

Response by Jan Pronk and others to Anonymous Referee #2 his comment on tc-2021-90.

Summary The authors undertake an analysis of velocity differences between lake and land terminating Himalayan glaciers. The authors show that lake terminating glaciers are associated with faster ablation-zone speeds than their land terminating counterparts. They then analyze other glacier metrics (e.g. orientation, slope, debris cover) and employ a numerical flow model to aid in the interpretation of their observations. I commend the authors for undertaking such an extensive study that presents some very interesting findings, but find two significant flaws (outlined in “main comments”) that must be addressed before the manuscript is ready for publication. I therefore recommend the manuscript undergo major revision.

We thank the reviewer for his/her thorough assessment of our study and for the positive comments on our results so far. We agree with the reviewer’s points about the benefits of an assessment of the relationship between glacier surface velocities and ice thickness over the glaciers in our sample. Indeed, we had conducted a prior analysis of the relationship between our surface velocity results and the ice thickness estimates of Farinotti et al. (2019). Although this ice thickness data has shown to be of great value for regional ice volume estimates, we initially decided against including these results in the paper because of the large uncertainties inherent with the ice thickness data when considering the ice thickness distributions as a stand-alone variable. Therefore, we feel that for the purpose of ice thickness evaluation along a flowline, such ice thickness data should be interpreted with caution. For the revised manuscript, we will put nevertheless more emphasis on this important variable and also consider showing the thickness figure in the supplement.

Main comments

1) The language is somewhat stilted in places, with awkward sentence structure and many imprecise/vague statements. The manuscript clarity could benefit from a close read with attention to improving sentence flow and increasing precision and concision. I found much of the writing very dense and difficult to digest and/or follow.

Response:

We thank the referee for his/her comment. We will go through the manuscript to improve the readability, focussing in particular on the clarity of the writing.

2) You explore covariance of terminus type and several glacier characteristics (orientation, slope, debris cover, etc.). However, it seems that ice thickness differences between the two groups is a very important confounding variable that is not closely considered. As you mention in the text, the lake and land-terminating glaciers have differences in slope, area, and debris cover characteristics, which suggests they would also have difference in ice thickness. If lake terminating glaciers tend to be thicker than land terminating glaciers, this could underlie a substantial fraction of the observed velocity difference between groups. The fact that velocities are close near the ELA suggests that there might not be a gross mismatch, but variations in the distribution of ice thickness between land and lake terminating glaciers could explain the observed velocity differences. This potential complication must be directly addressed. A compelling way to do this would be to utilize the Farinotti 2019 ice thickness

product to estimate near terminus ice thickness between these two groups. The fact that calving glaciers do not need ice thickness to go to zero at the terminus is one reason to suspect that lake-terminating glaciers could be thicker, and, hence, faster flowing here. Without investigating this link, you cannot make a casual claim that proglacial lakes cause the observed velocity difference (as is stated in your title), only that the difference exists.

Response:

We agree with the referee that ice thickness data are an essential variable that ideally must be considered. We initially did analyse the Farinotti et al. (2019) ice thickness product in detail to explore its potential. A limitation of this data however is that it comes with large uncertainties. This might be especially true at the glacier termini and glaciers with debris cover, where errors might be systematic due to the methodology by which ice thickness data is calculated, which heavily depend on SMB assumptions. Also, no information is available on whether uncertainties are systematic near the terminus of proglacial lakes. However, we fully agree that attention must be given to the general importance of this parameter.

Figure 1 (below) shows the median ice thickness of all land- and lake-terminating glaciers in our sample group, based on the ice thickness dataset of Farinotti et al. (2019). It shows that, from the middle part of the ablation zone onwards, the velocity contrast between lake- and land-terminating glaciers might be (partly) attributed to differences in ice thickness. Nevertheless, the data also shows a clear decrease in ice thickness for both land- and lake-terminating glaciers towards the termini. At the same time, the lake-terminating glacier velocity does not show a decrease towards the terminus, and even accelerates for half for the glacier sample group (see Figure 5). This indicates that ice thickness data is important and must be considered but cannot explain the whole velocity contrast at the glacier terminus.

