FunDivEUROPE

Functional significance of forest biodiversity in Europe

Project number: 265171

Sap flow measurements in trees using the radial flowmeter technique

FunDivEUROPE (FP7) field protocol

V1.0

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Content

1 Introduction

The radial sap flowmeter (Granier, 1985, 1987) is composed of 2 cylindrical probes, 2 mm in diameter, which are inserted in cylinders previously inserted into the sapwood. The cylinders (aluminium is used to optimise heat transfer) are typically 20 mm long, but shorter or longer probes can be used. The upper probe includes a constantan resistor and is heated by the "Joule effect" at a constant rate. The lower probe (reference probe) is not heated and remains at wood temperature. Each probe contains at mid-length a copper-constantan thermocouple. The temperature difference between the two probes **ΔT(u)** is measured as the 2 thermocouples are wired in opposition. This difference is influenced by the sap flux density **u** in the vicinity of the heated probe. Distance between the two probes is about 10-12 cm (Figure 1).

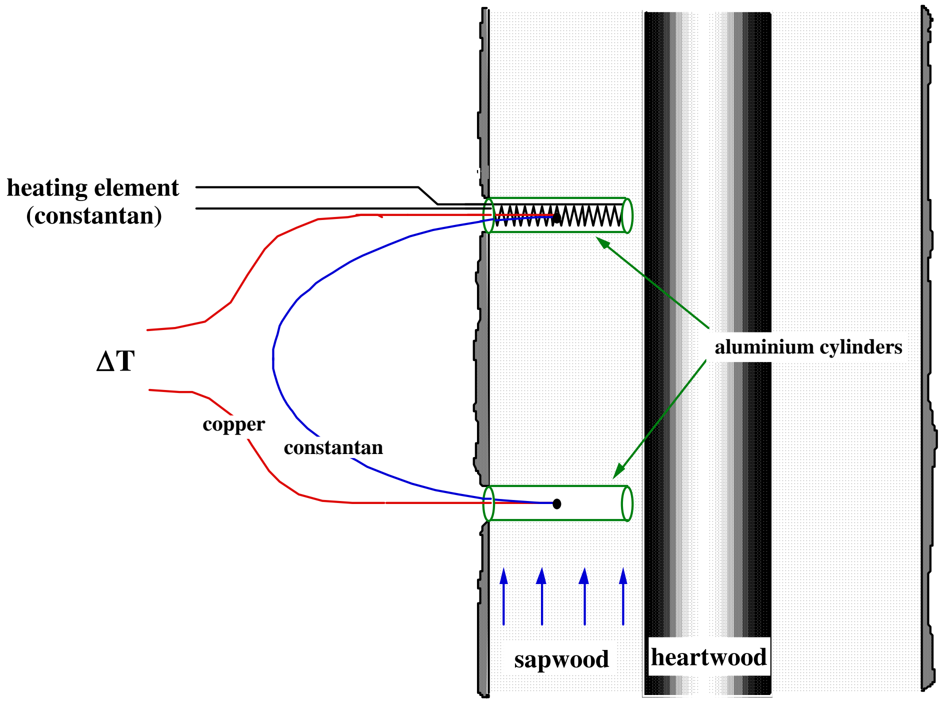

Figure 1: Scheme for installation of sap flowmeter.

When there is no sap flow (during the night, when vapour pressure deficit equals or is close to zero), all the energy is dissipated by conduction in the wood, and provokes a maximum temperature difference **ΔT(0)**. When sap circulates in the xylem, the temperature difference decreases, because the heated probe is cooled by convection.

The following relationship was fitted for a large number of trees and species (Granier, 1985, 1987). Laboratory tests showed that this relationship is independent on tree species:

$$u = 119*10^{-6} * K^{1.23} \qquad [1]$$

in which: u = sap flux density in $m^3_{H2O}\, m^{-2}_{sapwood}\, s^{-1}$

K = sap flux index = [ΔT(0)/ ΔT(u) - 1]

Tree sap flow F (m^3 s^{-1}) is calculated from:

$$F = u*SA \quad [2]$$

in which: SA = transverse cross-section of sapwood at the heated probe height (m^2)

Stand sapflow (T = tree transpiration) is calculated from individual tree measurements and from the sapwood distribution in the stand:

$$T = A_T * S (u_i * p_i) \quad [3]$$

where:

- A_T : plot sapwood area per unit of ground area (m^2 ha^{-1}),
- u_i : mean sap flux density of trees in the class of circumference i,
- p_i : proportion of sapwood of trees within each class i = A_i / A_T,
- A_i : sapwood area of the trees in the class of circumference i.

