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INVESTIGATION OF ATMOSPHERIC PARTICULATE MATTER (PM) MASS CONCENTRATION SPATIAL VARIABILITY BY MEANS OF ON-FOOT MOBILE MEASUREMENTS IN LILLE, NORTHERN FRANCE

BY

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Abstract. Air-quality and pollution levels in urban agglomerations are generally assessed by monitoring stations set up in fixed locations. However, the particulate matter ($PM_{10,\ 2.5,\ 1}$) mass concentrations at surface level, which are hazardous for environment and human health, can be highly variable in space and time even at a local scale. Thus, there is a need for assessing the spatial distribution of the particulate matter loadings at fine spatial scale. For this, we performed on-road mobile measurements of particle size distributions with a low-cost sensor, Alphasense OPC-N2, in order to estimate the $PM_{10,\ 2.5,\ 1}$ mass concentration. The measurements were performed in the urban regions of Lille metropolis, in northern France. In this work, we evidence the gradients of

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pollution levels between less and more densely populated areas. In our study, we found an increased level of PM_x concentrations higher than 40 µg/m^3 near the commercial centers, as well in the city center, whereas regions with less traffic and more rural areas (Villeneuve d'Ascq) are less polluted.

Keywords: PM; urban measurements; on-road measurements; low-cost sensors; pollution gradients.

1. Introduction

Aerosols are a ubiquitous and variable component in the Earth's atmosphere (Mann *et al.*, 2014). Their spatio-temporal distribution is highly variable (Kinne *et al*., 2006; Yu *et al*., 2012). The aerosol microphysical properties, such as size, shape, mixing state and also chemical composition strongly depend on their emission sources (de Meij *et al*., 2012; Fuzzi *et al*., 2015) and on the transformation processes they suffer during their transport from the source. Atmospheric processes occurring during the aerosol lifetime, *e.g*. heterogeneous reactions at the surface of each particle, hygroscopic growth due to the water uptake and physicochemical aging will undergo important changes on their microphysical and micro-chemical characteristics, but also on their optical properties (Johnson *et al*., 2005; Müller *et al*., 2017; Nessler *et al*., 2005; Niemi *et al*., 2006). Such properties and quantitatively assessment of the ambient particulate matter loadings are important for air-quality studies and evaluation of their impact on human health (Fuzzi *et al*., 2015; Ignotti *et al*., 2010; Pöschl, 2005).

In urban areas, the air quality and pollution levels are assessed by stationary monitoring stations, *e.g.* (Ielpo *et al*., 2014). As previously mentioned, the particulate matter of various sizes, namely PM_{10}, $PM_{2.5}$, and PM_1, which represent the mass concentration of particles with diameter sizes no larger than 10 µm, 2.5 µm and 1 µm, respectively, presents a high variability in space and time. The fixed air-quality stations can be located at various geographical distances, from couple of kilometers to hundreds of kilometers (see the World Quality Index website for a detailed map of the global locations of air quality monitoring stations: http://aqicn.org/). But, there is no information on the PM concentration levels at fine spatial scale. Chemistry transport models (Crippa *et al*., 2016) and satellites measurements and retrieved products can provide global maps of aerosol loadings and their physical, chemical and optical properties (Mallet *et al*., 2016), but their spatial scale is limited and varies from 1 km^2 to a couple of km^2. Thus, there is a need to study this variability of the ambient PM concentrations at fine scale.

In order to achieve such fine spatial scale studies, we perform on-road mobile measurements using a low-cost optical particles counter to measure particles size distribution and assess PM number and mass concentrations. This paper presents a simple methodology to conduct mobile measurements at small scale and results obtained from a field campaign conducted in the urban agglomeration of Lille, northern France. Taking into consideration the impact of air pollution on our lives, we evaluate the variability of PM mass concentration in various environments, *e.g.* more and less densely populated areas such as green spaces and the vicinity of the commercial centers.

