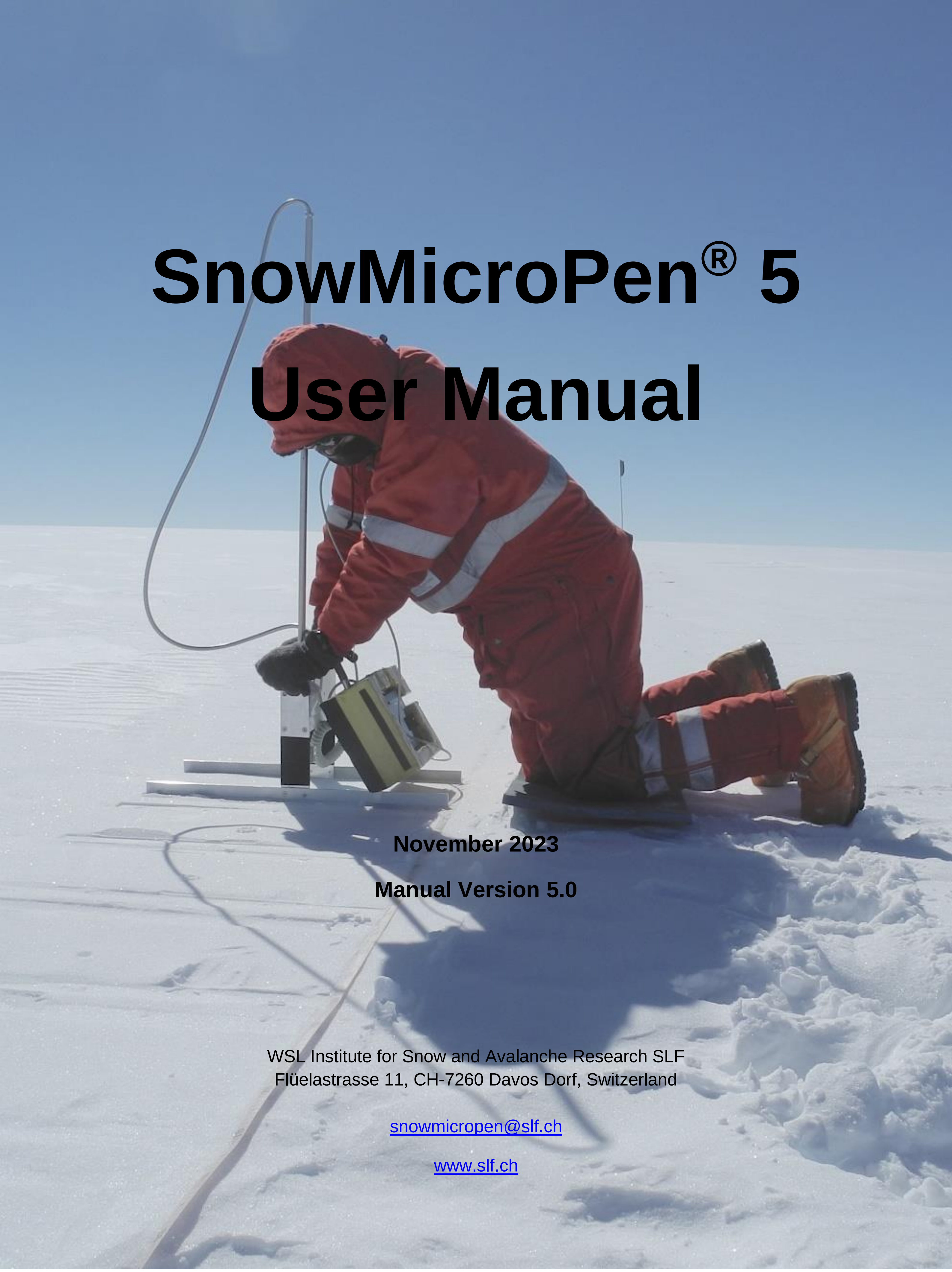


SnowMicroPen® 5 User Manual

November 2023

Manual Version 5.0

WSL Institute for Snow and Avalanche Research SLF
Flüelastrasse 11, CH-7260 Davos Dorf, Switzerland

snowmicropen@slf.ch

www.slf.ch

1 Introduction

The SnowMicroPen® (SMP) is a snow penetrometer developed and introduced more than 20 years ago (Schneebeli and Johnson, 1998). The high-resolution, penetration force-distance signal can be used to recover microstructural parameters, deriving stratigraphic and macroscopic snow properties such as snow density and specific surface area. The SMP is used in different applications such as snow profiling (avalanche forecasting, snow stratigraphy, remote sensing ground truth), ski track characterization (ski racing), or snow runway characterization (stability testing).

Because several electrical components have recently reached their end-of-life, a significant upgrade of the SMP was needed. Due to the extent of changes and modifications, we introduce the fifth generation of SnowMicroPen® (SMP5) including an updated user manual.

The principle of measurement using a piezoelectric force sensor to measure the penetration resistance as a function of depth has not been changed. However, most of the electronic components controlling the operation of the instrument have been upgraded and improved. These upgrades include an optimization of the signal acquisition, applying digital technology to control the rod movement, a low-temperature resistant display, and supporting the user with more intuitive menu guidance to a higher grade of modularity to exchange components in case of failure. Within this latest version – SMP5 – we provide a reliable and robust snow research instrument.

Nevertheless, some of the old properties of the SMP are kept untouched. Compared to a traditional snow profile, SMP takes much less time and is not biased by the observer. The instrument still consists of two main pieces: a motor and a control unit. The motor unit drives a high-sensitivity force sensor attached to a metal rod through the snowpack. The control unit controls the motor unit and displays and stores the measurement data in binary format on an SD memory card. The files on the SD memory card are on a FAT32-compatible file system and can easily be copied to a computer. The binary files can be read, plotted, and evaluated by theopen-source program "SnowMicroPyn", either as Python code or as a standalone executable on Windows, Mac, or Linux.

Although the SMP is designed for field applications and is supposed to be used under rough weather conditions, a careful and adapted handling is still required. The controller is protected against splash water but is not waterproof. Especially on sea ice, instrument maintenance is essential. The instrument works down to -30°C.

This manual aims at providing support for a correct setup and operation of the instrument to perform high-quality measurements and to accurately maintain the instrument. The more carefully you read this manual, the more likely it is to achieve high quality snow measurements.

Additional information you can find on the SnowMicroPen website:

http://www.slf.ch/snowmicropen

2 Safety guidelines

The SnowMicroPen is a high-sensitive force-measuring device. It is equipped with a piezoelectric force sensor (quartz). Low-level force sensors are sensitive measuring instruments that must be carefully handled. Since they do not have mechanical overload protection, jolts and shocks must be avoided!

- Do not drop the instrument
- Always protect the sensor and the measurement tip when the device is not being used or when it is under transportation
- Try to avoid condensation. Otherwise, let the instrument dry out in a warm environment (20°C)
- Do not measure when it rains
- Never probe into water (e.g., measuring on sea ice). The force sensor is only splash water protected and specified
- Never measure to overload in case the device is in a mechanical fixation (laboratory setup) and the ground is hard and mechanically rigid
- Remove/unscrew the measuring tip for transportation
- Do not charge the battery of the controller unit when the temperature is below 0°C
- Never plug or unplug cables on the powered controller. This action might severely damage the electronics

3 Device Specifications

probe length (*standard version)	270 mm / 830 mm / **1200 mm *** / 1720 mm / 2100 mm / 2600 mm
sampling rate	242 samples mm^{-1}
forward rod velocity	20 mm/s
backward rod velocity	55 mm/s
spatial sampling resolution	4 µm
layer resolution	0.5 mm
Piezoelectric force sensor	KISTLER Instruments, Type 9207, Range -50 N ... 50 N
Effective force range and resolution given through SMP	0-42 N, 0.01 N
noise	< ± 5 mN
resolution of A/D conversion	16 Bit
operating temperature	-30°C .. (65°C) *Laboratory tests at -40°C have shown that the instrument still works despite the display being out of order (very low illumination and very long response times). Experienced operators may navigate through the menus without seeing the menu items*
GPS module	± 2 m The GPS module is at the upper end of the rod
Data storage	SD memory card, up to 32 GB, pSLC technology, UHS-I, and extended temperature range -40°C .. 85°C
power supply	Rechargeable LiPo 6S 22.2V 2800mAh 35C/70C XT60 battery for up to 100 measurements. The battery is from an "iced power" type that has full performance down to -20°C Standard battery type providing charge balancing.
internal clock (RTC)	Onboard RTC (real-time clock) for measurement timestamp. RTC is updated every time there is a GPS connection available
operating weight	approx. 7 kg (1200 mm)
transportation weight	approx. 24 kg in a transportation box of 175 x 32 x 21 cm

Table 1: *SMP 5 specifications.*

4 Packing Instructions

4.1 Transportation Box

The SnowMicroPen is shipped in a hard case, providing wheels on one side.

Figure 1: *Hard case for SnowMicroPen shipping.*

The dimensions are:

175 cm x 32 cm x 21 cm, roughly 24 kg

4.2 Content of the Transportation Box

The following items belong to a complete set of SMP:

- ✓ SnowMicroPen5 motor unit with a metal rod with a black protecting tube (1x)
- ✓ SnowMicroPen5 controller unit containing a Lithium Polymer battery (1x)
- ✓ Metal brackets with spikes for flat field measurements (2x)
- ✓ Ski poles for slope measurements (2x)
- ✓ Plastic box (1x) containing brush ring (1x), quick release screws (6x), black cable with LEMO plugs to connect rod with controller unit (1x)
- ✓ Plastic box (1x) containing SD memory card reader (1x), SD memory card (1x), O-ring (3x), measuring tip (2x), USB C to USB cable, spare parts including screws, …
- ✓ Power supply 48 VDC with LEMO plug (1x)
- ✓ User manual as a print version (1x)
- ✓ A memory stick containing device documentation and the original configuration file

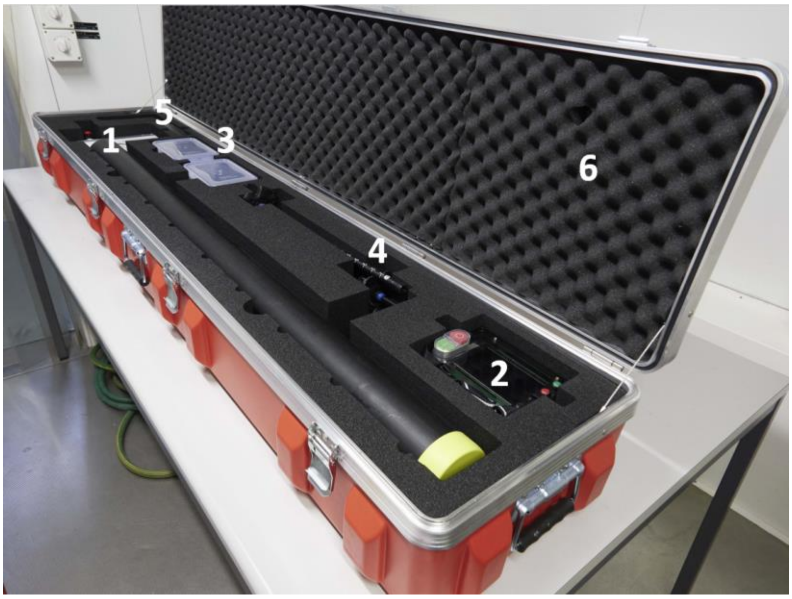


Figure 2: *Content of the SnowMicroPen transportation box. Motor unit with black protection tube (1), controller unit (2), plastic boxes with miscellaneous parts (3), ski poles (4), power supply (5), and user manual in a briefcase (6). The metal brackets can't be seen in this picture because they are located under the motor unit.*

5 Device Description and Glossary

5.1 Overview

Figure 3 provides an overview of the components of the device. The naming conventions used throughout the manual are summarized in Table 2 and detailed below.

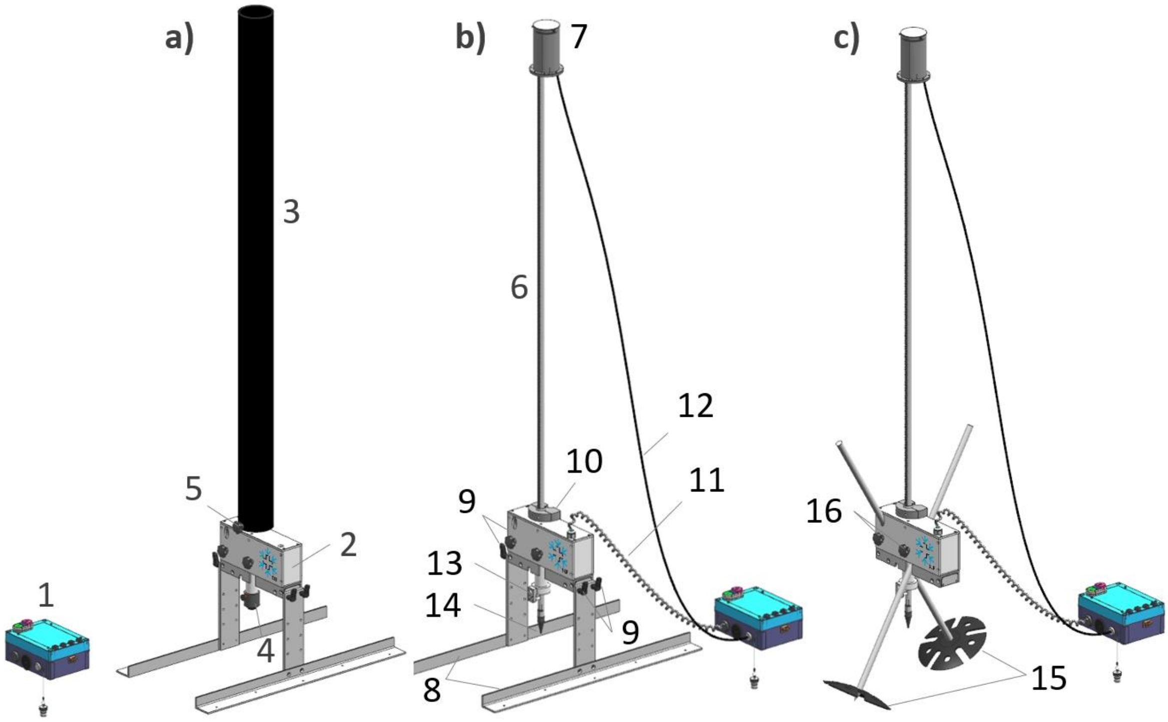


Figure 3: *Overview of the main components of a SnowMicroPen.*

Controller unit (1), motor unit (2), black protective tube for rod (3), protective cap (4) of the force sensor, and the locking screw (5) of the protective tube. After removing the black protective tube, the rod (6) and the charge amplifier box, including the GPS module called head (7), appear. The measurement support frame with spikes (8) is needed for flat field measurements shown in situation (b). Those aluminum brackets are fixed with four quick-release screws (9). The adapter to hold the protective tube (10) must not be dismounted for measuring. Both, the spiral motor cable (11) and the sensor cable (12) must be connected to the controller unit. A brush is mounted on a ring (13), which must be fixed to shed sticking snow on the rod. At the lower end of the rod, the highly sensitive piezoelectric force sensor and the measurement tip (14) are embedded.

To measure on sloping terrain, as shown in situation (c), ski poles (15) are used instead of the aluminum brackets (8). The ski poles can be fixed by using the ski pole screws (16).

As the piezoelectric force sensor (quartz) can easily be damaged by shear forces or too large of normal forces, a schematic representation is presented in Figure 4. The section view should clarify the design of the connection between the measurement tip and the force sensor. It shows that the position of the O-ring is essential to prevent the force sensor from too large shear forces and that the design does not mechanically protect the force sensor from too large normal forces.

As soon as the measurement tip (14) is screwed into the force sensor (19, 19a), the quartz of the force sensor (19b) can potentially be destroyed. Therefore, if the instrument is not supposed to be used, it is highly recommended to have the rod in the home position and have everything protected with the protective cap (4). The measurement tip (14) should be removed/unscrewed to additionally decrease the risk of a sensor break.

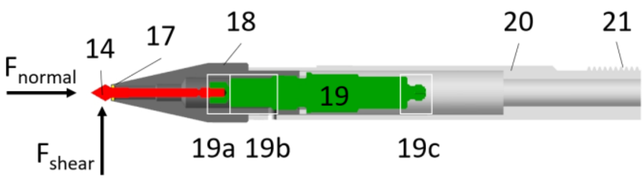


Figure 4: *Technical picture and section view through the rod (20), the piezoelectric force sensor (19), the cone (18), the O-ring (17), and the measurement tip (14).*

The tiny rubber O-ring (17) prevents the measurement tip from bending too much to the side and protects the sensor from potential shear forces. Additionally, the O-ring prevents snow from entering the hollow area between the measurement tip and the cone (18). From the piezoelectric force sensor, a capacitive cable (19c) is led through the rod to the charge amplifier box at the upper end of the rod (head, 7), where the signal is amplified and digitized.

The motor unit (2) is always kept perpendicular to the snow surface by either the aluminum brackets (8) or the two ski poles (15). The motor unit contains a built-in motor that drives the rod (6) with a standardized velocity of 20 mm/s into the snowpack. The measurement tip (14) breaks the bonds between the snow grains and transduces the force to the piezoelectric force sensor (19). The charge signal is transferred through a coaxial wire inside the rod (20) to the charge amplifier (7) at the top of the shaft. The analog signal from the amplifier is digitized next to the amplifier and saved in a temporary memory at the same place. After the penetration measurement, the temporarily saved signal is automatically transmitted through the sensor cable (12) to the controller unit and permanently saved on the SD memory card. Meanwhile, the rod is driving back into its home position. As snow might get stuck on the rod's teeth (21), the brush ring (13) should always be mounted.

The controller unit controls all functions of the SnowMicroPen. The controller unit (Figure 5) is designed for field applications, is splash waterproof and can easily be operated with thick gloves.

