Understanding the response of polar ice sheets to oceanic (and atmospheric) forcing

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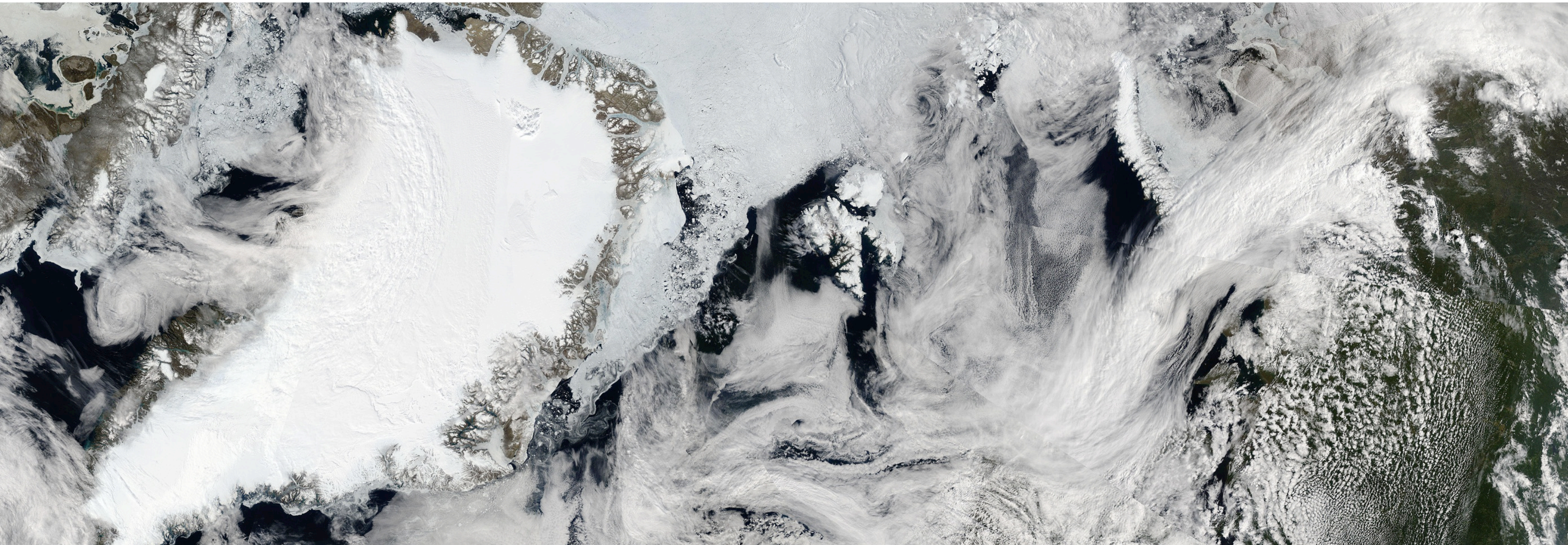


Cryospheric contributions to global sea level rise

Conversion: 100 Gt/y = 0.3 mm/y GMSL = 0.001 Sv

Table 1 | Estimated recent and current contributions to SLR

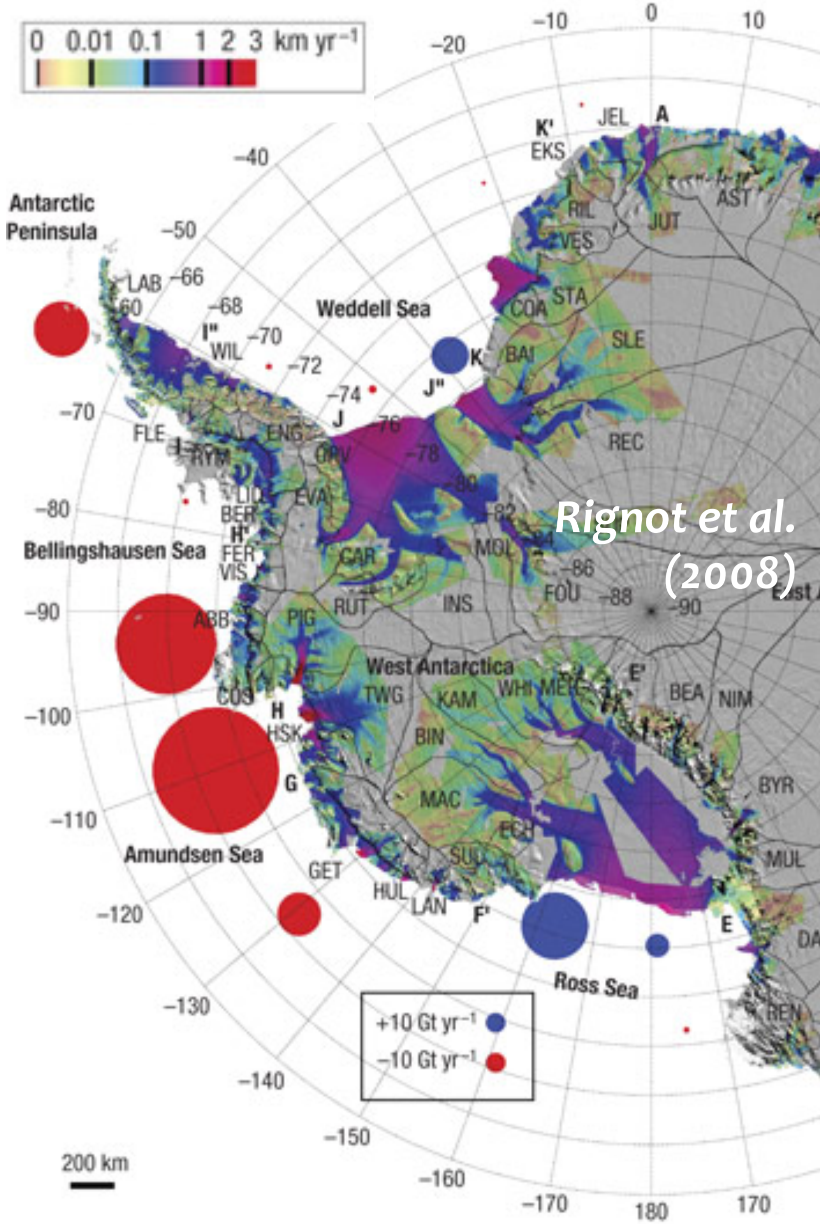
Source of contributions	SLR (mm yr^{-1})	
	1992/93 to 2008/11*	2000/03 to 2009/11*
GIS + AIS[2]	0.59 ± 0.20	0.82 ± 0.16
GICs[72,74]	1.40 ± 0.16	0.71 ± 0.08
Ocean thermal expansion[77,87,88]	1.10 ± 0.43	1.11 ± 0.80
Terrestrial water storage (1993–2008)[67,81]	0.02 ± 0.26	
Sum of contributions	3.11 ± 0.56	2.66 ± 0.86
Observed (1993–2008)[67]	3.22 ± 0.41	

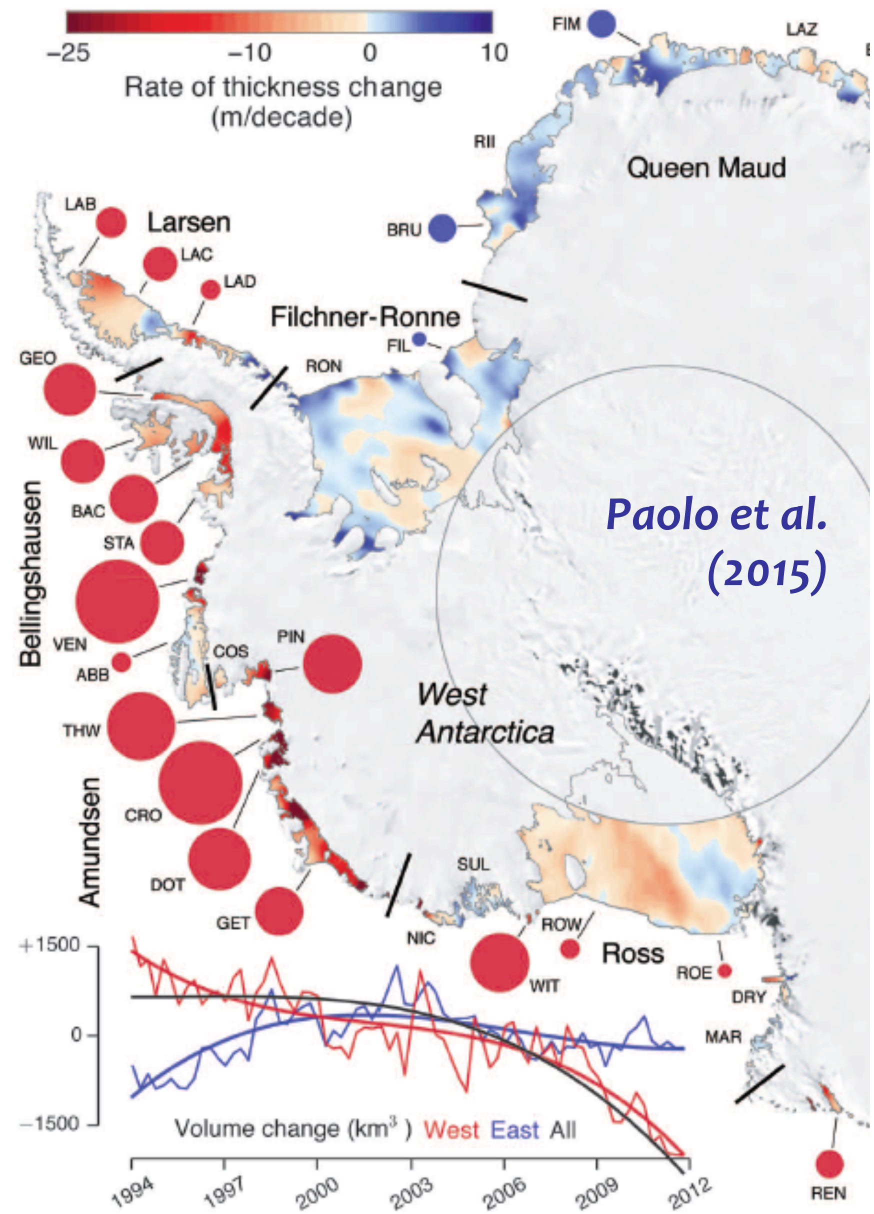
- Increasing role of polar ice sheets in global mean sea level rise
- Stated uncertainties in all components might be optimistic

IMBIE – Shepherd et al. (2012); Hanna et al. (2013)

