We would like to thank the reviewer for their valuable comments and suggestions which have improved this manuscript. We have modified the manuscript to include the proposed changes along with step-by-step answers to their suggestions. We would also like to inform the reviewer of a major addition in the manuscript which is the inclusion of 532 nm wavelength utilizing the PollyXT observations.

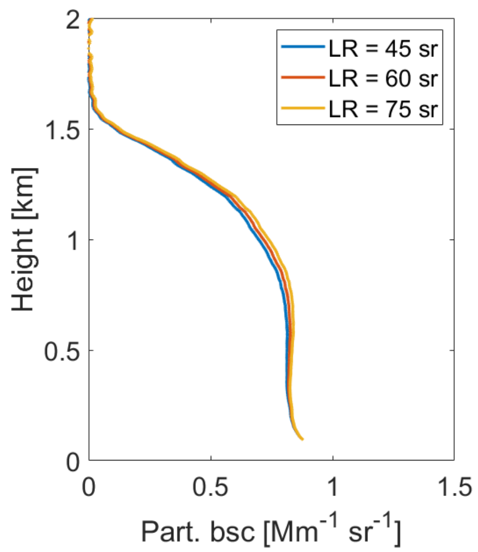
Reviewer #3

The manuscript presents a multi-disciplinary study that combines in-situ and remote sensing data to provide newly derived extinction to concentration conversion factors for Birch Polen particles at 905 nm. Such factors are of high importance in the lidar and ceilometer communities as they can be used for the monitoring of the vertical distribution of pollen concentration that is in-turn important for public-health and for studying aerosol-cloud interactions. The manuscript is well structured and clear. The techniques are described sufficiently. I recommend the publication of the manuscript after some minor revisions according to the comments below.

Lines 98-100: Is this uncertainty related only to the calibration? is the uncertainty due to lidar ratio biases taken into account too? If not please add the anticipated uncertainty if the lidar ratio is not 60 sr.

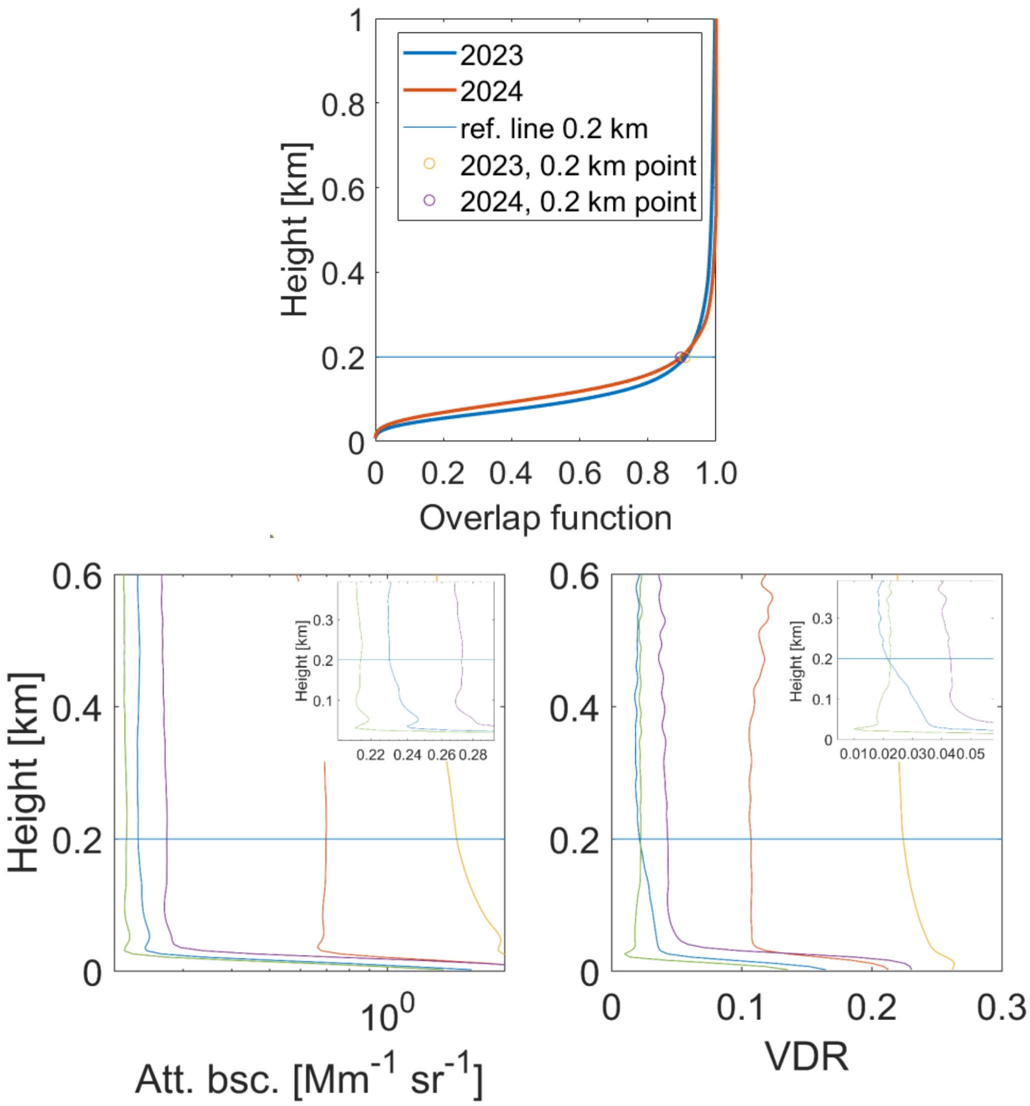
Thank you for your comment. This uncertainty refers to the particle backscatter coefficient. The lidar ratio selection introduces negligible uncertainty in the boundary layer for the forward inversion and thus omitted. This is visualized in the example below, where a forward Klett inversion has been performed for a variety of lidar ratios (LRs). In the backward Klett inversion the LR induces greater variability as shown in Shang et al., (2021). Note that all other parameters are kept constant except the LR.

