We thank the two reviewers for their constructive and thorough reviews that have helped us to strengthen our work. We address all reviewer comments in detail below.

Please find the reviewer comments in black and our responses in blue.

Reviewer Comment 2 (RC2)

Review of Larocca et al. 'Arctic glacier snowline altitudes rise 150 meters over the last four decades', The Cryosphere Discussions.

This paper uses satellite observations of Arctic glacier end of summer snowlines as a proxy for equilibrium line altitudes. Snowlines were mapped for 269 land-terminating glaciers from Landsat optical images between 1984 and 2022. Snow line altitudes were extracted from ASTER GDEM elevation information and then compared with field-based ELA measurements and ERA-5 reanalysis climate information. The authors relate their changes to summer warming, decreases in snowfall, and increases in rainfall. I liked the paper and think it will make a valuable contribution to the literature. The paper is substantive and rigorous, and both the quality of writing and figures is excellent. I had just a few questions and suggestions as I went through the manuscript and will list them here for inclusion by the authors into a revised manuscript.

Thank you. We thank anonymous reviewer 2 for their valuable feedback and insightful comments and questions that have helped us to improve our manuscript. We address all questions and suggestions below.

- 37, worth differentiating here how many of these 42 are in the Arctic (not many).

Thank you, this is a good point that will help to highlight the dearth of long-term observational evidence specifically for Arctic glaciers. The WGMS report did not note the locations of the 42 glaciers (updated annually) with >30 years of continuous records, so instead we have rewritten the sentence to make the same point about the ~60 WGMS 'reference glaciers' (~26 of which are located in Arctic regions):

"Although glaciological mass–balance observations from ~490 glaciers have been collected and are available at the World Glacier Monitoring Service (WGMS), only ~60 glaciers worldwide are considered 'reference glaciers', having continuous records spanning more than 30 years (less than half of which are in Arctic regions; WGMS, 2021).

- 40, there's another data source that is relevant but not mentioned here - longer term (multi decadal) records of glacier area (and sometimes) volume change from archival aerial stereophotogrammetry. Find and cite some of these studies.

We have added the following sentence to refer to these other data sources:

"Although the satellite era has opened expansive new opportunities for glacier monitoring from space, records that integrate historical data that precede the twenty–first century and that span multiple decades, are still lacking (e.g., Bauder et al., 2007; Papasodoro et al., 2015; Geyman et al., 2022)."

- 54-55, this sentence would be better placed in the previous paragraph.

We agree and have moved this sentence to the first paragraph.

- 62, can you specify what is meant by 'glacier morpho-topographic variables' here, as it's a bit of an unwieldy term. I don't really know what it means but it seems important for it to be known at this crucial part of the manuscript. Probably worth a mention of the representivity of using land-terminating glaciers only too, given that the larger mass losses tend to be a tidewater terminating glaciers.

Yes, thank you for pointing this out. We define as follows:

... "glacier morpho–topographic variables (i.e., characteristics that describe physical state and geographic setting)."

We chose to focus on land-terminating glaciers because they more directly respond to atmospheric climate variability (as compared to glaciers in marine settings). To make that more clear we have added that explanation to the sentence that describes our criteria for glacier selection:

"All measured glaciers fit within the following criteria: the glacier (1) terminates on land (and thus responds directly to atmospheric climate variability); (2) is in the Arctic (which we define as land area above 60 °N latitude); and (3) is not surging (or has no record of surging behavior)."

- Figure 1, I find the very light green shading difficult to see, can this be made a darker, more distinct colour? Likewise, the difference between a small black dot and a small pink dot with a thick black edge is also not distinct. What about solid black vs solid blue?

Thank you for pointing this out. We have revised Figure 1 as follows: (1) We have made the green glacierized regions darker; (2) We have made the glacier symbols more distinct using solid black and solid blue as suggested. We denote the study glaciers using large blue circles and denote the glaciers with long-term ELA observations using large black triangles. We also add the RGI region extents and numbers as requested in RC1. Please see revised figure and caption below.

