ALGORITHM AND SOFTWARE FOR THE RETRIEVAL OF VERTICAL AEROSOL PROPERTIES USING COMBINED LIDAR/RADIOMETER DATA: DISSEMINATION IN EARLINET

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ABSTRACT

Ten combined lidar and sun-radiometer stations in the European Aerosol Research Lidar Network (EARLINET) have been testing technique and software for retrieving aerosol microstructure parameters from coordinated lidar and sun-radiometer data with the aim of creating new type of routing cooperative observations. The paper presents description of a program package and preliminary results of testing measurements at some stations.

1. INTRODUCTION

Nowadays lidars and sun/sky-scanning radiometers are among the base equipment in complex experiments aimed at studying aerosol transformation and transport.

Aerosol properties retrieved from Sun radiometer and lidar data are complimentary pieces of information that characterize aerosol particles. The synergetic interactive processing of co-located radiometric and lidar observation data results in further enhancement of aerosol characterization and can provide superior characterization of aerosol as compared with the outcome of detached processing lidar and radiometer observations.

In such approach we deal with an optimal measurement procedure and calculate parameters of a heterogeneous aerosol layer that are in accordance with all measurement data.

The idea of combining lidar and Sun-radiometer measurements in the frame of EARLINET and AERONET and the method for retrieving vertical distributions of aerosol microstructure characteristics were posed in [1], developed in [2-4] and implemented in studying long range aerosol transport at the combined EARLINET and AERONET stations in Minsk (Belarus) and Belsk (Poland) [5].

Integration of lidar and radiometer observations in EARLINET and AERONET is in the order of the day and being realized by ten combined lidar and radiometer stations (Fig. 1) in the frame of ACTRIS, EC 7th Framework Programme project.

This paper presents a retrieving algorithm and uniform program package for processing data of combined lidar/radiometer measurements, as well as preliminary results of their application at the EARLINET stations.

2. ALGORITHM FOR PROCESSING LIDAR&PHOTOMETER DATA

The method of combined lidar and radiometer measurements envisages lidar atmosphere sounding over an altitude range contributing to integral aerosol parameters. Actually the majority of EARLINET stations provide measurements of backscatter signal at three wavelengths (355, 532 and 1064 nm) and a couple of cross/parallel polarization components of the signal for one wavelength.

In the case of a small number of lidar signals measured, an aerosol layer model with a set of its parameters $C_\gamma(z)$ should be constructed in view of the principle of minimal sufficiency: the number of parameters should be adequate to information capabilities of lidar/radiometer data.

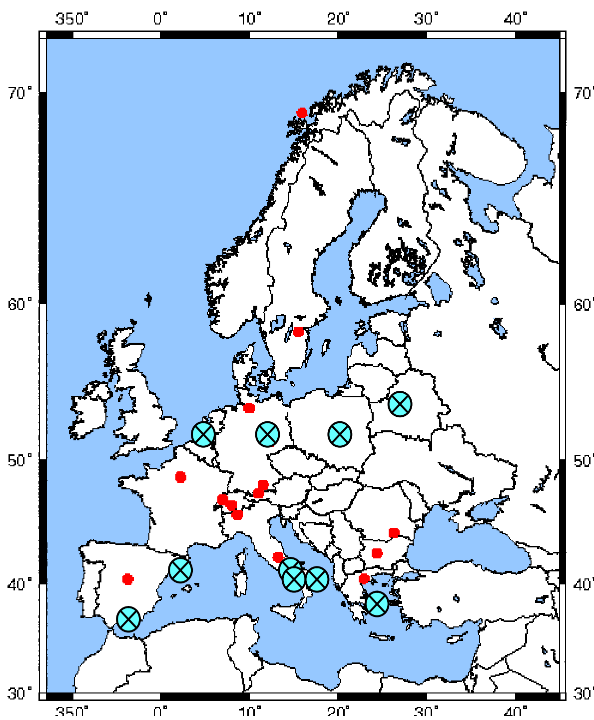

Figure 1. Stations of EARLINET; large blue dots are stations involved in implementation of cooperative combined lidar & radiometer observations

The aerosol model is formed as a mixture of spherical and spheroid particles with a size distribution $W_i(r)$ and refractive index n equal for all particles. The part of spherical particles in the aerosol mixture ("sphericity") doesn't depend on particles sizes.

