A NEW METHOD FOR THE RETRIEVAL OF AEROSOL OPTICAL PARAMETERS FROM ELASTIC BACKSCATTER LIDAR DATA

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ABSTRACT

This study focuses on a method for improving theoretical determination of the extinction-to-backscatter ratio, or lidar ratio [1], LR, height dependent, an optical property required to interpret remote measurements by elastic backscatter lidar.

The Environmental group in INOE developed a LabVIEW software based on an iterative hybrid regularization technique for lidar data processing and retrieval of the aerosols optical parameters. Atmospheric model, Mie model and Fernald-Klett method [5,6] have been used. A similar algorithm is also used by other Lidar groups (e.g. [7]), but we consider tropospheric aerosol as an external mixture of internally mixed components, each one being described by log normal distribution function, refractive indices and being dependent on atmospheric humidity profile as in Akerman's model [1].

We tested this algorithm in different meteorological conditions making measurements with our lidar system **LiSA** (**Li**dar **S**cattering **A**erosols) on Magurele Platform, Romania. It can detect in real time aerosols density profiles up to 10 Km high with a spatial resolution of 6 m. Humidity, pressure and temperature profiles have been used from NOAA [http://www.arl.noaa.gov/ready/cmet.html]

Our tests demonstrate validity, robustness, and the limitations of the current method.

1. INTRODUCTION

Aerosols have an important impact on human life because they affect human health, ecosystems and the composition of the atmosphere including the ozone layer, weather, and climate. LIDAR systems have demonstrated their ability to map aerosol variations throughout the atmospheric column and therefore they have has become a central technology in current strategies for tropospheric aerosol research. Its use is complicated, however, by the fact that the lidar signal contains a convolution of two basic optical properties of the aerosol particles: the backscatter coefficient and the extinction coefficient. A quantitative retrieval of either property requires knowledge of their relationship along the laser path which is referred as lidar ratio.

As previously determined by other groups, LR is dependent on humidity [1]. If the lidar ratio can not be measured by high spectral resolution lidar [2,3], or Raman lidar [4], then either an assumed value of LR must be used in the lidar retrieval, leading to very large uncertainties in light extinction , or models can be used for determination of LR profile. Our lidar is not equipped to measure LR, so we need to theoretically determine LR, for physically meaningful retrievals.

The variability of aerosols results mainly from the fact that for one aerosol type (maritime, continental, desert), the mixing ratios of the distinct components are unknown. On the basis of this assumption, this study focuses on a numerical investigation about the lidar ratio of tropospheric aerosols characterizing Romanian atmosphere.

2. RETRIEVAL ALGORITHM

To analyze the return signal in laser remote sensing means to find solutions for the equation which relates the characteristics of the received and emitted signal, and the propagation medium. The form of the equation depends of the interaction type [5]. For those applications which involves scattering (elastic or inelastic), the form of equation is quite simple:

$$S(Z) = C_S(Z) \cdot \frac{\beta(Z) \cdot \exp\left[-2\int_{Z_0}^{Z} \alpha(z)dz\right]}{Z^2} + S_{bg} \quad (1)$$

where Z is the distance to the scattering point, $S(Z)$ is the Lidar signal (power), $C_S(Z)$ is the so-called system function, $\beta(Z)$ is the backscattering atmospheric coefficient at distance Z, $\alpha(Z)$ is the extinction atmospheric coefficient at distance Z and S_{bg} is the background signal (power). In writing this equation, the multiple scattering was neglected.

Aerosol Lidar measurements at one wavelength can deliver aerosol backscatter profiles using inversion. Fred Fernald [5] realized that Lidar equation is a Bernoulli equation on first rang and obtained its solution in 'forward' form, choosing for calibration the closest point Z_0 in the investigation interval. This method works well if the backscattering coefficient in Z_0 can be provided by complementary measurements. Klett [6] proved that this solution becomes unstable if atmospheric extinction is important and in that case it diverges with increases of the distance. He suggested an 'inversion' of solution, that means to choose the references point Z at the end of the investigation interval. Rearrangement of integration limits and changing the divisor sign stabilize the solution, but difficult to obtain data in far field is requested.

