LIDAR INVESTIGATION OF AEROSOL PARTICLE SIZE DISTRIBUTION IN THE VICINITY OF CLOUDS

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ABSTRACT

We present Aerosol Particle Size Distribution (APSD) retrieved from multiwavelength lidar profiles in the vicinity of convective clouds. The data were collected in summer 2006 in Warsaw (Poland). For the retrieval of APSD a recent algorithm based on direct fit of this function to the lidar signals was employed.

INTRODUCTION

Remote and nonperturbative investigation with lidars provides information about profiles of atmosphere. In case of muliwavelength lidars aerosol particle size distribution (APSD) can be achieved. In this study we analyzed multiwavelength lidar returns collected in vicinity of boundary layer convective clouds. The data were gathered in July - August 2006 in Warsaw (Poland).

A multiwavelength lidar working at 5 wavelengths described elsewhere (Ernst *et al* 2003a, Chudzyński *et al*, 2006) was used. It consists of the optical sender with pulsed Nd:YAG laser generating at three harmonics (1064, 532 and 355 *nm*) and additional pulsed Ti:Sa laser generating at two harmonics (782 and 391 *nm*). Energies of the light pulses were about 200 *mJ*, while their repetition rate was 10 *Hz*. The laser beams were sent vertically to the atmosphere.

In the optical receiver a Newtonian telescope with the mirror of 40 *cm* in diameter and focal length of 120 *cm* was used. The light, collected by the telescope, was spectrally separated by a polychromator. Acquisition of the lidar echoes was done with a set of photomultipliers and 12 bit 50 *MHz* digitizers. The signals were averaged over 300 pulses.

For retrieval of APSD original method was elaborated (Ernst *et al*, 2003b, Jagodnicka *et al*, 2008). It is based on direct fit of particle size distribution to the lidar signals. APSD was approximated with combination of two lognormal modes with free parameters (Reidmiller *et al*, 2006). Using such function for each lidar wavelength the extinction and backscattering coefficients were calculated and substituted into the lidar equations (Measures, 1992). In this way synthetic lidar signals were achieved. Varying the parameters and using Monte Carlo sampling the best fit of the synthetic signals to experimental ones was found.

In principle, an inversion of the lidar signal is an ill-posed problem and requires many additional assumptions. First, refraction index of the aerosol is taken as this one for water. Second, aerosol particles are assumed spherical. Additionally, activation of CCN and growth of certain classes of particles with height is expected. Signature of this process should be seen in the retrieved particle size spectrum.

AEROSOL AT THE BASE OF CUMULUS

On July 26th at 09:40 UTC scattered *Cumulus* below a weak *Cirrostatus* cover was present. *Cumulus* clouds were developing in a humid marine polar air advecting from north. Noon sounding from Legionowo (~30 *km* north from the measurement site) showed the mixed layer present up to 2000 *m* height. The wind was weak, 3 *m/s* in the boundary layer and 6 *m/s* above. No significant directional shear was observed. The convection period was not long. After some development, the convective clouds disappeared around 14:00 UTC damped by *Cirrostratus*.

In Fig. 1(a - d) determined for single cumulus cloud is shown. Plots were done from below to the base of *Cu* passing through the lidar beam within 2 minutes period. The base (as seen in Figs 1 and 2) oscillated around 1.75 - 1.85 *km* altitude, which is in agreement with the sounding.

The effective radius was calculated according to the formula:

$$r_{eff}(z) = \frac{\int r^3 n(r,z)dr}{3\int r^2 n(r,z)dr}. \qquad (1)$$

Here *n(r,z)* denotes APSD as a function of particle radius *r* and distance from the lidar *z*. The distributions were achieved due to analysis of four consecutive profiles of lidar returns collected every 30 *s*

In all plots of Fig. 1 a rapid increase of effective particle radius is clear. It takes place within a layer of several tens of meters thick. Note that there is no data from the cloud interior. Due to extinction the lidar signals at higher altitudes weaken rapidly and the retrieval of APSD is not possible.

In Fig. 1a a steep increase of r_{eff} from 0.2 up to 1.3 *μm* within 45 *m* deep layer is evident. Vertical resolution of the lidar (~15 *m*) does not allow to see finer details of this layer. Strong gradient corresponds well to the results parcel model of CCN activation (Johnson, 1980).

