INSTRUCTION MANUAL

Model HFP01SC Self-Calibrating Soil Heat Flux Plate

Revision: 3/14

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Self-Calibrating Soil Heat Flux Plate

1. Introduction

The HFP01SC Self-Calibrating Heat Flux Sensor™ measures soil heat flux, typically for energy-balance or Bowen-ratio flux systems. It is intended for applications requiring the highest possible degree of measurement accuracy. At least two sensors are required for each site to provide spatial averaging. Sites with heterogeneous media may require additional sensors.

Before installing the HFP01SC, please study

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

The installation procedure is provided in Section 6, *Installation*.

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 HFP01SC is rugged, it should be handled as a precision scientific instrument.

3. Initial Inspection

- Upon receipt of the HFP01SC, 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 HFP01SC is shipped with a calibration sheet and an instruction manual or a ResourceDVD.

4. Overview

The HFP01SC Soil Heat Flux plate consists of a thermopile and a film heater. The thermopile measures temperature gradients across the plate. During the in-situ field calibration, the film heater is used to generate a heat flux through the plate. The amount of power used to generate the calibration heat flux is measured by the datalogger. Each plate is individually calibrated, at the factory, to output flux.

In order to measure soil heat flux at the surface, several HFP01SCs are used to measure the soil heat flux at a depth of eight centimeters. A TCAV, *Averaging Soil Thermocouple*, is used to measure the temporal change in temperature of the soil layer above the HFP01SC. Finally, a CS650, CS655, or CS616 water content reflectometer is used to measure the soil water content. The temporal change in soil temperature and soil water content are used to compute the soil storage term.

The -L option on the model HFP01SC Soil Heat Flux Plate (HFP01SC-L) indicates that the cable length is user specified. The HFP01SC-L has two cables; the first cable is the signal output cable and the second is the heater input cable. Two analog inputs are required to measure the HFP01SC-L. This manual refers to the sensor as the HFP01SC.

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.

5. Specifications

Features:

- Corrects for errors due to differences in thermal conductivity between the sensor and the surrounding medium, temperature variations, and slight sensor instabilities

- Compatible with most of our dataloggers

- Uses Van den Bos-Hoeksema self-calibration method to provide high-degree of measurement accuracy

Compatibility Dataloggers:	CR800 series CR1000 CR3000 CR5000 CR9000(X) CR7X CR10(X) CR23X 21X
Operating Temperature:	–30° to +70°C
Storage Temperature:	–30° to +70°C
Plate Thickness:	5 mm (0.2 in)
Plate Diameter:	80 mm (3.15 in)
Average Power Consumption:	0.02 to 0.04 W

Sensor:	Thermopile and film heater
Heater Voltage Input:	9 to 15 Vdc
Heater Voltage Output:	0 to 2 Vdc
Expected Accuracy:	±3% of reading
Sensitivity (nominal):	50 µV W^{-1} m^{-2}
Sensor Resistance (nominal):	2 Ω
Heater Resistance (nominal):	100 Ω
Duration of Calibration:	±3 min. @ 1.5 W; typically done every 3 to 6 hours
Weight without Cable:	200 g (7.05 oz)

6. Installation

6.1 Placement in Soil

The HFP01SC soil heat flux plates, the TCAV averaging soil temperature probes, and the CS616, *Water Content Reflectometer*, are installed as shown in FIGURE 6-1.

