

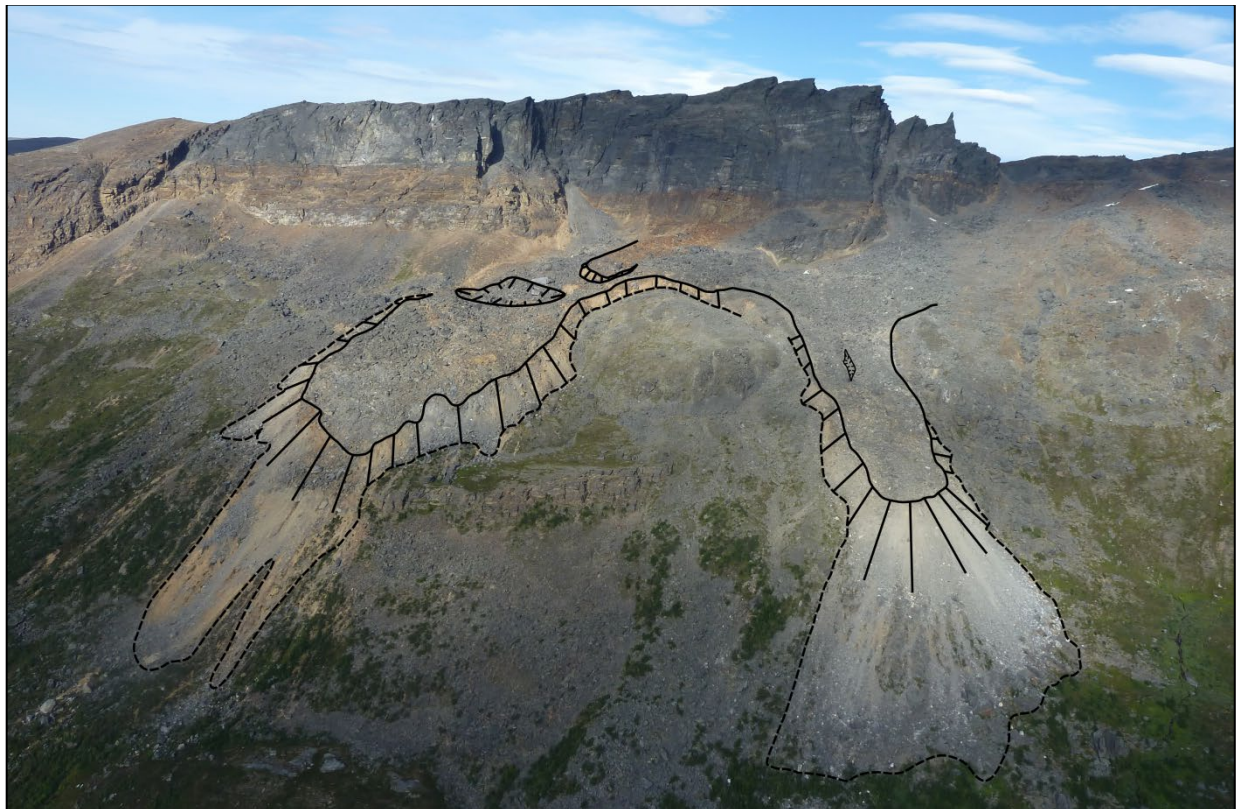
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## INSTRUMENTATION AND TEMPERATURE DATA (2014–2017) FOR THE ÁDJET MOUNTAIN IN SKIBOTN, TROMS



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Summary:

This report documents the setup and preliminary results from an ongoing temperature logging campaign (as of April, 2018) on the Ádjet Mountain and rock glacier close to Skibotn in Troms county. Results indicate that permafrost is probable on the rock glaciers and outside the rock glaciers. Temperature data, detailed maps, ESRI ArcMAP-projects, trial camera photos and logger-software from this campaign have been made available as Figshare-repositories.

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Keyword: **Monitoring; Temperature loggers; Rock glacier; Permafrost; GNSS; GPS; Time-**

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Notes:

I would like to acknowledge NVE in Manndalen for good help with logistics and accommodation during fieldwork. Many thanks to Patrick Larsen, Aleksander Amundsen and Markus Eckerstorfer for their contribution during field campaigns.

I am grateful to the Geological Survey of Norway for help regarding logistics, to Iselin Bakkhaug and Hannah Nopper for assistance in setting up temperature loggers, and to Stein Rune Karlsen for supplying the campaign with tripods. I acknowledge Pål Tengesdal and the rest of the group in the Tromsø Astronomy Association for letting us stay in their comfortable Skibotn Observatory during fieldwork.

This work was conducted as part of Harald Øverli Eriksen's PhD, funded by a grant (number RDA12/165) from Troms County Council. Email: haraldoerlieriksen@gmail.com, mobile +47 95935286.

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Front page:

Aerial photo of the northwestern part of the Ádjet mountain, Skibotn, Troms, with the two most active rock glaciers marked. The outline of the lobes, depressions and scree aprons are annotated. Debris in the rock glaciers originate from rockfall and rockslide activity from the sub-vertical and highly fractured headwall.

Photo courtesy Geological Survey of Norway.

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## PREFACE

This document and appendixes report on results from an ongoing campaign for temperature measurements on and around the rock glacier lobes at the Ádjet mountain close to Skibotn in Troms county. Locations and other descriptions of in-situ instrumentation used are also documented. Field work and set-up of instrumentation has been done as part of Harald Øverli Eriksen’s PhD (Eriksen, 2017).

# 1 INTRODUCTION

Rock glaciers are ice/debris permafrost landforms found in cold environments all over the world (Barsch, 1996; Haeberli et al., 2006; Humlum, 2000). Lately, some rock glaciers show a significant acceleration, and in some cases even collapse (Bodin et al., 2016; Ikeda et al., 2008; Kääb et al., 2007; Müller et al., 2016). We do not know the full details controlling this acceleration (Haeberli et al., 2010; Noetzli et al., 2016), but this development has been attributed to higher permafrost temperatures (Roer et al., 2005) and increased liquid water content (Ikeda et al., 2008). This work is important when it comes to understanding possible impacts of global warming related to degrading permafrost, and may be a contribution to improve forecasting of future geohazards and ensure reliable risk management in mountainous environments due to climate warming.

This report describes instrumentation and preliminary results from an ongoing campaign for temperature measurements started in 2014 at the Ádjet mountain in Skibotn, Northern-Troms. The report also describes the new instrumentation used after August 2017 when all existing temperature loggers were removed and loggers with wireless interface was installed.

Ádjet Mountain is a 1408 m (a.s.l.) high southwest facing hillside. Geomorphological features including debris fields, talus cones and slide blocks are widespread, and several generations of rock glaciers have been mapped (Bakkhaug, 2015; Nopper, 2015). The rock glaciers are thought to have origin from rockslides and rockfalls from the highly fractured and sub-vertical rock wall.

Temperature loggers distributed on and around two rock glacier lobes in the NW and SW part of the mountain give a first view of the ground thermal regime. This report will not discuss or go into details when it comes to explaining the observed temperatures. Instrumentation used in the campaign includes: Air Temperature Loggers (ATL) measuring temperatures 1 m above ground, Ground Surface Temperature (GST) loggers measuring temperatures just below ground surface, Ground Temperature Loggers (GTL) measuring air temperatures inside fractures and pore space between boulders, and a Rock Wall Logger (RWL) measuring temperatures in a shallow borehole on the steep face between the two rock glacier lobes. The report also describes position and characteristics of instrumentation used for measuring deformation. This includes GPS bolts annually measured, differential GPS points on boulders, and one time-lapse camera. In addition, two trail cameras were used for documenting snow distribution.

For many of the GTL locations described, temperature data from different depths exist, but only the deepest measured temperatures are presented in this document. Temperature data for all locations and depths (temperature gradients) can be downloaded from Figshare-repositories.

In addition, pictures captured from a time lapse camera (Harbortronics) of the NW-rock glacier lobe from summer 2014 to spring 2017 and a trail camera located in the SE part of the Ádjet mountain from summer 2014 to summer 2016, detailed maps, an ESRI ArcMAP-project and logger-software can be found in the same repository (Table 1).

The campaign is now the responsibility of Department of Geoscience, UiT–The Arctic University of Norway.

**Table 1 – Overview of supplementary data.**

Title	Description	Download link
Supplementary_Data_for_Norut_Rep ort_Adjet_Mountain_1_of_4.zip	The zip-file include: - ESRI Arcmap projects and shapefiles documenting the position of instrumentatio  - Measurements from temperature loggers  - Drivers and software used for setting up and downloading temperature loggers and time-lapse cameras  - Field pictures  - Maps presenting the location of the instrumentation	<a href="https://doi.org/10.6084/m9.figshare.6225056">https://doi.org/10.6084/m9. figshare.6225056</a>
Supplementary_Data_for_Norut_Rep ort_Adjet_Mountain_2_of_4.zip	The zip-file contains images from the time-lapse camera ADJ_TL_CAM from the period 2015–2016.	<a href="https://doi.org/10.6084/m9.figshare.6225074">https://doi.org/10.6084/m9. figshare.6225074</a>
Supplementary_Data_for_Norut_Rep ort_Adjet_Mountain_3_of_4.zip	The zip-file contains images from the time-lapse camera ADJ_TL_CAM from the period 2016–2017.	<a href="https://doi.org/10.6084/m9.figshare.6225083">https://doi.org/10.6084/m9. figshare.6225083</a>
Supplementary_Data_for_Norut_Rep ort_Adjet_Mountain_4_of_4.zip	The zip-file contains images from the trail camera ADJ_SNW_CAM2 from the period 2014–2016.	<a href="https://doi.org/10.6084/m9.figshare.6225086">https://doi.org/10.6084/m9. figshare.6225086</a>

## 2 METHODS

### 2.1 TEMPERATURE MEASUREMENTS

From summer 2014 to summer 2017, several DS1921G ThermoChron iButtons loggers made by Maxim Integrated were set out, emptied and maintained during annual summer campaigns.

In August 2017, all iButton loggers were replaced with M-Log5W-CABLE and M-Log5W-SIMPLE wireless temperature loggers from GeoPrecision.

Datasheets, documentation and applications regarding the loggers used can be found in the *Deliverables\Data-* folder in the Figshare-repository (Table 2).

Table 2 – Logger types used and location of datasheets, documentation and related applications found in the Figshare-repository (Table 1).

Instruments	Type	Manufactures	Location of documentation and applications
<b>ThermoChron iButton loggers (DS1921G)</b>	Temperature logger	Maxim Integrated	Hardware\iButtons-folder in the <a href="#">Supplementary Data for Norut Report Adjet Mountain 1 of 4.zip</a>
<b>M-Log5W-CABLE and M-Log5W-SIMPLE wireless temperature loggers</b>	Temperature logger	GeoPrecision	Hardware\GeoPrecision-folder in the <a href="#">Supplementary Data for Norut Report Adjet Mountain 1 of 4.zip</a> See also manufactures web page: <a href="ftp://80.153.164.175/GeoPrec/Docu_Software/GP_Wireless/">ftp://80.153.164.175/GeoPrec/Docu_Software/GP_Wireless/</a>
<b>UV565</b>	Trail camera	Uovision	Hardware\Trail cameras\Uovision UV565-folder in the <a href="#">Supplementary Data for Norut Report Adjet Mountain 1 of 4.zip</a>
<b>Time-Lapse Camera Package (Now discontinued)</b>	Time-Lapse camera	Harbortronics	Hardware\Time-lapse camera – Harbortronics-folder in the <a href="#">Supplementary Data for Norut Report Adjet Mountain 1 of 4.zip</a> See also: <a href="https://www.harbortronics.com/Products/TimeLapsePackage/">https://www.harbortronics.com/Products/TimeLapsePackage/</a>
<b>LTL ACORN Ltl-3310A</b>	Trail camera	ACORN	Hardware\Trail cameras\LTL ACORN Ltl-3310A-folder in the <a href="#">Supplementary Data for Norut Report Adjet Mountain 1 of 4.zip</a>

#### 2.1.1 IBUTTON TEMPERATURE LOGGER CAMPAIGN (2014–2017)

For measurement of air temperature, ThermoChron iButton (DS1921G) loggers from Maxim Integrated were used. These are small rugged, self-sufficient loggers. Air temperature measurements were collected using an Air Temperature Logger (ATL) in two different locations, from August 2014 to August 2016 on a rockslide

block (1026 m a.s.l.) in the SE part of the Ádjet mountain, and from August 2016 to August 2017 on the SE rock glacier lobe (858 m a.s.l.) in the NW part of the Ádjet mountain. The ATL contained two iButtons loggers mounted in a ventilated white plastic box. The loggers were isolated from the box using small closed-cell foam pads. The ATL-box was mounted 1 m above ground on a tripod facing north. To evaluate the ground thermal regime we used GTLs recording air temperature in fractures and pore space between boulders. Each logger containing several iButton loggers, mounted on plastic sticks, secured with duct tape or brackets, measuring air temperature in deep fractures and pore space between boulders. GTLs were located at different locations in the SE part of Ádjet (2014–2016) and on the rock glacier lobes in the NW part of Ádjet (2014–2017).

