Antarctic Peninsula warming triggers West Antarctic basal melting

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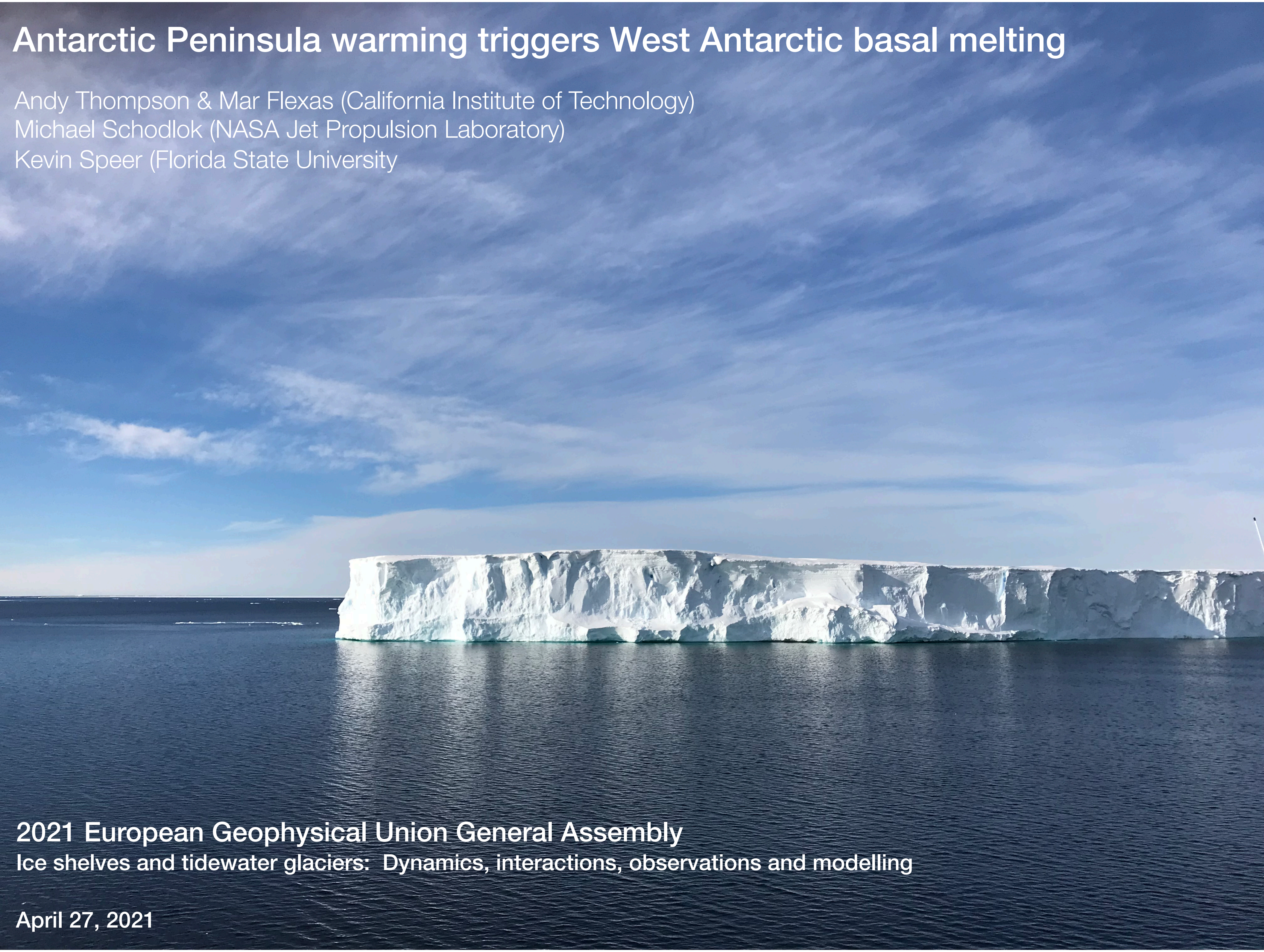


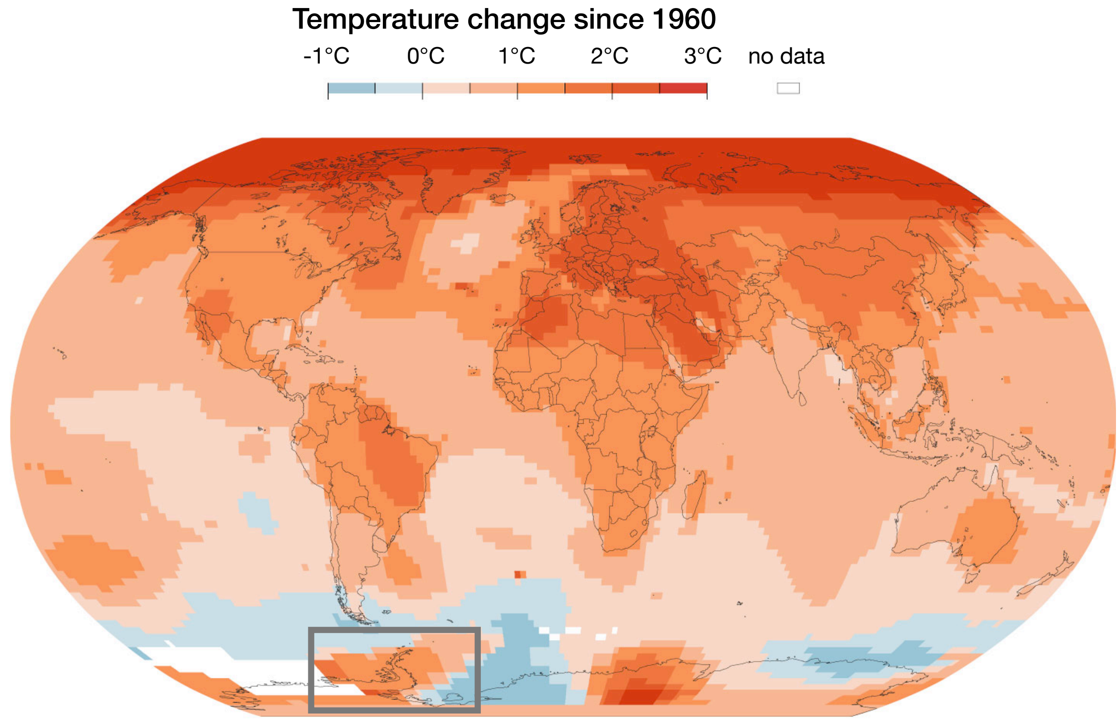
2021 European Geophysical Union General Assembly

