USER MANUAL **STP01**

Soil temperature profile sensor with self-test

Warning statements

⚠ Putting more than 2 Volt across the sensor wiring can lead to permanent damage to the sensor.

⚠ Putting more than 15 Volt across the heater wiring can lead to permanent damage to the heater.

⚠ Do not use “open circuit detection” when measuring the thermocouple sensor output.

Contents

List of symbols

Quantities	Symbol	Unit
Temperature	T	°C
Temperature difference	ΔT	°C, K
Thermal conductivity	λ	W/(m·K)
Voltage output	U	V
Voltage output as a function of heating time	U (t)	V
Voltage output difference	ΔU	V
Sensitivity	S	V/K
Heating power per meter	Q	W/m
Heater length	L	m
Time constant	τ	s
Time	t	s
Resistance	R	Ω
Depth of installation	x	m
Distance from the heater	r	m

Subscripts

property of a sensor	sensor
property of the reference temperature Pt100	reference
property at the (soil) surface	surface
property of the surrounding soil	soil
property of the heater	heater

Introduction

STP01 accurately measures the temperature profile of the soil at 5 depths close to its surface. It is used for scientific grade surface energy balance measurements. The sensor is buried and usually cannot be taken to the laboratory for calibration. The on-line self-test using the incorporated heating wire offers a solution to verify STP01's measurement stability.

STP01 soil temperature profile sensor offers an accurate temperature difference measurement at five measurement locations at 0.02, 0.05, 0.1, 0.2 and 0.5 m below the soil surface. It also has a well specified and fixed distance between the measurement locations.

STP01 contains 5 matched thermocouples, at locations A to E, and one reference temperature sensor (Pt100 type) at location E at 0.5 m depth (see figure 0.2). By having the reference temperature measurement in the sensor and only measuring differential thermocouple voltages (relative to the reference at 0.5 m), the uncertainty of the temperature difference measurement is very low: ± 0.02 °C is attainable. Simple copper-conductor signal wire is used in STP01's cable. As an extra, a heating wire is incorporated in STP01. Analysis of the temperature change during the heating interval serves as a self-test.

Soil temperature sensors are preferably left in the soil for as long as possible, so that the soil properties become representative of natural conditions. Using self-testing, the user no longer needs to take sensors to the laboratory to verify their stable performance.
The result is a much improved accuracy & quality assurance of the measurement relative to measurements with conventional sensor types.

Typically every 24 hours, the STP01 heater is switched on to perform a self-test.
When activating the heater for a self-test, this will lead to a local increase in temperature at the sensors at 0.02, 0.05, 0.1 and 0.2 m depth. The STP01 stability is monitored by analysis of yearly patterns of this step-response.

The step response of the temperature during the self-test can be used to measure the soil thermal conductivity at 3 depths; 0.05, 0.1 and 0.2 m. For more background on this measurement method, see the manual of model TP02 thermal needle. The possibility to perform this measurement is an experimental option, with an unspecified measurement accuracy.

STP01 is used for high accuracy, scientific grade measurement of the soil energy balance, with a high level of data quality assurance. Measurements with STP01 are often combined with soil thermal conductivity and volumic heat capacity measurements with sensor model TP01 and measurements with heat flux sensor model HFP01SC.

STP01 advantages are:

- high accuracy, scientific measurement of soil energy balance, with a high level of data quality assurance
- high accuracy K/m temperature gradient measurement by accurate positioning of the thermocouple joints (± 0.001 m), and accurate temperature difference measurement (± 0.02 K)
- high accuracy and stability of the relative distance between sensors (± 0.0005 m)
- thin, 0.6 x 10^{-3} m thickness, construction which leaves the soil structure intact
- simple copper-core signal wire; no special connectors needed
- self-test saves servicing time

Sensors made by Hukseflux are designed for compatibility with the most commonly used datalogger models. For many models we have example programs and wiring diagrams available.

Requirements for data acquisition and control are:

- for temperature measurement: four millivolt measurements, one Pt100 measurement
- for the optional self-test: one heater voltage measurement
- for the optional self-test: one relay with 12 VDC nominal output, switching the heater on and off

Equipped with heavy duty cabling, and potted so that moisture does not penetrate the sensor, STP01 has proven to be very robust and stable. It survives long-term installation in soils. For ease of installation with a minimum of disturbance of the local soil, Hukseflux offers IT01 insertion tool.

