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Including trees in the numerical simulations of the wind flow in urban areas: Should we care?

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ABSTRACT

Although trees are numerous in urban areas, their dynamic effects on the wind flow are usually approximated or neglected altogether in many wind engineering studies, especially those based on numerical modeling. This study investigates the effect of the inclusion of trees in numerical simulations of wind flow in urban area. Three approaches are used to include the dynamic effect of trees: the basic approach (tree effects are neglected), the implicit approach (tree effects are included in the surface parameterizations), and the explicit approach (trees are represented by porous media). Several test cases have been adopted in order to cover a wide range of urban complexities, wind directions, foliage densities, and tree planting configurations. The results show that there are significant effects of trees when the explicit approach is used compared to the basic and the implicit approaches. Thus tree effects need to be considered using an explicit approach to simulate wind flow in urban area. Also, many parameters such as wind direction, foliage density, and urban configuration are believed to influence the intensity of trees effects. This study emphasizes the importance to explicitly consider the effects of trees in numerical model investigations for the wind flow in urban areas.

1. Introduction

Planting trees in urban areas is employed in landscaping as a viable strategy to contribute to urban heat island mitigation (Akbari et al., 2001), reduced energy use (McPherson and Rowntree, 1993), and air pollution mitigation (Simpson and McPherson, 1998). For instance, urban tree species offer the ability of direct removal of air pollutants by dry deposition to plant foils. Street trees might also indirectly reduce power plant emissions by increasing the insulation of buildings and thus reducing the buildings energy consumption: in summer, urban trees reduce air temperatures via shading and evapotranspiration, while in winter trees act as windbreaks to shield buildings from the wind chill. Consequently, trees reduce the winter heating load. In addition, urban trees help to improve outdoor wind and thermal comfort by offering shade and shelter to pedestrians and buildings and by reducing the wind speed in locations associated with uncomfortable wind. As a side effect they take up CO_2 and thus add to the global CO_2 sink.

The estimated numbers of urban trees including street trees are given in Table 1 for some cities; many trees grow in these urban areas. The real numbers of urban trees are even higher than those reported here because these are only the trees registered by the corresponding local authorities. Also, many cities have set plans to increase the number of urban trees as an important element in their green infrastructure projects.

The number of trees in urban areas implies that besides buildings and other gray infrastructures, there is a considerable amount of “green obstacles”. Of course the effect of these green obstacles is different than that of buildings but still it modifies the near-surface turbulent and radiative exchange. This raises an important question: are urban trees studied in urban domains for wind effect by the wind engineering community so far? For this purpose, the authors performed a search for the word 'tree' in all the articles published in the Journal of Wind Engineering & Industrial Aerodynamics since 1980. The search included all the article’s fields (title, abstract, body, etc.). Similar words of tree are also used, such as 'trees' and 'vegetation'. The results are shown in Fig. 1 on a yearly basis. In total, only 6% of all articles published since 1980 include the term 'tree'. Out of them, only few articles have addressed the effect of trees in the core of the study as done by Mochida and Lun (2008) and Mochida et al. (2008).

In many studies of the wind flow and air quality in urban areas, especially those based on modeling, the tree effect is either implicitly considered in the subgrid scale parameterization (the surface roughness length, z_0) or is neglected altogether. This

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approximation is done mostly for two main reasons. The first reason is that explicitly resolving urban trees requires detailed information about the vegetation characteristics of the trees (e.g. leaf area density, height, crown diameter) as well as its exact location in the domain. The second reason is that modeling both the aerodynamic and the thermal effects of the interactions between trees and the surrounding air is a challenging task which inevitably involves wind speed reduction, turbulence dissipation due to drag forces from plant foliage elements as well as the radiation absorption and shading. However, approximating the effect from trees may lead to a high level of uncertainty, which should be considered in the analysis of the results.

However, some studies can be found in the literature to address the impacts of trees in street canyons on pollutant dispersion. These studies are mainly based on wind tunnel measurements (Buccolieri et al., 2009; Buccolieri et al., 2011; Gromke et al., 2008; Gromke and Ruck, 2007, 2008) and same on numerical modeling (Balczó et al., 2009). There are, however, numerical investigations of flows within or close to forests (Gross, 1987; Schlünzen et al., 2011b; Schlüter, 2006).

The current study aims to compare three approaches used to approximate the effect of urban trees: (1) neglecting the effect of trees (basic approach), (2) changing the surface roughness length (implicit approach) and (3) explicitly resolving trees (explicit approach). The focus of this study is the effect of trees on the flow. The objective of this comparison is to find out if there are differences in the simulation results in an attempt to answer the question raised in the title: should we care about including the effect of urban trees in the numerical simulation of urban areas?

