HFD8
Heat Field Deformation
Sap Flow Meter

Contents

Warning – The measurement needles of the HFD8 are made of 1.9mm diameter stainless steel. They can easily be bent, damaged or broken if basic care is not taken when handling the instrument.

1. System Requirements

ICT Combined Instrument Software (CIS) does not require a powerful computer. Recommended minimum system specifications:
Intel Atom 1.66GHz and 1GB RAM or higher.

CIS is compatible with the following operating systems:

- Windows 7
- Windows 8/8.1
- Windows 10
- Mac OS X

1.1 Install ICT Combined Instrument Software and USB Driver

Insert the supplied USB driver into your computer. Run HFD8.exe and install ICT Combined Instrument Software and USB Driver.
Alternately, the Windows and Mac installers can be found in the software folder on the USB driver, or on the ICT International website at:

http://www.ictinternational.com/support/software/

2. Installation Requirements

To install the HFD8, you will need:

- Cordless drill, suitable for use with 1.9 and 2mm drill bits. ICT International recommend the Dremel 8220, as the linear layout and battery position make it easier to drill parallel holes. These can be ordered from ICT International if necessary.
- 1.9mm and 2.0mm drill bits. (Included in the HFD Installation Kit)
- USB-A to Mini-B cable. (Included in the HFD Installation Kit)
- Computer with ICT Combined Instrument Software

Also Recommended:

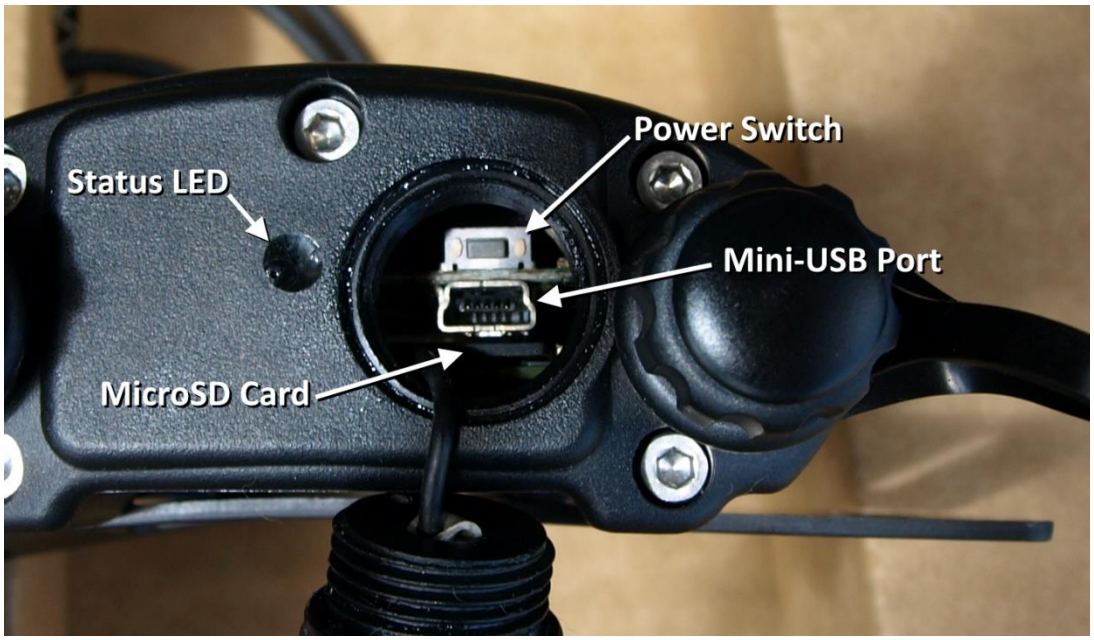
- HFD Drill Guide (Included in the HFD Installation Kit)
- Vacuum Grease (Included in the HFD Installation Kit)
- HFD Needle Sleeves (Included in the HFD Installation Kit)
- SFM Insertion Tool (Included in the HFD Installation Kit)
- 22W Solar Panel

Content of the HFD8 Installation Kit (left to right): HFD Drill Guide, 1.9mm drill bits, 2mm drill bits, HFD Needle Sleeves, MicroSD to SD and USB adaptors, USB Cable, SFM Insertion Tool, Dow Corning Vacuum Grease, Syringe for grease, USB Drive with Software and Documentation.

3. Turn the Instrument On

The HFD8 can be turned on manually by pressing and holding the power button for 2-3 seconds, or by connecting any external power supply, including USB (as covered in Chapter 4).

The HFD can be charged directly from a USB port when not logging.



4. Charging the HFD Internal Battery

The HFD8 is a self-contained instrument that incorporates a 4.8Ah lithium polymer battery and an automatic fast charge controller for battery management.
Before use, the instrument should be charged. Full charge is 4.20 volts (displayed in the software). A range of charging options are covered on the next pages.

Please note that ICT International do not recommend 12-volt external power supplies for the HFD8 as it has higher power requirements than other ICT Instruments. An external power supply voltage of 16 to 24 volts DC is recommended. Voltages above 16 volts allow the fast charge circuit to operate at up to a 700mAh charge rate.

A solar panel directly connected to the instrument (with no external battery) is recommended as this is the most efficient use of the solar panel.

4.1 Connecting a Power Supply to the Instrument

Important: Do not connect external power until the final step

1

Remove both bus plugs from either side of one end of the logger.

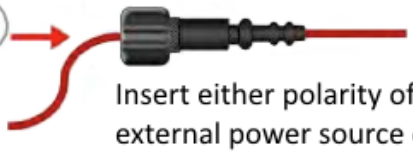
2

Unscrew the end of the plug 1 to 2 turns

3

Remove the sealing cap.

4



Insert either polarity of the external power source cable

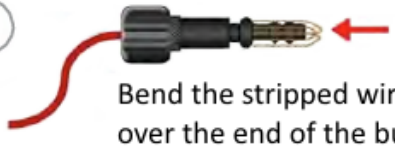
5

Strip about 15mm from from the end of the cable

6

Pull the cable back so that only stripped wire protrudes from the bus plug.

7



Bend the stripped wires back over the end of the bus plug.

8

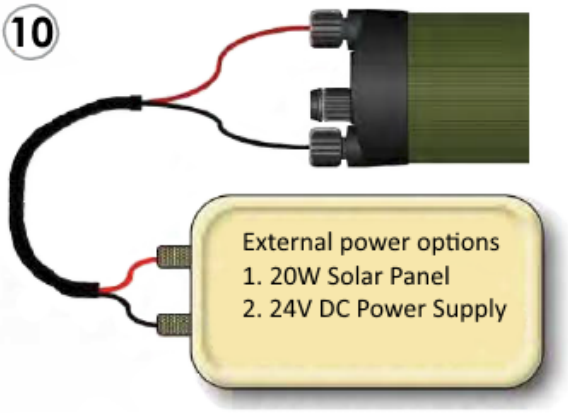
Important: Seal the cable against water ingress by tightening the end of the plug.

