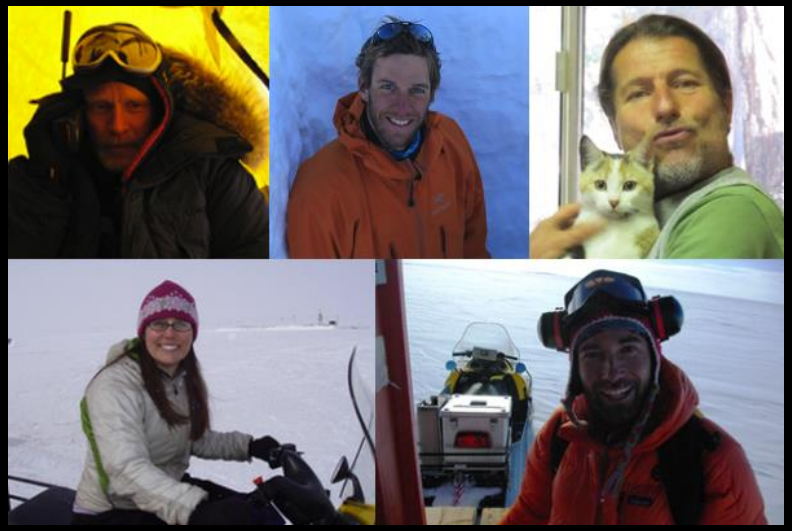
The Greenland Firn Aquifer: Discovering englacial water storage and motion

Lora S. Koenig[1], Clément Miège[2], Richard R. Forster[2] and Ludovic Brucker[3]

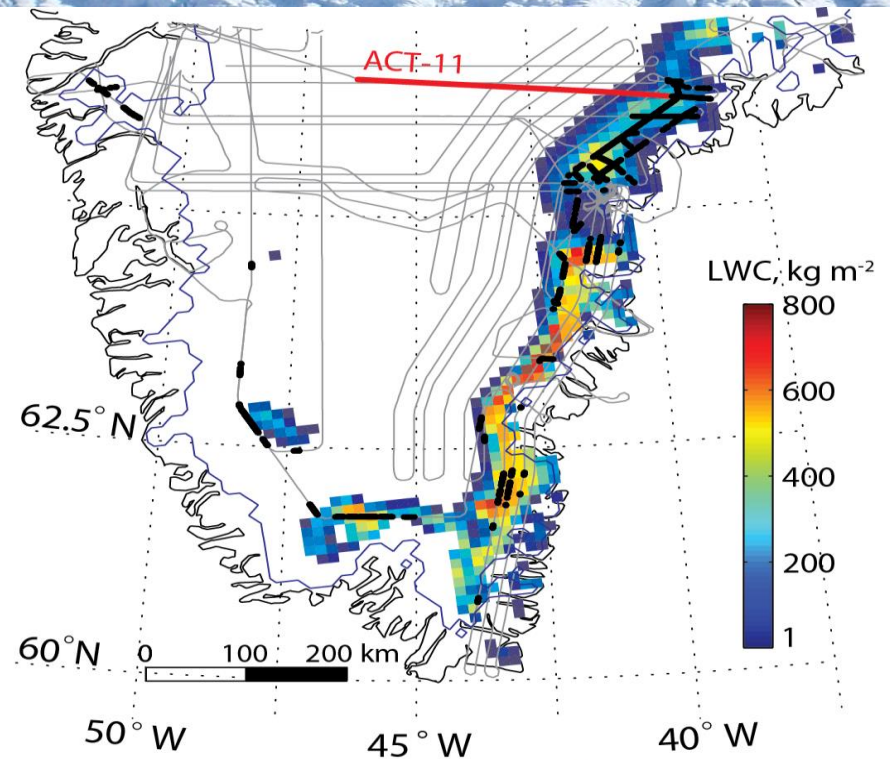


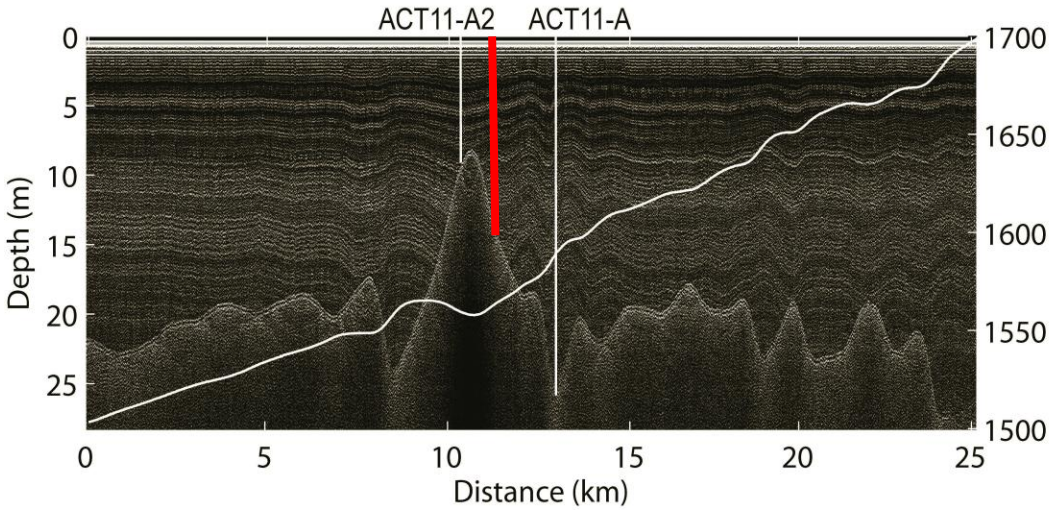
[1]NSIDC, University of Colorado
[2]University of Utah
[3]NASA GSFC, Universities Space Research Association

