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INSTRUMENTATION AND TEMPERATURE DATA (2013–2017), GÁMANJUNNI 3 ROCKSLIDE AND ROCK GLACIER, MANNDALEN, TROMS

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Summary:

This report documents the setup and results from an ongoing temperature campaign on the Gámanjunni 3 rockslide and rock glacier in Manndalen in Troms. Results indicate that permafrost is probable both in the rockslide and rock glacier and document temperature variations between 2013 and 2017. Temperature data, detailed maps, an ESRI ArcMAP-project, trial camera photos and logger-software from this campaign have been made available as a Figshare-repository.

Emneord: Temperature loggers; Unstable rockslope; Rockslide; Rock glacier; Permafrost.

Noter:

This work is part of Harald Øverli Eriksen's PhD, funded by a grant from Troms County Council. mailto:haraldoverlieriksen@gmail.com

I would like to acknowledge the people at NVE in Manndalen for help with logistics and accommodation during fieldwork. Thanks to NGU for helping out with logistics during fieldwork, and for sharing DEM and orthophoto from the Gámanjunni 3 rockslide. Many thanks to Patrick Larsen and Line Rouyet for their contribution during field campaigns.

Front page:
Gámanjunni 3 with interpreted geological and geomorphological structures. Modified after Eriksen et al. (2017). Aerial photo from NGU.

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Preface

This document and appendixes report on results from an ongoing campaign for temperature measurements in the Gámanjunni 3 rockslide and rock glacier in Manndalen, Kåfjord, Troms. This report is part of the Norwegian Water Resources and Energy Directorate (NVE) project «Kartlegging av 3D-bevegelsesmønster, og videreføring av temperaturovervåking på Gámanjunni, Kåfjord Troms.» In-situ instrumentations and field work was performed as part of Harald Øverli Eriksen’s PhD (Eriksen, 2017).

1 INTRODUCTION

The Gámanjunni 3 rockslide is defined as a high-risk object due to the possible catastrophic consequence if a collapse should occur (Böhme et al., 2016b). The knowledge about thawing permafrost and possible kinematic response to unstable slopes is still poor. This report describes instrumentation and results from an ongoing campaign for temperature measurements started in 2013 at the Gámanjunni 3 rockslide and rock glacier in Manndalen, Kåfjord, Troms.

The rockslide is located on a steep west-dipping valley slope and ranges in elevation from ca. 600 to 1220 ma.s.l. It is one of several active rockslides on the east side of (Bunkholt et al., 2013a; Bunkholt et al., 2013b; Henderson et al., 2011). The bedrock is mainly fractured along two steeply dipping fracture sets and the foliation is sub-horizontal. The upper part consists of a ~300 × 200m wedge-shaped block controlled by two back scarps, that has moved ~150 m downslope with a dip of 45° (Böhme et al., 2016b) (Figure 1).

Temperature loggers distributed from head to toe of the landforms give a first view of the ground thermal regime. Former and present instrumentation includes: Air Temperature Loggers (ATL) measuring temperatures 1 to 2 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 blocks, and Rock Wall Loggers (RWL) measuring temperatures in shallow boreholes on the steep faces of rockslide blocks. In addition, this document describes the instrumentation after a major upgrading of loggers in August 2017. Temperature trends from loggers are discussed for the rockslide for the period 2013–2016.

For many of the GTL locations, 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 a Figshare-repository (Table 1). Pictures captured by a trail camera located in the middle of the rockslide from summer 2014 to summer 2015, detailed maps, an ESRI ArcMAP-project and logger-software from this campaign can be found in the same repository (Table 1).

The continuation and responsibility of this campaign is now managed by Norwegian Water Resources and Energy Directorate (NVE).

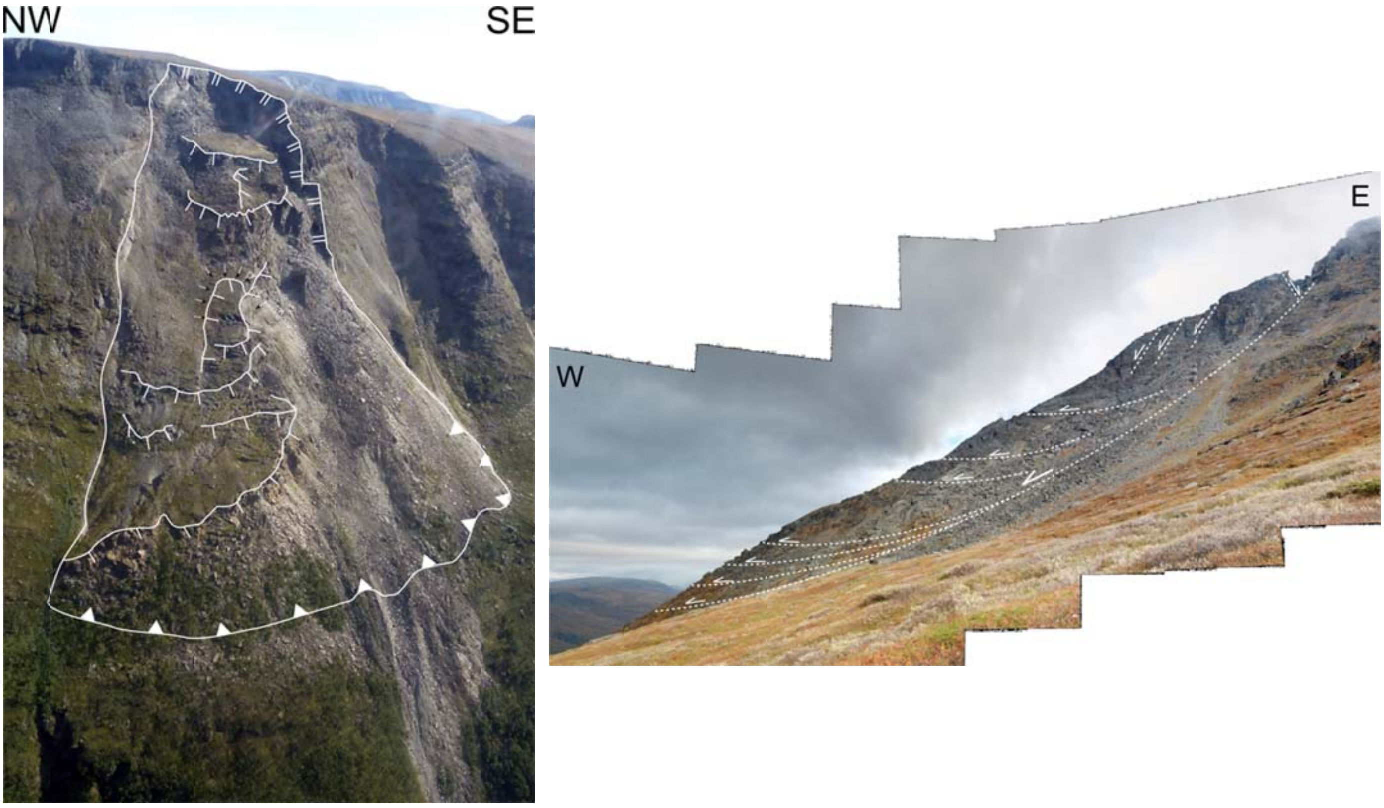

Figure 1 – Gámanjunni 3 with interpreted geological and geomorphological structures. Modified after Eriksen et al. (2017). Aerial phtot from NGU.

Table 1 – Overview of supplementary data.

Title	Description	Download link
Supplementary_Data_for_Norut_Report_Gamanjunni3_Instrumentation.zip	The zip-file includes: - An ESRI Arcmap project and shapefiles documenting the position of instrumentation - Measurements from temperature loggers and pictures from time-lapse cameras - Drivers and software used for setting up and downloading temperature loggers and time-lapse cameras - Maps presenting the location of the instrumentation cameras	https://doi.org/10.6084/m9.figshare.6254750
Gamanjunni3_Thermal_Regime_2013-2017.xlsx	The Excel file contains temperature measurements and graphs from the campaign.	https://doi.org/10.6084/m9.figshare.6256148

2 METHODS

2.1 TEMPERATURE MEASUREMENTS

From summer 2013 to summer 2017, three different kinds of loggers were used, a HOBO 4-Channel External Data Logger from Onset, a Tinytag logger from Gemini Data Loggers Ltd and several DS1921G Thermochron iButtons loggers made by Maxim Integrated.

In August 2017, all loggers, except for the HOBO-logger, 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\Hardware***-folder (Table 2).

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

Instruments	Type	Manufactures	Location
HOBO 4-Channel External Data Logger	Temperature logger	Onset	Deliverables\Hardware\HOBO\ Supplementary_Data_for_Norut_Report_Gamanjunni3_Instrumentation.zip
Tinytag Plus 2 (TGP-4020)	Temperature logger	Gemini Data Loggers Ltd	Deliverables\Hardware\Tinytag2 Supplementary_Data_for_Norut_Report_Gamanjunni3_Instrumentation.zip
Thermochron iButton loggers (DS1921G)	Temperature logger	Maxim Integrated	Deliverables\Hardware\iButtons Supplementary_Data_for_Norut_Report_Gamanjunni3_Instrumentation.zip
M-Log5W-CABLE and M-Log5W-SIMPLE wireless temperature loggers	Temperature logger	GeoPrecision	Deliverables\Hardware\GeoPrecision Supplementary_Data_for_Norut_Report_Gamanjunni3_Instrumentation.zip See also manufactures web page: ftp://80.153.164.175/GeoPrec/Docu_Software/GP_Wireless/
UV565	Trail camera	Uovision	Deliverables\Hardware\Trail camera Supplementary_Data_for_Norut_Report_Gamanjunni3_Instrumentation.zip

2.1.1 2013–2017 CAMPAIGN

For measurement of air temperature, Thermochron iButton (DS1921G) loggers from Maxim Integrated were used. These are small rugged, self-sufficient loggers. In each ATL, two iButtons loggers were mounted in a ventilated white plastic box. The loggers were isolated from the box using small closed-cell foam pads. ATLs were set out at three different elevations at Gámanjunni 3: on the top above the back scarp (1190 m a.s.l.), on the main slide block (1100 m a.s.l.) and in the middle part of the rockslide (838 m a.s.l.). The ATL on the top (ATL 1) was mounted 1 m above ground on a tripod, ATL on the block (ATL 2) and in the middle (ATL 3) were mounted ca. 2 m above ground on the radar satellite corner reflectors, SATREF1 and SATREF2, respectively.

To investigate the ground thermal regime, we used GTL recording air temperature in fractures and pore space between blocks. 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 blocks. GTLs were located from the back fracture of the main slide block down to the toe of the rockslide at 660 m a.s.l.

In 2015, one Tinytag ground surface temperature (GST) logger was set out on the main slide block in the upper part of the rockslide. It measured temperatures in the soil-cover, a couple of cm below the surface.

To measure temperatures in the back fracture of the rockslide, a HOBO logger with a main unit and four 15 m long thermistors were set out in the pore space between rocks filling up the back fracture related to the main block.

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. The same interval was used for the HOBO thermistors. The Tinytag logger measured temperature every hour.

Data from loggers were downloaded in the field using a laptop. Data from the HOBO main unit was downloaded using a standard USB cable and software from the manufacture. Downloading data from the Tinytag logger required a proprietary cable and software. An iButton reader with USB connection was used for reading out temperature data from the iButtons loggers. For redundancy all GTLs are equipped with at least two iButtons.

For a description of each logger used (name, operation time, location) within the rockslide, see Appendix 1, and for the rock glacier, see Appendix 2.

2.1.2 CAMPAIGN STARTED AUGUST 2017 WITH GEOPRECISION TEMPERATURE LOGGERS

In August 2017, all loggers accept for the HOBO-logger were replaced with wireless GeoPrecision temperature loggers with 225 cm cords (M-Log5W-CABLE) and without cords (M-Log5W-SIMPLE) (Figure 2). In addition, logging at some locations was stopped, and some new locations set up. GeoPrecision Rock Wall Loggers (RWL) were also mounted to record temperatures in ca. 20 cm deep boreholes in the steep faces of two slide blocks. The main reasons to replace iButtons loggers were to continue the campaign with loggers having longer battery duration, that can store more data, and have the 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 2 – 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/en/). The temperature logger, battery and wireless sender/receiver unit are 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 blocks were mounted inside plastic sticks (Figure 3). Loggers were secured inside the sticks using two screws, and a cord attached to the loggers eases the access to the logger.

Figure 3 – Mounting of GeoPrecision loggers inside plastic sticks and examples of placement in space between blocks.

For measuring temperature in rock walls, the M-Log5W-CABLE loggers were mounted in shallow boreholes using brackets (Figure 4, left), and for measuring ground surface temperature the logger was hidden below rocks, and the cord dug down into the upper soil cover. The end-point of the cord, measuring the temperature, was inserted below a few cm of untouched soil (Figure 4, right).

Figure 4 – Examples of mounting GeoPrecision loggers with cables for measurement of temperature in shallow boreholes in rock walls (left) and ground surface temperature (right).

