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REAL TIME MONITORING OF URBAN PARTICULATE MATTER ON A MOBILE PLATFORM

S. Castellini[1], *B. Moroni*[1], *M. G. Ranalli*[1] , *G. Lama*[2], *M. Eheim*[2], *R. Ferrera*[3], *A. Trapani*[3], *and D. Cappelletti*[1]

[1]DICA, SMAArt and DEFS, Università degli Studi di Perugia, 06125 Perugia, ingsilviacastellini@gmail.com
[2]Leitner Spa, via Brennero 34, 39049 Vipiteno (BZ)
[3]FAI Instruments s.r.l., 00013 Fonte Nuova , Roma

Abstract: The project main focus is the study of urban pollution dynamics, with a particular attention to vehicular traffic and generated aerosols. Techniques at work include fast pollutants and micrometeorology monitoring from both fixed and mobile stations as well as advanced statistical treatments of the data. Communication and dissemination of the results is also an important task of the project. The audience includes government policy-makers, media, environmental and health professionals, healthcare providers, the public, and vulnerable populations.

Keywords: mobile station monitoring, traffic, high frequency measurements, OPC, PBL monitor.

1. INTRODUCTION

Urban pollution and air quality are usually monitored with an approach based on measurements of pollutants concentration at fixed stations, typically those of the local environmental agency. The position of the stations is chosen following well-assessed criteria. The time resolution of measurements is regulated by law (*i.e.*, 24 h for particulate matter, 8 hour-average for O_3) based on the idea of monitoring the average exposure of the population. The choice of this approach is motivated by its easy implementation, which allows also to obtain reproducible information all over the country. Clearly, this methodology points at the monitoring of urban pollutants levels to verify the respect of the air quality law limits, with a scarce capability to obtain the critical information on the dynamics of urban pollution formation, sources, evolution and fate.

A more effective approach requires fast measurements of gases and particulate matter (PM), possibly size resolved, coupled with information on the evolution of urban microclimate and vehicular traffic fluxes. The best is to attain this information on a 3 dimensional scale for the overall urban area. Various exploratory studies have been performed so far in this field [1-4]. Some of them are based on pollution monitoring installations on cars or buses. The main difficulties in this case are the tracking of the mobile stations inside the urban area, and the low reproducibility of timings and positions due to traffic congestion. Herein, we propose to integrate aereosol and gas sensors into a cable train cabin, which runs continuously through the city of Perugia, on a monorail isolated from the urban traffic. This integrated cabin allows to get a snapshot of the urban pollution dynamics along a sector of the city at high spatial resolution. These data will be correlated with traffic rates, measured at crossings with the metro line, and managed in the framework of a long-term project whose final aim is to asses the impact of the vehicular traffic on urban air pollution.

2. THE TRANSPORT SYSTEM AND MONITORING INSTRUMENTATIONS

The municipality of Perugia has developed an urban transport system (Minimetrò) based on a relatively high number of cabins (in average 20) driven by a wire rope continuously running at medium low speed (4-5 m/s) along a radial transect (~3 km) over the city. The cabins travel on a monorail built 5 meters above the road level. The path starts from a large suburban parking area, it crosses various heavy traffic roads and road crossings, passes through a park, climbs Perugia hill, and finally reaches the city center inside a tunnel (Figure 1). All these features make the Minimetrò system a good mobile platform for real time investigation of the dynamics of formation and dispersion of pollutants in the urban area. In particular: (i) the variety of urban scenarios intersected by the monorail provides information on different environmental situations; (ii) the constant speed and high frequency of the cabins make the tracking of the monitors relatively easy and precise; (iii) the independence from any traffic congestion issues results in a good reproducibility of measurements; (iv) the low specific emissions of the system gets low interference with environmental measurements; (v) the presence of fixed monitoring stations at both ends in the metro line provides pollutants concentration and main meteorological parameters measurements at a sufficiently high frequency all over the day.

The basic idea has been to customize and integrate an Optical Particle Counter (OPC) in a Minimetrò cabin (Figure 2). Main challenges has been the miniaturization of the device in order to be fitted into the upper vane of the cabin (Figure 3); the reduction of the absorption (~ 80W) in order to be continuously feeded by the battery system of the cabin; the integration with the central software of the cabin in order to record precisely the position at any time.

