Firn aquifer study near Helheim Glacier based on geophysical methods and in situ measurements

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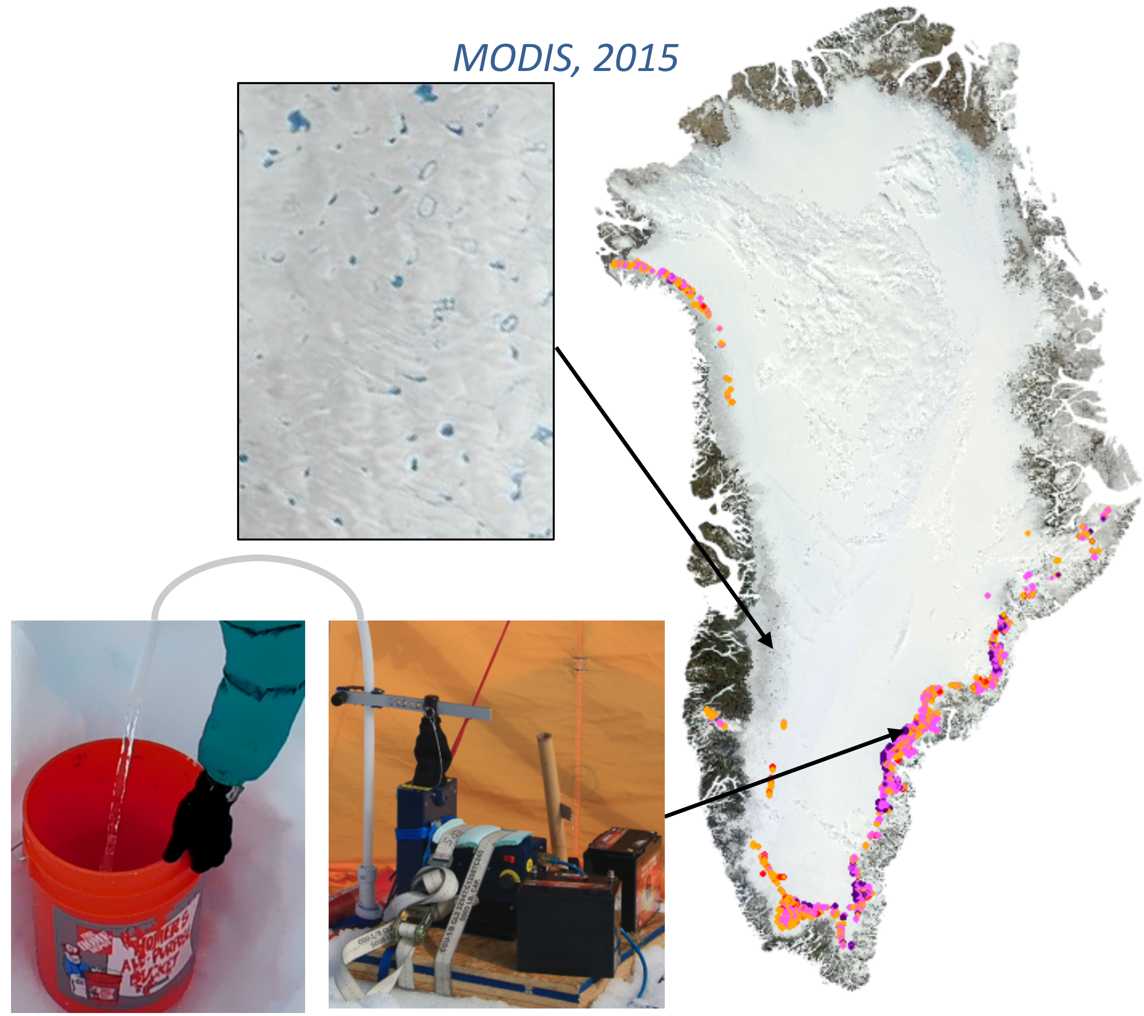
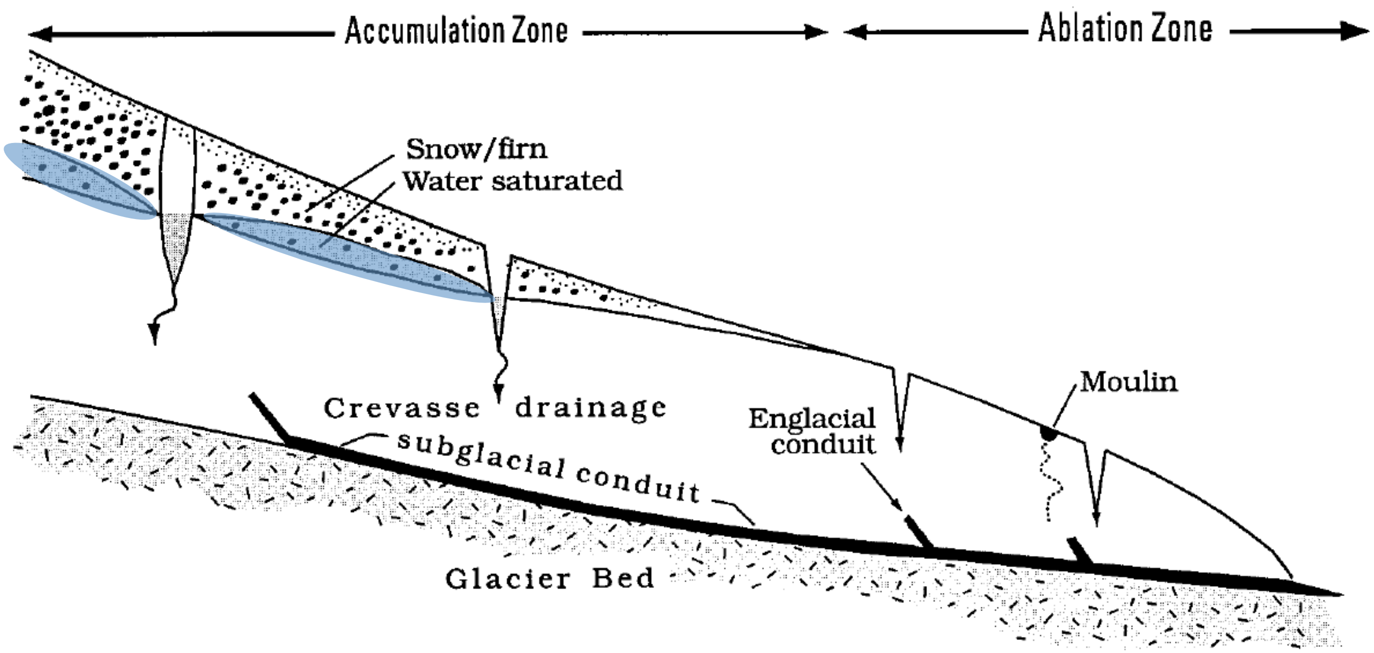




Fountain and Walder, 1998

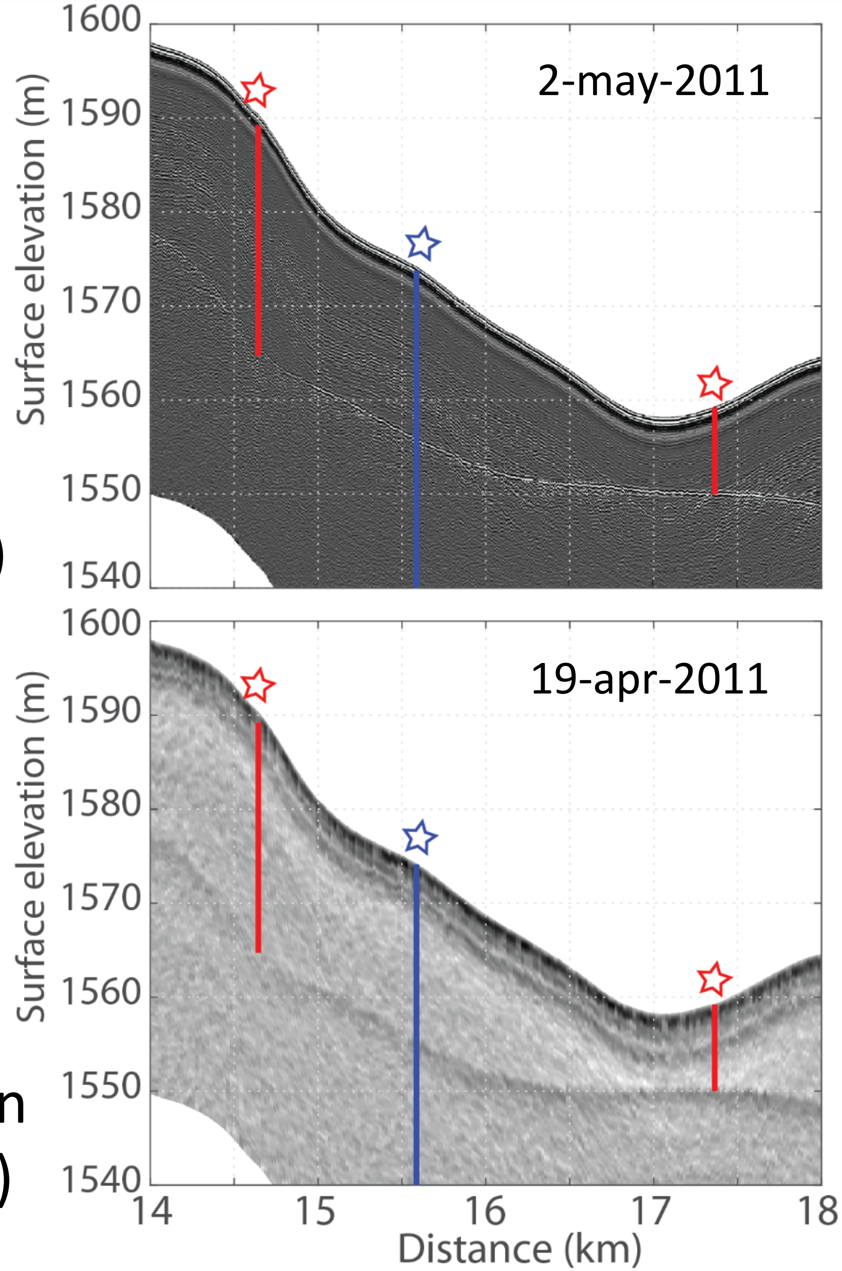
Firn aquifers:

