AGENDA 6-11-2021

U.S. Scientific Traverses on the Greenland Ice Sheet: a Planning Workshop

Friday June 11, 2022 via Zoom

Sponsors: U.S. Ice Drilling Program & Summit Science Coordination Office

Conveners: Joerg Schaefer, Mary Albert, Jason Briner, Zoe Courville

All times are Eastern zone

Opening Remarks

11:00 Welcome and workshop charge: Joerg, Jason, Mary & Zoe

11:05 NSF Remarks: Jen Mercer

Compelling science questions needing ground-based measurements on the GIS: short presentations

11:15 The ice sheet bed: GreenDrill and more– Joerg Schaefer and Jason Briner

11:25 Ice core evidence of past conditions – Erich Osterberg

11:35 Surface mass balance – Bob Hawley

11:45 Hydrology – Winnie Chu

12:00 Ice sheet surface processes - Brooke Medley

12:10 Drilling technology – Tanner Kuhl

12:20 Q&A and Discussion

12:45 BREAK: 15 minutes

Future science questions requiring a scientific traverse on the GIS: 5-minute 'pitches'

1:00 Pitches: 5 minutes for each presentation: what, why, where

- **Guy Paxman**: Paleo-lake basin sediments near Camp Century: a target for future seismic reflection surveying and/or subglacial drilling
- **Joe MacGregor**: Opportunities for surface sampling and ground-based geophysics across the Greenland Ice Sheet
- **Greg Balco:** Cosmogenic-nuclide concentrations in interior Antarctic nunataks preserve a multimillion-year record of ice sheet change. Is there anything like that in Greenland?
- **Zhen-Tian Lu**: 81Kr dating of oldest ice on Greenland
- **Knut Christianson:** Multipass profiling radar measurements to map Greenland Ice Sheet englacial velocities
- **Nathan Chellman**: Importance of understanding upstream deposition for flank sites
- **Juliana D'Andrilli**: Deciphering local and regional modern organic signatures across Greenland
- **William Colgan**: Benson 2.0: Multi-season overland traverses from Thule and Kanger to drill a transect of deep temperature profiles in areas where subglacial temperature is unknown.
- **Adrian McCallum**: Cone Penetration Testing (CPT) - a simple and repeatable means of assessing mass balance
- **Ken Mankoff: Snowmobot 1000: A fleet of general-use autonomous snowmobiles**
- **Dorthe Dahl-Jensen:** Ice cores, boreholes, and basal material

BREAK: 10 minutes

2:30 Discussion: identify breakout groups for white papers

3:00 Instructions for breakout groups / generic form for the white papers

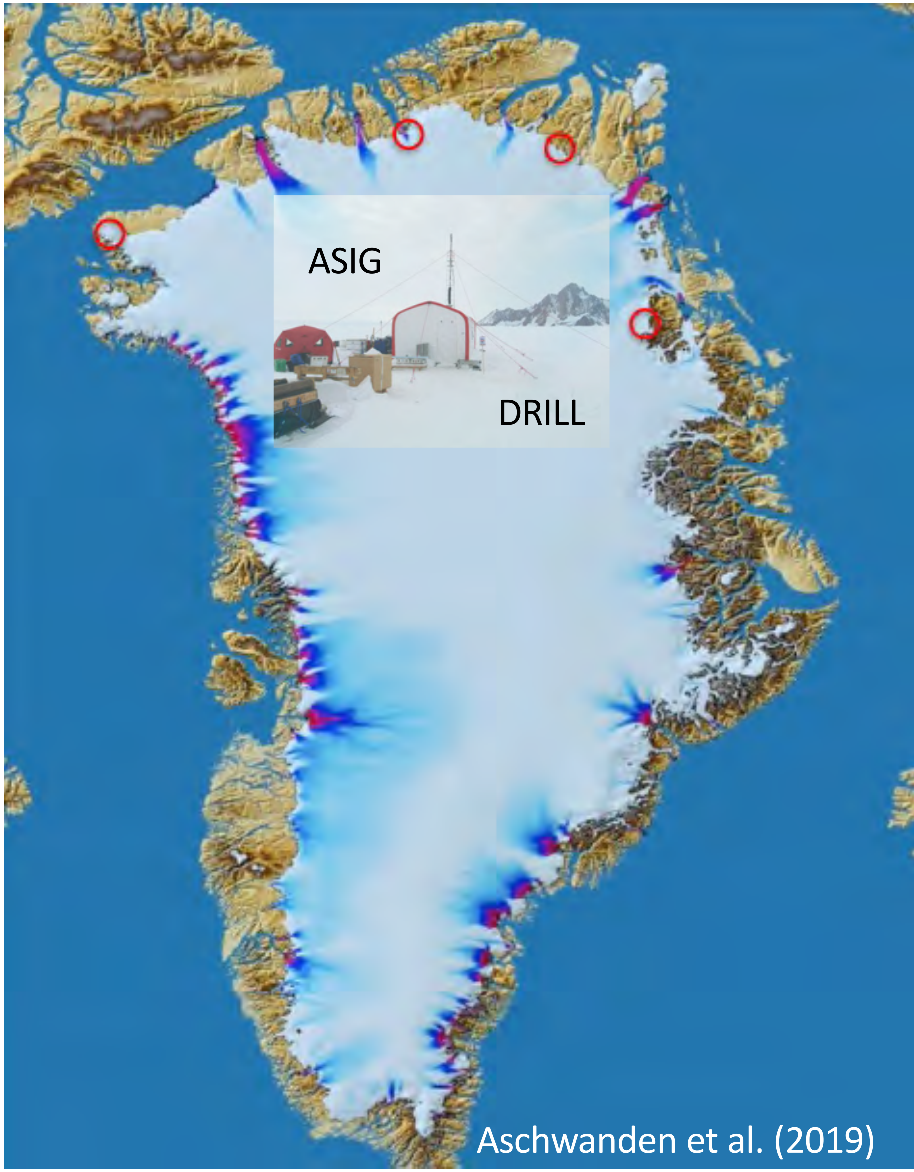
3:10 Breakout group work: outline the white paper content, then make a plan for completing the writing

4:00 Reporting back to the whole group

4:30 Discussion

4:45 Workshop summary, timeline, and instructions for completing the white papers

5:00 Meeting adjourned



GreenDrill (NSF # 1923927)

Collaborative Research: GreenDrill:
The response of the northern Greenland Ice Sheet
to Arctic Warmth- Direct constrains from sub-ice bedrock

Joerg Schaefer (Lamont/Columbia) & Jason Briner (U a Buffalo)

Sridhar Anandakrishnan (Penn State)

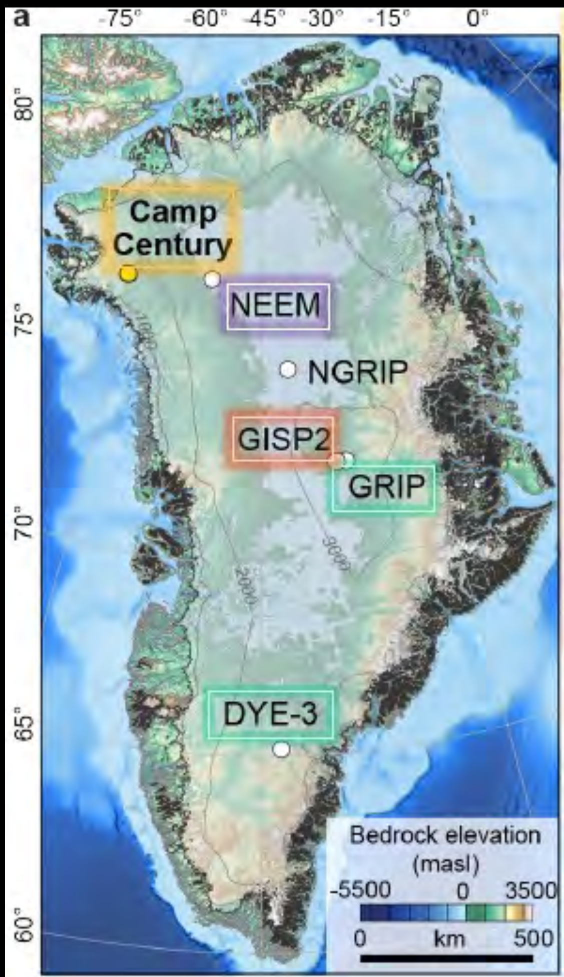
Rob de Conto (U Mass Amherst)

Investigators: Nicolas Young &Gisela Winckler (co PIs, Lamont)
Benjamin Keisling, Allie Balter, Steven Cox, Jacky Austermann,
Margie Turrrin (Lamont)

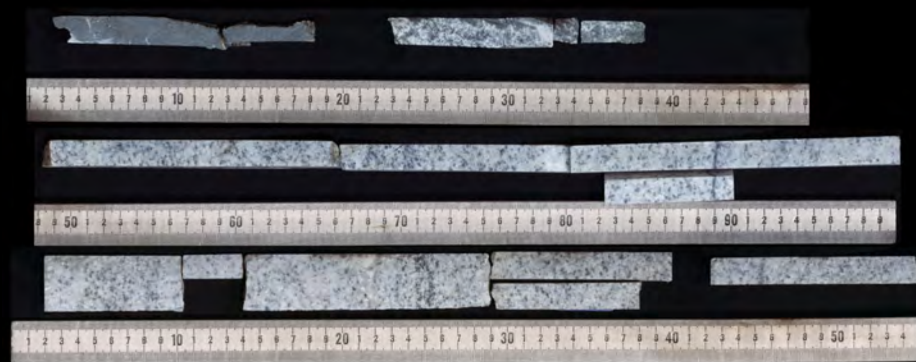
Collaborators: Kurt Kjaer (GEUS, Copenhagen),
Joe MacGregor (NASA), Eduard Bard (CEREGE), Marc Caffee (Purdue),
Alan Hidy (LLNL-CAMS), Ryan Vachon (INSTAAR).

To Greenland – Traverse (GreenT)

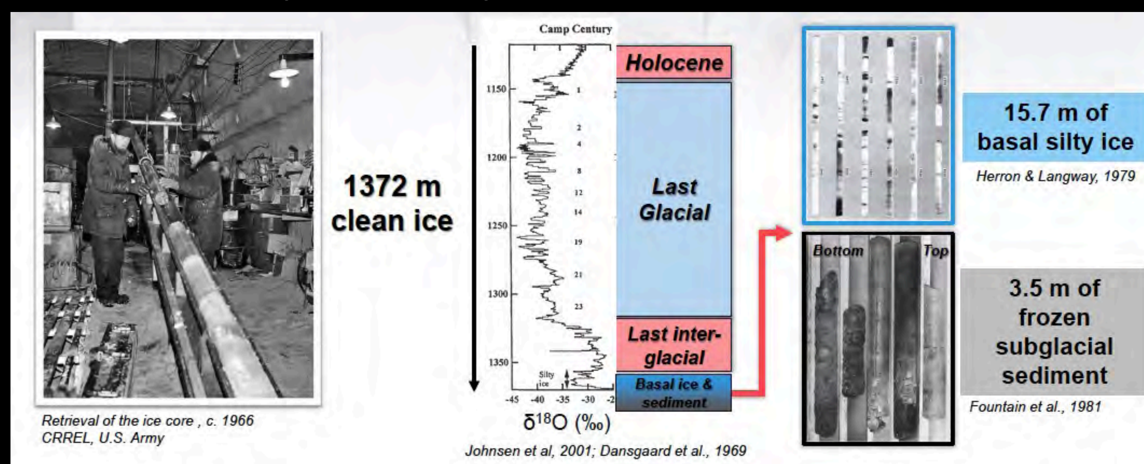
The Greenland Ice Sheet was gone in the recent geologic past – 2 basal tests, same result!



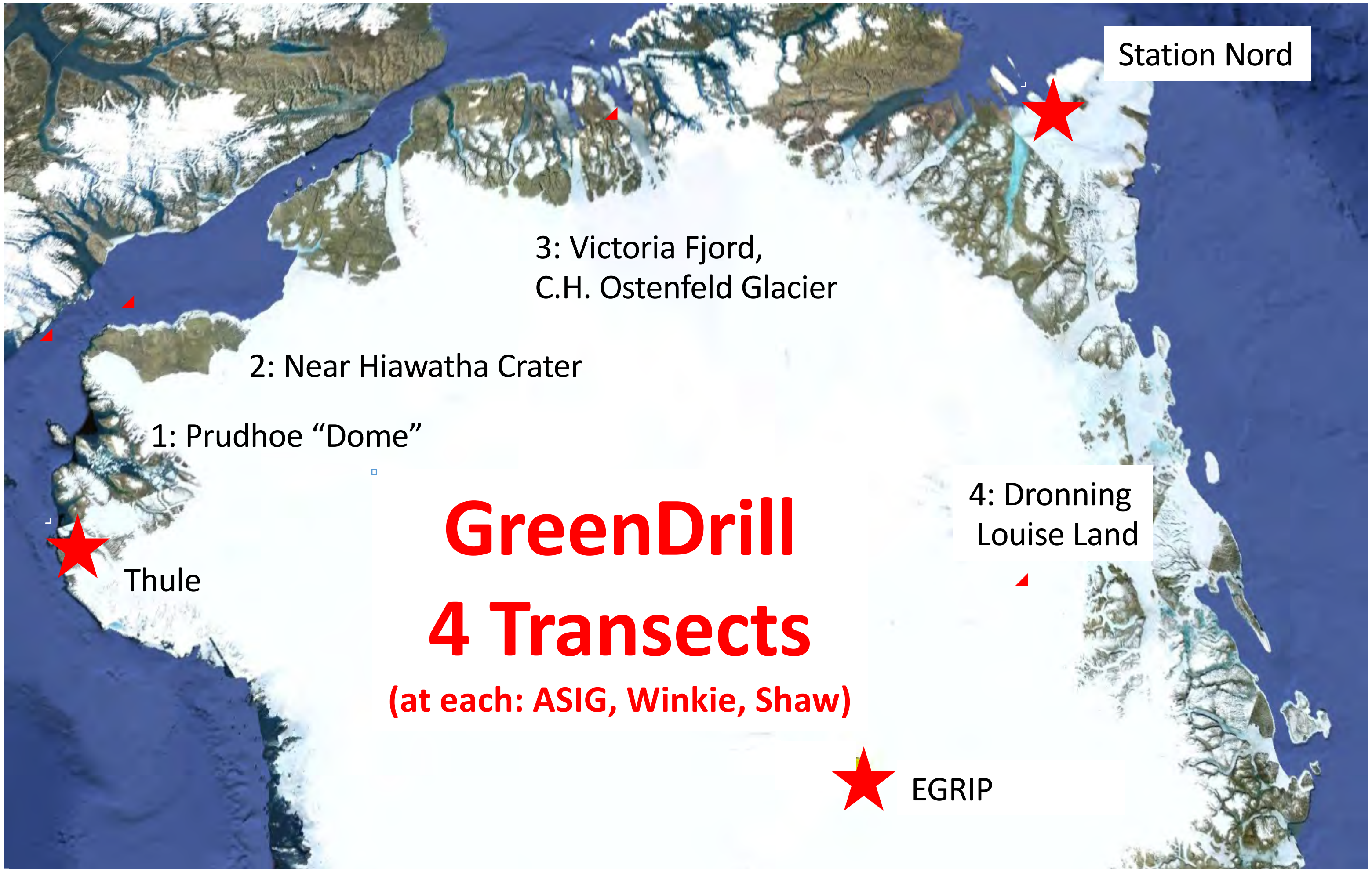
1. The GISP2 Bedrock Core



2. The Camp Century Basal Sediments



Christ et al., 2021



The selected sites check out for bedrock lithology; frozen bed; ASIG >ELA = DC3 landing; ice thickness; Stars = landing strips/stations

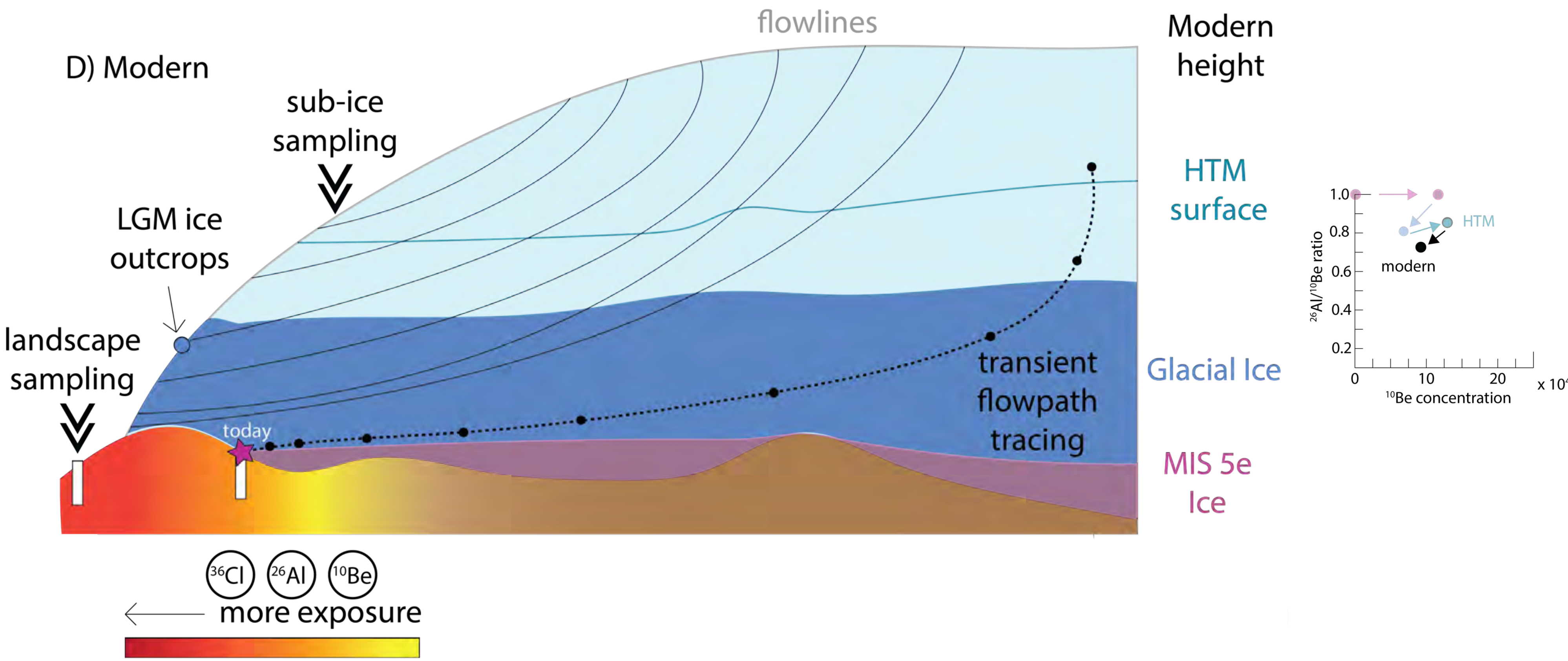
@ transect locations:

AISG Drill site: 500-300 m ice thickness.

Winke Drill site: 100 m ice thickness

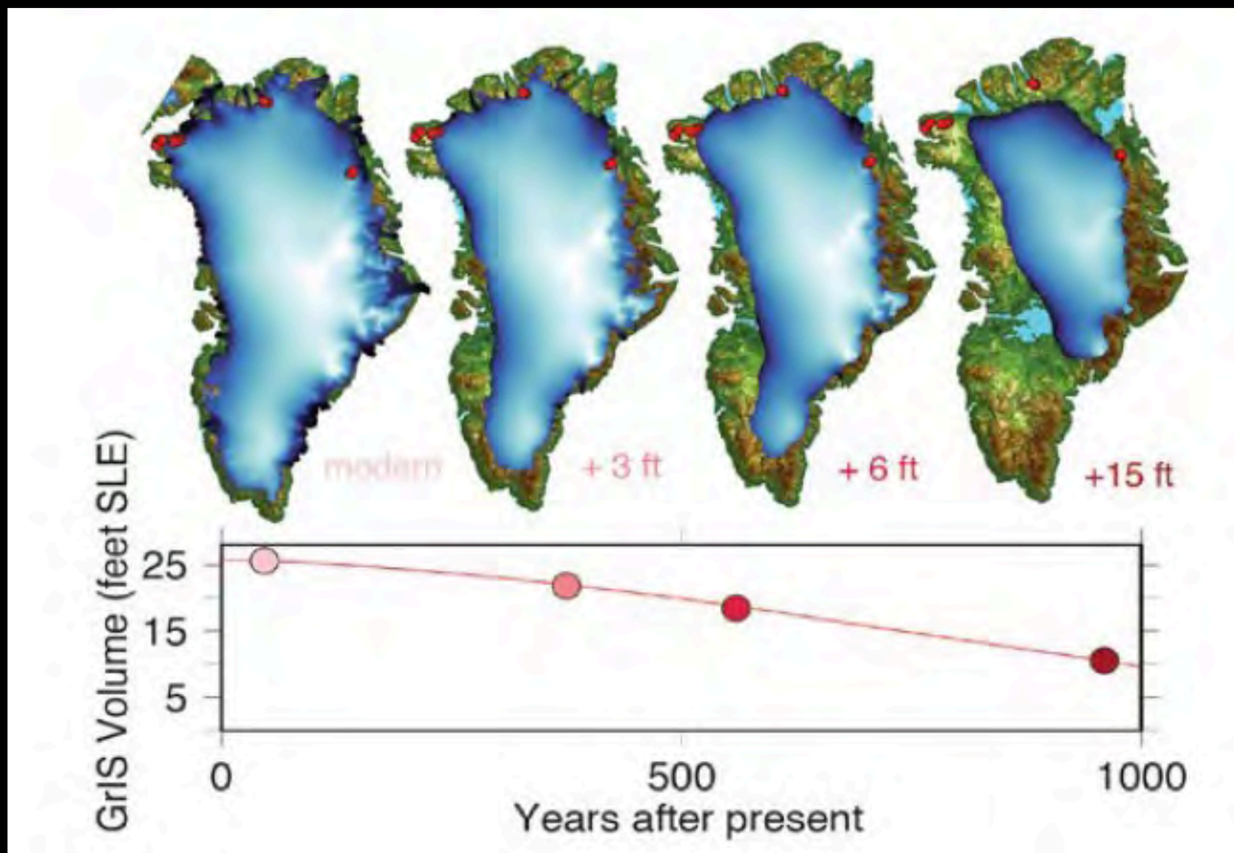
Shaw Drill sites: pro-glacial landscape

We will target 4+ m-long rock cores

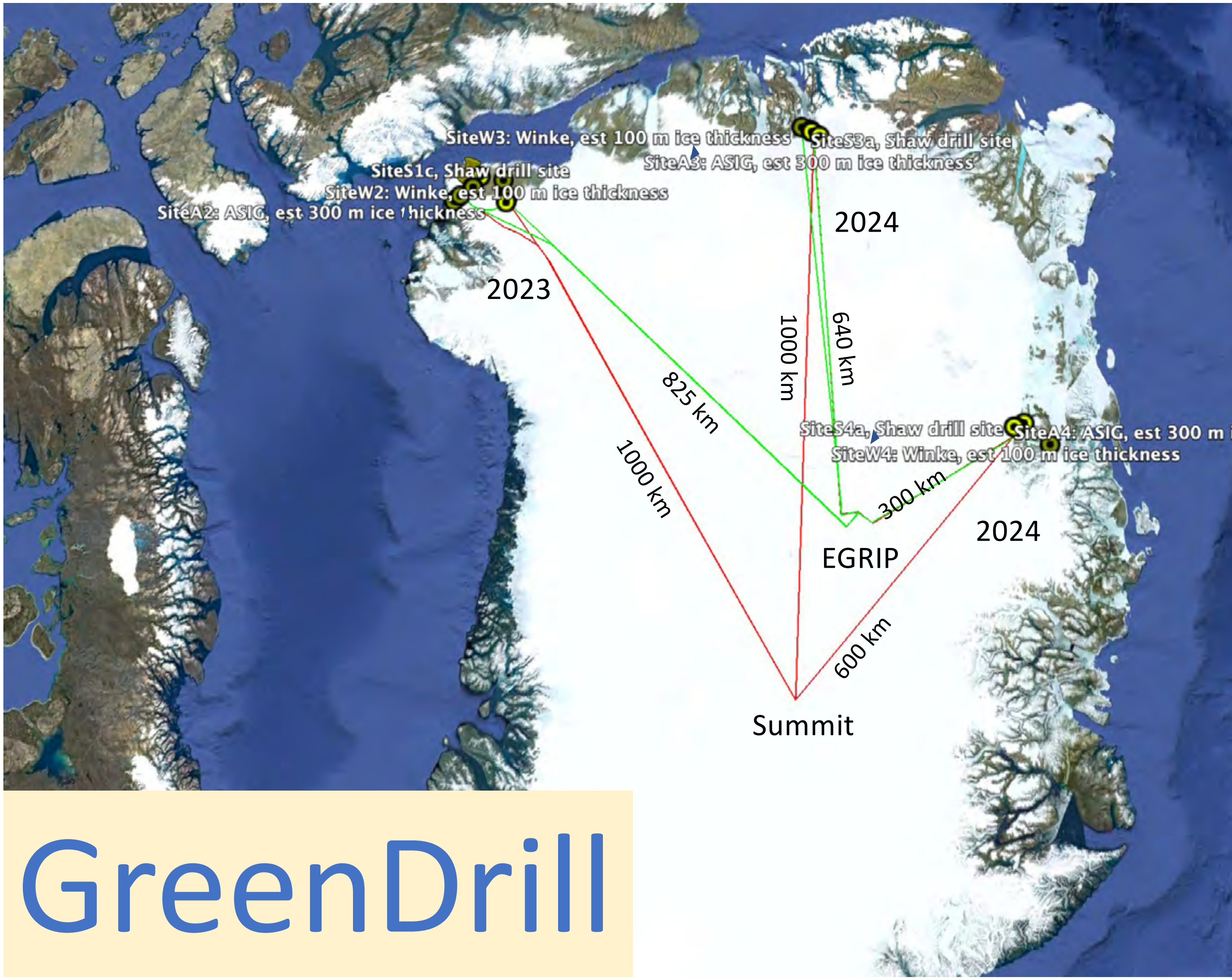


D) Modern
flowlines
Modern height
sub-ice sampling
LGM ice outcrops
landscape sampling
HTM surface
today
transient flowpath tracing
Glacial Ice
MIS 5e Ice
36Cl
26Al
10Be
more exposure
1.0
0.8
0.6
0.4
0.2
0
10
20
x 10^4
26Al/10Be ratio
10Be concentration
HTM
modern

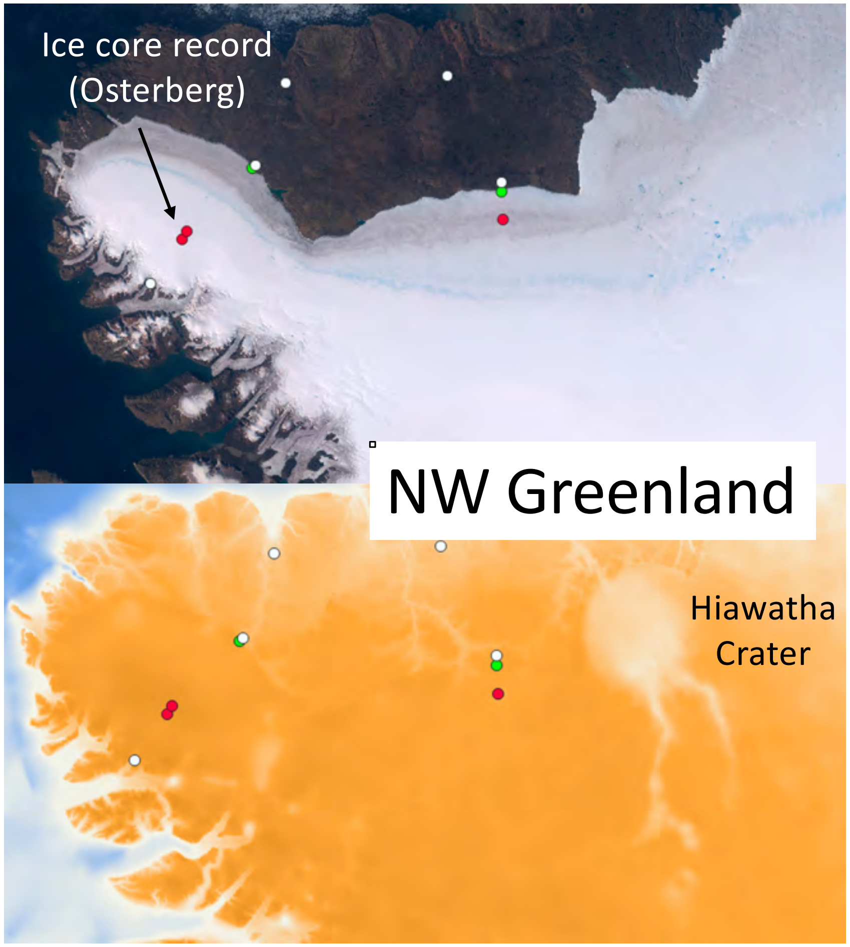
Onward: The critical first 3 feet of SLR from Greenland: Where from?

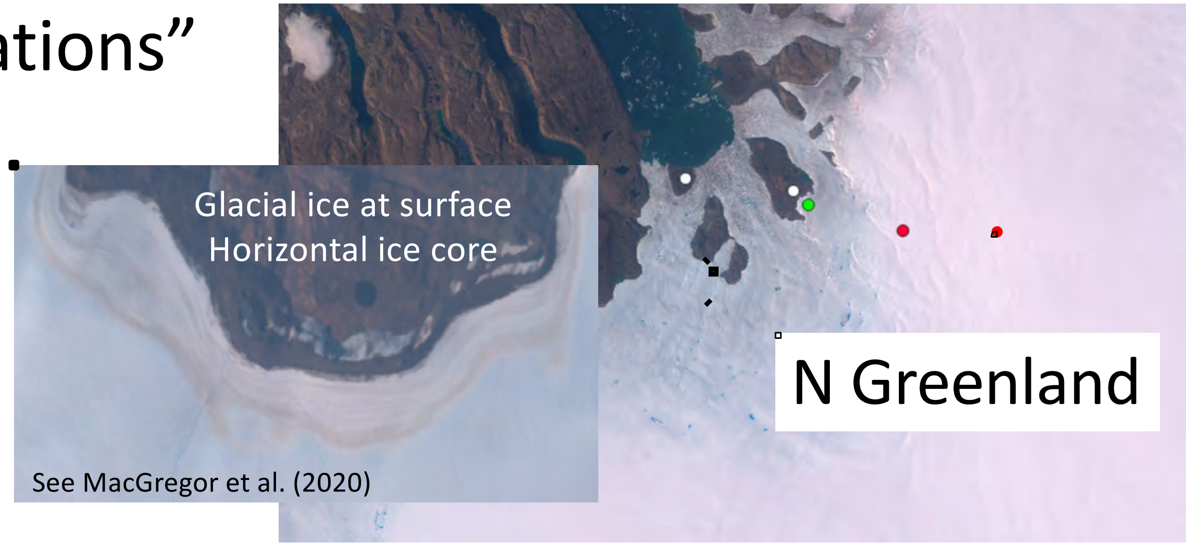


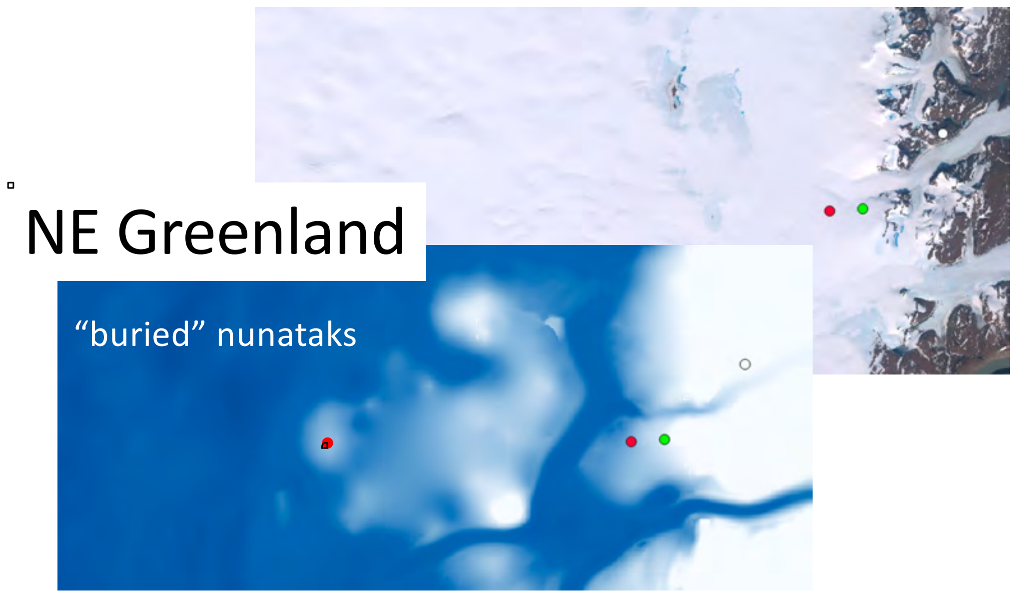
GreenDrill


SiteW3: Winke, est 100 m ice thickness
SiteS3a, Shaw drill site
SiteA3: ASIG, est 300 m ice thickness
SiteS1c, Shaw drill site
SiteW2: Winke, est 100 m ice thickness
SiteA2: ASIG, est 300 m ice thickness
2024
2023
1000 km
640 km
825 km
1000 km
SiteS4a, Shaw drill site
SiteA4: ASIG, est 300 m i
SiteW4: Winke, est 100 m ice thickness
300 km
2024
EGRIP
600 km
Summit

GreenDrill: “Base of Operations”





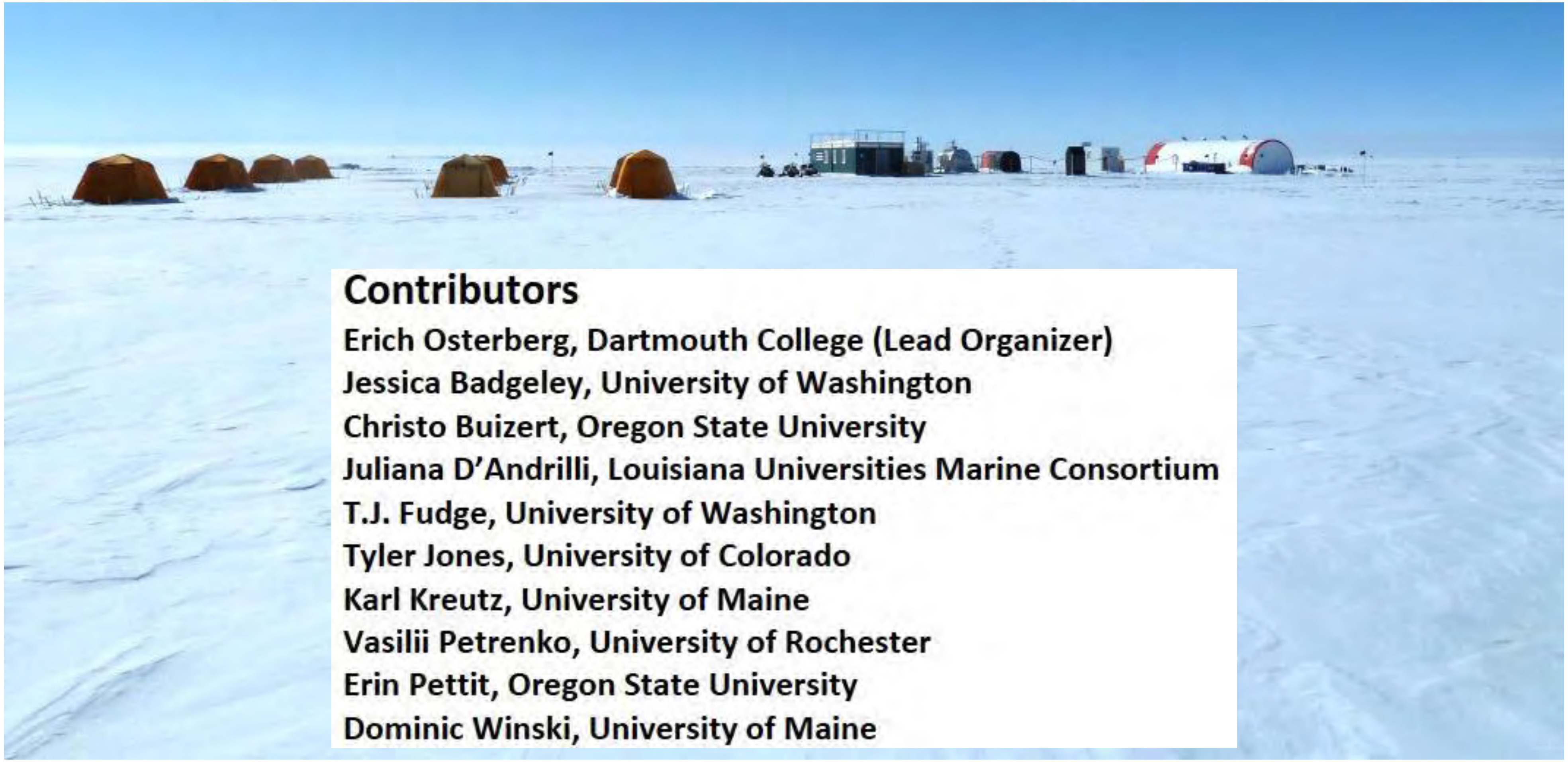


IDP Ice Core Working Group (IDP-ICWG)

Ice Core Research Priorities in Greenland

July 17, 2020

A white paper produced as a result of the IDP-ICWG Science Planning Meeting 2020



Contributors

Erich Osterberg, Dartmouth College (Lead Organizer)
Jessica Badgeley, University of Washington
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Tyler Jones, University of Colorado
Karl Kreutz, University of Maine
Vasilii Petrenko, University of Rochester
Erin Pettit, Oregon State University
Dominic Winski, University of Maine

Qaanaaq Ice Core (Near Camp Century): Driving Research Objectives (Summer 2025+)

- ***Climate forcing*** and ***ice sheet response*** during two key warm periods:
  - The Holocene Thermal Maximum = Transient Response
  - The Eemian = Equilibrium Response

Traverse from:
Summit?
NEEM?
Thule?

