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Interactive comment on "Holocene thinning and grounding-line retreat of Darwin and Hatherton Glaciers, Antarctica" *by* Trevor R. Hillebrand et al.

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Summary and recommendation

The paper presents an interesting combination of geochronological data (10Be, 26Al and 14C ages), flowband modelling and 3D ice sheet modelling, focused on Darwin and Hatherton Glaciers. The authors conclude that Darwin Glacier thinned gradually by 500 m during the Holocene, in contrast to other glaciers in the Transantarctic Mountains, and that this behaviour was possibly due to the convergent ice flow and lateral drag in the vicinity of Byrd Glacier.

A lot of work is covered in this paper. The manuscript is generally well structured, written and illustrated, the methods seem sound, and the conclusions are mostly sup-

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Discussion paper

ported by the results. The study provides new high-quality data for this region, a new understanding about the ice dynamics at Darwin and Hatherton Glaciers, and ideas related to deglaciation of the Ross Sea.

I recommend publication in The Cryosphere following some revision.

There are a few aspects where I think the paper could be improved. First, the rationale for the study needs to be better communicated, particularly in the Abstract and also Introduction. Why should the reader care? Second, it is not always clear what is new and what is "borrowed" from previous studies. This concerns the geochronological constraints and interpretations at Lake Wellman, and the ice sheet model ensemble. Third, the maximum ice limits at 9.5 kyr BP are not clearly supported by this study. There are no saturated in situ 14C samples from Magnis Valley and Bibra/Dubris Valleys, and the interpretation of Lake Wellman is based on another study, with limited description of why older samples are ignored. Fourth, the flowband modelling skips over some limitations in this approach, while the ice sheet model ensemble is short on detail. More details on these points are included below.

Detailed comments

Title: 'grounding-line retreat' is included, yet the paper concludes that it is not possible to gauge grounding-line retreat from the thinning data, and the modelling does not include grounding-line retreat of this system. Consider removing.

Line 17, and elsewhere: The Early and Mid/Middle Holocene are now formalised subepochs, so should be capitalised.

Line 42, and elsewhere: Grounded ice in the Ross Sea is not a true self-contained ice sheet. Rather it is a sector of the Antarctic ice sheet, or a region comprising ice from the East and West Antarctic ice sheets. Consider rephrasing.

Line 62: Dramatic thinning is also now recorded at Mawson Glacier (Jones et al.,

Geology, 2020) and David Glacier (Stutz et al., TCD, in review).

Lines 68-69: Can you describe Darwin and Hatherton Glaciers in relation to the glaciers mentioned above?

Lines 99-104: It might also be worth mentioning the model buttressing studies of Furst et al. (2016) and Reese et al. (2018), which show that this region has a large buttressing effect on the ice sheet (albeit based on the current ice configuration).

Lines 156-163: Slightly confusing timeline of research. It would probably be better to present in publishing order (Storey et al., 2010, Joy et al., 2014, King et al., 2020).

Lines 167-169: This last point seems a bit lost. Consider making it a third goal.

Line 172 ("erratics"): Technically, if they are erratics then their lithology should differ to the local geology; how they are 'erratic' should be described here. It would also be worth providing a broad description of the erratic size - cobbles, boulders?

Line 172 ("Diamond Hill, as well as from Bibra, Dubris and Magnis Valleys"): It would be useful to state here how far each of these sites are from the modern grounding line.

Line 173: "freshest" should be made clearer. Rocks that appeared least weathered?

Lines 174-180: As previous studies in the area (e.g. Storey et al., 2010; Joy et al., 2014) have highlighted the importance of sampling strategy, particularly regarding reworking by cold-based ice, it would be useful to point out how your approach is similar/different.

Lines 193-195: It would be useful here to clarify what is detectable given uncertainties in erosion rates and measurements.

Lines 218-219: It would be useful to quantify the impact of the scaling scheme on the exposure ages - what percent difference between schemes (e.g. Stone (2000) and Lifton et al. (2014) nuclide-specific scheme)? Also, what production rate dataset is used? This should be described here.

Lines 250-255: It is not clear how the maximum thickness is determined to be from at least 14 kyr. No potentially older samples were collected from higher elevations, and there are no in situ 14C measurements from here to test for saturation.

Lines 275-278: If no new ages from Lake Wellman are presented in this study, then this needs to be stated clearly here, indicating that data from previous studies are used to assist interpretation of ice history in the area. You also need to explain in more detail why the higher elevation erratic ages at 20 kyr are "pre-exposed" and therefore ignored.

