The Cryosphere Discuss.,
https://doi.org/10.5194/tc-2020-62-RC2, 2020

The Cryosphere Discussions

Interactive comment on "Daily water-level variations of supraglacial lakes in the southern Inylchek Glacier, Central Asia" *by* Naoki Sakurai et al.

Sam Herreid (Referee)

samherreid@gmail.com

Received and published: 4 May 2020

The article titled "Daily water-level variations of supraglacial lakes in the southern Inylchek Glacier, Central Asia" by Naoki Sakurai et al. uses an impressive dataset of daily high-resolution DSMs acquired from repeat drone flights over a subset of Inylchek Glacier for a window of time repeated over three consecutive years. Using these data, the authors record and interpret several supraglacial lake drainage events including instances where several lakes drain simultaneously. The authors go on to infer the location and behavior of the englacial drainage system during this time. I enjoyed reading this paper and found it mostly easy to follow. My comments below are

mostly minor, and I think a revised version of this manuscript would be well suited for publication in The Cryosphere. Some of the main points include the following: unclear langue regarding englacial and supraglacial flow, which was confusing throughout the manuscript. A horizontal correction was applied to the repeat DSMs, but a discussion of, or a correction for, vertical motion from factors like emergence, elevation loss due to moving down a slope and ablation was never addressed. There was a 45% filter to the lake elevation data which seemed high to me, I would like to better understand why so much of the lake elevation data seems to have had a non-zero surface slope. Lake volume changes were measured but only sparsely reported as context, I think this paper would benefit from having these results presented more completely. The paper does a good job providing a detailed chronology of events for this portion of this one glacier but most readers won't necessarily care about this particular location and will be looking for takeaway points that further our general process understanding of the system, which are thus far largely missing. These points, and additional minor comments, are detailed below.

L32-33: "In none of these cases did researches find evidence for a large proglacial lake prior to the drainage, but in all cases large supraglacial lakes had drained" Is there an unstated assumption here that we would only see drainage events from glaciers with a lake in front of the terminus? I'm not aware of this assumption, so maybe cite some occurrences of this in the literature.

L38-39: "Thus, recent large-scale drainages are related to supraglacial lakes and englacial conduits on debris-covered glaciers." This is a little odd with "recent" suggesting that these physics were different in the past? Better might be "These recent studies establish a coupling between large-scale drainage events and supraglacial and englacial water storage dynamics."

L41: Can you say how lake development is dependent on flow velocity? In principal a lake could grow on a flat portion of glacier moving at any speed. What is the intermediate process that prevents or allows lake formation? A flow velocity gradient coupled

with crevassing? A feedback loop with debris cover? Or a more efficient englacial channel system?

L43: This reference is recent and relevant to the acceleration of glacier ablation with respect to lakes/ponds: Miles, Evan S., et al. "Surface pond energy absorption across four Himalayan glaciers accounts for 1/8 of total catchment ice loss." Geophysical research letters 45.19 (2018): 10-464.

L46: This is written as, but does not seem to be, an exhaustive list of the mechanisms for englacial conduits closure and reopening. Thermal erosion comes to mind. Also similar to above, how exactly does glacier flow cause englacial conduits to open and reopen, there are some missing steps, I think. In the two paragraph begin at L49 you describe well supported seasonal evolution of lake systems. Can you also cite some long-term trends for context?

L57: Change to: “The timing of the maximum number..”

L60: Maybe this is a useful citation here as well: Bartholomaus, Timothy C., Robert S. Anderson, and Suzanne P. Anderson. "Growth and collapse of the distributed subglacial hydrologic system of Kennicott Glacier, Alaska, USA, and its effects on basal motion." Journal of Glaciology 57.206 (2011): 985-1002.

L63: Maybe say “[primarily] using an unmanned aerial vehicle” since you also use satellite data.

L65: Probably cite Fig. 1 here.

L68-69: “with surface-flow velocities in its upper part being faster than those in its lower part” This does not relay much information to the reader. Are your upper and lower in reference to where there is more debris and less debris, or do you mean this glacier has a particularly fast flowing accumulation zone? Consider taking this one step further so we know how this is useful to know.

L71: This annual seasonal drainage cycle from Narama etal., 2017 might be worth

describing here for another sentence since this seasonal evolution sounds particularly relevant to the rest of this study.

L72-77: Are meteorological data used beyond the statistics reported here? I don’t think it’s needed to establish abbreviated names and might not need to be in Fig. 1.

L82: Lake Merzbacher base camp is referenced like it is established or somewhere we should know. I assume it wasn’t established just for this study?

L82: This is very nice that you were able to fly every day. Can you please comment if you flew in rain, strong wind and fog, or if you adjusted your flight times to accommodate bad weather? Or maybe there was none?