Intermediate Drill

NW Greenland Has Strong Climate Forcing: Climate Signal Strongest Near the Coast; Summer Temps Key

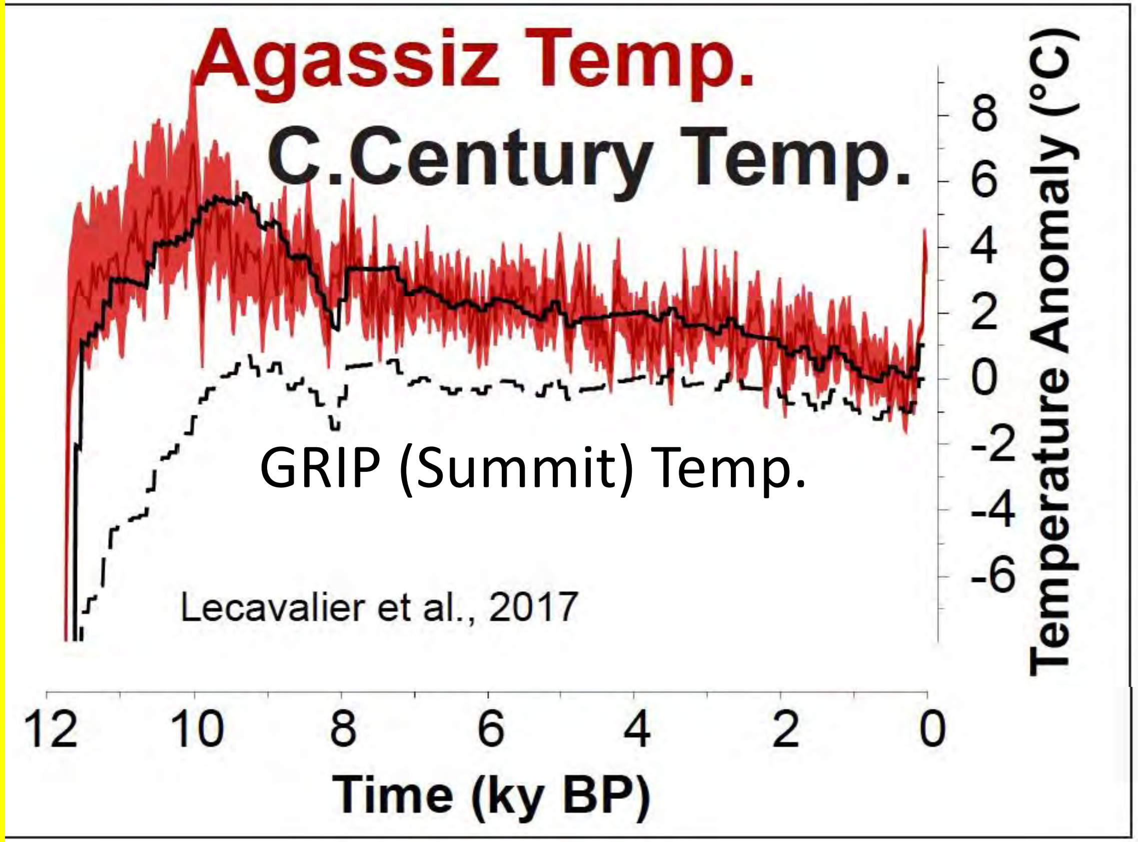
Pronounced summer warming in northwest Greenland during the Holocene and Last Interglacial PNAS

Jamie M. McFarlin[a,1], Yarrow Axford[a], Magdalena R. Osburn[a], Meredith A. Kelly[b], Erich C. Osterberg[b], and Lauren B. Farnsworth[b]

HTM summer temps 4-7°C warmer than modern (1952-2014)

Eemian summer temps 5.5-8°C warmer than modern

(McFarlin et al., 2018)

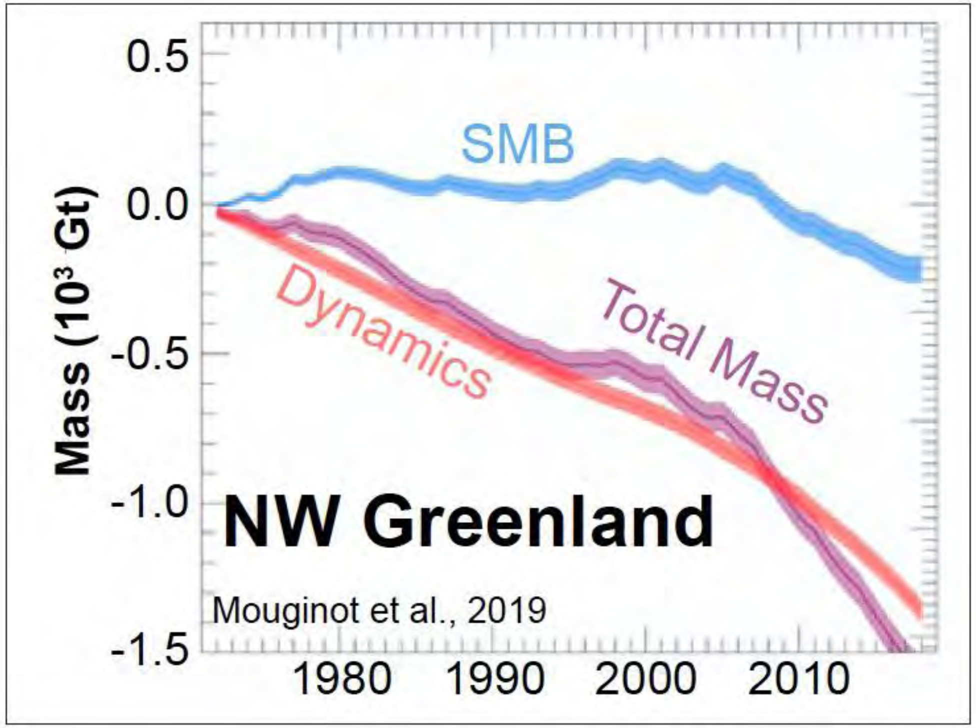


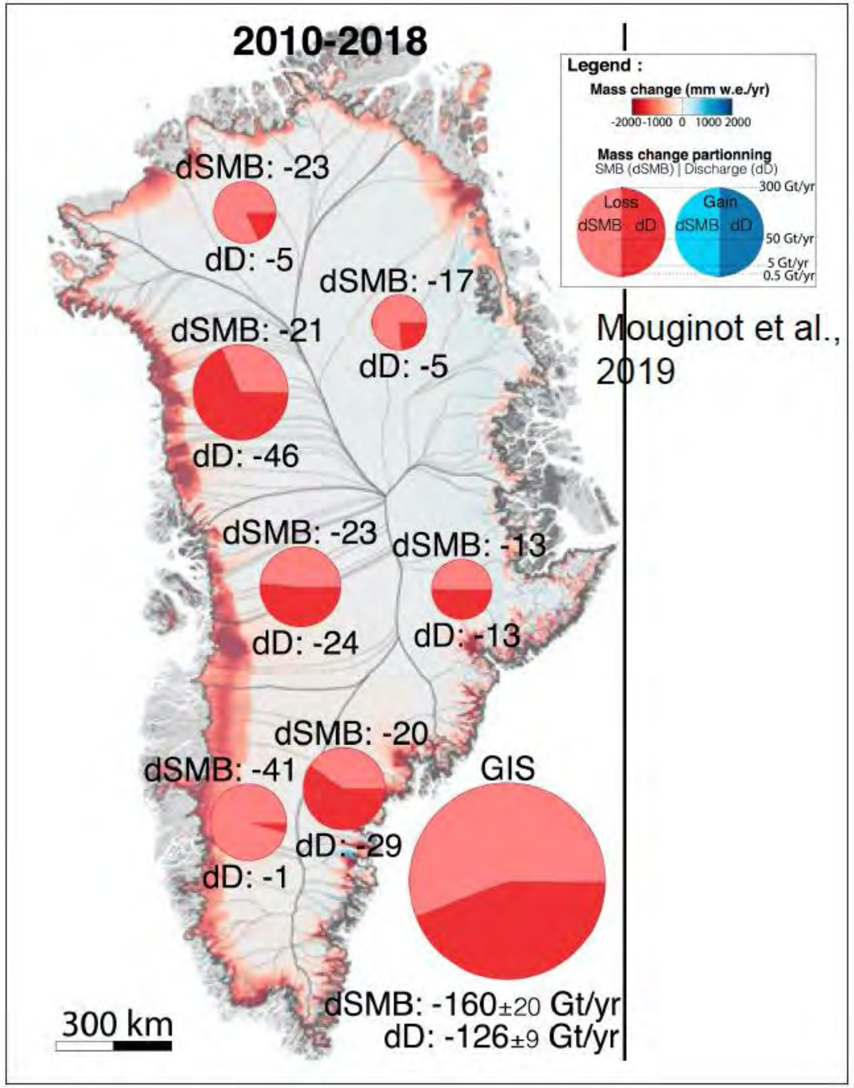
Annual Review of Earth and Planetary Sciences

Past Warmth and Its Impacts During the Holocene Thermal Maximum in Greenland

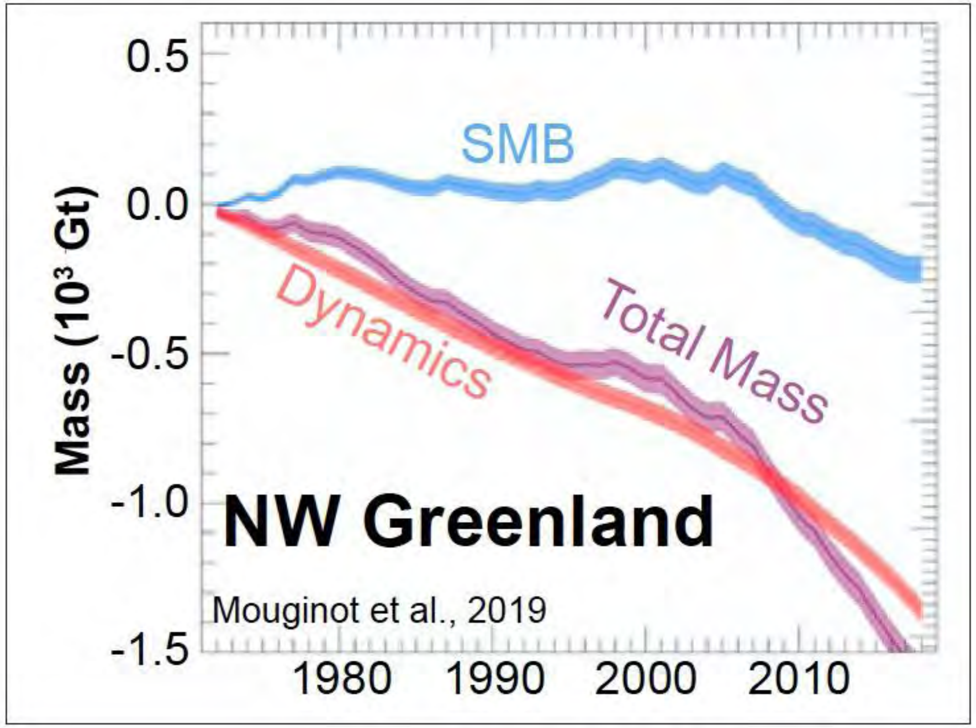
Yarrow Axford,[1] Anne de Vernal,[2] and Erich C. Osterberg[3]

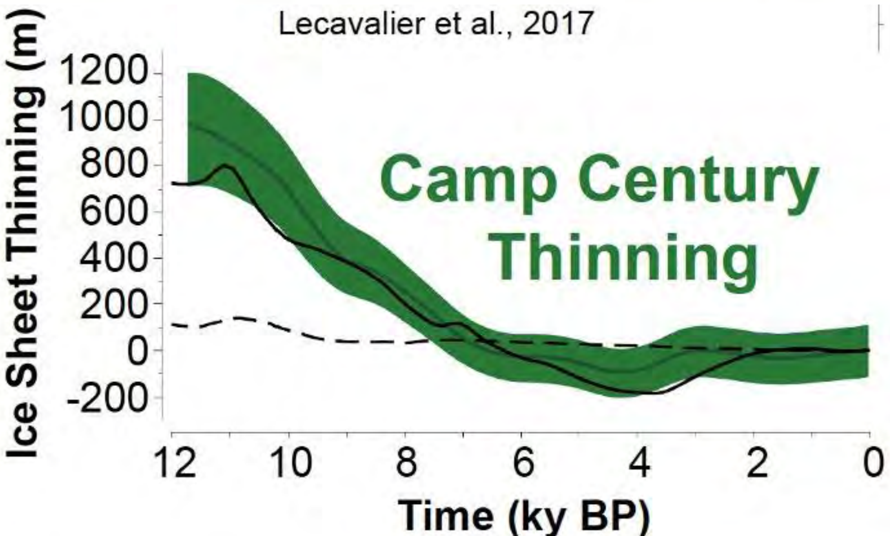
NW Greenland Is Melting Quickly Today…

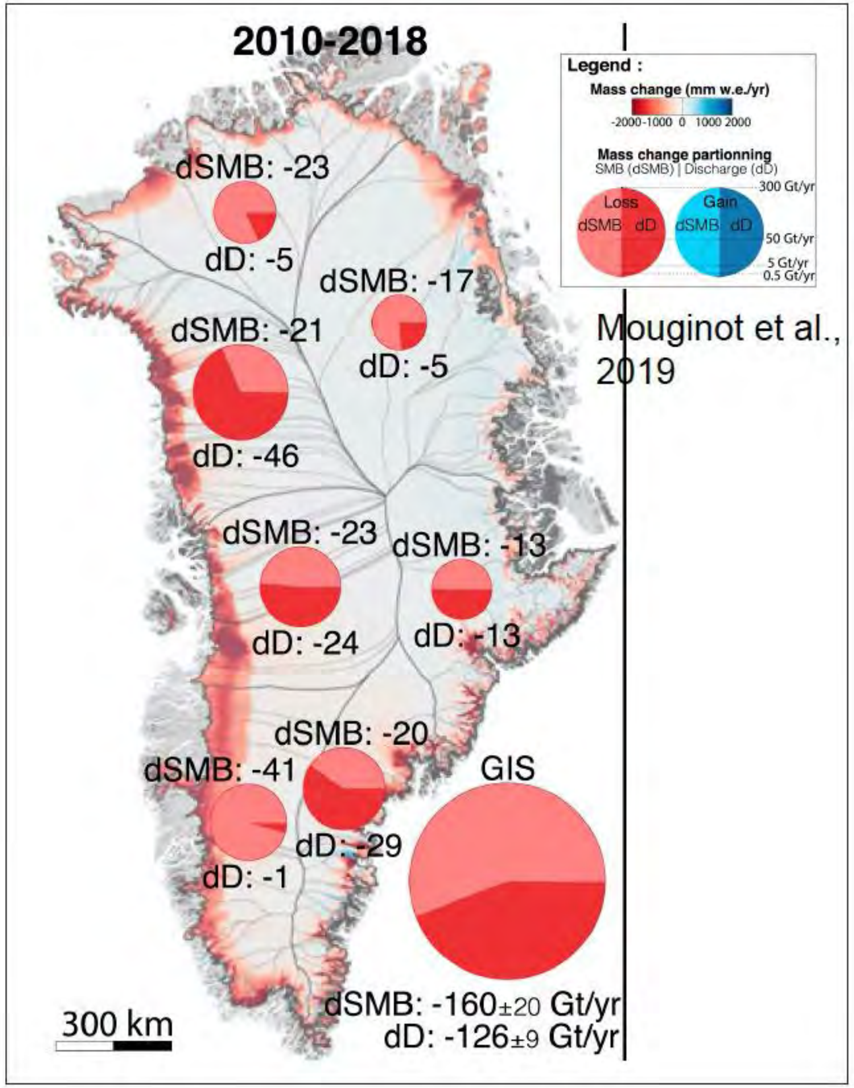




NW Greenland Is Melting Quickly, and did in Past Warm Periods







South Dome: Detailed Anatomy of Rapid Climate Change From the Holocene through the Last Glacial Period

Driving Research Questions:

Did D-O events, Heinrich Events, YD, HTM. 8.2, LIA occur synchronously across Greenland, or were there regional differences in their magnitude, timing and seasonality?

Can the relative phasing of changes in the cryosphere, ocean circulation, atmospheric circulation, biosphere and greenhouse gases reveal fundamental insight into their governing processes?

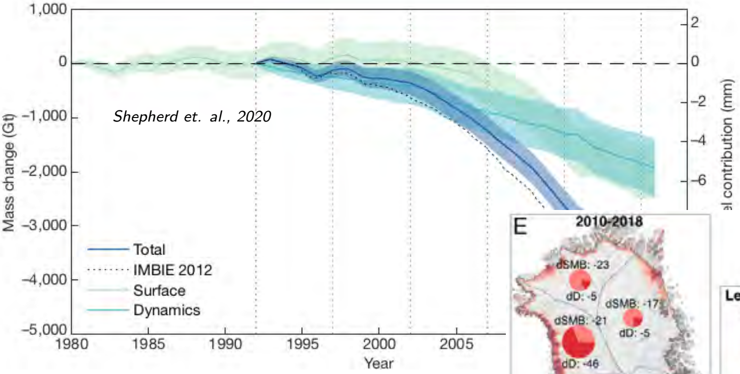
Science Drivers: Surface Mass Balance

Robert L. Hawley
Dartmouth

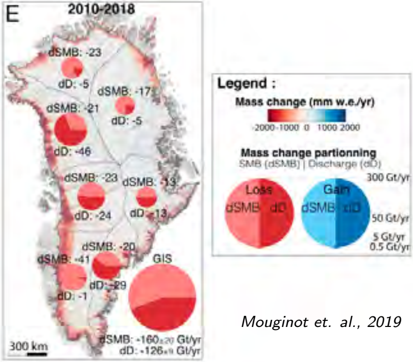
(With contributions from many others)
robert.l.hawley@dartmouth.edu

11 June 2021, US Traverse planning workshop

Surface Mass Balance is important



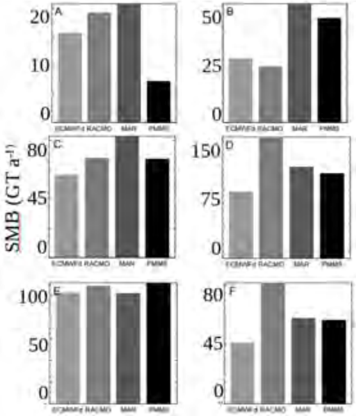
Shepherd et. al., 2020



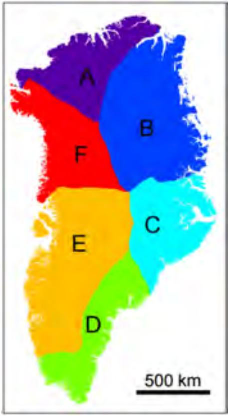
Mouginot et. al., 2019

SMB accounts for 50% or more of total Greenland Mass Balance

SMB is difficult to model



Vernon et. al., 2013

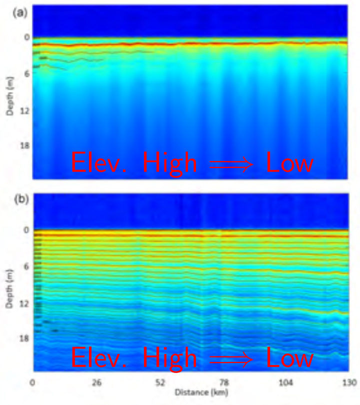


Significant differences between models, and variability by region

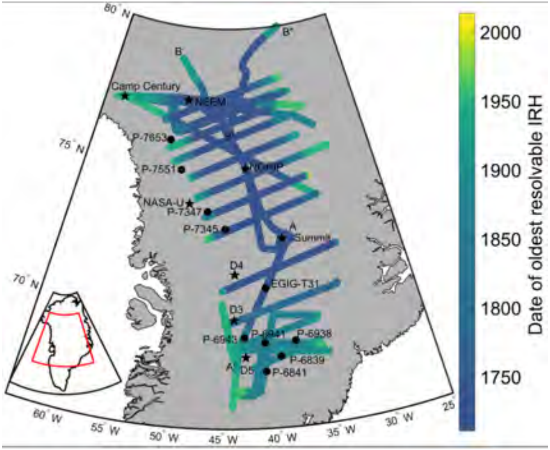
Four different regional climate models

SMB is difficult to measure remotely at lower elevations

Deep layers become unresolvable in airborne radar ⇒ lower elevations



Koenig et. al., 2016



Lewis et. al., 2019

SIPRE (→ CRREL) traverses, 1950's

Research Report 70

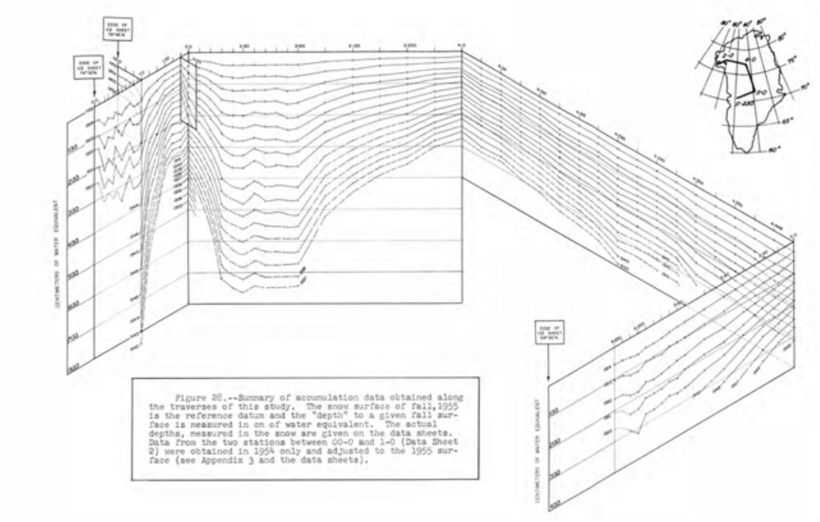
JULY 1962
Reprinted AUGUST 1996

Stratigraphic Studies in the Snow and Firn of the Greenland Ice Sheet

by Carl S. Benson

Deep snowpits at regular intervals for detailed stratigraphy.

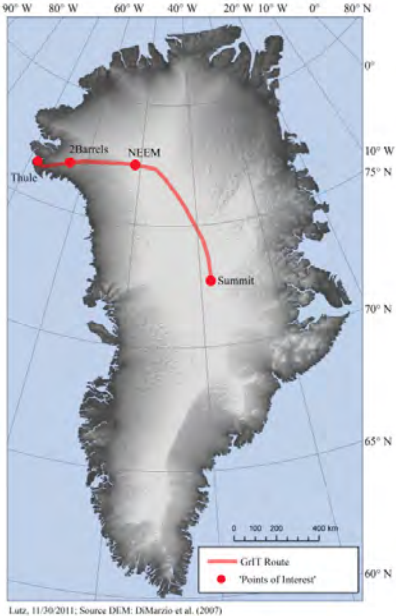
SMB from snowpit stratigraphy



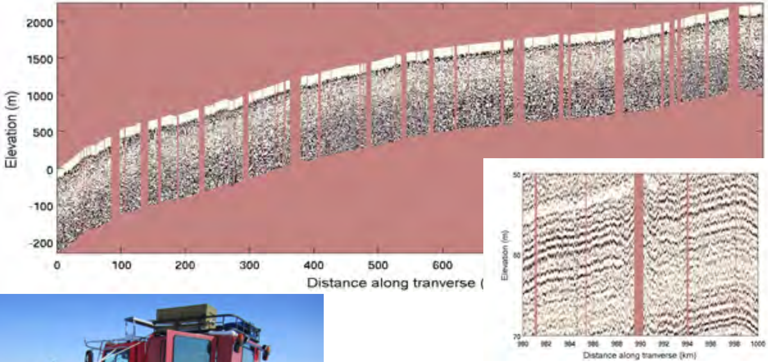
Benson, 2062
https://northernsoundings.com/2021/01/26/extreme-researchers-carl-benson-and-matthew-sturm/

GrIT Traverse: science rides along on a logistics platform

- Existing logistical traverse
- Follows 1954 traverse route
- "Leapfrog" approach
- Learning experience

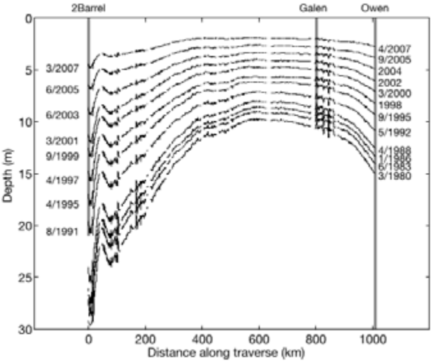


SMB strategy- GPR, pits, cores

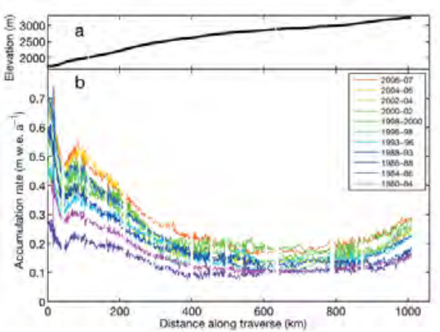


Profiles show continuous layering indicating accumulation patterns.

Accumulation results from GrIT



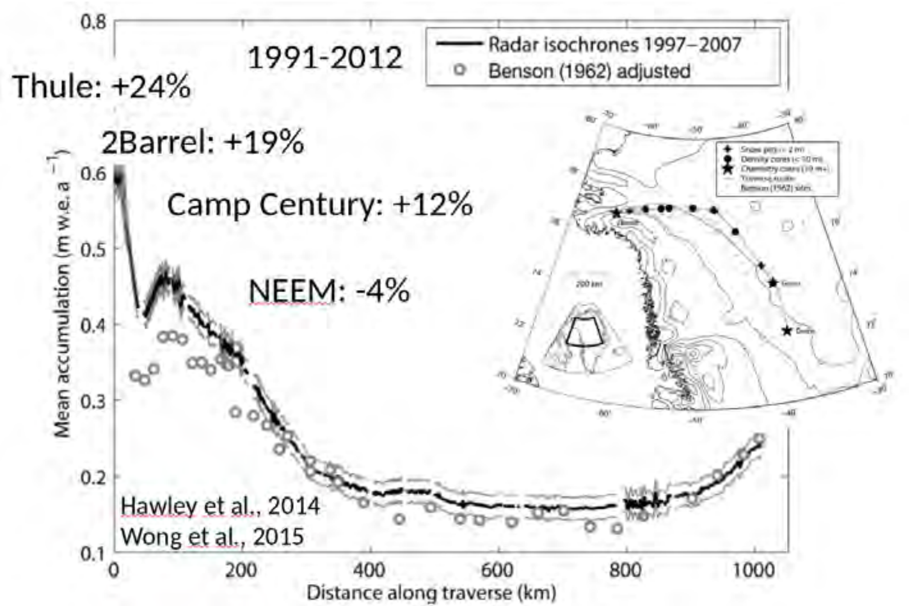
Trace isochrones dated using cores at either end



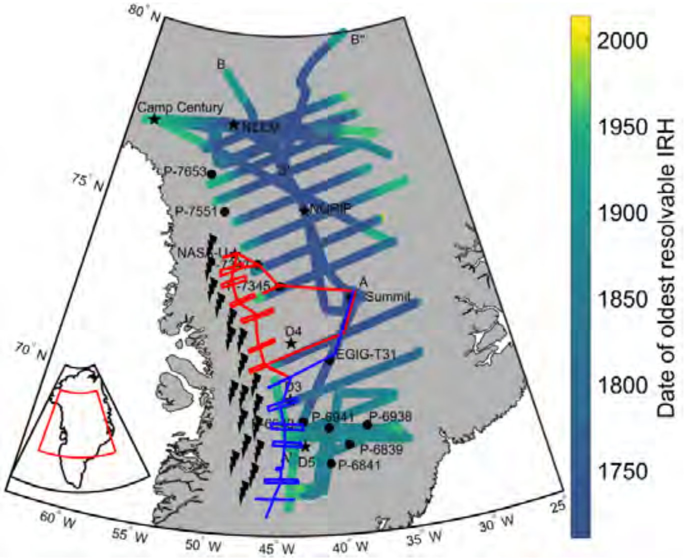
Accumulation rates over multiple epochs

Hawley et. al., 2014

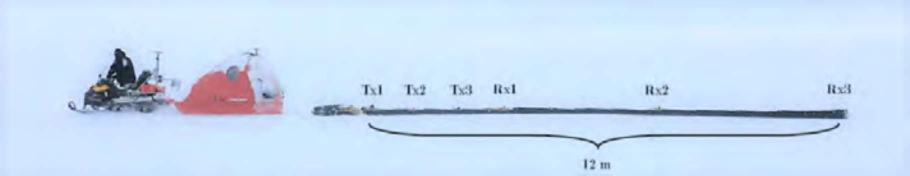
SMB increase since Benson, particularly towards the coast



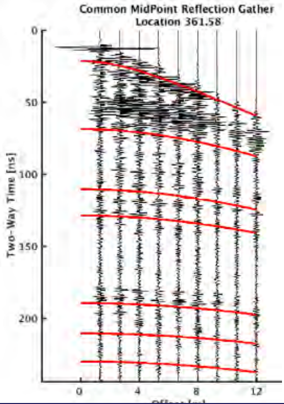
GreenTrACS: Filling in the gaps- western margin



Multi-offset radar for continuous density profiling



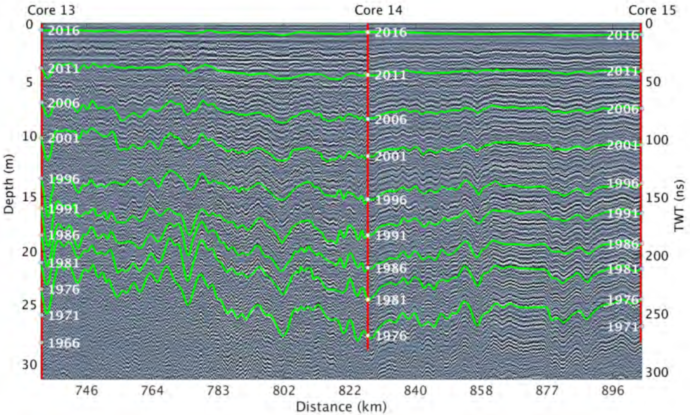
Meehan et. al., 2020



EM velocity depends on density

Multiple sources and receivers (9 different offsets) allow determination of a velocity profile ⇒ density profile

SMB decrease along GT

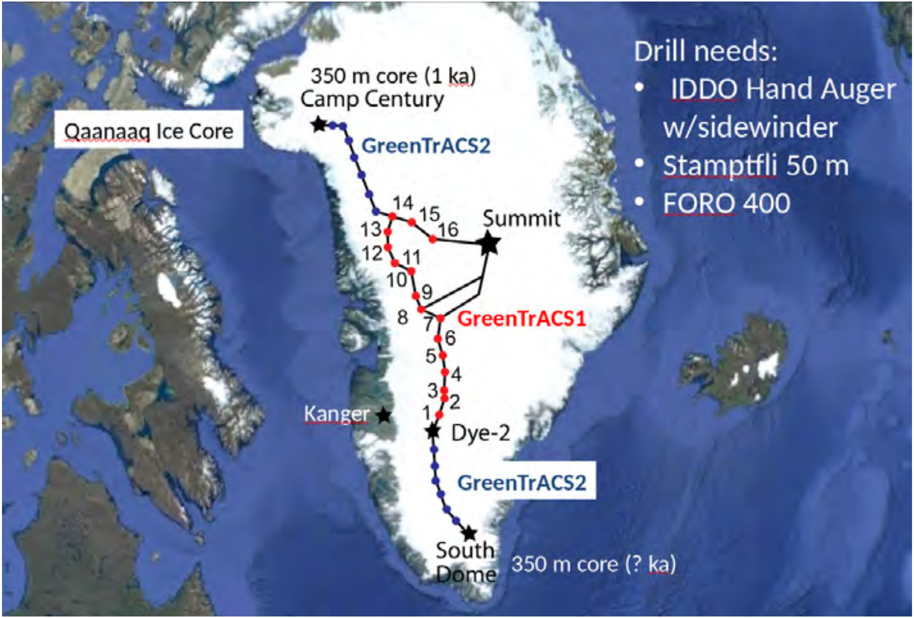


Recent precipitation decrease across the western Greenland ice sheet percolation zone

The Cryosphere, 13, 2797–2815, 2019
https://doi.org/10.5194/tc-13-2797-2019

Gabriel Lewis[1], Erich Osterberg[1], Robert Hawley[1], Hans Peter Marshall[2], Tate Meehan[2], Karina Graeter[3], Forrest McCarthy[4], Thomas Overly[5,6], Zayta Thundercloud[1], and David Ferris[1]

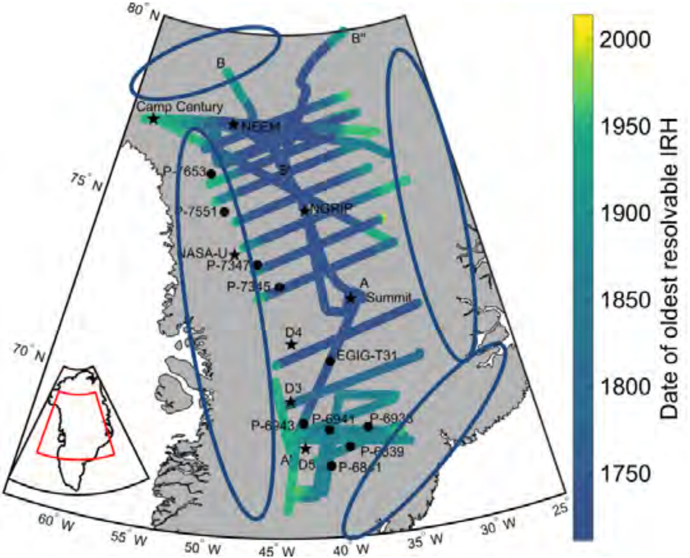
GreenTrACS2: Completing the western line



GreenTrACS2: Key Questions

- How has intensified summertime blocking affected snowfall and melt in northern vs. southern Greenland?
- How and why has surface melt changed since the peak in 2012? How is the firn evolving with this change in melt?
- How does modern surface melt compare to rates over the past 1000 years?
- How well do the latest generation of RCMs capture recent changes and spatial patterns in snowfall and melt?

Beyond GreenTrACS2



Thanks!

Traverse vehicles of the future...

What more can we learn about glacial hydrology from radar sounding

(with the help of ground-based traverse)

Winnie Chu

Georgia Institute of Technology

June 11, 2021

U.S. Scientific Traverses on the Greenland Ice Sheet: a Planning Workshop

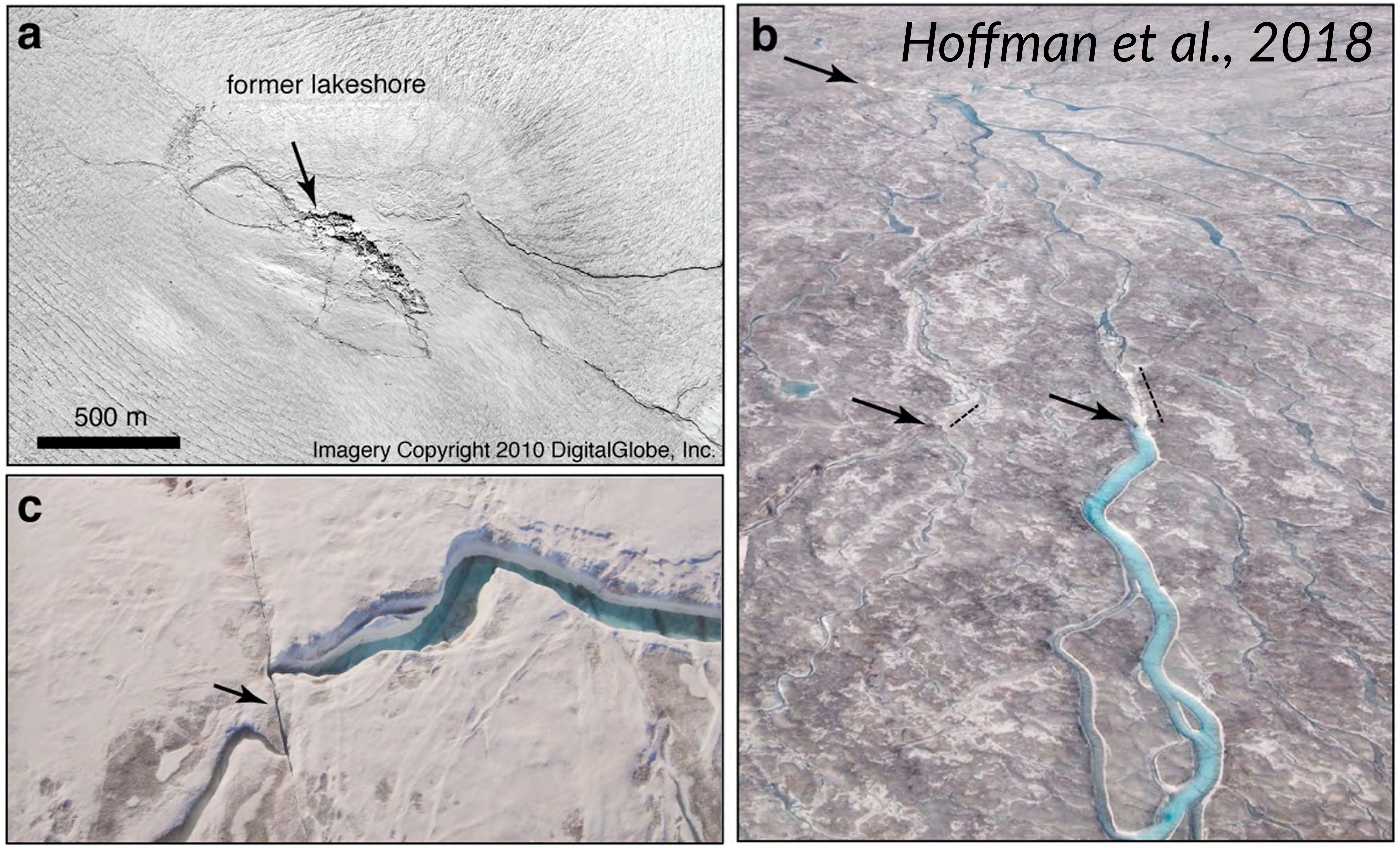
Special thanks to: Colin Meyer, Kristin Poinar, Riley Culberg, Joe Macgregor

NSF

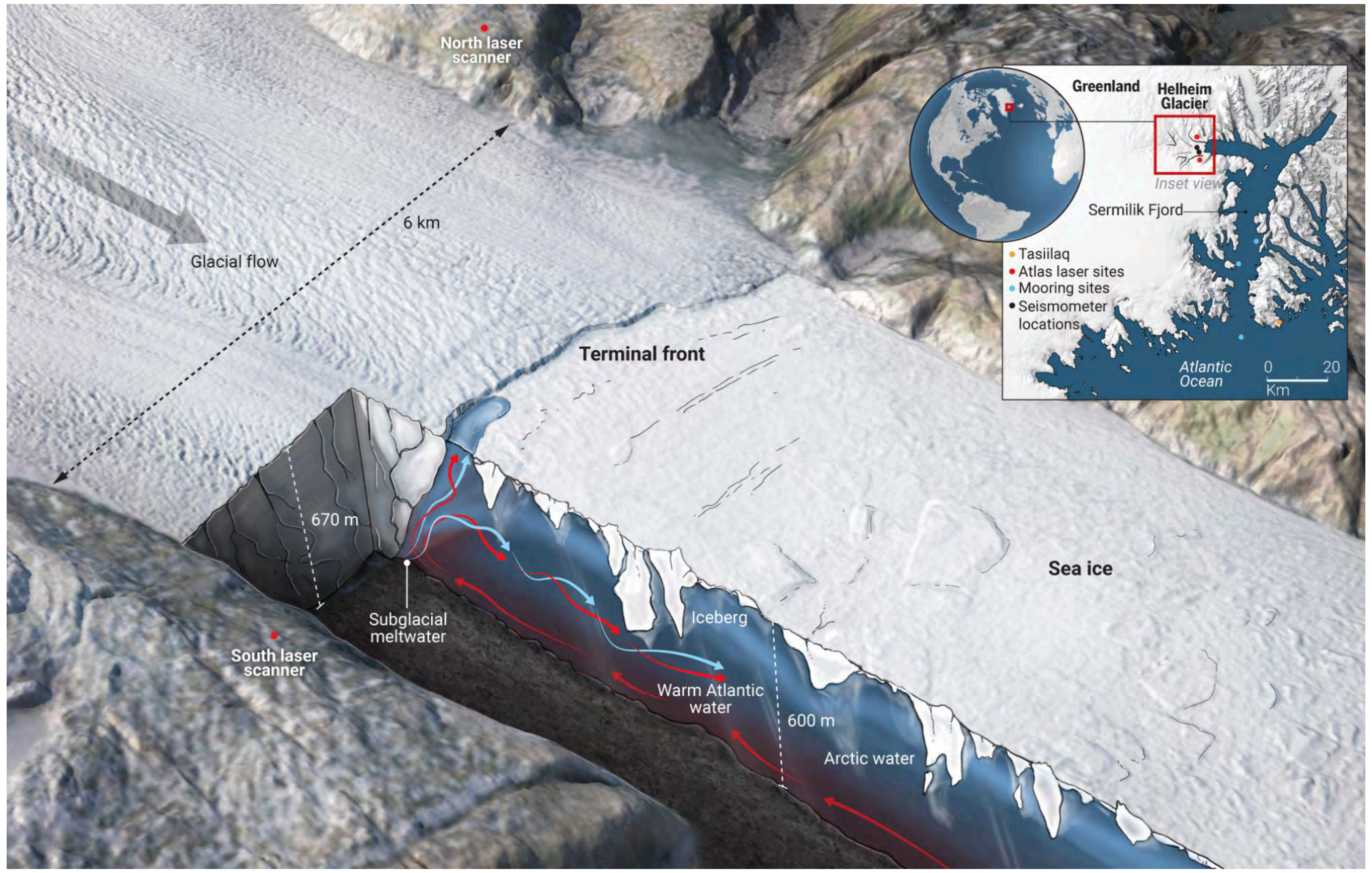
HEISING-SIMONS FOUNDATION

How fast will sea level rise due to melting in Greenland?

