

## Comments from Reviewer 1

The manuscript entitled “Multi-year black carbon observations and modeling close to the largest gas flaring and wildfire regions (Western Siberian Arctic)” by Popovich et al. presents a detailed study on Black Carbon (BC) measurements in a new Arctic station in Kara Sea. The study investigates the seasonal differences in measured optical properties and assess the inter-annual variability of BC sources using an atmospheric dispersion model. The manuscript is well structured for the readers to understand the analytical steps and the results obtained.

I recommend the publication of the manuscript following minor revisions. First I would like to mention a few general comments which apply to the whole manuscript:

(1) Please define the abbreviations the first you are using them and not each time in a new sentence, section or Table.

**Response:** We have defined the abbreviations the first time they are used. Notice that many of them are now defined in the Abstract (see Manuscript with Track Changes). To help to verification, we list all the abbreviations we have used below:

black carbon (BC)

equivalent black carbon ( $eBC$ )

mass-specific absorption coefficient ( $MAC$ )

absorption Angstrom exponent ( $AAE$ )

brown carbon (BrC)

biomass burning (BB)

“Island Bely” Station (IBS)

elemental carbon (EC)

site-specific absorption coefficient ( $SAC$ )

aethalometer-produced equivalent black carbon concentration ( $eBC_{AET}$ )

thermo-optical transmittance (TOT)

carbonate carbon (CC)

Lagrangian particle dispersion model FLEXPART

industrial combustion (IND)

energy production (ENE)

residential and commercial emissions (DOM)

waste treatment and disposal sector (WST)

transportation (TRA)

shipping (SHP)

gas flaring emissions (FLR)

Evaluating the CLimate and Air Quality ImPacts of ShortlivEd Pollutants (ECLIPSE)

Copernicus Global Fire Assimilated System (CAMS GFAS)

Light-absorption coefficients at 880 nm ( $b_{abs}(800)$ )

Light absorption at 370 nm ( $b_{abs}(370)$ )

Modelled surface BC ( $BC_{FLEXPART}$ )

European part of Russia (EURus)

(2) Be careful with the units. For BC/eBC you either use ng m<sup>-3</sup> or µg m<sup>-3</sup>, and then you present your statistics in ng m<sup>-3</sup>. Please choose one and do not show your results in both. It's confusing. Also be consistent and use ng m<sup>-3</sup> and not ng/m<sup>3</sup>. Correct everywhere.

**Response:** We completely agree with this comment. We have changed all units to ng m<sup>-3</sup> (see Manuscript with Track Changes).

(3) The numbers in the units must be in superscript. Correct everywhere.

**Response:** We have now tried to put all units in superscript (see Manuscript with Track Changes). From previous experience, this is usually taken over during typesetting (in case the manuscript is accepted), as we might have missed something.

Minor comments (The number of the lines below correspond to the submitted manuscript):

Lines 15-31: I am missing one-two sentences on FLEXPART and which are the main emissions sources the authors found to be contributing to BC at the station.

**Response:** We have added two lines answering to the question about the dominating sources (Lines 28-30, Manuscript with Track Changes)

Line 24: Define eBC

**Response:** eBC has been defined in Line 25 (Manuscript with Track Changes).

Lines 44-45: Please consider rephrasing this sentence – it's too vague. Which are the complicated processes? Define Arctic haze.

**Response:** We have rephrased the sentence and defined Arctic Haze in Lines 49-52 (Manuscript with Track Changes).

Lines 52-53: What about the latest AMAP report? Does the latest report provide updated results on forcing? If yes, please updated accordingly.

**Response:** To our knowledge, the latest AMAP report is AMAP (2021) as given in the manuscript. Please see the AMAP publication website here:  
<https://www.amap.no/publications> .

Lines 62-63: “The most complicated issue ..” Such as? Rephraise or be more specific.

**Response:** Rephrased (Lines 71-72, Manuscript with Track Changes).

Lines 70-72: If you link these sentences with your text earlier please rephrase - otherwise say why, it is not clear.

**Response:** We have used an adverb to link the two sentences (Lines 86, Manuscript with Track Changes).

Line 82 and wherever mentioned again: “Barrow”. Please consider using the local name Utqiagvik or as Barrow/Utqiagvik to be more respectful to the local community.

**Response:** We have added Barrow/Utqiagvik all over the manuscript (Lines 98, 374, 376, 1206, Manuscript with Track Changes).

Line 88: What about the results presented Matsui et al. 2022?

**Response:** We added some comments about the results from Matsui et al. (2022) in Lines 104-106 (Manuscript with Track Changes).

Line 89: replace “in” with “is”

**Response:** Changed in Line 107 (Manuscript with Track Changes).

Lines 105-106: Too vague. Please say a bit more here.

**Response:** We have rephrased in Lines 132-134 (Manuscript with Track Changes).

Lines 119-120: add a reference for your statement: “as the station is located along the main pathway of large-scale emission plumes from industrial regions and Siberian wildfires entering the Arctic.”

