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Atmospheric Measurement Techniques Discussions

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Interactive comment

Interactive comment on "Aerosol monitoring in Siberia using an 808 nm automatic compact lidar" *by* Gerard Ancellet et al.

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Answer to Anonymous Referee 2

The authors gratefully acknowledge the critical review of the manuscript and the remarks have been carefully taken into account in the corrected version. We hope the new version now emphasizes that a micropulse lidar backscatter can provide useful information about the AOD seasonal variability and the aerosol vertical structure, even though Raman/HSRL lidar remains more powerful tools to obtain a direct extinction vertical profile. The modifications are shown in red within the new version of the manuscript (see supplementary document).

MAJOR CONCERNS

FLEXPART is mainly developed for the analysis of air-masses, both in backward and forward models. The authors propose FLEXPART use in combination with hyphotesis of aerosol sources over different regions. However, I wonder why not using more sophisticated models that already include aerosol modules. An example could be the NASA Goddard Earth Observing System Model, Version 5 (GEOS-5, https://gmao.gsfc.nasa.gov/GEOS/) or other from ECWMF. These model already include aerosol emissions and depositions.

FLEXPART is a good trade-off between simple back-trajectory analysis from known aerosol source regions and 3D aerosol model simulations. FLEXPART is well adapted to represent air mass transport between a source and a measurement site (see Stohl et al. 2002). NASA GEOS5, ECMWF, NAAPS/NRL are indeed very useful if a quantitative assessment of the aerosol load is needed (e.g. for radiative transfer calculation). They generally provides aerosol mapping with a resolution coarser than the data from a single observing station. Furthermore in our study we only need to identify the aerosol type in order to select the appropriate aerosol optical properties to be used in the lidar data processing. A better justification is added p.10 l.7-l.13 in the introduction of section 3.

It is not clear the novelty proposed about the analysis of micropulse lidar data. Actually, authors claim in the conclusion section that they analyze extinction and backscattering measurements, which is not true because a micropulse system needs the assumption of an aerosol lidar ratio. This give a general ambiguety to the scientific discussion. The authors must clarify the novelty they propose.

We agree that the novelty of the methodology was not well described and we tried to improve this throughout the paper

First the old section 4 was thoroughly revised by:

- splitting the old section 4 into the methodology part (now section 2.3) and the discussion of the results in section 4 in order to clarify the contribution to lidar processing methodology and to new results about aerosol characterization in Siberia,

- adding a new figure (Fig. 4) with the lidar data processing flow chart in order to show that a non-standard methodology is indeed needed when dealing with a 808 nm lidar (no molecular signal during the day) and with a long 18-month period where measurement conditions changed (nighttime or daytime, cloudy or clear sky in the 4-7 km altitude range)

- adding a new paragraph at the beginning of section 2.3 (p.8 l.13 to p.9 l.10) to clarify that 4 different measurement conditions must be accounted for: (1) two cases with constrained lidar ratios with independent Ta2 measurements (daytime data with sun-photometer, nighttime with measurements of Ta2 above 7.5 km), (2) two cases with lidar ratios taken from a lookup table built in this work using the constrained lidar ratios and the FLEXPART analysis.

Second reference to extinction profile was removed in the conclusion.

Third, a backscatter lidar is of course limited in the assessment of AOD compared to Raman or HSRL lidar. We already recognized this in the initial manuscript but probably not enough. This is now stated in the introduction (see p.2 l.19-l.24 and p.3 l.20-l.24). Nevertheless, we disagree with the view that nothing can be done with a backscatter lidar in terms of AOD measurements. Various methodologies were used in previous works (external AOD measurement with a sun-photometer, aerosol type climatology, e.g. in the CALIOP algorithm) to provide indirect estimate of the AOD. The purpose of this paper is to propose a methodology combining direct (nighttime) and indirect (daytime) AOD retrieval corresponding to our specific measurement conditions in Siberia. We agree it is less straightforward than dealing with direct extinction profile measurements using a Raman lidar, but our first results, i.e. the comparison with sunphotometer

AOD (Fig. 8 and 9), and the variability of the lidar ratio for the different aerosol type (Table 1), look promising.

For example, when FLEXPART is used for obtaining lidar ratios, Are consistent with the cases when sun-photometer are also available?

The use of FLEXPART has been probably misunderstood. It is now clarified in the section 2.3 (see p.8 l.13 to p.9 l.10) and Fig. 4. FLEXPART is used to:

- build the lidar ratio lookup table (Table 1) using the sun-photometer or nighttime upper troposphere molecular signal from the calibrated lidar,
- select the lidar ratio from the lookup table for the cases where the lidar ratio cannot be constrained (daytime without sun-photometer or nighttime without a molecular signal detectable in the upper troposphere).

The consistency of the AOD using the lookup table with the sunphotometer AOD are indeed checked for the case studies shown in section 5.1 (see Fig. 9).

