Reply to the Referees’ comments

Referee #2 comments:

We thank the referee for the useful comments, which helped us to improve the quality of our manuscript.

In the following, the referees’ comments are given in black.

Our point-to-point replies are marked by “R” and are in blue.

Changes to the manuscript text are in green.

Referee #2 comments:

General remarks:

An intense Saharan dust outbreak was observed with two lidar systems and a sun photometer. The observations are compared to model prediction by ICON-ART model. Arrival time and dust layer heights agreed for the first dust plume, for the second dust plume at higher altitudes the agreement is less good. The backscatter coefficient was overestimated by the model, the AOD underestimated. A lot of work was put into the lidar analysis for one vertical pointing and one slanted (30°) and vertical pointing lidar system. The structure and the language needs improvements.

Comparing a single dust event with the model predictions of a single model is surely a lot of effort, but it is not state of the art anymore. Therefore, major revisions are necessary before publication.I would consider a single dust event evaluated with different dust transport models more interesting for the community. Doing so, the strengths and weaknesses of the models could be pointed out. At least two or three more dust transport models should be compared.

Or evaluate multiple dust events with the same model to get some statistics when the model predictions are in line with the observations and when not and to look for the reasons. One event evaluated with one model is surely not enough for a publication in 2021.

Already much more complex publications concerning the comparison of ground-based remote sensing (lidar) and dust transport models are present in literature, e.g. for a dust plume across the Atlantic Ocean (e.g., Kanitz et al., 2014), extreme dust events (e.g., Solomos et al., 2017), year-long statistics (e.g., Mona et al., 2014), multi-station statistics (e.g., Soupiona et al., 2020) and fine and coarse dust mass concentrations (e.g., Ansmann et al., 2017). It seems that the present study was performed without the knowledge of the progress made in the past decade.

The list of dust transport models mentioned in the introduction is not complete and should be updated. NMMB/BSC-Dust and SKIRON came immediately into my mind, but certainly there are more.

R: We are aware of previous comparisons of dust transport models and ground-based observations but it is not the aim of this work to provide a systematic evaluation of models. Our objective is to highlight the potential of multiple angle lidar measurement data in detailed validation of model outputs beyond optical depth and concentration. To do so, we need to know the underlying assumption and parameterization in the model system like dust optical properties. Such information are not simply provided alongside the forecast data. Instead, one need to work closely with the model developers closely to make sure that the comparisons are consistent and robust.
Currently 12 models are compared in an operational way through the WMO SDS-WAS (Sand and Dust Storm Warning Advisory and Assessment System) project. We added the reference to WMO SDS-WAS in the introduction. In additional, we have added some literature related to our work in introduction section to make our manuscript more complete. The added text is follows:

“Various studies characterized Saharan dust either near the sources as well as during and after long range transport. Freudenthaler et al. (2009) reported pure Saharan dust depolarization ratio profiling at several wavelengths during the Saharan

Mineral Dust Experiment (SAMUM) 2006. Kanitz et al. (2014) observed Saharan dust with shipborne lidar from 60° to 20°W along 14.5°N. Soupiona et al. (2020) studied dust properties and its impact on radiative forcing over the northern Mediterranean region based on EARLINET observations. The three-dimensional evolution of Saharan dust transport toward Europe was studied based on a 9-year EARLINET-optimized CALIPSO dataset (Marinou et al., 2017). The Copernicus Atmosphere Monitoring Service (CAMS) forecast systems simulated the aerosol transport events over the Europe during the 2017 storm Ophelia and validated these results with passive (MODIS: Moderate Resolution Imaging Spectroradiometer aboard Terra and Aqua) and active (CALIOP/CALIPSO: Cloud-Aerosol LIdar with Orthogonal Polarization aboard Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations) satellite sensors as well as ground-based measurements (EMEP: European Monitoring and Evaluation Programme). Osborne et al. (2019) compared model simulations with ground based remote sensing measurements (lidar and sunphotometer network). A comparison of dust observations by lidar and BSC-DREAM8b model results was studied by Mona et al. (2014). "

Literature is full of comparisons of models with observations. A more careful literature research is definitely necessary to place your observations in a broader context and to clearly state the novelty of your study.

R. We agree that there are various reports on different dust events in the literature. Many of them analysed the dust plumes also with advanced lidar systems e.g. employing multiple wavelengths and combinations of different remote sensing instruments. Furthermore, there are several attempts to improve, compare, and validate models predicting dust plume generation and transport. In contrast to these studies, we wanted to show potential advantages of multiple angle lidar measurements in terms of characterising dust particles especially concerning optical properties and for independently determining the lidar ratios. Furthermore, we wanted to use our observational data to compare the results with the ICON-ART model outcome. We wanted to investigate which parameters can be compared also to optimize our observations for future more systematic field measurements then allowing for evaluating multiple dust events with the same model. Therefore, our study is focused on the scanning lidar contributions to improve dust plume observations and a first comparison with the ICON-ART model. We think that the manuscript contains valuable results on the scanning lidar contributions to characterize dust plumes as well as the potential of the ICON-ART model for prediction of Saharan dust plumes which reward publication. We have added corresponding references to the introduction to clarify the objectives of this study compared to previous ones.

