ST01

Soil temperature sensor

st01 manual v1207

Hukseflux Thermal Sensors
http://www.hukseflux.com
The Netherlands
e-mail: info@hukseflux.com

Hukseflux
Thermal Sensors

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Introduction

ST01 is a high quality temperature sensor that is specifically designed for soil temperature measurement in extreme environments. Using top quality materials it is suitable for hostile conditions as encountered in outdoor installation (temperature, radiation, chemicals). It is designed to have a record-breaking lifetime with optimal stability. Employing a platinum sensor, at extreme temperatures a higher accuracy can be attained than with commonly used thermistors.

The measurement of soil temperature profiles has many applications, particularly in determining energy balances and monitoring of growth of agricultural crops.

The measurement of soil temperature is recommended by the World Meteorological Organisation at depths of 5, 10, 20, 50 and 100 cm.
Proper installation of soil temperature sensors requires a lot of effort. Once installed, sensors are usually left alone without calibration for a long time. This means that the sensor and cabling should be very reliable and stable over time.
ST01 is designed to be an ultra-stable sensor that can withstand the extreme conditions met in meteorological use; partially sub-soil, partially above-soil installation.

The ST01 cable as well as the sensor itself can be used across a very wide temperature range. The usual weak points of cabling have been eliminated; ST01 has a high resistance to the combination of high moisture & radiation and does not crack when bended at low temperatures. The needle and cable are resistant to virtually all chemicals, oils and fluids. The preference for Pt elements is because of their excellent stability (as opposed to thermistors that are known to behave unstably in case of thermal shock and exposure to temperatures higher than 70 degrees). Also the linearity of the Pt elements is such that the initial accuracy at extreme temperatures is much better than that of thermistor based sensors; + / - 0.25 °C between -50 and +50 °C . A one-point calibration in ice is usually sufficient as general quality assurance and to increase the accuracy to +/- 0.15 °C.

In case rodents are expected, installation of special conduits is recommended.

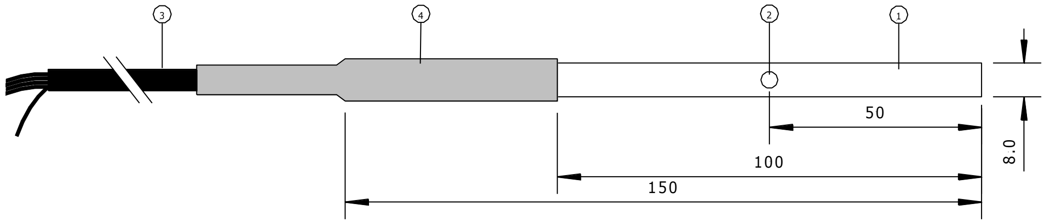

Figure 0.1 *ST01 Soil Temperature Sensor: The sensor consists of a stainless steel needle (1) with a temperature sensor (2) (normally Pt100, also Pt500 and Pt1000 available). The Pt elements are connected in a 4-wire configuration. The PTFE cabling (3) is welded (4) to the stainless steel.*
All dimensions are in mm.

1 Theory

The theory governing ST01 is quite simple. It is a sensor that contains a Platinum Resistance Thermometer (PRT) according to DIN IEC 751 class A. Apart from the sensor specifications, also the wiring complies with the same standard.

The theoretical behaviour of such a sensor is according to the following formula:

$$R_t = R_0 (1 + AT + BT^2) \qquad 1.1$$

With:
$A = 3.90802\ 10^{-3}\ °C^{-1}$
$B = -5.802\ 10^{-7}\ °C^{-1}$

R_t is the resistance value at T degrees C. R_0 the resistance value at 0 degrees C. R_0 equals 100 Ohms for a Pt100 type sensor. (For Pt1000 and Pt500 R_0 equals 1000 and 500 Ohms respectively)

The maximum error tolerances ΔT for class A sensors are in degrees C:

$$\Delta T = +/- (0.15 + 0.002\ |\ T\ |) \qquad 1.2$$

With | T | the absolute value of T in degrees C.

Formula 1.1 and 1.2 already imply that calibration typically is done at 0 degrees C.
From 1.2 it can be seen that if the calibration at zero degrees C is taken into account, an accuracy of +/- 0.15 degrees is attainable between -50 and +50 degrees C (typical extreme values for soil temperatures)

2 Specifications of ST01

ST01 soil temperature sensor is intended to measure temperatures in the soil in which it is inserted. It can only be used in combination with a suitable measurement system.

