Novel Sap Flow Sensor

SF-L Sensor

Patent pending

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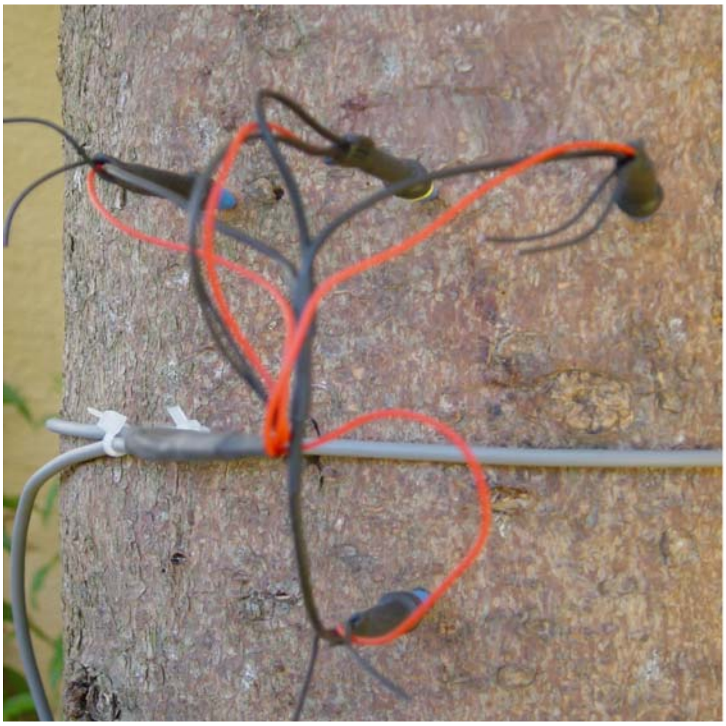
Sap Flow Sensor

Type SF-L



User manual

2005

Contents

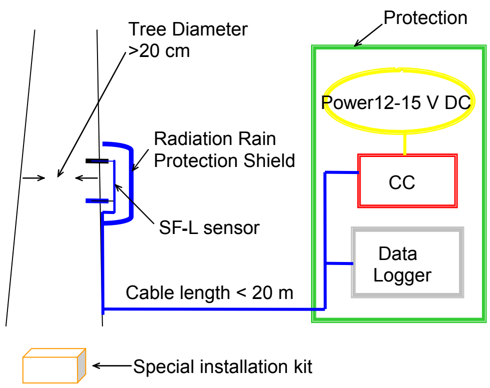
1. Introduction

Thank you for purchasing an Ecomatik SF-L sensor.
The SF-L is a noble sensor for measuring sap flow in trees. In comparison with the popular Ganier sensor (Thermal Dissipation Probe), SF-L sensor enhances accuracy and reliability and enables you to measure sap flow in the night time and also simplifies data processing.

This manual has been prepared to help you install and operate your SF-L sensor with least difficulty and desirable results. Please read it carefully before installing the sensor, and refer to it if you should have any difficulty with the sensor in the future.

The SF-L is a sensor component of the latest sap flow measuring system. This means that SF-L must be installed into a tree and connected to a special power supply unit and a data logger. The diagram below gives you an overview of the whole sap flow measuring setup for outdoor purposes. All indicated components are available at ECOMATIK.

Please note that the tree diameter at the level of installation must be bigger than 20 cm.



A Setup of SF-L sap flow measuring system

Blue part:	SF-L sap flow sensor
Red part:	Constant current source (CCS)
Gray part:	Data logger, >12 bits, at least 3 Channels
Yellow part:	Power supply, 12-15 V DC, at least 100 mA permanent current
Green part:	Protection box for data logger, CCS, power source in outdoor condition
Orange part:	Special installation kit
Black part:	Tree for investigation, its diameter at level of measurement >20 cm

2. Product Description

SF-L Sensor

Sap Flow Sensor Type SF-L

The sensor consists of:
1 SF-L sensor with 4 needles supplied with 0.7-m standard cable extendable to 20 m
1 radiation protection shield (70 cm x 70 cm)
1 tube of silicon paste for sealing the top of protection shield
8 aluminum tubes
1 adhesive tape for fixing the radiation protection shied on the tree

Constant current source (CCS)

Constant current source for supplying up to 3 SF-L sensors

Installation kit

Installation kit

Installation kit consists of:
1 hand drill
2 drill bits with 2 mm diameter for drilling the holes for the needles into the wood
1 drill bit with 8 mm diameter for bark isolation (incase of thick tree-bark that hinders the insertion of needles into the sapwood).
1 special needle for inserting the aluminum tubes into the tree
1 tube silicon-fat for improving heat dissipation from the needles into the wood

Contact your dealer incase any of the above items is missing.

