Icy secrets & radar revelations

Non-destructive probing of ice masses and their surroundings

Olaf Eisen

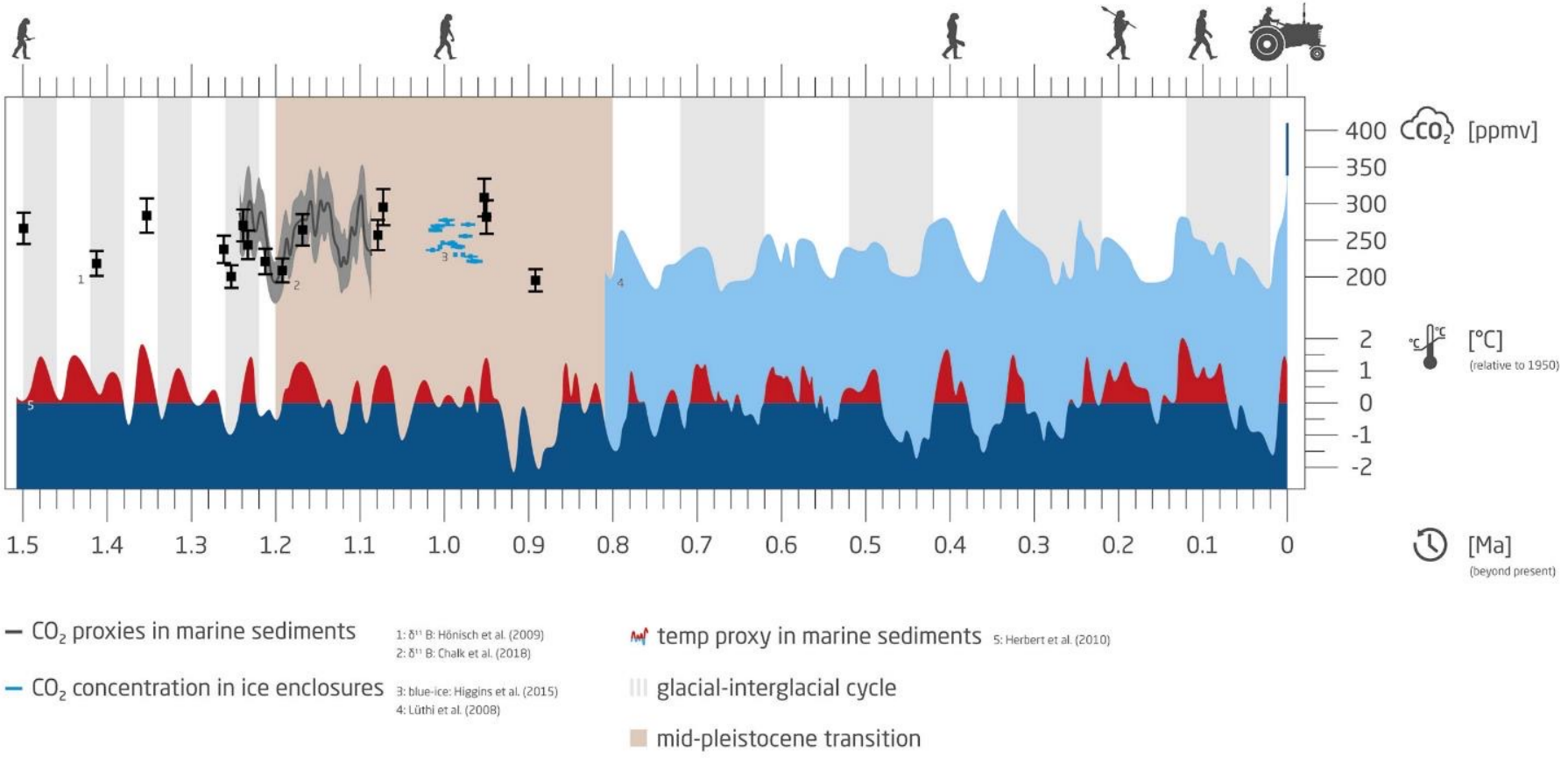
Professor for Glaciology
Alfred Wegener Institute
Helmholtz-Centre for Polar and Marine Research, Bremerhaven

University of Bremen, Bremen

USIAS Fellow at ITES/EOST 2021-2023
University of Strasbourg
Institute for Advanced Studies

Why are ice sheets important?

1. Paleo-climate archive



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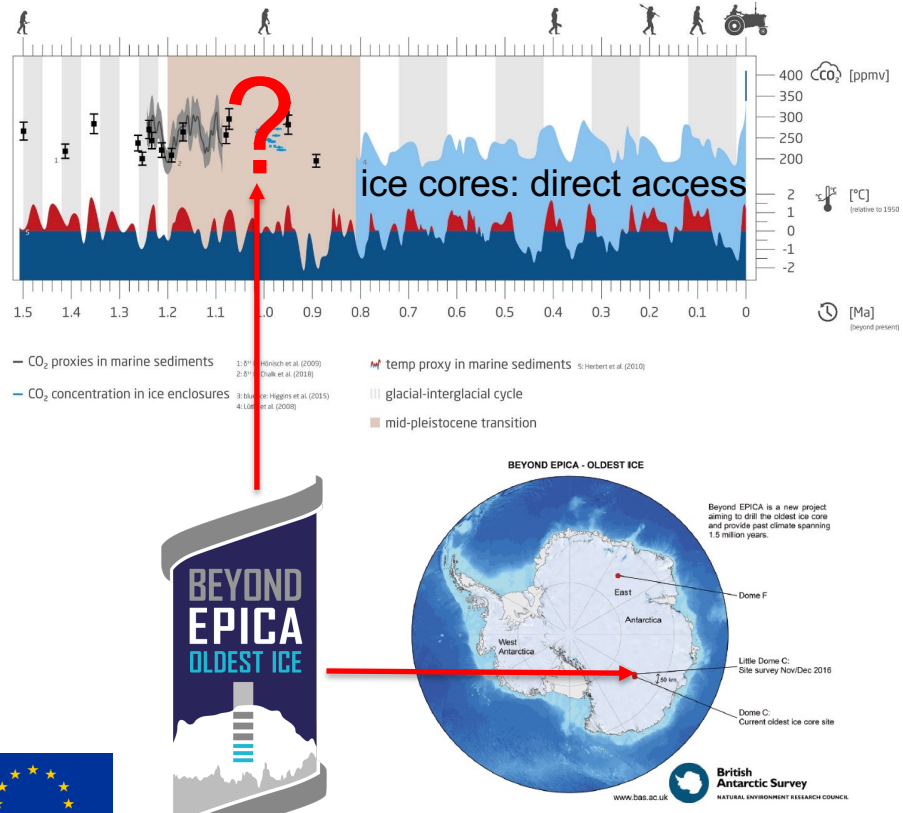
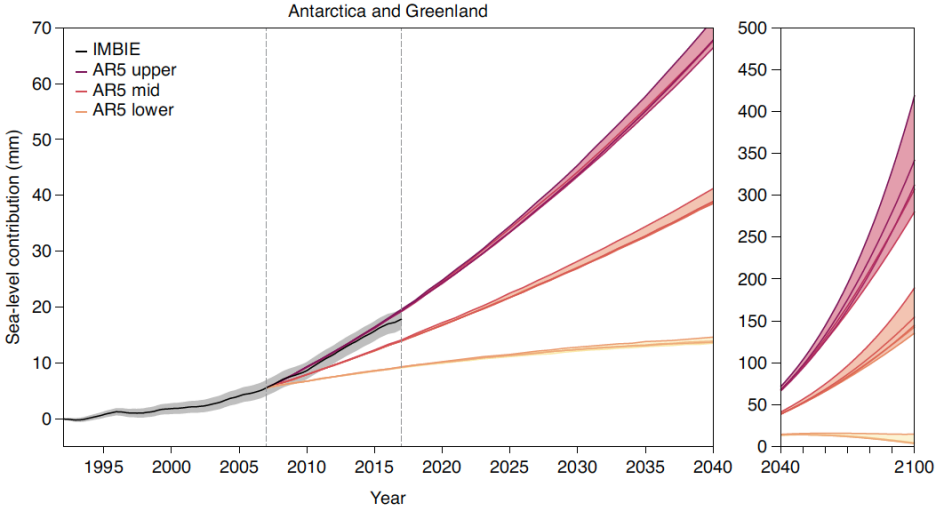


Beyond EPICA, 2019

2. Sea level change



Slater et al., NCC, 2020

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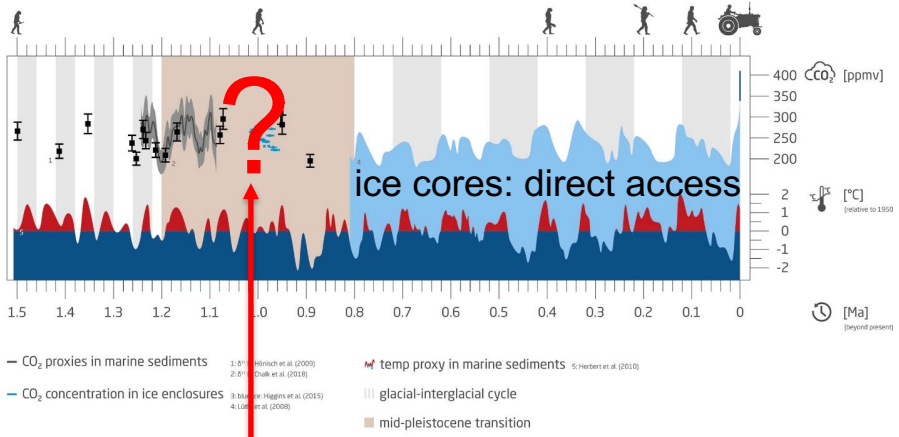

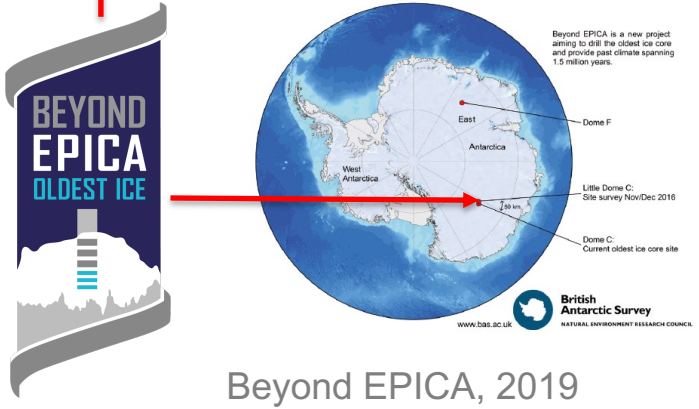

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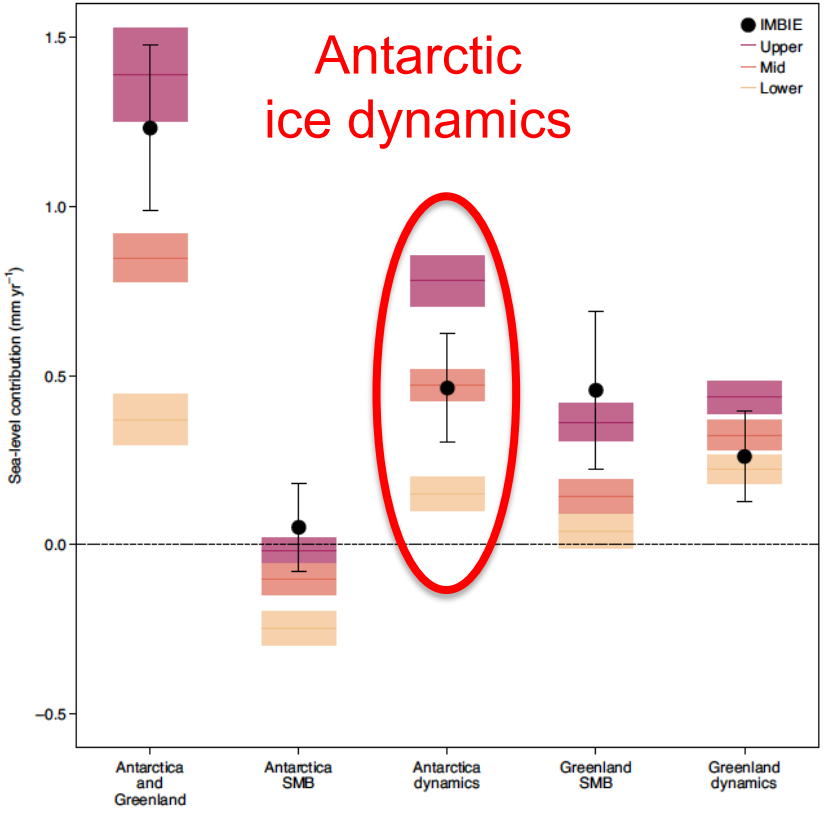


Slater et al., NCC, 2020

Why are ice sheets important?

