

Review of “Automated detection of ice cliffs within supraglacial debris cover”

by Sam Herreid and Francesca Pellicciotti

This study develops a new method to map ice cliffs based on the slope of a high-resolution (< 5 m) DEM. The method is developed on Canwell Glacier in Alaska and compared to ice cliffs that were delineated from high resolution visible and thermal images. The method was also applied to Ngozumpa Glacier, where a pre-existing dataset of ice cliff delineations used to assess the method’s broader applicability. The developed method is quite novel in its use of a centerline extension length, which enables the method to capture the smaller ends of the ice cliffs. Another novel part of the method is the generation of probability maps and the assessment of the model’s performance, which enables the accuracy and precision to be properly assessed.

For the most part, the manuscript is very well written and easy to follow. The problems associated with mapping ice cliffs are well described as is the relevance of this study. Specifically, ice cliffs on debris-covered glaciers are localized areas of high melt such that they can significantly alter the evolution of debris-covered glaciers; however, mapping ice cliffs remains difficult. The methods developed in this study are a major advance and will be a significant improvement once high resolution DEMs are available on a global scale.

The only general comments I had were concerning the use of 2D area versus 3D area and the accuracy of the validation datasets. All other comments were very minor. All in all, I believe this study is a sound contribution to the field and recommend this study for publication after minor revisions.

General Comments

One of the major improvements of this method is the ability to estimate the 3D area of the ice cliffs as opposed to 2D area typically derived from nadir-looking satellite imagery. First off, the authors refer to these areas in a variety of different ways throughout the text, e.g., true ice cliff area, area considering slope, and 3D area. While they are fairly easy to understand, it may be clearer for the reader to use one set of terminology throughout the paper. Furthermore, when comparing 2D area and 3D area (Section 4.1), the authors state the ice cliffs make up 4.9% of the map view area, but that this underrepresents the true area by 19%. This seems to imply that the true ice cliff area would be 19% greater (~6%) of the total glacier area; however, that does not factor into account what the true glacier area would be. I wonder how much the ice cliff area changes compared to the 3D glacier area? If this is substantial, then it would highlight the importance of assessing 3D area, while if it is negligible it may indicate that using 2D area is sufficient. Either way it could have important implications for modeling the evolution of debris-covered with ice cliffs included.

I found the discussion of how an ice cliff is defined to be very interesting. Specifically, determining how thin debris that is typically present on ice cliffs is considered is a challenging problem. The high resolution thermal imagery truly enabled this problem to be investigated, but I wonder how the authors “liberal outlines” influenced the ice cliff area? Is there a way to estimate the percentage of ice cliffs that were easy to include versus those that were questionable? Were the additional ice cliffs that were added to Ngozumpa Glacier all these questionable ice cliffs? If so, the percentage that was added could provide some indication as to the difference in ice cliff area that different individuals may have. Furthermore, this may enable the authors to quantify the uncertainty associated with the validation dataset, which did not

appear to be considered, i.e., this is different than the uncertainty associated with the developed method compared to the validation dataset.

Specific Comments

P1, L5: “include” not included.

P1, L14-16: Sentence is difficult to read. Perhaps, “... are still poorly understood processes, in part, due to a lack of base data, which is an obstacle for establishing a robust understanding...”

P1, L20-21: present *on* a debris *covered* glacier

P2, L16-17: “a small area of low angle... enclave” does not make sense. Both area and enclave are referring to a specific area, so it is difficult to understand.

P3, L2-3: “North and south facing ice cliffs will likely be optically distinct and crescent to circular ice cliffs will exhibit” does not make sense. Please clarify what you are trying to say.

P3, L28: “identify” not identifying

P5, L26-32: “Ngozumpa Glacier was selected for two reasons, first, ...”. The second reason does not appear until Line 32 making it difficult to following what the two reasons are. I would suggest either making it two separate sentences and keeping it the same, i.e., “Ngozumpa Glacier was selected for two reasons. First, ...” or state the two reasons in that sentence and then go on to describe them.

P5, L26-27: this sentence is repetitive. Distinctly different geographical location and notably different from Canwell Glacier mean the same thing.

P7, Eqn 1: Why the use of Y and N as opposed to 0 and 1, which is more typical of a binary system?

P7, L23: “Where” does not need to be capitalized. Also, does the paragraph after an equation, which is still part of the previous paragraph need to be indented? If not, then change this after all equations.

P8, L8: Is the $A_{\text{cliff},i}/\text{area}(\text{spatial domain})$ a comparison of 3D cliff area to 2D glacier area? If so, this seems as though you are comparing apples to oranges and it should be 3D area to 3D area or 2D area to 2D area.

P9, L16-17: I would recommend changing this to the positive instead of using a double negative – “it is critical that segments are large enough such that meaningful statistics can be computed”.

P10, L15: Once again, ice cliff area is 3D, but is the glacier 3D area also considered in this manner? I would imagine this would impact the area associated with false positives, etc.

P11, L28: Is thin debris cover quite sensitive to this pixel value threshold? Does it greatly alter the percentage of thin debris on the ice cliffs?

P12, L6-7: How does the 19% increase alter the percentage of the total glacier area (3D in this case)? See the General Comment.

P13, L16: I would suggest stating the distance from the terminus of the lower ablation zone or state the area that was investigated based in Section 2.2.2. It's shown in Figure 1, but it may be nice to have the text as well.

P13, L24-25: Sentence is confusing. Please clarify. Specifically, what is assumed to be transferable to Ngozumpa Glacier? The model input parameters, the methods?

P14, L6: "tested" not testing

Section 5.3: The use of high-resolution thermal imagery to map ice cliffs seems to be invaluable in assessing the thin debris on ice cliffs. I am surprised that this important dataset is not mentioned with respect to future work, i.e., while higher resolution DEMs will enable this method to be applied, it appears that high resolution thermal imagery is needed to assess the accuracy of the methods in other areas, correct?

Table 2. Appear to be missing blue/best error distribution?

Table 3. No bold font as alluded to in the caption. Also, no red TP rate or blue error distribution?

Figure 1. For someone not familiar with Ngozumpa and Canwell Glaciers it may be difficult to determine which glacier is which. I would recommend stating left and right or placing (a), (b), and (c) on the figures.

Figure 3. There are 3 colors in the inset plots and yet only 2 colors in the legend. What is the third color representing?

Figure 4. May be nice to show L_e on both sides.

Figure 5. The surface temperatures are counter-intuitive. Red is cold and blue is hot. Figure 10 has them as red is hot and blue is cold. I would recommend switching these such that they are intuitive and consistent.