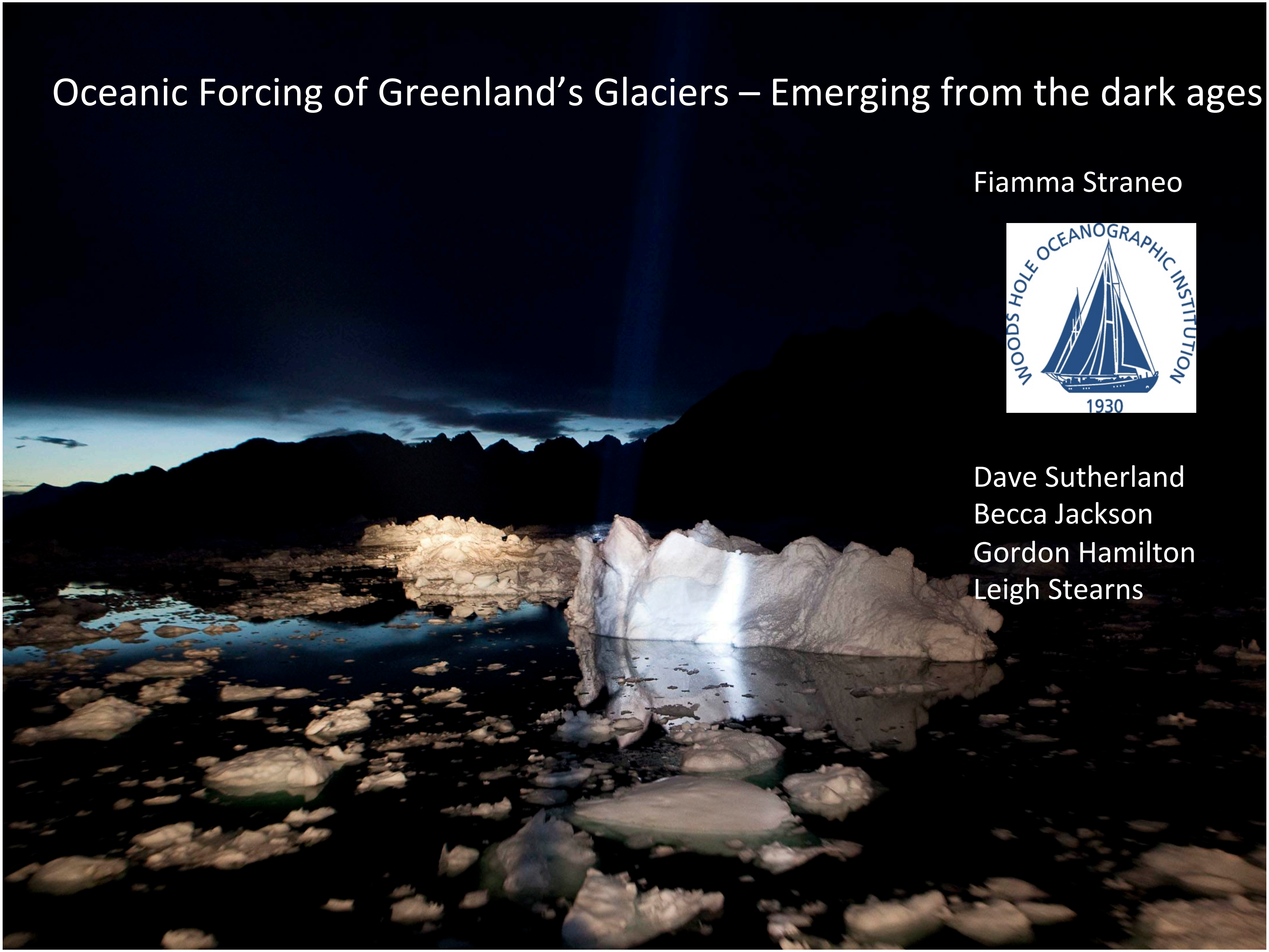


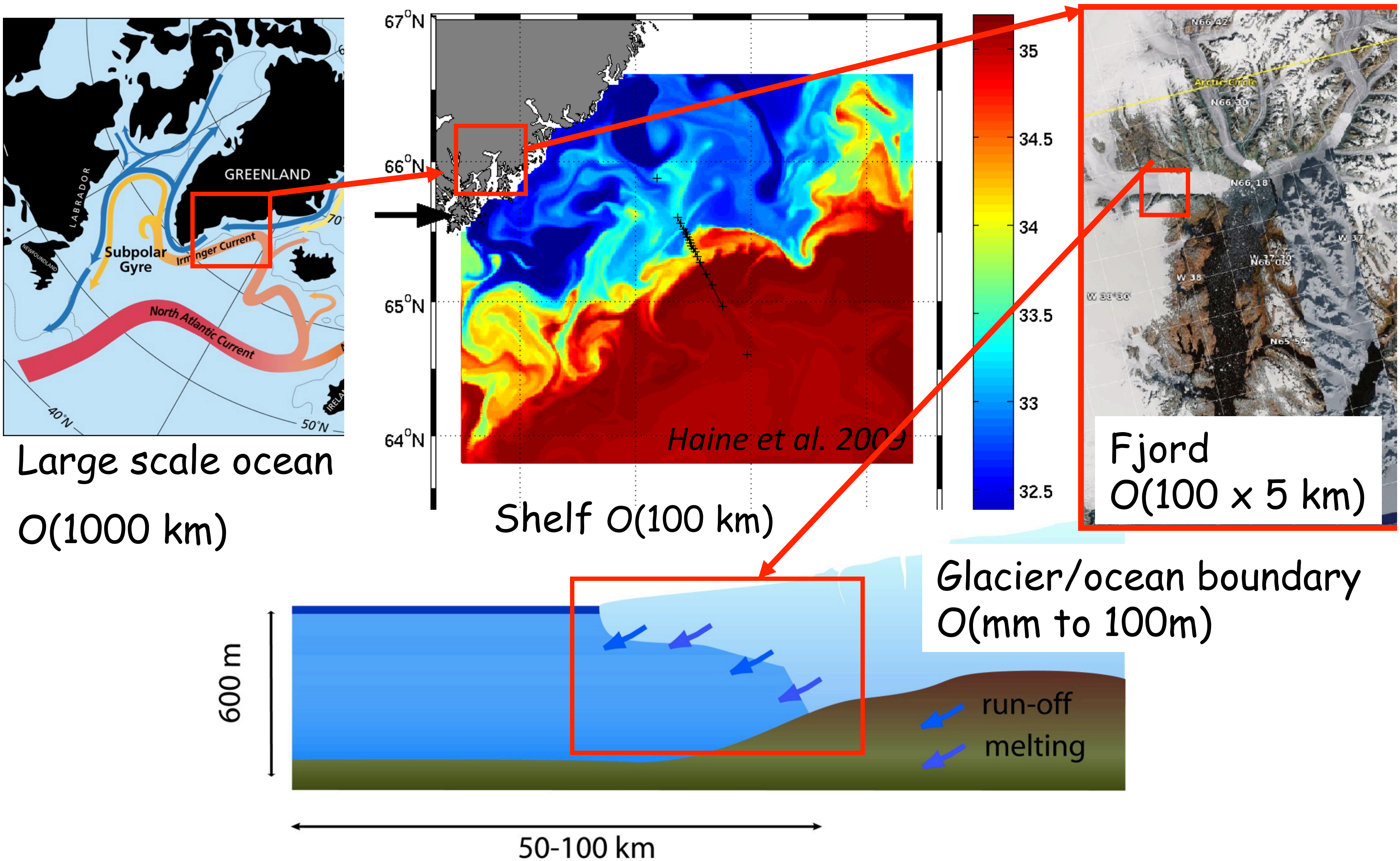
Oceanic Forcing of Greenland's Glaciers – Emerging from the dark ages

Fiamma Straneo

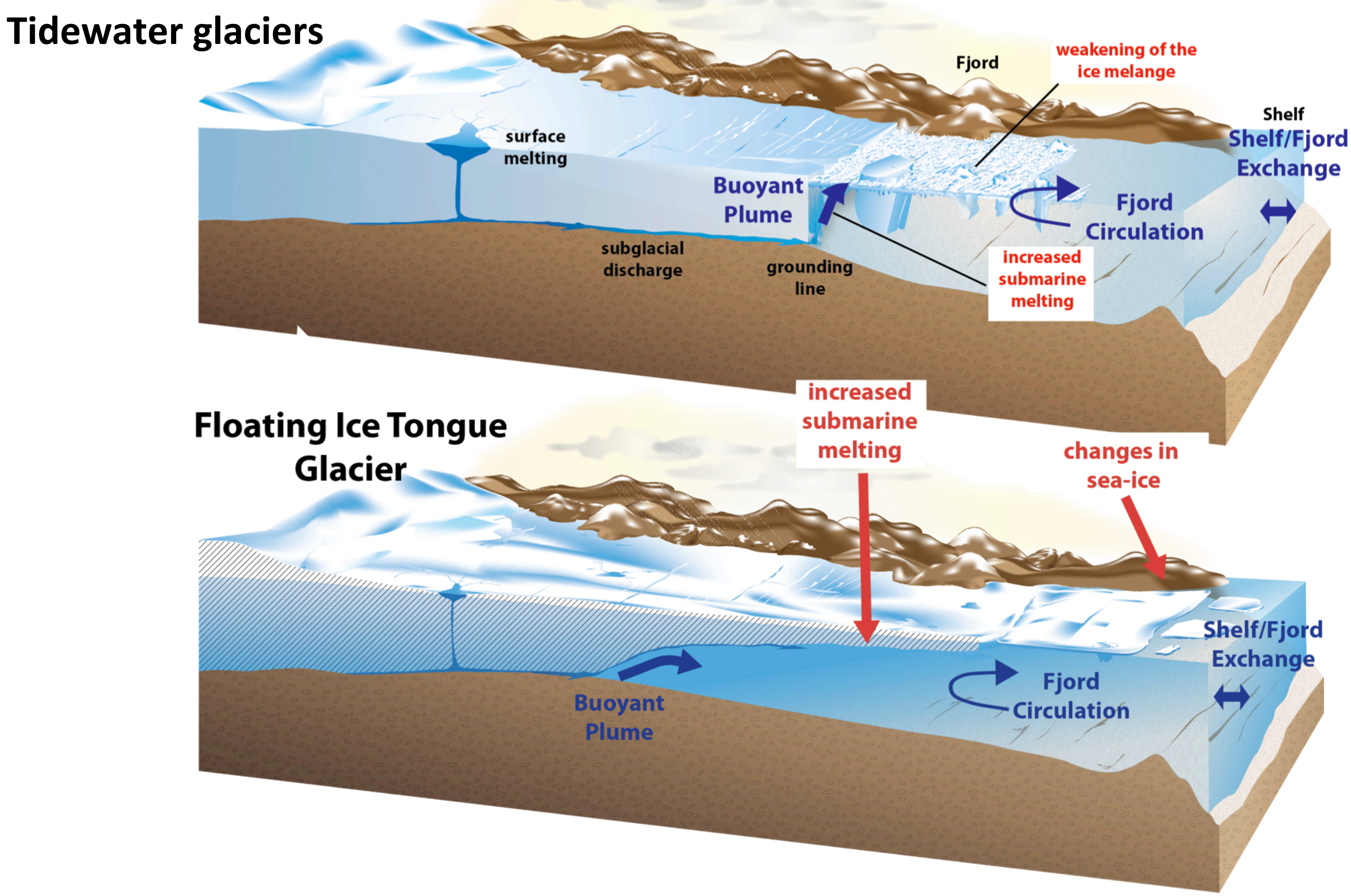
Woods Hole Oceanographic Institution 1930

Dave Sutherland
Becca Jackson
Gordon Hamilton
Leigh Stearns

Linking Ocean and Glacier Variability



What direct oceanic forcing affects Greenland's marine terminating glaciers?



