**Author's response to RC1**
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<u>**Anonymous Referee #1**</u>

**This paper described results from the comparison experiments using three different light absorption filter-photometers, MAAP, PSAP, and Aethalometer, at a boreal forest site in Northern Europe. Correction of the output from these instruments has been considered one of the most important issues on the accurate determination of light absorption coefficient $b_{abs}$. In this study, authors conducted systematic comparison works to derive corrected $b_{abs}$ from the measurements using three filter-photometers with different algorithms. The topics with which this paper deals meet the scope of Atmospheric Measurement Techniques (AMT); however, there are some points to be addressed before accepting the manuscript as an AMT paper. Please consider the following comments for the revision.**

**Major comments:**

**Relative humidity of air for $\sigma_{abs}$ measurement by MAAP:**

**In this study, $C_{ref}$ was determined by the Equation (19). One of the bases of this way is the accuracy of $\sigma_{abs,ref}$ measured using the MAAP. In my reviewing process, I could not find very important related studies, for example Kanaya et al. (2013). In their study, BC concentrations measured using a MAAP ($BC_{MAAP}$) were compared with those measured using a different filter photometer, COSMOS (Miyazaki et al., 2008). The dependency of MAAP sensitivity on relative humidity (RH) in MAAP has been discussed in relation to the changes in the optical properties of the glass filter tape (e.g., surface roughness). This change can be related to an increase in the surface roughness parameter to be used for the radiation transfer calculation (Petzold and Schönlinner, 2004) together with the RH. According to their studies, $BC_{MAAP}$, namely $\sigma_{abs,ref}$ can be affected by RH in MAAP, even though the values of RH were lower than the recommended value (<40%). I believe that authors should refer these papers in the discussion on the RH dependence of MAAP and discuss such uncertainty of MAAP related to RH condition. Some of conclusions, related to RH effect, should also be modified according to the discussion on the MAAP uncertainty.**

We added discussion with reference to these articles in the manuscript: *Kanaya et al. (2013) actually observed a slight dependency in the $\sigma_{abs}$ measured by MAAP so that at low RH (< 40 %) the $\sigma_{abs}$ increased with increasing RH, which is contrary to our results as we observed that MAAP observed relatively lower $\sigma_{abs}$ at higher RH. However, they also observed opposite behavior at higher RH (> 50 %). They suggested that the RH affects the surface roughness of the filter, which is used in the radiative transfer scheme (Petzold and Schönlinner, 2004), and therefore could affect the $C_{ref}$.*

**Readability:**

**Authors described the details of all the algorithms to correct the outputs of filter-photometers used in this study. I also believe that these descriptions are important, however, I, as one of readers, felt that the descriptions are somewhat lengthy because they are from previous studies, not originally from this study. To enhance the readability, I strongly recommend to reorganize the structure of the manuscript around the sections 2.3.1 and 2.3.2. The main part of these descriptions can be moved to Supporting Information or Appendix (which will be newly prepared in the revised manuscript). Only the essences (what types of**

**correction algorithms were used for AE31 and PSAP with proper references, what kinds of input parameters are needed for each algorithm, and so on) should be included in the main text.**

Here we received conflicting comments. We understand the recommendation of making the manuscript more compact. However, this time we decided to stick with the current structure because the algorithms are referred many times in the manuscript. We also thought that keeping the descriptions in the main manuscript prevents misunderstandings on what coefficients were used and how we used the algorithms in general.

**Specific comments:**

**P4-P5: The section 2.2 (instrument set-up) should be reorganized. The most important information is the set-up used in this study. So, the explanations about Fig 2 with the instrumental information should be describe as the basic experimental setup earlier than other information like the modification of the measurement flow line, the data availability, and the RH condition.**

The Sect. 2.2 was reorganized as recommended.

**P11 L8-17: RH of air directed to the Nephelometer should be described in this section (2.4) to clarify the humidity condition of light scattering measurements and its impact on the hygroscopic growth of water-soluble aerosols.**

We added the following text in Sect. 2.4: *Since scattering by aerosol particles is depends significantly on their size, the particulate light scattering is sensitive to hygroscopic growth. To prevent this, the integrating nephelometer operated with two Nafion-driers as shown in Fig. 1.*

**P11 L19-21: Authors should describe why the difference in the size cut did not so greatly affect the results of the comparison experiments. Were there little impacts of (local) dust particles at the site?**

As we discuss about absorption measurements with filter-based methods. When we correct the data depending on the ATN decreases because of both PM1 and PM10 and it is impossible to separate the effects of these in the loading correction. We added a sentence: *Since all the instrument measured the same sample air, combining the PM1 and PM10 data caused no discrepancies between the instruments.*

