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

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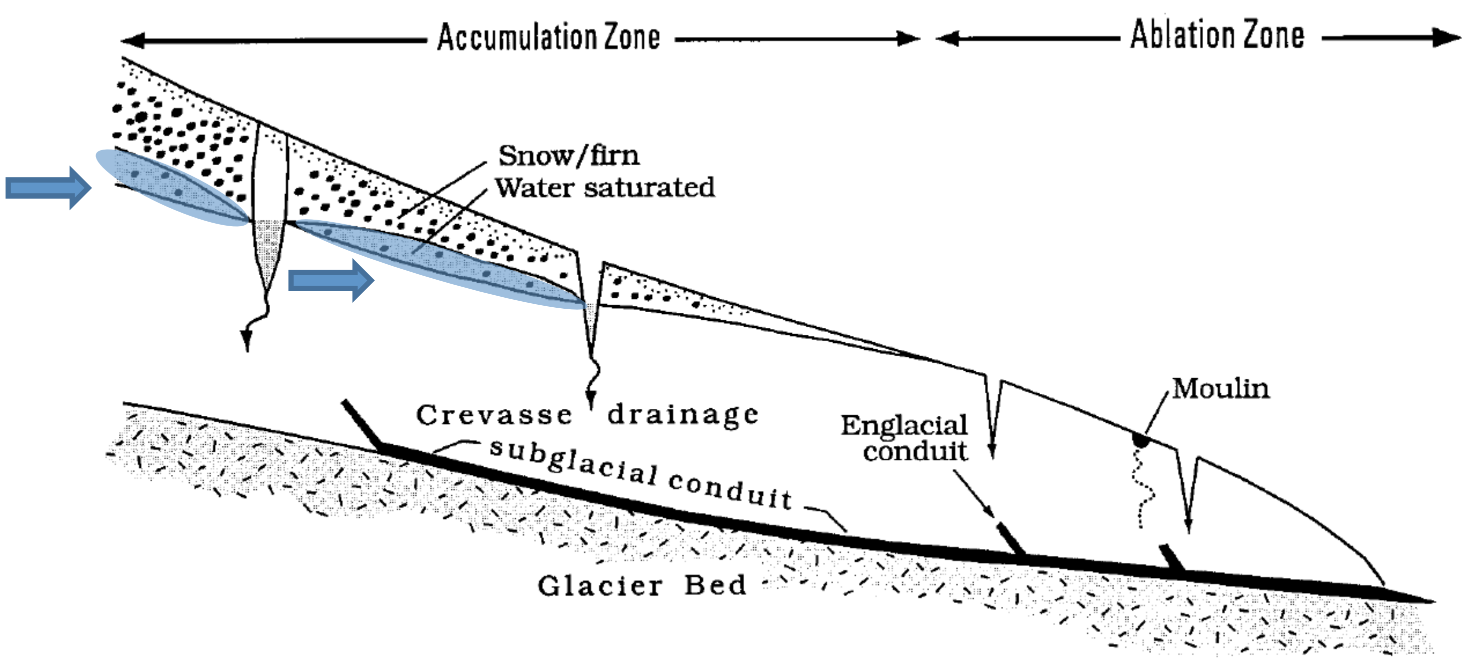
-- AGU 2015 --
Dec 14-18, San Francisco



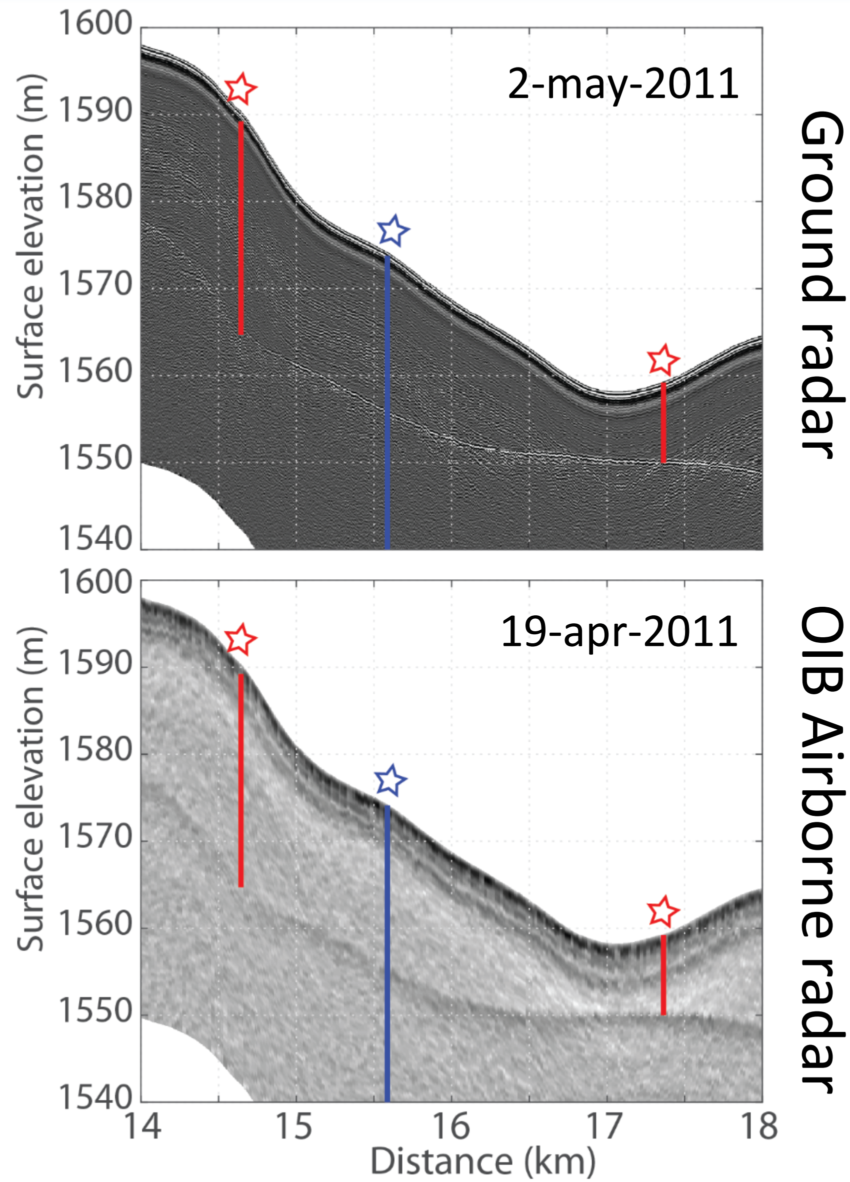
Fountain and Walder, 1998

Firn aquifers:

- develop at depth above the firn/ice transition
- sensitive to surface melt variations
- store and delay meltwater runoff
- change thickness over space and time

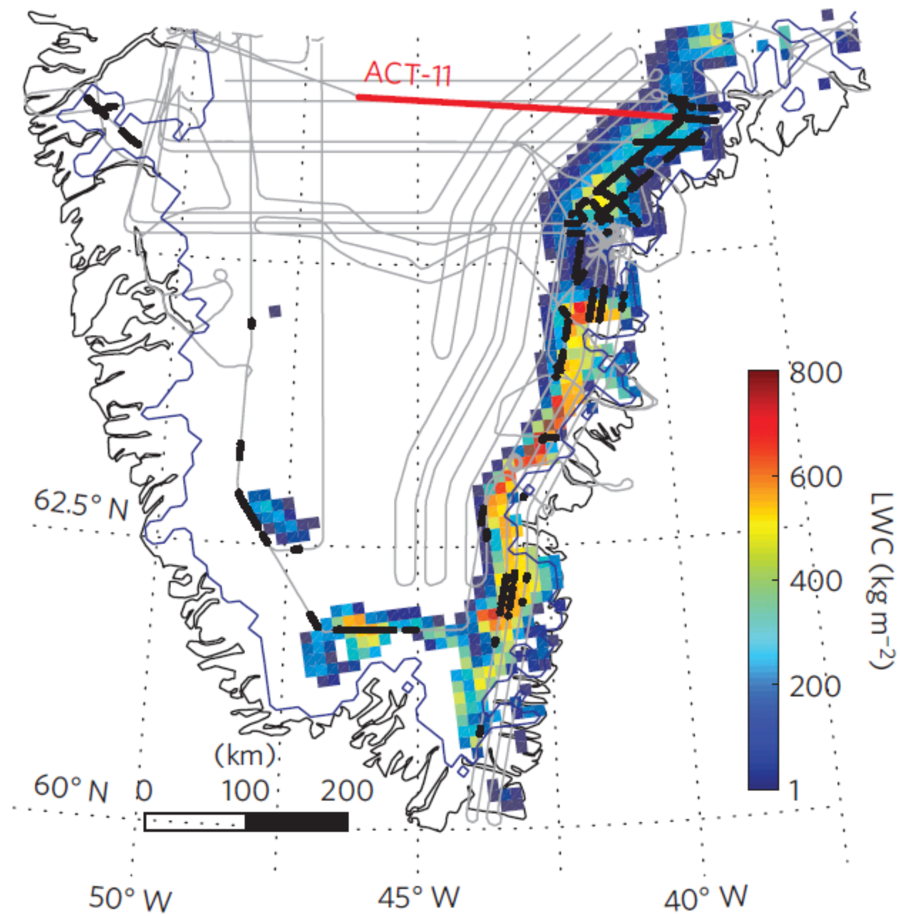
Greenland firn aquifers:

- detected before melt onset by firn cores and radars



Greenland firn aquifers:

- detected before melt onset by firn cores and radars
- mapped using 2011 airborne CReSIS radar data (OIB)
- matched with RACMO2 LWC output
- simulated over 70,000 km^2 in high accumulation regions for April 2011

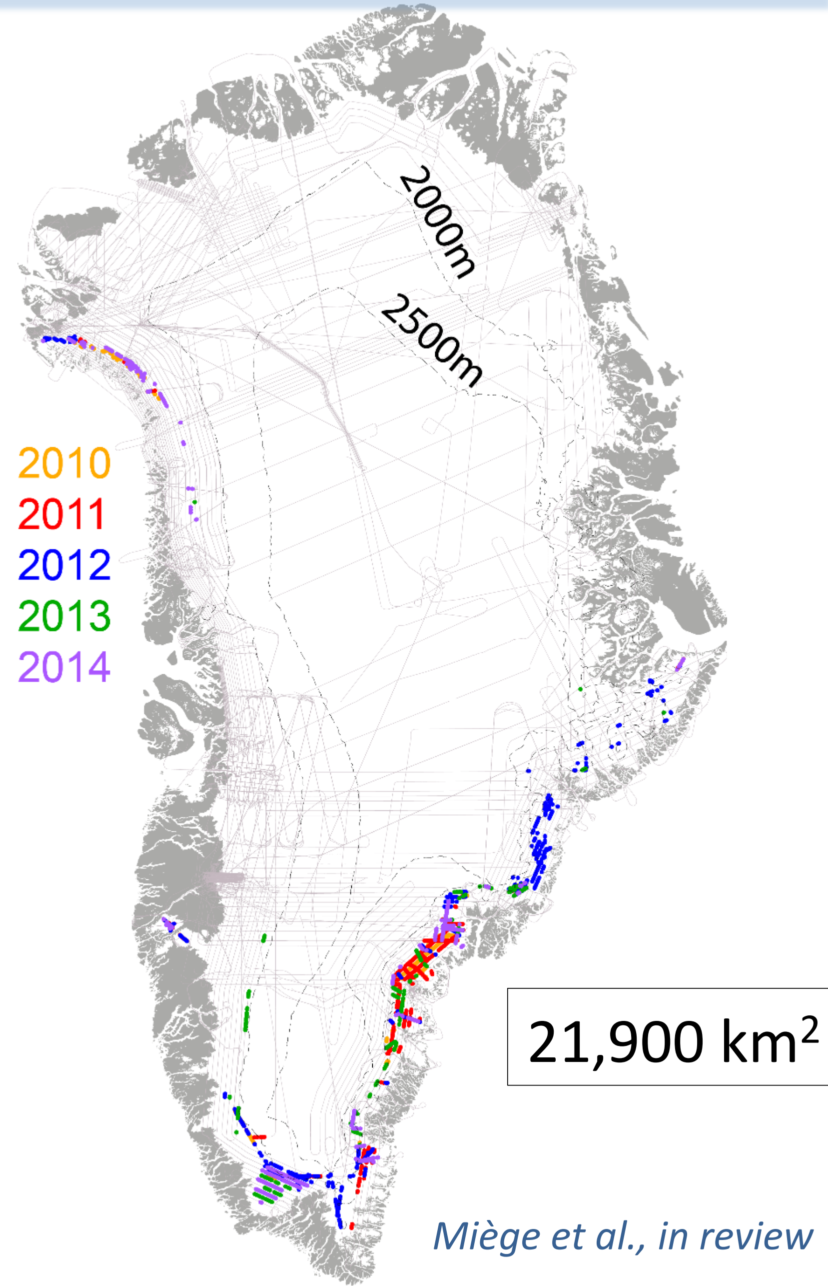


Forster et al., 2014

Greenland firn aquifers:

- detected before melt onset by firn cores and radars
- mapped using 2011 airborne CReSIS radar data (OIB)
- matched with RACMO2 LWC output
- simulated over 70,000 km^2 in high accumulation regions for April 2011
- updated from 5 years of CReSIS radar data (on board OIB P-3)

Details on Rick Forster's talk (C51E-01) tomorrow morning



Miège et al., in review

Motivations:

- Quantify firn aquifer volume, flow and discharge
- Firn aquifer impacts on ice dynamics and ice-sheet mass balance

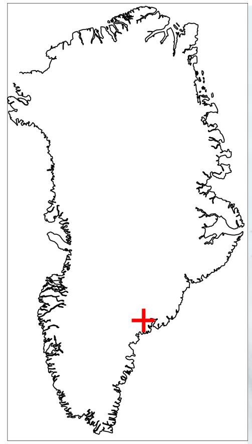
General objectives:

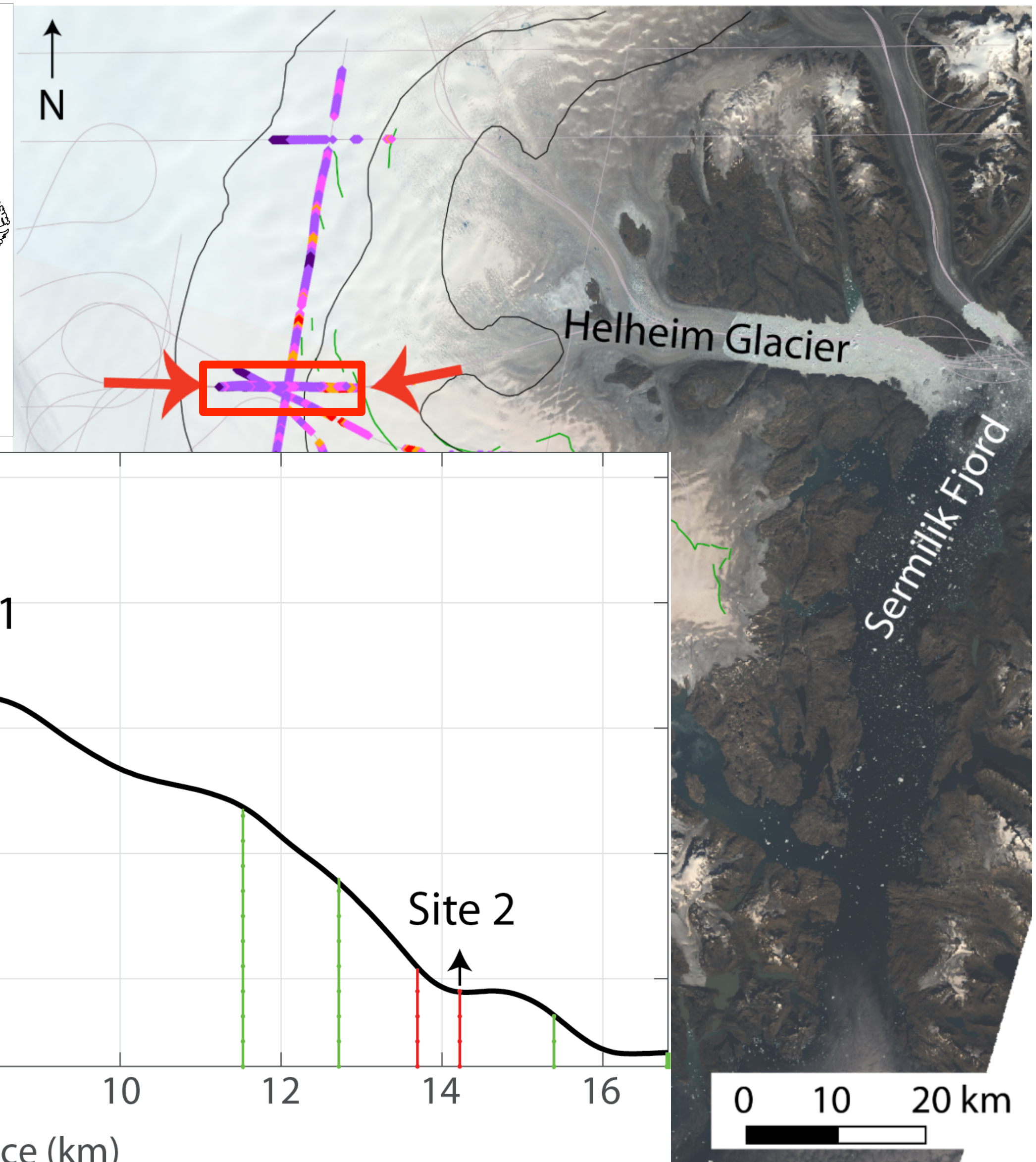
- Constraint firn aquifer volume and its variations in space and time
- Determine water residence time and flow rate through the aquifer
- Identify pathways, connections and water contribution to englacial hydrology