9

Repeat for second bus plug

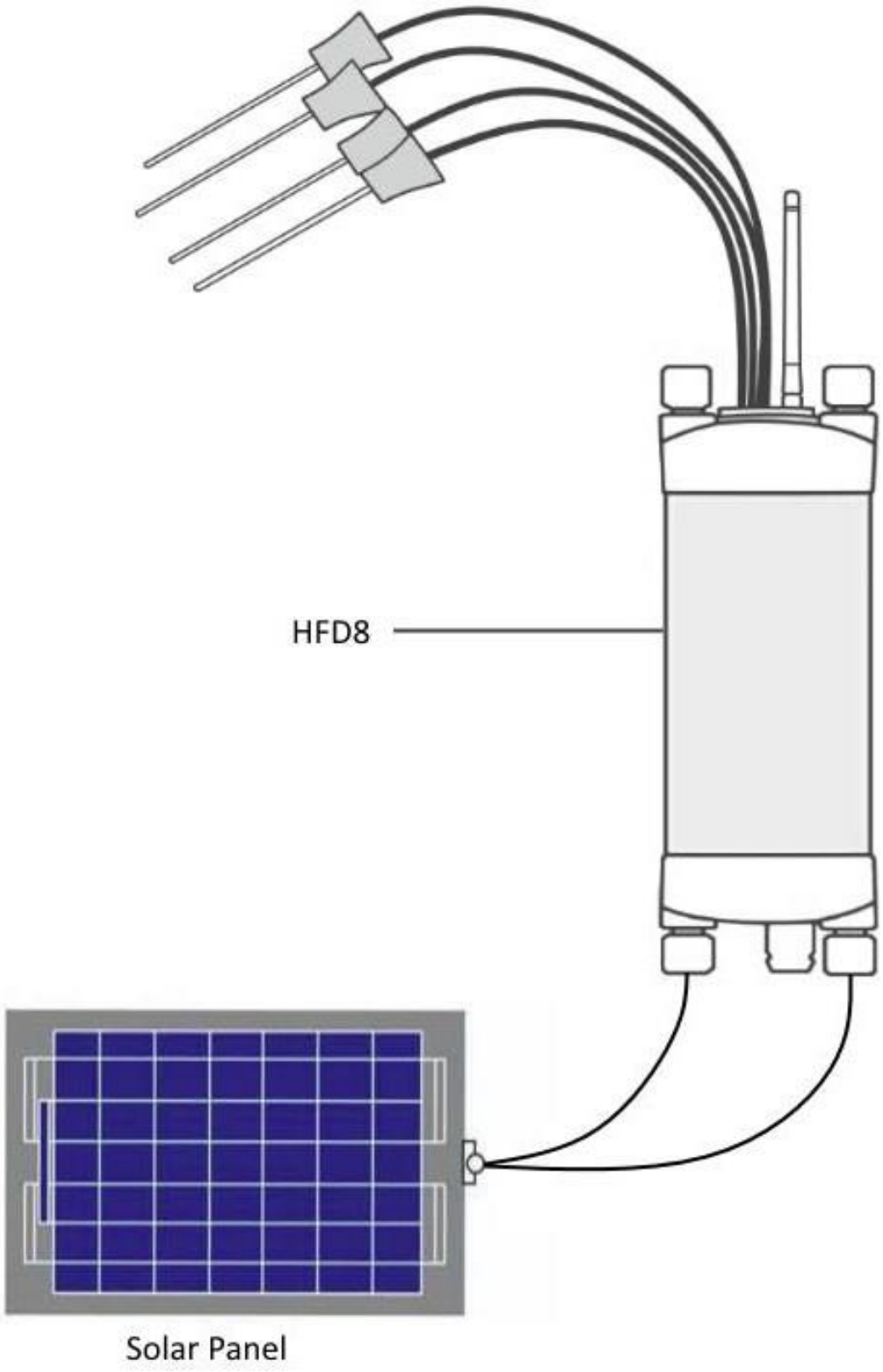
Insert the bus plugs into the endcap of the logger. The plugs can be inserted in either polarity and will click when seated.

10



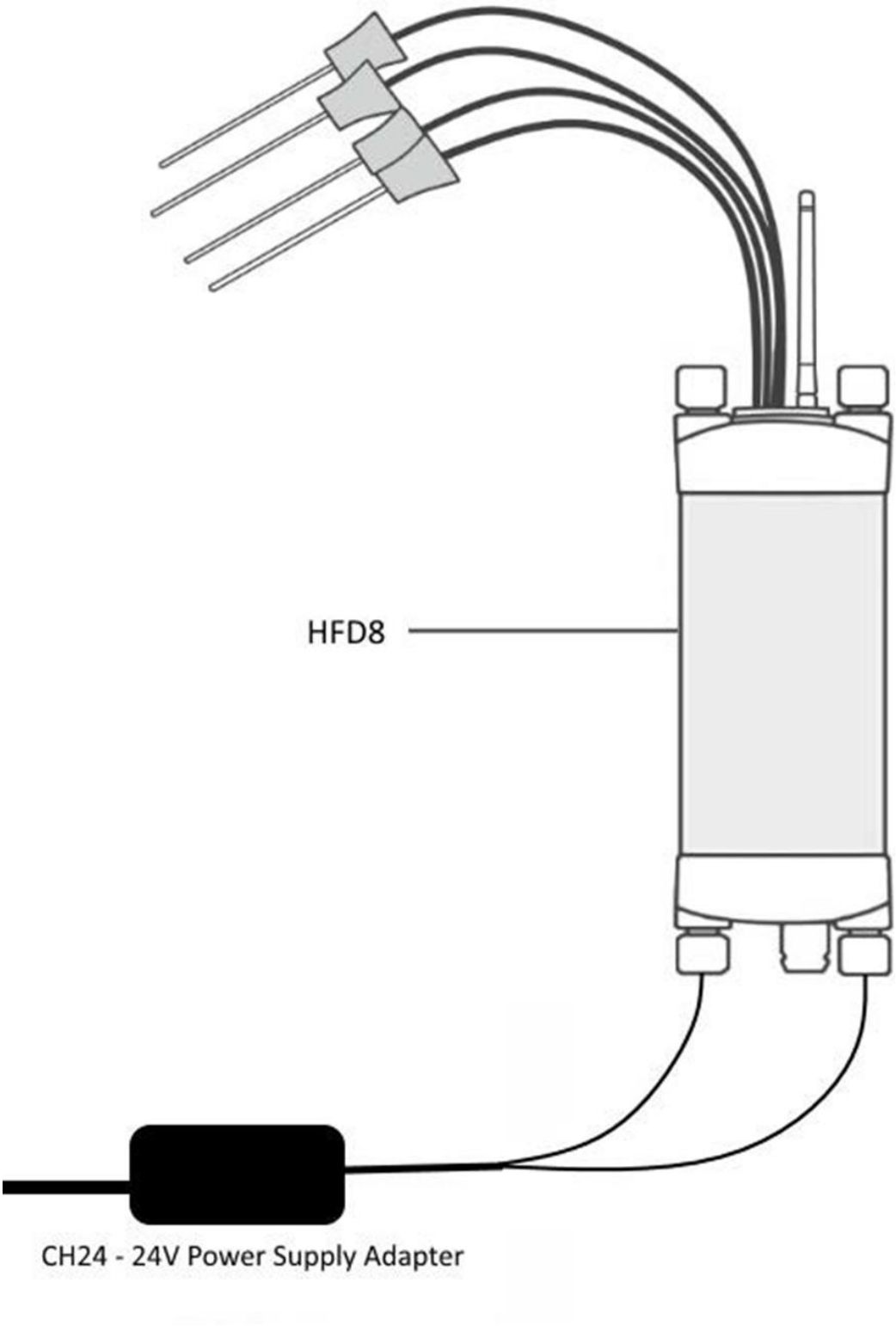
Connect the power cable to the external power source.

