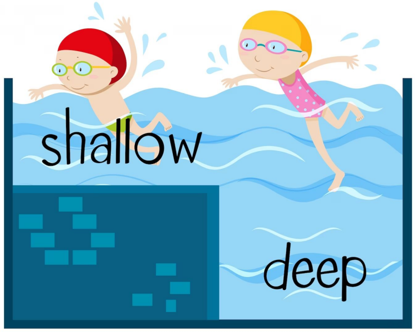
Ice shelf-ocean interaction at shallow depths needs more attention

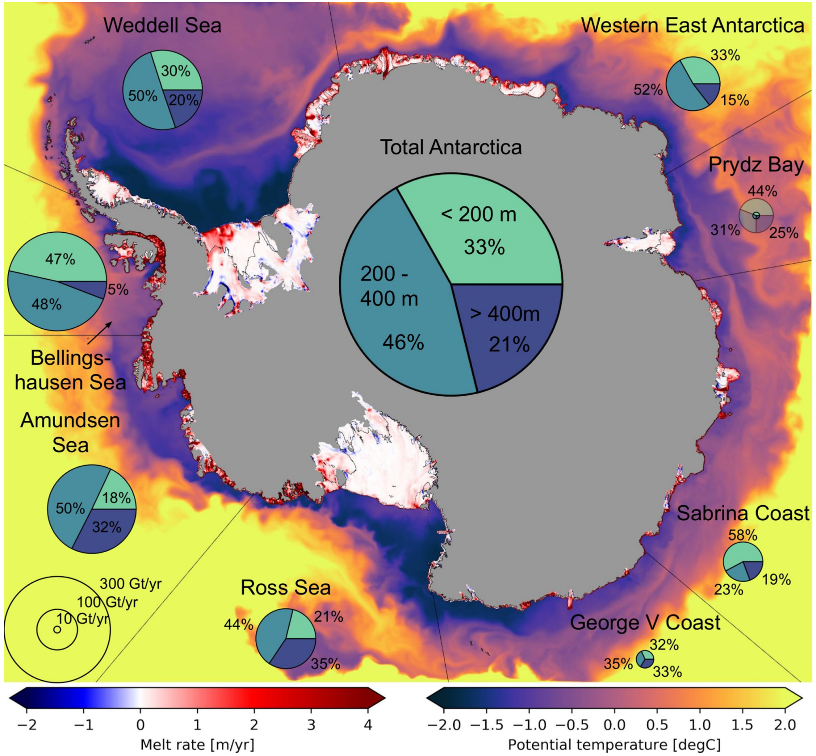
Ole Richter, Ben Galton-Fenzi, David Gwyther, Kaitlin Naughten,
Ralph Timmermann, Verena Haid



Modelled Antarctic ice shelf basal melting at high resolution

- Novel high resolution ocean model captures many of the small ice shelves
- Elevated melt rates towards the ice shelf front everywhere!
- Accumulates to substantial mass loss from shallow depths
- Artificial?