Figure 0.1 *STP01. Standard cable length is 5 m.*

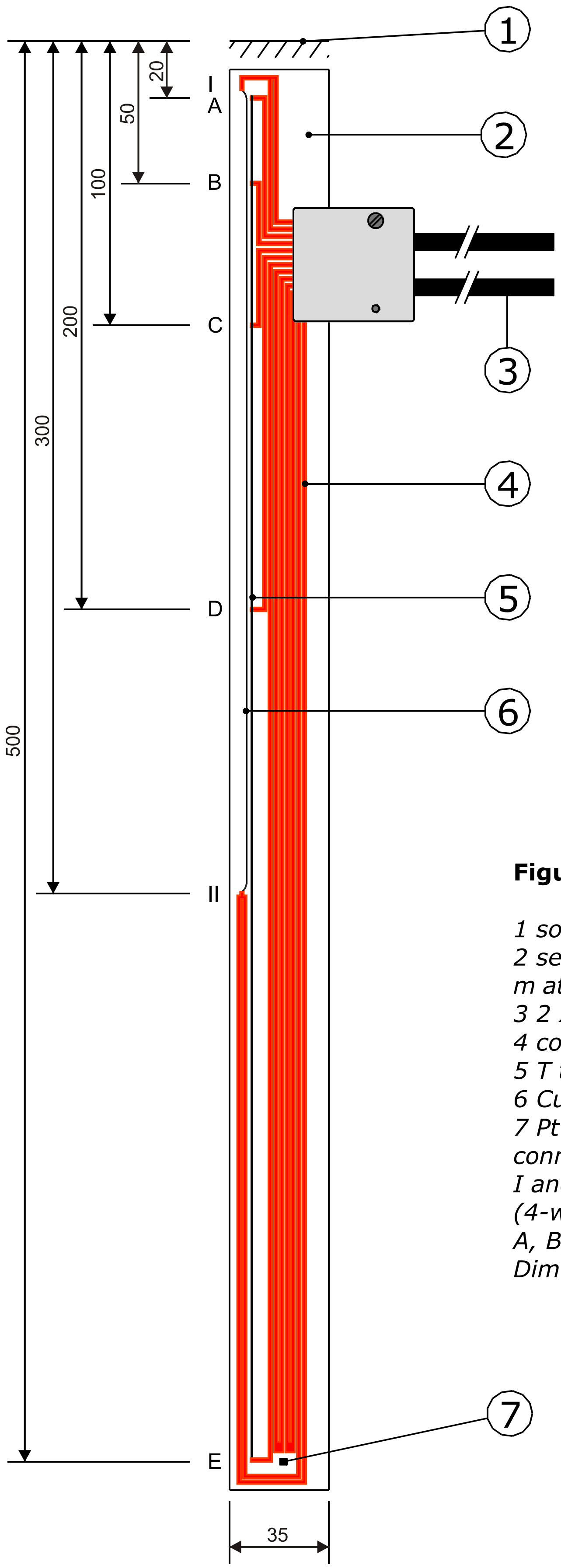

Figure 0.2 *STP01 layout and dimensions*

1 soil surface
2 sensor foil (0.6 x 10^{-3} m thickness, 2.5 x 10^{-3} m at Pt 100)
3 2 x cable 5 m (see options)
4 copper leads
5 T type thermocouple wire
6 CuNi heater wire
7 Pt100 reference temperature sensor (4-wire connection)
I and II: connection points of the heating wire (4-wire connection)
A, B, C, D and E: thermocouple type T joints
Dimensions in x 10^{-3} m

Options are:

- longer cable (2 x), in multiples of 5 m, cable lengths above 20 m in multiples of 10 m
- insertion tool IT01

Figure 0.3 *IT01 insertion tool is hammered down into the soil. After retracting it leaves a slit in which STP01 may be inserted.*

See also:

- model TP01 soil thermal properties sensor
- soil heat flux sensors HFP01 and HFP01SC
- view our complete product range of surface energy flux measurement products
  view our range of pyranometers and net-radiometers

1 Ordering and checking at delivery

1.1 Ordering STP01

The standard configuration of STP01 is with 2 x 5 metres cable.

Common options are:

- longer cable in multiples of 5 m, cable lengths above 20 m in multiples of 10 m. specify total cable length.
- insertion tool IT01

1.2 Included items

Arriving at the customer, the delivery should include:

- thermal properties sensor STP01
- cable of the length as ordered
- product certificate matching the instrument serial number

1.3 Quick instrument check

A quick test of the instrument can be done by connecting it to a multimeter.

1. Check the electrical resistance of the sensor and heater according to the tables in paragraph 5.3. Use a multimeter at the 50 and 500 Ω range. The typical resistance of the wiring is 0.4 Ω/m (added value of 2 wires). Infinite resistance indicates a broken circuit; zero or a lower than 1 Ω resistance indicates a short circuit.
2. Check if the thermocouple sensors react to heat: put the multimeter at its most sensitive range of DC voltage measurement, typically the 100 x 10^{-3} VDC range or lower. Measure between the thermocouple common and the other thermocouple joints. Look at the reaction when you heat one of the joints.
3. Inspect the sensor foil for any damage.
4. Check the sensor serial number on the cable labels (one at sensor end, one at cable end of both cables) against the product certificate provided with the sensor.

2 Instrument principle and theory

STP01 accurately measures the temperature profile of the soil at 5 depths close to its surface. A requirement for an accurate measurement is good thermal contact between soil and sensor. The sensor is buried and usually cannot be taken to the laboratory for calibration. The on-line self-test using the incorporated heating wire offers a solution to verify STP01's measurement stability. The user must incorporate STP01 in his own measurement and control system. For soil temperature measurement this system should perform 4 x voltage, and 1 x Pt100 readout. For the self-test you need power supply switching, and 1 x voltage readout.

