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Quantitative Lidar at 532 nm for Vertical Extinction Profiles and the Effect of Relative Humidity

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Abstract. An analysis of 532 nm lidar data is presented for the retrieval of vertical extinction profiles. The strong influence of the relative humidity on the extinction-to-backscatter ratio is parametrized for this purpose. A comparison is made between remotely sensed and locally measured extinction coefficients, using reference values in aircraft and at ground level.

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Quantitative analysis of laser-radar (lidar) data is of high interest for remote sensing applications in aerosol monitoring and trace-gas measurements. In the latter, highly selective laser wavelengths are used to match the absorption characteristics, while the former aerosol application employs non-specific wavelengths and measures ensemble-averaged Mie-scatter parameters. In order to cope with the inherent multivalued nature of the Mie scattering, usually additional assumptions or boundary values are necessary for interpretation [1].

In this letter paper we report on a parametrization of the extinction-to-backscatter ratio ($P = \alpha/\beta$) with relative humidity (RH). The RH is important in aerosol measurements, as it influences the scattering coefficients to a very large extent. With this parametrization, the quantitative lidar extinction profiles as a function of altitude were successfully compared with conventional extinction measurements in aircraft flights. The lidar system is schematically shown in Fig. 1. The optical pulse transmitter is a Quanta-Ray DCR Nd:YAG laser equipped with a second harmonic generator (KD*P SHG crystal). The weak, backreflected optical signal is collected and recorded as a function of flight-time (range) in a transient digitizer (Biomation 8100). Further dataprocessing (signal averaging, correction for geometric R^{-2}-loss and energy normalization) is performed in an online HP A600 microcomputer. The lidar signal S as a function of range R is described by

$$S(R) = R^{-2}\beta(R)\exp\left[-2\int_0^R \alpha(r)dr\right] \quad (1)$$

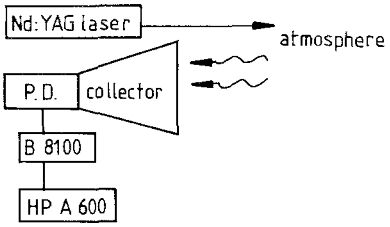

Fig. 1. Schematic outline of the lidar system. A 10 ns pulse is generated by the laser transmitter and subsequently reflected off the atmospheric aerosol. The main factors, which affect the received photosignal are: beam extinction, backscatter efficiency of the aerosol and the geometric R^{-2} loss factor in the reflected energy. For detection, IR-enhanced photodiodes or avalanche photodiodes were used. The Biomation 8100 digitizer records the time of flight signal, typically up to 6 km range. A Fortran-programmed HP A600 microcomputer averages the waveforms, corrects for the (fixed) R^{-2}-loss and controls the measurements

with $\beta(R)$ and $\alpha(r)$ representing the local backscatter and extinction coefficient, respectively. The exponential factor is the integrated beam extinction up to range R. The factor R^{-2} is due to the reflection loss of energy into a semisphere. For a homogeneous atmosphere the logarithm of the R^2-corrected signal, $\ln(S \cdot R^2)$ as a function of R, enables to obtain both β and α from intercept and slope, respectively. For inhomogeneous situations, solutions of (1) are tried with successive integration techniques, using either boundary conditions in α or employing a parameter reduction by means of a relation between α and β. The

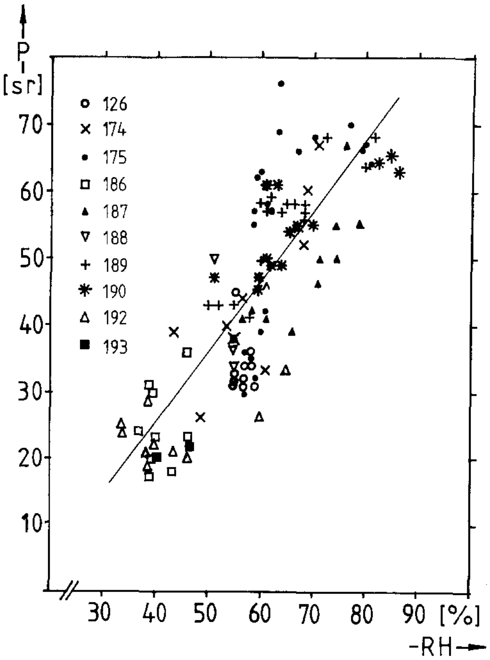

Fig. 2. The lidar ratio (extinction/backscatter) as a function of relative humidity. Although both α and β increase rapidly with RH (typically a factor of 15 and 5 respectively) their ratio displays a slower gradient. No clear distinction was found between 0.53 and 1.06 μm, which were both used for this figure

