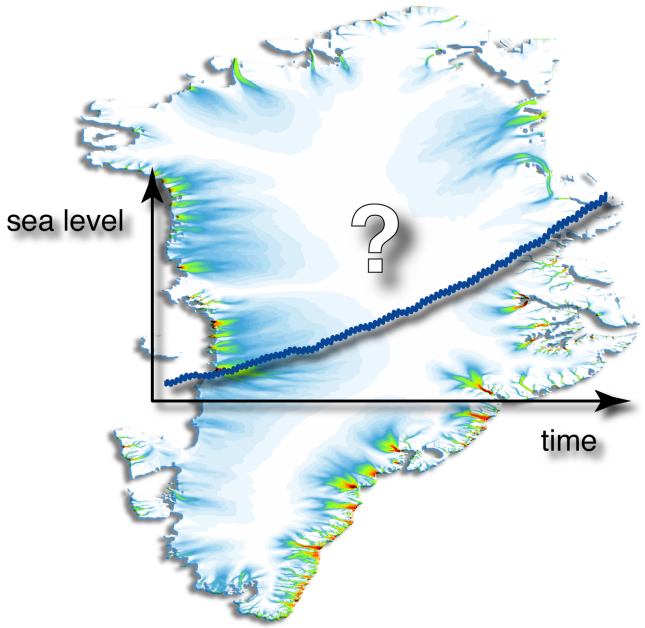
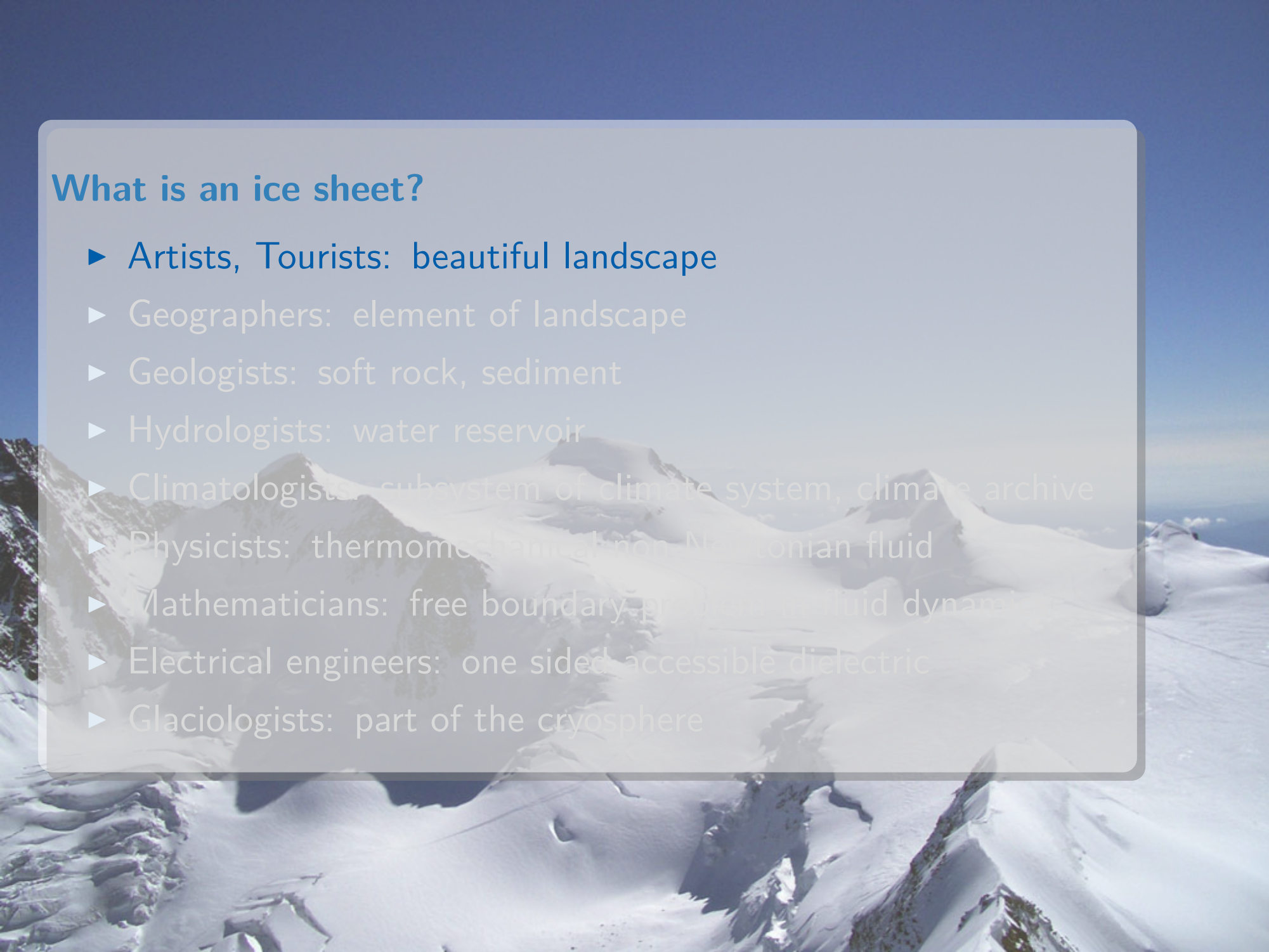
Understanding ice sheets through observations and models

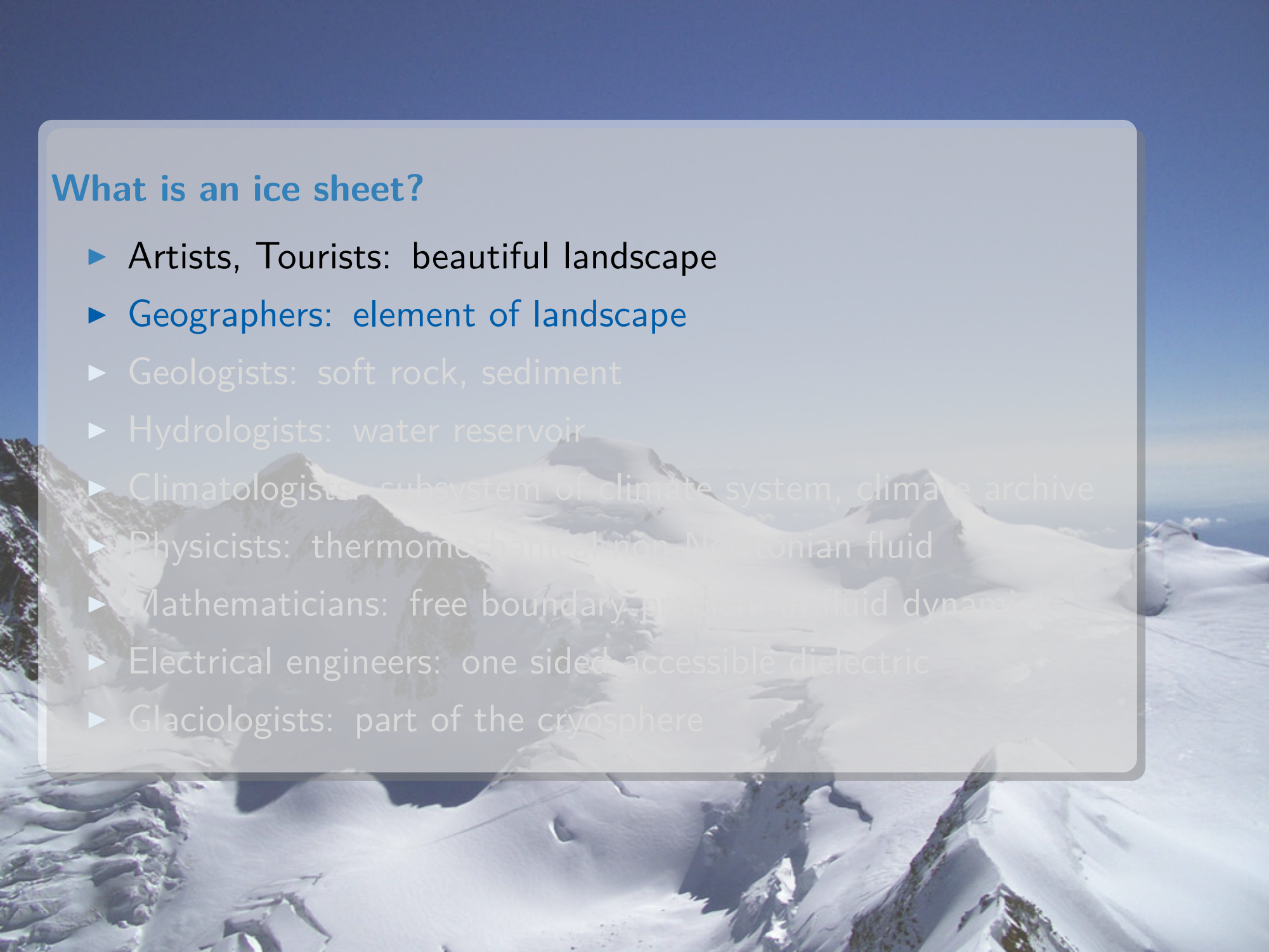
Andy Aschwanden





What is an ice sheet?

- Artists, Tourists: beautiful landscape
- Geographers: element of landscape
- Geologists: soft rock, sediment
- Hydrologists: water reservoir
- Climatologists: subsystem of climate system, climate archive
- Physicists: thermomechanical non-Newtonian fluid
- Mathematicians: free boundary problem, fluid dynamics
- Electrical engineers: one sided accessible dielectric
- Glaciologists: part of the cryosphere



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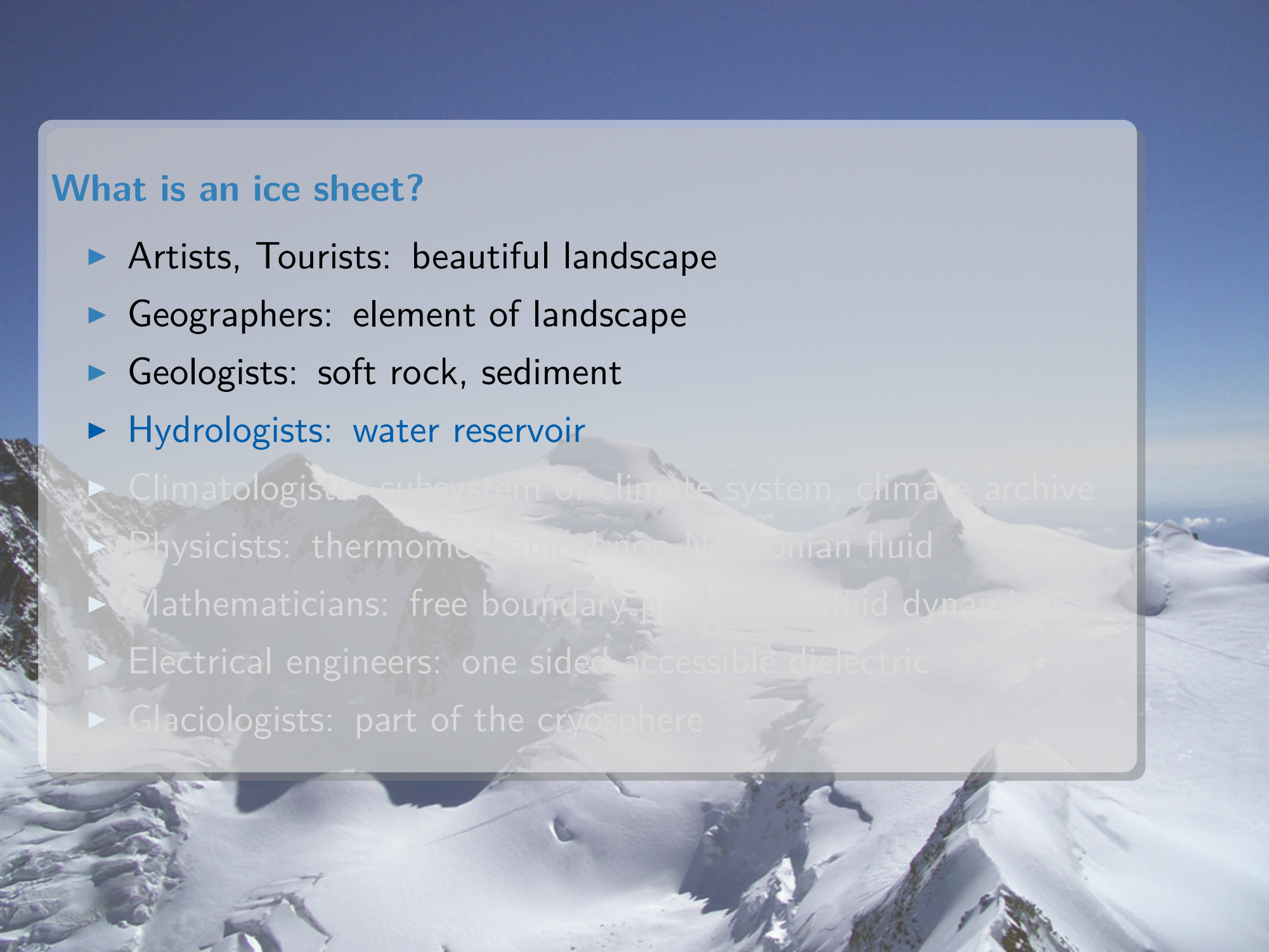

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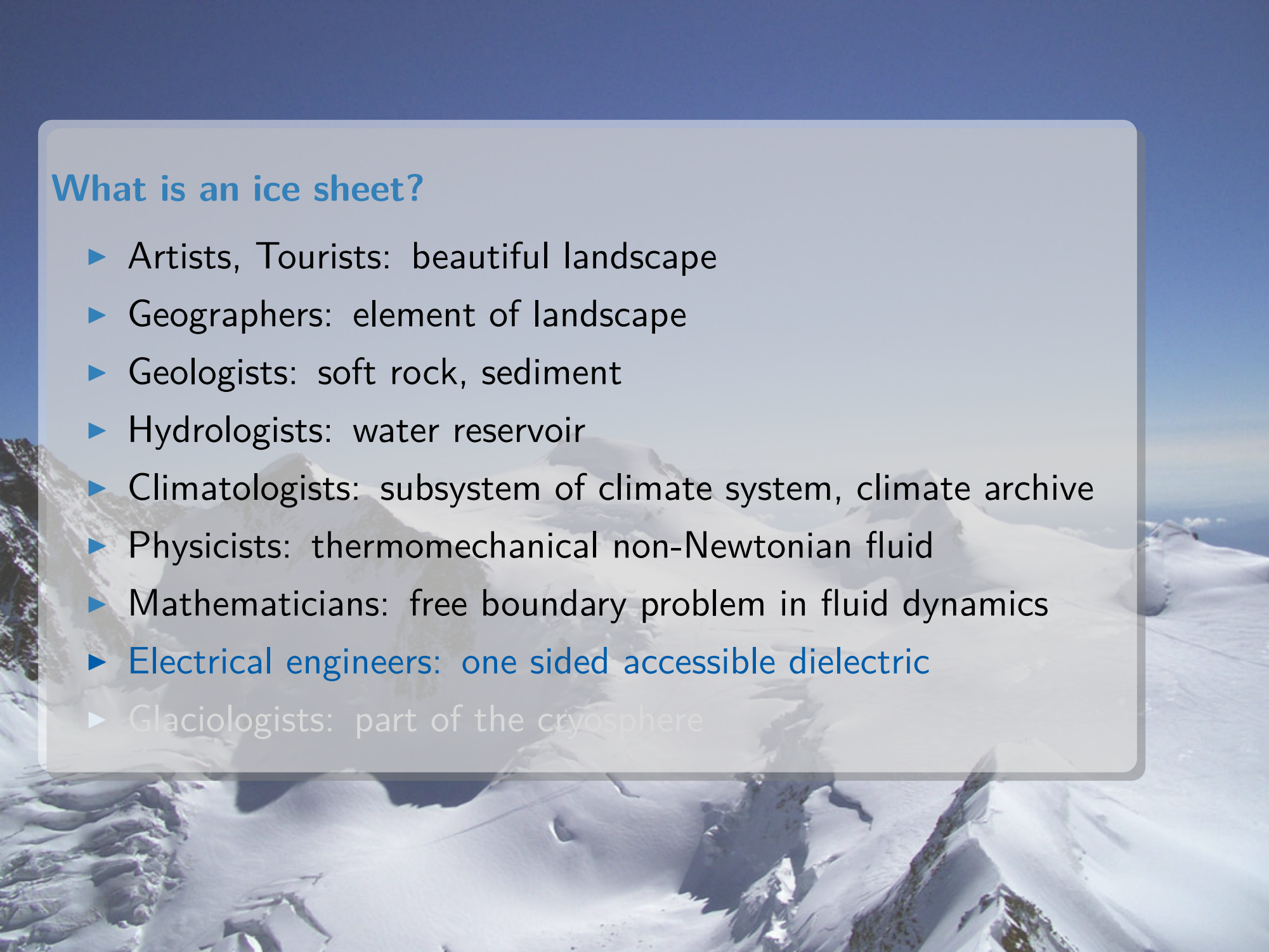

