



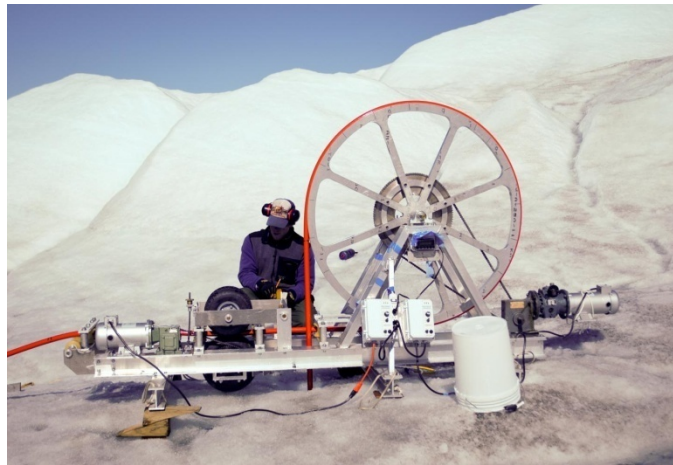
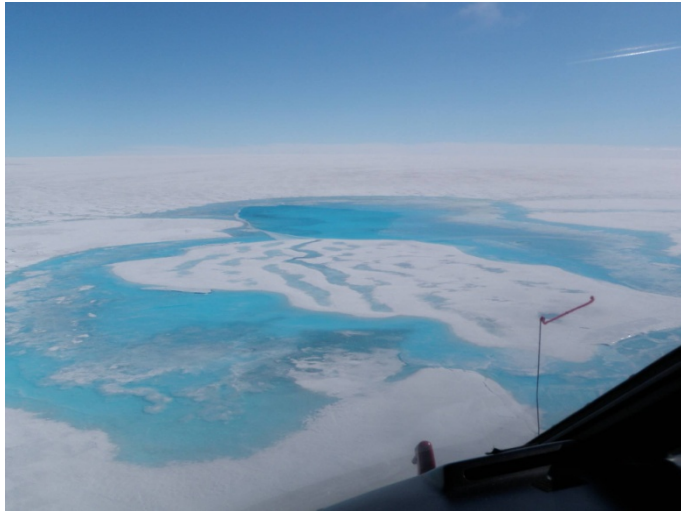
# Hydrogeological and hydrogeochemical conditions at the continental ice sheet margin

## Greenland Analogue Project (GAP)

Timo Ruskeeniemi, Lillemor Claesson Liljedahl, Anne Lehtinen,  
Alun Hubbard & Joel Harper

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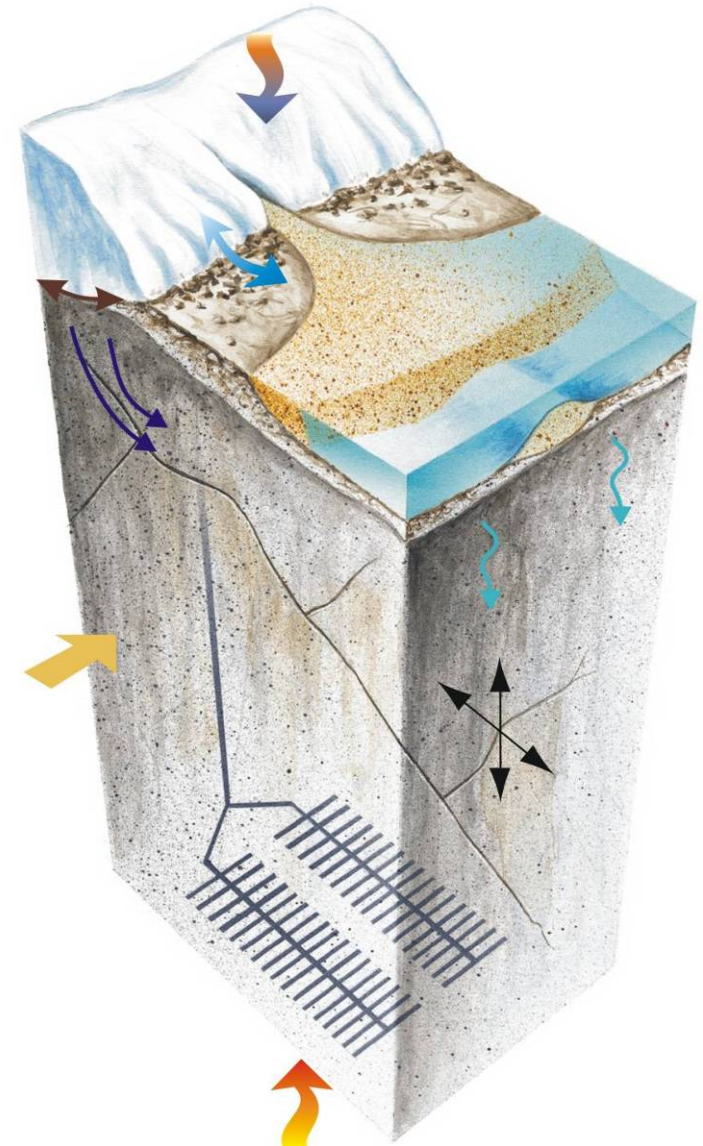


# Motivation

- Finnish and Swedish safety assessments indicate that periods of glacial conditions provide highest doses and risks
- 'We have a poor understanding, and therefore large uncertainties, concerning hydrological processes related to glacial conditions'
- In the authorities comments on the SKB and Posiva 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. Sweden, Finland, Canada and UK
- Results are important for the assessment of long-term safety (100 kyrs)

# Example of phenomena that can affect repository safety during 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)

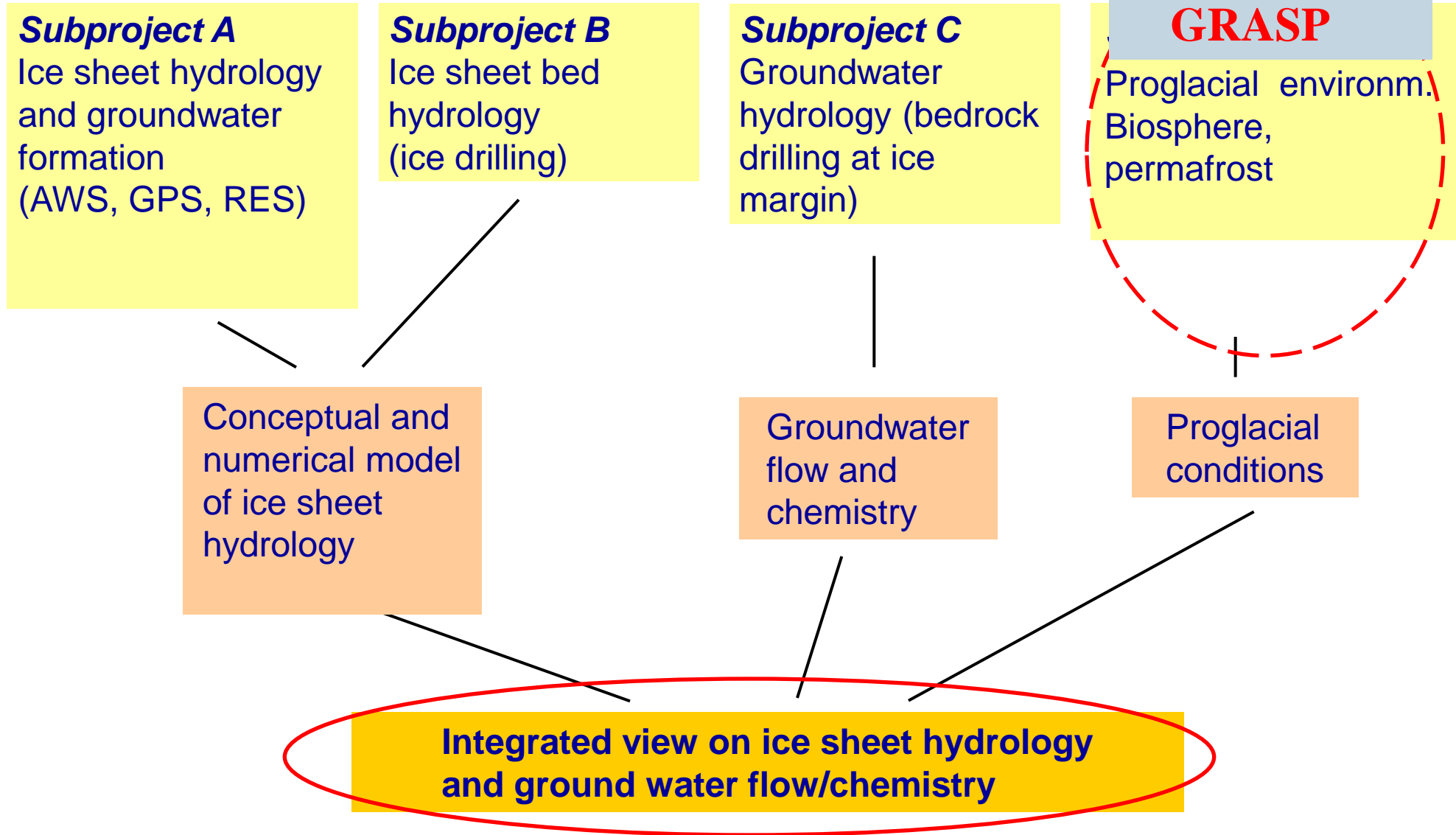


# GAP Project (2009 – 2012)

- Co-ordinating and funding organizations
  - SKB (Sweden), Posiva (Finland) and NWMO (Canada)
  - 4.1 M€ (6 MUSD) for 2009-2012
- Project Managers: Lillemor Claesson Liljedahl (SKB), Anne Lehtinen (Posiva) and Sarah Hirschorn (NWMO)
- 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 etc.
- [www.skb.se/GAP](http://www.skb.se/GAP)

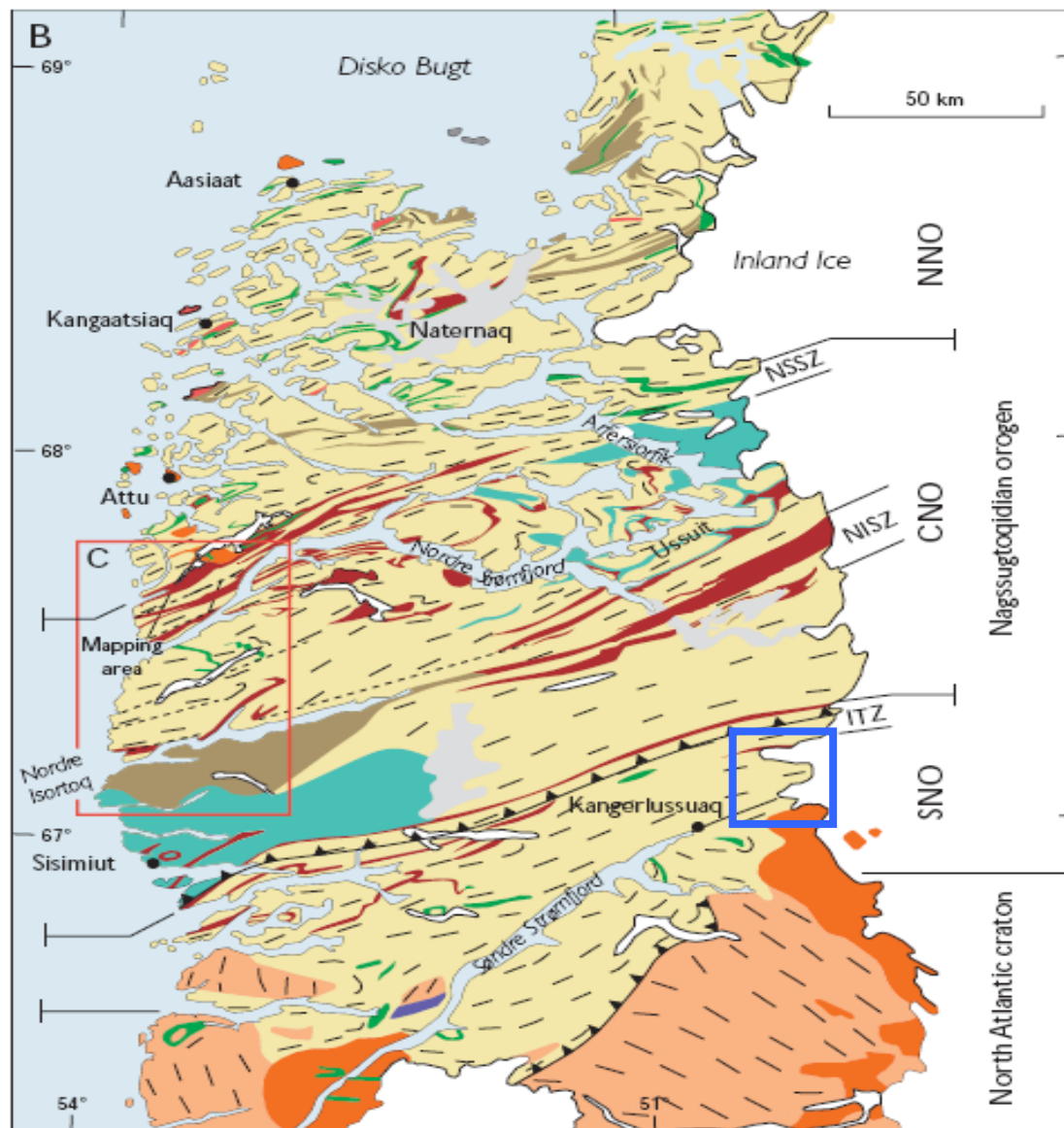
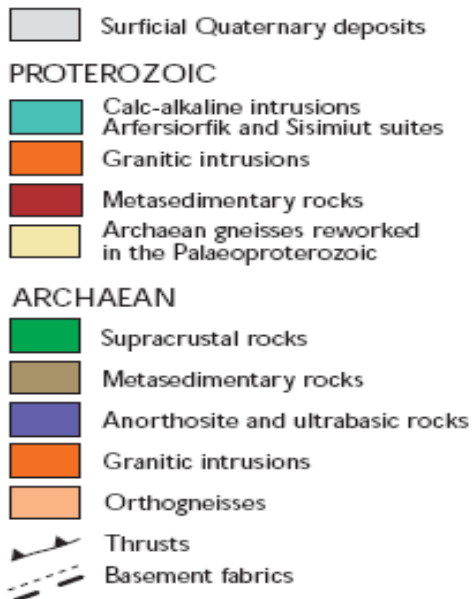
# Overall aims

