Aerosol Particle Size Distribution retrieval from multiwavelength lidar signals

A.Karolina Jagodnicka, Tadeusz Stacewicz,
Michał. A. Posyniak*, Szymon P. Malinowski*,

Institute of Experimental Physics, University of Warsaw, ul. Hoża 69,
00-681 Warsaw, Poland

*) **Institute of Geophysics**, University of Warsaw, ul. Pasteura 7,
02-093 Warsaw, Poland.

3rd International Workshop on Optoelectronic Techniques for Environmental Monitoring,
30 IX – 2 X, 2009 Bucharest, Romania

Aerosol Particle Size Distribution

APSD n(r,z)

$$n(r,z) = \frac{dN}{dr}$$

N – particle number
r – radius
z - distance

Extinction coefficient

$$\alpha_\lambda(z) = \int_0^\infty \pi r^2 n(r,z) Q^E(\lambda,r)\,dr$$

Backscattering coefficient

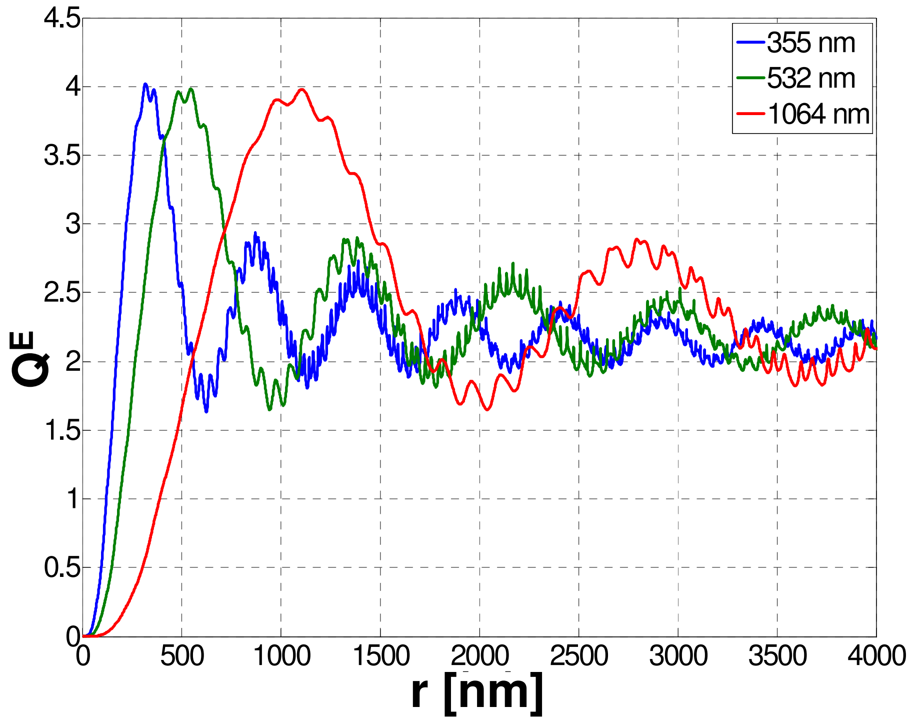
$$\beta_\lambda(z) = \int_0^\infty \pi r^2 n(r,z) Q^B(\lambda,r)\,dr$$