Also, the authors are correct in stating that lake-terminating glaciers are thicker near the terminus than terrestrial ones, due to the fact that they end at a calving cliff rather than a front that thins to zero. This may indeed influence the velocity. However, this difference in ice-thickness is also due to the presence of a lake. Although there is with this mechanism no direct positive feedback link by which ice mass loss is enhanced, it does describe a clear causal relation between the presence of a lake and elevated terminal velocities. We will formalise this when discussing mechanisms by lakes encourage higher velocities through the: 1) force imbalance at the terminus; 2) elevated water pressures; and 3) non-zero ice thickness at the terminus.

For the revised manuscript, we will consider showing the thickness figure in the supplement and devote some text to this important variable.

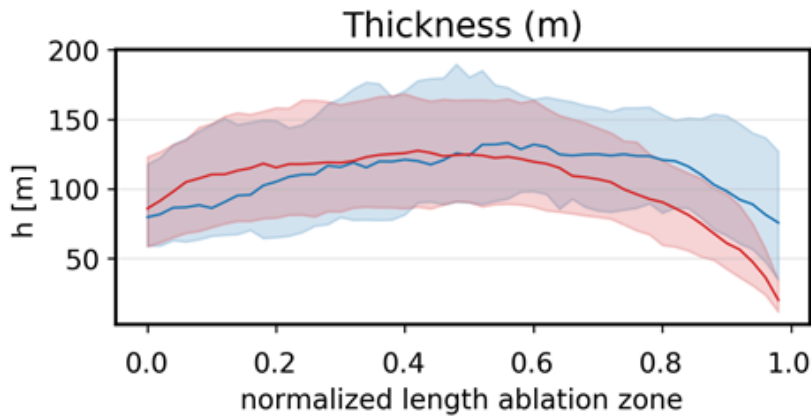


Figure 1: Median ice thickness of the ablation zone of land- (red, N=249) and lake- (blue, N=70) terminating glaciers, using the ice thickness dataset of Farinotti et al. (2019).

Minor comments

L10: the term appears as “proglacial” in the title and “pro-glacial” here. Please be consistent with one use (I think the non-hyphenated version is preferable).

Response:

We thank the referee and will use only “proglacial” in the revised manuscript.

L15: substantially more heterogeneity than what?

Response:

Indeed ‘than land-terminating glacier’s. We will rewrite this sentence to create more clarity. We will write:

“We find that centre flow line velocities of lake-terminating glaciers are more than double those of land-terminating glaciers (18.8 vs 8.24 m yr⁻¹) and show substantially more heterogeneity than land-terminating glaciers around glacier termini.”

L16: effects > affects

Response:

We will change this in the manuscript

L16: it is not clear what you are saying affects half of clean ice glaciers. Dynamic thinning? Terminal velocity heterogeneity?

Response:

Indeed, this refers to dynamic thinning. We will clarify this in the revised manuscript. We will write:

“We attribute this large heterogeneity to the varying influence of lakes on glacier dynamics, resulting in differential rates of dynamic thinning, which causes about half of the clean-ice lake-terminating glacier population to accelerate at the glacier termini.”

L41: do you mean “to cause” dynamic thinning?

Response:

We thank the referee his/her comment but think that ‘through’ might be more appropriate here.

L54: what do you mean by “rapidly evolving environments”? Vague term that makes the meaning of this clause uncertain.

Response:

We agree with the referee that we should be more specific here. We mean with this ‘a state of a glacier that is far out of balance caused by environmental conditions (i.e., temperature) that are rapidly changing’. We will adapt the text for more clarity.

L55: what is partially decoupled from climate? The transition from land to lake terminating?

Response:

Yes, we will rewrite this sentence to be clearer in the revised manuscript. We will write:

“In alpine settings, the transition from a land-terminating glacier to a lake-terminating glacier could therefore change the dynamic regime of the glacier, and such a transition might be partially decoupled from climate (Benn et al., 2012).”

