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Temporal variations in optical and microphysical properties of mineral dust and biomass burning aerosol derived from daytime Raman lidar observations over Warsaw, Poland

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HIGHLIGHTS

- Successful daytime Raman lidar profiling of aerosol optical properties.
- Untypical size of Saharan dust particles and transport pathway to Warsaw.
- First ever complex lidar analysis of aged biomass burning aerosol over Warsaw.

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ABSTRACT

In July 2013, favorable weather conditions caused a severe events of advection of biomass burning particles of Canadian forest fires to Europe. The smoke layers were widely observed, especially in Western Europe. An unusual atmospheric aerosol composition was measured at the EARLINET site in Warsaw, Central Poland, during a short event that occurred between 11 and 21 UTC on 10th July 2013. Additionally to the smoke layer, mineral dust was detected in a separate layer. The long-range dust transport pathway followed an uncommon way; originating in Western Sahara, passing above middle Atlantic, and circulating over British Islands, prior to its arrival to Poland. An effective radius of 560 nm was obtained for Saharan dust over Warsaw. This relatively small effective radius is likely due to the long time of the transport. The aerosol-polarization-Raman PollyXT-UW lidar was used for a successful daytime Raman retrieval of the aerosol optical properties at selected times during this short event. The aerosol vertical structure during the inflow over Warsaw in terms of optical properties and depolarization was analyzed, indicating clear distinction of the layers. The microphysical properties were inverted from the lidar derived optical data for selected ranges as representing the smoke and the mineral dust. For smoke, the effective radius was in the range of 0.29–0.36 μm and the complex refractive index 1.36 + 0.008i, on average. For dust, the values of 0.33–0.56 μm and 1.56 + 0.004i were obtained. An evolution of the aerosol composition over Warsaw during the day was analyzed.

1. Introduction

Boreal forest fires that occurred in Canada during the summer 2013 caused about 4.2 million ha of the forest area burnt (Rickford, 2014). Number of the active fires was about 10% lower than the 10 years average but the burnt area exceeded the average twice. The wildfires were exceptionally active in the Quebec province where burnt acreage was 10 times greater than the decade mean. The biomass burning aerosol was transported across Atlantic towards Europe and observed at first in Central Europe (until 11th of July) (e.g. Trickl et al., 2015; Janicka et al., 2016; Markowicz et al., 2016; Ortiz-Amezcua et al., 2017). After that date, the smoke layer was present over Western and Eastern Europe (e.g. Samaras et al., 2015).

These previous studies discussed various aspects of the 2013 Canadian smoke season. An overview on the Canadian smoke event that occurred at the beginning of July 2013 has been discussed by Markowicz et al. (2016) based on analysis of the ground-based

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measurements that were collected in place of the smoke emission and along the long-range transport path to Poland. For the analysis of extensive set of data obtained from satellite sensors, the Moderate Resolution Imaging Spectroradiometer (MODIS) and Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO), as well as the Navy Aerosol Analysis and Prediction System (NAAPS) model output were used. Their study regarded also the smoke radiative forcing implications, as the absorbing aerosol type, over selected sites in Poland. The radiative forcing of the biomass burning aerosol revealed values up to -35 W/m^2 at the stations of the Polish aerosol research network PolandAOD, indicating significant impact on the surface radiation budget.

The stratospheric intrusions of the Canadian smoke in July 2013 were detected over Germany and reported by Trickl et al. (2015); high ozone concentrations accompanied with dry conditions were found in the advected aerosol layers. Ortiz-Amezcua et al. (2017) attempted to parametrize the relation of the particle extinction coefficient to the particle volume concentration for the Canadian biomass burning aerosol based on the observations of the smoke layers in July 2013 conducted over USA and at a few lidar sites of the European Aerosol Research Lidar Network (EARLINET; Pappalardo et al., 2014). Samaras et al. (2015), discussed microphysical properties of aerosols originating from various fire sources that were captured over Bucharest. Their analysis was performed in the context of establishing relations between the derived microphysical and optical properties, e.g. correlation of aerosol effective radius and particle age, as indicted by lidar ratios.

However, in none of the mentioned publications extensive analysis of the diurnal evolution of the aerosol microphysical parameters was reported. This topic is addressed in the present paper. The results obtained for a specific day selected during the smoke event are discussed. On 10th July 2013, besides the biomass burning particles from Canada also mineral dust particles were advected in a separate layer over Warsaw. Such intrusions of Saharan dust are not unusual over Poland (e.g. Chilinski et al., 2016). The results discussed within the current paper make valuable complement to already existing studies; the Raman-derived optical properties along 10th July 2013 provided a unique data set which was then used for the inversion of the microphysical properties within the mentioned layers of interest.

Another aspect discussed within the present paper is the daytime aerosol extinction retrieval performed with the classical Raman technique, with no additional modifications applied on the system in order to sufficiently suppress the bright sky light during the daytime operation (e.g. decreasing field stop size or using specialized interference filters designed for rotational Raman lines, as e.g. in Veselovskii et al., 2015; Haarig et al., 2016).

