Charles University, Faculty of Science
Institute for Environmental Studies

Doctoral study program: Environmental Science
Summary of the doctoral thesis

ATMOSPHERIC AEROSOL: PHYSICAL CHEMICAL CHARACTERISATION AND SOURCE APPORTIONMENT

Atmosférické částice: fyzikální a chemická charakterizace a identifikace jejich zdrojů

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Abstract

Aerosol particles are emitted from natural and anthropogenic sources. Though the natural aerosol sources overweight the anthropogenic ones, the latter are dominant in urban environment: combustion of fossil fuels or biomass for vehicles and heating, industrial processes and energy production, waste incineration, resuspended road dust. Since anthropogenic sources are largely associated with high temperature processes, urban aerosol number SD is usually dominated by the smallest fraction: the ultrafine particles (UFPs, d<100 nm). UFPs can be inhaled deep into the respiratory tract and with high deposition efficiency, and they can carry organic or inorganic toxic air pollutants, among others, polycyclic aromatic hydrocarbons (PAHs). For this reason, the measurement and the source apportionment of UFPs is important in the aspect of human exposure. However, according to EU regulations, the standard metric for measuring air quality is the particulate matter (PM) mass concentration, but UFPs have high contribution to the

PM number concentration (NC) and negligible influence on PM mass.

In the recent past, there has been a significant increase in number of studies related to the characterization, monitoring, modelling and human exposure assessment of UFPs. Nevertheless, a number of inconclusive results on various aspects, for example a clear physical-chemical characterization of various sources, still remains. Various anthropogenic sources can emit particles in the ultrafine size range, for example vehicular traffic or industry. With a winter monthly sampling campaign, industry was found to emit high UFPs concentrations (during plume events: in average 2×10^4 particles cm^{-3}, peaks up to 1.4×10^5 particles cm^{-3}) in Ostrava Radvanice and Bartovice, an EU air pollution hot spot (manuscript 1). This study complements our previous source apportionment studies of size segregated aerosol particles in the same location, performed on PM mass elemental composition, in which UFPs were excluded because below the lower cut point of the impactor sampler. At the hot spot, the

size distribution (SD) is dominated by the UFPs, with a size range of 19−44 nm, enriched up to 4.5% of mass with PAHs. Since these particles are harmful for human health, the industrial impact at the hot spot is important. The aerosol NC and the SD can vary at different heights of the planetary boundary layer (PBL). Airborne measurements performed in a suburban location near Ostrava, revealed two temperature inversion layers in the early morning (70 m a.g.l. and 180-230 m a.g.l.) and coarse particles to be accumulated below the lower inversion layer, with mass concentrations up to 50 $\mu g m^{-3}$, reflecting coarse aerosol sources on the ground (manuscript 2). UFPs emitted from distant sources with high emission height, can be trapped at higher altitude in the PBL: high UFPs NC (up to 2.5×10^4 particles cm^{-3}), measured with the airship at higher altitudes (90-120 m a.g.l) may indicate a fanning plume. When the PBL stratification ceased and gradual turbulent mixing evolved, an increase of ultrafine particle concentration

was measured both at higher altitude and at the ground, indicating downward UFPs transport.

In the same European air pollution hot spot presented in the manuscript 1, a more comprehensive study on atmospheric particles sources was performed, spanning the whole size range: 14 nm - 10 µm (manuscript 3). Two factors were resolved in the ultrafine size range: industrial UFPs (28%, number mode diameter - NMD 45 nm), industrial/fresh road traffic nanoparticles (26%, NMD 26 nm), indicating the industry as major source of UFPs at the hot spot. Three factors were resolved in the accumulation size range: urban background (24%, NMD 93 nm), coal burning (14%, volume mode diameter - VMD 0.5 µm), regional pollution (3%, VMD 0.8 µm) and one factor in the coarse size range: industrial coarse particles/road dust (2%, VMD 5 µm). Industrial sources contribute not only to the UFP NC but also to the mass concentration. Compared to other locations in the Czech Republic, the highest mass concentration of PM_1, $PM_{1-2.5}$ and $PM_{2.5-10}$ with Fe as the predominant element in all

fractions was measured at the hot spot (manuscript 4). Form the point of view of atmospheric particles measurements strategy, combining airborne and ground based high-time-resolution instruments can facilitate the direct observation of the industrial plumes (manuscript 1 and 2). To perform a comprehensive air pollution study, the application of PMF on particle size spectra can elucidated the major air pollution sources down to UFPs. The gaseous species, the organic tracers, the wind direction, the pollutant temporal variations are crucial parameters to consider in the source apportionment (manuscript 3). The wind patterns and the relative humidity are very important because they influence the particle concentration and the SD (manuscript 4).

