EMS Brno

Data Acquisition Environment

Hardware – Software – Cloud application

www.emsbrno.cz

Sap flow system EMS 81

With internal datalogger composed of

MicroSet 8X

and

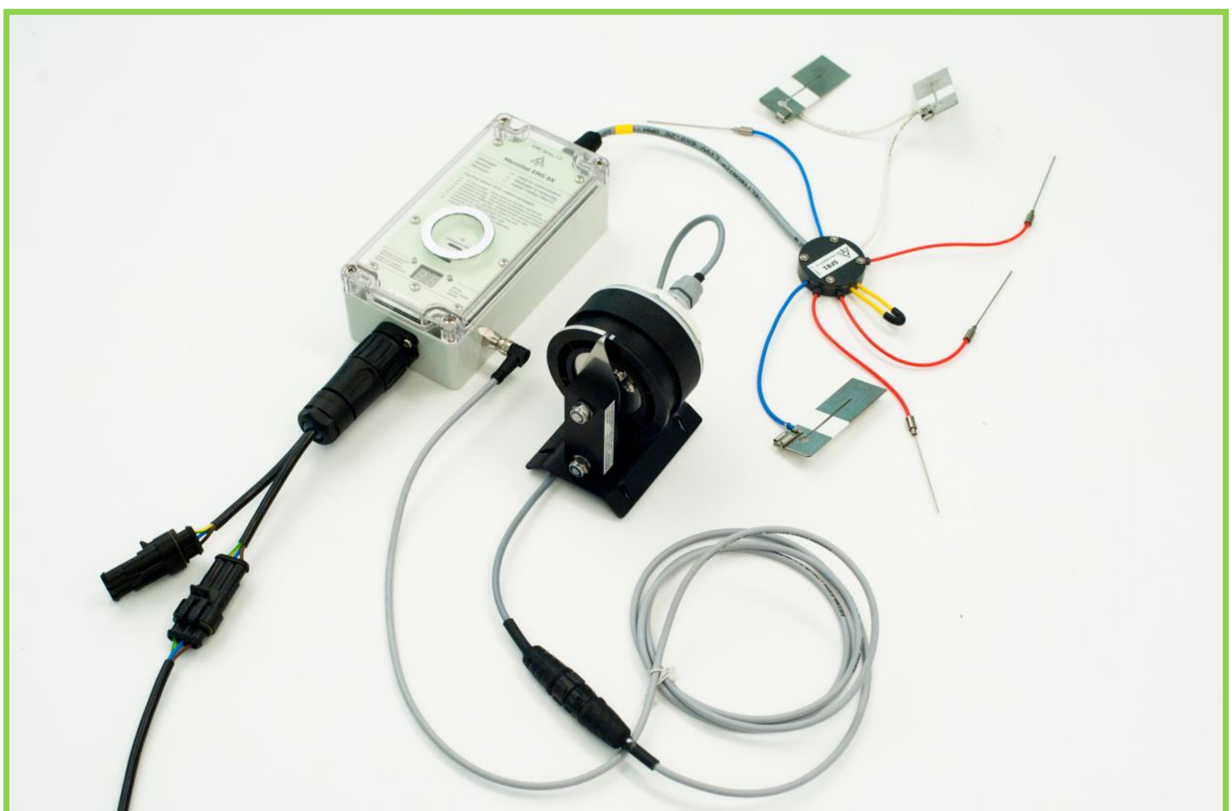
Sap flow sensor SF 81

and (optionally)

Stem Increment sensor DR26E

User's manual – 3-rd issue

Febryary 2018



Content:

1. Introduction

EMS 81 is the most recent version of sap flow system based on a tissue heat balance (HB) method. Since 1973 when it was established, the instrumentation was seriously upgraded and theoretical background was developed and verified.

The biggest advantage of this approach is direct heating of relatively large volume of xylem which brings high accuracy of the sap flow estimation.

The technology is relatively energy demanding (but comparable to other sap flow systems), the measuring unit is quite sophisticated and therefore also expensive but the underlying theory is clear, without any uncertain empirical parameters (*Tatarinov et al. 2005*) and without any need for field calibration.

Latest system EMS 81 enables connection of the sensor for continuous measurement of stem increment. This additional device synergistically increases the value of measured data (i.e. indirect estimation of the stem water potential, calculation of water use efficiency).

2. General features

Measuring system consists of the MicroSet 8X controlling unit, sap flow sensor SF 81, set of stainless electrodes, weather shields and connecting cables.

MicroSet 8X is the advanced electronic unit intended for measurement of sap flow rate using the HB method. Its hardware can support various sensors for sap flow measurements, depending i.e. on the size of the stem or branch. MicroSet 8X maintains set temperature difference between measuring and reference part of the sensor which is done by varying the heating power. Firmware of the unit can be sensors specific if necessary. The electronics is designed for maximal energy efficiency and flexibility in terms of connected HB sensors.

The unit contains datalogger and additional input for stem increment sensors with potentiometric transducer (i.e. DR26E).

Note: The electronics of the unit is quite complex due to following reasons:

- *It must supply heated xylem with alternating current in order to avoid electrochemical processes in the xylem tissues*
- *It must keep preset temperature difference between heated and reference parts of the measuring point (computed as the average value from three points) with accuracy better that 1 %.*

- *It must calculate exact effective value of power of non-sinusoidal power voltage*
- *It has to supply the load with the resistance between 200 to 25,000 ohms with the power ranging between 0.1 to 5 Watts*
- *It has to keep the overall efficiency of the electronics above 80 % in the whole range of operation.*

Sap flow sensor SF 81 is intended for continuous measurement of volumetric sap flow in tree trunks larger than 12 cm. The measurement values are nearly independent on the radial profile of sap flow density. The sap flow values in [kg h^{-1}] are calculated directly according to the sensor parameters in EMS Mini32 software.

Stem increment sensor DR26E

DR 26E is designed for long-term measurement of tree trunk circumference by stainless tape that encircles the tree trunk. Its length variations are measured with a rotary position sensor. The sensor output is either exact voltage or voltage divider ratio.

3. Measuring principle

The measuring principle is based on the HB method with internal heating and sensing *(Kučera et al.1977, Čermák et al. 2004)*.

Three stainless steel plate electrodes are used as terminals leading a.c. electric current to xylem. The xylem volume around electrodes is heated by flow of electric current among the electrodes. Insulated part of electrodes avoids passing of electric current through high-conductive phloem. Part of the heating energy is dissipated into the surroundings by heat conductivity of the xylem tissue while the rest is carried away by sap flow. Calculation of sap flow is based on the amount of heat carried away by the sap flow, which is computed from the power needed to maintain set temperature difference between heated and non-heated part of the stem.

3.1. System description

Measuring system consists of the MicroSet 8X controlling unit, sap flow sensor SF 81, set of stainless electrodes, weather shields and connecting cables.

The measuring point at the tree is protected against ambient factors, mainly against direct sun irradiation by means of reflective insulating weather shields. It reflects the sunshine and reduces the effect of the ambient temperature on the heat field. It also protects sensor against heavy rain and wind although a little wetness on the stem does not affect measurements.

The stainless electrodes (terminals) are hammered into the stem using special tools. The electrodes have to be inserted in parallel, according to installation manual. It is highly recommended to follow instruction for installation since even apparent details might be crucial for the accuracy of the measurement.

Thermosensor needles are inserted into the geometrical center of the part of electrode inside xylem. Highly conductive steel equalizes radial differences in temperature of the sapwood and allows measurement of mean xylem temperature.

Electronic unit controlling the measurement, MicroSet 8X, is attached to the sap flow sensor SF 81 and is hanging below the measuring point. It has a two-digit seven-segment display which, when activated by the magnetic head of communication cable, shows the status of the unit, mainly potential errors. Meaning of the symbols is explained on the front panel of the unit.

The unit is well protected against reverse polarity of powering and overvoltage (by solar powering, the voltage can reach up to 25 V when the battery is disconnected). The power supply is connected by robust connector on the bottom of unit.

Since the sensors contain built-in datalogger, they are principally independent on a data acquisition system. Therefore, there are two versions of power cables: cable for separate battery or cables for power network.

In the first case there is only one cable for connection to the 12 V battery, mostly with clips for fast connection to any type of battery terminals. For easy connection of more units to a power network, there is another power cable available with 'Superseal' connectors of different gender on their ends. Neighboring units are connected by standard 12 m or 8 m long cables in a chain. With a simple splitting box there is the possibility to create up to six individual chains of units (sensors). Since all cables have three wires, the network is ready for future connection to SDI-12 datalogging system.

3.2. Arrangement of the measuring point

Temperature of heated xylem is measured by needle sensors inserted in slots to the geometrical center of electrodes. Reference temperature related to non-heated part of stem is measured also in the slot in the same type of electrode installed 100 mm downwards. This arrangement provides thermal symmetry of the temperature sensing; it is significantly less sensitive to radial temperature gradients caused by daily changes of ambient temperature.

Temperature of a heated space along metal electrodes is quite uniform due to their high heat conductivity what makes the measurement nearly independent on the radial sap flow profile. There are three available lengths of electrodes (60, 70 and 80 mm) covering 25, 35 and 45 mm of sapwood depth. Considering the sap flow density decreasing with depth, those electrodes should cover main part of water conductive profile of most of tree species.