Q^B - backscatter efficiency
Q^E - extinction efficiency

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

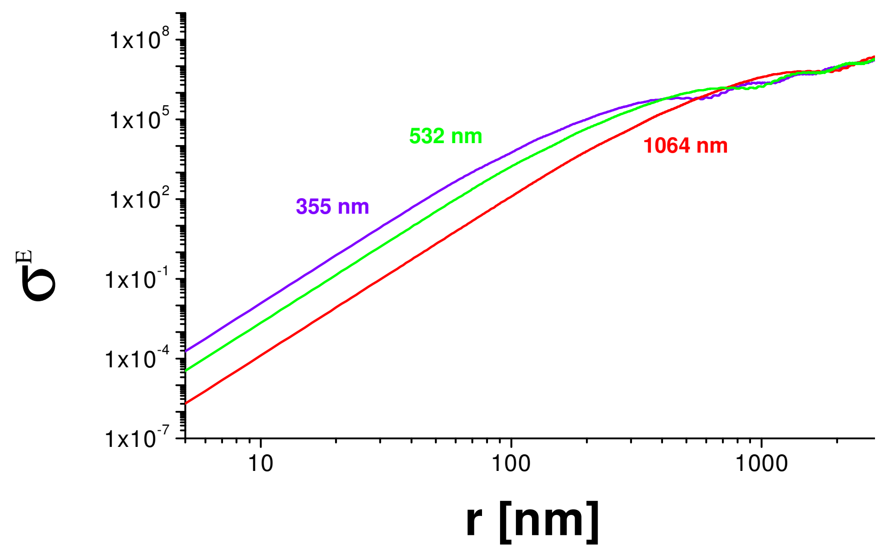
Mie-Lorenz scattering

extinction efficiency



$$Q = \frac{\sigma}{\pi r^2}$$

extinction cross section σ_E



Lidar signal elaboration

$$S(z) = \frac{A}{z^2} \cdot \beta(z) \exp\left[-2\int_0^z \alpha(x)dx\right]$$

A - lidar (apparatus) constant
z - distance
α - extinction coefficient
β - backscatter coefficient

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

1. **Range corrected lidar signals**

$$L(z,\lambda_1) = A(\lambda_1)\beta(z,\lambda_1)\exp\left[-2\int_{z0}^{z} \alpha(x,\lambda_1)dx\right]$$

$$\ldots$$

$$L(z,\lambda_k) = A(\lambda_k)\beta(z,\lambda_k)\exp\left[-2\int_{z0}^{z} \alpha(x,\lambda_k)dx\right]$$

Lidar signal elaboration

$$L(z,\lambda_1) = A(\lambda_1)\beta(z,\lambda_1)\exp\left[-2\int_{z0}^{z}\alpha(x,\lambda_1)dx\right]$$

...

$$L(z,\lambda_k) = A(\lambda_k)\beta(z,\lambda_k)\exp\left[-2\int_{z0}^{z}\alpha(x,\lambda_k)dx\right]$$

2. Ratio of signals from neighbouring distances

$$\frac{L_\lambda(z_{l+1})}{L_\lambda(z_l)} = \frac{\beta_\lambda(z_{l+1})}{\beta_\lambda(z_l)}\exp\{-\Delta z[\alpha_\lambda(z_l)+\alpha_\lambda(z_{l+1})]\}$$

Cost function

$$\chi^2(z_l) = \sum_{\lambda=1}^{\Lambda}\left(\frac{L_\lambda(z_{l+1})}{L_\lambda(z_l)} - \frac{\beta_\lambda(z_{l+1})}{\beta_\lambda(z_l)}\exp\{-\Delta z[\alpha_\lambda(z_l)+\alpha_\lambda(z_{l+1})]\}\right)^2$$

3. Substitution of α and ß coefficients…

$$\beta_\lambda(z) = \int_0^\infty \pi r^2 n(r,z) Q^B(\lambda,r)dr \qquad \alpha_\lambda(z) = \int_0^\infty \pi r^2 n(r,z) Q^E(\lambda,r)dr$$

… the unknown - n(r,z) (no lidar ratio)

4. n(r,z) is found with minimization technique

n(r,z)

Assumptions

•**APSD** as two mode distribution, each mode – in **log-normal** form

$$n\,(r,z) = \frac{N(z)}{\sqrt{2\pi}\cdot\log\sigma(z)}\cdot\frac{1}{r}\cdot\exp\left\{-\frac{\left[\log r - \log \mathrm{r_m}(z)\right]^2}{2\cdot\log^2\sigma(z)}\right\}$$

N – number concentration
σ - standard deviation
r_m – modal radius

• spherical droplets

• known refractive index (water, salt)

• coefficients of backscattering ***β*** and extinction ***α*** calculated with Mie theory steps

Parameters' ranges

$$70 < N_1 < 9000,\quad 50 < r_{m_1} < 240,\quad 1.5 < \sigma_1 < 2.7;$$

$$0.15 < N_2 < 52,\quad 230 < r_{m_2} < 1600,\quad 1.5 < \sigma_2 < 2.7;$$

Distribution

σ~2

$$n(r,z) = \frac{N_1(z)}{\sqrt{2\pi}\cdot\log\sigma_1(z)}\cdot\frac{1}{r}\cdot\exp\left\{-\frac{\left[\log r - \log r_{m_1}(z)\right]^2}{2\cdot\log^2\sigma_1(z)}\right\} + \frac{N_2(z)}{\sqrt{2\pi}\cdot\log\sigma_2(z)}\cdot\frac{1}{r}\cdot\exp\left\{-\frac{\left[\log r - \log r_{m2}(z)\right]^2}{2\cdot\log^2\sigma_2(z)}\right\}$$