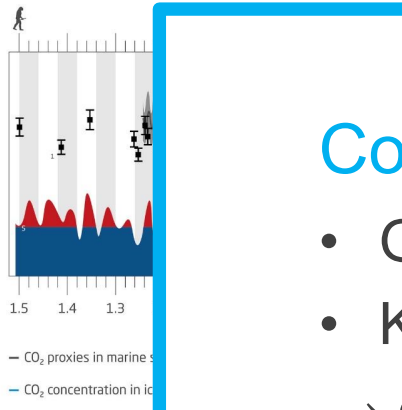
1. Paleo-climate archive

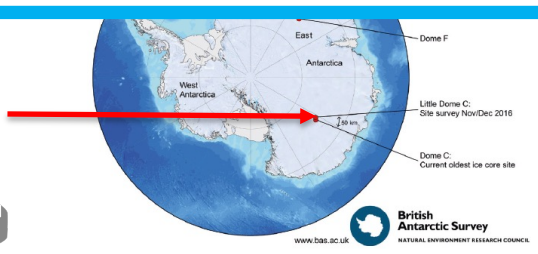
2. Sea level change

Correct interpretation & predictions:

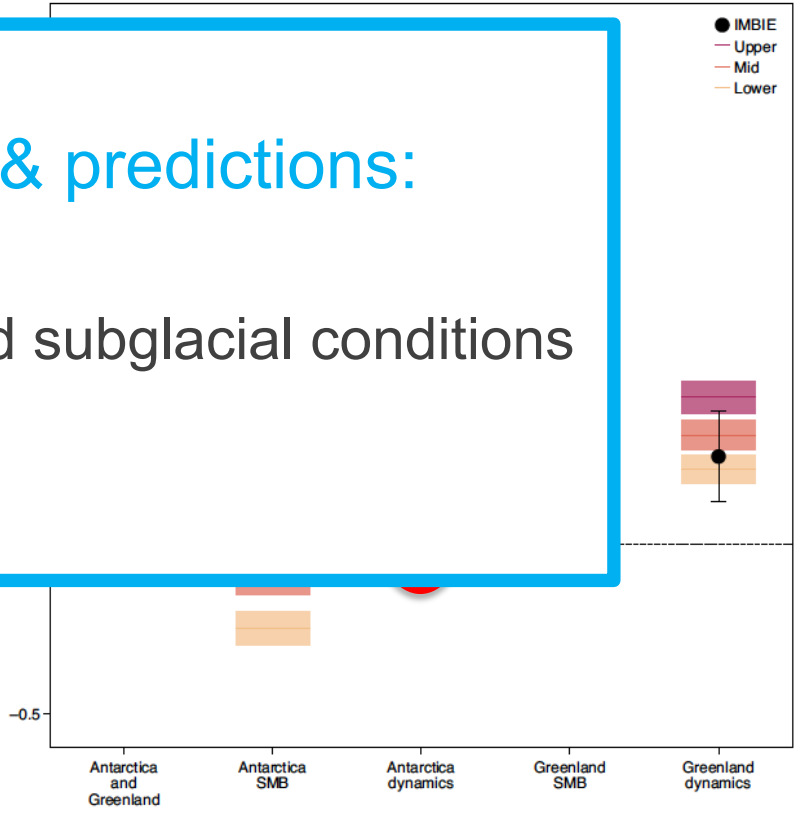
- Get ice dynamics right
- Know ice properties and subglacial conditions

⟶ on-site observations



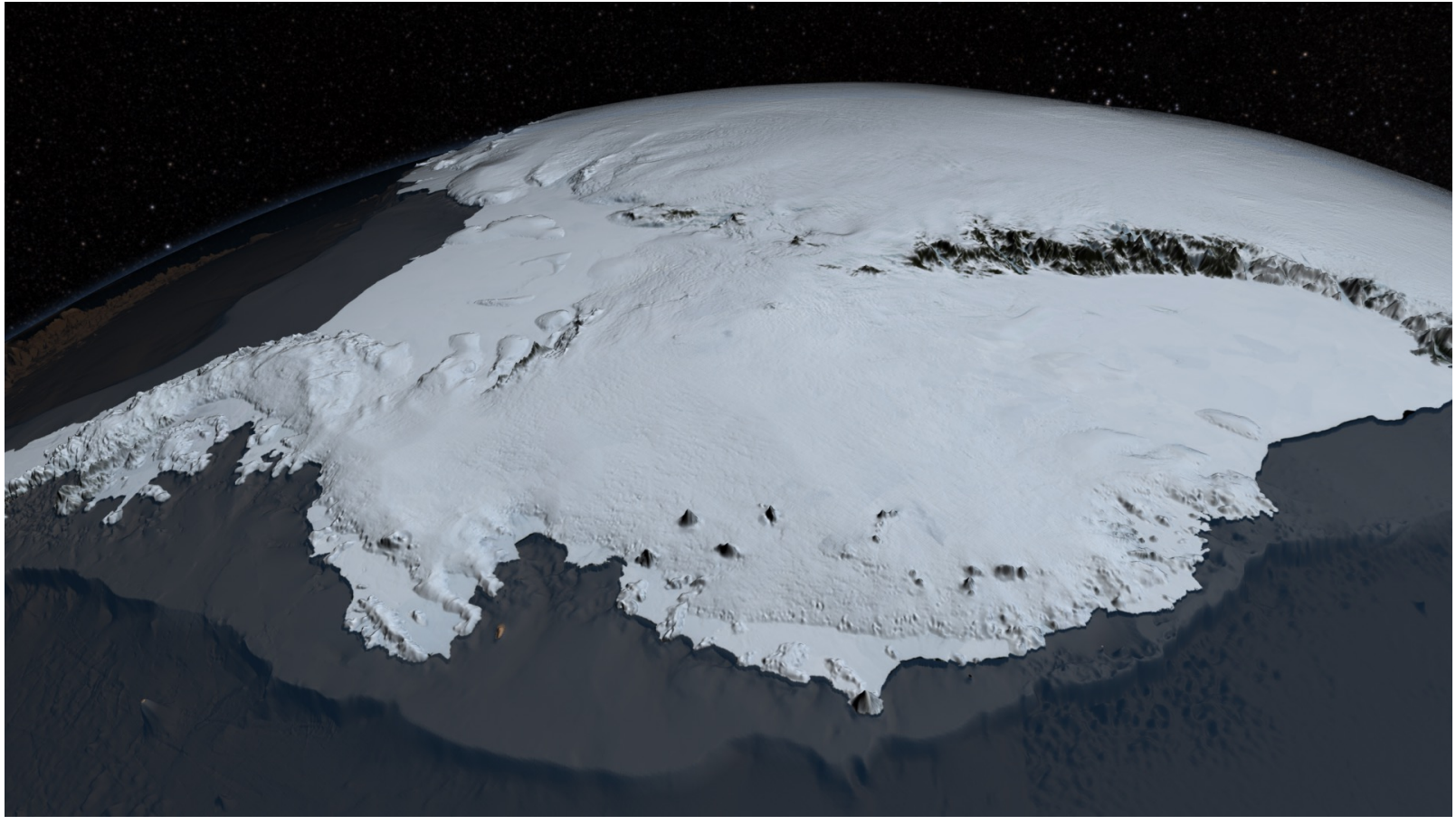


Beyond EPICA, 2019



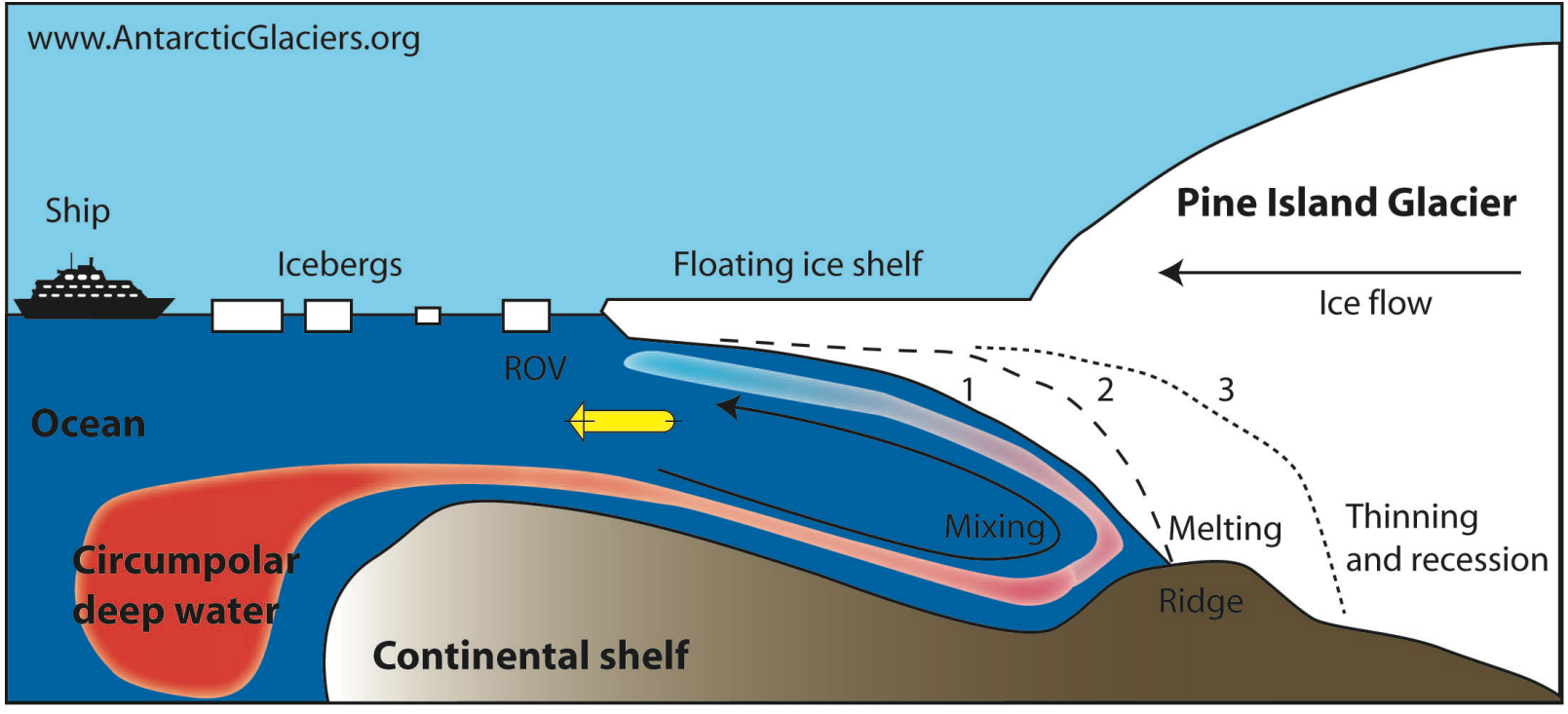
Slater et al., NCC, 2020

Importance of bedrock topography



Courtesy: NASA

Marine Ice Sheet Instability (MISI)



