Response to Reviewer Report #2 by Wang et al. on 31 March 2019

Dear Reviewer, Dear Editor,

We are grateful to Reviewer for all comments and suggestions that allowed us to improve this manuscript. In the following, answers to the Reviewer's comments are reported in directly below each related comment. All modifications of the initial version of the manuscript as well as additions are reported in color highlight in the revised version. We believe that we have fulfilled all of the required changes in the final version of the manuscript.

Review of "Interrelations between surface, boundary layer, and columnar aerosol properties over a continental urban site"

The focus of this paper is a description of multiwavelength Raman lidar measurements of aerosols within the boundary layer in Warsaw, Poland. Additional measurements also discussed include MFRSR and AERONET measurements of column AOD, and surface measurements of PM. The paper gives a general description of the lidar measurements of boundary layer aerosol properties such as extinction, extinction/backscatter ratio, particulate depolarization, as well as boundary layer height and aerosol optical depth within the boundary layer. The paper attempts to make general statements about the aerosol properties over Warsaw with this combination of measurements. However, for a Raman lidar system that performs "quasi-continuous 24/7 observations", the paper describes analyses that make use of a relatively small number of these profiles acquired during 2013, 2015, and 2016. Moreover, there were only a few periods during this time when measurements from all sensors were available and coincident so very limited combined information is available.

Authors' response: Thank you for this opinion. First of all, there was never our intention to make general statements based on the data restricted to observations during June-September months of 3 years of data. This is now clearly stated in the text. Indeed, the PollyXT Raman-polarization-watervapor lidar performs quasi-continuous 24/7 observations, however those are limited to weather conditions without precipitation and fog. Then, there are strict rules for the data evaluation accordingly to the EARLINET procedures limiting data evaluation for climatology (max. 3 profiles per week, atmosphere free of low and mid-level clouds.) giving maximum of 152 profiles for the selected 3 year period. The data evaluation scheme providing the complete sets of profiles for which all parameters ($2\alpha + 3\beta + 2\delta$) is possible to be derived is limited to using the Raman evaluation approach, which is challenging to be done especially for daytime; this evaluation is not automated but performed manually and results in high score of the QC tests that are applied regularly and externally to the EARLINET data of all sites. Accordingly to the latest test of Jan 2019, we comply in 97% with all tough quality criteria defined in the EARLINET-ACTRIS Data Base Quality Control. From July 2013 till present time, roughly 450 profiles of optical properties (particle extinction coefficient (α) at 355 and 532 nm, particle backscatter coefficient (β) at 355, 532 and 1064 nm, depolarization ratio (δ) at 355 and 532 nm) were submitted for Warsaw EARLINET station. There is no other site that provided such high number of complete sets of data profiles ($2\alpha + 3\beta + 2\delta$) evaluated with Raman approach to the data base, which makes the Warsaw EARLINET station unique in Europe. Out of this 450 sets of profiles, 246 sets of intact profiles ($2\alpha + 3\beta + 2\delta$) with low smoothing (only 49 range bins) calculated by classical Raman method are chosen for analyses, whereby as the representatively of these profile is highest for the June-September in years 2013,2015 and 2016, we clearly indicated this period not to generalized statements. Clearly, we did not constrain the analyses only to the climatology files but extended it as much as possible to all other files, baring in mind that majority of the non-climatology files

are related to the special event and aletr measurements of the EARLINET-ACTRIS community. This is why we furted restrict the analyses to only boundary layer, as it is expected to be affected much less by the long range transport in free-troposphere. In revision of the initial manuscript, we checked all of the files available in the EARLINET-ACTRIS data base for Warsaw, then re-extrapolated the particle extinction coefficient of all profiles according to the AOD threshold at two wavelengths (AOD obtained within lowermost 1km of 0.05 at 355 nm and 0.03 at 532 nm). This increased the number of profiles, as suggested b Reviewer and new comparisons and discussions are based on 246 profiles in entire time, 96 profiles in nocturnal time and 93 profiles in sunrise and sunset time.