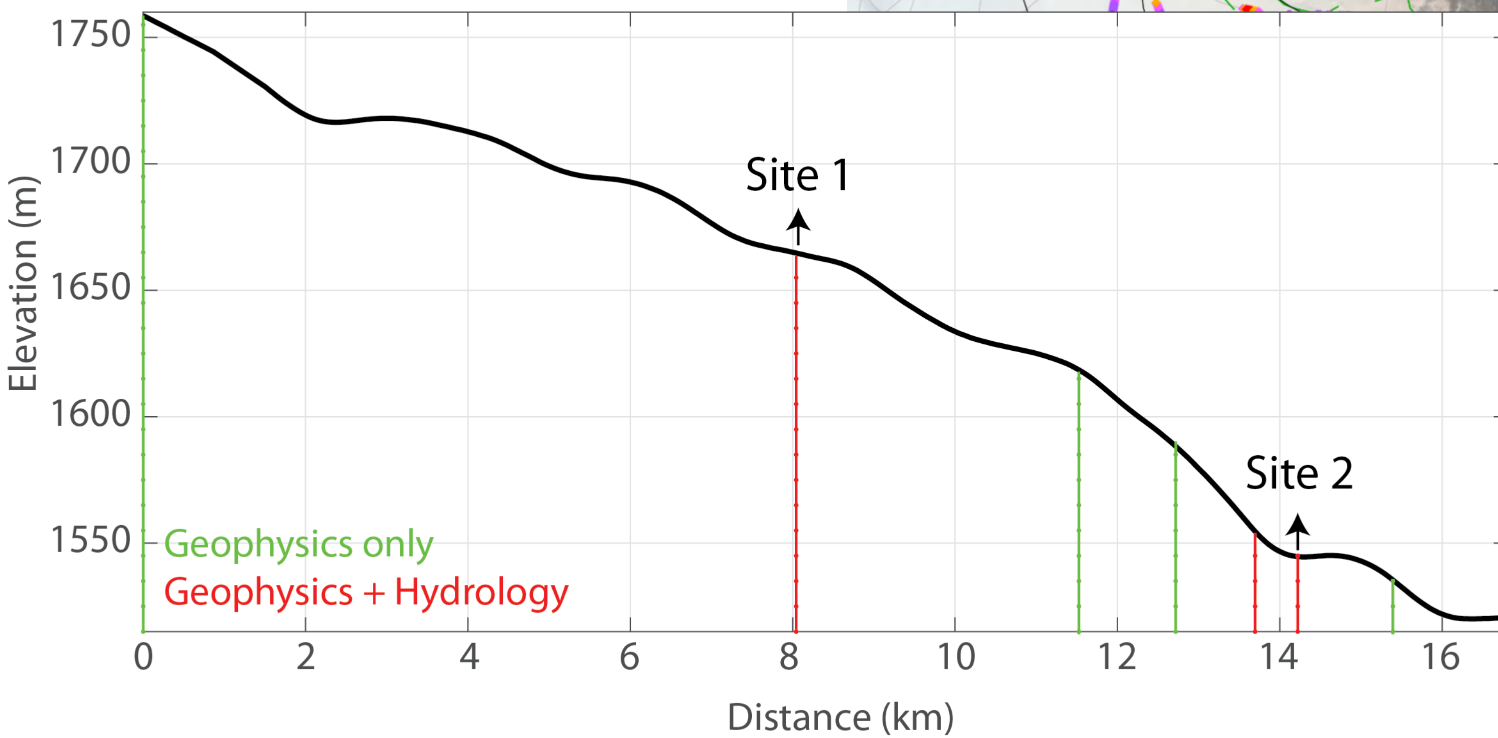
Study site chosen in the upper part of Helheim Glacier, SE Greenland where firn aquifer was detected by radar

Field site location:

Upstream of the southern arm of Helheim Glacier







Background: Landsat 8 (USGS)

Radar time series:

Surface melt duration (*Mote 2014*)
Accumulation (*Burgess et al., 2010*)

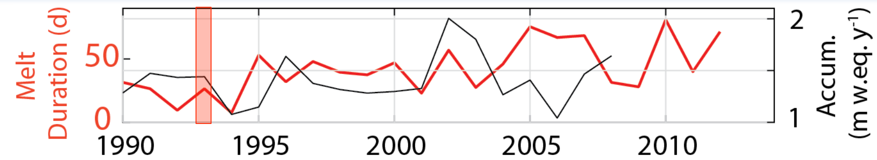
Radar depth sounder 195 MHz (*CReSIS*)

➡ Missing bed echoes related to water in the firn
1993 - 2014

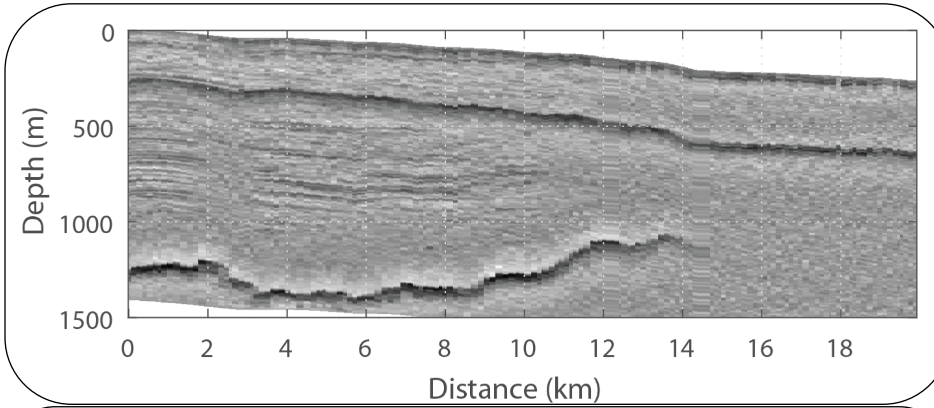
Accumulation Radar 750 MHz (*CReSIS*)