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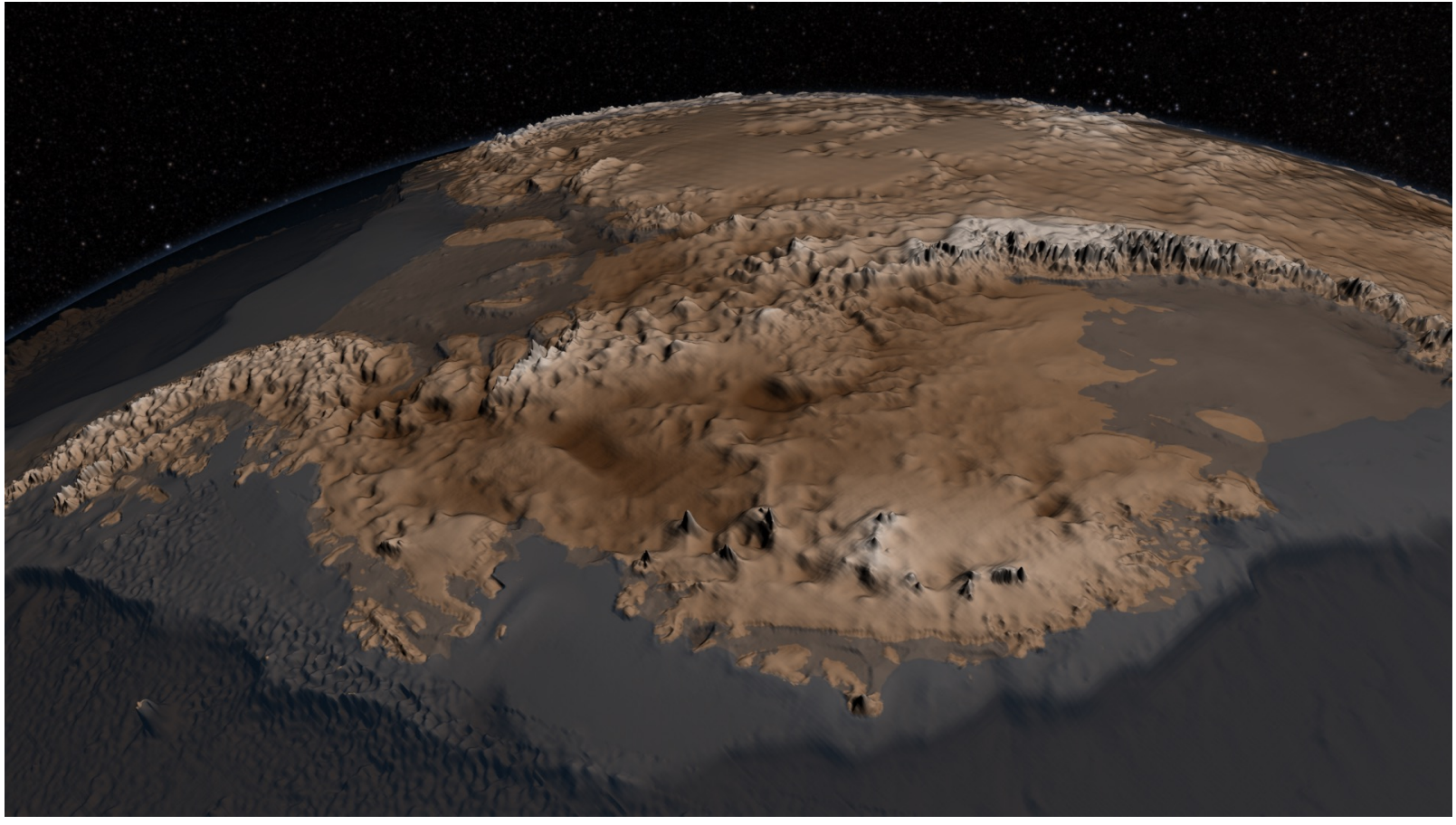
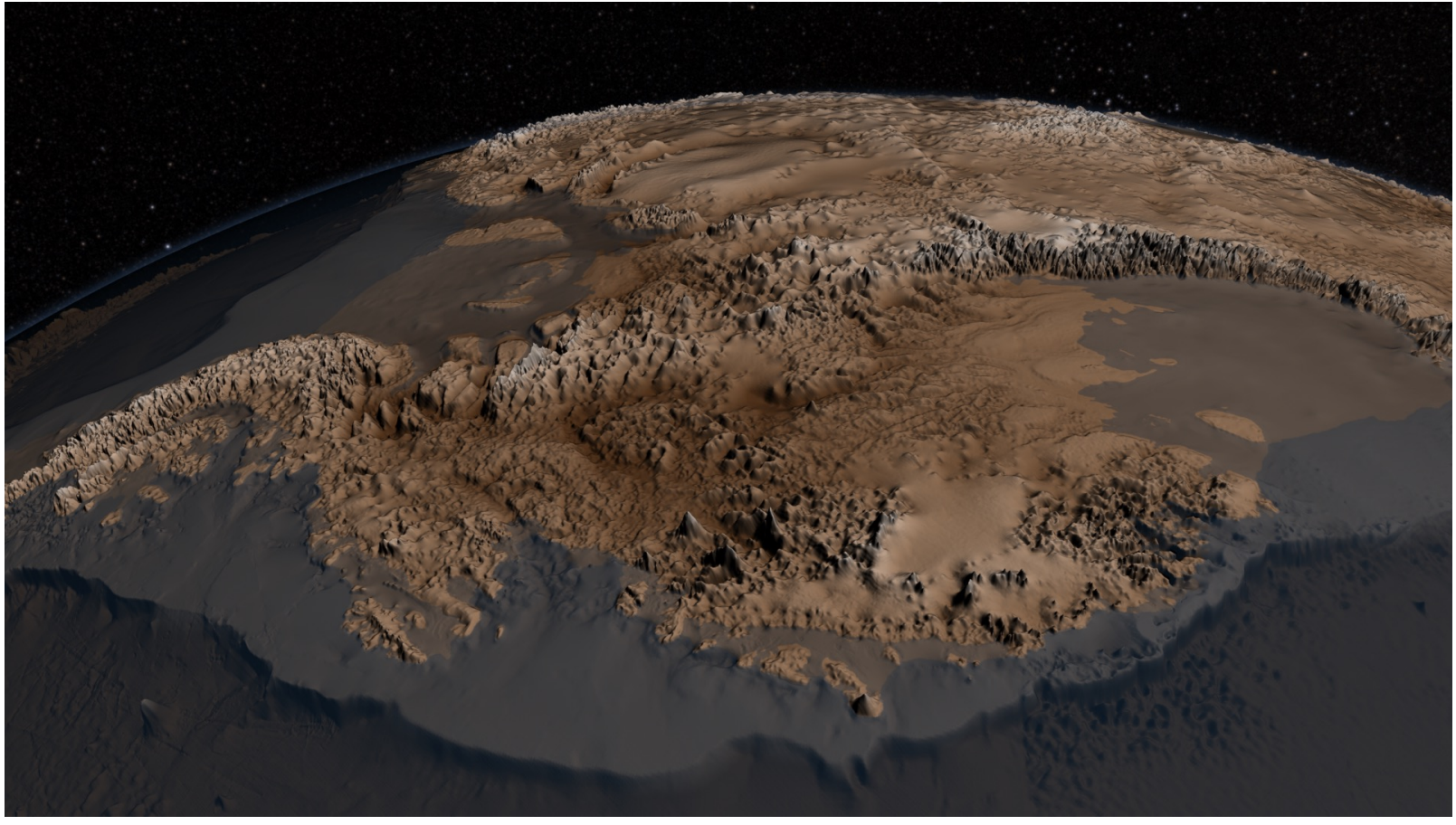


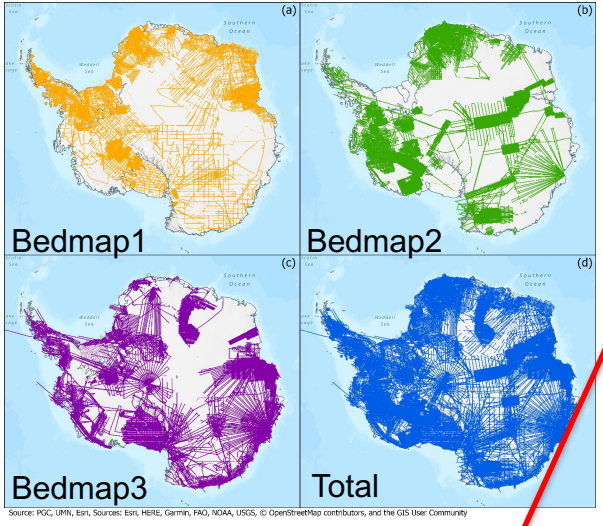
Courtesy: NASA, based on BEDMAP (2001)

Importance of bedrock topography

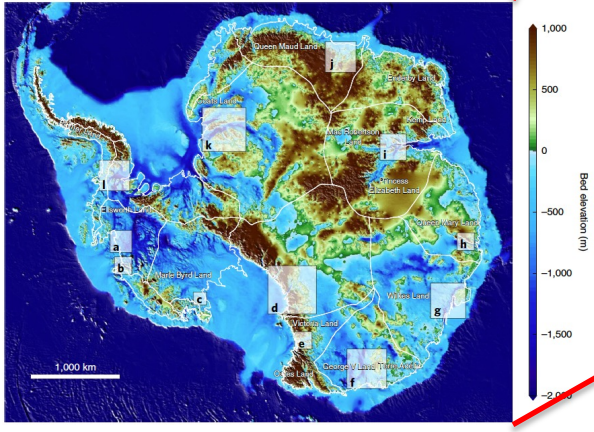


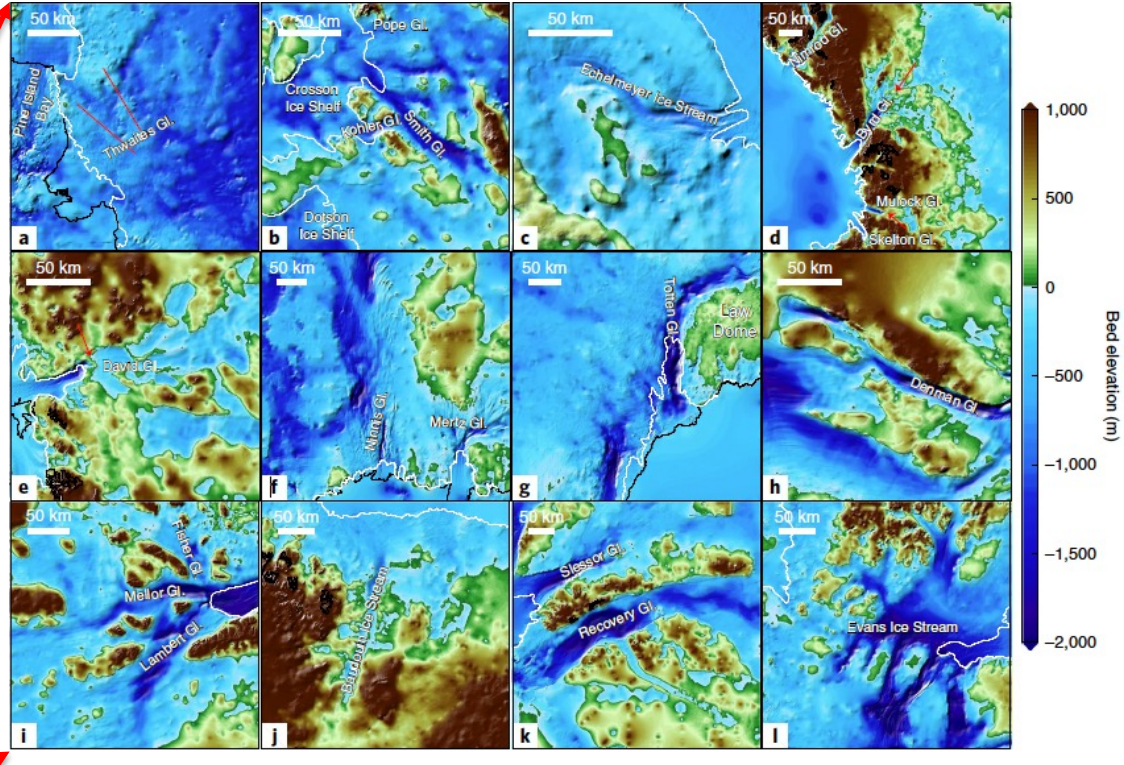
Courtesy: NASA, based on BEDMAP2 (2012)

Ice thickness coverage & products



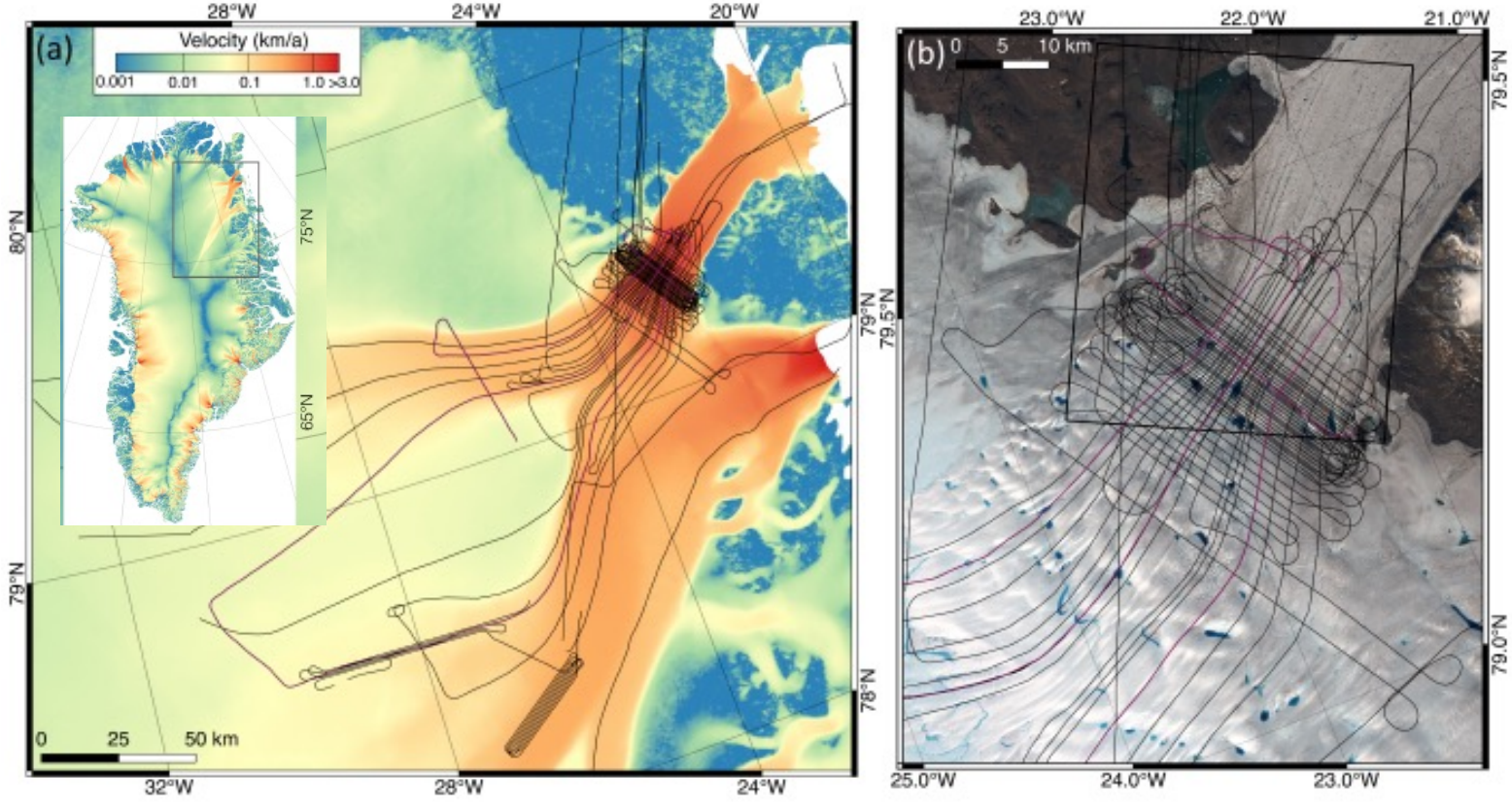
Bedmap3: 60 years of data sharing (Frémand et al, ESSD, 2022)





