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Atmospheric Measurement Techniques Discussions

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Interactive comment

Interactive comment on "Analyzing the Atmospheric Boundary Layer by high-order moments obtained from multiwavelength lidar data: impact of wavelength choice" *by* Gregori de Arruda Moreira et al.

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We thank the anonymous reviewers for their comments, corrections and suggestions, which have helped to improve the quality of the manuscript. According to the reviewers' reports, the following changes have been performed on the original manuscript and a point-by-point response is included below.

1. Please give the main specifications of lidar, e.g. laser pulse energy, beam pointing stability, laser pulse repetition rate, detectors and data acquisition. Can you please

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show the range-corrected signals or images at 1064-nm and 355-nm as Fig.2A?

In order to clarify this point, the text has been changed to provide lidar specifications as follows:

(Page 3, Lines 22-30) “The São Paulo Lidar station (SPU) has a coaxial ground-based multiwavelenght Raman lidar system operated at LEAL. The system operates with a pulsed Nd:YAG laser, emitting radiation at 355, 532 and 1064 nm, a laser repetition rate of 10 Hz and a laser beam pointing to zenith direction. The pulse energy (and stability) of each wavelength are 225 mJ (2mJ) at 355 nm, 400 mJ (4 mJ) at 532 nm, and 850 mJ (6 mJ) at 1064 nm. The MSPI lidar detects three elastic channels at 355, 532 and 1064 nm and three Raman-shifted channels at 387 nm, 408 nm (corresponding to the shifting from 355 nm by N2 and H2O) and 530 nm (corresponding to the Raman shifting from 532 nm by N2). This system is equipped with photomultipliers Hamamatsu R7400. The SPU lidar reaches full overlap at around 300 m a.g.l. (Lopes et al., 2018). This system operates with a temporal and spatial resolutions of 2 s and 7.5 m, respectively.”

The following figures has been added as supplementary material:

* Figure C1

* Figure C2

2. Page-3, Line-12, “. . .from July 2018 to July 2018. . .”? The manuscript only shows two cases studies, not the dataset or measurements from July 2018 to July 2018. We thank the Reviewer#1 for this comment. We performed a campaign from July 2017 to July 2018, however only the two best cases are presented in order not to extend the paper much more and to approach in more detail some specific cases. In order to clarify this point the text has been changed as follow:

(Page 3, Lines 17-18)

“. . .from July 2017 to July 2018; however, to illustrate the analysis, only two cases are discussed in detail in this article.”

3. Page-4, Eq.(2) and Line 1-3 about the relationship between the aerosol backscatter and number density. Please mention the Mie-theory and aerosol hygroscopic properties with the relative humidity (RH). Under what value of RH, the aerosol hygroscopic properties may be ignored. We thank the Reviewer#1 for this comment. In order to clarify this point, the text has been changed as follow:

(Page 4, Lines 7 - 17)

"In the analysis performed with elastic lidar systems, the variable of interest is the aerosol number density (N), from which we obtain its fluctuation (N') by the equation 1. However, elastic lidar systems do not provide directly the value of N. Therefore, considering the validity of Mie-theory (where the aerosol backscatter coefficient is linked to the backscatter efficiency, particle radius (r) and the number of particles with radius r we can write the equation 2, under several assumptions. The premises adopted here are (i) the variation of aerosol size with the relative humidity can be neglected, (ii) the atmospheric volume probed is composed by similar types of aerosol particles and (iii) the fluctuations of the aerosol microphysical properties are smaller than the fluctuations of the total number density in the volume probed by the lidar. More details about these assumptions can be found in (Pal et al., 2010). Feingold (2003) and Titos (2016) demonstrated the relation between relative humidity and hygroscopic growth, so that, such effects can start at 80% RH. The two cases presented in this work were gathered in winter, the driest season of São Paulo. In particular, RH was below 80% in both days (see section 4). Such value is lower than the RH threshold to hygroscopic effects indicated by the two papers above mentioned."

Feingold, Graham: Aerosol hygroscopic properties as measured by lidar and comparison with in situ measurements. Journal of Geophysical Research, Vol. 108, 4327, doi:10.1029/2002JD002842, 2003.