However, this approach is not quantitative mainly due to the fact that the Lidar equation contains two unknown aerosol parameters, the aerosol extinction and backscatter. All molecular parameters can be calculated with sufficient accuracy [8] from ground values of pressure and temperature using atmospheric model, but for solving the equation for the aerosol backscatter, a relationship between the unknown quantities (aerosol extinction and backscatter), is assumed:

$$LR_a(Z) = \alpha(Z)/\beta(Z) \tag{2}$$

It depends on the aerosol microphysics and can vary between less than 10 sr (ice crystals) and more than 100 sr (heavily polluted air) [1].It depends on humidity and aerosol mixture and therefore, on height. If $LR_a(Z)$ is known, the Eq. 3 can be solved. To know LR_a values over entire investigation distance it is not possible. For this reason, additional methods to eliminate non determination in Lidar equation were developed.

LiSA system signal processing method is based on Fernald-Klett combined, atmospheric model and Mie algorithm for direct problem (theoretical calculation of optical parameters), all integrated in an iterative program to identify the proportions of aerosol components for which the best fit between theoretical and retrieved optical parameters is achieved. The altitude profile of molecular extinction coefficient $\alpha_m(Z)$ is presumed known. In this case, Fernald-Klett solution of Lidar equation can be written as:

$$\beta(Z) = -\beta_m(Z) + RCS(Z)\cdot \exp\left[-2\left(LR_a(Z) - LR_m\right)\cdot \int_{Z_C}^{Z} \beta_m(z)dz\right]\cdot \left[\frac{RCS(Z_C)}{\left(\beta_a(Z_C) + \beta_m(Z_C)\right)} - 2LR_a(Z)\int_{Z_C}^{Z} RCS(z)\cdot \exp\left[-2\left(LR_a(z) - LR_m\right)\cdot \int_{Z_C}^{Z} \beta_m(z')dz'\right]dz\right]^{-1} \tag{3}$$

where $RCS(\lambda, Z) = S(\lambda, Z)\cdot Z^2$ is the range corrected signal, Z_c the calibration point, index m is for molecular component and a for aerosol component.

In our algorithm, it is assumed that the aerosol is an external mixture of internally mixed components. Each aerosol component (indexes s,i,c) is lognormally distributed with respect to the particle radius and representative to tropospheric continental aerosol type. Therefore we consider 3 types aerosol particles [1]: soluble(s), insoluble (i) and carbonic components (c) characterized by the number mixing ratio μ:

$$\mu_s + \mu_i + \mu_c = 1 \tag{4}$$

For given optical properties and a distinct relative humidity, the variability of the lidar ratio is caused by different number mixing ratios. The water soluble component is the only component whose properties are affected by the relative humidity. The mixing ratio μ_s can be varied between 0.1 and 1 in steps of 0.1. Accordingly, since μ_i is about four orders less, μ_c, chosen to be the controlling parameter in our algorithm, is iterated in 0.01 steps from 0.1 to 1.

On each iteration we calculate humid log normal distribution parameters and refractive indices for each aerosol's component using Akerman's model [1]. These will be input in Mie model for determination of theoretical extinction and backscatter coefficients $\beta_t(Z)$ and theoretical lidar ratio.

Molecular backscattering coefficients calculated by the atmospheric model, the lidar signal and $\beta_a(Z_c)$ in the calibration point Z_c are used by Fernald-Klett algorithm to derived the experimental backscattering coefficient $\beta_e(Z)$

The control parameter will be varied until the difference between $\beta_t(Z)$ and $\beta_e(Z)$ is less then a threshold. At this point conclusion is that the hypothesis made for the aerosols components is correct and microphysical aerosols parameters like AOD, effective radius, total volume concentration, can be derived. Also now we have the correct value for extinction and backscatter coefficients. For the next profile point the iteration will start with the controlling parameter determined.

