

# The Greenland Analogue Project – Investigation of the hydrogeological challenges during glacial conditions

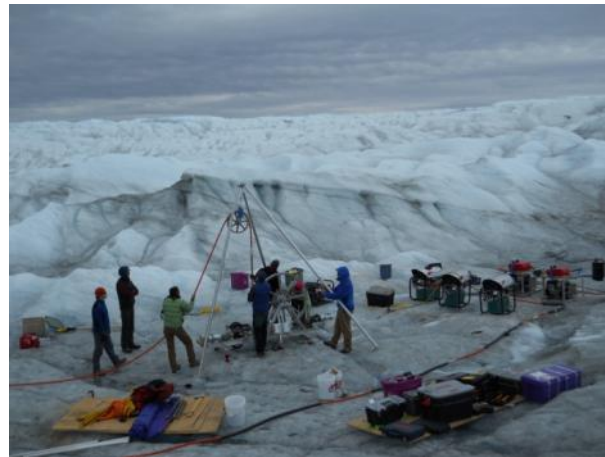


Anne Lehtinen

13<sup>th</sup> NAWG Workshop, May 13<sup>th</sup>-16<sup>th</sup> 2013, Nagoya

# Outline

- GAP project and its aims
- Subproject A: Ice sheet hydrology
- Subproject B: Subglacial ice sheet hydrology
- Subproject C: Bedrock hydrogeochemistry and hydrogeology

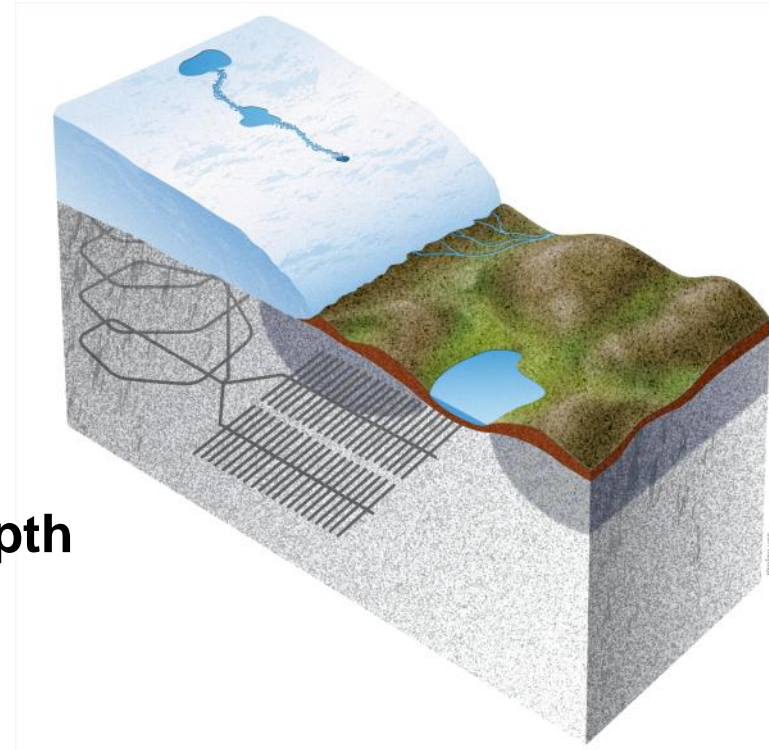


# Motivation

- Finnish and Swedish safety assessments indicate that periods of **glacial conditions**, specially the conditions after glaciation provide highest doses and risks
- 'We have a poor understanding, and therefore large uncertainties, concerning hydrological processes related to glacial conditions'
- In the comments from authorities on the Posiva and SKB safety assessments:
  - Large hydrological uncertainties for glacial cases
  - Suggest using analogues in order to increase knowledge and reduce uncertainties
- In other countries where ice sheets are expected in the future, same questions need to be answered in e.g. Canada and UK
- Results are important for the assessment of long-term safety (100 kyrs)

# Example of processes that can affect repository safety during the glaciations

- **Ground water oxygen concentration**  
(canister corrosion)
- **Groundwater salinity**  
(buffer stability)
- **Glacial erosion**  
(influences e.g. permafrost depth)
- **Glacially induced earthquakes**  
(canister failure)
- **Maximum pressure at repository depth**  
(canister failure)
- **Maximum permafrost depth**  
(canister failure, buffer function)



# GAP project (2009-2012)

- Co-ordinating and funding organizations
  - Posiva (Finland), SKB (Sweden) and NWMO (Canada)
  - 4.1 M€ (532.2 MJPY) for 2009-2012
- Project manager: Lillemor Claesson Liljedahl (SKB), and deputy PM Anne Lehtinen (Posiva)
- Research partners
  - GEUS, GTK
  - Universities: UK/Aberystwyth, Bristol, Edinburgh, Swansea; USA/ Montana, Wyoming, Colorado, Indiana, Princeton, Washington; Canada/Waterloo, Toronto; Sweden/Stockholm, Uppsala
  - Geosigma AB, Lawrence Berkeley National Laboratory, Pöyry etc.
- [www.skb.se/GAP](http://www.skb.se/GAP)

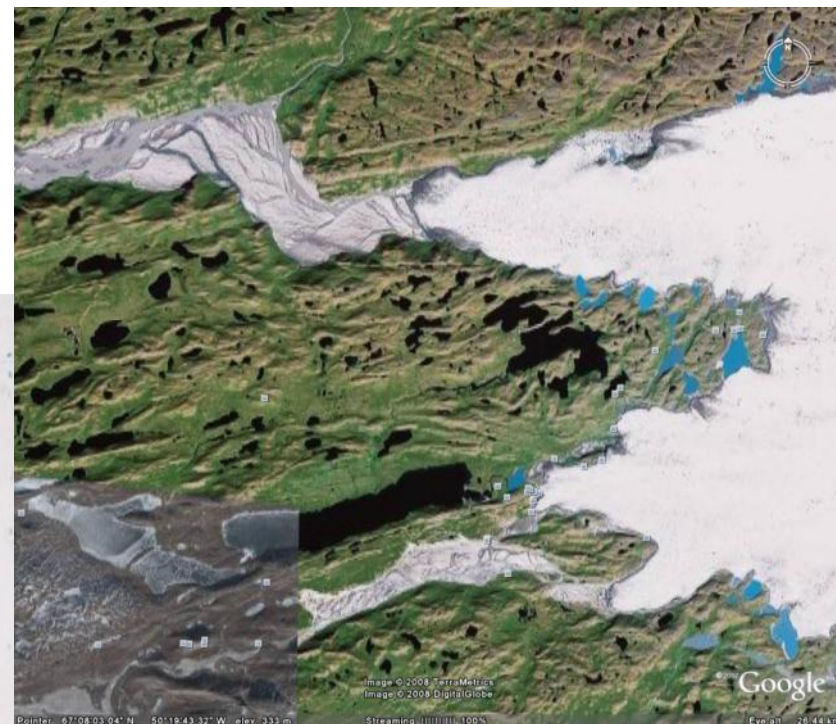
# Overall aims

- Observations of how an ice sheet forms groundwater; (incl. hydraulic gradients at ice sheet bed, driving groundwater flow)
- Observations of whether glacial meltwater may penetrate crystalline bedrock down to repository depth (500-700 m);
- Observations of chemical composition of groundwater if/when it reaches repository depth (e.g. oxygen content and salinity);
- Use a real world example of these processes, not only modelling results. Show that we have process understanding
- The project will provide us with an integrated view on ice sheet hydrology and groundwater flow/chemistry

# Project questions

- To what depth does glacial meltwater penetrate into the bedrock?
- What is the chemical composition of such water when and if it reaches repository depth?
- How much oxygenated water will reach repository depth?
- Where is the meltwater generated under an ice sheet?
- What is the hydraulic pressure situation under an ice sheet, driving groundwater flow?
- Does discharge of deep groundwater occur in the investigated pro-glacial talik in the study area?

# Project area



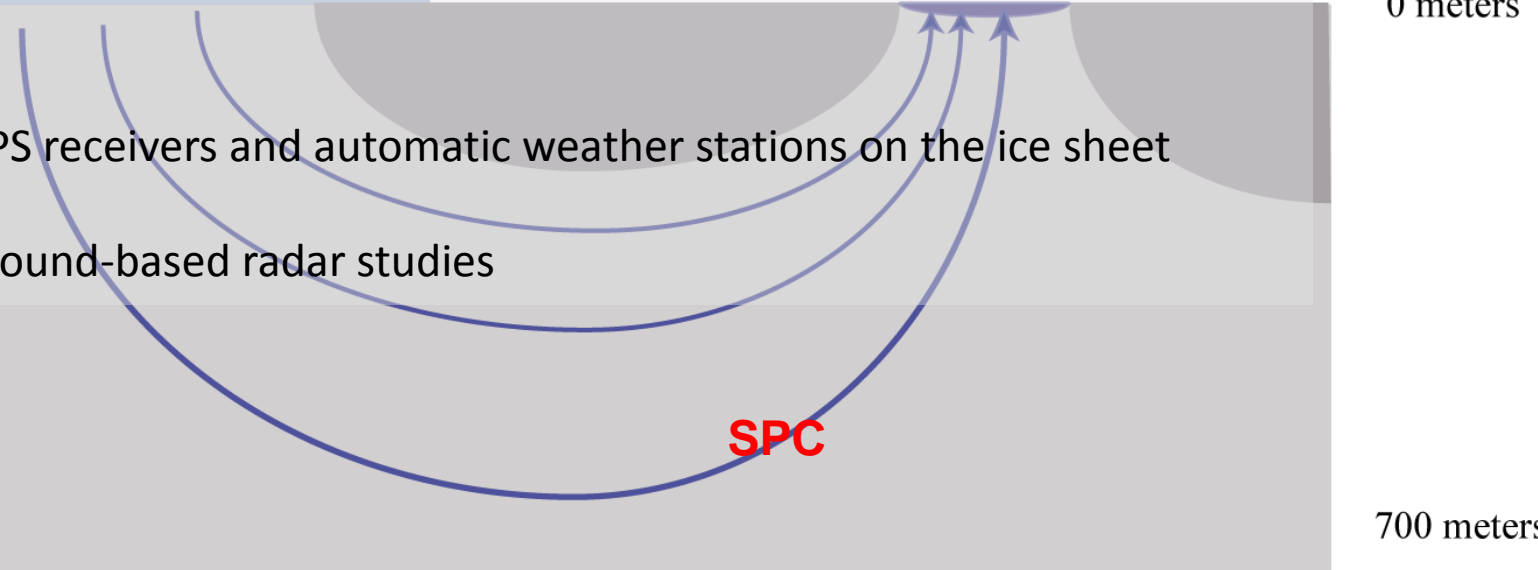


**SPA** Subproject A: Ice sheet hydrology  
(subproject manager: Alun Hubbard)

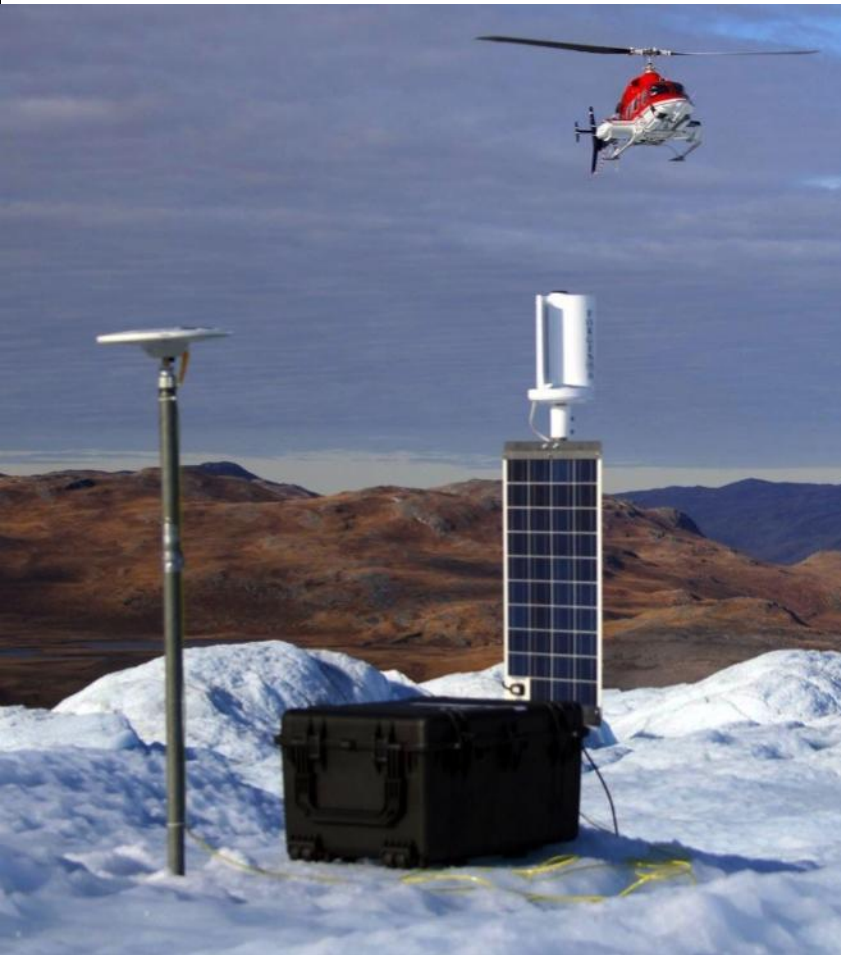
- **Aims** to improve the understanding of ice sheet hydrology
  - Quantification of ice sheet surface water production
  - Routing of the melt water from the surface to the base of the ice
- Basal topography of the ice sheet
- Thermal regime at the base → mapping warm based conditions

**Methods**

- Monitoring of GPS receivers and automatic weather stations on the ice sheet
- Remote sensing
- Airborne/ and ground-based radar studies



■ Bedrock    ■ Permafrost    ■ Ice Sheet



24 GPS in 2010  
19 GPS in 2011  
12 GPS in 2012

**GPS gives high-frequency, high-precision 3-dimensional records of ice-surface motion**

Ice surface velocity is a result of internal ice deformation and basal slip.