Modelled ice shelf melt rate and surface ocean temperature



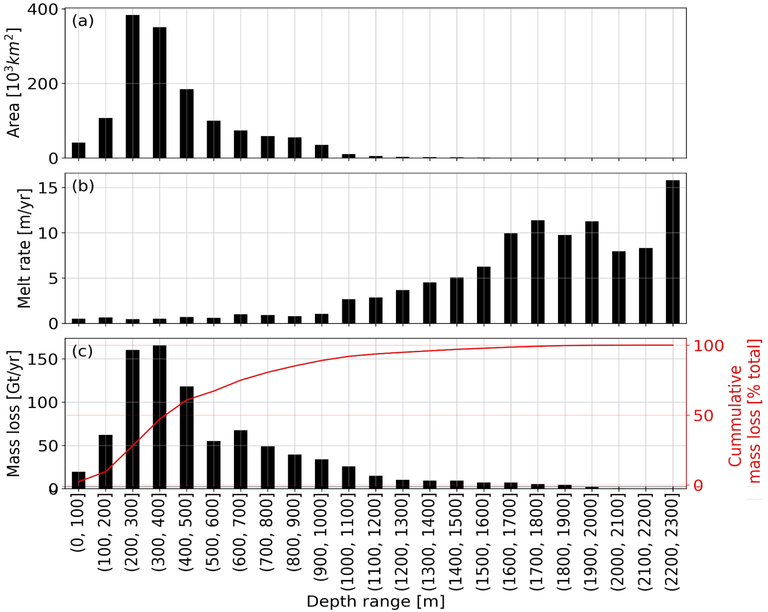
Richter Thesis 2020

Satellite-derived depth distribution

- Previously published satellite-derived melt rates from Adusumilli et al. 2020 (2010-2018 mean)
- Highest melt rates at greatest depths, but …
- 60% of total mass loss comes from depths shallower than 500m!
- Due to large areas at these depths (and refreezing of deep melt?).

→Model and satellite-methods agree that most mass is lost from shallow depths!

Satellite-derived Antarctic ice shelf area, mean melt rate and mass loss at different depths



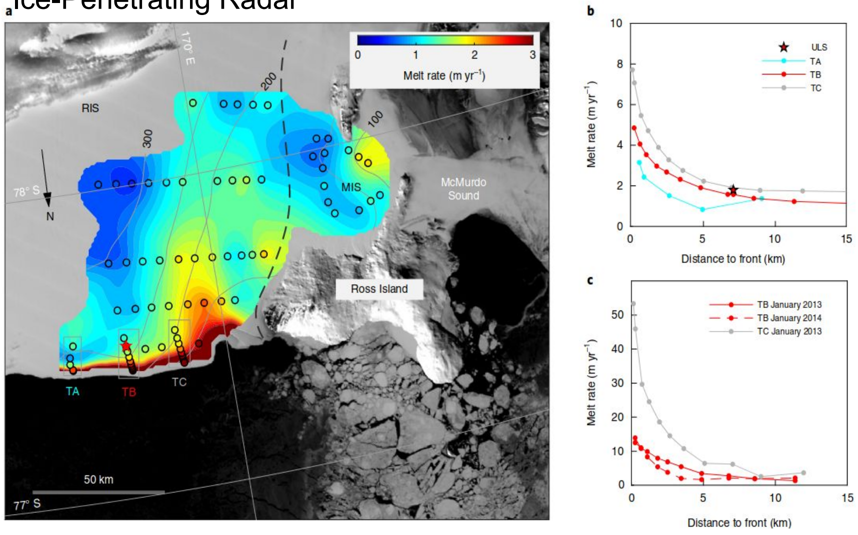
Richter et al. in prep.

Limitations

- In-situ observations highlight elevated melt towards the ice front
- Satellite methods poorly resolve calving regions
- Melting along submarine parts of calving face could be substantial too:

  e.g. Assuming 50 m/yr leads to 20% of total horizontal mass loss!

Annual mean basal melt rate under Ross Ice Shelf from Ice-Penetrating Radar



Stewart et al. 2019

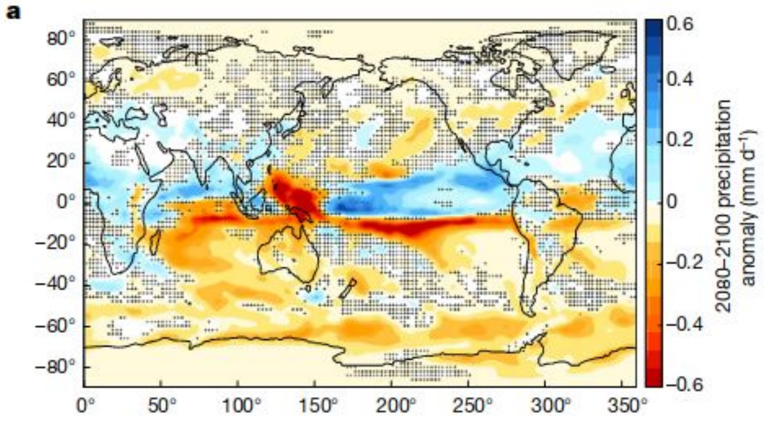
→Limitations only support our argument!