Thermodynamic Melting of terminus, ice tongue and ice melange

Mechanical - wave, tidal action, energy for mixing → submarine melting

What have we learned in the last 5-6 years about the properties and circulation in Greenland glacial fjords?

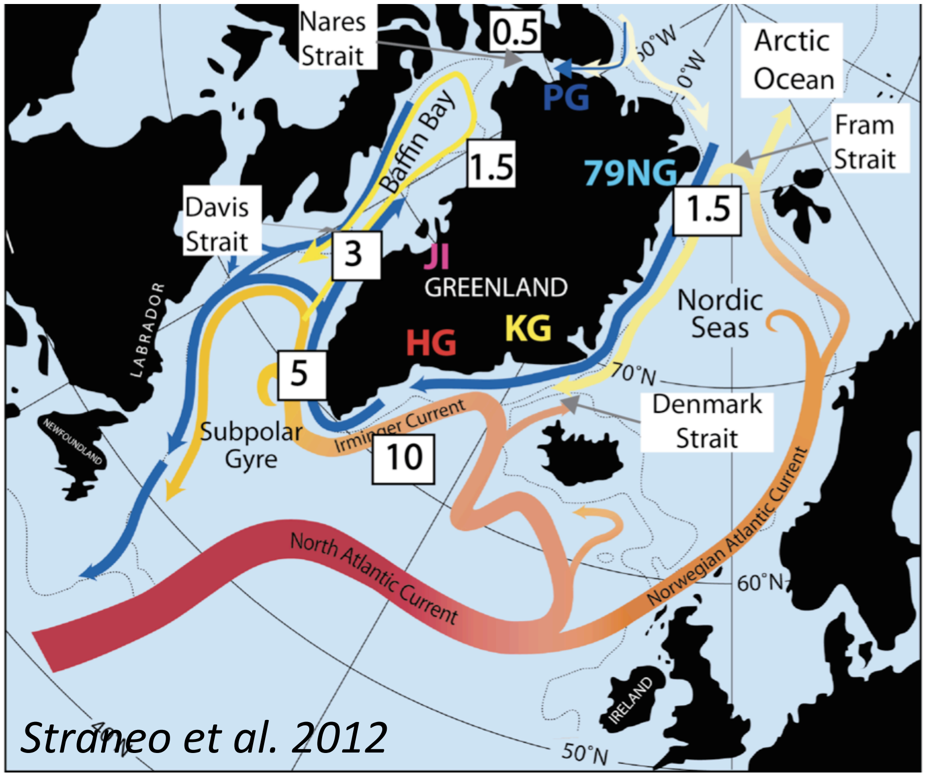
1. **Properties and origins of the fjord waters**

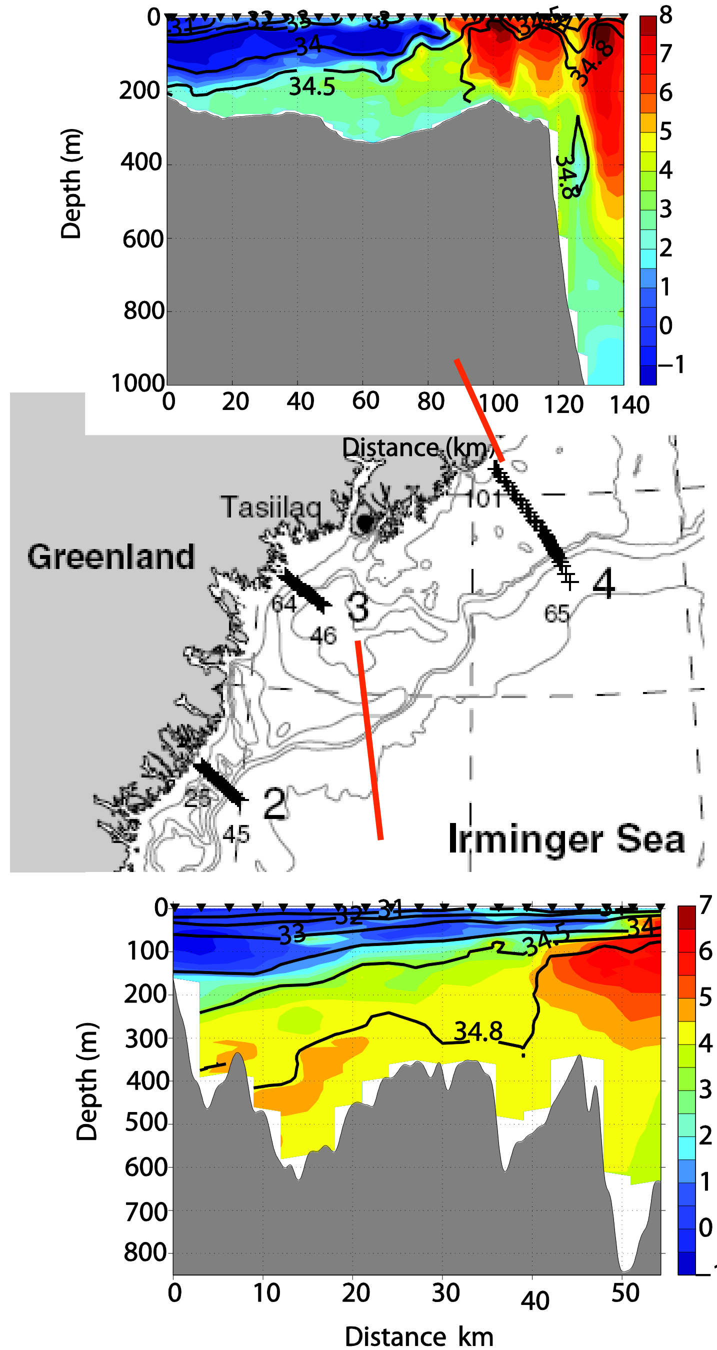
2. **Variability (Interannual, seasonal, shorter)**

3. **Circulation**

4. **Implication for submarine melt rates**

Shelf Circulation and Properties

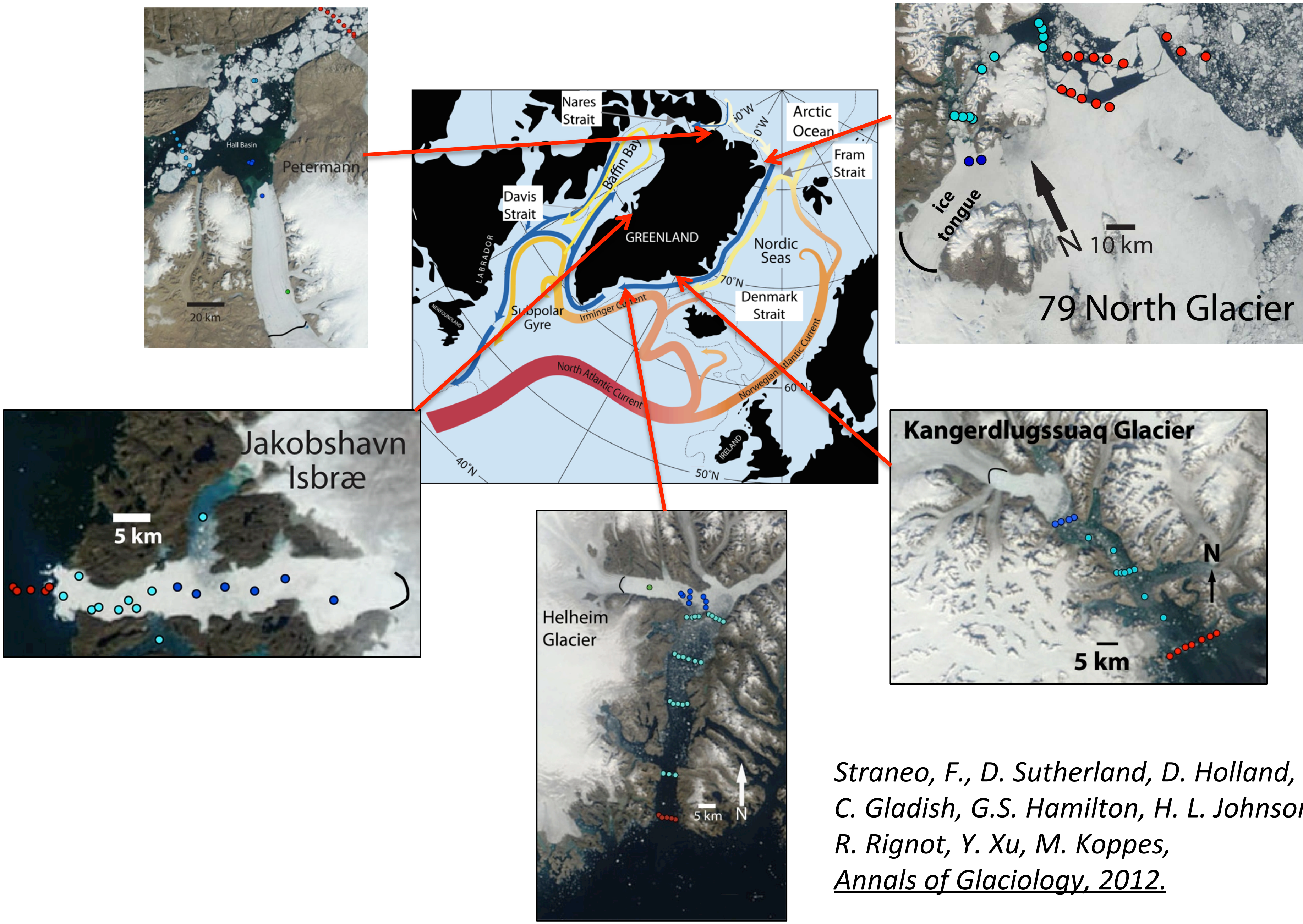




Sutherland and Pickart 2008

- **Arctic waters above/along Atlantic Waters all around Greenland**
- **Troughs enable Atlantic Waters to reach the coastal margins**

