Calculation of Backscatter Coefficients for Lidar systems by Mie-Scattering Theory and Atmospheric Properties

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A calculation method for atmospheric Backscatter Coefficients is shown. The calculation is based on typical atmospheric aerosol statistics and Mie-Scattering theory. The goal of this article is to close the gap of missing Backscatter Coefficients on certain wavelengths which are favorable for designing more cost-effective Lidar systems in the near future.

1 Introduction

The received power P_r of a Lidar system at a distance R is calculated by the Lidar equation [1]

$$P_\mathrm{r}(R) = K \cdot G(R) \cdot \beta(R,\varphi) \cdot T(R) \cdot P_\mathrm{s}. \qquad (1)$$

Within formula (1) K describes a performance factor, G a geometrical measurement factor, β the backscattering coefficient at a scattering angle φ, T a transmission coefficient and P_s the sending beam power. For typical air conditions $T(R)$ approximates to 1 near ground. The geometrical measurement factor $G(R)$ is 1 for Lidar systems that use the same optics for sending and receiving[2,3]. K is dependent on the actual optoelectronical sensitivity of the system and can be measured.

Finally, the backscatter coefficient $\beta(R,\varphi)$ is a crucial parameter to estimate the received power of any Lidar system for designing purpose. Nevertheless there is a gap of reliable backscatter coefficients in the near infrared and infrared region [4].

In this article a simple method and its tool chain is described to evaluate backscatter coefficients for any desired wavelength. For evaluation purposes the wavelength $1234\ \mathrm{nm}$ is chosen.

2 Atmospheric composition

A set of particle distributions [5] describes typical ideal compositions of air. The overall amount of one particle type N_i with radius r between the minimum and maximum cutoff radius $r_{\min}$ and $r_{\max}$ is

$$N_i = n_i \int_{r_{\min}}^{r_{\max}} \eta_i(r)dr \qquad (2)$$

with the log normal scaling factor n_i and the lognormal distribution function η_i.

Inner continental atmospheres are described by three of such particle types: insoluble (also called dust-like), water soluble and soot (also called carbonous).

Therefore the overall backscatter coefficient is the combination of the backscatter coefficients of each of those particle types [1]. The scattering angle φ can be assumed as π, especially when sending and receiving optics are the same and the measurement distance is far away in comparison to the receiving aperture.

$$\beta(\varphi = \pi) = \textstyle\sum_i \beta_i(\varphi = \pi) \qquad (3)$$

Furthermore a single backscatter coefficient of one particle type is calculated by

$$\beta_i(\varphi = \pi) = n_i \int_{r_{\min}}^{r_{\max}} \frac{d\sigma_i(r,\varphi=\pi)}{d\Omega} \eta_i(r)dr \qquad (4)$$

with the differential backscatter cross section $\frac{d\sigma_i(r,\varphi=\pi)}{d\Omega}$.

The differential cross section is calculated by Mie-Scattering theory using the software package of Maetzler [6]. Nevertheless refractive indices are only given for specific wavelengths [7]. Values in between can be linearly approximated for a rough estimate.

3 Results

An example result for standard continental air of different pollution levels is given in Fig.1 and Fig. 2 for the arbitrary wavelength $1234\ \mathrm{nm}$. Fig. 1 shows an overview of those absolute β-values.

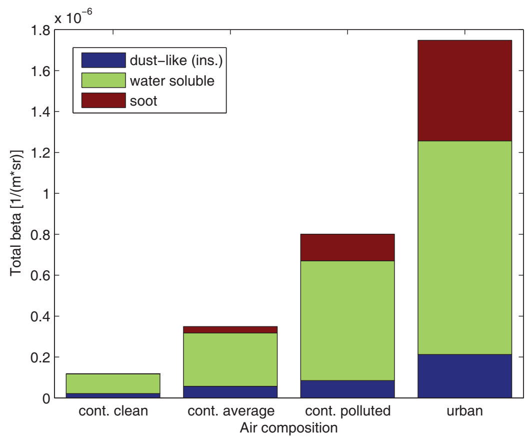

Fig. 1 *Overall backscatter coefficient separated by the aerosol types.*

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The cleanest pollution level has got a backscatter coefficient in the order of $\beta \approx 10^{-7} \frac{1}{\mathrm{m \cdot sr}}$ while the urban pollution level is in the order of $\beta \approx 10^{-6} \frac{1}{\mathrm{m \cdot sr}}$.

Fig. 2 depicts the relative impact of the different aerosol types in the actual signal. It is obvious that soot has a rising impact on the signal with rising pollution.

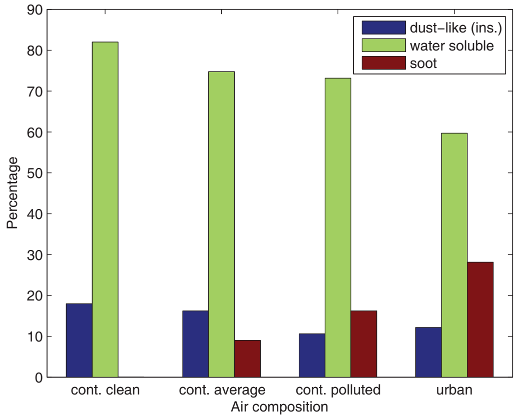

Fig. 2 *Impact of the aerosols on the overall beta value in percentage.*

4 Conclusion and future work

This article presents the theory, necessary literature and the tool chain to calculate backscatter coefficients for Lidar systems. The process is applied for an arbitrary wavelength of $1234\ \mathrm{nm}$.

In future a comprehensive backscatter analysis for several wavelengths is planned to support Lidar manufacturer and researchers.

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