Ice shelves and tidewater glaciers: Dynamics, interactions, observations and modelling

April 27, 2021

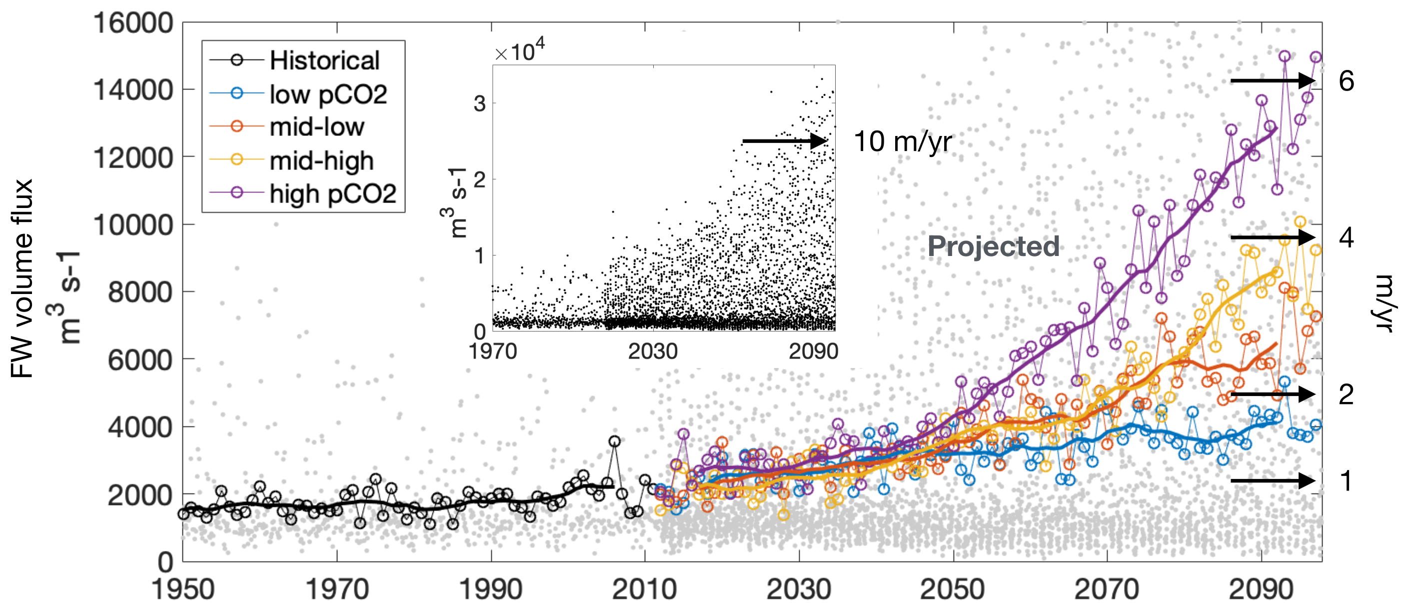
Climate change impacts at the Antarctic Peninsula

Since the 1960's the Antarctic Peninsula has experienced one of the most rapid rates of warming in the entire Southern Hemisphere.



This warming has contributed to enhanced melting of ice sheets in the northern part of the Antarctic Peninsula.

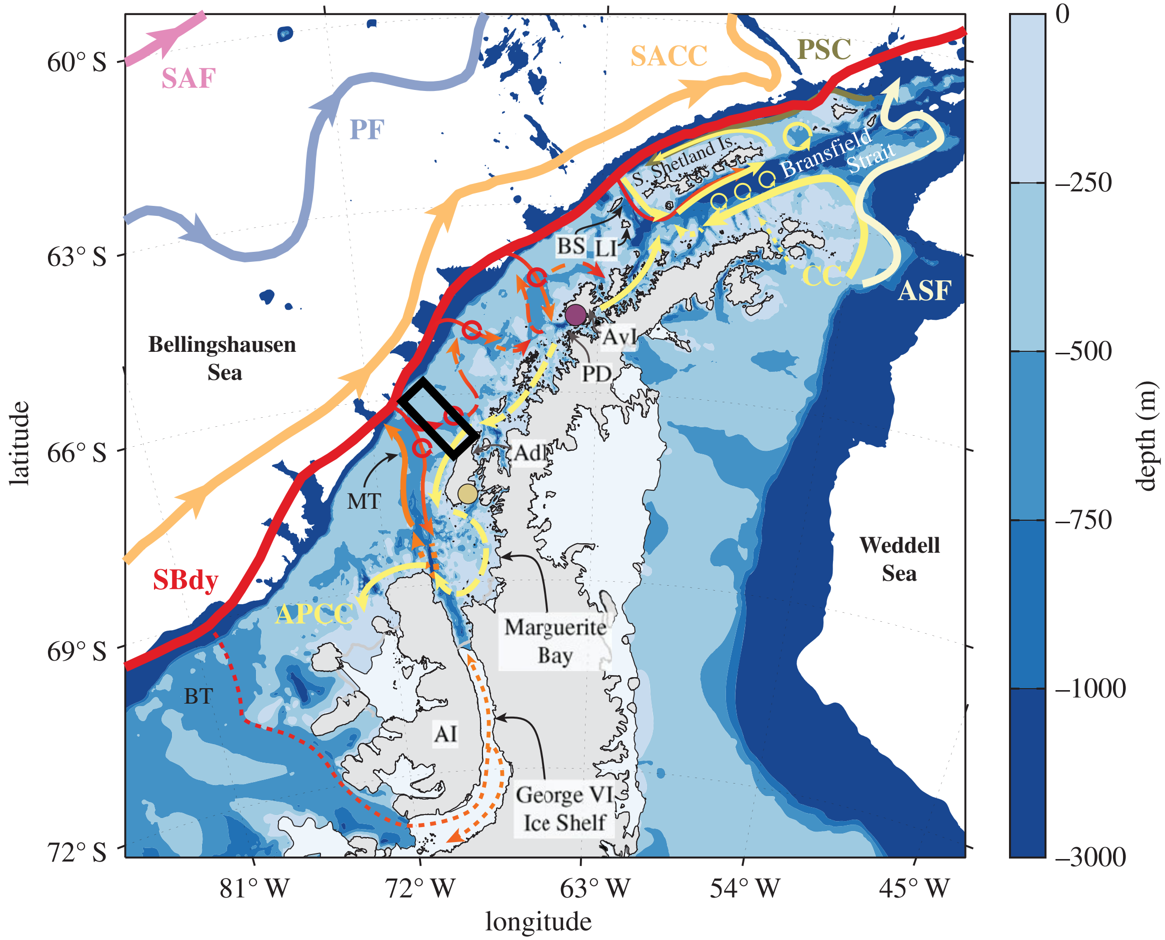
CESM2 (CMIP6) simulations predict that over the next century, changes at the Peninsula will result in a dramatic increase in freshwater forcing in the surrounding coastal ocean.



