12-12-2022

On the relative importance of offshelf/onshelf drivers of variability in mCDW inventory on the Amundsen Shelf, Antarctica

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Recommended Citation
St-Laurent, Pierre; Stammerjohn, S. E.; Maksym, T.; and Sherrell, R. M.. "On the relative importance of offshelf/onshelf drivers of variability in mCDW inventory on the Amundsen Shelf, Antarctica". 12-12-2022. AGU Fall Meeting 2022. https://doi.org/10.25773/chnp-gd30.

On the relative importance of offshelf/onshelf drivers of variability in mCDW inventory on the Amundsen Shelf, Antarctica

AGU FALL MEETING
Paper C15D-0621 Dec.2022, Chicago IL

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Session: C15D, Advancing our understanding of ice-shelf processes 1 (posters), Dec.12, 2022

Introduction

Ice shelves in the Amundsen Sea (west Antarctica) are melting rapidly and may raise global sea levels substantially over the coming century through reduced buttressing. The high basal melt rates are associated with the presence of warm modified Circumpolar Deep Water (mCDW) that intrudes across the continental shelf and melts the floating portion of the ice sheet from its base near the grounding zone. How much mCDW is present on the continental shelf (its volume inventory) is thus thought to be a key proxy for the year-to-year variability in ice shelf melt rates.

Over the past decade, the literature has linked this year-to-year variability to processes acting on the continental shelf ("onshelf"; *e.g.*, [7,13]) as well as processes acting offshelf (or at the shelf break; *e.g.*, [8,11,2,12]), but their relative influence remains unclear. (N.B. This categorization discriminates according to where the process is acting, but both onshelf and offshelf processes can ultimately have their time-variability driven by remote teleconnections; see, *e.g.*, [3]).

Hydrographic surveys from 2007-2018 in the Dotson-Getz Trough reveal a smooth high/low/high pattern in annual mCDW inventories ([7], gray curve in Fig.3) that could reflect processes acting offshelf, onshelf, or both. We investigate their relative importance in generating the observed high/low/high pattern.

Methods

A regional 3D sea ice-ice shelves-ocean model (Fig.1) simulates the period 2006-2022 while using historical reanalysis meteorology at the surface, historical sea ice concentration at the edges of the model domain, but the same oceanic conditions offshelf throughout this period. The simulation effectively evaluates how much of the observed high/low/high pattern can be reproduced in absence of offshelf oceanic variability (*e.g.*, [8]), providing insight into the relative importance of onshelf / offshelf processes.

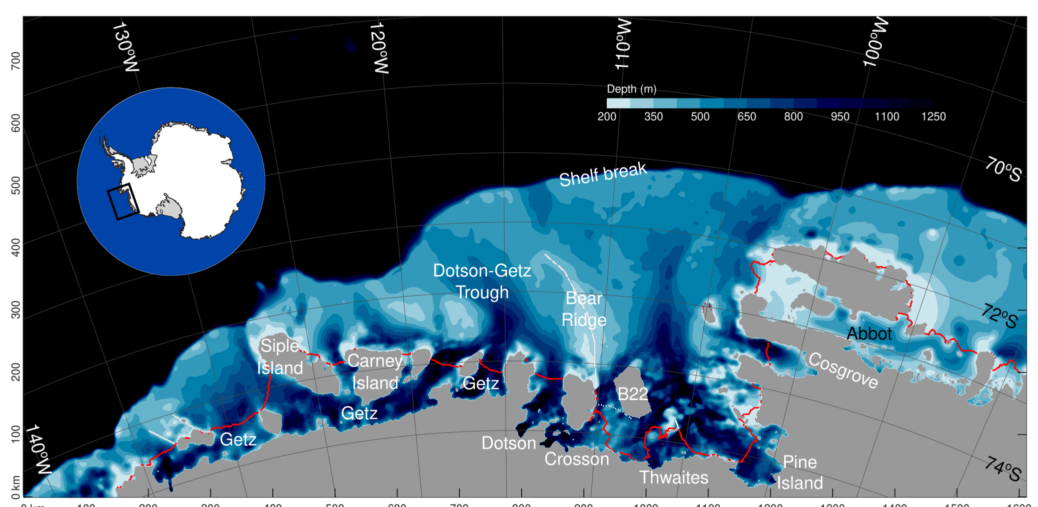
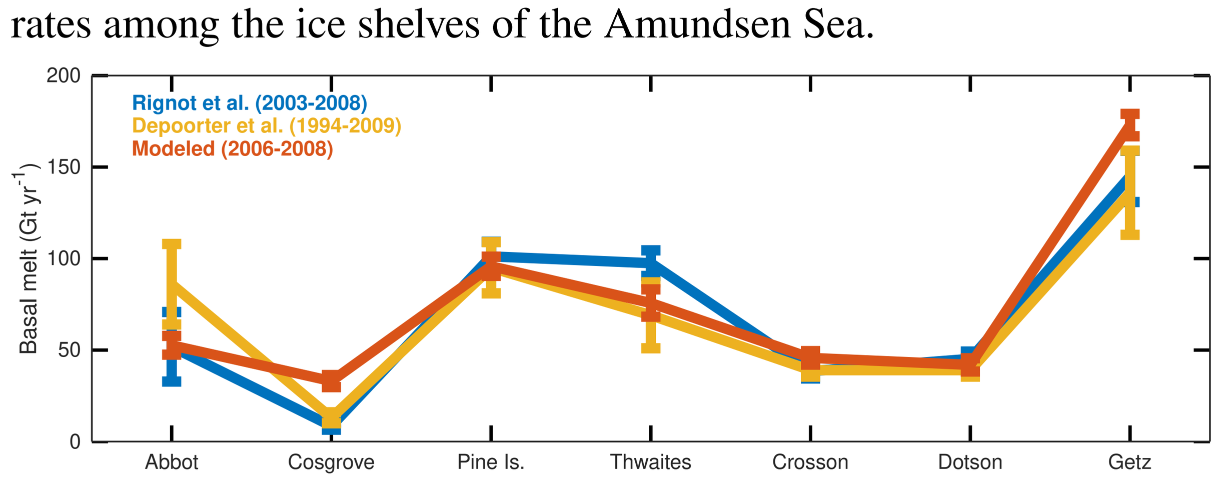