Antarctica:

Ice stream & shelf flow speed, mass loss, and thinning



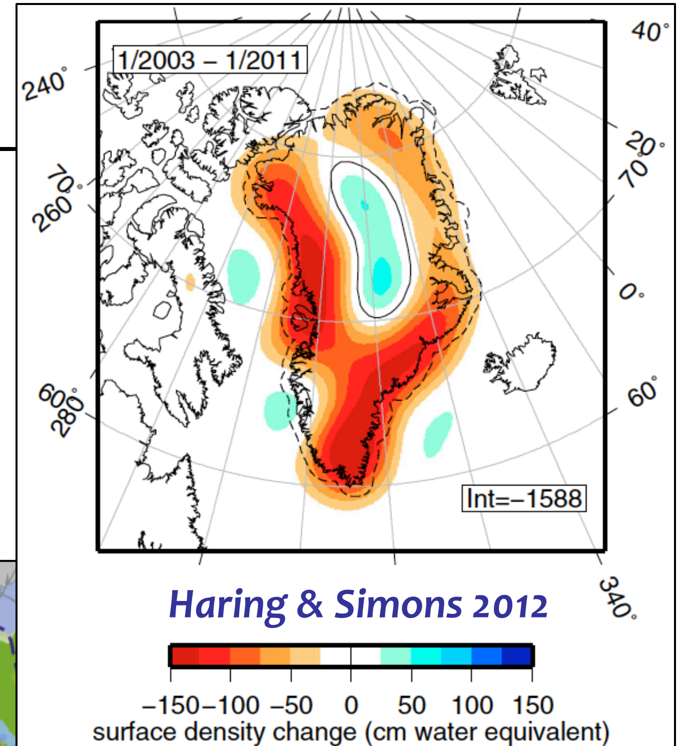


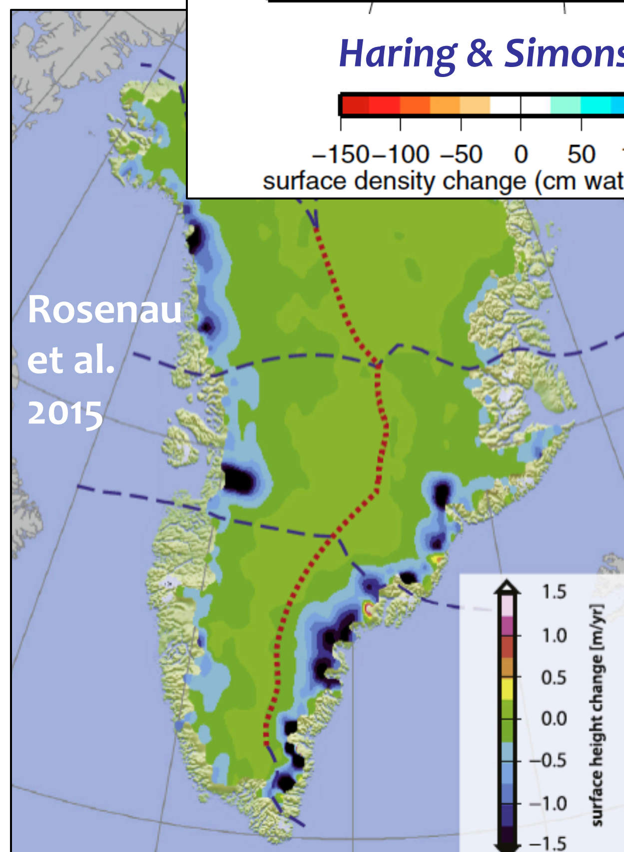
Greenland:

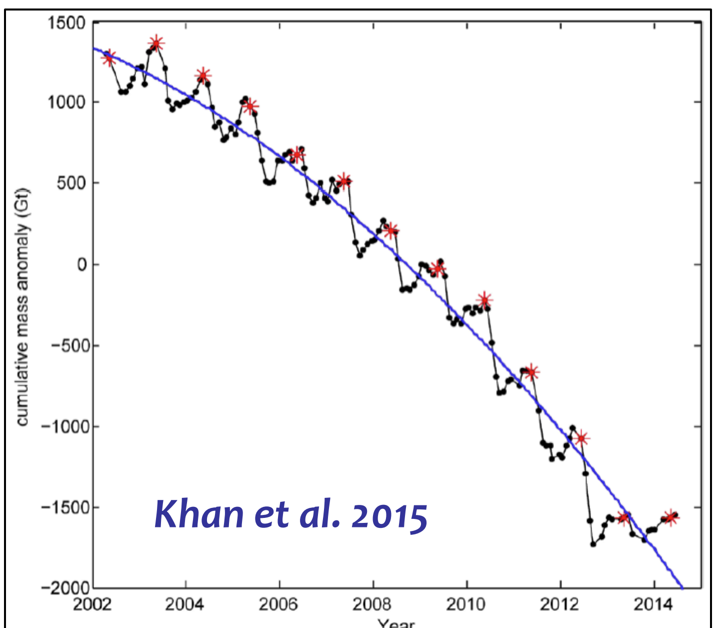
Decadal changes at Greenland's marine margins

- Quadrupled from 1992-2001 to 2002-2011 (Shepherd et al. 2012)
- Greenland mass loss now ~1/4 sea level rise (Church et al. 2011)
- Cumulative freshwater anomaly since 1995:

  3200 ± 350 km^3 (Bamber et al. 2012)
- 1970s Great Salinity Anomaly ~10,000 km^3 (Curry and Mauritzen, 2005)

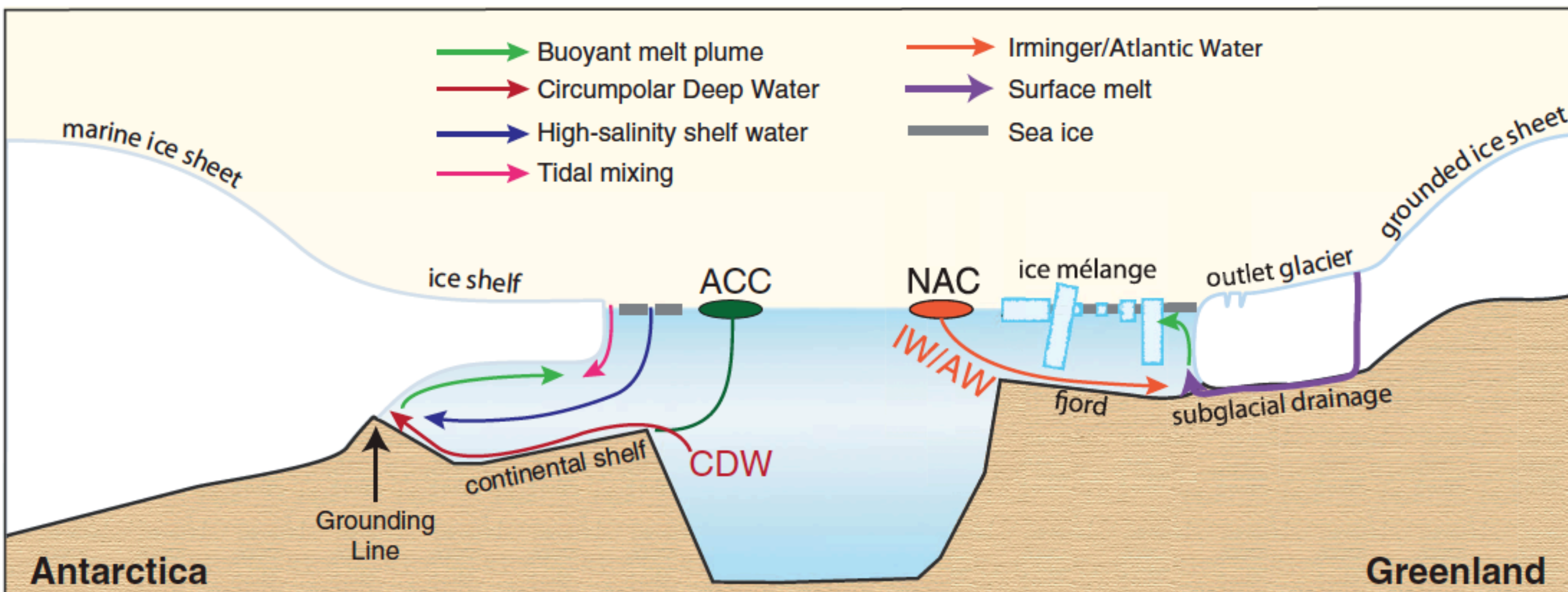






Ice sheet-ocean (and atmosphere) interactions

- Submarine melting at base of polar ice sheets is thought to be major contributor to observed recent increase in ice sheet mass loss
- Observed time-scales are seasonal to decadal



Joughin et al. (2012)

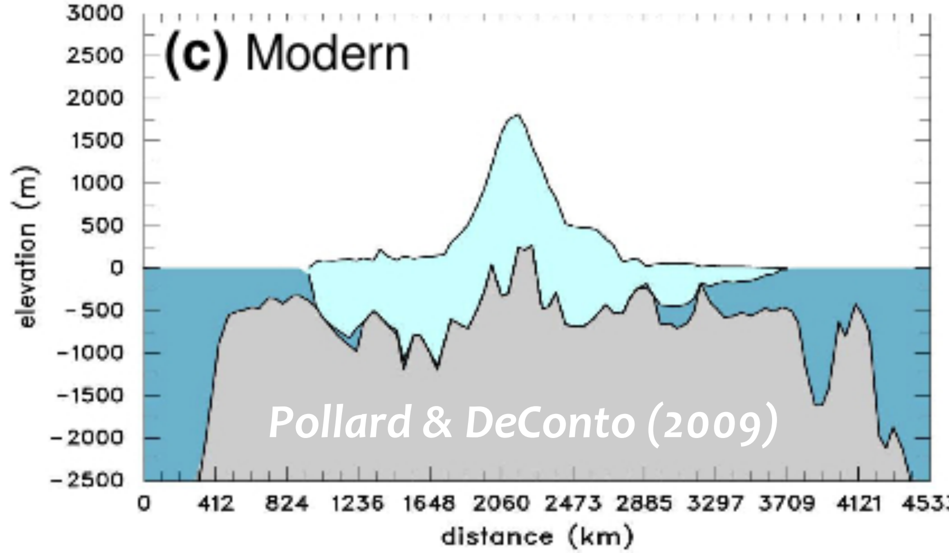
Why bother in the context of Decadal Climate Variability?