**Response:** We have shown this in Popovicheva et al. (2022), now added in Line 149 (see Manuscript with Track Changes).

Line 128: AAE – in line 73 – no need to define again

**Response:** Corrected (Line 164 in Manuscript with Track Changes).

Line 132: Add a sentence on what the following sections show.

**Response:** We do not consider this is relevant here, since the following sections have distinct titles, and we believe it is not necessary to plagiarize in an already long paper. We are willing to do this at a later stage and if the Editor thinks this is important for the flow of the paper.

Line 143: “.. snow coverage, wind speed, and relative humidity ...”

**Response:** “... and” removed from the sentence (see Line 178 in Manuscript with Track Changes).

Lines 145-146: On what criteria you base the split in two periods? If possible, mention.

**Response:** We have now written that the definition of cold and warm period is based on the prevailing temperatures (see Lines 180-181 in Manuscript with Track Changes).

Lines 144-149: Instead of providing an annual value please provide a value for the two periods (cold/warm) – would be easier for the reader to get an overall idea – as you do in lines 150-154

**Response:** Corrected, see Lines 277-278 (Manuscript with Track Changes).

Lines 155-161: Move this part in the beginning of the following sub-section (2.2) – it fits better there.

**Response:** Moved as the first paragraph of section 2.2 (see Line 193 in Manuscript with Track Changes).

Line 179 – equation 2: Define babs in equation 1

**Response:** Corrected (see Line 193 in Manuscript with Track Changes).

Line 213: “Both methods have important uncertainties ..”: Please give percentages/numbers. Also discuss/mention AE33 uncertainties here.

**Response:** We reported uncertainties in Line 303 (see Manuscript with Track Changes). We have not discussed uncertainties of BC instruments, since this paper is not a measurement or methodological review. We point to Petzold et al. (2013), Sharma et al., 2017 and Ohata et al., 2021) (see references therein Manuscript).

Line 235: Consider rephrasing the title to “Atmosphere dispersion modelling and emissions” or something similar

**Response:** We have changed the title in section 2.3 to “Atmospheric dispersion modelling and emission inventories”.

Line 235: From the text you provide here it is not clear for which periods/years you run the model. Please mention.

**Response:** Corrected (see Line 307 references therein Manuscript).

Line 241: Are 30 days sufficient period to account for Arctic Haze? Did you test longer periods? Where do you base the 30 days? Please justify your choice if possible.

**Response:** 30 days backward in time is sufficient to capture the majority of the emissions arriving at the receptor given a lifetime of 5-7 days for BC. In fact, the fraction of the emissions arriving at the receptor for 30 days tracking has been calculated to be >98%. Please see baseline papers such as Stohl et al. (1998; 2005) and Pisso et al. (2019) (references therein Manuscript).

Line 243: What is tracking?

**Response:** “Tracking” is a common term in Lagrangian modelling corresponding to the computational particle tracking. It is explained 2 lines above “... computational particles ... and tracked backward ...”. Please see baseline paper of Seibert and Frank (2004): <https://doi.org/10.5194/acp-4-51-2004>.

Lines 269-272: Mention that the satellite image is shown in Figure 1e. Also is there any particular reason you are mentioning this here? You could simply mention it once directly when you discuss Figure 1e.

**Response:** This is correct, and we appreciate for the suggested correction. We have now moved the lines where Figure 1 is mentioned for the first time (around Line 177 in Manuscript with Track Changes).

Line 272 and afterwards: Please consider discussing the main patterns for temperature, wind speed and direction in Section 3. It would be more interesting to see there the wind patterns.

**Response:** The description of wind patterns, precipitation etc... fall within the station characteristics and they are not actual results of our study. They are not discussed further in the Results section and therefore we intend to let them in section 2.1 in order to not disturb the sequence of our manuscript.

Lines 280-284: Do you know why? If yes, please discuss.

**Response:** It is well known that the seasonal variation resulting in the Arctic Haze in winter is caused by the formation of the Polar Dome. In our opinion, this is rather trivial to be mentioned in such a long paper, but we now explain it briefly (see Line 577 in Manuscript with Track Changes).

Lines 329-331: Why? Please clarify

**Response:** We have added a brief explanation (Lines 534-537 in Manuscript with Track Changes).

Lines 345-358: You compare your results with other studies at Zeppelin. What about at other Arctic sites where there published papers even if the period is a bit shorter, e.g. Barrow/Utqiagvik?

**Response:** Other Arctic stations such as Barrow experience completely different source contributions. In addition, in this section, we only aim to present the results during our intensive campaign in IBS. However, we complement the results from IBS with those from most of the other Arctic station in Figure 3.

Line 372: Why are you showing eBC in Fig. 2? You start discussing about eBC/BC from Fig.4. Consider showing eBC time series later.

**Response:** The section, where Line 372 is placed, is entitled "3.2 Black carbon and site-specific mass absorption cross-section". Figure 2 that corresponds to this section shows exactly what is mentioned on the title, namely babs(880) on top and eBC at the bottom. We do not see why this needs to be changed.