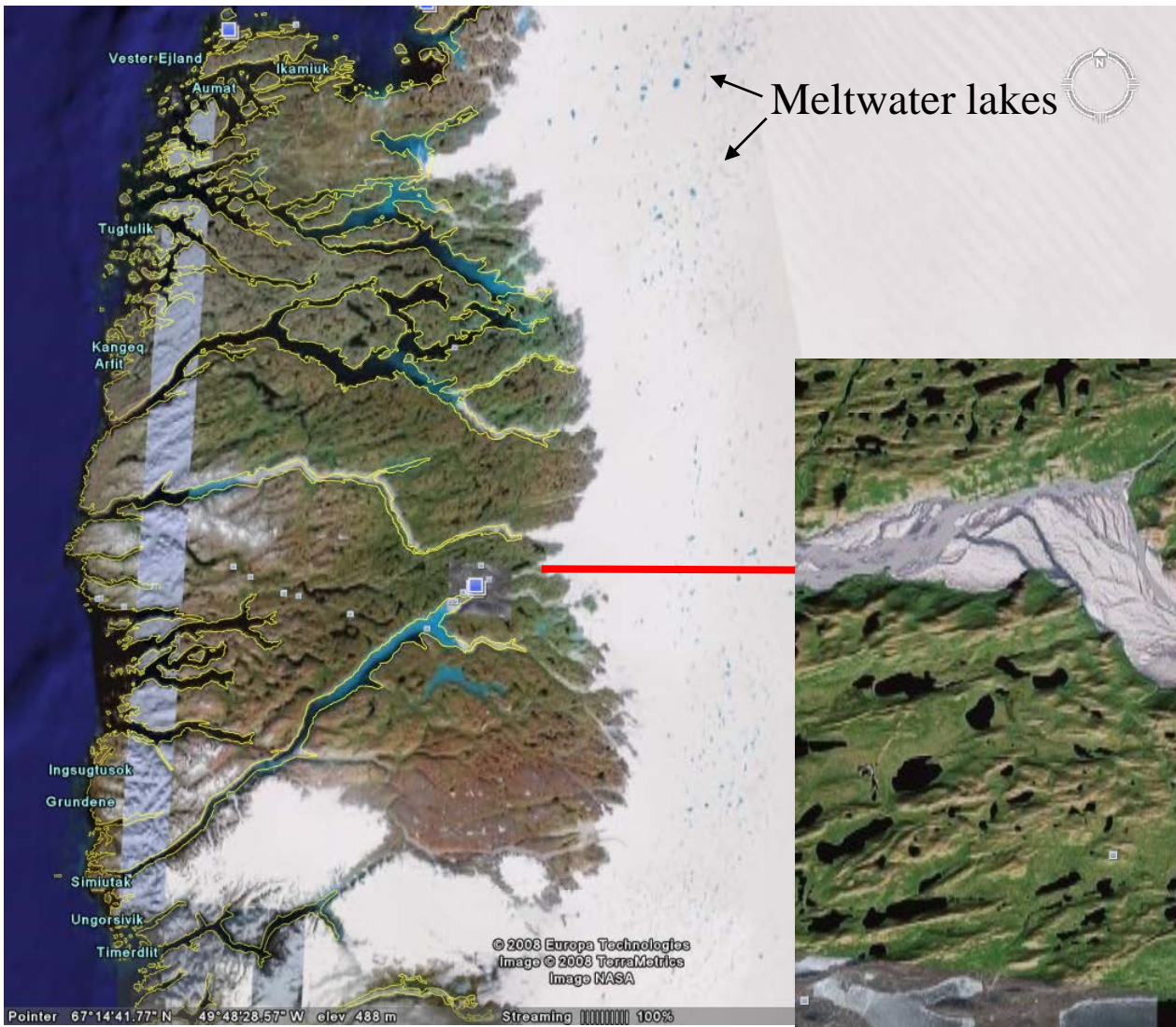
- Observations of how an ice sheet forms groundwater; (incl. hydraulic gradients at ice sheet bed, driving groundwater flow)
- Observations of whether glacial meltwater may penetrate crystalline bedrock down to repository depth (500-700 m);
- Observations of chemical composition of groundwater if/when 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 the necessary integrated view on ice sheet hydrology and groundwater flow/chemistry



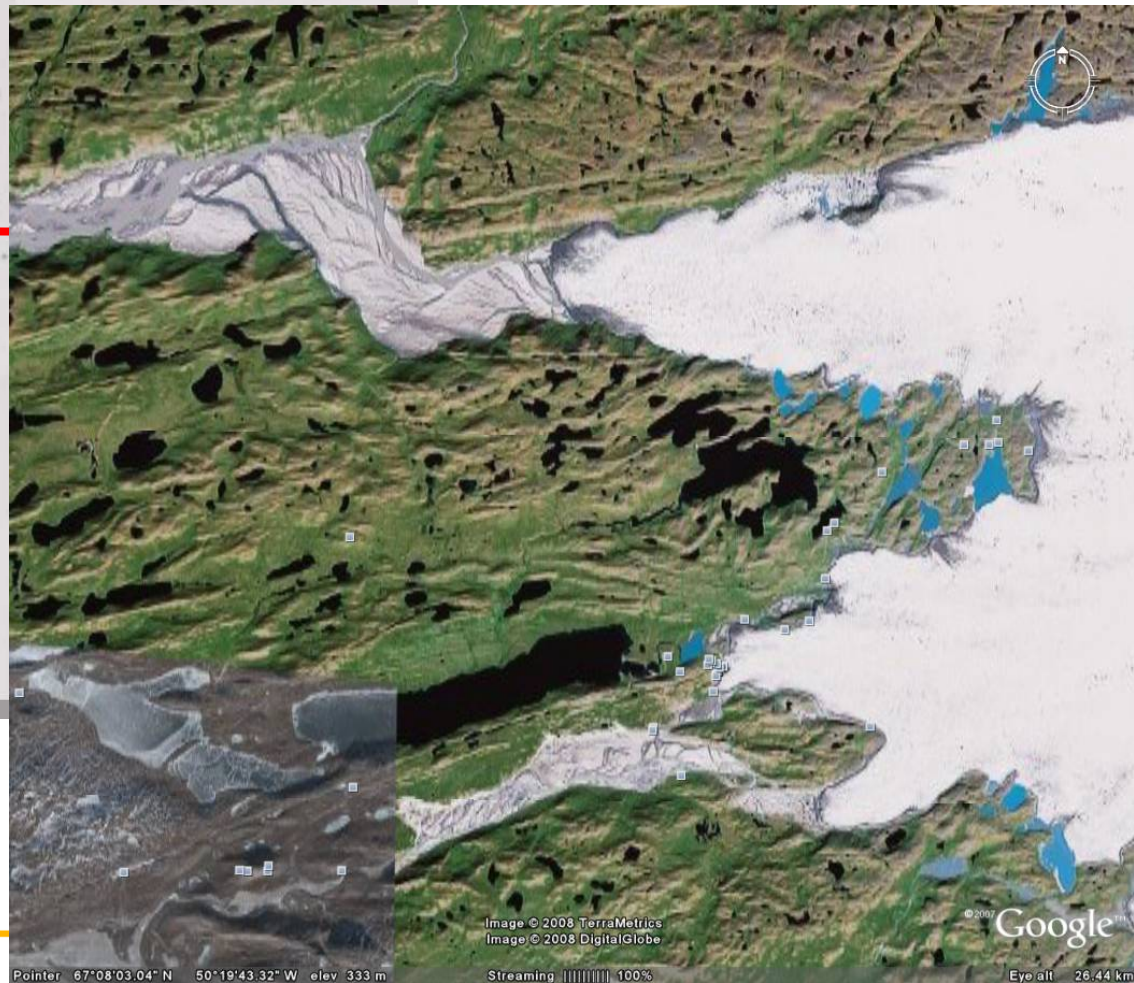
**Glaciological and hydrogeological modelling teams independent from GAP**

# Kangerlussuaq (Søndre Strømfjord)





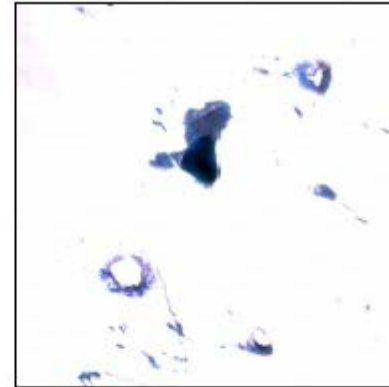
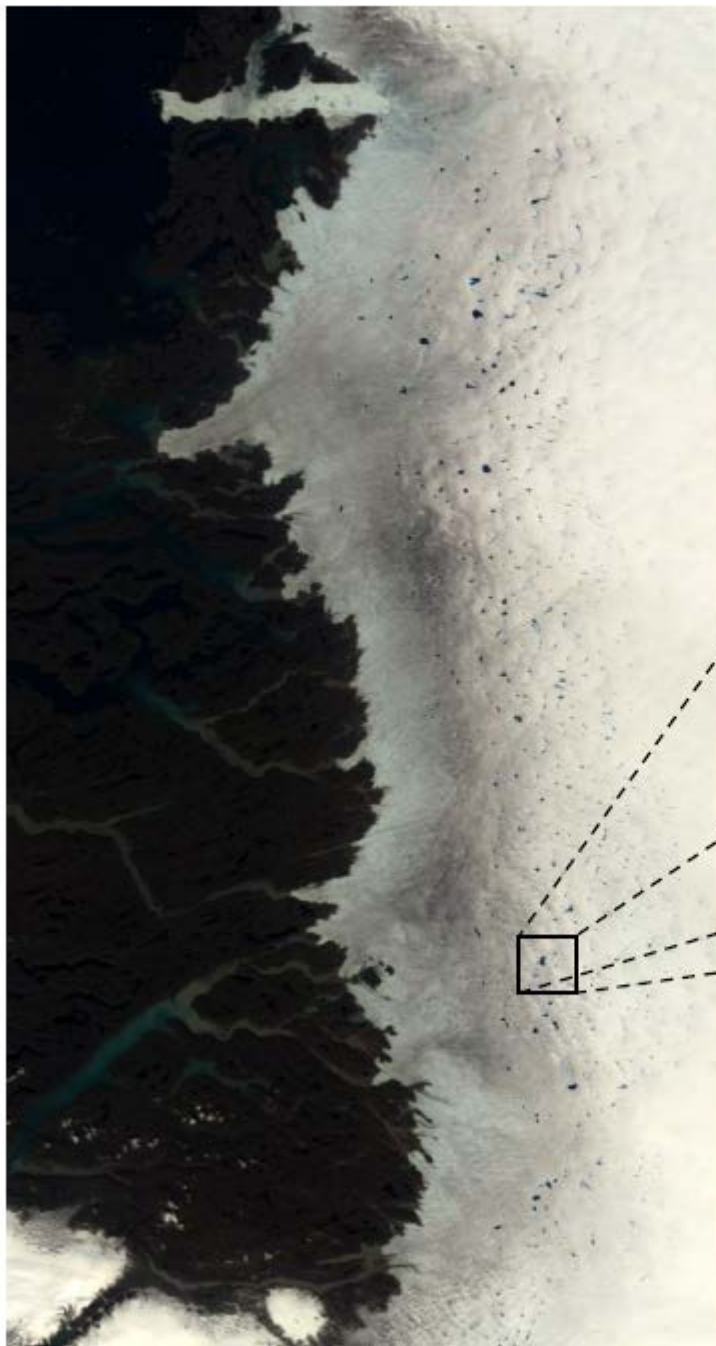
Meltwater lakes



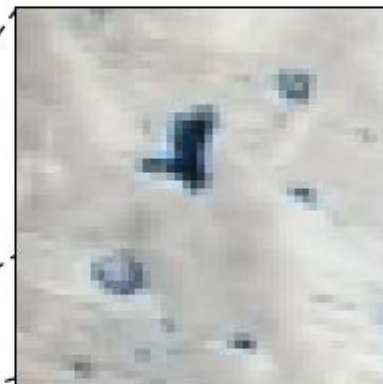
GTK

# SPA: Ice sheet hydrology and groundwater formation (SPM Alun Hubbart, Univ. Aberistwyth, UK)

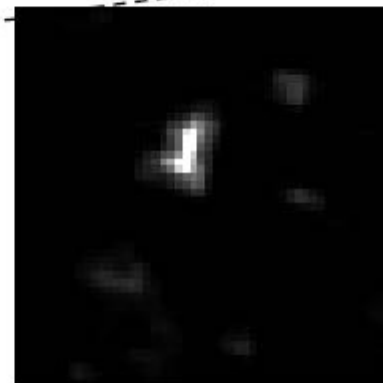
- Aims to improve the understanding of ice sheet hydrology
  - Quantification of ice sheet surface water production
  - Routing of the melt water from the surface to the base of the ice
- Basal topography of the ice sheet
- Thermal regime at the base → mapping warm based conditions
- Monitoring of GPS receivers and automatic weather stations on the ice sheet
- Remote sensing
- Airborne/ and ground-based radar studies



