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Greenland glacier retreat: drivers and impacts on the ocean and sea level

Prof. Fiamma Straneo
Scripps Institution of Oceanography
University of California San Diego

Sea Level Rise is one major consequence of climate change

150 Million People live within 1 m of sea level rise

Photo Credit: New Scientist, Jan 6, 2020

Anthoff et al. 2016

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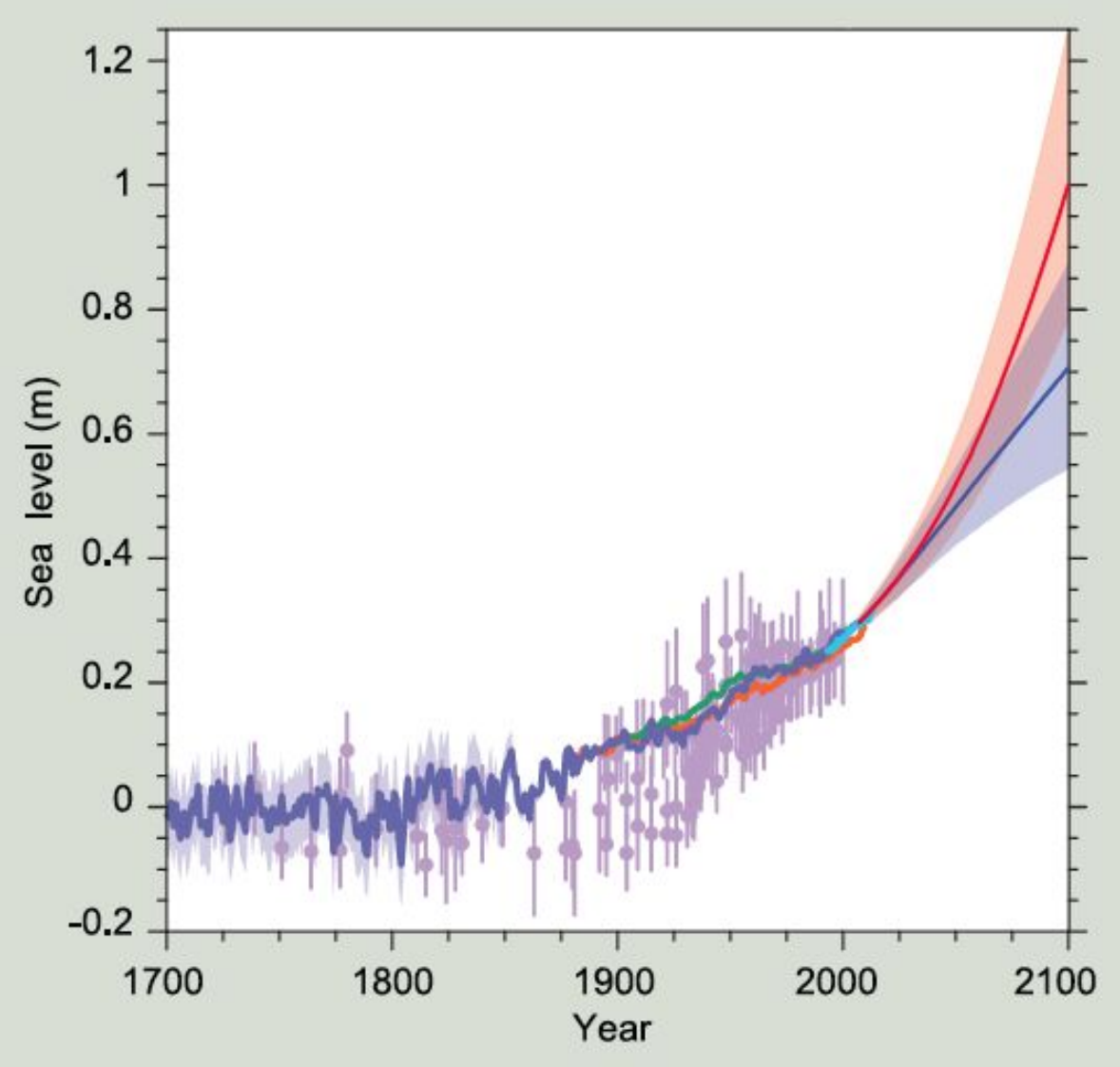
Past, Present and Future Global Sea Level Rise



High-Emission Scenario

Low Emission Scenario

Church et al., IPCC, 2013

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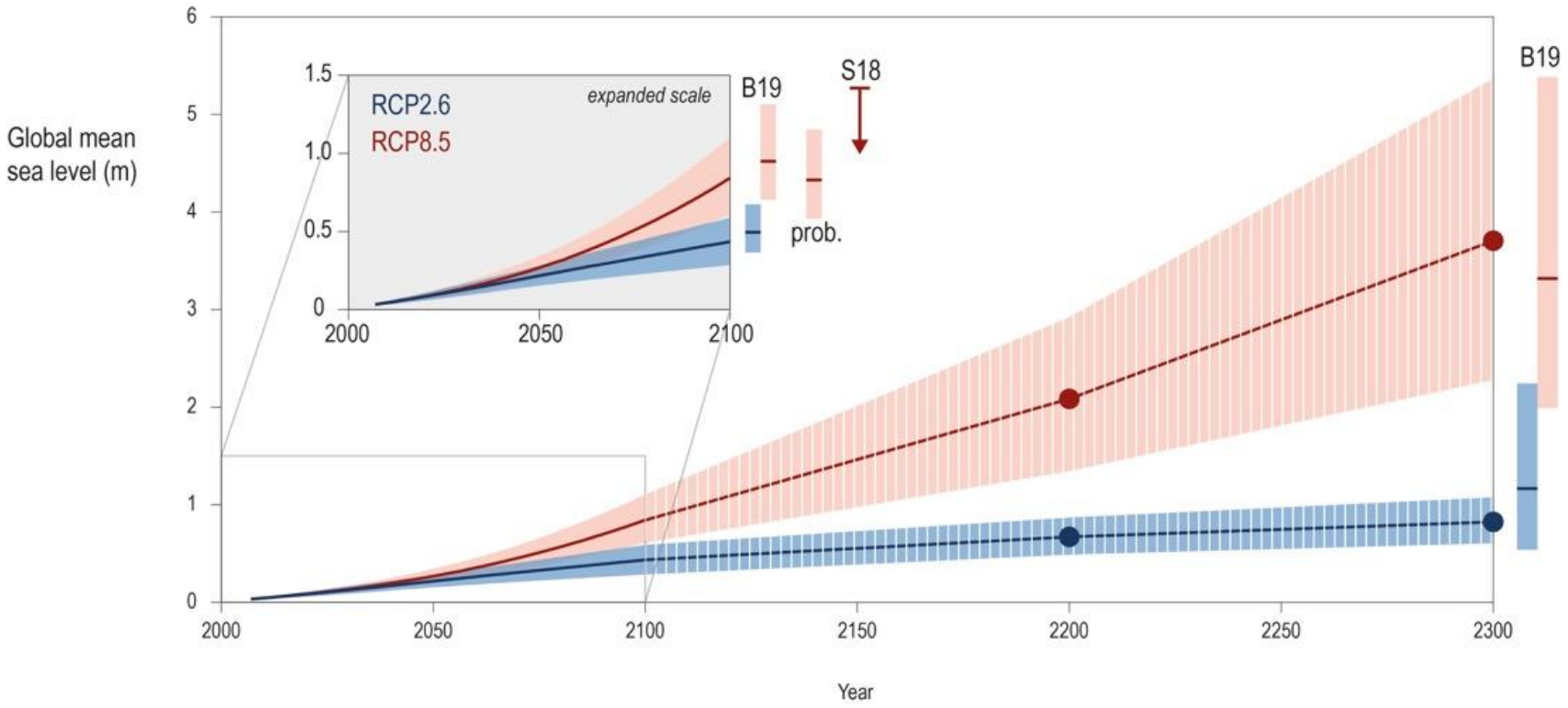
Long-Term Future
Global Sea Level Rise



High-Emission Scenario

Low Emission Scenario

Oppenheimer, SROCC, 2019

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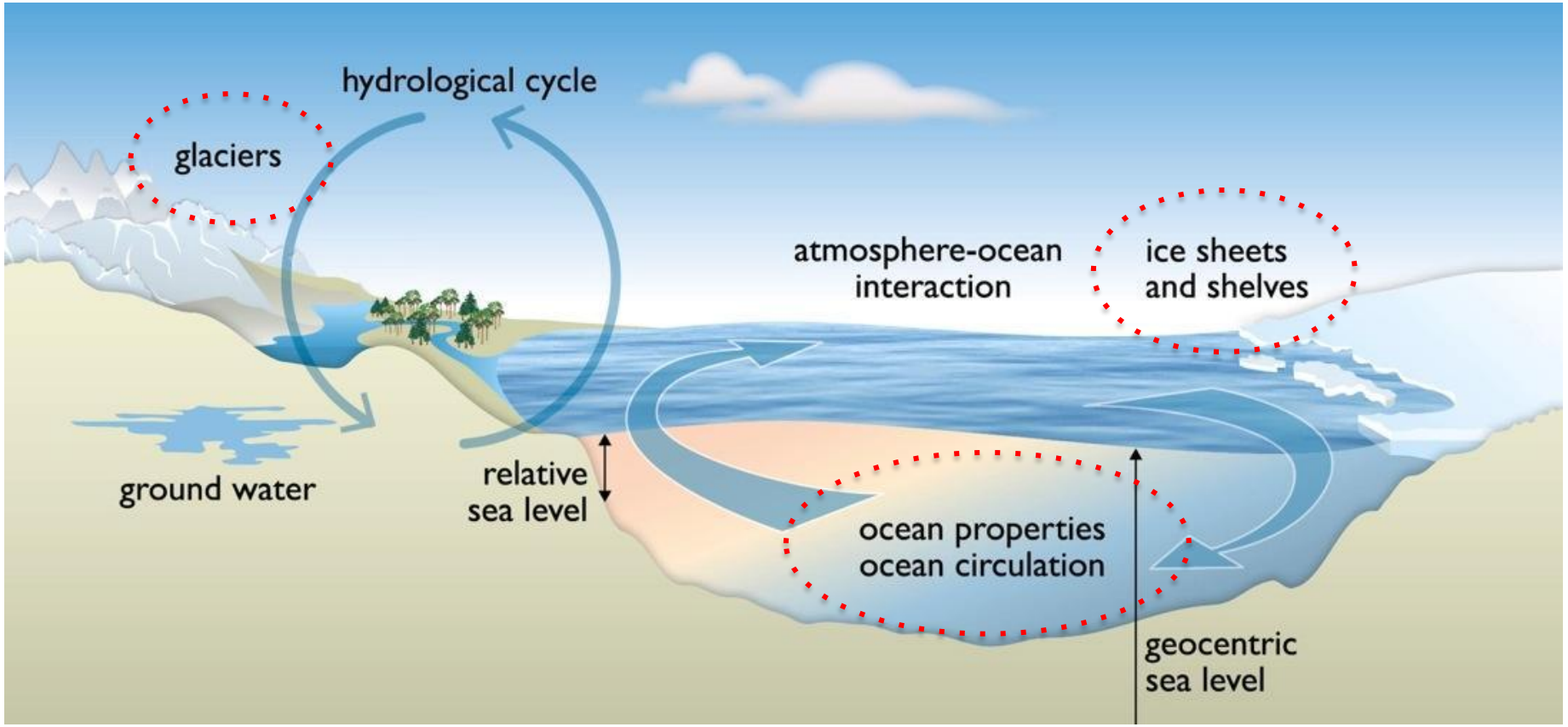
Processes affecting Sea Level Rise



Present global SLR 3.6 mm/yr

-50-60% land ice
- 40-50 % ocean thermal expansion

Church et al., IPCC, 2013; Oppenheimer, SROCC, 2019

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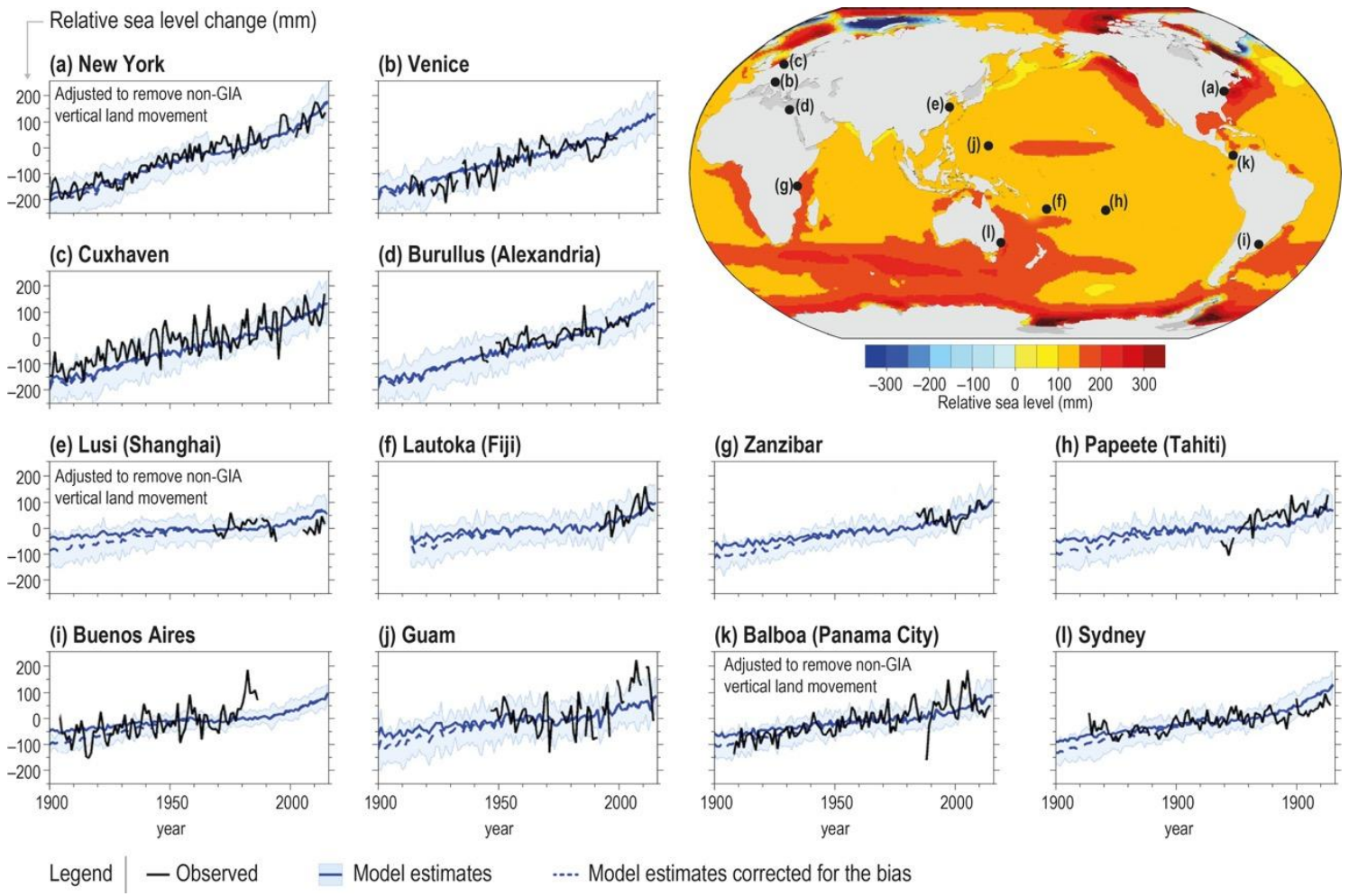
Regional Sea Level Rise