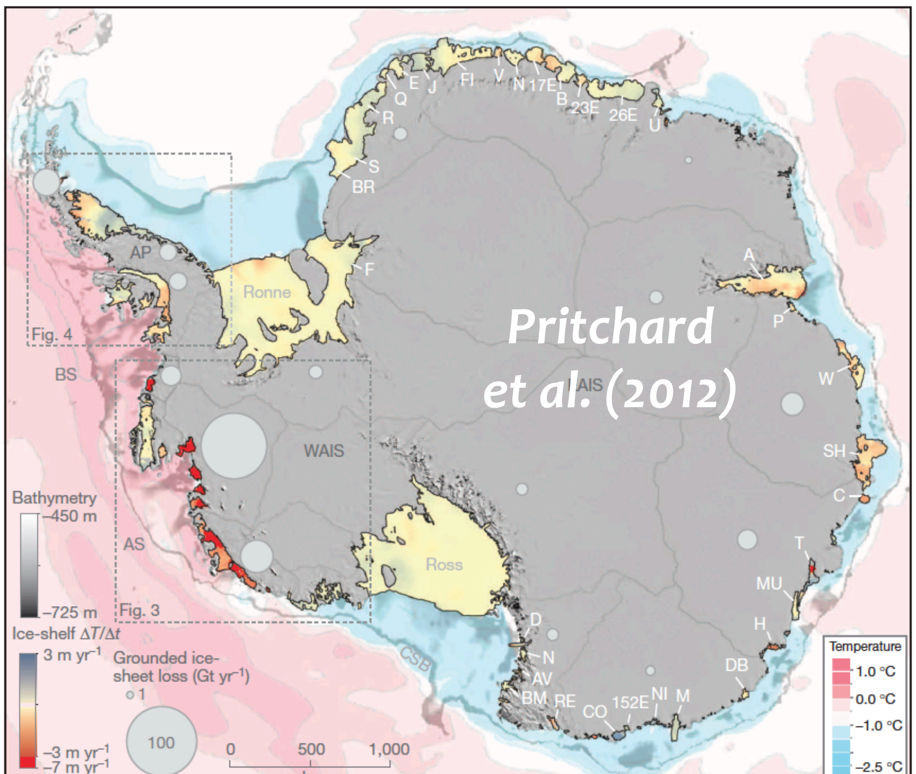
- Decadal climate variability may be significant driver of observed changes
- *Large-scale climate variability* triggers *small-scale processes* that amplify ice sheet change:
  - surface melting
  - submarine melting
  - calving
  - weakening of shear margins
- Changes controlled by:
  - dynamical (stress balance) response?
  - atmosphere/ocean circulation changes?
  - topography?

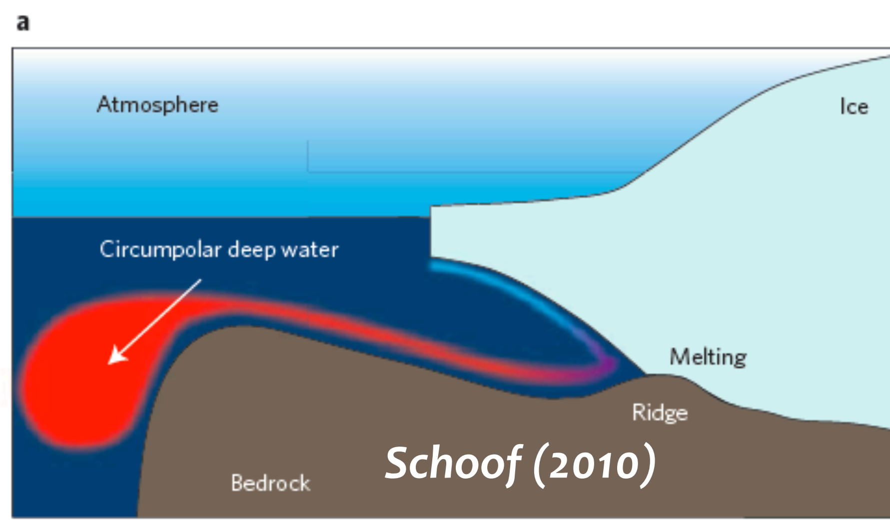
Antarctica

Antarctica: a marine-based ice sheet, large floating shelves

- Uneven extent of continental shelves & proximity to ACC
- Role of Southern ***ocean*** circulation changes, and role of ***atmospheric*** circulation changes in causing those



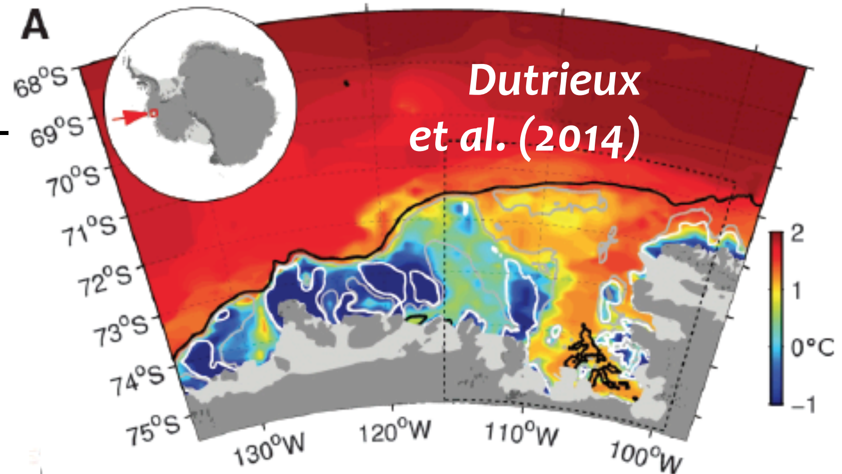


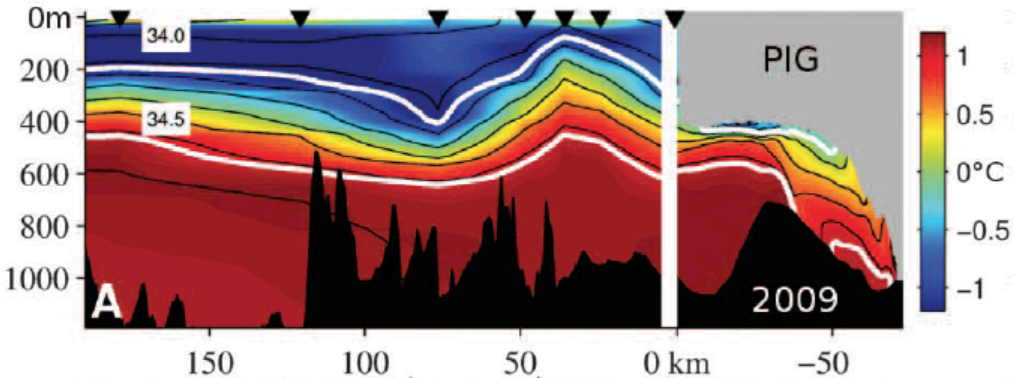


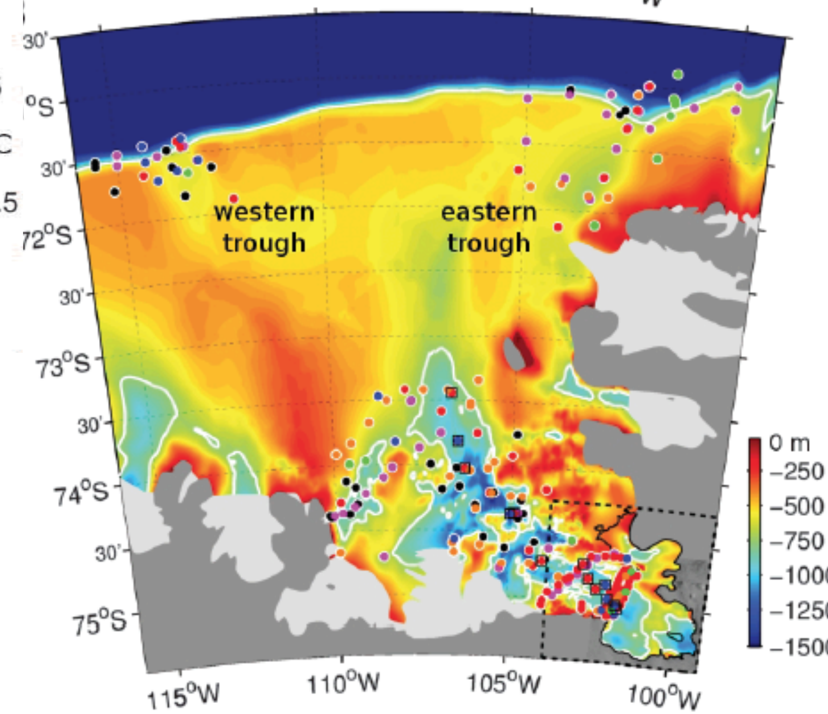
Climatic forcing of observed changes

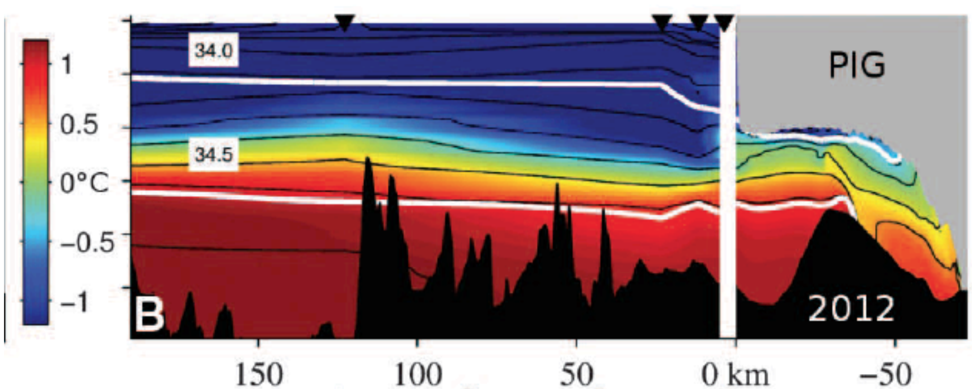
Pine Island Glacier, Amundson Sea Sector

Up-/down-movement of thermocline controls inflow of CDW into cavity, causing enhanced sub-ice shelf melting





