

The Cryosphere Discuss., referee comment RC2
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Comment on tc-2021-247

Chander Shekhar (Referee)

Referee comment on "Mapping liquid water content in snow at the millimeter scale: an intercomparison of mixed-phase optical property models using hyperspectral imaging and in situ measurements" by Christopher Donahue et al., The Cryosphere Discuss., <https://doi.org/10.5194/tc-2021-247-RC2>, 2021

The article is written well and convey properly the work carried out by the authors. The objectives were mentioned clearly by authors in lines 59-63 of paper. This study focused on quantitative two dimensional retrievals of snow surficial liquid water content (LWC) using near infrared hyperspectral imaging (NIR-HSI) measurements in two scenarios. Firstly, LWC was mapped in controlled laboratory scenario by comparing reflectance spectra (measured using NIR-HSI) of snow samples (07Nos.) at different time steps with simulated reflectance spectras of three theoretical models by tuning LWC and grain size parameters. The retrieved LWC values were compared with dielectric measurement (SLF Sensor) based LWC of same snow samples. It led to selection of best matching hyperspectral imaging based retrieval model among the three. RMSE was found to be around 1% in LWC for large retrieved snow grain size values ($>176\mu\text{m}$ and $<1000\mu\text{m}$). The LWC retrieval models did not performed well for small grain sizes with complex shapes. Secondly, in field scenario the applicability potential of selected NIR-HIS based model was demonstrated for quantitative two dimensional surficial LWC retrieval on the wall of snow pit with an artificial source of illumination. The efforts by authors are appreciated as limited work is available on quantitative two dimensional LWC using hyperspectral imaging sensors.

There are a few observations and suggestions that i think will help to improve the overall impact of the paper. Specific comments include concerns based on curiosity for actual applications and other minor comments/suggestions have been put in order of appearance in the paper, listed by the line numbers.

Specific omments

- For field retrievals of LWC using NIR-HSI, dry snow densities could not be measured that lead to certain uncertainties in LWC. Also, few of the potential sources of uncertainty were discussed in section 5.3 without any quantitative values for discussed ones (like spherical grain size, dry snow density, illumination source etc.). For lab scenario, what LWC would have been obtained if one proceeds without accounting for dry snow density, as happened in field scenario. The authors had already worked out for lab samples by inclusion of dry snow density values. Based on this, an uncertainty figure may emerge (for 07 samples) and it will provide confidence for actual field retrievals. An observation on initial and final snow parameters in lab experiment may also help. Authors can include discussion on this in uncertainty section (Section 5.3).
- The envisaged potential applications areas (in field/ air/ space borne modes) using proposed high resolution NIR-HSI method for quantitative two dimensional LWC may kindly be mentioned in introduction or background section (*Line 95*). It will provide clarity to readers why LWC details at high resolutions are required with advantages/ limitations *over low resolution LWC*. Suitable references may also be included.
- Power source of halogen lamps may be mentioned which were used in field conditions for illumination purpose. A discussion on advantages/ disadvantages of dielectric based (e.g. SLF sensor) and NIR-HSI based sensors (in terms of outputs obtained by both instruments, performance time, cost effectiveness, uncertainties involved, portability in field, preferable method/instrument for specific application etc.) may help to provide better insights to readers.
- The parameters of actual snowpack and those measured on snow pit wall are expected to be different as exposure of snow pit wall while digging leads to changes in snow pack parameters on the wall. It would be interesting to know whether illumination using halogen lamps and opaque tarp is imperative for HSI based field measurements. In a natural scenario, the signatures from snow pit wall under shadow will be of diffused sunlight and may affect the reflectance measurements and hence retrievals based on simulated reflectances. I am curious to know about applicability potential of NIR-HSI retrieval method in actual field scenarios.
- **Refer Figure 10:** To obtain the snow pack stratigraphy, one has to dig a snow pit. Ice layers can be easily recognised visually in layers of snow. It is known fact that LWC will have high values above the impermeable ice layer for a wet snow pack and can be measured easily using portable SLF sensor in any illumination condition. Definitely, resolution of NIR-HSI is better than SLF sensor. From application point of view, it is curiosity to know where and how this high resolution details will actually help, knowing the fact that (i) LWC has high spatial and temporal variability in snow pack and (ii) hyperspectral information retrieval is constrained to surface measurements only. Kindly mention.

