Raven Snow Science - ICECAPS-MELT 2024

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Draft 2: 11 March 2024, updated formatting, science questions, procedures and recommendations for snow science data collection

michael.town@esr.org

Executive Summary:

Contents: This document contains a summary of science questions, experiments, and field procedures for the snow science aspect of ICECAPS-MELT at Camp Raven during the Summer 2024.

Snow Science Questions: The snow science questions are centered around understanding heat transfer in snow to better predict when the snow in Greenland will melt. The data collection and monitoring are directed towards characterizing the snow stratigraphy to identify melt events and melt layers spatio-temporally. To support our understanding of this, models of heat transfer in snow need snow property data related to thermal conductivity and heat capacity. Some of the best proxies for the information needed for accurate modeling will be in the LWC, mechanical strength, and the density of the snow.

Measurement Plan: The field measurements described here in support of the science questions above include measurements to be made in a series of snow pits at a central location, spatial compression strength/NIR measurements made using the Lyte Probe (a digital ski-pole penetrometer), and high frequency (~5 GHz) snow radar. Recommendations for the execution of the field measurements are made below. Briefly, they are: 1) Snow pits made at the beginning and end of field campaign. 2) Lyte probe measurements made in close proximity to the snow pits. 3) 200-m Lyte probe transects (wind parallel and wind perpendicular) originating from the snow pit area. 4) 200-m high-freq radar transects (wind parallel and wind perpendicular).

Field Measurement Guidance: Guidance and 'manuals' for the snow science at Camp Raven are listed below.

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Section 1: Measurable Science Questions:

The **primary snow science questions** that are potentially directly measurable at Camp Raven in 2024 are:

1. What is the time-varying stratigraphy of the top meter of snow at Camp Raven? How does this vary on a range of time scales (30-min, monthly, across summer season)?

Density, hand hardness, compression strength, NIR reflectivity, shear strength, snow grain size/habit, LWC, dielectric constant (via radar), temperature, snow height.

2. What is the spatial variability of 1-m snow properties at Camp Raven? How does this vary on a range of vertical and horizontal spatial scales (0-10 cm, 0-10 m, 0-200 m)?

Compression strength, NIR reflectivity, dielectric constant

3. What is the relationship between snow properties measured traditionally (i.e., snow pit), the Lyte Probe, and the high freq snow radar?

We might curate data from representative case studies through a series of **opportunistic snow science questions**.
1. How do snow properties evolve in response to atmospheric forcing?
If an interesting event occurs, does it help to monitor snow properties as a function of time through the event (e.g., blowing snow, intense LW event, melting event, hoar frost formation)?

2. Can we identify a few types of representative events to make sure the energy and mass flux measurements are operational and collecting quality data?
e.g. a) *VSBL*: calm periods, heat into snow pack, possibly hoar formation (mass transfer *towards* surface interface (from atmosphere and from deeper in snow)),
b) *Neutral BL/small lapse*: calm, heat leaving snow pack, possibly mass leaving surface

Section 2: Field Measurement Guidance

The field measurement guidance here is broken into four categories: 1) Where to make the measurements, 2) What measurements to make in support of science questions, 3) How to make the measurements, 4) How to characterize the measurements themselves (i.e. random uncertainties and biases).