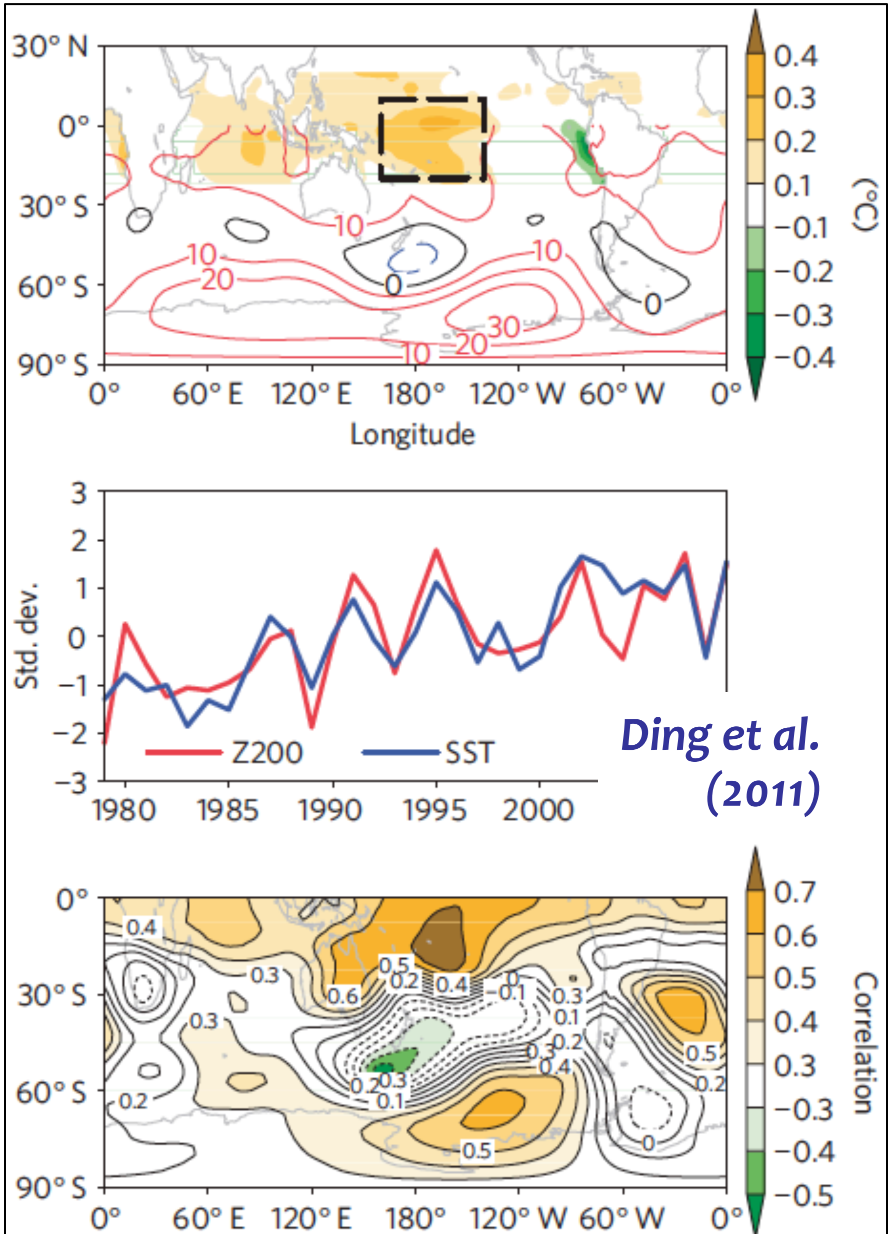


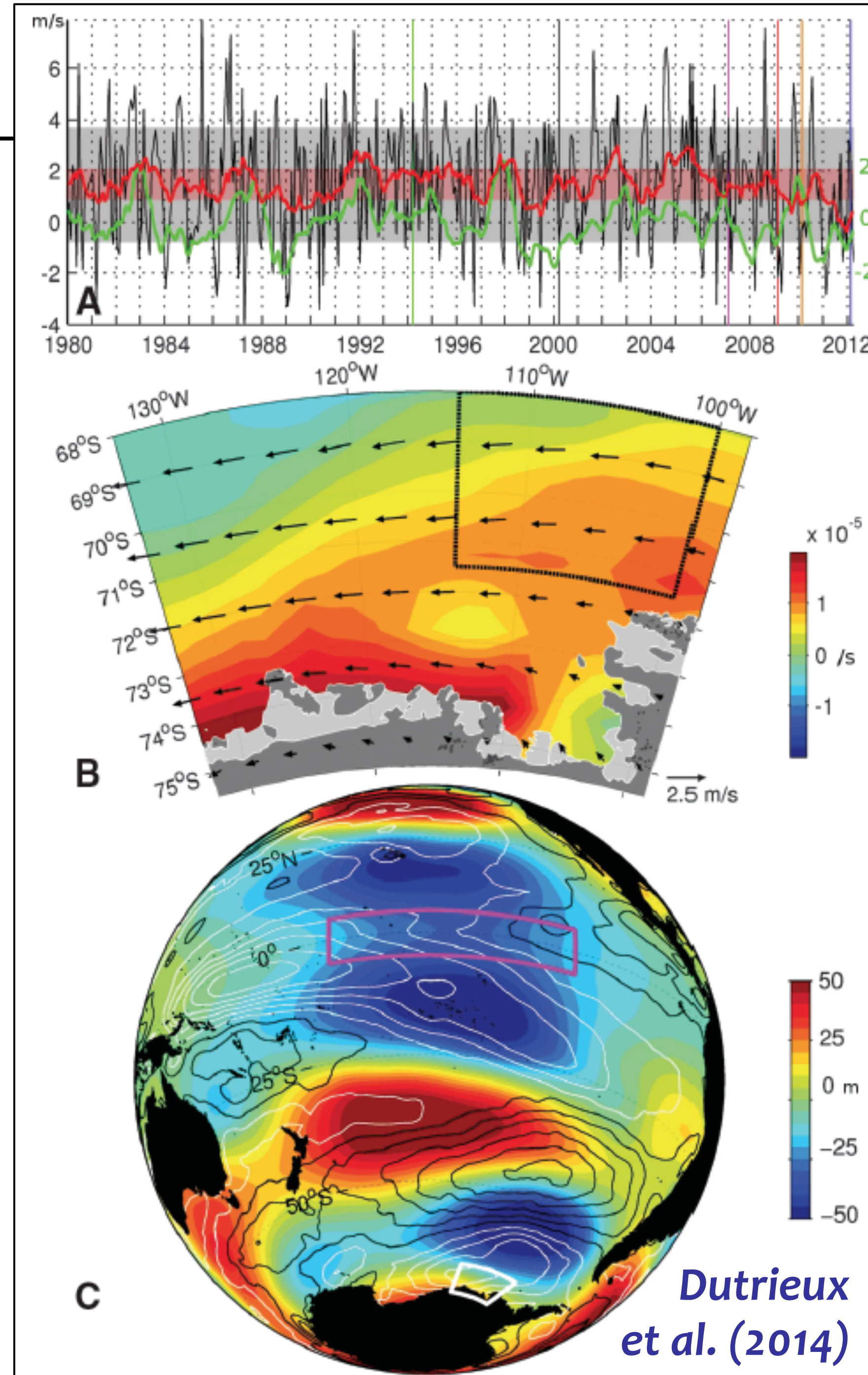


Thermocline depth variability determined by ASS wind anomalies, which in turn are modulated by NINO3,4 teleconnections