4.2 Connecting a Solar Panel



Note: The HFD8 is non-polarised.

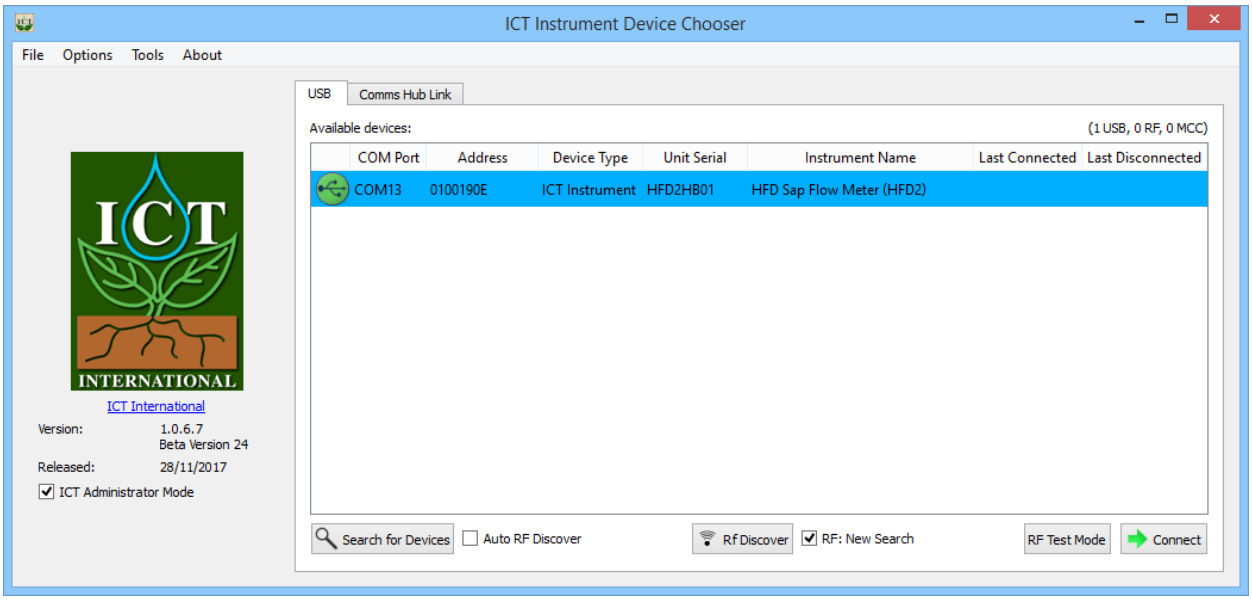
4.3 Connecting a CH24



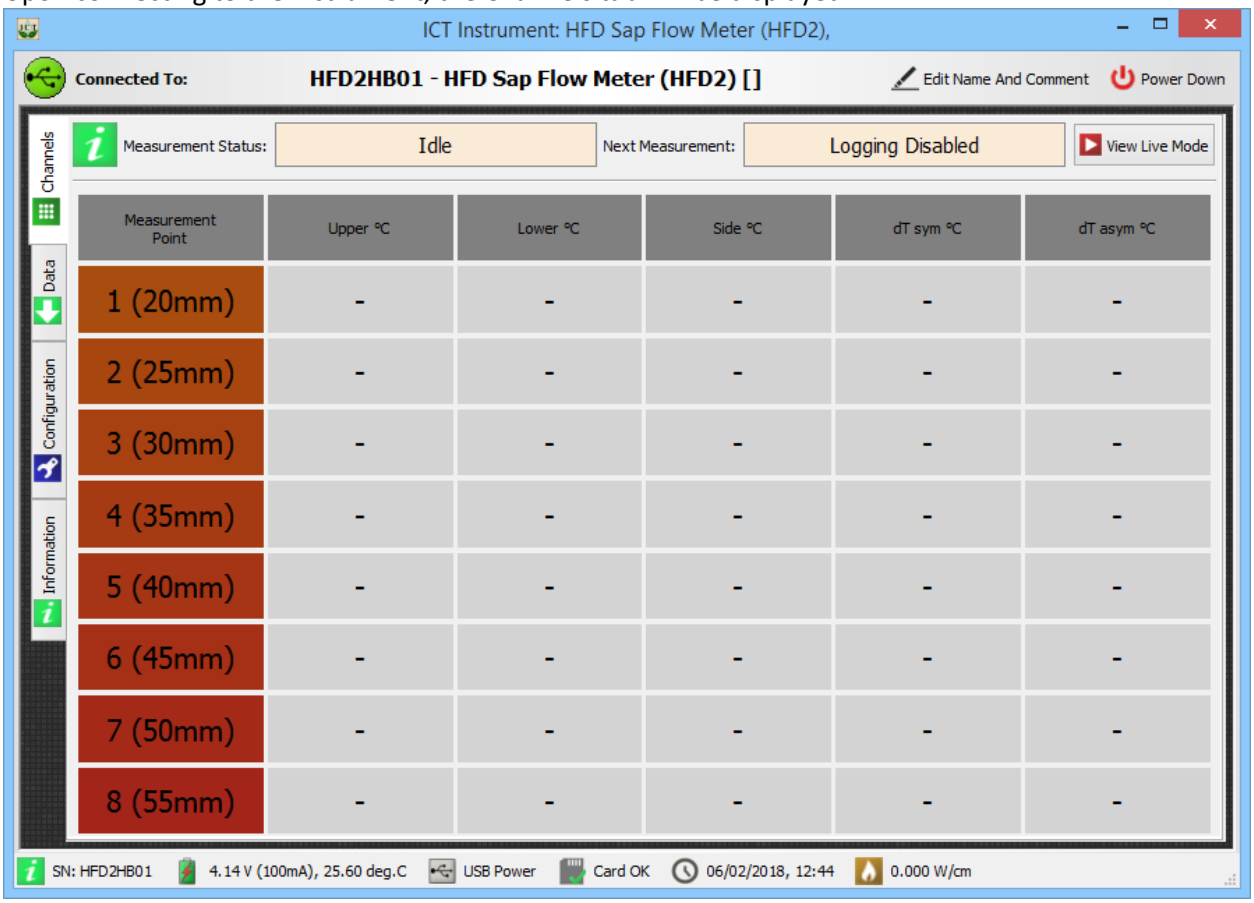
Note: The HFD8 is non-polarised.

5. Connecting to the Instrument

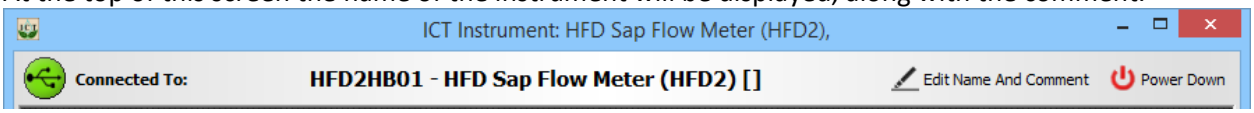
Connect the USB cable to the instrument. Open ICT Combined Instrument Software, Search for Devices and connect to the HFD8.



Upon connecting to the instrument, the Channels tab will be displayed.



