18th International Conference on
Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes
9-12 October 2017, Bologna, Italy

URBAN VEGETATION EFFECTS ON BLACK CARBON CONCENTRATION IN REAL SCENARIOS: CFD MODELLING AND EXPERIMENTAL MEASUREMENTS

J.L. Santiago[1], E. Rivas[1], F. Martin[1], R. Alonso[1], H. Calvete-Sogo[1], D. Elustondo[2], E. Baquero[3], M. Serrano[4]

[1] Atmospheric Pollution Division, Environmental Department, CIEMAT, Spain
[2] University of Navarra, Faculty of Sciences, Department of Chemistry, University Campus, 31080, Pamplona, Spain
[3] University of Navarra, Faculty of Sciences, Department of Environmental Biology, University Campus, 31080, Pamplona, Spain
[4] University of Navarra, School of Humanities and Social Sciences, Department of History, History of Art and Geography, University Campus, 31080, Pamplona, Spain

Abstract: This paper is aimed to study the impact of urban vegetation on air quality in an urban district of mid-sized town (Pamplona) in Northern Spain. Aerodynamic and deposition effects are investigated by means of experimental field campaigns and numerical CFD simulations in the framework of the LIFE+ RESPIRA project. In this paper, the results of experimental field campaigns and CFD simulations for the cases of streets with and without trees in the sidewalks are discussed. Aerodynamic effects are modelled by means of a sink momentum and sink/source of turbulent kinetic energy and its dissipation, while deposition is considered by means of a sink of pollutant concentration in the transport equation. The experimental data and CFD modelling results are compared and discussed. Finally, horizontal and vertical distributions of concentration within the streets are investigated in order to evaluate the effect of urban vegetation on air quality. Measurements of vertical profiles of wind speed and BC concentrations are reproduced by CFD simulations but these profiles are are not enough data to draw general conclusions about the effects of trees. However, from modelling results, it seems that the reduction of concentration due to pollutant deposition is relatively weak as compared with aerodynamic effetcs (perturbation of ventilation and transport of pollutants) but it depends of the case. More experimental campaigns and numerical studies in different scenarios are necessary to better understand the urban vegetation effects on air quality and to provide better information to urban planners.

Key words: *Urban air quality, urban vegetation, nature-based solution, CFD modelling, Black Carbon***.**

INTRODUCTION

One of the main objectives of LIFE+RESPIRA project, is to quantify the effects of urban vegetation on air quality in Pamplona (North of Spain) by using experimental data and numerical modelling. Urban vegetation affects air quality in two ways:

• Aerodynamic effects. Wind flow within streets is modified by trees, reducing in most of cases the ventilation of the street.

• Deposition effects. A fraction of pollutants is removed from air by means of deposition to tree leaves.

Aerodynamic effects usually have a negative impact on air quality; however pollutant concentration decreases due to deposition. Several recent modelling studies indicate that, in general, aerodynamic effects seem to be stronger than deposition, but more investigations in real scenarios are necessary.

In this study, the research is focused to analyze and discuss the results of experimental field campaigns and CFD simulations for the cases of streets with and without trees in the sidewalks are discussed. Black carbon (BC) was the selected pollutant as a good representative of the traffic pollution.

Concentrations are measured at different positions and height in order to quantify the ventilation in the street. These scenarios have been simulated by a CFD model taking into aerodynamic and deposition effects. The experimental data and CFD modelling results are compared and discussed. Finally, horizontal and vertical distributions of concentration within the streets are investigated in order to evaluate the effect of vegetation on air quality.

METHODOLOGY

Study area and experimental campaigns

The study area is a district of Pamplona´s city. The mean height of buildings is 25 m approximately (ranges from 11 m to 60 m). The extent of vegetation projected in a horizontal plane respect to the total plan area of streets and squares is 13.8%. The mean height of trees ranges from 5 m to 12 m.