The present paper is organized as follows. In section 2, an overview of lidar technical aspects and the retrieval methodology is given. In section 3, the aerosol properties and the analysis of air-masses transport paths based on the backward and forward trajectories are discussed. The qualitative analysis of the lidar profiles is given in subsection 3.1. In subsection 3.2, we analyze the origin of the aerosol layers present in free troposphere. Subsections 3.3 and 3.4 contain discussion of the optical and microphysical properties, respectively. In section 3.5, analysis of the aerosol vertical structure is included. The paper is summarized in Conclusions.

2. Methodology

The Radiative Transfer Laboratory RT-Lab in Warsaw, Poland (52.21°N, 20.98°E, 112 m a.s.l.) is equipped among other instrumentation with the 12-channel NeXT generation PollyXT-UW lidar (Engelmann et al., 2016; Stachlewska et al., 2016a). This lidar is providing the data to the lidar networks: the PollyNET (http://polly.tropos.de; Althausen et al., 2013) and the EARLINET (https://www.earlinet.org; Pappalardo et al., 2014). Moreover, the lidar data are also a part of the extensive data set of the national aerosol and radiation network PolandAOD (http://www.polandaod.pl; Markowicz et al., 2016, Appendix A).

Since July 2013, the main lidar unit provides quasi-automated measurements at 8 far-range channels with a so-called $3\beta + 2\alpha + 2\delta$ + WV detection module providing signals at 1064, 532 and 355 nm (3β; backscattering elastic channels); 532 and 355 nm (2δ; polarization elastic cross channels); 607 and 387 nm (2α; Raman N_2 channels) and 407 nm (WV; Raman H_2O channel, only nighttime). Build in February 2015, a compact near-range aerosol-Raman lidar receiver (NARLa) comprising a so-called 4-channel $2\beta + 2\alpha$ detection module operating at 532 and 355 nm (elastic), and 607 and 387 nm (Raman N2), can be used with the main unit or independently (Stachlewska et al., 2016a). The NARLa was not used in this study.

The lidar emits pulses with energies of 180 mJ at 1064 nm, 110 mJ at 532 nm, and 60 mJ at 355 nm with a repetition rate of 20 Hz. The laser beam is expanded to 45 mm diameter, which is resulting in a beam divergence <0.2 mrad. Two Newtonian telescopes receive the signals. For the far-range ($3\beta + 2\alpha + 2\delta$ + WV) detection, a 300 mm primary mirror with a pinhole of 0.9 mm diameter is used, resulting in 1 mrad field of view. For the near-range ($2\beta + 2\alpha$) detection, a 50 mm reflector with a fiber scrambler of 2 mm sapphire ball lens is used, resulting in 2.5 mrad field of view. The photon counting detection is performed with Hamamatsu H10721P-110 photomultipliers; for the 1064 nm Hamamatsu R3236 is used. Signal acquisition of 600 MHz photon counters provides 7.5 m height resolution. Signals are recorded up to 48 km including the pre-trigger of circa 250 range bins.

The lidar data are evaluated to obtain the optical properties: particle backscattering and extinction coefficients, particle depolarization ratio, particle lidar ratio, extinction related Ångström exponent (355/532) and backscattering related Ångström exponents (all elastic wavelengths combinations) whereby the EARLINET quality assurance procedures are in place. More details on the evaluation scheme are given in Baars et al. (2016). The Warsaw lidar site is recognized as one of rather new although very active EARLINET sites. Raman-derived backscattering and extinction profiles as well as linear depolarization profiles (all with uncertainties) are provided regularly to the EARLINET/ACTRIS data base (>1000 profiles evaluated since July 2013 till present). These profiles were used recently by Nicolae et al. (2017) to present the excellent potential of the EARLINET sites in Warsaw and Bucharest for an automated aerosol typing using a neural network approach.

As a standard, for the basic retrieval performed on the hourly bases, we use data at 532 nm elastic and elastic-cross channel averaged over 30 min. The particle backscattering coefficient is obtained using the classical backward approach (Klett, 1981; Fernald, 1984) with an assumption of the lidar ratio of 50 sr. This corresponds to the typical climatological value derived from the Raman long-term EARLINET measurements conducted at the Warsaw site, which are of 46 ± 15sr at 355 nm and 51 ± 12sr at 532 nm (e.g. Stachlewska et al., 2016b). The volume depolarization ratio is calculated with molecular calibration (Freudenthaler et al., 2009). Typical uncertainties for the nighttime (daytime) profiles are around 10 (20) % for β_{Klett} and of about 3 (10) % for δ_{vol}. We use such data set to identify potential areas of interest, that we then explore with more advanced and thus more time consuming data evaluation techniques.

As a second step, for the selected areas of interest, the nighttime and daytime retrieval of particle extinction and backscattering coefficient profiles was performed using the classical Raman approach (Ansmann et al., 1990). Due to the chosen evaluation type,