3.3. Sap flow calculation

The heat balance of xylem through which sap flows can be described by the general equation:

$$P = Q*dT*c_w + dT*z \qquad [1]$$

where P is power of heat input [W], Q is sap flow rate [kg s^{-1}], dT is temperature difference within the measuring point, c_w is specific heat of water [J kg^{-1} K^{-1}] and z is coefficient of heat losses from the measuring point [W K^{-1}]. Amount of water in terms of mass or volume passing through the measuring point in a stem is calculated from the power input and temperature rise of water passing through the heated space.

Calculation of sap flow derives from the equation [1]:

$$Q = \frac{P}{c_W * d * dT} - \frac{z}{c_W} \quad [\text{kg s}^{-1}\text{ cm}^{-1}] \qquad [2]$$

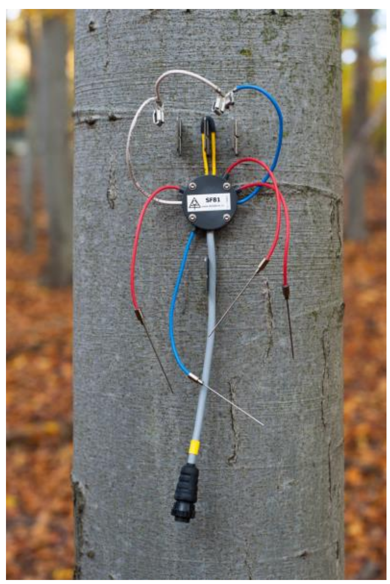
Where d is effective width of measuring point (5.5 cm). First term of this equation quantifies heat that is conducted by sap flow. Second term represents heat losses from the sensor, which can be estimated when sap flow approaches zero, i.e., during the rain or at night before sunrise. Supporting software Mini32 includes an option for easy graphic baseline subtracting.

Since the measuring point captures just a part of trunk cross section area, the output value has to be in terms of sap flow per unit of trunk circumference. Because this measuring method in nearly independent on the radial sap velocity profile, the output value is calculated in terms of sap flow per one centimeter of stem circumference. Whole tree sap flow is then calculated by multiplying the unit sap flow by stem circumference at cambium.

4. Operation

4.1. Sensor location on tree trunk

Sap flow sensors SF 81 may be installed on trunks with diameter larger than 12 cm. Fundamental criteria for location of measuring points on tree trunk are the homogeneity of tissue and height above ground. Highest temperature gradient which may interfere with the measurement occurs close to ground surface. Therefore, measuring points should be placed at least at the height 1 m above ground but still below the living crown. Stem tissues in the place of future measuring point should be homogeneous enough, i.e., with no irregularities such as knobs, mechanical or biotic injuries, or anything else that may affect normal xylem water flow. All possible circumstances should be considered at this point. Take into account the necessary space around the measuring point where the weather shield should be fastened.

In order to reduce the influence of natural variability of sap flow along the circumference of large or irregular tree trunks, two measuring points on opposite sides of tree trunks could be installed. This might be also useful in stands with complex soil conditions, in trees growing on slopes, etc. The whole tree sap flow is calculated as an average from sap flow values measured on both sides. However, with respect to the often limited budget, sap flow is usually measured only from one side of the trunk. Only when there are reasonable doubts about the regularity of sap flow along the stem circumference, two measuring points on one tree might be installed.

4.2. Sensor installation

In order to set up the measuring point at tree trunk properly it is necessary to have a certain standard level or surface (i.e. uniform bark thickness). Smooth bark surface of some species is convenient but sometimes is necessary to smooth the bark artificially. This may be done with a sharp drawknife. The bark and phloem thickness has to be less than 15 mm above the cambium. Attention must be paid to prevent any damage to living tissues below the cork layer of bark.

When two measuring points on the opposite sides of tree trunk are installed, they should be either in the same height (large trunks) or vertically separated by more than 30 cm (especially for thin trunks) to avoid warming of reference electrode from the opposite measuring point and also to allow setting up the weather shield.

The sensor installation requires special tools in order to hammer electrodes properly:

The installation process consists of following steps:

- bark and phloem thickness measurement
- hammering of electrodes
- cleaning slots in electrodes with a special rasp
- hanging sap flow sensor SF 81 on the central electrode
- inserting of thermosensors into slots in the electrodes
- connecting heating terminals to the electrodes
- connection of MicroSet 8X unit to the sensor
- connection of power cable to MicroSet 8X
- covering of the sensor by the weather shield

Note 1: It is good idea to run the measurement before installation of weather shield. In case of problem one can easy check the installation.

Note 2: When connecting the sensor to the unit it makes sometimes problems to find right position of both parts. Here are matting instructions of manufacturer:

First, align the notched keyway on both the panel mount and cord connector. Then, push the cord connector onto the mating connector. Grasp the coupling ring between the slots, push it toward the panel mount connector and rotate it clockwise nearly one half a turn. Continue rotating until you feel the coupling ring ride over the locking "bump". This is the locked position. The cord connector is not securely in place unless this procedure is followed.

The electrodes of proper length should in principle cover most of water conductive profile. The available electrode types (60, 70 an 80 mm) cover 25, 35 and 45 mm of sapwood depth. Therefore, general knowledge of the sapwood size and properties is necessary. On the other hand, the method is not too sensitive to the estimation of sapwood depth and bit longer electrodes are generally better that short ones. Weather shield protects the measuring point and the stem below it against direct sunshine and partially against rain.

The hammering of electrodes may seem as a horrible attack on tree tissues. In reality, sliding of thin stainless plates to the xylem is less disturbing that drilling holes that leaves saw dust inside the stem disrupt vessels above and below the hole and leads to cavitation of vessels around the hole.

Correct installation of measuring points on trees is an ultimate prerequisite of getting correct results. Interaction between sensors and living tissues belongs to important points of this type of measurement. From this point of view each type of HB sensor is a compromise between accuracy and interference with living organism. The more elements are installed into the tissues, the more is affected the water-conductive system at least in terms of water pathways and water potential.

See installation guide for description of the whole procedure.

4.1. Start of the measurement

The system runs immediately after connecting to power. **Note that high voltage can appear on the heating terminals. Never run the unit not properly connected to electrodes!** The operation after the system was set up does not require any human intervention.

Note that the system is automatically switched off when the power voltage drops bellow 10 V. The necessary voltage for restart is 11.7 V in order to avoid on/off oscillations under flat battery status.

The indicator of running sap flow measurement is the **green LED** that flashes every five second when the sap flow measurement is running.

The display shows some additional information as described in section (4.2.4) periodically when the datalogger in measuring or after putting the magnetic head of IrDA/USB data cable on the unit.

4.1.1. Connection of systems to power

The idea of independent sap flow sensor with its own datalogger brings a lot of flexibility into the measuring layout.

Sensors with individual small batteries can be spread over large area or they can be installed on one experimental site connected to one big battery or solar system.

Multiple sensors connection can be arranged as one or more chains (closed or open). Simple splitting box is available for easy branching.

The connecting cables are available in two standard lengths 8 m and 12 m. They are equipped with *Superseal* connectors (approved by automotive industry) what makes cables cheap and sturdy.

The cost of one cable is roughly equal to the price of industrial connectors. In case of cable damage by animals they can be easily replaced.

Note: Superseal connectors are connected to measuring unit by another robust 7-pin Amphenol C-16 connector. This way the connecting assembly can be easily replaced in case damage (mostly by rodent) and also the whole unit can be displaced until the powering chain is broken.

4.2. Set-up of the measuring unit MicroSet 8X

4.2.1. Preliminary remarks

The unit consists of two main parts – electronics controlling measurements and the datalogger. There is a two way communication between datalogger and controlling electronics. First, datalogger saves data provided by controlling electronics. Second, the datalogger has to mediate communication between computer and electronics controlling measurements when setting up the measuring part.

The unit operates principally in three modes that depend on the power voltage:

4.2.1.1. Between 10 to 16 V when the unit was not turned off due to low voltage (below 10 V)

The system works normally, e.g. sap flow part is running, logger is collecting data. Power consumption depends on the sap flow rate, preset temperature difference and a little also on the resistance between electrodes which influences the power efficiency.

4.2.1.2. When the voltage is over 7 V but the powering of sap flow measurement is off (due to a recent voltage drop below 10 V)

It means that the battery is nearly flat or recharging. The sap flow part has been turned off because the low voltage. Yet, under this situation the datalogger still measures and saves data on increment and internal temperature.

4.2.1.3. The battery is totally flat or disconnected.

The datalogger is set out of operation and power is supplied from internal back-up battery. The current consumption dropped to ca 2 μA just to keep running the internal clock and to be ready to wake up by magnet or by power voltage. The display is out of operation. The internal back-up battery will last under this condition for ca 10 years. **Important: Even in this mode the unit is ready for configuration or data download! On the other hand – under communication mode the battery is slowly depleting. Never let the magnetic head of the communication cable put on the unit longer that it is necessary.**

4.2.2. Datalogger configuration

4.2.2.1.1. General notes

The datalogger of the unit can be configured in two modes:

A/ Standard mode. Three variables are recorded:

- Sap flow in [kg h^{-1} per tree] or in [kg h^{-1} per centimeter of circumference]
- Stem increment [mm]
- Internal temperature. This variable is partially affected by heat loss of the electronic and therefore provides only rough information on weather conditions.

B/ Advanced mode. Besides of previously mentioned, six other variables are recorded in this mode allowing deeper knowledge of the system behavior:

- Electrical resistance among electrodes [Ω]
- Temperature difference of left electrode [K]
- Temperature difference of central electrode [K]
- Temperature difference of right electrode [K]
- Error status of sap flow measuring module [-]
- Power voltage

The recording mode can be changed only during initialization of the datalogger.

