Recent advances in glacier/ocean interactions

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GRISO
Greenland Ice Sheet Ocean Science Network

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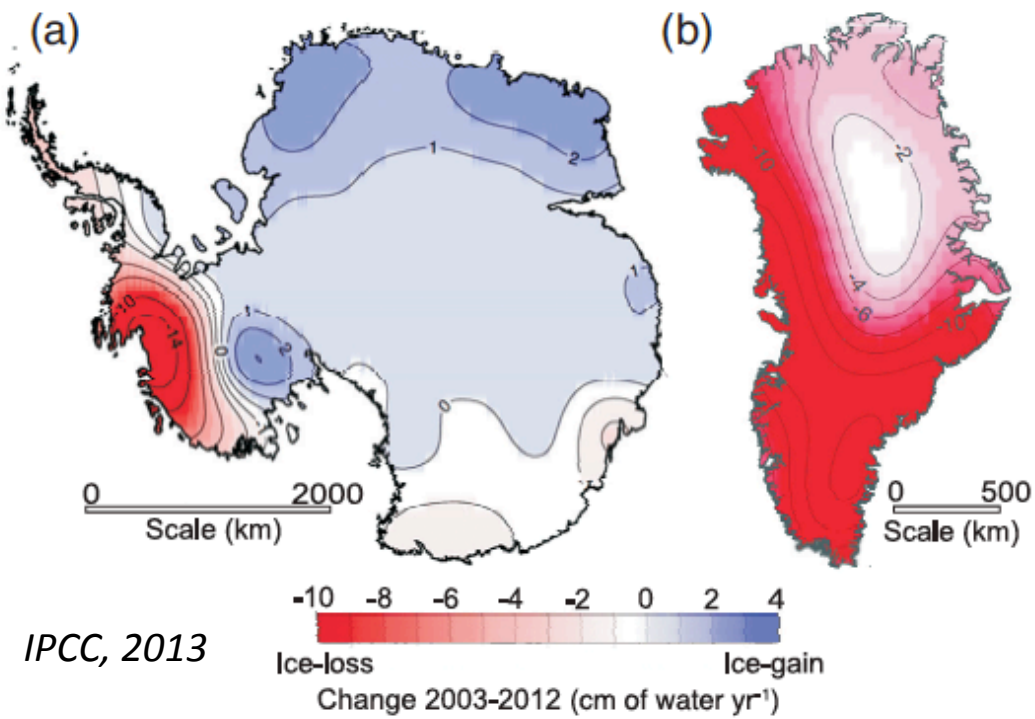
Advance collective understanding of Greenland and Arctic land-ice change, and its interaction with the climate system.

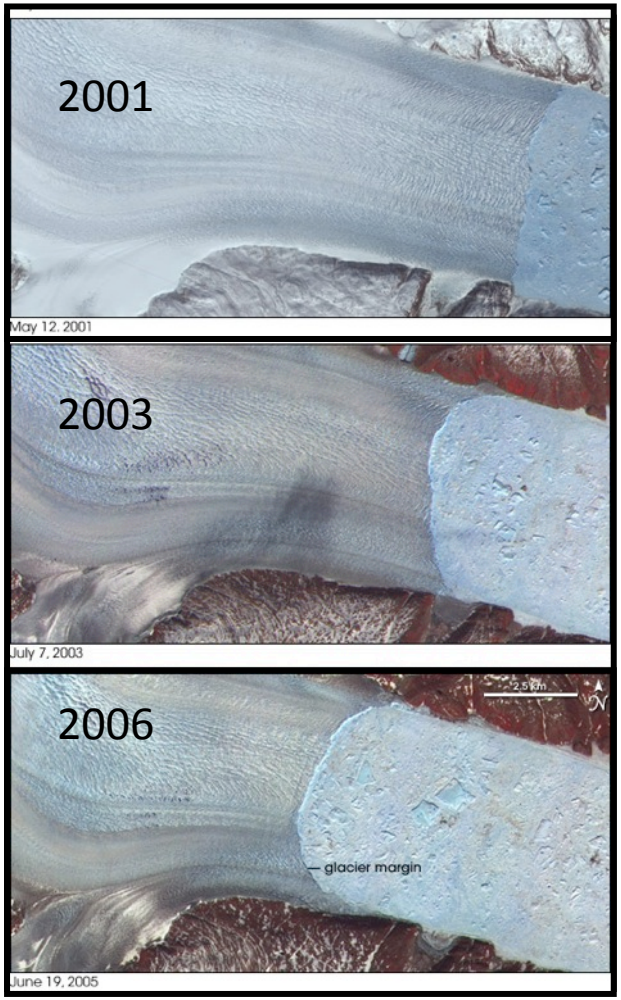
- Understanding the dynamic response of Greenland's marine terminating glaciers to oceanic and atmospheric forcing' US CLIVAR Report 2012-2, BAMS Article, Straneo et al. 2013.
- International Workshop and report synthesizing scientific priorities (Heimbach et al. 2014; US CLIVAR Report)
- Greenland Ice Sheet/Ocean Observing Network Workshop – Dec 12-13 2015, San Francisco in conjunction with ISMIP6 Meeting.

SEARCH Study of Environmental Arctic Change
NSF
US CLIVAR
CliC

1: Dynamic ice sheet mass loss triggered by ocean forcing



IPCC, 2013

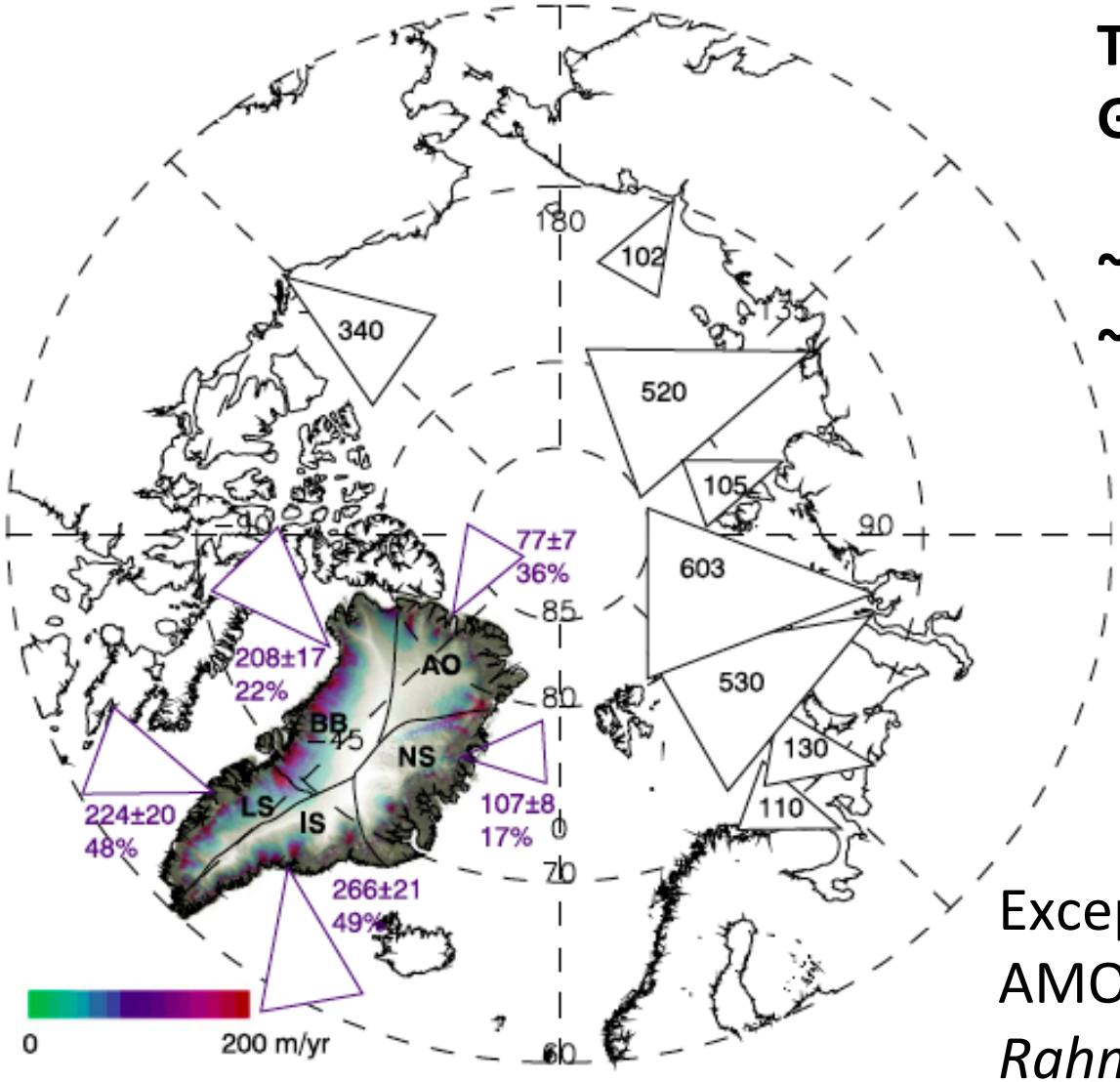


Greenland ice loss (twice that of Antarctica)

- Quadrupled over the last two decades
- Accounts for ¼ of sea level rise
- ½ is due to the speed up of glaciers

van den Broeke et al. 2009; Bamber et al. 2012; Shepherd et al. 2012; Enderlin et al. 2014