L86: “. . .as this period was hardly affected by weather and sunlight.” By “affected by sunlight” I assume you mean it was high enough above the horizon to illuminate the surface but not overhead to cause cast shadows. If this is correct could you state it, or be more precise in what you mean. Also, in the meteorological paragraph above maybe you could say that it’s common to have good weather early in the morning during this time of year, or some similar support to your saying here that the weather is almost always good.

L88: Do you mean to say you obtained an accuracy of around 20 cm? >20cm could mean almost anything.

L92: Do you have any constraint on the z accuracy of your DSMs? Did you find some to be better than others in your stack, and if so, any variable that you suspect is responsible?

L93: This is a strange location for a reference to Fig 2. I would remove.

L94: The sentence “Workflow of SfM software was almost automatic without setting of GCPs which we measured.” Is unclear and needs to be explained further.

L96: [an] ortho-image and DSM [remove: data] as the. . .

L96: This first step is unclear, are you shifting the DSM in only x,y space or also in some averaged z? There are competing signals of emergence, glacier melt and elevation loss as the features move down slope. With some more specific information about this glacier you may be able to make an argument to neglect these terms, e.g. your measured dz is much greater than the sum of these terms over the observation period or that the observation spatial domain is small enough that emergence at least can be assumed uniform, but they need to be addressed in some way since you compare absolute elevation data. It seems logical you would use the first image in a stack as the reference image but that isn't stated here, why not?

L99: Was the shift to correct for glacier flow linear? Meaning did you use only one tie point or several that then caused a nonlinear translation?

L101, Step 4: Are these points throughout the polygon or only along the perimeter?

L103: Excluding 45% sound like a lot. How did you choose this value? You must know a lot about SfM errors over the flat surface of water, could you add some detail about the errors? An oblique angle image of the ortho-image draped over the corresponding DSM could be useful for the reader to see and understand the source data and why a 45% filter was applied.

L103-104: You mention methods here for changes in water volume and periodically report values in the text but these results are never presented on their own. I think there is a lot of potential to tell a more complete story by presenting these findings as well.

L105-107: Lake area variations are not shown in any table or figure, I can see this being a useful measure to bridge the unknown periods between your windows of surface elevation measurements but this is not shown in your results, nor a discussion of how lake area and dz are coupled.

L111-114: All field glaciologist will empathize with deployed sensors not returning use-

ful data, but I don't think it's necessary to describe here. If the sensors in lakes 4 and 10 did not record any useful data, then it would ease the reading of this section to remove them from this paragraph altogether.

L125: Here you say the larger lakes are in the central part of the glacier, I assume you mean orthogonal to flow, not along flow, but this is not clear.

L127: I like the organization and discussion of drainage events, however I think there are still some bulk results that you can make here. Specifically, more comprehensive results of volume changes and maybe analysis of the spatial distribution of draining and not draining ponds as you show in the figures with colored numbers.

L129: "Consider the storage and drainage behavior of the nine lakes marked in Fig. 3a" Is an unnecessary sentence. Consider starting this section with a statement.

L131 and throughout: "...increased gradually by 0.3 m (2723 mˆ3)" Is this a rate per day? Please specify the time here. And considering sidewall slope, the volume will be different for identical surface changes or losses. Consider reporting an integrated change rather than a rate or be clear with assumptions/averages.

L136: Did you measure lake area change? It would be interesting to see a plot of lake area change vs volume change and I believe you have all the data to plot this. A statistically significant relation would make some inference on lake ice wall geometry.

L136: "a conduit with exposed parts" this is a recurring concept throughout this article that seems confusing to me. In my mind a conduit in glaciology is an englacial channel, while surface streams can thermally erode channels and sometimes briefly go under ice bridges, but I wouldn't call them a conduit. It's fine that you use terms differently, and perhaps my view is incorrect, but maybe in the introduction you could write a short section or few sentences describing how you define a conduit.

L137: "[That exposure parts, change to: These ice exposed parts] were caused by erosion from the drainage water..." I assume you mean erosion of both ice and debris

cover, if so, please state that to be more clear.

142-143: You write that lake 1 had a gradual increase of water, but in the sentence before you said it rose by 7.5 m in one day before the next drainage. This seems like a rapid refill to me, what do you mean exactly by gradual?

L145: For the lakes that maintain a stable water level do you have evidence, e.g. from satellite data, that they are also draining just not during this period? Can you say if any lakes persist throughout the course of a year or more?

L146: This section is essentially a figure caption. I think you should bring out more of the significance of why this event is one of your key results or consider merging it to a more general section listing events and citing figures. One key result that seems missing from this event is a plot of logger vs DSM derived change in water surface elevation.

L165: rewrite: increased by 0.6-2.0 mˆ-1

L167: For the lake(s) that gradually filled and then maintained a stable level, what can you infer about the water table of the glacier at this location and the bulk permeability?