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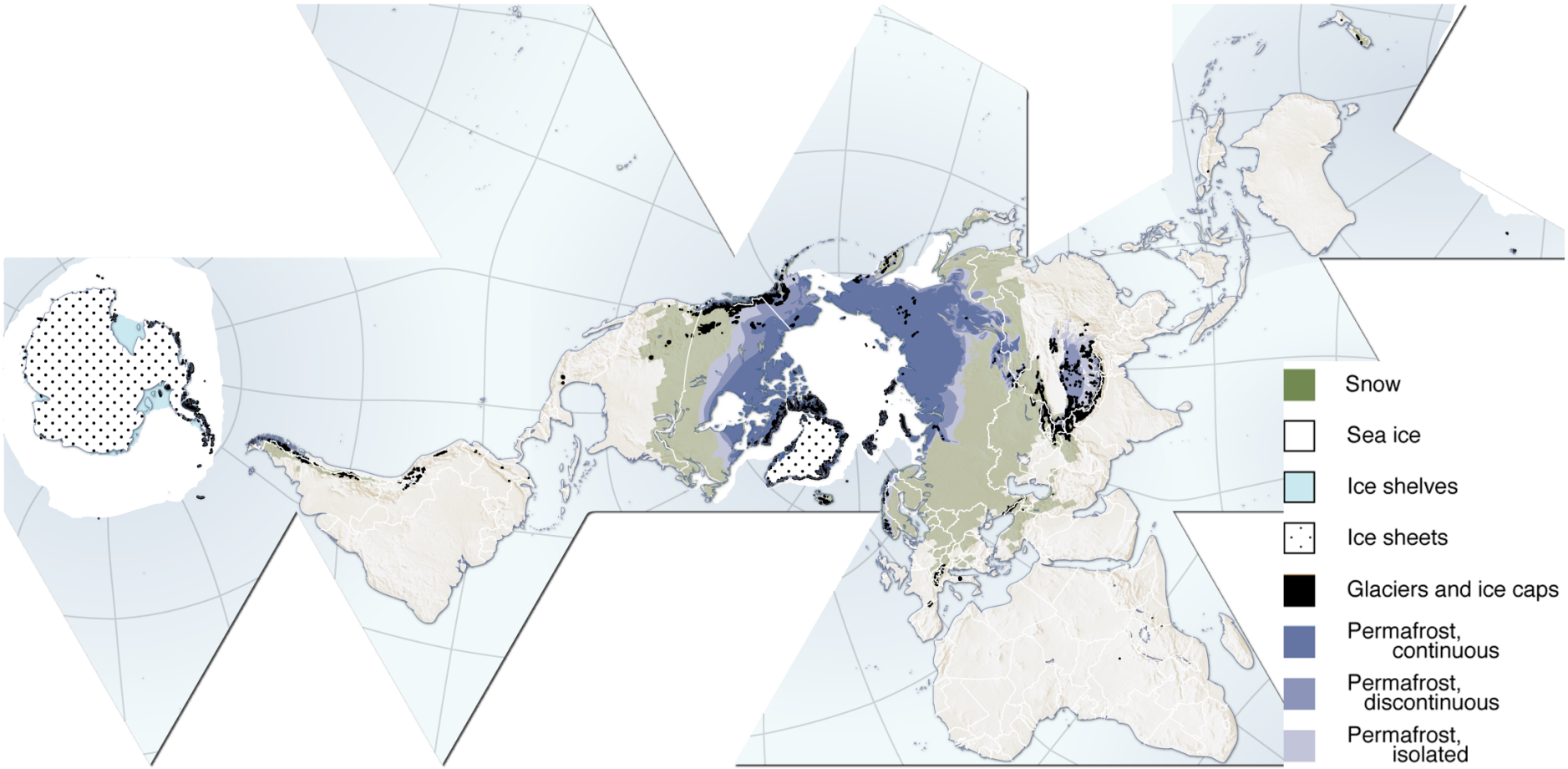
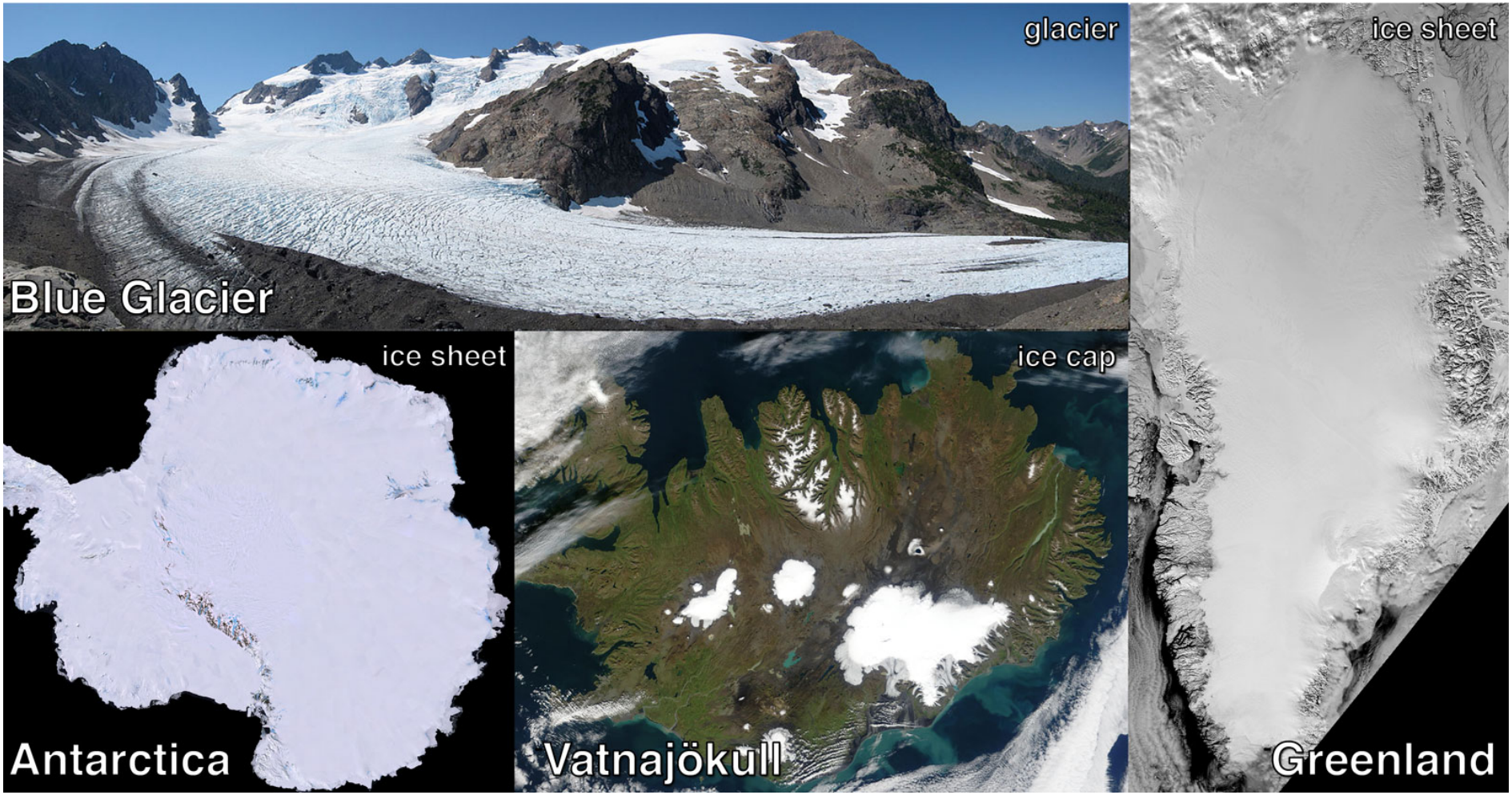
The Cryosphere



source: UNEP Outlook for Ice Sheets

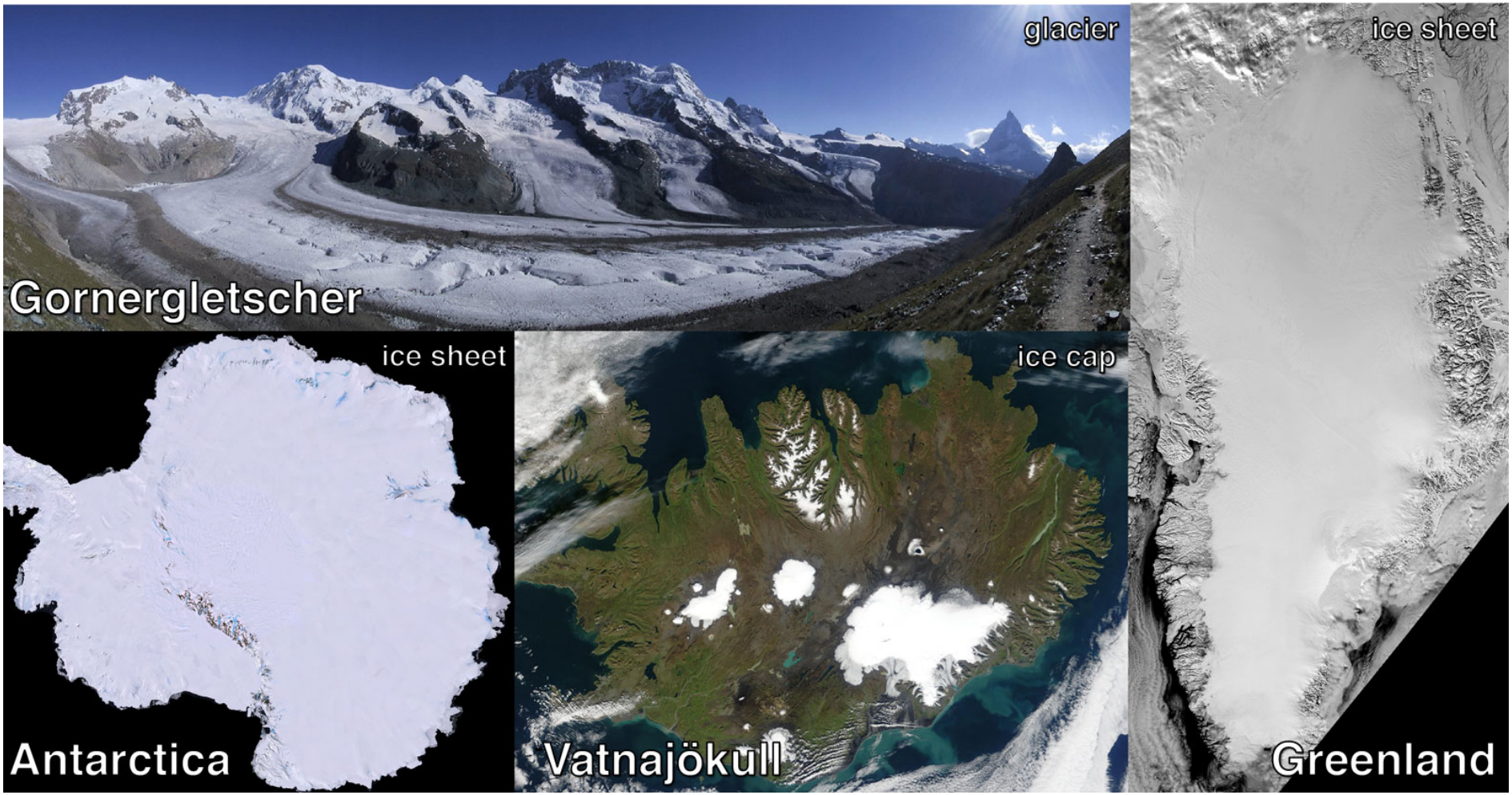
land ice $=$ { ice sheets, ice caps, glaciers}