Climatic forcing of observed changes

Tropical-high latitude teleconnections

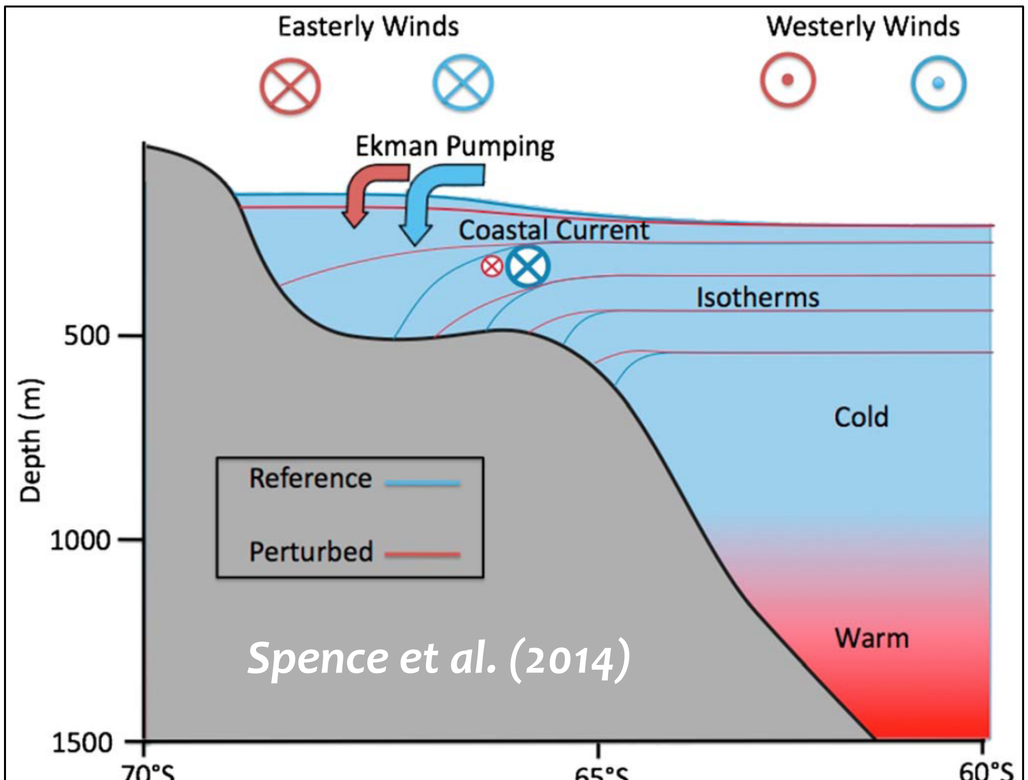


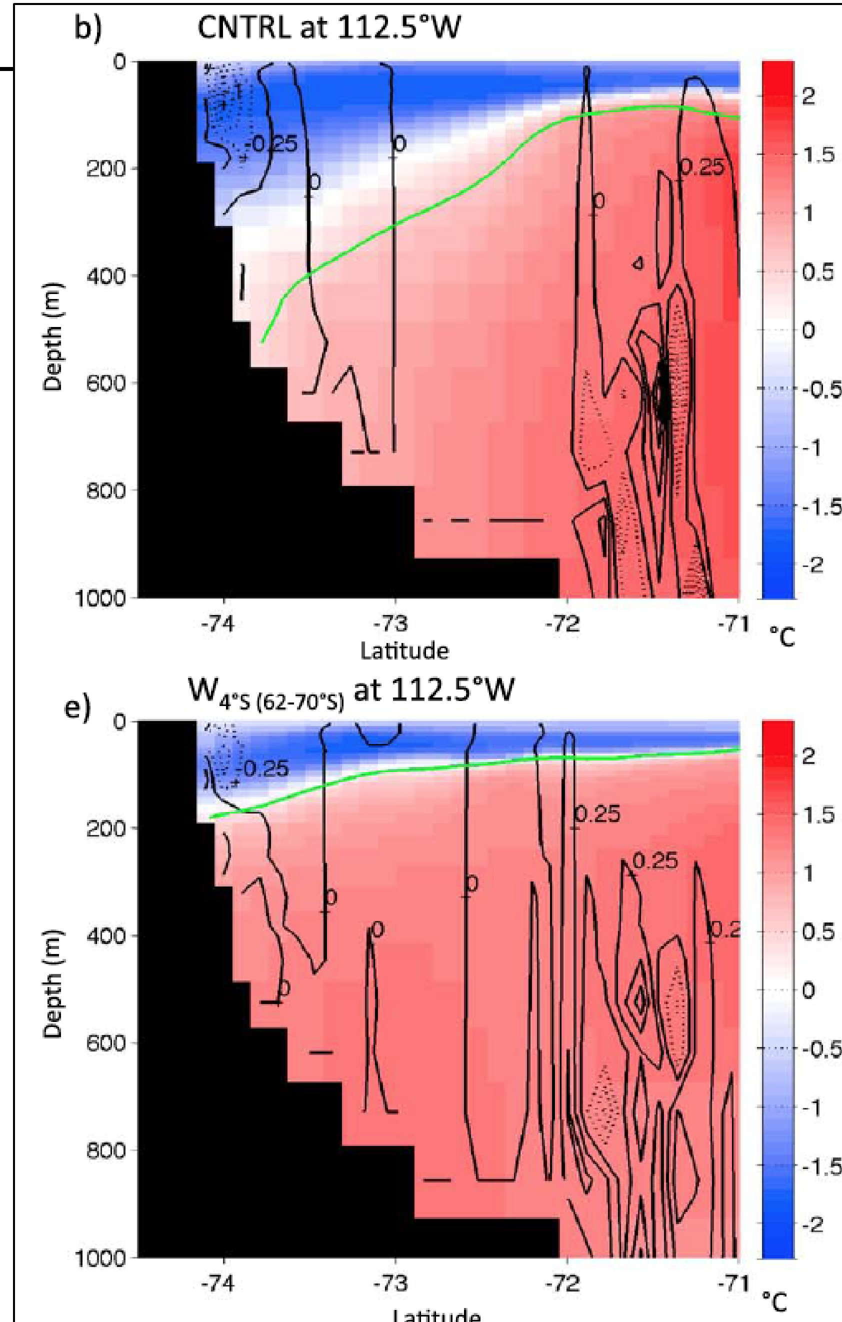


Shifting Southern Hemisphere Westerlies

Impact of poleward shift and intensification of SH westerlies:

- weakened near-shore Ekman pumping
- weakend coastal currents





Climatic forcing of observed changes

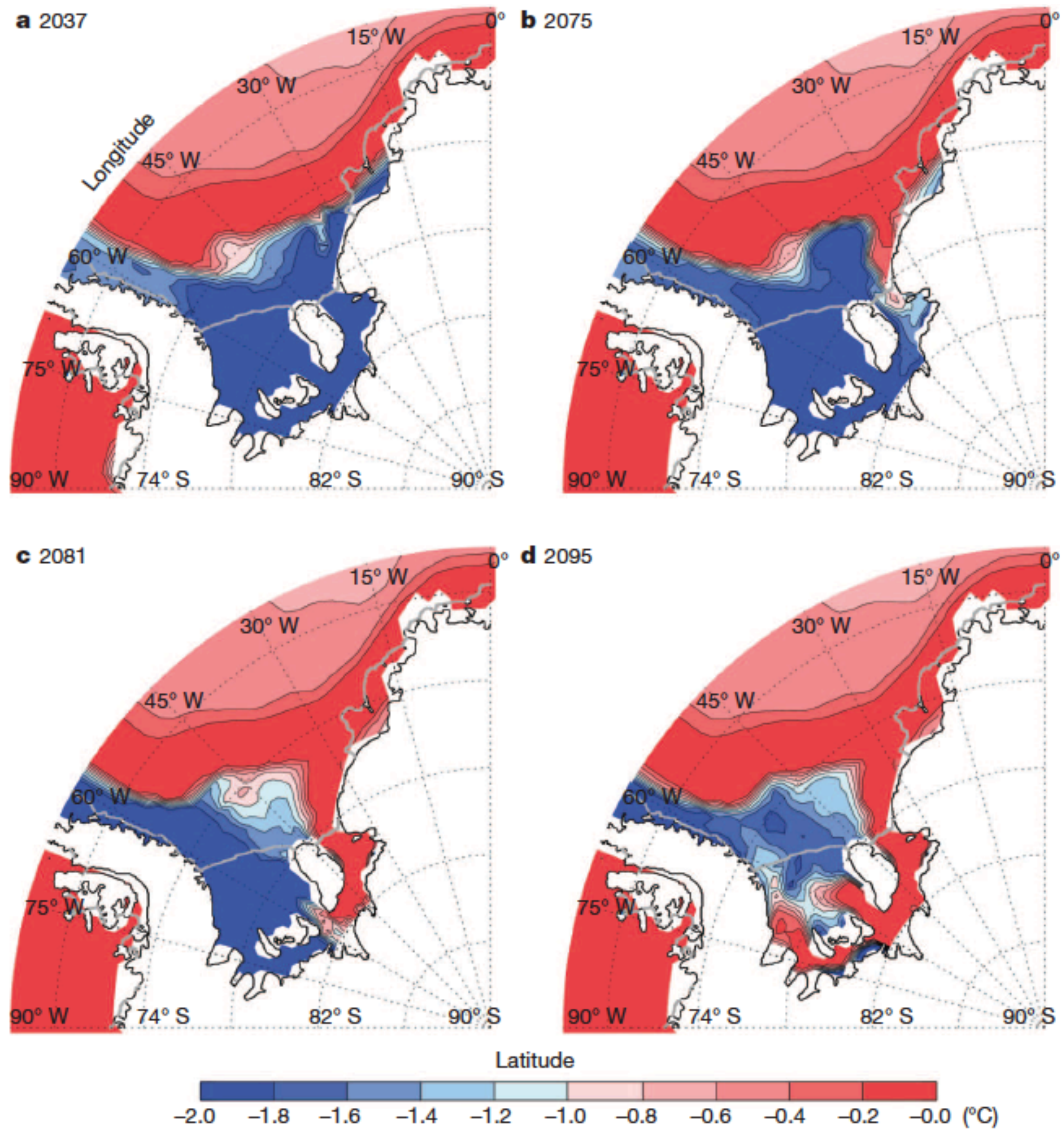
Weddell Sea & Filchner Ronne ice shelf through the 21st century

Twenty-first-century warming of Filchner-Ronne ice-shelf cavity by a redirected coastal current

Simulated evolution of near-bottom temperatures in the Weddell Sea suggests intrusion of warmer waters in mid-21st century.

How realistic/likely?

Hellmer et al. (2012)



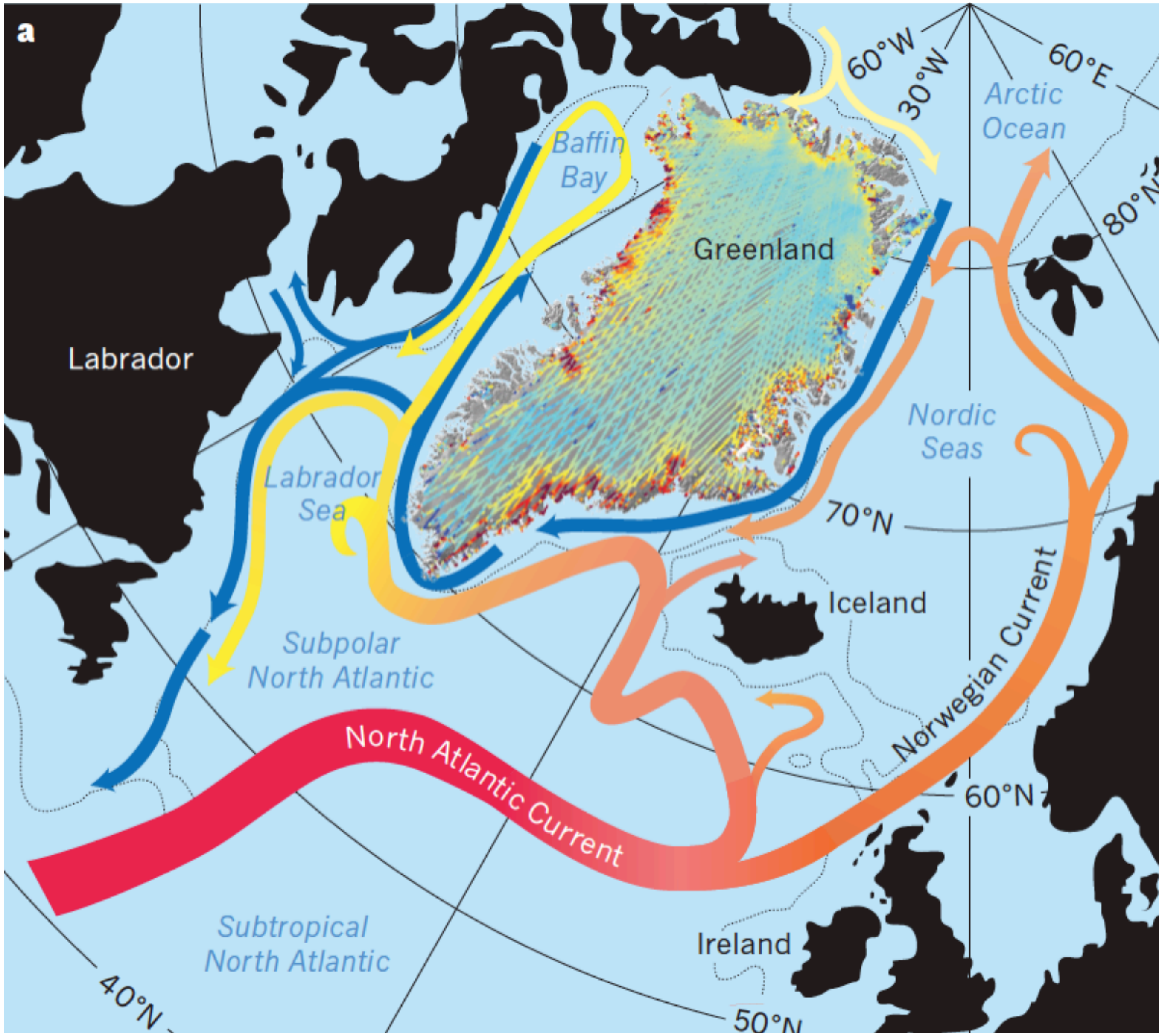
Greenland

Climatic forcing of observed changes

Ocean: North Atlantic circulation changes

Changes in North Atlantic circulation since the mid 1990s has brought more warm, salty water of subtropical origin to the margins of the GrIS and in contact with outlet glaciers

