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Atmospheric Chemistry and Physics Discussions

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Interactive Comment

Interactive comment on "Scavenging of black carbon in mixed phase clouds at the high alpine site Jungfraujoch" *by* J. Cozic et al.

J. Cozic et al.

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General comment:

We thank referee 2 for his/her helpful comments and will take them into account in the revised paper.

Scientific comments:

Referee: "1) The authors of this manuscript could consider putting the section on "Black Carbon measurements" into an Appendix to reduce the length and readability, but this is a minor point."

Response: We will shorten the section on BC measurements and will remove the intercomparison of the three instruments from this paper.

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Referee: “2) Most of the data are displayed with box charts. However, the statistics associated with the plots are not discussed. What do the boxes represent? Please describe completely the graphs and indicate what each symbol represents. Overall, I would like to see much more discuss on the statistics, and I would like the authors to backup there conclusions with a statistical analysis or discussion. Specific points are listed below.”

Response: Each asterisk is an average of N 10-min raw data points, e.g., in Figure 5a (Figure 3b in the revised manuscript) each box plot represents the results of 149 points (25h). The box plot represents the spread of the data in percentiles: 10th, 25th, 50th, 75th and 90th. This does not correspond to an error, but is due the variability in the data, because other factors than the one plotted on the x-axis exert an influence on the partitioning as well. The box plots were explained at the beginning of the analysis (section 3.4): “In the following, statistical graphs are represented as box plots containing the different percentiles (10th, 25th, 50th, 75th, 90th) and an asterisk representing the mean average. All symbols are based on the same amount of data as given by N (= number of 10-minute averages per symbol).” Nevertheless, it will be explained more clearly in the revised version and we will mention the meaning of the box plots also in the first box plot figure caption for clarity. We will also explain more clearly what N represents. We will also show a new graph with the raw data (Figure 3a in the revised manuscript) from which box plots are extracted (Figure 3b). In this way, the large scatter in the raw data is visualized. The statistical analysis will also be explained more clearly: We will investigate the significance of the trends by means of appropriate fits on the raw data and we will give 95 percent confidence intervals of the fit parameters, assuming an equal error on each point.

Referee: “Section 3.4.1: The authors suggest that FScav,BC increases with increasing LWC. I would agree that the data suggests this trend for T>-5°C, but I do not think the authors can make this conclusion for T<-5°C. The authors should perform a full statistical analysis to support their conclusion. My feeling is that the uncertainty is too

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great to make this conclusion. The authors indicate that the observed dependence is also weaker at lower temperatures, but I think even this is too strong of a statement. Maybe I do not understand the uncertainty in the data, but the authors should provide a statistical analysis to support this conclusion."

Response: Again, the box plots do not show the uncertainties but the spread of the data. We agree that there is no significant dependence of LWC on Fscav,BC for the cold conditions (T<-5°C). Therefore, no fit equation will be given for this graph. For the warm conditions (T>-5°C) a significant positive trend is observed and therefore we will show the appropriate fit equations in the revised manuscript, with the 95 percent confidence interval of the fit parameters. For the dependence of Fscav,BC on LWC we found a positive trend with increasing LWC in the warm temperature case (T>-5°C), Fscav,BC = (0.70 +/- 0.05) + (-0.55 +/- 0.06) * exp(-(5.29 +/- 1.7) * LWC[g/m3])

Referee: "Section 3.4.2: For Figure 6a, can the authors say with certainty there is a trend with BC concentrations? Except for maybe the first data point, there doesn't appear to be much of a trend. Please include a discussion on the statistics."

Response: The analysis of the influence of the BC concentration on the scavenged BC fraction at temperature T>-5°C (new Figure 4a) shows that there is a decreasing trend with a slope significantly different from zero (Fscav,BC = (-0.00064 +/- 0.00023) * BCtot [ng/m3] + (0.56 +/- 0.02)). This relation is even more pronounced for a higher split point temperature of T>-0.5°C: (Fscav,BC = (-0.0014 +/- 0.0004) * BCtot [ng/m3] + (0.63 +/- 0.04)). In the new manuscript we will add a new figure for T>-0.5°C (Figure 4b). For T<-5°C the exponential fit shows that the scavenged fraction is smaller at high BC concentrations than it is at low BC concentrations (Fscav,BC = (0.12 +/- 0.02) + (0.58 +/- 0.09) * exp(-(0.06 +/- 0.01) * BCtot [ng/m3]))).