From fall 2016–2017, iButtons in plastic sticks was used to measure ground surface temperature (GST) at two locations in the soil-cover, a couple of cm below the surface. One GST logger recorded temperatures in the middle part of the SE rock glacier lobe, and one recorded temperatures in the stable area between the NW- and the SE rock glacier lobe.

To ensure the longest measurement period before the iButton loggers would run out of memory, they were set up to sample with the longest possible delay between samples (240 minutes) and to ensure sampling at the same time each day. All iButtons collected temperatures at 00:00, 04:00, 08:00, 12:00, 16:00 and 20:00.

Data from loggers were read out from the iButtons loggers in the field using a laptop, and a USB iButton reader. For redundancy, all GTLs are equipped with at least two iButtons.

To follow the fast movements of the NW rock glacier lobe, a time-lapse camera from Harbortronics was installed in the stable area between the NW- and the SE rock glacier lobe. The camera is overlooking one GST logger and take one picture per day to document the snow cover. The camera contains a SD-card that can be emptied using a laptop with SD-card reader.

See the document “*DS2700 User Guide.pdf*” found in *Hardware\Time-lapse camera – Harbortronics\Time-lapse camera\Product Information\DigiSnap 2700-folder in the* Figshare-repository [Supplementary Data for Norut Report Adjet Mountain 1 of 4.zip](#)

For setup of the Harbortronics camera use the application “*DigiSnap\_Terminal.exe*”. The file is located together with the description “*Terminal instructions.pdf*” in the *Hardware\Time-lapse camera – Harbortronics\Time-lapse camera\PC Programs-folder* can be found in the same Figshare-repository.

For a description of each logger used (name, operation time, location) from the rock glaciers and the rockslide block see Appendix 1.

### 2.1.2 GEOPRECISION TEMPERATURE LOGGERS CAMPAIGN (AUGUST 2017–)

In August 2017, all iButton loggers (GTLs, GSTs and the ATL) were replaced with wireless GeoPrecision temperature loggers with cords/thermistors (225 cm) (M-Log5W-CABLE) and without cords (M-Log5W-SIMPLE) (Figure 1). In addition, logging at some locations was terminated, and some new locations set up. One GeoPrecision Rock Wall Loggers (RWL) was mounted to record temperatures in a ca. 20 cm deep borehole in a steep rock wall between the NW- and SE rock glacier lobes. The main reasons to replace iButtons loggers were to continue the campaign with loggers having longer battery duration, capability to store more data and capability of wireless data downloading. This would reduce the need for personnel to move into dangerous terrain, fractures and caves to read out data.



Figure 1 – Wireless GeoPrecision temperature loggers with cord (M-Log5W-CABLE) and without cord (M-Log5W-SIMPLE)

The GeoPrecision loggers are produced and sold by [GeoPrecision GmbH](http://www.geoprecision.com). The temperature logger, battery and wireless sender/receiver unit is encapsulated in a watertight container (IP69). To increase ruggedness, visibility of the installation in field, and ease the installation, GeoPrecision loggers used in fractures and pore spaces between boulders were mounted inside plastic sticks (Figure 2). Loggers were secured inside the sticks using two screws, and a cord attached to the loggers eases the access to the logger.





Figure 2 – Mounting of GeoPrecision loggers inside plastic sticks and examples of placement in space between boulders.

For measuring temperature in rock walls, the M-Log5W-CABLE loggers were mounted in shallow boreholes using brackets (Figure 3, left). For measuring ground surface temperature the M-Log5W-SIMPLE logger was mounted inside a plastic stick and covered by some cm of soil (Figure 3, right).



Figure 3 – Examples of mounting GeoPrecision loggers with cable (M-Log5W-CABLE) measuring temperature in a shallow borehole in a rock wall (left) and without cable measuring ground surface temperature inside a plastic stick (right).

The GeoPrecision loggers can be accessed wireless at distances up to 50 m using a USB-dongle and a windows laptop. The document *Doku\_FlexGate\_Software\_Eng\_v1.pdf* found in the *Hardware\GeoPrecision-folder* in [Supplementary Data for Norut Report Adjet Mountain 1 of 4.zip](#) explains how to install the necessary software, and how to access and wirelessly download data using the USB-dongle. Also see document *“Serial numbers and access codes used with GeoPrecision temperature loggers on the Ádjet rock glaciers, Skibotn, Northern Troms”* for access codes, ids and location of the different GeoPrecision loggers.

All Geoprecision loggers were set up to log the temperature once every full hour using the fg2\_shell.exe application. The configuration can be found in the file “*Setup of hourly reading - Used on Ádjet from August 2017.txt*” in *Hardware\GeoPrecision\ Setup of hourly reading - Used on Ádjet from August 2017-folder* in [Supplementary Data for Norut Report Adjet Mountain 1 of 4.zip](#), and can be loaded using the application fg2\_shell.exe.

With a storage capacity of 400.000 measurements, and a sampling every hour, there will be plenty of data space, so the limiting factor is the battery capacity. Under normal operation it is recommended to change the battery after 5–6 years when the logger is used in arctic conditions. See Appendix 3 for a procedure of changing of the battery GeoPrecision in the field.

## **2.2 CALCULATIONS AND INTERPRETATIONS BASED ON TEMPERATURE DATA**

From GTL and GST temperature time series from 2014–2017, we identify bottom temperature of snow during thick snow cover (BTS). BTS-values are defined as stable fracture/pore space air temperatures, decoupled from air temperature variations, under an assumed thick and isolating snow cover. We use BTS-values as proxies for ground temperatures and indirect indicators for the presence of permafrost as done for bottom temperature of snow (BTS) by Haeberli (1973) and Hoelzle (1992). Lacking borehole instrumentations, we rely on many loggers measuring air temperatures in fractures and pore space between blocks, and use bottom temperature of snow during thick snow cover (BTS) as proxies for the state of permafrost. Based on BTS-values, we divide the locations into three groups: (1) permafrost is probable, permafrost is possible, and permafrost is not present. Note that use of BTS-values as proxies for permafrost conditions can be biased by site-specific variations related to variability of snow cover, wind speed, degree of fracturing causing ventilation, micro-topography and vegetation. Particularly, variations in thickness and duration of snow cover is very important for the state of permafrost (Zhang, 2005; Zhang et al., 2001). The insulating effect of snow is visible in the temperature time series from fractures/pore spaces as damping of diurnal and annual variations. This damping correlates with snow cover thickness. In studies from the European Alps, bottom temperature of snow during period with maximum snow cover has been used as a proxy for presence of permafrost (Haeberli, 1973; Hoelzle, 1992). As a rule of thumb, BTS-temperatures  $< -3$  °C indicate that permafrost is probable, between  $-2$ °C and  $-3$ °C that permafrost is possible, and  $> -2$ °C that permafrost is not present.



### 3 LOCATION OF TEMPERATURE LOGGERS AND INSTRUMENTATION

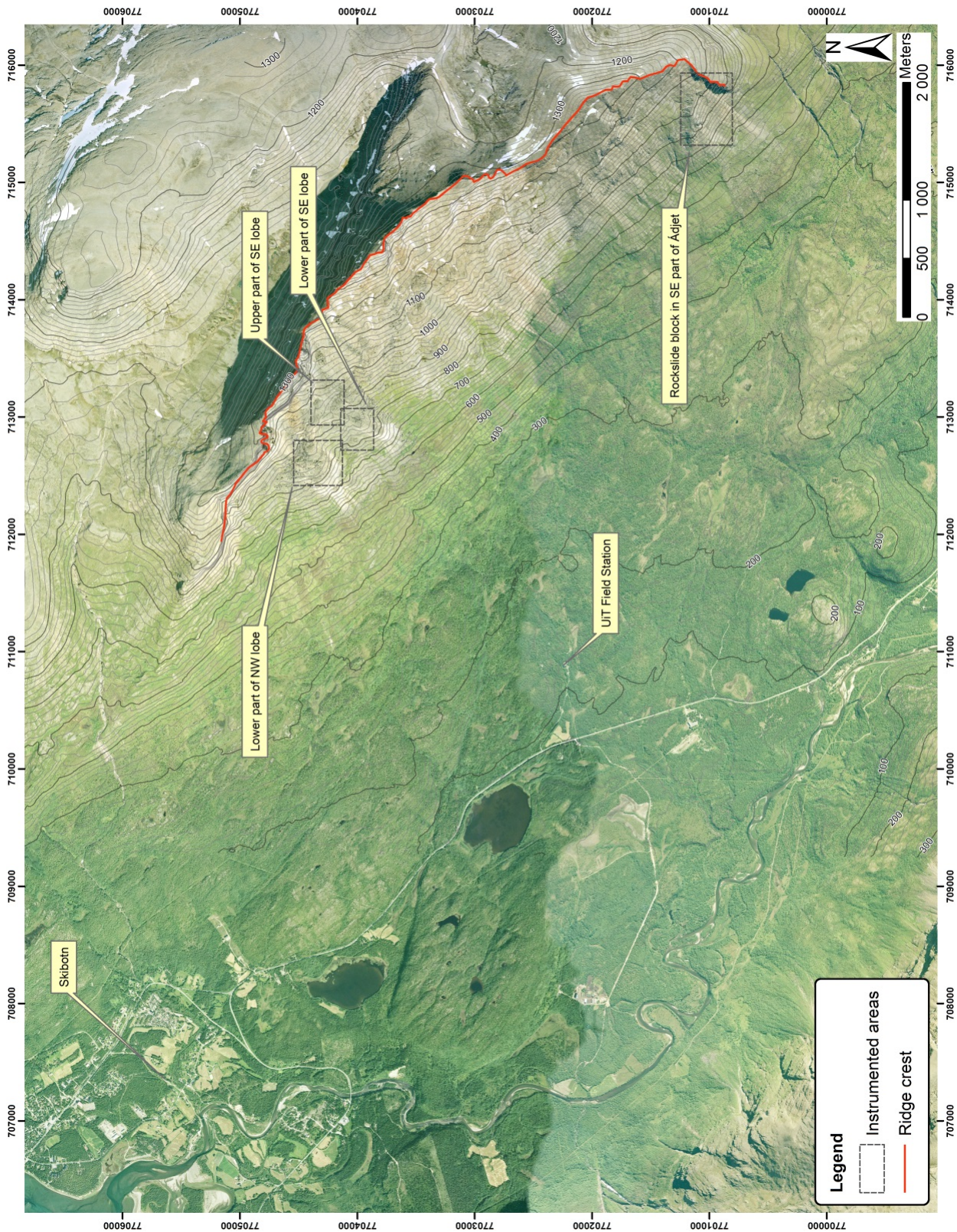


Figure 4 – Overview of Ádjet mountain and instrumented areas. Orthophoto from 2006 supplied by [www.norgebilder.no](http://www.norgebilder.no).