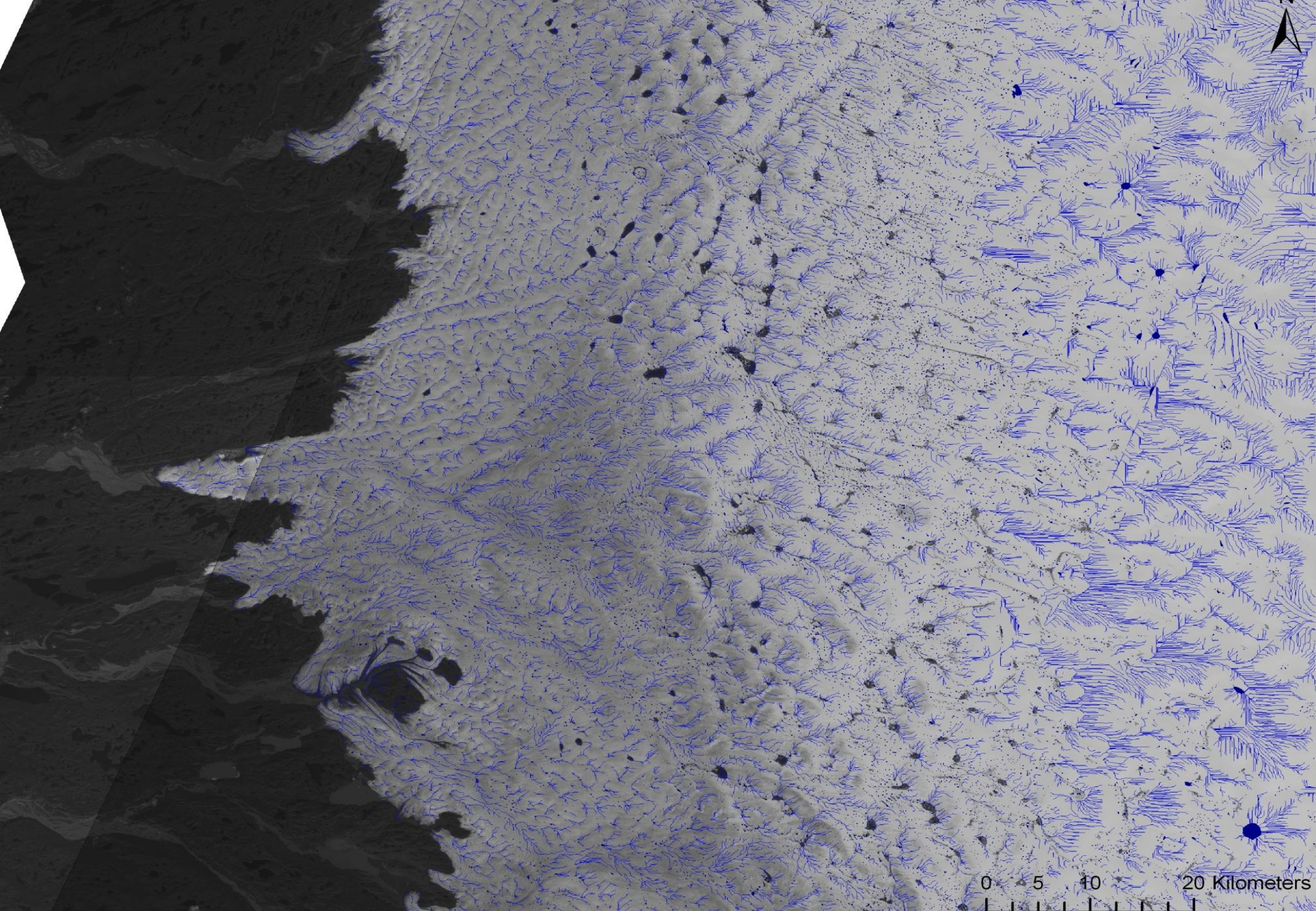
Landsat 7



MODIS



MODIS  
red/blue  
band math



# Surface mass budget model

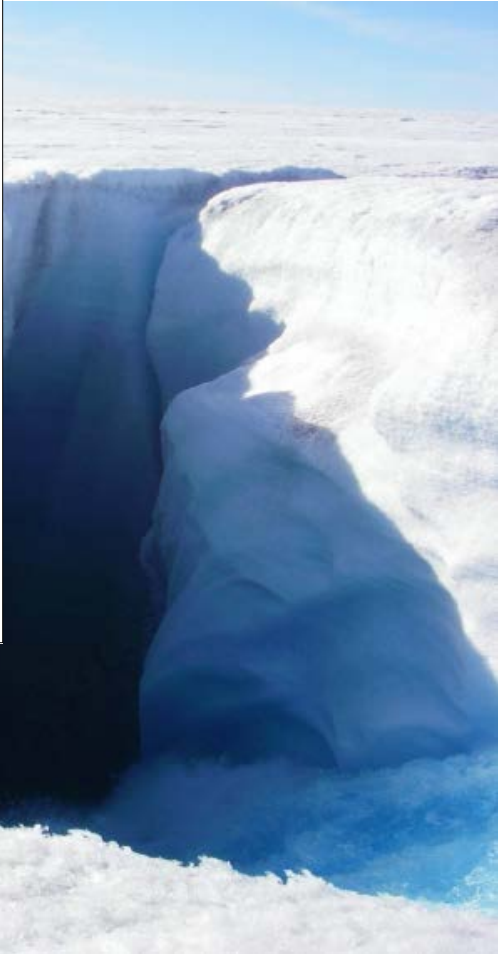
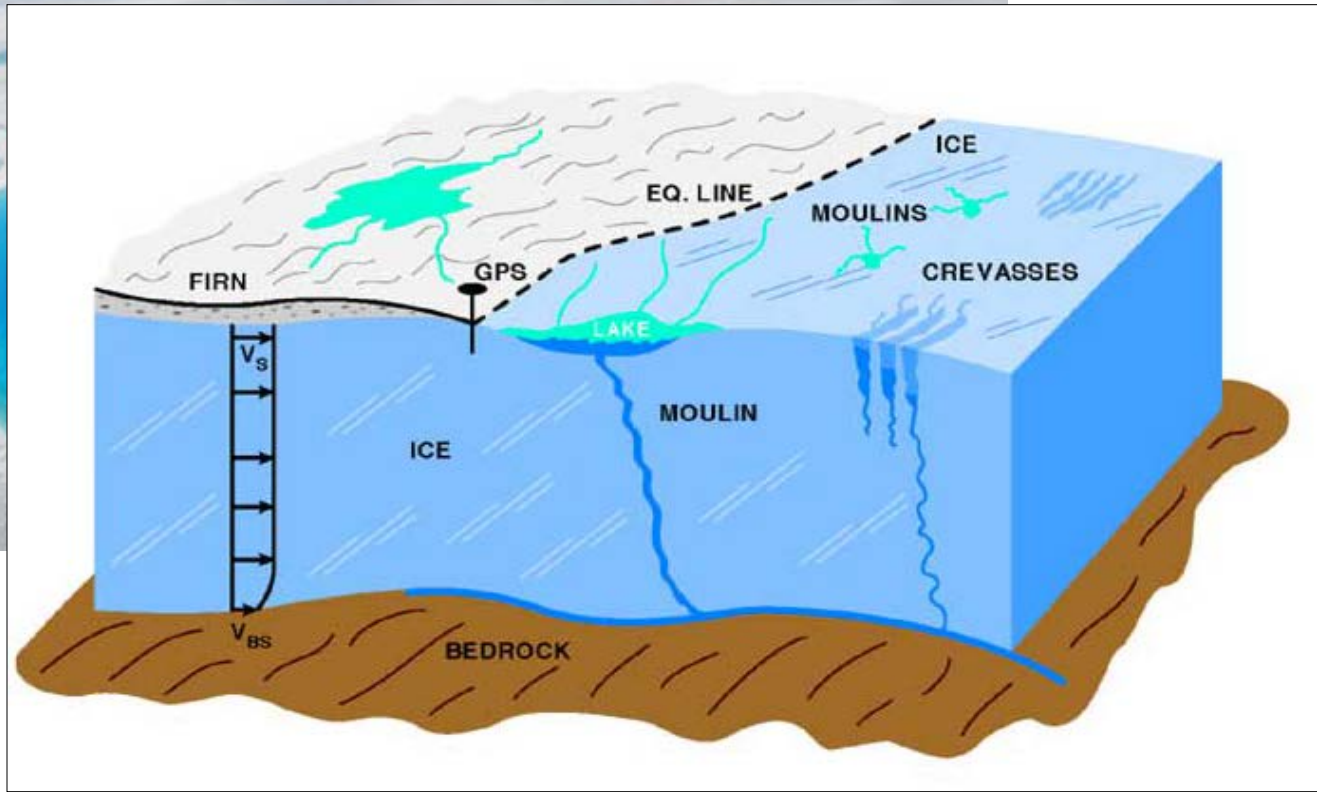
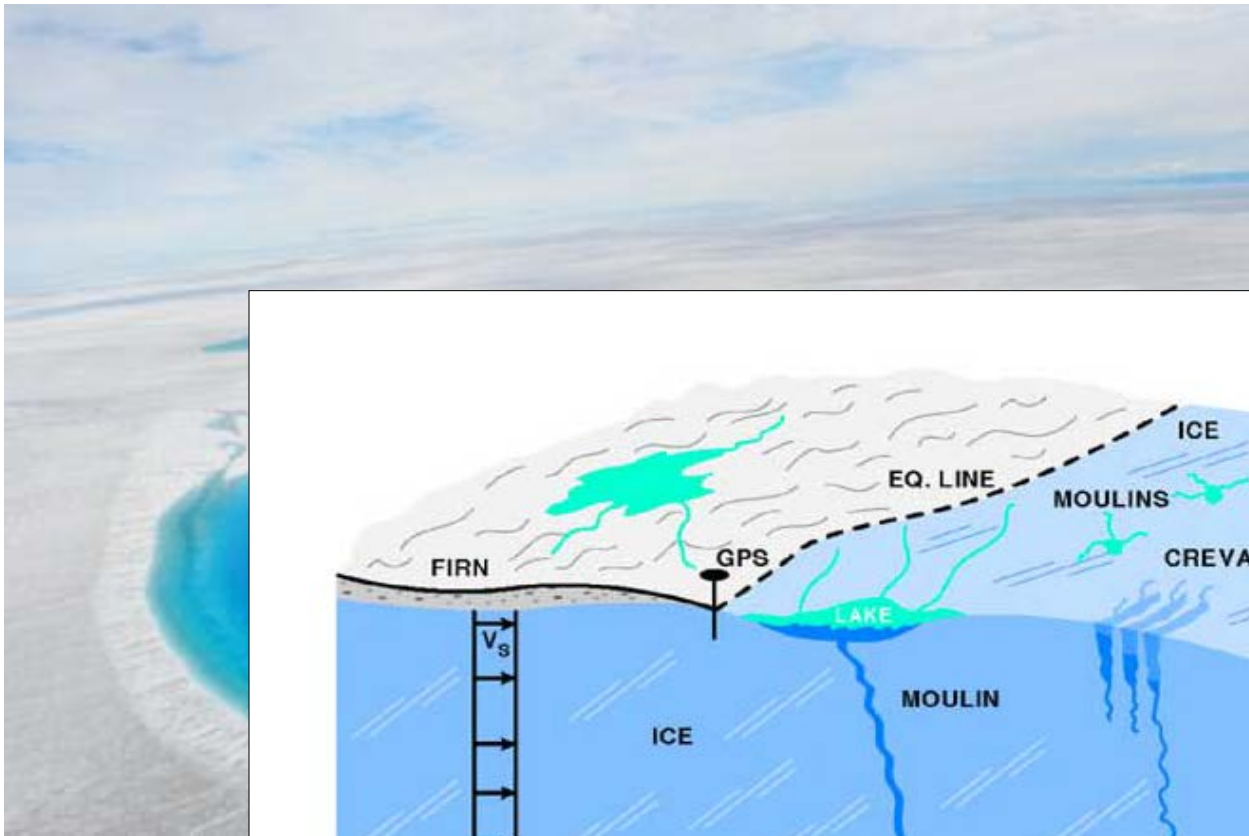
measurements:  
 $\rho$ ,  $T$ ,  $RH$ ,  $WS$ ,  $SR$ ,  
 $LR$

+

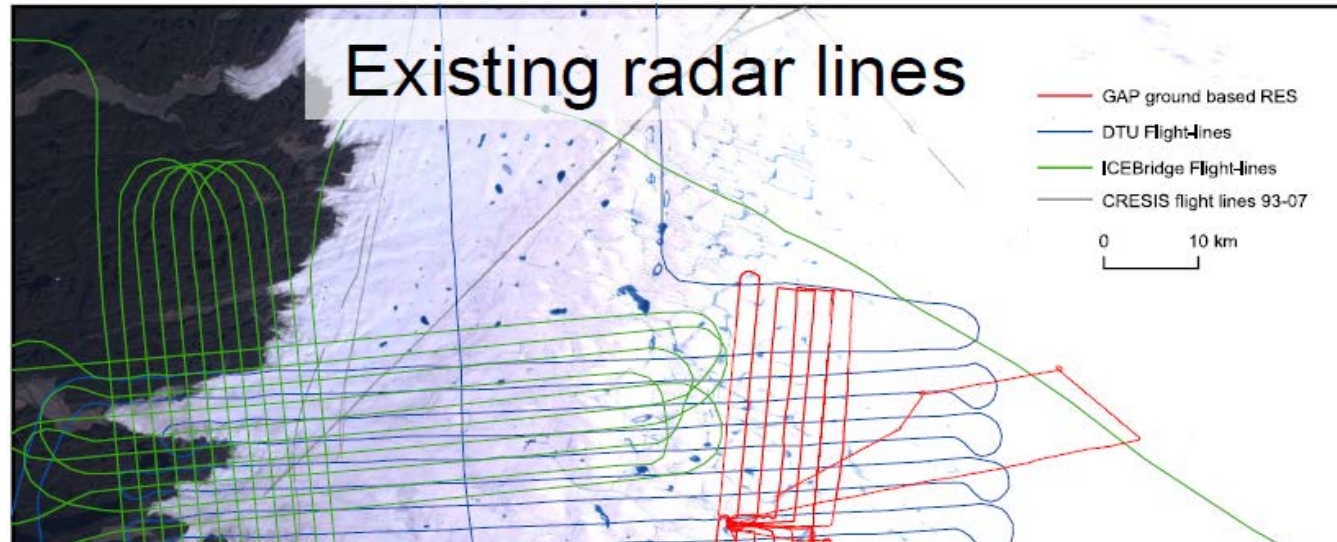
from literature:  
roughness length,  
snow density, etc.



