RC1: 'Comment on egusphere-2025-1893', Jason Box, 29 Jul 2025

Summary

The submitted article is very well written, is comprehensive in its treatment and has clear graphics. The synoptic compositing is effective in advancing process understanding. What would help advance process understanding would be the study present what role variable meltwater retention played in the extreme days and seasons, provided that the retention model has a realistic response to melt intensity and snowfall from the previous year, the latter factor (snowpack) to represent snow retention capacity.

Thank you very much for carefully reading our manuscript and providing helpful comments. Here, we address the reviewer comments and explain how we revise the manuscript. Reviewer comments are in black and our replies are in red. The line numbers in our replies are as in the original manuscript.

****high level critique** in no particular order of importance...**

Consider to analyze the rainfall for the 2015 and 2016 events from CARRA data?

We thank the reviewer for this suggestion, which helped us to resolve detailed precipitation pattern along the coast of Greenland. Composite analysis on the rain-induced peak runoff days revealed intensive precipitation in the northwestern part of the ice sheet with a fine spatial resolution of 2.5 km (Figure R1). It is clear that the CARRA data improves understanding of the precipitation events, thus we will include the composite map to Figure 7 in the revised manuscript.

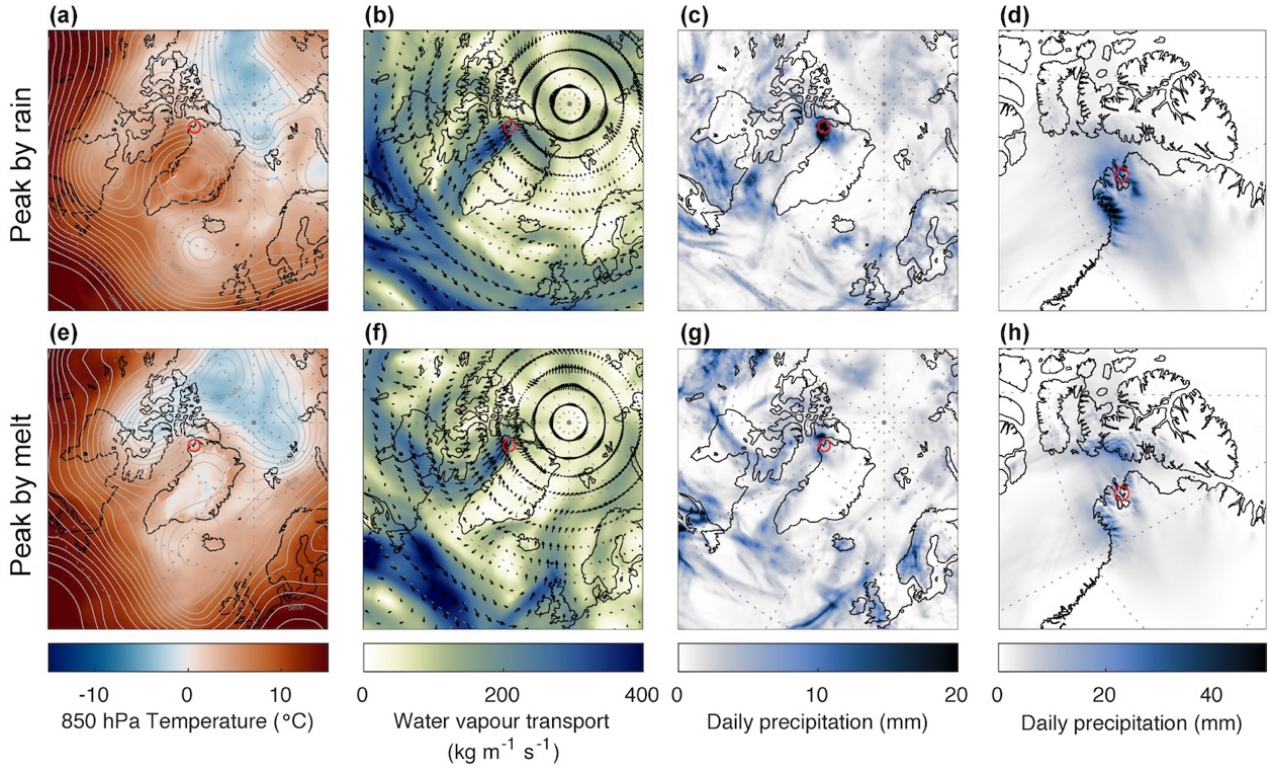

Figure R1: Composites of the ERA5 reanalysis data during the three largest runoff days caused by (a–c) rain and (e–g) glacier melt. Composites of the CARRA reanalysis data for the same days were also shown (d and h). (a and d) Air temperature at 850 hPa geopotential (color) and 500 hPa geopotential height (gray contours). (b and e) Vertically integrated water vapor transport (color) and wind vectors at 850 hPa geopotential (arrows). (c and f) Daily precipitation from ERA5 reanalysis. (d and h) Daily precipitation from CARRA reanalysis. The red circles indicate the location of Qaanaaq.

ERA5-Land reanalysis dataset, what about coarse resolution, how its downscaled is important and how representative of local gradients is a big question

