P1.7 INVESTIGATION OF ATMOSPHERIC AEROSOL WITH MULTIWAVELENGTH LIDAR

G. Karasinski, T. Stacewicz , S.Chudzynski, W. Skubiszak, S. Malinowski[1], A. Jagodnicka
Institute of Experimental Physics, Warsaw University, Poland
[1] Institute of Geophysics, Warsaw University, Poland

1. INTRODUCTION

In last years a particular interest has been given to the investigation of properties of atmospheric aerosol. Lidars working simultaneously at several wavelengths (λ.) provide opportunity for remote investigation of aerosol particle size distribution (APSD). This is possible due to different properties of the light scattering by particles of different sizes at various wavelengths. Let us consider the backscattering coefficient (β) and the extinction coefficient (α) of the aerosol. Assuming that it consists of spherical droplets and that the light emitted by the lidar is not absorbed by atmospheric gases, these coefficients can be related to *n(z,R)* function (APSD) by following equations (Van de Hulst, 1957):

$$\alpha(z,\lambda) = \int_0^\infty Q^E(R,\lambda)\pi R^2 n(z,R)dR$$
$$\beta(z,\lambda) = \int_0^\infty Q^B(R,\lambda)\pi R^2 n(z,R)dR \quad , \quad (1)$$

where *z* is a distance from the lidar, *R* is the particle radius, while $Q^E(R,\lambda)$ and $Q^B(R,\lambda)$ denote efficiencies of extinction and backscattering, respectively. These efficiencies can be calculated using e.g. Mie theory (Chudzynski et al, 2002).

Coefficients α and β are used in equation, which describes the return signal $S(z,\lambda)$ registered by the lidar receiver (Measures, 1992):

$$L(z,\lambda) = S(z,\lambda)\cdot z^2 = \\ = A(\lambda)\beta(z,\lambda)\exp\left[-2\int_0^z \alpha(x,\lambda)dx\right], \quad (2)$$

where $A(\lambda)$ denotes the apparatus constant and $L(z,\lambda)$-so called the range corrected lidar signal.

The common method of retrieving the *n(z,R)* function from the lidar data consists in determination of coefficients α or β for each lidar wavelength λ. For this purpose an assumed relation between these coefficients must be used (Klett, 1981). Usually so called the lidar ratio is applied:

$$\beta = const\cdot\alpha^k. \quad (3)$$

This relation was verified experimentally for the white light [Twomey and Howell, 1965]. It is not clear, however, whether it can be used for the monochromatic laser radiation. E.g. Curcio *et al* (1985) has shown, that in the linear case of (3) is well fulfilled for the white light only.

* *Corresponding author address:* Taduesz Stacewicz, Warsaw University, Institut of Experimental Phisics, Warsaw, Poland; e-mail: tadstac@fuw.edu.pl

2. TECHNICAL DETAILS

Our approach to this problem consists in substitution of relations (1) to equations (2). Due to that in the system of lidar equations only the function *n(z,R)* remains unknown. This function can be found by minimization technique.

Construction of our mobile multiwavelength lidar was described in Ernst et al (2003). Briefly, in the optical sender two pulsed lasers were used: Ti:Sa laser (working at 766 nm) and Nd:YAG laser (1064, 532, 355 nm). Energies of the light pulses were about 100 mJ, while their repetition rate was about 10 Hz. The radiation beams were sent vertically to the atmosphere. In the optical receiver a Newtonian telescope with the mirror of about 400 mm in diameter and focal length equal 1200 mm was used. The light, collected by the telescope, was spectrally separated by a polychromator and registered in separate channels corresponding to consecutive wavelengths. The signals from photomultipliers, installed at each channel, were digitized by 12-bits A/D converters (50 MHz). The system was software controlled.

3. MEASUREMENTS

Our investigation of the atmospheric aerosol by means of multiwavelength lidar was performed during two campaigns organized in Poland. The first campaign (31.08.2004 – 4.09.2004) took place in Wroclaw, town in southwestern Poland. The example result taken on 4.09.2004 at 1AM local time is presented in Fig.1.

Let us focus on a backscattering profile at 532nm presented in Fig.1a. Its values at the altitudes below 1000m are artificially underestimated due to the overlap of the beam. Between 1000m and 2200m a layered structures in the nocturnal boundary layer of the atmosphere are present. Above 2200m the backscattering coefficient drops down to values only slightly larger than expected for Rayleigh scattering by air molecules, estimated from formula proposed by Frohlich (1980). That suggests a negligible aerosol concentration in accumulation and coarse mode at high altitudes.