Fjord Surveys

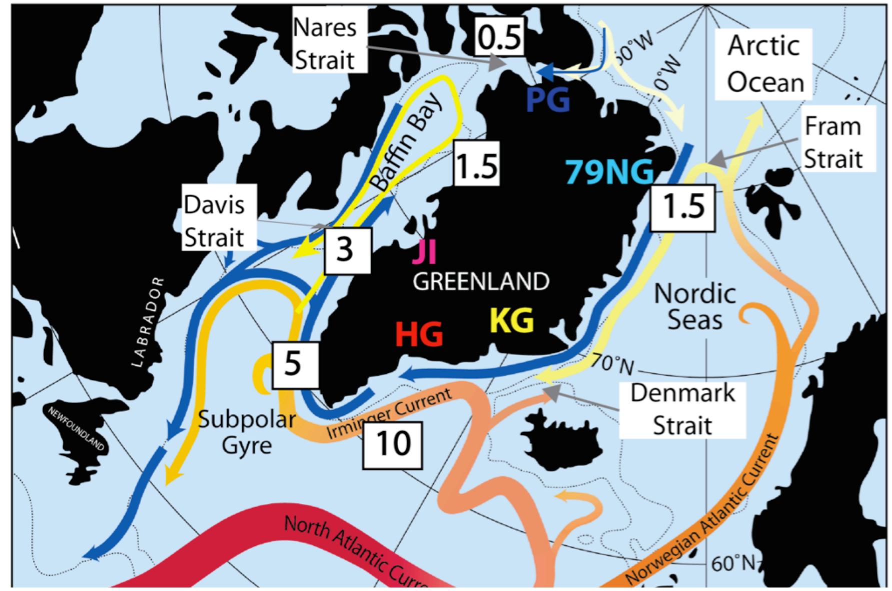


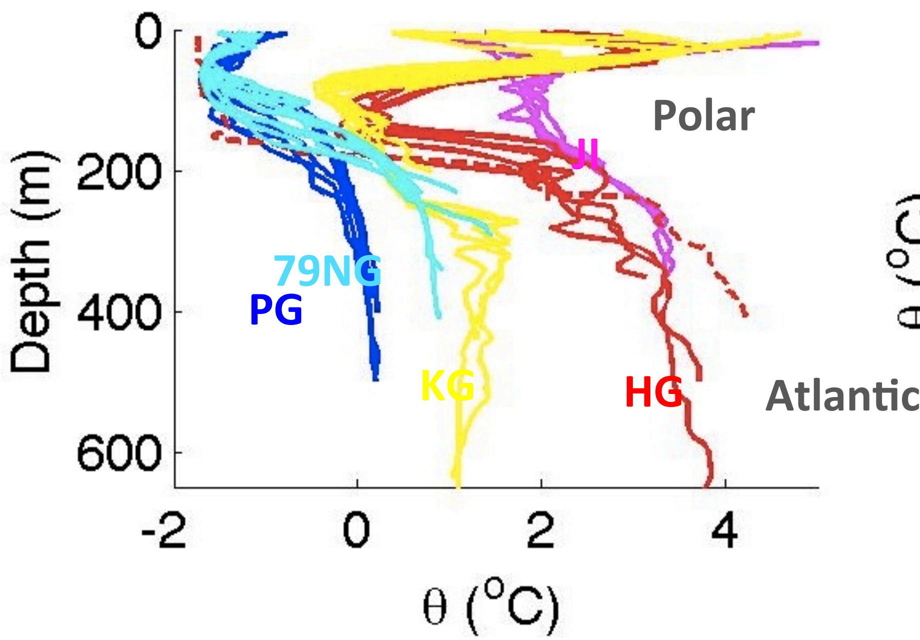
Straneo, F., D. Sutherland, D. Holland, C. Gladish, G.S. Hamilton, H. L. Johnson, R. Rignot, Y. Xu, M. Koppes, Annals of Glaciology, 2012.

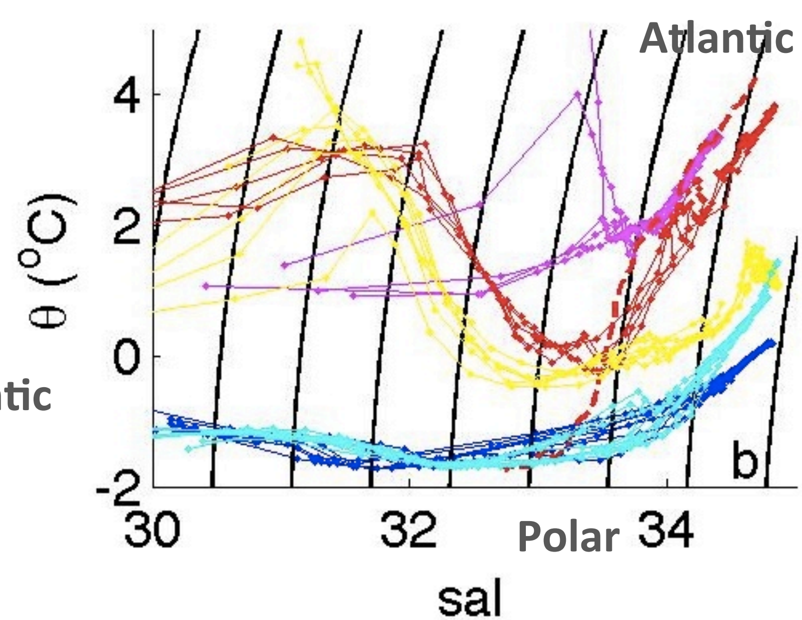
ÞYTUR
GREENPEACE
ARCTIC SUNRISE
MARINA ARCTICA
GASOLIE


LIFEVENTURE

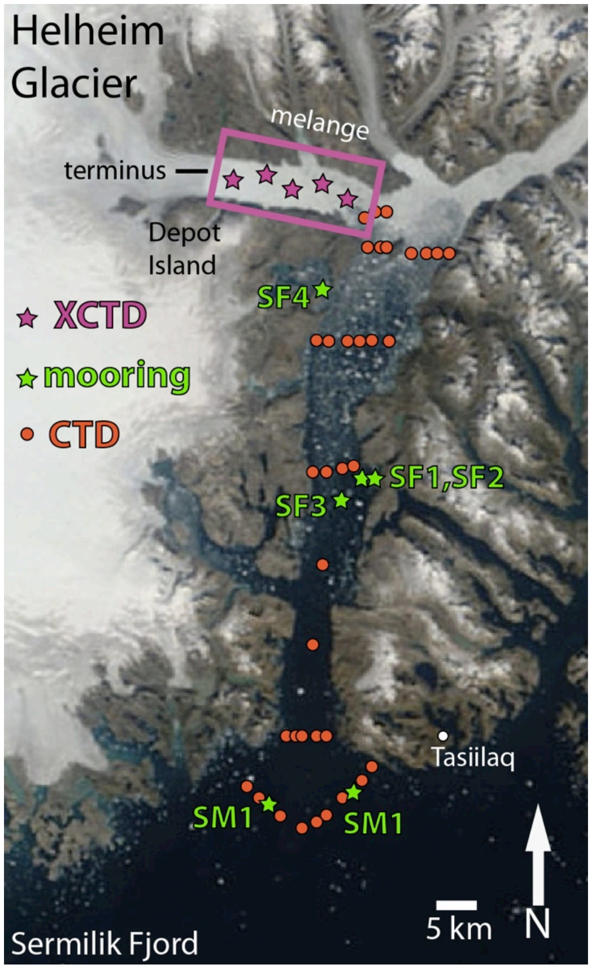
- Atlantic and Polar Waters in all major fjords around Greenland
- Fjords are strongly stratified
- Fjord properties roughly match the shelf but also indicate mixing

