the HFP01, inspect the packaging and contents for damage. File damage claims with the shipping company.

- The model number and cable length are printed on a label at the connection end of the cable. Check this information against the shipping documents to ensure the correct product and cable length are received.

- The HFP01 is shipped with a calibration sheet and an instruction manual or a ResourceDVD.

4. Overview

The HFP01 Soil Heat Flux Plate uses a thermopile to measure temperature gradients across its plate. Operating in a completely passive way, it generates a small output voltage that is proportional to this differential temperature. Assuming that the heat flux is steady, that the thermal conductivity of the body is constant, and that the sensor has negligible influence on the thermal flow pattern, the signal of the HFP01 is directly proportional to the local heat flux.

The HFP01's output is in millivolts. To convert this measured voltage to heat flux, it must be divided by the plate's calibration constant. A unique calibration constant is supplied with each sensor.

To get the soil heat flux at the surface, use at least two HFP01s to measure soil heat flux at a depth of 8 cm; a TCAV Averaging Soil Thermocouple to measure the temporal change in temperature of the soil layer above the HFP01; and a CS616, CS650, or CS655 water content reflectometer to measure soil water content (see Figure 6-1). The temporal change in soil temperature and soil water content are used to compute the soil storage term.

The -L extension in the model name (i.e., HFP01-L) indicates a user-specified cable length. This manual refers to the sensor as the HFP01.

The sensor's cable can terminate in:

- Pigtails that connect directly to a Campbell Scientific datalogger (option –PT).
- Connector that attaches to a prewired enclosure (option –PW). Refer to www.campbellsci.com/prewired-enclosures for more information.
- Connector that attaches to a CWS900 Wireless Sensor Interface (option –CWS). The CWS900 allows the probe to be used in a wireless sensor network. Refer to www.campbellsci.com/cws900 for more information.

NOTE A general discussion about the characteristics and principles of operation of heat flux sensors is shown in Appendix A.

5. Specifications

Features:

- Compatible with most of our contemporary and retired dataloggers
- Compatible with the CWS900-series interfaces, allowing it to be used in a wireless sensor network

Compatibility
Dataloggers: CR800 series
CR1000
CR3000
CR5000
CR9000(X)
CR7X
CR510
CR10(X)
CR23X
21X

Operating Temperature: -30° to +70°C

Plate Thickness: 5.0 mm (0.20 in)

Plate Diameter: 80.0 mm (3.15 in)

Weight (w/o cable):	200 g (7.05 oz)
Sensor:	Thermopile
Measurement Range:	±2000 W m^{-2}
Sensitivity (nominal):	50 µV W^{-1} m^{-2}
Expected Typical Accuracy (12 hour totals):	within -15% to +5% in most common soils
Nominal Resistance:	2 W
Sensor Thermal Resistance:	<6.25 x 10^{-3} Km^2W^{-1}

