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Ice shelf buttressing

a comparison of Antarctic ice shelves in a transient evolution

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TiPACCs — Tipping Points in Antarctic Climate Components

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Introduction

The accelerating loss of grounded ice in Antarctica at present is mainly caused by a thinning of the surrounding ice shelves and a subsequent reduction in **buttressing**. We here analyse buttressing of Antarctic ice shelves in diagnostic and transient simulations and compare it between models.

Models

The Parallel Ice Sheet Model (**PISM**) is run on a regular **8 km** grid. The ice sheet is initialized as described in Seroussi et al. (2020) into an **quasi-equilibrium** state close to the **present-day ice geometry.** The basal melt rates are perturbed with temperature anomalies to the Potsdam Ice-shelf Cavity mOdel (PICO).

Output of the ice model **Úa** from **Reese et al. (2018)** is reanalysed for shelf-wide buttressing. The grid is refined in vicinity of the grounding line to around **200 m**.

Buttressing Ratio

The buttressing ratio is given by the normal stresses at the grounding line compared to the stress-balance without an ice shelf:

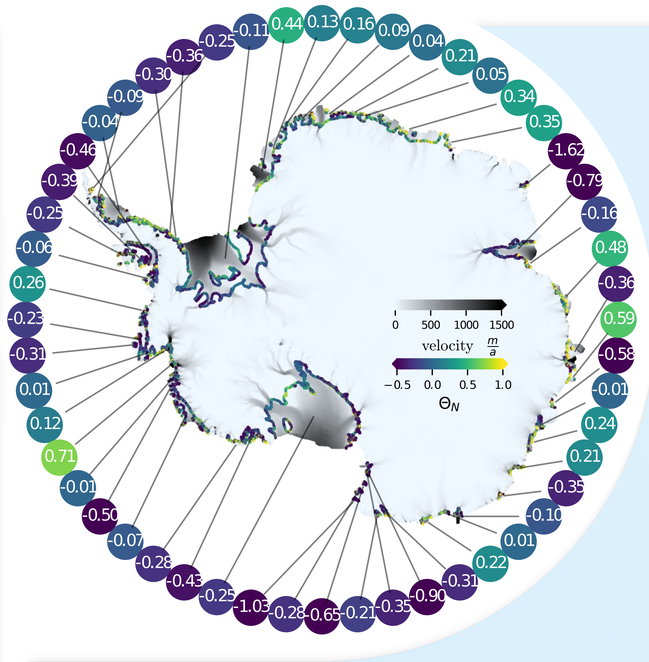
$$\theta_N = \frac{\boldsymbol{n} \cdot \boldsymbol{R}\, \boldsymbol{n}}{2\,\tau_f} \qquad \boldsymbol{R} = \begin{pmatrix} 2\,\tau_{xx} + \tau_{yy} & \tau_{xy} \\ \tau_{xy} & \tau_{xx} + 2\,\tau_{yy} \end{pmatrix}$$

In **Úa**, the local buttressing values are calculated on a piece-wise linear representation of the grounding line crossing all elements with floating and grounded nodes. On the center point of the linear segments, the stresses and ice properties are interpolated to compute θ_N.

In **PISM**, the buttressing is calculated on a staggered grid slightly upstream of the grounding line to circumvent numerical artefacts in grid cells affected by thinning. The normal vector is computed based on the mask of grounded and floating cells.

We define shelf-wide buttressing ratios given by these four aggregations which are applied to the local buttressing ratios on a per shelf basis.

- arithmetic mean
- median of the buttressing values
- average weighted by the thickness at the grounding line
- average weighted by the flux at the grounding line



perturbation: The ocean temperatures of PICO are increased. The offset increases linearly to +0.5 °C, +1 °C, +1.5 °C and +2 °C in the first 100 years and is kept constant in the subsequent 400 years.

Present-Day Buttressing

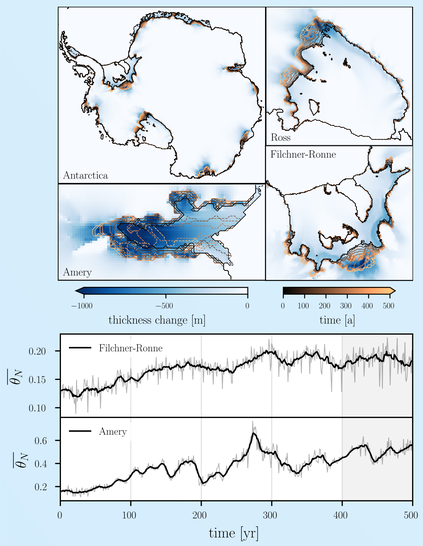
The local buttressing ratios at the grounding line are aggregated for each ice shelf. These range from high buttressing (e.g. Amery θ_N=–0.79) via medium buttressing (e.g. Pine Island Glacier θ_N=0.12) to low buttressing (e.g. Thwaites glacier θ_N=0.71).