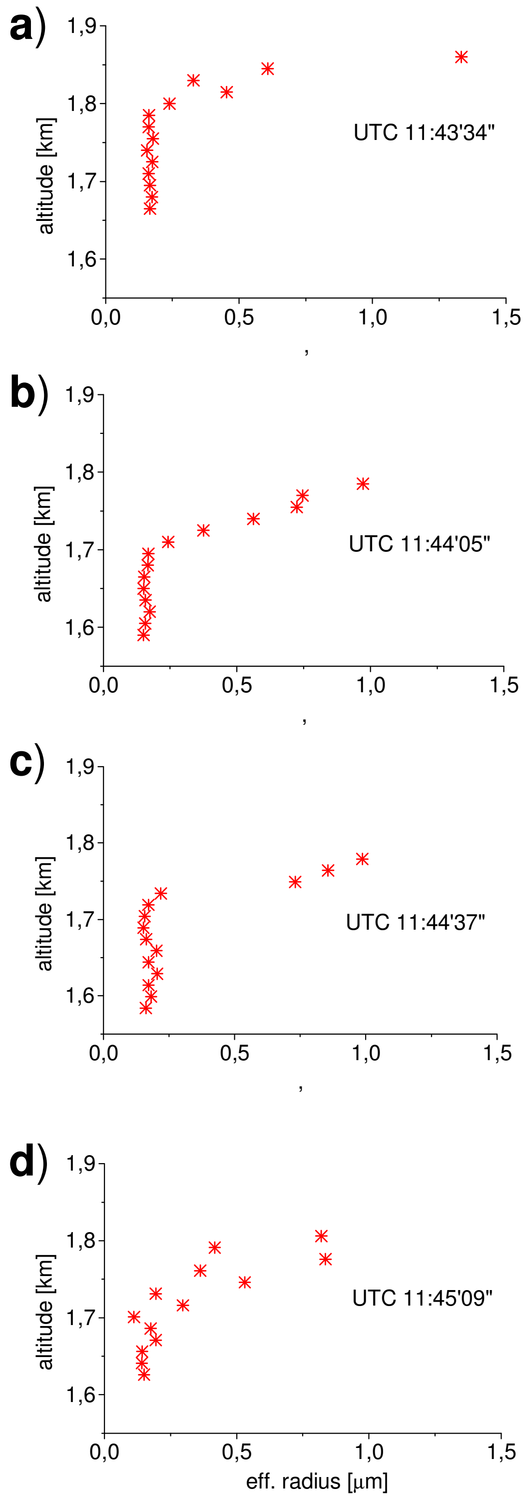

Fig. 1. Effective radius of aerosol particles below the cumulus cloud base (Warsaw, 26.07.2006)

Smaller vertical gradient of r_{eff} (growth from ~0.18 to 1 *µm* within 100 *m* deep layer) can be seen in Fig. 1b. Growth of particles begins at the level of 1.7 *km*, *i.e.* lower than 30 *s* earlier, suggesting spatial inhomogeneity of the updraft. In Fig. 1c, 30 *s* later, the gradient of r_{eff} is also steep what suggests that the growth of particles is similar to this shown in Fig. 1a. In Fig. 1d fluctuations of the effective radius are superimposed on the slower average growth. This may reflect nonuniformity of the APSD below the cloud base within 30 *s* averaging period.

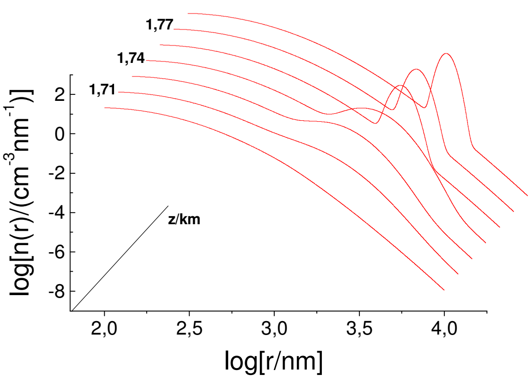

Fig. 2. Aerosol particle size distribution at 11:44'05" UTC (Warsaw, 26. 07. 2006).

In Fig. 2 the APSD taken from lidar profile 11:44'05" UTC (corresponding to r_{eff} in Fig. 1b) is shown. At the 1.7 *km* altitude large particles start to form. The initial modal radius of $r_m = 1$ *µm* grows quickly with height and at 1.8 *km* rises up to 3.2 *µm*. Droplet number concentration in this mode increases through first 50 *m* and then stabilizes. The relative width of the peak decreases with height and at the top of the detection range its value is about 1 *µm*. Such behavior is also consistent with adiabatic model of CCN activation in updraft (Johnson, 1980).

AEROSOL BELOW STRATOCUMULUS BASE

On July 30th, 2006 broken *Cumulus* clouds transformed around 11:00 UTC into stratocumulus. Noon sounding from Legionowo showed mixed layer under capping inversion at 1600 *m* height. Wind was from NW with constant speed of 10 *m/s* in the whole boundary layer and above it. Increased relative humidity in the upper part of the mixed layer corresponds well to the lidar-detected cloud base at the altitudes of 1.2 - 1.3 *km*.

