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Promoting the potential of flux-measuring stations in urban parks: An innovative case study in Naples, Italy

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ABSTRACT

Urban forests and parks are living systems integrated in highly anthropic areas, where they establish close interactions with all the other systems around. Thanks to those interactions, urban forests provide many ecosystem services to people and to the whole urban environment. One of the most important is the absorption of chemically and radiatively-active trace gases and thus the effect on local air quality. Beyond the main greenhouse gases (CO_2, H_2O and CH_4), in urban areas a relevant role is played by the photochemical pollution mainly constituted by O_3 and particulate matters. Despite their importance, experimental sites monitoring trace gases fluxes in urban forest ecosystems and parks are still scarce.

In this paper, we present for the first time the experimental station of Real Bosco di Capodimonte, located within the city of Naples. The vegetation is mainly composed by *Quercus ilex* with some patches of *Pinus pinea* and meadows. The site is equipped with state of the art instruments to measure concentrations and exchanges of CO_2, H_2O, CH_4, O_3, PM, VOCs and NOx by the eddy covariance technique. It represents an interesting and rare opportunity to investigate the interactions between urban vegetation, anthropogenic pollutants and secondary photochemical compounds.

1. Introduction

Urban areas cover only about 0.5% of the total land area (Schneider et al., 2009) but are responsible for up to 40% of all emitted Green House Gases (GHG) (Satterthwaite, 2008) with a sensible impact on the alteration of the Earth climatic system (IPCC, 2014). Moreover, a mix of primary and secondary pollutants such as nitrogen oxides, (NO_X), volatile organic compounds (VOC), ozone (O_3) and particulate matter (PM) influence the quality of the urban air, generating serious environmental and health problems (Weschler, 2006; WHO, 2006). Pollutants in urban areas are strictly related: the occurrence of VOC and NO_X, in presence of the UV component of sun radiation, promote the production of O_3 (Di Carlo et al., 2004). Moreover PM (mainly the finest one with $Ø \leq 2.5\,\mu m$), can also derive from nucleation, condensation or coagulation of nitrogen oxides, sulphur dioxide, ammonia, and volatile organic compounds present in the air (US-EPA, 2004a,b). High concentrations of those pollutants are often observed in Mediterranean climate conditions where the photochemical activity is enhanced during summer by the high temperatures, clear sky conditions and high solar radiation intensity (Cieslik, 2009).

Vegetation has an important role in urban environment establishing interactions with the surrounding environment by means of physical, chemical and biological processes (De Groot et al., 2002; Turner and Chapin, 2005). In particular, trees and more generally forests, provide important environmental services at local scale like the regulation of microclimatic conditions, the removal of air pollution, the improvement of the urban environment human health and well-being. Their main effect at global scale is the sequestration (sink) of CO_2 (Nowak et al., 2008). In this respect, CO_2 can be absorbed and stored in the woody components and in the soil through photosynthetic processes but, at the same time, an indirect avoidance of CO_2 emissions due to cooling effect and the

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consequent decrease of energy consumption should be considered (Nowak et al., 2004). The removal of oxides and other secondary pollutants like O_3 usually occur through leaf stomata (Calfapietra et al., 2015a) but in some cases also through chemical reactions with volatile organic compounds emitted by vegetation (BVOC) (Jardine et al., 2012). For other pollutants such as PM, the removal usually occurs through dry deposition on leaf surface (Sgrigna et al., 2015).

However, trees in urban environment can also cause disservices (Escobedo et al., 2011). In particular, for the air quality we should consider the emission of pollen (Cariñanos et al., 2015) and the emission of VOC, which in some specific conditions can favour the O_3 formation (Calfapietra et al., 2013).

Due to the relevant number of interacting factors, the estimation of air pollutants removal capacity by urban forests is mainly carried out by means of models (Escobedo and Nowak, 2009; Alonso et al., 2011; Barò et al., 2014; Kim et al., 2014). Unfortunately, only few studies have compared models with field measurements (Morani et al., 2014) and the uncertainty of these estimations remains quite high.

Particularly challenging is the full understanding of urban forests effect on O_3 levels considering the high reactivity of several biogenic VOC, the photochemical reactivity with NOx and other anthropogenic VOC and the parallel role of plants in O_3 removal and formation (Paoletti, 2009; Manes et al., 2012; Calfapietra et al., 2013). Another interesting gap of knowledge is represented by the complex adaptation of the plants to the urban conditions that can drastically influence their mitigation and removal capacity (Calfapietra et al., 2015b).