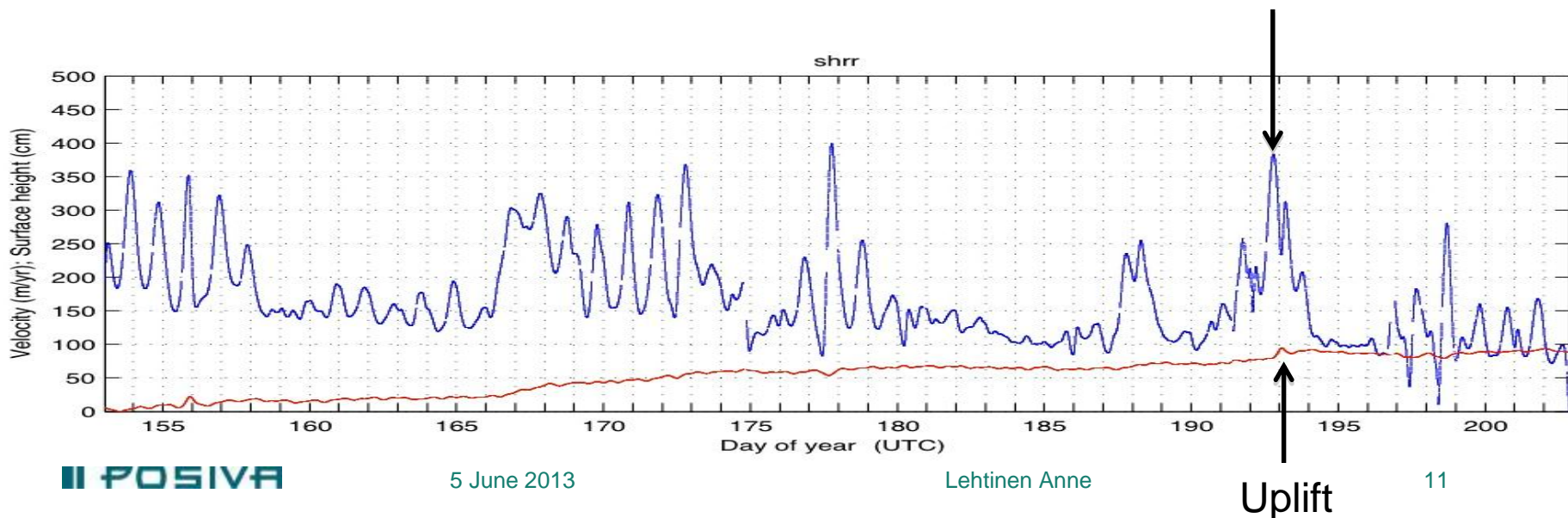
Basal slip is enhanced by reduced basal traction when subglacial water pressures approach or exceed overburden.

**High subglacial water pressures are caused by the delivery of water to the bed in pulses that exceed the capacity of the drainage system (e.g. diurnal melt, lake drainage and precipitation events).**

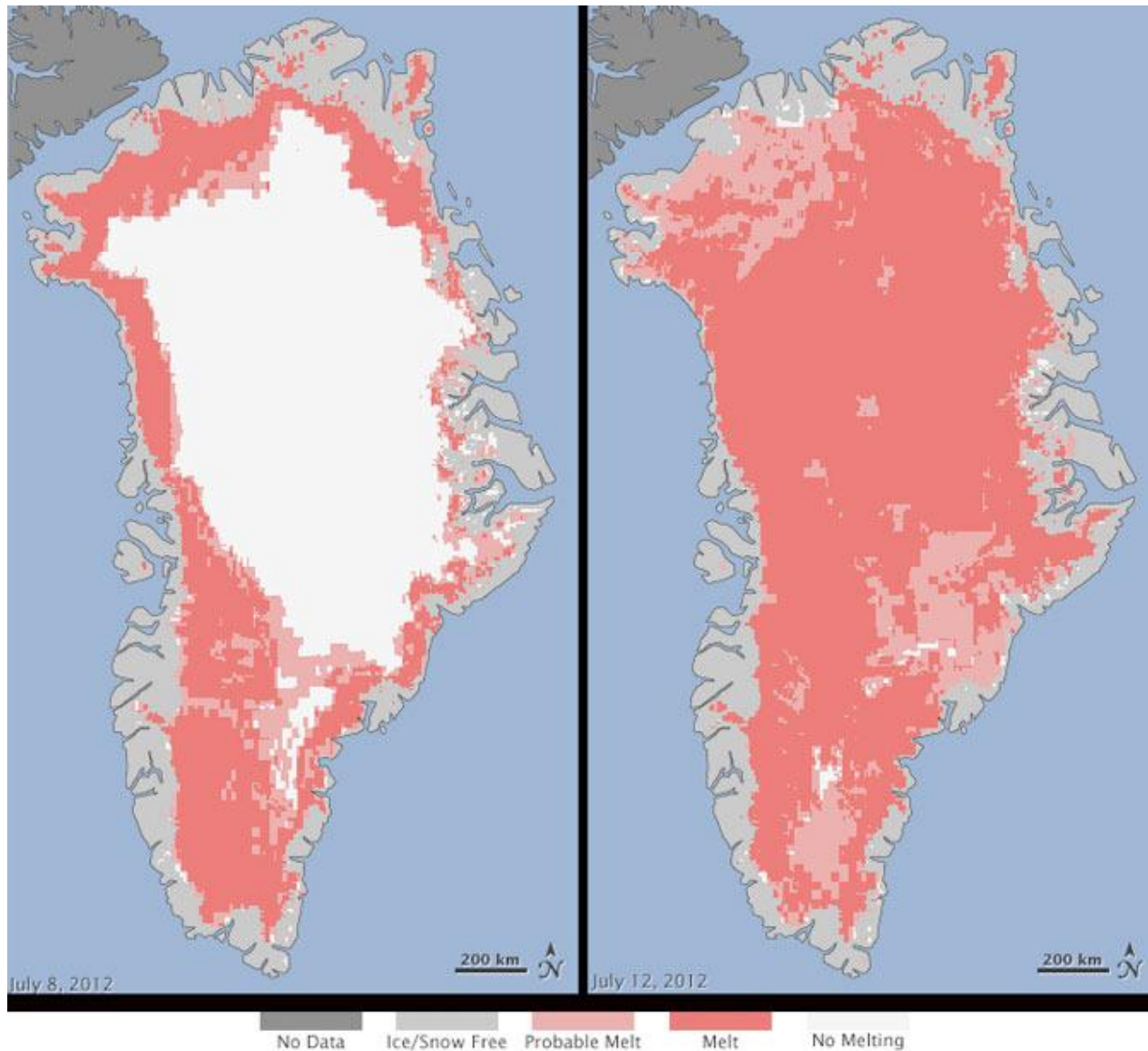
Subglacial water pressures exceeding overburden result in ice-bed separation and surface uplift that can be measured using GPS.

# GPS conclusions

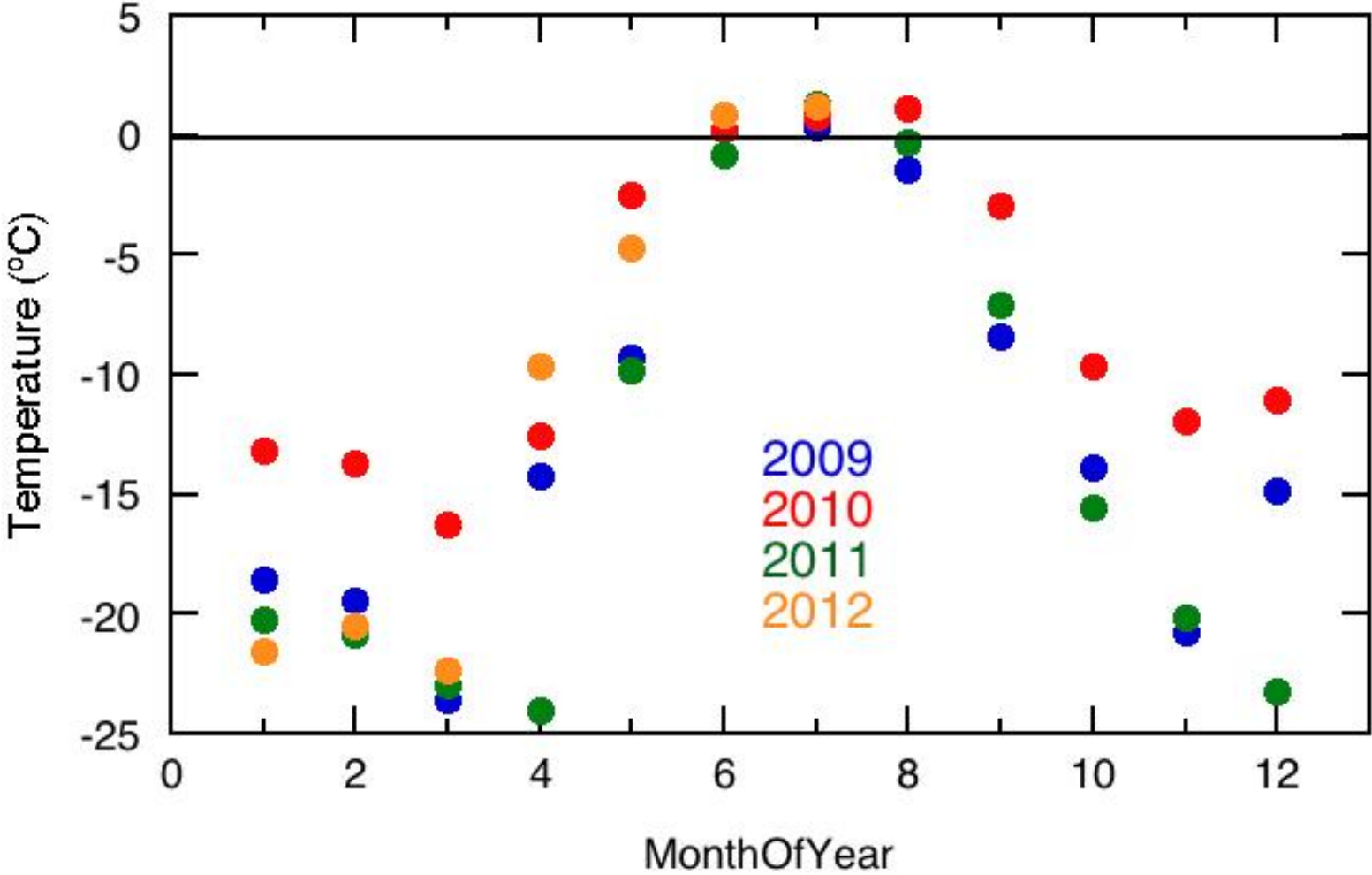
- There is correlated (lagged) diurnal variation in surface velocity, subglacial water pressure and surface uplift coupled to the diurnal melt cycle.
- Lake tapping events rapidly ( $\sim 2$  h) deliver large quantities of water to the ice-bed interface.
- High magnitude rainfall events cause significant glacier speed-ups and high proglacial runoff.
- Seasonal speed-up detected in all GPS up to 150 km inland.
- Velocity and uplift response to diurnal melt evolves through the melt season, as the drainage system adapts to increasing melt inputs.



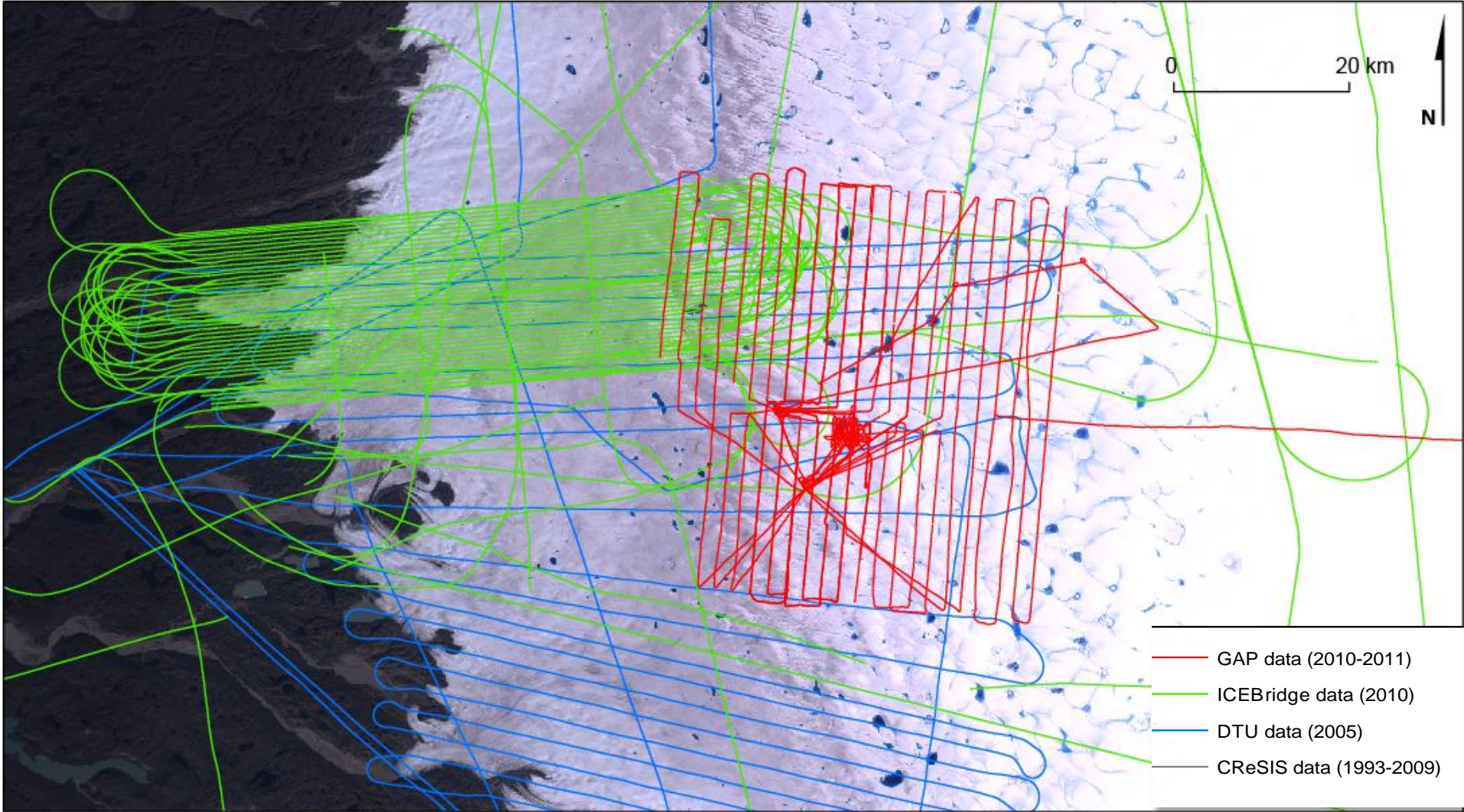
# Record surface melt (area) in July 2012