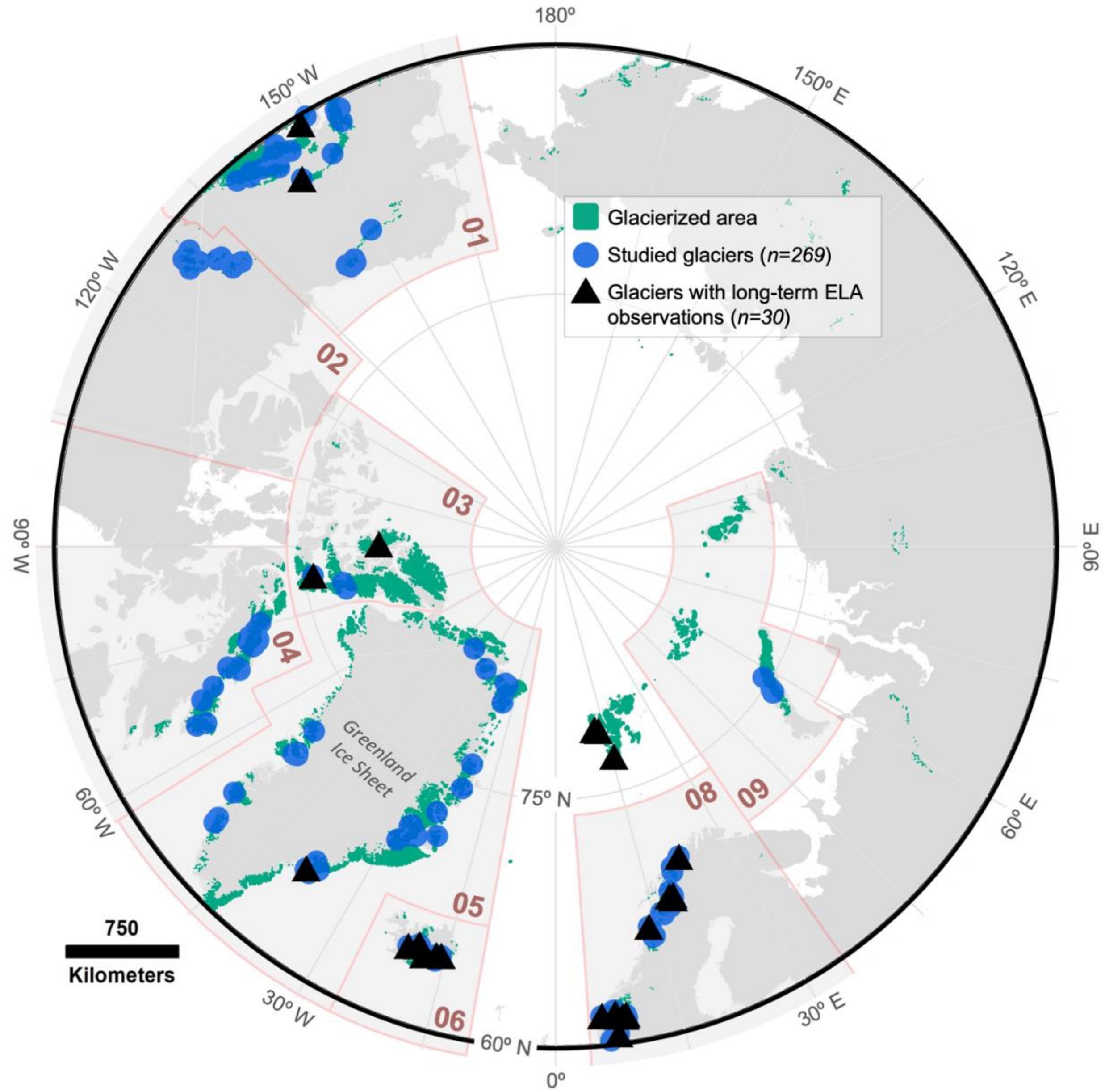

Figure 1. Map of the Arctic and glacier locations. Glacierized area distinct from the Greenland Ice Sheet is shown in green; the locations of the 269 land–terminating glaciers included in this study for which snowlines were digitized and analyzed are denoted by blue circles; and the locations of the 30 glaciers with long–term annual observations of equilibrium–line altitude (ELA) are denoted by black triangles. The latitude 60°N is denoted by the thick black line and first–order Randolph Glacier Inventory (RGI) region extents are defined by the shaded gray polygons with pink edges. The RGI regions are numbered as follows: 01 Alaska; 02 Western Canada and US; 03 Arctic Canada North; 04 Arctic Canada South; 05 Greenland Periphery; 06 Iceland; 08 Scandinavia; and 09 Russian Arctic. Glacierized area and first–order regions are from the RGI Version 6 (Pfeffer et al., 2014; RGI Consortium, 2017).

- Section 2.1, presumably an elevational range is important. Can you summarise the range of elevations over which these 269 glaciers lie (maybe ELA elevation). I would think you need a range of low, medium and higher elevation sites. If you do not have this, please justify why not.

Yes, elevation range is important, and we look closely at glacier morpho-topographic variables (including minimum, median, and maximum elevation; Fig. S2 summarizes glacier elevation ranges). Although, in general, our selected glaciers are higher in elevation than the Arctic-wide average, we do have a range of glaciers spanning lower, mid, and higher elevations. We find that SLAs on lower elevation glaciers are rising roughly twice as fast as those on higher elevation glaciers (Section 3.6).

- 97, sorry, I'm a bit unclear about this - you used a digitisation tool, yet digitised all SLs manually? Specify clearly what the tool was for, and what the tool did not do.

No worries. Yes, the tool allowed us to digitize glacier snowlines directly in Google Earth Engine (i.e., provides on-the-fly access without the need for downloading of large images files). We attempt to make this clearer in the tool's description:

"To digitize the position of the glacier SL, we used the Google Earth Engine Digitisation Tool (GEEDiT), which allows for rapid on–the–fly access to, and visualization of the full Landsat Tier 1 imagery collection, as well as rapid mapping of georeferenced vectors that can be exported with image metadata (Lea et al., 2018)."

- 98, as ever with these remote sensing-based estimates of snow line / ELA, how do you account for the presence and influence of the superimposed ice zone? [note, I see that this is addresses in section 4.1]. And then further, why do you not differentiate between the snow line and the firn line which you may be able to distinguish in optical imagery in some years.

Unfortunately, we cannot account for the presence of the superimposed ice zone, however our comparison with field-based ELA observations suggests that this does not present a major issue for our remotely-sensed SLA observations (i.e., we would expect the remotely–observed SLAs to be systematically higher than the field–measured ELAs if superimposed ice zones were consistently missed in the optical imagery).

Regarding the distinction between the snowline and firnline, please see our response to RC1 (general comment 1).

- 103-104, why do you include glaciers whose maximum altitude is higher than the snowline? With your sample size, I'm sure it would be straightforward to exclude all those glaciers with such low maximum elevations and include only those that allow the snowline to be measured every year. Inclusion of these glaciers is likely to bias your results in some way, so as an absolute minimum you need to account for this and discuss it.

Thank you for this question. Please see our response to RC1 (general comment 2).

- 109, will mean snowline elevations be affected by factors such as changing glacier hypsometry (as the snowline changes) and avalanching onto the glacier surface? These may be relevant at local scales. If you can quantify, do, otherwise mention as a potential source of uncertainty.

Thank you for this comment. Local scale processes (microclimates, shading effects, avalanching, wind, and redistribution of snow, etc.) can have strong effects on glacier snowline (L 171-175). We try to account for these local factors on SLA by including comparison to several variables that describe glacier morphology (Section 2.3).