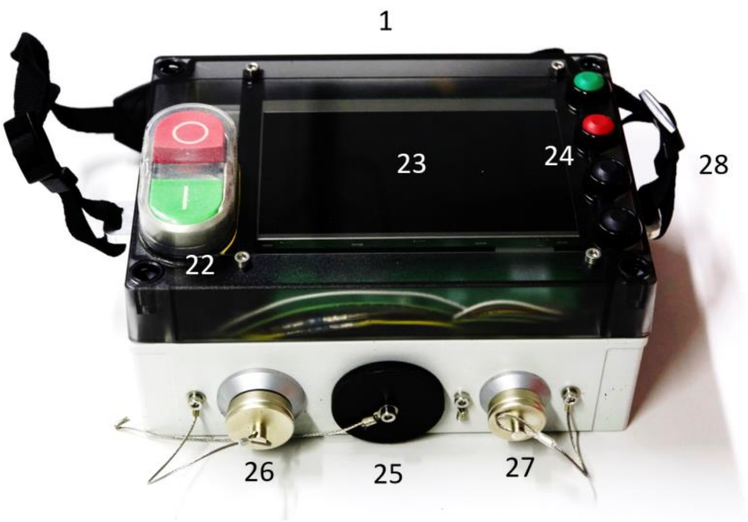


Figure 5: *SMP5 controller unit (1). Electrical main switch (22), low-temperature operable display (23), menu and navigation buttons (24), screwable lid to protect the SD memory card slot and USB 3 interface (25), female connector (26) to connect either spiral motor cable of motor unit or battery charger, female connector (27) to connect sensor cable and ribbon (28) to carry the controller unit around the operator`s neck.*

The main switch (22) under the flexible protection cap powers on or off the instrument. This main switch is not a mechanical but an electrical switch which allows automatically switching off the controller unit after a specific time of not using it.

The spiral motor cable and the sensor cable are connected to the corresponding connectors (26,27). Both connectors are from push-pull-type. The two connectors differ in their number of pins and, therefore, can't be plugged the wrong way around. The connector (26) is also used to recharge the internal LiPo battery.

Never plug or unplug the connectors while the controller unit is powered (ON)

The four buttons on the controller (24) are used to navigate through the menu and to operate the instrument: the green button has a confirm/enter, the red button has a discard/exit functionality, and the two black buttons are to jump up and down in the menu structure. For detailed navigation, please consult the corresponding chapter 6.

The controller unit provides only controlling and logging functionality so that a motor unit can be operated with any controller unit. The only requirement is to use the designated configuration file (config.txt) with parameters that correspond to the components of the motor unit (force sensor, amplifier, motor, etc.). The configuration file is saved on the SD memory card. Furthermore, please check the firmware compatibility of the controller and the motor unit with the manufacturer.

The main switch (22) of the controller unit must be used as an emergency stop in case of misbehavior of the instrument, cables getting stuck when the rod is homing, and other reasons.

In the unlikely case of a software-wise frozen display, the controller unit has to be restarted using the main switch.

At very low temperature less than -30°C, the display might react slowly and have a low to almost invisible luminosity. Nevertheless, if the operator knows the sequence of the buttons to push, the instrument can be operated without display support.

1	Controller unit
2	Motor unit
3	Black protective tube for rod
4	Protective cap for sensor
5	Locking screw to hold the protective tube
6	Rod
7	Head
8	Measurement support frame with spikes for flat terrain
9	Quick-release screws for measurement support frame with spikes
10	Adapter to hold and center the protective tube
11	Spiral motor cable
12	Sensor cable
13	Brush on a plastic ring
14	Measurement tip
15	Ski poles as measurement support on slopes
16	Screws to fix ski poles
17	O-ring
18	Cone
19	Piezoelectric force sensor (19a thread, 19b quartz, 19c electrical connector)
20	Rod
21	Teeth of the rod
22	Main switch of controller unit (also emergency stop)
23	Display of controller unit
24	Menu and navigation buttons
25	SD memory card slot
26	Plug to either motor unit (spiral motor cable) or battery charger
27	Plug for sensor cable
28	Ribbon

Table 2: *Summarizing glossary of the most important components of an SMP.*

5.2 SD Memory Card

5.2.1 Requirements

The SD memory card has two main functions. It is the memory to store the measurements but also the location of the configuration file (config.txt), which contains all instrumental-specific parameters.

There are no specific requirements for the SD memory card, but it is recommended to use a card with the following specifications:

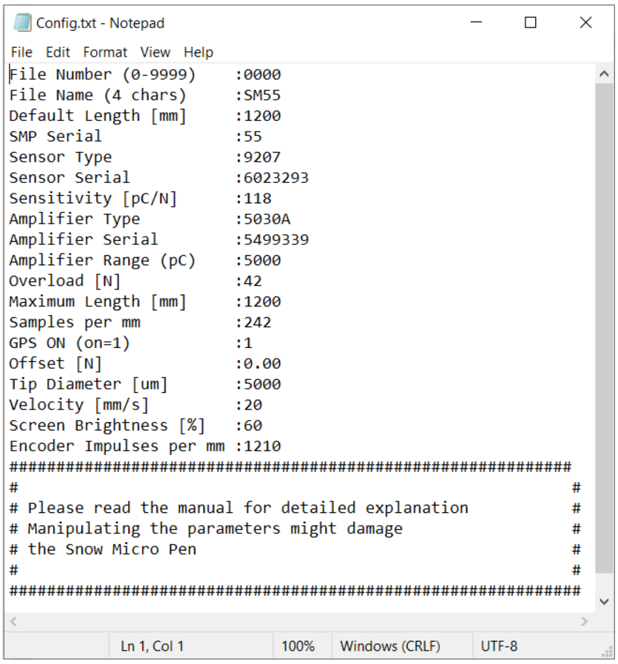
SDHC memory card, 8 GB (max 32 GB!), Industrial Grade, pSLC memory, UHS-1, class 10, extended temperature range down to -40°C, FAT32

Multiple SD memory cards can be used. The SD memory card must be inserted in the slot and protected against snow and split water by the screwable lid (Figure 5, (25)). We strongly recommend using the SD memory card in write-lock mode. Thus, the controller still writes on the storage card, but the PC cannot accidentally write or delete any files.

Figure 6: *The SD memory card is inserted with the golden pins facing downwards. The cardholder is not a push/push type. The card can simply be pulled out of the slot.*

5.2.2 Configuration File on SD card

The configuration file is a simple text file with its compulsory name "config.txt" and is saved on the SD memory card. In the configuration file, there are parameters which are essential to operate the SnowMicroPen properly and there are parameters which are copied into the header of each measurement file.



Config.txt - Notepad

File Edit Format View Help

```
File Number (0-9999)    :0000
File Name (4 chars)     :SM55
Default Length [mm]     :1200
SMP Serial              :55
Sensor Type             :9207
Sensor Serial           :6023293
Sensitivity [pC/N]      :118
Amplifier Type          :5030A
Amplifier Serial        :5499339
Amplifier Range (pC)    :5000
Overload [N]            :42
Maximum Length [mm]     :1200
Samples per mm          :242
GPS ON (on=1)           :1
Offset [N]              :0.00
Tip Diameter [um]       :5000
Velocity [mm/s]         :20
Screen Brightness [%]   :60
Encoder Impulses per mm :1210
############################################################
#                                                          #
# Please read the manual for detailed explanation          #
# Manipulating the parameters might damage                 #
# the Snow Micro Pen                                       #
#                                                          #
############################################################
```

Ln 1, Col 1 | 100% | Windows (CRLF) | UTF-8

Figure 7: *Example of the configuration file containing all instrumental-specific parameters (config.txt).*

Depending on your hard- and firmware version, the configuration file can slightly differ from others. Please always use the original configuration file that the manufacturer provided.

Parameters and their meaning:

Parameter	**Valid Values**	**Description**
File Number	[0:9999]	A consecutive, four-digit number is needed to generate the filename of a measurement (suffix). The start value can be defined in the configuration file, but then the controller increments/overwrites this parameter. It is recommended not to change this incrementor. When the number exceeds 9999, please set it back to 0 and save and delete all the files on the SD memory card.
File Name	[4 chars]	Exactly four ASCII characters must be defined, which are needed to generate the filename of the measurement (prefix). Therefore, a campaign-specific filename can be defined.
Default Length [mm]	[0:Maximum Length]	Each time you start up the controller unit, the measurement length is reset to the “default length”. Do not set the *Default Length* to higher values than *Maximum Length*. Higher values throw an exception during controller initialization and are automatically set to 300. However, the measurement length can be adjusted in the controller menu individually before each measurement.
SMP Serial	(int)	SMP serial number. This number represents the motor unit.
Sensor Type	[9207]	KISTLER force sensor type, usually 9207 (50 N).
Sensor Serial	(int)	KISTLER force sensor serial number. After a sensor replacement, this entry must be adjusted.
Sensitivity [pC/N]	[~105..125]	**One of the most crucial parameters!** Each piezoelectric force sensor from KISTLER is calibrated. The calibrated sensitivity is the factor between the sensor’s raw unit (pC) and the final force unit (N). If this parameter is wrong in the configuration file, the measured force values in Newton will be wrong. If the force sensor is replaced, the sensitivity in the configuration file must be corrected.
Amplifier Type	[5030A]	KISTLER charge amplifier type number.
Amplifier Serial	(int)	Charge amplifier serial number.
Amplifier Range [pC]	[5000, 10000]	The KISTLER charge amplifier provides two ranges, whereas the 5000 pC range is the default one. Assuming a force sensor with a sensitivity of 120 pC/N is used, the range of the charge amplifier will exceed after 41.66 N (5000/120). No higher forces than 41.66 N can be measured in this configuration because the charge amplifier is on its amplifying limit. If you want to use the 10000 pC range, please contact snowmicropen@slf.ch beforehand!
Overload [N]	(int)	**One of the most crucial parameters!** The maximum measurable force. Higher forces than the set value will lead to a force overload and immediately stop the running measurement. The maximum possible

		overload that can be set is calculated by (*Amplifier Range [pC] / Sensitivity[pC/N]) * 0.95*. Higher values lead to an error message during start-up and are automatically corrected. Note: A fast overload of the sensor e.g. when the tip of the rod is driven into a stone on the ground may still break the force sensor.
Maximum Length [mm]	(int)	Gives the limit of the penetration depth in millimeters. It is a hardware limit depending on the rod length and should not be changed unless another motor unit is used with a different rod length.
Samples per mm	[242]	Sampling rate per millimeter. Do not change this value!
GPS ON (on=1)	[0,1]	If the parameter is set to 1, the timestamp and coordinates are taken from the GPS. If the value is 0, the GPS module is off. In that case, the timestamp is taken from the onboard real-time clock (RTC) for each measurement. No coordinates are written to the file if the value is 0. As an RTC can deviate over time, using the GPS time or regularly synchronizing the RTC (see section xyz) is more accurate.
Offset [N]	(float)	Adjustable force sensor offset in Newton. The offset value is written into the header of a measurement file (*.pnt) but does not affect the raw data. For example, the offset value will be used for further processing (offset correction) in pyngui.
Tip Diameter [µm]	[5000]	Measuring tip diameter in µm which can be used to calculate pressure.
Velocity [mm/s]	[20]	Disabled parameter. Forward speed to perform a measurement. Only 20 mm/s is a valid value.
Screen Brightness [%]	[20..100]	Brightness of the display. To save battery power, try to operate the SMP with low values (<50 %). The LCD brightness can also be adjusted in the controller menu.
Encoder Impulses per mm	[500, 1210]	This value corresponds to the increments given by the encoder per full rotation. This value is hardware-given and must not be changed.

Table 3: *Parameters in the configuration file (config.txt), its meaning, and valid values.*

Wrong parameters will result in wrong measurement data or even damage the device. Only change the entries *File Name, Default Length, GPS, Offset, and LCD Brightness*. For all other parameters, please get in touch with the manufacturer first.

5.2.3 Format SD memory card

In some cases, the SD memory card has to be formatted. Therefore, use a Windows computer, right-click on the SD memory card drive, select “Format …” and use “FAT32” for the file system and “4096” byte for the allocation size. Using different format properties may lead to incompatibility with the SnowMicroPen controller unit.

5.3 Battery and Power Supply

The controller unit is powered by an internal lithium polymer battery (LiPo) from Swaytronic. The battery is from an “iced power” type, which means that the entire battery performance is available in an extended operating range down to -20°C. The battery's capacity should be large enough to perform more than 100 measurements. However, the residual battery capacity is always displayed when the controller is on.

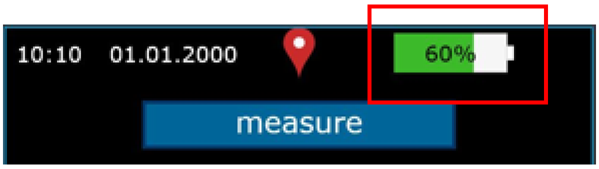


Figure 8: *The header of the display always shows the time, the date, if a GPS connection is established (location icon red or green), and the residual battery capacity.*

Never recharge the battery if the instrument temperature is below 0°C. When plugging in the battery charger, a temperature sensor inside the controller unit will trigger a warning message on the display if the temperature is less than 0°C. Then, it is recommended to disconnect the charger from the controller unit unless it has reached room temperature. If you do not disconnect the battery charger, the charging process will continue under the risk of seriously damaging the battery.

Only recharge the battery if the controller unit is at a temperature above 0°C

To recharge the battery, the provided power supply must be connected (Figure 5, (26)). The output of the power supply is 48 VDC, 2.5 A. A charge balancer is implemented in the controller unit to protect the battery from being overcharged or unequally loaded cells.

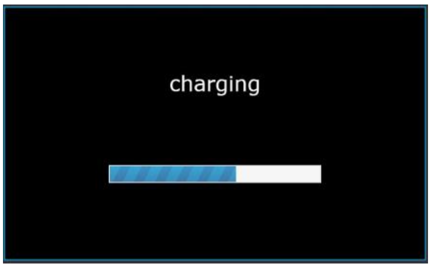


Figure 9: *Display while the battery is being charged.*

As soon as the charging device is connected, the display “charging” appears. If it does not appear and you can see a red light through the transparent lid, the battery is either disconnected or at a low voltage level (exhaustive discharge). As we assume that only the second reason could happen, please continue recharging the battery. After the minimal voltage level is reached, the red light will disappear, and the display “charging” will appear.

Figure 10: *Display when the battery charging has finished. Disconnect the charging device and switch off the controller a few seconds later.*

When the battery is fully charged, the operator is asked to disconnect the power supply and switch off the controller unit.

After recharging the battery and disconnecting the power supply, the controller unit must be manually switched off after a few seconds. Otherwise, it remains switched on, and the display's power consumption discharges the battery.

For long-term storage (one month or more) without using the SnowMicroPen, it is strongly recommended to put the LiPo battery in proper storage mode. According to the manufacturer, the battery should be charged 80% when unused. Both, completely discharged or fully charged batteries might get damaged with long-term storage. Therefore, the controller unit provides a menu which either charges or discharges the battery to the desired capacity of 80%. Please find the instructions in the chapter “6.4.3.6 LiPo Storage”

6 Controller Software Navigation

6.1 General Controller Navigation Features

The four buttons on the left side of the controller are used to navigate through the SMP menu. The red button cancels operations and is used to exit menus/submenus. The green button confirms user entries and enters menus/submenus. The two black buttons are supposed to navigate up and down in the menu list, decrease or increase values, or drive the rod manually in the corresponding menu.

While operating the controller unit, messages and displays are color-coded:

<table>
<tr>
<td>
</td>
<td>
</td>
<td>
</td>
</tr>
<tr>
<td>A blue-colored display indicates that something is going on. E.g., that the rod is being homed, a measurement is performed, …</td>
<td>An orange-colored display indicates a warning. This mainly happens if a value in the config file is out of range or the head is disconnected. Often, minor corrections solve the problem.</td>
<td>A red-colored display is always indicating a fatal error! Operating the instrument might not be possible. Depending on the message, resolve the issue or contact the manufacturer.</td>
</tr>
</table>

Table 4: *Color-coded displays on the controller unit.*

6.2 General Menu Structure

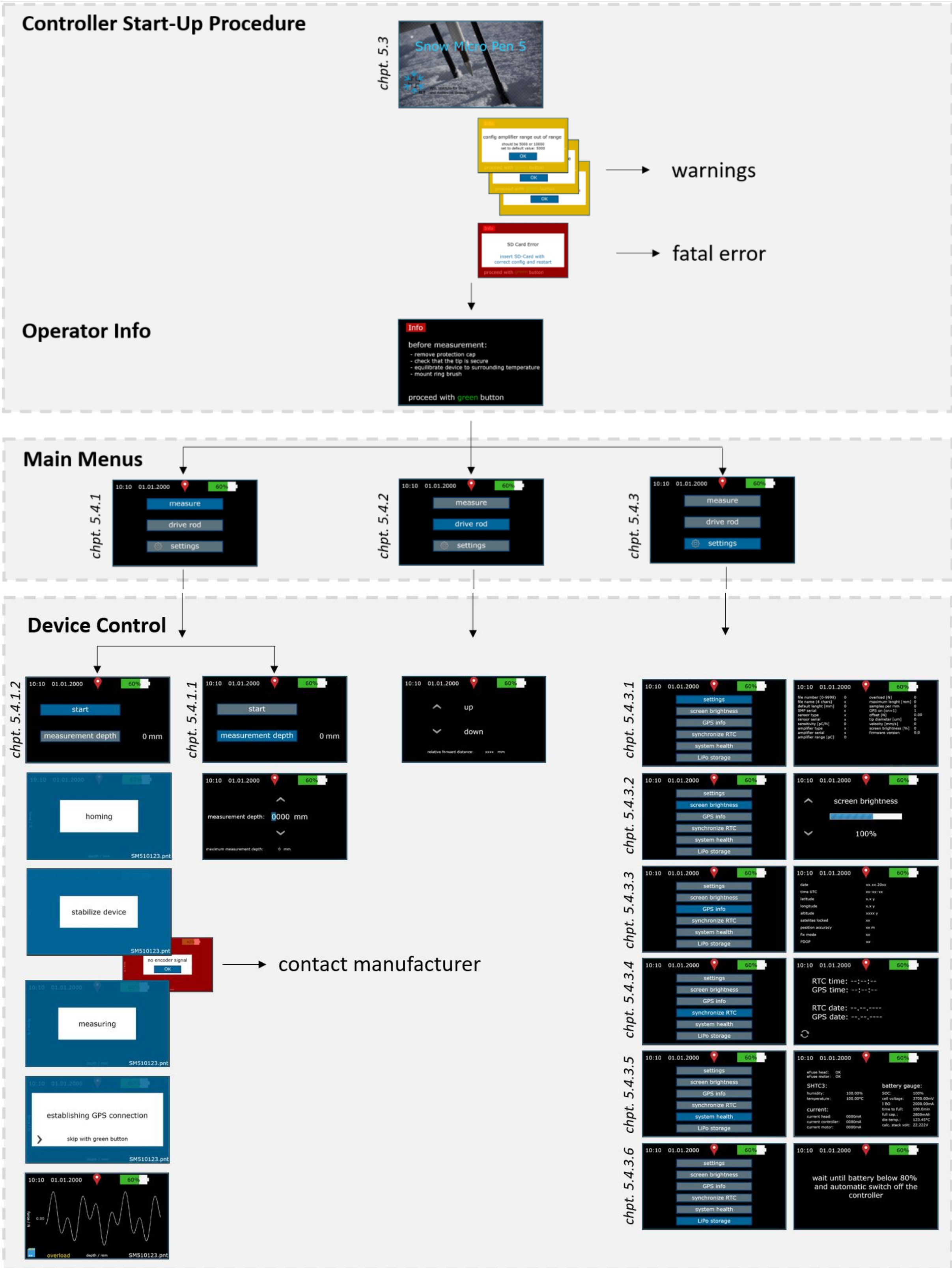


Figure 11: *Scheme of the menu structure on the controller unit.*

6.3 Controller Start-up Procedure

After switching on the controller unit, several things are checked in the background. To point out one, the controller verifies that an SD memory card with a valid configuration file (config.txt) does exist. Otherwise, a red-colored, fatal error message will appear on the display, and measuring with the device will not be possible.

