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Interactive Comment

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 thank Malte Thoma for his helpful and constructive comments on the manuscript. We have addressed his comments (shown in italics), and reply to each comment below. For some changes, we have included the sentence before and after. The corrected manuscript is included as a supplement.

1 Body

"This is a very interesting study, which I recommend to publish after a minor revision. Most of my comments should be addressable quiet easily, and addressing the reaming

few should take not to much effort."

p.2110 l.2: "From my understanding "much of it marine based" refers in a grammatical sense to "East Antarctic ice sheet", which is not correct. The EAIS is mainly ground-based."

We intended to highlight the large proportion of the Totten drainage area which is marine-based ice sheet. We have removed this phrase, instead using it later on.

Original: "The Totten Glacier drains a large proportion of the East Antarctic ice sheet, much of it marine based (grounded below sea level), and is rapidly losing mass."

Altered: "The Totten Glacier is rapidly losing mass."

*l.2 & l.26 "East Antarctica has about 14e6 km^2 if only 5e5 km^2 (4%) are drained through Totten Glacier, I would not consider this *large*."*

The drainage figure has been updated to a newer result (570,000 km^2;Rignot et al., 2008), and using the estimation of EAIS area from the same paper ($\sim$8,000,000km^2; Rignot et al., 2008) the percentage drainage is 7%. The reference to drainage in the abstract has been removed, and instead is used it in the introduction.

Originally: "The Totten Glacier (see Fig. 1) drains over 500 000 km^2 of East Antarctica (Rignot, 2002). Most of the ice sheet that drains through the Totten Glacier is marine based (i.e. the ice base is grounded below sea level; Roberts et al., 2011) making the region potentially vulnerable to rapid ice sheet collapse. "

Altered: "The Totten Glacier (see Fig. 1) drains over 570,000 km^2 of East Antarctica (Rignot et al., 2008). Most of the ice sheet that drains through the Totten Glacier is from the Aurora Subglacial Basin (Young et al., 2011) and is marine based (i.e. the ice base is grounded below sea level; Roberts et al., 2011) making the region potentially vulnerable to rapid ice sheet collapse."

p.2111 l.4-6 "More recent studies than Weertmann indicate, that lateral stresses allow

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an ice shelf/sheet system to be stable even for downward sloping. I suggest to mention this here."

We have altered this sentence to mention the possibility of stabilisation from lateral stresses (Jamieson et al., 2012). It is unclear how applicable this finding would be in the case of this portion of the EAIS, as lateral stresses would be smaller than for a narrow ice stream.

Original: "Weertman (1974) showed that ice grounded below sea level is inherently unstable, particularly where the bedrock slopes downwards, away from the ocean, as is the case in the Aurora Subglacial Basin, inland of the Totten Glacier (Young et al., 2011). "

Altered: "Weertman (1974) showed that ice grounded below sea level is inherently unstable, particularly where the bedrock slopes downwards, away from the ocean, as is the case in the Aurora Subglacial Basin (Young et al., 2011). More recent studies have indicated lateral stresses may act to stabilise ice retreat on a reverse bed slope (Jamieson et al., 2012), but the applicability of this on a broad drainage basin, where lateral stresses are lower, is uncertain."

l.17 "The way the 2800 m are mentioned here sound as if this would be some kind of mathematical limit. I suggest to reformulate this sentence to clarify, that the deepest part of AIS reaches down to 2800 m at present."

We have made this statement more broad, and moved the 2800m to directly refer to the AIS.

Original: "The sub-ice shelf seabed can reach depths of over 2800 m below mean sea level (e.g. the deepest part of the Amery Ice Shelf cavity; Galton-Fenzi et al., 2008)"

Altered: "The sub-ice shelf seabed can be found at depths of over 2800m below mean sea level (e.g. the deepest part of the Amery Ice Shelf cavity; Galton-Fenzi et al., 2008)."

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l.21 “I suggest to cite an article describing the sea-ice pump"

We have cited Lewis and Perkins, 1986 for the ice pump mechanism.