A major problem with the paper is the attempt to draw general conclusions about aerosol properties, and interrelationships among these properties, from this limited dataset where the correlations are weak at best. Figures 5, 6, 7, 9, 10, 11 display scatterplots which typically show small correlation coefficients (in absolute value) between the aerosol properties, yet the authors attempt to imply that there are some relationships between variables. Similarly, the paper also attempts to indicate that the aerosol properties during some periods were different from the properties observed during other periods; however, looking at the average and standard deviations of these values, it is not at all clear that these differences are statistically significant. In many instances, the paper uses previous measurements to indicate such a relationship exists, when the data presented in the current paper do not clearly support such a relationship. In short, the paper attempts to draw conclusions which the data, as presented, do not support.

Authors' response: Thank you, as I said before, there was no intention to make general statements and if it appeared as such I apologize, however note that it was well defined what data are used for analyses and did not show only those plots which 'look good' but we searched for all relations possible. We separated entire (ET), nocturnal (NT) and sunset and sunrise time (TT), because I expected that the relations of optical properties and PM, or interrelations of aerosol properties should be different in these 3 periods due to change of atmospheric conditions. They showed up for many relations not to be so strong, if any. I reckon this is worth to be shown. On the other hand, if I only calculated the relations in entire time (24h), some information will be lost, e.g. no relation of LR_{ABL} and FCMR in entire time is evident (Figure 7, new manuscript), but a weak positive relation of LR_{ABL} and FCMR can be observed in nocturnal time (NT) and their relations in sunrise/sunset time (TT) is negative. The relations of AE and FCMR also appear different during NT and TT, similar holds for RH and LR_{ABL} (Figure 13, new manuscript). Therefore, showing of aerosol optical properties, PM, RH in different periods is meaningful. In addition, we did not compare aerosol optical properties, PM, RH in daytime period (08:00-17:00 UTC) alone, as there were only 57 profiles in this period, the statistically significant is too low. Therefore, we only compare relations in nocturnal and sunrise and sunset time. Indeed we use examples of studies in which relationships between parameters existed (and all of those cited studies were related with special case-studies of specific aerosol type injections to boundary layer and/or in free troposphere or columnar atmosphere). I reckon it is worth showing that the case-study based relationships are hard to discern in a larger sample of data and they must not be generalized, at least for the Warsaw site.

Specific Comments:

1. Page 1, line 27 (associated) would be a better word than attributed.

Authors' response: Thank you. we changed "attributed" to "associated" in the text.

2. Page 2, line 3. Why no significant correlation between AOD_{ABL} and PM2.5?

Authors' response: I added the following explanation to the section 4 in the text: "The significant correlations (R> 0.5) of AOD_{CL} and $PM_{2.5}$ were reported mainly for eastern cities of China (Guo et al., 2009, Zheng et al., 2015, Zang et al., 2017) and United State (Liu et al., 2007, Hutchison et al., 2008, Wang et al., 2003), where are major industrial regions with extremely pollution. In those cases the majority of aerosol was expected to be present within boundary layer. The anthropogenic pollution in Warsaw is much lower if compared to the above mentioned regions; Zawadzka et al., 2012 reported on R=0.42 between AOD_{CL} and $PM_{2.5}$ in Warsaw, which was explained as due to significant load in free troposphere affecting this relation. The current study, show that also for AOD_{ABL} and $PM_{2.5}$ there is no significant correlation, which can be explained by low values of AOD_{ABL} and $PM_{2.5}$ obtained during investigated period due to lack of high pollution events in summer and early autumn in Warsaw. Note that in cited work Stachlewska et al., 2017b, 2018 showed AOD_{ABL} and $PM_{2.5}$ in Warsaw can be correlated, only under high aerosol load conditions during events of long-range transported pollution or biomass burning injection into the boundary layers.

New related references were added to the manuscript:

Zang, Z. L., Wang, W. Q., You, W., Li, Y., Ye, F., and Wang, C. M.: Estimating ground-level PM2.5 concentrations in Beijing, China using aerosol optical depth and parameters of the temperature inversion layer, Sci. Total Environ., 575, 1219–1227, https://doi.org/10.1016/j.scitotenv.2016.09.186, 2017.

Zheng, S., Pozzer, A., Cao, C. X., and Lelieveld, J.: Long-term (2001–2012) concentrations of fine particulate matter ($PM_{2.5}$) and the impact on human health in Beijing, China, Atmos. Chem. Phys., 15, 5715-5725, https://doi.org/10.5194/acp-15-5715-2015, 2015.