Oppenheimer et al. 2019, SROCC

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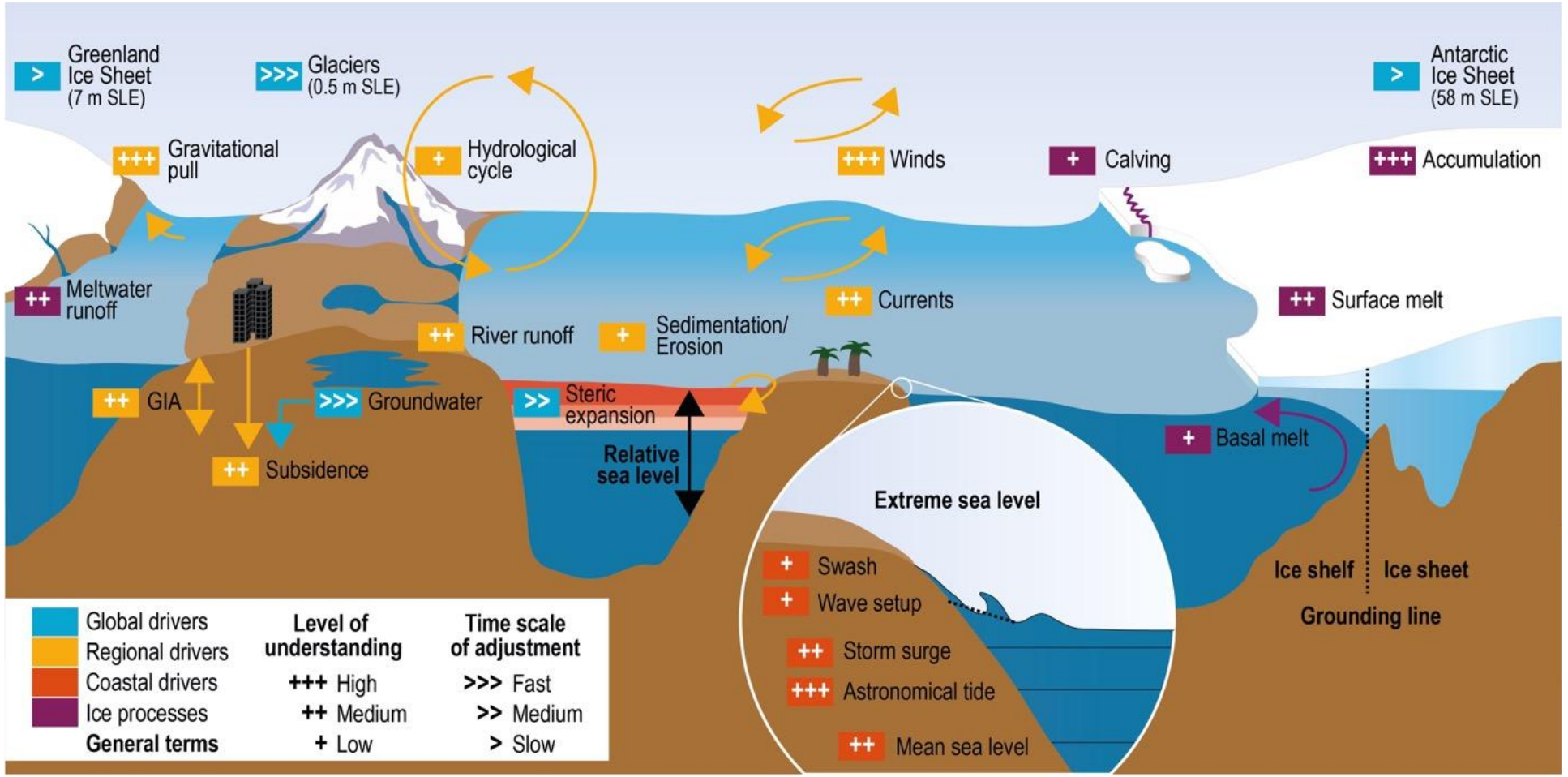
Details: processes affecting Sea Level Rise



Oppenheimer et al. 2019, SROCC

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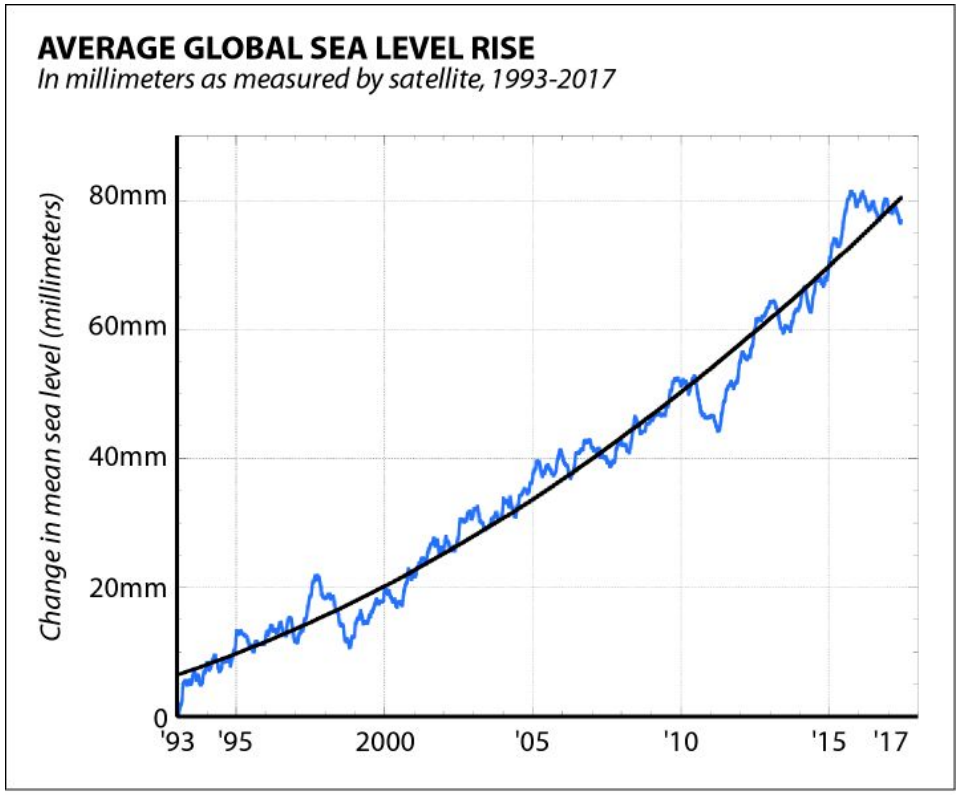
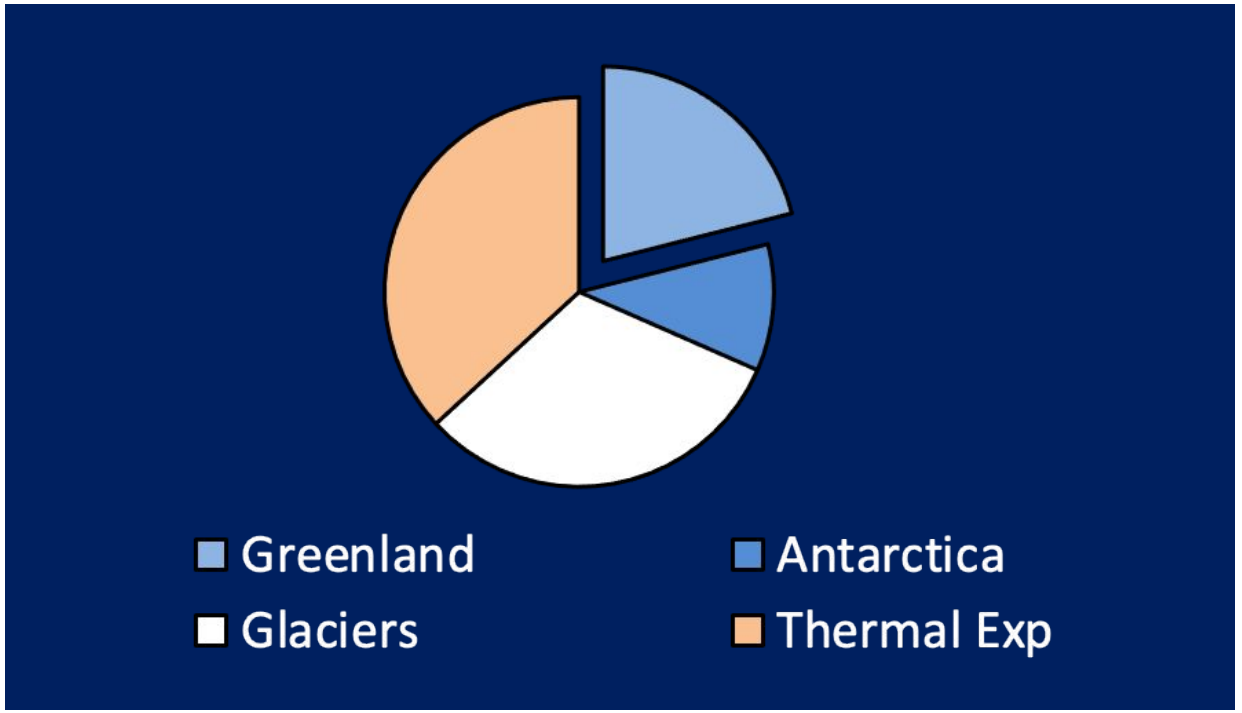
Ice Sheets are a major contributor to global sea level rise

Global Sea Level Rise 1993-2017



Contributions since 2000



Chambers et al., 2017

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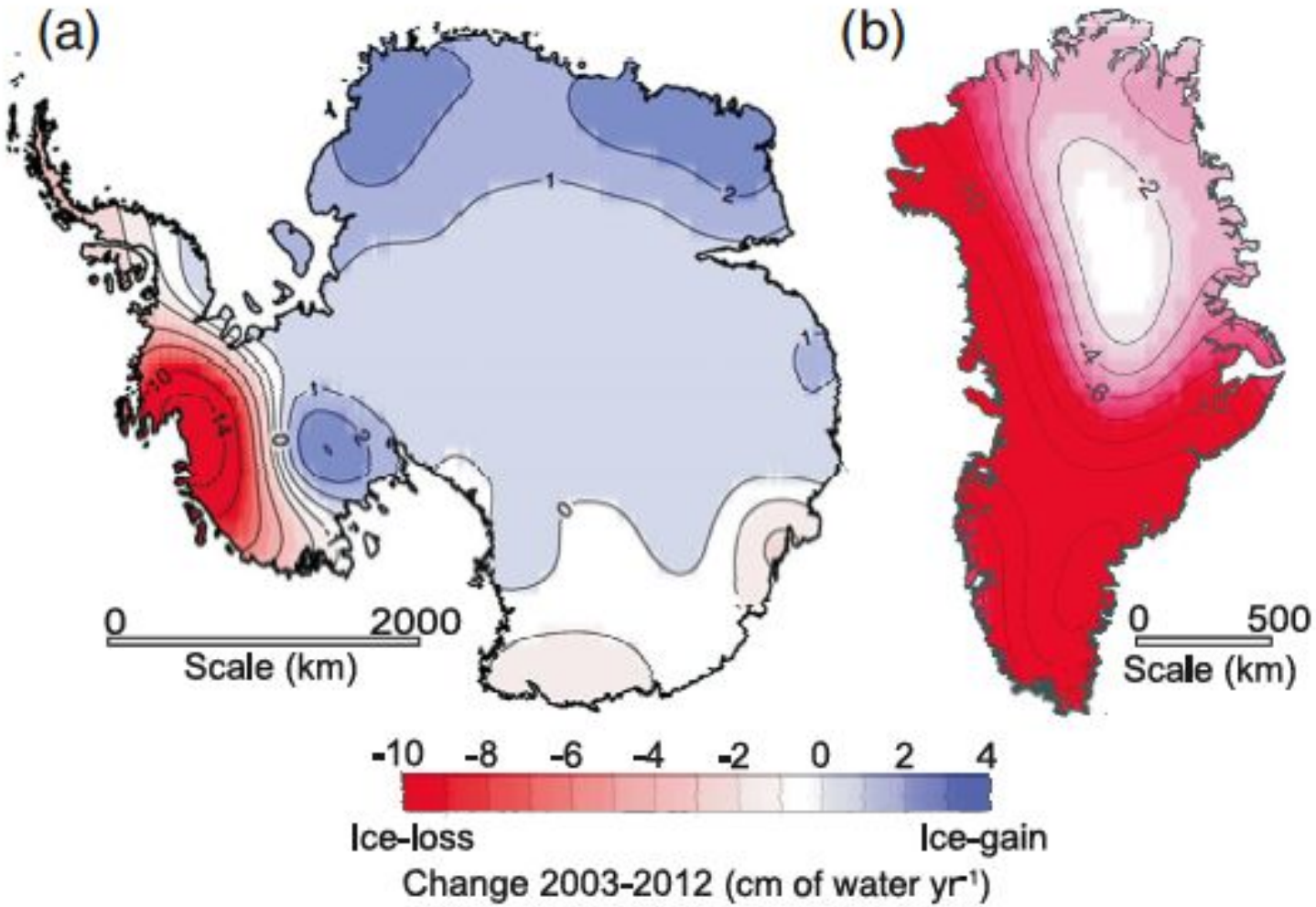
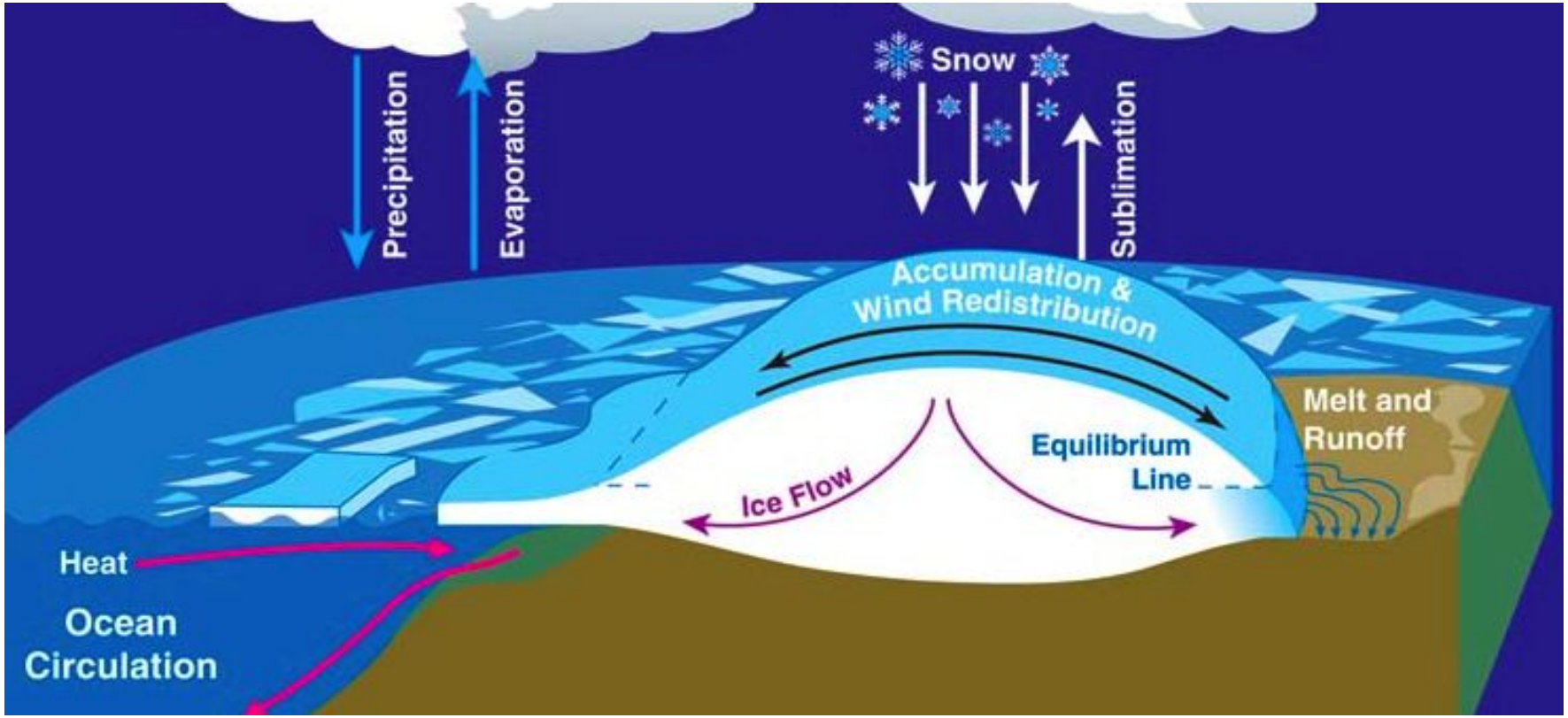


