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Interactive comment on:
"Mapping snow depth in open alpine terrain from stereo satellite imagery"
by R. Marti et al.

Reviewer #1 : General comments
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The paper entitled "Mapping snow depth in open alpine terrain from stereo satellite imagery" by R. Marti et al. investigates the potential of very high spatial resolution (VHR) optical satellite imagery for snow depth (HS) mapping in an alpine catchment. This investigation is to my knowledge the first attempt using such data for this purpose and is therefore a significant contribution for many different potential applications. The achieved precisions of the snow depth values compared to manual probe and UAV measurements are approximately 0.5 m. This is slightly better than the 0.7 m spatial resolution of the input imagery and therefore in line with other investigations applying digital photogrammetry from airplanes (Bühler et al. 2015, Nolan et al. 2015) and UAVs (Bühler et al. 2016, Harder et al. 2016, Vander Jagt 2015). In my opinion this contribution should be published after taking into account the following comments:

We would like to thank Y. Bühler for his constructive comments and suggestions, and for the time he spent on our manuscript. We agreed with most of its comments as detailed below in the point-by-point response.

(1) comments from Referees, (2) author's response, ***(3) author's changes in manuscript.***

1. During the process of generation the snow depth maps and its evaluation, systematic offsets between the summer and winter DSMs as well as the reference datasets are eliminated. These x,y and z-offsets are crucial for the final product as they influence the error by 100% or more. The calculation of these offsets and their elimination is described in the text. However, it is very hard to follow and to understand. I propose that you generate an overview in a table or a figure where you list the different offsets, their amount and how they were eliminated. What information is necessary to eliminate them ?

As suggested by the reviewer, we added a new table which provides an overview of the differents offsets identified and the adjustments performed accordingly. In the last column, we made a distinction between the values of adjustments performed during the workflow to produce the final product and the values of verification of these adjustments:

Table 3. Summary of the differents co-registrations and the bias corrections performed to produde the Pléiades and the UAV DEMs and dDEMS maps. SD means Standard Deviation.

Input data	Reference data	Type of coregistration	Values of adjustments	Comments
4 m-Pléiades winter DEM	4 m-Pléiades summer DEM	xy relative coregistration	-5.2 m North +2.8 m East	Workflow data Same shifts applied to the 1 m and 2 m-Pléiades winter DEMs
1 m-Pléiades winter ortho-image	1 m-Pléiades summer ortho-image	xy relative coregistration	-5.2 m North +3.2 m East	Verification data
1-2-4 m-Pléiades dDEMs	dDEM-snow free footbal field	z relative coregistration	$b_{1\,\mathrm{m}} = -0.46\,\mathrm{m}$ (SD=0.25 m) $b_{2\,\mathrm{m}} = -0.48\,\mathrm{m}$ (SD=0.20 m) $b_{4\,\mathrm{m}} = -0.44\,\mathrm{m}$ (SD=0.15 m)	Workflow data
2 m-Pléiades dDEMs	78 wide-spread points over snow-free areas	z relative coregistration	Median $b = -0.70\,\mathrm{m}$ Mean $b = -0.74\,\mathrm{m}$ SD $b = 0.26\,\mathrm{m}$	Verification data
1 m-Pléiades summer ortho-image	6 wide-spread points on the 0.50 m-IGN ortho-image	xy absolute coregistration	+3 m North (SD=0.38 m) -0.8 m East (SD=0.35 m)	Workflow data Same shifts applied to the dDEMS
0.1 m-UAV-dDEM	353 wide-spread points over snow-free areas	ΔZ-correction based on a trend surface of order 3	RMSE: 0.34 m	Post-treatment correction. Same correction applied on the 1 m and 2 m-UAV dDEMs

The proposed workflow does not require any external data to generate the snow depth map since the co-registration of the snow/no-snow DEMs is based on the Pléiades data only: (i) horizontal translation based on the minimization of the dDEM standard deviation (ii) vertical shift to remove the elevation bias found on a snow-free surface (Fig. 4).

However, for this study we had to perform an additional geometric correction to allow the comparison of the dDEMs with our validation datasets (snow probes and UAV surveys). Here we needed an external reference dataset (IGN aerial ortho-image). Note that the absolute registration of the dDEM is not required if the snow map calculation method is applied in another site where such high-quality reference data are not available (although validation data are always most welcome!).