February 2, 2015

NSIDC
National Snow and Ice Data Center
University of Colorado Boulder

2011 Aquifer Observed and Modeled

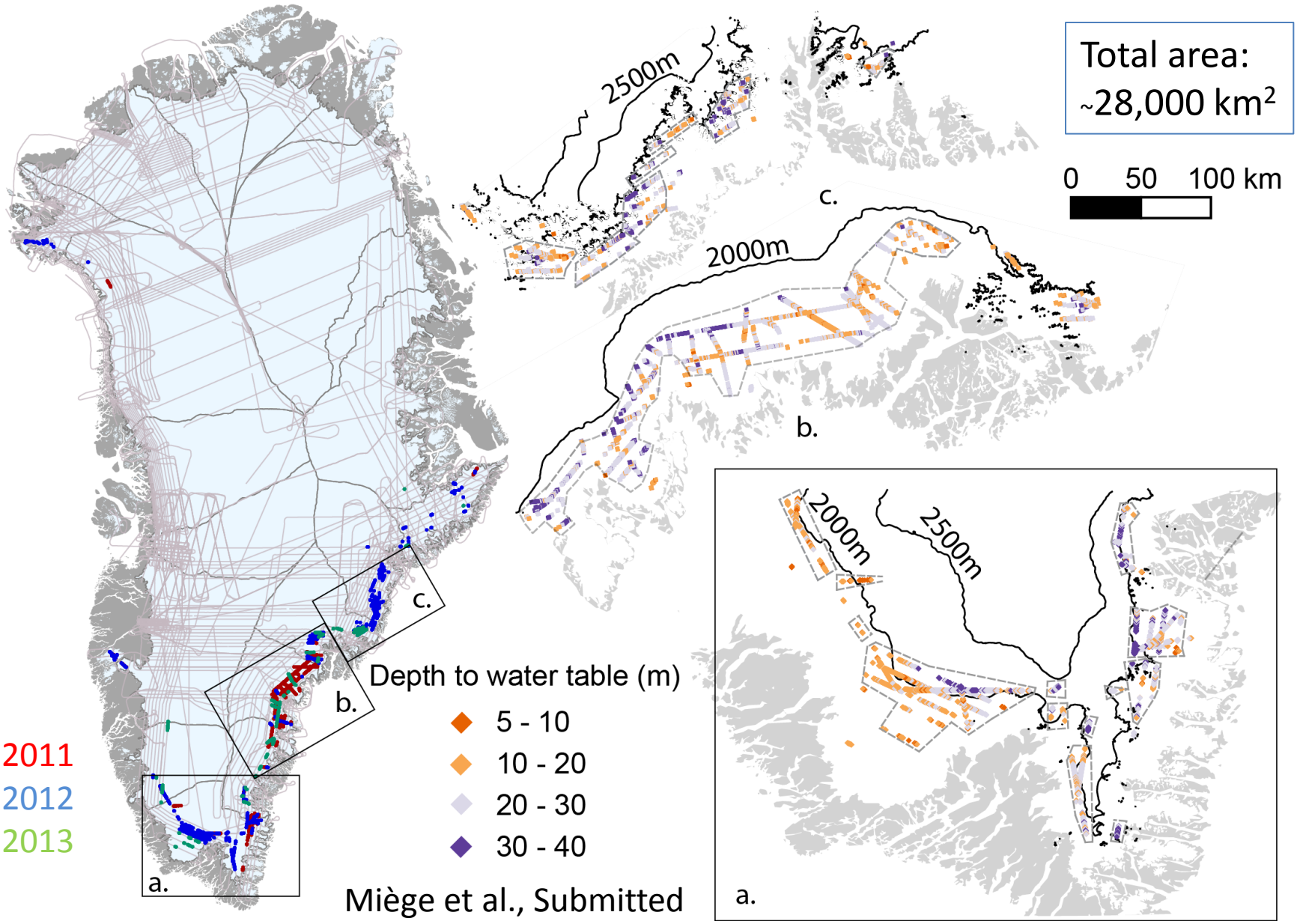




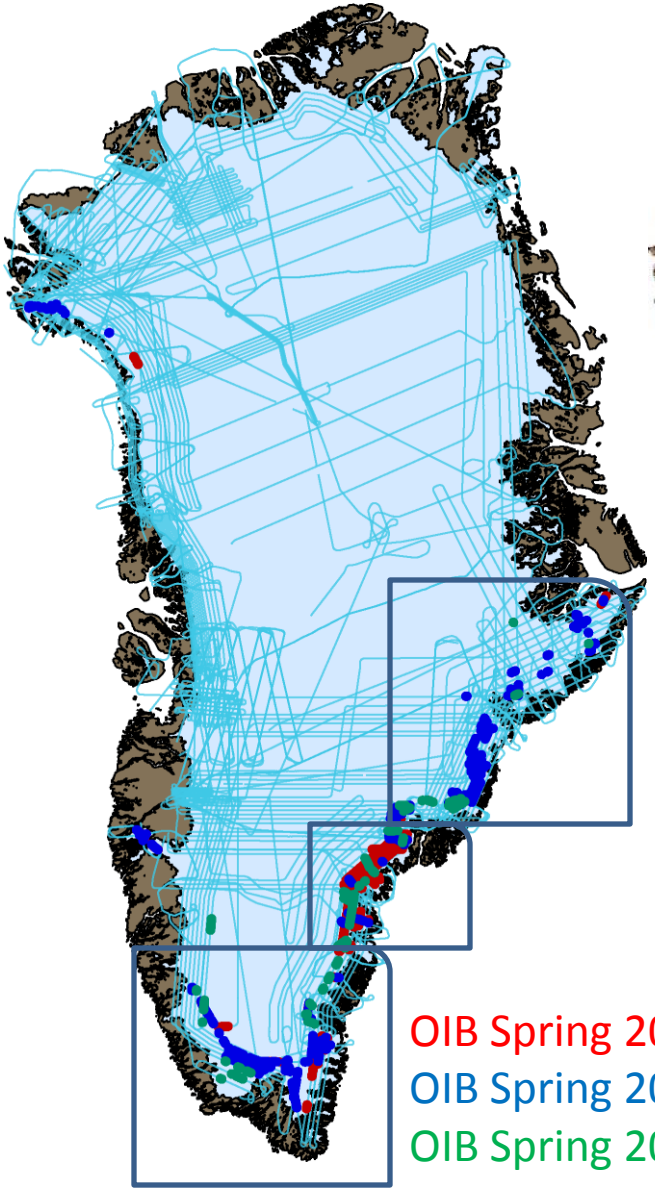
- First discovered 2011 ACT11-A2 core 1559 m
- Modeled Area: 70 ± 10 x 10^3 km^2
- Water persists through the winter
- Mapped with OIB radar

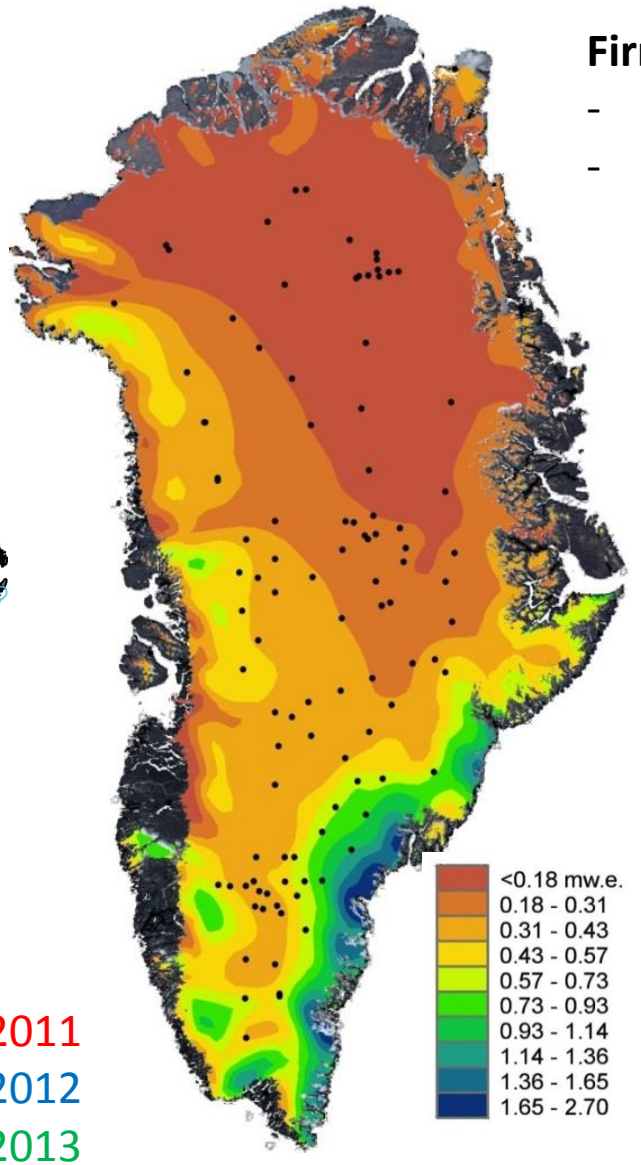
Forster et al., 2014

Firn aquifer mapped for three OIB campaigns (2011-2013)



Firn aquifer related to high accumulation regions

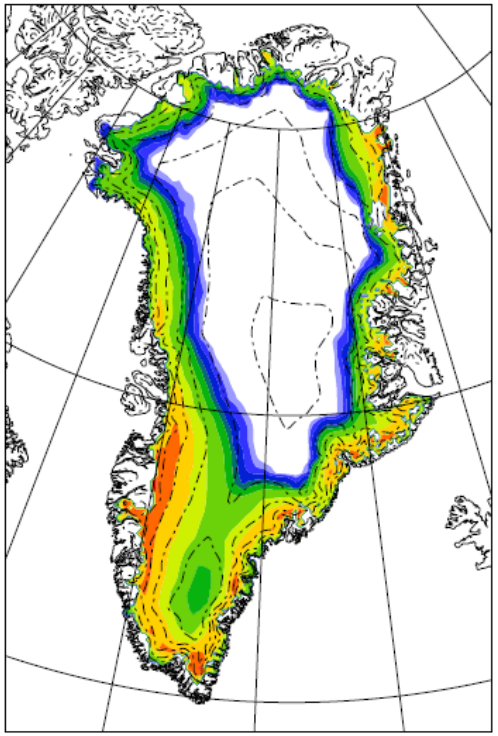




Accumulation map
(Burgess et al., 2010)