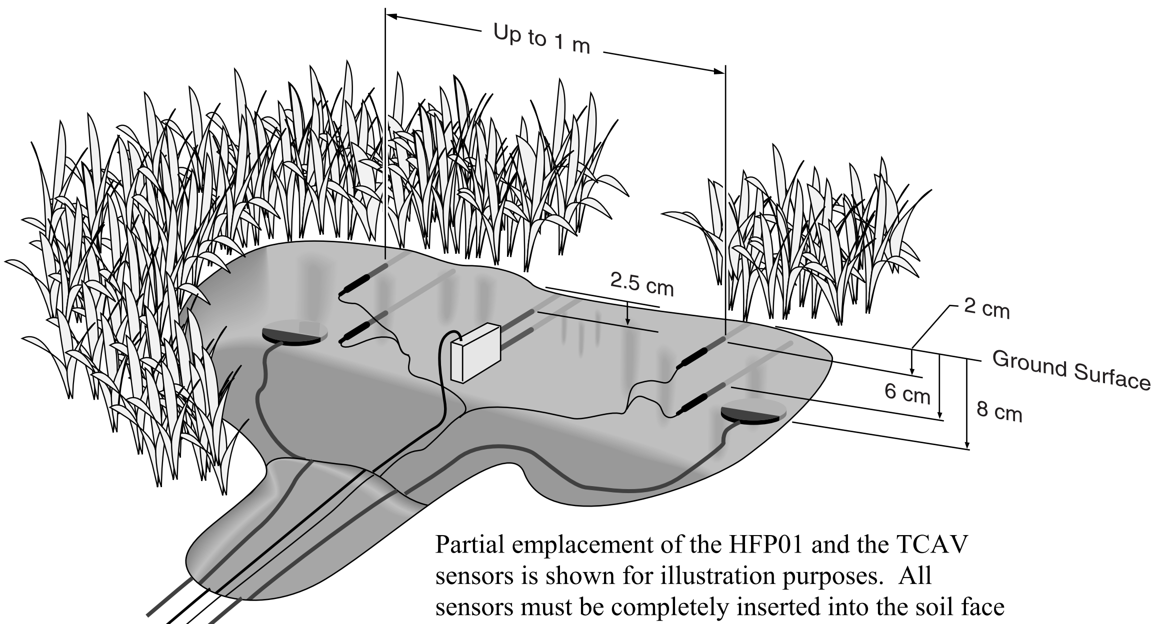

FIGURE 6-1. Placement of heat flux plates

6. Installation

6.1 Placement in Soil

The standard set of sensors for measuring soil heat flux includes two HF01 Soil Heat Flux Plates, one TCAV Averaging Soil Thermocouple, and one CS616, CS650, or CS655 water content reflectometer. These sensors are installed as shown in Figure 6-1.

The location of the heat flux plates and thermocouple should be chosen to be representative of the area under study. If the ground cover is extremely varied, an additional set of sensors is required to provide a valid soil heat flux average.

Use a small shovel to make a vertical slice in the soil. Excavate the soil to one side of the slice. Keep this soil intact so that is can be replaced with minimal disruption.

The sensors are installed in the undisturbed face of the hole. Measure the sensor depths from the top of the hole. With a small knife, make a horizontal cut 8 cm below the surface into the undisturbed face of the hole. Insert the heat flux plate into the horizontal cut.

NOTE Install the HFP01 in the soil such that the side with the red label is facing the sky and the side with a blue label facing the soil.

CAUTION In order for the HFP01 to make quality soil heat flux measurements, the plate must be in full contact with the soil.

Never run the sensors leads directly to the surface. Rather, bury the sensor leads a short distance back from the hole to minimize thermal conduction on the lead wire. Replace the excavated soil back into it original position after all the sensors are installed.

NOTE To protect sensor cables from damage caused by rodents, it is recommended to bury them inside of flexible electrical tubing.