Figure 12: *Fatal error during controller start-up because the SD memory card or the config.txt file is missing.*

To resolve the problem, an SD memory card containing the device-specific configuration file must be inserted. See chapter SD Memory Card and restart the controller unit.

Furthermore, the parameters in the configuration file are checked to be valid. Wrong parameters are automatically corrected and cause a warning on the display. In Table 5, it is shown which and how invalid parameters are corrected.

Parameter	**Check for valid value**	**Automatic corrected value**
File Number (0-9999)	=9999	0
Default Length	<0 or >Max Length	300
Maximum Length	>0 or <1200	1200
Sensor Type	=9207 or =9203	Otherwise, a warning on display
Amplifier Range (pC)	=10000 or =5000	5000
Overload Range [N]	If Overload Range [N] > Max Overload *Max Overload = (Amplifier Range / Sensitivity) - 1*	Max Overload
Velocity [mm/s]	≠20	20
Samples per mm	≠242 and ≠1210	242
GPS/ON FF	≠0 and ≠1	1

Table 5: *During the controller start-up procedure, some parameters from the config.txt file are checked and automatically corrected.*

If something is automatically corrected, the operator is informed with an orange-colored message that can be confirmed with the green button ("ok"). Despite the warning, it is possible to measure.

Figure 13: *Example of an orange-colored warning message. If the consecutive file number exceeds 9999, it will be automatically set back to 0.*

However, neither fatal errors nor warnings should happen in case of a correctly configured configuration file and a fully functional instrument. A successful initialization ends with an information screen, which reminds the operator of various points that should be checked on the instrument before measuring. An equilibration to the surrounding temperature can either be done by leaving the ready to measure instrument exposed to the surrounding air for 15-20 min, or by performing one or two measurements cooling the rod when penetrating the snow.

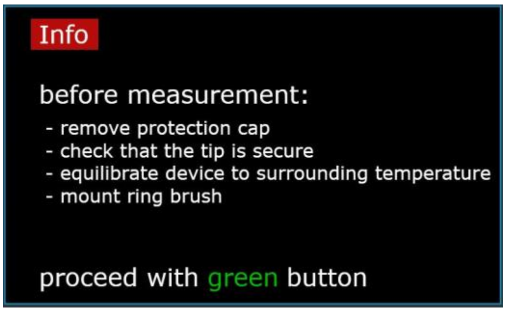
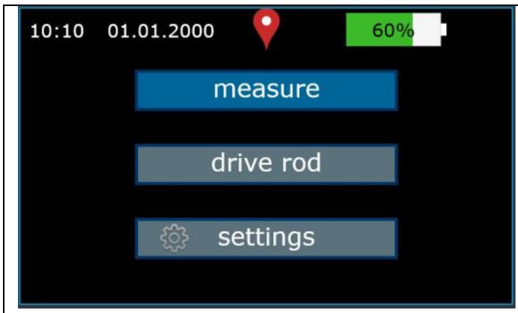


Figure 14: *Reminder of some SMP setup-specific points to consider before entering the measure menu.*

6.4 Main Menus

After the successful controller start-up procedure, there are three main menus available - "measure", "drive rod", and "settings". To toggle between the menus, use the two black buttons (up and down). To enter (exit) the menu, push the green (red) button.

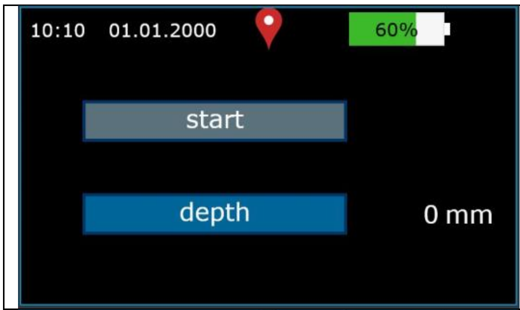
	In the top area of the display ("header row"), UTC, the state of the GPS connection, and the residual battery capacitance are shown. Beneath, there are the three main menus. The displayed UTC is given by the onboard real-time clock (RTC). Verify that it is correct. Otherwise, a GPS-RTC synchronization has to be done (menu "settings/synchronize RTC"). The location icon indicates whether there is a GPS connection (green/red). To get a GPS connection, it can take a while.

6.4.1 Measure

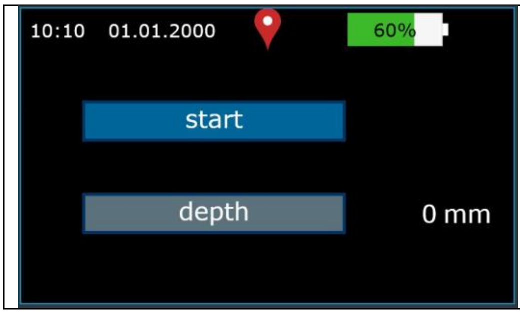
The main menu “Measure” is again divided into two submenus. It is “start” and “depth”. Using the submenu “start”, a measurement is triggered. The submenu “depth” allows the user to change the default penetration depth (taken from config file).

6.4.1.1 Depth

The submenu “depth” allows the operator to change the penetration depth on site.

	The submenu "depth" is to change the default measurement depth. The default penetration depth is the value in the configuration file and is set after switching on the controller unit. However, the submenu “depth” can change this default depth in the field. The new depth is valid unless the controller is being restarted.
 	Submenu “depth”: starting with the thousand digits, the value can be in- or decremented with the black buttons. To jump to the hundred digits, press the green button once. To jump to the ten digits, press the green button again. To confirm the penetration depth, press the green button a third time. If the value exceeds the “Maximum Length” in the configuration file, the value is highlighted in red. If you want to confirm a value higher than the “Maximum Length”, the value is automatically set to the “Maximum length” value.

6.4.1.2 Start

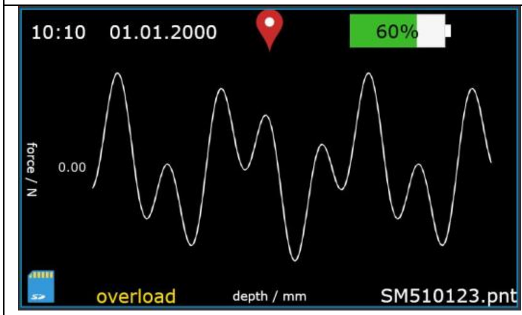
	The submenu "start" initiates the measurement.

	After pushing the start button, the rod is first going to the home position unless it is already there.
	When the rod is in its home position, the measurement (rod not yet moving) does not start immediately. For a few seconds “stabilizing device” is shown on display, which gives the operator the chance to put his bodyweight across the instrument and find an adequate and steady measuring position. After three seconds, the rod starts moving downwards.
	If the encoder signal which provides the rod’s position fails, the SMP can't be operated. This is a very unlikely but fatal error. If it occurs, you must get in contact with the manufacturer.
	After the 3-second delay, the instrument changes into measuring mode, the rod starts moving downwards, and the force is being acquired.

The rod is driven into the snowpack until one of the following events will occur:

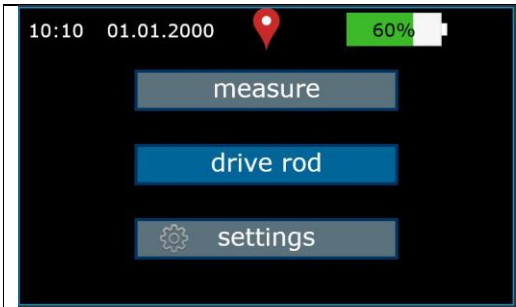
- The operator-defined penetration depth has been reached
- The measurement was aborted with the red button by the operator
- The force limit (overload) has been reached

	Independently of the terminating event of the measurement, the acquired data is written to the SD memory card, and the rod is automatically homed. While homing, a GPS connection is established to get accurate date/time and coordinates. If it is an indoor (laboratory) measurement where a GPS connection is impossible, the operator can skip this step by pushing the green button, or the

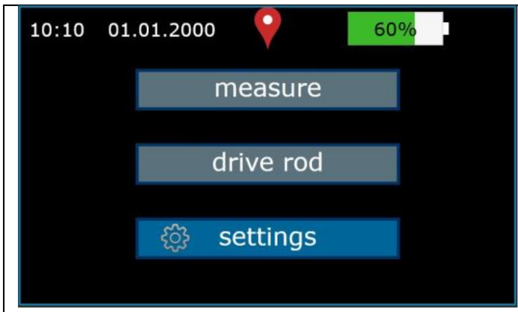
	GPS can be deactivated beforehand in the configuration file.
	After a successful measurement, a graph shows a simplified force-depth diagram due to limited display resolution (the signal in the measurement file is much more accurate). The graph mode pops up after succeeding GPS request and homing the rod. At the bottom right of the diagram, the file name of the measurement is shown. At the bottom left, the blue SD memory card icon is shown when the measurement is permanently saved on the SD memory card. Only then the graph mode can be exit by pushing the red button. The operator is then back on the menu level of "start" and "depth"; a consecutive measurement could be started immediately.

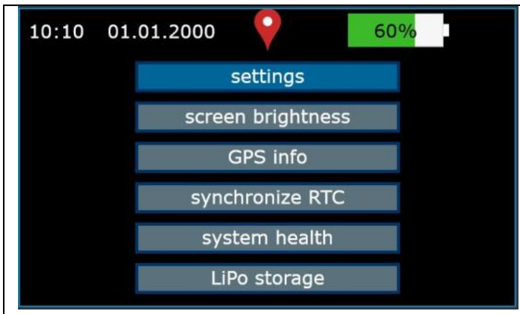
6.4.2 Drive Rod

The "drive rod" menu is used to drive the rod manually in and out. In this "operating" mode, neither measuring, nor acquiring, nor detecting a force is happening. This functionality is mainly needed to drive the rod out of the home position so that the measurement tip is accessible, or the entire rod can be cleaned with a brush or dried with a towel. Further, this menu can also be used if the rod does not do a proper homing after the measurement.

	"drive rod" menu to manually drive the rod in and out.
	With the lower black button, the rod drives down as long as the button is pressed. After releasing the button, the position of the rod is displayed. The upper black button drives the rod towards the home position. To exit this menu, press the red button.

6.4.3 Settings

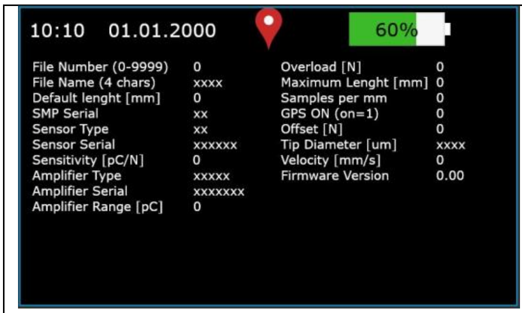
	In the "settings" menu, there are several submenus. Apart from the submenu "change backlight" and "synchronize RTC", only (system) parameter values can be obtained.



Under the settings menu, there are the following submenus:

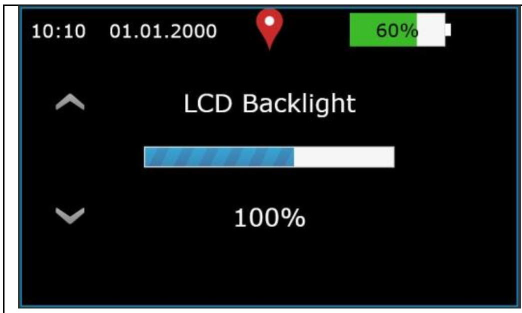
- Settings (to be renamed to “config.txt”)
- Screen brightness
- GPS info
- Synchronize RTC
- System Health
- LiPo storage

6.4.3.1 Settings



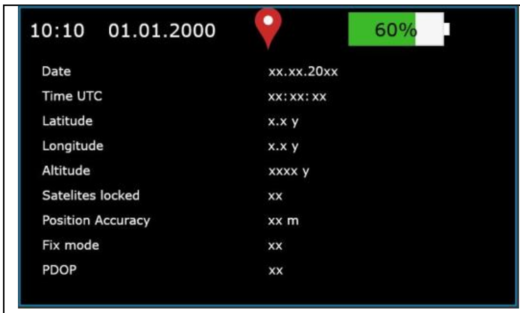
The submenu “settings” displays the configuration file's content on the SD memory card. It is not possible to modify the values in this menu. It is more to allow the operator to check if the correct settings are in the configuration file.

6.4.3.2 Screen Brightness



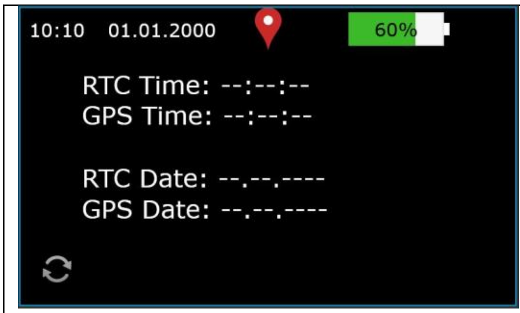
The submenu “screen brightness” allows the operator to make the display brighter or darker. The brighter the display is illuminated, the more power is used. It is adviced to have the display's brightness at a minimum so that it is still comfortable to operate it in the field. The brightness value is in percentage and can be set from 20% to 100%.

6.4.3.3 GPS Info



The menu “GPS info” displays GPS-related parameters.

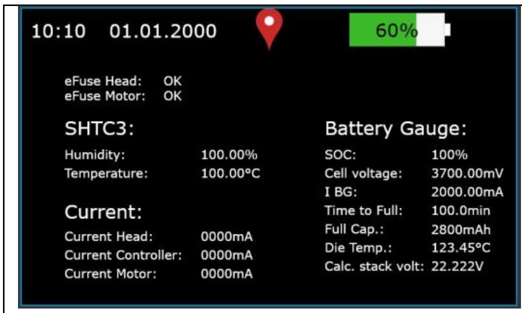
6.4.3.4 Synchronize RTC



The menu “synchronize RTC” can be used to reset the onboard clock with the date/time given by the GPS. The onboard clock (RTC) also operates if the controller is switched off because of a dedicated battery. However, the longer the RTC is not synchronized with an accurate date/time value from the GPS, the larger the date/time deviation may get.
When you open the menu “synchronize RTC”, a GPS connection is established. Both, date/time from RTC and date/time from GPS are displayed.

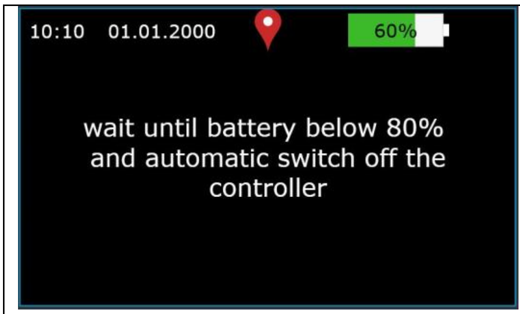
With the green button, you are going to request another synchronization. With the red button, you will exit the synchronization menu (=confirm RTC/GPS sync.)
As the RTC is synchronized during each measurement, this menu will typically not much be used.

6.4.3.5 System Health



The menu “system health” is mainly to facilitate remote support in case of a malfunction of the SMP.
No detailed description of these values is provided at this point.

6.4.3.6 LiPo Storage



If you enter the submenu “LiPo storage”, the controller unit remains powered “on” until the battery capacity has fallen below the threshold of 80%. Then, the controller unit is switched off automatically and is ready to be stored for several months without getting battery damage. This follows the battery manufacturer’s recommendations to ensure a long persistence.

The menu structure overall should be simple and allow operating the SMP without a vast training effort.

7 System Installation and Setup

The hand-drawn sketches in this chapter are provided by Amy Macfarlane (www.amacfarlane.weebly.com). These lovely sketches should motivate the operator to first read the manual and then use the SnowMicroPen. If the manual is not read carefully, the risk of damaging the SMP is quite high.