Scattering coefficients

$$\beta_\lambda(z) = \int_0^\infty \pi r^2 n(r,z) Q^B(\lambda,r)\,dr \qquad \alpha_\lambda(z) = \int_0^\infty \pi r^2 n(r,z) Q^E(\lambda,r)\,dr$$

$$\frac{L(z_{l+1})}{L(z_l)} = \frac{\beta_\lambda(z_{l+1})}{\beta_\lambda(z_l)}\exp\left\{-\Delta z\left[\alpha_\lambda(z_l) + \alpha_\lambda(z_{l+1})\right]\right\}$$

measured

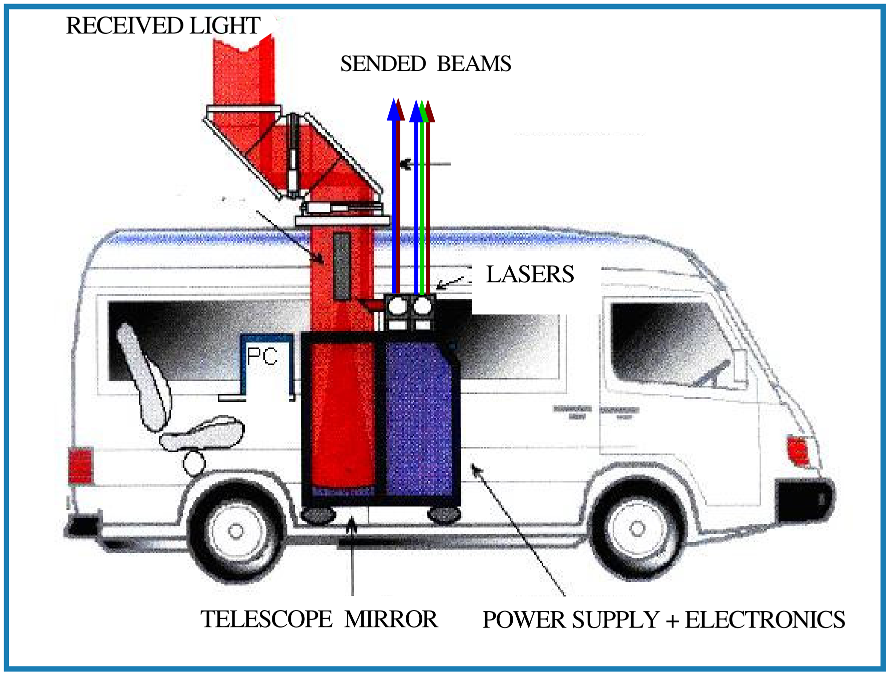
calculated

best fits selected

Multiwavelength lidar

Optical sender:

* pulsed laser:
Nd:YAG - 1064, 532, 355 nm;
E of the light pulses ~ 200, 100, 60 mJ,
repetition rate ~ 10 Hz.

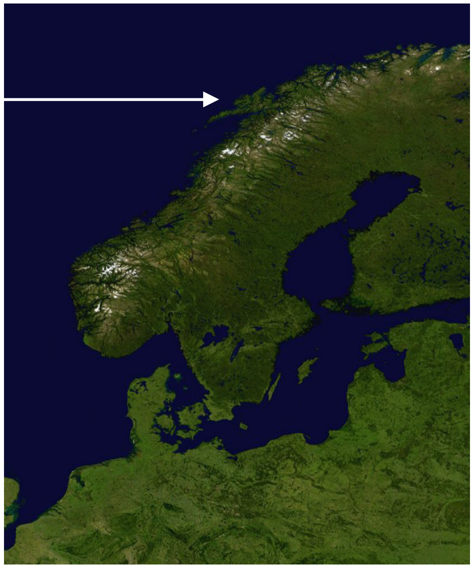


Optical receiver:

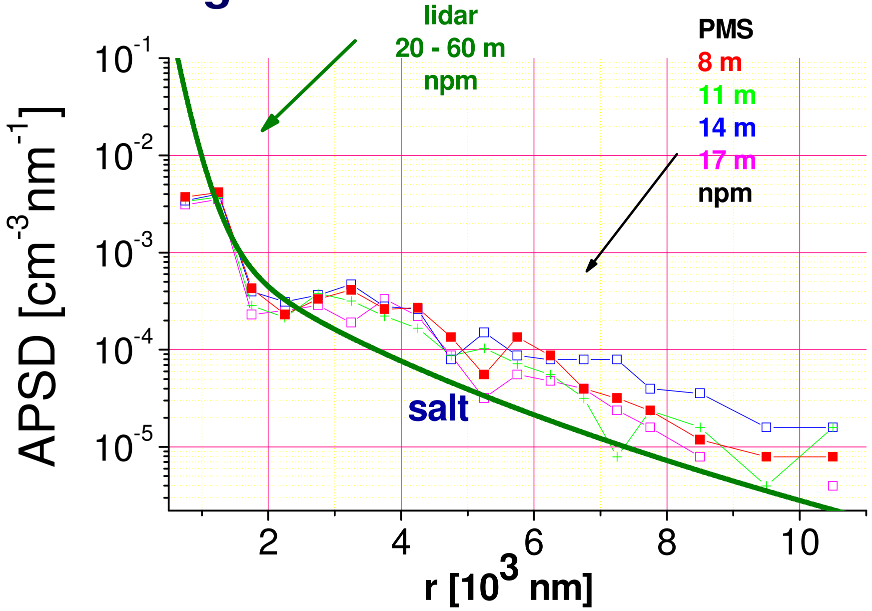
* Newtonian telescope
(mirror ~ 400 mm in diameter,
focal length = 1200 mm),
* 3-channel polychromator,
* 12-bits A/D converters (50 MHz)

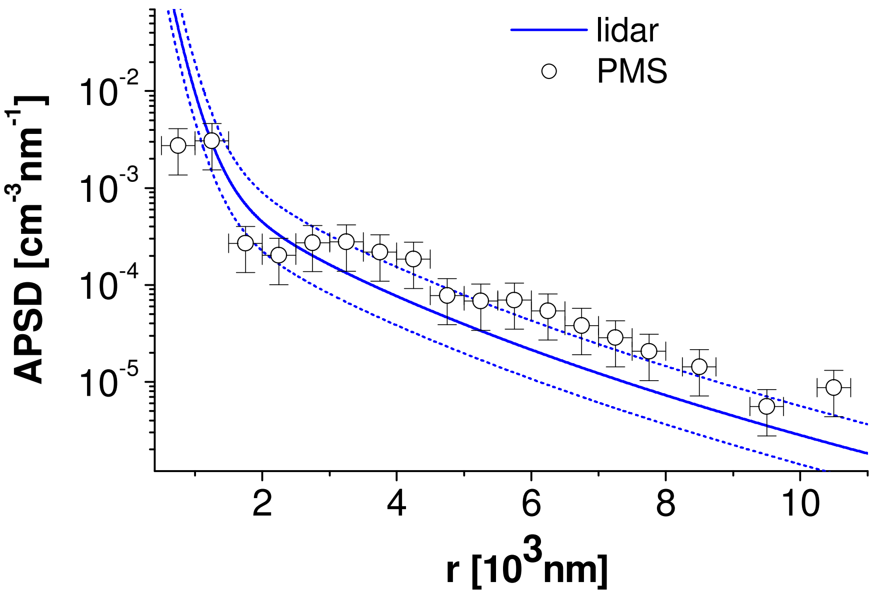
marine aerosol

Arctic Lidar Observatory for Middle Atmosphere Research (ALOMAR), Andoya, Norway, July/August 2007