Guo, J.-P., Zhang, X.-Y., Che, H.-Z., Gong, S.-L., An, X., Cao, C.-X., Guang, J., Zhang, H., Wang, Y.-Q., and Zhang, X.C.: Correlation between PM concentrations and aerosol optical depth in eastern China, Atmos. Environ., 43, 5876–5886, https://doi.org/10.1016/j.atmosenv.2009.08.026, 2009.

Liu, Y., Franklin, M., Kahn, R., and Koutrakis, P.: Using aerosol optical thickness to predict ground-level PM2.5 concentrations in the St. Louis area: A comparison between MISR and MODIS, Remote Sens. Environ., 107, 33–44, https://doi.org/10.1016/j.rse.2006.05.022, 2007.

Hutchison, K. D., Faruqui, S. J., and Smith, S.: Improving correlations between MODIS aerosol optical thickness and ground-based PM2.5 observations through 3D spatial analyses, Atmos. Environ., 42, 530–543, https://doi.org/10.1016/j.atmosenv.2007.09.050, 2008.

Wang, J. and Christopher, S. A.: Intercomparison between satellite-derived aerosol optical thickness and PM2.5 mass: Implications for air quality studies, Geophys. Res. Lett., 30, 2095, https://doi.org/10.1029/2003GL018174, 2003.

3. Page 4. The paper states that the Polly XT lidar performs quasi-continuous 24/7 observations. If so, why are only those measurements collected during the EARLINET observational periods used in the analyses? If this lidar operates nearly 24/7, why not take advantage of this capability and use more data in these analyses?

Authors' response: As explained above, the purpose of this paper is to use only QA&QC complete sets of profiles stored in the EARLINET Database to calculate and analyze the mean optical properties within ABL. All profiles are calculated only with the Raman method retrieval (otherwise we get no independent sets of extinction and backscatter coefficient profiles) which limits number of profiles, mainly due to the signal to noise ratio of the Ranam channels. Moreover, it takes one full day to evaluate manually single set of profiles, including the interpretation of the profile and allocation to one of the EARLINET special categories (e.g. frest fire). As for the Klett method retrieval (easier to performed as less prawn to signal

noise at elastic channels), it is affected by the assumption of lidar ratio and thus we do not submit these profiles to the data base, as we want to work only of the sets of independently derived profiles.

. 4. The paper states that there were only 49 profiles available during daytime conditions. Why so few?

Authors' response: Again, all profiles are calculated only with Raman method retrievals and full sets of profiles are stored in data base (which makes the Warsaw data set unique), but this evaluation type strongly depends of the signal to noise ratio, which is even more crucial for the daytime measurements due to sky-background radiation. This is the reason why the obtained profiles are mostly derived at night. Note that accordingly to the suggestion of the Reviewer, we extended analyses and rechecked all of the extinction coefficient profiles and in the final version of the paper 57 profiles is available during daytime conditions. Therefore we corrected in the text: "57 profiles were available at daytime".

5. The description of the periods is confusing. Dusk till sunrise (05-07 UTC) does not sound correct. Dusk starts around 20 UTC not 05 UTC. What is "Sunset to down"? Does this mean "sunset to dawn? If so, what time is this? What is the difference between "sunset to dawn" and nocturnal time? These periods need to be clearly described and defined.

Authors' response: Thank you for your comment. We clarified this in the text: "dawn (04:00-07:00 UTC), dusk (18:00-21:00 UTC)"

6. It sounds like the only periods for which there were coincident lidar and MFRSR data were the daytime profile? Correct?

Authors' response: Indeed, the MFR-7 and CE813 instruments collect data only at daytime. Moreover, data products are provided only in cloudless condition. We added following information in the text: "MFR-7 and CE813 collected data only at daytime".

7. What period of time corresponds to a profile? That is, are these profiles 1 min, 10 minute, 1 hour?

Authors' response: I clarified this and added the following sentences to the text: "The profiles of the particle extinction and backscattering coefficients, and particle linear depolarization ratio were averaged over 60min (60%) or 45min (23%) or 30min (17% of profiles), depending on the atmospheric conditions variability and the signal-to-noise ratio."