Shang, X., Mielonen, T., Lipponen, A., Giannakaki, E., Leskinen, A., Buchard, V., Darmenov, A. S., Kukkurainen, A., Arola, A., O'Connor, E., Hirsikko, A., and Komppula, M.: Mass concentration estimates of long-range-transported Canadian biomass burning aerosols from a multi-wavelength Raman polarization lidar and a ceilometer in Finland, Atmos. Meas. Tech., 14, 6159–6179, https://doi.org/10.5194/amt-14-6159-2021, 2021.



Lines 101-102: Is an overlap correction being applied down to 300 m (or 200 m). If yes, which is the real distance of full overlap where the correction starts? Please specify.

Thank you for your comment. Yes, an overlap correction is automatically included/performed in the attenuated backscatter coefficient provided by the manufacturer/instrument. The correction is applied from the lowest height bin up to the height of full overlap. Below are two overlap functions from 2023 and 2024 observations as the overlap function was not stored in CL61 files in 2021. An example of five 1h temporally averaged profiles of the attenuated backscatter (att. bsc) and volume depolarization ratio (VDR) up to 0.6 km in height is also shown. The 200 m level is marked with horizontal line. Regarding the overlap function, at 200 m about 89-90% of the beam is mirrored by the telescope. Regarding the 5 profiles, these are taken during clear skies with varying aerosol load and as minimal aerosol structure in the vertical direction as possible. A nested zoomed view is presented for the first 3 cases for the abovementioned quantities. We can see that there are structural similarities in the shape of the signal regardless of the aerosol load below 200 m. There are two local maxima present at about 50 m and 140 m. The VDR is less affected by these and information below 200 m can be possibly used for either optical property on a case-by-case scenario (e.g. for the high aerosol load case (yellow)). Below the selected height, information should be used with cautious and additional corrections may needed to be applied to derive useful information. Such corrections are outside of the scope of this paper.



Lines 179-181: In section 2.5.1 a size limit of 5.3 μm is reported for ICEMET. This seems to be in conflict with the 12-35 μm range mentioned here. The different values probably refer to different types of size distribution (number concentration and volume concentration) but this is not clearly mentioned. Please add a brief explanation.

