Response to RC1

General comments:

The authors present a technical study to retrieve conversion factors for the well-established POLIPHON (Polarization Lidar Photometer Networking) method at sites that are not as close to deserts to experience pure dust outbreaks, though, are still affected by mineral dust mixed with anthropogenic pollution aerosol (i.e. mixed dust). The presented method uses column-integrated sun photometer data which would not fulfill the usual criteria for the retrieval of pure dust conversion factors (based on Ångström exponent and AOD). Instead, to additionally confirm the presence of (mixed) dust, ground-based and, for a case study, space-based polarization lidar observations were used together with auxiliary tools like backward trajectories and the GRASP algorithm.

As the authors rightly state, the POLIPHON method is a powerful tool to comparably easy (via remote sensing) assess and potentially quantify dust/aerosol effects on cloud formation and glaciation and therefore, weather and climate. Nevertheless, the method is only as good as its input parameters and various ongoing validation efforts. This study provides a useful although error-prone method to retrieve further needed input parameters (conversion factors) and therefore, can be recommended for publication in AMT after revisions especially focusing on a discussion of these errors/uncertainties.

Response: We appreciate the reviewer's thoughtful review and constructive comments. All of the comments have been addressed in the revised manuscript, and the responses to the individual comments are given below. It should also be mentioned that $c_{250,d}$ value has been modified after correction to a programming mistake.

Specific Comments

Comments: The usage of the GRASP algorithm does not substantially support the presented method. It could also be omitted or more clearly stated as auxiliary in the single case study.

Response: Thank you for pointing out this issue. Indeed, the usage of the GRASP algorithm does not substantially support the presented method and it is just an auxiliary applied for deriving the particle size distribution from sun-photometer-measured spectral AODs. This is only a step between dust-case data-set selection and dust-related conversion factors obtainment. For clarity, we have added a methodological diagram and the following statements in section 3 to show that auxiliary function is provided by the GRASP algorithm (please see line 159-161 and figure 2).

'…The methodological diagram is given in Fig. 2. The related data or algorithms applied for each step are showed. In particular, it should be emphasized that GRASP algorithm is only used in the step of deriving the particle size distribution from spectral AODs.'

Comments: The main argumentation in this study, why one could also use cases of mixed dust to retrieve the POLIPHON dust conversion factors, is that Chen et al. (2018)

did not find a significant impact of urban pollution on ice nucleation in the immersion mode. This does not necessarily mean that the optical properties of pollution do not have an impact in the retrieval of the conversion factors.

I understand that you took the “most dusty” cases you could find at your site for your retrieval. Nevertheless, I suggest to add a more comprehensive analysis of your sun photometer data by also calculating the conversion factors for continental aerosol at your site as described in Mamouri and Ansmann (2016) ($c_{290,c}$). This provides the opportunity to compare your “dusty” conversion factors with the continental ones and to discuss the possible effect of the continental aerosol/pollution on your retrieval.

Response: For the first issue, to state the motivation of this paper more clearly, we have modified the following sentence in the introduction (please see line 72-76).

‘**Urban air pollution generally cannot affect the atmospheric INPC (Chen et al., 2018); however, their optical properties may have an impact on the retrievals of the dust-related conversion factors, and then the INPC for mixed dust situations in a megacity influenced by long-range transported dust plumes (Córdoba-Jabonero et al., 2018; Mamouri and Ansmann, 2017; Wang et al., 2021).**’

For the second issue, we have obtained the conversion factor $c_{290,c}$ (0.11±0.02 Mm cm^{-3}) for continental aerosols (Ångström exponent >1.6), which has been added in the updated figure 6. The related analysis and discussions have also been added. Moreover, when calculating the $c_{290,c}$, we found a programming mistake that APC_{280} was used for the original $c_{250,d}$ calculation rather the APC_{250} (as seen in Mamouri and Ansmann, (2015)), leading to an underestimate of $c_{250,d}$ (0.11 Mm cm^{-3}) in our original manuscript. As a result, the $c_{250,d}$ value has been replaced by 0.19±0.05 Mm cm^{-3} in the revised manuscript. We are sorry for the carelessness. Considering this modification, some results and discussions as well as Fig. 12c have also been revised as follow (please see line 20-26, 264-289, 352-353, 360, 394).