Land ice



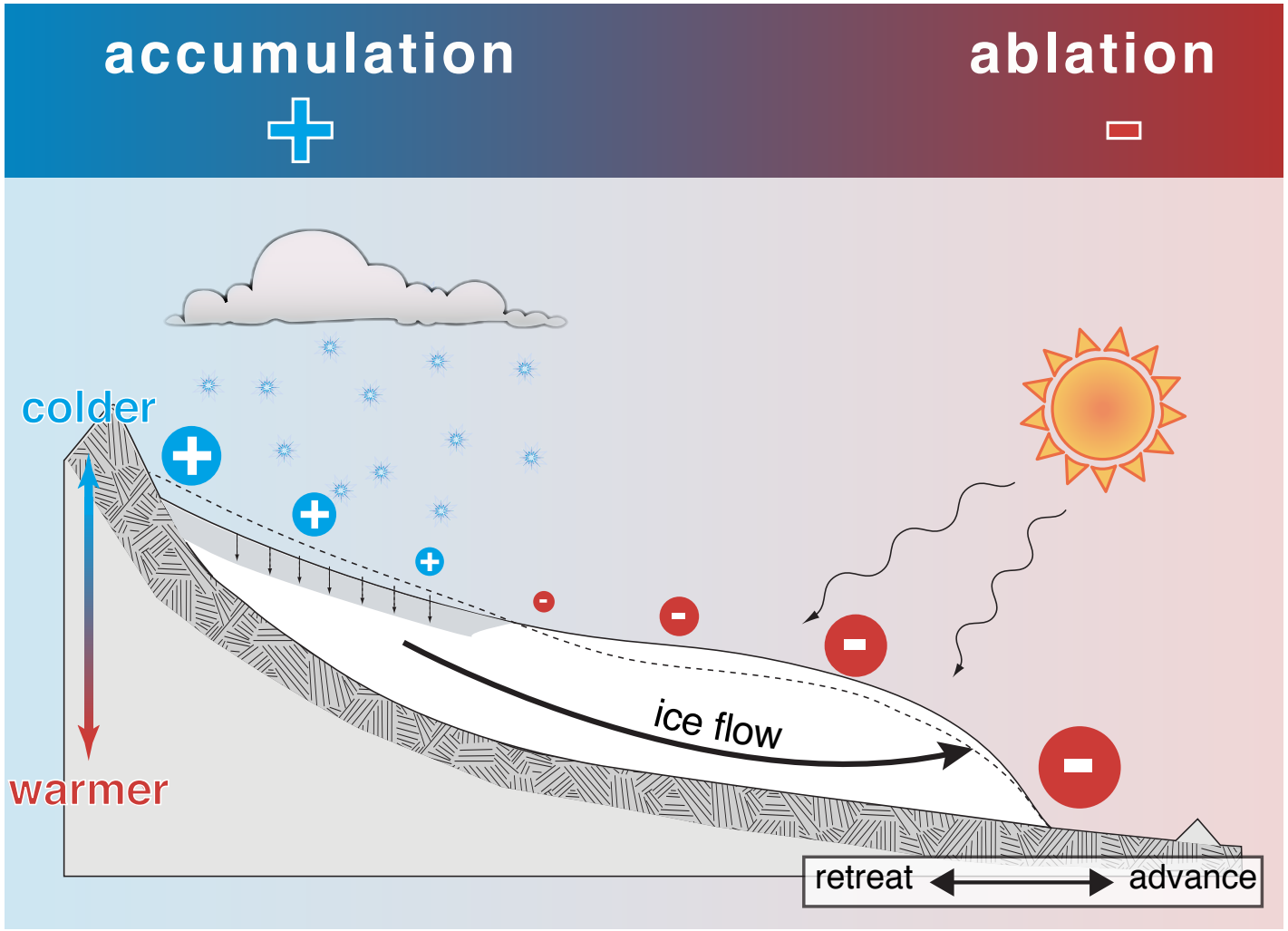
not to scale

Land ice



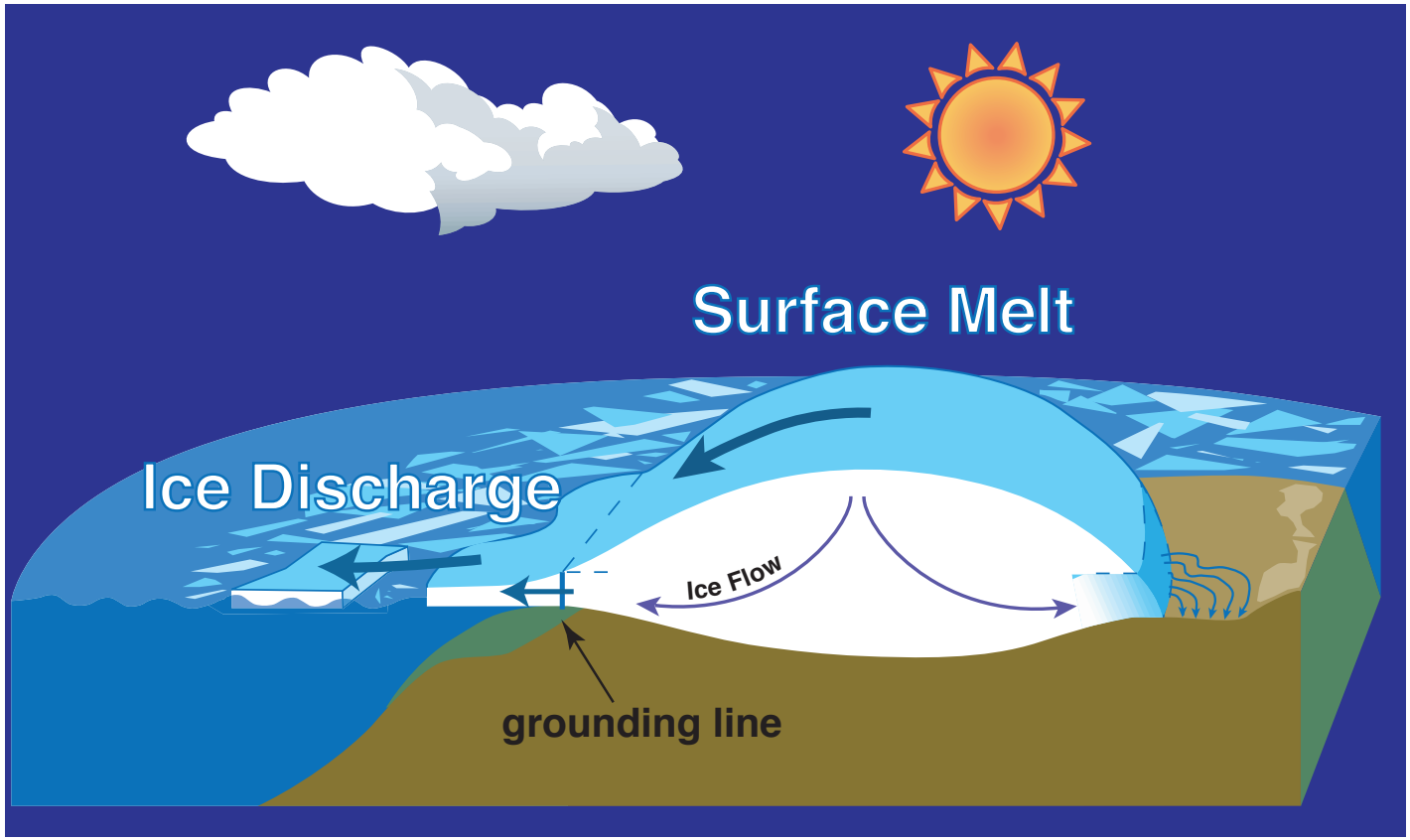
not to scale

Glacier response to climate



- glaciers can adjust to changes in climate $\Rightarrow$ stable

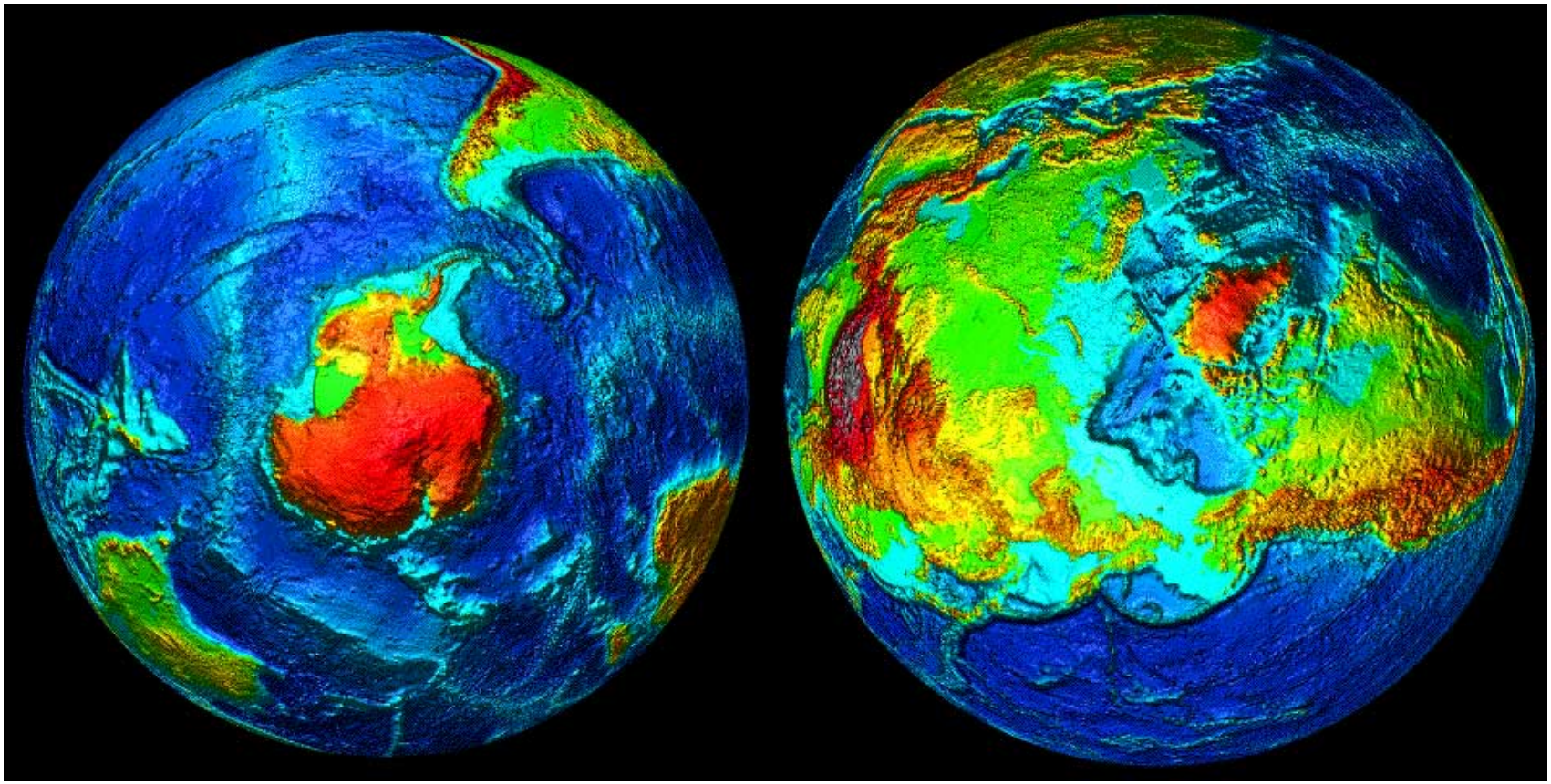
Ice sheet response to climate



modified from ICESat brochure

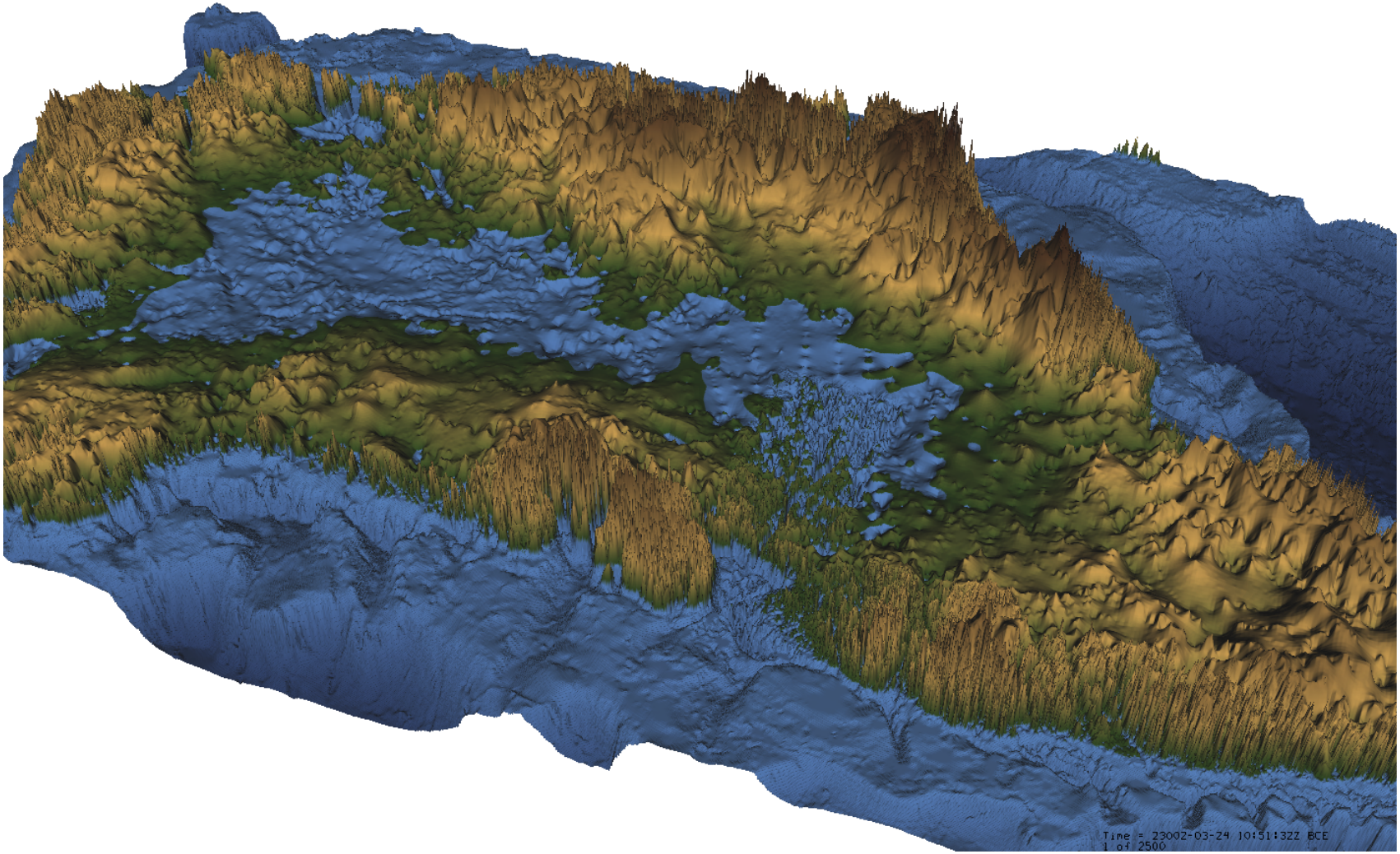
- ice discharge: vertically-averaged horizontal flow velocity $\times$ ice thickness
- 50/50 split for Greenland
- mostly ice discharge for Antarctica