We also added discussion in the results: *Because it is impossible to separate the effect of different size cuts from a loaded filter, here the PM1 and PM10 measurements were combined and averaged together. In general, PM1 accounted for about 90% of the PM10* $\sigma_{abs}$*; for the* $\sigma_{sca}$ *the fraction of PM1 was about 75%* (Luoma et al., 2019). Because absorbing particles, which is considered to consist mostly of black carbon, are typically in the fine mode (diameter < 1 µm), the σabs is not expected to deviate much between the different size cuts. However, the differing size cuts, which causes more deviation in the σsca, could have affected the σabs measurements since the particulate scattering causes apparent absorption and affect the multiple scattering in the filter. For example, the coarse particles (diameter > 1 µm) do not penetrate as deep in the filter as the fine mode particles, which could possibly influence on the Cref values. In an ideal situation the PM1 and PM10 absorption would have been measured by separate instruments.

**P13 L29: The $C_{ref}$ values determined by different algorithms were described. Together with these values, their variabilities (e.g., 95% confidence interval) should be clarified here to show the statistical significance**

**of the similarity and difference among correction algorithms. Statistical tests can help the discussion on the differences among variables.**

We added the confidence intervals in Table 2 as well as the following text in Sect. 4.1: *The results and their statistical variability are presented in Table 2. The relatively small standard error (SE) and the range of confidence interval (CI) indicate that the difference between the* $C_{ref}$ *values were statistically significant.*

**P14 L14-16: It is hard for me to understand this explanation. This can only describe the possibility to describe one of the reasons of differences between** $C_{ARN}$ **and** $C_{NC}$**, and never account for the higher** $C_{ARN}$ **than** $C_{NC}$**. Please clarify the what this describes here. And again, without the significance of the differences, this kind of comparison works could not be established.**

The Sect. 4.1 was reorganized so that first only the $C_{ref}$ values that were derived by linear regression ($C_{WEI}$, $C_{VIR}$, $C_{COL}$, and $C_{NC}$) were compared against each other. For these values the comparison was statistically justified. Since the $C_{ARN}$ was derived in a different manner, the $C_{ARN}$ is not necessarily comparable to the other $C_{ref}$ values.

**P16 L11: If the possible reasons of the lack of seasonal variations of** $C_{ARN}$ **are added, authors can discuss the difference in the potential benefits of** $C_{ARN}$ **compared to others (because the lack of seasonal variation is obviously beneficial). I believe that authors should discuss this point here to clearly differentiate the correction algorithms by their performance.**

To discuss more the advantages of both $C_{ARN}$ and $C_{VIR}$, we modified the paragraph in question in Sect. 4.1. The paragraph states now: *The seasonal variations for the* $C_{ARN}$ *and* $C_{VIR}$ *were less obvious than for* $C_{WEI}$*,* $C_{COL}$*, and* $C_{NC}$*. The lesser seasonal variation for the* $C_{ARN}$ *might be explained by the subtraction of the scattering fraction before the loading correction was applied and the* $C_{ARN}$ *was determined. For* $C_{VIR}$*, the lack of seasonal variation for was probably caused by the very strong seasonal variation of the compensation parameter (k; see Fig. 10a) as will be discussed below in Sect. 4.4. According to our results, the V2007 and A2005 accounted well the variations in the optical properties of the particles embedded in the filter and therefore the seasonal variations in the* $C_{VIR}$ *and* $C_{ARN}$ *were reduced.*

We also added the following statement in the conclusions: *According to our study the correction algorithms by Virkkula et al. (2007) and Arnott et al., (2005) performed the best in taking the seasonal variations of the aerosol particles into account.*

**P17 L29-P18 L5: I am suspicious about how largely the particles can grow by water vapor at such low values of RH. Typical inorganic species never indicate large hygroscopic growth at RH <40%, because their DRH are typically higher than 40% or so (even though considering the dehumidification process from higher RH condition). Furthermore, penetration depth of particles in filter is dependent on not only the particle size but also filter material properties and sampling flow rate (i.e., single fiber width, density of the fibers, and face velocity of air). The discussion here is highly speculative and fragmentary. Revisions to this discussion are strongly needed to better show precise interpretations.**

This part of the manuscript was reorganized and partly rewritten: *We observed slightly higher correlation ($R$ = 0.30, p-value < 0.05) between the* $C_{NC}$ *and relative humidity (RH), which is presented in Fig. 4 (the correlation was similar for* $C_{WEI}$ *and* $C_{COL}$*, but weaker, about 0.09, for the* $C_{VIR}$*). Therefore, one possible reason for the observed seasonal variation of the different* $C_{ref}$ *values could be caused by changes in the instrumental RH and* *the RH differences between the MAAP and AE31. The RH presented in Fig. 4 was measured in the MAAP and it varied between 5 – 40% since the periods when the filter of the MAAP was exposed for RH equal or larger than 40% were excluded from this study. Because the AE31 was equipped with Nafion-dryers, the RH in the AE31 varied less and was in the range of 5–20%. The RH can influence filter-based optical measurements by affecting to the optical properties of the aerosol particles and the filter fibers as well as by affecting the penetration depth of particles in the filter medium.*