2. I do not understand the comparably low precision (SD 0.6 m) of the UAV reference data set even though the correlation and the NMAD are better than for the Pleiades HS values. Recent studies report accuracies of approximately 0.1 m (Bühler et al. 2016, Harder et al. 2016, Vander Jagt 2015). Was the problem saturation of the imagery?

Even though the RTK signal was lost the relative accuracies within the DSM should be much better. Please explain this issue in more detail and relate your results to the recent studies mentioned here.

The reviewer is right that the accuracy of the HS values retrieved by the UAV approach in our study is somewhat disappointing, especially given the results of the most recent studies with similar instruments. A lower NMAD value (NMAD=0.35 m) than the SD value (SD=0.62 m) indicates that our UAV dDEM is affected by outliers.

In our case, we do not have a clear explanation on this issue, but we can only speculate that it is a combination of (i) the loss of the RTK signal (ii) the saturation of some areas (iii) the high values of the UAV camera view angle in some parts of the study area.

The main goal of our study is to evaluate if satellite data can play a role in snow depth mapping. To investigate this question, the 451 snow probe measurements is the foremost validation dataset We did not use the UAV dataset to compute the Pléiades snow depth accuracy.

The UAV survey and DEMs were performed by a private start-up company at no cost. As we noticed an important spatially heterogeneous bias, we proposed a correction based on a trend assessment. We consider that the UAV dataset remains an interesting, independent, dataset to further assess the *spatial* distribution of the Pléiades HS in spite of its relatively low accuracy. It shows snow depth patterns and transects that are consistent with those retrieved from Pléiades (Fig. 9).

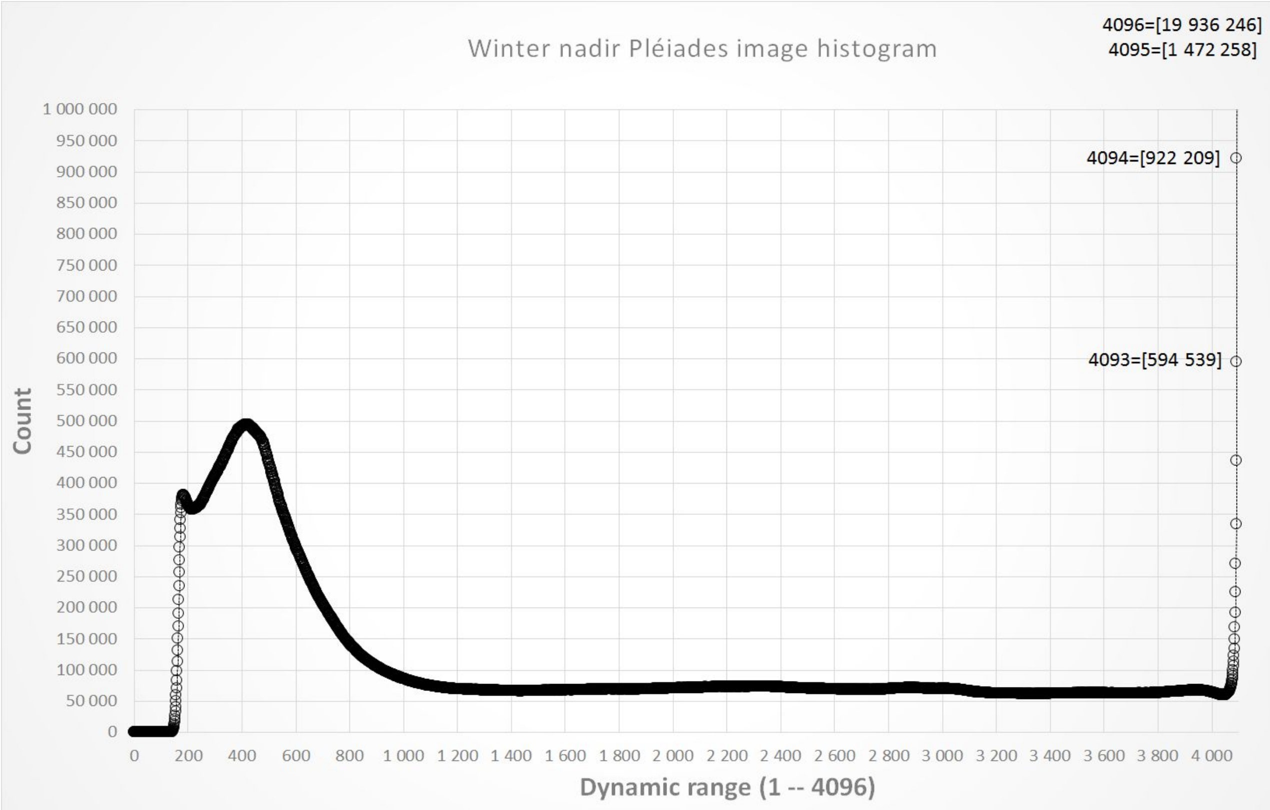
3. Compared to the manual reference data you achieve an underestimation of the HS values of approximately 0.15 m (median). Is there an explanation for this? Could it come from uprising summer vegetation such as bushes that are pressed down to the bottom by the snowpack as reported in Bühler et al. (2016)?