Relevant features of TP01 are:

- robustness, including a strong cable (essential for permanently installed sensors)
- IP protection class: IP67 (essential for outdoor application)
- low electrical resistance (low pickup of electrical noise)

2.1 General soil temperature measurement

Usually temperature gradients in the soil are made using separate sensors.
Shortcomings of this method are:

- temperature gradients are calculated by taking the difference between inaccurate measurements. The end result will have a large uncertainty
- the relative position is not accurately determined
- the sensor construction is often heavy, and conducting a significant amount of heat

Soil temperature and soil thermal properties vary slowly. Usually the data sampling is done with a 60 s interval and 10 minute averages are stored. You may choose to vary the data storage interval with depth.

2.2 STP01 soil temperature measurement

STP01 overcomes the traditional shortcomings:

- STP01 uses a string of thermocouples type T sharing one and the same CuNi wire and the same Cu wire (made from the same sheet). We claim that the thermocouples are "matched", i.e. have the same properties. The relative accuracy of such matched thermocouples is better than 0.05 °C.
- Determined by the manufacturing process, the relative position of the thermocouple joints is accurate within ± 0.001 m.
- The construction of STP01 consists of plastic foil and relatively thin conductors.

A thermocouple type T has an analogue voltage output and a sensitivity of around 40 x 10^{-6} V/K temperature difference between its two joints. The sensitivity is not a constant but is a function of T and ΔT.

$$U = S(T, \Delta T) \cdot \Delta T \qquad \text{(Formula 2.2.1)}$$

In order to measure absolute temperatures at the joints at depth x, the temperature at one reference joint must be measured. The Pt100 located at 0.5 m depth serves as "reference temperature". The thermocouple joint at 0.5 m serves as "reference junction".

A Pt100 is a standardised type temperature sensitive resistor. It is made of platinum (the element Pt) and has an electrical resistance of 100 Ω at 0 °C.

$$T(x) = T_{reference} + U / S(T, \Delta T) \qquad \text{(Formula 2.2.2)}$$

In commonly used dataloggers it is possible to define the reference temperature $T_{reference}$ and the thermocouple type. The datalogger internally calculates absolute temperatures T (x) using an internal lookup instruction.

2.3 STP01 on-line self-test

The purpose of the self-test is to judge if

- the temperature sensors still work, and if so
- if they are in good contact with the soil

Typically every 24 hours, the STP01 heater is switched on for 600 s to perform a self-test. When activating the heater for a self-test, this will lead to a local increase in temperature at the sensors at 0.02, 0.05, 0.1 and 0.2 m depth. The STP01 stability is monitored by analysis of yearly patterns of this step-response for every depth, corrected for the heater power. The heater power is, assuming that the resistance is constant, expressed as U_{heater}^2.

$$U = S \cdot T / U_{heater}^2 \qquad \text{(Formula 2.3.1)}$$

During the self-test, we recommend storing the measured data using a 1 [s] data storage interval. The time response for one sensor will vary with the soil thermal conductivity and with the contact between the sensor and the soil. You may look for yearly patterns.

2.4 Optional thermal conductivity measurement

The step response of the temperature during the self-test can be used to measure the soil thermal conductivity at 3 depths; 0.05, 0.1 and 0.2 m. For more background on this measurement method, see the manual of model TP02 thermal needle. The possibility to perform this measurement is an experimental option, with an unspecified measurement

accuracy. The measurement method is based on the thermal needle method. This requires both a heating wire and a temperature sensor close to the wire. From the response to a heating step the thermal conductivity of the soil can be calculated.
The method relies on a unique property of a line source: after a short transient period the temperature rise, ΔT, only depends on heater power, Q, and medium thermal conductivity, λ:

$$\Delta T = (Q / 4 \pi \lambda) (\ln t + B) \quad \text{(Formula 2.4.1)}$$

With ΔT in K, Q in W/m, λ in W/(m·K), t the time in s and B a constant. By measuring the heater power, and tracing the temperature in time λ is calculated.

The thermal conductivity can be calculated from two measurements at t_1 and t_2. For STP01 both t_1 and t_2 are higher than 200 s, and typically 200 s apart. ΔT is the temperature difference between the measurements at time t_1 and t_2, taking t = 0 at the moment that the heating starts.

$$\lambda = (Q / 4 \pi \Delta T) \ln(t_2 / t_1) \quad \text{(Formula 2.4.2)}$$

2.5 Conformity testing and traceability

During manufacturing STP01 has to pass an acceptance test. In the test we verify if the properties of the thermocouples, Pt100 and heating wire are within specifications. If the specified sensors are manufactured as required, we consider them traceable to SI. We rely on their material specifications which we verify by electrical resistance measurement.

During use, STP01 is buried and usually cannot be taken to the laboratory for calibration. The on-line self-test using the incorporated heating wire offers a solution to verify STP01's measurement stability.

2.6 Programming

In case the user writes his own software program for controlling the measurement with STP01, the program flow in table 2.6.1 may be used.