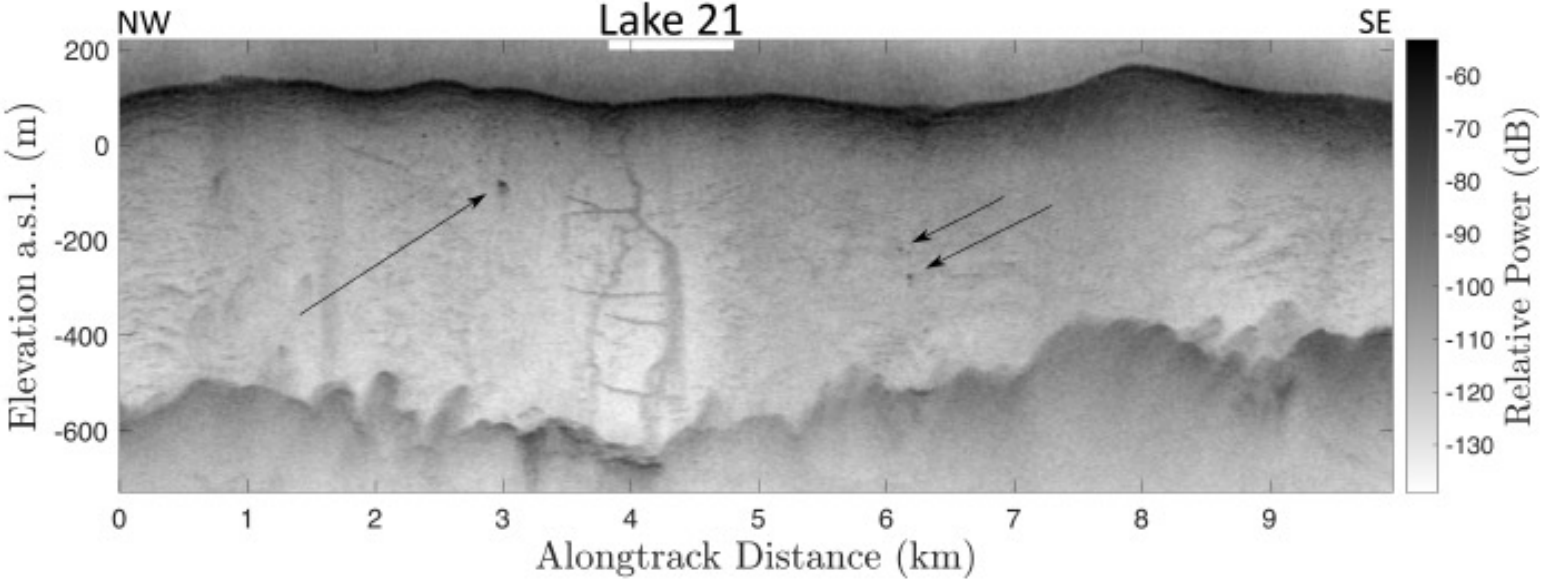
BedMachine Antarctica: Observation & Modelling
(Morlighem et al, Nat. Geo., 2020)

Greenland N79°: Englacial channels



Dörr, 2019

Englacial events: N79°



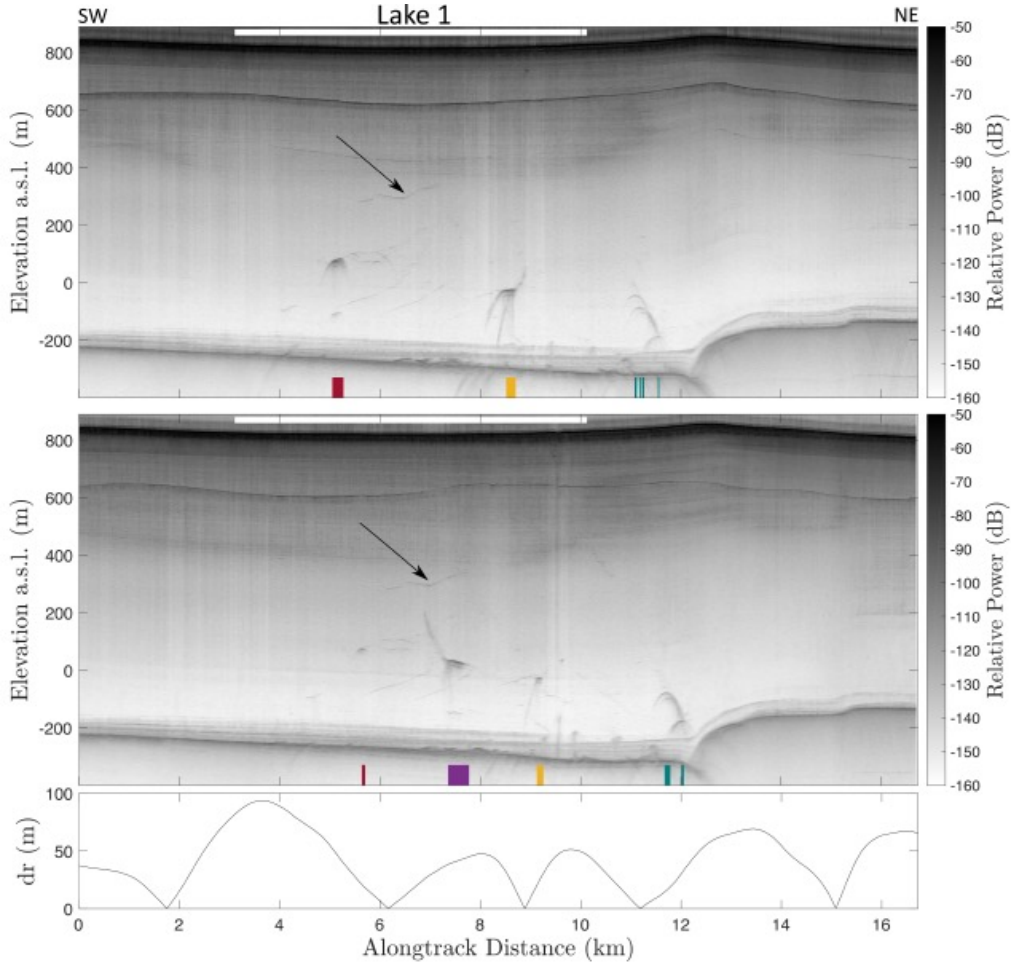
Signatures can be tracked

… in parallel flight lines

… repeatedly over time, but they change!

Dörr, 2019

Englacial events: temporal evolution



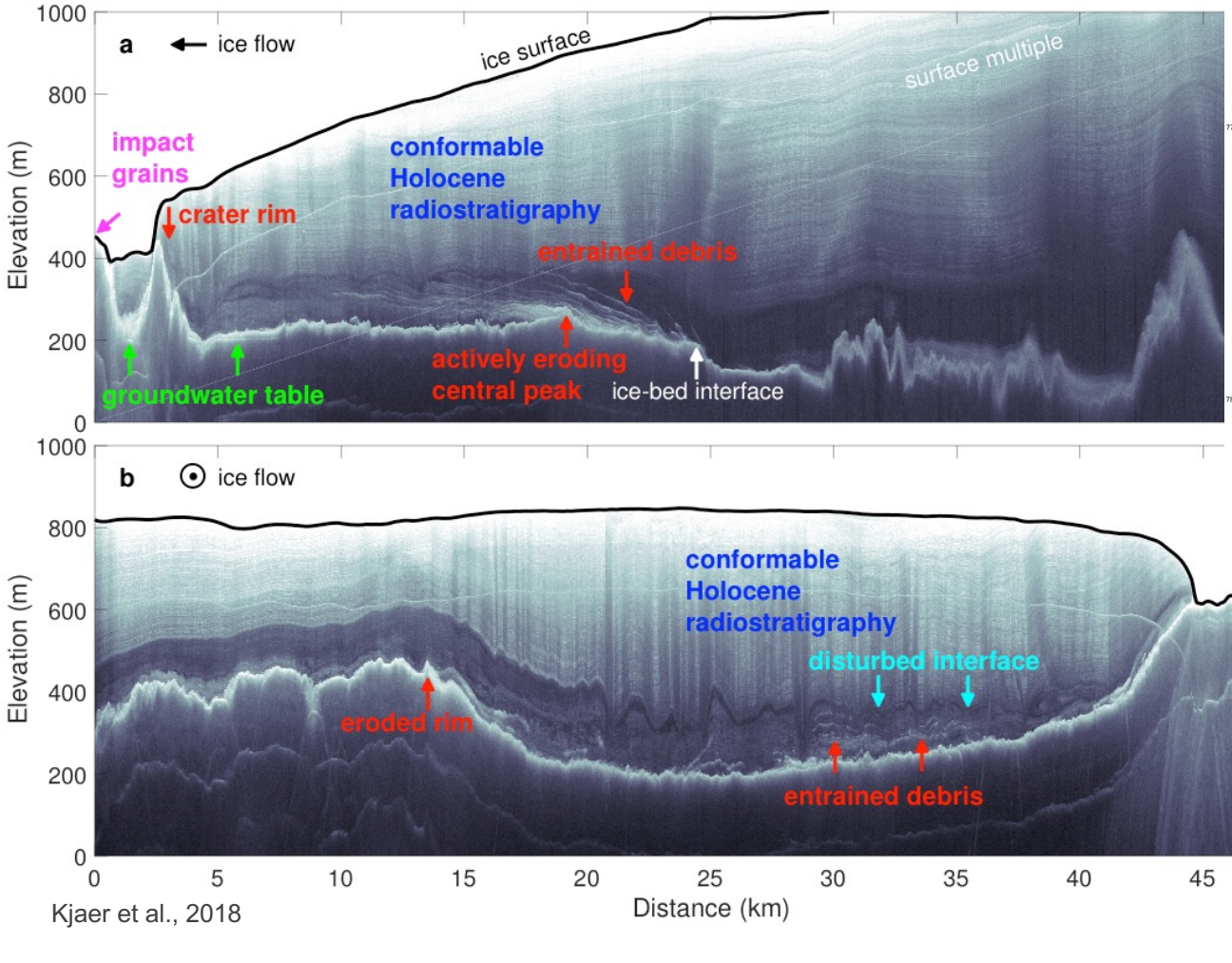
Reapeated flights in wide band survey mode:

2016

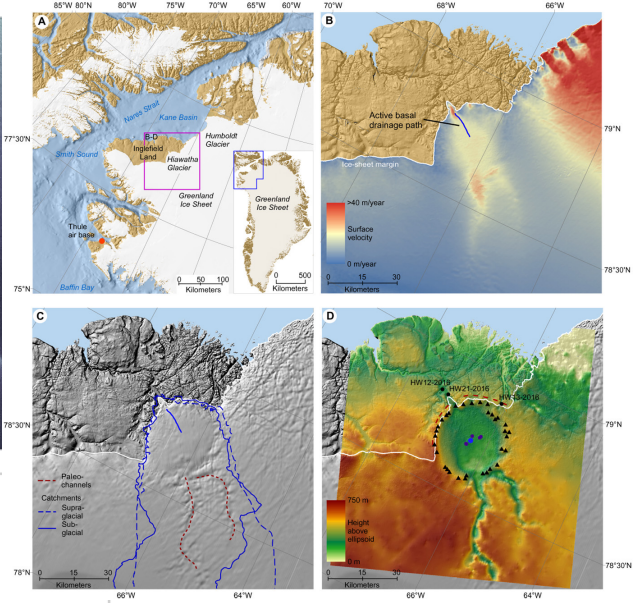
2018

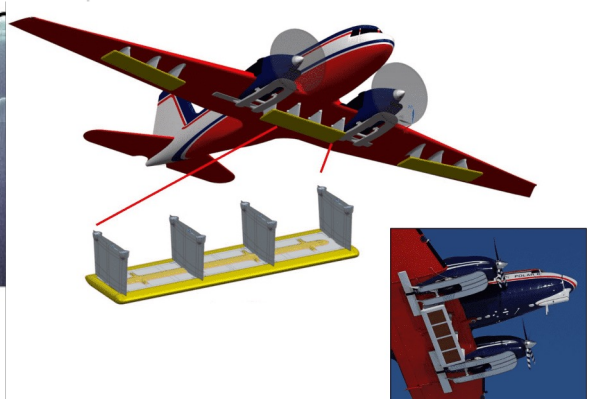
Dörr, 2019

Englacial & basal layer properties

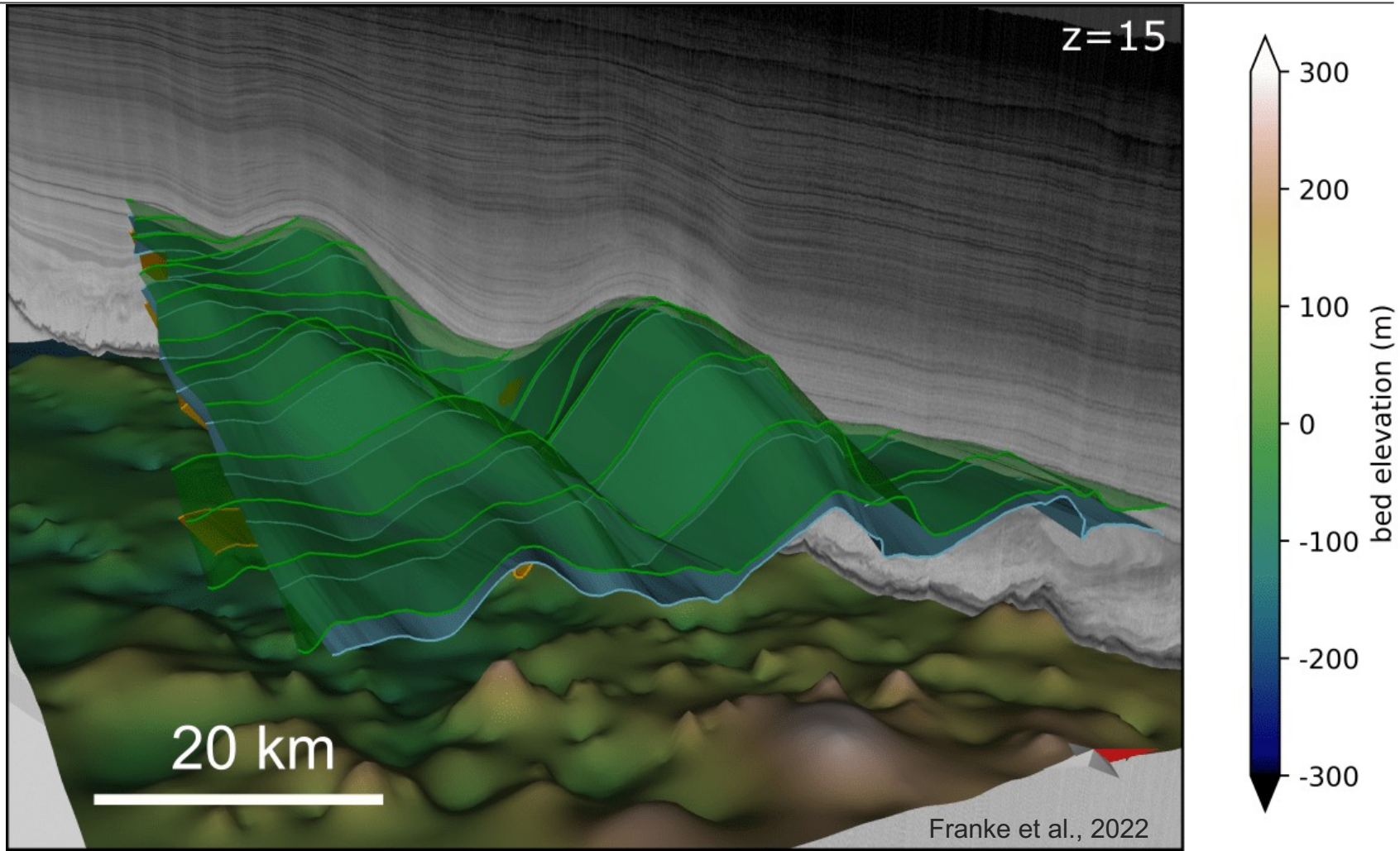


Kjaer et al., 2018





Internal layers: everything is 3D!

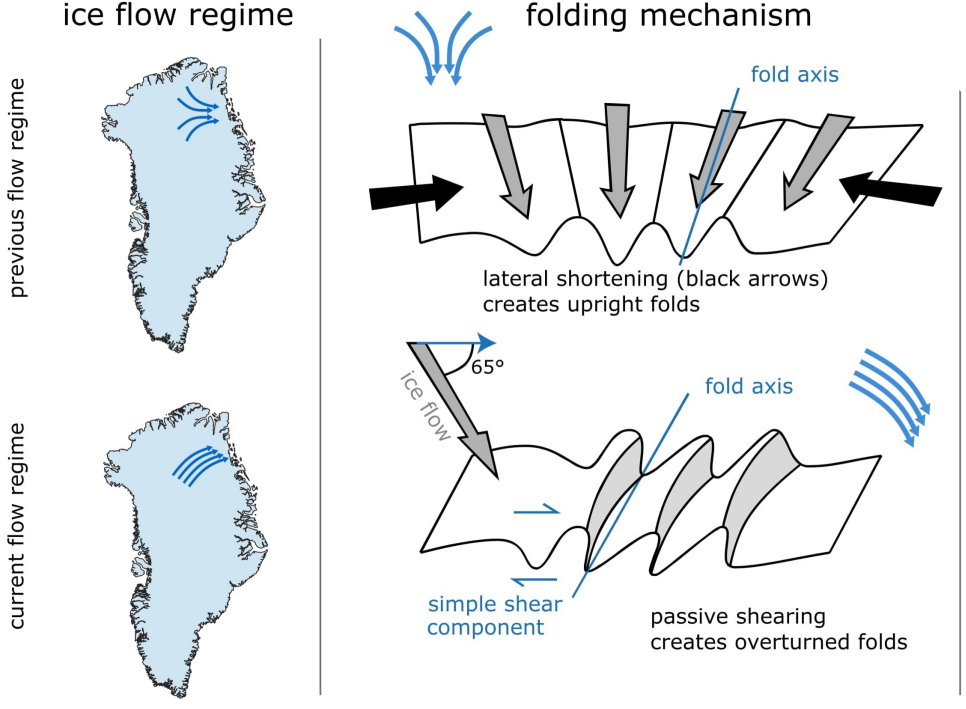


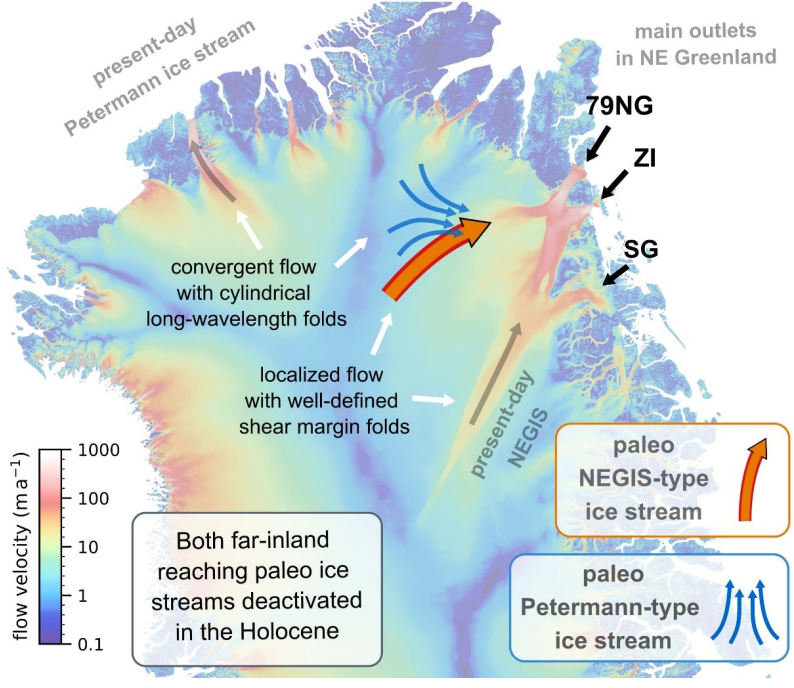
Structure => Dynamics

ALFRED-WEGENER-INSTITUT
HELMHOLTZ-ZENTRUM FÜR POLAR- UND MEERESFORSCHUNG

Holocene ice-stream shutdown in northeast Greenland

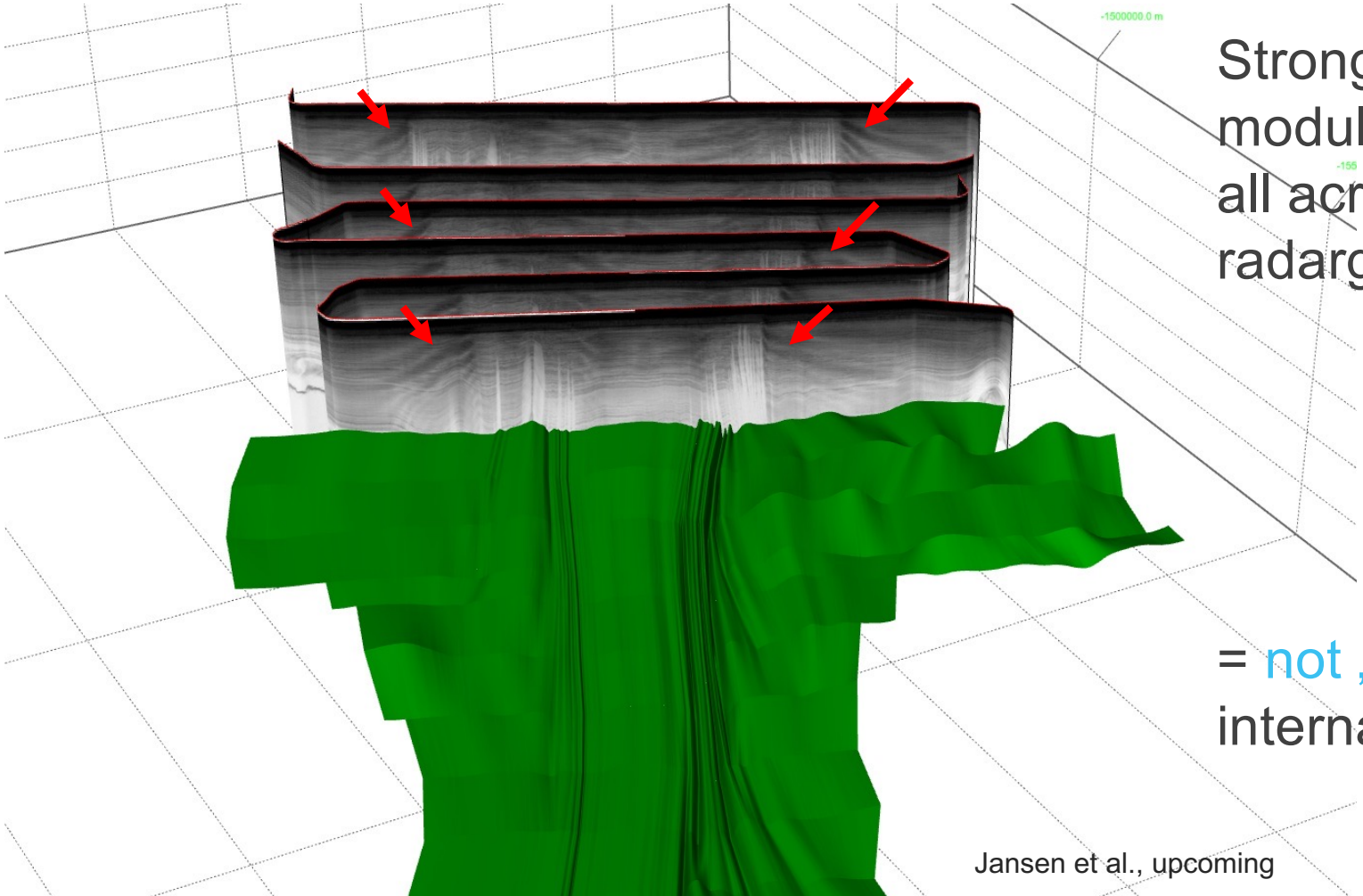
(and NEGIS likely < 4000 years old)





Franke et al., Nat. Geosci., 2022

Anisotropy: NE-Greenland ice stream

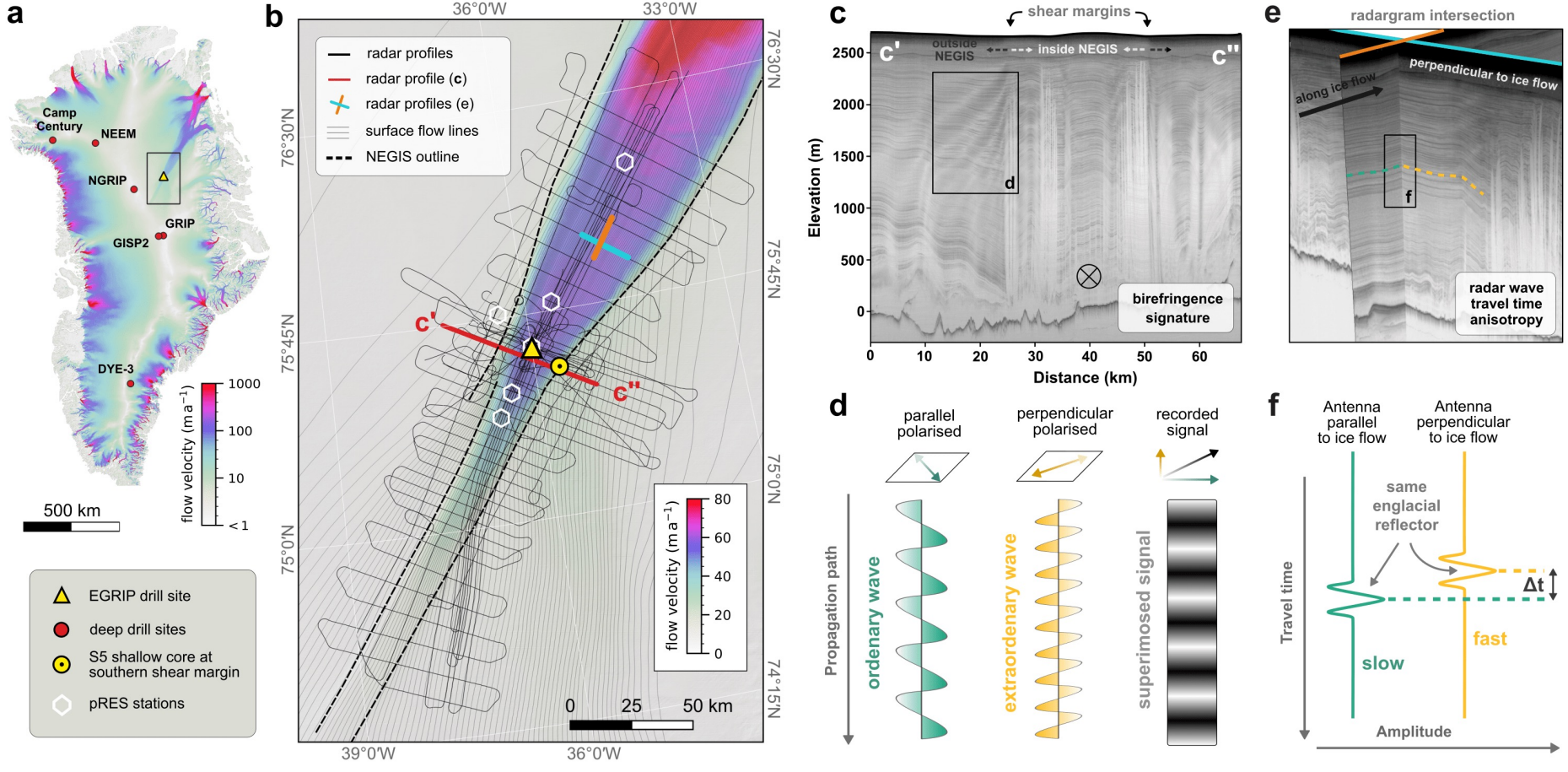


Strong amplitude modulations in all across-flow radargrams

= not „normal“ internal layers!