The aerosol layer is defined with two sets of parameters:

a) integrated parameters that characterize the aerosol layer as a whole: size distributions of fine and coarse aerosol modes, their total content (column concentrations), refractive index and sphericity (percentage of spherical particles in aerosol mixture);
b) concentrations $C_v(z)$ of aerosol modes that change over altitude.

We use the AERONET software to obtain integral characteristics of the aerosol layer.

Aerosol particle size distributions are characterized by two fractions (fine and coarse) with bounding radius of ~0.5 micrometers, as it is the convention in AERONET retrievals, when three backscatter signals measuring the altitude dependence of aerosol parameters are available. Particle size distribution of each fraction and refractive index is considered to be independent of the altitude and is fixed equal to corresponding fractions of columnar aerosol.

Spherical and non-spherical particles of the coarse mode are considered as two different fractions if measurements of couple of cross/parallel polarization components are available.

Sequential inversion of lidar and radiometer data is realized by means of preliminary calculation of a)-type parameters from radiometric measurements in accordance with the AERONET inversion algorithm and subsequent inversion of b)-type parameters using column characteristics of aerosol layer as a priori information.

The equation set includes three following subsystems:

- multi-wavelength lidar equations containing information on the vertical aerosol parameter profiles;
- integral characteristics of the aerosol layer provided by photometer measurements;
- restrictions on the vertical variability of the profiles $C_v(z_n)$; the limitation of the vector $\mathbf{C}_v$ is enforced by explicit limitation of the second derivatives:

$$\begin{aligned} \mathbf{L}^*(\lambda_j, z_n) &= \mathbf{L}(\lambda_j, \mathbf{C}_v(z_n), m_j, z_n) + \mathbf{\Delta}_L^j \\ \mathbf{W}^* &= \mathbf{W}(\mathbf{C}_v(z_n)) + \mathbf{\Delta}_F \\ \mathbf{0}_v^* &= \mathbf{S}_2\mathbf{C}_v + \mathbf{\Delta}_{0_v} \end{aligned} \qquad (1)$$

Here:

- $\mathbf{L}^*(\lambda_j, z_n) = \mathbf{L}^*(\lambda_j, z_n, P^*(\lambda_j, z_n))$ is a normalized measured lidar sounding signal $P^*(\lambda_j, z_n)$ at the wavelength λ_j; $\mathbf{L}(\lambda_i, \mathbf{C}_v(z_n), z_n)$ is a nonlinear function which depends on parameters $\mathbf{C}_v$ of aerosol model;
- $\mathbf{W}^*$ - total content of the aerosol fraction that is retrieved from photometer measurements; $\mathbf{W}(\mathbf{C}_v(z_n))$ is the integral of $C_v(z)$ over aerosol layer;
- $\mathbf{S}_2$ - the matrix of second differences, $\mathbf{\Delta}_0$ - defines deviation from zero.

Aerosol parameters are retrieved using the maximum likelihood method.

3. PROGRAM PACKAGE FOR PROCESSING DATA OF COMBINED LIDAR&PHOTOMETER SOUNDING

The uniform software SLP-2 (**SoftLidarPhotometer_v2**) has been designed for processing data that are measured at combined EARLINET & AERONET lidar and Sun-photometer stations (Fig. 1).

Program package structure is shown in the Fig. 2. Program package SLP-2 consists of 3 sub-packages.

Package 1 – **LIOPT** for preprocessing of Sun-photometer data. Program **LIOPT** creates the databank **DB-Ph** of column aerosol optical parameters at the lidar wavelengths by recalculation of AERONET data files.