Thank you for your comment. Although ICEMET provides the aerosol size distribution between 5.3 and 200 um and adding the NS/OPS aerosol size distributions we have the aerosol distributions for even smaller particle sizes, for the number and mass concentrations we have utilized the size range between 12 and 35 μm. The selection of 12-35 μm was chosen as representative of birch pollen particles, thus, the relationship between extinction and number/mass is more straightforward for this aerosol type. Nevertheless, in Sect. 4 (Lines 367-374) we discuss the selection of the lower size particle limit and its effect in the estimated conversion factors. More specifically, we mention that:

'For estimating the mass concentration, even if smaller coarse birch pollen particles or other biological material are present in the atmosphere (> 2.5 μm diameter), the uncertainty in the c_v factor is in the order of 5 % with a re–estimated c_v of 1.90 ± 0.10, which is within the uncertainty range of the 12–35 μm size range. Assuming an AERONET equivalent particle size range (1.2–30 μm diameter), c_v of 1.84 ± 0.08 is obtained which presents a 6 % discrepancy from the 12–35 μm size range. In comparison, when using the AERONET method (level 1.5), a c_v of 1.24 ± 0.06 is estimated. This is not the case for the number concentration estimation in which the inclusion of aerosol particles above 2.5 μm leads to an order of magnitude higher c_n factor than the 12–35 μm size range, with the relationship between volume concentration and extinction not to be linear anymore.

Lines 207-208: What are the two components? Is it pollen and water solubles (sulfate, nitrate organics)?

We assume a mixture of birch pollen (non-spherical component) and background aerosols which present a very low particle depolarization ratio (spherical component) (Shang et al., 2020; Bohlmann et al., 2019) for the decomposition method. Having said that, there are studies that have explored the chemical composition of the aerosol population in the area. For example, in Portin et al., (2014) sulfate, nitrate, ammonium and organics were all present at Kuopio (20 km from Vehmäsmäki station) where the inorganic to total ratio was about 42 (%). The following text has been added to the manuscript: 'Portin et al. (2014) have explored the chemical composition of the aerosol population in the area and found that sulfate, nitrate, ammonium and organics are present at Kuopio, about 20~km from Vehmäsmäki station, where the inorganic to total ratio was about 42%.'

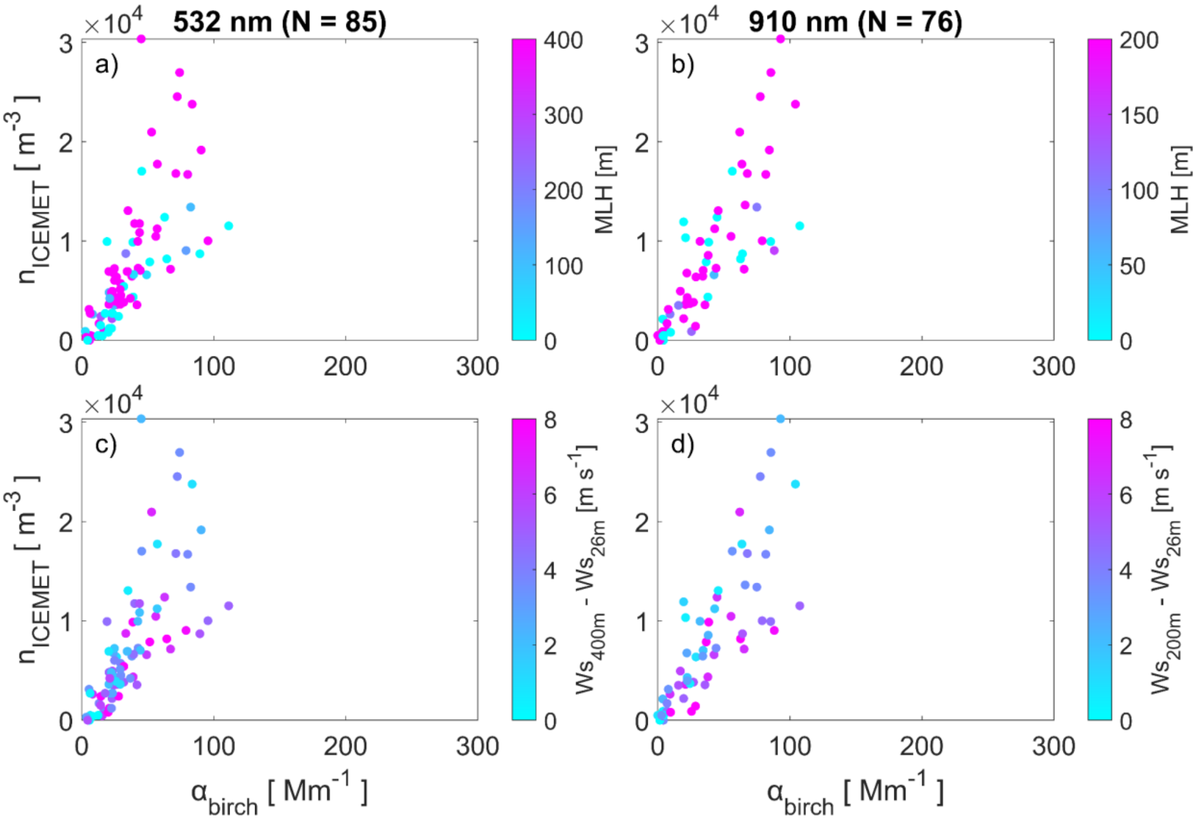
Portin, H., Leskinen, A., Hao, L., Kortelainen, A., Miettinen, P., Jaatinen, A., Laaksonen, A., Lehtinen, K. E. J., Romakkaniemi, S., and Komppula, M.: The effect of local sources on particle size and chemical composition and their role in aerosol–cloud interactions at Puijo measurement station, Atmos. Chem. Phys., 14, 6021–6034, https://doi.org/10.5194/acp-14-6021-2014, 2014.