2. Instruments and Methodology

The instrument used for measurements is an Optical Particle Counter (OPC-N2), from Alphasense (http://www.alphasense.com/), that measures the light (from a diode laser source) scattered by a particle from the sampled environmental air stream. Based on Mie theory (Van de Hulst, 1981), the instrument classifies the particles by their optical diameter and determines their number concentration. PM_1, $PM_{2.5}$ and PM_{10} mass concentrations are then calculated from the particle size spectra and the number concentration data. To calculate the mass concentration, it is generally considered that the particles density is 1.65 g/cm^{3}and the refractive index, RI, (a complex number with its imaginary part related to particles' absorption), is 1.5+i0 (Alphasense User Manual OPC-N2 Optical Particle Counter, 2015). OPC-N2 uses an elliptical mirror to create a sensing volume and a dual-element photo detector to measure the scattered light. The measurements are idealized by ignoring the absorption coefficient, which is usually in the range of 0.01 to 0.1 (Lieberman, 1992). The instrument can measure particles in the size range between 0.38 µm and 17 µm diameter and the detection limits are from 0.01 µg/m^3 to 1500 mg/m^3. The particle size is recorded in 16 size bins in a sampling interval from 1 to 10 seconds, with a maximum of 10000 particles/second (Alphasense User Manual OPC-N2 Optical Particle Counter, 2015). The sampling interval chosen in this study was 60 seconds.

Fig. 1 illustrates the setup for the mobile measurements. It consists of the optical particle counter (Fig. 1*a*) installed in the lateral pockets of the backpack, a GPS (Fig. 1*b*) and a laptop inside the backpack (Fig. 1*c*). A second OPC was installed, in case of technical problems with the first one. In order to visualize the recorded data during on-road measurements, a commercial USB Internet modem was used. This can assure the possibility of the user to access the real-time measurements by remote controlling software (Crilley *et al*., 2018; Bezantakos *et al*., 2017).

The GPS used for the measurements is a BU-353 model, water resistant and having an active patch antenna for a better accuracy. The GPS is connected to the laptop via an USB cable and there is no need of batteries or other power source (US GlobalSat Corporate, 2014).

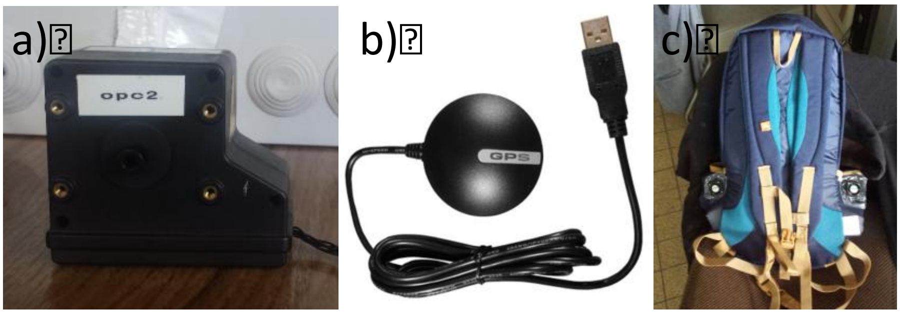

Fig. 1 – Illustration of the *a*) OPC-N2 Alphasense, *b*) GPS – model BU-353 and *c*) Backpack set up with two OPC mounted in the side pockets.

In order to evaluate the performance of the low-cost sensor, we compared measurements performed by OPC-N2 and a particle sizer, miniWRAS model 1371 - Mini Wide Range Aerosol Spectrometer (Grimm, 2017), arranged side by side. The miniWRAS instrument was considered as a reference instrument (Sousan *et al*., 2016). The size range of miniWRAS is from 0.01 µm u to 32 µm divided in 41 size channels and measurement data every minute (User Manual, Grimm, 2017) are provided. The measurements were performed on the rooftop of LOA (Laboratoire d'Optique Atmosphérique) at Lille University (50°36'29" N, 3°8'25" E), at an elevation of 20 meters above ground.

