Lidar measurements of aerosol depolarization ratio

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Lidar measurements of the aerosol depolarization ratio provide highly reliable informations to discriminate between spherical and non-spherical particles in the atmosphere and they can help to distinguish between liquid and solid phase aerosols.
These measurements can be performed by using a linearly polarized laser source and a hardware configuration of the receiving system including two channels detecting simultaneously the backscattered light polarized in the parallel and orthogonal direction with respect to the laser beam. In these conditions the total depolarization ratio, i.e. the depolarization induced by both aerosols and atmospheric molecules, can be obtained if a calibration of the system is performed.
In this paper three different calibration methods are described. For each method a sensitivity analysis is performed and the different contributions to the total error are evaluated by means of a numerical simulation.
Results from numerical simulations allow comparing the performances of the three calibration methods in different atmospheric conditions.

1. Introduction

Aerosols' impact on atmospheric systems is complex and not perfectly well-known. A deeper interest in understanding aerosols' role in climate balance and variable as well as their effect on human health is growing in these last years.
Moreover, aerosol data from satellite and ground-based systems can help improve atmospheric models and in real-time observations. In this context Depolarization-sensitive Lidar can help distinguish between solid and liquid phase water and characterize the particle's shape.
The depolarization measurements can be performed by using a linearly polarized laser source and a hardware configuration of the receiving system including two channels detecting simultaneously the backscattered radiation in the parallel and orthogonal direction with respect to the laser beam [Schotland et al., 1971].
The total depolarization ratio, due both to molecular and aerosol contributions, is simply the calibrated ratio of the orthogonal signal to the parallel one. So, a key question to obtain high quality depolarization measurements is performing a good calibration of the Lidar system [Alvarez et al., 2006].

In this work three different calibration techniques are analyzed by simulating lidar signals in different atmospheric conditions. The stability of atmosphere, the laser source polarization degree, the accuracy of polarization alignment and the background radiation are taken into account in the simulated depolarization measurements. The behaviours of these parameters and the choices of normalization/calibration range and calibration height are studied also. The final goal is to compare the results of the three techniques in order to find the best method for each atmospheric condition.

2. Methodology

The simulated signals of the two polarized channels were obtained using Monte-Carlo technique. It can generate signals starting from some input parameters. These are: vertical profiles of the backscattering and extinction coefficients, depolarization ratio for specific aerosols' layers and the instrumental parameters of the Lidar apparatus. A summary of Lidar apparatus' characteristics is reported in Table 1.

Characteristics	
Napoli Lidar system	
laser:	Nd:YagAG, flash-lamps pumped, Q-switched, frequency doubled and tripled
wavelengths:	532 nm, 355nm
pulse energy:	10300mJoule, 100m Joule
repetition rate:	20 Hz
receiver telescope:	0.3 m diameter
wavelength for depolarization measurements :	532 nm
bandwidth	0.5 nm
FOV:	1.2 mrad
vertical resolution:	60 m
Raman channels	386 nm, 407 nm, 607 nm

Table 1. Principal characteristics of Napoli Lidar apparatus

Elastic signals for both the polarization channels have been simulated by considering the following layers:

1) below 1.5 Km of altitude: a typical Planetary Boundary Layer (PBL) aerosol, with $\beta = 1 \sim 5 \times 10^{-6} \mathrm{sr}^{-1}\mathrm{m}^{-1}$; a Lidar Ratio (LR) between 70 and 80 sr and a depolarization ratio of 0.03;
2) from 3 to 4 Km: an aerosol layer with 0.05 total depolarization and LR of 40 sr;

3) between 4.5 and 5.5 Km: a Saharan dust layer with a typical depolarization ratio of 0.2 [Immler et al., 2003] and LR of 40.
4) for altitude between 9 and 10 Km: cirrus cloud with a 0.4 depolarization ratio and LR of 30 sr.

