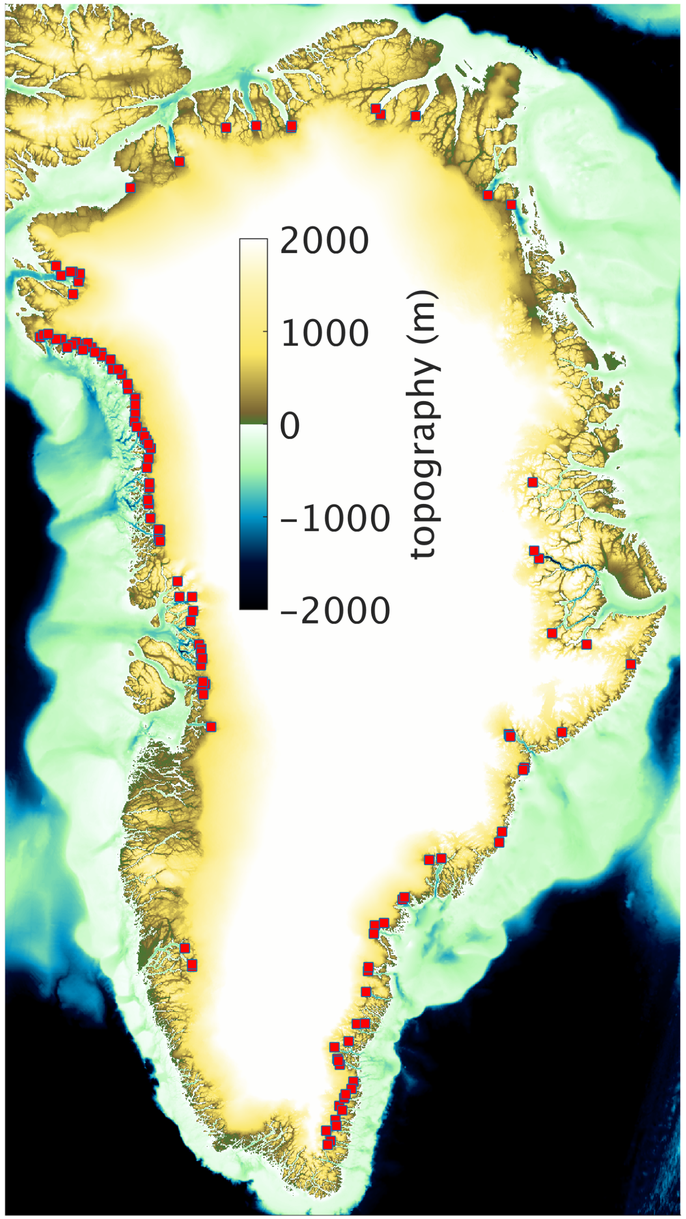
Depth and properties of freshwater export from the Greenland ice sheet to the ocean

Donald Slater[1,2] & Fiamma Straneo[2]

1 University of St Andrews
2 Scripps Institution of Oceanography

@donald_glacier
EGU 2020

Greenland as a freshwater source to the ocean (note 1 Sv = 10^6 m^3/s)



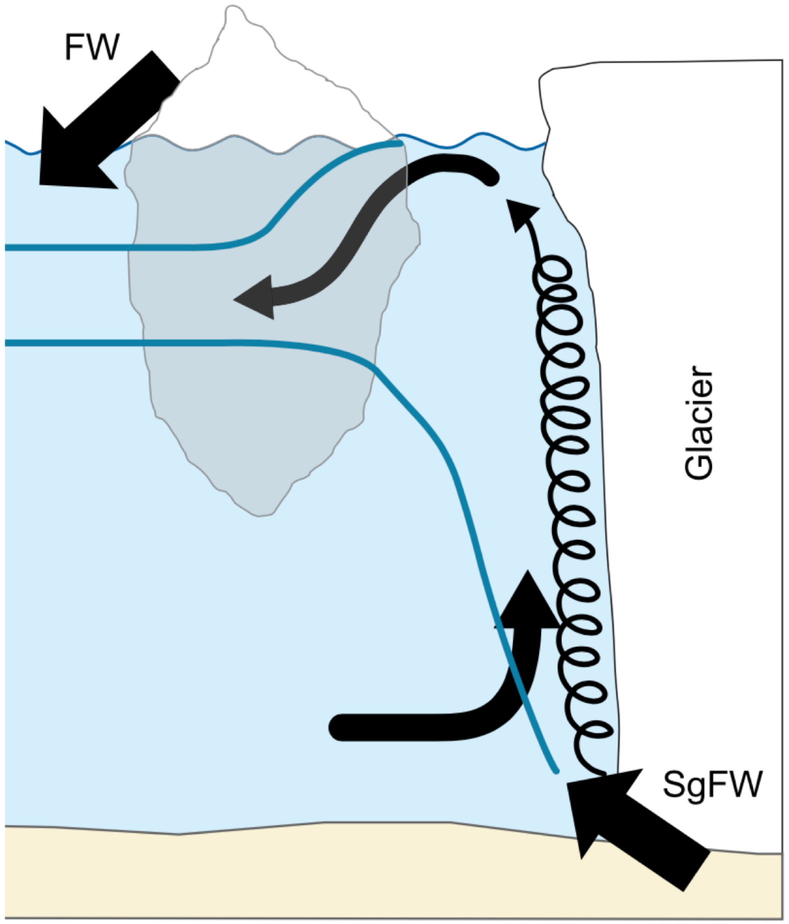
1991-2015 mean freshwater flux: 840 Gt/yr = 27 mSv

57% icebergs (melts into the ocean)

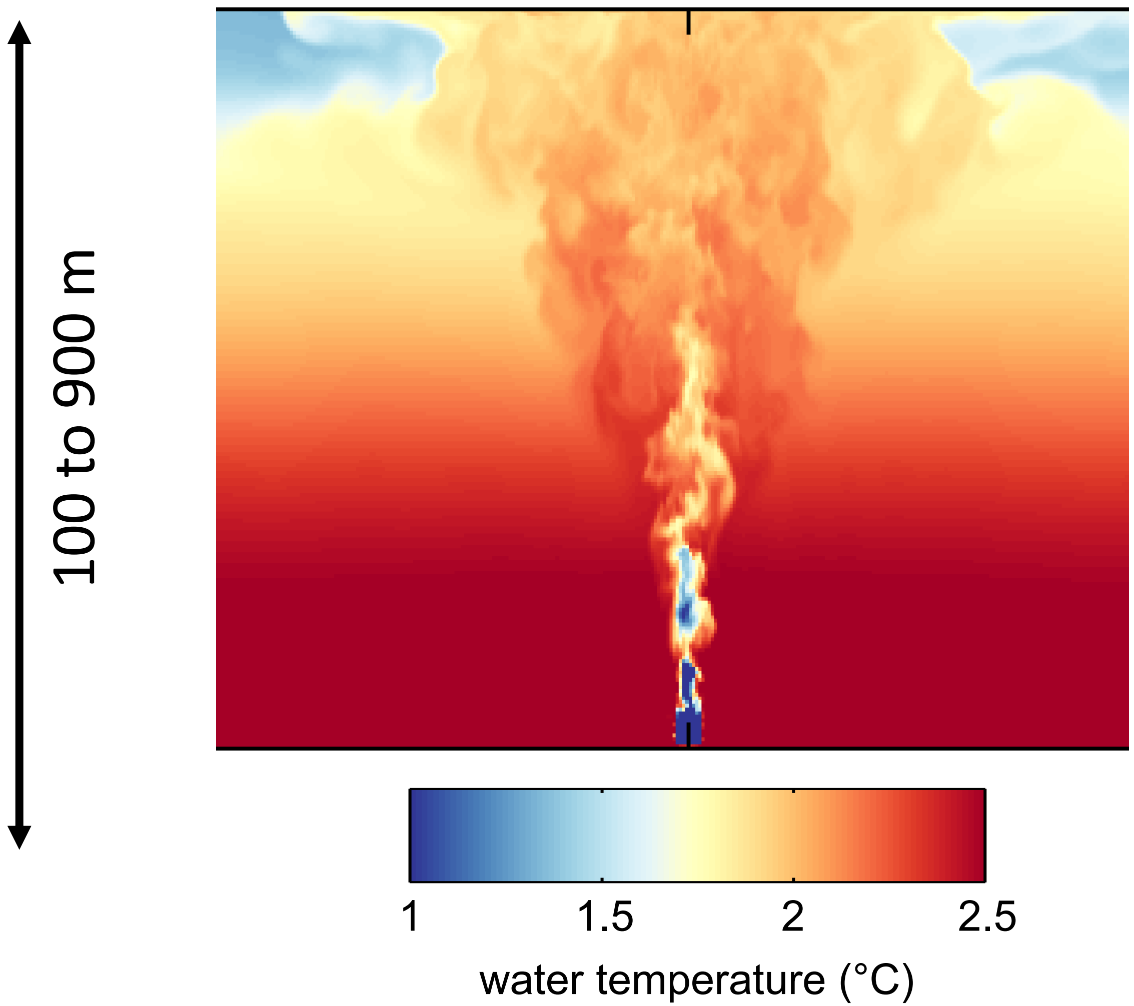
43% liquid freshwater (melted before reaching ocean)

van den Broeke 2016, Cryosphere

Liquid freshwater released at marine-terminating glaciers generates upwelling plumes

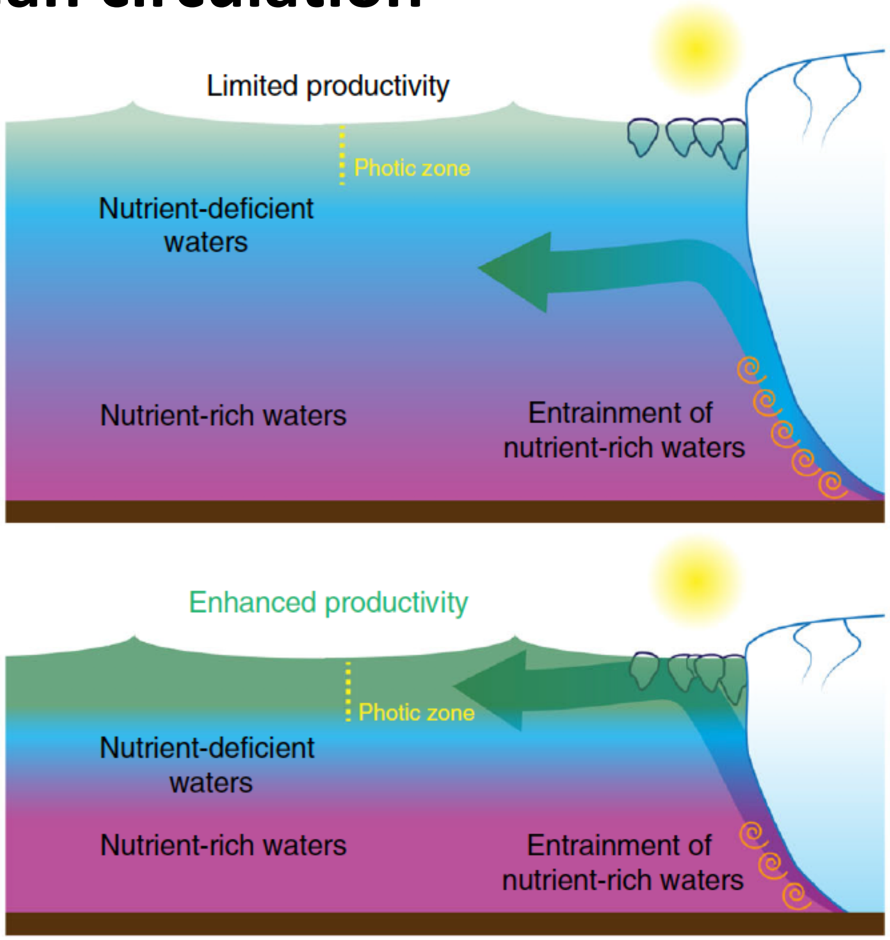


Meire et al., 2017, Global Change Biology

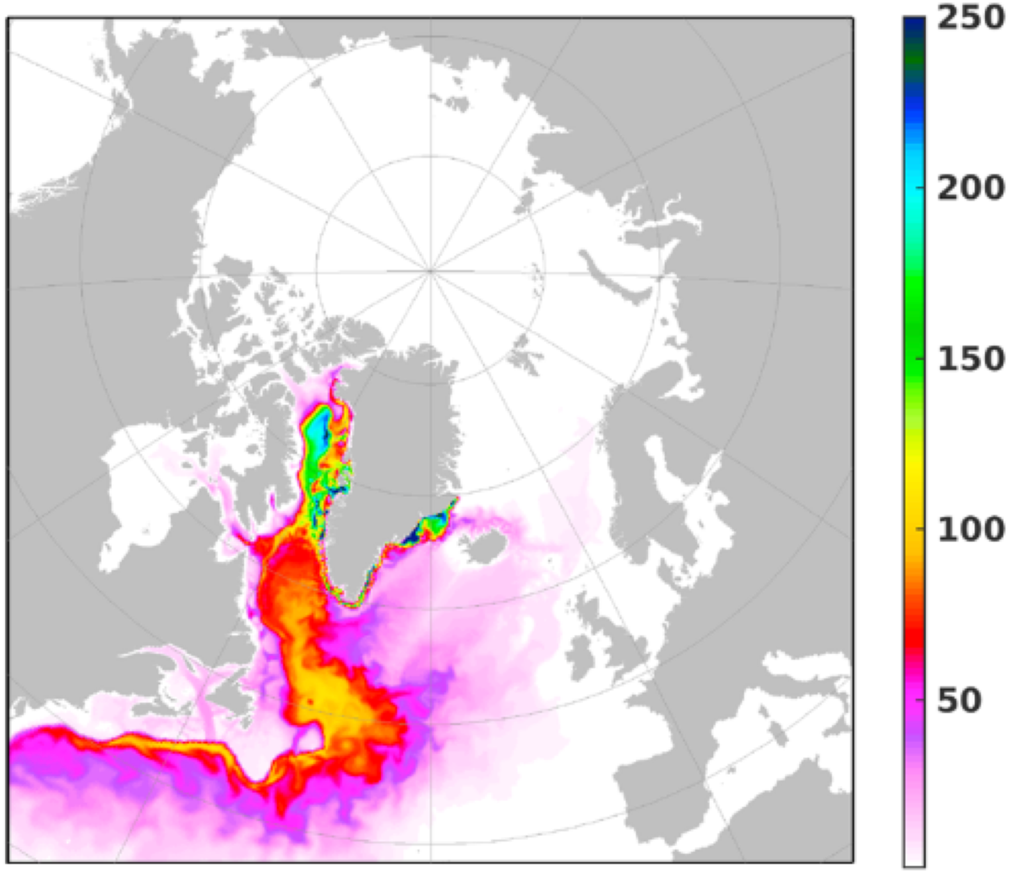


Slater et al., 2015, Geophysical Research Letters

This upwelling plays an important role in bringing nutrients into the photic zone and the freshwater exported to the ocean may influence large-scale ocean circulation