Citation added: Therefore, at the back of deep ice shelf cavities, the decreased freezing point of seawater provides a large potential for thermal driving of melting, leading to melting at depth and a buoyant melt water plume (Lewis and Perkin, 1986).

l.28 “There are more publications out showing the acceleration of LIS, I suggest to add “e.g., De Angelis ...""

We have cited Scambos et al., 2004 as well.

Citation added: For example, observations show surging, acceleration and retreat of tributary glaciers after the collapse of the Larsen A and B Ice Shelves (De Angelis and Skvarca, 2003; Scambos et al., 2004).

p.2112 l.6 “In the abstract you mention 9.1 m/yr of melting for TG, here you report a thinning rate of only 1.7 m/yr. I assume I missed something, but maybe this discrepancy could be explananed somehow?"

We have attempted throughout the paper to make the distinction between the Totten Glacier and the Totten ice shelf. Here, the 1.7m/yr thinning is referring to the decrease in elevation of the glacier surface at 1.7m/yr, while the 9.1 m/yr of melting is referring to ice melted off of the bottom of the Totten ice shelf.

l.8 “Until now you have not reported any "rapid retreat rate". I suggest to present an example here."

We have reworded this to remove the reference to "rapid retreat rate" and instead just reference recent satellite observations. I’ve left Larsen A and B as examples of rapid retreat.

Original: “The high thinning and rapid retreat rates of marine terminating glaciers suggests a common oceanic driving, for example through increased basal melting

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(Pritchard et al., 2012). ”

Altered: “Recent satellite observations have shown rapid and accelerated thinning of glaciers along the coastal margins of Antarctica (Pritchard et al., 2009).

l.20 ““Moscow University Ice Self", and in the following all named ice shelves should be capitalized with search-&-replace."

We have made an effort to use the capital case for each letter for only accepted names, such as Totten Glacier. We have used non-capitilised names where this is not (yet) an accepted name, for example, Totten ice shelf. Instances of Moscow University ice shelf have been changed to Moscow University Ice Shelf.

p2113 l.6 “The PIIS is better known to me as PIG, is there any reason why you choose the uncommon name? I also would like to see a number how many m/yr and Gt/yr are drained through PIG/PIIS."

We have now chosen to refer to the Pine Island Glacier ice shelf as the Pine Island ice shelf. We have removed the acronym ‘PIIS’, since as far as we know ‘Pine Island Ice Shelf’ is not yet an accepted name. This reasoning follows from the previous comment - we use non-capitalised names to refer to non-accepted names. The motivation for referring to the Pine Island Glacier ice shelf as the Pine Island ice shelf is to highlight the difference between the glacier (grounded) and ice shelf (floating). We have also added an estimate for basal mass loss for the Pine Island ice shelf.

Original: “And, unlike many other high melt regions, such as the Amundsen/Bellingshausen Sea coasts where the Pine Island Ice Shelf (PIIS) is situated, no definite causal mechanisms for basal melting of the Totten and Dalton ice shelves are known.”

Altered: “And, unlike many other high melt locations, such as the Pine Island Ice Shelf (PIIS) which is estimated to have an area-averaged mass loss of 101.2 $\pm$ 8 Gt/yr (Rignot et al., 2013), no definite causal mechanisms for basal melting of the Totten and

Dalton ice shelves are known.”

l.20 “This sentence puzzles me, you just introduced "proposed hypotheses" in the previous paragraph (l.9-l.15) and now you claim you present them is section 2. I suggest to remove paragraph 9-15 and/or include its content into section 2."

We have moved the short summary sentence from the end of the introduction into what was originally section 2, but is now section 3.

l.25 “I find the title improper: The “causal factor for basal melting" is (from my point of view) that $T_{ocean} > T_{ice\ at\ pressure\ melting\ point}$ I suggest a reformulation."

Changed heading to "Overview of drivers of basal melt".

p.2114 l.11 “I suggest to cite Thoma (2008) here as well."

