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Interactive comment on "Simulated melt rates for the Totten and Dalton ice shelves" *by* D. E. Gwyther et al.

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The authors wish to thank the anonymous reviewer for their comments and suggestions. Below, we have included the reviewers comments in italics and quotation marks and our subsequent reply. For some comments, we have included the original and altered sentence. We have also included the updated manuscript as supplementary material.

1 General suggestions

"This study offers an interesting and unprecedented numerical modelling perspective on ice shelf-ocean interactions in the Totten/Dalton ice shelves area. There is growing interest in this area of the world, and in this topic in general. This work will be of interest to numerous scientists including, but not limited to, oceanographers and glaciologists. I therefore think it should be published. I have however a number of issues with the present manuscript that I would like to see addressed, if possible. All the minor points, including notes about a missing figure, are marked in red in the attached pdf."

Baroclinic circulation onto shelf: *"One major issue I have is about the general lack of description of the baroclinic circulation. Given that a major point of the authors relies on inflow of warm water onto the continental shelf, a process that is inherently baroclinic, this point is critical and a better description could easily be made."*

We acknowledge the deficit of an exposition of baroclinic circulation across the shelf break. To address this issue, we have included a discussion of the water mass structure and the vertical variation in temperature, salinity and velocity. We believe this gives the reader some understanding of the baroclinic conditions along the shelf break and on the continental shelf.

New content added:

"Model output shows vertical water structure at the shelf break generally composed of relatively warm and salty CDW (with temperatures warmer than 1C and salinity approximately 34.7) overlayed with fresher and cooler Antarctic Surface Water (temperatures of $\sim$-2C and salinity of 34.2). Flow is mostly barotropic along the shelf break except for baroclinic bottom-intensified flows at areas of changing bathymetry (such as the Dalton rise).

On the Totten region continental shelf, the water masses include slightly cooler but salty CDW (MCDW formed through mixing with shelf waters); this is overlayed by cold

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and fresh Antarctic Surface Water; while along the coast, cold and salty HSSW (with temperatures of $\sim$-2C or less and salinity of 34.7 or greater) flows westwards. On the shelf, model output shows the westward flow of HSSW is bottom-intensified and can entrain surface waters with it. The flow of the ACoC is generally surface-intensified and carries meltwater from the Dalton ice shelf and ice tongue westwards, however, these two flows can combine to form approximately-barotropic westward flow. A large clockwise recirculation feature forms in the Totten basin. This feature, which is surface intensified, carries heat clockwise from the shelf break towards both major ice shelves, and is composed of water with temperature between -0.2C to 0.4C and salinity of 34.5 to 34.6."

Sea ice component:

"Another important point is that I would like to see clearer explanation about the sea-ice component of the model (or lack there of), and the impact a better (more realistic) model might have on the result. Assuming that the flux-correction used do not correctly represent the amplitude of sea-ice production and its variability, my personal (naive) expectations would be that a more complex model could tapper down or enhance the links between the melting of the neighbouring ice shelves. Again this would not have to take a large part part of the revised manuscript."

There are several sea ice models available which can be integrated into ROMS. However, we have chosen to not use a dynamic sea ice model. This choice was made as a large polynya exists within the model domain which is constrained by grounded icebergs; a feature that sea ice models do not reproduce are realistic polynyas. The polynya activity can be represented realistically using a parameterisation for heat/salt flux into the top of the ocean model, as obtained from satellite passive microwave measurements of sea ice concentration. As we are not running a future simulation there is no explicit requirement to simulate sea ice conditions, as we can obtain them from satellite observations.

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We have included some modifications to the model details section to describe and justify the choices made with the sea ice component of the simulation.

New content added:

“There are several sea ice models available for integration into ROMS (Budgell, 2005). However, sea ice production from coupled sea ice models is sensitive to the representation of grounded icebergs (Kusahara et al., 2010), leading to the possibility of poor representation of polynyas forming in the lee of grounded icebergs (such as the Dalton ice tongue polynya). Consequently, we parameterise sea ice formation from Special Sensor Microwave Imager (SSM/I) observed ice concentration for the period 1992-2007 using the heat and salt flux algorithms of Tamura et al. (2008).”

Heat budgets:

“Also important (but perhaps not as critical) is a need to go beyond hand waving arguments concerning heat budgets. Given that the authors are not strongly limited in terms of manuscript length, a quantification of each terms of the heat budget (detailing those due to air-sea fluxes, ice-sea fluxes, and, at least, advection) would be very beneficial in quantifying and strengthening the authors findings."

We agree that a nice study would be to quantify heat transport across the shelf break, through the ocean surface, into the ice shelf and onto the shelf break from the Western and Eastern boundaries. However, we feel that an analysis of that type, while definitely beneficial, would be beyond the scope of this paper. This is because we feel that this paper focusses on the determining the relationship between the ice shelves and the nearby polynya. For example, we have purposely avoided investigating the ‘satellite-inferred increased basal melt’ of ice shelves, instead focussing on the drivers of seasonal and interannual variability.