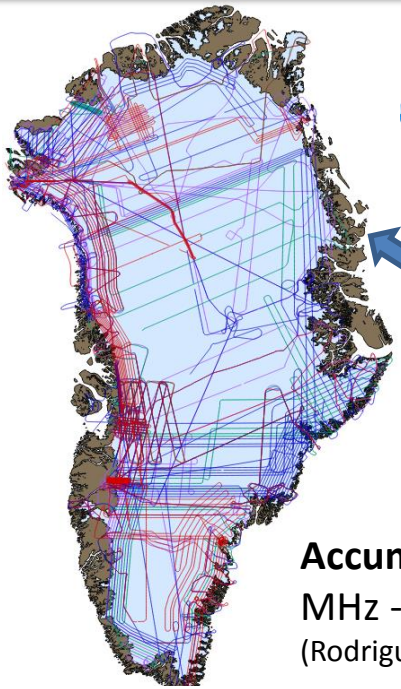
Firn aquifer found in:

- High accumulation areas
- Sufficient melt rates



Melt days for May-Aug 2007 from SSM/I
(Van Angelen et al., 2012)

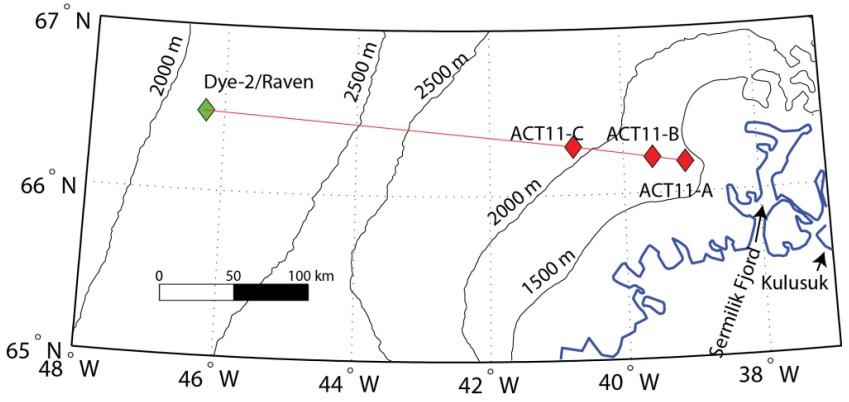
Accumulation Radar on board of NASA Operation IceBridge P-3

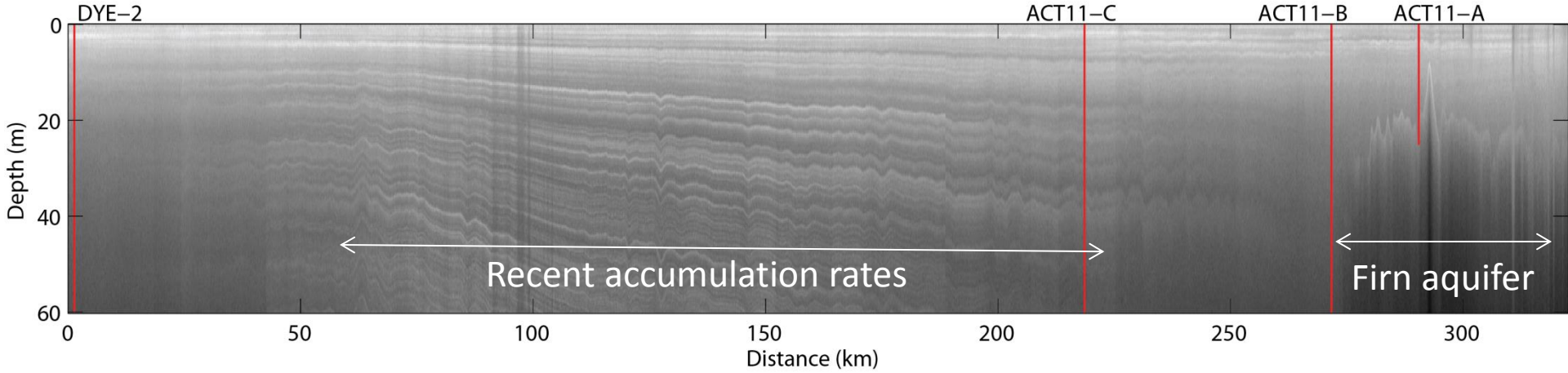


NASA Operation IceBridge (OIB) coverage for 2011-2014

Accumulation radar: Freq. 600 - 900 MHz - 65 cm vertical resolution
(Rodriguez-Morales et al., 2013)

Example of airborne data over the ACT-11 traverse: (Forster et al., 2014)

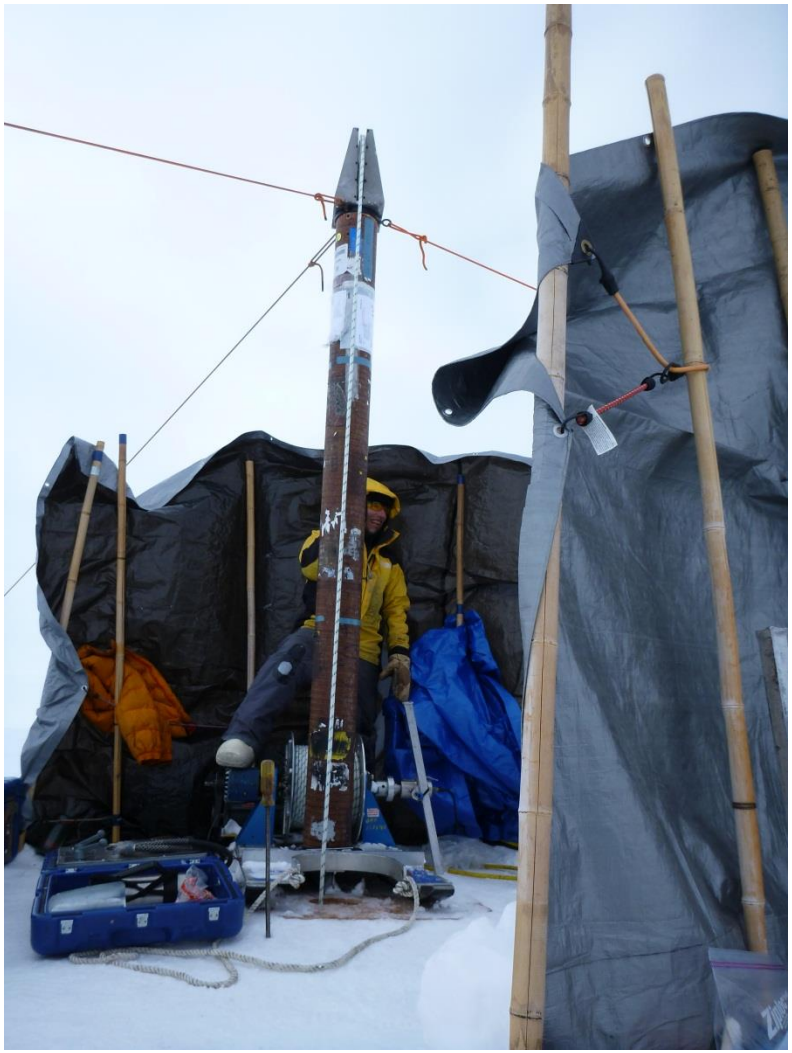




Fieldwork in April 2013

Side winder mechanical drill (for cold firn)