Hopwood et al., 2018, Nature Communications

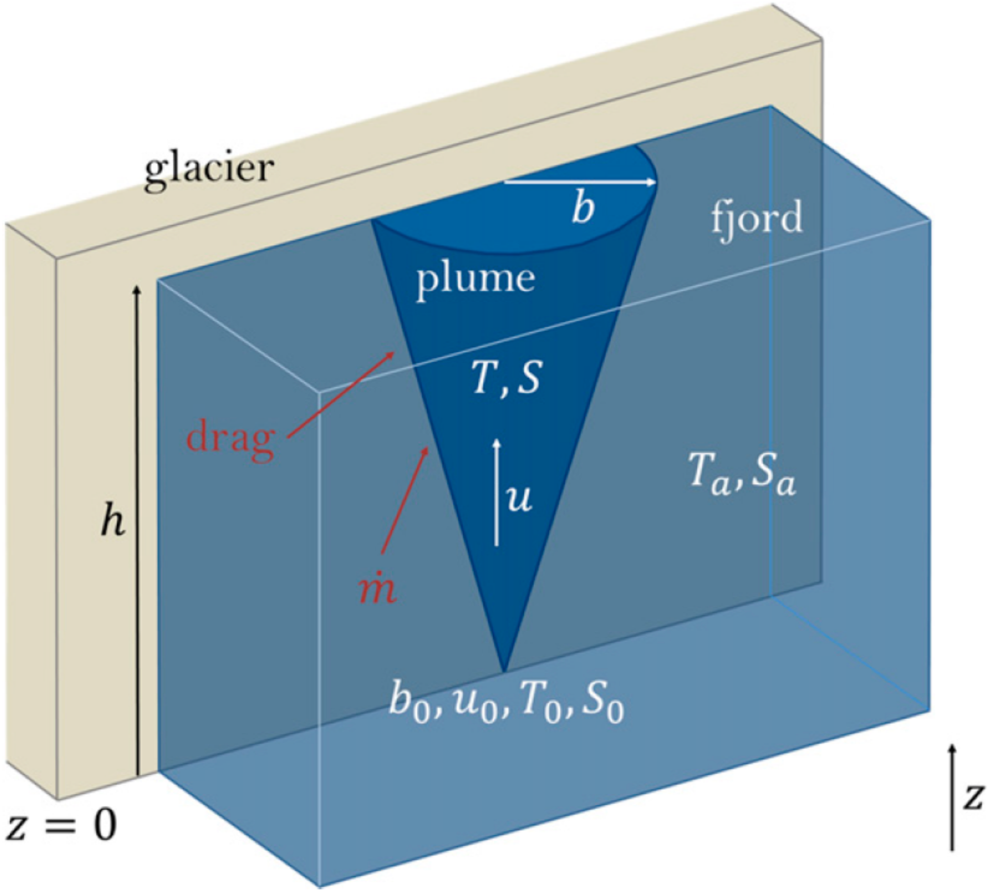


SE Greenland meltwater tracer

Gillard et al., 2016, Geophysical Research Letters

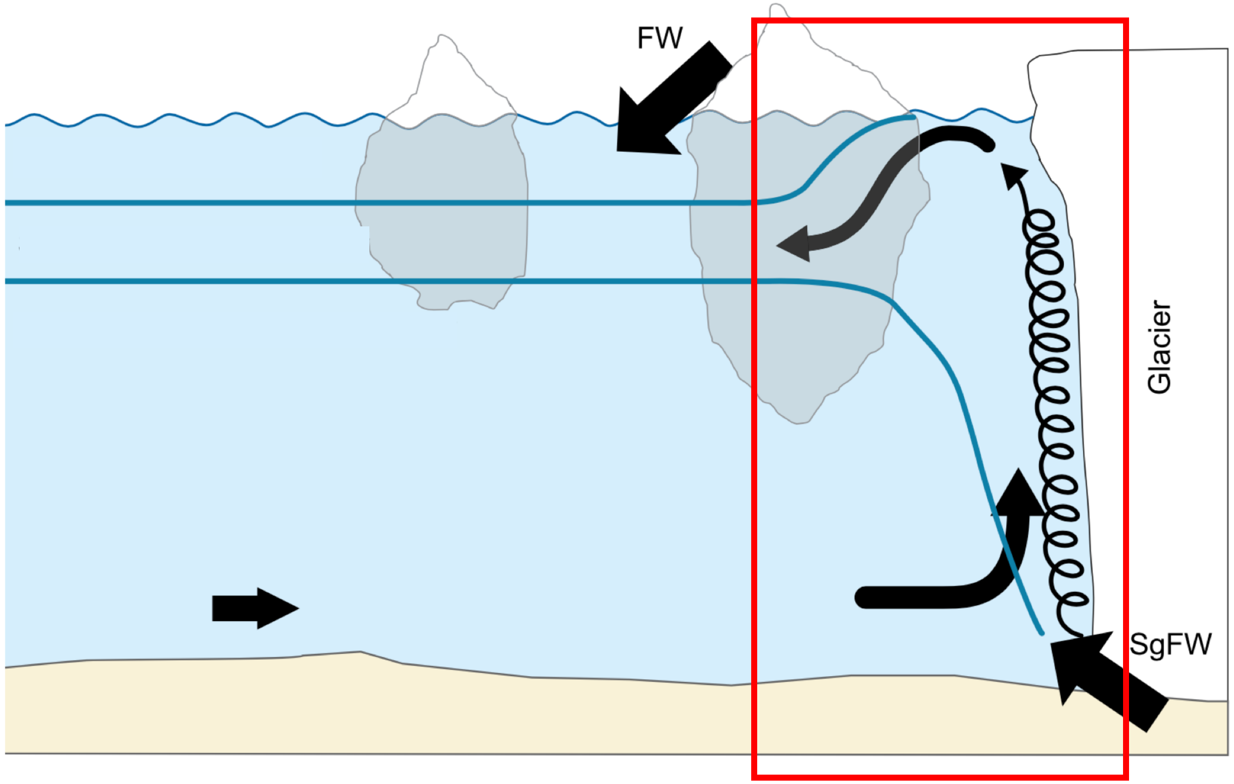
Aim of this study: Characterize the depth and properties of plumes of upwelling freshwater around the Greenland Ice Sheet

Methods – buoyant plume model to capture dynamics of upwelling



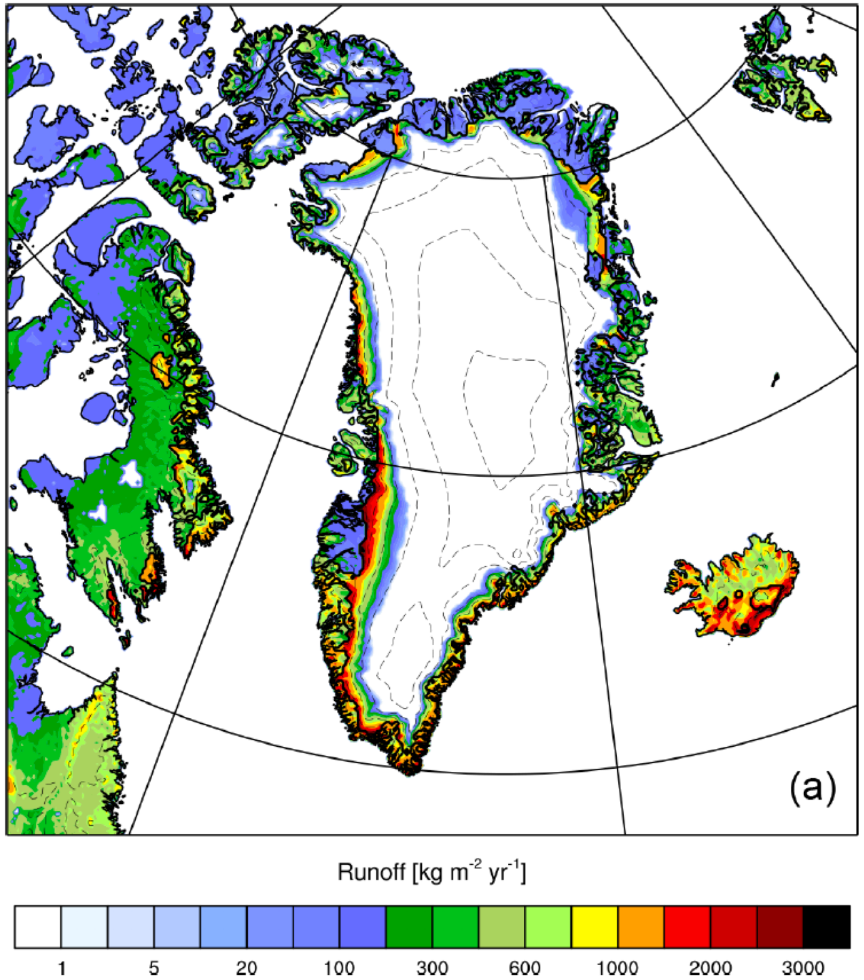
Morton, Taylor & Turner, 1956, Proc. RSL
Jenkins, 2011, JPO
Slater et al., 2016, JPO

Meire et al., 2017, Global Change Biology



Carroll et al., 2017, JGR Oceans
De Andres et al., 2020, Cryosphere Discuss
Sanchez et al. in prep.

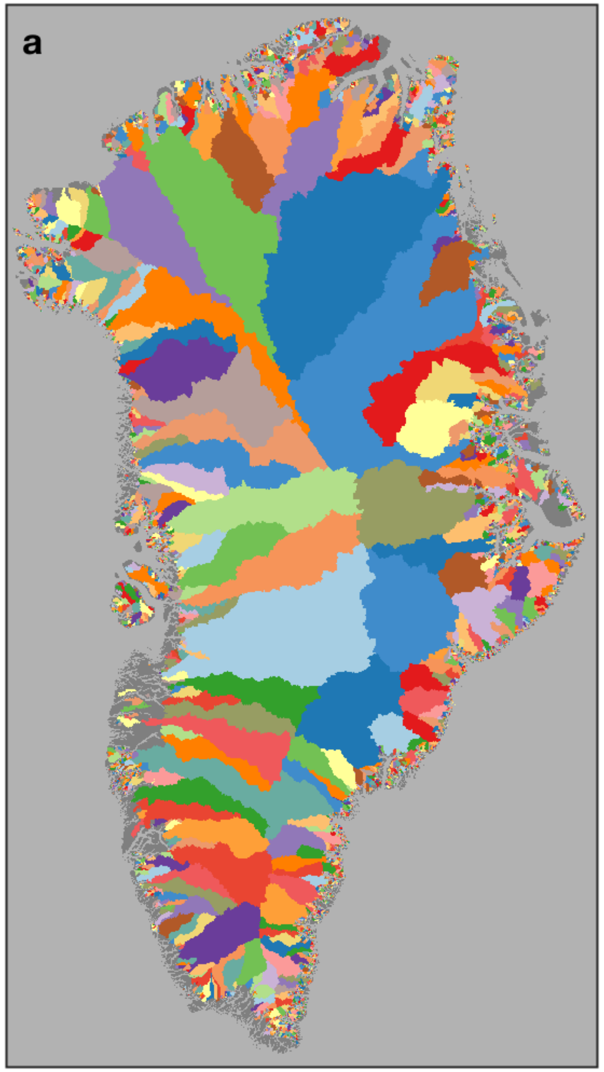
Data – freshwater input to ocean



Regional climate model RACMO2.3p2 for surface runoff

Noel et al., 2018, Cryosphere

+



Hydrological drainage basins

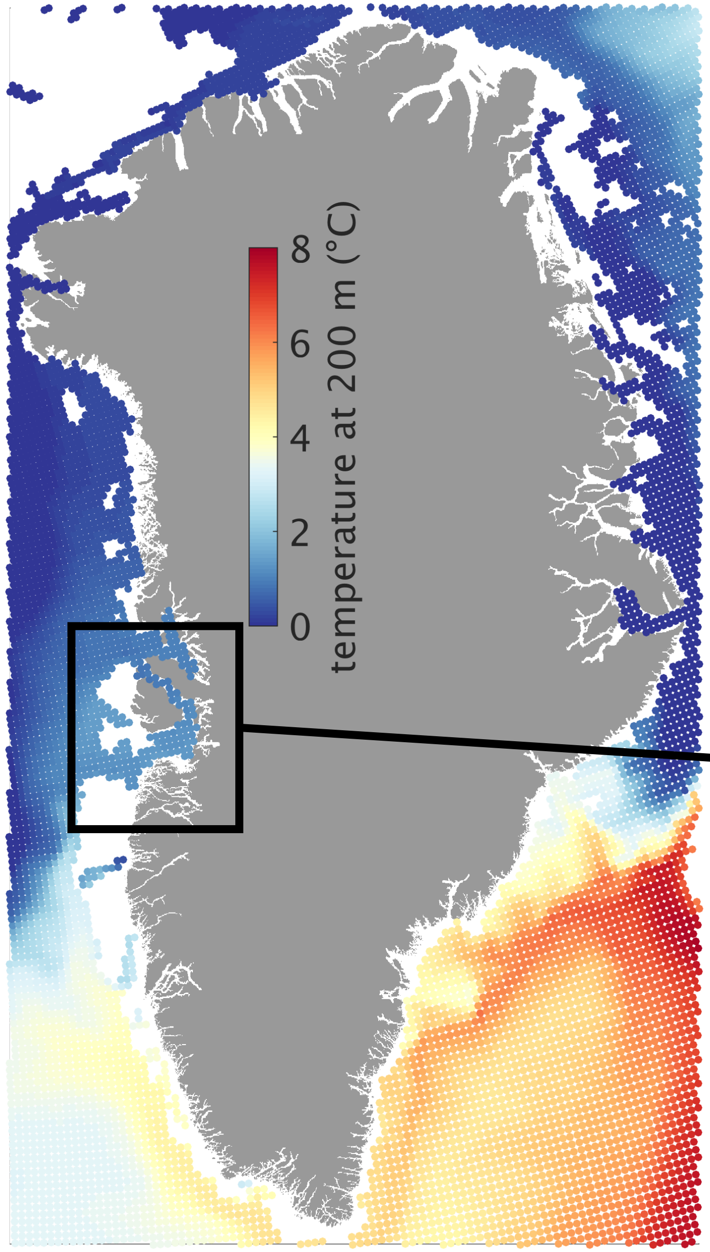
Slater et al. in prep.