Also, nighttime retrievals of lidar ratio are not clear. Appendices ‘A’ and ‘B’ do not provide any novelty to what is already known in lidar aerosol optical depth retrieval and in CALIOP depolarization ratio computation.

Yes we agree the Appendix are not meant to develop the innovative aspect but only to provide the basic lidar data processing for readers with no lidar background. The innovative aspect is now discussed in section 2.2 (lidar calibration) and section 2.3 (AOD retrieval combining direct and indirect method), while the methodology is explained in the new figure 4.

Regarding the nighttime retrieval, it is probably the point less commonly found in the lidar data processing literature and it is now better explained that the key point is that a calibrated lidar provide a direct Ta2 measurement using the molecular signal in the free troposphere during the night. A constrained integrated lidar ratio can then be also obtained during the night. Another approach would be to use a lunar photometer, but it was not possible to install one in Tomsk. It is better explained in section 2.3 and in Fig. 4.

Finally, the evaluation or the new methodology would need of correlative measurements of Raman/HSRL systems. If these measurements are not available, at least reference them in the text.

Yes direct comparisons between a Raman lidar and a micropulse data processing using our approach would be a nice follow-up of this work. Unfortunately it was not possible for the very remote place where the lidar was deployed. Nevertheless references to existing Raman lidar contribution are added in the introduction (p.2 l.13-l.24). Is is also discussed when the lidar ratio retrieved by our analysis are compared with the lidar ratios found in the existing literature, since the latter are often based on Raman/HSRL lidar (Burton et al. 2012, Hofer et al. 2017) . It is clarified in section 4.2 where the Table 1 shows the lidar ratio variability for different aerosol sources (p.13 l.21-p.14 l.9) and in section 5.1 using the S808 daily variability during the 3 selected episodes (p.18 l.2-l.10, and p.18 l.13-p.19 l.8 and p.19 l.13-p.20 l.2)

The authors selected three study cases and three months to present their analysis and the links with satellite observations. But to me it is not clear why these cases are representative.

We agree with the reviewer. This section was poorly written. It has been significantly changed to clarify the goal and to present the results.

The introduction of section 5 now reads:

" In this section, we focus on the time periods with elevated AOD observed by the AERONET network above Tomsk in order to (1) compare the results of our AOD analysis with AERONET values during 48 h around the selected lidar profiles and with satellite data (MODIS or CALIOP) (2) identify the likely aerosol sources derived from the FLEXPART analysis with satellite observations (MODIS, IASI, CALIOP) in the source areas . Looking at Fig. 8, there are 5 time periods with sun-photometer AOD > 0.25: mid-may 2015, end of may 2015, April 2016, mid-June 2016 and end of September 2016. We do not have enough lidar data for mi-June 2016. The end of September 2016 and mid-June 2015 cases both correspond to forest fire events, while end of may 2015 and April-2016 correspond to urban, flaring and dust emissions according to our FLEXPART analysis. Therefore the three time periods corresponding to periods A, B, C of Fig. 8 are analyzed in this section. The section 5.1 presents the daily variability of the lidar backscatter profiles and sun-photometer AOD, while the section 5.2 presents the analysis of satellite observations."

MINOR CONCERNS

Pag. 9: Authors say that Russia emissions are not well-known but they use ECLIPSEv4 dataset for emissions. That seems a contradiction. Please clarify

The ECLIPSEv4 dataset is only meant to identify the location of the flaring emission in section 3. Underestimation of the ECLIPSEv4 emission factor which is reported in the literature, will not strongly bias the assessment of the flaring source location. This underestimate would be detrimental only if the emission factor was used to calculate the aerosol concentrations and related aerosol optical properties. This does not apply to our work with ECLIPSEv4.

Pag. 2, Line 13: EARLINET network posses more sophisticated instruments such as Raman lidar, which provide further information on aerosol vertical-profiles. The authors should include this in the introduction. Also, there are many measurements of Raman lidars in North America, Asia and Latin America. The authors should not ignore that.

This was recognized in the previous introduction but not enough. More references to Raman lidar aerosol monitoring are added (see p.2 l.13-l.16).

Pag. 2, Line 15: Please define what is CIF.

Done

Pag. 2, Line 26: The best estimates of Angström exponent are provided by MISR satellite, not by MODIS. Please correct.

Done. Reference to MISR is added in the introduction (p.3 l.5-l.7). In the paper the AE is always derived from the AERONET sunphotometer observations and not from MODIS.

Pag. 2, Lines 29-30: CALIPSO does not provide direct estimates of aerosol extinction. CALIPSO is backscattering lidar. Please correct.

Sentence changed. CALIPSO still provides indirect aerosol extinction profiles (see Winker et al. 2013, Omar et al. 2009). See p.3. l.10.

Pag. 3, Line 8: Why not complementing your study with VIIRS satellite?