Introduction

Atmospheric aerosol is ubiquitous component of the Earth atmosphere. Aerosol particles are emitted from natural sources: biomass fires, vegetation, sea spray, soil dust, volcanic eruptions. With the industrial revolution and the fossil fuel burning, human activity has contributed to the total aerosol loading and the release in the atmosphere of massive quantities of industrial pollutants, with a direct and indirect harmful effect to the population and to the biosphere. Anthropogenic sources of PM are: combustion of fossil fuels or biomass for vehicles and domestic heating, industrial processes, energy production, waste incineration, mechanical processes. Each source can emit particles with distinct SD that can be modified by processes of growth, evaporation, and removal. Ambient particles range from few nanometers up to 100 μm, with the lower limit related to molecular clusters, and the upper limit is defined by fast sedimentation. The SD is characterized by a multi-lognormal structure, based on three main modes:

ultrafine, approximately <100 nm, accumulation, between 0.1 and 1 μm, and coarse mode with particles with diameter > 1 μm. The ultrafine and the accumulation mode together constitute the fine PM. In urban areas, the UFPs dominate the aerosol number SD. UFPs originate in the atmosphere by condensation of supersaturated vapours in fresh combustion emissions; they can form naturally when gases oxidize to compounds with lower vapour pressure and spontaneously nucleate. UFPs can be inhaled deep into the respiratory tract and with high deposition efficiency. The UPF's surface can carry large amount of adsorbed or condensed toxic air pollutants (oxidant gases, organic pollutants, transition metals).

Recent studies found that emissions from industrial combustion processes contribute mainly to the fine and ultrafine fraction (Riffault et al., 2016). Weitkamp et al, 2005, registered industrial plumes with UFPs peaking around 40 nm near a large coke production plant; Marris et al., 2012, observed particles of 10 – 30 nm downwind

from a steel production facility; Cheng et al., 2008, observed ultrafine particles with a mode at 46 nm in an iron foundry. Other sources that can produce UFPs are combustion processes and vehicle emissions. From the point of view of the number SD, most studies have shown a consistent SD with count median diameter of 100-160 nm for fresh biomass burning smoke. For coal combustion, the median diameter of the SD varies between 30-80 nm, depending on a range of factors: coal type, combustion temperature, dilution, residence time (Vu et al., 2015). Vehicles emissions are considered a major source in urban atmosphere; part of the emissions is generated directly from the engine or they form in the air by condensation and nucleation of hot gaseous emissions. The combustion generated particles consisting mostly of solid graphitic carbon with a smaller amount of metallic ash, hydrocarbons and sulfur compounds (Zhu et al., 2002). These particles are found mainly in the Aitken and accumulation mode, with a size ranging from 30 nm to 0.5 μm.

Since the smallest particles are strongly harmful for human health, recent studies focus on the source identification of UFPs with the application of receptor models. For example, Positive Matrix Factorization (PMF) is a powerful and widely used multivariate method that can resolve the dominant positive factors without prior knowledge of sources. Compared with traditional factor analysis, PMF method has the advantage of non-negativity constrains and scaling the uncertainty of each data point individually. PMF is generally applied to mass concentration and chemical composition, but recently also to the particle size spectra (Masiol et al., 2016, Beddows et al., 2015, Harrison et al., 2011). Source profiles based on particle NC and SD apportion the pollution sources down to nanoparticles, which can be difficult with the traditional methods employing PMF on data obtained with offline techniques and mass chemical composition.

List of publications included in the doctoral thesis

Manuscript 1: Leoni C., Hovorka J., Dočekalová V., Cajthaml T., Marvanová S. 2016. Source impact determination using airborne and ground measurements of industrial plumes. *Environmental Science and Technology*, 50(18), 9881-8, DOI: 10.1021/acs.est.6b02304

Manuscript 2: Hovorka J., Leoni C., Dočekalová V., Ondráček J., Zíková N., 2016. Aerosol distribution in the planetary boundary layer aloft a residential area. *IOP Conference Series: Earth and Environmental Science,* 44, 05-2017, DOI: 10.1088/1755-1315/44/5/052017