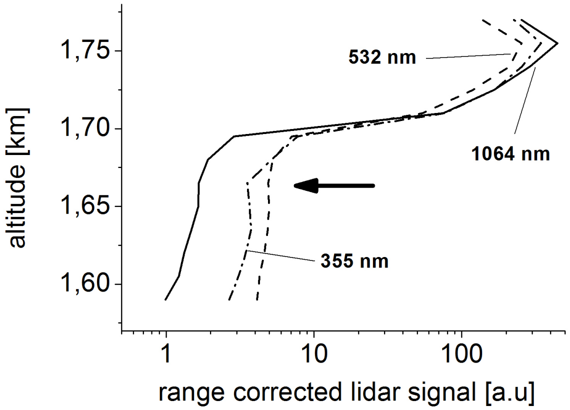


15th August

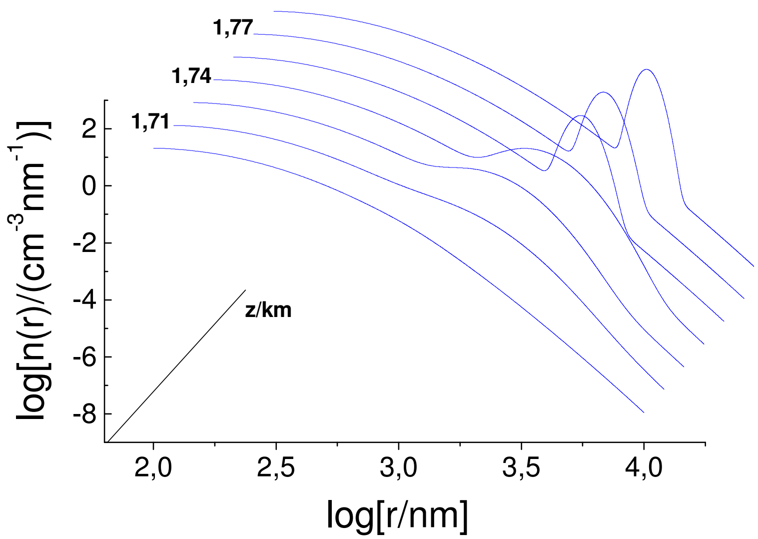




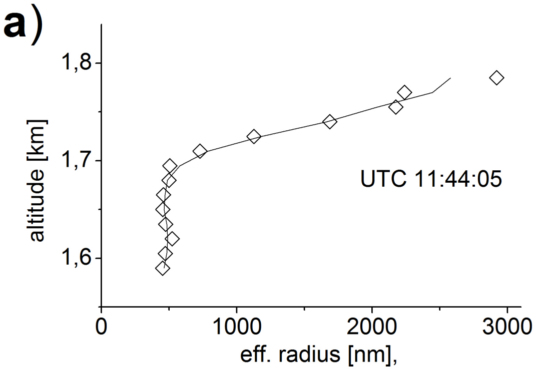
aerosol under cumulus cloud - 2006



APSD

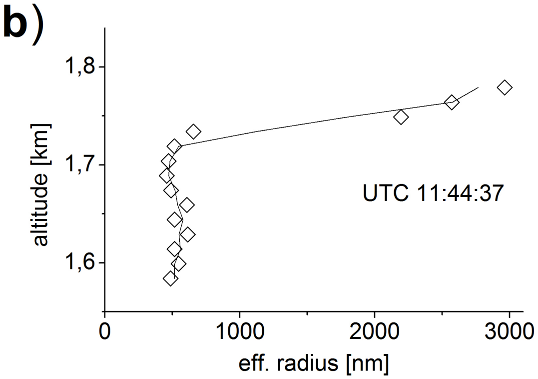


a)