2 Scope and application

The objective of this part of the manual is to provide harmonized and standard procedures to measure sap flow density of trees in the different plots at the Experimental and Exploratory sites of FunDivEUROPE. The protocol has been used for more than 20 years by the INRA's team in temperate or tropical sites.

A harmonised protocol for sap flow measurements for FunDivEUROPE is necessary to allow comparability between sites and species. Procedures are intended for application at both Experimental and Exploratory sites. The sensors will be set up by the INRA's team but the local technicians may have to replace some deficient sensors over the study period and should follow the same method described here to minimise any potential bias.

3 Objectives

Then objective of this task is to measure the sap flow density of trees of different species in mono or mixed conditions during the summer.

4 Location of measurements and sampling

In the Exploratory sites, we plan to set up sapflow sensors in the 6 ecoregions, for 5 plots per region (3 plots of monoculture and 2 plots of 3-species mixture). In each ecoregions, around 39 trees will be equipped with sap flow sensors.

In the Experimental sites, only 2 ecoregions are concerned: Finland and Germany. In FIN, we plan to sample 5 monospecies plots, and 1 fully mixed plot. In GER, we plan to sample 4 monospecies plots, and 1 fully mixed plot. In each MONO plots, about 5 trees will be sampled. In the MIXED plots, about 4-5 trees per species will be sampled.

In the Exploratory sites, measurements will be conducted in summer 2012 and 2013. Sensors should be set up around June and measurements will cover the full summer, until leaf fall.

In the Experiment sites, we plan to set up the equipments in May 2011. Measurements will cover the full summer, until leaf fall.

<u>Installation</u>

a- Checking the sensors before installation

Be sure that there is no electric contact between the heating constantan wire, the thermocouples, and the stainless steel needle.

b- Sensor insertion into the tree

- look carefully at the external aspect of the bark: homogeneity, absence of knurls, orientation (prefer to avoid sun exposed part of the trunk). In general the higher part of the trunk shows better homogeneity than the lower part, and distance between knurls (annual whorls) is larger.
- if the bark is thick, it can be partly removed using a sharp knife.
- drill two 2.1 mm diameter holes using a portable drill (<1000 rd/min). The holes need to be slightly larger than probes diameter, because some shrinkage of the fresh wood occurs. It is sometimes necessary to use a 2.2 mm drill when using fragile sensors or if wood shrinkage is larger. Hole depth depends on cylinder length. Vertical distance between both holes is about 10-12 cm.
- in the case of adhesive cylinder sensors, gently drive the heated probe into the upper hole and the reference probe in the lower one. If one uses a removable type sensor, drive in each hole an aluminium cylinder using an adapted tool, spread thermal silicon grease over the probes, and insert them into the cylinders. The following figure shows the accurate installation: use also a small amount of silicon grease to prevent evaporation from the injured sapwood zone, and to avoid pathogens penetration.

Important: The aluminium cylinders must be completely inserted into the wood and should not be in contact with the bark or the air.

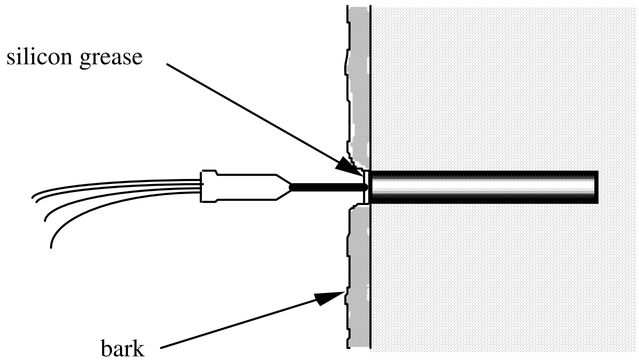

Figure 2: Detailed **s**cheme for installation of sap flowmeter.

- connect the sensor to the wires and cover with a shield extending at least 20 cm across the sensors. This shield should be made with a sheet of reflecting (aluminium covered) and flexible insulating material. When installing the shield, check carefully that the probes are not injured and remained totally inserted into the holes. The shield is necessary in order to:
    - smooth the quick changes of outside temperature,
    - avoid direct sunlight, that could reach only one probe, hence producing thermal interference,
    - protect against the rain.