Major comments:

1. The range limitations of KASCAL (Fig. 1) were not discussed. No data were reported above 6 km. Why?

   R: For this study, the scanning lidar was measuring alternating at two different observation elevation angles of 90° & 30° leading to shorter integration times compared to the continuously vertically pointing lidar. Due to the shorter integration time of 600 s and the existence of clouds for some periods, the quality of the KASCAL data is relatively low for the 6-8 km altitude range. However, in order to show these contour figures consistently, we replot this figure and show the data below 8 km for all measurements and model calculations. The modified figure 1 is shown below:

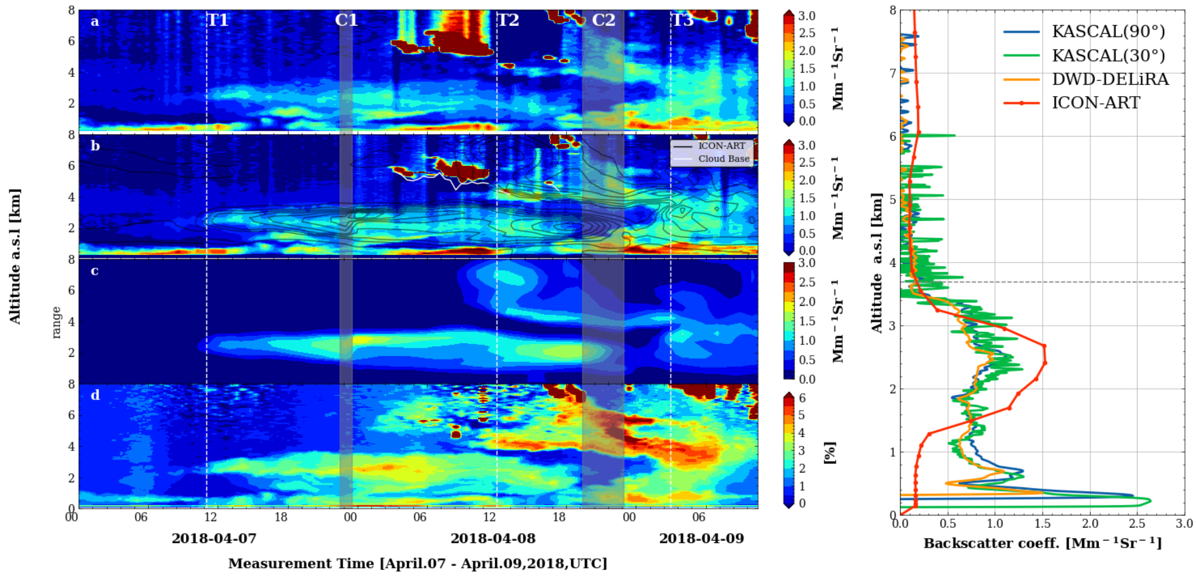

Figure 1: Time series of backscatter coefficients from KASCAL measurements (a) and from DWD-DELiRA measurements with ICON-ART results shown as black contour lines (b) as well as ICON-ART backscatter coefficients (c) and linear volume depolarization ratios from KASCAL measurements (d) from April 7th to 9th, 2018. Please note that the model data only includes the Saharan dust while the lidar data shows also other aerosol particles and clouds. The profiles of backscatter coefficients measured by the two lidars from 22:30 to 23:30 and predicted by ICON-ART for 23:00 on April 7th, 2018 (indicated as C1 in the contour plots) are shown on the right side of this figure. The vertical dashed lines in the contour plots indicate dust arrival (T1), second dust layer appeared (T2), and the two dust layers merged (T3). C1 and C2 represent time periods used for a more detailed data analysis.

2. Section 3, lines 149-180: The backscatter coefficient itself does not tell you, which layer is dust and which not. Throughout the section, you are writing “dust”. At this point, you haven’t shown the depolarization ratio yet to demonstrate, that your measured backscatter coefficient is really dust.

   R: We agree that the backscatter coefficients alone do not tell us which layer is dust. Therefore, we have reformulated the beginning of section 3 as follows and added the particle depolarization to figure 1.

   “The corresponding backscatter coefficients from the scanning lidar (a), the vertical pointing lidar (b), and the ICON-ART model simulation (c) together with the linear depolarization values of the KASCAL (d) for April 7th to April 9th, 2018 are shown in the Fig. 1”

3. Line 171: This statement is true for the first dust layer arriving on 7 April 2018. However, the second dust layer arriving in the evening of 9 April 2018 at around 5-6 km height was predicted by the model around 12 hours too early.