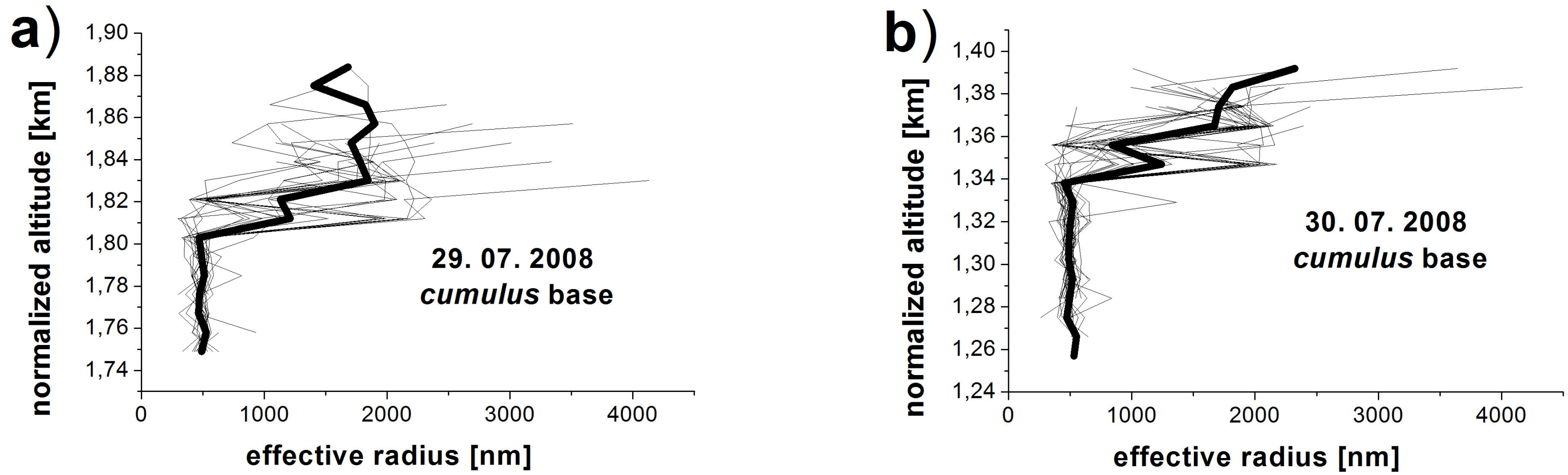


$$r_{eff}(z) = \frac{\int r^3 n(r,z) dr}{\int r^2 n(r,z) dr}$$

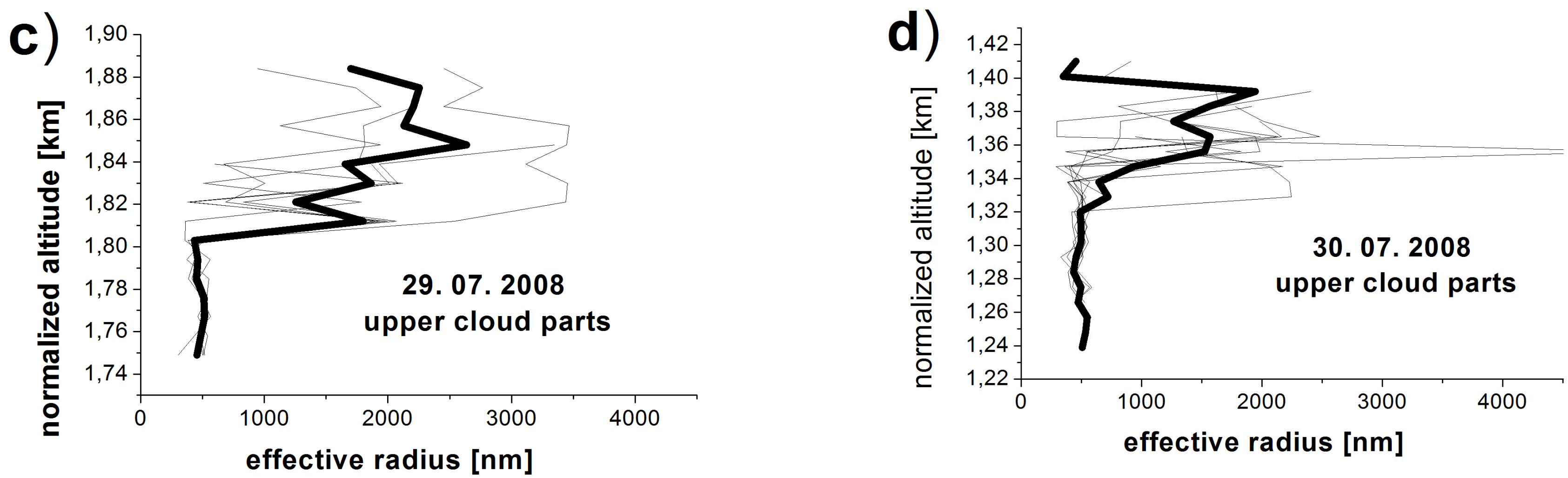
b)



aerosol under cumulus cloud - 2008



Normalized to reference height



Summary

• method to determine aerosol particle size distribution from multiwavelength lidar signals was presented
- assumed spherical shape and known refractive index of aerosol particles,
-lidar ratio not necessary

• experimental test - comparison with PMS

• method used for data under cumuli base – results seem to confirm (qualitatively!) CCN activation and growth under the cloud base

Thank You for attention


Laser monitoring of air pollution
ZAKŁAD OPTYKI Instytut Fizyki Doświadczalnej Uniwersytetu Warszawskiego
LIDA
ELIGHT
ms Teltow / Berlin
PL