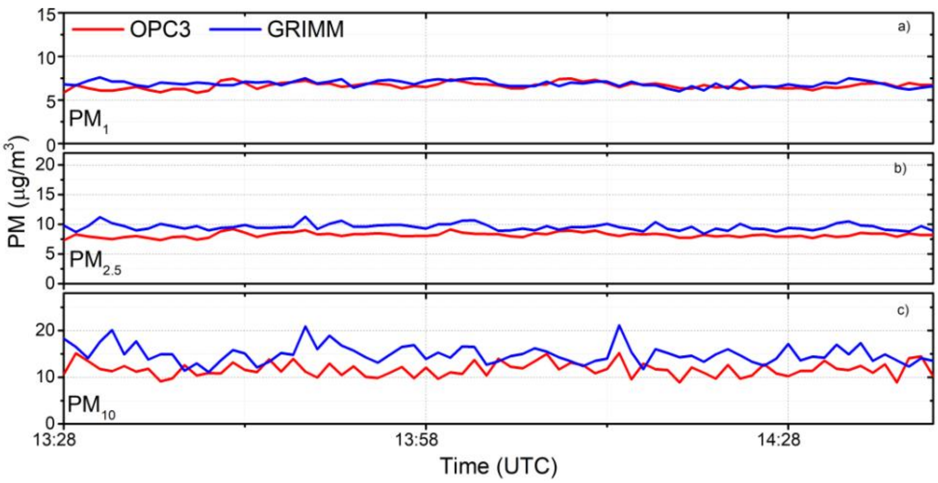

Fig. 2 – Illustration of the (*a*) PM_1, (*b*) $PM_{2.5}$ and (*c*) PM_{10} mass concentration variations as depicted from OPC (red line) and mini WRAS (blue line) measurements in Villeneuve d’Ascq, France, on the roof of LOA on 13/07/2017.

Fig. 2 shows the derived PM mass concentration from OPC and mini-WRAS stationary measurements on 13 July 2017, 13:28 – 14:40 UTC. We can observe that the OPC-N2 describes the same variability in PM_1, $PM_{2.5}$ and PM_{10} concentrations as the miniWRAS and that the discrepancy is small. The linear fit between coincident measurements of both particle sizers show a good correlation with a Pearson's r factor of 0.98 for all PM_{10}, $PM_{2.5}$ and PM_1 (not shown here). However, the slope values for PM_{10}, $PM_{2.5}$ and PM_1 comparisons are 0.83, 0.75 and 0.7, respectively, meaning that the OPC-N2 slightly underestimated the PM mass concentrations, compared to GRIMM mini-WRAS.

3. Mobile Measurements in Lille

The measurements were performed in the city-center of Lille, Citadel of Lille, Vauban Park, Porte de Paris and Jean-Baptiste Lebas Park on 28 and 29 August 2017. For these two days the air-quality forecast models predicted a pollution event in Lille area (Atmo Hauts-de-France - Mesures des stations de surveillance de la qualité de l'air, 2018).

Fig. 3*a* shows the PM_1, $PM_{2.5}$ and PM_{10} mass concentration variations derived from measurements with the low-cost sensor OPC-N2. The recorded mass concentrations are higher in the first part of the day,(8:10 UTC- 11:40 UTC), in the range of 22 - 80 μg/m^3, 25 – 100 μg/m^3 and 32 – 115 μg/m^3 for PM_1, $PM_{2.5}$ and PM_{10}, respectively. From 12:00 UTC to 14:30 UTC, the particle concentration starts to decrease; however some peaks can be observed in Fig. 3, most probably due to the city traffic.