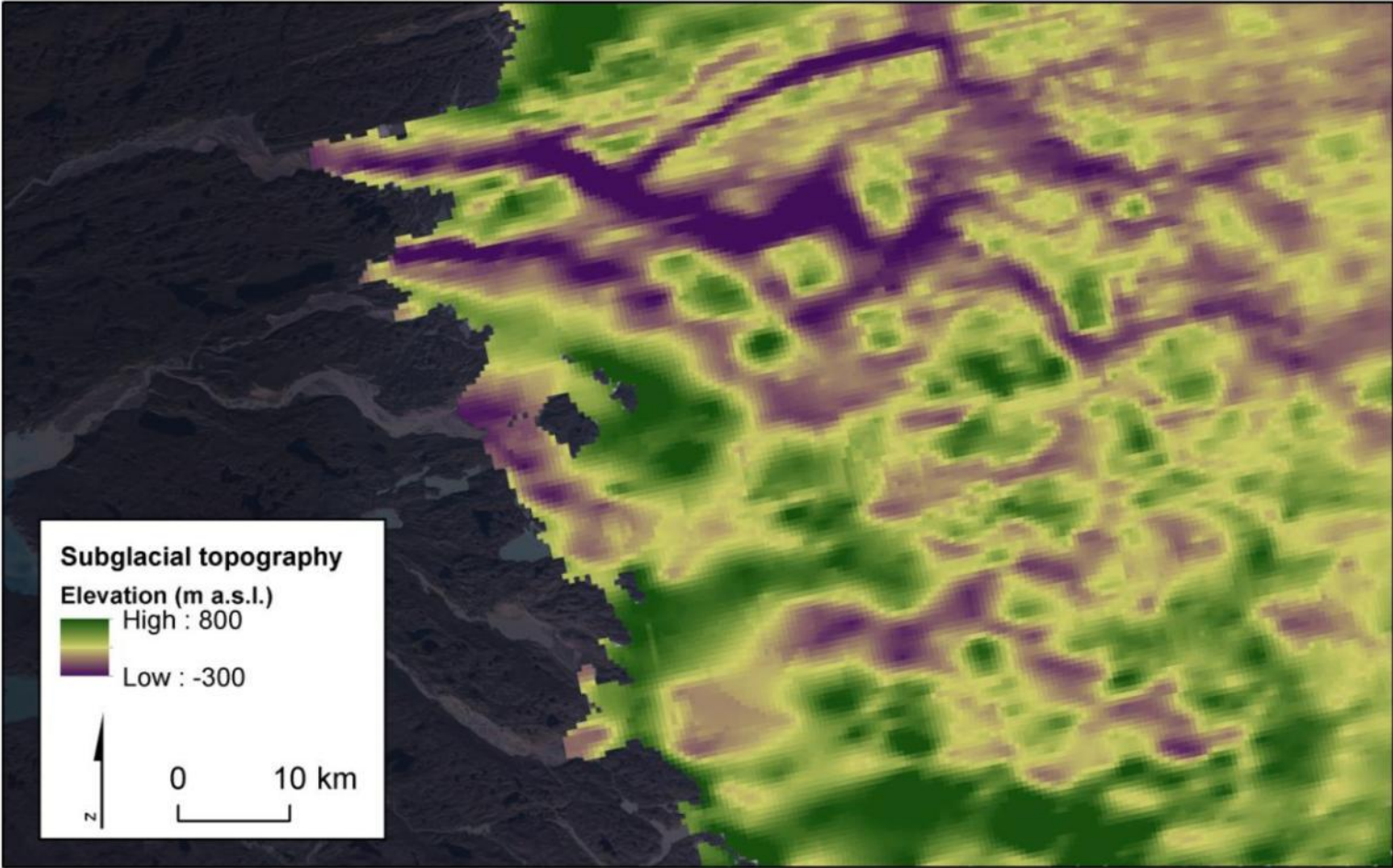
# Temperature at KAN\_M, monthly



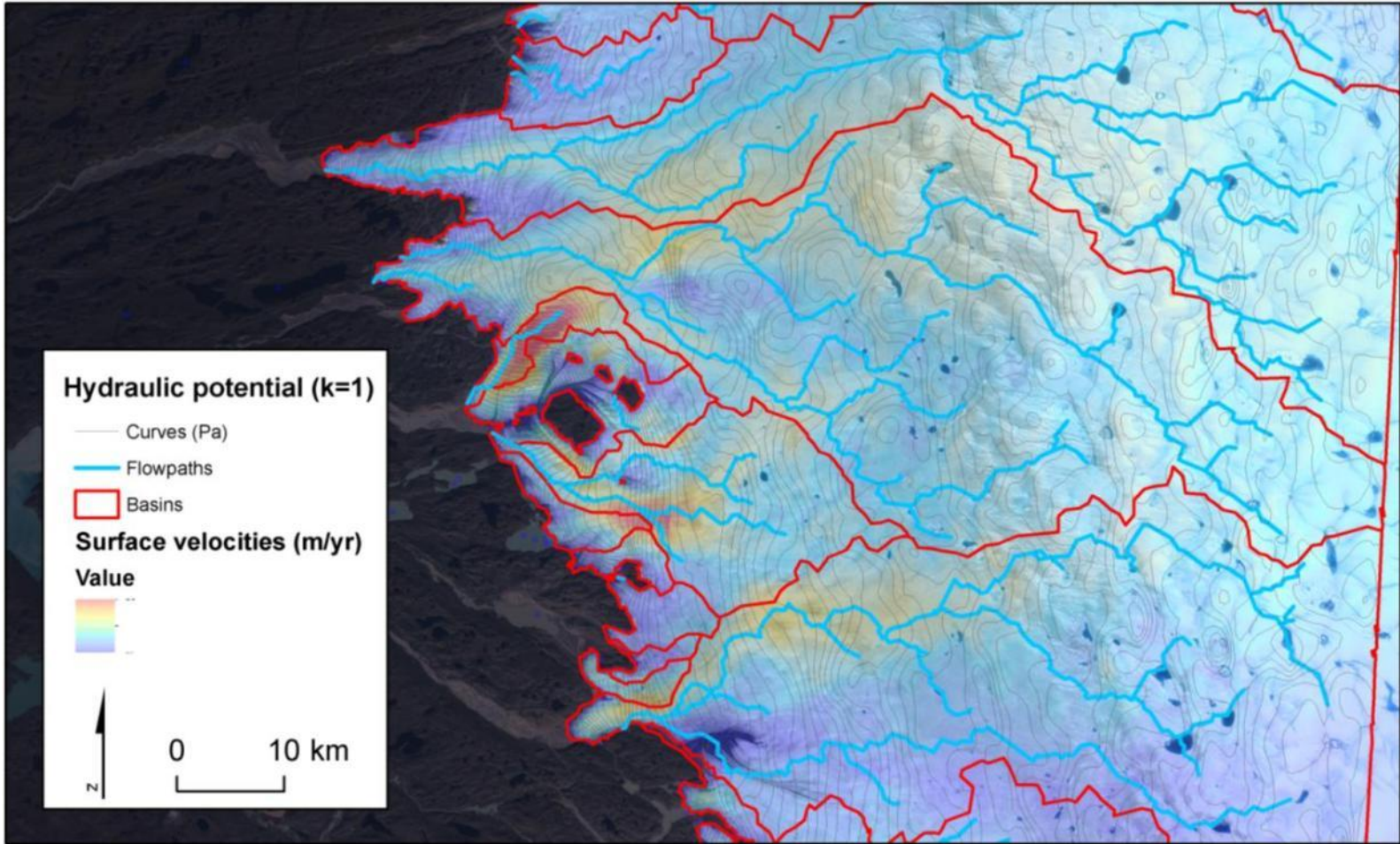
# Available radar datasets



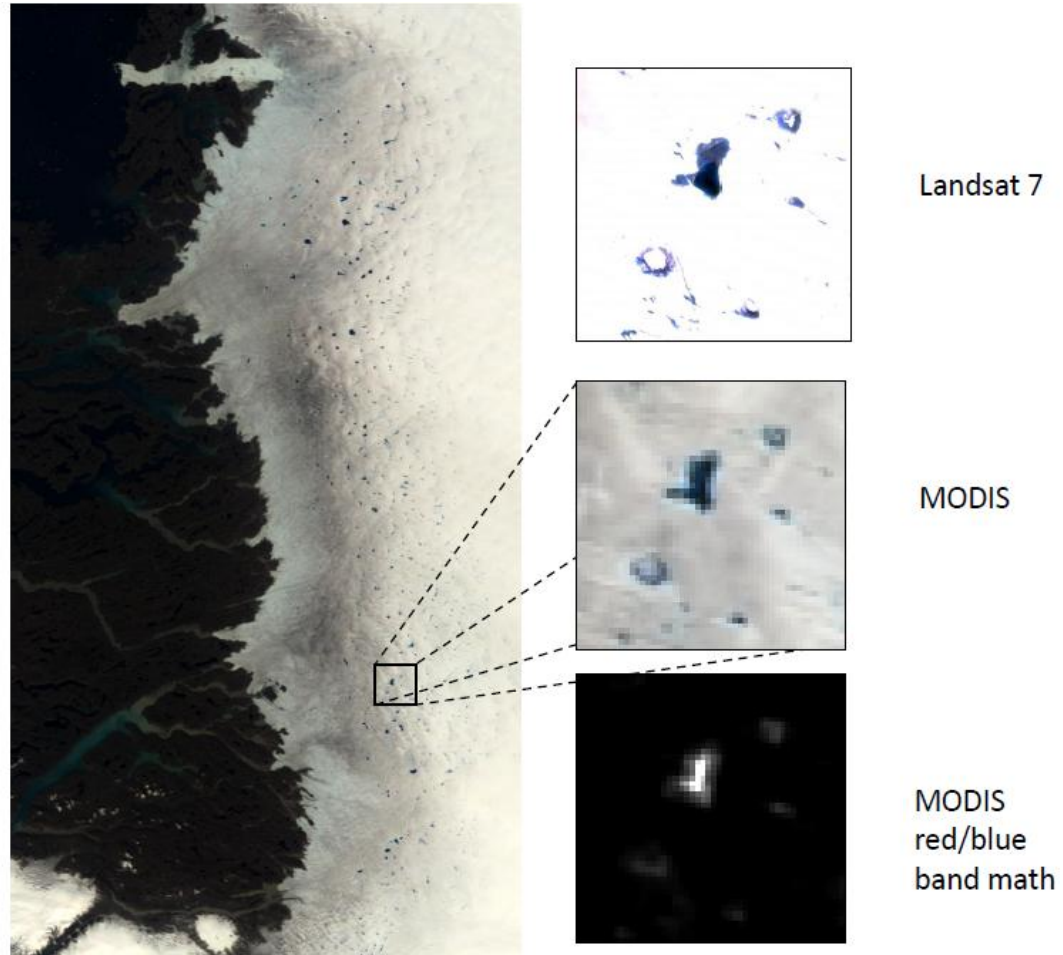
# Subglacial topography, version 2.0



# Hydraulic potential vs. velocity

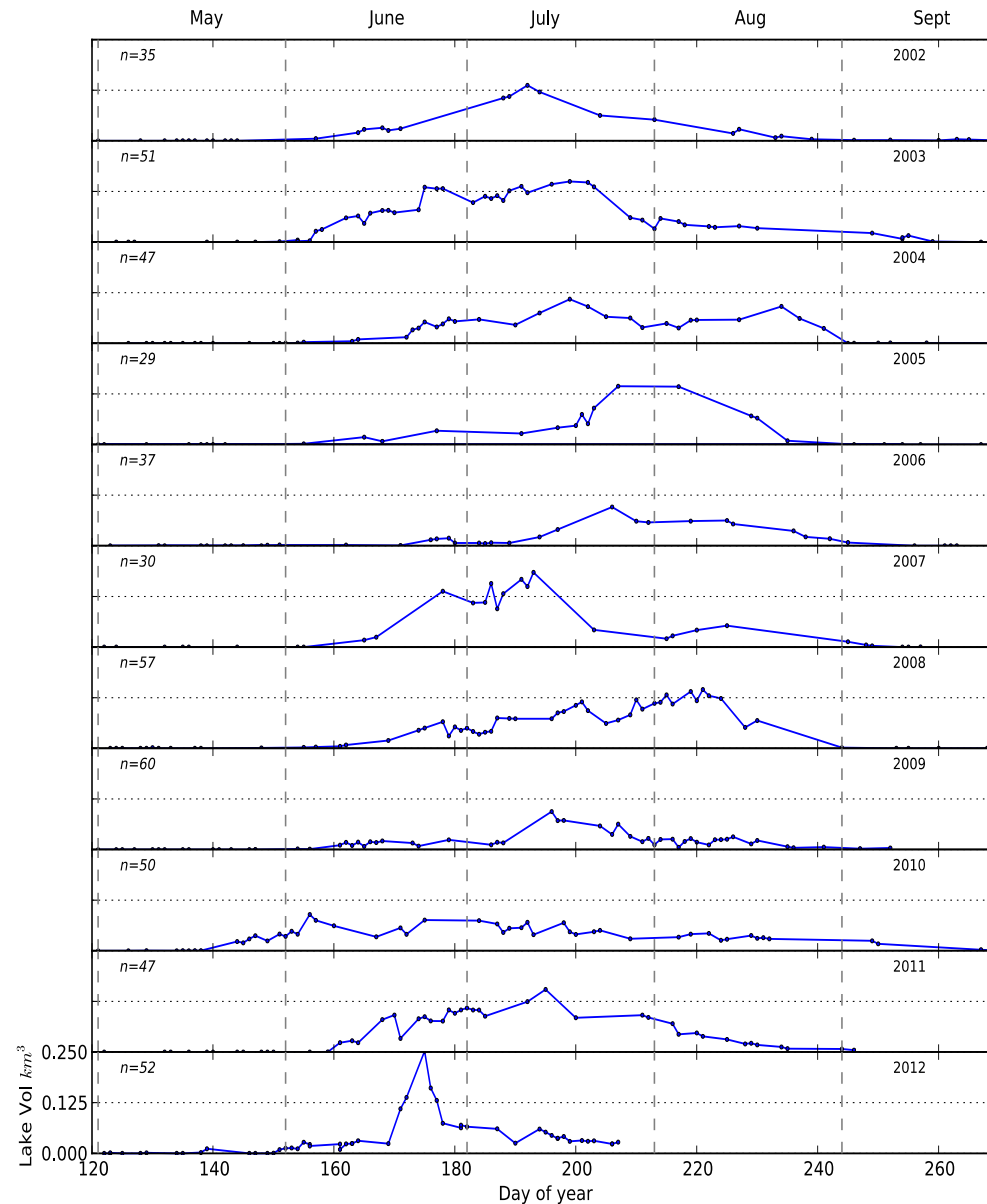


# Remote sensing of supraglacial lakes



# Remote sensing of supraglacial lakes

- Extract lake **volumes** from daily atmospherically corrected cloud-free Moderate resolution spectroradiometer (**MODIS**) imagery (250 m resolution)
- Monitored **~200** individual lakes between **2002-2012**
- Comparisons with modelled **runoff** data (van As *et al.*, 2012), and **discharge** record from the Watson River (Mikkelsen and others, 2012)
- Monitoring of rapidly draining lakes (Doyle *et al.*, 2012)
- Gain a better understanding of **spatial/temporal** patterns of lake drainage to quantify the timing, volume and locations of meltwater inputs to the subglacial system with Russell Glacier catchment



Lakes **form** and **drain** earlier in stronger melt years, eg 2003, 2010, 2012

Lakes form at **higher** elevations in **stronger** melt years eg 2003, 2012  
 – warming climate meltwater will reach the bed further up glacier

A critical size/volume **not** required for drainage – drainage mechanism?