   R: The detection of the dust layer predicted to arrive around 11:00 on April 9th, 2018 at an altitude of 5-7 km was impeded by the presence of clouds as indicated by the cloud base in the middle panel of Fig. 1. As shown in Fig. S4, we could detect the dust plume arriving at the same time as predicted but only below the clouds. However, we have to admit that this is obviously not an ideal example. The Fig.S2 has changed into Fig. S4 in the revised supplement.

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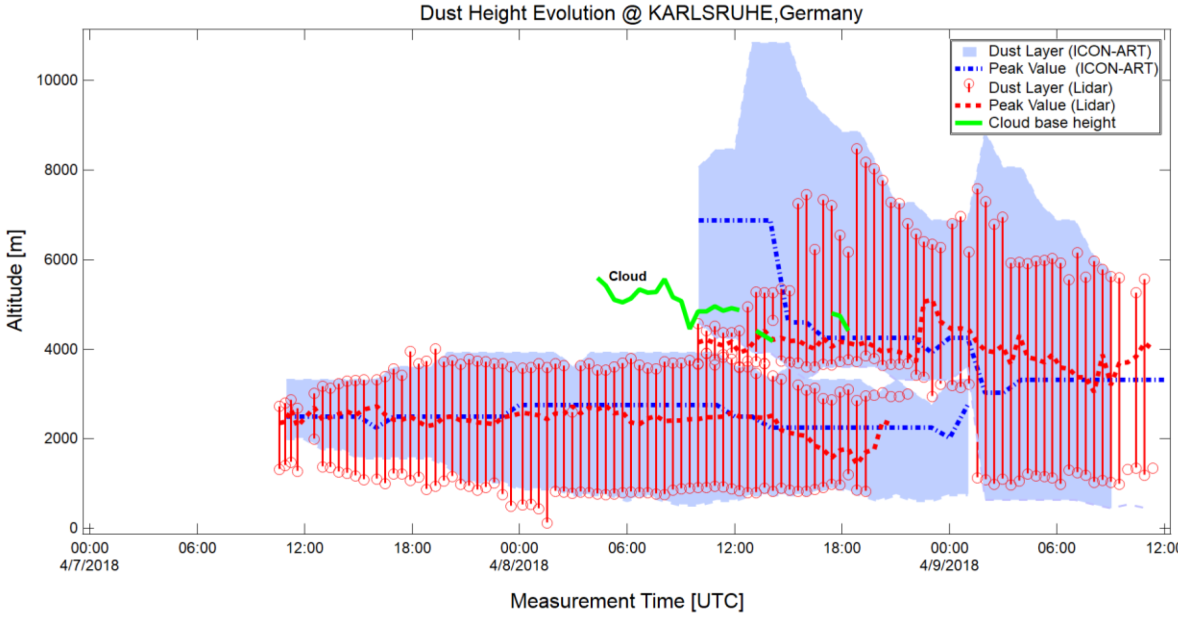

Figure S4 Time series of dust layer heights and peak heights (the heights for the maximum backscatter coefficients) for both lidar measurements and ICON-ART prediction as well as cloud base heights (green line) measured by lidar from 7th to 9th, April 2018.

4. Lines 176-177: How do you calculate the overestimation of the backscatter coefficient? Please provide more detail on how you get to that value.

   R: First, we interpolate the ICON-ART backscatter coefficients to the same temporal and spatial resolution as lidar data and select the data within dust attitude range. Then we divide the backscatter coefficients from the ICON-ART model by those from the lidar. Finally, we calculate the mean value and standard deviation of the quotients. We have modified the sentence in the revised manuscript as follows:

   "For this study, the altitude dependent backscatter coefficients and column AODs were used to compare ICON-ART calculations to the results from lidar and sun photometer measurements based on the three lognormal dust size distributions in ICON-ART and the mass backscatter cross sections, mass extinction cross sections provided by Meng et al. (2010)."

5. Line 211: Why do you chose lidar ratios of 30 and 50 sr? You measured different ones, reported some lines earlier.

   R: We agree that we should use the lidar ratios that we have determined. We have changed this in the text and in Fig. 3.

   "The lidar ratio for the dust particles is 46 ± 5 sr and for the boundary layer aerosol particles it is 31 ± 3 sr as average of both vertical and slant measurements. We parameterized these lidar ratios being 46 sr and 31 sr, respectively, as a function of altitude with a single step at 2 km and then used it as lidar ratio for the elastic lidar signal retrieval."