The next day, 29 August 2017, measurements were performed in the center of Lille, Citadelle of Lille, Vauban Park. The results shown in Fig. 3*b* indicate that the values of PM concentration are lower compared to previous day. The recorder mass concentrations are in the range of 5 - 20 μg/m^3, 7 - 25 μg/m^3 and 15 - 60 μg/m^3, for PM_1, $PM_{2.5}$ and PM_{10}, respectively. Moreover, a peak in mass concentration at 11:40 UTC can be observed, corresponding to the passage close to a building site, when PM_1, $PM_{2.5}$ and PM_{10} values are around 80, 200 and 1500 μg/m^3, respectively.

On 28 August 2017, in Lille city center the highest values were recorded, exceeding 100 μg/m^3 for PM_{10}, values that decreased during the day to around 20-40 μg/m^3 for PM_{10} in the green space areas, such as Citadel of Lille, Vauban Park, Jean-Baptiste Lebas Park. On 29 August 2017, PM_x concentrations for the same time interval were, on average, around 25 μg/m^3. The highest values are recorded in the city center, from 8:00 UTC to 9:00 UTC, decreasing during the day. In Vauban Park and Citadel of Lille, only PM_{10} mass concentration presented variations, while PM_1 and $PM_{2.5}$ contributions remained stable. In the university campus located in Villeneuve d'Ascq, the PM's mass concentration values were lower than 25 μg/m^3, showing low levels of air pollution.

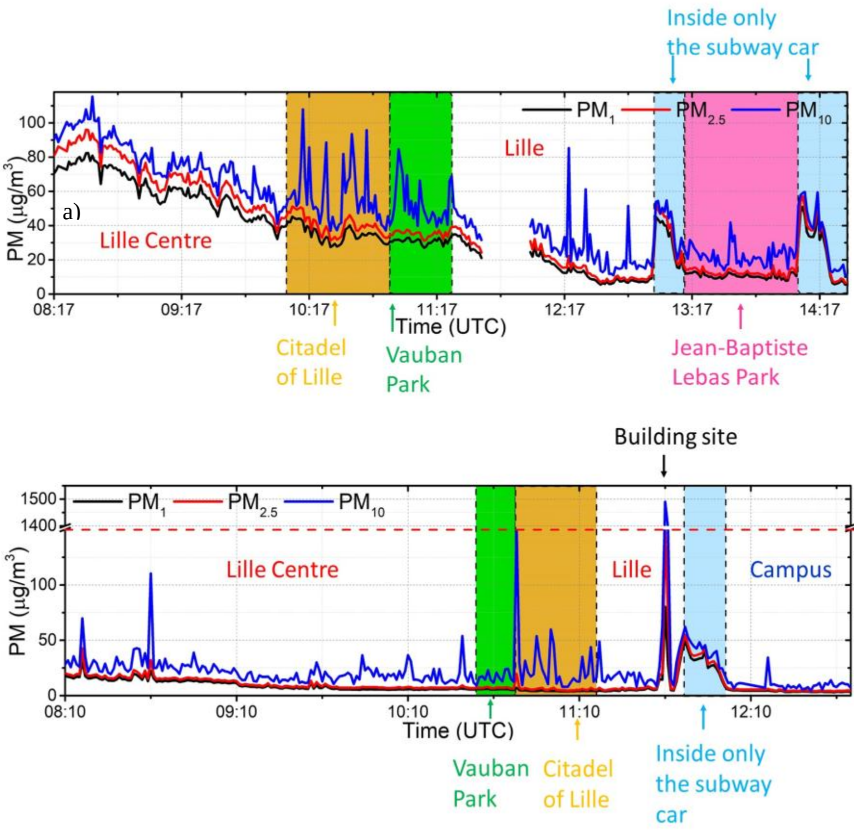

Fig. 3 – Illustration of the PM_1, $PM_{2.5}$ and PM_{10} mass concentration variations as measured by OPC-N2. *a*) Measurements in Lille on 28/08/2017. The black, red and blue lines represent the mass concentrations for PM_1, $PM_{2.5}$ and PM_{10}, respectively. *b*) Measurements in Lille on 29/08/2017. The black, red and blue lines represent the mass concentration for PM_1, $PM_{2.5}$ and PM_{10}, respectively. The red dashed line marks a break from 150 to 1400 µg/m^3.