A study investigating the causes of cross-shelf exchange, the variation in cross-shelf exchange and the link to increasing ice shelf melting would perhaps be a study better

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suited to this kind of heat budget analysis.

2 Replies to reviewers specific comments

p2112, l9: "Doesn't this statement hold for the Amundsen Sea only?"

Pritchard states that "Our analysis reveals that there is also evidence of net thinning through enhanced basal melt on the East Antarctic ice shelves Vigridisen, 17E, West, Shackleton, Holmes Glacier, Dibble, Rennick Glacier and the thicker part of Totten."

p2112, l20: "Comparatively"

Suggested word added.

Original: "The InSAR estimate for the Moscow University ice shelf show basal melt of 4.7 +- 0.8 m/yr"

Altered: "Comparatively, the InSAR estimate for the Moscow University ice shelf show basal melt of 4.7 +- 0.8 m/yr"

p2112, l29: Comma removed.

p2114, l1: Add references Depoorter et al., 2013, Jacobs et al., 2011; Jacobs et al., 2013

By re-arranging sections 2 and 3, and moving the 2nd last paragraph in the introduction in the "Overview of causes of basal melting" section, the Jacobs et al., 2011 has been included. I have also added Depoorter et al., 2013 and Jacobs et al., 2013.

p2115, l8: "Figure?"

Instead of including an extra figure, the sentence has been reworded to describe the locations of possible pathways more accurately. We have also added a sentence describing the need to acquire ship and airborne bathymetry data.

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Original: “The bathymetry in front of the Totten ice shelf is suggestive of possible pathways of MCDW intrusion onto the continental shelf at 120 E.”

Altered: “The bathymetry in front of the Totten ice shelf is suggestive of possible pathways of MCDW intrusion onto the continental shelf. For example, Paulding Bay (See Fig. 1) is bordered by a low continental shelf break, possibly allowing bathymetric intrusion. The western side of the Dalton Rise is another location where the deepening of the continental shelf break may allow intrusion of MCDW. Current bathymetry products of the continental shelf break and shelf proper in this region are informed by satellite gravity inversions, and have limited ship-based groundtruthing. Consequently, there is a strong need to acquire accurate ship-based and airborne bathymetry data.”

p2116, l1: “Unless you are interested in coupled dynamics, wind forcing on the ocean is not an ‘exchange with the atmosphere’”

This section has been renamed "Atmospheric forcing". However, the phrase ‘atmosphere-ocean exchange’ will be used through the text to refer to the exchange via heat loss and gain in the polynya region.

p2116, l5: “What are these? Thoma et al., 2008 look into the variability, not the main process leading to warm water intrusion on the continental shelf"

We have changed the wording to make these 2 paragraphs more accurate.

Original: “In some cases, local recurring conditions favour wind stress patterns that drive currents over the continental shelf break and on to shelf. For example, modelling of PIIS showed a strong correlation between flow of CDW onto the continental shelf and local synoptic wind stress conditions (Thoma et al., 2008).”

Altered: “In some cases, local meteorological conditions favour wind stress patterns that drive currents over the continental shelf break and onto shelf. For example, modelling of PIIS showed a strong correlation between flow of CDW onto the continental shelf and local temporal variations in synoptic wind stress conditions (Thoma et al.,

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2008).”

p2116, l28: “what is the region corresponding to figure 2a"

The region corresponding to that calculated in Fig. 2(a) is shown with blue shading in Fig. 1.

p.2117, l7: “This section comes a bit late."

This section has been moved so that it comes before "overview of causes of basal melting".

p.2119, l4-7: “Dubious, at best"

We used a constant offset down the centreline of the ice shelf cavity as accurate bathymetry/ice draft data is not accessible for this ice shelf. This method provides the best way to model circulation and melt/freeze within the cavity, and as its effect on ocean circulation on the continental shelf, and heat transport into the cavity is likely minimal, we believe this is a valid choice. It has been used by other recent studies (such as Khazendar et al., 2013). There is good agreement between modelled basal melt rates (9.1 m/yr) and the latest InSAR glaciological estimates of 10.5 m/yr. While this doesn’t by any means show that our cavity shape is accurate to the actual shape, it does give us some confidence in our decision of choosing a constant cavity thickness along the centreline and interpolating between it and the grounding line.

p2119, l17: “No sea-ice model... well... I guess it’s fine to get an idea of what drive variabilities in melting, but this is certainly far from being a realistic model..."

We have added a paragraph explaining why we have not included a sea ice model, and why the buoyancy fluxes of Tamura et al., 2008 serve to realistically simulate sea ice processes.