2. Impact of Ice Sheet Discharge on the Ocean



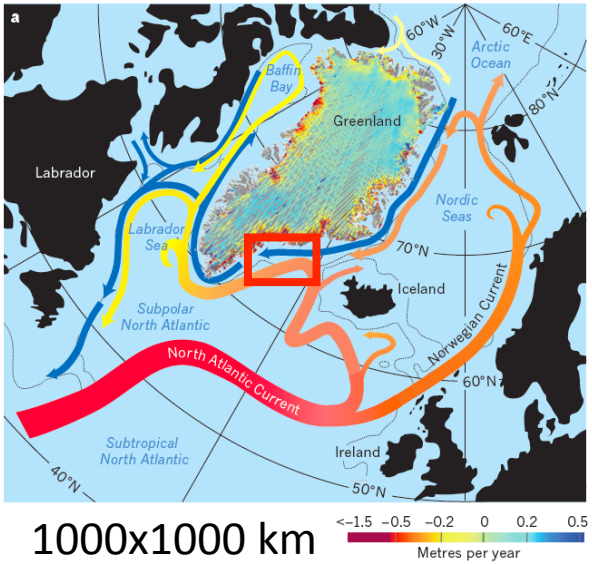
Total freshwater flux from Greenland

~ 900 km³/yr 1960-1990
~ 1200 km³/yr 2000-2010

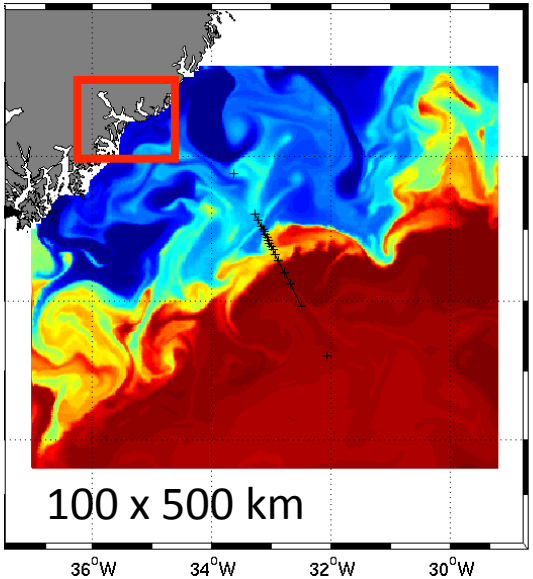
Exceptional slowdown of the AMOC due to Greenland melt?
Rahmstorf et al. 2015

van den Broeke et al. 2009; Bamber et al. 2012

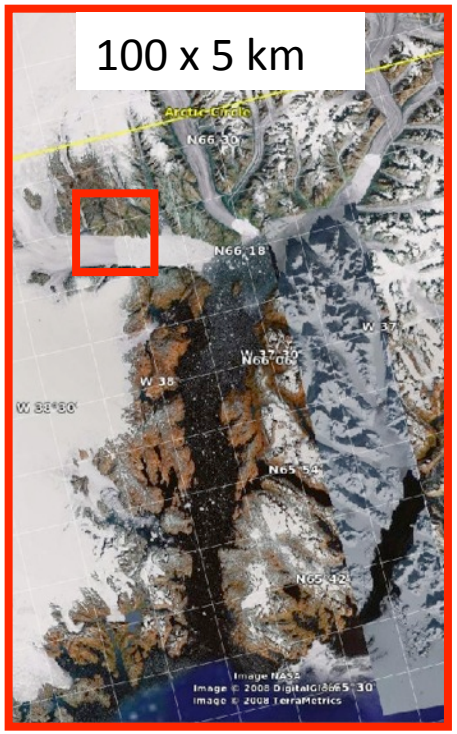
A hierarchy of scales and processes



1000x1000 km



100 x 500 km



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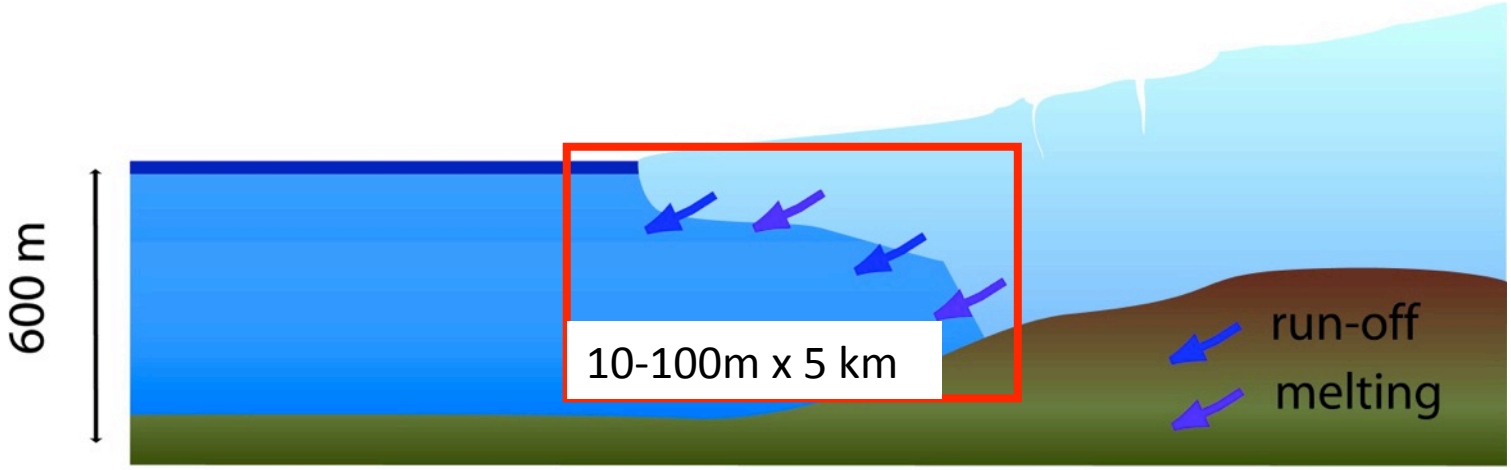
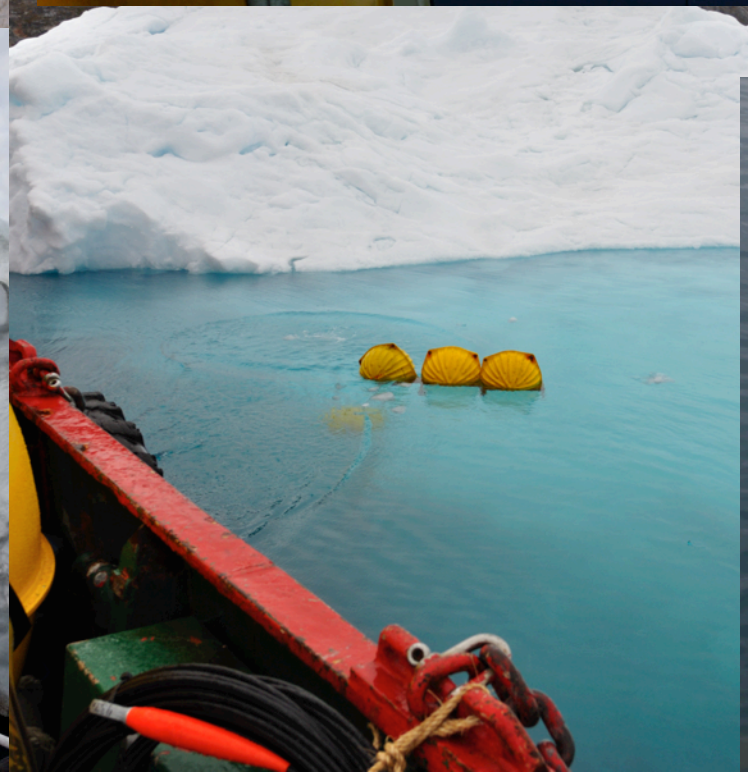
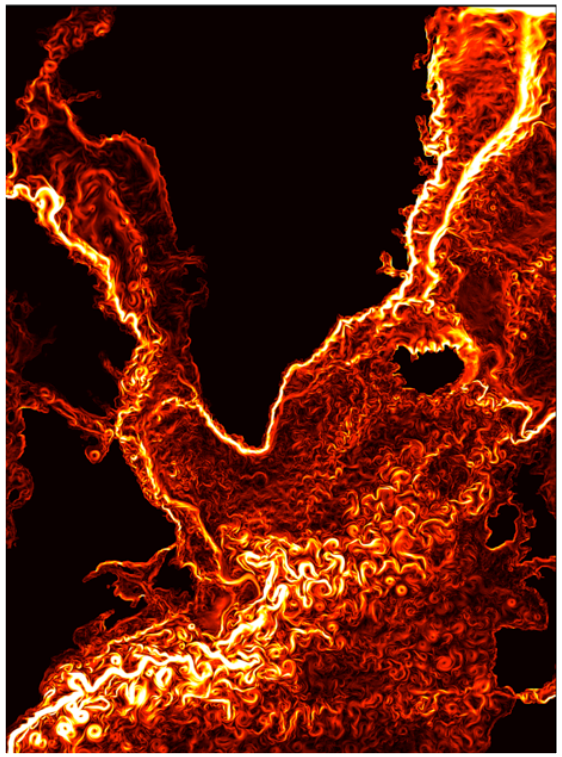