GENERAL	
Measurement range	-60 to +150 °C, cable remaining flexible
Attainable measurement accuracy between -50 and +50 °C	+/ - 0.25 °C +/ - 0.15 °C with individual calibration (both across -50 to +50 °C)
Expected lifetime	> 10 yrs (normal field conditions)
CE requirements	ST01 complies with CE directives
SENSOR SPECIFICATIONS	
Standard sensor	Pt100 according to IEC 751:1983 class A
WMO recommended installation depths	5,10,20, 50 and 100 cm below the surface
Alternative sensors	Pt500, Pt1000, thermistors, Pt resistors with higher accuracy resistance value at 0 °C
Recommended readout	Pt100 - 4 wire
Needle dimensions	length 150, diameter 8 mm
Standard cable length	3 meters
Weight	0.3 kg including 3 meters cable 0.8 kg including packaging (6 by 32 by 30 cm) and manual
Moisture protection needle and cable until wiring	IP 68
Pressure resistance	6 bar (all ST01 are subjected to a helium leakage test)
UV resistance	no UV degradation
Needle material	Stainless Steel
Cable material	Extruded PTFE
CALIBRATION	
Calibration traceability	To Internaltional Temperature Scale ITS 90
Recommended recalibration interval	Whenever possible, usually one single point calibration in an ice bath is sufficient.

Table 2.1 *List of ST01 specifications*

3 Short user guide

The sensor should be installed following the directions of paragraph 4. Essentially this requires a datalogger with capability to perform a direct Pt100 measurement or a resistance measurement followed by some calculations to calculate temperature from the resistance.

The first step that is described in paragraph 4 is and indoor test. The purpose of this test is to see if the sensor works. It can be done in a very simple way, just using a multimeter.

4 Putting ST01 into operation

First test the sensor functionality by checking the impedance of the sensor, and by checking if the sensor works, according to the following table:

Check the 4 wire connection of the sensor. Use a multimeter at the 100 ohms range. Measure between two wires that are connected at the same end of the sensor (white-white and red-red). The measurement will give the value of twice the cable resistance. Repeat at the other end of the sensor. Take down the measured value. This is the cable resistance.	The typical impedance of the wiring is 0.1 ohm/m. A typical impedance should be 1 ohms for the total resistance of two wires (back and forth) of each 3 meters. Infinite indicates a broken circuit, zero indicates a short circuit.
Check the sensor impedance. Use a multimeter at the 200 ohms range. Measure between two wires that are connected at opposite ends of the sensor (red-white). Subtract the resistance value that was measured during the previous measurement. What is left is the sensor resistance.	This should be between about 110 ohms (see table). Infinite indicates a broken circuit, zero indicates a short circuit. When the sensor is not yet installed, its proper functioning can be verified by touching the sensor with your hand, or by putting it into a temperature bath.

Table 4.1 *Checking the functionality of the sensor. The procedure offers a simple check to see if the sensor is OK.*

5 Installation of ST01

ST01 is generally installed at the location where one wants to measure. Typical depths recommended by WMO are 5, 10, 20, 50 and 100 mm. Additional depths may be included.

The better the ST01 needle is in contact with the soil, the better.
Typical insertion of soil thermometers is first to make a hole with a vertical side. The ST01 sensors are then inserted from the side into undusturbed soil. After installing the sensors, in case of stratified soils, an effort should be made to return the soil to its original position and density so that the soil temperature pattern still resembles as much as possible the pattern in the surrounding area.
The end of the ST01 cable, where the wiring is coming out, should be located in a dry environment.
In case rodents are expected, installation of special conduits is recommended.
It is recommended to fix the location of the sensor by attaching a metal pin to the cable. Attachment of the pin to the cable can be done using a tie-wrap.

Table 5.1 *General rules for installation of ST01.*

6 Maintenance of ST01

Once installed, ST01 is essentially maintenance free. Usually errors in functionality will appear as unreasonably large or small signals.
As a general rule, this means that a critical review of the measured data is the best form of maintenance.

7 Requirements for data acquisition system

Capability to measure	Pt100 in a 4-wire connection with +/- 0.25 degrees C (normal) or 0.1 degrees C (high) acccuracy
Alternatively: capability to measure	resistance measurement with a +/- 0.15% (normal) or +/- 0.05% (high) accuracy in the 80 to 120 ohms range, and to perform calculation of the temperature from the resistance value.

Table 7.1 *Requirements for data acquisition and control.*

8 Electrical connection of ST01

In order to operate, ST01 should be connected to a measurement system as described above. The numbering of wires is shown in figure 0.1. For the purpose of making a correct measurement of the Pt100 with an optimal accuracy it is recommened to use a 4 –wire connection. Two wires carry the current, the others are used for the measurement. Through these wires there is a negligible current, so that there is no voltage drop across the wires, and the true voltage across the heater wire is measured.
Alternatively a 3-wire connection can be used by omitting one of the wires.