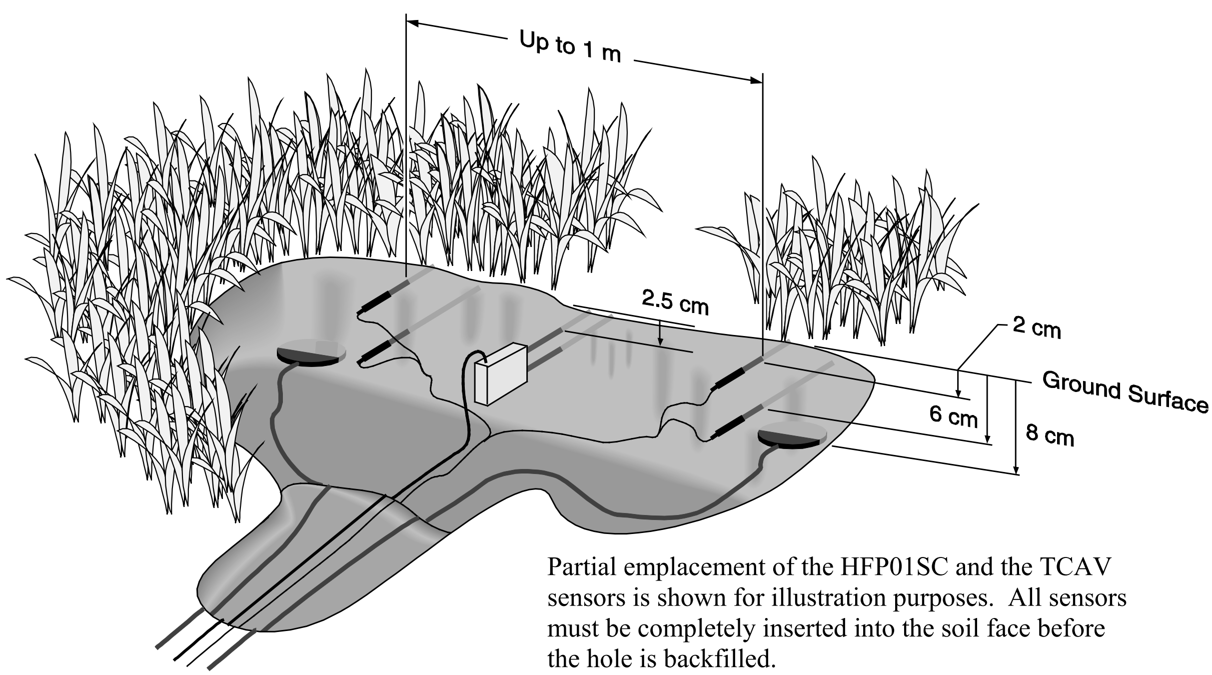

FIGURE 6-1. Placement of heat flux plates

The location of the heat flux plates and thermocouples should represent the area of study. If the ground cover is extremely varied, it may be necessary to have additional sensors to provide a valid spatial average of soil heat flux.

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 to ensure replacement 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 eight centimeters below the surface into the undisturbed face of the hole. Insert the heat flux plate into the horizontal cut.

NOTE Install the HFP01SC in the soil such that the side with the text "this side up" is facing the sky.

CAUTION In order for the HFP01SC 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 minimized thermal conduction on the lead wire. Replace the excavated soil into its original position after all the sensors are installed.

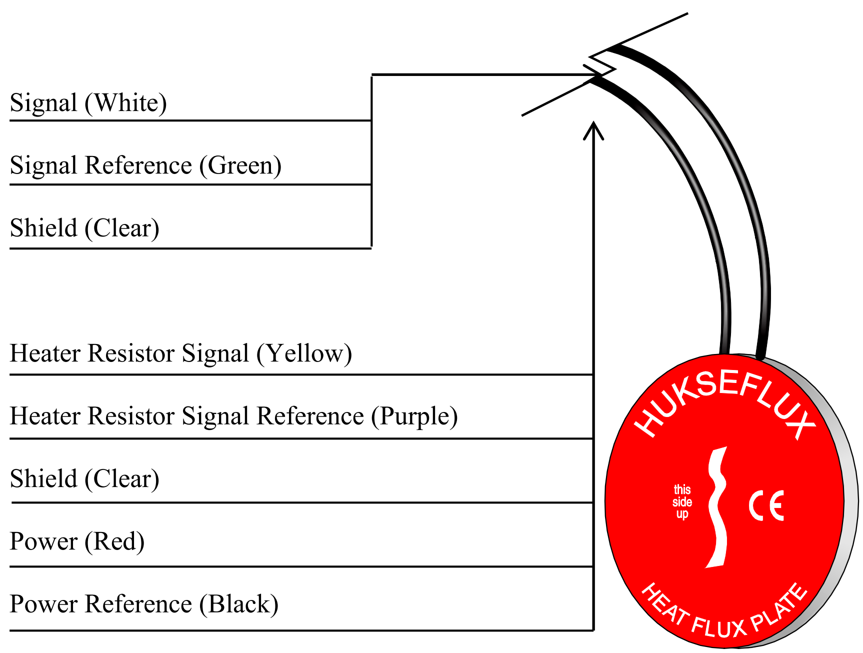

FIGURE 6-2. HFP01SC plate

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

Description	Color	CR10X	CR3000, CR5000, CR23X, CR9000(X), CR7, 21X	CR800, CR850, CR1000
Sensor Signal	White	Single-Ended Input	Single-Ended Input	Single-Ended Input
Sensor Signal Reference	Green	AG	⏚	⏚
Shield	Clear	G	⏚	⏚
Heater Resistor Signal	Yellow	Single-Ended Input	Single-Ended Input	Single-Ended Input
Heater Resistor Signal Reference	Purple	AG	⏚	⏚
Shield	Clear	G	⏚	⏚
Power	Red	SW12	SW12	SW12
Power Reference	Black	G	G	G
External Power Control	Jumper Wire	SW12-CTRL to Control Port	External Power Control Not Needed	External Power Control Not Needed

TABLE 6-2. Datalogger Connections for a Differential Measurement

Description	Color	CR10(X)	CR3000, CR5000, CR23X, CR9000(X), CR7, 21X	CR800, CR850, CR1000
Sensor Signal	White	Differential Input (H)	Differential Input (H)	Differential Input (H)
Sensor Signal Reference	Green	Differential Input (L)	Differential Input (L)	Differential Input (L)
Shield	Clear	G	⏚	⏚
Heater Resistor Signal	Yellow	Differential Input (H)	Differential Input (H)	Differential Input (H)
Heater Resistor Signal Reference	Purple	Differential Input (L)	Differential Input (L)	Differential Input (L)
Shield	Clear	G	⏚	⏚
Power	Red	SW12	SW12	SW12
Power Reference	Black	G	G	G
External Power Control	Jumper Wire	SW12-CTRL to Control Port	External Power Control Not Needed	External Power Control Not Needed

6.2 Wiring

Connections to Campbell Scientific dataloggers are given in FIGURE 6-1, TABLE 6-1, and TABLE 6-2. The output of the HFP01SC can be measured using a single-ended analog measurement (**VoltSE()** or Instruction 1), however, a differential analog measurement (**VoltDiff()** or Instruction 2) is recommended.

The wiring convention is that the white wire is positive with respect to the green wire, when energy is flowing through the transducer from the side with the text "this side up" to the other side.

