GlacioBasis Zackenberg Manual

Version 3 (June, 2025)

This is a complete revision of GlacioBasis Manual Revision 2 (April 2015) compiled by Michele Citterio. This version 3 is compiled by Signe Hillerup Larsen (GEUS)

Table of Contents

Preface

This manual provides the information required to properly carry out the monitoring of GlacioBasis Zackenberg. It includes instructions for fieldwork, data processing in the office, data storage, and data publishing.
Emphasis is placed on field procedures and post-processing, as adherence to these is essential for maintaining consistent data series. This is a working document.

Revision history

3rd November 2009, version 1

14th April 2015, version 2: provided more context and background for the Programme; updated and extended the GPS and GPR sections; updated AWS maintenance checklist; updated contacts information

2 June 2025, version 3: A complete revision of the manual

Working objective of GlacioBasis Zackenberg

Glaciers play an important role in the ecosystem by storing water and releasing it with a delay on seasonal to multi-annual timescales. This delayed release generates river runoff that is independent of rainfall and supports both terrestrial and marine life. On a larger scale, glacier ice functions as long-term water storage - accumulating in cooler climates and releasing in warmer periods - thereby influencing global sea levels.

Glaciers and ice caps, distinct from the main ice sheets, respond more rapidly to climate change. Globally, glacier melt is approximately 18% higher than that of the Greenland Ice Sheet and more than twice that of the Antarctic Ice Sheet.

Through the glaciological monitoring in GEM, we aim to:

1. Quantify the role of glaciers in the local ecosystem by monitoring key variables that define glacier mass balance and associated runoff.
2. Contribute to global sea level estimates by monitoring Greenland's peripheral glaciers and submitting critical in-situ observations to the World Glacier Monitoring Service (wgms.ch), which supports the calibration and validation of global glacier mass balance estimates.

Programme overview

The glaciological monitoring in GlacioBasis Zackenberg focuses on the glaciers relevant to the hydrological catchment of the Zackenberg River, where water discharges into Young Sund near the Zackenberg Research Station (Figure 1, also attached as a separate file).

The monitoring programme consists of permanent installations and field surveys conducted on the largest ice cap in A. P. Olsen Land (hereafter referred to as the A. P. Olsen Ice Cap; see Figure 2), as well as area mapping from satellite imagery of all glaciers in the region (outlined by the green line in Figure 1).

The field site was selected based on both accessibility and representativeness, as this part of the ice cap contributes the most to runoff within the river catchment.

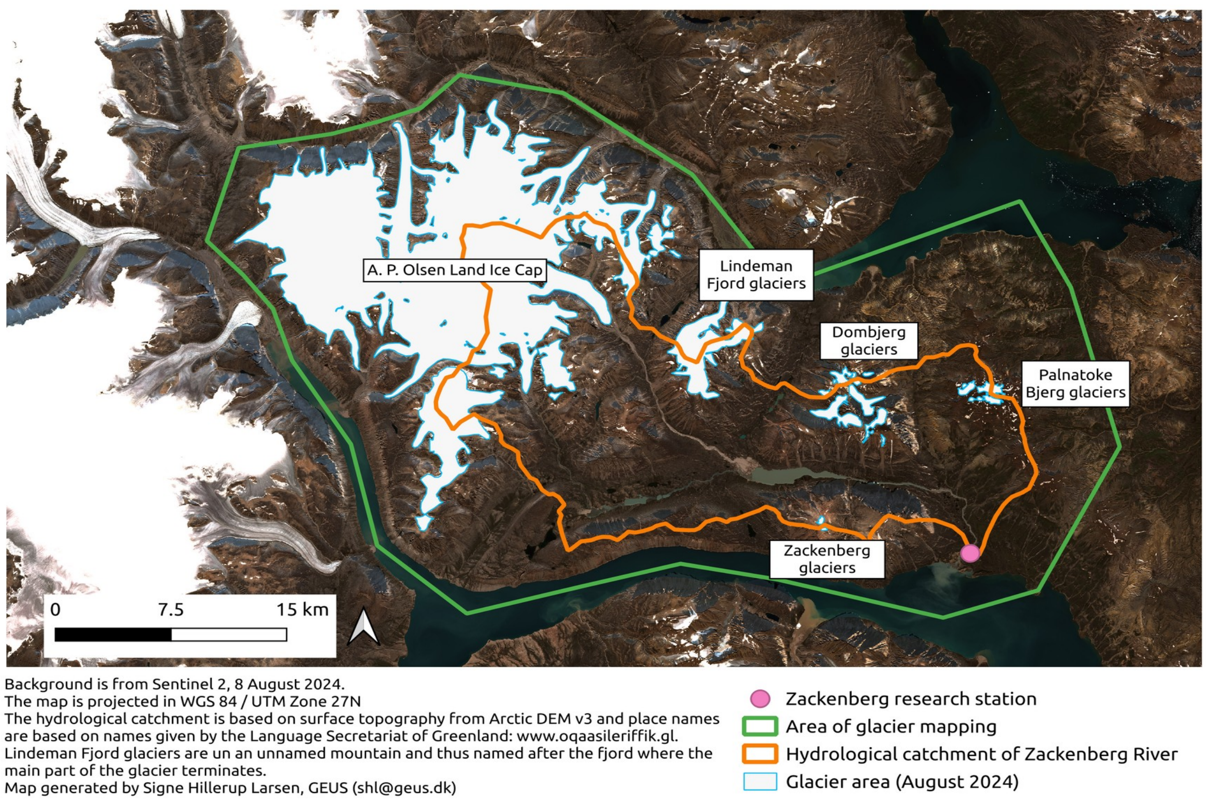

Figure 1: Overview of main area of interest for GlacioBasis Zackenberg.

Installations and surveys

Automatic ablation and weather stations

The core of the monitoring programme is a transect of three automatic ablation and accumulation stations, which continuously record variables such as snow accumulation, snow and ice melt, ice temperature, and surface climate conditions -including air pressure, air temperature, relative humidity, and radiation components (Larsen et al., 2024).

