

Interactive comment on “Measurements of light absorbing particulates on the glaciers in the Cordillera Blanca, Peru” by C. G. Schmitt et al.

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The authors would like to thank reviewer 2 for the thorough review. Replies to the reviewer questions are below.

Vertical variation: As Referee #2, I don't fully understand how the data from the surface and sub-surface samples are used. Are they all mixed together in the results, or are only surface samples used in some of the data presented? As Referee #2, I expect a discussion of the variability between these samples. You could potentially differentiate between these two types of samples in Figure 6.

As discussed in response to reviewer 1's question, there was a lot of variability which was determined to be caused by fresh snowfall. This led to the surface and sub-

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surface samples being up to $\sim 10x$ different in eBC determined values for samples taken in the same location with no apparent preference as to which was higher. As there was no clear trend (on the average, surface samples had $\sim 20\%$ higher eBC values, but the standard deviation was substantially higher) it seemed reasonable to mix the results together. Please see the response to reviewer 1 for the changes made to the manuscript.

Undercatch: As Referee #1, I worry about the undercatch in the quartz filters. On page 5086 lines 4-6 the formulation is a bit peculiar for me. You use a BC standard that is not well captured by the quartz filters. This sounds a bit strange for me. Have you tested a BC standard with larger particles, similar to those that likely occur in the snowpack?

The response to reviewer 1 explains why we are confident that the undercatch is not a major problem. Regarding lines 4-6 on 5086, since it was determined that the quartz filters did not adequately capture all of the BC particles in the standard, the Millipore filters (which captured between 97 and 99% of the mass) were used to create the calibration filters. Thus, the LAHM instrument was calibrated with filters where the mass was accurately known with a possible undercatch of 3% of mass with the Millipore filters. It was determined both filter types (Millipore and quartz filters) behaved identically when clean in the LAHM system. The signal (temperature increase) for clean filters of both types was about 0.6C while a signal from 5 micrograms of BC was $\sim 3.5C$. This gave us confidence that the LAHM technique could detect levels of BC of less than 5 micrograms on a filter. As explained in response to reviewer 1, in tests conducted in 2014, a maximum of 20% undercatch was estimated with values generally averaging 5%. While we have made no claim that the quartz filters capture all of the snowborne BC we are confident that the quartz filters do capture a high percentage and this is also part of the reason that we report an effective BC value and state that it is possibly underestimated. The fact that the eBC values from the LAHM technique are well correlated with the rBC values from the SP2 and the further measurements described in the response to reviewer 1 using the two different types of filters gives us confidence that

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undercatch isn't substantially affecting our measurements. Page 5081, line 25 to page 5082, line 4: References to BC emission statistics would strengthen your statements here. One candidate is Bond et al. (2004): A technology based global inventory of black and organic carbon emissions from combustion. Newer publications and more specific on the area around the Cordillera Blanca would be even better.

At this point, there are no black carbon inventories specifically developed for the region. Amazonian burning is said to account for about 50% of the carbonaceous aerosols in the amazon region (references now in the manuscript). Coal is not commonly burned in South America, as hydroelectric power is one of the largest sources of electricity. More detailed inventories of emissions are currently not available.

Further, how large is Huaraz in terms of population size and at what altitude?

The population of Huaraz is about 100,000. Huaraz is at 3052 meters in altitude.

Page 5083, lines 10-13: Snow can often have a highly variable concentration of dust from nearby outcrops or other landscape features that act as sources of dust. From personal experience of sampling snow, variability in dust concentrations in snow is often observed visually at site. Could you potentially add a sentence on how you selected areas to avoid areas highly influenced by local dust and sand particles?

The Cordillera Blanca is no exception to dust from local sources. Volunteers are instructed to collect snow in areas at least 100 meters distant from visible rock outcroppings and to avoid areas where avalanches or avalanche debris could have contaminated the area with dust. Generally, the mountains are sampled by the easiest climbing routes which are less likely to be affected by avalanche. This is now explained in the text. Page 5083, line 26 to page 5084 line 1: Can you explain better why you think the subsurface sample contain snow from the most recent snowstorm? Perhaps a reference to glacier or snow dynamics in tropic glaciers is in place and would help your statement? As the sampling is done in the dry season, I'm not totally convinced that the sub-surface samples contain snow from the latest snow storm. Could the snow come

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from different episodes and also include dry deposition and accumulation through melting?