Here, we show that this freshwater forcing will strengthen the Antarctic Coastal Current (AACC) and enhance ice-shelf basal melt rates throughout the West Antarctic shelf seas.

The Antarctic Coastal Current and inter-sea exchange

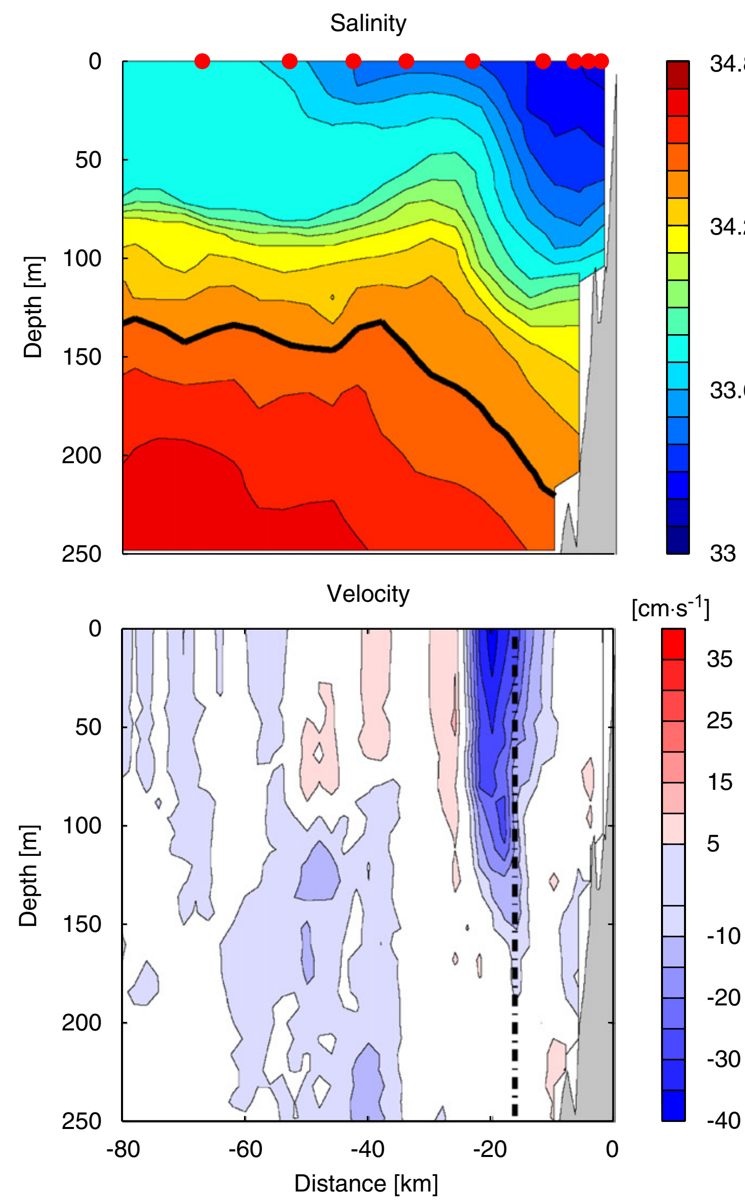
Moffat & Meredith (2018)



A key feature of the West Antarctic Peninsula circulation system is the southward-flowing Antarctic Peninsula Coastal Current (APCC, yellow curve). Due to its presence more broadly in West Antarctica, we will refer to it as the Antarctic Coastal Current (AACC).

The AACC is characterized by a freshwater anomaly near the coast, a positive sea surface height anomaly, and isopycnals that tilt down towards the coast in a narrow (~10-km) boundary current. This gives rise to a surface-intensified, southward geostrophic current.

Cross-shelf hydrographic section
(black box in map)

