Urban vegetation effects on black carbon concentration in real scenarios: CFD modelling and experimental measurements

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OBJECTIVE

- One of the main objectives of LIFE+RESPIRA project, EU funded, is to quantify the effects of urban vegetation on air quality in Pamplona (North of Spain) by using experimental data and numerical modelling.
- This study aims to analyse the effects of trees located on the street on black carbon (a traffic-related pollutant) dispersion by means of **CFD simulations evaluated with measurements from two campaigns.**

STUDY AREA AND EXPERIMENTAL CAMPAIGNS

- The study area is a district of Pamplona (northern Spain). 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 treeless (white dashed lines in Fig. 1).
- Experimental campaigns were carried out from 19th to 21st July in the street with trees (*Vedruna*, red point in Fig. 1), and from 26th July to 2nd August in the treeless street (*PC*, blue point in Fig. 1). In both cases, horizontal wind speed and black carbon concentration (AethLabs microAeth® AE51) were measured at 3 different heights. In addition, meteorological data were obtained from a nearby meteorological station (*Pamplona-GN*), representative of general atmospheric conditions.

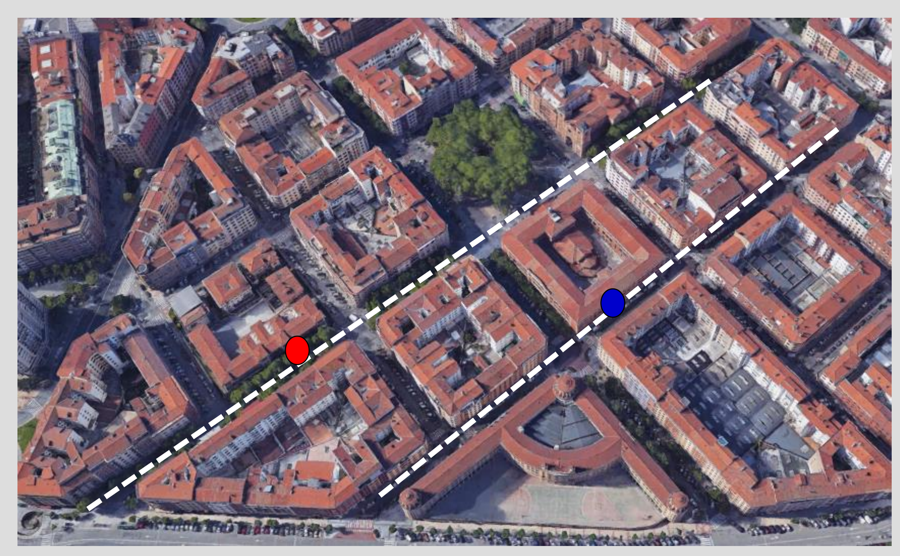

Fig. 1. Study area. Red point: Vedruna location (street with trees); Blue point: PC location (street tree-less)

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 Fig. 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 Fig. 2).
- The total number of grid cells is 7.4 x 10^6 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.

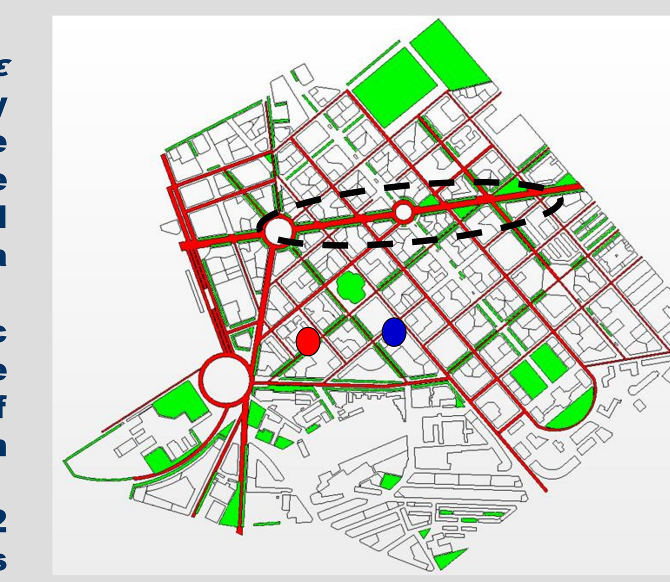

Fig. 2. Numerical domain. Green represents vegetation and red traffic emission zones.

MODEL EVALUATION

- For each inlet wind direction (given by *Pamplona-GN station*), experimental and numerical results are compared. In order to do this model evaluation:
  a) Measurements at sensors within the streets are hourly averaged.
  b) Wind speeds at sensors within the streets are normalized with wind speed at meteorological station.
  c) BC concentrations at sensors within the streets are normalized with concentrations measured at the lower level within the street.