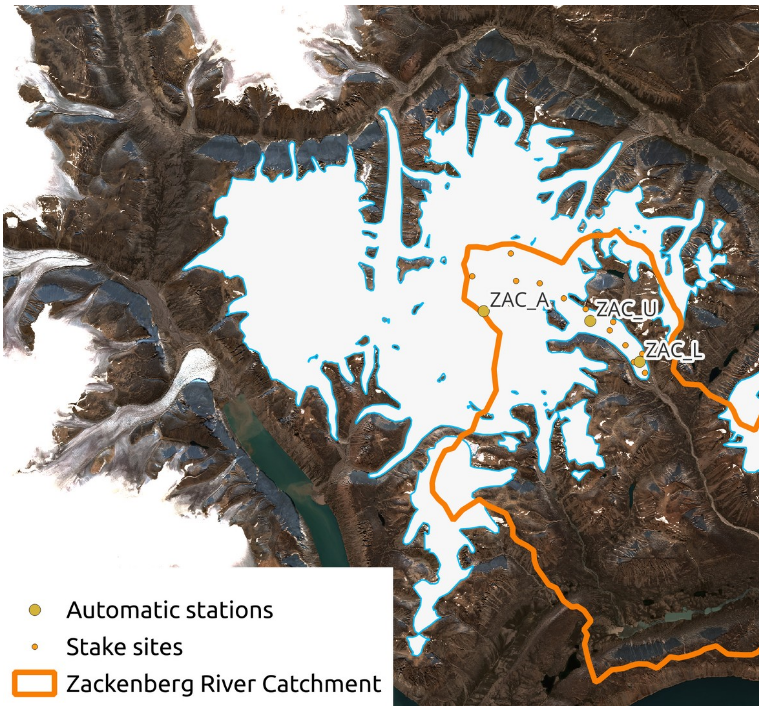

Figure 2: The main monitoring site and position of installations

The automatic stations transmit data hourly, and the transect consists of:

- **ZAC_L**: The main station located in the lower ablation zone (hence the underscore "L"). The first version of the station was installed in April 2008 and has been running steadily since, with only minor data gaps.
- **ZAC_U**: Located in the upper ablation zone (hence the underscore "U"). The first version was a minimal station installed in 2008, but over time, additional variables have been added.
- **ZAC_A**: Located at the summit of the A. P. Olsen Ice Cap in the accumulation zone (hence the underscore "A"). The first version was installed in 2009 and operated until 2020, when the station was unfortunately buried due to a lack of site visits during the COVID-19 pandemic. A new station was established in 2023.

In 2022, the two lower stations were replaced and in 2023 the top station was re-esatblished with new ones built to the standards of the PROMICE/GC-Net monitoring programme (promice.org). This upgrade provides GlacioBasis with the significant advantage of integrating into the open-source workflow of the well-established Greenland Ice Sheet monitoring programme. In addition to the practical benefits, a key advantage is that the data now meet the high standards required for input into meteorological forecasting models and reanalysis models such as CARRA and ERA6.

Stake network

Traditional glaciological monitoring involves a network of stakes drilled into the ice to establish a reference height. This allows for tracking changes in ice surface elevation due to melting. A stake network is established on the A. P. Olsen Ice Cap (see Figure 2).

The stakes are measured annually during the field visit in April. In the ablation zone, the change in ice surface height relative to the top of the stake—between the current year and the previous year—provides the total melt over the past year, i.e. the surface mass balance at that stake location.

Figure 3: Ablation stake

Because the field visit always takes place in April, surface mass balance observations from the stake network are consistently one year behind.

Snow depth from radar

Although automatic weather stations provide point measurements of snow depth, the interplay between complex terrain and wind in the Zackenberg region leads to high spatial variability in end-of-winter snow cover (Mernild et al., 2007).

To account for this variability on the A. P. Olsen Ice Cap, annual snow depth surveys are conducted by towing a ground-penetrating radar behind a snow scooter. The radar data, combined with snow pit and firn core observations, is then analyzed in the office to produce detailed snow depth estimates.

Snow density

Snow density of the end-of-winter snowpack has been measured in snow pits at at least one location during each field visit (see Figure 4). However, this method only provides information about the winter snowpack and does not capture the snow that remains after the previous summer—particularly in the accumulation zone.

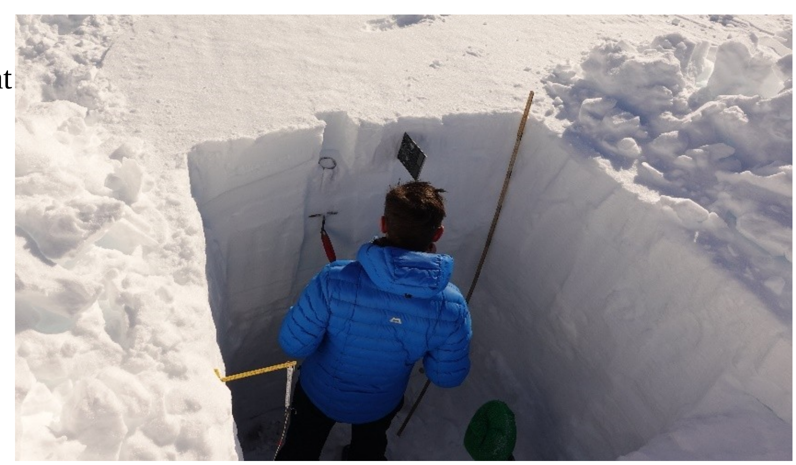

Figure 4: Above: snow pit, full column sampling. Right: Firn core

To address this gap, a firn corer was introduced in 2024, and a pilot study was conducted to investigate the feasibility of using firn cores (see Figure 4) to obtain full-year density profiles, as well as potential added value in understanding densification rates.

Geodetic mass balance and area changes

One of the primary objectives of GlacioBasis Zackenberg is to obtain observations of the surface mass balance of the entire A. P. Olsen Ice Cap. These data are essential for global mass balance assessments based on contributions to the World Glacier Monitoring Service (WGMS) database (wgms.ch).