=

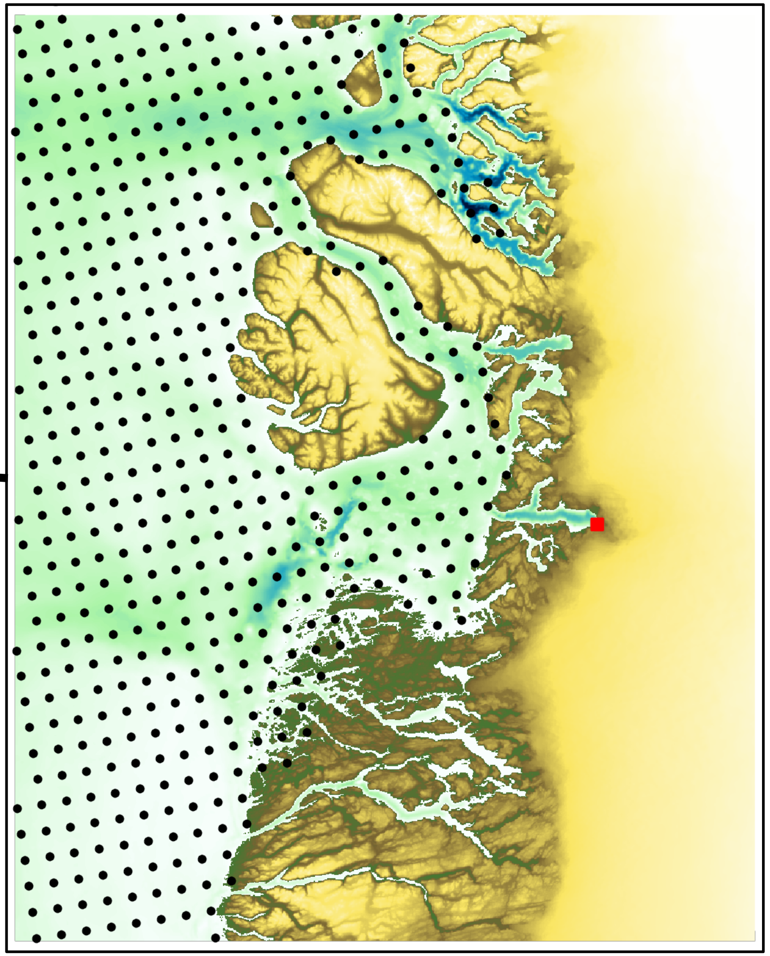
Locations and magnitude of liquid freshwater input to ocean

(2005-2017 mean)

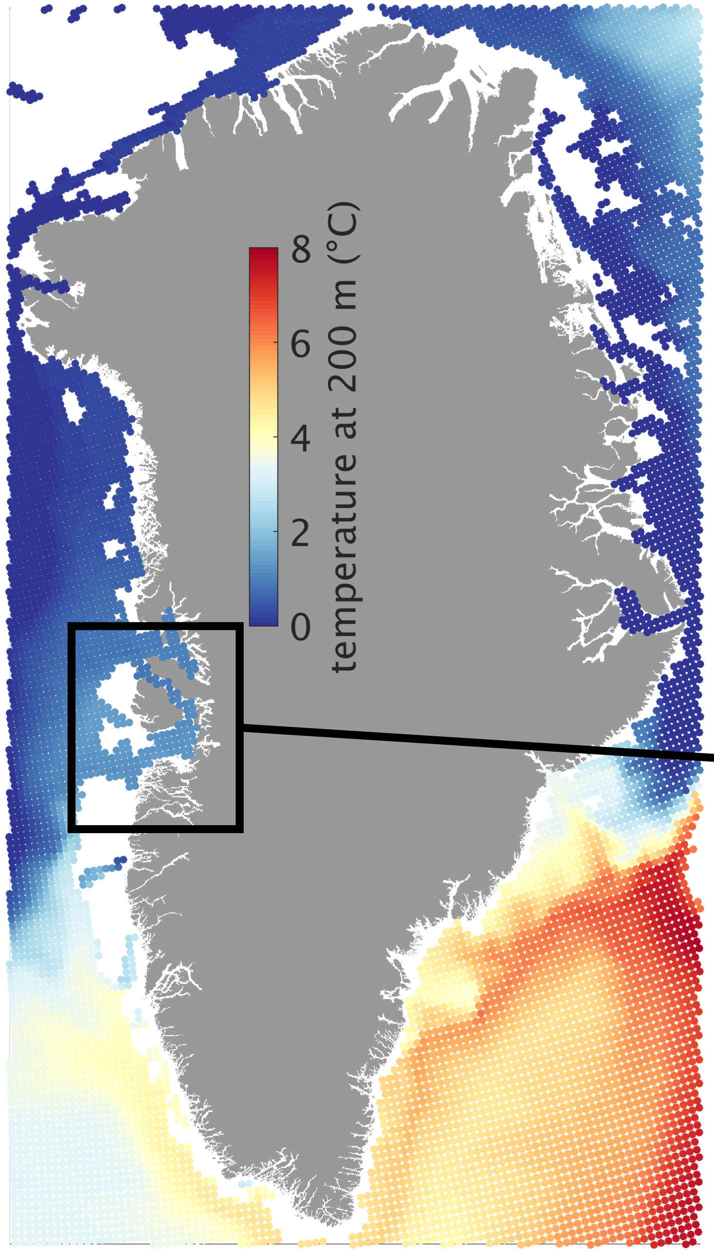
Data – ocean properties at calving fronts are extrapolated into fjords from the shelf, taking account of bathymetry. Shelf properties come from reanalysis



ORAS5 – ¼ degree ocean reanalysis
(2005-2017 mean)
Zuo et al., 2018, ECMWF

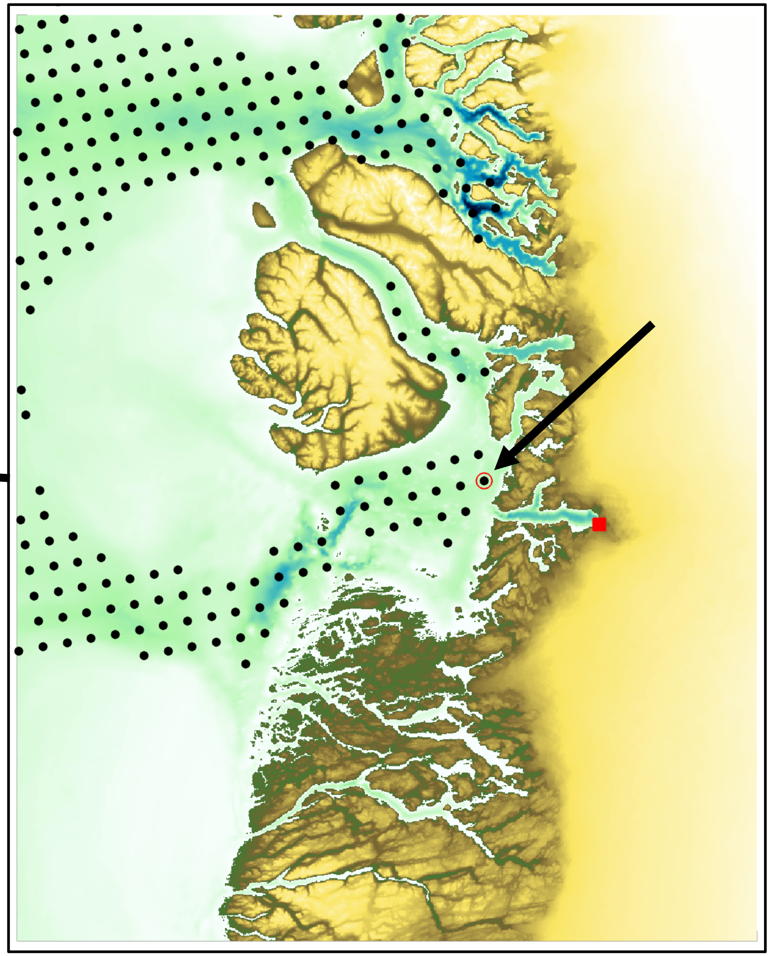


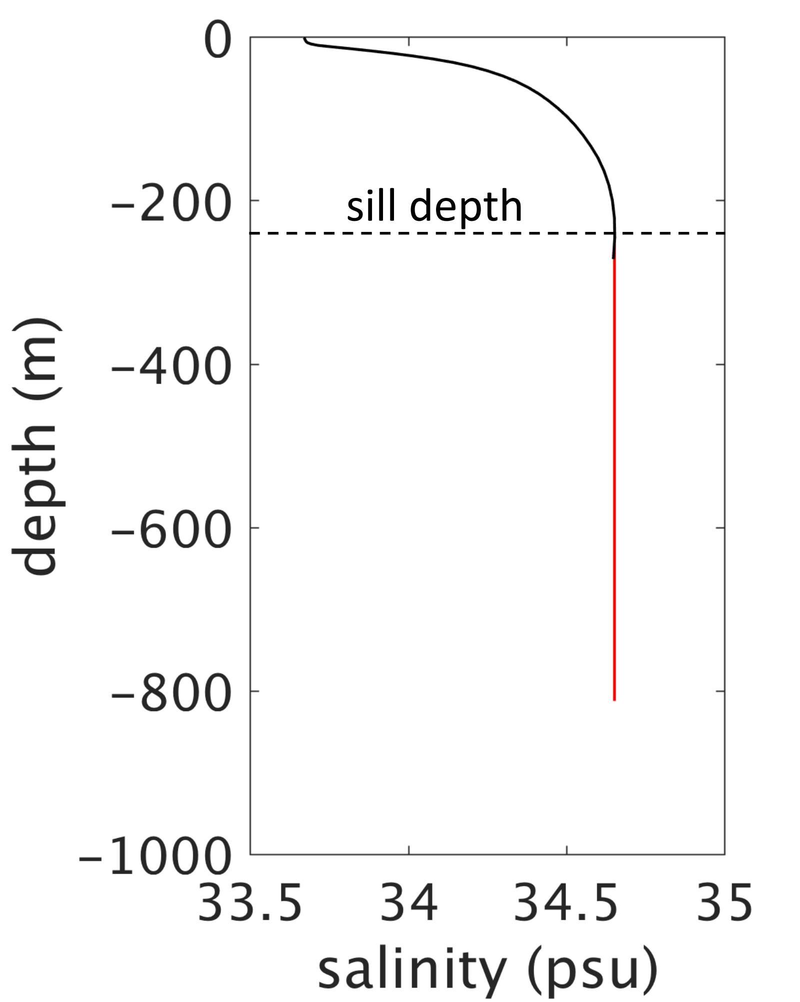
Data – ocean properties at calving fronts are extrapolated into fjords from the shelf, taking account of bathymetry. Shelf properties come from reanalysis



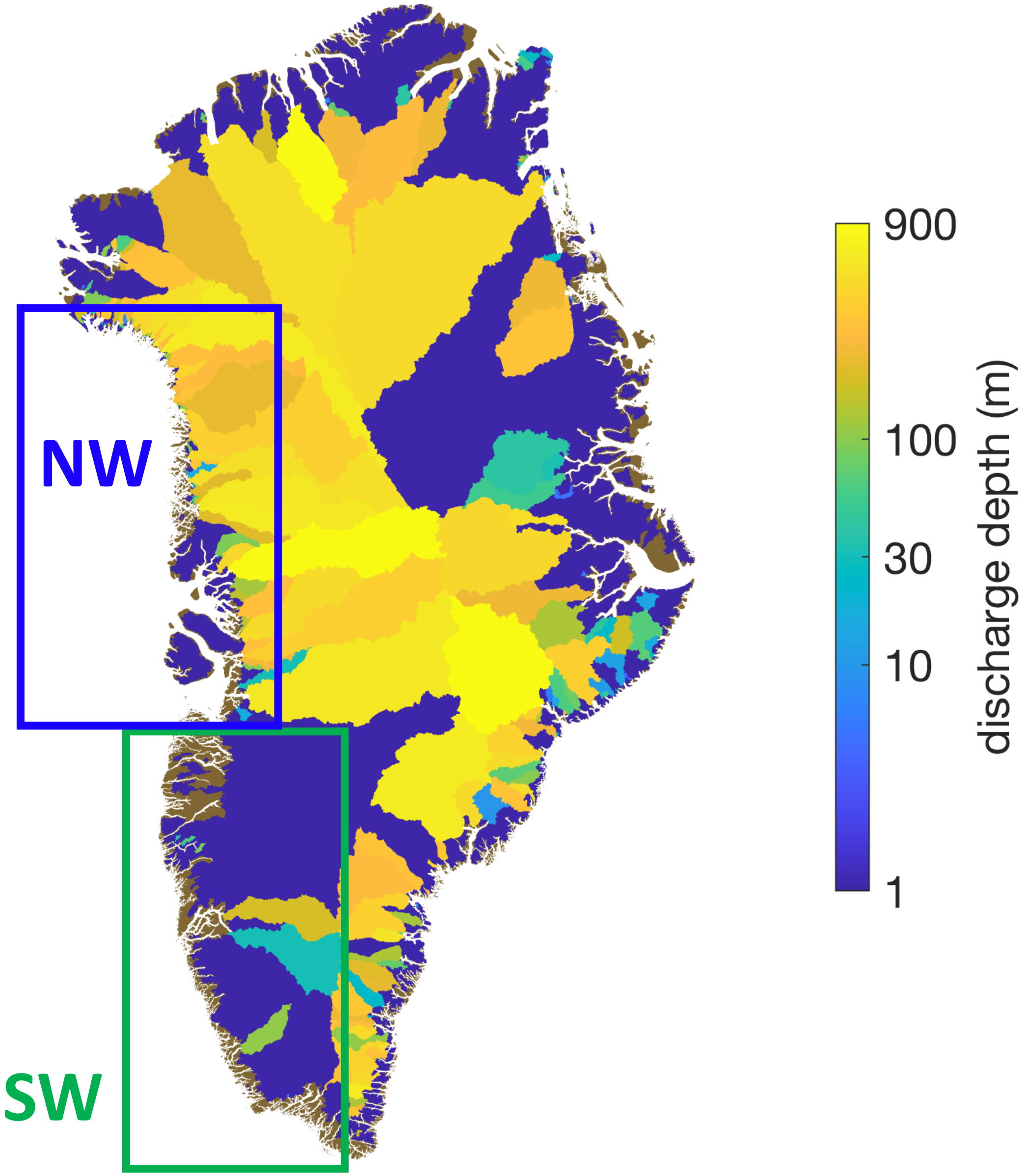
ORAS5 – ¼ degree ocean reanalysis (2005-2017 mean)

