Retrieving of aerosol microphysical properties by multiwavelength elastic lidar: simulations

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In recent years, Gobbi *et al* [1] have proposed a method to determine microphysical parameter of atmospheric aerosol population starting from optical thickness measured at different wavelenghts. To obtain vertical resolved information, we have applied the same method to the extinction coefficients that can be measured by lidar [2]. The calculation of the extinction $\alpha(z,\lambda)$ (z is the altitude and λ the wavelength)from the experimental lidar signal is obtained assuming a constant ratio between the extinction and backscatter coefficients $\beta(z,\lambda)$, the so-called lidar ratio (LR). The choice of this parameter can be constrained imposing that the integral of the extinction coefficient be equal to the optical thickness measured by a sun photometer. From the extinction at different wavelengths (355, 532, 1064 nm from an Nd:YAG laser in our case, labelled as 1,2,3 in the following) it is possible to obtain the Angstrom exponent between wavelength pairs, defined as

$$\delta_{ij} = -\frac{(ln(\alpha(\lambda_i)) - ln(\alpha(\lambda_j))}{ln(\lambda_i) - ln(\lambda j)} \tag{1}$$

and the quantity $\Delta = \delta_{12} - \delta_{23}$.

When aerosol are described by a distribution of spherical particles composed by two log-normal distribution in radius, it is possible to show that there is an approximate mapping between the quantities (δ_{13}, Δ) and (r_f, η), defined as the modal radius of the fine mode log-normal distribution and the fine mode contribution to the total extinction. Using a graphical method, this two quantities can be easily determined [1].

This method is attractive for its simplicity compared to other methods for retrieving microphysical aerosol properties, but it suffers of systematic errors that are due to several assumption such as: spherical particles, refraction indexes, width of fine and coarse modes, assumption of constant lidar ratios. To obtain some insights on the effect of the last assumption, we have generated synthetic lidar signals. For each lidar signal, (δ_{13}, Δ) are calculated and used to determine (r_f, η) at each altitude, and the final result is compared with the true (r_f, η) pair.

The purpose of these simulation is to have an estimation of the intrinsic, probable error of this method. Thus, we must reproduce a variety of possible profiles. We have started with simulations of profiles composed by different homogeneous layers. The relevant parameters that describe the layers are varied randomly and some hundreds of profiles are generated. For each profile, the extinction and backscattering coefficients profiles are calculated using the formulas of Mie theory. Then, using profiles of appropriate atmospheric and instrumental parameters, synthetic lidar signals are generated, and finally the signals are processed to get the profiles of optical coefficients and microphysical parameters.

We can now perform different comparisons. First of all, it is worthwhile to see if the lidar ratio that is found imposing a constraint on the optical thickness has some physical meaning. The reason is that the use of a constant lidar ratio chosen to reproduce the observed optical thickness is very diffused, but we are not aware of published studies on this subject. It seems reasonable to compare the retrieved lidar ratio with a weighted average of the real lidar ratio, since LR corresponding to low aerosol load should contribute less to the average. If we use as weighting function the backscattering coefficient, we get:

$$< LR >= \frac{\int_0^\infty dz\beta(z)\, LR(z)}{\int_0^\infty dz\beta(z)} = \frac{\int_0^\infty dz\alpha(z)}{\int_0^\infty dz\beta(z)} \tag{2}$$

which is simply the ratio between the integrated extinction and the integrated backscattering. The comparison between this quantity and the retrieved constant lidar ratio is given as a correlation diagram in Fig.1, that shows that actually the retrieved constant lidar ratio is a proxy to the averaged lidar ratio. For the comparison of the retrieved quantities (r_f, η) we must stress the fact that both the absolute error and the relative error are not meaningful quantities in all the range of possible values. As an example, if the fine fraction is very small, indicating a predominance of coarse mode particles, it is not very important to know accurately the r_f value. Thus, it seems more appropriate to define an acceptable error for different regions of the (r_f, η) plane to