The WGMS database requires records of area and length changes, as well as glacier-wide surface mass balance estimates, for inclusion in global glacier volume estimates. Therefore, this is a high priority for GlacioBasis Zackenberg.

Given the logistical limitations of conducting only one field visit per year, it is not feasible to obtain sufficient in situ data to estimate glacier-wide surface mass balance alone. To overcome this, satellite imagery will be used. The current focus is on deriving volume changes from ArcticDEM strips covering the period from 2016 to the present, and converting these volume changes to mass changes using density estimates informed by in situ observations.

The resulting geodetic mass balance will then be downscaled in time using snow and ice ablation data, following methodologies such as those described in Dussaillant et al. (in review). This work is ongoing, with the final glacier area and geodetic mass balance product expected to be developed and operationalized during 2025–2026.

River runoff

Quantifying the glacier’s contribution to local river runoff from meltwater is key to understanding its role in the surrounding ecosystem. In the future, we aim to provide detailed estimates of meltwater runoff to advance this understanding.

Achieving this goal depends on accurate, glacier-wide mass balance estimates and the application of surface mass balance modelling, informed and validated by in-situ glaciological observations. The development of this work is primarily supported by, and thus dependent on, collaboration with associated projects at GEUS.

Variables

The aim of GlacioBasis Zackenberg is to provide variables that quantify the glacier's role in the Zackenberg ecosystem specifically, as well as its broader significance at regional to global scales. In addition, the programme aims to monitor and deliver key climatic variables that drive the observed changes.

The following list (Table 1) includes both publicly available variables and those the project is actively working toward producing in the future. The table focuses on high-level, quality-checked variables that have been manually corrected for inclusion in the GEM database, making them directly usable by non-experts.

In addition, the ablation and accumulation stations transmit hourly data through the PROMICE/GC-Net workflow, where they undergo automatic quality control. These data files include a wider range of variables that are particularly useful for experts in climate and glaciology and are available via the GEUS Dataverse (dataverse.geus.dk).

Table 1: GlacioBasis Zackenberg variables

Variable	**Location**	**Where to find**
Point surface mass balance	Stakes in ablation zone	data.g-e-m.dk, wgms.ch
Hourly snow depth (in meters)	ZAC_L, ZAC_U, ZAC_A	data.g-e-m.dk,
Hourly snow melt rate (in water equivalent)	ZAC_L, ZAC_U, ZAC_A	In preparation
Hourly air temperature	ZAC_L, ZAC_U, ZAC_A	data.g-e-m.dk, dataverse.geus.dk
Hourly air pressure	ZAC_L, ZAC_U, ZAC_A	data.g-e-m.dk, dataverse.geus.dk
Hourly relative humidity	ZAC_L, ZAC_U, ZAC_A	data.g-e-m.dk, dataverse.geus.dk
Hourly precipitation	ZAC_L, ZAC_U, ZAC_A	data.g-e-m.dk, dataverse.geus.dk
Hourly radiation (four components)	ZAC_L, ZAC_U, ZAC_A	data.g-e-m.dk, dataverse.geus.dk
Hourly wind speed	ZAC_L, ZAC_U, ZAC_A	data.g-e-m.dk, dataverse.geus.dk
Bulk snow density	ZAC_L, ZAC_U, ZAC_A	data.g-e-m.dk
End-of-winter snow accumulation	Along GPR-survey lines covering A.P. Olsen ice cap	In prep. Available by the end of 2025 at data.g-e-m.dk and dataverse.geus.dk
Glacier area changes for selected years between 1987 and present	Entire A. P. Olsen ice cap	Expected to be available by the end of 2025 in both data.g-e-m.dk and wgms.ch
Geodetic surface mass balance	Entire A. P. Olsen ice cap	Expected to be available by the end of 2026 in both data.g-e-m.dk and wgms.ch
Surface mass balance and runoff based on in-situ data and modelling	The part of A. P. Olsen ice cap that is within the hydrological catchment of Zackenberg River	In preparation

General Instructions

All GlacioBasis personnel arriving at Zackenberg Station must read the *Zackenberg Site Manual* (available at zackenberg.dk) and commit to following its instructions. This is particularly important with regard to the restrictions on mobility within the protected areas surrounding the station.

Safety

Safety is the highest priority for all GlacioBasis personnel in the field. All instructions from the Zackenberg Station Manager must be followed strictly. Due care and sound judgment must be exercised at all times—particularly when leaving the immediate vicinity of the station, driving snowmobiles, travelling on the glacier, or crossing rivers.

All personnel must be confident in the use of firearms to defend themselves and their colleagues against polar bears and musk oxen. A rifle and ammunition must be carried whenever leaving the station's surroundings. Firearms, ammunition, and flare guns are provided by Zackenberg Station.

All GEUS personnel are required to have completed the following courses (or equivalent):

- GEUS shooting course
- Arctic/remote first aid course
- Glacier safety course

These courses are intended to enable participants to make informed assessments of safety conditions at all times.

Due to the terrain morphology, VHF radio communication is not possible between the glacier and Zackenberg Station. Therefore, an Iridium phone must be carried on every trip to the glacier. VHF radios may still be useful for local coordination while working on the glacier.

Each participant is responsible for preparing in advance of departure from Denmark to ensure that all required personal field gear is available and in good working condition. Personal safety equipment for GEUS personnel can be procured through GEUS.

GlacioBasis Zackenberg has a Garmin GPS with inReach functionality, which can be configured to send location updates - at an interval of your choice - to a webpage that can be shared with others. The GPS can be mounted on the snow scooters and charged while driving. It is recommended to use this system and share the tracking page with Zackenberg logistics and other relevant parties.

Safety when traveling on glaciers

Snow-covered or bridged crevasses, as well as moulins (vertical shafts where meltwater drains into the glacier), should always be considered potential hazards when traveling on glaciers. Although crevasses and moulins on the A. P. Olsen Ice Cap have not been observed to be very large, even smaller ones can pose serious risks. Importantly, glacier conditions change from year to year, including snow depth and surface structure, so previous experience cannot replace proper preparation.