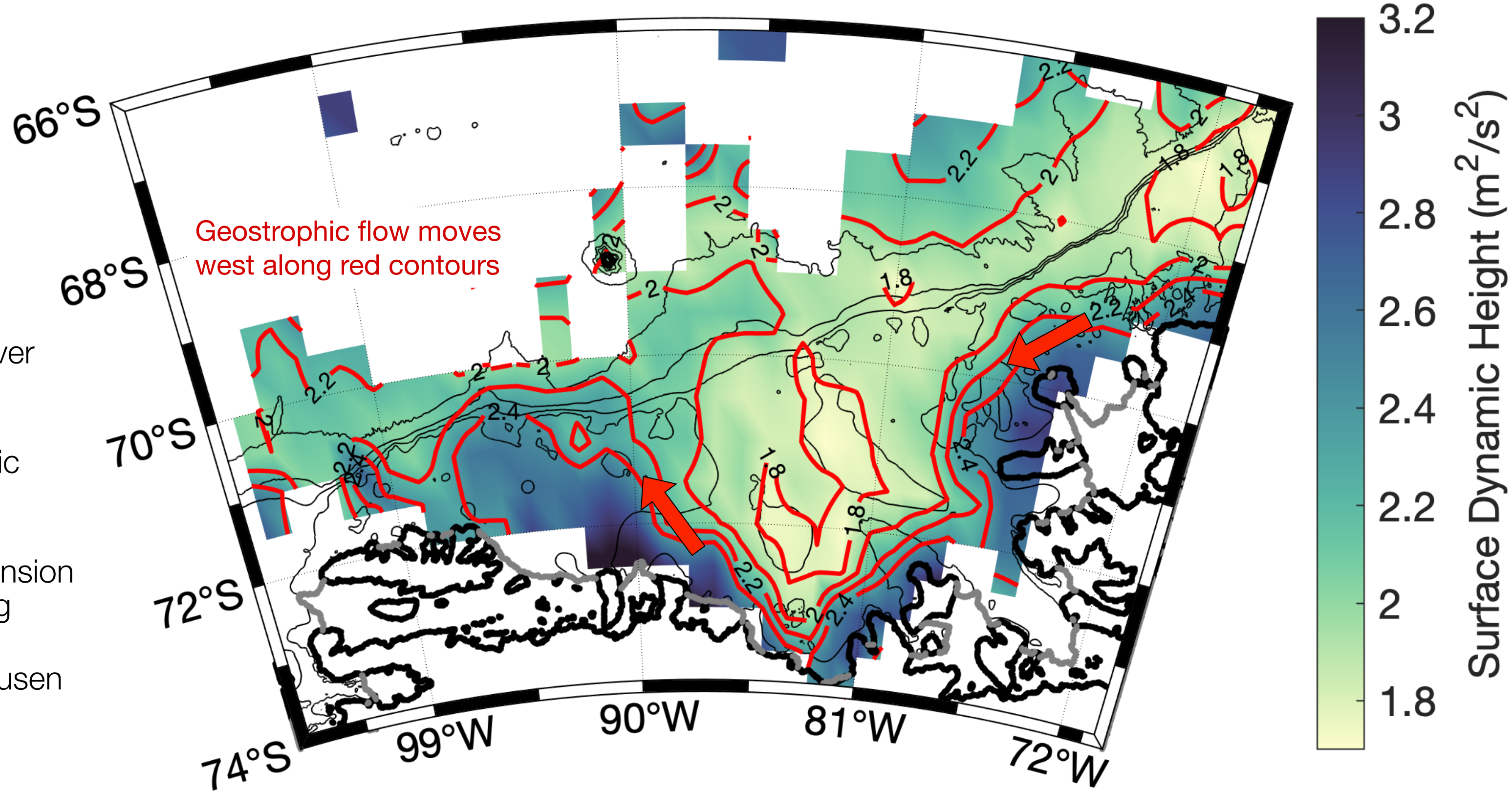


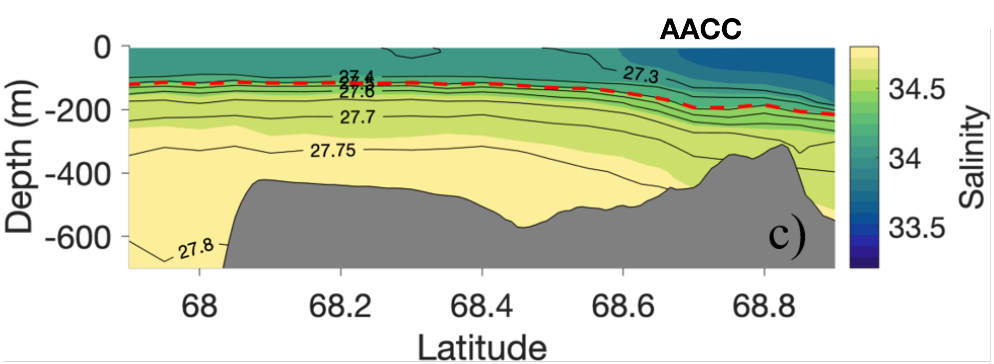
Moffat *et al.* (2018)

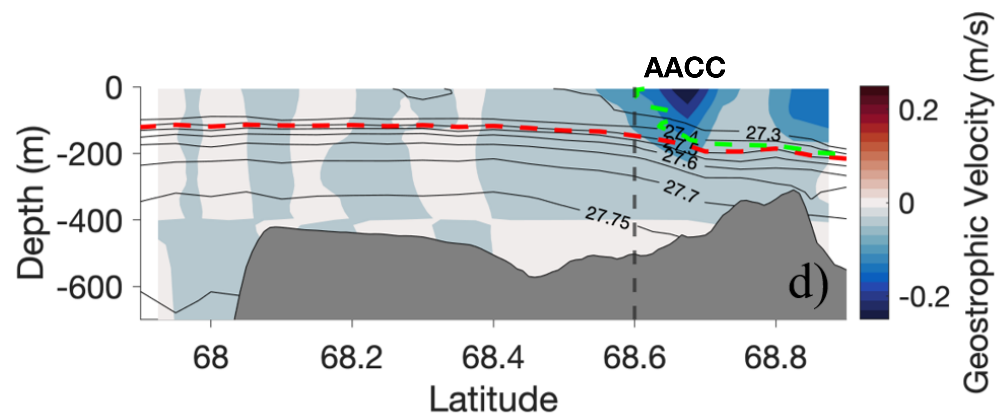
The Antarctic Coastal Current and inter-sea exchange

Using hydrographic observations collected from instrumented seals over the continental shelf in the Bellingshausen Sea, Schubert *et al.* (2021) constructed a map of dynamic topography for this region (map).

There is a clear signature of the extension of the AACC along the coast, flowing westward from the West Antarctic Peninsula throughout the Bellingshausen to the eastern Amundsen Sea.







Composite hydrographic sections constructed from the instrumented seal data show a freshwater anomaly near the coast, surface-intensified westward flow and downward tilting isopycnals in the pycnocline throughout the Bellingshausen Sea.

Thus, the AACC links the West Antarctic shelf seas.

Schubert *et al.* (2021)

Remote forcing of ice-shelf melt rates

How does freshwater input at the West Antarctic Peninsula impact ocean properties and ice-shelf melt rates in the Amundsen and Bellingshausen Seas?

We conduct a suite of sensitivity runs to model the effects of continental runoff at the West Antarctic Peninsula on the circulation of the Antarctic margins.

We impose a freshwater flux anomaly in the boxed region, between 0 and 10 m/yr.

(Further details provided in the supplementary slide).

