Quantifying Vertical Concentration of Long-Range Transported Biomass Burning Aerosols from Canadian Wildfire in 2023 Using Lidar Observations

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Abstract: During the unusually long wildfire season in 2023, the multi-wavelength Mie-Raman-polarization-fluorescence lidar recorded a long time series of transported biomass burning aerosols. With these observations, we obtained a comprehensive dataset about the optical and microphysical properties of BBAs. In this study, we present a method for estimating BBA volume/mass concentrations from lidar observation. The derived profiles of volume and mass concentration show good consistency with airborne measurements and model simulations, respectively.

1. Introduction

The wildfire season in 2023 is marked by its unusually early onset and record-breaking burning area. Copious quantity of biomass burning aerosols (BBA), containing black carbon (BC) and brown carbon (BrC), are emitted into the troposphere and stratosphere during the combustion. BBAs can impact directly the radiation budget through strong absorption, influence indirectly cloud processes and stay longtime in the atmosphere if lifted to the stratosphere. Therefore, quantifying the concentration, vertical distribution of BBAs and their relevant properties and processes are important to access their impacts.

Lidar observations have unique advantage in providing vertically resolved information in atmospheric remote sensing. This study is based on the observations of a multi-wavelength Mie-Raman-polarization-fluorescence lidar -- LILAS, operated at ATOLL observatory at University of Lille, in the north of France. LILAS is one of the state-of-the-art aerosol lidar systems, implemented with three elastic channels (355, 532 and 1064 nm, all with parallel and cross polarization pairs), three Raman channels (387, 408 and 530 nm) and one fluorescence channel at 460 nm [1][2]. Due to the unprecedented Canadian wildfires, LILAS observations show BBA layers are presented on 90% of the observational days during May-October 2023. These observations provide us a rich dataset of optical and microphysical properties about long-range transported BBAs, through which we derived the characteristics of aged BBAs and developed a method to estimate the vertical distribution of BBA particle concentrations from lidar measured extinction coefficient and/or fluorescence backscatter coefficient.

2. Result and Discussion

Concentration vs Extinction

The method is based on the study of Kolgotin et al., 2016 [3], where a relationship between V_t/R_{eff} (V_t: aerosol volume concentration, R_{eff}: aerosol effective radius) and aerosol extinction coefficient is established. This study provides a proxy for quantifying vertical aerosol concentration through lidar extinction profile, given that the size of long-range transported BBA particles varies in a minor to moderate range. Figure 1 shows that the linear relationship between the extinction coefficient at 532 nm and BBA volume concentration retrieved from $2\alpha+3\beta+3\delta$ lidar data using a retrieval algorithm--BOREAL, based on maximum-likelihood estimation [4]. The lidar observations are obtained in May to September 2023 from LILAS lidar at ATOLL. More than 30 smoke layers in the troposphere and stratosphere are analyzed and their retrieved volume concentration and effective radii are plotted in Figure 2.

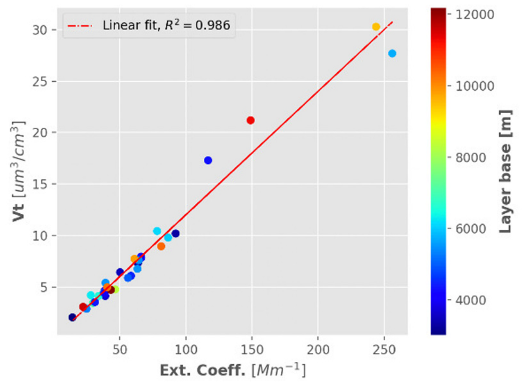

Figure 1. The linear correlation between the extinction coefficient at 532 nm and volume concentration of observed in long-range transported BBA layers over ATOLL observatory, Lille, France, in 2023.

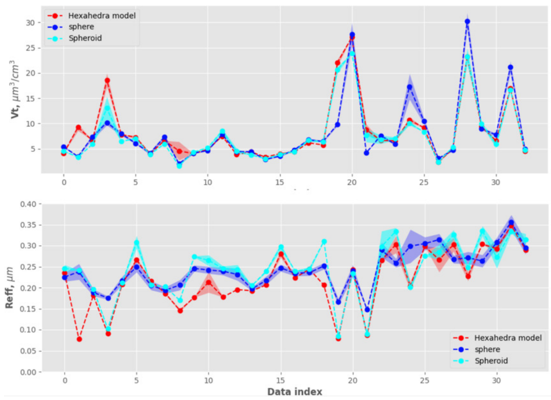

Figure 2. Volume concentrations (Vt) and effective radii (Reff) retrieved from BOREAL algorithms using different scattering model: hexahedra (red), sphere(blue) and spheroid (cyan). The input data for the retrieval is obtained from LILAS lidar observations at ATOLL observatory.