- develop at depth above the firn/ice transition
- sensitive to surface melt variations
- store meltwater and delay runoff
- are seasonal to multi-year features

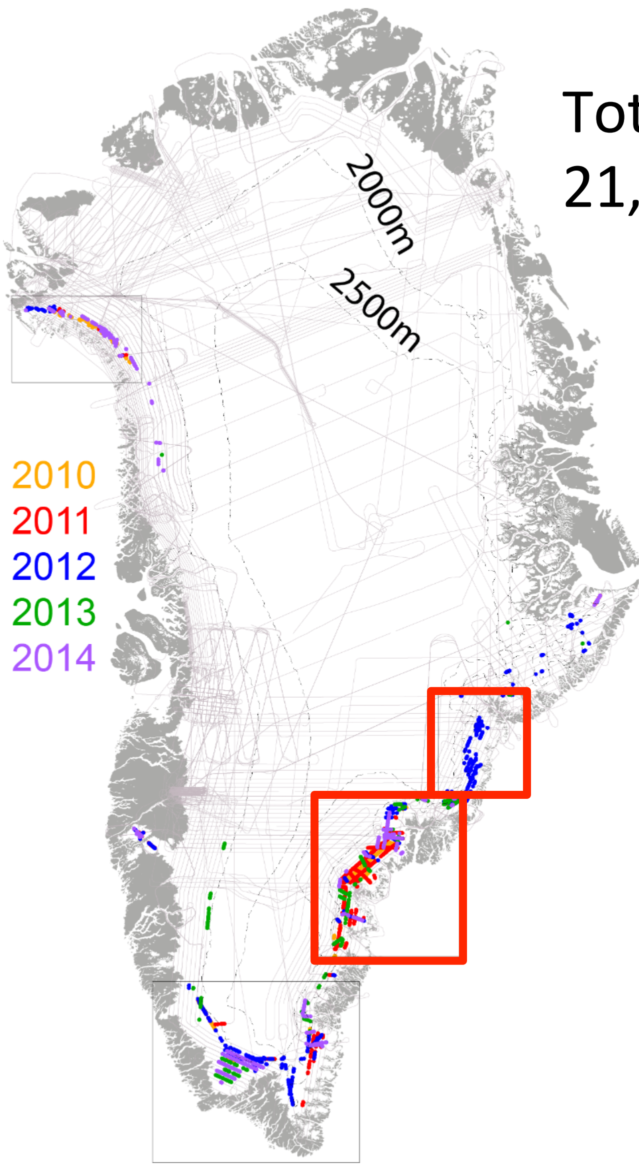
Greenland firn aquifer detections:

GSSI ground radar (400 MHz)

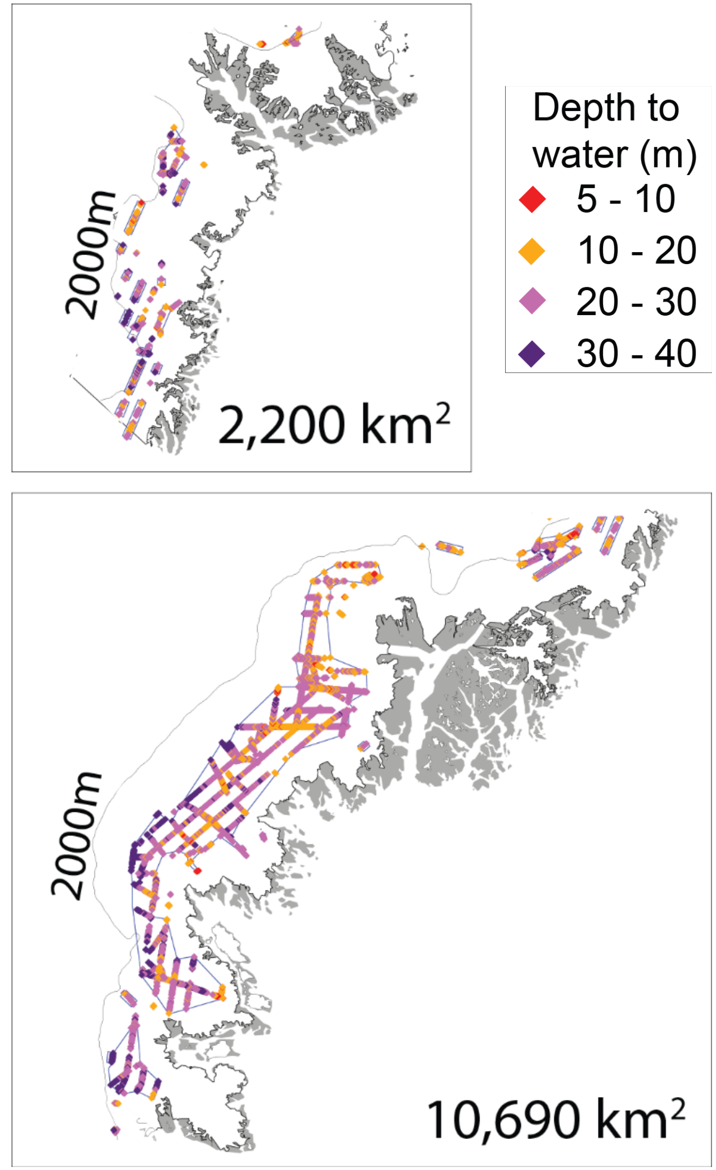
OIB Accumulation Radar (750 MHz)



OIB with Accumulation Radar onboard allows precise detection of firn aquifers



Total area:
21,900 km^2



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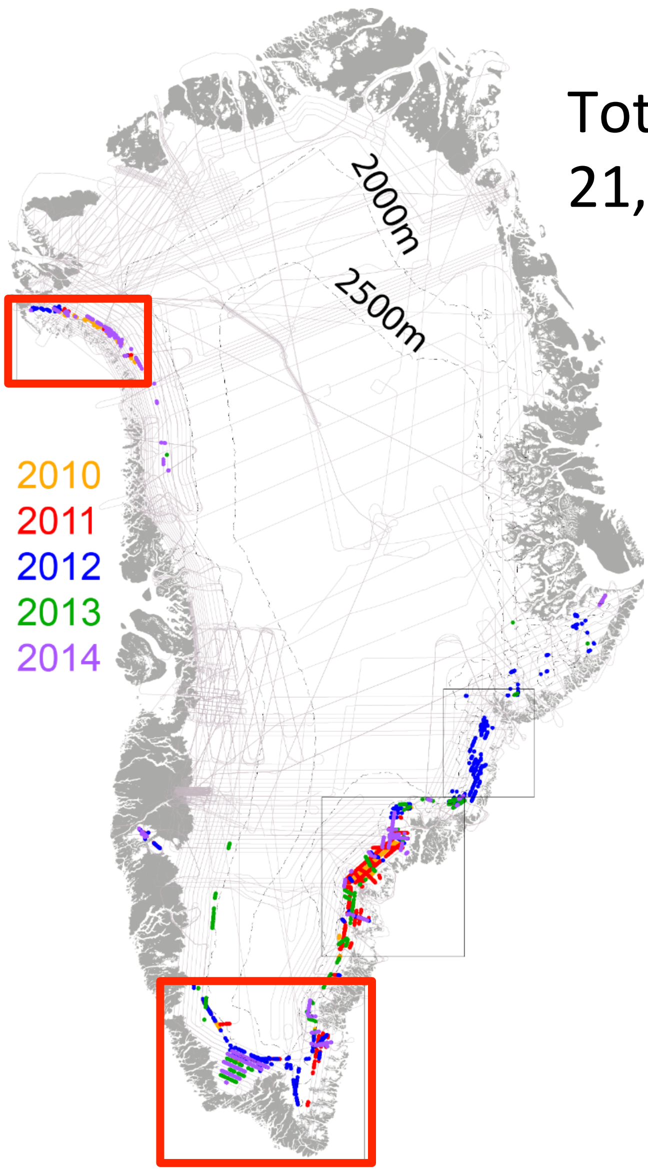