2.1 Field Measurement Layout

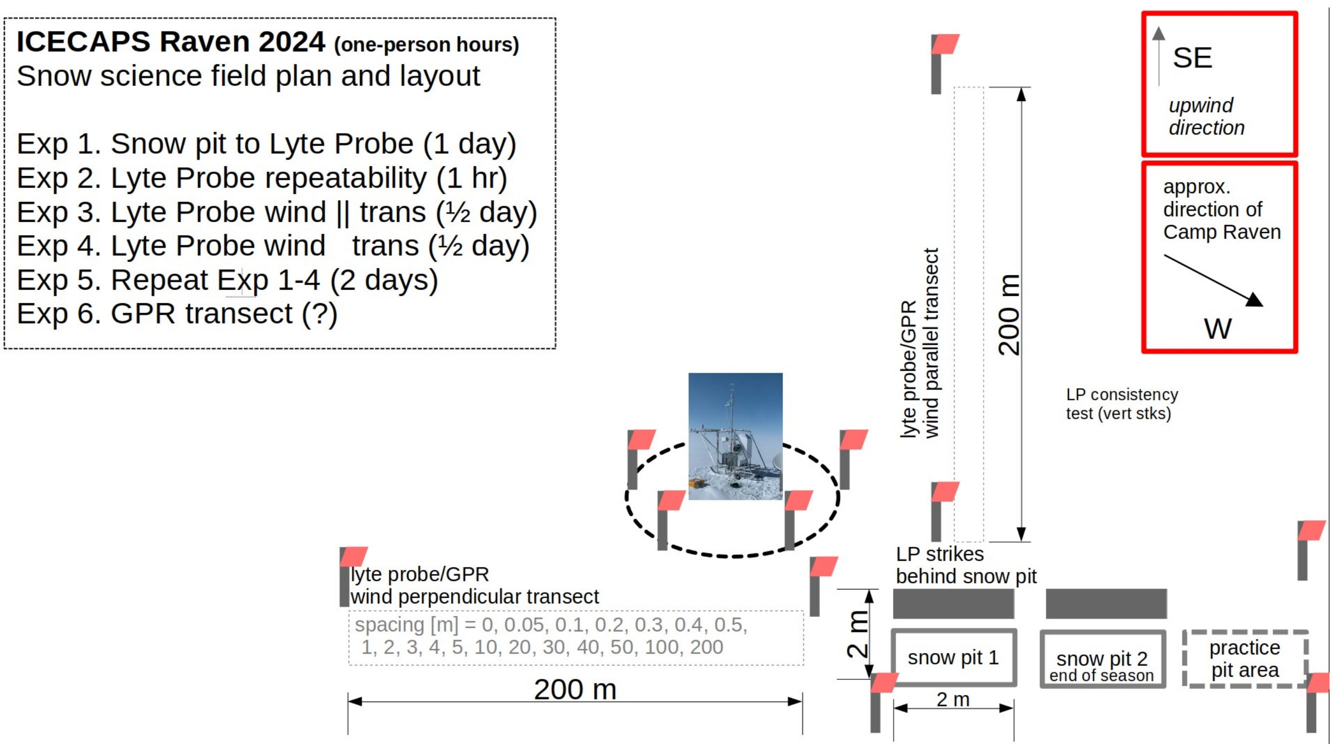


Figure 1. A top view of a potential ICECAPS-MELT field measurement schematic. Included are potential person-hours to complete each suggested measurement suite.

The field measurement schematic shows one concept of the observing platform positioning relative to other field science and the Raven Camp. Some important features and criteria here are:

1) Flag all important areas, or areas that are to be protected for surface science.

2) Keep the SLEIGH on the far side of the field site relative to snow science area, and basically upwind of the snow pits and snow transects.

3) Proximity of the SLEIGH to snow science is not that critical. It primarily matters to minimize the footprint of the experiment and make easier to protect the SLEIGH from interference.