6. Line 238: Why do you use an AE of 1? You have measurements of the actual AE.

   R: Indeed, we should use the measured values. We have now used the mean value of the AE from the sun photometer data at wavelengths of 340 nm & 380 nm. We have included the new values in the revised text: "However, the average AOD retrieved from the lidar data for two days is systematically lower by 0.041 ± 0.022 than that from the sun photometer after wavelength conversion to 340 nm. The AE used in this wavelength conversion is 0.471, which is calculated from the sun photometer data at wavelengths of 340 nm and 380 nm. The average stratospheric AOD of for the years 2018-2019 in Northern Hemisphere was 0.01 at 340 nm (Kloss et al., 2020). Hence, the averaged AOD measured by the sun photometer is still larger by 0.031 ± 0.022 than the AOD from the lidar measurement even considering the stratospheric AOD. This bias may due to an inappropriate assumption of constant backscatter coefficients in the overlap region of the lidar. Such an uncertainty of AOD corresponds to an uncertainty in backscatter coefficients of 4.1 ± 2.9 Mm^{-1} sr^{-1} in the overlap region"

7. The discussion about the single scattering albedo (SSA) and its comparison to literature values could be omitted. You use

the standard AERONET output and compare it to literature values. We do not gain additional information out of it.

R: We agree that this is mainly complementing the characterisation of the dust particles, moved the table S2 to the supplement, and shortened the text as follows:

"The single scattering albedos (SSA) determined for the wavelengths between 439 and 1018 nm range between 0.88 and 0.96 and agree quite well with data from previous observations (cf. table S2). "

8. Please state at some point, that you are referring to linear depolarization ratio (in contrast to the circular depolarization ratio).

   R: This is stated it in the abstract and at the beginning of the results section now.

   "The corresponding backscatter coefficients from the scanning lidar (a), the vertical pointing lidar (b), and the ICON-ART model simulation (c) together with the linear depolarization values of the KASCAL (d) for April 7th to April 9th, 2018 are shown in the Fig. 1."

9. Your conclusions (lines 282-284) are just qualitative. Please consider some more quantification of the model performance. Therefore, you would need more observations for comparison. Or you would need different models for the same dust event to compare the different model outputs and quantify the agreement.

   R: We agree that more observations also including different meteorological situations would be support a thorough and statistically sound evaluation of the model performance. However, as pointed out above this was not the aim of this study as model comparisons are performed in dedicated projects like a the Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS) which is a program of the World Meteorological Organization (WMO). Nonetheless, this limited analysis is useful to demonstrate how useful scanning lidar measurements are for aerosol characterisation and potential model validation. Furthermore, we have learned that improvements regarding calculation of the aerosol optical properties by the model are required. We have modified the conclusions including the fact that our findings are based on a single event only.

   "The comparison shows that dust plume arrival time, layer height and structure, and backscatter coefficients are consistent between lidar measurement and model simulation for this event. Although, the lidar data shows more details of the dust plume structures, the agreement with the model is quite good considering the relatively coarse spatial resolution used in this model run."

10. If the model could not even reproduce the columnar values such as the AOD (lines 291-297), I am not so confident, that the model compares so well as you stated. To reproduce the arrival time, simply the meteorological fields are correctly predicted. However, if the optical properties such as backscatter coefficient, AOD and AE (see Fig. 7) are not agreeing, the model is probably not the best choice for dust predictions. Here, a comparison to various dust transport models would be nice.

    R: In Fig. 4 and Fig. 7, the total mode AOD of the sun photometer is compared with the ICON-ART model calculation. Hence, the predicted AODs are expected to be underestimated due to the boundary layer aerosol. Fig. S6 shows the comparison between coarse mode AOD and simulated AOD, which show that the predicted AODs agree well with coarse mode AOD of the sun photometer at a wavelength of 550 nm. As for backscatter coefficients, the main reason for an overestimation is the assumption of spherical particles. In the revised manuscript, we used parameters for non-spherical particles provided by Meng et al. (2010) to calculate ICON-ART backscatter coefficients and the result is shown Fig.1 of the revised manuscript. After using parameters for non-spherical particles, the predicted backscatter coefficients are generally larger by only a factor of 1.01 ± 0.56 than lidar measurements at wavelength of 355 nm for this case. Hence, the model results shows a good agreement with remote sensing measurement after our revision. In addition, several studies have confirmed the profound ability of the ICON-ART model in dust forecasting on various scales (Gasch et al., 2017; Rieger et al. 2017; Hoshyaripour et al. 2019) using several AERONET stations and satellite data obtained during different events. Another evidence is the comparison of various dust transport models including ICON-ART performed by the

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WMO Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS) (https://sds-was.aemet.es/forecast-products/dust-forecasts/forecast-comparison, last access September 22, 2021). Among these models, ICON-ART forecast agrees very well with the multi-model median of AOD and surface concertation. Our model shows a relatively good performance in these comparisons but we admit that there is still room for improvements especially regarding processes and parameterizations. We have added the following text into section 3.2 to discuss this comparison.

