Author responses to Referee 1 comments on the paper "Integrative and comprehensive Understanding on Polar Environments (iCUPE): the concept and initial results" by Tuukka Petäjä et al.

The authors are grateful for the referee for the comments, which improved the manuscript considerably. We provide point-by-point responses below in **bold.**

(General comments) At first, I felt some difficulties to understand the manuscript as "Research article" which should "report substantial new results and conclusions from scientific investigation…" as expressed in the Manuscript types written on ACP Home Page. The manuscript is rather "Review" or "Overview article" for the special issue. Actually, it is indicated as the articles for the special issue, "Pan-Eurasian Experiment (PEEX)", and the manuscript most fits as "Special issue overview article".

We agree with the referee. The more suitable type of the manuscript is "Special issue overview article". Upon submission, we were not able to connect the paper to the PEEX special issue and this was done only at the technical edit phase. We hope that the type can be changed in the next editorial phase.

Even though, I was confused to the substance of the project "iCUPE", if it conducts observation itself or just works for analyzing activities, which are not clearly mentioned in the manuscript. I have found some expression in the iCUPE home page; iCUPE will 1) synthesize data from comprehensive long-term measurements, intensive campaigns and satellites, collected during the project or provided by on-going international initiatives, which clearly mentions the actual activities of the project. Please add this kind of explanation in the manuscript, then, it will be much understandable.

The connection between the paper and the iCUPE project is now clarified in the last paragraph of the introduction section as follows (new text indicated with red):

"The iCUPE project aims to synthesize data from comprehensive long-term measurements, intensive campaigns and satellites, collected during the project or provided by on-going international initiatives. The aim of this paper is to introduce an on-going project iCUPE and summarize its initial results. We put a specific emphasis on black carbon and persistent pollutants in the Arctic context. We explore snow and ice core samples to put the current concentrations in longer perspective. We underline the capacity of the continuous observations to monitor the impact of policies to reduce the emissions. We showcase the potential to address the pollution in the Arctic environment by integrating satellite remote sensing, airborne observations, in situ data and modeling. The modern comprehensive source apportionment can resolve the different sources of atmospheric aerosols and differentiate between sources within and outside the Arctic environment. We also discuss the iCUPE impact and relevance for the Arctic research and for the stakeholder communities."

The manuscript is not well organized, all of the substances are written in chapter 3, and still the sections are mixtures of methods (3.1, 3.2, 3.3, 3.7 and 3.8) and target species (3.4, 3.5 and 3.6), so, not easy to read and understand, partly, also, due to the question in the previous paragraph. 3.8.1 is also very difficult to follow, since the substances are cloud (microphysics) and precipitation, which are quite far from other items discussed in the manuscript.

It is true that the manuscript structure is not optimal. However, this reflects the variety of topics addressed by the iCUPE consortium. We organized section 3 with the following logic:

We start with the in-situ component of iCUPE with sections 3.1-3.6 and bring in to discussion the satellite remote sensing in section 3.7. Then we present selected integrating examples in 3.8, which include also method development and conceptualization. This is consistent with the iCUPE concept as a whole (multiplatform observations, modeling, synthesis, summarized in Figure 2).

We include a short explanatory paragraph in Section 3 as follows:

"In this section we summarize results and findings of iCUPE-project regarding the in-situ observations (Sect 3.1-3.6) and the satellite component (Sect 3.7). Then we selected integrating examples in Sect. 3.8, which include also method development and conceptualization. This is consistent with the iCUPE concept as a whole (multiplatform observations, modeling, synthesis, Figure 2)."

We edited the subsection names for 3.2 and 3.3 to be consistent with the others (removed word "Results").

(Specific comments)

For figures which were not the original of this paper, the citation should be shown.

We have included the references to the original work, when applicable.

- Papers which were not published yet should not cited, such as "to be submitted", "submitted", "in preparation", and so on. I am not sure for the paper "in press."

