<u>Response to reviewer 2: 'Seasonal evolution of the supraglacial drainage network at Humboldt Glacier, North Greenland, between 2016 and 2020'. Rawlins *et al.* (2023)</u>

We would like to thank the reviewer for their positive and insightful comments on our manuscript, which will lead to improvements. Our responses for each of the comments raised and how we addressed them are given below. Reviewer comments are italicised in blue with our responses in black. Please also find attached a revised manuscript with tracked changes. When referring to page numbers in the below text, these will be with page numbers associated with the revised (tracked change) manuscript.

This paper was a pleasure to read as it is written so well. I only have some minor comments (below), followed by minor specific line by line comments.

We thank the reviewer for their positive overall comments and for their constructive points below which have been addressed accordingly.

The incorporation of slush mapping is very interesting and novel, as I am not aware of prior studies that have mapped slush in detail Greenland(?), though this has been done by at least one study on Antarctic ice shelves (e.g. Dell et al 2022). So it would be great to see more details regarding how exactly slush was mapped in this study. Additionally, I think slush (e.g. as a component of total meltwater area fraction (MF)), could feature more heavily as a discussion point in the Results/Discussion.

Thank you for your comment on slush zones. Slush is defined as water-saturated snow when temperatures permit melting (above 0°C) which form a large expanse of surface ponded meltwater that can become mobile as slush flows or within rill-type channels. Slush zones are of great hydrologic importance for the initial mobilisation of surface meltwater at the beginning of the melt season and its migration upglacier to act as headwaters feeding the drainage network below as the melt season progresses, hence why they were retained within the mapped hydrologic network and not treated independently. Slush is identifiable in true colour satellite imagery as a dense, light blue zone representative of this shallow, water-saturated snow layer: distinguishable from the surrounding colour of snow (white), darker bare ice (grey) and other supraglacial rivers and lakes (turquoise blue: Holmes, 1955). An example of this slush zone is now provided as an extra panel in Fig. 2 (g). Additionally, in contrast to true colour images, in NDWI images, slush zones are more difficult to independently extract due to their similar spectral and linear shape signatures with other drainage components (i.e., rivers). This clarification is now added to the Methodology, lines 245 – 253.

I do not know Humboldt Glacier well, so I wondering how much of this marine terminating glacier is floating? Unless I missed it, the only mention of floating ice is on line 208, where a '7 km floating section' is mentioned. Depending on the area of this floating area of ice, I'd also be particularly interested to know whether the authors see a difference between lake/other meltwater feature characteristics on the floating versus grounded portions of the glacier? (For example, comparisons of meltwater features on floating vs. grounded ice have previously been made on Peterman Glacier

(Macdonald et al 218) and well as Paakitsoq (SW Greenland) vs. Larsen B Ice shelf, Antarctica (Banwell et al 2014).

A previous study by Carr et al. (2015) stated that within 25 km of the northern sectors calving front, HG is heavily crevassed (including water-filled), with the lower 6.5 km near floatation, producing large tabular icebergs. In this study, we avoid this area due to the potential for erroneous delineation of crevasses instead of rivers in the lower reaches of Humboldt Glacier (in particular the northern sector), due to their similar spectral characteristics. Therefore, the lower crevassed portion of Humboldt Glacier was removed using a manually-created crevasse mask to avoid impacts (i.e., overestimation) of calculated metrics of MF in these lower elevations. We are therefore unfortunately unable to provide further conjecture on floating vs grounded portion of HG, however appreciate the wider context this may have brought and an important consideration for future work. The use of the crevasse mask and why is stated in Section 3.2 (lines 226 - 233).

I am wondering why the authors choose to base the NDWI on the Green and NIR bands rather than the blue and red bands, e.g. as used by Bell et al (2017) and Williamson et al (2018). I am sure there were/are good reasons, but perhaps a sentence or two about this could be added to the paper. Also related to the use of the NDWI, I am wondering how/why the authors decided to use a threshold of 0.4, i.e. which they call a 'high-value global NDWI threshold'? Again, I am not suggesting this threshold is not appropriate, but perhaps some more detail and/or reference(s) be added about this choice of value?

The use of the NDWI (McFeeters, 1996) was used rather than $NDWI_{ice}$ due to the preferential inclusion of additional shallow meltwater characteristics, including slush zones, which $NDWI_{ice}$ was originally developed to reduce in order to produce fewer false classifications of water over blue ice and slush areas (see Yang and Smith, 2013). Also, a preliminary performance accuracy test in a sample area which examined their differences found NDWI (McFeeters, 1996) performed more regularly connected river channels than $NDWI_{ice}$ by 16.8%. We have now included a sentence about this in lines 221 – 226 (revised manuscript) and have included an additional figure in the Supplementary information (Fig S1) to show this.

In regards to the NDWI threshold of 0.4, this was chosen as best captured the boundaries of SGLs and wide supraglacial river segments. This threshold was also based on other literature (Lu et al., 2021) which has now been included as a citation here.

My final general comment is that I think the authors should add a short paragraph about uncertainty quantification, particularly regarding their MF analysis.

We have now included a new figure (Fig. 3 in the revised manuscript) of a small area of HG comparing both rivers derived from the automatic river detection algorithm and those which are manually digitised to assess performance accuracy. The results from this assessment show similarities between the overall spatial pattern mapped between both automated and manually digitised networks, however small gaps are present within the automated rivers, which quantify as 5.4% shorter than the manually digitised. This new section of writing and figure can be found in Methodology, Section 3.2, lines 258 – 262 (in the revised manuscript).