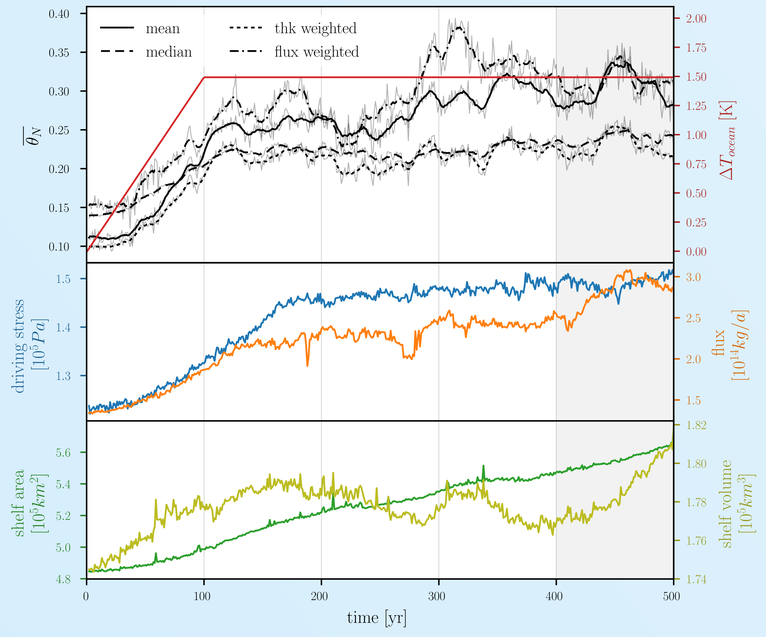
Overall larger and confined ice shelves show higher buttressing compared to open grounding lines.

Transient Buttressing

A retreat of the grounding lines is observed. Independent of the aggregation method, the buttressing of the **Ross ice shelf** weakens. The buttressing follows the shape of the forcing with a delay of ~30 – 50 years. Together with the reduction in buttressing, an increase in the driving stress at the grounding line and in the flux across the grounding line is observed.

These trends are similar in the **Filchner-Ronne ice shelf**, however the total effect is smaller. The more complex evolution in the **Amery ice shelf** is the result of the interplay of shelf thinning, grounding line retreat and ice front retreat due to increased calving.

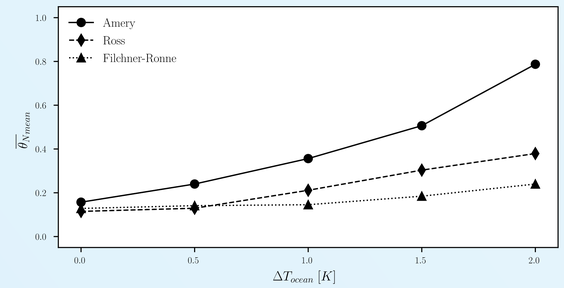




Figs.: Transient response of the ice shelves in PISM to 500 years of +1.5 °C temperature increase.

Temperature Dependence

The final buttressing in the last 100 years of the transient simulations decreases consistently in the **Ross**, **Filchner-Ronne** and **Amery** ice shelf. With higher temperature forcing, the effect on the buttressing increases.



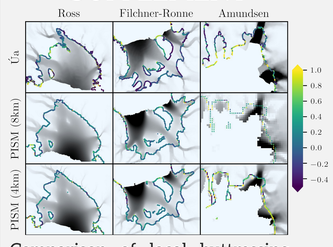
Key Messages

- Buttressing of Antarctic ice shelves ranges from low to very high
- large (e.g. FRIS, Ross) and confined (e.g. Amery) ice shelves have high buttressing; open grounding lines (e.g. Thwaites) have low buttressing
- buttressing of ice shelves decreases under idealized ocean warming perturbation
- transient evolution of ice shelves' buttressing is a complex interplay of grounding line movement, ice shelf thinning and calving

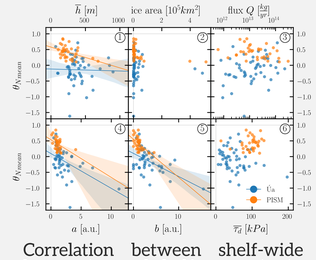
Next Steps

- Evolution of buttressing in tipping experiments
- Transient response in ice flux due to buttressing change

Supplement



Comparison of local buttressing ratios in Úa and PISM.



Correlation between shelf-wide buttressing and shelf properties in Úa and PISM

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