➡ Bright reflector corresponds to water table (firn aquifer surface)
2010 - 2014

1993

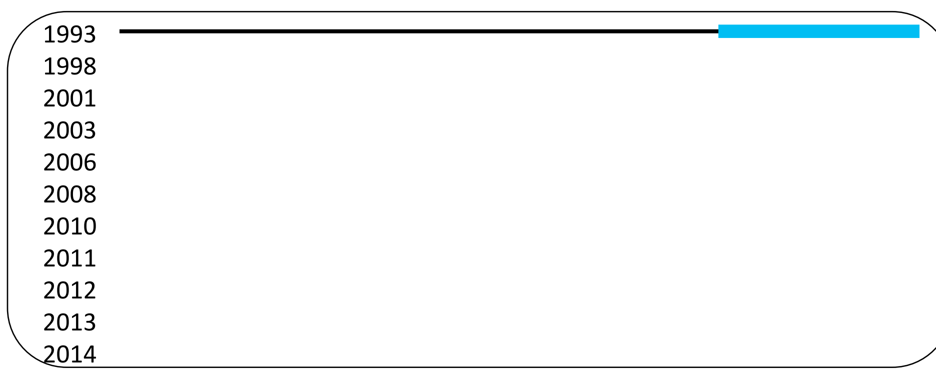


Radar depth sounder



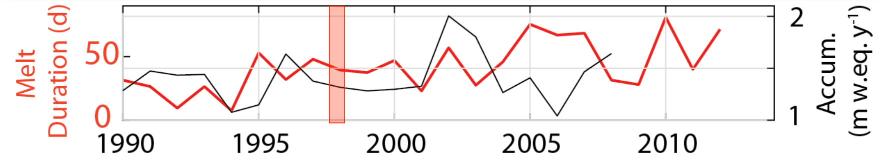
Accumulation Radar

Aquifer lateral extent

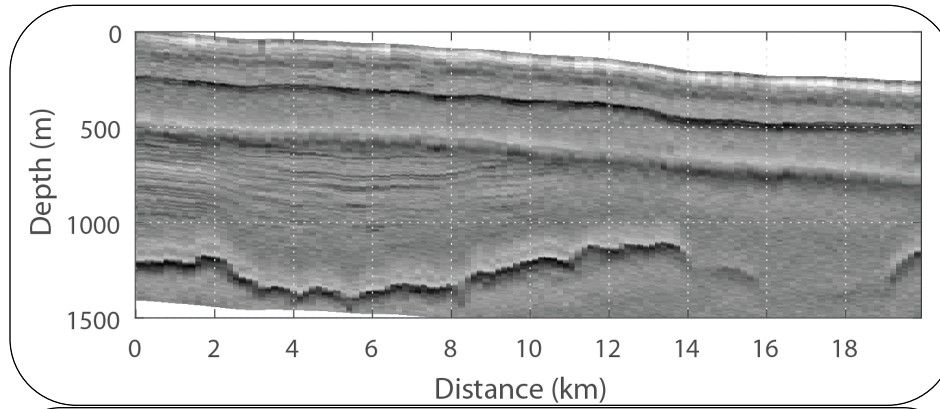


Miège et al., JGR in revision

1998

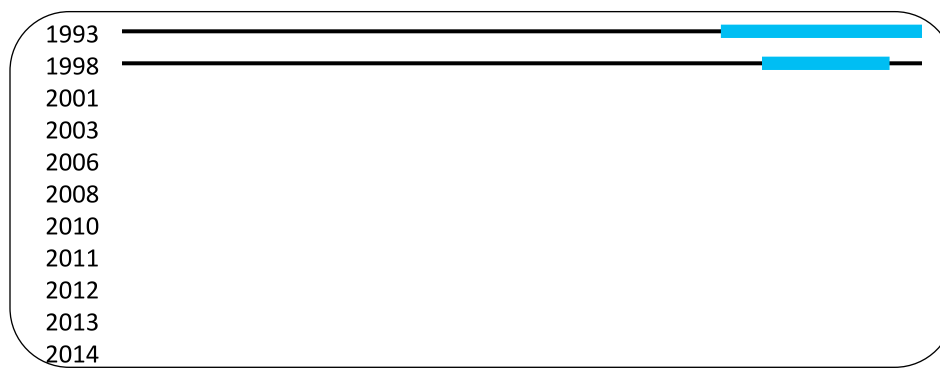


Radar depth sounder

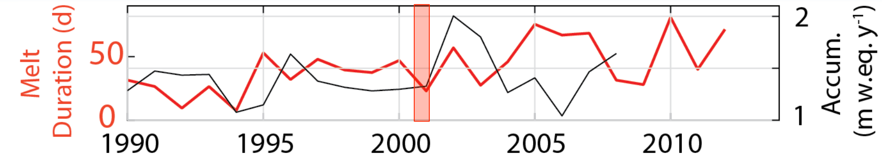


Accumulation Radar

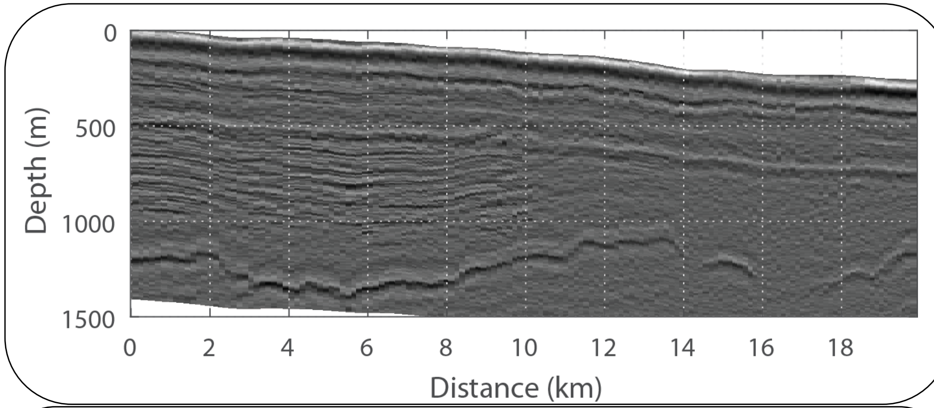
Aquifer lateral extent



2001

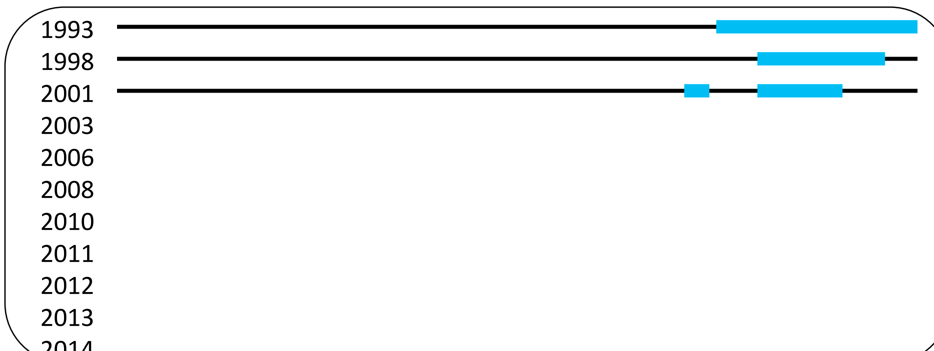


Radar depth sounder

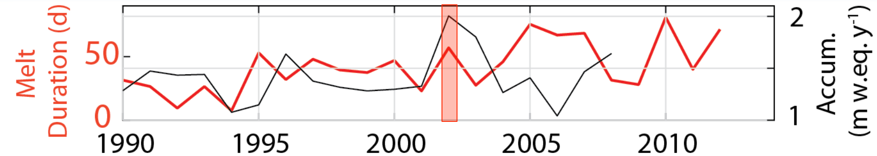


Accumulation Radar

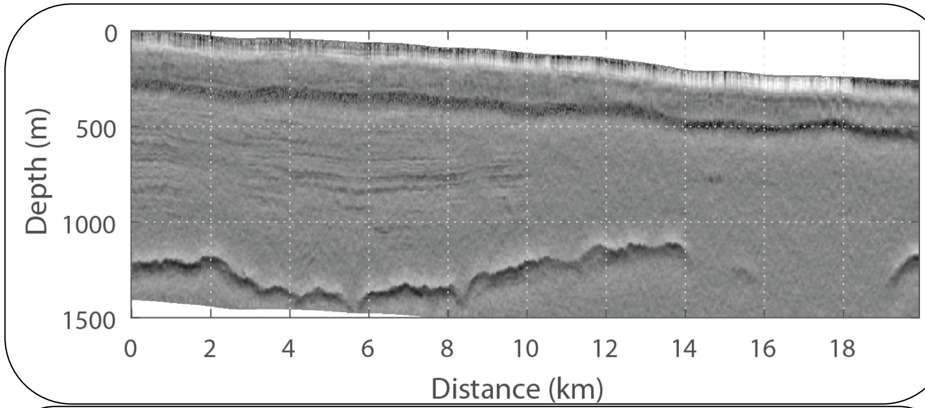
Aquifer lateral extent



2003

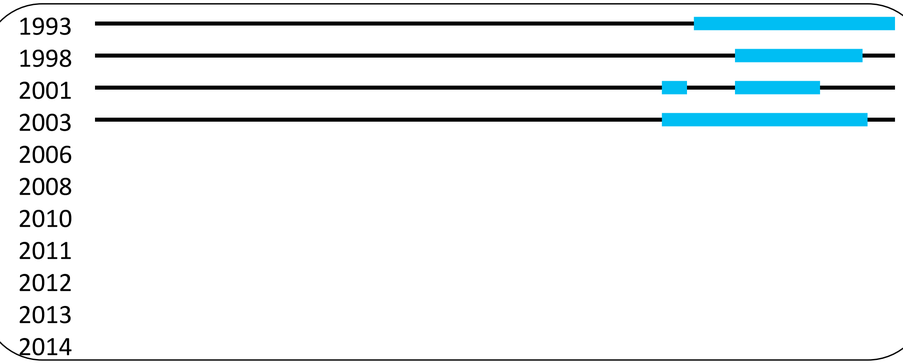


Radar depth sounder

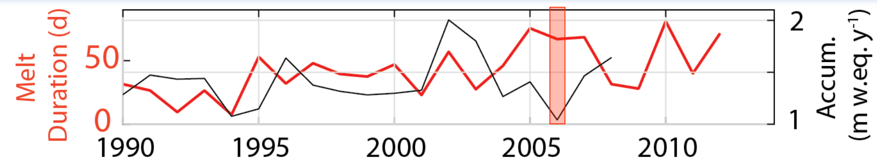


Accumulation Radar

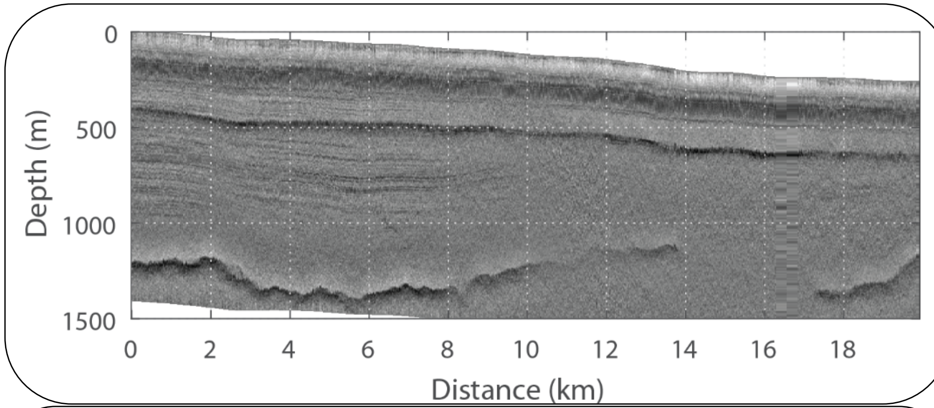
