Review on :

Mapping snow depth in open alpine terrain from stereo satellite imagery
by R. Marti and co-authors,
The Cryosphere Discuss., doi:10.5194/tc-2016-11

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Grenoble - 04/03/2016.

General comment
R. Marti and co-authors employ advanced methods of tri-stereo high resolution satellite imagery to retrieve DEMs and snow-cover thickness by DEMs differentiation in a mountainous open terrain. In a rigorous comparison with ground-based manual snow-probing, and UAV-derived DEMs differentiation, the authors find generally good agreement in these comparisons, the discrepancy been explainable by the natural scattering of the data, but also by some residual biases that remained unexplained. These favourable results should confer significant advances and improvements in mapping the snow mantle thickness over large open areas.
The paper is almost clear, well organized, and properly focuses the scope of the journal.

The paper would be much more valuable were it also to provide a much clear presentation of the bias corrections in both xy and z-vertical directions for the DEMSs derived from Pléiades and UAV flights. The resulting improvements in the residuals before/after adjustments are not clearly displayed (but dispersed along the text). A summary would be welcome with the numerical values of adjustments as an additional table or a supplementary column in Figure 4.

Regarding the results of the comparisons between measurement methods, some questions remain:
- Is the remaining bias (-0.12 — -0.16 m) between the Pléiades estimation of snow thickness relative to manual probing significantly different from 0 from your error analysis?
- Same question between Pleiades and UAV DEMs (-0.14m)?
A physical explanation should be attempted if you conclude theses biases to be significant.

Regarding specifically the UAV image acquisition and process from automatic correlation structure-from motion, much more needs to be said about the image orientation, whether the camera model was estimated from a self-calibration in the process, or fixed from standard values or an independent prior calibration.

A minor point that arises throughout the paper is the indistinct use terms of error in systematic and random meanings, which can sometimes be confusing for the reader. To avoid confusion, I would as much as possible use systematic error, bias, and discrepancy to quantify the incorrectness, and random error and scattering to denote inaccuracy. Moreover, the random error should be defined with respect to the standard deviation (one or 2 times the standard deviation for example). This will help you to decide about the differences between the results to be notified as significant or not. Random errors are combined assuming they are uncorrelated (page 5 of the supplement). This should be stated in the core of the text.

An additional figure would be helpful, setting z-vertical direction and the different almost-horizontal surfaces Z_s Z_w from Pléiades and UAV and GPS, to define the notations of the variables, their differences, and better understand how standard deviations combine in the equations of the supplement.

Here follow some detailed questions, comments, suggestions, and indications of minor typos in the paper.

Substantive comments

P1-L2. Specify ground resolution in meters for consistency with the rest of the paper (all lengths in meter elsewhere)

P1-L8. To me synonyms are accuracy and precision. Is it meant accuracy (random error) and correctness (bias or systematic error)?

P1-L21. I would set at first that snow cover is important in those areas for live and ecosystems, and second for anthropogenic needs.

P1-L16. The time for the seasonal snow thickness peak is very dependent on the elevation, varying from December at less than 1000 m a.s.l., to March in the 2000—2700 m range and April-May above 3000 m.

P1-L23. The natural spatial variability of the snow cover thickness is preliminary due to the variability in precipitations, and post-deposition processes as wind drift, avalanches, snow densification.

P4-L20. use units in metres for consistency with the rest of the paper

P4-L20. As far as I know, specify that this oversampling is carried out before image delivery

P4-L23. specify the local time.

P5-L11—14. It should be clarified between winter and autumn surveys, what set up is used among RTK, ground control points.

P5-L23. The z-vertical correctness and accuracy is generally less than that of the xy plane, especially a vertical bias is unavoidable without a geoid model or an independent altimetry adjustment on levelling points.

P5-L28. Make it explicit whether your refer to influences in radiometry or ground surface roughness.

P4-L8. Figure 4 introduced before Figure 3 (in page 9 L14)?

P4-L8—11. Define RCP acronym just after "…Earth imagery that uses the RPC…" instead of the next sentence.

P4-L13. It should be clarified that each of the three resolution DEMs is retrieved from a rasterisation of the 3 point cloud corpus (otherwise it may be understood that you derive one raster DEM per point cloud).

P4-L10. It should be clarified by a few words that RCP sets the image-to-ground geometry.

P4-L15. I would rewrite as: "…grid point, with the Gaussian curve as weighting function…"

P4-L17. Which is the RMS residual in z after co-registration?

P4-L23. Is it meant that the same xy shift is applied to the higher resolution DEMs without proceeding to a new minimization? Why? And why the 4 m-resolution as the resolution to proceed for all DEMs?

P5-L7—14. Please give more details about the UAV-on-board camera.
It is presumably a non-metric camera. Is it a fixed focal length lens camera? What is the focal length? How on board RTK corrections to tag image centre coordinates and ground control points are used jointly for orientation, and maybe the camera self calibration?
I suspect 5 ground control points insufficient for a calibration.

P7-L3. Are you really sure that the IGN ortho has a more correct xy referencing than your DGPS?

P7-L6. Does that bias mean than the co-registration was not optimal? How compares this value with the co-registration residual?

P7-L8. Which photo? Does this refer to the satellite winter and autumn images?

P7-L11. I am not sure it is correct to remove negative snow depths as these values may not be significantly different from zero considering random errors in both you snow probing and dDEM calculations. They may well be acceptable in terms of confidence interval.
Removing some values is nevertheless conceivable considering they might be abnormal (irregular) if they discard negatively from zero at 2 times sigma (or more), according the way you define "aberrant" values.

P7-L15—19. What is the result for the vertical bias calculated from these 78 points. Even if unused later in the paper, how does it compare to the bias calculated from the football field?

