Aerosol Distribution in The Planetary Boundary Layer Aloft a Residential Area

Jan Hovorka [1], Cecilia Leoni [1], Veronika Dočekalová [1], Jakub Ondráček [2], Naděžda Zíková [1]

[1] Institute for Environmental Studies, Faculty of Science, Charles University in Prague, Benátská 2, 128 01 Prague 2, Czech Republic
[2] Laboratory of Aerosol Chemistry and Physics, Institute of Chemical Process Fundamentals of the CAS, v. v. i., Rozvojová 2/135, 165 02 Prague 6, Czech Republic

E-mail: leonic@natur.cuni.cz

Abstract. Atmospheric aerosol is an omnipresent component of the Earth atmosphere. Aerosol particle of diameters < 100 nm or > 1 μm defines ultrafine or coarse aerosol particles, respectively. Aerosol particle concentrations within the planetary boundary layer - PBL are measured at the ground level while their vertical profiles in the PBL are usually estimated by modelling. The aim of this study was to construct vertical concentration profiles of ultrafine and coarse aerosol particles from airborne and ground measurements conducted in an urban airshed. Airborne measurements were done by an unmanned airship, remotely controlled with GPS 10 Hz position tracking, and electrically powered with propulsion vectoring, which allows average cruising speed of 6 $m.s^{-1}$. The airship carried three aerosol monitors and a temperature sensor. The monitors acquired 1 Hz data on mass concentration of coarse and number concentration of ultrafine particles. Four flight sequences were conducted on the 2nd of March 2014 above Plesna village, up-wind suburb of Ostrava in the Moravian-Silesian region of the Czech Republic. The region is a European air pollution hot-spot. Repeated flights were carried out in several height levels up to 570 m above ground level - a.g.l. Early morning flight revealed a temperature inversion in the PBL up to 70 m a.g.l. This lead to coarse particle concentrations of 50 μgm^{-3} below the inversion layer and 10 μgm^{-3} above it. Concurrently, air masses at 90-120 m a.g.l. were enriched with ultrafine particles up to $2.5x10^4$ cm^{-3}, which may indicate a fanning plume from a distant emission source with high emission height. During the course of the day, concentrations of ultrafine and coarse particle gradually decreased. Nevertheless, a sudden increase of ultrafine particle concentrations up to $3.7x10^4$ cm^{-3} was registered at 400 m a.g.l. at noon and also after a lag of 20 min at the ground. This may indicate formation of new aerosol particles at higher altitudes, which are then transported downward by evolved convective mixing. Detailed information acquired by the airship measurements allow us to better understand processes resulting in the increase of aerosol particle concentrations at ground level in urban air.

1. Introduction

The planetary boundary layer - PBL, the lowest part of the troposphere, is influenced by the exchange of heat, water vapour, trace gases and aerosol particles with the Earth surface [1]. Surface heating produces a turbulent, well-mixed PBL during the day, while surface cooling after sunset may lead to a temperature inversion which causes the PBL stratification. Key constituent of the PBL is atmospheric

aerosol, a colloid originating from natural and anthropogenic sources. While natural aerosol sources prevail over the anthropogenic ones at remote locations or open troposphere [2], anthropogenic sources dominate in urban environment. Additionally, temperature inversion in the PBL prevents mixing of the anthropogenic aerosol with the free troposphere. Therefore, knowing the atmospheric aerosol distribution within the PBL at urban microscale is important for human exposure assessment. Unmanned aerial systems offer advantages as research platforms because of the possibility to investigate atmospheric parameters at small scale and low altitudes. Airships have the possibility to fly with low cruising speed at constant heights, with minimal logistic requirements and lower costs compared to the aircrafts [3, 4, 5, 6]. Also, compared to drones, airships can carry heavier payload [7]. This work presents and discusses airborne and ground-based measurement of the aerosol particles concentration, performed in March 2014 in a suburb of Ostrava, Czech Republic. This city is known as a European air pollution hot-spot [8, 9, 10]. The aim of this study was to construct vertical concentration profiles of size-segregated aerosol particles from airborne and ground measurements conducted in this urban air pollution hot-spot.

