LIDAR BASED SEPARATION OF POLLUTED DUST OBSERVED OVER WARSAW (CASE STUDY ON 09 AUGUST 2013)

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ABSTRACT

This paper presents preliminary results of using an extended POLIPHON method for separation of dust and non-dust aerosol backscatter coefficient, applied on a case study of 9th August 2013. That day, long-range transport of mineral dust over EARLINET-ACTRIS lidar site in Warsaw was observed with the 8-channel PollyXT-UW lidar. The dust particles were also observed by the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) on board the CALIPSO satellite. The backward trajectories calculated using the HYSPLIT model confirmed the air-mass transport from Northern Africa. Results yield possible dust separation for the mixture of dust with other aerosol types, such as pollution, marine type, etc.

1. INTRODUCTION

Mineral dust is one of the major components of the atmospheric aerosol system that influences climatic and environmental conditions in several ways. It can affect climate directly by scattering and absorbing the incoming solar and outgoing terrestrial radiation fluxes. Indirectly, it can cause changes in the cloud cover, acting as nuclei for water vapor to create cloud droplets, which changes the optical properties and lifetime of clouds and may influence precipitation formation. The main sources of mineral dust observed over eastern and southern Europe are located in the North African and the Middle East deserts. Large amounts of mineral dust can be advected over long distances in the free troposphere, and therefore observed far from the source in different places over the globe [1]. In the case of climate modeling, different properties of the fine and coarse mode dust particles must be taken into consideration. The coarse mode covers the particle size spectrum with a diameter higher or equal 1 µm, whereas the fine mode is composed of particles with sizes below 1 µm. The particle linear depolarization ratios at 532 nm of 39±4% were reported for airborne mineral dust dominated by the coarse mode particles and of 16±5% for dust dominated by the fine mode particles [2].

In this study, the results of the separation of the contribution of the coarse dust, fine dust and non-dust within the particle backscattering coefficient profile for Raman lidar observations in Warsaw is presented.

2. METHODOLOGY

Data collected at the Remote Sensing Laboratory (RS-Lab) in Warsaw using the 8-channel PollyXT-UW lidar (details in [3]) were used. The quick look plots available via the PollyNET Website (*http://polly.tropos.de*) were examined to find the good-candidate case, which was defined as a day with strong aerosol load and depolarizing layer in the free troposphere that likely contained long-range transported mineral dust. The data provided by the CALIOP lidar onboard the CALIPSO satellite were searched for the corresponding overpass, defined as the nearest in time and distance from the RS-Lab site, with signatures of possible dust over Warsaw latitude. In this way, for analyses data on 9th August 2018 were selected. The HYSPLIT model [4] was used to calculate the backward trajectories of air-masses movement to estimate the possible source of aerosols with the use of the GDAS meteorological data for air-masses at 1.0, 2.5 and 3.8 km, lasting 168 h and ending at 01:00 UTC, 9th August 2018 in Warsaw.

The particle backscatter and extinction profiles at 355 and 532 nm were obtained independently, using the classical Raman approach [5] with an assumption of the Ångström exponent (AE=1) and the calibration of backscattering profiles at a range above 6 km. The particle depolarization ratio profiles were obtained at 355 and 532 nm, as described in [3], using the ±45° calibration method. All profiles were calculated with a coarse temporal resolution of 2 h for 7.5 m vertical resolution and smoothed with a running mean of 41 range-bins.

The separation algorithm was implemented in the way described in [1], using the threshold values on the particle depolarization ratios as provided in [1,2]. The separation algorithm was applied in two ways called the one- and two-step separation method. As a result of the one-step separation algorithm, the profiles of the particle backscattering coefficient due to dust and non-dust particles are separated within the particle backscattering coefficient profile. The dust particles contribution to the backscattering coefficient is obtained for the particle depolarization ratio δ_p between $0.05 \leq \delta_p \leq 0.31$. The non-dust contribution to the particle backscatter coefficient is obtained by subtraction of the dust backscattering contribution from the particle backscattering profile.