The specific comments express concern towards application potential of NIR-HSI based LWC retrieval methods with due recognition to actual field constraints, variability in field spectral reflectance signatures caused by number of dynamic factors (e.g. dynamic snow parameters, viewing/ illumination conditions and geometry etc.) and limited penetration of NIR radiations into the snow.

Other minor comments/suggestions:

L 1-3: Inclusion of appropriate scale in the title of paper at which work had been performed will provide clarity. As this work had not been tested for air/space borne sensors to cover large scales.

L 15: 'determine' to be changed to 'determined'.

L23: 'unprecedented detail' appears to be an exaggeration. Kindly use appropriate word/details.

L149: Inclusion of workflow diagram in Section 3 will provide quick easy understanding to the readers about the work that was carried out.

L 175: In laboratory setup, the distance (m) of halogen lamps and NIR-HSI imager from snow samples may kindly be mentioned.

Table 1: A column may be added for retrieved grain size values using SBA method for dry snow samples, that corresponds to grain size legend of Figure 8.

L 205-206: The distance (m) of halogen lamps and NIR-HSI imager from snow pit wall may be mentioned.

L 216: What were the implications of using 36% reflectance calibration panel during field experiments in place of 99% (that was used in lab scenario)?

Figure 4: The figure may be modified to depict clearly that upper 110cm of snowpit wall was imaged using NIR-HSI. It appear as if image was taken upto 150cm depth.

L 225: For words 'a small error', a quantified value may be mentioned.

L 250-254: It appeared that single scattering properties were tuneable using only two parameters LWC and r_e . Are there any other parameters also which have not been considered, under some assumptions/ approximations ? These can be mentioned.

Figure 7: SLF sensor measured LWC values corresponding to time steps in (A to D) may also be mentioned.

L 301-304: Criteria or reference statistical parameter (RMSE, Bias etc.) can be mentioned for the quoted relative best or poor performance of models.

Figure 8: Legends are same for Figure 8 (A – C) and can be placed outside the three figures to have better representation. Author can take a decision on this based on editor's suggestions.

Table 2: (1) The number of sample points used to arrive at RMSE and Bias corresponding to each sample need to be mentioned. The confidence level may also be mentioned. (2) The word 'RSME' need to be spelled correctly.

Caption of Figure 10: The words 'depth average of the SLF sensor area only' may be modified to provide clarity that it is HSI measurement corresponding to area covered by SLF sensor only. Description of 'NaN' can also be mentioned.

Table 3: Spelling corrections: 'Senor' to be replaced by 'Sensor'.

L 454-457: Kindly check whether these lines convey the correct message. It seems like inclusion of certain additional points has led to smaller SBA. Kindly verify.

L 469: A quantitative figure or reference for uncertainty of SLF sensor may be mentioned.

L 515: 'un-precedented detail' appears to be an exaggeration. Kindly use appropriate word/ details.

L 519-524: While using HSI based retrieval methods, kindly suggest the ways to account for the expected variability in reflectance signatures caused by illumination changes for air/space borne sensors. In this air/space borne sensor scenario, the level of uncertainty expected in LWC mapping using proposed simulated spectra approach may also be commented.

The article presented analysis on LWC retrieved from spectral reflectance signatures (in image form) and LWC measured using dielectric based, point form data acquired in synchronization for fair comparisons. It is nice set of information that will help research community to understand the potential of hyperspectral data for retrieval of LWC parameter of snow. The comments/ observations have been written with a constructive and curious spirit to improve the impact of the paper.

Best wishes.

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