It is included in the biomass burning aerosol source analysis (see section 3.2 p.11 l.17-l.23)

Section 2.1: Is the lidar system operating continously?

Yes see introduction of section 2 (p.4 l.1), but for the aerosol analysis we must use a 30 min. time averaging with no cloud between 0-4 km (p.4 l.27-l.33)

Section 2.1: What is the vertical resolution of your lidar system?

Vertical resolution is 15 m (see p.4 l.23) and additional 150 m vertical filtering for the assessment of the molecular signal (sentence added p.5 l.24).

Pag. 4, Line 33: Please, provide references for ERA-Interim. Done

Pag. 5: Please provide a better explanation of your iterative method for computing lidar ratio. Why starting at 60 sr? What happen with dust cases?

Thank you for suggesting to clarify this. The following text is added in section 4.2 p.13 l.19: "Starting with the largest expected lidar ratio allows a fast convergence towards the true value (e.g. Young95). Thirteen $S_{808} < 45$ sr could be retrieved with this method out of the 15 FLEXPART dust cases even though iteration starts with 60 sr."

Pag. 5: Please give a complete definitions of the variables in Line 2 and in equation 1.

I am not sure what the reviewer meant, variables are actually defined p.5 l.26 and p.6 l.3-l.4.

Pag. 7, Line 6: It is difficult to understand how you obtain the final accuracy on calibration factor. Please give a better description.

We agree it was not so clear. The text now reads (p.8 l.1):

"To estimate our error on K values for non-optimal conditions (red points in Fig. 3), a good proxy is the difference between two optimal calibration factors derived for two observations made with a time difference $<$ 1 day. Changes of K$_{op}$t for such a short time period cannot be expected when aiming at calibration of daytime observations with a nighttime calibrated profiles. There are 23 pairs of K$_{opt}$ values with a 1-day time difference and the standard deviation of their difference, DK$_{opt}$, is 2.5 10^{4}. Such a variability is then a limiting factor in our ability to calibrate the lidar for daytime observations or nighttime conditions with either AOD$>$0.06 or clouds between 4 and 7.5 km. The corresponding accuracy on the calibration factor K is then of the order of 8% (2.5 10^{4} / 3 10^{5})"

Pag. 8 and 9: Please provide the link for MODIS and VIIRS data. Done in section data availability

Pag. 9: Please, provide a link for ECLIPSEv4 database.

Done in section data availability

Pag. 10, Line 1: This statement is incorrect. Compation of AOD requires vertical-profile of lidar ratio which is possible with Raman and HSRL systems but not with micropulse lidars. Your approach assumes constant lidar ratio. Please correct.

We disagree with the reviewer. It is possible to derived directly the AOD during the night if the lidar is well calibrated and if the molecular signal can be detected in the upper troposphere. This is explained in section 2.3 and it is the backbone of our independent estimate of Ta2 during the night. Since it was not clear enough, now section 2.3 details the methodology and a specific section (section 4.1) presents the results obtained with the direct AOD measurements (see also answer to major comments).

Pag. 11, Line 3: This statement is incorrect. Currently, it is possible to obtain AOD during the night by star and moon photometry (see ACTRIS project for example). Please correct.

We agree. This possible alternative is included (sentence p.13 l.11) even though no lunar photometry was available in Siberia during our lidar measurement period.

Figure 5: Please, explain better how you compute your nighttime AOD. Particularly, how do you obtain nighttime lidar ratios.

This has been clarified (see answer to major comments)

Figure 7: It is difficult to follow how was the aerosol load during the different periods you claim. Why not adding AOD temporal evolution?

We thank the reviewer for suggesting this AOD comparison when validating the AOD lidar retrieval for the 3 case studies. A new figure is added (Fig.9) to discuss the AOD diurnal variability measured by the sunphotometer and the lidar. More lidar vertical profiles are also reported in Fig. 10 to 12. It is now discussed in section 5. 1 (see major comments)

Section 5.1.1 must be strenghten. The scientific discussion is poor. It is not clear the large diurnal variability in lidar values for Case C. Are each of the cases selected illustrative of the different atmospheric conditions over the study area?

We fully agree it was a weak point in the initial version. Section 5.1 has been strongly modified (see answer to major comments)

Pag 18, Line 6: It is not clear if you use standard CALIPSO data or your own computations,

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particularly for depolarization measurements.

We use our own computation for the CALIPSO backscatter ratio profile, AOD and depolarization ratio, but it is based on CALIOP Level 1 attenuated backscatter and level 2 aerosol and cloud data products. The IR imager brightness temperatures are also used to check the aerosol/cloud discrimination. Lidar ratio is usually based on the CALIOP L2 data products. It is explained in section 5.2.1 p.21 l.12-p.22 l.8 More details can be found in Ancellet et al. 2014.

Pag 20, Line 13: The PBL is a region in your profile not a source of aerosol emissions. Please correct this.

Done