Modelization of aerosol properties and comparison with a Raman - elastic lidar

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A commonly used method for inverting the elastic lidar equation is based on the assumption of a definite relationship between the extinction and backscattering coefficient of the form $\beta = C\alpha^k$ or an assumed lidar ratio profile. In most cases a constant lidar ratio **(1)**, related to the characteristics of the aerosols, is used. This *a priori* setting can be however an important error source, even if the origin of the air masses is known by the analysis of backtrajectories. In fact a constant lidar ratio is obtained only if a linear relationship between extinction (α) and backscattering (β) coefficients holds, which is not the general case if the properties of the aerosol mixture are not constant with altitude. This problem can be solved using a lidar equipped with both an elastic and a Raman receiving channel that allows for an independent measurement of the extinction coefficient. However this technique can be difficult to apply in situations like daytime or field measurements; furthermore, the Raman signal is much lower than the elastic one and longer integration times are needed. It is thus advantageous to have a good estimation of the functional relationship between the average extinction and backscattering coefficients; in this case the lidar equation can be inverted reducing the errors due to an assumed lidar ratio profile or a power-like relationship between α e β.

(1) $$L.R. = \frac{\alpha}{\beta}$$

(2)
$$\frac{dN_i(r)}{d\log r} = \frac{N_i}{\sqrt{2\pi}\log\sigma_i}\exp\left(-\frac{(\log r - \log r_i)^2}{2(\log\sigma_i)^2}\right)$$

$$n(r) = \frac{dN(r)}{dr} = \sum_i \frac{dN_i(r)}{dr}$$

In order to determine the function $\alpha(\beta)$, a Montecarlo approach has been used: many aerosol distributions and compositions are generated by a random picking up of the relevant parameters in a given variability range. To reproduce the several modes shown by tropospheric aerosols, the model employs a multimode lognormal size distribution **(2)**. The three parameters r_i, σ_i and N_i are so required to describe each lognormal mode (Tab.1 for maritime aerosol and Tab. 2 for desert aerosol). For each distribution generated parameters as backscattering and extinction coefficients and lidar ratio can be calculated using Mie theory **(3)**. In the case of desert dust, correction factors have been applied to take into account particles non sphericity. The so obtained parameters can be connected trough scatter plots to show the approximate reciprocal relationships. We have calculated the relationships $\alpha(\beta)$ at a wavelength of 351 nm, corresponding to the Raman lidar operating at the University of Lecce (40°20'N, 18°6'E), for different (20,000) aerosol chemical compositions and size distributions simulating aerosol with maritime and Saharan origin. The validity of the model has been tested using the Lecce elastic-Raman lidar.

(3)
$$\beta = \int Q_{bsc}(r,\lambda,m)\pi r^2 n(r)dr$$

$$\alpha = \int Q_{ext}(r,\lambda,m)\pi r^2 n(r)dr$$

In **(3)**, Q_{bsc} and Q_{ext} represent the extinction and backscatter efficiencies computed by the Mie theory for spherical particles of radius r, refractive index m at the lidar wavelength λ.

Tab. 1. Overall variability considered in the model for maritime aerosol parameters.

Marine Aerosol				
Component	**Mode** (i)	**Parameter** r_i (μm)	σ_i	N_i/N_{tot} (%)
Sea-salt	1	0.05-0.1	1.4-2.03	5-70
	2	0.4-0.6	1.4-2.03	0.4-3.0
(*)**Nss Sulfate**	3	0.02-0.1	1.4-2.03	30-90

(*) non-sea-salt sulfate

Tab. 2. Overall variability considered in the model for desert aerosol parameters.

Desert Aerosol			
Mode (i)	**Parameter** r_i (μm)	σ_i	N_i/N_{tot} (%)
1	0.02-0.08	1.9-2.1	93-98
2	0.3-1.5	1.9-2.0	2-7

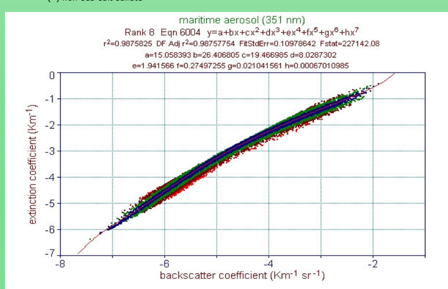


Fig.1. Scatterplot for logarithm of extinction and logarithm of backscattering coefficient obtained for chemical composition and statistical parameters corresponding to marine aerosol. The solid line is a polynomial interpolation with $y = log(\alpha)$ (km^{-1}) and $x = log(\beta)$ $(km^{-1}sr^{-1})$.