4.2.2.1.2. Communication with datalogger

Communication with the unit requires PC with operating system Windows XP or later with running Mini32 software produced by EMS. This software supports communication and operation with EMS systems and dataloggers. It is intended for viewing and processing of long-term data series on professional level.

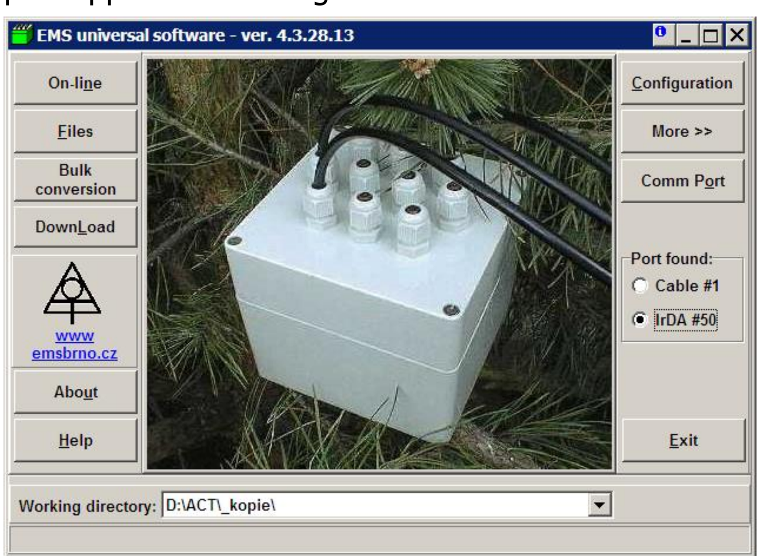
For wireless communication with the unit IrDA/USB data cable manufactured by EMS is necessary.

The unit can be configured also without external powering (chapter 4.2.1.3).

Note: The unit is activated by putting the magnetic cable head on the metal ring at the unit. Then, the system is ready for communication only for 20 seconds. During this time the Mini32 has to start to communicate with the unit. Otherwise the unit has to be woken up again by moving the cable head out of the unit and back there again.

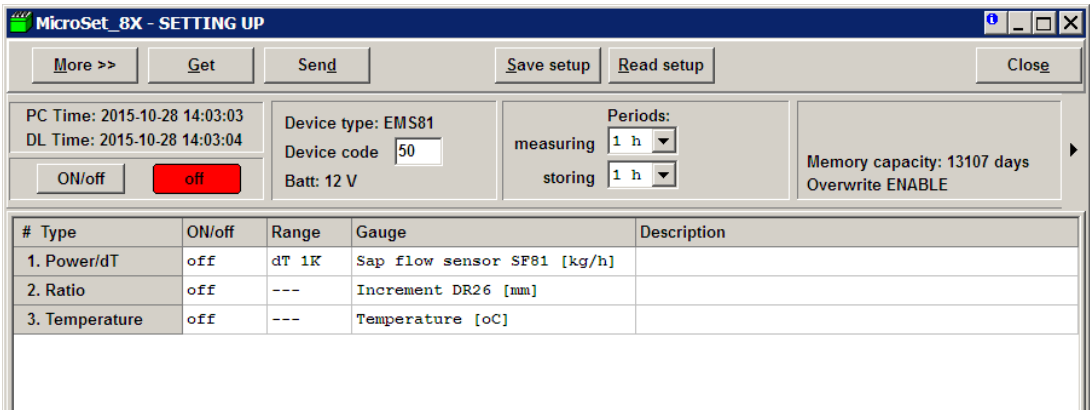
4.2.2.1.3. Configuration process

- Run Mini32. Make sure that you have the latest version. Newly-made instruments need updated software otherwise the software responses with 'Unknown device' message. Download the Mini32 software version from USB memory stick attached to delivered instruments.
- Connect the IrDA/USB data cable. Make sure information about the cable port appears on the right side of the Mini32 main screen.



- Put the magnetic head of IrDA/USB data cable on the metal ring on the lid of measuring unit. The display on the unit should respond with "**rd**" – ready for communication or with "**Lo**" when the sap flow measuring module was recently set off due to low voltage.

  In case when the battery is disconnected or totally flat, the green LED in lower left corner of the unit will indicate that the unit is also ready to communicate but it runs from the internal battery. Never use this mode longer than it is necessary. Remove the magnetic head of the communication cable as soon as you finish.
- Push "Configuration button" (not later than within 20 seconds after activation of the unit). By new units, the factory default configuration is displayed:



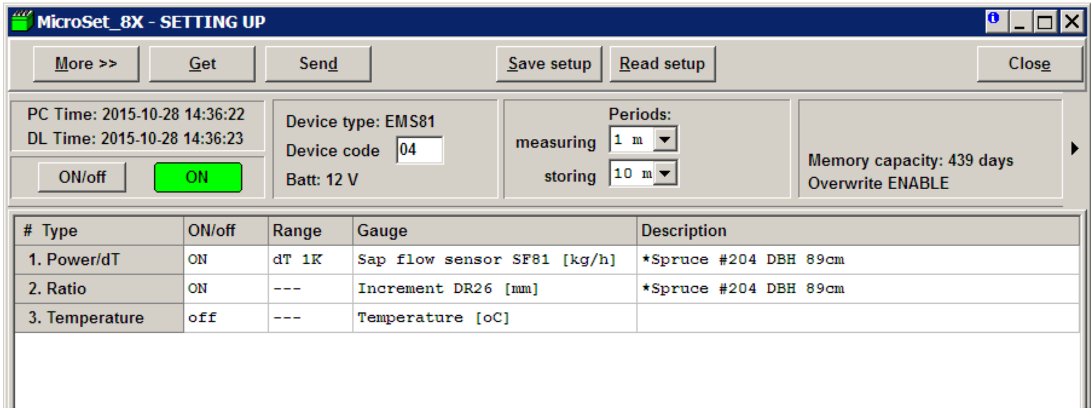
The screen shows computer time (clock time) and time of datalogger. Note that the datalogger time should be always solar time – Mini32 sets during initialization always solar time according to local computer setting independently on the season.

The actual status shows:

- System is off
- Battery Voltage is 12 V: the system can start (higher than 11.7 V)
- Device code is '50': these two characters are two last numerals of the serial number.
- Time periods means, that switched on, the unit would measure values each hour and store these values into the memory.
- Memory capacity provides information on available memory when the unit is on
- Measuring channels:

All channels are off, the set temperature difference in the measuring point (as the mean value from all three electrodes) is 1 K. There is no channel description.

Example of custom configuration:

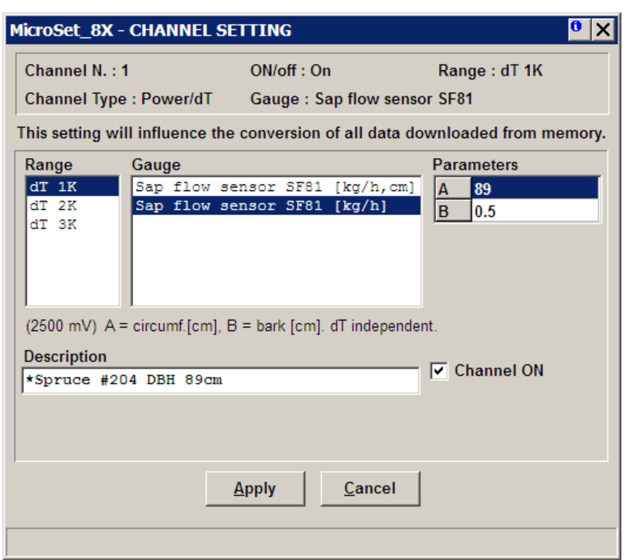


- System is on. It will record sap flow values when the voltage is over 10 V and if it have not drop below 10 V recently. Otherwise it will continue measuring the increment until the voltage drops below 7 V when datalogger switches off.
- Device code (alphanumeric code, unfortunately two characters only to maintain compatibility with older systems) is set by user, for example as a tree number.
- Time period of measurement – measuring every minute and storing of ten-minute averages is a common practice. The memory will last for more than one year as displayed.

First two measuring channels are on; internal temperature of the unit is off. Temperature difference in the measuring point is set to 1 K. Sap flow is calculated as whole tree value [kg h^{-1}]. Both active channels contain user defined description mentioning tree number and stem diameter.

Note: the asterisk regards to Y-axis description in graphs. When the channel description is missing, the graphics use 'Gauge' name instead of it. If the text of description begins with asterisk, both gauge name and description are displayed.

- Channel setting opens after double click on the appropriate line:



All information relevant to opened channel can be edited in this window:

- Preset dT
- Sap flow calculation; whole tree or per cm of circumference. In the first case (displayed), the stem circumference and bark and phloem thickness has to be filled in. The following calculation will consider the circumference in cambium layer.