The ERA5-Land variables were calibrated in this study to best reproduce the observed variations at SIGMA-B (Figure S2). Therefore, it represents the most suitable dataset for extending the analysis back to 1950. Since precipitation is not measured by the SIGMA-B AWS, direct comparison between the reanalysis and observed variations have not been made. To investigate the performance of the precipitation from ERA5-Land dataset, we compared it with that from the CARRA reanalysis data, which has a finer spatial resolution of 2.5 km than ERA5-Land (2.5 × 13.5 km) (Figure R2). Although extreme precipitation events (>60 mm d^{-1}) are not reproduced in ERA5-Land, overall performance exhibited fairly good agreement, showing that the linear regression lies along the slope of 1 (dashed line in Figure R2). The comparison indicates that the precipitation variability is very well captured in ERA5-Land, when compared with the higher resolution dataset. Even if the CARRA reanalysis were used as model input, the multiplier correction would likely yield comparable results with those from ERA5-Land. To describe the good performance of the calibrated precipitation timeseries from

ERA5-Land, we will add the results of the comparison with the CARRA reanalysis dataset in L212, and Figure R2 in the supplement of the revised manuscript.

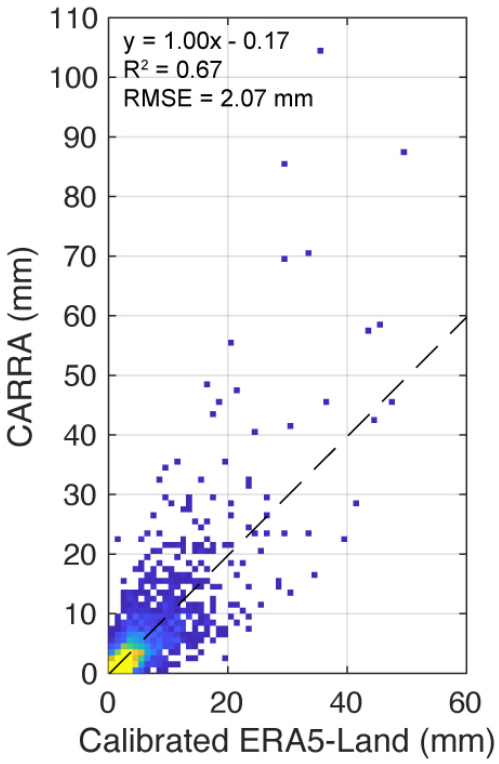

Figure R2: Daily precipitation in 1991–2023 from ERA5-Land calibrated by precipitation multiplier versus the CARRA reanalysis. The dashed line indicates a linear regression through the data. The linear regression equation is shown along with the coefficient of determination (R^2) and RMSE.

147, temperature lapse rate obtained from the daily ERA5 pressure level data, how do the numbers compare with Fausto et al 2009 'A new present-day temperature parameterization for Greenland'?

We compared monthly temperature lapse rate calculated in this study with that reported by Fausto et al. (2009) as well as the value used in Kondo et al. (2021) which was calculated by air temperature observations at Qaanaaq. Summer mean (June, July, August) lapse rate showed good agreement among the three dataset, with −5.1°C km^{-1} (this study), −5.0°C km^{-1} (Fausto et al., 2009), and −5.7°C km^{-1} (Kondo et al., 2021). However, seasonal variations of the lapse rate showed different characteristics between the values computed in Qaanaaq (this study and Kondo et al.) and that reported by Fausto et al. (Figure R3). The reason of the discrepancy is unclear and beyond the scope of this manuscript. Possible explanation for the difference is that Fausto et al. derived the lapse rate using the data between ablation and accumulation zones in the Greenland ice sheet, where geometrical characteristics substantially differs from coastal ice cap located at relatively low elevations up to 1150 m a.s.l. In the revised text, we will briefly describe the comparison with Kondo et al. (2021) as the most relevant

observational dataset on site.