Titos, G., Cazorla, A., Zieger, P., Andrews, E., Lyamani, H., Granados-Muñoz, M. J., Olmo, F. J., Alados-Arboleda, L.: Effect of hygroscopic growth

on the aerosol light-scattering coefficient: A review of measurements, techniques and error sources. Atmospheric Environment, Vol. 141, 494-507, https://doi.org/10.1016/j.atmosenv.2016.07.021, 2016.

4. Page-4, What is the difference between the Eq.(2) and Eq.(3)?

We thank the Reviewer#1 for this question. Eq. (2) presents the relationship between particle backscatter coefficient (β_aer) the aerosol number density (N). On other hand, Eq. (3) presents the relationship between the fluctuations of these same variables. The fluctuations are obtained from the Reynold's decomposition (Eq. 1).

5. Page-4, Eq.(6). Please describe or give the condition(s) or assumption(s) for deriving this equation. We thank the Reviewer 1 for this question. The Eq. 6 is obtained from Reynold's decomposition (Eq. 1). In order to clarify this point, the text has been changed as follow:

(Page 5, Line 11)

"…particles. Then, applying Reynold's decomposition (Eq. 1) over Eq. 5, the following equation is derived:…"

6. Page-6, Line-24, ". . . same type of aerosol is present in the entire atmospheric column . . .". You may assume it for the PBL aerosols, but please note that aerosol type generally depends on both the size distribution and chemical compounds. Thus, it is much different in the near surface, PBL, free troposphere and stratosphere. We thank the Reviewer 1 for this comment. In order to adjust this point, the text has been changed as follow:

(Page 7, Line 18)

"…the same type of aerosol is present in the entire atmospheric column in the ABL region…"

7. Page-7, Line 2-4 about the Fig.A3C. The aerosol angstrom exponent can help clas-

sify aerosol type in term of aerosol size information. However, it is generally not enough for the different species of aerosols. For instance, both urban aerosols and smoke aerosols are fine-mode particles (i.e. large Angstrom exponents), but they are different types with the different backscatter and extinction properties.

The Angstrom Exponent can give an indication of the aerosol type, however, it is not enough to classify different types of aerosol. Recently, a new method to aerosol classification was presented by Papagiannopoulos et. al., 2018) based on the intensive optical parameters retrieved from the European Aerosol Research Lidar Network (EARLINET). The predictive accuracy of this automatic classification method varies between 59âĂĹ% to 90âĂĹ% (maximum) applied to 8 to 4 aerosol classes. In order to apply this aerosol classification method the author used typical lidar configuration for the EARLINET lidars, a multi-wavelength Raman lidars combining a set of elastic and inelastic channels, the so-called 3β+2α configuration, in addition of polarization channels. Using or apply the aerosol classification method is not the aim of this work. Furthermore, it would not be possible considering that our lidar configuration, a multi-wavelength Raman lidar (3β+2α) with no depolarization, was set up in 2018. However, we used the 530 nm rotational Raman channel (Veselovskii et al, 2015) to the lidar ratio profile for the case of 29 of July 2018. As can be seen in the following figure, we could retrieve the lidar ratio (LR) profile up to 1500 m, as the ground level, which correspond the altitude of the atmospheric boundary layer. The LR oscillate around the mean lidar ratio of 53 $\pm$ 7 sr, which is a strong indication that there is no changes in the aerosol optical properties during the turbulence analysis period. Unfortunately, for the case of 26 of July 2017, it was not possible to retrieve the lidar ratio profile since we did not have the rotational Raman lidar configuration. However, since both cases are very similar when comparing the Relativity humidity, the mixing ratio, and the temporal distribution of the Angstrom exponent, we can assume that there are no considerable changes during the whole measurement period for 26 of July 2017.

* Figure C3

Papagiannopoulos, N., Mona, L., Amodeo, A., D'Amico, G., Gumà Claramunt, P., Pappalardo, G., Alados-Arboledas, L., Guerrero-Rascado, J. L., Amiridis, V., Kokkalis, P., Apituley, A., Baars, H., Schwarz, A., Wandinger, U., Binietoglou, I., Nicolae, D., Bortoli, D., Comerón, A., Rodríguez-Gómez, A., Sicard, M., Papayannis, A., and Wiegner, M.: An automatic observation-based aerosol typing method for EARLINET, Atmos. Chem. Phys., 18, 15879-15901, https://doi.org/10.5194/acp-18-15879-2018, 2018.

