

The Cryosphere Discuss., referee comment RC2  
<https://doi.org/10.5194/tc-2021-150-RC2>, 2021  
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## **Comment on tc-2021-150**

Anonymous Referee #2

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Referee comment on "Relating snowfall observations to Greenland ice sheet mass changes: an atmospheric circulation perspective" by Michael R. Gallagher et al., The Cryosphere Discuss., <https://doi.org/10.5194/tc-2021-150-RC2>, 2021

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### **Summary**

Gallagher et al. investigate the role of specific atmospheric circulation patterns on snowfall across Greenland. This is a good paper that deserves to be published in The Cryosphere. I was impressed by the novelty of the techniques which were mostly described thoroughly in the methods. Some of the writing and figures could be improved. I also remain a little skeptical about the technique used to quantify total snowfall for each month of the study period. Some more analysis about the intra-pattern snowfall variability is required before I can fully judge the robustness of this technique.

### **Specific comments**

L2-3: This is pretty poor first sentence. I've read "...the spatial and temporal variability of its contributions to mass balance have so far been inadequately quantified" multiple times and still can't figure out what it means. Please revise.

L8-9: "...with each daily occurrence of the most extreme southerly circulation pattern is contributes an average of 1.66 Gt of snow to the Greenland ice sheet" also doesn't make sense. Contributing?

L13-14: On the surface this statement is confusing because surely there are some atmospheric regimes that's produce any snowfall? I get that you always get a some snowfall if you sample thousands of atmospheric conditions. But that is not clear from just the abstract. Consider removing this sentence.

L26: Please consider capitalizing "ice sheet". It's the Amazon River, the Tibetan Plateau and should be the Greenland Ice Sheet.

L27: "recent years" will not be recent soon, could you be more specific about the timeframe over which Greenland contributed 0.47 mm to sea-level rise?

L30: Would be useful to add that snowfall is also difficult to model accurately.

L40-41: This part of the sentence is a little difficult to comprehend, replacing "observations of" with "observed" might help.

L40-41: I think this is too simplistic and not entirely true. McIlhatten et al. (2020) link ice-phase and super-cloud liquid water snow cases to atmospheric circulation patterns (see figures 14-17). Consider revising this statement.

L43-44: And Ryan et al. (2020) JGR

L45-46: Again, I don't feel like this statement is entirely true since it looks like they do link snowfall to atmospheric circulation patterns. Can you be more specific about what McIlhatten et al. (2020) does not do and why that matters (i.e. what it prevents them from concluding). I feel that clear statements of literature gaps are very important in this era of mass publication. This would then set-up lines 47-57 better (which provide a good overview of the paper's goals).

L60: Would read better if you reversed this sentence. Something like "We derived snowfall observations over the entire Greenland Ice Sheet using the..."

L62: Don't think "taken" is the right verb here, "derived from"? "acquired"

L65-67: Consider mentioning that the battery anomaly prevented observations during night-time here since this is not common knowledge to non-CloudSat users.

L69: Consider removing the Palerme et al. (2017) reference here because they did not evaluate CloudSat with in situ observations like the other two studies.

L69-70: This sentence seems irrelevant, consider removing.

L73-74: Ryan et al. (2020) also estimate that this causes an 8% underestimation of snowfall at Summit Station, consider including this reference.

L77: Consider adding "rare over the Greenland Ice Sheet". Also note that the reference for this statement is incomplete, please provide a peer-reviewed one.

L78: Capitalize "-Jackson"

L79-81: I don't understand how you can assume that CloudSat snowfall retrievals "represent the mean snowfall on the day of observation" when earlier you state that only "CloudSat observations from June 1 st 2006 to April 16 th 2011 were used... because this analysis requires uniform data to avoid assimilating diurnal biases tied to seasonality in the Arctic...". It's either one or the other. If hourly snowfall observations *do* represent the daily mean then why not use all CloudSat snowfall observations to 2017? Surely more observations makes it more likely that CloudSat's infrequent sampling represents mean conditions?