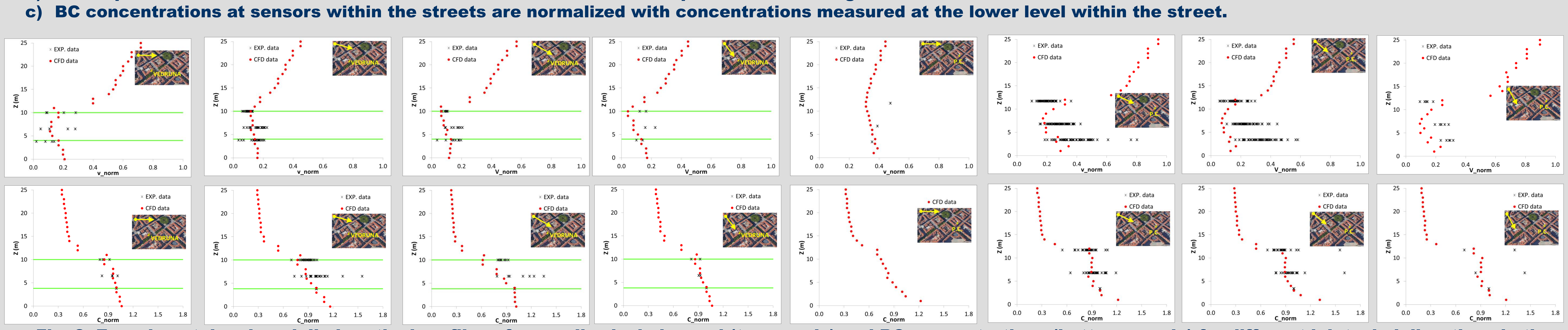

Fig. 3. Experimental and modelled vertical profiles of normalized wind speed (top panels) and BC concentrations (bottom panels) for different inlet wind directions in the two streets: with trees (left panels) and treeless (right panels).

- Experimental data within the streets shows a large variability of the normalized wind speed and concentration for the same meteorological conditions (wind direction).
- Vertical profiles obtained by CFD are within the experimental range of measurements. Therefore, 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.

EFFECTS OF URBAN TREES ON BC DISPERSION

·Modelling results are used to analyse 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 Fig. 4) show that the variation of concentration with height is a local phenomena (depends on the analyzed zone of the street). Therefore, it is difficult to draw general conclusions about real tree effects comparing both streets.

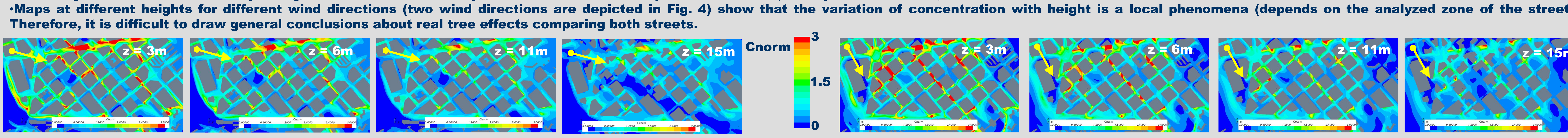

Fig. 4. Normalized concentration at different heights for WNW and NWN wind directions (left and right panels, respectively).

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, when we compare a simulation considering trees with another without any tree in the district (Fig. 5), 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.

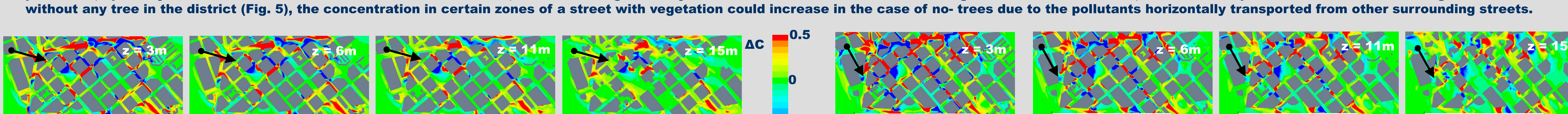

Fig. 5. Differences of normalized concentration at different heights between a simulation considering the aerodynamic effects of vegetation (no deposition) and a simulation without any vegetation in the domain.

Deposition effects

- Deposition effects are quantified comparing simulations with and without deposition of pollutants (Fig. 6). The effects, at pedestrian level, are only significant in the vegetation of parks, but within the street is lower than 10%.

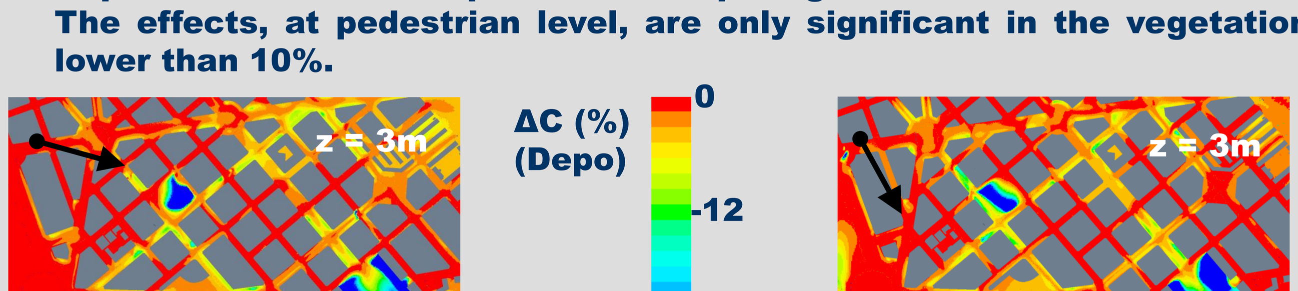

Fig. 6. Relative differences of concentration due to deposition effects (v_dep = 1 cm s-1).

CONCLUSIONS

- CFD simulations reproduce experimental measurements of wind speed and BC concentrations.
- 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.
- Trees affect vertical and horizontal transport of pollutants, and both are important to determine the concentration at certain locations.
- Reduction of concentration due to deposition is lower than 10% within the streets.
- 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.

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