Many supraglacial rivers end in moulins



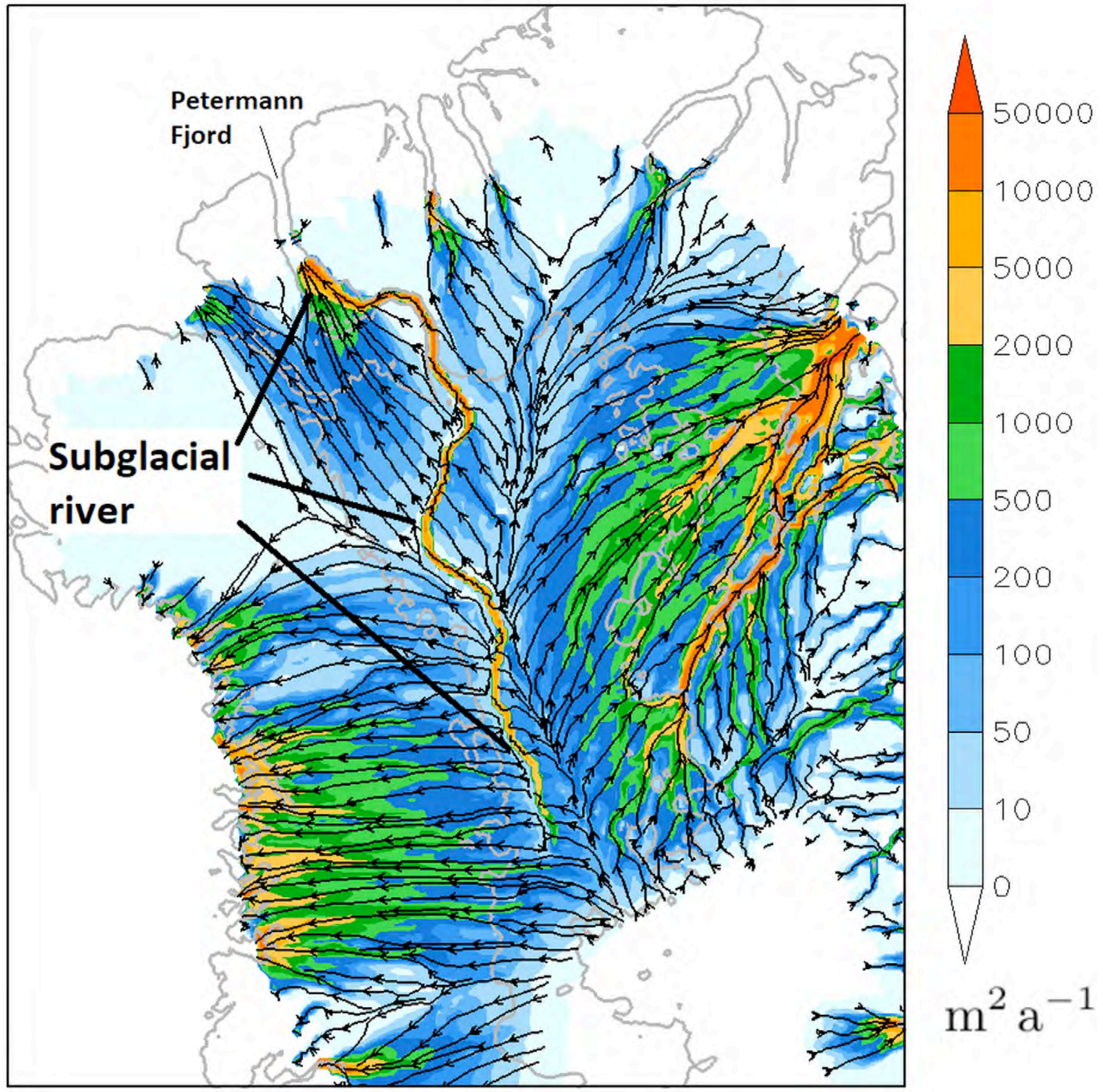
Water discharge into the ocean enhances submarine melt



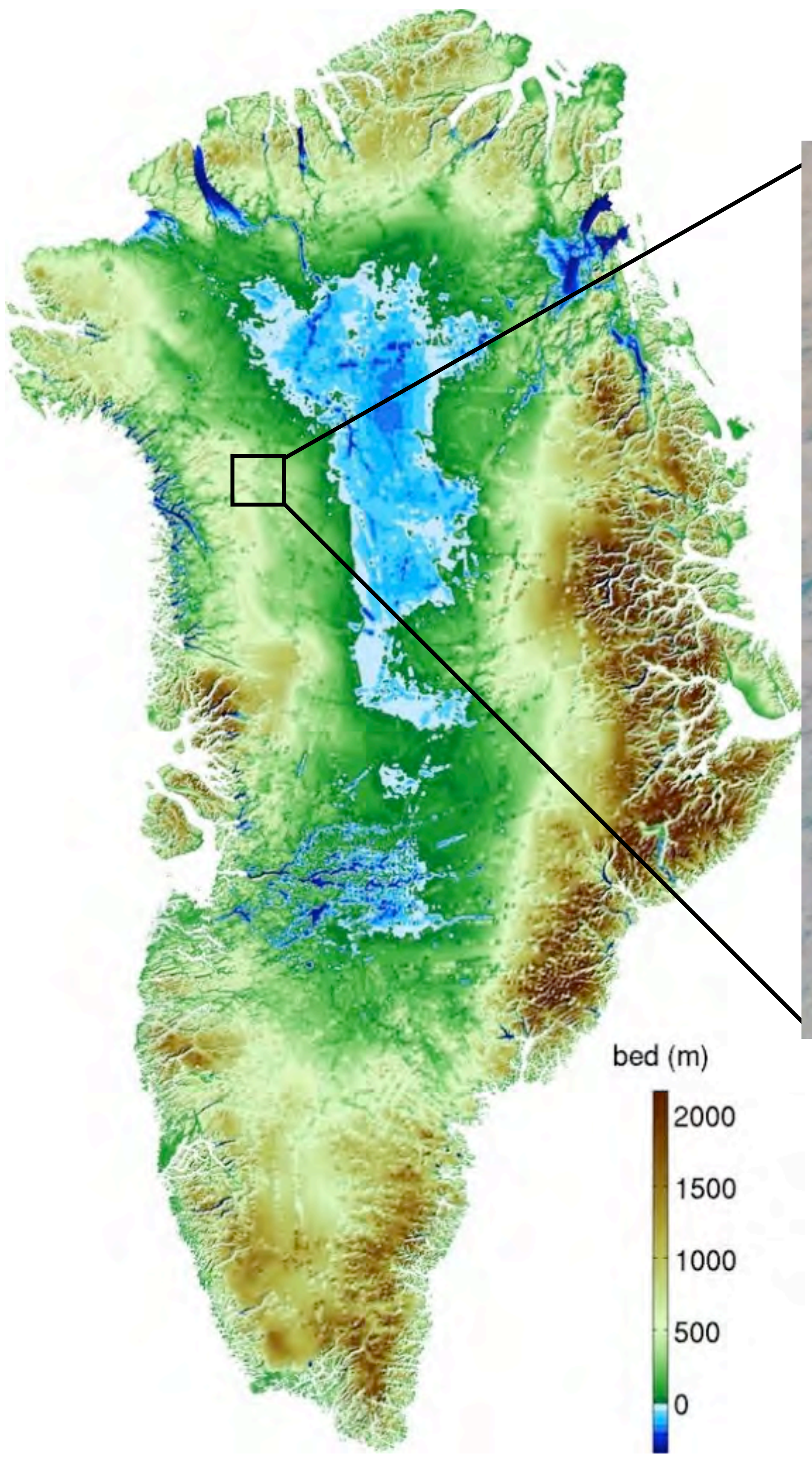
Credit: Paul Voosen

Evidence of meltwater contributions from the ice interior

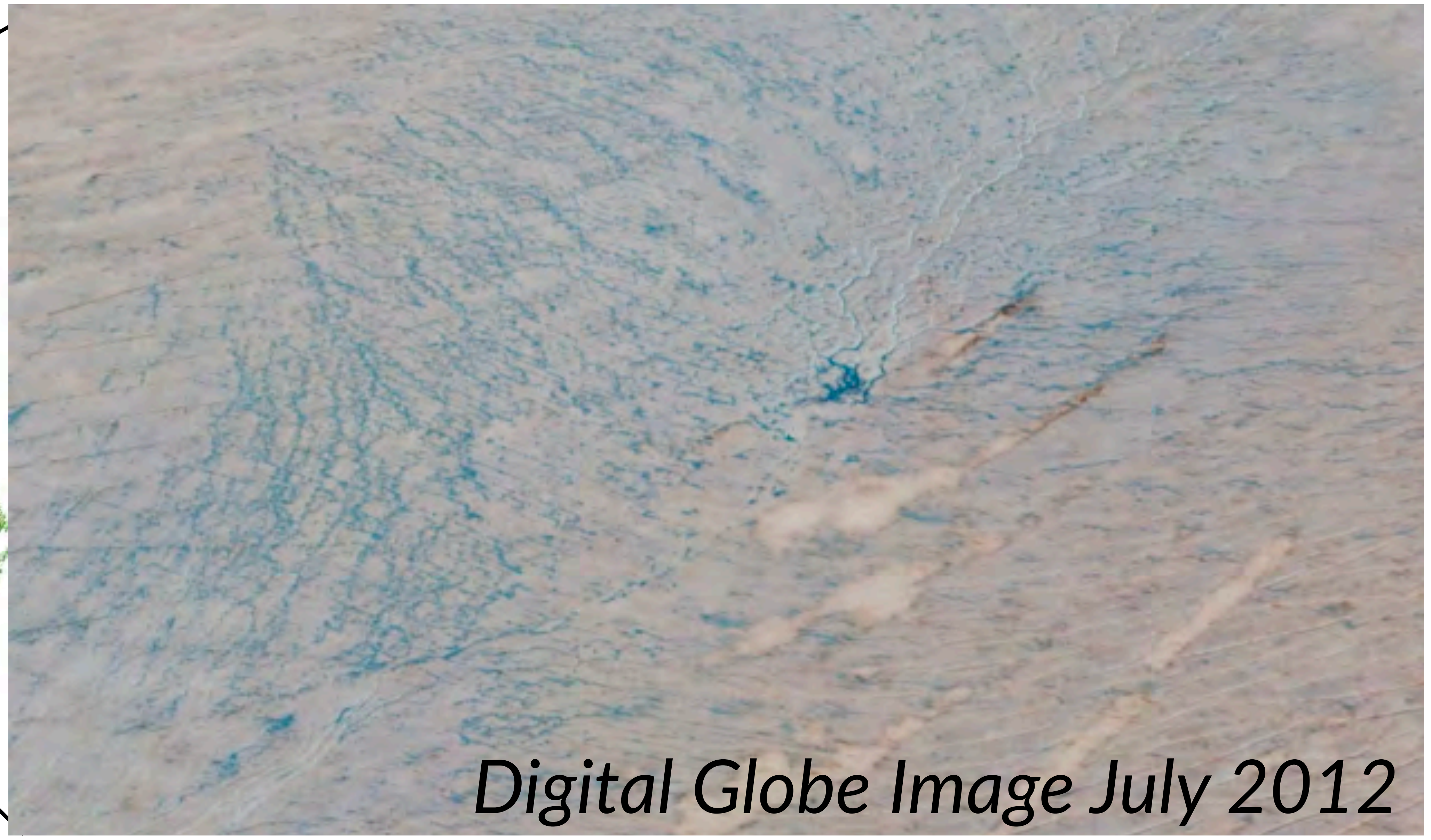
Large subglacial water catchment into the ice interior



Chambers et al., Cryosphere, (2020)



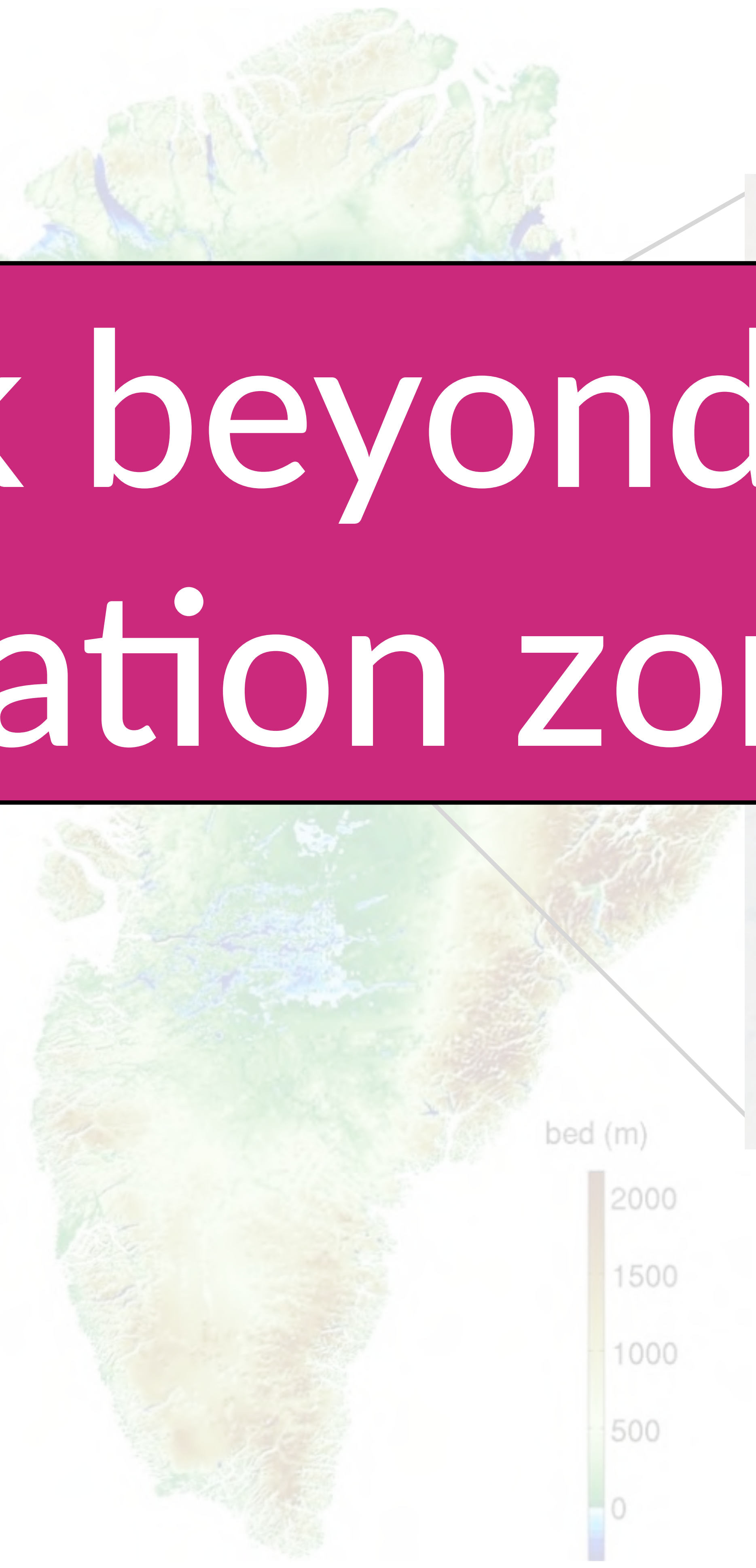
Rivers & moulins in the wet snow zone of NW Greenland!



Evidence of meltwater contributions from the ice interior

Large subglacial water catchment into the ice interior

Chambers et al., Cryosphere, (2020)

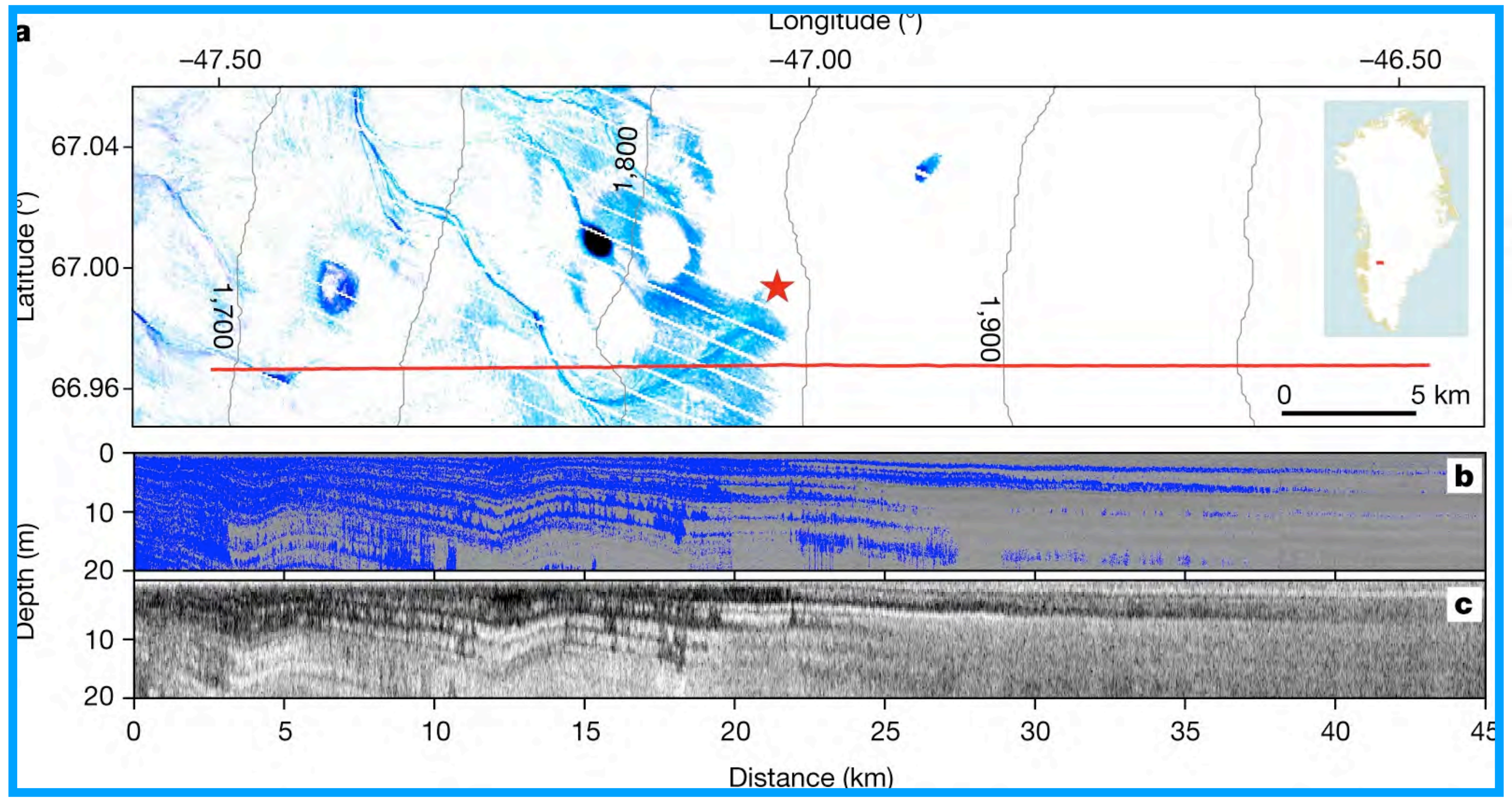


Rivers & moulins in the wet snow zone of NW Greenland!

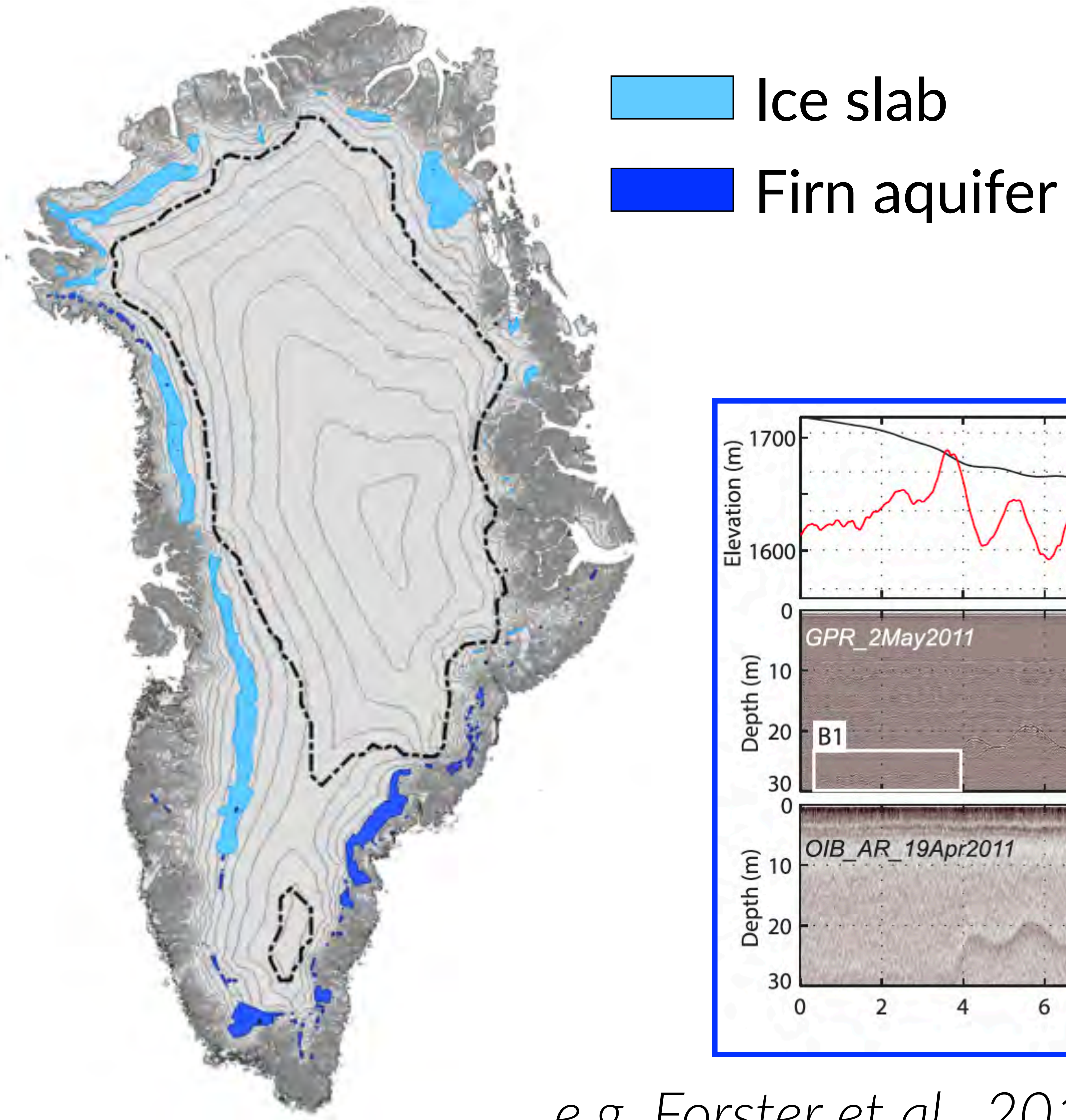
Digital Globe Image July 2012

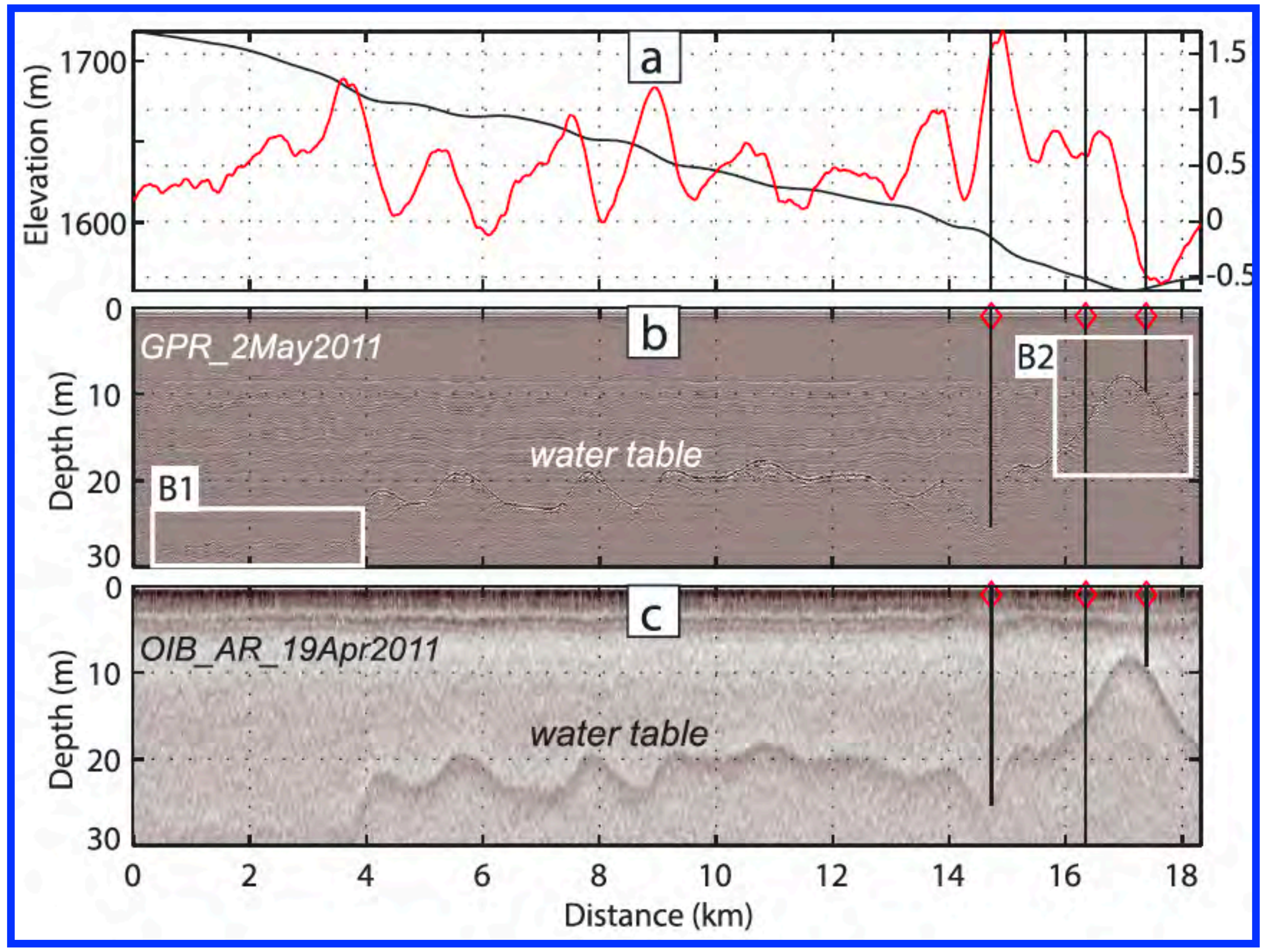
Look beyond the ablation zone!

Water doesn’t go straight to the bed in the accumulation zone



e.g. MacFerrin et al., 2019



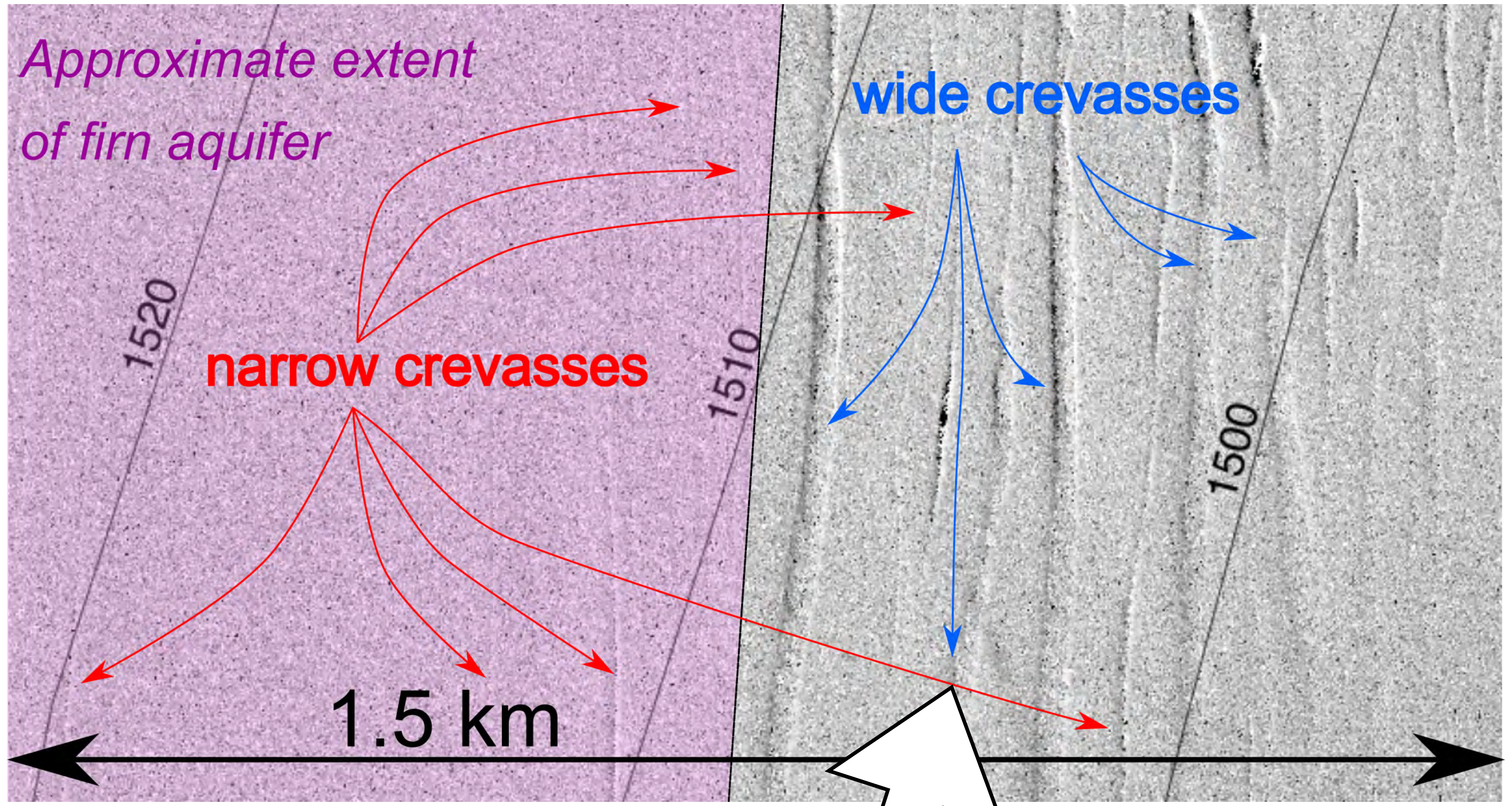


e.g. Forster et al., 2013; Miege et al., 2016

Compelling science questions for hydrology

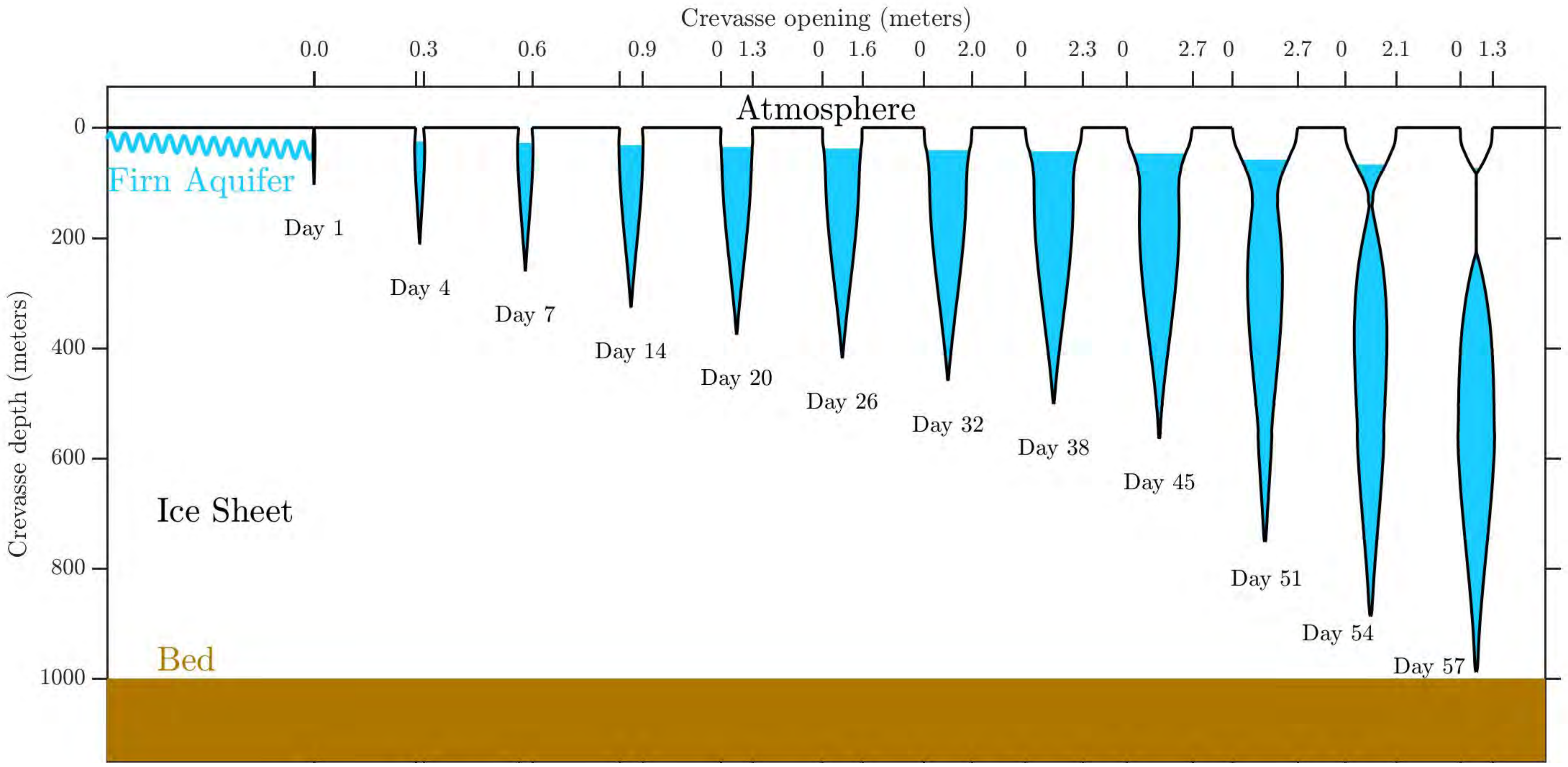
Question		
1. How does water connect from the ice surface to the bed? • What's happening englacially within the ice sheet?		

Helheim Glacier aquifer can offer insights about water connection



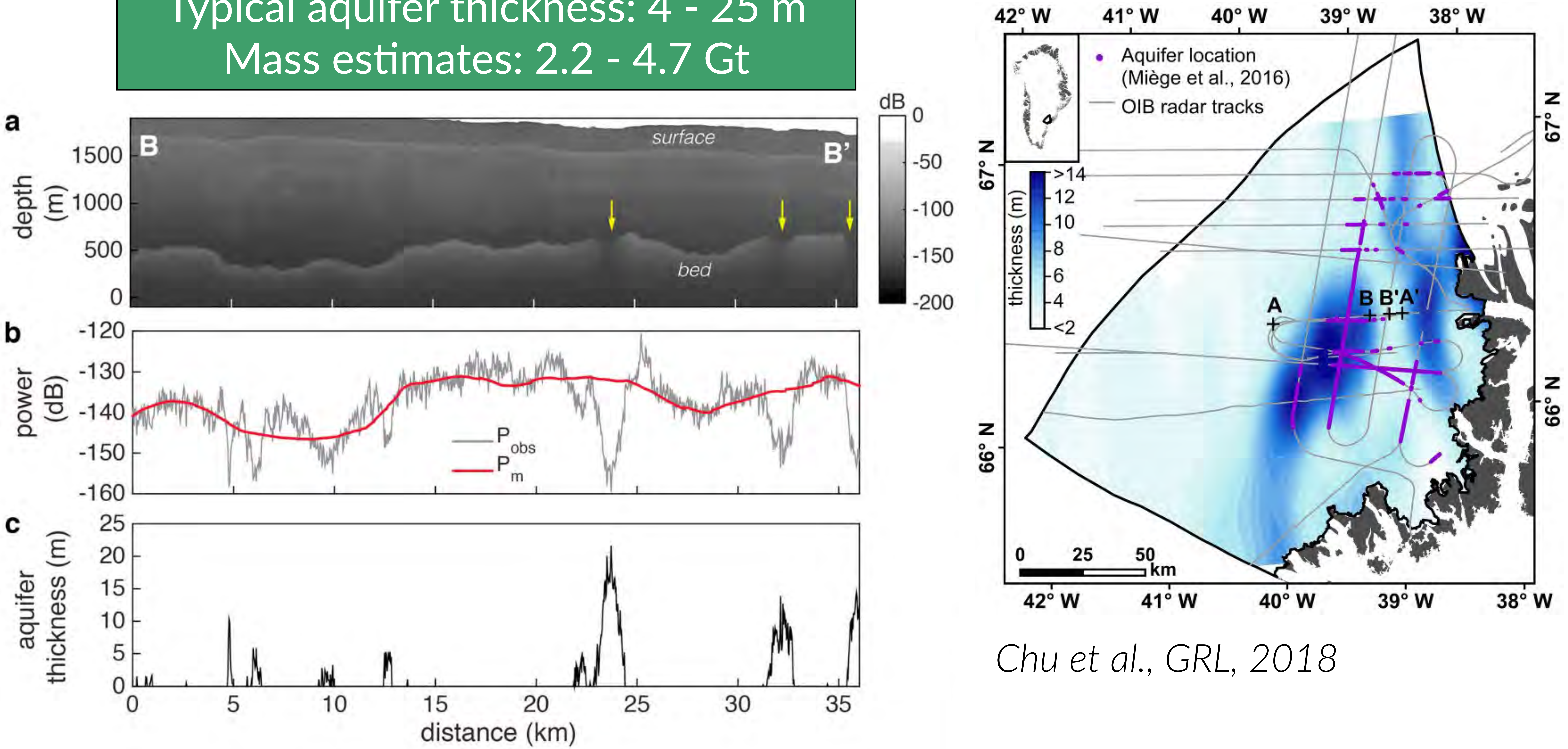
Crevasses near the firn aquifer can provide access for water to the bed

e.g. Poinar et al., Frontier, 2017; GRL, 2019



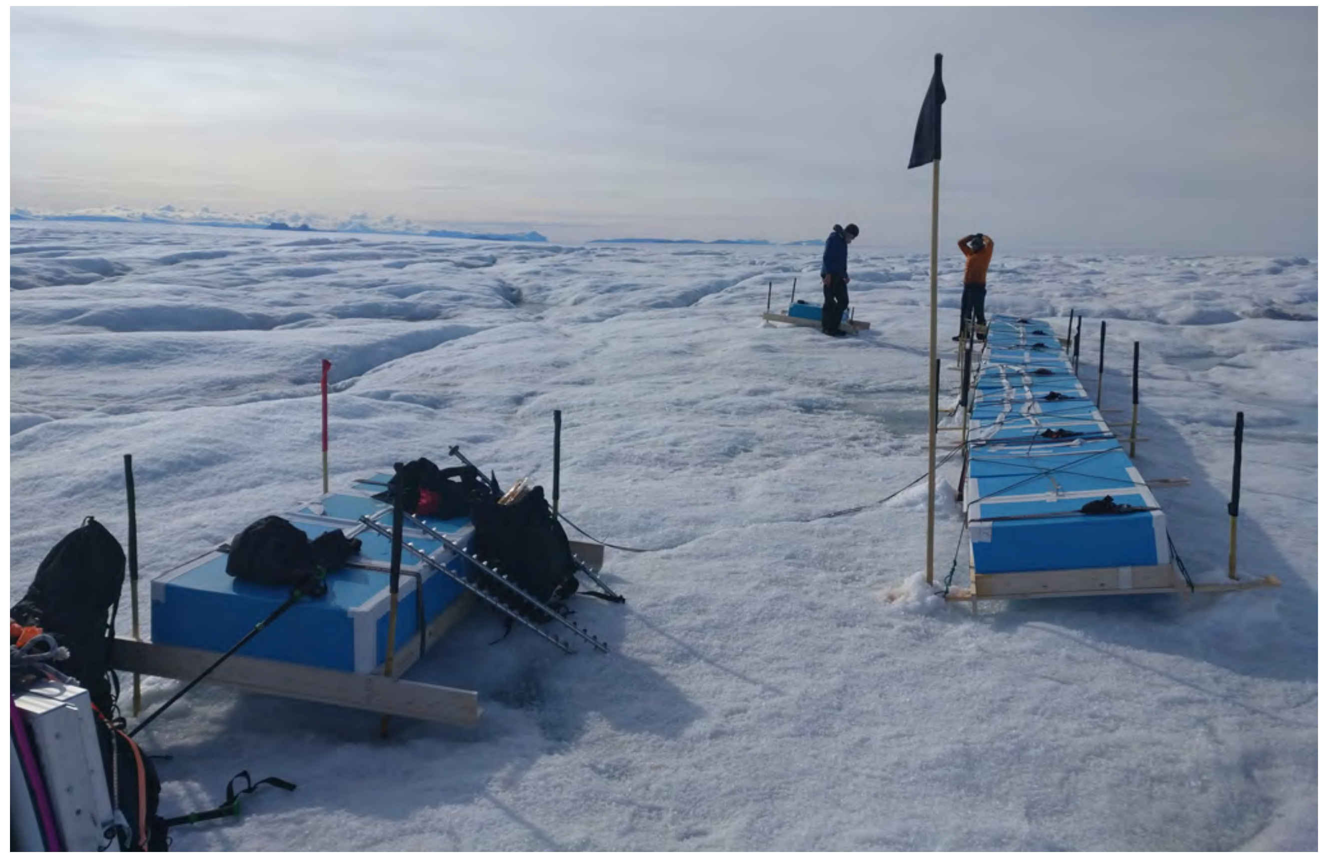
Radar observations show the aquifer stores a lot of water