Vaughan et al., IPCC, 2013

Mass Balance for an Ice Sheet (Greenland or Antarctica)



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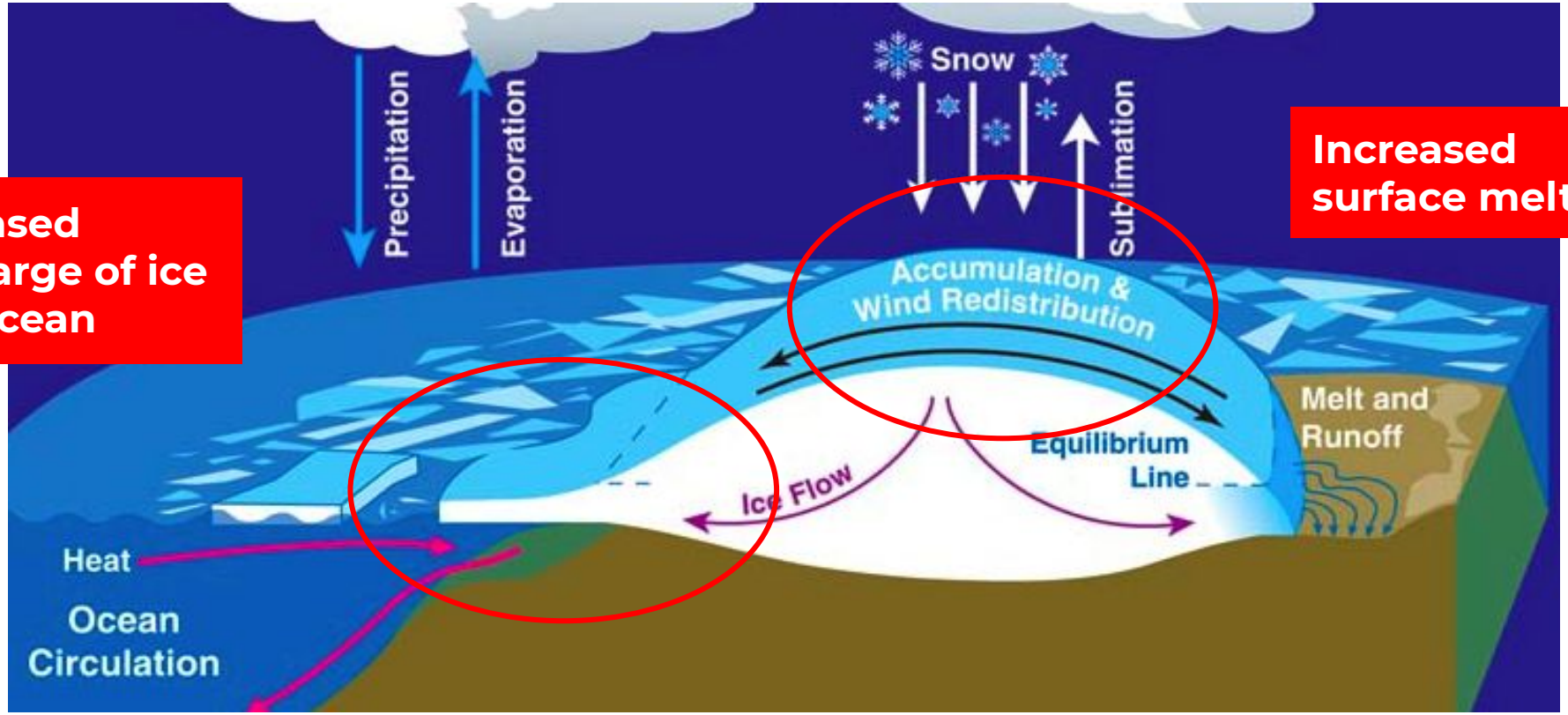
Mass Balance for an Ice Sheet (Greenland or Antarctica)



Increased discharge of ice into ocean

Increased surface melt

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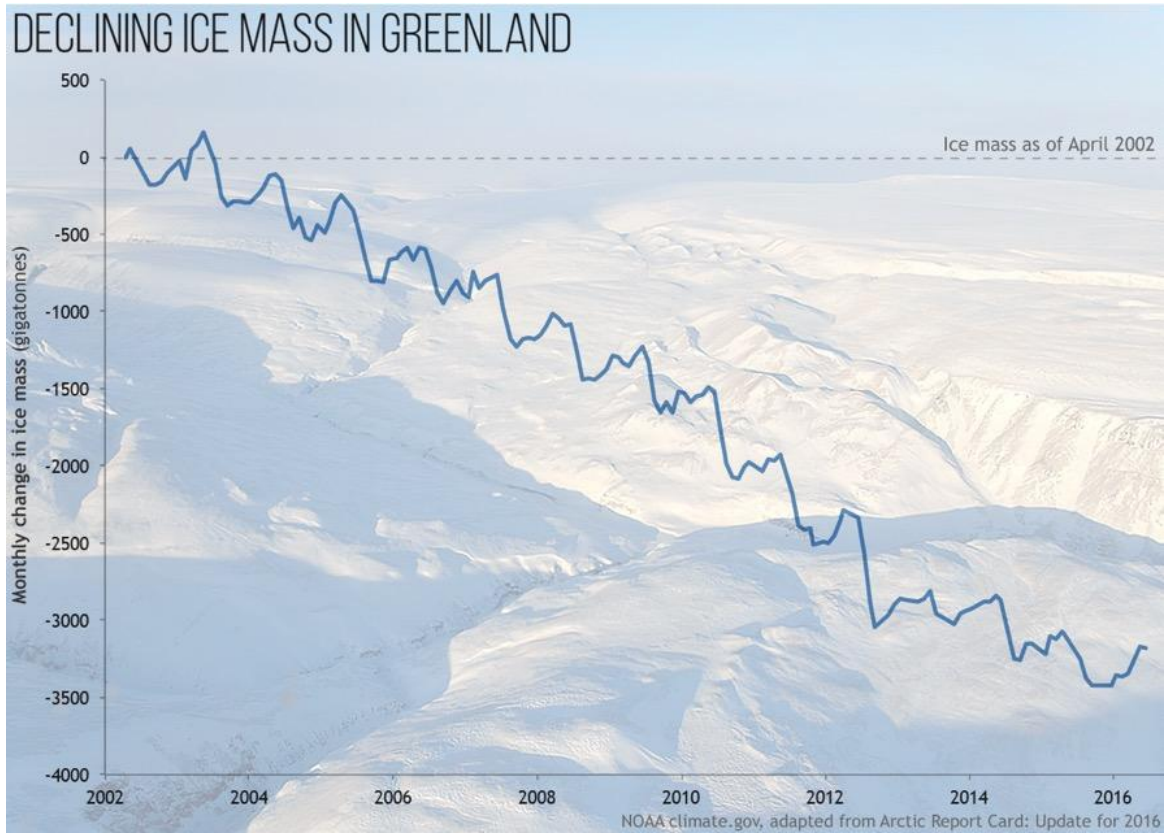
Greenland has lost 5000 Gigatons of ice since 1972

➡ Sea Level Rise of 13.7 mm



Ice Loss is due to:
60% increased ice discharge (dynamic change)

40% increased surface melt

Mouginot et al. 2019

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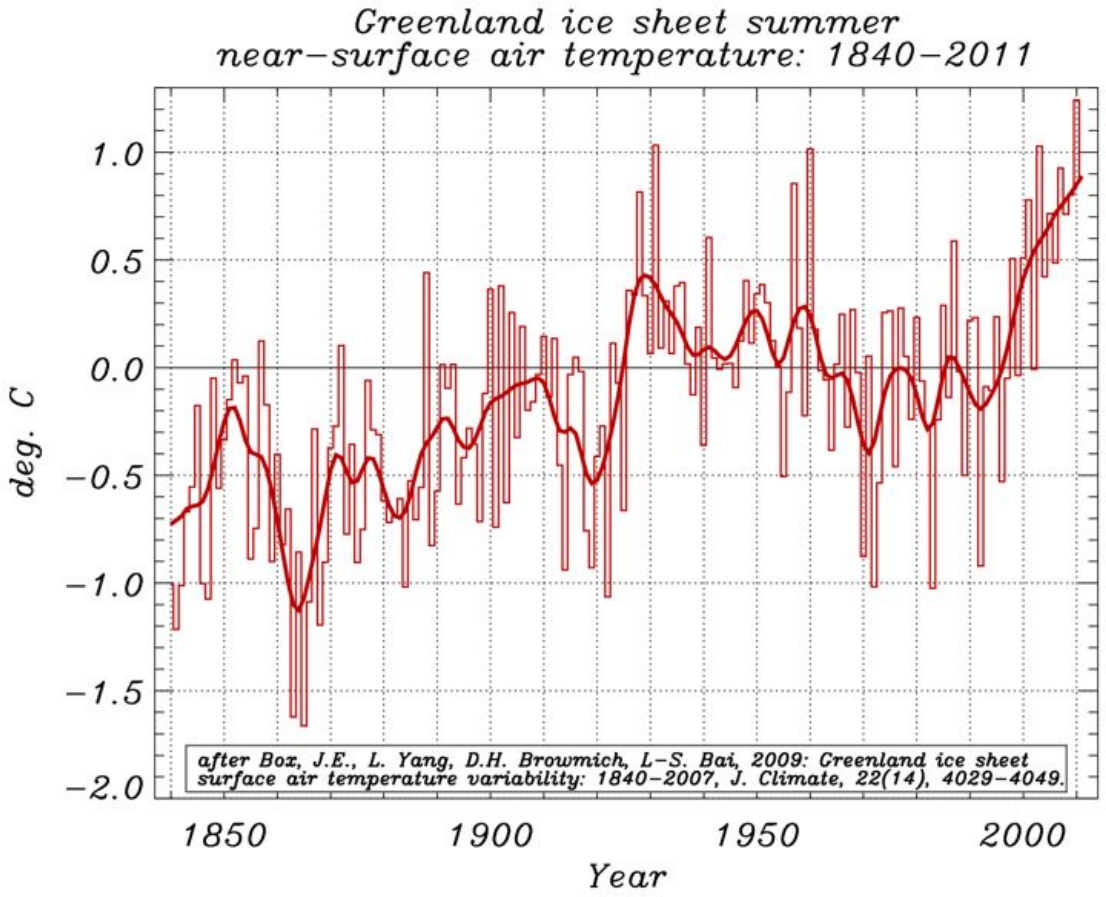
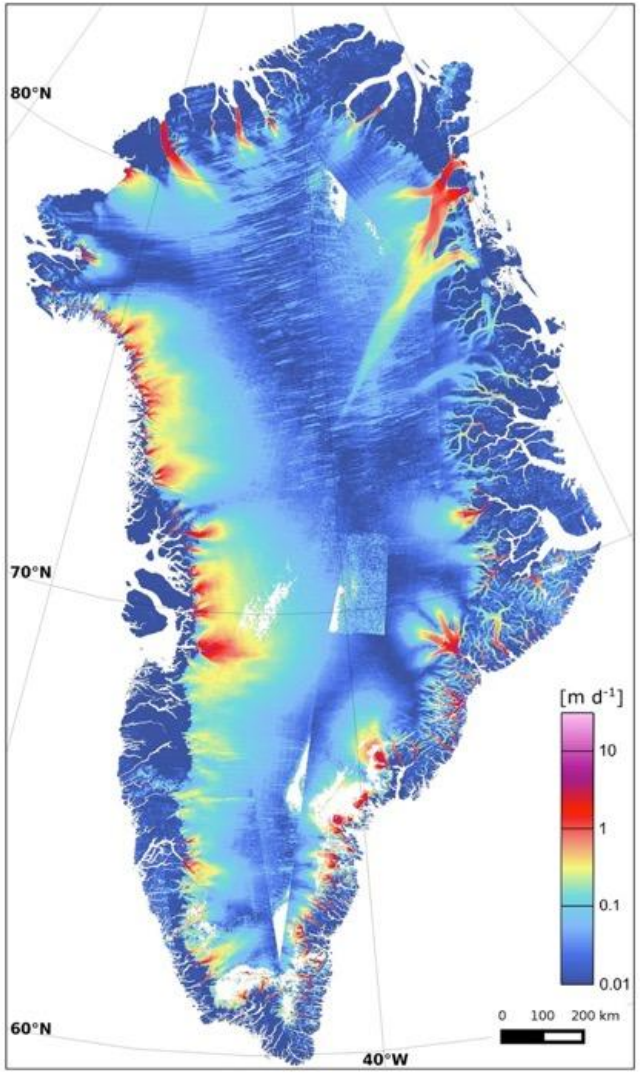
Greenland Ice Loss: increased surface melt



Tedesco et al. 2013; Box et al. 2009; van den Broeke et al. 2009; Enderlin et al. 2014