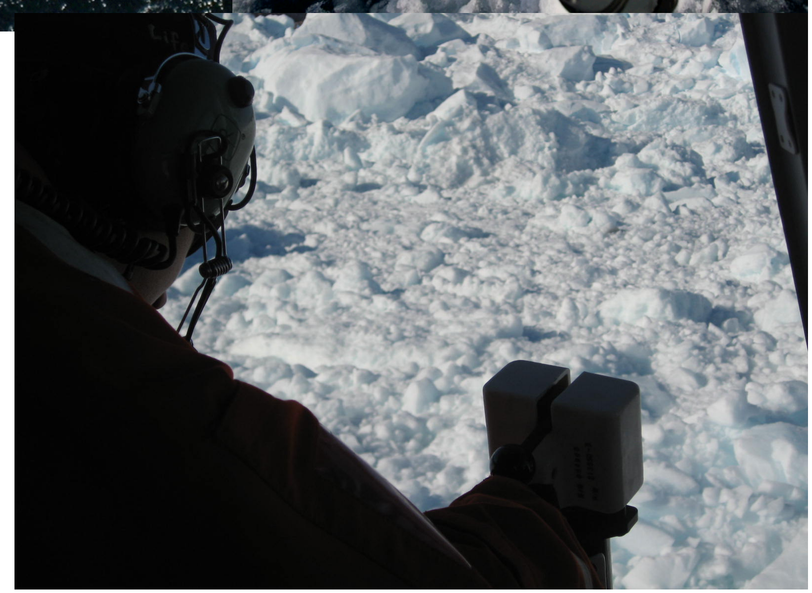




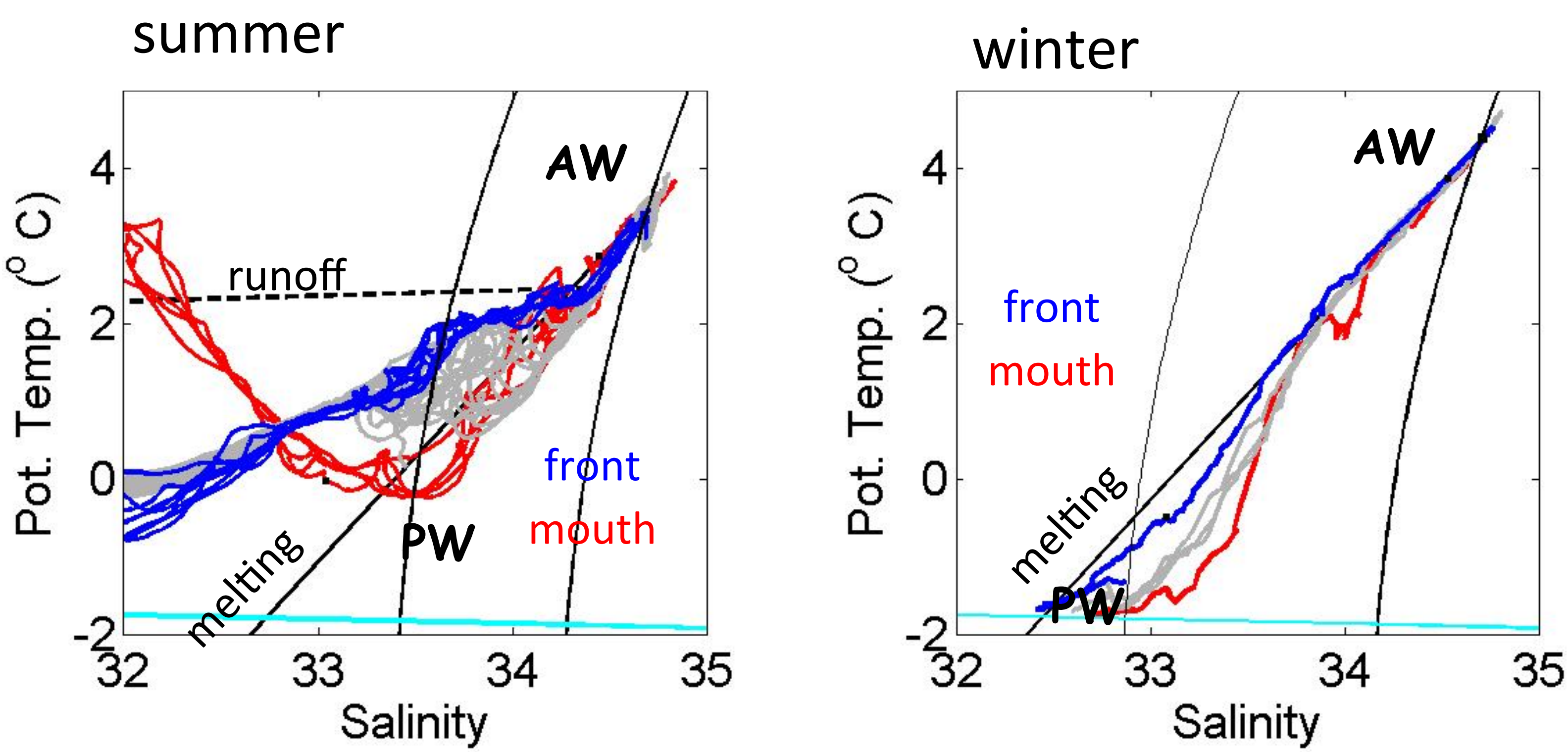


Fjord Sampling





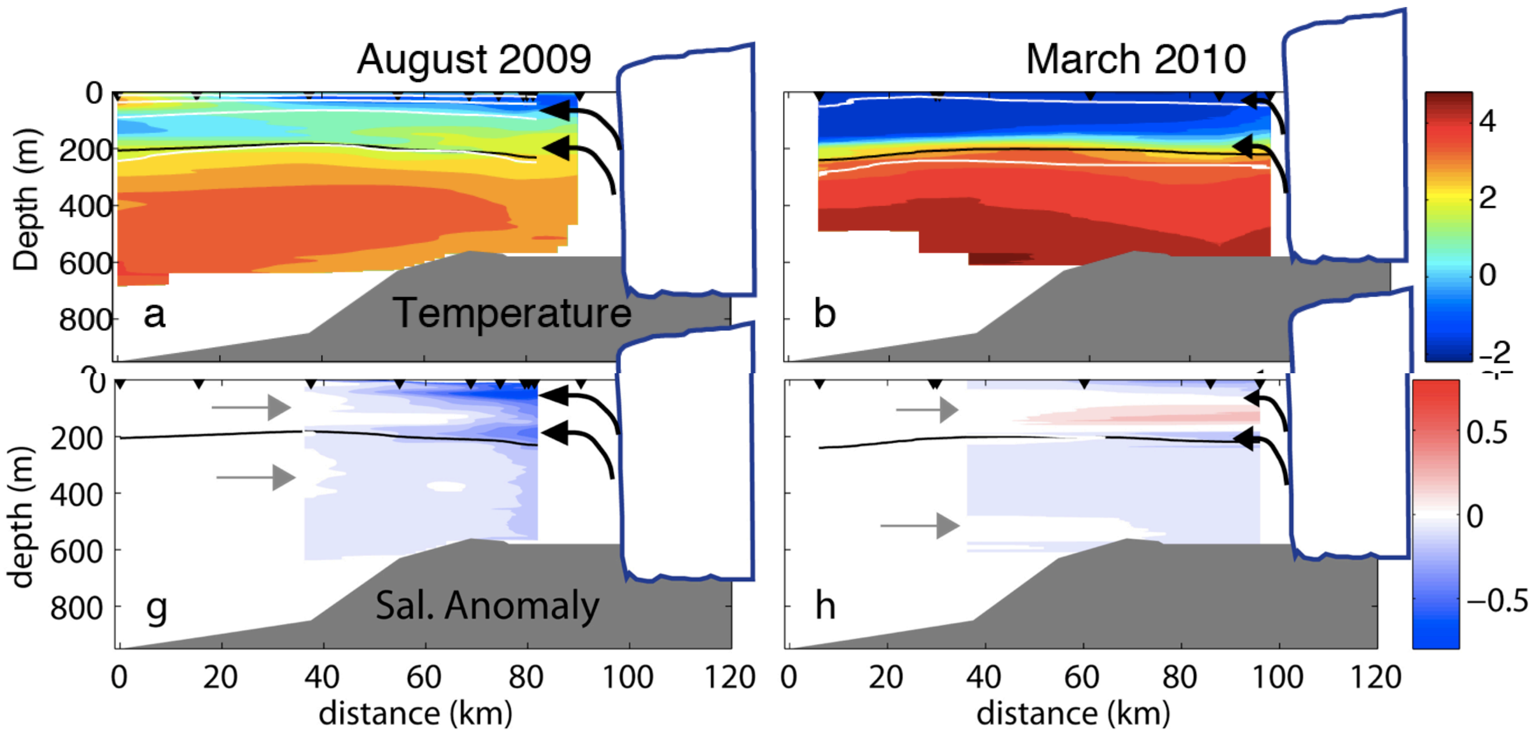
Seasonal Variability and importance of subglacial discharge



- **Mixture of melting and subglacial discharge in summer only**
- **Melting driven by Atlantic Waters**

Straneo et al. 2011

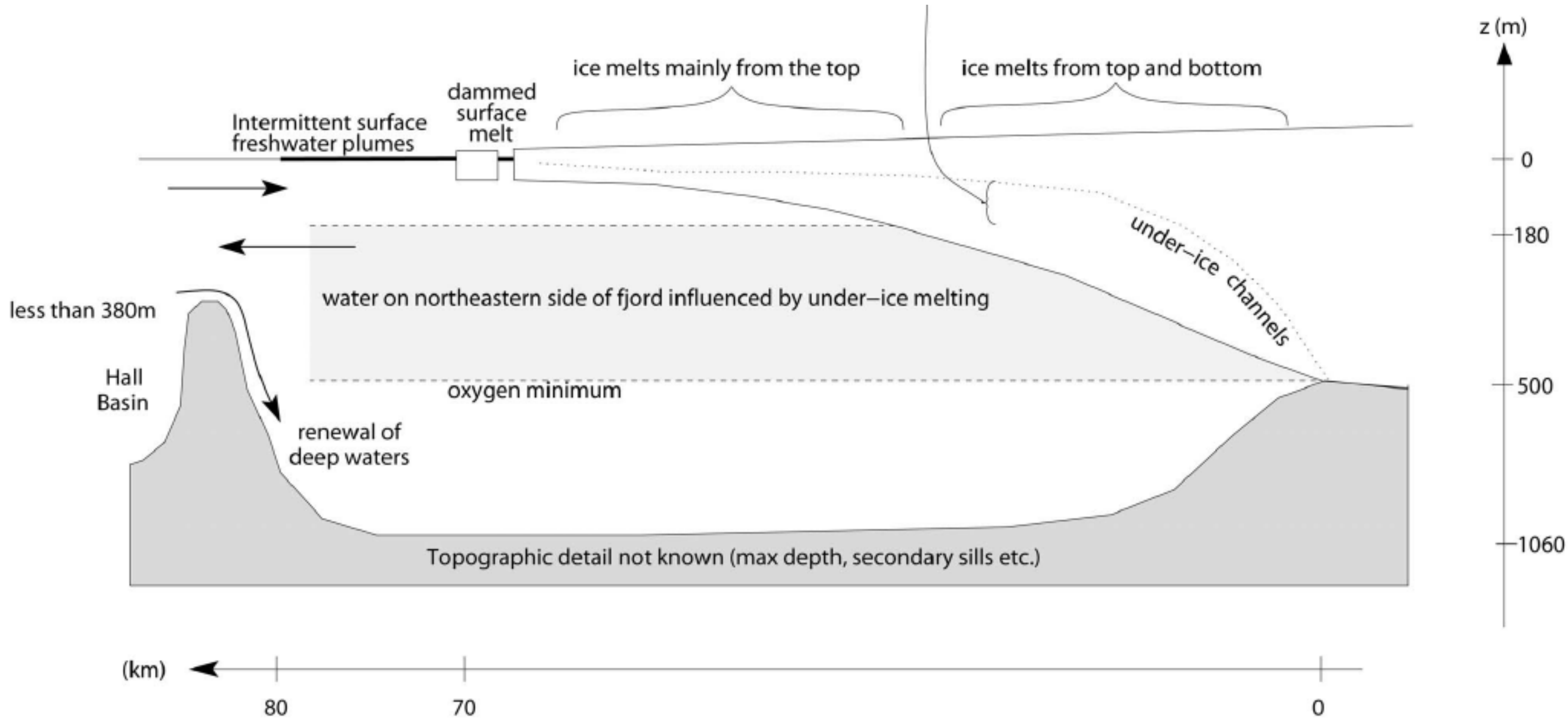
Inferring a circulation from property distribution



Summer - Subglacial discharge is mixed with sea water (and melt water) at depth and emerges both at the surface and at the AW/PW interface

Winter – no subglacial discharge, meltwater emerges mostly at AW/PW interface

Inferring a circulation from property distribution



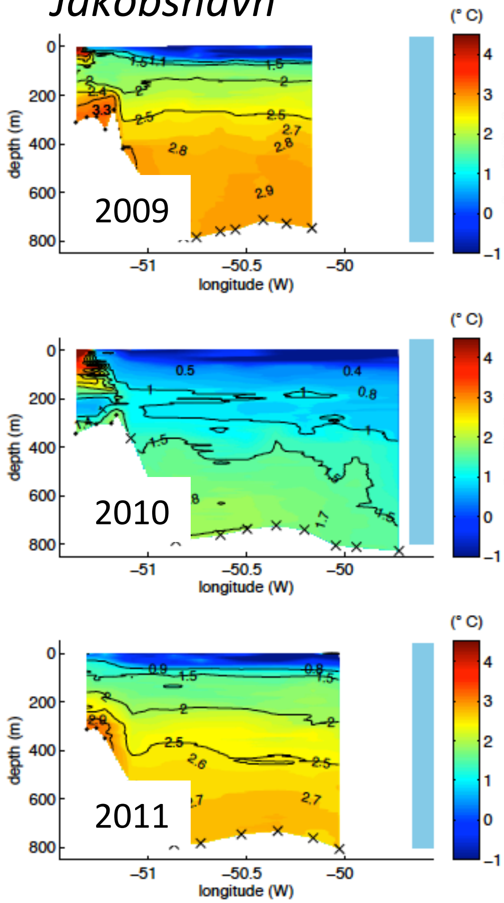
Johnson et al. 2011

Still have not talked about what drives the circulation.