Typical aquifer thickness: 4 - 25 m
Mass estimates: 2.2 - 4.7 Gt

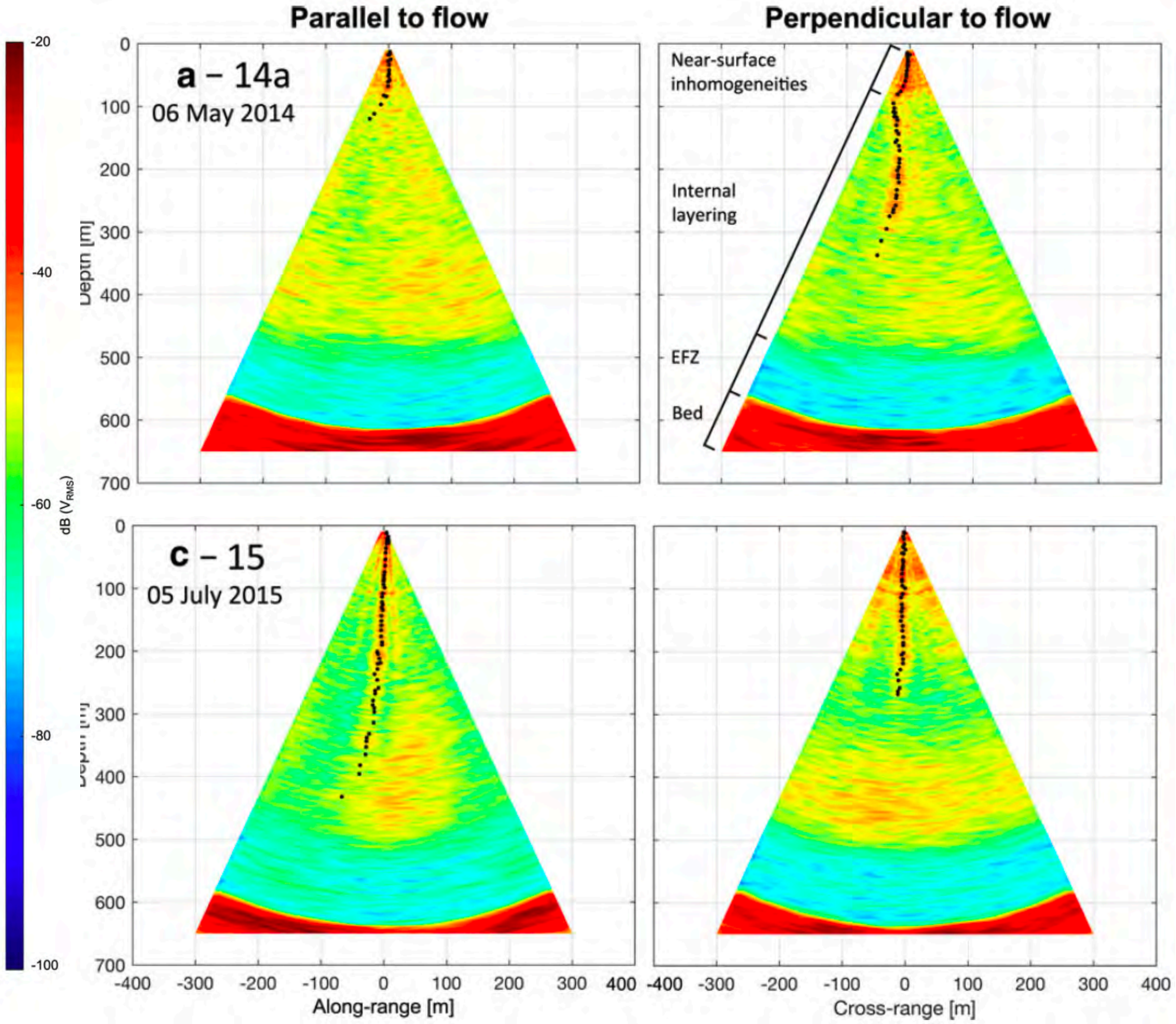


Chu et al., GRL, 2018

Long term stationary radar sounding stations to study how water from the aquifer get to the bed



ApRES (time series of radar image) to track how water connects to the bed



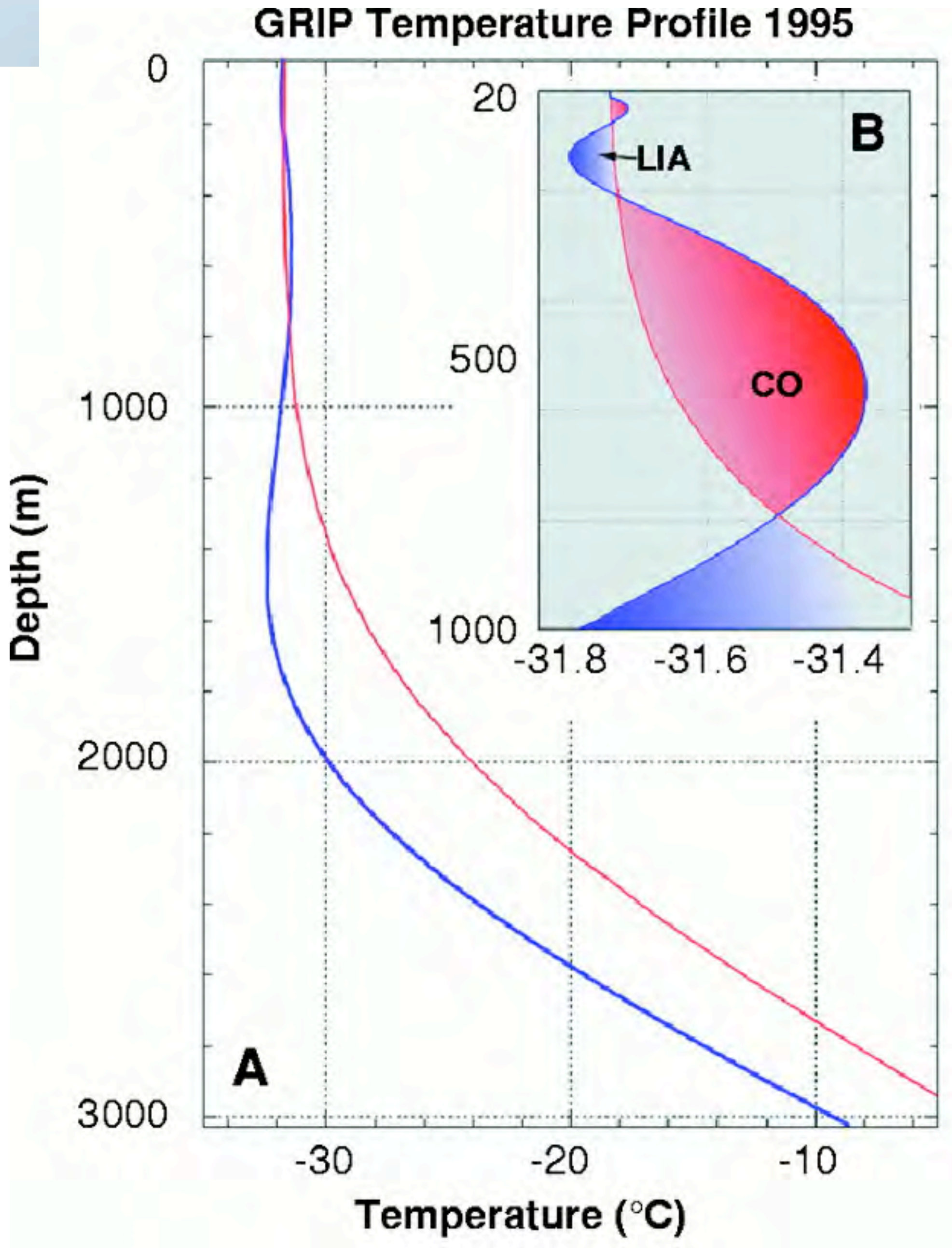
Young et al., 2019

Do this by looking at changes in radar velocity (phase) & power losses over time

e.g. Kendrick et al., 2018
Vankova et al., 2018

Biggest challenge: Absolutely calibrate radar layer power

To fix this: Need firn & ice cores close to radar sites



Useful field-based information:

- *DEP, ECM measurements*
- *Borehole temperature*

Improve radar dielectric model

1. *Better thermal correction to the real part of permittivity*

$$\sigma(z) = \sigma_m(z)\left[\frac{E}{R}\left(\frac{1}{T_0} - \frac{1}{T(z)}\right)\right]$$

2. *More realistic density model to calculate complex permittivity*

$$\epsilon'(z) = [1 + 0.845\rho(z)]^2$$

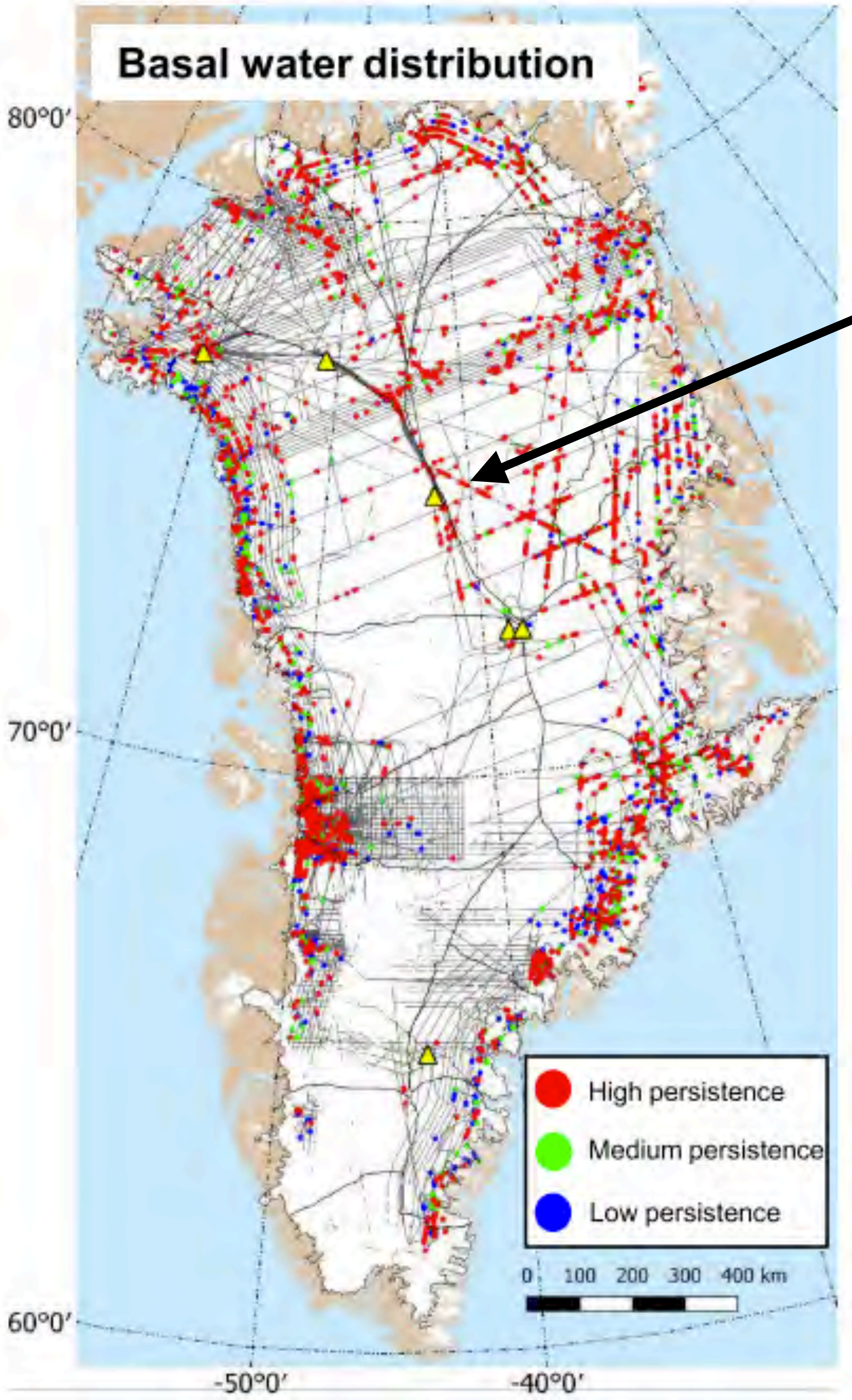
$$\epsilon''(z) = \frac{\sigma(z)}{2\pi f_c \epsilon_0}$$

Compelling science questions for hydrology

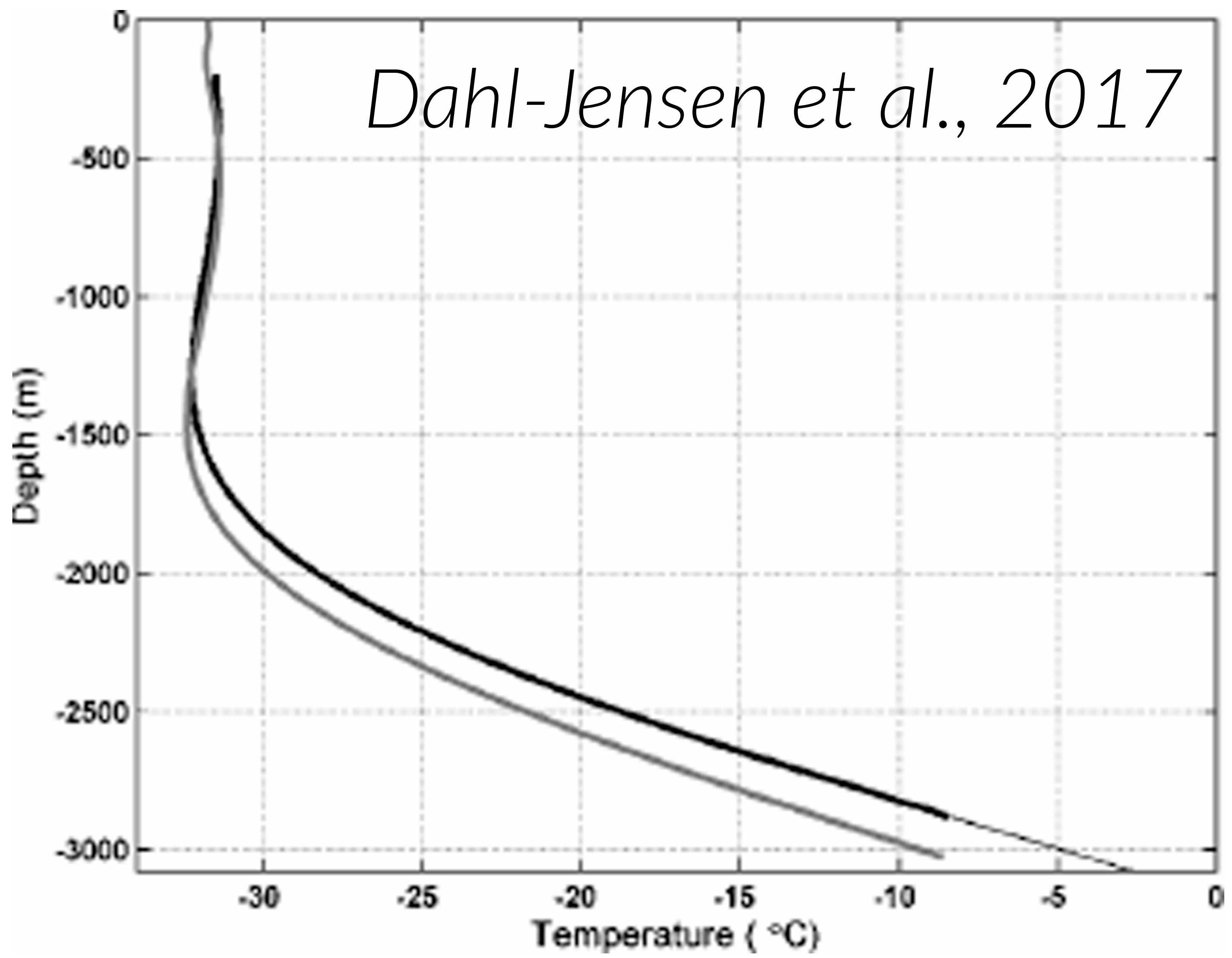
Question		
2. What's the basal thermal state of Northern Greenland?		

Northern GNLD interior has lots of basal water?!

High radar reflectivity at the ice divide

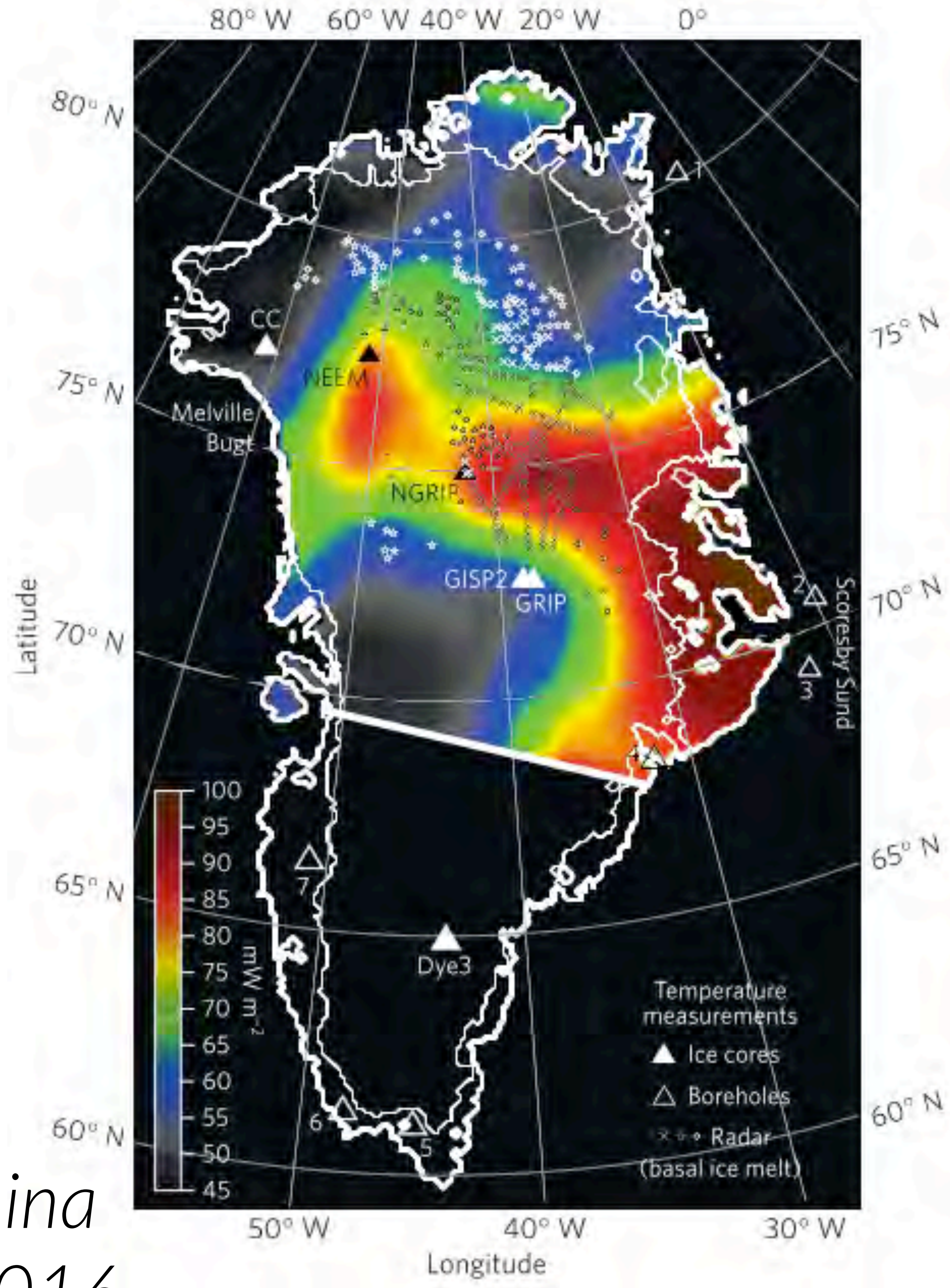


Jordan et al., 2018



NorthGRIP shows basal temperature at pressure melting pt.

Maybe related to GNLD passage over Icelandic hotspot (80 - 33 Ma)



Rogozhina et al., 2016

Ice sheet models have difficulty with ice temperatures in Northern Greenland

SeaRISE pressure-melting corrected basal temperatures

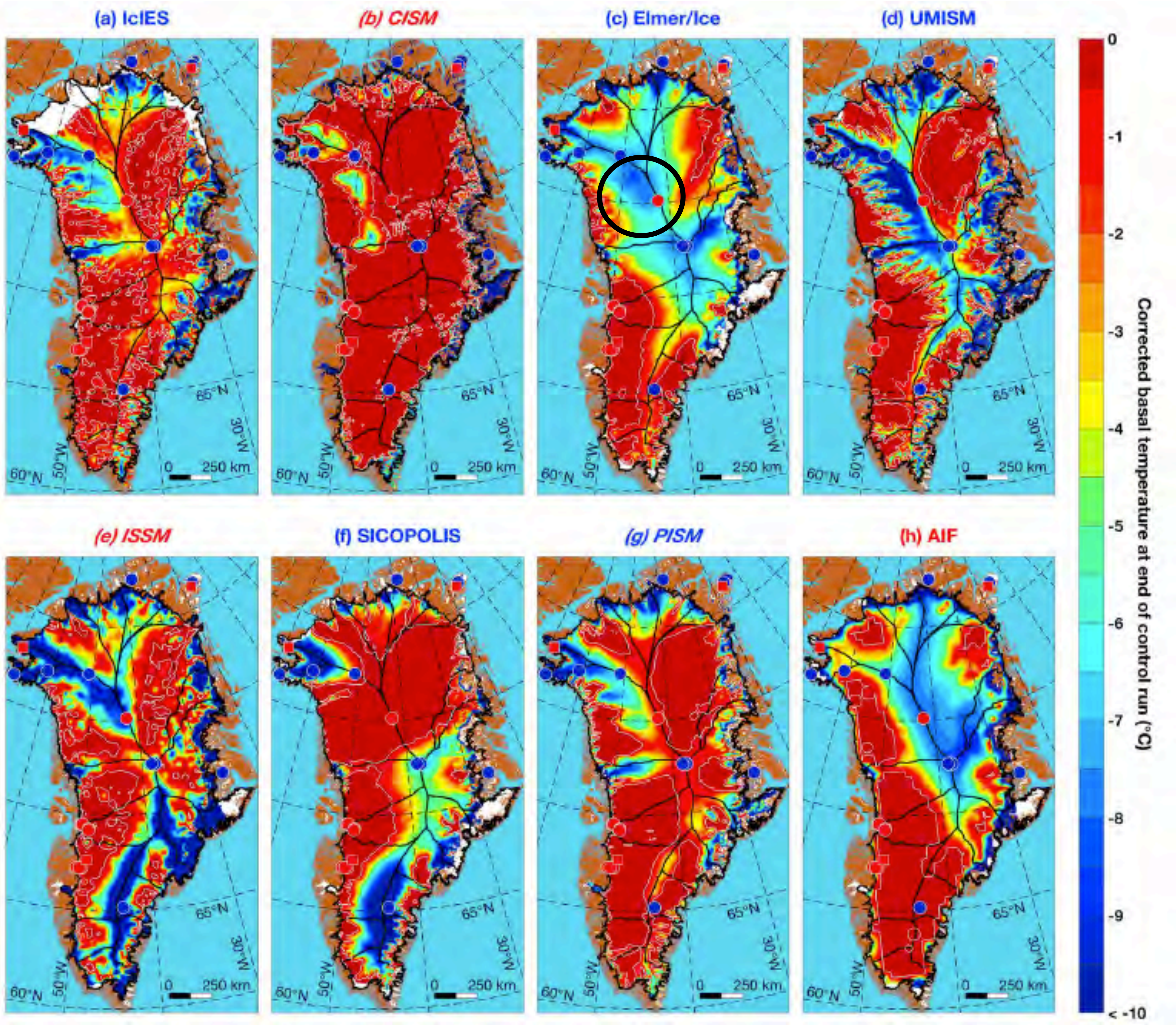
Wrong temperature

↓

Wrong rheology

↓

Wrong ice velocity



MacGregor et al., 2016

The updated ISMIP6 experiments show the same issue!

(esp. west of NorthGRIP)

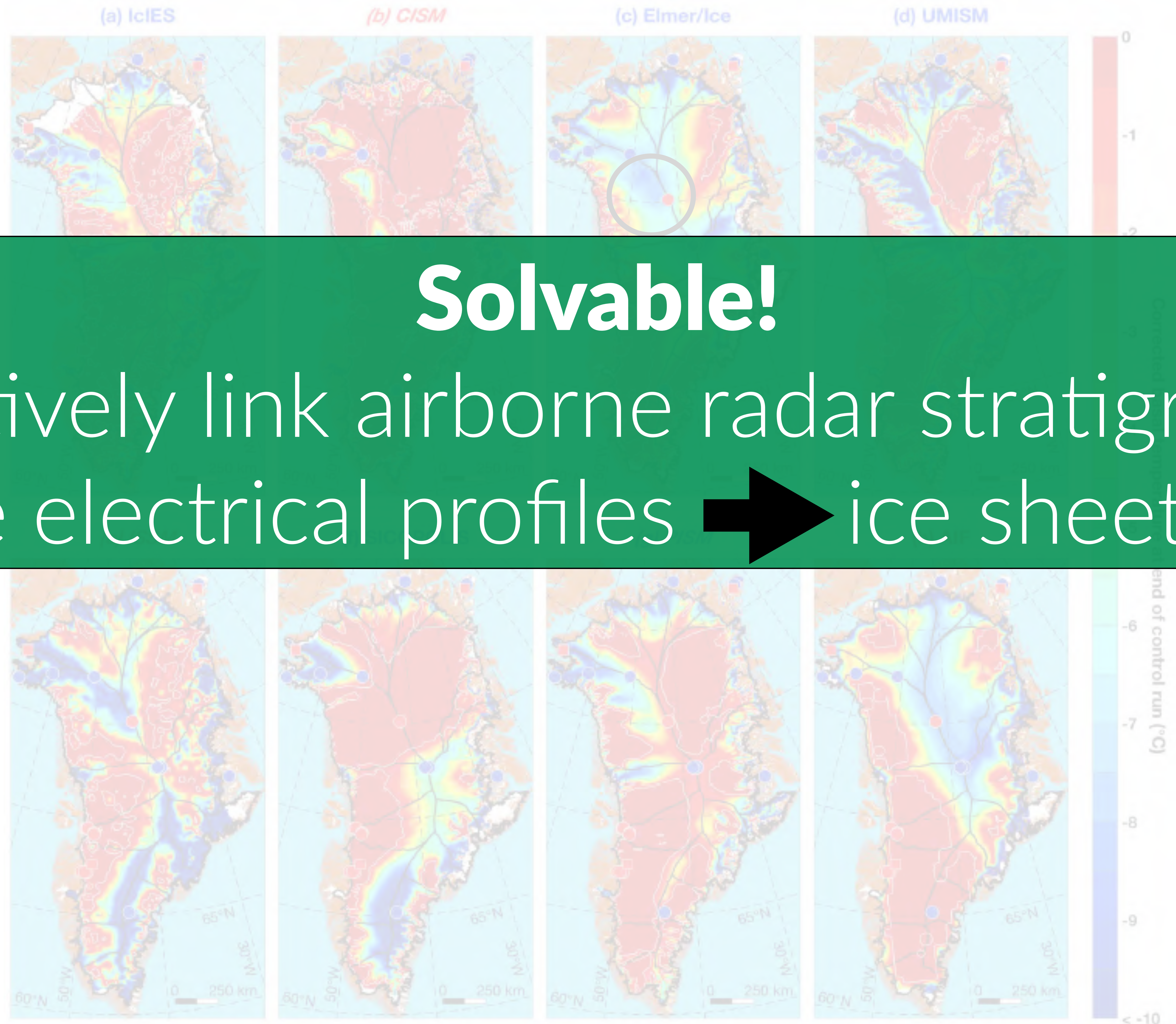
Ice sheet models have difficulty with ice temperatures in Northern Greenland

SeaRISE pressure-melting corrected basal temperatures

Wrong

Wrong rheology

Wrong ice velocity



MacGregor et al., 2016

The updated ISMIP6 experiments show the same thing!

(esp. west of NorthGRIP)

Solvable!

Quantitatively link airborne radar stratigraphy with ice core electrical profiles ➡ ice sheet models

Compelling science questions for hydrology

Question	Need	Tools
1. How does water connect from the ice surface to the bed?	Long term geophysical monitoring stations	• ApRES • Firn-Ice cores • *Joint inversion of radar & EM or seismic*
2. What's the basal thermal state of Northern Greenland?	Ice core with conductivity measurements (esp. 2/3 ice column)	• DEP measurements • GPR Transects *(overlap with airborne radar)*

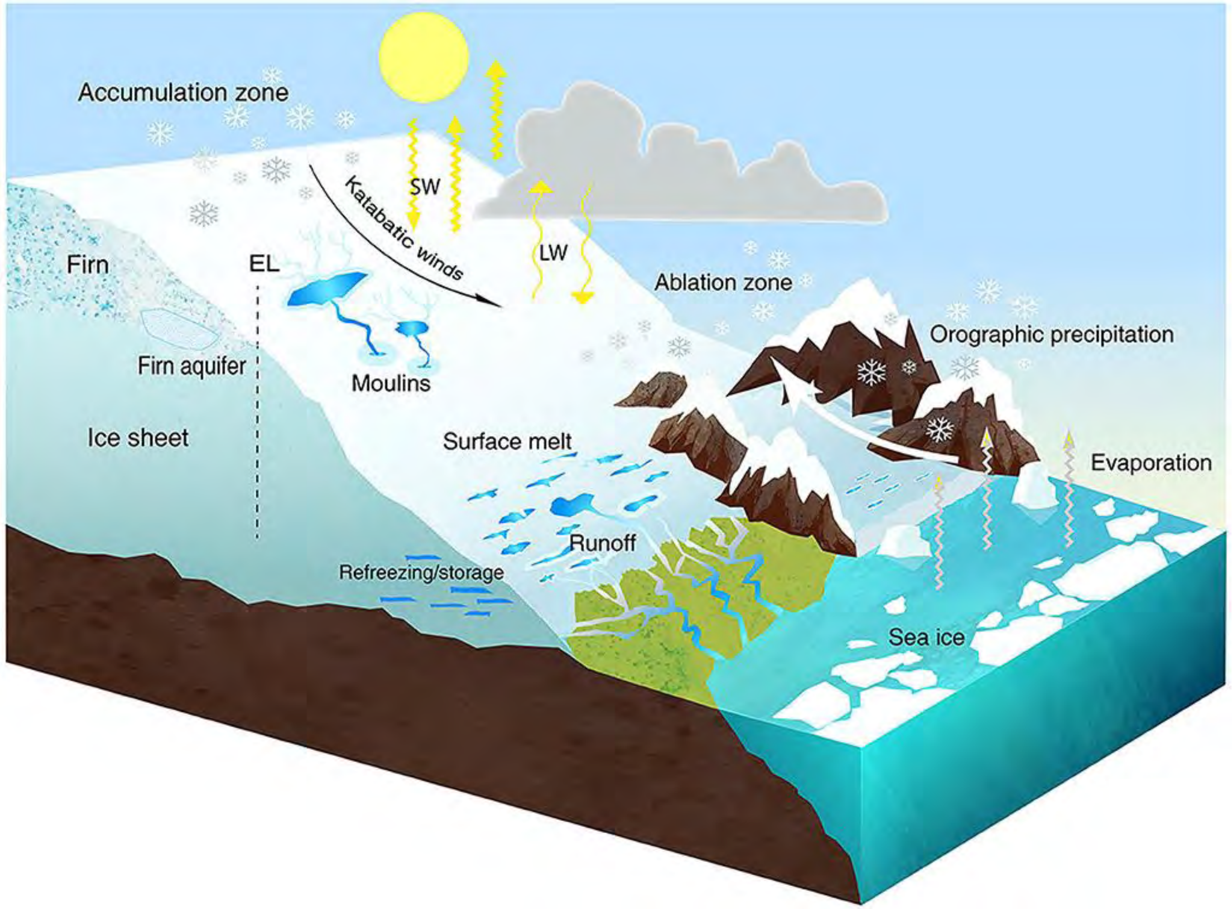
Compelling science questions: Surface Processes

Brooke Medley / NASA GSFC

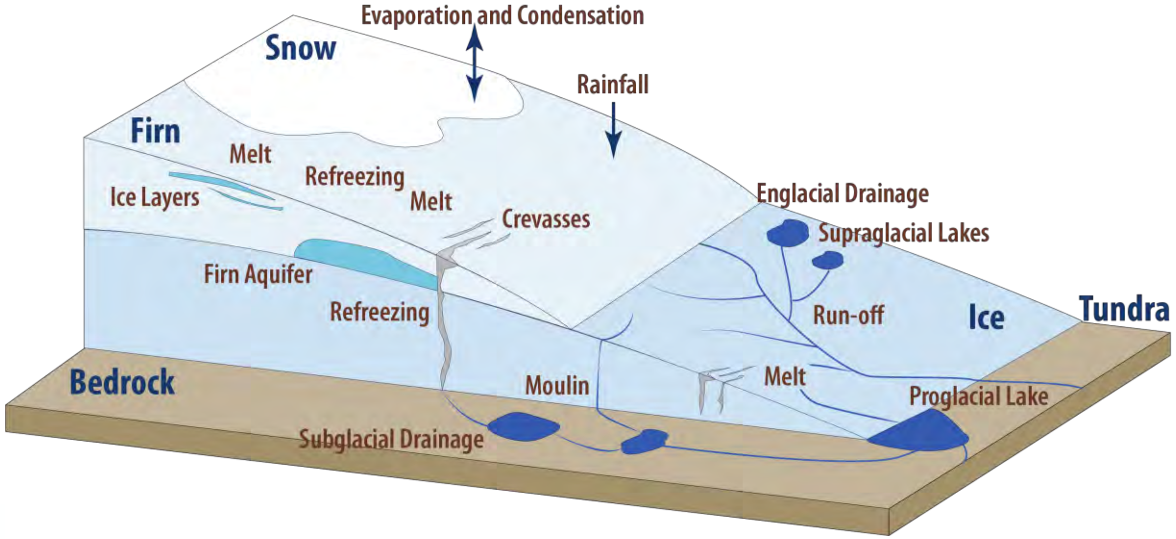
June 11, 2021

U.S. Scientific Traverses on the Greenland Ice Sheet: a Planning Workshop

GrIS Surface Processes
[to name a few...]



Lenaerts et al., *Reviews of Geophysics*, 2019



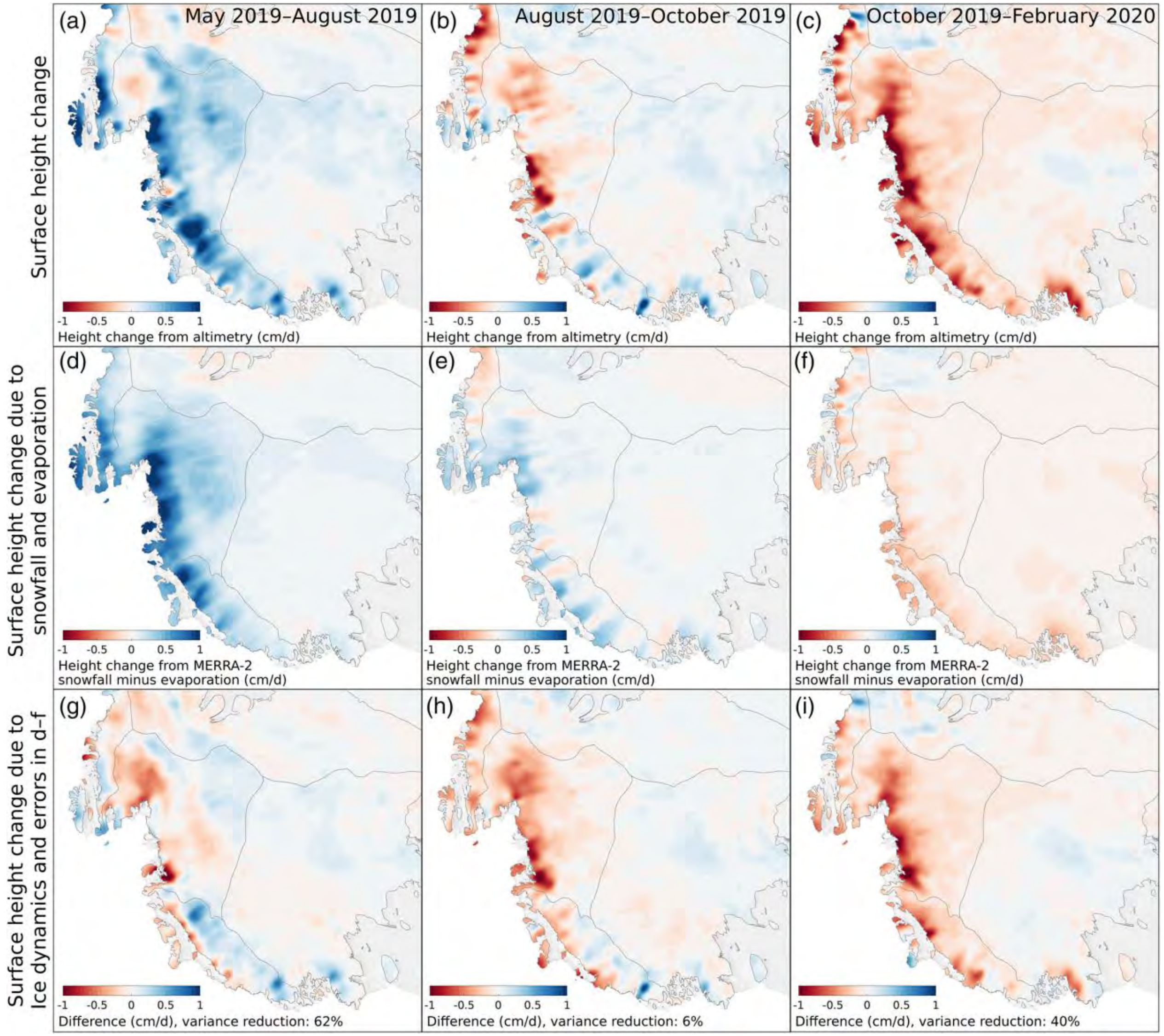
Adapted from Stager et al., *TC*, 2017

How does the ice sheet evolve on shorter time and length scales?

Observations of surface processes and their representation in firn/ice sheet models are challenged by their spatiotemporal signatures

How does the ice sheet evolve on shorter time and length scales?

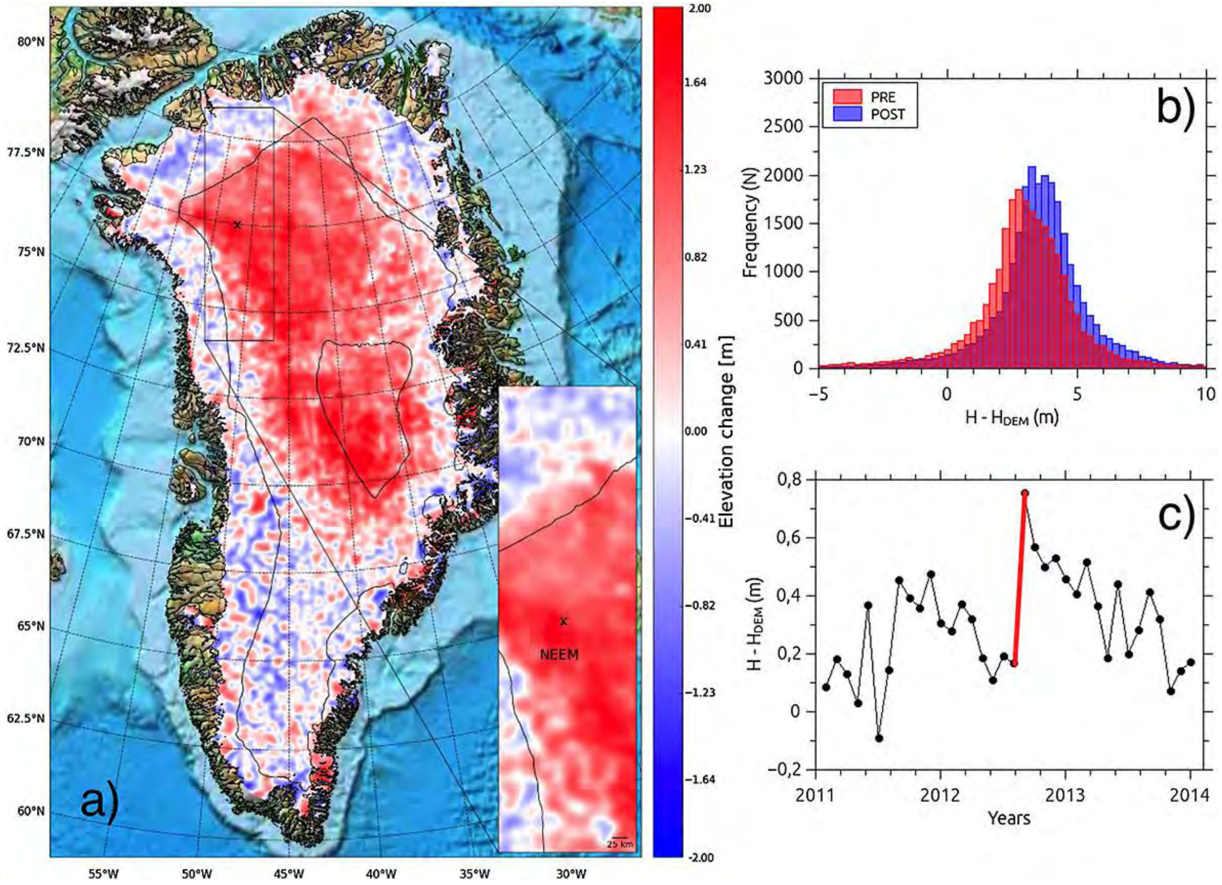
- Surface processes occur at the interface between the atmosphere and the ice sheet surface/near surface
- subject to extremes, events, seasons
- Snowfall events can “hide” underlying dynamics and droughts can mimic dynamic thinning



Adusumilli et al., *GRL*, 2021

How does the ice sheet evolve on shorter time and length scales?

