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# *Interactive comment on* "Meltwater Storage in the firn of Kaskawulsh Glacier, Yukon Territory, Canada" *by* Naomi E. Ochwat et al.

**Anonymous Referee #1**

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Ochwat and co-authors use firn cores drilled in the accumulation area of Kaskawulsh Glacier, Yukon Territory, Canada, to estimate changes in surface height over the period 2005 to 2018. In the deeper one of the firn core, they could observe a perennial firn aquifer at more than 30 m depth. Based on the cores they state that the surface at the drill site has lowered by ∼1.3 m over 2005 to 2018. They emphasize the importance of this result for geodetic glacier mass balance estimates of the glacier and the region.

Ochwat and co-authors make a valuable contribution to the understanding of firn properties in a heavily glacierized region. The area is also considered one of the key regions contributing to global sea level change. The authors address tow main points: (i) the perennial firn aquifer and (ii) surface lowering in the context of geodetic mass balance estimates. Both topics are very interesting scientifically and important in the context



of regional to global glacier change. However, I have the impression that in its current form, the manuscript fails in making sound contributions to either topic.

- The reporting on the discovery of the aquifer is very valuable, but the discussion of the observations remains unspecific, rather general with mostly qualitative comparison to other firn aquifers.

- I believe that the analysis of the firn core, the way it is presented, does not allow retrieval of thinning rates. To do so, additional information is needed, namely evidence of changing density or ice content over time. This evidence is missing, or little used in the argumentation. Consequently, I doubt in the main conclusion of the study.

- Uncertainty analysis generally appears incomplete (see below for details).

**Detailed Remarks**

2.1 Study area: Where is the longer-term average equilibrium line elevation (ELA) on Kaskawulsh glacier? This would be useful to better understand the glaciological situation of the drill site (e.g. 100 m or 1000 m above the ELA?)

Line 111: upper threshold of 917 kg $m^{-3}$: in a firn aquifer, higher densities are physically plausible provided that the water is still in the core segment when weighing. Was this an issue in the context of your study?

Lines 115-116: I do not understand why damage to sample bags affected density measurements, I understand density measurements were carried out in the field, before transporting samples?

Lines 120: What exactly is meant with "human error"?

Lines 145-146: Note that for example Harper et al. (2012) measured a lower density for pure ice (843±36 kg $^{-3}$). Furthermore, you list the wrong study of Machguth et al. (2006 instead of 2016) in the references. Please check references for more errors.

Lines 154-159: Why thinning? I would agree if reference is an ice core without ice

lenses, but it needs to be show that this theoretical reference actually existed at the drill site earlier (2005).

Discussion: The discussion is clearly structure but I perceived the flow of arguments as poor. The text meanders between more general, partly speculative and maybe too qualitative discussion of firn aquifers to the impact on geodetic mass balance estimates. It is not fully clear what the focus of the manuscript is, or what the main message(s) of the manuscript should be.

Lines 265: The statement cited from Christianson et al. (2015) appears incorrect. Already in the 1970s detailed studies of a perennial firn aquifer were carried out in the accumulation area of Abramov glacier (4400 m a.s.l.), Pamir-Alai, present-day Kyrgyzstan. In contrast to other studies, the scientists studied the aquifer in a deep firn pit (up to $\sim$25 m deep). This allowed continuous monitoring of changes in the water table in relation to, e.g., surface melt intensity. The related studies, however, are mostly published in Russian (Glazirin et al., 1977; Kislov, 1982) and thus not widely known to a broader glaciological audience.

Lines 270-272: Here an estimate of annual accumulation rate is mentioned, based on literature and the authors' own interpretation of the cores. Above (lines 196-198) the authors use a literature value (other sources than here) of 1.76 m w.e. yr$^{-1}$. How do these two numbers relate? Is the implicit assumption made that accumulation rates have remained stable since the 1960s? What is the uncertainty introduced by this assumption?

Line 284 (as well as 184-190): 2 kg m$^{-3}$ appears to be a very low level of overall uncertainty. I assume there must be some potential sources of systematic errors that prevent such a very low uncertainty?

Section 4.3: I think your interpretation stands on weak grounds. There is little evidence presented that accumulation rates from the 1960s are still valid today. As outlined below, the fact that ice lenses exist in the firn does not automatically mean that the



surface lowers. For this to be true, the ice fraction has to change over time. The authors present some evidence of an increase in ice content (lines 288 to 291), but not for the time period represented by the two cores.

Line 322: Surface lowering of 1.3 m: It is confusing to mention this result in cm yr$^{-1}$ in the abstract, not in the results (at least I couldn't find it there) and then again in m yr$^{-1}$ in the discussion.

Lines 322 – 332: I do not understand why there needs to be surface lowering because of the ice lens formation and refreezing? If we knew that there was no or less refrozen water in the firn in 2005, then the surface would have lowered as calculated. However, based on the evidence the authors present, I have the impression we do not know whether ice content has changes 2005-2018. If ice content in the firn would be constant, there would be no surface lowering. Furthermore, the authors make the critical assumption of annual accumulation rate equaling 1.76 m w.e. yr$^{-1}$, leading to the conclusion that the core represents the time period 2005 to 2018 (Lines 196-198). What is the uncertainty of this assumption? Accumulation rates could have changed since the 1960s. Associated uncertainties are neither assessed nor discussed.

Lines 353-355: The fact that an aquifer exist does not mean that the surface has to lower. Evidence is needed that firn properties altered over the time of investigation. If they have not changed (i.e. there was similar ice content earlier, an aquifer existed and accumulation rates remained constant), why should the surface lower?

**References not listed in the manuscript**

Glazyrin G.E., Glazyrina E.L., Kislov B.V. and Pertzinger F.I. (1977) Water level regime in deep firn pits on Abramov glacier [in Russian], volume 45. Gidrometeoizdat

Kislov, B.V. (1982) Formation and regime of the firn-ice stratum of a mountain glacier [in Russian]. Ph.D. thesis, SARNIGMI Tashkent.

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