EMS Brno

Data Acquisition Environment

Hardware – Software – Cloud application

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Sap flow system EMS 64

with (optionally)

Stem Increment sensor PDS 40P

Instruction Manual

(April 2022)

Contents:

1. General features

The EMS 64 is a single-channel battery operated sensor for continuous field measurement of sap flow in small stems or branches (hereafter referred to as stems) with a diameter of 6 to 20 mm. The system consists of a measuring sensor and an electronic module. The waterproof module is designed as a separate unit connected to the sensor by a 2 m cable.

There are two sizes of sap flow sensors according to the thickness of the stem (6 to 12 mm and 10 to 20 mm). Both sensor sizes have the same resistance of the heating elements (approximately 100 ohms), however, the measurement does not depend on the exact value of the resistance of the heating element nor on the resistance of the cable.

The module contains the electronics necessary for measuring the sap flow based on the SHB (stem heat balance) method with external heating. It maintains the temperature difference between the incoming and outgoing water passing through the heating element surrounding the stem.

This temperature difference can be set to three levels - 2, 4 or 8 K. The higher the temperature difference, the lower is the interference caused by environmental influences however, the power consumption increases proportionally. The maximum power available for maintaining the temperature difference is 3.2 W.

The heating power is directly proportional to volumetric sap flow with an offset due to conductive heating loss from the sensor. For minimizing of error caused by ambient factors (solar irradiation, temperature gradient, wind) is necessary to protect the sensor with a special Mylar shield.

The module is ready for connection of stem diameter sensor PDS 40P measuring in the range between 5 to 40 mm.

The module contains the datalogging unit which records mainly volumetric sap flow in [kg/h] and the stem diameter (if this sensor is connected), but also some other operating variables. There are two datalogging modes.

Standard mode records:

- Sap flow [kg/h]
- Stem diameter [mm]
- Internal temperature [oC]
- Supply voltage [V]

Advanced mode records additionally:

- dT up [K]
- dT mid [K] (reserved for future use)
- Operating status [1 to 6]

Those two modes are selectable during datalogger initializing process.

Communication between the system and the PC is wireless, mediated by infra-red. The data cable with built-in magnet activates the communication after putting on the metal ring on the front transparent panel of the module. On the front panel, there are also two LED indicators and two-character alphanumerical display indicating the status of the system.

The installation of measuring point is fast and easy. Just a special drill is necessary for drilling holes for needles in xyloid stems.

A weather shield is required in order to protect the sensor against direct solar radiation, wind and rain. Approximately 30 cm of free stem is required for proper sensor installation.

The module is supplied with 11 to 16 V D.C. The power consumption is proportional to the sap flow rate and it ranges between ca 20 and 300 mA.

2. Measuring principle

The measurement principle is based on the stem heat balance (SHB) method with external heating and sensing of internal temperature (Lindroth et al. 1995, Čermák et al. 2004). The sensor consists of two similar cylindrical parts. Each part encases the stem with polyurethane foam. One part contains linear heating elements which are gently pressed against the stem by the soft foam. A needle thermocouple is inserted into the stem in the radial direction at the level of the upper edge of the heating elements (in the direction of water movement). The second cylinder has no heating element and only covers the reference needle thermocouple for thermal symmetry. Water passing along the sensor is heated and the thermocouples are used to measure the temperature rise as the water leaves the heated area. The feedback loop of the EMS 6X module maintains the temperature difference at a preset level of 2, 4 or 8 K. The power input is then directly proportional to the amount of water passing through the sensor in kg/h. However, there is still some energy that is dissipated by heat loss from the sensor.

The heat balance of the heated part of the stem is described by the general equation:

$$P = Q*dT*c_w + dT*z \qquad (1)$$

where P is the heat input power [W], Q is the sap flow rate [kg/sec], dT is the temperature difference in the measuring point, c_w is the specific heat of water [J/kg, deg] and "z" is the coefficient of heat losses from the sensor [W/deg]. The amount of water in terms of mass or volume passing through the sensor is calculated from the actual power and temperature rise of water passing through the heated space.

The calculation of sap flow rate is derived from the equation [1], from which:

$$Q = \frac{P}{c_W * dT} - \frac{z}{c_W} \quad \text{[kg/s]} \qquad (2)$$

First part of the equation represents energy used for heating-up the water. The second part of this formula represents the heat losses from the sensor. Its magnitude can be easily estimated from the data recorded under condition of actual flow approximating zero, i.e., during a rain or at night before sunrise. The supporting software Mini32 includes an option for easy graphic baseline subtracting.

3. Specification

Stem diameter range	6 to 20 mm covered by two sensor types: 6 to 12 mm and 10 to 20 mm
Heating technique	external heating of stem
Output variable	heating power per dT [mW/K]
Sensor heater resistance	ca 100 ohm
Temperature sensing element	Thermocouple T-type in 0.8 mm needles
Necessary stem length for proper sensor installation (incl. radiation shield)	30 cm
Preset dT values	2, 4 or 8 K
Heating power	variable, up to 3.2 W
Power supply	11 – 16 Volts D.C.
Current consumption	Max 0.3 Amp. according to the sap flow magnitude
Working temperature	-10 to 60 °C
Weight	ca 0.47 kg module, 0.1 kg sensor
Module box size	160 x 80 x 60 mm

4. Operation

The sensor is designed to be easily installed on the stem as long as its diameter is within the specified range (6 to 12 mm for the small sensor and 10 to 20 mm for the large sensor). It needs about 20 cm of length per stem. If there is a node within this length, it should be placed under the cube of the thermosensor assembly. In addition, about 10 cm of stem is needed below and above the sensor to install the weather shield.

4.1. Sensor installation

Correct installation of measuring points on trees is an ultimate pre-requisite of getting correct results. Interaction between sensors and plants belongs generally to important points of this type of measurement.

4.1.1. Sensor location on stems

Fundamental criteria for location of measuring points are the necessary stem length for sensor installation and the height above the ground. The highest temperature gradient which may interfere with the measurement occurs close to ground surface. Therefore, the measuring points should be placed as high as possible. Measuring on seedlings or agricultural plants where the sensor has to be installed just close to the soil could be affected by a serious error especially in the morning when the temperature gradient close to the ground is huge. Higher level of dT helps at this matter.

Also in tree crowns, a shaded space for sensor installation is recommended in order to reduce a potential error caused by solar irradiation.

4.1.2. Sensor set up

Choose the right part of stem for sensor installation. At least 30 cm stem length is necessary.

Clean the stem from a rest of rough bark, needles etc.

Fix the thermocouples assembly on the stem

Insert needles into the stem. Drill holes for needles in xyloid stems if necessary.

Set the upper sensor part with heater on the stem. Watch the proper position:

1. the foam should be in touch with the cube of thermosensor holder
2. the sensor tin cover should keep its cylindrical shape and it should be placed symmetrically around the stem
3. the thermocouple needle cup should be pressed by both foam edges below the cover clip

Put the lower (unheated) part on the stem similar way. Make sure its position is symmetrical to the upper sensor part with respect to central cube.

Install the radiation shield. Fix the upper end with a PVC tape in a watertight manner.

Form the shield in the "diamond" like shape.

Fix lower end over the cable by PVC tape. Do not tight it too much – let a gap between the stem and the cable for drainage of condensed water.

Connect senor to electronic module.

See the installation instruction manual.

4.2. Starting the measurement

The system runs immediately after connecting to power. The operation after the system was set up does not require any operator intervention.

Note that the system is automatically switched off when the power voltage drops below 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.

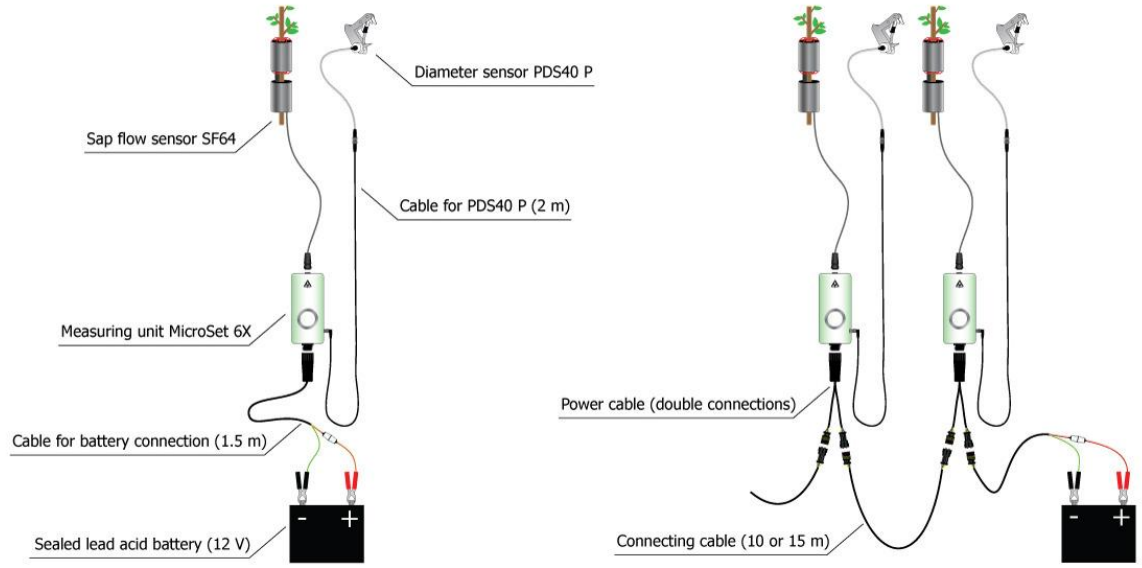
The display shows some additional information as described in section (4.2.4) periodically when the datalogger in measuring or after putting the magnetic head of IrDA/USB data cable on the unit.