Relevance to climate models: ice sheet forces ocean



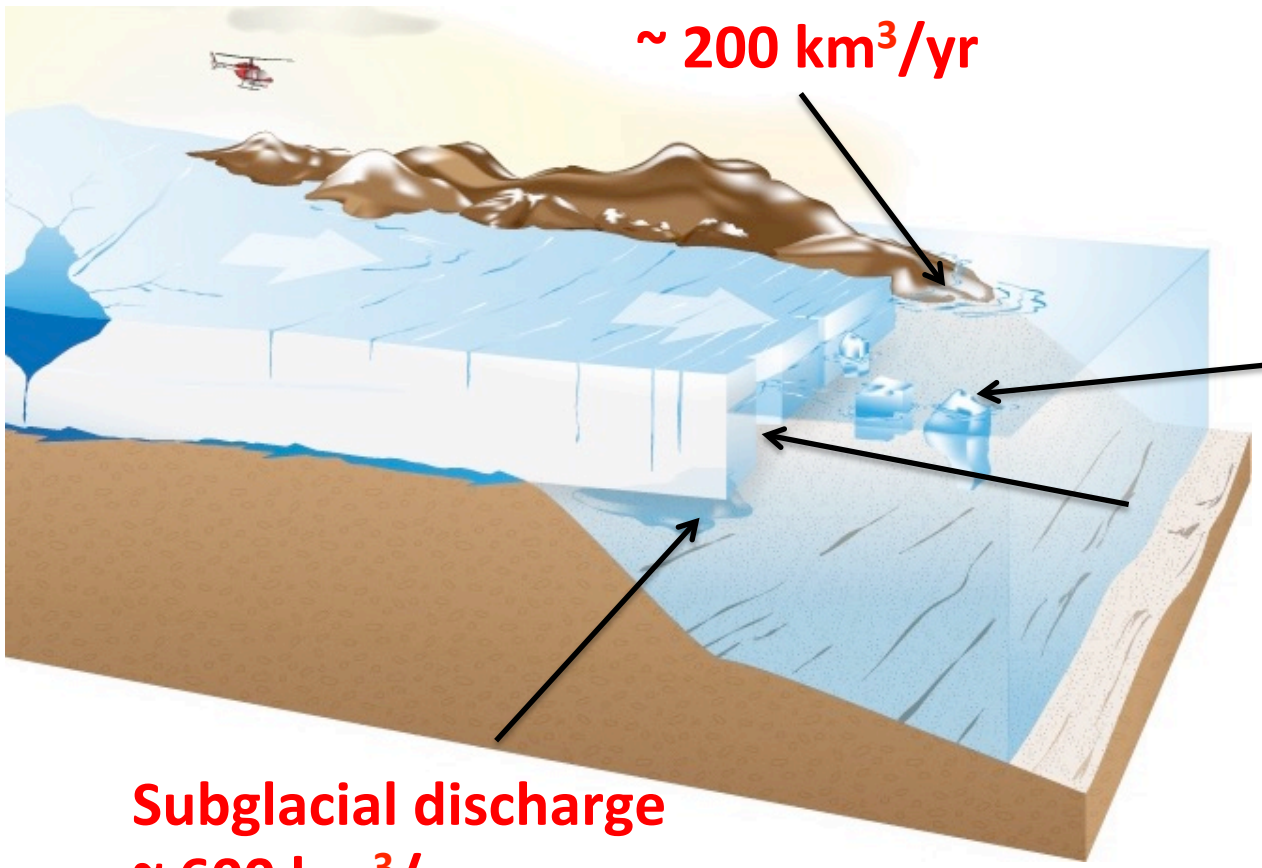
Ocean models include Greenland ice loss as a surface freshwater flux

Discrepancies exist in:

- Magnitude 0.01 to 1 Sv
  (1200 km^3/yr = 0.038 Sv)
- Input location (distributed versus localized)
- Timing

Eg Marsh et al, 2010; Weijer et al. 2012; Hu et al. 2013

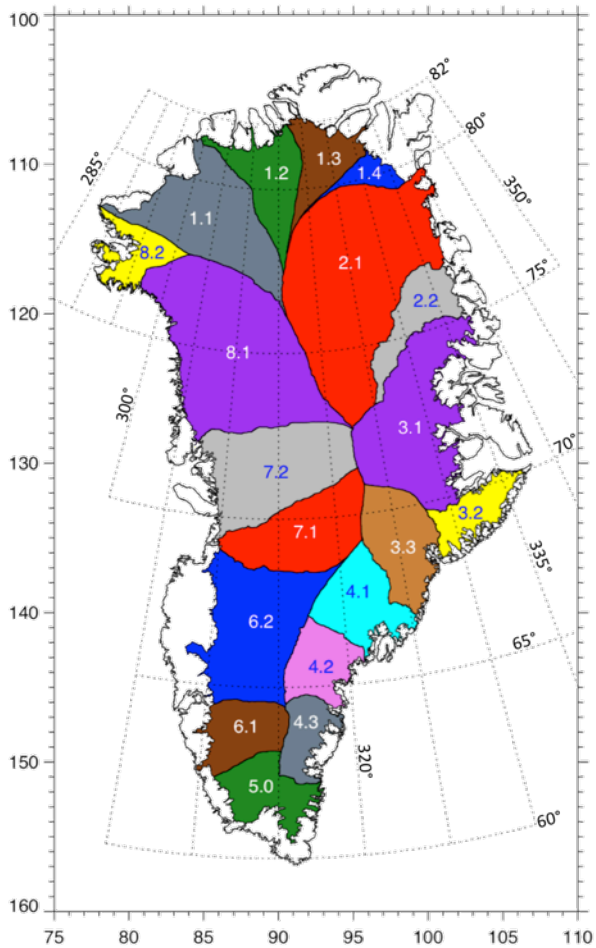
Discharge from the ice sheet is **not** a surface freshwater flux



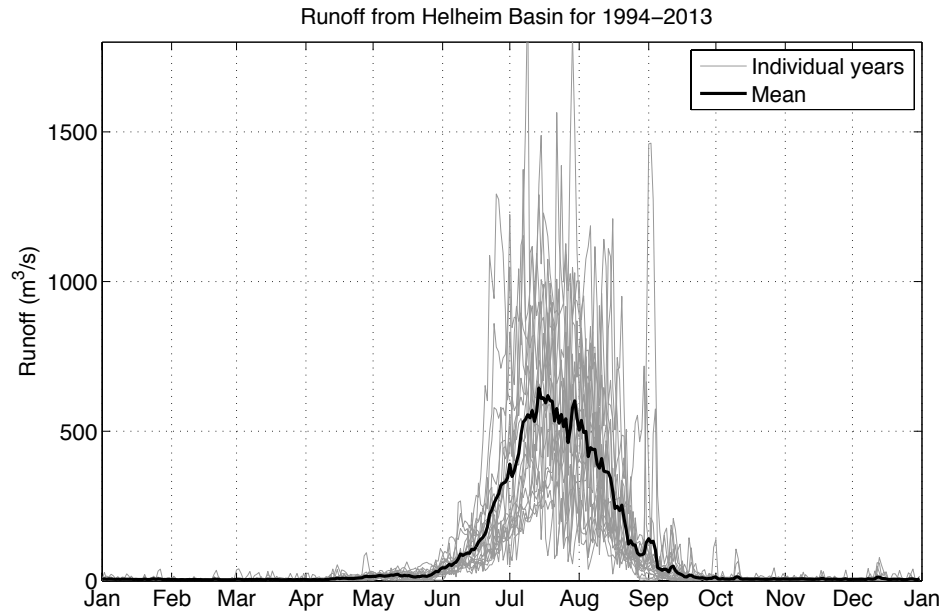
van den Broeke et al. 2009; Bamber et al. 2012; Enderlin et al. 2014

Discharge is highly seasonal and localized by drainage basins

Largest Drainage basins



Seasonal discharge from Helheim Basin
RACMO 2.3 Model

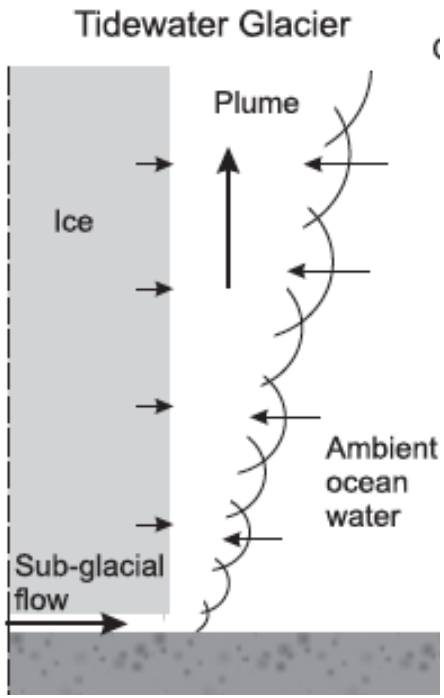


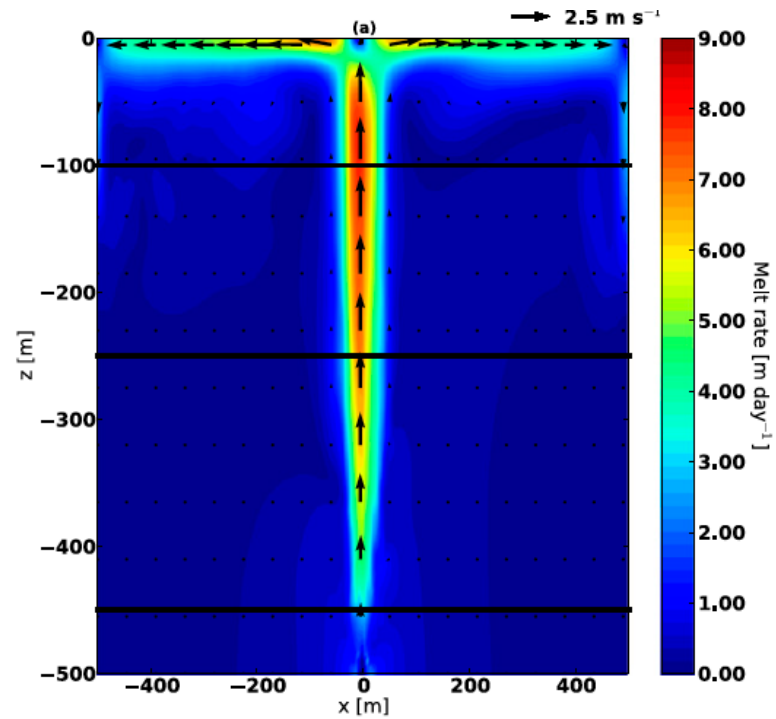
NASA ICESAT Data, van den Broeke et al. 2009; von Angelen et al. 2013