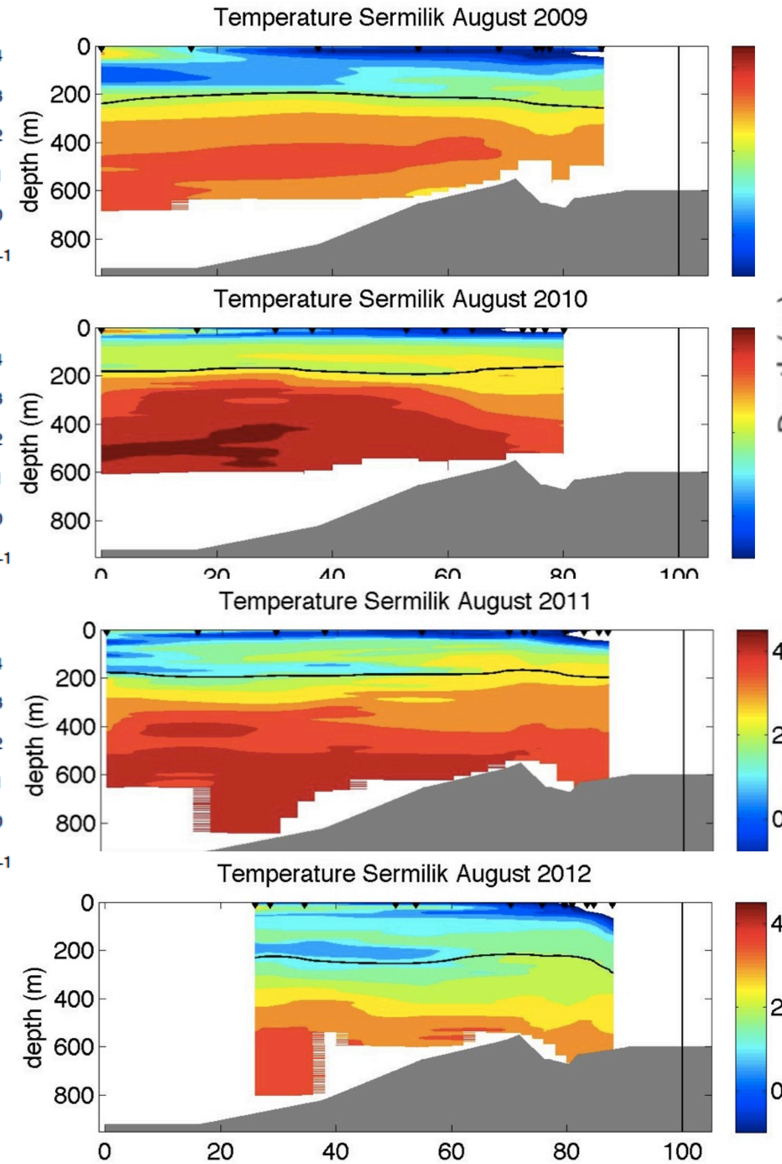
Variability

Interannual

Jakobshavn

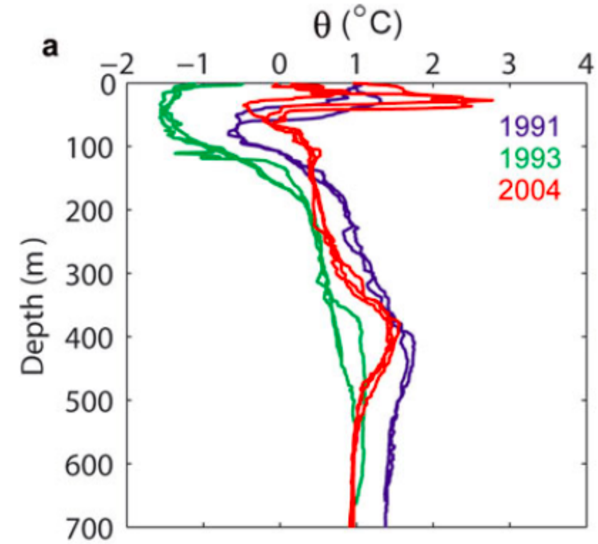


Gladish et al. in prep



Straneo et al. in prep

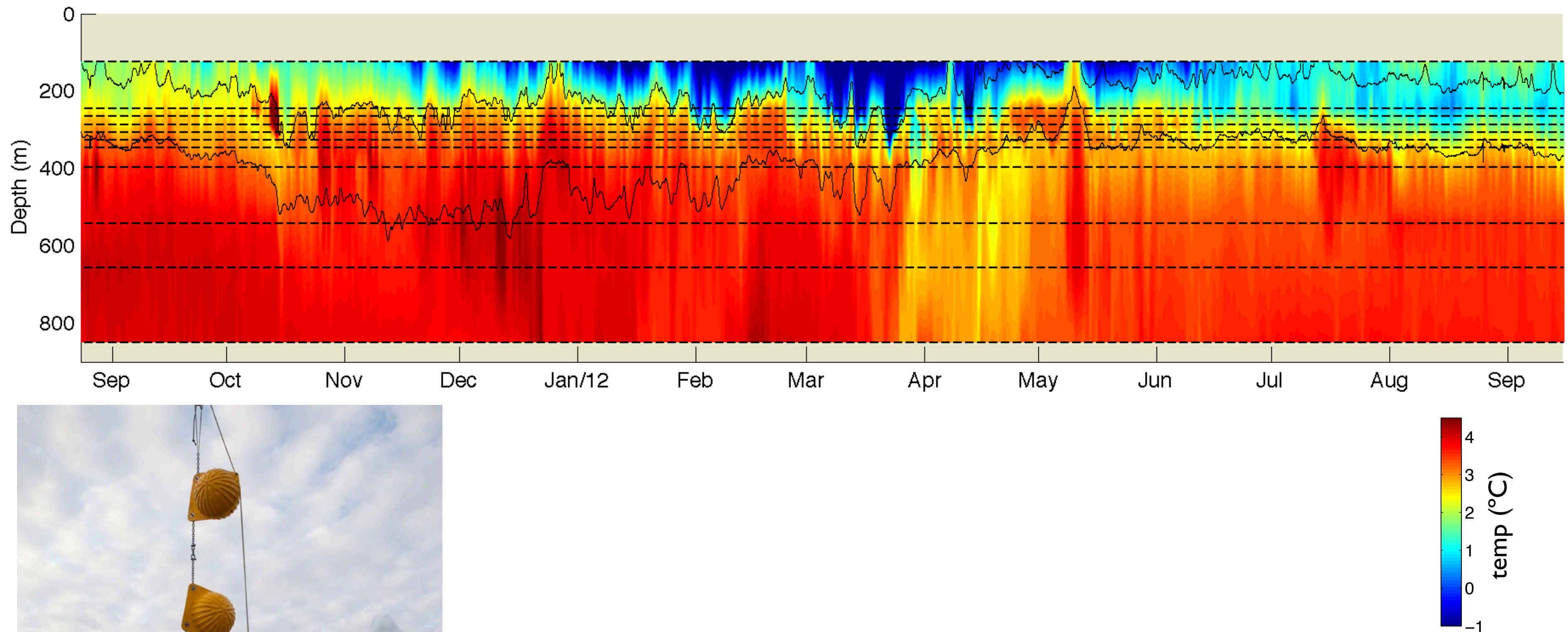
Kangerdlugssuaq



Christoffersen et al. 2012

Johnson et al. 2011, in Petermann Fjord; Mortensen et al. 2011 in Nuuk/KNS Fjord

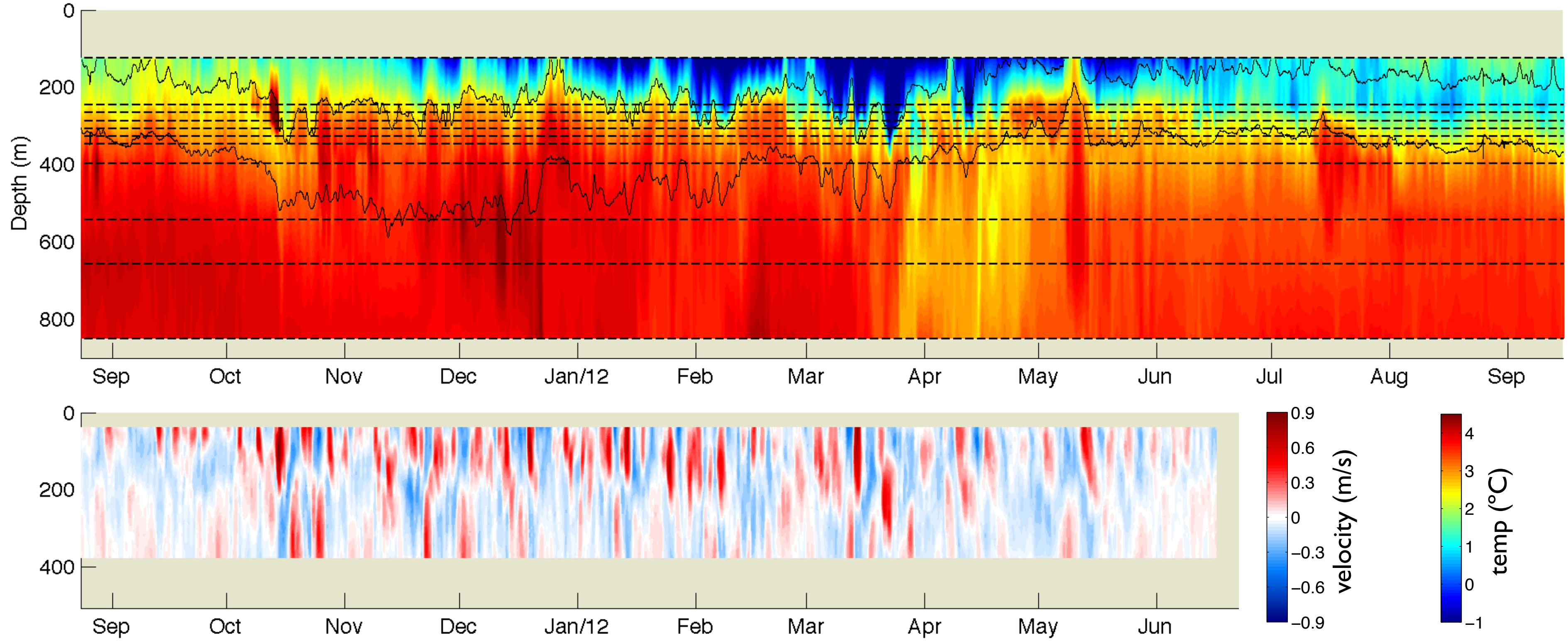
One year record of properties in Sermilik Fjord



Rapid changes in fjord properties on timescales of several days/weeks superimposed on a seasonal variability in the upper layer

Jackson et al. in prep.
and poster

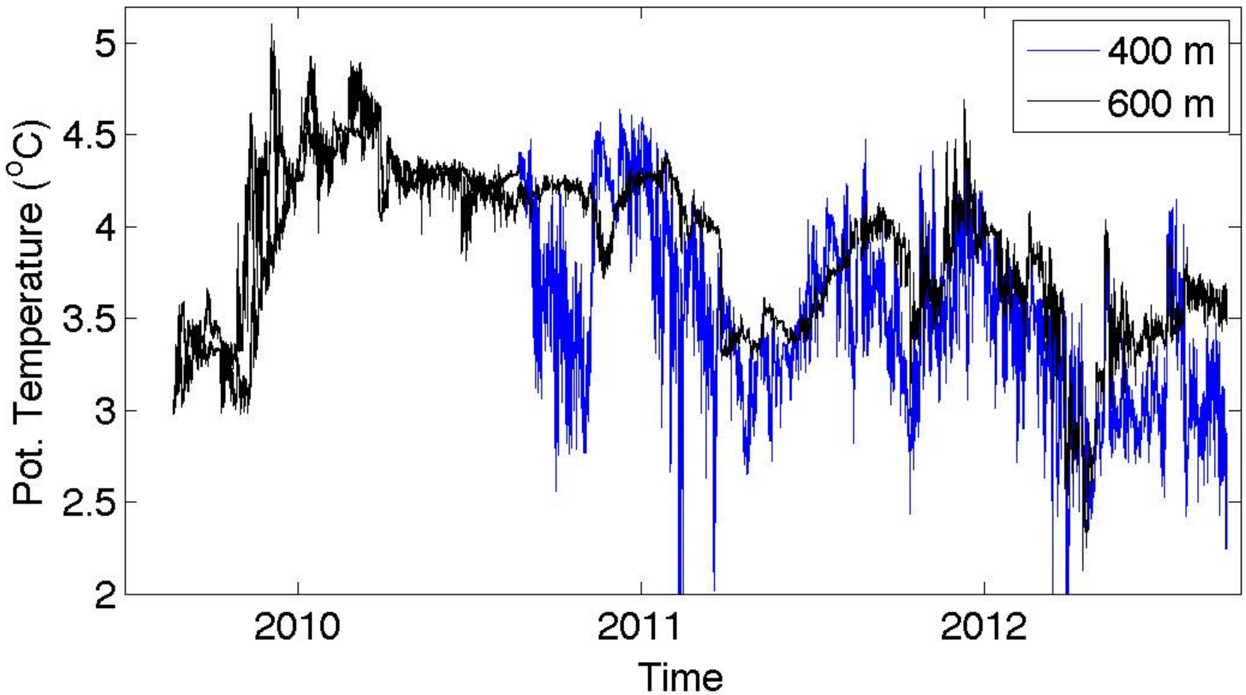
One year record of properties in Sermilik Fjord



