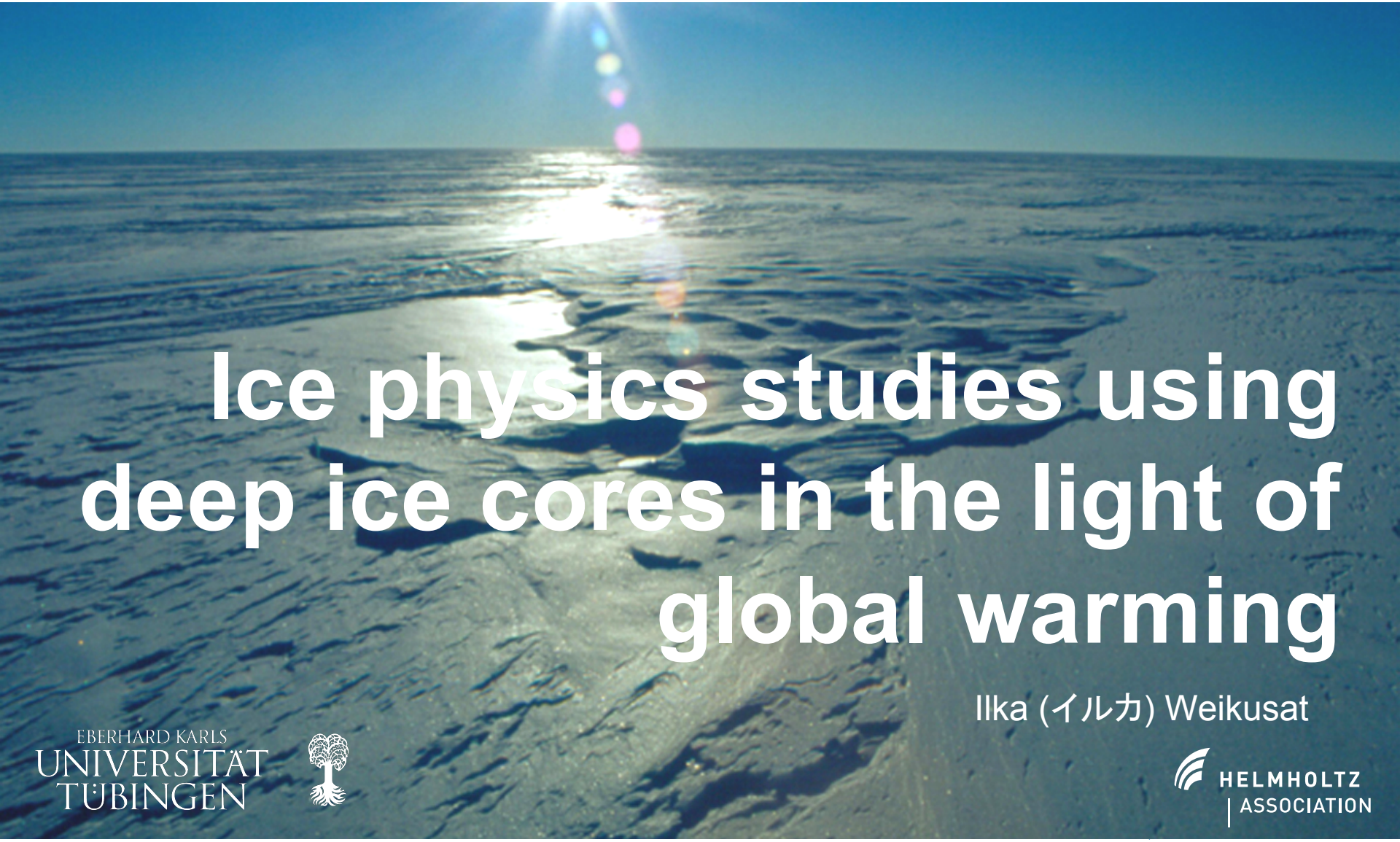


ALFRED-WEGENER-INSTITUT
HELMHOLTZ-ZENTRUM FÜR POLAR- UND MEERESFORSCHUNG

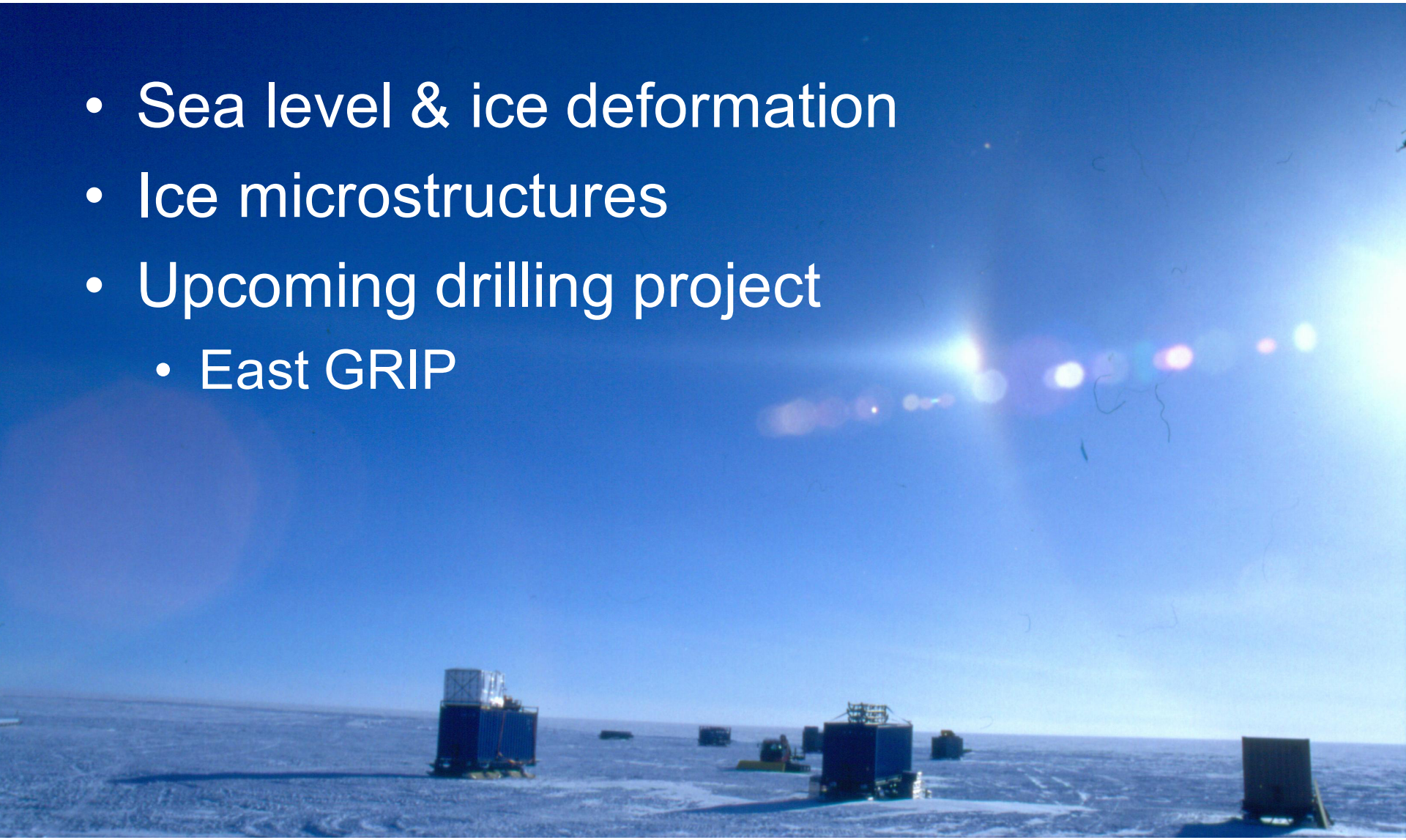
Ice physics studies using deep ice cores in the light of global warming

Ilka (イルカ) Weikusat

EBERHARD KARLS
UNIVERSITÄT
TÜBINGEN

HELMHOLTZ
ASSOCIATION

- Sea level & ice deformation
- Ice microstructures
- Upcoming drilling project
  - East GRIP

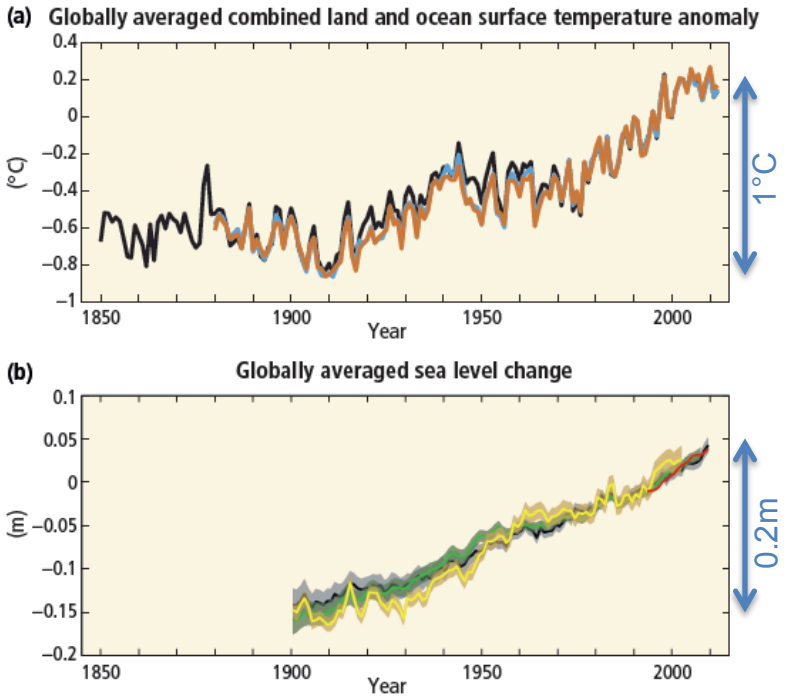


Bremerhaven

Located at estuary of river Weser into the North-Sea

Sea level

IPCC - Intergovernmental Panel on Climate Change
(set up by UN to assess of the scientifc basis of climate change for policymakers)

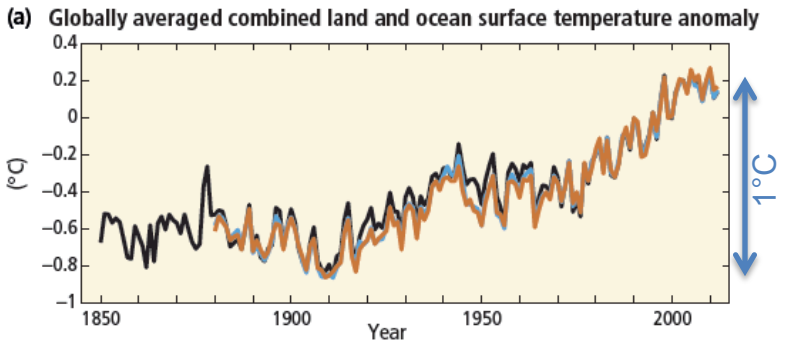


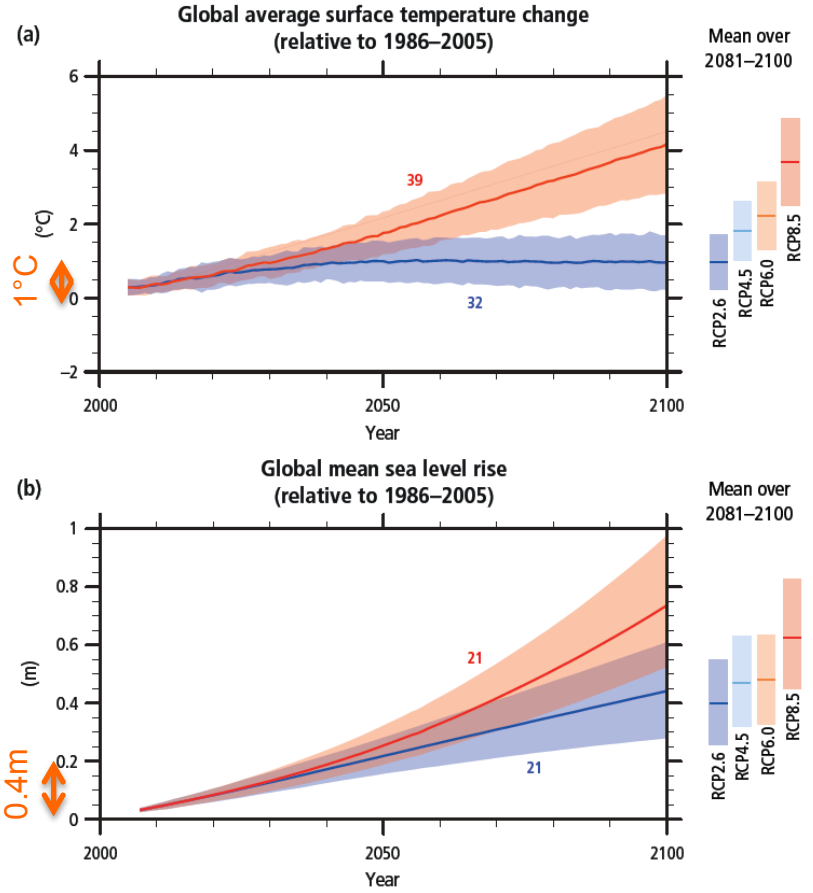
Observations (over ca. 100a)