Abstract lines 16 and 17: Not necessary to state areas to 1 d.p. Round up as is done for other area/elevation values in the abstract.

Amended.

Abstract line 19: I suggest adding an few extra words to explain what you mean by 'preconditioning' here.

Extra words have been added to the abstract.

56 – 57: Two relevant studies focusing on the surface hydrology of Petermann Glacier in NW Greenland could also be referenced here: Macdonald et al (2018) and Boghosian et al (2021).

Additional references added.

133: Gledhill and Williamson just have a 201~~7~~8 paper, but Williamson et al. have a 2018 paper (both are already in the reference list).

This has now been altered. Confusion in the original manuscript was between Gledhill and Williamson (2018) and Williamson et al. (2017; 2018). Thank you for raising this.

241 – 247: I find this paragraph confusing regarding the maximum extent of meltwater mapped, versus the maximum extent of the study region. For example, the first sentence says that rivers and lakes were mapped up to a "maximum melt extent of 1500 m a.s.l.". Is 1500 m the highest elevation of the study area analyzed, or is this the maximum elevation of observed melt? I assume the latter(?), but if so, then the following sentence is repetitive (i.e. this states "The mapped supraglacial drainage network across HG is shown extend up to 1500 m a.s.l,"). Also, later in the paragraph (line 246), it says rivers and lakes from up to a "maximum of 1440 m" (as opposed to 1500 m). So these sentences need to be re-written for clarity.

Maximum extent of meltwater mapped has now been clarified (lines 277 – 280 in the revised manuscript). Thank you.

253 - 255: For the sentence "In Figure 3b, we also see some evidence of a potential main-river reconfigurations, with the north-westward advection of a river channel that runs transverse to ice flow"; maybe this river in Fig 3b could be labelled? As I see various rivers/streams that are transverse to ice flow. Also, it looks to me as though similar examples may also be seen in panels c and e?

We have now identified the potential reconfigurations in Fig. 3b (now Fig. 4b in the revised manuscript), as well as panel e where this is also visible by red arrows.

310 – 314: Can the authors suggest a possible explanation for why these two parallel lines that track across glacier exist? Could they be fractures?

We believe these two parallel lines are depressions within the ice surface with potential fractures (i.e., moulins) associated with them due to the abrupt termination of main river channels here. We have included additional clarification about this in lines 338 - 341.

497 - 499: For the sentence:"… this study also notes that many well-established rivers that are longitudinal to ice flow, including many with canyonised features, also reoccupy locations.", studies focused on Petermann Glacier could also be mentioned here, which found similar findings I believe (Macdonald et al. 2018, Boghosian et al. 2021).

Studies have now been included within the citation (and reference list).

622/623: Mention Summer 2019 somewhere in this sentence to remind the reader which melt season is being described.

Summer 2019 added.

Fig 2: it would be interesting to know the locations of these figure panels, so perhaps an extra panel could be added to show this (e.g. as is done in Fig 3a), or perhaps the locations should be shown somewhere in Fig 1? Also, the 'off edge river termination' feature in panel 2c) is interesting, and I'm wondering how comparable this feature could be to the large river/waterfall described in Bell et al (2017)?

Thank you for this recommendation. We have now included an extra panel in this figure (Fig. 2 in the revised manuscript) of the locations for subsequent images for reference purposes. An extra panel (Fig. 2g) has also been added as an example of a slush zone on HG.

References (those in bold are not referenced in the current paper)

Banwell, A.F., Cabellero, M., Arnold, N., Glasser, N., Cathles, L.M., MacAyeal, D. 2014. Supraglacial lakes on the Larsen B Ice Shelf, Antarctica, and Paakitsoq Region, Greenland: a comparative study. Annals of Glaciology. 55(66), doi:10.3189/2014AoG66A049.

Bell, R. E., Chu, W., Kingslake, J., Das, I., Tedesco, M., Tinto, K. J., Zappa, C. J., Frezzotti, M., Boghosian, A., and Lee, W. S.: Antarctic ice shelf potentially stabilized by export of meltwater in surface river, Nature, 544, 344–348, 2017.

Boghosian, A.L., Pitcher, L.H., Smith, L.C. et al. Development of ice-shelf estuaries promotes fractures and calving. Nature Geoscience, 14, 899–905 (2021). https://doi.org/10.1038/s41561-021-00837-7

Dell, R., Banwell. A.F., Willis, I., Arnold, N., Halberstadt, A.R.W., Chudley, T.R., Pritchard, H. 2022, Supervised classification of slush and ponded water on Antarctic ice shelves using Landsat 8 imagery, Journal of Glaciology, 1–14. https://doi.org/10.1017/ jog.2021.114.

Gledhill, L. A. and Williamson, A. G.: Inland advance of supraglacial lakes in north-west Greenland under recent climatic warming, Annals of Glaciology, 59, 66-82, https://doi.org/10.1017/aog.2017.31, 2018.

Macdonald, G.J., Banwell, A.F., MacAyeal, D.R. 2018, Seasonal evolution of supraglacial lakes on a floating ice tongue, Petermann Glacier, Greenland. Annals of Glaciology, doi:10.1017/aog.2018.9

Williamson, A. G., Banwell, A. F., Willis, I. C., and Arnold, N. S.: Dual-satellite (Sentinel-2 and Landsat 8) remote sensing of supraglacial lakes in Greenland, The Cryosphere, 12, 3045-3065, https://doi.org/10.5194/tc-12-3045-2018, 2018.

These references have now been included as citations (where appropriate) and the reference list. Thank you.