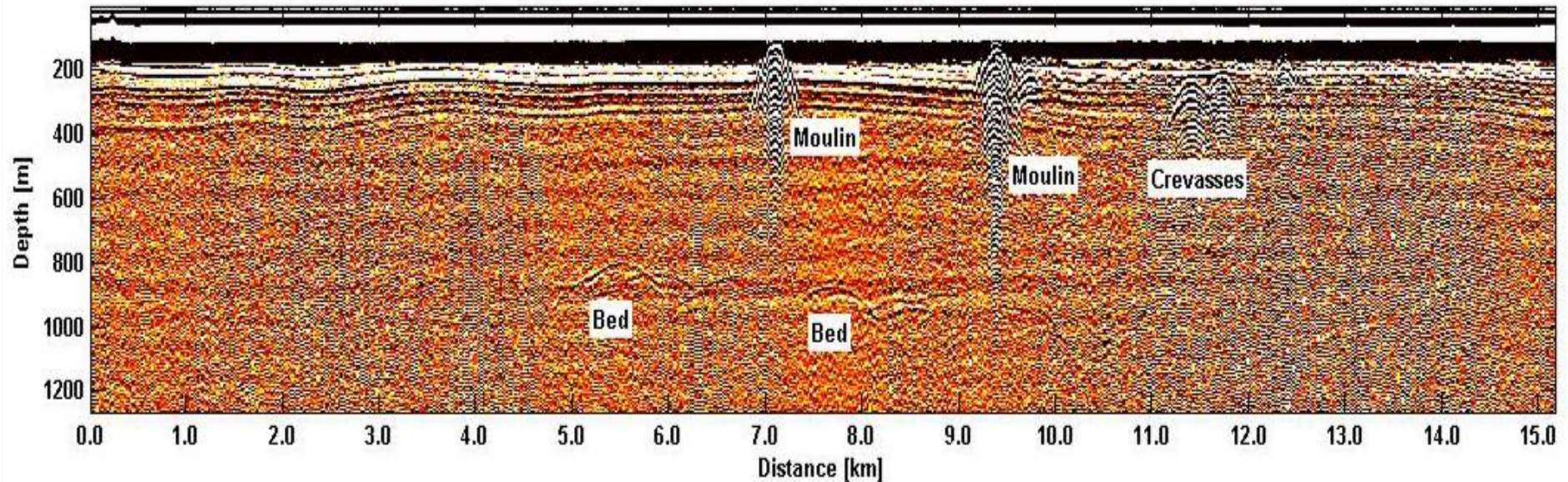
surface  
mass  
budget



# Radio-echo soundings

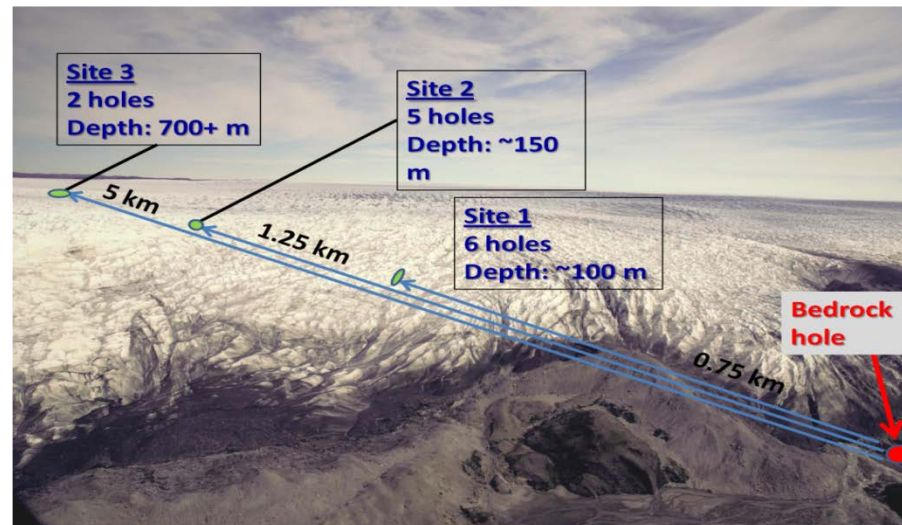


RGC 6v 09a



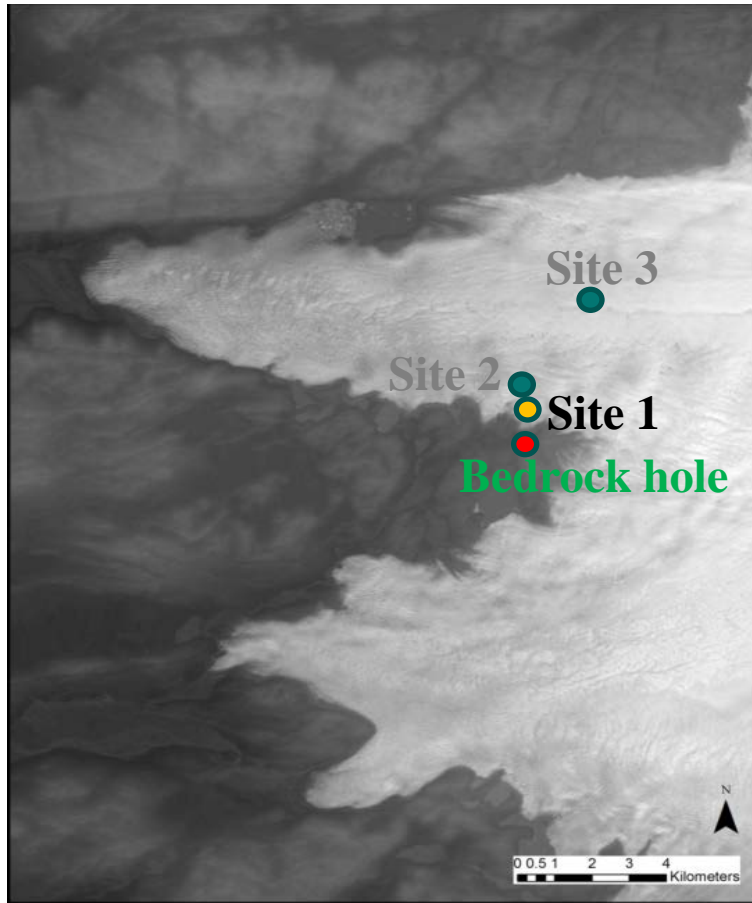
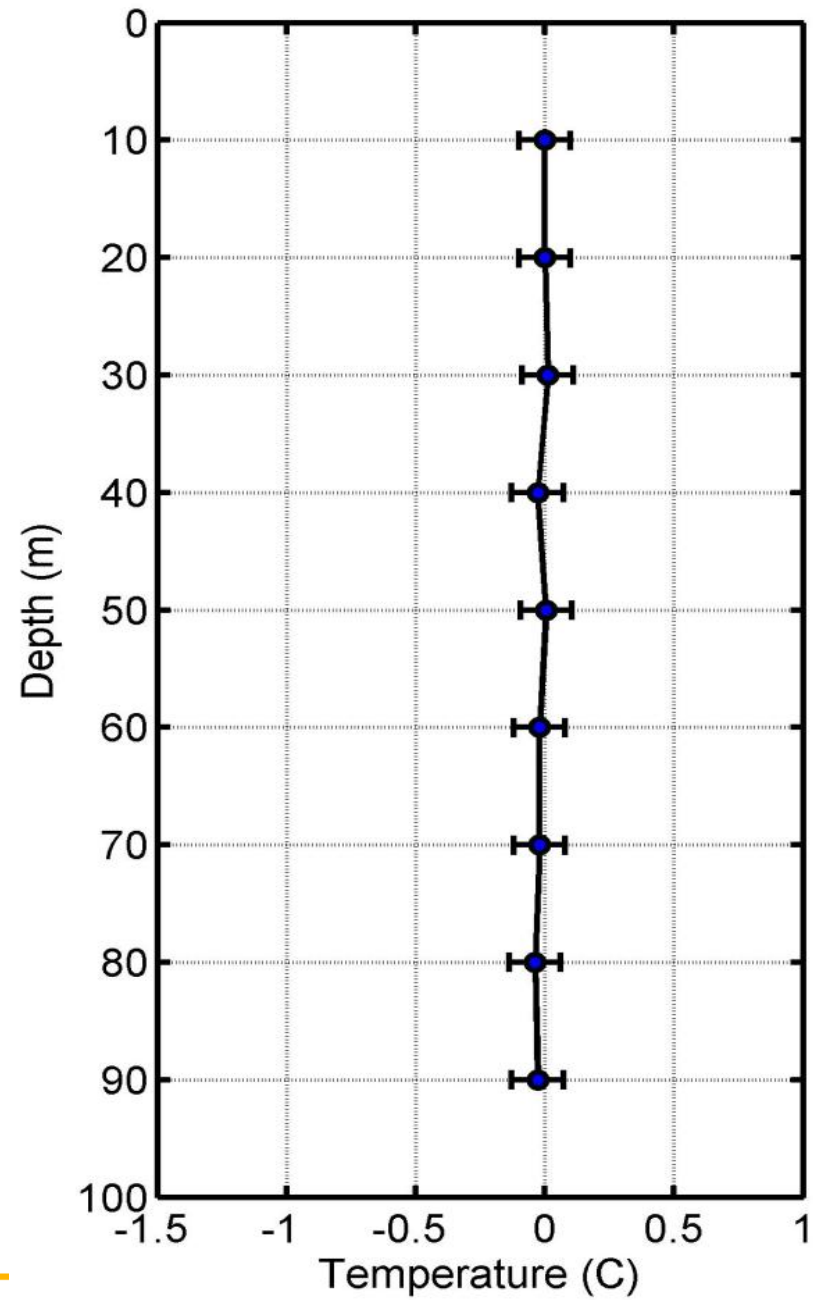
# SPB: Subglacial ice sheet hydrology (SPM Joel Harper, Univ. Montana, US)

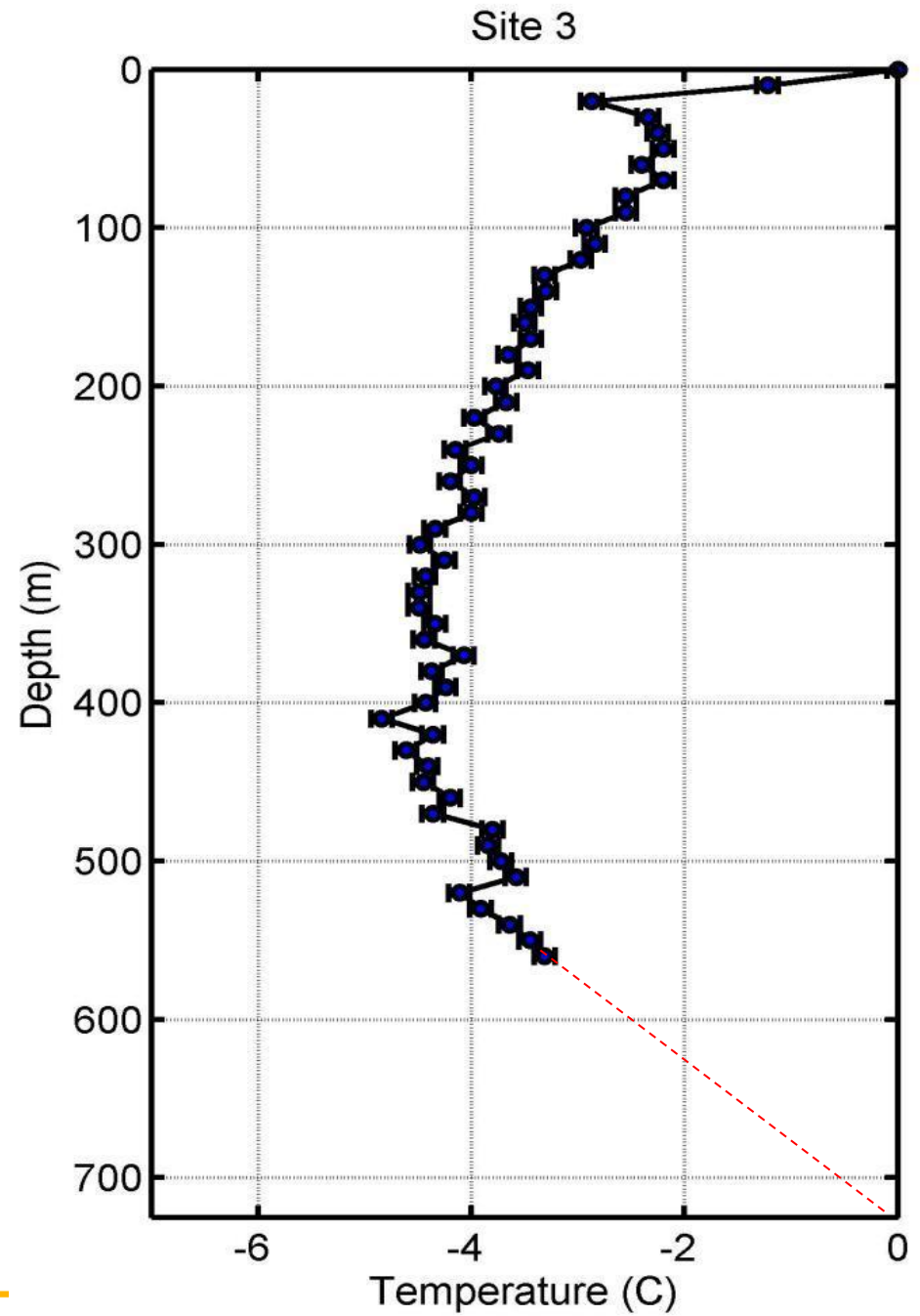
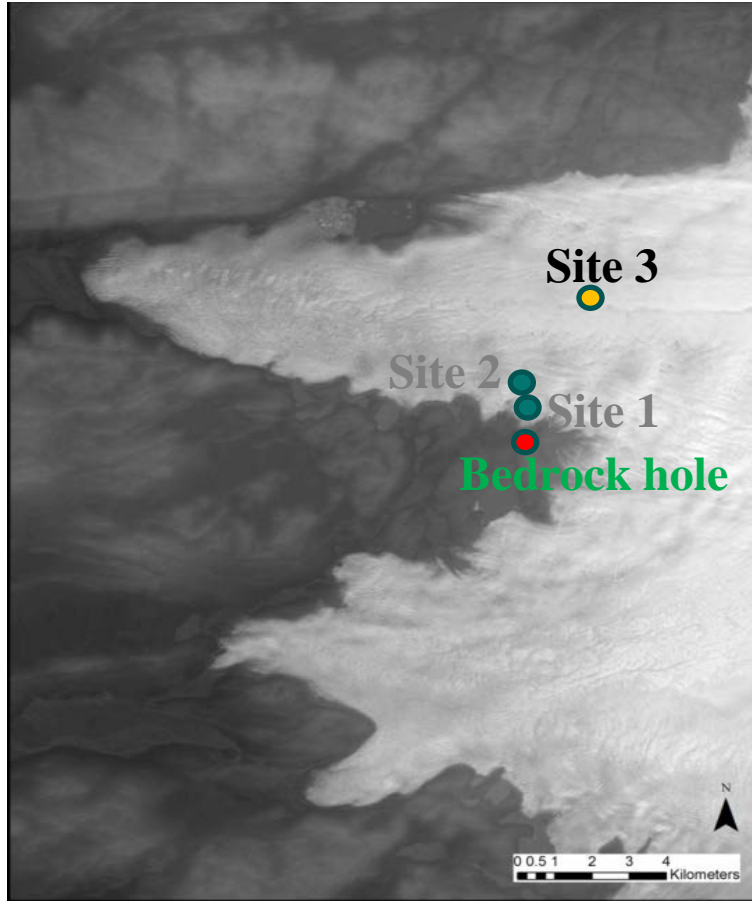
- Direct observations and measurements of the characteristics of the hydrological system at the base of the ice sheet
- Drilling through the ice sheet (up to 1800 m)
  - Wet-based areas identified by radar surveys in SPA
  - Water pressures and configuration (time/space) at the interface between the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