Zuo et al., 2018, ECMWF





Results – land-terminating versus marine-terminating



2005-2017 mean liquid freshwater export 363 Gt/yr

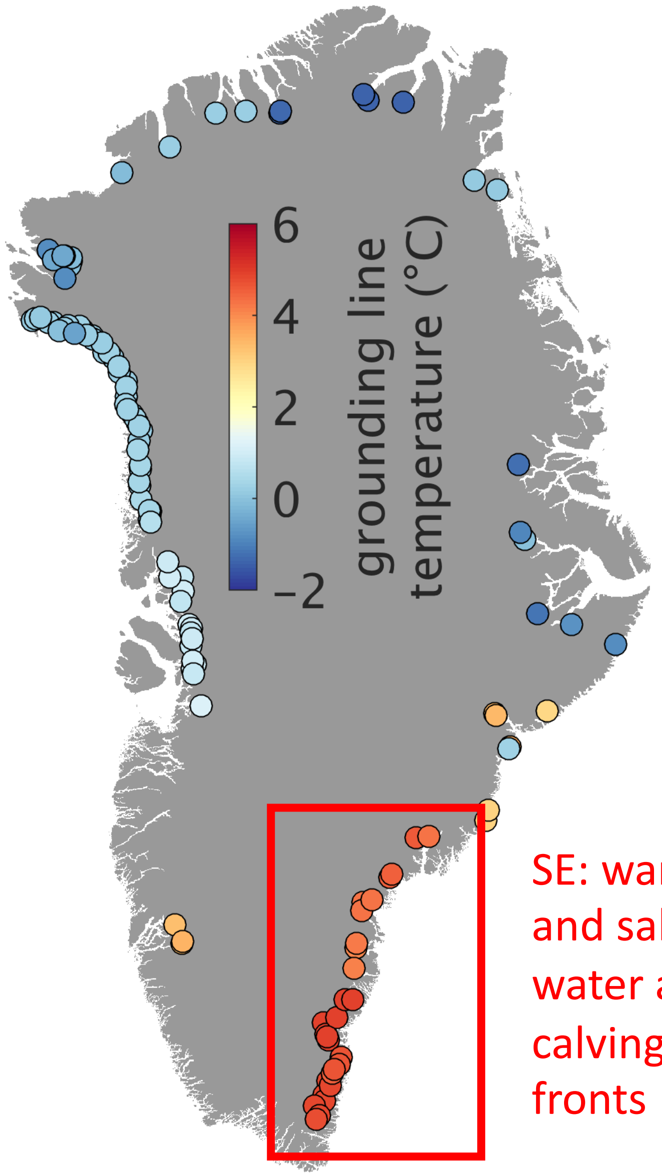
Marine-terminating
149 Gt/yr (41%)

Land-terminating
214 Gt/yr (59%)

SW: 14% marine, 86% land

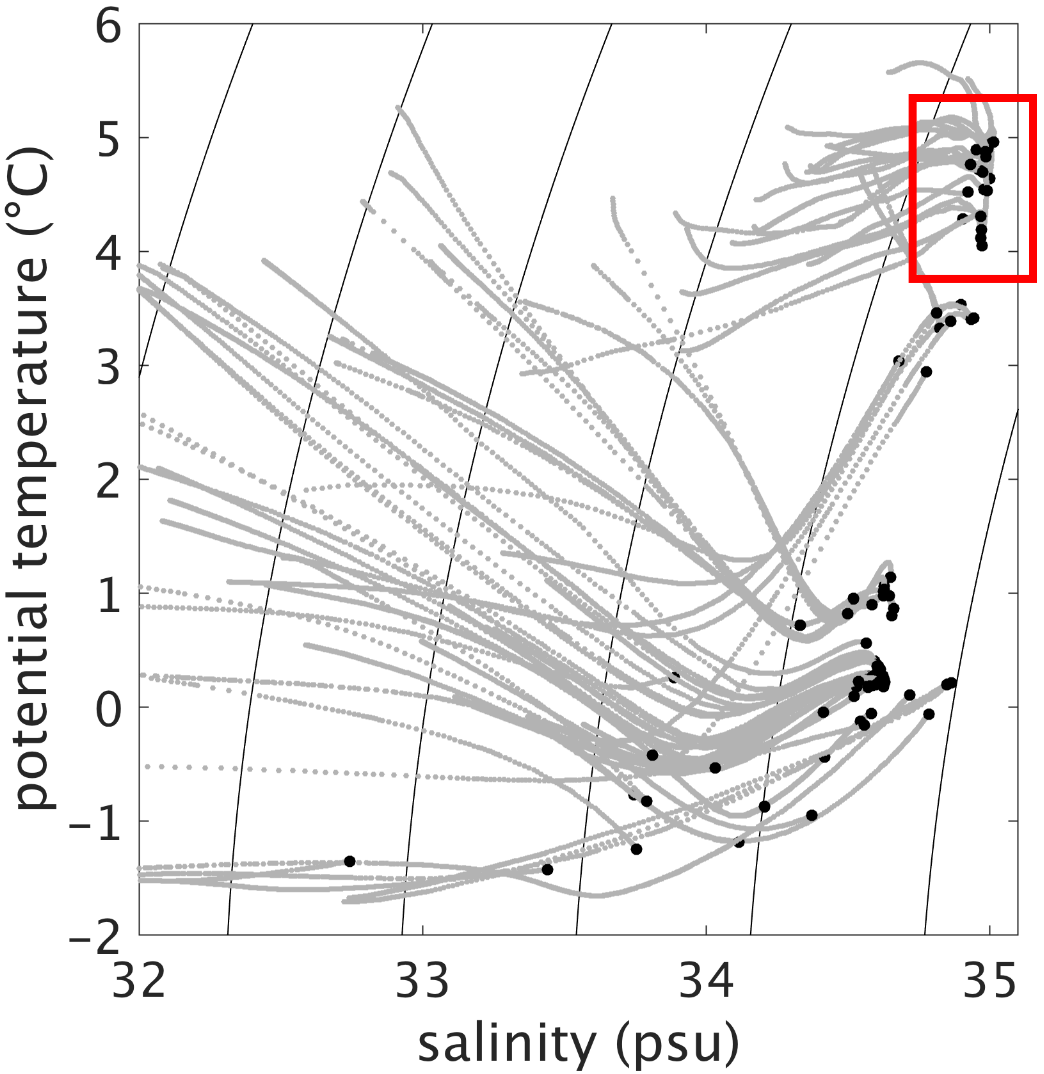
NW: 80% marine, 20% land

Results – calving front water properties



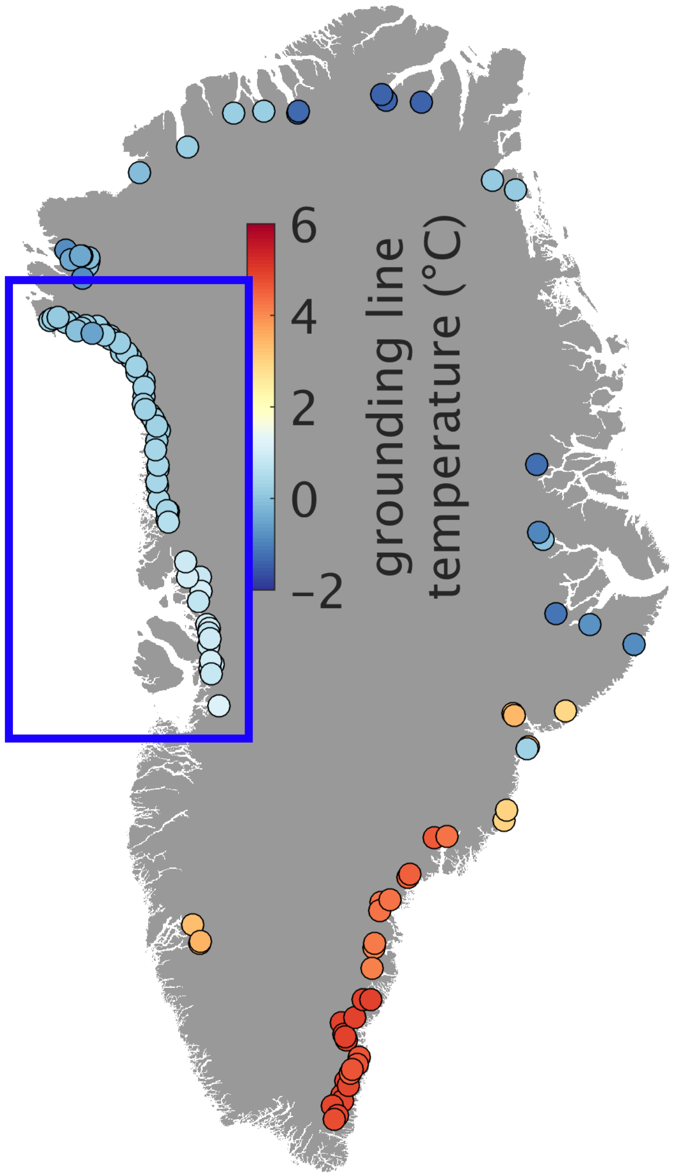
SE: warm and salty water at calving fronts

Black dots: values at the grounding line. Grey dots: full depth profiles.

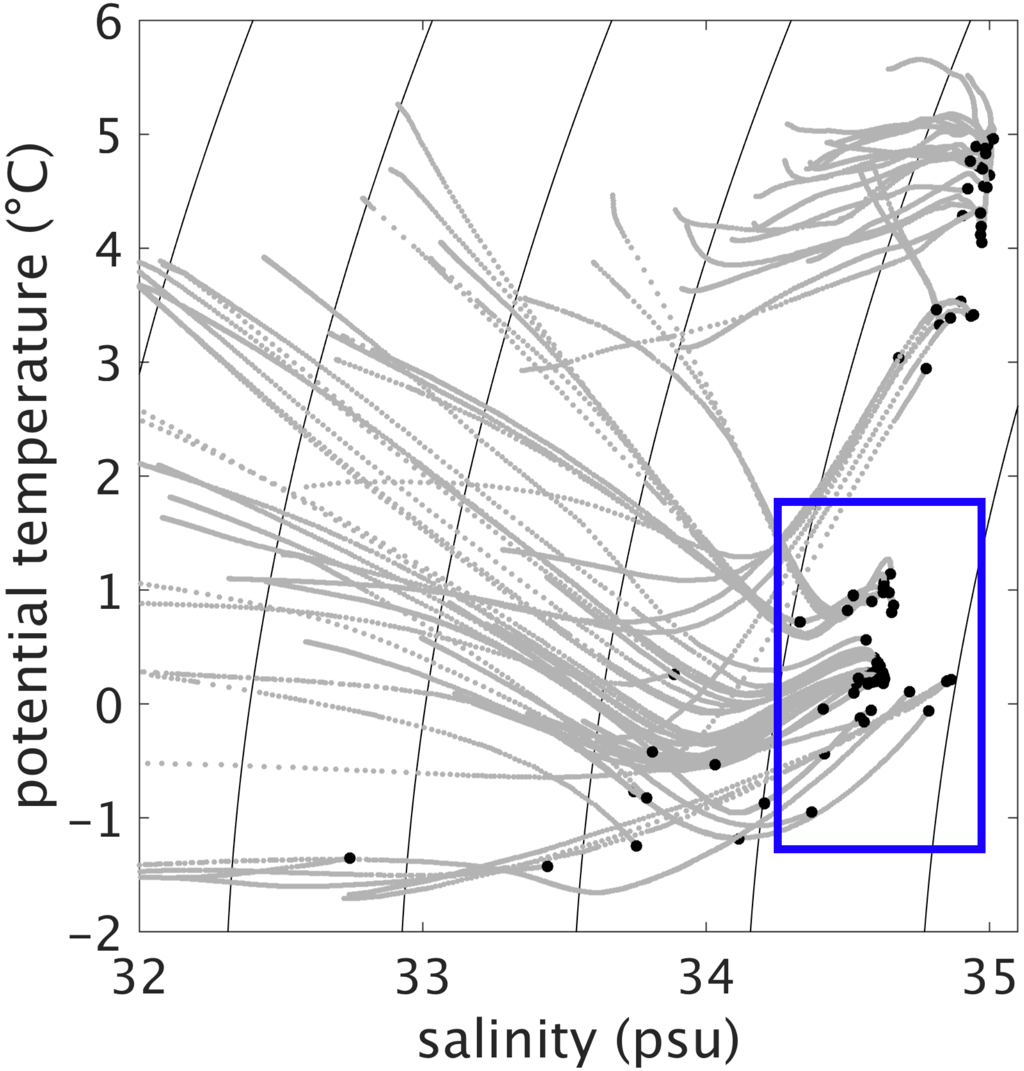


Results – calving front water properties

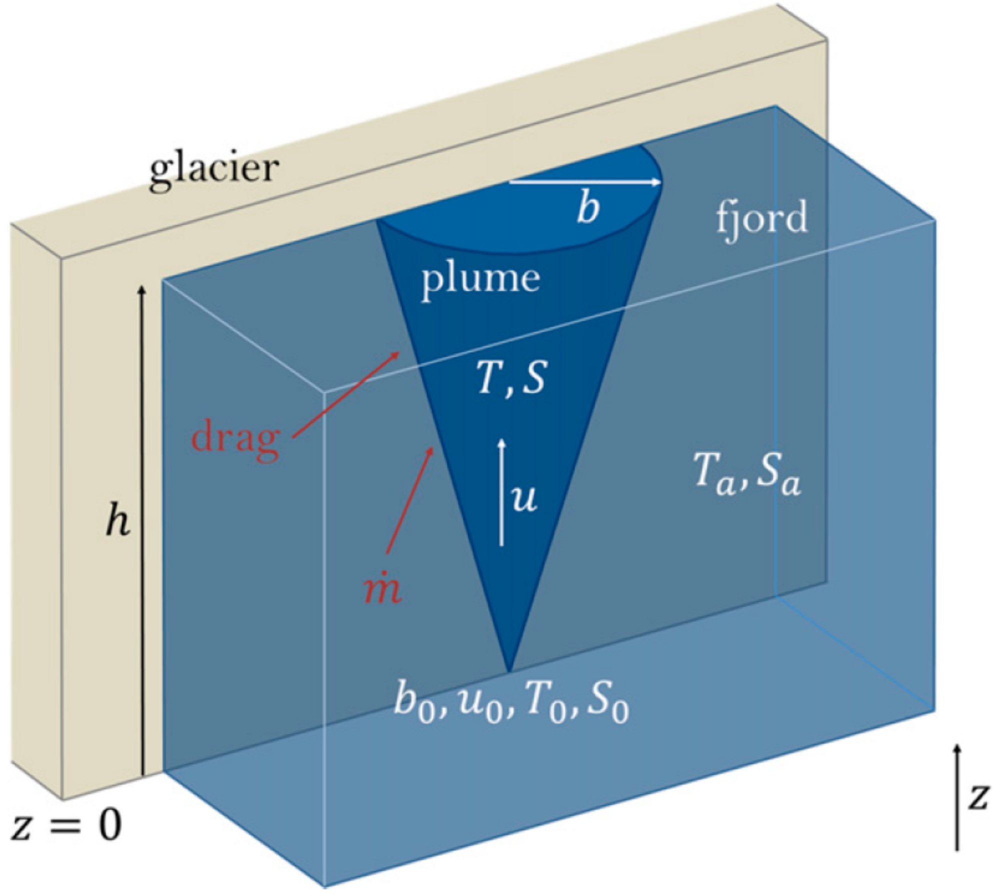
NW: cooler and slightly fresher water at calving fronts



