The response of the West Antarctic Ice Sheet to ocean warming beneath the Filchner-Ronne Ice Shelf

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Introduction

The ice flow at the margins of the West Antarctic Ice Sheet (WAIS) is moderated by large ice shelves. Their buttressing effect substantially controls the mass balance of the WAIS and thus its contribution to sea level rise. In this study, we focus on the Filchner-Ronne Ice Shelf (FRIS). We couple the ocean model FESOM to the ice flow model RIMBAY to investigate the sensitivity of the ice dynamics within the entire FRIS catchment with respect to simulated future basal shelf melt rates.



Fig. 1: Antarctic Ice Sheet with Filchner-Ronne Ice Shelf (Fig. by British Antarctic Survey, 2007).

Motivation





Fig. 2a: Warm water intrusion into the Filchner Trough within the 21st century (Hellmer et al., 2012).

Fig. 2b: Estimated mass loss of the Filchner-Ronne Ice Shelf (Timmermann et al., 2013).

Recent results of ocean circulation models (Hellmer et al., 2012; Timmermann et al., 2013) indicate that warm circumpolar water of the Southern Ocean may override the submarine slope front of the Antarctic continent and boost basal ice shelf melting. In particular, ocean simulations for several of the IPCC's future climate scenarios demonstrate the redirection of a warm coastal current into the Filchner Trough and underneath the Filchner-Ronne Ice Shelf within the next decades.

Filchner-Ronne Ice Shelf: Observations



Fig. 10: Ice shelf cavity after BEDMAP2 (Fretwell et al., 2013).



Fig. 11: Ice shelf thickness after BEDMAP2 (Fretwell et al., 2013).

Coupled models

FESOM

Finite elements Sea ice – ice shelf – ocean model

Timmermann et al., 2012

- Domain: global
- Horizontal resolution: 1.9 250 km
- Constant ice thickness assumed
- Validation: NCEP forcing

- Projections: atmospheric forcing from ECHAM5/MPIOM and HadCM3 for IPCC scenarios E1 and A1B

Prognostic experiments



Fig. 4: Modeled grounded ice loss and sea level equivalent by RIMBAY.





BEDMAP2 (Fretwell et al., 2013).



Fig. 13: Accumulation after Arthern et al. (2006)



Pollard, D. and DeConto, R., Description of a hybrid ice sheet-shelf model, and application to Antarctica, Geoscientific Model Development, 5(5), 1273–1295, 2012. Rignot, E., Mouginot, J., and Scheuchl, B., Ice flow of the Antarctic ice sheet, Science, 333, 1427–1430, 2011 Thoma, M., Grosfeld, K., Barbi, D., Determann, J., Goeller, S., Mayer, C. and Pattyn, F., RIMBAY – a multi-approximation 3D ice-dynamics model for comprehensive applications: model description and examples, Geoscientific Model Development, 7(1), 1–21, 2014. Timmermann, R., Wang, Q., and Hellmer, H., Ice shelf basal melting in a global finite-element sea ice–ice shelf–ocean model, Annals of Glaciology, 53(60):303–314, 2012. Timmermann, R., and Hellmer, H., Southern Ocean warming and increased ice shelf basal melting in the twenty-first and twenty-second centuries based on coupled ice-ocean finite-element modelling, Ocean Dynamics, 63 (9-10), 1616–7341, 2013.



RIMBAY

Finite differences Ice sheet – ice shelf model

Thoma et al., 2014

• Domain: FRIS and ice catchment Horizontal resolution: 20 km • Vertical resolution: 21 sigma layers Ice dynamics: SIA-SSA hybrid • Forcing: BEDMAP2 geometry and present-day surface temperatures and accumulation rates

Modeled shelf melt rates ...



Fig. 5: Modeled present-day melt rates by FESOM.





Fig. 6: Shelf melt after Beckmann and Goosse (2003) with A=0.011

additional 26 400 km²

Grounding line retreat

caused by warming scenario

High sensitivity of ice dynamics in the area between Möller and Institute Ice Stream due to slight grounding and underlying backward-sloped bedrock.

Fig. 14: Ice shelf surface velocity after Rignot et al. (2011).



Fig. 15: Height above flotation after BEDMAP2 (Fretwell et al., 2013).



Fig. 16: Ice surface velocity in ice model domain after Rignot et al. (2011).



Present day

Modeled present-day basal melt rates for the Filchner-Ronne Ice Shelf (Fig. 5) agree well with the few available in-situ measurements. Ice models commonly use parametrizations (Fig. 6-8) to incorporate shelf melt rates in their simulations, due to their lower computational costs. A comparison reveals that ocean models are much more suitable to capture the individual characteristics of an ice shelf cavity.

... vs. parametrizations

Fig. 7: Shelf melt after Beckmann and Goosse (2003) with A=0.05



Fig. 8: Shelf melt after Pollard and DeConto (2012) with Me=5, Mp=0.1



Fig. 9: Modeled grounding line position by RIMBAY: observed (thin line), initial steady state (black), present-day shelf melt forcing (white) and warming scenario shelf melt forcing until year 2200 (red). Bedrock after BEDMAP 2 (Fretwell et al., 2013).



Fig. 17: Bedrock elevation in ice model domain (BEDMAP2, Fretwell et al., 2013).





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References Arthern, R., Winebrenner, D., and Vaughan, D., Antarctic snow accumulation mapped using polarization of 4.3-cm wavelength microwave emission, Journal of Geophysical Research: Atmospheres (1984–2012), 111(D6), 2006. Beckmann, A. and Goosse, H., A parameterization of ice shelf–ocean interaction for climate models, Ocean modelling, 5, 157–170, 2003. Fretwell, P. et al., Bedmap2: improved ice bed, surface and thickness datasets for Antarctica, The Cryosphere, 7, 375–393, 2013. Hellmer, H., Kauker, F., Timmermann, R., Determann, J., and Rae J., Twenty-first-century warming of a large Antarctic ice-shelf cavity by a redirected coastal current. Nature 485(7397), 225–228, 2012.