3. Safety Information

The needles are fragile, please handle with care.
Never supply the sensor with power before it is installed into the tree. For test purposes, please put the needles in water so that heat the can be dissipated.
Pay attention to wiring instructions. Wrong connection could destroy the sensor.

4. Installation

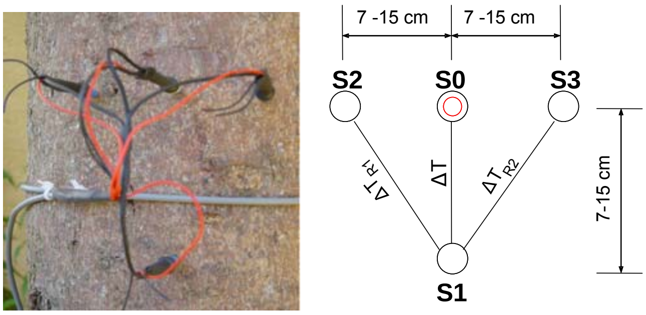
4.1 Preparation

Cable extension: Unless specified in the order, the standard cable length of the sensor is 0.7 m. This can be extended up to 20 m. Use 6-wire cable (Cross- sectional area of at least 0.25 mm^2).

Power supply: Irrespective of whether 1, 2 or 3 SF-L sensors are connected, the constant current source consumes about 100 mA. In case you use a car battery as power source, e.g. a 50-Amper-Hour battery may last 10 days.

4.2 Sensor

In order to avoid thermal effects the sensors should be installed higher than 1.5 m from the ground and on the north facing aspect of the tree.



Installation scheme of the SF-L sensor

The sensor consists of 4 needles (S0, S1, S2 and S2).The connection S0-S1 corresponds to the Granier sensor and provides the value ΔT. The needles S2-S1 and S3-S1 are built-in with two thermocouples to continuously monitor the background temperature gradients (ΔT_{R1}, ΔT_{R2}) of the sapwood.

Following the schematic diagram above, drill four holes of 2 mm diameter and about 23 mm depth into the wood. This depth does not include bark thickness. Use the 8 mm drill bit to isolate the bark. Also, if more than one needle set have to be installed deeper into the sapwood, i.e. incase of larger trees, then progressive holes of 23 mm depths into the sapwood are necessary.

Carefully insert the small aluminum tubes into the holes by using the special needle supplied in the installation kit. Ensure the tubes are tightly fitted and completely immersed into the wood (Extensions of the aluminum tube outside the tree trunk can cause erroneous results). Fill the aluminum tubes with silicon-fat to improve contact and heat dissipation between needle and wood. Dip the sensor needle into silicon-fat and insert the needle into the aluminum tube. Ensure that the labels on the needles correctly correspond to the above scheme.

4.3 Cable installation

Once the above installation is correctly carried out, fix the cable onto the tree stem so that the needles are protected from any accidental pull/ drag on the entire cable length. This can be done using a rope or cable straps. Ensure the suspension rope/strap is not so tight as to interfere with normal tree growth and expansion during the entire measurement period. Also, there should be no tension between the sensor and cable.

4.4 Protection shield

Corresponding to the tree diameter prepare a radiation protection shield such as one shown in the picture below.

Prepared protection shield

Install the prepared radiation-protection shield around the sensors using adhesive tape. Take care that the shield does not touch the needles. Seal off the top of the shield with silicon paste to protect the sensor from dripping rainwater.