Ice sheets really stick out

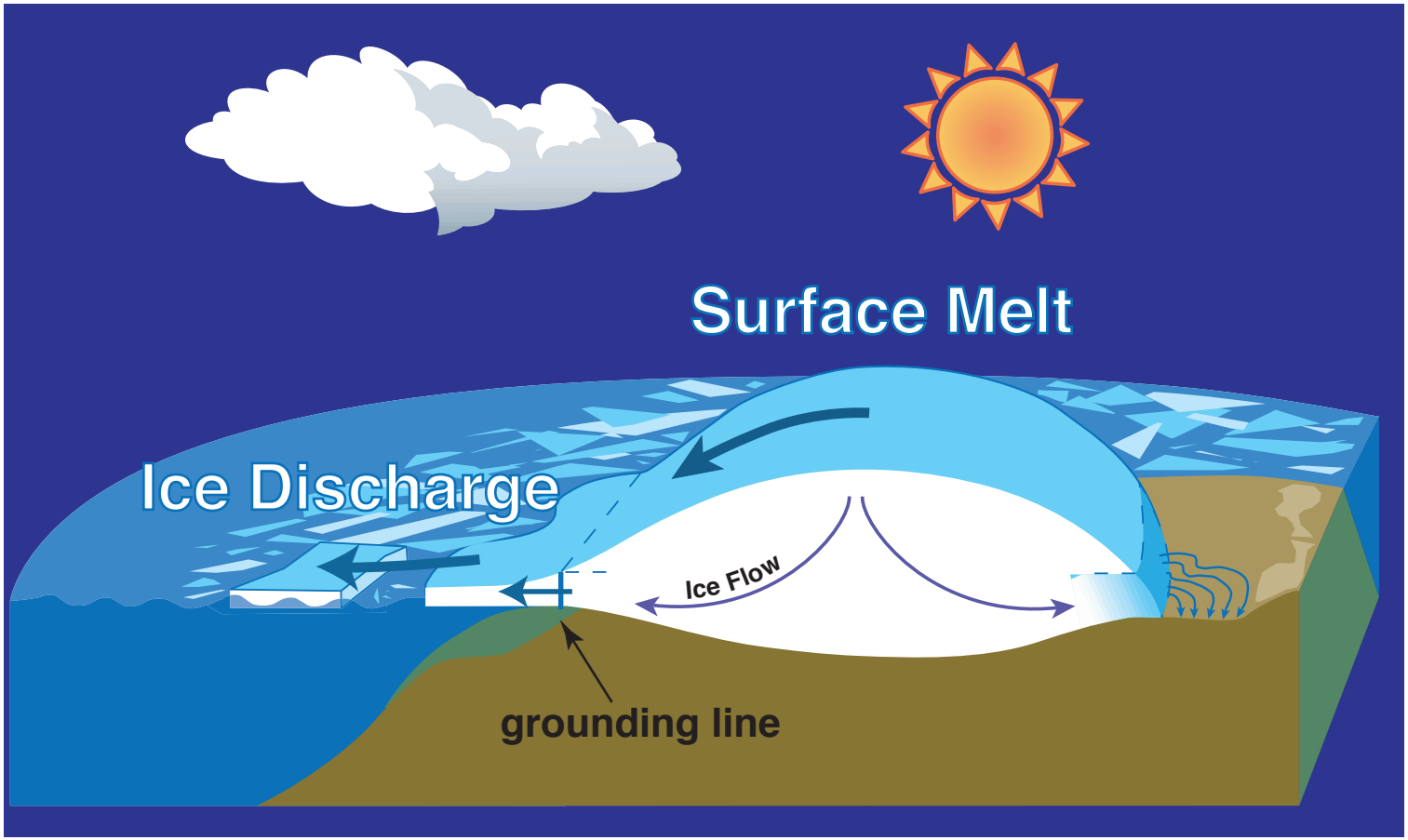


- ice sheets rise high enough to create their own weather

Build your own ice sheet



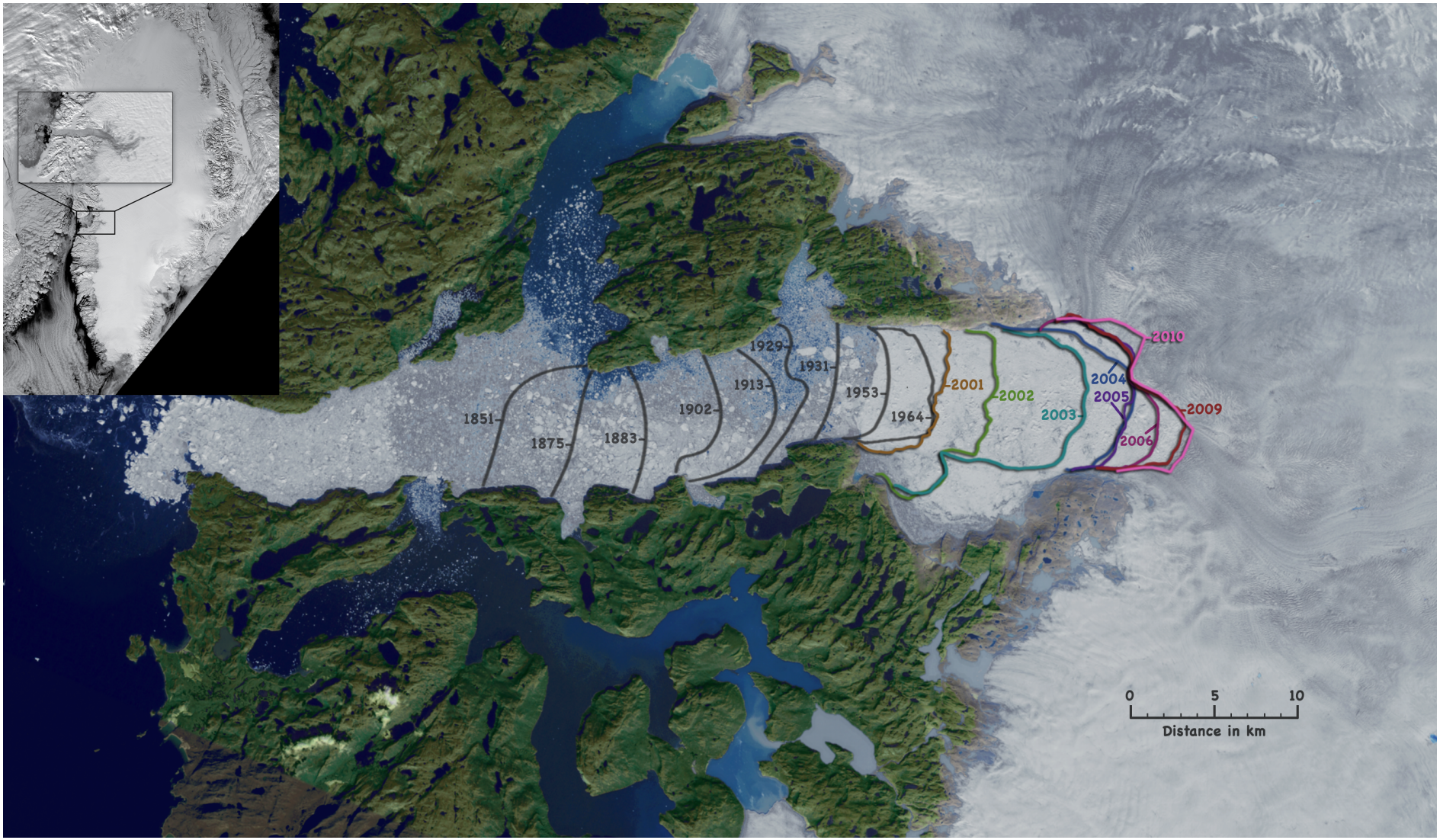
Ice sheet response to climate



modified from ICESat brochure

- surface processes are reasonably well understood
- ice discharge is the wildcard

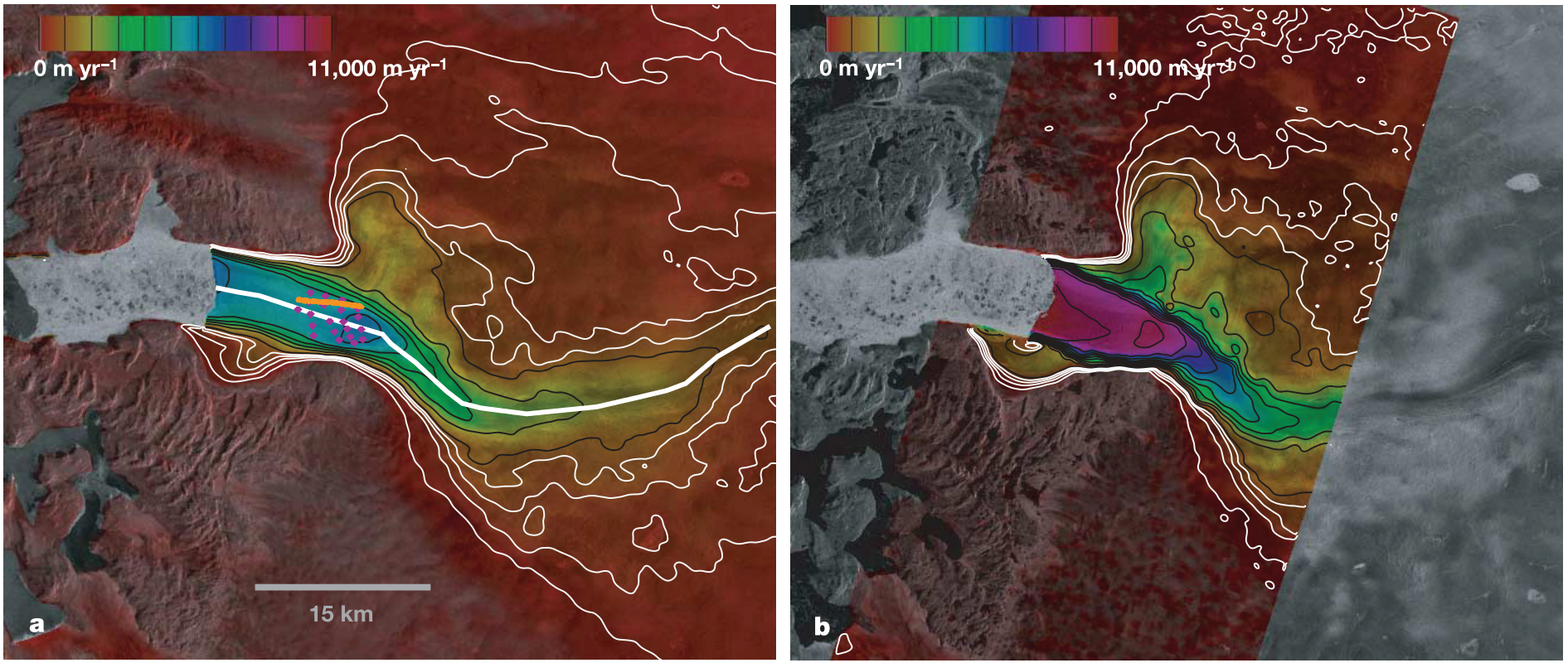
Jakobshavn Isbræ, west Greenland



credit: NASA SVS and M. Fahnestock

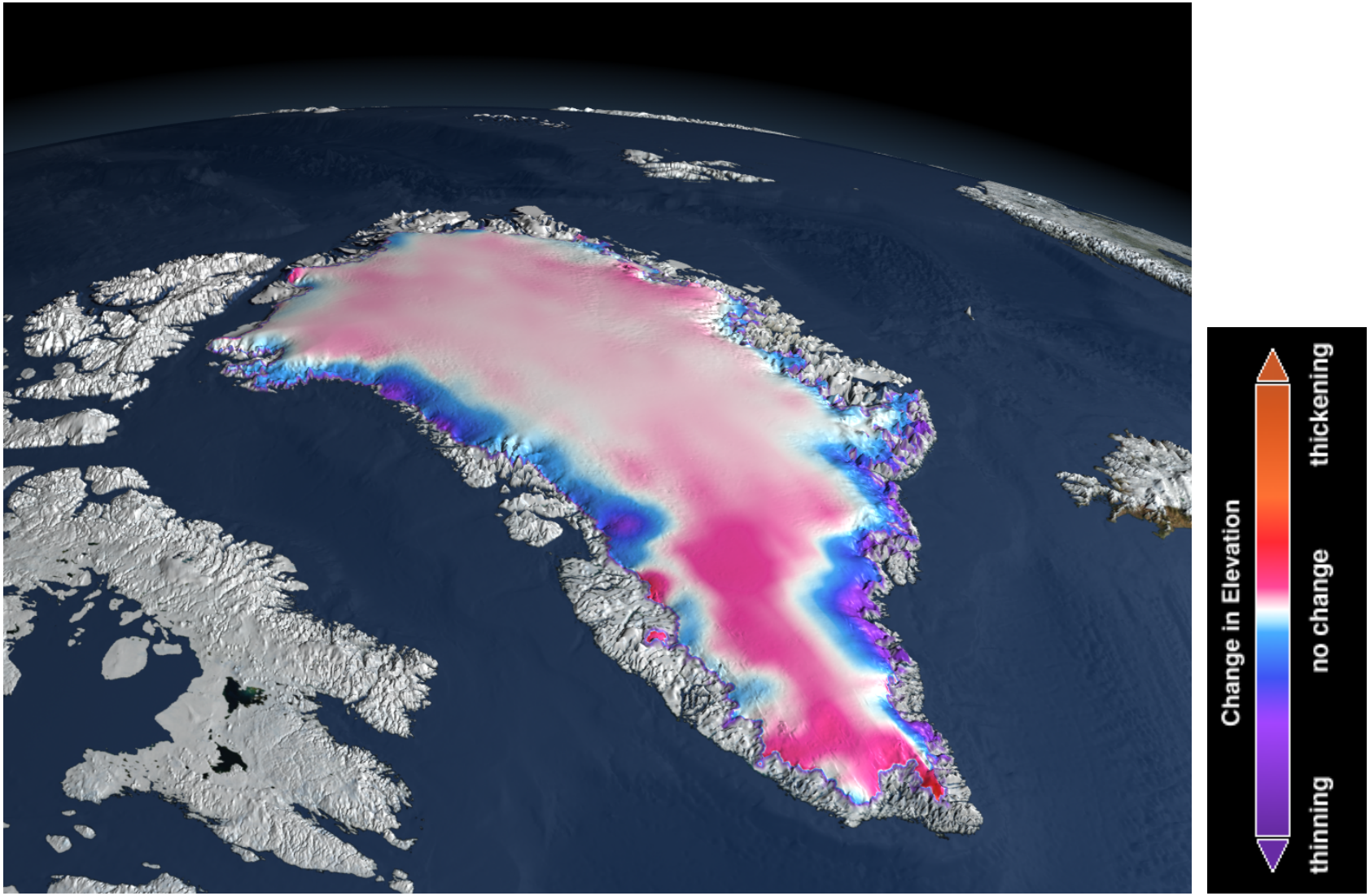
Speed-up of Jakobshavn Isbræ mid 80's–2008