The two-step separation gives the contribution of dust coarse, dust fine and non-dust particles to the initial profile of the particle backscattering coefficient. Firstly, the coarse dust particles contribution to the backscattering coefficient is obtained for $0.24 \leq \delta_p \leq 0.39$ and subtracted from the particle backscattering profile. Secondly, from the remaining backscattering profile, the fine dust contribution is obtained for $0.05 \leq \delta_p \leq 0.24$, and again it is being subtracted. The extant particle backscattering profile is assumed to be the non-dust contribution to particle backscattering profile.

3. RESULTS

On 9th August 2013, a strong aerosol loading was observed up to 6 km in several layers, as depicted in the ground-based PollyXT-UW lidar quick-look (Fig. 1) and the satellite CALIOP lidar data product related to aerosol-typing (Fig. 2).

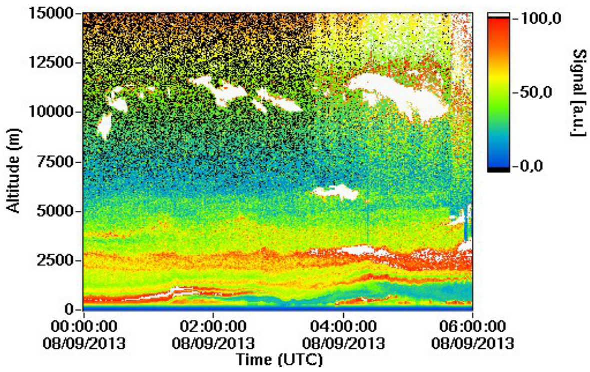

Fig. 1:Quick-look of the range corrected signal of PollyXT-UW lidar at EARLINET-ACTRIS site in Warsaw, Poland. Source:http://polly.rsd.tropos.de

On the PollyXT-UW lidar quick-look in Warsaw aerosol layers can be seen, within the boundary layer below 1.0 km, at 2.5 km and 3.7 km. The CALIOP lidar also detected aerosols up to 6 km during the corresponding CALIPSO overpass. For the layers observed, the backward trajectories were calculated using the HYSPLIT model (Fig. 3).

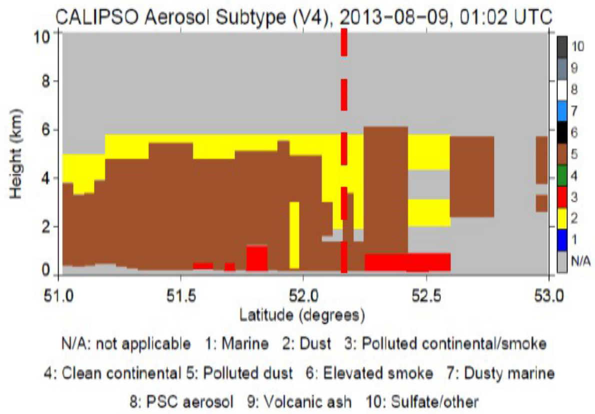

Fig. 2: CALIOP lidar aerosol subtype plot, with the latitude of Warsaw (52.22977) marked as red dashed line; dust (2) and polluted dust (5) particles were observed during this CALIPSO overpass in the nearest distance from the EARLINET-ACTRIS lidar site in Warsaw.

According to the backward trajectories, at both of those altitudes in the free troposphere (Fig. 3, in blue and green), one may expect aerosol load likely containing Saharan dust particles uplifted from over North Africa. As those warm and dusty air-masses were traveling for more than 6 days long before reaching Central Poland, it is highly probable that the mineral dust observed over Warsaw lidar site on that day, was composed of a mixture of different aerosol types; the air-masses mixing is indicated in Fig. 3 bottom panel. The aerosol carried by the air-mass marked in blue, from the area over the Mediterranean Sea that may contain marine aerosol mixed with the air-mass marked in green more likely containing pure Saharan dust. The dust observed over Warsaw is expected to be rather elderly, and therefore sorted due to dry deposition caused by gravitational sedimentation of coarse particles along its pathway. Hence, it shall have different optical properties than fresh/pure dust.