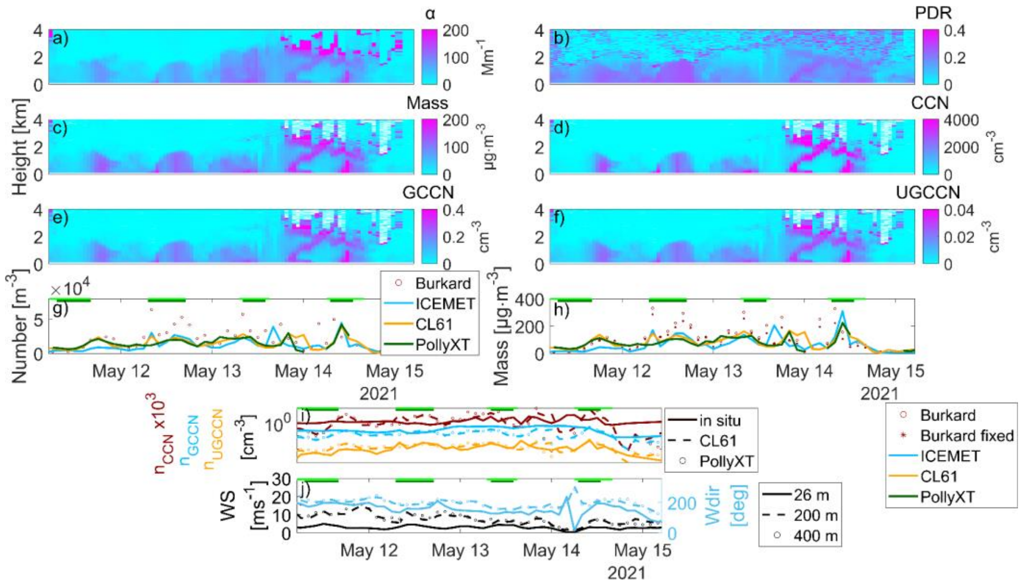
Lines 205-207: From which instrument/wavelength? Is this still the ceilometer?

The sentence relates to the methodology of retrieving the extinction-to-number (or mass) conversion factor and refers to any instrument/wavelength capable of providing the particle extinction coefficient. Since we have now added PollyXT lidar measurements and therefore, 532 nm wavelength was added, we have modified the sentence as follows. 'The second required parameter for the c_v (c_n) calculation is the α for the specific aerosol type. The birch extinction coefficient, α_{birch}, was derived by polarization lidar observations based on the backward (forward) Klett–Fernald inversion method for PollyXT (CL61) observations, respectively, and the birch component separation method from Tesche et al. (2009)'

Lines 211-212: Here it is implied, that a MLH ensures well mixed conditions up to 200 m so that the in-situ and the remote sensing retrievals can be combined. Is this the case? Please elaborate more as this is a key part of this study.

