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# Software for retrieval of aerosol particle size distribution from multiwavelength lidar signals[☆]

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ABSTRACT

Software to retrieve profiles of aerosol particle size distribution (APSD) from multiwavelength lidar signals is presented. The approach consists in direct fit of artificial signal generated using predefined distribution to the experimental signals. Combination of two lognormal functions with a few free parameters is applied for the predefined APSD. The minimization technique allows finding lognormal function parameters which provide the best fit. The approach was tested on the experimental signals registered at 1064, 532 and 355 nm. The software is designated for processing on PCs. The computation time was about several minutes.

**Program summary**

*Program title:* APSD_Software

*Catalogue identifier:* AEXV_v1_0

*Program summary URL:* http://cpc.cs.qub.ac.uk/summaries/AEXV_v1_0.html

*Program obtainable from:* CPC Program Library, Queen's University, Belfast, N. Ireland

*Licensing provisions:* Open Licence

*No. of lines in distributed program, including test data, etc.:* 12813

*No. of bytes in distributed program, including test data, etc.:* 878099

*Distribution format:* tar.gz

*Programming language:* Delphi 2010.

*Computer:* PC.

*Operating system:* Windows XP, Vista, 7, 8, 8.1.

*RAM:* 37MB

*Classification:* 13.

*Nature of problem:*

Aerosol Particle Size Distribution (APSD) is a very significant function for evaluation of atmospheric optical properties. Remote determination of APSD might be performed with multiwavelength lidar. Retrieval of profiles of APSD from multiwavelength lidar signals is an example of ill-posed problem in the atmospheric physics (in the sense of Jacques Hadamard).

*Solution method:*

The approach consists in direct fit of artificial signals to the experimental signals. The artificial signals are generated using predefined aerosol particle distribution, Combination of two lognormal functions with a few free parameters is applied for the predefined APSD. The minimization technique used in the software allows finding lognormal function parameters which provide the best fit.

☆ This paper and its associated computer program are available via the Computer Physics Communication homepage on ScienceDirect (http://www.sciencedirect.com/science/journal/00104655).

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*Additional comments:*
The input signal should be located into the SIGNALS directory which is automatically created by the software. The results are presented in the main form of the software. They are also saved into the same directory from which it was loaded input file. They are saved as a BitMap as well as the ASCII files. The software returns two main sets of files: first one "APSD.bmp" and "APSD_Iet.txt", and the second one "EffectiveRadius.bmp" and "EffectiveRadius.txt".

*Running time:*
195 s for an input file consisting 12 measurement points (altitudes).



## 1. Introduction

Aerosols have a substantial and complex impact on atmospheric processes. For many aerosol types their contribution to various phenomena (for example the Earth surface radiation budget [1]) is poorly constrained. Understanding their optical properties and the distribution in the atmosphere is crucial for assessing their role in local and global scale.

Active remote sensing with lidar technique is an important tool for investigation of the atmospheric aerosols [2,3]. The opportunities provided by multiwavelength lidars (MWL) are especially useful in this case since they enable determination of range resolved Aerosol Particle Size Distribution (APSD) which is a very important function for evaluation of aerosol optical properties.

## 2. Approach

Active remote sensing with lidar consists in sending of laser pulses at several wavelengths $\lambda$ ($\lambda = 1, 2, \ldots, \Lambda$) to atmosphere [2,4]. The light that is backscattered at distance $z$ reaches the lidar receiver, where wavelength is separated and digitized. In consequence it provides the signals $S_1(z), S_2(z), \ldots, S_\Lambda(z)$:

$$S_\lambda(z) = \frac{A_\lambda \beta_\lambda(z)}{(z - z_0)^2} \exp\left(-2\int_{z_0}^{z} \alpha_\lambda(y)\, dy\right). \tag{1}$$

Here $z_0$ corresponds to lidar position, $A_\lambda$ are the wavelength dependent apparatus constants while $\alpha_\lambda(z)$ and $\beta_\lambda(z)$ denote the spatial distribution of total atmospheric extinction and backscattering coefficients respectively. The exponential factor reflects the use of Lambert–Beer law for the radiation extinction while the factor of 2 in the exponent is caused due to double run of the laser beam to the point $z$ and back.

