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The Cryosphere Discussions

Interactive comment on "Rapid Wastage of the Hazen Plateau Ice Caps, Northeastern Ellesmere Island, Nunavut, Canada" *by* Mark C. Serreze et al.

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Editor, The Cryosphere:

Responses to the comments and suggestions to the second anonymous reviewer of manuscript tc-2016-201 Rapid Wastage of the Hazen Plateau Ice Caps, Northeastern Ellesmere Island, Nunavut, Canada, follow below. We appreciate the efforts of the reviewer, who clearly spent a great deal of time with this manuscript and as a result have greatly improved it.

Respectfully,

Mark C. Serreze

Director, NSIDC University of Colorado Boulder

Comment:

Overview: This paper documents the important and timely phenomenon of disappearing ice caps in the Canadian high arctic. A time series of area measurements is compiled primarily from previously published observations, with a small contribution of new measurements to document shrinkage and predict the timing of the demise of the plateau ice caps. Some previously published surface mass balance measurements are reported but not discussed. The area changes documented in this study are linked through qualitative comparison to annual temperature 850hPa radiosonde temperatures from Alert. A major shortcoming of this paper is the under-utilization of available long term records from other arctic glaciers to determine if the rate of glacier change over the Hazen plateau is representative or anomalous of the broader scale glacier changes occurring in the Canadian high Arctic. A more rigorous quantitative analysis of the complete time series of changes to the Hazen plateau ice caps should be made in order to contribute to the broader understanding of the rates of climate change in the Canadian high arctic and the current and future rate of contribution of ice caps and glaciers in this region to global sea-level rise.

Response:

We thank the reviewer for his/her efforts. Reviewer 1 and Reviewer 2 have highlighted the same shortcoming of our paper – a failure to adequately place the results from our paper on the context of other studies for the Canadian high Arctic. In response to Reviewer 1 we have made concerted efforts to rectify this problem. This includes comparisons with the efforts by Sharp et al. (2014), Fisher et al. (2012), Wolken et al. (2008) and the mass balance summaries provided in the annual American Meteorological Society State of the Climate Summaries. As noted, providing this fuller context required some reorganization of the text. We feel that the paper is now much more relevant.

Comment:

L58-60: A major shortcoming of this paper is lack of new geophysical data generated for this study, as such, there is no needs for a methods section. The distinction between which data were produced by the authors for this paper, and data/information from previously published material needs to be more clear.

Response:

Correct, we saw no need for a methods section. Apart from the ice cap areas our analysis does not provide new geophysical data, but we do not see this as a weakness. Indeed, by piecing together the old and the new, we have a 55+ year records of the behavior of these ice caps! We have amended the last paragraph to better distinguish what is old and new:

"This paper documents the behavior of the Hazen Plateau ice caps over the past 55+ years in the context of other glaciological studies in the Canadian Arctic. The analysis is based on a combination of past work using aerial photography, direct mass balance measurements from several field investigations, GPS surveys of ice cap areas collected as part of these investigations - along with new information on ice cap areas using data at 15 m resolution from the ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) instrument. ASTER flies onboard the NASA's Earth Observing System Terra satellite, launched in December 1999. It provides reflectance at a 15 m resolution and is a key asset of the international GLIMS initiative (Global Land Ice Measurements from Space) for mapping glacier outlines (Raup et al., 2007; Kargel et al., 2014)".

Comment:

While the authors illustrate the rate of shrinkage of the Hazen plateau ice caps though plots of the time series, there is no attempt made to determine if the rapid changes as determined from this study are occurring at anomalous relative to those documented for other high arctic glaciers.

Response:

Through efforts to place the results from our paper into a broader context, the rapid area reductions of the Hazen Platea ice caps are very much in line with what is happening in the rest of the Arctic. See especially the revisions to Section 3.1.

Comment:

L49: It would be more informative if the actual elevations of the ice cap are rather than just the maximum surrounding area (ie. ": : :ice caps are in an area with maximum elevations s between 750-900 m;: : :") as stated.

Response:

One of the problems here is that the elevation range has changed quite a bit over time. However, we have attempted to add some clarity to the text: "As of 2001, the larger St. Patrick Bay ice cap ranged in elevation between about 880 m and 720 m above sea level, with the smaller one spanning 820 m to 700 m. The Murray and Simmons ice caps lie in higher terrain; in 2001, both fell between about 1100 m and 1000 m above sea level".

Comment:

Extent of LIA glacier cover (Wolken et al.) should be included in the analysis to provide a longer term perspective to the changes discussed in this study.