Lakes important – large **pulses** of meltwater into subglacial system



**SPA**

**Subproject B: Subglacial ice sheet hydrology**  
**SPB (subproject manager: Joel Harper)**

• Direct observations and measurements of the characteristics of the hydrological system at the base of the ice sheet

**Method**

- Drilling through the ice sheet (up to 1800 m)
  - Wet-based areas identified by radar surveys in SPA
  - Water pressures and configuration (time/space) at the interface between the ice and bedrock
  - Bed cover

0 meters

700 meters

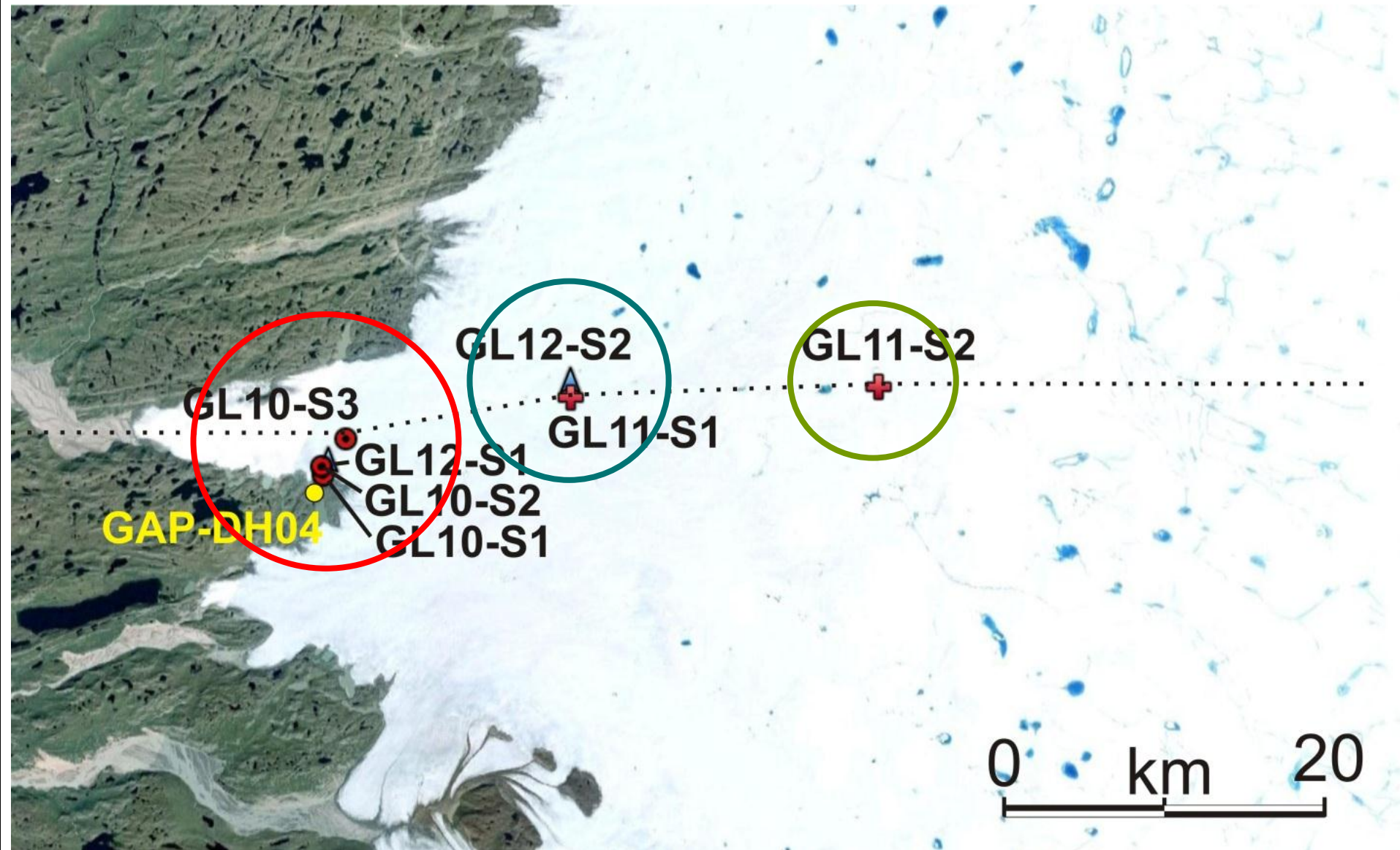
Bedrock

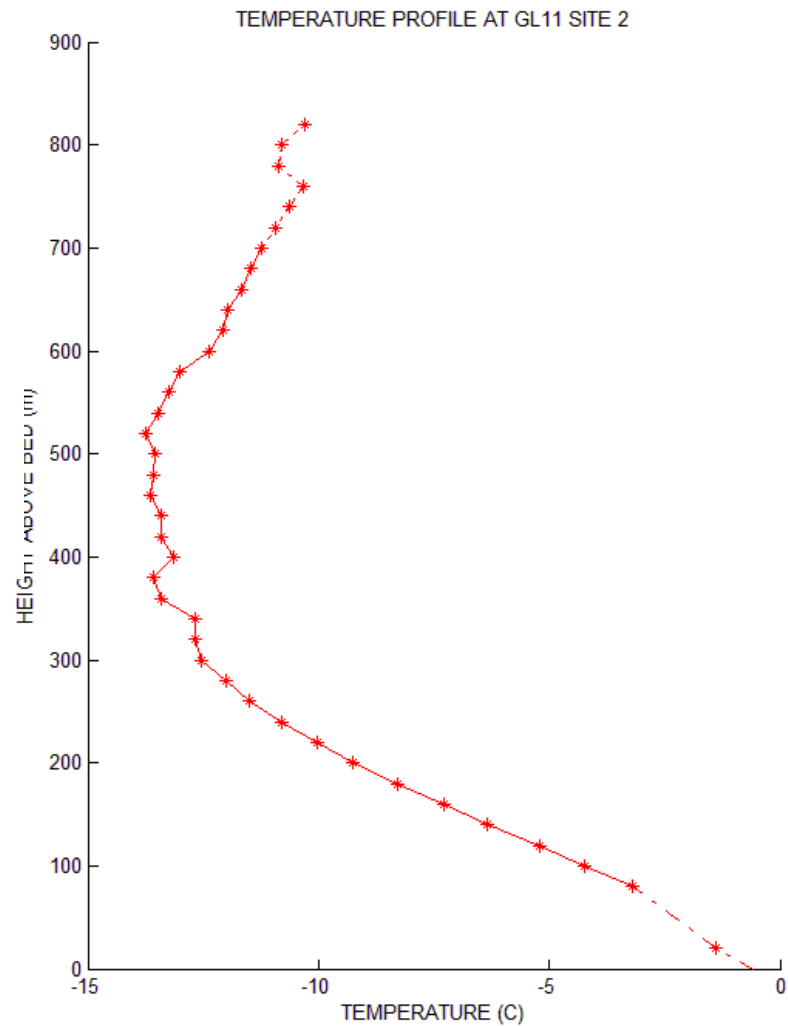
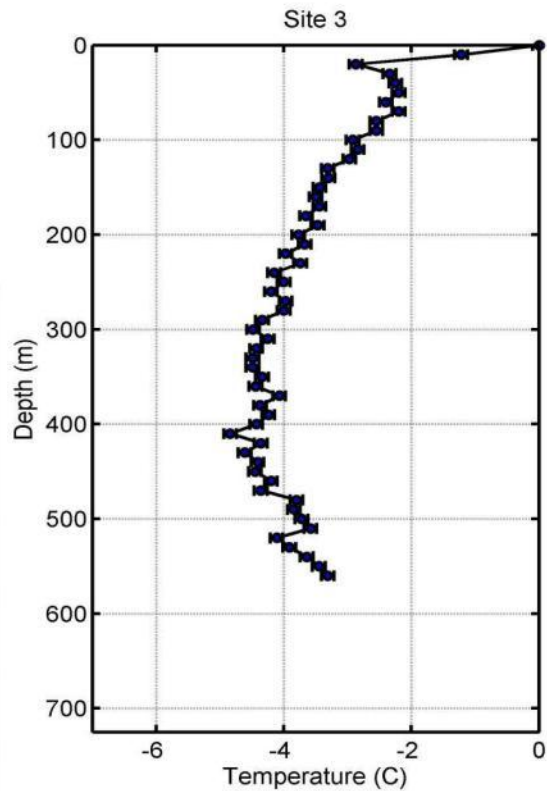
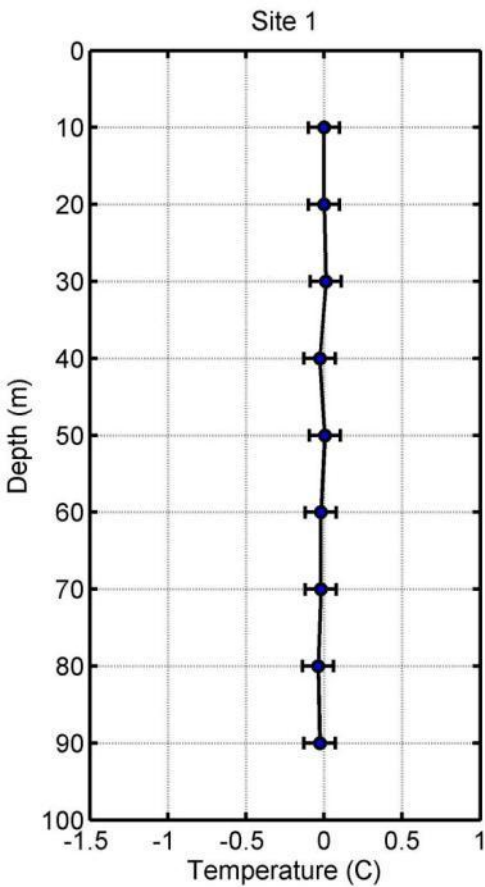
Permafrost

Ice Sheet



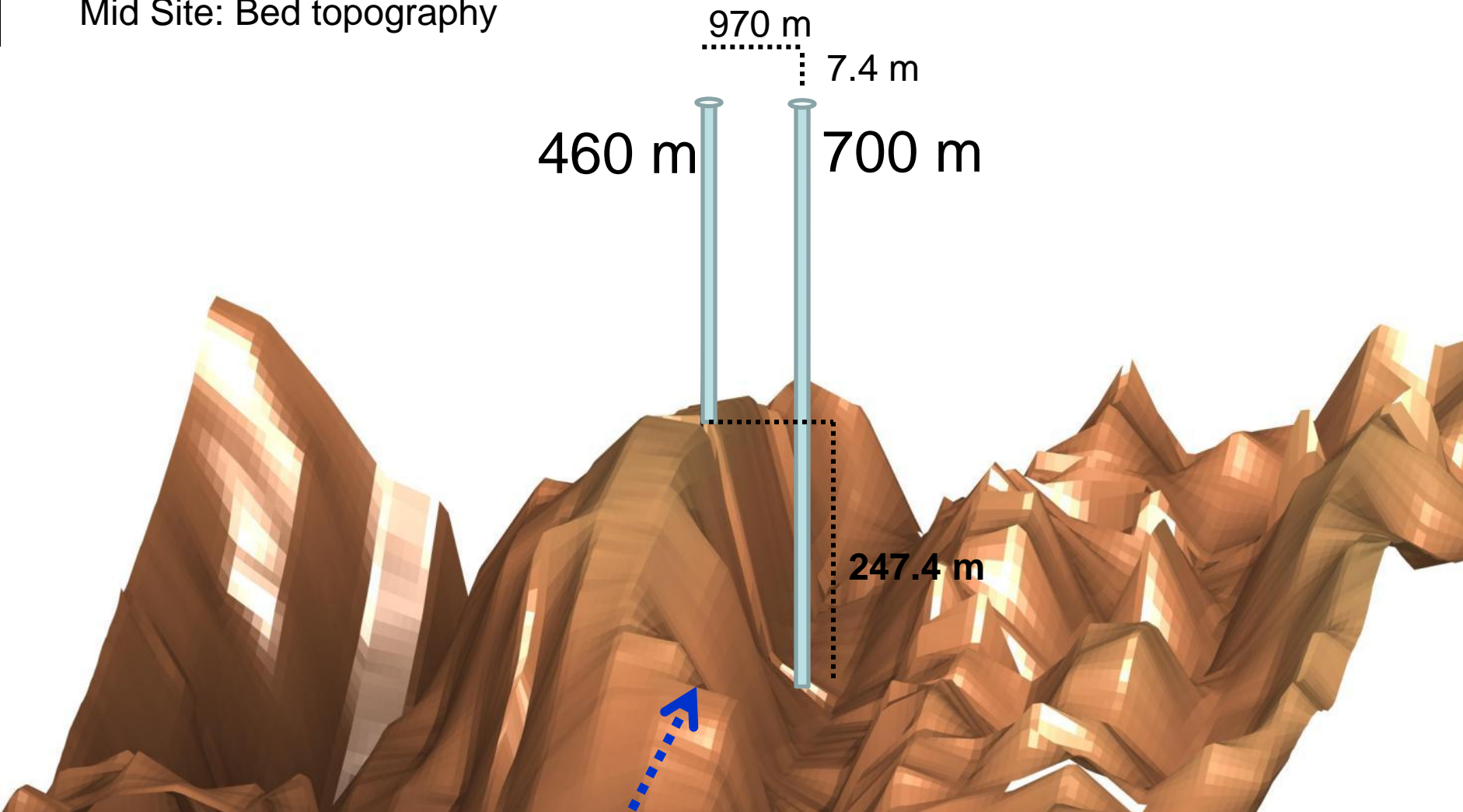
# SPB Ice drilling places 2010-2012





Site 1 an site 2 drilled in 2010

# Mid Site: Bed topography



Ice flow: ~120 m/yr

10 m/yr

**SPA**

- Subglacial recharge of melt waters into the bedrock
  - Pressure conditions
  - Penetration depth
  - Chemistry and oxic nature at repository depths