‘…As seen in Fig. 6, a good correlation between $n_{250,d}$ and α_d was found with a linear Pearson correlation coefficient of 0.976 for the period of 2011-2013. Each green point represents a pair of daily averaged values for the dust-occurring period of a dust-intrusion day (taking the day of 28 April 2011 shown above as an example). Note that these points represent the same dataset (i.e., the same 33 dust-intrusion days) as those green points in Figure 5. The $c_{250,d}$ value was 0.19±0.05 Mm cm^{-3} as computed by the equation below:

$$c_{250,d} = \frac{1}{J_d}\sum_{j=1}^{J_d}\frac{n_{250,d,j}}{\alpha_{d,j}} \qquad \textbf{(11)}$$

The standard deviation of 0.05 Mm cm^{-3} is similar to those obtained from other AERONET sites (0.02-0.05 Mm cm^{-3}) by Ansmann et al. (2019b). The $c_{250,d}$ value of 0.19 Mm cm^{-3} is approximately 27% larger than the value of 0.15 Mm cm^{-3} obtained at Lanzhou SACOL (36.0°N, 104.1°E) AERONET site as well as at Dalanzadgad, Mongolia (see Fig. 1), which are very close to the source region of Asian dust (Ansmann et al., 2019b). Mamouri and Ansmann (2015) mentioned that this dust-related conversion factor can almost be invariable from dust source (Morocco and Cape Verde) to downwind regions (Barbados). Therefore, this discrepancy indicates that Wuhan may not be only influenced by Asian dust. Note that the conversion factor 0.19 Mm cm^{-3} is more like the values of 0.16-0.20 Mm cm^{-3} for the North Africa (Saharan dust) and Middle East, suggesting that dust aerosols from these two sources are also possibly involved in the dust events observed over Wuhan. This

conjecture can be verified to some extent since the dust plumes over Wuhan can often be traced back to these two sources by HYSPLIT model simulation (He et al., 2021a). Kojima et al., (2006) confirmed that dust particles that have not undergone substantial aging or a cloud-processing event can be present thousands of kilometers from source regions. Furthermore, to analyze the potential impact of local emissions on $c_{250,d}$, the conversion factor for continental aerosols $c_{290,c}$ was also calculated for the period during 2008-2013 as seen from the purple points in Fig. 6 (Mamouri and Ansmann, 2016). The $c_{290,c}$ value of 0.11±0.02 Mm cm^{-3} for Wuhan is similar to those of around 0.10 Mm cm^{-3} for the two city sites, Limassol, Cyprus (34.7°N, 33.0°E) and Leipzig, Germany (51.4°N, 12.4°E) (Mamouri and Ansmann, 2016), meaning that this value depicts a typical conversion factor for the urban aerosol situations. Similar to the results in Limassol and Leipzig (Fig. 7b in (Mamouri and Ansmann, 2016)), $c_{250,d}$ is almost twice larger than $c_{290,c}$ in Wuhan, indicating lesser large particles are included in the local pollutions. This comparison suggests that there is no significant influence of urban aerosols on the retrievals of dust-related conversion factor $c_{250,d}$ in Wuhan, at least for the 'most dusty' cases which we selected for $c_{250,d}$ calculation in this study.'

Reference:

Ansmann, A., Mamouri, R.-E., Hofer, J., Baars, H., Althausen, D., and Abdullaev, S. F.: Dust mass, cloud condensation nu-clei, and ice-nucleating particle profiling with polarization lidar: updated POLIPHON conversion factors from global AERONET analysis, Atmos. Meas. Tech., 12, 4849-4865. doi.org/10.5149/amt-12-4849-2019, 2019.

Córdoba-Jabonero, C., Sicard, M., Ansmann, A., del Águila, A., and Baars, H.: Separation of the optical and mass features of particle components in different aerosol mixtures by using POLIPHON retrievals in synergy with continuous polarized Micro-Pulse Lidar (P-MPL) measurements, Atmos. Meas. Tech., 11, 4775-4795. doi.org/10.5194/amt-11-4775-2018, 2018.

Kojima, T., Buseck, P., Iwasaka, Y., Matsuki, A., and Trochkine, D.: Sulfate-coated dust particles in the free troposphere over Japan, Atmos. Res., 82, 3-4, 698-708, doi.org/10.1016/j.atmosres.2006.02.024, 2006.

Mamouri, R. E. and Ansmann, A.: Potential of polarization/Raman lidar to separate fine dust, coarse dust, maritime, and anthropogenic aerosol profiles, Atmos. Meas. Tech., 10, 3403-3427. doi.org/10.5194/amt-10-3403-2017, 2017.

Mamouri, R. E. and Ansmann, A.: Potential of polarization lidar to provide profiles of CCN- and INP-relevant aerosol parameters, Atmos. Chem. Phys., 16, 5905-5931. doi.org/10.5194/acp-16-5905-2016, 2016.

Wang, T., Han, Y., Hua, W., Tang, J., Huang, J., Zhou, T., Huang, Z., Bi, J., and Xie, H.: Profiling dust mass concentration in Northwest China using a joint lidar and sun-photometer setting, Remote Sens., 13, 1099. doi.org/10.3390/rs13061099, 2021.

Comments: Similarly, you need to provide uncertainty ranges (standard deviations) for the retrieved conversion factors as in Mamouri and Ansmann (2016). These need to be compared and discussed in detail as well. In addition, you state that your sun photometer has a substandard precision in compared to AERONET. How does this influence your retrievals with respect to the uncertainties?