The importance of shallow ice mass loss

- Predictions of global oceans and climate are sensitive to net freshwater flux
  - Southern ocean surface freshening
  - Sea ice thickening
  - Slow down of AABW formation
  - Changes in global precipitation pattern
  - …
- Glacial melt water can offset polynya activity in observations and regional models
  - Delay in bottom water formation (Prydz Bay, e.g. Aoki et al. 2022)
  - Support of deep warm water intrusions (Sabrina Coast, Amundsen Sea; Silvano et al. 2018)

→ **Net melt water leaving the cavity matters for regional/global oceans and climate!**

Antarctic melt water induced precipitation anomaly



Bronselaer 2018

How about ice sheet evolution?

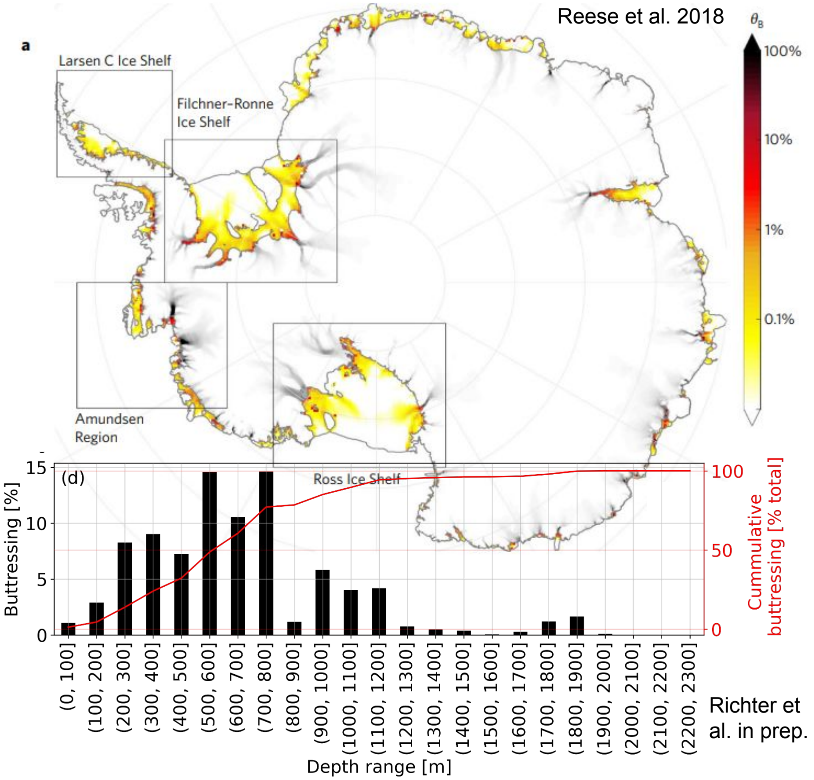
- Ice around deep grounding lines is often very valuable for buttressing
- Still, diagnostic ice sheet flow modelling shows:

  30% of the current buttressing importance comes from ice shallower than 500m!

