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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Black carbon variability since preindustrial times in Eastern part of Europe reconstructed from Mt Elbrus, Caucasus ice cores" *by* Saehee Lim et al.

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We would like to thank the two anonymous referees for their careful reading of the manuscript, and also the time they dedicated to evaluating this study. All comments were highly insightful. Please find below our point-by-point response to the critiques and a highlight to the changes made to the manuscript to address these. For ease of discussion, we have continuously numbered the reviewer's comments. We strongly feel that we were able to address all the points raised.

15 I agree with the comment of Referee #1 about the summer/winter layers subdivisions. If possible, I will recommend reinforcing the rBC-based annual layers determination with some other seasonally varying parameters, such as water stable isotopes,

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thus being in agreement with the other paper about the Elbrus ice core (Kozachek et al., CPD 2016).

: See reply to similar comment (#4) from reviewer #1. In addition, we added to the manuscript annual rBC variability (10th, 50th and 90th percentile values of annual snow layer; following figure) in Fig. 4c (Fig 1 here) with relevant description. The caption for Fig. 4c is as below.

Figure 4c. Annually averaged temporal evolution in rBC mass concentration of the ELB ice cores. Thin solid line is medians and dashed lines are lower and upper 10th percentiles of the annual rBC values. Thick line is 10-year smoothing of medians.

16. I have found the rBC particles' MMD time series and the related interpretation very interesting and promising. I agree with all the interpretations but, however, the seasonality is not clear since the 1960s; particularly, during the 1980s the winter MMDs are even larger than the summer ones. I don't think that the difference between summer and winter is statistically significant in the period 1960-2010, can you please add some comments and interpretations about that? Or at least describe the MMD time series more in details.

: See reply to similar comment (#5) from reviewer #1.

17. Line 37: it's better to write: "to be transported" instead of "to transport".

: It was rewritten to "to transport".

18. Line 38: "In high-altitude or –latitude areas ": missing word?

: Yes, "high" prior to "-latitude area" is missing. "In high-altitude or –latitude areas " in line 38 is thus revised to "In high-altitude or high–latitude areas ".

19. Line 39: "that may accelerate": it's better to write, "in accelerating".

: It was rewritten to "in accelerating".

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20. Line 47: “proximity”: how much? It’s better to specify for the sake of clarity.

: We agree with the reviewer. European Alpine sites such as Col du Dôme, Colle Gnifetti and Fiescherhorn are approximately ∼100 km away from big cities such as Lyon, France, Milano, Italy and Geneva, Switzerland, respectively. The sentence in line 47 was revised to “Particularly, the geographical proximity of the ice cores at high-altitude Alpine sites, e.g., European Alpine sites such as Col du Dôme, Colle Gnifetti and Fiescherhorn (Jenk et al., 2006; Legrand et al., 2007; Thevenon et al., 2009) to densely populated regions (approximately ∼100 km) allows us to observe. . .”.

21. Line 50: please add a phrase regarding the BC/EC relation and write that there aren’t other rBC records in this region.

: This is an important point: we agree that terminology of BC derived from different methods should be differentiated. We thus add a sentence in line 53 as follow: “It should be noted that EC refers to data derived from thermal methods which are different than optical methods providing BC (including rBC derived from incandescence methods) (Petzold et al., 2013)”. In line 63, we now stress that the ELB ice core rBC record is the first rBC record retrieved over Europe as follow: “For the first time, a high resolution, continuous rBC record is extracted from an ice core over Europe. The Elbrus rBC record thus brings new and unique information on long-term variability and evolution of BC European emissions.”

22. Line 102: “Nd YAG laser”: please write “Nd:YAG laser”, with colon.

: It was revised.

23. Line 123: “single rBC”, I will add “particle”.

: “single rBC” was replaced with “single rBC particle” as recommended.

24. Line 198: you may want to underline that the procedure is the same as for the entire atmospheric column.

: This is a good point. We added a sentence in line 198: "…, while the simulation procedure is the same as for the entire atmospheric column".

25. Line 228: try to be clearer, e.g. "The highest rBC mass concentrations were observed: : :"

: For clarity, the sentence was revised to "The highest rBC mass concentration of an annual snow layer was observed in summer snow layer".

26. Line 236: substitute "consistent to: : :" with "consistent with: : :"

: It was revised as recommended.

27. Line 259: if you write and compare the absolute values for the EC with you rBC analyses it will be better to write something about the conversion factor also in this part of the paper, or at least specify "how" to compare the values explicitly.

: This is an excellent point: we agree that the most accurate and clear way to compare the absolute values for the EC of CDD and CG cores with for our rBC of ELB cores is describing corrected values based on existing lab experiments to evaluate different methods (Thermal (or thermal-optical) method vs. SP2-based incandescence method). Previously, Lim et al. (2014) conducted inter-comparison of the SP2-based incandescence method and thermal-optical method (EUSAAR2 protocol) for different field samples (i.e., Elbrus firn core, CDD snow fit, Greenland summit firn and Himalayan snow). In the experiments, Lim et al. (2014) found that thermal-optical method had disadvantages for providing accurate EC mass concentrations because (i) filtration efficiency, that is necessary prior to thermal-optical method, was strongly dependent on BC particle size and OC loading on the filter, (ii) presence of dust can cause negative EC artifact and (iii) OC pyrolyzation can biase OC/EC split point and then generally cause a positive EC artifact. On the other hand, the rBC results of SP2-based method was dependent on the SP2 gain setting that determines lower and upper rBC size limits. As a results, EC/rBC ratios were 0.5+/-0.2 for CDD snow pit and 1.0+/-0.4 for

ELB firn core, and the results came from mixed factors such as particle morphology and chemical composition of the field samples. We thus conclude that describing the comparison of our ELB rBC with previously measured EC of CDD and CG cores using corrected values or conversion factor may cause another uncertainty because we do not know BC or EC size and chemical composition (amount of OC and amount/type of dust) of the ELB, CDD and CG cores. Therefore we added a sentence in line 264 of the manuscript about why direct comparison of the ELB rBC with the EC of CDD and CG should be made with caution. We further added a reference, Lim et al. (2014) at the end of the sentence to guide readers.