Table 2.6.1 *a summary of a program for control of the measurement with STP01*

initialisation	enter sensor and system information	serial number, upper and lower acceptance limits for T, U, thermocouple type T, R_{heater}	
every 1 s	measure	measure $T_{reference}$ and T (x) for 4 depths	
every 600 s	store	store average values	
	quality checks	acceptance intervals T (x)	
every 24 hr	perform self-test	measure U, U_{heat}, t	
		600 s heating interval	heater on
			measure U
			measure U_{heater}
		at 600 s	heater off
			store data
	quality checks	acceptance interval	
		acceptance interval U_{heater}	
		acceptance interval U(0) – U(600)	
	optional	calculate λ at 3 depths	

3 Specifications of STP01

STP01 measures the temperature profile of the soil at 5 depths close to its surface. It is designed for long-term monitoring of soils. Good thermal contact between soil and sensor is required. The on-line self-test, using the incorporated heating wire, offers a solution for on-site verification of STP01's functionality and measurement stability. STP01 can only be used in combination with a suitable measurement and control system. The possibility to perform a thermal conductivity measurement at 3 depths is an option with an unspecified measurement accuracy.

Table 3.1 *Specifications of STP01 (continued on next page)*

STP01 SPECIFICATIONS	
Sensor type	soil temperature profile sensor with self-test
Measurand	temperature at 5 depths from 0 to 0.5 m
Rated operating environment	surrounded by soil
Measurand in SI units	temperature in °C
Temperature sensors	matched thermocouples type T
Reference temperature sensor	Pt100, IEC 751:1983 class B
Measurement depths	0.02, 0.05, 0.1, 0.2 and 0.5 m
On-line functionality testing	self-test using the incorporated heater
Measurement range	-30 to +70 ˚C
Measurand	temperature difference between reference temperature at 0.5 m and the other measurement depths
Measurand in SI units	temperature difference in °C
Measurand	temperature gradient
Measurand in SI units	temperature gradient in K/m
Optional non-traceable measurand	thermal conductivity at 3 depths
Measurand in SI units	thermal conductivity in W/(m·K)
Thermocouple type T sensitivity	40×10^{-6} V/K (nominal)
Measurement function / required programming	thermocouple type T, using a Pt100 as a reference temperature measurement
Measurement function / required programming	for the self-test: see the paragraph on this subject
Optional measurement function/ optional programming	for thermal conductivity measurement: see the paragraph on this subject
Required readout and control	1 x Pt100 4 x thermocouple type T voltage using the junction at 0.5 m depth as a reference, input resistance > 10^6 Ω
Expected voltage output	-2 to 2×10^{-3} V (thermocouples) 0 to 15 VDC (heater)
Required uncertainty	10×10^{-6} V at 2×10^{-3} V 0.01 V at 12 V
Optional readout and control	only if the self-test is used heater: 1 x voltage channel which acts as a current measurement channel using a current sensing resistor heater: 1 x switchable 12 VDC, 0.06 A
Rated operating temperature range	-30 to +70 ˚C

Table 3.1 *Specifications of STP01 (started on previous page, continued on next page)*

Sensor foil surface dimensions	(500 x 35) x 10^{-3} m
Sensor foil thickness	0.6 x 10^{-3} m 2.5 x 10^{-3} m at Pt100
Connector block dimensions	(40 x 42 x 10) x 10^{-3} m
Thermocouple sensor resistance range	5 Ω (nominal) + 0.4 Ω/m cable
Standard governing use of the instrument	not applicable
Standard cable length (2 cables)	5 m (see options)
Wiring	0.15 m wires and shield at cable ends
Cable diameter	2 x 5.5 x 10^{-3} m
Cable markers	4 x sticker, 1 x at sensor and 1 x cable end, wrapped around the sensor cables. Both stickers show serial number and cable 1 / cable 2
IP protection class	IP67
Rated operating relative humidity range	0 to 100 %
Gross weight including 5 m cable	0.7 kg
Net weight including 5 m cable	0.6 kg
Packaging	box of 300 x 210 x 80 mm
HEATER	
Heater resistance (nominal)	200 Ω
Heater length	0.28 m
Heater rated power supply	9 to 15 VDC
Heater power supply	12 VDC (nominal)
Power consumption during heating interval	0.72 W (heater powered from 12 VDC)
SELF-TEST	
Power consumption daily average	0.005 W (heater powered from 12 VDC, 24 hr interval between tests)
Interval between self-tests	24 hr
Self-test duration	600 s
INSTALLATION AND USE	
Recommended number of sensors	2 per measurement site
Orientation	recommended orientation is with foil surface vertically oriented (usually this is perpendicular to the soil surface).
Installation	see recommendations in the product manual
Cable extension	cable extension of STP01 is discouraged: see chapter on cable extension