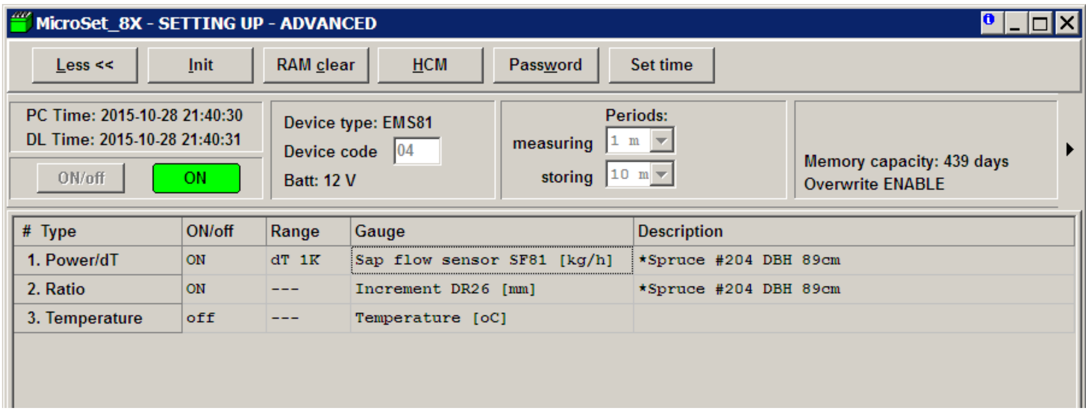
By other channels, there is nothing to edit – just to set them ON or OFF.

- When all setting is finished, push "SEND" button – the configuration will be send to the datalogger.

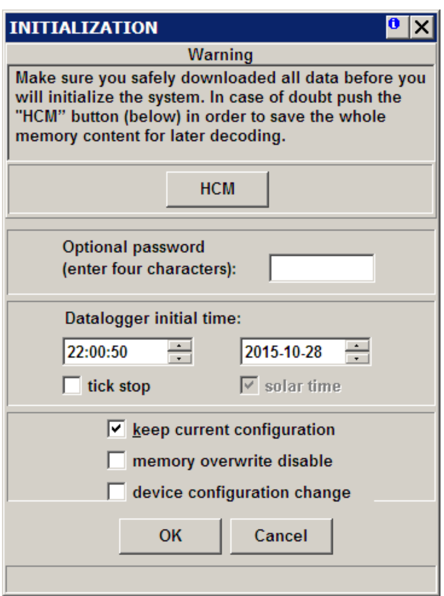
4.2.3. Process of initialization.

Initialization erases memory of the datalogger and synchronizes datalogger time with PC time. During the initialization is possible to switch between standard and advanced mode of operation.

Enter 'Configuration' and then push 'More'. This way you enter an advanced configuration option:

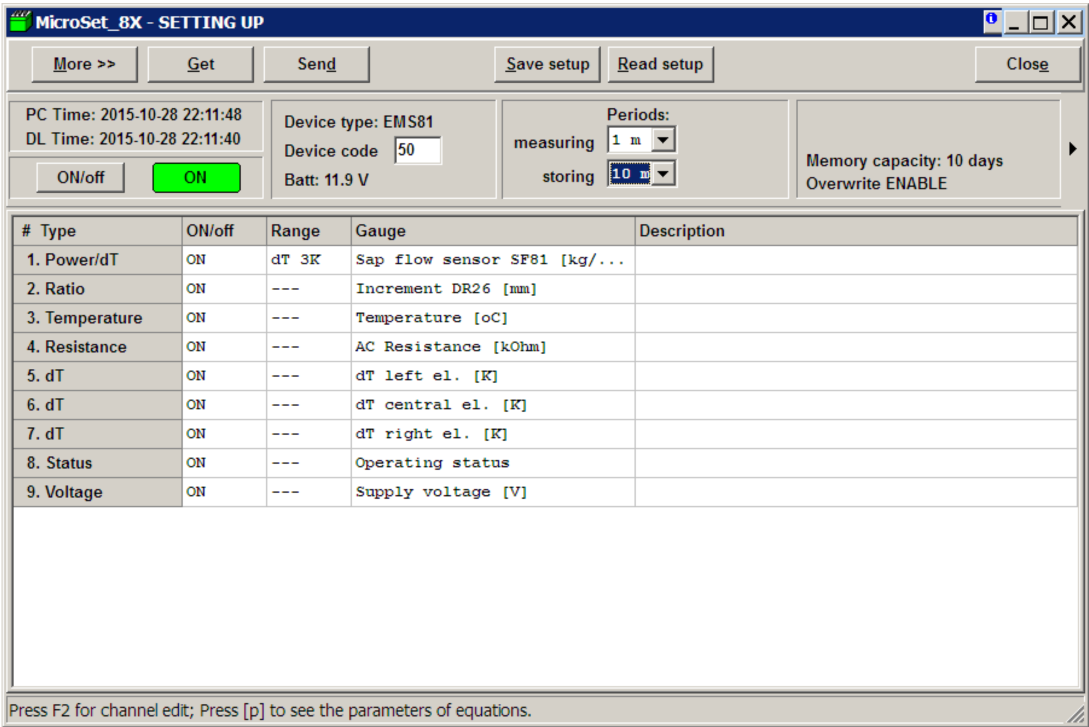


'RAM clear' deletes whole memory content but the configurations and datalogger time remains untouched.



Initialization ('Init') deletes whole memory content and offers some important possibilities like datalogger time setting, ('Set time' option available at any time has certain limits in setting time backwards) changing the memory operating mode (memory overwrite), returning to original (intact) factory setting and changing the mode of operation of the unit from standard to advanced and vice versa.

Advanced mode of operation expands the number of recorded variables for those interested in the measurement details. In this mode user can log temperature difference in all there electrodes, resistance among electrodes, power supply voltage and error status during the measurement:



After finishing the initialization, it is good idea to go back to configuration screen and doublecheck configuration of the unit.

Note: In order to keep the integrity of database the systems should be initialized when the measuring point is moved to another tree or to another side of the same trunk. Initialization means the memory erase, changing of the device code and the channel configuration – see above. Erasing the data which belong to another measured object is absolutely necessary since the calculations to physical values are made in PC according to last datalogger configuration. Without deleting of old data regarded to another object, also those data will be calculated according to new configuration what must be avoided.

4.2.4. Operating indicators of the module

A two-digit display shows the status of the unit, mainly potential errors. In order to save energy, the display shows the status of the unit at each of regular measurements and/or if the magnetic head of IR communication cable is set onto the metal ring. In such a case the system wakes up and the display is on for 30 seconds. In case of no communication attempt from connected computer with running Mini32 software during this time period, the display turns off. Next waking up of the system requires removing the head to some distance from the unit and then to put it back again.

There are also two LEDs (red and green) on the front panel on the each side of the display:

- green LED flashing each 5 seconds indicates running sap flow sensor

- red LED indicates wrong polarity of power supply. It does not damage the unit, but it is necessary to correct polarity of power voltage.

The indicators on the display are as follows:

'**nn'**–appears on the display for short time during each datalogger measurement. If there is a sap flow system malfunction, there will be an error message instead.

'**rd**' – ready for communication. It displays always when the communication is activated by magnet and the system works normally. Otherwise an error message displays followed by a warning beep.

'**rr**' – indicated the 'Regular reading' option when the logger sends on-line data to connected computer for visualization on the screen.

'**Lo**' – sap flow module was turned off due to low battery voltage. It will be reset when the voltage reaches 11.7 V of by communication with PC.

In case of a kind of problem, instead of '**rd**' or '**nn**' an error message like '**E1**', '**E2**', '**E3**' etc. is displayed. The meaning of those errors is (it is also written on the front panel of the unit):

E1 - dT out of range - steady state not reached yet

This situation mostly appears after the start of operation when the temperature difference in the measuring point hasn't reached the preset value with max. deviation ± 20%. It could also happen when the system does not have enough power to reach the presser value (high value of dT in coincidence with high sap flow rate).

Since such a situation can happen also when the dT is wrongly measured (sensor malfunction), the system switches off the heating power for some time period in order to avoid overheating the xylem. This stage is indicated by errors E5 and E6.

E2 - resistance too low - short-circuit or too wet tissues

The power booster can work only within certain range of electrical resistance among electrodes. Resistance among the electrodes can be too low when the xylem is filled by water or rotten since the metabolites of rot are highly conductive.

E3 - resistance too high - disconnected heater or too dry wood

This is similar case as above but on the opposite end of range. It indicates dry xylem of probably dead tree. The system has been switched off.

E4 - thermosensor malfunction - probably broken sensors

The input circuits of the unit can find out the disconnected of broken thermosensor. In this case power turns off.

E5 - insufficient power - sap flow at preset dT is too high

It happens when the system does not provide enough power to reach the preset value (High value of dT in coincidence with high sap flow rate).

Since such a situation can occur also when dT is wrongly measured (sensor malfunction): the system switches off heating power for some time period in order to avoid overheating the xylem.

E6 - temporarily off - run in full power for a long time

Heating was switched off because system had been running too long on full power and there was danger of overheating of stem (for instance should the thermosensors be broken).

E7 - temporarily reduced power - please wait

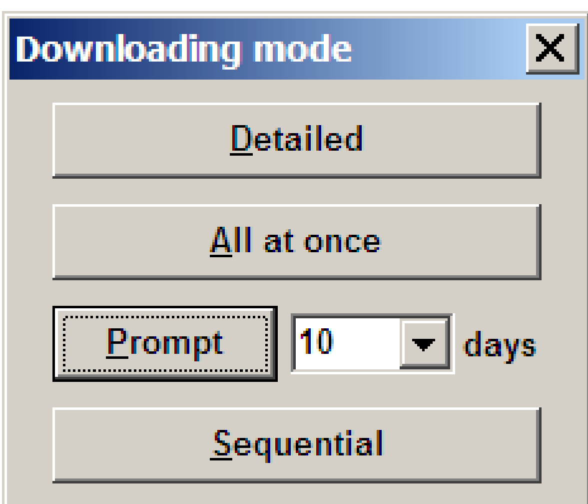
The power was reduced due to high electric current for heating. It could happen during the start in highly electrically conductive xylem.

