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Interactive comment on "Mapping snow depth at very high spatial resolution with RPAS photogrammetry" *by* Todd A. N. Redpath et al.

Anonymous Referee #2

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This study presents results for a small watershed in New Zealand where repeat unmanned aircraft flights were used to map surface elevations using photogrammetric methods, and then snow depth via digital surface model differencing. There was one snow free flight, and two snow on flights, one winter and one spring. Although the snow depth results are presented, the main focus of the paper is more technically focused on methods, uncertainty, and validation.

The use of unmanned aerial systems in earth science is growing in popularity for good reason; the units are small, relatively inexpensive, easy to deploy, and the software to carry out structure from motion photogrammetry is becoming more accessible and user friendly. This study is a relevant and useful contribution to the growing body of literature using UAS to map snow depth and cryospheric processes at high resolution,

fits within the scope of The Cryosphere, and should be accepted for publication after revisions. Following are broad recommendations that would improve the manuscript, namely in terms of readability and accessibility by a broader audience, particularly one that may not be familiar with mapping surface elevations/snow depth with UAS.

- The acronym RPAS was new to me, likely a regional difference in terminology that I am unfamiliar with. In terms of search-ability I would suggest the switch to UAV or UAS (which is already used in the paper- so that would simplify things), or at minimum, mention the different terms use for unmanned aerial systems in the introduction and justify the use of RPAS rather than UAS.

- The manuscript reads as if the authors assume the reader has some understanding of photogrammetry, which is not necessarily a safe assumption. Something as simple as 'overlapping pictures are used to reconstruct a continuous 3 dimensional surface' very early on in the introduction would be helpful to provide context to the reader, and also making sure important terms are defined (like tie point). Also aerotriangulation is simply the georeferencing method by which ground control values are assigned to points, this could be defined once and then the term georeferencing could be used afterwards, which is a more accessible term. This paper dives into the technical very quick, but shouldn't forget to cover the basics, as well, since this is still a relatively new method for mapping snow depth.

- This paper does a great job of covering uncertainty, but I think it is interesting and important to recognize the practical limitations of this method early on in the paper. It currently cannot scale up beyond small watersheds for practical reasons, namely flight times and flight restrictions, which vary widely from country to country. Also setting out ground control points can be just as time consuming and limiting as carrying out snow surveys, which is why the authors themselves wanted to reduce the numbers of GCPs used per flight. Also vegetation is a critical issue in watersheds that have thick brush, or trees for that matter, so it is only useful and accurate in alpine watersheds. Discussing how these issues might be be overcome in the future to make this method operationally

useful would be very interesting (i.e. that use of RTK on the UAS). As it stands snow in medium to large scale, and/or vegetated, watersheds can only be mapped with lidar, and while it is notably missing in the paper, repeat high resolution lidar flights for snow depth and SWE are being done in the Western US by the Airborne Snow Observatory at operationally relevant scales (https://doi.org/10.1016/j.rse.2016.06.018).

-In the introduction the authors emphasize how valuable this method could be for understanding spatial variability in snow depth at high resolution, but then spend very little time actually presenting snow depth results for the two snow-on flights. I do think the uncertainty discussion is important and relevant, but so is the snow depth results, and more time should be spent on them. Also, snow water equivalent is only mentioned briefly at the end, this should be an entire results in the section and the measurement of densities should be covered in the methods. An estimate of SWE for the two flights would be really interesting. (Minor note, on pg 9, line 29 the authors say the nominal accuracy for snow probes is +/- 1 cm, if this is from the literature it should have a citation, because I understand it to be much larger due mostly to user error, which they themselves recognize, in detail, later.)

-It is quite obvious that one of the authors has a thorough understanding of statistics. It gets tedious, and in these sections/figures most readers will just skip over. I would suggest for each relevant result adding 1 plain language summary before diving into the details to improve readability. 'Uncertainty is larger for more rapid changes in topography'.

-It is not clear to me why the authors spend so much space in terms of text and figures on georeferencing errors with older software when it could be covered in a few sentences, and more time could spent on more relevant results (i.e. the gist of this is that the old software had large errors, the new software performs better, so the old software should be avoided). This would also reduce the number of figures (there are so many).

- General editing comments: Writing structure and grammar need some attention, as

they were notable enough to distract from the science being presented. The first paragraph of the Intro needs to be rewritten to read more consistently and should introduce the context and motivation for this study specifically. All paragraphs should be at least three sentences in length. There are many run on sentences that made reading and interpreting intent challenging. Watch out for the use of colloquial terms in a scientific context ('hamper' or 'impair' for something that is a challenge or difficult, the use of the word 'see' or 'saw' for things that don't have eyes). A small but related note, I associate the term epoch with geologic time scales (a division of time that is a subdivision of a period and is itself subdivided into ages, corresponding to a series in chronostratigraphy), I suggest not using this term and in most places through out the text it is unnecessary. For overall readability of the technical sections it might be useful to think about what content contributes to the overall purpose of the study given the audience (like equations 1-5, I don't find these critical to include, interested readers could be provided with a reference to follow up with). It maybe useful to have someone that is a physical scientist, but not involved in the study, read through the paper and give feedback.

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