- Complementary field investigations
  - Structural geology
  - Distribution of permafrost
  - Hydrogeochemistry of surface waters

**SPB**

**SPC**

**Subproject C: Bedrock hydrogeochemistry and hydrogeology (subproject manager: Timo Ruskeenieni)**

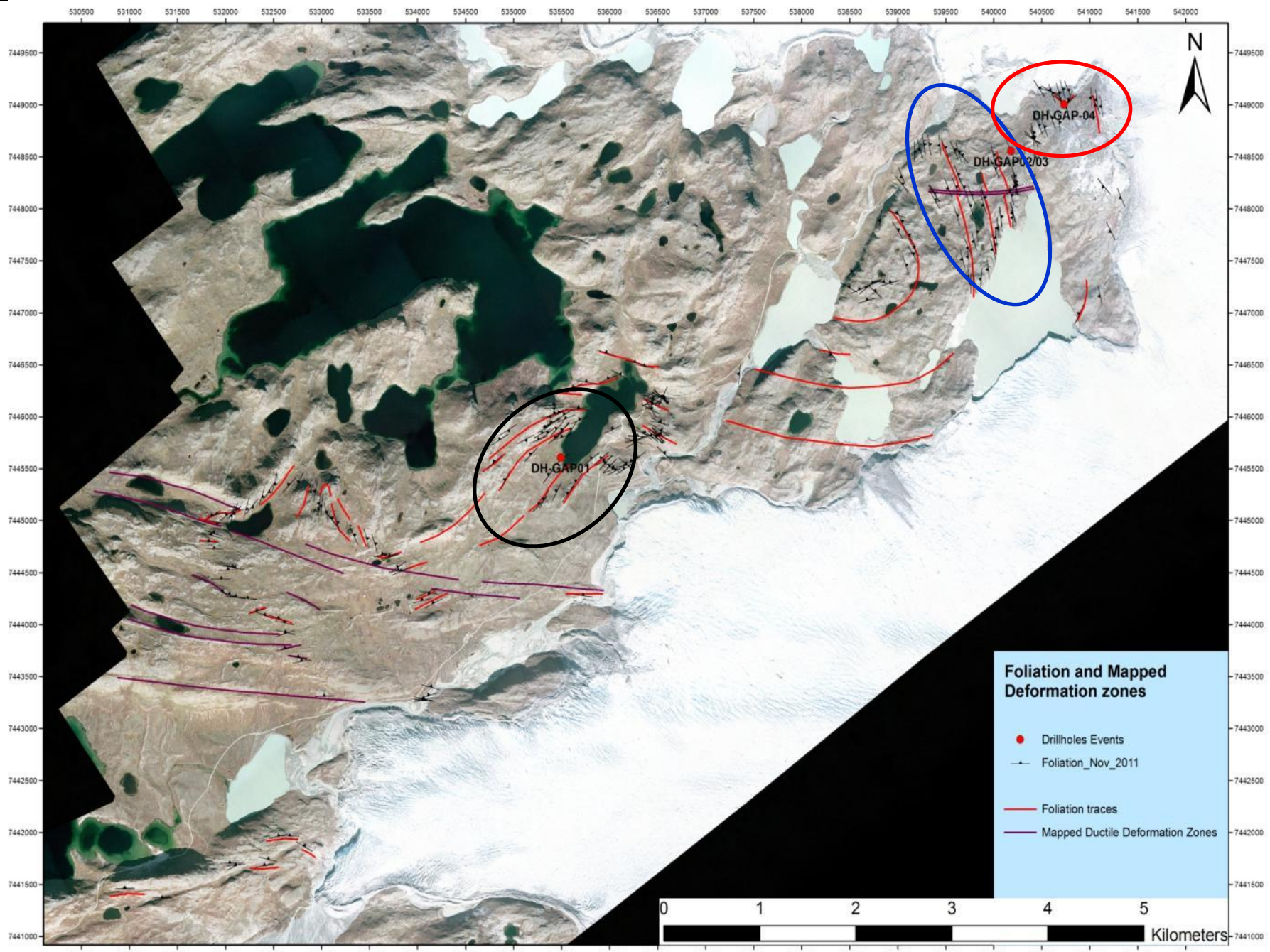
0 meters

700 meters

Bedrock

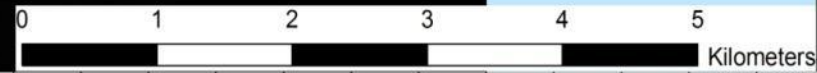
Permafrost

Ice Sheet

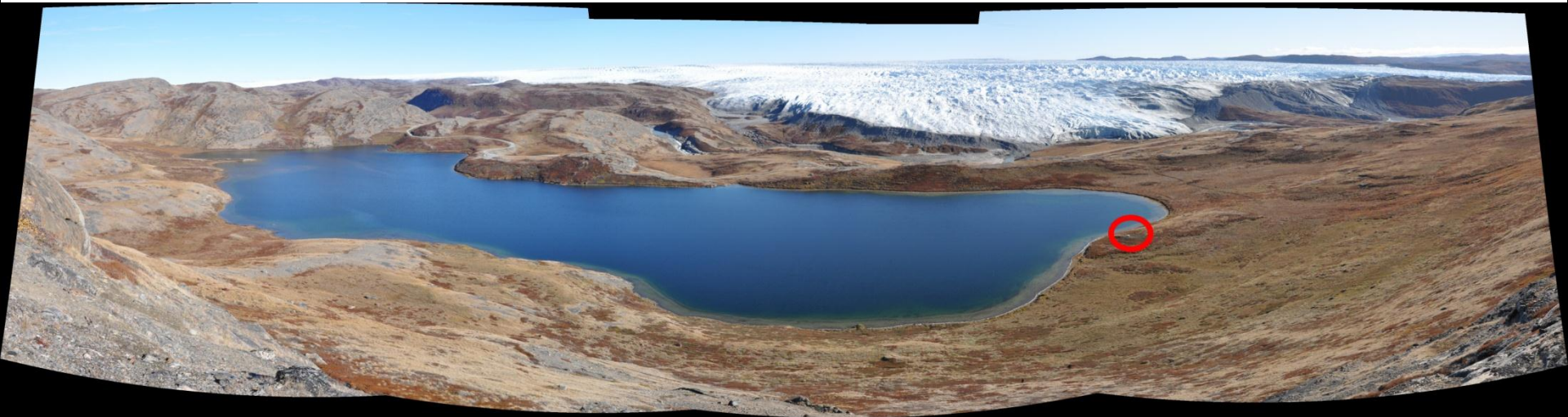


**Foliation and Mapped Deformation zones**

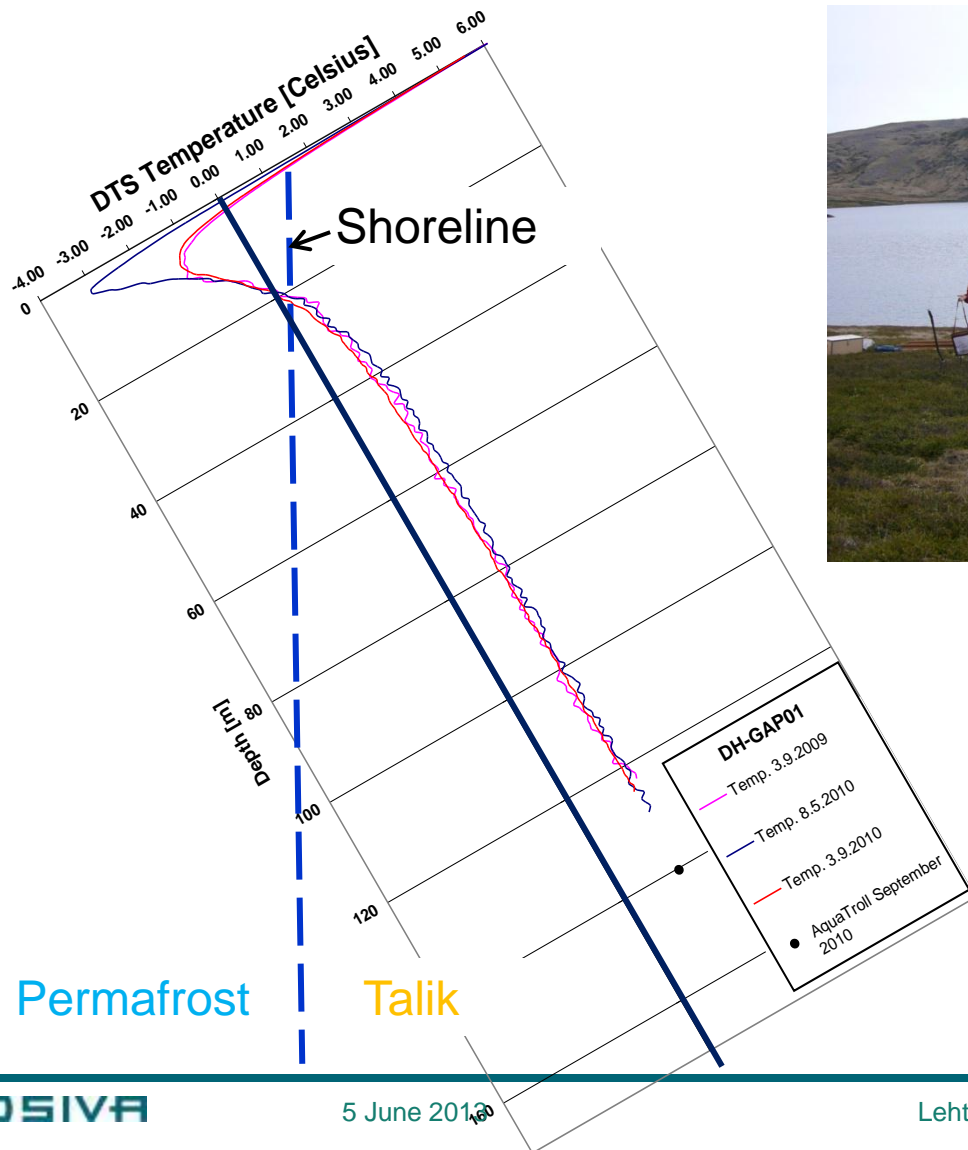
- Drillholes Events
- Foliation\_Nov\_2011
- Foliation traces
- Mapped Ductile Deformation Zones



# DH-GAP01 – The talik hole



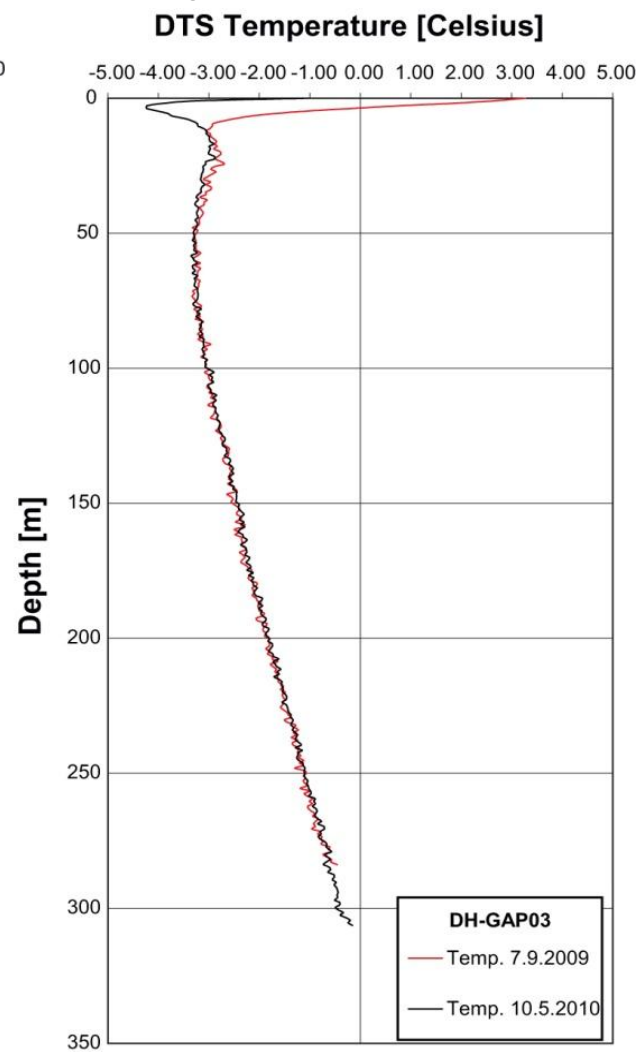
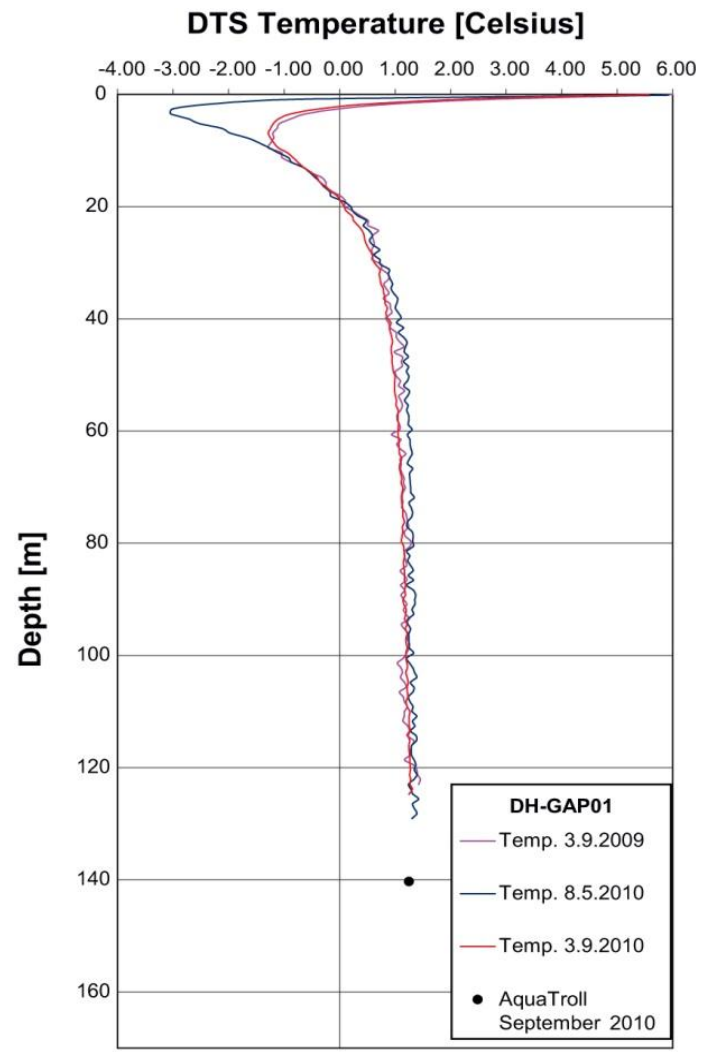
# DH-GAP01 – The talik hole