A spatial visualization of the polluted regions in the urban agglomeration of Lille can be achieved by plotting the data on Google Earth maps. Fig. 4 illustrates the map of PM_{10} mass concentrations recorded on 28 and 29 August 2017. On 28 August 2017, we can observe that in Lille city center, the PM_{10} mass concentrations are in the range of 90 – 100 µg/m^3 and they start to decrease down to 40 µg/m^3 in green space areas. However, the PM_{10} concentrations on 29 August 2017, on the same route, decreased considerably. In some places, the PM_{10} concentrations can exceed 100 µg/m^3, which can be explained by local emission sources, such as construction sites or other activities that suspend more particles in the atmosphere. This time, on 29

August, both in Lille city-center and in green space areas, the values are in the 20 – 40 μg/m^3 range, considerably lower than the previous day.

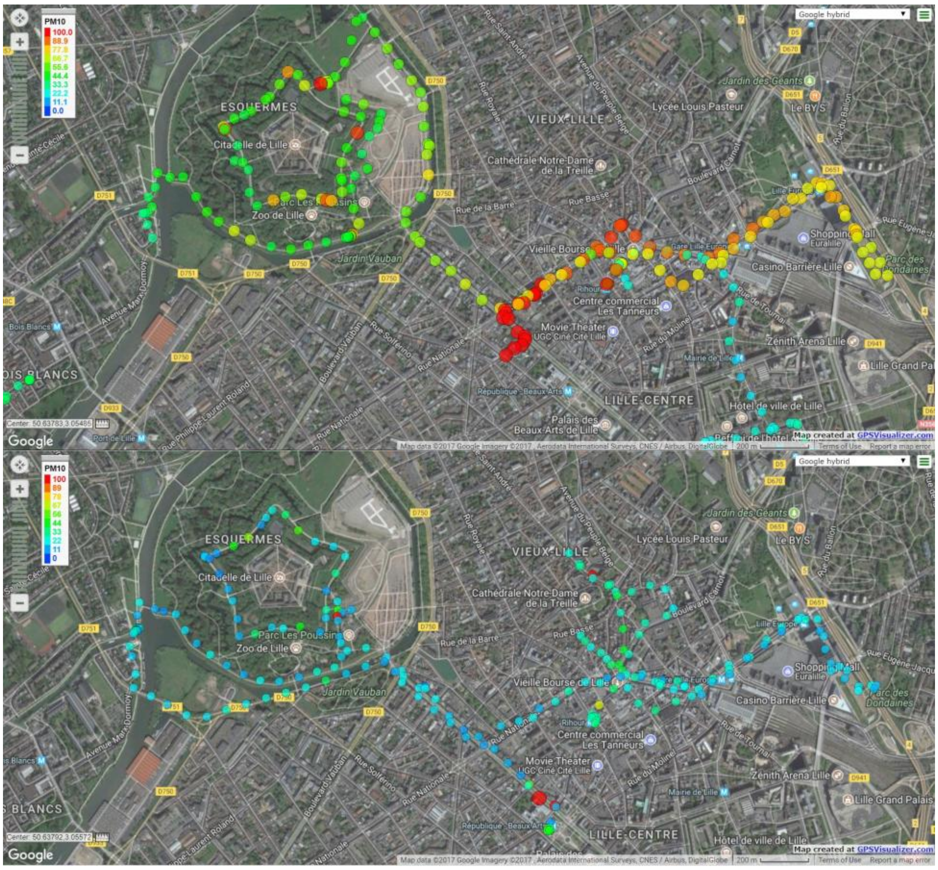

Fig. 4 – Illustration of the spatial variability of PM_{10}concentrations as measured by OPC-N2. Measurements in the urban agglomeration of Lille on *a*) 28/08/2017, *b*) 29/08/2017. The color scale is from 0 to 100 μg/m^3, with a step of 10 μg/m^3, from blue to red. The values exceeding the upper limit are also represented in red.

