COMNAP
Council of Managers of National Antarctic Programs

## Report on COMNAP Antarctic Fellowship 2016-2017

# On the importance of ice-shelf buttressing in Antarctica

Ronja Reese

Host: G. Hilmar Gudmundsson, British Antarctic Survey, Cambridge, UK

Home: Ricarda Winkelmann, Potsdam Institute for Climate Impact Research, Potsdam, Germany

**Figure 1: Calving front of Brunt Ice Shelf, Antarctica.**

**Scientific objectives:**

Ice shelves play a key role in linking ocean conditions to ice flow upstream of grounding lines. Although ice shelves are afloat and therefore do not affect sea level directly, they are able to modulate upstream flow and *indirectly* influence the mass balance of the Antarctic Ice Sheet. Ocean-induced thinning can lead to reduction in buttressing along grounding lines resulting in increased flow. Recent observations show that this process is likely the main reason for dynamically driven mass loss of Antarctica[1]. Changes in buttressing have been investigated in relation to calving

and so-called 'passive' shelf regions have been identified[2]: Calving of these regions does not affect the ice flow at the grounding line.

However, so far no studies have been conducted on how enhanced sub-shelf melting within the *'active'* shelf regions affects buttressing along the grounding lines of Antarctica. This is particularly important for example in the case of Filchner-Ronne Ice Shelf (FRIS) where Circumpolar Deep Water could intrude into the ice shelf cavity within the 21st century[3]. The relatively warm CDW would then reach these 'active' shelf regions and cause a sharp increase in sub-shelf melt rates.

To make statements about the instantaneous response of the ice velocity in FRIS and other Antarctic shelves to moderate thinning, an ice-flow model allowing for fine resolution along grounding lines is required. The finite-element model Úa uses unstructured grids and is therefore an ideal tool to conduct such a study. Previous work with Úa demonstrates that buttressing is as important for the stability of marine ice sheets as is local bedrock slope[4].

Within the COMNAP fellowship, we used Úa to study the role of buttressing reduction in Antarctica in order to improve the understanding of the link between ice-shelf thinning and dynamically driven mass loss in Antarctica.

**Methodology:**

During the COMNAP fellowship, we developed a new modelling framework to advance the theoretical understanding of the effect of ice-shelf buttressing on mass loss from the Antarctic ice sheet. The model experiments were performed with the ice-dynamics model Úa, which is a finite-element model that uses unstructured grids. Using its inversion capabilities we inverted directly for ice rheology and basal slipperiness. Doing so is essential for accurate calculations of buttressing and for estimating the transmission of stress gradients across grounding lines. Hilmar Gudmundsson develops Úa that has been used successfully to study ice shelves in Antarctica[5,6]. My research visits at the British Antarctic Survey gave me the opportunity to gain important Úa modelling skills. Together with Hilmar Gudmundsson, Ricarda Winkelmann and Anders Levermann, I investigated the role of ice-shelf buttressing and the effect of ice-shelf thinning in an Antarctic-wide setup, resulting in two publications.

In a first study[7], we derived transfer functions that relate ice-shelf thinning to changes in ice velocities at the grounding lines. This allows us to estimate changes along *any* sections of the grounding lines of the Antarctic Ice Sheet to *any* spatial perturbations in ice shelf thicknesses. Based on inverted ice softness and basal friction fields, we computed ice velocities: First for the

unperturbed state that corresponds to the current ice thickness of Antarctica, then for local perturbations of the ice thickness. Using these transfer functions, we created risk maps that indicate the regions where changes in ice-shelf thickness trigger the strongest or most distant responses.

In a second study[8], we extended on the insights from the previous study to analyze the effect of ice-shelf buttressing on ice flow in Antarctica. The buttressing parameter compares the axial stresses at the grounding line with the stresses that would act at the grounding line in the hypothetical absence of the ice shelf[9]. Using it, we analyzed buttressing along the grounding lines of all Antarctic ice shelves. We found that buttressing can be very large, and in some places, e.g. for Institute Ice Stream draining into Filchner-Ronne Ice Shelf, the buttressing parameter reveals that the grounding line is 'over-buttressed'. Our results further indicate that an analytical expression for grounding line flux, derived for the simple flowline case[10] and sometimes applied as a flux condition in numerical modeling studies, yields inaccurate, partly unphysical, estimates of ice flux for the complex flow regimes in Antarctica.

During the visits at the British Antarctic Survey, I gained modeling skills with the ice-flow model Úa and pursued the model experiments in order to accomplish the research questions. Combining the expertise at PIK and at BAS, we were able to develop two studies that provide insights into the role of ice-shelf buttressing in Antarctica. We are looking forward to extend this collaboration in the future.