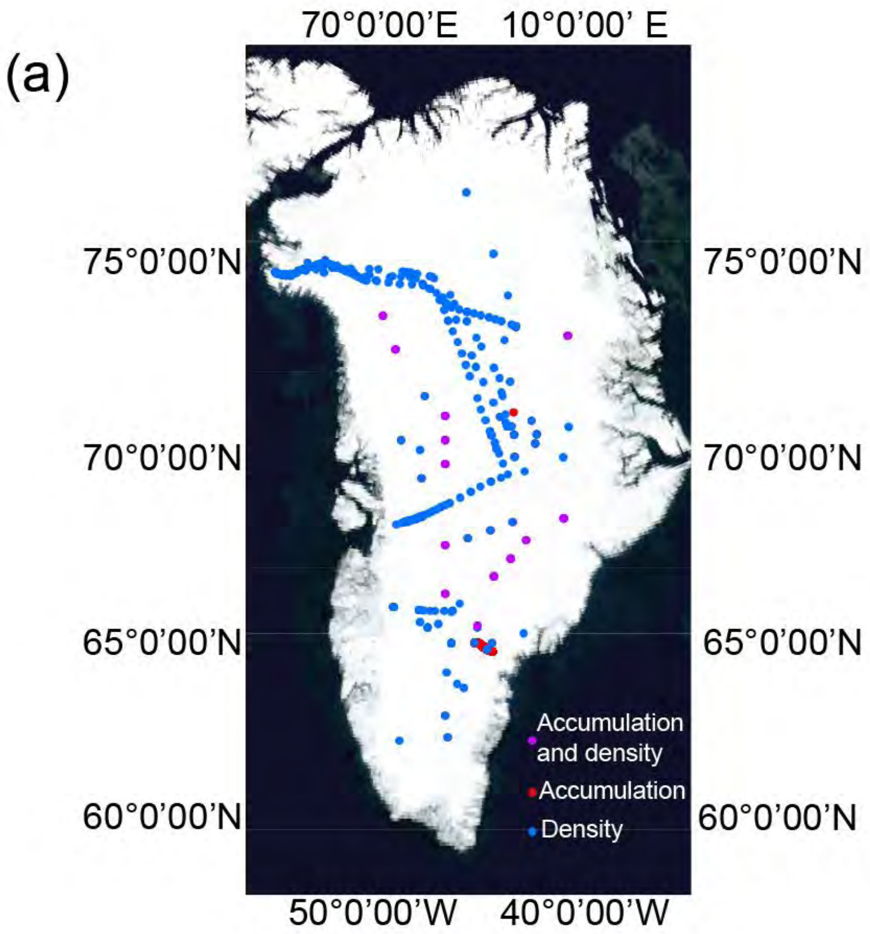
- Event-scale processes can have an immediate AND lasting impact on the firn evolution and properties
- e.g., single, extreme melt layer can inhibit meltwater infiltration
- Impacts how we *OBSERVE* ice sheets as well
- Refrozen meltwater during the 2012 melt season changed the scattering properties of the ice sheet
  - Raised the reflective surface
  - Yielding a false elevation INCREASE from CryoSat-2 radar altimetry



Nilsson et al., *GRL*, 2015

How does the ice sheet evolve on shorter time and length scales?

- Observe and understand surface processes to build better atmospheric and surface/firn models
  - leads to improved projections
- Scaling up from observations to models remains a significant challenge
  - What does meltwater infiltration/refreezing/runoff mean at the model scale (1s-10s km)?
  - How does a small lake/stream impact albedo? What if its partially frozen?
- No intermediate-scale observations to aid scaling
  - (point → grid cell → ice sheet)
- "snapshots" can't reveal dynamic processes



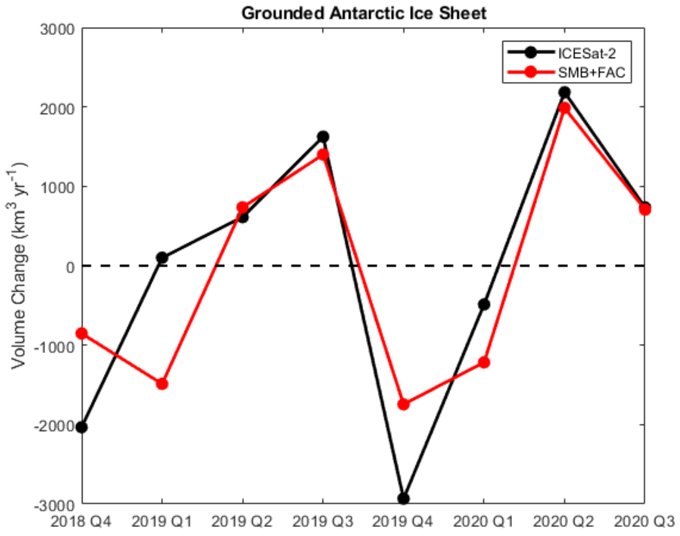
Montgomery *et al.*, *ESSD*, 2018

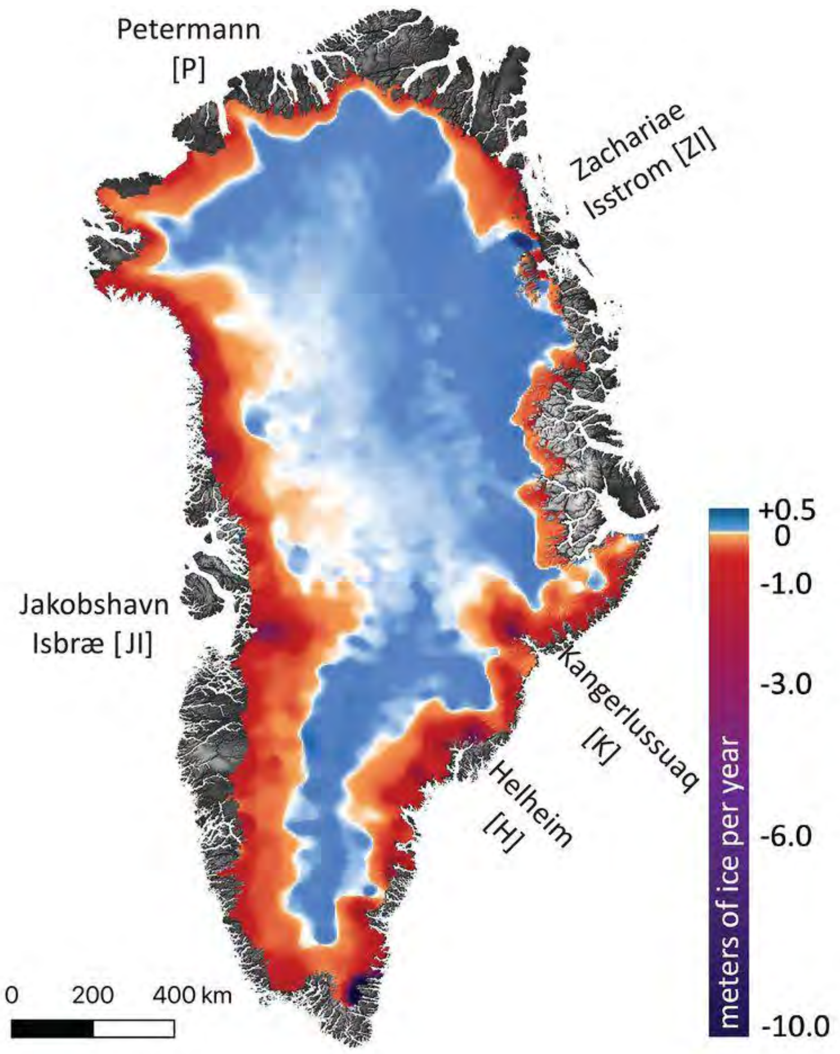
Can we disentangle observed changes into those driven by the atmosphere and ocean?

Firn evolution of the conceals dynamic changes underneath, especially considering shorter timescales

Can we disentangle observed changes into those driven by the atmosphere and ocean?

- GRACE/GRACE-FO: bulk mass change
- Altimetry: volume change
- Constraining mass balance from both requires a firn model, which are poorly constrained





Smith et al., *Science*, 2020

Thoughts on compelling science Q’s

- What are the respective contributions to GrIS mass change from the atmosphere and ocean? SMB v. Dynamics?
  - Is there seasonality? a trend?
- How has the firn structure/properties changed over the recent past, and what does it mean for future (surface) mass balance/SLR?
- How sensitive is melt/runoff to snowfall events, including their magnitude and timing?
- What is the meltwater storage capacity of the GrIS? Its vertical distribution and connectivity to the surface? What are the key drivers in its evolution (e.g., snowfall versus meltwater infiltration)?

More technical Q’s

- How do we scale point/transect observations to inform or evaluate models?
- How does the behavior of various processes scale over model resolutions (in both time and space)?
  - How much detail is necessary, and at what point is there too much?
  - Can we build parameterizations for local processes? Is it necessary?

Example Measurement Needs

Firn Model needs:

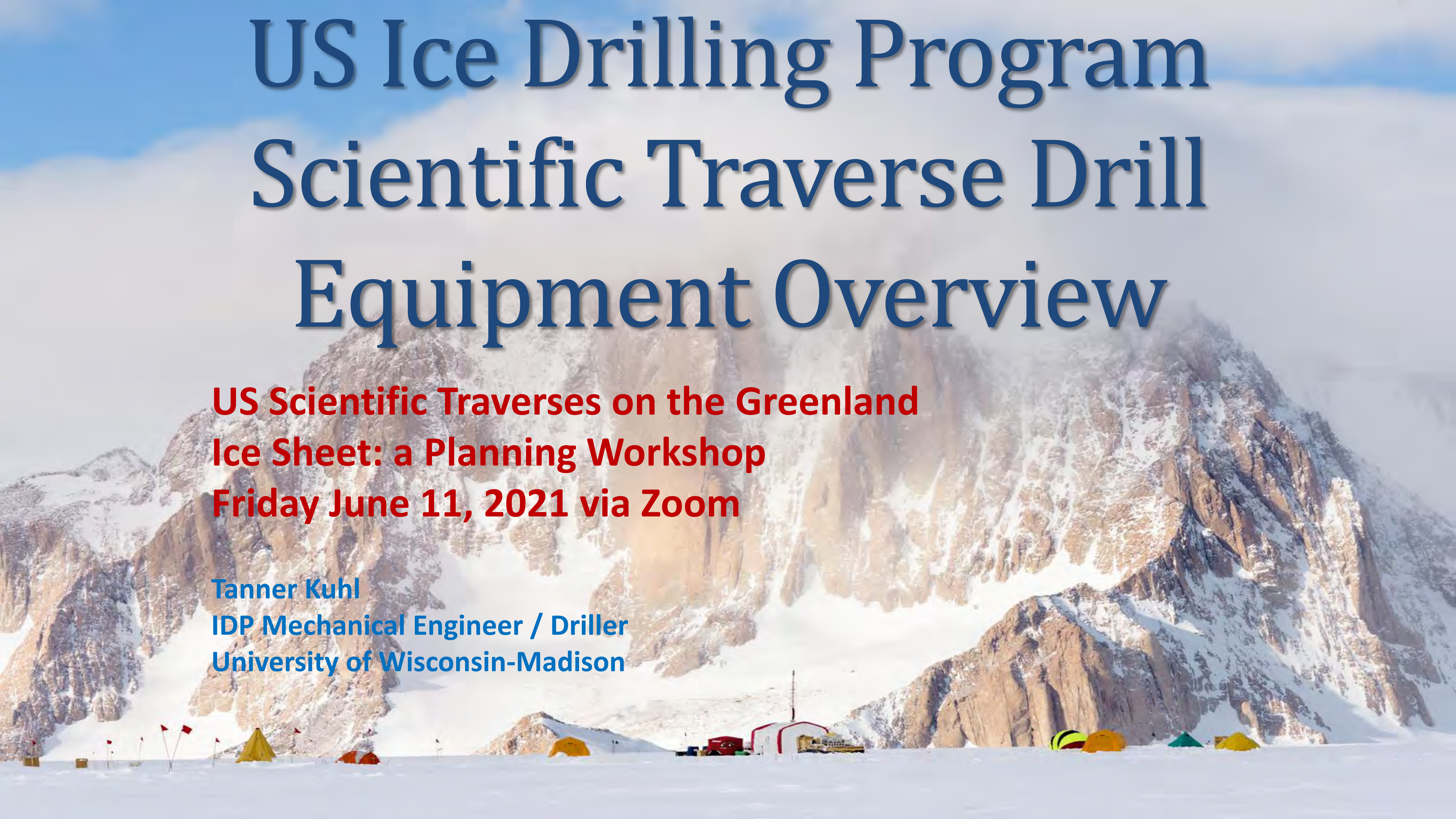
- Surface Density (lots!; big unknown)
- Depth-Density profiles (grid at model scale; investigate 3D structure)
- Repeat GPR (compaction)
- Firn strain meters
- Lysimeter (meltwater movement)
- ApRES (phase-sensitive radar; density and compaction rate)

Atmospheric Model needs:

- GPR (snow accumulation)
- AWS

Both Models:

- GNSS stations for reflectometry
- Albedo



US Ice Drilling Program Scientific Traverse Drill Equipment Overview

US Scientific Traverses on the Greenland Ice Sheet: a Planning Workshop
Friday June 11, 2021 via Zoom

Tanner Kuhl
IDP Mechanical Engineer / Driller
University of Wisconsin-Madison

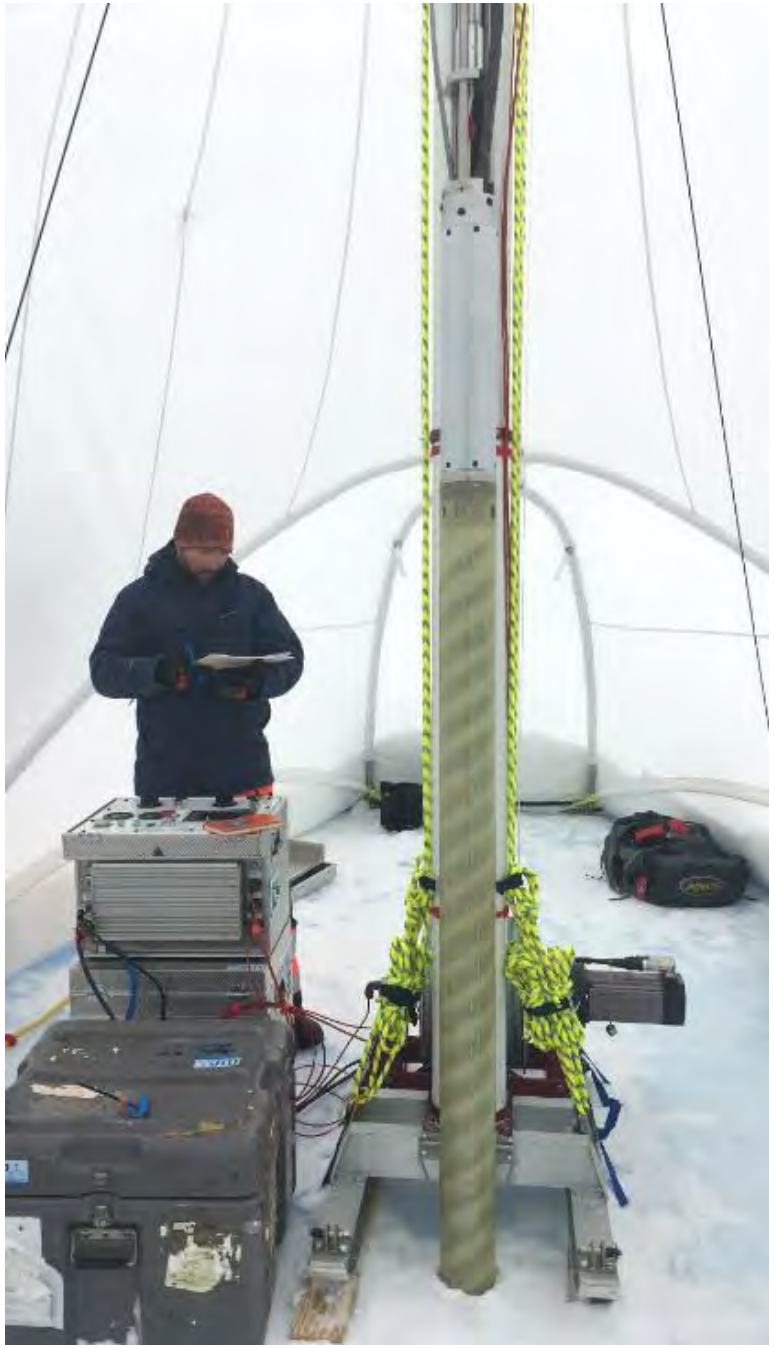
IDP Drill Systems for Scientific Traverses:

- Hand Augers, Prairie Dog, Sidewinder
  - 3 and 4-inch core diameters
  - 0 – 40 meters hole depth (max with Sidewinder winch)
  - 100 – 200 lbs shipping weight

- Agile Ice Coring Drills (Eclipse, Foro400, BID, etc)
  - 2, 3, 4, and 9.5-inch core diameters
  - 0 – 400 meters hole depth (dry)
  - 400 – 4500 lbs shipping weight
  - Requires 1-2 IDP Drillers to operate

- Non-Coring Drills (RAM, Small HWD, etc)
  - 3 – 10-inch hole diameter (4” for Ram, variable for HWD)
  - 0 – 100 meters hole depth
  - 400 – 23,000 shipping weight
  - Requires 1-2 IDP Drillers to operate, generally

- Borehole Logging Winches
  - 4000 meters max practical depth
  - 1000 – 4000 lbs shipping weight
  - Requires 1 IDP Operator, usually



IDP Drill Systems for Scientific Traverses (cont):

- Intermediate and Deep Coring Drills
  - 700-meter Drill (in development), Foro 1650 (formerly IDD), Foro 3000 (replacement for DISC Drill)
  - Large systems suitable for a fixed camp, often multi-year projects
  - Can be traversed to location, with other traverse-based scientific/drilling activities continuing in the area

- Rock, Mixed Ice/Rock Coring
  - Agile Sub-Ice Geological Drill (ASIG)
  - Winkie Drill
  - Detailed slides to follow

Visit https://icedrill.org/equipment

- Current Drill Inventory
- System Availability
- System Comparison Charts
- In-Development System Info
- Equipment Request Form

Best source of information on IDP projects and equipment

IDP Bedrock Coring Drill Systems:

Winkie and ASIG Drills

- Designed to drill through firn/ice to reach bedrock for subglacial sampling
- Firn cored or augered to reach impermeable ice
- Permeable layers are cased and sealed to impermeable ice with an inflatable packer
- Ice drilled in a continuous manner with a full-hole bit
- Ice and rock core recovery via wireline
- Continuous drilling fluid circulation and chip filtration
- Drilling fluid can be recovered/reused at project completion

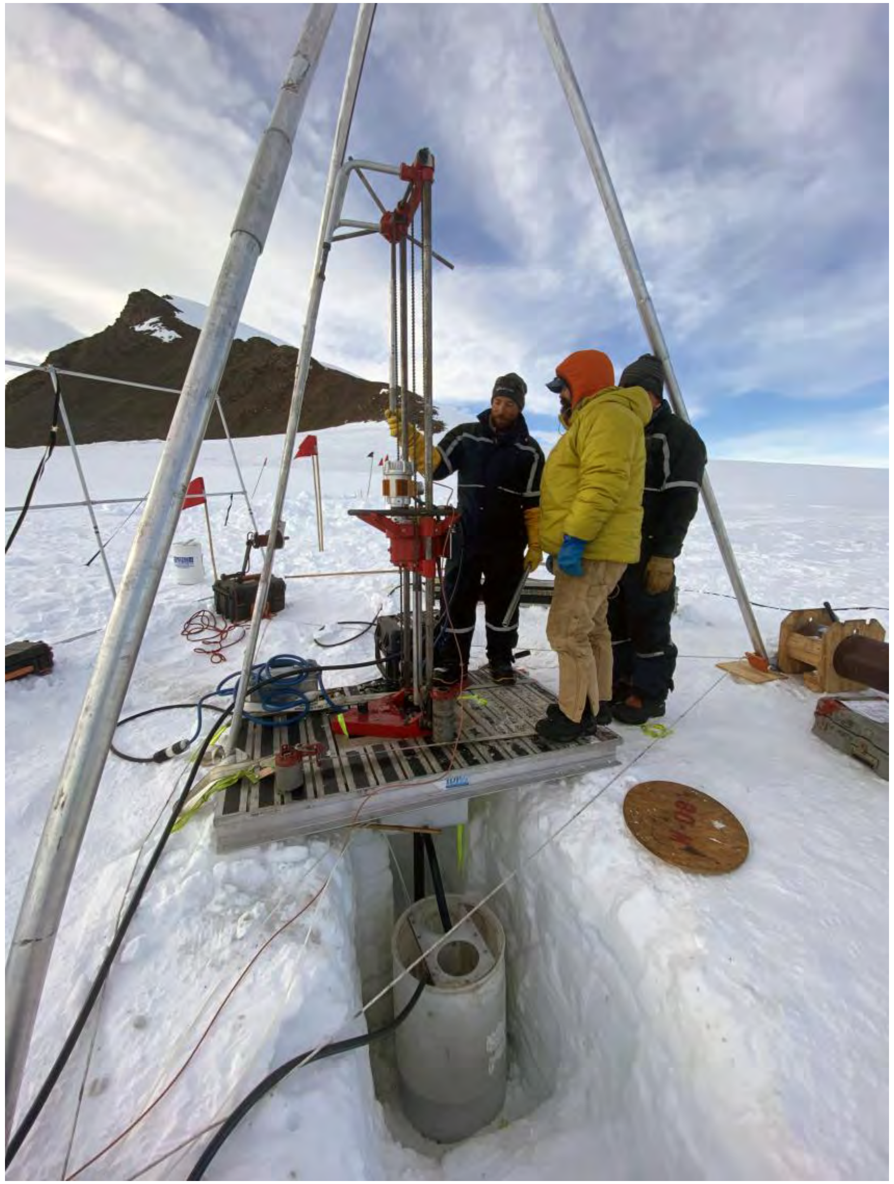
Requires frozen subglacial environment

US Ice Drilling Program

Winkie Drill System

Specifications

Drill Type	Surface Driven Rock Coring Rig	
Power Unit	Brushless DC Electric Motor, 3kW	
Drill Sting	Rigid, Single Wall Drill Rod	
Rod Tripping Mechanism	Tripod with Capstan Winch	
Drill Fluid	Isopar K	
Fluid Filtration	Yes, Gravity Forced Filter Bags	
Rod/Core Barrel Configuration	AW34	86T2
Core Size [mm]	33.4	71.7
Maximum Core Length [m]	1.52	3
Available Bit Configuration	Impregnated, GeoSet, PDC	Impreganted, GeoSet, PDC
Depth Capacity [m]	120	Untested
Drill Rod Material [-]	Aluminum (steel couplers)	Steel
Rod Weight [lbs/m]	5.9	11.3



Performance/Operation

- Set-Up
  - Drill set up can be achieved with 1-3 people. In good conditions, the drill can be set up in 4 hours.
    - During the 2016-17 field season the drill was disassembled, moved ~2 km, and reassembled at the new site all in the same day
- Operation
  - A minimum of two people is required to operate the drill. However, 3 operators can increase the production rate
  - Penetration Rate – Ice Auger
    - 25 m/hr (includes tripping augers out of the borehole)
  - Penetration Rate – Ice/Dirty Ice Coring
    - 3 to 5 m/hr
  - Penetration Rate – Rock
    - 0.5 to 3 m/hr

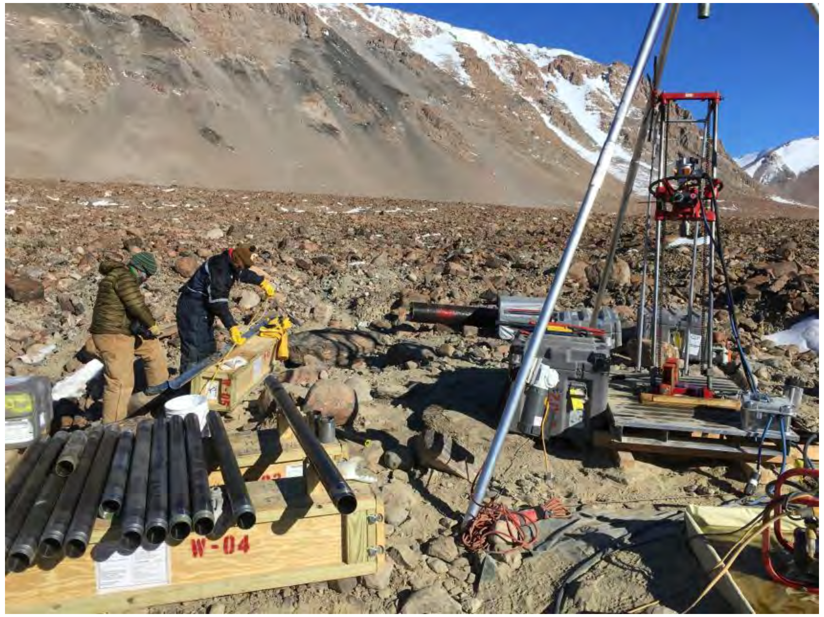
Cargo Logistics

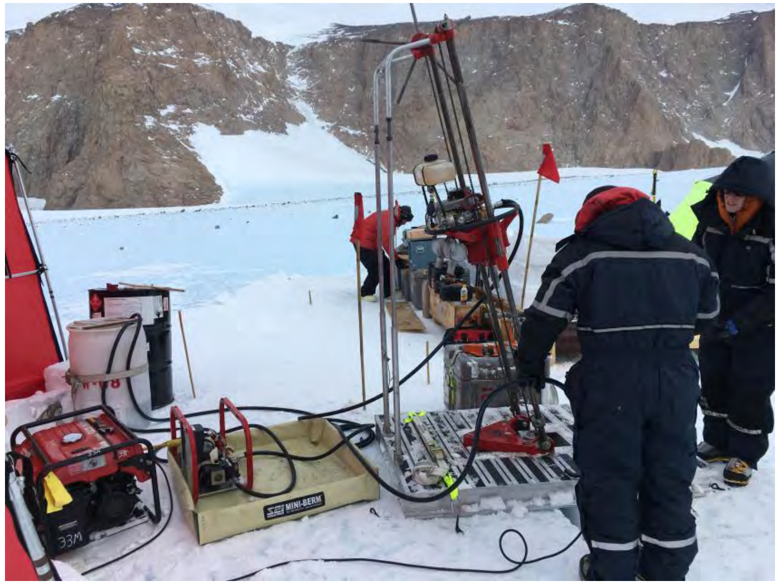
- Weight/Volume – Total weight and volume is highly dependent on depth and core diameter requirements

Component	Weight [lbs]	Volume [ft^2]
Drill Rig (IDDO Supplied)	1280	78
Drill Equipment (SIP Requests)	600	64
AW34 Drill Rod (68m)	510	24
86T2 Drill Rod (40.5m)	735	30
Drill Fluid [4 drums*]	1476	40
Fuel	370	10
TOTAL	**4250 minimum**	**216 minimum**

*4 drums of fluid were sent to Ohio Range but fluid requirements will vary with drill site

- All pieces of cargo will fit into a Twin Otter or a sling load for helicopter transport
- The maximum single piece weight (excluding drill fluid drums) is 250 lbs.
- The drill can be transported with minimal disassembly via a Siglin sled and snowmobile
- Potentially suitable for a snowmobile traverse, depending on project details





Agile Sub-Ice Geological (ASIG) Drill

US Ice Drilling Program

ASIG Drill System Specifications

Drill Type	Surface Driven Rock Coring Rig
Power Unit	4ct. Kubota D1105-T-E35B Diesel Engines (33 hp each)
Drill Sting	Rigid, Single Wall Drill Rod (Sandvik WL56)
Rod Tripping Mechanism	Rig mast hydraulics/chuck
Drill Fluid	Isopar K (Exxon-Mobil)
Fluid Filtration	Continuous - shaker table, secondary filter, chip melter
Rod/Core Barrel Configuration	Sandvik WL56 thin-kerf metric
Core Size [mm]	39 (larger core possible with different drill rod)
Maximum Core Length [m]	1.5 or 3.0
Available Bit Configuration	Hardened Steel (ice), Diamond-impregnated, GeoSet, PDC
Depth Capacity [m]	700 (~1500m max with modifications, needs testing)
Drill Rod Material	Steel
Rod Weight [lbs/m]	8.5 (for 39mm core)

ASIG Drill Performance/Operation

# of Operators	3 drillers, 1-2 core handlers (depending on core reqs.)
Initial System Assembly (hours)	30
Time-to-Depth (200m, 10m core, hours)	50
Time-to-Depth (700m, 10m core, hours)	100 (estimated)
Pilot Hole (auger, casing, m/hr)	10
Access Hole Drilling, total (m/hr)	8
Coring, total (m/hr)	1
Auger max. ROP (firn, m/min)	1
Ice max. ROP (non-coring, m/min)	1
Rock max. ROP (coring, m/min)	0.15
System Disassembly/packing (hours)	20

Approximate Time On-site:

200-meter Hole with 10m rock core recovery = 100* working hours (4-5 people)

700-meter Hole with 10m rock core recovery = 150* working hours (4-5 people)

***deep firn, drilling problems, mechanical issues, weather, etc. will significantly increase hours to completion**

ASIG Drill Transport Logistics

- System deployed via light aircraft, heavy-lift aircraft, or tractor traverse
- Heavy equipment not needed for assembly, but does speed operations
  - 600 lbs max single-piece weight
- Weight is highly dependent upon project requirements
  - # of holes
  - Firn depth
  - Bedrock depth
  - Spares*

*Spare components and extra drilling fluid improve project success, but increase system weight significantly.

Sample System Weights for Shallow and Deep Projects

DRILL EQUIPMENT		
Depth	200m	700m
Drill Rig	4565	4565
Drill Rod	1990	6971
Tools /Equipment	6533	6608
Equipment Weight (lbs)	**13088**	**18144**
Twin Otter Flights *	6-8	8-10
CONSUMABLES		
Depth	200m	700m
Casing	310	310
Drill Fluid	2749	7588
Fuel	2649	4013
Consumables Weight (lbs)	**5708**	**11911**
Twin Otter Flights *	3-4	6-8
TOTAL		
Total Weight (lbs)	**18796**	**30055**
Total Twin Otter Flights *	**9-12**	**14-18**

*one-way

Questions?

For more information visit:

https://icedrill.org

AGENDA 6-11-2021

U.S. Scientific Traverses on the Greenland Ice Sheet: a Planning Workshop

Friday June 11, 2022 via Zoom

Sponsors: U.S. Ice Drilling Program & Summit Science Coordination Office

Conveners: Joerg Schaefer, Mary Albert, Jason Briner, Zoe Courville

All times are Eastern time zone

Opening Remarks

11:00 Welcome and workshop charge: Joerg, Jason, Mary & Zoe

11:05 NSF Remarks: Jen Mercer

Compelling science questions needing ground-based measurements on the GIS: short presentations

11:15 The ice sheet bed: GreenDrill and more– Joerg Schaefer and Jason Briner

11:25 Ice core evidence of past conditions – Erich Osterberg

11:35 Surface mass balance – Bob Hawley

11:45 Hydrology – Winnie Chu

12:00 Ice sheet surface processes - Brooke Medley

12:10 Drilling technology – Tanner Kuhl

12:20 Q&A and Discussion

12:45 BREAK – 15 minutes

Future science questions requiring a scientific traverse on the GIS: 5-minute 'pitches'

1:00 Pitches: 5 minutes for each presentation: what, why, where

- **Guy Paxman**: Paleo-lake basin sediments near Camp Century: a target for future seismic reflection surveying and/or subglacial drilling
- **Joe MacGregor**: Opportunities for surface sampling and ground-based geophysics across the Greenland Ice Sheet
- **Greg Balco:** Cosmogenic-nuclide concentrations in interior Antarctic nunataks preserve a multimillion-year record of ice sheet change. Is there anything like that in Greenland?
- **Zhen-Tian Lu**: 81Kr dating of oldest ice on Greenland
- **Knut Christianson:** Multipass profiling radar measurements to map Greenland Ice Sheet englacial velocities
- **Nathan Chellman**: Importance of understanding upstream deposition for flank sites
- **Juliana D'Andrilli**: Deciphering local and regional modern organic signatures across Greenland
- **William Colgan**: Benson 2.0: Multi-season overland traverses from Thule and Kanger to drill a transect of deep temperature profiles in areas where subglacial temperature is unknown.
- **Adrian McCallum**: Cone Penetration Testing (CPT) - a simple and repeatable means of assessing mass balance
- **Ken Mankoff: Snowmobot 1000: A fleet of general-use autonomous snowmobiles**
- **Dorthe Dahl-Jensen:** Ice cores, boreholes, and basal material

BREAK: 10 minutes

2:30 Discussion: identify breakout groups for white papers

3:00 Instructions for breakout groups / generic form for the white papers

3:10 Breakout group work: outline the white paper content, then make a plan for completing the writing

4:00 Reporting back to the whole group

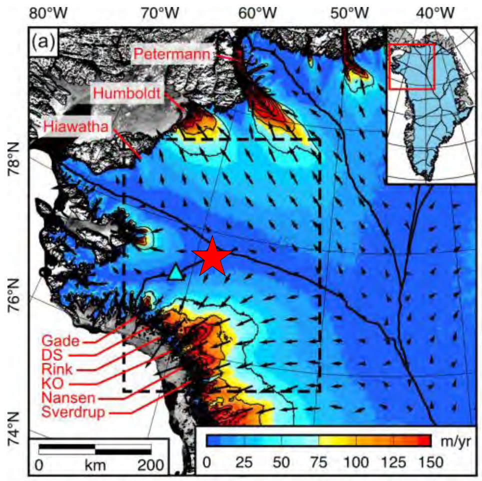
4:30 Discussion

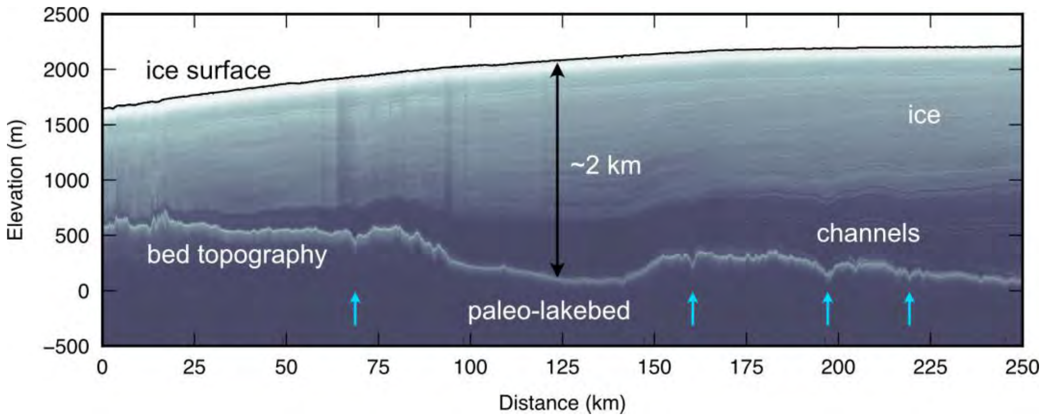
4:45 Workshop summary, timeline, and instructions for completing the white papers

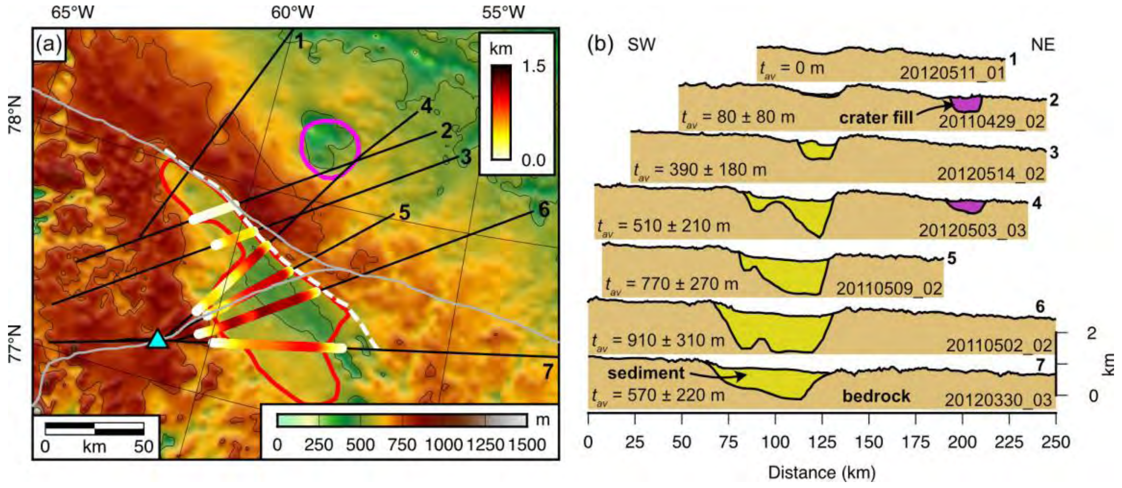
5:00 Meeting adjourned

A geophysically-imaged paleo-lake basin near Camp Century

Guy Paxman, Jacky Austermann, Kirsty Tinto
Lamont-Doherty Earth Observatory





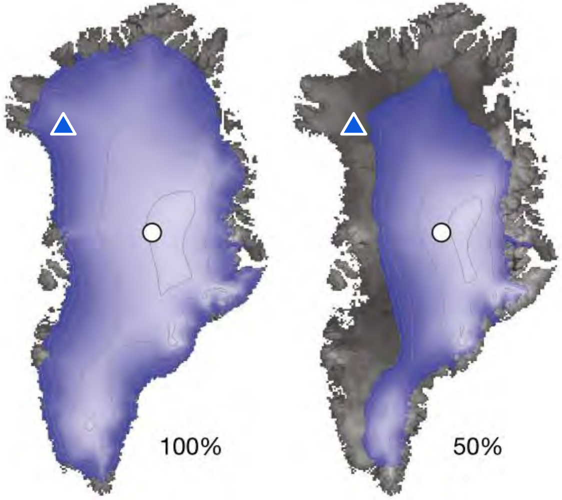


- ~100 km from Camp Century
- 150 km long, 20–60 km wide
- Ice thickness is 1.8–2.0 km
- Smooth basin floor
- Ice-free hydrological sink
- Up to ~1 km of sediment infill

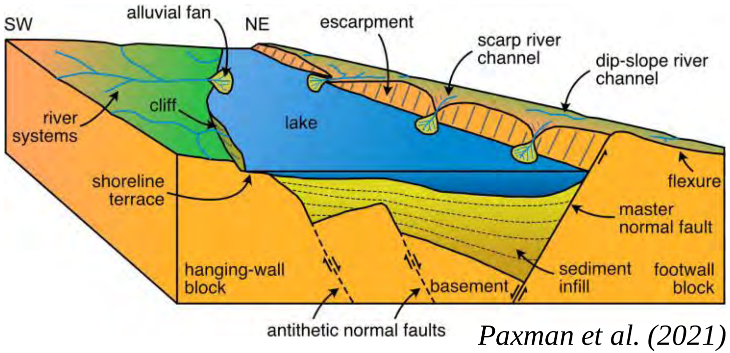
Paxman et al. (2021)

Science questions and future measurements

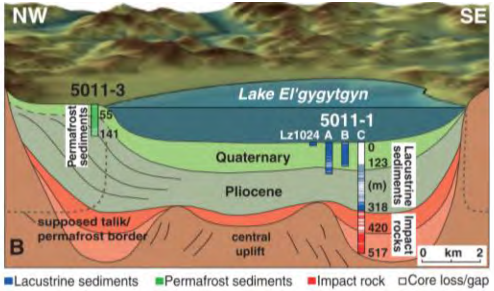
- ***Paleo-lakebed sediments:*** may provide a record of ice sheet, climate, and environmental change during past warmer climates
- ***Close to Hiawatha impact crater***: may contain ejecta deposits
- ***Structure of the basin***: insights into regional geology, tectonics, ice sheet boundary conditions, landscape antiquity



Schaefer et al. (2016)



Paxman et al. (2021)



Brigham-Grette et al. (2013)

<u>Potential future measurements</u>

- Seismic reflection survey: basal conditions, basin structure
- Drilling: shallow (1–10 metres) sediment recovery; paleo-climate and ice extent proxies
- Drilling: deep (100s metres) sediment coring; continuous record of past climate, glacial history, environmental conditions (drilling technology permitting!)