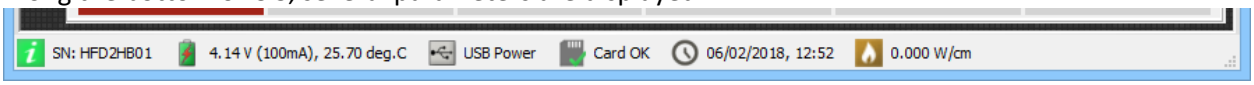
The channels tab displays information about the current instrument configuration.
At the top of this screen the name of the instrument will be displayed, along with the comment.



The name and comment can be changed with the Edit Name and Comment button. Name and comment should be set to something descriptive, to help you identify the instrument and installation location.

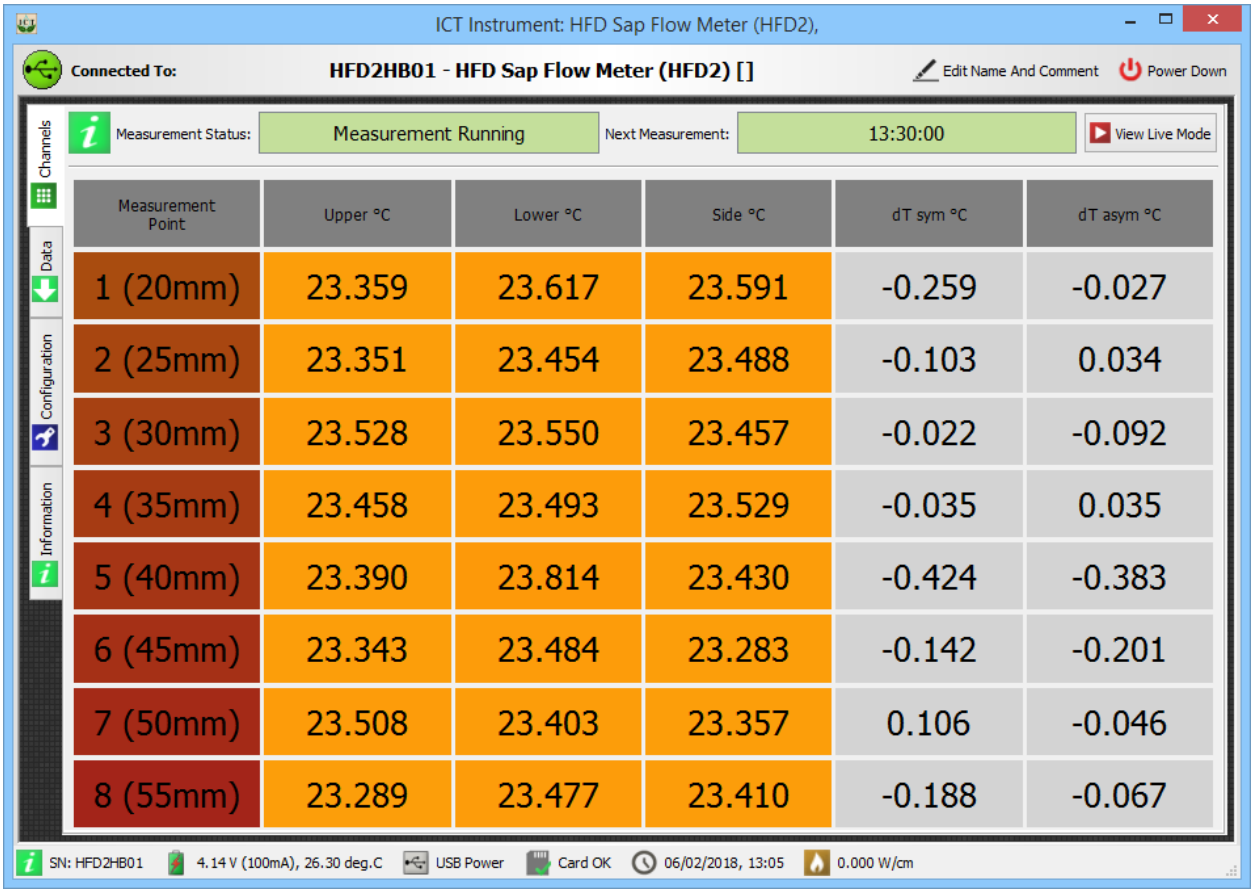
Power Down is used to turn off the instrument. The instrument cannot be turned off whilst external power is connected.

Along the bottom of CIS, several parameters are displayed.



SN (Serial Number): This is the unique identifier for the instrument. Serial numbers are assigned by ICT and cannot be changed.
Battery Status: Displays the current battery charge level (4.14 Volts), charge rate (100mA), and battery temperature (25.60°C).
External Power: Displays the external power supply input (volts/mA) when connected to a solar panel or CH24. Displays USB Power when connected to USB power only.
MicroSD Card Status: Displays Card OK when the MicroSD Card is inserted and working correctly, No Card Inserted when the MicroSD card is not inserted or is not detectable; or Card Error when there is an issue with the SD card.
Instrument Date and Time: Displays the current instrument date and time. This can be updated by clicking on the date and time.
Heater Status: Shows the current output of the HFD8 Heater.

5.1 Channels Tab



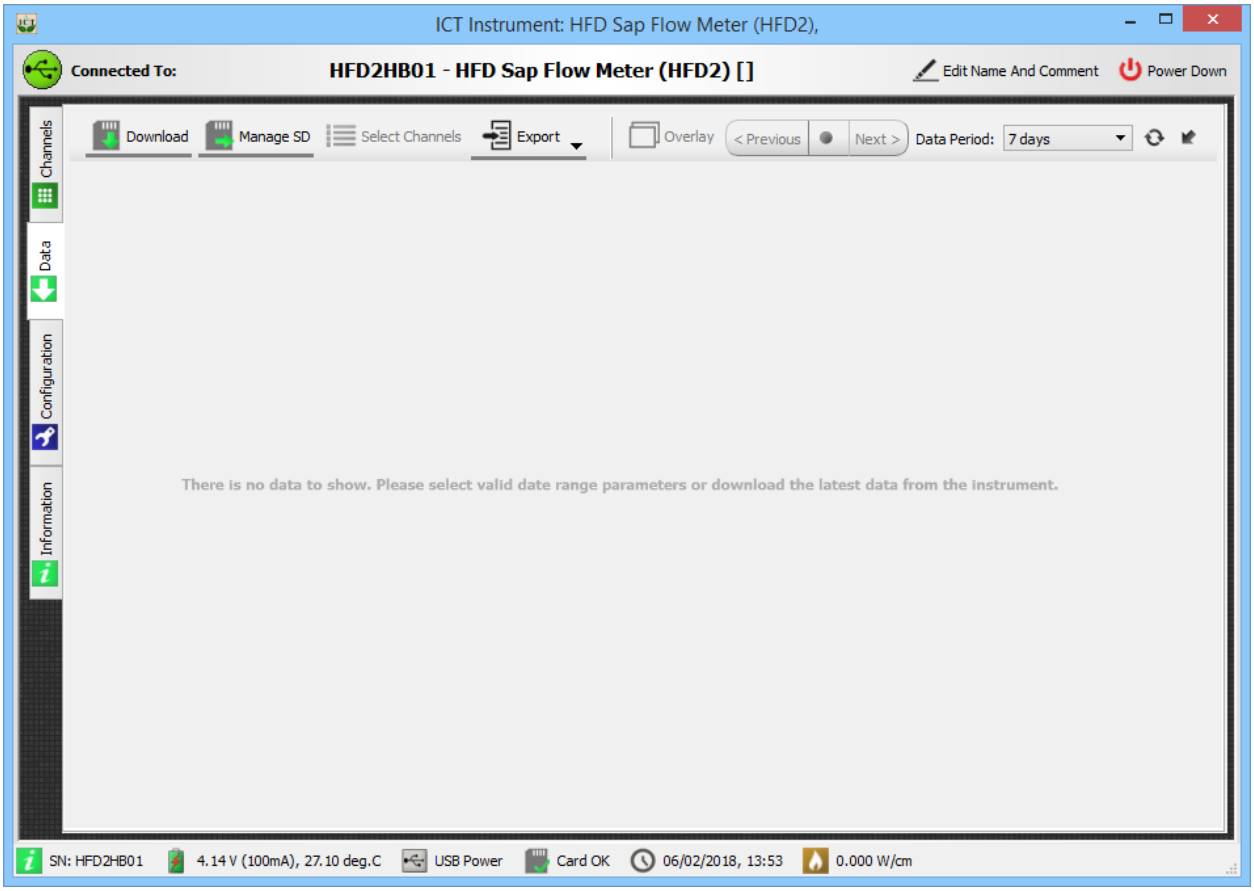
Measurement Point	Upper °C	Lower °C	Side °C	dT sym °C	dT asym °C
1 (20mm)	23.359	23.617	23.591	-0.259	-0.027
2 (25mm)	23.351	23.454	23.488	-0.103	0.034
3 (30mm)	23.528	23.550	23.457	-0.022	-0.092
4 (35mm)	23.458	23.493	23.529	-0.035	0.035
5 (40mm)	23.390	23.814	23.430	-0.424	-0.383
6 (45mm)	23.343	23.484	23.283	-0.142	-0.201
7 (50mm)	23.508	23.403	23.357	0.106	-0.046
8 (55mm)	23.289	23.477	23.410	-0.188	-0.067