Jansen et al., upcoming

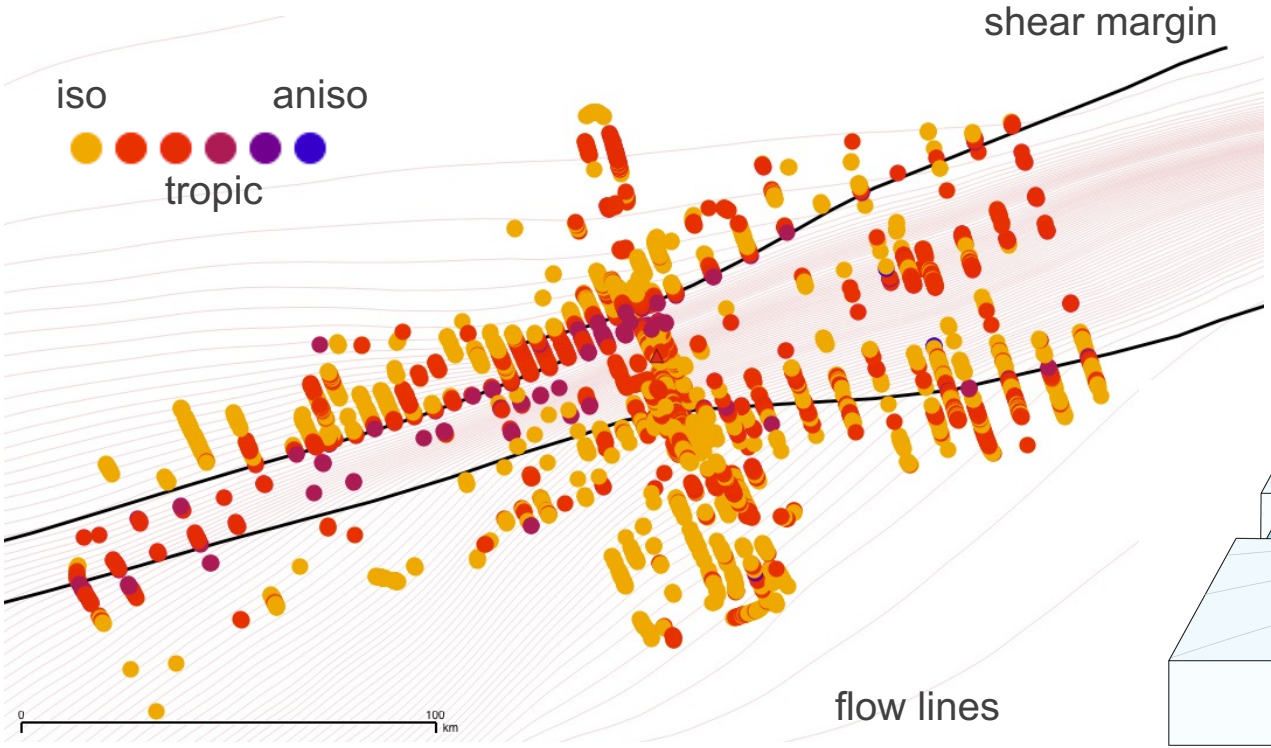
Shear-wave splitting in radar waves

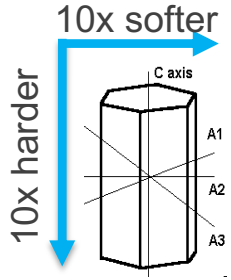


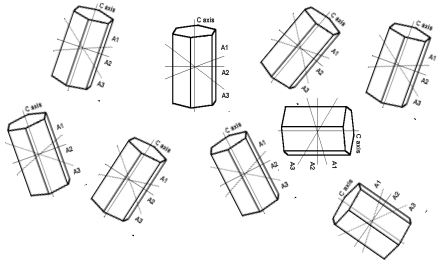
birefringence in ice: 1973, conceptual model: 2006, observation: 2018

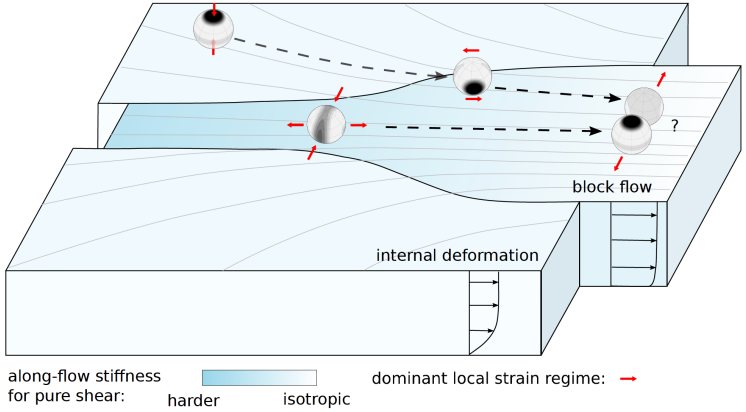
Mapping (bulk) crystal anisotropy

Spatial variation of anisotropy across shear margin
=> considerable effect on ice rheology



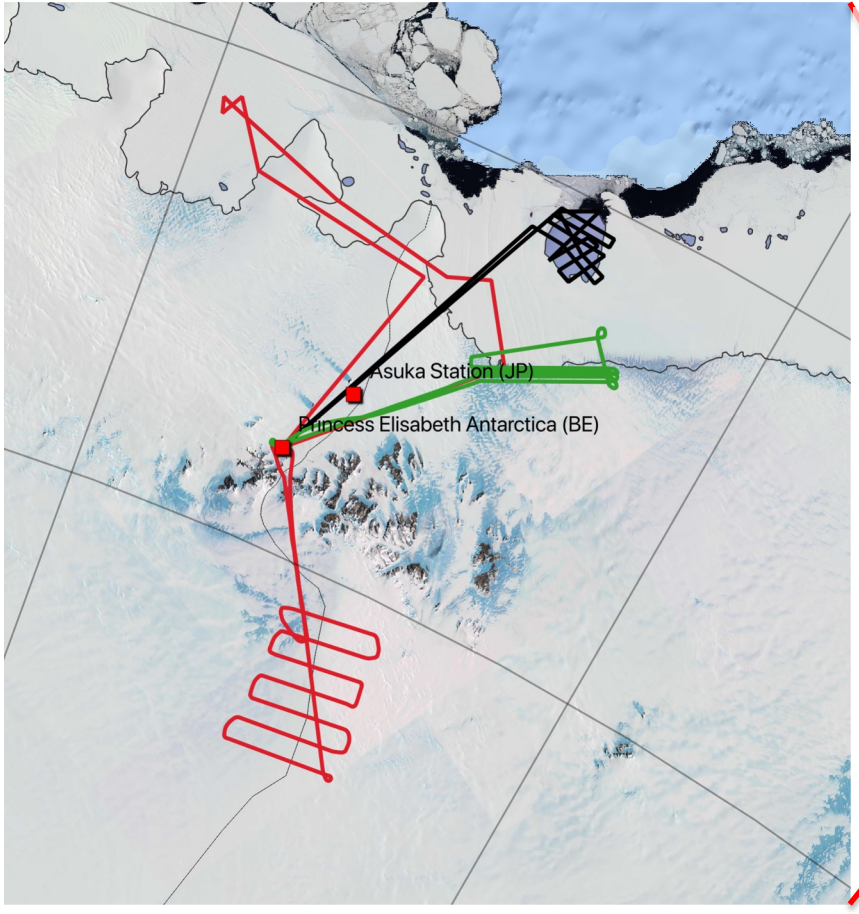




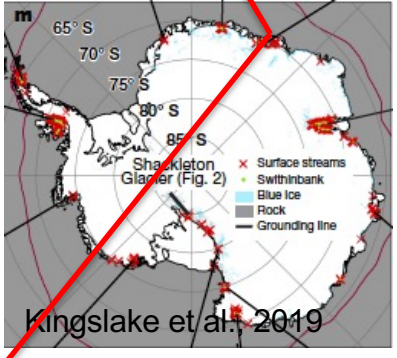


Gerber et al., submitted, 2022

Subglacial channels: Antarctica



- Melt channels and ice rises
- Radar stratigraphy and bedrock south of Sør Rondane Mountains
- Wide band survey mode
- Jan. 2019



Kingslake et al., 2019

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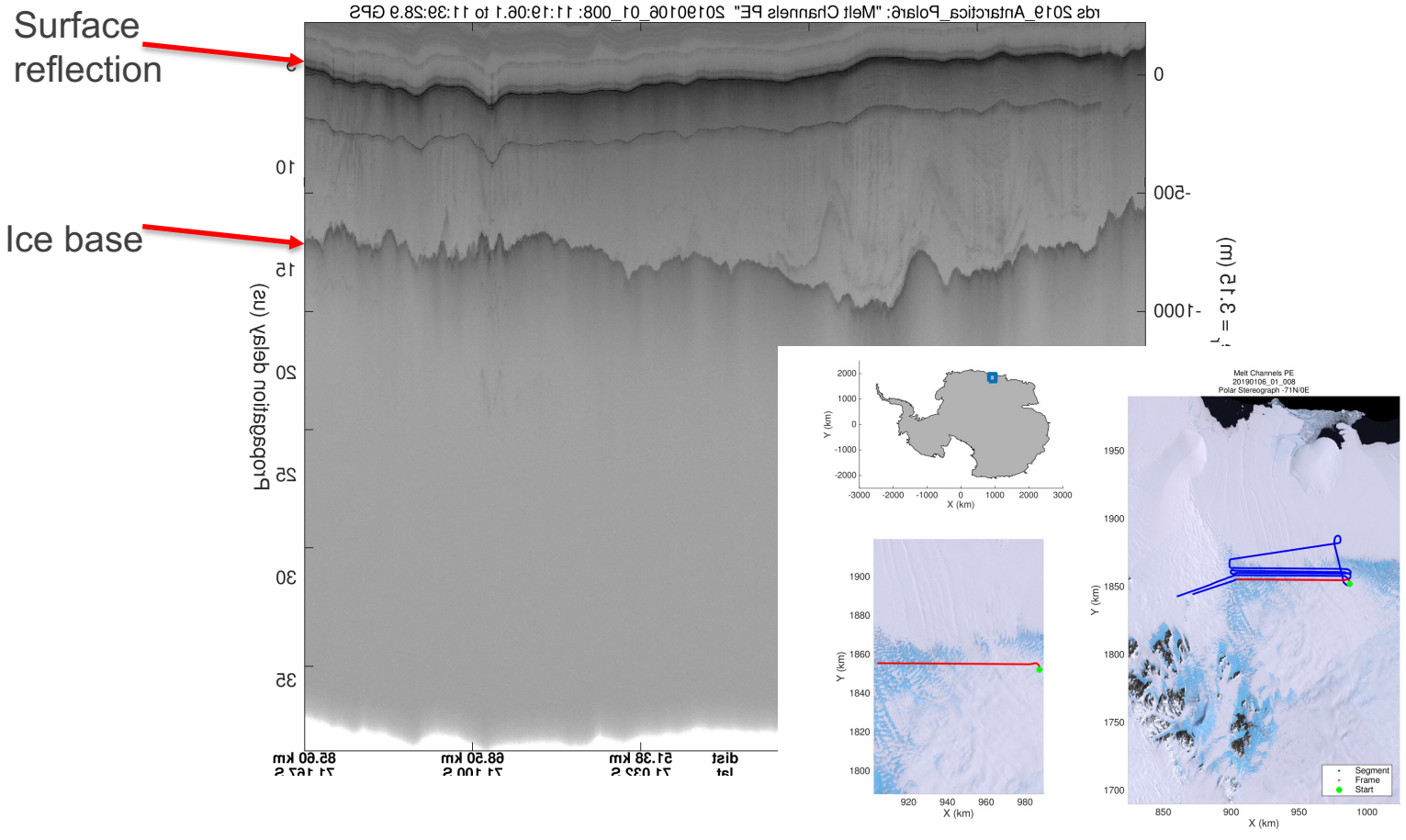