Timeframe: a field season for each of the above?

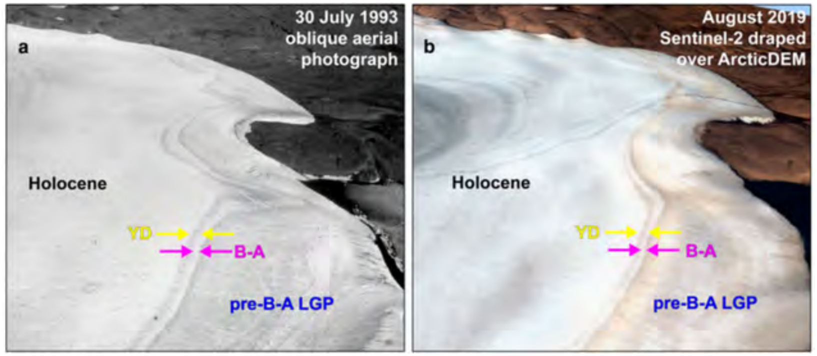
Opportunities for large-scale surface sampling of pre-Holocene ice in northern Greenland

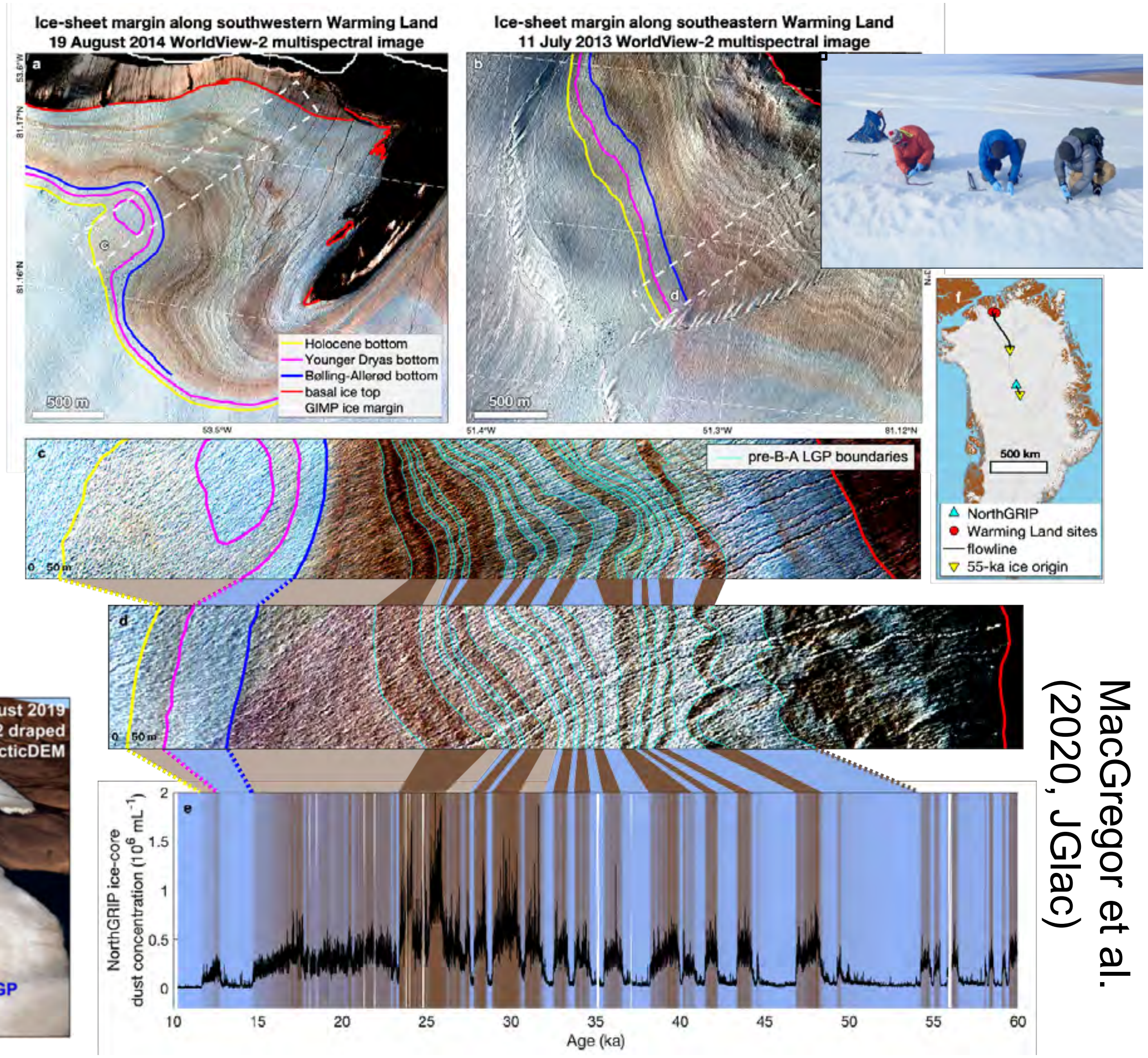
♨️ 🍰 Greenland is warming and its past is exquisitely preserved at Warming Land's ice margin.

🧊 🧪 Some paleoclimatic analyses still need large ice volumes and developing newer ones may be easier with more ice. Conformable marginal ice can fulfill that need.

👩🏾‍🚀 🌕 🪐 💪 Marginal ice sampling is a useful analog to some planetary missions being formulated (e.g., sampling of Mars' northern polar layered deposits).

⏳ Hours for reconnaissance sampling to days for larger volumes or more precise sampling.





MacGregor et al. (2020, JGlac)

Opportunities for ground-based radar sounding of unsurveyed and under-surveyed subglacial structures

NASA's Operation IceBridge has ended. New, extensive airborne surveys of the Greenland Ice Sheet could be many years away.

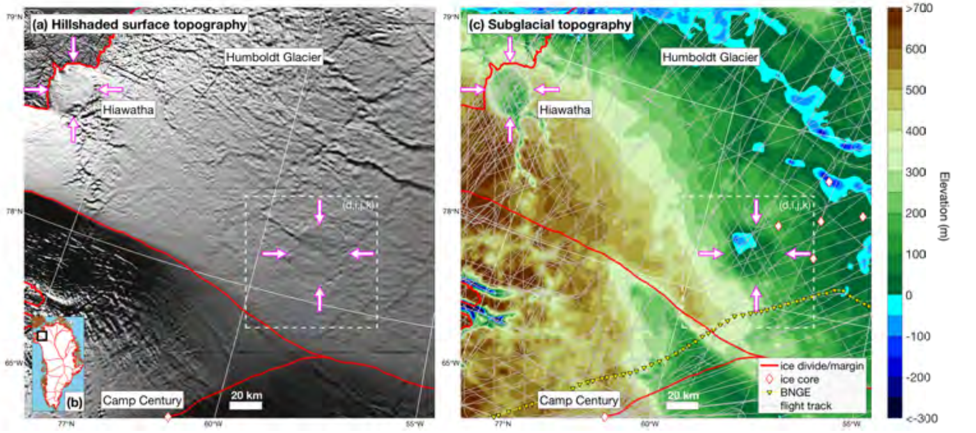
There are *many* places in Greenland's interior where surface relief hints at under-surveyed or unsurveyed subglacial structures. Lots left to discover!

Targeted, ground-based radar sounding of subglacial structures along or near traverse routes is straightforward.

Ground-adapted versions of newer ultrawideband radar sounders can detect subglacial groundwater and better resolve disrupted basal ice structures with disputed origins.

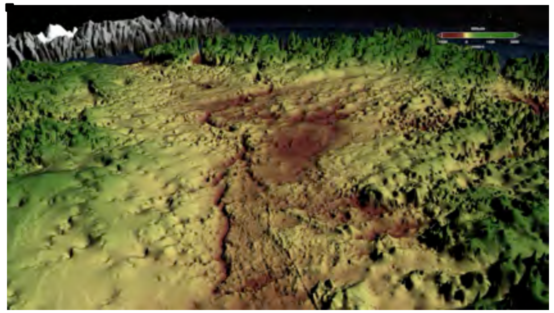
Hours to days; en-route or spin-off surveys.

Compelling under-surveyed structures



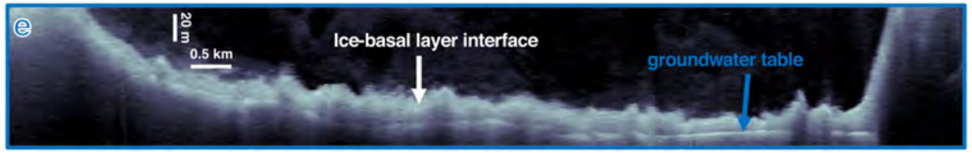
MacGregor et al. (2019, GRL)

Lots of unconnected "holes" remain



Morlighem et al. (2014, NG)

New tools: MCoRDS v5 on Basler



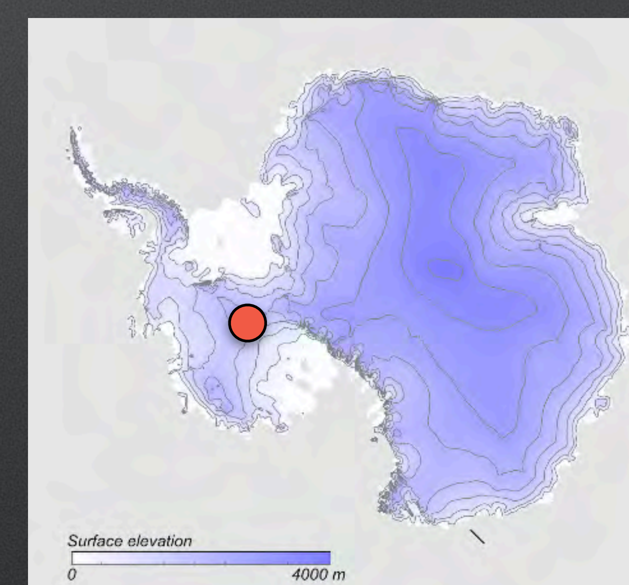
Bessette et al. (2021, GRL)

GREENLAND SCIENCE TRAVERSE COSMOGENIC-NUCLIDE DATA FROM BEDROCK?

The Whitmore Mountains, in the middle of West Antarctica.

Nunataks in the high-elevation interior of Antarctica have incredibly low erosion rates and enormously high cosmogenic-nuclide concentrations.

These are the Whitmore Mountains, in the center of the West Antarctic Ice Sheet. Bedrock exposed on these peaks has cosmogenic-nuclide ages up to 14 Ma. Basically, neither weathering or glacial erosion has happened during this time.



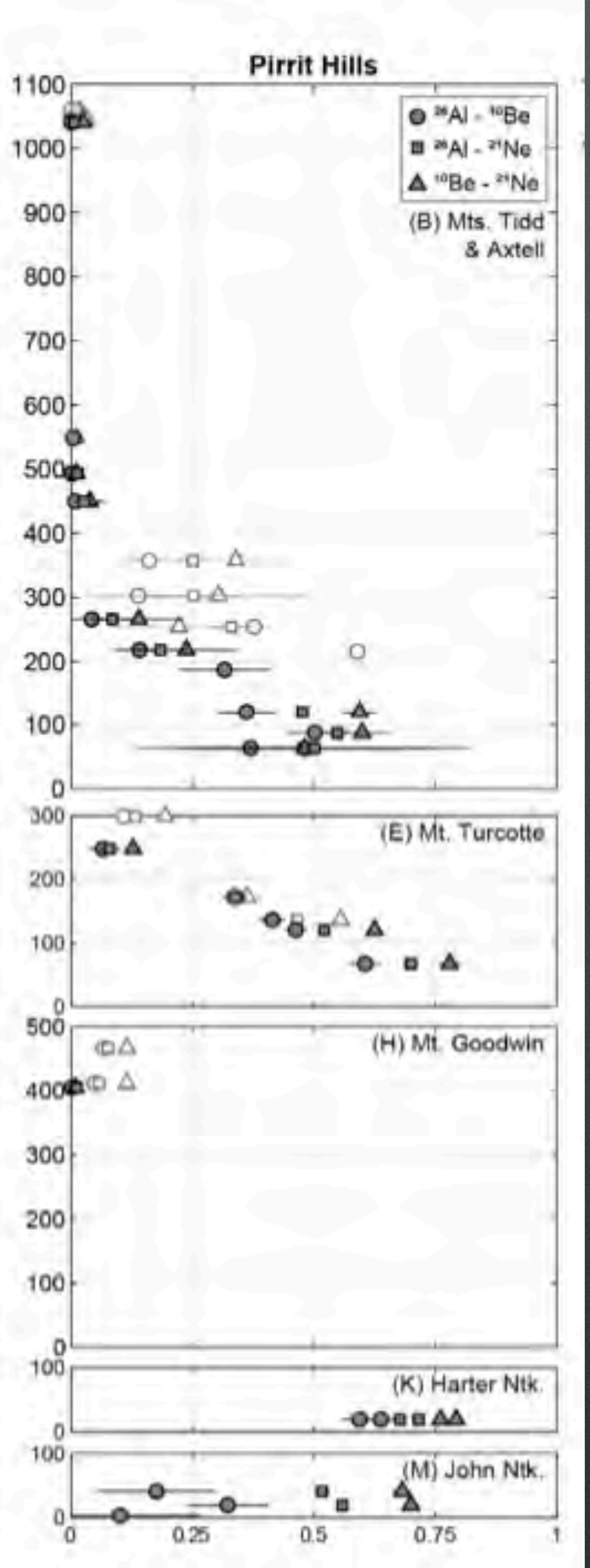
GREENLAND SCIENCE TRAVERSE COSMOGENIC-NUCLIDE DATA FROM BEDROCK?

The Pirrit Hills, also in the middle of West Antarctica, from Spector et al. (2020).

Much of the exposed topography of these peaks has been covered by the ice sheet in the past. However, because the ice sheet is always frozen to the bed at these elevations, there is no subglacial erosion.

We can tell this from measurements of cosmogenic-nuclide concentrations in bedrock, because concentrations of multiple nuclides with different half-lives can either be in equilibrium with each other if the surface is continually exposed, or out of equilibrium if the surface is periodically covered by ice.

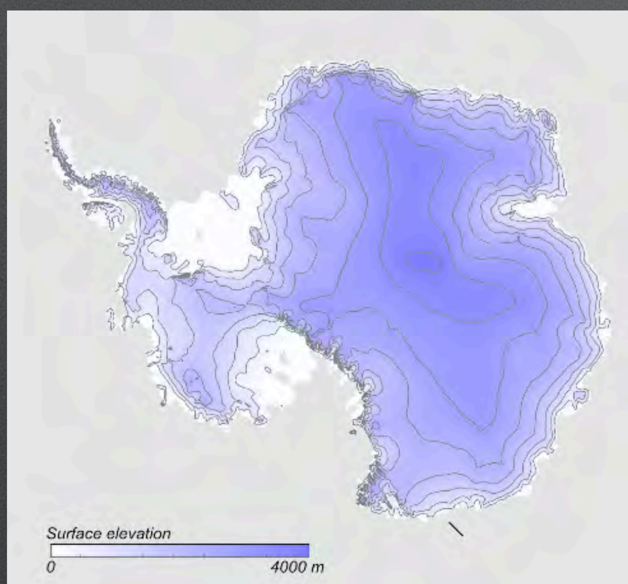
Summit samples show no evidence of exposure. Lower-elevation samples have been covered for up to 50% of their exposure history, which may extend back to 12-14 Ma.



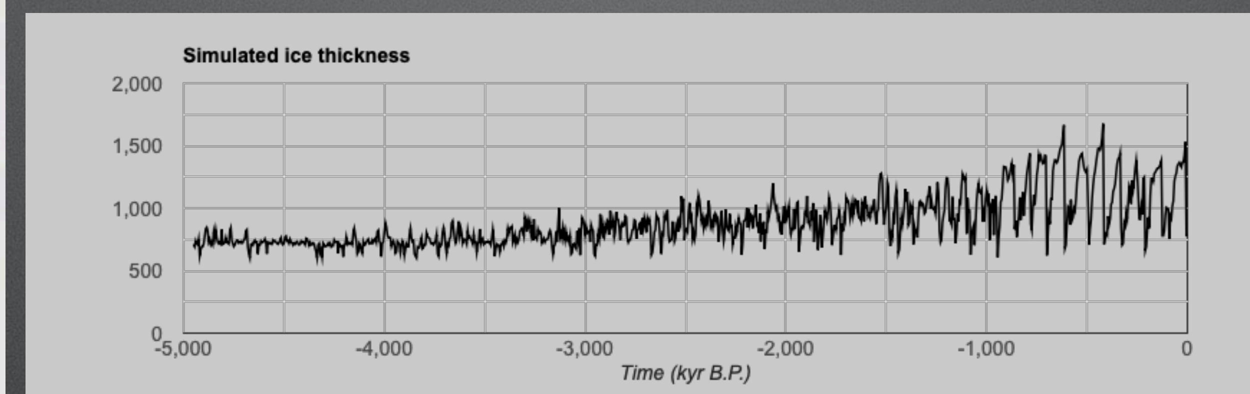
Fraction of exposure history covered by ice

GREENLAND SCIENCE TRAVERSE COSMOGENIC-NUCLIDE DATA FROM BEDROCK?

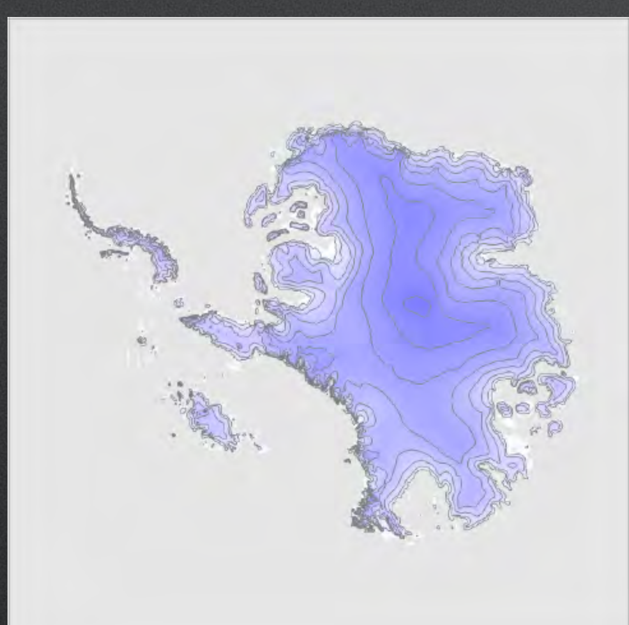
Estimates of cumulative ice cover frequency are interesting for lots of reasons, but one important one is that they are observable data that can be compared to models of long-term ice sheet change. This is a potential way to address the fundamental challenge of the absence of evidence of absence of ice sheets during past warm periods.



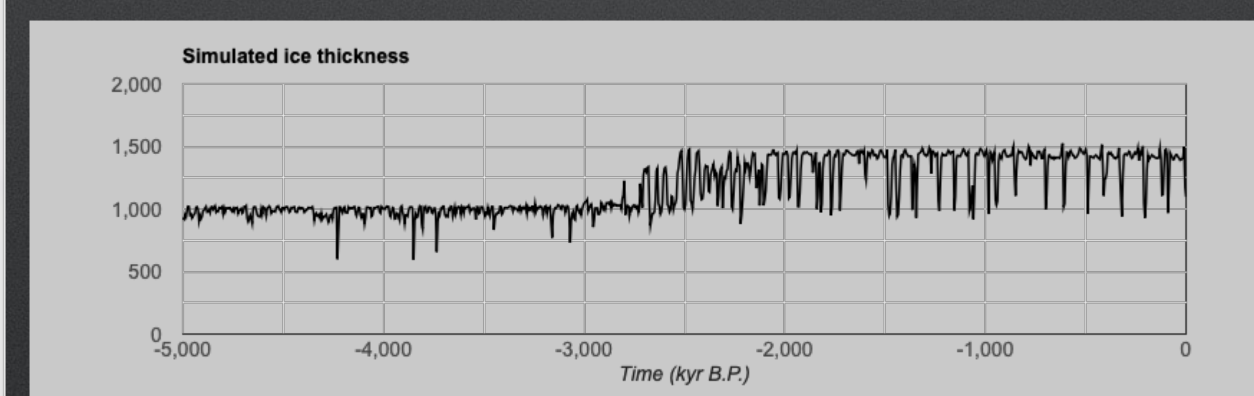
Ice sheet models WITHOUT strong nonlinear feedback (e.g., marine ice margin instabilities) predict interglacial states similar to the present and a high frequency of intermediate states.

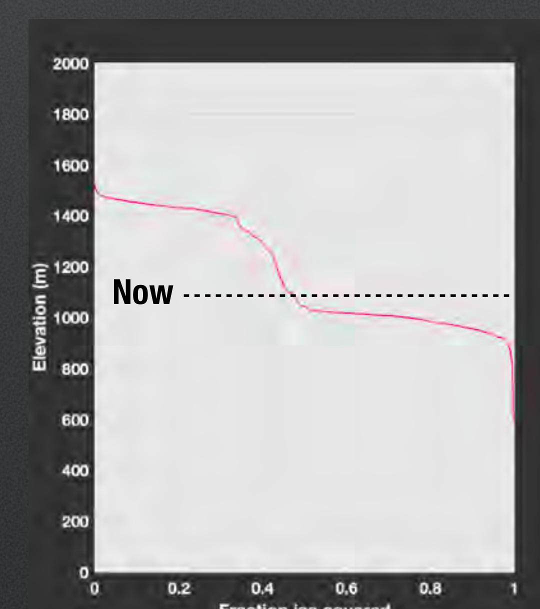


Ice cover frequency distributions: very different.



Ice sheet models WITH strong nonlinear feedback (e.g., marine ice margin instabilities) predict extensive marine sector collapses and have a high frequency of end member conditions.

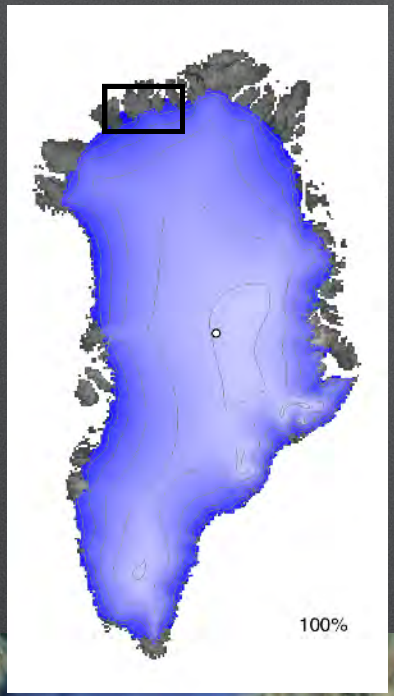




Model runs by Perry Spector using PSU ice sheet model

GREENLAND SCIENCE TRAVERSE COSMOGENIC-NUCLIDE DATA FROM BEDROCK?

Are there any bedrock exposures with anything like this kind of long exposure history in Greenland?



No one has looked. There are no cosmogenic-nuclide data from bedrock exposures in relatively cold and dry areas of Greenland where we would expect to see low erosion rates and surface preservation under frozen-based ice.

They might not exist, because (i) the geometry of exposed rock in Greenland and Antarctica is quite different, and (ii) Greenland is warmer, wetter, has vegetation, and is likely to have much higher erosion and weathering rates everywhere.

If they exist, they are probably in northern Greenland somewhere.

^{81}Kr Dating of the Oldest Greenland Ice

Zheng-Tian Lu, University of Science and Technology of China (USTC)
ztlu@ustc.edu.cn atta.ustc.edu.cn

Noble-gas advantages:

- Stable and uniform distribution in the atmosphere around the world
- Ice dirty, disturbed? No problem

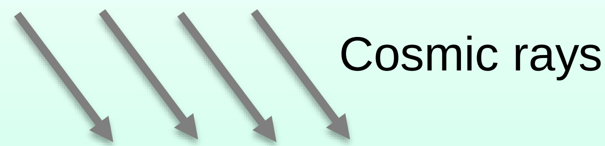
$$\frac{[^{81}Kr/^{83}Kr]_{sample}}{[^{81}Kr/^{83}Kr]_{air}} = 2^{-\left(\frac{\text{Age}}{\text{Half-life}}\right)}$$

^{81}Kr and ^{39}Ar are ideal isotopes for dating - Loosli & Oeschger, EPSL (1969)

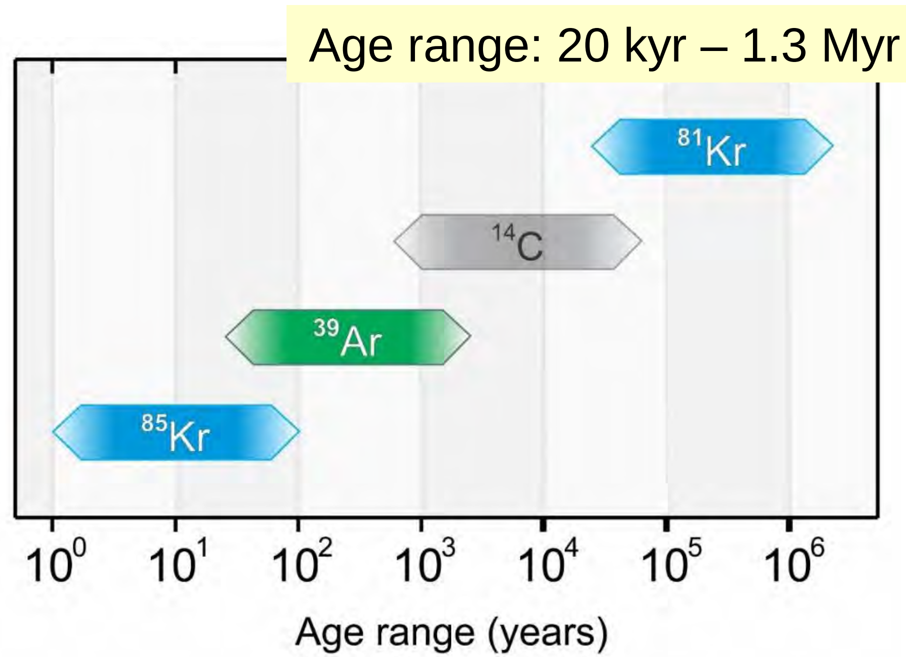
Technical challenges:

Isotopic abundance: 1 x 10^{-12}

Atoms per kg of ice: ~ 3000

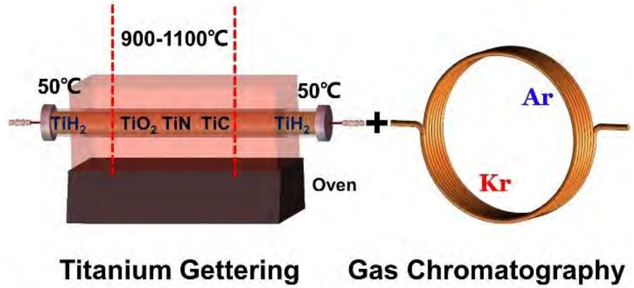


$^{80}Kr(n, \gamma)^{81}Kr$ Half-life: 230 kyr



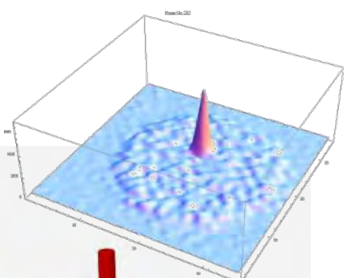
Atom Trap Trace Analysis (ATTA)

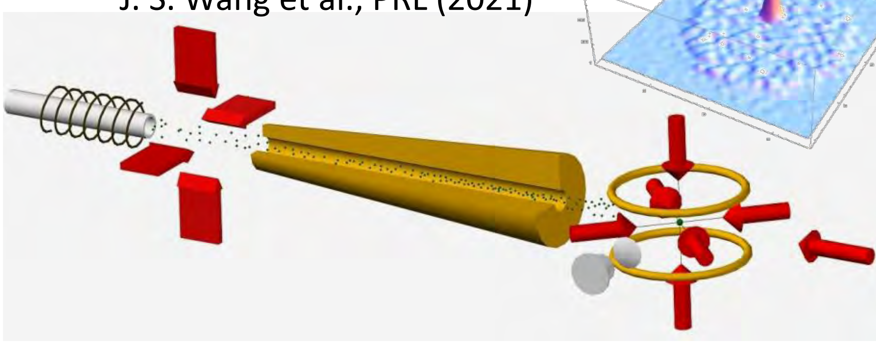
Google
ATTA primer

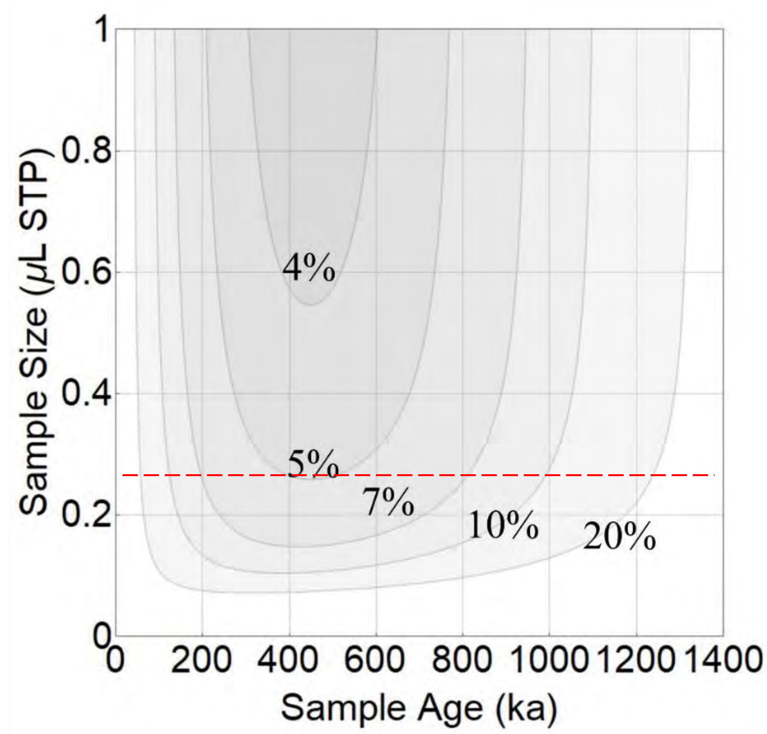


L. Tian et al., GRL (2019)
X.-Z. Dong et al., Analytical Chem. (2019)

C.-Y. Chen et al., Science (1999)
J. S. Wang et al., PRL (2021)







Sample:
0.25 μL STP Kr, ~ 2.5 kg ice

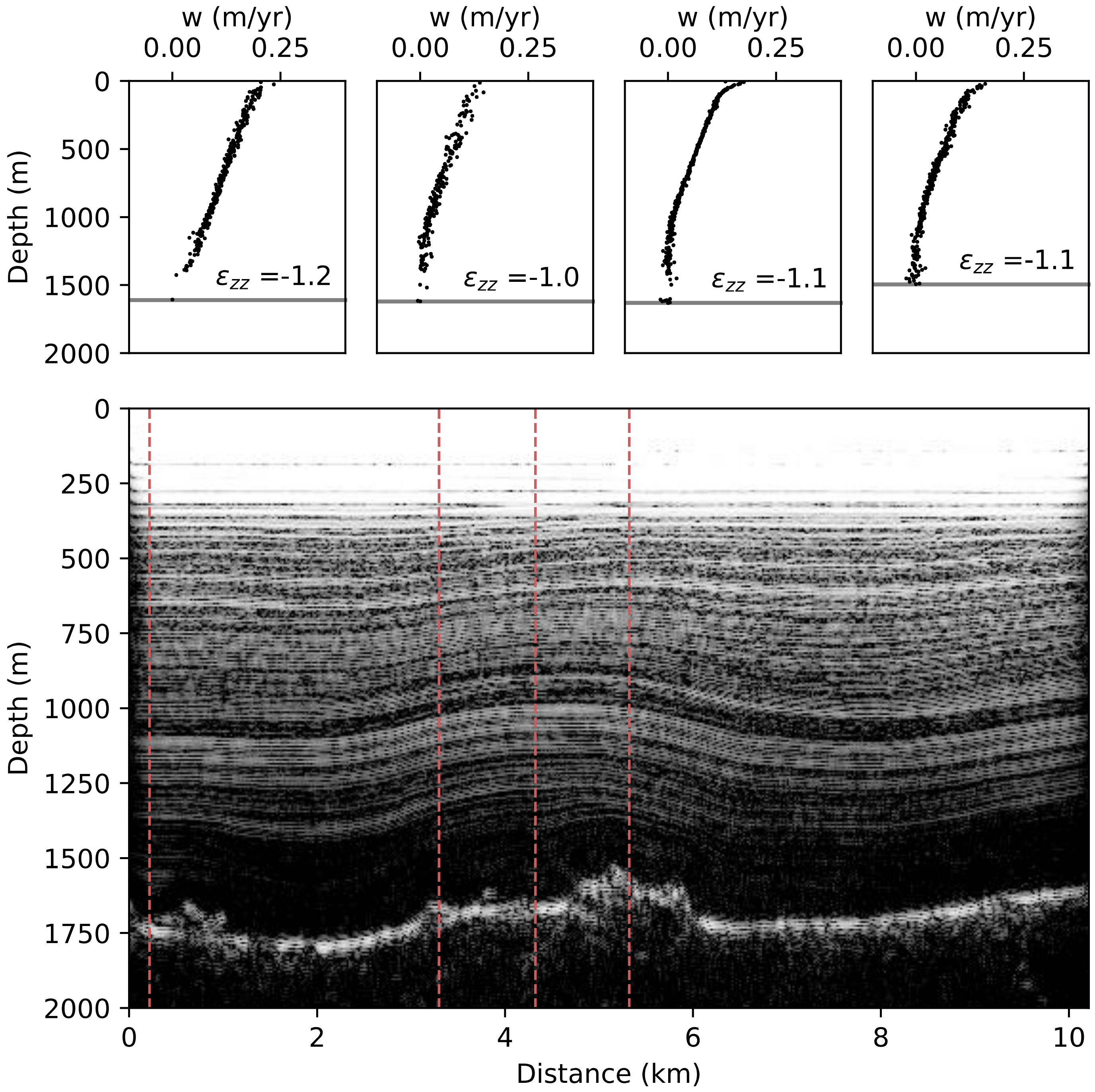
Collaborations on dating Greenland ice: Michael Bender, Princeton; Joerg Schaefer, LDEO; Dorthe Darl-Jensen, JP Steffensen, NBI

Multipass profiling radar measurements to map Greenland Ice Sheet englacial velocities

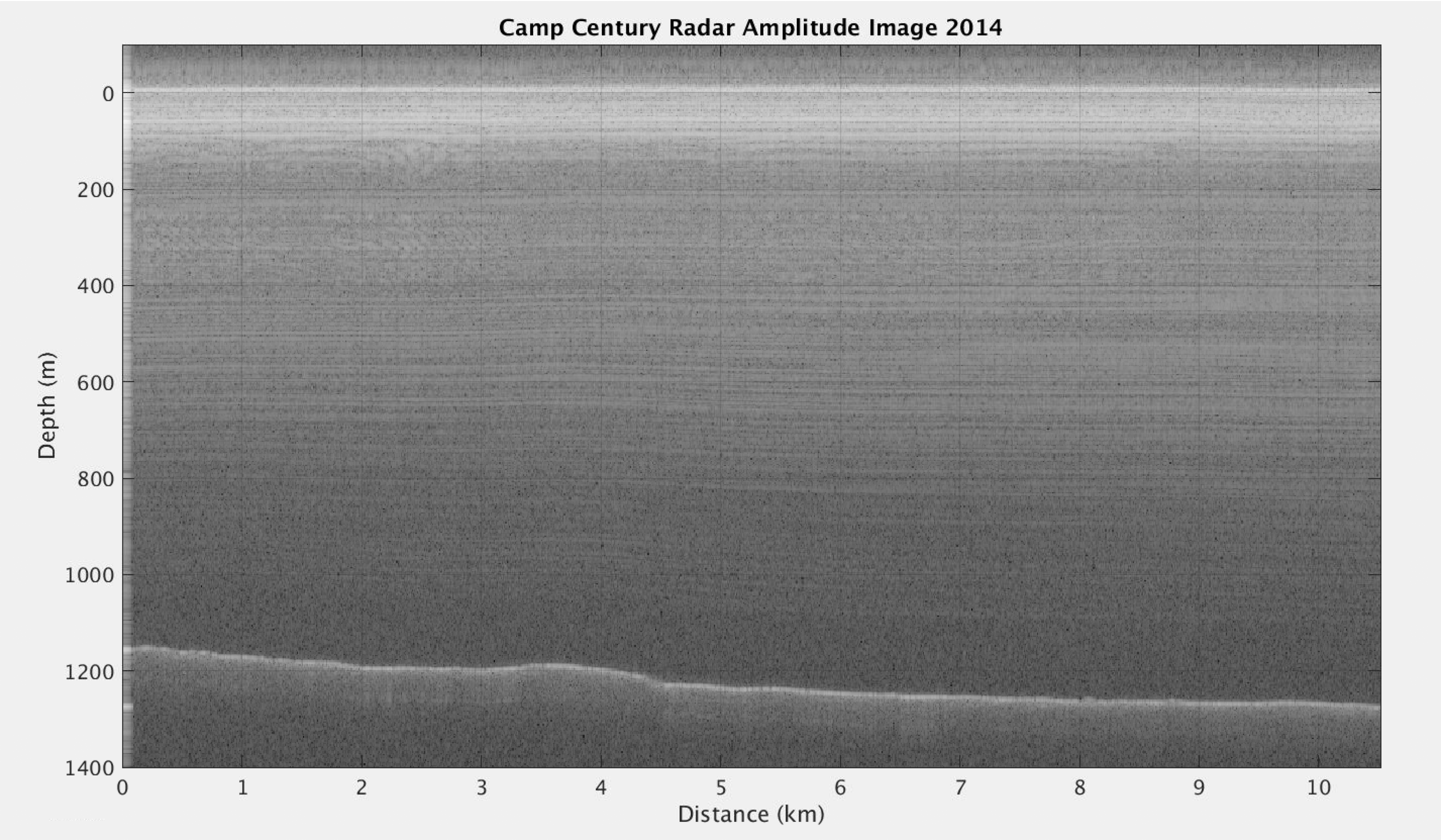
Knut Christianson, John Paden, Nick Holschuh, Andrew Hoffman, Gordon Ariho

11 June 2021

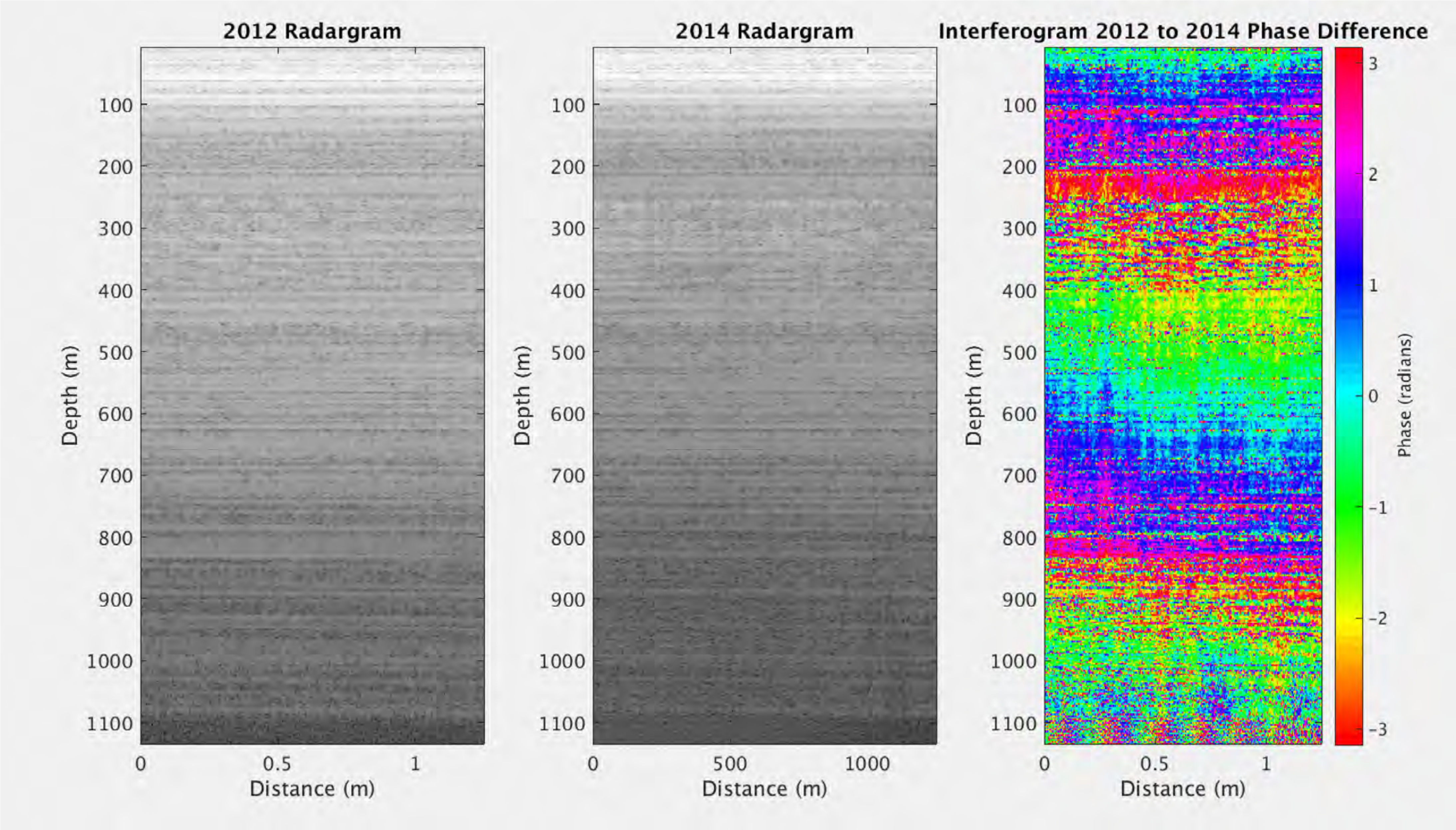
Vertical Velocities from Repeat Phase-Sensitive Radar at Western Hercules Dome, Antarctica



