Assessment of the systematic errors in constrained retrieving of aerosol parameters from multi-wavelength elastic lidar.

Ferdinando De Tomasi [1]

[1]Dipartimento di Fisica, Università del Salento, Italy

In recent years, the method proposed by Gobbi *et al* [1] for determining spatially averaged microphysical properties of atmospheric aerosol populations has been applied to multi-wavelength lidar signals to obtain information on the vertical profile of such quantities [2]. However, an assessment of the systematic errors of this method is lacking. We show here the results of large scale simulations that allow to associate a probability density function (PDF) to the the errors of the retrieved parameters. Preliminary results obtained by simulations have been reported in 2014 [3].

We remind that this method is based on the assumption that atmospheric aerosol are spherical and that their radius is described by a PDF composed by the sum of a fine and coarse mode:

$$\begin{aligned} P(ln(r), z) = {} & a_f(z) P_f(ln(r), r_f(z), \sigma_f) \\ & + a_c(z) P_c(ln(r), r_c(z), \sigma_c) \end{aligned} \tag{1}$$

where r is the radius of the particles, z is the altitude, P_f, P_c are log-normal functions with $ln(r_{f,c})$ as central values and $ln(\sigma_{f,c})$ as standard deviations. The weighting coefficients a_f and a_c sum to 1. The so called graphical method enables the retrieving of r_f and the contribution of the fine mode to the total optical extinction η (fine mode fraction), if the refractive index of the particles and the standard deviations of the two modes are assumed as *a priori* information.

In the simulations, one needs to generate a series of profiles that represent a significative sample of the real atmospheric profiles. As a starting point, we've decided to consider, as the simplest non trivial situation, profiles composed of two homogeneous layers. This is actually a not extremely idealized situation, because the troposphere is often characterized by a mixed boundary layer (ranging up to about 1000 m in temperate climates) and a residual layer which is decoupled with boundary layer. We remind that the experimental data are three elastic lidar signals at 355, 532, 1064 nm, and 3 measurements of the aerosol optical thickness at the same wavelengths; furthermore the analysis of the lidar signals gives the maximum height at which aerosol are present, so this quantity also can be considered an experimental datum. Since this height is scarcely higher than 5000 m, I've considered higher layers up to 2000,3000 and 4000 m. The boundary layer height is varied between 700 and 1200 m. The optical thickness at 355 nm is assumed to vary between 0.3 and 0.8, corresponding to the observed ranges. Profiles are generated varying the microphysical properties inside the two layers and varying the relative optical thickness between the two layers. For a better control, we have varied systematically in steps the different parameters, but added small random variations to avoid structures in the final data. For each high layer and optical thickness at 355 nm, 34650 synthetic lidar signals are generated; the results are stored in HDF5 files for further analysis. 6 values of optical thickness have been considered.

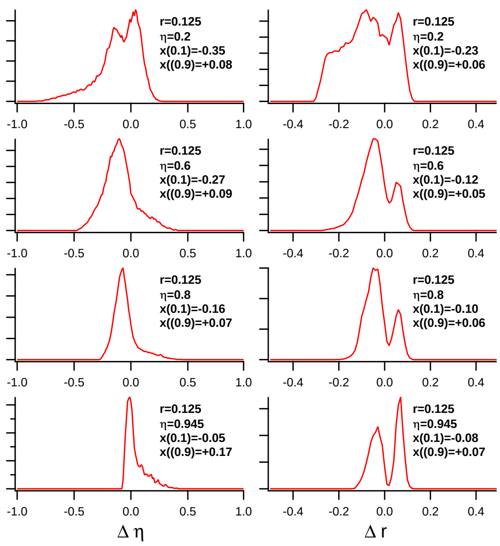

Figure 1. Some examples for the PDF of the errors of η (left) and r_f (right). The central values of r_f and η in the corresponding cell are reported. The parameters $x(0.1)$ and $x(0.9)$ are the 10th and 90th percentile of the PDF

After the retrieving of (r_f,η), the errors can be generated. A first analysis has been performed considering the graphical framework of the cited references. The retrieved pairs (r_f,η) are arranged in cells, the error statistics is performed for each cell separately, and a probability density function (PDF) is generated. This is important because different maximum errors are acceptable for different cells An example of the PDF's for some cells is shown in Fig. 1.