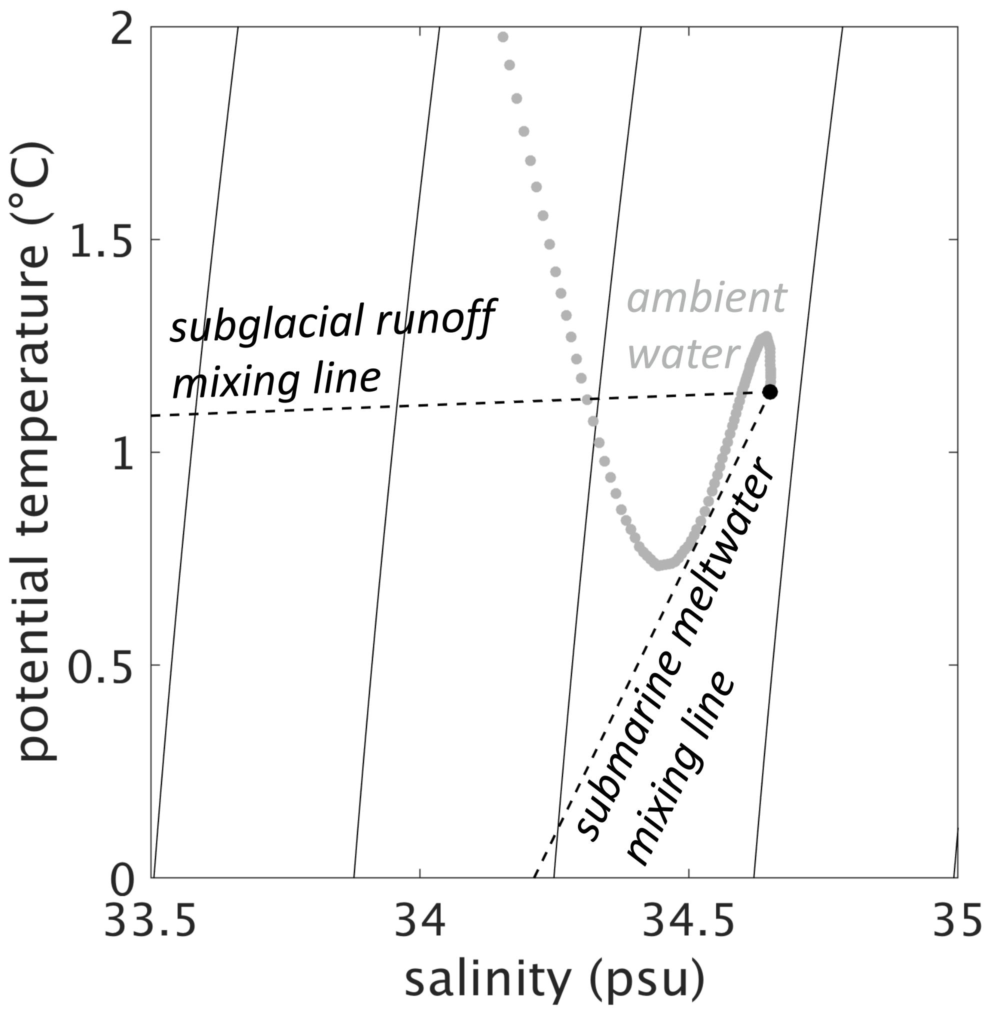
Black dots: values at the grounding line. Grey dots: full depth profiles.



Upwelling in plumes results in a mixing of ambient water and freshwater – use buoyant plume theory to quantify the mixture



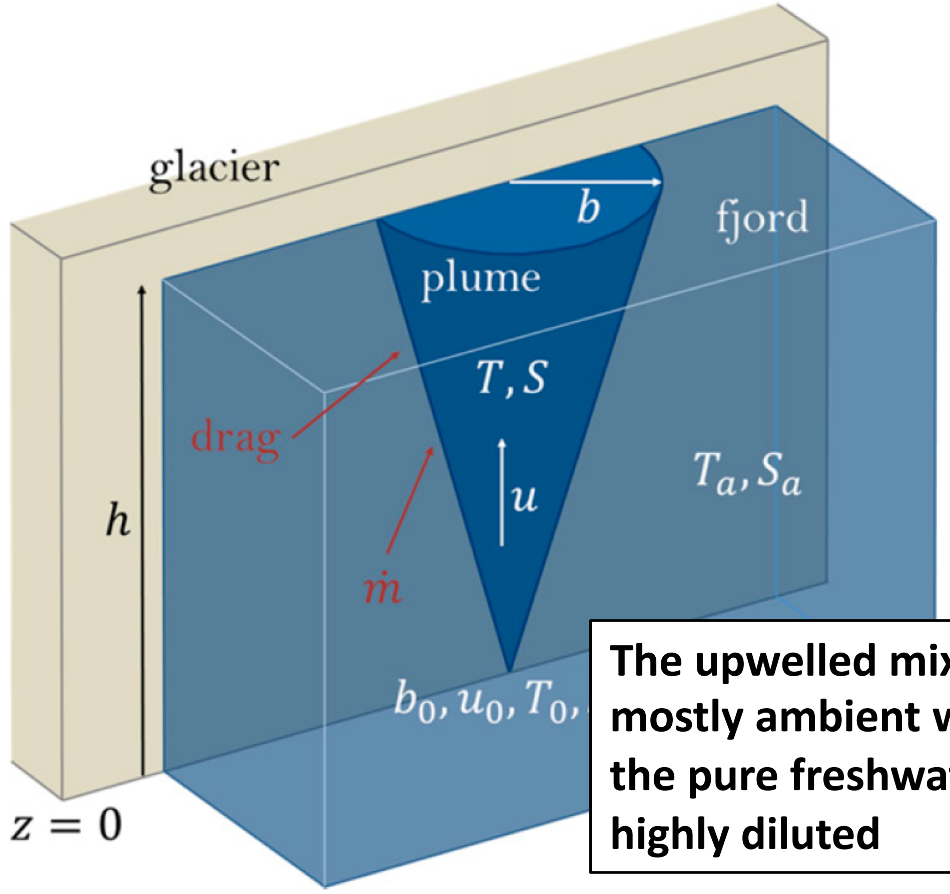
Slater et al., 2016, JPO



Example for Jakobshavn Isbrae, west Greenland

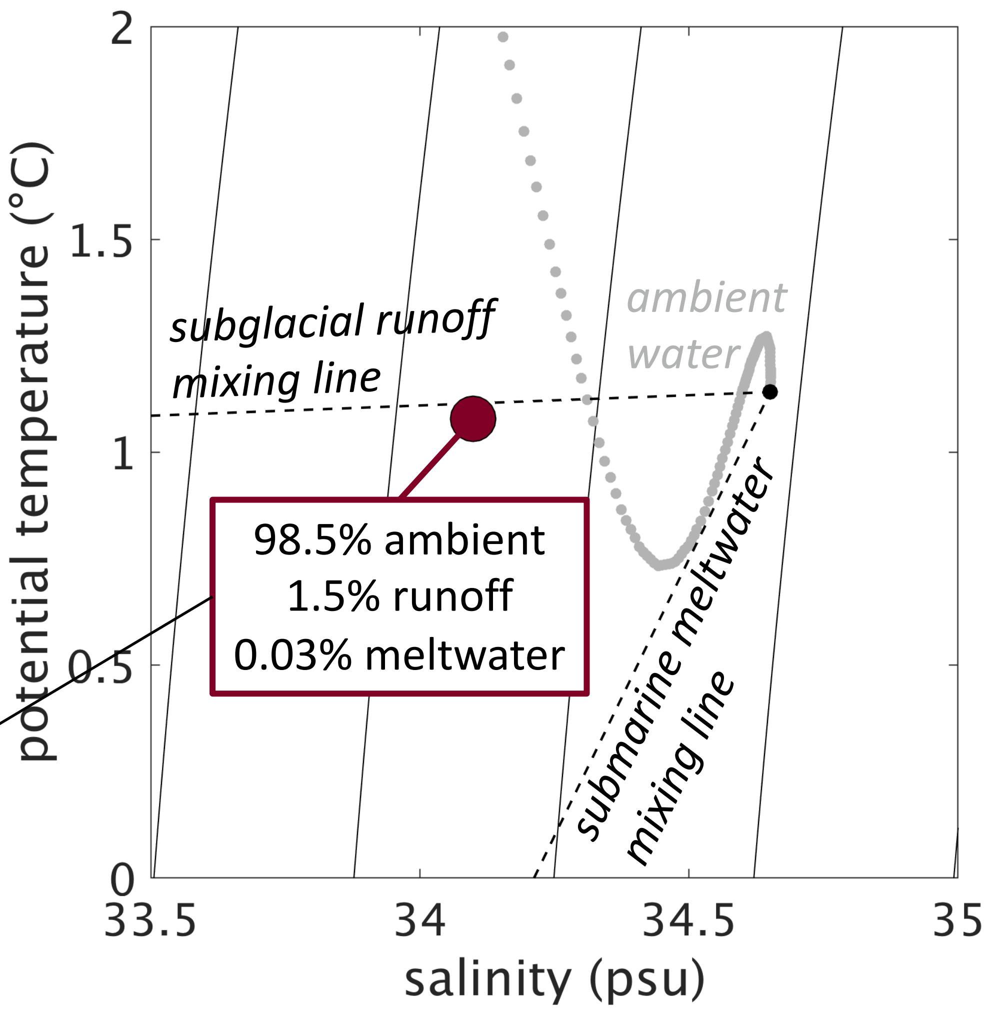
This mixture is close to what is exported from the fjord into the ocean

Upwelling in plumes results in a mixing of ambient water and freshwater – use buoyant plume theory to quantify the mixture



Slater et al., 2016, JPO

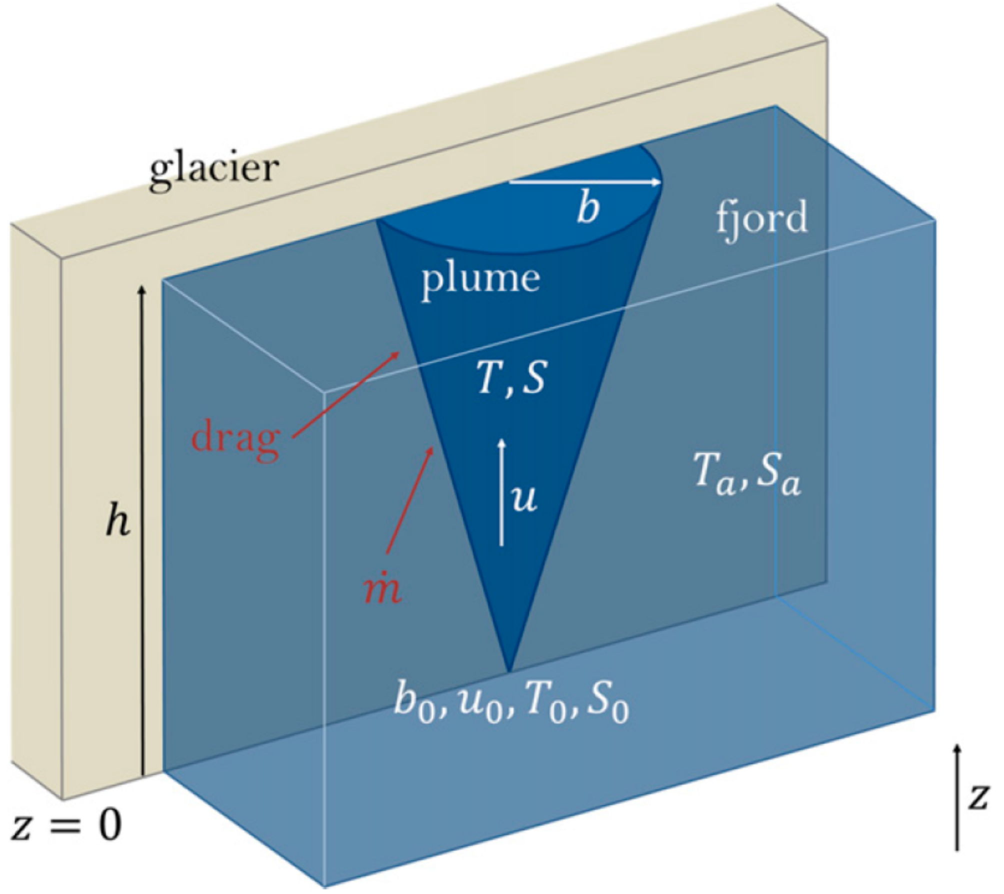
The upwelled mixture is mostly ambient water, so the pure freshwater is highly diluted



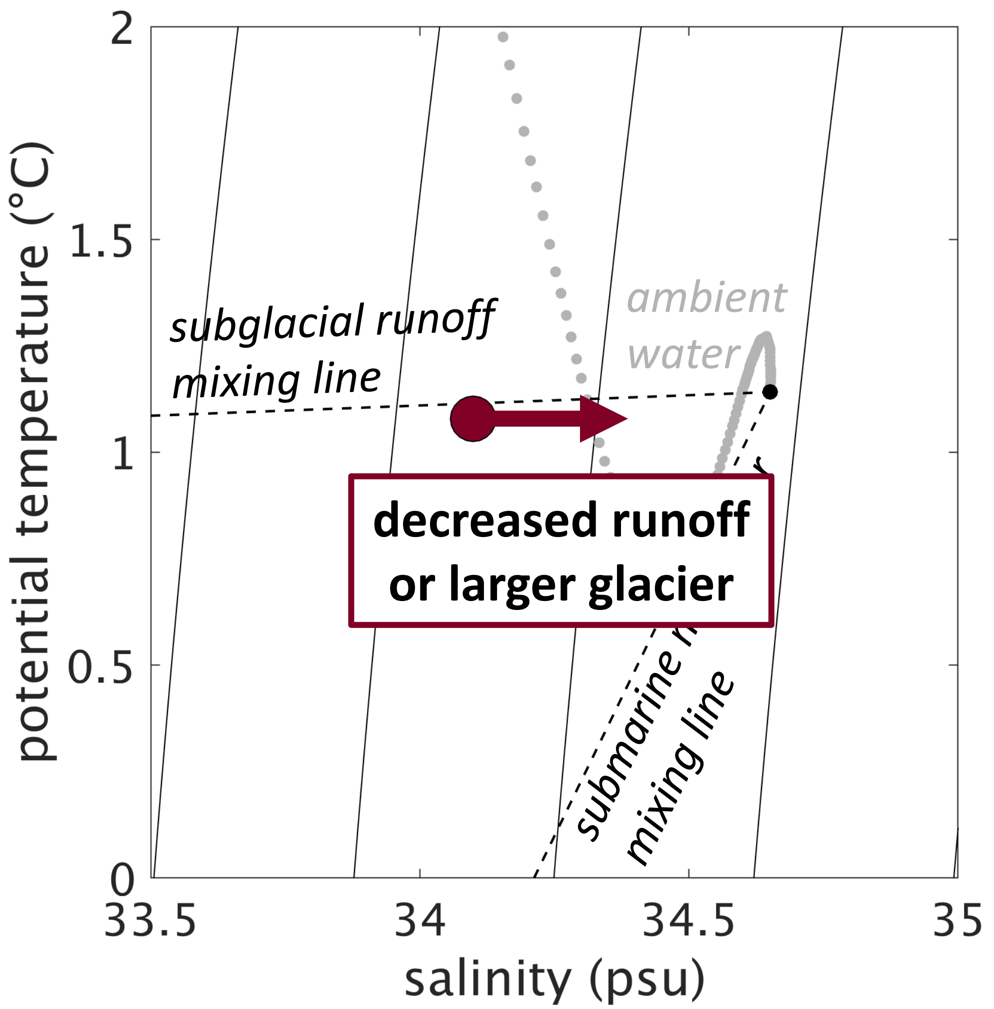
Example for Jakobshavn Isbrae, west Greenland