APSD retrieved with use of the lidar signals at 355, 532, and 1064 nm wavelengths is shown in Fig.1b in function of altitude. Again, values below 1000m are not conclusive due to geometrical compression effect. At the altitudes from 1200 m to about 2000 m the number density of small particles falls down while the number density of large particles increases. This effect can be explained by growth of the hygroscopic aerosol particles at high relative humidities in the upper part of the planetary boundary layer.

The second campaign was organized in April and May 2005 in Warsaw. Two cases from that campaign are shown in Figs 2 and 3.

Fig. 2a presents lidar signals registered on April 27^{th} at 22:00 local time (21:00 UTC). It is clearly seen that signals from Ti:Sa and Nd:Yag lasers have different noise characteristics. Two main maxima of the signals at the altitudes of about 2500 m and 3200 m can be acknowledged to the existence of layer clouds. Their altitudes are in agreement with the aerological sounding from Legionowo (12374 WMO, three hours later, about 20km NE from the measurement site), Fig.2c.

Calculations of APSD were performed up to 2500m (first cloud base) only. Here the geometric compression of the lidar beam was accounted for and low level results seem more reliable. Plot shown in Fig.2b: indicates that the number density of large particles increases with the altitude up to 2000m. Then a minimum is present at about 2300m which corresponds to the inversion height seen on the sounding. Then a steep increase of the number density of the large particles and decrease in the number density of small ones is seen at the cloud base.

The next observation was performed in the evening hours of May the 10^{th} at 21:00 local time, after the day with developed convective clouds. In Fig.3a the range corrected lidar signal registered at 532 nm as a function of time and altitude is presented. At the top of a boundary layer (1500 – 1700 m) the clouds (brown patches) were present sporadically.

APSD profile estimated from 4 wavelengths exhibits different behaviour than those in the former cases (Fig. 3b). Up to 1400 m altitude the APSD has almost constant shape, which suggests that the homogeneous, well-mixed residual layer was present in the atmosphere. Above this altitude the *n(z,R)* function becomes corrugated. The possible interpretation of this phenomenon is that we observe aerosol transported and processed by convective clouds during the day up to the free atmosphere and left there after cloud evaporation.

4. SUMMARY

In the paper possible applications and preliminary results obtained with the prototype multiwavelength lidar which is developed at the Warsaw University are shown. Lidar signals collected at three or four wavelengths covering visible band in the atmosphere allow to estimate aerosol particle size distribution. Example results showing various states of nocturnal boundary layer and are in agreement with meteorological soundings.

5. ACKNOWLEDGEMENTS

This work was supported by Polish Ministry of Science and Education, grant number 2 P04D 06927.