NOTE The switched 12 Vdc port can source enough current to calibrate four HFP01SC plates. If additional HFP01SC plates are needed, an external relay is required to power the additional plates (see example 4).

For dataloggers without a SW12V output (CR7X, 21X and CR10), a relay (A21REL-12) is required for the in-situ calibration (see Example 4).

6.3 Programming

The HFP01SC has a nominal calibration of 15 W m^{-2} mV^{-1}. Each sensor is accompanied by a calibration certificate. Each sensor also has a unique calibration label on it. The label is located on the pigtail end of the sensor leads.

6.3.1 Example 1. Sample CR3000 Program Using a Differential Measurement Instruction

TABLE 6-3 provides the wiring for Example 1.

TABLE 6-3. Wiring for Example 1

Description	Color	CR3000
Sensor Signal #1	White	9H
Sensor Signal Reference #1	Green	9L
Shield #1	Clear	⏚
Sensor Signal #2	White	10H
Sensor Signal Reference #2	Green	10L
Shield #2	Clear	⏚
Sensor Signal #3	White	11H
Sensor Signal Reference #3	Green	11L
Shield #3	Clear	⏚
Sensor Signal #4	White	12H
Sensor Signal Reference #4	Green	12L
Shield #4	Clear	⏚

Heater Resistor Signal #1	Yellow	13H
Heater Resistor Signal Reference #1	Purple	⏚
Shield #1	Clear	⏚
Power #1	Red	SW12-1
Power Reference #1	Black	G
Heater Resistor Signal #2	Yellow	13L
Heater Resistor Signal Reference #2	Purple	⏚
Shield #2	Clear	⏚
Power #2	Red	SW12-1
Power Reference #2	Black	G
Heater Resistor Signal #3	Yellow	14H
Heater Resistor Signal Reference #3	Purple	⏚
Shield #3	Clear	⏚
Power #3	Red	SW12-1
Power Reference #3	Black	G
Heater Resistor Signal #4	Yellow	14L
Heater Resistor Signal Reference #4	Purple	⏚
Shield #4	Clear	⏚
Power #4	Red	SW12-1

```
'CR3000 Series Datalogger

Const OUTPUT_INTERVAL = 30        'Online mean output interval in minutes.
Const CAL_INTERVAL = 1440         'HFP01SC insitu calibration interval (minutes).
Const END_CAL = OUTPUT_INTERVAL-1 'End HFP01SC insitu calibration one minute before the next Output.
Const HFP01SC_CAL_1 = 15          'Unique multiplier for HFP01SC #1 (1000/sensitivity).
Const HFP01SC_CAL_2 = 15          'Unique multiplier for HFP01SC #2 (1000/sensitivity).
Const HFP01SC_CAL_3 = 15          'Unique multiplier for HFP01SC #3 (1000/sensitivity).
Const HFP01SC_CAL_4 = 15          'Unique multiplier for HFP01SC #4 (1000/sensitivity).

'*** Variables ***

Public shf(4)
Public shf_cal(4)
Units shf = W/m^2
Units shf_cal = W/(m^2 mV)

'HFP01SC calibration variables.
Dim shf_mV(4)
Dim shf_mV_0(4)
Dim shf_mV_180(4)
Dim shf_mV_end(4)
Dim V_Rf(4)
Dim V_Rf_180(4)
Dim shf_cal_on_f As Boolean
Dim sw12_1_state As Boolean       'State of the switched 12Vdc port 1.
Dim ii As Long

DataTable (mean,TRUE,100)
  DataInterval (0,OUTPUT_INTERVAL,Min,10)

  Average (4,shf(1),IEEE4,shf_cal_on_f)
  Sample (4,shf_cal(1),IEEE4)
EndTable
```

```
BeginProg
  'HFP01SC factory calibration in W/(m^2 mV) = 1000/sensitivity.
  shf_cal(1) = HFP01SC_CAL_1
  shf_cal(2) = HFP01SC_CAL_2
  shf_cal(3) = HFP01SC_CAL_3
  shf_cal(4) = HFP01SC_CAL_4

  Scan (1,Sec,3,0)
    'Measure the HFP01SC soil heat flux plates.
    VoltDiff (shf_mV(1),4,mV50C,9,TRUE,0,_60Hz,1,0)

    'Apply calibration to HFP01SC soil heat flux plates.
    For ii = 1 To 4
      shf(ii) = shf_mV(ii)*shf_cal(ii)
    Next ii

    'Power the HFP01SC heaters.
    PortSet (9,sw12_1_state)

    'Measure voltage across the heater (Rf_V).
    VoltSe (V_Rf(1),4,mV5000,25,TRUE,0,_60Hz,0.001,0)

    CallTable (mean)

    'Begin HFP01SC calibration on a fixed interval.
    If ( IfTime (1,CAL_INTERVAL,Min) ) Then
      shf_cal_on_f = TRUE
      Move (shf_mV_0(1),4,shf_mV(1),4)
      sw12_1_state = TRUE
    EndIf

    If ( IfTime (4,CAL_INTERVAL,Min) ) Then
      Move (shf_mV_180(1),4,shf_mV(1),4)
      Move (V_Rf_180(1),4,V_Rf(1),4)
      sw12_1_state = FALSE
    EndIf

    If ( IfTime (END_CAL,CAL_INTERVAL,Min) ) Then
      Move (shf_mV_end(1),4,shf_mV(1),4)
      'Compute new HFP01SC calibration factors.
      For ii = 1 To 4
        shf_cal(ii) = V_Rf_180(ii)*V_Rf_180(ii)*128.7/ABS (((shf_mV_0(ii)+shf_mV_end(ii))/2)-shf_mV_180(ii))
      Next ii
      shf_cal_on_f = FALSE
    EndIf
  NextScan
EndProg
```

6.3.2 Example 2. Sample CR10(X) Program Using a Single-Ended Measurement Instruction

TABLE 6-4 provides the wiring for Example 2.