Significant amount discharged hundreds of meters below the surface

Subglacial discharge

Submarine melt of glaciers and icebergs

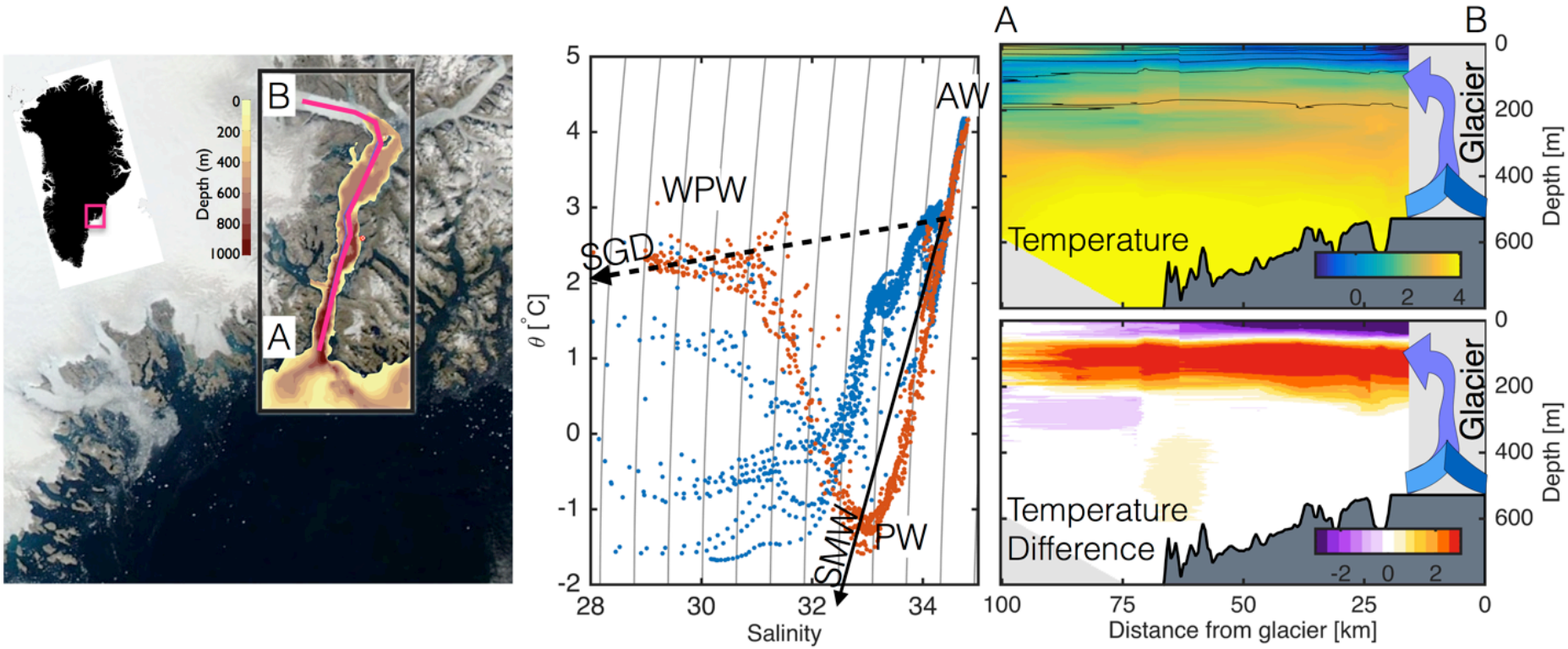




Kimura et al. 2015

Jenkins 2011;Straneo and Cenedese, 2015; Carroll et al. 2015; Stevens et al. 2015

Discharge at depth forms **glacially modified waters**

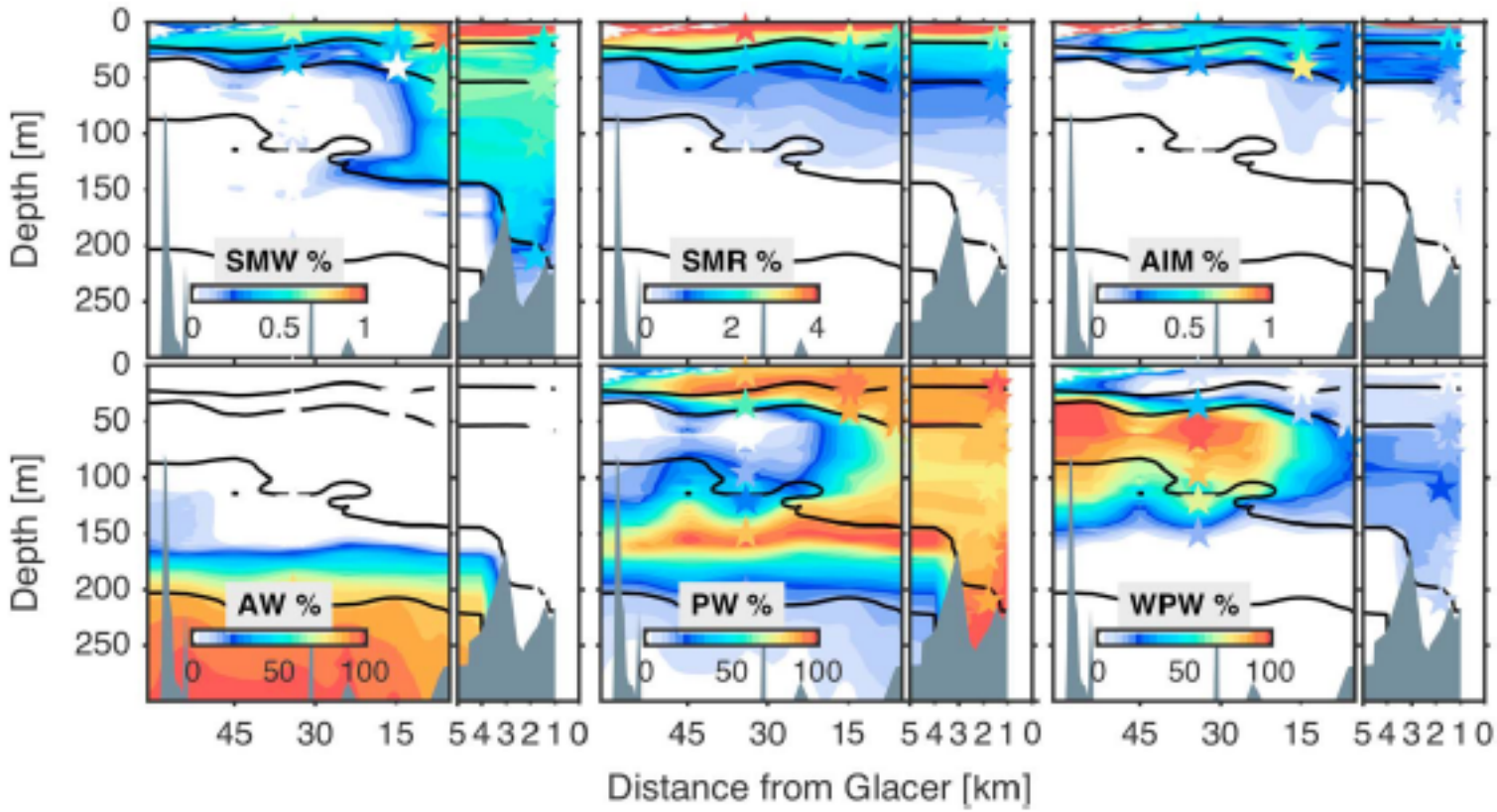


Land-Ice discharge at the head of the fjord → export of surface and subsurface water masses (not freshwater at the surface)

Straneo et al. 2011; Beaird and Straneo, in prep.