This is an interesting suggestion that we also considered while discussing the results before writing the paper. We associated an error to the snow probe measurements of 0.15 m to take into account this type of uncertainties, but such an error is mostly random and cannot explain the systematic deviation observed in the statistics of the residuals. The z-bias correction of the Pléiades dDEM is characterized by a SD of 0.25 m considering the whole dDEM (see new table 3 above). Therefore, even on a large flat areas as the snow-off football field, it remains difficult to determine a unique b vertical offset and to coregister the summer and winter Pléaides DEMs in z. This can lead to the observed underestimation of the HS values derived from the Pléiades dDEM.

4. You state that the major benefit of the Pléiades sensor is its 12-bit radiometric resolution compared to 11 bits of other comparable satellite sensors. I doubt this statement. I do not think that there is a significant benefit of 12-bit data compared to 11-bit data (while there should be one compared to 8-bit sensors!). Are really all 4096 digital numbers used ?

In my experience also 11-bit data never uses the whole dynamic range.
Could you show some histograms of the input imagery?

We show below the histogram of the winter nadir Pléiades image. The two other histograms from the backward and forwards images are very similar. The number of pixels with saturated values (coded as 4096 in the histogram) represent 3.1 % of the total number of pixels (N=[19 936 246])., Over 95% of the radiometric resolution is actually used.



I would guess that you get very similar results using 11 bit data.

This point is indeed very interesting and could open the door to an intercomparison between DEMs generated over a snow-covered area from various VHR satellite optical sensors with stereo-capability. Such comparison are beyond the scope of the paper but were addressed in the literature. For example, Poli et al. (2015) studied the radiometric and the geometric aspects of the VHR spaceborne imagery from stereo-pairs acquired by WorldView-2 and by GeoEye-1, and a triplet from Pléiades-1A in panchromatic and multispectral mode over a given reference surface. All the data considered showed a good noise robustness and DN stability in both panchromatic and multispectral bands and homogenous values from the Modulation Transfer Function analysis (MTF: this function is used to estimate the spatial performance of an imaging sensor by describing the noise level and the geometrical resolution and sharpness). However, some saturation and spilling effects were observed in GE1 and WV2 images that were not reported from the Pléaides images: "In general the radiometric analysis showed that all the Pléiades images are highly homogeneous, have low noise level and do not present saturation effects".
To acquire an optimal contrast on homogenous snow surface, Buhler et al. 2016 recommend using RAW image storage format with 12 bit, in the case of an UAV acquisition.

With 11/12 bit data you should get good results in shadowed areas but you have to mask them out. Can you explain why you do so ?

The 12 bits encoding does not prevent the decrease of the signal-to-noise ratio in the shaded areas, which decreases the correlation success rate. In addition the Pléiades operator does not allow the user to specify how the sensor gain should be adjusted to the target surface. It remains to be evaluated if it is possible to optimize the sensor gain so that a good correlation is achieved in both illuminated and shaded slopes in a mountainous area.

5. There should be a table listing all available and planned satellite sensors that could potentially be applied for HS mapping including their temporal, spectral, radiometric and spatial resolution.

We propose to include in the supplement this table of VHR optical (civil) satellites that have stereo capabilities comparable to Pléiades, i.e. that could be used for HS mapping based on the same method.