- more than doubled its flow speed between the mid-80's and 2008



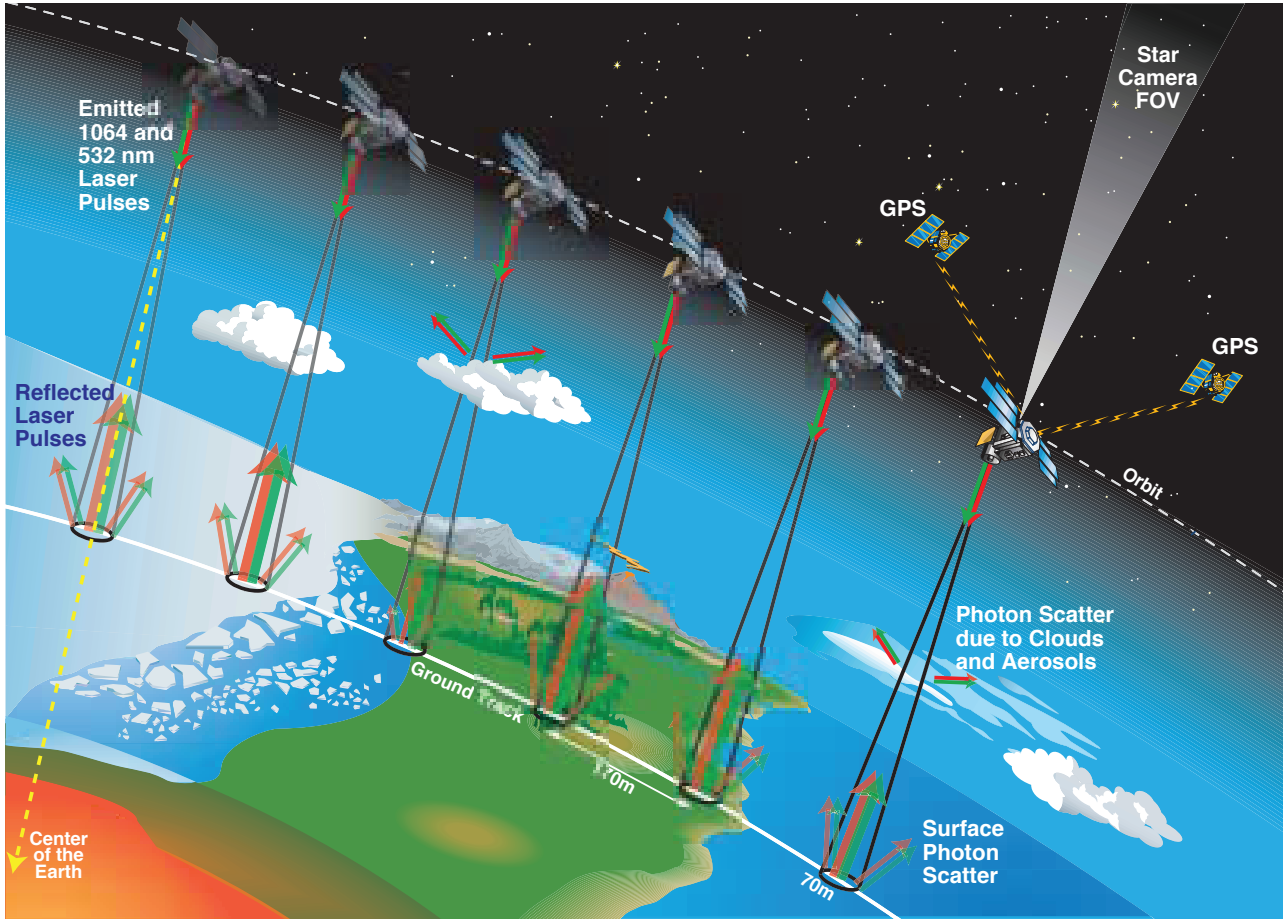
Joughin et al. (2004)

Elevation change between 2003 and 2006

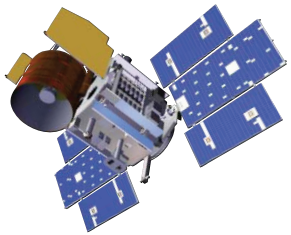


NASA/Goddard Space Flight Center Scientific Visualization Studio

Ice Cloud Land Elevation Satellite (ICESat)

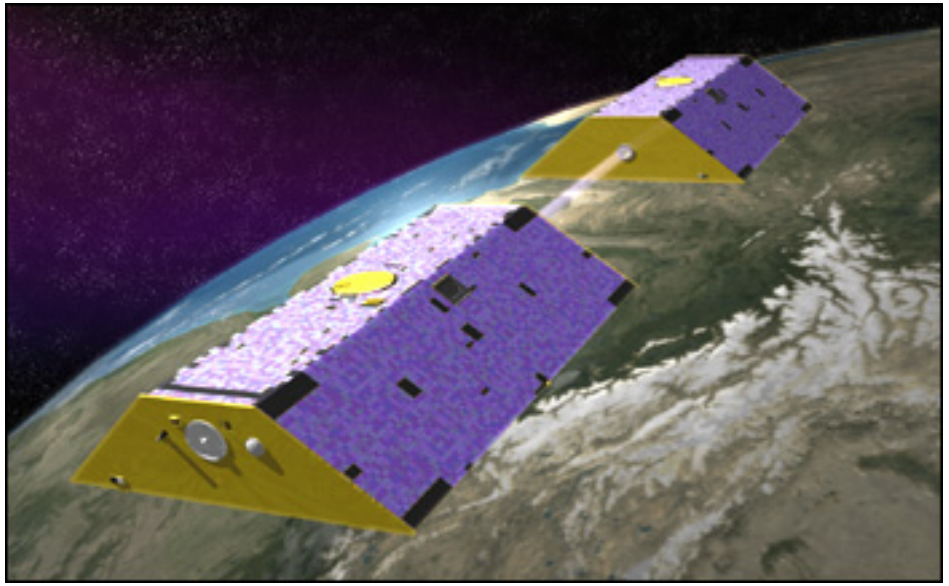


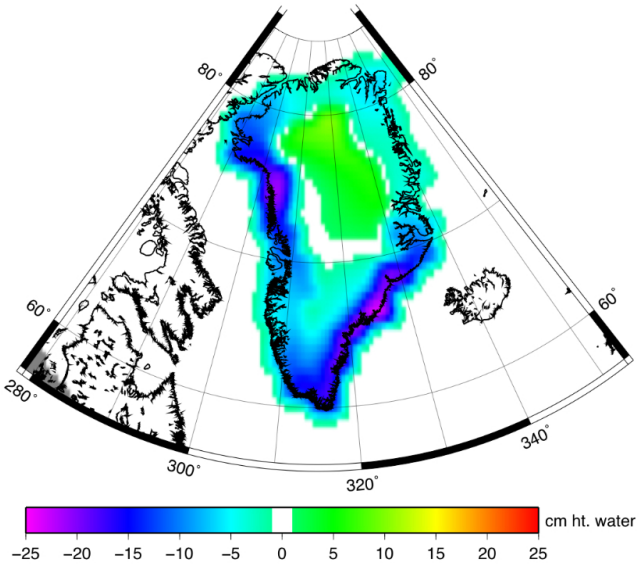
2003–2009



credit: NASA Goddard Space Flight Center

Gravity Recovery and Climate Experiment (GRACE)

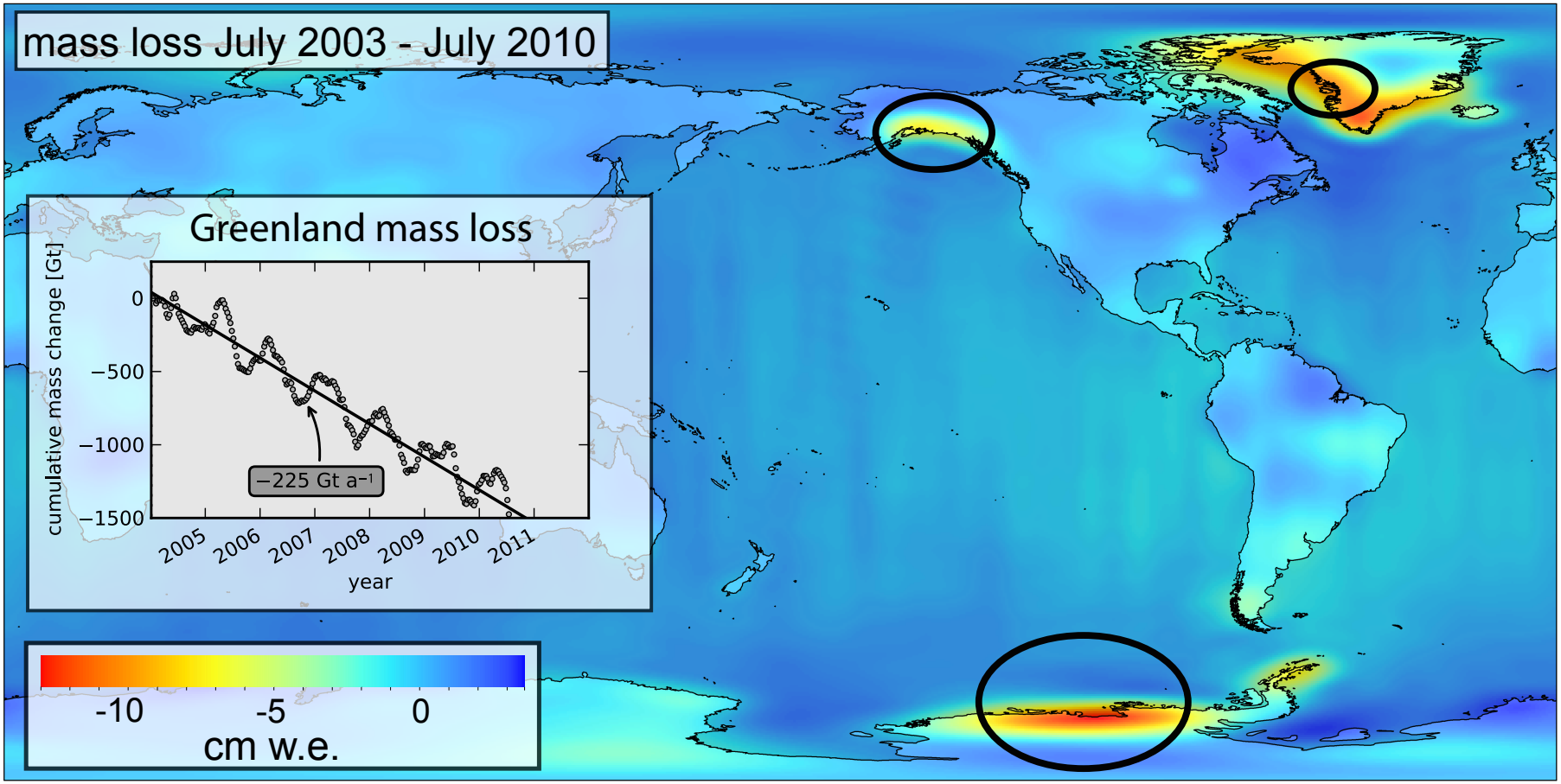




courtesy of A. Arendt

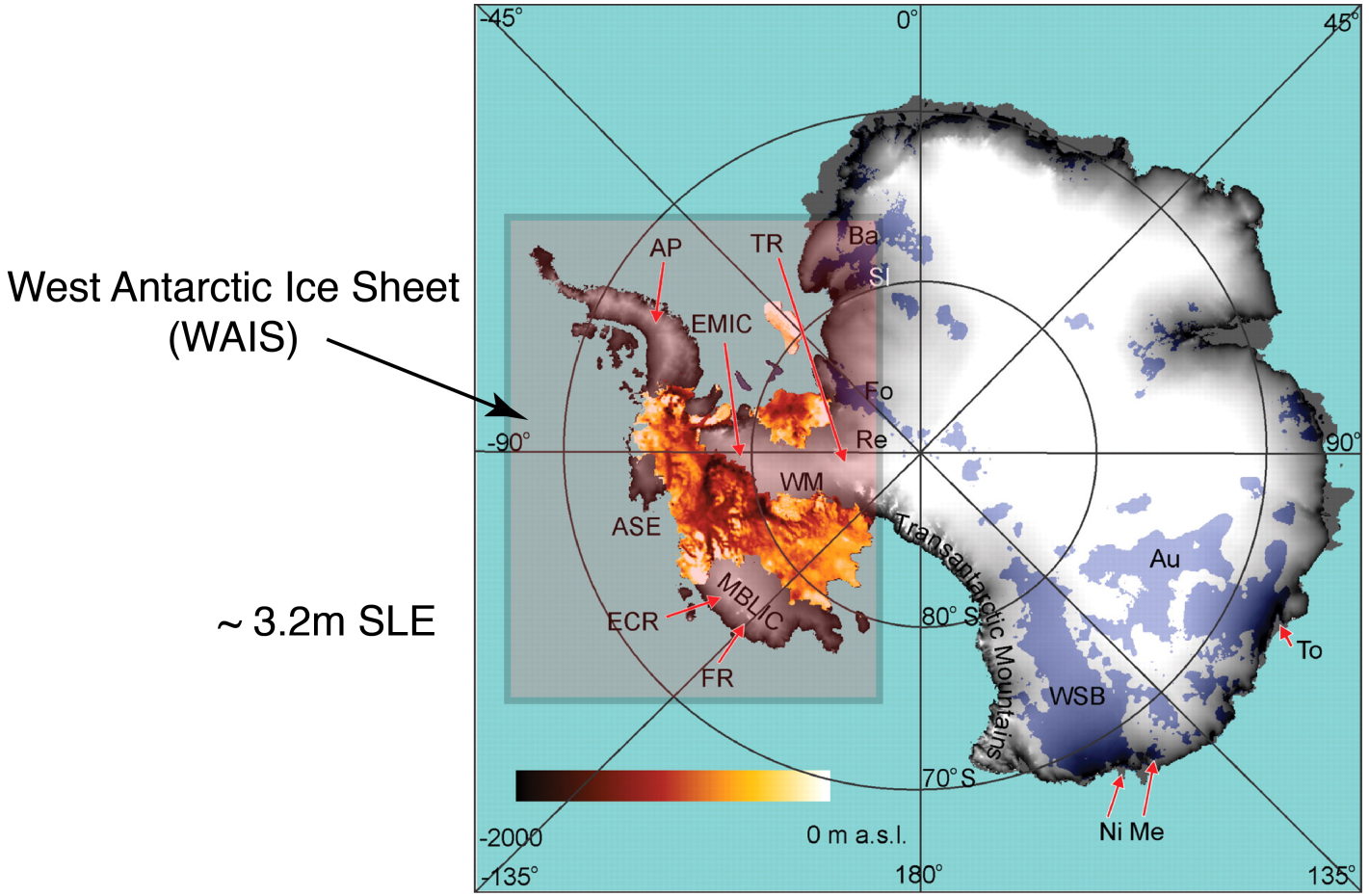
- precise measurements of orbital variations of tandem satellites are used to construct time variable gravity field