Veselovskii, I., Whiteman, D. N., Korenskiy, M., Suvorina, A., and Pérez-Ramírez, D.: Use of rotational Raman measurements in multiwavelength aerosol lidar for evaluation of particle backscattering and extinction, Atmos. Meas. Tech., 8, 4111-4122, https://doi.org/10.5194/amt-8-4111-2015, 2015.

8. Page-7, Line 10-12, the sentence is confused. Why talked about the Figure A2 here? How can you get the first height situated below the top of CBL and the last one at FT from Fig.A2? "As expected tau increases with height for all the wavelengths due to reduction of aerosol load with height. . ..”? I can't find it from the figure. C2 We thank the Reviewer#1 for this comment. In order to clarify these points, the text has been changed as follows:

(Page 7, Line 23)

"Thus, from the comparison of the figures A2 and A5 it is possible to observe that the altitude chosen at 1000 m (red line) is situated below the top of CBL, while the altitude chosen at 1700 m (light green line) is in the FT. As expected, the ε, which is represented by the peak on the lag 0 of the autocovariance function (fig.5), increases with height. . ."

9. Page 8, Line 31-35. Why do you choose the value of 3 as a threshold ("lower than 3 representing a well-mixed region and larger than 3 representing a low degree of mixing")? Figure A5 (28-35) shows the wavelength dependence of the kurtosis profile (KRCS), thus a single threshold seems so arbitrary. We thank the reviewer#1 for this comment. The kurtosis equation in the table A1 represents the kurtosis of a Normal

Distribution (ND), which is equal 3 (Bulmer, 1965). Therefore, due to we observe the variations of the high-order moments referred to ND, the value 3 is adopted as threshold for our kurtosis analyses. In order to clarify these points, the text has been changed as follows:

(Page 10, Line 3-5)

"The kurtosis equation presented in the table A1 represents the kurtosis of a Normal Distribution, which is equal 3 (Bulmer, 1965), consequently such value is applied as threshold in the analyses performed in this paper.

Bulmer, M. G., Principles of Statistics, 1965.

10. Page 10, Line 15-18 about the high-order moments of lidar backscatter signals (skewness and kurtosis). A negative S_corrˆRCS represents the downdraft while a positive value represents the updraft. Are there any other vertical wind measurements to demonstrate it?

Unfortunately, we do not have measurements of the vertical wind speed collocated to the SPU lidar. However, the conceptual definition of skewness (a measure of the asymmetry of the probability distribution) enable us to confirm that a negative S_corrˆRCS represents the downdraft while a positive value represents the updraft, and this fact was validated during the SLOPE-I campaign, which was performed with elastic and Doppler lidar in Granada-Spain during the summer of 2016 (Bedoya-Velásques et al., 2018, Moreira et. al, 2019).

Bedoya-Velásquez, A. E., Navas-Guzmán, F., Granados-Muñoz, M. J., Titos, G., Román, R., Casquero-Vera, J. A., Ortiz-Amezcua, P., Benavent-Oltra, J. A., de Arruda Moreira, G., Montilla-Rosero, E., Hoyos, C. D., Artiñano, B., Coz, E., Olmo-Reyes, F. J., Alados-Arboledas, L. and Guerrero-Rascado, J. L.: Hygroscopic growth study in the framework of EARLINET during the SLOPE I campaign: synergy of remote sensing and in situ instrumentation. Atmospheric Chemistry and Physics, 18, 10, 7001-7017,

http://doi.org/10.5194/acp-18-7001-2018, 2018.

11. Page-10, Line 19-20, “The Scorr RCS(z) obtained from the wavelengths 1064 and 532 nm presents identical pattern of behavior, demonstrating the occurrence of same phenomenon.” However, in the Figure A10., they show different and altitude-dependent positive or negative values at 1000-1500-m. For instance, the values at 1064-nm are negative (“downdraft”) at 1500-1000m while the values at 532-nm are near zeros. They show different patterns. Why do you call “identical pattern of behavior”?