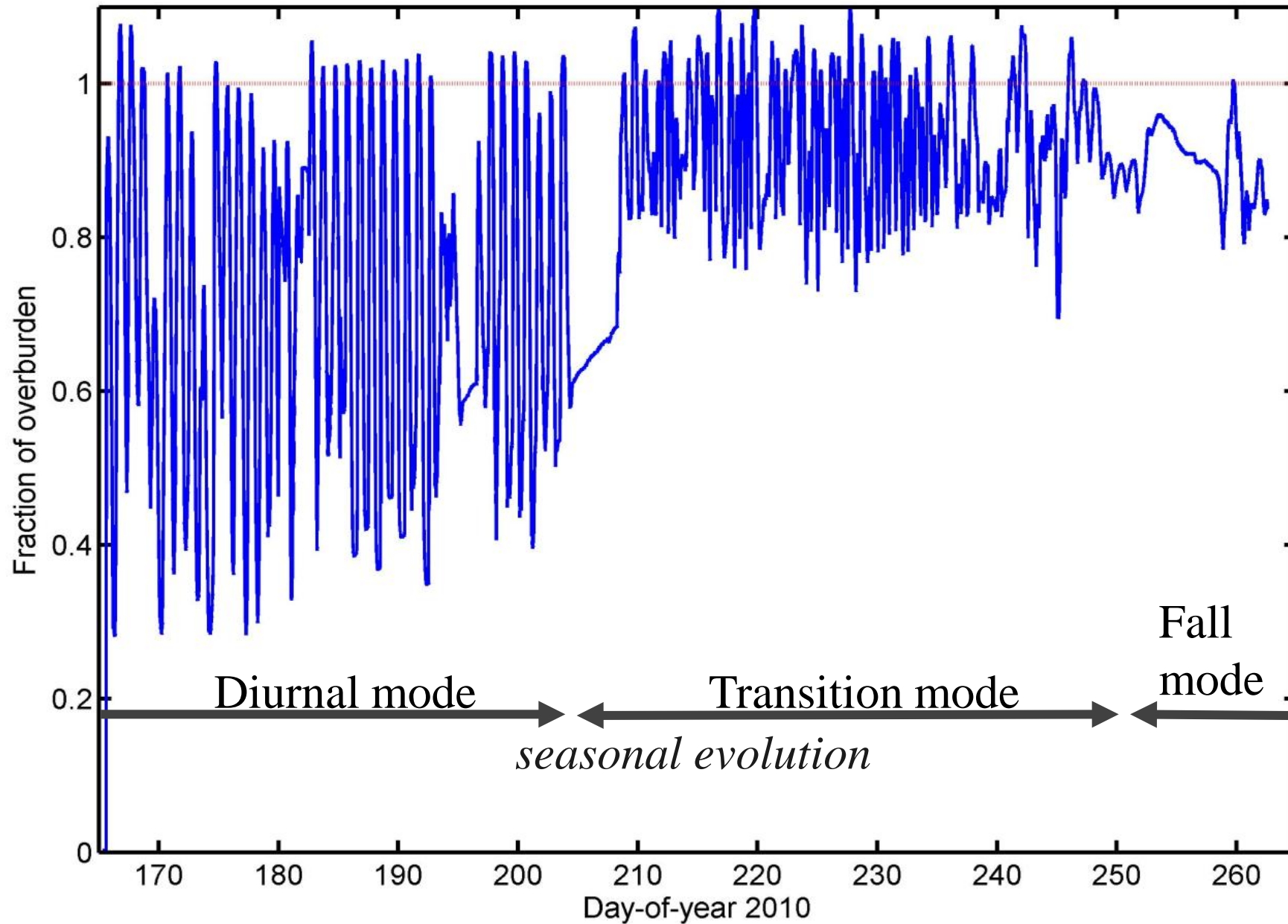


Site 1





Water Pressure: Hole GI10-1D



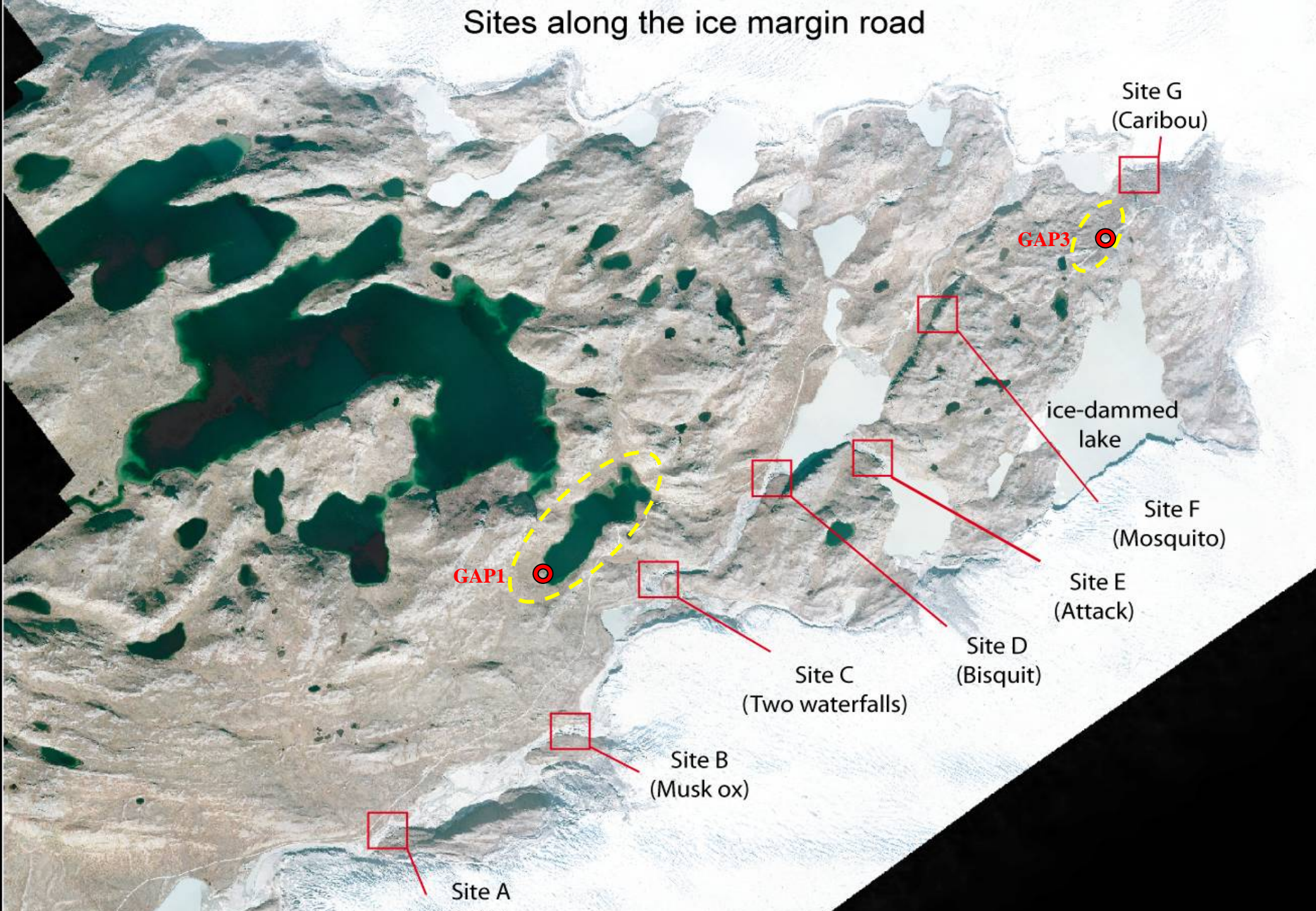


# SPC: Bedrock hydrogeochemistry and hydrogeology

(SPM Timo Ruskeeniemi, Geol. Surv. Finland)

- 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

# Sites along the ice margin road



Site G  
(Caribou)

GAP3

ice-dammed  
lake

Site F  
(Mosquito)

Site E  
(Attack)

Site D  
(Bisquit)

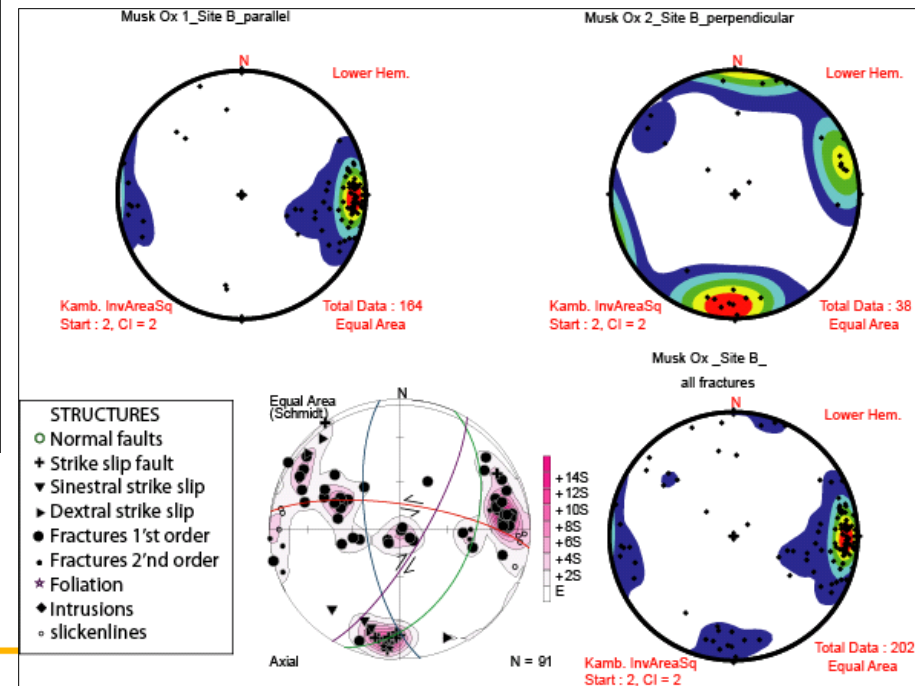
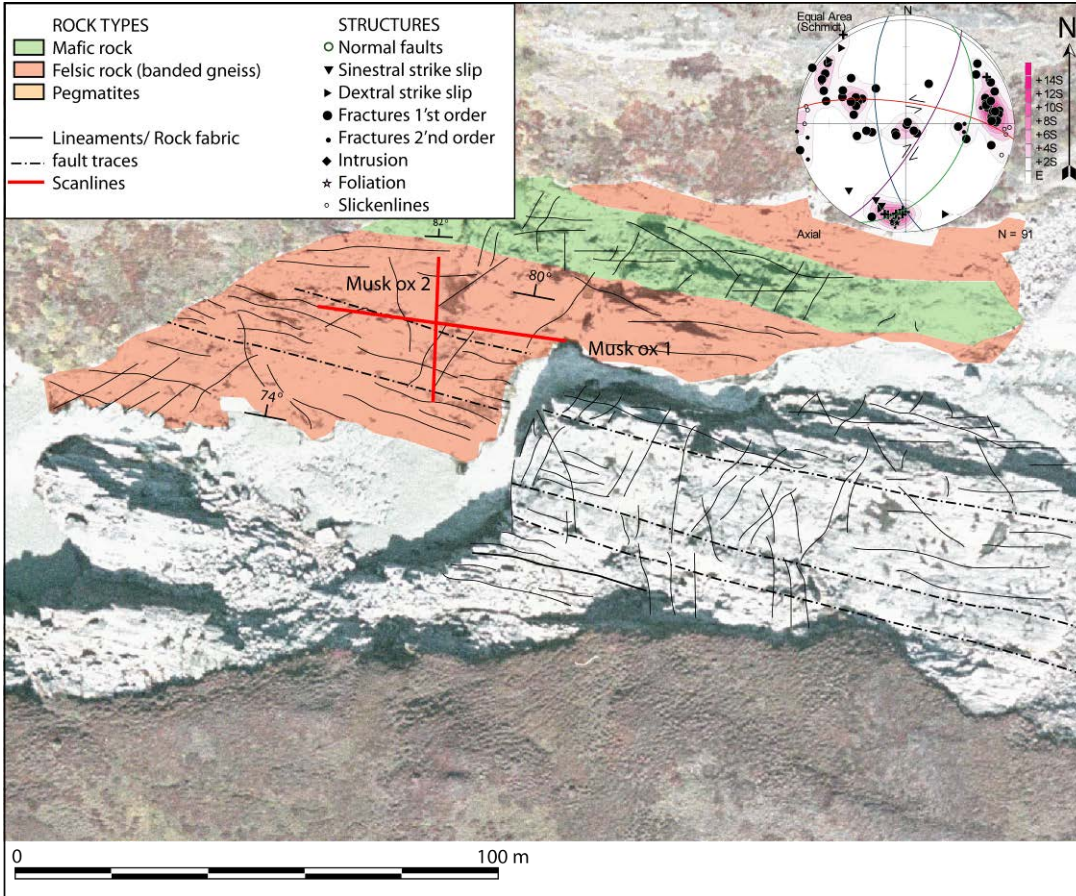
Site C  
(Two waterfalls)