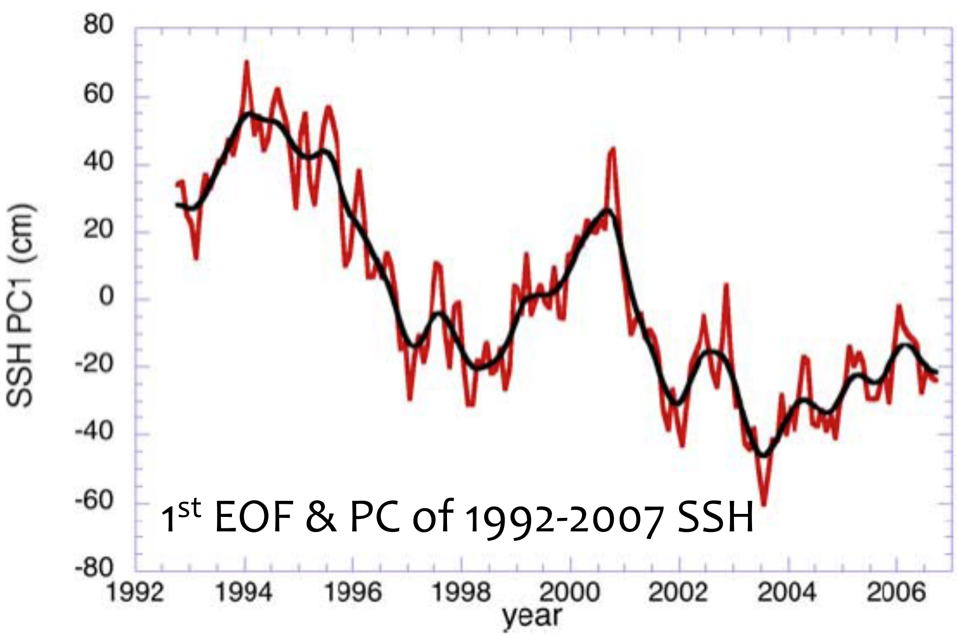
Straneo & Heimbach (2013)



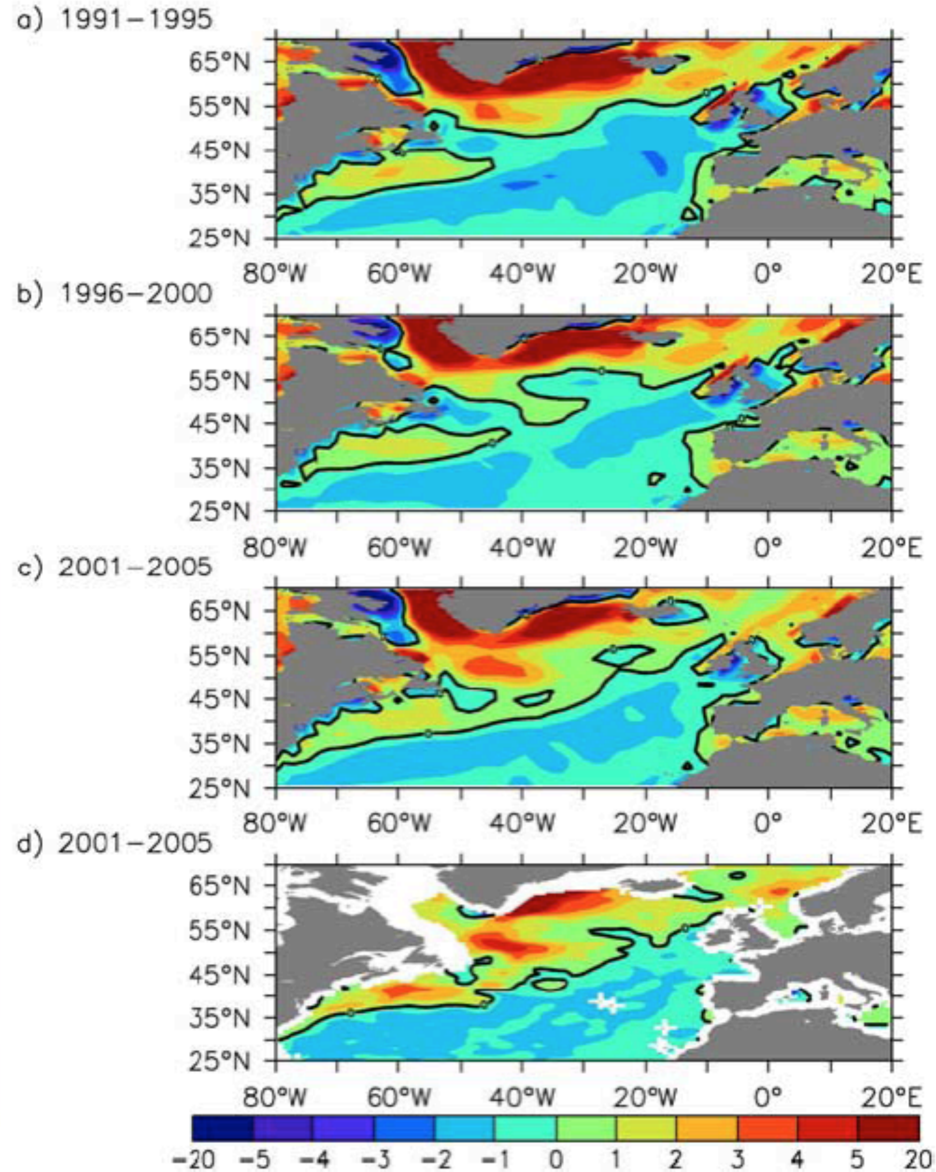
Subpolar gyre (SPG) decadal variability

- a cyclonic circulation pattern with mean negative SSH anomalies
- slowdown & warming of the SPG starting in the mid-1990's

Hakkinen & Rhines (2004,2009)