Rapid changes in fjord properties associated with STRONG, RAPIDLY VARYING, SHEARED FLOWS

Jackson et al. in prep.
and poster

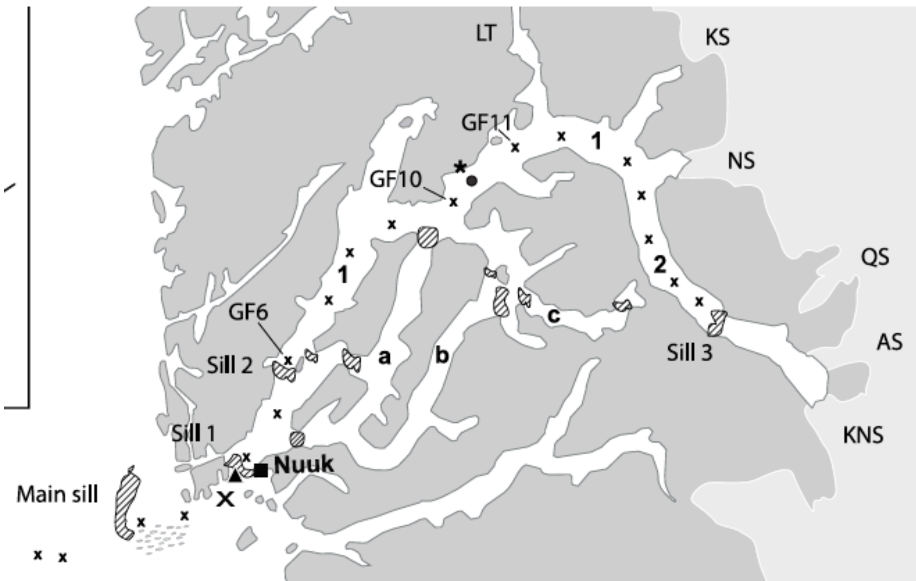
Multiyear records of AW properties from Sermilik Fjord

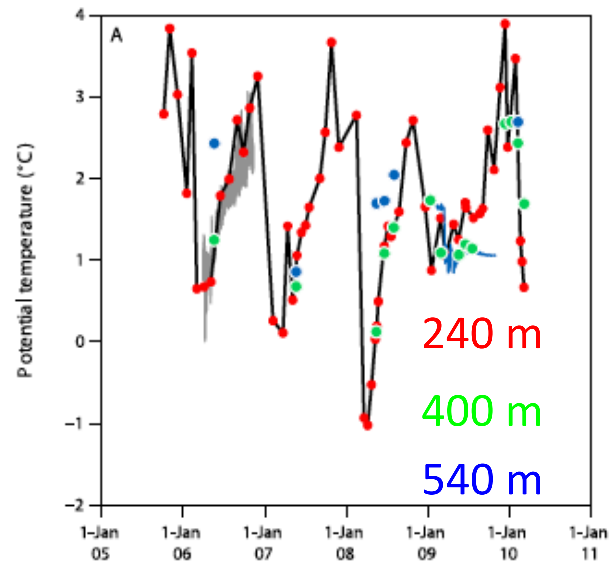


Fjord properties are rapidly changing

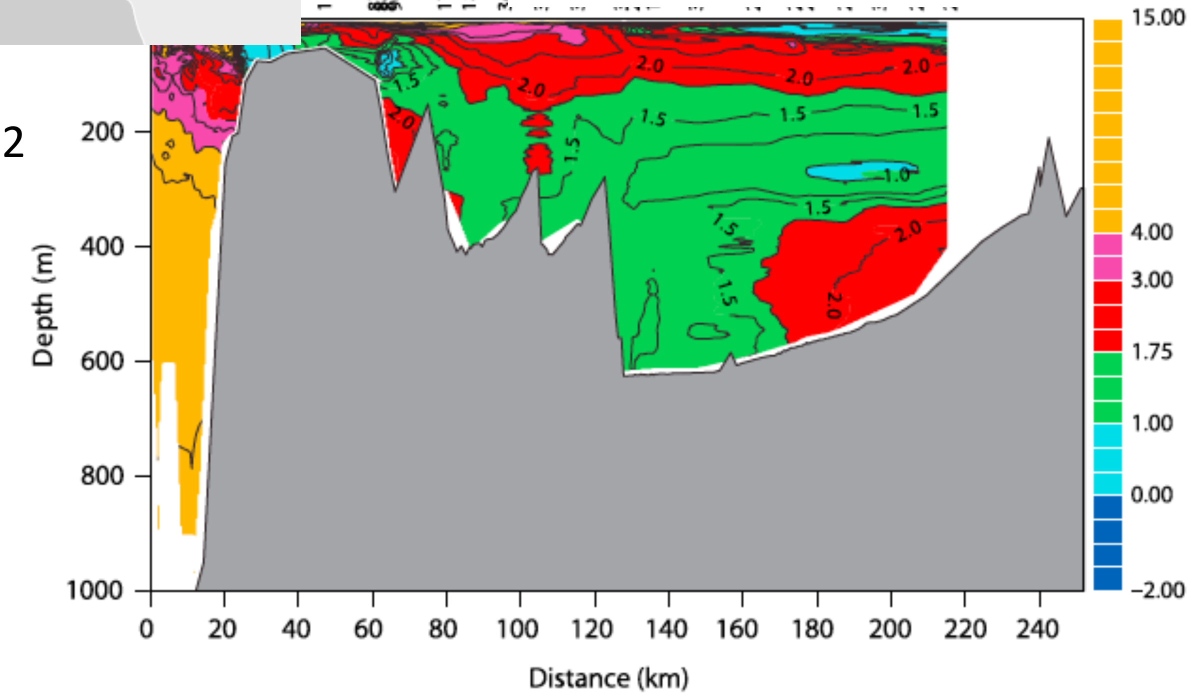
- Not just buoyancy driven
- Likely major contribution from fjord/shelf exchange (see Becca's poster)

Similar observations in a fjord with a shallow sill

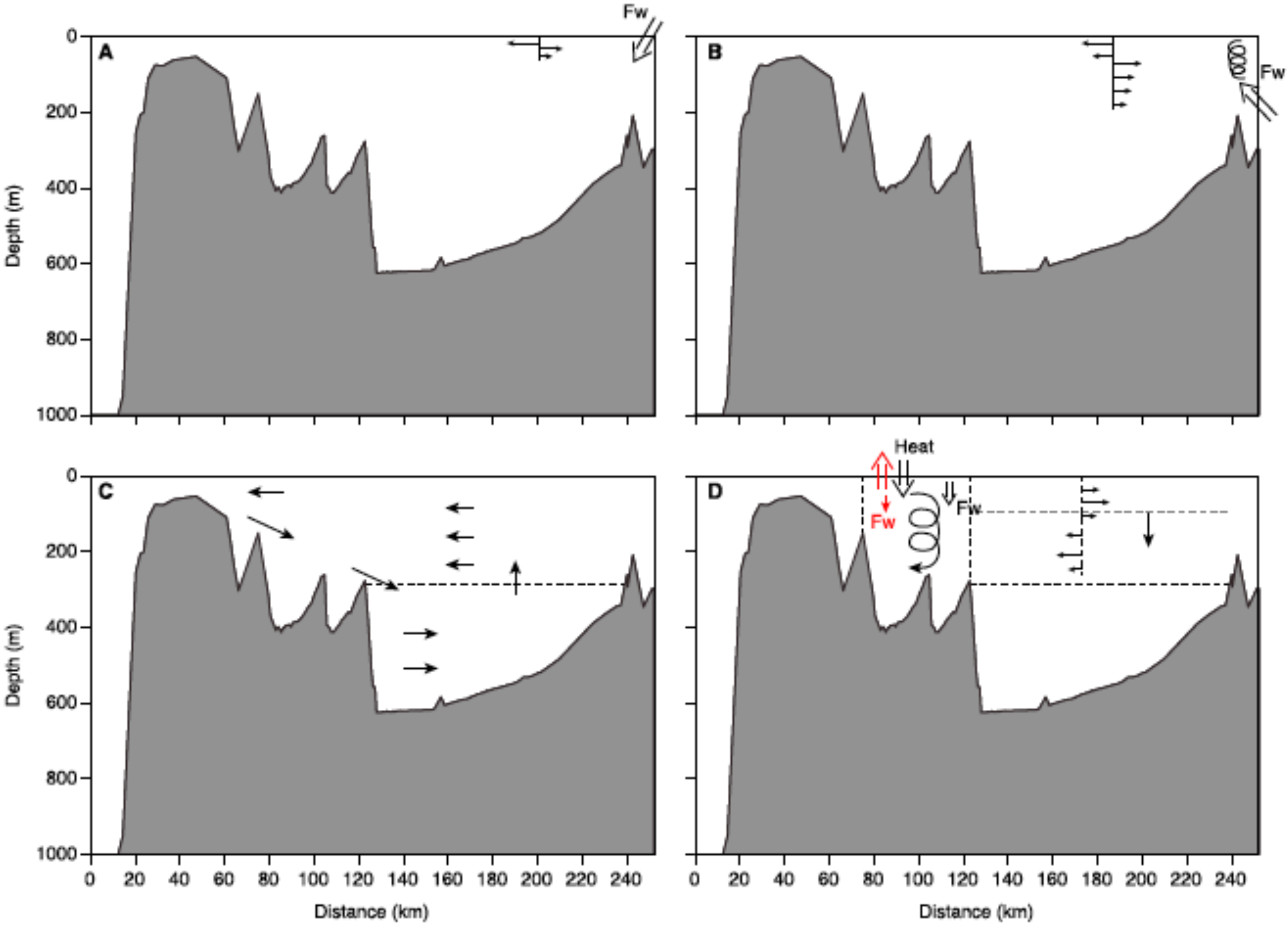




Mortensen et al. 2011 and 2012



Nuuk/KNS Fjord

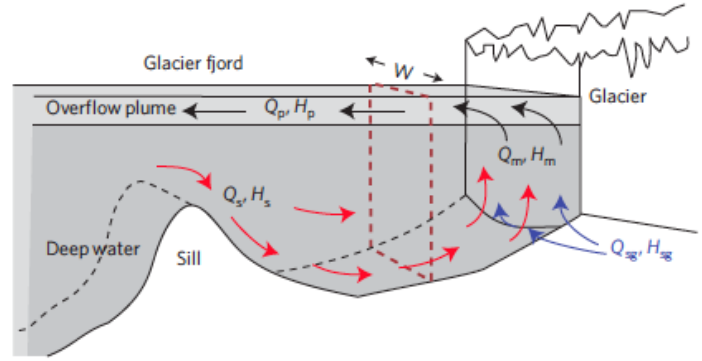


Mortensen et al. 2011 and 2012

Submarine Melting Estimates from Oceanic Heat Transport

Fjord (section)	Q 10^9 W	Q_m km^3 a^{-1}	M m a^{-1}
SF-2	22 (11–28)	2.1 (1.0–2.7)	500 (250–630)
SF-3	27 (21–34)	2.6 (2.0–3.2)	610 (480–770)
SF-4	51 (39–64)	4.8 (3.7–6.1)	1100 (880–1400)
SF-5w	21 (15–26)	2.0 (1.4–2.5)	480 (340–590)
SF-7	24 (11–42)	2.2 (1.0–4.0)	540 (250–950)
Petermann*	310	29.5	26
Avangnardleq†	86 ± 14	8.2 ± 1.3	1400 ± 290
Kangilerngata†	6.3 ± 0.9	0.60 ± 0.09	950 ± 180
Eqip Sermia†	1.7 ± 0.3	0.16 ± 0.03	250 ± 70
LeConte‡	6.9 ± 2.8	0.40–0.65	2400–4500