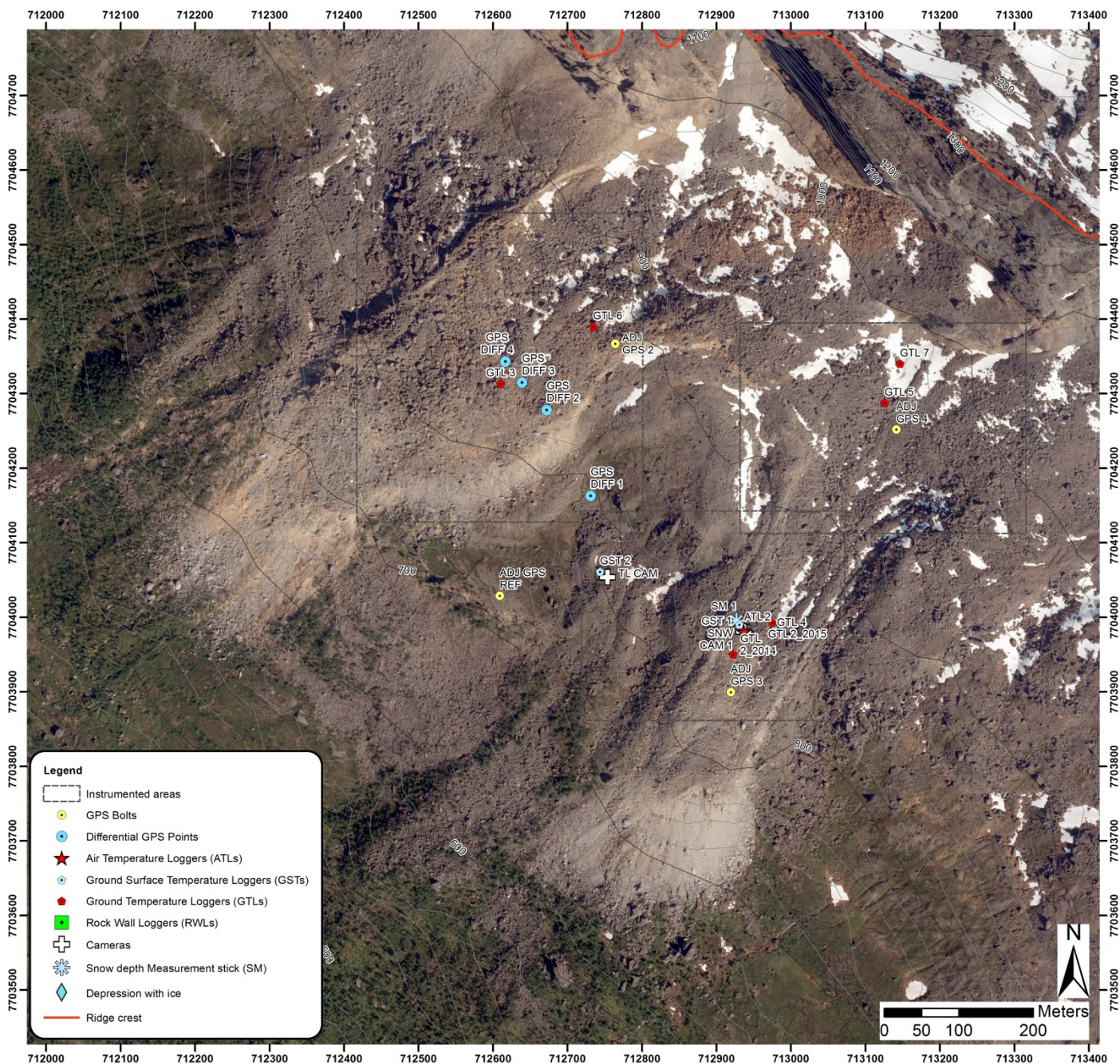


Figure 5 – The northwestern part of the Ádjet mountain, Skibotn, Troms, with the two most active rock glaciers. In-situ instrumentation, differential GPS points and GPS bolts, and areas (lower part of NW lobe, upper part of the SE lobe and lower part of the SE lobe) are annotated.



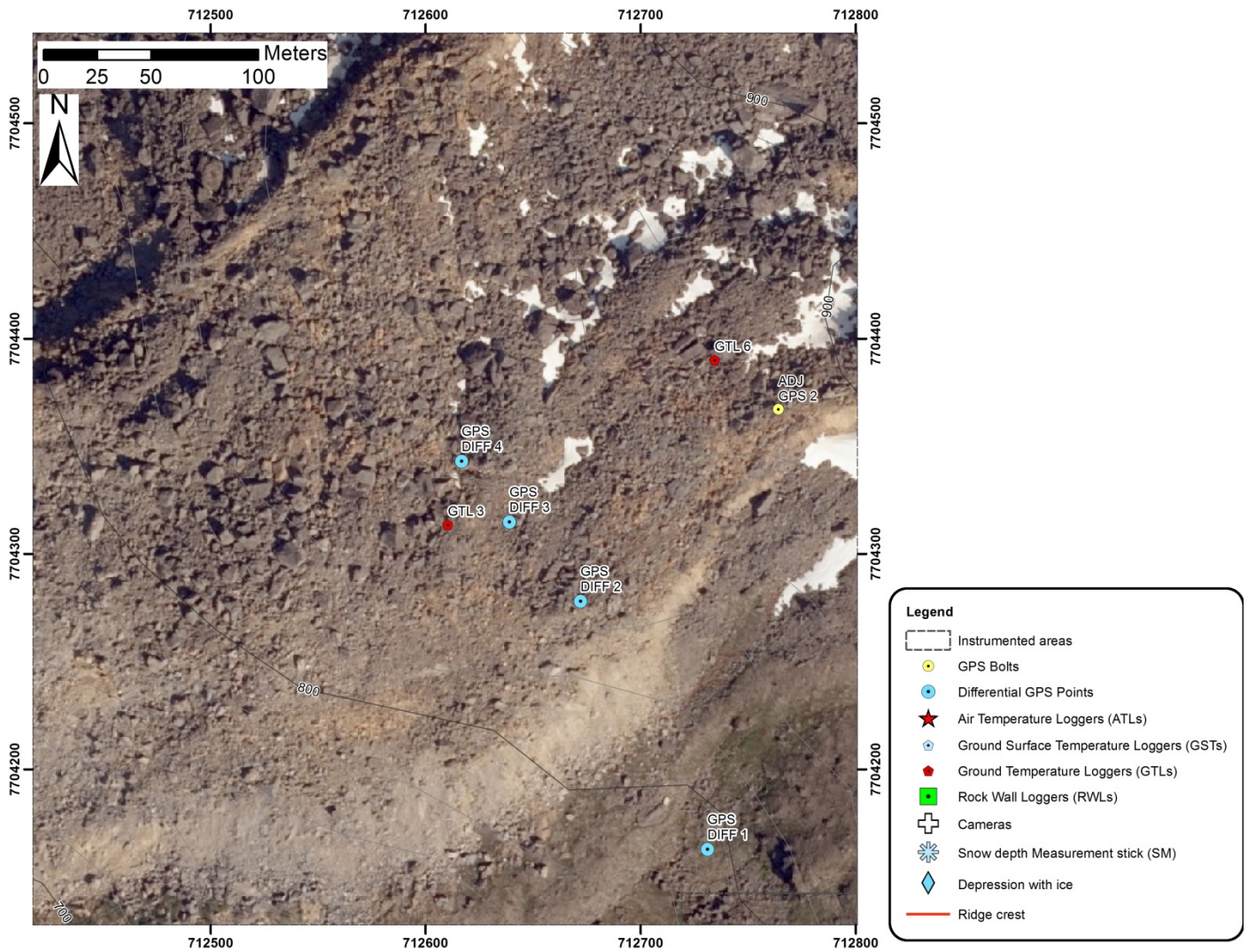


Figure 6 – The lower part of NW lobe in the northwestern part of the Adjēt mountain with in-situ instrumentation and Differential GPS points and GPS bolts annotated.

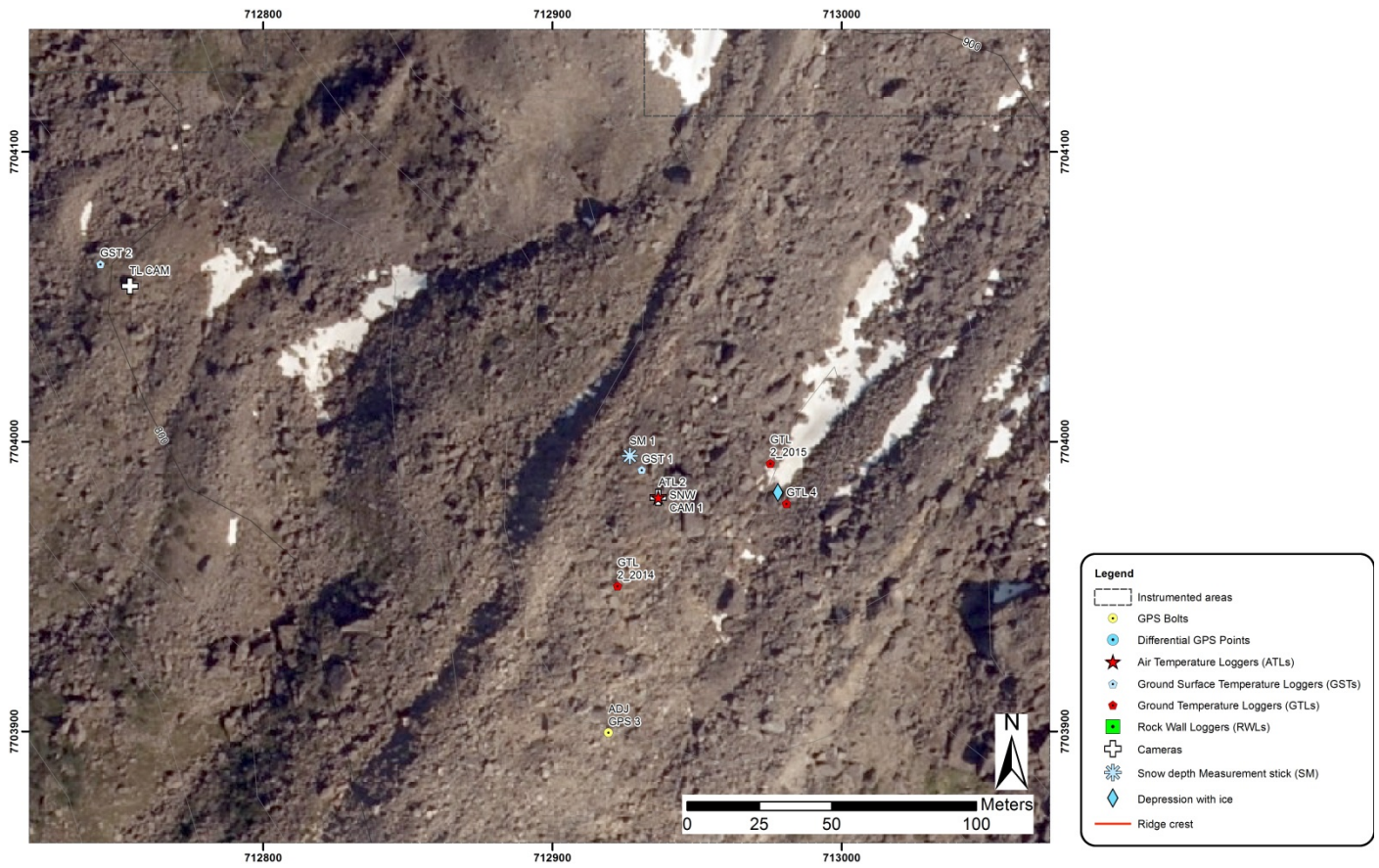


Figure 7 – The lower part of SE lobe in the northwestern part of the Ádjet mountain with in-situ instrumentation and GPS bolts annotated.



