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Geoscientific Instrumentation Methods and Data Systems Discussions

Interactive comment on "In-situ measurements of the ice flow motion at Eqip Sermia Glacier using a remotely controlled UAV" *by* Guillaume Jouvet et al.

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We would like to greatly thank you for your comments and suggestions, which will help to improve the manuscript. Among them, your comments 6, 7, and 8 call for some answers, which we give below.

6. "... we found an horizontal error between 23 and 45 cm... ": 23-45 cm of error while comparing with 70 cm of in situ displacement can be a huge uncertainty!

⇒ Absolutely, and this demonstrates why capturing short-term ice motion (i.e. average over ∼4 h) by remote sensing is inaccurate. By contrast, our in-situ GPS has an accuracy of ∼1 cm, which is ∼20 times better than the remote sensing method. **We propose to highlight this argument in the revised version.**

7. The text "The UAV was left in this inclined position and the battery voltage ... become impossible to salvage. Shortly before this happened" is unnecessary and should be removed. The first paragraph of "Recommendations" section related with this detailing should also be omitted. This is a case-specific issue and as such, does not arise due to methodological failures.

⇒ From our analysis, it is likely that the UAV could have been recovered if it landed closer to the targeted point (e.g. using RTK GPS) preventing it to flip over, or if we had installed guards under the propellers. Therefore, this directly concerns the methodology, and it seems important to us to fully describe the outcomes of our tests (including the failure to recover) in order to propose more robust solutions, as we do in 'Recommendations'.

8. I have several issues with the entire methodology, the purpose of this research, and the results. First, what was the actual error in your in situ measurement?

⇒ We have given estimates of error locations (1.1 cm horizontally and 1.6 cm vertically) in Section 4.3. **This will be clarified in the revised version.** This corresponds to the specifications of the Emlid Reach GNSS receiver (https://emlid.com/reach/), as well as error estimates given by other users (e.g. ()). This error translates into an error of 0.06 m/d in ice velocity when scaled to the 4.36 hours of recording time period as reported in the 'Result' Section.

Second, why is this study needed? Making a point measurement on glacier surface for

4 hours or less is not going to give any relevant information.

⇒ We fully agree that one point measurement on the glacier surface for ∼4 hours is very little data. However, the goal of this paper is not to make a glaciological analysis of the flow field of Eqip Sermia glacier, but instead to present and discuss the potential of a new method, which might lead to a greater dataset in the future, from a preliminary experiment. Our study must be understood as a proof-of-concept, which proposes a methodology – with large room for improvements – to place a light-weight sensor (not necessarily a GPS station) in an inaccessible or dangerous terrain remotely without setting foot on this terrain. Our study can therefore be of interest for glaciologists who need to place sensors on ice for a relative cheap price when compared to helicopter operations, or more broadly to geo-scientists who work on other hostile terrains.

Either deploy 10 UAVs simultaneously (which of course is logistically and economically not possible) to get area-wide measurements or simply use stake-based classic approaches if we really want in situ measurements.

⇒ In our recommendations, we suggest that a drop and recovery procedure for light-weight GPS stations is more appropriate to deploy multiple stations by UAV instead of landing single UAVs. Stake-based classical approach is impossible at Eqip Sermia as the glacier is mostly inaccessible (too crevassed, see Fig. 1c) similar to many other terminus of fast flowing glaciers. This is a key motivation of our study to deploy GPS stations remotely by UAVs.

The whole purpose of UAVs is to use them as an aerial remote sensing platform which can bridge the gap between spaceborne and in situ measurements.

⇒ Here we have a different opinion. While remote sensing applications remain the main market share in the drone industry, the part of 'cargo' applications has a great potential for urgent, short-range, and light-weight delivery **We propose to report**

this argument in the revised version giving some examples of pilot projects and applications. The goal of our paper is to show that UAVs should not be seen only as aerial remote sensing platforms, but can also be considered for in-situ sensing. This is of special interest for placing sensors over rough and inaccessible terrains.

Third, I am sure that you must be knowing how different glacier velocities can be in different hours of a day. This variation can further enhance across seasons. And on yearly scales, we can observe even more variability.