The GeoPrecision loggers can be accessed wireless at distances up to 50 m using a USB-dongle. The document ***Doku_FlexGate_Software_Eng_v1.pdf*** found in the ***Deliverables\Hardware\GeoPrecision***-folder 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 logger on Gámanjunni 3 rockslide and rock glacier, Manndalen, 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 hourly reading - Used on Gámanjunni 3 from august 2017.txt" in folder ***Deliverables\Hardware\GeoPrecision\Setup hourly reading - Used on Gamanjunni 3 from august 2017***, 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 2013–2017, 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 from ground temperatures and indicators for the presence of permafrost as done by Haeberli (1973) and Hoelzle (1992). In studies from the European Alps, BTS-vaules 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-values < -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. Modelled snow depth data from 850 m a.s.l. in Skibotn is from MET Norway (SeNorge.no). Average temperatures and mean annual air temperatures are based on six daily measurements (00:00, 04:00, 08:00, 12:00, 16:00, 20:00).

3 LOCATION OF TEMPERATURE LOGGERS AND INSTRUMENTATION

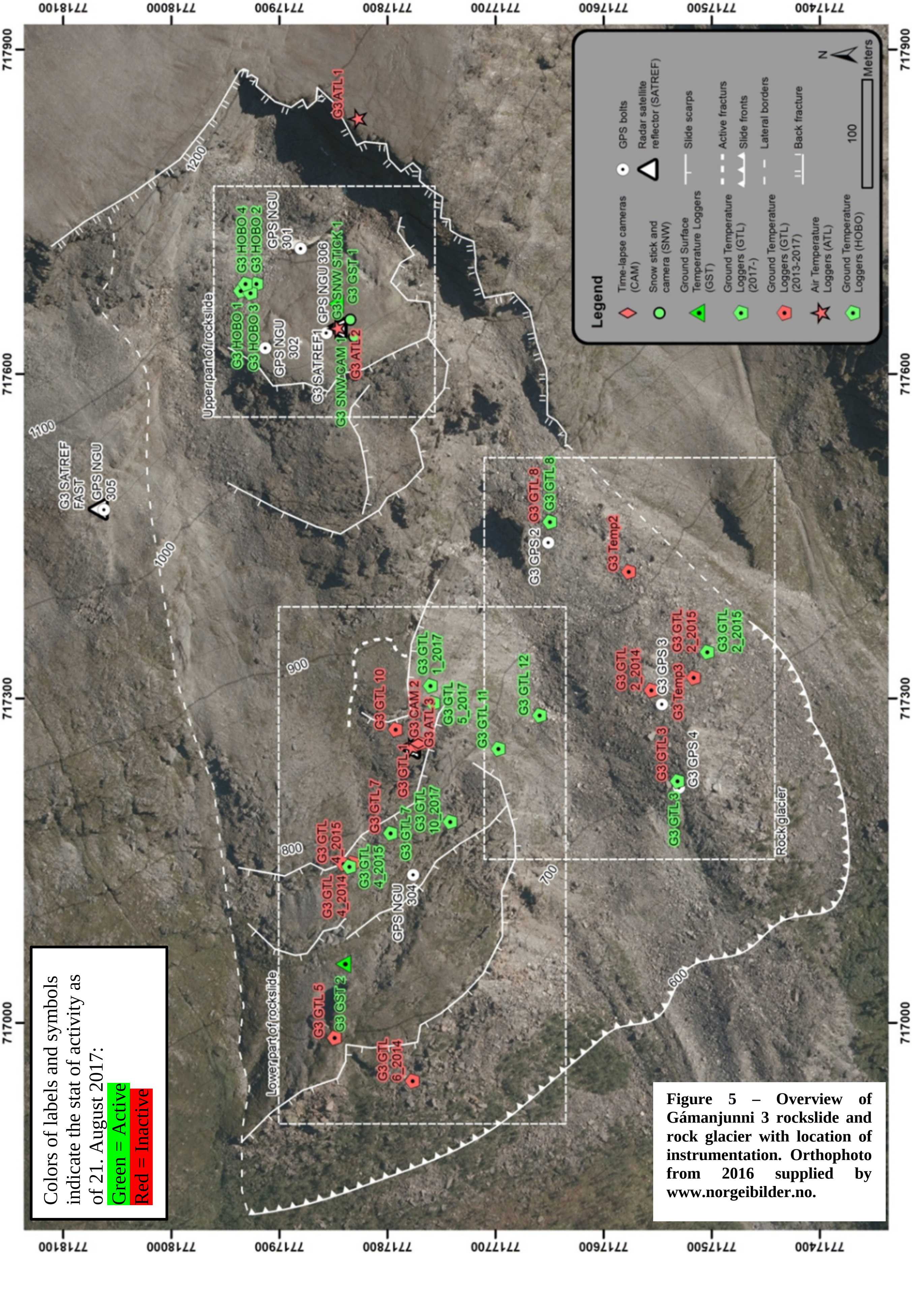

Figure 5 – Overview of Gámanjunni 3 rockslide and rock glacier with location of instrumentation. Orthophoto from 2016 supplied by www.norgeibilder.no.

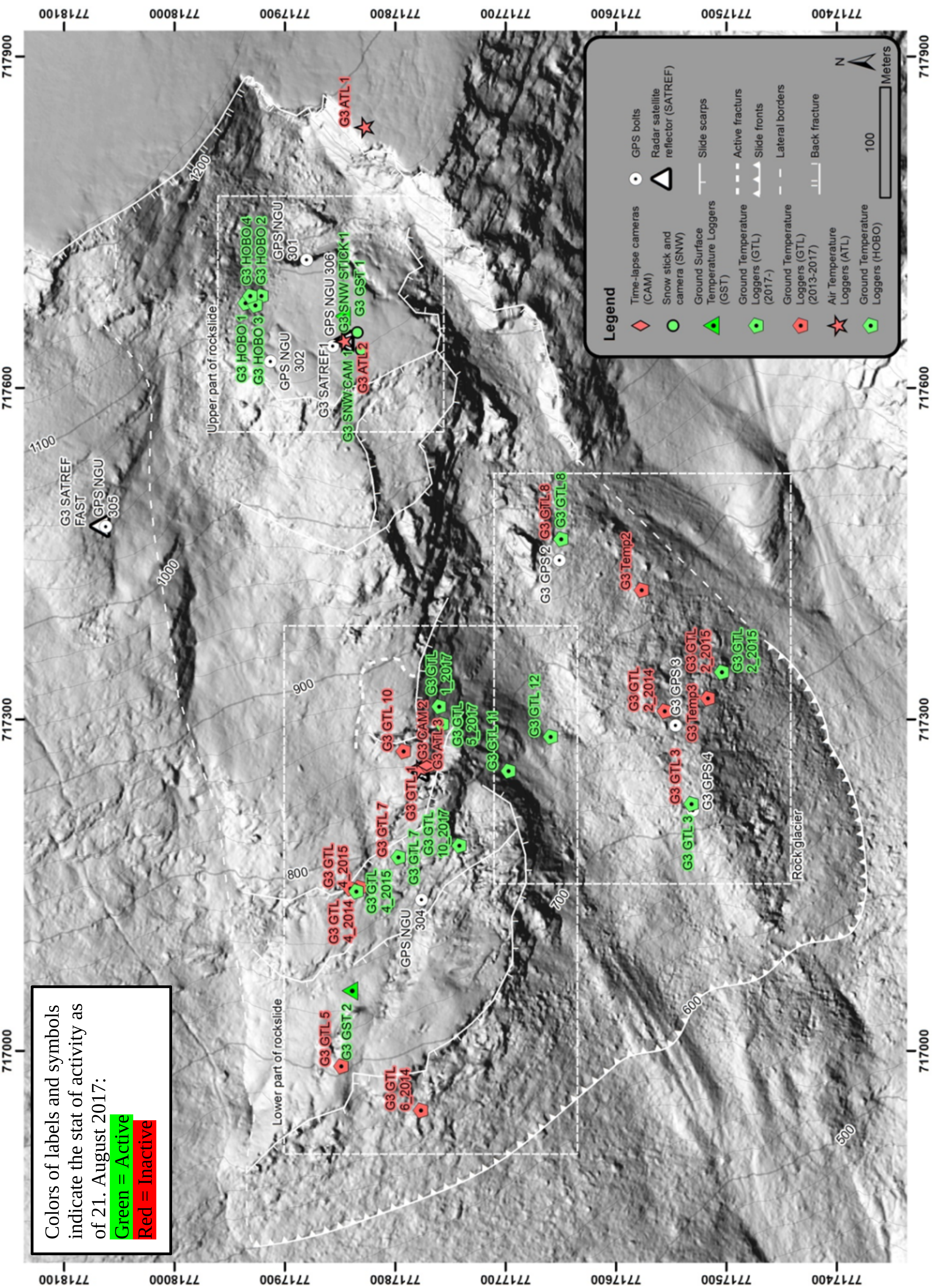

Figure 6 – Overview of Gámanjunni 3 rockslide and rock glacier with location of instrumentation. Hillshade from Norwegian Mapping Authority.

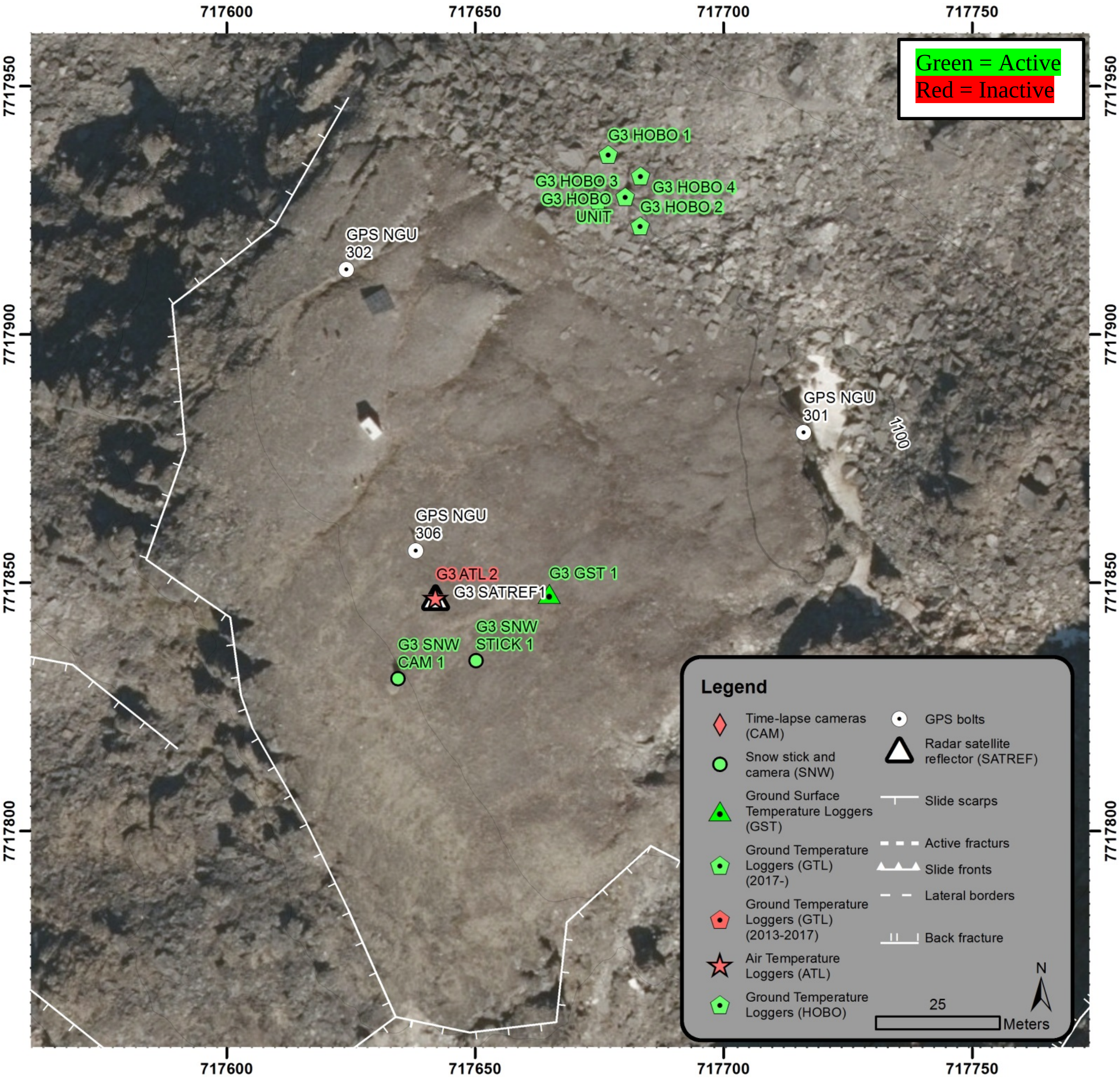

Figure 7 – Close-up of upper part (main block) for the Gámanjunni 3 rockslide with location of instrumentation. Colors of labels and symbols indicate the state of activity as of August 21, 2017 (Green = Active, Red = Inactive). Orthophoto from www.norgeibilder.no.