In Fig. 4, PollyXT-UW lidar-derived optical properties of the atmosphere are shown. The profiles of the particle backscattering coefficients show peaks of an increased aerosol load in the layers between 2.0-3.0 km and 3.2-4.2 km. The peaks are less pronounced in the particle extinction coefficient, but still visible, especially for 355 nm. The noise in the extinction profiles increases with altitude, however, the obtained with Raman approach extinction profiles are rather high-in-range for the low smoothing applied.

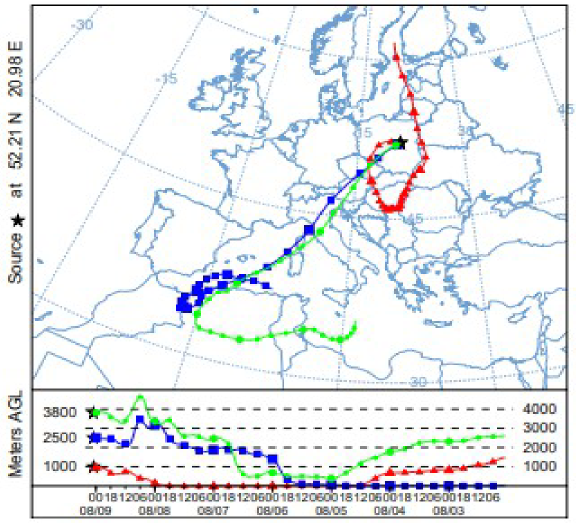

Fig. 3: HYSPLIT 168h-backward trajectories calculated for Warsaw, at 1.0, 2.5 and 3.8 km, ending at 01:00 UTC on 9th of August 2013.

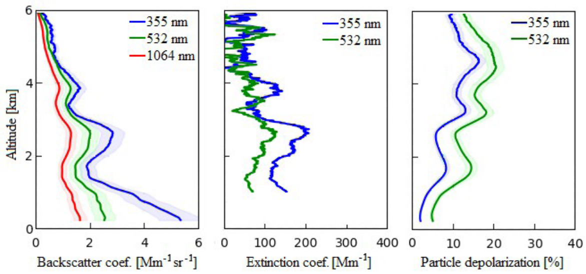

Fig. 4: PollyXT-UW profiles of the wavelength-dependent particle backscattering coefficient (left), particle extinction coefficient (center) and particle depolarization ratios (right), derived as average of 0:00-2:00 UTC on 9th August 2013 at the EARLINET-ACTRIS site in Warsaw.

The particle depolarization ratio increases with altitude, from 3-5 ±0.5% close to the ground to even 15-20 ±2% at 5 km and then starts decreasing. This indicates the existence of a high number of non-spherical particles. The particle lidar ratios (LR_{355} and LR_{532}) and Ångström exponent derived from the particle extinction AE_{α} (355/532) and backscattering coefficient profiles AE_{β}(355/532), AE_{β}(532/1064), AE_{β}(355/1064) were calculated. All of the AE_{β} were of 0.5±0.15. The AE_{α} was of 0.46±0.1 in the layer at 3.0-3.3 km and of 0.32±0.2 at 3.8-4.2 km. These values confirm the existence of large particles. The LR_{532} of 55±5 sr and LR_{355} was of 60±7 sr, hence within the range of the typical lidar ratios reported for Saharan dust between 50-60 sr [6]. For Leipzig, Saharan dust-related LR_{532} of 59 ± 11 sr and LR_{355} 65 ± 12 sr were reported [7]. Clearly, the values found for Warsaw correspond well with the latter.

The selected case was a great candidate to test the feasibility of the separation algorithm for Warsaw lidar data. The one- and two-step separation results are shown in Figs. 5 and 6, respectively. One can see that there is an interesting reverse relation between the particle backscattering coefficient and also non-dust contribution to the backscattering coefficient and particle depolarization ratio. When the peak in particle depolarization ratio is being observed, there is a local minimum in the backscattering coefficient profile. This kind of relation is not observed between dust contribution to the backscattering coefficient and particle depolarization ratio. It might be caused by the hydration of small aerosol particles, which causes the change of the shape of particles from non-spherical to more spherical ones. It also reveals that peaks of the particle depolarization ratio are likely to be caused by dust/coarse dust occurrence.