The study is focused on black carbon (BC) dispersion in two parallel streets: one with trees (deciduous species mainly Aesculus hippocastanum) and other tree-less (white dashed lines in Fig. 1). One experimental campaign was carried out in the street with trees from 19th to 21st July. Horizontal wind speed and black carbon concentration (AethLabs microAeth® AE51) are measured at 3 different heights (Vedruna, red point in Fig. 1). The other campaign was done in the tree-less street from 26th July to 2nd August and the same variables were measured at three different heights (PC, blue point in Figure 1). In addition, meteorological measurements were obtained from a meteorological station (Pamplona-GN) outside of the district which are representative of general atmospheric conditions..

Figure 1. Study area. Red point: Vedruna location (street with trees); Blue point: PC location (street without trees)

Model description

CFD simulations are based on RANS equations with k-ε turbulence closure. Dynamic effects of trees are modelled by means of a sink of momentum and sinks/sources in turbulence equations. Deposition is represented by a mass sink in the transport equation proportional to leaf area density and deposition velocity (see more details in Santiago et al., 2017a and 2017b). The numerical domain, buildings, vegetation (green) and traffic emission zones (red) are shown in Figure 2. Emissions are considered proportional to the daily average traffic intensity of each street. High emissions are located at the main avenue in the North of the district (dashed line in Figure 2). The total number of grid cells is 7.4 x 106 with a resolution of 2 m approximately in the center of the district, with smaller cells (of about 1 m) close to buildings, ground, emissions and in the narrowest streets. Inlet wind direction is taken from hourly mean wind direction measured at Pamplona-GN station, and neutral inlet profiles of velocity, turbulent kinetic energy and dissipation are used.

Figure 2. Numerical domain. Green represents vegetation and red traffic emission zones. Red point: Vedruna location (street with trees); Blue point: PC location (street without trees)

MODEL EVALUATION

For each inlet wind direction (given by Pamplona-GN station), experimental and numerical results are compared. Measurements at sensors within the streets are hourly averaged. Horizontal wind speeds at sensors within the streets are normalized with wind speed at meteorological station. BC concentrations at sensors within the streets are normalized with concentrations measured at the lower level within the street. Results of comparison between model and measurements in both streets (one with trees and other without trees) are shown in Figures 3 and 4.

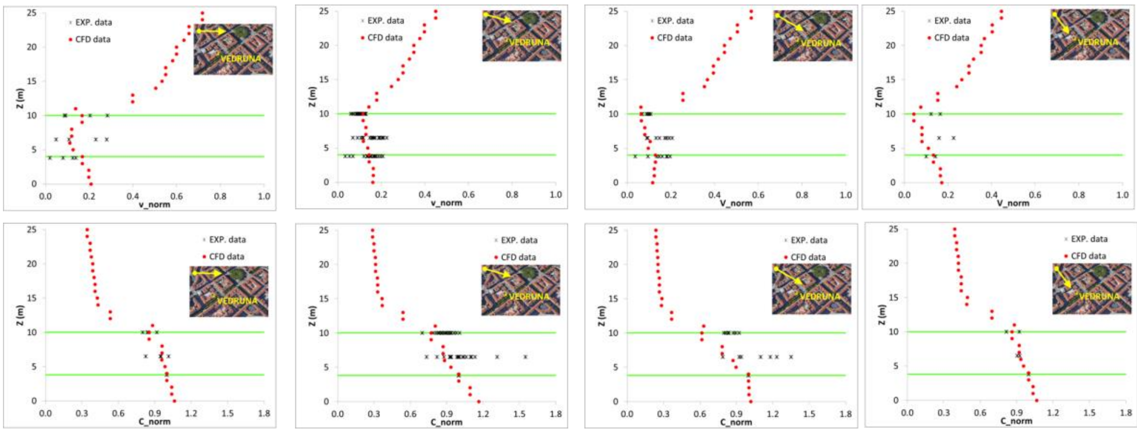

Figure 3. Experimental and modelled vertical profiles of normalized horizontal wind speed (top pannels) and BC concentrations (bottom pannels) for different inlet wind directions in the street with trees.