*Johnson and others (2011). Stated ranges were ±50%. To calculate M, glacier area of 70 km long by 16 km wide was used. Petermann Glacier advances on average ~1100 m a^{-1}.
†Rignot and others (2010).
‡Motyka and others (2003). Stated range for Q was ±40% and given for Q_m and M.



Motyka et al. 2003;
Rignot et al. 2010

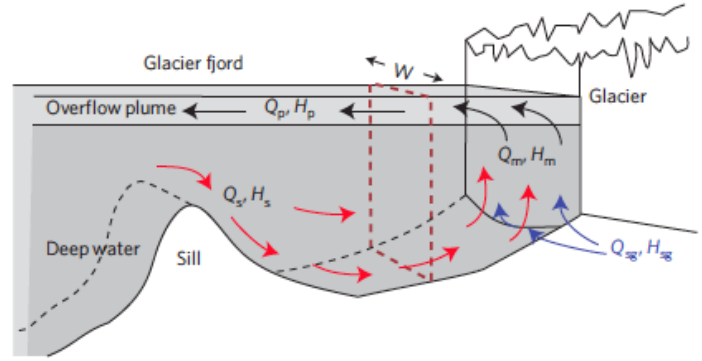
- Assumed a circulation pattern – e.g. *Rignot et al. 2010; Motyka et al. 2003*
- Measured instantaneous velocity, temperature across section – *Johnson et al. 2011*
- Used T and velocity measurements but removed high frequency variability – *Sutherland and Straneo 2012*

Submarine Melting Estimates from Oceanic Heat Transport

- Assumed a circulation pattern –

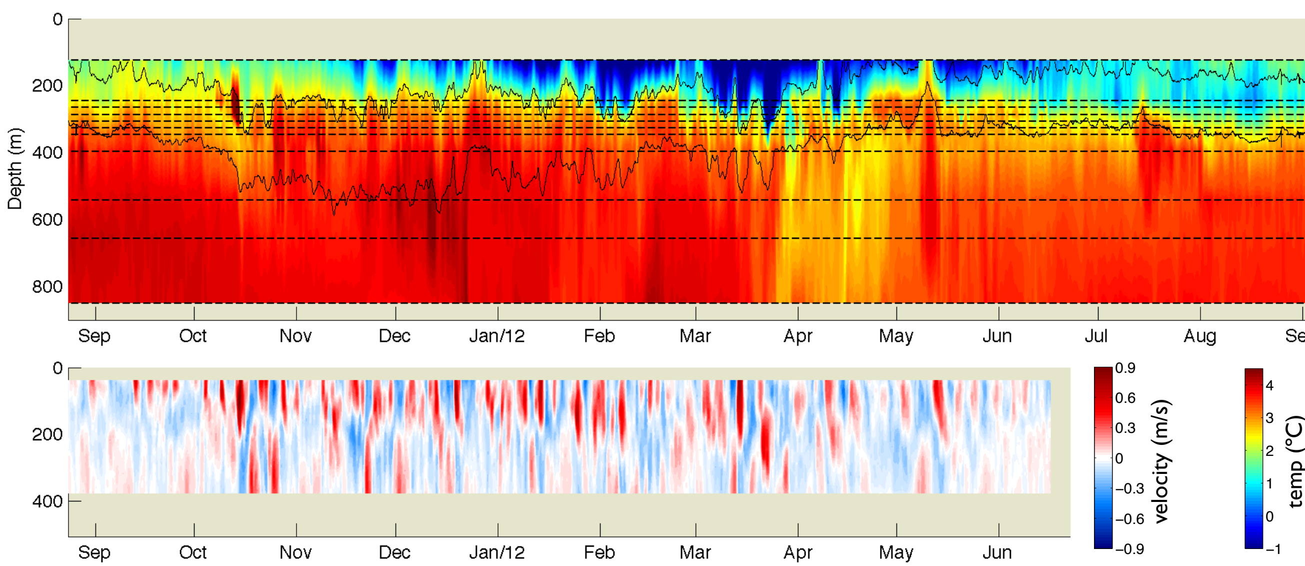
e.g. *Rignot et al. 2010; Motyka et al. 2003*

No evidence that this circulation governs heat transport in the fjords on any timescale



- Measured instantaneous velocity, temperature across section – *Johnson et al. 2011*
- Used T and velocity measurements but removed high frequency variability – *Sutherland and Straneo 2012*

Flows are highly variable as is heat content of the fjord! No steady state.



What have we learned in the last 5-6 years about the properties and circulation in Greenland glacial fjords?

1. Properties and origins of the fjord waters

Cold, fresh over warm salty for fjords with deep sills,
high stratification, roughly scaling with shelf properties

2. Variability (Interannual, seasonal, shorter) LARGE

Dominant variability is on short timescales likely tied to shelf forcing → fjords track shelf rapidly
AW/PW relative components and upper layer vary seasonally
Evidence of seasonal subglacial discharge

3. Circulation

Influenced by stratification (baroclinic)
Fast, rapidly changing driven by a variety of mechanisms
no evidence of a simple buoyancy driven circulation

What have we learned in the last 5-6 years about the properties and circulation in Greenland glacial fjords?

4. Implication for submarine melt rates

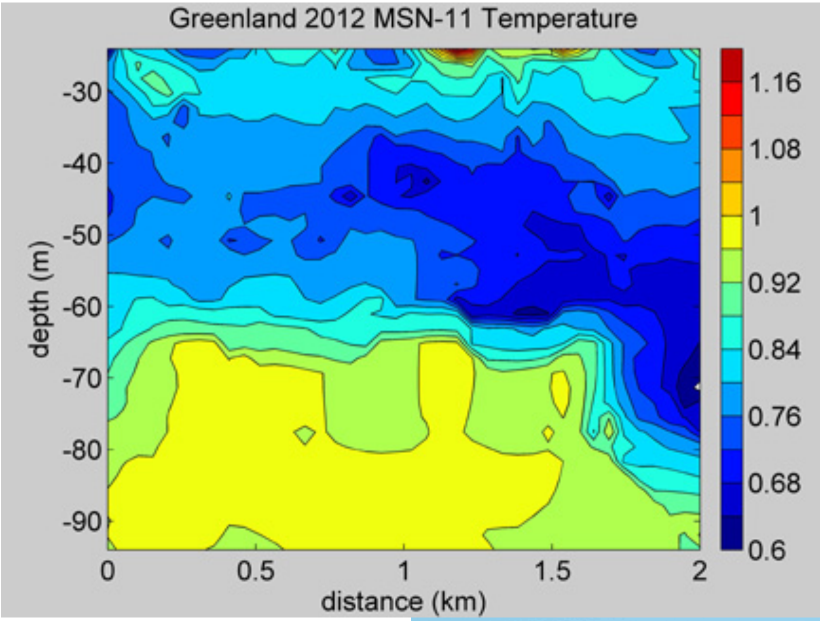
Plume is vertically constrained by stratification → ocean stratification (plus glacier driven stratification)