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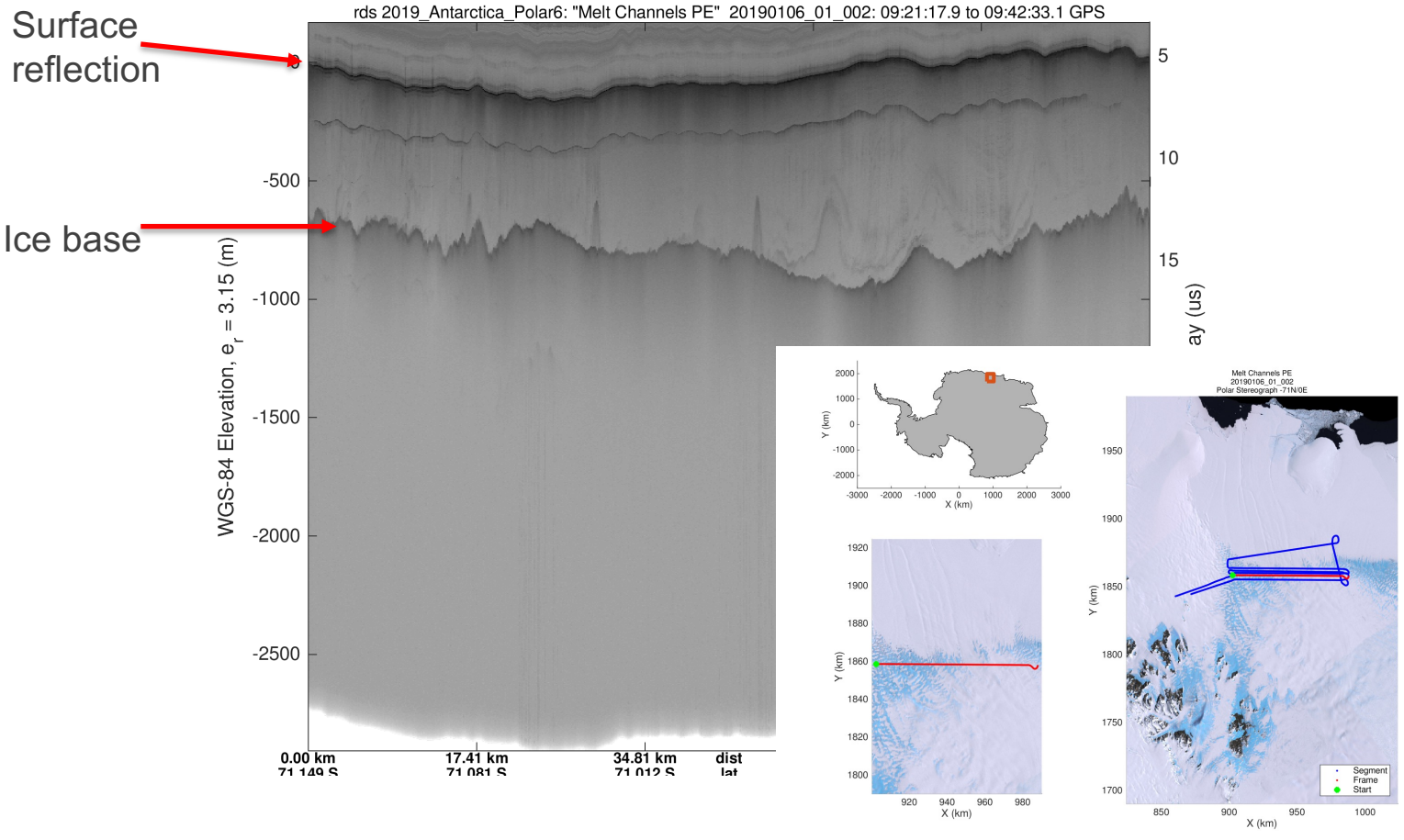

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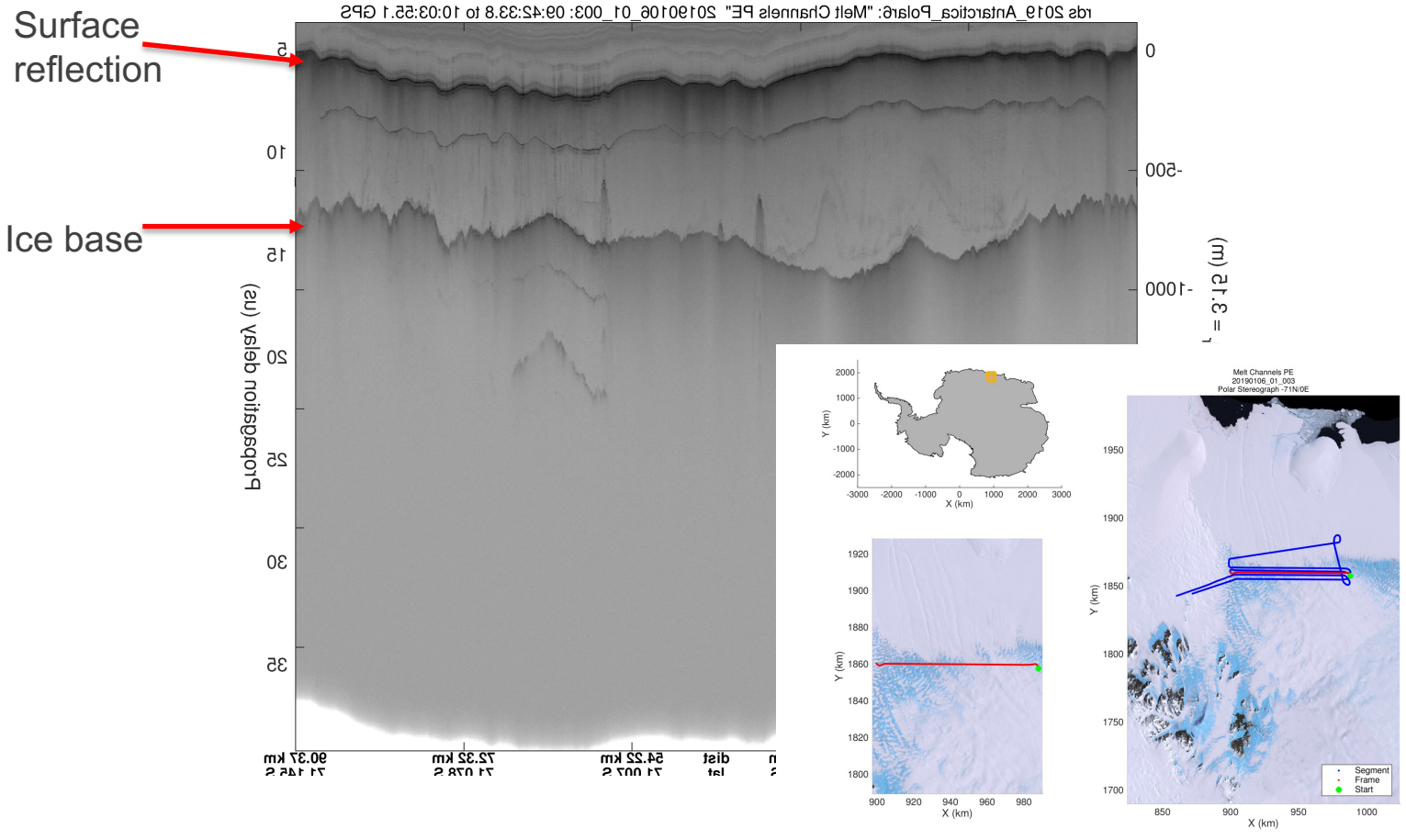

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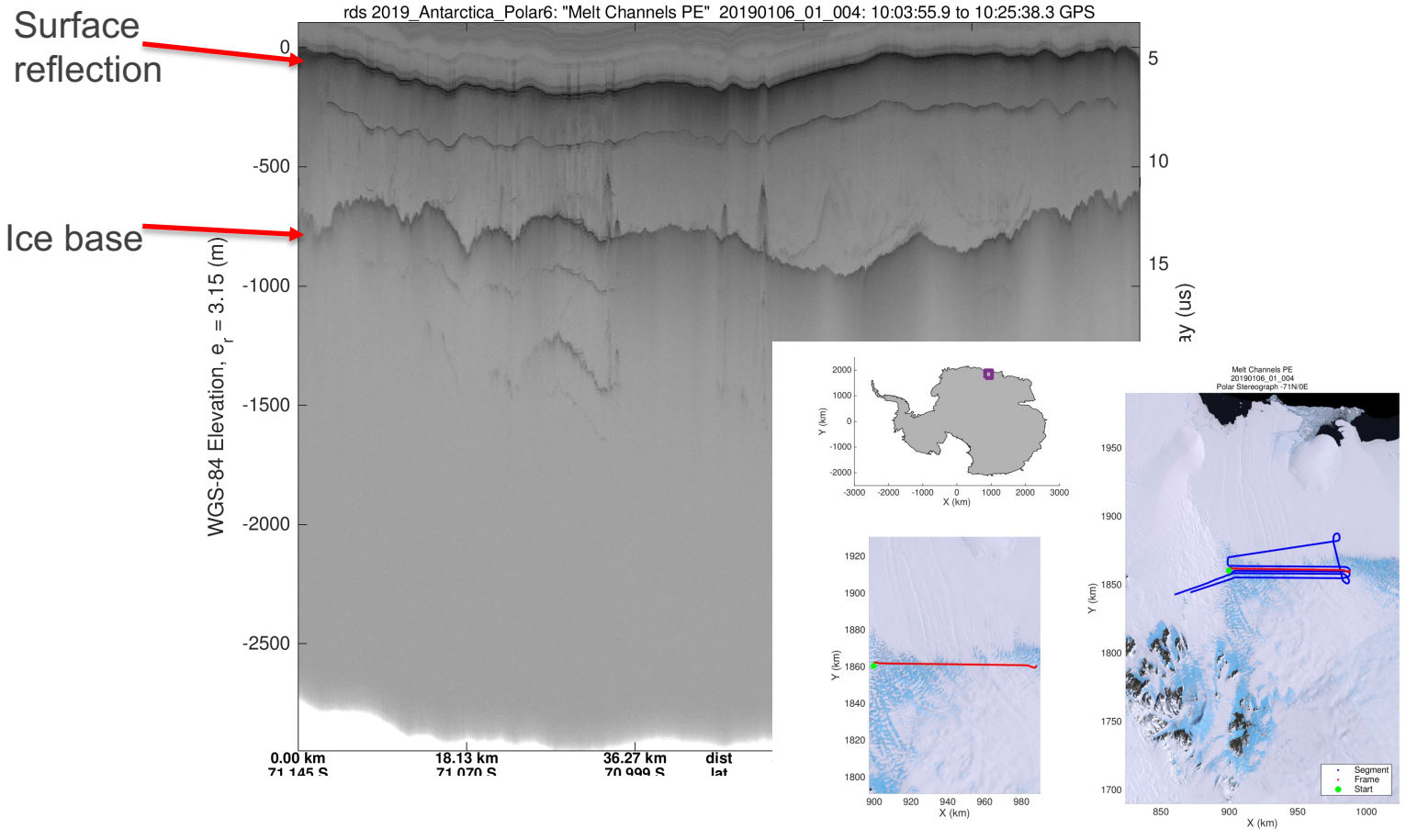