WAIS model domain
Subdomain from MITgcm LLC1080

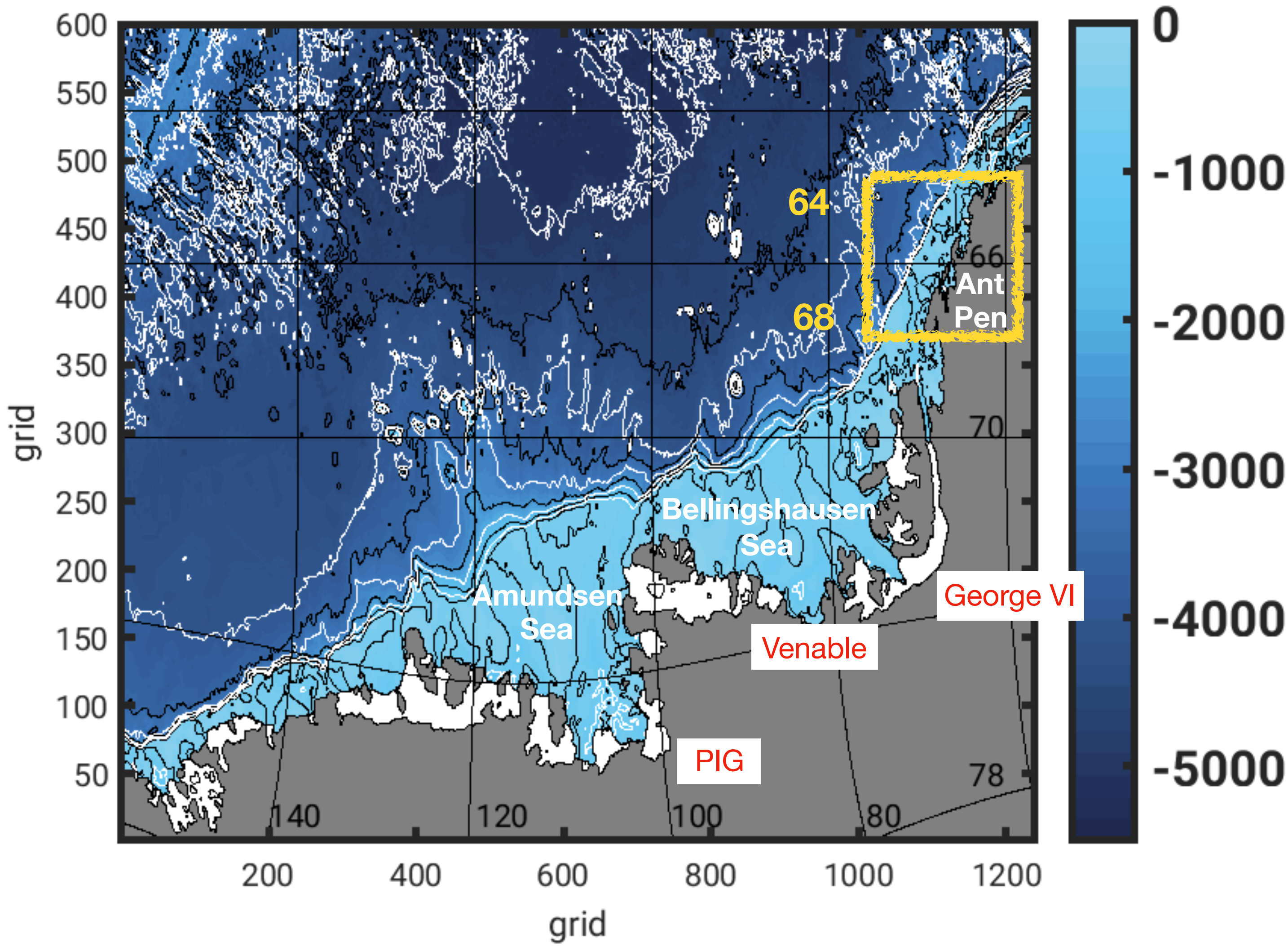
1240x600x113 grid points
Avg dx,dy = 3 km

Bathymetry:
IBCSO-Bedmachine ANT blend

Ice Shelf Draft:
Bedmachine ANT

Surface forcing, initial conditions and boundary conditions:
MITgcm ocean state estimate, LLC270

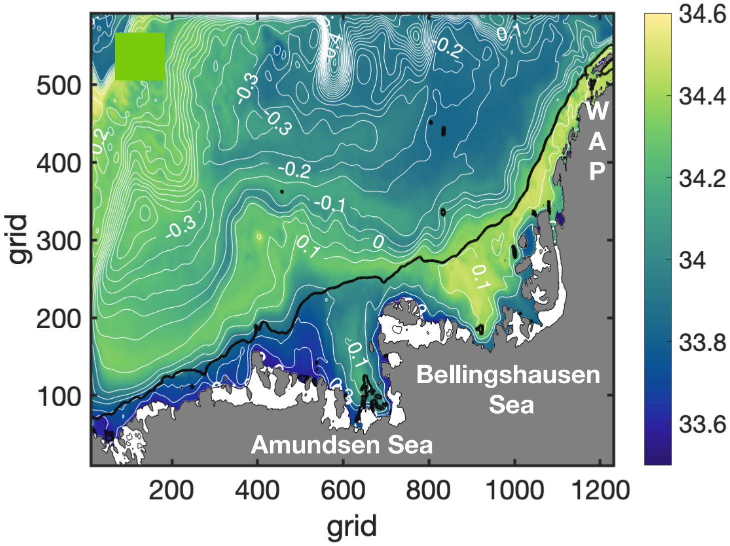
The model resolves flow in ice-shelf cavities and evolving basal melt rates.



The Antarctic Coastal Current and inter-sea exchange

Freshwater perturbations are propagated throughout the West Antarctic shelf seas via the Antarctic Coastal Current.

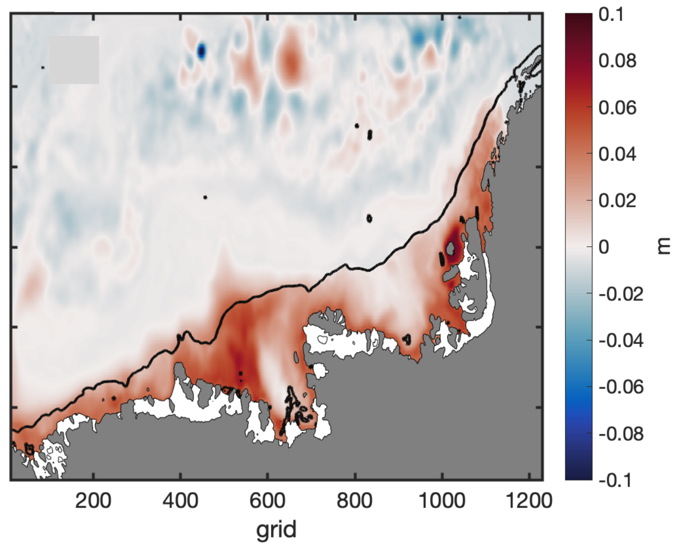
Control simulation
Color = salinity at 100 m
Contours = SSH (m)



A narrow freshwater anomaly is observed to extend from the West Antarctic Peninsula through to the Amundsen Sea.

Perturbation (10 m/yr) - Control

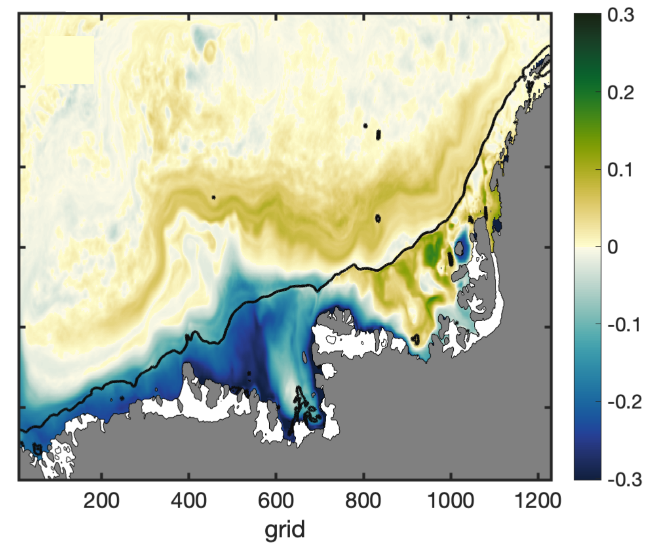
Sea surface height (SSH, m)



Freshwater perturbations over the West Antarctic Peninsula shelf lead to an increase in the SSH along the coast and an intensification of the westward flowing Antarctic Coastal Current.

