Reviewer 1.

Review for Smith et al., “Holocene history of 79ºN ice shelf reconstructed from epishelf lake and uplifted glacimarine sediments.” In Discussion at The Cryosphere. Reviewed October 2022.

Smith and colleagues present a new multi-proxy data set on epishelf lake sediment cores and nearby outcrops and discuss implications for the past and future stability of the 79ºN ice shelf in Northeast Greenland. Where possible, they present new radiocarbon dates on marine foraminifera and molluscs that constrain the timing of sea water in the epishelf lake basin that is interpreted to reflect times of a retreated or absent 79ºN ice shelf.

I enjoyed reading this paper and was quite excited (and convinced) of their main finding—that the 79ºN ice shelf was retreated or gone for thousands of years in the Holocene--on their chronology, between 8.5 and 4.4 ka. Zooming out, it is fascinating that in the last few years we have learned that two other modern North Greenland ice shelves were gone for thousands of years in the Holocene, with the Petermann Ice Shelf gone from ~7.0 – 2.2 ka (Reilly et al., 2019) and the Ryder Ice Shelf from ~6.3 – 3.6 ka (O’Regan et al., 2021). Thus, it is likely that there were about 2 thousand years in the middle Holocene where there were no (or significantly retreated) major floating ice shelves in North Greenland! Whoa! This makes for an interesting natural laboratory, as it is well documented that Arctic atmospheric, oceanic, and sea ice forcing where quite different in the early and middle Holocene. Accordingly, I couldn’t agree more with the authors statement, “In this context there is an urgent requirement for numerical modeling, utilizing the timing of changes presented in this study together with information on ocean and atmospheric forcing, to investigate the response of NEGIS to retreat or loss of the ice shelf.”

The paper is well written and well-illustrated. The observations are novel and from particularly valuable and rare types of samples. I think this paper will be suitable for publication in The Cryosphere and I only have a few minor comments.

We thank the reviewer for their positive comments.

Could you discuss how changes in relative sea level might influence and/or complicate your signal? While it is likely difficult to constrain, the amount of sea water that can enter the lake is likely a function of both the ice shelf draft and the sill depth of the epishelf lake. Because the sill depth was deeper in the early Holocene, is it possible that it would have been easier for sea water to enter the epishelf lake basin at that time? Could this complicate your interpretation—why or why not? If the current halocline is 145 m and the core site is 90 m, would tens of meters of RSL be significant when discussing the early Holocene?

Our findings show that relative sea-level (RSL) at Blasø fell from the marine limit at ~ 33 m a.s.l around 8.5 - 7.6 cal. ka BP through the Early and Mid-Holocene (cf. Bennike and Weidick, 2001). Water depths in the basin during this time would have reduced due to uplift but the basin was clearly marine and connected to the sea throughout this period. From 4.4 cal. ka BP the basin returned to freshwater conditions as the 79N grounding line re-advanced and the ice shelf reformed. In many regions of Greenland this Neoglacial re-advance of ice is associated with crustal depression and a rise in relative sea-level (Long et al., 2009), but irrespective of this whether this occurred in the Blasø area, marine conditions were unable to penetrate the basin due to the ice shelf grounding along the northern edge of Blasø through the Late Holocene. In contrast, the rapid rise in sea-level following the LGM, probably played a key role in driving deglaciation of the adjacent continental shelf.

The timing of ice shelf retreat/absence discussed here is entirely dependent on radiocarbon dates on marine carbonates. Probably the largest uncertainty on these ages is the choice of reservoir correction, which you use 550 years (Delta R of 150 on Marine13), which has been used in other North Greenland studies. Can you discuss, perhaps in Section 3.5 and/or 4.3, how large of an uncertainty there could be on this choice of reservoir age? I imagine the epishelf lake receives a great deal of meltwater, and you mention elsewhere that you think there is likely an old carbon effect from the local geology. I don't think you need to change your chronology (you've made an assumption and supported it with previous work), but it would be worth acknowledging the uncertainty and how large you estimate that uncertainty could be (e.g., decades, centuries, millennia?).

