Application of the PALM4U Model Coupled to WRF/Chem Model to Evaluate Wind Comfort and Air Pollution Impacts for Urban Scenarios

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Abstract. Air pollution and wind comfort are both important indicators of quality of life in urban environments. This study examines the influence of a tree area (Green Park) on the wind patterns and air pollution concentrations over a downtown urban area (1 km x 1 km) in Madrid (Spain) with the CFD PALM4U model (5 m spatial resolution) coupled with the WRF/Chem mesoscale chemical model. Two numerical experiments have been performed: a) with trees (BAU) and b) without trees (NOTREE) to investigate the impacts of trees on the wind patterns and air pollution concentrations. Nitrogen dioxide and ozone concentrations in the BAU scenario were compared with the values at the pollution monitoring station in the area to validate the simulations. The impacts (BAU-NOTREE) indicate that the pedestrian wind comfort and NO2 concentrations is greatly affected by the trees far away of the Green Park area. In some specific locations in the area the NO2 concentrations are found to increase up to 10% and in other locations, reductions of up to 20% are found. This results demonstrate the efficiency of using sophisticated CFD numerical models, such as PALM4U, for conducting air quality and micro-climate simulations in urban areas.

Keywords: PALM4U, CFD, wind and urban pollution

1. Introduction

Urban air pollution concentrations depend of the wind flows and their interactions with obstacles such us buildings (Chang & Meroney, 2003) that could reduce the ventilation (Du & Mak, 2018). Computational Fluid Dynamics (CFD) models are powerful modelling tools that allow us to reproduce the dispersion of pollutants, taking into account the realistic characteristics of urban environments. Trees are important elements influencing the dispersion of pollutants in the urban areas. In some reports, trees have been shown to be positive by decreasing pollutant concentrations (Pugh et al., 2012). However, trees can also increase concentrations in some street types by obstructing wind ventilation. In this study we analyse and quantify the positive and/or negative impacts of trees in the pedestrian wind comfort and NO2 concentrations.

2. Material and methods

The computational domain is 1000 m by 1000 m by 300 m in height with a 3D spatial grid resolution of 5 meters. The total area covered by trees represents 9.9% of the modelled area and the total area covered by buildings represents 43.9% of the modelled area, also the 1.4% of the area are water surface. The simulation period was established from June, 12th, 2017 to June, 19th, 2017. The CFD simulations were ran using the Parallelized Large-Eddy Simulation Model (PALM) adapted to urban areas (PALM4U) for atmospheric flows (Maronga et al., 2015) using the CBM-IV carbon mechanism (32 species and 81 chemical reactions). Initial and lateral boundary chemical and meteorological conditions were derived from a simulation with the Weather Research and Forecasting and Chemistry model (WRF/Chem) (Grell et al., 2005) with 1 km spatial resolution. The high spatial resolution emissions were estimated from the number of vehicles calculated with the microscale traffic model SUMO (Simulation of Urban Mobility) (Krajzewicz et al., 2012).

Two simulations were run. The first one, BAU (Business As Usual) simulation is the reference simulation where the trees were present. In this case the vegetation type in the CFD model is set to deciduous broadleaf trees (number 7 in the CFD model). The second one, NOTREE, the trees of the green area were removed and the land use in the CFD model was changed to "pavement". The CFD model in this version is using 4 land use types: pavement, building, water and vegetation type. The model uses 18 different vegetation types. The differences (BAU-NOTREE) show the impact of changing the trees by pavement in wind patterns and air pollution concentrations in all the area.

3. Results and conclusions

In the reference area, one pollution monitoring station is located near the Green Park. This station is not having meteorological observations however comparing the pollution concentrations from model and station provides an excellent refer-fence for the validation of our CFD simulation. Figure 1 shows daily average con-centration's of NO2, and O3 observed and modelled for the E. Aguirre monitoring site. In general terms, NO2 and O3 are slightly underestimated, NO2 7% and O3 24 % based on the statistical indicator Normalized Mean Bias (NMB). The squared hourly correlation coefficient for NO2 is 0.6 and for O3 is 0.7. These values are in the standard range for this type of simulations in the scientific literature. The preliminary perfomance evaluation report indicates that the BAU simulation for the NO2 and O3 dispersion with respect to the measured values in a specific location of the domain (5 m x 5 m where the monitoring station is located) is appropriate.