For intercomparison and validation, the estimated BBA volume concentration profile using lidar data on 21 July 2023 is compared with the measurements of a particle sizer onboard an aircraft overpassing the lidar station during the AEROHDF campaign. Figure 3 shows the estimate of volume concentration is very consistent with real measurements.

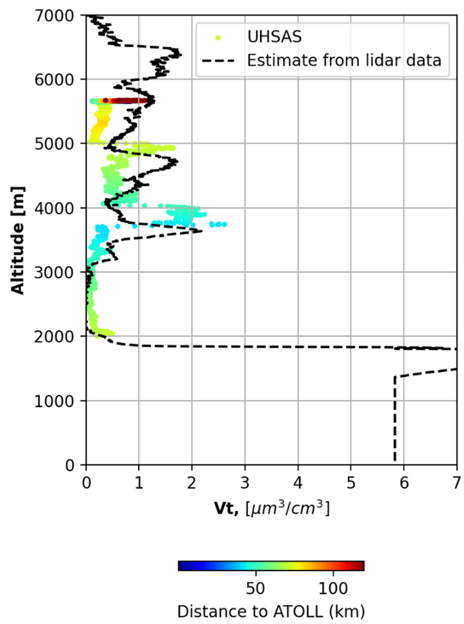

Figure 3. The comparison of volume concentration estimated from lidar derived extinction (12:00--12:40 UTC) and measured by UHSAS particle sizer (12:07--12:59 UTC) onboard aircraft on 21 July 2023 during the AEROHDF field campaign. The colors indicate the distance between the aircraft and ATOLL observatory.

Concentration vs Fluorescence Backscatter

Furthermore, we investigated the feasibility of estimating BBA volume and mass concentration from the fluorescence backscattering coefficient measured by lidar. The results, shown in Figure 4, indicate the two quantities are still strongly correlated in dry conditions, while the interferences arise from the hygroscopic growth of BBAs under high humidity conditions. Because the fluorescence signals are induced from the dry BBA substance. This indicates that we can use the fluorescence signal to derive the mass concentration of dry BBAs.

Figure 5 shows the comparison of BC mass concentration estimated from fluorescence backscattering and simulated by MOCAGE (Modèle de Chimie Atmosphérique de Grande Echelle) model. The BBA particle density is assumed to be 0.97 g/cm^3 [3] and the fraction of BC in the total mass of BBA is assumed to be 3%, since the BBA particles have undergone long-time aging.

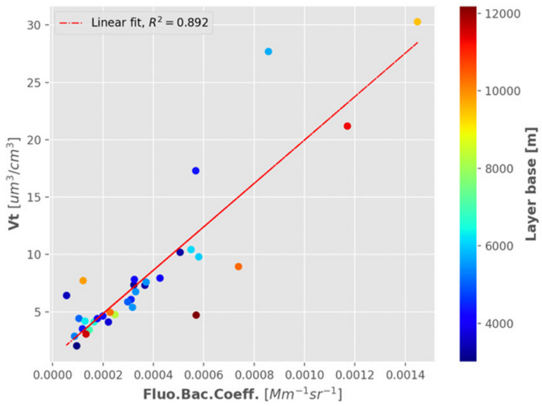

Figure 4. The linear correlation between the fluorescence backscatter coefficient and volume concentration of observed in long-range transported BBA layers over ATOLL observatory, Lille, France, in 2023.

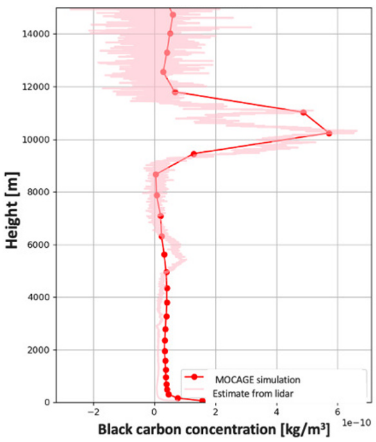

Figure 5. The comparison of black carbon vertical mass concentration from MOCAGE simulation (red dotted line) and the estimate based on lidar observation (pink solid line). The profile from MOCAGE corresponds to 20:00 UTC, 26 August 2023 and the lidar observations are averaged between 19:15 and 20:30 UTC, 26 August 2023.

3. Conclusion

This study presented a method of quantifying BBA vertical concentrations from lidar observations. It is based on a sophisticated dataset of optical and microphysical properties of BBA particles obtained from lidar observations at ATOLL observatory during the record-breaking wildfire season in 2023. The results show the vertical (volume or mass) concentration of BBA particles can be estimated from the extinction profile or alternatively from the fluorescence backscattering profile. The estimated BBA concentration profiles show good agreement with airborne in-situ instruments and model simulations. This study provides an efficient method for quantifying BBA vertical concentrations from lidar data and can be transferred to other lidar observations.

4. Acknowledgements

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5. References

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