Global mass changes observed by GRACE



credit: A. Arendt, S. Luthcke, modified

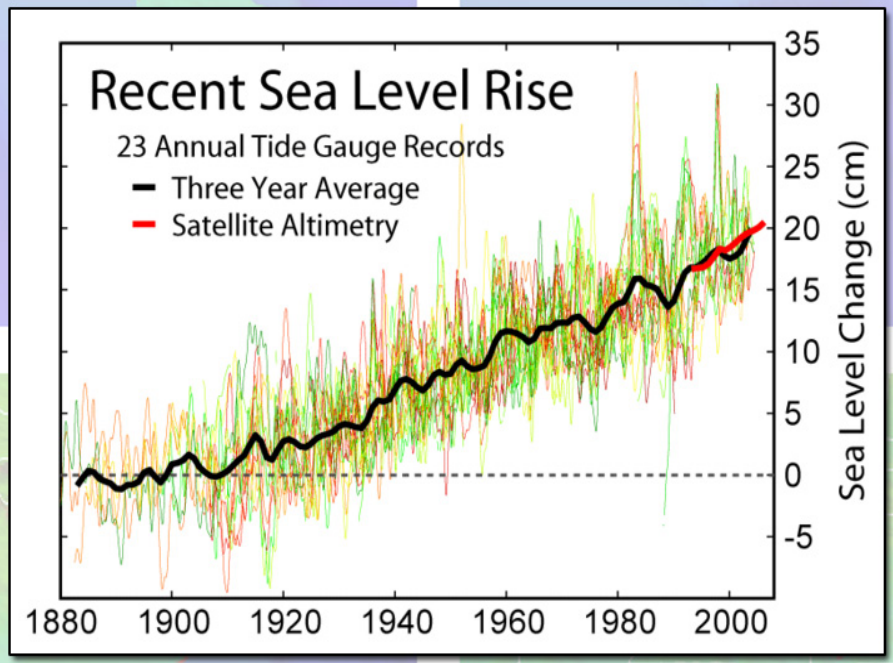
Antarctica



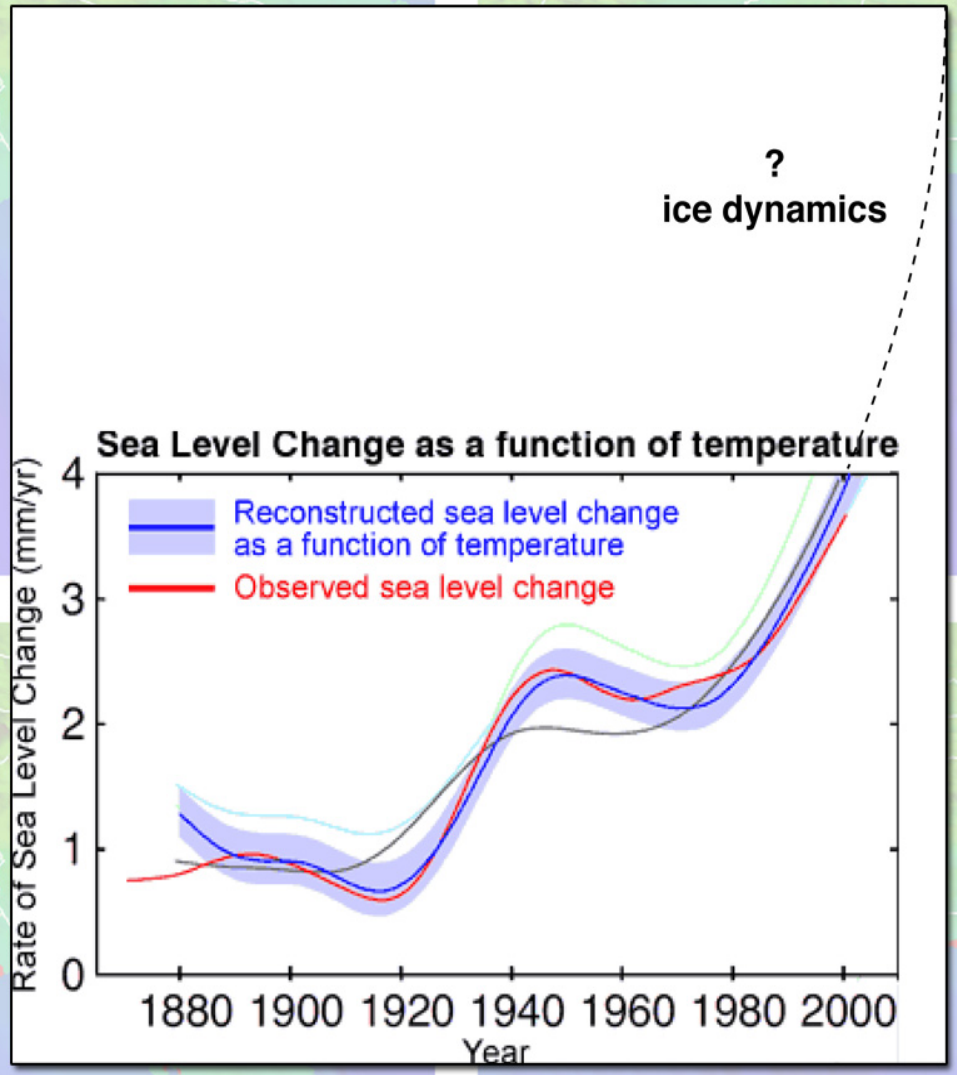
modified from Bamber et al (2009)

- WAIS is potentially unstable
- could raise global mean sea level by $\sim$3 m

Why we care

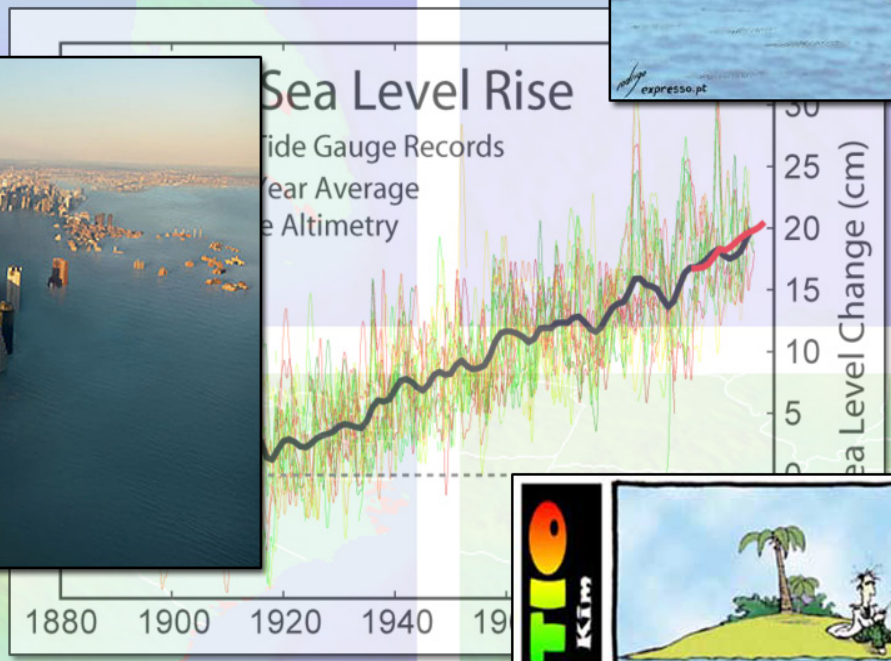

Recent Sea Level Rise
23 Annual Tide Gauge Records
Three Year Average
Satellite Altimetry
35
30
25
20
15
10
5
0
-5
Sea Level Change (cm)
1880
1900
1920
1940
1960
1980
2000

Why we care


?
ice dynamics
Sea Level Change as a function of temperature
Reconstructed sea level change
as a function of temperature
Observed sea level change
Rate of Sea Level Change (mm/yr)
0
1
2
3
4
1880 1900 1920 1940 1960 1980 2000
Year

Why we care


expresso.pt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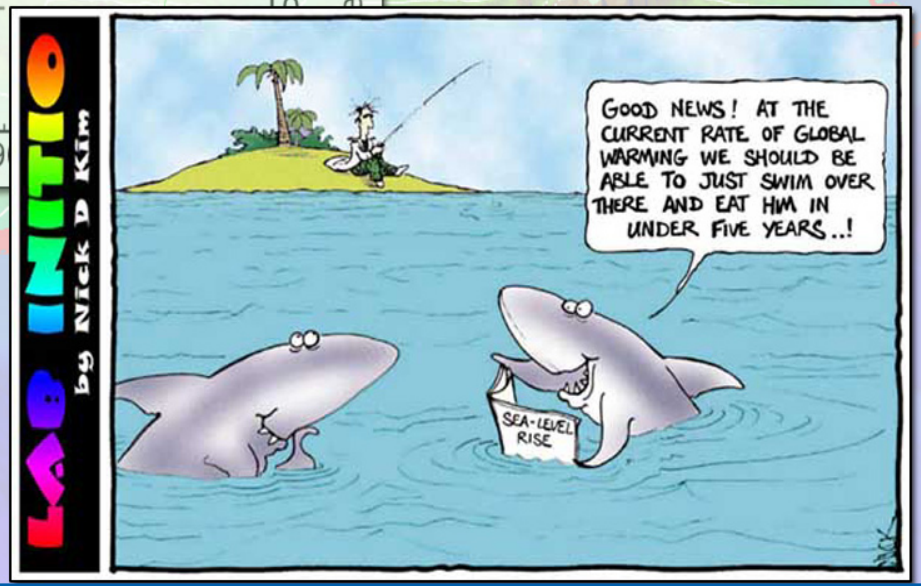

LAB INITIO
by Nick D Kim
GOOD NEWS! AT THE CURRENT RATE OF GLOBAL WARMING WE SHOULD BE ABLE TO JUST SWIM OVER THERE AND EAT HIM IN UNDER FIVE YEARS..!
SEA-LEVEL RISE

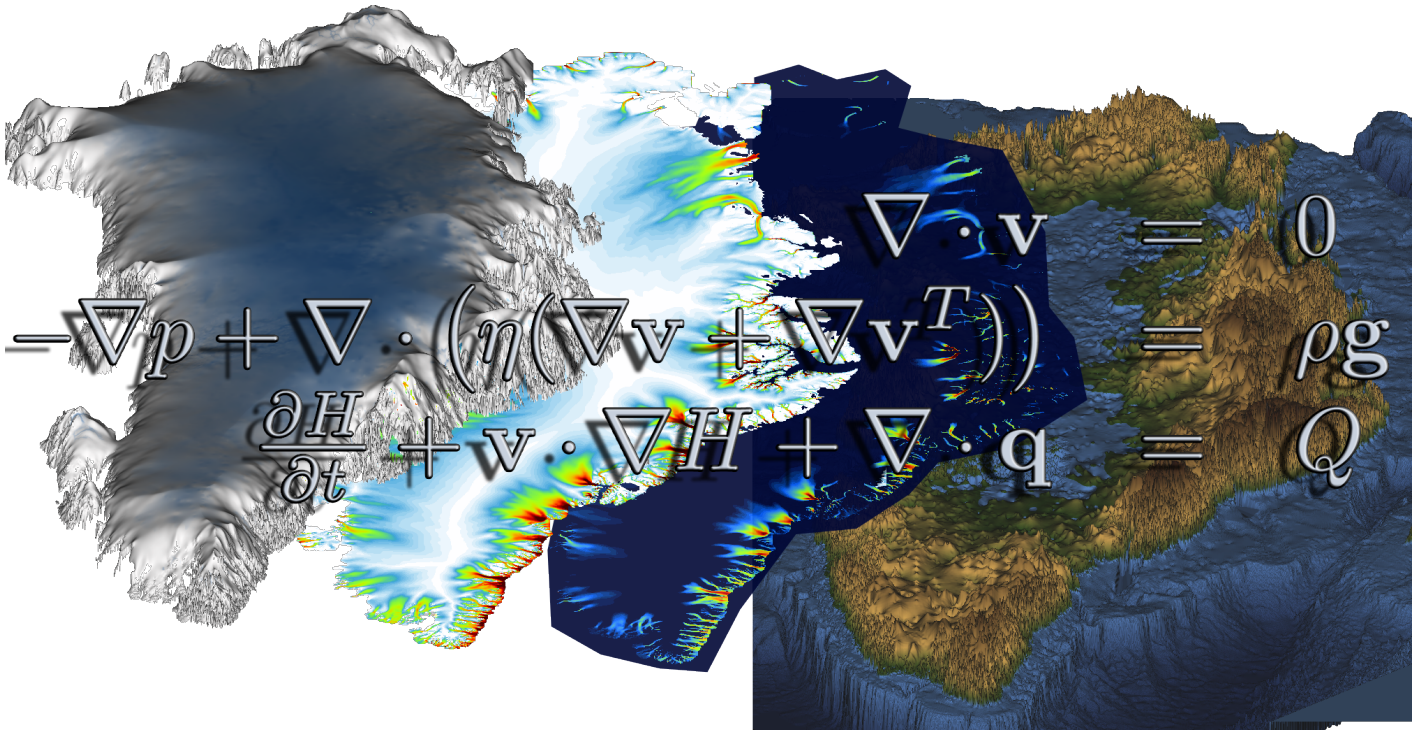
Why we care

- mitigation and adaptation efforts require long-term planning
- appropriate measures depends on projected sea-level rise

Why we need ice sheet models

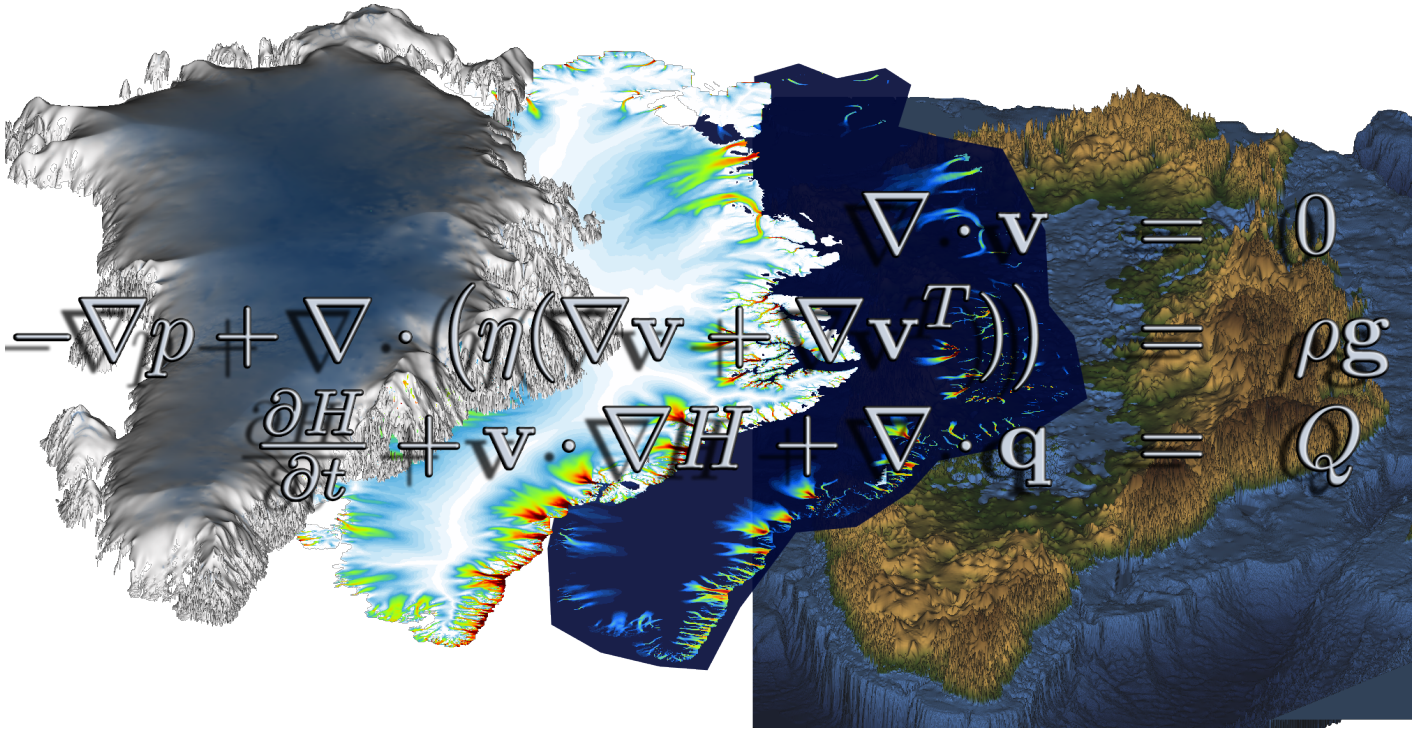
"Realistic projections of ice sheet response to a changing climate should be based on a physical understanding of the processes involved, rather than trend extrapolation of historical observations" (Arthern & Hindmarsh, 2006)

What is an ice sheet model?



