

## ***Interactive comment on “How unusual was 2015 in the 1984–2015 period of North Cascade Glacier Annual Mass Balance?” by Mauri S. Pelto***

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General comments:

This manuscript titled “How unusual was 2015 in the 1984–2015 period of North Cascade Annual Mass Balance?” highlights a great dataset and makes several interesting points. In particular, the regional homogeneity of inter-annual variability in the North Cascades is a great observation. However, it currently suffers from a lack of sufficient detail in the analysis, from a lack of clear focus, and from a confusing organizational scheme. I am left with significant questions about how the data were acquired and analyzed, and how important the implications are. With minor additional analysis and significant reorganization this could be a strong and compelling article.

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Specific comments:

The title suggests an evaluation of how much of an outlier 2015 was in terms of North Cascades annual glacier mass balances. The results show that 2015 was the most negative year during the period of record, but there is no statistical analysis to quantify the “How unusual” part of the title.

The first six sentences of the abstract contain a lot of detail that does not help the reader to understand the project, analysis or conclusions. Condense these into one or two sentences.

Section 2.0 Climate This section is part introduction to the region and part discussion that belongs after the mass balance results. Reorganize this section to reflect that. Section 2.0 should be some sort of site introduction that tells us about the North Cascades (and includes but is not limited to regional climate). It should also include something about total area, total glaciated area, elevation range, etc. All of section 2.1 Climate in 2015 should be moved to the discussion (prior to or combined with section 5.0 Climate correlations).

Section 3.0 Methods This section needs to include more details. At the very least, include what kinds of measurements are made, and what the AAR is calculated from. Describe the uncertainties better. This manuscript largely ignores uncertainties, and presents all of the numbers as if they are exact even in cases where they are not. Present uncertainties with the results, and in places where that is not possible the statements need to be re-worded to reflect why the uncertainty is unknown. At present, the only mention of uncertainties are two sentences devoted to citing previous work. The cited paper on uncertainties (Pelto, 2000) only looks at the random variability based on sampling strategy, it does not incorporate any geodetic check to assess for bias. Even a very small bias can create large errors in cumulative balances over time (e.g. Fischer 2011), which would have an impact on the % volume change.

Section 4.0 Results If the glaciological balances are robust in part due to the large

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sample numbers, then add a table with the number and type of measurements at each glacier. Add uncertainties to all of the reported numbers. Again, like the comment on the title, it would be appropriate to use a statistical test to quantify how much of an outlier 2015 is.

Section 5.0 Climate Correlations It would be useful to evaluate the direct correlation between mass balances, snowpack at the SNOTEL sites mentioned previously, and the average ablation-season temperatures. All of this data is mentioned in the manuscript, yet no formal analysis was made. That is the intermediate step linking broad-scale regional forcing mechanisms to the actual climate at the scale of the North Cascades region.

Section 6.0 Conclusions The conclusions do not mention 2015. Based on the title I expected that to be the core of the paper. After the first two sentences, the entire paragraph reads like a part of the discussion, citing other papers on the potential impacts of continued mass loss from the North Cascades Glaciers. Move this to the discussion and replace it with conclusions about 2015, the correlations with climate, and the correlations with regional forcing mechanisms.

Line comments:

P1L7 Remove the comma after “range”

P1L10 Add “Monitoring of” or similar before “Foss Glacier”

P1L11 Change “has” to “had”, or remove “has” entirely.

P1L12 This statement is only partially correct as the paper uses glacier mass balance data from NCGCP, NPS, and USGS to compare to regional climate. Please reword to be precise.

P1L15 Here and elsewhere in the manuscript change the dashes separating a range of numbers to en-dash(–), and the dashes that represent negative values to minus signs (–).

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P1L13 The sentence starting with “The mean annual. . .” is superfluous, primarily functioning to alert the reader to the fact that the units in the following sentences are in m w.e. Delete the sentence and change the units. If you want to keep the mention of WGMS work it into one of the first two sentences.

P1L15 Remove the apostrophe in “glacier’s”

P1L16 This sentence is written as if 30% volume loss is precisely calculated in the manuscript, which is an overstatement. The cumulative loss number needs an uncertainty, or at the very least needs to be rewritten to qualify that the % volume change is based on estimated ice thickness for most of the glaciers and on a mass balance time series that lacks geodetic constraint. See comments below.

P1L19 The sentence starting with “The correlation coefficient of Ba. . .” is misleading, given that the previous sentences are referring to 2015. In the text it is pointed out that balances for South Cascade end in 2012, so there is no correlation between NCGCP glaciers and South Cascade glacier in those years.

P1L21 The last sentence of the abstract is not well developed in the manuscript. I think it is beyond the scope of this manuscript. If it is included it needs to be supported in the discussion.

P1L27 Here and elsewhere I encourage the use of the “Oxford comma”, meaning the comma between the second to last and last items of a list. E.g., a list should look like a, b, and c, rather than a, b and c. This resolves the ambiguity between lists and clauses.