We have updated the reference list and only published papers are listed.

- Line 218-220: The sentence "When the Polar Front retreats, anthropogenic emissions are no longer able to penetrate into the High Arctic" is missleading. -→ . . ., even anthropogenic emissions penetrate into the High Arctic, they could not kept as high concentration.

We clarified and edited the paragraph as follows:

"When the Polar Front retreats, transport of anthropogenic emissions is limited to the High Arctic as only emissions north of the Polar Front can find a direct way to high Arctic sites and the front is located much further north. Also, wet removal processes reduce the build up of high concentrations. Other transport processes would only be pathways in high altitudes and then penetrating the Polar Dome by descending air masses through entrainment reaching high Arctic sites, which is rarely being observed."

- 3.2.2. Black Carbon: What is the equivalent black carbon concentration (eBC)? There is no explanation here. We could not access to the paper by Kalogridis (2019), which is just "to be submitted". There is no explanation for the correction to the aethalometer BC concentration proposed by Sinha et al. (2017, JGR). It was reported that BC concentrations measured by aethelometer (Sharma et al., 2013) or by PSAP (Hirdman et al., 2010) at Ny-Alesund were 20 – 30 % larger compared to the value obtained by C2. This is also in Fig. 5.

The definition of equivalent black Carbon concentration is given in the text with the appropriate reference. The reference to Kalogridis (2019) was removed as the submission is still pending.

The eBC data here are consistent with all previous publications where the specific mass absorption efficiency of the instrument is used. When the data are reported as aerosol absorption coefficients, then the compensation algorithms proposed in the literature can be used. The different measurement techniques undergo separate treatment and corrections which are specific to the various instruments. Here we do not employ any data obtained by the Ny Aalesund PSAP and it is not appropriate to refer to findings regarding this instrument. We do have evidence from a short study on the relationship among several instruments at then Zeppelin station, where the variability in the multiple scattering compensation parameter C is discussed but as mentioned above this is applied when the data are reported in terms of the aerosol absorption coefficient. The loading effect compensation for the Aethalometer at the Zeppelin station was found in Zanatta et al, 2018 to be an insignificant source of uncertainty. This reference and the work by Backman et al., 2017 contains all the information regarding the currently available quality assurance for the aethalometers at Ny Ålesund and is added instead of (Kalogridis, 2019).

As a result, the two first paragraphs in the section 3.2.2. 3.2.2 Black Carbon concentrations at Mt Zeppelin, Svalbard, was edited as follows:

"Black Carbon (BC) is one of the key short-lived climate forcers contributing to the warming of the Arctic both by absorbing the solar radiation but also by enhancing snow and ice melt by surface deposition (e.g. Bond et al., 2013). As part of the atmospheric observations, the ACTRIS and IASOA networks (Fig. 3) operates a network of aethalometers to determine the atmospheric concentration of BC in the air (Uttal et al., 2016). Although BC is the common term we use for light absorbing carbon, it is now more appropriate to report mass concentrations in terms of equivalent black carbon (eBC), especially when filter-based optical techniques are employed. Equivalent black carbon mass concentration is considered to be the mass of an equivalent amount of light absorbing carbon with a given mass absorption efficiency causing the attenuation of light observed by the instrument at a given wavelength (Petzold, 2013). The quality assurance of data for eBC and the corresponding aerosol absorption coefficient has greatly improved over the last years. Compensation schemes for measurement artifacts as well as harmonization of data obtained by different instruments have been established (Backman et al., 2017) and are continuously updated (Zanatta et al., 2018).