- use an adhesive tape to fix the shield to the bark, and spread over the tape (in the upper part) silicon glue to make a waterproof joint.

c- Power supply, connections, and adjustments

- o Due to the low voltage coming from the thermocouples (200-600◎V), the wires are commonly connected to a data logger in differential mode in order to avoid electric interactions; nevertheless, common mode can be used after checking that signal is clean (absence of noise). Shielded cables must be used (4 wires). In the differential mode, connect the thermocouple wire from the heated probe to the + terminal, and wire from reference probe to –. Under the common mode, connect the heated probe wire to either + or – terminals and the reference wire to the ground terminal.
- The heating wires can be connected in serial (per groups of 2 or 3) in order to optimise the energy consumption. But nevertheless, individual power supplies should be preferred since under the serial mode connexion, resistor

breaking of one of the heated probes stops measurements of all the others. Connect an ampere meter in order to adjust the intensity. It should be typically 0.120 A (depending on sensors!).

- The other two wires are connected to the datalogger (Campbell CR1000 or CR800).
- We typically use a 10 to 30 s time interval measurements and store the 15 or 30 min averages in the data logger.
- We will power each system (1 per plot) with car batteries (or gel ones), except maybe in Spain. Batteries usually last 5-7 days. After this period, local technicians should carry them back to the office to reload them, and connect them back after about 2 weeks for another 5-7 days period of measurements.

Remarks

- check carefully the junctions: there should be no oxidation of wires and they must be tightly fastened to the data logger terminals.
- the number of heaters powered by one channel depends on the electric resistance of the sum sensor+cables and on the characteristics of the power supply.
- if connectors between the sensors and the cables are used, choose connectors with golden pins to ensure a better contact; small dimension ones are preferred.

<u>Monitoring and maintenance</u>

a- Consumption and batteries

- heating probes: a group of 3 probes typically consumes ≈ 0.15 A under 12V.

Note: Do not discharge lead batteries more than 50% of their full capacity!

- check the datalogger batteries: min. 11.75V for lead batteries, 10V for alkaline batteries.

b- Temperature gradients

Vertical temperature gradients are one of the most annoying problems that frequently occur under field conditions. Temperature gradients depend on many factors: day-to-night variations in air temperature, direct radiation on the bole, temperature difference between air and soil, tree diameter and species, etc. In general, thermal gradients are higher:

- on the sun-exposed side of the trunk,
- close to the soil,
- in small diameter stems.

Those gradients can modify the sensor response to a large extent; they generally show a diurnal pattern. In all experiments, the presence of temperature gradients must be checked carefully by recording the sensors output without heating during several bright days. A maximum day-to-night variation of ± 5◎V is acceptable.

Solutions

- if there is no significant azimutal variation of sapflow in the trunk (difficult to prove...), sensors can be installed on the shaded side of the trunk.
- use a protective shield extending lower over the trunk.
- after measuring temperature gradients without heating, a time-dependent model can be ascribed from climatic variables (air temperature, global or net radiation, etc.) in order to correct the measured output.

c- Sapflowmeters

- be sure that no water is flowing at the vicinity of probes during and after rainfall.
- removing the probes from the tree: often difficult, even impossible!
- after long term measurements (4 to 12 months), some troubles in the measurements may happen, which are linked to the sapwood wounding leading to a lower sensitivity and therefore underestimation of sapflow, drift of the output.

Those problems can be detected in the processed files. It is therefore necessary to process the data files (collected every week if possible) as soon as possible.

One of the problems is the drift of ◎T(0) during a succession of days: its value (zero flow conditions) depends on the thermal characteristics of the wood at the vicinity of the heated probe. When a wound occurs, as provoked by drilling a hole, xylem may dehydrate and the thermal conductivity between aluminium cylinder and sapwood decreases. Therefore ◎T(0) progressively increases (this can be observed over a 7-10 days periods). But in some species (see Waring and Running, 1978 in Douglas-fir), water stress also provokes a decrease in sapwood moisture and therefore an increase in ◎T(0); in this case, this drift is observed on each sensor, and rehydration by rainfall is be followed by a decrease in ◎T(0).

5 References

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Waring R.H. and Running S.W., 1978 - Sapwood water storage: Its contribution to transpiration and effect upon water conductance through the stems of old-growth Douglas-fir. Plant, Cell, Environ., 1, 131-140.