REMOTE SENSING MEASUREMENTS OF THE URBAN BOUNDARY LAYER OF ROME UNDER THE EU LIFE+ EXPAH PROJECT.

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ABSTRACT

The EC funded the EXPAH project (EXPAH "Population Exposure to PAHs") under the LIFE+ program. The aim of EXPAH is to identify and quantify the population exposure to Polyciclic Aromatic Hydrocarbon (PAH) in highly urbanized areas, and to assess the impact of the PAH on human health. A collection of meteorological measurements is required to feed the modeling system that simulate the emission, dispersion and transformation of PAH in the target studied area, which has been chosen to be the metropolitan area of Rome, Italy. Since December 2010 the project is collecting upper air and surface meteorological data. In addition to the existing monitoring network, four stations have been located in the city of Rome and its surroundings. Remote sensing systems are used in this intensive field campaign. A SODAR-RASS has been located in a urban park of the city to collect wind and temperature vertical profiles. A ceilometer is located in the same site to measure the vertical backscattering aerosol profiles which will be used to retrieve the PBL height and for monitoring the PBL aerosol structures. At CNR-ISAC Tor Vergata science park, located in the suburbs of Rome, the wind and temperature profiles are measured by means of respectively a SODAR and a microwave radiometer. The combination of these remote sensing techniques will allow to monitor the spatial extensions of the meteorological phenomena, identifying urban effects and the observation of both mountain-valley and sea-land circulations in the basin area. After the first year of measurements, preliminary results are presented.

1. THE POPULATION EXPOSURE TO PAH (EXPAH) PROJECT

1.1 Aim and objectives

In order to addresses the environmental and health problems induced by emission, dispersion and transformation of Polycyclic Aromatic Hydrocarbons (PAHs) compounds, the European Commission funded the "Population Exposure to PAH" (EXPAH) project (Oct 2010-Dec 2013; http://www.ispesl.it/expah) under the LIFE+ program. The overall goal of the project is to identify the sources and quantify the exposure of children and elderly people to particulate PAHs in highly urbanized areas, and to assess their impact on human health. More in detail the EXPAH objectives are:

- to develop a state-of-the-art PAH emission inventories for the city;
- to improve and integrate air pollution models to describe the emissions, diffusion, atmospheric transformations, and removal of PAHs;
- to estimate the actual concentrations of PAHs to assess the human exposure in different living places and to develop an outdoor-indoor infiltration model;
- to estimate the mean exposure of the target populations to particles and PAHs by means of an exposure model;
- to estimate the short-term and long-term health impact of particles and PAHs and to improve exposure-response relationships of PAHs;
- to evaluate the health impact in view of EU policies in order to provide recommendations for adaption and mitigation strategies.

The city of Rome (Italy) was chosen as study area due to its serious pollution problems, particularly for PM_{10}, NO_2 and O_3. Several studies have reported health effects due to air pollution in this city [1] and an increase of 10 $\mu g/m^3$ of PM_{10} is expected to be responsible for an increase of 1.1% in cardiovascular and respiratory mortality.

1.2 Meteorological monitoring under the EXPAH project

Upper air and surface meteorological measurements are being collected in the metropolitan and sub-urban areas of Rome in order to get information on the climatology of the target area. In particular the correlation of PM and PAHs concentrations with the local meteorology and circulation is the objective of our study. The existing monitoring network has been extended with four stations located in the city of Rome and its surroundings. An intensive experimental campaign started in January 2011 in which at two of the four stations were added ground based remote sensors. The first site, named Villa Pamphili, is located in one of the urban park of Rome, (North-west of the city). A Metek DSDPA-90 phased array SODAR-RASS was mounted in this station to measure wind and temperature vertical profiles. A Vaisala CL31 ceilometer was also running to get vertical back-scattering aerosol profiles to retrieve the Planetary Boundary Layer (hereafter PBL) height and investigate the aerosol structures. The second station is set at the ISAC-CNR facilities, located at Tor Vergata in the south suburbs of Rome. Wind and temperature profiles are measured respectively by means of a SODAR and a MTP 5-P microwave radiometer. Complementary turbulence measurements are also carried out at both sites using sonic anemometers. The turbulence information is fundamental for dispersion models. The local circulation regimes around the city of Roma has been studied by different authors [2]. The local circulation is characterized by two prevailing circulations: land and sea breezes, and drainage flows from the mouth of the Tiber valley. A strong seasonal dependence of the diurnal behavior of wind speed and direction were also found.