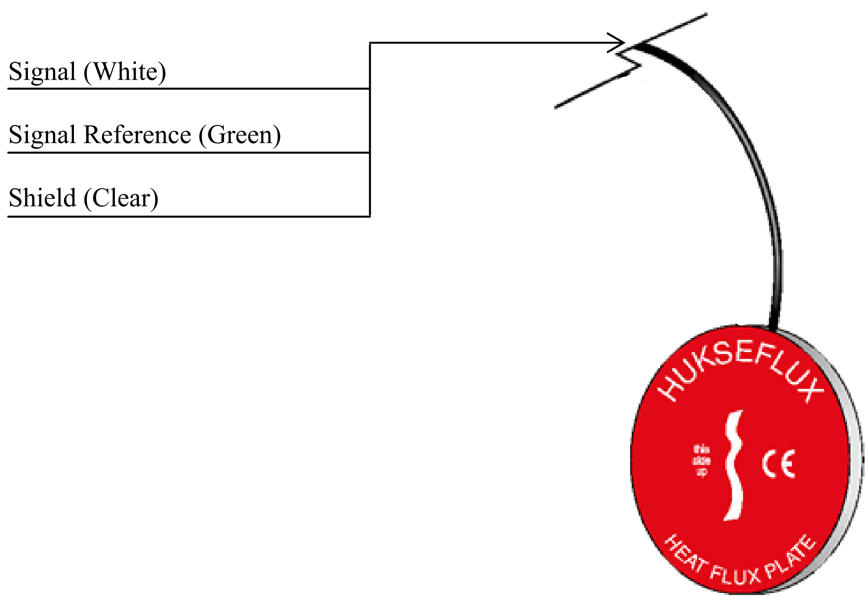

FIGURE 6-2. HFP01 plate to datalogger connections

6.2 Wiring

Connections to Campbell Scientific dataloggers are given in Table 6-1 and Figure 6-2. The output of the HF01 can be measured using a single-ended analog measurement (**VoltSE()** in CRBasic or Instruction 1 in Edlog) or a differential analog measurement (**VoltDiff()** in CRBasic or Instruction 2 in Edlog).

TABLE 6-1. Datalogger Connections for a Single-Ended Measurement

Description	Color	CR10(X), CR510, CR500	CR800, CR850, CR1000, CR3000, CR5000, CR23X, 21X, CR7,
Signal	White	Single-Ended Input	Single-Ended Input
Signal Reference	Green	AG	⏚
Shield	Clear	G	⏚

6.3 Programming

To calculate the calibration multiplier, divide 1000 by the nominal calibration sensitivity (i.e., 1000/sensitivity). The nominal calibration sensitivity is unique for each HFP01. Each sensor is accompanied with a calibration certificate and has a label on it with the calibration values. The label is located on the pigtail end of the sensor leads.

In example 1, the nominal calibration sensitivity is 67.1 $\mu V/W^{-2}$ for the HFP01#1 and 67.0 $\mu V/W^{-2}$ for the HFP01#2. In examples 2 and 3, the nominal calibration sensitivity is 67.1 $\mu V/W^{-2}$.

TABLE 6-2. Wiring for Example 1

Description	Color	CR3000
Sensor Signal #1	White	7H
Sensor Signal Reference #1	Green	7L
Shield #1	Clear	⏚
Sensor Signal #2	White	8H
Sensor Signal Reference #2	Green	8L
Shield #2	Clear	⏚

Example 1. Sample CR3000 Program using Differential Measurement Instructions

```
'CR3000 Series Datalogger

'Copyright (c) 2007, Campbell Scientific, Inc. All rights reserved.

'This datalogger program measures two HFP01 Hukseflux soil heat flux sensors

'*** Wiring ***

'7H     HFP01 #1 signal (white)
'7L     HFP01 #1 signal reference (green)
'gnd    HFP01 #1 shield (clear)

'8H     HFP01 #2 signal (white)
'8L     HFP01 #2 signal reference (green)
'gnd    HFP01 #2 shield (clear)

'*** Constants ***
Const  HFP01_CAL_1 = 14.90  'Unique multiplier for HFP01 #1.  1000/sensitivity (1000/67.1)
Const  HFP01_CAL_2 = 14.92  'Unique multiplier for HFP01 #2.  1000/sensitivity (1000/67.0)

'*** Variables ***

'Energy balance sensors.

Public shf(2)
Dim shf_cal(2)              'Soil heat flux plate calibration coefficients.
Units shf = W/m^2

'*** Final Output Data Tables ***

DataTable (soil_hf,TRUE,-1)
  DataInterval (0,30,Min,10)

  Average (2,shf(1),IEEE4,FALSE)

EndTable

'*** Program ***

BeginProg

'Load the HFP01 factory calibration.
  shf_cal(1) = HFP01_CAL_1
  shf_cal(2) = HFP01_CAL_2

  Scan (1,Sec,3,0)

    'Measure the HFP01 soil heat flux plates.
    VoltDiff (shf(1),2,mV50C,7,TRUE,200,250,shf_cal(),0)

    CallTable soil_hf

  NextScan
EndProg
```