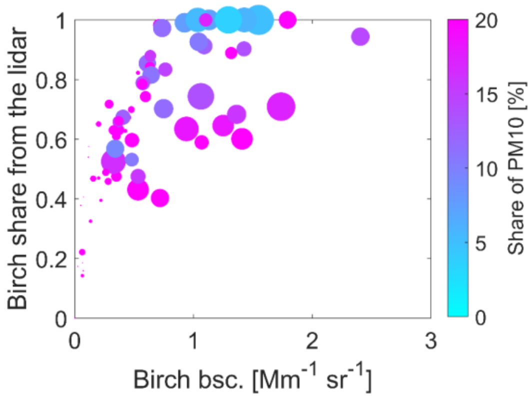
The MLH was selected as an indicator of similar aerosol conditions between the ground and the 200m level. The MLH was estimated using a threshold in the Turbulent Kinetic Energy (TKE) dissipation rate profile which is informative of the intensity of turbulence for a given flow. Having said that, whether the aerosol size distribution is similar between the surface and the 200m height level is multi-dimensioned and it depends on the particle size and wind conditions. One more factor to be considered is the 2h temporal averaging that can affect the aerosol distribution, especially during the transition times of the boundary layer and can introduce dissimilarities in the concentrations between the lidars and the in-situ instruments. An indicator of whether pollen is distributed equally in the vertical direction would be the shape of the particle depolarization ratio (PDR). Unfortunately, this information is missing close to the surface and conclusions relying on the shape of the PDR profile can be made for heights above 200 m or higher, depending on the lidar. The graph below shows similar information to figure 5 for the number concentration and birch extinction coefficient but without filtering the MLH nor the dust/bc cases. We can see that the MLH presents an efficient way to facilitate comparisons between the two height levels (panels a) and b)). Furthermore, data points following linear relationship present smaller wind speed difference between the surface and the elevated layer compared to those with similar wind speed conditions between the two height levels (panels c) and d)). Note that we have added PollyXT observations, therefore, the same information is additionally presented at 532 nm where the observations are available above 400 m due to the overlap limitation. The highest birch concentration on site, is represented with the topmost point in all four panels. It was observed by Burkard instrument during the 12th of May 2021 at 8 UTC (7-9 UTC). We see that in 532~nm this point deviates from the linearity, and it can be due to the transitioning of the boundary layer which resulted to averaging heterogeneous aerosol layers together with the wavelength sensitivity to the aerosol particle size population. To this direction, we have added to Fig.7 the wind speed-direction at three levels (surface, 200m and 400m), the times that the mixing layer height was above the 200m (400m) height level as light green bar (dark green bars) as indicated by the HALO Doppler lidar and enhanced the discussion by adding the following sentences. 'In fact, the smaller the wind speed difference between the surface and the elevated layer is the better the agreement between these two height levels. In turn this implies that, during unstable atmospheric conditions, higher discrepancies between the lidar- and in situ-estimated quantities are anticipated, due to the long temporal averaging of non-uniform aerosol layers together with the sensitivity of the specific wavelength to the aerosol particle size distribution.' The updated figure 7 can be also found below.





Lines 211-212: Does the birch share correspond to volume or number concentration fraction? Please specify. Recommendation: It would be interesting to know how does 90% contribution to the volume (or number) concentration translate to extinction (or backscatter) contribution? This can be estimated with the same methodology described here.

Thank you for your comment. The birch share in Lines 211-212 corresponds to the number concentration, and it refers to the share of birch pollen compared to the rest pollen types without accounting the contribution of other aerosols in the mixture. In this way, we know that in the considered cases, the effect of birch pollen is studied. Then, during the decomposition lidar method, the share of birch pollen to the total particle backscatter coefficient (birch share from lidar) can be determined using the PDR value of birch which for the 910nm is 0.23 (Filioglou et al., 2023). To this direction, the birch particle backscatter coefficient to the birch share from the lidar can be also estimated using the decomposition method. The color indicates the share of PM10 to the total mass using the method described in Filioglou et al., (2023). Specifically, the share of PM_{10} in the aerosol mixture was calculated as follows: $100 \cdot PM_{10}$ $(PM_{10} + PM_{pollen})$. We have used a birch pollen diameter of 25~μm for the conversion of number pollen concentration to mass. The size indicates the number concentration of birch pollen from Burkard estimations. Note that all cases are included here without filtering the data with the MLH or for bc/dust contributions. We can see that the estimated birch share from the lidar and the share of PM10 are anticorrelated where the higher the contribution of birch pollen is in the lidar observations (implying higher PDR), the less the contribution of PM10 is in the aerosol mixture. This is the behaviour we expect. Then, mixtures of birch with other unspherical aerosol particles, can deviate from this trend. For example, in such cases SPPs of birch pollen or/and other biological material (e.g., spores, fungi, algae etc) having different PDR than birch pollen with not know concentration can be present.