L82: Consider adding something like "All observations were initially gridded at 1 x 1 degree but later binned into eight regions identified by cluster analysis (Section X.X)" so that it is obvious to the reader that the Figure 1c represents the main spatial unit of analysis, not 1 x 1 degree.

L125: And Ryan et al. (2020)

L128-134: This paragraph is pretty vague and much of the text is repeated in the next paragraph (just with more detail). Consider removing some of this text or placing it below lines 135-143, once we know more about the details of the cluster analysis.

L132-133: What is meant by "...minimum of 90% daily sampling coverage..."

Figure 1a/b: Having different y-axis scales for these figures is confusing since it would be nice for the reader to be able to compare snowfall rates in different regions. Also the caption does not make sense since the two of lines look like they have minima in March, not summer. I get that having eight lines on the graph is busy but the distinction between (a) and (b) is not really working here. Consider revising.

L148 and L151 (and elsewhere): I don't agree with "annual variability" here. Season to season differences (i.e. winter vs. summer) should be "seasonal variability". In L426 and L449 you refer to this variability as "seasonal".

L156-163: These sentences don't add much, consider removing.

Figure 2. Would be useful to have some arrows on this figure. I also don't think the colorscale works very well. The dark green is too similar to dark blue, consider using a more distinctive colorscale. Finally, consider adding labels (a, b, c and 1, 2, 3 etc.) so that the reader can easily refer to a specific panel after reading the text.

198-205: This should be moved to the results section

206-211: This is also results so should be moved

L222-224: Would be nice to reference figure 1 here.

L225-227: Irrelevant and repetitive text, consider removing.

Figure 4: Is this gigatonnes per year? Or during the whole GRACE record? Consider adding maps next to these panels to make it more obvious which regions of the ice sheet they are referring to.

L301-302: For the whole ice sheet? Or for a specific region? Please clarify.

Figure 5: I don't understand why the dots are colored in orange for "melt months". Earlier you stated that little melt occurs above 2 km elevation (L257: "...surface melt generally does not occur."). Even if there is some melt at these high elevations, it's unlikely that it happens in May and September. So the distinction between orange and blue does not make a lot of sense.

Figure 5: The statement "Each dot is colored by the time of year that it occurred" is misleading because it makes it sound like the dots are colored on a continuous scale when actually they are just arbitrarily divided into two groups.

Figure 5: please explain the histograms on each axis in the caption.

L301-307: I remain a little skeptical about the technique used to quantify total snowfall for each month of your study period. I get that it is a necessary (due to infrequent CloudSat sampling for each month) and potentially powerful approach. But I think a few more details need to be provided for me to fully judge how robust it is.

For example, does pattern c1 always produce 1.2 Gt of snowfall on average? Surely this is very much dependent on which grid cells CloudSat sampled on that day? Could the authors provide some more statistics for each pattern (e.g. standard deviation, histogram)? Pattern c1 may produce 1.2 Gt in July but does it also produce 1.2 Gt in April? This should be checked because, if not, you may consider not using all months when computing average cumulative snowfall for each pattern. This information does not have to go in the main paper but could be added to the supplementary materials.

Figure 6: Similar comments to Figure 5.

L361-L362: Agreed, would be nice to explore this intra-pattern variability a little more.

Figure 8: The black lines are a little thick making it hard to see how the coverage of the orange and red areas, consider making them thinner or removing.

L443: I think you did something a little more specific than "looking at CloudSat snowfall observations..." Please revise.

L447-453: It should be clarified that these findings are not original contributions. Please provide a little more attribution to previous studies to indicate this point. Something like "confirming previous modeling and observational studies by XXX".

L463: These "anomalously extreme days" have not been discussed in the manuscript. Please provide some more information about these intra-pattern extremes as per previous comment.

L464-465: Repetition of L453-455

L465-466: These statements left me wondering how frequent these southerly and

northerly events are. I realized that Figure 3 is barely discussed in the results or discussion section. Would it be fair to say that the increase in summer snowfall can partly attributed to an increase in southerly events during summer? I think this an important point that could be developed further. I don't think this study needs to provide the final word but it could be interesting to touch on in regards to Clausius–Clapeyron vs. atmospheric circulation debates.