

Response to Referee #1

We thank the reviewer for the constructive comments.

General comments

5 months are a short period to draw conclusions for the applicability of the method over a multi-year data set. In those 5 months you cover a large range of typical spring and early summer conditions. Please discuss risks in extrapolating your findings to the multi-year data set.

↳ The limitations of a 120 day dataset are now emphasized in the manuscript.

“Additionally, it must be emphasized that the measurement period of 120 days does not resolve possible annual or long-term trends and that the results may be site-specific.” (Conclusion)

You wrote that part of your results are “valid only for the site- and instrument-specific set-up”. Could you elaborate on the value of this paper for the overall scientific community?

↳ In the conclusion of the manuscript, it is now clarified that this study highlights the potential and limitations of ceilometers for aerosol remote sensing.

“This study highlights the potential of automatic lidars and ceilometers for aerosol remote sensing.” (Conclusion)

Specific comments

Page 2, line 38 - This network will soon be integrated into the ACTRIS network (Pappalardo, 2018; Laj et al., 2024). -

Note: Wasn't Earlinet part of ACTRIS from the beginning?

↳ This is correct, and the manuscript was updated accordingly.

“This network was integrated into the Aerosol, Clouds and Trace Gases Research Infrastructure (ACTRIS) network (Pappalardo, 2018; Laj et al., 2024).” (Introduction)

Page 2, line 40 - the total number of installed instruments is currently limited to 27 -

Note: I don't think the number is limited, it's just low for the reasons you mention. I suggest to remove "limited to".

↳ The manuscript was updated accordingly.

“[...] the total number of installed instruments is currently 27 (TROPOS, 2025), [...]” (Introduction)

Page 2, line 53 - This study aims to quantify the uncertainty of using an existing multi-year ceilometer dataset to derive aerosol properties. -

Note: This is misleading. You may aim to apply your workflow to the multi-year data set. However, here, only 5 months of data are used. Please rephrase.

↳ The manuscript was updated accordingly.

“To quantify the uncertainty in using an existing multi-year ceilometer dataset to derive aerosol properties, this study evaluates a five-month dataset.” (Introduction)

Page 4, line 75 to 77 - JOYCE is equipped with a suite of remote sensing, in situ and radiation measurement instruments. These instruments are among others an ABB Atmospheric Emitted Radiance Interferometer (AERI), a Metek MIRA-36 Doppler cloud radar, two ceilometers (Vaisala CT25k, Luft CHM15k, Sec. 3.1), a RPG humidity and temperature profiler and a CIMEL sun photometer. -

Note: Present separately the instruments that are used in this study, and any additional instrumentation at JOYCE. Or remove those which are not relevant to this study.

↳ The Atmospheric Emitted Radiance Interferometer was removed from the list. An additional sentence was added, to indicate, which instruments are directly used in this study and which instruments are used as references or to run the Cloudnet target classification.

“The instrumentation comprises a Metek MIRA-36 Doppler cloud radar, two ceilometers (Vaisala CT25k and Luft CHM15k; see Sec. 3.1), an RPG humidity and temperature profiler, and a CIMEL sun photometer. In this study, only the ceilometer measurements are analyzed using the sun photometer to estimate the lidar ratio (Sec. 4.2), while the remaining instruments provide input for the Cloudnet target classification (Sec. 3.3).” (Observational site)

Page 5, line 89 - following equation (Hervo et al., 2016):

Note: The lidar equation is older than that. Hervo has described it well for the application to ceilometers, but the equation itself was used long before that. Klett 1981 could be used as a reference for example.

↳ *The references were updated to include both publications:*

“(Klett, 1981; Hervo et al., 2016)” (3.1 Ceilometers)

Page 6, line 114 - It does not filter out any particles larger than 10 -

Note: I'm not sure how to understand “filter out” in this context. Do you mean that no particles larger than 10 micrometre pass through the instrument for sampling, or that only particles larger than 10 micrometre are sampled? I guess it's the first, but then I'd suggest rephrasing this sentence.

