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## ***Interactive comment on “Retention and radiative forcing of black carbon in Eastern Sierra Nevada snow” by K. M. Sterle et al.***

**K. M. Sterle et al.**

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Thank you for your comments regarding this manuscript and for acknowledging the strong relevance of this work for the scope of The Cryosphere. Many of your comments can be rendered by providing the raw data and field notes (ie: snow density, snowpack stratigraphy, lysimeter collection). This data will be uploaded as supplementary files. Specific responses to your concerns are given below.

1. Several uncertainties in the presented paper remain and some important topics such as snow metamorphism and snow density profiles (claimed to be measured) have not been discussed at all (and presented). The data set, presented to be botched by another referee, seems to be valuable but not easily understandable as it is presented. Figure 2 is particularly questionable as the number of points is not the same on each

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subplot.

Response 1. The number of points is not the same because not all parameters were measured for each snow pit due to varying field methods (ie: whether surface snow was collected), limited sample mass and instrument availability. See clarifications below.

Figure 2a: Surface samples were not collected or measured on 18-Apr or 30-May. Figure 2b: For 18-Apr, there was not enough sample to measure ions. The ion data from 10-May was lost. Figure 2c: Dust was not measured for 18-Apr because there was not enough sample.

2. In section 3, authors stipulated that concentrations showed little temporal variations according to figure 1 and that there are much more variations in surface according to figure 2a. Figure 2b shows averaged profiles of rBC normalized to values of maximum accumulation on 29th April and figure 2c shows the same type of data but for rBc and dust and only in the top 30 cm of the snowpack. Caption and legend of figure 1 and 2 are not very clear. In figure 1, while caption stipulates values in cm water equivalent, the legend stipulates values in cm above soil. What is the good one? I do believe this is in cm water equivalent, according to the number of points and the fact that sampling was done every 10 cm increments in the snowpack.

Response 2. The “above soil” axis label does suggest depth, but this is there as a reference for the reader in that the SWE increases with snowpack depth. The caption is correct, but this should be clarified by removing the “above soil” label.

3. Regarding figure 2, authors always speak about thickness of layers (2 cm for the surface), titled section 3.3 as “dust in the top 30 cm snow depth” but they described in section 4.3 that they calculated the effect of rBC and dust radiative forcing in the top 30 cm of snow water equivalent....?? I am confused...but I do believe that data of figure 2a and 2c represent values respectively for 2 and 30 cm of water equivalent isn't it? If it is not in cm of water equivalent, where are the snow density data? 30 cm of snow will include deeper snow layers over time so that it is normal than rBC increases...

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Response 3. The snow profile samples were taken using a 1-L density cutter, and that is what is shown in Figure 1. Figure 2a shows the surface snow concentrations which were not taken using a density cutter. Rather, these samples were collected with a sterilized scoop device in order to collect just the top 2 cm of snow. You are correct in that all the data was converted and analyzed to SWE. “Depth” is used when explaining the amount of sample analyzed (see methods). The goal is for the reader to understand that we took the 0-10 cm, 10-20 cm, etc. . . of depth snow sample, labeled a Whirlpack bag, weighed the sample, melted the samples individually, measured rBC, and then assigned that rBC concentration to the corresponding SWE so that the more dense samples with high rBC concentrations (for example) were weighted accordingly.

4. If it is in cm of equivalent water, where is the correspondence between data of fig 1 and fig 2a? Figure 1 should be modified; we can barely estimate any values.

Response 4. Perhaps the difference in Figure 1 and Figure 2a is not clear. Figure 1 is the raw snow profile data. Figure 2a is the range of rBC measured in the 2 cm of snow at the surface (see response 3). The top 10 cm depth collection from the snow pit is not the same as the surface scrape. There is no correspondence because they are not the same data.

5. As I am not sure of what is presented in figure 2 (cm of snow or cm of water equivalent), analyse of that work is hypothetic and needs precision before going further. In both cases, why is there missing data on 18th of April? After reading author’s answer to referee 1, it seems that authors were missing snow for analyses. Is it because the snow was too less loaded in particles to obtain enough sensitivity in your measurement technique? That would explain why you concentrated efforts and measurements on main profile (fig 2c), then on 30 cm profile (fig 2b) and afterwards on surface profile (fig 2a). Please present a clear statement on this point.

Response 5. See response 1 for clarification on data availability for 18-Apr. All snow we collected, we analyzed in the following order: rBC, dust, ions. In the case of 18-Apr

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there was not enough sample left to measure dust or ions.

6. Nevertheless, some others aspects of that work are questionable. In both cases (cm of snow or cm of water equivalent), the snow density is missing as well as the snow stratigraphy and authors claimed that they have been both recorded (section 2.1). Even if snow start to melt after 29th of April, melt water will not go through the snowpack before snow is really wet.

Response 6. The raw data and field notes will be provided as supplementary material.

7. When snow starts melting, liquid water tends to stay in the snowpack and be located at the grain joint and form grain clusters. This would increase the snow density. When snow is really in an advanced melting stage, liquid water will be located around the grain and tends to form rounded particles with a core of ice and a shell of water [Fierz et al., 2009]. If too much liquid water is present then water goes through the snowpack. Liquid water content of the snowpack would have been a very valuable data set to add to this study in order to determine where is located the liquid water and if some of the melt water is retained in the deeper snow layers or released from the snowpack. Snow metamorphism, i.e. increase of snow density and vapour fluxes through the snowpack, is not taken into account. Could it affect your results?