In addition, several aluminum stakes and automatic weather stations are installed as part of the GlacioBasis monitoring programme. When covered in snow - particularly the stakes - they can be difficult to see. Care must be taken to avoid colliding with these installations.

When traveling on snow-covered glaciers, there is always a risk that snow bridges over crevasses may collapse. While a snow scooter may not break through due to its size, an individual dismounting the scooter might. Therefore, **before stepping off the snow scooter, always probe the area**.

When crossing bare ice areas, snow scooters may get stuck. The following equipment **must be carried on each snow scooter**, and **a harness must be worn by all personnel when traveling on the glacier**:

- Static climbing rope
- Harness and crevasse rescue gear
- Crampons and compatible boots
- A means of communication: satellite phone or inReach
- Snow probe
- Snow shovel

Zones with known crevasses are mapped in Figure 5.

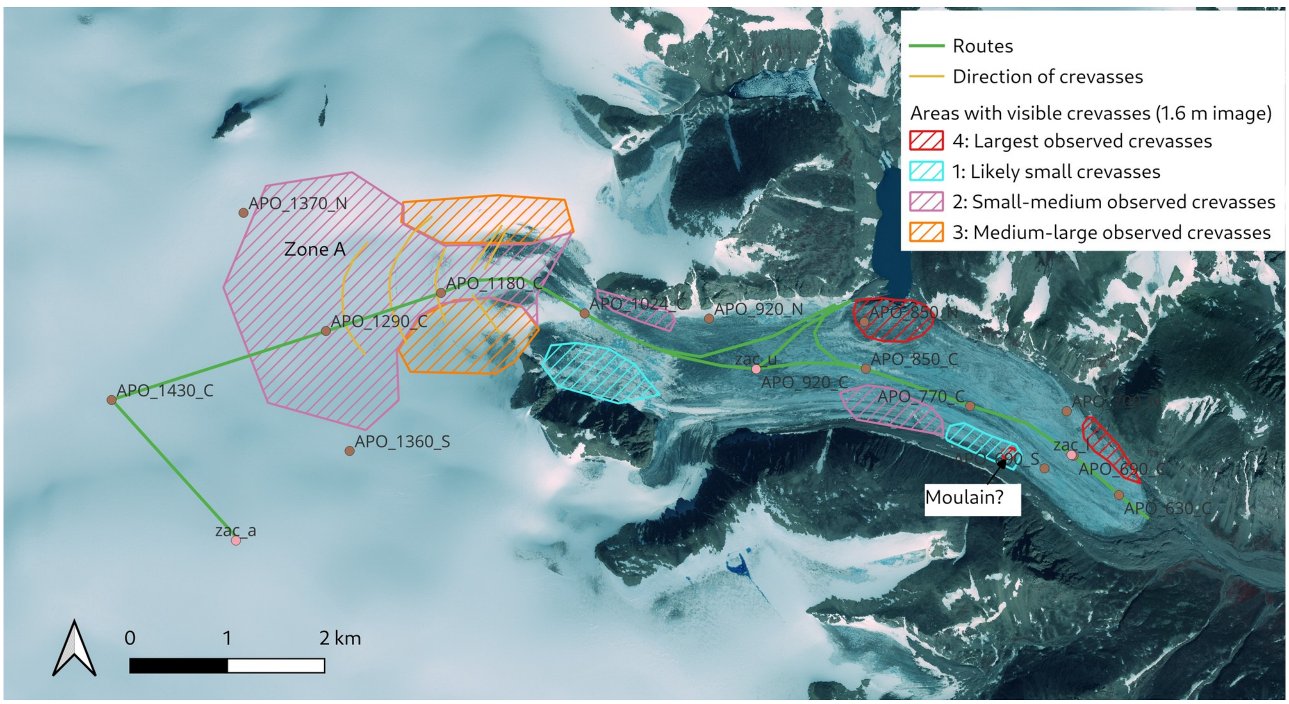

Figure 5: There are known crevasses on A. P. Olsen Ice cap. Please be aware that this might change from year to year. The map shows some general information about how to travel on the glacier.

Data safeguarding and documentation standards

The best way to safeguard data is by publishing it in well-established databases that assign a permanent DOI. Data from GlacioBasis Zackenberg is published in the **GEM database** (data.g-e-m.dk) and in the **GEUS Dataverse**, both of which issue permanent DOIs.

At GEUS, all data is archived on local storage maintained and backed up by **GEUS IT**. The structure is as follows:

- **Raw data, field notes, and photos** are stored in the archive folder: `glaciologi/GlacioBasis/Zackenberg/archive/`
- **Post-processed and analyzed data**, as well as scripts and this manual, are stored in the working folder: `glaciologi/GlacioBasis/Zackenberg/working/`

Data description publications

GlacioBasis strives to document its procedures publicly to ensure transparency and reproducibility. For example, the process of merging data from the older, non-standardized automatic stations with the newer standardized stations is described in:

> Larsen, S. H., Binder, D., Rutishauser, A., Hynek, B., Fausto, R. S., and Citterio, M. (2024): *Climate and ablation observations from automatic ablation and weather stations at A. P. Olsen Ice Cap transect, northeast Greenland, for May 2008 through May 2022*, *Earth System Science Data*, 16, 4103–4118. https://doi.org/10.5194/essd-16-4103-2024

In addition, a description of the standardized snow depth observations is currently under review in the *Journal of Glaciology*, under the title:
"Winter snow accumulation variability and evaluation of reanalysis data over A. P. Olsen Ice Cap, Northeast Greenland."

Published scripts

Standardized scripts used in GlacioBasis Zackenberg are publicly available on GitHub:
https://github.com/GEUS-Glaciology-and-Climate/GlacioBasis_Zackenberg

These scripts support transparency, reproducibility, and collaboration by providing access to the methods used for data processing and analysis.