The Fig 1: I would suggest using the term “excluded” rather than “uncovered” because of “uncovered” sometimes being used synonymously with “clean” or “debris-free” in a debris covered glacier context.

Response:

We thank the referee and follow his/her suggestion.

L100: A reference like Anderson & Anderson, 2016 seems relevant here. Link: <https://doi.org/10.5194/tc-10-1105-2016>

Response:

We thank the referee and follow his/her suggestion.

L138: “The maximum number of image pairs separated by one year was selected for the month of November, as this month is associated with low cloud cover and a relatively high snow line.” – It is unclear what you mean by this. Where is a “maximum number” coming from this analysis? Are you saying you’re using November as an end-of-year date?

Response:

We use all available imagery from the month November. ‘Maximum number’ is indeed somewhat misplaced here and will be omitted in the revised manuscript.

Sec 3.1.2 & Table 2 - we need more detail about what velocity fields represent? Rather than just “effective date”, it would be useful to know the date of the first and second images used for each correlation. Or at least the midpoint date and the time span between the two images used. Otherwise we don’t know if we are seeing annual velocities, seasonal velocities, or some combination. Perhaps this could be visualized as a plot showing the temporal distribution of image pairs for each footprint?

Response:

We thank the referee for his/her useful suggestion. We will prepare a plot as suggested and add this to the appendix, as we feel that it might be less appropriate for the main text.

L146-148: does the off-glacier used for estimating coregistration error have a similar aspect & slope distribution as the studied glaciers? If not (e.g., steep glaciers & flat area for uncertainty estimate), this error estimate may not be accurate.

Response:

For the off-glacier area we used mountainous areas that likely do not show a lot of mass movement or creeping surfaces (see figure 2). Very steep slopes in high permafrost areas (around the glaciers) are not appropriate as we cannot expect this to be zero. Also, glacier ice surfaces, especially the ablation zone, do not show such these extreme slopes. Therefore, we think that the stable area chosen is adequately representative.

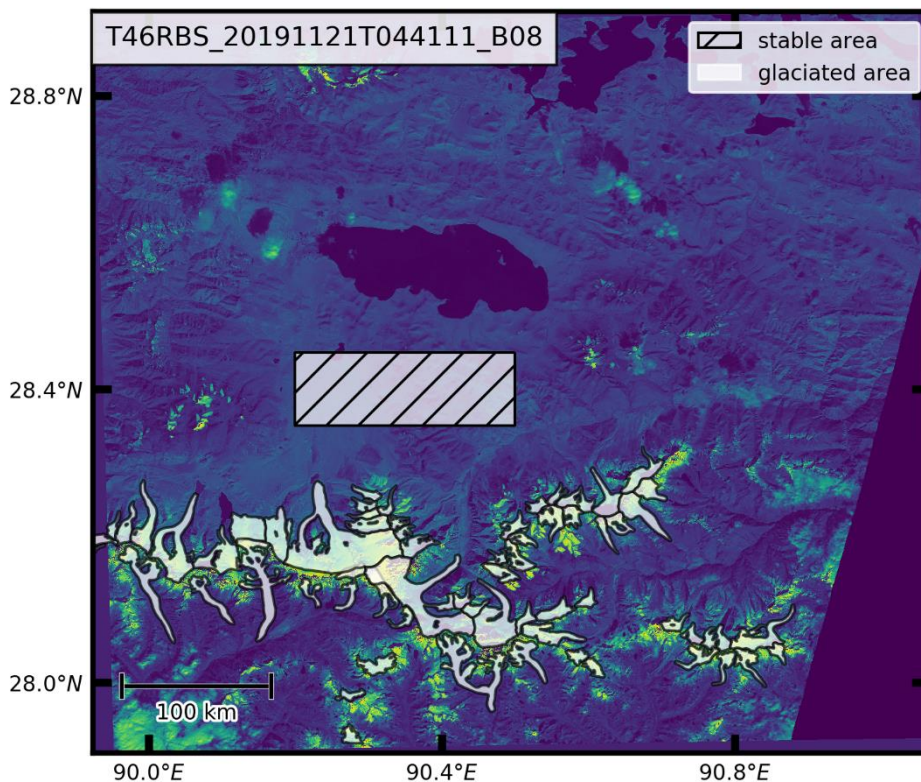


Figure 1: Image showing one of the stable areas selected for each image tile location.

