Interactive comment on “Brief Communication: Light-absorbing impurities can reduce the density of melting snow” by O. Meinander et al.

Reply to the Anonymous Referee #1

We thank the Anonymous Referee#1 for all the valuable comments. Here we give our reply.

Referee:
“This study observed that density in a melting snowpack decreases as BC content increases. For a cold non-melting snow there is no correlation between BC content and density, except for a single data point forced with an artificial LAI deposition with extremely high BC content. While the title specifies light absorbing impurities, the relationship is based on measured BC (EC). The observed relationship that results between measured BC and reduced density is mainly dependent on artificially deposited impurities at one location. The result is very interesting, but would be strengthened by additional measurements in more locations for both cold and melting snow (which is acknowledged by the authors).”

Our comment:
In this first paragraph, the Referee makes a summary, to which we totally agree.

Actually, after we had submitted our manuscript, we made a small laboratory experiment. These new experimental data were found to support our hypothesis, presented in our Brief Communication TCD-paper, that BC may decrease the liquid water retention capacity of melting snow. We found that snow with added soot released melt water sooner than snow without added soot.

For this new experiment, we added a known amount of soot to a snow sample, mixed the soot and snow, and let then the snow melt indoors, while measuring the melt water on a drip pan as a function of time. The results showed that while the control snow started to release melt water after 40 minutes, the snow with added soot released melt water already after 12 minutes. When cold water was added on snow, the control snow released water after 29 minutes, while the same amount of water in sooted snow caused water to release already after 7 minutes. All the snow samples were of the same size (same weight and volume) representing the same natural snow, and mechanically treated the same way whether soot was added or not, e.g., the control snow was also mixed although no soot was added.

In consequence, we’d like to suggest the following new sentences to be added in the Discussion and conclusions of our revised manuscript (p. 264, after line 24):

“Furthermore, according to our recent laboratory experiment (unpublished data), we found that snow with artificially added soot released melt water sooner than snow without added soot. For this experiment, we added a known amount of soot to a snow sample, mixed the soot and snow, and let the snow melt indoors, while measuring the melt water on a drip pan as a function of time. The results showed that while the control snow started to release melt water after 40 minutes, the snow

with added soot released melt water already after 12 minutes. When cold water was added on snow, the control snow released water after 29 minutes, while the same amount of water in sooted snow caused water to release already after 7 minutes. All the snow samples were of the same size (same weight and volume) representing the same natural snow, and mechanically treated the same way whether soot was added or not, e.g., the control snow was also mixed although no soot was added. Hence, these new experimental data were found to support our hypothesis that BC may decrease the liquid water retention capacity of melting snow."

Referee's Comments:

Referee: "Artificially dirty snow caused earlier run off (melt)/ released water Clarification on density measurement methods- i.e. density cutter, snow tube, or other method? Why was only surface density, and not full column, measured during SoS-2013? "

Our reply:
Snow tube was in use for SR and SNORTEX data (whole snowpack), and density cutter for SoS-2013 (layers).

The reason for measuring surface density during SoS-2013 was a quick decision due to simple curiosity on various aspects related to snow melt: Why would dirty snow melt faster? (Everyone is talking about faster snow melt, but I would like to know why.) For example, could dirty snow have a lower water holding capacity than clean snow? How to study this? In the field, it is more difficult to measure the amount of melt water released. Instead, under these experimental conditions of the SoS experiment, we could easily measure (simultaneously) the density of dirty melting snow and compare it to the clean snow density. That is why the density of the visually dirty melting snow of SoS-2013 experiment was measured. The visually dirty snow was on the surface. If the whole snow pack would have appeared dirty, we would have measured the density of the whole snow pack. The reference snow of SoS was measured the same way, to allow comparison.

On the basis of these Referee comments, we suggest the following clarified sentence to be included in the revised manuscript (p.262, lines 12-14 in our discussion paper):

"The snow densities (weight per volume) were measured manually, for either the whole snowpack vertical column (snow tube for SR and SNORTEX data), or for separate horizontal snow layers (density cutter for SoS data to measure the density of the visually dirty surface snow). One density measurement for each location was made."

Referee: "The relationship between impurity content and density is really dependent on measurements at 1 location (SoS-2013), the discussion of the other studies may be unnecessary. This paper could be simplified to a process study at one location."