Place names

We strive to use official place names as designated by the Language Secretariat of Greenland:
https://oqaasileriffik.gl

Field procedures

Getting to the glacier

The A. P. Olsen Ice Cap is located approximately 35 km from Zackenberg Research Station. Transport to the glacier is by snow scooter with sledges. **Camping gear and spare food must always be carried on one of the sledges.**

Snow scooters typically have a range of about 200 km on a full tank, so spare fuel is generally not necessary for the trip.

On the first day, a track must be established. This route can vary from year to year depending on snowdrifts and surface conditions, but it typically follows the river almost all the way from Zackenberg research station to the glacier terminus. Establishing a track may take several hours, and as the glacier is approached, it may be necessary to “build” roads (see Figure 6).

Once a track is in place, the journey typically takes between **1 and 1.5 hours**, depending on snow and weather conditions.

Figure 6: Digging a road

The best tracks from previous years are saved in:
`glaciologi/GlacioBasis/Zackenberg/working/fieldwork/planning/tracks/`

Crossing large blue ice areas just below the moraines - when approaching the glacier - can be challenging and may require extra caution. Be sure to have crampons (and boots to mount them on) available on the scooter in case of the scooter stopping in the middle of a slippery zone. The ice is likely to bee to slippery to walk on without crampons.

Ablation stakes

A transect of stakes is distributed along the central flowline of the glacier (see Figure 2). Each stake consists of 4 or 5 segments of 2-meter sections, assembled into a total length of 8–10 meters. The segments are marked from the bottom up: I, II, III, IIII, IIIII.

Stakes are installed using a **Kovacs Auger drill set** (https://kovacsicedrillingequipment.com/about-ice-auger-drills/) together with a standard battery-powered drill. **Three fully charged drill batteries** are typically sufficient to drill at least ten 8-meter holes.

Stakes are made of either aluminum or carbon fiber. When drilling, take care to allow the ice cuttings to exit the hole via the auger—this means drilling slowly and occasionally letting the auger rotate in place without applying downward pressure. **Never leave the auger standing in the hole without rotation for longer than necessary**, as this can cause it to freeze or jam.

[Update when available: insert picture of stake connection]

During field visits, snow depth is measured at each stake, along with the length of the stake still in the ice.

For example: If the segment marked "III" is visible 150 cm above the ice surface, then segments I and II (totaling 4 meters) are still in the ice. This means 450 cm of the stake remains embedded.

Melted-out stake segments are removed and reused

In the lower ablation zone, the average melt rate is approximately 2.5 meters per year. This must be considered when determining when to install a new stake. New stakes are always drilled up-glacier from the previous position.

Stake positions are measured using GNSS, when possible. A base station is set up in the morning and taken down before departure.

Required Equipment

- Kovacs augers (at least 8 × 1 m flights)
- Drill head + spare
- Drill adapter
- Battery-powered handheld drill
- Measuring tape
- Avalanche probe
- Field notebook

Snow pits

The most important data obtained from a snow pit are the **water equivalent depth** and the **density profile** of the snowpack. Additional observations should be made whenever possible, following this priority:

1. Temperature profile
2. Snow crystallography
3. Dust layers
4. Penetrability profile

Snow Pit Procedure

1. Mark the intended outline of the snow pit on the surface, orienting it so that the observation wall faces **away from the sun**.
2. Take a photo to document the unexcavated site.
3. Record the **position**, **date**, **time**, **photo number**, and **air temperature**.
4. Excavate the snow pit, taking care **not to disturb the observation wall**.
5. Dig until reaching **glacier ice** or the **previous summer surface**, then prepare the vertical wall for measurement.
6. Measure the **temperature profile**, allowing sufficient time for the thermometers to stabilize.
7. Identify and mark the **snow stratigraphy** and the boundaries of each layer.
8. Measure and record the **total snowpack thickness** and the **thickness of individual layers**, noting any **dust-enriched surfaces**.
9. Using a known-volume sampler, take a **horizontal core at 1/3 from the bottom** of each snow layer and weigh the sample using a **precision spring scale**.
10. Describe the **crystal types** in each layer, then proceed to the next.
11. Take **photos** documenting the completed snow pit.
12. **Backfill** the snow pit before leaving the site.

Required Equipment

- Map and handheld GPS
- Camera and field notebook
- Avalanche probe
- Shovels:
    - Broad, lightweight shovel
    - Smaller shovel with sharpened edge (for hard, wind-drifted or refrozen snow)
- **Snow pit kit**, containing:
    - Known-volume sampler
    - Rubber-head hammer
    - Plastic sample bags
    - Precision spring scale
    - Snow stratigraphy survey forms

- Reference scale and crystal type card
- Insertion thermometers
- Magnifying lens
- Foldable measuring bar or measuring tape

Automatic accumulation and ablation station maintenance

The automatic stations follow the standards of GEUS's PROMICE|GC-Net monitoring programmes. A station log is maintained over each station to track the age of the instruments. The station logs are found in: `glaciologi/GlacioBasis/Zackenberg/working/station_log.`

An overview of the instruments installed on the stations is found in Table 1.

Sensor Overview and Installation

- **Air Temperature, Relative Humidity, Air Pressure, and Precipitation**
  These are measured by the **WS401 from OTT Lufft** (hereafter referred to as the *Lufft sensor*).
  - **ZAC_A**: 2 Lufft sensors
  - **ZAC_U & ZAC_L**: 1 Lufft sensor each
- **Wind**
  Measured by an **anemometer from R.M. Young**.
  - **ZAC_A**: 2 anemometers
  - **ZAC_U & ZAC_L**: 1 each

  The small black box on the anemometer must point toward the **mast and the radiometer**, which should ideally be facing **geographic south**.
- **Radiation (Four-Component)**
  Measured by a **CNR4 radiometer** (1 per station).
  - Comes pre-assembled with a **compass and tilt meter**, build in the GlacioLab workshop at GEUS.
  - The radiometer **must be aligned to geographic south** during installation.
- **Snow Depth (Sonic Ranger – SR50)**
  - **ZAC_A**: 2 SR50s mounted on separate booms
  - **ZAC_U & ZAC_L**: 1 SR50 on a boom and 1 SR50 on a stake

    - The **stake** is assembled from 4 segments, marked I–IIII, and is part of the stake network. It is drilled approximately **7 – 7.5 meters** into the ice.
    - The **SR50 cable (15 m)** is laid loosely on the ice surface to allow for vertical movement as the stake emerges during melt season.