The method we are using is a regularization one because implies a regularization cycle for controlling parameter, μ_c until we are getting an theoretical profile of β_a almost equivalent to the measured one. This is a hybrid method because on each iteration, for derivation of experimental β_a by lidar inversion we are using as an input the theoretical value of the lidar ratio LR_a obtained with Akerman and Mie model.

3. RESULTS

For experiments we used LiSA system of the National Institute of R&D for Optoelectronics, which is an elastic backscattering Lidar based on a Nd:YAG laser, working separately or simultaneously at two wavelengths (1064 and 532 nm) on Magurele Platform, 5 km away from Bucharest.

The city and region of Bucharest, monitoring site is urban environment with an intense traffic and surrounded by industrial platforms, which gives rise to a variety of aerosol and gaseous pollutants. This location put some problems related to optimal choosing of the calibration point, when slant sounding is made. Magurele Platform, where the system is placed, is about 5 Km away from Bucharest and is separated from it by much less populous zone, much less polluted in consequence. Most important contribution to the backscattering signal comes from the aerosols over the city, but the contribution of Magurele sources cannot be neglected, having in view that even here there is some industrial activity and traffic. For this reason, the calibration point cannot be selected at the end of the sounding path, where the atmospheric extinction coefficient is very high due to the city. But neither can be selected at the beginning of the path because – by the forward integration – the solution of Lidar equation becomes unstable. The calibration point must be selected between the 2 limits, as possible in the area where the atmospheric extinction coefficient is smallest, but in our case this area is dependent of weather and time of the day [9]. Therefore we have used the combined Fernald-Klett for back and forward inversions starting in the calibration point. The hybrid method gives us a better choice for calibration point and $\beta_a(Z_c)$ than a simple Fernald-Klett method.

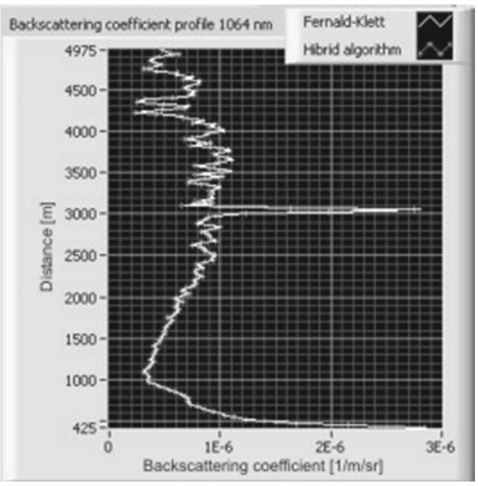

Fig.1 Backscattering coefficient profile 1064 nm on February 21st,2006

The figures 1 to 5 present the data versus distance from Lidar location with an horizontal elevation angle of 27°. In order to demonstrate the viability and robustness of our iterative hybrid regularization technique we compare the results of the backscattering coefficient profiles and lidar ratio profiles with the ones obtained using only Fernald-Klett method, where lidar ratio in the calibration point been considered constant over the entire vertical range.

Only measurements from 2 days have been chosen here to illustrate the importance of the height dependent lidar ratio. Fig.1 depicted a cloud about 3 km HIGH from the Lidar location. The difference between the 2 profiles using different methods of inversion is not eloquent when the lidar ratio is constant with height as determined by the hybrid method, but becomes very important when there is a cloud (Fig 1-3 about 3km distance) or a aerosol layer (Fig.4-5 about 3-5 km distance). In a cloud the soluble component of the aerosol is much bigger than carbonic component and therefore the lidar ratio has a much smaller value (43 versus 51). Same type of variation is seen if there is low visibility (light fog). If an aerosol layer is present the hybrid algorithm proved to be able to determine accurately the carbonic and soluble components proportions and lidar ratio values, in accordance with Akerman's model [1].