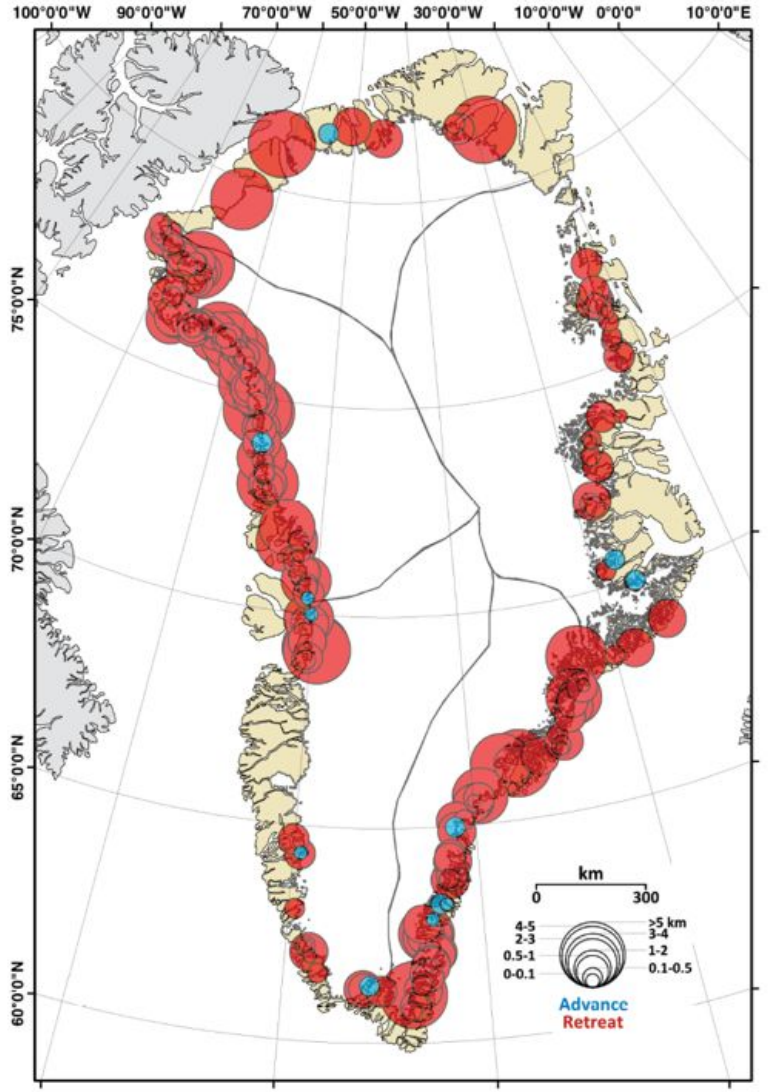
Ice loss from dynamic changes

Ice velocity



Source: ESA

Glacier retreat



Murray et al. 2015

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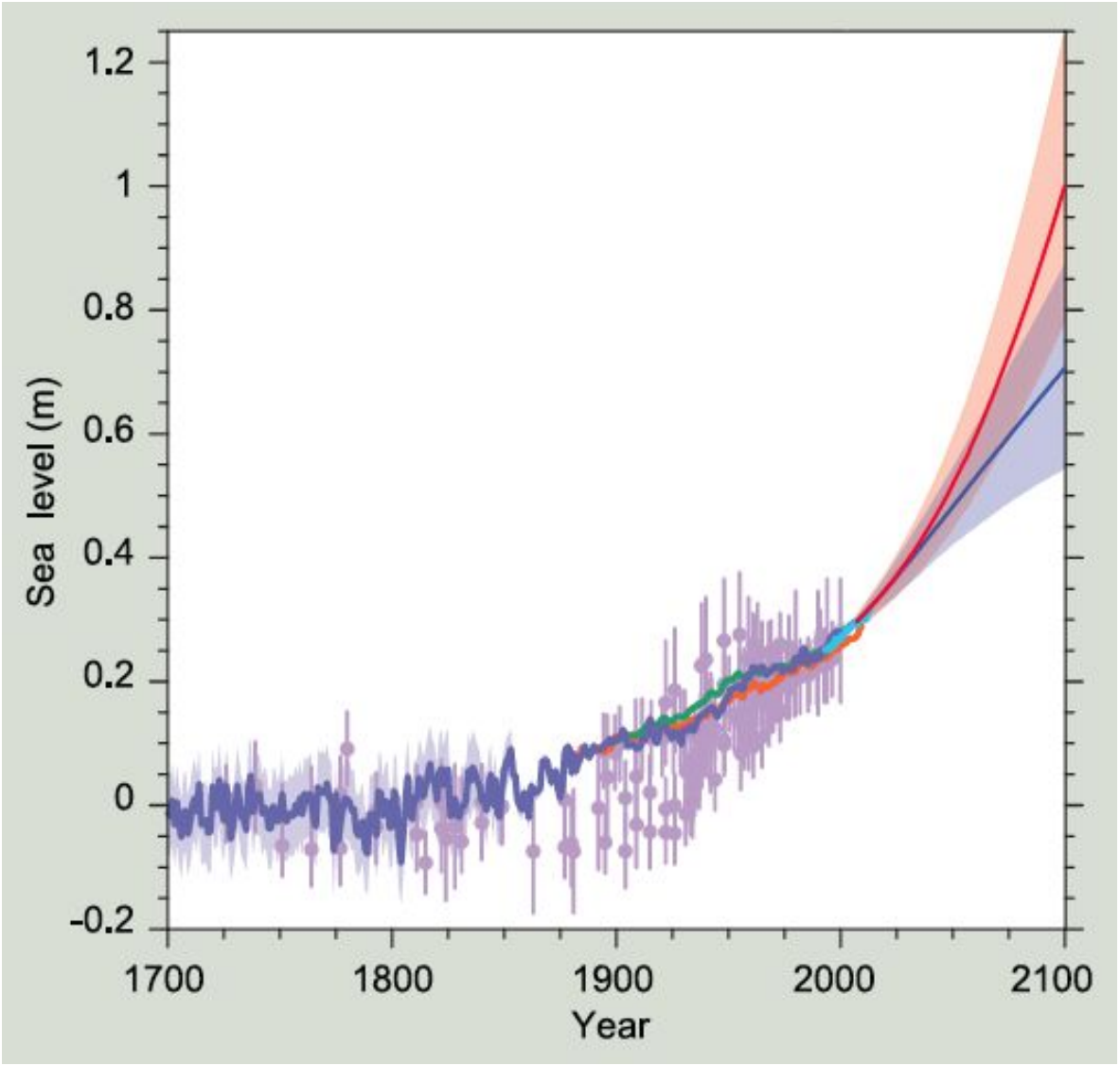
Dynamic changes are not represented in climate models



High-Emission Scenario

Low Emission Scenario

Church et al., IPCC, 2013

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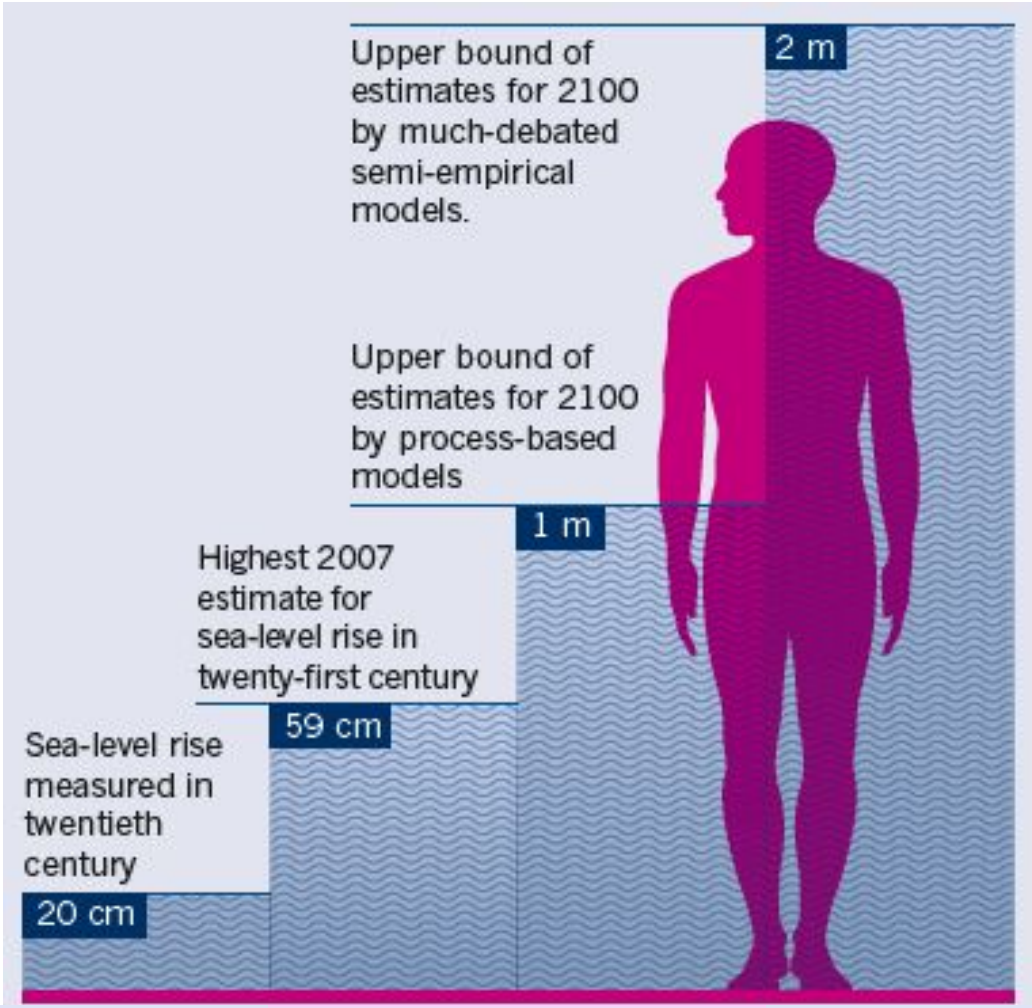
Dynamic changes of ice sheets: a relatively new problem



IPCC, Reports

1990
No mention

1995
High risk/low probability

2001
Important

2007
Major uncertainty

2013
Incomplete, missing in models

Nature Editorial, 2013

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July 2008, Tasiilaq, Greenland
Photo: Nick Cobbing

July 2008, Tasiilaq, Greenland

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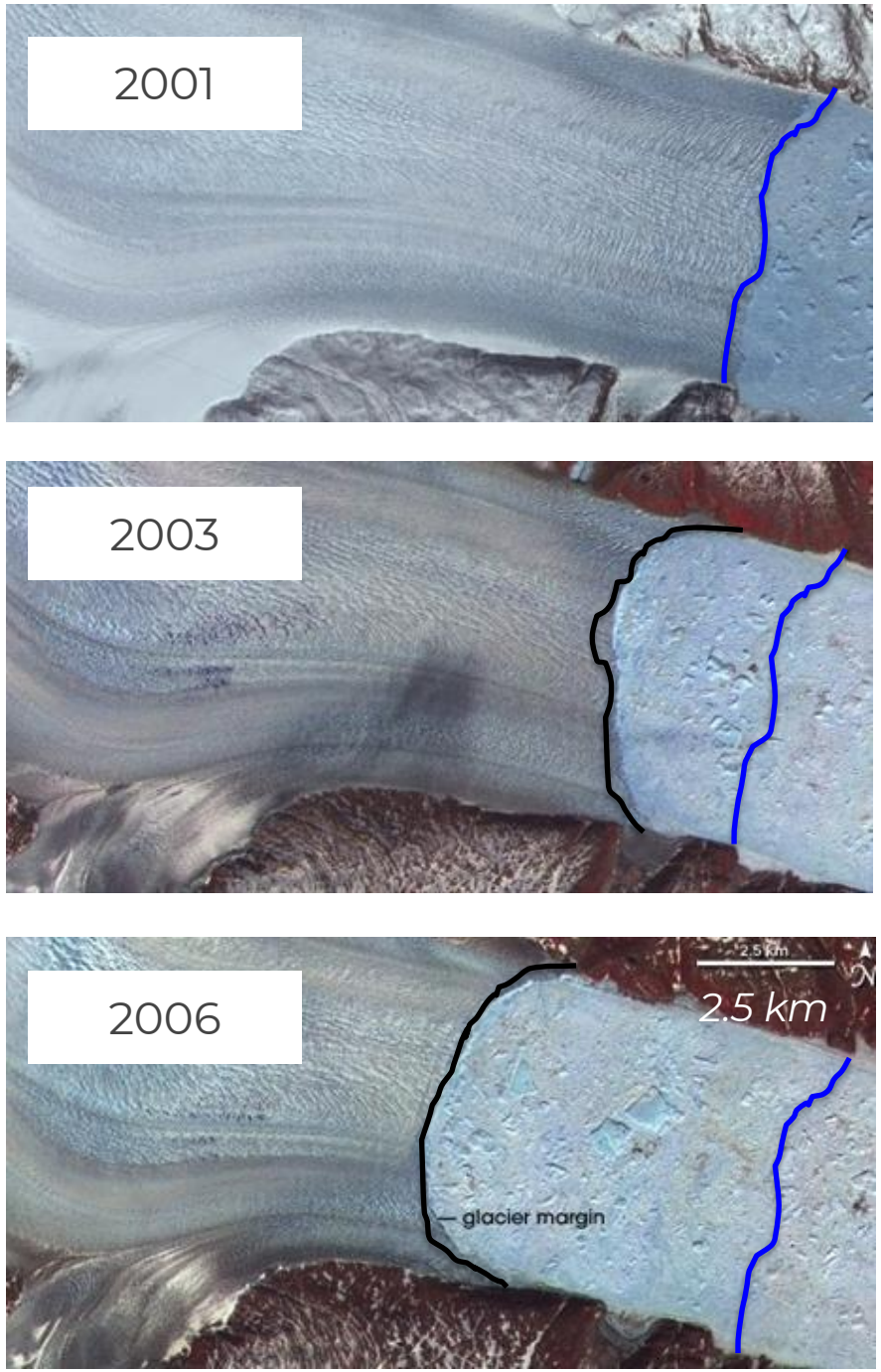
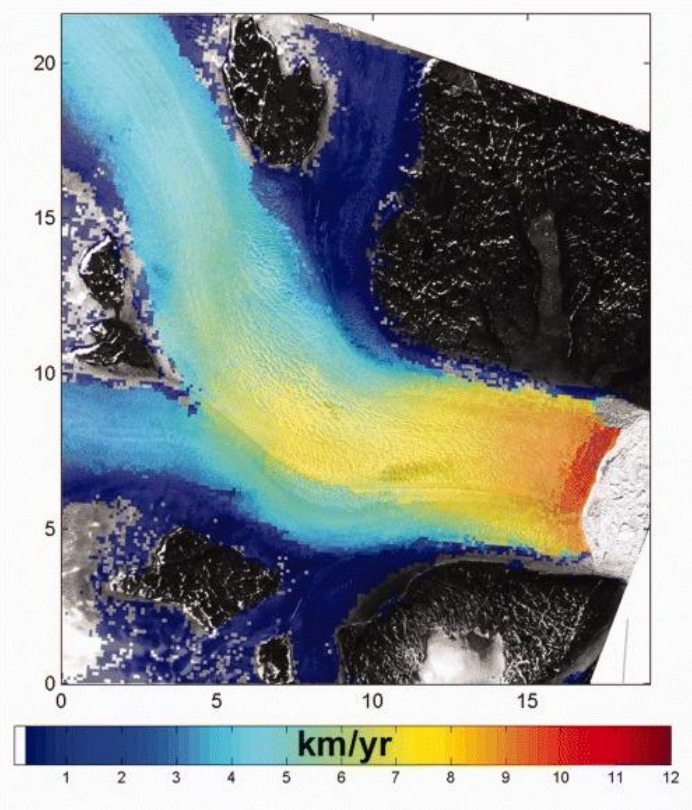
Retreat and speed up of Helheim Glacier