The simulated signals are shown in Fig. 1

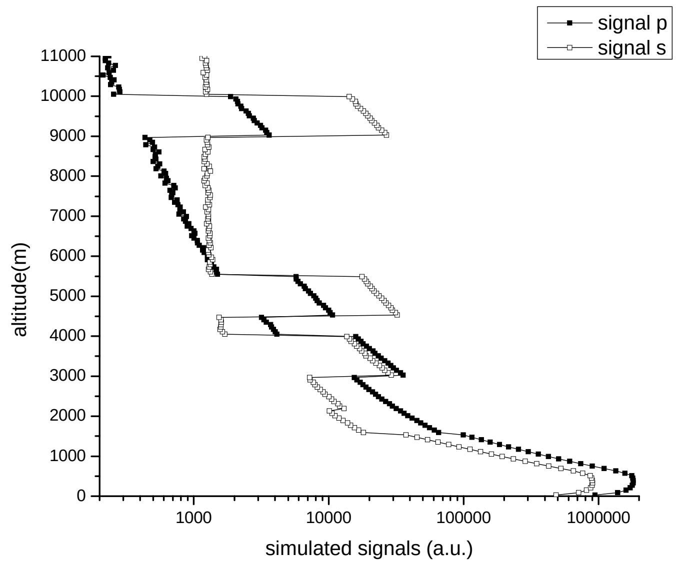

Fig.1 Simulated signals for parallel and orthogonal directions of polarization. The parallel one is indicated by the full square and the orthogonal one by the empty square.

2.1 Depolarization equations

Indicating with $P(z)$, $\beta(z)$, $\tau(z)$ and g the received power as a function of the altitude, the backscattering coefficient, the optical depth, and the electro-optic signal gain for each channel, respectively, the Lidar equations for the signals corresponding to the two polarized elastic signal components under the hypothesis of single scattering, are :

$$\begin{cases} P_{//}(z) = g_{//}\left[P_{0//}(\beta_{//}(z))e^{-2\tau_{//}(z)} + P_{0\perp}(\beta_{\perp}(z))e^{-2\tau_{//}(z)}\right] \\ P_{\perp}(z) = g_{\perp}\left[P_{0//}(\beta_{\perp}(z))e^{-2\tau_{//}(z)} + P_{0\perp}(\beta_{//}(z))e^{-2\tau_{//}(z)}\right] \end{cases} \quad (1)$$

The total depolarization ratio, defined as: $\delta = \dfrac{\beta_{\perp}}{\beta_{//}}$ (2) can be obtained from the ratio of the equations (1) if a calibration of the system is performed.

The first calibration technique performs an instantaneous calibration using the normalization of the real signals to the molecular elastic backscattered ones. This normalization can be done in an altitude range where the signal is due only to the molecular contribution, whose depolarization ratio is known [Sauvage et al., 1999] and assumes a constant value of 0.00376 in our experimental conditions [Behrendt et al., 2002]. Usually these conditions are reached only at high altitudes, therefore the signal to noise ratio limits the performances of this method. In the simulated case, the range for molecular calibration is chosen between 6 and 8 Km. The results for depolarization ratio are showed in fig.2 together with the exact value.

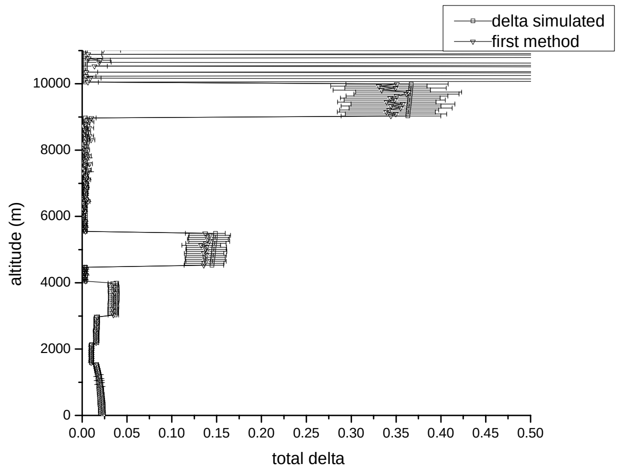

Fig. 2 Comparison of the total depolarization ratio vertical profile obtained by calibrating with molecular contribution and the simulated profile.

The second calibration technique is performed in two steps by taking measurements in two different conditions, corresponding to a rotation of the polarization direction of the laser by ninety degree. In this way the polarization direction of two channels in the receiver system is exchanged. In figure 3 the results of the application of this calibration technique under the hypothesis of perfect atmosphere stability are shown.
It’s important to point out here that to perform this calibration a set of two measurements taken at two different times is needed. Therefore, instabilities of the atmosphere can introduce noise and systematic errors in the results.