TABLE 6-4. Wiring for Example 2

Description	Color	CR10(X)
Sensor Signal	White	1H
Sensor Signal Reference	Green	AG
Shield	Clear	G
Heater Resistor Signal	Yellow	1L
Heater Resistor Signal Reference	Purple	AG
Shield	Clear	G
Power	Red	SW12
Power Reference	Black	G
External Power Control		jumper wire SW12-CTRL to C8

```
;{CR10X}
;
*Table 1 Program
  01:  1          Execution Interval (seconds)

;Measure HFP01SC on smaller range.
;
1:  Volt (SE) (P1)
  1:   1          Reps
  2:   22         7.5 mV 60 Hz Rejection Range
  3:   1          SE Channel
  4:   2          Loc [ shf_mV    ]
  5:   1          Mult
  6:   0          Offset

;Measure HFP01SC on larger range.
;
2:  Volt (SE) (P1)
  1:   1          Reps
  2:   23         25 mV 60 Hz Rejection Range
  3:   1          SE Channel
  4:   8          Loc [ shf_mV_a  ]
  5:   1          Mult
  6:   0          Offset

;Load in the factory calibration.
;
3:  If (X<=>F) (P89)
  1:   3          X Loc [ cal       ]
  2:   1          =
  3:   0          F
  4:   30         Then Do
```

```
;Factory calibration in W/(m^2 mV) = 1000/sensitivity.
;
4:  Z=F (P30)
  1:   1          F                      ; <- Enter the unique calibration here
  2:   0          Exponent of 10
  3:   3          Z Loc [ cal       ]

5:  End (P95)

;Use data from the larger measurement range.
;
6:  If (X<=>F) (P89)
  1:   2          X Loc [ shf_mV    ]
  2:   4          <
  3:   -99990     F
  4:   30         Then Do

7:  Z=X (P31)
  1:   8          X Loc [ shf_mV_a  ]
  2:   2          Z Loc [ shf_mV    ]

8:  End (P95)

;Apply custom calibration to the raw soil heat flux measurement.
;
9:  Z=X*Y (P36)
  1:   2          X Loc [ shf_mV    ]
  2:   3          Y Loc [ cal       ]
  3:   1          Z Loc [ shf       ]

;Output data.
;
10:  If time is (P92)
  1:   0          Minutes (Seconds --) into a
  2:   20         Interval (same units as above)
  3:   10         Set Output Flag High (Flag 0)

11:  Real Time (P77)
  1:   0110       Day,Hour/Minute (midnight = 0000)

12:  Resolution (P78)
  1:   1          High Resolution

;Do not include the calibration data in the soil heat flux.
;
13:  If Flag/Port (P91)
  1:   18         Do if Flag 8 is High
  2:   19         Set Intermed. Proc. Disable Flag High (Flag 9)

14:  Average (P71)
  1:   1          Reps
  2:   1          Loc [ shf       ]

15:  Do (P86)
  1:   29         Set Intermed. Proc. Disable Flag Low (Flag 9)

16:  Sample (P70)
  1:   1          Reps
  2:   3          Loc [ cal       ]

;Add other processing here.

;Call calibration routine.
;
17:  Do (P86)
  1:   8          Call Subroutine 8
```

```
*Table 2 Program
  02: 0         Execution Interval (seconds)

*Table 3 Subroutines

;Calibration routine.
;
1:  Beginning of Subroutine (P85)
  1:  8         Subroutine 8

;Perform in-situ calibration.
;
2:  If time is (P92)
  1:  1         Minutes (Seconds --) into a
  2:  180       Interval (same units as above)
  3:  30        Then Do

3:  Z=X (P31)
  1:  2         X Loc [ shf_mV    ]
  2:  4         Z Loc [ mV_0      ]

;Begin heating for calibration.
;
4:  Do (P86)
  1:  48        Set Port 8 High

;Used to filter data during and after calibration.
;
5:  Do (P86)
  1:  18        Set Flag 8 High

6:  End (P95)

;End site calibration three minutes after calibration started.
;
7:  If time is (P92)
  1:  4         Minutes (Seconds --) into a
  2:  180       Interval (same units as above)
  3:  30        Then Do

;Measure voltage across current shunt resistor (10 ohm 1% 0.25 W 50
;ppm/deg C) during calibration.  This measurement is used to
;compute power.
;
8:  Volt (SE) (P1)
  1:  1         Reps
  2:  25        2500 mV 60 Hz Rejection Range
  3:  2         SE Channel
  4:  7         Loc [ V_Rf      ]
  5:  .001      Mult
  6:  0         Offset

9:  Z=X (P31)
  1:  2         X Loc [ shf_mV    ]
  2:  5         Z Loc [ mV_180    ]

;Turn off the soil heat flux plate heater.
;
10:  Do (P86)
  1:  58        Set Port 8 Low

11:  End (P95)
```

```
;Stop filtering data.
;
12:  If time is (P92)
  1:   39        Minutes (Seconds --) into a
  2:   180       Interval (same units as above)
  3:   30        Then Do

13:  Do (P86)
  1:   28        Set Flag 8 Low

;Compute in-situ calibration.
;
14:  Z=X (P31)
  1:   2         X Loc [ shf_mV    ]
  2:   6         Z Loc [ mV_end    ]

15:  Z=X*Y (P36)
  1:   7         X Loc [ V_Rf      ]
  2:   7         Y Loc [ V_Rf      ]
  3:   3         Z Loc [ cal       ]

16:  Z=X*F (P37)
  1:   3         X Loc [ cal       ]
  2:   128.7     F
   3:  3         Z Loc [ cal       ]

17:  Z=X+Y (P33)
  1:   4         X Loc [ mV_0      ]
  2:   6         Y Loc [ mV_end    ]
  3:   9         Z Loc [ work      ]

18:  Z=X*F (P37)
  1:   9         X Loc [ work      ]
  2:   .5        F
  3:   9         Z Loc [ work      ]

19:  Z=X-Y (P35)
  1:   9         X Loc [ work      ]
  2:   5         Y Loc [ mV_180    ]
  3:   9         Z Loc [ work      ]

20:  Z=ABS(X) (P43)
  1:   9         X Loc [ work      ]
  2:   9         Z Loc [ work      ]

21:  Z=X/Y (P38)
  1:   3         X Loc [ cal       ]
  2:   9         Y Loc [ work      ]
  3:   3         Z Loc [ cal       ]

22:  End (P95)

23:  End (P95)

End Program

-Input Locations-
1 shf
2 shf_mV
3 cal
4 mV_0
5 mV_180
6 mV_end
7 V_Rf
8 shf_mV_a
9 work
```