We agree that the choice of marine reservoir (MRE) is important, which is why our approach followed previously published studies from the region so that our chronology is comparable with existing literature. As noted below, the choice of MRE/calibration curve (Marine13 vs. Marine20), results in minimal differences in the calibrated ages i.e., delta R = 150±50 (Marine13) or delta R = 0±0 (Marine20). In this example, the 'uncertainty' is 'decades'. In our opinion, as long as the method of calibration is clearly documented, and the 14C data is publicity available, then future work can re-calibrate our 14C should approaches change.

However, because several recent papers e.g., Hansen et al. (2022), Davies et al. (2022), Pados-Dibattista et al. (2022) have applied Marine20 to calibrate 14C ages from the NE Greenland Shelf we plan to re-calibrate all of our ages with Marine20 in our revision. We intend to follow Hansen et al. (2022) who applied a delta R of 0±0 years. This takes account of the increased reservoir ages in the Marine20 calibration curve, and results in near-identical calibrated ages (compared to Marine13).

Regarding meltwater influence, the reality is that all near-shore, glacier-proximal sites would have been influenced by glacial melt during deglaciation, and there is no easy way of assessing divergence between dated-remains that were influenced by significant input of freshwater and those in the deeper ocean which likely remained isolated from this. To do this we would require independent chronological control, either from terrestrial macro-fossils incorporated into the lake sediments, detection of well-dated tephra and/or application of other chronostratigraphic tools not influence by marine reservoirs i.e., relative paleointensity dating. Note that our future work intends to explore some of these dating methods.

In our revision – and as noted in the comments above and below – we intend to re-calibrate using Marine20 (delta R of 0±0).

We will briefly discuss this 'uncertainty' in section 3.5 and in doing so we will refer to O'Reagan et al. (2021) who also outlined some of these issues.

Line 94: The Bentley et al., in prep study sounds fascinating, but the water column data would be useful here in this study. Is there a possibility that those data could be presented here as well?

Apologies, our original plan was to submit both papers simultaneously so that reviewers would have oversight of all the relevant data. Bentley et al., is now under review for TCD so can be viewed here: https://tc.copernicus.org/preprints/tc-2022-206/.

Line 154-155: Or terrigenous source variations (i.e. siliciclastic vs carbonate rocks)? You discuss limestones in this region elsewhere?

Yes, that's right. We will amend this sentence.

Line 213-214: I have no problem with you using Marine 13. But to be fair, the Marine13 paper makes a similar caveat about the complexities of working in high latitude environments (Reimer et al., 2013)—the problem of unknown, large, and variable ΔR is not unique to Marine20.

We completely agree with the reviewer's comments – Marine20 was just more explicit in voicing the complexities associated with 14C calibration in high latitudes/polar environments. The polar community has long been aware that this also applied to Marine13. Unfortunately a reviewer of a separate (earlier) submission asked us to revert to Marine13 because of the explicit statement in the Heaton et al. (2020) paper ('it is not suitable for calibration in polar regions'), so we followed this recommendation for the current paper. The reality is that as long as everything is clearly documented, then the chronology in our paper will be forward (and backward) compliant as calibration curves and marine reservoirs develop and/or change.

However, as an illustration, if you follow the recent paper by Hansen et al. (2022), who advocated a delta R 0±0 years because this essentially replicates/is directly comparable to a delta R of 150±50 years/Marine13 (e.g., Larsen et al., 2018), then the resulting 14C ages are within the analytical error of the ages presented in our original submission (Marine13 = delta R 150±50). Similarly if you follow Heaton et al. (2020) and use the nearest radiocarbon data point in the Marine20 database (MapNo. 31 = delta R 3±60; Funder, 1982) then the calibrated ages are also very similar.