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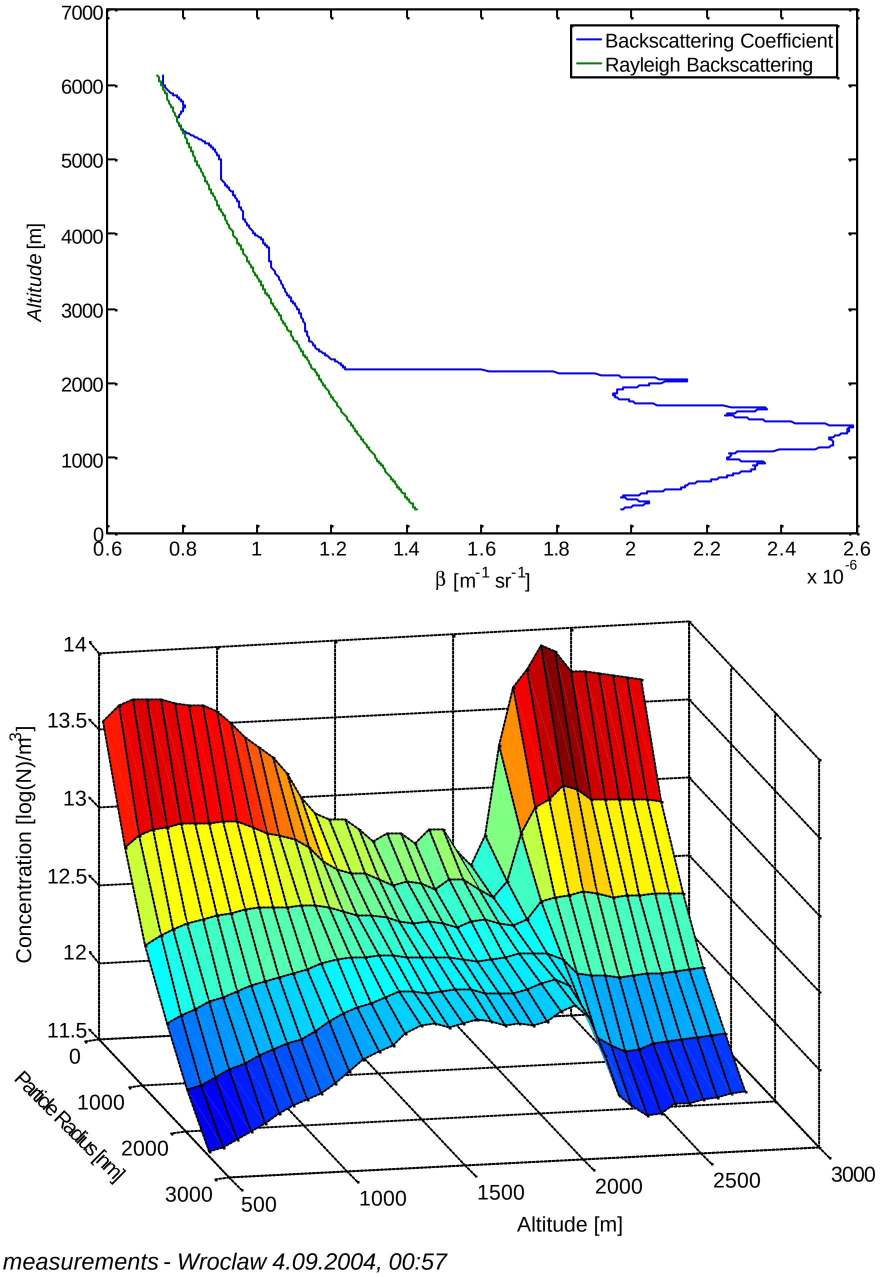
a)



b)