Satellite platform (launch date)	Stereo-capabiliy	Swath width at nadir	Temporal resolution	Spectral resolution (P)	Radiometric resolution	Spatial resolution at nadir
Pléiades 1A and 1B (2011 and 2012)	tri and stereo	20 km	1 day with Pléiades 1A and 1B	480 - 830 nm	12 bits	0.70 m (P) 2.50 m (XS)
GeoEye-1 (2008)	stereo	15.2 km	8.3 days at 10° and 2.8 days and 28° off nadir look angles, respectively	450 - 800 nm	11 bits	0.46 m (P) 1.84 m(XS)
WorldView-1 (2007)	stereo	17.7 km	1.7 days at 1 m GSD. 5.4 days at 20° off-nadir (0.52 m GSD)	400 - 900 nm	11 bits	0.50 m (P)
WorldView-2 (2009)	stereo	16.4 km	1.1 days at 1 m GSD. 3.7 days at 20° off-nadir (0.52 m GSD)	450 - 800 nm	11 bits	0.46 m (P) 1.85 m (XS)
WorldView-3 (2014)	stereo	13.1 km	1 day at 1 m GSD. 4.5 days at 20° off-nadir or less	450 - 800 nm	11 bits	0.31 m (P) 1.24 m (XS)
SPOT 6 and 7 (2012 and 2014)	tri and stereo	60 km	1 day with SPOT 6 and SPOT 7	450 - 745 nm	12 bits	1.50 m (P) 6 m (XS)

(P) Panchromatic
(XS) Multispectral

6. In my opinion there should be a discussion of potential important applications.
For what applications the identified precision of 0.5 m is sufficient ?
What are the applications where you need better precision for example generated from UAV or laser scanning data?

We agree that the Pléiades snow maps are not accurate enough for a variety of applications. We have added a comment on this aspect in the conclusion:

This accuracy might be insufficient in areas where the snowpack remains thin even at peak accumulation (North American prairies, semiarid mountains), and for the study of small-scales snow features like sastrugi or penitents.

However, the potential applications depend from several tradeoffs that snow-product users are prepared to accept. Bühler et al. 2015 provide an overview of the current available methods depicting their strengths and weakness to map snow depth in high alpine terrain at large-scale. We agree with their conclusion: "which method should be applied in a specific case depends on many differents factors and should be evaluated with care". As mentioned in the discussion part, Pléiades derived snow-maps do not present the same accuracies as state-of-the-art airborne Lidar or photogrammetry. It could represent an interesting alternative when such techniques are not available. If the reviewer think it is relevant, wa can add a new table which summarizes some simple considerations of the various techniques to map HS from remote sensing, which columns heading could be:
Remote sensing techniques / (typical) spatial resolution / spatial extent / systematic and random errors in z (HS) / Potential applications.

Technical corrections:

P1L1: there is passive microwave; you describe this later in the paper.

P1L1. "To date, there is no direct approach to map snow depth in mountainous areas from spaceborne sensors."
We consider that passive microwave is not a mature approach to map snow depth in mountainous areas as it requires "complex and problematic inversions in order to infer the depth" (Nolan et al., 2015). The kilometer-scale resolution of current passive microwave sensors is not well adapted in *mountainous* areas. Passive microwave sensors offer real-time global SWE estimates but suffer from several problems like subpixel variability in the mountains (Dozier et al., 2016)

Therefore we propose to change the word "direct" by "definitive":
P1L1. "To date, there is no **definitive** approach to map snow depth in mountainous areas from spaceborne sensors."

P1L2: optical stereo satellites

Thank you for that remark. This term will be corrected accordingly in the text:
P1L2: Here,we examine the potential of very-high-resolution (VHR) **optical** stereo satellites to this purpose.

P1L12: please give the calculated precision vs. the UAV data here

According to the reviewer's comment, we completed the sentence as follows:
P1L12: The UAV-derived snow depth map exhibit the same patterns as the Pléiades-derived snow map, **and a median of -0.11 m and a SD of 0.62 m when compared to the snow probe measurements.**

P1L14: I think it is very dangerous to propose the application of remote sensing data without any field data! You need at least some reference measurements to be sure your values are OK. I really suggest deleting this statement!

We totally agree that field data are always welcome to assess remote sensing products! We would always recommend to check the Pléiades results with ground truth observations whenever possible. We only meant that the processing of the Pléiades data does not require mandatory field data like ground control points. We emphasize this aspect because field work can be costly and unsafe in high-elevation mountainous areas. This is the result of a remarkable feature of the Pléiades images (excellent native georeferencing without ground control points).