Table 3.1 *Specifications of STP01 (started on previous pages)*

CONFORMITY TESTING AND TRACEABILITY	
Factory conformity testing	the STP01 functional test compares the electrical resistance of the produced sensor against the acceptance interval. This is done for the thermocouples, Pt100 and heater.
Functional test	STP01 functional test
Calibration traceability	to SI units
Calibration method	by referral to inherent calibration references: type T thermocouple and Pt 100
Production certificate	included (confirming result of the functional test)
MEASUREMENT ACCURACY	
Uncertainty of the measurement	statements about the overall measurement uncertainty can only be made on an individual basis. see the chapter on uncertainty evaluation.
Uncertainty of temperature difference measurement	1.5 % of measured value plus measurement system uncertainty in x 10^{-6} V/40
Uncertainty of reference temperature measurement	± 0.7 °C plus measurement system uncertainty
Uncertainty of relative position	± 0.001 m
Uncertainty of optional thermal conductivity measurement	not specified
VERSIONS / OPTIONS	
Order code	STP01/cable length in m
Longer cable (2x)	in multiples of 5 m, cable lengths above 20 m in multiples of 10 m option code = total cable length
ACCESSORIES	
Insertion tool	IT01 insertion tool

3.1 Dimensions of STP01

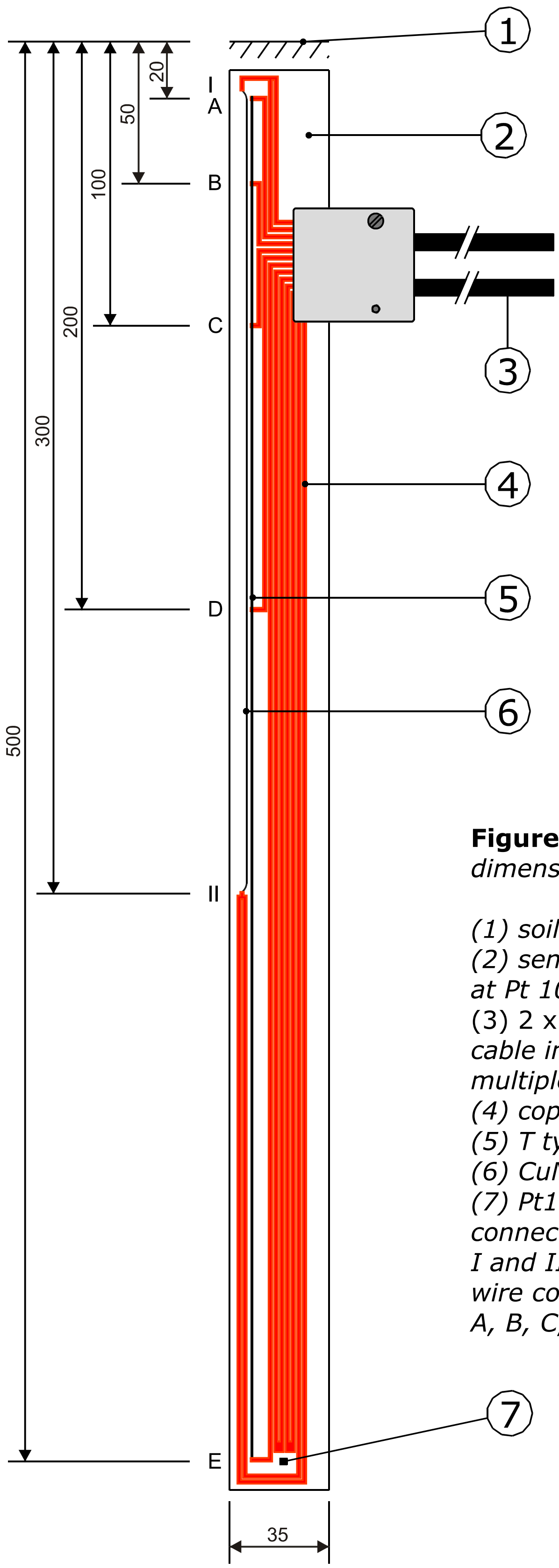

Figure 3.1.1 *STP01 soil temperature profile dimensions in x 10^{-3} m*

(1) soil surface
(2) sensor foil (0.6 x 10^{-3} m thickness, 2.5 x 10^{-3} m at Pt 100)
(3) 2 x cable *(standard length 5 m, optionally longer cable in multiples of 5 m, cable above 20 m in multiples of 10 m)*
(4) copper leads
(5) T type thermocouple wire
(6) CuNi heater wire
(7) Pt100 reference temperature sensor (4-wire connection)
I and II: connection points of the heating wire (4-wire connection)
A, B, C, D and E: thermocouple type T joints

4 Standards and recommended practices for use

STP01 sensors measure temperature as a function of depth in soils, as part of meteorological surface flux measuring systems. Typically the total measuring system consists of multiple heat flux- and temperature sensors, often combined with measurements of air temperature, humidity, solar- or net radiation and wind speed.

There are no standardised operating practices for use of STP01 sensors. The next chapters contain recommendations of the sensor manufacturer.

Usually this measurement is combined with measurements of the soil heat flux, soil thermal conductivity and soil heat capacity to estimate the heat flux at the soil surface. Knowing the heat flux at the soil surface, it is possible to "close the balance" and estimate the uncertainty of the measurement of the other (convective and evaporative) fluxes.