Experimental data within the streets shows a large variability of the normalized horizontal wind speed and concentration for the same meteorological conditions (wind direction). Vertical profiles obtained by CFD are within the experimental range of measurements. Therefore, horizontal wind speed and black carbon dispersion within streets seems to be suitable captured by the model. Due to the complex air flow patterns within the streets, the comparison of both streets with few local profiles seems to be insufficient to quantify the global effects of vegetation.

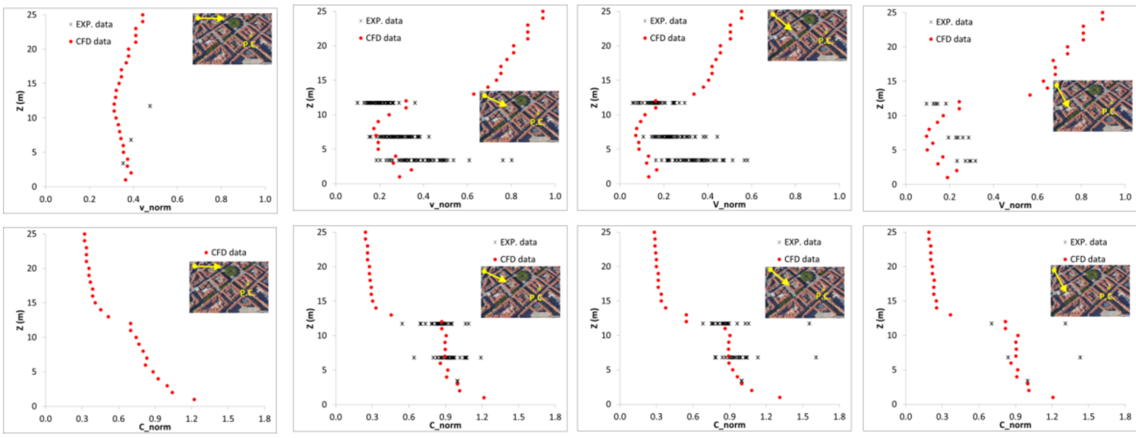

Figure 4. Experimental and modelled vertical profiles of normalized horizontal wind speed (top pannels) and BC concentrations (bottom pannels) for different inlet wind directions in the street without trees.

EFFECTS OF URBAN TREES ON BC DISPERSION

Modelling results are used to analyze vegetation effects on BC dispersion. Concentration maps are normalized, as in previous section, with the concentration at 3 m at Vedruna.

Maps at different heights for different wind directions (two wind directions are depicted in Figure 5) show that the variation of concentration with height is a local phenomenon (depends of the analyzed zone of the street). Therefore, it is difficult to draw general conclusions about real tree effects comparing both streets.

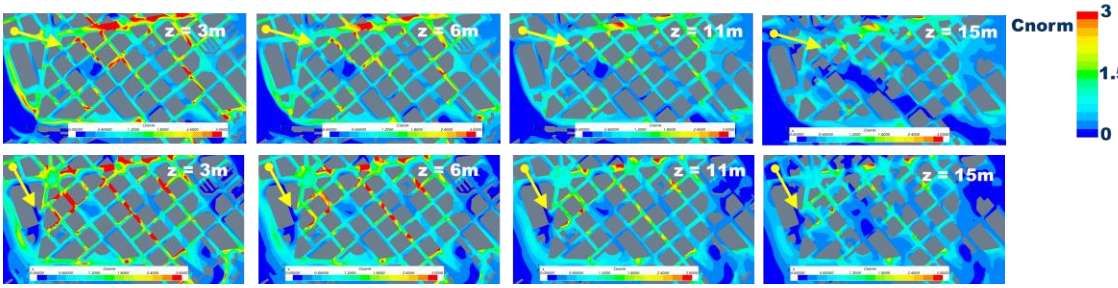

Figure 5. Normalized concentration at different heights above ground level (AGL) for WNW and NWN wind directions (above and below panels, respectively).