Sample ID_	^{14}C Age	error	Marine13 = dR 150±50 yr				Marine20 = dR 0±0 yr (Hansen et al., 2022)				Marine20 = dR 3±60 yr (MapNo. 31)			
depth (cm)			Min	Max	**Mean**	**kyr**	Min	Max	**Mean**	**kyr**	Min	Max	**Mean**	**kyr**
LC7-229 cm	4170	30	3868	4215	**4042**	**4.0**	3881	4230	**4056**	**4.1**	3821	4292	**4057**	**4.1**
LC7-378.5 cm	5670	30	5735	6061	**5898**	**5.9**	5690	6025	**5858**	**5.9**	5651	6090	**5871**	**5.9**
LC12-279 cm	4345	30	4096	4430	**4263**	**4.3**	4100	4447	**4274**	**4.3**	4053	4517	**4285**	**4.3**
LC12-371 cm	4970	25	4933	5281	**5107**	**5.1**	4908	5274	**5091**	**5.1**	4858	5293	**5076**	**5.1**
LC12-307 cm	5910	30	6006	6287	**6147**	**6.1**	5974	6280	**6127**	**6.1**	5919	6302	**6111**	**6.1**
LC12-337 cm	4895	40	4835	5218	**5027**	**5.0**	4823	5211	**5017**	**5.0**	4789	5260	**5025**	**5.0**
LC12-347 cm	5035	35	4972	5384	**5178**	**5.2**	4962	5329	**5146**	**5.1**	4911	5399	**5155**	**5.2**
LC12-297 cm	4465	25	4267	4609	**4438**	**4.4**	4274	4621	**4448**	**4.4**	4209	4696	**4453**	**4.5**
LC12-327 cm	4705	25	4569	4881	**4725**	**4.7**	4570	4896	**4733**	**4.7**	4514	4961	**4738**	**4.7**
LC12-357 cm	5025	25	4984	5313	**5149**	**5.1**	4974	5311	**5143**	**5.1**	4892	5362	**5127**	**5.1**
Blaso_DIV_Sh01	7168	38	7407	7618	**7513**	**7.5**	7321	7595	**7458**	**7.5**	7282	7634	**7458**	**7.5**
Blaso_DIV_Sh02	7117	35	7363	7574	**7469**	**7.5**	7283	7558	**7421**	**7.4**	7241	7584	**7413**	**7.4**
Blaso_DIV_Sh03	6958	36	7208	7441	**7325**	**7.3**	7137	7420	**7279**	**7.3**	7068	7452	**7260**	**7.3**
Blaso_DIV_Sh05	7019	35	7260	7493	**7377**	**7.4**	7181	7464	**7323**	**7.3**	7147	7505	**7326**	**7.3**
Blaso_DIV_Sh013	7012	35	7255	7486	**7371**	**7.4**	7174	7456	**7315**	**7.3**	7142	7502	**7322**	**7.3**
Blaso_DIV_Sh015	6845	37	7078	7376	**7227**	**7.2**	6988	7313	**7151**	**7.2**	6937	7351	**7144**	**7.1**
Blaso_Delta_SP2A	7420	50	7592	7889	**7741**	**7.7**	7548	7865	**7707**	**7.7**	7511	7904	**7708**	**7.7**
Blaso_Delta_SP2B	7345	40	7548	7805	**7677**	**7.7**	7481	7776	**7629**	**7.6**	7442	7814	**7628**	**7.6**
Blaso_Delta_SP2C	8205	35	8374	8663	**8519**	**8.5**	8362	8675	**8519**	**8.5**	8320	8758	**8539**	**8.5**
Blaso_Delta_SP1A	5858	36	5962	6262	**6112**	**6.1**	5917	6240	**6079**	**6.1**	5885	6273	**6079**	**6.1**
Blaso_Delta_SP1B	5794	37	5903	6191	**6047**	**6.0**	5858	6185	**6022**	**6.0**	5782	6214	**5998**	**6.0**
Blaso_Delta_SP1C	5900	38	5991	6285	**6138**	**6.1**	5953	6275	**6114**	**6.1**	5908	6298	**6103**	**6.1**