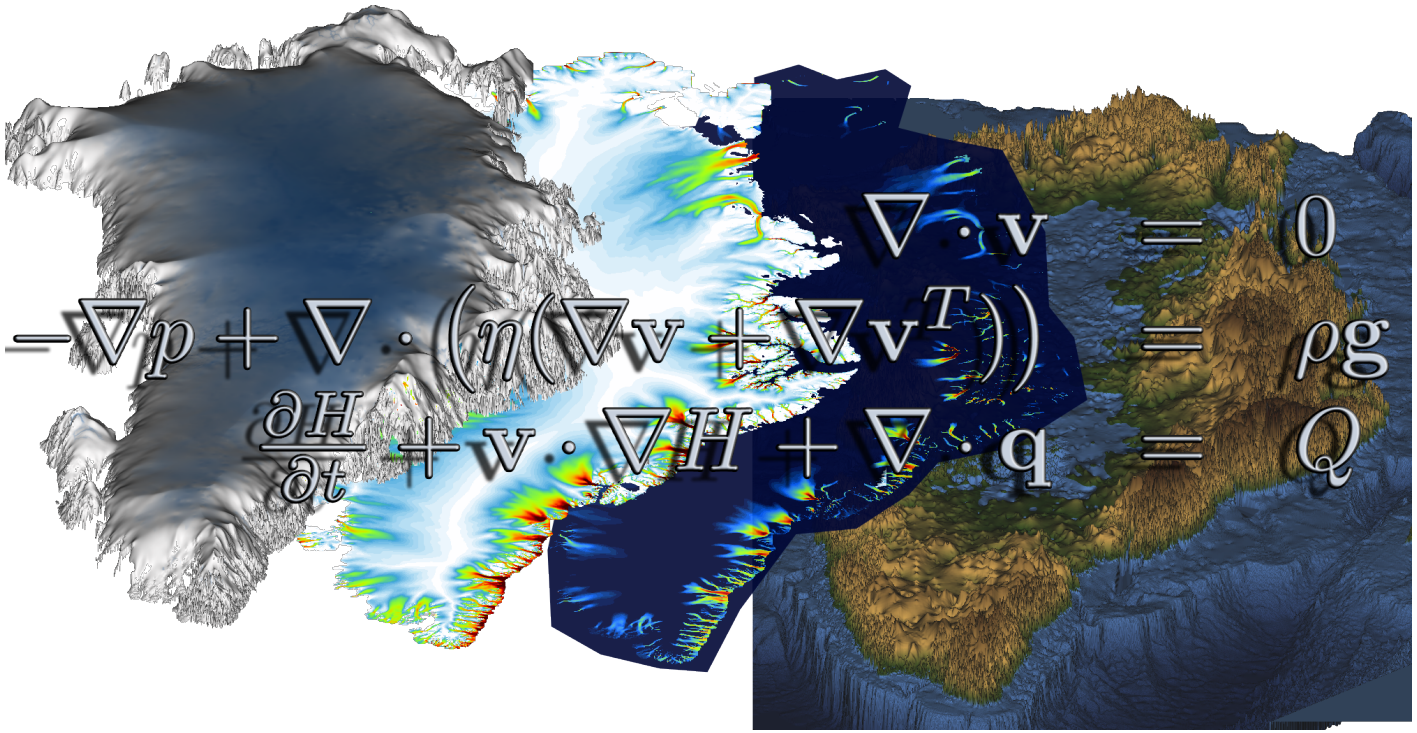
- ice dynamics
- thermodynamics
- surface processes
- boundary conditions
- hydrology
- ice-ocean interaction (e.g. calving)

Why ice sheet modeling is easy



- composed of a single, largely homogenous material
- flow governed by the Stokes equations known since the mid-19th century
- flows slowly: we can ignore turbulence, Coriolis and other inertial effects

Why ice sheet modeling is so hard

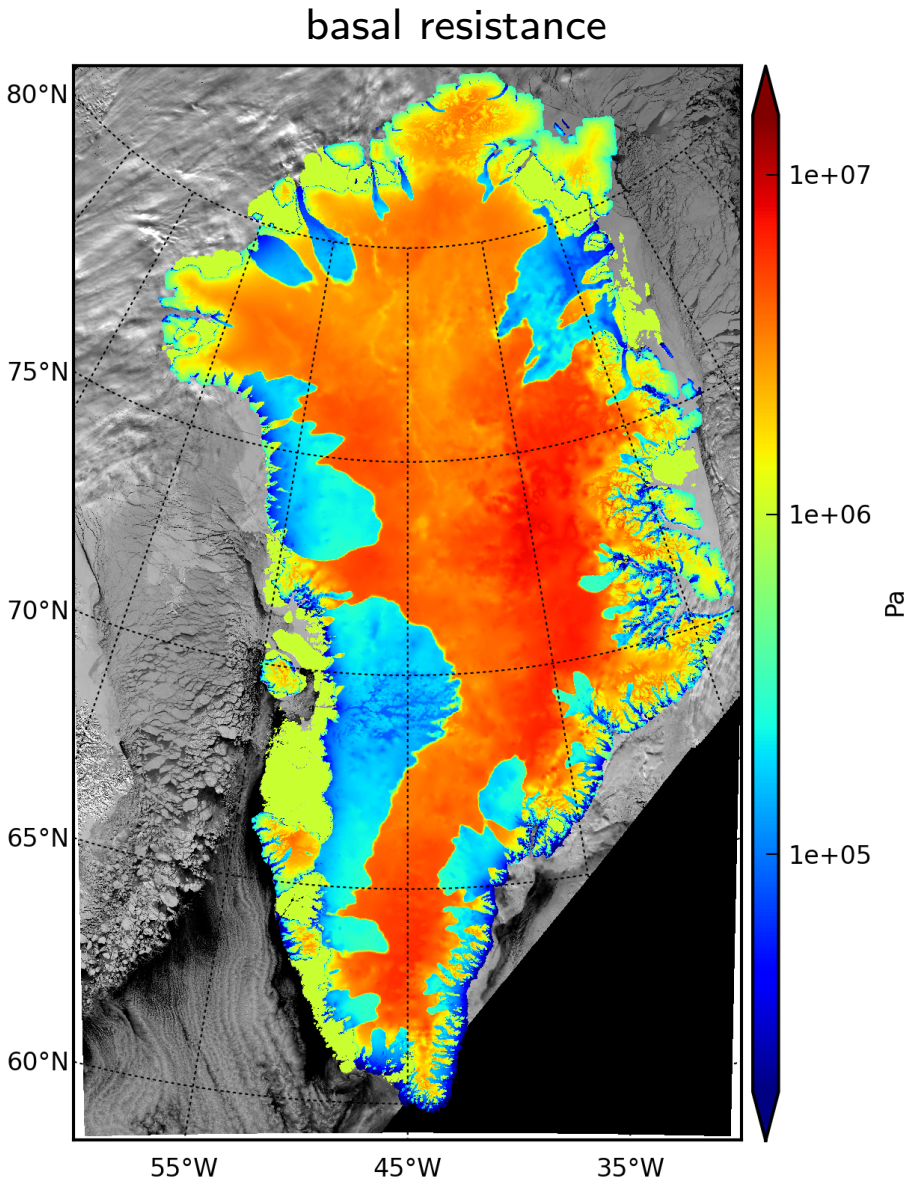


Specifying the stress boundary condition at the

- seaward margin
- base

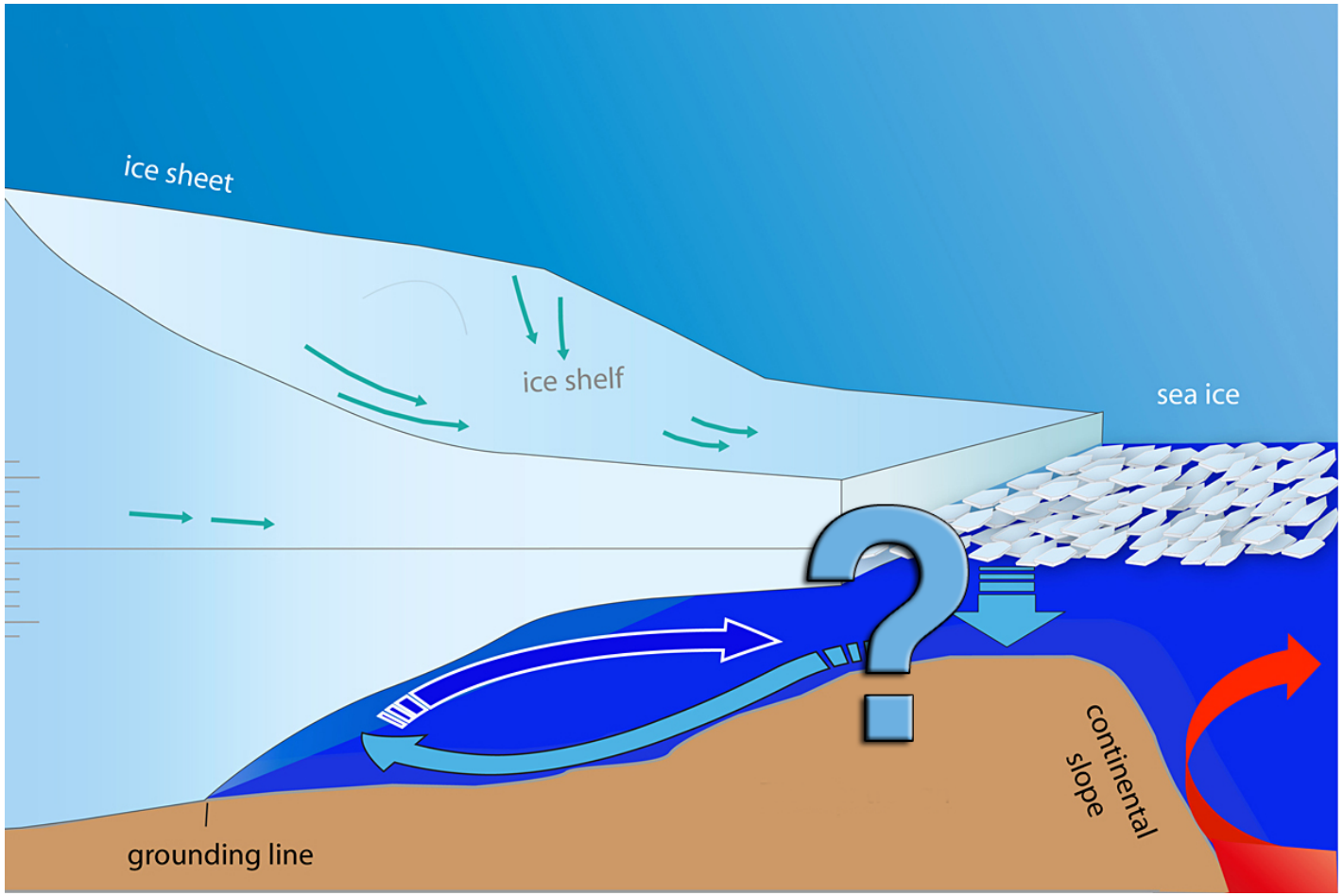
is challenging.

Challenge: ice base



- stresses vary by orders of magnitude
- transience and complexity of basal water flow
- despite more than 5 decades of research, we only have crude parametrizations

Challenge: seaward margin



- ocean circulation $\Rightarrow$ basal melt rates
- calving mechanism

IPCC and ice sheet models

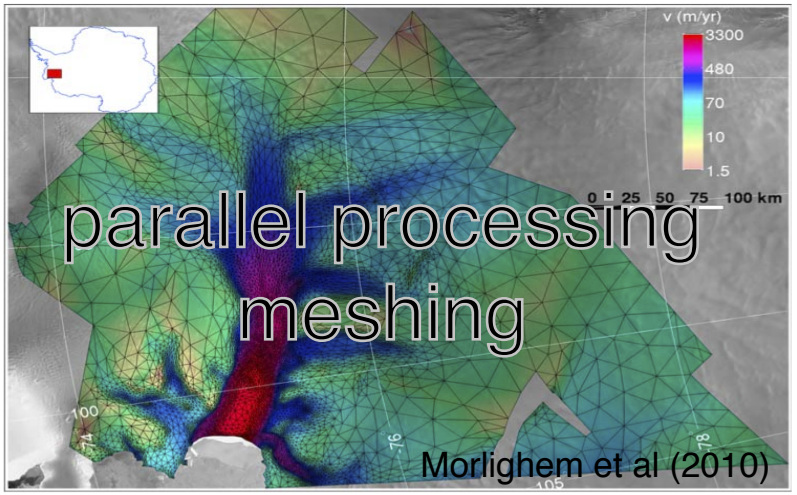
IPCC (2007), Box 4.1: Ice Sheet Dynamics and Stability

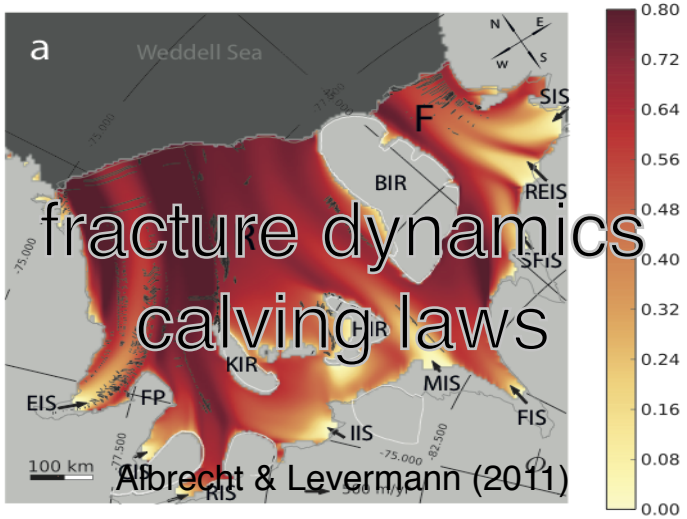
"...but recent changes in ice sheet margins and ice streams cannot be simulated accurately with these models, ..."