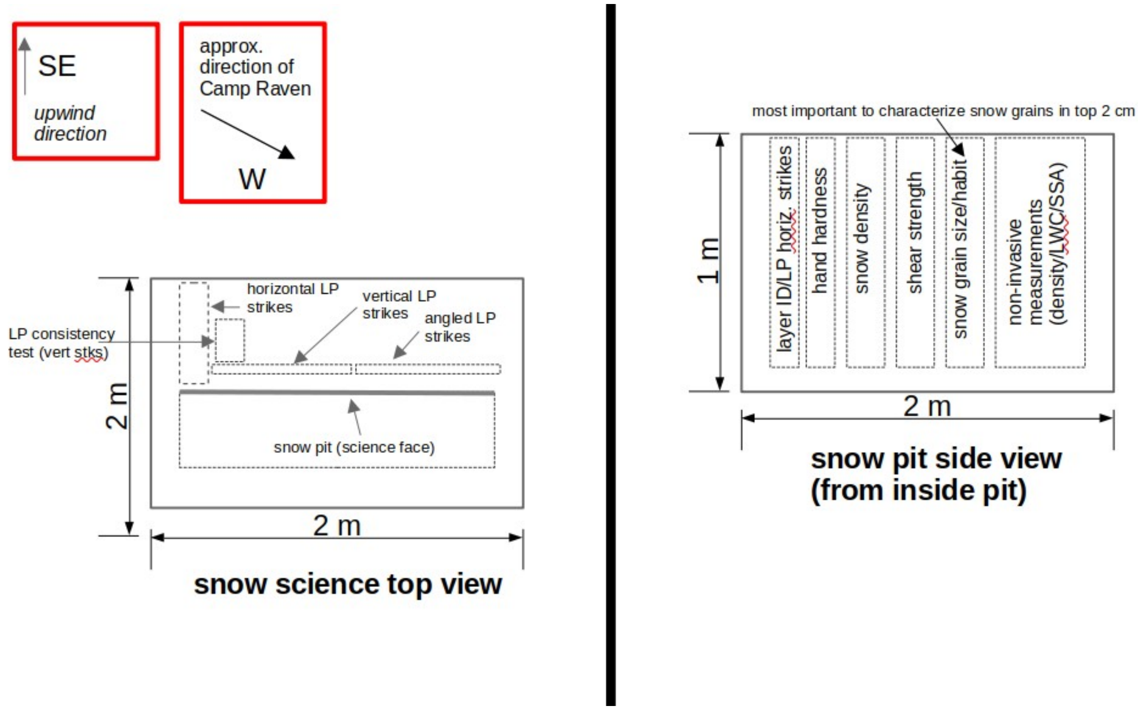


Figure 2. Snow pit diagrams from top view (left) and side view (right). Measurements in this diagram are listed in the next section on Snow Science Measurements.

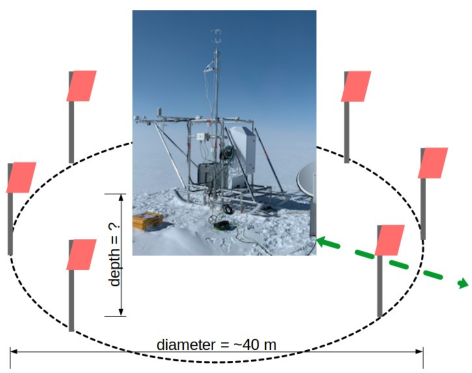


Figure 3. A figure of the SLEIGH deployment with suggested no-impact diameter, approach (**green**), and reminder to measure the depth of anchors and posts for compaction modeling. NOTE: It could be interesting to do a *final survey (snow pit, lyte probe)* at the SLEIGH site after breakdown.

2.2 Snow Science Measurements

Below are lists of measurements to make broken down by field operation task. Included in each table is a list of measurements for 'calibration' or 'uncertainty' of specific tools/measurements. The lists are in checklist form for use in the field.

*Record all field data in green **Rite in the Rain** notebook.*

Snow pit

Table 1. A list of measurements and calibration tasks for the snow pit. The right-hand side of the table is a field checklist.

Measurement	Priority	Reference	Practice	May 2024	Aug 2024
Layer ID (manual)	1	SWAG CH2			
Hand hardness (manual)	1	SWAG CH2			
Snow density (manual)	1	SWAG CH2			
Shear strength (manual)	1	SWAG CH2			
Snow grain size (manual/photo)	1	SWAG CH2			
Snow grain habit (manual/photo)	2	SWAG CH2			
Liquid water content (manual)	2	SWAG CH2			
Liquid water content (A2 Wise)	1	Section XX			
Infrasnow SSA measurement	2	Section CC			
Temperature profile (manual)	3	SWAG CH2			
NIR pit-face image (camera)	1	Section YY			

NOTES:

Layer ID - identify summer layers, crusts, and other holistic changes in material properties.

Profile resolution - try to get up to 3-cm resolution in all things. Of course, the layer ID will help you identify when that is appropriate, and when it is unnecessary. Layer ID will have higher precision than anything else (~ 1cm or less).

Profile sampling protocols - try to sample above and below crusts/hoar/and other thin layers with things like HH, snow density, shear strength. Try to sample thin layers separately whenever possible (e.g. snow grain size, snow grain type).

Practice pit - settle on minutae for procedures during the practice pit. Record procedures in notebook (or videos). Upload procedures for review by 'instrument stewards' if possible.

Manual temperature measurements - Lots of considerations here. Assess any solar bias by shading sensors as much as possible (Thomas umbrella or other). Take measurements quickly after exposing snow pit face, or dig deep into pit face, ~30 cm/day the face has been exposed.

Final survey at SLEIGH site? - Could be interesting to do a final, complete survey where the SLEIGH was looking after extraction.

Transect Measurements (Lyte Probe, Snow Surface Height, GPR)

Lyte probe measurement procedure (and important metadata) are described in Section ZZ.

Lyte Probe Adjacent to Snow Pits

Table 2. Lyte probe measurements that ought to be made adjacent to the snow pits shown in Figure 2 are list below.