Electrothermal drill (for wet firn & 0C ice)

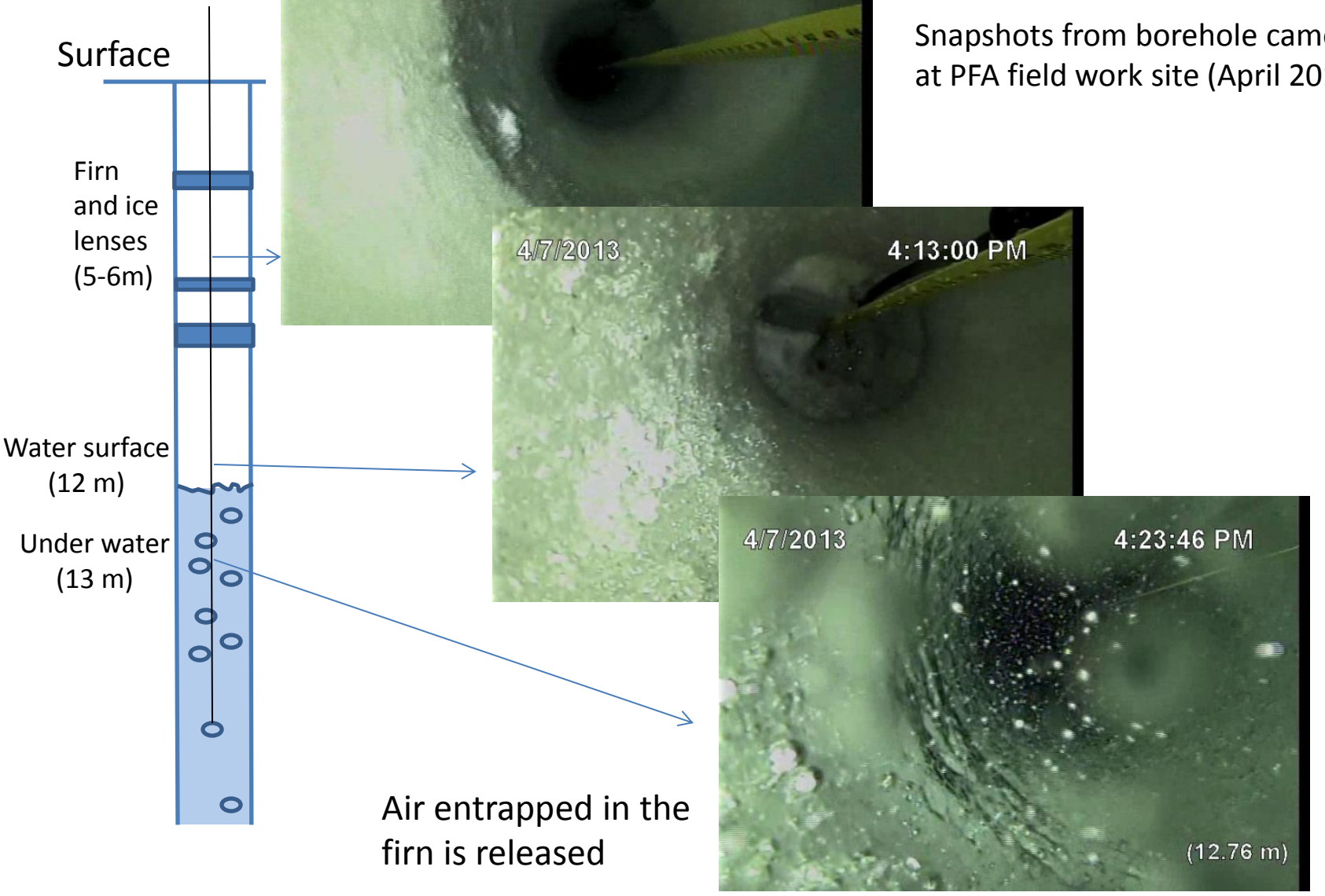


Drills provided by IDDO

Aquifer Borehole Video

Stable water table at 12.2 m ± 0.1, water filled bore hole

Drilling into the firn aquifer



Snapshots from borehole camera taken at PFA field work site (April 2013)