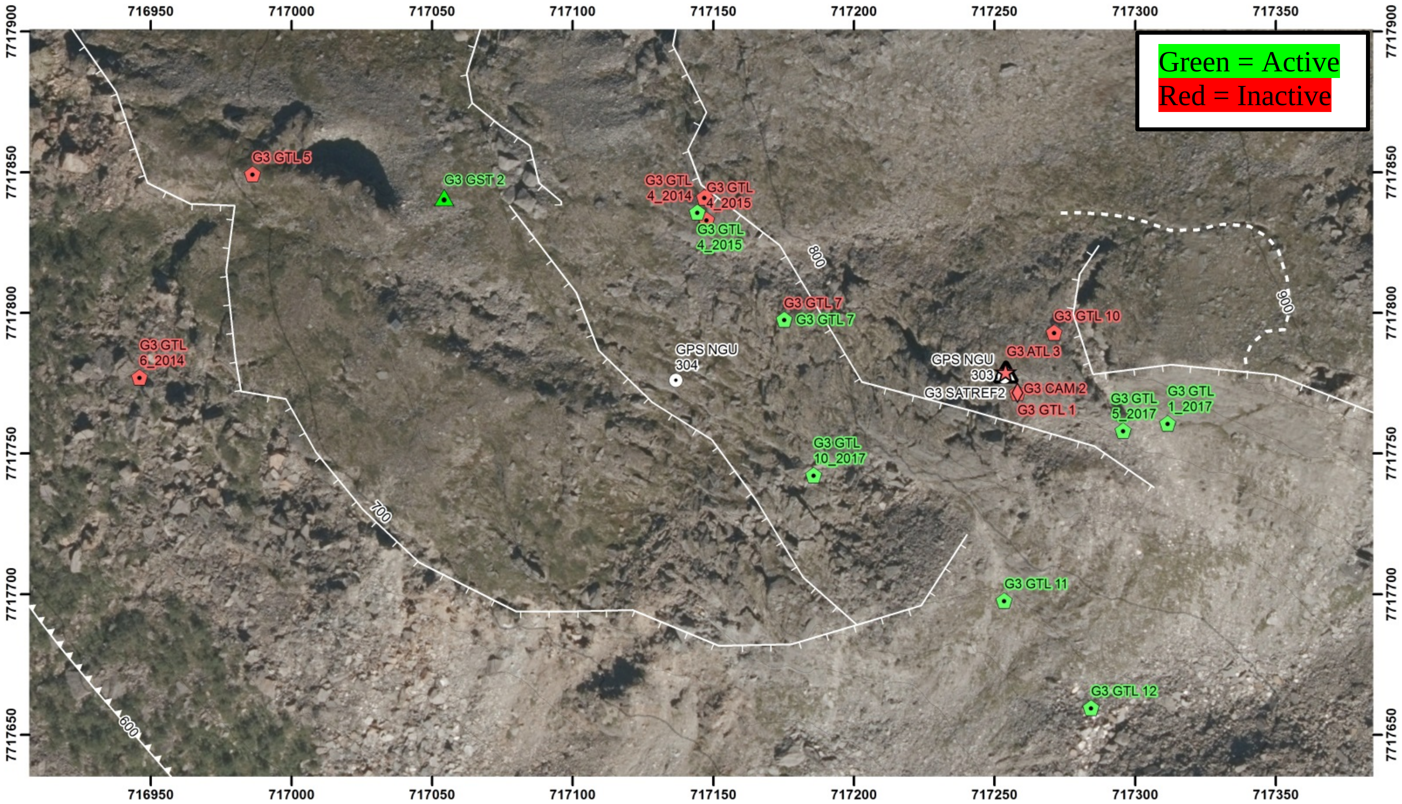

Figure 8 – Close-up of lower part of Gámanjunni 3 rockslide with location of instrumentation. Colors of labels and symbols indicate the state of activity as of 21. August 2017 (Green = Active, Red = Inactive). Orthophoto from www.norgeibilder.no.

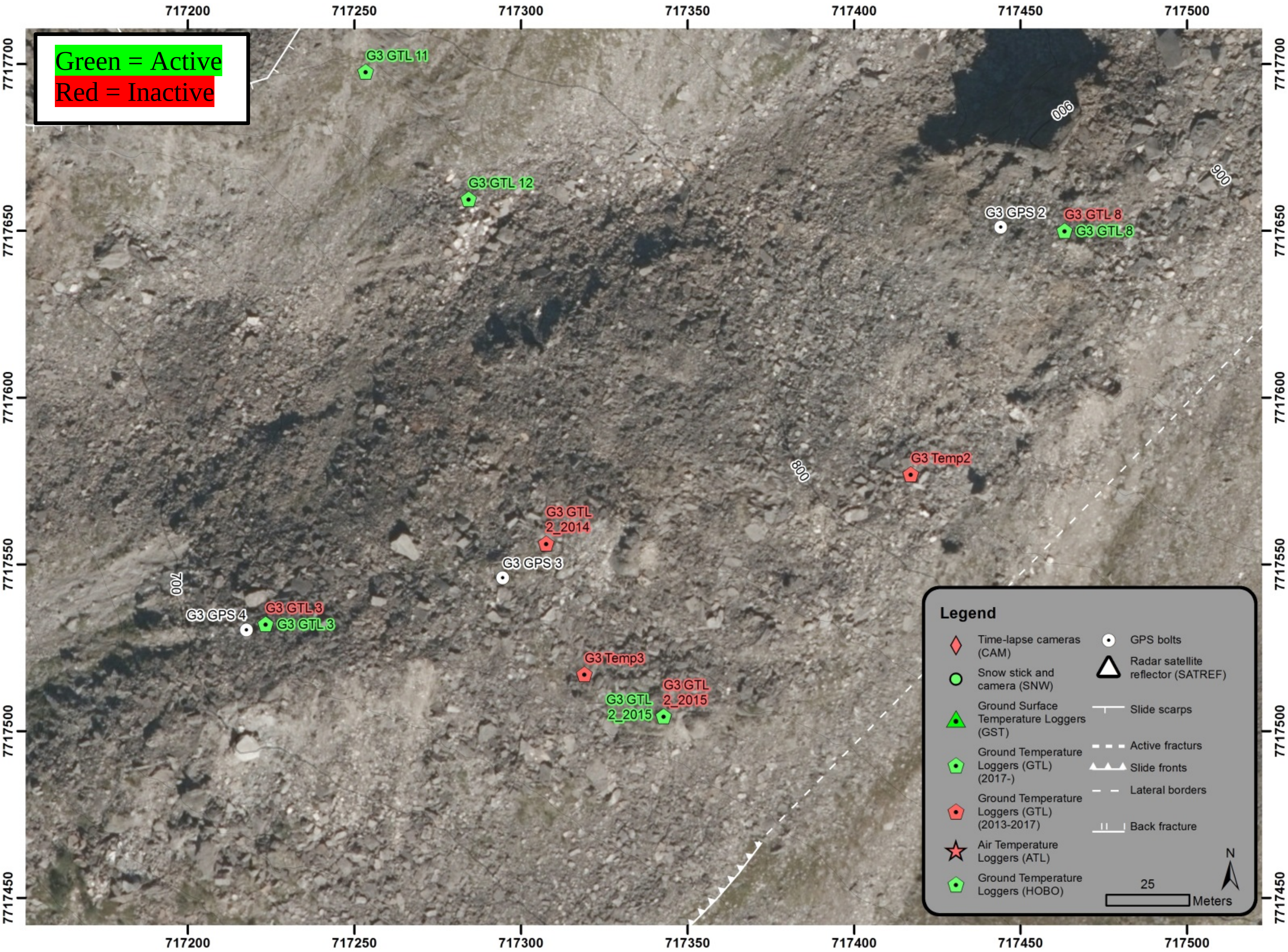

Figure 9 – Close-up of Gámanjunni 3 rock glacier with location of instrumentation. Colors of labels and symbols indicate the state of activity as of 21. August 2017 (Green = Active, Red = Inactive). Orthophoto from www.norgeibilder.no.

4 2013–2017 TEMPERATURE REGIME OF ROCKSLIDE AND ROCK GLACIER

A subset of data from loggers at different locations at the Gámanjunni 3 rockslide and rock glacier are presented in the following. In September 2013, the first loggers were set out on the rock glacier and during August 2014 several more on the rockslide (Table 3). Some of the loggers are still in their original position and some have been relocated during the campaign, see Appendix 1 and 2 for details. Presented results concentrate on data from loggers located deepest in the ground at each location. Data from additional loggers giving temperature gradient in fracture/pore space is omitted here, but can be found in the supplied datasets. 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 and made it hard to calculate annual temperatures for most of the locations. For comparison of ground thermal state between years, we computed average temperature based on available data from each year.

Table 3 – Total loggers used during the campaign. Only a subset of data are presented for each location in this report. Data from additional loggers can be found in the *Deliverables\Data*-folder.

Time periods	Number of temperature locations in the rockslide	Number of temperature locations in the rock glacier	Total number of loggers
2013–2014	0	3	32
2014–2015	12	4	69
2015–2016	15	2	88
2016–2017	14	3	39
2017–	15	3	18

4.1 2013–2016 AIR AND GROUND TEMPERATURES FROM THE ROCKSLIDE

In this section, we present logged temperatures, computed average temperatures and interpreted BTS-values from the Gámanjunni3 rockslide. Location of loggers can be found in Section 3 and Appendix 1.

Average air temperatures from ATL 1 and 3, mean annual air temperatures (MAAT) and cumulative freeze and degree days from ATL 2 document colder conditions from 2014–2015 than 2015–2016 (Table 5, Table 6 and Figure 10e). The temperature increase is reflected in measurements from the back fracture at 1100 m. a.s.l. The annual temperatures for the four HOBO thermistors (HOBO 1-4), located in the blocks filling up back fracture, reported colder mean annual temperatures in 2014–2015 (between -2.87 and -2.60 °C) than in 2015–2016 (between -1.49 and -0.85 °C) (Table 7). From about 5. February 2015, we see damped variations in air temperature in fracture with respect to air temperature (Figure 10a, c). After this, all HOBO loggers registered steadily increasing temperatures. From May 16. 2015 and the next 9 days, air temperatures increased while bottom temperature of snow during thick snow cover (BTS) levelled out at temperatures from -4.4 °C to -3.6 °C (Figure 10a, b). In December and January 2016, cold air lowered temperatures in the back fracture. In the end of January, temperatures were still affected by air temperature, but with damped variations (Figure 10c). From the end of March 2016, variations were small, indicating an intact snow cover.

BTS-values were now slowly increasing, to -4.4 to -3.5 °C, corresponding to a small increase compared to 2015, except for HOBO 1.

On the same block as the HOBO-loggers, measurements of ground surface temperature (GST) started in the autumn 2015. GST 1 measured 6 days with stable temperatures around 0 °C (zero-curtain) before increasing in the beginning of May 2015, meaning that the snow cover disappeared during this period (Figure 10b). GST 1 measured a bottom temperature of snow (BTS) of -3.6 °C in the beginning of May 2016.

In the middle part of the rockslide, GTL 1 (836 m a.s.l.) measured damped temperature variations from the beginning of February 2015 (Figure 10a, c). After period of cold weather, GTL 1 logged stable temperatures from end of February until beginning of May ending at a BTS-value of -5.25 °C. In 2016, the snow cover period at this location was shorter, with stable temperatures from March 16 to April 25. BTS-values were between -5 and -4 °C.

GTL 4_2014 (780 m a.s.l.) and GTL 7 (789 m. a.s.l.) in the middle part of rockslide/upper part of toe, measured damped and steadily increasing temperatures from February to the end of April 2015, ending at -3°C and -3.5°C, respectively. On the contrary, the GTL 7 and GTL 10 measured decreasing trends from early January 2016 to stable BTS-values of -3.5 and -4 °C in the end of April. The GTL 4_2015 logger seems to be located in a ventilated fracture having open access to air temperature variations even during maximum snow cover, because the measured temperatures follow the same pattern as the air temperatures. This logger therefore cannot be used as a proxy for ground temperature and BTS-values.

In the front of the rockslide toe, the GTL 6 logger (660 m a.s.l.) followed air temperature variations with steadily decreasing temperatures during end of 2014 and January 2015. From the beginning of February until the end of April 2015, GTL 6 temperature decoupled from the air temperature. From the beginning of February, temperatures were increasing toward a stable BTS-value of -2.5 °C in end of April. The same pattern is visible in 2016, but shifted in time. The logger was decoupled from air temperature variations ca. on December, 8, about two months earlier than in 2015. This resulted in a higher BTS-value of -1.5 °C in 2016.

The two iButtons at GTL 5 show unusual variation with respect to temperature patterns observed from the other loggers. From beginning of November 2014 to the end of June 2015, and from end of November to the end of May 2016, temperatures were stable between -0.5 to 0.5 °C. The same pattern is repeating in the winter of 2016–2017. From the annually abrupt repeating temperature pattern at GTL 5, we suspect that the loggers are kept warm during the winter with temperatures around freezing-point, because of release of latent heat from freezing of groundwater seepage. In spring, the temperature stays at 0 °C until all ice has melted. This can explain why we see the same pattern repeating in the winter of 2014–2015, 2015–2016 and 2016–2017 for both iButtons (Figure 10).

GTL 6 was isolated from air temperatures about two months longer in 2015–2016 than 2014–2015. BTS-values vary between temperatures indicating that permafrost is possible (between -2°C and -3°C) and not present (> -2°C). This may indicate that the GTL 6 logger is located at the limit of local permafrost.

Table 4 – Color scale used for temperatures in tables below. Temperatures are given in °C (Haeberli, 1973; Hoelzle, 1992).

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

Table 5 – Average air temperature. Average temperatures are based on available data, not spanning full years. Mean annual temperatures based on measurements from full years are bold and underlined. See Table 3 for legend of the background colors.