Source: NASA



Enderlin et al 2014

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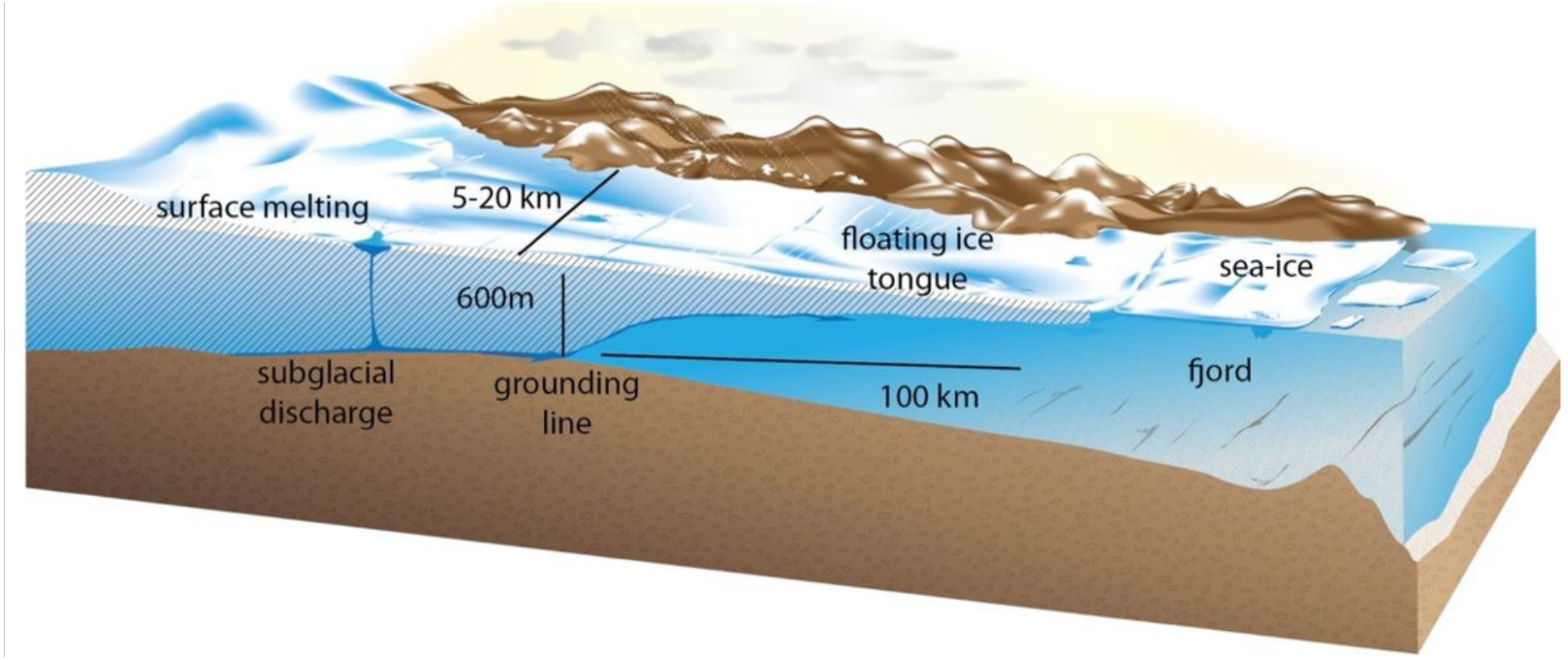
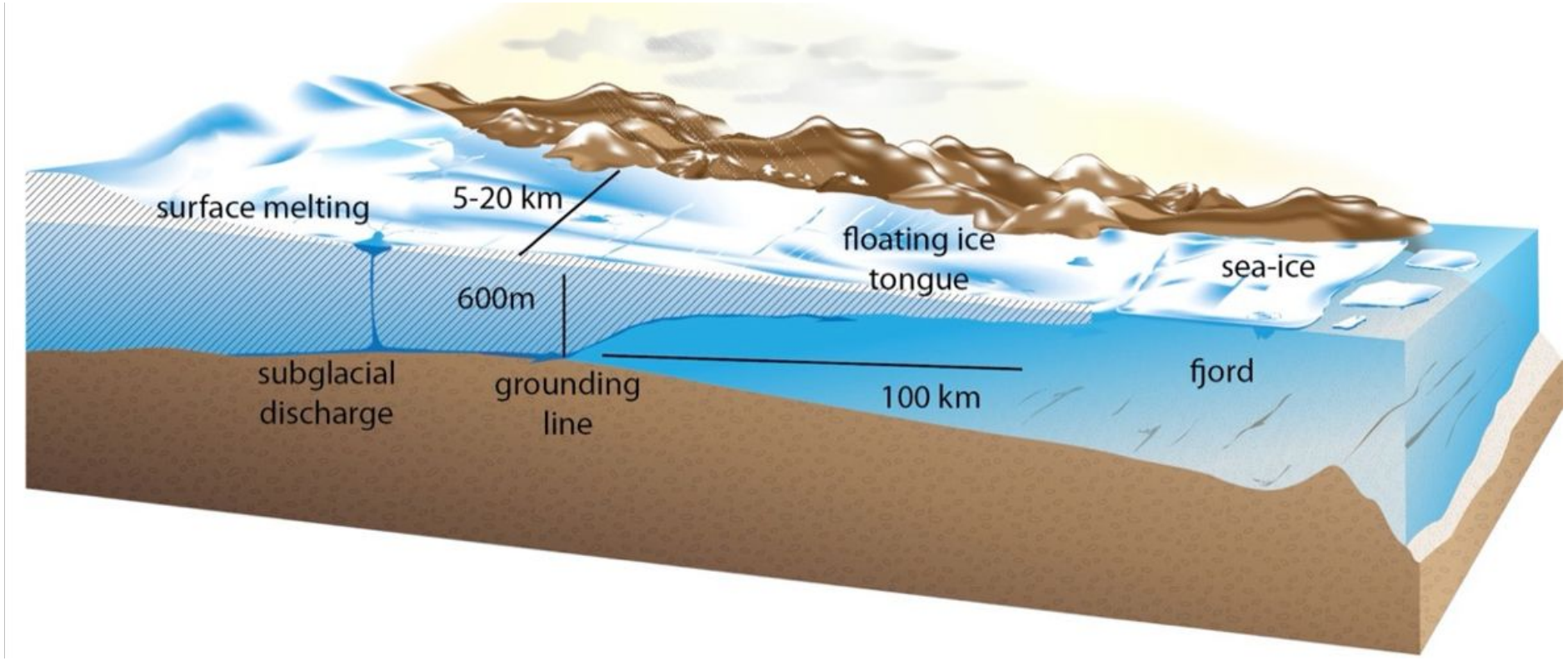
Why were the glaciers speeding up?



Data and models suggest that the retreat was triggered by changes at the ice/ocean boundary



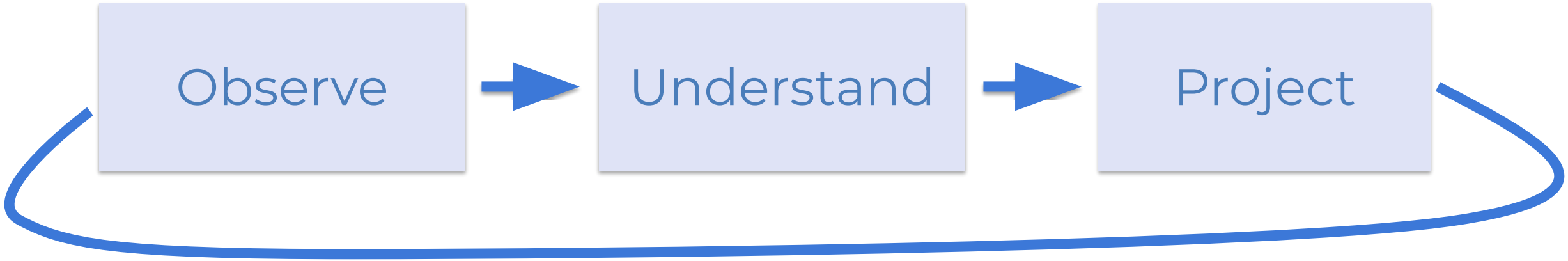
Sole et al. 2008; Price et al. 2008; Joughin et al. 2004; Thomas et al. 2004

Summary: The Problem

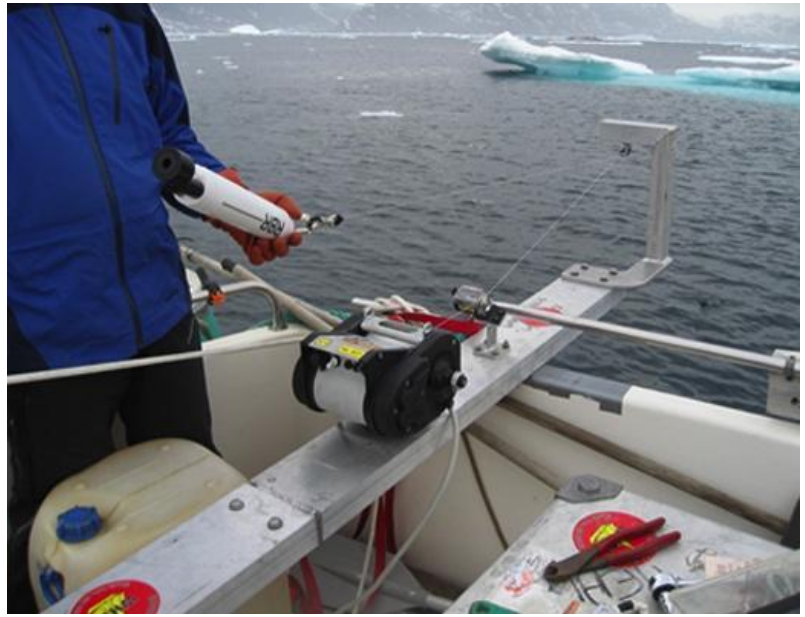
1. Greenland is rapidly losing mass and driving global sea level rise

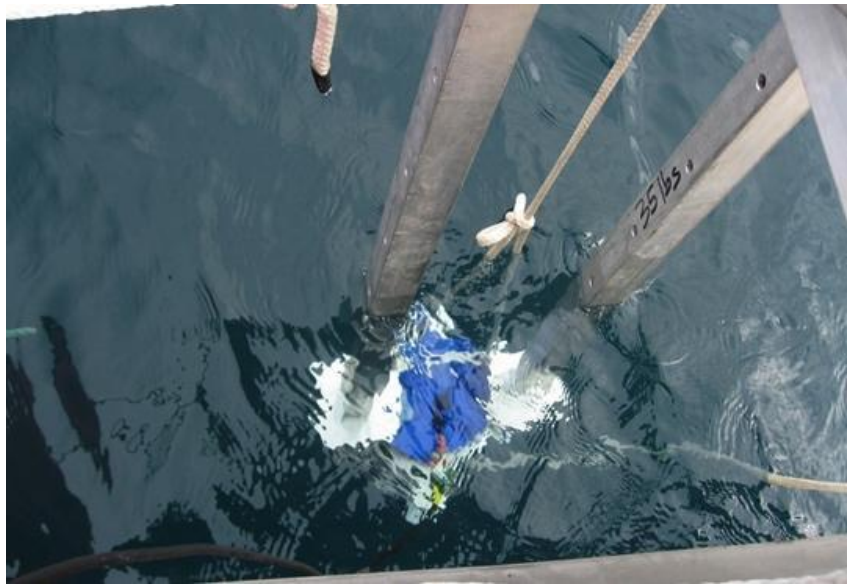
2. Half of the ice loss is due to glacier speed up potentially triggered by changes at the ice/ocean interface

3. These processes are absent from climate projection models

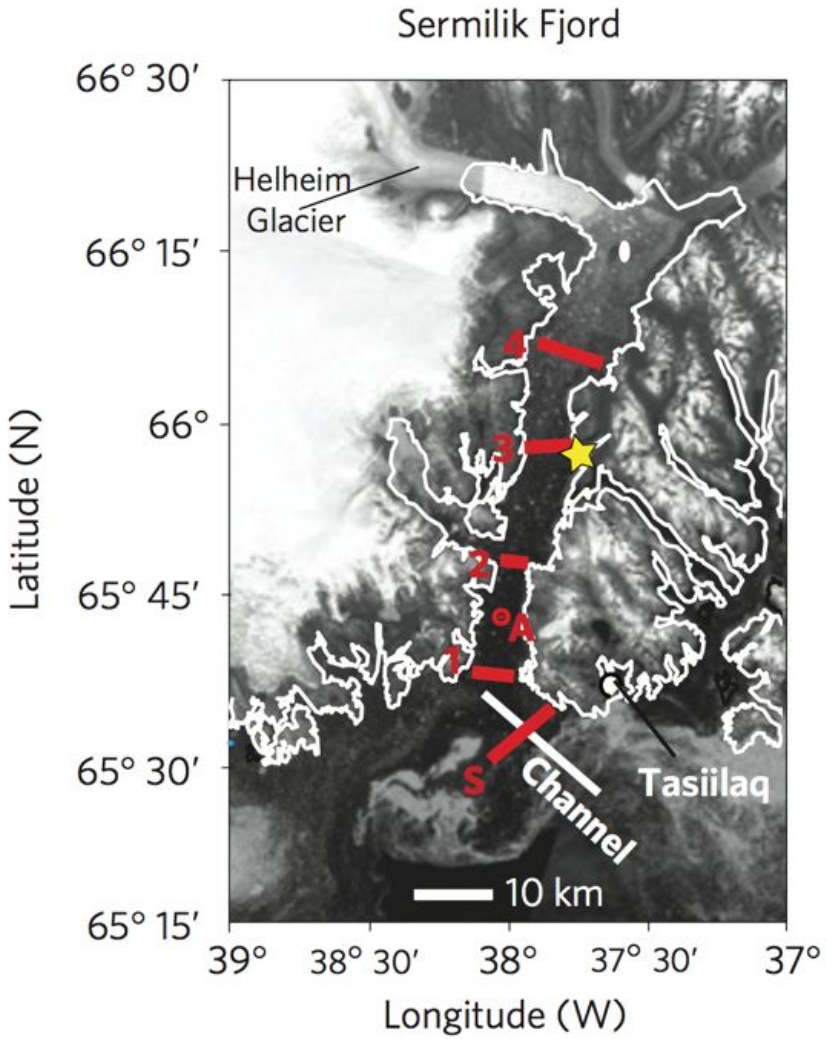


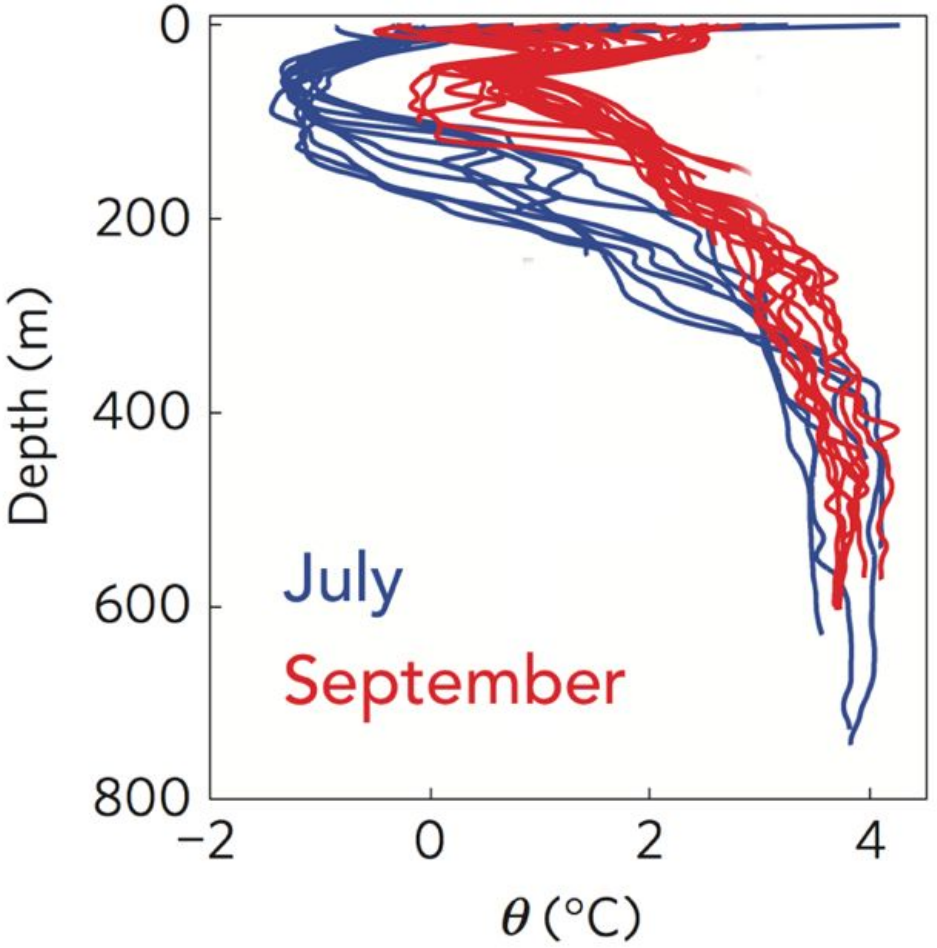
Summer 2008





Fjord waters are warm!