This mixture is close to what is exported from the fjord into the ocean

Upwelling in plumes results in a mixing of ambient water and freshwater – use buoyant plume theory to quantify the mixture



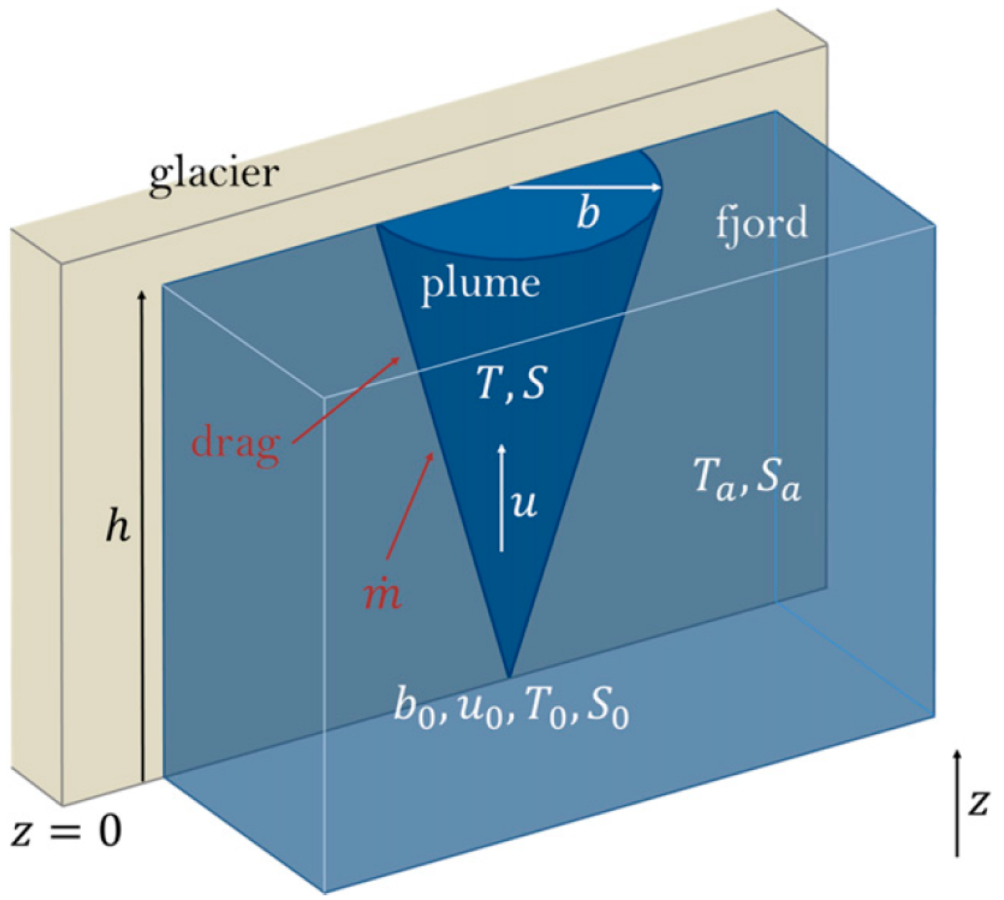
Slater et al., 2016, JPO



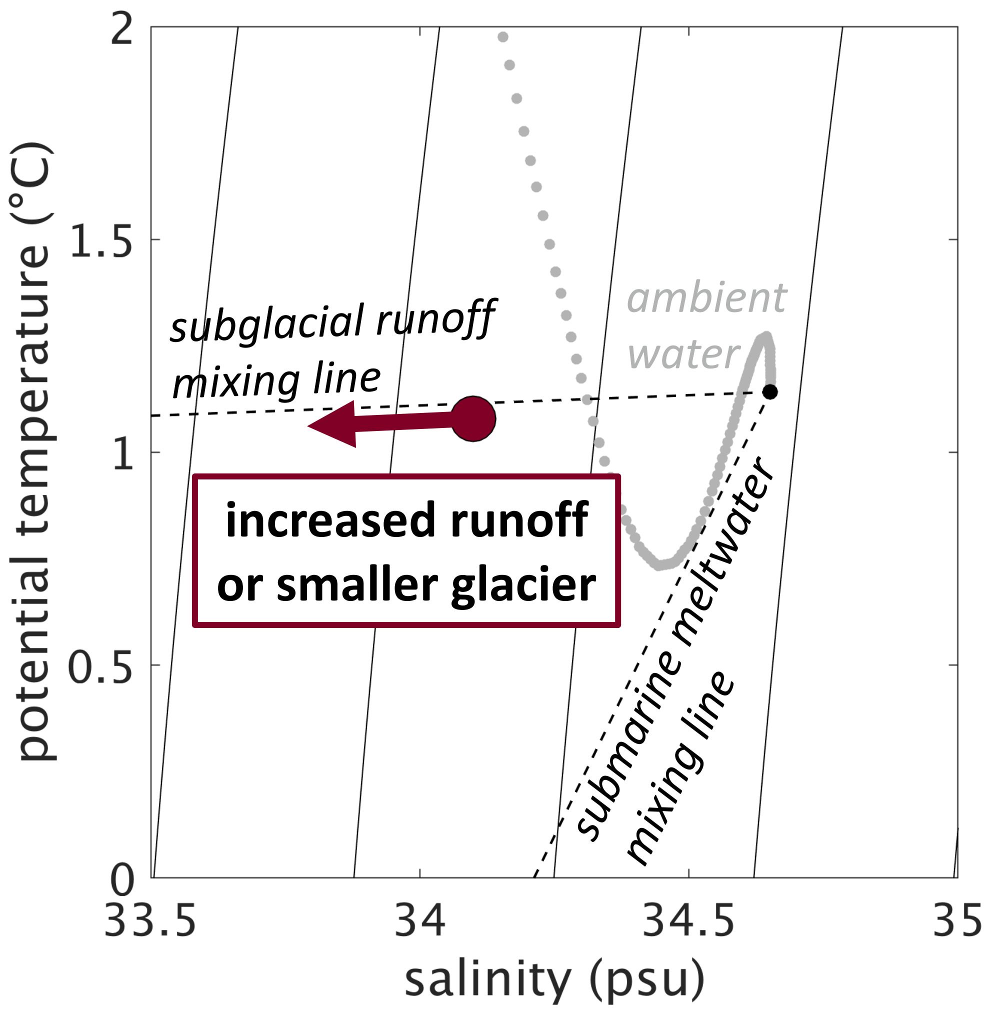
Example for Jakobshavn Isbrae, west Greenland

This mixture is close to what is exported from the fjord into the ocean

Upwelling in plumes results in a mixing of ambient water and freshwater – use buoyant plume theory to quantify the mixture



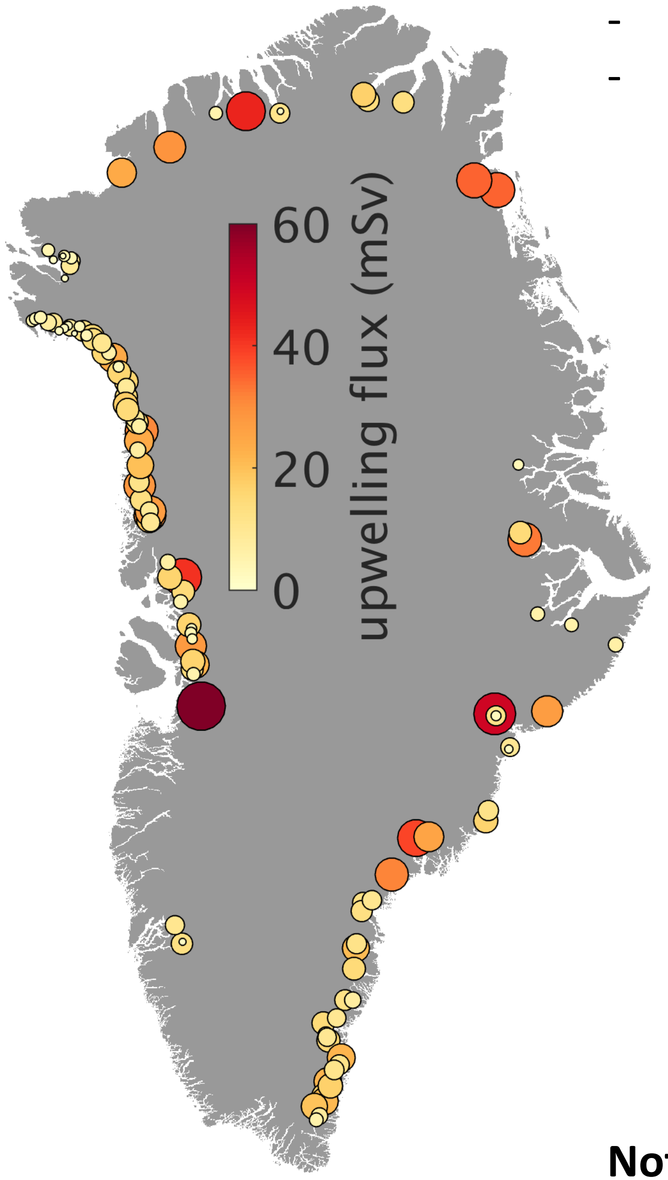
Slater et al., 2016, JPO



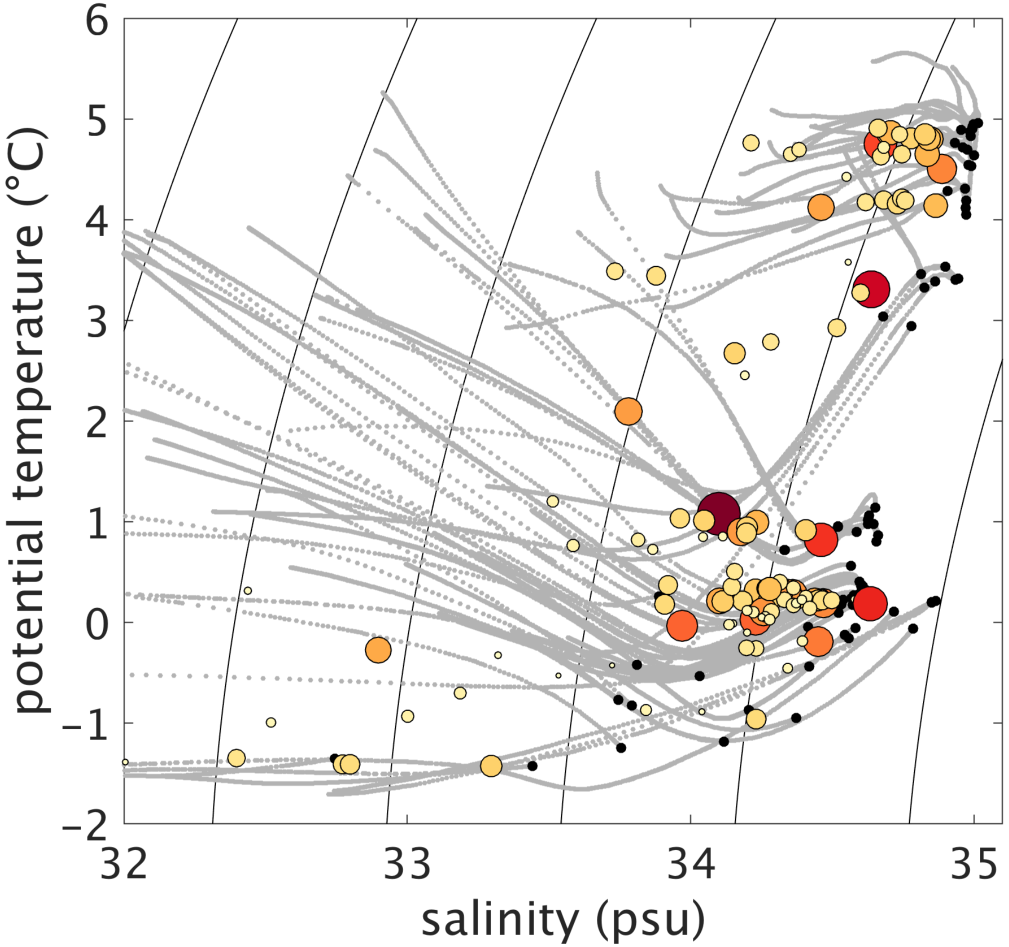
Example for Jakobshavn Isbrae, west Greenland

This mixture is close to what is exported from the fjord into the ocean

Quantification of the flux and properties of waters exported from fjords to the ocean



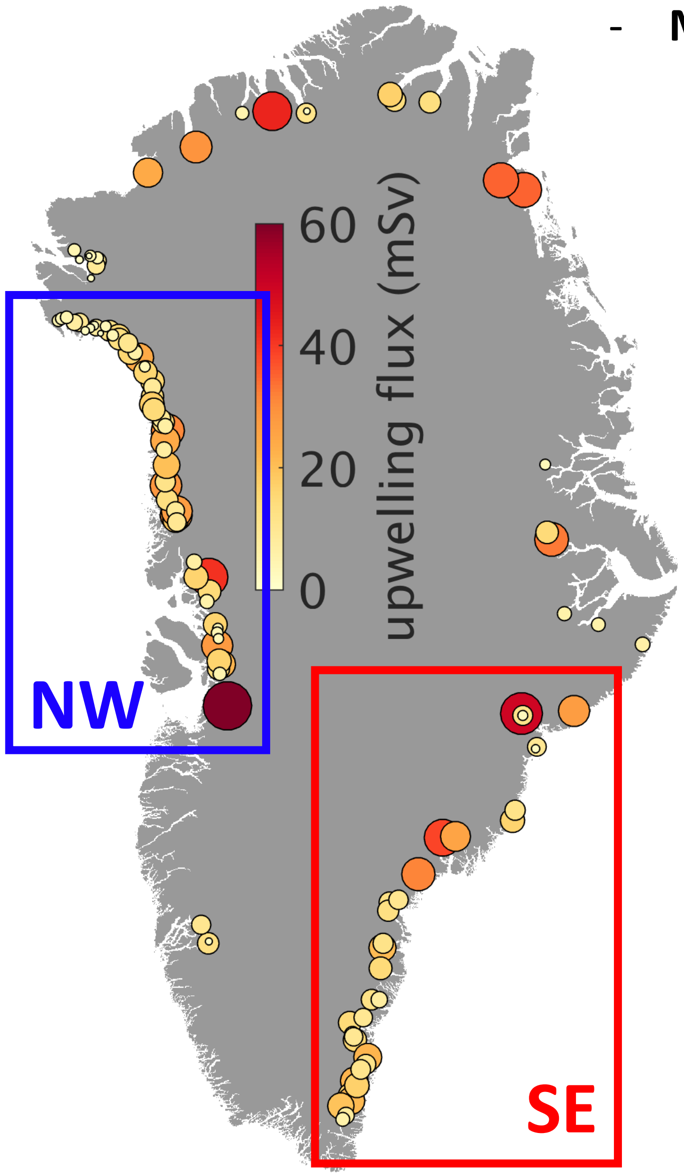
- **Export is dominated by the large tidewater systems**
- **Within regions, different systems export water that has similar properties**