TABLE 6-3. Wiring for Example 2

Description	Color	CR10(X)
Signal	White	SE 5 (3H)
Signal Reference	Green	AG
Shield	Clear	G

Example 2. Portion of CR10(X) Program using the Single-Ended Measurement Instruction

NOTE The instruction below does not store data in final storage. P92, P77, and an output processing instruction are required to store the data permanently.

```
01:  Volt (SE) (P1)
  1:   1            Reps
  2:   2            7.5 mV Slow Range      ;CR510 (7.5 mV);CR23X (10 mV); 21X, CR7 (5 mV)
  3:   5            SE Channel             ;White  wire (SE 5), Green wire (AG)
  4:   1            Loc [ HFP01    ]
  5:   14.90        Mult                   ;Enter Calibration
  6:   0            Offset
```

TABLE 6-4. Wiring for Example 3

Description	Color	CR23X
Signal	White	9H
Signal Reference	Green	9L
Shield	Clear	⏚

Example 3. Portion of CR23X Program using the Differential Measurement Instruction

NOTE The instruction below does not store data in final storage. P92, P77, and an output processing instruction are required to store the data permanently.

```
;Measure the HFP01 Soil Heat Flux plate.
;
01:  Volt (Diff) (P2)
  1:   1            Reps
  2:   21           10 mV, 60 Hz Reject, Slow Range  ;CR510, CR10(X) (7.5 mV); 21X, CR7 (5 mV)
  3:   9            DIFF Channel                     ;White wire (9H); Green wire (9L)
  4:   1            Loc [ HFP01     ]
  5:   14.90        Mult                             ;Enter Calibration
  6:   0            Offset
```

6.4 Soil Heat Flux and Storage

The soil heat flux at the surface is calculated by adding the measured flux at a fixed depth, d, to the energy stored in the layer above the heat flux plates. The specific heat of the soil and the change in soil temperature, ΔT_S, over the output interval, t, are required to calculate the stored energy.

The heat capacity of the soil is calculated by adding the specific heat of the dry soil to that of the soil water. The values used for specific heat of dry soil and water are on a mass basis. The heat capacity of the moist soil is given by:

$$C_s = \rho_b\left(C_d + \theta_m C_w\right) = \rho_b C_d + \theta_v \rho_w C_w \quad (1)$$

$$\theta_m = \frac{\rho_w}{\rho_b}\theta_v \quad (2)$$

where C_S is the heat capacity of moist soil, ρ_b is bulk density, ρ_w is the density of water, C_d is the heat capacity of a dry mineral soil, θ_m is soil water content on a mass basis, θ_v is soil water content on a volume basis, and C_w is the heat capacity of water.

This calculation requires site specific inputs for bulk density, mass basis soil water content or volume basis soil water content, and the specific heat of the dry soil. Bulk density and mass basis soil water content can be found by sampling (Klute, 1986). The volumetric soil water content is measured by the CS616 water content reflectometer. A value of 840 J kg^{-1} K^{-1} for the heat capacity of dry soil is a reasonable value for most mineral soils (Hanks and Ashcroft, 1980).

The storage term is then given by Eq. (3) and the soil heat flux at the surface is given by Eq. (4).

$$S = \frac{\Delta T_s C_s d}{t} \quad (3)$$

$$G_{sfc} = G_{8cm} + S \quad (4)$$

7. Maintenance

The HFP01 requires minimal maintenance. Check the sensor leads monthly for rodent damage.

Recalibrate the HFP01 for every two years of continuous use. Obtain an RMA number before returning the HFP01 to Campbell Scientific for calibration.

8. References

Hanks, R. J., and G. L. Ashcroft, 1980: *Applied Soil Physics: Soil Water and Temperature Application.* Springer-Verlag, 159 pp.

Klute, A., 1986: *Method of Soil Analysis.* No. 9, Part 1, Sections 13 and 21, American Society of Agronomy, Inc., Soil Science Society of America, Inc.