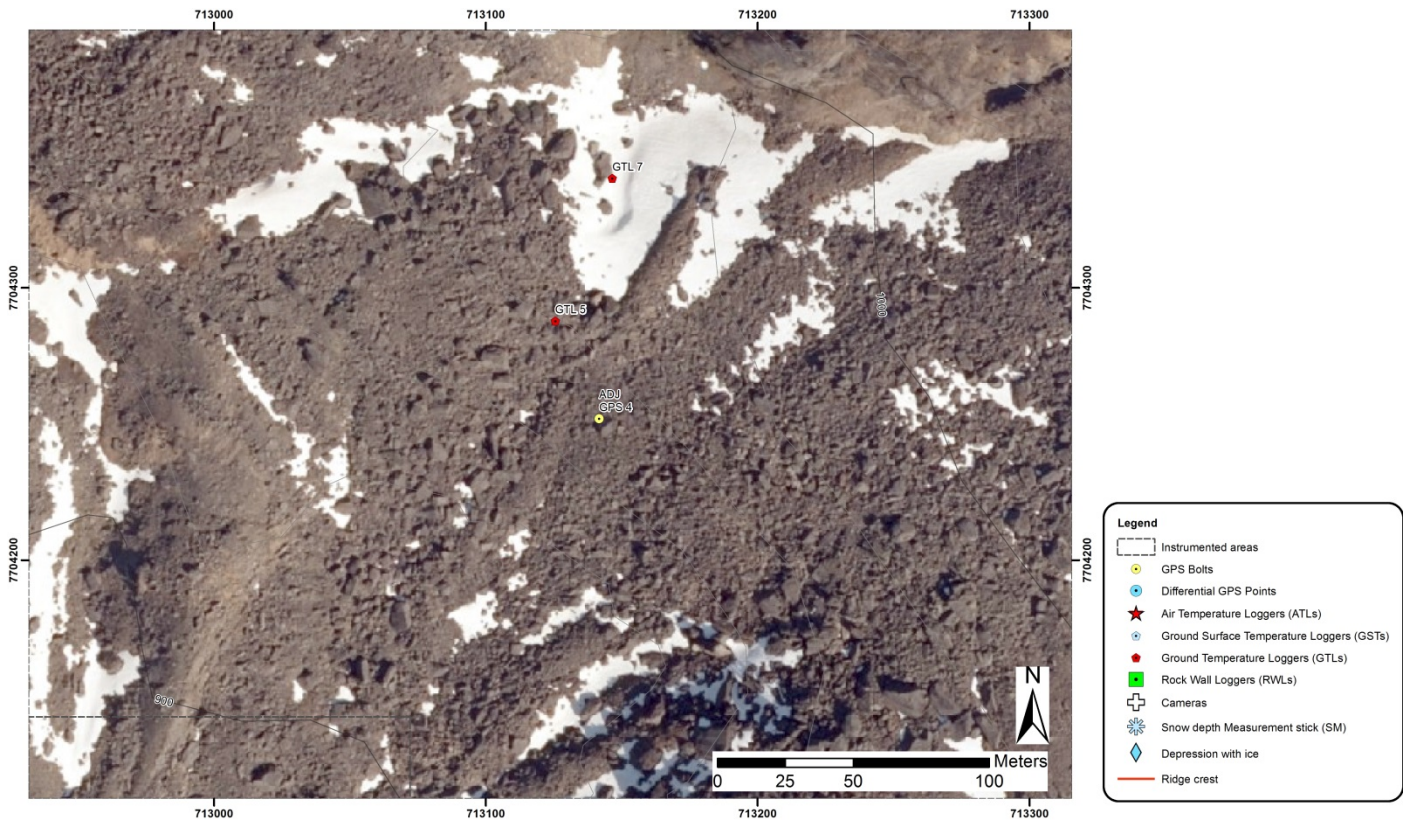


Figure 8 – The upper part of SE lobe in the northwestern part of the Ádjet mountain with in-situ instrumentation and GPS bolts annotated.

## 4 RESULTS 2014–2017

A subset of data from loggers at different locations from the Ádjet mountain and rock glaciers are presented in the following. See Appendix 1 for details. Presented result concentrate on data from loggers located deepest in the ground at each location. Data from additional loggers giving temperature gradients in fracture/pore spaces are omitted in this report, but can be found in the supplied datasets (Table 1). Unfortunately, some of the iButtons used were only able to store temperature data spanning parts of the year. This resulted in gaps in the time series. For comparison of ground thermal state between years, we computed average temperature based on available data from each year.

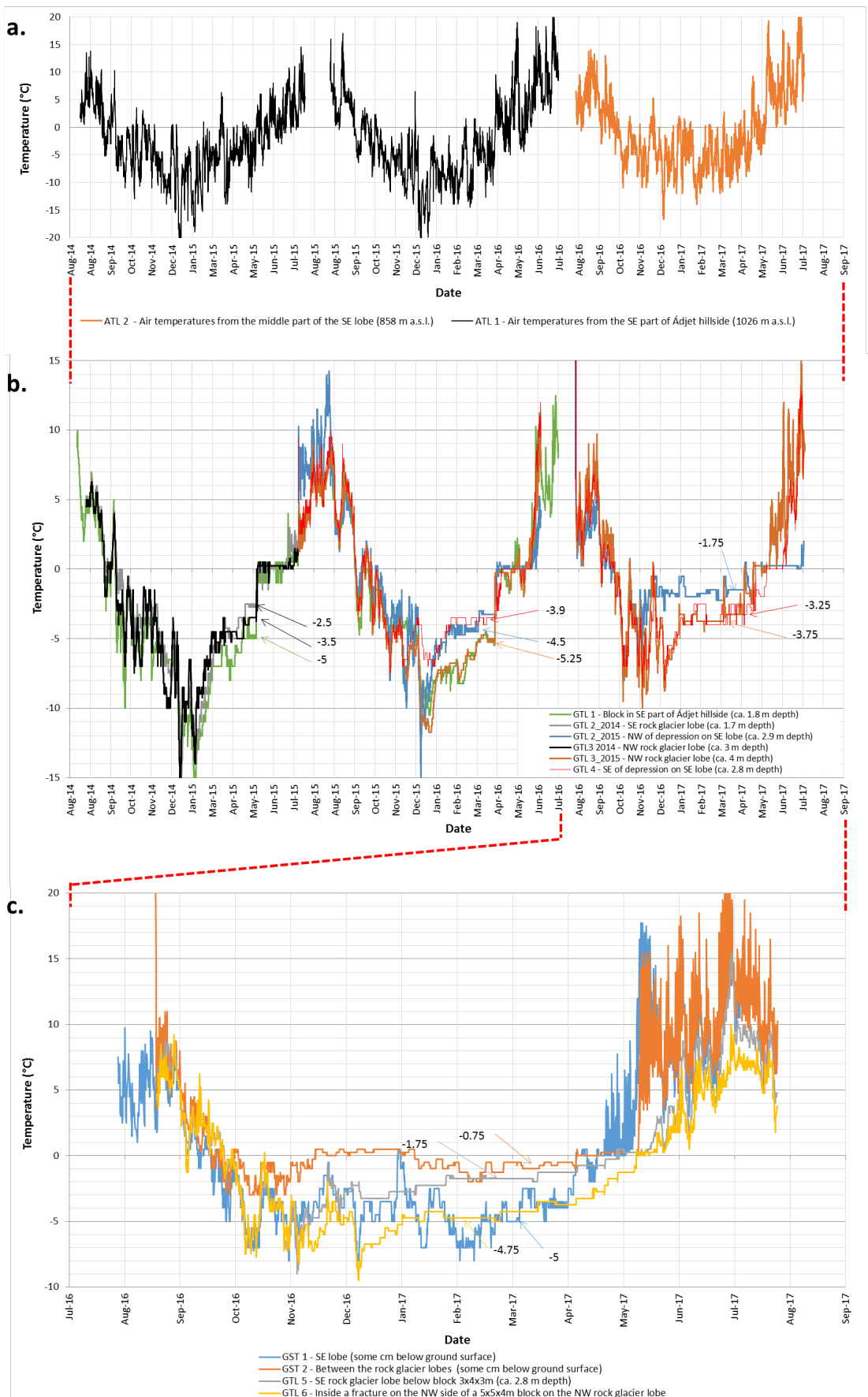
In Table 4, the average temperature recorded by the air temperature loggers (ATL) are summarized. In Figure 9, graphs with overview of temperature observations and interpreted BTS-values are shown. See tables and descriptions in Appendix 1, for details on each logger used. Location of loggers can be found in Section 3 and Appendix 1.

**Table 3 – Color scale used for temperatures in tables below. Temperatures are given in °C.**

≤ -4	-4 – -3	-3 – -2	-2 – -1	-1 – 0	0 – 1	1 – 2	2 – 3
permafrost is probable		permafrost is possible		permafrost is not present			

**Table 4 – Average air temperature. Background color indicate temperatures, see Table 2.**

Logger	Altitude (m a.s.l.)	Average temperature of 336 days from 16-AUG-2014 – 18-JUL-2015 (°C)	Average temperature of 340 days from 24-AUG-2015– 31-JUL-2016 (°C)	Average temperature of 341 days from 26-AUG-2016– 02-AUG-2017 (°C)
ATL 1	1026	-2,88	-2,02	-
ATL 2	858	-	-	-0,78



**Figure 9 – Air and ground thermal regime for Ádjet rock glaciers. a) Air temperatures from the SE and NW part of the Ádjet mountain. b) Air temperatures in pore spaces and open fractures between boulders on Ádjet rock glacier lobes in NW and the rock glacier lobe in SE of Ádjet mountain. c) Ground surface temperatures and air temperatures in pore spaces and open fractures between boulders both on and outside Ádjet rock glacier lobes. All temperature plots are averages of two IButton-loggers. Arrows show bottom temperature of snow (BTS).**

## 5 INDICATIONS OF PERMAFROST

Permafrost is a thermal condition with temperatures at or below freezing point for two consecutive years (French, 2007). Borehole instrumentations are very useful when investigating the state of permafrost, giving variations in depth of the active layer, direct measurements of ground temperatures variations with depth. This gives very high temporal detail on a specific spot, but no information about spatial variations of ground temperature.

BTS from ground surface temperatures from the middle part of the SE-rock glacier lobe (GST 1) are cold ( $-5^{\circ}\text{C}$ ) indicating that permafrost is probable here. Ground surface temperature outside the lobe (GST 2) show warmer BTS temperatures ( $-0.75^{\circ}\text{C}$ ) indicating that permafrost is not present.

BTS-values from ground temperature logger measuring temperatures in pore spaces between boulders and in fractures indicate also presence of permafrost. GTL 3\_2014, GTL 3\_2015 and GTL 6 on the NW-lobe, GTL 4 on the SE-lobe, and GTL 1 outside the rock glacier lobes give indications that permafrost is probable.

There are also loggers indicating no permafrost condition. For GTL 5 in the upper part of the SE rock glacier lobe, BTS-values indicated that permafrost is not present during winter 2017. Variations exist, for example did GTL 2\_2015, located NW of depression with solid ice in the middle of the SE rock glacier lobe, vary between permafrost is probable (winter of 2016) to permafrost is not present (winter of 2017). This may indicate no permafrost conditions, but could also be due to the effect of annual variation in snow coverage. Observed annual variations in average temperatures and BTS-values could be due to changed air circulation because of opening of fractures or because of yearly variability in snow cover insulation (duration and thickness). Unfortunately, all air temperature loggers (ATL) 1 and 2 have data gap during July and August (2014: 29 days, 2015: 25 days and 2016: 24 days). This made it impossible to calculate mean annual air temperatures (MAAT).

Even though there are variations and gaps in the data making calculations of mean annual temperatures impossible, the indications of presence of permafrost is strong due to observations of solid ice three years in a row (Figure 12) and low BTS-values in many loggers. Recently investigation of deformation of the NW- and SE-rock glacier lobe at Ádjæt Mountain using ground- and satellite-based radar have documented high velocities and recent acceleration (Eriksen et al., 2018; Rouyet et al., 2015). Such high velocity, also on low topographic gradients, do indicate that deformation must be taking place as creep in ground-ice and/or sliding along internal shear zones, possibly affected by elevated pore pressures.

## 6 CONCLUSION

Using loggers measuring air-, ground- and fracture/pore space temperatures, the 2014–2017 campaign documents that permafrost is probable on Ádjet Mountain. Year to year average temperatures have some variations, possibly due to differences in timing and distribution of snow cover, or to changed air circulation patterns in the active layer as new fractures opens and blocks are rearranged. Recently observation of high deformation using remote sensing also indicate presence of ground-ice (Eriksen et al., 2018; Rouyet et al., 2015).

The rock glaciers at the Ádjet Mountain are a unique laboratory due to the long time series of temperature measurements, and availability of deformation data from satellite- and ground-based radar campaigns.

