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Application of the theory of contrast structures to describe the turbulent exchange at the forest edges

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An adequate description of the exchange processes different substances between spatially inhomogeneous forest vegetation with e.g. treefall gaps, clearing of different size and the atmosphere requires an accurate parameterization of the wind and turbulent at the forest boundaries (forest edges), as well as descriptions of exchanges processes within the vegetation cover. As an attempt to solve this problem, we developed a mathematical model of turbulent exchange based on the theory of "contrast structures" (CS).

CS is a function the graph of which has an interior layer. Some boundary value problems can have a solution in form of CS. The main advantage of the CS method is that it gives a possibility to find a stable stationary solution for the Navier-Stokes system of equations for the interior layer.

The developed 2D model was applied to describe the 2D wind vectors and turbulent coefficients at some typical forest edge and to analyse how the forest canopy with different structure (different tree height, density), different wind speed and wind direction can influence the spatial patterns of the modeled parameters.

We consider the system of equations in 2dimensional coordinate system - horizontal x and vertical z. According to our model the wind speed profile near the forest edge is described by a system of three differential equations: two momentum equations and the equation of continuity:

$$K_x \frac{\partial^2 u}{\partial x^2} + K_z \frac{\partial^2 u}{\partial z^2} - \frac{\partial u}{\partial t} = u\frac{\partial u}{\partial x} + w\frac{\partial u}{\partial z} + F_x, \quad K_x \frac{\partial^2 w}{\partial x^2} + K_z \frac{\partial^2 w}{\partial z^2} - \frac{\partial w}{\partial t} = u\frac{\partial w}{\partial x} + w\frac{\partial w}{\partial z} + F_z,$$

$$\frac{\partial u}{\partial x} = -\frac{\partial w}{\partial z}$$

in a rectangle $0 \leq x \leq 1000\,m,\ 0 \leq z \leq 100\,m$ over a period of time $0 \leq t \leq T$.

The boundary conditions at the borders are as follows:

$$\left.\frac{\partial u}{\partial x}\right|_{x=0,\, x=1000} = \left.\frac{\partial u}{\partial z}\right|_{z=100} = \left.\frac{\partial w}{\partial x}\right|_{x=0,\, x=1000} = \left.\frac{\partial w}{\partial z}\right|_{z=100} = 0 \quad ;$$

$$\left.u\right|_{z=0} = u_{init}\left(x\right), \quad \left.w\right|_{z=0} = w_{init}\left(x\right) \quad .$$

where u and w are horizontal and vertical components of the wind speed, respectively, K_x and K_z- turbulence coefficients, F_x and F_z are some nonlinear functions of pressure gradient, change of air density and the drag coefficients of vegetation. In our study we set them as continuous functions of the coordinates and the wind speed components so that the solution of the boundary value problem had interior layers in the vicinity of the plane $x = 500m$.

Results of modeling experiments indicates that an implementation of the CS theory in our model allows to describe adequately the turbulent exchange within and above a non-uniform forest canopy using the minimum number of equations.

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