Response: The standard deviations for the retrieved conversion factors and related comparison and discussion have been added in the revised manuscript (please see line 20-21, 24, 267-271, 299, 305-208 and 381-385). The updated conversion factors are $c_{250,d} = 0.19 \pm 0.05\ \mathrm{Mm\ cm^{-3}}$ and $c_{v,d} = (0.52 \pm 0.12) \times 10^{-12}\ \mathrm{Mm\ m^3 m^{-3}}$.

Our AOD measuring errors are given under the optical air mass of 1.0 (Zhang et al., 2021), which is corresponding to the summer solstice in the Northern Hemisphere. Considering the 33 dust-intrusion days are selected from spring and winter, those AOD errors should be divided by a factor of 1.6 and 2.4, respectively. Therefore, the AOD errors for our sun photometer should be similar as those for AERONET instruments. Torres et al. (2017) analyzed the influence of AOD errors on the aerosol size distributions (in subsection 3.4 therein). The tests with random simulated errors showed that the uncertainties in the GRASP bimodal log-normal size distribution parameters increase as the aerosol loads decreases. Considering the averaging AOD_{440} value of 0.92 for the 33 days selected in our study, we use the uncertainties in bimodal log-normal size distribution parameters from the coarse-mode aerosol prevailing case cluster with AOD_{440}=0.9 (i.e., 'SOLV3' in Table 2 and 7 therein) to estimate the uncertainty involved in APC_{250} and total volume concentration. The same AOD errors for each wavelength as AERONET instruments were introduced. Taking the simulated uncertainties of GRASP bimodal log-normal size distribution parameters into account, the uncertainties in APC_{250} and total volume concentration caused by AOD errors are estimated to be <3.2% and ~0%. The uncertainty in AOD_{500} is ~2%. Torres and Fuertes (2021) compared the aerosol size properties derived by GRASP-AOD application with those obtained by AERONET retrieval algorithm. When AOD_{440} >0.4, the uncertainty in total volume concentration was estimated to be 23%. Mamouri and Ansmann (2015) mentioned that the uncertainty in AERONET algorithm derived APC_{250} is 10-15%. Propagating all the uncertainties above into the conversion factors obtained in this study, the final uncertainties in $C_{250,d}$ and $C_{v,d}$ are conservatively estimated to be both <28%. The related statements have been added in the revised manuscript (please see line 110-114 and 308-320).

Reference:

Mamouri, R. E. and Ansmann, A.: Estimated desert-dust ice nuclei profiles from polarization lidar: methodology and case studies, Atmos. Chem. Phys., 15, 3463-3477. doi.org/10.5194/acp-15-3463-2015, 2015.

Torres, B., Dubovik, O., Fuertes, D., Schuster, G., Cachorro, V. E., Lapyonok, T., Goloub, P., Blarel, L., Barreto, A., Mallet, M., Toledano, C., and Tanré, D.: Advanced characterisation of aerosol size properties from measurements of spectral optical depth using the GRASP algorithm, Atmos. Meas. Tech., 10, 3743-3781. doi.org/10.5194/amt-10-3743-2017, 2017.

Torres, B. and Fuertes, D.: Characterization of aerosol size properties from measurements of spectral optical depth: a global validation of the GRASP-AOD code using long-term AERONET data, Atmos. Meas. Tech., 14, 4471-4506, doi.org/10.5194/amt-14-4471-2021, 2021.

Zhang, Y., Zhang, Y., Yu, C., and Yi, F.: Evolution of aerosols in the atmospheric boundary layer and elevated layers during a severe, persistent haze episode in a central China megacity, Atmosphere, 12, 152. doi.org/10.3390/atmos12020152, 2021.

Comments: Furthermore, it has to be made clearer in the whole manuscript that these parameterizations (DeMott et al. 2010, 2015) are for immersion mode INP, than just the one sentence stating the Ullrich et al. (2017) parameterization is valid for deposition nucleation. This is important as Ullrich et al. (2017) indeed provide a deposition nucleation parameterization also for soot aerosol.
Response: Thank you very much for pointing out this issue. Considering most dust layers over Wuhan appear at relatively low altitudes with warmer condition, we only considered the immersion nucleation in this study. Indeed, as the reviewer mentioned, U17 is an important parameterization, especially for the deposition freezing regimes as well as the soot-aerosol-related parameterization scheme. For clarity, we have added the following statements about the U17 and have also emphasized that we obtained the dust-related immersion-mode INP concentration in abstract, section 4, and section 5. (please see line 26, 211-216, 351, and 391).

'Note that these two parameterizations (D10 and D15) are used for immersion freezing. Ullrich et al. (2017) developed another important parameterization for heterogeneous ice nucleation that quantifies the INPC as a function of ice nucleation active surface site density (related to temperature and ice saturation ratio). This parameterization included both desert dust and soot aerosol and was applicable for both immersion nucleation and deposition nucleation. Most dust layers over Wuhan appear at relatively low altitudes with warmer meteorological conditions; hence, immersion nucleation takes place more generally. Therefore, we only applied D10 and D15 parameterizations in this study.'

Comments: Some textual suggestions in the attached PDF.
Response: The related texts have been revised according to your suggestions.