Review 2 – B. Raup

The following response addresses the comments made by B. Raup point by point. *Sections in italic are comments made/issues raised by the reviewer.* Regular sections are comments/responses by the authors.

34. *This paper is an important contribution to the field of automated glacier mapping. As is well described in the paper, centerlines are important for a variety of reasons, including glacier flow modeling, automated glacier length change determination, and estimating glacier volume. Glaciers are numerous, so it is important to have an automated way of obtaining centerlines of glaciers, as manual methods are prohibitively expensive for large-scale studies.*

    Thank you very much for the review, which improved our manuscript. We have implemented all the suggested changes except for the additional comparison between the centerlines (see answers to comments 35/47). Most importantly, in response to comment 53, we now quantify our errors in a more consistent way.

35. *Overall, this contribution is well structured, well written, and covers an important new method. Thus I recommend that it is published with only minor changes. The largest of the minor changes would be a quantitative comparison between centerlines from this method and another method along the entire length of the centerlines – not just looking at their lengths. This could be easily done, for example, but looking at the mean distance between the vertices of one centerline and the corresponding one from another method. Also, a figure showing centerlines from different methods would help the reader understand the differences in quality.*

    To our knowledge, only the tool 'Flow Length' from the ESRI ArcGIS software package has been applied on a large scale so far. While this tool yields a length parameter for every glacier (page 5206, lines 21 to 24), it does not output an actual physical line that could be checked as suggested by the reviewer. Accordingly, we would first have to manually digitize such independent lines. To allow for a useful analysis, this would have to be done for many glaciers of each glacier type (page 5212, line 27), which is very time-consuming.

    It is correct that the technical implementation of determining the mean/median/summed distance between the lines is relatively easy. However, the resulting numbers can not be readily interpreted. For example, we do not know whether a large glacier with a mean distance of 200 m is better than a small glacier with a mean distance of 30 m. To be comparable among glaciers, these numbers would have to be related to the respective widths of the glaciers, which are not derivable easily. Comparing lengths from different approaches, as done in this study, does not raise such problems, as length ratios can be calculated easily.

    We agree with the reviewer that a quality analysis as suggested should be implemented in the near future. However, given the focus and the length of the manuscript, we prefer to incorporate the comparison into a follow-up study. To help the reader better understand the quality of our centerlines without the suggested analysis, we have added an additional map (new Figure 9) that shows the final centerlines for the Eastern Alaska Range. Medial moraines are numerous on these glaciers and can be used to independently check our centerlines.

36. *Page 5191, line 14: 'thereof' → 'the resulting'*

    Revised.

37. *Page 5192, line 16: 'either one of them often required' → 'both of which are frequently requirements'*

    Revised.

38. *Page 5194, line 10: Remove comma (',') after the word 'areas'.*

    Revised.

39. *Page 5195, line 8: Change 'We consider filling and filtering as most important for large receding glaciers, ending in flat terrain, that are generally characterized by a rough surface with numerous depressions.' to 'In this method, filling and filtering are most important for large receding glaciers, which end in flat terrain and are generally characterized by a rough surface with numerous depressions.'*

    Revised.

40. *Page 5195, line 16: Is it assumed that the spacing of vertices in the polygons is always less than the 100 m sample spacing? Otherwise, it would make sense to look at the vertices themselves rather than sample every 100 m. Please clarify in the text.*

    We have to avoid sampling the same DEM cell multiple times as our local maxima approach would not work properly in this case (neighboring cells could have the same elevation even in the case of an actual glacier head). By using a 60 m DEM (Page 5193, line 6) in conjunction with a 100 m sampling distance, sampling of the same DEM cell can be avoided. In fact, an 85 m sampling distance would be sufficient if the glacier outlines were completely straight on a sub-pixel scale. To allow curvature on a sub-pixel scale, we use a 100 m sampling distance.

    We revised the text to make this clearer: 'Our algorithm samples the 60 m DEM in predefined steps (100 m) along the glacier outline, including nunataks. The 100 m sampling distance precludes repetitive sampling of the same DEM cell. Each sampled elevation is then compared to its neighboring points along the outline.'

    One could conduct the search for local elevation maxima on a DEM with higher spatial resolution and denser sampling distance. However, tests indicated that the results do not improve, while the computing time increases.

41. *Page 5197, lines 20-25: Normalizing and then rescaling using f1 and f2 seems like overcomplication. Why not remove f1 and f2 entirely, and then tune a and b to the normalized values? That would remove two parameters. It would also make the method more scale independent, I think. Alternatively, f1 and f2 could be replaced by one parameter f, where $0 \leq f \leq 1$, by multiplying the first term by f and the second by (1-f).*

    The first comment is related to comment 24 of reviewer 1 as well as our 'Discussion' section (page 5221, lines 17 to 21). We certainly believe that there are shorter functioning equations. However, we have conducted the largely manual quality control with the equation as given in Eq. 2. A recalibration would yield slightly different cost grids, so the entire quality control

would need to be repeated. Given the very large study area, this is not feasible in a timely manner. We also question whether shorter equations would be more intuitive than the equation as is.