Our reply:
We totally agree that the observed relationship between measured BC and reduced density is dependent on artificially deposited impurities at one location. However, our new laboratory experiment results supported our TCD-paper results and hypothesis. Hence, the new data strengthen our original results. Also, in our TCD-paper, we have gathered all the existing snow density data coupled with BC in snow, and measured by the Finnish Meteorological Institute in Sodankylä. Concerning any possible future research results by any scientist, it is also important to realize, that the results of snow density and BC may be dependent on the differences between cold snow and

melting snow. In principle, we expect the relationship to exist for the melting snow only. The cold snow cases support this assumption. Therefore, the cold snow studies are not unnecessary. As a conclusion, we'd like to suggest that all the original results of our TCD-paper would be included.

Referee: "Given the relative low contribution to bolstering the results of the study, discussion of hard hardness, grain size, and grain shape observations in the methods section could be summarized in a more concise fashion."

Our reply:
The referee makes a good point to which we agree. The new shortened paragraph is suggested to be:

"In the SoS-2013 data, snow hardness, grain sizes, and grain shapes were estimated and classified according to the International Classification for Seasonal Snow on the Ground (Fierz et al. 2009)."

Referee:
"A greater discussion of the impurities deposited at the SoS-2013 site would be useful both in section 2 and section 3. How were they deposited - sprinkled over the surface? Is there any knowledge of the absorbing qualities (i.e optical properties) of these impurities? It is mentioned that only 3 spots are used in the study- were more study plots administered with other impurities? What were they and what were the relationships for density in those plots?"

Our reply:
We agree that a greater discussion could be useful. In the SoS-2013 experiment, a chamber was lifted on snow and the impurities were blown into it. The optical properties of the impurities were studied, too, and here was a total of 13 impurity spots in addition to the control spots. The SoS impurities were soot, silt and volcanic sand. A manuscript with more detailed description of SoS-2013 is in preparation by Svensson et al. (2014). All the Referee's questions will be answered there, and these data are not included here. In the current paper, we focus on snow impurities and density. But, on the other hand, all the SoS-2013 impurity data coupled with the snow density data are presented in the current Brief Communication-paper, together with all the previous snow impurity and density data from Sodankylä. As a result of this Referee comment, we have now identified the various impurities of the 3 spots that were used for the study (volcanic sand, soot from oil burner and wood burning soot).

Referee:
"In the result section the concentrations for melting snow are said to range from 9-730 ppb, would plot 2b change if individual samples, rather than spot averages, were plotted? How was each spot sampled and why do the number of samples vary per plot? Additional description in this section would strengthen the results presentation."

Our reply:
It is true that the number of samples for BC analysis per spot varies. For example, more samples were gathered for reference snow to gain information on the natural variability. Also, despite all our efforts, the soot was not evenly spread on every spot surface. Hence, the more uneven the spot surface appeared, the more samples were made. If individual samples were plotted in Figure 2b, the same relationship of BC and density would remain, but due to the variability of the number of EC concentration results versus one density measurement, the relationship would appear slightly weaker. The 95 % confidence interval of the slope of the Eq. 1 is from -0.46 to 0.08, i.e., we are 95

% confident that the true slope of this equation is in the range defined by -0.27±0.19. This information we suggest to be added in the revised version, after the Eq.1 (p.264, line3):

“The 95 % confidence interval of the slope of the Eq. 1 is from -0.46 to 0.08, i.e., we are 95 % confident that the true slope of this equation is in the range defined by -0.27±0.19.”

Referee:
“Figure 1- Which impurity plot is pictured in C- sand or soot? The picture of the gravel surface under the snow is not necessary unless the authors are concerned it played a role in absorption for a snowpack that was not optically thick- if this this the case for any of the points, they should be thrown out because the relationship is not only due to surface absorption by measured concentrations.”

Our reply:
The impurity in Fig 1c is volcanic sand. The Fig 1b on the gravel surface was included in order to pay reader’s attention to two facts: 1) although the experimental field was an airport, the ground was natural and not covered by concrete or asphalt; ii) snow density is affected by various environmental factors, explained in the last paragraph of our paper. Due to the Referee’s comments, we suggest the following new text explaining the Figure 1:

“Figure 1. The SoS-2013 experiment. a) Top. The flat and open experimental field with the seasonal snow pack; b) Bottom left. The ground under the snow, i.e., a natural gravel surface, not covered by concrete or asphalt, offered an uniform surface for the snow cover; c) Bottom right. Previously added impurities were visible on the surface of the melting snow, here volcanic sand.”

Referee:
Figure 2- Color-coding would make these plots more clear. Natural (control) points should be a different color from the artificial points-differentiating the artificial points between soot/volcanic sand would also be useful.

Our reply:
We agree. The plots in the revised manuscript are now color-coded, as suggested by the Referee.