Environmental Pollution 183 (2013) 113–122

Contents lists available at SciVerse ScienceDirect

Environmental Pollution

journal homepage: www.elsevier.com/locate/envpol

Improving local air quality in cities: To tree or not to tree?

Peter E.J. Vos*, Bino Maiheu, Jean Vankerkom, Stijn Janssen

Environmental Modelling Unit, Flemish Institute for Technological Research (VITO), Boeretang 200, 2400 Mol, Belgium

ARTICLE INFO

Article history:
Received 20 July 2012
Received in revised form
18 October 2012
Accepted 19 October 2012

Keywords:
Urban vegetation
Air quality
Street canyon
CFD
Elemental carbon

ABSTRACT

Vegetation is often quoted as an effective measure to mitigate urban air quality problems. In this work we demonstrate by the use of computer models that the air quality effect of urban vegetation is more complex than implied by such general assumptions. By modelling a variety of real-life examples we show that roadside urban vegetation rather leads to increased pollutant concentrations than it improves the air quality, at least locally. This can be explained by the fact that trees and other types of vegetation reduce the ventilation that is responsible for diluting the traffic emitted pollutants. This aerodynamic effect is shown to be much stronger than the pollutant removal capacity of vegetation. Although the modelling results may be subject to a certain level of uncertainty, our results strongly indicate that the use of urban vegetation for alleviating a local air pollution hotspot is not expected to be a viable solution.

1. Introduction

Because of its adverse effect on human health, air pollution is an environmental problem of major concern. Due to the high traffic density, cities often face increased concentrations of air pollutants in comparison with its surroundings. In order to mitigate these air pollutant problems, the use of urban vegetation is often promoted as an effective measure to reduce concentrations. This measure is based on the underlying argument that trees (and vegetation in general) have the capability of cleaning the air by filtering out the pollutants. Vegetation leaves absorb gaseous pollutants through their stomata, while particles are removed from the air by deposition onto the leaves and the branches. Different studies (Beckett et al., 2000; Freer-Smith et al., 2005; Lovett, 1994) have experimentally assessed the deposition rate at which pollutants are taken up by the urban vegetation. However, Litschke and Kuttler (2008) pointed out that the uncertainty associated to the published values is still large.

Nowak and Crane (2000) have developed a deposition model that is able to estimate the pollutant removal capacity of a so called 'urban forest'. Many studies using this model have reported impressive mass removal estimates for different cities (McPherson et al., 1994; Nowak et al., 2002; Tallis et al., 2011) in order to demonstrate the beneficial effect of urban green on the air quality. However, the resulting decrease in ambient concentrations is much less reported and if so, the effect of the urban forest on the city averaged air quality appears to be rather limited, often not exceeding an improvement of 1–2% (Tallis et al., 2011). In addition, Pataki et al. (2011) recently argued that there is lack of empirical evidence that support the findings of these deposition model simulations thereby concluding that the air quality benefit of urban green may be overestimated.

Although subject to a certain level of uncertainty, this city scale mitigating capacity of urban trees is merely one part of the story. Despite the fact that they effectively remove pollutants from the air, urban trees may under certain circumstances induce a *local* increase of concentrations. It has been shown (Gromke, 2011; Gromke and Ruck, 2007, 2009, 2012; Wania et al., 2011) that trees in urban street canyons obstruct the wind flow thereby reducing the ventilation leading to higher pollutant concentrations. This potentially negative effect of vegetation on the local air quality is much less known amongst policy makers and the broad public. Based upon the general idea that trees clean the air, there still is the misconception that trees are good for air quality in all cases and under all circumstances. Therefore policy makers and urban planners when faced with a local air pollution hotspot, often intuitively reach for trees to alleviate the problem, thereby potentially aggravating the situation.

The study presented in the current paper may be viewed in light of this. The initial goal was to investigate how urban vegetation can be used to improve the local air quality on inner city roads with busy traffic. The study consisted of two parts. In the first part, we conducted a sensitivity analysis where we analysed how different parameters (building geometry, pollutant type, wind conditions and vegetation type, size, position, porosity, filtering capacity)

---

* Corresponding author.
E-mail address: peter.vos@vito.be (P.E.J. Vos).