2. Methods

The measurements were performed in Ostrava city suburb Plesna (Figure 1) mainly composed of family houses. The suburb is relatively far from any direct industrial and/or traffic pollution. The airborne measurements were realized with an unmanned airship, remotely controlled with GPS 10 Hz position tracking and electrically powered with propulsion vectoring, which allows average cruising speed of 6 $m.s^{-1}$. The precision of the airship position tracking was 5 – 10 m vertically and 5–8 m horizontally. The scientific payload was composed of a laser nephelometer (DustTrak DRX-8533, TSI Inc.), two condensation nuclei counters (P-track 8525, TSI Inc.), and temperature sensor (111DL, Voltcraft). The nephelometer measured the mass concentration of coarse aerosol particles. Each of the counters was equipped with Particle Size Selector - PSS (model 376060. TSI Inc.) at the aerosol inlet but with different adjustments. The first PSS housing holds 7 screens, which raises the smallest detectable particle size limits to about 100 nm while there were no screens at the second PSS housing.

Figure 1. Aerial view of Plesna village, Ostrava city suburb, indicating the fixed site and the airship launch site; the scale bar shows the distances in meters of the airship-flying track

Therefore, the first counter detects particles within the size range of 100 – 1000 nm while the second within the size range of 20 - 1000 nm. The particle number concentrations - PNC within the ultrafine size range 20 – 100 nm are obtained by the difference of the first and second counter. The temperature sensor and also aerosol monitors acquired 1 Hz data. Concurrent ground measurements were conducted at fixed site (49°51'57.31"N, 18° 7'55.52"E, 290 m altitude), approximately 300 m far from the airship launch site (Figure 1). Five minute integrates of particle number concentrations and size distribution in size range 14 – 10000 nm were measured by a Scanning Mobility Particle Sizer (SMPS model 3936L75, TSI Inc.) and an Aerodynamic Particle Sizer (APS-3321, TSI Inc.). Meteorological parameters (wind speed, wind direction, relative humidity and temperature) were also recorded.

3. Results and discussions

Four flights were conducted: 1st at 06:40-7:50, 2nd at 8:13-9:40, 3rd at 9:55-11:11 and 4th at 11:25-12:19. During the first flight in the early morning, two temperature inversion layers were observed (Figure 2, left). The first was formed up to 70 m a.g.l. while the second reached heights 180-230 m a.g.l. Coarse aerosol mass concentrations 20-50 μgm^{-3} below the first inversion layer reflected coarse aerosol sources on the ground, also indicated by the elevated coarse particle concentration recorded at the fixed site on the ground (Figure 5, top). Above the first inversion layer, the concentration dropped to less than 10 μgm^{-3} (Figure 2, right). In contrast to coarse particles, ultrafine particle number concentrations were very high, up to $2.5x10^4$ cm^{-3}, at heights 90-120 m a.g.l., which may indicate a fanning plume from a distant emission source with a high emission height (Figure 3, right).

