Answer to Referee #2

-- *Comments and questions of reviewers in black*
-- *Answer to reviewers in blue*

Anonymous Referee #2
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SUMMARY

Larue and colleagues present both in-situ observations and a Rough Surface Ray Tracer (RSRT) model to assess the impact quantify the impact of surface roughness on snow albedo. Their observations show that surface roughness features have a strong impact at albedo reductions. This impact is already apparent for low roughness values, but becomes more pronounced for higher roughness values, where the albedo reduction depends strongly on the roughness orientation relative to the sun. Besides the observations, Larue and colleagues also introduce for the first time a model that allows to account for surface roughness in snow albedo simulations. Simulations with the model show that albedo simulations are improved by a factor 2 compared to those assuming a smooth surface. The model gives moreover insight in the role of Specific Surface Area (SSA), slope, the solar zenith angle and the roughness orientation. Finally, the paper highlights the necessity to take into account the roughness effects to compute the surface energy budget.

GENERAL COMMENTS

The paper of Larue and colleagues touches upon an important topic, is well written, extensively analyzed. As such it build further on earlier work of Warren, Cathles, Pfeffer, Lhermitte and many others, but with the clear novelty that it adds new well designed measurements and the RSRT model that allows to assess the effects in 3D (versus earlier 2D models). Based on these comments I think the paper is well suited and already well written and organised to merit publication in TC. Nevertheless, I have some minor comments that might be addressed in an eventual revised version of the paper.

MINOR COMMENTS

L124 "by uniformly pressing a rectangular metal bar into the snow" : What would be the effect of compression and corresponding differences in density/SSA on the observed albedo values. Do you expect this to interfere with the observations? If so/not, why and what would be the effect?

By compacting the snow, we locally increase the snow density at the surface and it may lead to a small decrease of the SSA (Legagneux et al., 2002 ; Dominé et al., 2007..). It is true that for experiments A and B, we may have disturbed surface SSA observations in the cavities by pressing the bar into the snow. But as the compaction was weak (2cm), and the SSA values were small (7.2 and 4.5 m²/kg before the compaction), we can consider that the observed albedo values were not, or weakly, affected by the compaction.
To be clearer, we added the following sentence line 190:
« Note that compacting to create the roughness features may have lowered the SSA locally. As the compaction was small (2 cm depth), and as the SSAs were initially low over the studied surfaces, we assumed here that the effect of the compaction on the observed albedo is negligible.”

For experiment C (fresh snow), we measured 3 surface SSAs at each albedo acquisition to have a good representativeness: over the sides facing, and facing away from the sun, and over the smooth

surface (between the cavities). The differences of SSA measured over each surface are lower than 10 %. We took the mean SSA to compute the albedo, as for each studied area the percentage of surfaces facing, facing away from the sun and smooth are similar. To be clearer on this point we added the following sentence in the paper (line 192) :
"For the two experiments C and D, three SSA values were measured at the surface at each albedo acquisition: two in the cavities (one over the side facing the sun, one over the side facing away the sun) and one over the smooth surface between cavities. The standard deviation of these three SSA is always lower than 10% of the mean SSA, showing that the compaction effect is negligible compared to measurements uncertainties. The mean of these three SSA values is used in our albedo simulations."

Measured albedo values above 1: the paper shows several figures with spectral albedo values above 1 which is physically impossible. It would be good to explain where these values come from and what it means in terms of uncertainty (also for the rest of the observations and conclusions).
See comment 1 of Reviewer 1. We introduced a new section (section 2.4) and a new figure (new Figure 4) to fully explain why albedo values may exceed 1 in the visible range. It is because our studied surfaces presented small slopes, and we measured the apparent albedo (with a sensor placed horizontally, over a titled terrain), whereby it differs from the true albedo (strictly ranges between 0-1, with a perfectly flat surface).

Figure 1: Based on this figure it seems that the sun is oriented North. I know that it is only an illustration and a minor detail, but it might be clearer if the sun is positioned south for norther hemisphere experiments.
We modified the Figure 1 to position the sun South in the illustration (see new Fig. 1).

Figure 5: Comparison between the simulated smooth and observed albedo values seems to show still some minor contamination by LAP's in shorter wavelengths. Perhaps worthwhile to mention that as well when discussing this graph?
This is true, we changed the sentence line 426 to mention the weak contamination by LAP's in shorter wavelengths :
"For both experiments, the pattern of the measured spectra between 600-700 nm is probably led by the presence of impurities (not visible to the naked eye on the field). Previous studies showed that the even a small concentration of snow LAPs induces a drastic decrease of the albedo in the visible range (Warren, 1984; Dumont et al., 2017), and may explain why measurements and simulations differs in the 600-700 nm range. "

L650 "large scale": it would be good if the authors could already add a discussion point of what the current results would mean for larger scale roughness features and/or how the conclusions from this paper can (or not) be extrapolated to larger scale roughness features.

The RSRT model can be used at a larger scale if driven by an adapted DEM. Nevertheless, at this large scale, the most challenging work would be to include the atmospheric effects in the Monte Carlo algorithm. However this would strongly increase the computing time by increasing the number of photon hits drastically. The algorithm needs to be well optimized.

To be clearer on this point, in the simulation framework section we explain that the atmosphere is not directly taken into account in the Monte Carlo algorithm, by adding the following sentence Line 356:
"Each simulation assumes clear sky conditions, and no atmosphere is considered in the Monte Carlo algorithm. The only atmospheric parameter used in the model is the diffuse-to-total illumination ratio (which depends on atmospheric conditions). This parameter was measure in the field at each albedo acquisition. At our small scale, the effect of the atmosphere is negligible

between the sensor and the surface. Future work will focus on setting up the atmosphere in RSRT for applications over large-scale natural surfaces (mountainous areas).”

To discuss the future work concerning the model adaptation at larger scale, we added the following sentences at the end of the section 4.5, line 748:
“*The RSRT model was evaluated with artificial roughness here, and the next step will logically concern natural rough surfaces. An interesting perspective would be to apply this model at a larger scale for remote sensing applications, in particular in complex terrain (mountainous area). Nevertheless, this work will prove challenging since at such a scale, the atmosphere scatterings have to be integrated in the Monte Carlo algorithm which will drastically increase the number of photon hits (i.e the computing time).*”