IPCC 2014

Sea level

IPCC - Intergovernmental Panel on Climate Change
(set up by UN to assess of the scientifc basis of climate change for policymakers)





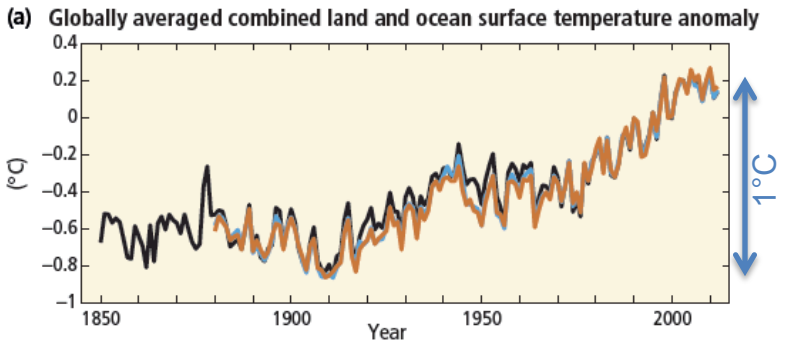
Observations (over ca. 100a)

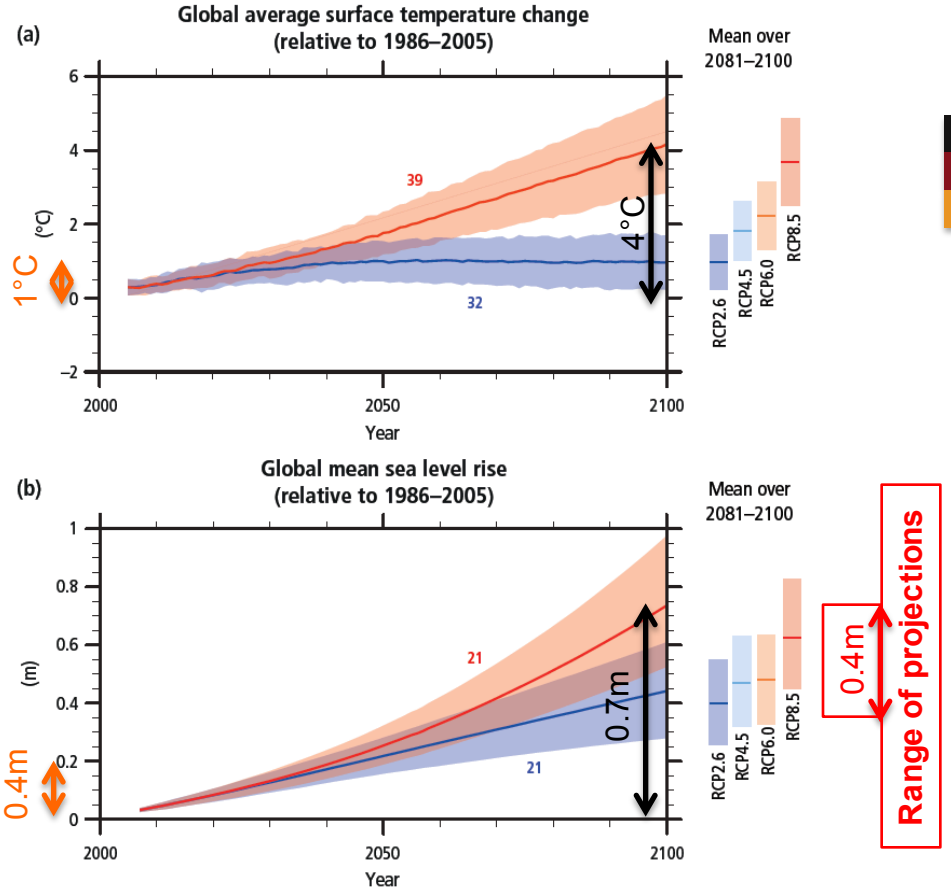
Projections (for ca. 100a)

IPCC 2014

Sea level

IPCC - Intergovernmental Panel on Climate Change
(set up by UN to assess of the scientifc basis of climate change for policymakers)





Observations (over ca. 100a)

Projections (for ca. 100a)

IPCC 2014

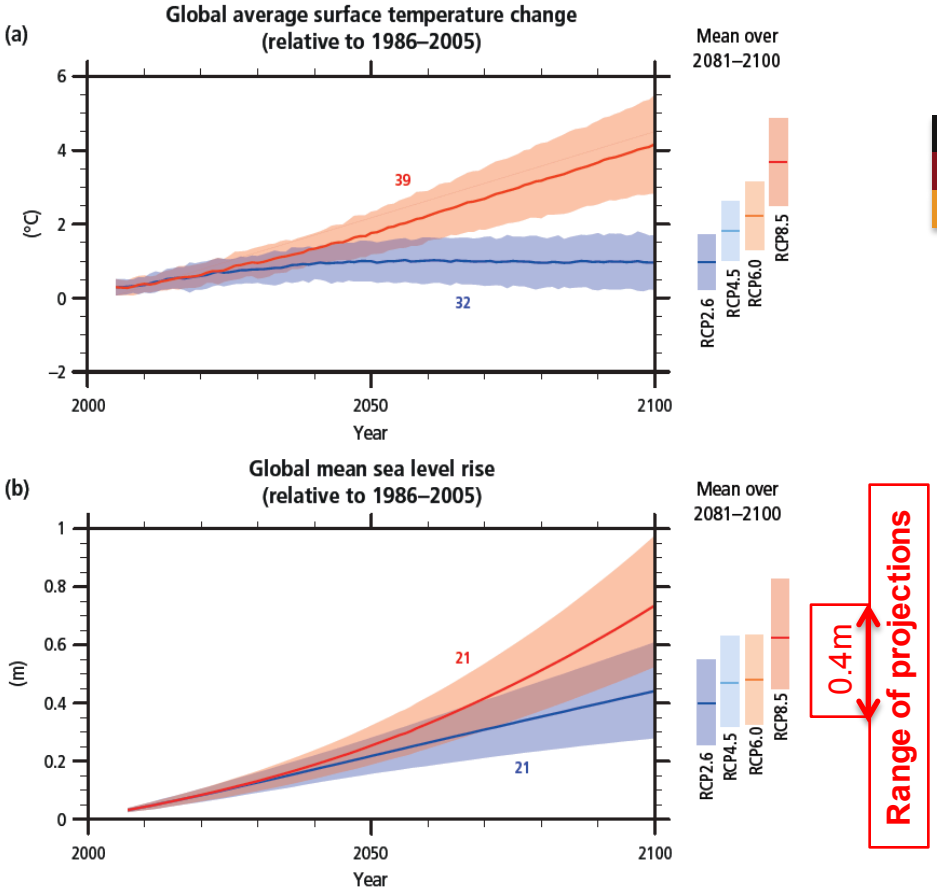
Ice sheets & Sea level

IPCC - Intergovernmental Panel on Climate Change
(set up by UN to assess of the scientifc basis of climate change for policymakers)

IPCC 2014:
-*low confidence* in the available models' ability to project **solid ice discharge**

-models *likely* underestimate **ice sheet contribution**

->underestimation of projected **sea level rise**



Projections (for ca. 100a)