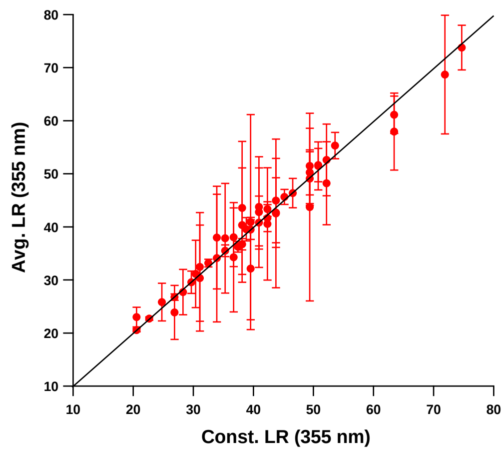

Figure 1. Correlation diagram between the retrieved constant lidar ratio at 355 nm and the averaged lidar ratio from the synthetic profiles. Error bars are the standard deviations of the lidar ratio profiles.

define a normalized error for the two quantities, so that the acceptable error will be a function $err(r_f, \eta)$. Once the profiles of acceptable errors are defined, we can collect all the profiles and get statistics for the errors. Results are reported in

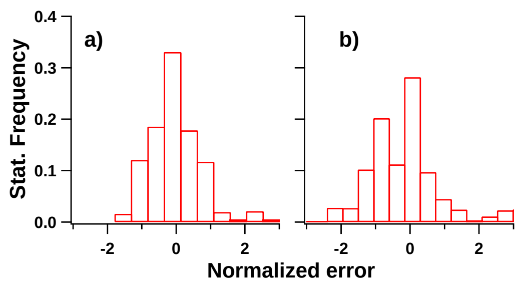

Figure 2. Distribution of normalized errors for r_f (a) and η (b)

Fig. 2, that shows that most of normalized errors are in the ± 2 range, and that there is not a defined bias. This cumulative analysis however does not give information about the agreement of profiles of (r_f, η). In the comparison of retrieved and real profiles, large errors could occur in region where the aerosol load is low, and these errors are clearly less important that the corresponding ones where aerosol load is high. Furthermore, it is interesting to understand how errors are distributed along the profile. This is a general exigence when retrieving profiles of some quantities. We introduce for such kind of comparison a χ^2-like indicator of the discrepancy between retrieved and true quantities:

$$\chi^2 = \sum_{i=1}^{N} \left[\frac{y_i^{tr} - y_i}{err(y_i)} \right]^2 w_i \qquad (3)$$

where y is a generic retrieved profile, y^{tr} is the true profile,w_i is a weighting factor, $err(y)$ the acceptable error. In case of extensive quantities the weighting factor can be just $1/N$ where N is the number of points in the profile. If, for each point, the errors are lower then the acceptable error, $\chi^2 < 1$. In case of intensive quantities, not dependent on the total number of particles, large discrepancies in regions of low aerosol load should be appropriately weighted. As a weighting function, we could use the relative optical thickness of the layer corresponding to the resolution of the calculation:

$$\chi^2 = \frac{1}{AOT} \sum_{i=1}^{N} \left[\frac{y_i^{tr} - y_i}{err(y_i)} \right]^2 [\alpha(z_i)\Delta z] \qquad (4)$$

This definition reduces to the unweighted χ^2 when all the points have the same extinction. The results obtained for (r_f, η) are shown in Fig. 3,where it is possible to see that $\chi^2 < 1$ in 70% and 90% of the cases for (r_f and η) respectively.

This work will be extended to other cases and the sensitivity to other parameters will be checked. The final result will be the assignment of a probable error to the retrieved values (r_f, η) to assess the validity conditions of this method.

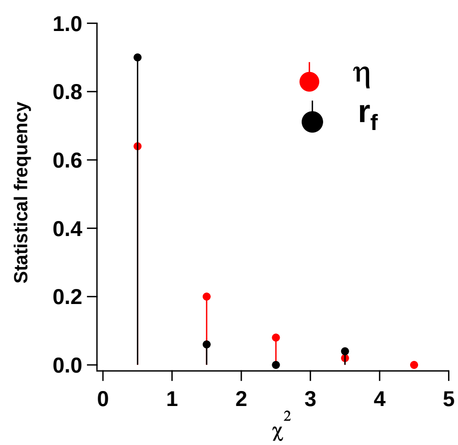

Figure 3. Frequency of the modified χ^2 for r_f (a) and η (b)

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2. M. R. Perrone, F. De Tomasi and G.P. Gobbi Atmos. Chem. Phys., 14 (2014) 1185.