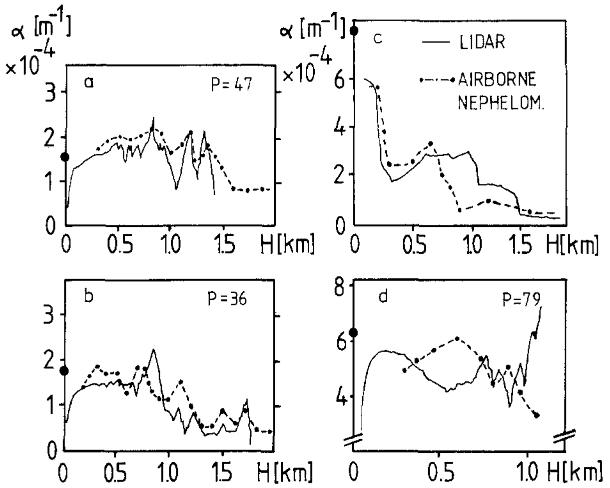

Fig. 3a–d. Vertical extinction profiles at 0.53 μm. Calculated from 0.53 μ lidar (——), measured in aircraft spirals (·—·—·) and at ground level (●). The parametrization of Fig. 2 was used in the lidar calculation. The reference measurements were made at 0.5 μm

lidar ratio $P=\alpha/\beta$ is sometimes used for this purpose [2, 3].

For homogeneous conditions, we have determined α and β as a function of RH, using the above mentioned slope method. Both α and β increase rapidly with high RH: typically a factor of 15 for α and a factor 5 for β when RH increases from 60% to 90%. The lidar ratio P was determined for many RH conditions (Fig. 2). The α/β ratio vs. RH displays much less scatter than either α or β vs. RH; therefore, the use of the lidar ratio as a good parameter for the solution of (1) is suggested. No systematic difference in the lidar ratio was found between 0.53 and 1.06 μm, which were both used in Fig. 2. Due to their wavelength dependence, of course the α and β values at 1.06 μm are about a factor of 3 lower than at 0.53 μm. In Fig. 2, the data for different days tend to cluster accordingly, indicating a day-to-day scatter which is less than the overall scatter; this might be due to differences in aerosol properties (size distribution, composition) on the involved days.

Under various RH situations, the average line in Fig. 2 was used to calculate extinction profiles at 532 nm from (1). Comparisons were made with boundary values of α at ground level and with vertical α-profiles using aircraft mounted extinction meters (Fig. 3). The appropriate RH values were obtained from radiosondes at the lidar site, which were released simultaneously with the aircraft measurements. Also, the lidar observations were intensified from regular 30-min intervals to continuous probings at 10 Hz rate during the aircraft spirals; averaged profiles from 100 s of operation were used for the α-profiles.

The solutions for α from (1) were calculated with

$$\beta(R)=S(R)\,R^2\Big/\left[C-2P\int_0^R \beta r^2\,dr\right] \qquad (2)$$

and the lidar ratio $\alpha=P\beta$ [2, 3]. Good agreement was found between the local and remote extinction measurements. The discrepancy at 1.0 km in Fig. 3c is probably due to spatial inhomogeneity in the probed regions. The strong difference in Fig. 3d at 1.0 km is due to a large change in RH, which was not incorporated in the lidar calculation.

Presently, experiments are under way to calculate the 532 nm extinction from lidar data at 1064 nm, where extinction is lower and pulse energy higher; also the aerosol properties will be reflected in the wavelength dependence.

Summarizing, lidar measurements of atmospheric extinction and backscatter coefficients are reported in the presence of significant relative humidity. The resulting lidar ratios (extinction divided by backscatter) were used to solve the lidar equation for vertical extinction profiles. Good agreement was found with groundbased and aircraft-mounted extinction meters.

This type of parametrization of the lidar ratio will be useful in routine calculations of quantitative scatter data from lidar observations.

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