EE - unspecified error - general system malfunction

4.3. Data download

Data download is fully supported with Mini32 software. It required a PC with Windows operating system XT or higher and the IrDA/USB data cable with correctly installed driver.

There are four different data downloading modes:

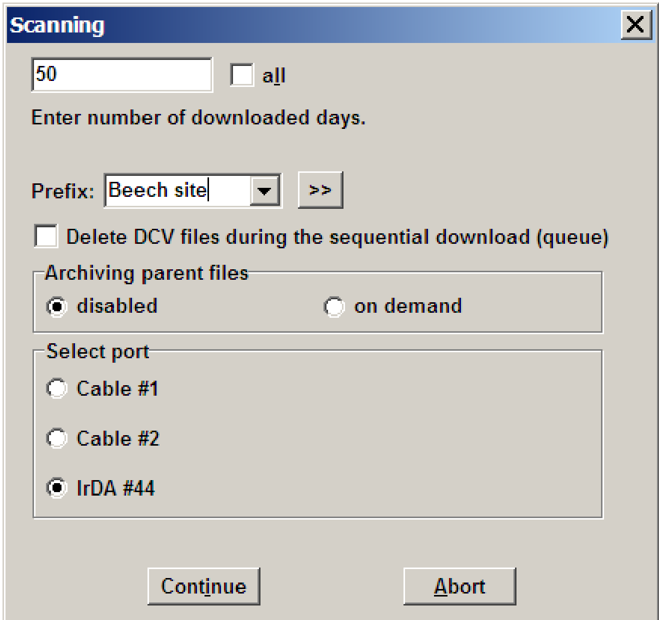


Detailed – amount of data in terms of days has to be entered, the file name can be edited.

All at once – all data in memory will be saved to file. The filename is created automatically in format "DC_yyyy_mm_dd.hex" (DC is device code assigned to the unit).

Prompt "X" days – the same as above with limited number of downloaded days.

Sequential – special option for fast downloading of more sensors in close neighborhood:



In sequential mode, the computer is continuously searching sensors. If it establishes connection, it immediately downloads the preset amount of data (in days) and saves them in file.

The file name is created automatically with optional prefix (Beech site_DC_yyyy_mm_dd.hex).
After the download, the HEX file is converted to DCV file and first four variables are displayed in two windows on the screen. This feature helps to quickly discover possible problems with the measurement.

When pushed space key or a symbol (<=) on touch screen, the software returns back to look for sensors.

4.4. Data handling

All operations with data are supported by Mini32 software. The software offers many features from data downloading, chaining files downloaded during the season into one longer file, mixing files containing data from other trees or from other measuring systems (meteorological data, soil water data) up to advanced processing (non-linear multi-regression analysis, user programming calculation etc.). Big advantage of Mini32 software is fast viewing and processing of long time series with respect to details. See 'Mini32_intro.pdf' and 'Mini32_users_manual.pdf' documents for more information.

4.4.1. Sap flow values calculation

Sap flow values are calculated according to equation (2) automatically during the conversion from downloaded HEX file to DCV file format which allows further operation.

According to datalogger configuration (4.2.2.1.3) the sap flow value can be calculated in terms of the sap flow per 1 cm of stem circumference [kg h^{-1} cm^{-1}] or per whole tree [kg h^{-1}] according to formula:

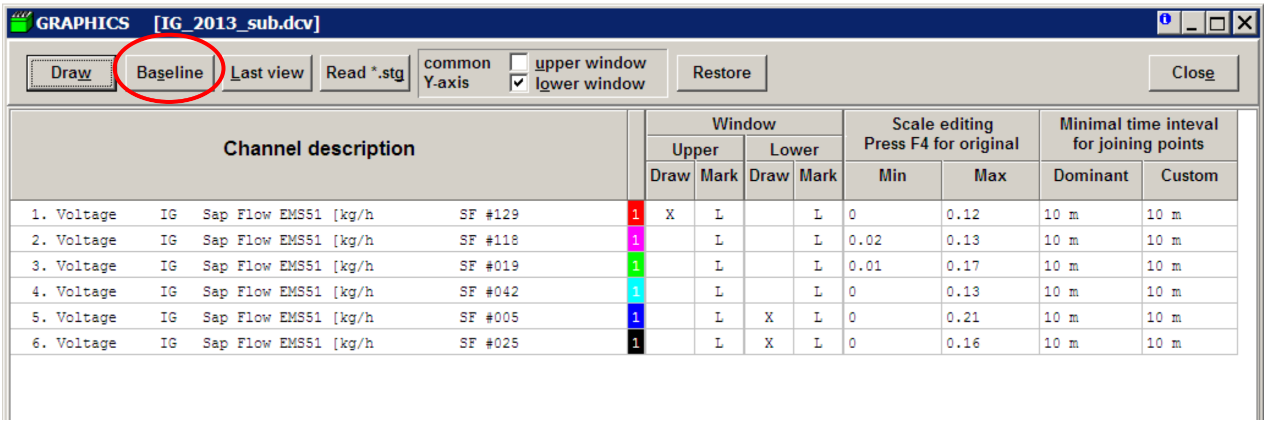
$$Q_{tree} = Q*(A - 6.28*B) \quad [\text{kg h}^{-1}] \qquad [3]$$

Where A is tree circumference in [cm] and B is the thickness of bark and phloem [cm].

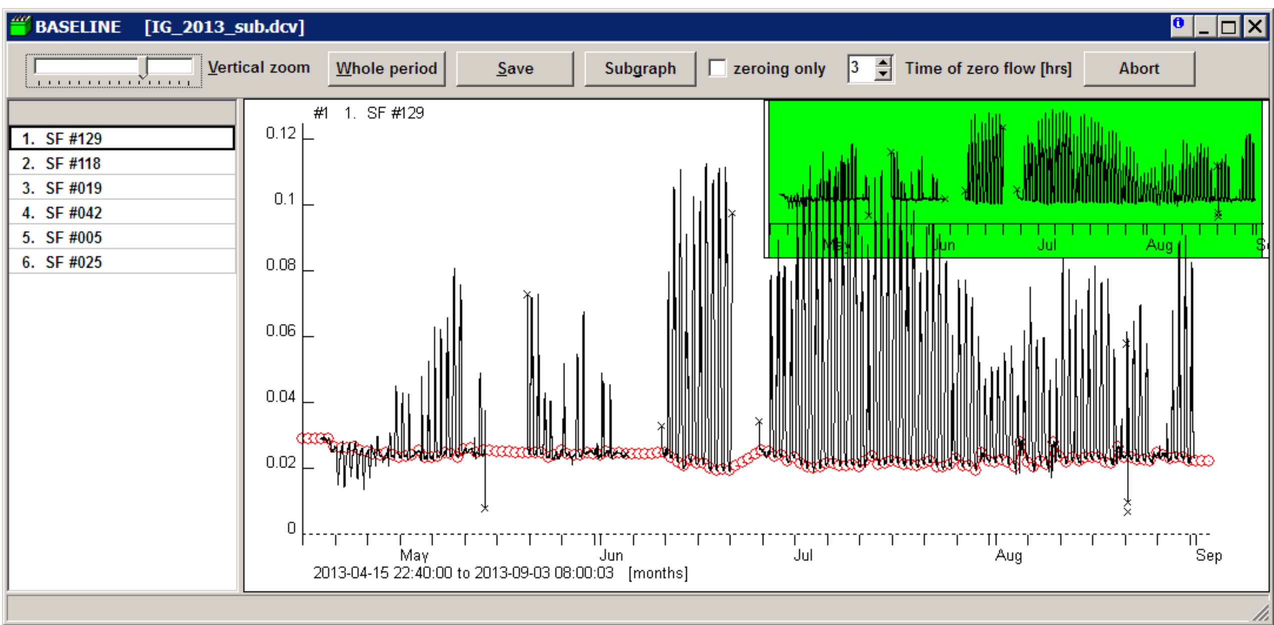
4.4.2. Baseline subtraction

Calculated values still include that part which represents heat loss by heat conductivity of xylem. In order to get 'net' sap flow data, it is necessary to manually subtract baseline representing the 'fictitious flow' due to heat loss from the heated space.