Perturbation (10 m/yr) - Control

Salinity at 100 m



The freshwater perturbation also produces a strong freshwater anomaly along the coast throughout the West Antarctic shelf seas.

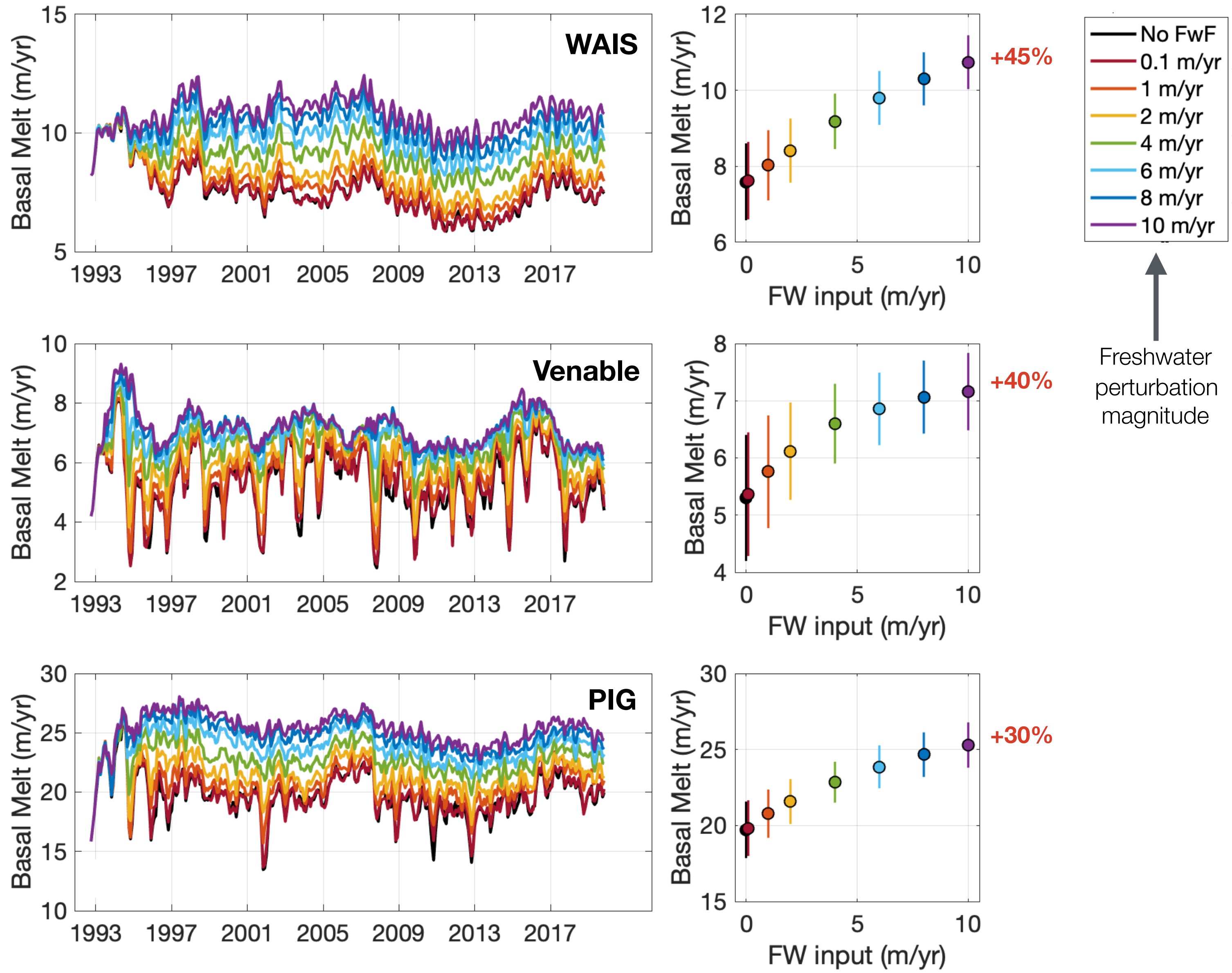
Changes in ice-shelf basal melt rates

Freshwater forcing at the West Antarctic Peninsula increases ice-shelf basal melt rates throughout West Antarctica.

Basal melt rates for all West Antarctic ice shelves increase approximately linearly with increased freshwater perturbation.

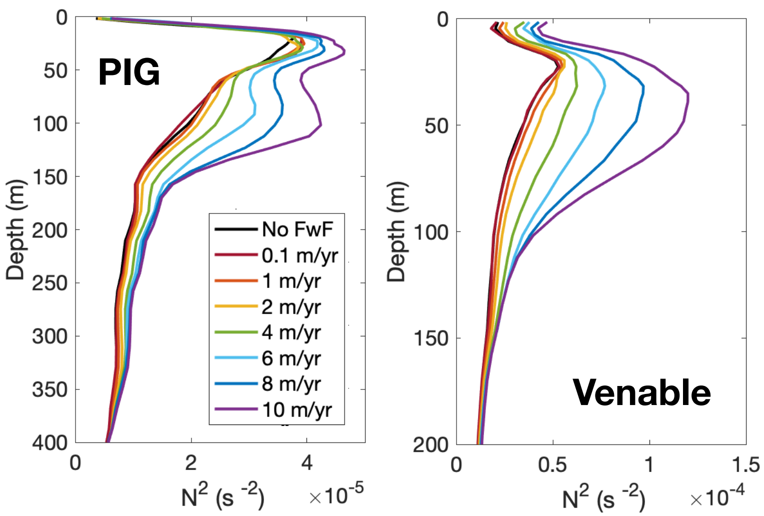
Increased freshwater perturbation can suppress seasonal and inter-annual variability in melt rates. This occurs due to the suppression of convection during sea-ice formation.

Enhanced melting only occurs after the freshwater signature reaches the ice shelf via advection by the AACC — approximately 2 years for Pine Island Glacier (PIG).