Note that we intend to re-calibrate our ages in the revision following Hansen et al. (2020) and will update our text accordingly. Our justification for doing this is that several other recent papers broadly follow this choice of delta R e.g., Pados-Dibattista et al., 2022 (delta R = 0±50 years); Davies et al. 2022 (delta R = 1 ± 32 years).

Line 414: or lake ice?

Thanks – this should be lake ice – we will update our text!

Line 488: LF7 to LC7

Thanks!

Figure 1: Indicate what the brown triangles represent in the caption. (grounding zone?)

We will add this information to the caption (and yes, triangles indicate position of grounding line).

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Reviewer 2.

Holocene history of 79°N ice shelf reconstructed from epishelf lake and uplifted glacimarine sediments

General comments: This manuscript reconstructs the Holocene history of 79°N Glacier and its ice shelf. This is one of the only remaining ice shelves of the Greenland Ice Sheet and it is an important glacier system that drains a large proportion of the ice sheet. I found the paper interesting and enjoyable to read. The conclusions are well supported by data and the analysis of the future behavior of the 79°N ice shelf is well reasoned. The combined lacustrine and raised marine sediment approach provides the greatest scope in time for reconstruction of the ice shelf, and the multiproxy analyses from Blasø showing marine and lacustrine sediments provides multiple lines of evidence for the presence/absence of the ice shelf. Note that I do not feel qualified to comment on the biomarker data and interpretation.

We thank the reviewer for their positive comments.

My comments are all small corrections and/or recommendations to make the manuscript clearer and easier to read.

Specific comments:
Make it clear when you are referring to 79°N ice shelf or 79° Glacier…or both. It can be confusing especially because when you use the term 'reformation' you probably mean

reformatioon of the ice shelf. An example is L258 where I think you are referring to the ice shelf….it would be clearer if you added ice shelf after 79°N.

We will review our text add this information throughout.

Also Line 466 and 467 at start of discussion, do you note intervals of increased IRD during times when the 79° ice shelf is absent? During the 8.5 to 4.4 cal ka BP interval (Fig. 11b) when the 79°N ice shelf was absent, did the 79°N Glacier calve significant ice bergs and leave a record of increased IRD?

There is no clear IRD signal in Blasø, although a minor increase in coarse-silt is observed during ice shelf absence (LF1, LC12). Lack of coarse-material, probably relates to the bathymetry of Blasø – and specifically ridges at both sides of the central basin which act to block large bergs reaching the core sites. We will add a sentence stating this when reporting the grain-size data.

L126 or thereabouts - Include description of coring platform…it was a raft according to line 220.

We will add 'Coring was undertaken from an UWITEC raft, fitted with a 15 horse power Yamaha outboard' to line 126.

In the study area and approach section include some background on bedrock geology so that the reader knows what was the goal and rationale of XRD. Wat did you expect to discover with XRD. You include a lot of this information in the sections on interpretation of Blasø lithofacies in cores, but it would be useful to have it given in the study area section.

We will add the following to 'Study area and approach':
Blasø is located within the East Greenland Caledonides, a series of W-directed thrust sheets displaced against the rocks of the Palaeo- to Mesoproterozoic foreland (Higgins and Kalsbeek, 2004). The crystalline basement, consisting of strongly deformed Archaean and Palaeoproterozoic granitoid rocks, is overlain by Mesoproterozoic-Neoproterozoic and lower Palaeozoic strata. To the east of Blasø, outcrops of quartzite/sandstones (Hovgaard Ø Formation), dolerites and flood basalts (Midsommersøte Dolerite Formation) are exposed. Moving westwards these are overlain by the Neoproterozoic Rivieradal Group consisting of conglomerate, sandstone turbidite and mudstone units (Smith et al., 2004). In turn, these are overlain by the limestones, mudstones and dolomites of the Odins Fjord, Turesø and Børglum River formations further west (Smith et al., 2004).