Tracers show that glacially modified waters contain less than 1-4% meltwater

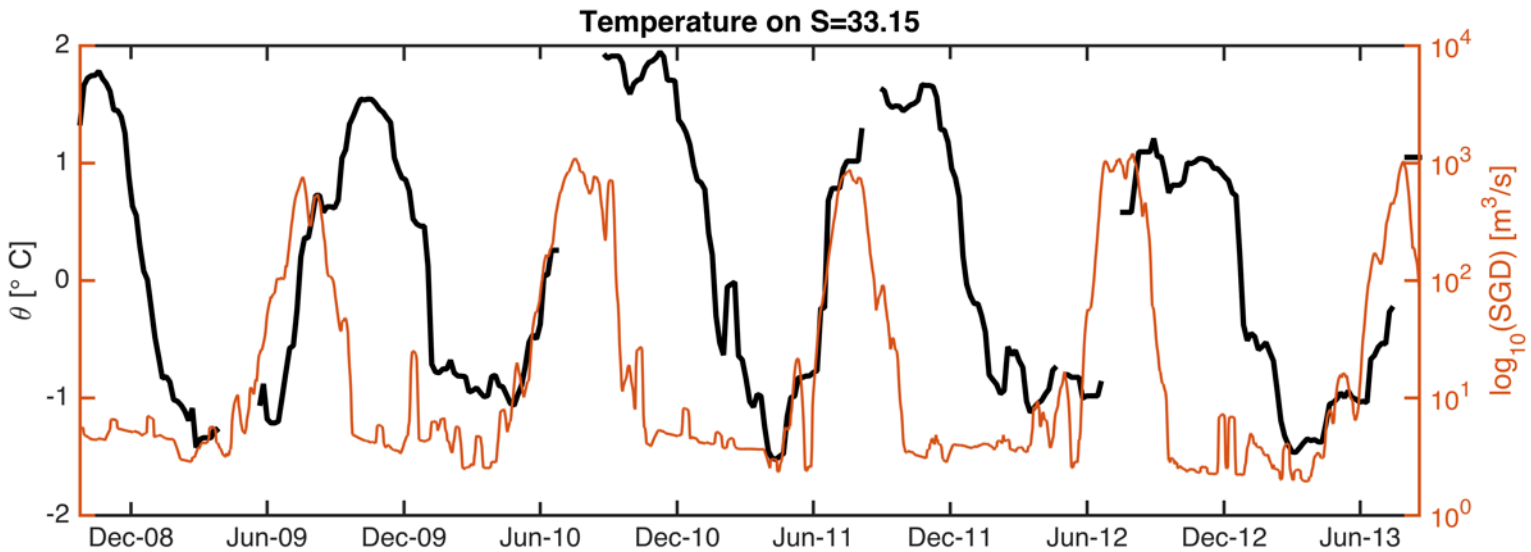
→ Volume of transformed waters about 30-100 times glacial input



Beaird, Straneo and Jenkins, 2015, GRL

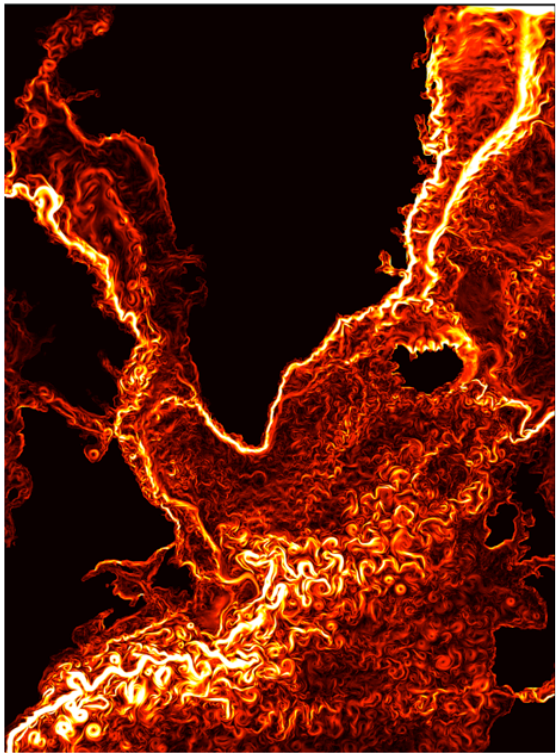
Export of glacially modified waters onto shelf is lagged with respect to land-ice input (fjord dynamics)

Glacial meltwater observed from moorings in Sermilik Fjord, SE Greenland



Beaird and Straneo, in prep.

Relevance to climate models: ice sheet forces ocean



Target – Improved boundary conditions for ocean models

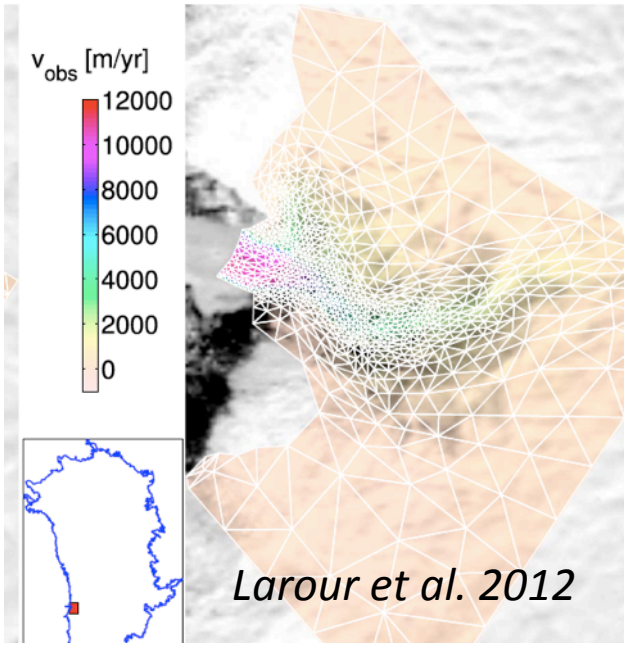
1. Localized, seasonal discharge

2. Separation into different components

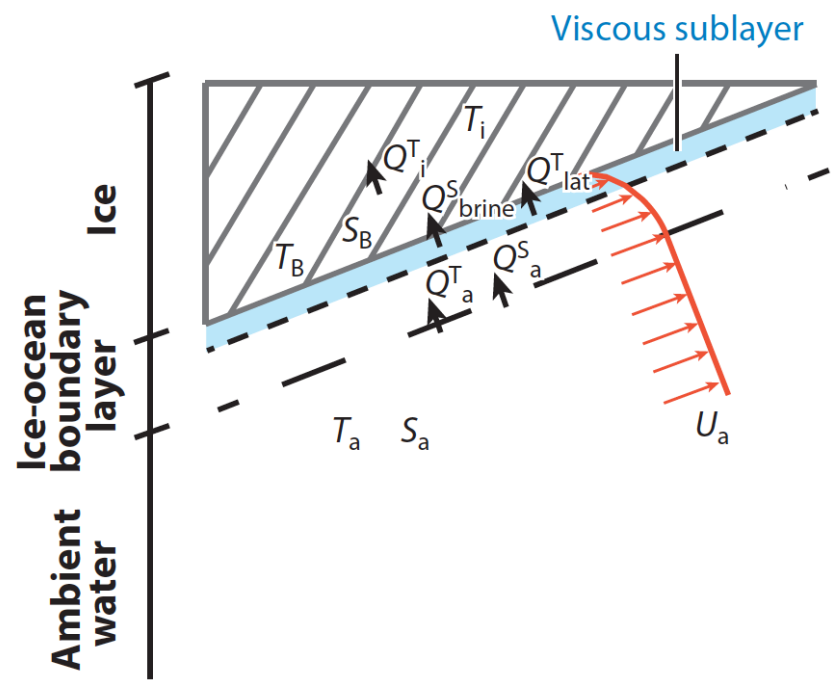
3. Parameterization Plume Dynamics: Transformation of discharge based on plume dynamics, laboratory, and numerical simulations → GMW formation

4. Parameterization: Fjord dynamics that governs the timing of the export of glacially modified waters

Relevance to climate models: Ocean forces ice sheet



*Ice sheet models need submarine melt rates → SMR (**x**,t)*

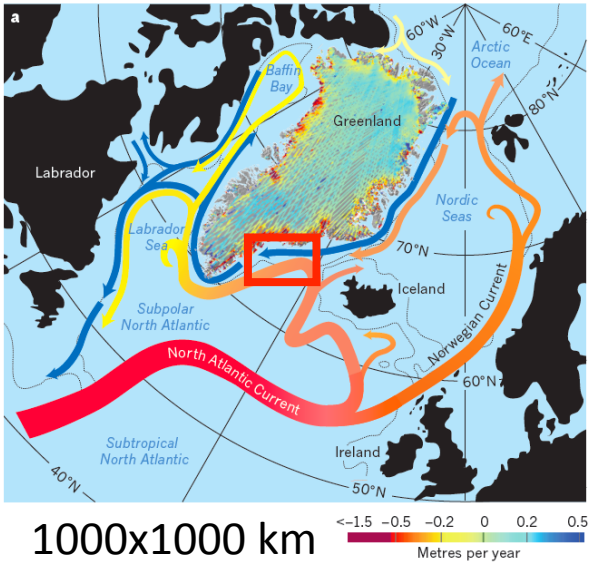


Ice/Ocean Boundary Layer Parameterization

$$SMR(\mathbf{x},t) = f(U_A, \vartheta_A)$$

Hellmer and Olbers, 1989; Holland and Jenkins 1999; Jenkins et al. 2010

A hierarchy of scales and processes



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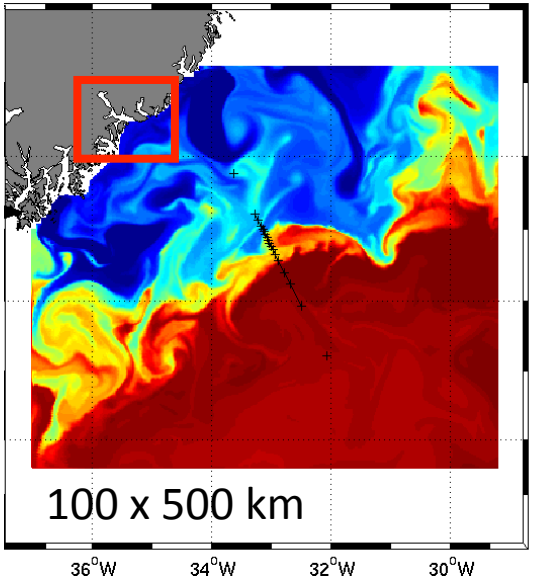