Citation added.

l.20 “Please reformulate the expression “can not be definitely attributed as""

Changed line to indicate that the lack of observations limits the ability to determine if MCDW is the driver of melting.

Original: “Consequently, MCDW can not be definitely attributed as the water source driving melting of the Totten ice shelf.”

Altered: “Consequently, it is not yet clear whether MCDW is the water source driving melting of the Totten ice shelf.”

l.22 “Actually the "Circumpolar Deep Water intrusions" do depend on "bathymetric features", therefore I do not understand why these are two different subsections. "

In this section, we intended to illustrate the important drivers that control basal melt. MCDW is an important driver for melting and bathymetry controls these intrusions. But the bathymetry is an important factor itself, excluding the link with MCDW, as bathymetry steers water masses on the shelf, and therefore is a factor in controlling

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basal melt. Therefore, the factors controlling melting are possibly a combination of all of the subsections in section 2 (overview of drivers of melt), and bathymetry should not be implicitly included with the MCDW section.

l.2116 l.10 “This sounds as if the polynya is a steady and everlasting feature - which might be the case for the observed era, but that should be mentioned. Some sentences about the duration and variability of this specific poynya would be nice. "

The duration of the polynya has been described. The long-term variability of the polynya is discussed in the next paragraph.

New addition: “Between approximately mid-February and mid-November the polynya removes heat from the ocean. The persistence and duration of this polynya before the satellite era is unknown.”

p.2117 l.7 “A informative as this section is, the placement puzzles me. I suggest to exchange sections two and three."

The reviewer is absolutely correct - we have swapped sections 2 and 3.

Original: 1. Introduction 2. Overview of causes of basal melting 3. Description of Region 4. Model details 5. Results 6. Discussion 7. Conclusion

Altered: 1. Introduction 2. Description of Region 3. Overview of drivers of basal melting 4. Model details 5. Results 6. Discussion 7. Conclusion

l.26 “To my knowledge, it is not possible to separate the ACoC and the ASC apart from the areas where the coastline is far away from the shelf break. The latter is only the case in the Ross and FRIS-area, but not in the Totten area. Therefore the authors should explain why they discuss mainly the ASC and where the differences to the ACoC are in there area of investigation."

Part of the motivation for this studying is that the oceanography is so uncertain in this region. Oceanography voyages in this area have only reached the continental shelf

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break, and not explored the near-coast region. Thus differences between the ACoC and the ASC are not fully explored. We treat them differently here as (at least in the model) they are clearly differentiable and have very different interactions with the ice shelf. This is one of the paper's conclusions. We have included a small modification to indicate that the two currents are differentiable in model results.

Original: The ASC is also reproduced, flowing westwards along the continental shelf break (see Fig. 5b). The current is channelled by bathymetric features, such as where the shelf break curves north-west at 116E, 64.5S and approximately flows between the 2000 m and 2500 m isobaths. Currents for the ASC can be as high as 20 cm s^{-1}, but have a mean flow of approximately 5 cm s^{-1}. These model simulated currents agree well with the sparse nearby observations of Bindoff et al. (2000) and Williams et al. (2011), which reported observed currents of approximately 2-15 cm s^{-1} and 2.3-6.4 cm s^{-1}, respectively. Modelling studies of circum-Antarctic ASC transport predict similar velocities (Mathiot et al., 2011).

Altered: The ASC is also reproduced, flowing westwards along the continental shelf break (see Fig. 5b). The current is channelled by bathymetric features, such as where the shelf break curves north-west at 116E, 64.5S and approximately flows between the 2000 m and 2500 m isobaths. Consequently, the ASC is differentiated from coastal flow associated with the ACoC by both the zonal location and temperature of water within the flow. Currents for the ASC can be as high as 20 cm s^{-1}, but have a mean flow of approximately 5 cm s^{-1}. These model simulated currents agree well with the sparse nearby observations of Bindoff et al. (2000) and Williams et al. (2011), which reported observed currents of approximately 2-15 cm s^{-1} and 2.3-6.4 cm s^{-1}, respectively. Modelling studies of circum-Antarctic ASC transport predict similar velocities (Mathiot et al., 2011).

p.2119 l.16 "I miss a figure indicating that the model has reached a quasi-steady state after these 32 spin-up years and that there is no model trend after this time any more. The polynya seems to play an important role is this feature somehow prescribed by an

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input data set and/or is this variable in time?"