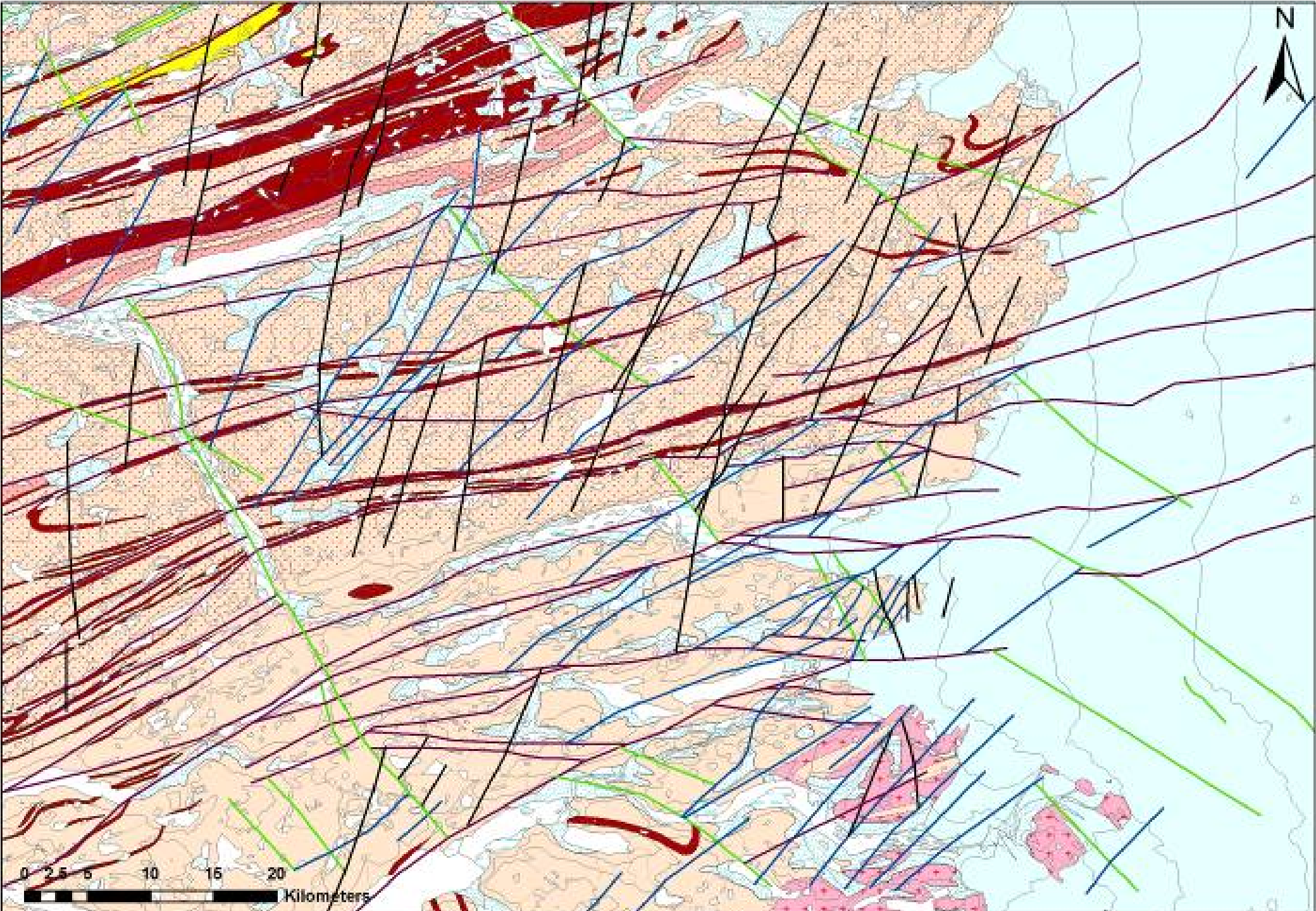
Site B  
(Musk ox)