8. Page 6. Line 6. It sounds like some contrast between the summer and winter boundary layer is being made. What is this contrast?

Authors' response: Thank you, we clarified this and added the following sentences to the text: "The lidar derived aerosol boundary layer height values in Warsaw in 2013, 2015 and 2016, were above 1.1 km during summer and autumn, while during winter they were below 0.8 km.

9. The paper does not include any significant discussion or evaluation of the impact of the different in locations among the various measurements. Given the extensive discussion later in the paper regarding correlations (or lack thereof) among these various measurements, there must be

more extensive discussion about the impact of the different locations on these correlations. This is particularly true for measurements made at or near the surface.

Authors' response: Thank you for this comment. Indeed, we cannot expect a perfect comparison result of AOD_{ABL} and AOD_{CL}, and PM obtained by different instruments. PM measures dry particles near the near surface. AOD_{ABL} measures mean aerosol particle properties within ABL. Detection angle of daytime CE318 and MFR-7 is changing when sun moves. But detection angle of this lidar is solid (zenith). This is why we do not expect perfect matching AOD from radiometer and lidar even if they are at the same site. Zawadzka et al., 2013 reported the relations of AOD_{CL} at Warsaw and Belsk and PM at Warsaw-Ursynow.

The different sites were compared therein, and therefore, we do not want to repeat the discussion of the impact of the different locations and the various measurements again. Thus, we aimed at study of relations of AOD_{ABL} and PM in Warsaw. At the same time our results are consistent with those reported by Zawadzka et al.2013. Several studies showed the air quality monitoring station at Ursynow is the most representative PM site for comparisons with lidar site (Zawadzka et al., 2013, Stachlewska et al., 2017b, Stachlewska et al., 2018). Therefore, we selected it.

As for the daytime observations with the rural AERONET station at Belsk used for AOD_{CL} it was used only as an indicative that the PolandAOD measurements with MFR-7 at urban site in Warsaw show similar values of the AOD_{CL}, then clearly indicates that the measurements at these two sites for the 33 compared cases were indeed having relatively high aerosol load that should be primarily be related to aerosols in free troposphere (for sure the boundary layer AOD_{ABL} at the two sites would be different. Note that the MFR-7 is located in the RS-Lab 20m off the lidar at altitude of 21m , the difference in location for comparison of results of AOD_{CL} obtained by MFR-7 and lidar-derived AOD_{ABL} can be ignored, thus the difference of the two values is related to free troposphere aerosol load.

We just add following sentences to the text: "The PM site is in the residential area of Ursynow (about 6.5km from RS-Lab), the RS-Lab is located at the University campus shrouded b green parks, between the two sites there is no possible industrial pollution sources and anthropogenic pollution is related to traffic. As for the CIMEL located at about 43.7 km away from the RS-Lab, and about 2 km from the village of Belsk its results are used only as an indicative that the free tropospheric aerosol load above Warsaw and Belsk existed. The surrounding of this Belsk site is a typical agricultural region with fertile soil and trees.

10. Page 6, line 14. For those readers who are not familiar with the "classical Raman retrieval approach", it would be good to provide a brief (few lines) summary of what is referred to.

Authors' response: Thank you, I added the following sentences to the text: "The particle extinction coefficient profiles at 355 and 532 nm are calculated form the Raman lidar equation using Rayleigh law for molecules and Angstrom law (AE=1) for aerosol particles. The particle backscatter coefficient profiles at 355, 532 and 1064 nm are derived with the use of the particle extinction coefficient profiles at 355nm and 532nm (used for the two larger wavelengths) and calibrated at the height range free of aerosol.

11. Page 7, line 3. How many profiles were excluded because of this AOD threshold?

Authors' response: In the initial manuscript, 24 profiles were excluded by AOD threshold at 355 and 532 nm. In the new manuscript, we extended the analyses and re-extrapolated particle extinction coefficient to the ground. Previously the threshold was applied if the AOD calculated in the range from the ground to 1

km (being well above the overlap range) was below 0.05 (355 nm) and 0.03 (532 nm), such set of profiles was removed from analyses. Now, if this is the case, I do not remove the set of profiles from the analyses but re-extrapolate a particle extinction coefficient from a range-bin just above it down to ground, this in an iterative manner until the AOD values within 1 km meat the given above thresholds. Number of such iterations being limited to 10, results in no profiles was excluded. Thus, we changed these statements in the manuscript accordingly.