We will also add to section 3.2, line 165:
Illite/chlorite are detrital clay minerals which are typically derived from physical weathering of crystalline/basement rocks i.e., granitoids and low-grade, chlorite-bearing metamorphic and basic rocks i.e., dolerites, respectively. Smectite normally reflects volcanic sources i.e., basalts and volcanic glass, whilst kaolinite is a product of chemical weathering, characteristic of moist, temperate to tropical regions. Kaolinite generally indicates the presence of older sedimentary strata i.e., mudstones/shales.

3.3 Foraminiferal analysis (~L175). Did you use unbuffered distilled water?

Yes, we will add this information to the methods.

I noticed that you looked for foraminifera in other intervals than the 8 and 6 samples that you present in Figures 4 and 5. In fact in Section 3.3 you say you analysed 16 samples in LC12. You mention finding a few specimens in some samples. If you found samples to be barren or having too few forams to calculate percentages, it is still very useful to put the number per gram on the concentration column of those figures. It looks like you only looked at the samples within LF1, but I gather that you did more intervals than that, which makes sense as it would aid in determining the marine/lacustrine boundary. Please show all of your data (samples with #/g) and if you did not quantify just say that you saw a trace or very few…so we can see that on figures 4 and 5.

That's correct – we did look at samples in LF2 and LF3 but with the exception of trace (<20) forams in the surface sediments, they were barren. As recommended, we will capture this information in figures 4 and 5 (b=barren, t=trace). In addition, the raw data is available here:

https://doi.org/10.5285/3d37a409-c1e2-4c25-bdbc-fe495ccff653

Also note that the concentration data in figure 5 was incomplete (I used an out-dated spreadsheet when plotting this data). For clarification, we analysed 14 (LC12) and 6 (LC7) samples so will amend the text.

Also on Figure 5 (LC12) there is a barren zone that coincides with the silt peak (that also has the out of stratigraphic order 14C age) but the text, line 232 says the whole interval contains forams. Maybe you should describe the silt layer and its low faunal content within this section to support your later determination of reworking.

That was an error on our part – we will amend the text to read, 'Benthic foraminifera are present throughout LF1 (370.5-282 cm) with the exception of one horizon at 314 cm, which was entirely barren. The assemblage is dominated by…'

Figures: overall the figures are quite well drafted. However, the labels on the maps are sometimes hard to read as even in the online versions the labels fade into the background colors. This is true on Figures 1, 2, 4 and 5. Make the labels as large as possible and consider using white labels or a white background.
Figure 12 has a problem in the top panel. The aspects were squeezed so that this part cannot be read.

Yes, we can make these changes.

Suggested technical corrections:
L56 change exit to exist. OK
L153. Presumably not austral summer? Maybe just use the dates of fieldwork in 2017. We will add the dates.
L119. Configuration not configurations. Thanks
L123. Suggest you add the glacially fed rivers that enter Blasø to the map (Fig. 1 or 2). We will add location of glacially fed rivers to Fig. 2.
L147. Has to had. suggest…had been digested samples were centrifuged…OK, we will amend this sentence.
L148. Provide the concentration of sodiume hexametaphosphate…and change defloculate to disaggregate. OK (conc. was 35%).