The most accurate way to assess the role of urban forest on air quality is a direct measure. The eddy covariance (EC) technique is a reliable method to assess exchange of masses (gases, PMs) between biosphere and atmosphere (Baldocchi, 2003), and is widely used to measure CO_2 and H_2O exchange above several surfaces such as terrestrial and aquatic ecosystems, urban areas and even landfills (Grimmond et al., 2002; Aubinet et al., 2012; Gioli et al., 2012). The development and availability of new instrumentations is gradually allowing the application of the technique to many other gases like O_3 (Fares et al., 2013), CH_4 (Kroon et al., 2010; Gioli et al., 2012), NO_X (Geddes and Murphy, 2014), VOCs (Muller et al., 2010a,b) and particle matter (Velasco and Roth, 2010). It is known that urban environments are not ideal for the application of the EC technique due to the particular surface roughness characteristics (e.g. Christen 2014; Ward et al., 2015), and this is especially true when it is applied over urban forests due to their reduced extension. Some attempts of application of the EC technique in the urban vegetated context have been made in the recent past and related to pure parks (Kordowski and Kuttler, 2010), to mixed areas within the urban context (Järvi et al., 2012; Liu et al., 2012) and to a green residential area (Ward et al., 2015) although mostly restricted to CO_2 and H_2O fluxes.

The concurrent and continuous field measurements of trace gases and the main air pollutants are even rarely implemented in natural or periurban ecosystems due to the logistic complexity and the costs of the equipment. The best, long-lasting example is probably the "*SMEAR II*" (Hari and Kumala, 2005) and, more recently, the "*Castelporziano Estate*" (Fares et al., 2014) which however have to be considered as rural (SMEAR II) or periurban (Castelporziano Estate) forest ecosystems.

In this paper, we present for the first time an EC station in an urban forest, in which are simultaneously measured fluxes of CO_2 and H_2O along with several other trace gases, most of which are harmful pollutants for plants and humans. The station was established in the "*Real Bosco di Capodimonte*", a large urban park within the large city of Naples in Italy. The park, besides its historical value, is quite unique for the large size of the evergreen oak forest just in the middle of the city. Moreover the Naples urban area, characterized by high levels of atmospheric pollution due to heavy traffic and to the large harbor (Adamo et al., 2008), high level of radiation and temperature, offers the unique opportunity to study the interactions between vegetation and biogenic and anthropogenic compounds, a number of pollutants and GHG.

We describe this complex station with the aim of showing its potential in measuring the main target compounds and starting analyzing the source area from which these compounds originates. This is done showing trends of high frequency concentration data for contrasting periods of the year and also presenting fluxes in order to evidence when the vegetation acts as a sink or a source.

2. Material and methods

2.1. Site description

The experimental site is located inside the Real Bosco di Capodimonte, a green area of about 125 ha located inside the urban area of Naples (Fig. 1A). The flux tower is located above the roof of the San Gennaro church (coordinates: lat. 40.8741, long. 14.2504, 133 m above sea level). The climate is Mediterranean with prolonged warm and dry summer periods and mild winters (La Valva et al., 1992), the mean annual temperature is 16.3 °C while mean temperatures of the coldest and warmest months are 8.4 and 24.7 °C, respectively. Mean annual precipitation is 855 mm. During the winter, the main wind direction is from North-East, while during summer periods it is from South-West (La Valva and De Natale, 1994). The Real Bosco di Capodimonte is characterized by the presence of several autochthonous and exotic tree species. However, the area interested by the tower footprint, the upwind area that generate the sensed flux, is mainly characterized by a mixed Mediterranean forest dominated by *Quercus ilex* with a mean height of 22 m, and few but large individual trees of *Pinus pinea*. Moreover, within the oak forest some areas of meadows are present, mainly composed by species of *Trifolium* and *Medicago*.

2.2. Eddy covariance system

The eddy covariance technique (EC) is a micro-meteorological technique based on the turbulent air movement (eddies) transporting trace gases and masses (Baldocchi, 2003). Since its first applications the EC got a large consensus in the ecological community as it allow to measure atmosphere-biosphere trace gas exchanges without altering the surrounding environment. A detailed description of the technique can be found, e.g., in Aubinet et al., 2012; Baldocchi, 2003 and Foken et al., 2012. Here, for completeness of information, we report its basic equation:

$$F_c = \overline{w'c'} \quad (1)$$

where F_c is the trace gas flux, w the vertical wind speed and C the concentration of the scalar (trace gas or mass). The prime sign state for the instantaneous deviation from the mean and the over-bar the time average. Flux measurements with the eddy covariance require a sonic anemometer to measure wind speed and temperature fluctuation and a scalar sensor for gas and mass concentrations both operating at high frequencies ($\geq$10 Hz).

The EC tower was installed above the San Gennaro Church (Fig. 1B) at the end of 2014. The top of the tower is located at 26 m above the ground level, due to the height of the tower (12 m) and that of the church (14 m). The EC system at its top includes a 3-D sonic anemometer (WindmasterPro, Gill, United Kingdom) and a number of fast-response analysers, namely a CO_2/H_2O closed path infrared gas analyser (LI-7200, LI-COR, Lincoln, NE, USA) and a CH_4 open path analyser (LI-7700, LI-COR, Lincoln, NE, USA). The sonic anemometer is located at a distance of 20 cm from the air inlet and