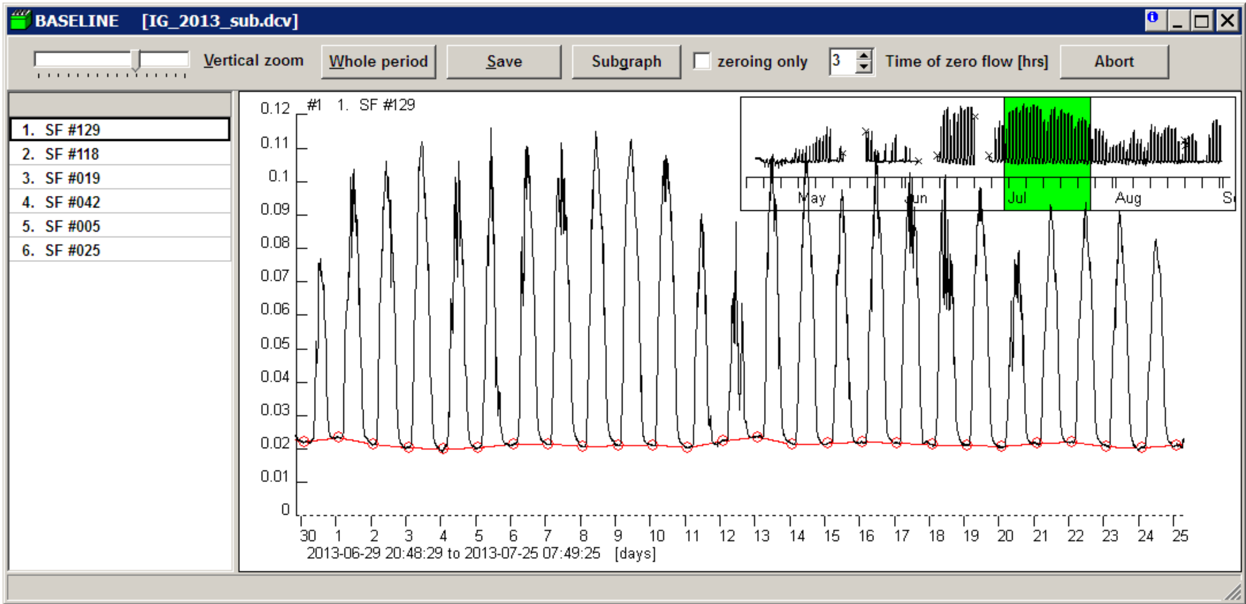
Mini32 software is ready for graphic subtracting of the 'baseline' that represents heat losses from the measuring point (see Eq. [2]). This option is offered in the graphic setup screen:



When entering the 'Baseline' option another graph showing measured variables is displayed:

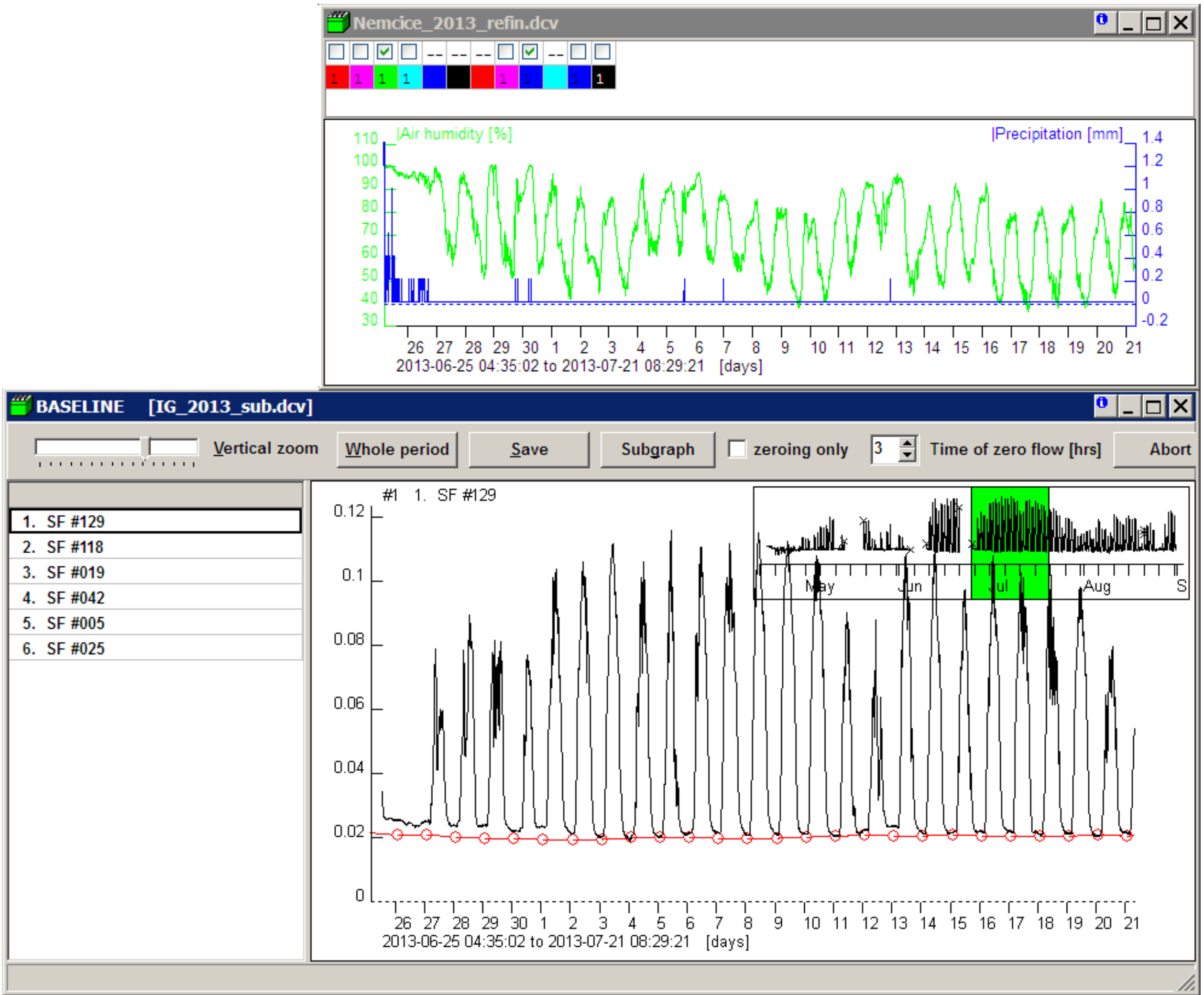


The part in a green window shows whole time period for the case of zooming of a main graph:



The red line with circles is created automatically – it connects values at 3 a.m. when the lowest or zero sap flow is expected (this time point can be changed if necessary in the gray window above the graph). The task of baseline subtracting is to adjust this line the way which should represent the heat loss. This part of data processing requires user's cooperation. In some cases sap flow can be considerably high even in the night (i.e. when there is still a significant vapor pressure deficit or the sap flow continues because of low tree water potential due to insufficient soil water supply). Then user has to move red circles in vertical direction in order to create the line in terms of sap flow which will be subtracted from recorded values.

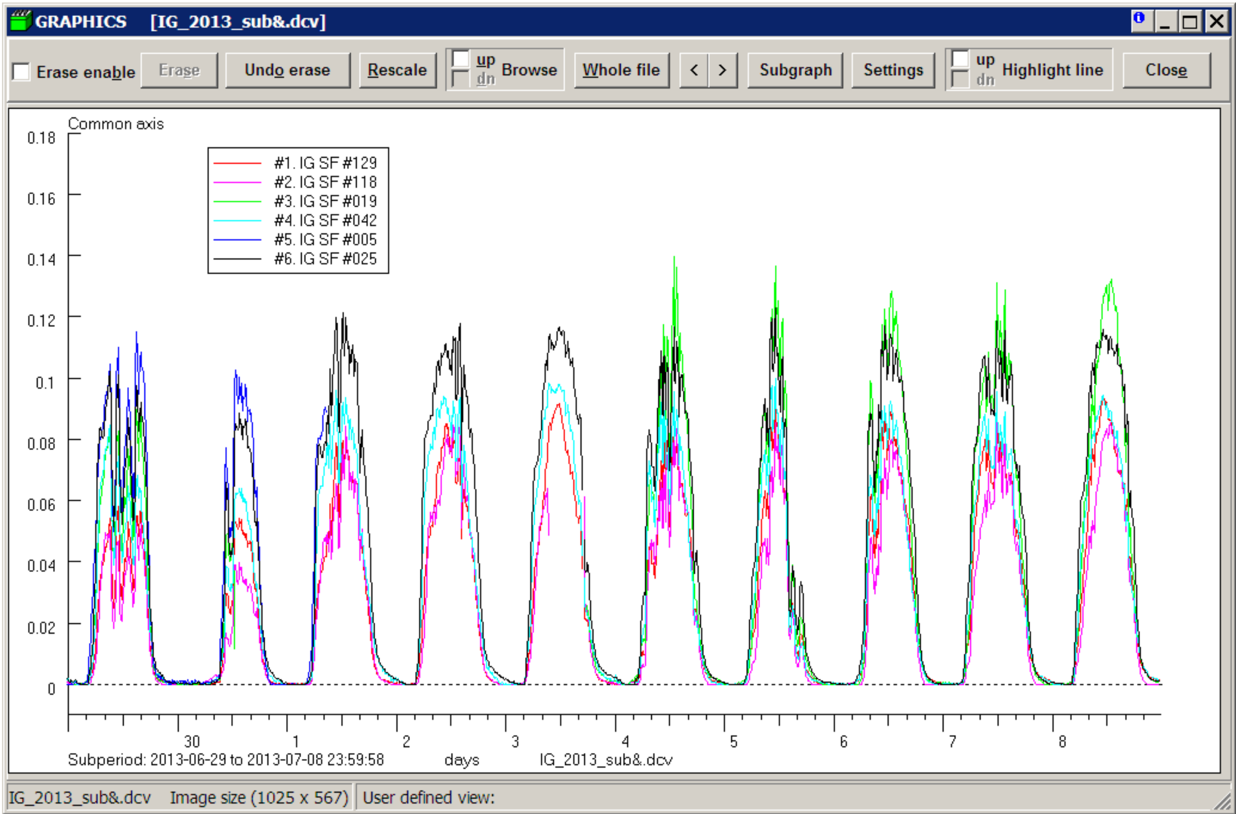
If more information is needed (for example about vapor pressure deficit), another graph with relevant meteorological data can be displayed; the values can come either from the same or from different file ('Subgraph'). The right position of the 'subgraph' window on the screen has to be set manually, but the main advantage of this arrangement is that the time axis of 'subgraph' window moves synchronously with main graph. The whole working environment then looks like this:



The air humidity and precipitation variables were selected in the upper window. There are only a few nights with high air humidity and also only four rainy events with the 0.2 mm of precipitation only. The baseline created with respect to those weather conditions for selected subperiod of time is shown.