Figure 4.1 *typical meteorological surface energy balance measurement system with STP01 installed in the soil*

5 Installation of STP01

5.1 Site selection and installation

Table 5.1.1 *Recommendations for installation of STP01*

Location	Preferably install in a large field which is relatively homogeneous and representative of the area under observation.
Depth	The top of the sensor should be 0.01 m below the soil surface
Orientation	Recommended orientation is with foil surface vertical, (in most cases that is perpendicular to the soil surface)
Performing a representative measurement	At every measurement site we recommend using > 2 sensors at a distance of > 5 m. This redundancy improves the assessment of the measurement accuracy.
Installation	There should be no air gaps between sensor and soil. Use the insertion tool IT01 or a spade (with a flat blade) to make a vertical cut in the soil. Make sure the soil around the sensor foil remains intact. Make sure the sensor and connection block will fit into the cut. Insert the sensor foil into the cut. Never run the sensor cable directly to the surface. Bury the sensor cable horizontally over a distance of at least 1 m, to minimise thermal conduction through the lead wire. Put the excavated soil back into its original position after the sensor and cable are installed.
Fixation / strain relief	For mechanical stability and in order to avoid exerting too much force on the sensor foil, provide sensor cables with additional strain relief, for example connecting the cable with a tie wrap to one or more metal pins that are inserted firmly into the soil.
Armoured cable	In some cases cables are equipped with additional armour to avoid damage by rodents. Make sure the armour does not act as a conductor of heat or a transport conduit or container of water.
Added heat flux sensors	Heat flux sensors are typically located closely to the sensor.

5.2 Electrical connection

An STP01 must be connected to a measurement and control system, typically a so-called datalogger. STP01's thermocouple sensors are passive sensors that do not need any power. The Pt100 needs a low-power voltage excitation. The heater is powered from 9 to 15 VDC, using a user-supplied relay to switch it on and off.

The 4-wire connections to the heater and Pt100 make it possible to perform a heater and Pt100 voltage measurement that do not depend on the cable length. In a 4-wire resistance measurement, two wires carry the heater current, the others are used for the measurement. No current flows through the latter wires, so that there is no voltage drop across them, and the true voltage across the resistance is measured.

The thermocouple measurements are independent of cable length. However thermal voltage offsets may be generated at the points where cables are soldered or connected, if this is combined with temperature differences between the joints. This is a potential danger for the accuracy of the temperature (difference) measurement.

⚠ Putting more than 2 Volt across the sensor wiring can lead to permanent damage to the sensor.

⚠ Putting more than 15 Volt across the heater wiring can lead to permanent damage to the heater.

Cables may act as a source of distortion, by picking up capacitive noise. We recommend keeping the distance between a datalogger or amplifier and the sensor as short as possible. For cable extension, see the appendix on this subject.

The thermocouple sensor outputs are connected to a differential or single-ended voltage input.

Table 5.2.1 *connections of the STP01 cable 1. The cable internally also has pink, yellow and grey wires, which are not used and not visible when supplied from the factory. The wires extend 0.15 m from the cable end.*

CABLE #	WIRE	FUNCTION	MEASURING SYSTEM
1	Brown	thermocouple 0.5 m (common)	analogue voltage [-] or ground
1	Green	thermocouple 0.2 m	analogue voltage [+]
1	Red	thermocouple 0.1 m	analogue voltage [+]
1	White	thermocouple 0.05 m	analogue voltage [+]
1	Blue	thermocouple 0.02 m	analogue voltage [+]
1	Yellow	not connected	not connected
1	Pink	not connected	not connected
1	Grey	not connected	not connected
1	Black	ground	shield / ground

Table 5.2.2 *connections of the STP01 cable 2. The wires extend 0.15 m from the cable end.*

CABLE #	WIRE	FUNCTION	MEASURING SYSTEM
2	Yellow	heater measure [+]	analogue voltage [+]
2	Pink	heater power [+]	12 VDC
2	Brown	Pt100 [+]	analogue voltage [+]
2	Blue	Pt100 [+]	excitation [+]
2	Red	Pt100 [-]	analogue voltage [-] or ground
2	Green	Pt100 [-]	excitation ground
2	White	heater measure [-]	analogue voltage [-] or ground
2	Grey	heater power [-]	switched relay to ground
2	Black	ground	shield / ground

5.3 STP01 diagnostics

The following tables are use for checking and trouble shooting STP01.

Table 5.3.1 *Resistance checks for diagnostics of STP01 cable 1*

CABLE #	WIRE	WIRE	RESISTANCE ACCEPTANCE INTERVAL
1	Brown	Green	2.5 Ω plus 0.4 Ω/m cable (approx.)
1	Brown	Red	3.5 Ω plus 0.4 Ω/m cable (approx.)
1	Brown	White	3.9 Ω plus 0.4 Ω/m cable (approx.)
1	Brown	Blue	4.1 Ω plus 0.4 Ω/m cable (approx.)