IPCC 2014

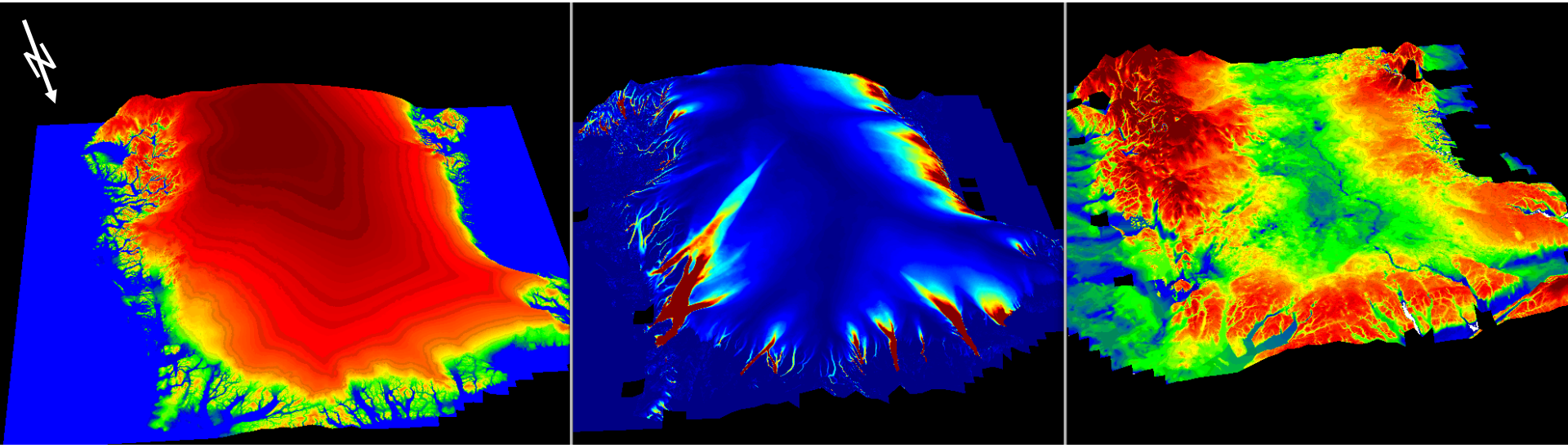
Ice sheets

Greenland ice sheet
ice volume ~6m sea level

Antarctic ice sheet
ice volume ~60m sea level

Ice sheet discharge

Ice streams in N-Greenland

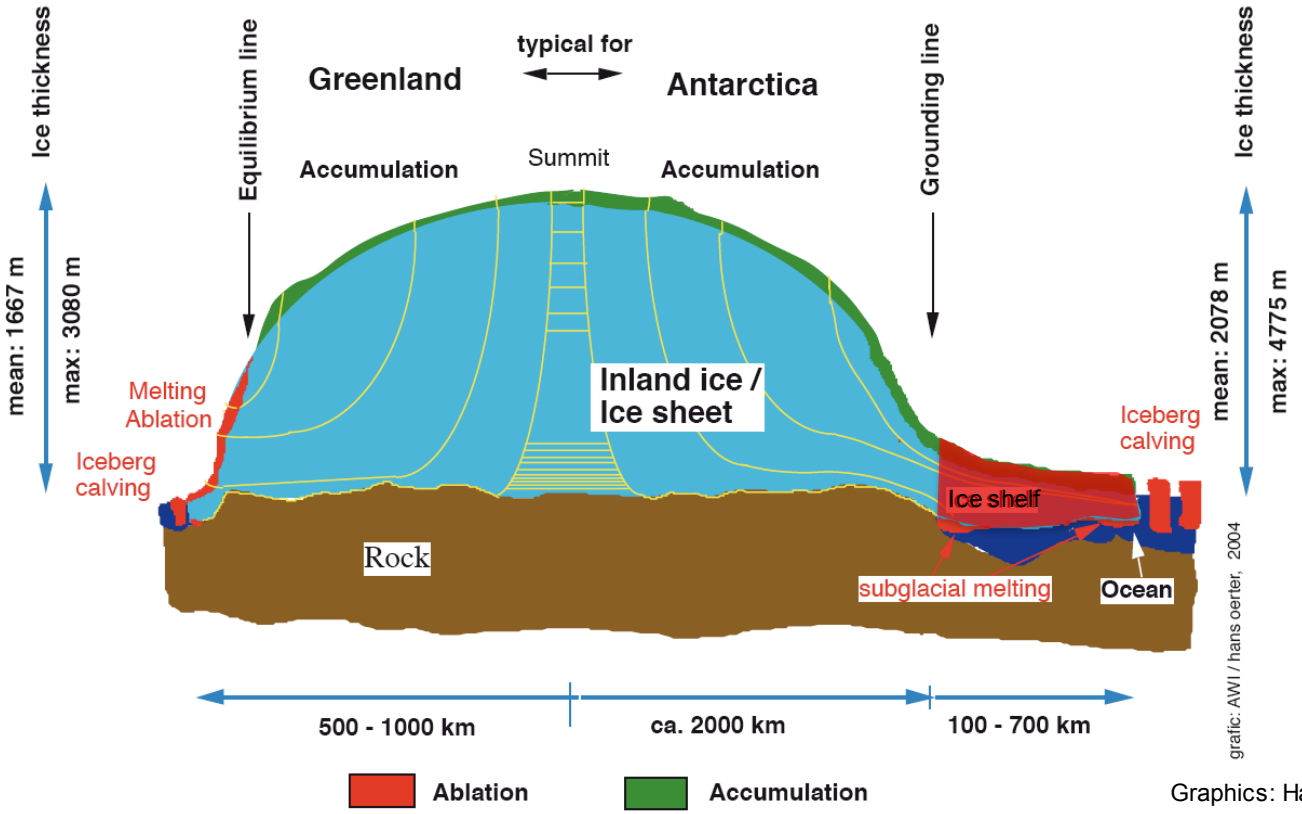


Ice surface elevation | Ice surface velocities | Bedrock elevation

< 10m/a (“sheetish”)
> 50m/a (“streamish”)

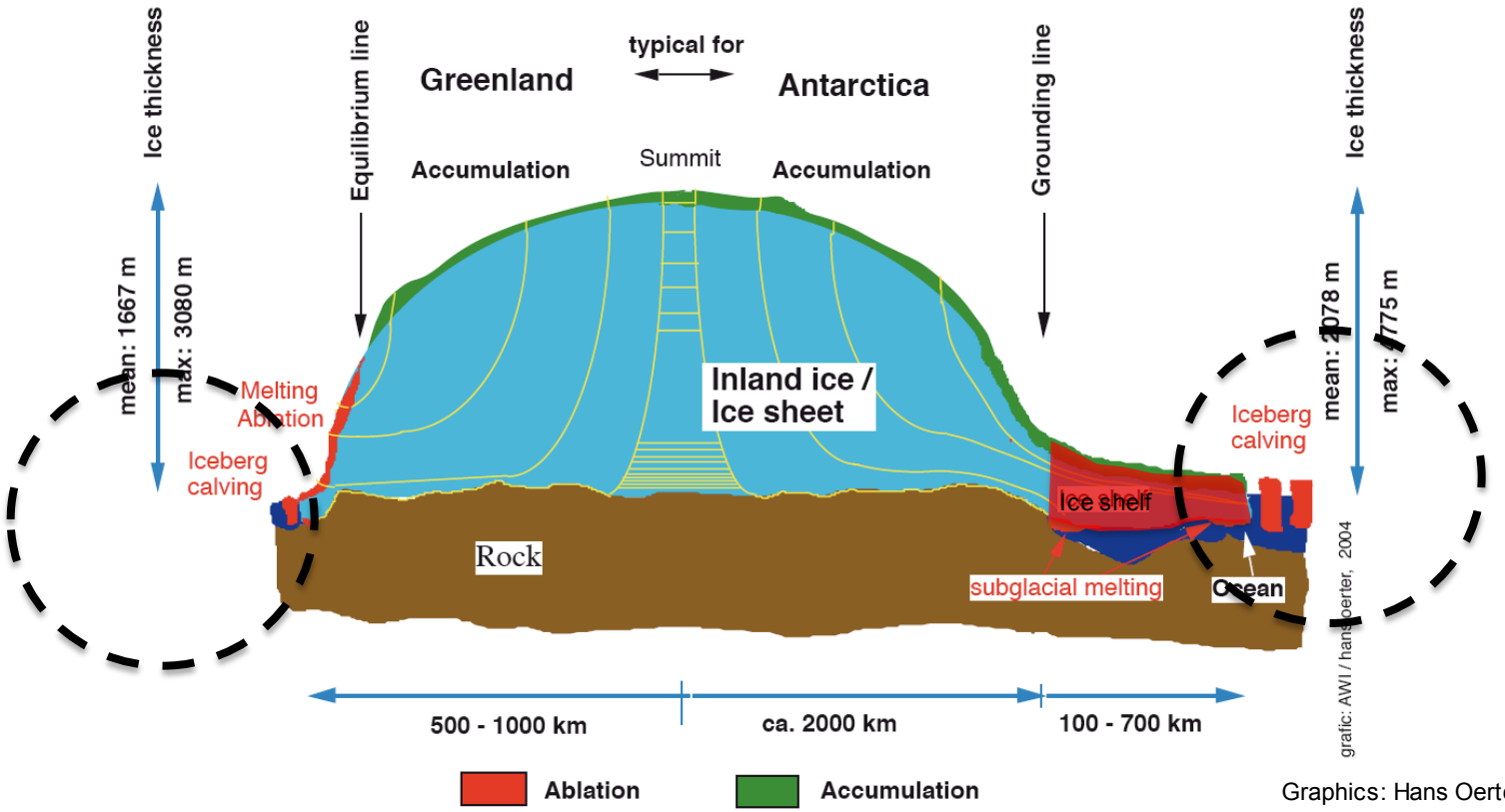
Bamber et al. 2013, Joughin et al. 2016, illustration: Jansen

Ice sheet discharge



Graphics: Hans Oerter

Ice sheet discharge



Graphics: Hans Oerter

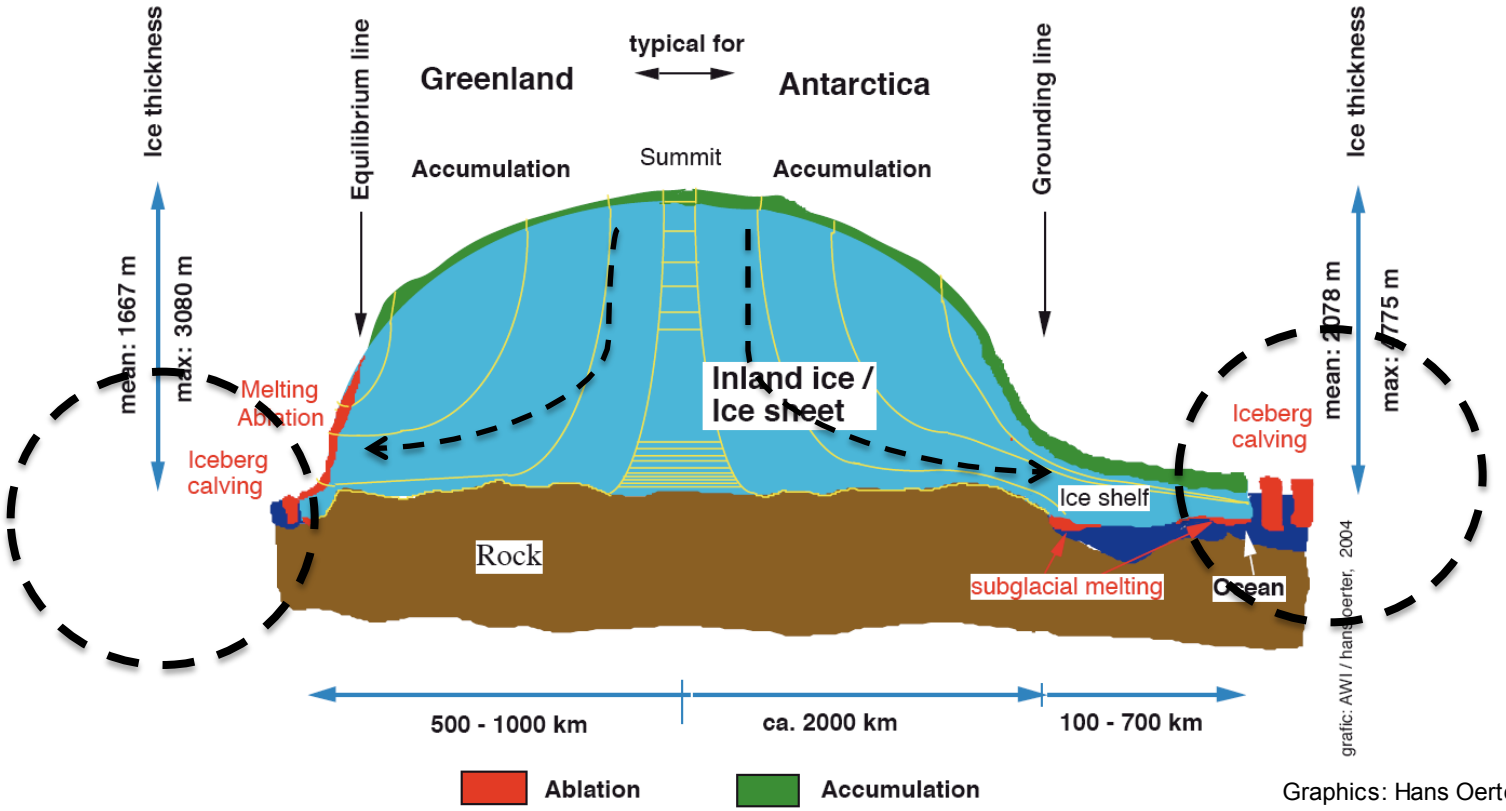
Negative Massbalance Part = Sea level contribution Part

- Melting (top & basal)
- Solid ice discharge (calving at edge & supply from inland)