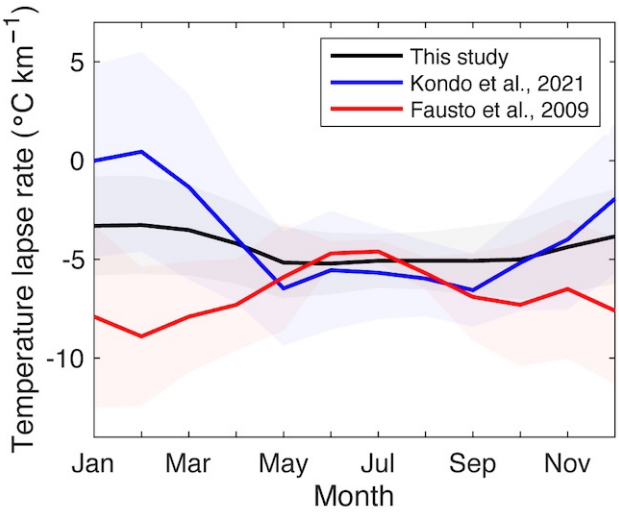

Figure R3: Monthly mean air temperature lapse rate presented by this study (black), Kondo et al. (2021), and Fausto et al. (2009).

Fausto, R. S., Ahlstrøm A. P., Van As D., Bøggild C. E., Johnsen S. J.: A new present-day temperature parameterization for Greenland. J. Glaciol., 55, 95–105, doi:10.3189/002214309788608985.

Kondo, K., Sugiyama, S., Sakakibara, D., and Fukumoto, S.: Flood events caused by discharge from Qaanaaq Glacier, northwestern Greenland, J. Glaciol., 67, 500–510, doi:10.1017/jog.2021.3, 2021.

263 "78% of the runoff on both days" very interesting, perhaps unique finding, if I understand that rainfall was the majority of runoff. If so, try to highlight the result in abstract and conclusions

We thank that the reviewer for finding a value in the number. We will include it in abstract and conclusions.

314 "rainfall exhibited a 2.2-fold increase from 1951–1960 to 2010–2020" try to highlight the result in abstract and conclusions

We will add the text in abstract and conclusions.

fig 6 suggest instead of °C/decade, try "change" or "trend" as the trend slope from regression multiplied by the number of years. Then possibly in abstract and conclusions can state temperature increased by _°C over the period...same with precipitation parameter trends

The number ("/decade") in the manuscript is calculated by the trend slope from regression analysis. To clarify this point, we will add text in the caption of Figure 6, for example, "The dashed lines in (c) and (d) are linear regressions of the data with $p < 0.01$. The trend slope of the regression is also shown.". The numbers of the

trend will be added in abstract and conclusions as suggested.

329 "top three daily runoff events being caused primarily by rainfall", discuss retention on those dates, how depleted? saturated snow?

According to the model results, the snowpack in the elevation range of 1050–1150 m a.s.l. had mean water retention capacity of 13 mm w.e. on 21 August 2023, a day before the largest peak runoff on 22 August 2023. Almost all of the retention capacity (>99%) has depleted as a result of the rain event on 22 August, which lead to runoff from the region above 1050 m a.s.l. However, contribution of the snow-covered area to the total runoff remained minor (11%), which is below the average on the annual maximum runoff days (18%). Similar conditions were found on the second and third largest runoffs in 2001 and 2012, when the snowpack was saturated on the annual maximum runoff days. It is clear that the snowpack was saturated by the rain events, however, such conditions commonly occurred when rain and melt events were recorded and is not unique to the top-ranked runoff days. Therefore, we believe further discussion on the retention processes is not very informative, and would like to leave the text as it is.

334 "unclear relationship", what about retention findings from model?