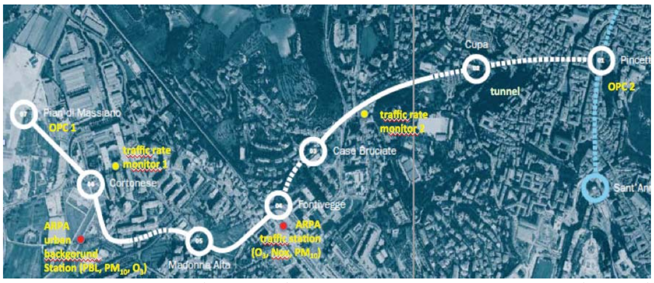

Figure 1 - General map of the monitoring project: Minimetrò line with main stations (circled dots), ARPA monitoring stations (red), and traffic counter points (yellow).

Figure 2 - The PMetro cabin.

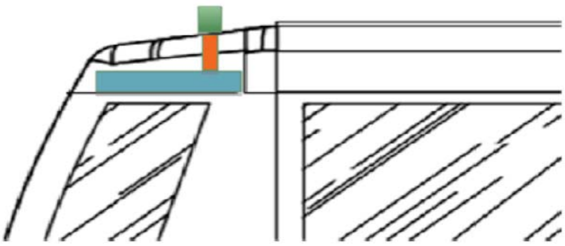

Figure 3 – Layout of the PMetro cabin and the Optical Particle Counter inside the upper vane.

This device allows to record (every 6 seconds or ~25 meters spatial resolution) the aerosol size distribution in the size range typical of an OPC (22 channels in the range 0.3-10 µm). Every approx. 20 minutes the cabin covers a transect of the town. The OPC has been integrated with the cabin control software, which allows to monitor and to log information on the cabin position along the path. To complement the information coming from the mobile station, two other fixed OPCs (FAI Instruments) have been installed at both ends of the Minimetrò line. These instruments record continuously (24h at 1 minute resolution) the aerosol size distribution (22 channels in the range 0.3-10 µm). Moreover the Minimetrò line passes at short distance (50 m) from the urban background and traffic monitoring stations. These provide hourly averaged O_3, NO_x, Benzene and CO concentrations, as well as 24h PM_{10} and $PM_{2.5}$ data records. In addition, the main weather parameters are recorded at the urban background station; a PBL stability monitor (FAI Instruments) is also present in this station. This instrument (based on the measurement of the Radon level in the atmosphere; 1h time resolution) allows inferring the stability condition of the urban mixing layer. Finally, traffic rates are recorded on a 24h base in two points along the Minimetrò line at 5 minutes resolution.

The presence of two fixed instruments at the Minimetrò line ends provides a description of the situation at two very different places in the town. In fact the monitoring station at Pian di Massiano is affected by high traffic (it is a suburban parking area), while the monitoring station at Pincetto is located in an elevated, very ventilated area at relatively low traffic conditions.

Combined evaluation of PM data from the mobile and the fixed weather stations allow to evaluate the effect of the synoptic conditions (*e.g.*, wind, relative humidity, rain, temperature) in different places in the town during the day and/or the week. This is because it is now known that the levels of pollution are not exclusively related to human activity but they are also affected by different climatic, synoptic and microclimatic/topographic conditions affecting the distribution of airborne pollutants within the mixing layer.

3. DATA TREATMENT & PRELIMINARY RESULTS

All data are recorded daily and preprocessed with a Matlab code for a first visualization and for subsequent use by statistical analysis. The data pre-processing will be optimized on the basis of the needs of the various statistical tools employed for the data mining.

The high-resolution datasets along the full Minimetrò line could also be exploited for studying the dynamics of aerosol formation and diffusion in different urban scenarios (*e.g.*, road crossings, parks, tunnels). It is expected that the data mining strategy will be fine tuned during the project. This task will include also the generation of meaningful information on air quality to be communicated to the public, by means of web pages, social networks and cellular phones.

Data from this integrated system can be employed at different levels. From a general point of view, they access a number of informations on meteorological and local conditions such as traffic. As an example, traffic flows are reported in Figure 4. Preliminary results show very regular patterns of daily and weekly traffic flows.