Loggers	Altitudes (m a.s.l.)	MAAT 01-SEP-2014– 31-AUG-2015 (°C)	MAAT 24-MAY-2015–23-MAY-2016, (°C)	Average temperature based on 339 days from 9-AUG-2014 – 14-JUL-2015 (°C)	Average temperature of 341 days from 28-AUG-2015 – 03-AUG-2016 (°C)	Average temperature of 341 days from 25-AUG-2016 – 01-AUG-2017 (°C)
ATL 1 (iButtons)	1190	-	-	-4.13	-2.97	-
ATL 2 (iButtons)	1085	**-2.21**	**-1.78**	-3.15	-	-2.34
ATL 3 (iButtons)	838	-	-	-1.70	-0.56	-

Table 6 – Cumulative freeze degree days (FDD) and cumulative temperature computed based on air temperatures from ATL 2 at the block 1100 m a.s.l.

Period	Cumulative FDD (°C)	Cumulative temperature (°C)
9-AUG-2014 – 23-MAY-2015	-8731.75	-7164.25
09-AUG-2015 – 23-MAY-2016	-8227	-5752.75

Table 7 – Average temperature and fracture temperatures below thick snow cover (BTS) for loggers at the Gámanjunni 3 rockslide. Average temperatures are based on available data, but not spanning full years. Mean annual temperatures based on measurements from full years are bold and underlined. Loggers are sorted by altitude. See Table 3 for legend of the background colors.
[1] **Data missing due to cut thermistor cable.**
[2] **Fracture temperature follow same pattern as air temperature, therefore it is not possible to find the BTS-value.**
[3] **It is not possible to interpret BTS-values from temperatures.**

Loggers	Depths	Altitudes (m a.s.l.)	Average temperatures 2014–2015	Average temperatures 2015–2016	Average temperatures 2016–2017	2015 BTS, °C	2016 BTS, 2. °C	2017 BTS, °C
HOBO 1	7.5 m	1100	**-2.60 °C,** 01-SEP-2014– 31-AUG-2015, 365 days	-1.0 °C, 01-SEP-2015– 24-AUG-2016, 359 days	[1]	**-3.9**	**-4.4**	[1]
HOBO 2	7 m	1100	**-2.75 °C,** 01-SEP-2014– 31-AUG-2015, 365 days	-1.09 °C, 01-SEP-2015– 24-AUG-2016, 359 days	[1]	**-4.3**	**-4.0**	[1]
HOBO 3	2.5 m	1100	**-2.64 °C,** 01-SEP-2014– 31-AUG-2015, 365 days	-0.85 °C, 01-SEP-2015– 24-AUG-2016, 359 days	**-1.89 °C** 01-SEP-2016–31–AUG-2017, 365 days	**-3.6**	**-3.5**	**-2.8**
HOBO 4	5 m	1100	**-2.87 °C,** 01-SEP-2014– 31-AUG-2015, 365 days	-1.49 °C, 01-SEP-2015– 24-AUG-2016, 359 days	**-2.29 °C** 01-SEP-2016–31–AUG-2017, 365 days	**-4.4**	**-4.2**	**-3.66**
GST 1 (Tinytag)	2-3 cm	1090	-	**1.197 °C,** 15-SEP-2015– 14-AUG-2016, 365 days	**0.014 °C,** 21-AUG-2016– 20-AUG-2017, 365 days	-	**-3.6**	**-2.6**
GTL 10 (iButtons)	3 m	850	-	-0.42 °C, 28-AUG-2015– 03-AUG-2016, 341 days	-0.38 °C, 25-AUG-2016– 01-AUG-2017, 341 days	-	**-4.0**	**-2.75**
GTL 1 (iButtons)	4 m	836	-2.87 °C, 10-AUG-2014– 13-JUL2015, 337 days	-0.73 °C, 28-AUG-2015– 03-AUG-2016 341 days	-0.01 °C, 25-AUG-2016– 01-AUG-2017 341 days	**-5.25**	**-4 – -5**	**-3.0**
GTL 7 (iButtons)	7.5 m	789	-1.34 °C, 10-AUG-2014– 14-JUL-2015, 338 days	-0.73 °C, 14-SEP-2015– 21-AUG-2016, 341 days	-1.09 °C, 25-AUG-2016– 01-AUG-2017, 341 days	**-3.5**	**-3.5**	**-3.25**
GTL 4_2014 (iButtons)	6 m	780	-1.54 °C, 10-AUG-2014– 14-JUL-2015, 338 days	-	-	**-3**	-	-
GTL 4_2015 (iButtons)	15 m	781	-	-1.83 °C, 14-SEP-2015– 21-AUG-2016, 341 days	-0.92 °C, 25-AUG-2016– 01-AUG-2017, 341 days	-	[2]	**-2.25**

GTL 5 (iButtons)	3 m before, and 5 m after 14-SEP-2015	705	0.84 °C, 10-AUG-2014–14-JUL-2015, 338 days	1.57 °C, 14-SEP-2015–21-AUG-2016, 341 days	1.24 °C, 25-AUG-2016–01-AUG-2017, 341 days	**3**	**3**	**3**
GTL 6 (iButtons)	3 m	660	-2.65 °C, 10-AUG-2014–14-JUL-2015, 338 days	-0.46 °C, 14-SEP-2015–21-AUG-2016, 341 days	0.04 °C, 25-AUG-2016–01-AUG-2017, 341 days	**-2.5**	**-1.5**	**-1.25**

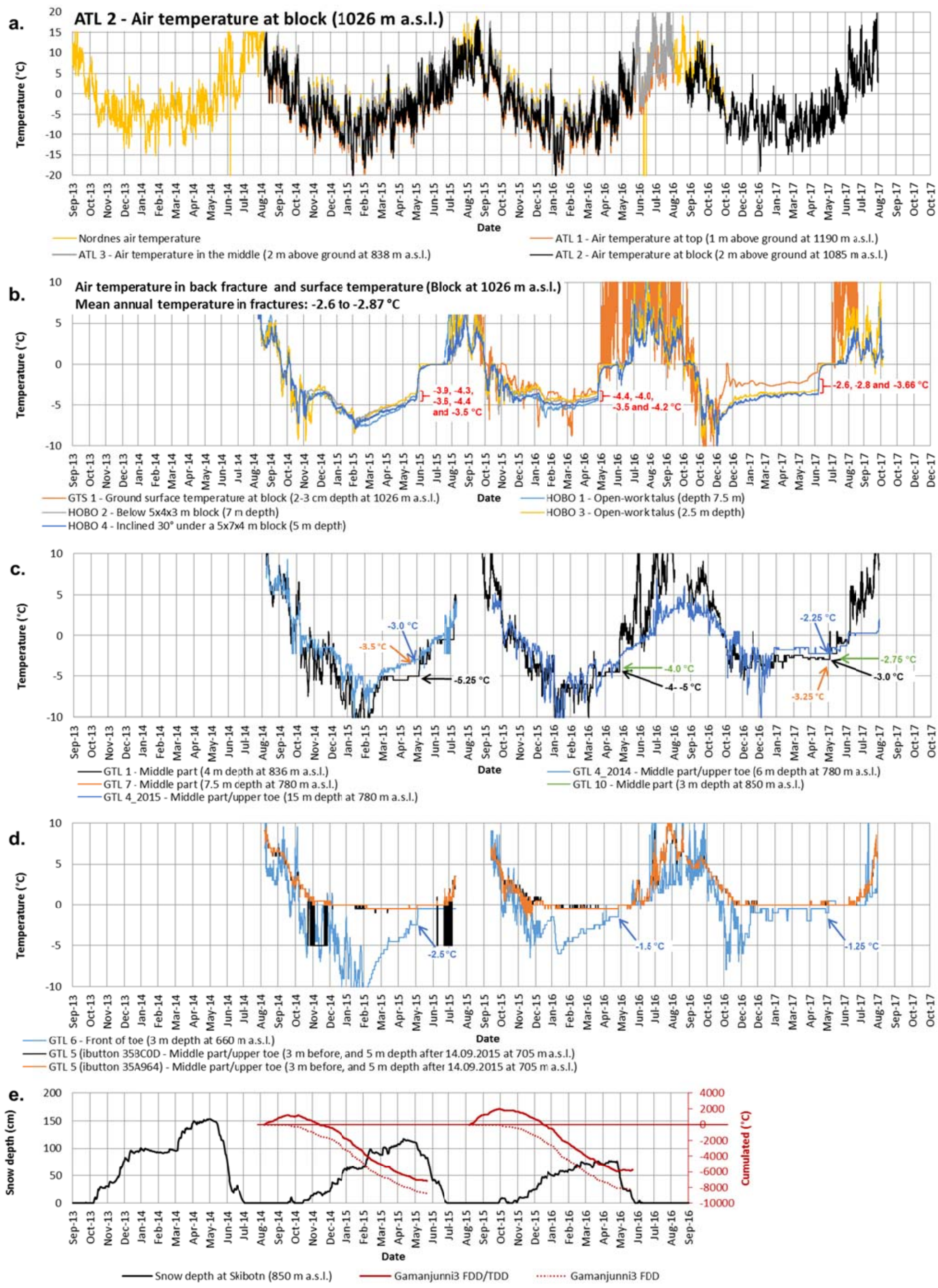

Figure 10 – Air and ground thermal regime for Gámanjunni 3 from loggers (a–e) with MET-Norway modelled snow depth data from 850 m a.s.l in Skibotn for comparison (e). Freeze and thaw degree days (FDD/TDD) are based on values from ATL 2 located at the block of Gámanjunni 3 (1085 m a.s.l.). Modelled snow depth at 850 m a.s.l. in Skibotn from MET Norway (SeNorge.no).

4.2 TEMPERATURE REGIME FOR THE ROCK GLACIER

This section summarizes average temperatures, interpreted BTS-values and temperature time series for loggers located on the rock glacier southeast of the rockslide. Locations of loggers are given in Section 3 and Appendix 2.

Table 8 – Characteristics of ground temperature loggers at the Gámanjunni 3 rock glacier. Average temperatures are based on available data, not spanning full years. Mean annual temperatures based on measurements from full years are <u>bold and underlined</u>. Loggers are sorted by altitude. See Table 3 for legend of the background colors.

Loggers	Depths	Altitudes (m a.s.l.)	Average temperatures 2013–2014 (°C)	Average temperatures 2014–2015 (°C)	Average temperatures 2015–2016 (°C)	Average temperatures 2016–2017 (°C)	2014 BTS (°C)	2015 BTS (°C)	2016 BTS (°C)	2017 BTS (°C)
GTL 8 (iButtons)	1.7 m from 2014–2015 and 1.3 m from 2015	872	-	-2.25 04-AUG-2014–28-MAY-2015, 288 days	-0.06 17-JUN-2015–23-MAY-2016, 341 days	-0.5 25-AUG-2016–02-AUG-2017, 341 days	-	**-4.5**	**-4.25**	**-2**
Temp2 (iButtons)	2 m	817	0.05 18-SEP-2013–06-AUG-2014, 322 days	-	-	-	**-4**	**-**	**-**	**-**
GTL 2_2014 (iButtons)	1 m	765	-	-1.33 13-AUG-2014–13-JUL-2015, 335 days	-	-	-	**-1.5**	**-**	**-**
GTL 2_2015 (iButtons)	5 m	742	-	-	-0.87 28-AUG-2015–03-AUG-2016, 341 days	-0.61 25-AUG-2016–02-AUG-2017, 341 days	-	-	**-3**	**-2.25**
Temp3 (Tinytag)	5 m	750	-1.20 01-JAN-2014–31-DEC-2014 **<u>365 days</u>**	-1.935 26-AUG-2014–25-AUG-2015 **<u>365 days</u>**	-	-	**-3.5**	**-3.5**	**-**	**-**
GTL 3 (iButtons)	3.5 m	725	0.74 19-SEP-2013–18-SEP-2014, **<u>365 days</u>**	-0.11 14-JUL-2014–13-JUL-2015 **<u>365 days</u>**	-	-0.093 25-AUG-2016–02-AUG-2017, 341 days	**-3**	**-3.5**	**-**	**-2.75**