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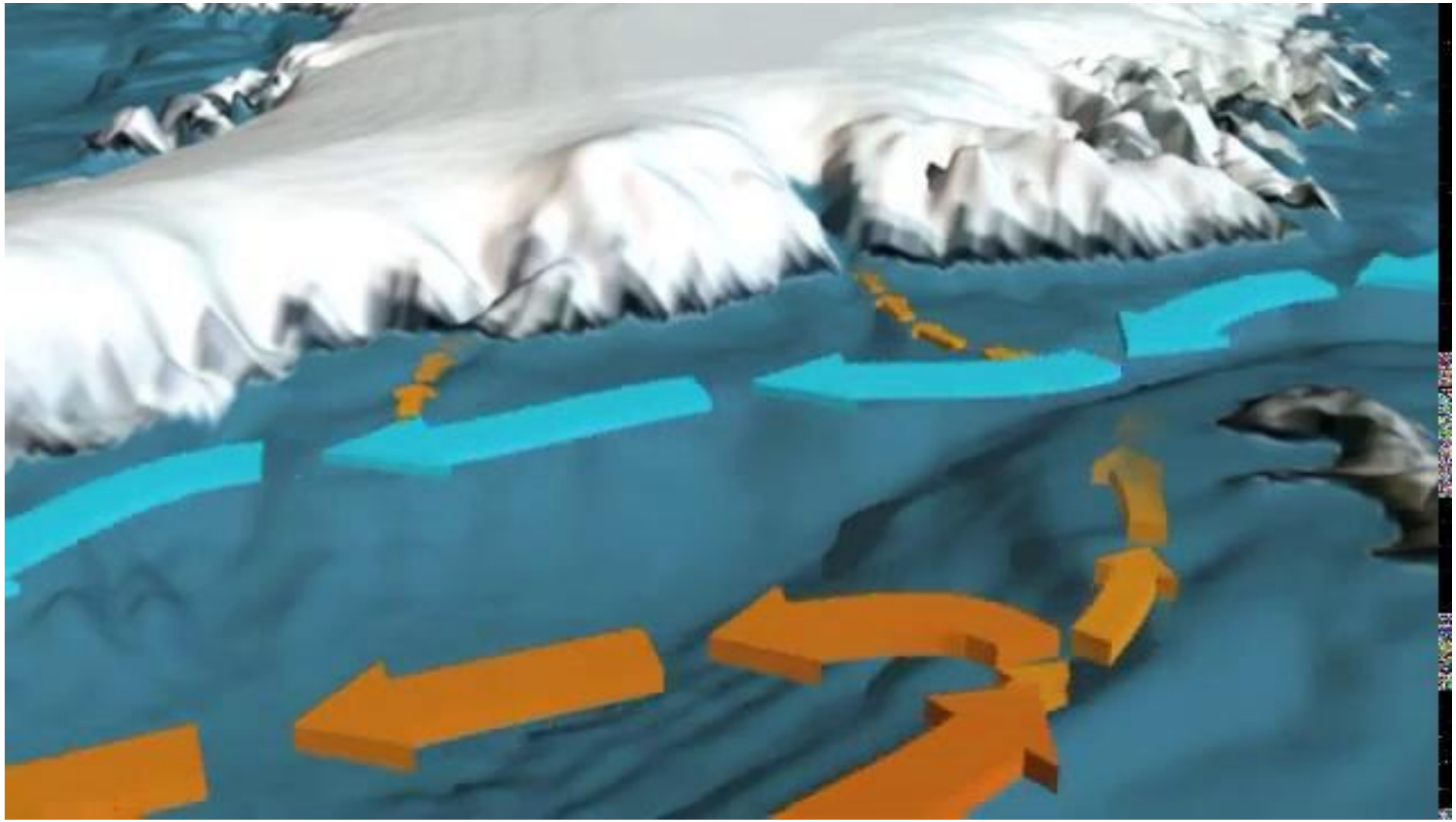
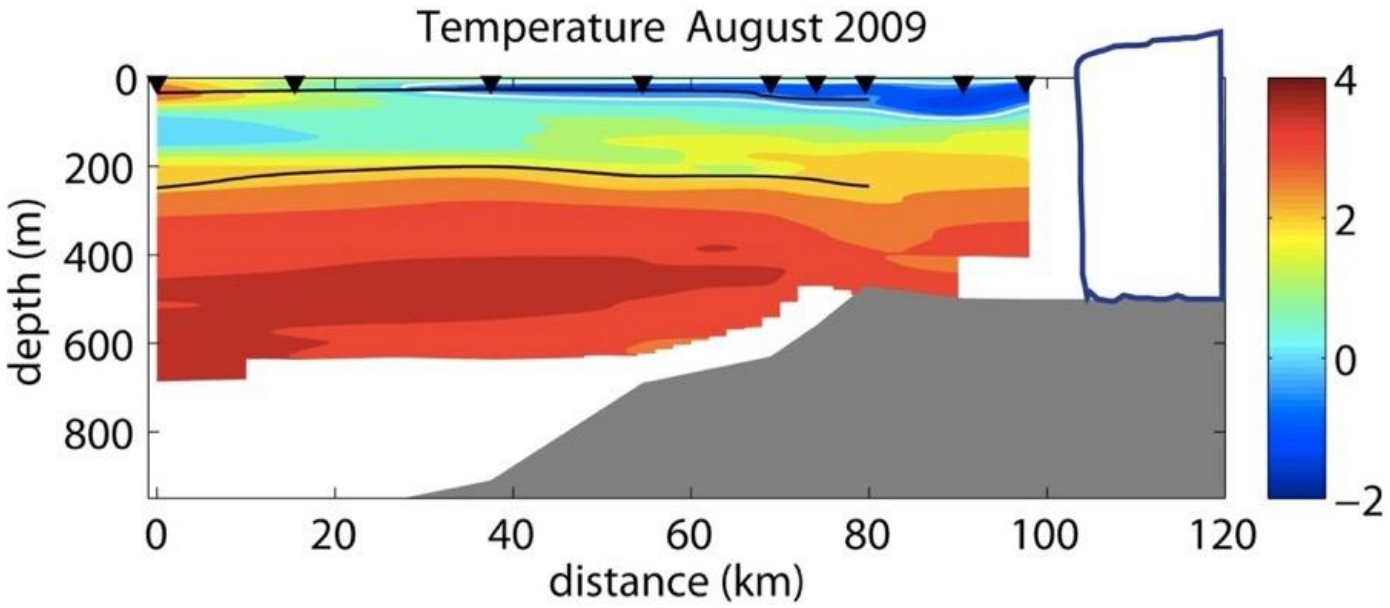
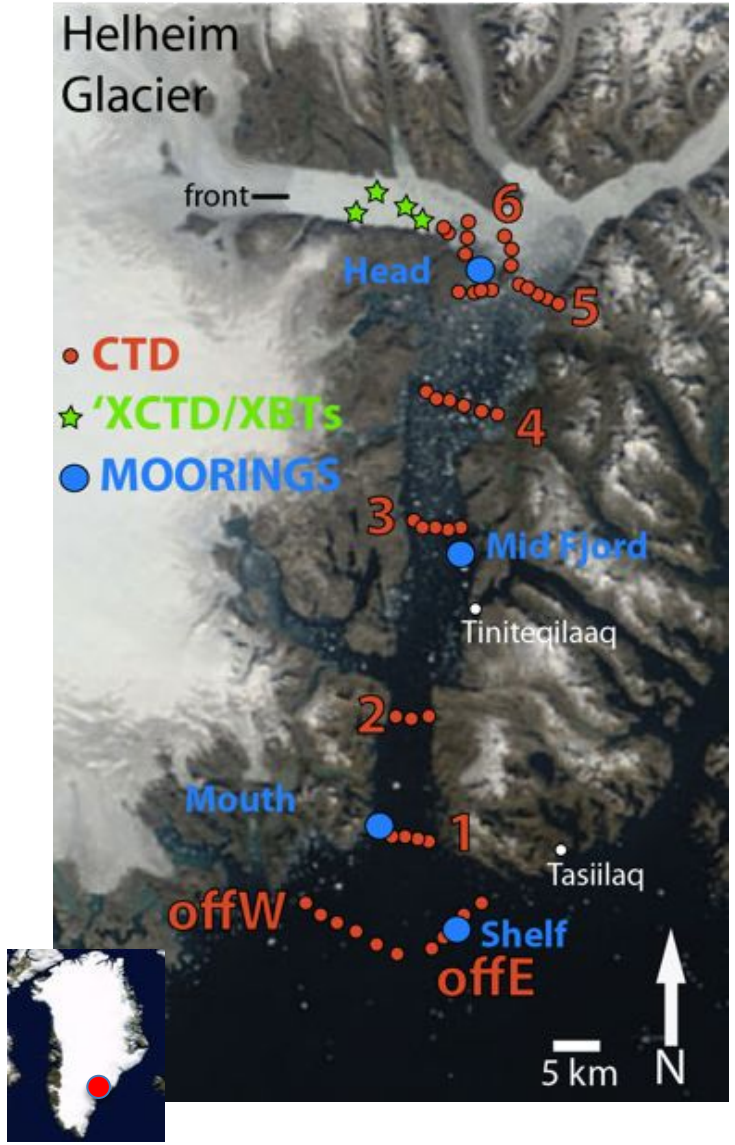


Getting close to the edge of the glacier





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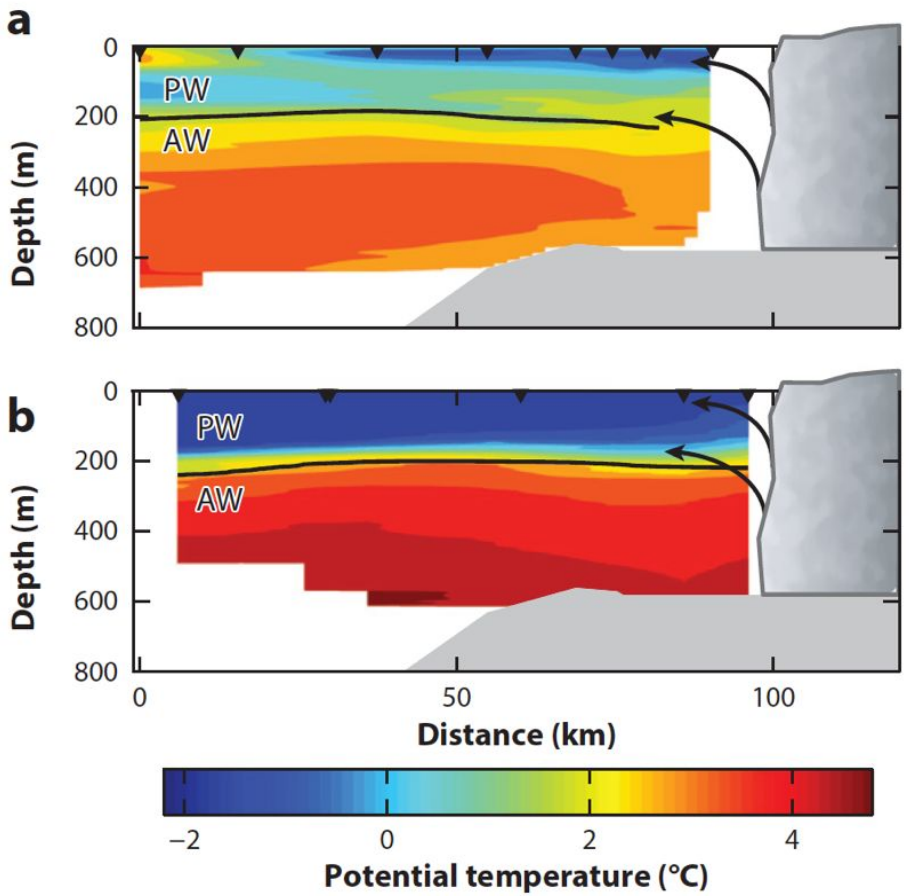
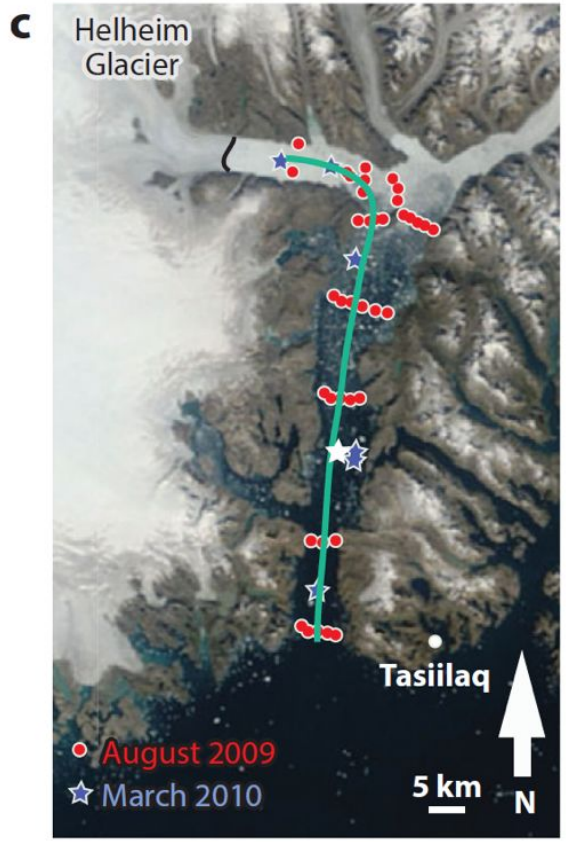
March 2010


DO NOT LEAN ON
RGENCY EXIT WINDOW
IGALAAQ QIMAAFFISSAQ
IIGARFIGINAGU

Differences in summer and winter: large amount of freshwater at depth in summer

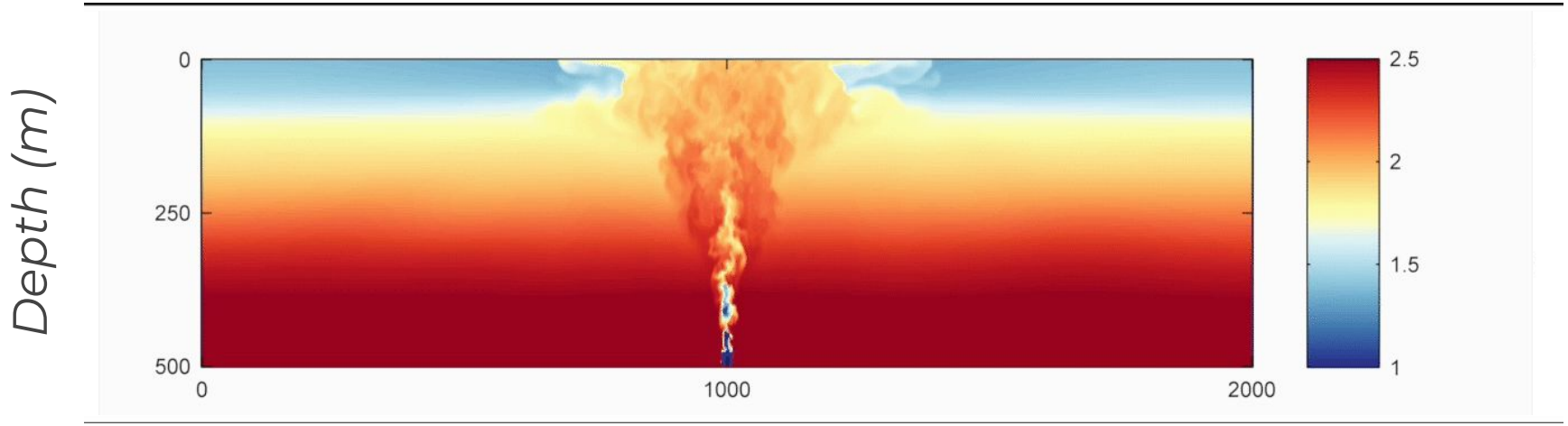




Straneo et al. 2011

Surface melt enhances submarine melt

Modeled ocean temperature (°C) - front of a glacier



Slater et al. 2015; Sciascia et al. 2013

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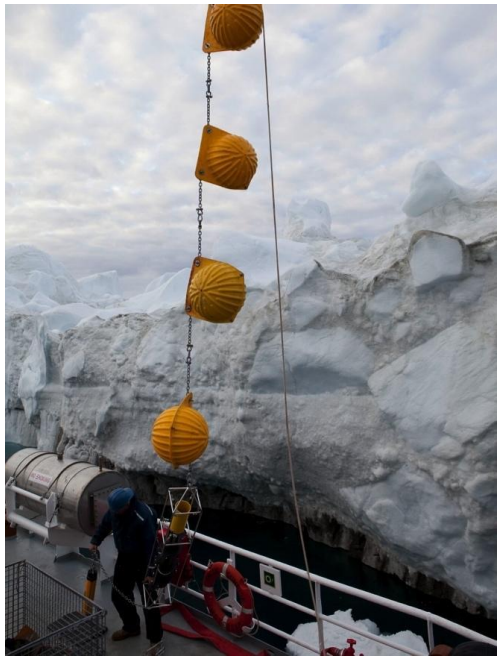