4.5 Wiring

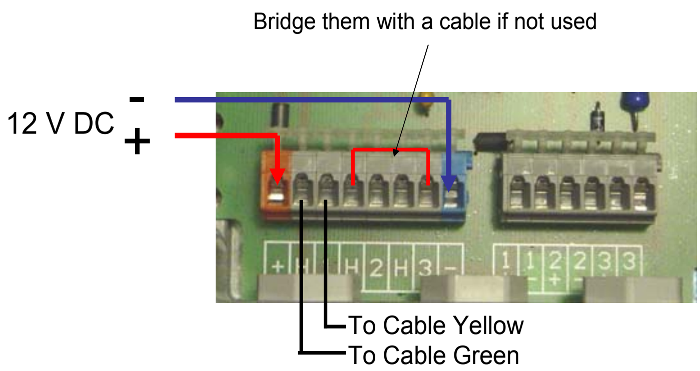
The SF-L sensor requires constant power supply (CCS) and provides three signals. Wiring should be done as shown in the table.

Wiring description

Use	Wire color	Connected to
Heating +	Green	CCS +
Heating -	Yellow	CCS -
Signal S1	Brown	Channel one – Channel two – Channel three –
Signal S2	Gray	Channel one +
Signal S0	White	Channel two +
Signal S3	Pink	Channel three +

If the sensor is wired as shown in the table, then the value of ΔT_{R1} is recorded in channel one, ΔT in channel two and ΔT_{R2} in channel three.

Connect the heater wires to the CCS as shown in the picture below. One CCS can supply three SF-L sensors. If only one or two SF-L sensors are used, the open sockets must be bridged. Press the trigger from top with a small screwdriver to open the clamps and to insert or remove the wires.



Connection of CCS

4.6 Logger configuration

The SF-L sensor signal output in channel two (S0-S1) range from +100 to +800 µV DC and in channels one and three from -100 to +100 µV DC. All loggers with voltage resolution <10 µV can be used for SF-L sensors. Please specify the channels for SF-L sensor so that it can measure voltage in the required range i.e. from -100 to 1000 µV DC.

Some loggers directly convert the µV values into temperature. In this case, the expected outputs are from 2.5 to 20 °C in S0-S1 channel and from -2.5 to +2.5 °C in S2-S1 and S3-S1 channels.

5. Data processing

In order to calculate the sap flow of the tree the data measured are processed in tree steps.

Step 1: Data correction

$$\Delta TC = \Delta T - (\Delta T_{R1} + \Delta T_{R1})/2 \qquad (1)$$

Where ΔTC is the corrected temperature difference in µV or in °C

ΔT is voltage or temperature signal between white and brown wires in µV or in °C.

ΔT_{R1} is voltage or temperature signal between gray and brown wires in µV or in °C.

ΔT_{R2} is voltage or temperature signal between pink and brown wires in µV or in °C.

Step 2: Calculating the Sap flow density

$$U = 0.714 \times \left(\frac{\Delta TC_{\max} - \Delta TC}{\Delta TC} \right)^{1.231} \qquad (2)$$

Where

u is sap flow density in ml/(cm^2×min).

ΔTC is voltage or temperature signal calculated after formula 1.

ΔTC_{max} is ΔTC value in cases when the tree is saturated i.e. no radial tree-trunk increment and the air humidity is 100% with transpiration tending to zero. Tree stem increment and its refilling status can be monitored by the ECOMATIK dendrometer, which continuously measure radial changes of the tree trunk. If no dendrometer is used, choose the maximum ΔT after long rains as your $\Delta TC_{max.}$ For further information please see section 6 "physiological background".

Step 3 Calculating the Sap flow

$$F=u\times SA \qquad (3)$$

Where

F is Sap flow in ml/min.

u is sap flow density in ml/(cm^2×min), calculated after formula (2).

SA is sap wood area of the tree in cm^2 .

The equations apply irrespective of the units (V, mV, µV or °C) in which data is recorded so long as ΔT_{max}, ΔT, ΔT_{R1}, ΔT_{R2} have the same units.

6. Physiological background of SF-L sensor

The SF-L is an improved Granier sap flow sensor (Granier, 1985) i.e. thermal dissipation probe. Due to its simplicity, reliability and affordability, numerous scientists have used the Granier technique all over the world. However, the technique has had limitations, which required improvement. These include:

1). Granier technique determines arbitrarily the sap flow to zero every night. This contradicts the fact that transpiration can occur at night (Granier, 1987) and the refilling process of tree body that occurs at night when transpiration stops, clearly visible from the changes in tree diameter measured by dendrometers (fig. 2).