The knowledge about thawing permafrost and possible kinematic response to unstable slopes is still poor. To investigate and understand how displacement of unstable slopes and permafrost landforms will respond to climatic warming, it is vital to ensure continuation of the temperature campaign at the Ádjet Mountain. This temperature campaign was a part of Harald Øverli Eriksen's PhD. The continuation of this campaign is now managed by Department of Geoscience, UiT-The Arctic University of Norway.

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## 8 APPENDIX 1 – DESCRIPTION OF INSTRUMENTATION

This appendix contains a listing of instrumentation used for measuring air temperatures in fractures and pore spaces (GTL), ground surface temperatures (GST), air temperatures (ATL), rock wall temperatures. Also included are descriptions of cameras and measurement stick used for observing snow depth and distribution, boulders measured using differential GPS and GPS bolts measured annually.

### 8.1 CHARACTERISTICS OF GROUND TEMPERATURE LOGGERS

Table 5 – Characteristics, average temperature and fracture temperatures during maximum snow cover (BTS) from ground temperature loggers. BTS (bottom temperatures of snow from Haerberli, 1973; Hoelzle, 1992) are indicated with background colors < -3 °C, permafrost is probable, between -2°C and -3°C, permafrost is possible, and > -2°C, permafrost is not present.

Color scale used for temperatures in tables below. Temperatures are given in °C.

≤ -4	-4 – -3	-3 – -2	-2 – -1	-1 – 0	0 – 1	1 – 2	2 – 3
permafrost is probable		permafrost is possible		permafrost is not present			

Name	Active	Operation time	Location	34W East UTM	34W North UTM	Altitude (m a.s.l.)	Depth (m)	Average temperature 2014-2015	Average temperature 2015-2016	Average temperature 2016-2017	2015 BTS (°C)	2016 BTS (°C)	2017 BTS (°C)	Comment
GTL 1	No	Start: 11.08.14 End: 18.07.15  Start: 24.08.15 End: 31.07.16  Status: Discontinued	Located in pore spaces between boulders on the edge of a terrace in the terrain interpreted to be an old rockslide block in the SE part of Ádjet mountain.	479559	7691587	1026	1.8	-3,61°C, 11.08.14–18.07.15 340 days	-1,98°C, 24.08.15–31.07.16 341 days	-	-5	-	-	2014–2016: Measurement of air temperatures in pore spaces between boulders using 19 DS1921G Thermochron iButton loggers (Maxim Integrated) mounted on plastic sticks down to ca. 1.8 m depth.  See Figure 24 for setup and surroundings.
GTL 2_2014	No	Start: 26.08.14 End: 08.07.15  Status: Discontinued	Located in pore spaces between boulders in the lower to middle part of the SE- rock glacier lobe.	477127	7694628	840	1.7	-3,16°C, 26.08.14–08.07.15 316 days	-	-	-2.5	-	-	Measurement of air temperatures in pore spaces between boulders using 9 iButton loggers mounted on plastic sticks down to ca. 1.7 m depth.
GTL 2_2015	Yes	Start: 08.07.15 End: 05.07.16	Located NW of depression with solid ice in the middle of the SE rock glacier lobe.	477183	7694664	860	1.7	-	-0,74°C, 08.07.15–05.07.16 362 days	-0,80°C, 25.08.16–01.08.17 341 days	-	-4.5	-1.7	2015–2016: 4 iButtons in a plastic stick at ca. 2.9 m depth. Measures air temperatures

		Start: 25.08.16 End: 01.08.17  Start: Replaced iButtons with Geoprecision logger 23.08.17												in the pore space between large boulders. The logger is located above the waterline at the time of the readout. Logger is secured in a rope marked with a red plastic bag for visibility.  2016–2017: Same setup as above, but with 2 iButton loggers.  2017– : Same setup as above, but with 1 GeoPrecision logger (M-Log5W-SIMPLE).
GTL 3_2014	No	Start: 25.08.14 End: 08.07.15  Status: Discontinued	Located in the middle part of the NW rock glacier lobe.	476842	7695012	Ca. 845	3.0	-3,42 °C, 25.08.14- 08.07.15 316 days	-	-	-3.5	-	-	2014–2015: Measurement of air temperatures in pore spaces down to ca. 3 m depth between boulders using 7 iButton loggers mounted on a plastic stick.
GTL 3_2015	Yes	Start: 08.07.15 End: 05.07.16  Start: 26.08.16 End: 03.08.17  Start: Replaced iButtons with Geoprecision logger 23.08.17	Located in the middle part of the NW rock glacier lobe.	476852	7695020	Ca. 845	4.0	-	-1,92 °C, 08.07.15–05.07.16 362 days	-0,95 °C, 26.08.16–03.08.17 341 days	-	-5.25	-3.75	2015–2017: Measurement of air temperatures in pore spaces down to ca. 4 m depth between boulders using 9 iButton loggers mounted on a plastic stick.  2017– : Same setup as above, but with 1 GeoPrecision logger (M-Log5W-SIMPLE).
GTL 4	No	Start: 08.07.15 End: 05.07.16  Start: 25.08.16 End: 01.08.17  Status: Discontinued	Located SE of depression with solid ice in the middle of the SE rock glacier lobe.	477187	7694650	Ca. 860	2.8	-	-0,76 °C, 08.07.15– 05.07.16 362 days	-1,47 °C, 25.08.16– 01.08.17 341 days	-	-3.9	-3.25	2015–2016 Measurement of air temperatures in pore spaces down to ca. 2.8 m depth between boulders using 5 iButton loggers mounted on a plastic stick.  2016–2017: Same setup as above, but with 2 iButton loggers.
GTL 5	Yes	Start: 17.09.16 End: 23.08.17  Start: Replaced iButtons with Geoprecision logger 23.08.17.	Located in the upper part of the SE rock glacier lobe.	477362	7694944	Ca. 960	2.8	-	-	0,16 °C, 17.09.16– 23.08.17 340 days	-	-	-1.75	Measurement of air temperatures in pore spaces down to ca. 2.8 m depth below a boulder (3x4x3 m). Ventilated during summer and snow covered during winter.  2015–2016: Used 2 iButton loggers mounted on a plastic stick.

														2017- : Same setup as above, but with 1 GeoPrecision logger (M-Log5W-SIMPLE).
GTL 6	Yes	Start: 17.09.16 End: 23.08.17  Start: Replaced iButtons with Geoprecision logger 23.08.17.	Located in the middle part of the NW rock glacier lobe.	476983	7695084	Ca. 894	Ca. 2	-	-	-1,56 °C, 17.09.16–23.08.17 340 days	-	-	-4.75	Located on the NW side of a 5x5x4 m boulder in a fracture Snow covered during winter.  2016–2017: Used 2 iButtons in the end of a 5 m rope. Plastic bag, cairn and spray paint for visibility.  2017- : Same setup as above, but with 1 GeoPrecision logger (M-Log5W-SIMPLE).
GTL 7	Yes	Start: 23.08.17	Located in the upper part of the SE rock glacier lobe, in an area assumed to have large snow accumulation during winter.	477388	7694994	Ca. 966	Ca. 2	-	-	-	-	-	-	2017- : GeoPrecision logger (M-Log5W-SIMPLE) inside plastic stick is fixed to the end of a rope and located under 8x3x3 m boulder in an area with snow, ice between boulders and a meltwater pond in August 2017. Boulder marked with spray paint on the SE side for visibility.
GST 1	Yes	Start: 26.08.16 End: 03.08.17  Start: Replaced iButtons with Geoprecision logger 23.08.17.	Located in the middle part of the SE-rock glacier lobe some meters to the SE from the snow measurement stick (SM 1).	477139	7694667	Ca. 860	Some cm below ground surface	-	-	0,05 °C, 26.08.16–03.08.17 340 days	-	-	-5.0	Measurement of ground surface temperature SE rock glacier lobe 2-3 cm depth in the soil cover. Snow conditions in the area where the logger is placed is captured by the time-lapse camera (SNW CAM 1).  2016–2017: Using 2 iButtons inside a plastic stick.  2017-: Same setup as above, but with 1 GeoPrecision logger with cord (M-Log5W-CABEL) inside a plastic stick.
GST 2	Yes	Start: 16.09.16 End: 23.08.17  Start: Replaced iButtons with Geoprecision logger 23.08.17.	Located in the area between the NW- and SE-rock glacier lobes.	476960	7694755	Ca. 808	Some cm below ground surface	-	-	2,43 °C, 16.09.16– 23.08.17 340 days	-	-	-0.75	Measurement of ground surface temperature SE rock glacier lobe 2-3 cm depth in the soil cover. Snow conditions in the area where the logger is placed is captured by the time-lapse camera (TL CAM).



### 8.1.1 GTL 1 – BETWEEN BOULDERS IN THE ROCKSLIDE BLOCK, SE PART OF ÁDJET (1026 M A.S.L.)

See table in Section 8.1 for details and Figure 24 pictures of setup and surroundings.

### 8.1.2 GTL 2\_2014 – LOWER TO MIDDLE PART, SE ROCK GLACIER LOBE (840 M A.S.L.)



Figure 10 – Location and surroundings of GTL 2\_2014 logger (yellow arrows).



### 8.1.3 GTL 2\_2015 AND GTL 4 – MIDDLE PART, SE ROCK GLACIER LOBE (860 M A.S.L.)

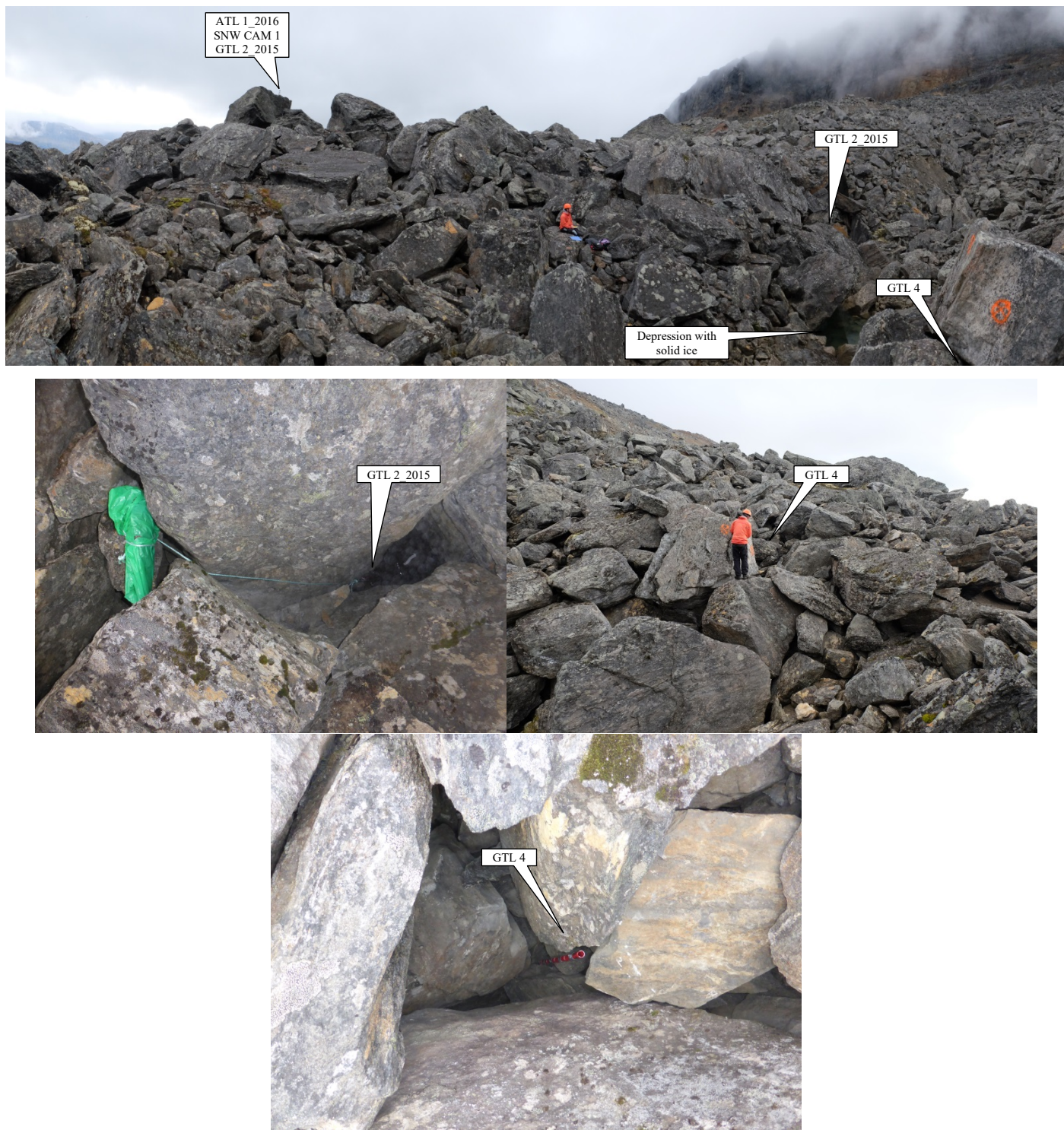


Figure 11 – Location and surroundings of GTL 2\_2015 and the GTL 4 logger located on the NW and SE sides, respectively, of the depression with solid ice.



