Dynamics of a barotropic current at an ice shelf front: an idealized modelling study

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Motivation: Blocking of a barotropic current at Getz Ice Shelf, West Antarctica

Article

Ice front blocking of ocean heat transport to an Antarctic ice shelf

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Mass loss from the Antarctic Ice Sheet to the ocean has increased in recent decades,

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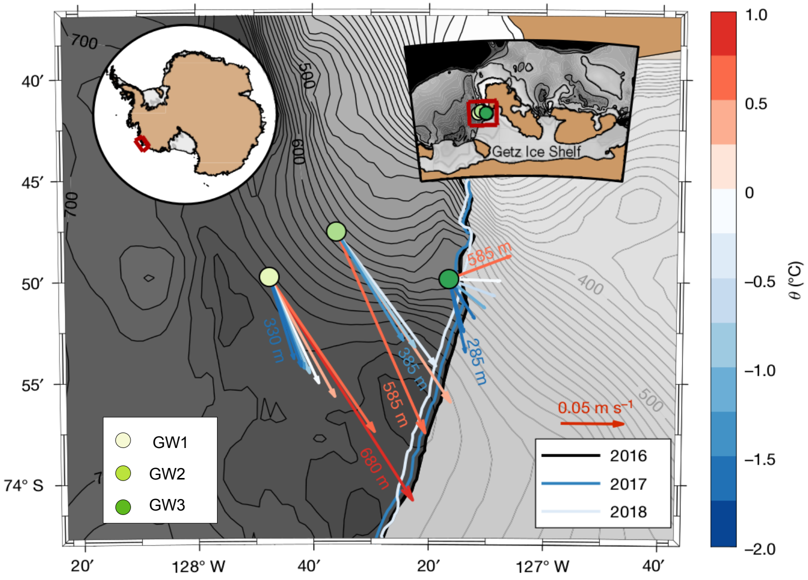
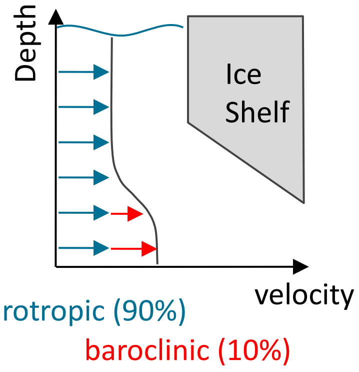


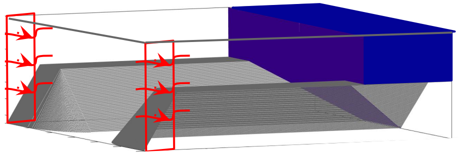
Feather plot of time-averaged (Jan 2016– Jan 2018) velocities and their temperatures (color) at different depths measured by three moorings (GW1, GW2, GW3) in front of Getz Ice Shelf (Wåhlin et al. 2020).

- About **90% (roughly 0.6 Sv) of the volume transport** towards Getz Ice Shelf and **70% of the temperature transport** is linked to the **barotropic component** of the inflowing current.
- An ice shelf front represents a **discontinuity in f/H contours** and thus a **topographic barrier** to barotropic flows that are governed by PV-dynamics.
- Mooring measurements show a **deflection of the barotropic component** at the ice shelf front (see figure to the left).

For full paper see Wåhlin et al. (2020) or follow the EGU discussion on 08 May, 16:15 – 18:00



Main findings of this study



We use an idealized setup of MITgcm to investigation the dynamics governing barotropic flow in the vicinity of an ice shelf front.