- Transient idealised experiments highlight importance of shallow melting
  - Ice shelf shape (Nakayama et al. 2022)
  - Cumulative buttressing (Feldmann et al. 2022)

→ **Shallow melting should not be neglected in future studies of ice sheet evolution.**

Grounding line flux response to ice shelf thinning

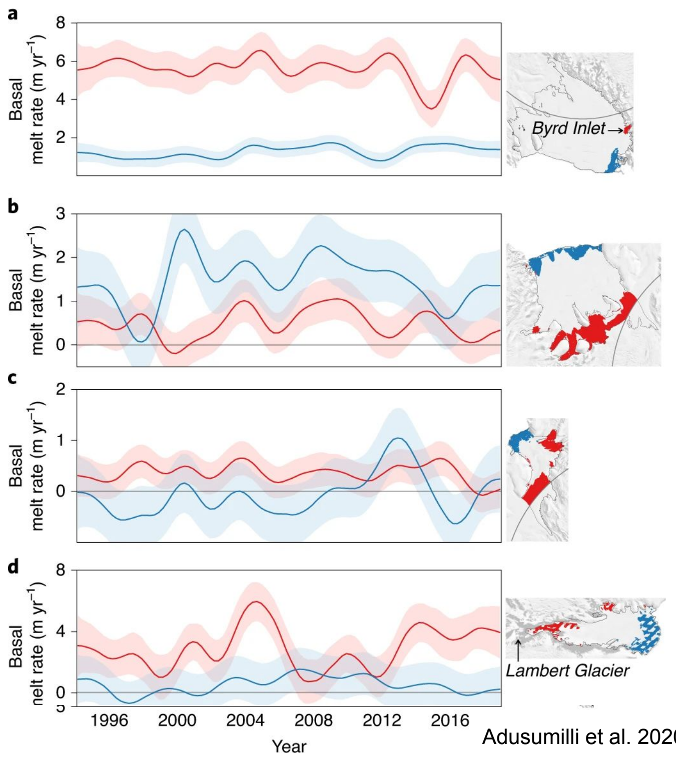


Oceanic drivers and expected future change

- Solar heated surface water intrusions known to play a role in shallow regions (Mode 3)
- Model projections indicate broad loss of sea-ice cover until 2100!
- Other important processes could be:
  - Winter water layer protection (Padman et al. 2012)
  - Tidal vertical mixing of deep heat (Richter et. al 2022)
  - Feedbacks with biology ?
  - …

→ **Response to climate change might be very different compared to the one at depth.**

Interannual melt rate variability in different regions



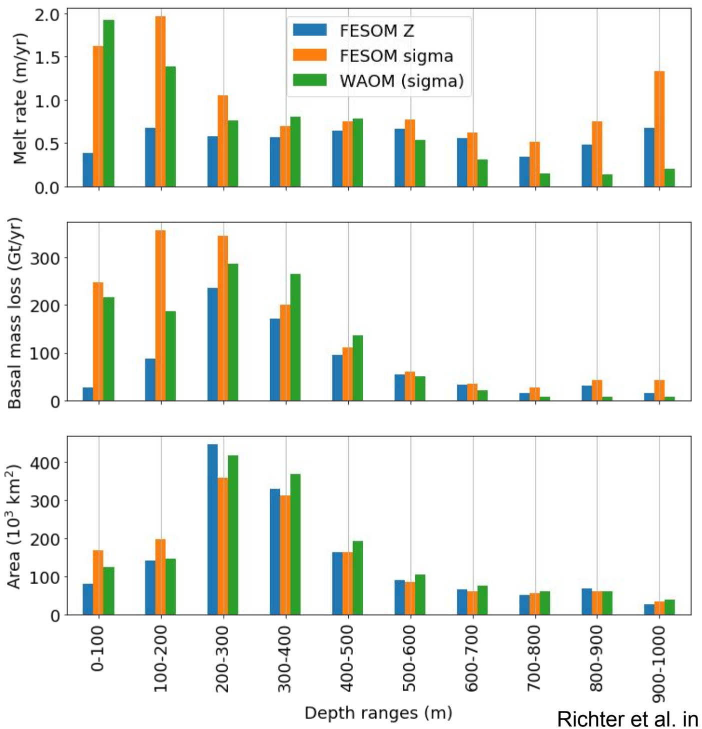
Adusumilli et al. 2020

Model intercomparison

- Three experiments:
  - FESOM-Z (multiyear mean)
  - FESOM-sigma (equivalent FESOM-Z)
  - WAOM (sigma, 2007 snapshot)
- Choice of vertical coordinate impacts predicted shallow ice mass loss.
- Sigma models show higher mass loss and melt rates towards the front.
- Supports enhanced Mode 3 melting in sigma coordinates
- Which model is more accurate is not clear:
  - Wedge mechanism (Malyarenko et al. 2019)!