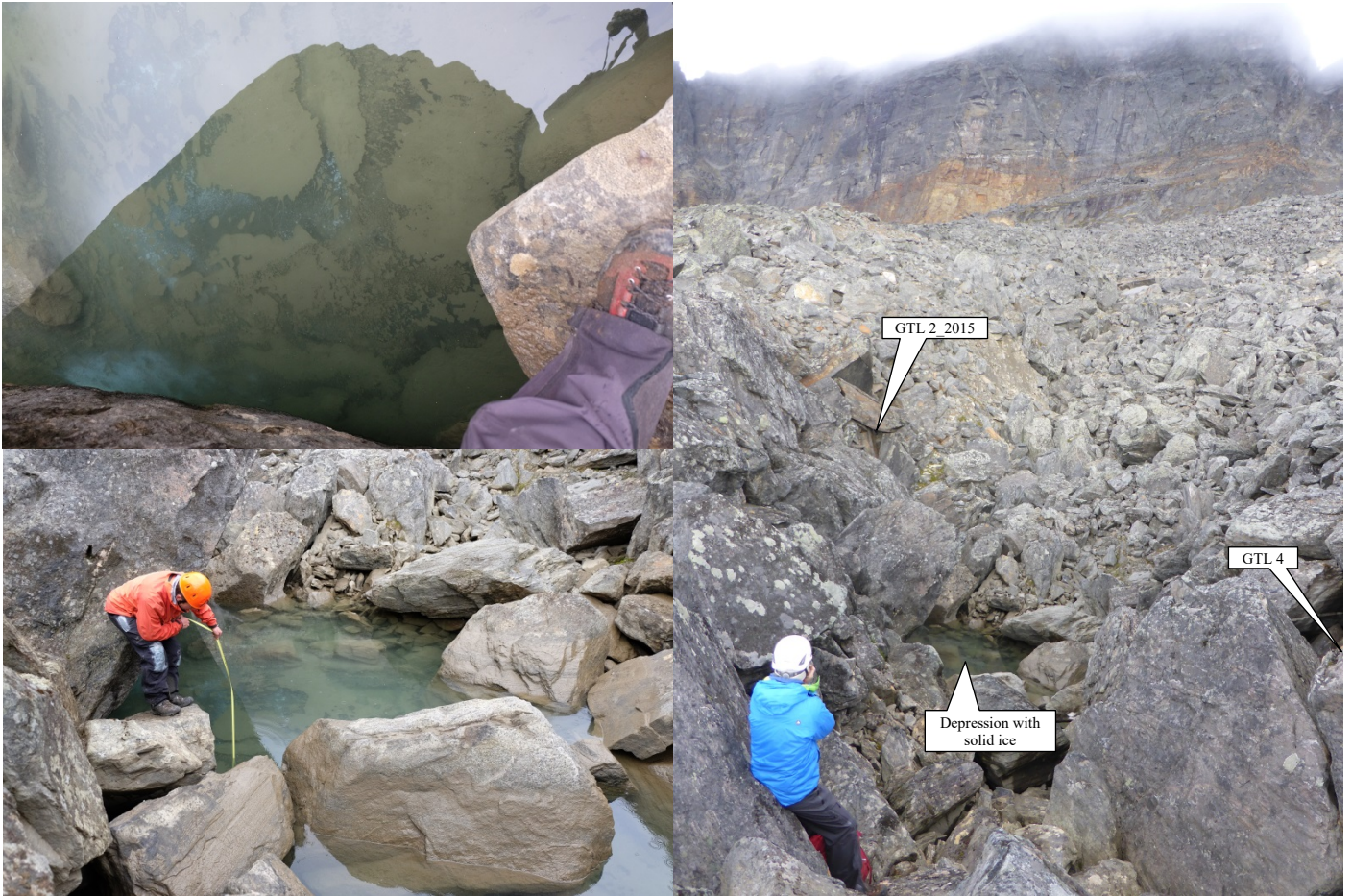


Figure 12 – Solid ice surrounding blocks on the bottom on a small pond in a depression on the SE rock glacier lobe. Location of GTL 2\_2015 and the GTL 4 is given.



#### 8.1.4 GTL 3\_2014 – MIDDLE PART, NW ROCK GLACIER LOBE (860 M A.S.L.)



Figure 13 – Location and surroundings of GTL 3\_2014 logger.



8.1.5 GTL 3\_2015 – MIDDLE PART, NW ROCK GLACIER LOBE (845 M A.S.L.)



Figure 14 – Location and surroundings of GTL 3\_2015 logger.

### 8.1.6 GTL 5 – UPPER PART, SE ROCK GLACIER LOBE (960 M A.S.L.)



Figure 15 – Location and surroundings of GTL 5.



**8.1.7 GTL 6 – MIDDLE PART, NW ROCK GLACIER LOBE (894 M A.S.L.)**



**Figure 16 – Location and surroundings of GTL 6 inside a fracture on the NW side of a 5x5x4m block on the NW rock glacier lobe**



### 8.1.8 GTL 7 – UPPER PART, SE ROCK GLACIER LOBE (966 M A.S.L.)



Figure 17 – Location and surroundings of GTL 7 in an area assumed to have large snow accumulation during winter and meltwater pounds during summer.

### 8.1.9 GST 1 – MIDDLE PART, SE-ROCK GLACIER LOBE (860 M A.S.L.)



Figure 18 – Location and surroundings of GST 1. See also Figure 23.



### 8.1.10 GST 2 – AREA BETWEEN THE NW AND SE ROCK GLACIER LOBES (808 M A.S.L.)

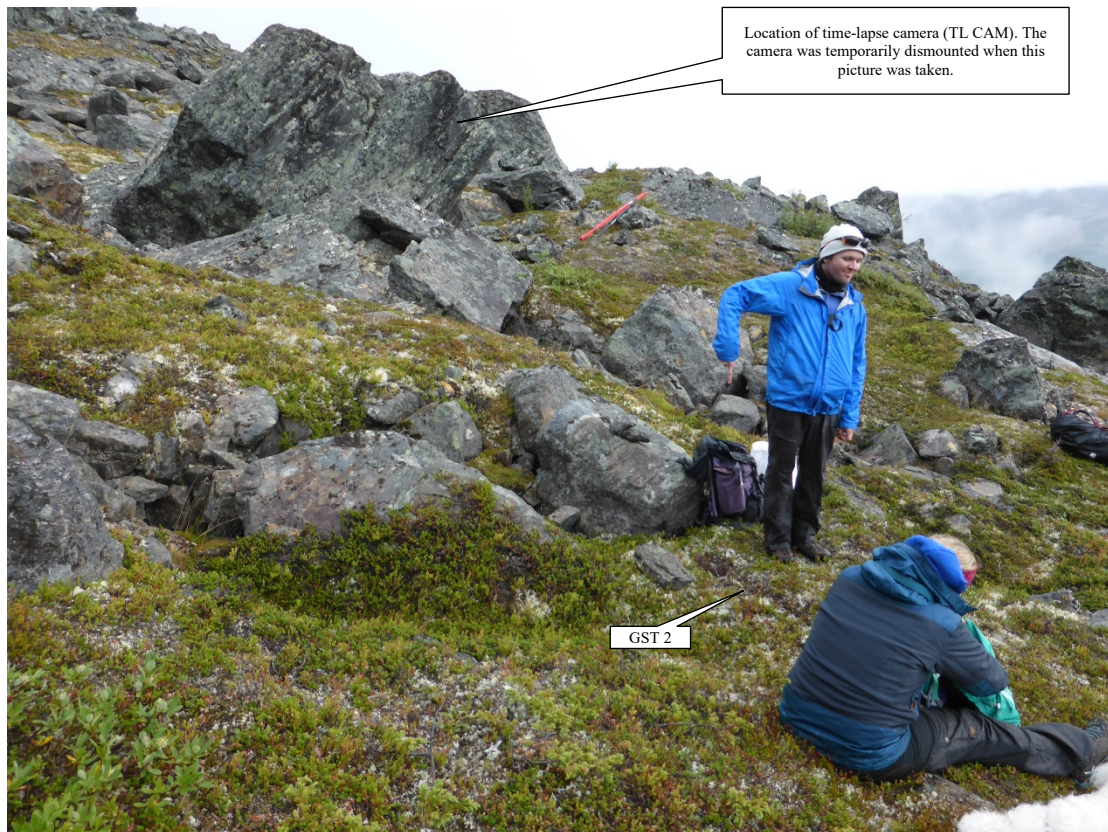


Figure 19 – Location and surroundings of GST 2 in front of time-lapse camera (TL CAM).



## 8.2 CHARACTERISTICS OF AIR TEMPERATURE LOGGERS

Name	Active	Operation time	Location	UTM East_34W	UTM North_34W	Altitude (m a.s.l.)	Comment
ATL 1_2014	No	Start: 16.08.14 End: 18.07.15  Start: 24.08.15 End: 31.07.16  Status: Discontinued	Located on rockslide block in the SE part of Ádjet mountain.	479559	7691586	1026	Two iButtons (DS1921G) mounted in a ventilated white plastic box, isolated from the box using small closed-cell foam pads. The box was mounted using a 1 m tall tripod facing north. Same location as SNW CAM 2 and GTL 1.  See Figure 24 for setup and surroundings.
ATL 1_2016	Yes	Start: 26.08.16 End: 02.08.17  Start: 23.08.17  Start: Replaced iButtons with Geoprecision logger 23.08.17.	Located on large a boulder in the middle part of SE-rock glacier lobe.				From 2014–2016: Two iButtons (DS1921G) mounted in a ventilated white plastic box, isolated from the box using small closed-cell foam pads. The box was mounted on 1 m tall tripod facing north. Same location as SNW CAM 1 and close to GST 1.  From 2017–: iButtons were replaced with Geoprecision logger with cord (M-Log5W-CABLE) 23.08.17.  See Figure 20 for setup and surroundings.



Figure 20 – ATL 1\_2016 measuring air temperature on top of a large boulder in the middle part of the SE-rock glacier lobe

### 8.3 CHARACTERISTICS OF ROCK WALL LOGGERS

Name	Active	Operation time	Location	UTM East_34W	UTM North_34W	Altitude (m a.s.l.)	Comment
RWL 1	Yes	Start: 23.08.17	Located in cliff face with SW aspect in bench formation between the NW- and SW- rock glacier lobe.	476907	7694672	Ca. 750	Geoprecision logger with cord (M-Log5W-CABLE) was mounted in a steep rock wall, sheltered from rock fall. Thermistor inserted and sealed using silicone into ca. 20 cm deep borehole.

#### 8.3.1 RWL 1 – ROCK WALL TEMPERATURE LOGGER (832 M A.S.L.)



Figure 21 – Location of rock wall temperature logger mounted on SW facing cliffs. Nearby rock marked with spray paint.