2). This technique also ignores the natural temperature gradients of the sapwood, which range between +/- 1.5 °C and can cause considerable error in the measuring results (fig. 1).

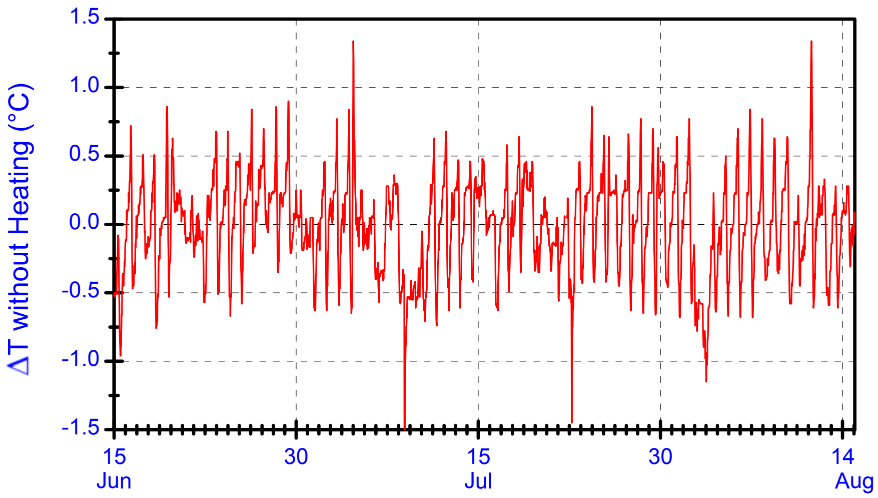


Fig.1 Vertical temperature gradients of 40 years old spruce tree, measured with a Granier sensor without heating.

The new SF-L sensor takes into account effects due to natural temperature gradients of the sapwood. The sensor constitutes two reference thermocouples to record the background natural temperature gradients (ΔT_{R1}, ΔT_{R2}). During data processing, values of the temperature differences between the heated needle and the sapwood ambient temperature (ΔT) are corrected for natural temperature gradients by the ΔT_{R1}, ΔT_{R2}.

The SL-L sensor therefore considerably enhances accuracy and reliability of the sap flow measurements.