Manuscript 3: Leoni C., Pokorná P., Hovorka J., Masiol M., Topinka J., Zhao Y., Křůmal K., Cliff S., Mikuška P., Hopke P. K., 2018. Source apportionment of aerosol particles at a European air pollution hot spot using

particle number SDs and chemical composition. *Environmental Pollution*, 234, 145-154. DOI:10.1016/j.envpol.2017.10.097

Manuscript 4: Kozáková J., Leoni C., Klán M., Hovorka J., Racek M., Ondráček J., Moravec P., Schwarz J. Chemical characterization of $PM_{1\text{-}2.5}$ and its associations with the PM_1, $PM_{2.5\text{-}10}$ and meteorology in urban and suburban environments (submitted to Aerosol and Air Quality Research).

Aims

Manuscript 1. Study of the SD properties and dynamics, with focus on the ultrafine fraction, in a European air pollution hot spot. Develop and test a methodology that combines highly time-and-space airborne and ground-level measurements.

Manuscript 2. To investigate vertical atmospheric aerosol profiles, of size-segregated particles and the PBL dynamics.

Manuscript 3. Perform the source apportionment of atmospheric aerosol with PMF receptor modelling in the EU air pollution hot spot; with number SD spectra as input and focusing on the smallest fractions. Test the methodology of combining PMF application on particle number SD and particle mass chemical composition.

Manuscript 4. To elucidate the particles SD dynamics in terms of intermodal fraction; investigate the associations between $PM_{1\text{-}2.5}$ and fine (PM_1) and coarse ($PM_{2.5\text{-}10}$) fractions based on statistical analysis, chemical composition analysis, and meteorological analysis, in various locations, during both winter and summer.

Methods

Manuscript 1

The measurements were performed from the 5th of February to the 7th of March 2014 in the residential district of Ostrava-Radvanice and Bartovice. Ground measurements were conducted using a mobile sampling station, airborne measurements were preformed using an airship. A large metallurgy complex is located 1.5 km southwest of the sampling station.

The airship was equipped with a specially designed gondola carrying a lightweight sampler for size segregated aerosols, a temperature sensor, a laser nephelometer, and two condensation nuclei counters. Ultrafine particles (20-100 nm) and coarse particles (PM_{1-10}) were measured. The following parameters were recorded with 5-min integration time: particle NC and SD (14 nm - 10 μm) with aerosol size spectrometers; wind speed and direction, temperature, CO, NO_2, NO, O_3, SO_2, CH_4, with automatic analyzers. 24-h samples of UFPs

were collected on the backup filter of an 8DRUM impactor; eight carcinogenic PAHs, in UFPs collected on the filter, were measured with gas chromatography coupled with mass spectrometry detector.

Manuscript 2

The measurements were performed in Ostrava city suburb Plesná, composed of single family houses. The airborne measurements were realized with an airship, with an 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, two condensation nuclei counters, and a temperature sensor. Concentrations of UFPs (20-100 nm) and coarse particles (PM_{1-10}) were measured.

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. Five minute integrates of particle NCs and SD in size range 14

nm – 10 µm were measured by aerosol size spectrometers. Meteorological parameters (wind speed, wind direction, relative humidity and temperature) were also recorded.

Manuscript 3

As for manuscript 1, the sampling campaign was performed from the 5th of February to the 7th of March 2014, in the EU hot spot. Five-minute integrated particle NC and SD (14 nm - 10 µm) were measured with aerosol size spectrometers. Size segregated PM was collected with the 8DRUM impactor, from the 10th to 28th of February and is used to provide 2-h resolved PM compositions. The 8DRUM collects particles in 8 size ranges, from 0.09 to 10 µm. The five smallest size range samples, from 0.09 µm to 1.15 µm, were analysed for 24 elements (Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, As, Se, Br, Rb, Pb) using synchrotron X-ray fluorescence. For the modelling, data from the five size ranges were merged in $PM_{0.09\text{-}1.15}$ to overlap the size

range of the number SD. The 2-hours mass concentrations were measured with beta attenuation monitor.

Five-minute PM_{10} mass concentration, wind speed and direction, precipitation, CO, NO_2, NO, O_3, SO_2, CH_4, were measured with automatic analyzers. Hourly concentrations of organic and elemental carbon – OC/EC in the $PM_{2.5}$ were measured in semi-continuous regime (45 minutes collection and 15-minute analysis) but only total carbon (TC) was eventually available for the data analysis. 24-hours levoglucosan, 16 US-EPA PAHs, 22R-17α(H),21β(H)-homohopane and 22S-17α(H),21β(H)-homohopane were determined in PM_1 collected on quartz filters using a high volume sampler and analyzed with gas chromatography-mass spectrometry.