12. Page 7, line 8 What is the basis of the lidar ratio values used for aerosol type determination? It may be better to move this sentence to later on this page when discussing other studies of aerosol types.

Authors' response: Thank you, we moved this to results and discussion section, as suggested, and to clarify this sentence, we added the following descriptions to text: "A review of aerosol types include in the classification scheme values reported by Groß et al., 2013, 2015, based on which LR for the marine particles is varying from 16-30sr at 355 nm and 18-26sr at 532 nm, the biomass burning varying from 50-95sr at 355 nm and 60-90sr at 532 nm, the mineral dust varying from 50-70sr at 355 nm and 45-65sr at 532 nm, the pollution varying from 50-65sr at 355 nm and 50-60sr at 532 nm. "

Two new references were added to manuscript:

Groß, S., Esselborn, M., Weinzierl, B., Wirth, M., Fix, A., and Petzold, A.: Aerosol classification by airborne high spectral resolution lidar observations, Atmos. Chem. Phys., 13, 2487–2505, https://doi:10.5194/acp-13-2487-2013, 2013.

Groß, S., Freudenthaler, V., Schepanski, K., Toledano, C., Schäfler, A., Ansmann, A., and Weinzierl, B.: Optical properties of long-range transported Saharan dust over Barbados as measured by dual-wavelength depolarization Raman lidar measurements, Atmos. Chem. Phys., 15, 11067–11080, https://doi.org/10.5194/acp-15-11067-2015, 2015.

13. Page 7. Line 13 4-8 should be 0.04 -0.08.

Authors' response: Thank you, indeed it is a typo, we corrected it in the text.

14. Page 8, line 2. Looking at the average values and st. deviations, are the ABL values of aerosol extinction and AOD really statistically significantly different for the sunrise/sunset period than the other two periods? It doesn't look that way. (Likewise for the Angstrom exponent…is it really statistically different for the nocturnal period?)

Authors' response: Thank you once again for this comment. I understand that this was not clearly stated in the text. Well, I separated entire (ET), nocturnal (NT) and sunset and sunrise time (TT), because I expected them to be different in those periods. Indeed for the mean values given in the Table, the differences in the mean properties between the three periods are very small, if any. However, as I said before, if we look only at the relations between the parameters on the scatter plots, in the entire time (24h), some information is lost, e.g. the relations of AE and FCMR appear different during NT and TT (Figure 13, new manuscript). Therefore, I thought it is meaningful to show the mean aerosol optical properties in different periods.

15. Table 1. It would be helpful to include the ABL height for each period.

Authors' response: Thank you, we added the ABL height derived in the period of ET, NT and TT to Table 1 as following shows:

Table 1. Mean values of the aerosol optical properties derived within aerosol boundary layer (ABL) from PollyXT lidar at the EARLINET site in Warsaw for measurements at 355nm and 532 nm conducted in period of July-September of 2013, 2015, and 2016. Symbols denote particle extinction coefficient (α), particle backscatter coefficient (β), aerosol optical depth (AOD), lidar ratio (LR), particle linear depolarization ratio (δ) and Ångstrom exponent (ÅE) and aerosol boundary layer height (ABLH).

Optical Properties	Entire time (ET) 24/7		Nocturnal time (NT) 23:00-3:00 UTC		Sunrise/sunset time (TT) 5:00-7:00 & 18:00-20:00 UTC	
	355 nm	532 nm	355 nm	532 nm	355 nm	532 nm
α_{ABL} (Mm^{-1})	160 ±78	89±47	155 ±73	85±46	172 ±75	96±46
β_{ABL} ($Mm^{-1}sr^{-1}$)	3.2±1.4	2.0±0.6	3.3±1.1	2.0±0.6	3.0±1.2	1.9±0.8
AOD_{ABL}	0.28±0.15	0.15±0.09	0.23±0.12	0.13±0.07	0.31±0.18	0.16±0.09
LR_{ABL} (sr)	49±15	43±16	46±13	40±15	55±18	47±15
δ_{ABL}	0.02±0.01	0.05±0.01	0.02±0.01	0.05±0.02	0.02±0.01	0.05±0.02
$ÅE_{ABL}$	1.54±0.44		1.58±0.41		1.47±0.47	
ABLH	1.66±0.43 km		1.56±0.37 km		1.74±0.48 km	

16. Page 9, line 17. This sentence "twice larger wavelength" is confusing.

Authors' response: Thank you. We stated explicit what was meant: 532 nm wavelength.