$\Rightarrow$ Short-term variability of the ice flow of tidewater glaciers has been observed multiple times (e.g.). Minute-scale velocity responses to large iceberg calving events have been reported by , observed the tide modulation of the ice flow of a tidewater glacier, and one-day-long speed-up events have been captured by and for giving a few examples. Some processes like calving event, tide, or supra-glacial lake outburst might cause short-term variations in the ice dynamics, which in turn might affect calving. Therefore, one needs methods that can reliably capture the ice flow variability also at short time scales as well. **For clarification, we propose to focus the application of our method to tidewater glaciers in the revised version.** We fully agree that the seasonal variability is even more important, however, it is not our intention to propose a method to capture this as our method is anyway not designed for long record periods, and remote sensing methods perform very well for that purpose.

It will really be a blunder to extrapolate 70 cm in 4.36 hours to 3.7 ± 0.06 m/d and compare it with daily photogrammetric measurements!

$\Rightarrow$ 3.7 ± 0.06 m/d is the 'instant' velocity averaged during the 4.36 hours of recording, and it is not our intention to extrapolate this velocity to a longer period. Method-wise, it is much easier to infer ice velocity averaged over long periods with classical remote sensing methods (UAV or satellite) than capturing short-term ice velocity, as this can be done only by in-situ measurements (below a certain time period). Here, we tackle the challenge of measuring the ice flow in short time scales.

⇒ In our paper, we compared the 'instant' in-situ record with a 3-day long photogrammetric-based measurement for validation purpose only. Ideally, this should have been done comparing exactly the same time period (3 days), unfortunately, we were not able to leave our UAV on ice for 3 full days. Therefore, we can not exclude that natural ice flow variability explains part of the discrepancy observed between the two methods. Yet it must be stressed that the variability mostly affect the speed of ice and to a lower extent the flow direction. Therefore, the good match between the ice flow directions of the two methods (one degree of discrepancy) provides a reliable validation. **This argument will be added to the revised manuscript.**

Moreover, if you report that the two methods show only less than 5% of difference, then what is the need of the in-situ measurement when it in any case is not feasible for a monitoring at relevant spatio-temporal scale!

⇒ This small percentage difference shows that we can not evidence high temporal variability of the ice flow in the present reported case. However, we can not exclude that one or several short-lived accelerations occurred between July 8 and 11 without being captured (as being asynchronous with the in-situ measurement time period).

However, in this 5% difference, you are not considering (adding/subtracting?) the 23-45 cm of error in photogrammetric method and the error in the in situ method.

⇒ The 23-45 cm of error in photogrammetric method is taken into account. However, as the error in ice flow velocity linearly decreases with the time period (the longer the time duration, the larger the displacement and the smaller the relative errors), the errors in ice velocity gets very small: 23-45 cm over 3 days produces an error of ~ 0.06 m/d, which is small compared to absolute speed (~ 3.7 m/d).

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Discussion paper

Next you write: “The key advantage of in-situ GNSS receivers is that they can determine the ice flow motion in much higher temporal resolution and with greater accuracy than any remote sensing method.” Why?

⇒ GNSS receivers can log typically at 10 Hz. However, due to positioning errors, we can not directly derive velocities from positions, but from average-in-time positions to reduce the noise. Therefore, the true temporal resolution is reduced to approximatively the time needed to move by the positioning error length (here the ice moves by ∼ 1 cm during ∼4 min).

⇒ Relative positioning errors are ∼1 cm with in-situ GNSS receivers, and 23-45 cm with UAV photogrammetry (with Post Processed Kinematic as used here). The error in ice flow velocity is the location error divided by the time of the recording period. Therefore, for a long time period (e.g. 3 days), the two methods perform similarly well as the two errors are small compared to the absolute ice speed recorded. By contrast, the in-situ GNSS approach has a clear advantage for short time periods as the location errors (and then the ice flow error) are much smaller.

⇒ Another advantage of GNSS receivers is that they can record the vertical motion of ice as well (e.g. in response to tide). **We will add this information in the revised manuscript.**

If the difference is within 5%, I would on any given day prefer a remote sensing measurement covering wide area in lesser time! What is the use of high temporal resolution measurements if they are only for 4 hours and just for a single point?! The different facies of glacier show widely varying flows even during a day and such an in situ measurement is not going to give us any relevant information unless we are investigating a known particular case.