7.1 DON'T's

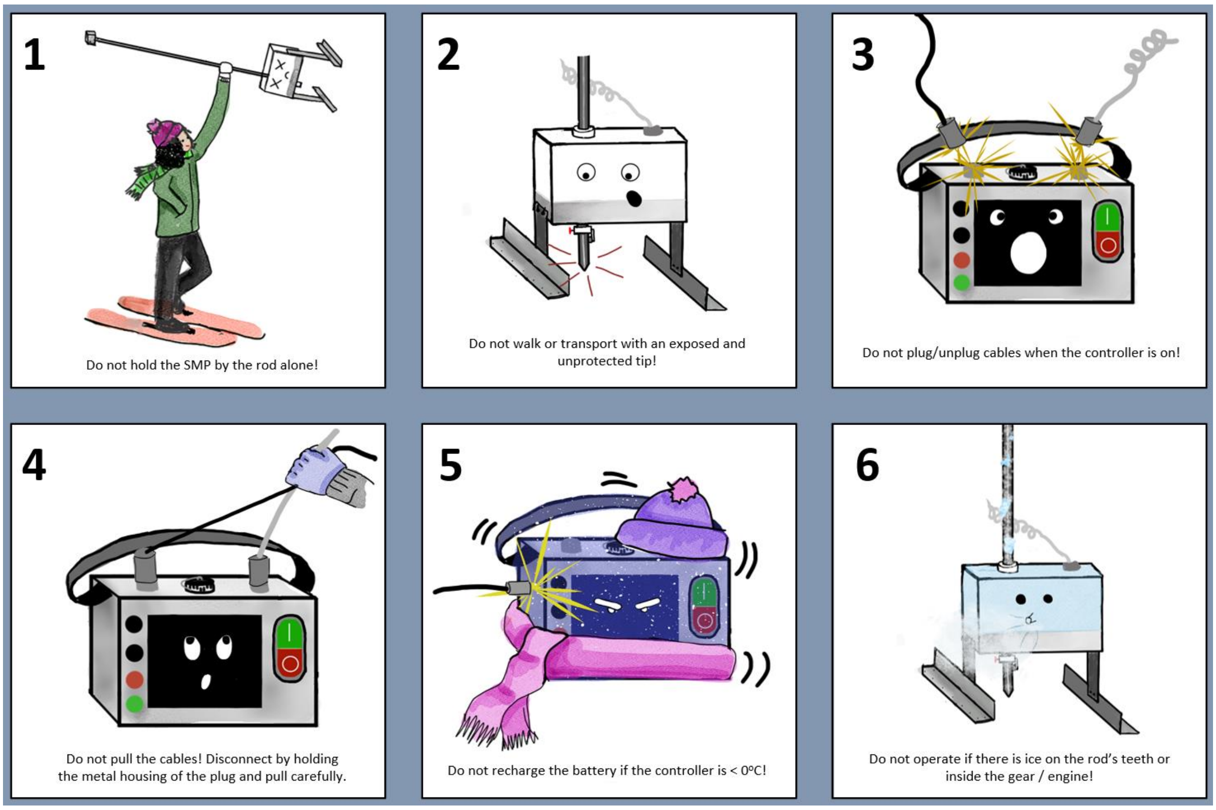


Figure 15: *Avoid all these things to ensure the SMP's long life.*

1) Never hold and carry around the SMP on the rod. Hold it on the motor unit as well.

2) Do not walk or move the SMP, when the rod is not in its home position. As soon as the measurement tip is “visible”, it is kind of “unprotected” and the force sensor could break in case of an unexpected force impact. Use always the black protective cap when moving the SMP.

3) Do not connect or disconnect the plug when the controller is on.

4) For disconnection the cables, pull on the metal housing of the plug. Do not pull at the cable itself.

5) Never recharge the battery when the controller is at cold temperatures (<0°C).

6) If the rod is not moving despite of a triggered measurement, do not force the rod moving. Ice on the rod or in the gear can damage the engine. Please see chapter 10.3.

7.2 Preparation at Home

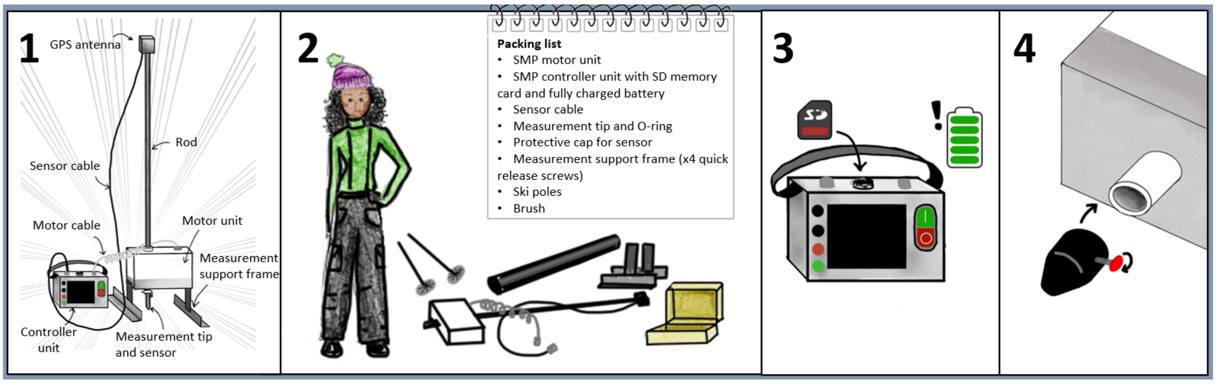


Figure 16: *Sketch about "what to prepare at home" that the instrument should principally work in the field.*

1) Check, that the components of the SMP are complete, dry, and clean
2) Properly pack the SMP and all its components into the transportation box according to the packing list
3) Make sure, that the config.txt file is on the SD memory card and that there is still enough free memory available
3) Ensure to have the battery fully charged
4) The measurement tip and O-ring are correctly inserted and protected with the black protective cap.

7.3 Preparation in the Field

For a trouble-free operating of the SMP and an efficient coordination between other snow measurements, we recommend the following procedure when arriving at your test site. As the instrument might still be warm (>0°C), setup up the SMP in a first step and take care that any snow melts on the warm surface. Refreezing water on the instrument (rod or measurement tip) will most probably lead to an instrument's failure. However, during the time the SMP is equilibrating to the ambient temperature, something else can be done.

7.3.1 Fixation of Measurement Support Frame

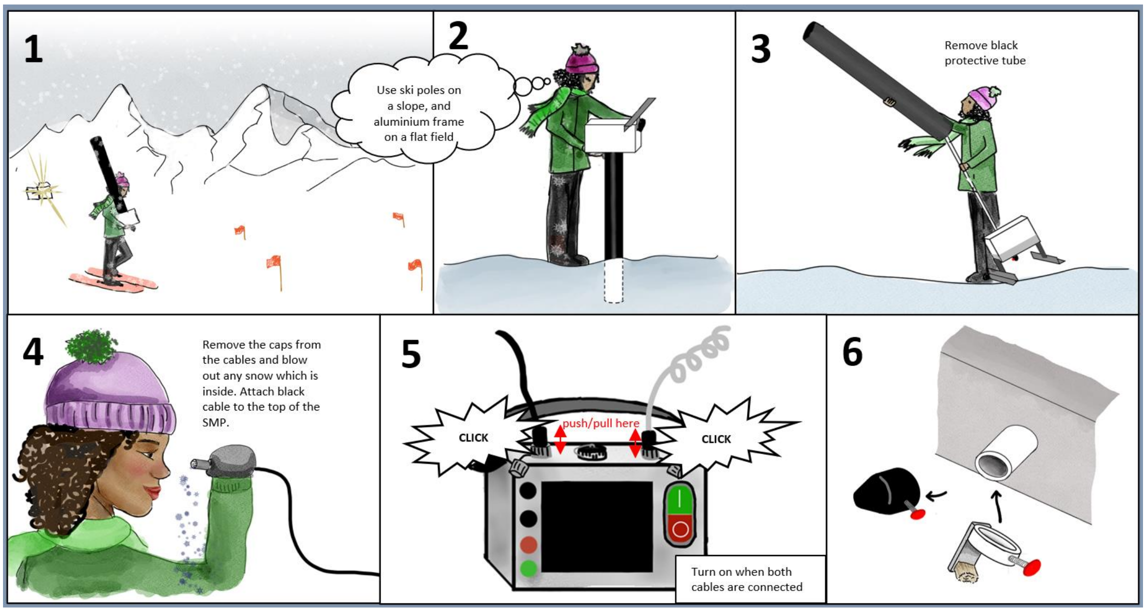


Figure 17: *Sketch about "how to setup the SMP in the field".*

1) Bring the SMP safely to the site where you want to measure.

2) Having/holding the instrument upside-down in front of you (standing on the black protection tube) and mount either the measurement support frame or the ski poles as shown in Figure 18 in more details

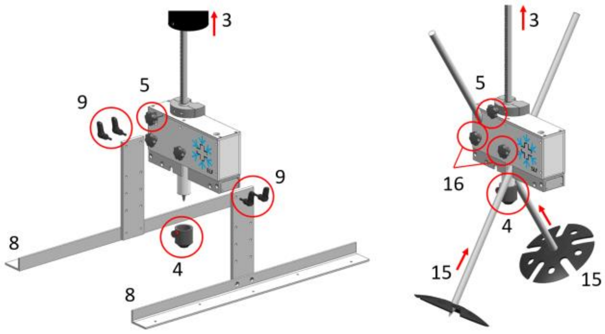


Figure 18: *Assembly instruction of the SMP for measuring in flat terrain using the measurement support frame (8) with the four quick release screws (9) on the left side or the ski poles (15) with the two fixations screws (16) in sloping terrain on the right side in the figure.*

3) Now, the device can be turned, and it is self-standing on the snow surface. Remove the black protective tube so that the rod is free and can adapt to the ambient temperature.

4) Check, that all the plugs are free of snow. As it is shown in Figure 19, the sensor cable (12) has to be connected at the upper end of the rod (head) and on the controller unit, whereas the motor cable (11) has to be connected on the controller unit. For that step, the controller unit is still switched OFF.

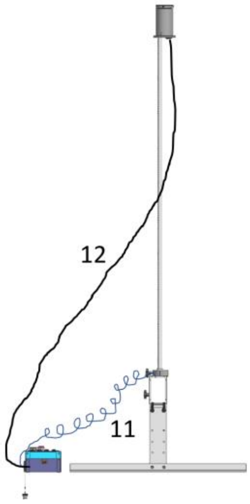


Figure 19: *Connecting the sensor cable (12) and the motor cable (11) to the controller unit.*

5) The connectors are push-pull type. If you hear a gentle “click”, the plug is correctly connected to the socket. Then, switch the controller unit ON.

6) Now, remove the protection cap of the sensor and fix the ring brush.

7.3.2 Tip and O-ring check

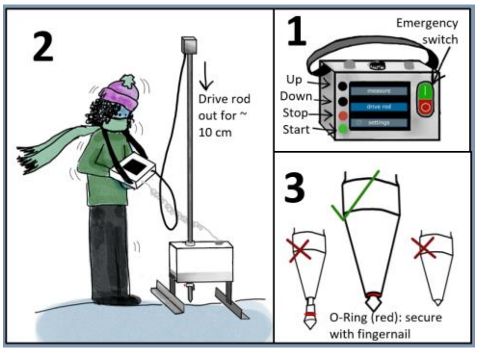


Figure 20: *The measurement tip and the O-ring has to be checked regularly.*

1) Navigate to the “drive rod” menu.

2) Manually drive the rod out of the home position unless you can see and access the measurement tip and the cone. This is roughly 10 cm.

3) Now check if the position of the O-ring on the measurement tip is correct, the O-ring is not twisted and free of cracks and that the surface of the measurement tip is smooth and not damaged. The correct position of the O-ring is shown in Figure 21 in more details.

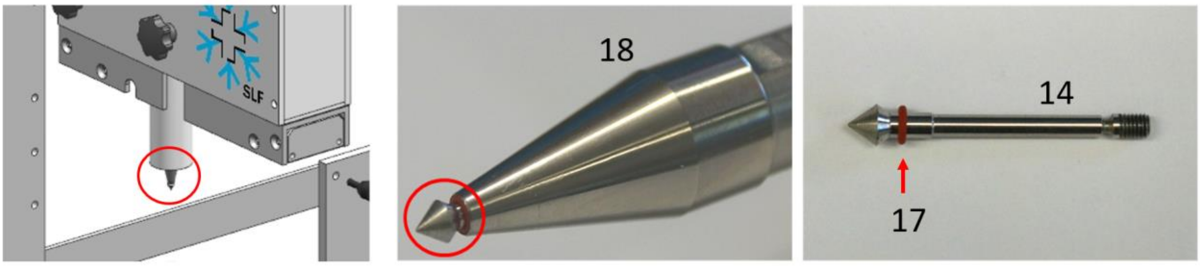


Figure 21: *Drive the rod out of the home position that you can see and access the measurement tip and the O-ring in the cone (left). The middle picture shows a correct positioned measurement tip and O-ring. If the arrangement of the measurement tip and the O-ring is not correct, unscrew the measurement tip and reposition the O-ring correctly (right).*

If all requirements are met, as it is shown in the middle picture of Figure 21, the rod can be homed by pressing the upper black button in the “drive” menu.

Otherwise, and to troubleshoot, unscrew the measurement tip with your bare hands. Unfortunately, it is almost impossible to do this with gloves. Also using tools (pinzers, etc.) is not allowed. If required, replace the tip and/or O-ring or just put the O-ring in the correct position on the tip (check, that it is not twisted). Then, screw the tip into the sensor/cone.

It is recommended to check the measurement tip and the O-ring regularly. Especially when the measurement tip is bent sidewards because of hard layers, the O-ring may start to move upwards along the shaft of the tip.

7.3.3 Cool down and let the SMP equilibrate to ambient temperature

The SMP should equilibrate to the ambient temperature. As a rule of thumb, we recommend waiting for around twenty minutes. While equilibrating to temperature, the instrument should be shadowed and protected from direct solar radiation.

The reason for having the instrument "cold" is that snow does not melt on remaining warm components. The reason for having it "equilibrated" is that temperature changes on the instrument (especially rod and force sensor) during a measurement are kept as small as possible. Unstable temperature conditions at the force sensor causes a linear drift of the force signal which should likely be avoided.

However, a snow profile is rarely isothermal why the rod and necessarily also the force sensor experience a temperature change during the measurement. Therefore, the force signal will always slightly drift, but generally negligible if well adapted to temperature.

Special care about equilibrating the device to ambient temperature should be taken on relatively warm spring days with high solar radiation and a rather cold snow profile. Shading and measuring in the early morning is essential.

7.3.4 Simple system check

This chapter should give you the ability to recognize if your device is fully operable or if there is a potential malfunction. An early detection of malfunctions can protect your instrument from getting damaged. Therefore, a "simple system check" has been developed and is explained here. When the instrument is thermally equilibrated with the ambient temperature (after around 20 minutes), we recommend performing a simple functional check as shown in Figure 22. On one hand and referred to as a finger tip test, the small and gentle forces to the measurement tip show if the SMP is "sensitive" to forces at all. On the other hand, the operator verifies that a measurement can be started, that the rod is moving and how it is moving (smooth or rattling) and finally if the measurement can be stopped by pressing the red button.

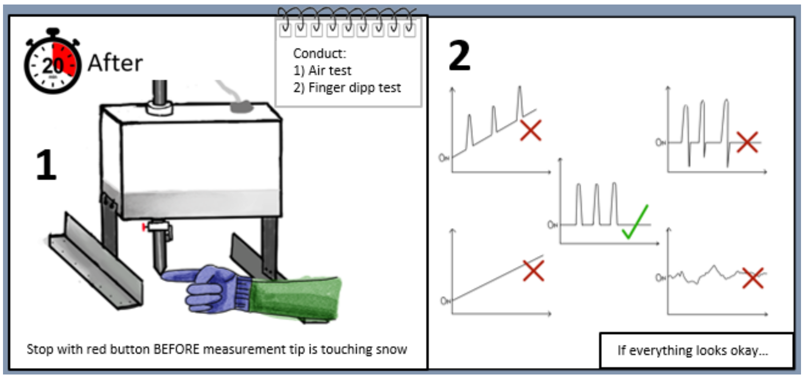


Figure 22: *Simple, functional check of the SnowMicroPen.*

1) Directly after starting the measurement, a few very gentle contacts of a finger dipp has to be applied against the measurement tip. The measurement is then aborted by pushing the red button on the controller unit before the measurement tip is approaching the snow. The rod starts homing. During the rod is moving, listen to it and try to distinguish if the rod moves smoothly or not.

2) The operator must mainly judge from the force-distance graph on the display whether the SMP works fine or needs further investigations. How and what can be interpreted out of this simple functional check, is listed in Table 6 below:

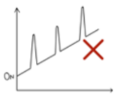
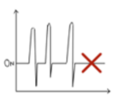
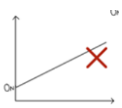
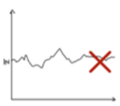
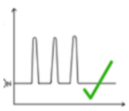
Behavior	**Issue and bug fix**
Rod does not move at all	Probably, there is ice between the gear cog and the rod → warm the instrument up, use the "drive rod" menu to drive the rod in and out and dry the rod with a towel
Rod rattles	Either there is partially ice on the cog wheel or between some teeth of the rod, or the cog wheel has broken → first try to solve the issue by warming the SMP up and drying the rod. If de-icing is not improving the behavior, the cog wheel must probably be replaced → contact SLF
Rod moves only a few millimeters and starts homing immediately	No encoder signal from the motor available. SMP needs a repair service → contact SLF
Rod does not stop when pushing the red button	Use immediately the main switch as an emergency stop → contact SLF
	Instrument is not equilibrated well enough to the ambient temperature. The force sensor is still adapting to the temperature and therefore the signal drifts away → try to better adapt the SMP to the ambient temperature. Shadow the SMP
	The force signal does not immediately reach the zero level between the finger dips → probably O-ring is twisted → trouble shoot as shown in Figure 21
	The finger dip force peaks are not visible → most probable that there is ice between the cone and the measurement tip → warm the SMP up, unscrew the measurement tip (Figure 21) and let everything dry out properly
	Either the force sensor is broken or there is moisture between the force sensor and the capacitive cable (inside the rod) → contact SLF to discuss the troubleshooting
	If the force-distance graph looks like this, the rod moved smoothly and the red button had aborted the measurement, then the SMP is ready to measure!

