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Application of a two-dimensional hydrodynamic model for calculating the CO_2 and H_2O fluxes over complex terrain

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Within the framework of the study a two dimensional hydrodynamic model of turbulent transfer of greenhouse gases was developed and applied for calculating the CO_2 and H_2O turbulent fluxes within the atmospheric surface layer over the heterogeneous land surface with mosaic vegetation and complex topography. The vegetation cover in the model is represented as the two-phase medium containing the elements of vegetation and the air.

The model is based on solving the system of averaged Navier-Stokes and continuity equations for the wind velocity components ($\vec{V} = \{V_1, V_2\}$), using the 1.5-order closure scheme (Wilcox 1998, Wyngaard 2010). The system of the main equations includes also the diffusion and advection equations for turbulent transfer of sensible heat, CO_2 concentration (C_s) and specific humidity (q) at soil - vegetation -atmosphere interface (Sogachev, Panferov 2006, Mukhartova et al. 2015, Mamkin et al. 2016):

$$\frac{\partial V_i}{\partial t} + \left(\vec{V}, \nabla\right) V_i = -\frac{1}{\rho_0} \cdot \frac{\partial}{\partial x_i} \delta P - \frac{\partial}{\partial x_j} \left\{ \frac{2}{3} \delta_{ij} \bar{e} - K \cdot \left(\frac{\partial V_i}{\partial x_j} + \frac{\partial V_j}{\partial x_i} \right) \right\} + g \cdot \frac{\delta T_v}{T_0} + F_i, \quad i, j = 1, 2,$$

$$div \vec{V} = 0,$$

$$\frac{\partial T}{\partial t} + \left(\vec{V}, \nabla\right) T + \gamma_a \cdot \frac{T_v}{T_0} \cdot V_2 = div\left(K_T \cdot \nabla T\right) + \frac{\gamma_a}{T_0} \cdot K_T \cdot \frac{\partial T}{\partial x_2} + \frac{1}{\rho_0 c_p} \left(\vec{V}, \nabla\right) \delta P - \frac{H}{\rho_0 c_p},$$

$$\frac{\partial C_s}{\partial t} + \left(\vec{V}, \nabla\right) C_s = div\left(K_C \cdot \nabla C_s\right) + F_C, \quad \frac{\partial q}{\partial t} + \left(\vec{V}, \nabla\right) q = div\left(K_v \cdot \nabla q\right) + \frac{E}{\rho},$$

where x_1, x_2 – horizontal and vertical coordinates respectively, ρ_0 – the density of dry air, δP – the deviation of mean air pressure from the hydrostatic distribution, $\bar{e}$ – the turbulent kinetic energy, T – the temperature of the air, $\delta T_v = T \cdot (1 + 0.61q) - T_0$ – the deviation of virtual temperature from the adiabatic temperature $T_0\,(x_2)$ for dry air, F_i – the components of the viscous drag forces induced by the presence of vegetation, K, K_T, K_C, K_v – turbulent exchange coefficients for momentum, sensible heat, $CO_2$and H_2O respectively, $\gamma_a = g/c_p$, c_p – the specific heat of the air at constant atmospheric pressure, F_C – the sources/sinks of CO_2in vegetation, H – sensible heat flux, E – evaporation rate.

For the numerical solution of the corresponding initial-boundary problem the efficient finite-difference scheme, based on the splitting for processes, was developed.

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