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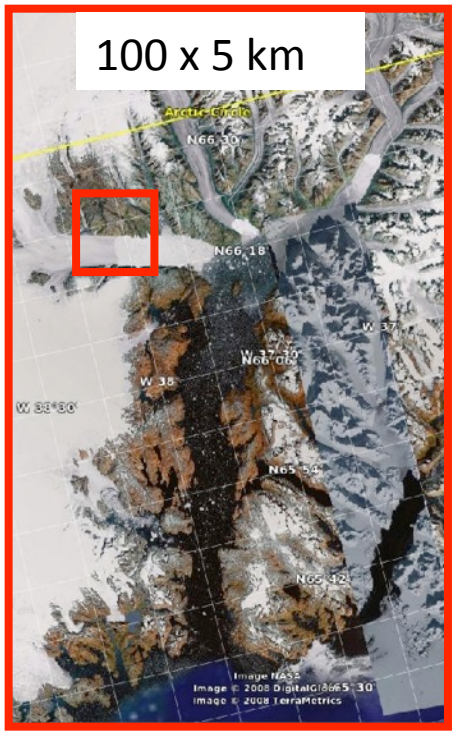

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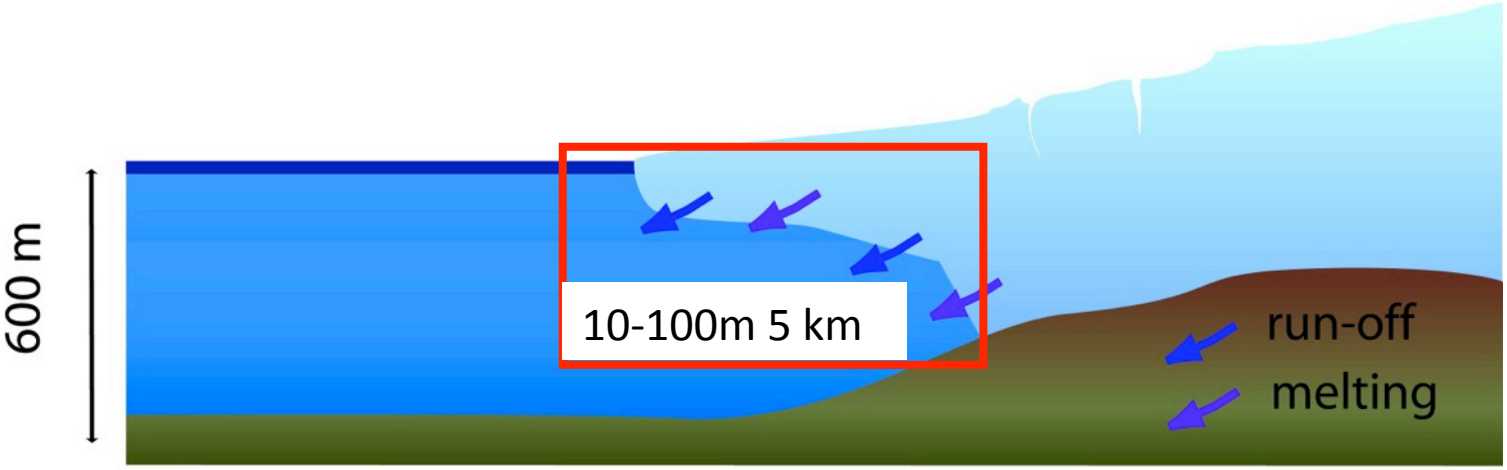
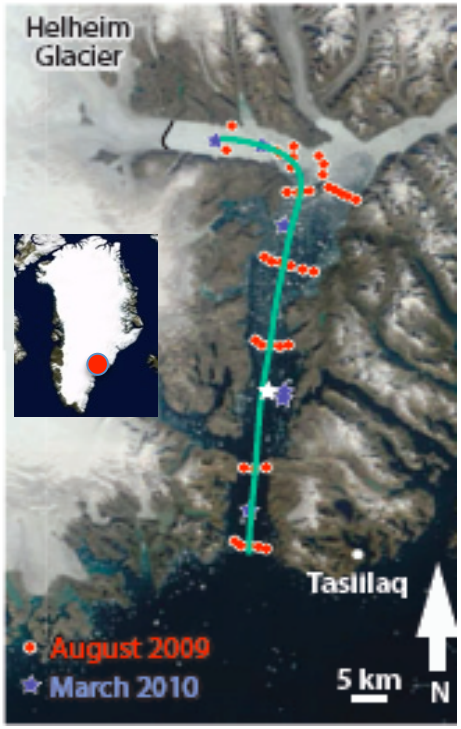
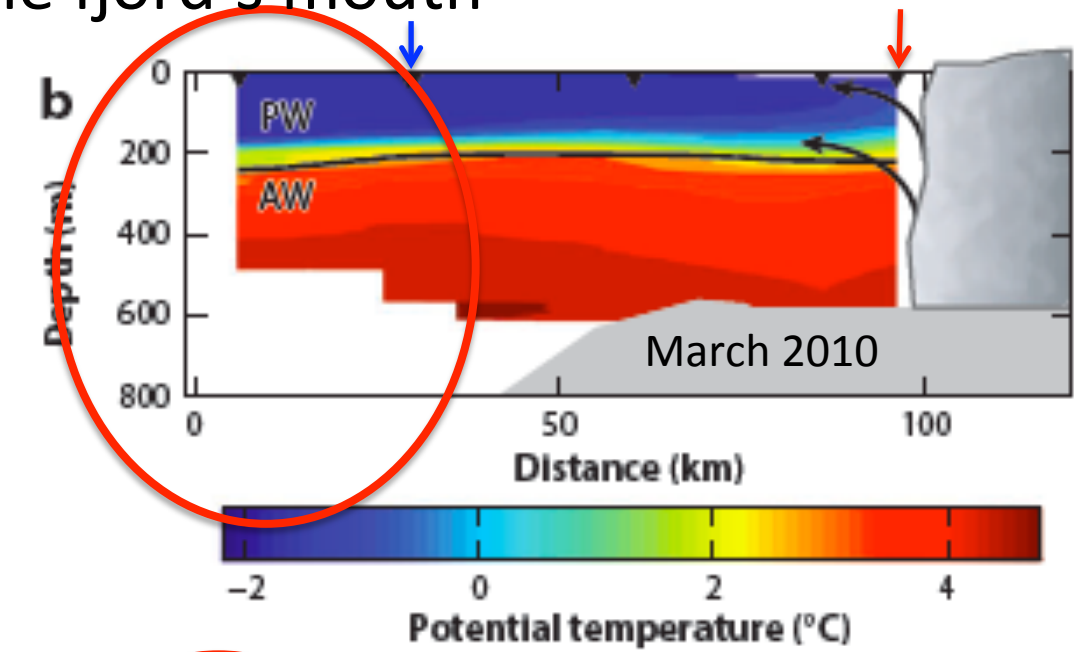
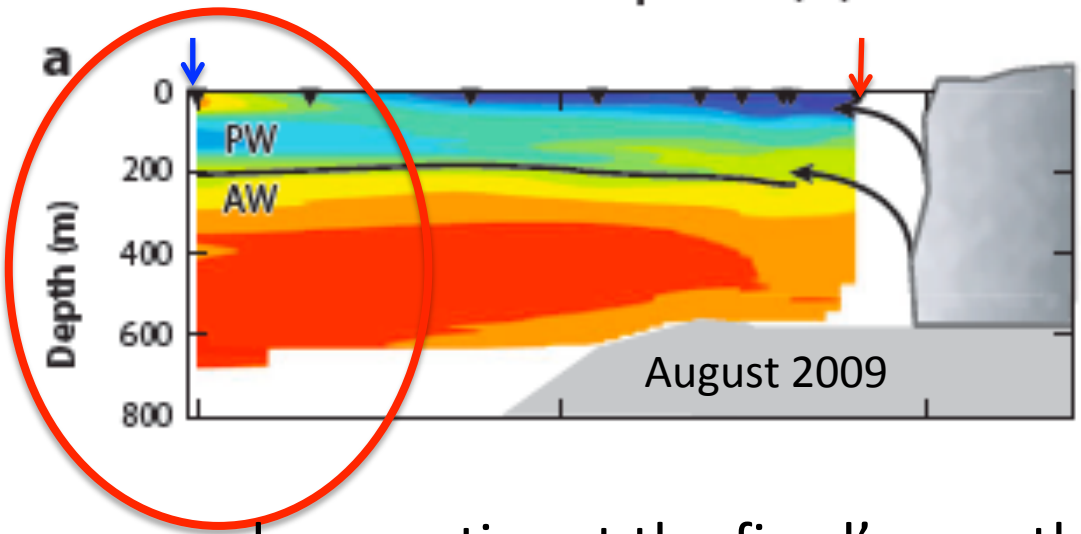