Site A

GAP1

# Location B, Musk ox

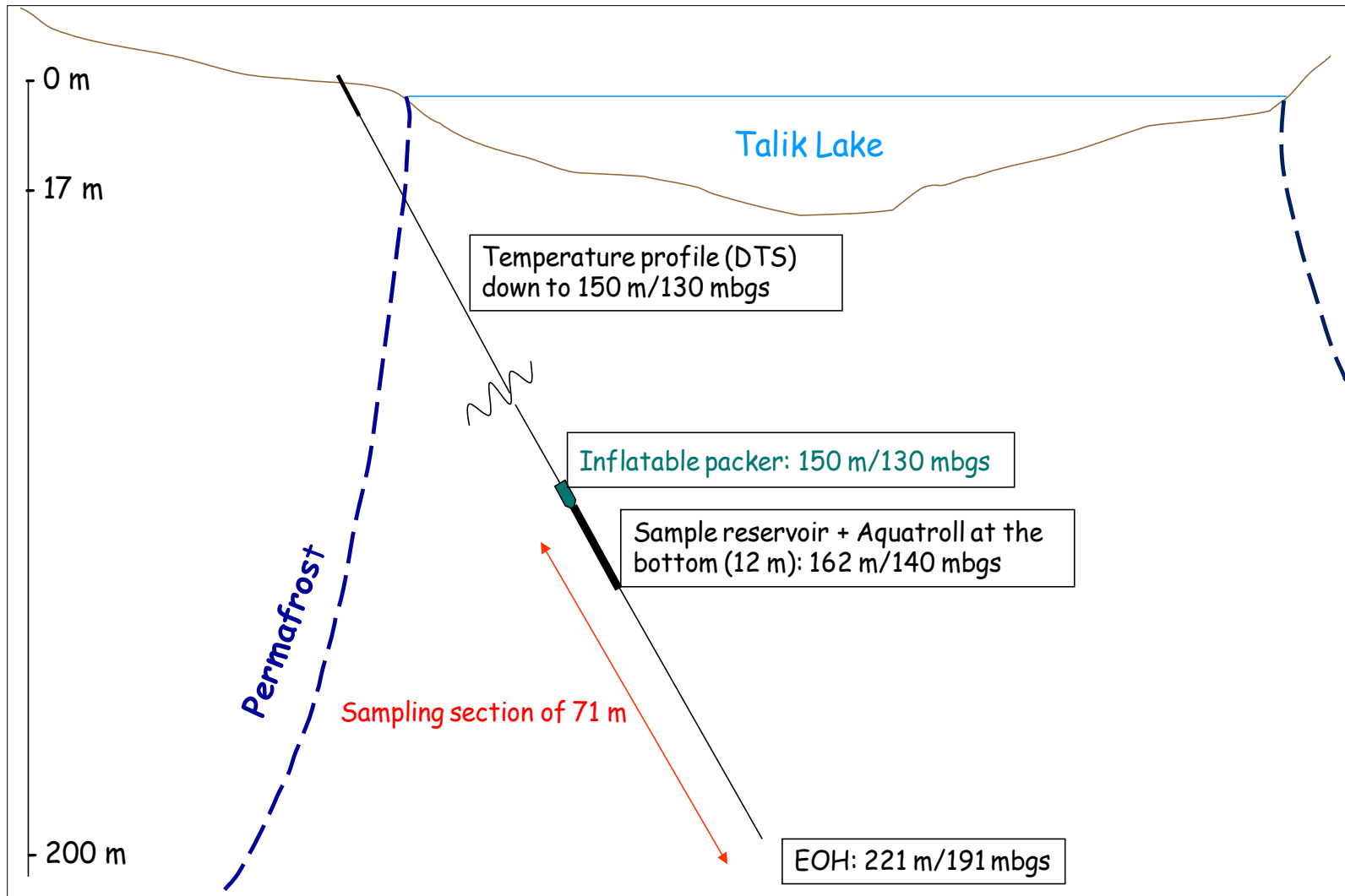


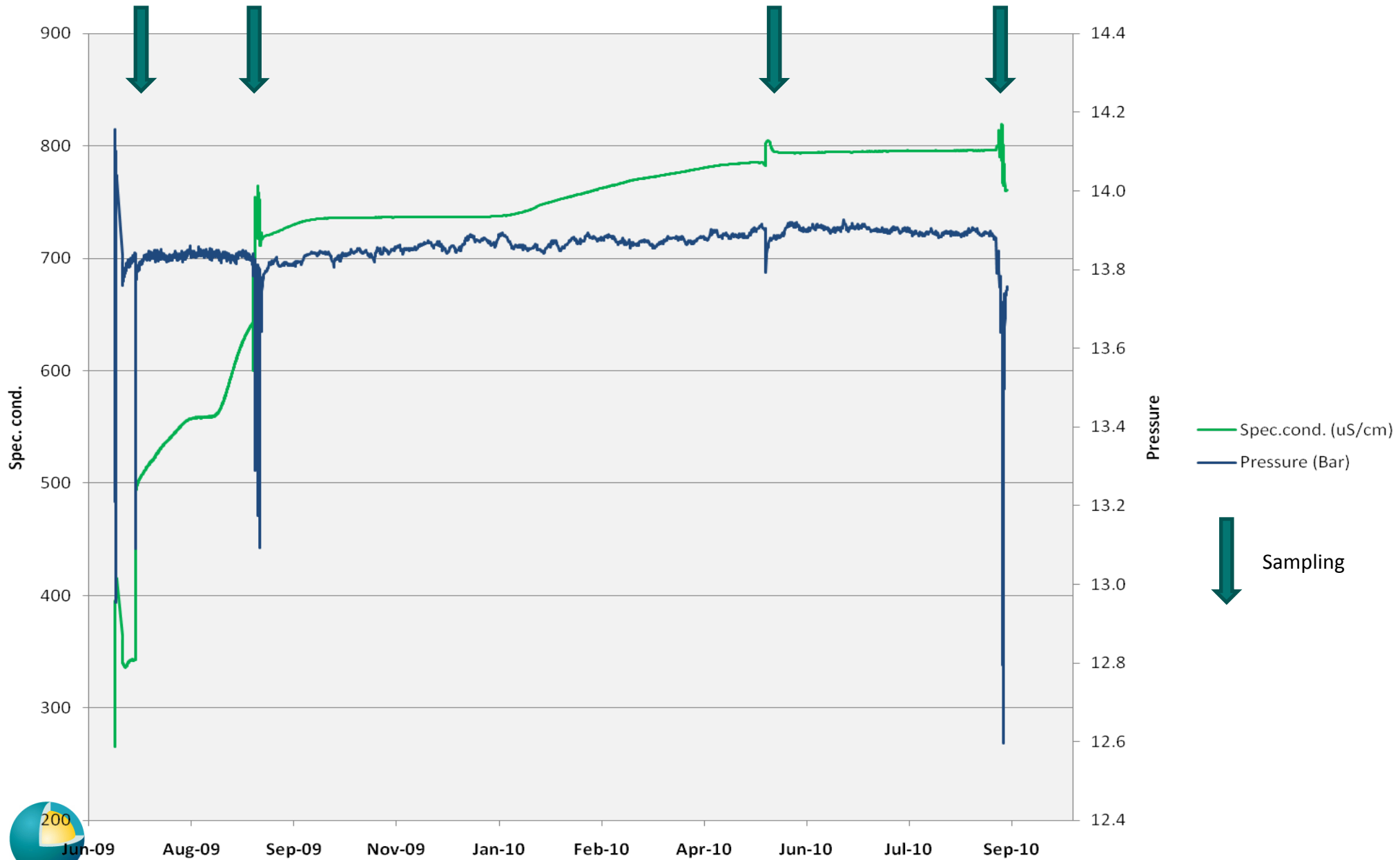




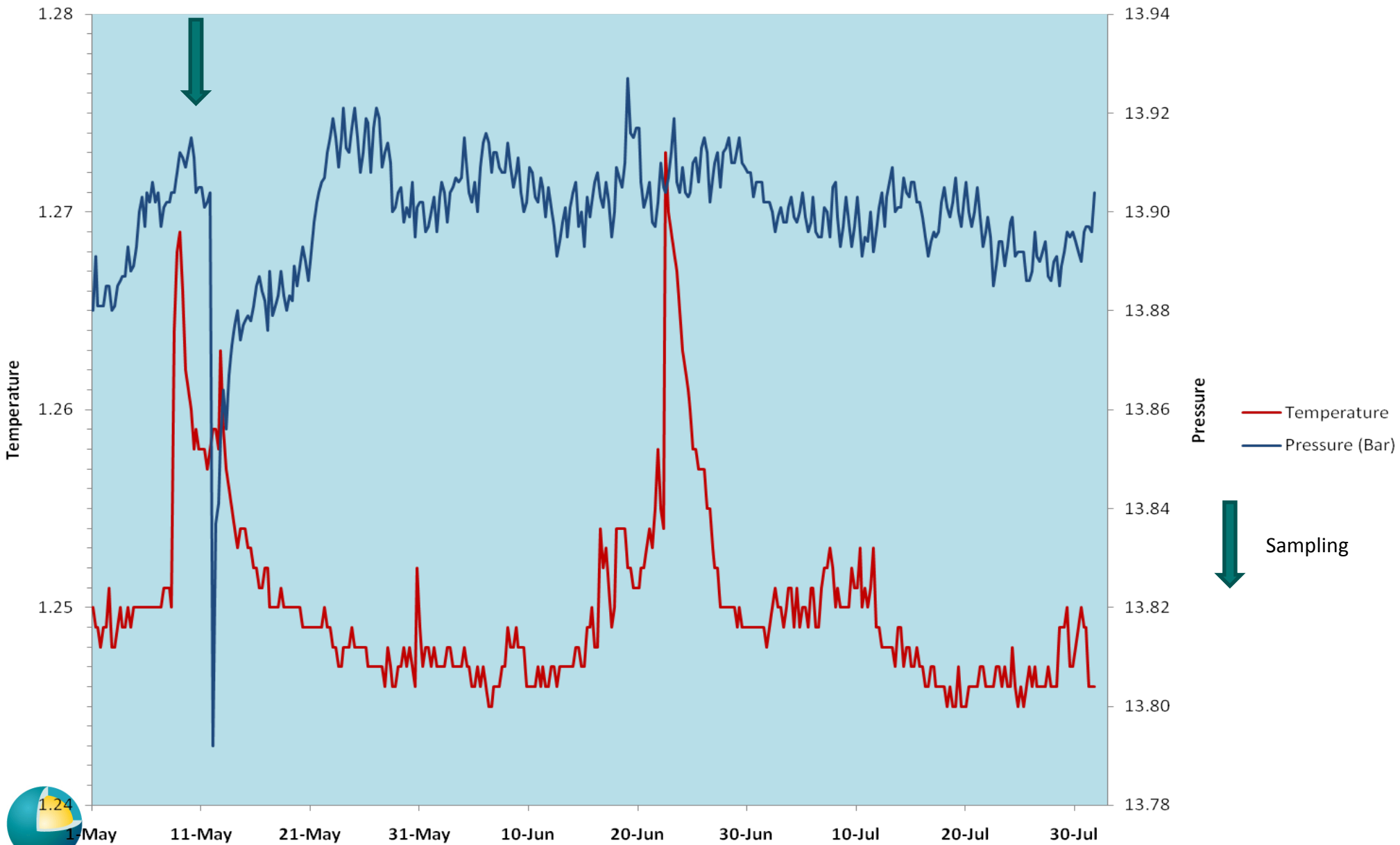


# Instrumentation of DH-GAP01





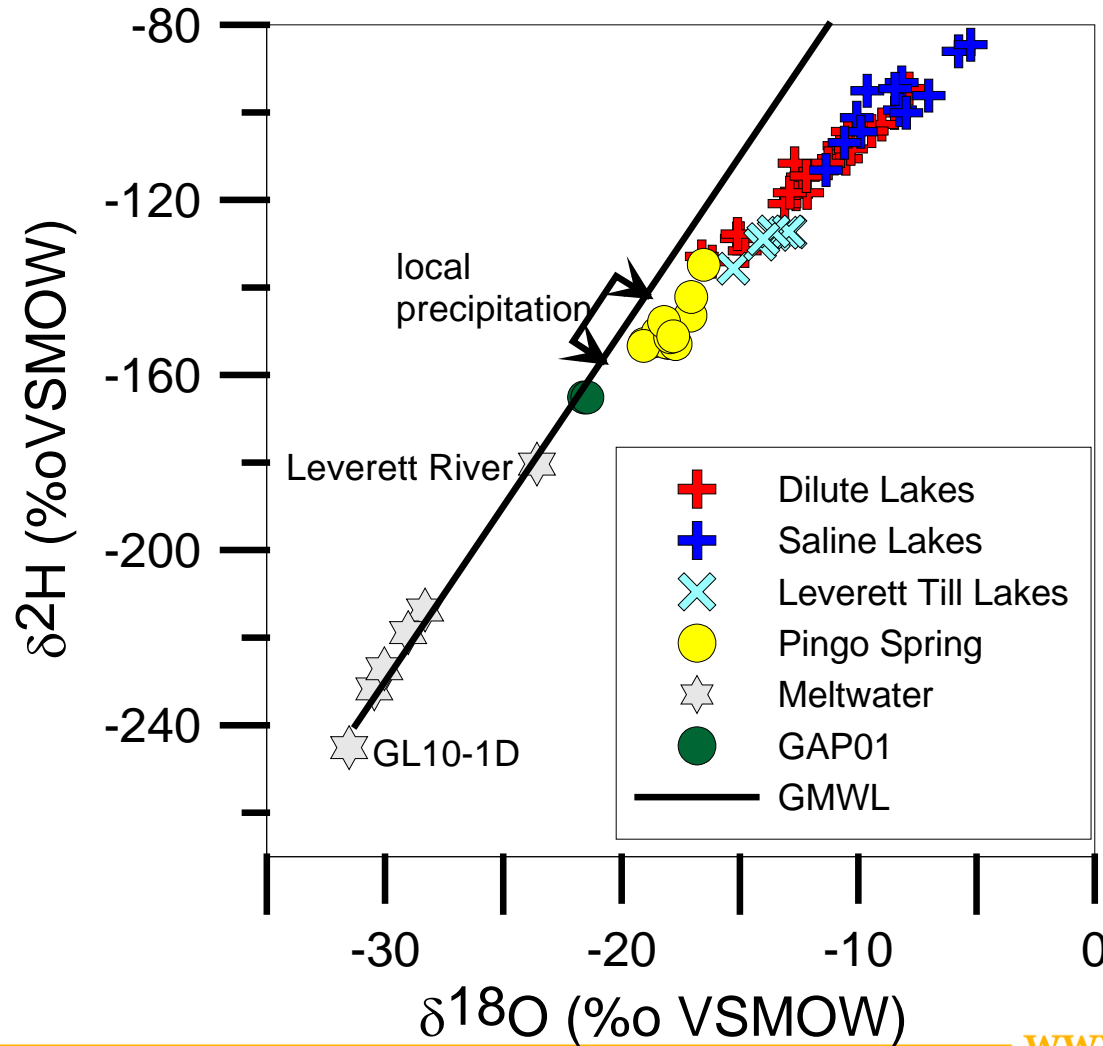
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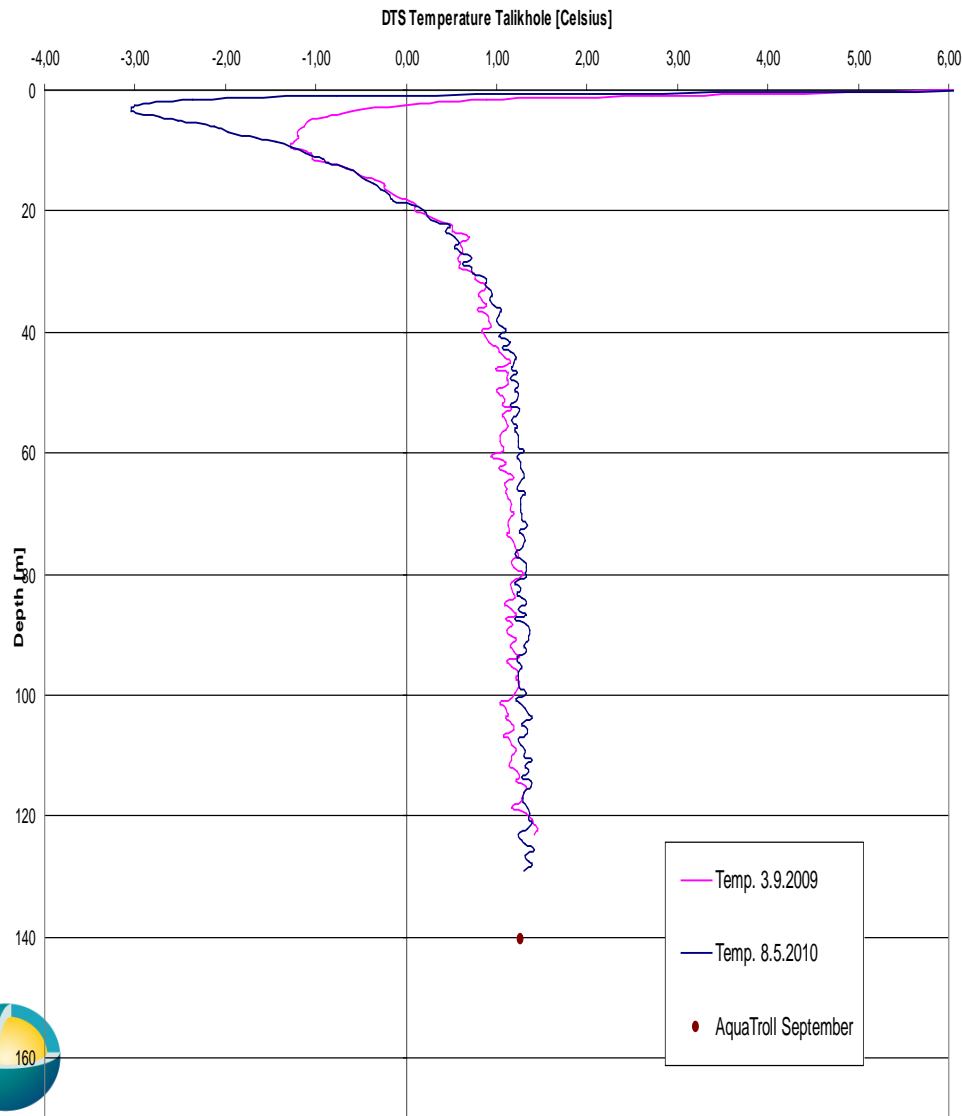
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[www.gtk.fi](http://www.gtk.fi)

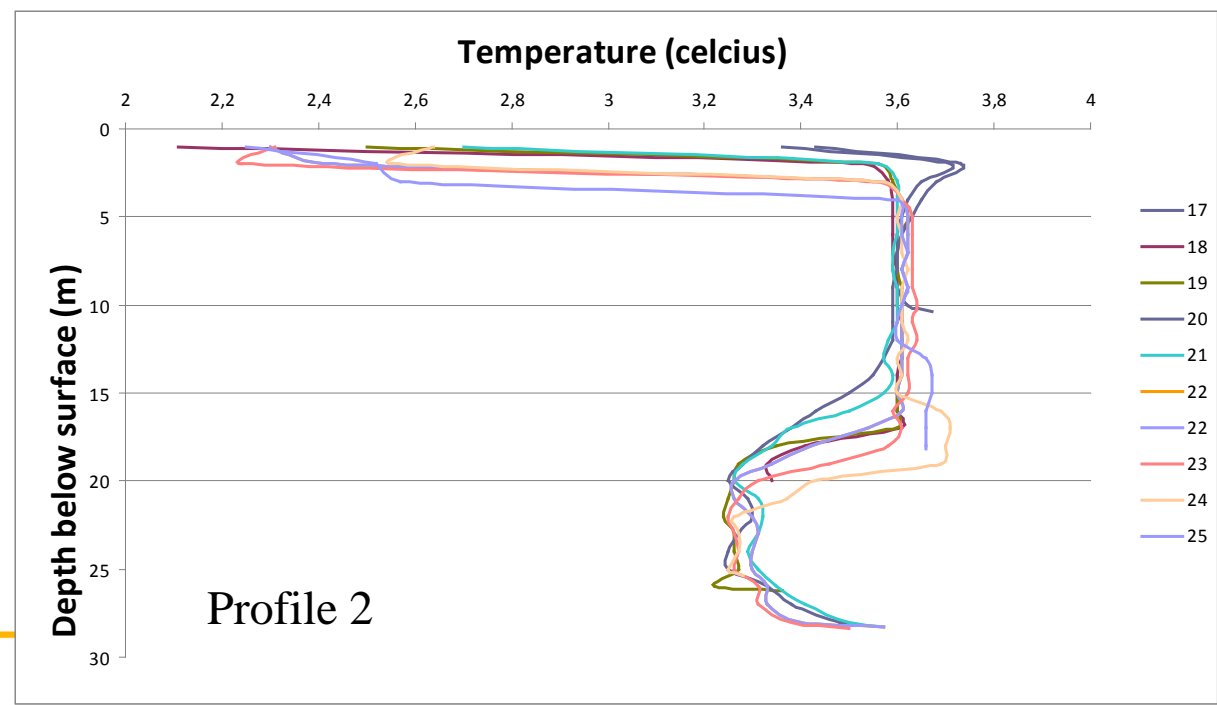
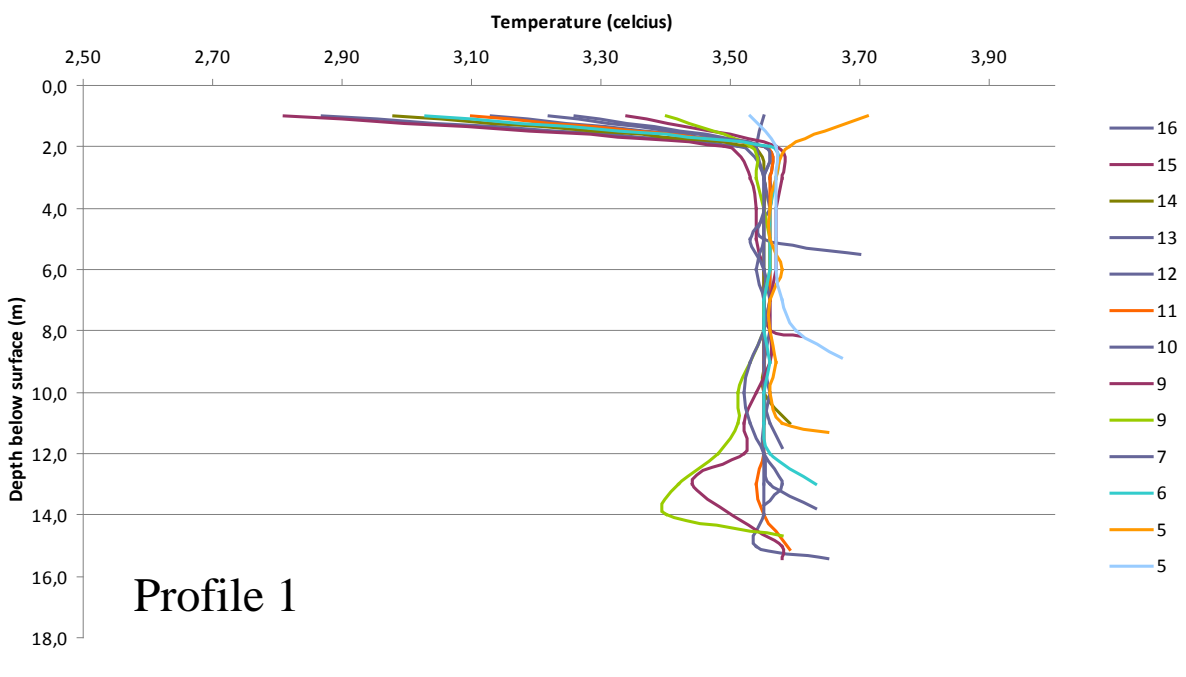
# Hydrogeochemistry