L169: It's great that you use satellite imagery to complement your timeseries but it leaves us guessing when you were monitoring this region. Could you please add a timeline figure or subfigure that shows the sensor, datatype and timing of each acquisition you used for this analysis.

L172: Change to "This result suggests the drainage route was. . ." and later "lakes 14 and 15 after the 13 May.."

L174: "For [the] drainage.."

L174: That the "conduit" is visible in Fig. 8 means it is a supraglacial stream or channel not englacial.

L176: The sentence starting "The drainage route with exposed ice wall. . ." Should be

rewritten more clearly, I think your key point is the water took a different drainage path but the positioning relative to ice walls is unclear.

L177: Consider: "This difference indicates a change in drainage route between"

L182: Cite a figure and consider just describing the outcomes here that are notable, it currently reads more like a literal description of a figure.

L189: This sentence would also benefit from citing a timeline figure of data sources. Maybe above the timeline you could have the number of the lake that drained at that time.

L195: Why was the route unclear? There was no geomorphological change evident? Does this suggest it was a smaller event? Or are you considering the drainage went truly englacial?

L201: "..despite being." This sentence is incomplete.

L204: "indicating that some part of the englacial conduit system changed" I would like to have a sense for what is truly englacial and what is supraglacial.

L205-207: This is almost a direct quite from the introduction.

L207-208: How can you be sure there wasn't always some flow through the lake? In other words, is the water truly cut of during this time, as you state here, or is there a, possibly small, but constant in and out flow while the lake level is stable?

L216: give the figure number along with the letter for each reference, here and below.

L217 Do you have any evidence suggesting why a lake would partially drain? The conduit is not at the deepest point of the lake? Or there is a blockage during the first half of draining?

L239: You can't really say "this observed behavior is consistent with the distribution of englacial conduits shown in Fig. 11" because you drew the conduits shown in

Fig. 11. You can say “We estimated the location of conduits following the theoretical model put forth by x (citation) and guided by the behavior we observed” Or were these supraglacial channels that you could map and not infer?

L243-245: Does conduit reuse have a limiting depth within the glacier? I assume at some depth overburden pressure will close any unpressurized channel.

L251-254: The sentence beginning “ This behavior indicates that the opening” is unclear. It starts as a general statement “of an englacial conduit” but then changes to a past tense description of a particular event “maybe have been caused by.” The further point relating water pressure and water volume is also not clear to me. The following sentence is also unclear, I believe the conduit would need to be pressurized to have commutative lake level fluctuations.

L260-261: Please explain further how other studies found use for hydraulic potential and if they also found a linear relation with a similar slope. A gradient from 5 points is not very convincing, could you please find/plot this gradient for all of the multi-lake drainage events you constrain and then build on your interpretation of what this means or infers.

L275-276: What measure would be needed between monitoring from satellites and reducing damage? I think a key first step is establishing how robust these channel patterns are over many years.

L282-283: It’s not enough to say “The englacial conduit system changes over a timescale of months”, you need to qualify this with a summary of what exactly changed.

L286: Why not take this one step further and consider lake area change to infer conduit connectivity?

Figure 1: I don’t understand breaking the glacier into a debris covered part and the rest of the glacier along an arbitrary line, roughly mapping the debris cover for this figure would be more logical.

I don’t see the reason for putting Koilu Station and Tien Shan Station on this map or in this paper.

Figure 2: 3 GNSS points concentrated in the lower right of panel C doesn’t seem like very many ground control points. Was there a loss of DSM accuracy with increasing distance from these ground control?

Why did you change the lake color to blue? The red lines show which lakes you identified and any variation in turbidity captured in the color of the water itself is also interesting.

Figure 3 (and Fig 6): I like these figures a lot, however it would be slightly easier to follow if rather than random colors, the lakes and water-level elevation lines were colored in a gradient color-scheme with distance from the lowest down glacier point in the image. This would allow the reader to easily know the relative elevation ranking of each lake.

Figure 3: Why was the obvious lake in the lower right excluded?

Figure 4, 8 and 9: If you can see the expression of ice and rock erosion of a drainage event from a drone in the sky, it is be definition not englacial. Please correct this throughout the manuscript. There may be instances where the water is englacial, particularly at the lake itself, but I think a clear distinction needs to be made.

Figure 4: Since this lake does not drain completely and looking at the drainage path, it looks more like a thermally eroded ice dam that caused the partial drainage.

Figure 5: Please add here or in a separate figure the same water level variations from both the logger data and the DSM data.

Figure 10: After considering the semantic, englacial vs supraglacial channel points made several times above, please re-evaluate this figure and insure it appropriately shows water below the surface only when there was in fact water flowing in channels below the surface.

Figure 11: Missing scale. It also might help to have a vector showing the general direction of ice flow.

Interactive comment on The Cryosphere Discuss., https://doi.org/10.5194/tc-2020-62, 2020.