The measurements performed in Lille center and green space areas revealed that there was a significant level of air pollution on 28 August 2017 and the regions affecting notably the city center and the green space areas, *e.g.* Citadel of Lille and Vauban Park. Of course, one must also consider the time scale of the conducted field measurements and the temporal atmospheric variability. The second day, on 29 August 2017, the levels of PM mass concentration were at a quarter of the previous day levels. Higher winds that dispersed the pollutants and “cleaned” the atmosphere can explain the lower PM’s concentrations.

4. Conclusions

On-road mobile measurements presented in this study use techniques that involve low-cost (about 300 – 400 euro) particle sensors (OPC) for the measurement of particulate matter (PM) concentrations. The reliability of OPC measurements was checked against a reference instrument, GRIMM mini-WRAS aerosol spectrometer, in this study, and results show good agreement between the two instruments.

The setup equipment for mobile measurements is quite simple, consisting of a low-cost particle sensor (OPC), a GPS and a laptop, mounted in a backpack and carried by a person to conduct on foot measurements. Spatial variability is then illustrated on Google Earth maps using the GPS data.

Mobile measurements were conducted in Lille urban agglomeration, France, in the period August-September 2017. Examples shown here illustrate a high variability between two days, 28 and 29 August, at an urban scale. A pollution event on 28 August was investigated at a fine spatial scale using the low cost OPC. PM_{10} concentrations exceeded 100 μg/m^3 in the city center in the morning, while PM_1 and $PM_{2.5}$concentrations recorded in green space areas were in the range of 30-50 μg/m^3. The fine particles are known to be more dangerous for health and this is particularly important for persons doing physical exercises in these green space areas.

This type of measurements can be used in studies of the human exposure to pollutants in urban and rural areas. The advantage is that any user can perform this type of measurements. Of course, the measurement methodology could be improved (*e.g.* using smartphones for multiple measurements in the same time) and preliminary data could alert the population to avoid certain areas during particular time intervals based on PM_x concentrations. Since on road measurements indicate that human exposure to pollutants can be quite variable, more real-time measurements, accessibleto the population, would be of real importance.

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MĂSURATORI MOBILE ALE DISTRIBUȚIEI GRANULOMETRICE ȘI ESTIMAREA CONCENTRAȚIILOR DE MASĂ CU UN SENZOR DE COST REDUS ÎN LILLE, NORDUL FRANȚEI

(Rezumat)

În general, în aglomerările urbane, calitatea aerului si nivelurile de poluare sunt evaluate de stațiile de monitorizare aflate în locații fixe. Cu toate acestea, concentrațiile de masă a particulelor ($PM_{10,\ 2.5,\ 1}$) la nivelul suprafeței, care sunt periculoase pentru mediul înconjurător și pentru sănătate, pot fi foarte variabile în spațiu și timp chiar și la scară locală. Astfel, este necesar să se evalueze distribuția spațială a pulberilor de particule la scală spațială fină. Pentru aceasta, am efectuat măsurători mobile pe drumuri ale distribuțiilor granulometrice cu un senzor low-cost, Alphasense OPC-N2, pentru a estima $PM_{10,\ 2.5,\ 1}$. Măsurările au fost efectuate în zonele urbane ale orașului Lille, în

nordul Franței. Aici, evidențiem gradientul nivelului de poluare dintre zonele mai mult și mai puțin populate. A fost găsit un nivel crescut de poluare în apropierea centrelor comerciale, unde PM_{10} poate fi mai mare de 40 $\mu g/m^3$.