INFLUENCE OF MULTIPLE SCATTERING ON MEASUREMENTS WITH ELISE

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1 Introduction

Clouds and aerosols influence our climate significantly. Changes in their properties (microphysics, size distribution, etc.) will alter today's climate. Model simulations predict an average rise of temperature between 1 and 5K over the next five decades due to man's activities on earth. The large discrepancy between predictions of the individual models is partly due to our insufficient knowledge about horizontal and especially vertical distribution of clouds and aerosols.

The lidar technique has proved to be capable to yield observation data with very good height resolution. In 1994 NASA's LITE mission (Winker et al. 1996) additionally showed that the lidar technique is also applicable to spaceborne measurements. However, the LITE mission was too short to allow for a systematic observations of atmospheric variability.

During the last years Japan's National Space Development Agency (NASDA) has been developing a two-wavelength backscatter lidar for spaceborne observations of the atmosphere. It was designed for a lifetime of one year or more, hence giving the possibility to collect measurement data covering all seasons and the whole earth (see e.g. Sasano 1998). Theoretical studies using the single scattering lidar equation have shown that the system will be capable of detecting both aerosol layers and clouds and additionally can give information about their vertical distribution (Liu and Sugimoto 1998).

However, in the case of spaceborne measurements the single-scattering lidar equation does not describe the backscatter intensity completely, as multiple scattering effects enhance the signal (Spinhirne 1982). A simple approximative way to account for multiple scattering was proposed by Kunkel and Weinman (1976). They introduced a so-called multiple scattering factor F in the lidar equation:

$$P_{tot}(R) = \frac{C}{R^2}\beta(R) \times \exp\left(-2[1-F(R)]\int_0^R \sigma(r)dr\right). \quad (1)$$

Here $P_{tot}(R)$ is the total signal which seems to be backscattered from distance R, σ and β are extinction and backscatter coefficient, respectively, C is a constant including various parameters of the system. If F is known the measurement data can be inverted in a similar way as in conventional algorithms for the single scattering lidar equation (e.g. Klett 1981, Fernald 1984). Yet, F cannot be estimated from conventional backscatter lidar measurements but has to be determined a priori. This can be done with the help of model simulations. We used a Monte Carlo model (Kerscher et al. 1995) to calculate lidar signals including multiple scattering. The model yields both the total backscatter intensity as function of the distance and the respective in-

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tensitities due to individual scattering orders. The multiple scattering factor can then be calculated by

$$F = \frac{1}{2\tau(R)} \ln \left(\frac{P_T(R)}{P_S(R)} \right) \quad (2)$$

with P_T and P_S the total and single scattering intensity, respectively and $\tau(R)$ the optical thickness between lidar and distance R. F depends both on the scattering properties of the atmospheric layer which is investigated and on the system parameters of the lidar. Therefore, multiple scattering factors calculated for other missions, e.g. for LITE cannot be expected to be correct for ELISE.

2 Results

We simulated lidar returns for various different atmospheric conditions and calculated F for each case. In this contribution we will only discuss water cloud cases.

The microphysical properties of atmospheric clouds (e.g. liquid water content, size distribution) vary over large ranges, depending on the origin and the development of the cloud. It is not feasible to consider all possible combinations of parameters, however, we chose several parameter sets from the OPAC climatology (Hess et al. 1998) which can be considered to be representative for both convective and stratus cloud types. The respective size distributions are shown in Figure 1. The clouds were assumed to be homogeneous in their composition and to have a constant extinction coefficient. For better comparison the same atmospheric model was used in all cases with a cloud base at 2km altitude (i.e. 548km distance from the lidar) and the cloud top at 4km (546km distance). Below and above the cloud layer the extinction profile of a US Standard Atmosphere with only molecular scattering was assumed.

Figure 2 shows examples for the multiple scattering factor for different cloud types when an extinction coefficient of 3km^{-1} is chosen. In front of the cloud where multiple scattering portions can only result from molecular scattering, F decreases with increasing distance from the lidar. This is typical for the case where the largest part of the photons which are scattered in another direction than backward to the lidar leave the observed volume without contributing to the detected signal. One reason for that is the small extinction coefficient which results in large mean free paths of the photons. Another reason is the uniform angular scattering distribution which is characteristic for scattering in the Rayleigh regime and which effects large amounts of sideward scattering. In the cloud layer both the mean free path is much shorter (due to larger extinction) and the dominant forward scattering maximum of the phase function increase the probability that a scattered photon stays in the observed volume and contributes to the backscatter signal. This and the special geometry of a spaceborne lidar result in that F remains fairly constant throughout the cloud with values close to 0.4. On the other side Kunkel and Weinman (1976) found a significant dependence of F on the penetration depth in the cloud layer for ground-based lidars. Figure 2 also reveals that the size distribution of the cloud droplets only has small influence on F. Behind the cloud layer F rises sharply. The reason is that here the single scattering contribution to the total signal drops drastically due to the sharp decrease of the backscatter coefficient. However, the multiple scattering intensity still remains quite large. It is predominantly due to photons which experience a path elongation due to several scattering events inside the cloud. The fluctuations of F inside and especially behind the cloud are due to the Monte Carlo procedure which was used in order to calculate the signals.