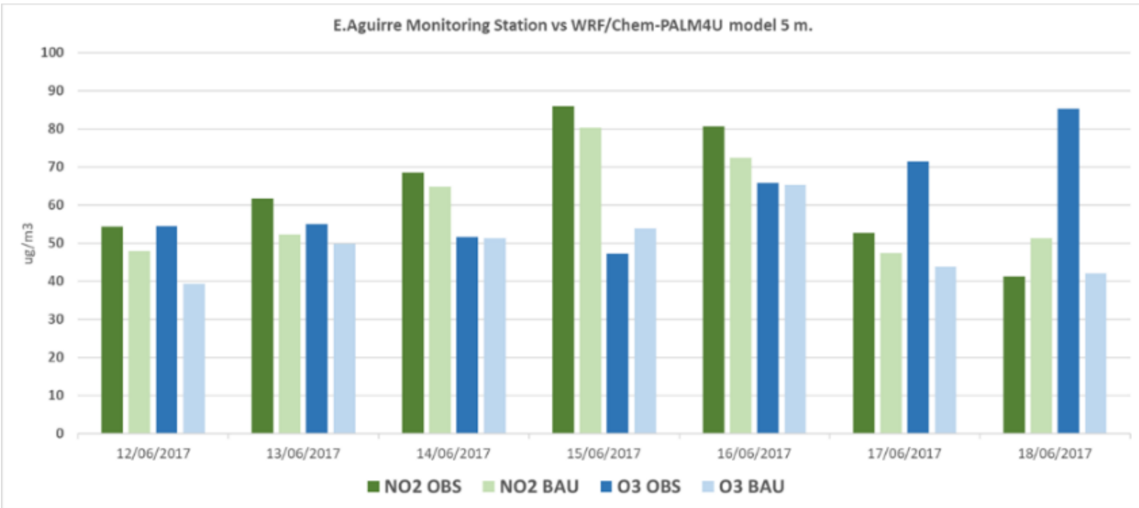

Figure 1. Daily average concentrations from 12/06/2017 to 18/06/2017 from E.Aguirre monitoring station and WRF/Chem-PALM4U results with 5 m. resolution.

Once BAU simulation is validated, the BAU and NOTREE simulations are used to evaluate the effects of trees. As an indicator of wind comfort we used the probability that a threshold of 5 m/s wind speed (P(WS>5) is exceeded following the criteria for wind comfort and danger in NEN 8100 (Willemsen & Wisse, 2007). Figure 2 shows the results for the BAU simulation and the effects (BAU-NOTREE) of the trees. There is a zone (upper-right corner) with strong winds (poor wind comfort) and in this zone there are taller buildings than in the rest of the domain. This is a clear factor to increase the wind at building pedestrian level. Figure 2 shows also the distributions of the effects of the trees on the P (WS>5). Trees not only decelerate the wind velocity around the trees area but also increase the wind velocity in some streets canyons far way of the tree area.