4.2.1. 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.

The sensors can be used with separate batteries or connected in series to the main power unit (battery).



Because the modules are equipped with dual opposite-sex connectors, they are ready for easy chaining.

The connecting cables are available in two standard lengths 10 m and 15 m. They are equipped with *Superseal* connectors (approved by automotive industry) what makes cables cheap and sturdy.

The price of the entire cable is roughly equal to the price of one multi-pole industrial connector. If the cable is damaged (e.g. by wildlife), it can be replaced instead of repaired on site for a reasonable price.

4.2.2. Set-up of the measuring unit MicroSet 6X

The unit consists of two main parts - the electronics controlling the measurement and the datalogger. There are two ways of communication between the datalogger and the controlling electronics. First, the datalogger stores data provided by the control electronics. Secondly, the datalogger mediates the communication between the computer and the controlling electronics when setting up the measuring part.

The instrument operates basically in three modes which depend on the supply voltage:

1 - Between 10 to 16 V when the unit was still 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 and on the preset temperature difference.

2 - The voltage is between 7 and 11.5 V, but the power supply of the sap flow meter has been turned off due to a recent voltage drop below 10 V, it means that the battery is almost discharged. Sap flow measurement has been switched off due to low voltage. Nevertheless, the datalogger still measures and stores stem increment and internal temperature variables.

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.

4.2.3. Datalogger configuration

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

Standard mode. Four variables are recorded:

- Sap flow [kg/h]
- Stem diameter [mm]
- Internal temperature [oC]
- Supply voltage [V]

Advanced mode. Besides of previously listed, three other variables are recorded in this mode allowing deeper knowledge of the system behavior:

- dT up [K]
- dT mid [K] (reserved for future use)
- Operating status [1 to 6]

Recording modes can be changed only during initialization of the datalogger. Warning: All data and configuration get lost during the shifting between operating modes.

4.2.3.1. Communication with datalogger

Communication with the unit requires PC with operating system Windows 10 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.

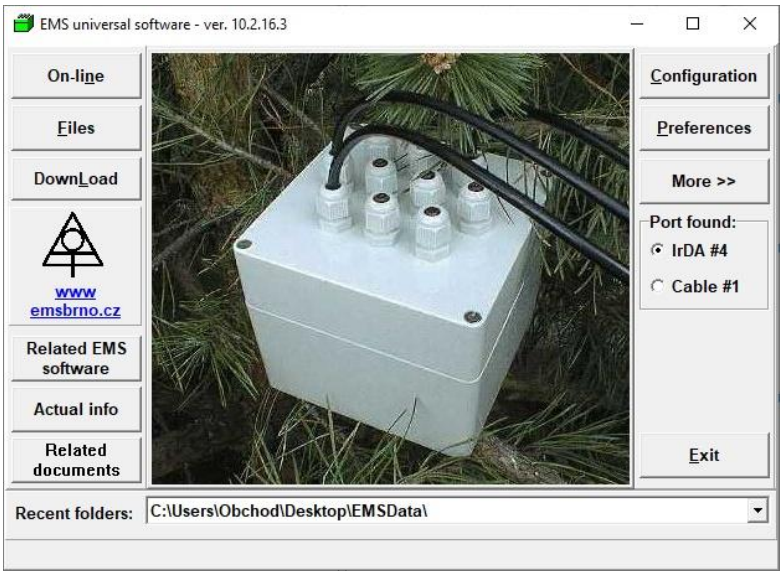
For wireless communication with the unit IrDA/USB data cable manufactured by EMS is necessary.

The unit 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.

Note: The unit can be configured also without external powering (chapter 02).

4.2.3.2. Configuration process

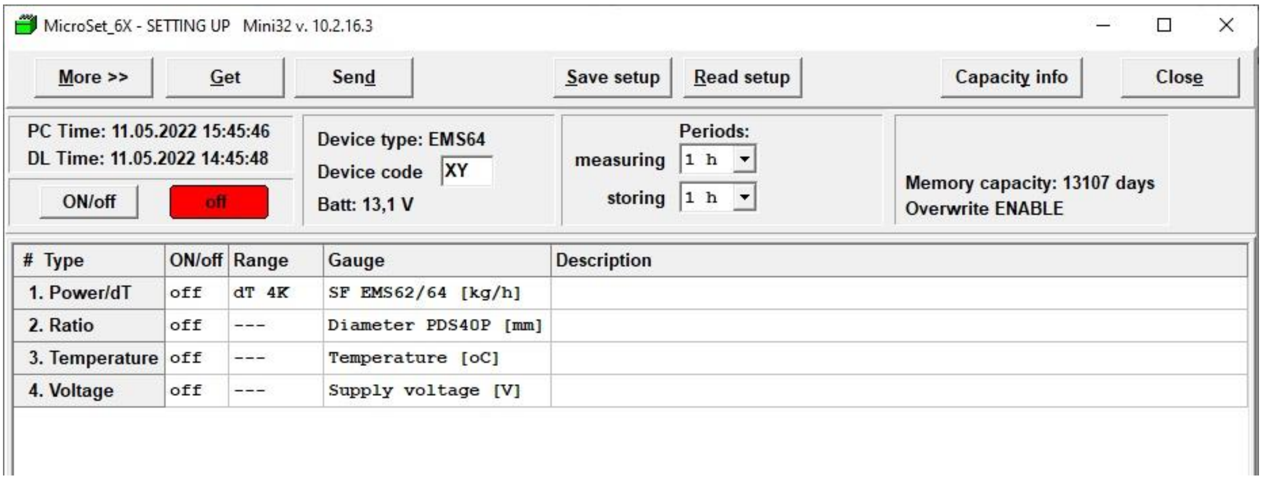
Run Mini32. Make sure that you have the latest version. Newly made instruments need updated software otherwise the software responses with "Unknown device" message. Download the Mini32 software version from USB memory stick attached to delivered instruments or from manufacturer web site.



Connect the IrDA/USB data cable. Make sure that the information about the cable port appears on the right side of the Mini32 main screen. Otherwise install the USB driver from the installation package (push "Related EMS software" button).

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:

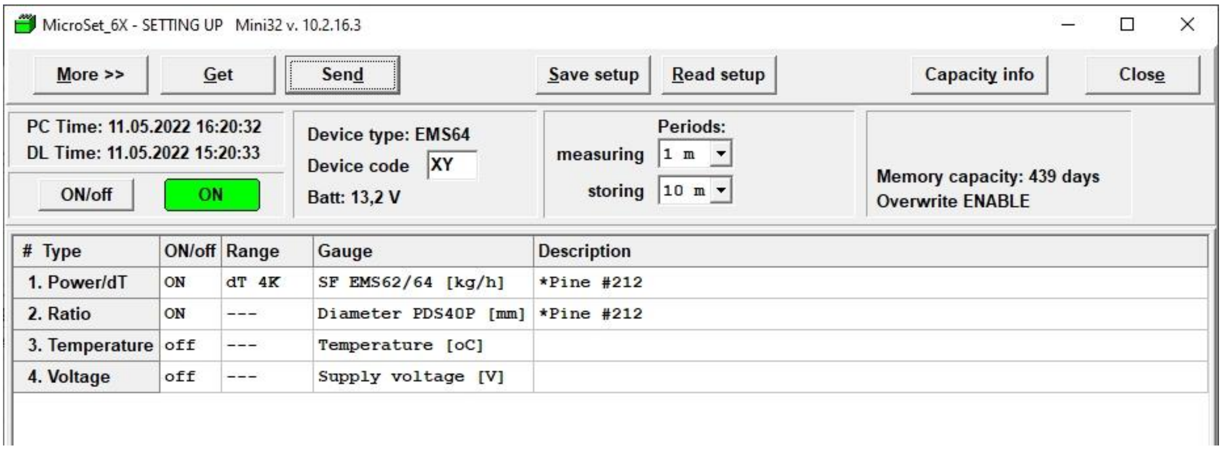


The screen shows computer time (clock time) and time of datalogger. Note that the datalogger time should be always solar time – Mini32 sets during initialization always solar time according to local computer setting independently on the season.