Lines 215-218: Is the LR of birch particles 60 sr or is this a general climatological value? Please specify and add a reference here.

Thank you for your question. The LR is a climatological value as reported in Bohlmann et al. (2019) and Shang et al. (2020, 2022) studies where birch was present. The following references have been added. Also, we have added two tables, one for each wavelength, presenting a sensitivity study to the selection of the LRs to the estimated conversion factors.

Bohlmann, S., Shang, X., Giannakaki, E., Filioglou, M., Saarto, A., Romakkaniemi, S., and Komppula, M.: Detection and characterization of birch pollen in the atmosphere using a multiwavelength Raman polarization lidar and Hirst-type pollen sampler in Finland, Atmos. Chem. Phys., 19, 14559–14569, https://doi.org/10.5194/acp-19-14559-2019, 2019.

Shang, X., Giannakaki, E., Bohlmann, S., Filioglou, M., Saarto, A., Ruuskanen, A., Leskinen, A., Romakkaniemi, S., and Komppula, M.: Optical characterization of pure pollen types using a multi-wavelength Raman polarization lidar, Atmos. Chem. Phys., 20, 15323–15339, https://doi.org/10.5194/acp-20-15323-2020, 2020.

Shang, X., Baars, H., Stachlewska, I. S., Mattis, I., and Komppula, M.: Pollen observations at four EARLINET stations during the ACTRIS-COVID-19 campaign, Atmos. Chem. Phys., 22, 3931–3944, https://doi.org/10.5194/acp-22-3931-2022, 2022.

Lines 215-218: According to section 2.2 the ceilometer full overlap is 300 m. How much is the systematic uncertainty due to the incomplete overlap at 200 m? Is an overlap correction being applied between 200 and 300 m. Please specify

We would like to refer the reviewer to the second comment as we have combined the answers from this question there.

Lines 221-222: Please don't forget to mention which concentration is being used each time, number or volume?
Thank you for your suggestion. We have added the missing information in places where it was missing.

Lines 236-238: Suggestion: Move this sentence higher up in this section so that the readers can follow more easily the discussion.

Moved according to reviewer's suggestion.

Lines 225-226: As this is a multi-disciplinary study, it would be beneficial to provide a brief explanation of what kappa-value is for non CCN experts.

Thank you. We have added the following text: 'At this supersaturation, Mikhailov et al. (2021) found the hygroscopicity of birch pollen particles, kappa–value, to be k = 0.13 ± 0.02 and an estimation of the activated particles can be made according to.....'

Lines 243-250: The factor f_ss, birch is never introduced. Please add a description.

Added according to reviewer's suggestion.

Lines 240-261: Most of the factors/variables here were never properly introduced. Please add a discription of what each factor corresponds too. The subscripts are not sufficient to deduce the variable's role.

Added according to reviewer's suggestion.

Lines 284-285: Are sea salt particles expected at the site?

According to Portin et al., (2009) and Leskinen et al., (2012), the site is a receptor of air masses originating both from continental and marine environment.

Portin, H. J., Komppula, M., Leskinen, A. P., Romakkaniemi, S., Laaksonen, A., & Lehtinen, K. E. J. (2009). Observations of aerosol–cloud interactions at the Puijo semi-urban measurement station. Boreal Environment Research Publishing Board

Leskinen, A., Arola, A., Komppula, M., Portin, H., Tiitta, P., Miettinen, P., Romakkaniemi, S., Laaksonen, A., and Lehtinen, K. E. J.: Seasonal cycle and source analyses of aerosol optical properties in a semi-urban environment at Puijo station in Eastern Finland, Atmos. Chem. Phys., 12, 5647–5659, https://doi.org/10.5194/acp-12-5647-2012, 2012.