Even if the information about the absolute value of the microphysical parameters is relevant, very often it is important to know if there is some defined trend in an aerosol profile. In the considered cases, as an example, it could be more important to know what are the relative differences of the two layers than the absolute values of the parameters. Thus, an analysis of the correlation between the true and retrieved profiles has been performed. In the case of the η fraction, (the correlation coefficient ranging in (-1,1)) , the fraction of coefficients lower than -0.5 is 0.3, the fraction in the range (-0.5, 0.75) is 0.08 and the fraction in the range (0.75,1) is 0.62. In the case of fine mode radius r_f the corresponding fractions are (0.37,0.12,0.51) Thus, there is a relatively large fraction of retrieved profiles that are poorly correlated, or anti-correlated with the corresponding true profile. Thus, care must be taken when assessing a trend of retrieved profiles using this method.

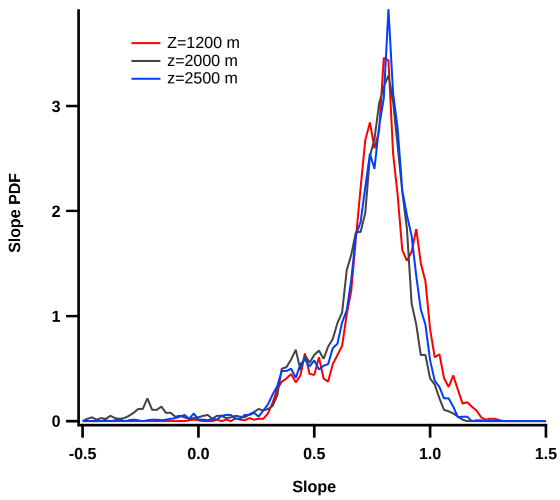

Figure 2. PDF for the slope of the retrieved η vs the true value at different altitudes, for an event in which the coarse mode weight increase temporally in the higher layer.

Other two kinds of simulation have been performed. The original formulation of the method in ref. [1] aims to the detection of events in which aerosol properties change in a definite way because of some physical process. In particular, advection of large particles could reduce the η fraction leaving the r_f unchanged (coarse mode event), or an accretion of r_f due to aerosol hydration would change both r_f and η (fine-mode event). We have tested if the method can detect such events. First, we have simulated such events from the temporal point of view. We have considered modifications of the higher layer, not depending on altitude, and have tested if the retrieved parameters follows the true variation. For coarse mode events, we expect that the η fraction of the high layer reduces while r_f stays unchanged. At the same time, the parameters of the first layer must remain unchanged. Two indicators of the event have been considered: the slope of the η_t vs η_r curve, that in the ideal case should be 1, and the standard deviation of the the retrieved parameters that should stay constant (normalized to their average). In Fig. 2 we show the PDF of the slope at different altitudes for a layer altitude of 3000 m. This slope has a peak around 0.8, with a FWHM about 0.2. However, to assess if the retrieving method has catched the event, one should look to the other indicators and fix some criteria. First of all, we have chosen a restricted number of altitudes in each layer, and calculated slope and standard deviations. The results at different height have been quadratically summed. Then, we have chosen that an event can be considered detected if the slope is larger than 0.5, and normalized standard deviations lower than 0.5. A total of 6912 events have been generated and the percentage of detection is 84%.

A similar test have been applied to fine mode accretion events. In this case, both r_f and η change, so that two slopes are considered in the higher layer. Applying the same criteria for slopes and standard deviations, the detection percentage is 36 %.

Thus, we can conclude that this method can be applied to detect coarse mode events, but not to fine radius accretion events. A similar analysis will be applied to the case of spatial events, in which the variation of η or r_f vary systematically with altitude.

REFERENCES

1. G.P. Gobbi, Y.J. Kaufman, I. Koren, and T.F. Eck, Atmos. Chem. Phys., 7 (2007) 453.
2. M. R. Perrone, F. De Tomasi and G.P. Gobbi Atmos. Chem. Phys., 14 (2014) 1185.
3. F. De Tomasi, Annual Report (2014)