The configuration says that:

- System is off
- Battery Voltage is 13.1 V - the system can start (higher than 11.7 V)
- Device code here is ‘XY’. From the factory, these two characters are two last numerals of the serial number.
- Time periods means, when 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 running
- All channels are off, the set temperature difference in the sensor is 4 K.

For example, the actual custom configuration looks like this:



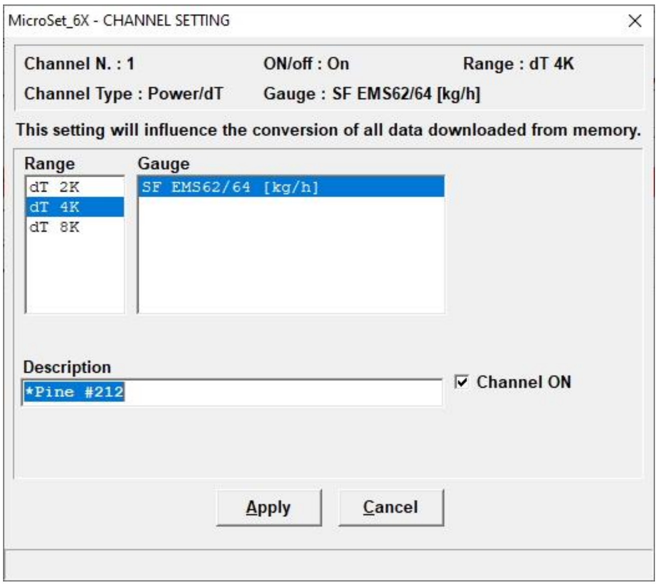
System is on. The voltage 13.2 V shows good battery status. Device code (alphanumeric code, unfortunately two characters only due to compatibility with older systems) is set by user.

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 measurement of the unit is off. Temperature difference in the measuring point is set to 4 K. Sap flow is calculated as whole tree value [kg/h]. Both active channels contain user defined description mentioning tree species and number of tree.

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 windows opens after double click on the appropriate line:



Preset dT and filling the channel description can be edited here.

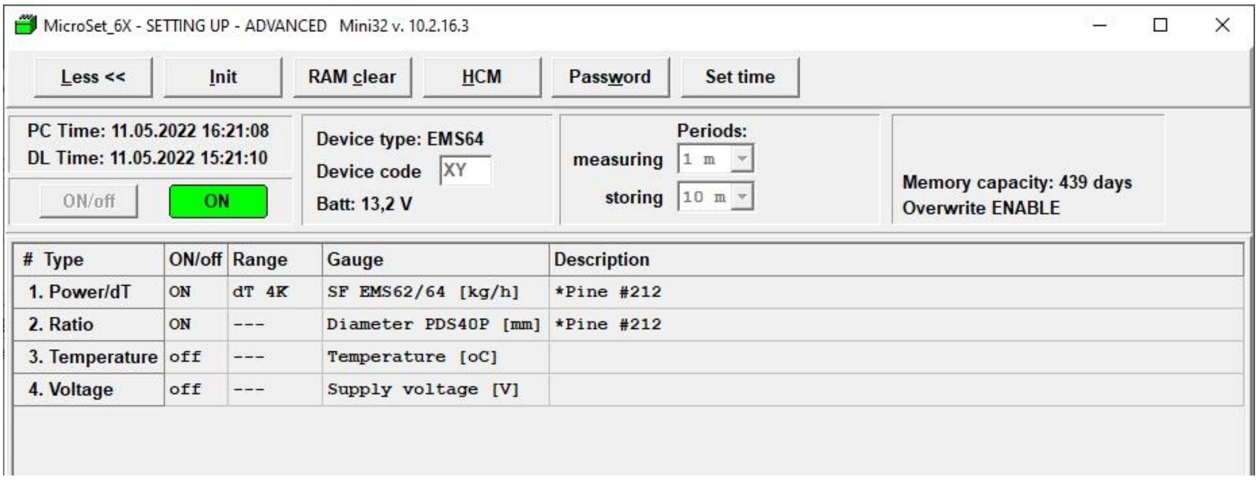
By other channels, there is besides of description nothing to edit – just to set them ON or OFF.

When all setting is finished, push "SEND" button – the configuration will be sent to the datalogging part.

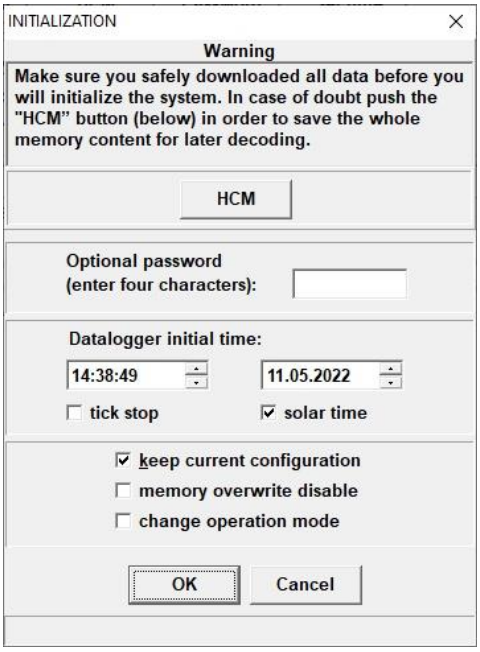
4.2.3.3. Process of initialization.

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

Enter 'Configuration' and then push 'More'. This way you enter second level configuration option:

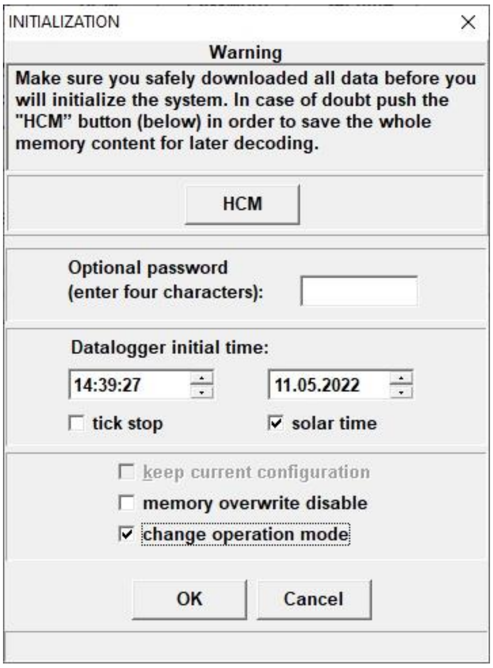


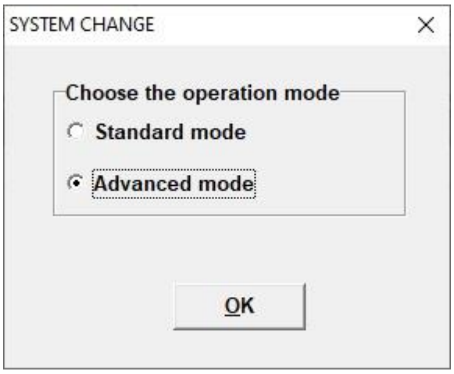
'RAM clear' deletes whole memory content but the configurations and datalogger time remains untouched.



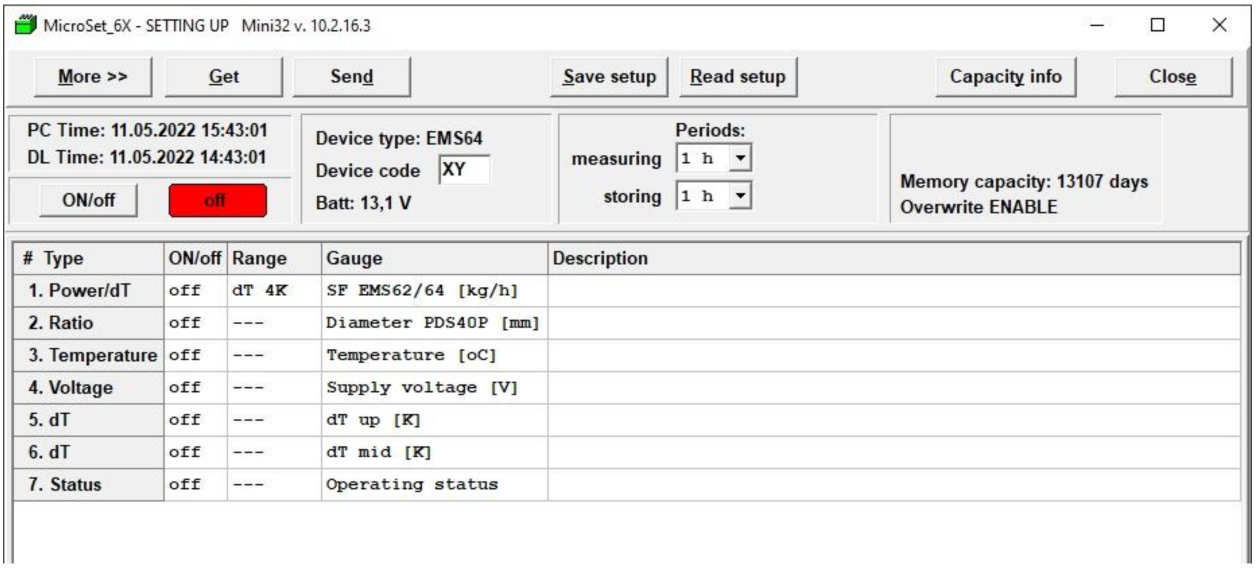
On the contrary, initialization ('Init') deletes whole memory content and offers some important possibilities like datalogger time setting, ('Set time' option available at any time has certain limits in setting time backwards) changing the memory operating mode (memory overwrite), returning to original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

Note: The current configuration get lost during the shift between operation modes!