The channels tab displays information about the current instrument configuration. Measurement Status displays Measurement Running when a measurement is being taken; a countdown to the next measurement; or idle if logging is disabled.
View Live Mode can be used to display the current temperatures at all the measurement points. This can be done at any time, and is useful for testing the measurement needles.

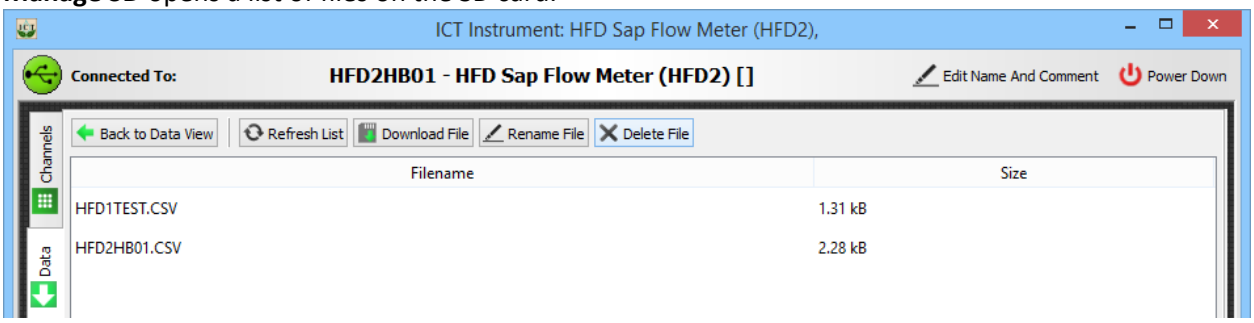
The table displays the output from the measurement needles if a measurement is taking place or if View Live Mode has been clicked.
Measurement Point 8 is closest to the tip of the needle, point 1 is closest to the blue base of the needle.

dT sym °C is the difference between the lower and upper needle measurement points.
dT asym °C is the difference between the lower and side needle measurement points.

5.2 Data Tab

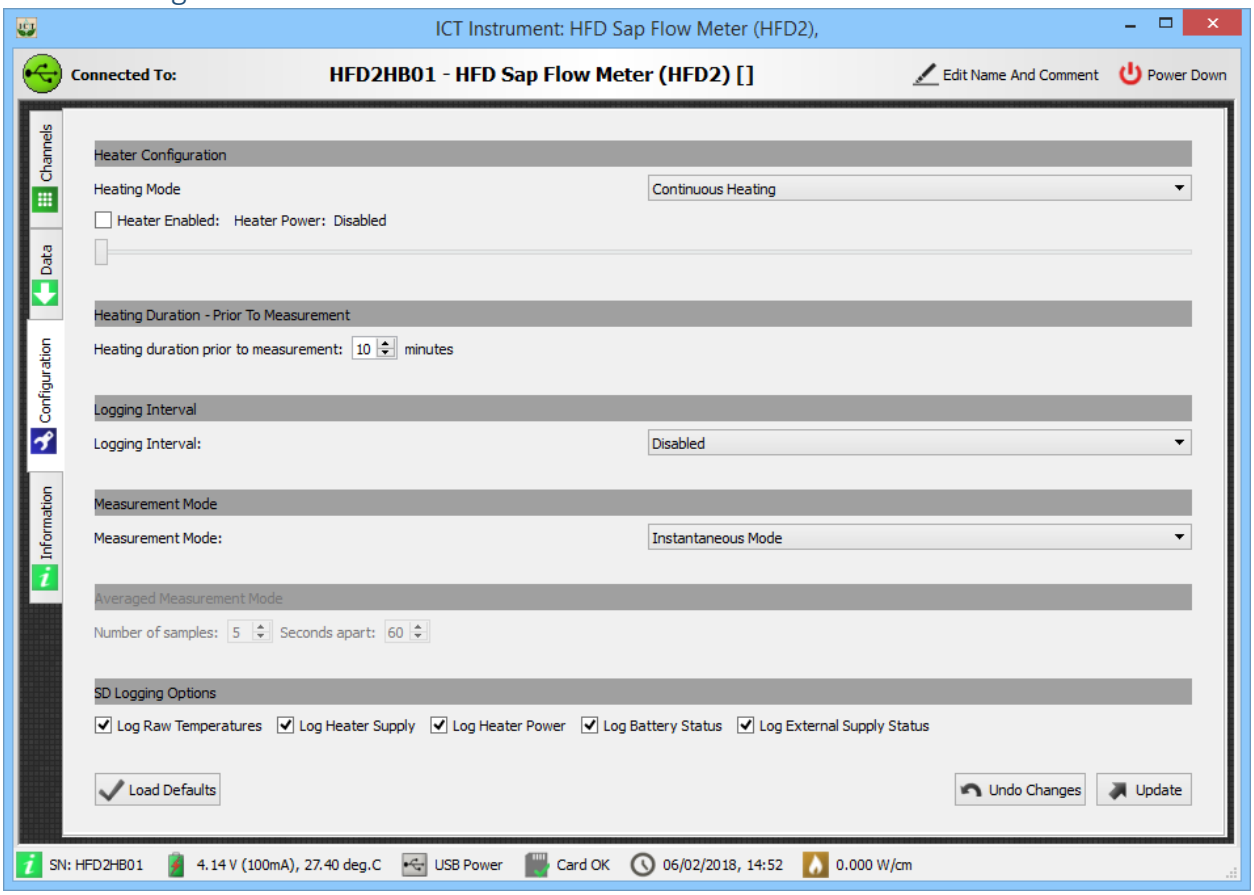


The Data tab is used to download and manage instrument data.
Download saves the instrument data to the ICT Dataview repository for visualisation.
Export allows you to save copies of the datafile with or without header information.
Manage SD opens a list of files on the SD card:



Download File saves the file to a location of your choice.
Rename File renames the data file. If the main datafile is renamed, a new one will be started.
Delete File erases the file from the SD card.