*Due to the hygroscopic growth, the aerosol particles scatter more light in humid conditions compared to dry conditions. The enhanced scattering induced by higher RH could then increase the scattering and optical path in a particle-laden filter medium. However, at SMEAR II increasing RH should cause decreasing $C_{NC}$, since hygroscopic growth would increase the particulate scattering especially in the reference instrument MAAP. The hygroscopic growth may also affect the penetration depth of the particles in the filter (Moteki et al., 2010). When particles are penetrated deeper in the filter, the effect of the multiple scattering is higher increasing the measured $\sigma_{ATN}$. Because the RH in the MAAP was higher than in the AE31, the particles directed in the AE31 may have penetrated relatively deeper in the filter than the particles directed in the MAAP filter, in summer, larger difference in the RH between the instruments could increase the measured $C_{ref}$. However, the hygroscopic growth should not be significant in RH conditions below 40%, which is why the effects related to hygroscopic growth seem unlikely explanations.*

*Also, the optical properties of the filter may change if the filter is exposed to high RH conditions. The aerosol particles may take up water even below super saturation and when the liquid particles collide on the filter the moisture is taken up by the filter. Kanaya et al. (2013) compared the MAAP against Continuous Soot Monitoring System (COSMOS; Miyzaki et al., 2008) and actually observed a slight dependency in the $\sigma_{abs}$ measured by MAAP so that at low RH (< 40 %) the $\sigma_{abs}$ increased with increasing RH, which is contrary to our results as we observed that MAAP observed relatively lower $\sigma_{abs}$ at higher RH. However, they also observed opposite behavior at higher RH (> 50 %). They suggested that the RH affects the surface roughness of the filter, which then affects the scattering properties of the filter fibers.*

*The results show that even though we excluded the high RH data, the instruments seem to be sensitive to variations in RH even below the recommended 40%. However, the reason for the sensitivity remains unclear and would require more research and measurements and therefore further analysis is omitted from the scope of this article.*

**P18-P19 (sections 4.2 and 4.3): The performances of the correction algorithms as a function of *ATN* or *Tr* were evaluated in these sections. The slopes of $\sigma_{abs,AE31}$ (or $\sigma_{abs,PSAP}$)– $\sigma_{abs,ref}$ correlations and values of Absorption Ångström exponent $\alpha_{abs}$ were determined by the linear regression analysis. For better evaluations, it is beneficial to include the analyses of r2 values as a function of *ATN* and *Tr*. In terms of the measurement precision, *ATN* and *Tr* should be considered for quality control and quality assessment of the data obtained using filter-photometers. As an example, an evaluation of a miniaturized Aethalometer (AE51) in a previous study (Miyakawa et al., 2020) suggested that AE51 showed lower precision (i.e., lower r2) results in case of heavy aerosol loading on a collection filter (than not-used filter case).**

We added a table (Table 3) with the slopes and $R^2$ values for different *ATN* intervals and referred to this in the text. We also added discussion on the $R^2$ values: *According to the $R^2$ values presented in Table 3, the precision of* *the AE31 decreased with increasing ATN. For example, the data corrected with the A2005 algorithm, the $R^2$ decreased from 0.96 for a clean filter (ATN < 20) to 0.90 for loaded filter (ATN > 60). However, the decrease in R2 was quite minor. Miyakawa et al. (2020) observed also rather high $R^2$ values between Aethalometer (model AE51) and a reference instrument (single particle soot photometer and COSMOS) when the ATN was below 70. When the ATN exceeded 70, the $R^2$ decreased more rapidly.*

**P19 L17: I believe that this sentence is not correct and not scientific (not -slope of a linear fit, simply slope of linear fit, because "-1" was multiplied in front of the slope term). So, this should be rephrased by using an equation or a proper expression.**

This was modified to: *The $\alpha_{abs}$ was determined as a linear fit over all the selected wavelengths according to Eq. (16).*

**P22 L25-28: These sentences should be included in discussion part, because they are not the actual outcome from this study.**

The text was moved to Sect. 4 Results and discussion.

**Captions of Figures 7, 8, 9: I think that "The explanation for the boxplots is the same as in Fig. 3" not Fig. 5. Furthermore, the marker types indicating the mean values are not always same for all figures (Figs. 3, 7, 8, 9). Please confirm the consistency and properly revise them.**

Fixed this.