Response 7. Certainly – there are many factors that were not evaluated that may affect the results. However, the timing of rBC versus soluble ions during the melting phase of the snowpack indicates that the rBC was retained since the ions decreased between 29-Apr and 17-May.

The reference you site is very interesting, however our field campaign did not focus on physical melting properties of the snowpack or snow metamorphism. The following reference describes the findings from the other field campaign:

Bair, E. H., Dozier, J., Davis, R. E., Kaempfer, T., Colee, M., Mielke, R., and Blackford, J.: Observations of two seasons of sintering in a mountain snowpack, in: 2009 Interna-

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tional Snow Science Workshop, edited by: Schweizer, J. and van Herwijnen, A., Davos, Switzerland, 115–119, available at: [http://www.issw.ch/proceedings/ISSW09\\_Proceedings.pdf](http://www.issw.ch/proceedings/ISSW09_Proceedings.pdf), 2009.

Our team did record some notes on these physical properties from the field, they were too speculative to draw any conclusions related to rBC elution. We did not focus monitoring and observation on these factors and therefore it is only speculated off previous studies in the same area. However, the observations we did note will be available in the supplementary materials.

8. As most of non-permanent snowpack, the studied snowpack should experience melt refreeze events. The presence of melt refreeze crust could considerably affect the amount of liquid water able to go through the snowpack and ice lenses could create preferable pathways in the snowpack. Where is the stratigraphy claimed to be retrieved?

Response 8. The snowpack in Mammoth is dry, and thus it is assumed that no melt refreeze events occur beyond the surface. The observed stratigraphy is provided in supplementary materials, but was not consistent enough across pit sampling to draw any conclusive remarks.

9. In section 3.1, authors said that rBc fluxes from the base of the snowpack were estimated on 23th May using lysimeters and measured melt water fluxes in between 23 and 30th of May. Amount of percolated water should also be presented. Such method imply the assumption that there is no relation between the amount of percolated water and the amount of insoluble material release, i.e. liquid water fluxes and size of particles susceptible to be entertained. [Conway et al., 1996] clearly mention the effect of particle size during the melting period in their study.

Response 9. The lysimeter data will be provided in the supplementary data, but since this was a pilot study, the method of capturing water needs to be improved. It was useful for our purposes in order to prove that flushing and melt was in fact occurring, and

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increased throughout May. Two major reasons this data is not used in the calculations of rBC elution is 1) we could only get that water when we were at the site (usually occurring at the peak time of day  $\sim 13:00$ ), so this may not be representative of any one period. 2) We could be missing the release of ions and rBC, as we speculate the snowpack is not melting at an equal rate and the impurities are not flushing at an equal rate. Therefore, this is not conclusive enough to use.

10. In fig 2c, rBc and Dust profiles does not show the same pattern. The most important difference is on 10th of May: why the dust concentration on fig 2c on 10th of May is decreasing of 50% while rBC is increasing? Don't you think there is an effect of particles sizes here? This can also be seen in the geometric mean values for dust that are the same ( $12 \mu\text{g.g}^{-1}$ ) for both periods but the range is higher during the accumulation. If dust is not released and accumulated on surface, higher value than  $53 \mu\text{g.g}^{-1}$  should have been detected during the melt season, as it is the case for rBC.

Response 10. Yes, particle size should be considered for future evaluations.

11. It seems also in fig 1 that the bottom layers are a bit more concentrated in BC during the melting period. A simple integration of the surface area below the curves for each 30 or 50 cm depth increment would not be clearer? For me, it seems that BC is moving down over time but it does not mean that a part of it does not stay on the surface. Why BC should stay on surface at the beginning of the melt period and suddenly, in end of May, should be released while 65% of the snow is still present. If BC stays on surface during the melting period, rBc should be even greater in end of May. What is causing a flush in end of May?

Response 11. If we consider air temperature in Mammoth, we can assume that no flushing occurs during the accumulation season because the snowpack is drying. Once the snowpack becomes isothermal and the snow grains increase, we observe more percolation as indicated by the lysimeter activity below. There is a delay in this activity, but isothermal snowpack conditions were measured on 29-Apr. We do speculate that

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some threshold is reached that causes the final flush at the end of May, however, many factors contribute to this.

12. Finally, on the modelling study, authors made calculations over the 30 first cm of the snowpack equivalent water using a range of grain size in between 0.1 to 1 mm. In section 2.1, authors claimed that main of the snowpack is constituted of coarse-grain snow cluster (typical of melt refreeze snowpack by the way) with mean grain diameter of 2 mm. Why did you present calculations between 0.1 and 1 mm? This will not change results but will be logical. How is related the forcing calculated with the profiles as the bigger are the grain sizes and the deepest the light will penetrate in the snowpack.

Response 12. These were the assumptions based on the model.

13. A depth study could show different results if rBC is more able to stay on surface compared to dust for instance...Dust profiles should be compared to rBc profiles in the 30 first cm with radiative forcing. If dust contributes 1.5 more than rBc in the forcing, it should be included in the title or black carbon replaced by impurities or insoluble particles.

Response 13. Yes, but goal was to investigate rBC. Dust forcing being 1.5 times greater than rBC is what we learned from the radiative forcing model.

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Interactive comment on The Cryosphere Discuss., 6, 2247, 2012.

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