This process has to be done for the whole time period and for all measured trees. Finished baseline has to be subtracted from each variable (offered in pop-up menu).

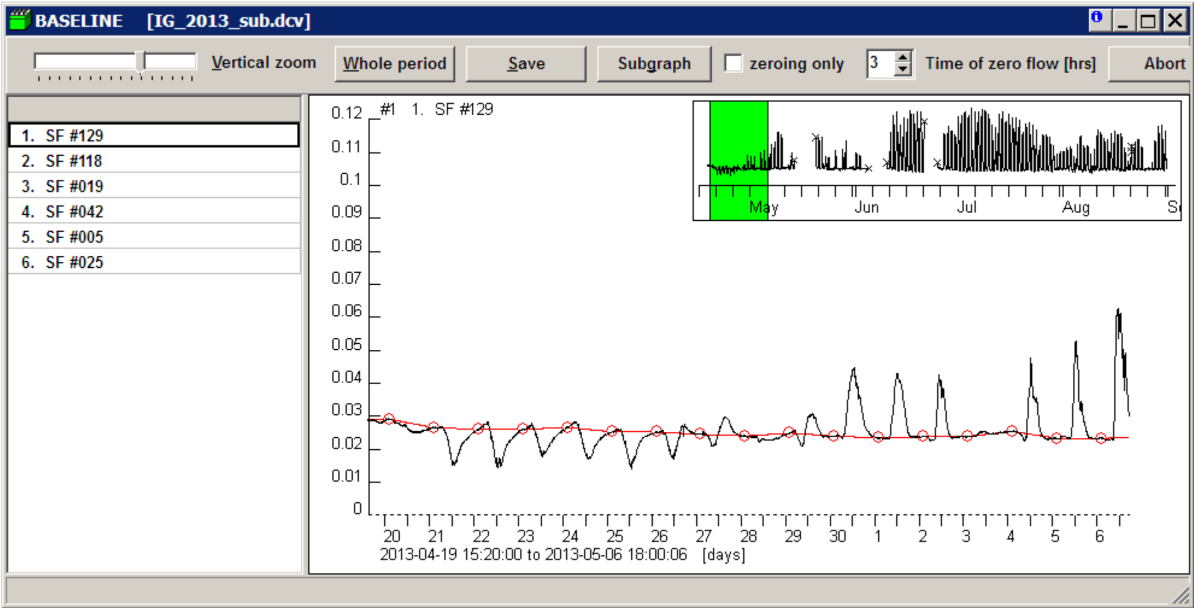
When all variables are processed, new file with '&' behind the filename is created and saved:



Baseline business is the trickiest part of data processing. The HB method working with low value of temperature difference (in order to save energy) is sensitive to external disturbing factors (like ambient temperature gradients, temperature inhomogeneities inside the measuring points etc.) under very low water movement.

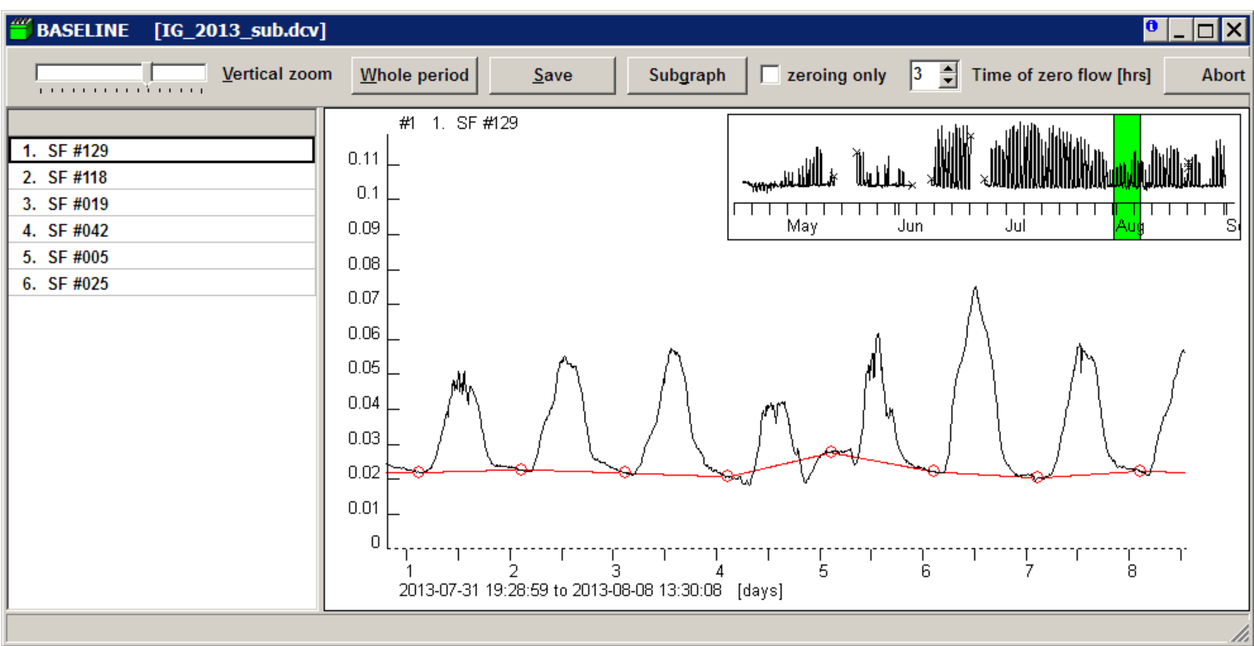
The baseline as the level of heat loss should be theoretically a straight line with little deviations due to change in stem water content and growth. However, some other factors like rain or fast temperature changes are interfering with theory. The only what really helps is practice and good understanding of the method.

Here are few examples which could help:

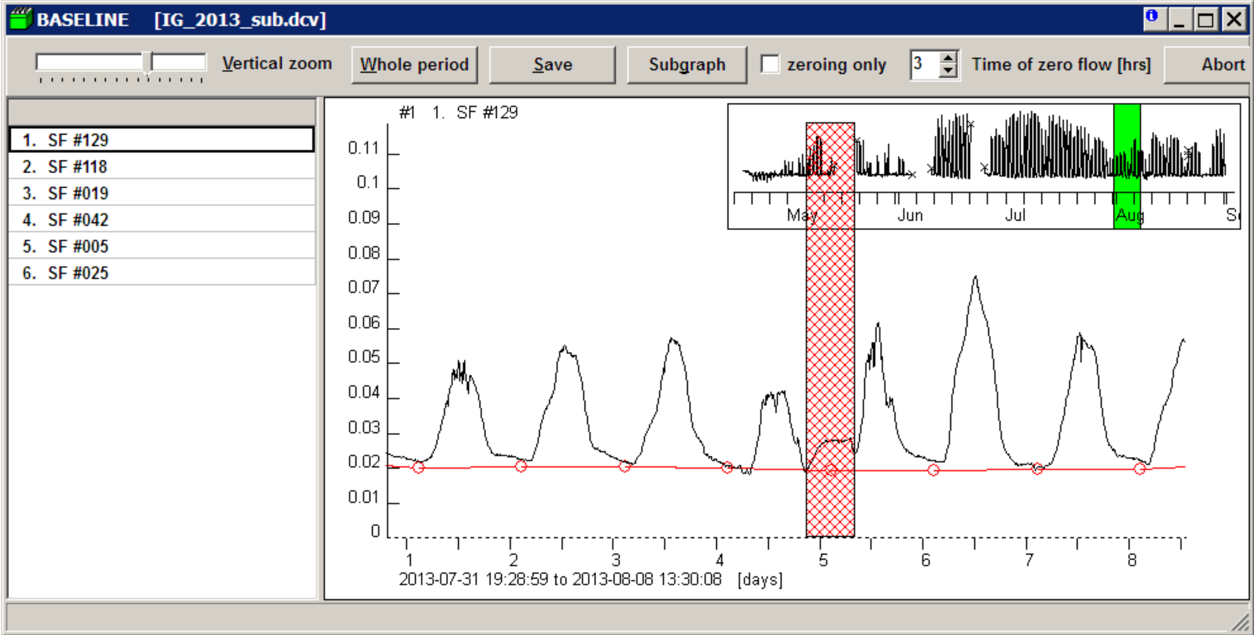


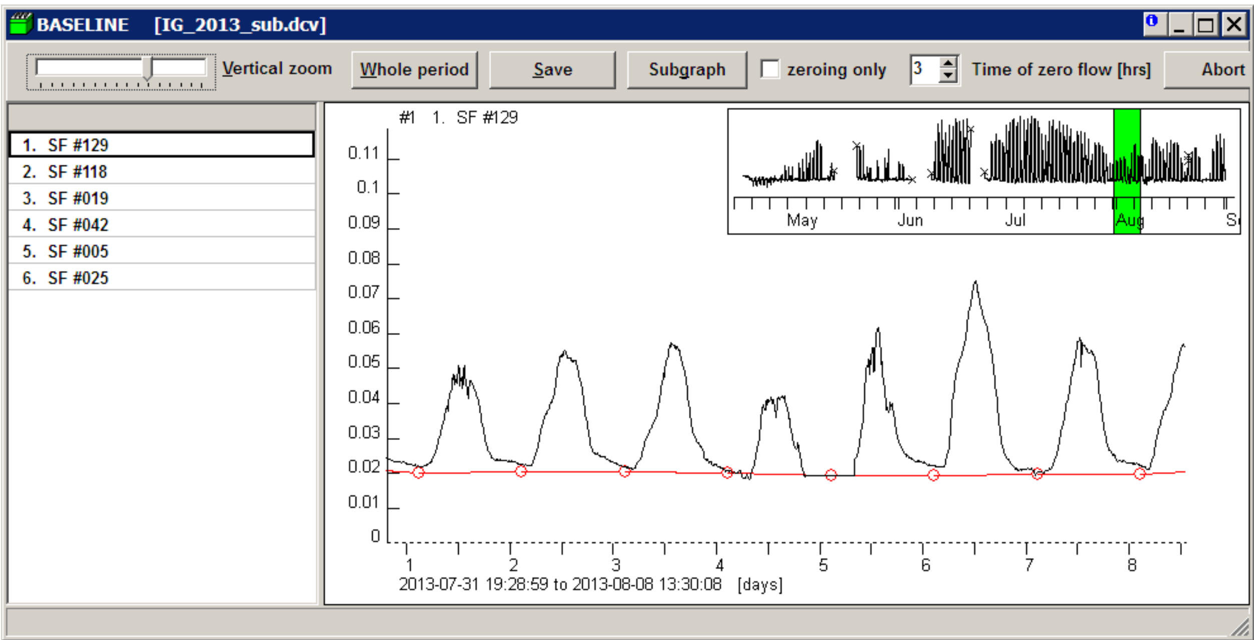
Typical situation at the beginning of growing season: European beech after the bud break. The strange pattern in days with 'negative' sap flow values can be explained by high vertical temperature gradient within the stem or outside. The system reduced power because this gradient helped to reach set temperature difference. The situation improved with the first leaves – the water stream 'smoothes' disturbing gradients.

Here the stem flow (beech!) disturbed the measurement:



The baseline has to be shifted downwards and the false night values have to be set to zero (mouse click + Ctrl):





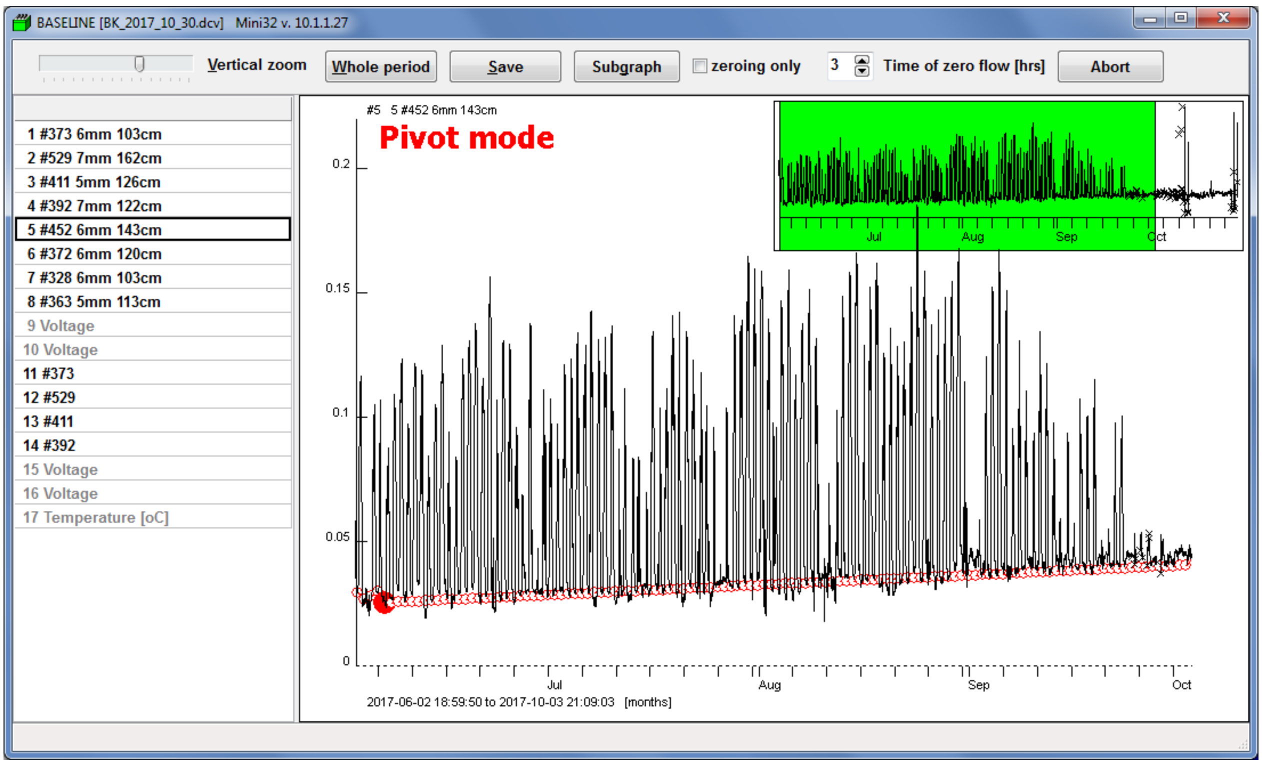
Note that the false values are not deleted but set to zero!

4.4.2.1.1. Pivot mode

The most recent approach to baseline is based on processing of huge amount of data files. The general idea is that the baseline should be straight line slowly rising up along the growing season due to radial increment.

The main exception is rainy period when the long-time period without a water movement allows the heat field reaches the reference electrode. Such a situation looks like virtual sap flow through all rainy days. In this time period the baseline should copy measured values.

For the fast construction of baseline based on previous assumption there is a trick: clicking on a circle with simultaneous pressing "Q" make a pivot. Shifting any other circle up or down will move the line anchored in pivot:



It depends on user how much time is he going to spend with baseline business. The night values with negligible sap flow rate are most vulnerable to influence of ambient temperature gradient. Therefore, there is rising a question whether the hard work with baseline has adequate effect.

4.5. Switching off

Disconnect the 7-pin connector from the unit or disconnect the powering of the whole network.

4.6. Sensor dismounting

Sequence of dismounting operations:

- Remove the weather shields.
- Disconnect the cable connectors.
- Unplug the unit from the measuring point set.
- Remove the terminals from electrodes.
- Remove the thermosensor needles - use a special tool at any case. Do not break connecting hoses with tiny wires inside!
- Remove the electrodes with a special tool.
- Fill the holes in a trunk after electrodes with a natural wax.

4.7. Maintenance

The measuring equipment does not need any special maintenance. Clean up the electrodes and thermosensors after sensor dismounting. Use a mixture of spirit and light petrol. Do not immerse thermosensors to this solution for longer than a few minutes otherwise hoses get hard and brittle.

When the insulation of electrodes is too damaged, remove the rest of it by immersing them into spirit for a few hours. New isolation can be put on the electrodes with a special tool – ask manufacturer for tool and spare tapes.

5. Specification

5.1. MicroSet 8X

Power part:	
Nominal power voltage	12 V d.c.
Starting voltage	11.7 V
Turn off voltage	10 V
Maximum operating voltage	16 V
Maximum sufferable voltage	60 V
Maximum current consumption	ca 400 mA
Maximum heating power	4 W (limited)
Average efficiency	better than 90 %
Range of load resistance	200 Ω to 25 kΩ
Heating voltage	1 kHz, non-sinusoidal, max 150 V_{ef} @25 kΩ
Average current consumption*	Approx. 20 mA to 50 mA daily average (according to the sap flow rate)
Preset temperature difference*	1, 2 or 3 K
Datalogger:	
Working range	7 to 16 V
Memory capacity	ca 120,000 readings (ca one year of 10 minutes reading of sap flow and increment)
Memory type	non-volatile
Back-up battery	SAFT 14250 keeps internal clock
Lifetime	10 years
Communication	Infrared (with IrDA/USD special cable)
Physical:	
Working temperature	-20 to 50 deg.C
Weight	ca 0.5 kg
Box size	160 x 80 x 60 mm

** in cooperation with EMS 81*

5.2. Sap flow sensor SF 81

Measured values	kg h^{-1}, cm of stem circumference
Range	0 to 0.25 kg h^{-1} cm^{-1}
Heating	direct heating of stem tissues by passing of electrical a.c. current
Terminals/electrodes	three stainless plates 25 x 1 mm, 60, 70 or 80 mm long
Distance between electrodes	20 mm
Temperature sensors	thermocouples Cu-Co (T-type)
Thermosensor arrangement	three needles 1 mm in diameter placed in the middle of electrodes, one reference
Controlled temperature	average of all three electrodes

6. Warranty

The producer warrants right function of the sap flow rate measuring device for three years after it is accepted by customer. All the faults will be removed free of charge during this time, at the measuring device itself as well as at sensors. The producer is not responsible for the faults originated by careless manipulation, incorrect operations, wrong applications or theft.