Line 376: add ", respectively" after Table S2.

**Response:** Added in Line 369 (Manuscript with Track Changes).

Line 377: You mention p-value here for eBC. Could you calculate the p-value for all the measurements you provide? Also mention how did you calculate the p-value.

**Response:** We do not understand how bombarding the readers with p-values would ease the flow of the manuscript. All the calculated p-values were  $< 0.05$ . The calculation is easy to be done with statistical software and even easier with object-oriented tools such as python. Accordingly, since we have a t-test for independent samples the t statistic is:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \text{ where } \bar{X}_1, \bar{X}_2 \text{ the sample means, } s_1, s_2 \text{ the variances and } n_1, n_2 \text{ the size of the samples.}$$

The p-value is obtained from the t-distribution:

$$p = 2 \times P(T > |t|)$$

where  $P(T > |t|)$  is the probability of observing a t-value greater than the computed one, based on the t-distribution with df degrees of freedom (computed with Welch's formula).

Line 413: It seems it's missing something before the parenthesis "(370 and 520 nm)"

**Response:** Corrected (see Line 518, Manuscript with Track Changes).

Line 444: Do you mean 0.82 instead of 0.7? Based on the Figure 7.

**Response:** We appreciate for pointing this typo. Now corrected in Line 554.

Line 445: What about biases? Can you calculate them as well and provide the numbers?

**Response:** We added calculated bias in Lines 565-566 (see Manuscript with Track Changes).

Line 452: Do you think if you have used CAMS emissions, with a resolution 10 km<sup>2</sup>, you would have got better results?

**Response:** The reason why we use 0.5 degree resolution emission inventories is because the meteorological fields we use in FLEXPART have the same resolution. If we go higher resolution using 0.5 degrees resolution in the meteorological input (ECMWF ERA5), it is simply an interpolation. Of course, using high-resolution emissions is always an asset, but it is computationally inefficient when focusing on long-range transport mechanisms.

Lines 461: How many vertical levels did you use in the model? Did you allocate the emissions in the surface or did you distribute them at different levels? Please mention in the relevant section.

**Response:** The model uses 137 vertical levels extending from the surface until approximately 80 km. The anthropogenic releases occur at ground level (0-100 m). The BB emissions occur at higher altitudes. We have mentioned this in Lines 345-347 of the Methods section.

Line 574 – Conclusions: This section is way too long. It also reads as a grocery list and not as a scientific discussion. Please consider re-writing this section by interpreting your main findings and the main take away message the reader should take.

**Response:** The Conclusions section has been re-written and shortened as reviewer suggested. Please see Manuscript with Track Changes.

Line 665: The link for the supplement material is missing. Please provide.

**Response:** The link to the supplements is added by the journal if the manuscript is published. The Supplements for review are provided as an external file, at present.

Lines 1059-1074: Please consider correcting Barrow to Barrow/Utqiagvik. In the manuscript you mention Tiksi, Pallas and Villum. Please show their location in the Figure.

**Response:** We have corrected this everywhere in the manuscript (see previous comments and Lines 401, 403, 1253 (Manuscript with Track Changes). We also show the location of the other Arctic stations in Figure 1.

Lines 1082-1088: Figure 3. Please consider correcting Barrow to Barrow/Utqiagvik.

**Response:** Please see line 1253 (legend of Figure 3). We have not added local name Utqiagvik in the Figures, because the name becomes too long and the figures overloaded.

Lines 1075-1081: Figure 4. Add a legend in Fig.3a showing cold and warm period. In the babs time series there is a peak after 04.20 showing in blue. For eBC the same peak is shown in red. Why? The same goes for 04.21. Also please consider changing the format of the date axis in this figure and whenever else (in the rest of the figures) is applicable. It took me some time to realise these are dates. The format you are using is confusing.

**Response:** We struggle to understand what the reviewer means here. The lines and symbols differ in color to show the cold (blue) and warm period (red). All time axes have been corrected as suggested by the reviewer (see Manuscript with Track Changes).

Lines 1102-1108: Figure 6 - In figure 6a you mention “-0.96” while in the text you discuss 0.96. Why? Is 2019-2020 included in the warm/cold period? If no, why?

**Response:** Equation 2 denotes:  $b_{abs}(\lambda) = b_{abs}(\lambda_o) \times \left(\frac{\lambda}{\lambda_o}\right)^{-AAE}$ . To have the curve as in Figure 6a, one can easily understand that the power needs to be a positive number.

Lines 1109-1115: Figure 7 - What do the slopes show? Please mention

**Response:** In a scatter plot, the slope of the regression line, m, is given by  $y = mx + b$ . So, if the regression line is  $y=5x+10$ , then  $m=5$  means that for every 1-unit increase in x, y increased by 5.

Lines 1116-1121: Figure 8 – In the title you refer to the station as “Bely station”. Please be consistent and refer to the station as “Island Bely” station

**Response:** Corrected! Please see Figure 8 in the Manuscript with Track Changes.