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Discussion paper

⇒ For the present case of Eqip Sermia, we agree that the gain of having in-situ GPS (against remote sensing method) is very limited as the results do not evidence high temporal variability. Our method aims to be applied to glaciers, which show a significant variability of the ice flow at short time scales as illustrated in aforementioned references.

Although I acknowledge the efforts of the authors, owing to the methodological and conceptual issues with this work which I mentioned above, I really find majority of the recommendations and conclusions repetitive/case-specific (⇒ see our answer to 7.) and lacking in novelty.

⇒ To our knowledge, no one before has ever deployed a sensor in-situ on an inaccessible glacial area in a remotely controlled way with a UAV. The key novelty of our paper is not the UAV photogrammetry (it is now commonly used for glacier surveying) nor the measurement technique it-self (GPS stations are commonly used to record ice dynamics), but the deployment technique by UAV, which does not require to set a foot on ice. We agree that the amount of data we collected for this study is modest, however, our paper does not aim to do an in-depth glaciological analysis of the ice dynamics of Eqip Sermia glacier, but instead reports on the potential of a new technique for an instrumentation journal. **We suggest to clarify in the beginning of the paper that this is a proof-of-concept study, which focuses on the remote and unmanned deployment of GPS sensors on ice using UAVs.**

In short, I do not see this work as a conceptual advancement in UAV-based glaciological research simply because the reasoning for justifying the need and relevance of this work is not strong enough in my view.

⇒ **We suggest to revise our manuscript to strengthen "the reasoning for justifying the need and relevance of this work" as follows:**

- **Better emphasize the need (high temporal resolution data, validation) to perform in-situ surveys of the ice motion by the means on GPS stations in complementarity to remote sensing methods, and illustrate the glaciological added-value of in-situ measurements (high temporal data, vertical motion captured, high gain in accuracy, weather independent method, ...) against remote sensing methods, especially in the case of tidewater glaciers.**
- **Better illustrate that manned in-situ deployment of sensors on ice can be dangerous, costly, and even impossible when the glacier is too crevassed.**
- **Better evidence that remote sensing methods can not capture high temporal resolution data, which are relevant to study some processes of tidewater glaciers.**
- **Clarify that we used Eqip Sermia glacier for test only to assess and validate the method.**

References

T. R. Chudley, P. Christoffersen, S. H. Doyle, A. Abellan, and N. Snooke. High-accuracy uav photogrammetry of ice sheet dynamics with no ground control. *The Cryosphere*, 13(3):955–968, 2019.

SH Doyle, B Hubbard, Poul Christoffersen, Tun Jan Young, C Hofstede, M Bougamont, JE Box, and A Hubbard. Physical conditions of fast glacier flow: 1. measurements from boreholes drilled to the bed of store glacier, west Greenland. *Journal of Geophysical Research: Earth Surface*, 2018.

G. Jouvet, Y. Weidmann, M. Kneib, M. Detert, J. Seguinot, D. Sakakibara, and S. Sugiyama. Short-lived ice speed-up and plume water flow captured by a vtol uav give insights into subglacial hydrological system of bowdoin glacier. *Remote sensing of environment*, 217:389–399, 2018.

T. Murray, M. Nettles, N. Selmes, L. M. Cathles, J. C. Burton, T. D. James, S. Edwards, I. Martin, T. O'Farrell, R. Aspey, I. Rutt, and T. Baugé. Reverse glacier motion during iceberg calving and the cause of glacial earthquakes. *Science*, 2015.

D. Podrasky, M. Truffer, M. Fahnestock, J. M. Amundson, R. Cassotto, and I. Joughin. Outlet glacier response to forcing over hourly to interannual timescales, jakobshavn isbræ, greenland. *Journal of Glaciology*, 58:1212–1226, 12 2012.

S. Sugiyama, D. Sakakibara, S. Tsutaki, M. Maruyama, and T. Sawagaki. Glacier dynamics near the calving front of Bowdoin Glacier, northwestern Greenland. *Journal of Glaciology*, 61:223–232, 2015.

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