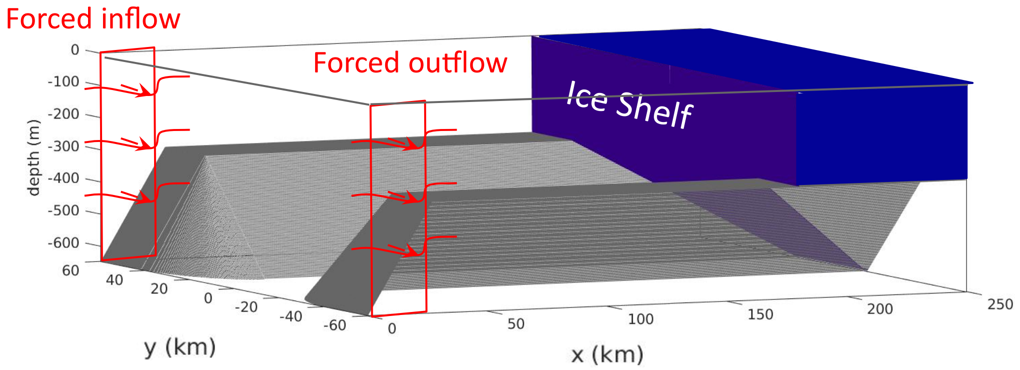
- An externally driven barotropic current can cross the ice shelf front in a homogeneous ocean, which is associated with large vertical velocities →Slide 5
- **Relative vorticity** and **friction** allow the flow to cross the discontinuity in f/H →Slide 6
- Stratification influences the amount of blocking: →Slide 7
  Without stratification: large vertical velocities and subduction into the cavity
  With stratification: subpressed subduction and more blocking. A small baroclinic component develops that can enter the cavity
- Large velocities along the ice shelf front **increase melt rates** and possibly enhance calving. →Slide 8
- Stonger stratification makes the ice shelf base less vunerable to the barotropic circulation outside the cavity

Model approach with MITgcm

- MITgcm with ice shelf package (Losch, 2008)
- Resolution: dx = dy = 500 m; dz = 5 m; dt = 120s
- Forcing: Barotropic currents at the boundaries with core velocity of 0.1 m/s

- Control run (CTRL):
  - **no basal melt**
  - **no stratification**

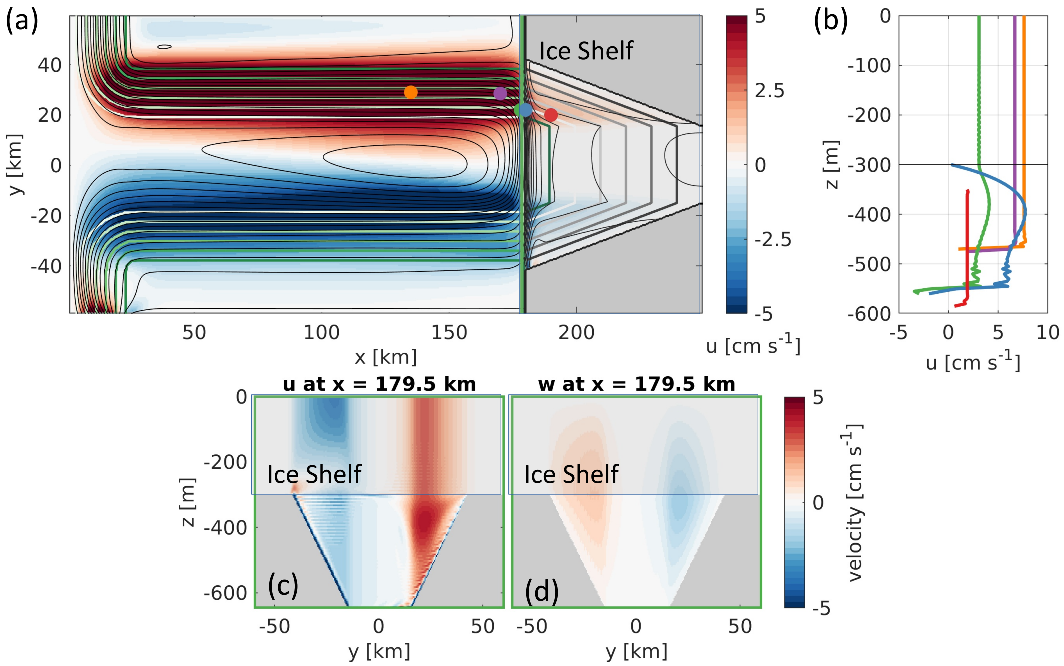
- Experiments:
  - varying draft depth
  - linear stratification
  - basal melt



Idealized geometry of channel and ice shelf used in the CTRL with barotropic velocity-forcing along continental slope.

Results: Mean velocity field in homogeneous ocean

For comparison with stratified run jump to Slide 7



Velocity field in a homogeneous ocean. (a) depth-averaged u-velocity (in positive x-direction; in color), barotropic streamlines (black contours) and lines of constant depth (green contours); (b) depth-profiles of u-velocity at locations marked as dots in (a); (c-d) u- and w-velocity in front of ice shelf with depth (at the green line in (a)).

a) Barotropic streamlines follow lines of constant depth.
Velocities largely reduces inside the cavity. A strong lateral current develops at the ice shelf front.

