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.

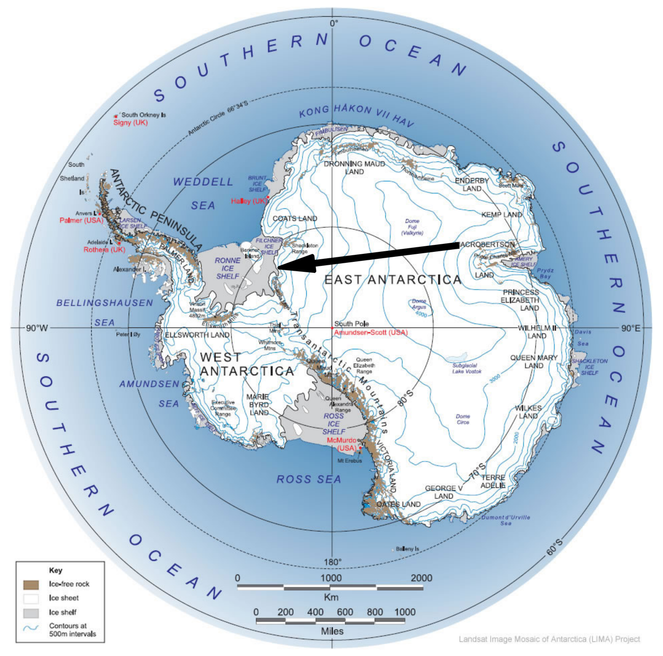

Fig. 1: Antarctic Ice Sheet with Filchner-Ronne Ice Shelf (Fig. by British Antarctic Survey, 2007).

Motivation

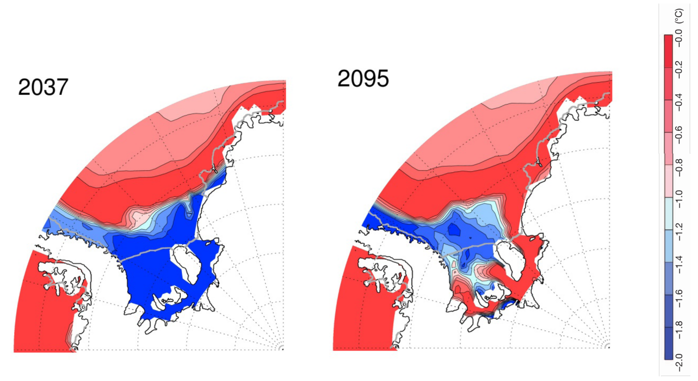

Fig. 2a: Warm water intrusion into the Filchner Trough within the 21st century (Hellmer et al., 2012).

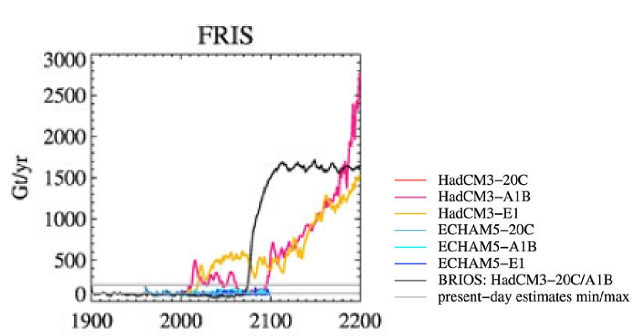

Fig. 2b: Estimated mass loss of the Filchner-Ronne Ice Shelf (Timmermann et al., 2013).

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.

