Variability of Aerosols and Chemical Composition of PM10, PM2.5 and PM1 on the Platform of the Prague Underground Metro

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VARIABILITY OF AEROSOLS AND CHEMICAL COMPOSITION OF PM_{10}, $PM_{2.5}$ AND PM_1 ON THE PLATFORM OF THE PRAGUE UNDERGROUND METRO

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INTRODUCTION

One of the principal measures employed by developed countries to combat traffic congestion and emissions in urbanised areas is through the promotion of public transport. Of the various modes of public transport available in many urban areas, underground trains are considered one of the cleanest from an environmental perspective. This is due to a number of factors, including the metro system's capability of carrying a large number of passengers who may otherwise use automobiles, reducing traffic congestion and emissions at surface level. Furthermore, the trains are powered electrically with subsequent lower local emissions compared to traffic. However, numerous studies have highlighted the poor air quality on underground platforms and inside the trains themselves (Aarnio *et al.*, 2005). Considering the routine use of many passengers on metro systems (during commuting for example), it is important to understand and characterise the air quality in these specific microenvironments in order to determine what type of aerosols passengers are regularly exposed to. The aim of this study is to describe aerosol concentrations and variability, and chemically characterise PM sampled during a 24 hour period on a platform of the Prague underground metro system. To this end, PM and particle number concentration and size distribution are described, and the chemical composition of PM in various size fractions is discussed, both for periods when the metro was out of operation and operational.

EXPERIMENTAL SETUP

Measurements were performed at the city centre metro station Museum (platform of line A, direction Dejvická), which is at the intersection of line A and line C. The platform is at a depth of 34 metres below ground and is separated from the train moving in the opposite direction by two walls and a central tunnel. Trains commence at 4:40 h and the last train leaves the terminus station at 00:00 h, with a frequency between three to ten minutes depending on the time of day. Both on-line and off-line sampling were performed during hours when the metro was shut down and closed to the public (for background sampling), and when the metro was in operation and open to the public. Real-time measurements of particle mass concentrations and particle number concentration and size distribution were performed on site. Total particle number

concentrations were measured using a Condensation Particle Counter (CPC 3025 TSI) for particles of diameter 3 nm and above. The particle number size distribution of sub-micron particles was measured using a Scanning Mobility Particle Size (SMPS 3936 TSI), comprised of a Differential Mobility Analyser (DMA 3081 TSI) coupled with a CPC (3775 TSI), which provided the size distribution of particles of diameter 14-640 nm. Number size distribution of particles in a size range of 0.5-20 μ was measured in real-time by an Aerodynamic Particle Sizer (APS 3321 TSI). A range of meteorological parameters were measured alongside all the instrumentation employed. Gravimetric sampling of PM_{10}, $PM_{2.5}$ and PM_1 was performed using low volume samplers (2.3 m^3 h^{-1}, LECKEL) equipped with quartz fibre filters. Samples were collected when the metro was out of operation and closed to the public in order to sample background aerosol (3:03 to 4:35 a.m.), and during operational hours (5:03 to 0:08 (+1 day) a.m.). Different analytical techniques were employed for the chemical characterisation of PM collected on each filter, providing concentrations of secondary inorganic aerosols (SO_4^{2-}, NH_4^+, NO_3^-, Total Carbon, Fe and major and trace components). Size segregated elemental composition was determined using a 12 stage BLPI impactor.

RESULTS AND CONCLUSIONS

Fig. 1 shows the variation of the particle number size distribution, and total mass concentration ($PM_{0.5\text{-}20}$, measured by APS) and number concentration ($N_{14\text{-}637}$) measured on the metro platform for 24 hours. The results show that concentrations during background hours (period A in Fig.1) are at their lowest as a result of no passing trains and no passengers on the platform.