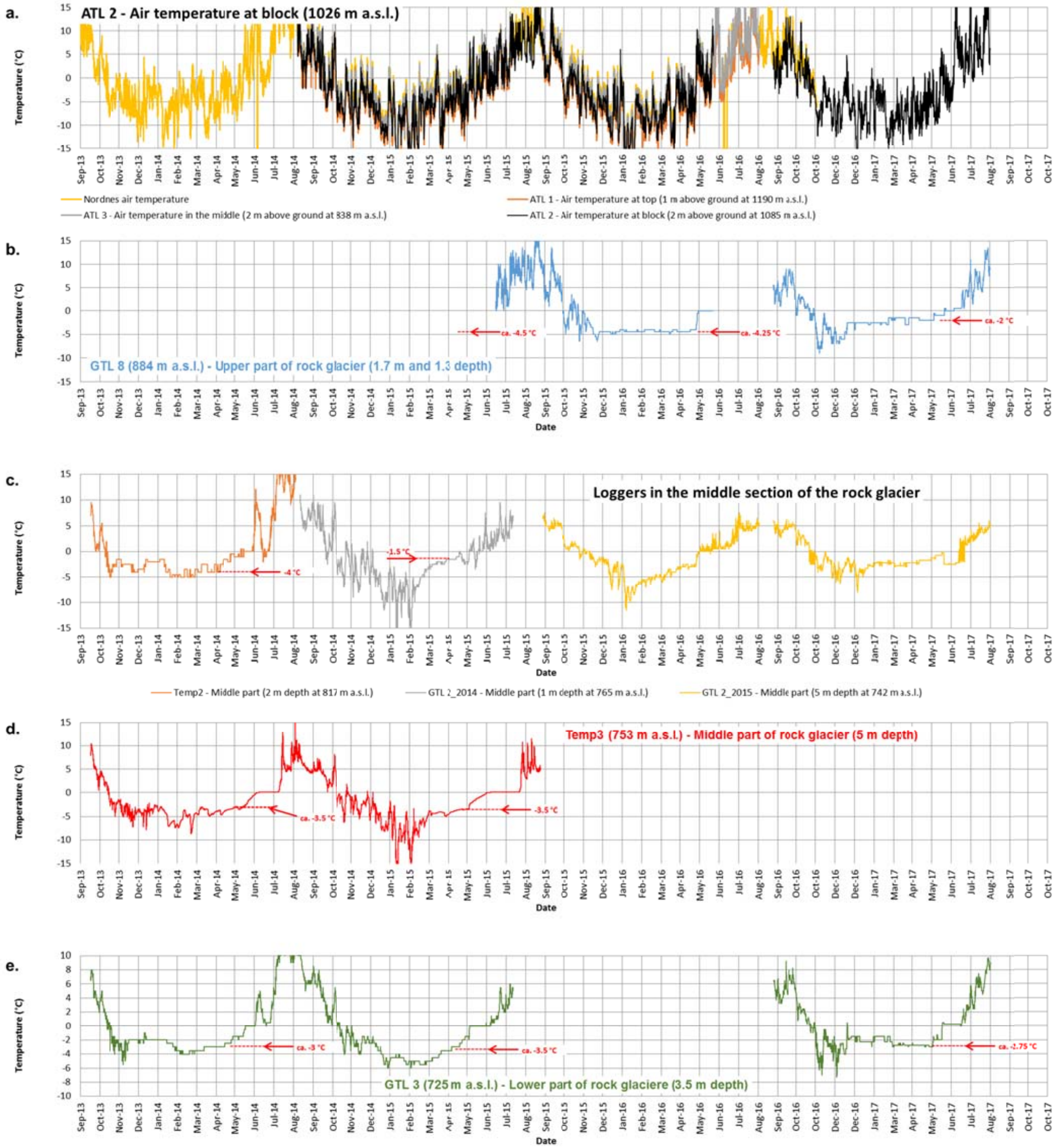

Figure 11 – Temperature data for the rock glacier southeast of Gámanjunni 3 rockslide.

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 little information about spatial variations of ground temperature.

Lacking borehole instrumentations, we rely on many temperature measurements 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 the upper part of the rockslide, average annual temperatures (HOBO 1–4) and BTS-values, measured at depths from 2.5 to 7.5 m between blocks filling up the back fracture of the main rockslide block, clearly indicated permafrost conditions (Table 7 and Figure 10). Average air temperatures indicate coldest conditions on the top of the slope with higher average air temperatures in the middle part and lower part. Annual ground surface temperatures from the main rockslide block (GST 1) are above freezing, though conditions are still favorable for formation of permafrost, as indicated by cold mean annual air temperatures (MAAT) (ATL 2) (Table 5). In the middle and lower part of the rockslide, average temperatures and BTS-values are somewhat higher, but except for the two lowermost loggers (GTL 5 and 6), temperatures indicate that permafrost is probable or possible.

Measurement from the nearby Jettan rockslide document permafrost conditions almost down to sea level Blikra and Christiansen (2014). This is possibly due to the Balch effect (Barsch, 1996), which significantly cools the fracture and surrounding rock promoting permafrost development. The thermal regime around GTL 6 is most likely affected by the Balch effect, in addition to the duration and thickness of snow cover, making it impossible to conclude that this is the lower limit of permafrost.

Except for one logger (Temp2) BTS-values indicated that permafrost is probable or possible on the rock glacier (Table 8). As with the rockslide, varied but mostly cold average- and annual temperatures document permafrost conditions (Figure 11).

For the rockslide and rock glacier together, we observe a possible trend from 2013 to 2017 indicating increasing average temperatures and BTS temperatures (Table 7 and Table 8).

Observed year to year variations in average temperatures and BTS-values can be due to changed air circulation because of opening of fractures or because of yearly variability in snow cover insulation (duration and thickness).

6 CONCLUSION

Using loggers measuring air-, ground- and fracture/pore space temperatures this campaign documents that permafrost is probable both on the Gámanjunni 3 rockslide and rock glacier.

Year to year average temperatures have some variations, possibly due to variations of air temperatures, differences in timing and distribution of snow cover, or maybe because of changed air circulation patterns in the active layer as new fractures opens and blocks are rearranged. Nevertheless, temperature measurements from 2013–2017 may show a week warming trend of ground temperatures.

Böhme et al. (2016) found by dating that the initial movement of the Gámanjunni 3 rockslide started about 7100±1800 years ago. The total movement have been ca. 150 m giving a mean velocity of 2±0.5 cm/yr. Today ground- and satellite based radar together with in-situ instrumentation (GNSS) document a mean velocity of ca. 5 cm/yr (Böhme et al., 2016a; Eriksen et al., 2017), indicating an increasing trend.

To investigate and understand how displacement of unstable slopes respond to climatic warming, it is vital to ensure continuation of temperature measurements at Gámanjunni 3.

This site is a well-suited candidate and a perfect laboratory due to the long time series of temperature measurements, and deformation data from satellite-, and especially, ground-based radar campaigns.

This campaign was a part of Harald Øverli Eriksen’s PhD. The continuation and responsibility of this campaign is now managed by Norwegian Water Resources and Energy Directorate (NVE).

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9 APPENDIX 1 – DESCRIPTION OF ROCKSLIDE INSTRUMENTATION

This appendix contains a listing of instrumentation used for measuring air temperatures in fractures and pore spaces (GTL and HOBO), ground surface temperatures (GST), air temperatures (ATL), and a measurement stick and trail cameras used for observing snow depth and distribution in the rockslide.

9.1 CHARACTERISTICS OF GROUND TEMPERATURE LOGGERS

Name	Active	Operation time	Location	UTM East_34W	UTM North_34W	Altitude (m a.s.l.)	Comment
HOBO control unit	Yes	Start: 08.08.14 End: Still logging	Measurement of air temperatures at various depths between large boulders filling up the back fracture of the main block at ca. 1100 m. a.s.l.	483227.52	7708065.19	1101.333	The main unit (HOBO® U12 4-External Channel Outdoor/Industrial Data Loggers - Part # U12-008) connected four loggers called HOBO 1-4. The loggers were connected using thermistor cables to the main unit. Thermistor cables were shield inside 20 mm plastic cables fixed in place by bolts.
HOBO 1	Yes	Start: 08.08.14 End: Still logging	Thermistor is inserted close to vertical 7.5 m into the pore spaces between blocks.				
HOBO 2	Yes	Start: 08.08.14 End: Still logging	Located under a large block (5x4x3 m) at 7 m depth.				
HOBO 3	Yes	Start: 08.08.14 End: Still logging	Located at 2.5 m depth in the pore spaces between blocks.				
HOBO 4	Yes	Start: 08.08.14 End: Still logging	Inserted 5 m under a 5x7x4 m block at ca. 30° inclination.				
GST 1	Yes	Start: 15.09.15 End: 21.08.2017 Start: Replaced by Geoprecision logger 21.08.17	Located E of SATREF1 on the rockslide block at 1090 m. a.s.l.	483210.009	7707987.633	1090.098	2015–2017: Measurement of ground surface temperature from the rockslide block at 2-3 cm depth in the soil cover using Tinytag-logger Gemini Data Loggers Ltd with 5 m cord. From 21.08.17: Tinytag replaced with Geoprecision logger with cord (M-Log5W-CABLE). Same location and depth.
GST 2	Yes	Start: 21.08.17	Located in the toe area of the rockslide.	482596.707	7708040.436	729.257	2017–: Measurement of ground surface temperature at 2-3 cm depth in the soil cover using a Geoprecision logger (M-Log5W-SIMPLE) inside a plastic stick.
GTL 10	No	Start: 28.08.15 End: 03.08.16 Start: 25.08.16 End: 01.08.17 Status: Relocated to a new position (GTL 10_2017) and upgraded to Geoprecision logger 21.08.17	Located ca. 20 m NØ from SATREF2. Located in the middle part of the rockslide, in a fracture	482807	77079710	850	2015–2016: Measurement of air temperatures in a fracture using 9 DS1921G Thermochron iButton loggers (Maxim Integrated) in a stick at ca. 3 m depth. 2016–2017 Same setup as above, but now at with 2 iButtons.
GTL 10_2017	Yes	Start: 21.08.17	Located ca. 75 m SW of SATREF2 in a fracture.	482717.88	7707929.676	775.827	2017–: Measurement of air temperatures in a fracture using a GeoPrecision (M-Log5W-SIMPLE) logger encapsulated in a stick.
GTL 1	No	Start: 10.08.14 End: 13.07.15 Start: 28.08.15 End: 03.08.16 Start: 25.08.16	4 m NE from SATREF2. Located in the middle part of the rockslide, in a fracture above the block containing SATREF2. Located in a ventilated fracture.	482792	7707951	836	2014–2016: Measurement of air temperatures in a fracture using a 2 m long plastic stick with 19 (DS1921G) Thermochron iButton loggers, secured in fracture using a 3.5 m long rope. Measurement of temperatures from ca. 3.5 to 5.5 m depths vertical down.

		End: 01.08.17 Status: Relocated to a new position (GTL 1_2017) and upgraded to Geoprecision logger 21.08.17					2016–2017 Same setup as above, but now with two iButtons-loggers at ca. 4 m depth.
GTL 1_2017	Yes	Start: 21.08.17	Ca. 60 m ESE from SATREF2. Located in the middle part of the rockslide in a deep horizontal fracture. Logger tied to rope and rock with red plastic bag for visibility.	482844.847	7707935.097	849.373	2017–: Measurement of air temperatures in a fracture using a GeoPrecision (M-Log5W-SIMPLE) logger encapsulated in a stick.
GTL 7	Yes	Start: 10.08.14 End: 14.07.15 Start: 14.09.15 End: 21.08.16 Start: 25.08.16 End: 01.08.17 Start: Replaced by Geoprecision logger 21.08.17	Located in the area between the middle part of rockslide and upper part of toe, S of small ravine. Logger is marked with small cairn.	482712.244	7707985.316	789.929	2014–2016: Measurement of air temperatures in a fracture using 5 iButtons-loggers (DS1921G) mounted on a plastic stick. The loggers were placed at ca. 7.5 m depth in ca. 1.5 m wide fracture. 2016–2017: Same fracture and depth as above, but now with two iButton-loggers. From 21.08.17: iButtons were replaced with one GeoPrecision (M-Log5W-SIMPLE) logger. Same depth.
GTL 4_2014	No	Start: 10.08.14 End: 14.07.15 Status: Measurements not continued	Located in the middle part of the rockslide, upper part of toe. Fracture is closed.	482688	7708031	780	2014–2015: Measurement of air temperatures in fracture using a stick with 2 iButton-loggers at ca. 6 m depth in a fracture striking into the slope (212/52).
GTL 4_2015	Yes	Start: 14.09.15 End: 21.08.16 Start: 25.08.16 End: 01.08.17 Start: Replaced by Geoprecision logger 21.08.17	Located in the middle part of the rockslide, upper part of toe. Fracture is closed.	482685.807	7708026.747	781.132	2015–2017: Measurement of air temperatures using stick with two iButtons (DS1921G) at ca. 15 m depth in a fracture oriented horizontal into a the slope. The logger was tied with rope to a rock covered by a plastic bag in the opening of the fracture for visibility. From 21.08.17: iButtons were replaced with one GeoPrecision (M-Log5W-SIMPLE) logger at ca. 15 m depth. Same setup as described above.
GTL 5	No	Start: 10.08.14 End: 14.07.15 Start: 14.09.15 End: 21.08.16 Start: 25.08.16 End: 01.08.17 Status: Measurements not continued	Located in the toe area.	482529	7708055	705	2014–2016: Measurement of air temperatures in a fracture using a stick with 2 iButtons, secured in fracture at 3 m depth below surface. Stick was secured with rope, and a small cairn marked the position. 2016–2017: Same fracture and setup as above, but now at 5 m depth.
GTL 5_2017	Yes	Start: 21.08.17	Ca. 45 m SE from SATREF2. Located in the middle part of the rockslide in a deep horizontal fracture. Logger tied to rope and rock with red plastic bag for visibility.	482828.566	7707935.595	844.765	2017–: Measurement of air temperatures in a fracture using one Geoprecision logger encapsulated in a stick.
GTL 6	No	Start: 10.08.14 End: 14.07.15 Start: 14.09.15 End: 21.08.16 Start: 25.08.16 End: 01.08.17 Status: Measurements not continued	Located in the front of the toe.	482482	7707987	660	2014-2016: Measurement of air temperatures using a plastic stick with 10 iButtons (DS1921G) in a fracture at ca. 3 m depth. Stick was secured with rope and the position was marked with orange spray paint. 2016–2017: Same setup as from 2014–2016, but now with two iButtons.

