

Atmos. Chem. Phys. Discuss., author comment AC2  
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## Reply on RC2

Olga B. Popovicheva et al.

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Author comment on "Siberian Arctic black carbon: gas flaring and wildfire impact" by Olga B. Popovicheva et al., Atmos. Chem. Phys. Discuss.,  
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### General comments:

The Arctic has warmed three times more quickly than the planet as a whole, as the most sensitive area for climate changes. To understand the impacts of BC emissions on the arctic from source regions, particularly from the Siberian Arctic, the authors reported new measurements of equivalent BC (eBC) concentrations for the period of 2019-2020, carried out at the recently established station "Island Bely" which is at the Siberian gateway of the highest anthropogenic pollution to the Russian Arctic.

Through coupling with FLEXPART Lagrangian particle dispersion model and the most updated BC emission inventories for anthropogenic and biomass burning sources, a detailed aerosol aging spectrum, the source region attribution and the source sector apportionment have been investigated for the entire period as well as for the pollution episodes. This is a nice work showing that the observations verified the model simulations and the emission inventories, as well as that the model was able to provide detailed source attributions in terms of emission regions and sectors. Interesting results include

Russian emissions dominate during the entire year, while European and Asian emissions contributed up to 20% in the cold periods;

the annual contribution from anthropogenic sources is dominant, ranging from 75 to 80%;

FLR and BB emissions contribute the largest share of EBC to the "Island Bely" during the cold (by FLG) and warm (by BB) period, respectively;

Gas flaring (FLG) is dominant during cold season (Nov – May) over all the anthropogenic sectors ranging from 47 to 68%;

Biomass mass burning played the biggest role during warm seasons (Jun- Oct.), contributing ~ 80% as the maximum in July;

Those results have improved the source apportionment of Siberian arctic BC, particularly for gas flaring and wildfire impact. This manuscript should be accepted for publication with minor revisions (see the specific comments below).

Response: We appreciate Reviewer's positive manner and his/hers kind comments.

It would be nicer if the contents in sections 3.2, 3.3 and section 4 are presented further succinctly in the revised version.

Response: We have done our best to correct all sections following the very useful comments from the reviewers.

Specific comments:

L37: Based on Table S2, the maximum value of BB is in July instead of June.

Response: We appreciate the reviewer for catching this typo error. It has been corrected in Line 37 (see manuscript with Track Changes).

L38-L39: Based on Table S4, for the BB events during warm seasons, the AEE varies between P2 (BB: ~ 64%) and P6 (BB: > 99%), ranging from 0.8 to 1.35. This suggests that AAE is not a sensitive tracer for distinguishing BC between anthropogenic and biomass burning sources. This sentence needs to be rephrased.

Response: We have rephrased this sentence stating that AAE during BB events was mostly above 1, excluding two outlier values (see manuscript with Track Changes, Line 39).

L148-L151: This sentence is not well expressed and please re-phrase it.

Response: We have rephrase this sentence as reviewer suggested! Please see L.153-156 in the manuscript with Track Changes).

L222-L224: I am wondering why the authors use 1500 kg/m<sup>3</sup> as BC density instead of 2000 kg/m<sup>3</sup>.

Response: For the BC tracer, we used a density of 1500 kg/m<sup>3</sup>, which is the one we traditionally use and same as in Stohl et al. (2013). Our choice originates from a very useful review article (Long et al., 2013), who gathered all available measurements for the density of ambient BC. All values are between 1000-1900 kg/m<sup>3</sup> (1-1.9 g/cm<sup>3</sup>, see Table 2, bottom line in Long et al.)

Stohl, A., Klimont, Z., Eckhardt, S., Kupiainen, K., Shevchenko, V. P., Kopeikin, V. M., and Novigatsky, A. N.: Black carbon in the Arctic: the underestimated role of gas flaring and residential combustion emissions, *Atmos. Chem. Phys.*, 13, 8833–8855,

<https://doi.org/10.5194/acp-13-8833-2013>, 2013.

Long, C. M., Nascarella, M. A., and Valberg, P. A.: Carbon black vs. black carbon and other airborne materials containing elemental carbon: Physical and chemical distinctions, *Environmental Pollution*, 181, 271-286, 2013.

L263-L266: I am wondering whether the authors use two biomass burning emission inventories (GFED v4.1 and CAMS GFAS). Are there any comparison results between the two inventories?

Response: We thought about this comparison, when writing the manuscript. However, we have decided to exclude any comparison of the two products, because it is beyond the scope of this article. In addition, GFED and GFAS products are very different ones, both in terms of methodology and temporal resolution (GFED4 is given monthly, GFAS daily), hence any comparison/criticism would be unfair. In the present case, we found that GFAS gave concentrations closer to our measurements and captured most of the observed peaks. We believe this is because of the high temporal resolution of this product.

L374-L377: I am wondering if it is possible to provide the uncertainties of the model results in Table S1, S2 and S3.