## 8.4 CHARACTERISTICS OF CAMERAS AND SNOW DEPTH-MEASUREMENT STICK

Name	Active	Operation time	Location	UTM East_34W	UTM North_34W	Altitude (m a.s.l.)	Comment	Unit
TL CAM	Yes	Start: 09.07.15 End: 03.07.16  Start: 24.08.16	Located in the area between the NW- and SE- rock glacier lobes	476969	7694747	Ca. 795	Camera is placed in a water tight housing mounted on a the side of boulder overlooking the NW-rock glacier lobe from the side. The camera captures one pictures per day. It also document the snow conditions in in the area of ground surface temperature logger (GST) 2.	Time-lapse camera with housing from Harbortronics (discontinued). The camera is equipped with extra battery and a solar panel and operates all year. Hardware\Time-lapse camera – Harbortronics-folder in the <a href="#">supplementary data</a> . <a href="https://www.harbortronics.com/Products/TimeLapsePackage/">https://www.harbortronics.com/Products/TimeLapsePackage/</a> <b>Yearly maintenance:</b> - <b>Download pictures using a laptop with SD-slot.</b> - <b>Erase the SD card.</b> - <b>Re-lube</b> the sealing ring to keep the housing water tight - <b>If water has intruded the housing, camera and housing to the office and let it dry out. Change or warm the desiccant pack in an oven.</b>
SNW CAM 1	Yes	Start 23.08.17	Located on the middle part of the SE-rock glacier lobe.	477144	7694657	Ca. 874	Captures images of the middle part of the SE-lobe where the snow measurement stick (SM 1) and ground surface temperature logger (GST 1 are located. Camera document snow conditions once a day. Camera is on 1 m tall tripod on top of large boulder together with ATL 1_2016.	LTL ACORN Lti-3310A trail camera. See documentation in in folder Hardware\Trail Cameras\LTL ACORN Lti-3310A-folder in the <a href="#">supplementary data</a> .  <b>Yearly maintenance:</b> - <b>Change batteries (8 x Energizer Ultimate Lithium AA batteries)</b> - <b>Download pictures using a laptop with SD-slot.</b> - <b>Erase the SD card.</b> - <b>Re-lube</b> the sealing ring to keep the housing water tight - <b>If water has intruded the housing, camera and housing to the office and let it dry out. Change or warm the desiccant pack in an oven.</b>
SNW CAM 2	No	Start: 12.08.14 End: 07.08.16  A total of 1358 pictures, with one to two pictures per day.	Located on rockslide block in the SE part of Ádjet mountain	479559	7691586	Ca. 1026	The camera was mounted on a tripod ca. 1 m above ground, looking E covering the area where GTL 1 and ATL 1_2014 was located. Unfortunately, due to wind, icing and snow the camera was tilted during the campaign.	Uovision UV565 trail camera See documentation in in folder Deliverables\Hardware\Trail Cameras\Uovision UV565  Images can be found in: Data-folder in the <a href="#">supplementary data</a> .
SM 1	Yes	Start: 23.08.17	Located on the middle part of the SE-rock glacier lobe.	479558	7691587	Ca. 859	Wooden stick with 10 cm markers dug down and secured with rocks and wires.	Snow measurement stick.



#### 8.4.1 TL CAM – TIME-LAPSE CAMERA OVERLOOKING NW ROCK GLACIER LOBE (795 M A.S.L.)



Figure 22 – Location, line-of-sight and setup of a time-lapse camera (TL CAM) overlooking the most active rock glacier lobe (NW) on Ádjet.



#### 8.4.2 SNW CAM 1 – TRAIL CAMERA OVERLOOKING THE MIDDLE PART OF THE SE-ROCK GLACIER LOBE (874 M A.S.L.)

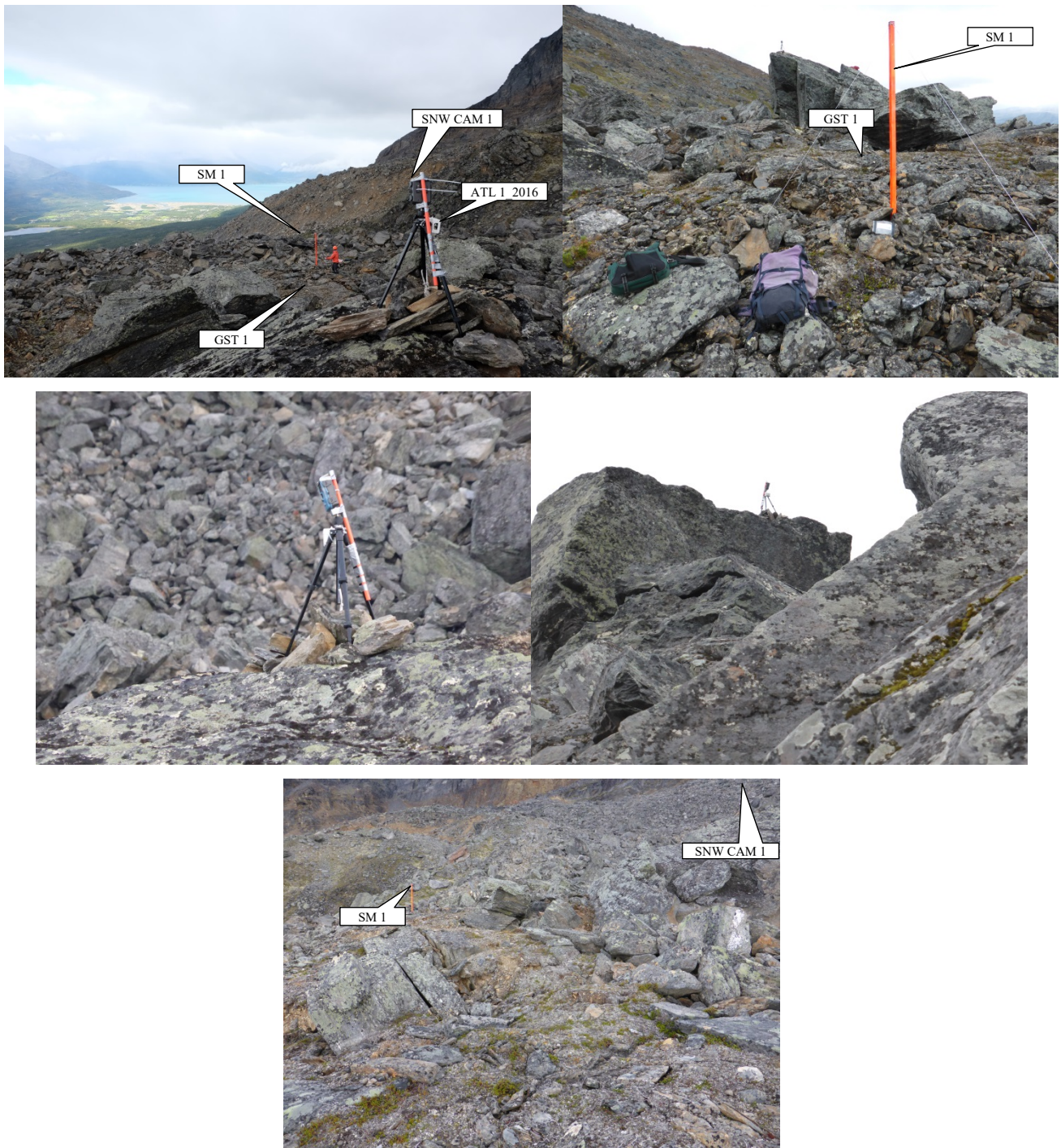


Figure 23 – Location, line-of-sight and setup of a camera SNW CAM 1 (yellow solid line) overlooking the middle part of the SE rock glacier lobe containing ground surface temperature logger (GST 1) and Snow depth Measurement stick (SM 1).



### 8.4.3 SNW CAM 2 – TRAIL CAMERA, ROCKSLIDE BLOCK, SE PART OF ÁDJET (1026 M A.S.L.)

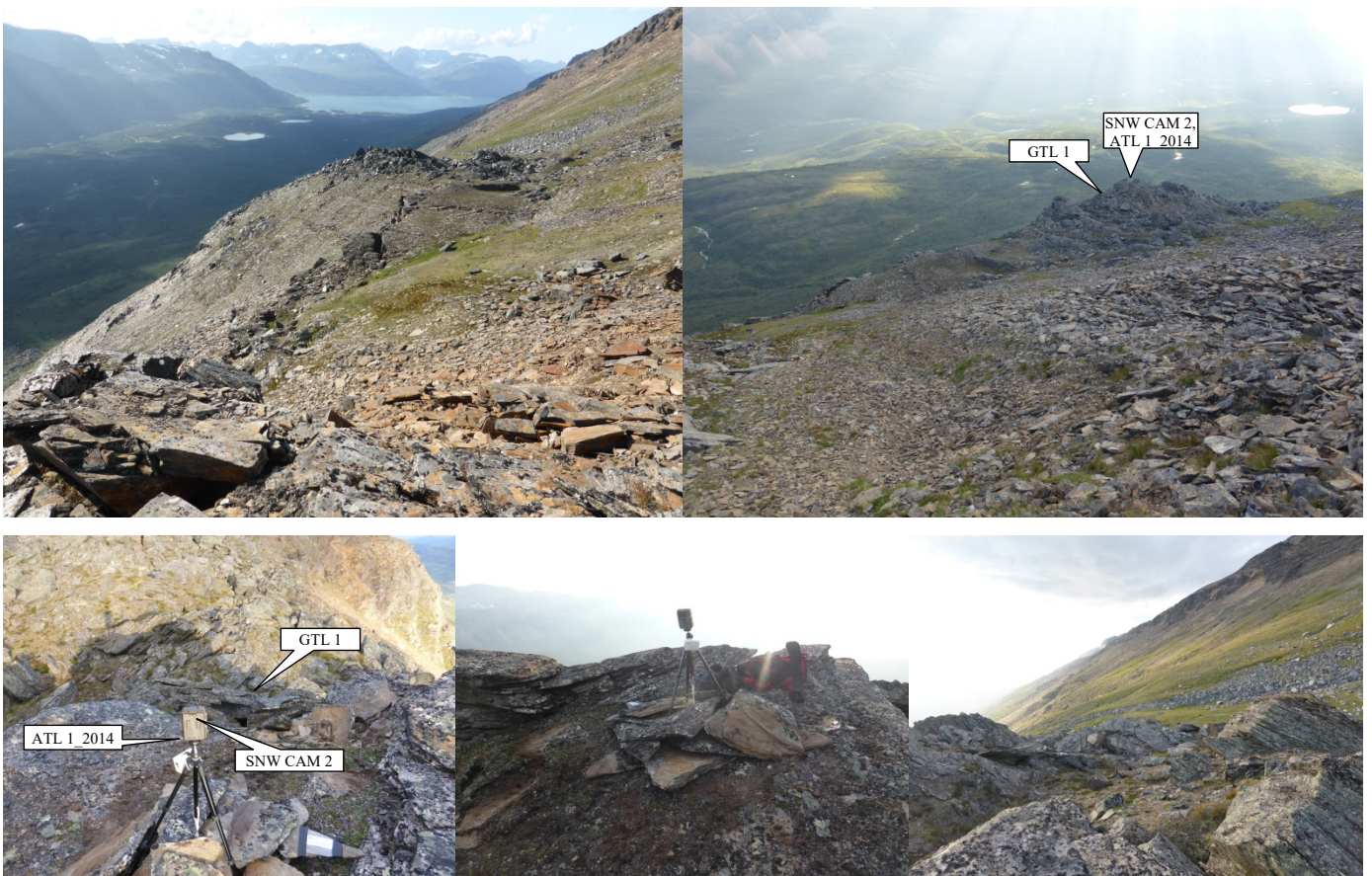


Figure 24 – Overview of camera setup (SNW CAM 2) and location of ground temperature logger GTL 1 and air temperature logger ATL 1\_2014.