GTL 11	Yes	Start: 21.08.17	Located in the toe area ca. 80 m S of SATREF2.	482780.594	7707878.15	778.179	2017–: Measurement of air temperatures in a fracture using a GeoPrecision (M-Log5W-SIMPLE) logger encapsulated in a plastic stick.
GTL 12	Yes	Start: 21.08.17	Located in the area between the rockslide and the rock glacier on the southern lateral rock slide limit. This is assumed to be an area with large snow accumulation.	482807.624	7707837.965	772.235	2017–: Measurement of air temperatures in the pore space between blocks using a GeoPrecision (M-Log5W-SIMPLE) logger encapsulated in a plastic stick.

9.1.1 HOBO 1-4 - FRACTURE TEMPERATURE IN BACK FRACTURE AT 1100 M A.S.L.

Temperatures are measured at four different locations and thermistors immersed into the pore spaces and open fractures between blocks filling up the back fracture of the main rockslide block. The thermistor cables are protected inside plastic tubes. The end-point of the thermistor is close to the opening of the protective tube. The HOBO-control unit is located in a watertight housing. Where the thermistor exists, the protective tube at the surface close to the HOBO-control unit is sealed to avoid ventilation of air from the surface to the subsurface.

Figure 12 – Location of HOBO control unit (yellow diamond) and loggers in pore spaces between blocks. Close-up of some of the installation.

9.2.1 GST 1 – GROUND SURFACE TEMPERATURE AT THE UPPER BLOCK (1085 M A.S.L.)

Figure 13 – Location of ground surface temperature logger (GST 1) at the rockslide upper block. From 2015–2017 a Tinytag logger was used, and from 21. August 2017 an Geoprecision logger with cord (M-Log5W-CABLE) was used at the same spot.

9.2.2 GST 2 – GROUND SURFACE TEMPERATURE AT TOE (729 M A.S.L.)

Unfortunately, picture of logger is missing.

9.2.3 GTL 10 – FRACTURE TEMPERATURE IN THE MIDDLE PART (850 M A.S.L.)

Figure 14 – Location of GTL 10 in the middle of the rockslide indicated by yellow diamond

9.2.4 GTL 1 – FRACTURE TEMPERATURE IN THE MIDDLE PART (836 M A.S.L.)

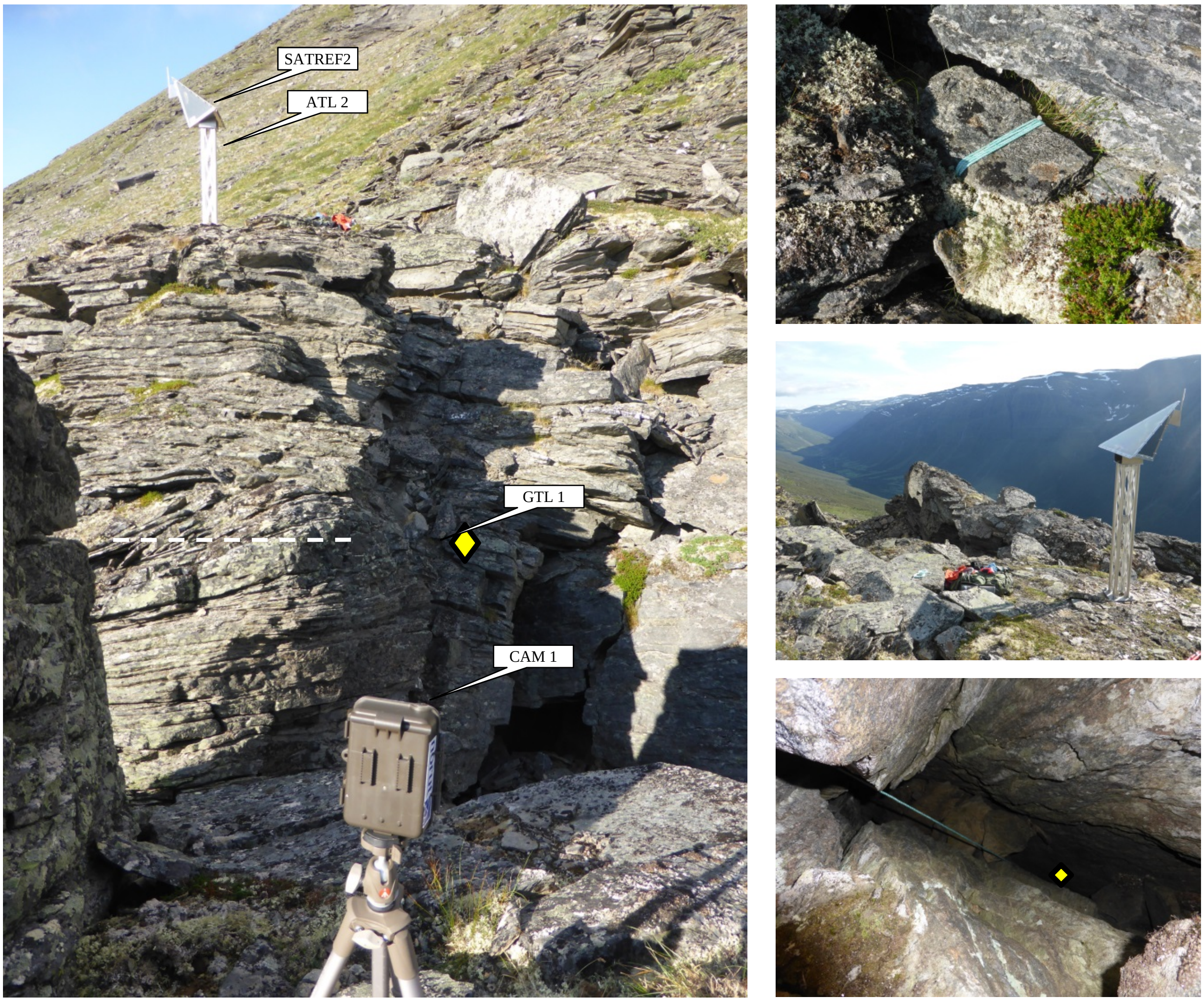


Figure 15 – Location of GTL 1. White stipple line and yellow diamond indicate location of GTL 1 temperature logger behind loose block. Trail camera (CAM 2) captured two pictures per day from August 2014 to August 2015 of the fracture containing GTL 1.

9.2.5 GTL 1_2017 – FRACTURE TEMPERATURE IN THE MIDDLE PART (849 M A.S.L.)

Figure 16 – Location of GTL 1_2017. Red plastic bag marks start of rope tied to stick with Geoprecision logger.

9.2.6 GTL 7 – FRACTURE TEMPERATURE IN THE MIDDLE PART (789 M A.S.L.)

Figure 17 – Location of GTL 7 indicated by yellow diamond.

9.2.7 GTL 4_2014 – FRACTURE TEMPERATURE IN THE MIDDLE PART/UPPER TOE (780 M A.S.L.)

Figure 18 – GTL 4_2014 inside fracture.

9.2.8 GTL 4_2015 – FRACTURE TEMPERATURE IN THE MIDDLE PART/UPPER TOE (781 M A.S.L.)

Figure 19 – Location of GTL 4_2015 indicated by yellow diamond.

9.2.9 GTL 5 – FRACTURE TEMPERATURE IN THE MIDDLE PART/UPPER TOE (705 M A.S.L.)

After 14.09.2015 I was able to lower the logger further down because the fracture had open up, increasing the depth from 3 to 5 m.

Figure 20 – Location of GTL 5 indicated by yellow diamond.

9.2.10 GTL 5_2017 – FRACTURE TEMPERATURE IN THE MIDDLE PART (844 M A.S.L.)

Figure 21 – Location of entrance to fracture containing GTL 5_2017 is marked with spray paint. Red plastic bag mark the start of the rope attached to the logger.

9.2.11 GTL 6 – FRACTURE TEMPERATURES AT THE FRONT OF THE TOE (660 M A.S.L.)

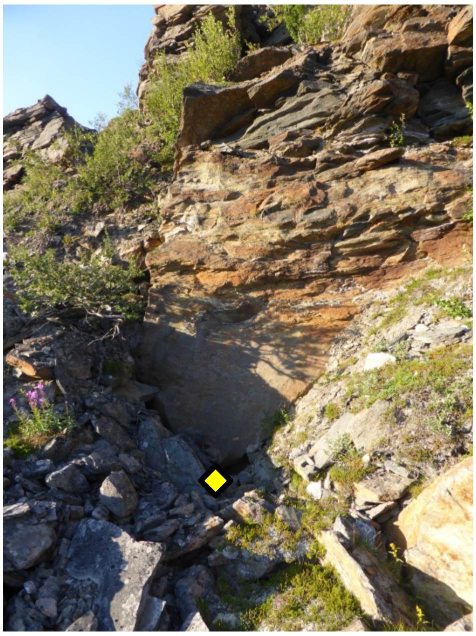


Figure 22 – Location of GTL 6 at the front of the toe indicated by yellow diamond.

9.2.12 GTL 10_2017 – FRACTURE TEMPERATURES AT THE FRONT OF THE TOE (775 M A.S.L.)

Figure 23 – Location of the entrance to fracture containing GTL 10_2017

9.2.13 GTL 11 – FRACTURE TEMPERATURES AT THE FRONT OF THE TOE (778 M A.S.L.)

Unfortunately, picture of location is missing.

9.2.14 GTL 12 – TEMPERATURE FROM PORE SPACE IN AREA ASSUMED TO HAVE LARGE SNOW ACCUMULATION (772 M A.S.L.)

Figure 24 – Location and surroundings of logger GTL 12.

9.3 CHARACTERISTICS OF AIR TEMPERATURE LOGGERS

Name	Active	Operation time	Location	UTM East_34W	UTM North_34W	Altitude (m a.s.l.)	Comment
ATL 1	No	Start: 09.08.2014 End: 14.07.2015 Start: 27.08.2015 End: 02.08.2016 Status: Measurements not continued	Located on the edge of the crest above the rockslide block.	483372	7707951	1190	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 a 1 m tall tripod facing north.
ATL 2	No	Start: 09.08.2014 End: 23.05.2016 Start: 25.08.2016 End: 01.08.2017 Status: Measurements not continued	On the satellite reflector (SATREF1) on the rockslide block.	483181	7707988	1085	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 2 m above ground, facing north, on the satellite reflector on the block (SATREF1).
ATL 3	No	Start: 09.08.2014 End: 14.07.2015 Start: 28.08.2015 End:03.08.2016 Start: 25.08.2016 End: 01.08.2017 Status: Measurements not continued	On the satellite reflector (SATREF2) in the middle part of the rockslide.	482788	7707958	838	Two iButtons (DS1921G) mounted in a ventilated white plastic box, isolated from the box using small closed-cell foam pads. The box was mounted 2 m above ground, facing north, on the satellite reflector (SATREF2).

9.3.1 ATL 1 – AIR TEMPERATURE AT THE TOP (1190 M A.S.L.)

Figure 25 – Air temperature loggers on the crest above the block. Loggers are mounted in white box under camera.

9.3.2 ATL 2 – AIR TEMPERATURE AT THE UPPER BLOCK (1085 M A.S.L.)

Figure 26 – Air temperature loggers on the block. Loggers are mounted in white box on satellite reflector (SATREF1)

9.3.3 ATL 3 – AIR TEMPERATURE LOGGER IN THE MIDDLE PART (838 M A.S.L.)

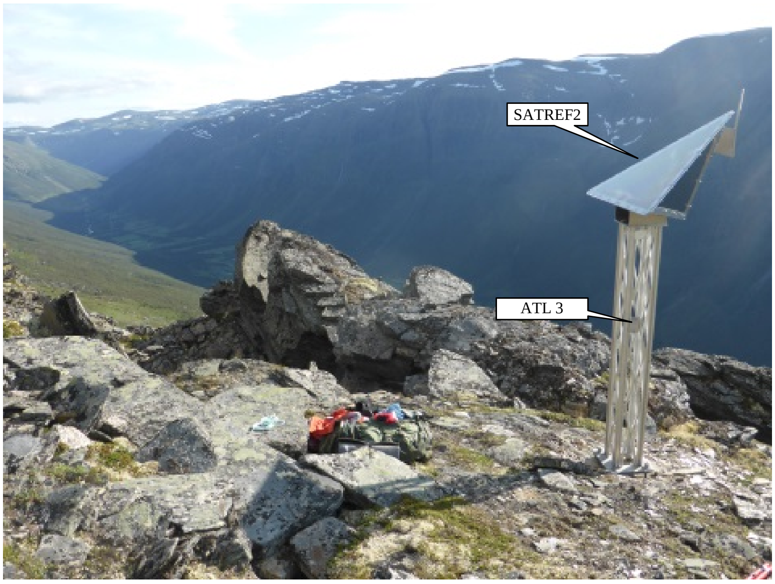


Figure 27 – Air temperature loggers in the middle part of the rockslide. Two iButton loggers are mounted in white box on satellite reflector (SATREF2).

9.4 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: 21.08.17	Ca. 30 m S of SATREF2	482787.647	7707929 812	832.02	Mounted in a vertical rock wall on E side of large rockslide block. Thermistor inserted and sealed using silicone into ca. 20 cm deep borehole.
RWL 2	Yes	Start: 21.08.17	Ca. 55 m SSW of SATREF2	482772.935	7707907.76	798.112	Mounted a SW facing steep rock wall. Thermistor inserted and sealed using silicone into ca. 20 cm deep borehole.