Logger Box Assembly

Logger boxes are pre-assembled in the **GlacioLab workshop at GEUS**. They include:

- **CR1000X data logger**
- **Iridium modem**
- **GPS antenna** (attached to the top of the box with Velcro)
- **2 silica gel bags** to reduce moisture inside the box

All instruments are pre-wired and connected via bottom plugs on the logger box. While field rewiring is possible, **prefer swapping the entire box** if problems occur.

Thermistor String & Pressure Transducer

These are installed 10 meters deep in the ice and must be re-installed approximately every 3 years as they melt out of the ice.

Maintenance Procedures

Upon field visit follow the instructions here and in the chacklists provided as appendix:

- Take **photos of all instruments and wiring**, before and after maintenance (more is better).
- Download data to a **field laptop**.
- Instruments scheduled for calibration should be replaced with a newly calibrated unit.
- Replace the **silica gel bags** inside the logger box.
- For **ZAC_A** (in the accumulation zone), the mast must be extended to prevent burial:
    - Dig out the battery box.
    - Extend the mast by adding a new segment using the **c**ustom connector. The extension can be done at the top of the mast, whereafter the booms and loggerbox are moved up.
- Align the **solar panel and radiometer to geographic south** (if station rotation is possible).

Required equipment:

- Tools and utilities as described in table 3 and 4 of the
- Silica gel/Desiccant bags, 2 for each stations
- Field laptop, mini USB cable for data download, spare SD card to swap the card if necessary. Loggernet has to be installed on field laptop.
- Drilling machine, 3 drill batteries, drill head, drill adapter
- Checklists specific for the station (see appendix)

[Update when available: Schematics of GC-Net and PROMICE type weather stations]

Table 2: Instruments installed on automatic stations

Instrument type	**Manufacturer**	**Model**	**Accuracy (unit)**	**Calibration interval**
Barometer	OTT Lufft	WS401	±0.5 (hPa)	2 years
Thermometer, aspirated	OTT Lufft	WS401	±0.2 °C (-20 - +50 °C) or ±0.5 °C (> -30 °C)	2 years
Hygrometer, aspirated	OTT Lufft	WS401	±2 %	2 years
Precipitation	OTT Lufft	WS401	2.0 %	2 years
Anemometer	R. M. Young	05103-5	±0.2 ($m\ s^{-1}$) or 1 (%) of reading	N/A
Radiometer	Kipp & Zonen	CNR1 or CNR4	±10 (%)	4 year
Sonic ranger	Campbell Scientific	SR50A	±1 (cm) or ±0.4 (%) of reading	Membrane swapped each visit
Pressure transducer	Ørrum & Jensen in GEUS assembly	NT1400 or NT1700	±2.5 (cm)	Around 3 years when redrilled
Thermistor string	GEOPRECISION	Digital chip	±0.1 °C @ -5 to +50 °C, ±0.5 °C @ -40 to +85 °C	Around 3 years when redrilled
Compass/ Inclinometer	Rion (placed inside radiometer)	DCM260B compass system	0.2% (azimuth accuracy: 0.8%)	4 years
GPS antenna	Trimble/Tallysman	SAF5270-G/ TW4020	2.5 (m)	N/A
Iridium modem	NAL Research	9602-LP	-	N/A
Iridium antenna	Campbell Scientific	30741	-	N/A

Data logger	Campbell Scientific	CR1000X	-	5 years
Battery pack	Panasonic (4 x 28Ah)	LC-XC1228P, Lead acid	-	N/A
Solar panel	RS PRO	RSPRO 20W	-	N/A

Table 3: Tool box item list

Item	**RS #**	**Packed/ Comments**
Ruler, 2m	513-391	
Bits, various	876-6641	
Pipecutter	206-3463	
Taps/thread cutter, M3-M10	669-9407	
Drills, 1-10 mm, various	216-690	
Drills 5 mm x 2	213-045	
¼ inch hex key (Allen)	537-805	
5/16-inch hex key (Allen)	537-805	
Measuring tape, 5 m.	848-7613	
Handheld compass	Friluftsland	
Soldering iron, 12V	162-8075	
Multimeter	123-3239 / 123-1939	
Stanley knife	546-742	
Socket wrench for battery screws, 8 mm.	310-0096	
Screwdriver, straight notch, 1x5.5x100 – BE-8150	264-3126	
Screwdriver, straight notch, 0.5x3x60 – BE-8020	264-3126	
Screwdriver, Philips, Cross shards, PH 1x75 – BE-8610	264-3126	
Screwdriver, Philips, Cross shards, PH 2x100 – BE-8620	264-3126	
Screwdriver, straight notch, 0.8x4x100 – BE-8040	264-3126	
Screwdriver, straight notch, 1.2x6.5x125 – BE-8155	264-3126	
Screwdriver, straight, campbell flat	Look around	

Snips / bidetang, small	187-8343	
Snips / bidetang, big	187-8315	
Adjustable wrench, 110 mm.	539-520	
Adjustable wrench, 155 mm.	539-536	
Papegøjetang, 250 mm. length	668-5900	
Rachet wrench, 10 mm.	382-9400	
2x Rachet wrench, 13 mm.	382-9444	
Rachet wrench, 17 mm.	382-9488	
Iron saw, 150 mm.	182-9801	
Allen key set, inches	541-7324	
Allen key set, mm.	541-7324	
Flashlight, small	715-7709	
Permanent marker, Red	696-1816/Betjentstuen	
Permanent marker, Blue	696-1807/Betjentstuen	
Permanent marker, Black	179-4024/Betjentstuen	
Luggage weight	205-9611	
Metal file, round	192-3688	
Metal file, flat and half round	192-3687	
Inclinometer/bubble level	Level Developments BI-10	
Spidstang	238-6938	
Hammer	449-9858	
Kabelsko tang	499-2313	
Flat pliers, fladtang	158-5502	
Key to ablation box	124-3424	
Wirecutter, guywire	705-5984	
Afgrater, med håndtag	193-9369	
Afgrater, rund	206-3479	
Topnøglesæt	337-3957	
Hacksaw	442-0515	
Hacksaw blades	439-6311	