Ice sheet discharge

Solid ice discharge

Flow of solid ice (deformation)
Predictions by large scale flow models

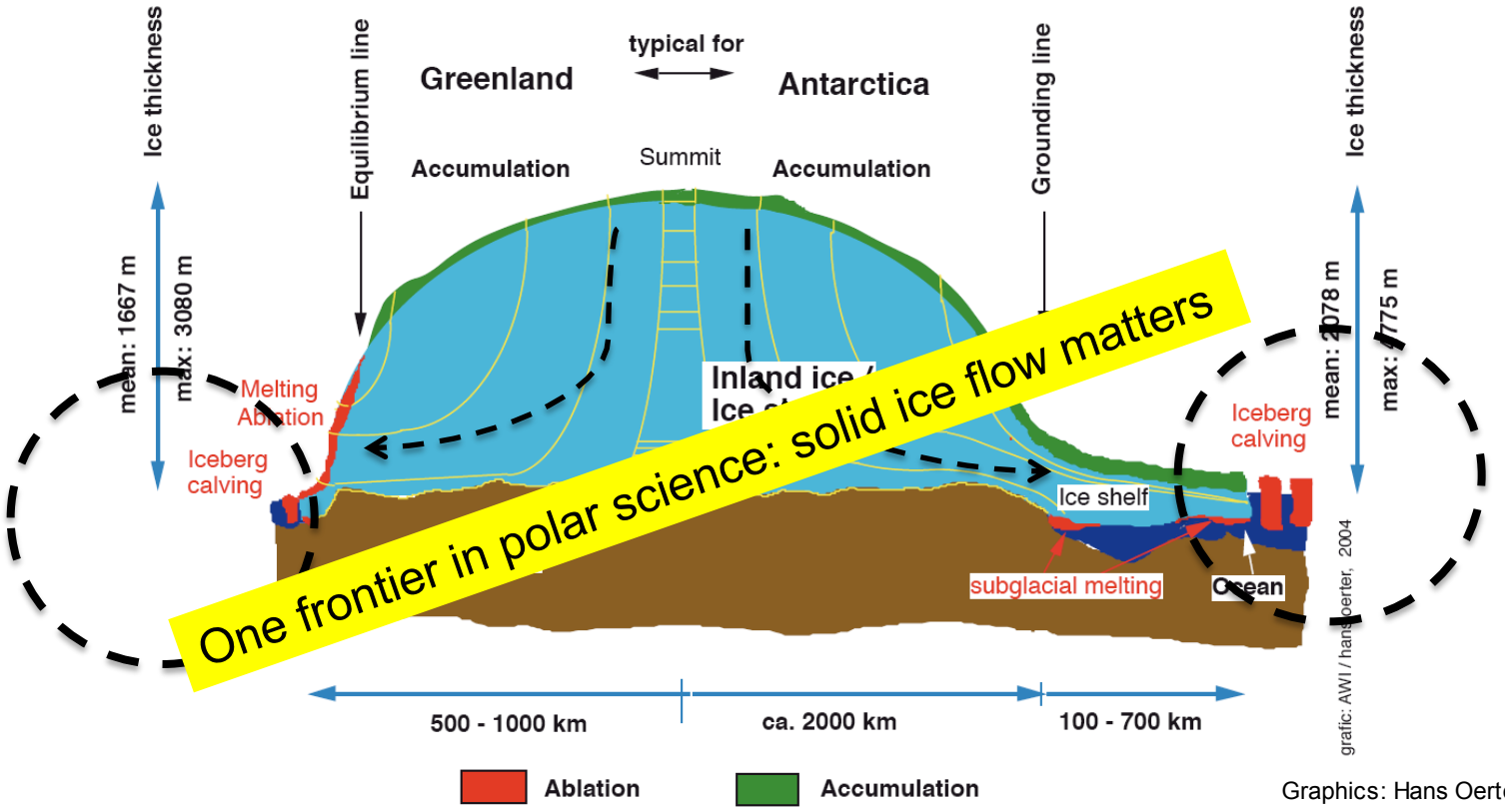


Graphics: Hans Oerter

Ice sheet discharge

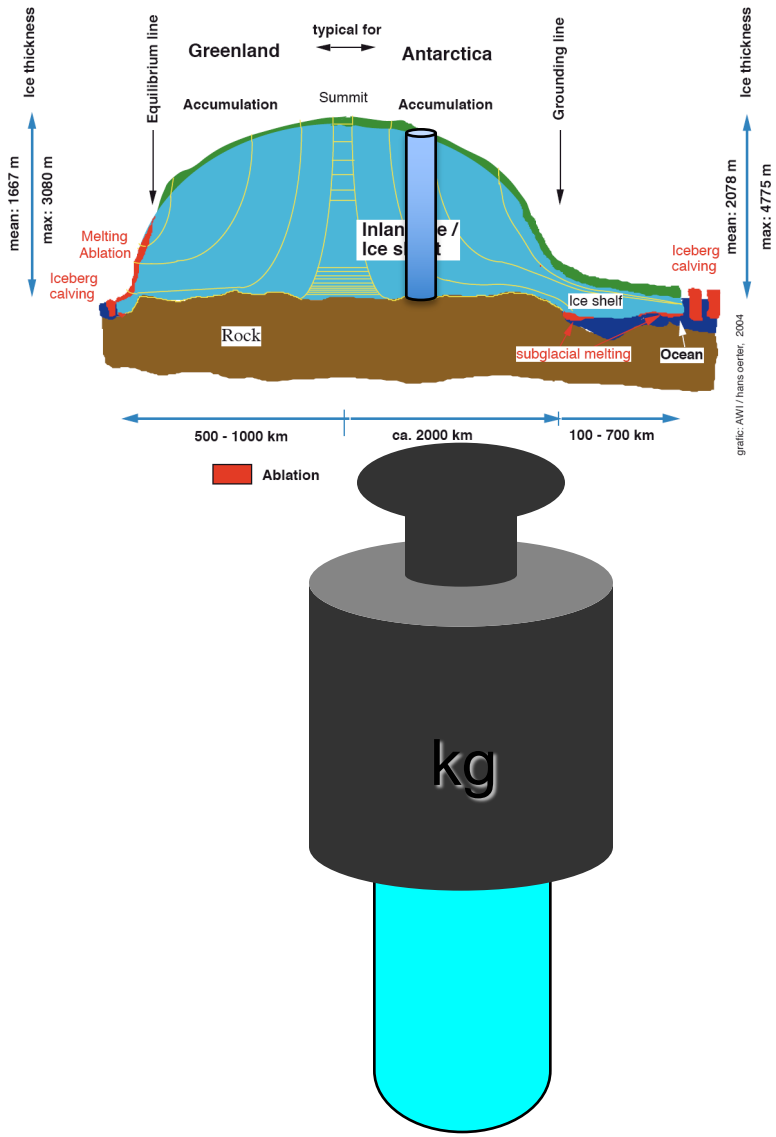
Solid ice discharge

Flow of solid ice (deformation)
Predictions by large scale flow models



Graphics: Hans Oerter

Ice deformation

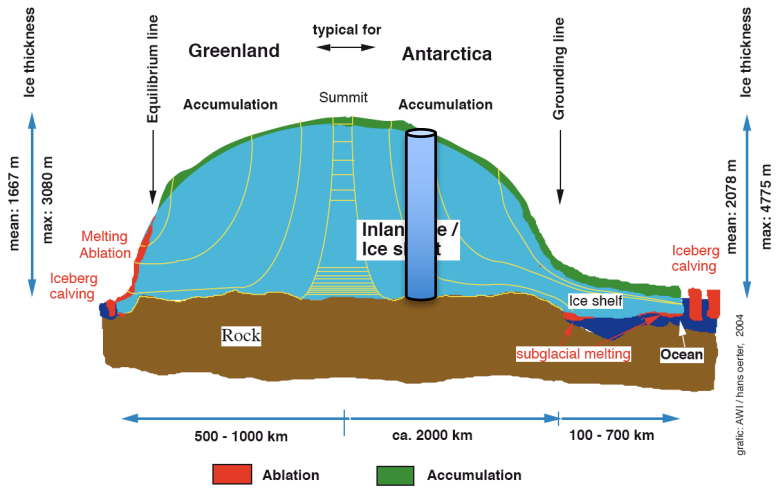


Predictions by large scale flow models

Glen‘s flow law

Glen 1955

Ice deformation



Predictions by large scale flow models

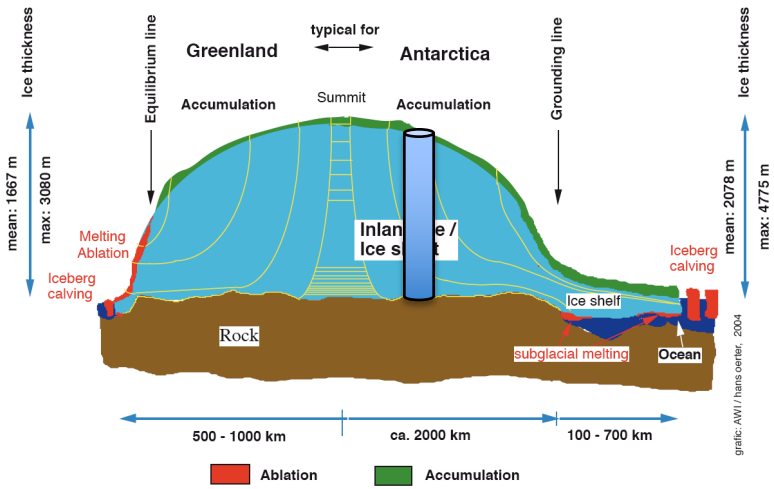
$$\dot{\varepsilon} = B \cdot \exp(-Q/RT) \cdot \sigma^n$$

$\dot{\varepsilon}$ = strain rate („How fast do we deform?“)
σ = stress („How much do we press?“)
T = temperature
R = ideal gas constant („general physical constant“)
B, n, Q = **treated** as constant („tunig parameters“)

Glen‘s flow law

Glen 1955

Ice deformation



Predictions by large scale flow models

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$\dot{\varepsilon}$ = deformation rate
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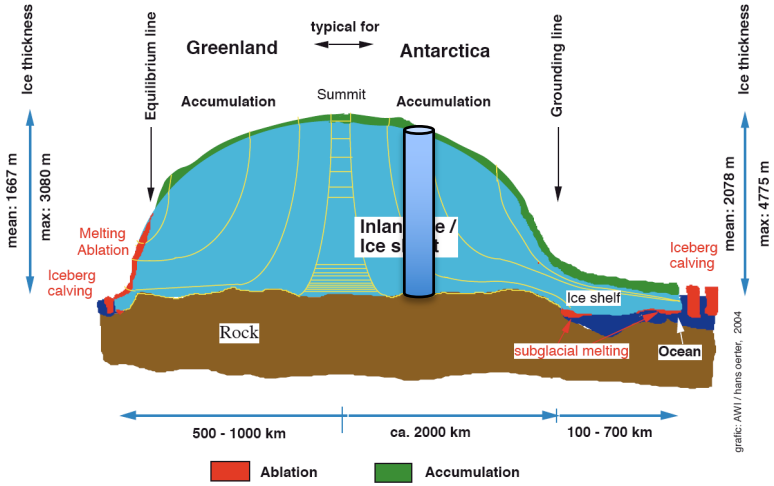
B, n, Q = **treated** as constant

Glen‘s flow law

Problems / Challenges: upscaling (time & space)

Glen 1955

Ice deformation

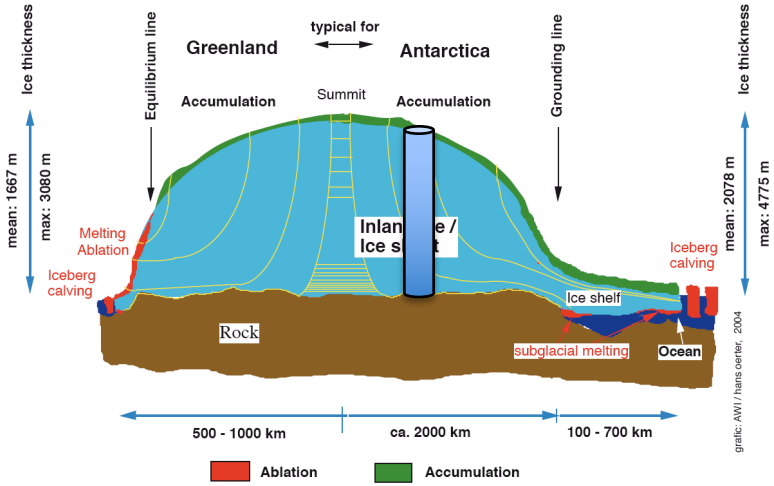


ice cores

physical properties
&
microstructure

Size & shape of grains
C-axis orientation
subgrain structures
Inclusions

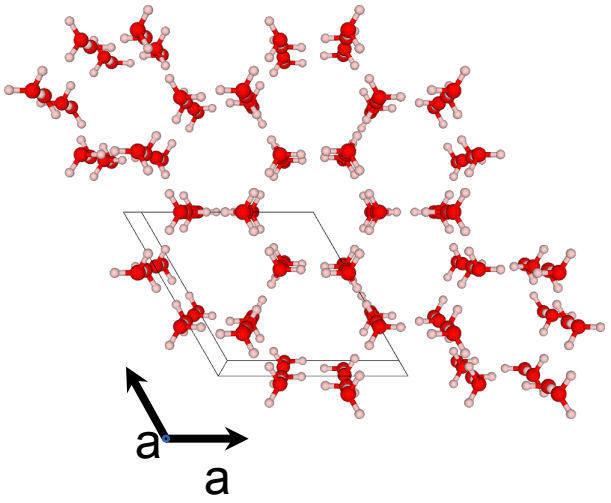
Ice deformation

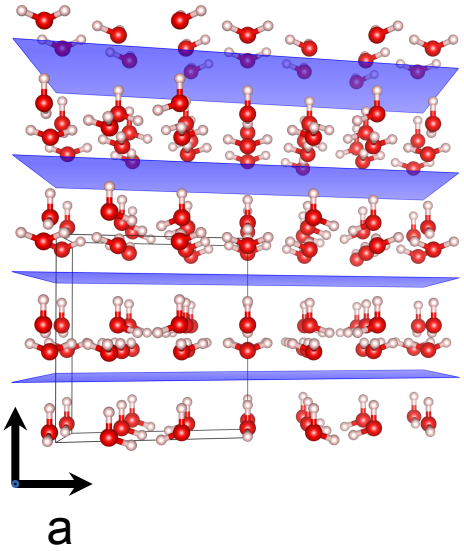


ice cores

physical properties
&
microstructure

Ice is crystalline (hexagonal on Earth)