17. Page 9, lines 28-30. These lines show percentages of different aerosol types. How were these percentages determined? What is the uncertainty in these percentages?

Authors' response: We clarified this as the following sentences in the text: "Firstly, the classification was done based on the lidar ratio (Figure 2), which was used as an indicator for the aerosol type. Secondly, the particle depolarization ratio was used for the separation of aerosol types. Thirdly, the HYSPLIT backward trajectories were used to assess the source of aerosol particles of each profile (these were obtained as 3-10 days backward starting at altitude of 0.5, 1.2, and 3km, applied on GDAS). The estimated aerosol composition consisted mainly of i) pure urban anthropogenic pollution of local origin or transported from areas below or above of the Czech Republic via Silesia and/or Germany (60%), with its mixtures with ii) grass and peatland biomass burning aerosols transported from Russia over Ukraine and Belarus (12%), iii) pollen emissions of strictly local origin form the many semi-natural Warsaw's green parks (8%), iv) arctic/marine particles transported mainly from Arctic over Baltic Sea (6%). For remaining cases, identification of aerosol composition was regarded as due to a mixture of more than two sub-component (14%). The given percentage were derived as related to the number of profiles with estimated origin to the total number of profiles, and therefore are given without uncertainties."

18. Figure 2 shows no color (no blue or red symbols); only black and white.

Authors' response: Thank you, we provide new Figure 2 (Now Figure 3) to follow the request of the Revier #1, where the AOD and AE values of the CE3108 and MFR-7 we scaled to the lidar valelengths; the new fig caption is a following sentence:

Figure 3. Hourly averages of aerosol optical depth (AOD) and Ångstrom exponent (ÅE) derived within boundary layer at 355 and 532 nm from PollyXT lidar at the EARLINET site in Warsaw (open circle/square), and in atmospheric column measured by CE318 CIMEL (380 and 500nm) at the AERONET site in Belsk (grey/triangle) and MFR-7 radiometer (415 and 500nm) at the PolandAOD-NET site in Warsaw (black /circle). AOD_{CL} at CE318 and MFR-7 were scaled to 355 and 532 nm using Angstrom law. Note, only data points for which all 3 measurements were available are plotted. For day of year 182-274, for all years (2013, 2015, 2016) we superimpose available data points (33 cases) on single plot (note 2016 was a leap year).

19. Page 10, line 12. The fraction of AOD within the ABL varies widely with location and period, so no blanket statements should be made.

Authors' response: Thank you, we rewritten this sentence as following: "It can be expected that $AOD_{ABL} < AOD_{CL}$ (e.g. Sicard et al., 2011)."

20. Page 10, line 21. Table 2 shows AOD values of 0.15 (355) and 0.07 (532 nm) for EARLINET during cases of no long-range transport. Why does line 21 say 0.2 (355) and 0.1 (532 nm)?

Authors' response: Thank you. The values in the text were rounded, now values in the text are the same as Table 2.

21. Page 11, line 4. There doesn't appear to be much of an anti-correlation between the ABL and column Angstrom exponents in Fig. 2.

Authors' response: Thank you. Indeed, no clear correlation between AE_{CL} and AE_{ABL} can be observed from the scattering plot (Figure 1a). We corrected this statement in the manuscript.

22. Page 11. There is no satisfactory explanation given why there is an apparent decrease in AOD (column) with increasing ABLH. The total column amount of AOD should not depend on the ABLH, unless the aerosols that get mixed into the ABL are somehow removed. However, this is not necessarily true nor demonstrated.