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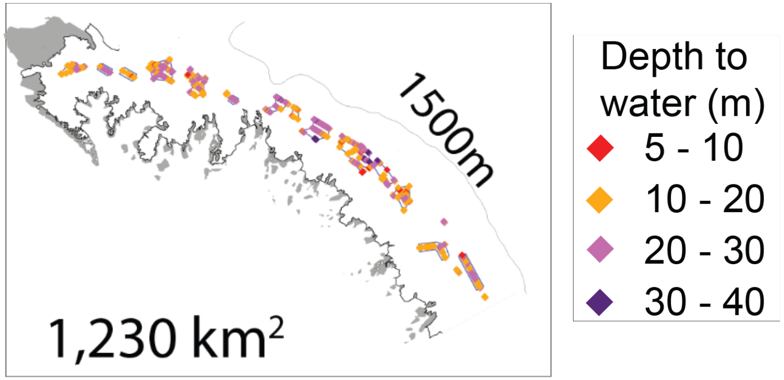
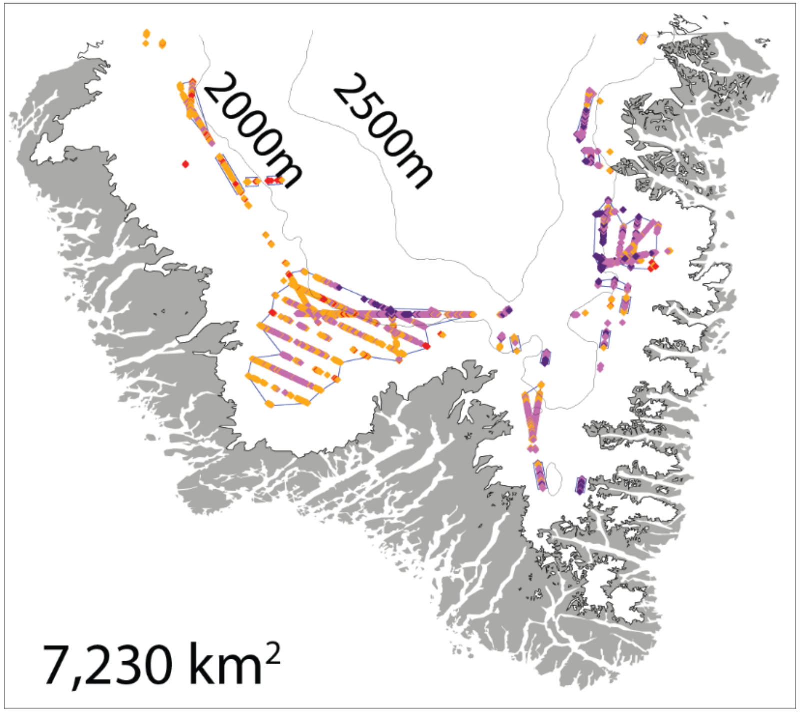


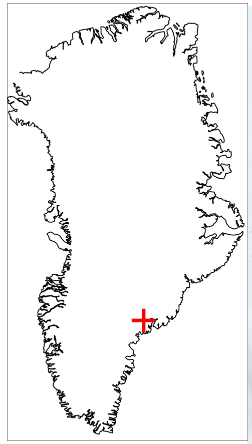


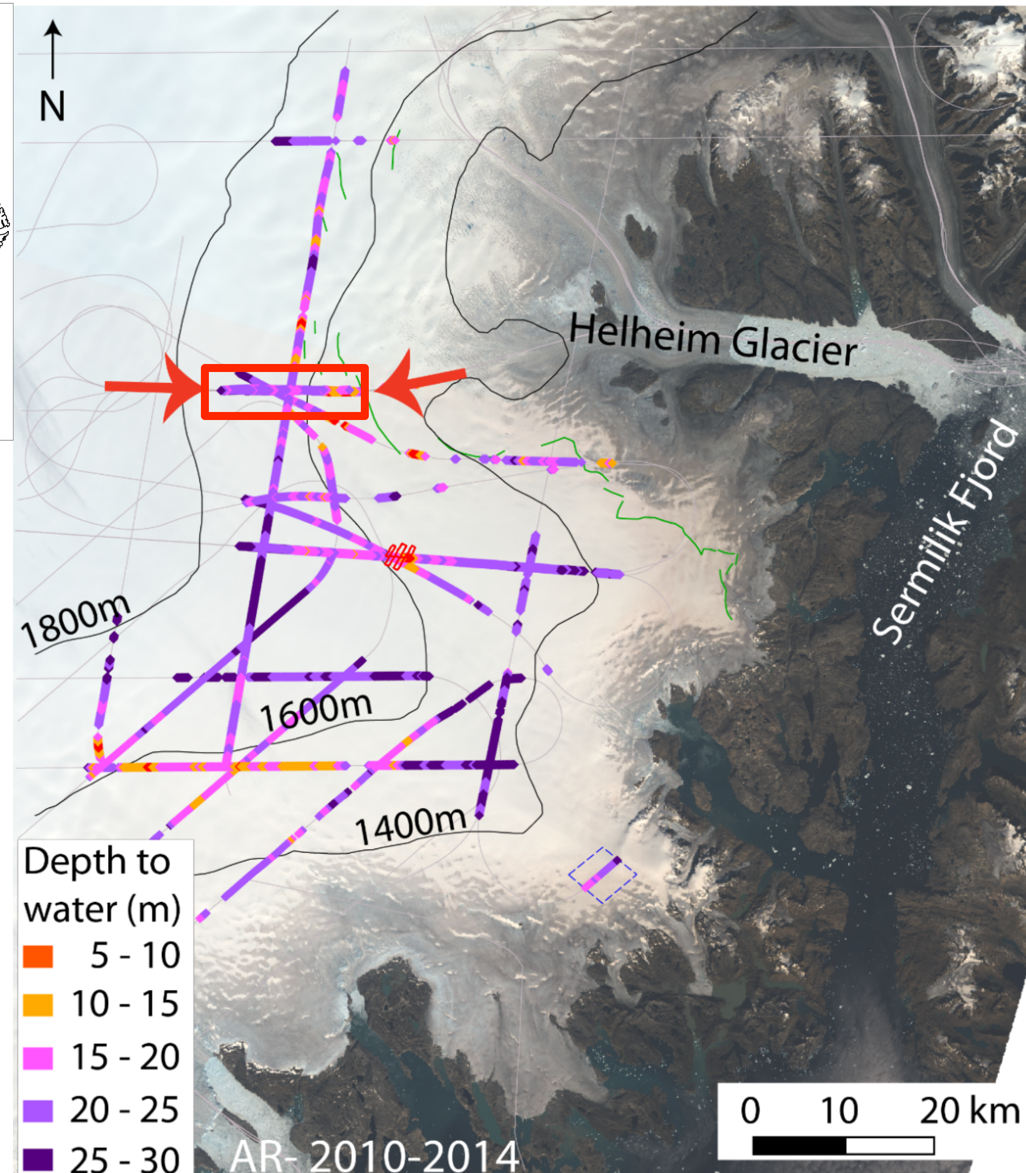
Objectives of this study:

- Characterize firn aquifer evolution for the last 2 decades
- Constrain aquifer water volume
  and its variations in space and time
- Determine water residence time
  and flow rate through the aquifer
- Identify pathways, connections
  and water contribution to englacial hydrology

Study site:

Upstream of Helheim Glacier, SE Greenland





Background: Landsat 8 (USGS)