Response:

See above, this was also pointed out by Reviewer 1 and has been addressed in the first bullet of Section 3.1: "To place these findings in a broader context, for the Queen Elizabeth Islands as a whole, trim lines based on high-resolution satellite imagery point to a 37% reduction in perennial snow and ice extent between the LIA and the year 1960. Over the lower lying central and western islands, a complete removal of perennial snow and ice occurred by 1960 (Wolken et al., 2008)".

Comment:

L53-54: the authors should clarify what form of precipitation this statement (": : :, with a late summer and early autumn maximum..") refers to ie. Rain or snow, or a combination of both, as they can have opposite impacts on the mass balance of small ice caps with no firn to absorb liquid precip.

Response:

Based on personal experience, it can be either. The text has been amended: "Like much of the Queen Elizabeth Islands, the Hazen Plateau is presently a polar desert; annual precipitation is typically only 150-200 mm, with a late summer and early autumn maximum (Serreze and Barry, 2015). Summer precipitation may be variously rain or snow."

Comment:

L83: Presumably these ice caps are stagnant. However, the authors refer to the ice caps ": : :extending its margins,.." which may be misinterpreted as advancing via flow, which is almost certainly not the case. It is most likely that the" extended" margins are actually perennial snow packs which would be of lower density material than the original ice cap. This should be clarified

Response:

This comes directly from the Hattersely-Smith and Serson (1973) paper published in Journal of Glaciology. We have attempted to clarify as follows: "They concluded that while the ice cap had been in decline (as suggested from the 1947 and 1959 photographs), by the early 1970s it had returned to good health, "thickening slightly and extending its margins" (icy firn was observed atop the dirty melt surface and a perennial snow cover extended beyond the ice cap margins).

Comment:

L83: ": : :thickening slightly : : :" how was 'thickening' determined?

Response:

See above, they observed firn atop the former melt surface.

Comment:

L91: "Assuming that the 1982 melt season had largely ended by early August: : :" unless there is temp data to support this claim, there is no reason to assume that the melt season ended in early august. High arctic glaciers at these elevations commonly experience melting into late august.

Response:

Reviewer 1 also pointed this out and the text has been amended accordingly. "Assuming that the 1982 melt season had largely ended by early August (all visible melt had stopped by the time that the field camp had been evacuated), the 1981/1982 mass balance for the larger ice cap was estimated at -0.14 m w.e.. Given that more melt may have occurred, this is likely a minimum estimate." The new Table 1 (the measured mass balances) also indicates that this is a minimum estimate.

Comment:

L94 and 103: it is more informative (and more common in glaciology) to report mass balance as an annual (ie a-1) value even when measurements span multiple years.

Response:

Conversions for periods spanning multiple years have been provided in both the text and in the new Table 1 requested by Reviewer 1.

Comment:

192 " While arguably it might be better to look at the 925 hPa level," the authors need to explain why this is the case.

Response:

Simply put, it is closer to the plateau surface. The text has been amended to point this out.

Comment:

L178/179: the studies referenced refer to loss of ice mass or surface mass balance, not specifically area change. This is an important distinction (and should be discussed) because area reductions of the larger dynamic ice caps are also a function of dynamic response time whereas the margins of small plateau ice caps respond immediately to surface ablation and would shrink at faster rates relative to the dynamic ice masses.

Response:

Reviewer 1 pointed this out as well. We now include more references, which include studies of both mass and area changes. The sentence has been amended: "This is in turn consistent with the broader pattern of reductions in mass and area of Arctic glaciers. . ..."

Comment:

Figure 5: it would be helpful to integrate the annual and multi year average surface mass balance measurements and/or area change values from all studies (this one and all referenced herein) into fig 5 in order to show the relationship between temp change and ice cap response.

Response:

Reviewer 1 wanted to see all of the directly measured mass balances, and in response, we added a new table new (Table 1). Trying to integrate all of the information into Figure 5 proved awkward and crowded. Hence we have compromised, and have indicated on Figure 5 the annual mass balance estimates for the larger St. Patrick Bay (SBP) ice cap for the 1981/1982 and 1982/1983 balance years, and for the Murray Ice Cap (M) for the

1999/2000, 2000/2001, 2001/2002 and 2002/2003 balance years (in m w.e.). We then added some text to more completely discuss the relationships between temperature anomalies and mass balances. The figure caption has also been edited.

Comment:

L54: the Serreze and Barry 2015 is listed as 2014 in the refs.

Response:

It should be 2014; the text has been amended.

Comment:

Figure 2. scale and north arrow unreadable – too small.

Response:

We should have caught this. The scale and north arrow have been made much bigger. We of course edited Figure 3 as well.

Comment:

Figure 1. need to indicate location of Environment Canada weather stations from which data is used. Alert is identified, but should be stated in the caption that it is one location of the long term temp data. Eureka (from which precip data is obtained) is not on the map at all.

Response:

The caption has been amended and the figure has been amended to show station Eureka.

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