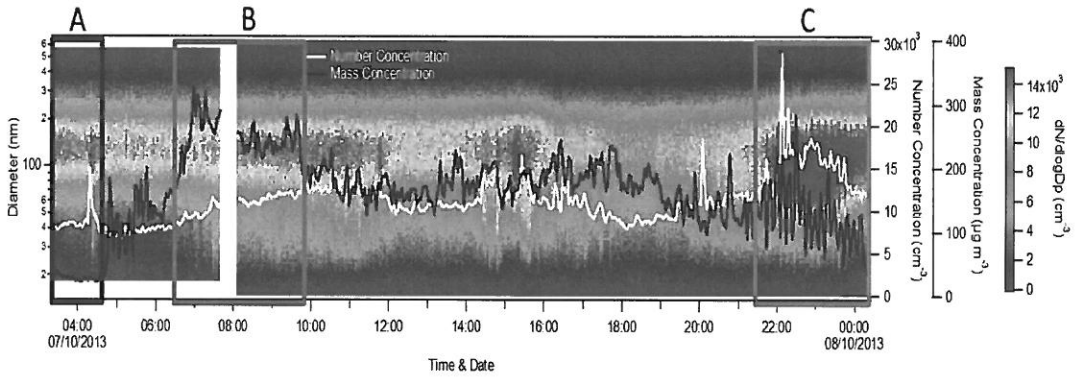

Fig. 1: Particle number (CPC) and mass concentration (APS), and size distribution (SMPS) measured for 24 hr on the metro platform. Periods of note highlighted (A, B, C)

Mass concentrations increase instantly with the arrival of the first train at 4:47 hr, with PM_{10} (estimated gravimetrically from LECKEL samples) increasing to 214.8 μg m^{-3} during metro operational hours. PM levels are at their highest during rush hour (B in Fig. 1), when trains were most frequent (every 2-3 min. until 9:30 hr) and passenger numbers were at their highest. Number concentrations did not increase as abruptly, with a gradual steady increase during period B. Both mass and number concentrations reach a relatively steady state following rush hour, when trains run with a frequency of 4-5 min. until 20 hr. During the final part of the day (period C in Fig. 1) a significant change in the variation of mass and number concentrations occurs. PM commences a

decreasing trend with a well-defined oscillating profile. This is not reflected in the particle number concentration, but number concentrations increase to their highest recorded for the entire day ($1.4x10^4$ cm^{-3}). The opposing trend for particle mass and concentration may be related to the removal of sub-micrometre particles through coagulation by high concentrations of coarse particles throughout the day. When the mass concentration decreases, the sub-micrometre particles are not scavenged as efficiently and can accumulate within the metro tunnel later in the evening. This decoupling of variations in PM and sub-micrometre particle concentrations has been described previously in Milan (Colombi et al., 2013), indicating that sub-micrometre particles are of an alternative source to that of PM.

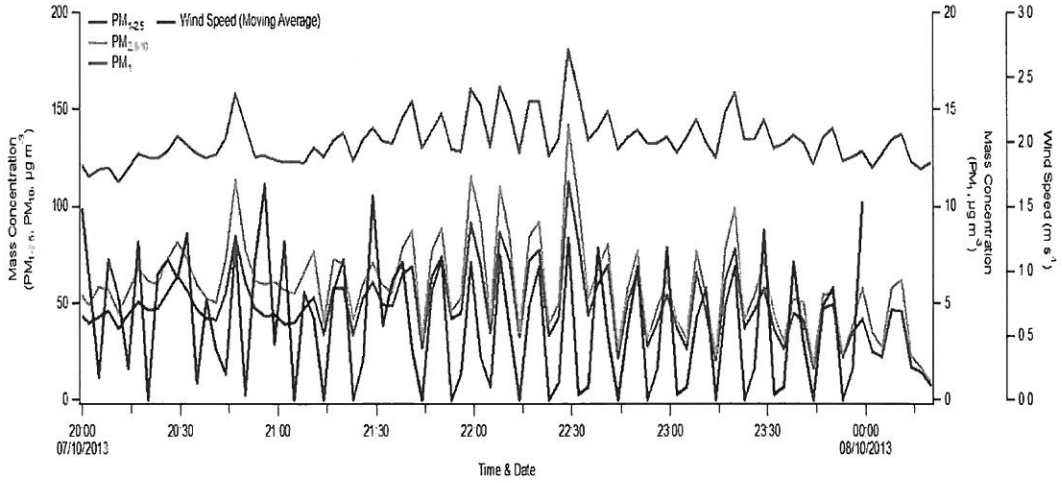

Fig. 2: Variation of PM and wind speed measured for 24 hr on the metro platform.