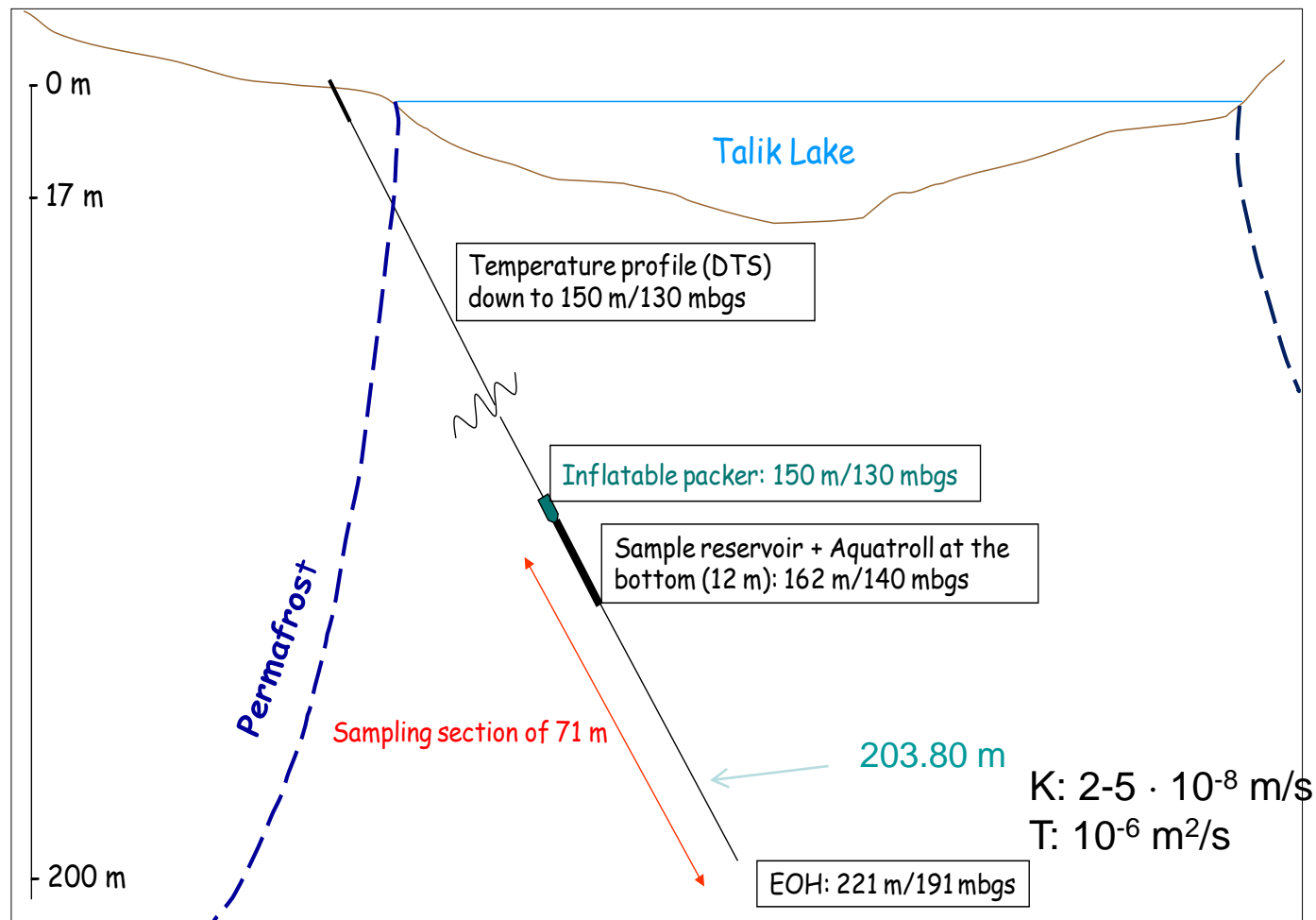
- T at 130 m vertical: 1.3°C
- Through talik or open talik?

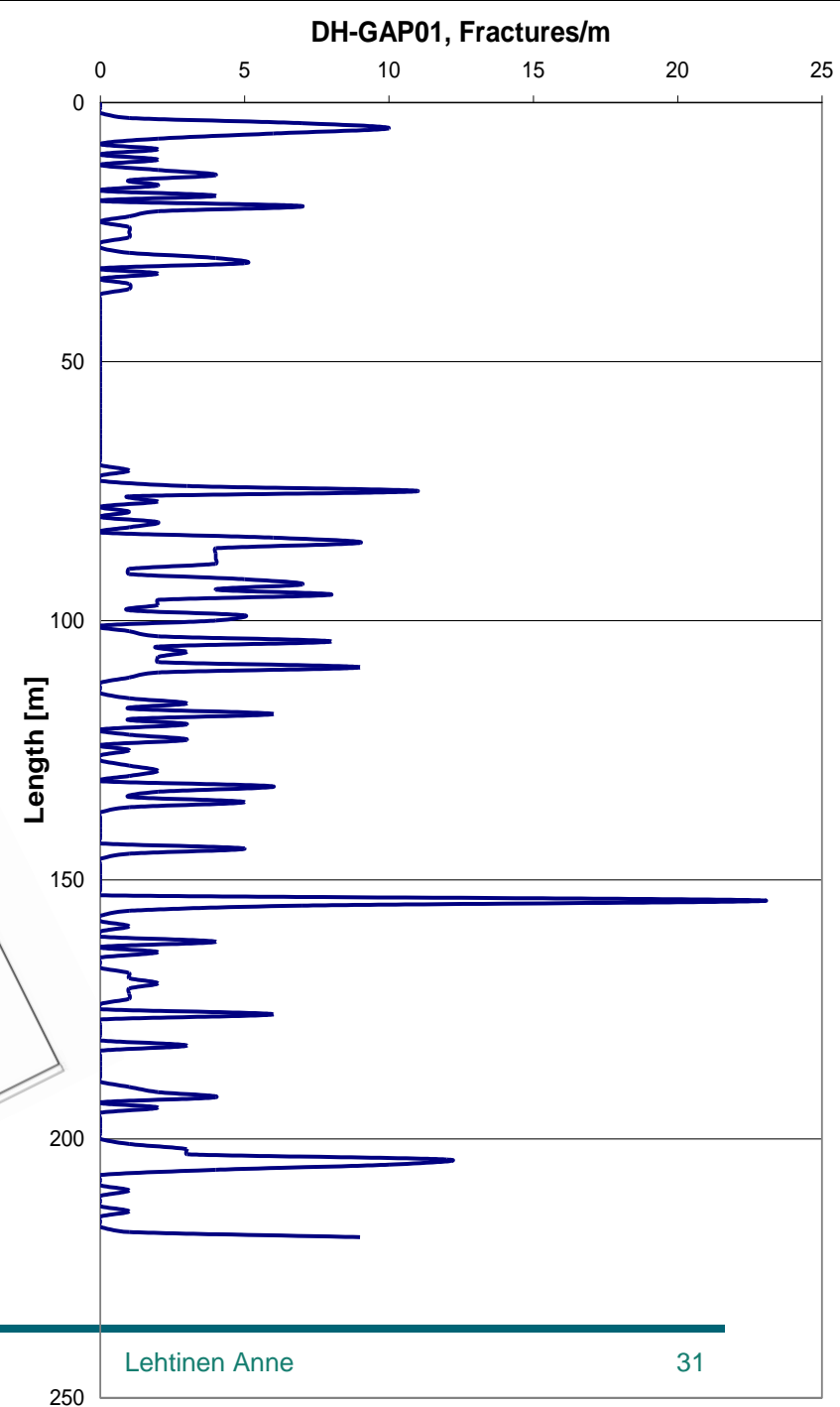
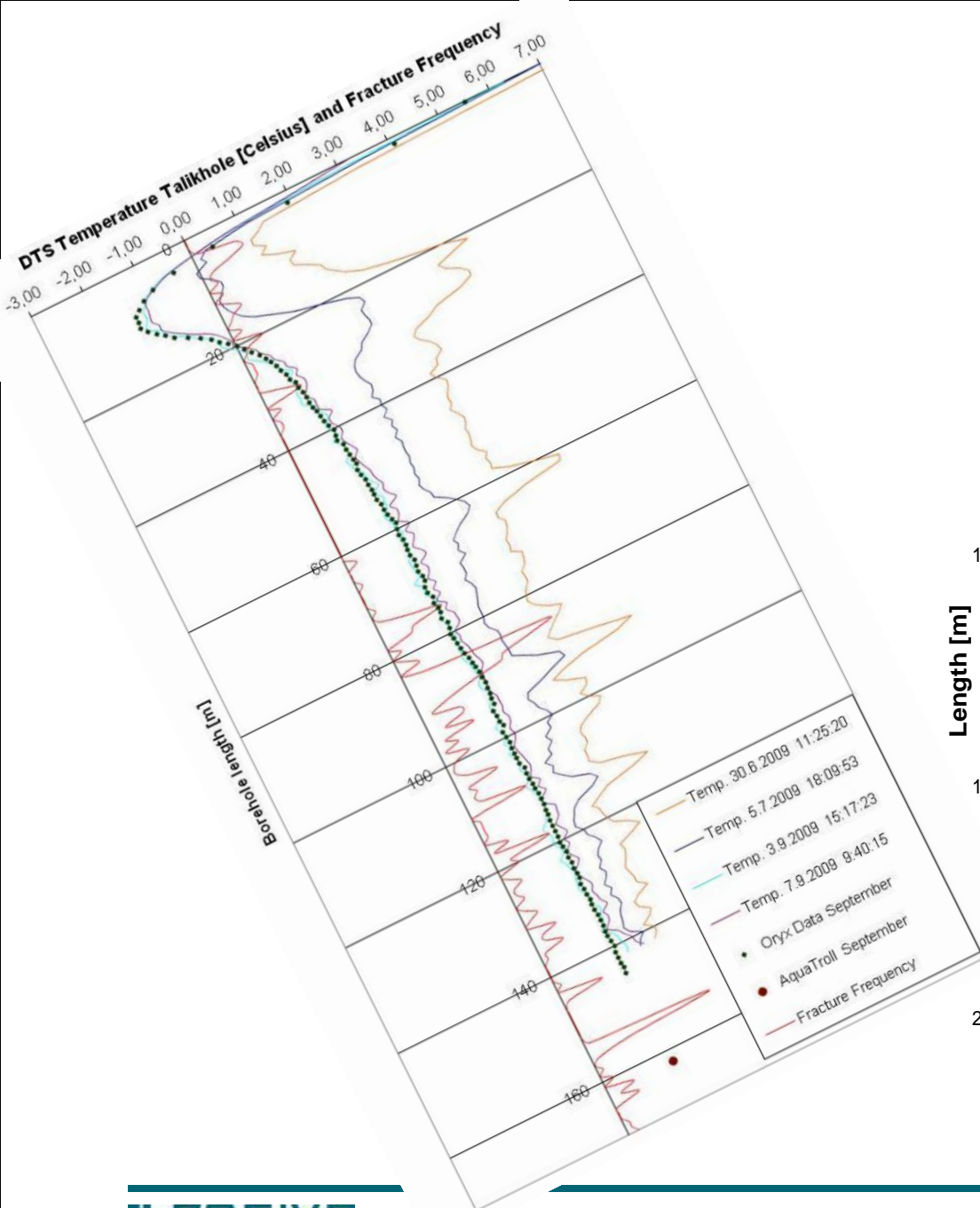
# Temperature profiles in DH-GAP01 (left) and DH-GAP03 (right) calculated for vertical depths.

Note that the vertical depth extension is not the same in the two figures.