Aquifer lateral extent



2006



Radar depth sounder



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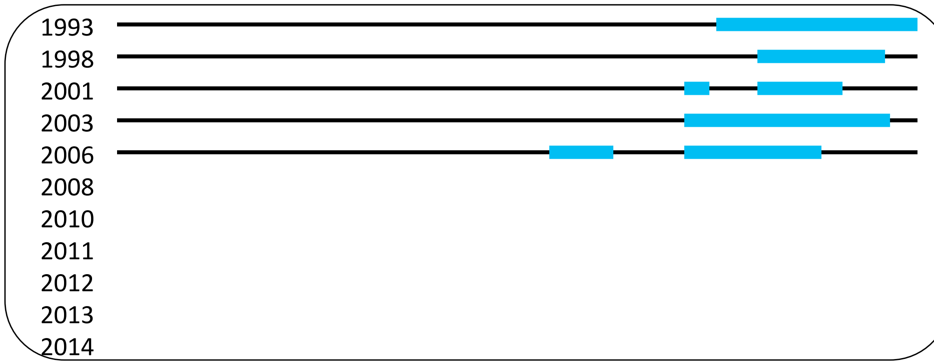
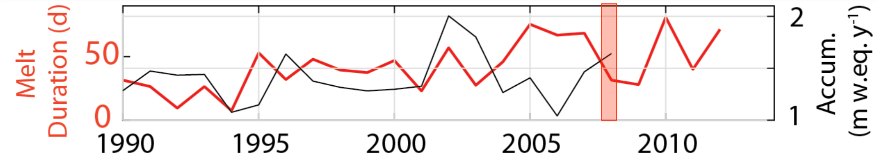
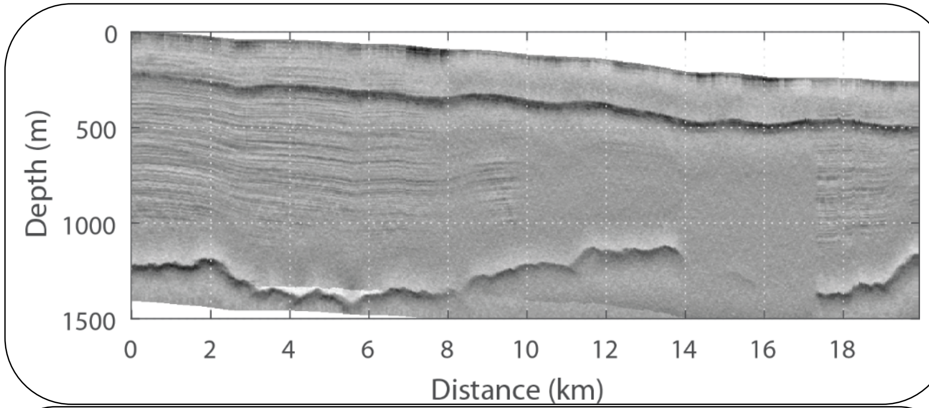


2008



Radar depth sounder



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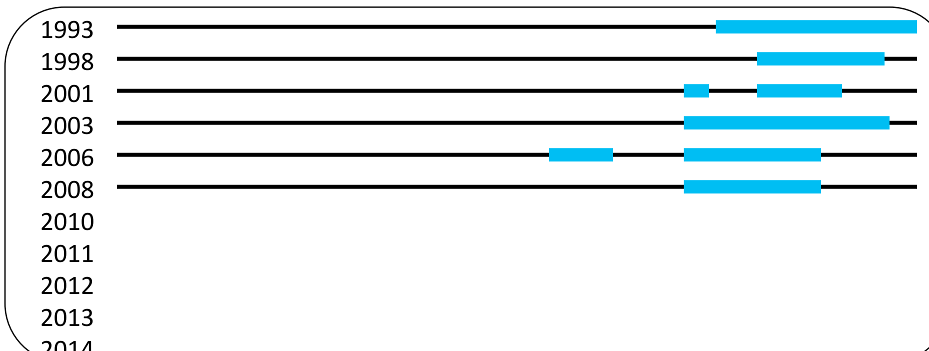
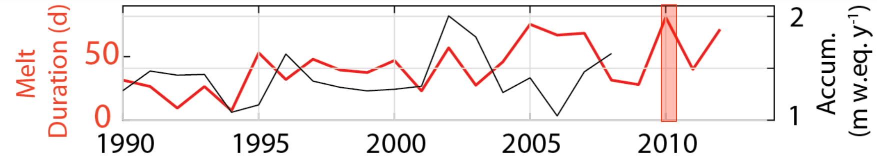
Aquifer lateral extent

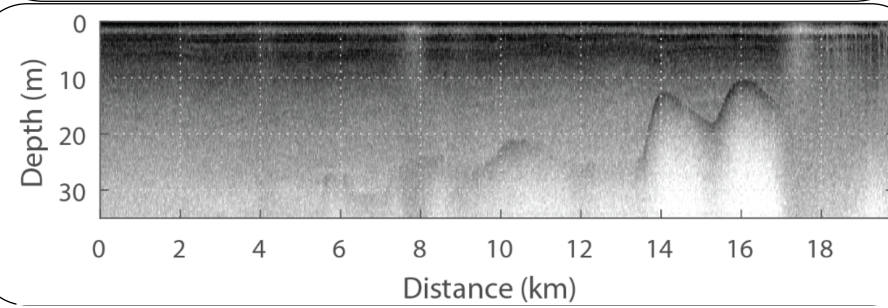


2010

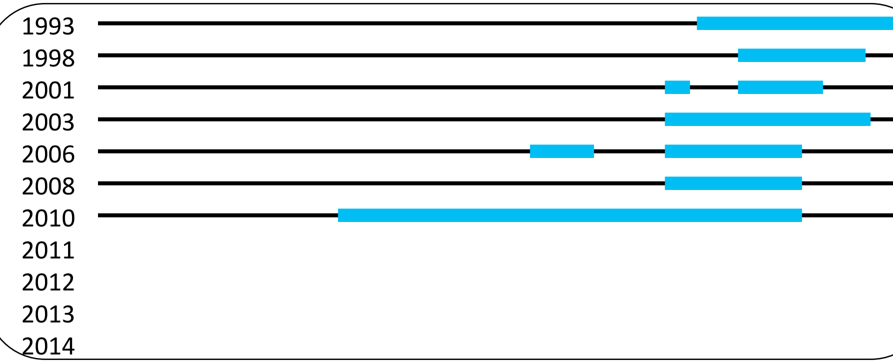


Radar depth sounder

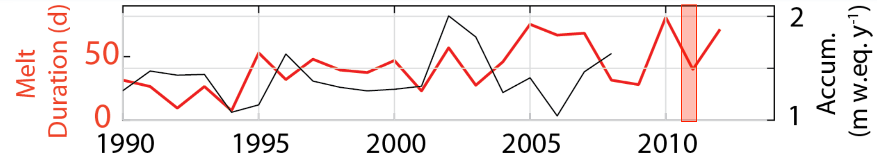
Accumulation Radar



Aquifer lateral extent

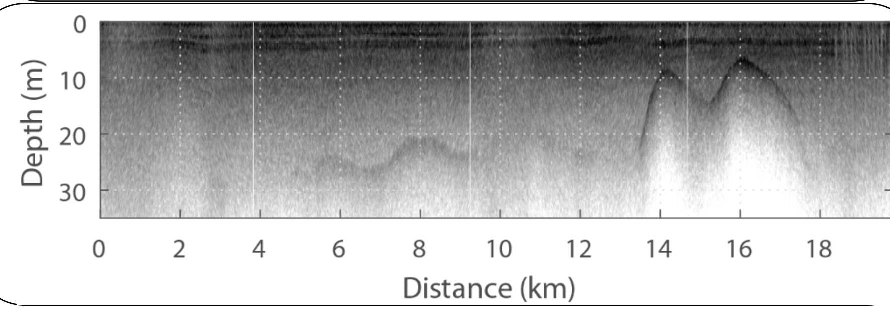


2011



Radar depth sounder

Accumulation Radar



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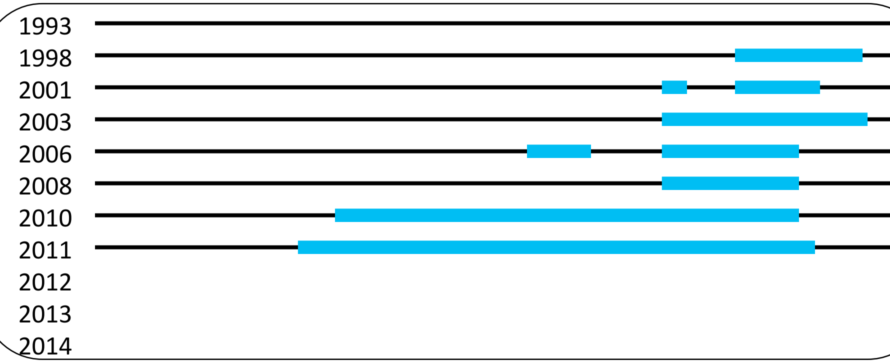
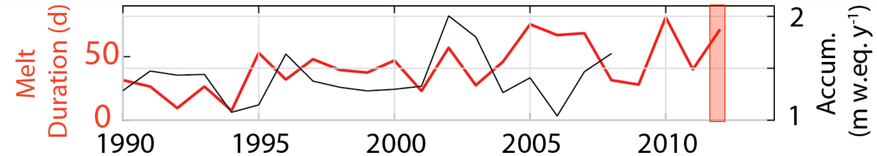
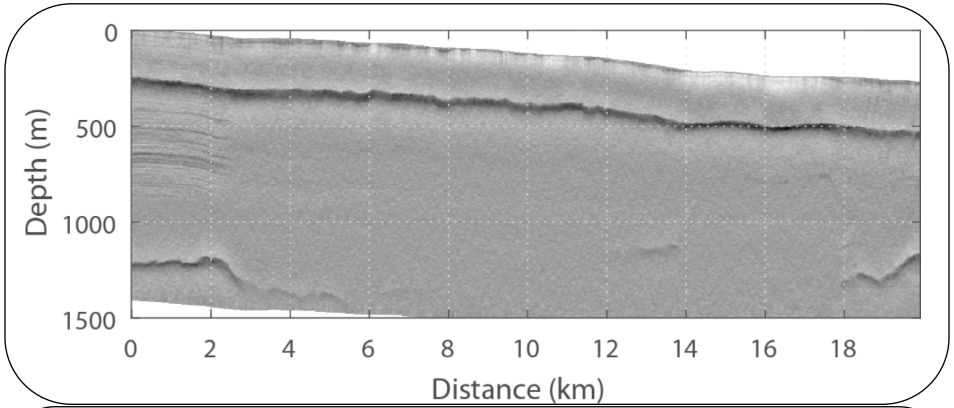