0269-7491/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.envpol.2012.10.021

influence the impact of roadside vegetation on the local air quality. In the second part, we assessed the effectiveness of 19 different green street designs, designed by urban planners for actual implementation in various cities within Belgium and the Netherlands in order to improve the air quality. Throughout this paper, we will refer to the first part as the *sensitivity analysis* and to the second part as the *case studies*. The entire study was based on computer modelling using the micro-scale model ENVI-met (Bruse and Fleer, 1998).

Although similar studies (Gromke et al., 2008; Buccolieri et al., 2011; Wania et al., 2011) have been published before, from a scientific point of view the current study differs in the following sense:

- **Focus on multiple and traffic related pollutants**. Previous studies are often limited to a single and non-traffic specific pollutant such as PM_{10}.
- **Different types of vegetation**. We do not only consider trees but also study hedges and green barriers.
- **Beyond idealised street canyon geometries**. We also focus on an idealised non-street canyon case (detached building geometry) and study various real life geometries.

The paper is structured as follows: Section 2 describes the general modelling methodology. The sensitivity analysis and the case studies are presented respectively in Section 3 and Section 4. In Section 5 we discuss the results and draw the conclusions.

2. Methodology: the ENVI-met model

All simulations in this work are performed by the ENVI-met model.

2.1. Description of the model

ENVI-met (Bruse and Fleer, 1998) is a three dimensional computational fluid dynamics (CFD) model that is particularly tailored for simulating different urban atmospheric processes such as pollutant dispersion and microclimate effects. The flow solver is based upon the Reynolds averaged Navier–Stokes (RANS) equations and uses an E-ε model for describing the turbulence effects. ENVI-met is freely available from http://www.envi-met.com.

2.1.1. Pollutant dispersion

ENVI-met uses a Eulerian approach to study the dispersion of pollutants. Both gaseous and particulate pollutants can be included. In this work, we have focussed on PM_{10} and the more traffic related pollutants NO_2 and elemental carbon (EC). As elemental carbon mainly resides in the smaller size fractions of the particulate matter (Healy et al., 2012), it is accounted for in ENVI-met as if it were $PM_{0.2}$. For the dispersion of NO_2, we also take into account the chemical reaction between NO_2, NO and O_3 (De Maerschalck et al., 2010). The traffic emissions are in principle represented by line sources. However in order to account for the mixing by the traffic induced turbulence, they are spread out over the entire width of the traffic lane and a height of 1.5 m, see also Figs. 2 and 4.

2.1.2. Vegetation

The exact geometry of vegetation (i.e. leaves and branches) is not explicitly modelled in ENVI-met. The presence of vegetation is represented by introducing additional terms in the governing equations in order to mimic its effect. For the computational cells that coincide with the location of the vegetation, a sink term is added to the momentum equation in the RANS equations in order to account for the flow resistance (or pressure drag) induced by the vegetation. This is analogue to the way porous media are often dealt with in CFD. Also the E-ε equations are equipped with an additional term to simulate the effect of vegetation on the turbulence variables. As explained in Bruse and Fleer (1998) these terms describing the aerodynamic effect of vegetation in ENVI-met only depend on a single plant parameter, i.e. the leaf area density (LAD, total leaf area divided by total volume of vegetation). The filtering capacity of trees is represented by a sink term in the dispersion equation. In ENVI-met this term reads (Bruse, 2007)

$$S = v_d \cdot \mathrm{LAD} \cdot C,$$

where v_d is the deposition speed ([m/s]) and C is the pollutant concentration.

From the above, it can be appreciated that within ENVI-met the effect of vegetation essentially only depends on two parameters: the leaf area density LAD on one side and the deposition speed v_d on the other side. ENVI-met contains further parameterisations to calculate the deposition speed. However, because these calculated values tend to be rather low we will set these parameters equal to values found in the literature (see Section 2.2.2), at least for the particulate pollutants.