Authors' response: Thank you, well AOD_{CL} will also decrease if the aerosol from free troposphere is removed – which is anyhow more likely in the case of urban environment. We clarified this in the text: By definition, the scatter plot show spread of the data for which there is no explicate temporal relation, thus the negative correlation does not imply that the decrease in AOD (column) means increase of ABLH, and vice versa. In the 33 cases of daytime measurements, majority of which were taken under clear sky conditions and are related to existence of biomass-burning and mineral dust layers in free troposphere. In such cases, for lower AOD_{CL} higher ABLH was detected. At the same time, higher AOD_{ABL} is detected for higher ABLH. The two relations are not connected strait forward. Over an urban site that this can be explained as the AOD_{ABL} grow due to an increase of pollution in urban boundary layer, which adds to the

ABLH grow due to Sun-driven turbulence, at the same time the AOD_{CL} decrease would be observed when free tropospheric aerosol load decreases or the type of aerosol present in free troposphere (e.g absorbing aerosols) can cause negative radiative effects at the surface."

23. Page 11, line 28. It seems unlikely that, in these cases where the AOD in the free troposphere is less than 0.3 or 0.4, these elevated aerosol layers reduce solar radiation sufficiently to significantly lower ABLH. If so, the authors should present a more convincing case.

Authors' response: Thank you. We added more explenation on in the text: "Dust layers can leading to a decreasing of ABLH were reported by several previous studies. The boundary layer decreasing down to 400 m during the Saharan dust intrusion episode in summer at Izaña (South of Spain) was reported by Alastuey et al. (2005). During an intense Saharan dust outbreak in summer, the mixed layer range in the range od 300-400 m in urban area of Barcelona was reported by Pérez et al. (2004). The low mean mixed layer was detected during dust outbreak period at 609±128 m in October in Barcelona by Pandolfi et al. (2013)."

24. Page 12, line 21. Where do the particle densities come from? Also, given these large standard deviations, the difference in these densities among these periods does not look to be statistically significant. Are these significant?

Authors' response: The particle densities are derived as mean values with standard deviation of hourly $PM_{2.5}$ (corresponding to ±1h to lidar profile retrievals times). They were obtained from WIOS air quality station in Warsaw-Ursynow. Although the standard deviations are large, the mean values give an idea that nocturnal $PM_{2.5}$ is higher than for other two periods during analyzed period in Warsaw.

25. Page 12, line 22. There is very little trend of FCMR with ABLH.

Authors' response: Thank you, we rewritten this sentence in the text as following: "There is very little trend of FCMR with ABLH."

26. Page 14. Fig. 7 shows essentially no correlation of AOD within the ABL and surface PM2.5. This should be stated more clearly in the text. This is not what one would typically expect; some more focused discussion about why this was observed would be appreciated.

Authors' response: Please note the answer to Your point no.2

27. Page 14. Was there any relationship between RH and AOD in the ABL? Or relationship between mean extinction and RH? Also any relationship between RH and the optical properties (LR, Angstrom exponent)?

Authors' response: Thank you for your question. We made this plot of AOD_{ABL}, AE_{ABL}, LR_{ABL} and δ_{ABL} with RH. We added the new plots and following comments to the text: "The AOD_{CL} was reported to increase with ambient relative humidity for hygroscopic particles due to hygroscopic growth (Bergin et al., 2000, Altaratz et al., 2013). A negative relation between AOD_{ABL} and surface RH is found in the current study, except for nocturnal time in Figure 2 (new, below). With high surface RH lower AOD_{ABL} is

observed. The size and optical properties can change as aerosol particles uptake water. Higher RH is more favorable for hygroscopic growth of pollution particles (Tang, 1996). During observational period, the main composition within boundary layer was due to urban anthropogenic aerosols, increase of RH leads to increasing pollution particle size, which is visible especially at nighttime (AE and RH show weak negative correlation, while no correlation is found between AE_{ABL} and RH at transition), being in accordance with the FCMR and AE scatter plots. Pollution particle within boundary layer due to weaker convective mixing at nighttime, are prone to surface water uptake which contributes to an increase of aerosol particle size Cheng et al. (2008). The relationship between LR_{ABL} and RH shows weak negative correlation in entire time and transition time and weak positive trend in nocturnal time. In the nighttime, the increasing LR due to accumulation of hygroscopic smoke particles was reported by Giannkaki et al. (2010). Convection and energy exchange is stronger in the transition time (Stull.2012), leading to anthropogenic aerosol dominated in aerosol boundary layer, increasing surface RH results in the rise of aerosol particles size, and thus contributes to decreasing LR_{ABL}. The negative trend of relationship between δ_{ABL} and surface RH in three analyzed period is in agreement with trend obtained for WV_{ABL} and δ_{ABL}.