Manuscript 4

Size-resolved PM measurements were performed in four locations: an urban industrial and a suburban site in Ostrava during winter 2014; at an urban traffic and a

suburban site in Prague, Czech Republic, Central Europe, during summer 2014 and winter 2015.

24-hour and 5 to 10-min size-resolved PM mass, NC and SD were measured with a personal cascade impactor sampler (PCIS) and two aerosol size spectrometers, respectively. The PCIS had airflow of 9 l min^{-1} and a cyclone was employed to cut PM_{10} upstream of the inlet. The PCIS separated particles of aerodynamic diameter (d_a) in the following five size stages: A: $10>d_a>2.5$ µm; B: $2.5>d_a>1$ µm; C: $1>d_a>0.5$ µm; D: $0.5>d_a>0.25$ µm; P: $d_a<0.25$ µm. Meteorological data, including wind speed, wind direction, temperature and relative humidity were measured in all sites. Ion chromatography was used for the determination of Ca^{2+} and SO_4^{2-} mass concentration in every aerosol size fraction. Ca^{2+} was selected as a marker for $PM_{2.5-10}$ due to its abundant presence in the mineral coarse fraction. SO_4^{2-} was chosen as a marker of PM_1 since it is one of the major constituents of fine particles in outdoor environments in Central Europe. A scanning electron microscope equipped with an energy

dispersive spectroscope was used for the elemental semi-quantitative microanalysis (C, F, Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, Cr, Mn, Fe, and Zn) of all aerosol size fractions.

Major findings

Manuscript 1: Leoni C., Hovorka J., Dočekalová V., Cajthaml T., Marvanová S. 2016. Source impact determination using airborne and ground measurements of industrial plumes. *Environmental Science and Technology*, 50(18), pp. 9881-8, DOI: 10.1021/acs.est.6b02304

The first study performed in Ostrava, an air pollution hot spot in Europe, clearly identifies industrial sources of UFPs. When downwind a large metallurgy facility, UFPs NCs suddenly increased and were always higher than 2×10^4 particles cm^{-3} (median 2.4×10^4 particles cm^{-3}, max. 1.4×10^5 particles cm^{-3}). The study reveals that the industrial particles have a size of 19−44 nm. This finding matches with particle diameters of 10−30 nm downwind from large steel complex (Marris et al., 2012); about 35-45 nm in industrial plumes near a large coke production plant (Weitkamp et al., 2005); or 32−56 nm emitted by

an iron foundry (Cheng et al., 2008). The 80 m tall chimneys of the dedusting unit of the sinter plant represent a dominant UFPs source at the metallurgical complex. This result was found with the airborne measurements performed with the airship and it matches with our previous source apportionment studies (Pokorná et al., 2015, 2016).

The UFPs are enriched up to 4.5% of mass with carcinogenic PAHs, contributing to the elevated carcinogenic PAHs concentrations at the hot spot. This also help to assess better industrial UFPs possible impact to human health, since particles of 20–40 nm in diameter exhibit twice the deposition efficiency in pulmonary alveoli than other UFPs.

The physical and chemical properties of atmospheric particles, observed in the vicinity of industrial activities, demonstrates the need of new methodologies development. These methodologies have to focus on the particle size, one of the main factors, and on the plume deposition. Integrated measurement strategy combining

high-time-resolution instruments with filter collections can facilitate the direct observation of the industrial plumes. The methodology of source impact measurements presented in the manuscript 1, combining highly time-and-space airborne and ground-level measurements, is good example of such integrated measurements and can be applied to identify specific industrial sources in other hot spots.

Manuscript 2: Hovorka J., Leoni C., Dočekalová V., Ondráček J., Zíková N., 2016. Aerosol distribution in the planetary boundary layer aloft a residential area. *IOP Conference Series: Earth and Environmental Science,* 44 052017, DOI: 10.1088/1755-1315/44/5/052017

In this study, airborne measurements reveal early morning temperature stratification of the Planetary Boundary Layer (PBL) and coarse particles to be accumulated below the inversion layer. Two temperature inversion layers were observed: the first at

70 m a.g.l. while the second reached heights 180-230 m a.g.l.. Coarse aerosol mass concentrations up to 50 μgm^{-3} below the first inversion layer reflected coarse aerosol sources on the ground.