P2L2 delete “for example”

P2L4 replace “North Cascades and in the conterminous United States” with “conterminous United States, both in the North Cascades:”

P2L7 add a comma after “elevation”. Add a comma after “others”.

P2L17 Add comma on either side of “Foss Glacier”, or delete “One other glacier”.

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P2L20 Add a comma after “Columbia Glacier” or delete “One glacier;”.

P2L22 Reword. Perhaps: “Combined with South Cascade Glacier, this network represents the best distribution and density of direct measurements of glacier mass balance over a given mountain range. This allows us to separate the impacts of geographic characteristics and climate on glacier mass balance, and place the exceptional 2015 mass balance year in context.”

P3L16 Why examine May-September and June-September? I suspect it has to do with the fact that most of the ablation measurements are made June-September, yet May is also part of the ablation season? Explain.

P4L18 Figure 2. Directly contradicts this statement, showing 3 years with freezing levels above 1500m. Revise the statement or revise the figure if there is an error in the figure.

P5L25 You have already defined Ba, however for most readers it would be easier to read if it was written as annual balance rather than abbreviated.

P5L28 This is the third time this description shows up in this paper. It should be presented once, either here or in a site introduction.

P5L31 Why bring up key geographic variables? Either give us data on what those variables are, and use that data in the analysis, or make a more useful statement.

P6L27 Starting with “The mean Ba. . .” These are not results, they belong in the discussion.

P6L30 These citations have measured thicknesses for a couple of glaciers in this study, most of the glaciers have not been measured directly, and it should be pointed out that most of the thicknesses come from Post et al., (1971) which are qualitative estimates based on measured thicknesses of a couple of glaciers. Either present measured thicknesses or be more precise in describing the given data. Strengthen your argument by showing that even with maximum plausible ice thicknesses the % volume change is

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large.

P7L4 Most of section 4.3 is giving an introduction to what AAR is and what it means. It does not belong in the results. The actual results here could be combined with the previous section as it should only be 1-2 sentences.

P8L31 This sentence about “the global climate signal is the dominant driver of mass balance losses” is not well developed. What correlation are you talking about? If you have done some sort of analysis present it. Either develop the idea or delete it, both here and in the abstract. In any case, the citation of Zemp et al., (2015) is appropriate for “the cumulative mass balance records of glaciers in various alpine glaciated regions around the globe”, but not the “indicate the global climate signal is the dominant driver of mass balance losses” part of that sentence.

P15 Table 1. Accumulation seems to be unused in the analysis. The area and elevation values do not have any context. Mention the range of glacier areas and something about the elevation ranges within the North Cascades in a site description.

P18 Table 4. Table 4 seems like a little bit of a waste, as all it does is compare 2015 to the mean value. Why not do a multi-variable regression between the annual values of April-1 SWE., Summer temperature, and mass balance values?

P20 Figure 1. The resolution of this figure is very low. Consider using a hillshade in addition to color coding the elevation. Please change the symbology to clarify the difference between glaciers and water. Perhaps make the glaciers white with a thin blue outline. Add a small inset with an overview map showing where the North Cascades are. Add a north arrow. Add some position information (as in a few latitude and longitude marks on each side).

P21 Figure 2. Why is there such a difference between these freezing levels and those in table 4? What do you use these freezing levels for? I assume that the purple arrow points to the summit elevation of Mt. Baker? If so, be explicit. Also, “Mt. Baker” looks

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like a title. Shrink the font and offset, or change the way you present that information on the chart to reduce ambiguity. Why is Mt. Baker even significant? Is it that the highest elevation glaciers in the North Cascades are located there? That information should go into some sort of site introduction. . .

P22 Figure 3. This figure is incredibly hard to read. Please use thinner lines and higher resolution.

P23 Figure 4. Again, there is too much data on one plot with heavy lines and symbols.

P24 Figure 5. Again, the resolution is too low. Consider using a combination of color coding and hillshade to make the terrain easier to see. The text needs to explain where this kind of data comes from. Satellite? Air photos? Field book sketches? Label the glaciers that are part of the NCGCP.

P25-27 All three picture figures make it appear that there is more accumulation zone that is not visible in the picture, and because of that they don't add to the story. Select a picture with a better angle or skip it entirely.

References: Fischer, A.: Comparison of direct and geodetic mass balances on a multi-annual time scale. *The Cryosphere* 5 107-124, doi: 10.5194/tc-5-107-2011, 2011  
Pelto, M.S.: The impact of sampling density on glacier mass balance determination. *Hydrol. Proc.* 14:3215-3225, 2000.  
Zemp, M., and 16 others: Historically unprecedented global glacier decline in the 21st century. *J. Glac.* 61(228), 745-762, doi: 10.3189/2015JoG15J017, 2015

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Interactive comment on *The Cryosphere Discuss.*, <https://doi.org/10.5194/tc-2017-62>, 2017.