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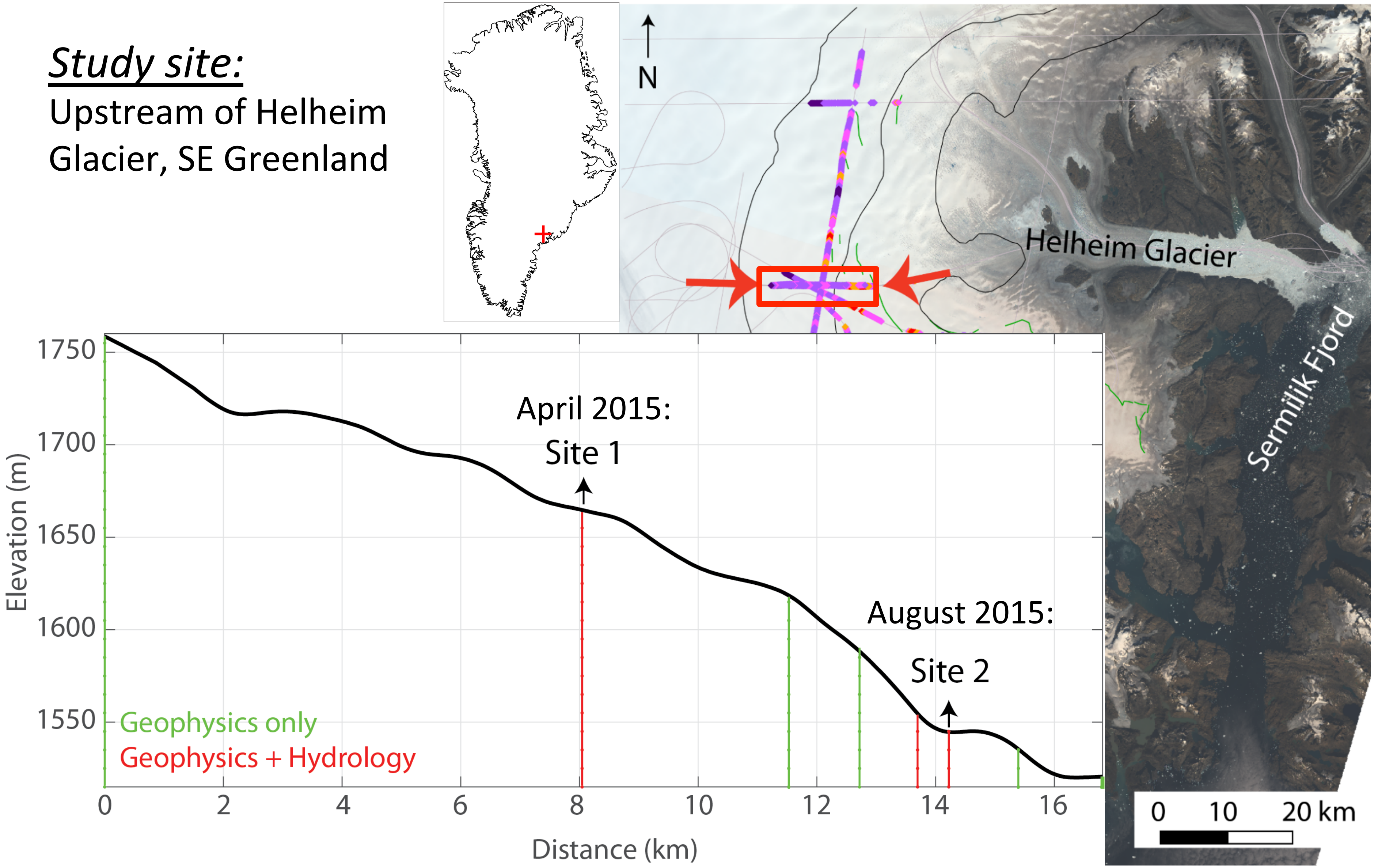

Background: Landsat 8 (USGS)

Geophysical investigations:

- Ground and OIB radars

Objectives:

- aquifer extent mapping
- aquifer temporal progression
- water-table elevation changes
- relate to volume changes

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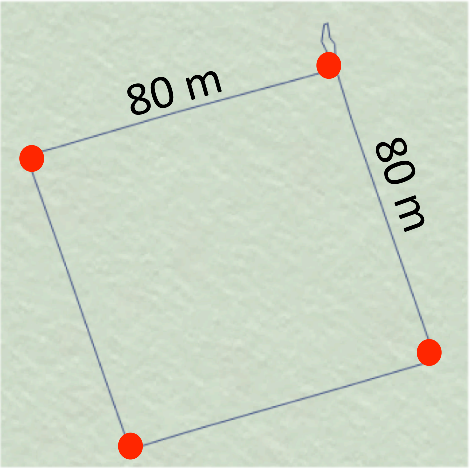
- Magnetic resonance soundings (MRS) (LTHE, Grenoble)



Worldview image (DigitalGlobe©)

Photo: L. Montgomery

Objective:

- Integrated water volume to 40 m

Geophysical investigations:

- Ground and OIB radars
- Magnetic resonance soundings
- Seismic refraction (Univ. Maryland)

Survey line:

Photo: L. Montgomery

Objectives:

- Vertical stratigraphy
- Velocity structure -> variations in water volume through the aquifer

Geophysical investigations:

- Ground and OIB radars
- MR soundings
- Seismic refraction

In situ measurements:

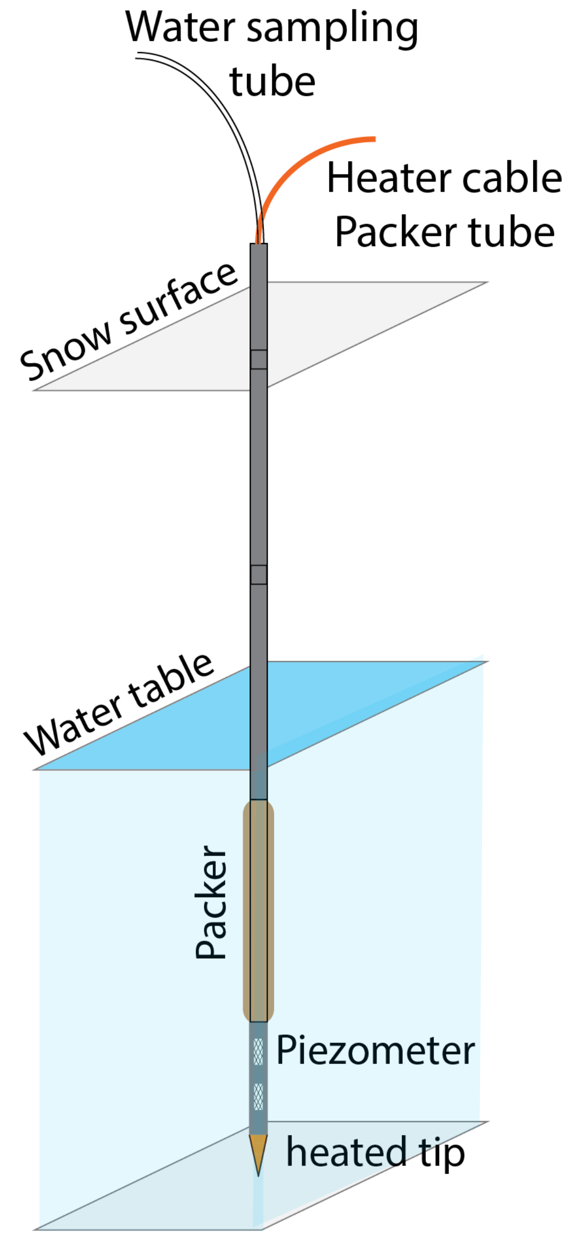
- Firn/ice densities
- Hydraulic conductivities
- Water dating (CFCs, Tritium, noble gases)

Objectives:

- Vertical structure
- Water age
- Water residence time
- Flow rates

Saturated firn (within aquifer ~20 m)