P7-L21—23. A bit more needs to be said about the image orientation (calibration?) process from the UAV acquisition.
Particularly, calibration for non-metric cameras is known to be critical and can generate significant orientation error when processed through automatic correlation Structure-from-Motion'based software as used here.
Which camera model is used for the orientation process? Did you used a simultaneous self-calibration or a prior calibration? If calibrated, which camera parameters are estimated (decentration, radial distortion and associated polynomial coefficients—how many? , focal length)?
Can you give the orientation residuals? This will help you to discuss about the discrepancy between Pléiades and UAV results to be significant or not.

P8-L9. It should be explained how σ_{probe} is estimated as it is surprisingly high.

P8-L16. Instead of error, I would write "…is the median of the dDEM/probe discrepancies.".

P9-L11. Section 4.4.3. From the section 3.4, I expected here an analysis of the ground surface roughness effect, both on manual snow probing and in Z_s uncertainty from the 2 DEMs.

P10-L31. How can you interpret physically this remaining systematic bias for the Pléiades snow thickness estimation? Is it significantly different from zero from your error analysis?

P11-L5. Why did you force the intercept to be zero and did not fit to Y=aX+b in search of a systematic difference?

P11-L11. I would expect a much lower value for the residual from the UAV DEM.
Can you comment this in relation to the orientation residual of the images and the overall quality of the DEM geometry?

P11-L12. The subscript for the residual R is inconsistent with notations from equations 3, 5, 6 ?

P14-L8—17. I would also question the bias you identified here in relation to the quality of the geometry of the UAV DEM to originate from the orientation of your images.
More needs to be said about cameras, camera models, and the statistics of orientation results. Instability is frequently associated to inaccurate or residual correlated camera model parameters after least-square adjustment (none unicity of solutions) which can result in poor quality of the geometry of the 3-D model (such as doming or bowl effects) after image orientation.

P14-L27. Is "dynamic" much more appropriated than "resolution" to denote the 12-bits depth?

P14-L28. To make a better distinction between accuracy/correctness concepts, use bias instead of "error" when you refer to a systematic error. Or systematically qualify errors as random or systematic to avoid confusion.

P15-L18. Inflect somewhat writing "…for clear-sky/limited cloud cover conditions…"

P15-L34. "In hydrology **and water resource** applications, there remains…"

P16-L8. This result is not trivial. The snow cover thickness you can estimate is not significantly different from that of the snowpack model, considering the overall uncertainty in both estimations.

P16-L26—29. I would mitigate/inflect your conclusions here mentioning that you nevertheless need an altimetry control/adjustment on a snow-free flat surface —as your z-vertical bias corrections demonstrate— that you have to infer on each satellite imagery. But this control surface can be located kilometres apart and at lower elevations.

Supplement

It is not clear to me why σ_{probe} appears in equations 3, 4 and 5. I would only expect this term in the uncertainty associated to the comparison of dDEMs with HS.

Figures
P23-Figure 1 — caption. "Pyr**én**ées mounta**ins**. Bottom: Bassi**ès**…"
Identically, in the legends of top right and main maps : "Bassi**ès**"

P24-Figure 2 — caption. "Comparison of **terrestrial** oblique pictures taken by automatic **cameras**…"
The local time is mentioned here but not in the text.

P30-Figure 8 —left map. Add a title "Snow depth" at bottom right corner as you did for the 2 other maps at top left.

P32-Figure 10 — caption. Add plot colours "…and the 2m-Pléiades dDEM (black bars) according to the probe Id ranked in the ascending HS (red line) order (see equation section 4)."

P32-Figure 10 — labels. Point of notation: define the units for the residual errors as (m), and not (in m). Same for HS in the right-hand axis.

Stylistic comments
P1-L1. At present…

P1-L19. Snow Coverd Area…. Snow Height

P1-L20. Snow Water Equivalent (SWE)

P4-L1. Bassi**ès** and Pyr**én**ées

P4-L7 " 6.6°C and the mean annual precipitation is 1640mm

P4-L9 "…and 25% by vegetation-free rock and bare soils."

P4-L30. erase "which was"

P4-L30. "…115km^2, and centred on the Bassiès catchments, as achieved for snow-free images."

P4-L32. "…-&4° along track direction…"

P5-L1. "…-6.4° across track direction."

P5-L9 "…mean Ground Sampling Distance (GSD)…".

P5-L13. "…installed in a nearby mountain refuge…"

P5-L16. "We collected up to 501 hand-probed…"

P5-L19. "…10 March 2015, at the time of the UAV survey…"

P5-L19. "…snow probes with length**s** of 2.2m and 3.2m,…"

P6-L3. "…to i) limit the areas **potentially** masked by the rugged topography…"

P4-L24. "…1-m resolution **from** their respective DEMs…"

P7-L24. "…s**n**ow probe"

P8-L1. "…the flat dropping zone of the mountain hut…"

P8-L15. Here and in lines 5 and 18 on page 11, don't know the correct sign to use for multiplication between dot and cross signs following the journal style? my preference is cross…

P9-L14. space to add between 3.2 m and (Fig.3).

P12-L27. "tie-point measurements, whose effect is equivalent…"

P14-L4. space to erase after "safe"

P14-L28. In upper case letters "Motion Unit"

P15-L3. Unclear sentence to correct, it seams that "by" is missing before Jagt et al. (2015)?

P36-Table 3 — caption. Remind the reader what the acronym NMAD denotes.

P36-Table 4 — caption. It would be helpful to remind the reader that ***** denotes significant correlations as mentioned in Table 3 caption.

P36-Table 4. What does reversed brackets denote in the interval bin column?