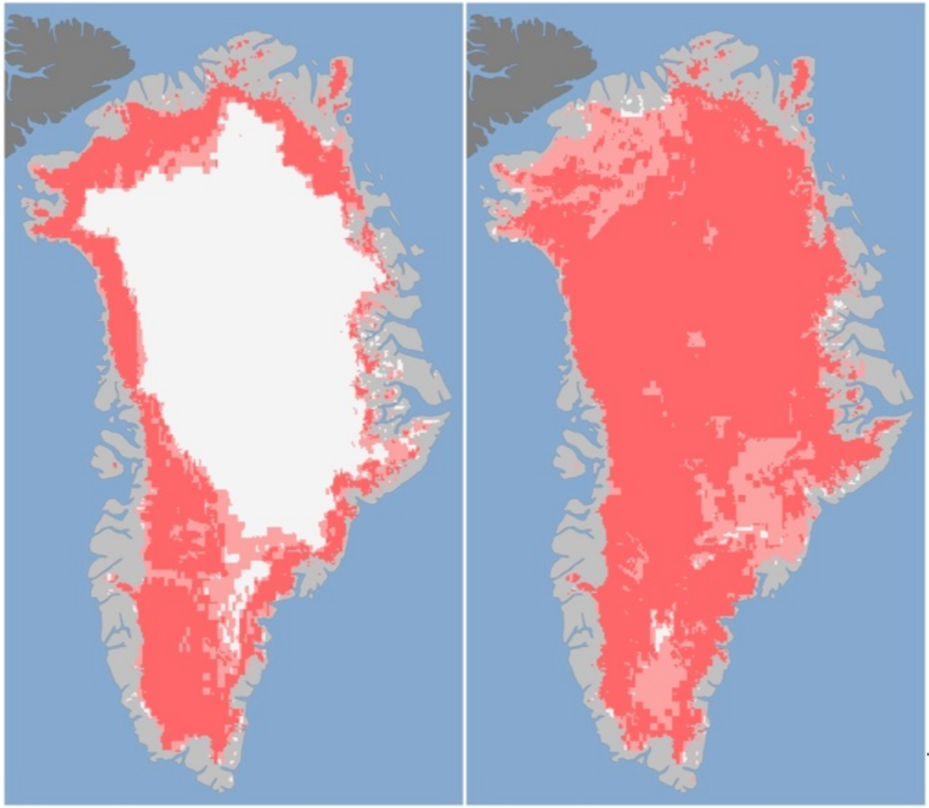


JAN to MAR wind stress curl



Climatic forcing of observed changes

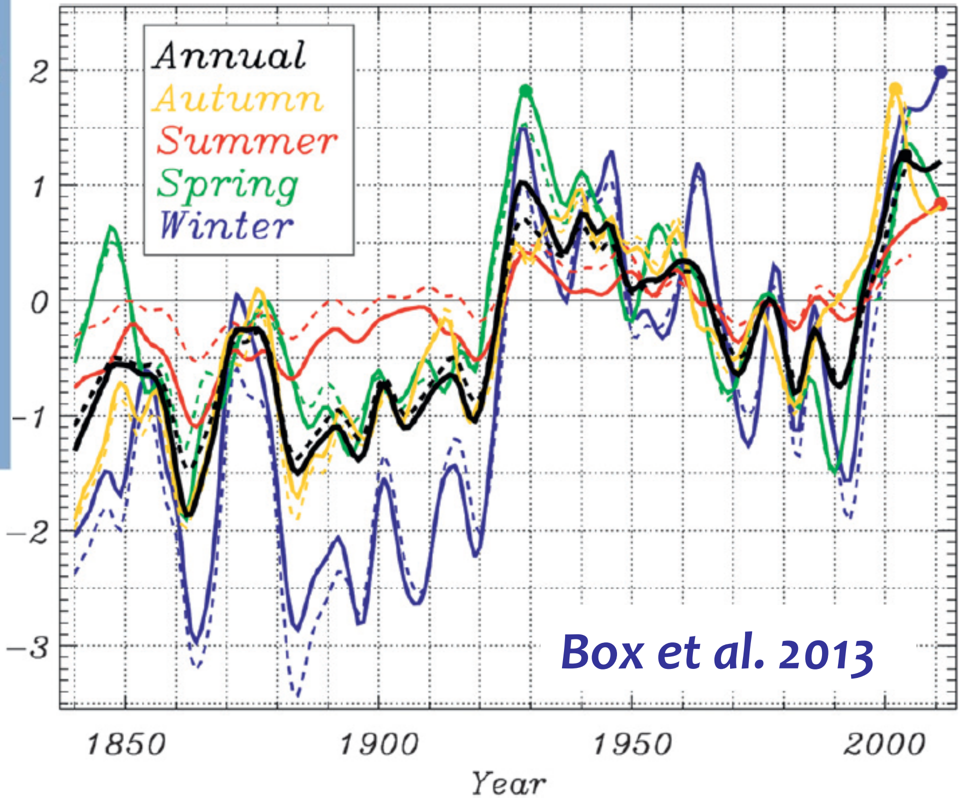
Atmosphere: Increased surface melting



July 8, 2012 July 12, 2012

Unprecedented Greenland Surface Melting 2012

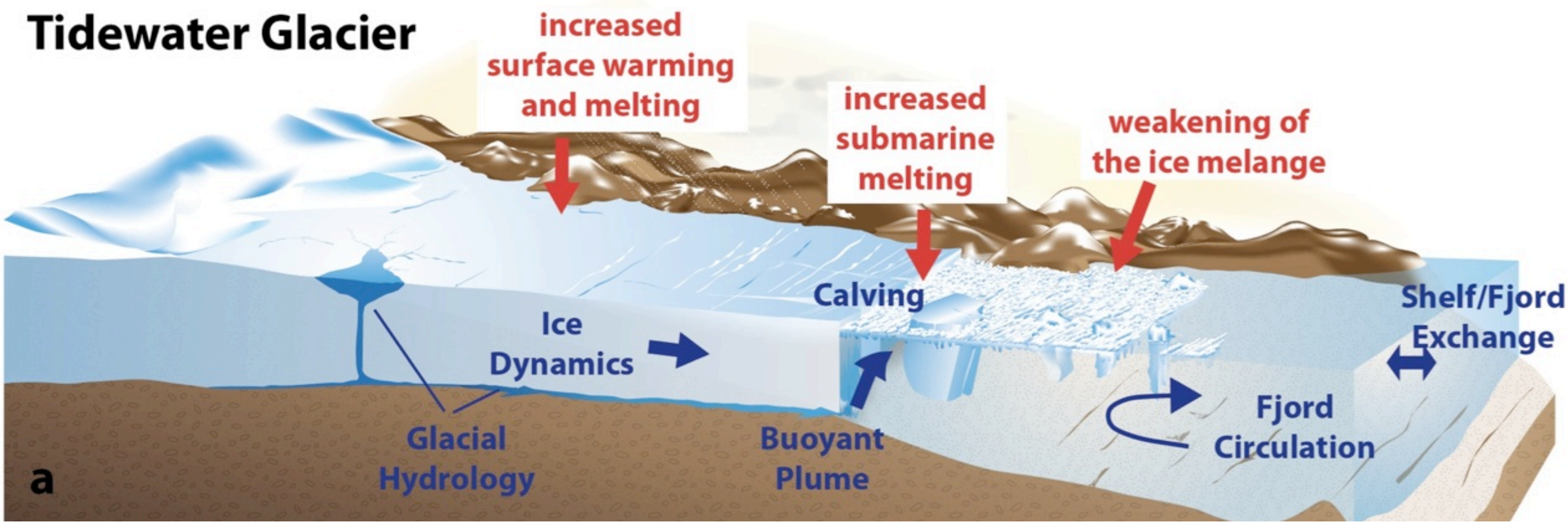
Seasonal and annual Greenland surface-air-temperature anomalies relative to the 1951-1980



Source:
http://www.nasa.gov/topics/earth/features/greenland-melt.html

Processes: dominant controls at the process level

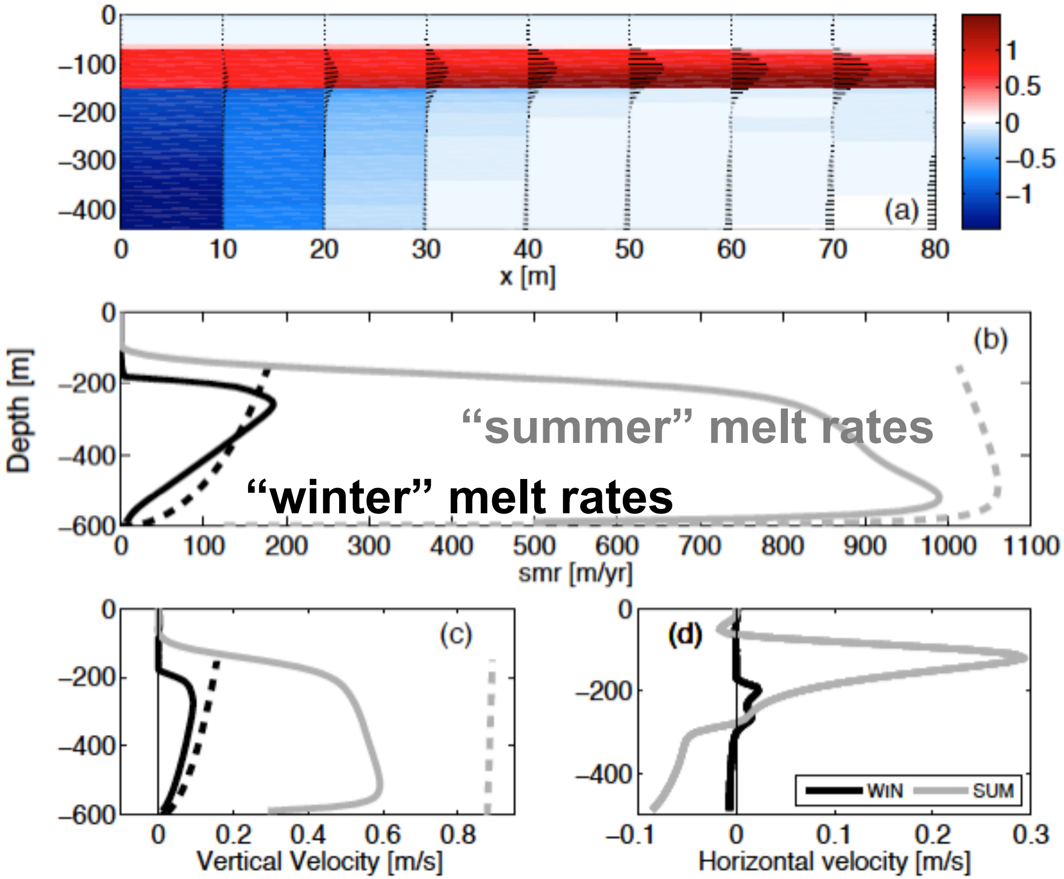
- Climatic amplifiers of thinning/acceleration/retreat of marine-terminating outlet glaciers:
  - warm subsurface waters of subtropical Atlantic origin
  - subglacial runoff originating from surface glacial meltwater
  - weakening of ice melange in the fjord
- Increased melting & calving elicits glacier dynamic response



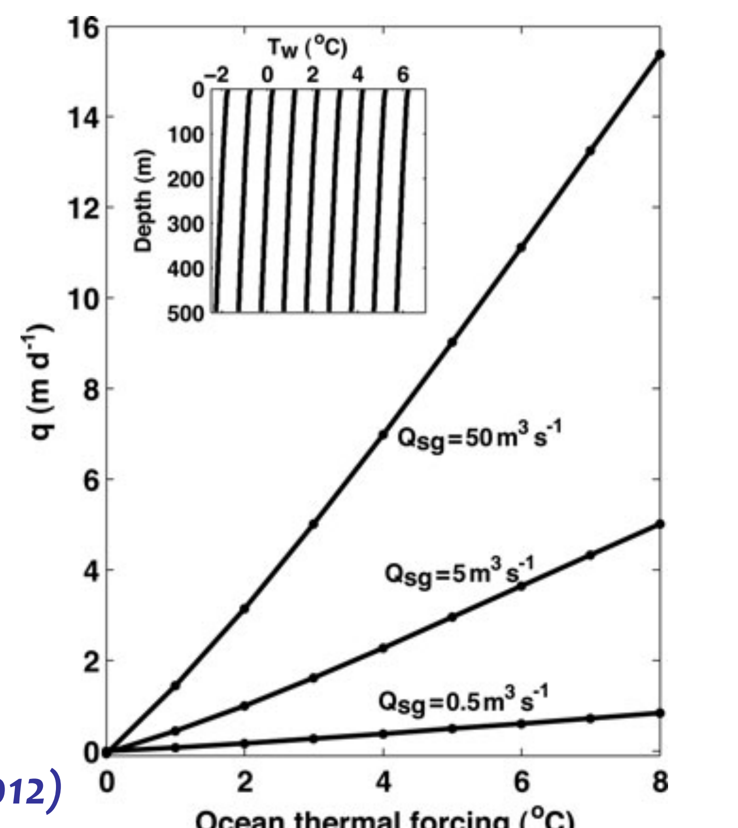
Straneo et al. (2013); Straneo & Heimbach (2013)

Climatic forcing of observed changes

Sciascia et al. (2013)



Melt rate estimates for typical winter (black) vs. summer (grey) discharge rates using the MITgcm (solid) and a plume model (dashed)