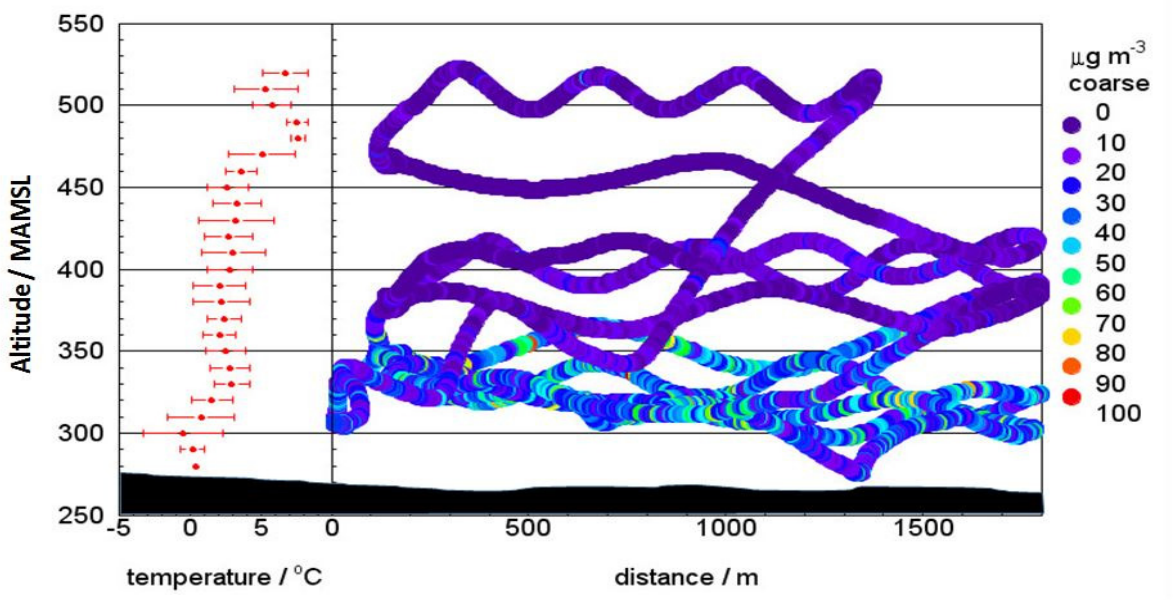

Figure 2. The PBL vertical profile of temperature (left) and coarse particle concentrations at the scale distances above Plesna village (right) during the 1st flight, 06:40-7:50

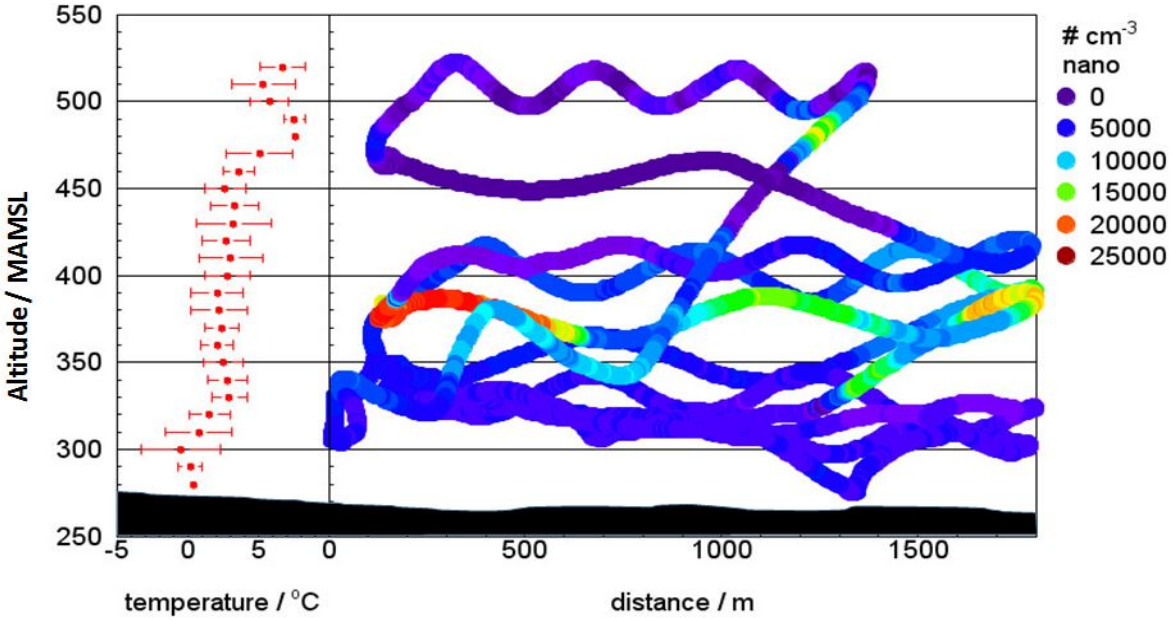

Figure 3. The PBL vertical profile of temperature (left) and ultrafine particle concentrations (right) at the scale distances above Plesna village during the 1st flight, 06:40-7:50