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 behind the heater, 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.

***Warning**: To maintain the integrity of the database, systems should be initialized when the sensor is moved to another tree. Initialization will cause a memory wipe as well as restoring system time from the connected computer. Clearing the data belonging to another measurement object is **absolutely necessary** because the calculations to the physical values are performed on the PC according to the last configuration of the datalogger. Without deleting the old data* *that belong to another object, this data will also be calculated according to the new configuration, which should be avoided.*

4.2.4. Operation indicators of the module

The two-digit display shows the status of the unit, especially any errors. In order to save energy, the display shows the status of the unit at each periodic measurement and/or when the magnetic head of the IR communication cable is mounted on the metal ring. In this case, the system wakes up and the display is illuminated for 30 seconds. If no communication is attempted from a connected computer running the Mini32 software during this time, the display will turn off. Further waking up of the system requires removing the head on a distance of about 1 m from the unit and reinserting it.

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'** – faulty heater* - The heating element is broken or damaged. Power has been turned off.

***'E2'** – broken thermosensors* - The thermosensor is broken or damaged. Power has been turned off.

***'E3'** – the sensor is running in full power* - 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).

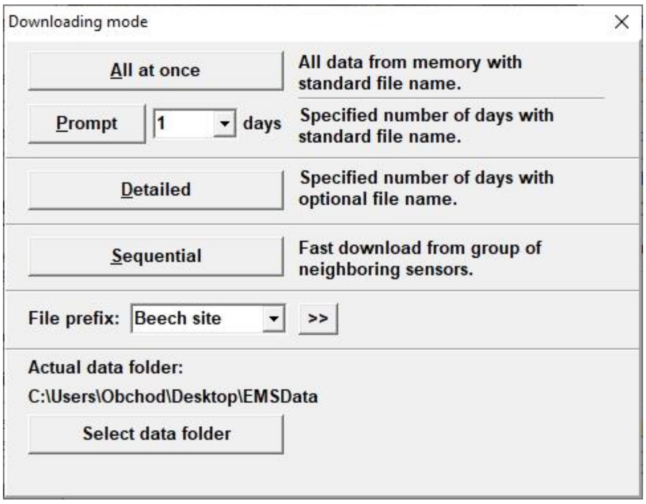
Since such a situation can happen also when the dT is wrongly measured (sensor malfunction or wrong installation), the system switches off the heating power for some time period in order to avoid overheating the xylem. This status is indicated by errors '**E4**'.

*'**EE**' - unspecified error - general system malfunction*

4.3. Data download

Data download is fully supported with Mini32 software. It required a PC with Windows 10 operating system or higher and the IrDA/USB data cable with correctly installed driver.

There are four different data downloading modes:

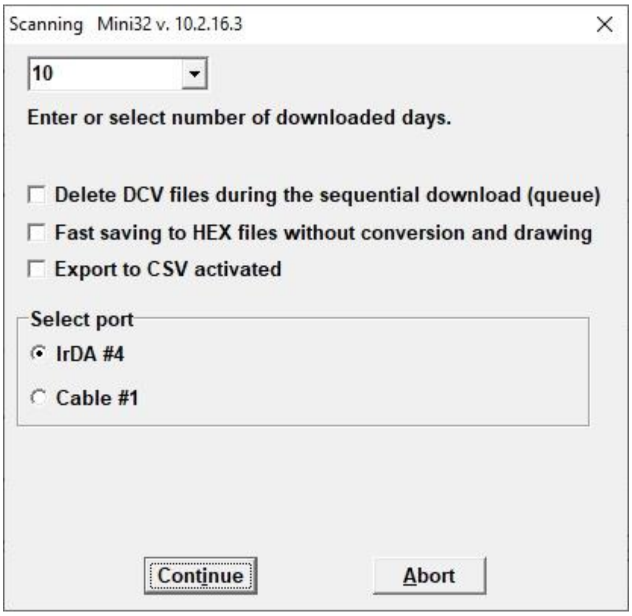


All at once – all data in memory will be saved to file. The filename is created automatically in format "DC_yyyy_mm_dd.hex" (DC is device code assigned to the unit).

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

Detailed – the same as above, the file name can be edited.

Sequential – special option for fast downloading of more sensors placed close to each other:



In sequential mode, the computer is continuously searching for sensors. If it establishes connection, it immediately downloads the preset amount of data (in days, max 999) and saves them to 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 next 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 calculation.

Sap flow values are in terms of [kg/h] are calculated from the output signal [mV] according to the formula

$$Q = -0.0215 + 0.000215 * U_{sig} \qquad (3)$$

The formula is derived from equation (2) with respect to module output signal conversion factor [mV] > [mW/K].

Note that this way calculated sap flow values include the power loss from the measuring point that has to be (graphically) subtracted!

Derivation details:

$$Q[kg/h] = \frac{P[W]*3600}{c_W[J/K,kg]*dT[K]} - Q_{idle}[kg/h]$$

The calculated sap flow rate is in terms of sap flow per whole stem.

*The value "3600" converts the sap flow values from kilograms per second to kilograms per hour (note that "J" = "W.sec"). The following equation considers the preset constant dT (2 K or 4 K) and module conversion factor (-25 + 0.25*mW/K, mV). The value "1000" converts [mW] to [W]. Note that the output signal is in terms of P/dT [mW/K]:*

$$Q[kg/h] = \frac{(-25 + 0.25 * U_{sig}[mV]) * 3600}{4186.8[J/K,kg]*1000} - Q_{idle}[kg/h]$$

and after calculation

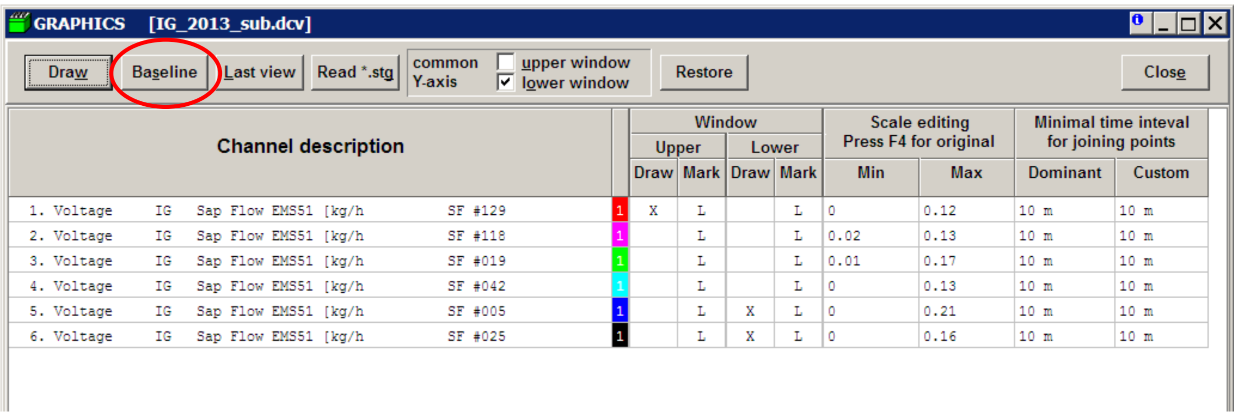
$$Q[kg/h] = -0.0215 + 0.000125 * U_{sig}[mV] - Q_{idle}[kg,h]$$

The calibration of the method was published here:
http://www.emsbrno.cz/r.axd/pdf_v_Urban__2012_u_pdf.jpg?ver=