We thank the reviewer#1 for asking this question. The main goal of the turbulence analysis by aerosol lidars is to provide a characterization about the phenomena (like as direction of vertical movements and/or level of mixing), and not its absolute values. Therefore, in this kind of analysis the turbulence cannot be estimated but only characterized. Although the skewness of 1064 nm presents absolute values higher than that observed from 532 nm, in both cases the vertical pattern of skewness is the same in the most of the profile and, therefore, the same phenomena can be observed in both profiles. This is the reason why we affirm an identical pattern of behavior.

12. With the low clouds or residual aerosol layers, can the methodology (high-order moments) in this study be applied?

We thank the Reviewer 1 for this question. Yes, such methodology can be applied in the presence of clouds or aerosol residual layers. The presence of low clouds provides results where a predominance of cloud-driven turbulence can be observed. In the cases where the residual layer is present, it is possible to observe its interaction with the CBL and FT. Examples of these situations are shown in Moreira et. al (2019).

In order to clarify these points, the text has been changed as follows:

(Page 7, Line 5 - 6) “Examples of the application of such methodology in varied meteorological scenarios (presence of clouds and aerosol sublayers) are presented in Moreira et al. (2019).”

Are the high-order moments sensitive to the time window length (e.g. 1-hour long in this paper, 17:00-18:00 UTC for the 1st case, and 18:00-19:00 UTC for the 2nd case)?

Yes, as the window length is reduced the integral time scale is affected, what can reduce the region of atmospheric column where the lidar system can solve the high-order moments. Based on our elastic lidar resolution and earlier papers (Paul et al., 2010 and McNicholas et al., 2014) we decide to use the time window of 1 hour. Considering the lidar system used in this paper, small time windows do not enable us to estimate the high order moments in the whole PBL region. In order to clarify these points, the text has been changed as follows:

(Page 6, Line 23)

"one-hour (the influence of time-window is demonstrated in Moreira et al. (2019))"

Technical corrections or typos:

Page-1, Line-6, "aerosol layers moviments (skewness). . .". moviments or movement? ". . .aerosol layers movement. . ."

Page-2, Line-5, "air surface temperature", surface air temperature? ". . .surface air temperature. . ."

Page-2, Line-8, the meaning of this sentence is confused. The sentence has been rewritten as presented below: "Slightly before sunset, the decrease of the incoming solar irradiance at the surface results in a radiative cooling of the Earth's surface."

Page-3, Line-14, ". . . located at installed ", some typo. The sentence has been rewritten as presented below: "This lidar facility is installed at the Nuclear and Energy. . ."

Page-3, Line-17, "SPU"? full name? The sentence has been rewritten as presented below: "The São Paulo Lidar station (SPU). . ."

Page-3, Line-18 and 19, please add the unit for the wavelength "387 and 407". The sentence has been rewritten as presented below: "... three Raman-shifted channels at

387 nm, 408 nm (corresponding to the shifting of 355nm by N2 and H2O)…"

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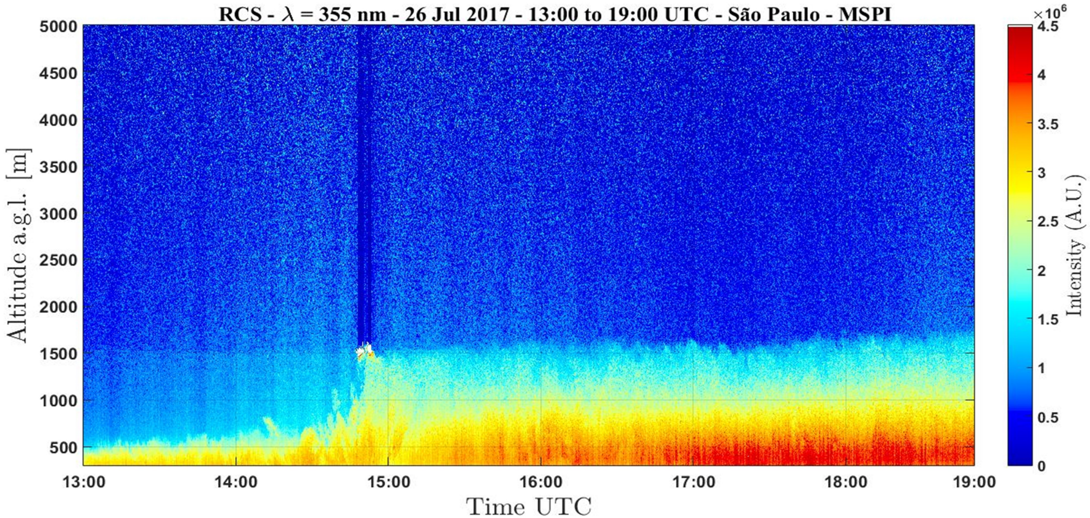