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

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

Prognostic experiments

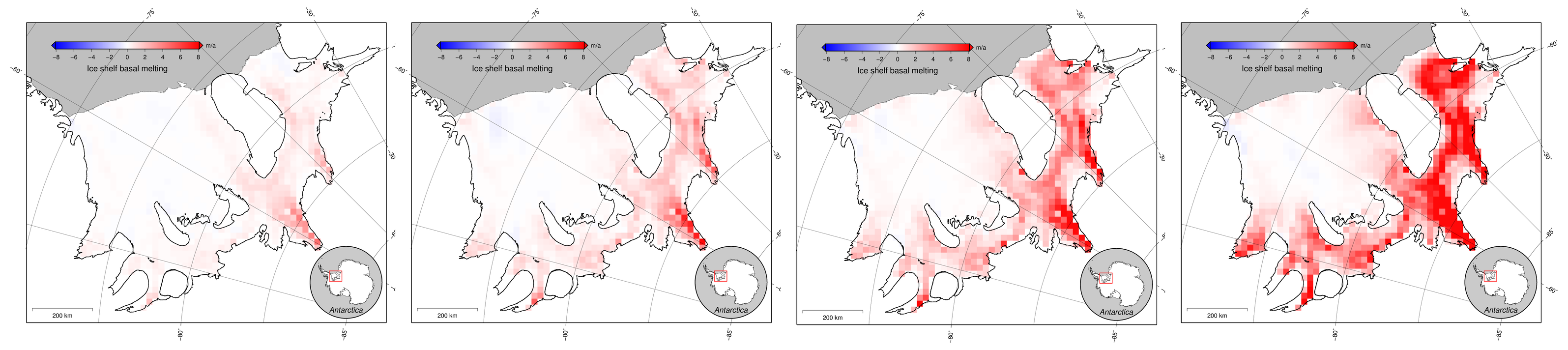

Fig. 3: Modeled present-day and prognostic melt rates by FESOM.

additional 26 mm

Sea level rise

caused by warming scenario

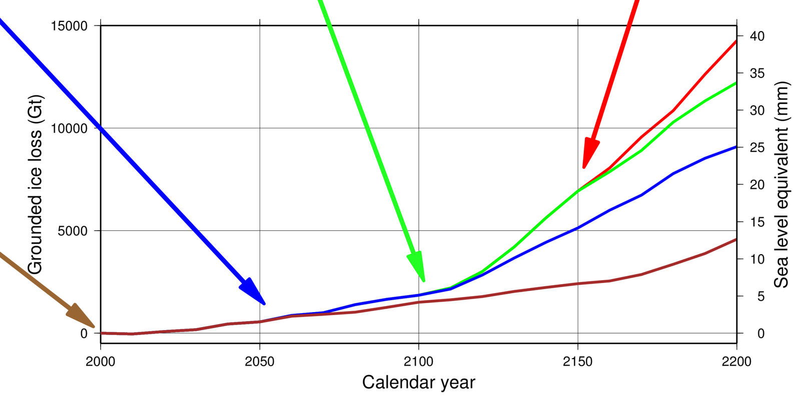

Fig. 4: Modeled grounded ice loss and sea level equivalent by RIMBAY.

Present day

Modeled shelf melt rates …

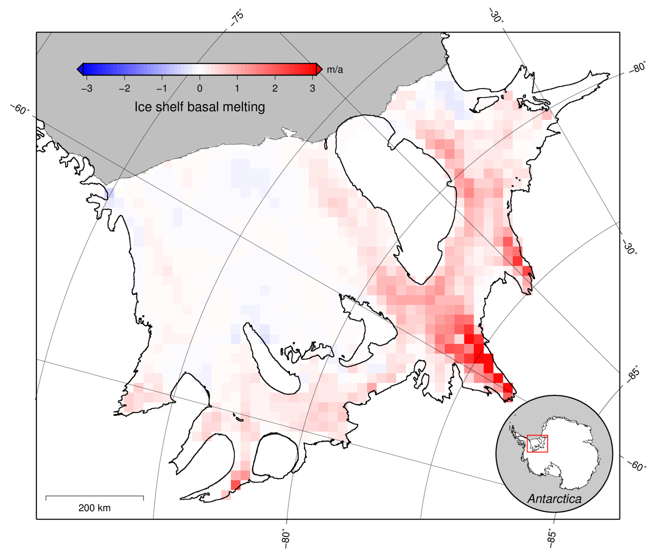

Fig. 5: Modeled present-day melt rates by FESOM.

