Mathematical modeling of the effects of vegetation heterogeneity and complex topography on turbulent exchange of GHG within the atmospheric surface layer

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Accurate projection of the possible changes of climate conditions in future requires adequate parameterizations of the land surface-atmosphere interaction and fluxes of GHG at the land surface - atmosphere interface. One of the key topics of the modern studies of land surface - atmosphere interaction is an estimation of effects of land surface heterogeneity (topography, vegetation) on atmospheric fluxes (H_2O, CO_2 and other GHG). Most of existed modeling approaches are based on assumption describing the land-surface as a horizontally uniform layer. A world-wide used eddy covariance approach for continuous flux measurements is also 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 framework of the study 2D and 3D models allowing for effects of surface topography and vegetation heterogeneity were developed and stable finite-difference schemes for a numerical solution of the corresponding initial-boundary value problems were suggested. The initial-boundary value problem includes the system of averaged Navier-Stokes equation, continuity equation, two equations for turbulent kinetic energy and the rate of its dissipation, and the diffusion-advective equation for gas concentration. The problem is solved in the domain with a curvilinear lower boundary that simulates the surface topography. The conversion of variables is made to transform the calculation domain into some rectangle (in 2D case) or parallelepiped (in 3D case). As the result of this variable conversion the additional terms, containing mixed derivatives, were appeared. The proposed finite-difference scheme is based on the method of splitting by processes that leads to two auxiliary problems: the Poisson equation for excess pressure and diffusion-advection type equations for all other functions. For their numerical solution the stable algorithms, based on matrix sweep method and implicit schemes, were developed. The results of numerical experiments with developed model showed that the influence of non-uniform surface topography on atmospheric fluxes within the atmospheric surface layer is relatively large. It is depended on surface slope and elevation range and can exceed observed effects of spatial vegetation heterogeneity. Over a hilly area with a mosaic vegetation cover ignoring the horizontal advection, disturbances in the wind field that appear at surface topography irregularities, and boundaries between different vegetation communities can lead under summer conditions to circa 26% underestimation of the total CO_2 flux. To derive the surface heterogeneity on atmospheric fluxes we provided a series of additional experiments 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 and kinetic energy at some height above vegetation cover are insignificant or lower than some threshold values. In particular, our numerical simulation showed that the air flow settling after crossing the forest edge (forest of 20 m height) takes place at the distance of circa 400-500 m from the forest edge. Lower distances can results in significant uncertainties in flux estimations using e.g. eddy covariance technique. This study was supported by grants of the Russian Science Foundation (Grant 14-14-00956).

Keywords: turbulent exchange of GHG , atmospheric surface layer, surface heterogeneity