In Figure 3 presents multiple scattering factors for different extinction coefficients in the cloud layer. All cases are for a cloud of cumulus maritime type. Again a US Standard Atmosphere is assumed below and above the

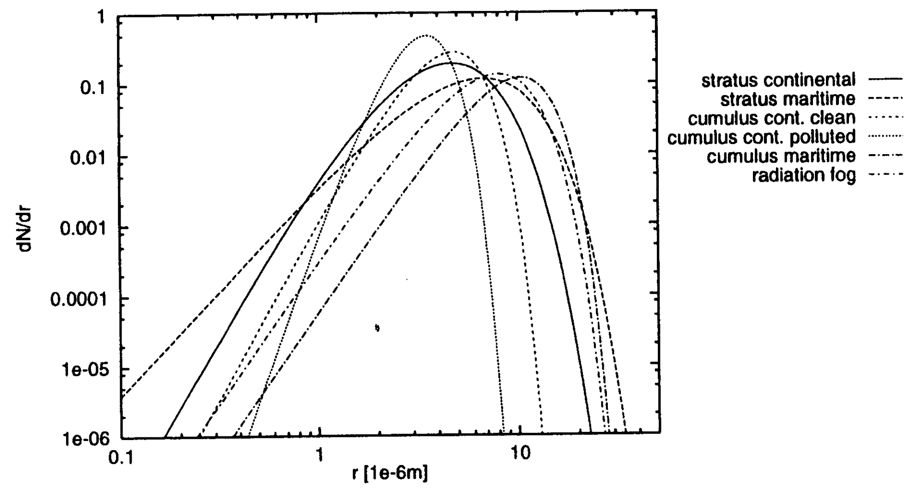

Figure 1: Size distribution of different cloud types according to OPAC (Hess et al. 1998).

cloud. Apparently, the dependence of F on the extinction coefficient is more significant than the dependence on the size distribution as F increases with σ. Additionally we found that F remains fairly constant throughout the cloud layer when $\sigma \leq 3\text{km}^{-1}$. In these cases the same explanation holds for the constant F as was given for Figure 2. For clouds with stronger extinction higher scattering orders more and more dominate the backscatter signal. Also the number of photons increases which are leaving the observed volume in sideward direction after one or several scattering events. However, since the volume under observation is relatively large (compared to a ground-based lidar) also scattering back into the volume happens frequently. This results in an increase of F with penetration depth. Yet, for the system parameters as proposed for ELISE it has to be expected that in case of a cloud with very large extinction coefficient an inversion is not possible since the backscatter signal decreases too fast. Other cloud types show very similar characteristics of F (without figure).

In order to examine the influence of system parameters we performed similar calculations for a lidar system with specifications of LITE (Figure 4). Comparison with the respective cases observed by a lidar with ELISE's specifications (Figure 2) shows that the same dependence of F on the pentration depth can be found. Also here the variation of F for different cloud droplet size distributions is only marginal. However, compared to ELISE's geometry the multiple scattering factor is systematically slightly higher with values around 0.5. This results from the larger contribution of multiple scattering intensities to the total signal in measurements under LITE which is due to the larger field of view. The differences in F underline the importance to perform multiple scattering simulations with special emphasis on ELISE's parameters.