Measurement	Priority	Reference	Practice	May 2024	Aug 2024
vertical strikes along pit face	1	Section ZZ			
consistency test	1	Section ZZ			
angled strikes along pit face	1	Section ZZ			
horizontal strikes into pit face	2	Section ZZ			

NOTE:
When to measure - Try to make these LP measurements within a day or two of digging the snow pit. Try to make the LP measurements on the upwind side of the snow pit after the pits have been sampled.

Consistency test - In this box, keep strikes around 5 cm apart. Suggest to record the pattern (if possible) after completion (a small circle or square). Be careful to make strikes vertical. Use clineometer to check angle of attack *in situ* to self-calibrate on angle of attack. An angle of 3 deg should correspond to about 5 cm deviation from vertical over 1 m.

Transects (Lyte Probe, Snow Surface Height, GPR)

We ask for at least four (4) transects during the field season. Two in May and two in August. They ought to be wind-parallel and wind-perpendicular, approximately 200 m in length at variable resolution including a transects of surface height, Lyte probe strikes, and GPR measurements.

Table 3. Lyte probe measurements along transects.

Measurement	Priority	Reference	May 2024	Aug 2024
vertical strikes along wind parallel transect	1	Section ZZ		
angled strikes along wind parallel transect	2	Section ZZ		
vertical strikes along wind perpendicular transect	1	Section ZZ		
angled strikes along wind perpendicular transect	2	Section ZZ		
Survey of surface height (cm resolution)	2	Section AA		
GPR Survey	1	Section BB		

NOTES:
LP Strike locations - These transects can be measured with 100 m tape, and marked out initially using the popsicle sticks or other temporary marking. The transect lines should be marked at each end with flagged bamboo poles. Strike locations should be at a progressively coarse resolution so that fine

resolution measurements are made, but not overburdening the field crew. Probe strikes in a line parallel/perpendicular to prevailing wind (and surface structure axes). Use variable spacing, out to 100-200 m. Variable spacing should match expected surface structure changes (e.g. dunes/sastrugi, small hills, megadunes, etc...). Transects begin at central snow pit.

Surface height survey - This may be accomplished by one of the following apps.
https://apps.apple.com/us/app/theodolite/id339393884,
or simply a reasonable laser level with distance measurement (e.g. tape measure). Needs tripod. A theodolite with tripod and measuring stick would be better.

SLEIGH Installation Characterization

Two ideas for the SLEIGH installation characterization:
1. Shade the area to assess solar bias of SIMBA temperatures.
2. Final snow pit, lyte probe, and mobile GPR survey after the SLEIGH is demobilized.

Section 3: Measurement Manuals

3.1 Lyte Probe

Probe was developed by Micah Johnson and team at Adventure Data. Its intended purpose has been to have an accurate field probe for back country travelers that will help quickly assess snow structure.

In collaboration with Micah J. and HP Marshall, we are finding the LyteProbe useful for scientific purposes.

Resources:

A list of necessary resources for Linux and/or Windows platforms to use the Lyte Probe for field science applications. Von Walden also has data acquisition and processing capabilities on his laptop, but this is only for backup.

Table 1. Resources located on the ESR Lyte Probe Surface and online.

Resource name	**link**
Adventure Data Website	https://github.com/adventuredata/
Lyte Probe command line interface data acquisition and probe settings software	https://github.com/AdventureData/radicl
Lyte Probe command line interface data acquisition and probe settings software for research projects	https://github.com/AdventureData/study_lyte
Windows Surface USB probe driver install	C:/Users/micha/lyteProbe/programs/driver_install.bat
Windows Surface GPS driver install	C:/Users/micha/lyteProbe/programs/ubloxGnss_sensorDevice_windows_3264_v2.24.exe
Windows data acquisition software	C:/Users/micha/lyteProbe/programs/Lyte Probe for Research - ESR.exe
Windows lyte probe settings software	C:/Users/micha/lyteProbe/programs/RADICL-ESR.exe
Field data *Profile* quality code (use with Spyder)	C:/Users/micha/lyteProbe/programs/lyteProfile_ICECAPS.py
Field data *Transect* quality code (use with Spyder)	C:/Users/micha/lyteProbe/programs/lyteTransect_ICECAPS.py

Dependencies:

Python 3.11 - Lyte Probe data acquisition software depends on Pandas. Pandas can currently only be used with Python 3.11. Many computers are coming with Python 3.12 installed as the default. If you are starting from scratch with a new daq computer, please check this dependency.