6.3.3 Example 3. Sample CR23X Program Using a Differential Measurement Instruction

TABLE 6-5 provides the wiring for Example 3.

TABLE 6-5. Wiring for Example 3

Description	Color	CR23X
Sensor Signal	White	9H
Sensor Signal Reference	Green	9L
Shield	Clear	⏚
Heater Resistor Signal	Yellow	10H
Heater Resistor Signal Reference	Purple	10L
Shield	Clear	⏚
Power	Red	SW12
Power Reference	Black	G

```
;{CR23X}
;
*Table 1 Program
  01:  1          Execution Interval (seconds)

;Measure HFP01SC on smaller range.
;
1:  Volt (Diff) (P2)
  1:   1          Reps
  2:   21         10 mV, 60 Hz Reject, Slow Range
  3:   9          DIFF Channel
  4:   2          Loc [ shf_mV    ]
  5:   1          Mult
  6:   0          Offset

;Measure HFP01SC on larger range.
;
2:  Volt (Diff) (P2)
  1:   1          Reps
  2:   25         5000 mV, 60 Hz Reject, Fast Range
  3:   9          DIFF Channel
  4:   8          Loc [ shf_mV_a  ]
  5:   1          Mult
  6:   0          Offset

;Load in the factory calibration.
;
3:  If (X<=>F) (P89)
  1:   3          X Loc [ cal       ]
  2:   1          =
  3:   0          F
  4:   30         Then Do
```

```
;Factory calibration in W/(m^2 mV) = 1000/sensitivity.
;
4:  Z=F (P30)
  1:  1          F                      ; <- Enter the unique calibration here
  2:  0          Exponent of 10
  3:  3          Z Loc [ cal       ]

5:  End (P95)

;Use data from the larger measurement range.
;
6:  If (X<=>F) (P89)
  1:  2          X Loc [ shf_mV    ]
  2:  4          <
  3:  -99990     F
  4:  30         Then Do

7:  Z=X (P31)
  1:  8          X Loc [ shf_mV_a  ]
  2:  2          Z Loc [ shf_mV    ]

8:  End (P95)

;Apply custom calibration to the raw soil heat flux measurement.
;
9:  Z=X*Y (P36)
  1:  2          X Loc [ shf_mV    ]
  2:  3          Y Loc [ cal       ]
  3:  1          Z Loc [ shf       ]

;Output data.
;
10:  If time is (P92)
  1:  0          Minutes (Seconds --) into a
  2:  20         Interval (same units as above)
  3:  10         Set Output Flag High (Flag 0)

11:  Real Time (P77)
  1:  0110       Day,Hour/Minute (midnight = 0000)

12:  Resolution (P78)
  1:  1          High Resolution

;Do not include that calibration data in the soil heat flux.
;
13:  If Flag/Port (P91)
  1:  118        Do if Flag 18 is High
  2:  19         Set Intermed. Proc. Disable Flag High (Flag 9)

14:  Average (P71)
  1:  1          Reps
  2:  1          Loc [ shf       ]

15:  Do (P86)
  1:  29         Set Intermed. Proc. Disable Flag Low (Flag 9)

16:  Sample (P70)
  1:  1          Reps
  2:  3          Loc [ cal       ]

;Add other processing here.

;Call calibration routine.
;
17:  Do (P86)
  1:  8          Call Subroutine 8
```

```
*Table 2 Program
  02: 0         Execution Interval (seconds)

*Table 3 Subroutines

;Calibration routine.
;
1:  Beginning of Subroutine (P85)
  1:  8         Subroutine 8

;Perform in-situ calibration.
;
2:  If time is (P92)
  1:  1         Minutes (Seconds --) into a
  2:  180       Interval (same units as above)
  3:  30        Then Do

3:  Z=X (P31)
  1:  2         X Loc [ shf_mV    ]
  2:  4         Z Loc [ mV_0      ]

;Begin heating for calibration.
;
4:  Do (P86)
  1:  49        Turn On Switched 12V

;Used to filter data during and after calibration.
;
5:  Do (P86)
  1:  118       Set Flag 18 High

6:  End (P95)

;End site calibration three minutes after calibration started.
;
7:  If time is (P92)
  1:  4         Minutes (Seconds --) into a
  2:  180       Interval (same units as above)
  3:  30        Then Do

;Measure voltage across current shunt resistor during calibration.
;This measurement is used to compute power.
;
8:  Volt (Diff) (P2)
  1:  1         Reps
  2:  25        5000 mV, 60 Hz Reject, Fast Range
  3:  10        DIFF Channel
  4:  7         Loc [ V_Rf      ]
  5:  .001      Mult
  6:  0         Offset

9:  Z=X (P31)
  1:  2         X Loc [ shf_mV    ]
  2:  5         Z Loc [ mV_180    ]

;Turn off the soil heat flux plate heater.
;
10:  Do (P86)
  1:  59        Turn Off Switched 12V

11:  End (P95)

;Stop filtering data.
;
12:  If time is (P92)
  1:  39        Minutes (Seconds --) into a
  2:  180       Interval (same units as above)
  3:  30        Then Do
```

```
13:  Do (P86)
  1:   218       Set Flag 18 Low

;Compute in-situ calibration.
;
14:  Z=X (P31)
  1:   2         X Loc [ shf_mV    ]
  2:   6         Z Loc [ mV_end    ]

15:  Z=X*Y (P36)
  1:   7         X Loc [ V_Rf      ]
  2:   7         Y Loc [ V_Rf      ]
  3:   3         Z Loc [ cal       ]

16:  Z=X*F (P37)
  1:   3         X Loc [ cal       ]
  2:   128.7     F
  3:   3         Z Loc [ cal       ]

17:  Z=X+Y (P33)
  1:   4         X Loc [ mV_0      ]
  2:   6         Y Loc [ mV_end    ]
  3:   9         Z Loc [ work      ]

18:  Z=X*F (P37)
  1:   9         X Loc [ work      ]
  2:   .5        F
  3:   9         Z Loc [ work      ]

19:  Z=X-Y (P35)
  1:   9         X Loc [ work      ]
  2:   5         Y Loc [ mV_180    ]
  3:   9         Z Loc [ work      ]

20:  Z=ABS(X) (P43)
  1:   9         X Loc [ work      ]
  2:   9         Z Loc [ work      ]

21:  Z=X/Y (P38)
  1:   3         X Loc [ cal       ]
  2:   9         Y Loc [ work      ]
  3:   3         Z Loc [ cal       ]

22:  End (P95)

23:  End (P95)

End Program

-Input Locations-
1 shf
2 shf_mV
3 cal
4 mV_0
5 mV_180
6 mV_end
7 V_Rf
8 shf_mV_a
9 work
```