Table 5.3.2 *Resistance checks for diagnostics of STP01 cable 2*

CABLE #	WIRE	WIRE	RESISTANCE ACCEPTANCE INTERVAL
2	Grey	Pink	190 Ω plus 0.4 Ω/m cable (approx.)
2	White	Yellow	190 Ω plus 0.4 Ω/m cable (approx.)
2	Grey	White	0 Ω plus 0.4 Ω/m cable (approx.)
2	Pink	Yellow	0 Ω plus 0.4 Ω/m cable (approx.)
2	Green	Red	0 Ω plus 0.4 Ω/m cable (approx.)
2	Blue	Brown	0 Ω plus 0.4 Ω/m cable (approx.)
2	Green	Blue	110 Ω plus 0.4 Ω/m cable (approx.)
2	Red	Brown	110 Ω plus 0.4 Ω/m cable (approx.)

5.4 Requirements for data acquisition / amplification

The selection and programming of dataloggers is the responsibility of the user. To see if directions for use with STP01 are available: contact the supplier of the data acquisition equipment.

Table 5.4.1 *Requirements for data acquisition, amplification and control equipment for STP01 in the standard configuration*

Capability to measure small voltage signals	4 x differential voltage preferably: 10 x 10^{-6} V uncertainty minimum requirement: 20 x 10^{-6} V uncertainty (valid for the entire expected temperature range of the acquisition / amplification equipment) Input resistance > 10^{6} Ω
Capability to measure the heater voltage	the heater is powered from 12 VDC preferably: 0.01 V uncertainty minimum requirement: 0.1 x 10^{-3} V uncertainty Input resistance > 10^{6} Ω
Capability to switch the heater on and off	a relay must be used. In case you are working from 12 VDC at 0.06 A (nominal values)
Capability for the data logger or the software	to store data, and to calculate absolute temperatures from the reference temperature and thermocouple type T voltages. to perform comparison of measurement results against the acceptance limits to time and control the self-test
Open circuit detection (WARNING)	open-circuit detection should not be used, unless this is done separately from the normal measurement by more than 5 times the sensor response time and with a small current only. Thermopile sensors are sensitive to the current that is used during open circuit detection. The current will generate heat, which is measured and will appear as a temporary offset.

6 Making a dependable measurement

6.1 Uncertainty evaluation

A measurement is called “dependable” if it is reliable, i.e. measuring within required uncertainty limits for most of the time and if problems, once they occur, can be solved quickly.

The measurement uncertainty is a function of:

- application errors: the measurement conditions and environment in relation to the sensor properties, the influence of the sensor on the measurand, the representativeness of the measurement location

It is not possible to give a single estimate for STP01 measurement uncertainty. Statements about the overall measurement uncertainty can only be made on an individual basis.

6.2 Contributions to the uncertainty budget

6.2.1 Non- representativeness of the measurement location

The representativeness of the measurement location may be assessed by performing multiple measurements at various locations in the same area.

6.2.2 measurement uncertainties for the reference temperature measurement

STP01 is equipped with a Pt100 platinum resistance thermometer. It is classified as class B according to DIN EN 60751. It has a resistance of 100 Ω at a temperature of 0 °C.

To convert resistance in Ω to temperature in °C, one can use the following equation:

$$T = \frac{-A + \sqrt{A^2 - 4B\left(1 - \frac{R_{Pt100}}{100}\right)}}{2B}$$ (Formula 6.2.2.1)

with R_{Pt100} the resistance in Ω, T the temperature in °C, A and B the Pt100 coefficients

A = 3.908×10^{-3}
B = -5.775×10^{-7}

The tolerance values of the temperature are: 0.3 + 0.005 |T|. In the rated temperature range of STP01, Hukseflux’ interpretation is that the absolute temperature measurement with the Pt100 has an uncertainty of 0.7 °C, and relative measurements with the Pt100 an uncertainty of 0.4 °C. Typical added uncertainties due to electronics and in the order of 0.2 °C for absolute temperature measurement and 0.1 °C for relative temperature measurements.

6.2.3 Differential measurement with matched thermocouples

Hukseflux estimates that matched thermocouples type T measure temperature differences with an uncertainty of better than 1.5 % in the -20 to + 70 °C temperature range. This estimate is based on their linearity specification in that temperature range.

7 Maintenance and trouble shooting

7.1 Recommended maintenance and quality assurance

STP01 measures reliably at a low level of maintenance. Unreliable measurement results are detected by scientific judgement, for example by looking for unreasonably large or small measured values during the self-test. The preferred way to obtain a reliable measurement is a regular critical review of the measured data, preferably checking against other measurements.