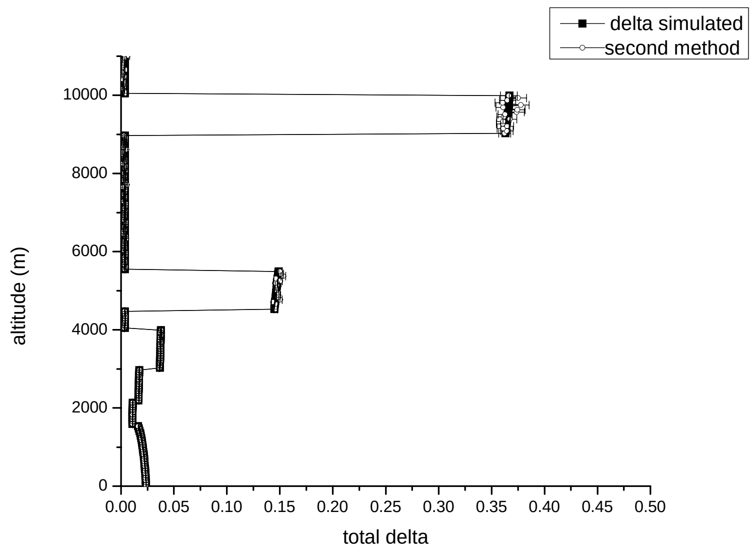

Fig.3 Comparison results between total depolarization ratio simulated and obtained using the calibration technique based on polarization rotation of ninety degrees.

The third calibration procedure requires three steps: first performing a measurement with the parallel receiving channel aligned with the direction of the laser polarization, then rotating the polarization direction of the laser by 45 degree and then rotating it again by 45 degree but in the opposite direction. Even though three steps are required, this calibration method is insensitive to atmospheric instability. In figure 4 the results obtained by applying the third calibration method to simulate signals are shown.

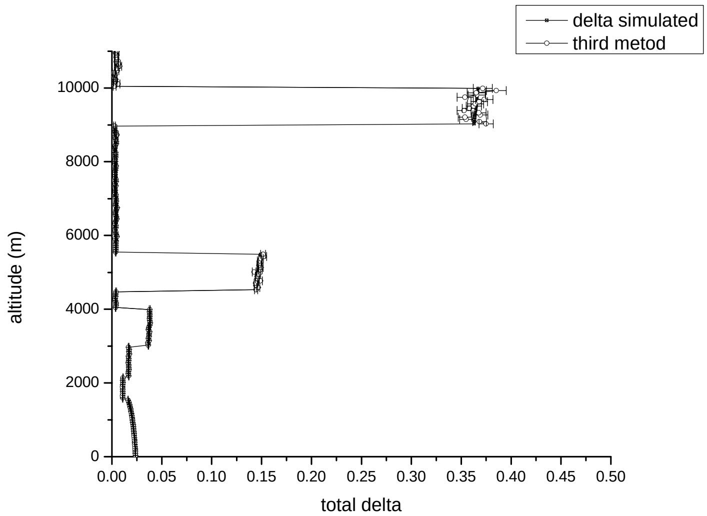

Fig. 4 Comparison results between total depolarization ratio simulated and obtained using by the three-steps calibration technique

The relative error of total depolarization obtained from the two-steps calibration procedure for the three aerosol layers is around 3% when the atmosphere is supposed stable. If a variability of the atmospheric parameters (i.e the backscattering and extinction profiles) of about 10% is introduced, the relative error from the two steps method grows up to about 3%~9%.
On the contrary, the three-step method results to be almost independent on atmospheric variability. In fact, no appreciable changes in the results are obtained also if values of the atmospheric parameters are changed by 50%.

4. Conclusion

In this work a comparative analysis of three calibration tecniques to obtain total depolarization ratio from lidar simulated measurements is reported.
The first method performs an instantaneous calibration to the molecular backscattered signal calibrating the signal on the molecular contribution in an aerosol free region. The advantage of this method is that the calibration is performed at the same time of each measurement. The disadvantage is that results are affected by a high noise level.
The second and the third methods are based on rotation of the polarization of the laser source by 90 degree and 45 degree in two opposite directions, respectively. These two methods need additional hardware in the optical path. Moreover, the second method is sensitive to atmospheric instabilities.
The three-steps method seems to be the most accurate and reliable in every atmospheric conditions.

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6. References

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