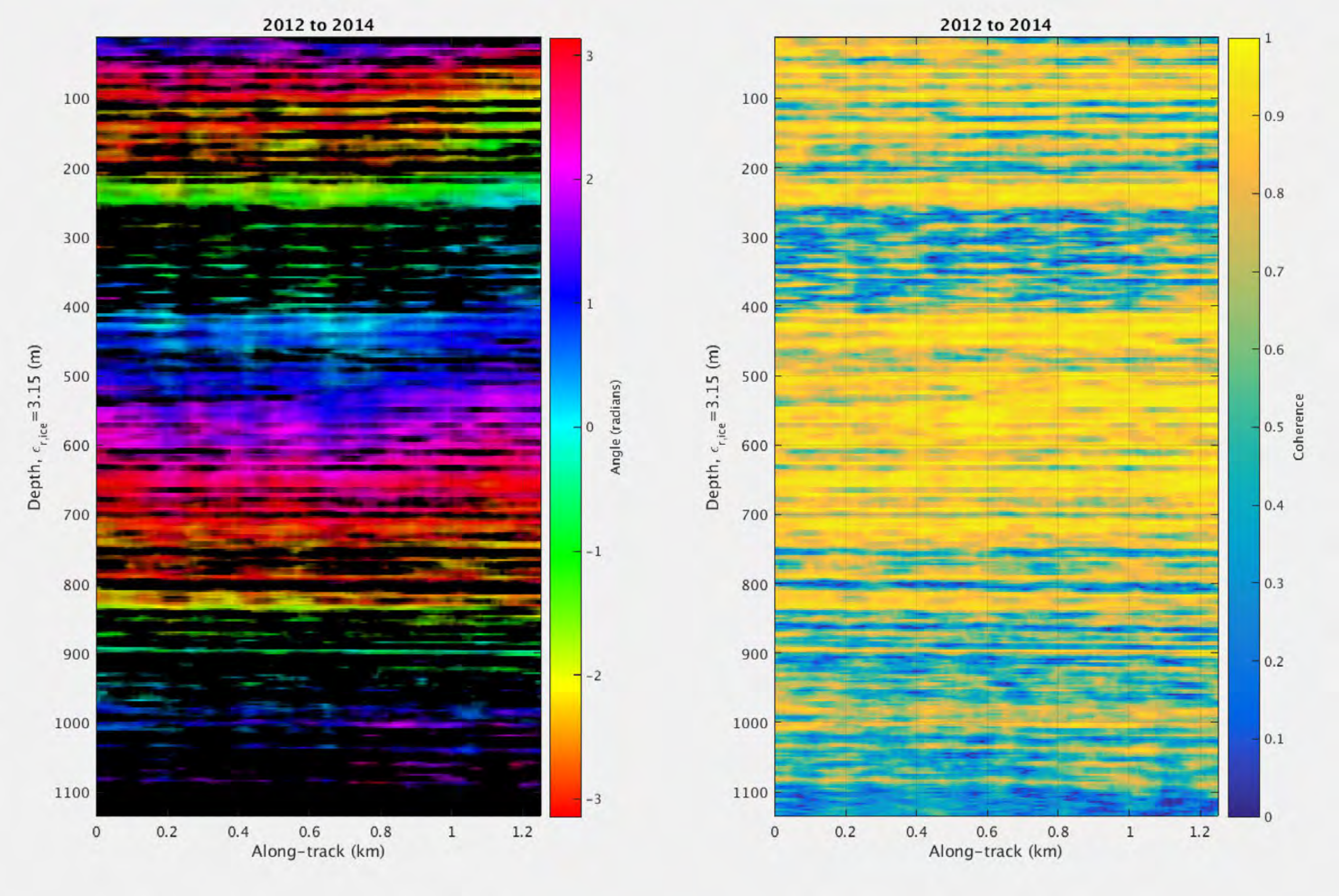
Camp Century Radar Line Amplitude



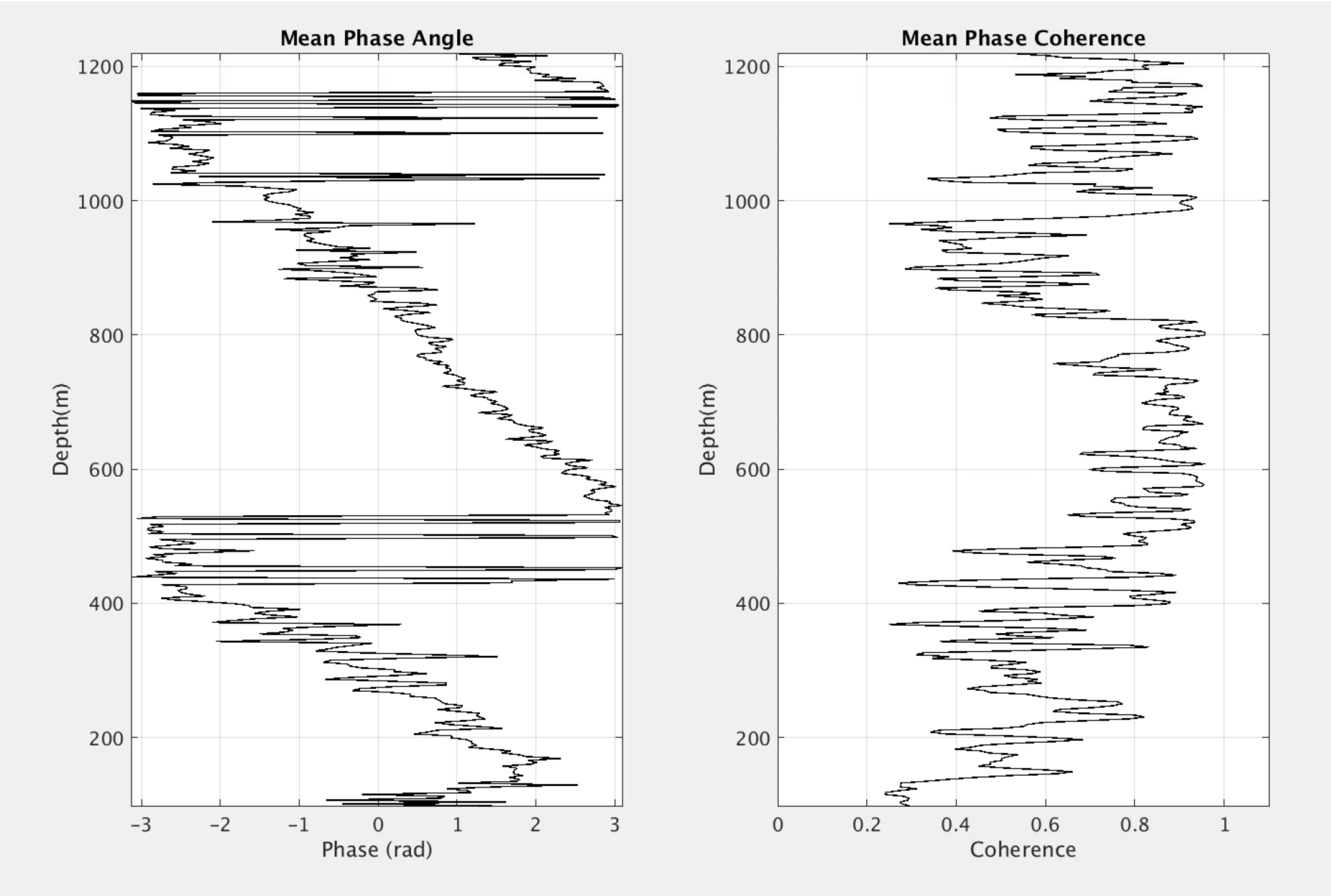
Camp Century 2011-2014 Interferogram



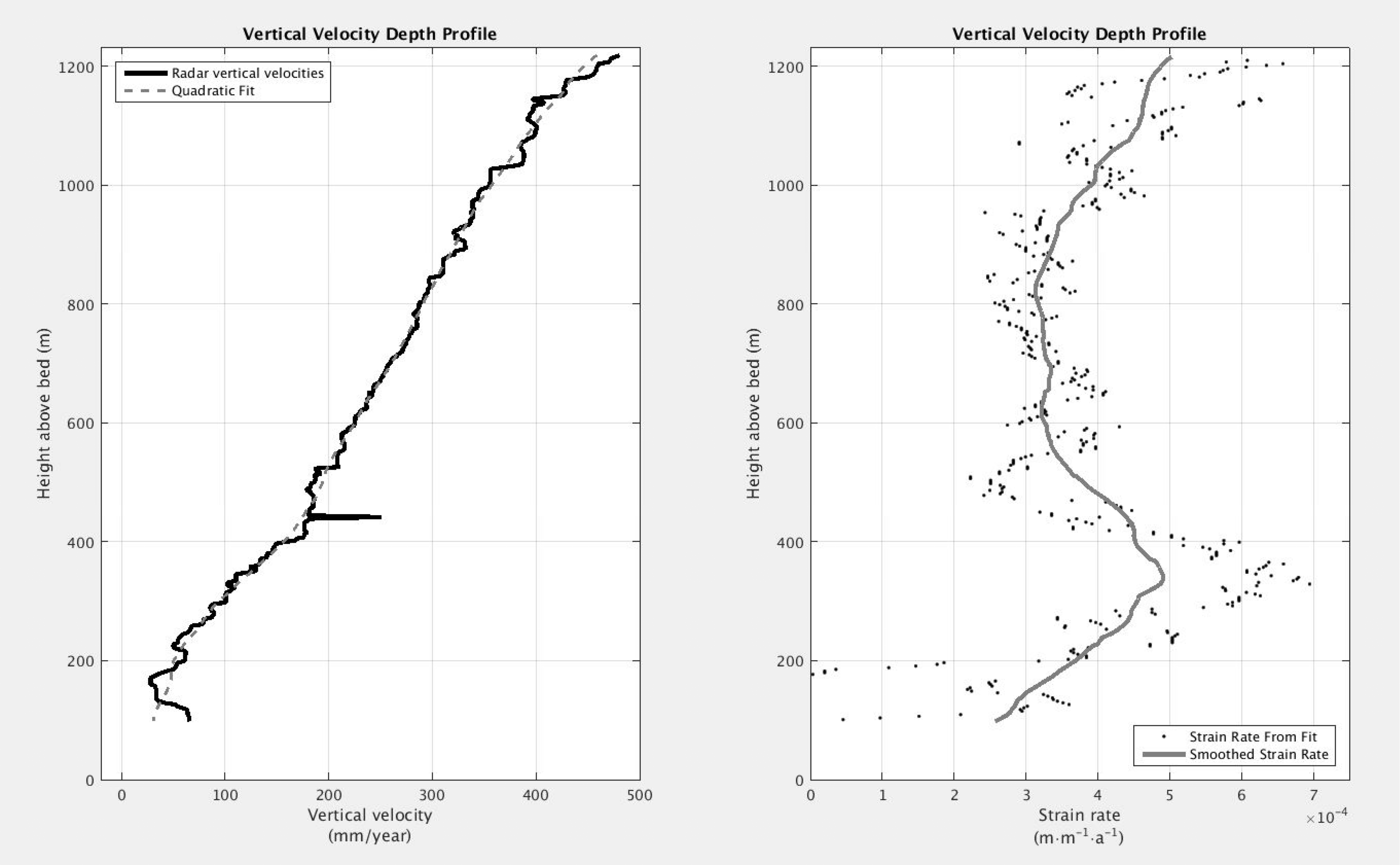
Camp Century 2011-2014 Flattened/Baseline-Corrected



Camp Century 2011-2014 Phase and Coherence

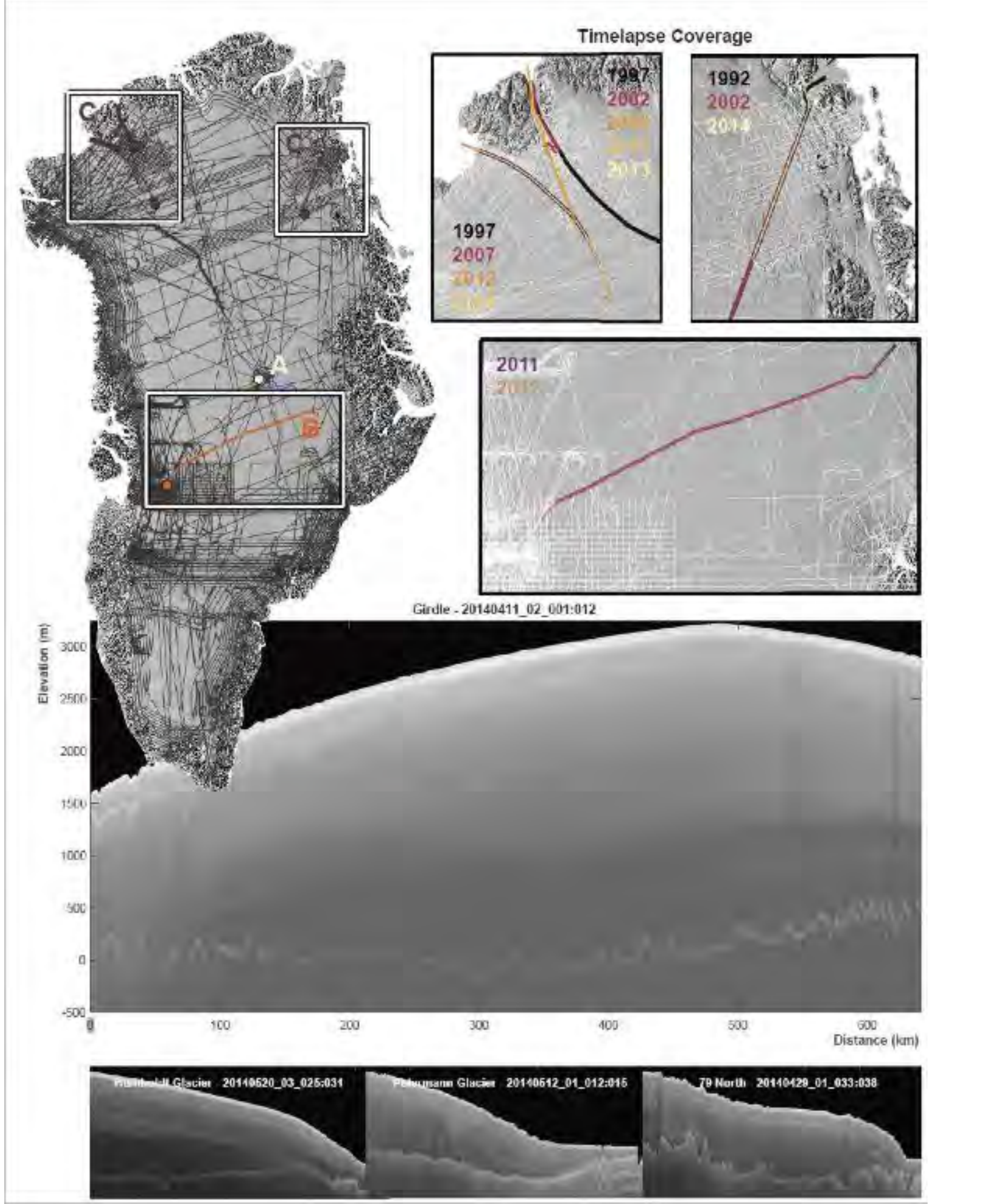


Camp Century 2011-2014 Median Filter



Traverse Measurements

- Multipass measurements are Eulerian whereas ApRES are Lagrangian – fundamental differences in measurement interpretation.
- By installing stakes on traverse lines, we can make an interferometric measurement with zero baseline that moves with the ice.
- Collecting ApRES measurements along the same profile will allow better calibration and also better establish limitations of both measurements.



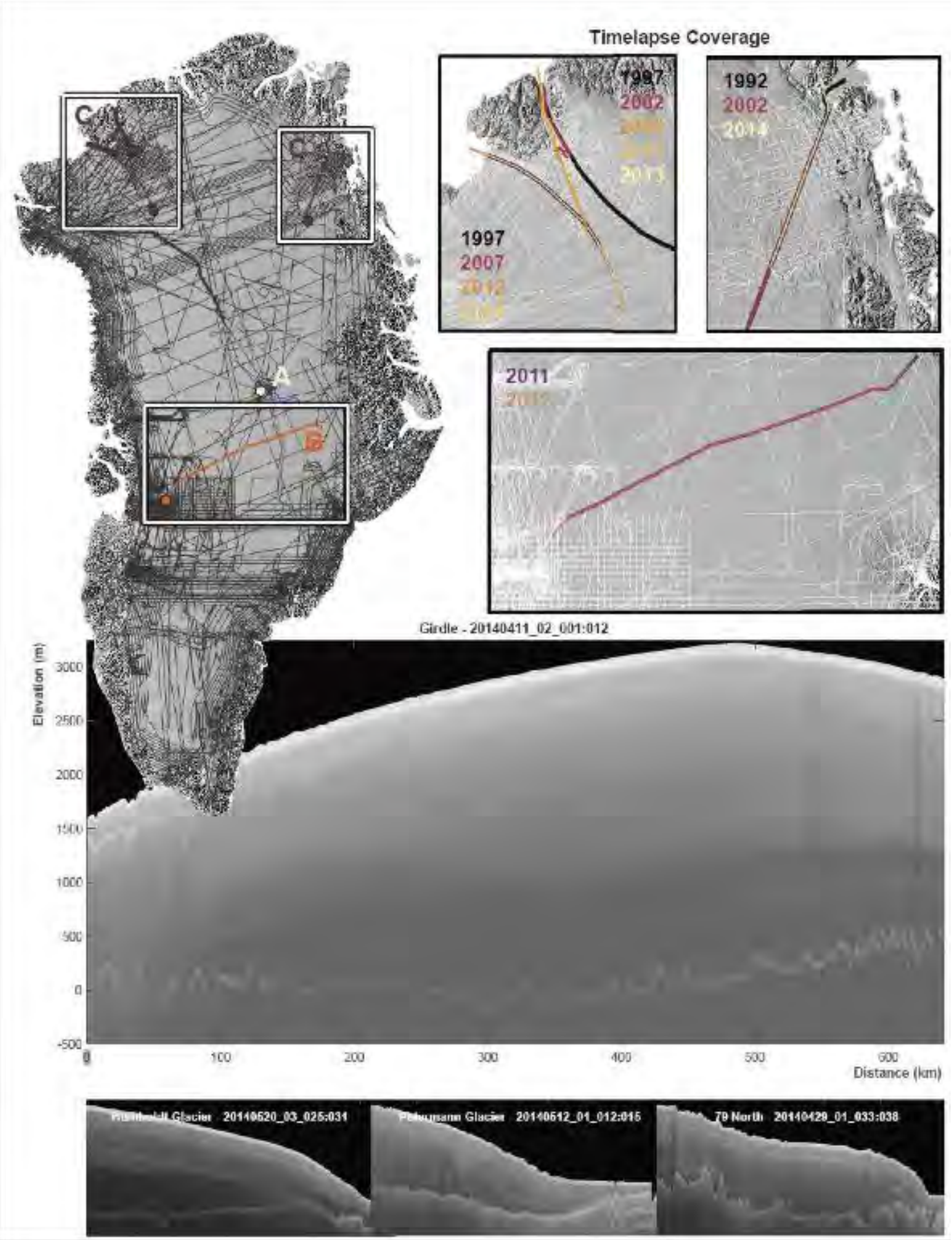
Traverse Measurements

1) Scientific Question: How do we measure englacial velocities ?

2) Where on the ice sheet: Someplace in the interior that is a line orthogonal to the central divide.

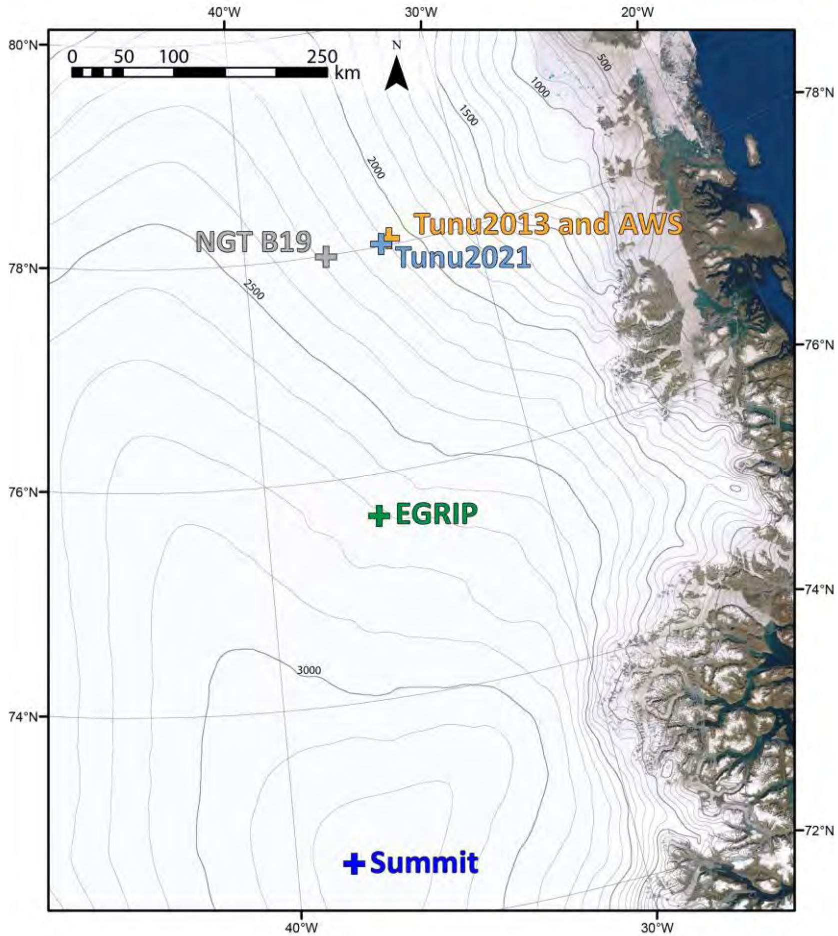
3) Measurements: ApRES and multipass ground radar along a ~25 km line that cross the ice divide.

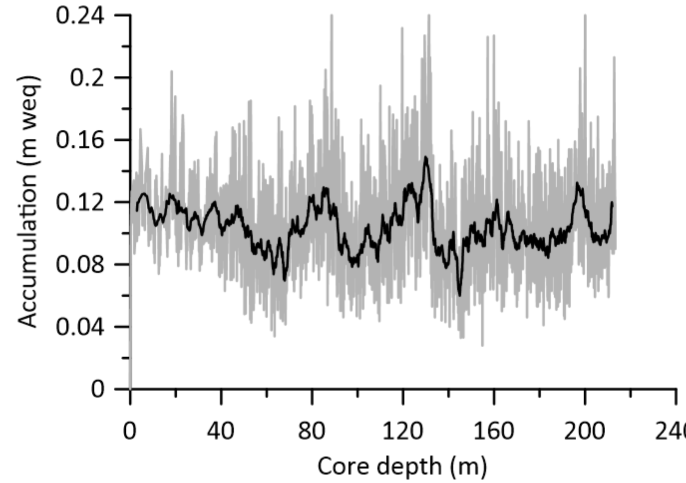
4) Time-on-each-site: Roughly a day to install continuous ApRES site; otherwise, radar can travel with the traverse at the same speed.

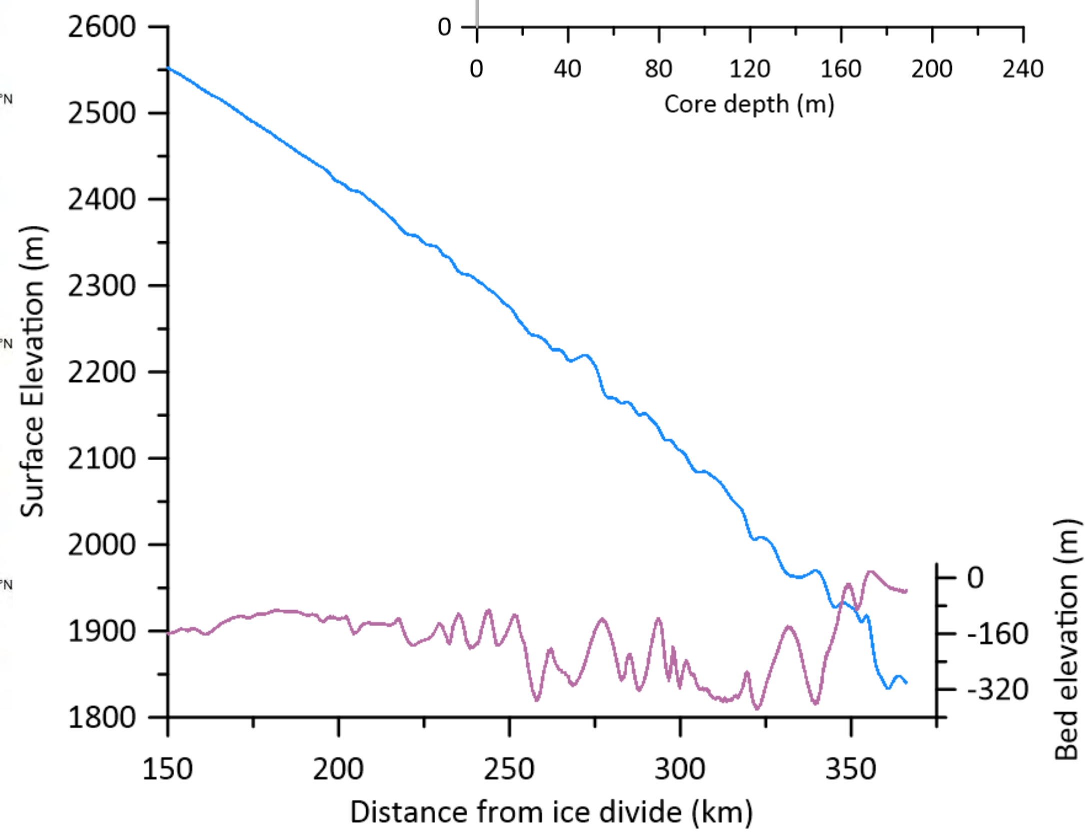


Importance of understanding upstream deposition

Nathan Chellman, Desert Research Institute

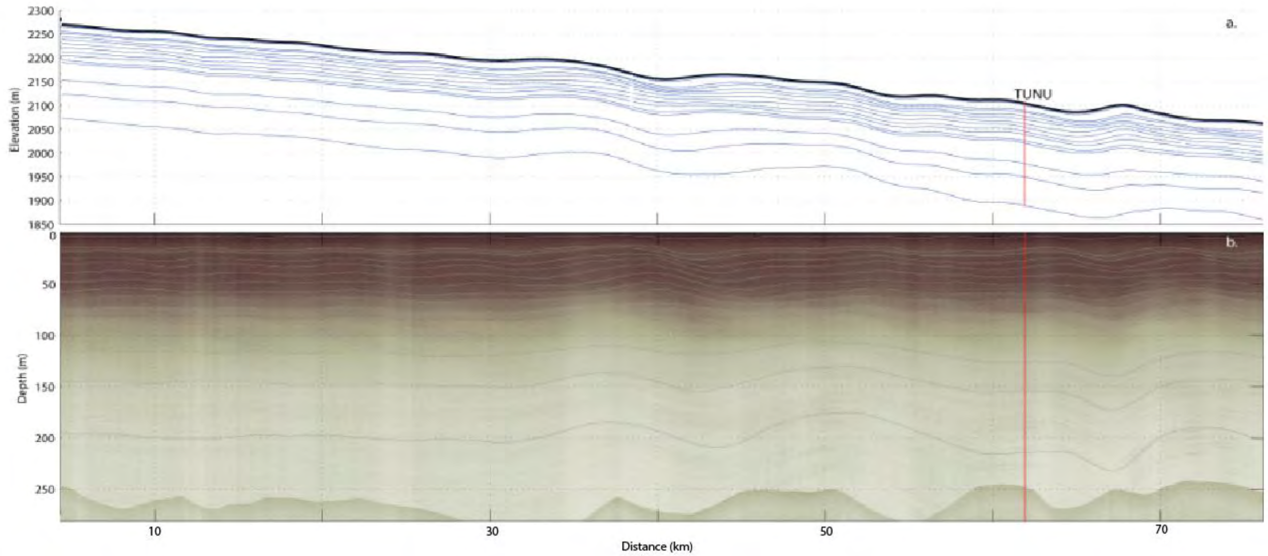






Importance of understanding upstream deposition

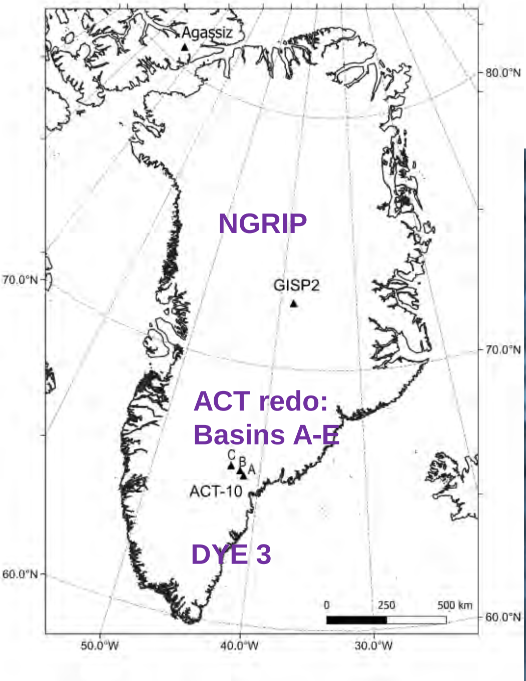
Nathan Chellman, Desert Research Institute



- **Question:** How does upstream topography impact ice core accumulation and chemical measurements?
- **Where:** Northern Greenland (but can be applied most areas)
- **Measurements:** Ground-based GPR coupled with shallow coring
- **Time on site:** 0.5-2 days per location

DECIPHERING LOCAL AND REGIONAL MODERN ORGANIC SIGNATURES ACROSS GREENLAND

...LET'S TRAVERSE!

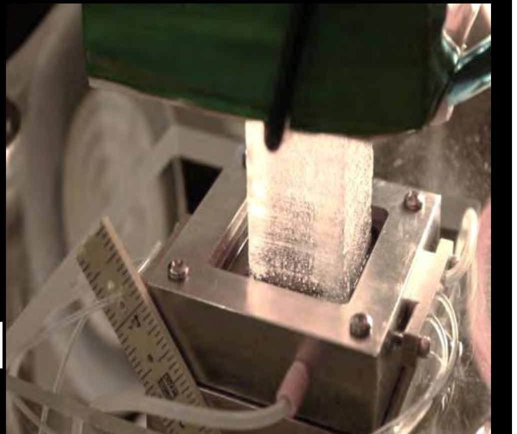


What is the question?

How are modern organic matter signatures influenced by local environmental factors? What are they?

Where is the work?

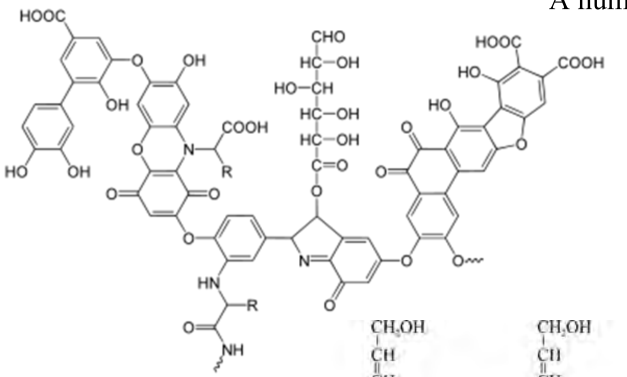
High priority traverse locations:
ACT Basins A-E, Dye 3, GISP2, NGRIP, and further north?
Surface snow and shallow ice

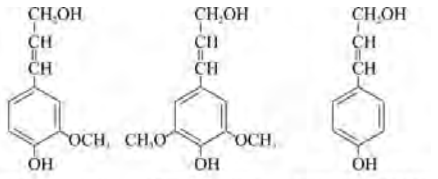


DRI continuous melting with discrete sample collection
*can also do manual melting

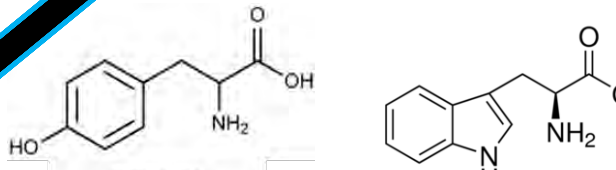
Organic compounds in ice reflect materials produced and transported from local and distant ecosystems

A humic acid

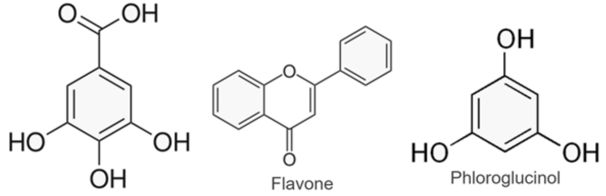




coniferyl alcohol
sinapyl alcohol
p-coumaryl alcohol



tyrosine
tryptophan



Gallic acid
Flavone
Phloroglucinol

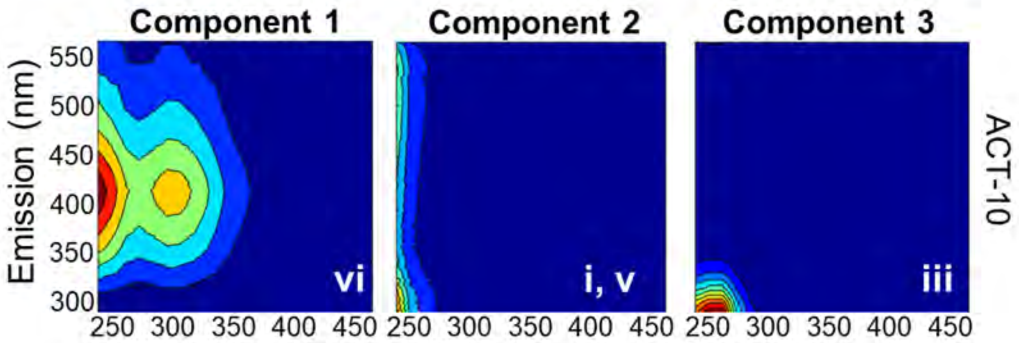
Juliana D'Andrilli

Louisiana Universities Marine Consortium

HOW ARE MODERN ORGANIC MATTER SIGNATURES INFLUENCED BY LOCAL ENVIRONMENTAL FACTORS?

Three organic matter (OM) fluorescence markers:

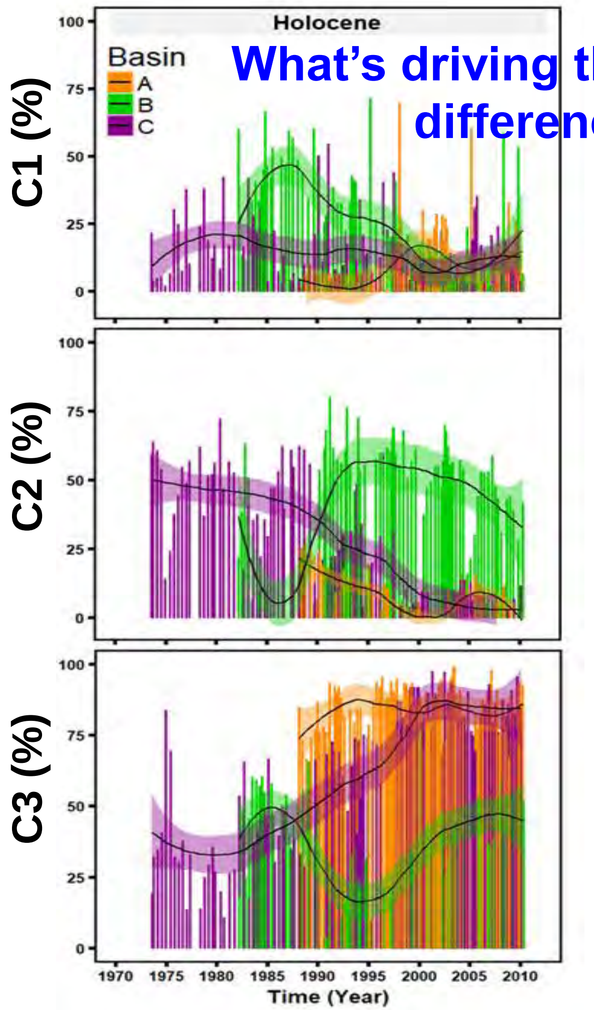
1. “humic-like” supporting trends of higher plant influences in warmer climates
2. monolignol- and non-amino acid-like describing simple, lignin-like precursors and microbial degradation products of more complex OM from plants/soils
3. amino acid- and tannin-like OM indicating microbial degradation of simple chemical species



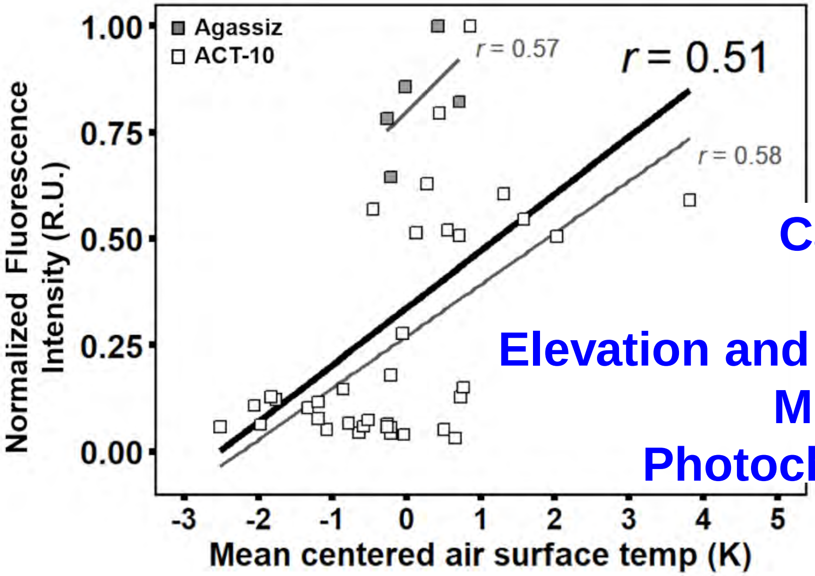
More bioreactive: lower molecular weight and low aromatic nature, less photoreactive

Label	Description
i	monolignol-like
ii	tyrosine- and tannin-like
iii	tyrosine-like
iv	simple phenol / amino acid- & tannin-like
v	plant/soil decomposition intermediates
vi	mid- to large-size humic-like

More photoreactive: higher molecular weight and high aromatic nature, less bioreactive



What’s driving these differences?



Is it temperature?
Carbon productivity?
Coastal proximity?
Elevation and accumulation rate?
Microbial processes?
Photochemical processes?

What measurements are needed?

Discrete samples of surface snow, firn, and shallow cores

- absorbance and fluorescence spectroscopy (5-10mL meltwater)
- OM carbon concentration (10 mL)
- collaborative measurements include: elevation, deposition rate, distance to coast, temperature, nutrient, CO_2, and CH_4 concentrations, microorganisms…

Time-on-each-site?

Snow grab samples (1-2 days) and ice core shallow drill and recovery (4-6 days)

D’Andrilli & McConnell *J. Glaciology*. 2021, doi:10.1017/jog.2021.51

Benson 2.0: Multi-season overland traverses from Thule and Kanger to drill deep temperature profiles in areas where subglacial temperature is unknown.