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

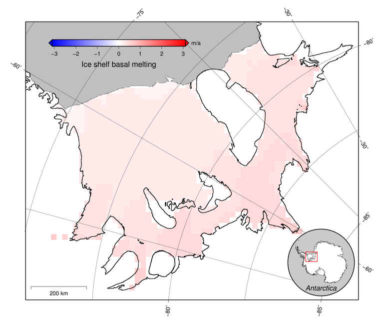

Fig. 6: Shelf melt after Beckmann and Goosse (2003) with A=0.011

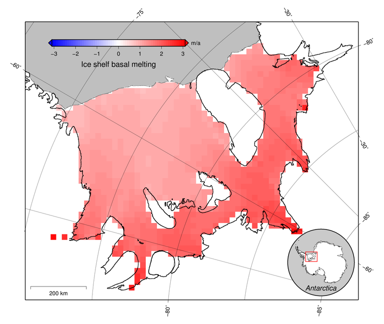

Fig. 7: Shelf melt after Beckmann and Goosse (2003) with A=0.05

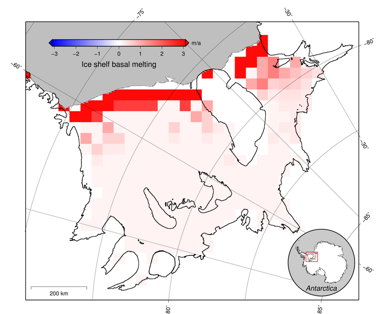

Fig. 8: Shelf melt after Pollard and DeConto (2012) with Me=5, Mp=0.1

additional 26 400 km^2

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.

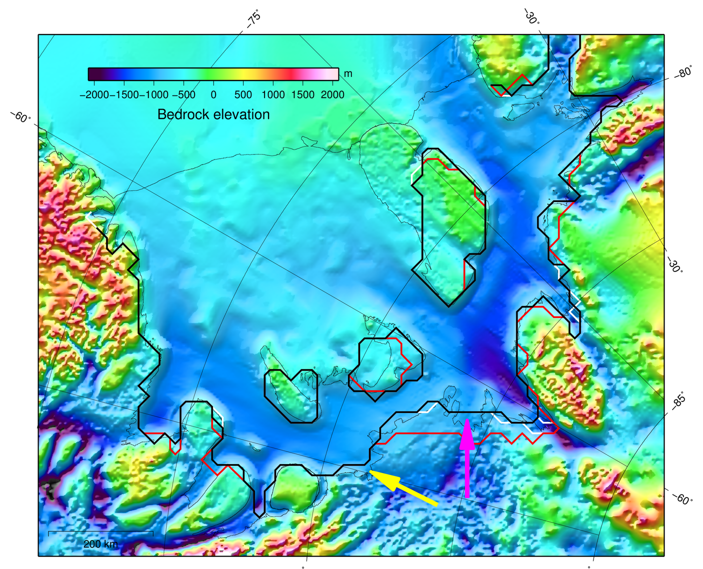

Fig. 9: Modeled grounding line position by RIMBAY: observed (thin line), initial steady state (black), present-day shelf melt forcing (white) and warming scenario shelf melt forcing until year 2200 (red). Bedrock after BEDMAP 2 (Fretwell et al., 2013).

Filchner-Ronne Ice Shelf: Observations

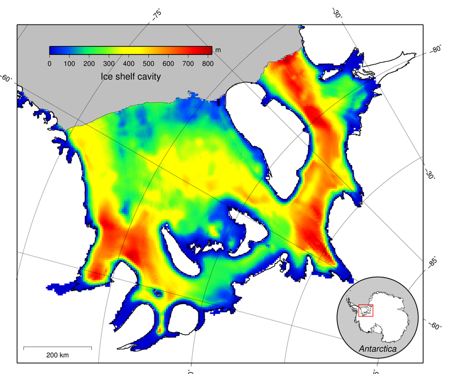

Fig. 10: Ice shelf cavity after BEDMAP2 (Fretwell et al., 2013).

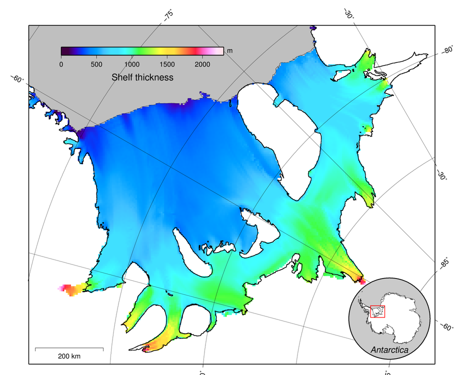

Fig. 11: Ice shelf thickness after BEDMAP2 (Fretwell et al., 2013).