Not using ground control points before the co-registration of the seasonal DEMs was also emphasized by Nolan et al. 2015 when presenting its airborne photogrammetry-based system to map snow depth:
(abstract section) “The system is simple enough that it can be operated by the pilot without additional assistance and the technique creates directly georeferenced maps without ground control, further reducing overall costs.”
(conclusion section) “ The mapping technique is based on digital photogrammetry that [...] requires no [...] ground control.”

We propose to mitigate the corresponding sentences as follows:
P1L13-14: This study demonstrates the value of VHR stereo satellite imagery to map snow depth in remote mountainous areas **even when no field data are available.**
P16L27-28: Indeed, **the processing of the Pléiades data does not require mandatory field data like ground control points, although such reference measurements are always highly desirable**.

P1L23: From my experience it is more wind, snow avalanches and terrain features that generate the high spatial variability of alpine snow depth distribution.

We modified this sentence as follows:
P1L21--23: Even for small mountain catchments with areas of a few square kilometres, the spatial variability of the snow height and water equivalent is high because **of the elevation gradient of snow fall that is modified by the interaction of snow cover and topography, which leads to a large range of processes: preferential deposition of precipitation, redistribution of snow by wind, sloughing and avalanching (Grunewald,2014).**

P2L27: The main advantage of near-nadir looking instruments against TLS is that you have no holes caused by terrain features such as ridges or bumps and that you can cover the entire area spatially continuous.

Thank you for this comment, we have added this sentence in the manuscript:

P2L27: **However, holes in the dataset caused by convex landforms such as hills or moraines may limit the spatial covering of the TLS acquisition (Buhler, 2016).**

P3L29: UAS?

We considered that the accuracy of the UAV snow depths was not sufficient to extend this analysis to the UAV-Pléiades residuals.

P5L6: It would be nice if some more details on the UAS campaign could be given here. How many images were acquired? What camera did you use? . . ..

In winter, 785 images during four parallels flights were acquired by a Canon IXUS 127 HS mounted on board (4608 x 3465 pixels, sensor dimension: 6.170 mm x 4.628 mm). The focal length is 4.380 mm, and this value is optimized during the images processing.

During the summer campaign, 964 images during four parallels flights were acquired Sony DSC-WX220 (4896 x 3672 pixels, sensor dimension: 6.170 mm x 4.628 mm). The focal length is 4.572 mm, and this value is optimized during the images processing.

P5L16: approximately 501?

Thank you, we have removed “approximately” from the sentence:

P5L16: We collected up to 501 hand-probed depth measurements on 10 March 2015

P6L13: Why did you choose these spatial resolutions? Please justify.

These are the typical resolutions at which Pléiades DEMs are computed (e.g. Berthier et al. 2014, Marti et al. 2014). Resolutions lower than 1 m are not relevant given the original image resolution and resolutions higher than 4 m will smooth out most of the interesting snow depth features. This was added in the manuscript.

P6L15: Gaussian distribution?

We modified this sentence as follows:
P6L15: “The elevation values at a given grid point were obtained as a weighted average of the elevations of all points in the cloud within the search radius of the grid point, with the Gaussian curve as weighting function...”

P6L17: What are the drawbacks of this method? The winter and summer surface is not similar due to the snow cover. Why is this approach still working? Or did you only use snow free areas to do the SD calculations? Why did you use the 4 m DEMs? This is not clear to me.

This method is frequently used in glaciology (Berthier et al. 2007) and is based on the same principles that Nuth and Kääb 2011. It works because, in our study region of high relief, the average dissimilarity between both DEMs due to the snowpack (as measured by the standard deviation) is lower than the dissimilarity introduced by the horizontal offset across the whole image. So snow-covered area are used for the SD calculation. This method would not perform that well if the analyzed area would present a narrow histogram of aspect (i.e. if the terrain is characterized by a main orientation) and if the terrain was very flat.

We used the 4m DEM because the calculation was faster.

P6L27: Can you give some more details on the classification? What happens if snow is in shadow areas?

Two intensity thresholds were visually adjusted in order to treat specifically the case of the shaded snow surfaces from the general case. Added to the manuscript.

P7L11: I think it is a bit dangerous to sent negative snow depth to no data as you might change the statistics significantly. There might also be many false values, which are slightly positive. These values might differ out more or less. Can you discuss this point and give some indications?