***Table 6:** Table to interpret the simple functional test of the SMP to judge if the instrument can be used or not.*

If the operator comes to the conclusion that the SMP works properly from the instrumental perspective, the focus should then be on a suitable measurement technique which will be addressed in the next chapter.

8 Measurement Technique

The aim of this chapter is to make the user aware that, depending on the environmental conditions, a different or adapted measurement technique should be used. The recommendations given below should primarily lead to a good quality of the measurements, but also that the device is not damaged.

8.1 Levelling of the instrument

The direction of penetration should always be perpendicular to the snow surface. The alignment is usually determined by eye.

Figure 23: *The SnowMicroPen is always perpendicular to the slope.*

8.2 How to deal with different initial sinking depths

It is necessary that the measurement starts at least a few centimeters above the snow surface, so that the first part of the acquired signal is not representing snow penetration force. To ensure this, Figure 24 makes clear how the measurement support frame can be adapted to different initial sinking depths.

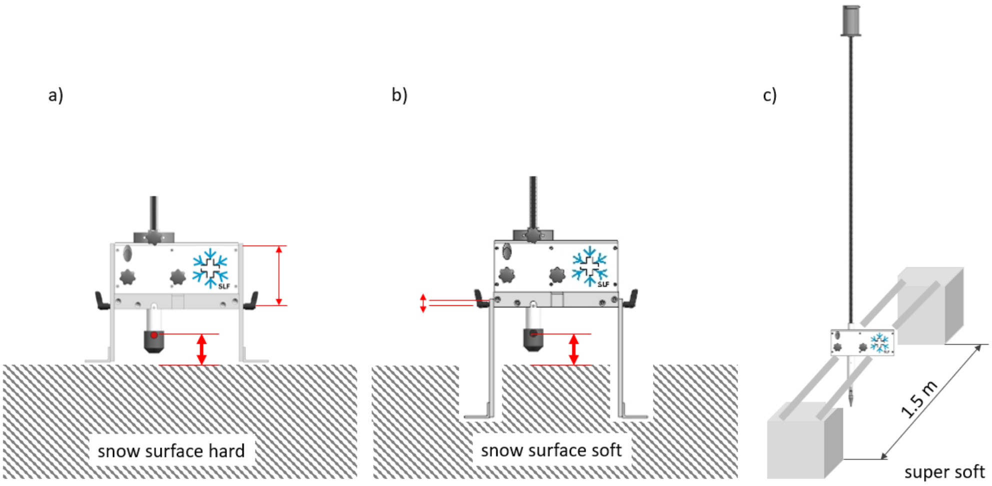


Figure 24: *Three measurement situations because of the varying hardness of the snow surface.*

Depending on the hardness of the snow surface, it is recommended to adjust the position of the measurement frame. Natural conditions commonly fall into one of the three situations where situation a) has a hard snow surface, situation b) has a soft snow surface, and situation c) the top snow surface layer is soft and deep.

The measurement support frame is well suited for a) and b). By adjusting these aluminium brackets in height (four quick-release screws), the sinkage depth can be compensated in a way that the measurement tip never touches the snow surface before the measurement.

In situation c) we usually use something with a large contact area and tall enough that it does not entirely disappear in the snow. These two stages are positioned roughly 1.5 meters apart from each other. Then, we put something like two stable bars on it from where the SMP measurement can be conducted. These extra items to deal with situation c) are not part of the SMP standard equipment.

In case that you are not using the measurement support frame, but the multi-part ski poles, they can also be extended depending on the sinking depth. The softer the snow surface is, the longer the ski poles should be.

8.3 How to correctly hold the SMP in the stable measuring position

One strong requirement during a measurement is to hold the SMP in a stable position. To guarantee a stable position, the operator has to adapt the way "how the SMP is being hold" depending on the overall snowpack hardness. It is clear that the cross-sectional area of the rod is mainly responsible for the resistance-reaction force and not the measurement tip itself. Even though the measurement tip measures a force less than the overload (~40N), which corresponds approximately to 4 kg, the holding force on the instrument (motor unit) can be much higher.

As shown in Figure 25, while situation a) on a relatively soft, alpine snowpack does not require a significant effort from the operator, situation d) on a hard, wind-pressed polar snowpack requires even two people to prevent the instrument from being lifted. It is not only the rather small measurement tip that causes the force on the instrument but the tip plus the entire cone and rod which is much larger.

Figure 25: *Ways, how to hold the SMP while conducting a measurement.*

Typically, the SMP can be operated by one person either leaning with the upper body against the motor unit like in b) or standing on it with your entire body weight as shown in c).

And now, the most critical and crucial thing that an operator has always to have in mind while measuring:

If the SMP can't be held in the initial position while the rod is moving down, the operator's holding load has to be instantly released, the measurement has to be stopped (red button or emergency button), and the motor unit has to be uplifted for a few centimeters by the operator so that the measurement tip is completely unloaded! Then, make sure that the rod drives back into the home position.

If the position of the SMP can't be held in a stable position, the correlation between penetration depth and force gets anyway wrong. So, there is no reason to continue the measurement as it has to be sorted out. The intuitive response of an operator to a lifting device is the increase of the holding force. Increasing the holding force can lead to a fast and uncontrolled force situation on the measurement tip. It must be avoided in any circumstances. A fast and uncontrolled force situation on the measurement tip can severely damage or destroy the force sensor (quartz).

Figure 26 shows a situation when the overload detection does not work and the motor unit would start to lift the operator. The measurement tip is in an "empty" space between two rocks and there is no force on the sensor. Nevertheless, the cone and the rod start to increase the resistance-reaction force. If the operator would then increase its holding force and try to avoid the lifting, the rocks could move sideways whereas the measurement tip would be immediately rammed into the ground. The force sensor (quartz) would break.

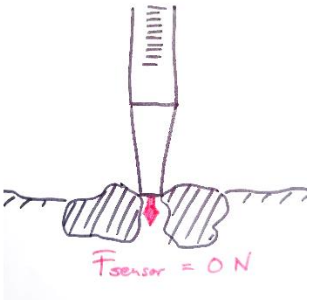


Figure 26: *Example of a situation when the overload detection of the SMP does not work.*

Rocky ground is an example, but ice layers can provoke a similar behaviour. Therefore, it is never allowed to increase the holding force when the motor unit is lifted instead of the rod is moving down.

8.4 How to deal with a weak layer close to a hard snow surface layer

Sometimes, the snow surface is hard, but the layers beneath are weak, and as soon as you start to put a load on the surface, you can hear how the layers are collapsing. In such a situation, making two parallel cuts with a long saw (1 m) to "detach" the snow you want to measure from the snow affected by the operator's and the SMP's load can be helpful. The principle is illustrated in Figure 27.

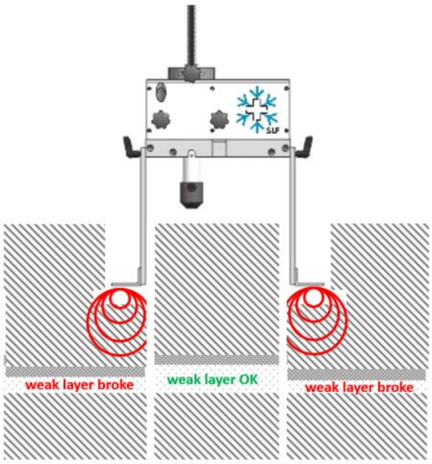


Figure 27: *How to deal with weak layers near the snow surface.*

8.5 What to consider with different ground types

The snow can lay on (sea) ice, on rocky ground, on soil or in laboratory applications on another hard material. If the ground is hard and mechanically rigid, the force on the measurement tip increases quickly and the electronical overload detection might be too slow to stop the movement of the rod which can severely damage or break the force sensor. Therefore, it might be worth to limit the penetration depth (chapter 6.4.1.1) so that the measurement tip does not hit the ground at all. If the fixation of the motor unit is the load of a human, it might be ok to hit a hard ground with the measurement tip, because a human is not mechanically rigid and can slightly deform. But when the ground and the fixation from the motor unit are mechanically rigid, e.g., in a laboratory setup, the operator must limit the penetration depth so that the measurement tip does not hit the ground at all.

When you are measuring in a tundra area or somewhere with soft, unfrozen soil, it can happen that the rod penetrates also through the soil without reaching the overload limitation. In principle, this is not an issue, but the teeth, the rod, the measurement tip and the O-ring will probably be full of dirt and must be cleaned each time. Therefore, the limitation of the penetration depth is very useful.

8.6 General measurement pattern

To get a representative set of data from one place of interest, we recommend to take at least five measurements. To ensure that the single measurements do not affect each other, we recommend taking them at a minimal distance of approximately 20 cm. As the SMP measurement itself is destructive and also the measurement support frame does destroy the snow in the area around the measurement, it makes sense to optimize the measurement alignment as shown in Figure 28.

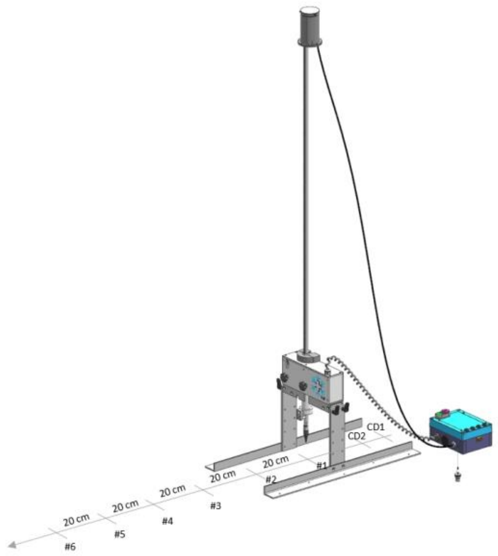


Figure 28: *Recommended measurement pattern with the SnowMicroPen.*

We also suggest measuring in the opposite direction compared to the cable falling. If the cables, especially the force sensor cable, are on the right, the measurement direction should be toward the left. It should be avoided that the cables destroy the snow surface on the side where you want to take the measurements.

8.7 Cool down measurement

Even though the instrument is equilibrated to the environmental temperature (chapter 7.3.3), the force sensor will be exposed to the temperature regime in the snowpack, which is usually something from “cold” at the surface to 0°C at the snow-ground-interface. Therefore, to bring the force sensor towards an averaged snowpack temperature, we conduct two so-called “cool-down” measurements (CD1, CD2, indicated in Figure 28) before the five measurements, considered to be usable, are taken.

9 Operating Protocol

9.1 How to conduct an SMP measurement

Providing that these steps are done:

- ✓ The O-ring and tip are correct (chapter 7.3.2)
- ✓ The simple check has passed (chapter 7.3.4)
- ✓ 2 cool down measurements are done (chapter 8.7)

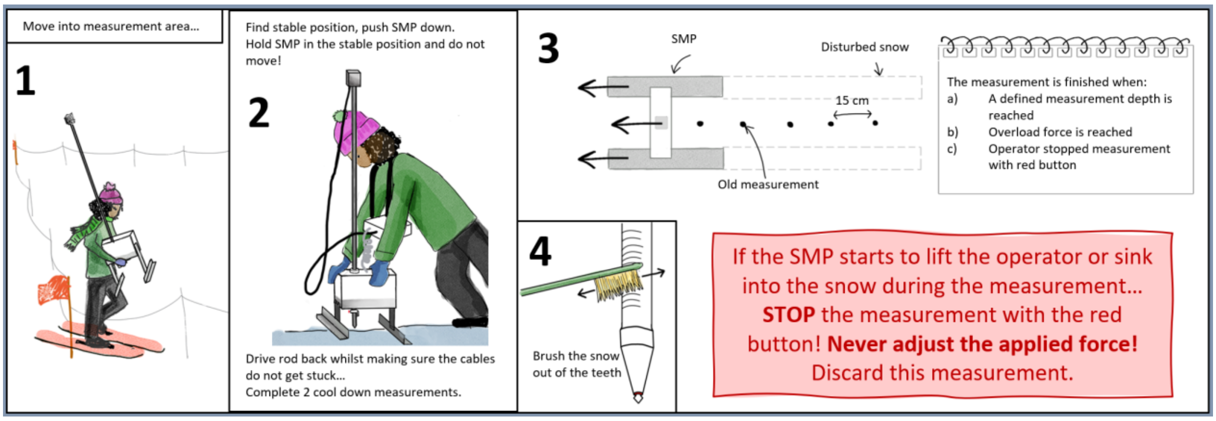


Figure 29: *How to conduct a SMP measurement.*

1) Bring the SMP to place where you want to measure. The controller is still connected with the motor unit and is switched ON.

2) Bring the SMP in a good measuring position whereas the rod is perpendicular to the snow surface (chapter 8.1). Put your bodyweight onto the motor unit (chapter 8.3, holding force), so that a stable position can be ensured during the measurement. Release from the motor unit and start a measurement on the controller unit within the measure menu (chapter 6.4.1.2). The measurement, or the starting of the rod, will be shortly delayed to give the operator the chance from operating the controller unit to go back into the holding position of the motor unit. Do not move as long as the rod is moving down.

3) When the measurement has been finished (chapter 6.4.1.2) the rod will immediately start to home. Then, release the holding force and make sure that any cables do not get stuck somewhere. When the rod is homed, move to the next measurement position (chapter 8.6).

4) While the rod is homing, try to support the ring brush with additionally cleaning off the teeth of the rod with the provided hand brush.

9.2 Tutorial movies

Tutorial movies demonstrating how to use the SMP can be found on the enclosed memory stick or request a download link on snowmicropen@slf.ch

10 System disassembling

10.1 After Usage in the Field

- Make sure that the rod is in the home position
- Remove the ring brush
- Protect the sensor with the black protective cap
- Switch off the controller and unplug all cables (never pull on the cables!)
- Protect the plugs with their corresponding lid
- Wipe off snow and potential water wherever you can
- Protect the rod with the black tube
- Put the components back into the transportation box

10.2 Storage of the controller unit

We recommend putting the cold controller unit into a plastic bag and warming it to room temperature to avoid condensation. Then, the battery can be charged, and the measurement files can be downloaded from the SD memory card.

10.3 Storage of the motor unit

One major mistake is to warm up the motor unit but omit cleaning and removing melting snow. If there are wet components, the next time you use the instrument, the measurement tip and the gear wheel of the rod might be frozen, so the instrument can not be used. Warming the instrument up always requires a proper drying procedure. Remove the measurement tip and the black protective tube and let the instrument dry out for several hours.

Otherwise and instead of warming the motor unit up, the motor unit can be stored in a cold environment bellow 0°C (protected from sun light, wind and precipitation). For an ongoing campaign, this might be more comfortable then warming it up each time having used it. Thus, the risk of refrozen water inside the instrument, resulting in a malfunction of the SMP, is minimized.

11 Data inspection

11.1 Downloading the measurement files

Unscrew the lid on the controller unit to remove the SD memory card. The SD memory card can be pulled out of the cardholder (it is not a push/push card holder type!).

Connect the SD memory card to your computer using the USB to SD-card adapter, which belongs to the SMP equipment. The file format system on the SD memory card is a regular FAT32 system. The SD memory card appears as an additional drive, and the files can be moved by copy/paste.

We do not recommend deleting the files as long as there is enough memory on the SD memory card. The SD memory card is your backup.

After transferring the files, the golden pins face downwards to reinsert the SD memory card into the controller unit.

11.2 The architecture of the binary file

The PNT file is binary and consists of two sections. The first section is a 512-byte data block containing header information. The second block always starts at Byte 512 and has a flexible length depending on the penetration depth measured with the SMP.

A detailed list of all the parameters included in the header section can be found in the Appendix. Nevertheless, as long as you are not developing your own reader software, the detailed architecture is irrelevant, and you shouldn't care about it. It's good to know that each measurement is provided with some header data. An incomplete list of header data is:

- Name of file
- Timestamp of measurement
- GPS coordinates
- System components and serial numbers
- …

Some header data are just copied into the *.pnt from the configuration file on the SD memory card (e.g., serial number of force sensor, sensitivity of force sensor, etc.). So, the values in the configuration file must be correct. Some other data are generated corresponding to the measurement (measurement number, timestamp, GPS coordinates, etc.).

The measurement values are stored as 16-bit signed integer values (I16, 2 bytes) following blocks. The first measurement point starts at byte 512 and ends at byte 512+2*(number of force samples). The unit of the values in this particular second section is Voltage. A conversion factor is needed to convert the voltage values into force values (Newton). The conversion factor is part of the header section and is automatically calculated by the force sensor's sensitivity and the range of the charge amplifier.

11.3 Data file inspection software

11.3.1 Where to Download the Software

The architecture of the binary files sounds complicated. The good message is that the user does not have to worry about it because we provide software to read, analyze, and export data.

The Python-based software package is called *SnowMicroPyn* and contains two entities:

- An API to automate reading, exporting and post processing pnt files using the Python language. You'll need some basic programming skills to use it.
- pyngui, a desktop application to read, export and post process pnt files. pyngui uses the API itself too.

In any case, a Python 3 environment is required. Then, for the installation of the latest version of snowmicropyn, use pip command. When the snowmicropyn package is installed, a simple script to start pyngui is registered too. Open a Terminal Window and type pyngui and hit return. There you are! Happy examining!

The source code is managed and shared on GitHub.