Line 394: The text in this section does not convincingly support the claim that ice was at its maximum at 9.5 kyr. There are no saturated in situ 14C samples from these sites, and there is limited justification of why older samples are ignored. Clarify and expand on this point in the above text, or revise this claim.

Line 396: You should probably include a study that directly dates grounding-line retreat in the Ross Embayment (e.g. McKay et al., 2016; Prothro et al., 2020).

Line 414: Jones et al. (2016) is not included in the references.

Lines 416-417: The model flowband/domain needs to be shown somewhere, perhaps in Figure 1c.

Lines 420-423: While this point is largely true, the flowband is a very simple model and so the limitations should be stated. What key stresses are not calculated? What aspects of the deglacial history can versus cannot be tested?

Lines 423-430: As far as I can see, this model does not account for lateral drag, which the conclusions indicate is potentially very important. How might this impact the flowband results?

Line 428: How many grid points? What is the horizontal resolution used?

Line 438: How is SMB scaled using the scaling factors for LGM scenarios?

Lines 452-453: To what extent does modification of the downstream boundary represent perturbations (e.g. reduce buttressing, grounding-line retreat) downstream of this point? As mentioned above, you should make clear what processes are and are not accounted for, and what can be tested.

Line 468, and elsewhere: What is meant by 'LGM' in the context of these sites? The proposed local ice maximum? The Antarctic or global glacial maximum?

Lines 597-599: This interpretation should be in Section 2.

Lines 646-648: Is this a new set of model simulations, and not output from previously published simulations? This would be a considerable effort and requires more description here. No need to describe all the of the model physics, but state that this can be found in a different paper. What ocean and atmosphere forcings are applied? What are the values of other parameters that were not examined? Some readers would expect to see these details, even if described in the Supplementary Material.

Lines 712-714: How might the model resolution impact this finding?

Line 722: McMurdo Sound deglaciated in the Mid Holocene, so "Early to Mid Holocene" is probably more correct.

Lines 728-279: I agree that more data are required from the lower reaches of Skelton Glacier. But, to be picky, the erratic age at 6 kyr is <20 km from the modern grounding line, which is not "far" considering the scale of these glaciers. Consider rephrasing.

Line 735: In what context is there no record of "an exceptionally fast period of thinning"? How is this quantified? Is this relative to modern observations or other thinning estimates from TAM?

Lines 748-749: As most thinning at Mackay Glacier to the north occurred at 7.5-6.5 kyr, McMurdo Sound became free of ground ice between 6.5 (not 7.5) and 9 kyr BP.

Line 755: Also the case with Mawson Glacier and David Glacier (see references

above).

Lines 773-777: The argument regarding glacial isostatic adjustment could be clearer. How greater isostatic depression at Minna Bluff could resolve the elevation differences between Darwin Glacier and Minna Bluff needs a little more explanation. Is this just considering the relative lowering of the LGM elevations at Minna Bluff, or also the impact on the age constraints? It is possible to estimate the relative elevation difference?

Lines 796-797: This was done for the Ross Embayment alone in Lowry et al. (2019, 2020), yet still some large differences in the timing of thinning between simulations and geological data.

Lines 805-809: While this is a useful discussion with the suggestion that the confluence of Byrd-Hatherton-Darwin Glaciers may explain gradual thinning at Darwin despite the topography at Discovery Deep, it is a bit of a push to hint that the results from this study support the hypothesis that Byrd Glacier is of fundamental importance to the stability of ice in the Ross Sea sector.

Line 818-819: As mentioned previously, the reported evidence does not convincingly indicate that ice could not have been thicker at the LGM. This conclusion may not be wrong, but it is currently not well-supported.

Figure 1: Label the Ross Sea, McMurdo Sounds and Mackay Glacier, which are mentioned in the text.

Figures 3, 5, 7: It would be worth stating that these points represent the mean ages with total uncertainty at 1 standard deviation. For clarity, perhaps use a different colour for the horizontal blue line; some readers may automatically associate this line with the Britannia I limit in the maps. It is difficult to understand how these ages relate to the samples and deposit limits in the maps. It would help if you showed the elevation of the Britannia I limit in these plots.

Figure 9: The 14C-saturated sample could probably be better represented in the figure.

Is it trying to say that the apparent age is from 11.5 kyr to infinity?

Figure 13: Can the figure be annotated to highlight the main interpretations from these results?

Supplemental Data Table: Units are not included for all columns, on all sheets. The scaling scheme and production rates used for the ages should be clearly stated.

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