Number	Name	Color
1	Temperature sensor side A	White
2	Temperature sensor side A	White
3	Temperature sensor side B	Red
4	Temperature sensor side B	Red
Shield	Shield	Grey (sleeve)

Table 8.1 *Wiring schedule of ST01. The temperature sensor can be a Pt 100 , Pt500, Pt1000 or any thermistor.*

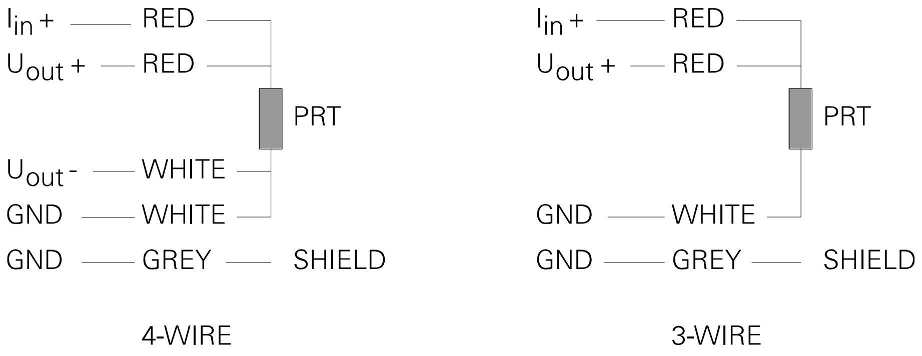

Figure 8.1 *ST01 in a 4-wire connection (preferred) or a 3-wire connection.*

Some datalogger types do not have standard inputs for Pt 100's. Most notably these are the loggers of Campbell Scientific. The usual wiring to these loggers is as follows:

4WFB120	4-wire full bridge module, matched to Pt100. One differental channel per sensor. Recommended with short cables only (<5m).
3WHB10k	3-wire half bridge module. Can be used with one differential channel per sensor. Recommended with short cables only (<5m).
4WPB100	4-wire PRT bridge module. More accurate measurement than 4WFB120 or 3WHB10K because no assumtions are made about equality of the cable resistances. Can be used with long cables. When used with one sensor, 2 channels per sensor. Possibility to use one 4WPB100 with up to 5 Pt100's by linking the GND wire of one sensor to the I_{in} + of the next sensor. In thiscase the number of differential channels needed is equal to the number of sensors plus one.
Multiplexing	The 4WFB120, 3WHB10k and 4WPB100 can be used with the multiplexer AM416. In this case up to 16 sensors can be used, using one of the above mentioned modules in the configuration to control one sensor.

Table 8.2 *Using the ST01 with Campbell Scientific dataloggers. NOTE: in case Pt500 or Pt 1000 is used, different modules might be used.*

9 Appendices

9.1 Calibration of ST01

Calibration of ST01 can be done in any laboratory that has the necessary electronic equipment. In this procedure it is assumed that the electronics that is making the ST01 measurement is calibrated according to its own calibration procedure.
The procedure for calibration is as follows:

First put the sensor in a temperature bath of zero degrees C. This bath (+/-0.05 degrees C) can be created by taking frozen distilled water. The ice should be chopped into little pieces and be put in a thermically insulated flask. By adding water, or allowing the ice to melt, a homogeneous mixture of water with ice is obtained. Care should be taken that the ice is homogeneously distrubuted all around in the flask and that the needle of ST01 is inserted for more than 200 mm into the flask.

The value that is obtained now (in 4 wire connection) is R_0 of formula 1.1.

$$R_t = R_0 (1 + AT + BT^2) \qquad 1.1$$

With:
$A = 3.90802\ 10^{-3}\ °C^{-1}$
$B = -5.802\ 10^{-7}\ °C^{-1}$

R_0 the resistance value at 0 degrees C. This is 100 Ohms for a Pt100 type sensor. The class A allows a deviation of +/- 0.06 Ohms.
The value obtained for R_0 can be used to refine the measurement.

9.2 Cable extension for ST01

From the point of view of measurement accuracy it is recommended to keep the cable length of ST01 as short as possible. The cable acts as a possible source of electromagnetic disturbances by picking up noise (usually capacitive). Also the number of connections should be kept as low as possible.

In case of ST01 the cable is made out of extruded PTFE, which has many advantages in terms of temperature resistance, chemical resistance etc. The disadvantages are the price (high) and the fact that it is not easy to glue. For the latter two reason extension of cables is generally discouraged.

There are two ways of extending the cable beyond the usual 3 meters:
1 use connectors. Take care that the connection to the ST01 is water tight and that the quality of the connector is such that it does not introduce additional errrors. Extension wire does not necessarily need to be the same type as long as all four extension wires have the same resistance.
2 Order sensors with longer cables

9.3 Trouble shooting

This paragraph contains information that can be used to make a diagnosis whenever the sensor does not function.