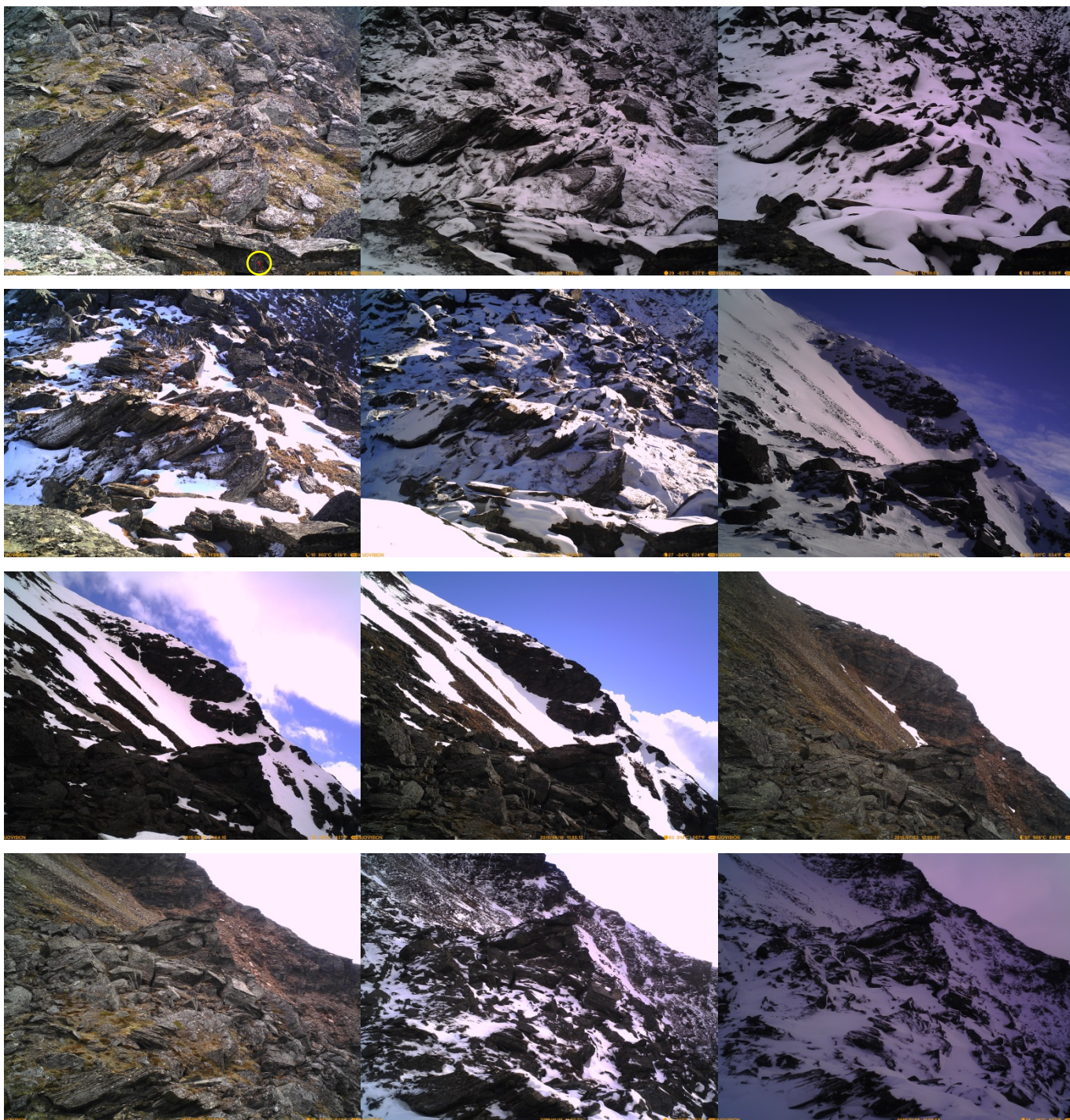


Figure 25 – Some pictures from trail camera SNW CAM 2 from different times of year. The area where GTL 1 was located are marked with a yellow circle.



## 8.5 CHARACTERISTICS OF DIFFERENTIAL GPS POINTS

Name	Active	Date	Location	Lat	Lon	Altitude (m a.s.l.)	Comment
GPS DIFF 1	Yes	First measurement 23.08.17	Start of traverse placed on a presumed stable boulder on the S side of the NW lobe.	69°21'43,85264"N	20°24'51,10075"E	826,02	Setup: Pole with quick release adapter giving 200 cm from tip to center of antenna. Photos: 9658, 9659.
GPS DIFF 2	Yes	First measurement 23.08.17	Point #2 in traverse on NW lobe.	69°21'47,72472"N	20°24'46,64631"E	889,896	Setup: Pole with quick release adapter giving 200 cm from tip to center of antenna. Photos: 9969.
GPS DIFF 3	Yes	First measurement 23.08.17	Point #3 in traverse on NW lobe.	69°21'49,00285"N	20°24'43,93615"E	887,218	Setup: Pole with quick release adapter giving 200 cm from tip to center of antenna. Photos: 9945.
GPS DIFF 4	Yes	First measurement 23.08.17	Point #4 in traverse on NW lobe.	69°21'49,97265"N	20°24'42,13265"E	891,562	Setup: Pole with quick release adapter giving 200 cm from tip to center of antenna. Photos: 9959.

### 8.5.1 GPS DIFF 1 (826 M A.S.L.)



Figure 26 – The location of the measured point GPS DIFF 1 is given by the tip of the pole (left) and the white arrow (right).



### 8.5.2 GPS DIFF 2 (889 M A.S.L.)



Figure 27 – The location of the measured point GPS DIFF 2 is given by the white arrow (left) and the tip of pole (right).

### 8.5.3 GPS DIFF 3 (887 M A.S.L.)



Figure 28 – The location of GPS DIFF 3 is marked with a small cairn and the measured point is located inside the circle of rocks (white arrow).

### 8.5.4 GPS DIFF 4 (891 M A.S.L.)







**Figure 29 – The location of GPS DIFF 4 is marked with a small cairn and the measured point is located between two rocks (white arrows and end of the probe).**

## 8.6 CHARACTERISTICS OF GPS BOLTS

Name	Active	Lat	Lon	UTM		Altitude (m a.s.l.)	Comment
				UTM_E	UTM_N		
GPS BOLT 1	No			476199	7691357	247,423096	Old GPS reference point used in the SE part of Adjet mountain.
GPS BOLT 2	Yes			477010	7695058	897,75	Placed on a 3x2x2 m boulder on the lateral side of the NW rock glacier lobe.
GPS BOLT 3	Yes			477118	7694577	844,87793	Placed on a 2x3x3 m boulder on the frontal part of the SE high velocity rock glacier lobe.
GPS BOLT 4	Yes			477374	7694906	963,599854	Placed on a 5x3x3 m boulder on the upper part of the SE-rock glacier lobe.
GPS BOLT 5	No			479559	7691587	1026,325439	Bolt on the rockslide block in SE part of Adjet.
GPS BOLT REF	Yes	69°21'39,928"N	20°24'38,93"E	476822	7694737	785,007	Bolt placed on bench between the NE and SE rock glacier lobe.

### 8.6.1 GPS BOLT 2 (897 M A.S.L.)



Figure 30 – Photos of GPS BOLT 2.



### 8.6.2 GPS BOLT 3 (844 M A.S.L.)



Figure 31 – Photos of GPS BOLT 3.

### 8.6.3 GPS BOLT 4 (963 M A.S.L.)



Figure 32 – Photos of GPS BOLT 4.

#### 8.6.4 GPS BOLT REF (785 M A.S.L.)



Figure 33 – Photos of GPS BOLT REF.

## 9 APPENDIX 3 – GEOPRECISION TEMPERATURE LOGGERS

This appendix contains specifications of the GeoPrecision temperature loggers, instructions of how to change batteries and links to description of how to install software, set up the logger, and readout temperature data.

On the Ádjet mountain two types of GeoPrecision temperature loggers produced by [GeoPrecision GmbH](#) have been set out; one version measuring the temperature on the tip of a 225 cm cord (M-Log5W-CABLE) and one without cord (M-Log5W-SIMPLE). All the following apply to both types.

For information on how to install software and readout the temperature data follow the instruction in the document *Doku\_FlexGate\_Software\_Eng\_v1.pdf* found in the *Hardware\GeoPrecision-folder in the supplementary data*.

GeoPrecision software and drivers can be found in the *Hardware\GeoPrecision\Applications-folder in the supplementary data*, at <http://www.geoprecision.com/en/downloads-en>, or at [ftp://80.153.164.175/GeoPrec/Docu\\_Software/GP\\_Wireless/](ftp://80.153.164.175/GeoPrec/Docu_Software/GP_Wireless/)

### 9.1 SPECIFICATIONS

- Temperature range: -40°C to +85°C; (Tidbit: -20°C to +50°C)
- Memory: 512k, good for about 8.5 years at hourly sampling rate without clearing the memory; (Tidbit 32k)
- Typical accuracy <+/- 0.2°C in the range -20°C to +40°C; (Tidbit: +/- 0.4°C at 21°C)
- Resolution: 0.01°C; (Tidbit: 0.3°C)
- Battery: Re-changeable. Work for 8 years (and at least for 5 years under arctic conditions)
- Contact to logger via radio communication via a USB-dongle for the PC. No need to touch the logger or move into dangerous terrain to readout the logger (e.g., year by year). Therefore, measurement conditions will be stable for at least 5 years.
- The battery voltage is sampled every time logger is red out.

### 9.2 REPLACING THE BATTERY

With the permission of Dr. Harald Pauli, the instructions below are adapted from procedures developed in the GLORIA project (see <http://www.gloria.ac.at> for more information). More documents and guidelines from the GLORIA project can be found the *Hardware\GeoPrecision\GLORIA project documents-folder* in the [supplementary data](#).



## **Required tools:**



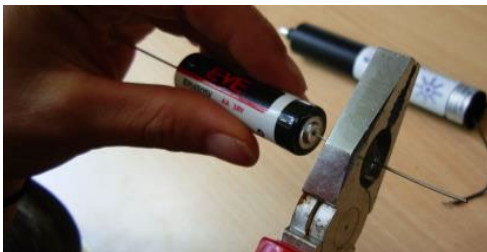
1. Geo-Precision MLog5W Data logger
2. Battery (3,6 Volt lithium AA-size battery with soldering wires. E.g. "Saft LS14500 axial")
3. Gas-fired (gas-powered) soldering iron (For example <https://www.conrad.de/de/gasloet-set-toolcraft-pt237-1300-c-130-min-588418.html>, or the ERSA GaslötKolben Independent 130).
4. Refill gas tank (lighter gas)
5. End-cutting (universal) pliers
6. Tin-solder (soldering wire)
7. Heat-shrink tubing: inner diameter unshrunked (original) ca. 2-3 mm
8. Petroleum spray or vaseline (not shown)
9. Paper-clip (optional)
10. Tweezers (optional)

## **Preparations of battery before going into the field:**

Battery type to be used is

- Lithium, 3.6 V
- Size AA with solder tail already mounted to the battery
- High pulse load capability
- E.g. "Saft LS14500 axial"

1. Shorten the solder tails of the batteries to approx. 5-8 mm.

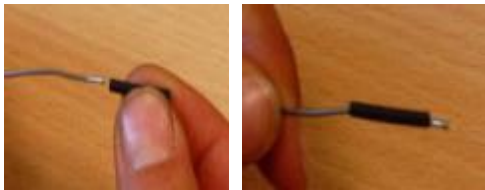


### Replacing battery in the field:

1. Readout the temperature data by following the instructions in the document *Doku\_FlexGate\_Software\_Eng\_v1.pdf* found in the *Hardware\GeoPrecision\Applications-folder* in the [supplementary data](#).
2. Open the screw lock at the rear side of the logger and remove the battery.
3. Slide away the old heat-shrinking tube from the contact (only on the positive pole) and desolder the old battery. Remove the contact from the negative pole before removing the contact from the positive pole. Remember which contact is positive and which negative (usually positive is red) and remove the old heat-shrinking tube.



4. Cut a piece of 5-10 mm of the new heat-shrinking tube and slide it over and down the positive contact. The heat-shrinking tube will protect the contacts from interfering with each other.



5. For installation of the new battery solder the **positive** pole first. You may use tweezers to hold the contacts in place while soldering.



6. Slide the heat-shrinking tube from the contact up to the battery and over the soldered **positive** pole and heat it up with the soldering iron so that it shrinks and secures the positive contact from interfering with the negative one.



7. Solder the **negative** contact. There is no heat-shrinking tube needed.



8. Slide the battery back into the data logger.
9. Use petroleum spray to seal the screw lock of the logger and lock it again tightly.
10. Check with your laptop and the USB-dongle mounted if the logger is properly working and if time settings and parameters are still appropriate. Just check the settings and adjust if necessary, but do not clear (do not delete) the old data on the logger.
11. After having successfully checked the loggers settings, take a note of the start date (start date), start time (time) and UTC-difference (UTC diff).