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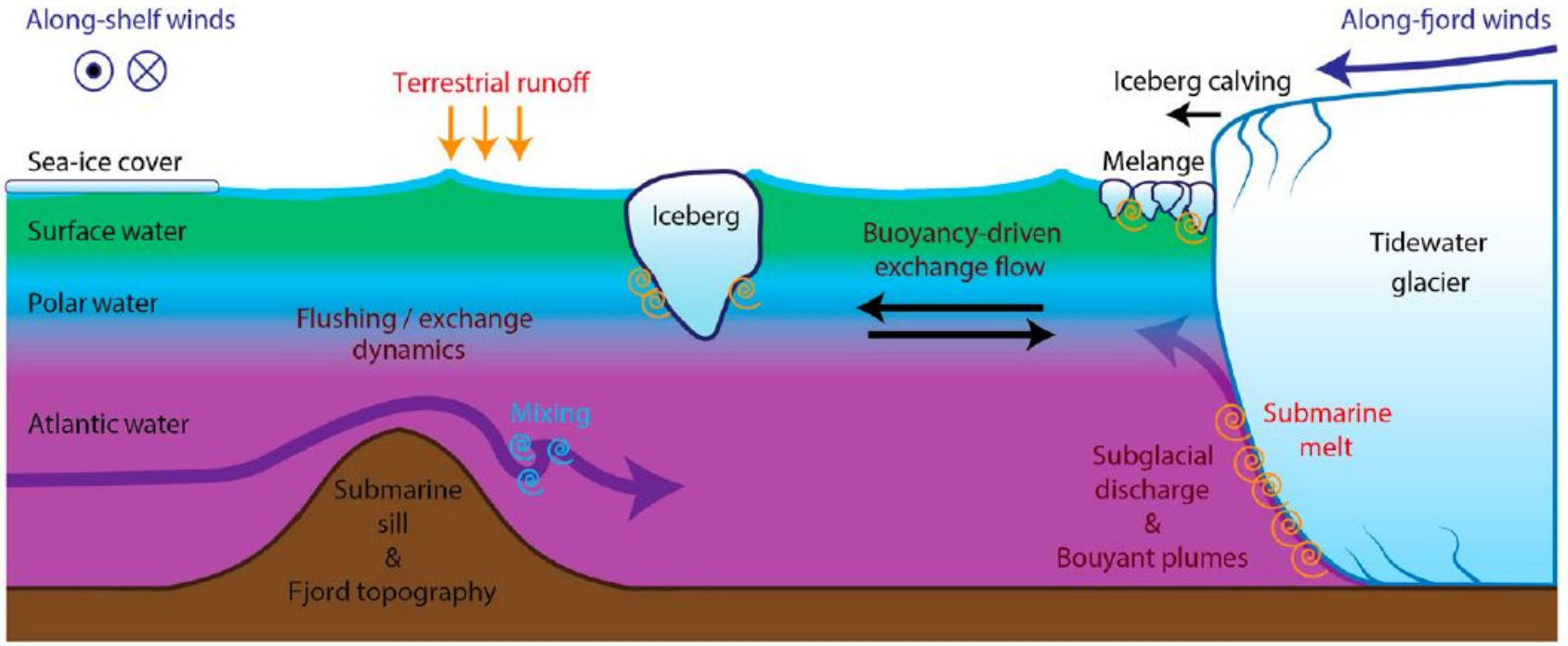
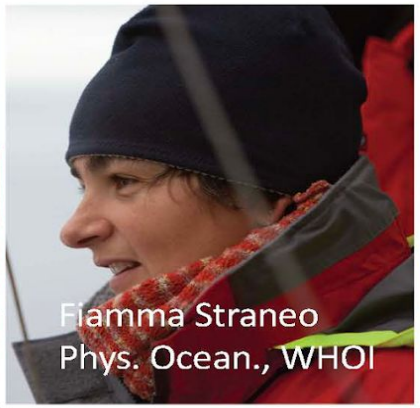
Drivers of fjord circulation: winds and glacier discharge

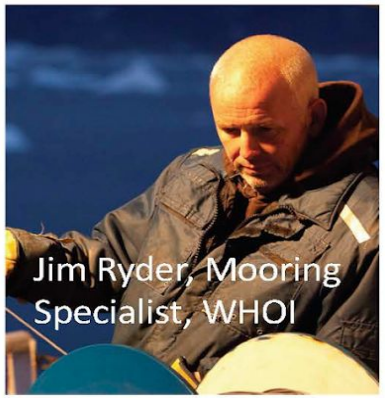


Straneo et al. 2019

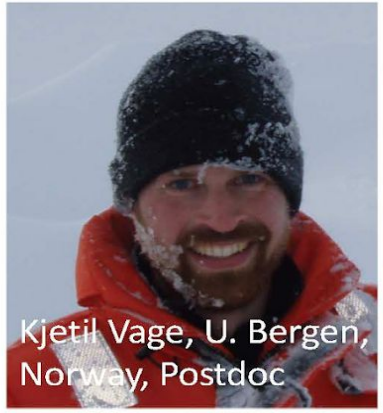
What have we learned so far

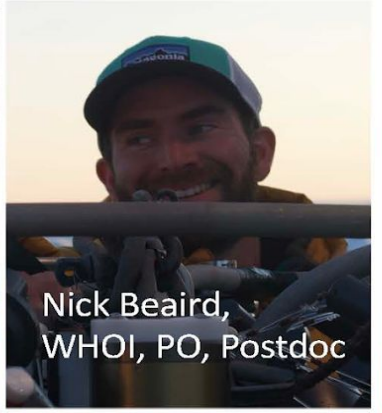
1. Warm Atlantic waters reach glacier
2. Melting is larger in summer because of surface melt
3. Processes that govern the supply of warm water to the glacier



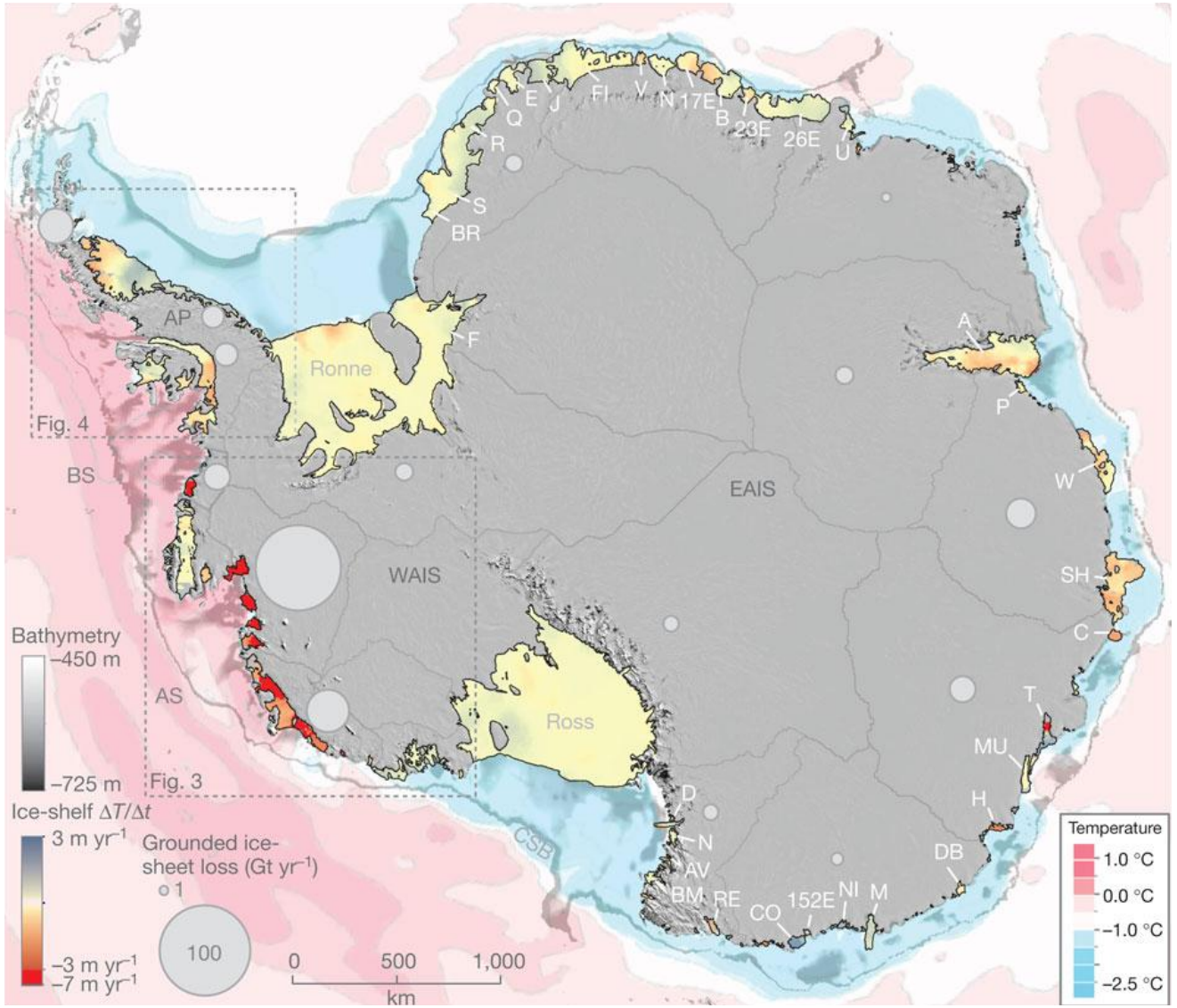


Field Team Sermilik





The same problem applies to Antarctica



Pritchard et al. 2012

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The same problem applies to Antarctica

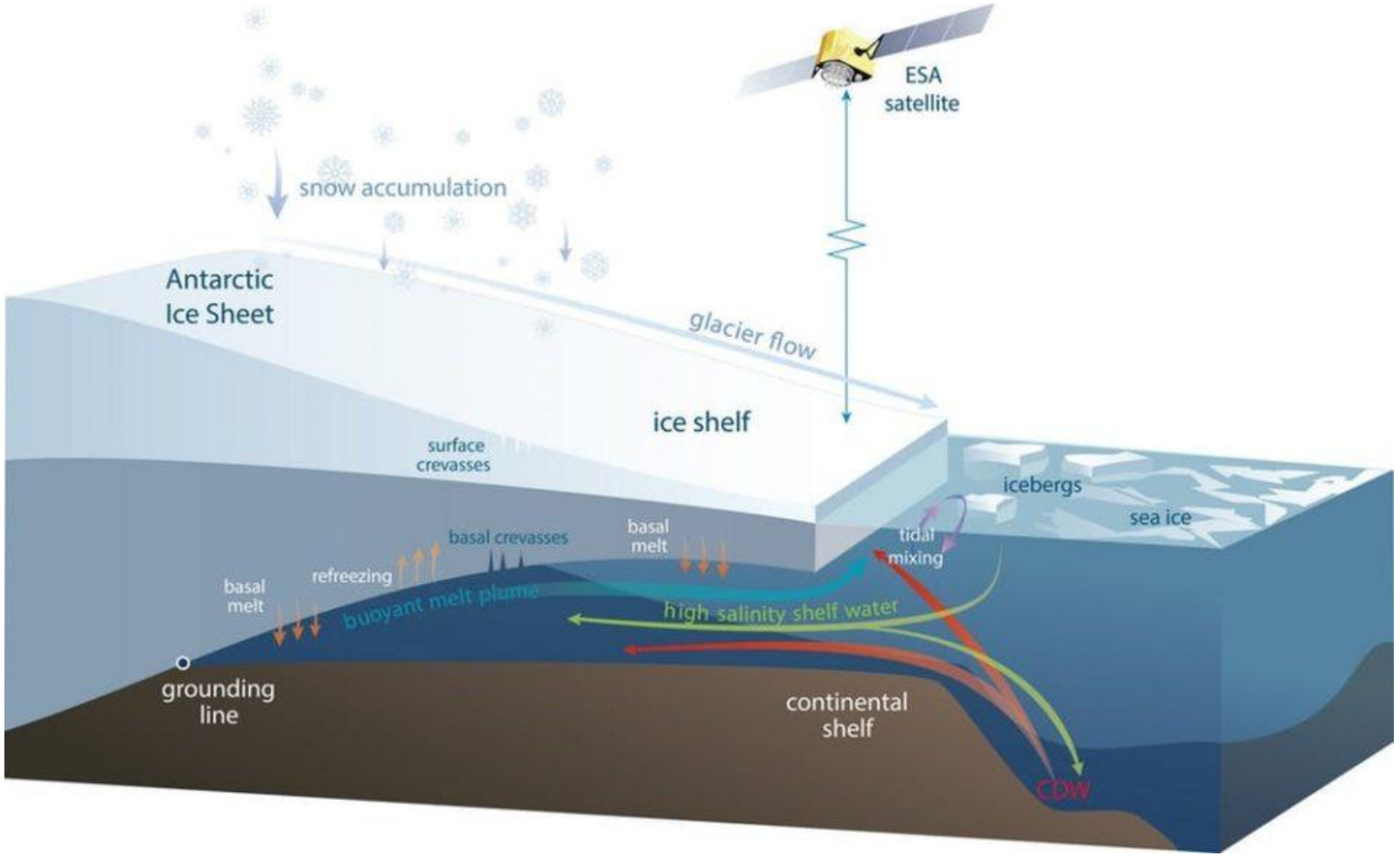

Image courtesy of H. Fricker (SIO)