We have added the spin-up figure and changed the description of the spinup phase. The spinup is for 16 years, but the total model run is for 32. The polynya does indeed play an important role. The polynya is prescribed by an input data set. SSM/I satellite observations and algorithms, developed by Tamura et al., 2008, are used to prescribe heat and salt flux into the surface of the model. This information is already presented in the Model Details section, and in the Atmosphere Forcing section.

p.2121 l.6 "What do these observations show?"

Observations of Bindoff et al., 2000 and Williams et al., 2008 have been added for reference.

Original: These model simulated currents agree reasonably with sparse nearby observations (see Bindoff et al., 2000; Williams et al.,2011)."

Altered: "These model simulated currents agree well with the sparse nearby observations of Bindoff et al. (2000) and Williams et al. (2011), which reported observed currents of approximately 2-15 cm/s and 2.3-6.4 cm/s, respectively."

*p.2122 l.4 "I can identify three periods of decreasing melt rates and two periods of Fig.2c increasing melt rates in Fig.2c. The decreasing seems to take be longer than the increasing, but I do not see an *increasing* from 1992 to 1994, but a slight decrease."*

This period is complicated by the competition of the below average strength wintertime polynya (increasing potential for melting) and the cold summertime (decreasing melting). The 2.5-year smoothed Totten melt is a balance between these competing factors. This is why the melt rate appears to be decreasing for 1992-1994. However, if you examine the 3-month smoothed melt rate (red line), you will see for 1992-1994, taking into account seasonal variation, the minimum and maximum melt rates do actually increase from 1992-1994. We have added a phrase in parentheses to clarify this.

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Original: “The 2-3 yr modulation of melt rate signal is noticeable as an increasing annual average melt between 1992 to 1994, 1998 to 2002, 2004 to 2007 and decreasing annual average melt between 1994 to 1998 and between 2002 and 2004.”

Altered: “The 2-3 year modulation of melt rate signal is noticeable as an increasing annual average melt between 1992 to 1994 (most visible in the 3-month Totten melt rate, shown as the red line in Fig. 2c), 1998 to 2002, 2004 to 2007 and decreasing annual average melt between 1994 to 1998 and between 2002 and 2004.”

p.2123 l.24 “I am not convinced yet, that the atmosphere-ocean exchange through the polynya is the cause or "dominant mechanism determining melt rates". If warm water is available, than the potential for both, the heat exchange through the polynya as well as basal ice melting is increased."

We think it’s fair to reword this statement to highlight that important role the polynya has, without diminishing the role of warm water for driving melting. I have modified this to be more precise with the wording, by describing the effect from the polynya as ‘modulating’ the melt rate, rather than ‘determining’.

Original: “The years with a strong seasonal variation in melt rate (see 1992 through to 1996) are years when atmosphere-ocean exchange (in the form of heat loss to the atmosphere) is the dominant mechanism determining melt rates. Other years, such as 1998 and 2003, display a more complex melt rate evolution.”

Altered: “The years with a strong seasonal variation in melt rate (see 1992 through to 1996) are years when atmosphere-ocean exchange (in the form of heat loss to the atmosphere) is the dominant mechanism modulating seasonal variation in the melt rate. Other years, such as 1998 and 2003, display a more complex melt rate evolution that is likely a combination of atmospheric forcing and melting caused by a time-dependent warm water source.”

p.2128 l.2 “The remote sensing shows the thinning only for a specific time frame. You

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should mention this."

We have added the period for the thinning rates in the introduction section.

