Response to comments of reviewer #2

The authors would like to thank the reviewer for the time and effort taken to review this manuscript, which is very much appreciated.

Following the response to the other reviewer (reviewer '#1), the authors would like to point out that we believe there was a slight misunderstanding with regards to the validity of the method used (retrieval of backscatter), which negatively biased the review criteria mark of reviewer 1 and possibly reviewer 2.

We have made substantial improvements to the manuscript that will hopefully help to show that the method to retrieve backscatter is different to pulsed lidars and ceilometer, but no less valid. For more details, please see response to comments of reviewer #1.

We furthermore made improvements to readability of the manuscript by changing the scaling of backscatter value in the graphs as requested by the reviewer #1 and by improving the structure of the discussion and result sections.

Changes made to the manuscript are highlighted in yellow.

The manuscript suggests correlation between visibility measurements from in-situ visiometers and backscatter coefficient measurements from a continuous-wave wind Lidar. Datasets from two measurement campaigns are used, one in **Cabauw** (Netherlands) and one in **Pershore** (UK). The study falls into the scope of AMT. Yet, there are important differences between visibility from CW wind lidar and visiometers, arising from the different aerosol properties. Also, calibration of CW wind lidar against a visibility sensor in a similar mean aerosol scene area to the one of its intended use is necessary, creating limitations to future applications.

At L 104-106 when describing the CW wind lidars, it is said that "the return signal is not sensitive to atmospheric extinction, but is practically governed by the backscatter coefficient only. This leaves the backscatter coefficient as the most obvious proxy of visibility of a CW lidar." Thought at L43 it has been mentioned that "by measuring light extinction σ, MOR can be derived". Basically, it looks like the most important parameter is overlooked. Could you give more details on that?

Response:

Yes, this is the "standard" way of doing it. This paper presents an alternative way because cw wind lidar is not sensitive to extinction but only backscatter.

For clarity we added the following phrase on l 82:

The question arises, whether MOR can be retrieved from only one of the two parameters, backscatter coefficient or extinction coefficient.

Added in l 50:

This is also the height at which state of the art visibility sensors, or visiometers, determine MOR, using Eq. 1.

We have added a small calculation that illustrates that a cw wind lidar signal is not sensitive to extinction:

The paragraph now reads:

As opposed to pulsed aerosol lidar described above, CW wind lidar has a lower measurement range. In addition, CW wind lidar operates in the short wave infrared region close to 1550 nm, which is a factor of 1.5 to 3 longer than for typical aerosol lidar and ceilometer systems (Werner et al., 2005; Gasteiger et al., 2011; Navas-Guzmán et al., 2013; Shibata et al., 2018). Compared with pulsed aerosol lidar, at normal working ranges (up to 300 m), the return signal of a CW wind lidar is thus not sensitive to atmospheric extinction, but is practically governed by the backscatter coefficient only. This is illustrated in the following example. Assuming a common visibility of 10 km (slightly hazy), the maximum extinction (i.e. at range 300 m) would only be $e^{-600\,m\,5\times10^{-5}m^{-1}} = 0.97$. This leaves only the backscatter coefficient (henceforth termed backscatter) as the most obvious proxy of visibility of a CW wind lidar.

L538-539 “This can be explained by different aerosol types and size distributions at play for different backscatter coefficients” I find it hard to understand the grammar of this sentence.

Response:

The phrase has been amended as follows:

This non-linearity suggests the lidar ratio is constant over a limited range of backscatter values only, which in turn is consistent with the contribution of different aerosol types and size distributions for different backscatter coefficients at a given location over the course of time (Fenn et al., 1966).

I think that the small agreement between CW Doppler lidar and visibility sensor measurements, mainly for Pershore, should be mentioned in the conclusions and briefly explain the reason of these differences.

Response:

L 509: Deleted following phrase since a reasonable explanation is provided further down from l 509:

While we do not have an explanation for it, it also appears to be related to the site-specific average aerosol type.

Amended and added the following phrase at l 525:

This also implies that the use of polychromatic light yields a backscatter intensity less dependent on the aerosol SD than the highly monochromatic light of a coherent wind lidar.

The result by Tworney and Howell (1965) suggests that the use of monochromatic light contributes to the spread observed in the correlation between backscatter and visibility with a factor of ~2, but it does not explain a systematic offset. The latter is more likely to be caused by a different local aerosol SD to which the backscatter is more sensitive than forward scatter at the angular ranges used in the visibility sensors.

To

This also implies that the use of polychromatic light yields a backscatter intensity less dependent on the aerosol SD than the highly monochromatic light of a coherent wind lidar. The result by Tworney and Howell (1965) suggests that, due to this effect, the spread of backscatter for a given visibility (Figs. 5, 6, 7, and 9) is up to twice as high as it would be for a measurement with polychromatic light. The magnitude of the spread is likely also a function of the variety of aerosol types and hence SD present over the data acquisition period, which increases non-uniqueness of the relation between visibility and backscatter (Fenn 1966). This suggests that, relative to Cabauw, Pershore experienced a higher variety in aerosol type and SD.

In the Conclusions we added (l 598):

For larger ranges of visibility and backscatter coefficients, the correlation was found to be less linear. The method deems, therefore, practical only over a limited parameter range. This implies that the lidar ratio is constant over a limited range of backscatter values only. In addition, the results indicate a spread of backscatter values for a given visibility, with the spread being dependent on the location. The spread corresponds to a nonunique relation between visibility and backscatter. Both the nonlinearity and the nonuniquenes are linked to the contribution of a variety of aerosol types and size distributions for a given backscatter coefficient at a given location over the data acquisition period (Fenn 1966). Related to this, differences in local dominant aerosol type between two locations (even at a given time) lead to differences in lidar ratio between the two sites and thus differences in the transfer function.