9.4.1 RWL 1 – EAST FACING ROCK WALL TEMPERATURE LOGGER (832 M A.S.L.)

Figure 28 – Location of rock wall temperature logger mounted on a rockslide block and marked with spray paint.

9.4.2 RWL 2 – SOUTHWEST FACING ROCK WALL TEMPERATURE LOGGER (798 M A.S.L.)

Figure 29 – Location of rock wall temperature logger mounted on the SW facing side of a rockslide block. Marked with spray paint.

9.5 CHARACTERISTICS OF SNOW MEASUREMENT STICK AND SNOW-CAMERA

Name	Active	Operation time	Location	UTM East_34W	UTM North_34W	Altitude (m a.s.l.)	Comment	Unit
G3 SNW CAM 1	Yes	Start: 21.08.17	Mounted on a tripod strapped to the satellite reflector G3 SATREF1 on the rockslide block.	483172	7707973	1084	Trail camera overlooking the snow measurement stick G3 SNW STiCK 1. Camera is attached to a continuous GPS station using a tripod, strips and tape.	Uovision UV565 trail camera See documentation in folder Deliverables\Hardware\Trail Camera.
G3 SNW STICK 1	Yes	Start: 21.08.17	Located on the rockslide block about 15 m from the camera.	483188	7707975	1086	Wooden stick with 10 cm markers dug down and secured with rocks and wires.	

9.5.1 SNW CAM 1 AND SNW STICK 1 – SNOW-DEPTH MEASUREMENT STICK AND TRAIL CAMERA (1084 M A.S.L.)

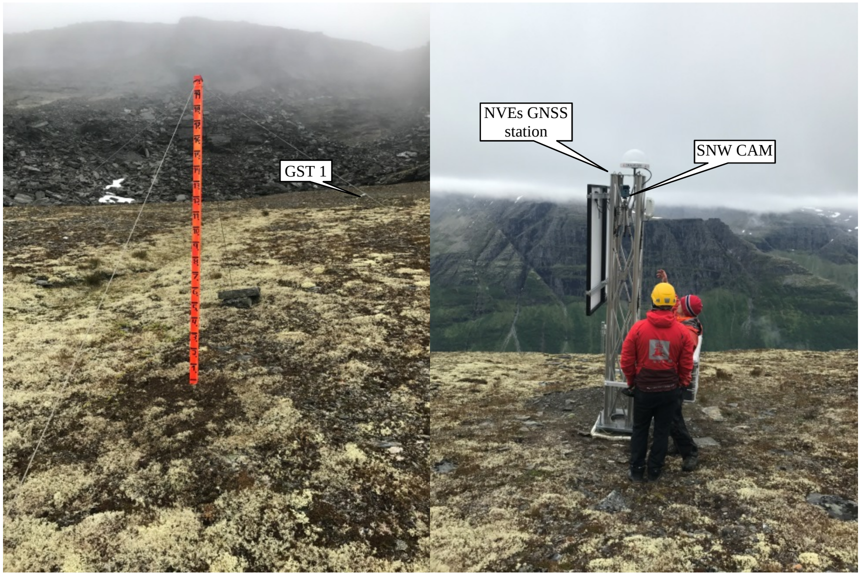


Figure 30 – Location of stick (left) and camera (right) mounted on a continuous GPS station. Camera takes one picture per day to be used for snow-condition estimates. Note the location and surroundings of the ground surface temperature GST 1.

9.6 CHARACTERISTICS OF TRAIL CAMERAS

Name	Active	Operation time	Location	UTM East_34W	UTM North_34W	Altitude (m a.s.l.)	Comment	Unit
G3 CAM 2	No	Start: 10.08.14 End: 28.08.15 A total of 768 pictures, with two pictures per day.	Located 2-3 m lower and ca. 10 m S of the satellite reflector SATREF2 in the middle part of the rockslide.	482788	7707958	838	The camera was mounted on a tripod ca. 1 m above ground, looking NNW. The first part of the campaign the camera captured the view of some fractures close to satellite reflector SATREF2, air temperature logger ATL 3 and ground temperature logger GTL 1. During the campaign the camera was tilted upward capturing more of the surrounding terrain.	Uovision UV565 trail camera See documentation in in folder Deliverables\Hardware\Trail Camera. Images can be found in: Deliverables\Data\2014-2015\Time-lapse_photos\GAM_3_CAM_2

9.6.1 CAM 2 – TRAIL CAMERA FROM MIDDLE PART OF UPPER BLOCK (838 M A.S.L.)

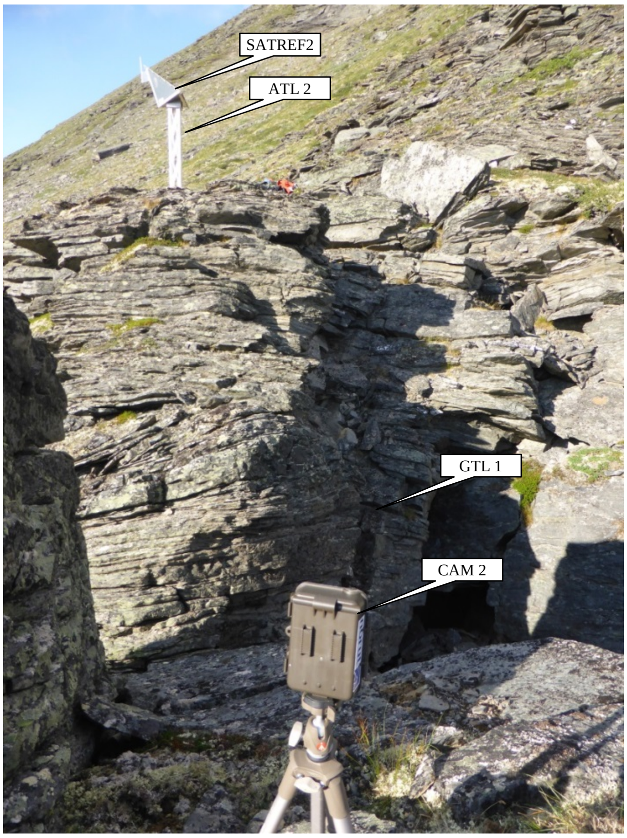


Figure 31 – Overview of camera setup (CAM 2) and location of ground temperature logger GTL 1 (yellow diamond) and radar satellite reflector SATREF2. See description in table and pictures of GTL 1 in appendix more details.

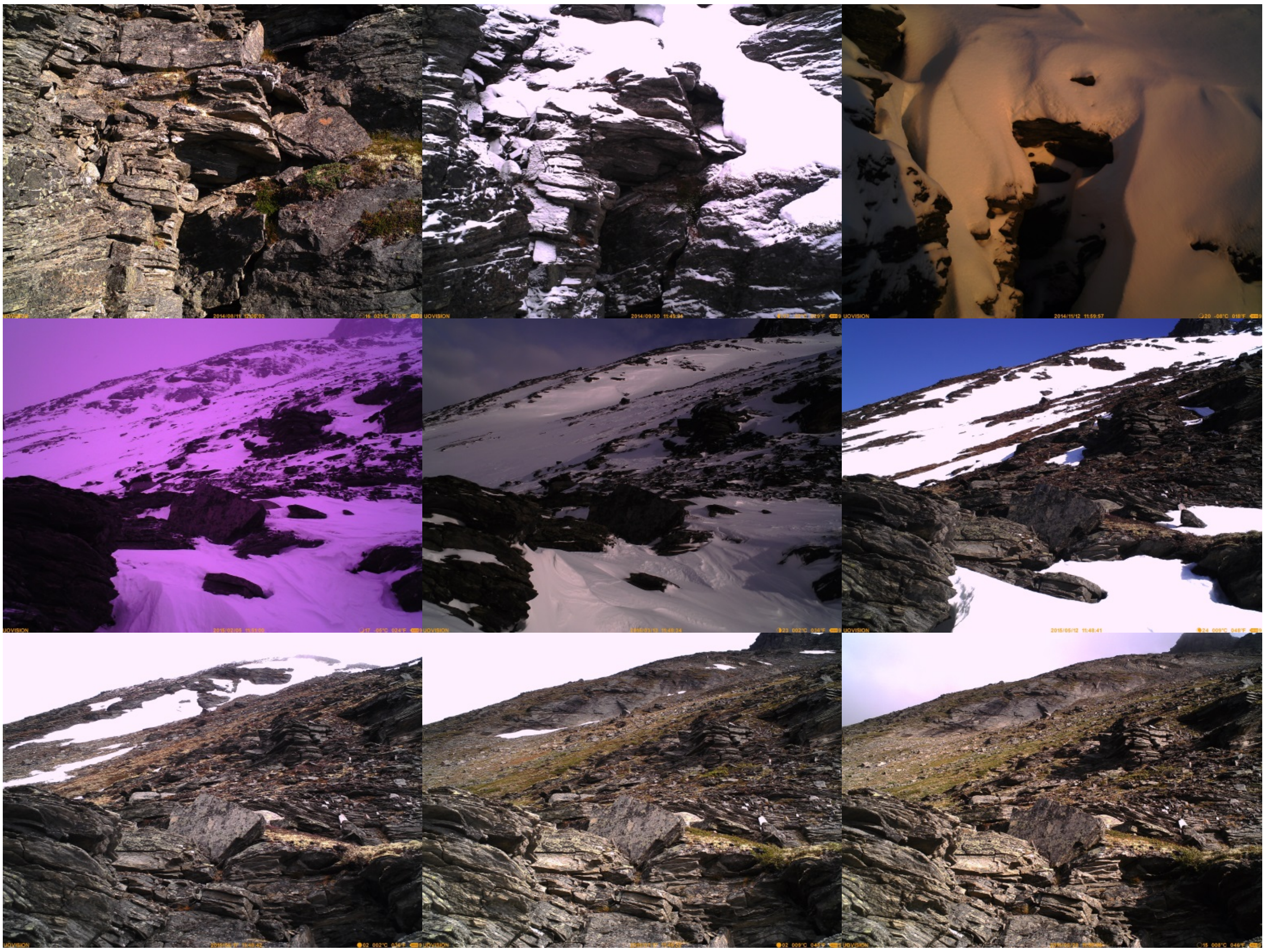


Figure 32 – Some pictures from trail camera CAM 2 covering the fracture and surroundings at different time of year.

10 APPENDIX 2 – DESCRIPTION OF ROCK GLACIER INSTRUMENTATION

This appendix contains a listing of loggers with operation time, location and description of installation. The characteristics are divided into sections describing ground temperature loggers (GTL) located on the rock glacier with images of loggers as mounted in the field.

10.1 CHARACTERISTICS OF TEMPERATURE LOGGERS

Name	Active	Operation time	Location	UTM East_34W	UTM North_34W	Altitude (m a.s.l.)	Comment
GTL 8	Yes	Start: 14.08.14 End: 28.05.15 Start: 17.06.15 End: 23.05.16 Start: 25.08.16 End: 02.08.17 Start: Replaced by Geoprecision logger 21.08.17	Located in the upper part of the rock glacier. About 30 m ESE from GPS 2 bolt.	482984.312	7707810.062	876.859	2014–2016: Measurement of air temperature in the pore space between blocks down to ca. 1.7 m depth. 10 iButtons (20 cm between each) mounted on a 2 m stick. 30 cm of the stick was above ground surface. 2016–2017: Blocks had moved and the maximum depth was now 1.3 m. From 21.08.17: iButtons were replaced with one Geoprecision (M-Log5W-SIMPLE) logger measuring air temperatures in the pore space of the rock glacier.
TEMP2 or GTL 2_2013	No	Start: 18.09.2013 End: 05.08.2014 Status: Measurements not continued	Located in the upper part of rock glacier.	482931	7707742	817	2013–2014: Measurement of air temperatures in pore spaces between blocks using a 2 m stick with 18 iButtons loggers. The stick was emerged about 12 cm above the surrounding blocks and was standing on finer material at ca. 2 m depth. Both names TEMP2 and GTL 2_2013 are used on this logger. This logger was relocated and renamed in summer 2014 and summer 2015, GTL 2_2014 and GTL 2_2015, respectively.
GTL 2_2014	No	Start: 13.08.14 End: 13.07.15 Status: Measurements not continued	Located in the middle part of rock glacier.	482820	7707732	765	2013–2015: Air temperature gradient in pore space in rock glacier using a 2 m stick with 16 iButtons loggers. Deepest point was at ca. 1 m.
Temp3	No	Start: 18.09.13 End: 25.08.15 Status: Measurements not continued	Located on small kink in the slope from 30 to 33 degrees in the middle part of the rock glacier on the S edge.	482828	7707692	750	2013–2015: Measurement of air temperature 5 m below surface inside a cave under a large block. Measured using a Tinytag-logger with 5m cord. This logger was relocated summer 2015 to measure ground surface temperature on the block (new name GST 1).
GTL 2_2015	Yes	Start: 28.08.15 End: 03.08.16 Start: 25.08.16 End: 02.08.17 Start: Replaced by Geoprecision logger 21.08.17	Located in the middle part of rock glacier on the SE edge.	482850.876	7707677.314	752.074	2015–2016: Measurement of air temperatures in a 5 m deep ventilated fracture measured with stick containing 15 iButtons. Fracture is 1.5 m wide in the opening. 2016–2017: Same setup as from above, but now with two iButtons. From 21.08.17: iButtons were replaced with one Geoprecision (M-Log5W-SIMPLE) logger at 5 m depth, same setup as described above.
GTL 3	Yes	Start: 18.09.13	Located in the lower part	482734	7707718	725	2013–2015:

		End: 13.07.15 Start: 25.08.16 End: 02.08.17 Start: Replaced by Geoprecision logger 21.08.17	of rock glacier, on the south side of a block containing the bolt of GPS 4.				Measurement of air temperatures in pore spaces using 18 iButtons on a stick lowered vertical down with rope to a maximum depth of 3.5m. Marked with a plastic bag filled with stones. 2015–2016: No measurements recorded. Summer 2016–summer 2017: Same setup as during 2013–2015, but now with two iButtons at 3.5m depth. From 21.08.17: iButtons were replaced with one Geoprecision logger at 3.5m depth, same setup as described above.