On the other hand, UFPs emitted from distant source with high emission height, can be trapped at higher altitude in the PBL. In this study, the high UFPs NCs, up to $2.5x10^4$ particles cm^{-3}, were measured with the airship at higher altitudes (90-120 m a.g.l), which may indicate a fanning plume from a distant emission source with a high emission height. During the course of day, the PBL stratification ceased and gradually turbulent mixing evolved. This may lead to a downward transport of UFPs that were before at higher elevations. A sharp increase in NCs of UFPs, up to $3.7x10^4$ particles cm^{-3}, recorded at noon at heights of 380-400 meters a.g.l., is followed by a sudden increase of UFP concentration ($1.5\text{-}2x10^4$ particles cm^{-3}) at the ground, after 20 minutes. This finding confirms the observation of a recent study (Platis et al., 2016), where new particle formation was

measured at 400-500 m a.g.l. and after the break of the PBL stratification, the nanoparticles were measured at the ground level, showing the downward mixing of the inversion.

Manuscript 3: Leoni C., Pokorná P., Hovorka J., Masiol M., Topinka J., Zhao Y., Křůmal K., Cliff S., Mikuška P., Hopke P. K., 2018. Source apportionment of aerosol particles at a European air pollution hot spot using particle number SDs and chemical composition. *Environmental Pollution*, 234, 145-154. DOI:10.1016/j.envpol.2017.10.097

The application of PMF on NC and SD resulted in six factors/pollution sources. Two factors were resolved in the ultrafine size range: industrial UFPs (28%, number mode diameter - NMD 45 nm), industrial/fresh road traffic nanoparticles (26%, NMD 26 nm); three factors in the accumulation size range: urban background (24%, NMD 93 nm), coal burning (14%, volume mode diameter

- VMD 0.5 µm), regional pollution (3%, VMD 0.8 µm) and one factor in the coarse size range: industrial coarse particles/road dust (2%, VMD 5 µm). The PMF analysis of $PM_{0.09\text{-}1.15}$ mass chemical composition revealed four factors: Secondary inorganic aerosol/coal combustion/biomass burning (SIA/CC/BB, 52%), road dust (18%), sinter/steel (16%), iron production (16%). The factors in the ultrafine size range resolved with number SD have a positive correlation with sinter/steel production and iron production factors resolved with chemical composition. Coal combustion factor resolved with number SD has moderate correlation with SIA/CC/BB factor. The organic markers homohopanes correlate with coal combustion and the levoglucosan correlates with urban background factor. The PMF applications to the number SD and the chemical composition datasets elucidates components in common, as well as others unique to each method, for example, the factors in the ultrafine size range. PAHs in PM_1 were found to be associated with coal combustion

factor, with (r^2 = 0.68); PAHs showed positive correlation with R-homopane (r2=0.88) and levoglucosan (r^2 = 0.67). According to the previous and present studies, various sources contribute to particulate pollution at the hot spot and to PAHs concentration: industrial emissions of UFPs with southwesterly wind, combustion emissions (biomass and coal) of fine particles with north-north easterly wind. Nevertheless, the results presented in this research work do not enable to quantify the sources of PAHs at the hot spot. Higher time resolution analysis can give further insight to quantify the sources of PAHs at this location. Highly resolved PAH analysis and comparison with the wind speed and direction provide information on the variable impact of industrial/combustion emissions, and consequently can elucidate the major PAHs source.

Manuscript 4: Kozáková J., Leoni C., Klán M., Hovorka J., Racek M., Ondráček J., Moravec P., Schwarz J. Chemical characterization of $PM_{1\text{-}2.5}$ and its associations with the PM_1, $PM_{2.5\text{-}10}$ and meteorology in urban and suburban environments (submitted to Aerosol and Air Quality Research).

The SD dynamics vary according to the meteorological conditions and the particles sources. The intermodal fraction (IMF, $PM_{1\text{-}2.5}$) accounts for 3-8% of PM_{10} mass in all the sampled locations in the Czech Republic (Ostrava industrial-residential; Plesná suburban-residential; Benátská-urban; Suchdol-suburban). The highest mass concentration of IMF, PM_1, and $PM_{2.5\text{-}10}$ with Fe as the predominant element in all fractions was measured at the Ostrava industrial-residential site. Crustal elements were similarly distributed in the IMF and in the coarse fraction at every site. No seasonal differences were found in Ca^{2+} concentrations. PM_1 showed the highest

SO_4^{2-} concentrations, especially at the suburban and urban sites in the winter.