"In order to consider effects of particle shape on dust optical properties in ICON-ART (Hoshyaripour et al. (2019)), parameterisations provided by Meng et al. (2010) are used. Fig. S6 shows the backscatter coefficients of two lidar measurements and two model calculations using spherical (SPH) and non-spherical (NSP) particle parameterisations, respectively. This figure shows that the ICON-ART model would overestimate backscatter coefficients by a factor 2.6 ± 1.1 at wavelength of 355nm if assuming spherical particles to calculate backscatter coefficients. The reason for backscatter coefficients are so much overestimated for SPH particles is that the spherical particles have larger backscatter coefficients (at 180°) than non-spherical particles as shown in Fig.2 of Hoshyaripour et al. (2019). The physical meaning behind this phenomenon is that for spherical particles surface waves can contribute to the backscatter, hence causing larger backscatter coefficients for spherical particles (Hovenac and Lock, 1992). The vertical profiles of backscatter coefficient from two lidar measurements and two ICON-ART modes are shown in Fig. S7 for two selected periods as indicated C1 and C2 in Fig. 1. Comparing Fig. S6 and Fig.S7, we found that ICON-ART can predict dust layer structures quite well for most of the time of this event but also shows substantial differences with lidar measurements figure e.g. for the time period C2 (cf. Figure S7 right). The coarse mode AOD of the sun photometer and ICON-ART results for spherical and non-spherical particle models are shown in Fig. S5. All AOD values follow a similar trend but the model results are higher by a factor of 1.25 ± 0.21 for NSP particles and 1.14 ± 0.18 for SPH particles at a wavelength of 550 nm."

The Figures S6, S7, and S8 from the supplement are shown below:

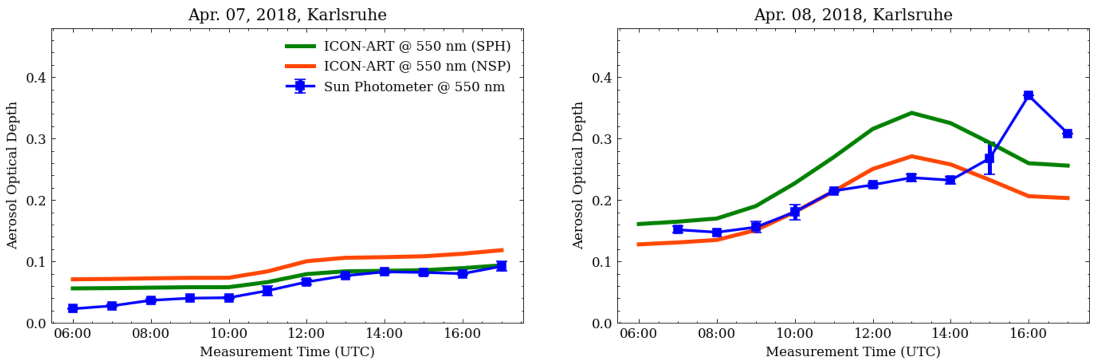

Figure S5: AOD from the sun photometer (coarse mode) and ICON-ART for both SPH and NSP particles model simulation on 7th and 8th of April for 1hour temporal resolution. SPH = spherical; NSP = non-spherical.