3 Summary

Multiple scattering contributions to the backscatter signal cannot be neglected in spaceborne lidar measurements. In order to estimate the influence of multiple scattering we performed model simulation. We showed that for water clouds the multiple scattering factor F has only a marginal dependence on the cloud type. For the cases which are still penetrable for lidar the multiple scattering factor remains approximately constant in the cloud layer with values around 0.4. A change

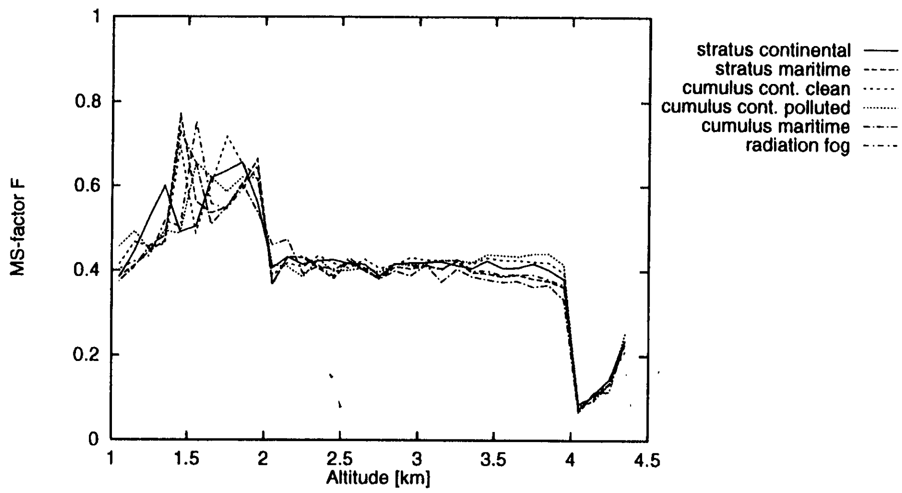

Figure 2: Multiple scattering factor F for cloud types from Figure 1 with the extinction coefficient $\sigma = 3\text{km}^{-1}$ inside the cloud and a US STandard Atmosphere below and above.

of system parameters will also result in a different F.

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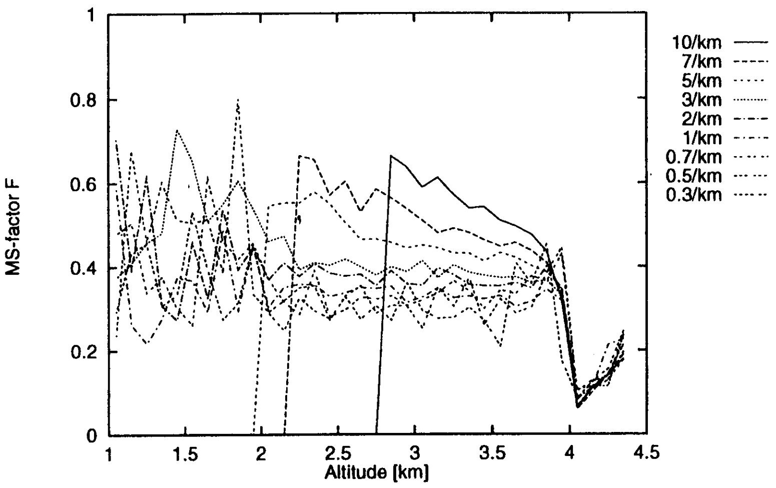

Figure 3: Multiple scattering factor F for a maritime cumulus (Hess et al. 1998). Variation of the cloud's extinction coefficient.

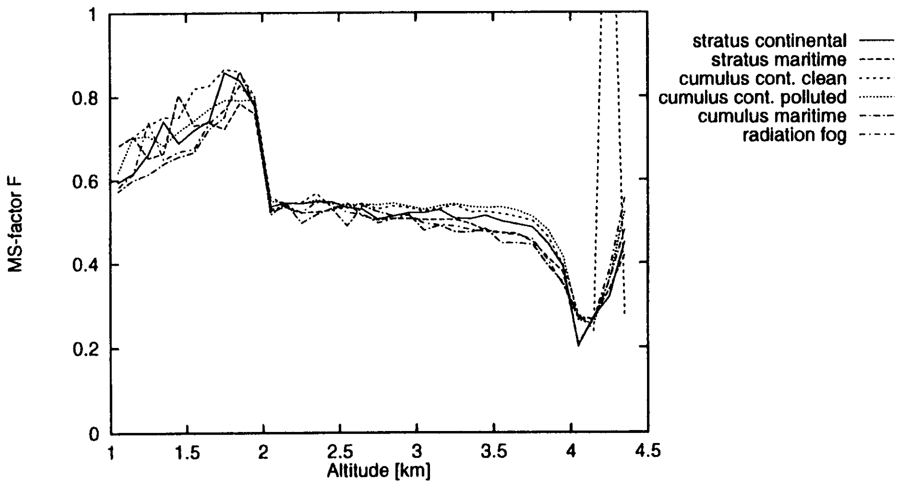

Figure 4: Multiple scattering factor F for measurements using the LITE geometry. Variation of cloud types with $\sigma = 3\text{km}^{-1}$ inside the cloud.