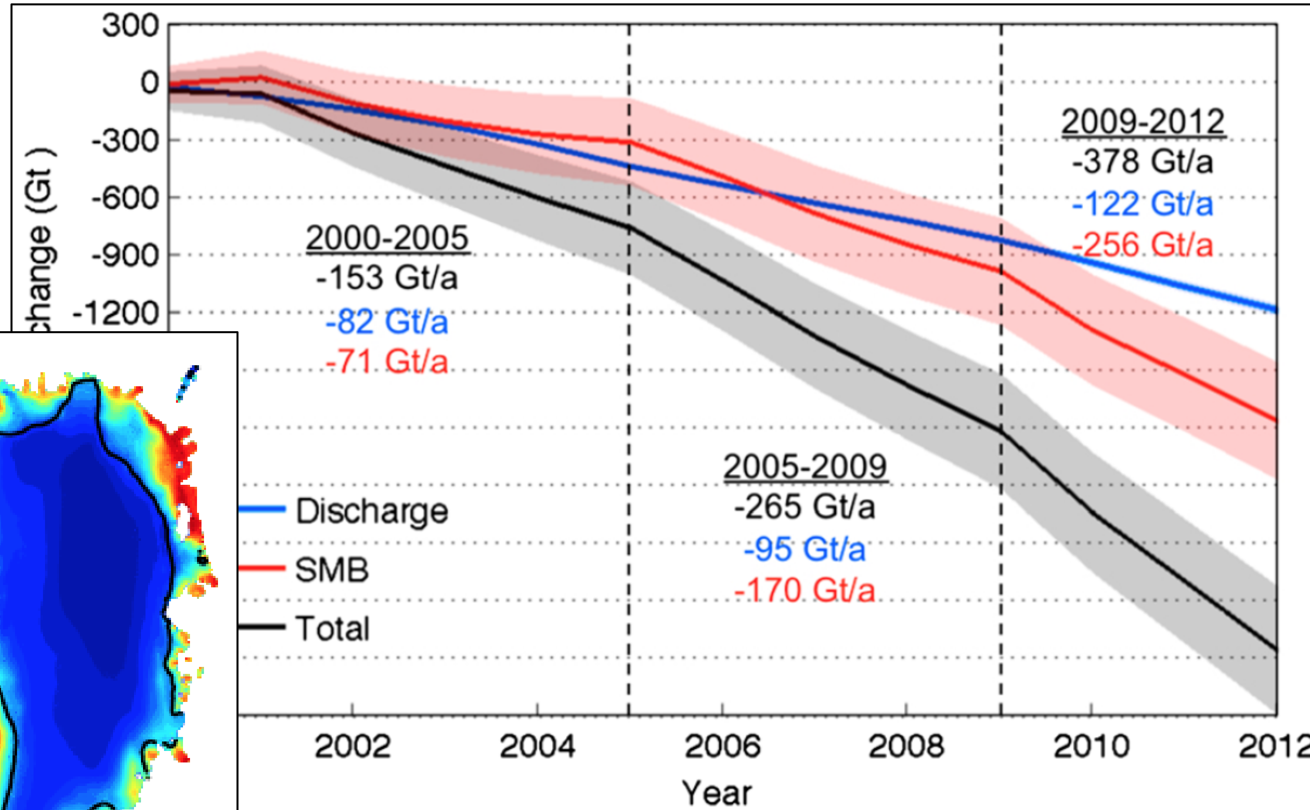


Subglacial runoff a dominant control on submarine melt rates

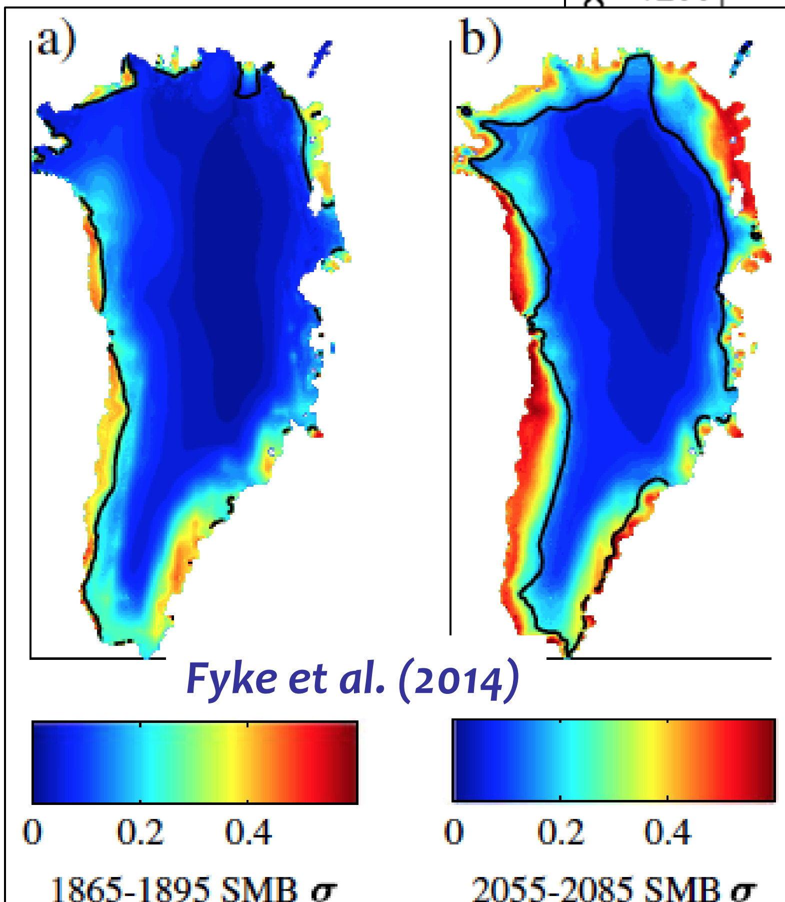
Xu et al. (2012)

An important part not discussed here: Role of "Surface Mass Balance"

Significant increase in interannual SMB variability over time due to ablation area expansion.



Enderlin et al. (2014)

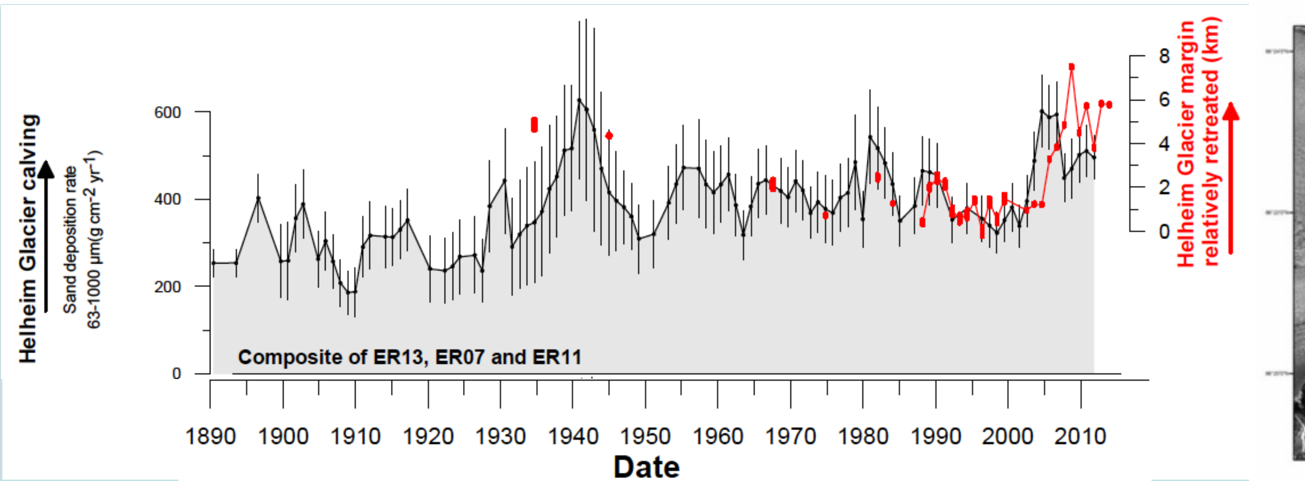


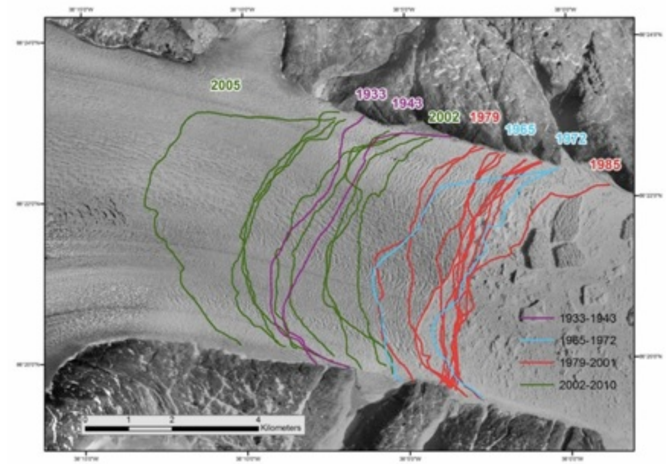
Fyke et al. (2014)

Shift over time from ice discharge- to SMB-dominated contribution to Greenland mass loss and global sea level rise

Support for climate forcing hypothesis

Towards centennial reconstructions

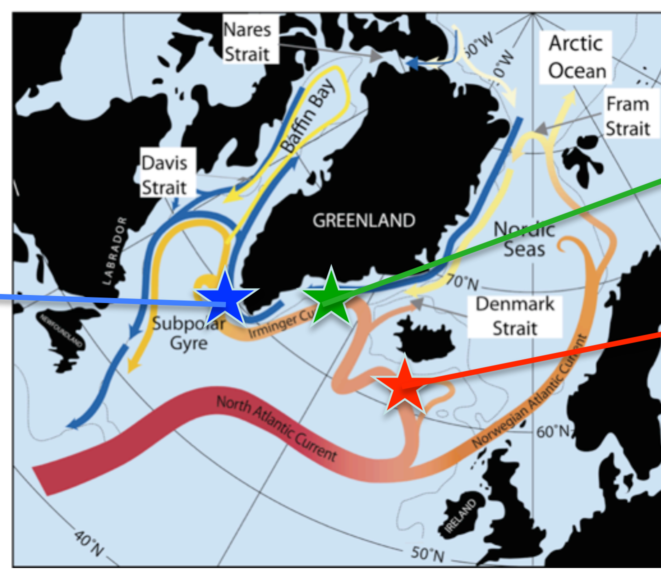




Helheim Glacier responds to short-term fluctuations of large-scale oceanic and atmospheric conditions, on timescales of 3–10 yrs

Polar Water/*Storis*

North Atlantic Oscillation (*Hurrell*, 1995)



Shelf Index
Combined Atlantic and Polar Variability

Atlantic Water Index
SST south of Iceland

Andresen et al. (2012)

Conclusions & outlook

- DCV(P) ***is*** relevant in the context of
  - understanding recent changes in polar ice sheets,
  - their future contribution to global sea level rise
- Causal mechanisms remain uncertain
- Observations are sparse, challenging to obtain, and time series of too short duration
- Detailed process understanding required to unravel link between climatic forcings and glacier response
- Requires in turn:
  - small-scale observations (ocean/atmosphere/ice sheet)
  - long-term monitoring at marine margins
- A fundamentally multi-disciplinary & international challenge
- A role to play for climate dynamicists