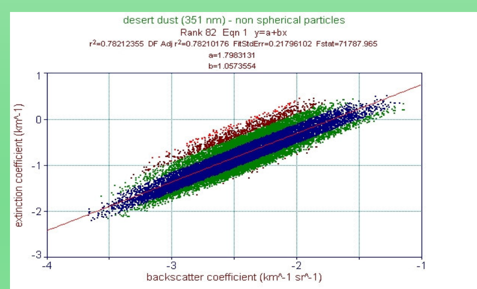
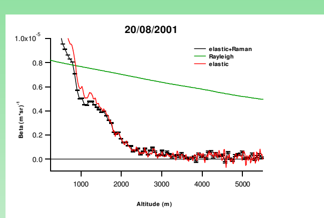
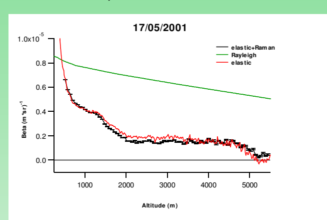


Fig.2. Scatterplot for logarithm of extinction and logarithm of backscattering coefficient obtained for chemical composition and statistical parameters corresponding to Saharan dust, corrected for non spherical particles. The solid line is a polynomial interpolation with $y = log(\alpha)$ (km^{-1}) and $x = log(\beta)$ $(km^{-1}sr^{-1})$.

We have performed checks of the presented modeled $\alpha=\alpha(\beta)$ relationships using an elastic-Raman lidar based on XeF excimer laser. If we can make an hypothesis on the nature of the aerosol we could thus compare the aerosol parameters obtained by Raman measurements to the same result obtained inverting the lidar equation through the functional relationships $\alpha(\beta)$. This hypothesis can be made from the analysis of the air mass backtrajectories (performed by the German Weather Service).



3.a)



3.b)

Fig.3. Comparison between backscattering coefficients calculated by combined elastic - Raman measurement and by elastic measurements and the functional relation $\alpha(\beta)$ obtained by the model. **3.a)** The function $\alpha(\beta)$ corresponding to maritime aerosols has been used in all the range of calculation. **3.b)** The function $\alpha(\beta)$ corresponding to non spherical desert dust particles has been used in the range 2000 -7000 m, while the function to maritime aerosols has been used in the range 250 - 2000 m.

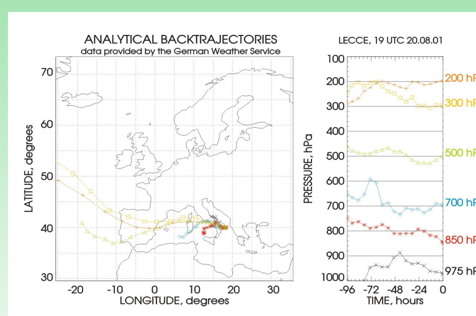


Fig.6. Backtrajectories of May 17, 2001, 19 UT (*).

(*) The program for visualization of backtrajectories was performed by Ina Mattis (ITR Leipzig).

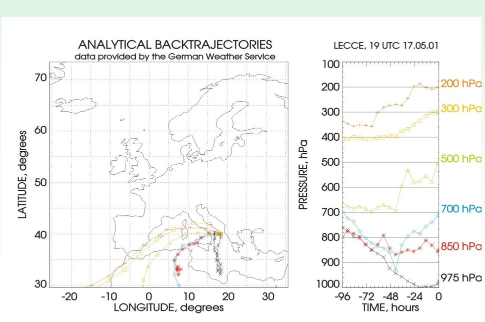


Fig.5. Backtrajectories of August 20, 2001, 19 UT.

Conclusions

The model developed by Barnaba and Gobbi for determining the functional relationships $\alpha(\beta)$ at the wavelength of 532 nm has been used to determine similar relationships at 351 nm for maritime and desert dust aerosols. The original model has been validated using sun photometer data and it is now routinely employed for data analysis of an elastic lidar operating at 532 nm at ISAC, Rome. A test of this model has been made using an elastic-Raman lidar operating in Lecce at 351 nm. We see that in the case in which the backtrajectories analysis provides a good guess of the aerosol origin, the model provides a good prediction of the relationship $\alpha(\beta)$. This relationship can thus be used, as an example, for daytime measurements and other situations where the Raman technique cannot easily be used.