Typical examples of the retrieved effective radius profiles below the cloud base are shown in Fig. 3. In most cases $r_{eff}(z)$ shows some fluctuations and less regular behavior than below *Cu* clouds. There are no evident cases which could be attributed to adiabatic activation of CCN. Note, that at 10 *m/s* wind speed averaging of lidar signal over 30 *s* corresponds to 300 *m* spatial averaging in horizontal. While this value is less than the size of typical convective cell in *Sc*, it is more than the size of large turbulent eddies. It is not surprising, that turbulent mixing, almost certain in stratocumulus topped boundary layer results in the variability of the observed profiles.

SUMMARY AND CONCLUSION

We demonstrated the ability to retrieve effective radius of the aerosol particle size distributions in the vicinity of the clouds from remote sensing with the multivavelength lidar. Presented results seem to confirm presence of process of CCN activation and growth in updraft. First achievements seem encouraging, despite many issues in the measurement technique and retrieval details.

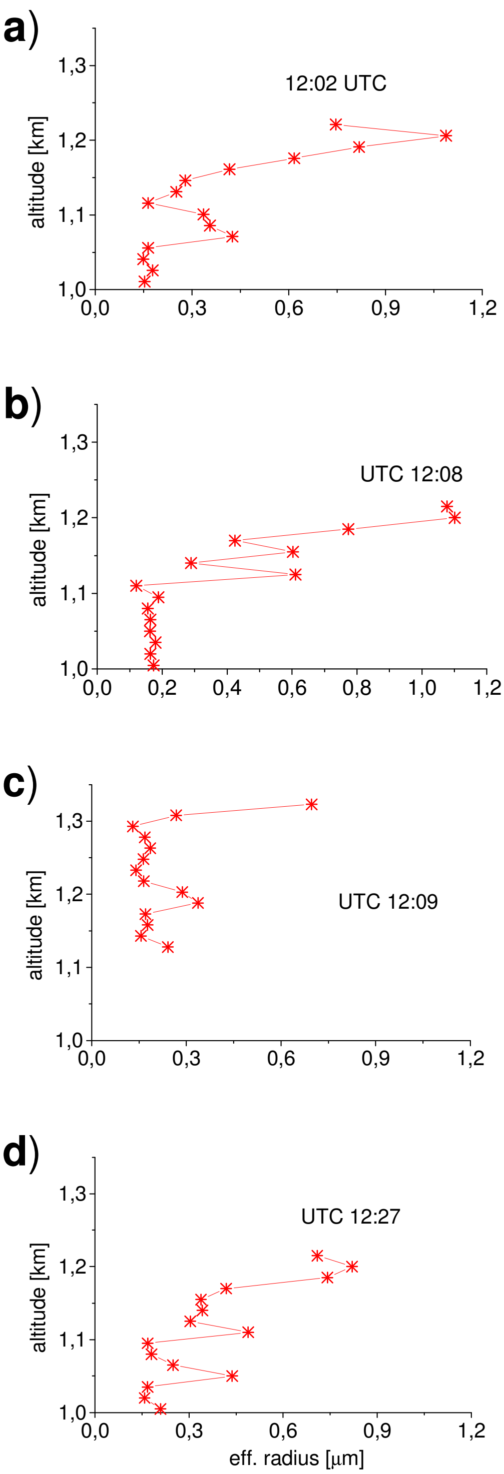

Fig. 3. Profiles of the effective radius of aerosol under stratocumulus deck (Warsaw, 30 of 2006).

For example there are problems with APSD retrieval close to sharp cloud boundaries. In Fig. 4 we present observation of orographic cloud in ALOMAR lidar observatory in northern Norway. Rapid changes in extinction prevent from retrieval of APSD inside the cloud. The model of aerosol below the cloud is also uncertain because an assumption that it consists of water droplets is doubtful.

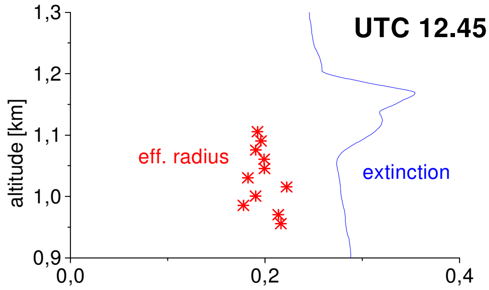

Fig. 4. Effective radius of aerosol particles and the aerosol extinction coefficient in vicinity of thin stratus layer (Andøya, Norway, 3. 07. 2007).

Nevertheless, we believe that further development of presented approach will help to resolve some important problems in cloud physics – e.g. problem of aerosol closure.

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