Furukawa
http://www.lowtem.hokudai.ac.jp/ptdice/english/aletter.html

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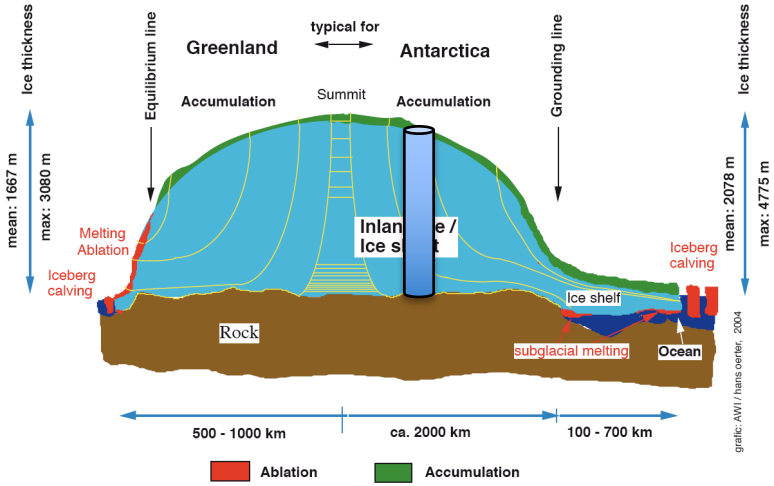
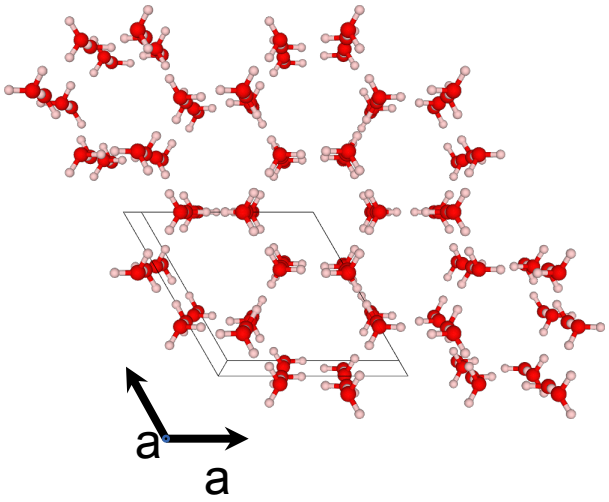
Ice deformation



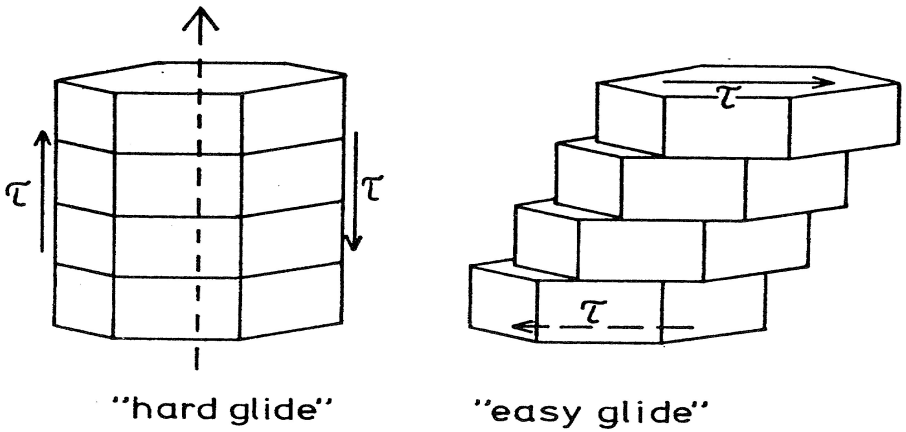
ice cores

physical properties
&
microstructure

Ice is crystalline

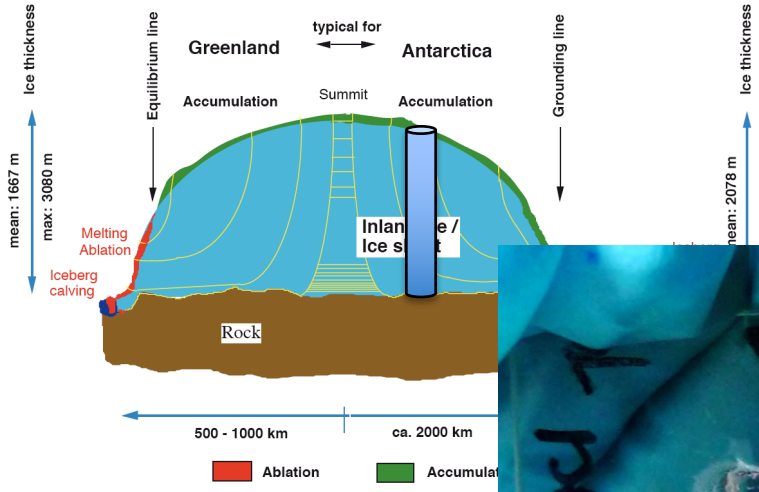


Anisotropy of ice

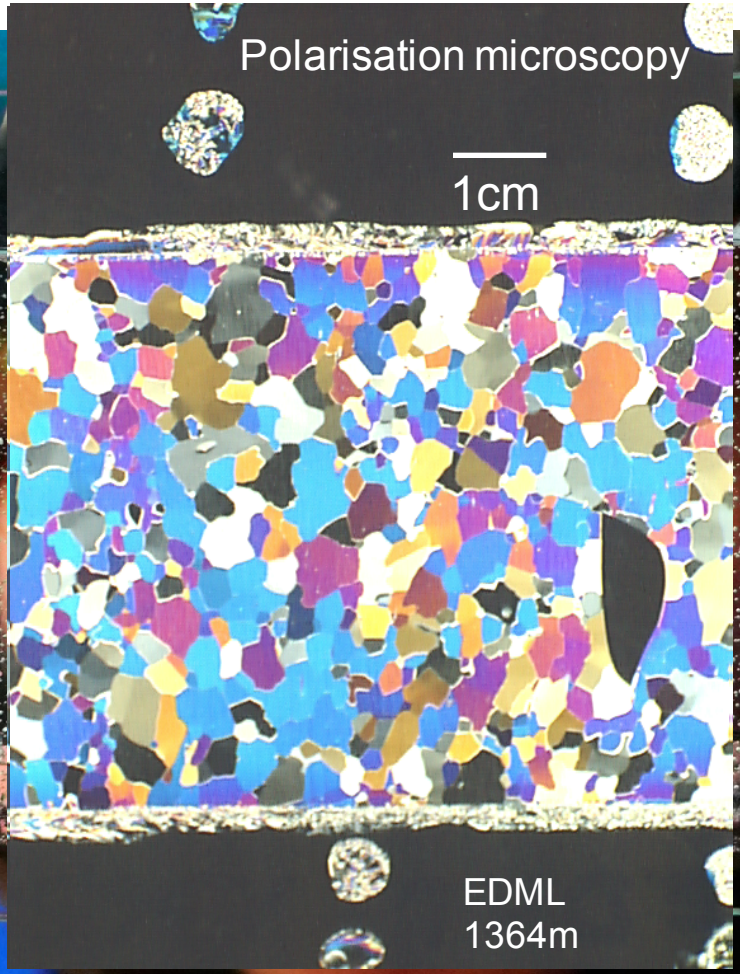


HELMHOLTZ ASSOCIATION

Microstructure



Crystal orientation analysis of ice



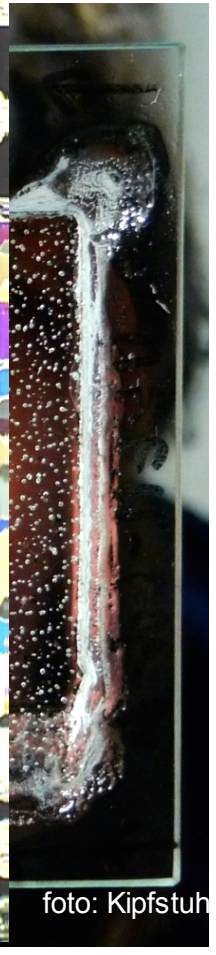
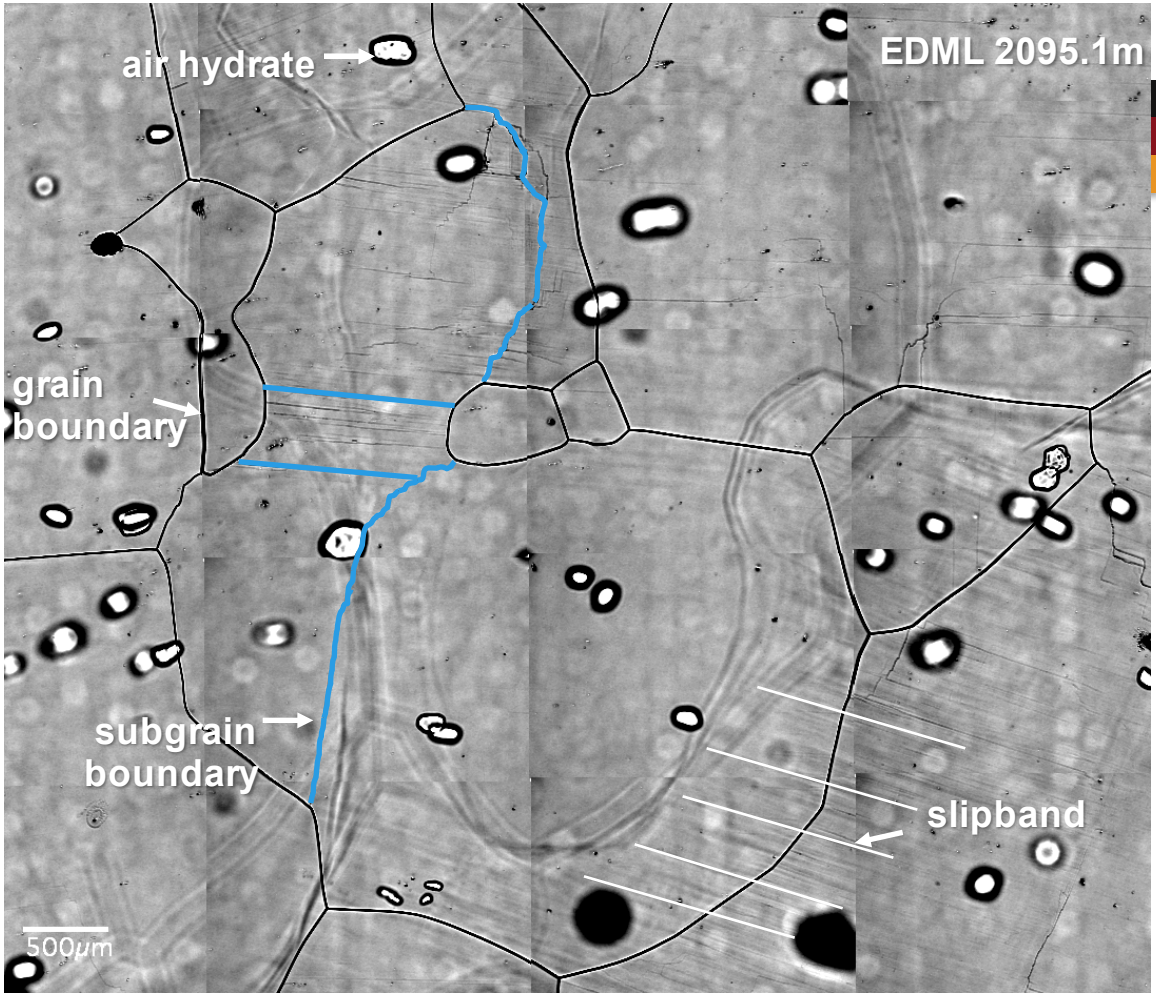