William Colgan and Ken Mankoff*

HotRod:

- 6kW heater in 50 mm Ø
- Thermistor strings to the bed on one-way trip
- 500 m capability (depends on ice temperature)
- >1000 m version planned by 2024

**Apologies from W.C., it's late in Copenhagen!*

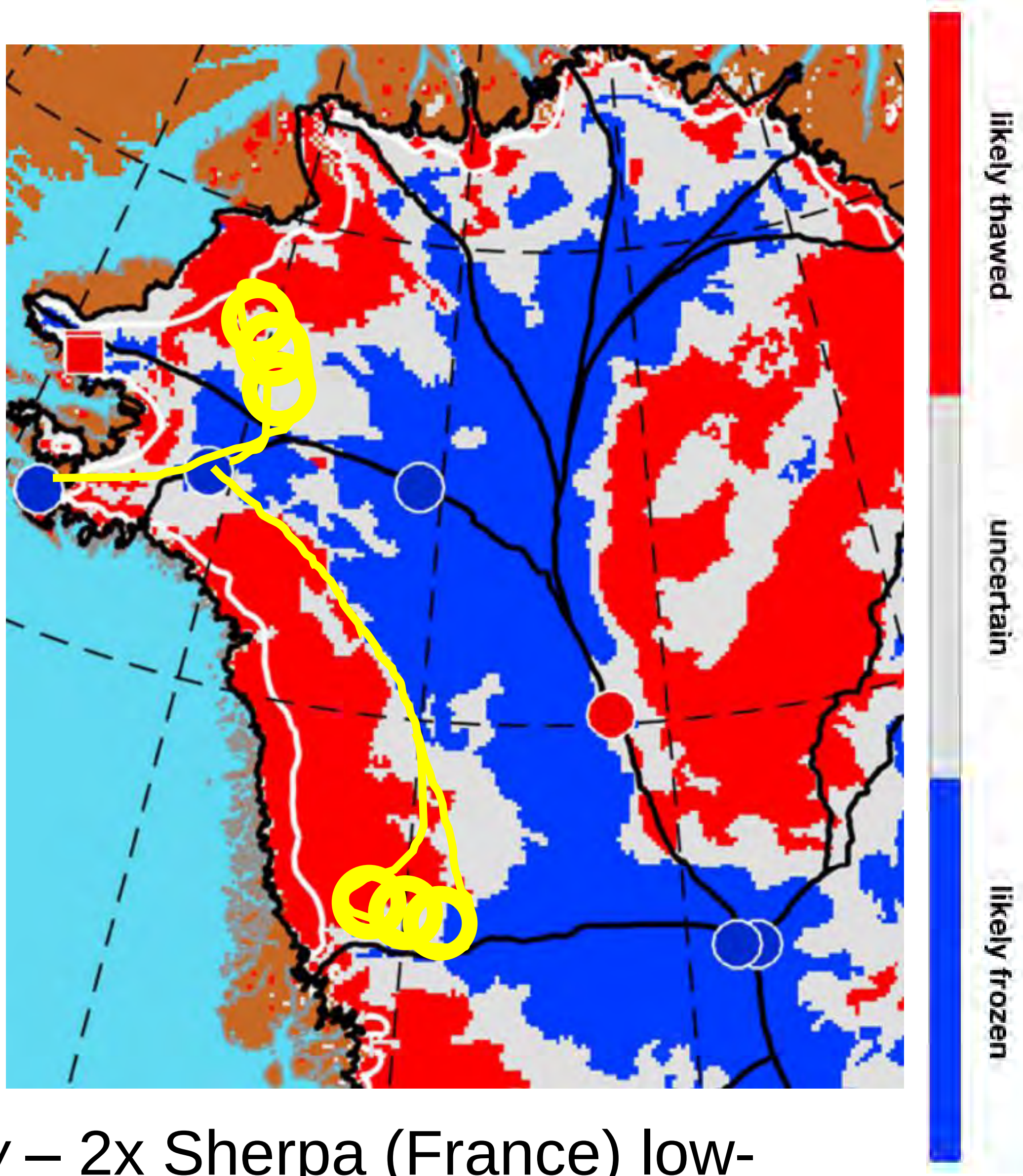
GEUS

1) *Why* – To resolve basal ice temperatures where poorly understood

2) *Where* – Starting in NW Greenland, with ice depths up to 1500 m

3) *What* – Insert full ice-sheet thermistor strings at each site

4) *When* – About 14 days per site in 2025/2026 (proposals in October 2021 and February 2022)



5) *How* – 2x Sherpa (France) low-ground pressure vehicles. Fuel caches dropped by RDAF

Snowmobot 1.0

- Two electric snowmobiles
  - No reduction in capabilities compared to ICE
- Autonomous
  - GPS waypoint following
  - Offset follow
  - Remote control (visual)
  - Remote control (remote via StarLink)
  - Object detection and stop/avoid
- Proof of concept science:
  - Deploy out 15 km of fiber optic cable

Snowmobot 1000

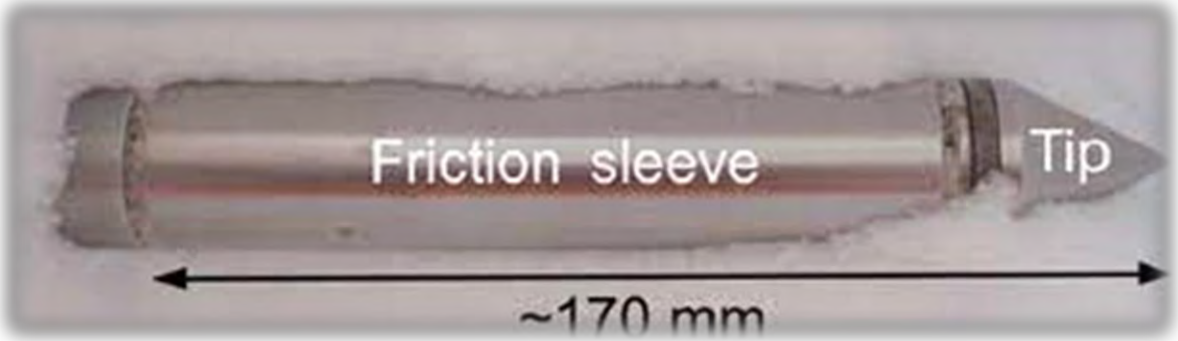
- A fleet of autonomous vehicles
- A facility for access
  - Like UNAVCO or IRIS/PASSCAL

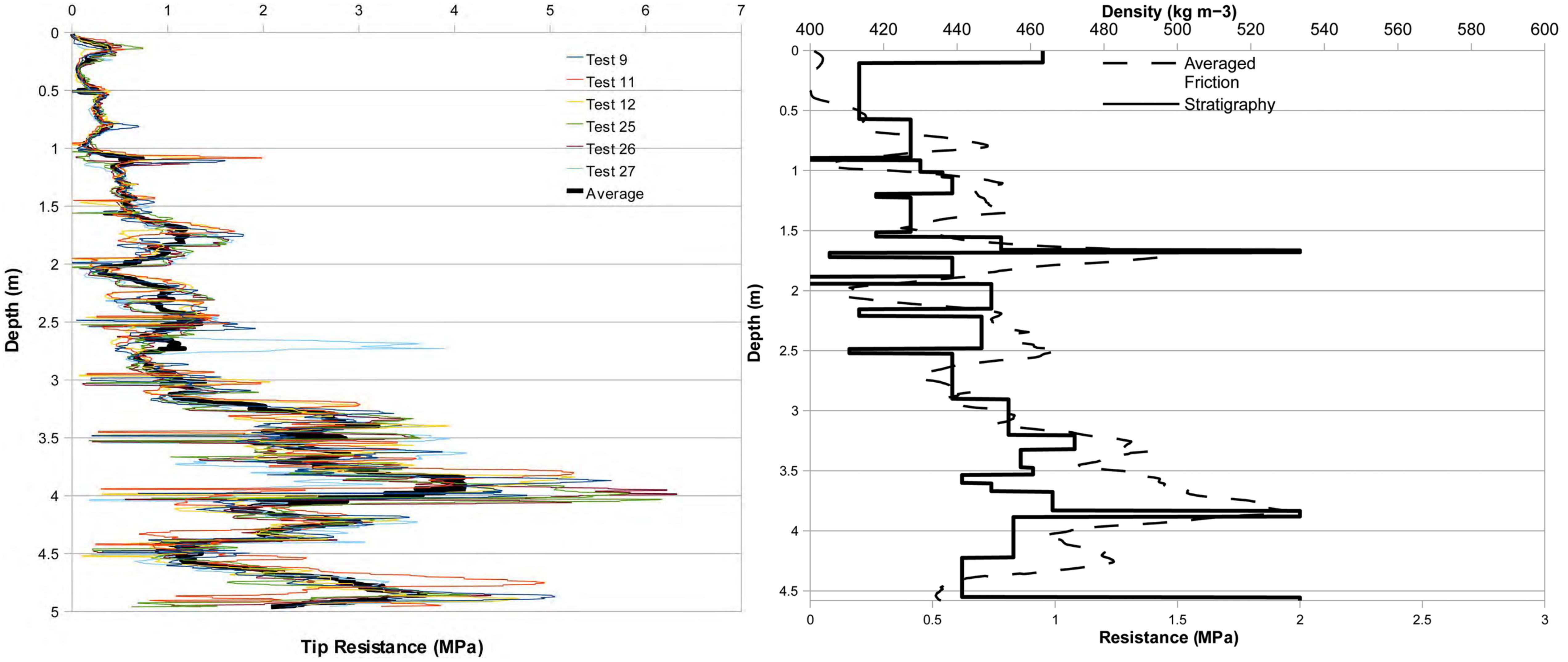
Cone Penetration Testing (CPT) - a simple and repeatable means of assessing mass balance?

Adrian McCallum, University of the Sunshine Coast, Australia

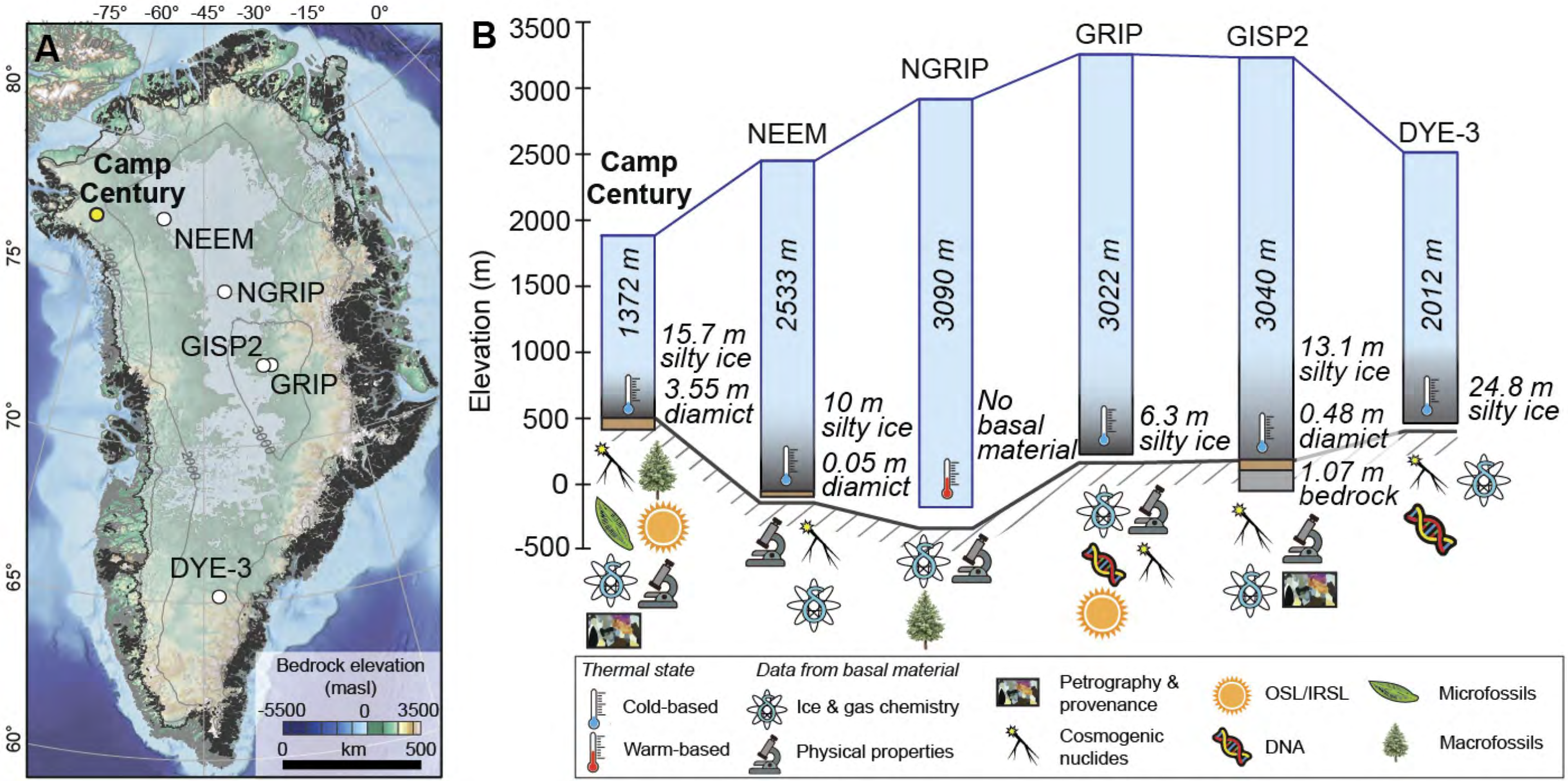
amccallu@usc.edu.au

(Further info: https://www.cambridge.org/core/journals/journal-of-glaciology/article/assessing-mass-balance-with-the-cone-penetration test/54338A649F43C35CCC0C54FB7689E636)





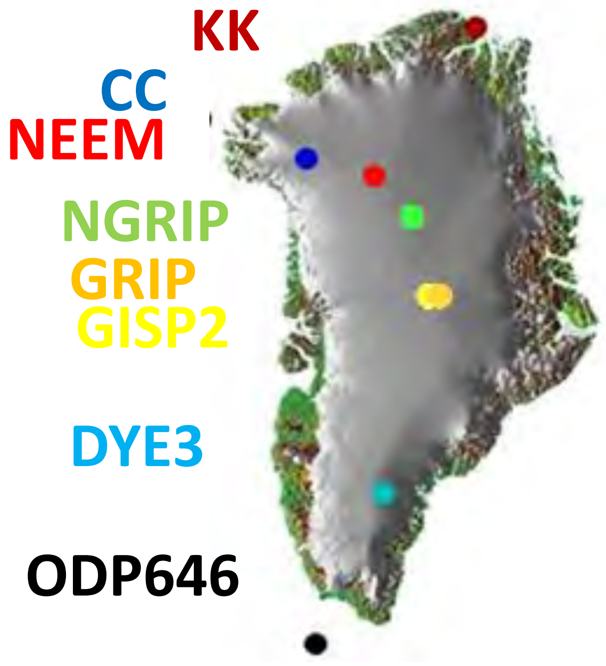
0
1
2
3
4
5
6
7
Test 9
Test 11
Test 12
Test 25
Test 26
Test 27
Average
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Depth (m)
Tip Resistance (MPa)
Density (kg m−3)
400
420
440
460
480
500
520
540
560
580
600
Averaged Friction
Stratigraphy
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Depth (m)
0
0.5
1
1.5
2
2.5
3
Resistance (MPa)


A
-75°
-60°
-45°
-30°
-15°
0°
80°
75°
70°
65°
60°
Camp Century
NEEM
NGRIP
GISP2
GRIP
DYE-3
Bedrock elevation (masl)
-5500
0
3500
0
km
500
B
Elevation (m)
3500
3000
2500
2000
1500
1000
500
0
-500
Camp Century
1372 m
15.7 m silty ice
3.55 m diamict
NEEM
2533 m
10 m silty ice
0.05 m diamict
NGRIP
3090 m
No basal material
GRIP
3022 m
6.3 m silty ice
GISP2
3040 m
13.1 m silty ice
0.48 m diamict
1.07 m bedrock
DYE-3
2012 m
24.8 m silty ice
Thermal state
Cold-based
Warm-based
Data from basal material
Ice & gas chemistry
Physical properties
Petrography & provenance
Cosmogenic nuclides
OSL/IRSL
DNA
Microfossils
Macrofossils

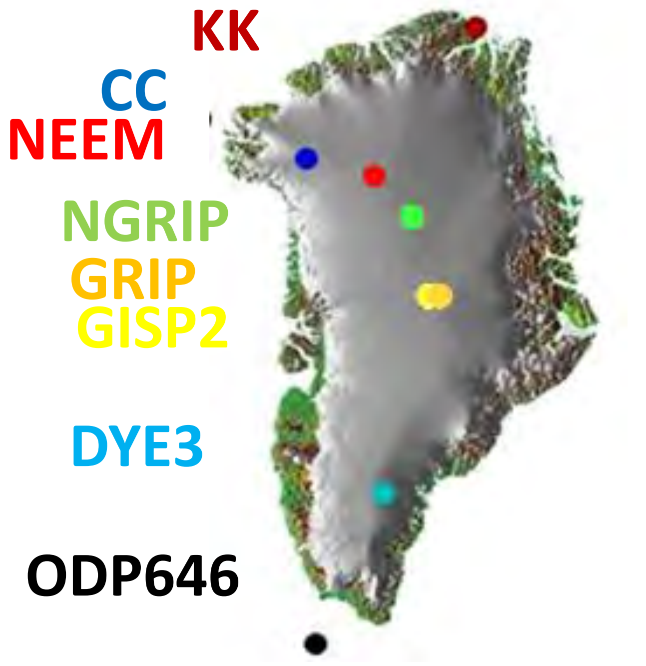
Basal material is found in all ice cores

NGRIP

Drilled: 2008-2012
Ice Thickness: 3090 m
Basal Material: none
Basal Temperature: -2deg C

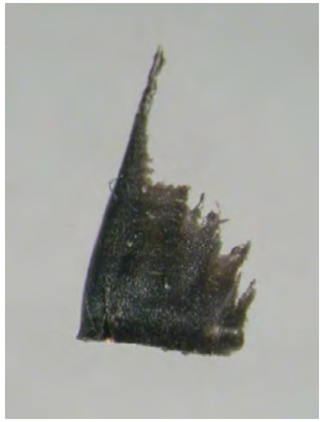


Basal material is found in all ice cores



NGRIP

Drilled: 2008-2012
Ice Thickness: 3090 m
Basal Material: none
Basal Temperature: -2deg C
Willow+Spruce



Basal material is found in all ice cores

DYE3

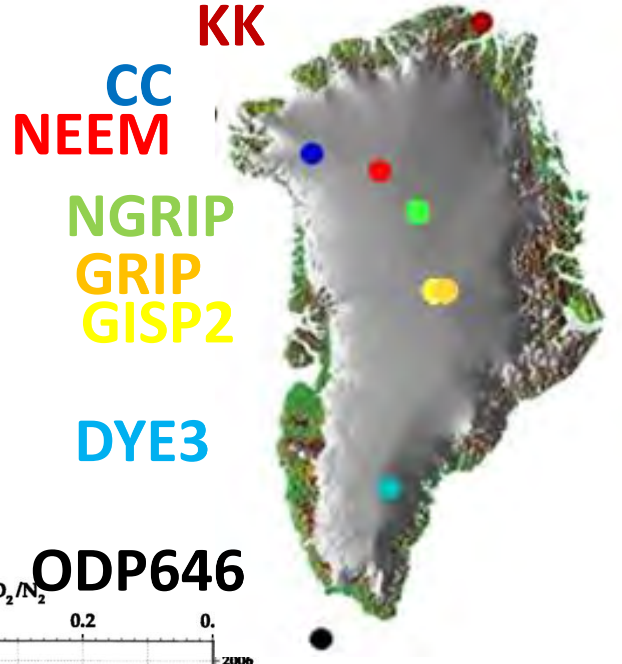
Drilled: 1979-1981

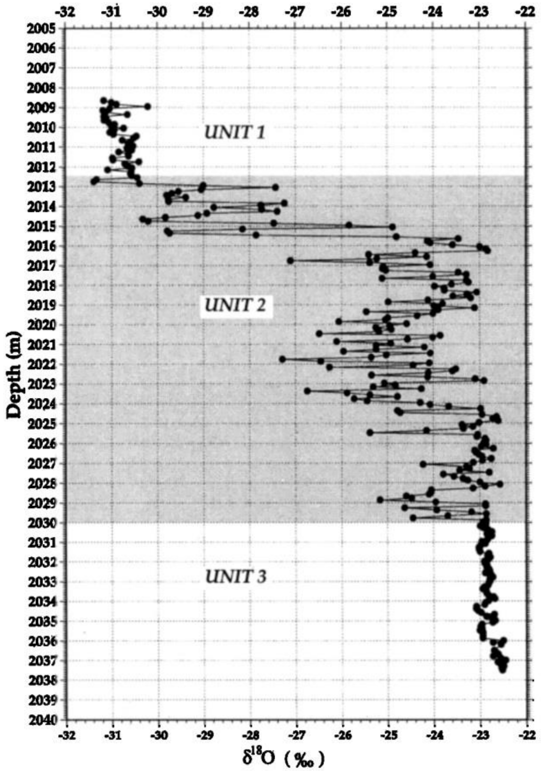
Ice Thickness: 2025 m

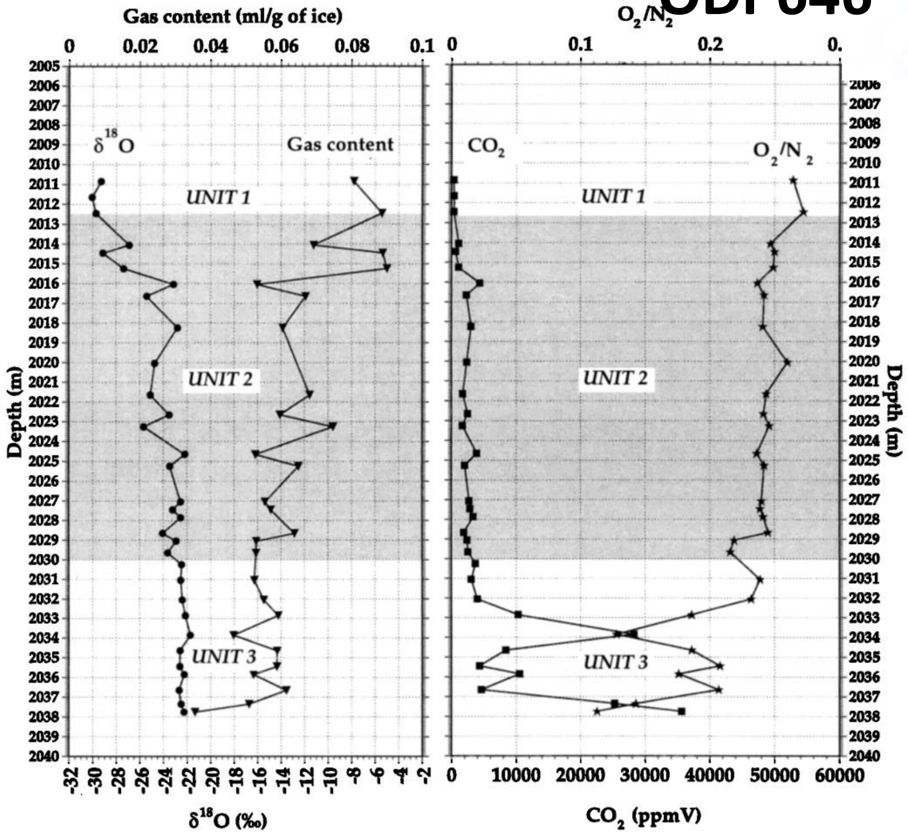
Basal Material: m

Basal Temperature: -13 deg C

DNA: Boreal Forest

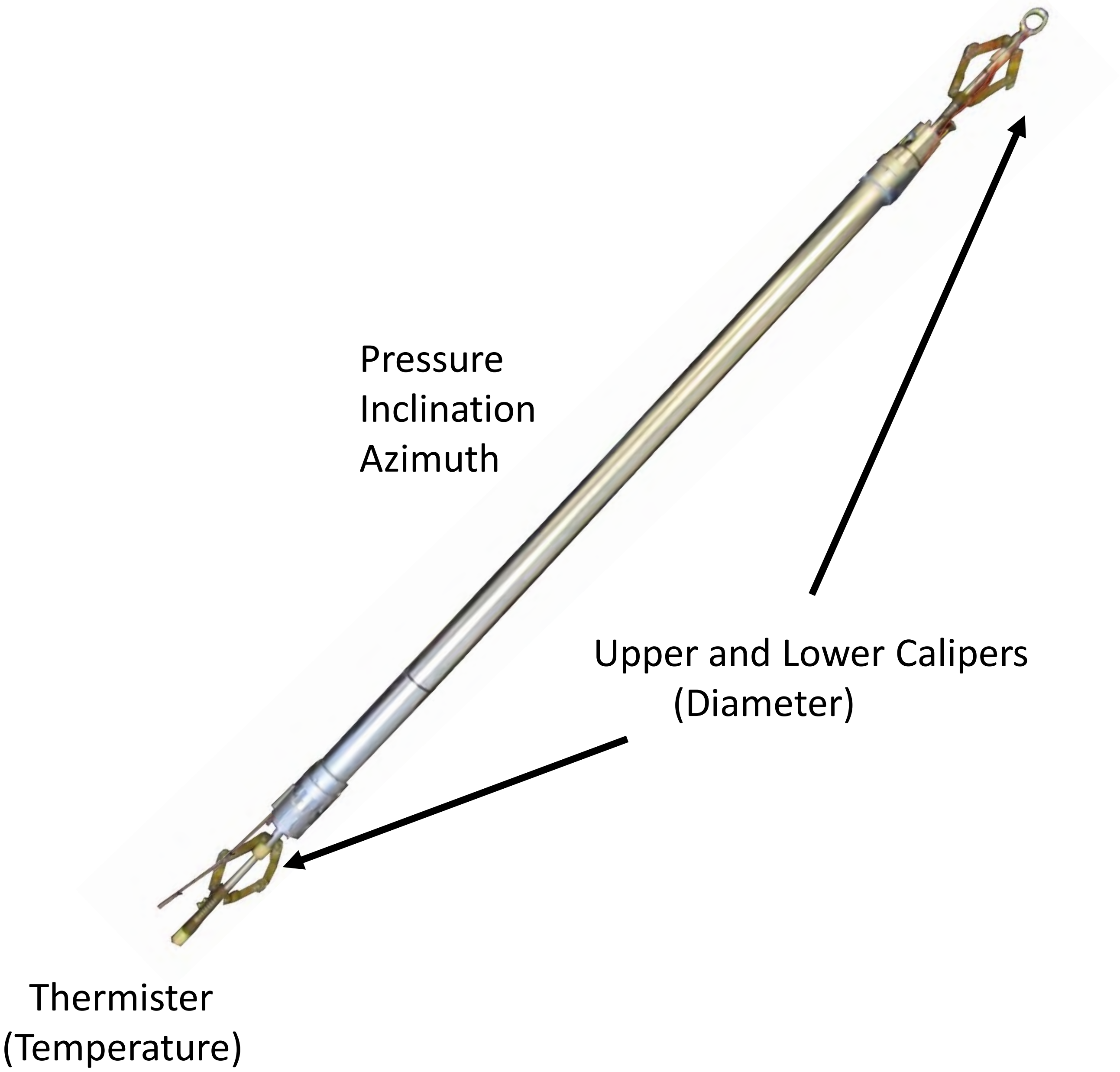


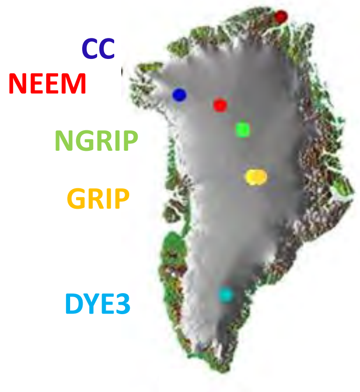




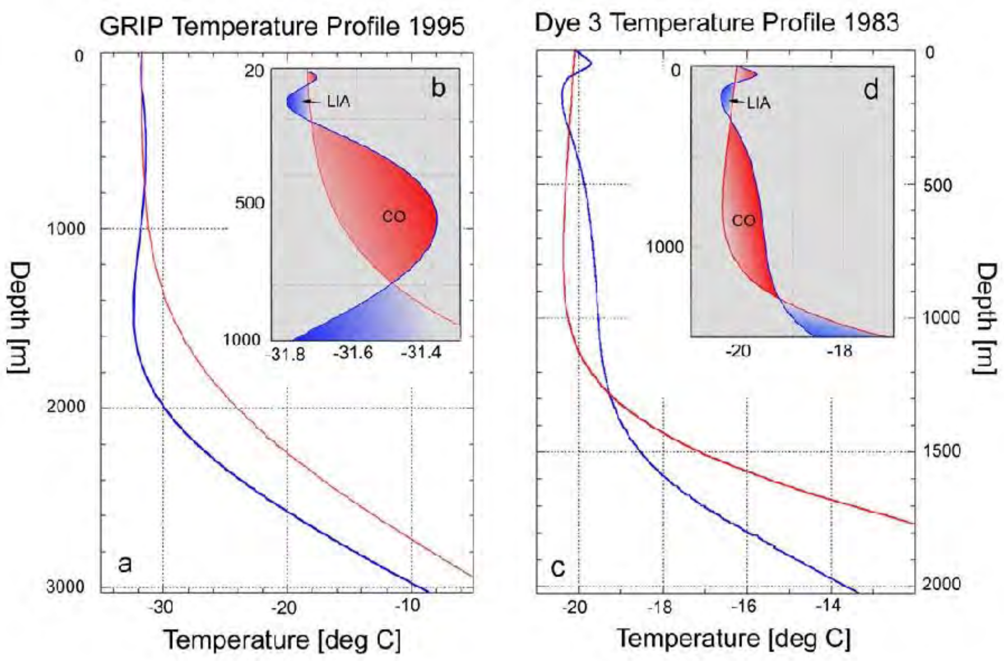

POLAR 5

Reconstruction of the past climate from temperature





Logging of the GRIP and Dye 3 borehole



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Mountain building and the initiation of the Greenland Ice Sheet

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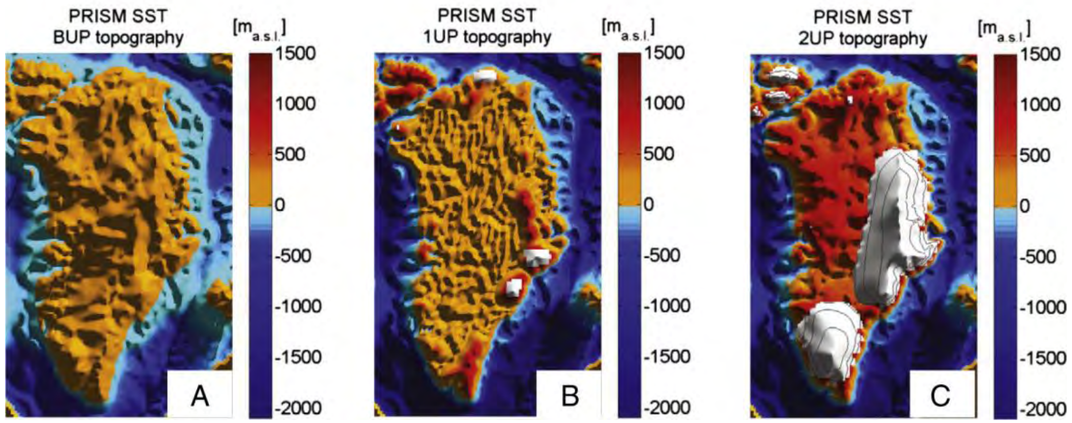
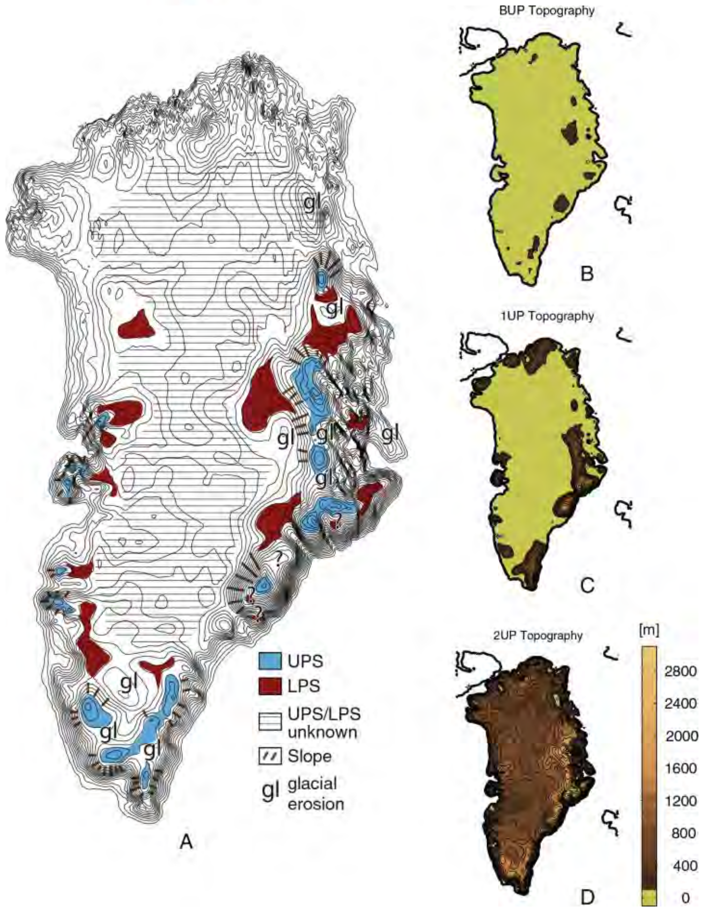
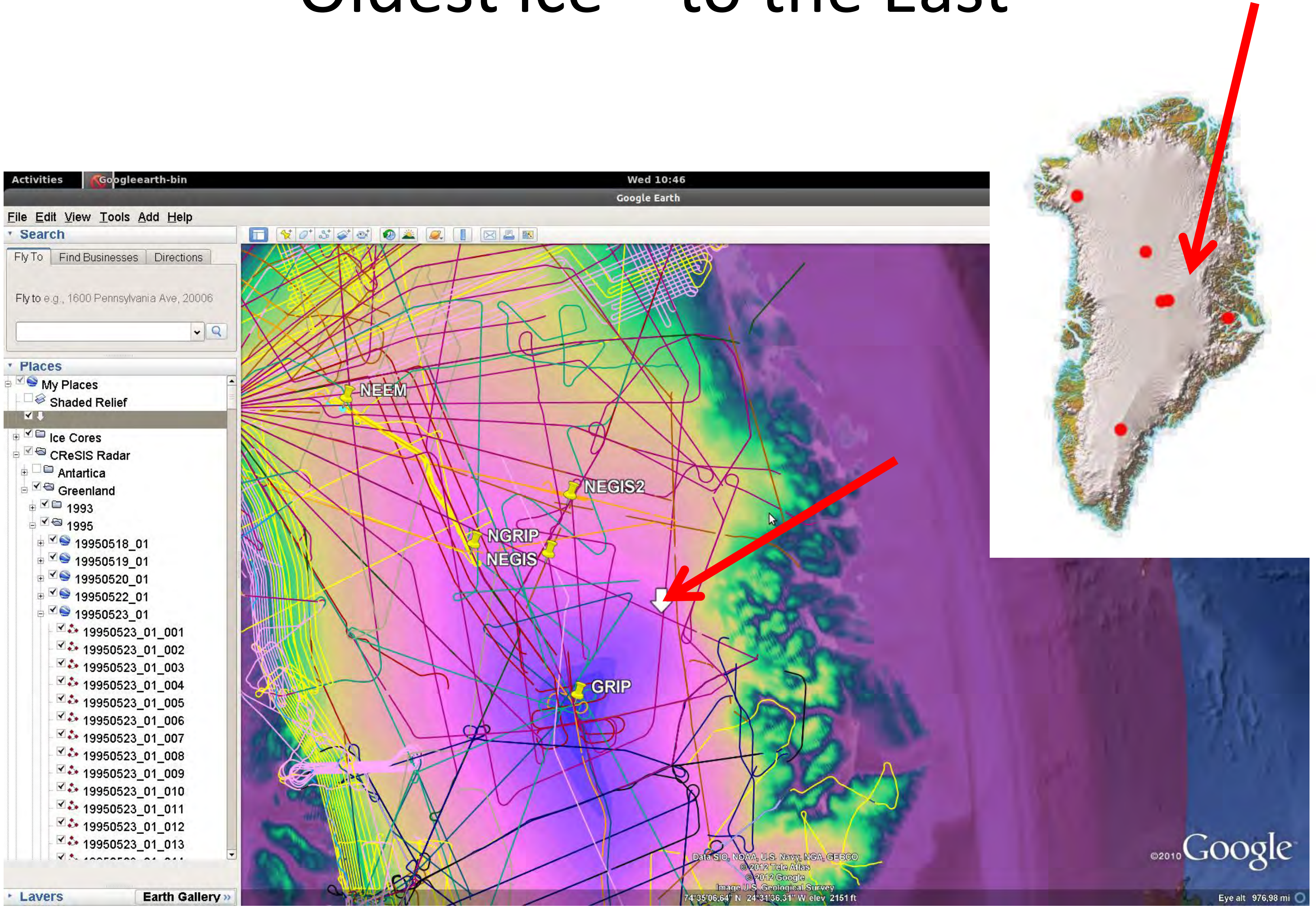
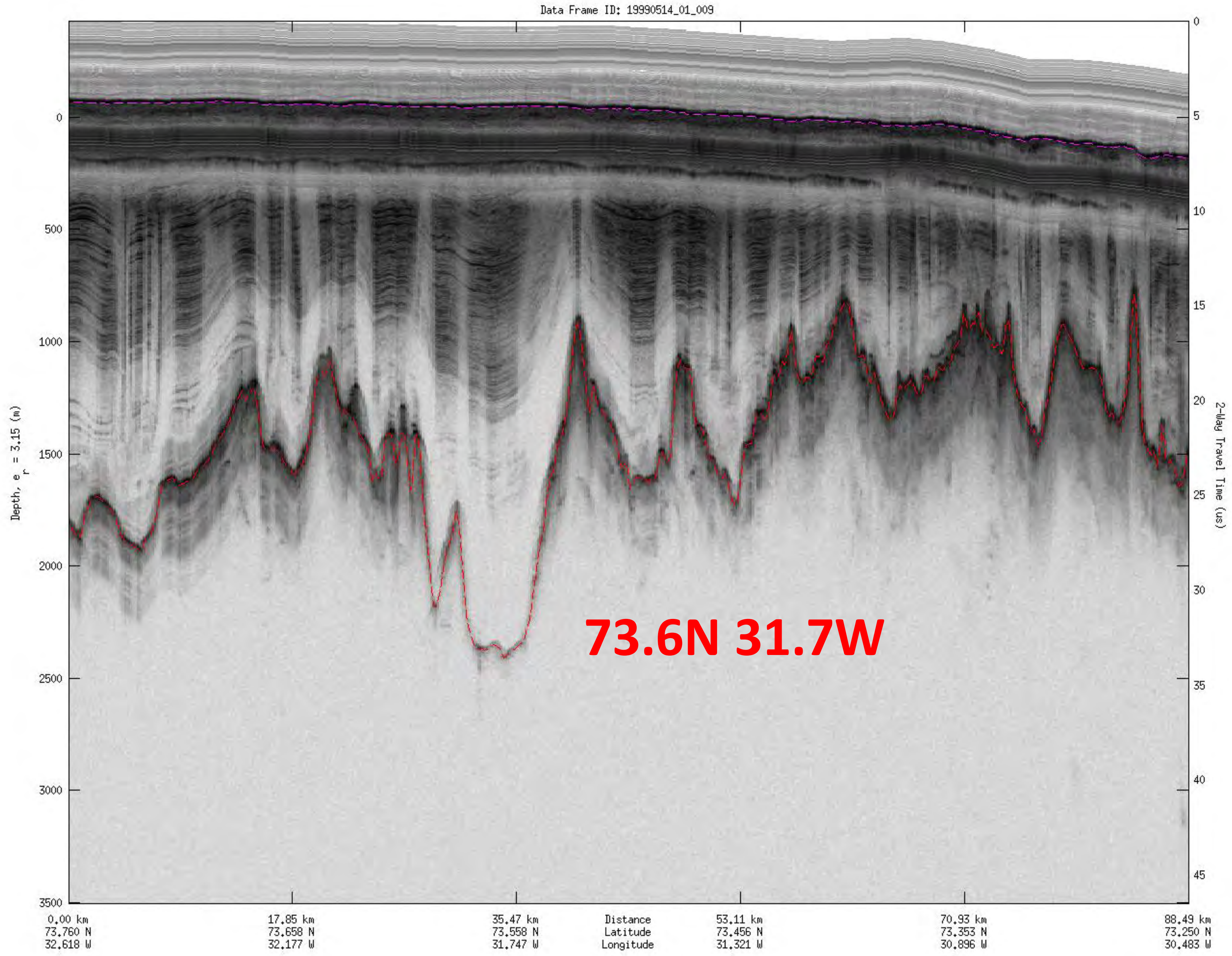




Oldest ice – to the East





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500
1000
1500
2000
2500
3000
3500
2-Way Travel Time (us)
0
5
10
15
20
25
30
35
40
45
0.00 km
73.760 N
32.618 W
17.85 km
73.658 N
32.177 W
35.47 km
73.558 N
31.747 W
Distance
Latitude
Longitude
53.11 km
73.456 N
31.321 W
70.93 km
73.353 N
30.896 W
88.49 km
73.250 N
30.483 W
73.6N 31.7W