Table 4: Utility box item list

No	Item		
1 pcs	Pelicase, IM2200		
1 roll	Duct tape		
1 roll	Super88, electrical tape		
1 pcs	Boom mount		
1 pcs	Kovacs drill head		
1 pcs	Kovacs drill adapter		
1 pcs	Tripod leg bracket		
3 pcs	Kee Klamp, L45/6 (infinity)		
2 pcs	Kee Klamp, LM50-6		
2 pcs	Kee Klamp, LF50-6		
1 handfull	Zipties, 361 mm		
1 handfull	Zipties, 186 mm		
1 pcs	SR50 bracket, u-bolt		
1 pcs	**Box, RS: 435-0236**		
8 pcs	AA non-rechargeable batteries		
12 pcs	AAA non-rechargeable batteries		
1 pcs	9V non-rechargeable battery		
1 pcs	Campbell datalogger battery		
1 tube	Silicone 732 including hood		
Various	5, 6, 8, 10 mm bolts		
Various	5, 6, 8, 10 mm and aluminum/messing/lock nuts		
Various	6, 8, 10 mm washers		
Various	Aluminium straps		
4-5 pcs	Shackles, 8 mm.		
Various	Cable glands		
5 pcs	Screws for SR50 membrane		
5 pcs	Clevis pins, incl. ring for carbon fiber rod		
Various	Cable Lugs, kabelsko		
2 pcs	Diodes, 80 sq, 045N1911, 8A		
1 pcs	Solder tin		
Various	Colored wires		
1 pcs	Screw terminal		
1 pcs	Resistor 5 mOhm		

GPR Surveys

Snow depth profiles are surveyed using an **800 MHz shielded antenna**, operated in either:

- **Constant time mode** (0.25 seconds), or
- **Constant distance mode** (0.5 meters)

The antenna is mounted on a **fiberglass sled** towed by a snowmobile. The GPR monitor should be set up so that the **snowmobile driver can view the data in real time** and adjust driving speed accordingly for optimal data quality.

Every few hundred meters—and **whenever unclear features appear on the display—**the snowmobile must stop, and **snowpack density measurements** should be taken using an **avalanche probe**. All individual measurements should be recorded, **not just the average**.

Data Handling

- GPR data files must be **downloaded to a USB stick**
- At the end of each day, files should be **backed up to a second storage device** to be kept at **Zackenberg Station.**

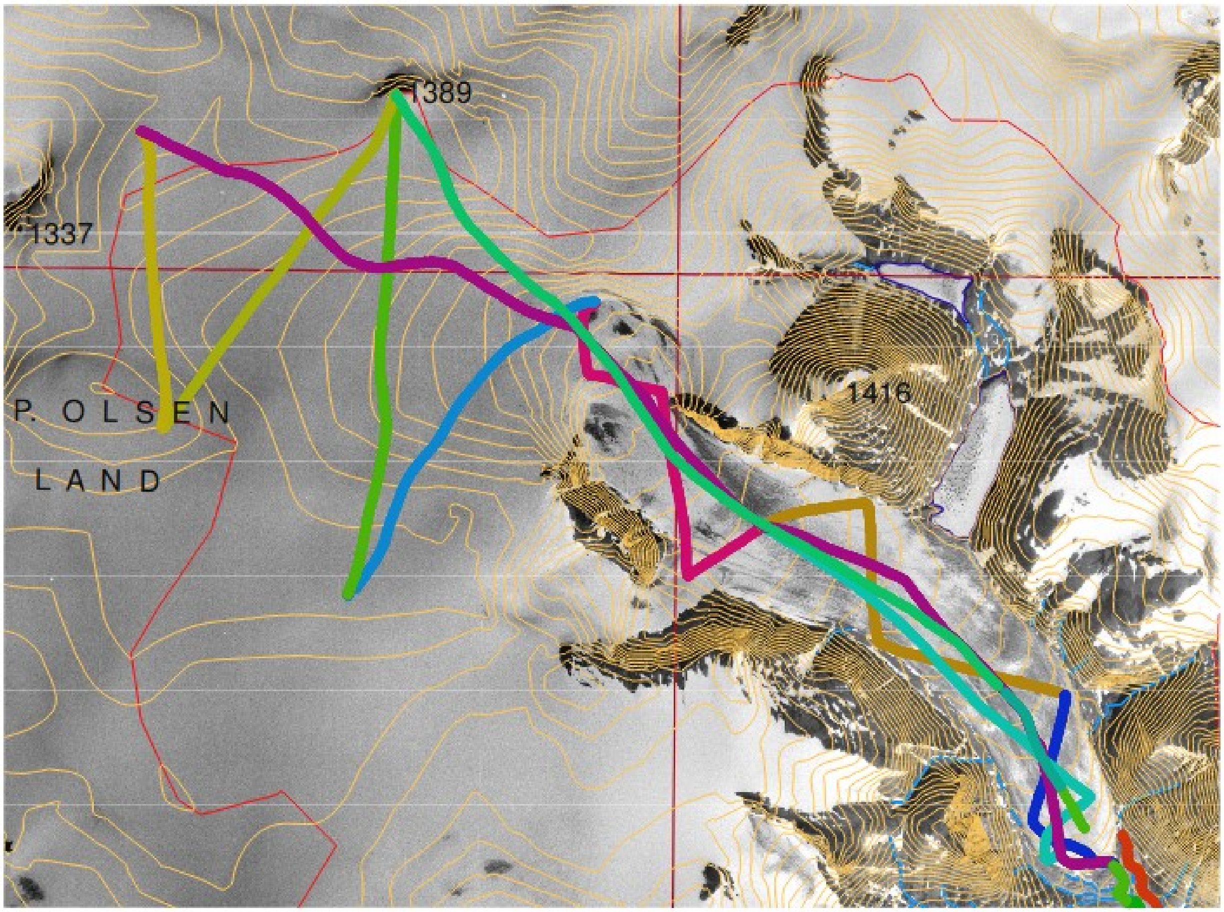

Figure 7: GPR snow depth survey tracks

Post processing of data

Automatic stations

The three automatic stations are standardized according to PROMICE | GC-Net protocols, which means data is transmitted hourly into the `pypromice` workflow, as described in How et al., (2023) and Fausto et al., (2021).