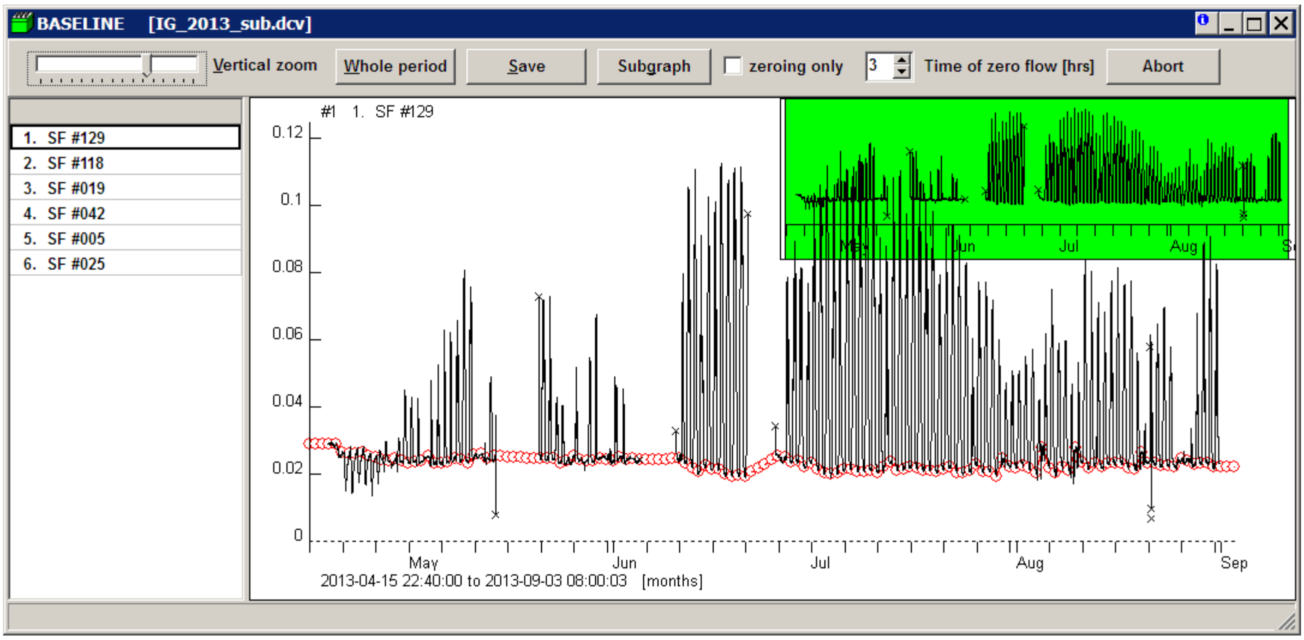
4.4.2. Baseline subtraction

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.

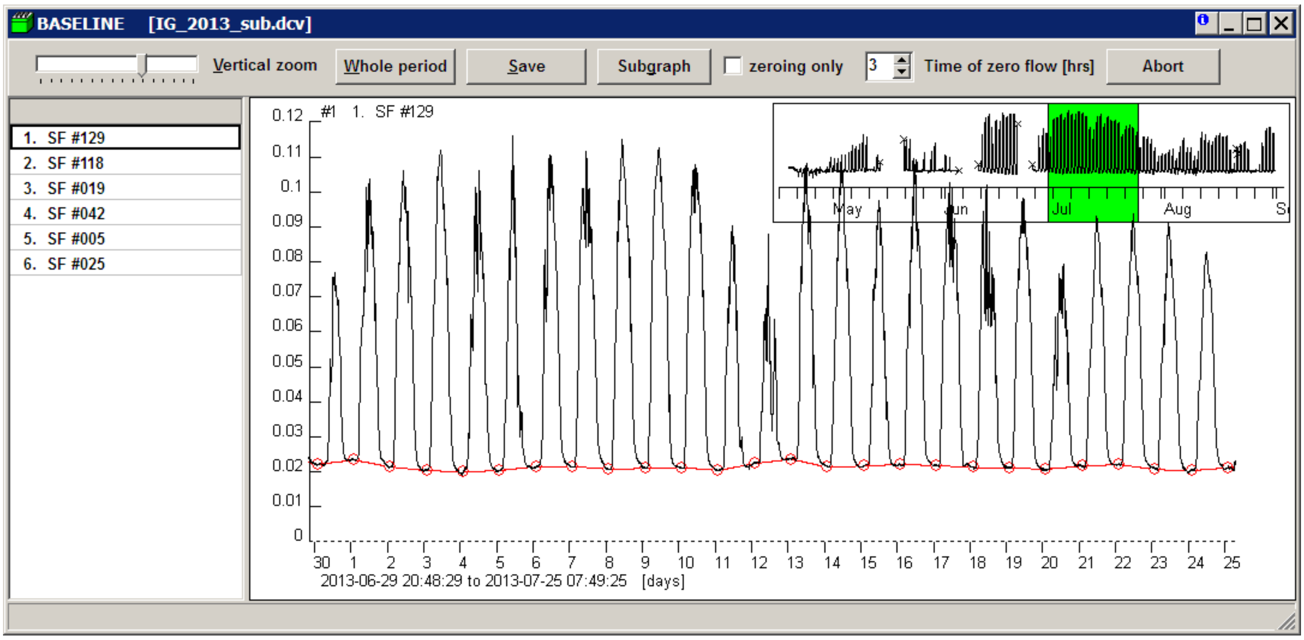
Mini32 software is ready for graphic subtracting of the 'baseline' that represents heat losses from the measuring point (see Eq. [2]). This option is offered in the graphic setup screen:



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

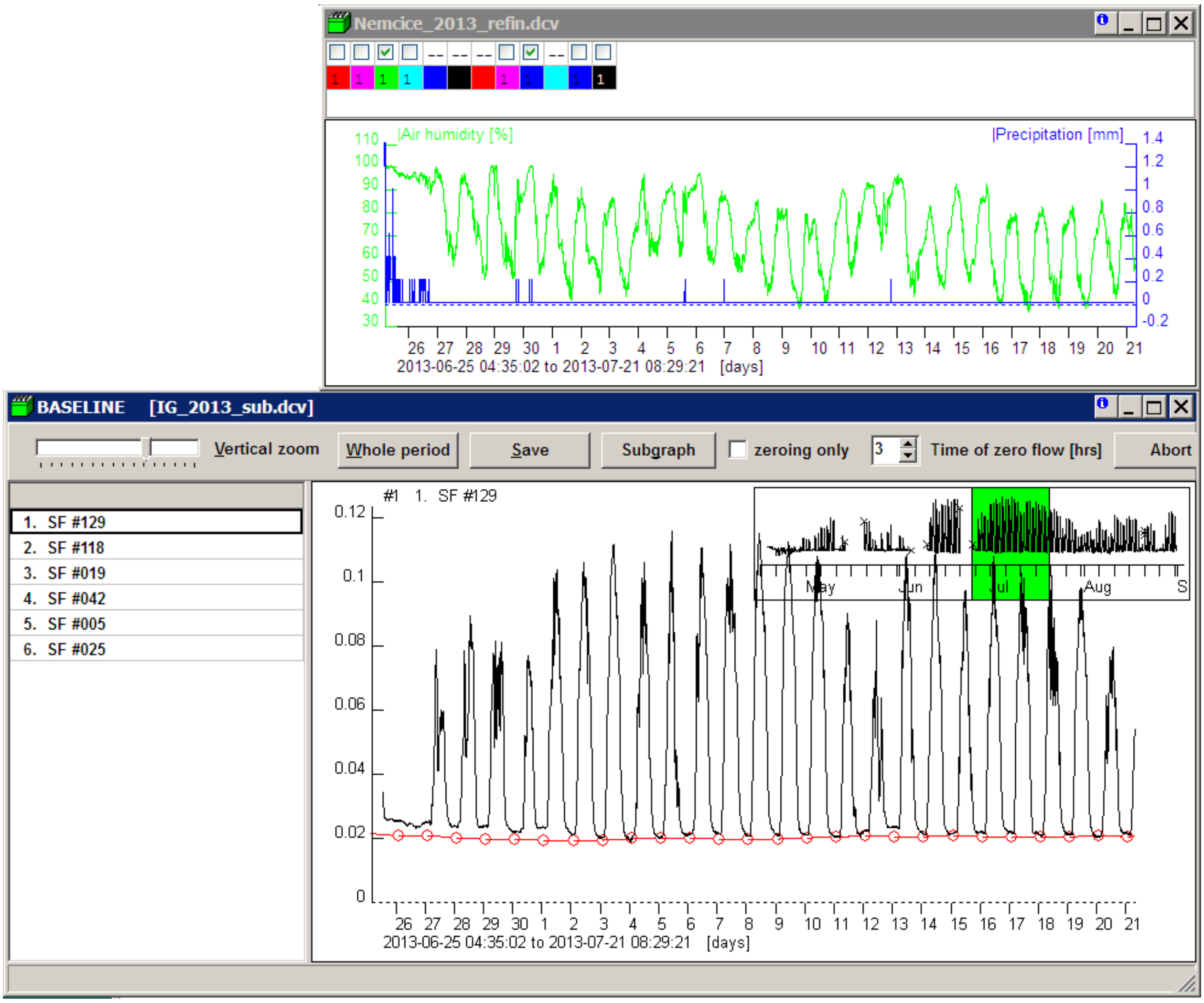


The part in a green window shows whole time period for the case of zooming of a main graph:



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'):