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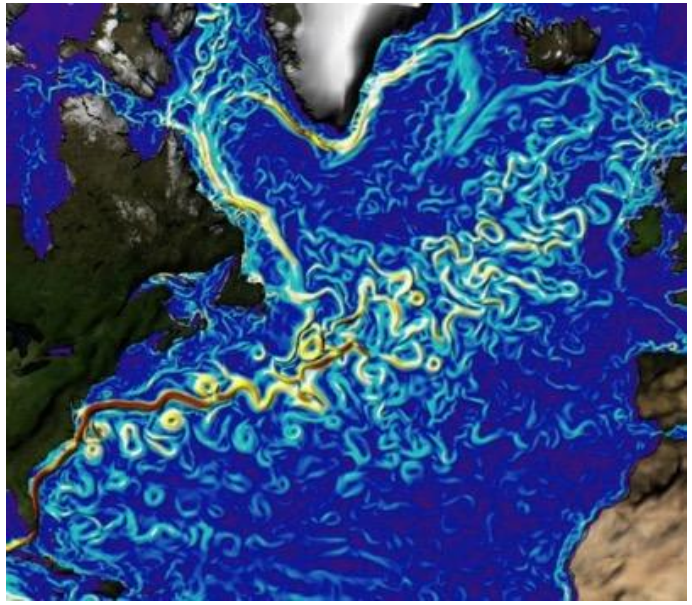
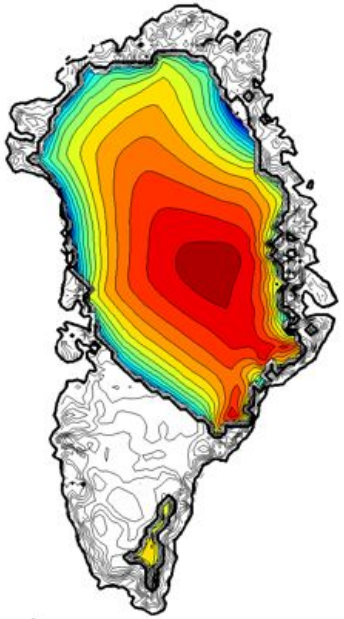
Improved Sea Level Rise Projections

Climate (Ocean and Atmosphere)
Model Projections



Understand

Ice Sheet Models



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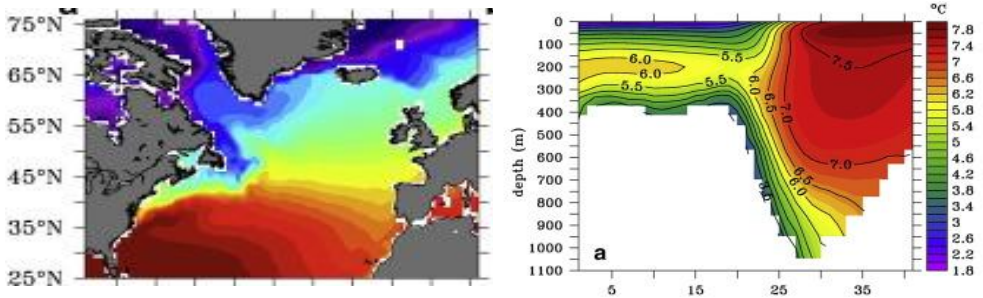
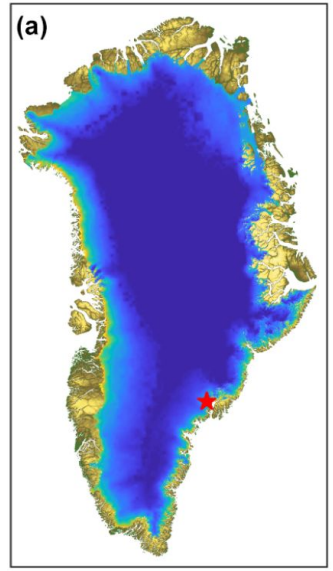
Translating understanding into the climate models

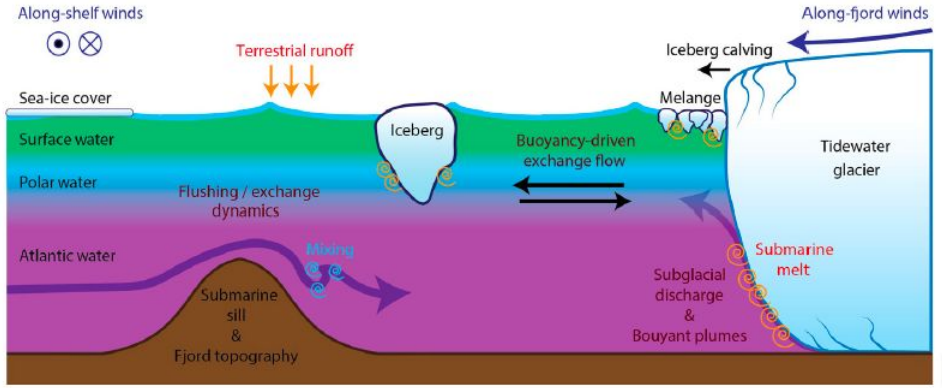
ISMIP6
Ice Sheet Model Intercomparison Project for CMIP6

Ocean Model



Atmosphere Model





Figures from Marzocchi et al. 2015; Straneo et al. 2019; Slater et al. 2020

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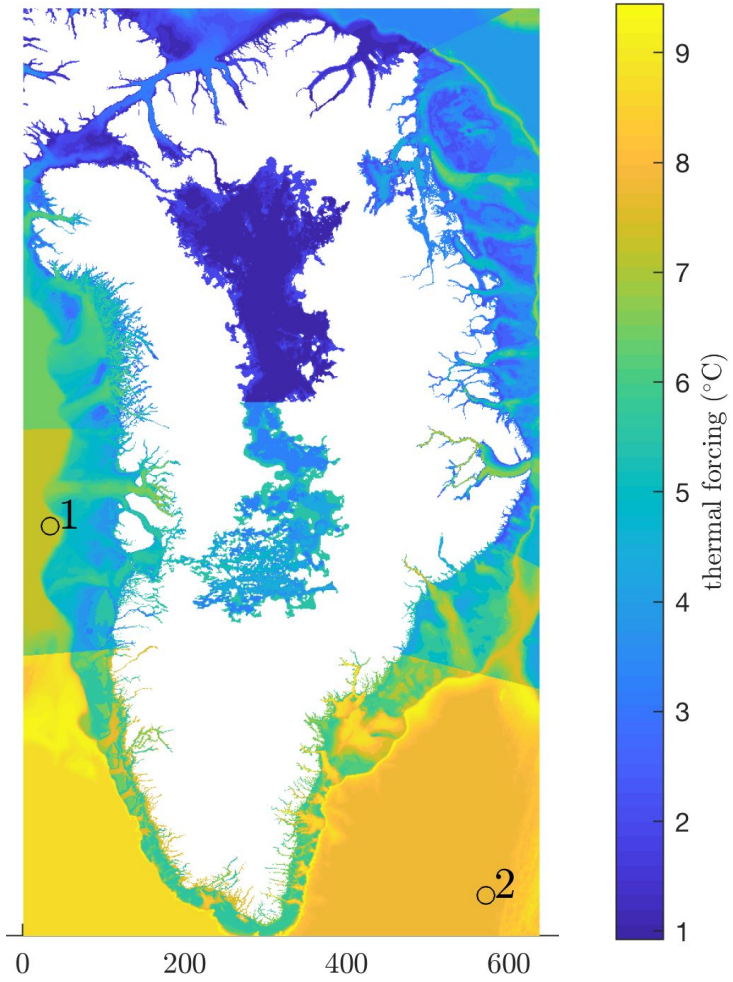
Greenland: Ocean Forces Retreat of Glacier

Extrapolation of properties in fjords



Retreat Parameterization

$\Delta L = K \times \Delta(Q^{0.4}\, TF)$

Slater et al., 2019,2020

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The ISMIP6 Ocean Forcing Team

Ice Sheet-Ocean/ Model

Nico Jourdain
CNRS, FR

Xylar Davis
LANL, USA

Ice Sheet/Ocean Obs

Fiamma Straneo,
SIO-UCSD, USA

Tore Hatterman,
NPI, NO

Ice Sheet Modelers

Helene Seroussi
JPL, USA

M. Morlighem
UCI, USA

H. Goezeler
IMAU, NL

S. Nowicki
NASA GIS, USA

Glaciology

D. Slater,
SIO-UCSD, USA

D. Felikson,
NASA GIS, USA

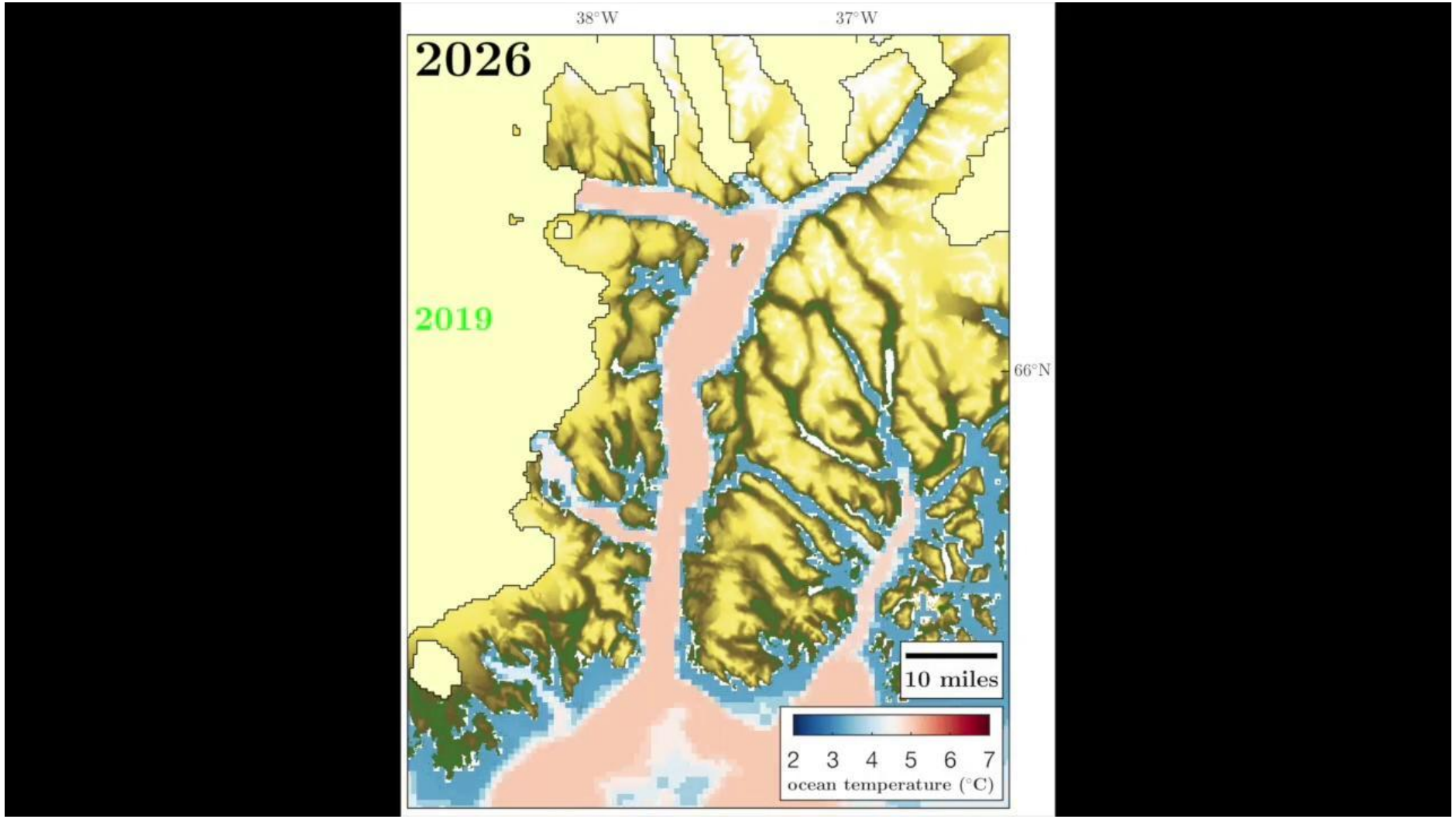
Surface Mass Balance

Xavier Fettweis,
U. Liege, BE

Climate/Ocean Models

Alice Barthel
LANL, USA

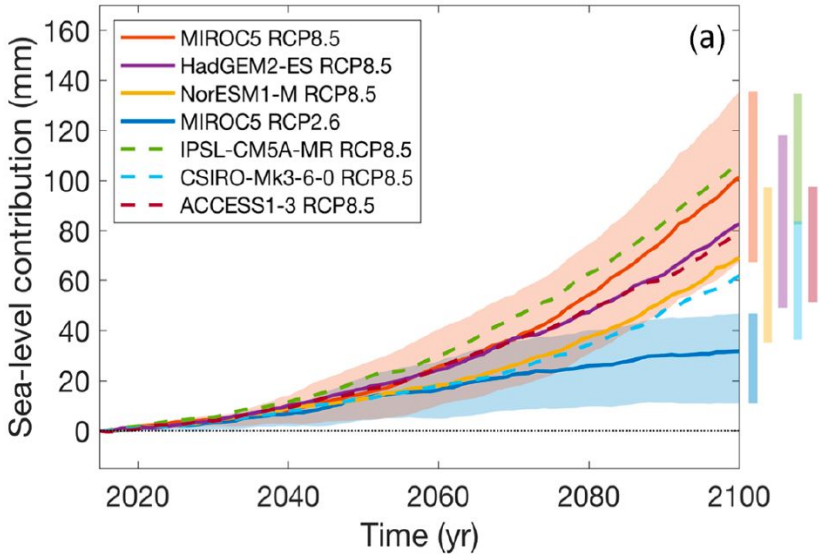
Chris Little
AER, USA



Slater et al. 2019, 2020

Ice Sheet Model projections from climate models

Greenland: 16 simulations from 13 modeling groups from 8 countries



Goelzer et al. 2020

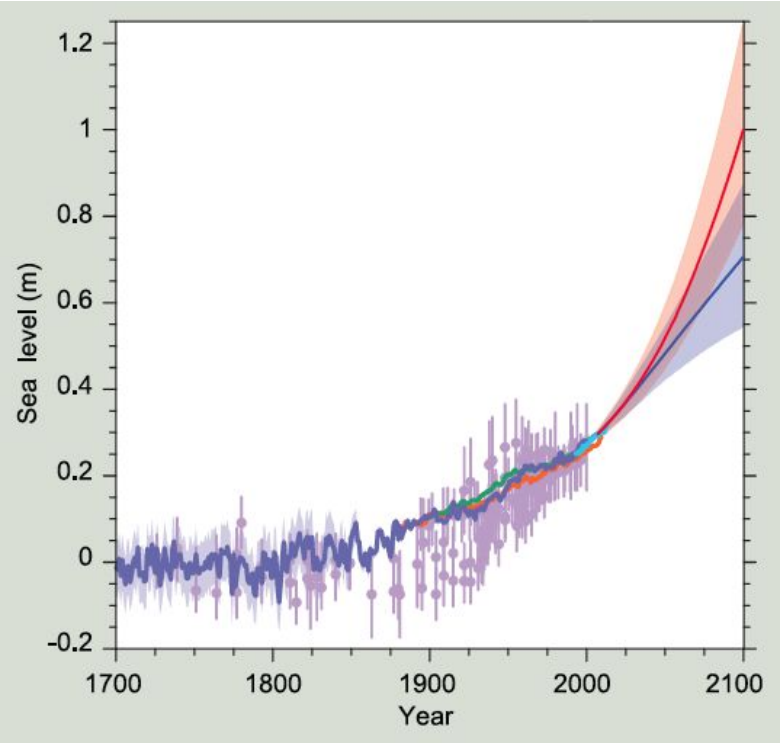
Conclusions

Observe

Understand

Project

} Improved Projections



1. Climate science is done by (international) teams
2. It requires collaboration across disciplines and methodologies
3. Scientific progress is achieved (faster) by healthy, interactive community


Photo: Nick Cobbing

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