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REMOTE SENSING OF BIOMASS BURNING AEROSOL BY THE MEANS OF MULTIWAVELENGTH LIDAR MEASUREMENTS IN WARSAW

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Abstract

Long-term remote sensing of the atmospheric aerosol is crucial for climate studies. Biomass burning aerosol is of special importance, as it scatters and absorbs solar radiation, whereby the latter leads to local warming of the atmosphere. In this study, a comparative analyses of particle optical properties of biomass burning aerosol, as derived from the vertical lidar profiles within the troposphere, is discussed. The profiling was done with the multi-wavelength, double field-of-view, Raman-Mie, polarization, and water vapor Lidar. The selected cases represent different-origin episodes of biomass burning aerosol advection over Warsaw.

1 Introduction

Small particles suspended in the atmosphere, called atmospheric aerosol, play an important role in the Earth's climate system due to their interactions with the solar radiation: aerosol particles scatter and/or absorb solar light, dependent on its wavelength. Scattering leads to the cooling of the atmosphere, whereas absorption causes heating of the atmosphere at a layer at which absorbing aerosol are present. Therefore, studies of absorbing aerosol are so important for the climate change modelling [1].

The crucial aerosol component that is absorbing solar radiation constitute black carbon. It can be released into the atmosphere by the combustion processes of fossil and bio fuels, that among others, can originate from wildfires of natural ecosystems or agriculture areas. Additionally to the black carbon, biomass burning aerosol (BBA) consist of organic carbon and inorganic particles [2]. Emission of the BBA during the episodes of forest or grassland fires is huge, can last long-time, and results in release of large amounts of heat. The released heat causes deep convection, which can uplift the aerosol (even up to the stratosphere) and redistribute over long-distances from the place of BBA origin [3]. After the emission, the BBA is subject to the intense ageing processes, which causes changes of its optical and microphysical properties. Consequently, that makes the BBA influence on the Earth's radiation budget significant.

In this study a few particular events of long-range BBA transport over the Warsaw are analysed, whereby the episodes represent different places of aerosol origin and different aerosol age.

2 Methodology

Advanced lidar systems are very convenient tools for atmospheric aerosol studies, as they can provide vertical profiles of optical properties of the atmosphere. Advanced lidars can detect the laser light scattered elastically backwards on the aerosol particles, but also using the Raman scattering on the atmospheric nitrogen molecules. Thus, they can provide independent profiles of the aerosol particle extinction and backscattering coefficients. Information of the particles shape (spherical or aspherical) is provided by the detection channels measuring the cross- and parallel-polarization of the emitted linearly polarized laser light changed by aerosol particle. Using the data-products derived from lidar at several wavelengths, lidar provides the data set sufficient to be used as an input for the mathematical inversion algorithms [4], which allow to obtain microphysical aerosol properties such as: particle effective radius, particle refractive index, number, surface, and volume concentrations, and single scattering albedo. The latter can be directly used for the estimation of the radiative forcing due to aerosol [5].

2.1 Instrument

The modern 12-wavelength PollyXT lidar system [6] operates in the Remote Sensing Laboratory (RS-Lab) at the Institute of Geophysics, Faculty of Physics, University of Warsaw since July 2013. The system was build with the scientific cooperation with the Leibniz Institute for Tropospheric Research (TROPOS). The system provides the quasi-continuous vertical lidar measurements with the emitted Nd:Yag laser light at 355, 532, and 1064 nm. Backscattered light is collected by two Newtonian-type telescopes (narrow and wide field of view) and is divided into 8 detection channels for the far-range (0.6 -15 km) and into 4 detection channels for the near-range (0.12 – 3.5 km), respectively. Combination of two telescopes minimizes the effect of incomplete overlap of the laser beam and the narrow telescope field of view. The far-range channels are 355, 532, 1064 nm elastic; 355, 532 nm cross-polarized; 387, 607 nm Raman-shifted on N_2 and 407 nm Raman-shifted on H_2O to provide profiles of water vapour mixing ratio. The near-range channels are 355, 532, 387, and 607 nm. Signals are detected with photomultipliers (in photon counting mode) with raw resolution of 30 s and 7.5 m.

The lidar operates within the European Aerosol Lidar Network *EARLINET* [7], the worldwide network of PollyXT lidars - *PollyNET* [8] and the Polish Aerosol Research Network *PolandAOD* [9].

2.2 Data evaluation

The particle optical properties profiles: particle backscatter coefficients (β) at 3 wavelengths and particle extinction coefficients (α) at 2 wavelengths were derived using the classical Raman approach, according to the evaluation scheme given in [10]. The profiles of linear depolarization ratios (δ) at 2 wavelengths were derived with the ±45° calibration method [6]. The water vapour mixing ratio (wv) was calculated as given in [11].

