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Atmospheric Chemistry and Physics Discussions



# *Interactive comment on* "Do contemporary (1980–2015) emissions determine the elemental carbon deposition trend at Holtedahlfonna glacier, Svalbard?" *by* Meri M. Ruppel et al.

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Dear Anonymous Referee #1,

We are grateful for your efforts and overall positive evaluation of our manuscript, and the constructive comments that have helped us to further improve the paper. We find all your comments well-justified and have revised the manuscript accordingly. Below we give our detailed responses to your comments and describe the revisions prepared for the manuscript. The Referee comments are cited with REFEREE 1, our responses follow in regular type, while revisions prepared to the manuscript are marked with quotation marks.



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Discussion paper

REFEREE 1: P4, Line 14: Exchange “surface area” with “cross sectional area” for clarity.

Thank you, done (page 4, line 14-15 of revised manuscript).

REFEREE 1: P5, Line 29: Define Dp.

Sorry, Dp means particle diameter. This has been clarified in the revised manuscript (P6, L4).

REFEREE 1: P5, Line 36: Take care to specify when you are taking about atmospheric concentrations. Here it just says “modelled BC levels”.

Thank you, the statement has been clarified to “modelled BC concentrations and deposition” (P6, L16).

REFEREE 1: P5, Line 36: “: : :systematically low, but the seasonality in atmospheric BC concentrations is captured well: : :” Can you show this somehow? What are the observations like? Could you for example plot observed atmospheric BC concentrations at Ny Ålesund on your Figure 5. So far you have not shown or given any numbers to support your statement.

Thank you, we agree that it is important to show data to support our statements. Consequently, we have added two paragraphs for model validation in the model results section 3.3. and a new Figure 5, according to the suggestions of the reviewer. By adding the atmospheric concentration measured at Ny-Ålesund the reader can see that the model, though underestimating, reproduces the decreasing trend in surface concentrations (Fig. 5a). Furthermore, Figures 5b and c show that the model reproduces the seasonal pattern of EC concentration, though underestimates the size of the Arctic Haze spring peak in atmospheric BC concentrations.

The following text was added (P7, L4-19): "To evaluate the performance of the SILAM model for Svalbard, atmospheric BC observations made at the Zeppelin measurement site were compared to model results from the correspondent model grid-cell in Figure

5. Figure 5a shows the model results for the whole study period from 1980 to 2015 while atmospheric observations were available only for 2002 to 2011. Both the observations and model results show large variation in atmospheric BC concentrations from one year to the next, but with an overall decreasing trend (Fig. 5a). However, compared to the observations, the model significantly underestimates the atmospheric BC concentrations (by a factor of five on average). Such underestimations of atmospheric BC concentrations are particularly common for the Arctic where previous comparisons to observations have shown BC concentrations being underestimated in chemistry models by up to a magnitude (e.g. Koch et al., 2009; Lee et al., 2013; Dutkiewicz et al., 2014). Figure 5b and c present the seasonality of observed and modelled monthly BC concentrations in 2006 and 2007. The evaluation of the monthly model performance shows that the model captures the seasonality seen in the observations but fails to reproduce the magnitudes observed especially in spring time. Note that the timing of observed spring peaks (Arctic Haze) varies from year to year. This corroborates with several multi-model studies (Shindell et al., 2008; Koch et al., 2009; Eckhardt et al., 2015) showing that atmospheric models are usually not able to simulate the seasonality of BC in the Arctic precisely, typically underestimating the Arctic haze season occurring during the winter and early spring. A more detailed discussion on the uncertainties of the model and input driving the runs is presented in Section 4."

REFEREE 1: P6, Line 4: Please exchange “generally similar” with “in the same range” or something along those lines.

Sure, done (P6, L17).

REFEREE 1: P6, Line 24: “: : : no clear decadal trend”. Did you check this statistically? Visually, there seem to be a decreasing trend. You also make a statement that there is a weak trend both on p10, Line 15 and p 13 line 7.

Thank you for pointing this out. We have clarified our statements and added the statistics of the discussed trends (P7, L21-25): “The modelled annual atmospheric BC con-

centrations decrease quite constantly from 1990 onwards after notably higher values modelled for the 1980s (slope -1.3 $\times$ 10-5 $\mu$g m-3 yr-1; p < 0.001). The modelled BC deposition on the other hand shows significant variation from year to year with no clear trend over the study period. Statistically, the deposition trend decreases weakly over 1980 to 2015, but this trend is not significant (slope = -3.9 $\times$ 10-3 $\mu$g m-3 yr-1; p = 0.09)."

The weakly declining trend is also clarified in the other parts of the manuscript pointed out by the reviewer.

We also added description on the regression model used for the estimation of trends in the method section (P6, L 11-14): "Subsequent to the SILAM runs, a multilinear regression model based on the median values for atmospheric BC concentrations and deposition for every single year, between 1980 and 2015, was used to estimate the slope of the modelled temporal BC trends, with coefficients being estimated with 95% confidence intervals. An F-test was applied to test if the linear regression relationship between the response and predictor variables was significant."