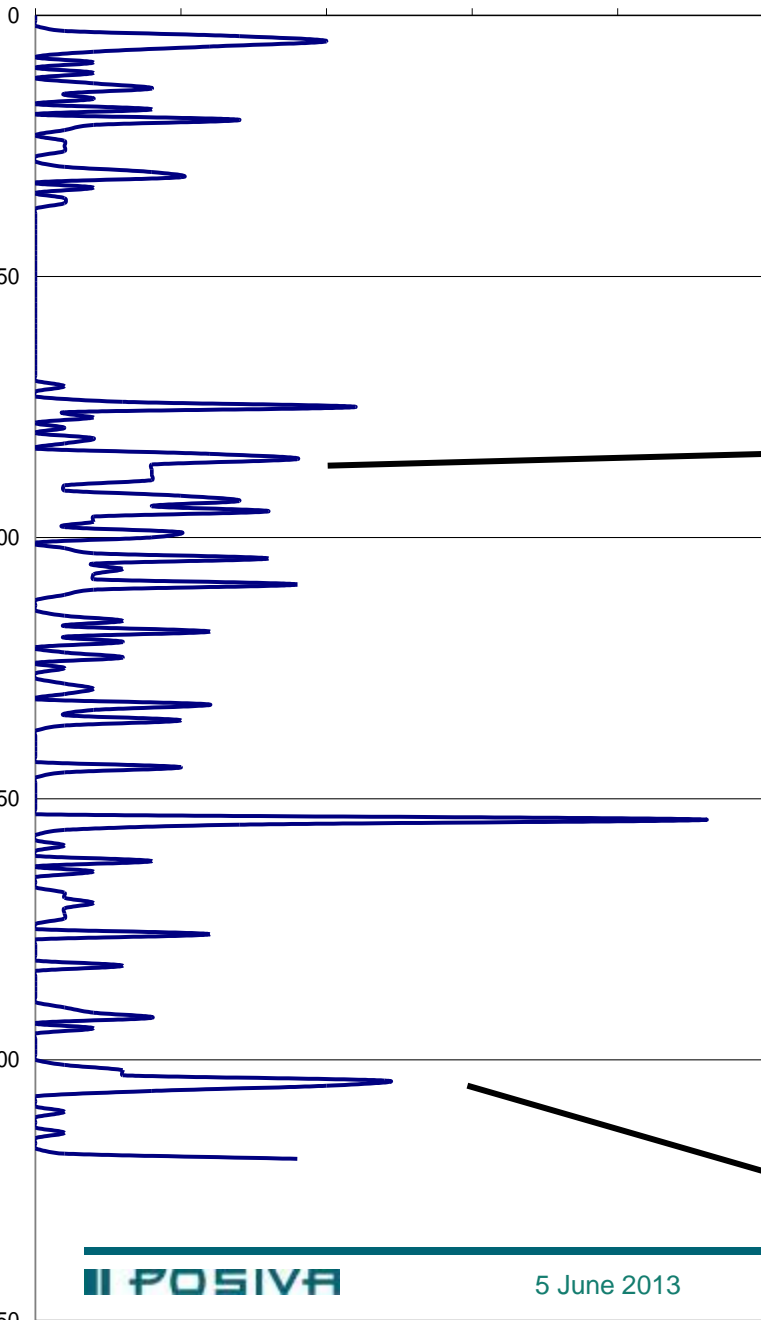
# DH-GAP01

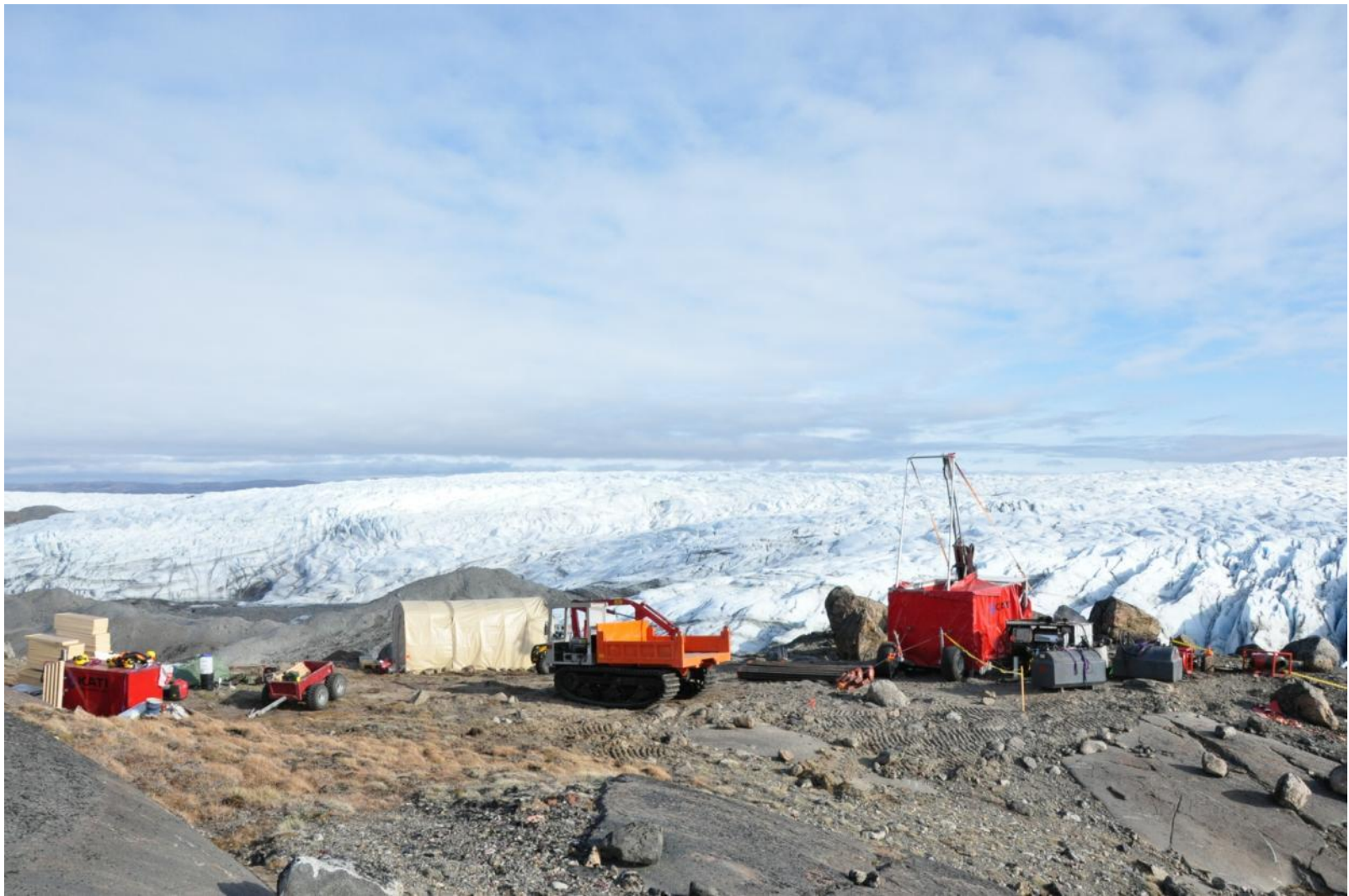


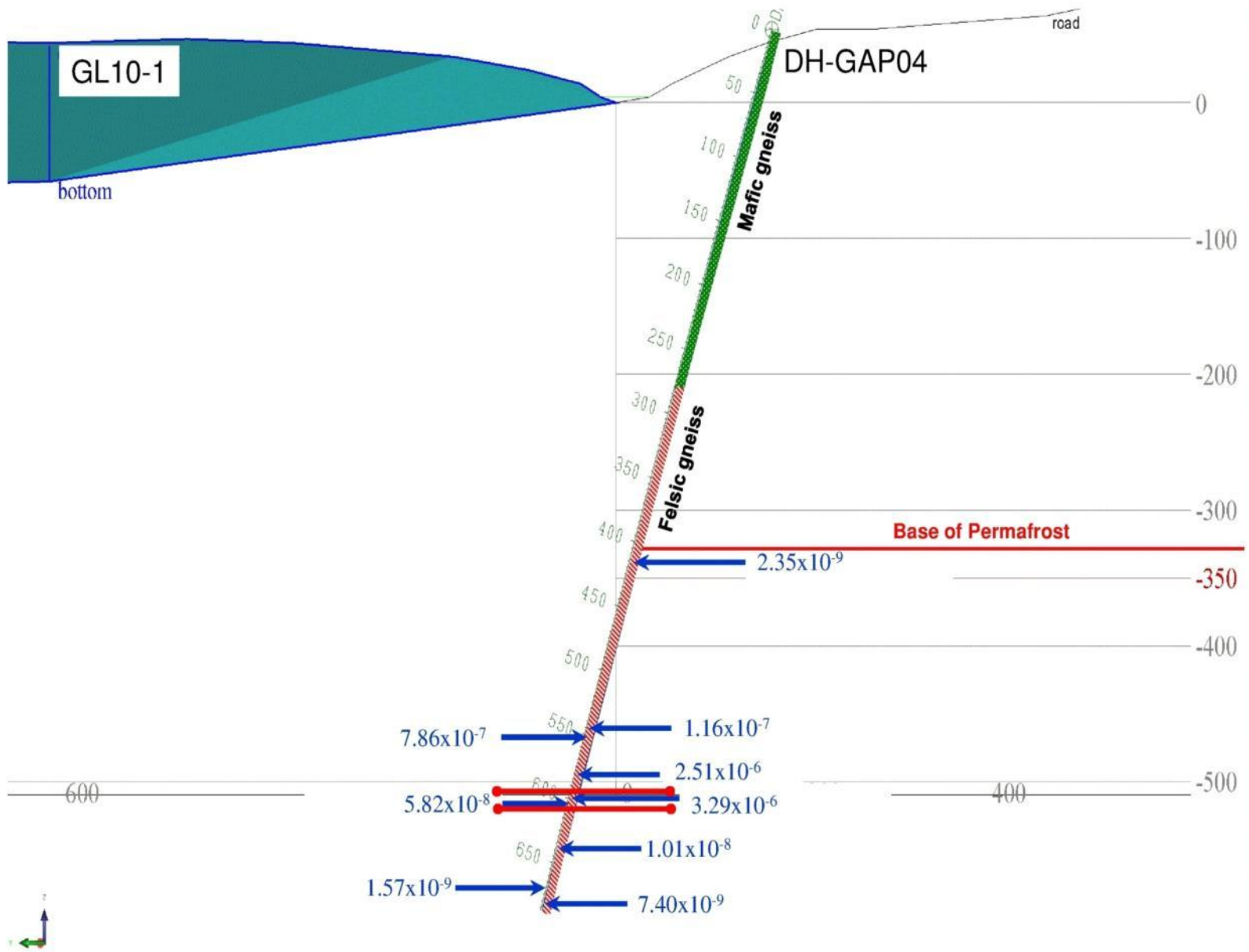


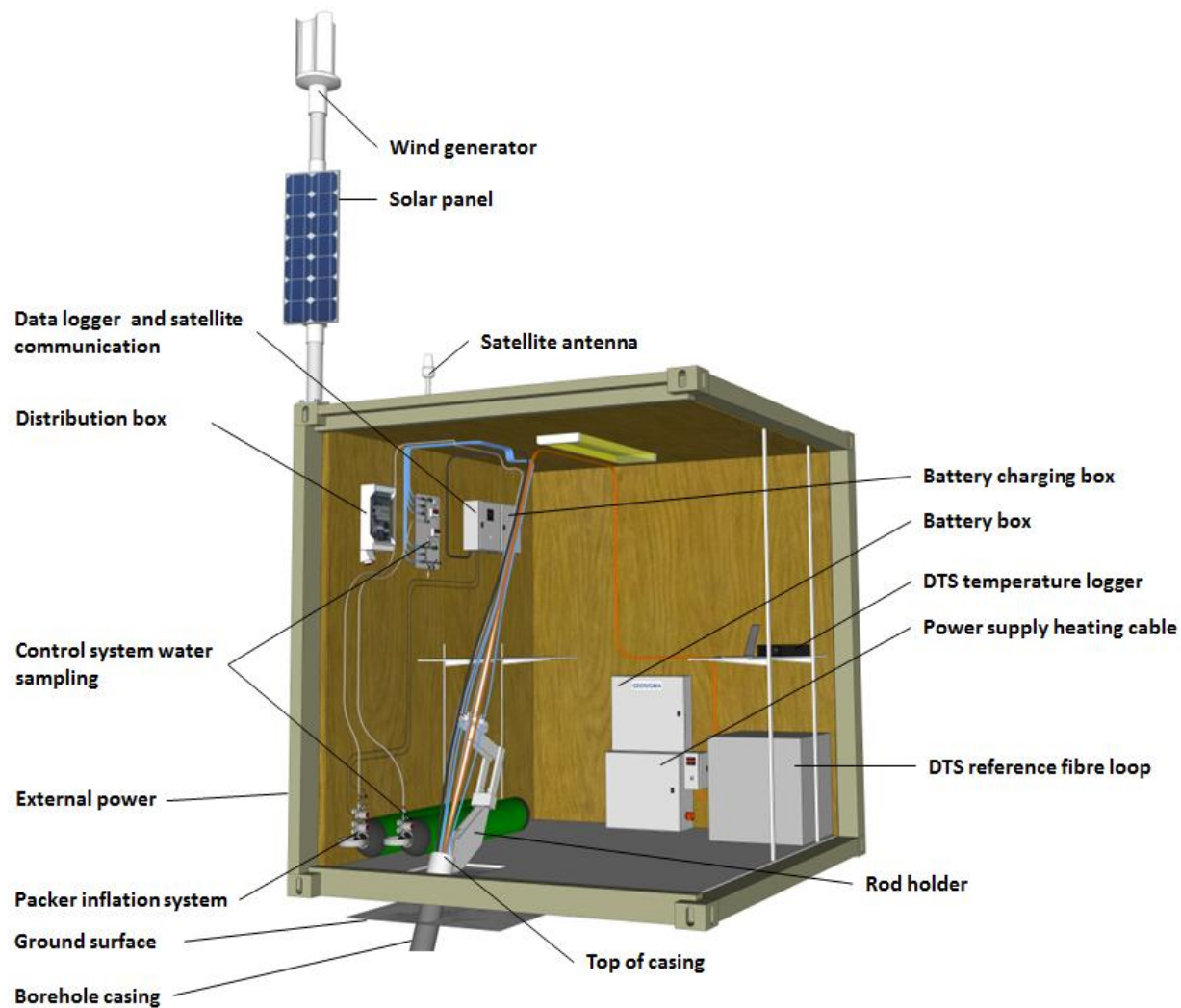
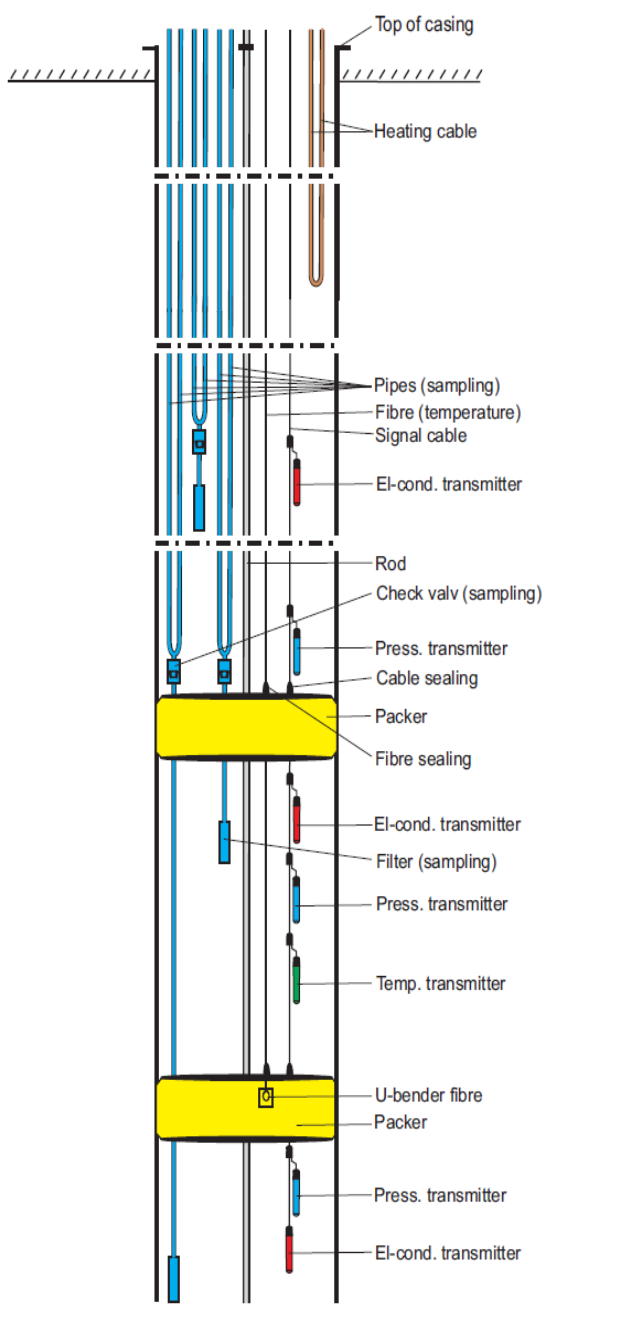
# DH-GAP01, Fractures/m