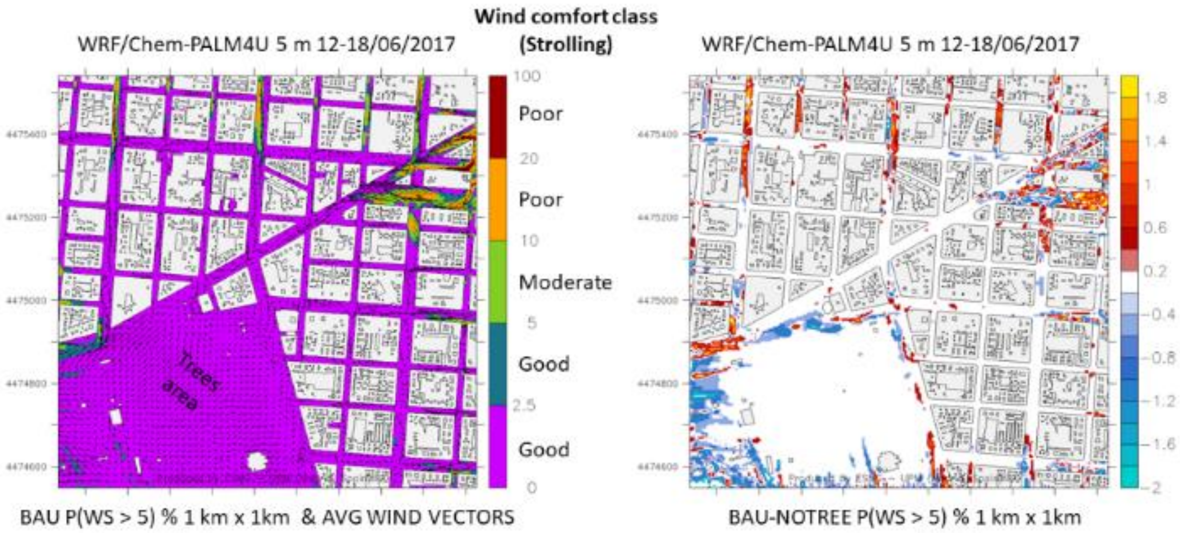

Figure 2. Probability of a wind velocity greater than 5 m/s (P WS>5) and the corresponding wind com-fort class (left). Changes (BAU-NOTREE) in the P (WS>5) produces by the trees area.

Figure 3 shows the spatial distribution of the 99.8 percentile (P98.9) of the hourly NO2 concentrations for BAU simulation, and the differences (BAU-NOTREE/BAU) between BAU and NOTREE simulation. P98.9 corresponds with the 19th highest hourly value of the weekly simulation and it is related with the hourly limit value of 200 µg/m3 which cannot be exceeded more than 18 times per year according to the EU air quality directive.

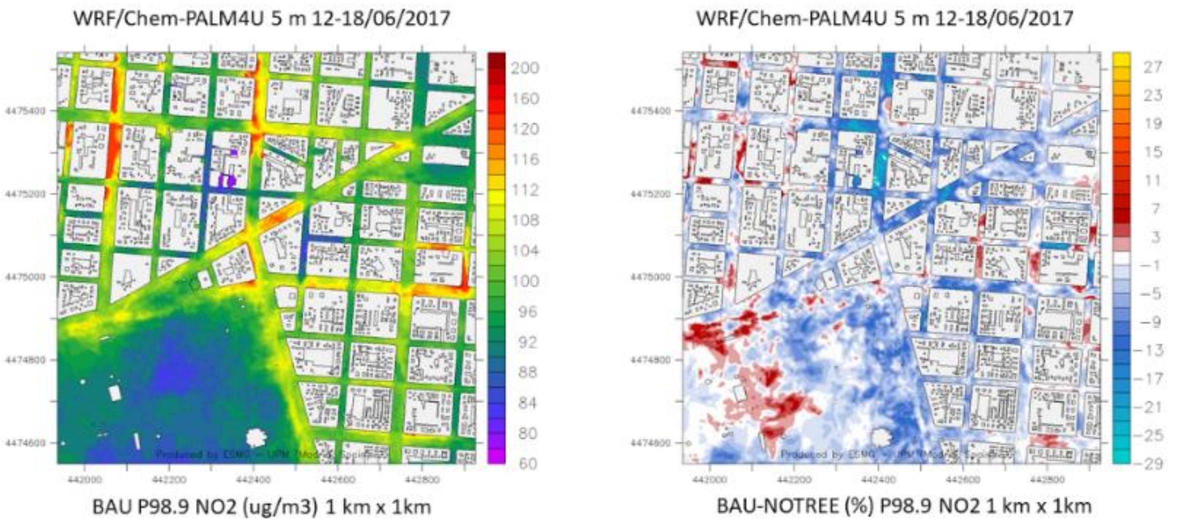

Figure 3. The 99.8 percentile of the NO2 hourly concentrations for BAU simulation (left) and the effects (%) of the trees in the P98.9 values (right).

NO2 concentrations differ from street to street, ranging from 60 to 200 µg/m3. The tree area has no direct traffic emissions and therefore has the lowest concentrations. It can be seen that several streets are on the limit of the EU directive of 200 µg/m3. The trees, in general terms, decrease the NO2 concentrations in most of the streets, although there is an area to the left of the tree zone where they cause a slight increase in pollution concentration by obstructing the ventilation of the pollution. The impacts of trees are very heterogeneous even within the same street. The contribution of trees on wind comfort and pollutant concentrations are studied from a CFD simulation results with the WRF/Chem-PALM4U modelling tool. The results show that trees can increase or decrease the pollutants concentrations and/or wind velocity so we need modeling tools to analyze effect of urban scenarios.
A robust and efficient simulation tool is required to visualize the wind patterns around buildings and air pollution concentrations. This results demonstrate the efficiency of using sophisticated CFD numerical models, such as PALM4U, for conducting air quality and micro-climate simulations in urban areas and to achieve a comprehensive evaluation of urban scenarios.

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