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Discussions
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Interactive comment on "High accuracy UAV photogrammetry of ice sheet dynamics with no ground control" *by* Thomas R. Chudley et al.

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The manuscript "High accuracy UAV photogrammetry of ice sheet dynamics with no ground control" outlines a method for the collection of high accuracy DEMs and orthomosaics from UAV without the use of GCPs, referred to as GNSS-AT. This method is applied to two study sites (calving face and internal region) on the Store glacier in Greenland. Perhaps the greatest limitation to UAV surveys is the collection of GCPs, this is particularly true for glacier environments where access to the survey area is often impossible. The method outlined by the authors provides a low cost, relatively simple method to solve this problem. It is important to point out that this solution is not especially novel, as it has been implemented relatively widely outside of glaciology. However, this is certainly one of (if not) the first applications of the method to

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glaciology and is applied over an interesting and challenging environment, providing new insights into these systems. I believe this paper is a unique contribution and will find widespread interest within the glaciologic community, and within the broader earth sciences. The authors do an excellent job of explaining the method in a logical and easy to follow manner. The manuscript is well written and logically laid out.

Major Comments:

One issue that is not discussed is the role of UAV pitch, roll and yaw on the accuracy of the camera positions. The authors apply a standard offset of -7.9cm in Y direction and +13.2cm in the Z direction. However, the actual offset between the antenna centre and the camera sensor centre will change as a function of the attitude of the UAV itself. The only way to correct this is to collect accurate IMU measurements of the UAV/Camera attitude at time of image capture. Given the financial constraints of a high quality IMU (which are clearly discussed) this is not possible. But it would be good to include mention of this as a possible error source and to calculate a ballpark estimate of this error. This can be done by looking at the IMU record from the pixhawk to identify the range of pitch/roll/yaw experienced during the flight and then calculating the impact of these values on the offset values. Also, a picture of the UAV setup showing this offset would help. Finally, I presume that the Y offset would flip depending which direction the UAV is flying? Is that the case? And if so how is it accounted for? Best practice for this design and without an IMU is to install the GNSS antenna directly above the camera so that only the Z offset is considered, and this is more or less static given vertical offsets are typically small.

While this technique is relatively new in its application to glaciology, there have been a number of journal publications and grey literature that discuss the benefits and accuracy of GNSS-AT methods. The authors should include some of these citations and briefly mention this work in the introduction and/or discussion. Also some of these papers and industry grey literature compare GNSS-AT methods against more common GCP methods, which is arguably the best way to assess the accuracy of GNSS-AT.

This is not done in this paper so would provide strong justification for the viability of the method.

One final critique is the accuracy assessment. While I believe what was done is acceptable and does prove the method, it would be beneficial to have some sort of external comparison. Either by comparing the GNSS-AT method to the more typical (and accurate) GCP method, or to some other dataset, e.g. terrestrial/airborne LiDAR. This could be done over a small subset area where access is not as much of an issue – e.g. the bedrock zone.

Specific Comments:

3:4 technically the second ‘bedrock’ exposure area is feasible to install GCPs, reword this accordingly.

3:5 prohibits should be prohibit

3:12 at last 1948 should be at least 1948

3:16 missing units, guessing km – should be “at least 30 km inland”

4:7 Delete “a” – “the UAV is capable of $\sim$1hour of flight time at $\sim$60km”

4:16 “allowing flight plans to avoid collision with cliffs” this sentence is awkwardly worded, perhaps rephrase

4:18 “Out camera” should be “Our camera”

4:25 Great method! Is there a reason you didn’t do this over the calving face as well?

5:15 Repeats information presented briefly at 4:10 – Perhaps you can remove the text at 4:10 as an expanded discussion is included here.

6:14 “was achievable” do you mean “was located nearby”

6:14 If you used the EMLID reach in RTK mode you would be using the EMLID as the base station, correct? In which case the base station would only be single frequency.

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So this is another reason not to use the EMLID in RTK mode I believe. Or can EMLID interpret RTK corrections from other base station receivers (e.g. trimble etc?). On that note, I didn't see the make and model for the local dual frequency base station "B1". Also, reference station is trimble Net R9 receiver, but antenna not provided. Good to include these details if available.

6:15 PPK solutions are also often more accurate than RTK solutions as precise ephemeris data for the GNSS satellites is available during post processing.

8:20 detected over "a" six-hour period

8:27 More "than" 48 hours. . ..

11:5 reveals, perhaps reveal?

12:1 Couldn't you install the on ice base station for a few days (anywhere on the ice) and then process that data using the NRCAN PPP kinematic processing method (or OPUS) and then just pull the position of the base station at the time of the flight and use that as the static position for PPK processing of the UAV. That would mean you could work anywhere on the ice sheet and wouldn't be constrained to the 60km distance from the static reference station installed on bedrock.

14:4 the peak of which "is" centred

15:27 "moving one-ice GCP" should be "on-ice"

17:35 I think another point here is that dual frequency tends to provide more accurate positions on moving objects (i.e. UAV) especially in the vertical.

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