Earth Syst. Sci. Data Discuss.,
https://doi.org/10.5194/essd-2018-145-RC2, 2019

Open Access Earth System Science Data Discussions

Interactive comment on "A high-frequency and high-resolution image time series of the Gornergletscher – Swiss Alps – derived from repeated UAV surveys" *by* Lionel Benoit et al.

Anonymous Referee #2

Received and published: 14 January 2019

The manuscript "A high-frequency and high-resolution image time series of the Gornergletscher - Swiss Alps - derived from repeated UAV surveys" presents a series of UAV derived datasets for the Gorner glacier in Switzerland collected at ~two weekly interval over the summer of 2017. Datasets include, DEM's and "matching maps" (velocity fields" for each date at high (centimetre) spatial resolution, over a relatively large area of the glaciers ablation zone. As such the dataset exploits both the spatial and temporal benefits of UAV data collection and could thus be useful to others in glaciology, and more broadly within geomorphology and the earth sciences. In general the article is well written, datasets are properly documented and the processing workflow is generally adequately described. However, some issues with what I would consider

non-standard nomenclature and processing methods, e.g. the matching maps makes the article somewhat difficult to follow.

Despite these positive aspects I believe there is a fundamental issue in the dataset that limits its suitability for use and widespread dissemination, and therefore I unfortunately cannot recommend publication until this has been remedied. These issues are related to the lack of ground control, which I will expand on below.

There are three typical methods used for positional/measurement accuracy of UAV and structure from motion (SfM) photogrammetric surveys, and a number of examples in glaciologic applications (Bhardwaj et al., 2016). 1) in scene distance measurements – where features of known length are distributed across the scene, e.g. 1m length rulers, or distances between features that are manually measured. This can provide accurate distances within a scene but not absolute positioning in space, vertical distances are also often prone to error with this method. 2) In scene ground control points – where targets are installed and surveyed with differential GNSS (cm accuracy) and used to force the SfM model into real world coordinates. This is probably the most widely used method, e.g. (Hugenholtz et al., 2013; Immerzeel et al., 2014; Westoby et al., 2012; Whitehead et al., 2013; Wigmore and Mark, 2017) and when ground control is well distributed provides the most accurate results. 3) positioning of the UAV, generally less accurate than in scene ground control and heavily dependent on positional accuracy of the UAV platform. The gold standard is dual phase L1/L2 differential PPK/RTK GNSS positioning combined with high resolution IMU measurements (~cm accuracy of UAV positon), poorest quality is using consumer grade GPS (~3m horizontal, ~10m vertical error).

In this case it appears the authors used the later method relying on consumer grade GPS positions of the UAV to generate the 9 June orthomosaic and DEM, all other datasets are then coregistered to this 'master' dataset using stable bedrock features. What this means is that the stacks themselves are co-registered accurately and we can therefore observe changes between images pairs fairly precisely. However, the master 9 June dataset is likely to be so inaccurate positionally that any measurements made from these data are likely to be highly inaccurate. A number of papers of have investigated the errors associated with using no/insufficient ground control in conjunction with low accuracy platform positioning (Gindraux et al., 2017; Hugenholtz et al., 2016; James et al., 2017; James and Robson, 2014, 2012; Tonkin et al., 2014; Tonkin and Midgley, 2016). Furthermore these products are highly likely to result in significant 'doming' or 'fishbowling' where the edges of the SfM survey area curve upwards or downwards (James and Robson, 2014). Both horizontal and vertical errors are highly likely. These publications suggest that these combined positional errors are likely on the order of 1-10m in the horizontal and vertical which means any slope, distance, velocity, elevation, etc measurements made from the DEM are probably highly inaccurate. Given that measured amounts of glacier change reported in this article are less than the magnitude of the potential error, I do not believe this is acceptable. Furthermore there is no external validation of the datasets accuracy – using either additional ground control targets, LiDAR or other datasets. As such I don't believe this data should be published in its current form. Below I have outlined a few potential methods for remedying this issue.

1) Install ground control targets in the survey area and conduct another survey of the glacier, then use this as the master dataset to co-register the other datasets to, using stable/no change locations. This is that was done in the (Immerzeel et al., 2014; Kraaijenbrink et al., 2016) articles that the authors use as justification for the co-registration method they employed. Obviously installing ground control targets on glaciers and over a large area is extremely difficult and often not possible given access, safety and logisitical challenges. This is one of the major limitations of collecting research grade UAV datasets over challenging environments. Because of these limitations we are often forced to live with poorly distributed or inadequate numbers of ground targets. In the glacier context this means ground control is often restricted to installations along the moraine edges, but even this is much better than none. And, would in my opinion provide an acceptable product in line with other UAV/glacier publications. Furthermore,

the authors did use some 'on-ice' GNSS data to assess the accuracy of the velocity measurements - these stations could be used in conjunction with moraine ground control targets alongside perhaps two more on ice targets - e.g. one near terminus, one near middle, limiting labour/time investment. 2) Fly a UAV equipped with L1 or L1/L2 differential GNSS and use an RTK or PPK positional solution to derive a more accurate master data set. Then use this dataset to co-register the other dates. An example of this method as applied to glaciers is currently under review in the cryosphere discussions: Chudley et al., 2018. 3) If there is a high quality DEM and imagery data from other sources e.g. LiDAR/airborne imagery/high resolution satellite data, then authors could extract ground control positions from these data and co-register the UAV datasets to this. If available the raw point clouds could also be co-registered using cloud compare or similar software. This method is likely to be the least accurate as it depends on the positional accuracy of the base data used. However, it is the easiest to implement and would provide an acceptable level of accuracy in my opinion, and given the challenges of 1) and 2) above may be the most feasible.

Given the significant issue outlined above I have omitted a detailed line by line review of grammar/spelling etc., but am happy to do so once my main concern has been dealt with. Finally, I have read the other posted review for this paper and agree with their suggestions regarding the matching maps. Further description of how these were derived is needed as they are non-standard, and ideally more widely used methods for velocity field derivation should be applied – e.g. COSI-CORR as this would be 1) easier to follow, 2) likely to be more useful to other researchers.

Additional points: To prevent the use of incorrect data by others the authors should clip out obviously erroneous regions in the DEM and orthomosaic, i.e. along the edges of the survey area. Ideally all datasets could be clipped to a common extent boundary and raster grid for ease of use, though this is less important.

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Interactive comment on Earth Syst. Sci. Data Discuss., https://doi.org/10.5194/essd-2018-145,

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