↳ *In contrast to other PM10 inlets with a defined cutoff size, this inlet does not block aerosols with a certain size. This sentence is confusing at this point and is not required to understand the setup. Therefore, this sentence has been removed from the manuscript.*

Page 6, line 118 - OPS setup is illustrated in panel (b) of in Fig. -

Note: remove “in”

↳ *The typo was corrected.*

Page 7, line 128 - taken as 1.5 g cm⁻³ -

Note: Why this value?

↳ *Without knowledge about the “real” particle density, this value was selected as a typical density for aerosols in the range specified by Osborne et al., 2024 as already indicated in the manuscript.*

“[...] the particle density (typically in the range 1.2 to 2.5 g cm⁻³ (Osborne et al., 2024)) taken as 1.5 g cm⁻³ [...]” (3.2 Optical Particle Sizer)

Page 8, line 143 - At JOYCE, the Cloudnet target classification -

Note: Out of curiosity, which of the ceilometers is used for the Cloudnet target classification at JOYCE?

↳ The Cloudnet target classification at JOYCE is based on the Lufft CHM15k. This information has been added to the manuscript.

“At JOYCE, the Cloudnet target classification, which utilises the Lufft CHM15k ceilometer, [...]” (3.3 Cloudnet)

Page 11, figure 3 caption - (e) ground air pressure -

Note: Measurement height is mentioned for all parameters. Is air pressure measured at 2 m? You could add it here for consistency.

↳ Yes, the air pressure was measured 2 m above ground. The manuscript was updated accordingly.

“[...], (e) ground air pressure p at 2 m, [...]” (Figure 3, caption)

Page 13, line 226 - In the time range from 0:00 to about 8:00 low aerosol mass concentrations of -

Note: From figure 4 it looks like aerosol mass concentration was low until around 9:00.

↳ Yes, that is true. The manuscript was updated accordingly.

“In the time range from 0:00 to about 9:00 low aerosol mass concentrations [...]” (5.1 Dataset overview and example day)

Page 15, line 260 - the statistical relation obtained here is valid only for the site- and instrument-specific set-up. -

Note: And it is only valid under certain conditions. Those which were observed in the 5 months and not filtered out.

↳ An additional sentence was added to point this out.

“Additionally, they represent only measurements during defined environmental conditions, as described above, from a five-month dataset.” (5.2 Aerosol mass concentration and attenuated backscatter coefficient)

Page 17, line 272 - extinction coefficient of $1.4 \times 10^{-3} \text{ km}^{-1}$ -

Note: Do you have an uncertainties estimate of this?

↳ We estimated an uncertainty of 25 % for the extinction coefficient based on the signal resolution of the CT25k. The paragraph was changed accordingly:

“The intercept value can be converted to a pure air backscattering coefficient of about $(1.7 \pm 0.4) \times 10^{-4} \text{ sr}^{-1} \text{ km}^{-1}$. Taking the theoretical Rayleigh scattering lidar ratio of $8\pi/3 \text{ sr}$, an extinction coefficient of $(1.4 \pm 0.4) \times 10^{-3} \text{ km}^{-1}$ at 120 m was obtained. This estimate is in reasonable agreement with a value of $(1.50 \pm 0.04) \times 10^{-3} \text{ km}^{-1}$ for 906 nm derived from the literature for the measurement conditions (Bucholtz, 1995).” (5.3 Aerosol mass concentration and extinction coefficient)

Page 17, line 273 - with a literature value of $1.53 \times 10^{-3} \text{ km}^{-1}$ -

Note: Did they report uncertainties? Your value might be within the uncertainty range.

↳ The previously stated literature value of $1.53 \times 10^{-3} \text{ km}^{-1}$ applied for standard atmosphere conditions at sea level and is very accurate (0.1 %). However, the actual value depends on temperature and pressure. We therefore derived a reference range of $(1.50 \pm 0.04) \times 10^{-3} \text{ km}^{-1}$ based on the observed mean temperature and mean ground pressure (corrected for a height of 120 m) where the uncertainty covers the standard deviations of temperature and pressure.