6.3.4 Example 4. Sample CR10X Program Using External Power and Relay

TABLE 6-6 provides the sensor wiring for Example 4, and TABLE 6-7 provides the datalogger wiring for Example 4.

TABLE 6-6. Sensor Wiring for Example 4

Description	Color	CR10X	A21REL-12
Sensor Signal #1	White	1H	
Sensor Signal #2	White	1L	
Sensor Signal #3	White	2H	
Sensor Signal #4	White	2L	
Sensor Signal #5	White	3H	
Sensor Signal #6	White	3L	
All Signal References	Green	AG	
All Shields	Clear	G	
Heater Resistor Signal #1	Yellow	4H	
Heater Resistor Signal #2	Yellow	4L	
Heater Resistor Signal #3	Yellow	5H	
Heater Resistor Signal #4	Yellow	5L	
Heater Resistor Signal #5	Yellow	6H	
Heater Resistor Signal #6	Yellow	6L	
All Heater Resistor Signal References	Purple	AG	
All Shields	Clear	G	
Sensor Power #1	Red		REL 1 NO
Sensor Power #2	Red		REL 1 NO
Sensor Power #3	Red		REL 2 NO
Sensor Power #4	Red		REL 2 NO
Sensor Power #5	Red		REL 3 NO
Sensor Power #6	Red		REL 3 NO
All Power Reference	Black	G	