**Accomplishments:**

Given the opportunity provided through the COMNAP Antarctic Fellowship, I traveled three times to the British Antarctic Survey, UK, to visit Hilmar Gudmundsson and to work together on the role of buttressing in Antarctica. The results obtained through this collaboration make an important contribution to my PhD thesis. They were further combined into two publications and presented at international conferences.

<u>Resulting studies</u>

- The far reach of ice-shelf thinning in Antarctica,
  *R. Reese, G.H. Gudmundsson, A. Levermann, R. Winkelmann*, Nature Climate Change (2017), DOI: 10.1038/s41558-017-0020-x
  with related News & Views by Gagliardini (Nature Climate Change, 2017), DOI: s41558-017-0037-1, title cover page of Nature Climate Change and media coverage

- Grounding-line flux formula applied as a flux condition in numerical simulations fails for buttressed Antarctic ice streams,
  *R. Reese, R. Winkelmann, G.H. Gudmundsson,* The Cryosphere (accepted), DOI: 10.5194/tc-2017-289

Presentation of the results at international conferences and meetings

- Oral presentation at the EGU General Assembly 2018 in Vienna:
  *The far reach of ice-shelf thinning in Antarctica,*
  *R. Reese, G.H. Gudmundsson, A. Levermann, R. Winkelmann*
- Oral presentation of the results by R. Winkelmann at the AGU General Assembly 2017 in New Orleans
- Presentation at the Úa User Meetings, May 2016, at British Antarctic Survey, Cambridge, UK
  *Úa case study: Ice-shelf thinning, buttressing and the grounding line flux formula,*
  *R. Reese, G.H. Gudmundsson, R. Winkelmann*
- Presentation at the Úa User Meetings, May 2017, at British Antarctic Survey, Cambridge, UK
  *Úa case study or kicking the ice's buttressing,*
  *R. Reese, G.H. Gudmundsson, R. Winkelmann*

**Budget expenses**:

Expenses provided by the COMNAP fellowship ($6100) covered the costs of a 2-month stay at the British Antarctic Survey, divided into three periods: June 2016, Feb-March 2017 and May-June 2017. They further support the dissemination of results, e.g., participation in the EGU General Assembly. Financial support has been fully spent for

- Accommodation in Cambridge $2100
- Living expenses $1800
- Travelling between Potsdam and Cambridge $900
- Further expenses for presentation of results (EGU General Assembly), computer software, and health insurance during travel: $1350
- Total $6150

**Acknowledgements:**

I am deeply grateful to COMNAP for their fellowship that gave me the fantastic opportunity to work at the British Antarctic Survey during my PhD. I would like to thank my host G. Hilmar Gudmundsson for his helpful and welcoming support during my research visits and the great collaboration. I would also like to thank my supervisors at PIK, Ricarda Winkelmann and Anders Levermann, for their fantastic support and ongoing encouragement.

**References:**

1. Pritchard, H. D. *et al.* Antarctic ice-sheet loss driven by basal melting of ice shelves. *Nature* **484,** 502–505 (2012).
2. Fürst, J. J. *et al.* The safety band of Antarctic ice shelves. *Nat. Clim. Chang.* 2014–2017 (2016). doi:10.1038/NCLIMATE2912
3. Hellmer, H. H., Kauker, F., Timmermann, R., Determann, J. & Rae, J. Twenty-first-century warming of a large Antarctic ice-shelf cavity by a redirected coastal current. *Nature* **485,** 225–228 (2012).
4. Gudmundsson, G. H., Krug, J., Durand, G., Favier, L. & Gagliardini, O. The stability of grounding lines on retrograde slopes. *The Cryosphere* **6,** 1497–1505 (2012).
5. De Rydt, J., Gudmundsson, G. H., Rott, H. & Bamber, J. L. Modeling the instantaneous response of glaciers after the collapse of the Larsen B Ice Shelf. *Geophys. Res. Lett.* **42,** 5355–5363 (2015).
6. Royston, S. & Gudmundsson, G. H. Changes in ice-shelf buttressing following the collapse of Larsen A Ice Shelf, Antarctica, and the resulting impact on tributaries. *J. Glaciol.* **62,** 905–911 (2016).
7. Reese, R., Gudmundsson, G. H., Levermann, A. & Winkelmann, R. The far reach of ice-shelf thinning in Antarctica. *Nat. Clim. Chang.* **8,** 53–57 (2018).
8. Reese, R., Winkelmann, R. & Gudmundsson, G. H. Grounding-line flux formula applied as a flux condition in numerical simulations fails for buttressed Antarctic ice streams. *Cryosph. Discuss.* **2018,** 1–22 (2018).
9. Gudmundsson, G. H. Ice-shelf buttressing and the stability of marine ice sheets. *The Cryosphere* **7,** 647–655 (2013).
10. Schoof, C. Ice sheet grounding line dynamics: Steady states, stability, and hysteresis. *J. Geophys. Res. Earth Surf.* **112,** 1–19 (2007).