Geophysical Research Abstracts
Vol. 20, EGU2018-3513, 2018
EGU General Assembly 2018

Effects of vegetation heterogeneity on turbulent exchange within the atmospheric surface layer – results of numerical experiments

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Experimental and modeling studies of the possible influence of spatial land surface heterogeneity (vegetation, topography) on turbulent exchange within the atmospheric surface layer are very important in respect of the demand to accurately describe the energy and gas (passive and reactive) components exchange between land surface and the atmosphere. A world-wide used eddy covariance approach for continuous flux measurements is based on numerous assumptions including horizontal and uniform terrain (vegetation, topography), negligible density fluctuation, air flow divergence and convergence, etc. (Burba, Anderson, 2010). It is obvious that any flux measurements over heterogeneous surface can result in large uncertainties in flux estimations.

Within the frameworks of this modeling study the series of numerical experiments were provided to describe the process of the air flow settling after its interaction with some obstacles (e.g. forest edge). We analyzed the distances from the surface obstacle when the horizontal gradient of e.g. vertical wind component, turbulent exchange coefficient, kinetic energy at some height above vegetation cover are insignificant or lower than some threshold values. For numerical experiments the two-dimensional model based on solution of the Navier-Stokes and continuity equations using the one-and-a-half order closure scheme (Garratt 1992, Panferov and Sogachev 2008) was applied. In respect to the previous model version (Mukhartova et al. 2015) the present model allows to take into account the air density fluctuations caused by the air flow interaction with surface obstacles. Using the known relation between pressure and density of the air, the linear dependence of the density deviation from some constant value ($\delta\rho$) on the pressure deviation from hydrostatic value (δp) was assumed. The refined averaged continuity and Navier - Stokes equations can be written as:

$$\frac{\partial}{\partial x_i}\left(\overline{\rho}\cdot V_i\right)=0,\quad \overline{\rho}\left(\frac{\partial V_j}{\partial t}+V_i\frac{\partial V_j}{\partial x_i}\right)+\frac{\partial}{\partial x_i}\left(\overline{\rho}\cdot\overline{v_i'v_j'}\right)+\frac{\partial}{\partial x_i}\left(\overline{\delta\rho'\cdot v_i'v_j'}\right)=-\frac{\partial}{\partial x_j}\delta P+F_j,$$

where $v_i=V_i+v_i'$ are the wind velocity components, $\overline{\rho}=\rho_0+\overline{\delta\rho}$ is the mean air density, $\delta\rho=\overline{\delta\rho}+\delta\rho'$ is the deviation of the air density from the value ρ_0, δP is the excess pressure, F_j are the components of vegetation resistance force. The additional terms, containing velocity and density covariance, need to be parameterized using the high order closure schemes.

The results of numerical experiments showed that the air flow disturbances at the forest edge are manifested at a long distance from the forest edge depending on the height and density of forest canopy, mean wind velocity, and many other factors. Such distances have to be taken into account for selecting the flux tower locations with minimal boundaries effects.

This study was supported by grants of the Russian Science Foundation (Grant 14-14-00956).