New paragraph: There are several sea ice models available for integration into ROMS (Budgell, 2005). However, sea ice production from coupled sea ice models is sensi-

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tive to the representation of grounded icebergs (Kusahara et al., 2010), leading to the possibility of poor representation of polynyas forming in the lee of grounded icebergs (such as the Dalton ice tongue polynya). Consequently, we parameterise sea ice formation from Special Sensor Microwave Imager (SSM/I) observed ice concentration for the period 1992-2007 using the heat and salt flux algorithms of Tamura et al. (2008).

p.2120 l14-15: "But in slight disagreement with the latest estimates..."

The area average melt rate ranges between 4 to 16m/yr, but has an average (over the 1992-2007 period) of 9.1 m/yr. This is very close to the glaciological estimates. The other estimates (Rignot, 2002; Rignot and Jacobs, 2002) are not averaged over the whole ice shelf area, but rather refer only to the grounding line region. Our estimates for this region (16m/yr to 45m/yr with average of 28m/yr) agree very well. All model results compare very well with estimates. However, we have reworded this section slightly to clear up any confusion.

p2121, l19: "Why limiting current and tracer analysis to the barotropic component?"

See response above where we have described how we now treat the baroclinic analysis.

p2121, l25: "What is the temperature of a current? again, are these features only barotropic???"

We have slightly reworded this, but please also see response regarding baroclinic component analysis above.

Original: "In general, temperature at each layer of the model decreases polewards. The ASC is typically between 0C to 0.4C, though at several points during the 1992-2007 time period, the temperature rises to approximately 0.5C. The water that makes up the ACoC (-1C to -0.5C) is cooler than the ASC, as a result of mixing with cold meltwater from glaciers and ice shelves, and heat lost to the atmosphere."

Altered: The temperature at each layer of the model generally decreases polewards.

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The water that makes up the ASC is typically between 0C to 0.4C, though at several points during the 1992-2007 time period, the temperature rises to approximately 0.5C. The water that makes up the ACoC (-1C to -0.5C) is cooler than the ASC, as a result of mixing with cold meltwater from glaciers and ice shelves, and heat lost to the atmosphere.

(Please also see top for baroclinic analysis paragraph.)

p2122, l9-10: “missing words above and below"

Corrected.

Original: “However, there is no overall trend between 1992 and 2007 Totten ice shelf melt discernible above the 2-3 yr melt variation. Thus, we focus analysis on understanding the processes governing simulated interannual variability in melt rates.”

Altered: “However, there is no overall trend (over the 1992-2007 period) in Totten ice shelf melt discernible above the 2-3 year melt variation. Thus, we focus the analysis on understanding the processes governing simulated interannual variability in melt rates.”

p2123, l5: “Lags are unclear from figure"

We have reworded this sentence to better illustrate the cause-and-effect of increased HSSW production and decreased melt, hopefully making the lag (as seen by comparing Fig.2(a) and Fig.2(c)).

Original: “However, the timing of the peak in polynya activity and thus HSSW production in June lags the minimum of Totten ice shelf melt (compare Fig. 2c and a).”

Altered: “However, the timing of the minimum of Totten ice shelf melt (generally in December) lags the peak in polynya activity and HSSW production in June (compare Fig. 2c and a).”

p2123, l9: “become” has been changed to “becomes”.

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p2123, l17: "How about showing heat content timeseries?"

We feel that the heat flux analysis provided (See Fig.2(a) and Fig.2(b)) illustrates the seasonal and interannual variability in polynya activity. The variability in heat content beneath the ice shelf over the 1992-2007 period is highly correlated with melt rate. We feel that this may not be necessary to include. However, we have this figure available if the reviewer wishes it included.

p2124, l10: "Very weak analysis of shelf edge exchanges: are they barotropic? baroclinic eddy driven? etc..."

Please see general response above regarding baroclinic analysis and the general response to using a heat budget analysis. In summary, this paper is less focussed on cross-shelf exchange processes, and more focussed on the drivers of seasonal and interannual variation in melt rate of these two ice shelves, such as the nearby polynya.

p2124, l24: "The dynamics in St Laurent et al. is a little more complex than what you describe."

We have deliberately kept this section short, without going into detail on the dynamics shown by St Laurent et al. However, this section has been reworded to be more accurate, and more detail has been added to the description of Rossby wave/bathymetry interaction as mentioned in 3.3 Eddies.

Original: "The narrow current formation is supported by idealised modelling studies, which suggest a significant onshore flow generated by troughs, in agreement with previous dynamical understanding (St-Laurent et al., 2013)."

Altered: "The narrow current formation is supported by idealised modelling studies, which suggest a significant onshore flow is generated by interaction with along-shelf break flow and a trough (St-Laurent et al., 2013)."

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