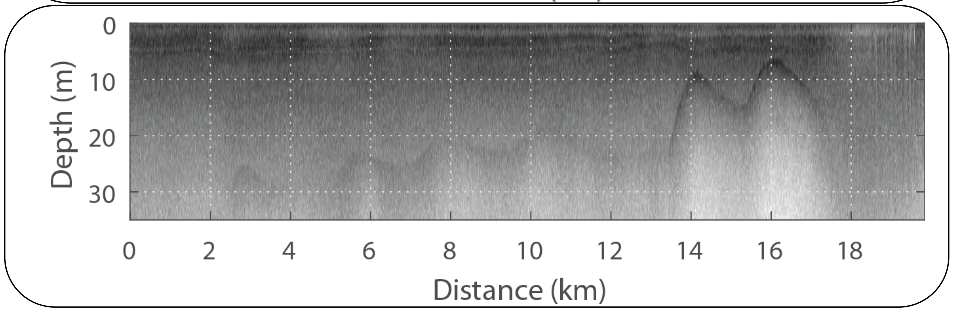
2012



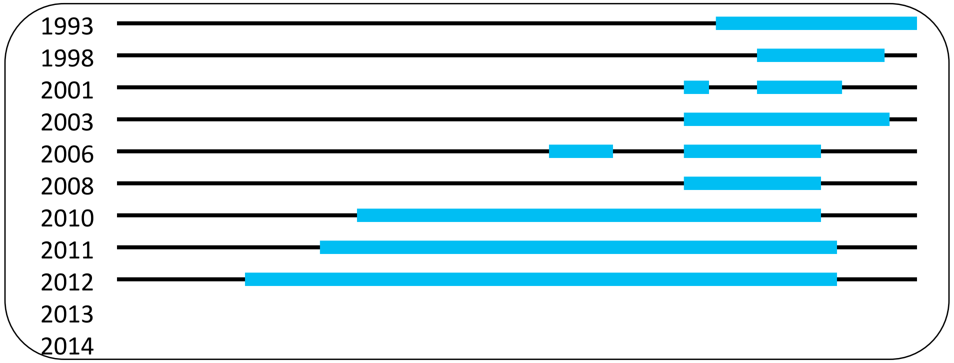
Radar depth sounder



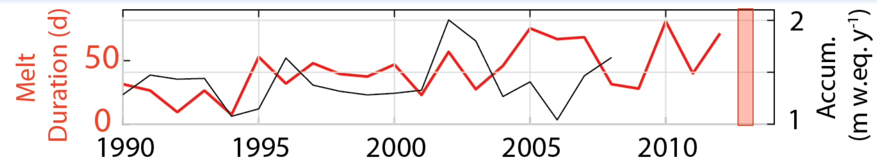
Accumulation Radar



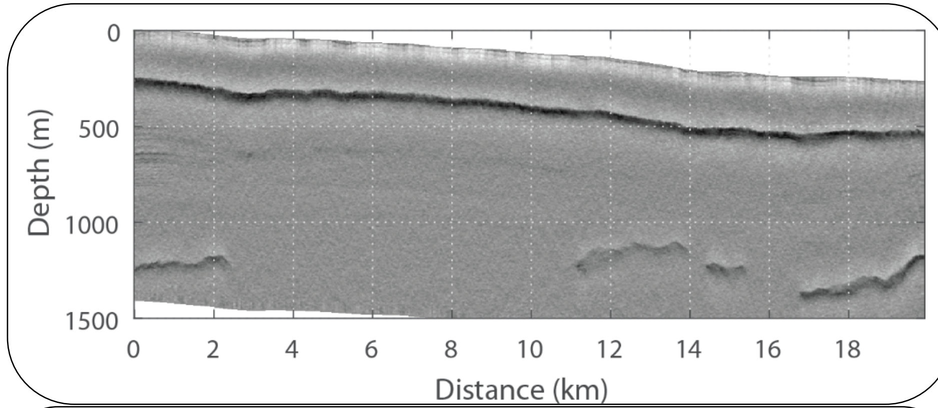
Aquifer lateral extent



2013



Radar depth sounder



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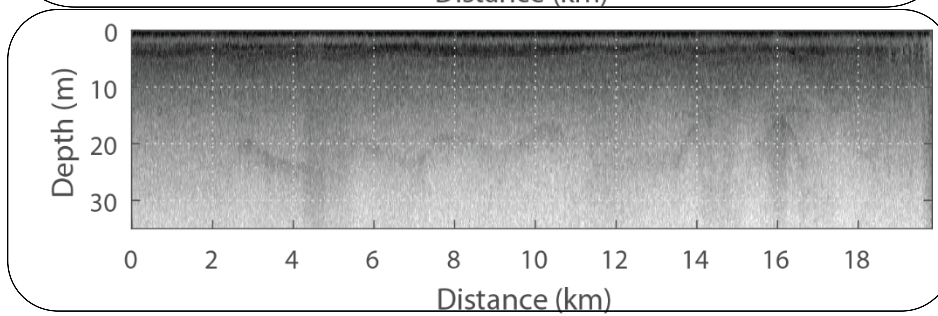
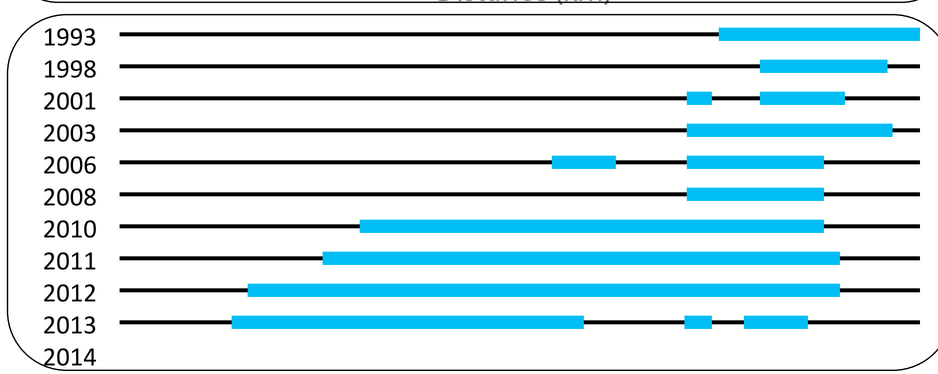
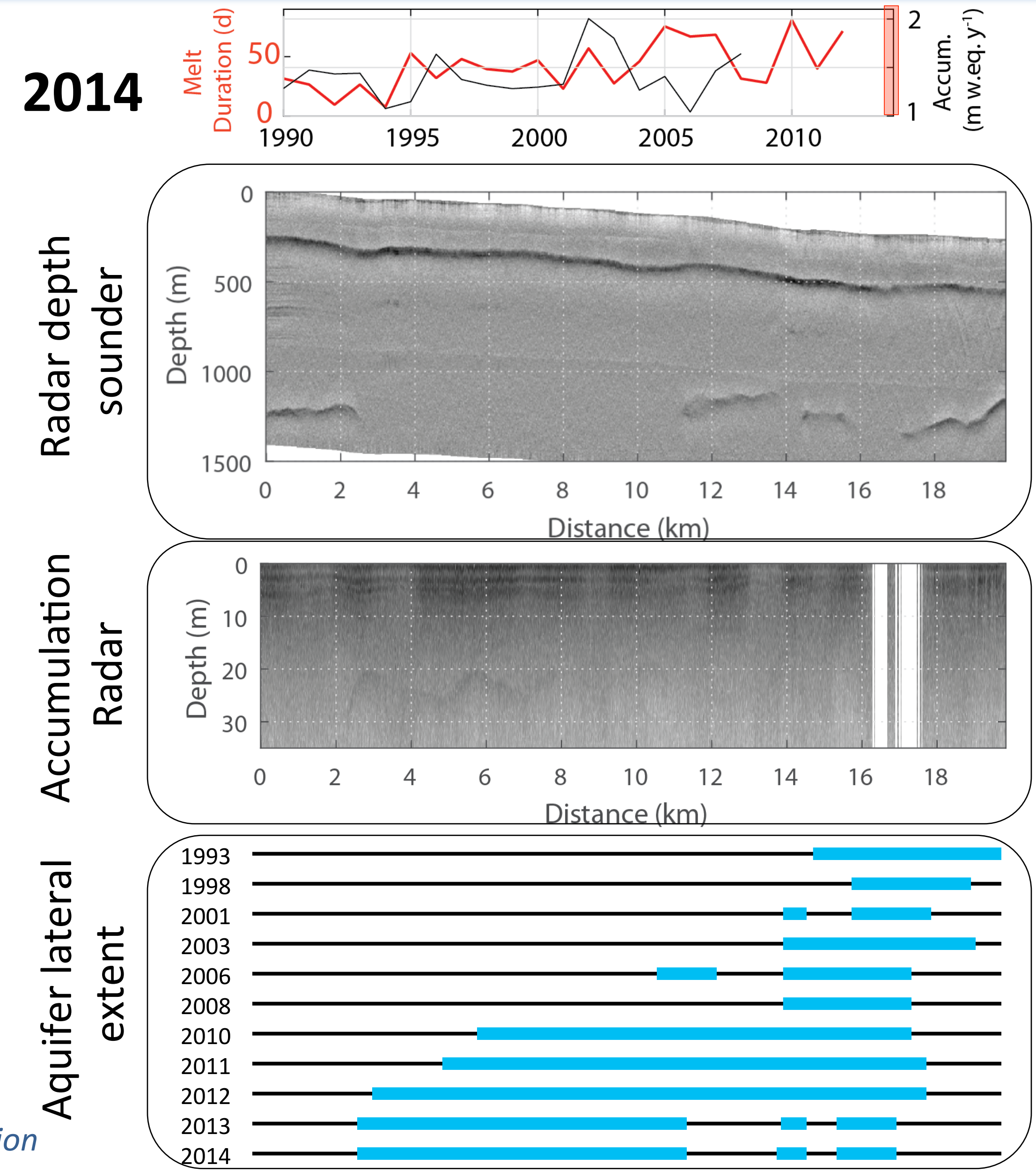