Aerodynamic effects

Trees not only reduces vertical transport of pollutants emitted by traffic inside the streets, but also modifies the horizontal transport of pollutants emitted from other streets. In this case, the horizontal transport of pollutants, specially from the main avenue in the North of the district, contributes significantly to the concentration within surrounding streets. For this reason, comparing a simulation considering trees with another without any tree in the district (Figure 6), the concentration in certain zones of a street with vegetation could increase in the case of no- trees due to the pollutants horizontally transported from other surrounding streets.

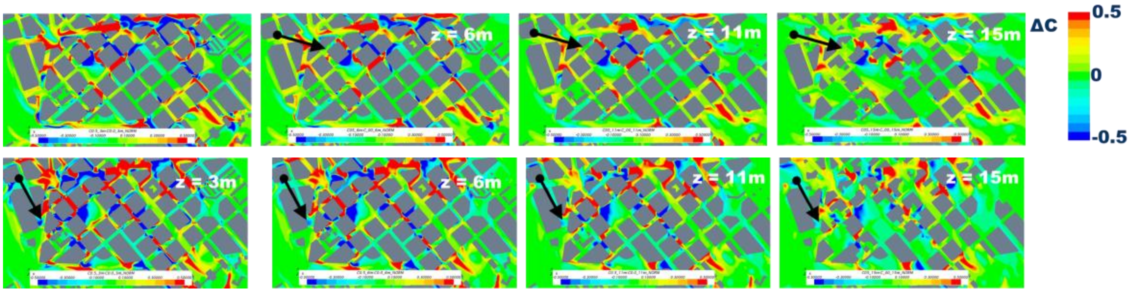

Figure 6. Differences of normalized concentration at different heights AGL between a simulation considering the aerodynamic effects of vegetation (no deposition) and a simulation without any vegetation in the domain for inlet wind direction from WNW (above) and NNW (below).

Deposition effects

Deposition effects are quantified comparing simulations with and without deposition of pollutants (Figure 7). The effects, at pedestrian level, are only significant in the vegetation of parks, but within the street is lower than 10%.

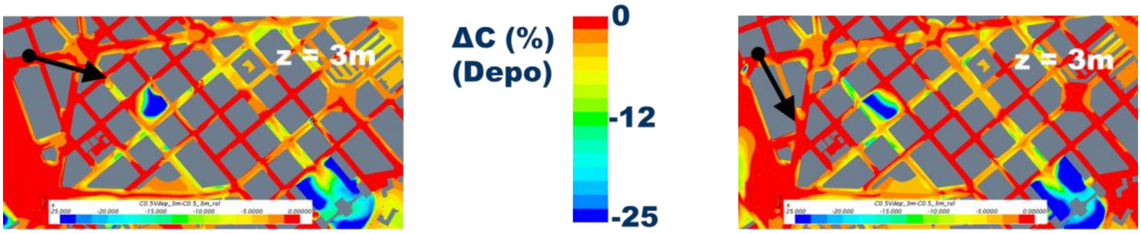

Figure 7. Relative differences of concentration due to deposition effects (deposition velocity = 1 cm s^{-1}).

CONCLUSIONS

The main findings of this study are:

1. CFD simulations reproduce experimental measurements of wind speed and BC concentrations.
2. Local concentration profiles inside the streets are not enough to draw global conclusions about the effects of trees. However, this experimental information is very important to evaluate numerical simulations.
3. Trees affect vertical and horizontal transport of pollutants, and both are important to determine the concentration at certain locations.
4. Reduction of concentration due to deposition is up to 10% within the streets.
5. More experimental campaigns and numerical studies in different scenarios are necessary to better understand the urban vegetation effects on air quality and to provide better information to urban planners.

ACKNOWLEDGEMENTS

This study has been supported by the project LIFE+ RESPIRA (LIFE13 ENV/ES/000417) funded by EU. Authors thank to CETA-CIEMAT by helping in using its computing facilities for simulations. CETA-CIEMAT belongs to CIEMAT and the Government of Spain and is funded by European Regional Development Fund (ERDF).

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