Appendix A. General Theory of Heat Flux Sensors

This Appendix discusses the general theory and characteristics of heat flux sensors similar to the HFP01.

A.1 General Theory

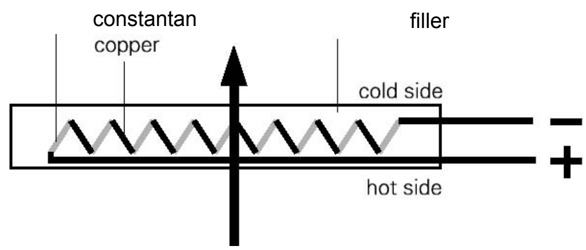

FIGURE A-1. General characteristics of a heat flux sensor

When heat is flowing through the sensor in the indicated direction, the filling material will act as a thermal resistance. Consequently the heat flow, φ, will follow a temperature gradient across the sensor, flowing from the hot to the cold side. Most heat flux sensors are based on a thermopile—a number of thermocouples connected in series. A single thermocouple will generate an output voltage that is proportional to the temperature difference between the joints (copper-constantan and constantan-copper). Provided that errors are avoided, the temperature difference is proportional to the heat flux—depending only on the thickness and the thermal conductivity of the sensor. Using more thermocouples in series will enhance the output signal. In Figure A-1, the joints of a copper-constantan thermopile are alternatively placed on the hot and the cold side of the sensor.

The thermopile is embedded in a filling material, usually a plastic.

Each individual sensor will have its own sensitivity, E_{sen}, usually expressed in Volts output, V_{sen}, per Watt per square metre heat flux, φ. The flux is calculated:

$$\varphi = V_{sen}/E_{sen}$$

The sensitivity is determined by the manufacturer, and is found on the calibration certificate that is supplied with each sensor.

When used for measuring soil heat flux, heat flux sensors such as the HFP01 reach a limited level of accuracy. This has to do with the fact that thermal parameters of soil are constantly changing (soil moisture content) and with the fact that the ambient temperature is not fixed. A realistic estimate of the error range is ±20% over a thermal conductivity range from 0.1 to 1.7 W/mK (dry sand to water-saturated sand) across the temperature range of -30° to +70°C. The accuracy is better if the soil conditions are closer to the reference conditions (see the sensor specifications) and, in an actual experiment, the expected error range will probably be ±10%.

The reference conditions for the calibration are a thermal conductivity of 0.8 W/mK and a nominal temperature of 20°C.

A.2 Extended Theory

It is obvious that there is the possibility that the sensor itself can significantly disturb the phenomenon that it is supposed to measure. By adding a sensor to the material under observation, you can add additional, and sometimes differing, thermal resistances.

The deflection error, as shown in Figure A-2, represents the effect that, as a result of differing resistances, the flow pattern will change, especially at the edges of the heat flux sensor. The order of magnitude of this error for strongly different thermal conductivity values between the sensor and its environment (for example 0.6 for a typical sensor and 0.03 for an insulating wall) is about 40%.

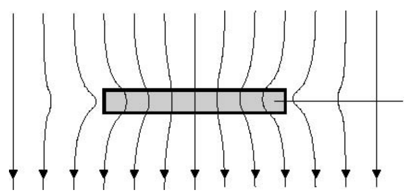

FIGURE A-2. Deflection error

The heat flux is deflected at the edges of the sensor. As a result, the heat flow at the edges is not representative.

Apart from the sensor thermal resistance, the contact resistance between the sensor and surrounding material require special attention.

The conductivity of air is approximately 0.02W/mK which is ten times smaller than that of the heat flux sensor. It follows, therefore, that air gaps can form major contact resistances. In all cases the contact between sensor and surrounding material should be as close and as stable as possible, so that it will not influence the measurements.

The aspects of differing thermal properties between sensor and its environment can also be dealt with during the measurement using a higher accuracy self-calibrating type of heat flux sensor.

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