5.3 Configuration Tab



Heating Mode:

- Continuous Heating (default) powers the heater needle continuously.
- Heating Prior to Measurement powers the heater for several minutes prior to taking a measurement. This can be used to save power and prolong instrument battery life if necessary.

Heater Enabled:

Check box to enable/disable the heater. Heater Power can be set with the slider. The available range is 0.016 W/cm (4.5 volt) to 0.181 W/cm (15.0 volt).

Heating Duration Prior to Measurement:

Sets the heating duration prior to a measurement taking place. By default, this is set to 10 minutes. Not applicable to Continuous Heating mode.

Logging Interval:

Sets the interval at which measurements take place, from every 10 seconds to every 60 minutes.

Measurement Mode:

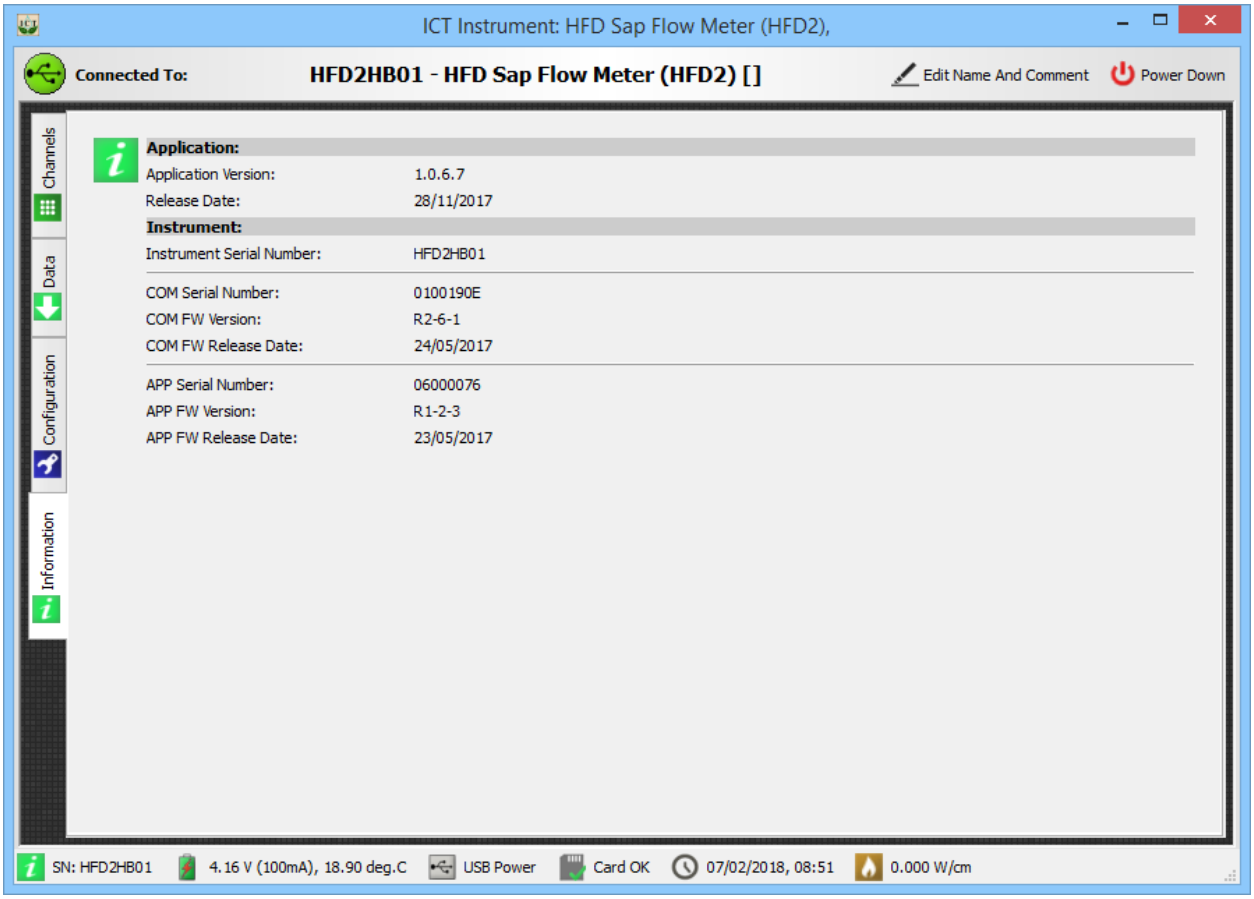
- Instantaneous Mode (default) takes a normal measurement at the set interval.
- Averaged Mode takes a number of samples over a period of time and averages these to get a result. This is set under **Averaged Measurement Mode**. By default, 5 samples are taken 60 seconds apart.

SD Logging Options:

- Log Raw Temperatures records the uncorrected temperatures as measured.
- Log Heater Supply records heater voltage and current draw.
- Log Heater Power records the W/cm of the heater.
- Log Battery Status records the internal battery voltage and temperature.
- Log External Supply Status records external supply voltage and mA.

By default, all of these options are enabled.

5.4 Information Tab



The information tab provides version information and serial numbers for the instrument and components.
The ICT International website (http://ictinternational.com/support/software/) should be checked periodically for new versions of GCB and HFD firmware.

6. Installation

6.1 Needle Position

Positioning the first measurement point is crucial to the interpretation of the measured data.
All measurement needles (HFD8-100 and HFD8-50) have a 20mm distance between the base and the first measurement point. To accurately position this outer measurement point below the bark, an insulating spacer should be used.

Begin by measuring the bark thickness at the installation site, if the bark is less than 15mm thick a spacer should be used to position the outer measurement point 5mm below the cambium. This position is the default value used in Sap Flow Tool, and ensures that the sphere of influence of the measurement point is entirely within sapwood.
If the plant has rough, fibrous or flaky bark, the bark surface must be smoothed.

If the bark is more than 15mm thick, bark should be removed such that there is 15mm of bark. This will act as a spacer to ensure that the measurement points are correctly located.

Preparing spacers for HFD installation using polyethylene foam.

When preparing the bark surface and spacers, it is important to note that the reference point be equal for all needles both in the axial and tangential directions around the heater. This is to ensure that all measurement points are located at the same depth below the cambium and across the radial profile of the sap wood.

6.2 Drilling

Once you have selected and prepared the installation site, attach the HFD drill guide firmly to the tree, ensuring that the holes are aligned with the vertical axis of the tree.
Use a 1.9mm drill bit, drill speed should be high, but not so high that the hole is burnt. The moist sapwood of the tree will become stuck in the flutes of the drill, so the hole should be drilled in short increments, stopping regularly to clean the flutes of the drill to prevent burning the surrounding tissue.

After all 4 holes have been drilled, remove the drill guide and check that the holes are parallel by partially inserting the sleeves. If the holes are not parallel, a new installation will be required.

6.3 Installing Sleeves

The HFD sleeves are made from surgical grade 316 stainless steel and designed to prevent corrosion when installed in the stem. The longer sleeve is to be installed in the center most hole (Heater position), with the shorter 3 sleeves in the top, bottom and right-hand side holes.