TABLE 6-7. Datalogger-to-A21REL-12 Wiring for Example 4

Description	CR10X	A21REL-12
Power	12V	+ 12V
Power Reference	G	GROUND
Control	C8	CTRL 1
Control		jumper from CTRL 2 to CTRL 1
Control		jumper from CTRL 3 to CTRL 2
Power		jumper from REL 1 COM to +12V
Power		jumper from REL 2 COM to REL 1 COM
Power		jumper for REL 3 COM to REL 2 COM

```
;{CR10X}
;

*Table 1 Program
  01:  1          Execution Interval (seconds)

;Measure HFP01SC on smallest range.
;
1:  Volt (SE) (P1)
  1:   6          Reps
  2:   22         7.5 mV 60 Hz Rejection Range
  3:   1          SE Channel
  4:   7          Loc [ shf_mV_1  ]
  5:   1          Mult
  6:   0          Offset

;Measure HFP01SC on larger range.
;
2:  Volt (SE) (P1)
  1:   6          Reps
  2:   23         25 mV 60 Hz Rejection Range
  3:   1          SE Channel
  4:   44         Loc [ shf_mV_1a ]
  5:   1          Mult
  6:   0          Offset

;Load in the factory calibration.
;
3:  If (X<=>F) (P89)
  1:   13         X Loc [ cal_1     ]
  2:   1          =
  3:   0          F
  4:   30         Then Do

;Factory calibration in W/(m^2 mV) = 1000/sensitivity.
;
4:  Z=F (P30)
  1:   1          F                ;<- Enter the unique calibration for plate 1 here.
  2:   0          Exponent of 10
  3:   13         Z Loc [ cal_1     ]

5:  Z=F (P30)
  1:   1          F                ;<- Enter the unique calibration for plate 2 here.
  2:   0          Exponent of 10
  3:   14         Z Loc [ cal_2     ]

6:  Z=F (P30)
  1:   1          F                ;<- Enter the unique calibration for plate 3 here.
  2:   0          Exponent of 10
  3:   15         Z Loc [ cal_3     ]

7:  Z=F (P30)
  1:   1          F                ;<- Enter the unique calibration for plate 4 here.
  2:   0          Exponent of 10
  3:   16         Z Loc [ cal_4     ]

8:  Z=F (P30)
  1:   1          F                ;<- Enter the unique calibration for plate 5 here.
  2:   0          Exponent of 10
  3:   17         Z Loc [ cal_5     ]

9:  Z=F (P30)
  1:   1          F                ;<- Enter the unique calibration for plate 6 here.
  2:   0          Exponent of 10
  3:   18         Z Loc [ cal_6     ]

10:  End (P95)
```

```
11:  Beginning of Loop (P87)
  1:  0         Delay
  2:  6         Loop Count

;Use data from the larger measurement range.
;
12:  If (X<=>F) (P89)
  1:  7 --      X Loc [ shf_mV_1  ]
  2:  4         <
  3:  -99990    F
  4:  30        Then Do

13:  Z=X (P31)
  1:  44 --     X Loc [ shf_mV_1a ]
  2:  7 --      Z Loc [ shf_mV_1  ]

14:  End (P95)

;Apply custom calibration to raw soil heat flux measurement.
;
15:  Z=X*Y (P36)
  1:  7 --      X Loc [ shf_mV_1  ]
  2:  13 --     Y Loc [ cal_1     ]
  3:  1 --      Z Loc [ shf_1     ]

16:  End (P95)

;Output data.
;
17:  If time is (P92)
  1:  0         Minutes (Seconds --) into a
  2:  20        Interval (same units as above)
  3:  10        Set Output Flag High (Flag 0)

18:  Real Time (P77)^25251
  1:  0110      Day,Hour/Minute (midnight = 0000)

19:  Resolution (P78)
  1:  1         High Resolution

;Do not include that calibration data in the soil heat flux.
;
20:  If Flag/Port (P91)
  1:  18        Do if Flag 8 is High
  2:  19        Set Intermed. Proc. Disable Flag High (Flag 9)

21:  Average (P71)^21989
  1:  6         Reps
  2:  1         Loc [ shf_1     ]

22:  Do (P86)
  1:  29        Set Intermed. Proc. Disable Flag Low (Flag 9)

23:  Sample (P70)^21779
  1:  6         Reps
  2:  13        Loc [ cal_1     ]

;Add other processing here.

;Call calibration routine.
;
24:  Do (P86)
  1:  8         Call Subroutine 8

*Table 2 Program
  02:  0        Execution Interval (seconds)
```

```
*Table 3 Subroutines

;Calibration routine.
;
1:  Beginning of Subroutine (P85)
  1:   8          Subroutine 8

;Perform in-situ calibration.
;
2:  If time is (P92)
  1:   1          Minutes (Seconds --) into a
  2:   180        Interval (same units as above)
  3:   30         Then Do

3:  Beginning of Loop (P87)
  1:   0          Delay
  2:   6          Loop Count

4:  Z=X (P31)
  1:   7 --       X Loc [ shf_mV_1  ]
  2:   19 --      Z Loc [ mV_0_1    ]

5:  End (P95)

;Begin heating for calibration.
;
6:  Do (P86)
  1:   48         Set Port 8 High

;Used to filter data during and after calibration.
;
7:  Do (P86)
  1:   18         Set Flag 8 High

8:  End (P95)

;End site calibration three minutes after calibration started.
;
9:  If time is (P92)
  1:   4          Minutes (Seconds --) into a
  2:   180        Interval (same units as above)
  3:   30         Then Do

;Measure voltage across current shunt resistor during calibration.
;This measurement is used to compute power.
;
10:  Volt (SE) (P1)
  1:   6          Reps
  2:   25         2500 mV 60 Hz Rejection Range
  3:              SE Channel
  4:   37         Loc [ V_Rf_1    ]
  5:   .001       Mult
  6:   0          Offset

11:  Beginning of Loop (P87)
  1:   0          Delay
  2:   6          Loop Count

12:  Z=X (P31)
  1:   7 --       X Loc [ shf_mV_1  ]
  2:   25 --      Z Loc [ mV_180_1  ]

13:  End (P95)

;Turn off the soil heat flux plate heaters.
;
14:  Do (P86)
  1:   58         Set Port 8 Low
```

```
15:  End (P95)

;Compute in-situ calibration.
;
16:  If time is (P92)
  1:  39        Minutes (Seconds --) into a
  2:  180       Interval (same units as above)
  3:  30        Then Do

17:  Do (P86)
  1:  28        Set Flag 8 Low

18:  Beginning of Loop (P87)
  1:  0         Delay
  2:  6         Loop Count

19:  Z=X (P31)
  1:  7 --      X Loc [ shf_mV_1  ]
  2:  31 --     Z Loc [ mV_end_1  ]

20:  Z=X*Y (P36)
  1:  37 --     X Loc [ V_Rf_1    ]
  2:  37 --     Y Loc [ V_Rf_1    ]
  3:  13 --     Z Loc [ cal_1     ]

21:  Z=X*F (P37)
  1:  13 --     X Loc [ cal_1     ]
  2:  128.7     F
  3:  13 --     Z Loc [ cal_1     ]

22:  Z=X+Y (P33)
  1:  19 --     X Loc [ mV_0_1    ]
  2:  31 --     Y Loc [ mV_end_1  ]
  3:  43        Z Loc [ work      ]

23:  Z=X*F (P37)
  1:  43        X Loc [ work      ]
  2:  .5        F
  3:  43        Z Loc [ work      ]

24:  Z=X-Y (P35)
  1:  43        X Loc [ work      ]
  2:  25 --     Y Loc [ mV_180_1  ]
  3:  43        Z Loc [ work      ]

25:  Z=ABS(X) (P43)
  1:  43        X Loc [ work      ]
  2:  43        Z Loc [ work      ]

26:  Z=X/Y (P38)
  1:  13 --     X Loc [ cal_1     ]
  2:  43        Y Loc [ work      ]
  3:  13 --     Z Loc [ cal_1     ]

27:  End (P95)

28:  End (P95)

29:  End (P95)

End Program

-Input Locations-
1 shf_1     1 1 1
2 shf_2     0 0 0
3 shf_3     0 0 0
4 shf_4     0 0 0
```

```
5 shf_5     0 0 0
6 shf_6     0 0 0
7 shf_mV_1  1 5 2
8 shf_mV_2  1 0 1
9 shf_mV_3  1 0 1
10 shf_mV_4  1 0 1
11 shf_mV_5  1 0 1
12 shf_mV_6  1 0 1
13 cal_1     5 5 3
14 cal_2     9 0 1
15 cal_3     9 0 1
16 cal_4     9 0 1
17 cal_5     9 0 1
18 cal_6     9 0 1
19 mV_0_1    9 1 1
20 mV_0_2    1 0 0
21 mV_0_3    0 0 0
22 mV_0_4    0 0 0
23 mV_0_5    0 0 0
24 mV_0_6    0 0 0
25 mV_180_1  1 1 1
26 mV_180_2  0 0 0
27 mV_180_3  0 0 0
28 mV_180_4  0 0 0
29 mV_180_5  0 0 0
30 mV_180_6  0 0 0
31 mV_end_1  1 1 1
32 mV_end_2  0 0 0
33 mV_end_3  0 0 0
34 mV_end_4  0 0 0
35 mV_end_5  0 0 0
36 mV_end_6  0 0 0
37 V_Rf_1    5 2 1
38 V_Rf_2    9 0 1
39 V_Rf_3    9 0 1
40 V_Rf_4    9 0 1
41 V_Rf_5    9 0 1
42 V_Rf_6    17 0 1
43 work      1 4 4
44 shf_mV_1a 5 1 1
45 shf_mV_2a 9 0 1
46 shf_mV_3a 9 0 1
47 shf_mV_4a 9 0 1
48 shf_mV_5a 9 0 1
49 shf_mV_6a 17 0 1
```