Fig. 2 highlights a specific period towards the end of the day (Period C in Fig. 1) for wind speed and PM concentrations. Fig. 2 shows that as trains become less frequent later in the day (every 7-10 min.) a clear correlation between PM and wind speed emerges. Concentrations peak with maximum wind speed as a result of train arrivals, indicating that the incoming and outgoing trains directly affects PM within the tunnel, and when the air settles again (when velocity is at 0 m s^{-1}) PM levels reduce in the tunnel once more. It is noteworthy that when trains are more frequent (when there is constant movement of air within the tunnel), the overall net effect on PM is a direct increase. However, when trains are less frequent, PM concentrations reduce, but are also subject to short-lived increases in concentrations. This indicates a two-fold effect of the passage of trains: production of particles by mechanical processes and resuspension by turbulence. This is further evidenced by the differences in PM chemical composition measured during background hours and metro operational hours, as shown in fig. 3.

As evidenced in Fig 3, the majority of PM is in the coarse fraction during operational hours. During this period PM_{10} reached 214.8 μg m^{-3}, followed by 93.9 μg m^{-3} for $PM_{2.5}$ and 44.8 μg m^{-3} for PM_1. Background levels were significantly lower for PM_{10} (96.3 μg m^{-3}) and $PM_{2.5}$ (69.4 μg m^{-3}). However background PM_1 concentrations were actually higher at 58.2 μg m^{-3}. Fe_2O_3 is the dominant species in the coarse fraction by a significant margin, comprising 66% of PM_{10} (141.4 μg m^{-3}) and 40% of $PM_{2.5}$ (37.1 μg m^{-3}). This percentage composition reduces to 13% (5.8 μg m^{-3}) for PM_1. For the background samples, Fe_2O_3 becomes a much less significant species, indicating that the source of Fe_2O_3 is dominant during metro operational hours only. The abundance of iron

compounds in underground metro tunnels has been documented previously (Aarnio et al., 2005; Querol et al., 2012) and is directly related to emissions from wheel-rail mechanical abrasion. Total Carbon and Secondary Inorganic Aerosols are the second most abundant compounds, the sources of which are mostly likely found at ground level and are entrained to the metro tunnel from the surface.

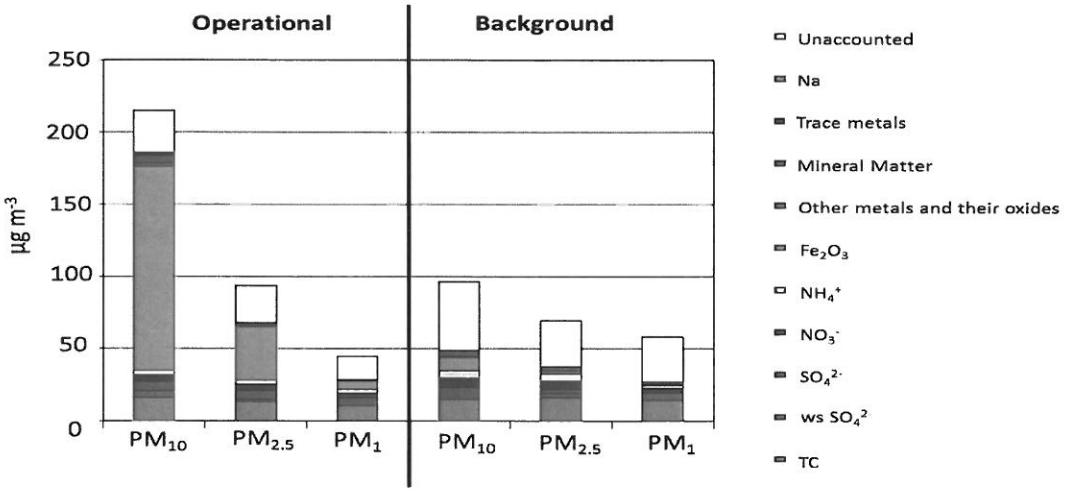

Fig. 3: Chemical composition of PM_{10}, $PM_{2.5}$ and PM_1 for operational and background hours on the metro platform

Certain trace elements exhibit significantly higher concentrations than others, and are specifically enriched in the coarse fraction during operational hours. Ba, CuO, MnO, ZnO, Cr_2O_3, Mo, Sb, Sn, Ni, Co, Li and Cd are all enriched during the hours when trains are passing the platform. The probable sources of these elements are emissions from wheel/rail friction, sparking from electrical cables, wheel-rail abrasion and brake pads.

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