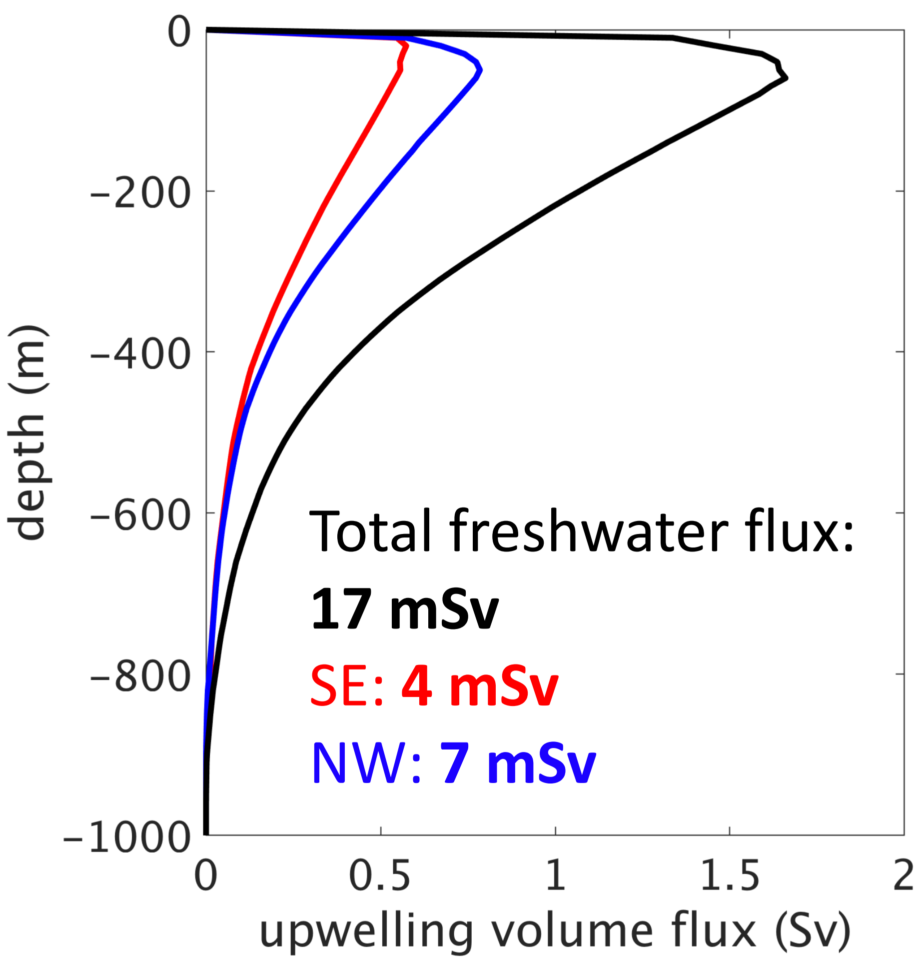


Note caveat: there are additional processes in fjords, beyond upwelling, that can modify the export and that are not accounted for here

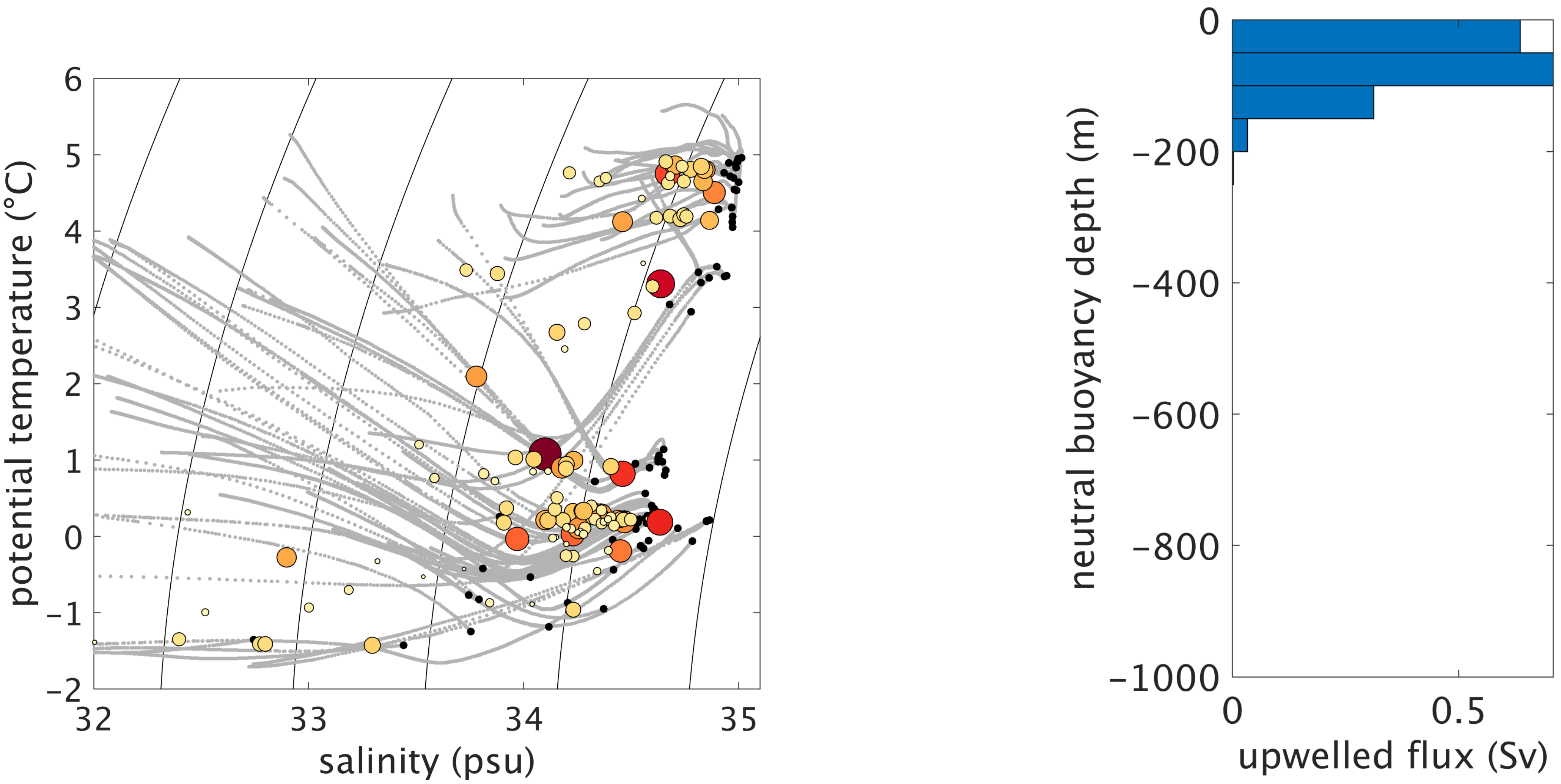
Total upwelling

- **Just 17 mSv of freshwater input drives >1 Sv of upwelling**
- **Most is in SE and NW Greenland as these have many tidewater glaciers**





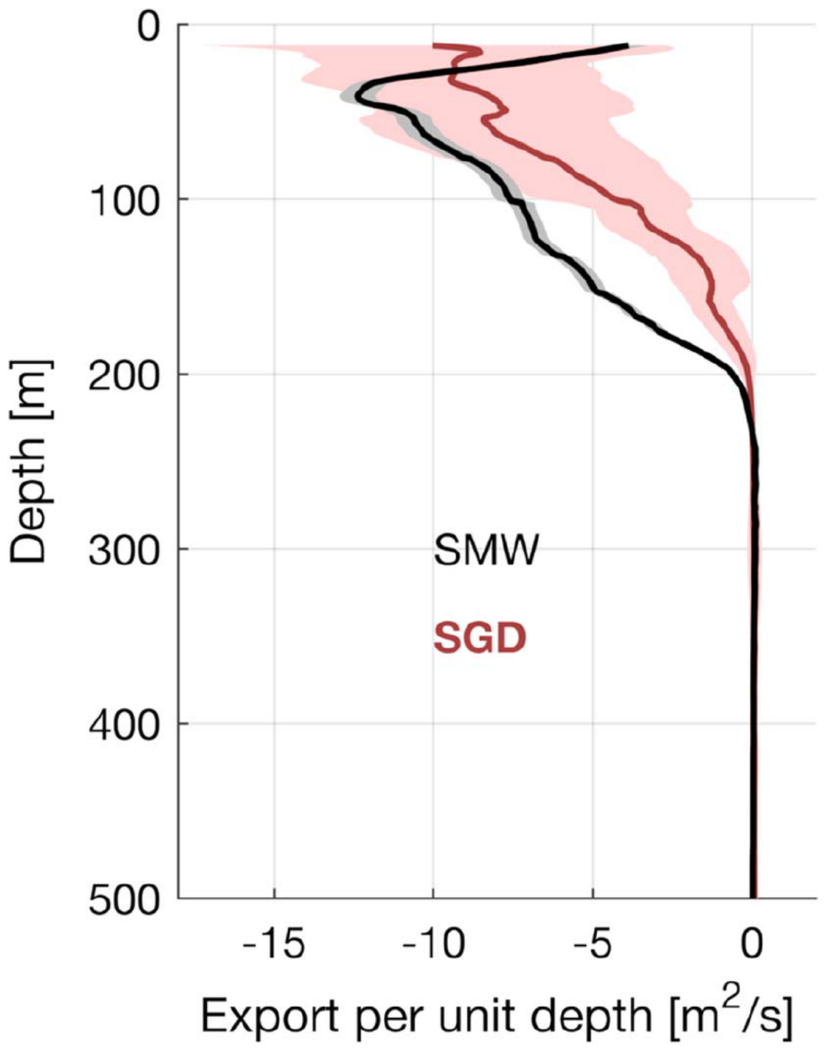
At what depth is the export from fjords to the ocean occurring?

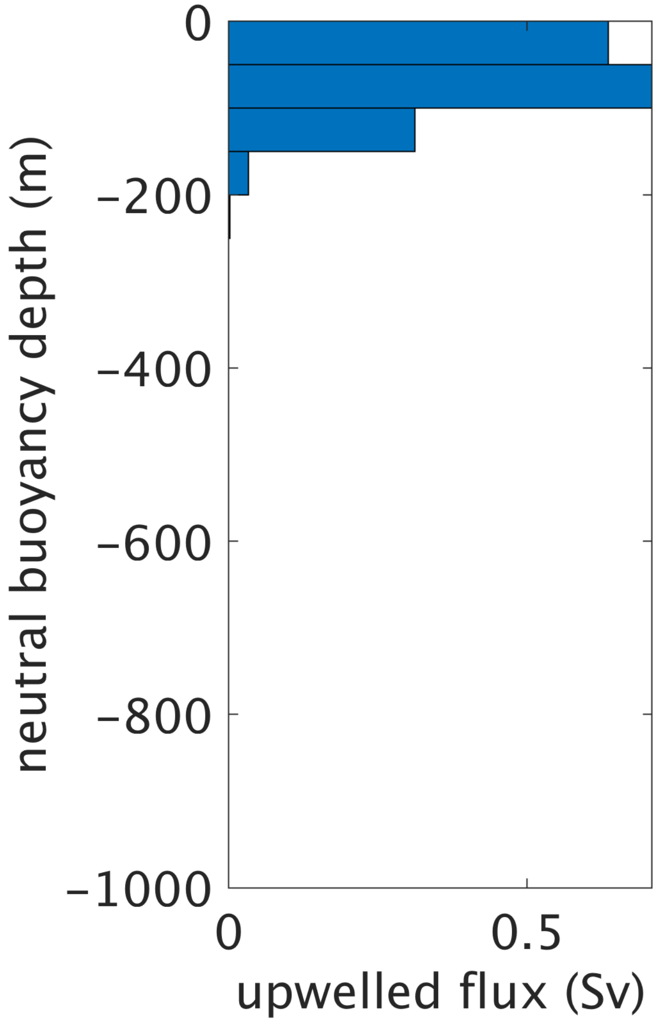


- **Vast majority in upper 200 m, but a majority is below 50 m, not at the surface (as commonly imposed in ocean models)**

At what depth is the export from fjords to the ocean occurring?