No big melt or rain events have been computed in 1997, which is the reason why the annual maximum runoff was suppressed (3.4 $m^3 s^{-1}$). Even if there was no capacity of water retention within the snowpack, the runoff will be 4.1 $m^3 s^{-1}$ and still holds the unclear relationship, given even greater runoff was computed as 4.8 $m^3 s^{-1}$ in 1995. Therefore, we consider water retention of snowpack had minor effects on this point. However, the model may not adequately reproduced thick firm layer formed prior to 1950 as well as formation of ice layers within the firn which can hamper downward water infiltration and facilitate runoff from the accumulation area (Machguth et al., 2016; Mikkelsen et al., 2016). These points will be added in the text (L335) as overall limitation of the model results.

Machguth, H., MacFerrin, M. van As D., Box, J. E., Charalampidis, Colgan, W., Fausto, R. S., Meijer, H. A. J., Mosley-Thompson, E., van de Wal, R. S. W.: Greenland meltwater storage in firn limited by near-surface ice formation, Nature Clim. Change, 6, 390−393, doi:10.1038/nclimate2899, 2016.

Mikkelsen, A. B., Hubbard, A., MacFerrin, M., Box, J. E., Doyle, S. H., Fitzpatrick, A., Hasholt, B., Bailey, H. L., Lindbäck, K., and Pettersson, R.: Extraordinary runoff from the Greenland ice sheet in 2012 amplified by hypsometry and depleted firn retention, Cryosphere, 10, 1147–1159, doi:10.5194/tc-10-1147-2016, 2016.

****low level comments****

"io" means "instead of"

Main Text

"local glaciers" io "peripheral glaciers", peripheral is a recent language mistake we can fix by using a more accurate term

We correct the term throughout the text as suggested.

"relatively small area of Greenland (4%)," depends on level of connectivity, see doi:10.5194/tc-6-1483-2012 and use a range of % and cite the article

We add the range of area percentage and citation.

37 "from local glaciers" io "from glaciers"

We correct the text as suggested.

40-50 is also possible to find reports of infrastructure bridge damage near Nuuk, for example in Kobbefjord after rainfall in 2022 https://x.com/NuukNERO/status/1573959848991014913

We will add text here.

66 cite also Ahlstrøm 2017 Sci Reports

We include Ahlstrøm et al., 2017 Sci. Adv. in the citation.

83 add day/month the aws installed

We add the installation date of 19 July 2012.

90 perhaps add Williamson PNAS or other supporting work outside of Japanese publications

This paragraph describes darkening processes revealed specifically on Qaanaaq Glacier by the studies conducted on site. We are hesitant to include studies reported on the other sites since the biological processes may differ from the studied glacier.

188 "agreement" io "good agreement"

We correct the text as suggested.

190 what is RMSE after bias correction, would be smaller than 0.07?

We add the RMSE after the bias correction (0.02).

197 "runoff was measured in the summer periods during 2017–2019 at 1.4–2.0 km from the glacier terminus (Mankoff et al., 2020;" how is the Mankoff data used? I think that is not a measurement but a model?

The data of the discharge measurements were included and published in Mankoff et al. (2020) as validation for the RCMs. Detailed analysis on the discharge data was conducted in Kondo et al. (2021) to elucidate mechanisms of the flood events happened in Qaanaaq. Therefore, we include both of the citations here.

214 "slightly" add % difference

We add the percentage difference as suggested.

218 "good agreement" add % difference

We add the percentage difference as suggested.

265 see also Fausto GRL and Frontiers from 2016 for possible citation in addition to (Nghiem et al., 2012).

We add Fausto et al. (2016) GRL in the citation to describe the melt event covering the Greenland ice sheet on the day. We refrain to include Fausto et al. (2016) Frontiers since the study focuses on regional characteristics of ice melt on southern Greenland.

Fig 5 red stars do not seem needed as the maximum is illustrated already

We delete the red asterisks from Figure 5.

Fig 5 runoff "fraction" seems better than depth

We correct the text as suggested.

301 "glacier mass budget surplus" io "positive glacier mass balance"

We correct the text as suggested.

303 "climatic mass balance" is more conventional than "glacier mass balance", see Glossary of Glaciology, IAHS Cogley

We appreciate the suggestion. The text is corrected throughout the text.

355 "rain event at Summit station on the Greenland ice sheet in the summer of 2021" was more like "light rain" or "mist" which ocurred after snowfall, see Summit Figure S5a in Box study Supplement and relevant discussion

We correct the text from “rain event” to “light rain (3.4 mm)” according to the study by Box et al. (2022).

450 good point "atmospheric circulation patterns are not captured by the Earth system models used in CMIP5 and CMIP6"

Thank you very much for finding the value here.