11.3.2 Main Functionalities of pyngui

Out of the *SnowMicroPyn* Python package, the executable *pyngui* can be called. This is an application providing a graphical user interface. Some of the most important functionalities are described in this chapter, but for a complete software description, please read the documentation under the weblink above:

1. Open (multiple) measurement files (*.pnt) for visual/qualitative checking
2. Pre-evaluation by setting markers (e.g., snow surface, ground, etc.) for each signal
3. Set markers can be saved as a *.ini file (one separate *.ini file for each measurement)
4. Export functions: penetration force, header, and derivatives from penetration force (snow density, SSA) can be exported and written into a text file

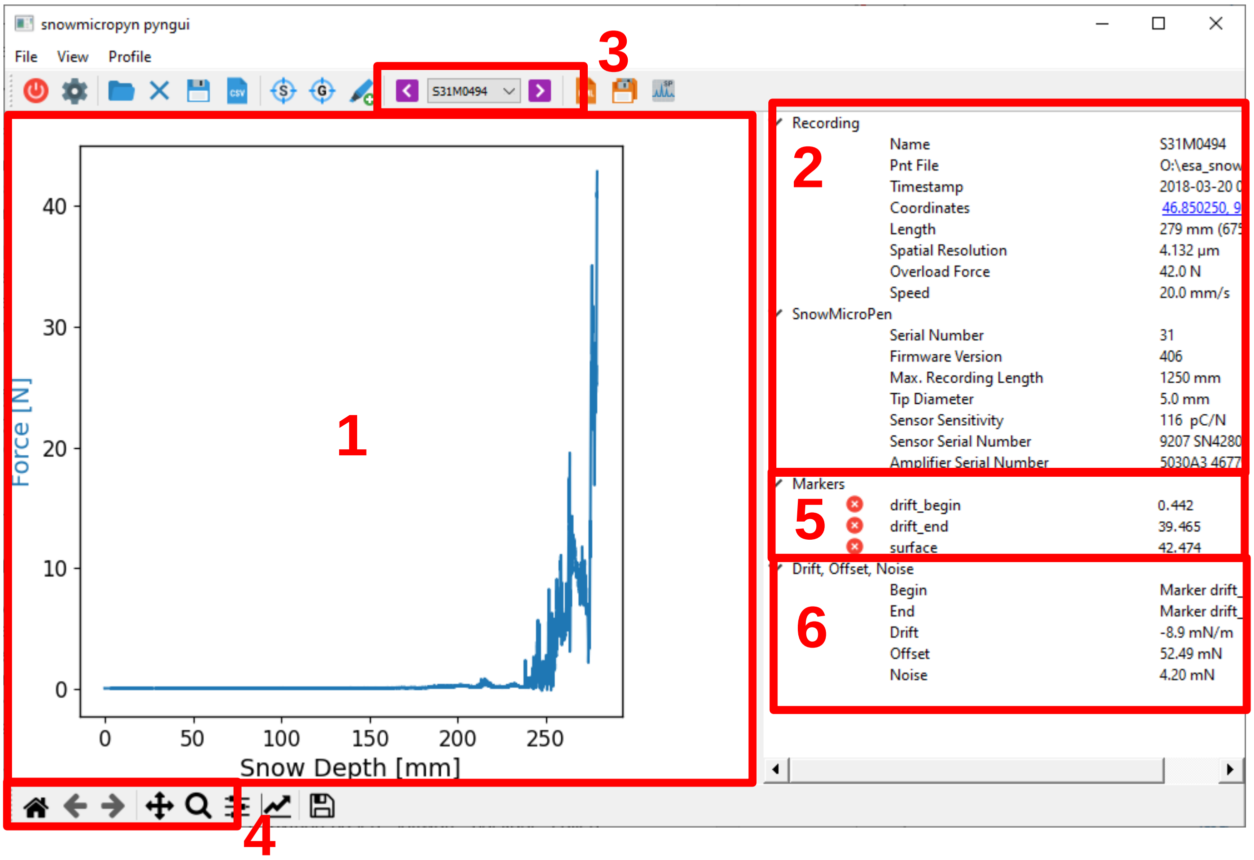


***Figure 30:** The graphical user interface pyngui as an executable application. 1) plotting area for a selected measurement with 2) its corresponding header data. 3) measurement selection in case multiple measurements were loaded. 4) zoom and "zoom-home" buttons, a 5) list of set markers, and a 6) standard signal-drift evaluation between the markers "drift_begin" and "drift_end".*

The plotting area (Figure 30, (1)) can be customized. Depending on what is enabled/disabled in the menu *View*, more or less is shown.

11.3.3 Markers and How to Set it

A marker is "something" at a specific penetration depth manually set by the user. All set markers are stored in a *.ini file in the user's working directory.

A brief list of common markers:

Marker	Description
surface	The surface marker is used to define the transition between air and snow. It's when the SMP first penetrates the snow pit. As the position of the SMP above the snow surface is not always the same, this marker is a reference. It may be necessary to overlay multiple measurements starting on the snow surface. If a surface marker does exist, the exported files, such as *_samples.csv and *_derivatives.csv, do not contain the data points of the signal from the beginning to the surface marker. This part of the signal (called "air signal") will be cut off.
ground	Ground markers can be set to define the end of the snow pit. Usually, the ground leads to a force overload, and the

	measurement will be aborted, which means that the end of the snow pit is clear. But if the ground is soft (e.g., tundra) and the transition between snow and soil needs to be clarified, a ground maker can be helpful. If a ground marker does exist, the exported files, such as *_samples.csv and *_derivatives.csv, do not contain the signal's data points from the ground marker to the end of the signal. This part of the signal will be cut off.
drift_begin, drift_end	Markers to define the beginning and the end of the “air signal”. A linear regression is calculated between those two markers, which can be used as a first quality check, if the signal drifts or not.
depth_hoar (user defined)	Arbitrary, user-defined marker. The information can be used for further processing if such a marker is applied to a series of measurements.

Table 7: *Markers and their meaning.*

To set any marker within the force signal, locate your mouse arrow on the desired position, click your right mouse button, and select the marker you want. It is possible to create user-defined markers.

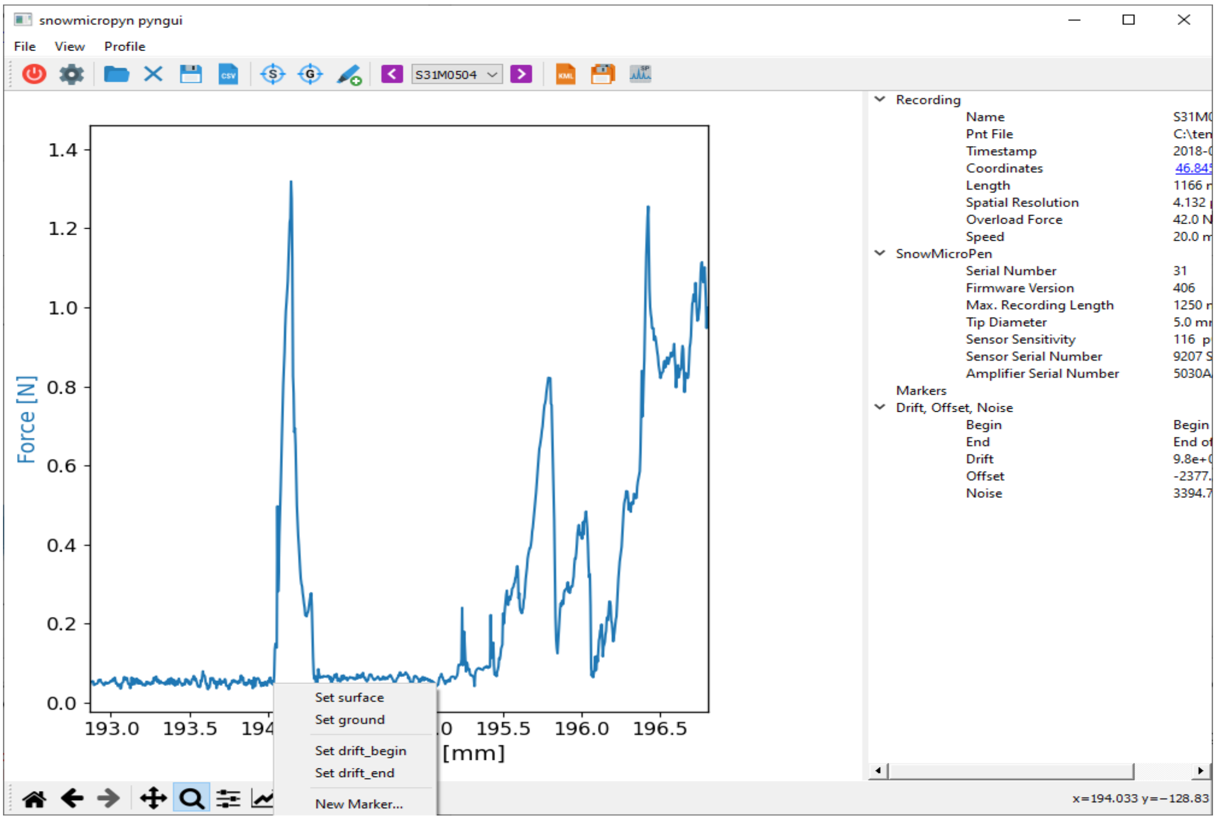


Figure 31: *How to set a marker within the force signal.*

If you go through all opened measurements and have set your required markers, you can use the *Save/Save All* function from the *File* menu to create/overwrite the corresponding *.ini file(s) in the same working directory as the measurements.

If you open a *.pnt file with pyngui, the program checks if there is a corresponding *.ini file in the same directory and would then reload existing markers as well.

11.3.4 How to apply an SSA & Density Parametrization

Furthermore, different parametrization tables are included in the SnowMicroPyn package. These parametrizations and the high-resolution penetration force-distance signal can recover microstructural parameters such as snow density, specific surface area, etc. In the menu *View->Plot Density->…,* different parametrizations can be applied to a measurement.

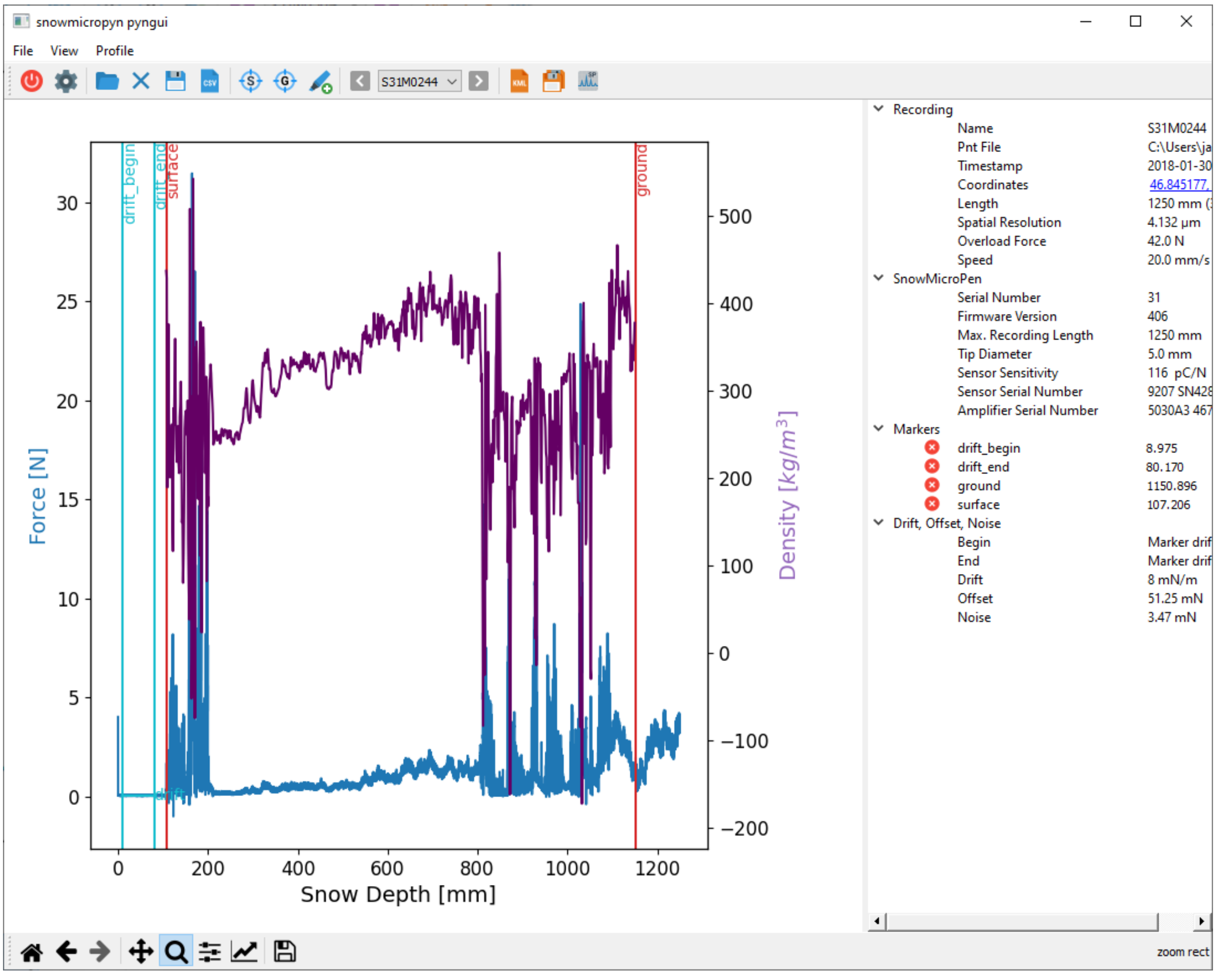


Figure 32: *An example is applying a parametrization to the force signal to derive snow density.*

Using *File->Export All* creates/overwrites files such as *_derivates.csv, *_meta.csv, and *_samples.csv in the working directory. *_samples.csv contains the force signal, *_meta.csv contains the header data, and *_derivatives.csv contains the derived physical properties depending on the selected parametrization in a text file. If a surface or a ground marker is applied to the signal, the derivate only considers data points in between.

For more information about the different parametrizations, please read the publications (chapter 15).

11.4 Preliminary quality check of measurements

The operator is asked to make a regular rough quality check of its measurements to ensure that the instrument works according to its specifications and that the applied measurement technique leads to sufficient measurement quality. The following aspects should be assessed:

- Signal drift, noise, and offset
- Are negative force values present?

From the start of the measurement to the snow surface, the force sensor continuously “travels through the air”, and this first part of the signal without any force impact can be assessed concerning drift, noise, and offset. For that purpose, the operator has manually set the markers “drift_begin” and “drift_end” for each measurement. The “drift-noise-offset” analysis is shown on the right of Figure 30 (6).

11.4.1 Linear Drift

A temperature disequilibrium of the piezoelectric force sensor induces linear drift. The better the SMP is equilibrated to the environment temperature before performing measurements, the smaller the linear drift will turn out.

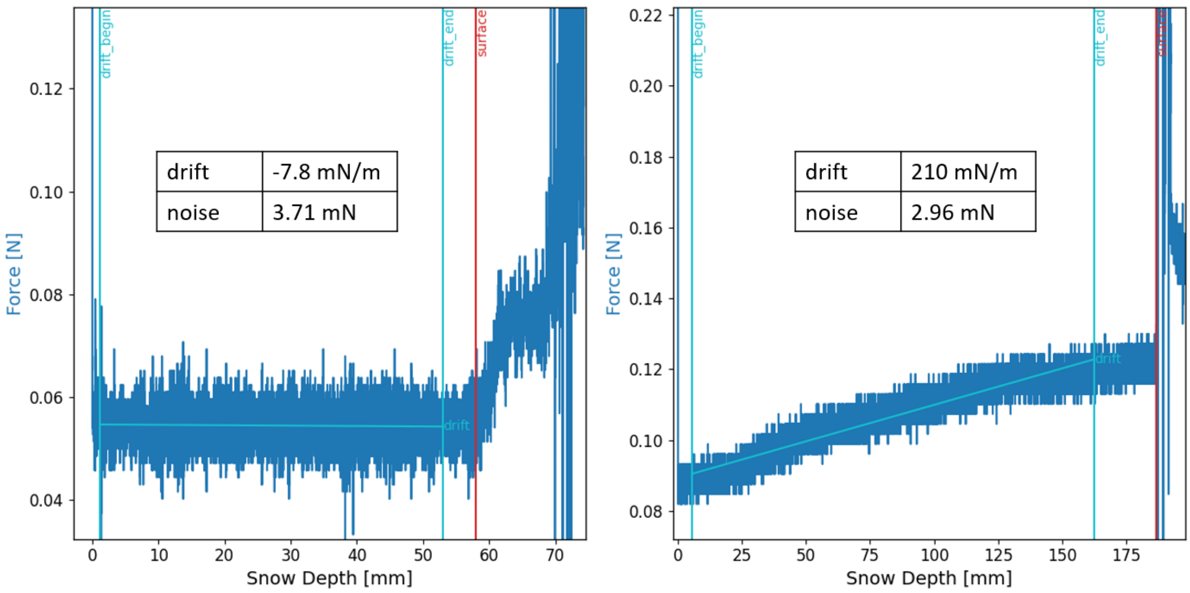


Figure 33: *Examples of linear drift. A slight linear drift of -7.8 mN/m (left) and a large linear drift of 210 mN/m (right).*

Under laboratory conditions, we accept a linear drift of ≤10 mN/m so that we say the drift is negligible and a signal-drift correction is needless. But if the linear drift is much larger than this 10 mN/m, we suggest discarding the measurement if there are others with less drift from the same profile or making a signal-drift correction. However, if the operator is aware of letting the SMP equilibrate to the environmental temperature, linear drift can nearly be avoided.

11.4.2 Signal Noise

The system induces noise to signal and indicates “how smoothly the mechanics work and how much vibrations are induced”. A good measurement technique can reduce this kind of noise. On the other hand, there is noise in the signal from the electronic components. Overall, the noise value should not exceed 5 mN. A higher noise level probably indicates that something in the electronics is broken or that the force sensor is battered. If you notice a much larger noise, please contact snowmicropen@slf.ch

11.4.3 Offset

The signal offset is mainly device-dependent. The offset, particularly the average "air signal" level, should be more or less constant for one specific device. An offset correction is recommended.

11.4.4 Negative Force Values

The piezoelectric force sensor can capture both – tensile and compression forces. But when measuring snow stratigraphy with a SnowMicroPen, only compression forces make physically sense. Despite that, sometimes negative values occur. There are several reasons for negative force values and patterns, and the interpretation is explained in the following graphs.