10.1.1 GTL 8 – PORE SPACE TEMPERATURE IN THE UPPER PART (872 M A.S.L.)

Figure 33 – Location of GTL 8 in the upper part of the rock glacier, using iButtons from 2014–2017 (left picture) and from August 2017 using Geoprecision loggers (right picture).

10.1.2 TEMP2 – PORE SPACE TEMPERATURE IN THE MIDDLE PART (817 M A.S.L.)

Figure 34 – Location and close-up of temperature logger Temp2 (marked with a yellow diamond). Overview image has a view against ENE.

Figure 35 – Location and close-up of temperature logger Temp2.

10.1.3 GTL 2_2014 – PORE SPACE TEMPERATURE IN MIDDLE PART (765 M A.S.L.)

Figure 36 – Location of temperature logger GTL 2_2014.

10.1.4 TEMP3 – PORE SPACE TEMPERATURE IN MIDDLE PART (750 M A.S.L.)

Figure 37 – Location of temperature logger Temp3.

10.1.5 GTL 2_2015 – FRACTURE TEMPERATURE IN MIDDLE PART (742 M A.S.L.)

Figure 38 – Location and close-up of temperature logger GTL 2_2015 on the southern edge. Logger is inside the fracture next to the person standing.

10.1.6 GTL 3 – PORE SPACE TEMPERATURE IN LOWER PART (725 M A.S.L.)

Figure 39 – Location of temperature logger GTL 3 marked with yellow diamond. Rope tied around rock and marked with red plastic bag for visibility.

11 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.

In the Gámanjunni 3 rockslide and rock glacier, 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 ***Deliverables\Hardware\GeoPrecision-*** folder.

GeoPrecision software and drivers can be found in the ***Deliverables\Hardware\GeoPrecision\Applications-*** folder or at http://www.geoprecision.com/en/downloads-en

or at ftp://80.153.164.175/GeoPrec/Docu_Software/GP_Wireless/

11.1 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.

11.2 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 ***Deliverables\Hardware\GeoPrecision\GLORIA project documents***-folder.

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 unshrinked (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

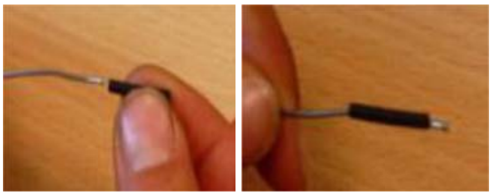
1. Shorten the solder tails of the batteries to approx. 5-8 mm.

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 ***Deliverables\Hardware\GeoPrecision\Applications***-folder.

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.



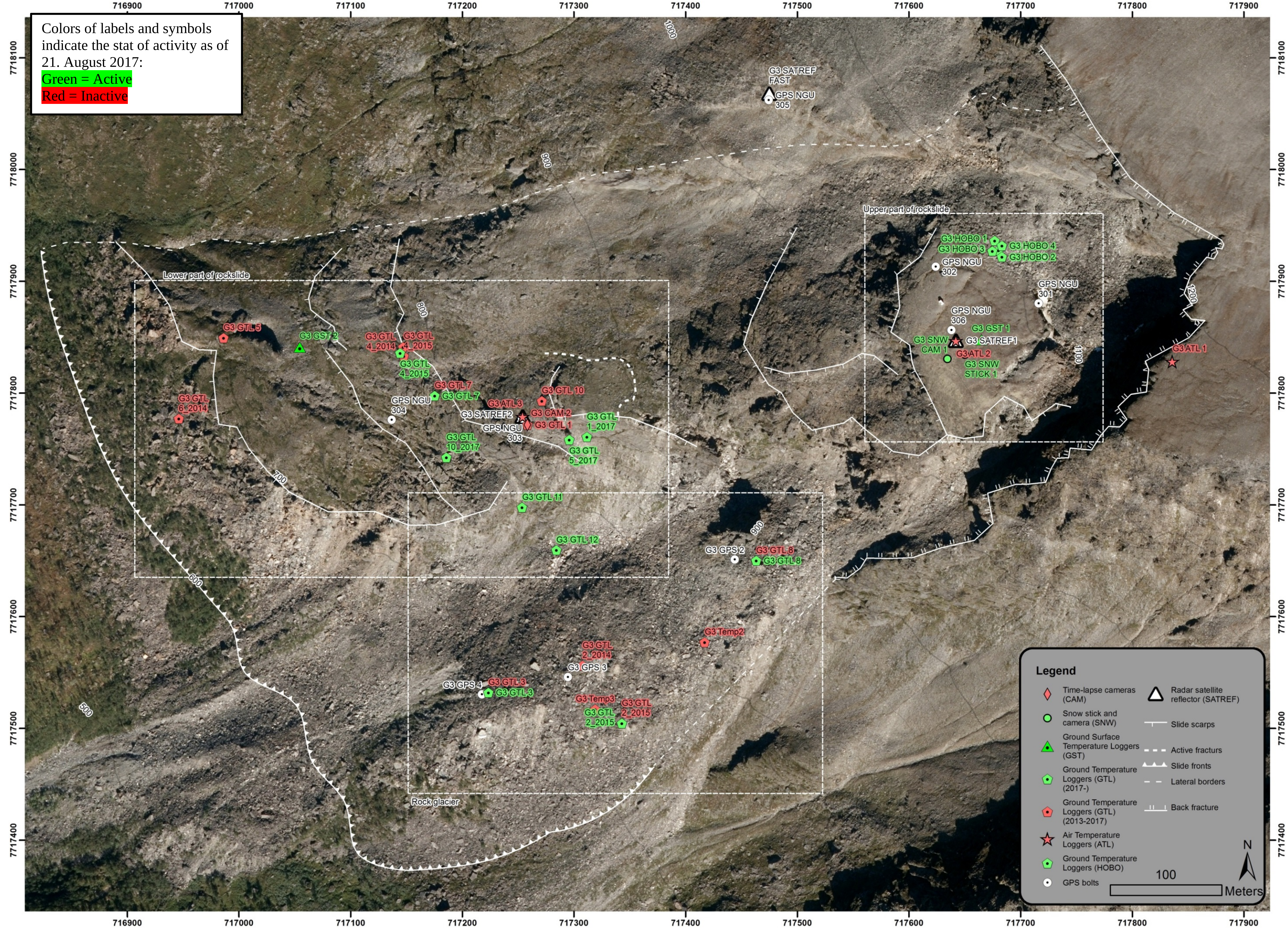
5. For installation of the new battery, solder the **positive** pole first. You may use tweezers to hold the contacts in place while soldering.

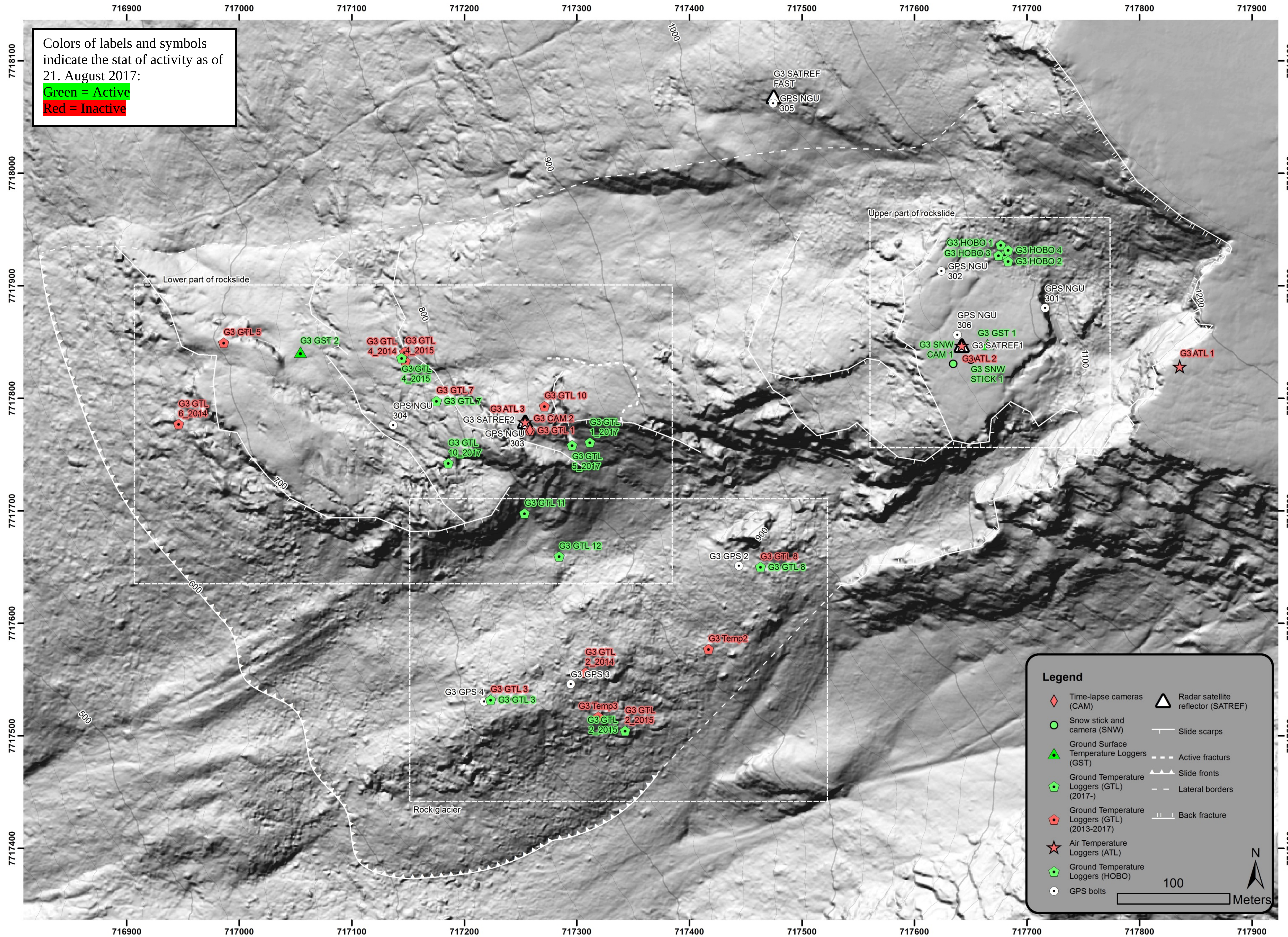
6. Slide the heat-shrinking tube from the contact up to the battery and over the soldered **positive** pole and heat it up with the soldering iron so that it shrinks and secures the positive contact from interfering with the negative one.

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).

12 APPENDIX 4 – DETAILED MAP OF INSTRUMENTATION





Colors of labels and symbols indicate the stat of activity as of 21. August 2017:
Green = Active
Red = Inactive
G3 SATREF FAST
GPS NGU 305
Upper part of rockslide
Lower part of rockslide
Rock glacier
G3 HOBO 1
G3 HOBO 3
G3 HOBO 4
G3 HOBO 2
GPS NGU 302
GPS NGU 301
GPS NGU 306
G3 GST 1
G3 SATREF1
G3 SNW CAM 1
G3 ATL 2
G3 SNW STICK 1
G3 ATL 1
G3 GTL 5
G3 GST 2
G3 GTL 4_2014
G3 GTL 4_2015
G3 GTL 4_2015
G3 GTL 7
G3 GTL 7
G3 GTL 6_2014
GPS NGU 304
G3 ATL 3
G3 GTL 10
G3 SATREF2
G3 CAM 2
G3 GTL 1
GPS NGU 303
G3 GTL 1_2017
G3 GTL 10_2017
G3 GTL 5_2017
G3 GTL 11
G3 GTL 12
G3 GPS 2
G3 GTL 8
G3 GTL 8
G3 Temp2
G3 GTL 2_2014
G3 GPS 3
G3 GPS 4
G3 GTL 3
G3 GTL 3
G3 Temp3
G3 GTL 2_2015
G3 GTL 2_2015
Legend
Time-lapse cameras (CAM)
Snow stick and camera (SNW)
Ground Surface Temperature Loggers (GST)
Ground Temperature Loggers (GTL) (2017-)
Ground Temperature Loggers (GTL) (2013-2017)
Air Temperature Loggers (ATL)
Ground Temperature Loggers (HOBO)
GPS bolts
Radar satellite reflector (SATREF)
Slide scarps
Active fractures
Slide fronts
Lateral borders
Back fracture
N
100
Meters