Fig. 1. Lidar measurements - Wroclaw 4.09.2004, 00:57

a) distribution of backscattering coefficient ß for 532 nm laser beam

b) Aerosol Particle Size Distribution

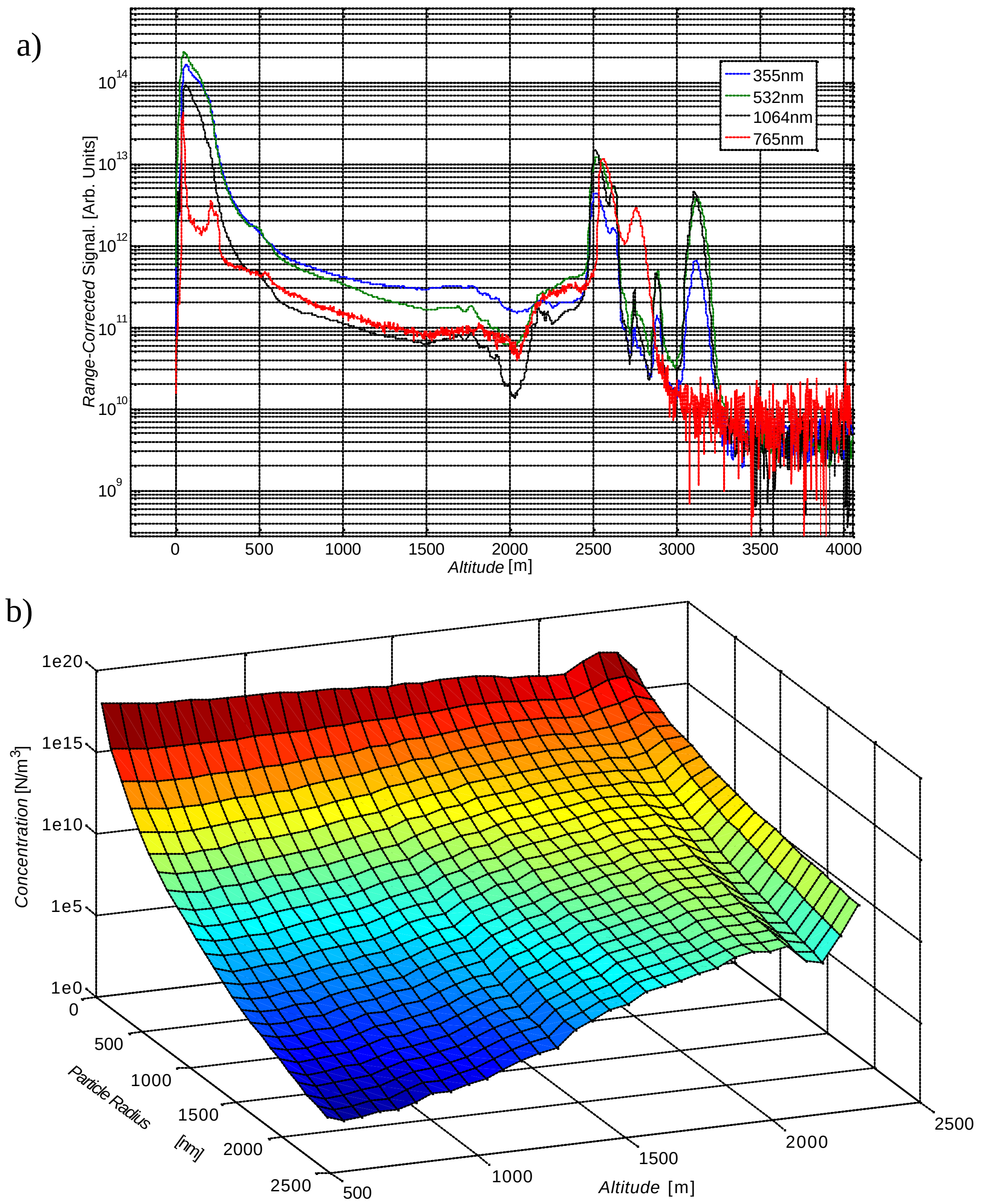


Fig. 2. Lidar measurements - Warsaw 27.09.2004, 22:00
a) lidar signals for different wavelengths
b) Aerosol Particle Size Distribution

c)

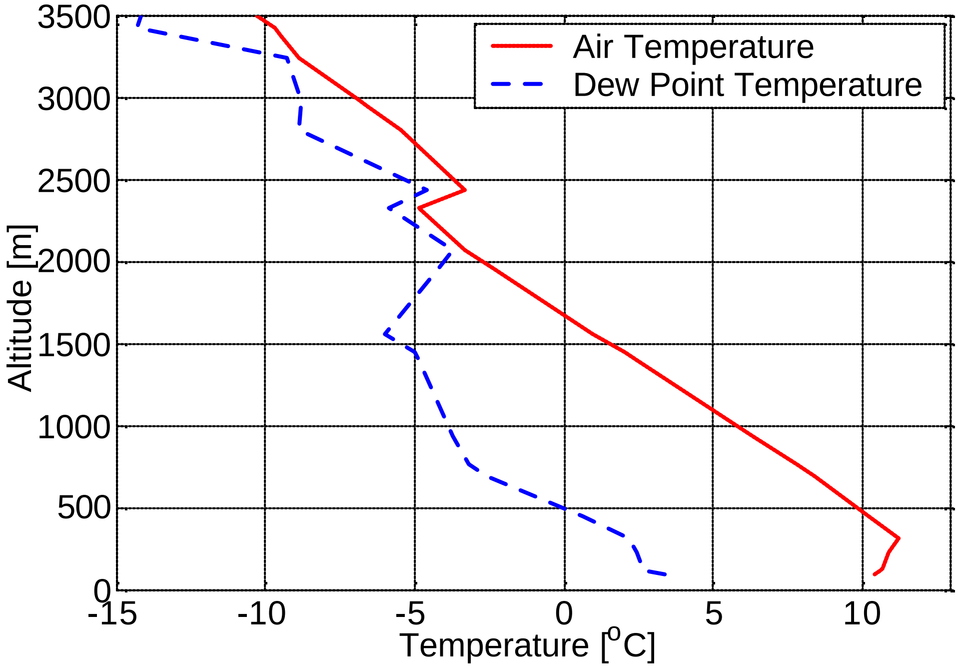
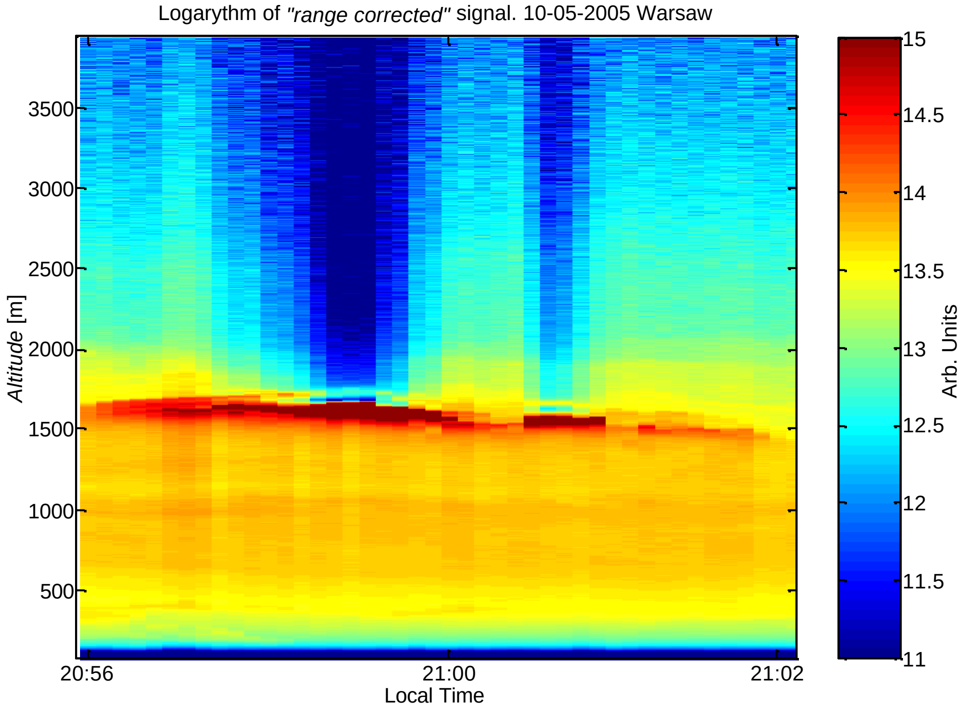