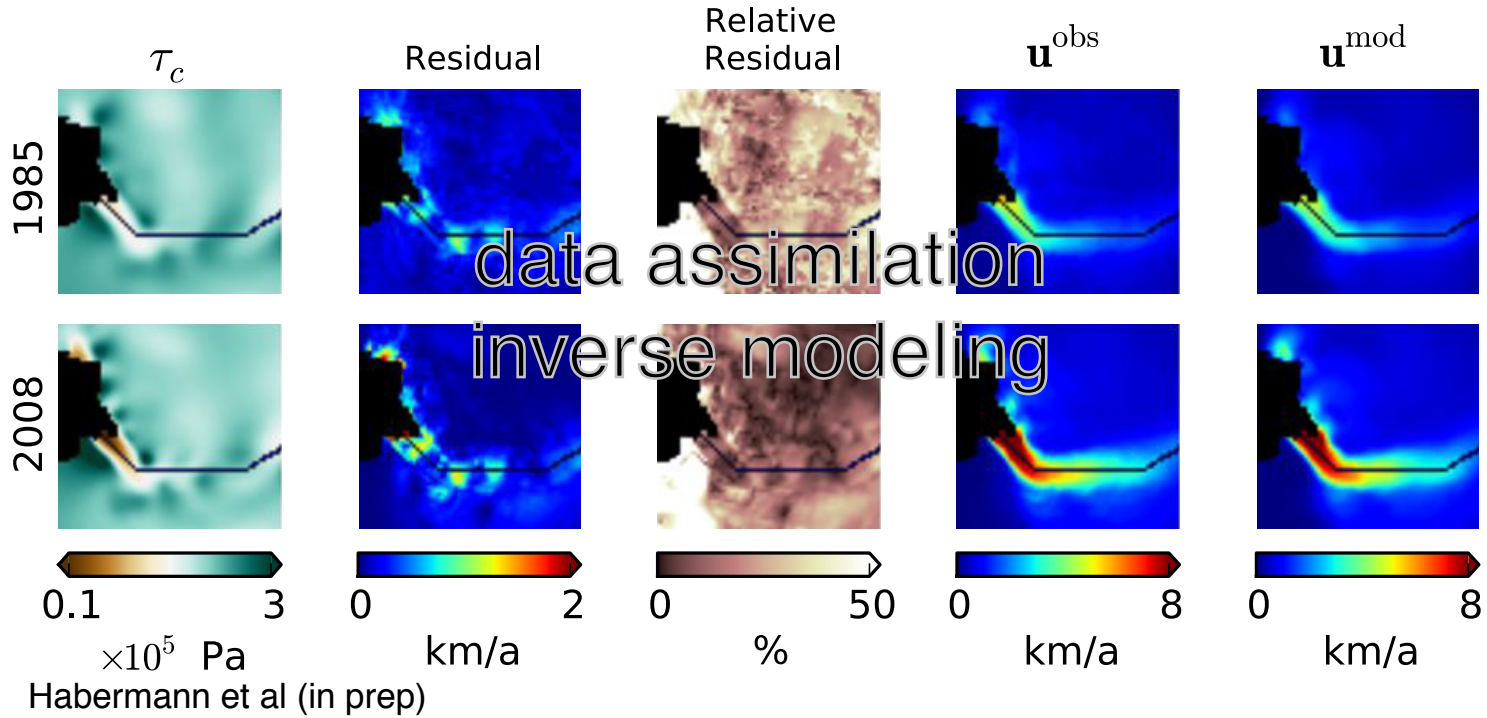
- the above statement received lots of attention
- triggered projects such as SeaRISE (Sea Level Response to Ice Sheet Evolution) and ice2sea

Ice Sheet Models, 2007–

Ice Sheet Models, 2007–today





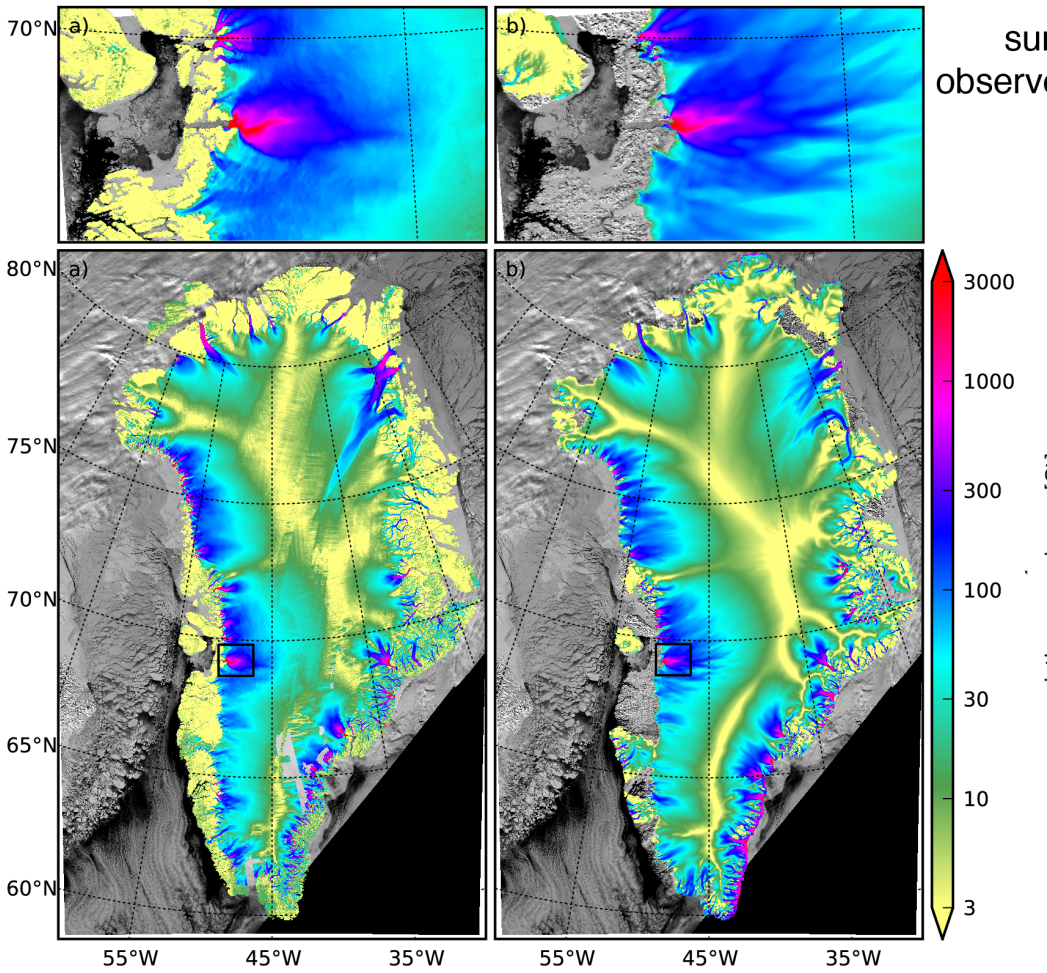


Habermann et al (in prep)

A word of caution

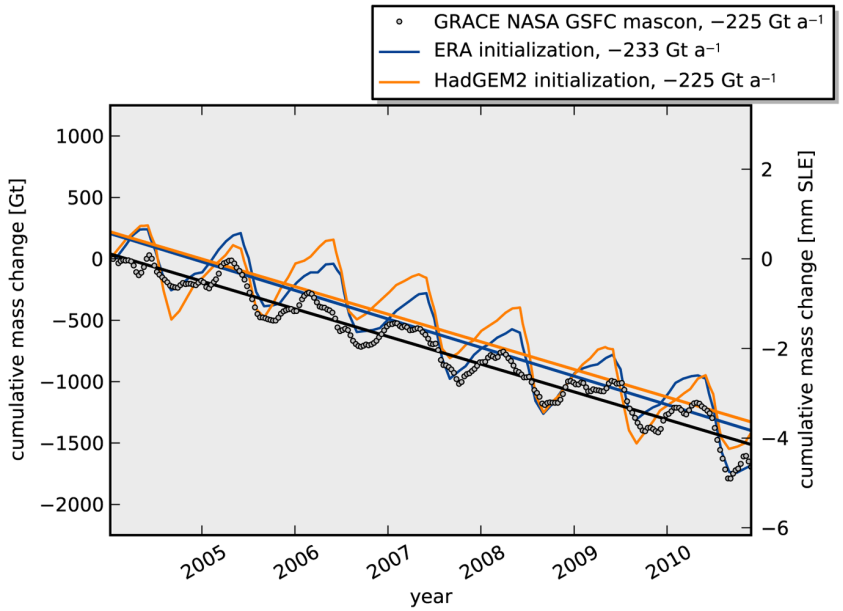
- ice sheet models should not be used as a "black-box"
- require serious modeling choices (physics, physical and numerical parameters, etc) based on glaciological knowledge
- "garbage in $\Rightarrow$ garbage out", sometimes "garbage in $\Rightarrow$ gospel out"
- a model is only as good as the input data (at best)

Ice Sheet Models, 2007–today

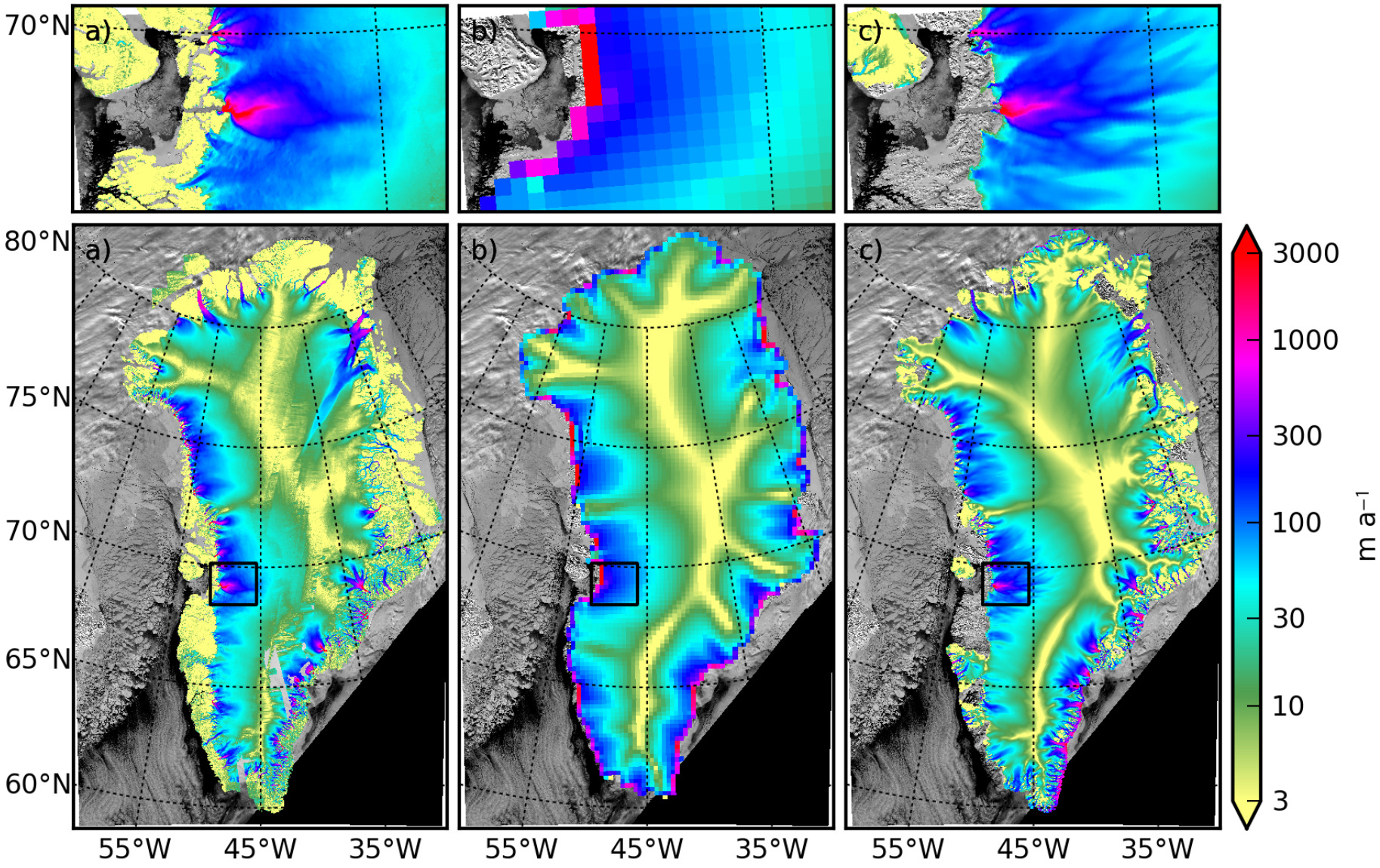


surface speeds
observed and simulated

Greenland total mass loss
observed and simulated

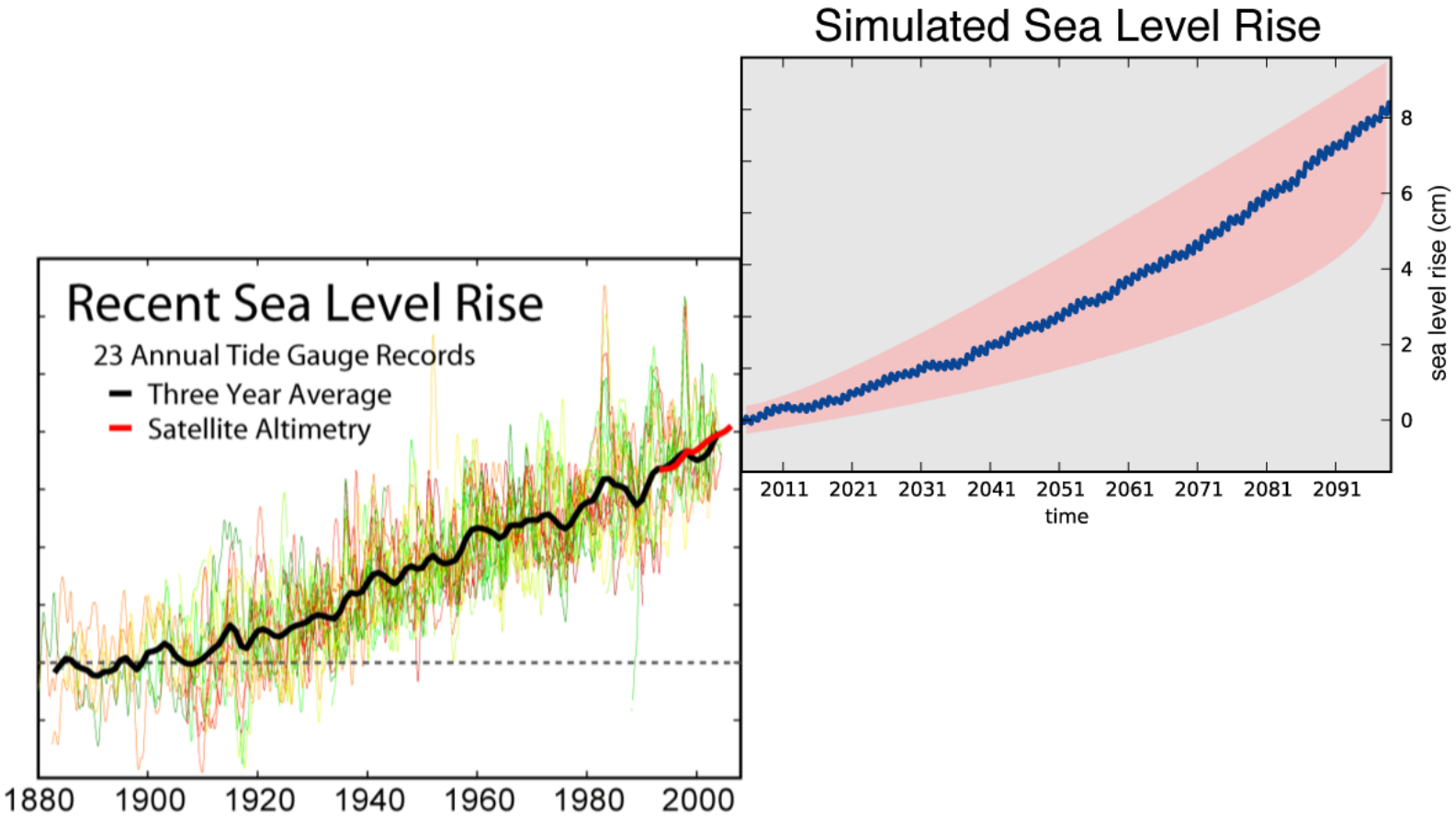


Modeling in 1995 and today



a) observed b) model 1995 c) model 2013

Ready for the future?



- we now have decent numerical ice flow models
- but we need uncertainty quantification