The lidar ratio was calculated as $LR_\lambda=\alpha_\lambda/\beta_\lambda$ at particular wavelength; this parameter is useful for aerosol type identification. Ångström exponent (related to extinction) was calculated as $AE_{355/532}= -\ln(\alpha_{355}/\alpha_{532})/\ln(355/532)$.

The analysis was supported by the data products of the MODIS measurements onboard satellite and the model output backward trajectories runs with HYSPLIT [12] to assess and better specify the aerosol place of origin (Figure 1).

3 Results

Four episodes of BBA advection over Warsaw were chosen for comparative study (Figure 1):

a) long-range transport of the smoke from Canadian forest fires on 9th July 2013 [13];

b) fast transport of the BBA from wildfires in Ukraine driven by the clean Arctic air-mass on 19th March 2015;

c) advection during the heat wave on 10th August 2015 from the southern Ukraine through Southern and Central Europe;

d) advection of the aged BBA from the Iberian Peninsula through southern edge of Western Europe on 1st September 2018.

The lidar ratios for analyzed cases are in the range of 35-100 sr, whereby the lowest and the highest one was for 355 nm (Table 1). In the cases of Ukrainian BBA sources, the LRs are high (68-100 sr) and the values for 355 nm are higher than the ones for 532 nm. The relation of $LR_{355}>LR_{532}$ indicates stronger absorption of short waves. The opposite relation was observed for the case of long-range transport of smoke from Canadian forest fires and from the Iberian Peninsula with lower LR values (35 sr at 355 and 67 sr at 532 nm). The relation of $LR_{355}<LR_{532}$ is often observed for the aged BBA [14], as the ageing processes lead to the increase of the particles size.

The extinction related Ångström exponent had the lowest value of 0.64 for the Iberian fires, higher of 0.97 for the Canadian fires and the highest of 1.62-1.71 in the Ukrainian cases. This values confirm hypothesis of larger particles in the aged BBA, as low values of AE indicate larger particles size.

The particle linear depolarization ratio was in the range of 1.2-8.3 %. Higher values were obtained at 532 nm for all cases. The values of 5.4 % (355 nm) and 8.3 % (532 nm) (the highest ones) were observed for the case of the fast aerosol transport in the Arctic air-mass. Such high depolarization can be related to the very dry condition of the Arctic air (relative humidity data not shown here for brevity) and to the short time after aerosol emission. Small values up to 3 % were observed on 10th August 2015 and 1st September 2018 and can be attributed to high relative humidity. For the Canadian fires, the depolarization was relatively low of 3.3-3.5 % and almost equal for both wavelengths.

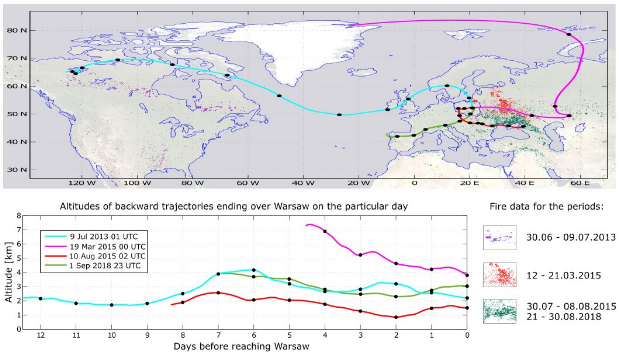

Figure 1 *The HYSPLIT backward trajectories on episodes of BBA advection to Warsaw chosen for comparative study and corresponding active fire data from the MODIS satellite sensor.*

	9 Jul 2013 blue	19 Mar 2015 pink	10 Aug 2015 red	1 Sep 2018 green
LR_{355} [sr]	43	100	86	35
LR_{532} [sr]	61	71	68	67
$AE_{355/532}$ [-]	0.97	1.71	1.62	0.64
$\delta_{part355}$ [%]	3.3	5.4	1.4	1.2
$\delta_{part532}$ [%]	3.5	8.3	3	1.7

Table 1 *Mean lidar-derived properties of BBA in four episodes of advection to Warsaw.*

4 Conclusion

Quasi-continuous lidar measurements of atmospheric aerosol performed in the RS-Lab allow to observe episodes of biomass burning aerosol advection of different origin and time of transport in the atmosphere. The presented comparative study of four cases show, that the aged aerosol originating from Canada and the Iberian Peninsula differ significantly from the ones from Ukrainian sources: the lidar ratios were lower and the relation of LRs was reversed, Ångström exponent and the depolarization ratios were relatively low for the aged aerosols.

The data obtained in the analysis of biomass burning aerosol over Warsaw will be used for the inversion of microphysical aerosol parameters for selected cases.

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