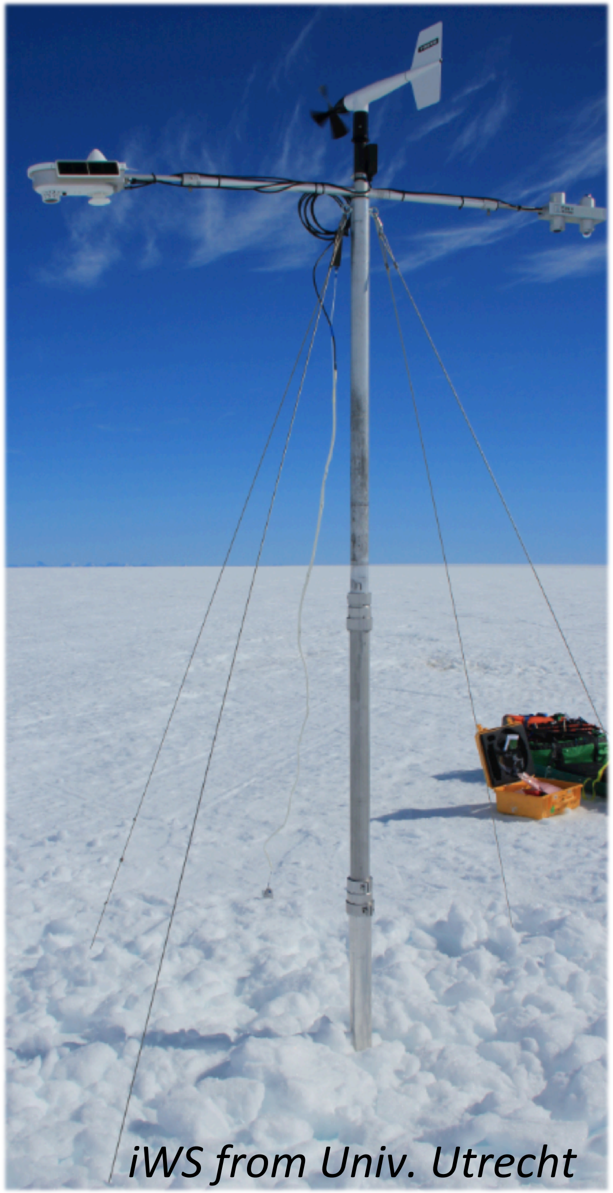
Clear ice layers (below aquifer ~ 35 m)



Geophysical investigations:
- Ground and OIB radars
- MR soundings
- Seismic refraction

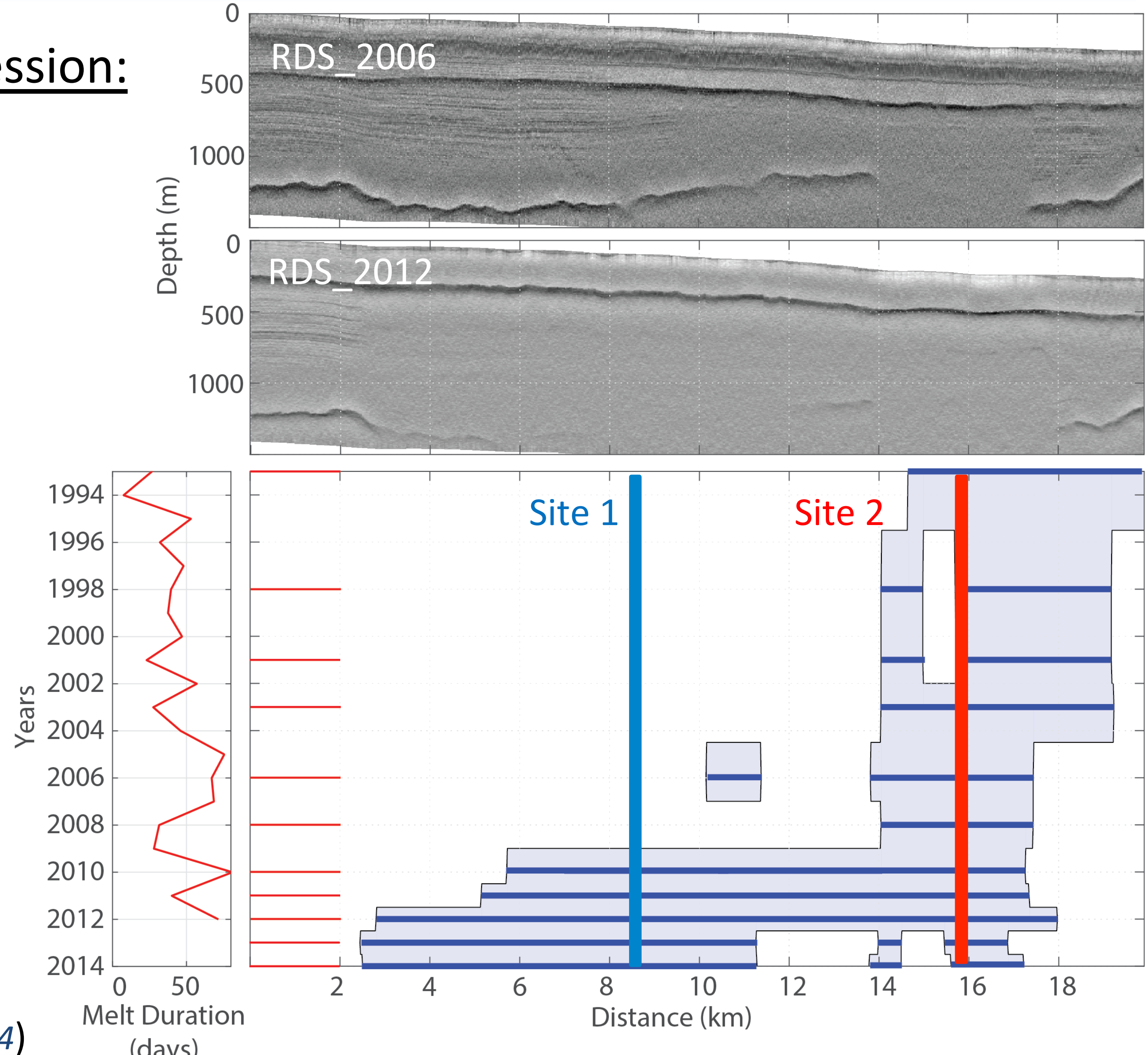
In situ measurements:
- Firn/ice core extraction
- Hydraulic conductivities
- Water dating

Monitoring:
- Firn and air temperatures
- Water level changes
- Compaction rates (Univ. Colorado)
- Energy balance (Univ. Utrecht)


iWS from Univ. Utrecht

Firn aquifer progression:

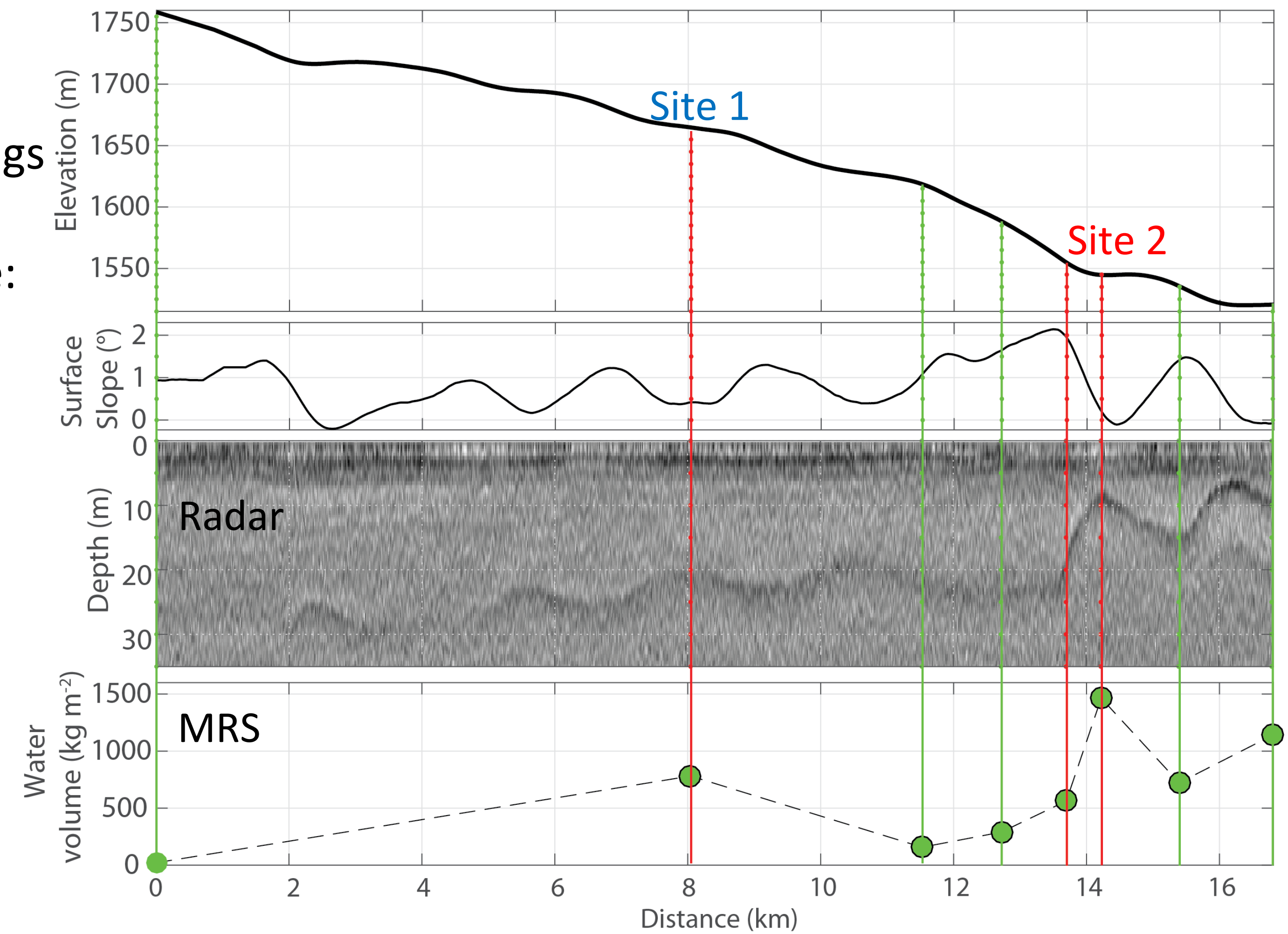
- Aquifer extends to higher elevations past spring 2008
- Small drainage (2-3 km) observed prior to spring 2013
- Aquifer progression is related to surface melt
- Younger aquifer at Site 1 compared to Site 2