Sleeves should be installed using the SFM insertion tool as the edges are quite sharp. You should be able to push the sleeves in fairly easily. If you find that it is difficult to insert the sleeve, use one of the 2mm drill bits to carefully enlarge the hole, allowing the drill to follow the existing hole.

6.4 Installing the HFD

Use the provided plastic mounting brackets to attach the HFD to the tree. For small to medium trees, a strap can be passed through the mounting bracket and fastened to the tree. For larger trees, it may be necessary to screw or nail the mounting bracket to the tree.
Install the HFD below the drilling site with the antenna pointing upward if possible.

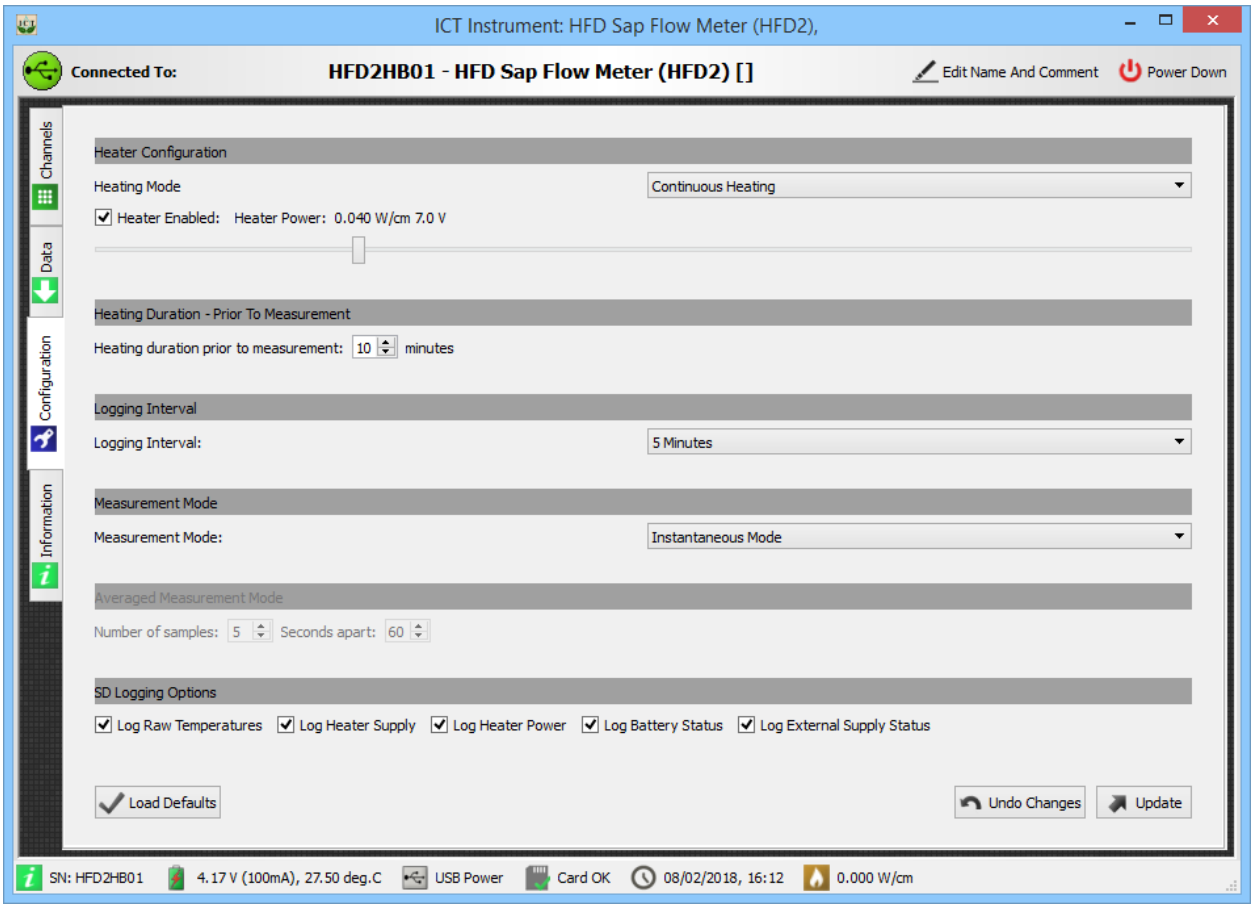
Apply some grease to the needles and insert them into the sleeves, ensuring that a gentle curve is placed in the cables to provide strain relief.

6.5 Insulation

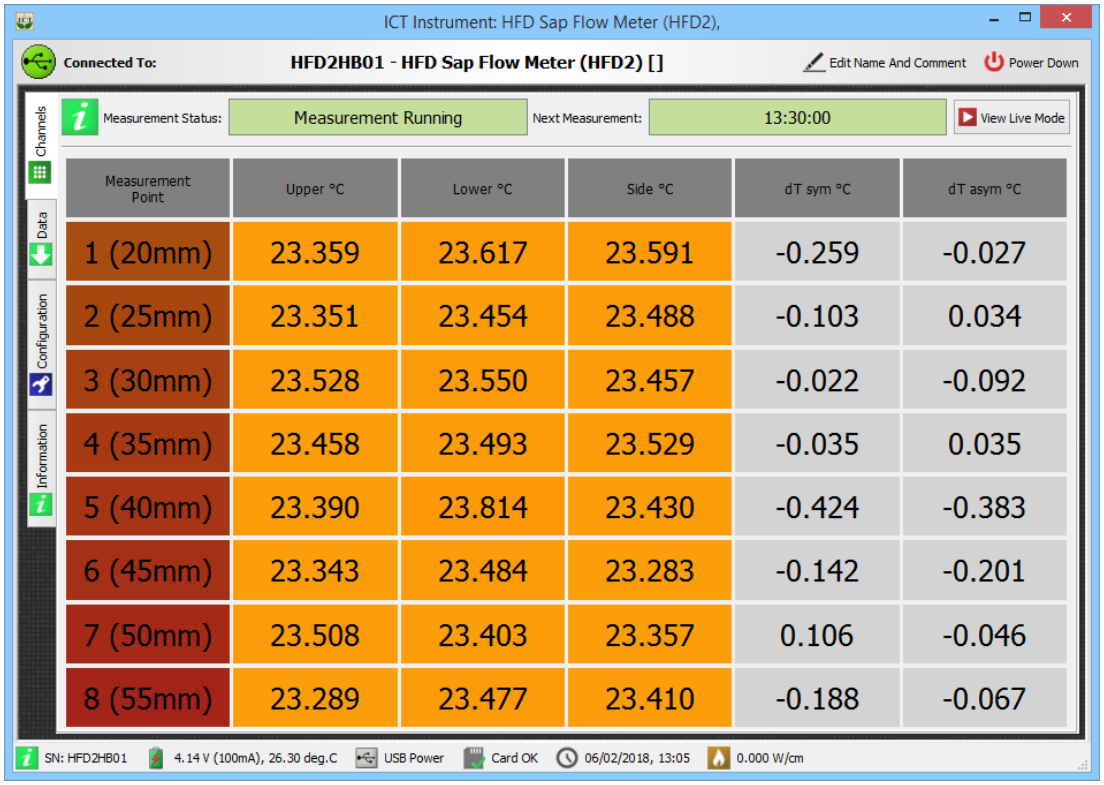
For the greatest accuracy the installation site can be insulated against ambient conditions.
Once installed, fasten the base of all needles together, then wrap the head of the needles with foam. Finally, cover the foam with aluminium foil or similar to reflect radiant energy. The foil can be fastened to the stem at the top of the installation using electrical tape or similar.