Upgrade pip to 23.3.2.

This dependency has been sorted for the ESR Surface that comes with the ESR Lyte Probes.

Contact info:

michael town - michael.town@esr.org
micah johnson - micah@adventuredata.com

LyteProbe Setup and Software Installation

LyteProbe Basics:

The LyteProbe to be used for ICECAPS came with three sensors and one empty channel.

Sensor 1 - Force
Sensor 2 - NIR Passive
Sensor 3 - NIR Active
Sensor 4 - empty channel

The force calibration information is listed below. *The probe diameter is 0.005 m* +/- (unknown). We are waiting on tolerances for the diameter measurement. We can measure ourselves with calipers when available.

Our sensor was initially setup with the accelerometer range as +/- 16gs. We are currently taking g = 9.81 m/s2. This may be an assumption to revisit later.

Adjusting Probe Setup:

0. NOTE: You should not need to do this. Both probes have been set with appropriate settings for this experiment.
1. Plug probe into computer (green light will turn on, then red light)

2. Start RADICL-ESR from C:\Users\micha\lyteProbe\programs\

```
WELCOME TO THE LYTE PROBE CLI

WARNING:
        Warning: This CLI is not meant to run with the mobile app.
        Please make sure your RAD app is closed out.


Things you can do with this tool:


        * Plot various data from the probe.
        * Write various data to a file. (In development)
        * Modify probe settings.  (In development)
        * Update the firmware (In development)

radicl.serial INFO No COM port provided. Scanning for COM ports...
radicl.serial INFO Using /dev/ttyACM0
radicl.api INFO Attached device: PB3, Rev=1, FW=1.46.5.0

What do you want to do with the probe? (daq, settings, update, help, exit)
```

3. Choose settings from the following list, with the ideal settings for our work in parentheses.

===== Probe Settings =====
  accrange (16)
  accthreshold (0)
  acczpfo (0)
  alg (1)
  appp (2)
calibdata (Sensor 1) = [0, 4095]
calibdata (Sensor 2) = [0, 4095]
calibdata (Sensor 3) = [0, 4095]
calibdata (Sensor 4) = [0, 4095]
  help
  ir (1)
  ppmm (2)
  samplingrate (16000 Hz)
  tcm (1)
  usertemp (None)
  zpfo (2)
  home
  help
  exit

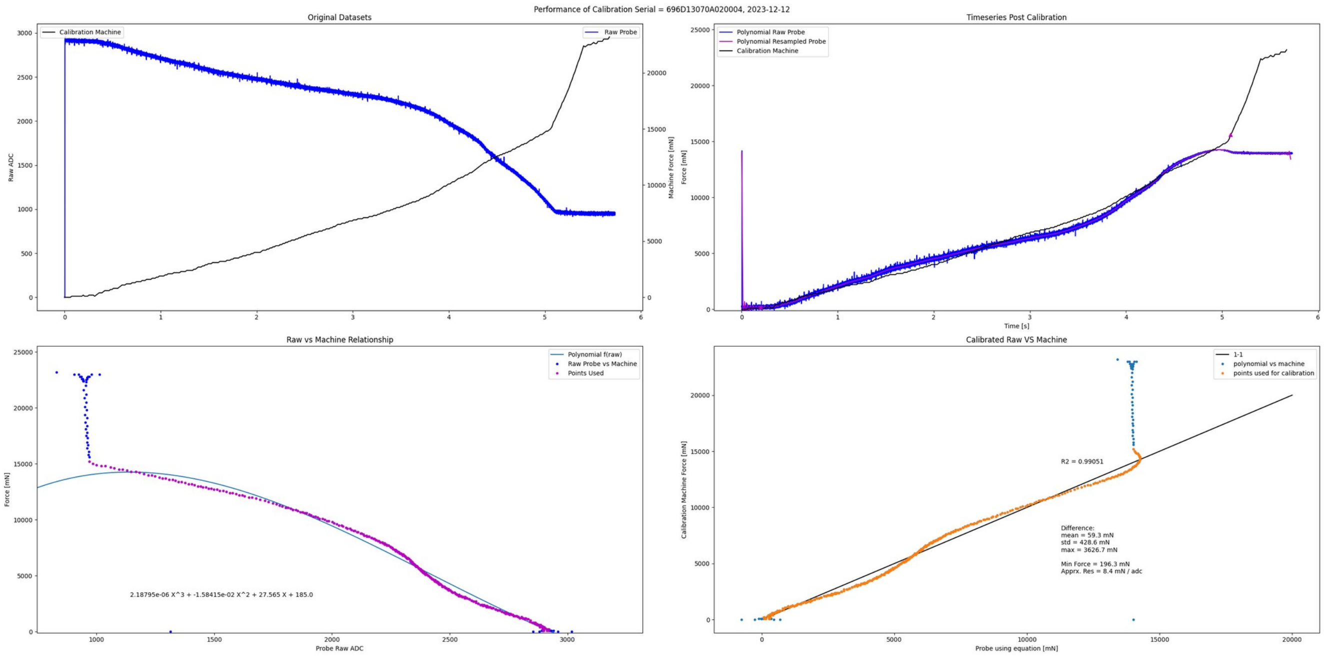
Force Calibration:

Calibration of the force sensors are in Table 2. These are embedded in the code used to process the data after it has been collected.

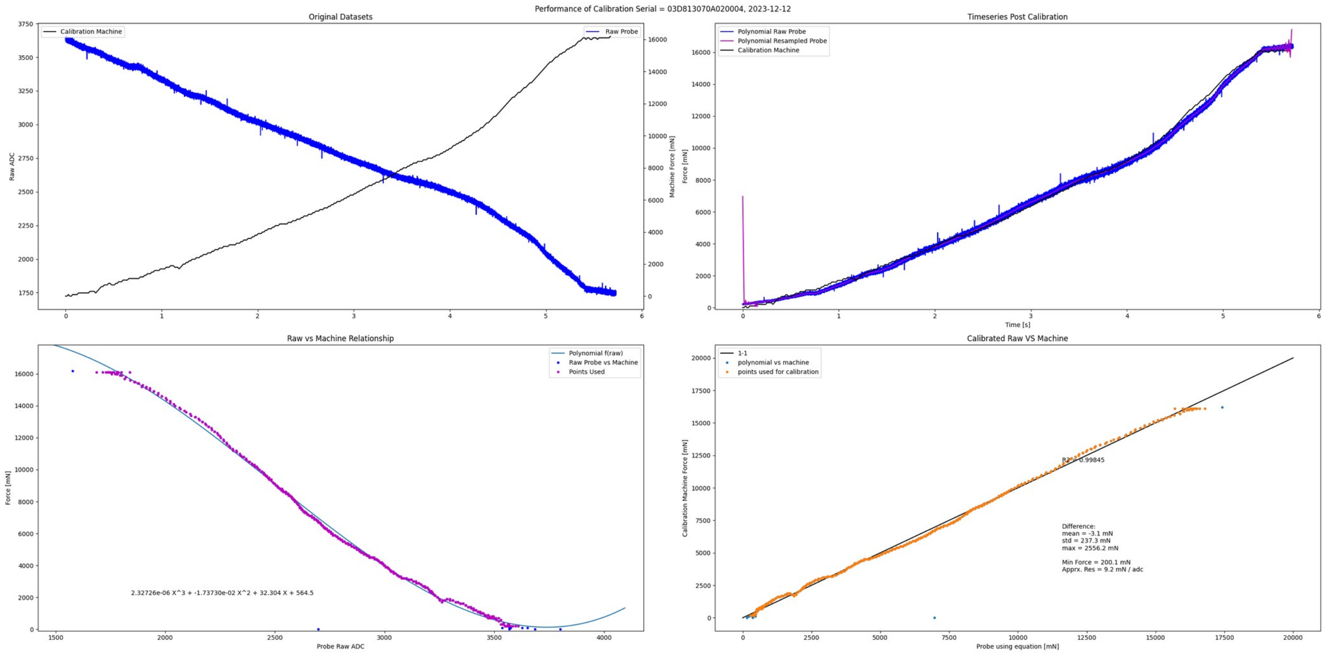
Table 2. Calibration coefficients for ESR Lyte Probes. Converts force sensor signal (Sensor 1) to force in Newtons. Range should be up to ~0-15 N.