Aquifer lateral extent



Radar time series summary:

- Good correlation between the two radars
- Aquifer expands to higher elevations past spring 2008
- Substantial filling (+4 m) after summer 2010
- Small drainage (2-3 km) observed in 2013
- Did not recover in 2014



Miège et al., JGR in revision

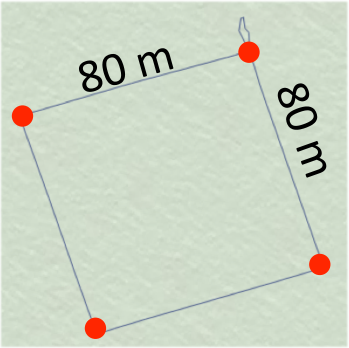
Geophysical investigation:

- Ground-penetrating radar

Objectives:

- Obtain spatial variations of the water-table elevation
- Infer volume changes with calibration

- Magnetic resonance soundings (MRS) (LTHE)



Worldview image (DigitalGlobe©)

Methods:

- Pulse of alternating current
- Magnetization of liquid water protons
- Receive signal in the same loop before next Tx
- 2-3 hours per sounding

Objective:

- Water volume to depths of 30-40 m

Geophysical investigation:

- Ground-penetrating radar
- Magnetic resonance soundings
- Seismic refraction (Univ. Maryland)

Details on Lynn Montgomery's poster (C51B-0696) tomorrow morning

Survey line:

Objectives:

- Vertical stratigraphy: distinction between dry & wet firn, temperate & cold ice
- Using velocity structure -> variations in water saturation in the aquifer

Geophysical investigation:

- Ground penetrating radar
- Seismic refraction
- Magnetic resonance

In situ measurements:

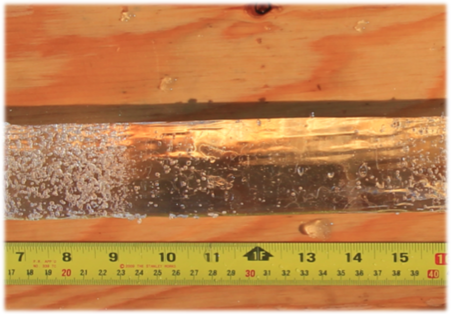
- Firn/ice core extraction (density, stratigraphy)
- Hydraulic conductivities (slug tests and aquifer test)
- Water dating (CFCs, Tritium, Ar)

Details on Olivia Miller's poster (C51B-0695) tomorrow morning

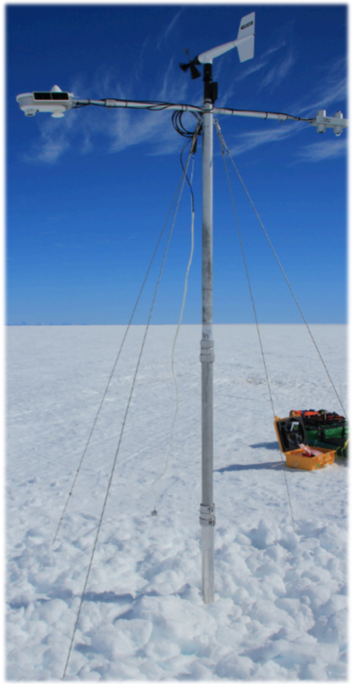
Monitoring:

- Firn and air temperatures
- Water level changes
- Compaction rates (CIRES)
- Energy balance (Utrecht iWS)