L151. Provide. OK
L152. Change is to are. OK
L155. Delete 'an'. OK
L195. Do you really mean bacteria, phytoplankton and grasses? I was not sure about grasses. This was an error on our part, we will delete 'grasses'!
L233. *Elphidium clavatum* is the accepted name now for E. excavatum clavata…see Darling et al., 2016. *Marine Micropalaeontology* 129:1–23. doi:10.1016/j.marmicro.2016.09.001. The name is misspelled on Figures 4 and 5. Suggest you do a search and replace throughout the text. Thank you, we will do this.
L234. Suggest you add in the parentheses about *S. horvathi* (variable but up to 15% below 300 cm). We will do this.
L242. Suggest you say 'Most of LF1 (377-248 cm) is dominated by….OK.
L245. You might want to add to this statement that the top sample has the greatest # forams per gram…is that because the S. horvathi increased? Yes that is correct, we will add this information.
L251. Define TAR. OK (this is the "terrestrial to aquatic ratio").
L254, L311, 369. Suggest you add descriptors to your heading. *L1 Paleoenvironmental Interpretation*, or something like that. We will do this.
L273. Peaks in the. Thanks
L274. Suggest delete 'an'. OK
L313. Did the ice shelf reform? Or did it advance or expand? If this time period represents Fig. 11b to c, then the ice shelf reforming is what is shown. I am just curious how clear it is that the ice shelf had completely disintegrated. For Blasø to become a marine embayment the ice shelf must have disintegrated completely. This is also confirmed by recovery of whale and seal bones around Blasø and along the margin of Nioghalvfjerdsfjorden (see Bennike and Weidick, 2001). We discuss how the ice shelf might have reformed in section 5.2.
L343. Very rare >2 mm clasts? See earlier comment relating to lines 466-467.
L431. Silty sand and fine gravels or silty sand and fine gravel. The latter – we will change the text!
L439. Suggest start new sentence after (Hendy et al., 2000). OK.
L448. Anomalously? Yes, thanks.
L449. Do you think limestone in the catchment will affect bulk organic matter dates? Yes – we will add a sentence along these lines in section 4.3, line ~447-448.
L480. Figure 11b indicates 33 and 22 m asl rather than 33 and 15 m asl. Thanks! We will revise – it should be 15 masl in Figure 11.
L492. The foraminiferal fauna. OK.
L504. On figure 12 this looks like 10,800 to 8000 years. I spent a while looking at Figure 12 to check the timing. The age intervals are every 400 years which is fairly awkward. If it is not too difficult I suggest making the age intervals work easily for a 2000 year interval…every 500 years? Yes, we will do this.
L505. Core also (OK!); Atlantic Water advection to where? Into the fjord, toward the ice shelf cavity? Grounding line? Actually, we need reword to 'AW persisted in Fram Strait between 10.6 and 8.5 cal. ka BP'.
L546. Refer to Figure 12. OK.
L572. Suggest change switch back to 'return'. We will.
L576. Span. OK
L577. Indicate. OK
L527. The glacier is still there but the ice shelf disintegrated? Clarify. Yes, that's correct, although we assume the glacier retreated inboard of its present position to allow marine water incursions at the western mouth of the lake. We will clarify this in the text.

L628. The Spalte Glacier is confusing. It looks more like a continuation of 79°N ice shelf. I cannot see well enough on the map Figure 1, but in Figure 12 drawings it looks like the ice shelf enters that area. Can you clarify this? The Spalte Glacier was a large floating glacier, and a northern offshoot of the 79N ice shelf. The distinction between the floating part of the 79N and Spalte Glacier is arbitrary, and related to different catchments. However, your point highlights a potential ambiguity, which will clarify in the text. Figure 12f depicts 'recent changes' i.e., the past ~100 years. We will explicitly state this in the revised MS.

Figures:
4 and 5. foram concentration column. Add all values and title needs to say number per cc. OK.

5. make a notation of which age is reversed in core LC12. Asterisk? OK.

Figure 9. include the key for the fossils. Use larger fonts where possible. OK.

Figure 11. add dashed line is grounding line of 79°N Glacier. The yellow star is very very small. OK, we will make this bigger.

Are the hatched white polygons sea ice? Yes, we will add this to the caption

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