50-100 km

Water properties at the fjord's mouth

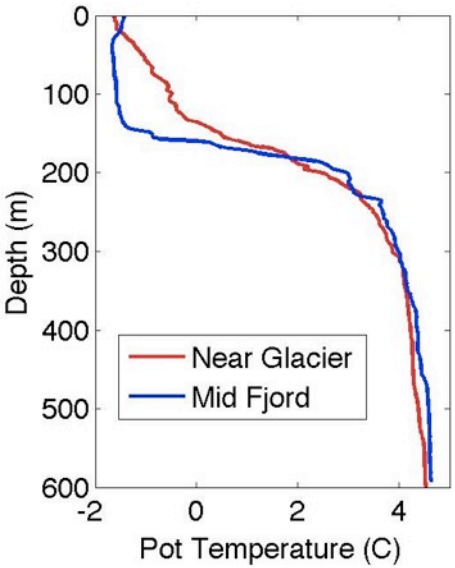


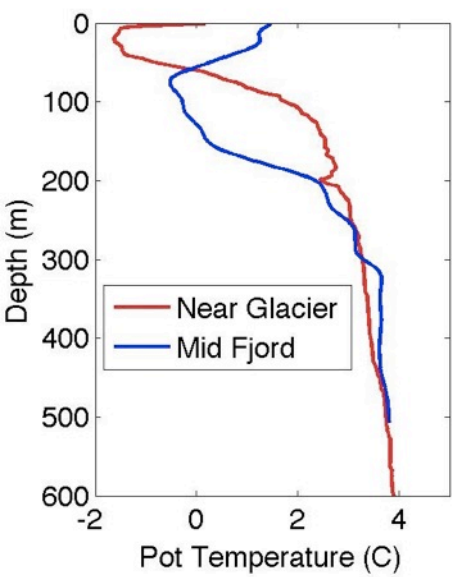


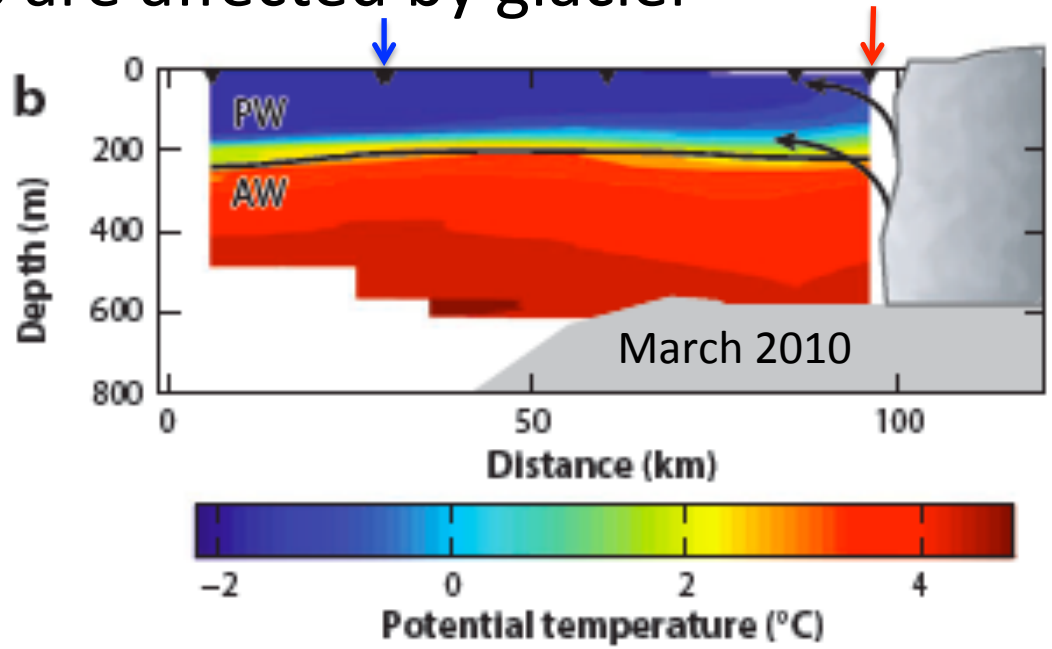


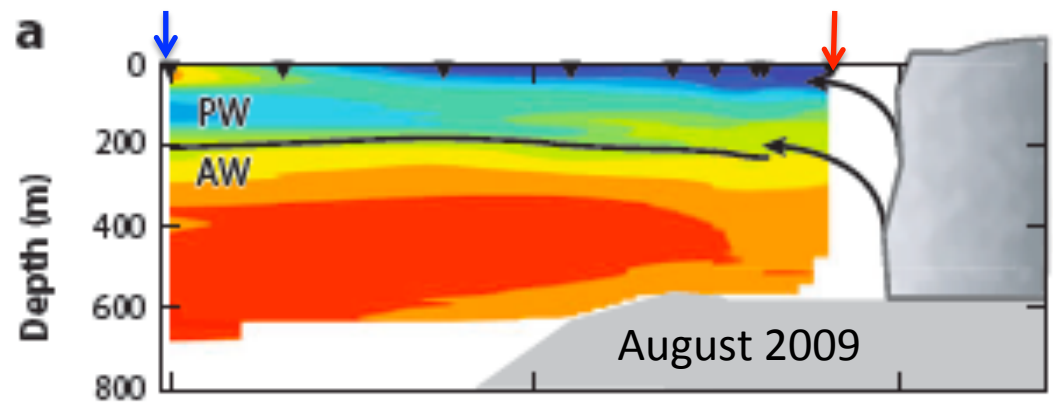
Link between shelf processes and properties at the fjord's mouth

Near glacier properties are affected by glacier



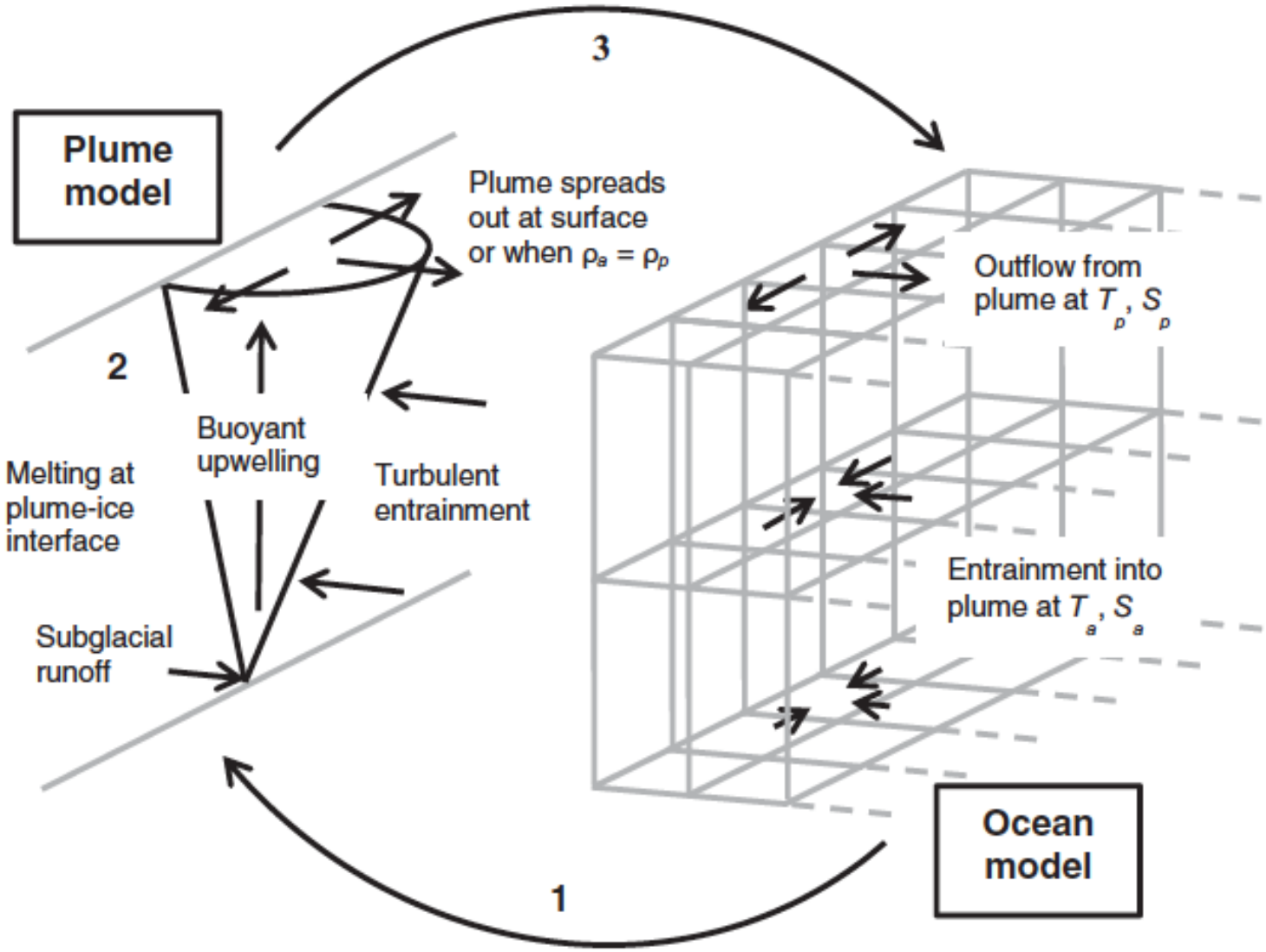






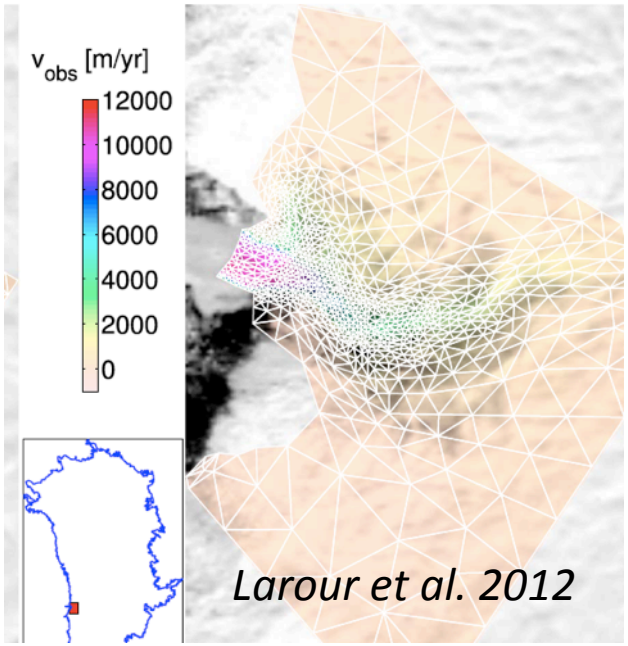
Implication → ice/ocean exchange must be resolved or parameterized in the model