Fig.1. Model domain and bathymetry with ice shelves labeled.

Model-data comparisons

Fig.2. Model-data comparison for long-term averaged ice shelf basal melt rates, based on [1,10]. This model reproduces the variations in basal melt rates among the ice shelves of the Amundsen Sea.



Results

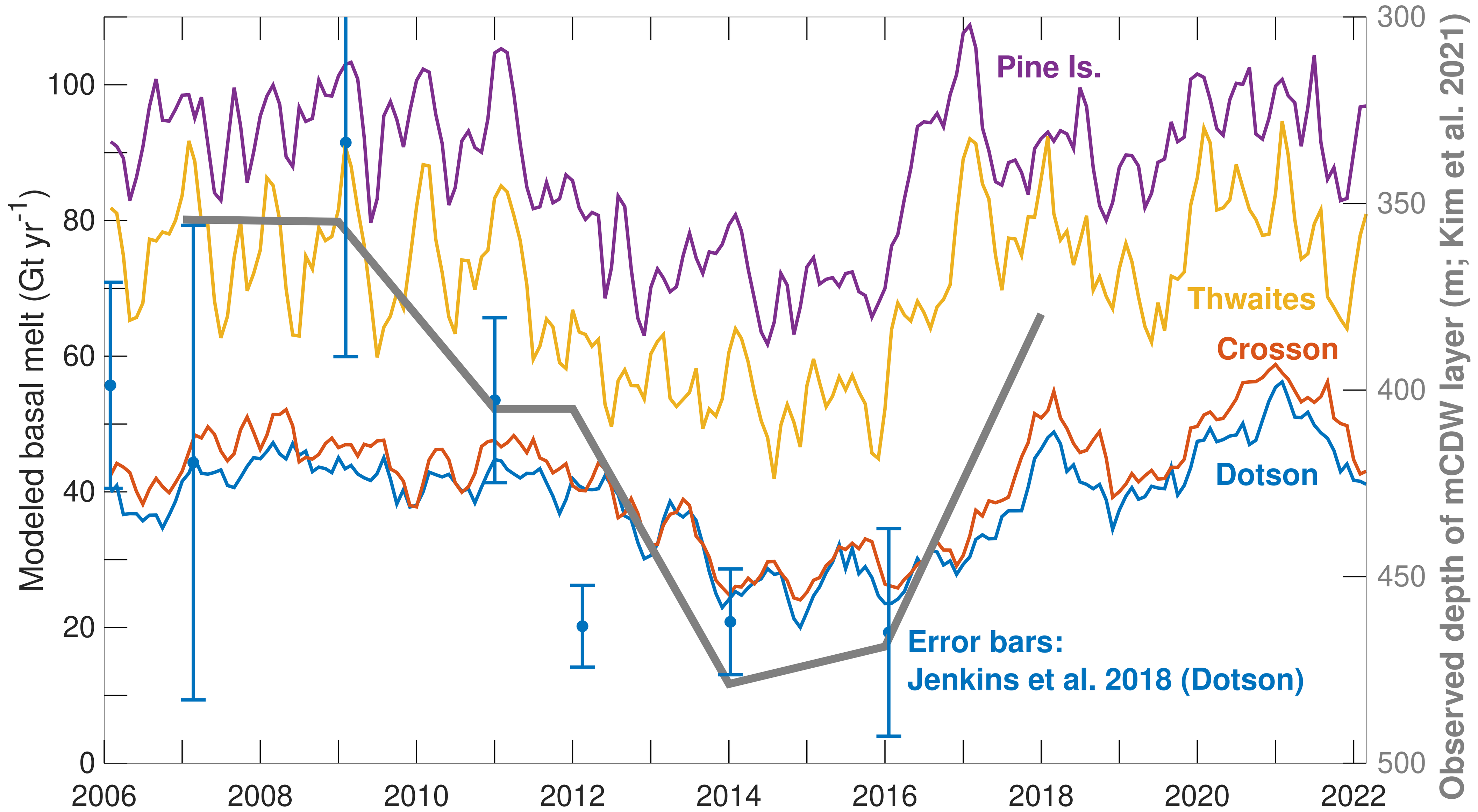


Fig.3. Modeled basal melt rates over the period 2006-2022 compared to the mCDW inventory of [7] (gray curve) and to estimated basal melt rates for Dotson (blue error bars; [5]).

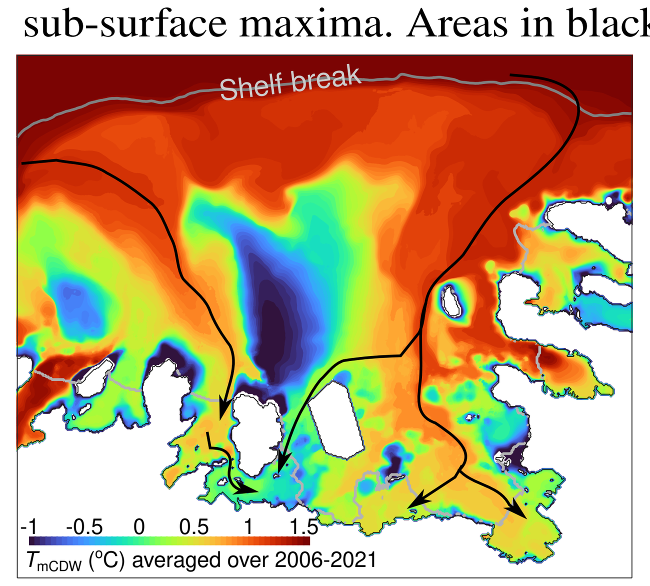
The observed high/low/high pattern in mCDW inventory (gray curve, Fig.3) is qualitatively reproduced in the basal melt of Pine Island, Thwaites, Crosson, and Dotson ice shelves (Fig.3). The "low" represents a decrease of as much as ~25 Gt/yr for Pine Island and Thwaites.

While the "low" becomes apparent as early as summer 2012 for some ice shelves, the timing of the recovery varies. Ice shelves positioned in the east are the first ones to recover (ca. mid-2016). This recovery extends to Crosson and Dotson ~2 years later, reflecting the fact that these two are primarily fueled by a separate pathway of mCDW on the continental shelf (Fig.4).

Dotson's melt rates estimated from in situ observations (error bars in Fig.3) are highly variable with values as high as ~90 Gt/yr in 2009 and fairly large error bars. Nevertheless, they support the existence of high rates in 2006-2011 (~55 Gt/yr on average) and low rates in 2012-2016 (~20 Gt/yr) for an overall decrease of ~35 Gt/yr. The model suggests a smaller decrease (~20 Gt/yr) fully achieved ~2 years after the observations (2014 vs. 2012; Fig.3).

Water temperatures along the main pathways of mCDW remain largely the same during the periods of "high" and "low" melt rates (see white areas in Fig.5). In other words, the characteristics of the mCDW crossing the continental shelf are not substantially different between the two periods. Cold anomalies are most apparent far downstream of the main inflowing branches (Figs.4-5).

Fig.4. Long-term averaged (2006-2021) core temperature of the simulated mCDW layer in the eastern Amundsen Sea, defined as the sub-surface maxima. Areas in black are essentially devoid of mCDW. Black arrows represent the pathways of simulated mCDW on the continental shelf.