foto: Kipfstuh

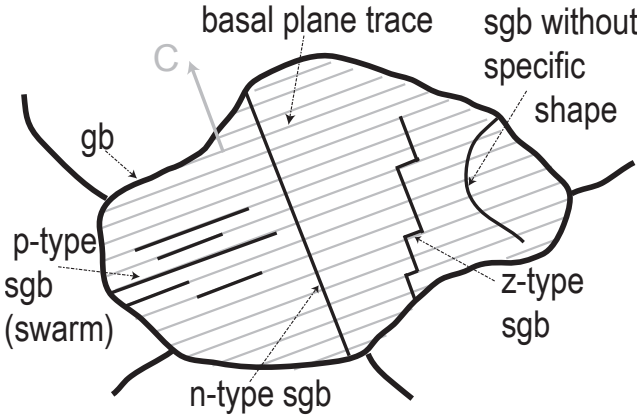
Microstructure

- Microscopy methods (optical, SEM)
- Spectroscopy
- Diffractometry



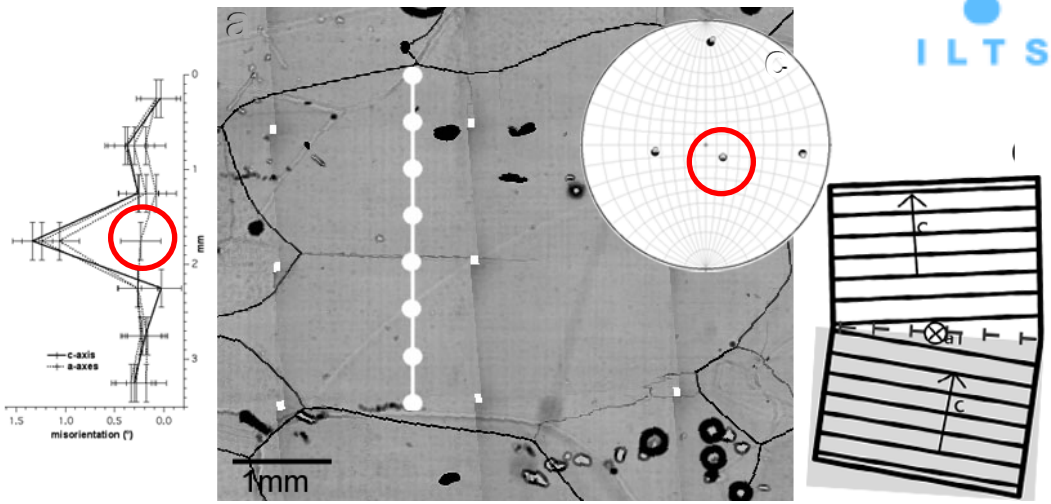
(Sub-) Grain structures

Subgrain structure characterisation



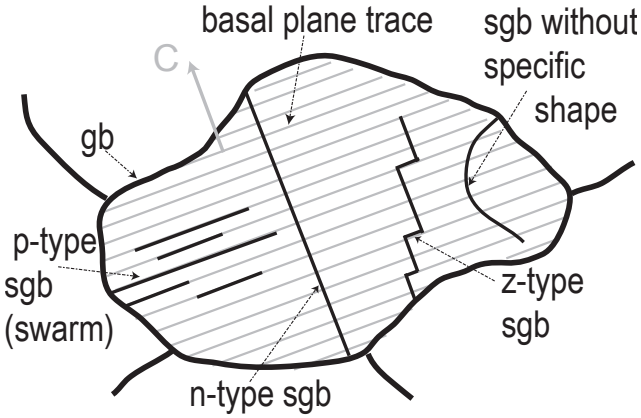
- x-ray Laue diffraction
- EBSD (Electron Backscattered Diffraction)

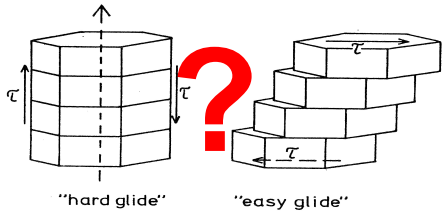
x-ray Laue diffraction

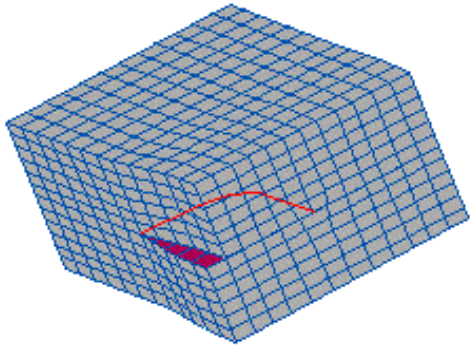


Miyamoto et al. 2011

Subgrain structure characterisation



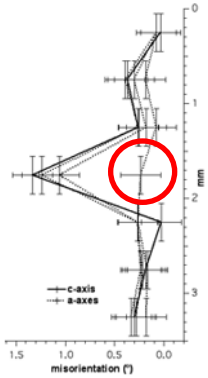


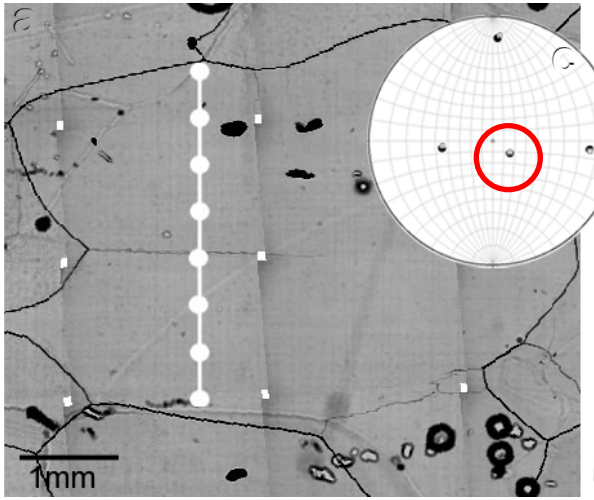


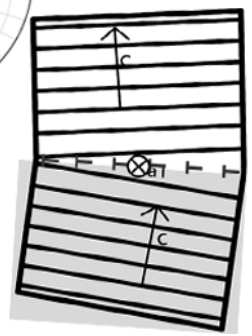
Dislocation

http://www.geo.lsa.umich.edu/~vdpluijm/animations/edgescrewglide.mov

X-ray Laue diffraction





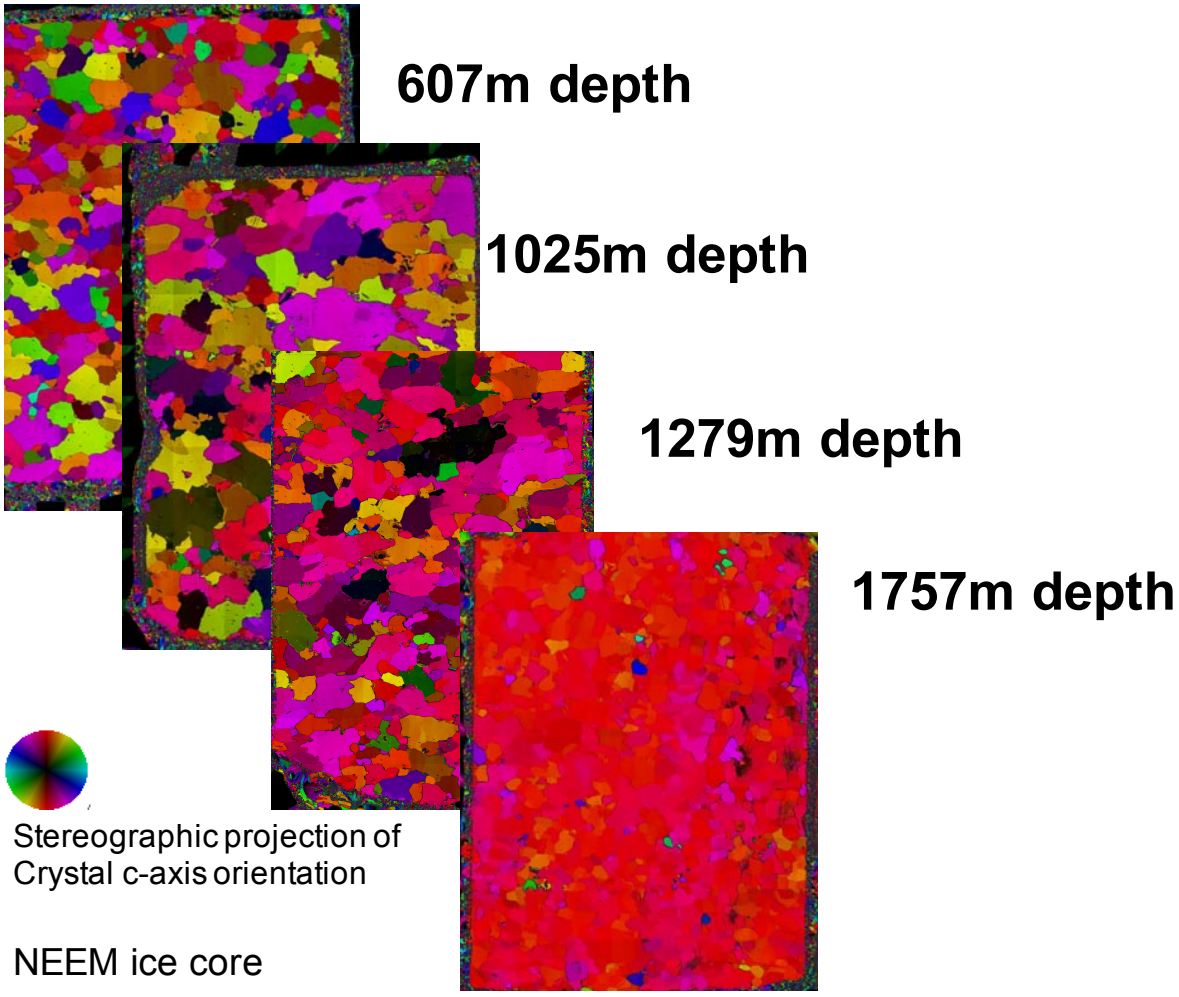


Miyamoto et al. 2011

Deformation mechanisms

Dislocation creep, (diffusion creep, grain boundary sliding, ... ?)

mechanistic approach

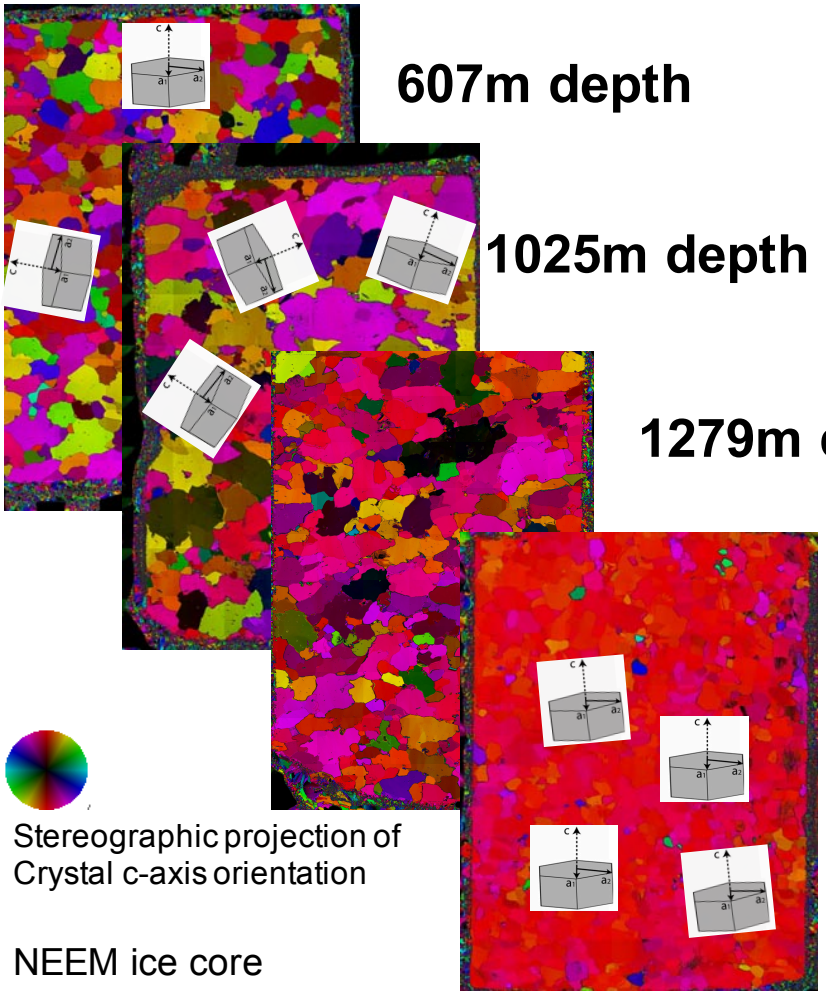


microstructural modelling

Stereographic projection of
Crystal c-axis orientation

NEEM ice core

Deformation mechanisms



Stereographic projection of
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NEEM ice core