Air entrapped in the firn is released

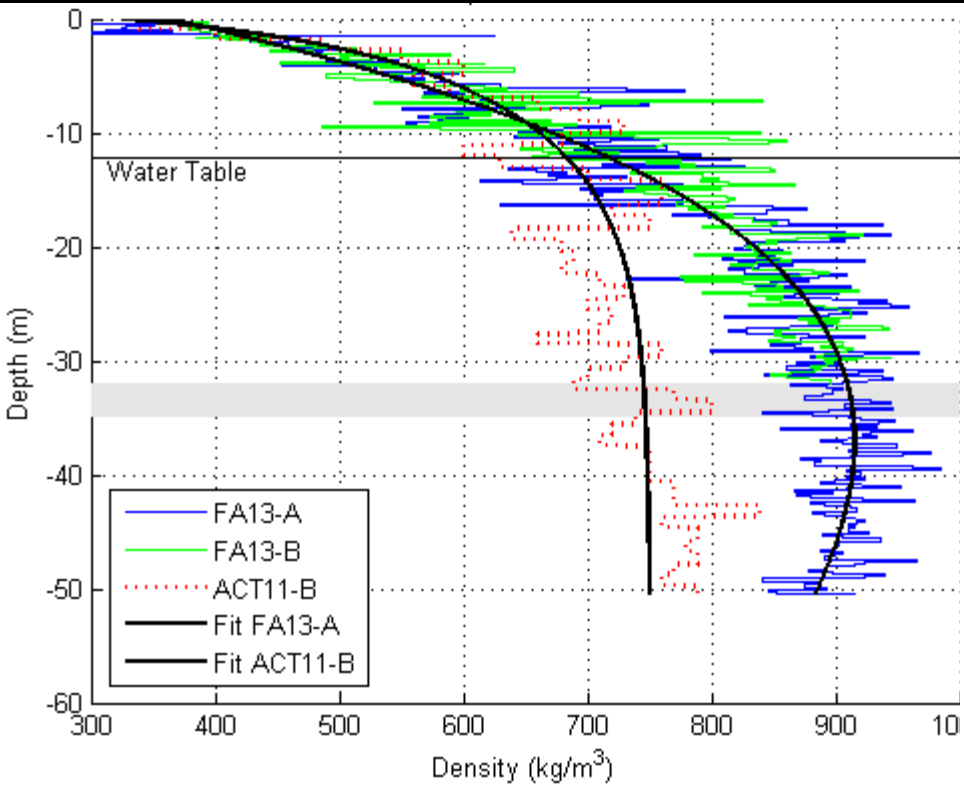
Piping

Water Percolating/Sloshing in Core

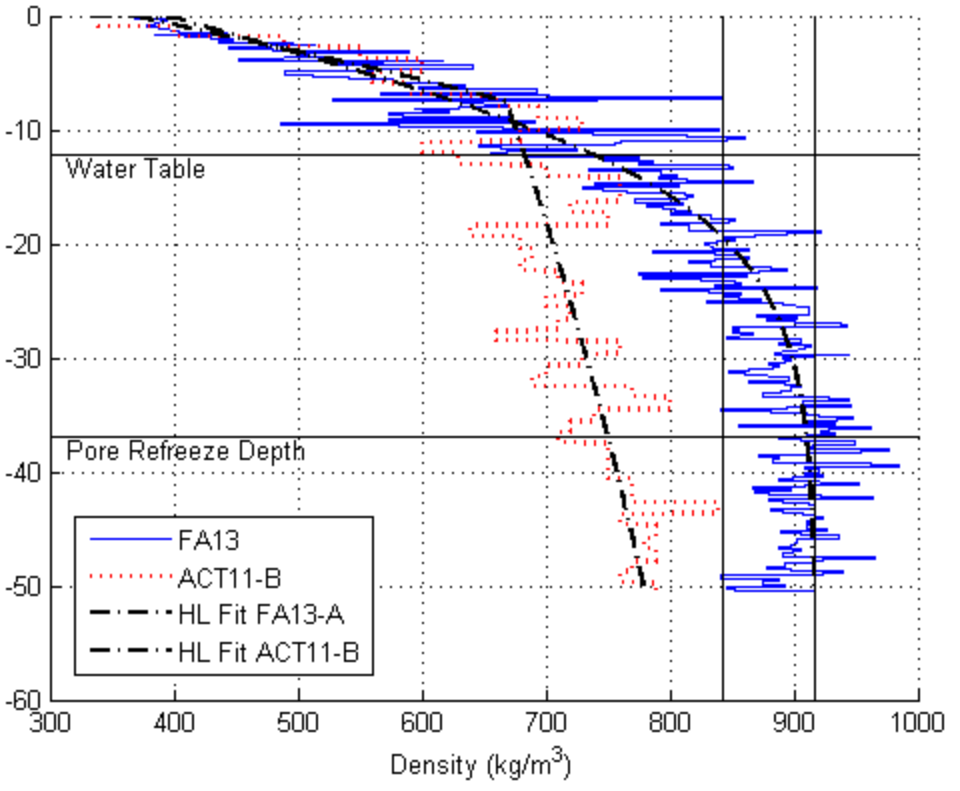
Density Comparison

Water table is
24.7 m thick

Exponential Fit



Modified HL Fit

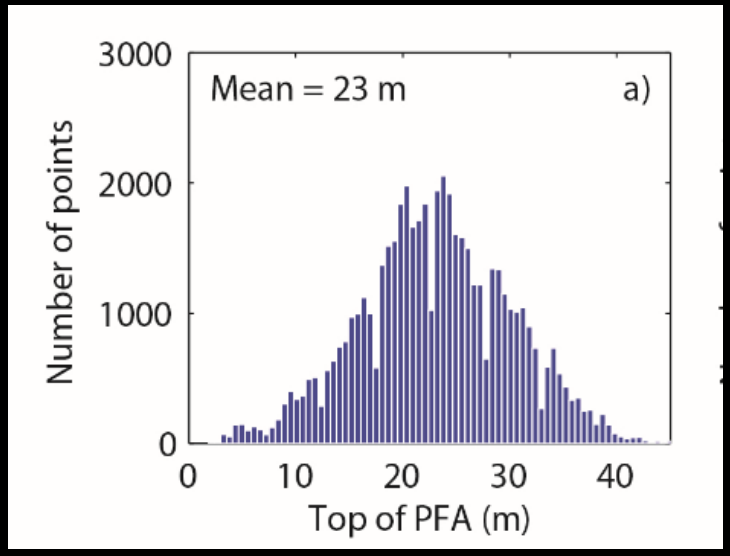


Koenig et al, 2014
Hörhold et al. 2011; Herron and Langway, 1980

Estimating Volume

Assumptions:

- Porosity determined by closest seasonal dry firn core (ACT11B)
- Area of Aquifer: 70 ± 10 x 10^3 km^2
- Density of water: 134 kg/m^3
- Bottom constant : 37 m
- Thickness: 2-σ range of 0 to 28 m, mean 14 m