It is recommended to start any kind of trouble shooting with a simple check of the sensor impedance.

Check the 4 wire connection of the sensor. Use a multimeter at the 100 ohms range. Measure between two wires that are connected at the same end of the sensor (white-white and red-red). The measurement will give the value of twice the cable resistance. Repeat at the other end of the sensor. Take down the measured value. This is the cable resistance.	The typical impedance of the wiring is 0.1 ohm/m. A typical impedance should be 1 ohms for the total resistance of two wires (back and forth) of each 3 meters. Infinite indicates a broken circuit, zero indicates a short circuit.
Check the sensor impedance. Use a multimeter at the 200 ohms range. Measure between two wires that are connected at opposite ends of the sensor (red-white). Subtract the resistance value that was measured during the previous measurement. What is left is the sensor resistance.	This should be between about 110 ohms (see table). Infinite indicates a broken circuit, zero indicates a short circuit. When the sensor is not yet installed, its proper functioning can be verified by touching the sensor with your hand, or by putting it into a temperature bath.

Table 9.3.1 *A copy of the table 4.1. Checking the functionality of the sensor.*

No signal from the sensor	Check the sensor impedance as in table 9.3.1. This can also be done while the sensor is still in place
	Check the data acquisition system putting a known resistance (100 ohm +/-0.1%) to its input.
	Check the sensor connection
Signal too high or too low	Check the data acquisition system putting a known resistance (100 ohm +/-0.1%) to its input.
Signal shows unexpected variations	Check is there are no large currents in your system which can cause a ground loop. If these are there, switch them off, and see if any of these is causing the disturbance.
	Check the surroundings for large sources of electromagnetic radiation. Radar installations, microwave emitters, etc.
	Inspect the sensor itself. The surface should be smooth and have no scratches.

Table 9.3.2 *Extensive checklist for trouble shooting.*

9.4 Platinum resistance thermometry

°C(t_{90})	0	1	2	3	4	5	6	7	8	9
-60	76.33	75.93	75.53	75.13	74.73	74.33	73.93	73.53	73.13	72.73
-50	80.31	79.91	79.51	79.11	78.72	78.32	77.92	77.52	77.12	76.73
-40	84.27	83.87	83.48	83.08	82.69	82.29	81.89	81.50	81.10	80.70
-30	88.22	87.83	87.43	87.04	86.64	86.25	85.85	85.46	85.06	84.67
-20	92.16	91.77	91.37	90.98	90.59	90.19	89.80	89.40	89.01	88.62
-10	96.09	95.69	95.30	94.91	94.52	94.12	93.73	93.34	92.95	92.55
-0	100.00	99.61	99.22	98.83	98.44	98.04	97.65	97.26	96.87	96.48
0	100.00	100.39	100.78	101.17	101.56	101.95	102.34	102.73	103.12	103.51
10	103.90	104.29	104.68	105.07	105.46	105.85	106.24	106.63	107.02	107.40
20	107.79	108.18	108.57	108.96	109.35	109.73	110.12	110.51	110.90	111.29
30	111.67	112.06	112.45	112.83	113.22	113.61	114.00	114.38	114.77	115.15
40	115.54	115.93	116.31	116.70	117.08	117.47	177.86	118.24	118.63	119.01
50	119.40	119.78	120.17	120.55	120.94	121.32	121.71	122.09	122.47	122.86
60	123.24	123.63	124.01	124.39	124.78	125.16	125.54	125.93	126.31	126.69
70	127.08	127.46	127.84	128.22	128.61	128.99	129.37	129.75	130.13	130.52
80	130.90	131.28	131.66	132.04	132.42	132.80	133.18	133.57	133.95	134.33
90	134.71	135.09	135.47	135.85	136.23	136.61	136.99	137.37	137.75	138.13

Table 9.4.1 *Resistance vs temperature relationship over the range -60°C to +90°C for platinum resistance thermometer detector elements. The values are for Pt100 elements, for PT 500 and Pt1000 multiply by 5 and 10 respectively. A typical meteorological temperature range for soil temperatures is -50 to +50 °C.*

9.5 CE Declaration of conformity

According to EC guidelines 89/336/EEC, 73/23/EEC and 93/68/EEC

We: Hukseflux Thermal Sensors

Declare that the product: ST01

Is in conformity with the following standards:

Emissions:	Radiated:	EN 55022: 1987	Class A
	Conducted:	EN 55022: 1987	Class B

Immunity:	ESD	IEC 801-2; 1984	8kV air discharge
	RF	IEC 808-3; 1984	3 V/m, 27-500 MHz
	EFT	IEC 801-4; 1988	1 kV mains, 500V other

Delft
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