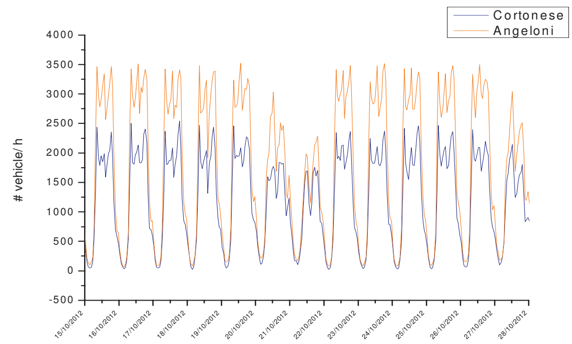

Figure 4– Example of traffic flux pattern

The data provided by the cabin can be directly managed to allow the mapping of the city as a function of space and time in order to highlight the presence of special/recurring situations in specific areas of the city or time spans during the day and/or the week: combined treatment of PM mass and size distribution and traffic count rate measurements in the two intersections next to the Minimetrò line provide correlations between the dust pollution and vehicular traffic as a function of time. Fine particle distributions resemble the effect of direct traffic emissions, while coarse particles distribution can be affected by different processes. As an example, in Figure 5 the effect of increasing traffic rates following office and school hours (between 8:00 and 10:00 a.m.) is well evidenced. On the other hand, the coarse particle patterns of distribution in the same day (Figure 6) are not related to traffic rates. Rather, they reflect the influence of a long range dust intrusion occurring in that date. This fact clearly results when comparing the PM_{10} levels at the urban station (Pincetto) and the background site (Monte Martano): starting from the mid afternoon of October 20, just in concomitance with the occurrence of the dust intrusion, the PM_{10} levels increase in both sites from ~ 10 to ~ 22 µg m^{-3}, and reach their maxima in the subsequent days (Figure 7).

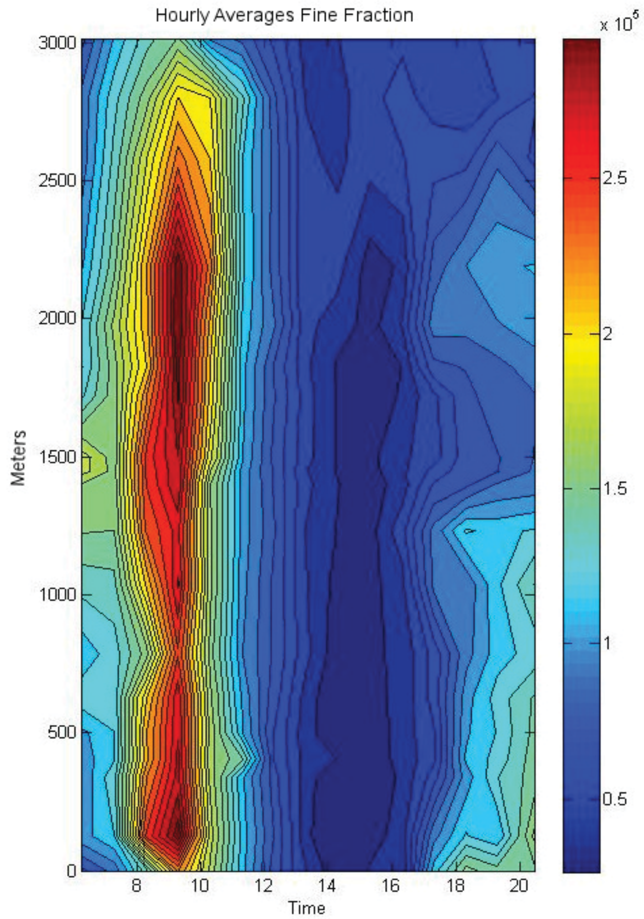

Figure 5 – Spatial distribution of hourly average fine fraction in date 20/10/2012. The color code represents particle Number concentration. The y-axis shows the meters traveled by the cabin along the line between the two terminal.