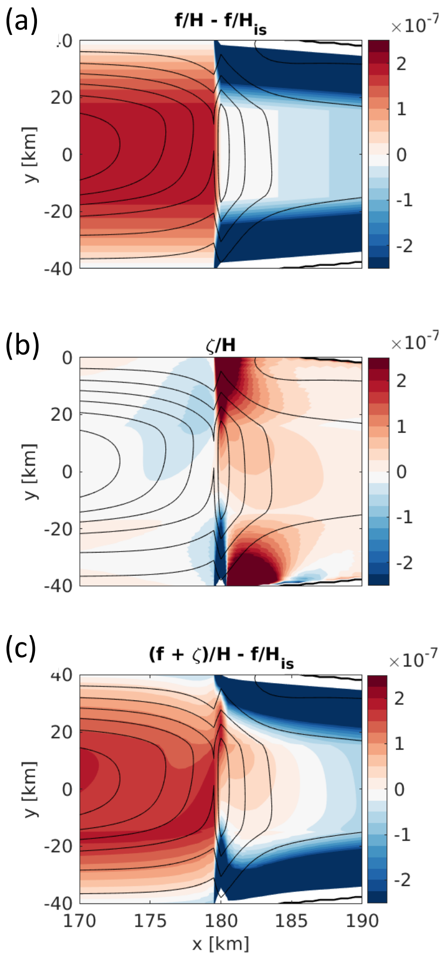
b) u-velocity **speeds up** across ice shelf front (green to blue line in b)

c) u-velocity not constant in depth at ice shelf front

d) Large vertical velocities in front of ice shelf
→ water can subduct and enter cavity

Large vertical velocities at the ice shelf front allow parts of the current to cross the ice shelf front.
Only a small fraction reaches further into the cavity.

Results: Conservation of potential vorticity at the ice shelf front



In colors: (a) f/H relative to f/H at the ice shelf front (f/H_{is}) (b) relative vorticity ζ/H of the depth-averaged velocities and (c) lines of constant potential vorticity PV = (f + ζ)/H relative to f/H_{is} .
Black contours in all plots are depth-averaged (barotropic) streamlines. The ice shelf front is at x = 180km.

Relative vorticity and friction allow parts of the flow to bypass the disontinuity in f/H contours that the ice shelf front represents

a) Lines of f/H are discontinuous at the ice shelf front. Most of the lines outside the cavity do not continue inside the cavity (red contours in (a), where $f/H - f/H_{is} > 0$).

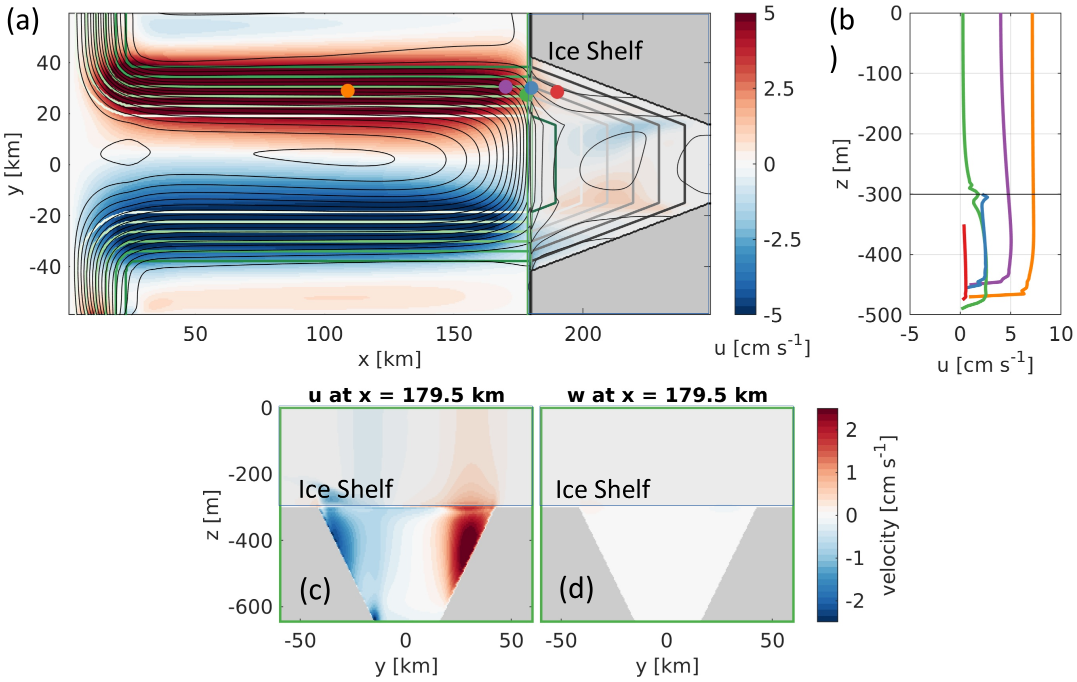
b) Relative vorticity ζ reaches magnitudes comparable to f at the ice shelf front. It changes sign from ζ <0 in front of ice shelf to ζ >0 inside cavity.