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 is given by Equation 1 and Equation 2:

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

$$\theta_m = \frac{\rho_w}{\rho_b}\theta_v \tag{2}$$

where C_S is the heat capacity of moist soil, ρ_b is the bulk density, ρ_w is the density of water, C_d is the heat capacity of a dry mineral soil, θ_m is the soil water content on a mass basis, θ_v is the 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 Equation 3 and the soil heat flux at the surface is given by Equation 4.

$$S = \frac{\Delta T_s C_s d}{t} \tag{3}$$

$$G_{sfc} = G_{8cm} + S \tag{4}$$

where S is the storage term, G_{8cm} is the soil heat flux at 8 cm, and G_{sfc} is the soil heat flux at the surface.

6.5 In-Situ Calibration Theory

For detailed information on the theory of the in-situ calibration, see the Theory section of the Hukseflux manual or visit the application section of the Hukseflux web site at *www.hukseflux.com/downloads/thermalScience/applicAndSpec.pdf*.

Equation 6 in the Hukseflux manual is used to compute a new calibration every three hours. The heater is on for a total of 180 seconds. TABLE 6-8 lists the variables used in the Hukseflux manual and those in the example datalogger programs.

TABLE 6-8. Hukseflux and Campbell Scientific Variable Names

Description	Hukseflux	Campbell Scientific
Soil Heat Flux	φ	shf
Output of Sensor in mV	V_{sen}	shf_mV
1/Sensitivity	$1/E_{sen2}$	cal
Output of Sensor during calibration at t=0 seconds	V (0)	mV_0
Output of Sensor during calibration at t=180 seconds	V (180)	mV_180
Output of Sensor after calibration and just before output	V (360)	mV_end
Voltage Across fixed 10 Ω resistor	V_{cur}	V_Rf

7. Maintenance

The HFP01SC requires minimal maintenance. Check the sensor leads monthly for rodent damage.

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.

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