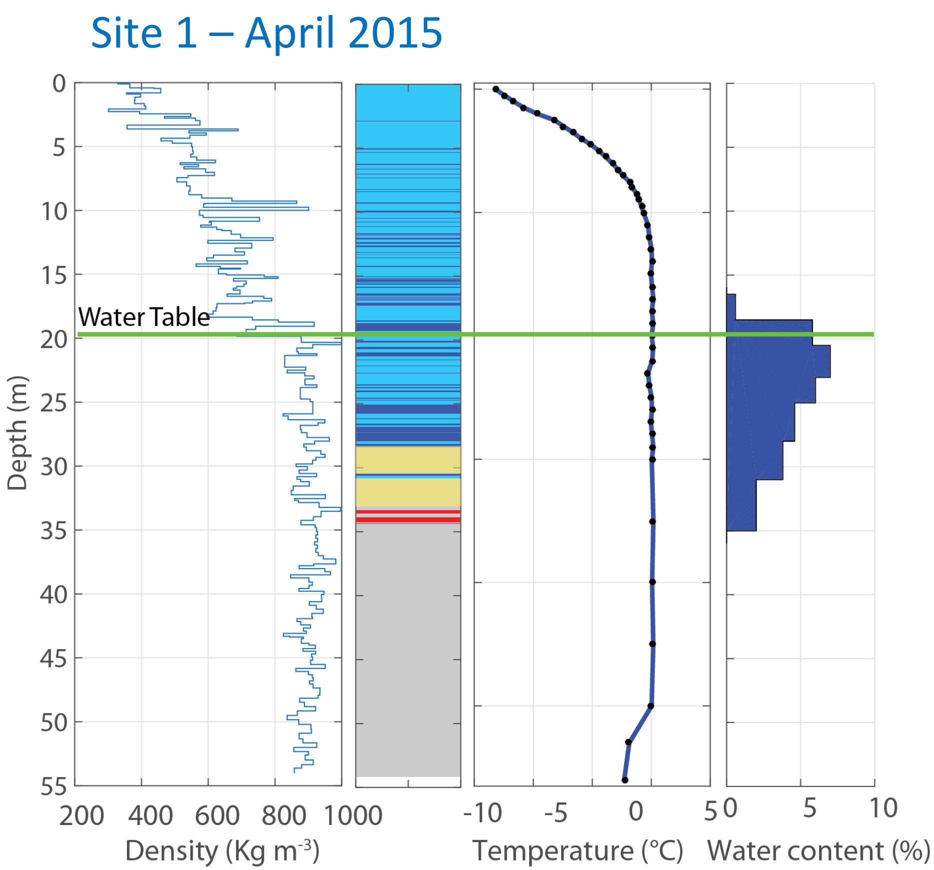
Melt duration (*Mote 2014*)

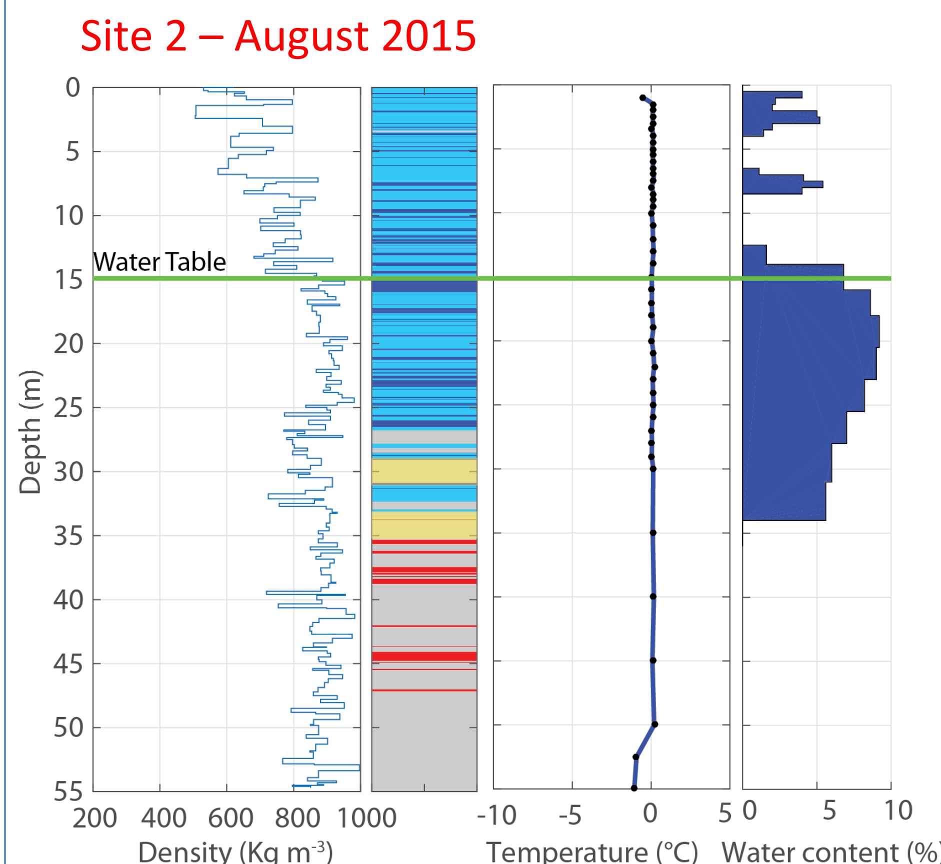
Water volume variations across a 16-km transect:

- 8 magnetic resonance soundings
- MRS water volume: 200 to 1500 kg m^{-2}
- Water volume higher in local depression (slope minima)
- Radar depth to water alone is not sufficient to infer volume



Firn-aquifer vertical structure:

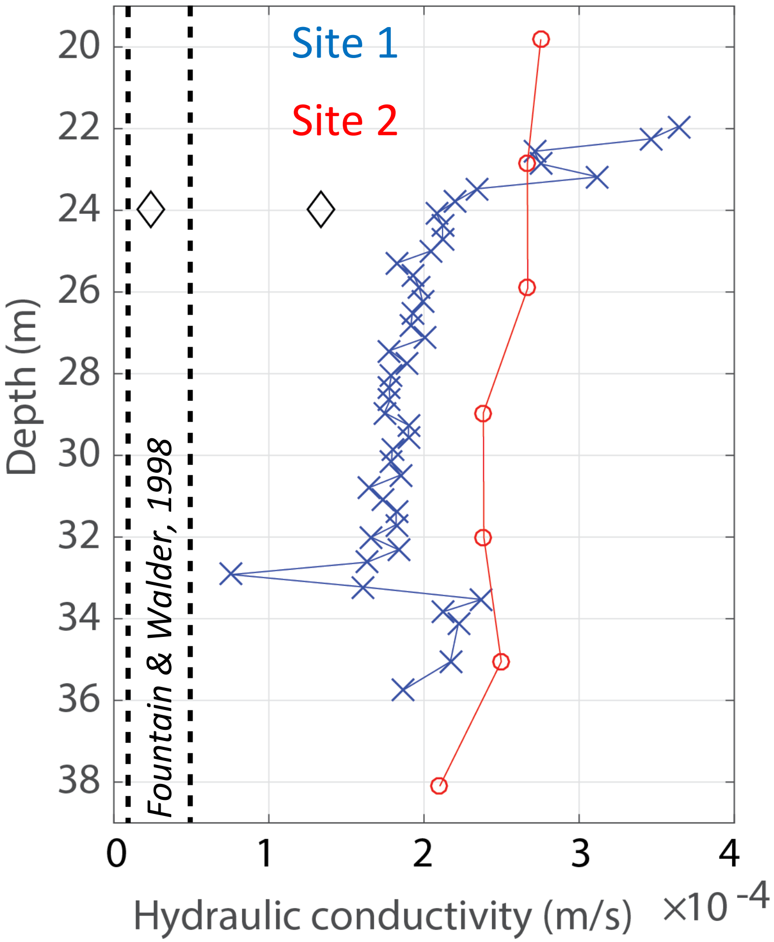




- Progressive firn/ice transition at similar depths
- Past aquifer imprints as clear-ice layers
- Temperate to colder ice transition at ~ 50 m