Table 7.1.1 *Recommended maintenance of STP01. If possible the data analysis should be done on a daily basis.*

MINIMUM RECOMMENDED SOIL TEMPERATURE SENSOR MAINTENANCE			
	INTERVAL	SUBJECT	ACTION
1	1 day	self-test	at least one self test per day
2	1 week	data analysis	compare measured data to the maximum possible or maximum expected temperatures and to other measurements for example from nearby stations or redundant instruments. Historical seasonal records can be used as a source for expected values. Look for any patterns and events that deviate from what is normal or expected. Analyse the measurement results. Compare to acceptance intervals.
3	6 months	inspection	inspect cable quality, inspect mounting, inspect location of installation look for seasonal patterns in measurement data and results of the self-test
4	2 years	lifetime assessment	judge if the instrument will be reliable for another 2 years, or if it should be replaced

7.2 Trouble shooting

Table 7.2.1 *Trouble shooting for STP01*

General	Inspect the quality of installation. Inspect if the wires are properly attached to the data logger. Check the condition of the cables. Inspect the connection of the shields (typically connected at the datalogger side). Check the datalogger program in particular if the right thermocouple type and reference temperature are entered. Check the sensor serial number on the cable labels (one at sensor end, one at cable end) against the product certificate provided with the sensor.
The sensor does not give any signal	A quick test of the instrument can be done by connecting it to a multimeter. Check the electrical resistance of the sensor and heater according to the tables in paragraph 5.3. Use a multimeter at the 50 and 500 Ω range. The typical resistance of the wiring is 0.4 Ω/m (added value of 2 wires). Infinite resistance indicates a broken circuit; zero or a lower than 1 Ω resistance indicates a short circuit. Check if the thermocouple sensors react to heat: put the multimeter at its most sensitive range of DC voltage measurement, typically the 100 x 10^{-3} VDC range or lower. Measure between the thermocouple reference at 0.5 m and the other thermocouple joints. Look at the reaction when you heat one of the joints. Inspect the sensor foil for any damage. Check the sensor serial number on the cable labels (one at sensor end, one at cable end of both cables) against the product certificate provided with the sensor.
The sensor signal is unrealistically high or low	Check the cable condition looking for cable breaks. Check the data acquisition of the thermocouple sensor measurement by applying a 1 x 10^{-6} V source to it in the 1 x 10^{-6} V range. Look at the measurement result. Check if it is as expected. Check the Pt100 measurement by replacing it with a 100 Ω resistor with 4 wire connection. The results should be 0 °C. Check the data acquisition of the heater voltage measurement by applying a 1 V source to it. Look at the measurement result. Check if it is as expected. Check the heater voltage power supply. It should be in the 12 V range. Check the data acquisition by short circuiting the data acquisition voltage inputs with a 50 Ω resistor. Look at the measured value. Check if the output is close to 0 V.
The sensor signal shows unexpected variations	Check the presence of strong sources of electromagnetic radiation (radar, radio). Check the condition and connection of the shield. Check the condition of the sensor cable. Check if the cables are is not moving during the measurement.

8 Appendices

8.1 Appendix on cable extension / replacement

For STP01, Hukseflux discourages extension or replacement of cables because any connection involving conductors of different composition may cause thermal offsets. This applies to soldered and clamped connections and also to connectors. Thermal offsets are usually in the microvolt range and are generated by temperature differences between the 2 joints in one sensor loop. They can be avoided by locating connections in environments that are in thermal equilibrium, and by locating connections physically close to one another. Thermal offsets cause errors when they interfere with small thermocouple voltages. STP01 is equipped with two cables. Keep the distance between data logger or amplifier and sensor as short as possible. Cables may act as a source of distortion by picking up capacitive noise. In an electrically "quiet" environment the STP01 cable may be extended without problem to 100 metres. If done properly, the sensor signals, although small, will not significantly degrade because the sensor resistance is very low (which results in good immunity to external sources) and because there is no current flowing (so no resistive losses). Cable and connection specifications are summarised below.

Table 8.1.1 *Preferred specifications for cable extension of STP01*

Cable	8-wire, shielded, with copper conductor
Extension sealing	make sure any connections are sealed against humidity ingress
Conductor resistance	< 0.2 Ω/m
Outer diameter	5.5 x 10^{-3} m
Length	cables should be kept as short as possible, in any case the total cable length should be less than 100 m
Outer mantle	with specifications for outdoor use (for good stability in outdoor applications)
Connection	for STP01 we discourage cable extension or replacement. if cable extension is needed, use high quality gold-plated and metal shielded connectors. If connectors cannot be used, solder the new cable conductors and shield to those of the original sensor cable, and make a waterproof connection using heat-shrink tubing with hot-melt adhesive, or use gold plated waterproof connectors. Always connect the shield. Make sure the soldered connections are thermally protected and as much as possible in thermal equilibrium. This may be achieved by using a heavy metal mantle.

8.2 EU declaration of conformity

We, Hukseflux Thermal Sensors B.V.
Delftechpark 31
2628 XJ Delft
The Netherlands

in accordance with the requirements of the following directive:

2014/30/EU The Electromagnetic Compatibility Directive

hereby declare under our sole responsibility that:

Product model: STP01
Product type: Soil temperature profile sensor

has been designed to comply and is in conformity with the relevant sections and applicable requirements of the following standards:

Emission:	EN 61326-1 (2006)
Immunity:	EN 61326-1 (2006)
Emission:	EN 61000-3-2 (2006)
Emission:	EN 61000-3-3 (1995) + A1 (2001) + A2 (2005)
Report:	08C01340RPT01, 06 January 2009

Eric HOEKSEMA
Director
Delft
September 08, 2015