mechanistic approach

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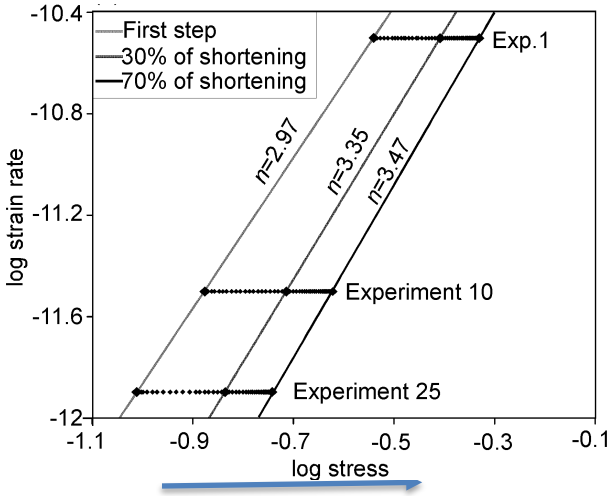
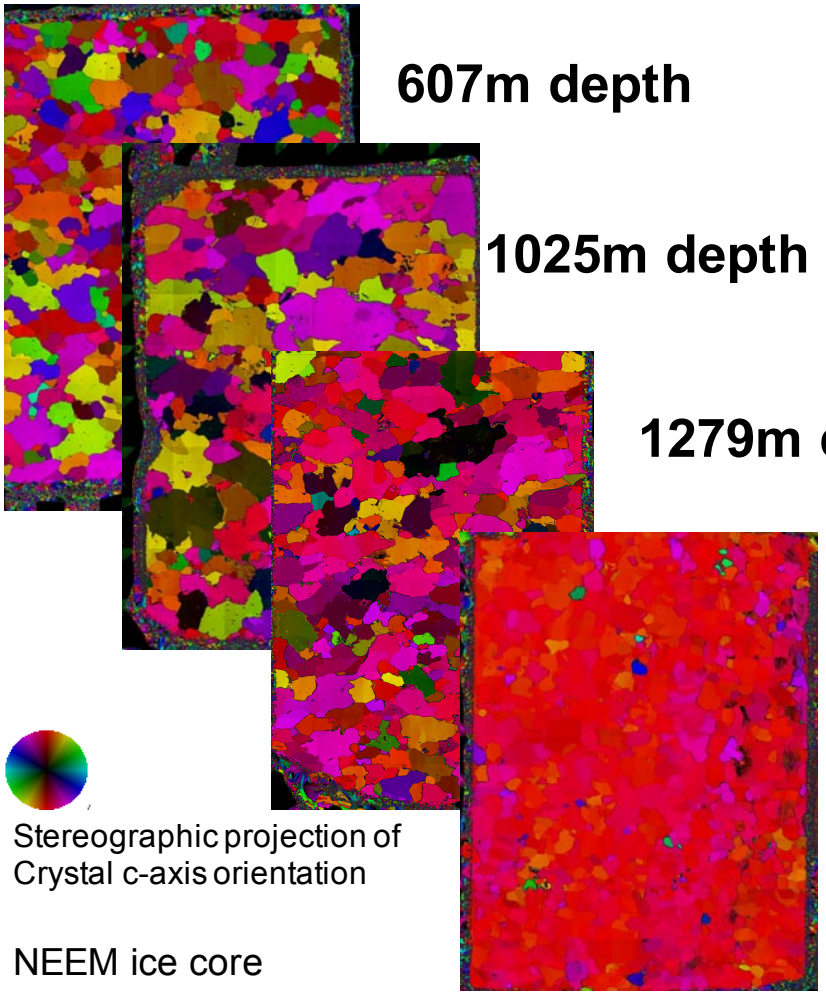
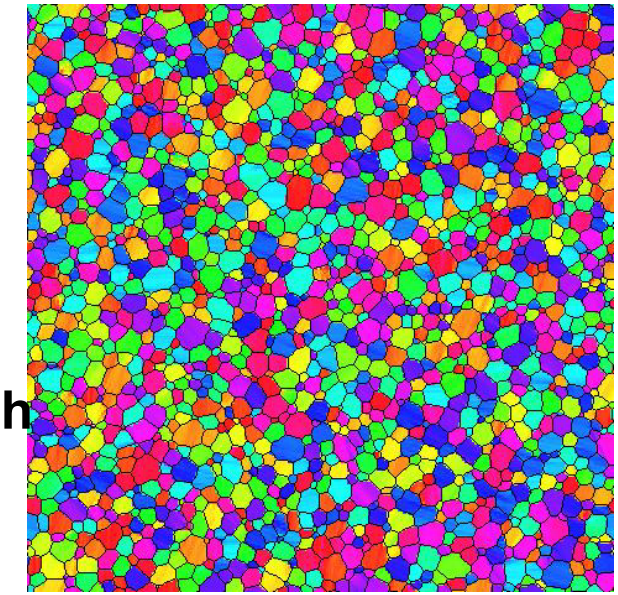
Deformation mechanisms





Numerical micro



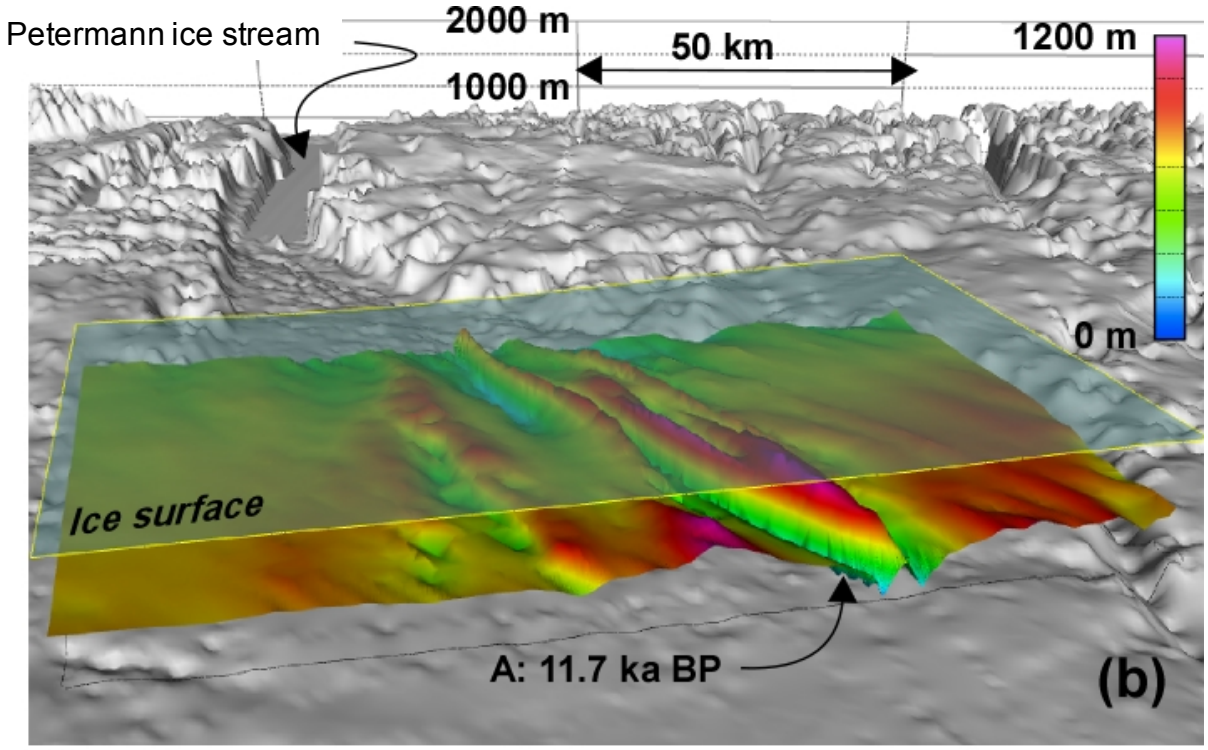
Stereographic projection of Crystal c-axis orientation