Range corrected form of the signals (1) is more useful for the analysis:

$$L_\lambda(z) = A_\lambda \beta_\lambda(z) \exp\left(-2\int_{z_0}^{z} \alpha_\lambda(y)\, dy\right). \tag{2}$$

Solution of these lidar equations provides both $\alpha_\lambda$ and $\beta_\lambda$ coefficients. Each coefficient can be expressed as a sum of constituents [5]:

$$\alpha_\lambda(z) = \alpha_{R\lambda}(z) + \alpha_{A\lambda}(z) = \alpha_{R\lambda}(z) + \int_0^\infty Q_\lambda^E(r)\, \pi r^2 n(z, r)\, dr, \tag{3}$$

$$\beta_\lambda(z) = \beta_{R\lambda}(z) + \beta_{A\lambda}(z) = \beta_{R\lambda}(z) + \int_0^\infty Q_\lambda^B(r)\, \pi r^2 n(z, r)\, dr. \tag{4}$$

The first constituent of (3) or (4) corresponds to Rayleigh scattering. For standard atmosphere $\alpha_{R\lambda}(z)$ and $\beta_{R\lambda}(z)$ can be evaluated using the approach of Bodhaine et al. [6] assuming the standard atmosphere profile as the basis. Aerosol scattering coefficients $\alpha_{A\lambda}(z)$ and $\beta_{A\lambda}(z)$ described by relevant integrals can be evaluated by one of several possible aerosol models [7–13]. Mie theory can be used in the case of spherical particles [14]. In Eqs. (3)–(4) $r$ denotes particle radius, and $Q_\lambda^E$ and $Q_\lambda^B$ — extinction and backscattering efficiencies, respectively. The inversion of Eqs. (3) and (4) provides $n(z, r)$ — distance dependent aerosol particle size distribution (APSD) which is the matter of investigation.

For each distance APSD can be derived in a predefined form. Recently more often log-normal function:

$$n_j(z, r) = \frac{C_j(z)}{\sqrt{2\pi} \cdot \log\sigma_j(z)} \cdot \frac{1}{r} \cdot \exp\left\{-\frac{\left[\log r - \log R_j(z)\right]^2}{2 \cdot \log^2 \sigma_j(z)}\right\}, \tag{5}$$

or a linear combination of log-normal modes:

$$n(z, r) = \sum_{j=1}^{K} n_j(z, r), \tag{6}$$

is applied. Here $R_j$ denotes the modal radius, $C_j$ — the concentration of aerosol in a given mode, and $\sigma_j$ — the mode width. Junge function with two free parameters is also used for this purpose. Then the inversion is reduced to the determination of optimal function parameters.

Various inversion techniques have been proposed. The review of early approaches to this problem was presented by Zuev and Naats [15]. Herman et al. [16] fitted Junge distribution to the signals, while Rajeev and Parameswaran [17] have shown the iterative method without any assumed shape. The approaches to multifrequency lidar signals inversion were also performed by Piskozub [18] and Zieliński [19]. Heintzenberg et al. [20] proposed randomized minimization to derive an assumed histogram distribution. Similarly Müller and Quenzel [21] used this technique to test APSD determination assuming Junge and lognormal functions. Müller et al. applied Tikhonov regularization for the inversion [22–25]. Veselovskii et al. [26] utilized the eigenvalue analysis for this purpose. A detailed review of different approaches to APSD retrieval was done by Böckmann [27] whose hybrid method was later applied to the experimental data analysis and the refractive index and single-scattering albedo retrieving [28].

Another solution was proposed by Shifrin and Zolotov [29]. They assumed APSD function in a form of combination of several log-normal functions. Using these distributions $\alpha_\lambda$ and $\beta_\lambda$ were calculated and their values were compared to those measured by lidar technique. Then the mean ordinates over the solutions were calculated then the APSD closest to the mean ordinates was taken as the most probable aerosol distribution [30].

Ligon et al. [31,32] used the Monte Carlo method in order to shorten the calculation time. Kaufman et al. [33] expanded the method to invert Moderate Resolution Imaging Spectroradiometer (MODIS) and Cloud-Aerosol Lidar and Infrared Pathfinder Satellite