Standardized data is published approximately once per month with a DOI on the **GEUS Dataverse**:

> **"PROMICE and GC-Net automated weather station data in Greenland"**
> https://doi.org/10.22008/FK2/IW73UU, GEUS Dataverse, V24

Legacy Data (2008–2022)

Post-processing of GlacioBasis Zackenberg data from **2008 to 2022** followed a slightly different approach, documented in Larsen et al. (2024) and available:

> **"GlacioBasis Zackenberg - Level 1 data 2008–2022"**
> https://doi.org/10.22008/FK2/X9X9GN, GEUS Dataverse, V2

Data is available in both NetCDF and CSV formats.

Real-Time Data and Access

For field preparation and near real-time monitoring, data transmitted directly from the stations undergoes an **automatic workflow** and is published on the **GEUS THREDDS database**:
https://thredds.geus.dk/thredds/catalog/catalog.html

Further Post-Processing for GEM Database

Selected variables from the dataset are subject to **additional post-processing** to ensure they are accessible and usable for **non-expert users**. These datasets are published on the **GEM database**.

Detailed documentation of the processing steps is available in the file:
https://github.com/GEUS-Glaciology-and-Climate/GlacioBasis_Zackenberg/database_delivery.org

This script performs the following key tasks:

- **Merges** data from 2008–2022 with the latest available data to create the **longest possible continuous record**
- Performs a **manual quality check** to detect and flag inconsistencies in the time series
- Derive **snow depth** from sonic ranger data, which measures the distance between the sensor (on boom or stake) and the surface. Snow depth is calculated by:
  - Resetting the baseline distance at mid-summer
  - Multiplying by -1 to convert distance-to-surface into snow depth above the previous summer surface
- Derive i**ce ablation** from either:
  - **Pressure transducer assembly**, or
  - **Sonic ranger on stake**
  - In both cases:
    - Snow melt periods are filtered out
    - Data is reset at the start of each **ice melt season**

Finally, the script formats and exports the processed data into files compatible with the **GEM database ingestion system**.

Stake data

Field notes from stake observations are recorded in the following documents:

- `working/data/stakes/stake_field_notes.ods`
- `working/data/stakes/stake_balance.ods`

The **point mass balance** is filled out directly in the `stake_balance.ods` file, following the format provided in the sheet.

These point mass balance observations are reported to the **World Glacier Monitoring Service (WGMS)**:
https://wgms.ch

Snow radar

Radar data is processed and analyzed with a combination of python scripts and ReflexW.

Interpolate coordinates *[insert script when available]*.

Load the data as following:

[insert figure of loading data]

The general processing flow is the following:

1) Dewow-filtering: Processing → 1D Filter → subtract mean (dewow)
2) Time-zero correction: Enable individual trace window view, to select the onset of the radar signal. Then go to Processing → Static correction/muting → move starttime, enter the selected time offset (e.g. -3.7 ns).
3) Butterworth bandpass filter (e.g. use cut-off frequencies of 300-1500 MHz)
4) Remove background ringing via subtracting the mean amplitude from ~500 traces from each trace: Processing → 2D filter → subtract average
5) Apply a linear gain function to enhance amplitudes from greater depths: Processing → Gain → manual gain (y), e.g. use 5dB applied at 30 ns depth, and 10 dB at 100 ns depth. Could also use a different gain function.
6) Export the processed data. *[add more information]*
7) Pick the last summer surface using the ReflexW picking tool.

8) Export the picks. It is important to export the trace numbers, so they can be matched with the original raw & processed data, as well as with coordinates, and picks can be plotted on top of a radargram at a later stage, e.g. using python.

Once the LSS picks are exported from Reflexw, use python script *[insert script title when available]* to process them, including a conversion from traveltime to depth and swe.

Variables derived from satellite

Glacier area is a new variable introduced from 2025 onward. For historical reference, the glacier area has been mapped for the years **1987, 2011, 2016, and 2021**, and starting from **2024**, it will be updated **annually**.

The mapping is performed in **QGIS**, using available satellite imagery. An image from **early August** is selected based on the best available data found via the **Copernicus Browser**:
https://browser.dataspace.copernicus.eu

The process involves copying the glacier outline shapefile from the previous year and adjusting it to fit the current year's image.

Data Storage and Project Files

- Shapefiles and related data are stored in: `working/data/GlacierInventory/`
- The corresponding QGIS project file is located at: `working/glacier_outlines.qgz`

Contacts

Programme manager:

Signe Hillerup Larsen

Department of Glaciology and Climate, GEUS, Copenhagen

shl@geus.dk

Alternative contact:

Signe Bech Andersen, Head of Department

Department of Glaciology and Climate, GEUS, Copenhagen

siba@geus.dk

References

How et al. (2023). pypromice: A Python package for processing automated weather station data. Journal of Open Source Software, 8(86), 5298. https://doi.org/10.21105/joss.05298.

Fausto et al. (2021). Programme for Monitoring of the Greenland Ice Sheet (PROMICE) automatic weather station data, Earth Syst. Sci. Data, 13, 3819–3845, https://doi.org/10.5194/essd-13-3819-2021, 2021.

Larsen et al. (2024). Climate and ablation observations from automatic ablation and weather stations at A. P. Olsen Ice Cap transect, northeast Greenland, for May 2008 through May 2022, Earth Syst. Sci. Data, 16, 4103–4118, https://doi.org/10.5194/essd-16-4103-2024

Appendix:

Checklist for ablation area automatic stations

Checklist for accumulation area automatic stations