An equation without the factors f_1 and f_2 has been considered. This would always yield a penalty grid with values between 0 and 1, no matter the used exponents a and b. Different a and b values would only change the curvature of the penalty grid. Tests indicate that penalty values must be much larger than 1, which calls for at least one factor to scale the penalty values. A working equation is suggested in our 'Discussion' section (page 5221, lines 17 to 21). Here, we take the same value for f_1 and f_2, together with recalibrated a and b parameters. This reduces the factors by one (f_1 and f_2 become f), still providing results of good quality.

42. *Also, the power-law form for the terms in equation 2 tend to produce a cost grid with a flat bottom (low curvature) to the cross-glacier minimum. Did you try other forms that would yield a sharper notch, such as f*abs((max(d)-d)/max(d))?*

    The flat bottom and the very steep edges provided by this equation are required to obtain natural centerlines. This is explained between page 5197, line 26 and page 5198, line 6. The very steep edges prevent the lines from reaching too close to the glacier edges (or even touching the glacier boundaries) and the flat bottom prevents the lines from being hardcoded to the glacier center. Ideally, the lines are not hardcoded to the glacier center as this would require considerable smoothing prior to the final derivation of the centerlines (the hardcoded lines reflect small changes in the outlines and thus lead to ragged initial results).

43. *Page 5198, line 24: PEAK and its expansion don't match. Should be PAEK. Should have a reference as well*

    Revised. We also added a reference.

44. *Page 5205, line 7: I would say that 'deceeded' isn't a word yet. Though it appears in Merriam-Webster online dictionary in the 'new words and slang' section, it appears not to be widely understood. Thus, replace: 'The proximity analysis is applied only within the glacierized terrain, that is, a branch separted by nunataks is not flagged unless k is deceeded at a point without nunatak between branch and reference branch.' with 'The proximity analysis is applied only within the glacierized terrain. That is, a branch separated by nunataks is not flagged unless the distance is less than k at a point without any nunataks between the branch and the reference branch.' Note the correction of the typo in 'separated' in the above.*

    Revised.

45. *Page 5205, line 22: 'Glacier termini are moved...' – make it clearer that this is not the algorithm, but the manual adjustments.*

    We have changed the sentence to 'Glacier termini are manually moved...'

46. *Page 5205: It's not clear to me how the decision is made to optimize or not. Is this done automatically, or manually?*

    During the quality analysis, we inspected visually to decide whether a head, terminus or centerline needs to be corrected.

We added the word 'visually' in the sentence of page 5205, line 18: 'We assess visually...'

47. *Page 5206, line 15: It would be good to see quantitative comparisons between at least a few pairs of centerlines. This could be done by computing the mean distance between vertices of one and the other, for example. Also, a figure showing pairs of comparable centerlines plotted together would help the reader understand the quality of these results.*

    See answer to comment 35. To help the reader better understand the quality of our centerlines without the suggested comparison, we have added an additional map that shows the centerlines for the Eastern Alaska Range. Medial moraines are numerous on these glaciers and can be used to independently check our centerlines.

48. *Page 5208, line 24: Change 'In Alaska and northwest Canada, only a handful of glaciers drain into multiple tongues, therefore, the amount of manual intervention remains relatively small.' to 'In Alaska and northwest Canada, only a handful of glaciers drain into multiple tongues, hence the amount of manual intervention required is relatively small.'*

    Revised.

49. *Page 5209, line 17: Change 'constellations' to 'combinations'.*

    Revised.

50. *Page 5212, line 6: maxima → interfere*

    Revised.

51. *Page 5212, line 11: ... in any error 'category' (should be singular)*

    Revised.

52. *Page 5213, line 9: insert 'than' between 'results' and 'from'.*

    The sentence was rephrased to: 'Calculating the ratios of the lengths obtained from different methods allows a comparison among glaciers.'

53. *Page 5220, Table 2: Why isn't the total number of centerlines equal to the number of heads? Is it because some centerlines are deleted later, essentially deleting heads too?*

    This is because 11,350 lines are deleted within step 3. We acknowledge that deleting the centerlines essentially deletes the heads, too. Accordingly, we now relate the number of deleted and added heads to the final number of heads after step 3 (41,860) rather than to the number of heads initially determined in step 1 (53,210 heads). Because we now relate 'deleted heads' and 'added heads' to different totals, their percentages have changed ('deleted heads': 3.5% → 4.4%. 'added heads': 2.0% → 2.6%). Table 2 has been updated accordingly.

54. *Page 5227, Figure 7d: There's a major tributary to the '4' branch missing from the result, but this is not discussed in the text.*

    This is discussed on p. 5209, lines 2-9, using Figure 7b as an example. 'The corresponding centerline covers one branch, other branches that may originate from the same area remain without centerlines. This is illustrated in Fig. 7b, where not all branches have centerlines allocated.'