c) Barotropic streamlines largely align with lines of constant potential vorticity PV = (f+ζ)/H. Largest deviation at the ice shelf front.

Advection is important for cross-front flow. At the ice shelf front where the barotropic streamlines don't align with lines of PV, **Friction** acts both as a sink and source of PV.

Results: Mean velocity field in linearly stratified ocean

For comparison with homogeneous run go to [Slide 5]



Velocity field in a linearly stratified ocean. (a) depth-averaged u-velocity (in positive x-direction; in color), barotropic streamlines (black contours) and lines of constant depth (green contours); (b) depth-profiles of u-velocity at locations marked as dots in (a); (c-d) u- and w-velocity in front of ice shelf with depth (at the green line in (a)).

Differences to homogeneous run:

a) Gyre further upstream → Current turns over a longer distance from the ice shelf.
Separate reversed circulation inside cavity

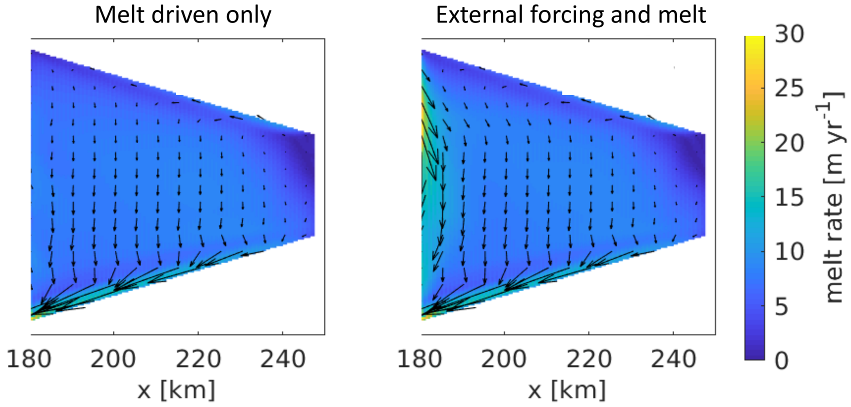
b) No speedup across the ice shelf front (green to blue line in b)

c) Velocities entering cavity due to **baroclinic component** that develops in the vicinity of the ice shelf front with stratification

d) Small vertical velocities in front of ice shelf

Stratification subpresses subduction at the ice shelf front
→ More effective blocking by the ice shelf front
→ Baroclinic component develops that can enter the cavity

Implications: Basal melt



Melt rates at the ice shelf base and velocities in uppermost 10 m for a circulation driven by (a) only basal melt and (b) basal melt and a superimposed barotropic current. Initial ocean temperature and salinity is T=0°C, S = 34.4 psu.

- Melt driven circulation:
  Freshwater plume creates a strong current at the outflow with high melt rates
- With external forcing: additional strong melt rates along the ice shelf front
- Stratification makes ice shelf base less vulnerable to externally forced barotropic current ⟶ see Slide 7
- Undercutting at the ice shelf front due to high melt rates caused by baroropic current can increase calving rates. (Benn et al., 2017)

BENN, D., ÅSTRÖM, J., ZWINGER, T., TODD, J., NICK, F., COOK, S., . . . LUCKMAN, A. (2017). Melt-under-cutting and buoyancy-driven calving from tidewater glaciers: New insights from discrete element and continuum model simulations. Journal of Glaciology, 63(240), 691-702. doi:10.1017/jog.2017.41