Review of "Geodetic point surface mass balances: A new approach to determine point surface mass balances from remote sensing measurements" by C. Vincent et al.

Vincent et al. present a method to derive glacier point surface mass balances from vertical ice velocities and surface elevation changes. Their method avoids the large uncertainties associated with determining representative surface slope with which to calculate emergence velocities. Typically, surface roughness and irregular larger-scale glacier surface topography account for considerable uncertainty in slope estimates. By eliminating this large error source, this method reduces uncertainty on estimates of geodetic point surface mass balance. Determining vertical velocity at the glacier surface remains a challenge, which here, the authors measure at ablation stakes. Their method demonstrates the potential for expanding the limited number of point observations available globally of surface mass balance, which are labor-intensive. The authors demonstrate that their method can also be used with remote sensing information—necessary for wider applicability of this approach. The challenge of well-representing the vertical velocity, particularly with respect to time, requires further attention. If attended to, this method represents a valuable contribution to the glaciological community.

There are numerous uses for this method beyond the primary aim, including the establishment of new records of mass balance, or the filling of data gaps in glaciological records. When new glaciological records are established, this method could be applied to extend the point mass balance record to the years preceding the in situ record by collecting geodetic data until in situ measurements can begin. Further, glaciological observations for some glaciers, or some portions of some glaciers, are incomplete in some years, due to logistical or other challenges. This year (Covid-19) offers one such example for some glacier records. This method would allow for point mass balance to be determined from only remote sensing information for given points or a given glacier, avoiding the issue of gaps in valuable long-term records.

Like Reviewer 1, I agree that some form of a sensitivity analysis regarding the spatial and temporal representation of vertical ice velocities would be beneficial, and not onerous to conduct. I elaborate this point in comments below.

I also find it interesting that the trend of vertical ice velocity decrease seems relatively constant e.g. Figure 11, and that the potential bias introduced by assuming constant vertical ice velocity may in part be accounted for by applying a empirically-based decrease-rate factor (perhaps via horizontal velocities using the ratio of horizontal ice velocity to vertical ice velocity for a given area (either modeled or observed)) to represent the decline in vertical ice velocities expected to accompany horizontal ice velocity over decadal-scales.

Below I present specific line-comments.

Specific comments

1 Add "glacier" to the title.

L 54-60 Are valid statements, though it should be highlighted that a series of point surface mass balance observations, e.g. across an entire glacier or elevation band, can be considered a direct climate signal. Individual point balances may indeed respond to climate, but may represent local processes (wind scour, avalanching, etc.). Perhaps this should be briefly discussed.

L107-109 Were there any observations taken to constrain this error? It is often useful to test a few control points with the same method (occupation length etc.) to assess uncertainty.

L112 Emergence measurements seems confusing to me. This refers to stake height, or stake protrusion, correct? I would re-word for clarity, as emergence velocity is used throughout this manuscript, it is confusing to use emergence to describe measuring a different quantity, even though the word is correctly used here.

L133-135 Resampled from 1.0 m to 0.1 m? But I thought the ortho was 0.1 m-resolution and then used to produce a 1.0 m-resolution DEM. Perhaps clarify.

L149 The contours are nearly invisible. Either make them stand out more or reduce their number (larger interval). The blue and green dots are difficult to make out as well.

L174 Perhaps down-glacier direction instead of downslope direction, local slopes will often be upslope but down-glacier.

L217-219 Yes, and perhaps most importantly, will not be affected by the advection of surface topography, that is, if we measured a given point through the year, crevasses, surface roughness, supraglacial streams, etc, may be advected over a given point, but your formulation, measuring a stake embedded in the ice, avoids these complications.

L264 Nice graphic, it seems to me that the vertical ice velocity is in fact changing over the three-year period, with a decrease across the three years, as can be seen in the horizontal velocities in the figure as noted in L242-244. The vertical velocities are decreasing with the horizontal velocity decrease.

L281 It may be valuable to describe how slope was determined, between the two GPS survey locations? From the DEM? From slope measurements around the two survey points? It may be worthwhile to test using different methods to determine slope, if remote methods can be used, does this represent the slope better, or not? Either way the conclusion will be of value.

L298 Figure 7. Certainly greater dispersion, but the comparison does not look unfavorable. The decrease in emergence velocity through time can be seen with the red dots below the black. Why not add in the regression lines?

L337 Figure axes labels are difficult to read at this size. Perhaps use only a single y-axis label and slightly increase font size for all text.

L377 remove extra period

L517-530 This section describes the competing factors which influence vertical velocities well. Overall, the authors make a compelling argument for minor changes in vertical ice velocity. However, two primary issues arise from their formulation: 1) that this method is only suitable for relatively low-angle glacier terrain, which implies that this method can primarily only be applied for valley glacier tongues; and 2) that while the change in vertical ice velocity is indeed minor, that it may not be negligible. As the authors point out, the horizontal ice velocity decreased by around 4% per year---regardless of whether this trend were to continue---such a rate of decrease over a decade is substantial, and thus is cannot be assumed that vertical ice velocity is stable over decadal scales. Decreasing ice velocity has been observed for many glaciers around the globe (Dehecq et al., 2019; Heid and Kääb, 2012), and given the current rate of ice wastage, that is, disequilibrium of glaciers (Christian et al., 2018; Zemp et al., 2015), assuming stable vertical ice velocities is questionable. Figure 11 highlights this, with vertical velocity falling by 0.5 m a^{-1} to 1.0 m a^{-1} over a decade which likely would present a non-negligible bias in assessing surface mass balance from remote data with this method over decadal periods. As the authors state, part of the decrease in vertical ice velocity will be compensated by reduced ice flux convergence/divergence produced by bedrock topography.

L469 An uncertainty of 0.2 m w.e. a^{-1} seems optimistic for decadal periods, but accurate for short periods, like the three-year window of this study. Perhaps it would be best to state this directly, that surface mass balance can be obtained from this method with an accuracy of about 0.2 m w.e. a^{-1} over periods of 1-5? years, but over periods of 5-10+ years with an accuracy of XX m w.e. With the XX value determined by calculating the uncertainty or bias in using one year's vertical ice velocity to calculate mass balance for years in the 5-10 year range for stakes where that length of record is available in this study.

L591 It is not clear what the range represents: 0.2 m w.e. if the elevation accuracy is determined to be 0.1 m and 0.6 m w.e. if it is determined to be 0.3 m? This is a critical point that should be expanded upon. If this method is to be applied elsewhere—e.g. with other remote datasets, what accuracy/resolution is needed, or how will uncertainty scale with reduced accuracy/resolution?

L616 Change "dataset" to "datasets".

Citations: I suggest adding DOIs to all references for which one exists. Currently only some entries have a listed DOI, and some DOIs are "https:…" and others just the DOI itself. Ensure consistency with the TC formatting guidelines.

References

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Heid, T. and Kääb, A.: Repeat optical satellite images reveal widespread and long term decrease in land-terminating glacier speeds, The Cryosphere, 6(2), 467–478, doi:10.5194/tc-6-467-2012, 2012.

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