2. RESULTS

2.1 Statistical analysis

In order to characterize the urban site of Pamphili, a statistical analysis of the wind velocity derived by SODAR between 40-400 m was made. The measurements, averaged over a period of 10 minutes, refer to the year 2011. Figure 1 shows the wind rose for the entire year. The different colors represent the wind occurrences (in percent units). Two prevailing wind directions are shown: NE and W-SW. For both the directions the distribution presents a peak corresponding at a wind speed of about 5 m/s, with the NE direction more frequent than W-SW one. Detailed analyses indicate that these prevailing wind directions have a seasonal behavior as shown by the wind roses of Figure 2.

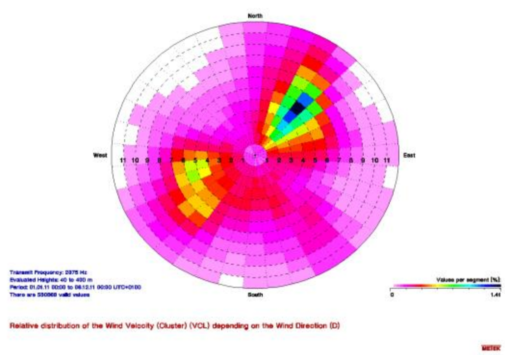


Figure 1. SODAR wind rose at the Pamphili urban park of Rome during year 2011.

The NE peak is observed during all the seasons (Figure 2). During the summer (left lower panel of Figure 2) the occurrence is lower and the sector interested is narrower than during the other seasons.

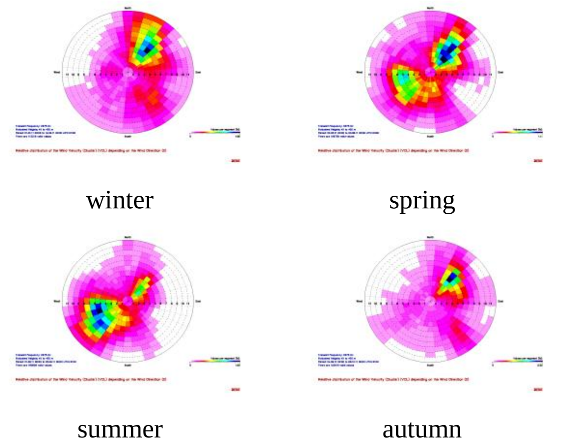


Figure 2. Seasonal wind roses for the same site and period of Figure 1.

The presence of this peak is due , as shown in the paper by Petenko et al. [2], to a drainage flow from the Tiber valley. The W-SW peak, which occurs in spring and summer, is due to the sea breezes which normally develop in this area. In order to characterize this behavior the measurements were grouped into four time intervals: 0-6; 6-12; 12-18; 18-24 LT. Figure 3 shows the corresponding wind roses. Winds from NE are observed during both night and morning hours (upper and bottom right panels of Figure 3). The westerly winds are found instead during the warmest hours (bottom left panel) of the day confirming its sea breeze origin. The observations for the late afternoon evidence both the wind regimes, however a larger spread in the wind distribution occurs.

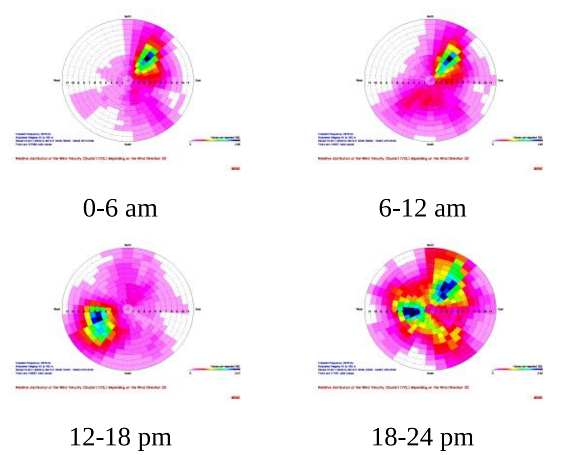


Figure 3. SODAR wind rose for different time intervals collected at Pamphili urban park during year 2011.

2.2 Detection of urban vertical structures by means of SODAR/RASS and MTP profiles

The SODAR measurements in Rome evidenced the existence of a consistent wind rotation during the early morning hours for cloudless days and stable conditions, in presence of an high pressure system. As an example Figure 4 shows this behavior for February 7th at the Pamphili urban park. More than 100 degrees of wind rotation from north to south is observed. The rotation starts from about 380 m on 0200 am LT and penetrates with time into the residual layer reaching the minimum height of 180 m at about 0700 am LT. This regime lasts up to about 1000 am when the heating of the sun removes its structure. A decreasing of the wind speed with height is observed during the same time interval.