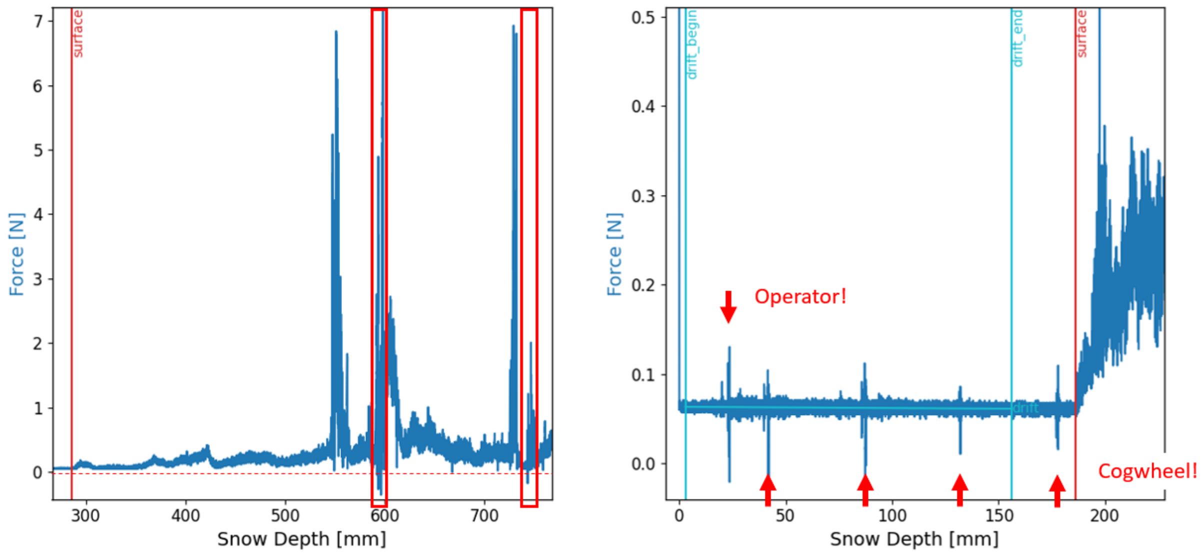


Figure 34: *Short negative force peak induced by a rapid change of the snow layer hardness (left). Repetitive negative force peaks due to a broken tooth in the cogwheel or an instrument motion induced by the operator (right).*

When the hardness of the snow suddenly changes from "soft to hard" as shown in the left figure of Figure 34, often a short negative force peak occurs. The negative force peak happens because the measurement tip is not only exposed to compression forces but also to shear forces. The piezoelectric sensor misbehaves with shear forces, resulting in negative force values. We can't avoid this phenomenon because we can't change the snow stratigraphy. Because these negative peaks are often relatively short, averaging the signal makes them disappear.

On the right of Figure 34, we see a repetitive pattern of negative peak forces approximately every 40 mm. A bent or broken tooth of the cogwheel can explain this. The cogwheel should be replaced! Another disruption of a proper air signal is labeled with "Operator!". This was probably induced because the operator moved the instrument while measuring. A short oscillation on the rod can cause an imperfect catching between the cogwheel and the rod. As the signal disruption is in the "air part", it is cut off anyway and out of interest. But anyway, it can be the starting point of damaging the teeth of the cogwheel, so the operator should always try to avoid instrument motion while the rod is driving.

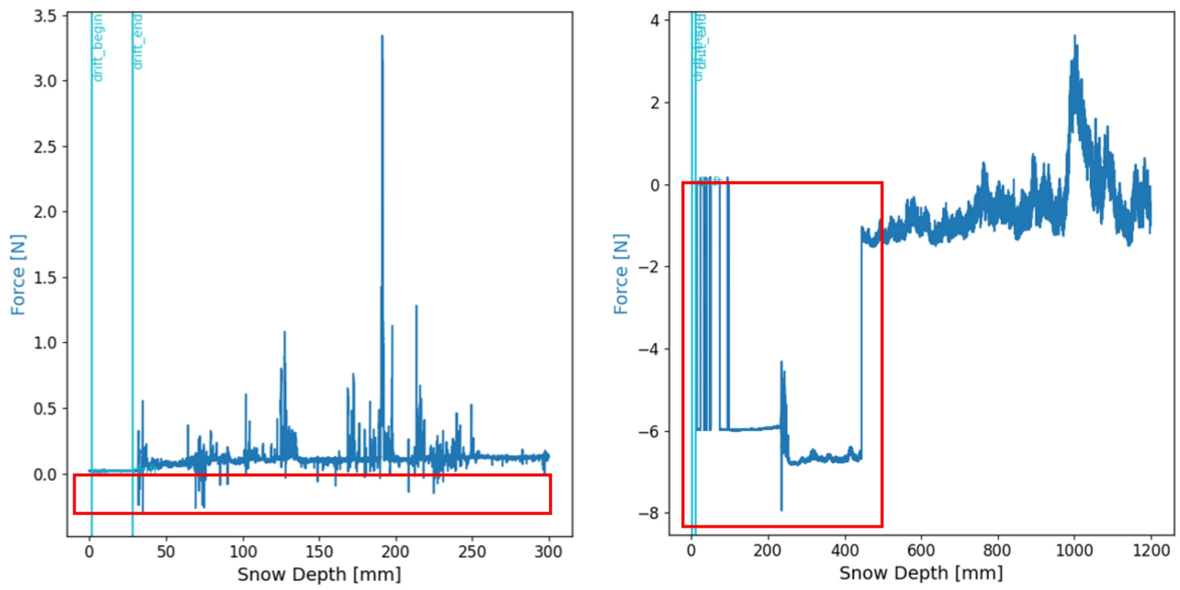


Figure 35: *Many and randomly distributed negative force peaks (left) and utterly wrong offset even though the signal sometimes looks reasonable (right).*

Out of the perspective of snow stratigraphy, all these random positive and negative force peaks, as shown in the left figure of Figure 35, do not make sense. Such a noisy signal is the probable result of ice between the teeth of the rod and ice on the cogwheel, which makes the rod drive rough and produces a lot of vibrations. Whereas the signal on the right in Figure 35 looks fine at first glance but is shifted to negative force values. Here, we are facing an electrical problem. The electrical ground (GND) is not on a constant and stable value, which makes the signal jump. Often, the reason is moisture in the system (between electrical connectors) and a poorly defined electrical ground level and electrical resistance/capacity.

To solve these issues, the SnowMicroPen should be thoroughly dried. A complete disassembling of the motor unit and rod might be necessary, which we can remotely support. If the problem can't be solved, the instrument needs to be maintained/repaired by SLF.

To summarize, a quality check of each SMP measurement should be done. A better measurement technique can avoid some issues, and other issues could be solved by maintaining the SMP. Despite having both under control, measurement technique and well-maintained instrument, unsatisfying quality of measurements can arise. If many measurements were performed, the easiest way to deal with it is to select the good measurements and discard the bad ones. If that is not an option, signal treatment such as linear drift correction, noise reduction by averaging, and others might be necessary. However, further signal processing is not part of this manual. And if nothing helps, contact SLF to arrange an entire maintenance service.

11.5 Set Snow Surface and Drift Markers

11.5.1 Set Surface Marker

The operator wants to define the snow surface within the force signal. Theoretically, there is an implemented function for automatically detecting the snow surface (*Profile->Auto Detect Surface*), which is often inaccurate. This means that the marker "surface" should be set manually. The set surface marker is displayed in the graph window in case *View->Plot Surface & Ground* is enabled.

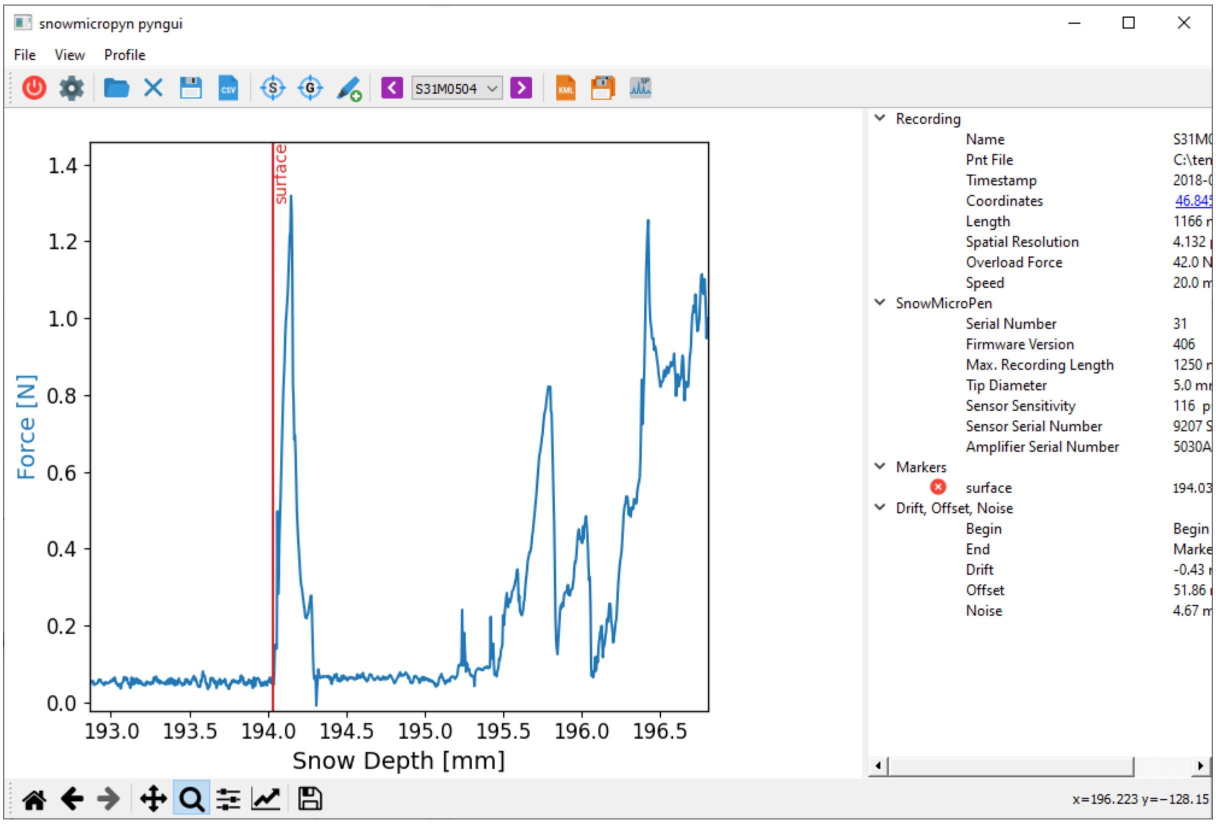


Figure 36: *Manually set "surface" marker at the snow surface.*

Additionally, the marker appears in the marker list on the right by name and its value. Any set marker can be removed by clicking on the white cross in the red circle.

To save the markers (*.ini), use *File->Save/Save All*.

When the snow surface is hard, setting the surface marker is a piece of cake. But when the surface snow only consists of low-dense and fresh snow, it can be challenging to figure out the point in the penetration depth when the SMP first hits the snow. For that purpose, it might be helpful to note the approximate height between the measurement tip and the snow surface as a confirmation to set the marker correctly. Especially in low-density snow, the sinkage depth of the measurement support frame can vary a lot between single measurements within the same snow pit.

11.5.2 Set Drift Markers

By default, the drift evaluation (Figure 30, 6) considers the signal from 0 mm to the marker "surface". If the surface marker is not yet set, the drift evaluation considers the whole signal, which is meaningless. The user should set either the "surface" and or "drift_end" marker.

12 Maintenance

12.1 Regular checks and recommendations

The device does not need considerable maintenance effort, but checking the following points is recommended:

- Store the device in a warm and dry environment above freezing point (when it is not used in an ongoing campaign)
- Remove dirt from the rod by using a soft brush (use the “drive rod” menu to drive in and out to be able to clean the entire rod)
- Make sure all parts are dry. If there is moisture inside the gear, drive the rod in and out several times and dry the rod with a towel (use the “drive rod” menu)
- Remove the measurement tip carefully and let the inside of the cone dry out well (several hours). If there is constant moisture around the sensor, this can lead to permanent damage to the force sensor as the sensor is not perfectly sealed (only IP65 enclosure)
- Make sure that the O-ring on the measurement tip is intact (not brittle, no rips) and in the correct position
- To reinsert/re-screw the measurement tip into the force sensor, a “mechanical end stop” must be perceived. The force sensor might loosen if the “mechanical end stop” feels soft. In that case, please contact snowmicropen@slf.ch
- Check the measurement tip. The frontmost part (1^{st} cone) should not show any scratches. The surface should be smooth (polished) and sharp-edged. Otherwise, please replace it
- Make sure that the screws on the charge amplifier box at the end of the rod (head) are tightened
- Make sure that any plugs and sockets are secured against twisting and that cables are securely connected to the plug
- The display can be cleaned with a soft cloth
- Check that the entire length of the rod drives smoothly through the motor unit (listen and look). If rattling happens, contact SLF
- Use the LiPo storage menu to charge/discharge the battery to 80% for long-term storage purposes (chapter 6.4.3.6)

12.2 Firmware Updates

You will be informed if a firmware update is available for your SMP controller unit.

To update the controller unit, the following components are necessary:

- Opened SMP controller unit (needs a cross-tip screwdriver)
- STLINK-V3SET compiler kit, including the attached "rainbow" cable
- Computer (admin rights) with a complete installation of STM32CubeProgrammer software, including the additional driver file (*.stldr) provided by SLF
- USB micro to USB A extension cable
- The new firmware file (SMP5_controller_v5_*.elf) provided by SLF

Figure 37: *Components used for the firmware update of the SnowMicroPen.*

For the firmware update, please follow the described procedure step by step.

The STM32CubeProgrammer software package and the additional driver file should be available on the memory stick within the SMP equipment. Nevertheless, if the memory stick is lost/missing, the STM32CubeProgrammer software package can also be downloaded from the manufacturer's homepage. The driver file and the firmware update file are always provided by SLF (request snowmicropen@slf.ch).

Step 1: Download and installation of STM32CubeProgrammer software

To communicate with the microcontroller in the SMP controller unit, STM32CubeProgrammer software is needed. The software can be run on Windows, Linux, or Mac operating systems. To install the software, administrator rights are necessary. Make sure that there is one free USB port on your computer.

- To get the STM32CubeProgrammer software, visit https://www.st.com/en/development-tools/stm32cubeprog.html (or check out the memory stick)
- Create a download link by selecting the needed software (WIN32, WIN64, Mac, Linux)
- The download link is sent by email

- Download the software, unzip it, and run the SetupSTM32CubeProgrammer_*.exe

Step 2: Copy the necessary driver file into the STM32 environment

Apart from the standard microcontroller libraries, an additional driver file is needed. For that purpose, please copy the following file (SMP5_CONTROLLER_flashloader_MT25QL128ABA1EW7_V2_0.stldr) to the path specified below:

- WIN: C:\Program Files\STMicroelectronics\STM32Cube\STM32CubeProgrammer\bin\ExternalLoader
- Linux: ~/STMicroelectronics/STM32Cube/STM32CubeProgrammer/bin/ExternalLoader
- Mac: unfortunately has not been tested yet

Step 3: Connect the SMP controller unit to your computer

- Open the SMP controller unit by loosening the four screws in the corners of the transparent lid (cross-tip screwdriver)
- If you can protect the work from electrostatic discharge (ESD protection), please do it! Ask your colleagues in the electronics department!
- Position the opened controller according to Figure 37
- Connect the "rainbow" cable from the compiler module, as shown in Figure 38, to the main electronic board (plug J5). The pin, which is indicated with a small arrow on the black plug (2) from the rainbow cable, must be connected to the pin that is marked with a small white spot (1)
- Connect the compiler module with a USB extension cable to your computer
- Switch the SMP controller unit on with the green main plug

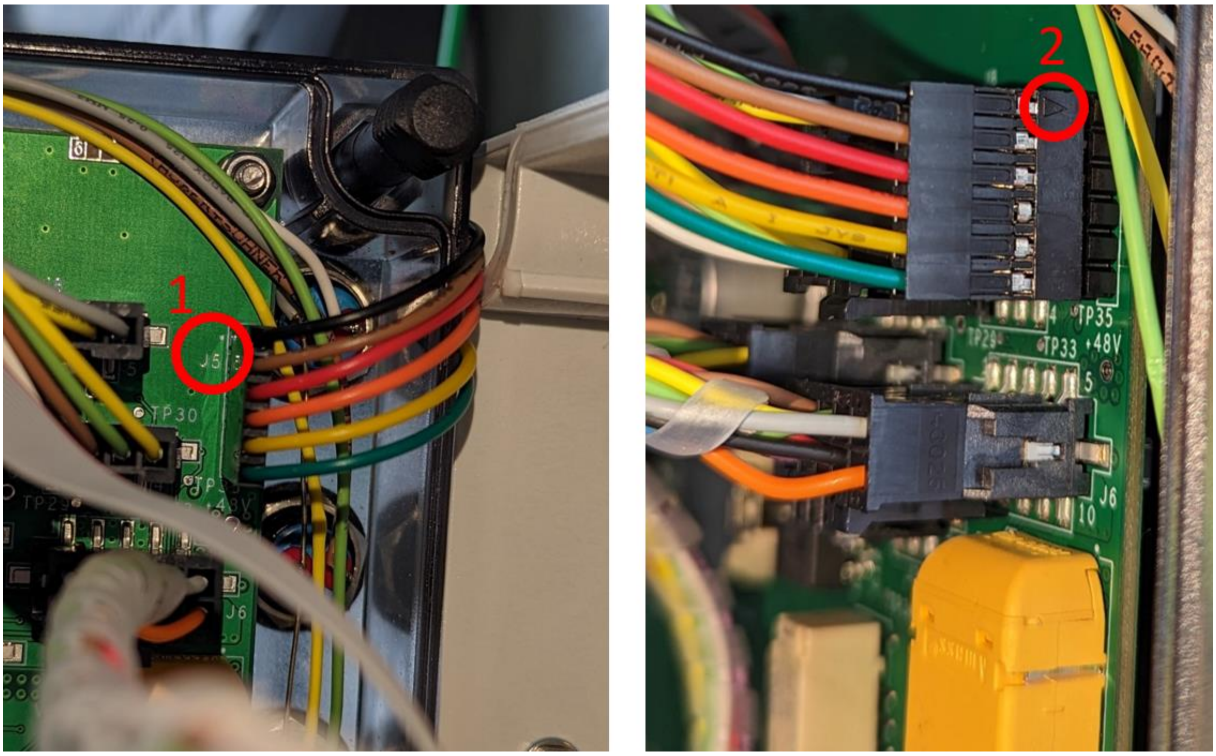


Figure 38: *Connector J5 on the main electronic board and the "rainbow" cable from the compiler module to perform a firmware update.*