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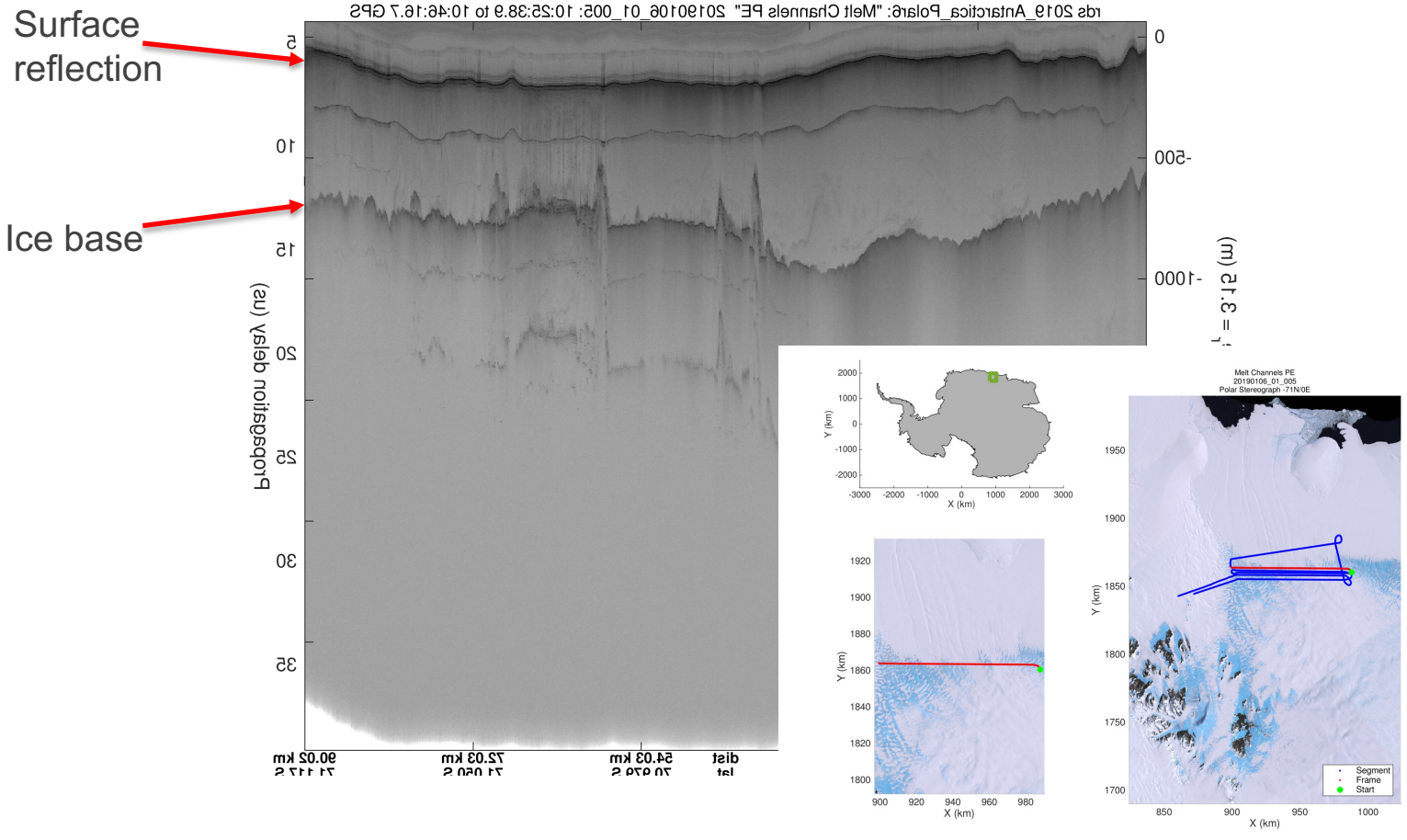
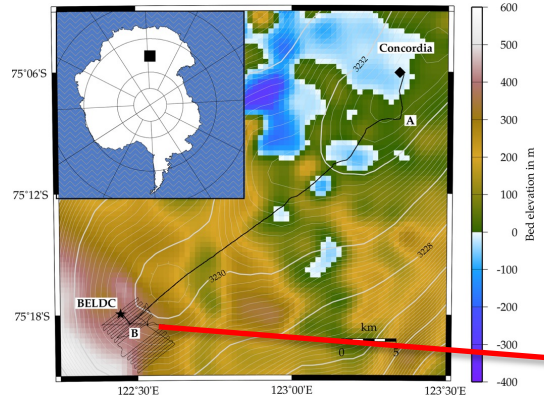
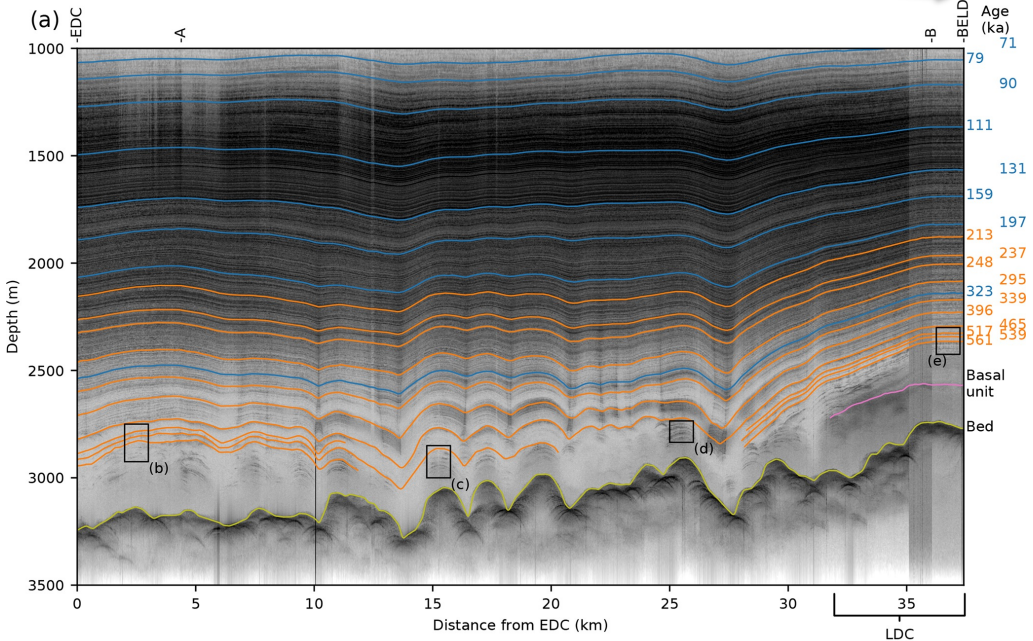
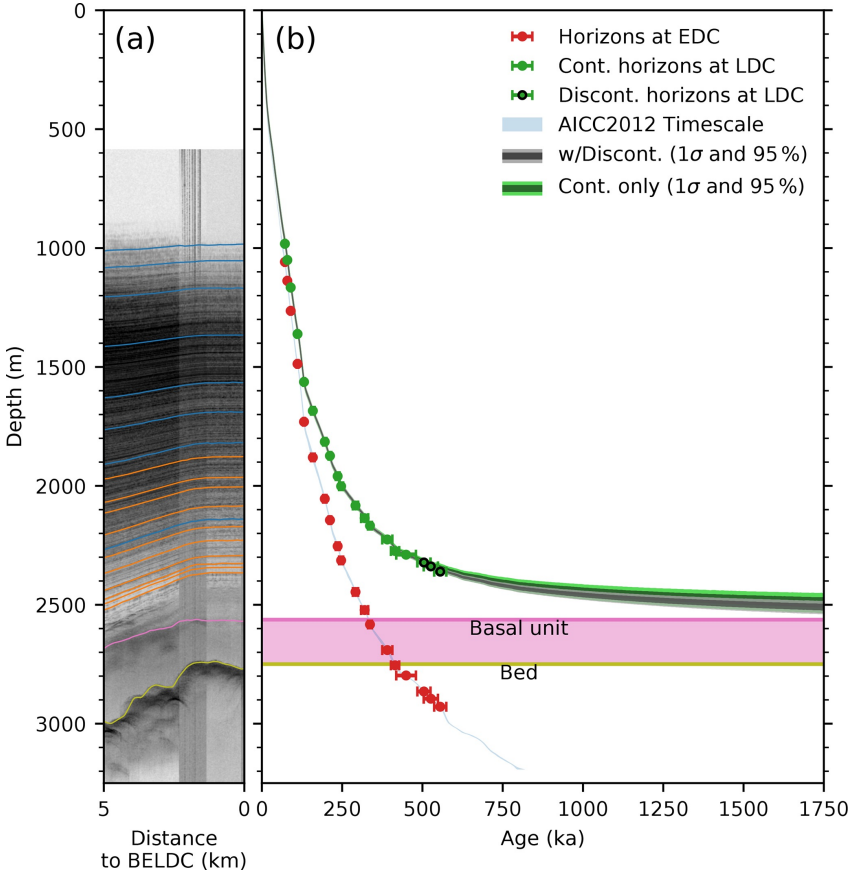


How to decide on an ice-core drilling site?







Radar capabilities & uses

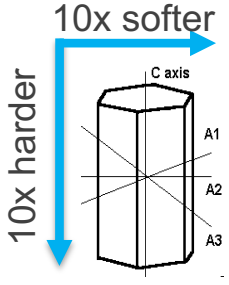
- ice thickness (flux geometry, undulations, …)
- bed conditions (subglacial lakes, grounding lines, boundary condition for modeling)
- internal layer architecture (dynamics, accumulation, ice core synchronisation, model calibration)
- density distribution (firn-ice transition, porosity, …)
- polythermal boundaries (cold-temperate, change over time, geothermal heat flux)
- liquid water content (hydraulics, mass balance)
- internal conduits (hydraulics, boundary conditions, dynamics)
- crevasse detection (ice shelf stability, logistics, …)
- inclusion (sediments, boulders, airplanes)

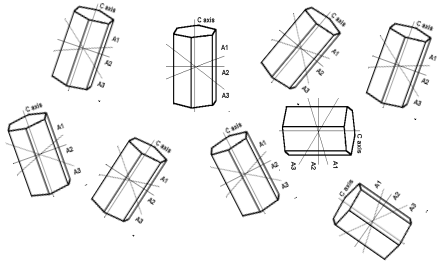
Picture:
S. Franke

Ice dynamics depends on properties

- Ice anisotropy

Direction of crystals:

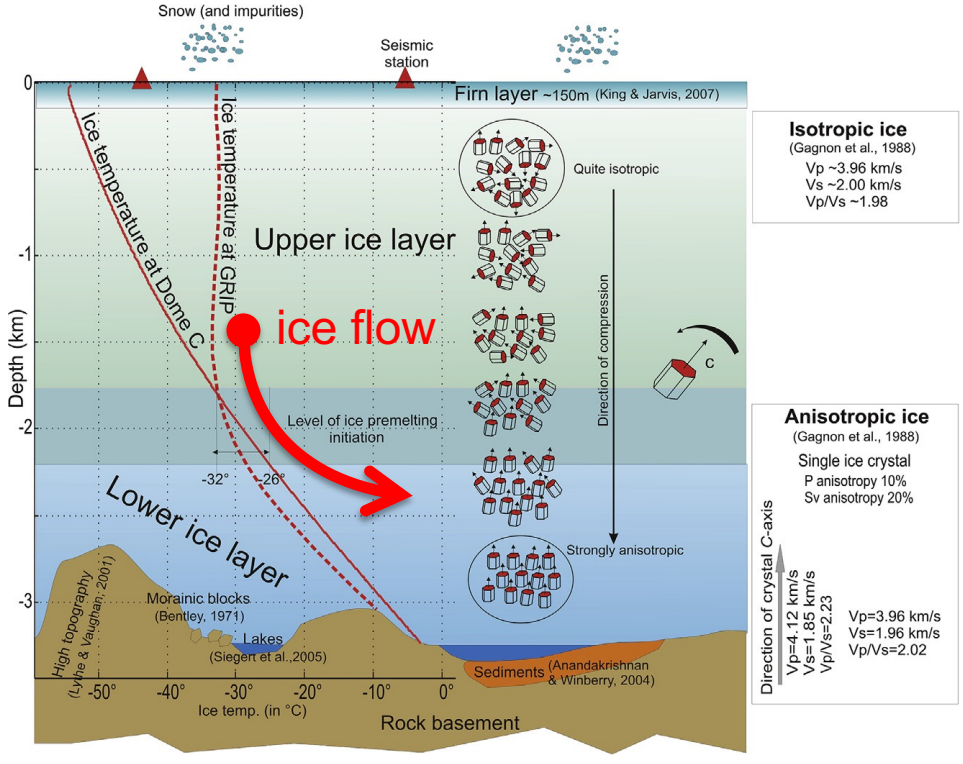




- Subglacial conditions

Hard bedrock or soft sediments?

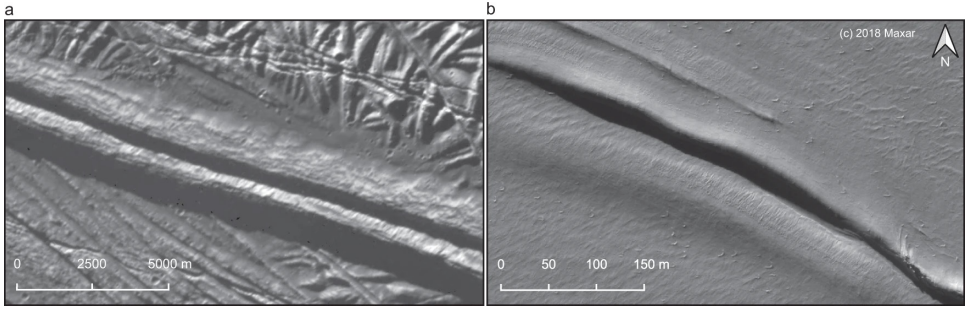
Frozen or melting?

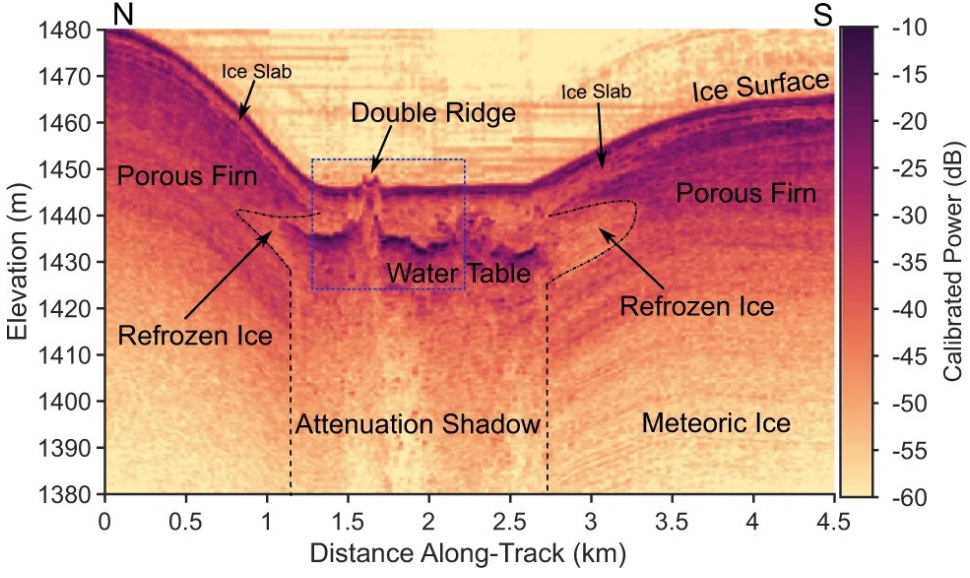


Wittlinger et al., 2012, 2014

→ Use geophysics to observe

Interpretation: learning from Earth …





Culberg et al., 2022
(Europa)