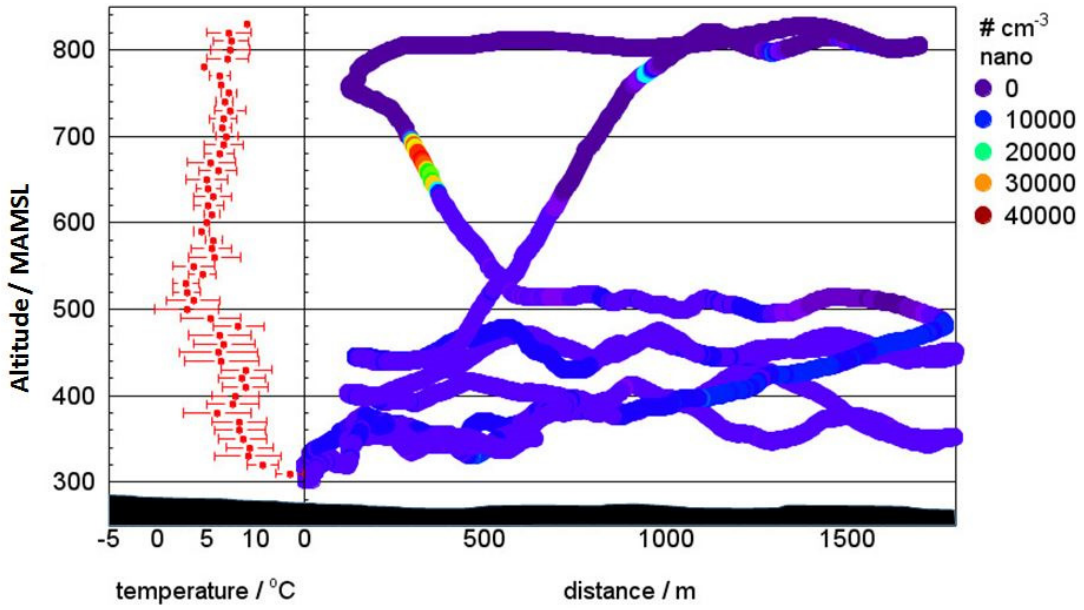

Figure 4. The PBL vertical profile of temperature (left) and ultrafine particle concentrations (right) at the scale distances above Plesna village. 4. Flight, 11:25-12:19

During the second flight, temperature inversion layer was observed only at heights 150-280 m a.g.l. as a consequence of surface heating. There were concentrations of coarse particle mass up to 39 μgm^{-3}

and number of ultrafine particles up to $20x10^4$ cm^{-3} recorded in this layer. During the third and fourth flights, the inversion disappeared due to the heating of the Earth's surface. Air masses can vertically mix and the concentration of both coarse and nanoparticles in the PBL decreased. Nevertheless, sharp increase in number concentrations of ultrafine particles up to $3.7x10^4$ cm^{-3} was recorded at heights of 380-400 meters a.g.l. (Figure 4, right) during the descending flight of the airship at 12:00:23-12:00:47. After a delay of 20 minutes, at 12:20-12:50, there was also a sudden increase of ultrafine particles concentration $1.5\text{-}2x10^4$ cm^{-3} observed at fixed site on the ground (Figure 5, bottom). This may indicate the process of formation of new particles occurring at higher altitude, which are subsequently transported downward by enhanced convective mixing and registered on the ground. Similar spatial/temporal dynamic of the PBL were observed in Melpitz, Germany [11].