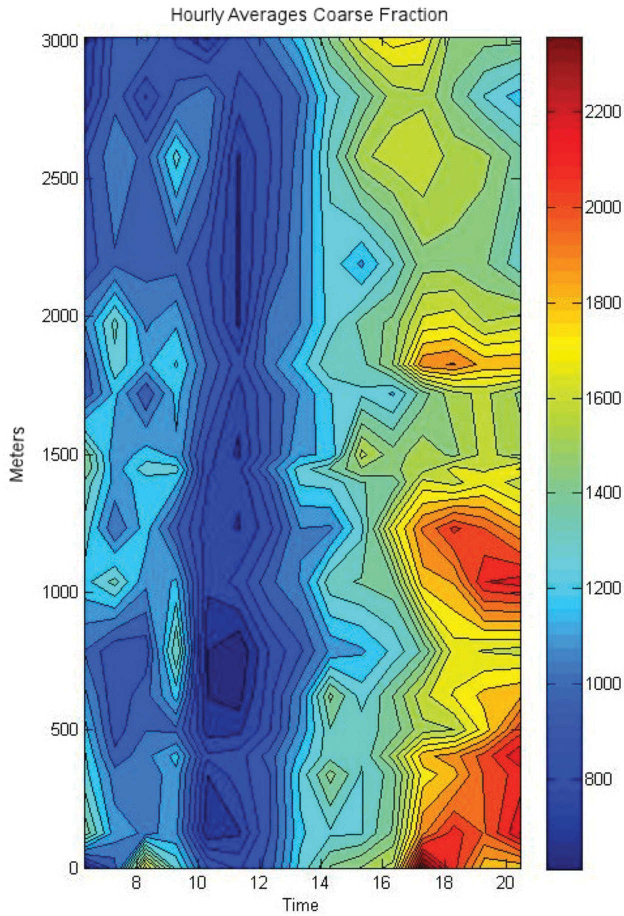

Figure 6 - Spatial distribution of hourly average coarse fraction in date 20/10/2012. It is possible to notice an Saharan intrusion arriving after 05:00 PM

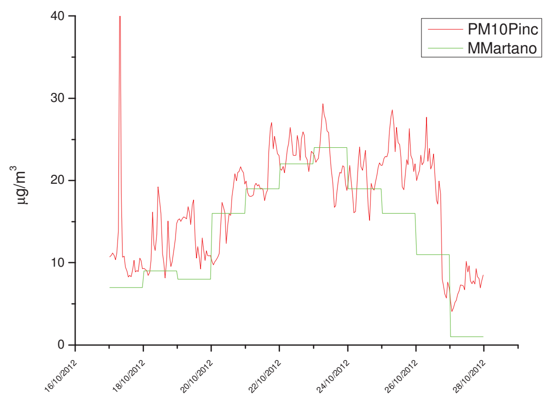

Figure 7 – PM_{10} levels at Monte Martano (background site) and Pincetto (urban site).

As a starting idea, statistical analysis has been conducted using additive mixed models [6-7] to understand which variables affect the behavior over time of the fine and coarse particles . To this end three databases have been merged for two locations at the finer common time resolution (30 minutes): cabin OPC, meteorological info and traffic counts. From some preliminary analysis on a reduced time slot (one week), the log-count of fine and coarse particles are quite correlated and show different patterns that depend on the day and, within the day, on the time of the day. Autocorrelation functions show that they both follow a long memory process. Additive mixed models are an extension of classical regression models that allow for some continuous covariates to enter the model non-parametrically, i.e. without a pre-specified functional form for the relationship with the outcome, and allow for correlation among subsets of observations (e.g. clustering). Model selection shows that good predictors of the log-count of particles are some meteorological variables, like rain and relative humidity (linearly negatively related), net solar radiation (linearly positively related), mean wind speed (more complex function with a decreasing shape) and PBL (more complex function with an increasing shape). Traffic count is also a significant predictor, linearly positively related, that explains, other things being equal, the difference between the two locations considered. The final model is able to account for almost all of the variability of the response variables and to explain the long-memory process underpinning. However, residuals from the model still seem to follow an AR1 (autocorrelated of order 1) process, by this showing that short term dependence (from measurements 30 minutes apart) are difficult to capture with available covariates. These preliminary analyses are promising and will be extended to longer time slots (at least three months) to check the robustness of the association between covariates and outcome variables. Finally, multivariate additive models will also be employed to exploit the correlation between fine and coarse particles, and among particle counts at different channels in general.

4. FUTURE DEVELOPMENTS

The PMetro methodology can be reasonably subjected to extension and instruments development. In particular:

1. integration with a high resolution micrometeorological (sonic anemometer), nanoparticle, CO_2, and black carbon monitoring system based on a fixed station along the metro line.

2. integration of fast (and light) gas sensor on the mobile monitoring station (Minimetrò, but also public buses). This will require a GPS localization system in the case of buses.

These tasks will be the subject of dedicated projects of research to be exploited in the next future.

5. REFERENCES

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