Step 4: Upload the new SMP firmware with STM32CubeProgrammer software

- Execute the STM32CubeProgrammer application
- Connect (connect button) your hardware as shown in Figure 39, indicated by 1
- Change to the “External loaders” menu as shown in Figure 39, indicated by 2
- Activate/tick the driver file SMP5_*.stldr as it is shown in Figure 39, indicated by 3
- Change to the “Erasing & Programming” menu as shown in Figure 40, indicated by 1
- Browse the new firmware file you want to upload to your SMP controller unit, as shown in Figure 40, indicated by 2
- Tick options accordingly to Figure 40 indicated by 3
- Upload the firmware by confirming the settings with the button “Start Programming” as it is shown in Figure 40, indicated by 4
- After successfully uploading the new firmware (it takes a while, several messages pop up, etc.), disconnecting your hardware (Figure 39, 1), unplug the compiler module and carefully close the lid of the controller unit without pinching cables
- Check the current software version on your SMP controller with the “settings” menu (chapter 6.4.3.1)

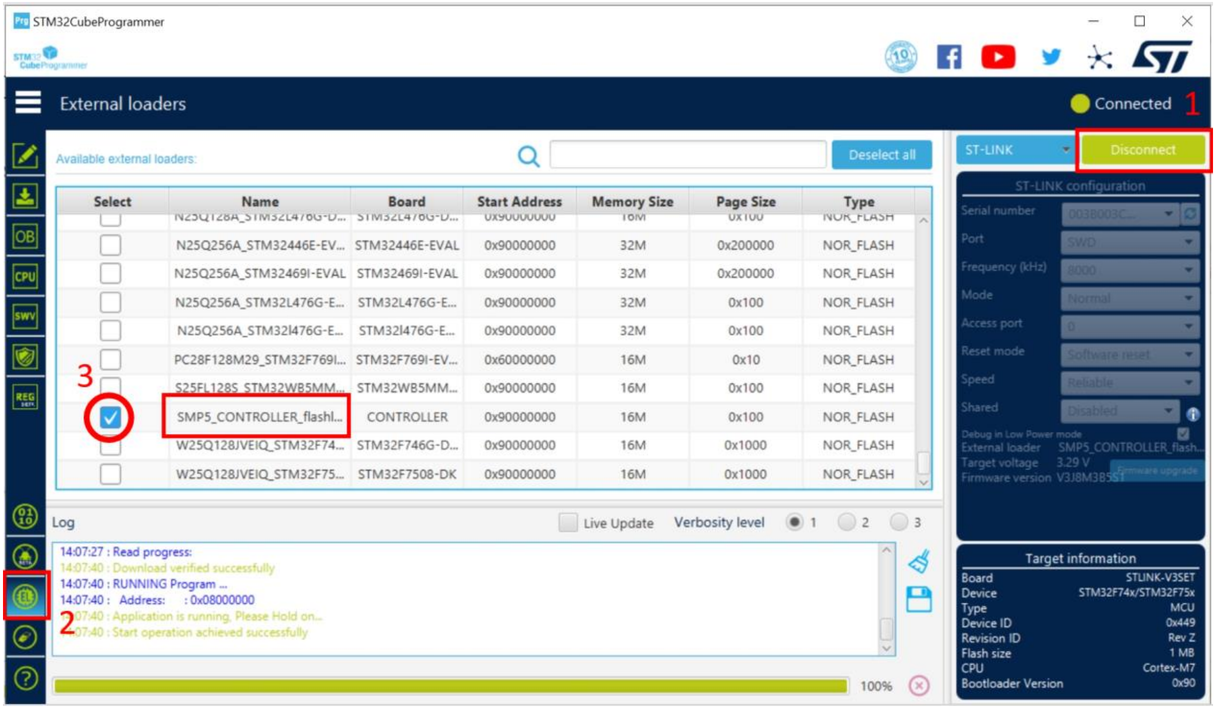


Figure 39: *STM32CubeProgrammer software to connect to the SMP controller unit and to tick the necessary additional driver file.*

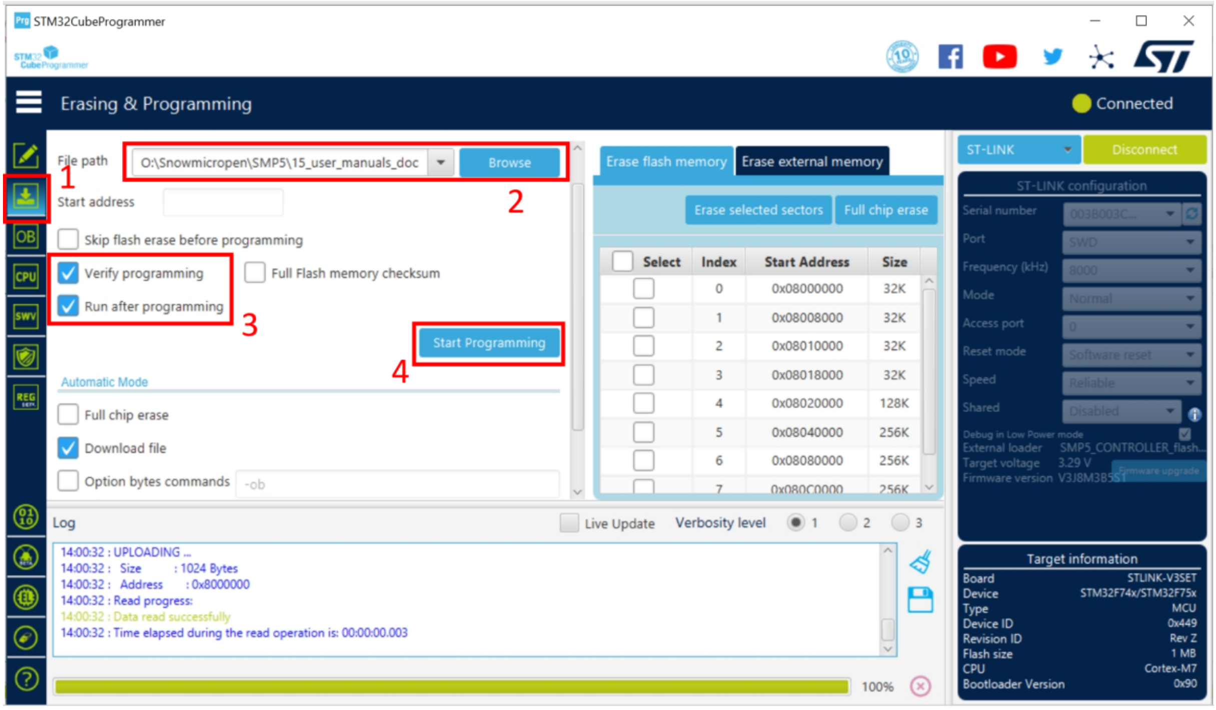


Figure 40: *STM32CubeProgrammer software to upload the firmware to the SMP controller unit.*

13 Shipping

13.1 Preparing the Instrument for Transportation

For the transportation of the SnowMicroPen, it is recommended to unscrew the tip from the high-sensitive piezoelectric force sensor, cover the rod with the black protection tube, switch off the controller unit, and have the equipment dry and clean (no water or snow inside the box).

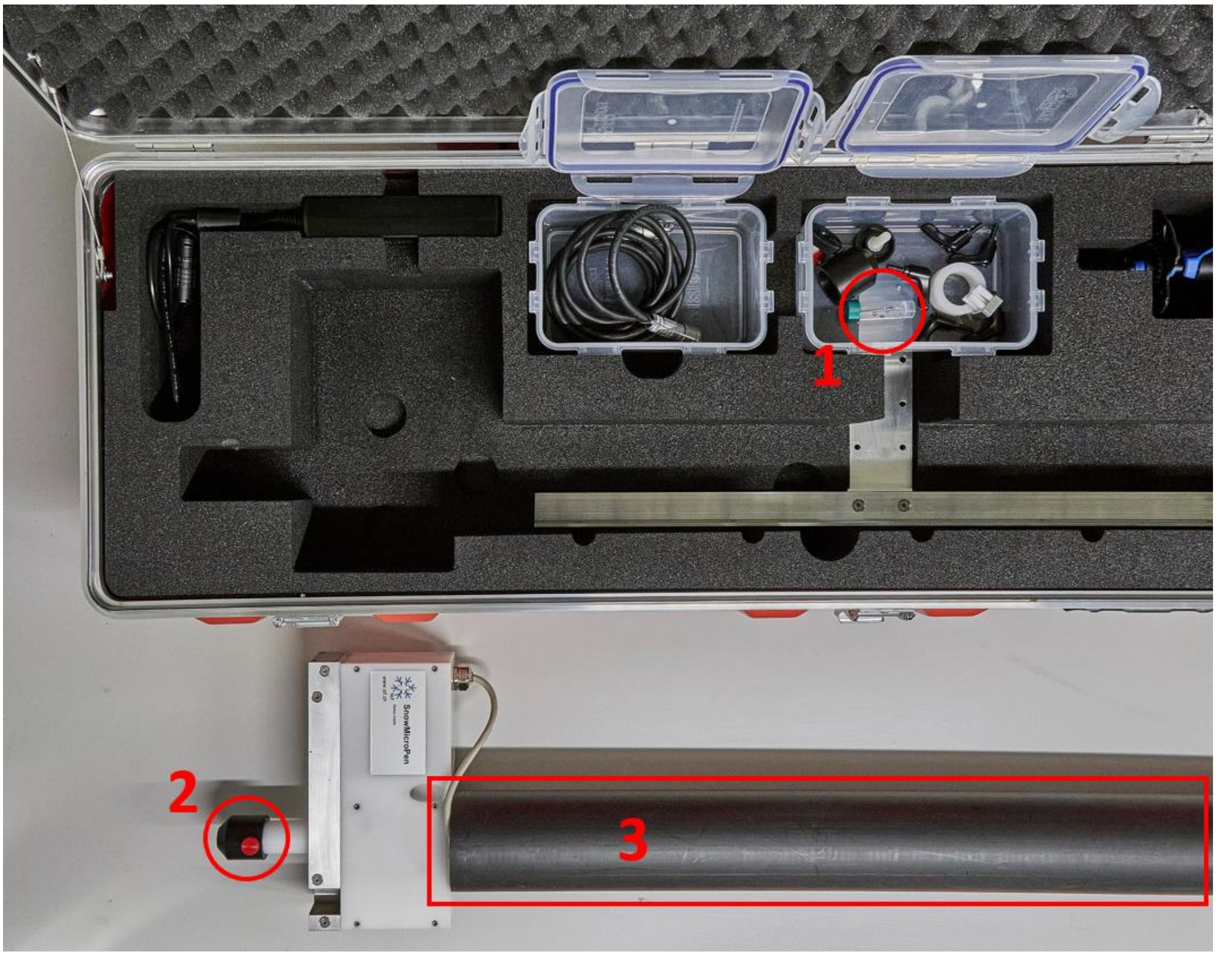


Figure 41: *Make the SMP ready for transportation by unscrewing the measurement tip (1) from the force sensor, putting the protection cap in place (2), and having the black protection tube around the rod.*

If the SMP is transported as a personal luggage by plane, the controller unit must be carried in the hand luggage rather than inside the SMP transportation box. Lithium polymer batteries are not allowed on passenger airplanes except in your hand luggage (cabine). If the SMP is shipped by an agency, the controller unit including the battery can remain in the transportation box, but must be properly declared.

13.2 Dimensions and Weight

The dimensions of the hard case that is provided for the default SnowMicroPen (rod length 1.2 m) are:

175 cm x 32 cm x 21 cm, roughly 24 kg

13.3 Mandatory Customs Information

For customs clearance, the description of the good, the instrument's serial number, a general customs tariff number (HS code), and a commercial value are needed at the minimum on a commercial invoice and packing list.

The SnowMicroPen can be described as a “Snow hardness measurement device”. The serial number of your instrument is revealed on a silvery adhesive label on the motor unit. For the customs tariff number (HS code), use 9015.8000 (CH) and 9015.8020 (EU).

As the value of the instrument is decreasing over the years, the commercial value for customs declaration can approximately be calculated with the given formula:

Value for Declaration = Original value – (Original value / 10 Years) * Time in Operation [Y]

For example, 5 years after purchasing the SMP, a realistic commercial value of the SMP for customs declaration is CHF20’000.- which comes out of the formula CHF40’000 - (CHF40’000 / 10) * 5.

13.4 Battery declaration

The controller unit contains a Lithium Polymer battery. For transportation declaration, especially for aircraft transportation, the Li-Polymer battery must be mentioned to the shipping agent, even though the built-in battery is smaller than the limitation defined by IATA (International Air Transport Association). The relevant regulations to which you can refer to are summarized within:

UN3481 Lithium Ion Batteries, in compliance with Section II of PI967, contained in equipment

Which means in other words:

- The battery is "contained in equipment"
- The Watt-Hr-Rating per cell is ≤ 20Wh
- The Watt-Hr-Rating of all packed batteries is ≤ 100Wh
- The allowable number of batteries is one to power the device and two spare sets
- The allowable mass of batteries per packaging is ≤ 5 kg
- A lithium battery mark on the outer side of the packaging is necessary

The Lithium Polymer battery that is built-in in the SMP controller unit is less than 5 kg and has a Watt-Hr-Rating of 62.16 Wh. The battery is enclosed by the chassis of the instrument (controller unit), why it is categorized as “contained in equipment”. There are no spare sets.

If the SMP is shipped with an agent, please give the instruction that the following information is necessary on the airway bill (AWB):

"Lithium-ion batteries, in compliance with Section II of PI967, contained in equipment" on AWB.

14 Terms of warranty

There is a 2-year warranty on the SnowMicroPen, except for the piezoelectric force sensor from KISTLER. The piezoelectric force sensor at the SMP is mechanically not protected against overload because this would lowering the overall sensitivity of the instrument. As incorrect handling of the SMP can lead to an overload situation whereby the sensor can get severely damaged or even break, WSL/SLF can not be held responsible for the piezoelectric force sensor.

In a warranty repair case, WSL/SLF does not carry the cost of transportation.

15 Contact, Links and Publications

If there are any questions related to the SnowMicroPen, please do not hesitate to contact snowmicropen@slf.ch, or call +41 81 417 01 11

The following links may be helpful:

SnowMicroPen (webpage)	SMP project website with further information and downloads
Tutorial movie (youtube)	Tutorial movie made for SMP version 4
SnowMicroPyn (download)	PiPy, python package index, *pip install snowmicropyn*
SnowMicroPyn (documenatation)	
SnowMicroPyn (source code, GitHub)	

Publications :

Calonne, N., Richter, B., Löwe, H., Cetti, C., ter Schure, J., Van Herwijnen, A., Fierz, C., Jaggi, M., and Schneebeli, M.: The RHOSSA campaign: multi-resolution monitoring of the seasonal evolution of the structure and mechanical stability of an alpine snowpack , The Cryosphere, 14, 1829–1848, https://doi.org/10.5194/tc-14-1829-2020, 2020.

Proksch, M., H. Löwe, and M. Schneebeli (2015), Density, specific surface area, and correlation length of snow measured by high-resolution penetrometry, J. Geophys. Res. Earth Surf., 120, 346–362, doi:10.1002/2014JF003266.

King, J., Howell, S., Brady, M., Toose, P., Derksen, C., Haas, C., and Beckers, J.: Local-scale variability of snow density on Arctic sea ice, The Cryosphere, 14, 4323–4339, https://doi.org/10.5194/tc-14-4323-2020, 2020.

16 Appendix

16.1 Comparability to former SMP versions

A comparability study was done between SMP version 4 and SMP version 5. Unfortunately, the final report is still under construction and will be published later on.

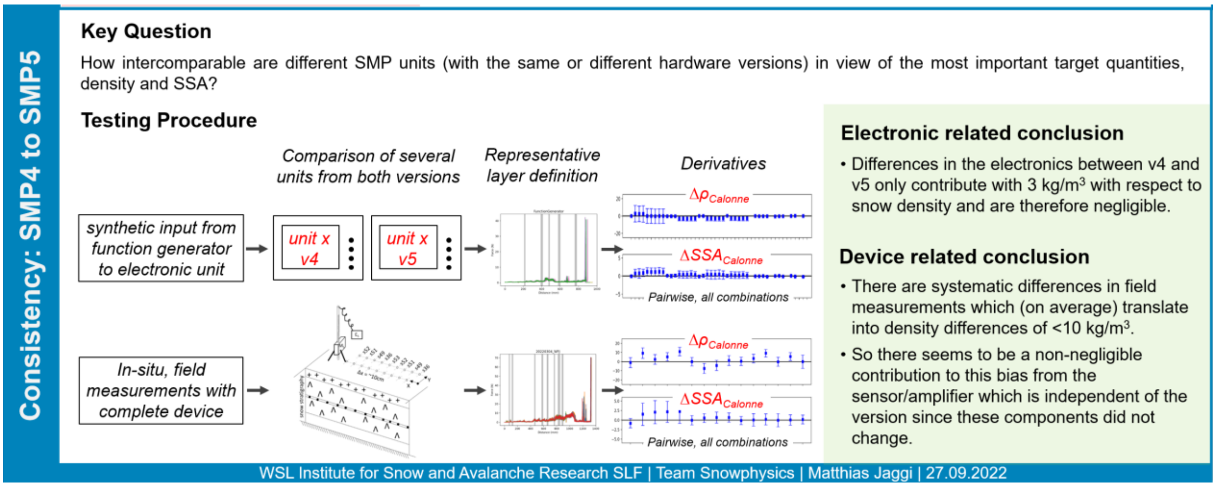


Figure 42: *Poster 91A3903 at IGS conference 2022 in Davos, Switzerland, about SnowMicroPen version 5.*