Forster et al., 2014
Koenig et al., 2014

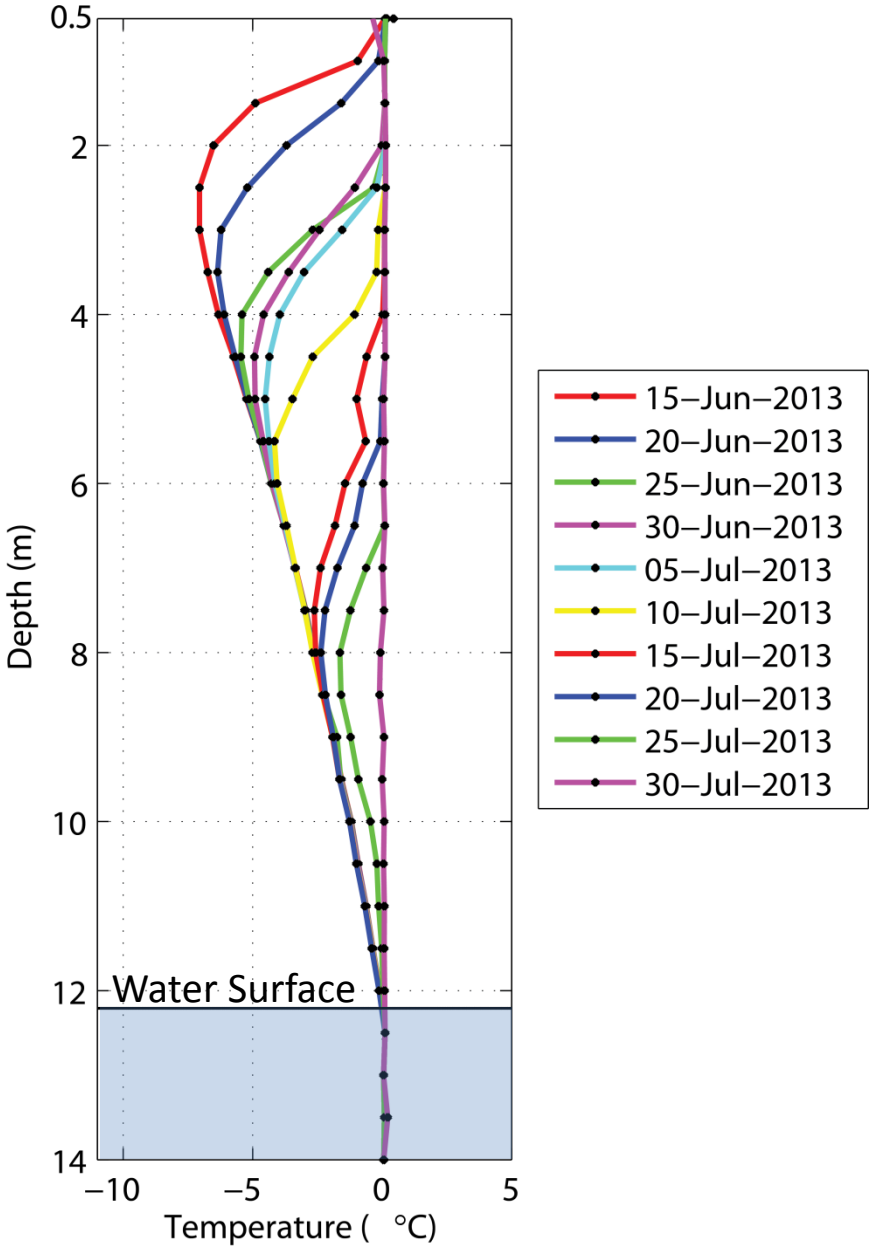
Firn Aquifer Volume:
980 ± 140 km^3

Stored Water:
140 ± 20 Gt or ~0.4 mm of SLR

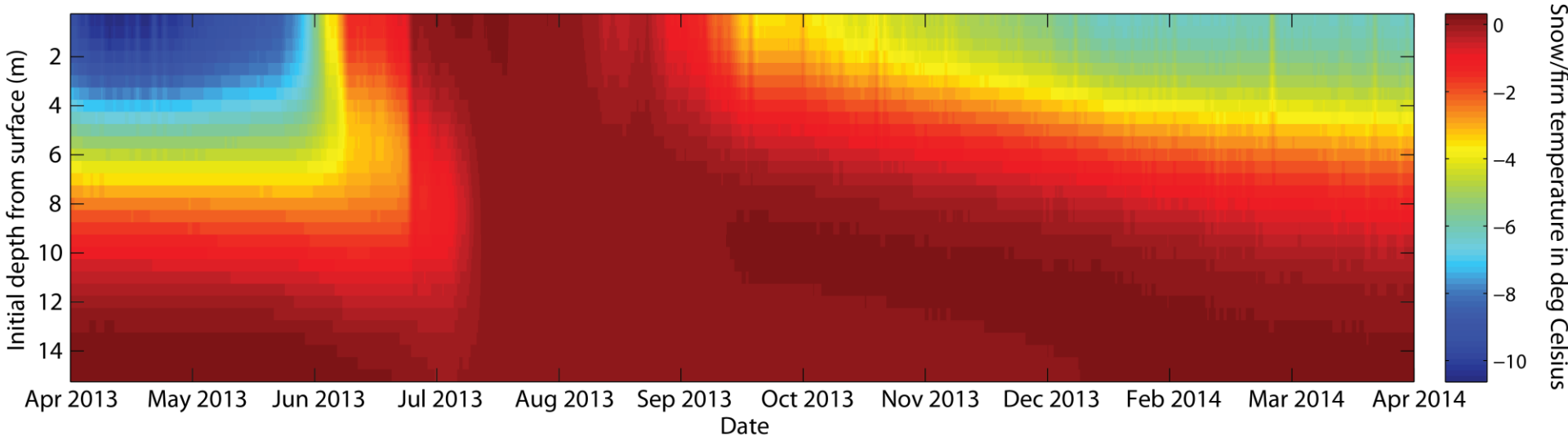
1-D temperature study: Progressive Summer warming

Slow progress of the wetting front from the surface

<u>Dates:</u>
Surface melt onset: June 12
Firn column at 0°C: July 31
Surface < 0°C : Aug 14



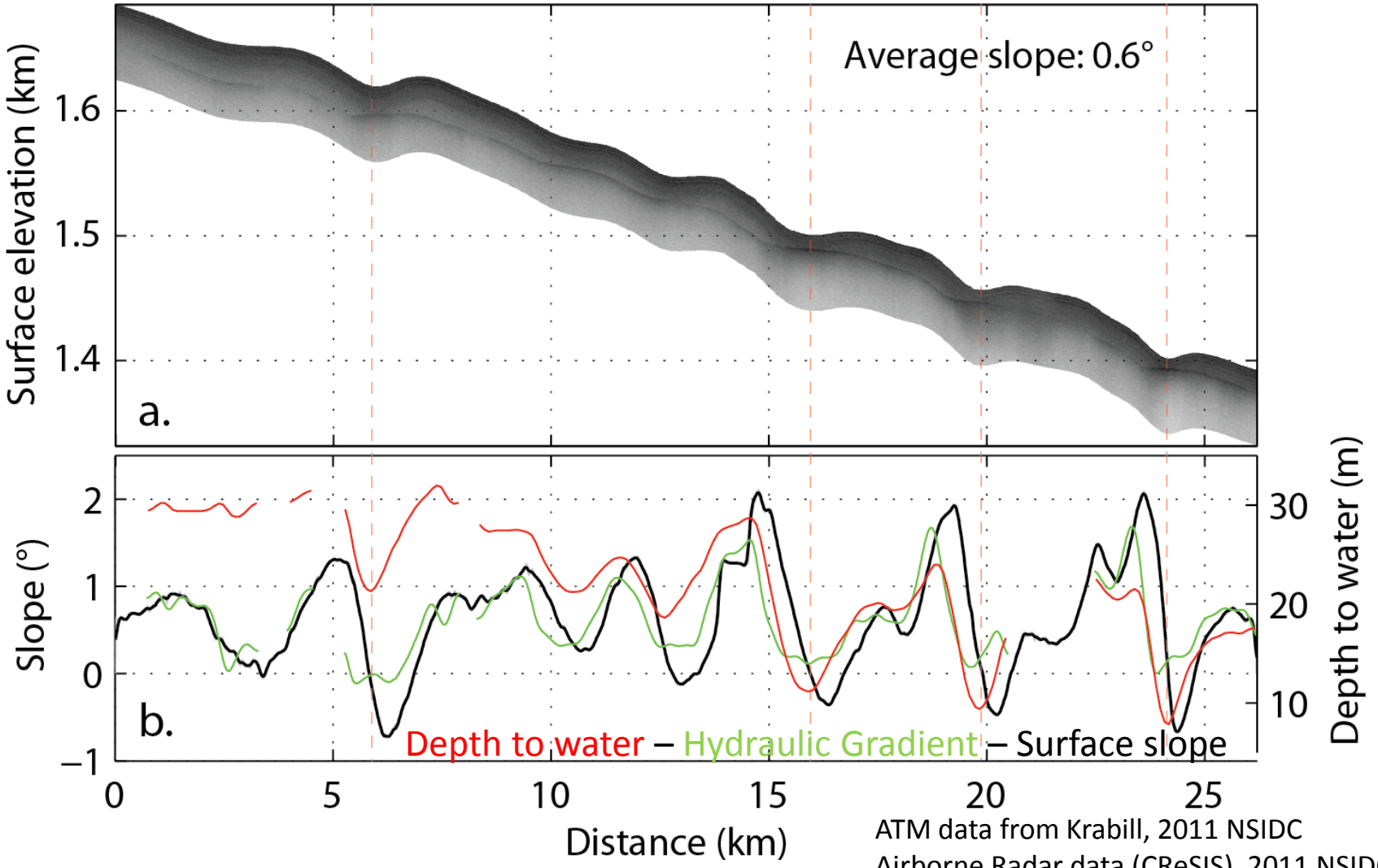
Temperature evolution between April 2013 – April 2014



*Note that the sensor depth is valid for April 2013 and the new snowfall added during the winter are not taken into account here.

Influence of the ice-sheet surface undulations

Water table follows the topography
in an unconfined system



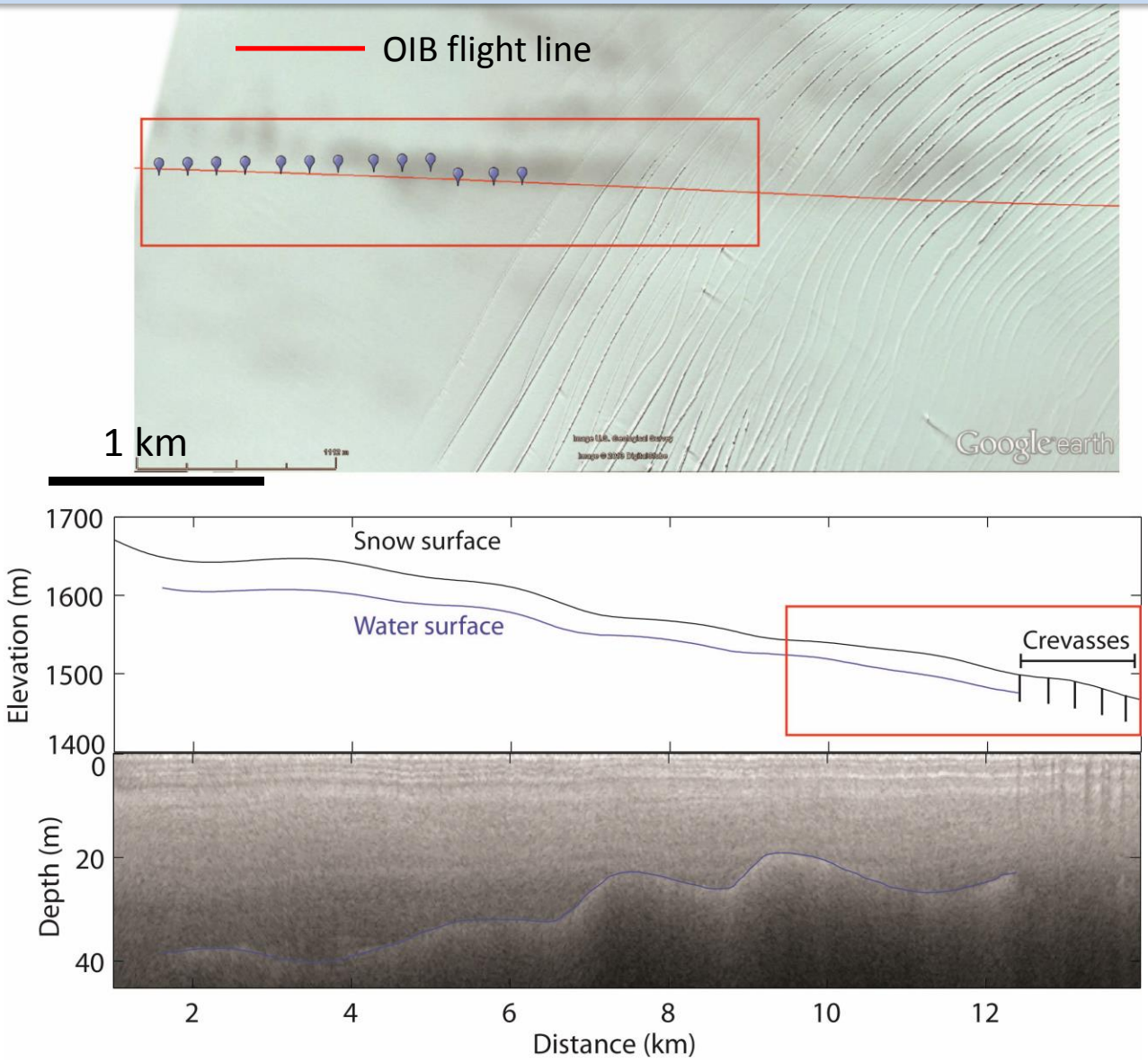
ATM data from Krabill, 2011 NSIDC
Airborne Radar data (CReSIS), 2011 NSIDC