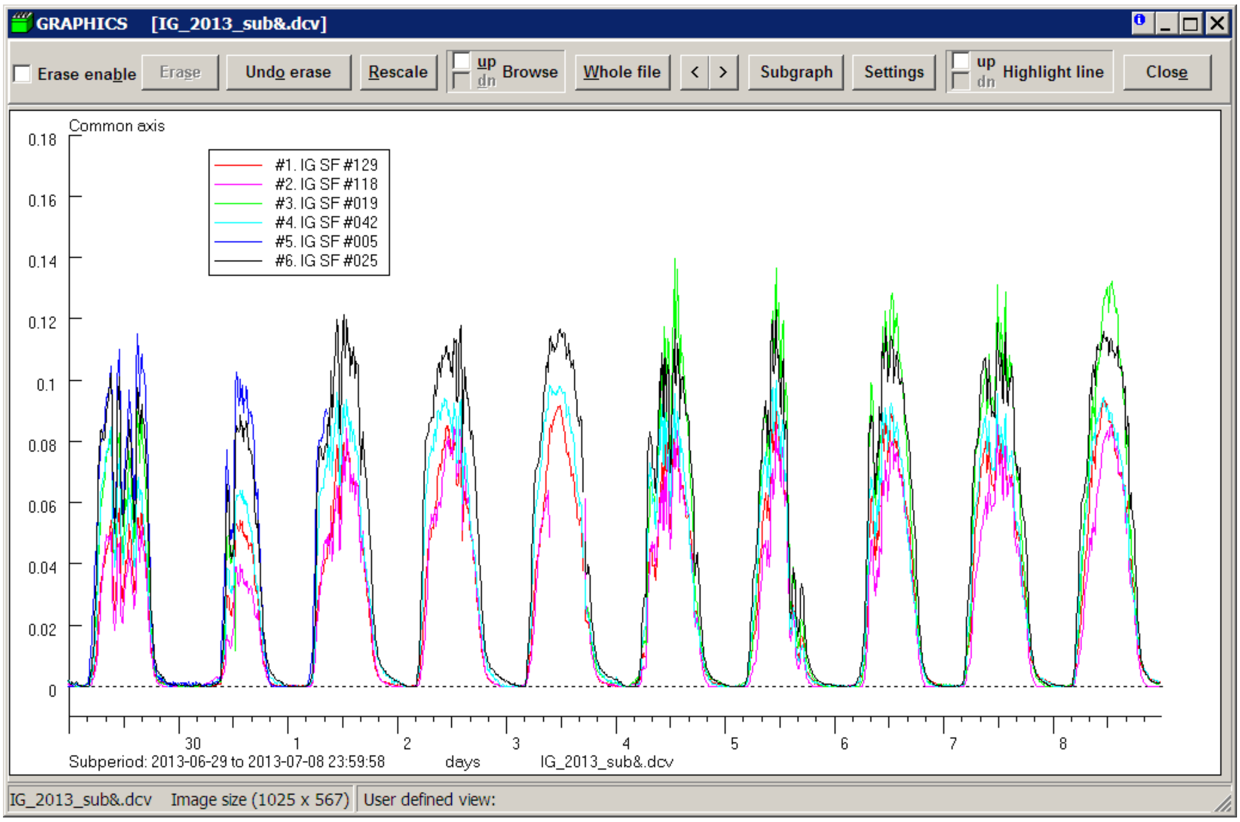
The right position of the 'subgraph' window on the screen has to be set manually, but the main advantage of this arrangement is that the time axis of 'subgraph' window moves synchronously with main graph. The whole working environment then looks like this:



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).

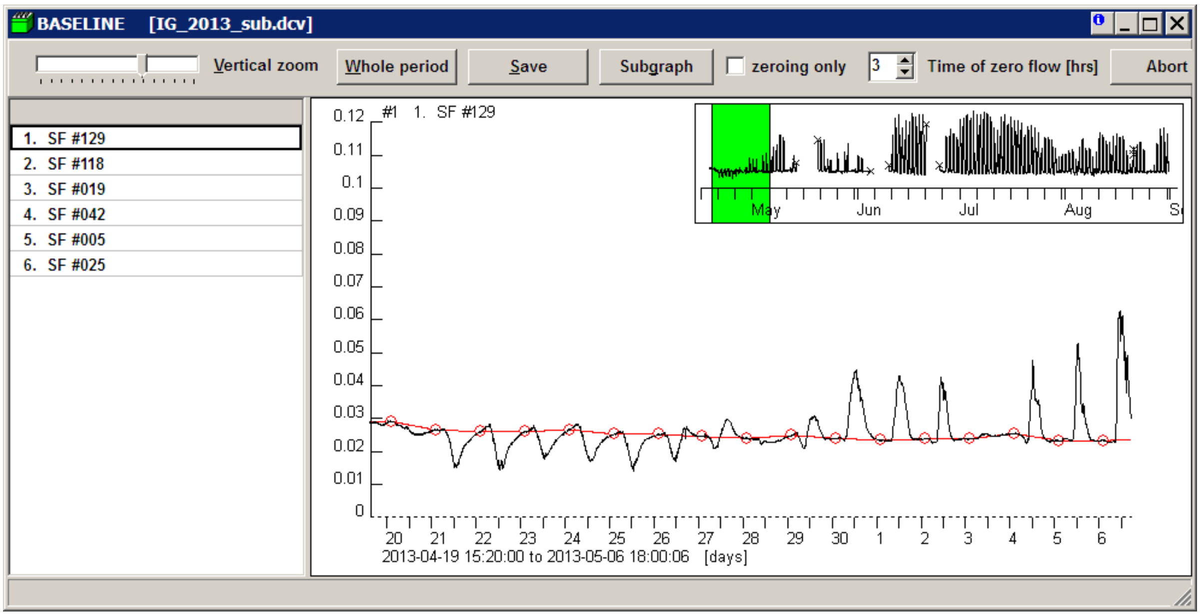
When all variables are processed, new file with '&' behind the filename is created and saved:



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.

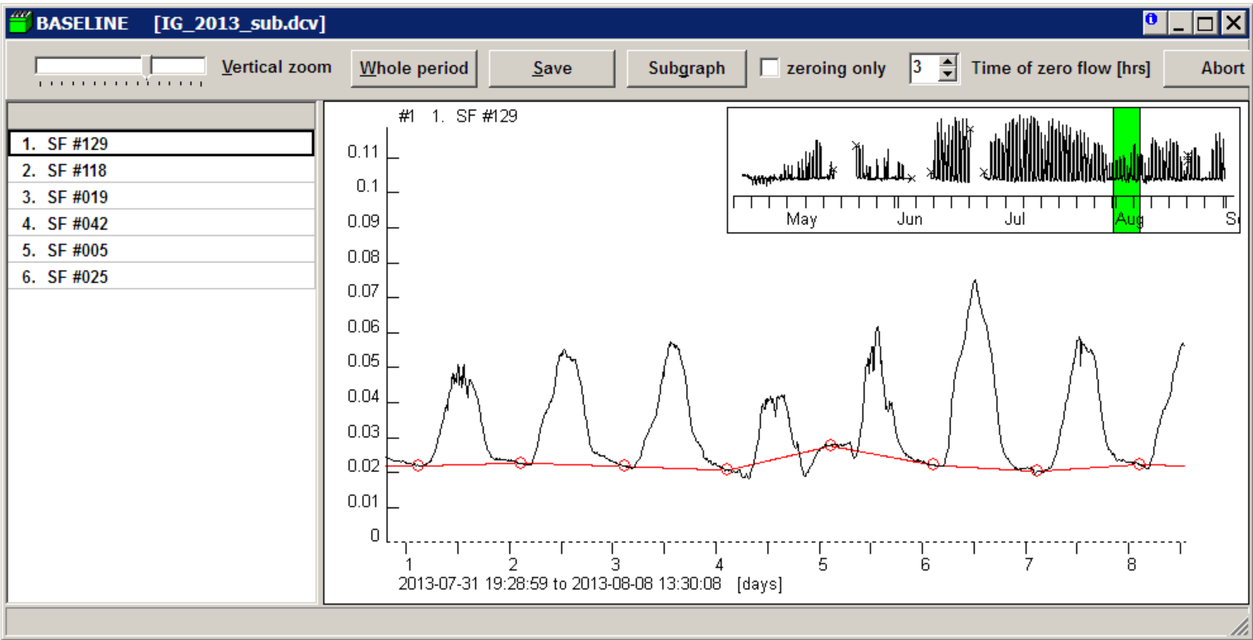
The baseline as the level of heat loss should be theoretically a straight line with little deviations due to change in stem water content and growth. However, some other factors like rain or fast temperature changes are interfering with theory. The only what really helps is practice and good understanding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

Here are few examples which could help:

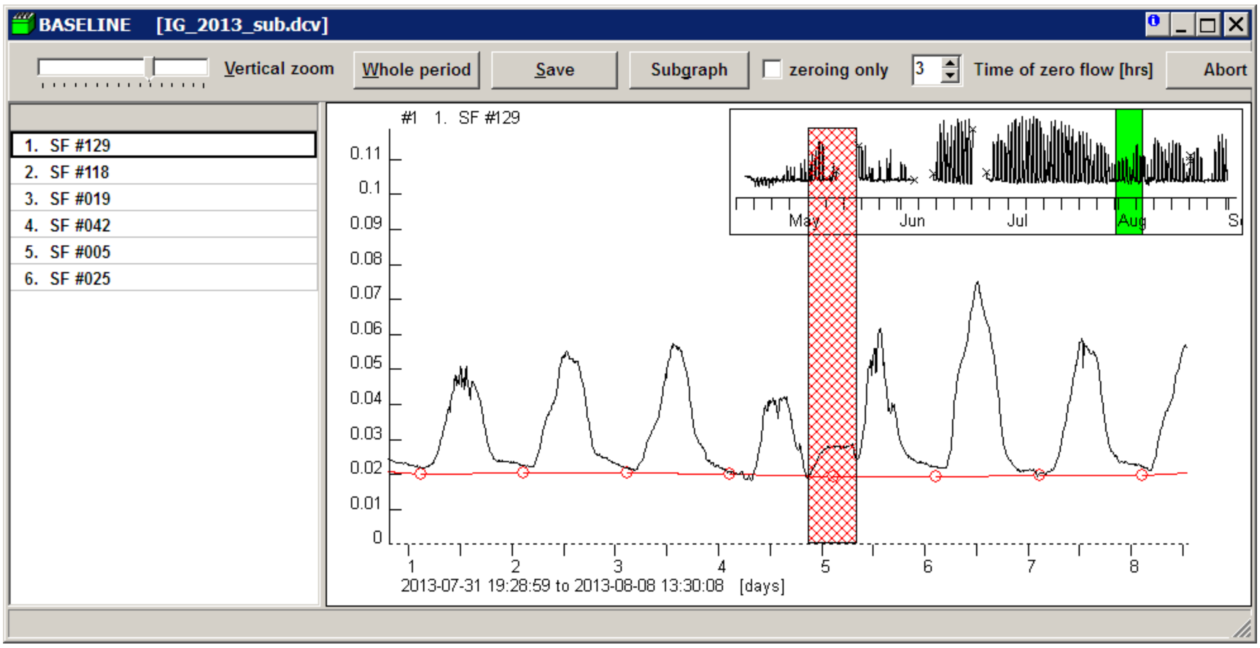


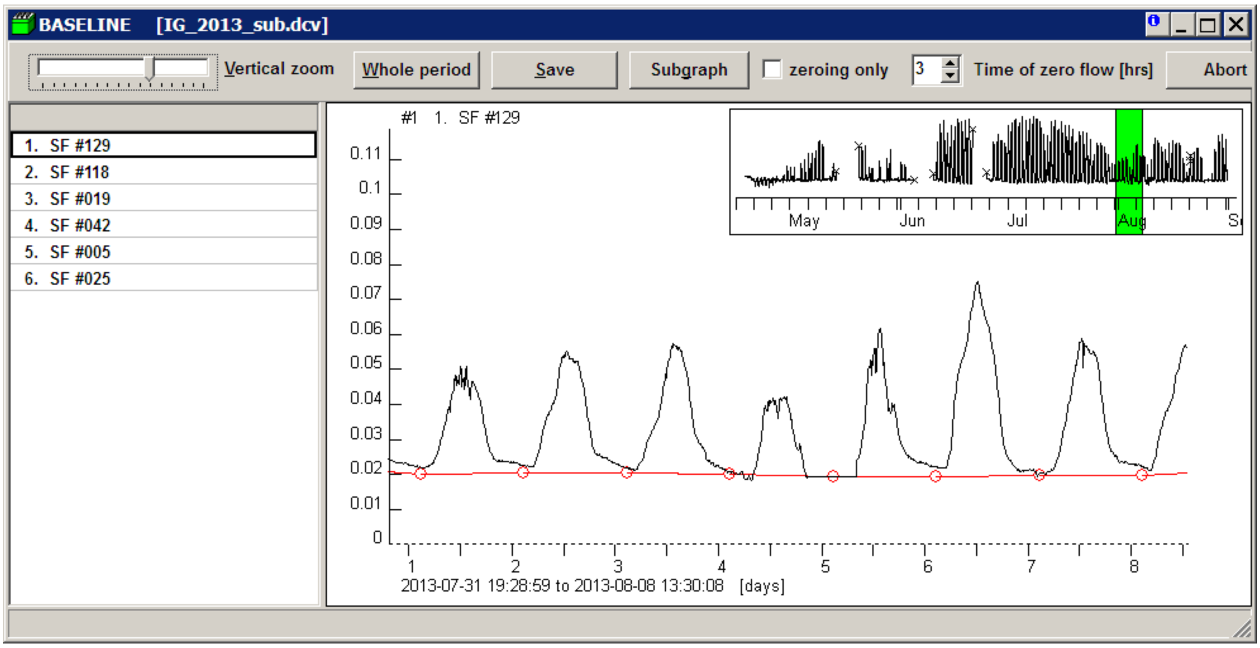
Typical situation at the beginning of growing season: European beech after the bud break. The strange pattern in days with 'negative' sap flow values can be explained by high vertical temperature gradient within the stem or outside. The system reduced power because this gradient helped to reach set temperature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

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



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





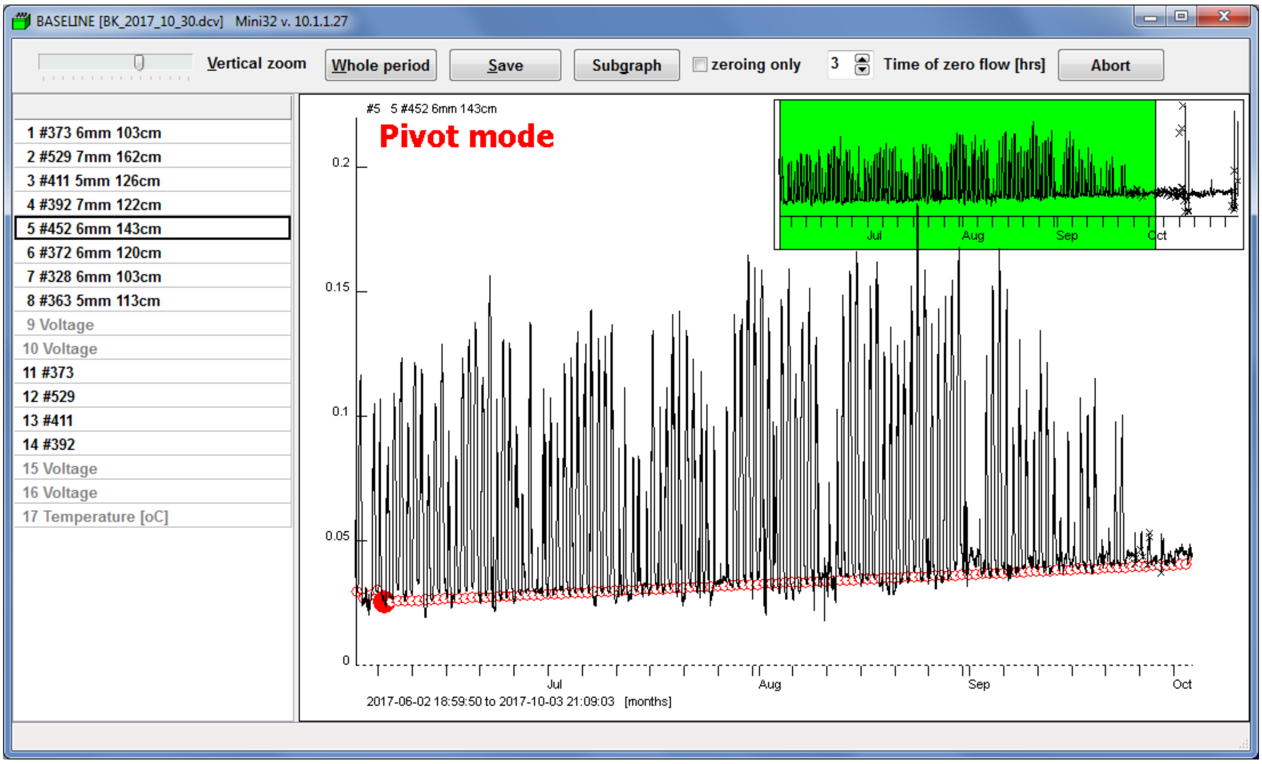
Please notice that the false values are not deleted but set to zero!

Pivot mode

The other 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.