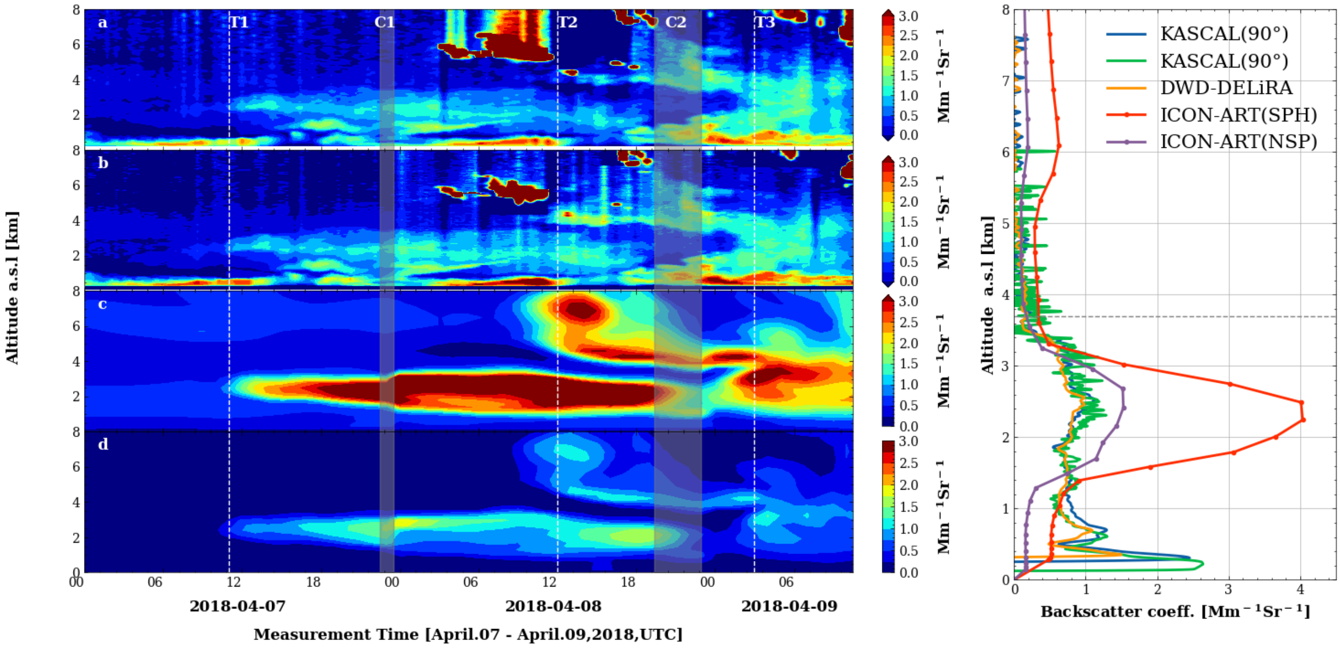

Figure S6: Time series of backscatter coefficients from KASCAL measurements (a) and from DWD-DELiRA measurements with ICON-ART results shown as black contour lines (b) as well as ICON-ART results for SPH particles (c) and as ICON-ART results for NSP particles from April 7th to 9th, 2018. Please note that the model data only includes the Saharan dust while the lidar data shows also other aerosol particles and clouds. The profiles of backscatter coefficients measured by the two lidars from 22:30 to 23:30 and predicted by ICON-ART for 23:00 on April 7th, 2018 (indicated as C1 in the contour plots) are shown on the right side of this figure. The vertical dashed lines in the contour plots indicate dust arrival (T1), second dust layer appeared (T2), and the two dust layers merged (T3). C1 and C2 represent time periods used for a more detailed data analysis. SPH = spherical; NSP = non-spherical.

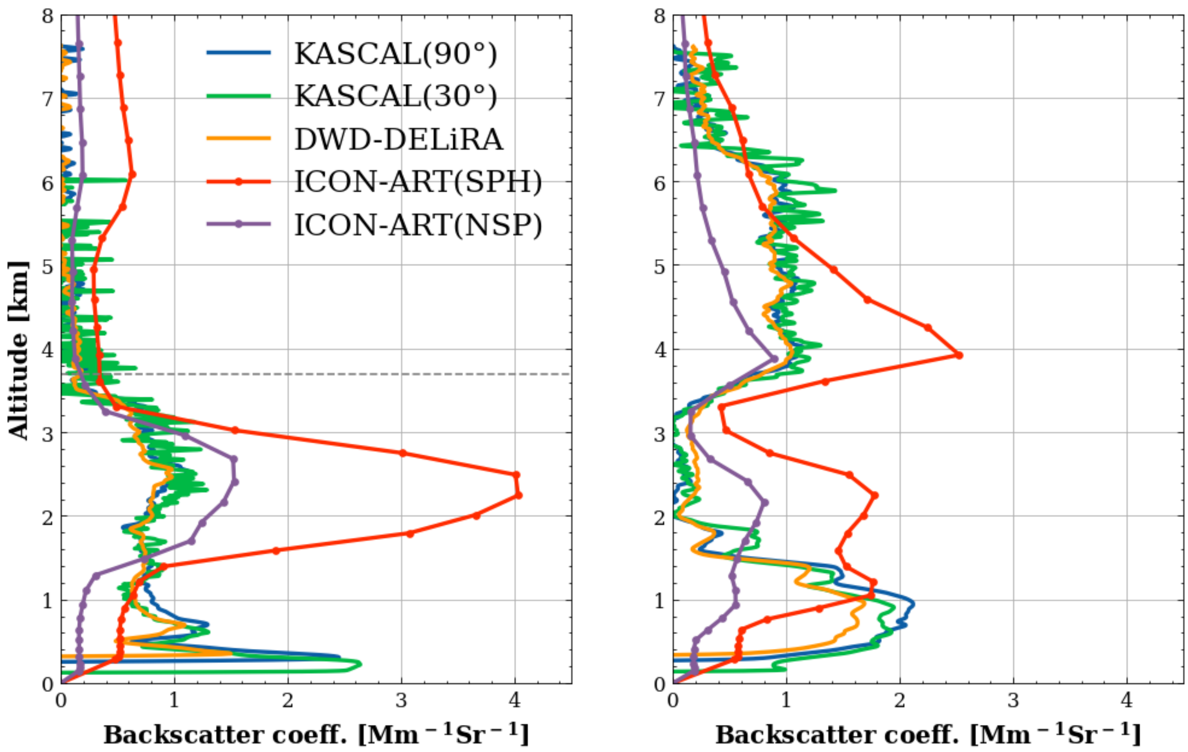

Figure S7 Profiles of backscatter coefficient from KASCAL (both vertical and slant direction), DWD-DEliRA measurements as well as ICON-ART model simulation for two typical cases indicated C1 and C2 in Fig.1. SPH = spherical; NSP = non-spherical.