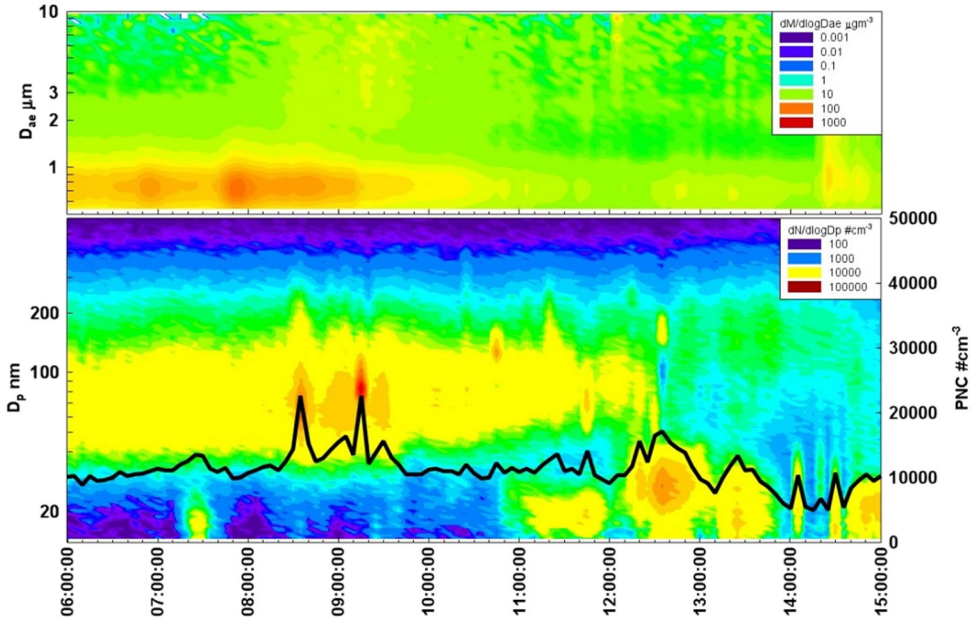

Figure 5. Contour graphs of the temporal variation of aerosol size distribution for mass (top, size range 0.5-10 µm) and for number (bottom, size range 14-732 nm), and ultrafine particle number concentration registered at the fixed site

4. Conclusions

Dynamics of vertical profiles for temperature, coarse and ultrafine aerosol particle concentration in the PBL in microenvironment of urban airshed was revealed by measurements with an unmanned airship. Early morning, temperature stratification of the PBL caused coarse particles to be accumulated below the inversion layer while ultrafine particles, emitted from distant source with high emission height, were trapped at heights 90-120 m a.g.l. During the course of day, the PBL stratification ceased and gradually evolved turbulent mixing led to a downward transport of ultrafine particles newly formed in higher elevations. Detailed information allows us to understand processes and apportion sources of aerosol particles in ground level in the urban micro environment and unmanned airship seems to be an optimal platform for airborne measurements.

Acknowledgment(s)

This project was supported projects No. P503/12/G147 of the Grant Agency of the Czech Republic and 1354314 of the Grant Agency of the Charles University in Prague.

References

[1] Finlayson-Pitts B., and Pitts J. N. 1999. *Chemistry of the Upper and Lower Atmosphere*, Academic Press, U.S.A.

[2] Jaenicke R. Is atmospheric aerosol an aerosol? - A look at sources and variability. *Farad. Discuss.*, 2008, 137, 235-243.

[3] Frick G.M., Hoppel W.A. Airship measurements of aerosol size distributions, cloud droplet spectra, and trace gas concentrations in the marine boundary layer. *B. Am. Meteorol. Soc,* 1993, 74(11), 2195-2202.

[4] Frick G.M., Hoppel W. A. Airship measurements of ships exhausts plumes and their effect on marine boundary layer clouds. *J. Atmos. Sci.,* 2000, 57, 2625–2648.

[5] Kantor G., Wettergreen D., Ostrowski J. P., Singh S., 2001. Collection of environmental data from an airship platform. *In: proceedings of SPIE Conference on Sensor Fusion and Decentralized Control IV*, October 28-29, 2001, vol. 4571, pages: 76-83.

[6] Gozzi F., Della Ventura G., Marcelli A. Mobile monitoring of particulate matter: state of the art and perspectives. *APR*, 2016, 7, 228-234.

[7] Brady J. M., Stokes M. D., Bonnardel J, Bertram T.H. Characterization of a quadrotor unmanned aircraft system for aerosol-particle-concentration measurements. *Environ. Sci. Technol.*, 2016, 50, 1376-1383.

[8] Pokorná P., Hovorka J., Hopke P. K. Elemental composition and source identification of very fine aerosol particles in a European air pollution hot-spot. *APR*, 2016, 7(14), 4671–679.

[9] Pokorná P.; Hovorka J.; Klán M.; Hopke P. K. Source apportionment of size resolved particulate matter at a European air pollution hot spot. *Sci. Total Environ.*, 2015, 502, 172-183.

[10] Šrám R. J., Dostál M., Libalová H., Rossner P., Rossnerová A., Švecová V., Topinka J., Bartonová A. The European hot spot of B[a]P and $PM_{2.5}$ exposure at the Ostrava region, Czech Republic: Health research results. *ISRN Public Health*, 2013, article ID 416701, 12 pages.

[11] Platis A., Altstädter B., Wehner B., Wildmann N., Lampert A., Hermann M., Birmili W., Bange J. An observational case study on the influence of atmospheric boundary-layer dynamics on new particle formation, *Boundary-Layer Meteorol.*, 2016, 158, 67–92.