# Bedrock temperatures beneath the Talik Lake



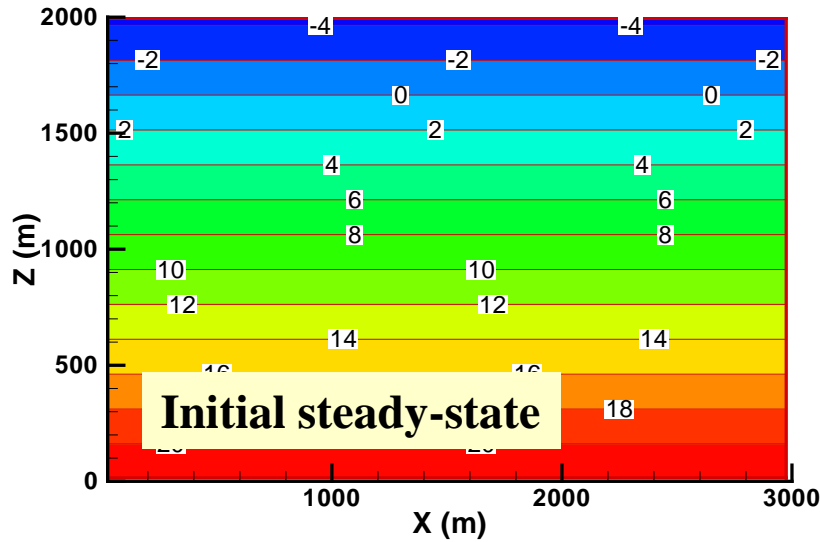
- DTS profile DH-GAP01 (dip 60°)
- Determination of active layer thickness not reliable due to steel casing
- Talik entered at 18 m depth (about 20 m drillhole length)
- Coincides with the lake shoreline
- Temperature in talik down to 140 mbgs 1.26°C



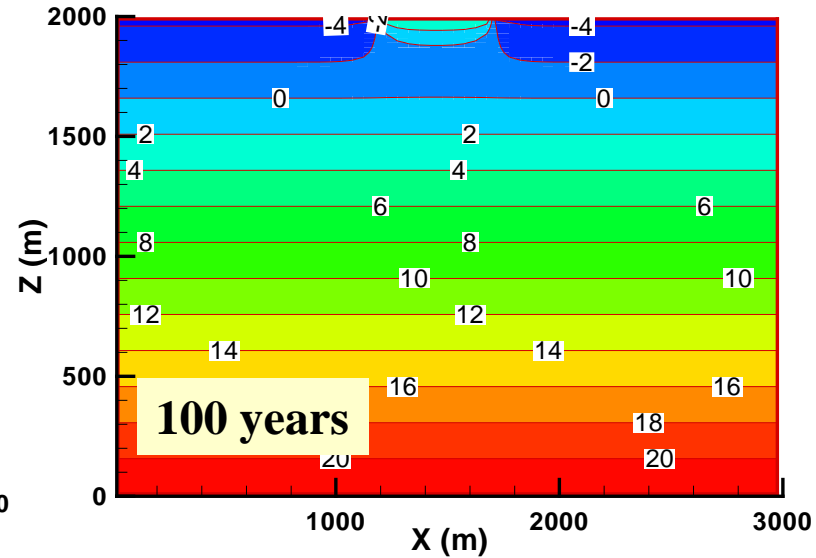
# Development of a talik

Initially ground surface at  $-4.4\text{ }^{\circ}\text{C}$ , lake with bottom at  $+4\text{ }^{\circ}\text{C}$  appears at 0 years

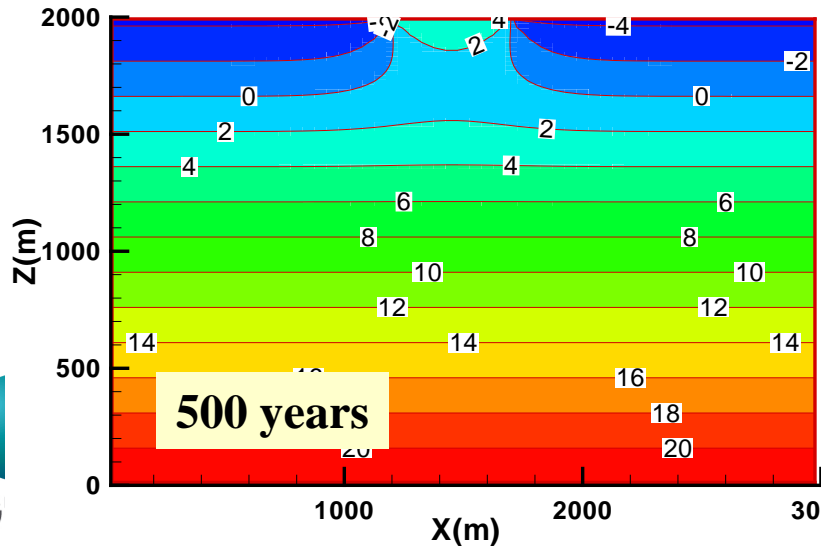
### No lake



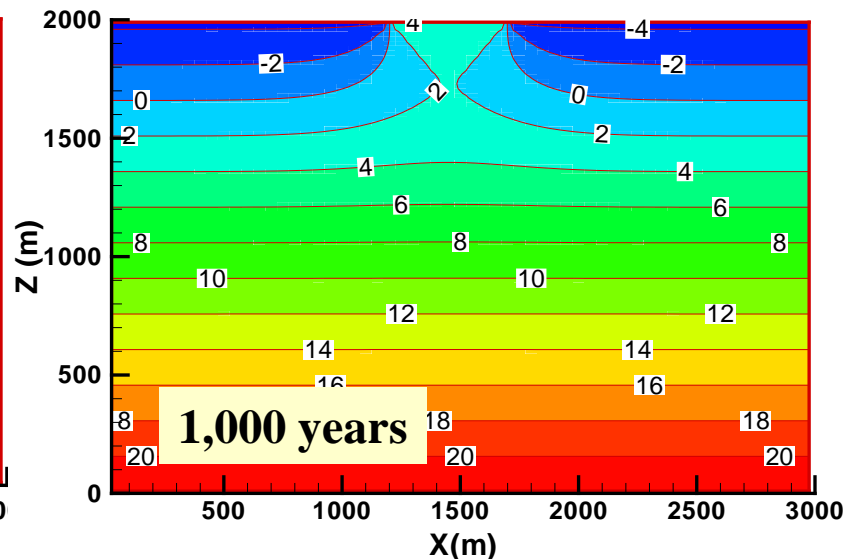
### Lake with open talik



### Lake, with a through talik



### Lake, with a through talik

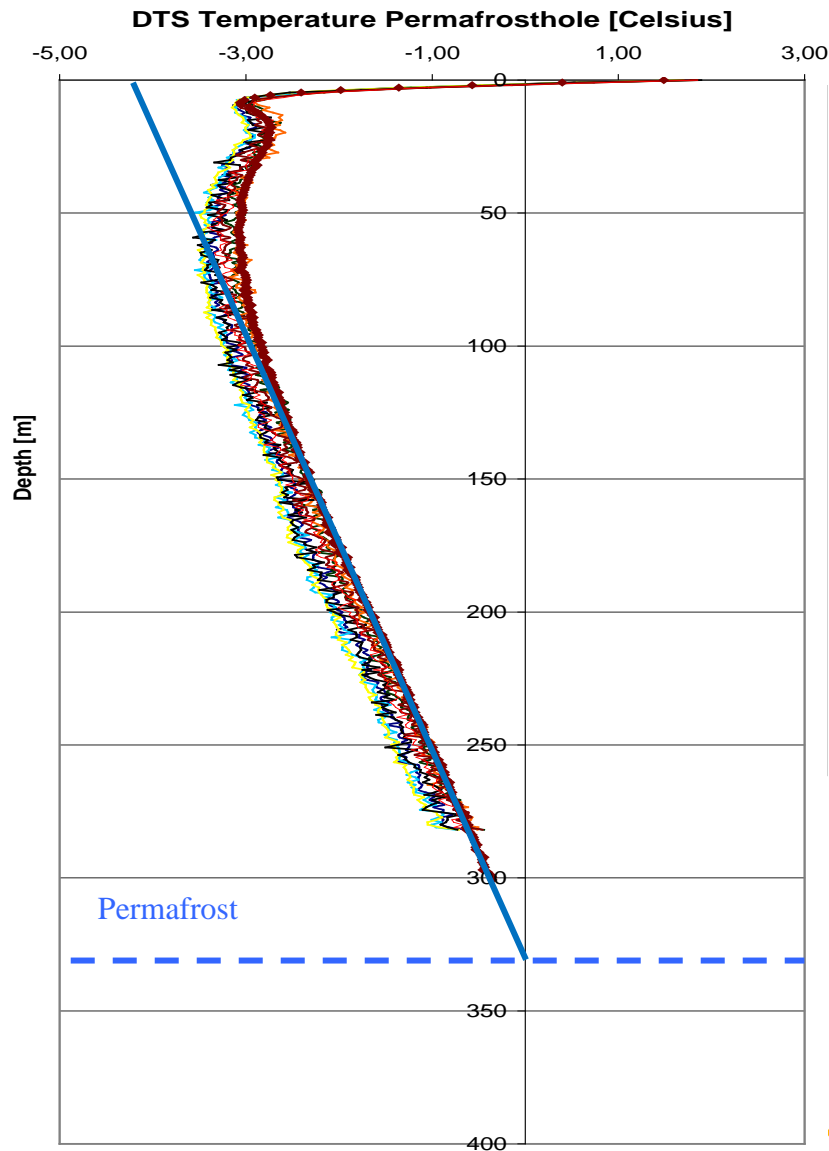








# Permafrost (MAAT 1960-1990: -5.7°C)



- DTS profile from DH-GAP03
- Zero annual amplitude  $\approx 13$  m/ $-3.05^\circ\text{C}$
- Determination of active layer thickness not reliable due to steel casing
- Lowest temperature  $-3.3^\circ\text{C}$  at 50-60 m depth
- Base of permafrost at 330 m

## Model:

Initial steady-state  $T_0 = -4.4^\circ\text{C}$

Increase of  $T_0$  to  $-2.5^\circ\text{C}$  15 years ago

Most of the change seems to be recent



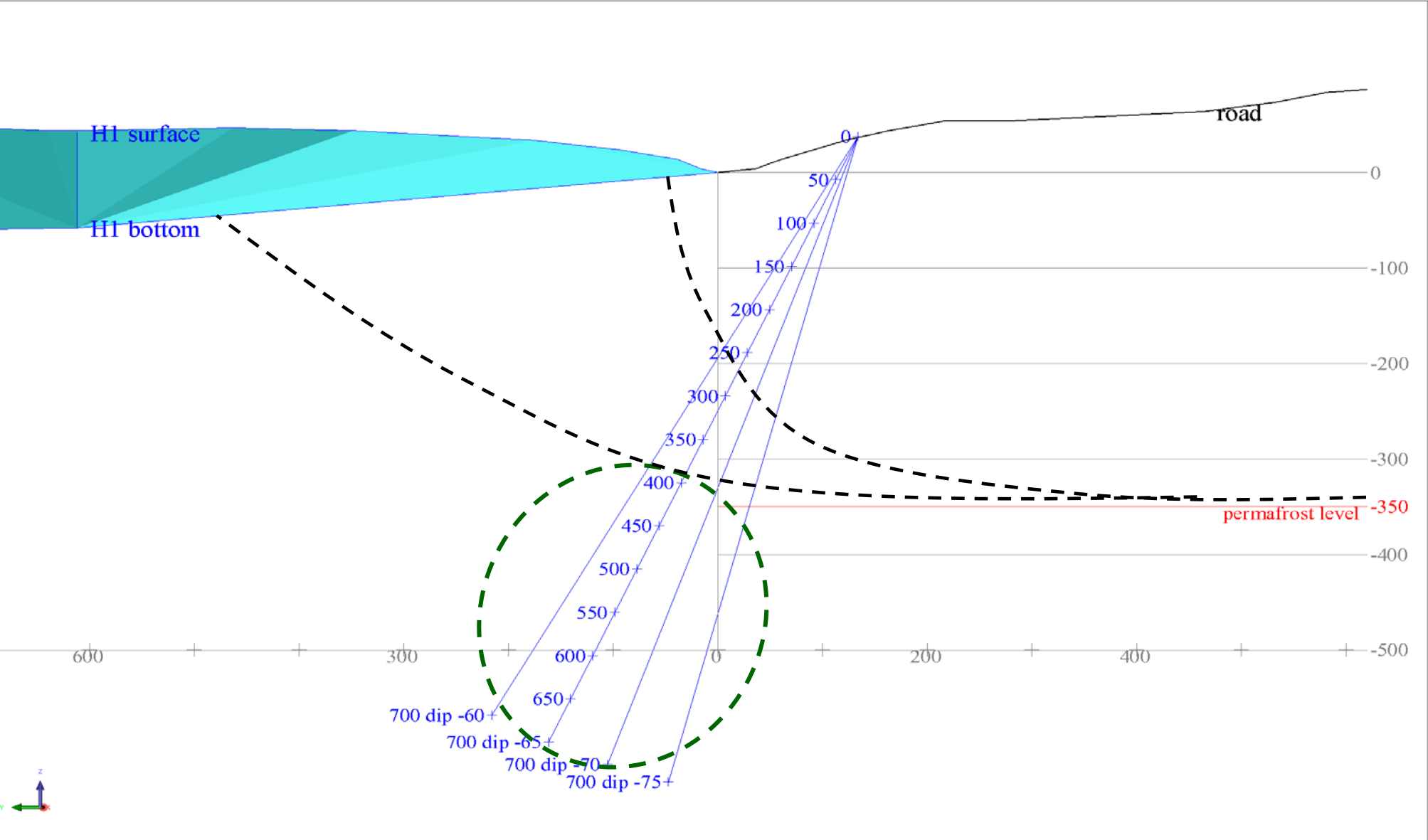
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Suc





# Drilling of deep research drillhole in 2011



# GAP Reports

- Aaltonen, Ismo; Douglas, Bruce; Claesson Liljedahl, Lillemor; Frape, Shaun; Henkemans, Emily; Hobbs, Monique; Klint, Knud Erik; Lehtinen, Anne; Lintinen, Petri; Ruskeeniemi, Timo 2010. The Greenland Analogue Project, sub-project C : 2008 field and data report. Posiva. Working report 2010-62. Olkiluoto: Posiva. 135 p ([www.posiva.fi/databank/working\\_reports](http://www.posiva.fi/databank/working_reports)).
- The Greenland Analogue Project, Yearly Report 2009. SKB Report R-10-59 (in print)
- The Greenland Analogue Project, Yearly Report 2010 (in prep).



Thank you!