Parameterization of plumes



Cowton et al. 2015; Carroll et al. 2015; Straneo and Cenedese, 2015

Submarine Melting of glacier



*Ice sheet models need submarine melt rates → SMR (**x**,t)*

$$SMR(\mathbf{x},t) = f(U_A, \vartheta_A)$$

Steps to provide SMR

1. Large scale model provides properties on shelf near fjord mouth

2. Fjord/shelf exchange either resolved or parameterized

3. Plumes at ice edge parameterized to provide properties at the ice edge → submarine melt rates

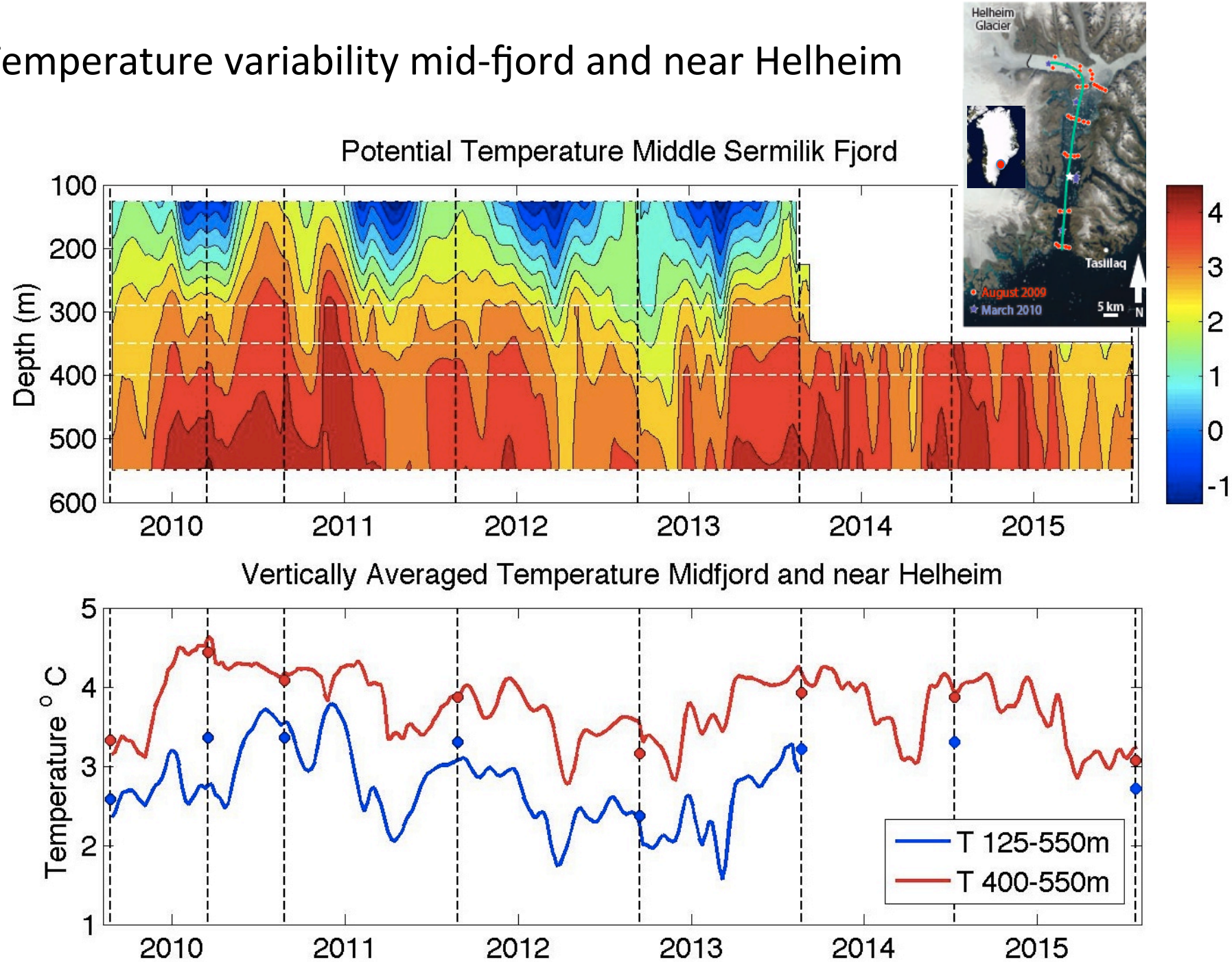
Land-ice/Ocean exchanges are absent or poorly represented ice sheet, ocean and climate models

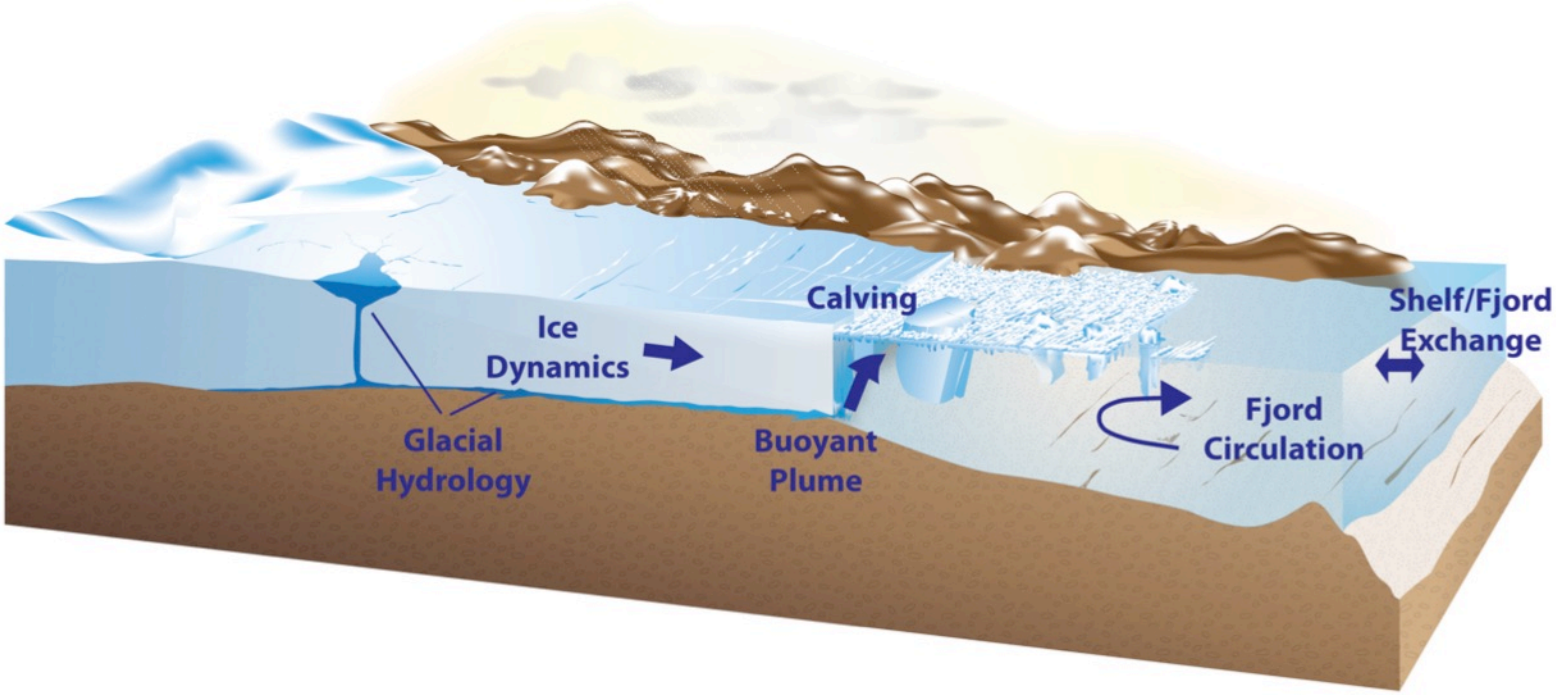
→Even though we need to predict ice sheet variability and its impact on the climate system

Good News – Considerable progress in understanding
– fjord, ice/ocean exchanges, plume dynamics

Parameterizations needed for glacier/ocean exchanges (improved boundary layer, plumes) and fjord transformation

Temperature variability mid-fjord and near Helheim




Calving
Ice
Dynamics
Shelf/Fjord
Exchange
Fjord
Circulation
Glacial
Hydrology
Buoyant
Plume