Aquifer test pump



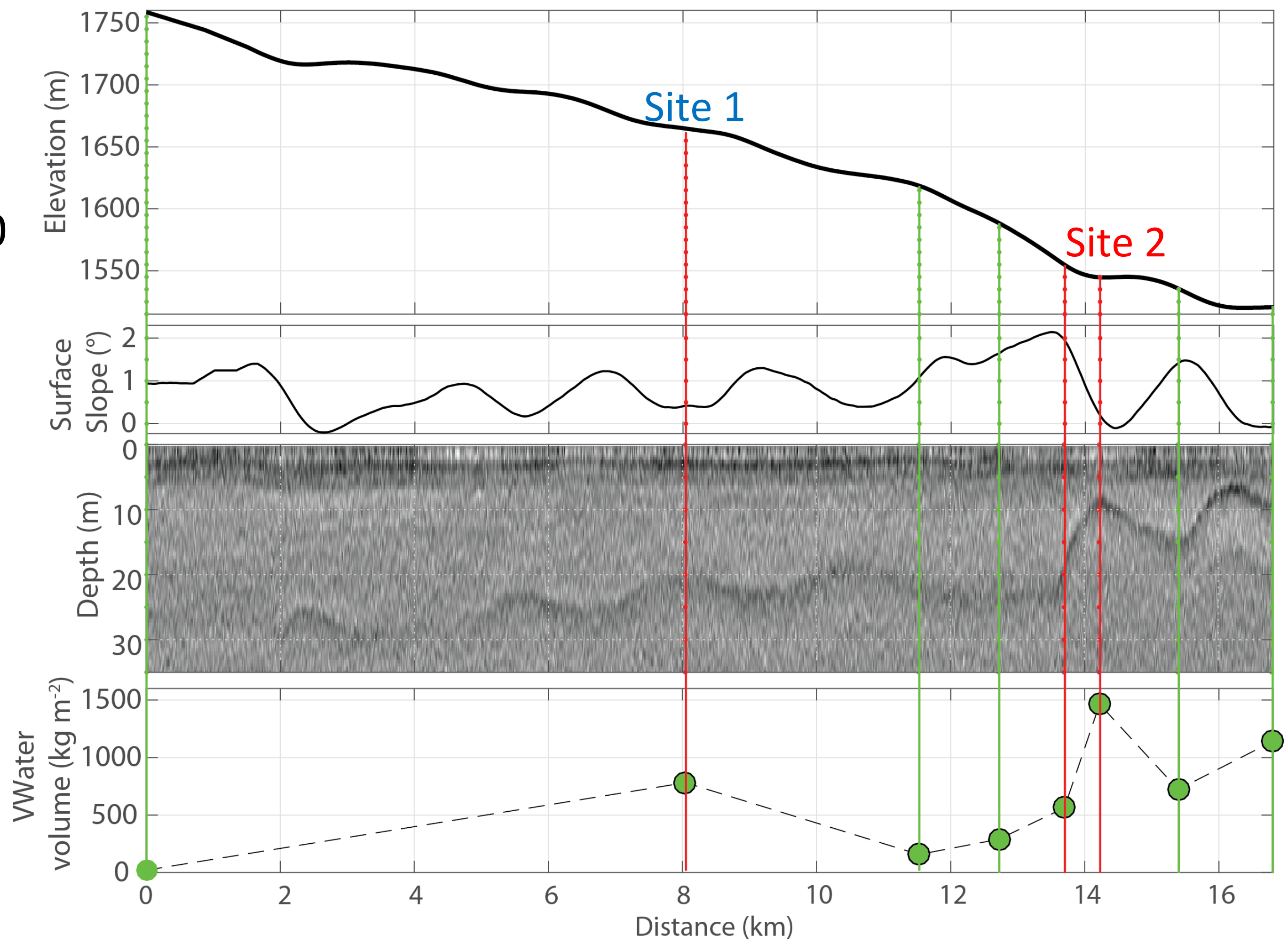
Clear ice layer



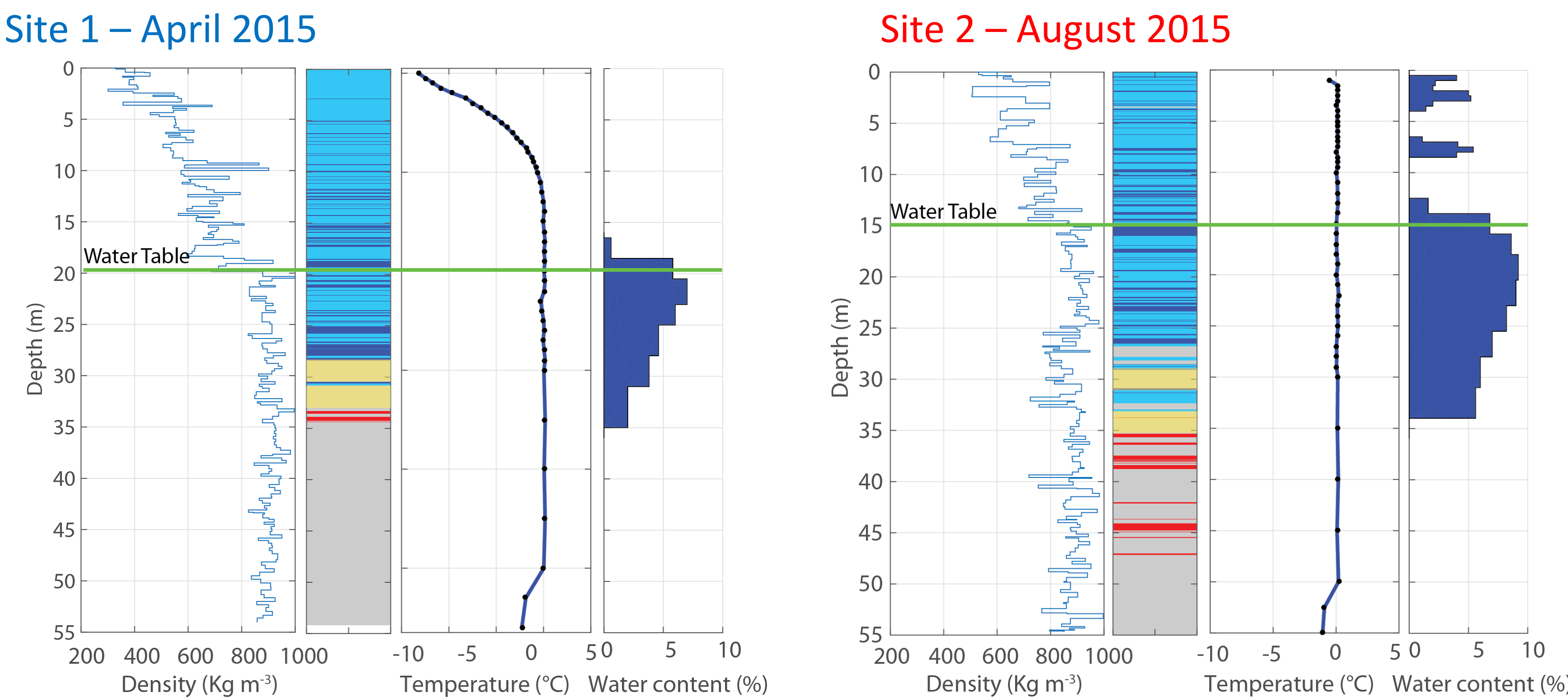
iWS from Univ. Utrecht

Water volume spatial variability:

- 8 MRS soundings
- Dry control site
- Volume range: 200 and 1500 kg m^{-2}
- Radar depth to water is not sufficient to infer volume
- water volume higher in local depression (slope minima)



Firn aquifer vertical stratigraphy: spring vs. summer

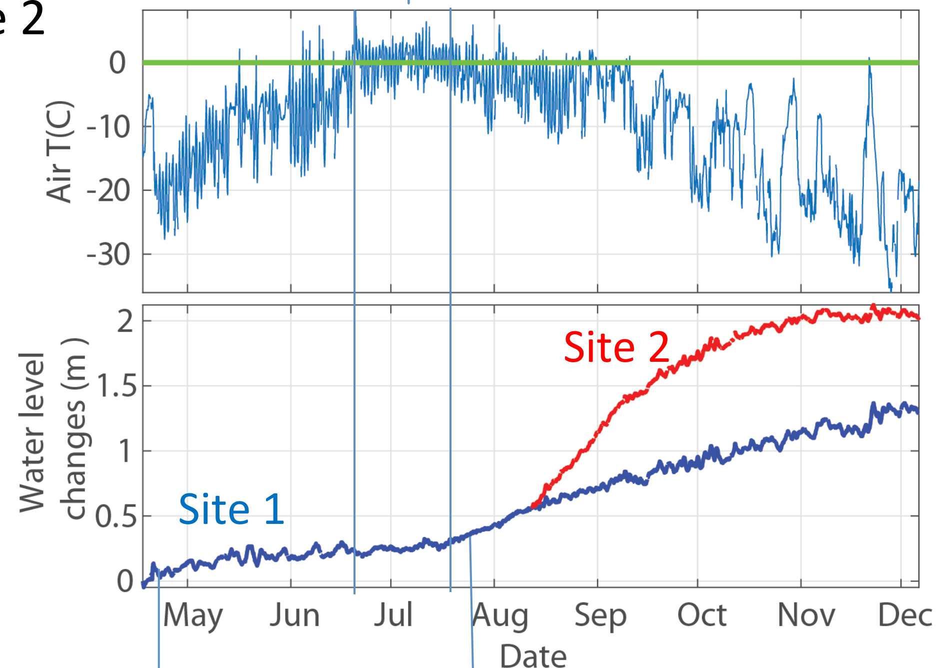


- Fast densification (1 m of surface lowering)
- Different aquifer thicknesses (+5 m for site 2)
- Firn/ice transition at ~ similar depths (clear ice at 35 m)
- Temperate to colder ice transition at ~ 50 m

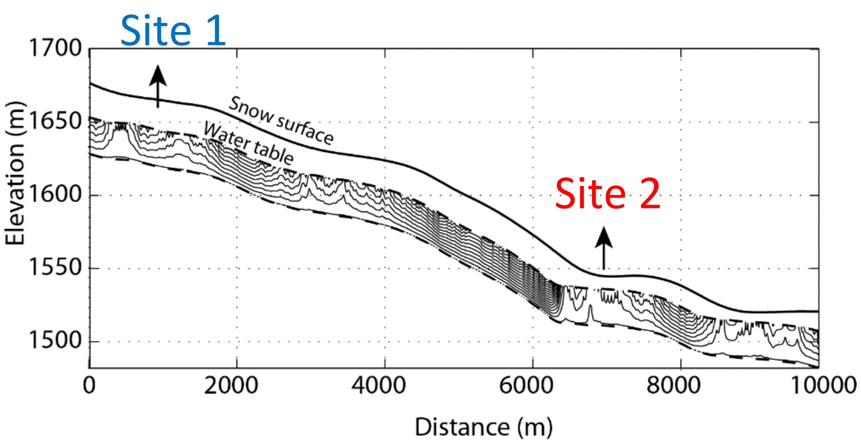
Stratigraphy:
Firn – ice layers – clear ice
bubbly ice – Transition

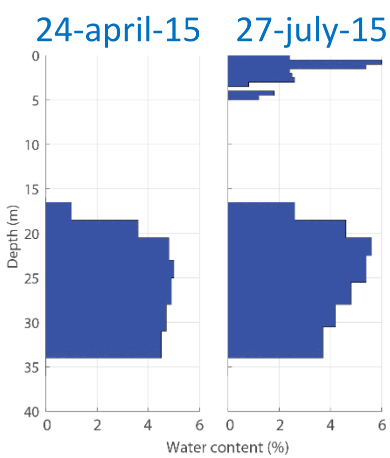
Water level changes since mid-april, 2015:

1 month for meltwater to reach aquifer



Flowlines simulated at steady state: a potential for higher local discharge at Site 2





Recharge of 5cm (at steady state)

Recharge of 3cm (specific yield of 0.09)

⇨ 2 independent recharge estimates agree

Level changes after melt season's end

Take-home points:

- Firn-aquifer earlier evidence dates of 1993
- Aquifer expansion past 2008 due to increase surface melt
- Water volume ranges between 200 and 1500 kg m^{-2} spatially
- Seasonal recharge delayed by 1 month to bring snow/firn to 0°C.
- Fast densification
- Firn-ice transition observed at ~35 m
- Water accumulates at steep-flat transition

Coming work:

- Simulate aquifer formation, lateral water flow
- Characterize and quantify discharge

Thanks for your attention!

Funding:

NSF

Field support:

CH2MHILL Polar Services

air greenland

109th AIRLIFT WING

Radars and GPS:

CReSIS Center for Remote Sensing of Ice Sheets

UNAVCO