Review Response B - Snow Water Equivalent Retrieval Over Idaho, Part B: Using L-band UAVSAR Repeat-Pass Interferometry

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We wish to thank Dr. Mathieu Le Breton for his comments and feedback on this study. We generally agree and provide specific replies to his comments (italized) below:

However, I am concerned by a potential methodological flaw. The article claims to retrieve the Snow Water Equivalent using aerial SAR data. Yet, on line 171-173, you say that for each image pair, you use the mean density (equivalent to dielectric permittivity) from insitu observation, in order to estimate snow depth and SWE from UAVSAR. As it is, I would rather say that the method estimates snow depth, by combining UAVSAR+insitu density measurements. SWE is then derived using again this average density.

While we do utilize the aggregated in situ measurements to provide an estimate of insitu density it is an extremely limited contributor to the overall performance of the retrievals. InSAR measurements are quite insensitive to errors in the estimation of permittivity from dry snow density as discussed in this paper [lines 59-62], and (1) which compares extreme values of snow density and find under a 7 % error from those extreme values of snow density. Additionally (1), (2), (3) all discuss approximations for SWE directly from phase and incidence angles due to the limited impacts on SWE retrievals from snow density. Finally, (4; 5) evaluated paired snow depth and SWE measurements and found

the majority of variability derived from snow depth rather than density variations. The limited effect (<7%) on performance and densities limited variability are why we say we are capturing SWE even though we do utilize the aggregated snow densities.

We do agree it is very important to clarify that this snow depth retrieval technique requires either an estimate of snow density or an approximation such as those in (1; 2; 3) in the discussion and to clarify that based on previous work our retrievals are quite insensitive to errors in this estimate of density. We think adding a few sentences to section 1.2 (Previous Work) discussing the relative variations in density vs depth (6; 5) along with the previous sensitivity analysis on density relative to phase (1) and previous SWE approximations will be a useful addition to clarify this methodological choice and can re-reference that previous work section in section 3.2 (Setting the UAVSAR Reference Phase) when we discuss using the insitu densities.

Following this point of view, comparing results that use insitu data, with the same insitu data, seems sloppy. In consequence, accuracy estimation (figure 10, figure 11, section 7.1), one of the article's question, seems sloppy.

Figure 11 - uses interval boards (which were not used in the density estimations or phase reference setting) and are thus independent.

Figure 10 and section 7.1 - We agree that future work with increased numbers of data points should definitely consider using completely separate validation and calibration in situ datasets. We had 64 in situ snow depth changes, and 57 swe change measurements over two winters and 10 flight dates. Since we only used the aggregated snow depth change, density across all the insitu measurements, and the scene-wide phase for each flight [discussed in section 3.2 - lines 152-160] the agreement between in situ and retrieved swe and snow depth changes will be primarily due to phase variation across the scene matching snow

depth and swe variation across the scene.

We can add in an additional sentence to Section 7.4 (Future Work) discussing the need for future analysis to evaluate the importance and limitations of setting the reference phase and using a larger in situ dataset to evaluate the impact of different method of setting the scenes reference phase.

175: the UAVSAR timeseries represents what? How about - "UAVSAR snow and swe depth retrieval timeseries"

177: retrieved mean snow depth or SWE : is it snow depth or SWE ? This line [177] should read "retrieved mean snow depth **and** swe" not or.

5 and 118 : What is SNOTEL, how does it measure SWE ? 97 : what are the telemetered stations ? We can add a citation (7) for those unfamiliar with the Snotel network and text such as - "Snotel Network - a system of 900 telemered stations with snow depth, snow water equivalent, and temperature. Which measures SWE with a pressure measurement from a glycol filled bladder, measuring the weight of the snowpack."

what are the models for SWE ?

These are 100 m resolution SNOWMODEL outputs of SWE. The SWE model is described in section 2.4 and referenced there for additional reading.

112: Which nine pairs did you use ? As we mention in the text [112] we used the pairs that successfully unwrapped for most analysis. For a list of those see Table 1 which has a column showing which successfully unwrapped.

Fig 2: Maybe indicate the buffer boundary here, to clarify relation with fig 3.

Thank you for this suggestion. We can definitely add the buffer boundary in to clarify that relation.

Fig 3: What do you mean by clipping the data, and buffer zone ?

Clipping - "a small piece trimmed from something". In line [190] we discuss

that we use a 1-kilometer buffer around a line connecting the interval board locations to select UAVSAR swe changes to compare to the in situ interval board swe changes. We will add in "1-kilometer buffer around a line connecting the interval board locations" to this caption to clarify what this is showing

Fig 4: Is it cumulative precipitations ? It looks there is no melting.

This is SWE - the x ticks on this are the date of observation and only go through April 1st before the melt season has begun. We can increase the size of the xlabels to make it clear that this is during the accumulation period.

Fig 4: Can you add snow depth ?

Yes, we can definitely add snow depth.

128: Did you use Liston's model ? (you state it 'can' be used, not that you used it)

Yes, SnowModel (developed by Liston and others) is the snow-evolution model that we used at all other points where we discuss modeled SWE. To clarify that we use this Liston model (called SnowModel) we will change "can" to "did" use and add a parenthetical reference to SnowModel in the first sentence of the dataset section where we generally describe that we used a SWE snowmodel and include the section number (2.4) where we describe SnowModel.

132: Not clear what you used for computing the snow model. (ok: explained later) What is the altitude of the plane ? How do you compute the phase ? What is the emitted frequency exactly ? How do you ensure in your method that the phase is dominated by the ground reflexion, and not by the reflexion on the top of the snow ?

Altitude of the plane can be incorporated into the section 2.2 (UAVSAR imagery). ≈13,700 m.

Phase is computed by taking the complex conjugate of one image multiplied by the other image (can be added into the second sentence of the first paragraph

of section 2.2).

Uavsar's sensor frequency is 1.26 GHz or 23.84 cm. We can add that into section 2.2 (UAVSAR imagery).

There is a decent amount of previous work analyzing where backscattered energy at different frequencies come froms in alpine snowpacks. We can add in a citation (8) that discusses where the majority of returned signals arise at different wavelengths and showing that almost all the backscattered signal returns from the snow-ground interface at L-band.

166: What is a retrospective atmospheric to remove atmospheric phase ? Is it what is described in the previous paragraph ?

Yes it is a reanalysis of atmospheric conditions. We will change this to use consistent terminology such as "reanalysis-based phase delay estimation" consistently between these two paragraph to clarify that the two paragraphs are discussing the same atmospheric reanalysis product.

174: From the title of part 4, we expect results, yet this is still the method. Also, section 2 is called method (which it is) bu parts 3 and part 4, that are also methodological, are called differently. That is minor but a bit confusing.

We agree that that section should be a subsection (3.5) instead of 4. We will change this.

Fig. 7 is not straightforward to grasp and use. I may suggest a simpler graph more focused on the unwrapping limits. It could be for example a 2D graph with just a line representing 2pi phase shift, depending on the angle of incidence and on SWE variation (several lines for several fixed densities). It would be more informative.

We can add an additional pair of subplots showing SWE vs incidence angles with phase visualized as a 2d colormap for 250kg/m3 and 350 kg/m3.

1 References

References

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