REFEREE 1: P6, Section3.3: This section is a bit confusing. There are clear conclusions drawn here like "The model results suggest that 98.7 % of BC is wet-deposited at Holtedahlfonna." while there is no mentioning of model limitation in treatment of this or any other process for that matter. There is discussion in section 4, but at the very least, this discussion needs to be mentioned in section 3.3. The fact that the model underestimates the atmospheric concentration by a factor of ten (?) should be emphasized and discussed in greater detail. Why does this happen? It there too much wet or dry deposition? Is the transport off? Are the emission inventories that off? Are all processes equally badly/well treated so that your statement that 98.7% of the BC is wet-deposited holds? When 9/10 of the BC is missing (is it?) it seems a bit crude to give such a specific number for the source of surface BC?

This is a well-justified comment by the reviewer. For clarity, section 3.3. presents

results from the model, and these are discussed and analyzed in section 4. Therefore, we have not included discussion of model limitations in Section 3.3. However, based on this and other comments of the reviewer, we have included some model performance evaluation in Section 3.3., as discussed above. In addition, according to the suggestion of the reviewer, we mention in the revised Sect. 3.3. that discussion on the model limitations follows in Sect. 4 (see above).

In the revised manuscript we emphasize that chemistry models very commonly underestimate BC observations in the Arctic by even a magnitude (Sect. 3.3.). In addition, we have included discussion in Section 4.1.2. on the limitations of the used model set-up and why these may affect the different BC concentration and deposition magnitudes between model results and observation.

P12, L16-31: "Possible underestimation of anthropogenic (e.g. Stohl et al., 2013; Huang et al., 2015) and natural fire (Soares et al., 2015) BC emissions significant for the Arctic and their spatial and emission sectoral miss-allocation (Winiger et al., 2017) in the emission inventory driving the model, may partly cause the underestimations of atmospheric BC concentrations and consequently lower BC deposition in the model results compared to the observed ice and firn core EC deposition, and may potentially affect the modelled BC deposition trend. Furthermore, the current model set-up does not include a parameterization for aerosol ageing, while models with ageing processes tend to show higher BC mass concentrations in the remote Arctic (e.g. Liu et al., 2011). The dry and wet deposition schemes of SILAM have been evaluated (Kouznetsov and Sofiev, 2012; Khan et al 2017, Sofiev et al, 2011), but currently in SILAM BC particles grow only based on relative humidity which may enhance dry deposition of relatively large BC particles close to the sources, allowing the dispersion of only very small particles to the remote Arctic. Consequently, too little BC (in mass) may be transported and deposited annually in the Arctic in the model, especially during the Arctic Haze season (Fig. 5). However, without ageing in SILAM, the particles do not grow via condensation of soluble material during transportation, resulting in the particles being too small for

dry deposition when reaching the Arctic. The lack of ageing processes may lead to an over-domination of Arctic wet-scavenging in the model as particles are too small for dry deposition, and consequently the result of 99 % wet-deposition at Holtedahlfonna may be exacerbated."

In addition, we mention also in the conclusions of the manuscript how the limitations of the model may affect the result of the model indicating that 98.7 % of BC is wet-deposited at Holtedahlfonna (see next response).

REFEREE 1: P13, Line 9: Model limitations/uncertainty in the 99% number should be mentioned here as well.

No specific uncertainty range can be given for the 99 % number but discussion on the model limitation is added here as well (in addition to the comment above).

P14, L22-26: "Our results show that almost 99 % of BC mass is wet-deposited at Holtedahlfonna. This number is probably exacerbated by the lack of aerosol ageing processes in the model which results, for instance, in the transported particles being too small for dry deposition in the Arctic, and consequently wet-scavenging overly dominating the deposition. Nonetheless, the results based on the current settings of SILAM corroborate with the 85 to 90 % of BC wet-deposition generally suggested for the Arctic by Wang et al. (2011)."

REFEREE 1: P13, Line 19-21: Sentence starting with "The fact that the observed EC deposition trend: : :" How so? Please elaborate."

The reviewer was correct to point out that the respective sentence was unclear. We have deleted the sentence, as we thought it was a circular argument.

REFEREE 1: P13, Line 27: Consider removing "somewhat". The numbers are lower, not only briefly so."

Thanks, done.

REFEREE 1: Figure 4a): Would be nice to have time of year on the figure as you are referring to seasonality in this figure on P6 Line6.

In the revised Figure 4a the April 2015 layer at the surface of the snow pit and the approximate September 2014 layer at the bottom of the snow pit are indicated.

REFEREE 1: Technical corrections: P3, Line 25-28: Give coordinates either for both sites or none of them.

OK, coordinates given for both coring sites in the revised manuscript.

REFEREE 1: P3, Line31: Please rewrite the sentence: “To obtain a hard surface to drill 80 cm of the snow pack were removed”. It is confusing.

Sure, the sentence reads now (P3, L31-32): “Before drilling, the top 80 cm of the snow pack were removed to obtain a hard surface to drill.”

REFEREE 1: P5, Line 35: Misspelled the word like.

Thanks, corrected.

REFEREE 1: P6, Line 27: Punctuation

Thanks, corrected.

REFEREE 1: P10, Line 21:Please insert the word “one”, that is: “: : :deposition from one data point to the next: : :”

Thanks, done.

REFEREE 1: P11, Line7: “...the second may: : :” Correct typo.

Thanks, done.

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