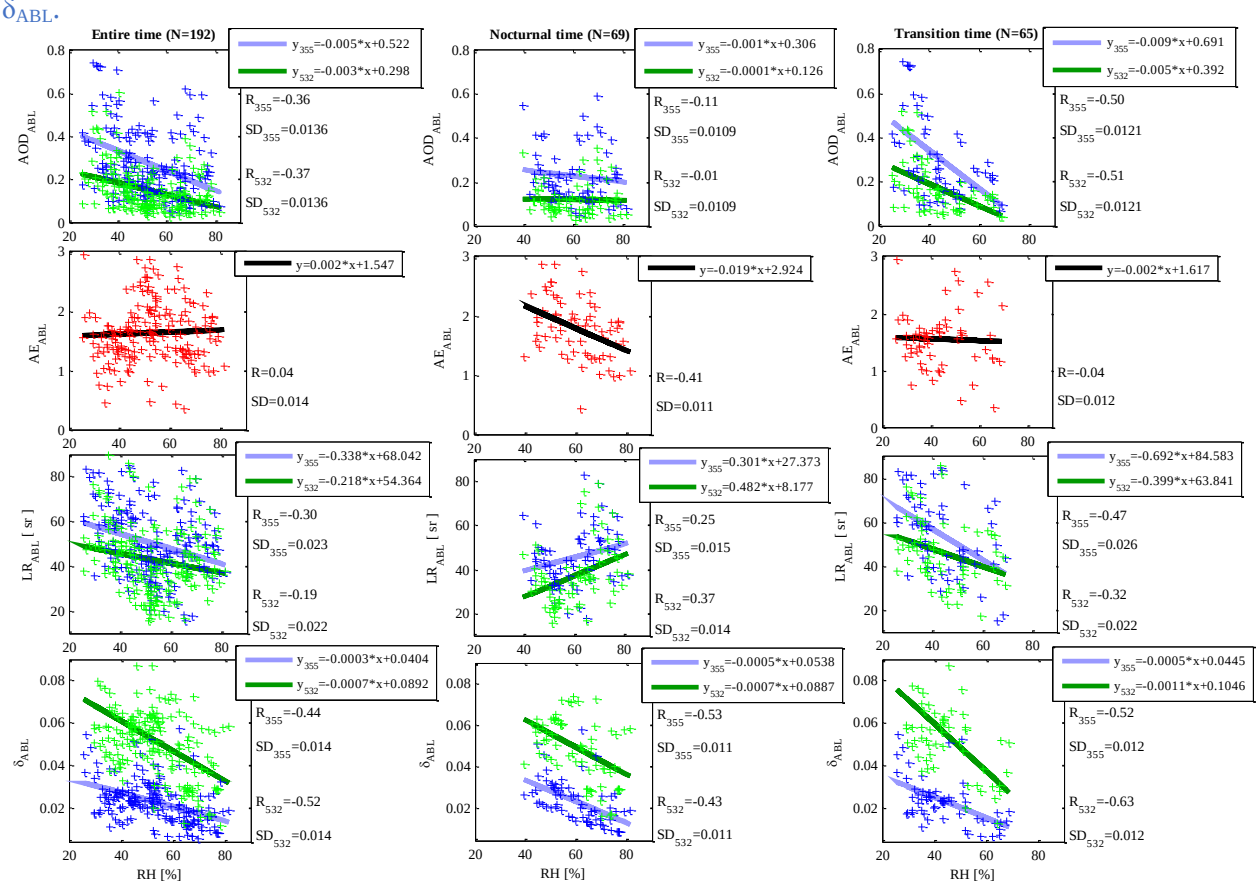

Figure 2. Comparison of hourly averaged near-surface relative humidity (RH) measured by the weather transmitter WXT510 (Vaisala) with aerosol optical depth (AOD), Ångstrom exponent (ÅE), lidar ratio (LR) and particle linear depolarization ratio (δ) derived within boundary layer at 355 and 532 nm from PollyXT lidar at the EARLINET site in Warsaw in period of July-September of 2013, 2015, 2016.

Five new references were added to the manuscript:

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