Original: "For example, Pine Island Glacier thinned at rates up to 6 m/yr while the Totten Glacier displayed thinning rates of 1.7 m yr , three times the rate previously reported (Rignot, 2006)."

Altered: "For example, Pine Island Glacier thinned at rates up to 6 m/yr while the Totten Glacier displayed thinning rates of 1.9 m/yr for the period 2003-2007 (Pritchard et al., 2009), three times the rate previously reported (Rignot, 2006)."

l.4 "The phrases "It is generally believed" and "a series of possible processes" sound a bit colloquial, I would prefer a reformulation and maybe some references for the "generally believed" facts."

We purposely avoided including references within the conclusion, however, this paragraph has been changed to address your concern.

Original: "It is generally believed that enhanced exchange of heat across the shelf break, through a series of possible processes, is the main mechanism causing increased basal melting."

Altered: "Previous studies have indicated that enhanced exchange of heat across the shelf break is a major cause of increased basal melting (See for example Jacobs et al., 2013)"

p.2128 "Reformulate: "... and provides valuable information ...""

Changed.

Original: "This is the first such modelling study of this region, and will provide valuable information for directing future observations."

Altered: "This is the first such modelling study of this region, and provides valuable

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information for directing future observations."

2 Figures

*Fig.1: "I have great difficulties to identify the many details within this figure. I would consider the "white shading" a "bright shading", because there is nothing *white* in the figure. From the caption I have the impression, that "Dalton Rise" is an Iceberg, because the arrow points towards the dark shading, is that meant? I am unable to identify any "blue shading" polynya in the figure. CORRECTION: After I looked on the pdf, I can identify the mentioned features, however, I would prefer a figure that is also understandable as printout."*

Changed: Figure 1. is now clearer in colour and in black and white. The polynya highlighting is now mauve with a dark outline. Arrows have been added to indicate the polynya, icebergs and fast ice. We have also adjusted the wording in the caption.

Fig.2: "As far as I know, a polynya is defined as an area of open water surrounded by sea ice. How can this be "stronger"? I assume you mean "more heat is lost through the ocean"? The "1 standard deviation" should have a unit. The order of (c) and (d) and (c) seems awkward."

Changed: 'Polynya heat flux', shown in Figure 2b, has been altered to be the difference from the climatology (rather than 1992-2007 mean), which makes more sense (the difference from the yearly average is more important that the difference from an arbitrary length mean) and presents a clearer result. The caption for Fig.2(b) has been altered accordingly. We have added the value and units of the 1 standard deviation. The order of (c) and (d) was chosen as it follows the presentation of the results; heat flux and wind then polynya anomaly; melt rate; then difference between melt rates. The order of the subplots is chosen to reflect this.

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Fig.3: "This figure shows very interesting results. However, the order of the figures seems arbitrary and the notation within the figures (e.g.,1995.9 for OCTOBER) is confusing."

The order of the subplots in Figure 3 is important. Note that it is also the same order as Fig.4, with OCT 1995 top left, SEP 2003 top right, JAN 1999 bottom left, FEB 1994 bottom right. This order is important as it is the same order as the interactions are shown in Figure 5. It makes sense to list them in this order in Figures 3-5, as the top row is strong polynya, the bottom row is weak polynya, the first column is no Dalton flow and the second column is with Dalton flow. The notation of the date on the figures has been changed to be clearer.

Fig.4: "I would like to have a much larger figure. There arrows are barley visible and very hard to interpret."

Changed: The style of the date notation in Figure 4 has been changed and the figures have been enlarged. Note that the Figure 4 Malte Thoma was referring to is now Figure 5, due to the inclusion of another figure (ocean heat content during spinup).

*Fig.5: "I really like this very instructive figure :-) However, the bold *P* is hard to read"*

Altered figure, hopefully making it easier to read. Also included the meaning of the bold and normal-weight 'P' in the caption. Note that the Figure 5 that Malte Thoma was referring to is now Figure 6 due to the inclusion of a new figure.

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