0 5 10 15 20 25



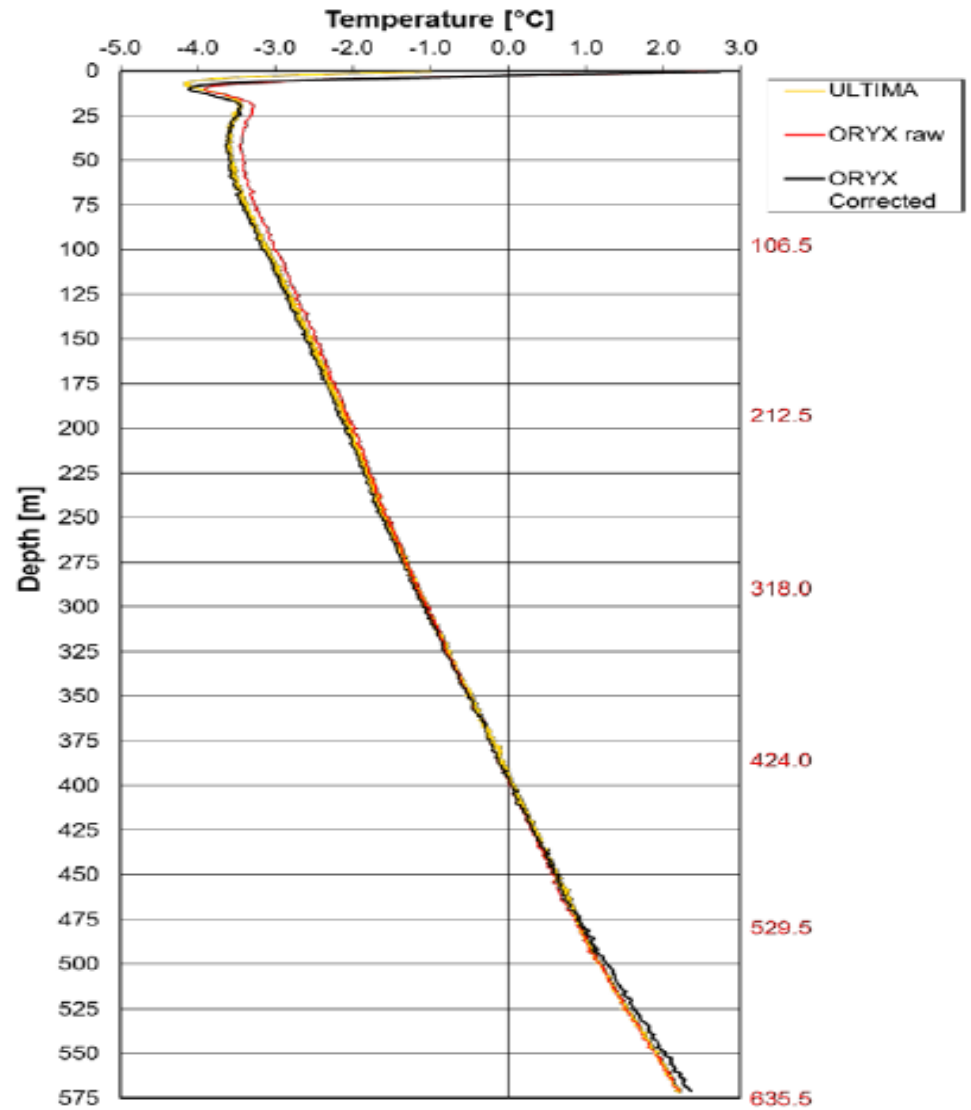




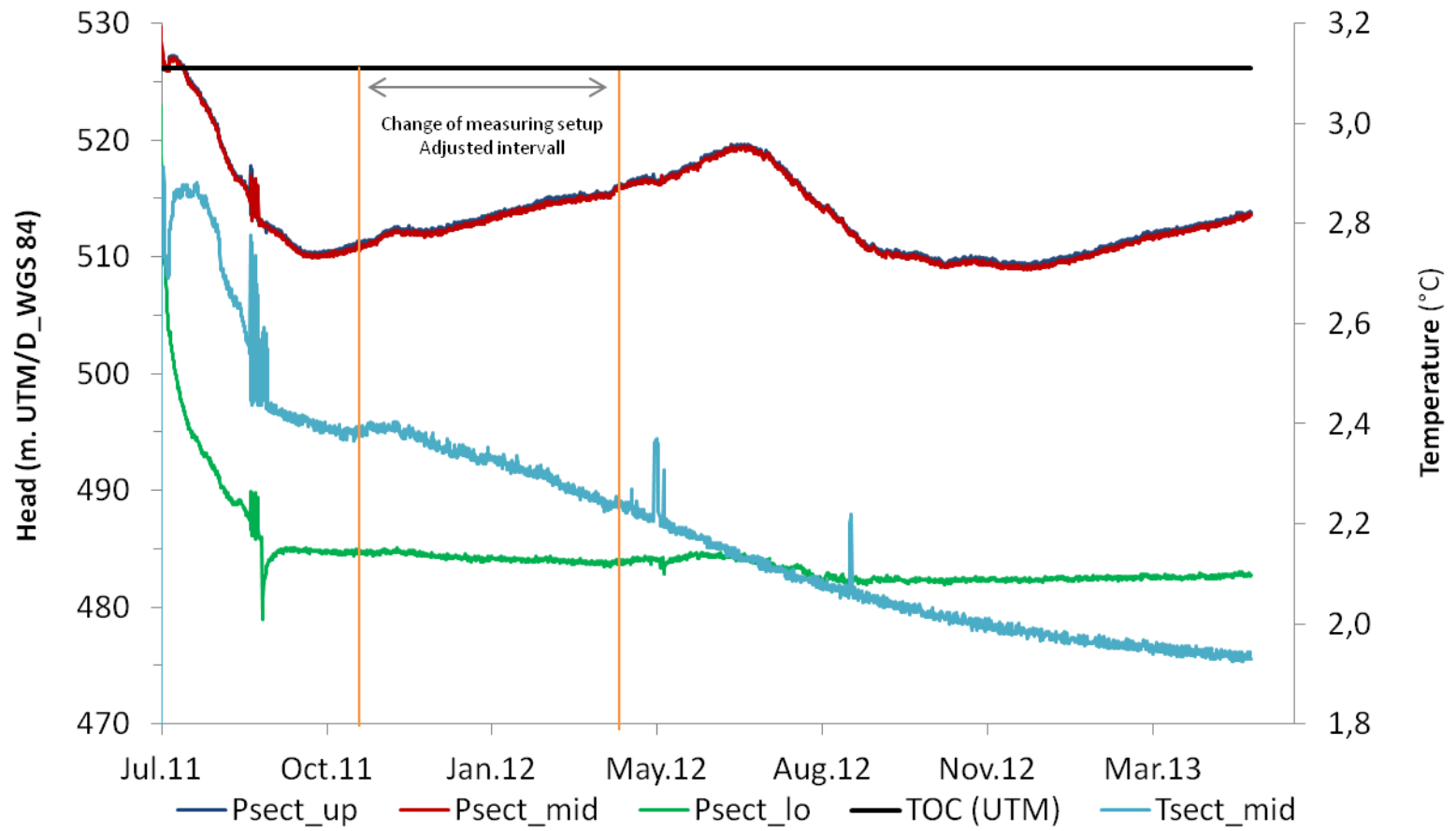


## Post data correction

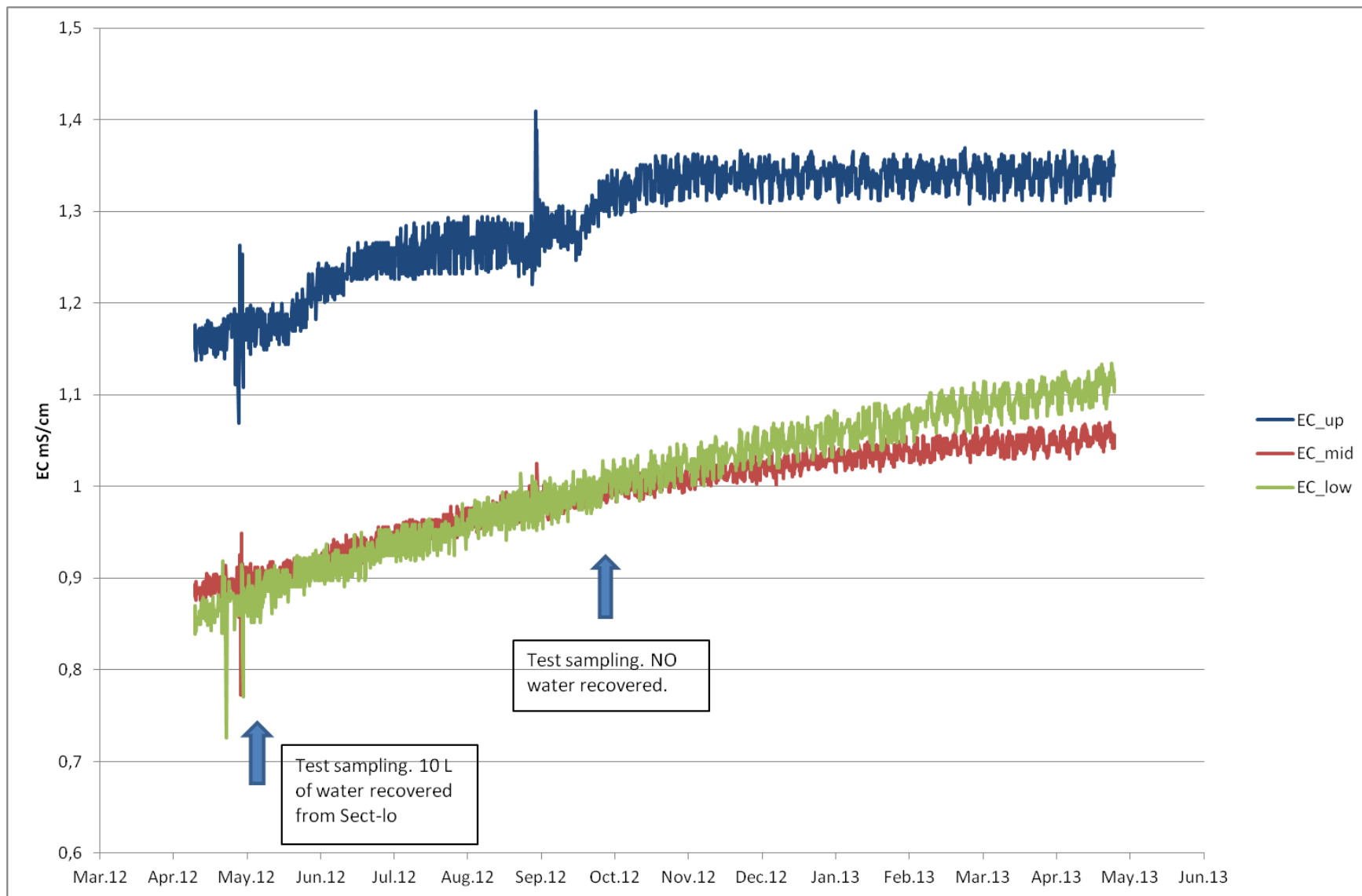
DH-GAP04  
Permafrost depth  
ca 400m depth



Head and temperature in DH-GAP04 from July 2011 to March, 2013



# GAP04 EC values



# GAP project today

- DH-GAP04 sampling
- GAP Data, processes and conceptual understanding report (Data report)
  - The report will present the objectives of the research and investigations, present the different data sets that have been collected throughout the project, and describe the conceptual understandings developed for each of the SPs. The report will describe to what extent the collected data supports these conceptual understandings.
- The GAP Final report will be a synthesis report, but will also in part be a summary report which summarizes and integrates the conceptual understandings presented in the Data Report, and also summarizes the key data/understanding gained during GAP.



nwmo





**Thank You !**