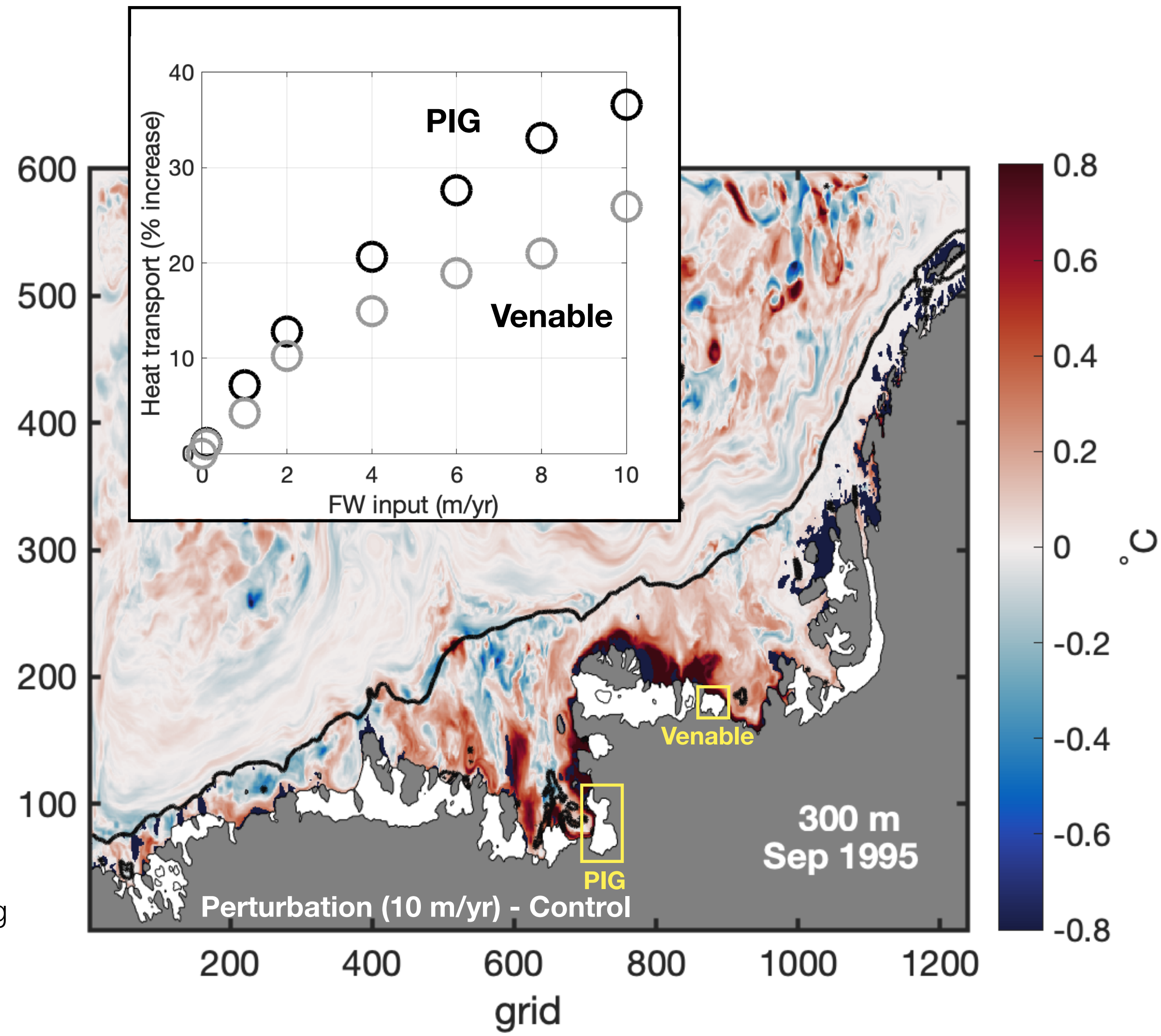


Changes in ice-shelf basal melt rates

The strengthening of the AACC enhances vertical stratification, which traps heat at depth and increases the transport of heat into ice-shelf cavities.



Advection of freshwater by the AACC leads to an increase in vertical stratification (N^2) in front of all West Antarctic ice shelves.



Changes in temperature in the Circumpolar Deep Water layer are confined to regions near the coast, with warming below 300 m.

The oceanic heat transport, across the ice-shelf front and into the ice-shelf cavity at Venable and Pine Island, increases with the same magnitude (%) as the basal melt rate for a given freshwater perturbation.