Figure C1. Time Height plot of

Fig. 1.

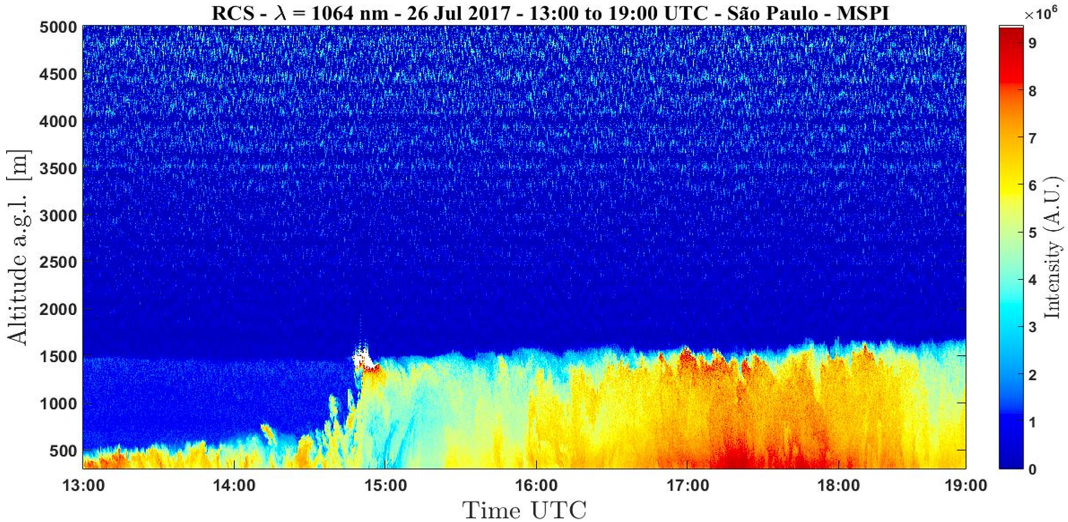

Figure C2. Time Height plot of

Fig. 2.

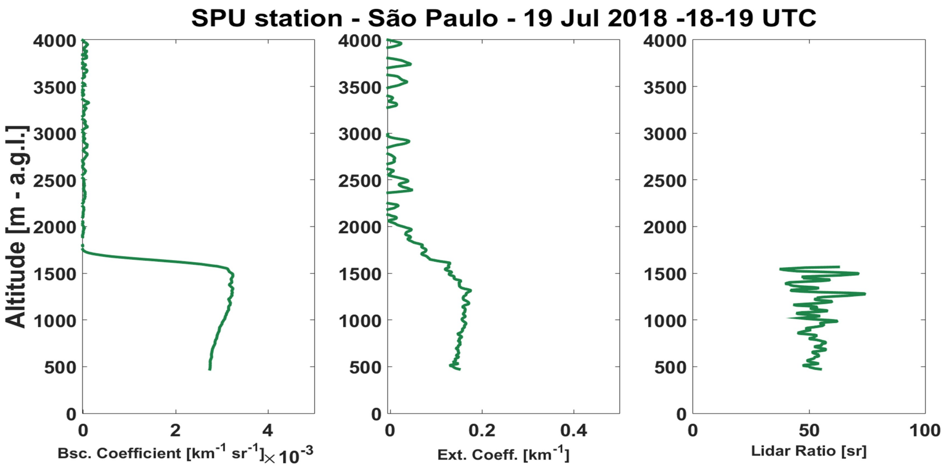

Figure C3. Backscatter, extinction and Lidar ratio profile retrieved using Rotational Raman lidar analysis for 19 of July 2018.

Fig. 3.

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