Fig.2. Aerological sounding Warsaw 27.09.2004

a)



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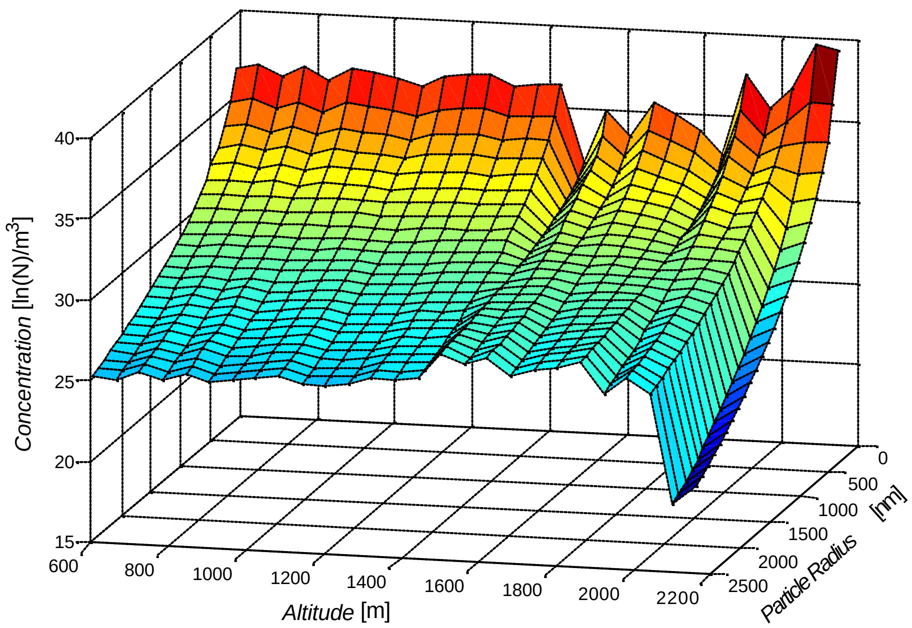

Fig. *3. Lidar measurements - Warsaw 10.05.2005*

a) logarithm of range-corrected lidar signals (color scale) for 532 nm laser beam

b) Aerosol Particle Size Distribution