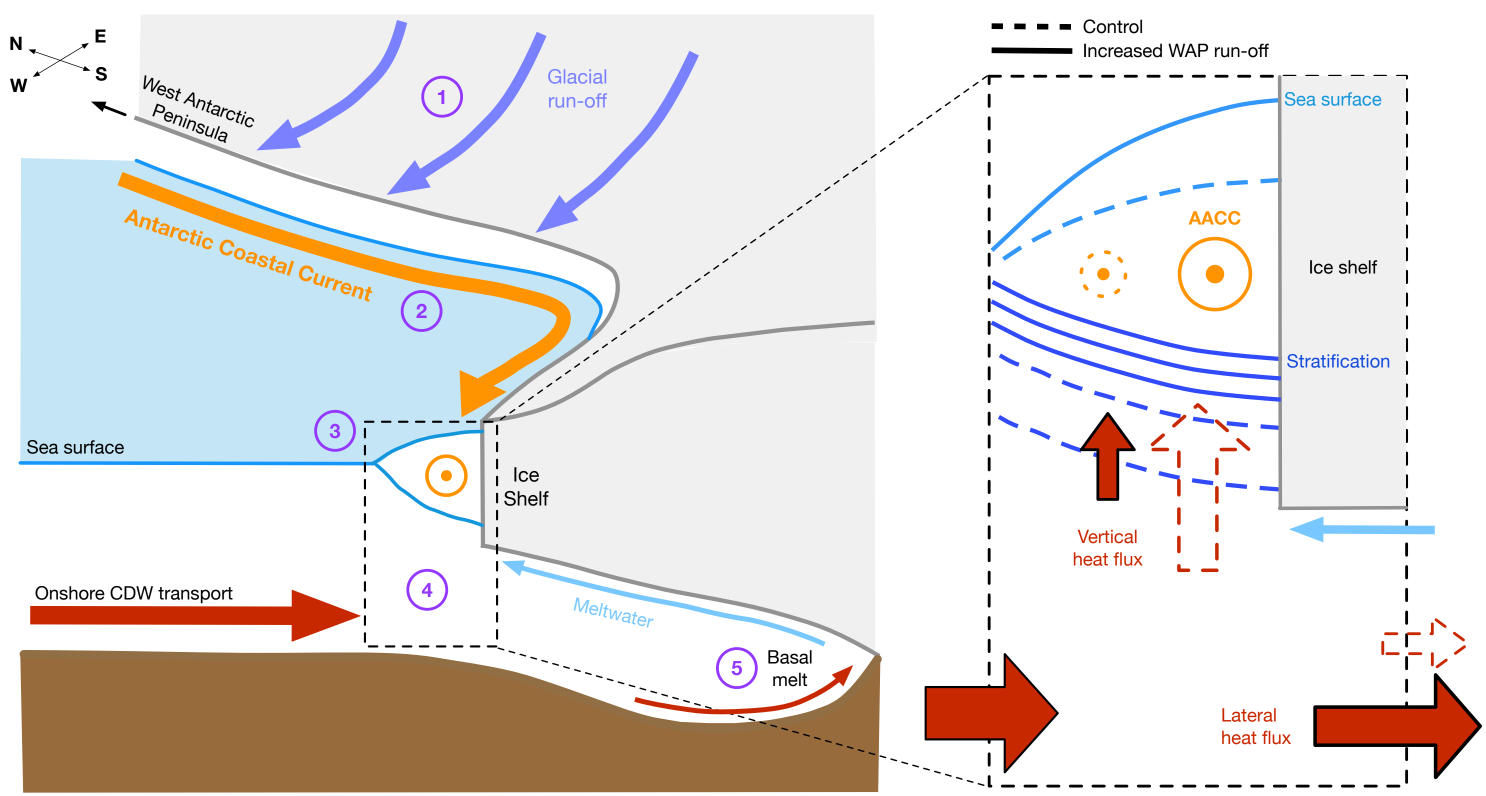
Summary & Conclusions

- Previous studies have linked variability in heat content of the West Antarctic shelves to changes in atmospheric wind forcing.

- **We show that ice-shelf basal melt rates are strongly sensitive to remote freshwater perturbations, propagated throughout West Antarctic shelf seas by the Antarctic Coastal Current.**

- Changes to the AACC give rise to modifications in the water column's stratification in front of ice shelves, which feeds back on lateral heat transport into ice-shelf cavities.

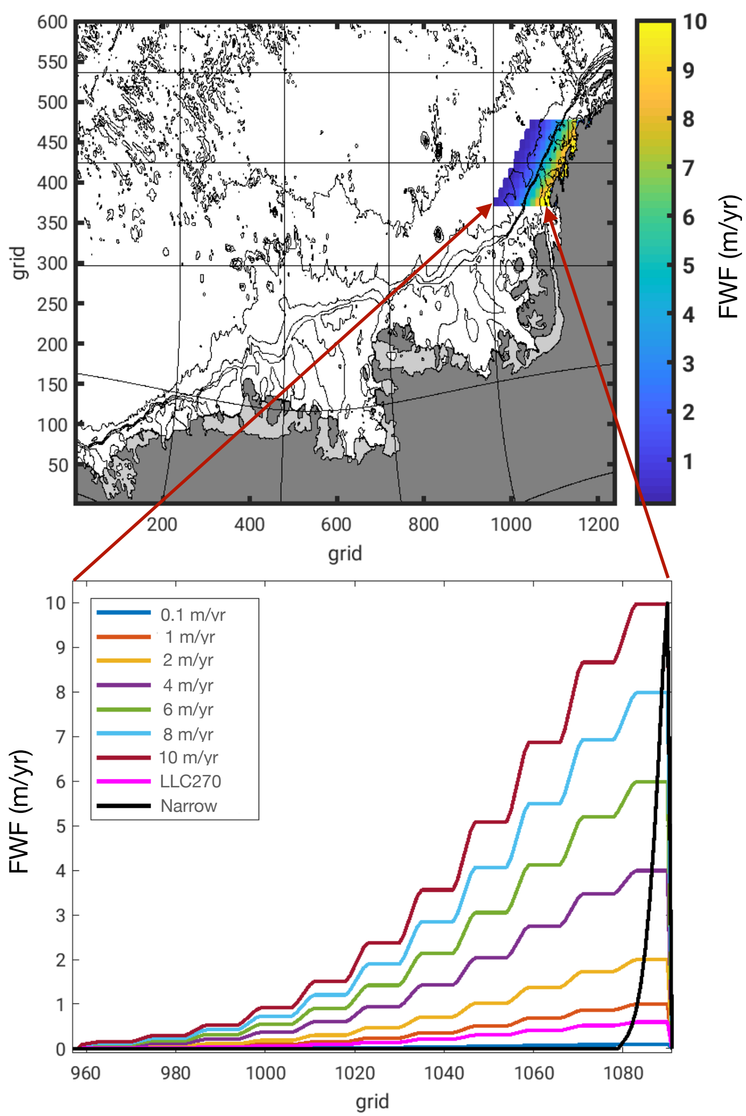
- In future decades, changes to coastal properties and dynamics, poorly resolved in current climate models, could provide the dominant control on ice-shelf melt rates.



Flexas *et al.* (2021, submitted)

Supplemental: Freshwater perturbation at the West Antarctic Peninsula

(a) Freshwater input function



(b) List of sensitivity runs

Run	Runoff (volume flux per km of coastline)	Total FW volume flux (m3/s)	Ice discharge* (Gt/yr)	Runoff wrt LLC270
Control	0	0	0	0
0.1 m/yr	0.1	244	7	0.2
LLC270	0.8	1459	42	1.0000
1 m/yr	1.3	2435	70	1.7
2 m/yr	2.6	4870	141	3.3
4 m/yr	5.2	9741	282	6.7
6 m/yr	7.8	14611	423	10
8 m/yr	10.4	19481	563	13.4
10m/yr	13.0	24351	704	16.7
Narrow 10 m/yr	1.5	2779	80	1.9
Seasonal 10 m/yr	5.4	10146	293	7.0

* The equivalent ice discharge is calculated using an ice density of 917 kg/m3. For reference, the estimated discharge at WAP from observations (Gardner et al. 2018) was 88+/-13 Gt/yr in 2008 and 91+/-12 Gt/yr in 2013, leading to an overall range of 75-103 Gt/yr for the 2008-2013 period.

Freshwater perturbations: (a) Freshwater input function. The freshwater input function is imposed at the ocean surface with maximum values at the coast decreasing exponentially 300 km offshore along 1881 km of coastline. Top panel: Model domain showing FW input function for the 10 m/yr run. Bottom panel: Zonal distribution for the sensitivity runs. (b) List of sensitivity runs, with freshwater volume flux imposed at the WAP and glacier ice discharge equivalent for reference.