Both $PM_{2.5-10}$ and PM_1 contribute to the IMF. The relative humidity is the most important parameter that influences the SD. Hygroscopic ions, which account for a significant fraction of fine PM, enhance the fine particles growth to sizes larger than 1 μm. On the other hand, with dryer atmospheric condition, the IMF is associated to coarse PM, composed mainly by crustal dust or resuspended road dust.

This investigation on IMF at four different locations in the Czech Republic suggests that in case of dry atmospheric condition, the PM_1 can be monitored as better representation of the fine fraction. On the other hand, with higher relative humidity, the fine fraction contributes to the IMF, and the $PM_{2.5}$ can be a more representative indicator.

Conclusion

The most important finding is this research work is: high UFPs NC, in Ostrava Radvanice and Bartovice, EU hot spot for air pollution, is emitted by industry. Plumes of UFPs impact the residential areas in the surroundings, when downwind the metallurgical facility. The UFPs are highly enriched with PAHs, contributing to their high concentration at the district. This discovery was achieved thanks to the airborne measurements performed with and airship, which enabled to track and measure the industrial plumes with high emission heights, integrated with ground measurements at the receptor site. The combustion sources (biomass and coal) for local heating purposes, constitute another source, contributing to the fine particulate matter mass ($PM_{0.9\text{-}1.15}$). It is evident that different sources emit PAHs at the hot spot, and it is plausible that industrial emissions of UFPs are dominant with southwesterly wind, while combustion emissions are dominant with north-northeasterly wind. Nevertheless, the contribution of industrially emitted

UFP to the accumulation fraction especially with calm wind conditions it is difficult to quantify. High time resolution PAHs SD analysis, for example hourly resolved, can give further insights on their sources. Highly resolved PAH analysis, compared with the wind speed and direction, provides information on the variable impact of industrial/combustion emissions, and consequently can quantify PAHs sources with precision.

The conclusive reflection is: the EU air pollution hot spot Ostrava Radvanice and Bartovice, in the Moravia Silesian region, needs that EU and national policies incentivize cleaner fuel types for domestic heating, and cleaner technologies for industry. EU has established concentration thresholds and objectives of quality, but exceedances of PM limits are still registered in different areas of Europe, especially in the winter (EEA report 2016). Effective air quality policies call for action and cooperation at global, European, national and local levels, extending across most economic sectors.

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April 2017-ongoing: Project Control trainee at the European GNSS Agency, Janovského 438/2, 170 00 Prague, Czech Republic.

Support in Project Control for Galileo: budget management, reporting, processes and procedures, configuration and documentation management, tender evaluations for procurement, quality management, document management system, cost modelling and cost engineering

Oct. 2013 – ongoing: Ph.D. study at the Institute for Environmental Studies, Faculty of Science, Charles University, Benátská 2, Prague, Czech Republic.

Research project on atmospheric aerosol science and source apportionment. Tasks include: project management, data analysis, undergraduate students' supervision, laboratory and field work, collaboration with other research institutes, international conference presentations and scientific publications.

Sept. 2011 – Sept. 2013: Researcher at the Centre de Recherche et d'Enseignement de Géosciences de l'Environnement (CEREGE), Technology park of Arbois-

Méditerranée, Aix-en-Provence, France.

Regional project on particulate matter industrial emissions in the Provence mining region. Tasks included: data analysis and presentation, reports writing, technical and analytical tasks, communication with stakeholders.

Jan. – July 2011: Master internship at the CEREGE on the chemical and physical characterization of atmospheric particulate matter, using GNSS Geographic Information Systems.

Sept. 2009 – Feb. 2010: Bachelor internship at the University of Milan, Food and Agricultural Technologies Department, Celoria street n. 2, Milan, Italy. Project on freshwater microbiological analysis with molecular biology techniques.

EDUCATION:

Master degree University of Milan – Bicocca, Piazza della Scienza, Milan, Italy - Sciences and Technologies for the Environment and the Territory (points: 107/110).

Erasmus project in Environmental Management and Analysis, University of Aix-Marseille, France.

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Languages: English, French (Advanced); Czech (Intermediate)

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PUBLICATIONS:

Scientific papers:

- Leoni C., Hovorka J., Dočekalová V., Cajthaml T., Marvanová S. *Source Impact Determination using Airborne and Ground Measurements of Industrial Plumes.* Environmental Science Technology, 2016, 50 (18), pp 9881–9888.
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