L290-291: I am a little confused by this because it seems like basal friction and effective pressure should depend on each other (not be independent as stated). For example, a bed with lower effective pressure will be more slippery (lower friction). Can you better justify this statement or better describe what this experiment is meant to test? If you're not changing sliding rates (through reduced basal traction) by altering lake level, then what exactly are you doing?

Response:

Thank you for this comment. In our manuscript we wrote in line 49-50:

'Two key factors can be identified which make lake-terminating glaciers distinctively different from their land-terminating counterparts, namely the stresses at the bed and the terminus of the glacier.'

In our experiment we try to get insight in both of these factors. Firstly, we conduct an experiment where basal friction is effective pressure dependent, allowing for both stresses at the bed and the terminus of the glacier. Secondly, we perform the same experiment, but let basal friction be independent of effective pressure, which then would depend on other factors such as drag from surface roughness. Although not necessarily realistic, this experiment enables us to separate the influence of the proglacial lake on the glacier velocity through either basal friction or forces at the terminus of the glacier. We will rewrite this section to describe this experiment more clearly.

L292: exponent in A_s is not superscripted.

Response:

We thank the referee for spotting this mistake.

Sec 4.1: How does the absence/presence of debris cover affect velocity uncertainty? Are there systematic differences in debris cover between lake & land terminating glaciers?

Response:

We have already partially answered the latter question and devoted some text on this in the discussion. We wrote in line 521-522:

"This, together with the over-representation of clean-ice glaciers in the lake-terminating glacier population (50 out of 70), explains a large part of the lake-land velocity contrast (Fig. 8a)."

We will analyse the uncertainty distribution among debris-covered glaciers and clean glaciers. We will incorporate this into the text if this analysis shows to be important.

Sec 4.2: it seems like the most relevant thing here is whether there are systematic differences between mismatch land & lake terminating glaciers between your estimates & those in ITS_LIVE. If all of your velocities are faster than ITS_LIVE, that doesn't seem like that big of an issue because your study focuses on differences between these groups and is less concerned with absolute accuracy of speeds. However, there would be a problem if lake

terminating glaciers are systematically fast biased and land terminating glaciers are slow biased. This analysis should be undertaken.

Response:

We agree with the referee that is an important consideration. However, as Figure 4 shows, the largest differences in velocity estimates between the different datasets are observed away from the glacier termini, where any contrasts in methodology or imagery should be most apparent (relating to reference window). This suggests that there is no indication why, around this area of interest, lake-terminating glaciers would be positively biased and, which forms a part of the referee's argument, land-terminating glaciers would be negatively biased.

Table 5: I think you mean ± 4.1 for lake terminating slope (written as 41).

Response:

We thank the referee for spotting this mistake.

L392: Do you mean “concurrently, IF a large fraction...”? Or are you saying that this is true?

Response:

We are saying that this is true as this is observed from our results. However, we will go through this sentence again and try to create more clarity.

L473: I think you mean 1 km, not 1 km² ?

Response:

We thank the referee and will correct this flaw.

L517: This sentence is fairly awkward and it is hard to determine what you are trying to say.

Response:

We will rewrite this section to create clarity.

References:

Farinotti, D., Huss, M., Fürst, J. J., Landmann, J., Machguth, H., Maussion, F. and Pandit, A.: A consensus estimate for the ice thickness distribution of all glaciers on Earth, Nat. Geosci., 12(3), 168–173, <https://doi.org/10.1038/s41561-019-0300-3>, 2019.