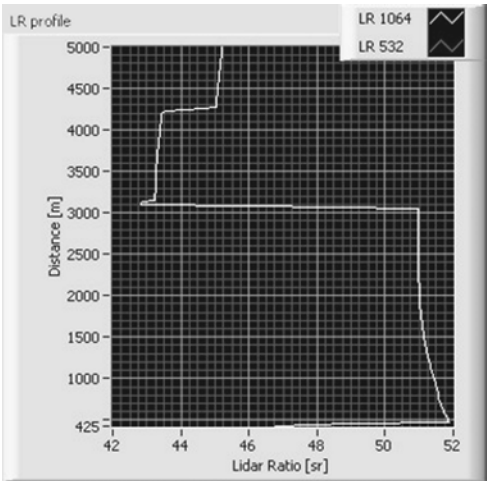

Fig.2 Lidar Ratio vertical on February 21st, 2006

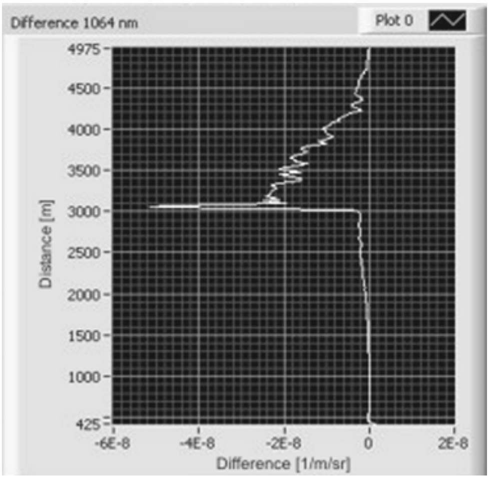

Fig.3 Difference of backscattering coefficient profiles Fernald-Klett method and Hybrid algorithm for February 21st,2006

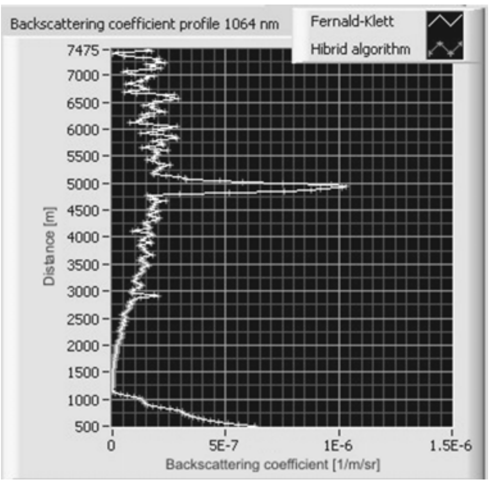

Fig. 4 Backscattering coefficient vertical profile 1064nm on March 3rd, 2006

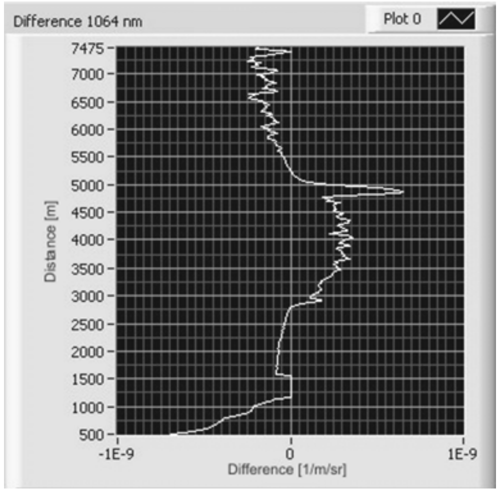

Fig. 5 Difference of backscattering coefficient profiles Fernald-Klett method and Hybrid algorithm for March 3rd,2006

4. CONCLUSIONS

This method allows us to determine the local lidar ratio profile, height dependent in an iterative way, when is not possible to be determined experimental. The practical application of this iterative method is not limited because it can be adapted for different types of aerosol [1]. The algorithm presented in this paper can be applied successfully to determine the cloud and aerosol microphysics from elastic backscatter LIDAR data.

The method proves to be stable when applied to experimental data. Future work will investigate the aerosol microphysical parameters derived only from elastic backscattering canals in different meteorological conditions and dust loading. Also we will analyze the errors introduced by this method, comparing lidar ratio profiles with results of measurements from Raman Lidar.

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