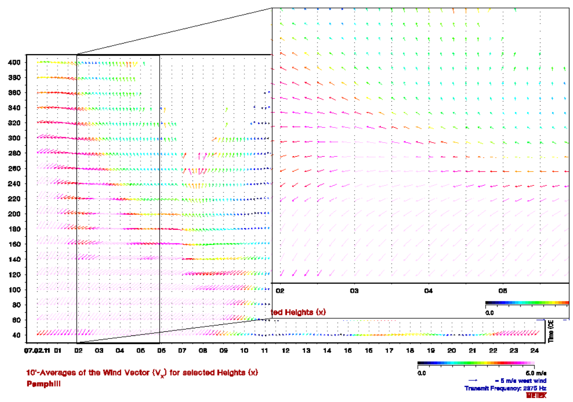


Figure 4. Wind profile structures detected at Pamphili urban park on February 7th, 2011.

The potential temperature profiles measured by a co-located RASS system (Figure 5), show the existence of a well defined stable layer with a depth of about 160 m in correspondence of the layer characterized by the highest wind velocities. The low height coverage of the RASS did not allow to detect the height of the residual layer, which was instead evidenced at 400 m by the MTP 5-P radiometer as shown in Figure 6. The availability of two temperature profiles might also be used to study the urban heat island effect in Rome.

The facsimile recording of the SODAR located at Tor Vergata, for February 7th is shown in Figure 7. The echogram confirms the presence of a very strong stratification in the low atmosphere with a shallow stable boundary layer of 200 m depth, which decrease up to 100 m in the early morning. The correspondent nighttime SODAR wind profiles are shown in Figure 8. A wind rotation with height is detected also at this site from 0230 am LT up to about 0400 am, but with weaker intensity than the Pamphili site. This behavior indicates that the urban boundary layer might introduce some effects in triggering this process. Early morning profiles exhibit stronger northern wind in the first 150 m respect to the wind above, confirming a decoupling of the local flow.

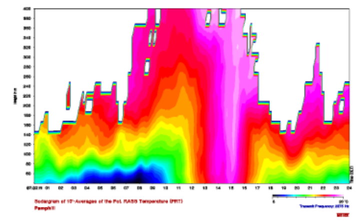


Figure 5. The RASS potential temperature profile measured at Pamphili urban park on February 7th . 2011.

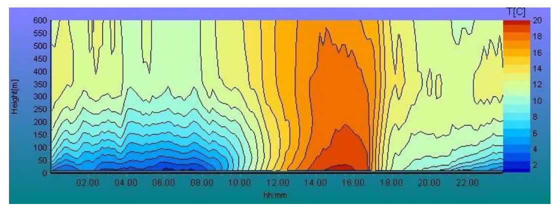


Figure 6. MTP-5P microwave radiometer temperature profile collected at Tor Vergata.

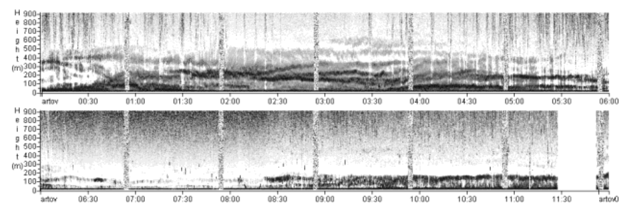


Figure 7. Facsimile representation on February 7th , 2011 given by ISAC SODAR located at Tor Vergata.

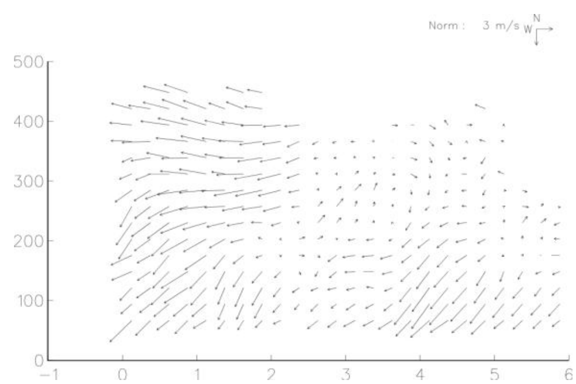


Figure 8. Wind profile structures detected at Tor Vergata on February 7th ,2011 0000-0600 am LT.