6.6 Verification

Connect to the instrument and set Heater Power (Configuration Tab) to 0.04 W/cm, using Continuous Heating mode.
Select the preferred logging interval, for long term measurements an interval between 1 to 5 minutes is appropriate.
For short term dynamic experiments, such as cut stem, a logging interval between 1 second or 10 seconds should be used.
Measurement Mode should be set to Instantaneous Mode.



Note: Click Update to send the settings to the logger.



Check the values displayed on the channels tab. All temperatures should be similar. If the temperatures of some measurement points are significantly different (especially towards the bark) check the position of the needles and the insulation.

Installation can be further verified by checking the dT asymmetric value for the outer measurement point (point 1) at night. This value should be at least 1°C, but not significantly higher. A temperature difference of at least 1°C is required to achieve sufficient measurement sensitivity, however, increasing the temperature above 1°C does not significantly improve sensitivity and will unnecessarily damage plant tissue.

If night time dT asymmetric is consistently below 1°C, heater power should be increased in steps of 0.005 W/cm.

7. Appendices

7.1 The Heat Field Deformation Method

The Heat Field Deformation (HFD) method consists of a heater needle and 3 measurement needles, two installed symmetrically downstream and upstream of the heater, with one asymmetric needle installed horizontally next to the heater.
Sap flux densities are calculated for each position according to the following equation:

$$Q_i = 3600 . D . \frac{Z_{ax}}{Z_{tg}} . \frac{1}{L_{sw}} . \left(\frac{K + Symmetric - Asymmetric}{Asymmetric} \right)$$

or for reverse flow situations:

$$Q_i = -3600 . D . \frac{Z_{ax}}{Z_{tg}} . \frac{1}{L_{sw}} . \left(\frac{Asymmetric - K}{Symmetric - Asymmetric} \right)$$

Where:
Q_i is the sap flux density ($cm^3\ cm^{-2}\ h^{-1}$) at position *i*.
3600 (s^{-1}) is a factor to convert seconds into hours.
D is the thermal diffusivity ($cm^2\ s^{-1}$).
Z_{ax} the axial distance (cm).
Z_{tg} the tangential distance (cm).
L_{sw} the sapwood depth (cm).
K the K-value (°C) and Symmetric (°C) and Asymmetric (°C) the measured symmetric and asymmetric signals.

Note: The HFD 'K'-value should not be confused with 'k' which is used in many sap flow publications to denote thermal diffusivity. The HFD equations use 'D' for thermal diffusivity.
The HFD 'K'-value is an absolute value reflecting a condition of zero flow.

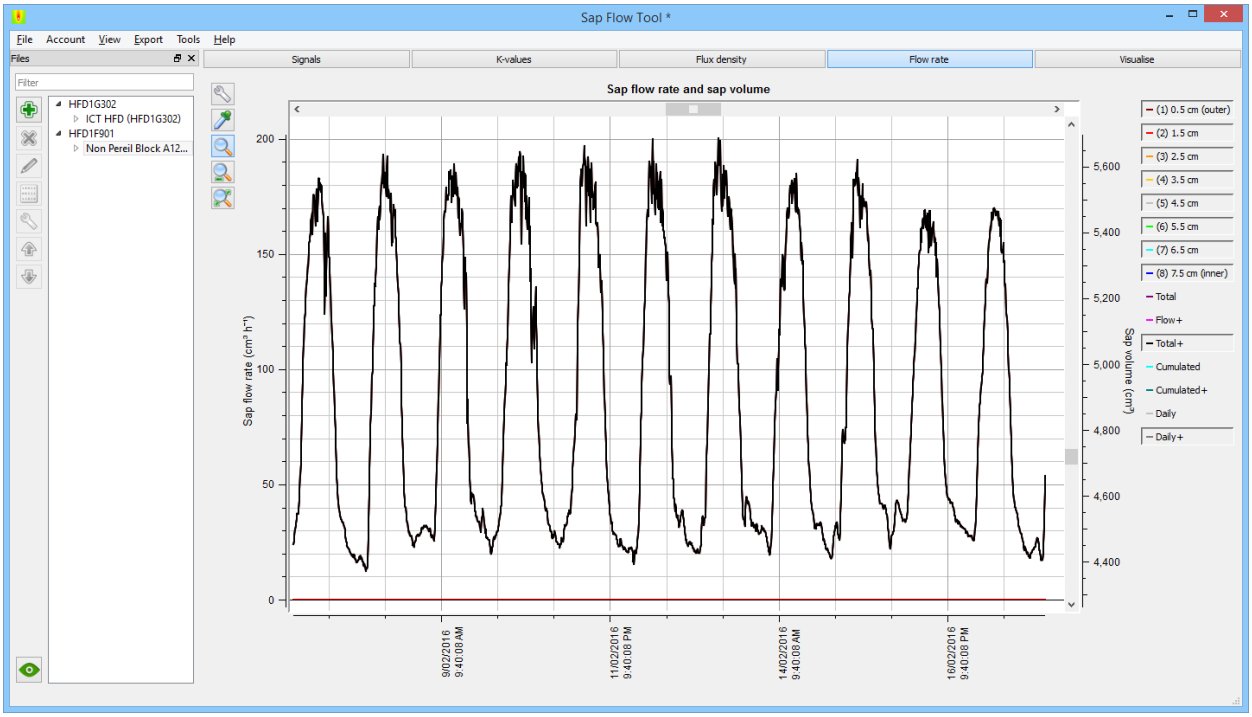
For more information, refer to:

Nadezhdina, N., Cermák, J., Gaspárek, J., Nadezhdin, V. and Prax, A. (2006). Vertical and horizontal water redistribution in Norway spruce (Picea abies) roots in the Moravian Upland. Tree Physiology, 26(10), 1277-1288.
Poyatos, R., Cermák, J. and Llorens, P. (2007). Variation in the radial patterns of sap flux density in pubescent oak (Quercus pubescens) and its implications for tree and stand transpiration measurements. Tree Physiology, 27(4), 537-548.
Nadezhdina, N., Vandegehuchte, M. W. and Steppe, K., (2012). Sap flux density measurements based on the heat field deformation method. Trees, 26:1439–1448.

7.2 Data Interpretation

The Sap Flow Tool software can be used to more easily interpret HFD data.
A free 30-day trial is available from: http://www.sapflowtool.com

For more information or assistance, please contact ICT International: sales@ictinternational.com.au



Sap Flow Tool offers automatic calculation of K-values, Flux Density and Flow Rate based on measured parameters of the plant.

7.3 Data Storage

The HFD8 stores data on a removeable MicroSD card. A 4GB card comes pre-installed in the unit.
4GB is enough to measure all raw parameters and optional diagnostics at a 1 second logging interval for at least 12 months.

ICT Loggers use FAT32 formatted MicroSD cards (default formatting).

MicroSD cards can be removed from the instrument whilst it is on and logging for data download.
Logging will resume when a card is re-inserted.

Data files are saved as *.CSV, openable in most text editors and Excel.
Regional settings (delimiters and decimal point) for the CSV format are based on the settings of the computer used to set up the instrument.

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