Glacier hypsometry should only have indirect effects on snowline (through the variables mentioned above). For example, a steeply sloped glacier with most of its area concentrated at high elevations might be more affected by avalanching. However, the distribution of the glacier surface area with altitude does affect how changes in SLA translate into changes in glacier mass balance.

Below we show that the relationship between the rate of SLA rise and glacier hypsometry is not significant. We quantified the hypsometric character of each glacier, using a hypsometric index (HI) as defined in Jiskoot et al. (2009):

$HI = (H_{max} – H_{med}) / (H_{med} – H_{min})$, and if $0 < HI < 1$, then $HI = –1/HI$,

where H_{max} and H_{min} are the maximum and minimum glacier elevation, and H_{med} is the median elevation. We also then grouped the glaciers into five HI index categories defined by Jiskoot et al., (2009), where: $H < –1.5$ is very top heavy; $–1.5 < H < –1.2$ is top heavy; $–1.2 < H < 1.2$ is equidimensional; $1.2 < H < 1.5$ is bottom heavy; and $H > 1.5$ is very bottom heavy (Jiskoot et al., 2009).

We found that the relation between glacier SLA change and the HI index on an individual level is not significant. An ANOVA revealed statistically significant differences between the five HI categories in terms of mean rate of SLA change ($F(4, 263)=3.46$, $P=0.009$). However, post-hoc comparisons using Tukey's HSD test showed that none of the differences between categories were significant ($P \geq 0.05$).

Reference: Jiskoot, H., Curran, C.J., Tessler, D.L. and Shenton, L.R.: Changes in Clemenceau Icefield and Chaba Group glaciers, Canada, related to hypsometry, tributary detachment, length–slope and area–aspect relations. *Annals of Glaciology*, *50*(53), pp.133-143, 2009.

- Table 1, spectral range of bands (if different)?

We used optical imagery only (RGB).

- Figure 3, why no glaciers in Svalbard which surely is the most well studied of these regions? But Svalbard is in the Figure 4 plot?

We did not place the same constraints as far as temporal coverage on the glaciers with long-term ELA measurements. In other words, none of the glaciers in Svalbard met our requirements for temporal coverage for inclusion in the subset of 269 glaciers in which we carried out the larger analyses with climate, etc. Our requirements are 5 or more total SL observations over the observational period; at least 1 observation in each third of the observational period; and a maximum gap of 15 years between SL observations).

- 128, Cite the RGI paper as well as the dataset (Pfeffer et al., 2014, doi: 10.3189/2014JoG13J176.

Thank you. We have added this citation to the reference list and cite it throughout the paper along with the RGI dataset reference.

- 183, *n*=?

n=278. We have added the number of SLA-ELA observations as follows:

*“We find a robust relationship between the remotely–observed SLAs and the field–measured ELAs for the 30 glaciers (n=278) with long–term, quality observations (**Fig. 4a**; R^2=0.92, p<0.001).”*

- 307, more could be said about the correlations between SLA and spring rainfall. I would expect spring rain to result in less snow due to melting from latent heat release and then enhanced rates of compaction and will likely lead to an earlier snow melt and then higher ELA.

Thank you, this is a great suggestion. We have added more discussion on spring rainfall. Please see our response to RC1 (comments on P15_L304-309 and P22_L448-450).

- 378, It would worth attempting to quantify the error in the rate of SLA rise due to glacier thinning and include it here and in the main summary of results. Also, 'deflating' here and elsewhere is an odd word choice. Suggest 'thinning', or 'lowering'.

We now include the maximum error (~1 m per year) due to glacier thinning in the Abstract and Summary. We also change the term “deflating” to “thinning” or “lowering” throughout.

- Dowdeswell ref in main text not in the ref list, and Jiskoot ref in list not in the main text

Thank you. We added Dowdeswell and removed Jiskoot from the main manuscript reference list.

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