28. Line 293: please clarify why dry deposition is not playing a significant role in the rBC particles diameter changing.

: Black Carbon particles are deposited in snow by either wet (i.e., in precipitation) or dry deposition. In general, BC removal from the atmosphere by wet deposition is estimated to be 3 times more efficient compared to dry deposition processes (Bauer et al., 2013). However, in some regions, dry deposition is considered to be the main process (or relatively more important than in other regions) for BC removal in the atmosphere (e.g., Khumbu valley in the Himalayas, Bonasoni et al. (2010); Yasunari et al. (2010). As discussed in replies to comment (#1) and (#11) we expect wet deposition to be the main deposition process at the ELB site, with an equal distribution along the year. Hence, it is reasonable to assume that BC deposition processes at the ELB site do not vary strongly along the seasons, and mainly involve wet removal by precipitation. We cannot quantify the proportion of dry deposited BC aerosols in snow, but this dry deposition effect should not be higher in specific month or season because observed monthly or seasonal precipitation rate is regular (e.g., at Klukhorskiy Pereval station). Once deposited, in addition to wind drift and erosion, particles can experience sublimation (snow to water vapor transition) or snow melt (Ginot et al., 2001; Schotterer et al., 2001). These postdeposition processes might affect BC concentrations and/or morphology within the snowpack. Only few studies have investigated how post-deposition processes impact BC in snow (Hagler et al., 2007a, 2007b). Hagler et al. (2007b) showed relatively conservative behavior of EC in the 4-year snow pit layers at Summit, Greenland, where summer snow melting is limited similar to the ELB site, while water-soluble and –insoluble OC would undergo substantial post-depositional processing. Hence, it is reasonable to assume that post deposition processes are not impacting BC on snow at the ELB site.

29. Line 295: should surface snow melting modify the rBC size distribution? Explain and add references.

: To our knowledge, we do not know the studies of relationship between snow melting and rBC size modification. But there are plenty of studies showing that snow melt increase snow grain size. We first mentioned that ".. post-deposition processes are thus not expected to alter rBC size distributions." in line 295. We revised this sentence as follow: "Similarly, significant snow melt was not observed in the ELB summer ice layers. Although there is a lack of studies about the impact of snow melting on rBC size distribution, such processes would not be expected at the ELB drilling site"

30. Line 332: can you exclude the surface snow melting effect in increasing the rBC MMD in the 2003 summer layer? Please explain.

: The 2003 summer ice layer shows a clear shift on rBC MMD, which we attributed to influence of particle deposition from biomass burning plumes. This 2003 summer snow layer experienced some melting (Kozachek et al., 2016), but we can rule out that such melting is driving the unusual MMD signal described above. We actually observed others snow layers with melting event (e.g., summer layers of year 2001 and year 2000), and all of these event did not show any anomalies of rBC MMD toward larger values.

31. Line 386: "BC depositing to snow": "BC depositing ON snow".

: It was corrected.

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32. Line 462: “as new a proxy”: write “as a new proxy”.

: It was corrected.

33. For what concern the figures I would personally prefer having the deepest and the oldest parts always on the right or on the left (but this is up to you).

: We drew the figure by both methods, but finally decided the current one, because two of three papers that reported the alpine EC records (Jenk et al., 2006; Legrand et al., 2007; Thevenon et al., 2009) showed the figure of the past EC variability having the deepest parts on the left. We thus followed the method to help readers to compare their EC and our rBC records.

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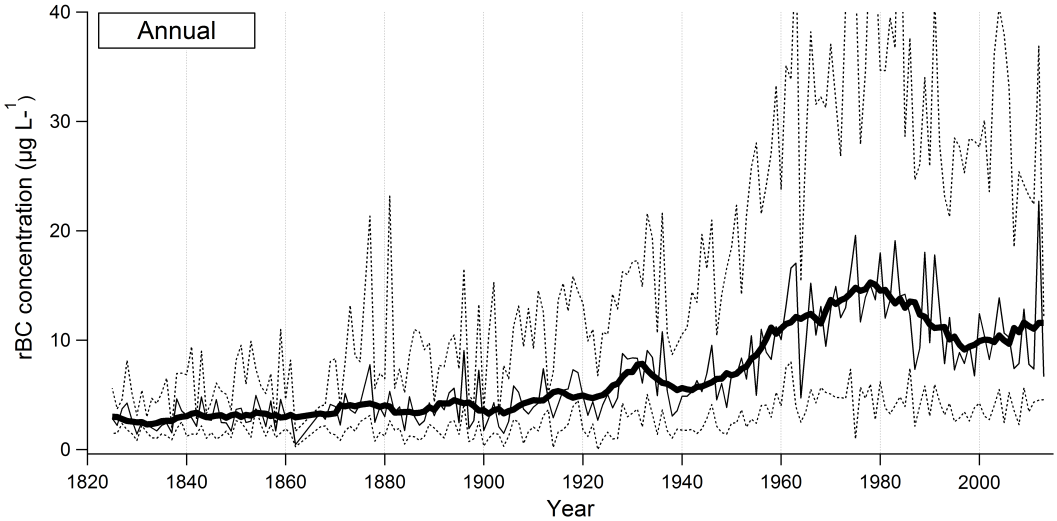

Fig. 1. Annually averaged temporal evolution in rBC mass concentration of the ELB ice cores.