2.2. Configuration of the model

2.2.1. Computational domain and mesh

For all simulations presented in this work, the computational domain has been chosen sufficiently large in order for the domain boundaries not to influence the solution. Conform to the best practice guidelines prescribed by Franke et al. (2007) we have chosen to keep clear a distance of 8 H upstream the buildings, a distance of 15 H downstream the buildings, a distance of 8 H in lateral direction, and a height of 10 H above the buildings (where H represents the building height). For the computational mesh we use a non-uniform Cartesian grid with a resolution of 0.5 m inside the canyon which is sufficiently fine to ensure the minimally recommended amount of 10 × 10 cells in the canyon cross-section (Franke et al., 2007). The grid size increases towards the boundaries of the domain with the expansion factor not exceeding the value of 1.3. A grid sensitivity analysis has been performed for the street canyon geometry out of Section 3 (the reference case without vegetation and with perpendicular wind). Next to the fine resolution of 0.5 m, simulations with a maximal resolution of 1 m (medium grid) and 2 m (coarse grid) have been assessed. The results in Fig. 1 show that the computed wind speed inside the canyon is independent of the grid size. For the pollutant concentration inside the canyon, we see that the results on the coarse grid differ from the results on the fine grid. The correlation between the fine and medium grid is remarkably better, although not perfect for the highest concentrations which occur close to the pollutant source central in the canyon. Because the focus in this work will be on the concentration at the footpaths, and since the grid dependence in this area is minimal for the fine and medium grid (see Fig. 1), we believe a resolution of 0.5 m is justified for all simulations in this study, especially taking into account the overall uncertainty of the modelling approach as discussed in Section 2.3.

2.2.2. Boundary conditions and parameter values

In ENVI-met, the profile of the flow variables at the inflow boundary is calculated by the built-in one-dimensional model. This 1D model requires the wind speed at a height of 10 m and for all simulations in this study, this has been set to 3 m/s. Table 1 contains an overview of the default values of a list of other parameters that are of importance for this study. The chosen default values for the parameters LAD and v_d are based on typical values published in the literature. The range of reported particle deposition speeds v_d is large (Beckett et al., 2000; Freer-

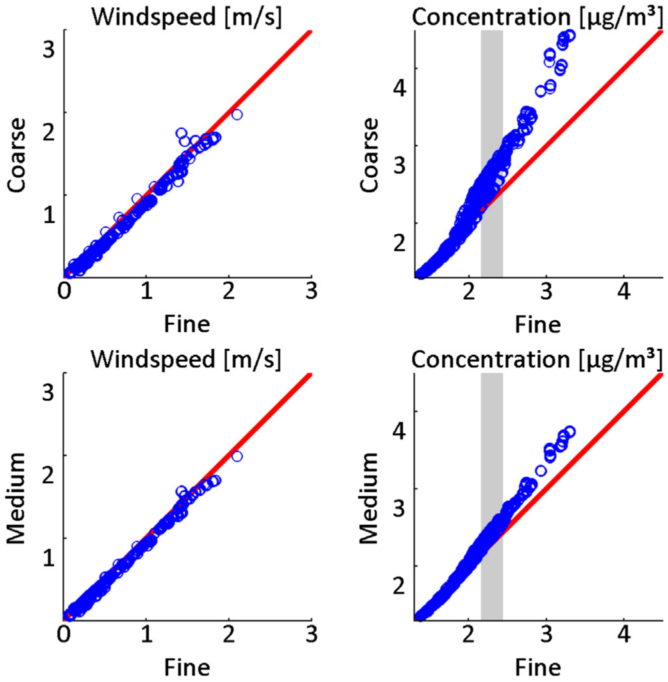

Fig. 1. Comparison of results (Left: Wind speed – Right: Concentration of Elemental Carbon) depending on the resolution of the grid (Top: Coarse versus Fine – Bottom: Medium versus Fine). Depicted are all the values inside the canyon, sampled at the resolution of the coarse grid. The shaded area corresponds with the range of the EC concentrations calculated at the footpaths.