→**Better understanding of frontal processes and model evaluation very much needed.**

Depth distribution of modelled Antarctic ice shelf mean melt rate, mass loss and area

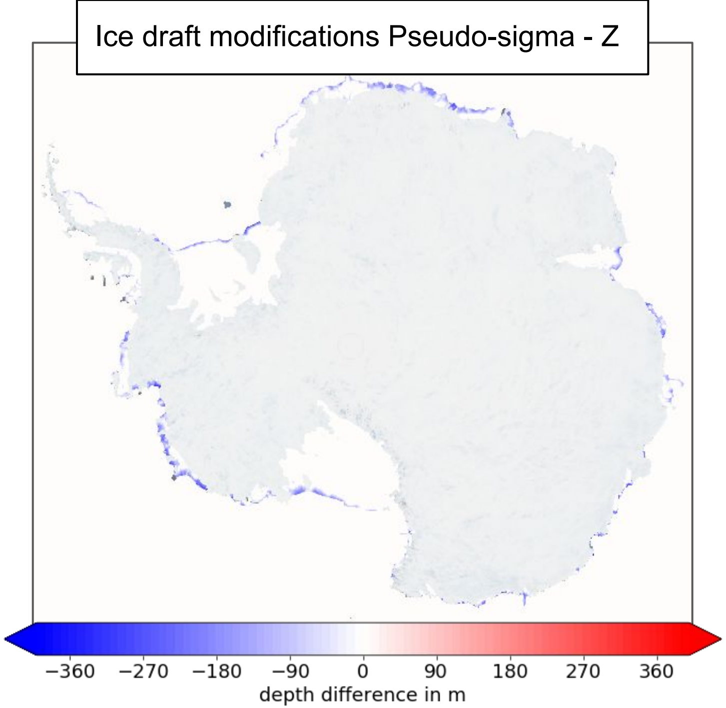


Richter et al. in prep.

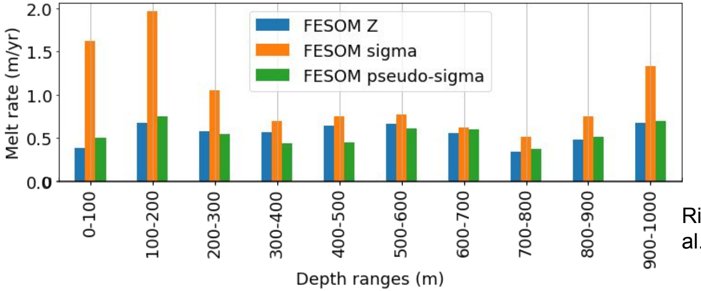
The role of the ice front representation

- Sigma-coordinates necessitate smoothing of the ice front geometry
- This might support surface water intrusion and explain elevated frontal melt in sigma models
- Additional experiment to isolate geometric effects:
  - FESOM-Z with sigma-like front (pseudo-sigma)
- Frontal smoothing explains only a small part of the differences

→ **It's more complicated than "just" geometry**



Melt rate depth distribution from the three experiments



Richter et al. ??

Summary

- Antarctic ice shelves lose most of their mass from shallow depths (at least 60% from 500m and shallower)
- Climate predictions are sensitive to net freshwater flux
- Some evidence that shallow ice melting also matters for ice sheet evolution
- Vertical coordinate system in models impacts melting at shallow depths
- Oceanic drivers of shallow ice melting are not well quantified, but might respond rapidly to climate change

→ **Future research into Antarctic ice shelf-ocean interaction should be more balanced between deep and shallow processes.**