“[...] a value of $(1.50 \pm 0.04) \times 10^{-3} \text{ km}^{-1}$ for 906 nm derived from the literature (Bucholtz, 1995).” (5.3 Aerosol mass concentration and extinction coefficient)

Page 23, line 314 - In contrast, the C_m to β_{Mie} relationships and the $SMie$ exhibit a much greater variation -

Note: I'm not sure, where I can see evidence of this. Please explain which figure or table you are referring to. Doesn't this contradict R values shown in table 3, which are higher for $C_m \sim \beta_{a_Mie}$ compared to $C_m \sim \sigma_{a_Mie}$?

↳ This statement refers to the dependence on refractive indices in Tab. 3, which is now clarified in the manuscript.

“In contrast, the C_m to β_{Mie} relationships and the $SMie$ exhibit a much greater dependence on refractive index, compared to the C_m to σ_{Mie} relationships (Tab. 3) because of strongly increasing backscattering efficiencies with increasing refractive index.” (5.4 Calculation of aerosol backscatter and extinction coefficients)

Page 23, line 322 - linear relationships between C_m and σ_a are robust with regard to variations of refractive -

Note: Again, I am a bit lost here. What exactly do you mean with "robust"? The lower R values indicate that $C_m \sim \sigma_a$ is less "robust" than beta. Also, values of r_3 are decreasing with increasing m. Could you please elaborate?

↳ The statement regarding robustness refers to the changes of the C_m/σ_a slopes with refractive index. This is relevant because a natural aerosol will be composed of particles with different refractive indices and the composition can vary with time. This is now clarified in the manuscript.

“Nevertheless, the theoretical calculations summarized in Tab. 3 confirm that the slopes of the empirical linear relationships between C_m and σ_a are robust with regard to variations of refractive indices in the particle phase. This is relevant because a natural aerosol will be composed of particles with different refractive indices and the composition can vary with time.” (5.4 Calculation of aerosol backscatter and extinction coefficients)

Page 26, figure 11 - Mean aerosol number size distribution $dC_n/d \log D$ (A), cumulative, relative contribution to total aerosol mass concentration C_m (B) and to simulated aerosol extinction coefficients σ_{Mie} (C) (01 February to 20 June 2023 at the meteorological tower in 120 m). -

Note: I find this caption confusing. Suggestion: "A) Mean aerosol..., B) cumulative, relative ..., and C) cumulative, relative contribution to simulated (01 February...)"

↳ The caption was updated accordingly.

“A) Mean aerosol number size distribution $dC_n/d \log D$, B) cumulative, relative contribution to total aerosol mass concentration C_m , and C) cumulative, relative contribution to simulated aerosol extinction coefficients σ_{Mie} (01 February to 20 June 2023 at the meteorological tower in 120 m).” (Figure 11, caption)

Page 28 - It is recommended to reevaluate the approach with state-of-the-art instrumentation for future applications. -

Note: I'd also suggest to extend the time period of this experiment and investigate the behaviour of different aerosol types. Possibly it could be an option to find an existing data set from elsewhere. I know that Mace Head used to have an aerosol inlet on a small tower. They also have two ceilometers (Lufft and Vaisala, both older models though). There might be other sites sampling aerosols at an elevated height with a (Vaisala) ceilometer.

↳ We thank the reviewer for this suggestion. We consider contacting researchers from other sites who may have comparable datasets, as now pointed out in the conclusion. A continuation of the study at JOYCE is currently not foreseen because of the discussed limitations of the in situ instrument.

“This could be achieved for example by using already existing long-term datasets from other field sites.” (Conclusion)

Technical corrections

Page 23, line 320 - in the aforementioned ceilometer networks (Osborne et al., 2024) in agreement with the value used in this work. However, a -

Note: There is a typo: aforementioned

↳ The typo has been corrected.

Page 25, line 330 - correctly discarded because of scattered light signals that are too high. On the other hand, such particles will contribute to the -

Note: There is a typo: particles

↳ The typo has been corrected.

Page 26, figure 11

Note: There is a typo in the secondary y-axis label: contribution or contributions

↳ The typo has been corrected.