Probe #	Serial Number	Calibration equation (converts to Newtons)	Range
1	696D13070A020004	F = 2.18795E-06 x^3 + -1.58415E-02 x^2 + 27.565 x + 185.0	0-14 N
2	03D813070A020004	F = 2.32726E-06 x^3 + -1.73730E-02 x^2 + 32.304 x + 564.5	0-16 N

Probe 1:



Probe 2:



Probe Operation:

BEFORE SAMPLING:

0. Record site information/location in field notebook.

Probe number (1 or 2), Date, Time, Location, Purpose of collection, description of snow surface or other environmental conditions, Name of Experiment (YYYYMMDD_X). Measure full length of probe.

1. Lay out strike data collection table(s) in field notebook for your measurement. Example below

Strike #	Transect location	Length to collar	Hilt height	Notes
1	0 m	61 cm	5.5 cm	hard surface crust, ended at slight angle
2	2 m	N/A	N/A	ghost strike
3	2 m	57 cm	10 cm	hard surface crust, sudden stop at end

Notes may include: surface structure, angle input, sudden accelerations during strike, NIR sensors clogged with snow (before or after strike), any 'ghost strikes' (times when the user hits the action button accidentally, etc...

Hilt height - this measurement is used to help check on the total distance traveled by the probe.
Length to collar - this measurement is use to help check the total distance traveled by the probe. The probe may 'shorten' if it hits a hard crust or frozen layer.

DURING SAMPLING:

0. Power on the MS Surface computer (Code = 1918). Secure to body with strap and case.

1. Remove the quick release basket from the probe.
2. Power on the probe by pressing the *action button* on side of handle
    green light when not plugged into the computer
    red light when plugged into the computer
3. Connect the probe and G-Mouse GPS to your computer via USB splitter (long, white USB cable to probe). Mini-usb connection is on the top of the probe.
    NOTE: Probe draws charge while connected to computer.

4. Click on the 'Lyte Probe for Research' icon on the desktop taskbar. Wait for Command Prompt Screen.
5. Use Surface keyboard (on screen or flip-keyboard) to hit '**enter**' to being measurement. **Wait** for software to respond.
6. Hold the probe above the surface, *turn NIR sensors away from the Sun*, and **press the action button** (the LED will flash).
    Use two hands, but be careful to not push the action button before you want to start strike, or or during the strike (ending your measurement early).
    Do not bend the usb cable at the top.
7. **Wait for 2 seconds** for collection to begin in the probe.
8. **Insert the probe** into the snow somewhere **around 1 m/s**, it should feel "natural"
    Drive to full desired depth then stop and let go. OK to push through layers. Try not to experience 'sudden' stops.
9. **Wait 1-2 seconds** at bottom of strike.
10. **Press the action button** again **to stop** (LED will flash again)
11. The **software will download the data** and save it to a file **in the directory with the 'Lyte Probe for Research'** exe.
    Examine field plot the data to make sure y-acceleration is flat on both ends of strike. If not, repeat strike.
    This strike information will be cleared automatically after a few seconds.
12. Clear snow out of NIR holes between strikes
13. **Repeat** the **process** starting from **number 6**.
14. When finished, hit **ctrl-c** to stop data collection.

Things to note (and some troubleshooting advice):
* The probe LED is **red** when the battery is low.
* Power off the probe by holding the action button for a few seconds (LED will turn off)
* The LED will be **orange** if something has gone wrong, almost always fixable by a power cycle.
* The probe can take data (one strike) prior to informing the computer to listen with a key stroke. This looks like turning the probe on (button push, then **green** light), then button push (start) and strike and button push (stop). The data will automatically download and display when the computer is told to listen. *These data have not proven to be reliable. Do not follow this proc unless told otherwise.*
* The Lyte Probe LED light also lights up **green** when plugged into the laptop because it is charging. This does not mean that the Lyte Probe is on. It always needs to be turned on by pressing the 'action' button.
* **For an angled strike** - point the NIR sensors horizontally away from the striker (and away from the Sun).
* If the NIR profiles are constant, check if the sensors are clogged with dirt or other debris. Clogging with snow should *not* result in constant NIR profiles.

AFTER SAMPLING

0. Data are stored in C:\Users\micha\lyteProbe\programs\. Move files to appropriate directory for more permanent storage (two USB drives provided in 'tea container'). Suggest naming folders YYYYMMDD_X, where X may be the number of the experiment for the day.

Review data, rename files if necessary.

1. Plot data with field scripts to check what happened.
2. Upload data or visual output/check to cloud if possible.

3.2 GPR Instructions

3.3 A2 Wise LWC Sensor

3.4 Infrasnow