Package 2 – **SignalSuite** for preprocessing lidar data. As the first step the package **SignalSuite** creates the databank of raw lidar signals **DB-Lidar_raw** from a set of lidar signals measured at the EARLINET stations by means of converter **nc2mdb**. Some stations use the special executable code **ULIS** that creates databank in measuring procedure. Program **Synthesizer** provides fusion of some lidar data measured to the effective lidar signal over the whole aerosol layer. Program **Tropoexport** is meant for preprocessing of lidar signals and calculation of errors of signals measured.

Package 3 – **ProfileRetriever** for calculation of aerosol mode concentration profiles. Depending on the list of input parameters concentrations of two or three aerosol modes are retrieved. Program **Output Viewer** provides viewing of the profiles of aerosol mode concentrations.

4. PRELIMENARY RESULTS OF APPLICATION OF COMBINED LIDAR&PHOTOMETER SOUNDING METHODS AT EARLINET STATIONS

Developed technique and program package are tested at ten combined lidar & radiometer stations (Fig. 1) with the aim to arrange specific routine coordinated lidar and photometer observations in the frame of EARLINET/AERONET.

Results of calculation of the vertical profiles of aerosol modes volume concentrations from two types of processing are shown in Fig.3. Measurements were performed in Granada, 15-05-2011. The profiles of coarse non-spherical aerosol particles confidently define a dust layer at the altitude of about 2 km. Figure 4 shows close fit of measured and calculated lidar signals.

Test processing of combined lidar and photometer data was carried out for different kinds of aerosol events: dust particles, fire smoke, volcano ash, background conditions. Some examples of retrieved aerosol mode profiles are presented in Fig. 5 and Fig. 6. In any case calculated concentrations profiles were stable relative to change of input data.

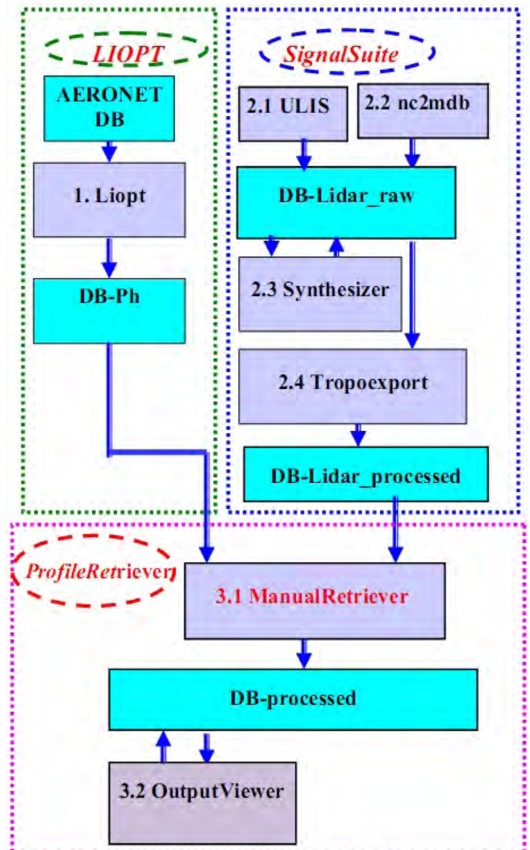

Figure 2. Structure of program package SLP-2.