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Minor comments:

11. The English language has to be checked again, especially in the introduction.

    R: We revised the introduction and checked the language throughout the manuscript.

12. Keep a uniform format for the dates throughout the paper.

    R: We unified the date format throughout the manuscript.

13. Line 30: You are not studying dust-cloud interactions in the present study.

    R: The importance of potential aerosol cloud interaction should be mentioned in the introduction as one motivation for our study. Actually, we would need additional observations and model runs to study the potential aerosol-cloud interactions which may have occurred on April 9th, 2018.

14. Line 42/43: The sentence could not be understood without the knowledge of the location of SAMUM-1 and SAMUM-2. Please provide the locations and distance from dust source.

    R: We have included this information in the revised manuscript: "In addition, intensive field campaigns such as SAMUM investigated the relation between chemical composition, shape, morphology, size distribution, and optical effects of dust particles with emphasis on vertical profiling of dust optical properties. The SAMUM experiment consist of two campaigns – SAMUM-1 and SAMUM-2. SAMUM-1 was mostly conducted at Ouarzazate (30.9◦N, 6.9◦W, 1133 m asl) and Tinfou near Zagora (30.24°N and 5.61°W about 730 m asl) in 2006 and SAMUM-2 was conducted at Praia (Sao Vicente island, Cape Verde, 14.9°N, 23.5°W, 75 m asl) in 2008.(Freudenthaler et al., 2009; Müller et al., 2010; Ansmann et al., 2011; Heintzenberg, 2009; Petzold et al., 2009; Kandler et al.,2009). By these field campaigns, e.g. the chemical/mineralogical composition, microphysical characteristics, and optical properties of Saharan dust were studied. The chemical composition is beyond the scope of this paper. Here we briefly summarize the latter two characteristics. On the African continent, particles with diameters significantly larger than 10 µm were observed e.g. during the SAMUM-1 study. However, in 80% of the cases, the measured particle diameters were below 40 µm. During SAMUM-2, the mean dust particle diameter was significantly smaller than during SAMUM-1 (Weinzierl et al., 2009; Kandler et al., 2009; Kandler et al., 2011)."

15. Line 72-74: Why do you mention the results from the North Pacific? There is almost no connection to your work.

    R: We have deleted this information to focus the introduction on more relevant aspects.

16. Line 244: The sun photometer works only under clear sky conditions as well.

    R: The sun photometer did also show some data gaps but there are still sufficient cloud screened quality assured data points (level 2.0 data, AERONET) to plot hourly averages for that day. We have modified the text as follows:

    "On April 8th, clouds lead to increased uncertainties in AOD retrievals from the lidar measurements and also some data gaps in the sun photometer. Hence, the AOD from lidar measurements can be given only for some selected clear sky periods while the sun photometer has still enough valid data points to calculate hourly averages."

17. Lines 251-252: Please check again Freudenthaler et al., 2009. The values reported at 355 nm are lower than 0.33.

    R: Indeed the linear depolarisation values we have determined are about 20% higher than values observed for relatively fresh and aged Saharan dust particles but still within the combined uncertainties (Freudenthaler et al., 2009, Haarig et al, 2017). Therefore, we have changed the text in the revised manuscript as follows:

    "The particle depolarization ratio of this dust plume was 0.33 ± 0.07 which is very similar to depolarisation ratios determined at 532 nm for Saharan dust particles (Freudenthaler et al., 2009) but about 20% larger than typical values reported for fresh and aged Saharan dust at 355 nm (Freudenthaler et al., 2009, Haarig et al., 2017). However, this is still within the combined uncertainty limits and furthermore the day to day variability of values given by Freudenthaler et al. (2009) is ranging from about 0.22 to 0.31."

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Figures:

18. 1: Is there a special reason to show this specific profile? Please indicate the time of the profile with a vertical bar in the time-height plots on the left. Are the heights reported above ground level or above sea level?

    R: We want to show an example with distinct single dust layer. All heights are reported in Fig.1 above sea level. We have added this information to all plots.

19. 2: The figure is too small. Details can't be spotted. With elastic method, you mean the retrieval using the Klett algorithm? Which filter was applied to the plots shown?

    R: We have enlarged figure 2 to make details better visible. The elastic method refer to the Klett algorithm. The related sentence can be found in section 2.1 as follow.

    "Extinction and backscatter coefficients at 355 nm were both calculated from the elastic channel using the Klett-Fernald method (Klett, 1985;Fernald, 1984)".

    We used different hamming filter length for different retrieval methods. For extinction coefficients calculated with the Raman method, hamming windows filters whose window length is 300 m (40 bins) were applied to Raman signals. But for other retrieval methods (kettle-fernald method, Raman backscatter coefficient), the window length is 75 m (10 bins). We have add the filter information in section 2.1 as follow.