Concerning the site specific differences, it should be mentioned that if backscatter from other types of instruments (e.g.ceilometers) was used, the same differences between the two sites would have arisen and also provide an example of correspondingly data. The site specific differences are very important and every site will present different aerosol scene and properties.

Response:

That is a good point that I already have addressed in response to reviewer #1. I haven't put it in the manuscript yet, but I will do.

We added at l609:

Both nonlinearity and nonuniqueness are independent of the setup used to measure backscatter (e.g., CW lidar, pulsed lidar, flash light, Curcio and Knestrick, 1958; Doherty et al., 1999; Werner et al., 2005, p. 172).

Since the study assesses if backscatter from CW wind lidar can be used to retrieve visibility, a conclusion about seasonality observed for backscatter in the two sites (Fig 10), along with the MOR connection to this seasonality, would be really helpful for the reader.

Response:

Not directly related to your request, but still relevant: Following the request of reviewer #1, we have already added in the discussion other paper that found seasonality in aerosol scattering and backscattering using other techniques.

On l 482 we added:

However, depending on the year, the result suggests uncertainties up to a few kilometres if a transfer function for a given month was used to predict visibility for the same month of a different year.

In the conclusions we added:

For the 2-year data set used here, selecting a subset of the data (season, month etc.) did not improve the accuracy of the transfer function, i.e., accuracy of predicting visibility for the corresponding subset of the same year or a different year. Data sets acquired over more than two years may improve the accuracy of the transfer function

Have you checked what happens if you use Ct=2% in eq. (1)? Eg. (8) would change to $4/(\beta(\pi)S(\lambda_1/\lambda_0)^{\alpha})$. Would this have an important effect on the results?

Response:

It wouldn't affect the conclusions, to ideally have secondary measurements of S and $^{\alpha}$. It would increase the lidar derived visibility by 30% , which does not automatically mean it would be 30% higher than the visiometer readings, since the misfit varies along the x-axis, plus S and $^{\alpha}$ where not found by fitting the visometer reading, which means the fit might actually improve at places, but overall the visometer readings would be overestimated by probably at least 10%. The overestimated lidar visibilities could be "corrected" by increasing S and/or $^{\alpha}$, so:

by a) increasing the lidar ratio by up to 10% or more, or

b) the Angstrom exponent by up to ~13%, or

c) a combination of both, obviously with lower factor of increase

Options a) and b) would lead to parameters a bit high, but not impossible (Doherty et al., 1999, see Bibliography in manuscript), c) would entail lidar ratio and Angstrom coefficient to be fully within average values at Cabauw.

We have added more information on lidar ratio and Angstrom exponents at Cabauw and how to get them in the manuscript:

Although the Ångström exponent does vary over short periods of time (hours to days), it does so in a confided manner. For certain sites, including Cabauw, Ångström exponents are available from the aerosol optical depth (AOD) product from the Aerosol Robotic Network (AERONET, https://aeronet.gsfc.nasa.gov/new_web/data_description_AOD_V2.html, last accessed 28/07/2022). For a few sites, lidar ratios are measured within the Portable Raman Lidar Network (PollyNet, Baars et al., 2016). For Cabauw, although none of these are available for autumn and winter 2018 from both networks, the Ångström exponent retrieved within AERONET at Cabauw varies usually between 0.1 and 2.0 over the course of any given day and is bounded by these limits over the course of a year. This makes $S = 70$ sr, $\alpha = 2$ more likely than $S = 28$ sr, $\alpha = 2.6$. Figure S1 shows an example where time series of Ångström exponent at Cabauw from the AERONET (O'Neil et al., 2001) were used to improve the agreement with the visiometer especially for lower visibilities, while the agreement for the higher visibilities reduced, since a constant lidar ratio data was assumed.

Also, lidar ratio S is considered constant, but as also described in the manuscript, presents strong variability depending on the aerosol type. This should also be mentioned in the conclusions (L 537-544) along with the "less linear correlation".

Response:

This has been added now in the conclusions as follows:

In the Conclusions we added (l 598):

For larger ranges of visibility and backscatter coefficients, the correlation was found to be less linear. The method deems, therefore, practical only over a limited parameter range. This implies that the lidar ratio is constant over a limited range of backscatter values only.

Other changes made by the authors:

Removed the following phrase from l543, as it is redundant:

More long-term tests are needed to assess to which extend the calibration needs to be repeated or if it needs to be repeated if the location is kept fixed.

L546:

Added:

Furthermore, a landfill, located ~800 m to the southwest of the lidar location, could also produce enhancements in Diesel aerosol from the operated machinery and aerosols common to landfills (Nair 2021).

Added reference:

Nair AT. Bioaerosols in the landfill environment: an overview of microbial diversity and potential health hazards. Aerobiologia (Bologna). 2021;37(2):185-203. doi: 10.1007/s10453-021-09693-9. Epub 2021 Feb 4. PMID: 33558785; PMCID: PMC7860158.

L615:

Changed the phrase:

Going forward, it might be useful to confirm or refine this conclusion by measuring at more sites globally and categorize them into sites with similar predominant mean aerosol SD. Obtaining visibility data from more sites is desirable to test how site specific the transfer function is and how comparable it is between similar environmental settings.

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Going forward, it might be useful to acquire transfer functions at more sites globally and categorize them into sites with similar predominant mean aerosol size distributions. Obtaining visibility data from more sites is desirable to test how site specific the transfer function is and how comparable it is between similar environmental settings.