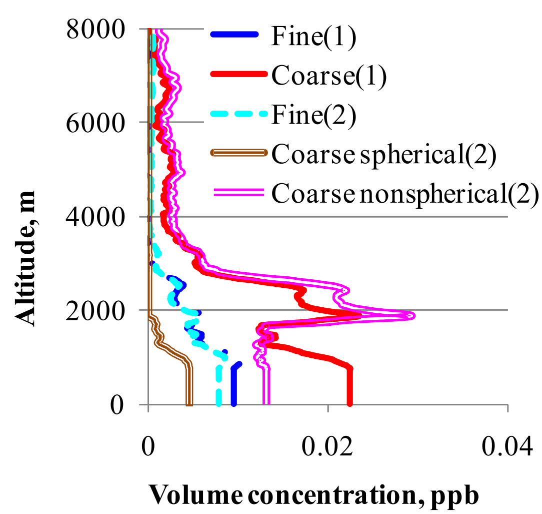

Figure 3. Vertical profiles of aerosol volume concentrations of aerosol modes from two types of processing of combined lidar and photometer input data: (1) – backscatter lidar signals for three wavelengths; (2) – additional couple of cross/parallel polarization measurements; Granada, 15-05-2011.

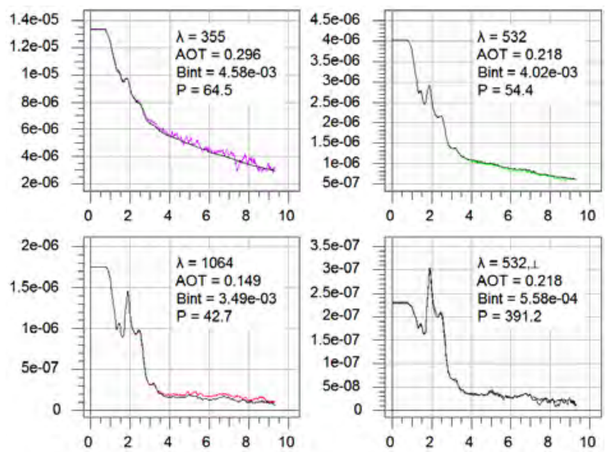

Figure 4. Corrected lidar signals measured (black lines) and calculated (colour lines) from the retrieved parameters of aerosol layer, Granada, 02-09-2011.

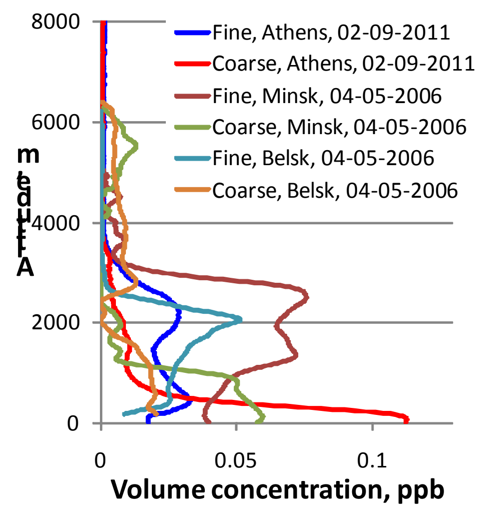

Figure 5. Vertical profiles of aerosol volume concentrations of fine and coarse aerosol modes, fire smoke events in Athens, Minsk and Belsk.

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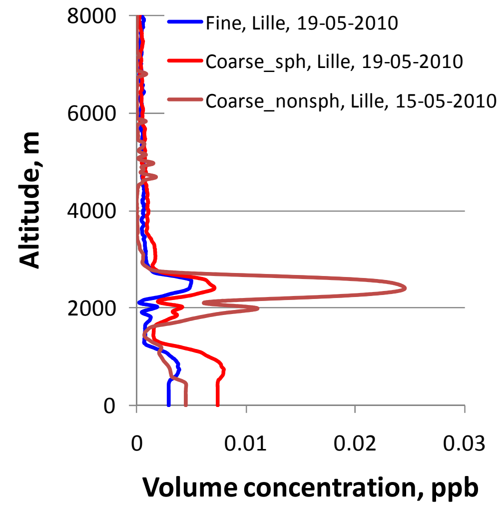

Figure 6. Vertical profiles of aerosol volume concentrations of fine, coarse-spherical and coarse-non spherical aerosol modes, Eyjafjallajökull volcanic ash event in Lille, 19-05-2010.

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