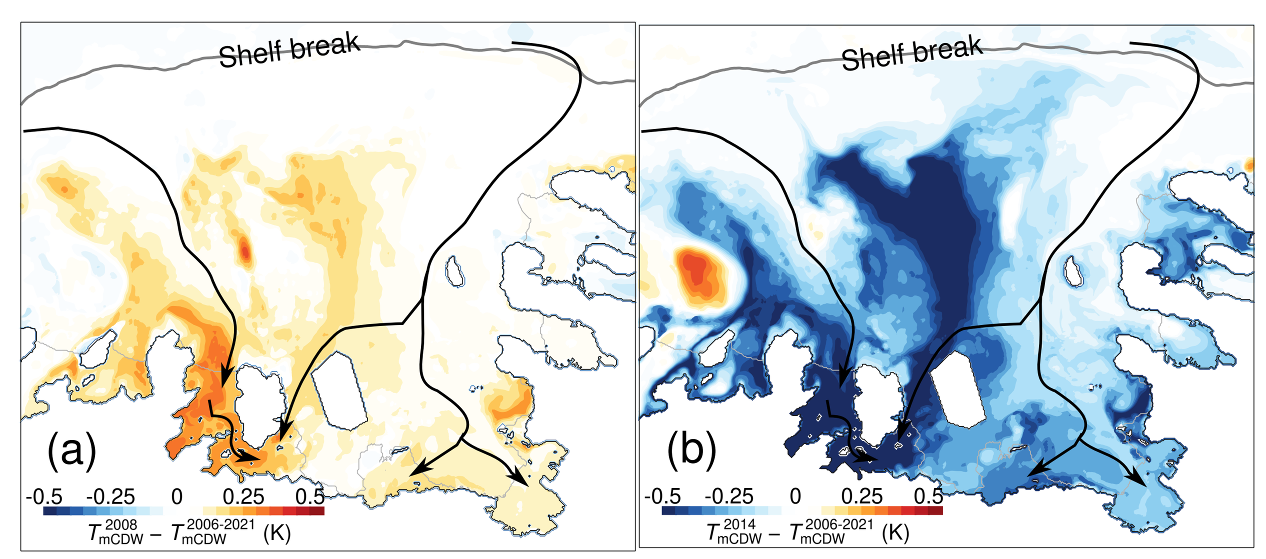


Fig.5. (a) Temperature anomaly for year 2008 (*i.e.* before the cooling) relative to the 2006-2021 average of Fig.4. (b) Same, but for year 2014 (lowest point of high/low/high pattern).

Discussion

The fact that the basal melt rate of the modeled ice shelves decrease by as much as 25 Gt/yr during the "cool" period, *i.e.* comparable to the ~35 Gt/yr decrease estimated by [5] between 2006-2011 and 2012-2016, indicates that offshelf oceanic conditions are not the primary driver of this pattern. The high/low/high pattern must be due to processes taking place somewhere inside the limits of this regional model domain, either on the continental shelf (e.g., [7,13]), or at the shelf break itself. (A similar outcome was reached in a different 3D regional model similarly forced by climatological oceanic conditions at its edges [9], albeit with a less complete recovery following the "cool" period.)

Although the cool period could not be attributed to a change in the characteristics of the mCDW crossing the shelf break (Fig.5b), a slow down in the rate at which mCDW enters the continental shelf (*i.e.*, the poleward heat flux) remains a possible cause for the cold period. Future analyses should distinguish between these aspects.

Centennial scale simulations with regional ice sheet models indicate that transient (*i.e.*, temporary) oscillations in basal melt rates, such as the decadal high/low/high pattern described here, are ultimately irrelevant for the ice shelves' contribution to global sea level rise [6]. (The relevant figure is the centennial scale-averaged basal melt rate.) In terms of in situ hydrographic observations, the period of observational record in the Amundsen Sea (1994-Present; see [4]) is short enough that "oscillations" and "trends" remained largely undistinguishable until recently.

Such oscillations can nevertheless play an important role in: (1) determining the degree of realism of a given model, and (2) helping determine the relative importance of specific components of the ice/ocean system such as sea ice-mediated processes [7,13], or in this case the offshelf oceanic variability.

Acknowledgments & References

This research was supported by NASA (award 80NSSC21K0746, Antarctic sea ice, fast ice and icebergs: Modulators of ocean-ice shelf interactions (AMICUS)) and by NSF (collaborative awards 1941292, 1941327, 1941304). The authors acknowledge William & Mary Research Computing (https://www.wm.edu/it/rc) for providing computational resources and/or technical support that have contributed to the results reported within this document.

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