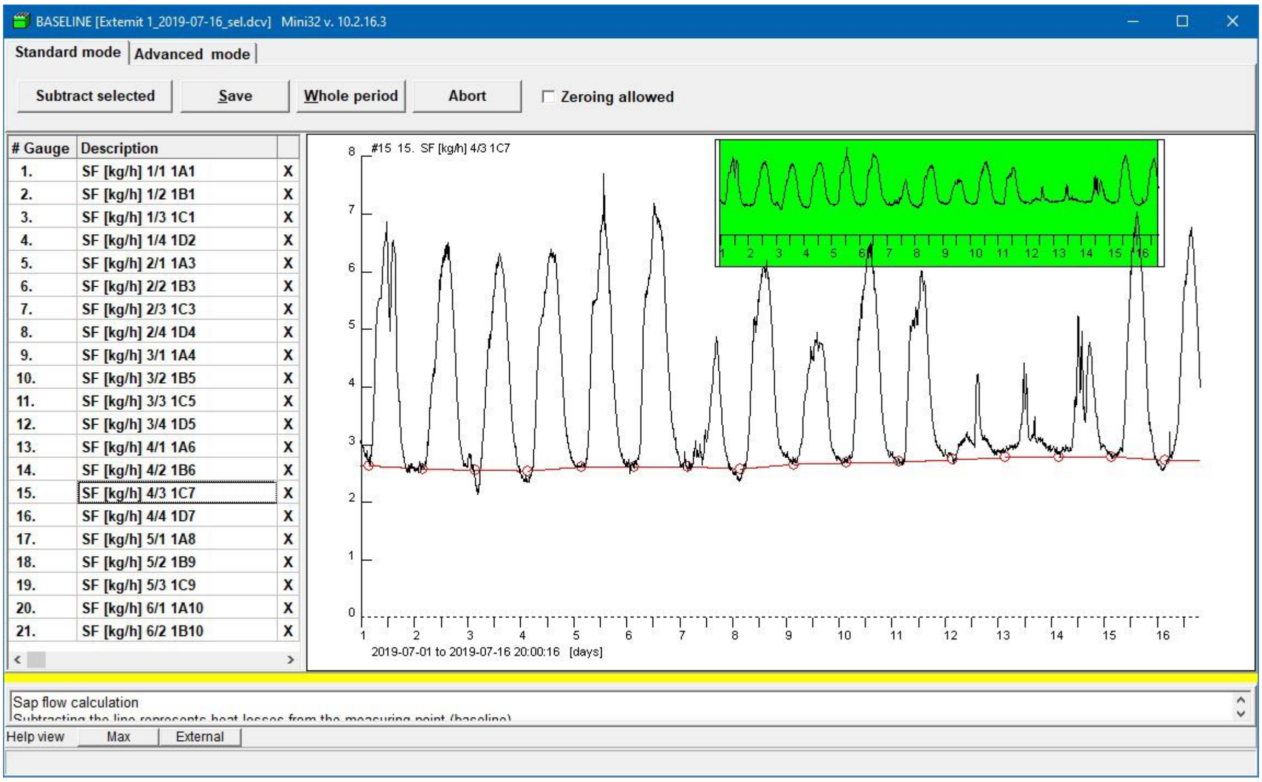
For the fast construction of baseline based on previous assumption there is a trick: clicking on a circle with simultaneous pressing "Q" make a pivot. Shifting any other circle up or down will move the line anchored in pivot:

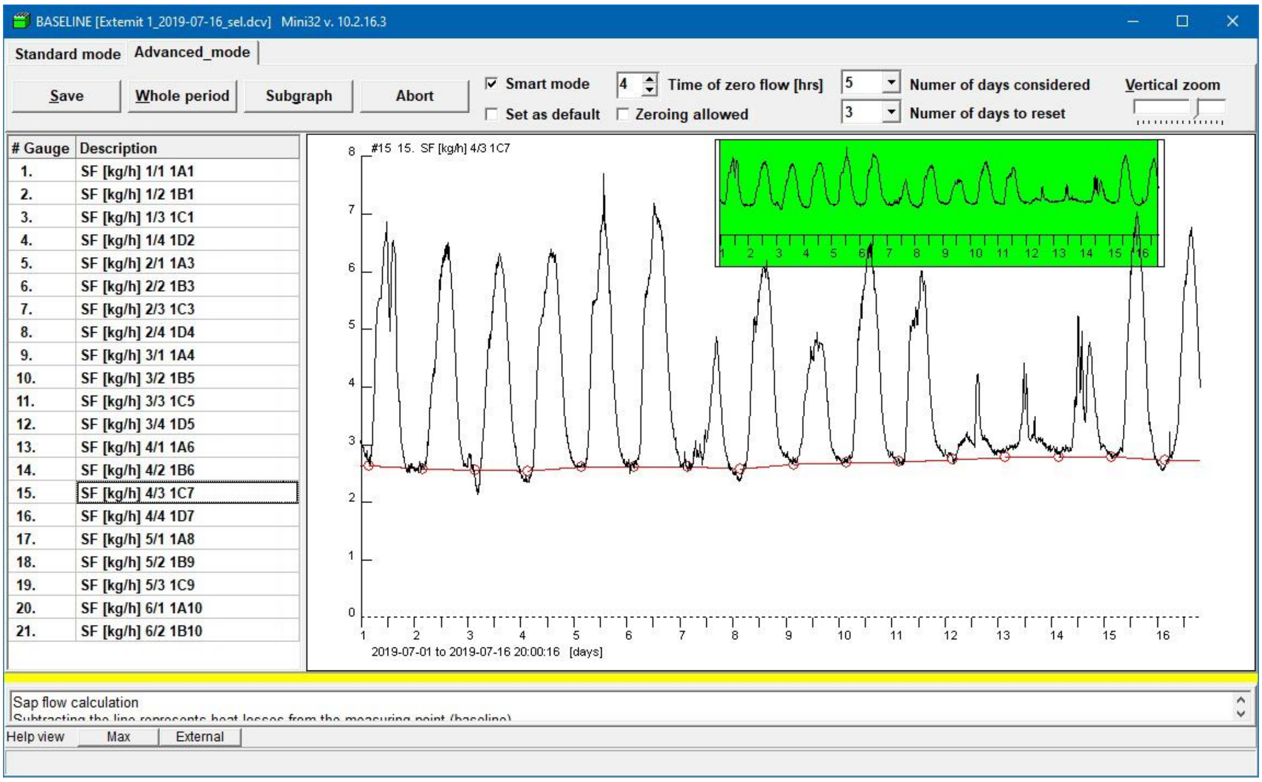


It depends on user how much time is he going to spend with baseline business. The night values with negligible sap flow rate are most vulnerable to influence of ambient temperature gradient. Therefore, there is rising a question whether the hard work with baseline has adequate effect.

Automatic baseline subtraction

Besides of the above-mentioned procedure the Mini32 software since version 10.2.8. offers an automatic baseline estimation using the method of "Exponential feedback weighting". Nevertheless, even this way designed baseline can be improved manually in "Advanced mode". Here the user can choose also the expected time of zero sap flow as well as other parameters of automatic process.





Please refer to the manuscript available here: http://www.emsbrno.cz/r.axd/pdf_v_Kucera__2020__baseline_u_pdf.jpg?ver=

4.5. Switching off and sensor dismounting.

Sequence of dismounting operations:

1. Remove the radiation shield
2. Disconnect cable connectors
3. Open both sensor parts
4. Remove both needle sensors from the stem
5. Fill potential stem wounds with a natural wax.

4.6. Maintenance

Principally, the sap flow rate measuring equipment does not need any special maintenance. Remove the resin from foam parts if necessary by plant oil. Do not immerse sensor into any dilution.

4.7. Tools

The only tool sometimes necessary for installation is a drill.

The drill is necessary for drilling holes for sensor needles (0.6 mm diameter) in xyloid stems. It is strongly recommended to use a drill with controlled revolutions according to tissue hardness. The drill should keep revolutions nearly independent to drilling load in order to avoid overheating or burning plant tissues.

A special cordless drill set is offered to this purpose:

It consists of the drill, battery box with electronics and battery charger. The drill keeps low revolutions until it faces a hard xylem. Then, it increases the power until the drilling resistance gets low again. The recommended drill bit diameters ranges between 0.8 to 1.0 millimeters. Proper bits should be chosen according to xylem properties. Principally, the smaller hole the better.

The drill battery should be kept fully charged. Hook it to the charger after each use and also after each three months for a few hours. Few days long recharging does not make anything wrong.

5. Warranty

The producer warrants right function of the sap flow rate measuring device for three years after it is accepted by a 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.

6. Literature:

Kucera, J., Vanicek, R., Urban, J. (2020). Automated exponential feedback weighting method for subtraction of heat losses from sap flow measured by the trunk heat balance method. *Acta Horticulturae,* (1300), 81–88.

Lindroth, A., Cermak, J., Kucera, J., Cienciala, E., and Eckersten, H. (1995). Sap flow by the heat-balance method applied to small-size salix trees in a short-rotation forest. *Biomass and Bioenergy* (8), 7–15.

Cermak, J., Kucera J., Nadezhdina, N. (2004). Sap flow measurements with some thermodynamic methods, flow integration within trees and scaling up from sample trees to entire forest stands. *Trees* (18), 529–546.

Urban, J., Krofta, K., Kučera, J. (2012). Calibration of stem heat balance sensors upon a study of water balance of the hop plantation. *Acta Horticulturae* (951), 79–86.