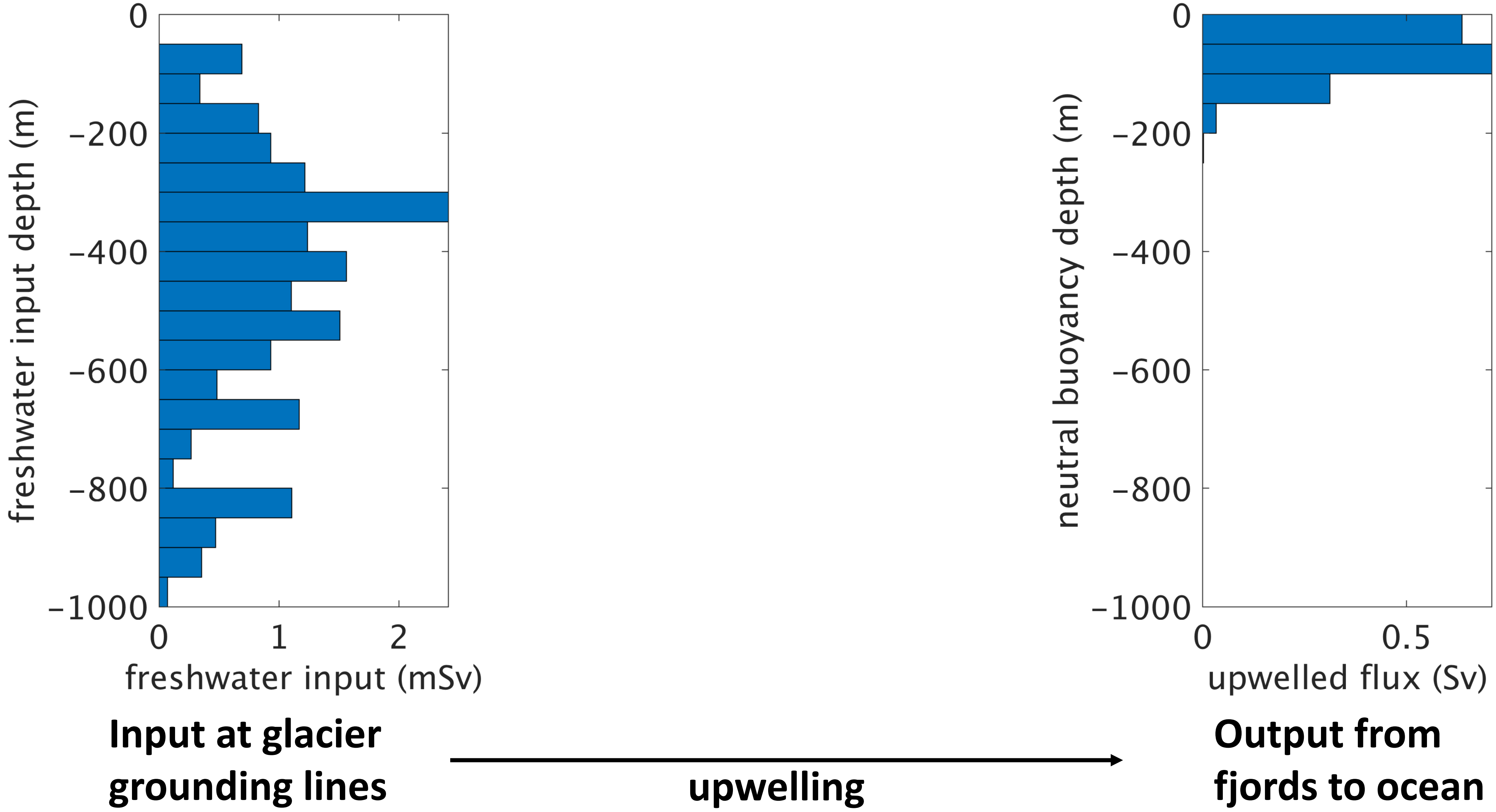
- **Results here are consistent with observations from Sermilik Fjord, SE Greenland**



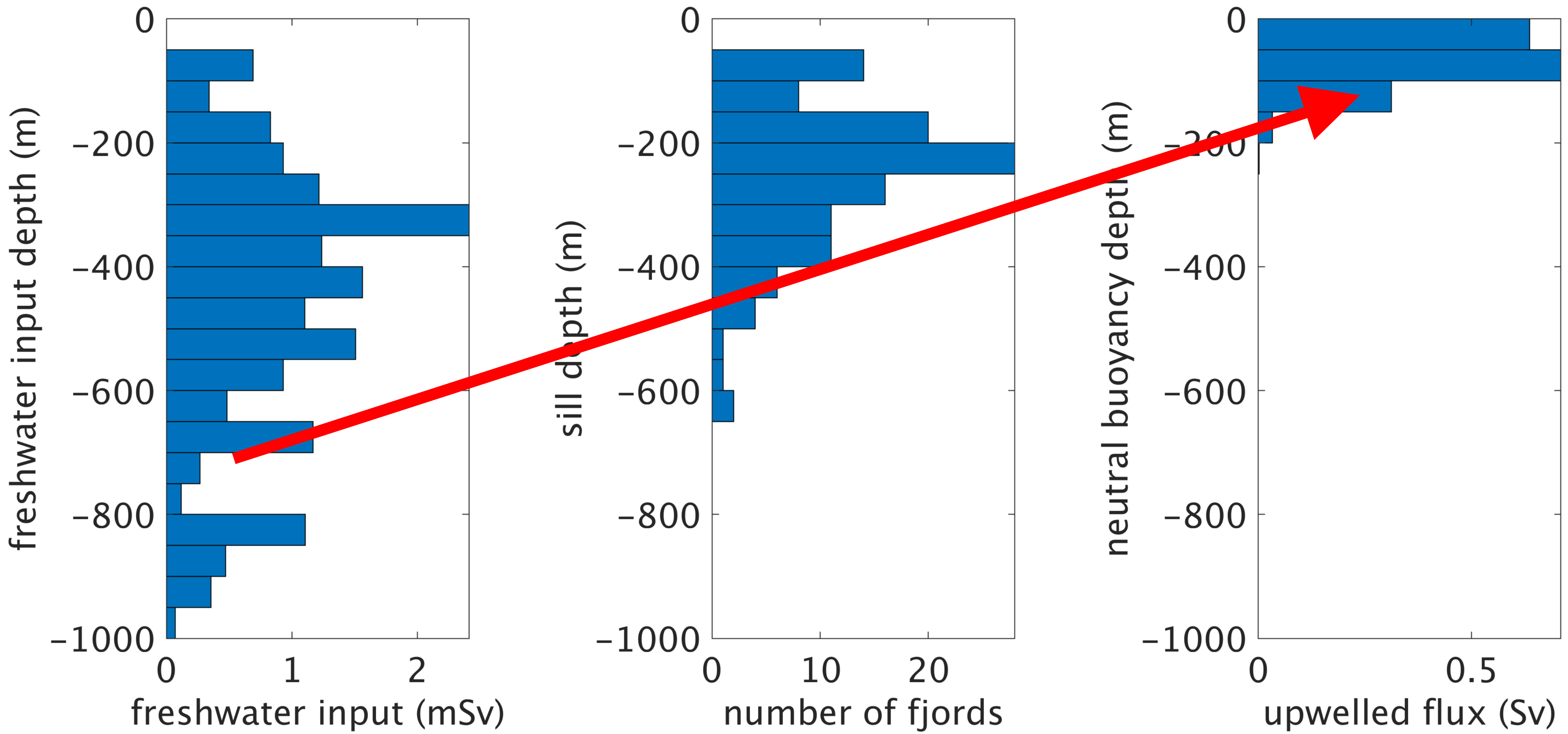


Beaird et al., 2018, GRL

At what depth is the export from fjords to the ocean occurring?



Freshwater export depth



Input at glacier grounding lines

Fjord sill depth (strong control on water properties mixed into upwelling)

Output from fjords to ocean

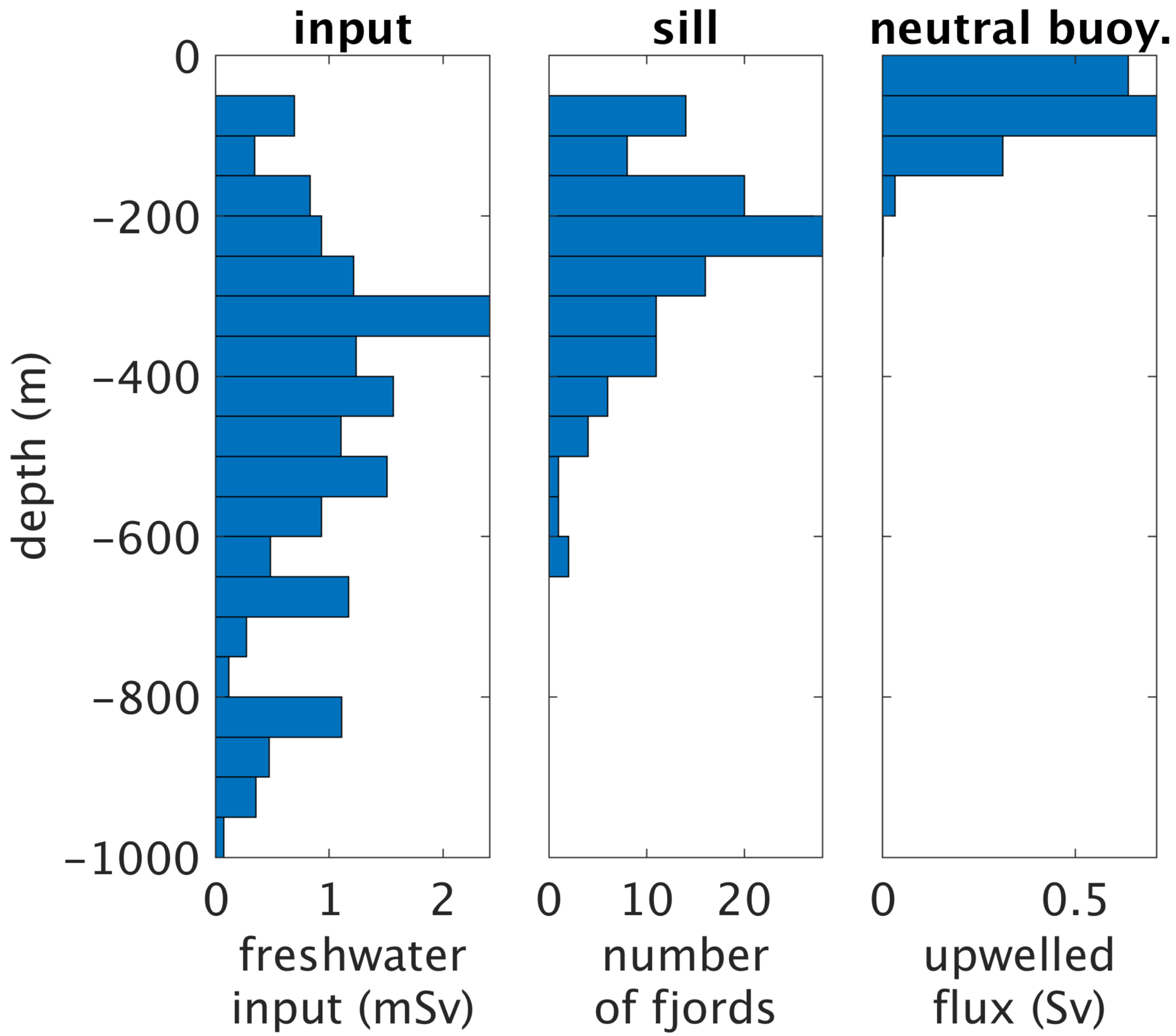
Summary

Presented a climatology for freshwater export from Greenland's tidewater glacier fjords to the ocean – a **key boundary condition** for ocean models

Just 17 mSv of freshwater entering fjords at grounding lines drives upwelling (and export) >1 Sv. Thus, while the pure freshwater input is quite small, what is exported is a much larger flux of diluted freshwater, which may therefore have a role in setting the properties of Greenland's boundary currents

The diluted freshwater mixture would find neutral buoyancy at depths 0-200 m on the shelf, so there is significant subsurface export of freshwater to the ocean

Highly regional process – almost all ice sheet-driven upwelling occurs in SE and NW Greenland



@donald_glacier

Full references

Beaird, N. L., Straneo, F., and Jenkins, W.: Export of Strongly Diluted Greenland Meltwater From a Major Glacial Fjord, Geophysical Research Letters, 45, 4163–4170, https://doi.org/10.1029/2018GL077000, 2018.

Carroll, D., Sutherland, D. A., Shroyer, E. L., Nash, J. D., Catania, G. A., and Stearns, L. A.: Subglacial discharge-driven renewal of tidewater glacier fjords, Journal of Geophysical Research: Oceans, 122, 6611–6629, https://doi.org/10.1002/2017JC012962, 2017.

De Andrés, E., Slater, D. A., Straneo, F., Otero, J., Das, S., and Navarro, F.: Surface emergence of glacial plumes determined by fjord stratification, The Cryosphere Discussions, 2020, 1–41, https://doi.org/10.5194/tc-2019-264, 2020.

Gillard, L. C., Hu, X., Myers, P. G., and Bamber, J. L.: Meltwater pathways from marine terminating glaciers of the Greenland ice sheet, Geophysical Research Letters, 43, 10 873–10 882, https://doi.org/10.1002/2016GL070969, 2016.

Hopwood, M. J., Carroll, D., J., B. T., Meire, L., Mortensen, J., Krisch, S., and Achterberg, E. P.: Non-linear response of summertime marine productivity to increased meltwater discharge around Greenland, Nature Communications, 9, https://doi.org/10.1038/s41467-018-05488-8, 2018.

Jenkins, A.: Convection-Driven Melting near the Grounding Lines of Ice Shelves and Tidewater Glaciers, Journal of Physical Oceanography, 41, 2279–2294, https://doi.org/10.1175/JPO-D-11-03.1, 2011.

Meire, L., Mortensen, J., Meire, P., Juul-Pedersen, T., Sejr, M. K., Rysgaard, S., Nygaard, R., Huybrechts, P., and Meysman, F. J. R.: Marine-terminating glaciers sustain high productivity in Greenland fjords, Global Change Biology, 23, 5344–5357, https://doi.org/10.1111/gcb.13801, 2017.

Full references

Morton, B., Taylor, G., and Turner, J.: Turbulent Gravitational Convection from Maintained and Instantaneous Sources, Proceedings of the Royal Society of London Series a-Mathematical and Physical Sciences, 234, 1–23, https://doi.org/10.1098/rspa.1956.0011, 1956.

Noël, B., van de Berg, W. J., van Wessem, J. M., van Meijgaard, E., van As, D., Lenaerts, J. T. M., Lhermitte, S., Kuipers Munneke, P., Smeets, C. J. P. P., van Ulft, L. H., van de Wal, R. S. W., and van den Broeke, M. R.: Modelling the climate and surface mass balance of polar ice sheets using RACMO2 – Part 1: Greenland (1958–2016), The Cryosphere, 12, 811–831, https://doi.org/10.5194/tc-12-811-2018, 2018.

Slater, D. A., Nienow, P. W., Cowton, T. R., Goldberg, D. N., and Sole, A. J.: Effect of near-terminus subglacial hydrology on tidewater glacier submarine melt rates, Geophysical Research Letters, 42, 2861–2868, https://doi.org/10.1002/2014GL062494, 2015.

Slater, D. A., Goldberg, D. N., Nienow, P. W., and Cowton, T. R.: Scalings for submarine melting at tidewater glaciers from buoyant plume theory, Journal of Physical Oceanography, 46, 1839–1855, https://doi.org/10.1175/JPO-D-15-0132.1, 2016.

van den Broeke, M. R., Enderlin, E. M., Howat, I. M., Kuipers Munneke, P., Noel, B. P. Y., van de Berg, W. J., van Meijgaard, E., and Wouters, B.: On the recent contribution of the Greenland ice sheet to sea level change, The Cryosphere, 10, 1933–1946, https://doi.org/10.5194/tc-10-1933-2016, 2016.

Zuo, H., Alonso-Balmaseda, M., Mogensen, K., and Tietsche, S.: OCEAN5: The ECMWF Ocean Reanalysis System and its Real-Time analysis component, https://doi.org/10.21957/la2v0442, 2018.