Referee: "Section 3.4.3. line 8: "At higher temperatures, T>0 C, a reverse trend is observed." This appears to be based on one data point, which has a rather large uncertainty. Statistically, can the authors say with certainty there is a reverse trend?"

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Response: As mentioned above, each box plot represents many data points; in this case 317 points of 10-minute averages (53 hours of data). The observed reverse trend with increasing temperature is significant.

Referee: “Section 3.4.4, line 10: “According to equations 7 and 8, 16 percent of the BC mass concentration is found in the ice residuals whereas only 2 percent of the aerosol mass is found in the small ice crystals.” Please state the uncertainties (i.e. error bars) of these numbers?”

Response: Several tests were performed to see if a ratio or a difference between the BC and volume scavenged fractions (Fscav,BC and Fscav,V) shows an enrichment in BC in ice residuals. The scatter in the data did not allow for a significant quantification of this enrichment. We therefore decided to remove this part of the comparison in the new manuscript. We will nevertheless present a new figure (Figure 6) in which the two scavenged fractions are plotted versus the ice mass fraction. The fact that Fscav,BC and Fscav,V show a very similar dependence on the ice mass fraction indicates that BC is internally mixed. The exponential fit equations for this analysis and the 95 percent confidence interval will be given in this paragraph (Fscav,BC = (0.05 +/- 0.02) + (0.92 +/- 0.25) * exp(-(8.95 +/- 2.17) * sqrt(IMF)); Fscav,V = (0.06 +/- 0.01) + (1.07 +/- 0.25) * exp(-(9.33 +/- 1.90) * sqrt(IMF))).

Referee: “Section 3.4.3: The authors state that the observed trend is explained with the Wegener-Bergeron-Findeisen process. This statement is too strong. Could other factors such as updraft velocities also explain the results? The authors should state that the trend could possibly be due to the Wegener-Bergeron-Findeisen process, but other factors could also explain the trend (unless the authors can prove that this statement is false).”

Response: Concerning the influence of the updraft velocity: One could imagine that the updraft velocity depends on ambient temperature which would then (partially) explain the observed temperature dependence of the scavenged fraction. Several tests

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were performed based on local measurements of the vertical wind speed with a sonic anemometer (Ian Crawford, University of Manchester, personal communication). This vertical wind speed is not identical to, but expected to correlate with updraft velocity at least at the altitude of the cloud where we are sampling. The analysis shows no dependence of vertical speed on the scavenged BC fraction. The same was observed for the dependence between vertical wind speed and temperature. Therefore we believe that the observed partitioning can be explained with the WBF mechanism.

It should also be mentioned that in mixed phase clouds in these temperature ranges the ice crystals are most likely formed via the liquid phase, so by default the WBF process has been active. Liquid droplets are very unlikely to form in an ice cloud. However, liquid drops and ice crystals could have formed simultaneously, in which case the fast growing ice crystals could decrease the supersaturation so as to prevent more CCN from activating. This can not be easily distinguished from the evaporation of drops, but the underlying mechanisms are the same (water vapour is taken up by the growing ice crystals at the expense of liquid drops). It will be mentioned in the revised paper that what is important here is the partitioning and that the process that governs such partitioning will not change the observation.

Referee: “Page 11881 line 6: “The scavenged number fraction is defined as the fraction of the total number of particles (particle diameter D > 100 nm) that are incorporated into cloud droplets and ice crystals.” Why was D > 100 nm chosen?”

Response: The scavenged number fraction was calculated for D > 100 nm to omit the influence of small particles that do not contribute much to activation. This threshold value is the same as used by Henning et al. (2002) and is the 50 percent activation diameter determined in summer. Those authors also showed in a sensitivity analysis that changing the diameter from 20 percent did not significantly change the results. To be consistent with this earlier study we used the same size cut.

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Henning, S., Weingartner, E., Schmidt, S., Wendisch, M., Gäggeler, H. W. and Baltensperger, U.: Size-dependent aerosol activation at the high-alpine site Jungfraujoch (3580 m asl), Tellus B, 54, 82-95, 2002.

Interactive comment on Atmos. Chem. Phys. Discuss., 6, 11877, 2006.