The reviewer is right that it could potentially affect significantly the statistics of the residuals of the comparison between the Pléiades dDEM and the snow probes measurements. However as in indicated in the text (P7-L11) and in the table 3, it concerns only 8 to 10 occurrences (pixels) of the 451 snow probe measurements, therefore 2% or less of the number N of the whole validation dataset.

P7L26: What do you mean by bad stereo orientation? I do also not completely understand you approach with the trend surfaces. These points need a better description.

By trend surface we meant a polynomial interpolation that fits a surface defined by a polynomial function to the input sample points. Here we tried polynomial functions of order 1, 2 and 3. This processing was done using ArcGIS Spatial Analyst toolbox.

P8L9: How do you get to the error value of 0.15 m for probe measurements? Please justify. I would assume it is much less, something around 0.05 m.

We agree that the snow depth can be easily read at 5 cm resolution using a graduated probe. The error due to the probe tilting during the measurement will introduce a few centimeters error. The probe tip penetration in the soil also contributes to increase the error by a few centimeters. The horizontal positioning of the probe sampling point is probably the main source of error. A shift of a few centimeters can change the snow depth by >10 cm because the underlying surface is very heterogeneous. We considered that all these terms represent an error term of 15 cm.

P8L24: (Fig. 9) P10L15: Where and why do you get these data gaps in the point clouds?

The large data gap in the West of the area corresponds to a lake which serves as a dam for the hydropwer production (visible in figure 2). The other data gaps correspond to the steepest slopes of the watershed. The lake surface was masked as it not considered as a relevant surface (aberrant values). The steepest slopes areas presented a very low correlation rate and led to these data gaps areas.

P1**1**L18: 527.10[**^**]3 what entity is this? Also pts.m2 throughout the document.

P11-L18: This is the number of points (sample size). Added to the manuscript.
P11-L29: The density of the raw photogrammetric point clouds issue from the correlation processes (before rasterization to DEM) are expressed in pts by square meters, or pts.m^2 (please see figure 2 and 3 of the supplement).

P11L19: SD and NAMD are pretty bad compared to the other results. Can you explain why? The NMAD Satellite/Probe is 0.45 m and the NMAD UAV/Probe is 0.35 m. Are they both shifted in the opposite direction? Or how can you get to a NMAD of 0.78 m?

These results are not surprising given the accuracy of each dataset as previously evaluated using the snow probes. In this case we were unlucky as the errors did not compensate.

P12L17: Why?

Considering the influence of the land-cover, the mineral and the shrub classes are associated with the most important dispersion in the residuals distribution (SD are 0.79 and 0.63 m). In the case of the shrub class, this result seems consistent with the fact that the shrubs are highly compressed by the presence of the snowpack.

P14L15: Discuss your [UAV] results in the context of the results published by Harder et al.(2016), Bühler et al. (2016) and Vander Jagt et al. (2015).

We moved the results of Vander Jagt et al. (2015) from the section "Limitation and perspectives" to this section "Comparison to the UAV dDEM" in order to be consistent. The performance presented by Vander Jagt et al. (2015) are very satisfactory, but the snow probe sampling (N=20 snow-probe measurements) limit strongly the significance of the statistics.

To take into account the very recent work in HS mapping by UAV techniques, we rewrote the section "Comparison to the UAV dDEM" incorporating the following considerations:
P14 L15: **Recent works based on UAV systems to map snow depth highlight much better performance than the results reported in this study (2-m-UAV dDEM: SD=0.62m, NMAD=0.35m, median=-0.11m, see Tab. 4). Jagt et al. (2015) used a DSLR camera mounted on a multi-rotor UAV platform to map the snow depth at a very high spatial resolution (GSD 6:10^-3 m) over a small mountainous terrain (0.07 km2) with thick vegetation cover. A comparison with a reduced sample of snow-probe measurements**

