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Modelling of the Influence of Vegetative Barrier on Concentration of PM10 and PM2,5 from Highway

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Abstract: The influence of different types of the vegetative barrier near a highway on dustiness was studied. Transport, dispersion and sedimentation of pollutants PM10 and PM2.5 emitted from the highway was numerically simulated. Mathematical model was based on the Navier-Stokes equations for turbulent fluid flow in Boussinesq approximation. The AUSM-MUSCL scheme in finite volume formulation on structured ortogonal grid was used. The influence of the shape of the barrier and of its obstructing properties on the concentration of pollutants was studied.

Mathematical model

The air flow in atmospheric boundary layer is described by RANS (Reynolds Averaged Navier-Stokes) equations for the viscous, imcompressible, turbulent and stratified flow with variable density (in general). The system of equations is simplified with Boussinesq approximation, in 2D it is written:

$$\begin{aligned} \frac{\partial u_j}{\partial x_j} &= 0, \\ \frac{\partial \rho'}{\partial t} + \frac{\partial u_j \rho'}{\partial x_j} &= u_2 \frac{\partial \rho_0}{\partial x_2} \\ \frac{\partial u_i}{\partial t} + \frac{\partial u_j u_i}{\partial x_j} + \frac{1}{\rho_0}\frac{\partial p'}{\partial x_i} &= \frac{\partial}{\partial x_j}\nu\left(\frac{\partial u_i}{\partial x_j}\right) - \frac{\rho'}{\rho_0} g\delta_{i2} + T_i, \end{aligned} \tag{1}$$

where u_i ($i \in \{1, 2\}$) are velocity components, ρ' resp. p' are perturbations of density resp. pressure, ρ_0 is background density and T_i is the aerodynamic resistance of the barrier. The viscosity was composed from the molecular kinematic viscosity and the turbulent viscosity $\nu = \nu_m + \nu_T$. The turbulent viscosity was computed from Blackadar algebraic turbulent model (see [1], [2]).

The vegetative barrier was modelled by adding volume force T, which simulates the aerodynamic resistance caused by the vegetation:

$$T_i = r_h |U| u_i, \tag{2}$$

here $|U|$ is the velocity magnitude and r_h is an obstructing coefficient of the vegetative barrier (as in [3]). Different profiles and different values of these coefficients have been tested.

The contaminant is a non-hygroscopic, primary emitted dust which can be considered as passive scalar in the flow field. The transport of concentration c_i size fraction is described by:

$$\frac{\partial \rho c_i}{\partial t} + \frac{\partial(\rho u_1 c_i)}{\partial x_1} + \frac{\partial((\rho u_2 - v_{si})c_i)}{\partial x_2} = \frac{\partial}{\partial x_j} D\left(\frac{\partial c_i}{\partial x_j}\right) + Z_i, \tag{3}$$

where v_{si} denotes the sedimentation velocity, D is dispersion coefficient (turbulent in general) and Z_i is loss term due to the vegetation.

Numerical approximation and computational set up

The finite volume AUSM scheme was used for the inviscid terms with MUSCL velocity reconstruction and Hemker-Koren limiter. The inviscid terms was approximated by the central way on dual (diamond type) mesh. The resulting system of ODEs was integrated in physical time by a backward differentiation formula. The time discretization of the equations was done via artificial compressibility method in dual time. The suitable Runge-Kutta multi-stage scheme was used.

The computing domain was 300 × 150 m, the highway is situated in position $x_1 \in \langle 20, 45\rangle$ m. The vegetative barrier of height h = 15 m is located in position $x_1 \in \langle 50, 80\rangle$ m. Four dust sources were situated in the center of lanes.

Results and conclusions

First results for velocity field was obtained for simple obstructing coefficient profile:

$$r_h(z) = \begin{cases} r \, \frac{x_2/h}{0.75} & \text{for} \quad 0 \le x_2/h \le 0.75 \\ r \, \frac{1-x_2/h}{1-0.75} & \text{for} \quad 0.75 \le x_2/h \le 1.0. \end{cases} \tag{4}$$

Different constants $r \in \langle 0, 0.5\rangle$ and different heights $h \in \langle 0, 15\rangle$ m were tested .

Fig. 1 shows the influence of the vegetative barrier on the horizontal velocity field. The results were obtained for neutrally stratified atmosphere ($\frac{\partial \rho_0}{\partial x_2} = 0$) and for $r = 0.1$ resp. 0.3.

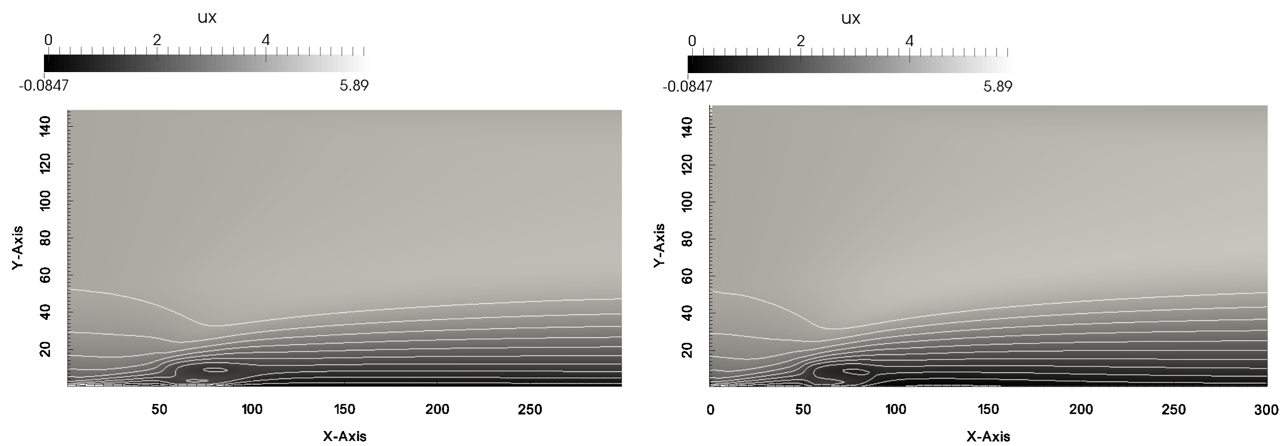

Fig. 1: Isolines of the horizontal velocity fields for $r = 0.1$ (right) and $r = 0.3$ (left)

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