Response: The model uncertainty cannot be really assessed in a way that good give results in a Table. The reason for this is because model uncertainty originates from a number of factors that do not always depend on the parameterization made in the model. For example, to run FLEXPART we need to know the meteorological conditions at the time of the simulation. This is taken from operational analyses for the European Centre for Medium Range Weather Forecasts (ECMWF). As a separate product, the u and v component of the winds that are necessary to run the model are associated with an uncertainty. Furthermore, other parameters are also used from ECMWF as an input to FLEXPART, which affect scavenging and removal of species from the atmosphere. For instance, the real position of the clouds is also used from ECMWF, which affect where in-cloud and below-cloud scavenging occurs (see Pissò et al., 2019, of the manuscript), as is again associated with an uncertainty. More than this, the parameterizations that have been performed in the model are associated with an uncertainty (e.g., turbulence). To calculate model uncertainty, separate sensitivity tests have been performed each time investigating how each parameter affects the overall result. Besides, FLEXPART – as an open access algorithm – is of the most widely used algorithms in the world and is continuously validated against observations, while assessing its sensitivity to different model parameters. A few papers that have investigated model uncertainty are the following:

Evangeliou, N., Hamburger, T., Cozic, A., Balkanski, Y., and Stohl, A.: Inverse modeling of the Chernobyl source term using atmospheric concentration and deposition measurements, *Atmos. Chem. Phys.*, 17, 8805–8824, <https://doi.org/10.5194/acp-17-8805-2017>, 2017.

Evangeliou, N., Thompson, R. L., Eckhardt, S., & Stohl, A. (2018), "Top-down estimates of black carbon emissions at high latitudes using an atmospheric transport model and a Bayesian inversion framework", *Atmospheric Chemistry & Physics*, 18, 15307-15327, <https://doi.org/10.5194/acp-18-15307-2018>, 2018.

Kristiansen, N. I., Stohl, A., Oliv  , D. J. L., Croft, B., S  vde, O. A., Klein, H., Christoudias,

T., Kunkel, D., Leadbetter, S. J., Lee, Y. H., Zhang, K., Tsigaridis, K., Bergman, T., Evangeliou, N., Wang, H., Ma, P.-L., Easter, R. C., Rasch, P. J., Liu, X., Pitari, G., Di Genova, G., Zhao, S. Y., Balkanski, Y., Bauer, S. E., Faluvegi, G. S., Kokkola, H., Martin, R. V., Pierce, J. R., Schulz, M., Shindell, D., Tost, H., & Zhang, H. (2016), "Evaluation of observed and modelled aerosol lifetimes using radioactive tracers of opportunity and an ensemble of 19 global models", *Atmospheric Chemistry & Physics*, 16, 3525-3561, doi:10.5194/acp-16-3525-2016.

Grythe, H., Kristiansen, N. I., Groot Zwaaftink, C. D., Eckhardt, S., Ström, J., Tunved, P., Krejci, R., and Stohl, A.: A new aerosol wet removal scheme for the Lagrangian particle model 674 FLEXPART v10, *Geosci. Model Dev.*, 10, 1447-1466, 10.5194/gmd-10-1447-2017, 2017.

Pisso, I., Sollum, E., Grythe, H., Kristiansen, N. I., Cassiani, M., Eckhardt, S., Arnold, D., Morton, D., Thompson, R. L., Groot Zwaaftink, C. D., Evangeliou, N., Sodemann, H., Haimberger, L., Henne, S., Brunner, D., Burkhardt, J. F., Fouilloux, A., Brioude, J., Philipp, A., Seibert, P., and Stohl, A.: The Lagrangian particle dispersion model FLEXPART version 10.4, *Geosci. Model Dev.*, 12, 4955-4997, <https://doi.org/10.5194/gmd-12-4955-2019>, 2019

L396-L397: It is not convinced that the observed AAE values in this study are sensitive to BB influenced in both cold and warm seasons (Table S4).

Response: The reviewer is correct here, and this is what we have tried to clarify in this paragraph. Of course, one cannot expect that during a long-range transport event where mixing and aging occur, an AAE value representative for BB will always be observed. However, AAE can be used as a proxy for whether BC originates from biomass burning or fossil fuels. We have tried to rephrase the paragraph (see Lines 464-471, manuscript with Track Changes).

L405-L406: How about the results by FLEXPART with GFED v4.1?

Response: Like we wrote in a previous comment, we do not show the results of the two products to avoid comparisons of two very different fire products (both in methodology and temporal resolution). We present the closest-to-observations model results we got.

L408-L410: Should the "Figure 5b" be replaced by "Figure 4c" for monthly median contribution of sources to BC in the cold period?

Response: Yes, Figure 4c is the correct figure when it comes to monthly median. We thank the reviewer for seeing this detail. We have corrected accordingly (see Track Changes at page 14).

L525: Typo (?): please replace "ageing" with "aging".

Response: Not sure what is correct here, but we guess the editorial office will correct in a later stage. According to grammar.com ([https://www.grammar.com/ageing\\_vs.\\_aging](https://www.grammar.com/ageing_vs._aging)), "ageing" is used in British English, "aging" in American English. We used the British

version throughout the manuscript and have now changed to American English as reviewer suggested.

L543-L544: This sentence needs to be rewritten. It has been observed that while the AAE value is between 1- 1.35, the BC could be also influenced dominantly by FLG (Table S4).

Response: Very good point! We have corrected this part as reviewer suggested. Please see Line 662 in manuscript with Track Changes.

L862-L874: Is it possible to have the data plotted in Figure 4b, 4d included in individual Tables of the supplement as the Table S1 for Figure 4c? Each of the Tables should also include corresponding AAE values.

Response: The monthly climatology of BC is now given in Supplementary Table S 1. In addition, we have made all the model results from this study publicly available, including plots and ascii files with source, continental contributions, ageclasses etc... Please find all the results in our interactive webpage ([https://niflheim.nilu.no/NikolaosPY/Bely\\_2020\\_cams.py](https://niflheim.nilu.no/NikolaosPY/Bely_2020_cams.py)). This is also highlighted in the Data availability statements at the very end of the manuscript.

L892: At the end of line, the "(bottom row)" is missing.

Response: Legend in Fig. 7 was corrected. Same correction was performed in the Legend of Fig. 8 (manuscript with Track Changes).