Firn aquifer connection with crevasses

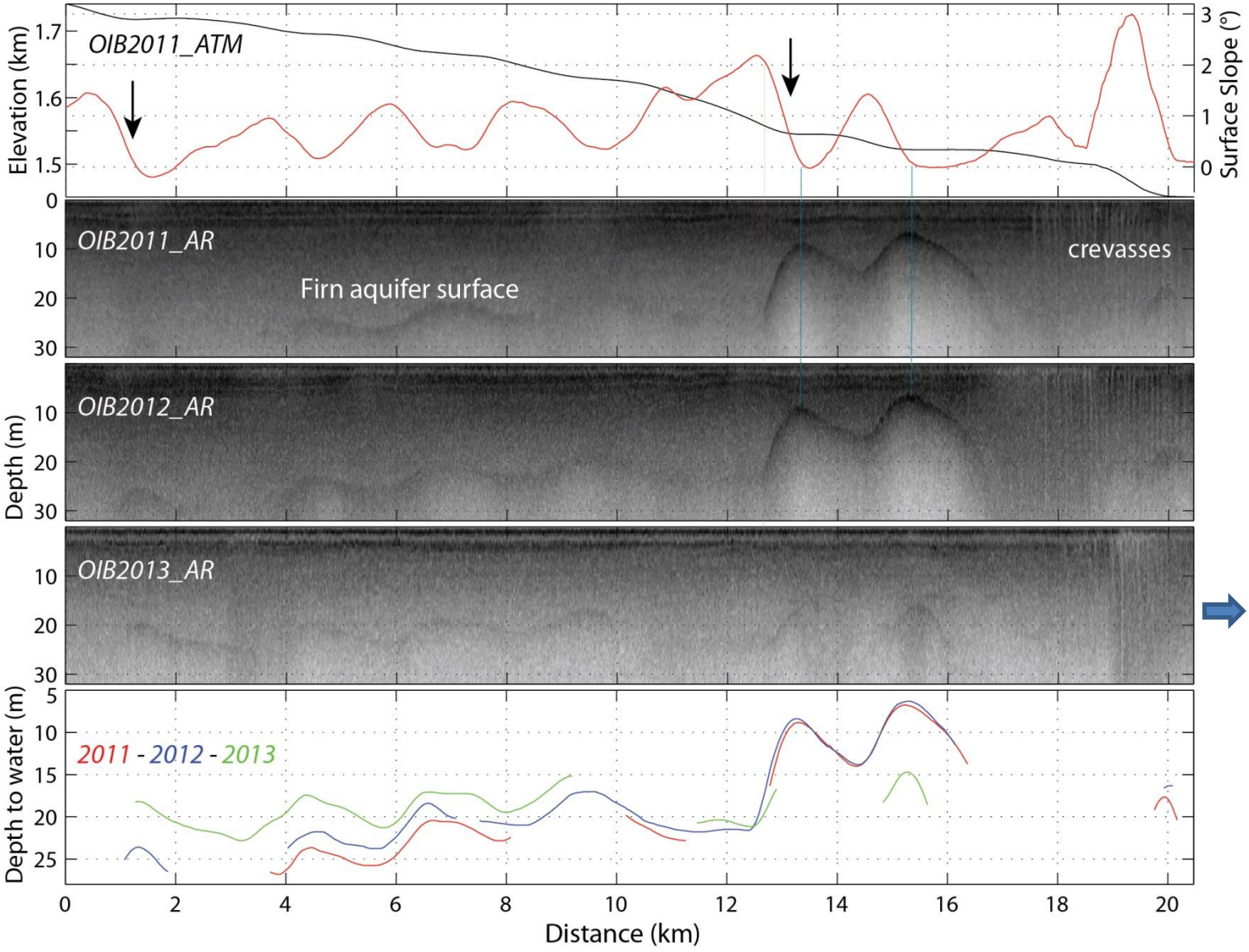
Crevasses observed
- High-res images
- Radar profiles

➡ Marks the end of the aquifer.

Drainage of water is suspected but further investigation is needed to quantify runoff volume and fate of the liquid water



Evolution of the firn aquifer for the upper part of Helheim Gl.

