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Road Dust Emission Modelling

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Abstract: Atmospheric particulate matter (PM) is a well known risk to human health. Vehicular traffic is one of the major sources of particulates in an urban setting.

Here we study a problem of road dust dispersion. Using CFD solver based on RANS equations, we investigate the effect of a vegetation barrier on the concentration of airborne PM induced by road traffic. Simplified 2D model of a porous obstacle adjacent to a road source of PM2.5 and PM10 serves as an idealization of a real-world situation.

Introduction

Near road vegetation barriers have been suggested as a way to mitigate the particulate matter pollution in neighbouring areas. Its effectivity is influenced by a number of parameters: atmospheric conditions, properties of the particulates, vegetation type or its position (see eg. [1], [2] and references therein).

Here we set out to explore the effect of the wind speed on the barrier effectivity using simplified 2D model.

Numerical Model

Flow in the domain is modelled using equations of incompressible turbulent flow,

$$\frac{1}{\beta}\frac{\partial p'}{\partial t} + \nabla \cdot \boldsymbol{u} = 0, \tag{1}$$

$$\frac{\partial \boldsymbol{u}}{\partial t} + (\boldsymbol{u} \cdot \nabla)\boldsymbol{u} + \nabla(p'/\rho_0) = \nu_E \nabla^2 \boldsymbol{u} + \boldsymbol{g} + \boldsymbol{F}, \tag{2}$$

$$\frac{\partial \theta}{\partial t} + \nabla \cdot (\theta \boldsymbol{u}) = k/c_v \left(\nabla \cdot (1/\rho \nabla \theta)\right). \tag{3}$$

Here pressure and density are split into background component in hydrostatic balance and fluctuations, $p = p_0 + p'$ and $\rho = \rho_0 + \rho'$. Vector $\boldsymbol{u}$ stands for velocity, ν_E is the effective viscosity, $\nu_E = \nu + \nu_T$, $\boldsymbol{g}$ is the gravity term, $\boldsymbol{F}$ represent momentum sink due to the vegetation, θ is a potential temperature. Artificial compressibility with parameter β is utilized. Particulate matter C_i is modelled as passive scalar,

$$\frac{\partial \rho C_i}{\partial t} + \nabla \cdot (\rho C_i \boldsymbol{u}) - (\rho C_i u_s)_y = \nabla \cdot (D \nabla C_i) + \rho f_c. \tag{4}$$

Here u_s is settling velocity of the particle and f_c is the source term. Discretization is done by finite volume method, using numerical flux AUSM$^+$-up [3]. Algebraic mixing-length model according to [4] is used to account for the effects of turbulence.

Case settings

Computational domain is 300 m long and 150 m high. Four-lane road is modelled as four line sources of PM10 and PM2.5 particulates, placed at 23.125, 29.375, 35.625 and 41.875 m from the inlet at height 0.8 m. Intensity of each source is 1 mg/m/s for both PM10 and PM2.5. The vegetation barrier of length 30 m and height 15 m is located at 50 m from the inlet. Size of the computational grid is 300 x 120 cells.

All simulations were performed under assumption of weakly stably stratified atmosphere with inlet velocity according to log wind profile.

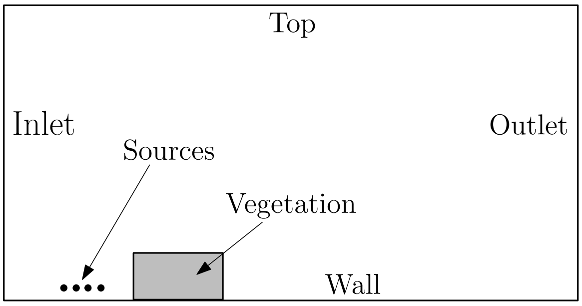

Fig. 1: Sketch of a computational domain.

Results

We investigated the effect of the wind speed on the effectiveness of the filtering by the vegetation block. Four scenarios with wind speeds of 2.5, 5.0, 7.5 and 10 m/s at the top of the domain were considered. For each scenario, two cases were computed - with and without the vegetation block.

In Fig. 2 following quantities of interest are shown: particle mass concentration at 250 m from the inlet at height of 2 m and 10 m for both cases without (C_F) and with vegetation (C_V). Their ratio C_V/C_F, describing the effectivity of the barrier, is shown as well.

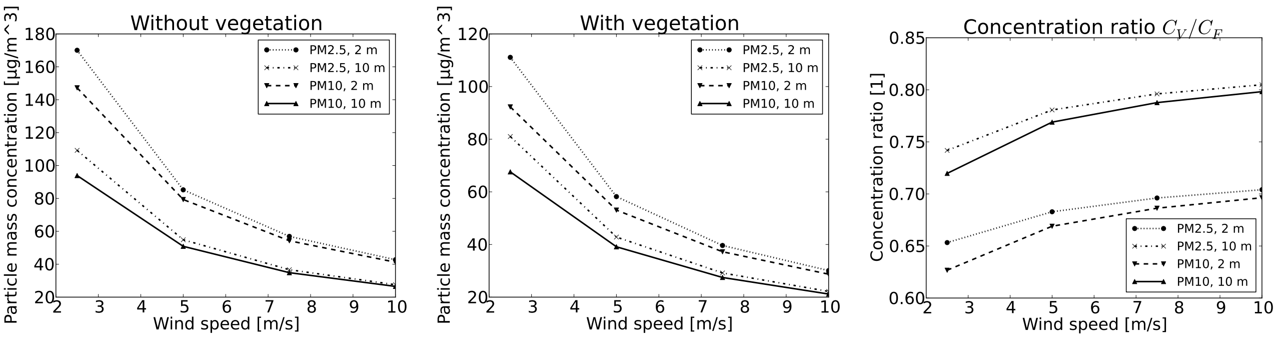

Fig. 2: Particle mass concentration at x = 250 m for case without (left) and with vegetation (middle), and their concentration ratio C_V/C_F (right).

Decreasing efficiency of the barrier with increasing wind speed is indicated by the results. Also, significantly lower effect of the barrier on the pollutant concentration higher above ground is apparent.

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