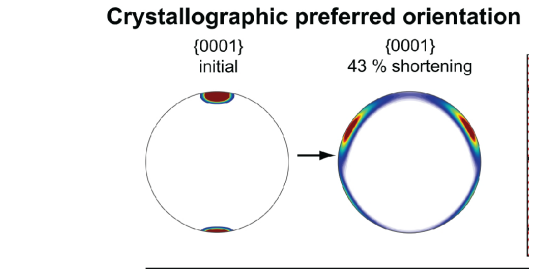
NEEM ice core

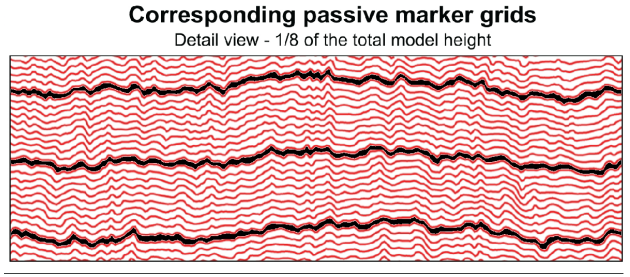
Llorens et al. 2016 **(ELLE/FFT)**

EBERHARD KARLS UNIVERSITÄT TÜBINGEN

Connection to the large scale



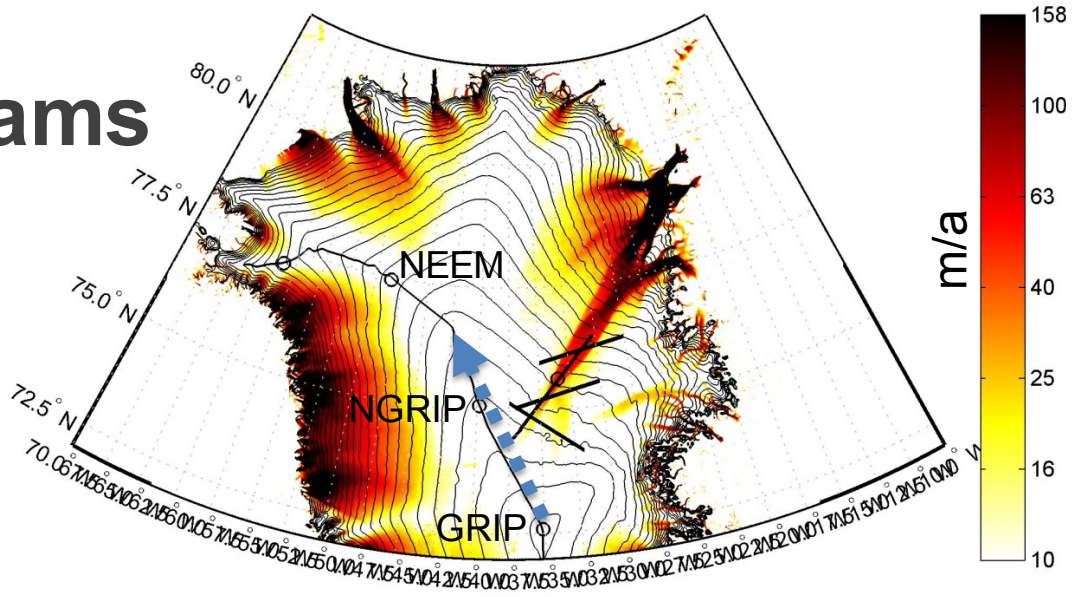


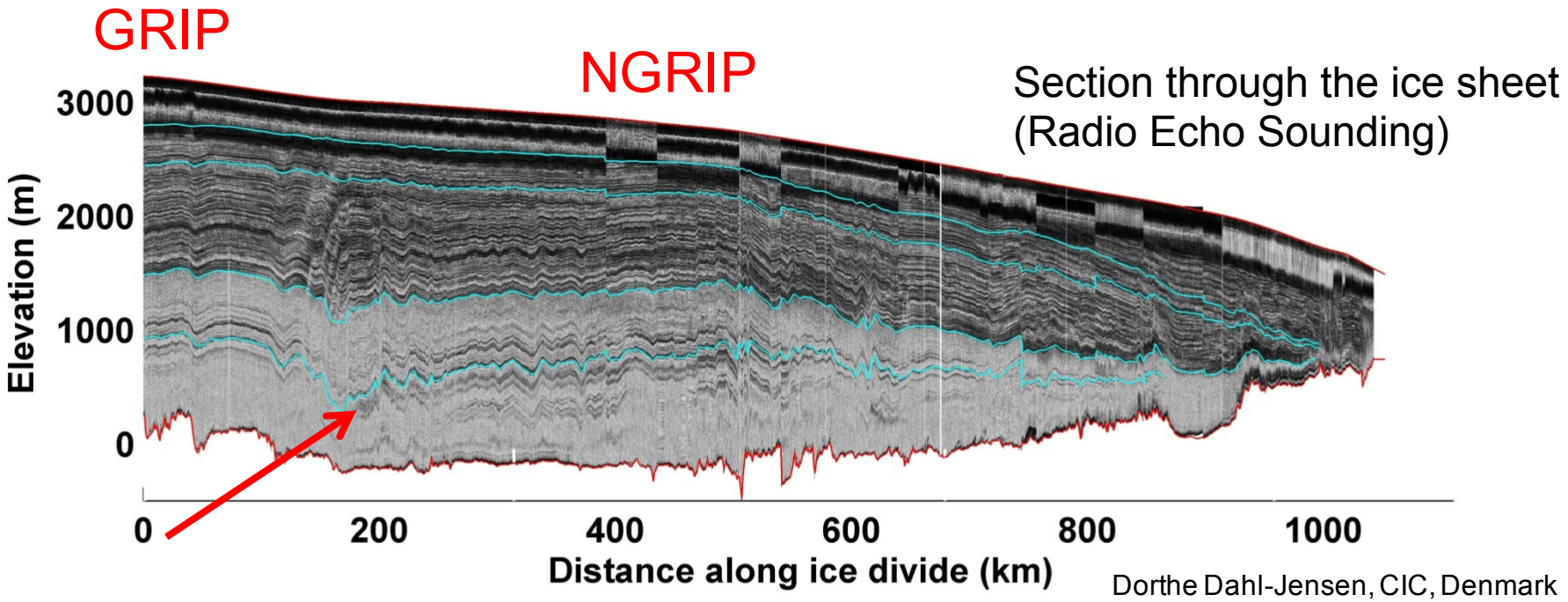


Bons et al. 2016

Ice streams

North-**E**ast **G**reenland **I**ce **S**tream (NEGIS)





Section through the ice sheet (Radio Echo Sounding)

Dorthe Dahl-Jensen, CIC, Denmark

New ice coring activity

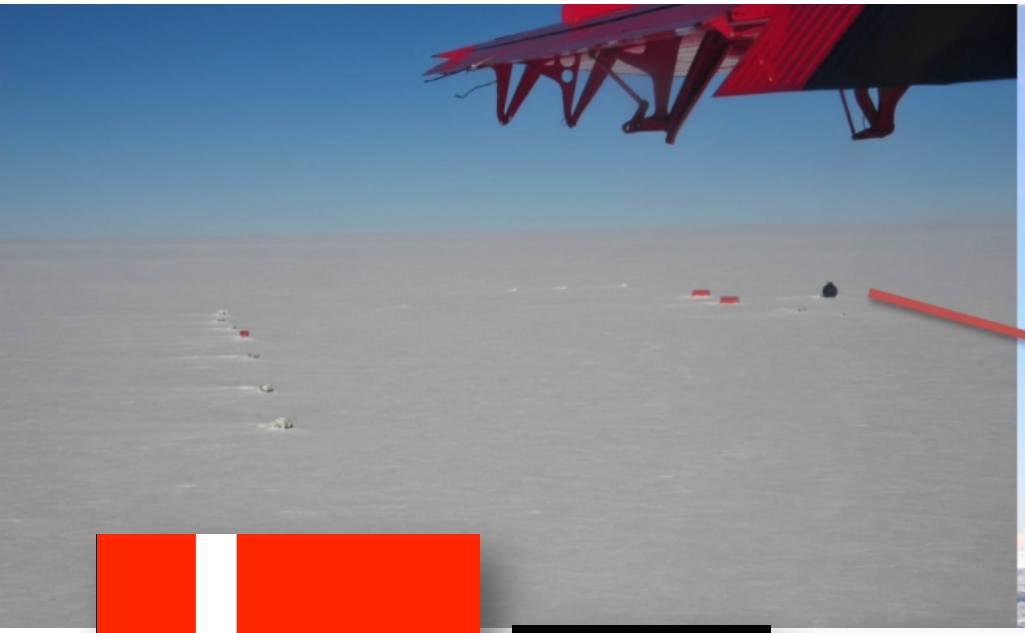
With Japanese & German participation

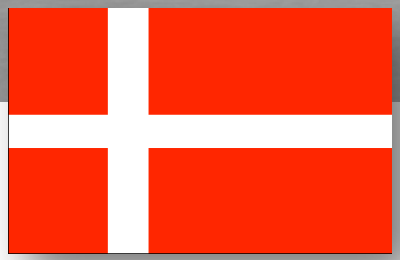
EastGRIP (2016-18): East Greenland Ice Core Project

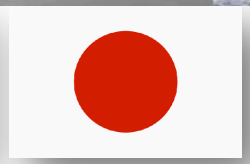
www.eastgrip.org

(~70M€)

Leader: Dorthe Dahl-Jensen



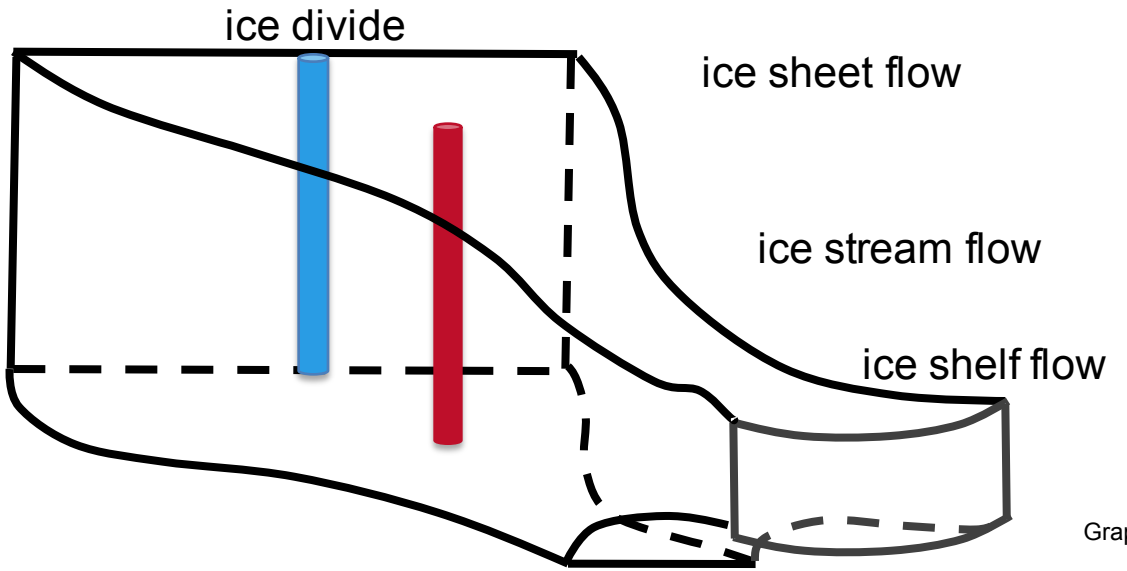




Total ~10 nations

EastGRIP

Drilling @ ice divides / drilling @ ice streams



Graphics: Angelika Humbert

logistically motivated | palaeo-climate motivated | physically motivated

1960 | 1970 | 1980 | 1990 | 2000 | 2010 | 2020

Camp C | Dye 3 | GRIP | NGRIP | NEEM | **EGRIP**

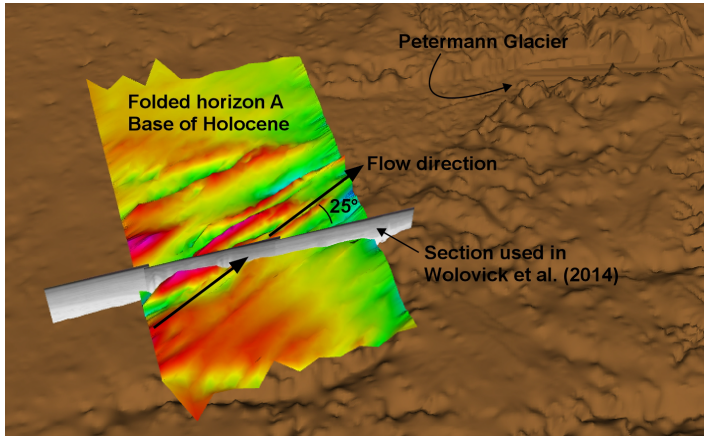
GISP

Byrd | Vostok | EDC

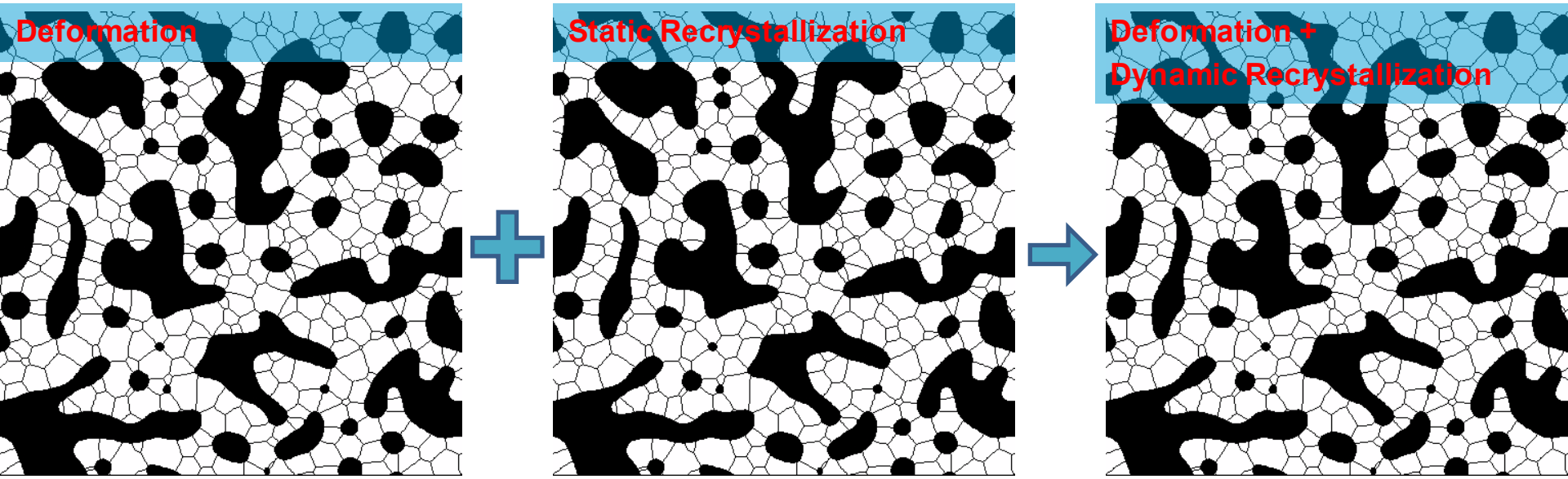
EDML

DomeF

Summary



- Ice flow matters
- IPCC (conservative estimate) does not yet include ice flow sufficiently
- Advances in understanding the material ice are on the way ....
  - moving towards mechanistic description (deformation mechanisms) to improve phenomenological descriptions



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Thank you.
ありがとうございます。

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