(N=20) highlighted an RMSE of 0.096m using GCPs, and 0.184m without (0.084m with one point of coregistration). In Bühler et al. (2016), an UAV-octocopter was used to collect imagery at two alpine sites of the region of Davos in the swiss Alps (1940m and 2500m a.s.l., respectively). The images were acquired with a customized Sony NEX-7 camera with an overlap of 70% along and across-track. Reference data were constituted by plots of one square meter with five manual snow depth measurements. Four snow depth maps were produced and assessed with the manual plots (between 12 and 22 plots according to the map). Accuracies of 0.07 to 0.15m RMSE are reported in a detailed analysis, according to the study sites and the land cover classes. Considering all the reference plots in the valley bottom site, the HS RMSE is 0.25 m and there is an average systematic underestimation of HS by 0.2m. In Harder et al. (2016), a Sensefly Ebee Real Time Kinematic (RTK) UAV was used to collect imagery at a cultivated agricultural Canadian Prairie and a sparsely-vegetated Rocky Mountain alpine ridgetop site (2 300m a.s.l.). In the alpine site, the images were acquired with a Canon IXUS, with a lateral overlap of 85%, a longitudinal overlap of 75%, and a flight altitude of 100m. Multiple acquisitions (43) were performed with careful flight plans. The snow depth was measured with five snow depth measurements in a 0.4m x 0.4m square at the locations of the GNSS survey locations. The average snow depth of the five values was then compared to the snow depth determined by the UAV, with a number of snow depth measurements between three and 20 measurements per flight. The reported snow depth accuracy is characterized by a RMSE of 0.085 m.

In the case of our study, the DEM of the snow-covered area was generated from a unique flight plan. Some problematic flights were reported by Harder et al. (2016) (5 from 43 flights for all sites, or 11.6%) with DEMs showing an RMSE of up to 0.32m. The results mentioned above were extracted from multiple surveys with well spread GCPs and more dedicated survey. We did not use GCPs during the winter survey and only 5 GCPs in summer, not well spread (bottom of the valley only). According to Harder et al. (2016), GCPs are needed to achieve the sub-decimetric accuracy, and a bias correction may also be necessary. Furthermore, residuals of the comparison between the UAV dDEM and the HS manual snow measurements were not filtered (e.g. a statistic criteria like 1 sigma threshold, the land cover classes or the slope). Therefore, despite the discrepancies observed in this study, we consider that the UAV dDEM map was a valuable independent source to evaluate the Pléiades snow depth map because the comparison revealed similar snow depth patterns, while the random and systematic errors of both dDEMs are comparable.

P16L1: Please explain CV

We added its meaning (coefficient of variation):
P16L1 The corresponding **coefficient of variation (**CV**)** value was 0.80 (**CV is** the ratio of the SD to the mean snow depth).

P16L18: Please mention the result of the Satellite / UAS HS comparison

We added the results of the Satellite / UAS HS comparison presented in section 5.3.

P16L28: This statement is dangerous! You need at least hand probe measurements in the file to get an idea about the achieved accuracies.

This sentence was revised (see above).

P16L29: What is the outreach of these results compared to HS measurements with LiDAR, airplanes and UAV? What are potential applications?

See above our response to this comment.

Figures

P27 Fig. 5: Please indicate the outline of the UAV extent in the Pleiades extent.

Done.

P28 Fig. 6: The chosen bins are too wide. If you change to a continuous color scale ranging over more than one color, you can make much more details visible. Please adapt the color scale.

We would prefer to keep a discrete color scale. We think that a continuous color scale is not adapted here because the data are skewed. A continuous colormap would highlight the outliers. By using bin color classes we can group the high snow depth values into a single class. The finer distinctions are lost but the map is easier to analyse. To improve the contrast of the snow pattern, we switched to a 7-classes white-blue-purple color scheme from http://colorbrewer2.org.

P31 Fig. 9: Please change the color scale as in Fig. 6.