2.3 Backscattering aerosol profiles

The effects of the wind field and thermal structure on the vertical distribution of the aerosols can be observed in the signal provided by the Ceilometer located at the Pamphili site. Figures 9 and 10 show respectively the plot of the backscatter signal collected on February 7th and the correspondent PBL heights as estimated by means of the gradient detection algorithm embedded in the Vaisala BLVIEW software. The backscattered signal confirms the presence of a weak aerosol layer (dark green on Figure 9) which starts at 2 am from the upper part of the residual layer, penetrates progressively in the stable layer and ends at about 1000 am in correspondence of the wind rotation mentioned above.

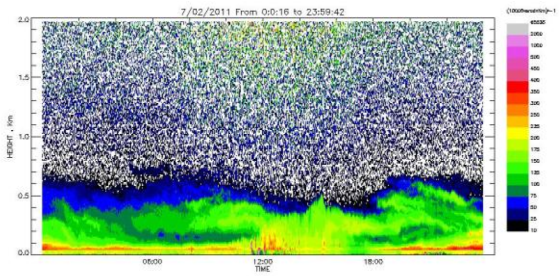


Figure 9. Backscatter signal of the Ceilometer collected at Pamphili urban park on February 7th, 2011.

The southern winds present in the upper layers might bring some less polluted air from outskirt areas of the city. The PBL heights (Figure 10) exhibit a strong stable layer 120 m high topped by a residual layer which extends up to 500 m for the whole day, confirming the strong stability conditions for this day.

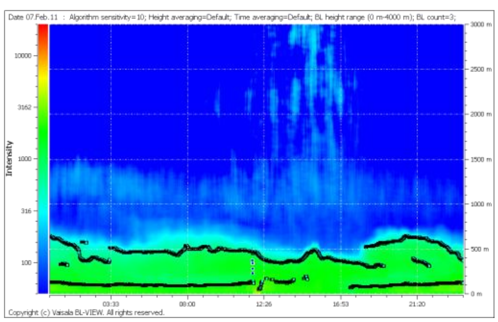
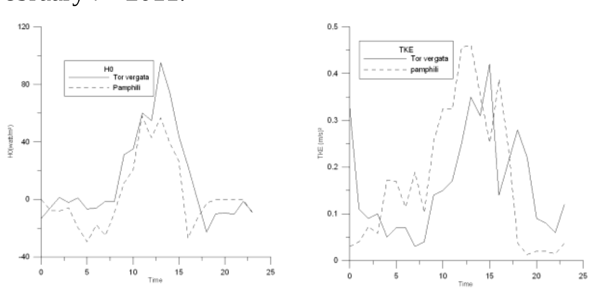


Figure 10. Intensity of backscatter signal and PBL heights (dots) of the Ceilometer collected at Pamphili urban park on February 7th, 2011.

2.4 Surface turbulence measurements

Both at Pamphili and Tor Vergata sites surface turbulence measurements were carried out. Figures 11a and 11b show respectively the time series of sensible heat (H_0) and turbulence kinetic energy (TKE) for February 7th 2011.



a) b)

Figure 11. Sensible heat fluxes (a) and turbulence kinetic energy (b) collected at Pamphili (black dotted line) and Tor Vergata (black full line) sites on February 7th, 2011.

The sensible heat flux measured at the Pamphili (black dotted line) shows negative values when the vertical structures mentioned above where detected. This downward fluxes might also produce the decoupling of the local atmosphere, which in turns might affect the observed wind vertical structures. An analogous behavior is not detected in the suburbs area of Tor Vergata (black full line). Similar behavior is shown by the turbulent kinetic energy which shows higher values at the urban site respect to the suburbs one.

3. DISCUSSION AND CONCLUSIONS

The complementary results provided by different remote sensors allowed to monitor the different features of the local atmosphere such as wind structures, PBL heights, thermal stratifications and aerosol vertical distribution. The long time serie of these measurements in the city of Rome have also made possible the identification of two prevailing wind regimes: one is linked to the drainage flows coming from the north of Tiber valley, the other is the sea-breezes circulation which develops in this area.

Wind vertical structures were often observed at the urban site late in the night and in the early morning in coincidence of very stable and cloudless nights under high pressure conditions. Thermals, as well as, aerosol structures are well correlated with these events. The availability of remote sensing systems at different city sites, allows to identify the main pattern of the urban circulation. The wind vertical structure at the urban site of Pamphili is generally more defined than the one of Tor Vergata site (south of Rome). This means that the city of Rome exhibits an urban circulation regime which might be driven by the larger thermal circulation pattern.

ACKNOWLEDGMENTS

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