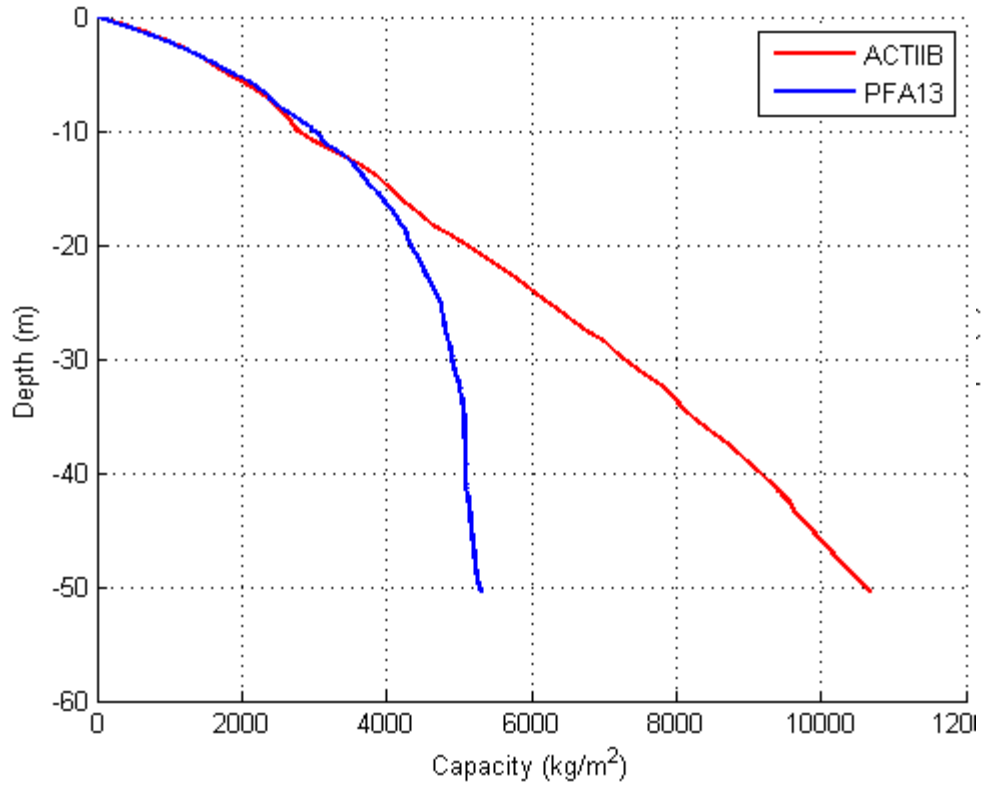


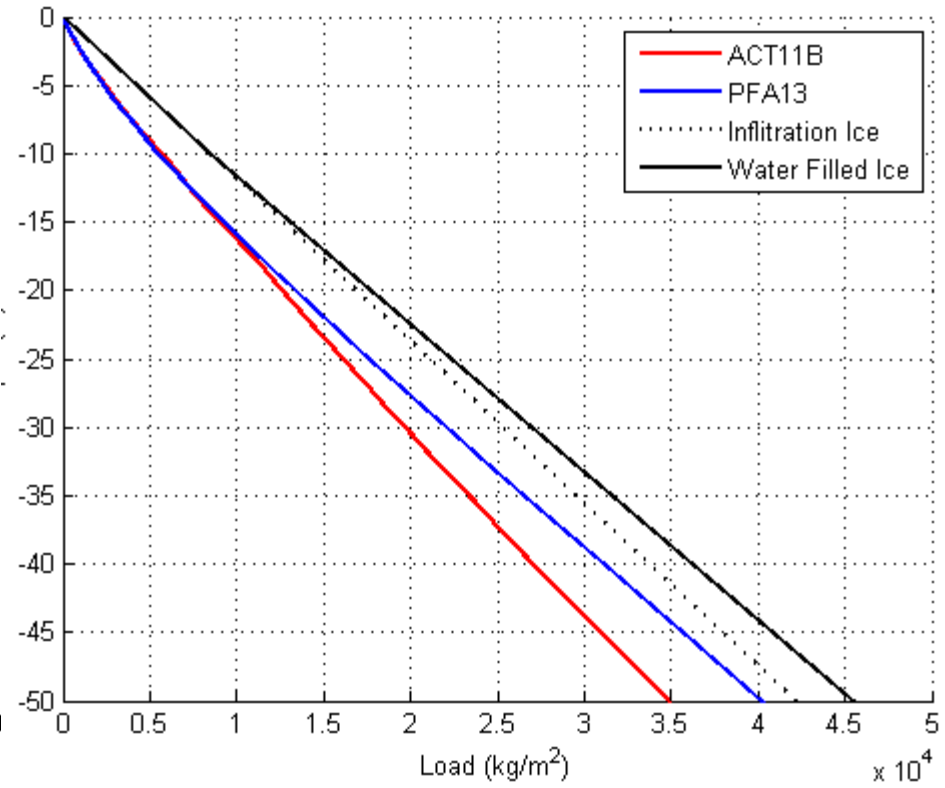
Partial Drainage?

Storage Capacity

Site measured is filled to 50% capacity

Aquifer regions can store 8.9 % more mass than refreezing

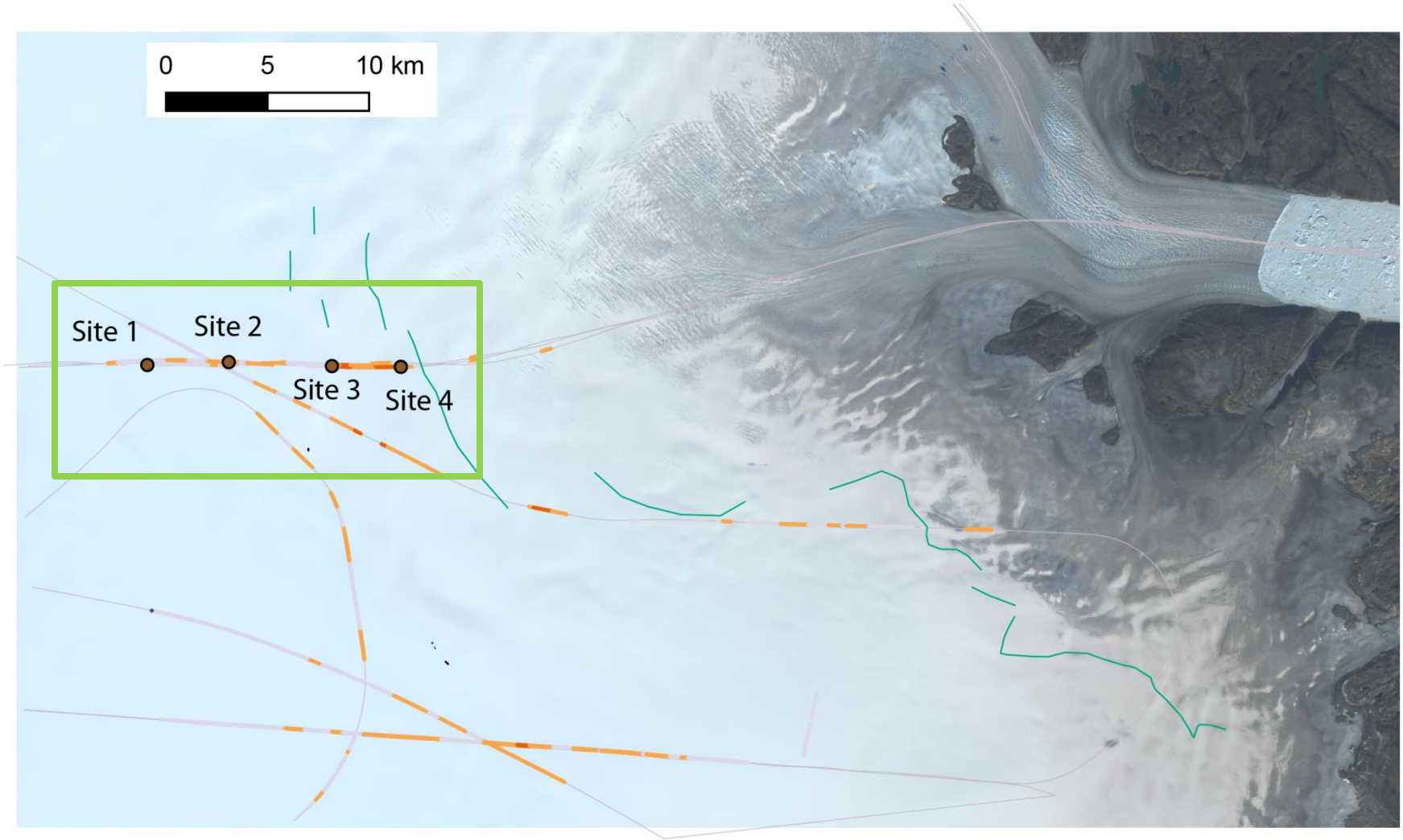




Koenig et al., 2014

Harper et al. 2012

Firn aquifer in the vicinity of Helheim Glacier



Field work location for April – May 2015

Aquifer estimated at ~140 Gt of water, ~0.4 mm of SLR

Two end member hypothesis for Aquifer discharge need further investigation:

1) Stored water connected to a well established englacial hydrologic system (seasonally discharging).
2) Stored water fills over long time scales and then drains catastrophically.

Likely both contribute and more work /measurements are needed to further constrain this new glacier facies

Acknowledgements:
Susan Zager and the PFS team and J. Kayne and the IDDO team for drilling support.
NSF grant #1311655 and the NASA Cryospheric Sciences, NIP and ESS programs.