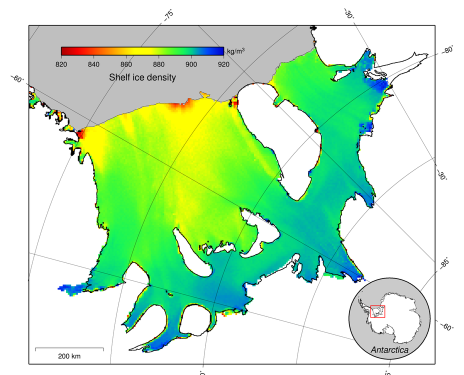

Fig. 12: Ice shelf density after BEDMAP2 (Fretwell et al., 2013).

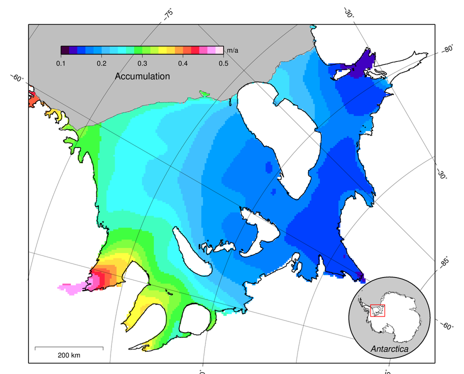

Fig. 13: Accumulation after Arthern et al. (2006).

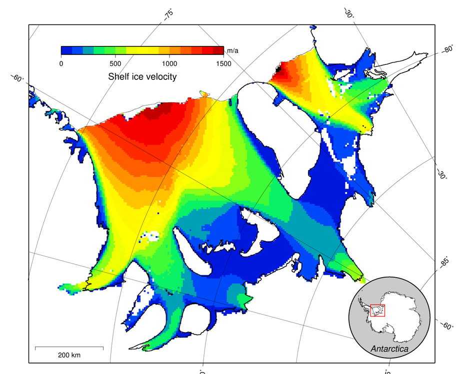

Fig. 14: Ice shelf surface velocity after Rignot et al. (2011).

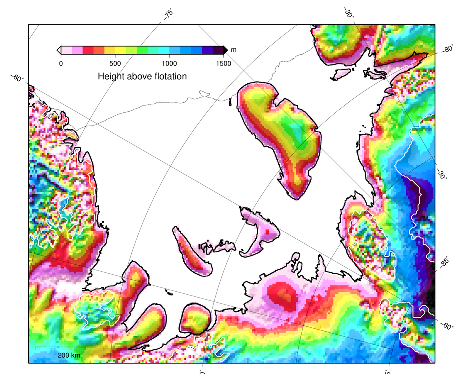

Fig. 15: Height above flotation after BEDMAP2 (Fretwell et al., 2013).

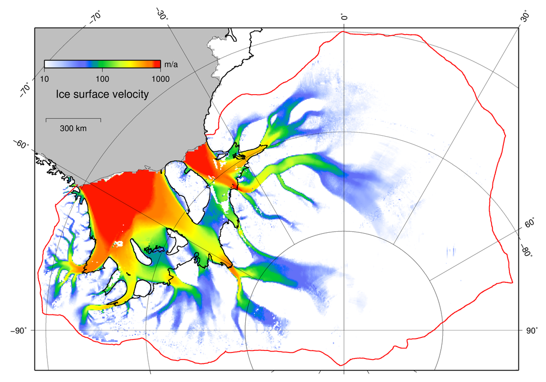

Fig. 16: Ice surface velocity in ice model domain after Rignot et al. (2011).

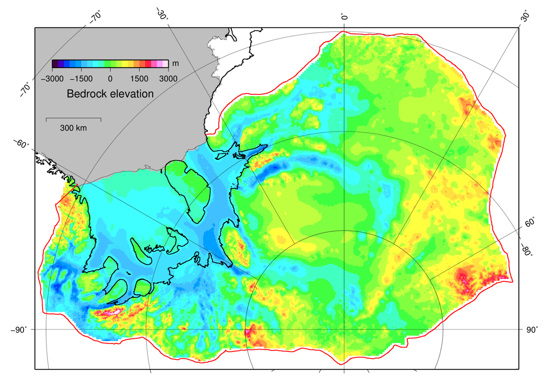

Fig. 17: Bedrock elevation in ice model domain (BEDMAP2, Fretwell et al., 2013).

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