    "Firstly, hamming windows filters whose window length is 75 m (10 bins) were applied to raw lidar signals. Then extinction and backscatter coefficients at 355 nm were both calculated from the elastic channel using the Klett-Fernald method (Klett, 1985;Fernald, 1984) and are also calculated from the elastic and Raman channels (Ansmann et al., 1992). The extinction coefficients and lidar ratios were also retrieved using a multi-angle method, which is also called ratio method in this paper (Adam, 2012;Gutkowicz-Krusin, 1993). For extinction coefficients calculated with the Raman method, hamming windows filters whose window length is 300 m (40 bins) were applied to Raman signals, and subsequently the retrievals were done with an average vertical resolution of 150 m. "

20. 4: Which are the uncertainties for the lidar and the model output? Please add error bars to the data points. Caption in not complete, model (green squares) is missing.

    R: We have added uncertainties to the data points for the lidar. However with respect to model uncertainty, for both AOD and BSC, it is difficult to quantify it (except with ensembles etc). But we can say the sources of uncertainties are in model processes (e.g. emission parameterization etc), dust properties (PSD, optics) and model configuration (resolution etc).

21. 5: Which smoothing was applied to the data?

    R: For this data analysis, we perform temporal averaging and spatial (vertical) smoothing.

    1. Temporal averaging

    The integration time of one profile for vertical and scanning lidar measurements was 30s and 60s. The first step is to do temporal averaging to improve the signal noise ratio of lidar. For data shown in figure 1, we averaged 10 continuous files (10 minutes) for scanning lidar measurement and averaged 60 continuous files (30 minutes) for vertical lidar measurements. For data shown in figure 2, we averaged lidar data from 20:21 to 23:54 for both lidar measurements. The relate information is given in section 3 as follow:

    "The scanning lidar was operated doing vertical and slant measurements at 90° and 30° elevation angle alternatingly with integration times for each observation angle of 300 s. The data shown for KASCAL is averaged over two of these measurement periods. The data shown for the DWD-DELiRA is averaged for 30 minutes. "

    2. Spatial (vertical) smoothing

    We used different hamming filter length for different retrieval method. For extinction coefficients calculated with the Raman method, hamming windows filters whose window length is 300 m (40 bins) were applied to Raman signals. But for other retrieval methods (kettle-fernald method, Raman backscatter coefficient), the window length is 75 m (10 bins). We have added this to section 2.1 as follow.

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"Firstly, hamming windows filters whose window length is 75 m (10 bins) were applied to raw lidar signals. Then extinction and backscatter coefficients at 355 nm were both calculated from the elastic channel using the Klett-Fernald method (Klett, 1985;Fernald, 1984) and are also calculated from the elastic and Raman channels (Ansmann et al., 1992). The extinction coefficients and lidar ratios were also retrieved using a multi-angle method, which is also called ratio method in this paper (Adam, 2012;Gutkowicz-Krusin, 1993). For extinction coefficients calculated with the Raman method, hamming windows filters whose window length is 300 m (40 bins) were applied to Raman signals, and subsequently the retrievals were done with an average vertical resolution of 150 m. "

In additional, we also tested different filter types and different filter length son retrieving extinction coefficient from Raman data. We found that the mean values of extinction coefficients for different filter types and filter lengths remain almost constant. In contrast, their uncertainties vary from around 35 to 5 Mm^{-1} with window length from 82.5 m to 1207.5 m for different types of filters. Hence, the Raman extinction coefficients are affected more by the filter window lengths than the filter type (Shen and Cao, 2019). The information is given in figure S2 and Table S1.

Additional references:

Ansmann, A., Rittmeister, F., Engelmann, R., Basart, S., Jorba, O., Spyrou, C., Remy, S., Skupin, A., Baars, H., Seifert, P., Senf, F., and Kanitz, T.: Profiling of Saharan dust from the Caribbean to western Africa – Part 2: Shipborne lidar measurements versus forecasts, Atmos. Chem. Phys., 17, 14987–15006, https://doi.org/10.5194/acp-17-14987-2017, 2017.

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Freudenthaler, V.; Esselborn, M.; Wiegner, M.; Heese, B.; Tesche, M.; Ansmann, A.; Müller, D.; Althausen, D.; Wirth, M.; Fix, A.; Ehret, G.; Knippertz, P.; Toledano, C.; Gasteiger, J.; Garhammer, M. & Seefeldner, M.: Depolarization ratio profiling at several wavelengths in pure Saharan dust during SAMUM 2006, Tellus B, Blackwell Publishing Ltd, 2009, 61, 165-179

Hoshyaripour, G., Bachmann, V., Förstner, J., Steiner, A., Vogel, H., Wagner, F., Walter, C., and Vogel, B.: Effects of Particle Nonsphericity on Dust Optical Properties in a Forecast System: Implications for Model‐Observation Comparison, J. Geophys. Res. Atmos., 124, 7164-7178, https://doi.org/10.1029/2018JD030228, 2019.

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Best regards,

Hengheng Zhang and all co-authors