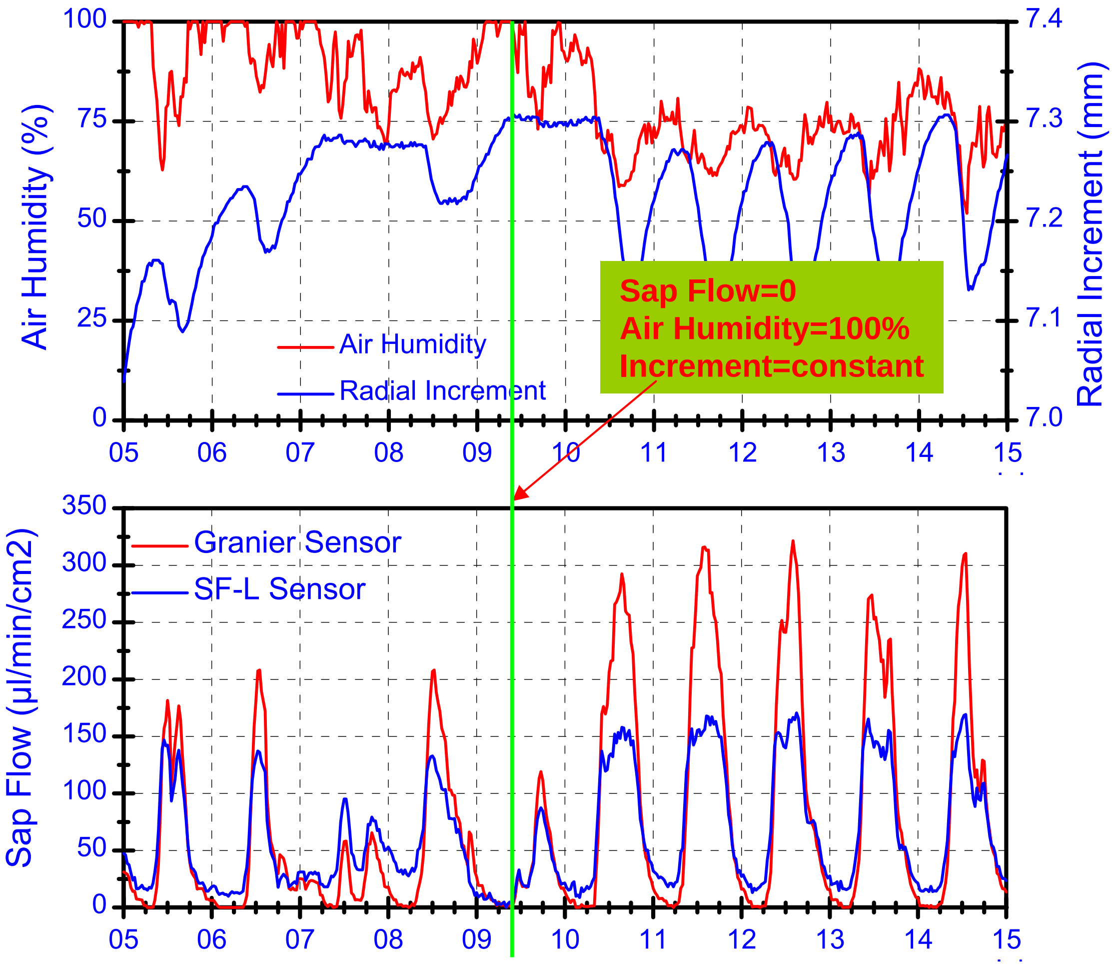


Fig. 2 Above: Air humidity and radial changes of 40 years old spruce tree measured with an Ecomatik dendrometer type DD. Increase in diameter at night indicates that the tree continues to take up water even during nighttime hence sap flow continues until the beginning of transpiration in the next morning.

Below: Comparison between sap flow measured with Granier sensor (red line) and with SF-L sensor (blue line). The Granier sensor shows zero sap flow every night while the SF-L detects zero value only on the night of 9. July, when air humidity reached 100% and the tree body fully saturated with water.

In contrast to Granier technique, SF-L sensor provides a very stable and more accurate ΔT_{max} value (temperature difference between the heated needle and the sapwood ambient temperature when sap flow=0). ΔT_{max} value is dependent on sap flow and is attained under conditions of zero transpiration and zero tree-body refilling. This means 100% air humidity and zero tree diameter expanse. During drought, when transpiration demand is greater than root water supply to the shoots and also increased vapor pressure deficit, a considerable amount of water continues to be lifted into the plant tissues even during the night. Fig. 2 shows a comparison of a Granier sensor with a SF-L sensor.

7. Technical Specification

Sensor	
Sensor composition	4 needles
Needle size	33 mm length, 1.5 mm diameter
Heating zone	20 mm from top of the needle
Cable length	0.7 m, extendable to 20 m
tree size	Diameter>20 cm
Power consumption	0.2 W +/-5%, 84 mA DC, stabilized
Output	-100 µV to 1000 µV DC
Logger requirement	3 differential channels
Power supply	
Input	12 -15 V DC
Output	84 mA stabilized, suitable for 1 to 3 SF-L sensors

8. Literature

Granier A (1985): Une nouvelle méthode pour la mesure du flux de sève brute dans le tronc des arbres, Ann. Sci. For., 1985, 42 (2), 193-200.

Granier A (1987): Mesure du flux de sève brute dans le tronc du Douglas par une nouvelle méthode thermique. Ann. Sc. For., Seichamps, 44.

Liu J C, Firsching B M, Payer H D (1995): Untersuchungen zur Wirkung von Stoffeinträgen, Trockenheit, Ernährung und Ozon auf die Fichtenerkrankung am Wank in den Kalkalpen. GSF-Bericht 18/95, 236 S.

Do F and Rocheteau A (2002): Influence of natural temperature gradients on measurements of xylem sap flow with thermal dissipation probes. 1. Field observations and possible remedies. Tree Physiology 22, 641-648.

Do F and Rocheteau A (2002): Influence of natural temperature gradients on measurements of xylem sap flow with thermal dissipation probes. 2. Advantages and calibration of a noncontinuous heating system. Tree Physiology 22, 649-654.

Pearcy R W, Ehleringer J, Mooney H A and Rundel P W (1989): Plant Physiological Ecology – Field Methods and Instrumentation. Chapman and Hall.