Stratigraphy:
Firn – ice layers – clear ice
bubbly ice – Transition

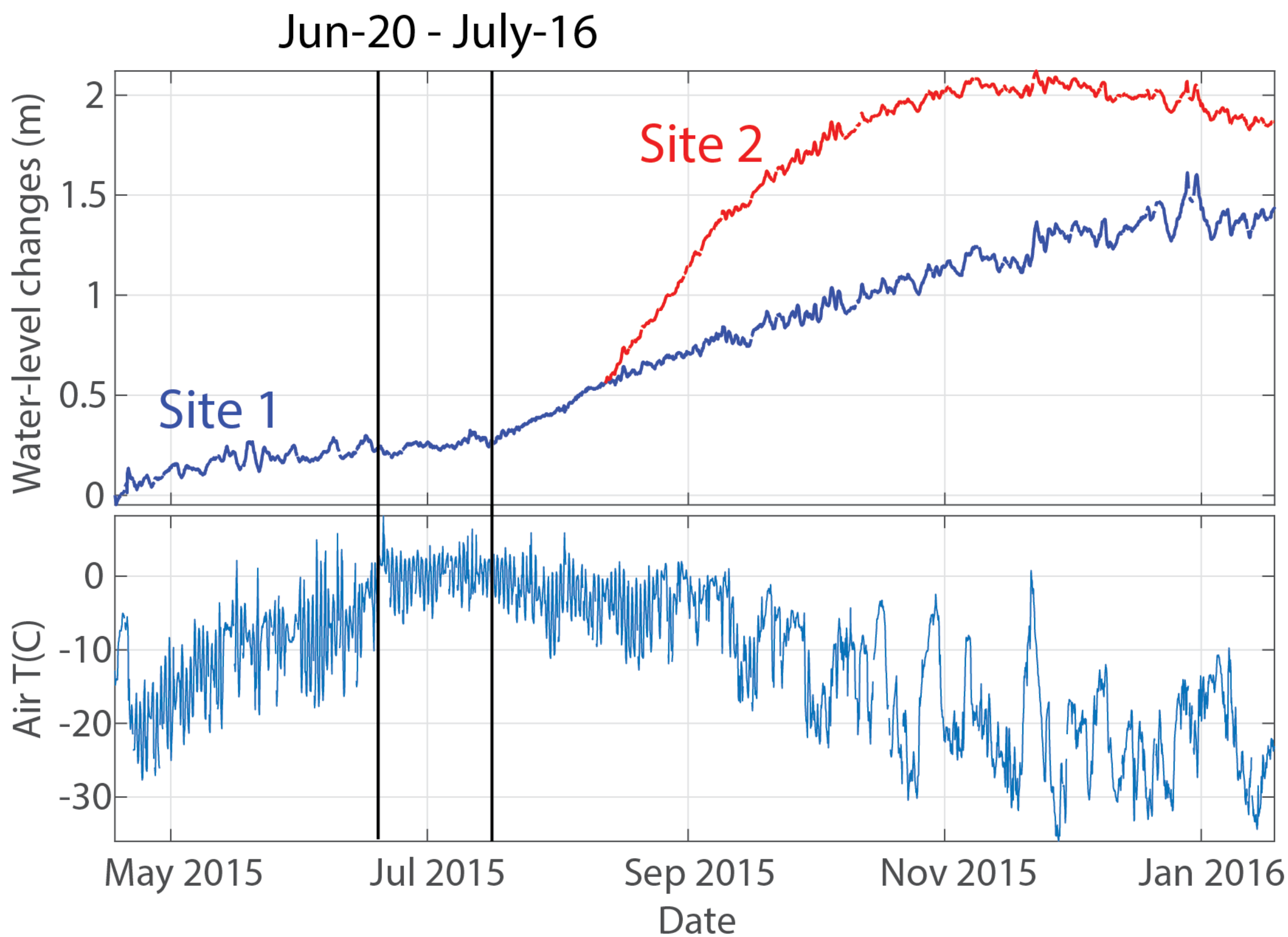
Firn-aquifer hydraulic conductivities:



<u>Initial hydrology results:</u>

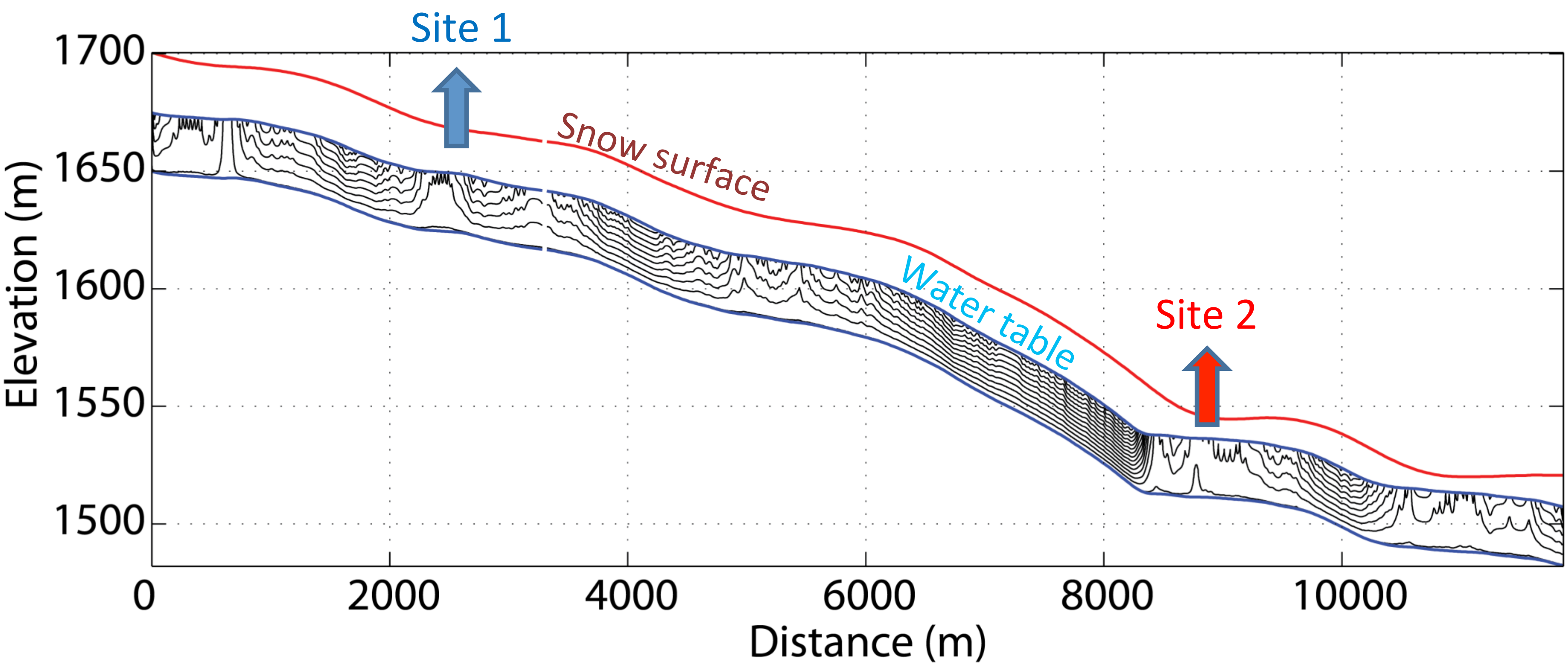
- High hydraulic conductivities
- Water will be replaced in the aquifer between 2-20 years
- CFCs indicate a rapid recharge (vertical percolation rates)
- Tritium shows age younger than 60 years

Water-level changes since April 2015:



- 1 month to bring water to the water table
- Water-level increase continues after surface melt shutdown

Agreement with a flowline simulation at steady state:



- Both sites located in local discharge areas

Main findings:

- Firn aquifer inferred since 1993, expand upstream after 2008
- Significant water volume variability (200-1500 kg m^{-2}) over 16 km
- Water residence time: 2-20 years
- Lateral flow observed within the aquifer through the fall/winter

Future work:

- Fieldwork during summer 2016
- Simulate aquifer interannual changes, lateral water flow and discharge
- Characterize connections to englacial hydrology

Thanks for your attention!