Experimental ideas often don't pan out in practice, which is why I used the wording "should" for these statements. As discussed in the response to the surface samples compared to the sub-surface samples, your concern is obviously correct. Only after more substantial snow storms were the "previous" surface layers completely buried. That said, all measurements were collected at altitudes above the zone of ablation and volunteers were instructed to avoid any obviously old snow (that would be in the ablation zone). In the three expeditions (and 2014 as well), visually, seasonal snow was still present on glaciers down to 5000 meters or lower. This is addressed in the new section on the difference between the surface and sub-surface measurements.

Page 5087, lines 23-24 and the following sentences: The statement about the correlation between dust content and heat capacity is not very firm. Could you find any support for this finding in the literature? I understand this is not the main scope of the publication, but a strengthening of this part would be helpful.

This statement was made based on results from filters collected in in other regions which contained very high concentrations of dust that were subsequently analyzed using the LAHM technique. The dusty filters were collected after a dust storm had very high eBC values (50-100) and by color were very different from Cordillera Blanca filters. The temperature curves measured by the LAHM instrumentation for the dusty filters were substantially steeper than the steeper curve shown in figure 4. This discussion is now included in the manuscript.

Page 5088, lines 6-7: What is your reason to believe the reduction is 25%? I understand this issue concerns only a small part of the total samples, but I would like some more reasoning.

The filters that were affected had a pattern of concentric circles where the filter holder had been in contact. Upon removal, the particles that would have been on the filter

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were attached to the filter holder's concentric rings. The area where particles were removed was relatively easy to determine. 25% is a subjective estimate based on observation of the filters and the filter holder as well as the coloration of the "clean" circles on the filters. While not exact, it seemed better to adjust the values within the expected margin of uncertainty rather than average in values that were known to be incorrect. The values reported in the figure were only increased by 5 to 10% when the 25% was added to the affected filters.

Page 5088, lines 15-17: Could you please clarify whether the snow was tested by both LAHM and SP2, or if snow samples from the same sites were used for the two measurements. Variability on micro scale in the snow pack is well known; hence, it is very unlikely to get a perfect correlation if different snow samples from the very same sites are analyzed.

The LAHM filtering takes place in the field and it is therefore not possible to preserve the exact same water in a way that it would be useable for the SP2. Yes, it is very possible that some of the differences between LAHM and the SP2 measurements were due to micro-scale variability. Also, LAHM filtering uses on the order of one liter of water while SP2 measurements can be conducted with only a few grams of snowmelt.

Page 5089, lines 1-7: You could also compare to other regions, such as sites in Europe similar to that in your study.

More comparisons are now made in the text.

Page 5090, lines 16-17: How do you know the crevasse was newly opened? You don't need to elaborate about this in the paper, but I ask to check the quality in your findings.

I have personally climbed Vallunaraju every year for the past four years. It is relatively easy to identify how long crevasses have been open based on the amount of icicles on the more shaded side. There were very few icicles on the shaded side of this crevasse while in a crevasse a few hundred meters higher with the same aspect, there were

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numerous. Also, these samples were collected in 2012 and I did not recall there being a crevasse in that location in 2011.

Page 5090, lines 21-23: If possible, you should find and refer to literature on the stratification of annual layers in tropical glaciers to find support for your statement.

I asked numerous local glacier experts about these layers and this statement is made based on their responses. A technician who has been conducting glacier measurements for the Peruvian ministry of water for decades climbed Vallunaraju with me in 2014 and agreed with this conclusion.

Figure 3, caption line 3: Rewrite “of data 12 temperature profiles”. The current formulation is odd. x

Changed to “standard deviation for 12 temperature profiles shown in 3a”

Interactive comment on The Cryosphere Discuss., 8, 5077, 2014.

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