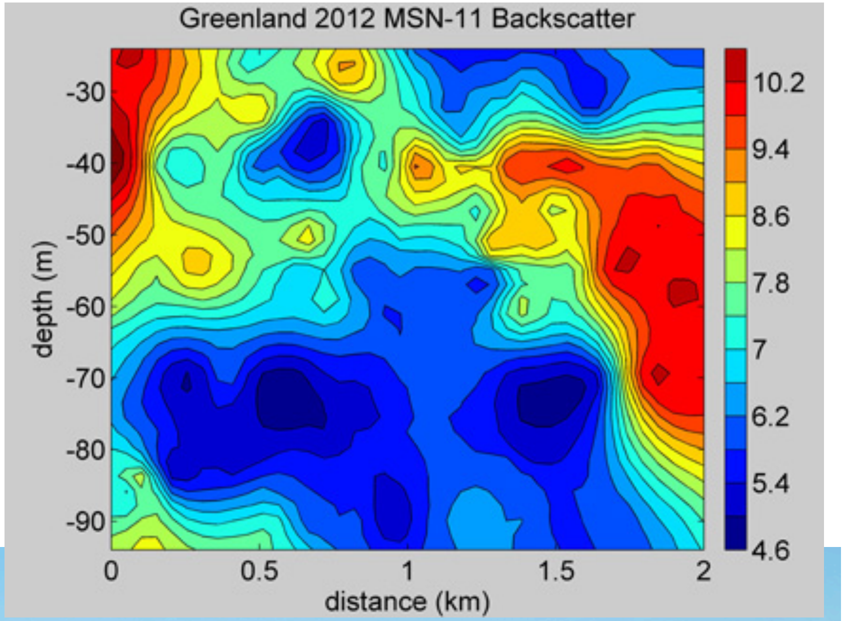
No simple model or model + data so far

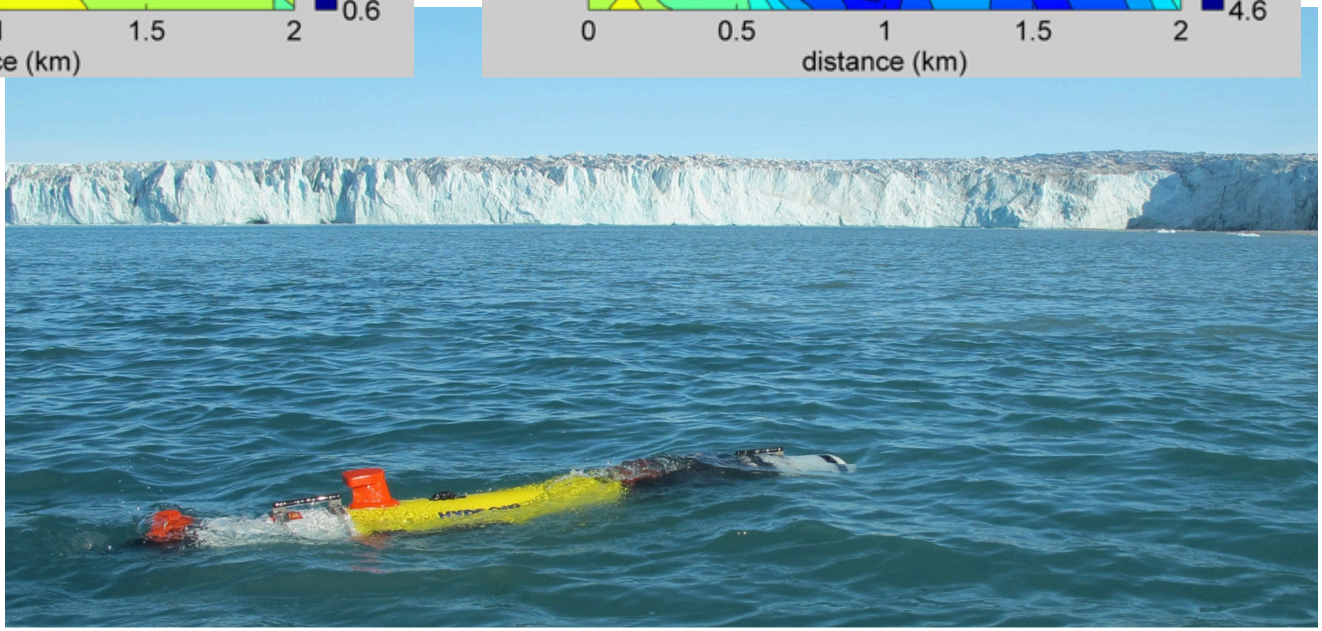
We have to be cautious about interpreting instantaneous heat transport measurements

Measurements near glacier fronts

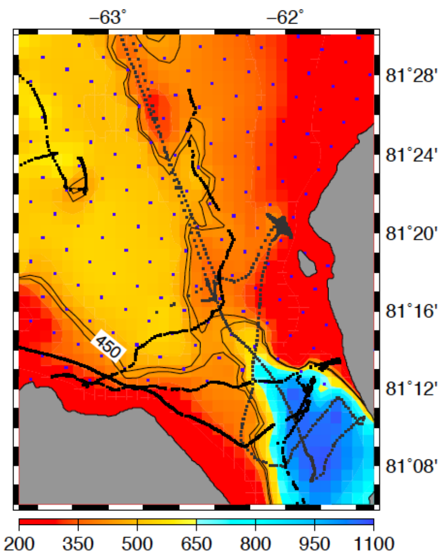
Measurements near glacier fronts



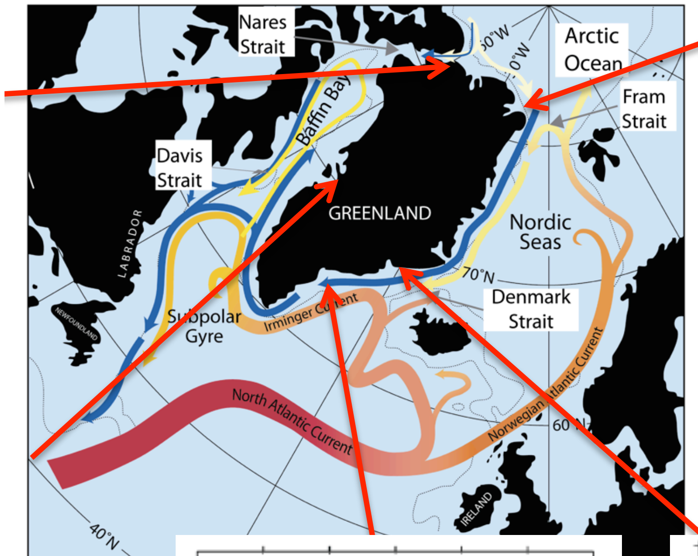


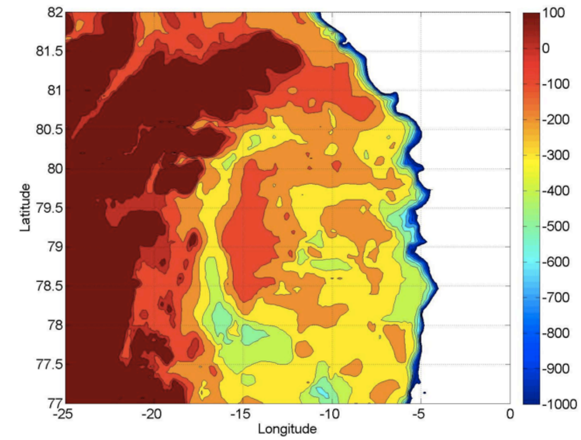


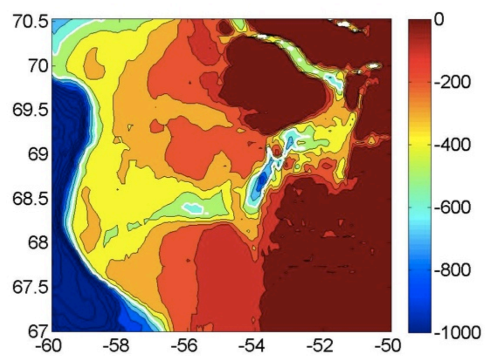
Bathymetry – Large troughs across the shelf, 'deep sills'

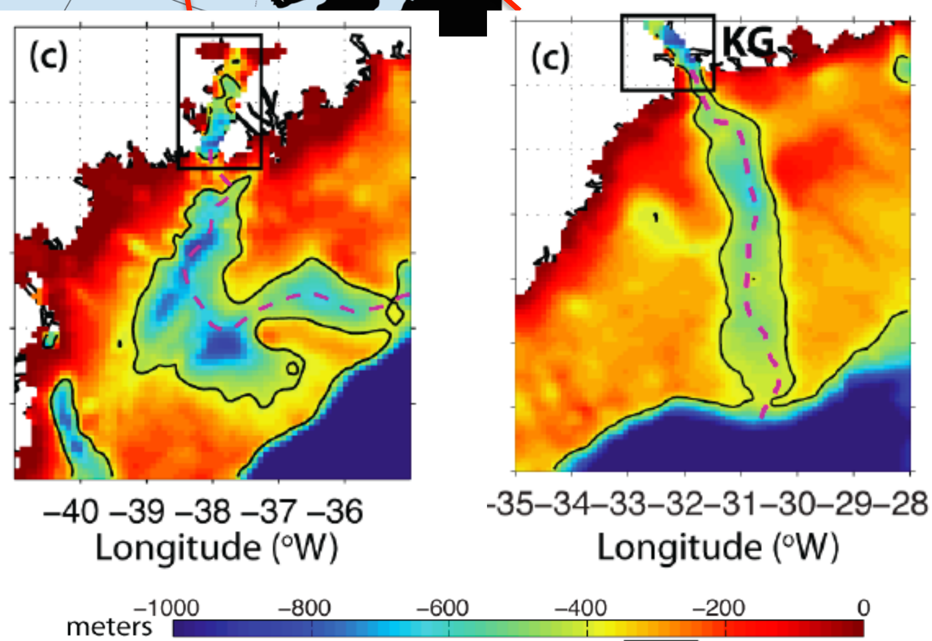


Johnson et al. 2011



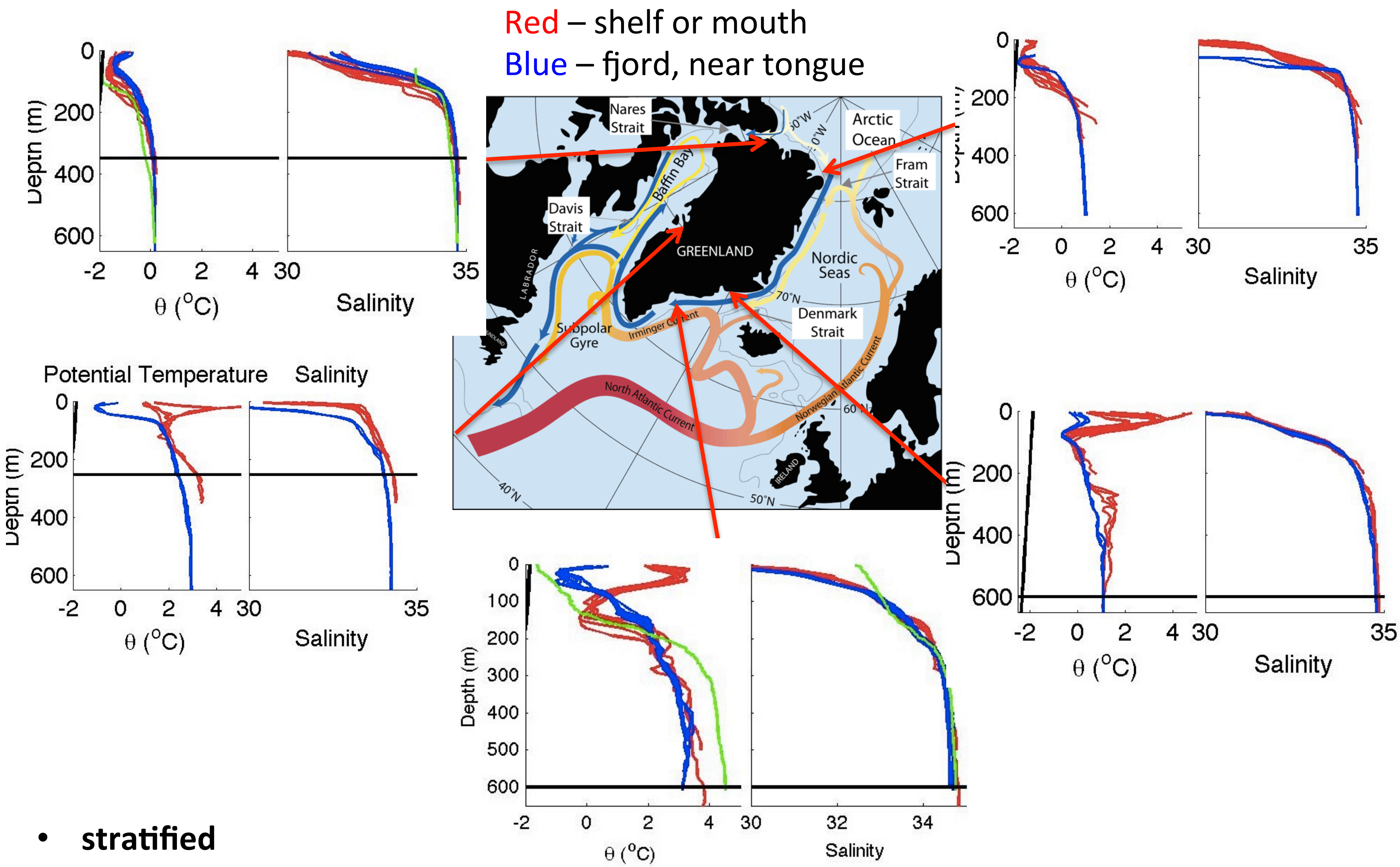






Sutherland et al. 2012

Atlantic (modified) and Arctic Water Layering in all the 5 fjords



- **stratified**
- **Deep sills relative to AW/PW interface**

Straneo, F et al.
Annals of Glaciology, 2012.