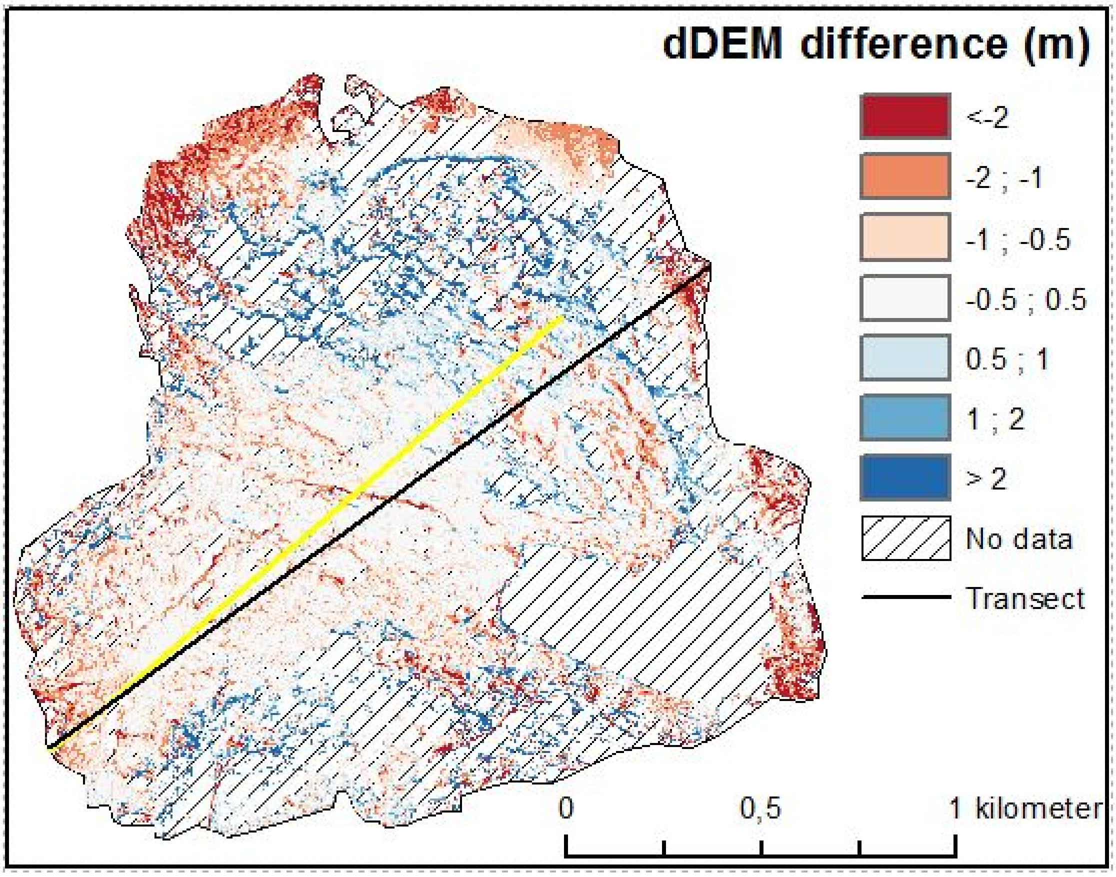
P31 Fig. 9 (top): To improve the comparison of the snow pattern between the UAV and the Pléiades dérived dDEMs, we used a new sequential color scheme.

P31 Fig. 9: Also the error bins are too wide in my opinion. You only see the very large errors of more than one meter like this.

P31 Fig. 9 (bottom): To improve the readability of the spatial discrepancies between the UAV and the Pléiades dDEMs, we reduced the bins to 0.5 m.

Could you set the profile from one end to the other, like this you do not display the big errors in the northeast because you stop just before that.

We extended the transect from the South-West to the North-East, but in the North-East sector there are lots of “no data” values which are due to the high cliffs.



Legend: Comparison between the UAV and the Pléiades dDEMS.
In black the new extended transect line, in yellow the previous transect line (figure 9).

P32 Fig. 10: How do you get errors compared to the probe measurements for the summer DSM?

The residuals on the summer DEM are computed as follow (equation 6):

$$R_{Z_w} = \mathbf{Z}_{sw} - (Z_{w,\mathbf{DGPS}} - HS)$$
(2)

This is explained in the section "Residual analysis on the Pléiades data (4.4)", and the subsection "Residual analysis on the Pléiades data (4.4.2)".

I do not really understand the figure caption, please clarify.

We propose to modify the figure caption as follows:
Figure 10. **Top: Residuals of the comparison between the winter 2 m-Pléiades DEM and the winter DGPS measurements (see equation 5, section 4.4.2), after removal of the bias (median of the residuals).**
Middle: Residuals of the comparison between the summer 2 m-Pléiades DEM and the estimated summer surface elevation (see equation 6, section 4.4.2), after removal of the bias (median of the residuals).

Bottom: Residuals of the comparison between the 2 m-Pléiades dDEM (black bars) and the snow probe measurements according to the probe Id ranked in the ascending HS (red line) order, and after removal of the bias (median of the residuals).

P36 Tab4: Why is there only one cos value for all snow depth classes ? The same for the slope classes and the aspect classes.

We considered more interesting to present the correlation on the whole dataset to assess the influence of the magnitude of the snow depth in the residuals.

What does the star mean?

Thank you for that remark, we omitted to mention it in that table. We have added::
P36 Tab 4: **Significant correlations (p values <0.05) are marked with asterisks.**

References:

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