The results from long-term observations at Zeppelin have been discussed and assessed in several works elaborating on the climatology of BC in the Arctic i.e. (Eleftheriadis et al., 2009.; Sharma et al., 2013; Breider et al., 2017; Schmeisser et al., 2018). The results presented here is the longest continuous eBC reported record by a single instrument in the European High Arctic (Torseth at al., 2019) and globally the second longest after those obtained between 1989-2009 in Alert (Sharma et al., 2019). As an example of long-term observations of BC, we show the latest eBC concentration time series from Zeppelin Station at Svalbard (Fig. 5). The results show a continued gradual reduction in the annual mean value of observed eBC, while the time series is strongly modulated by a seasonal cycle well known in the Arctic with minima in the summer and maximum in late winter spring. One can observe this long-term decline with a linear trend line applied only as a crude estimate for these data. The long-term data series we present here makes it possible to derive some descriptive statistics. The eBC annual mean value has been reduced from an annual mean value of31 ng m^{-3} at the beginning of the previous decade to 12

ng m^{-3} during the last years with an average reduction of 7 ng m^{-3} per decade which amounts to a reduction 4% annually or approximately 44% per decade. However, trend analysis for aerosol climatology records need to be practiced with caution in order to remove the effects of the seasonal cycle. When the extracted absorption coefficient from our data was thoroughly examined for a shorter period (2005-2018) the trend was not found to be statistically significant (Collaud Coen et al., 2020). Minimum values over the summer often drop below the detection limits of the instrument while maximum values vary greatly with their occurrence usually related to large scale biomass burning events across Siberia and Alaska. The continuous reduction in fossil fuel usage is a reason for this reduction but it is well known that emissions are not uniformly changing on a global scale or at least in the Northern hemisphere (Evangeliou et al., 2018)."

- Line 729-733: Validation of satellite cloud profiling radar by comparing with the ground based radar, as in Fig. 24 is not clear. It is better to compare the vertical profile from both the radars.

We have updated the text to made a clearer explanation of the Fig. 24 as follows:

"To prepare for the upcoming ESA Earthcare validation activities, preparatory studies were performed on how ground-based radar observations can be used to validate space-based radar observations of vertical profiles of clouds and precipitation. A comparison between such observations, in this case we use CloudSat, is shown in Fig. 24. The figure shows vertical profiles of radar reflectivity as observed using ground-based and satellite-based cloud radars. As can be noticed there are detectable differences in the observed values. The CloudSat observed values are higher at cloud tops and lower in precipitation if compared to the ground-based radar. These differences are caused by attenuation of ground-based radar measurements in rain and melting layer and in cloud and melting layer for CloudSat observations. Therefore, a direct comparison of observed vertical profiles requires a method that can into account the attenuation. As a part of iCUPE Li et al., (2019) has studied the impact of melting layer of precipitation on cloud radar observations. The results of this study will be used for the EarthCare validation in the future."

- Are the greenhouse gases not the targets of the project? Only atmospheric trace gases are expressed in line 865-866. Methane anthropogenic emission is discussed in 3.8.2.

The emissions of greenhouse gas emissions are not a specific target of the project. In our terminology, we prefer to use "trace gases", which include also the greenhouse gases, such as CO_2 and methane as they are in the atmosphere in trace amounts.

References

Petzold, A., Ogren, J. A., Fiebig, M., Laj, P., Li, S.-M., Baltensperger, U., Holzer-Popp, T., Kinne, S., Pappalardo, G., Sugimoto, N., Wehrli, C., Wiedensohler, A., and Zhang, X.-Y.: Recommendations for reporting "black carbon" measurements, Atmos. Chem. Phys., 13, 8365–8379, https://doi.org/10.5194/acp-13-8365-2013, 2013.

Zanatta, M., Laj, P., Gysel, M., Baltensperger, U., Vratolis, S., Eleftheriadis, K., Kondo, Y., Dubuisson, P., Winiarek, V., Kazadzis, S., Tunved, P., and Jacobi, H.-W.: Effects of mixing state on optical and radiative properties of black carbon in the European Arctic, Atmos. Chem. Phys., 18, 14037–14057, https://doi.org/10.5194/acp-18-14037-2018, 2018.