The one-step separation method results, depicted in Fig. 5, indicate that dust particles could have been present from 0.5 km up to 6 km. There was less dust than other aerosols only in the lower troposphere (<3 km). The same local maxima as in Fig. 4 are captured. The results lead to the conclusion that on 9th August 2013 a strong desert dust influx over Warsaw took place.

The two-step separation method results, depicted in Fig. 6, indicate that, if any, the coarse mode dust particles have been present only at 2.7-5.5 km (orange profile, left subplot) and at about 1.8 km. There was a quite large amount of fine mode dust particles (purple profile, right subplot), with several local maxima exceeding the non-dust contribution. The much lower load of the coarse dust than the fine dust particles can be explained as due to the gravitational fallout of coarse dust particles during the long-range transport from Sahara to Warsaw.

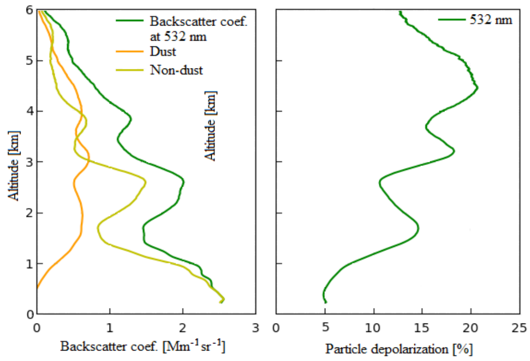

Fig. 5: The one-step separation algorithm applied to 532 nm particle backscattering coefficient profile for assessment of the dust and non-dust contribution and the particle depolarization ratio profile at 0:00-2:00 UTC on 9th August 2013 at Warsaw lidar site.

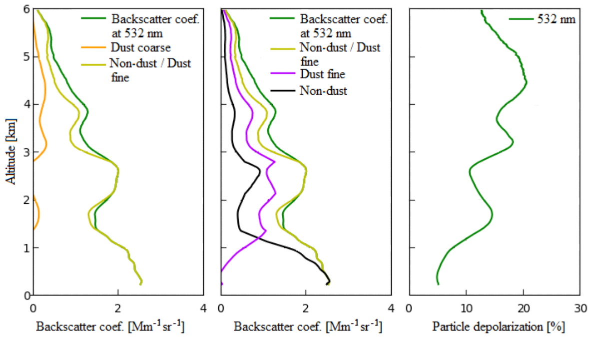

Fig. 6: The two-step separation algorithm applied to 532 nm particle backscattering coefficient for assessment of the coarse mode dust, fine mode dust and non-dust contribution at 0:00-2:00 UTC on 9th August 2013 at Warsaw lidar site.

4. CONCLUSIONS

The first results of a successful application of the separation algorithm proposed by [1] applied to the lidar data at the Warsaw EARLINET-ACTRIS site are presented. In the near future, adjustments of the evaluation procedure will be undertaken. For example, the profile obtained for testing the approach was derived for rather long temporal averaging, so as to work with a significantly high aerosol loading in order to ease the particle contribution separation. The threshold values currently used for testing of the separation algorithms ([1, 2]) are characteristic for pure mineral dust aerosol. In general, this shall not be the case for Warsaw affected by complex aerosol injections not only into the free troposphere [8] but also into the boundary layer [9, 10]. It is expected that the values of the particle depolarization thresholds must be different for mixtures of non-pure/non-fresh dust with other types of aerosol observed over Warsaw (e.g. local and advected anthropogenic pollution [10], long- and short-range transported biomass-burning [11, 12, 13],or Arctic marine air [9]). The higher number of dust observation episodes over Warsaw will be analyzed to refine the threshold values, which will be used in the separation algorithm.

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