The method used in this study is given in Section 2. The results of the three approaches are given in Section 3 and are discussed in Section 4.

Table 1
Number of street and park trees in urban areas of some cities. The normalization is done for the whole city area.

City	Street trees (tree/km^2)	Urban park trees (tree/km^2)
Hamburg[a]	250,000 (360)	660,000 (950)
Tokyo[b]	704,980 (320)	1,500,000 (681)
New York City[c]	592,130 (488)	5,212,000 (4295)

[a] Retrieved from: http://www.hamburg.de/hamburgs-stadtbaeume/ on 07.07.2014.
[b] Retrieved from: http://www.kensetsu.metro.tokyo.jp/kouen/gairojyu/hyoushi5/index.html on 07.07.2014.
[c] Retrieved from: http://www.nycgovparks.org/ on 07.07.2014.

2. Method

2.1. Microscale model

In this study the obstacle resolving microscale model MITRAS (Schlünzen et al., 2003) is used to simulate the wind field in a typical urban area. MITRAS is a 3-dimensional, non-hydrostatic, prognostic, numerical model for wind, temperature, humidity and concentrations within the obstacle layer (Salim et al., 2014a). MITRAS solves the three-dimensional Reynolds-Averaged Navier Stokes equations (URANS) with the k-ε model as turbulence closure. It resolves obstacles (buildings, trees, etc.) explicitly including overhanging obstacles (bridges, overpasses, wind turbines, or similar objects) to account for the aerodynamics and the thermodynamic effects including shading and heat transfer of such obstacles. It is capable of incorporating different domain sizes ranging horizontally between a few hundred meters (individual street canyons) and a few kilometers (suburb) and vertically from a few hundred meters to the depth of the troposphere. MITRAS includes Coriolis force effects, however, these are neglected in the current investigation. Model validations have been performed according to the Association of German Engineers (VDI) guidelines (VDI, 2005) for obstacle resolving micro-scale models (Grawe et al., 2013; Salim et al., 2014b).

2.2. Treatment of urban trees

The three approaches of the treatment of urban trees are shown in Fig. 2 and are described in the following subsections. The same meteorological conditions are used in each case. The simulation results of these three groups are used to quantitatively identify the impact of urban trees to highlight the foot print as well as the magnitude of such impacts.

2.2.1. Basic approach

In this approach the effect of urban trees is neglected altogether. The domain is simply simulated as if there was not a single tree in the domain. Although this approximation is extreme as it ignores all the green obstacles in the domain, it is used in most of the studies in the wind engineering community (Fig. 1). However, this approach can be typically used when trees or shrubs lose their leaves in some seasons (most commonly during autumn and winter) after the abscission process.

2.2.2. Implicit approach

The effect of urban trees is implicitly considered in the surface parameterization, using a representative value of the roughness length z_0, which is used in the wall function. This is done by allocating the equivalent vegetation surface cover class for the

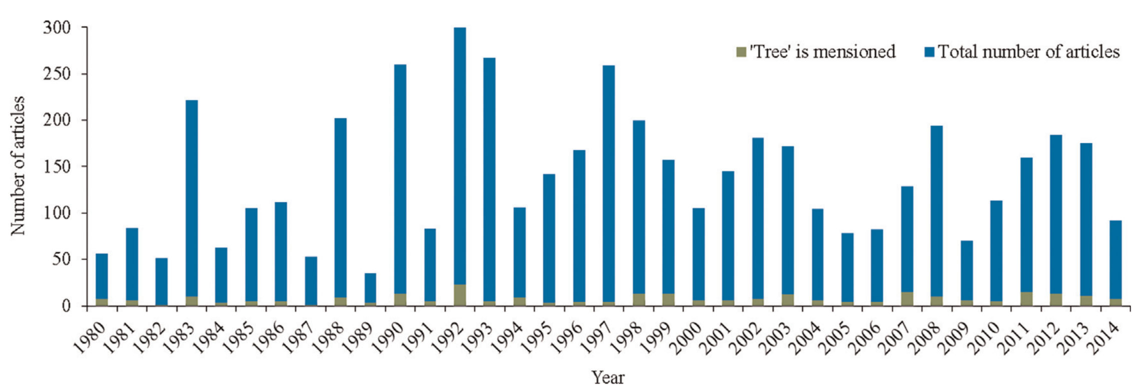

Fig. 1. Number of published articles in the Journal of Wind Engineering & Industrial Aerodynamics and those which include the term 'tree' in the time period from 01.01.1980 to 01.07.2014.