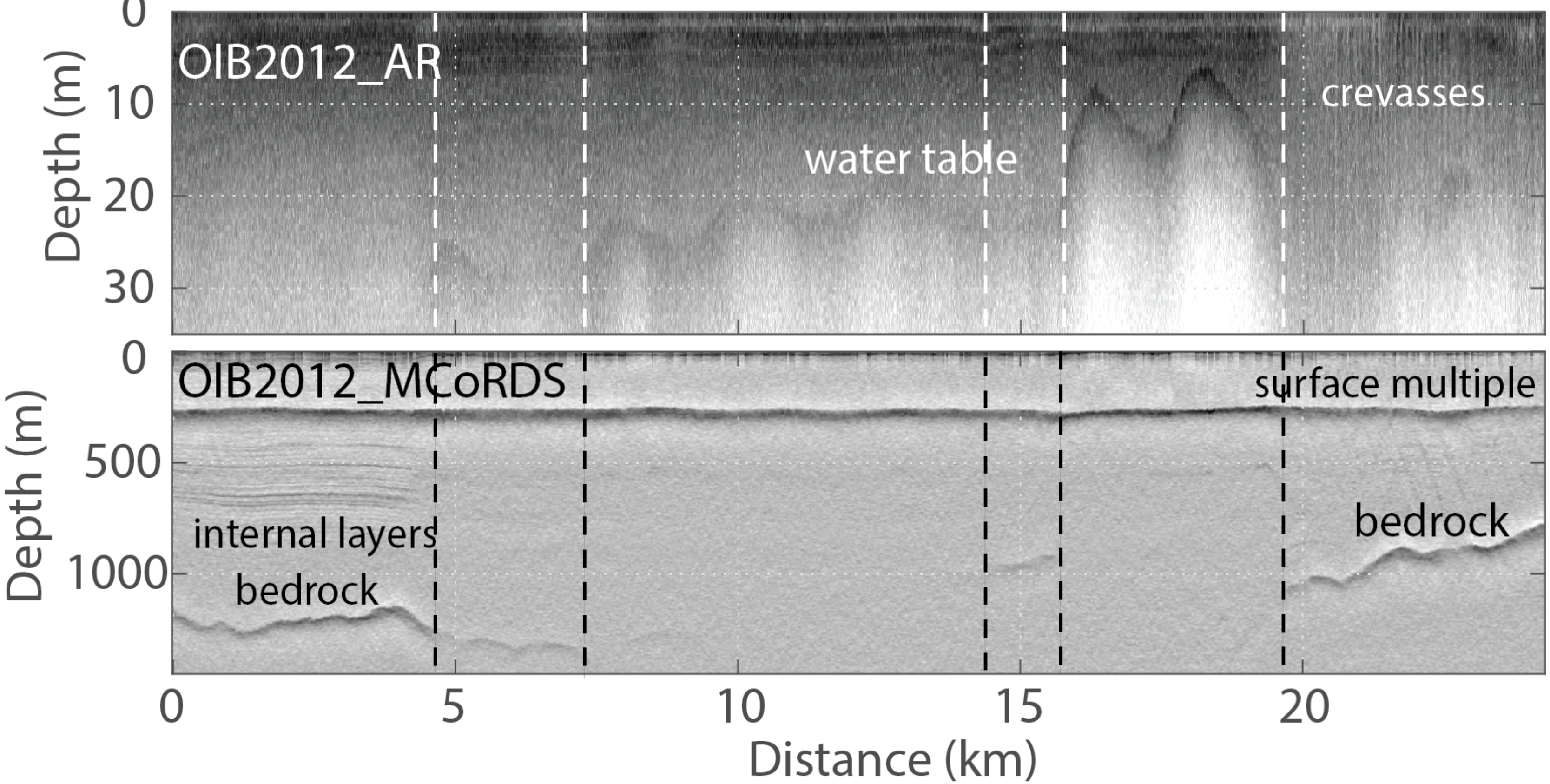
Funding: NASA, NSF

Field support: CH2MHILL Polar Services, air greenland, 109th Airlift Wing

Radars and GPS: CReSIS Center for Remote Sensing of Ice Sheets, UNAVCO

Accumulation Radar (AR)
750 MHz (*CReSIS*)

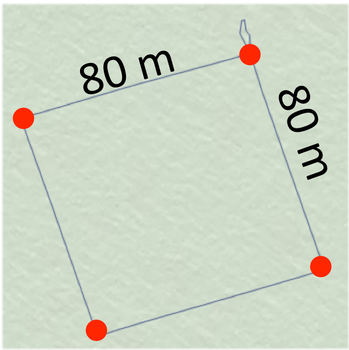
Bright reflector corresponds to the water table



Radar depth sounder (MCoRDS)
195 MHz (*CReSIS*)

Water in the firn inferred from missing bed echoes

- Magnetic resonance soundings (MRS) (LTHE, Grenoble)



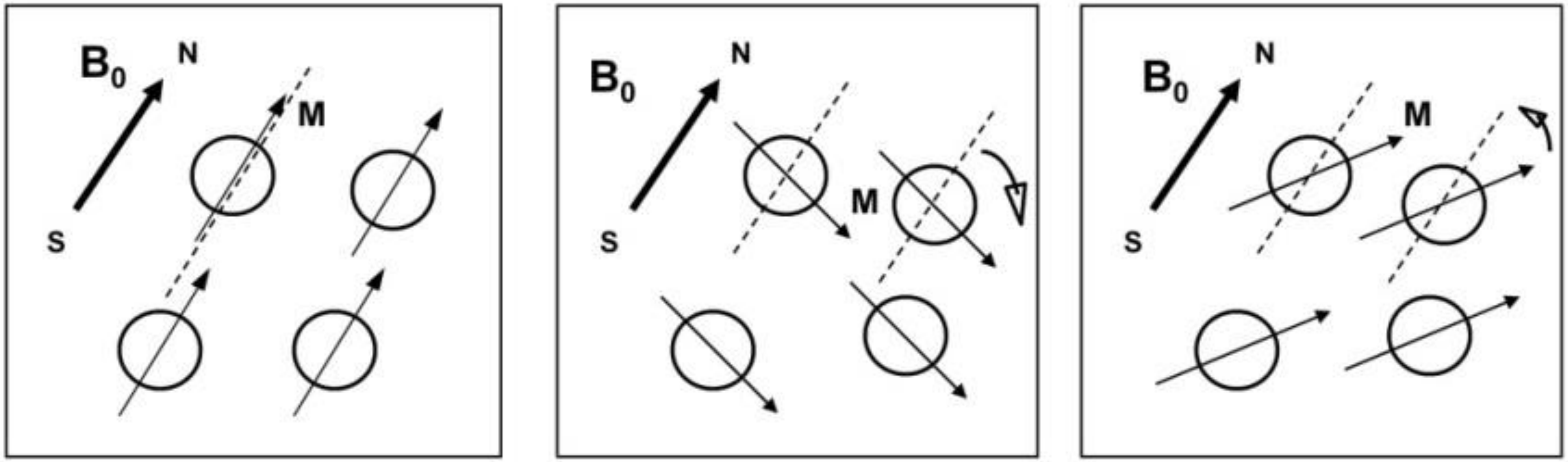
Worldview image (DigitalGlobe©)

Methods:

- Loop = transmitting / receiving antenna
- Pulse of alternating current
- Record magnetic resonance response

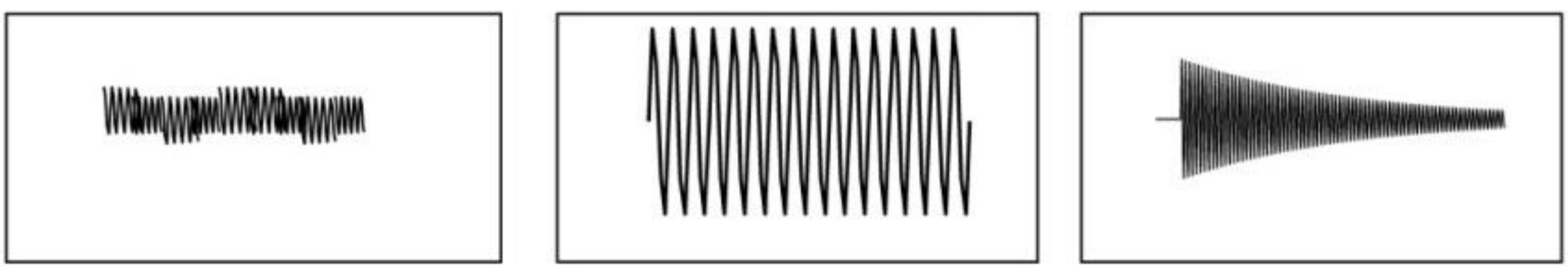
Typical phases of a magnetic resonance experiment

a) ***Undisturbed state*** b) ***Pulse transmission*** c) ***Signal measurement***



B$_0$ – static magnetic field; **M** – nucleus magnetic moment

Corresponding magnetic resonance measurement



Ambient electromagnetic noise ***Pulse of oscillating current*** ***Received signal***