Effects of clear-cutting on carbon dioxide fluxes in a boreal forest ecosystem - results of numerical experiments with a three-dimensional turbulent exchange model

Yulia Mukhartova[3], Maria Dyachenko[3], Polina Mangura[3], Alexander Krupenko[3], *Alexander Olchev[1,2]

1. Faculty of Geography, Lomonosov Moscow State University, 2. A.N. Severtsov Institute of Ecology and Evolution, Russian Academy of Sciences, 3. Faculty of Physics, Lomonosov Moscow State University

To estimate the possible effects of clear-cutting on the air flow disturbances within the atmospheric surface layer as well as on the spatial patterns of vertical carbon dioxide (CO2) fluxes and horizontal advection terms within and around the clear-cut area a process-based three-dimensional (3D) hydrodynamic momentum, energy and CO2 exchange model was developed. Clear-cutting is one of the most widespread logging practice, which can substantially transform the energy, water vapor and CO2 exchange between forest ecosystems and atmosphere and affect the climate system at multiple scales. Developed 3D hydrodynamic model is based on a 1.5-order closure scheme and uses a system of averaged Navier-Stokes and continuity equations for the mean wind speed components, as well as the reaction-advection-diffusion equation for CO2 transfer within the atmospheric surface layer (Mukhartova et al. 2015). The model applies Reynolds's decomposition and expresses the wind speed and concentrations of CO2 as sums of their mean values and deviations. The 1.5-closure scheme assumes that the turbulent fluxes can be expressed using the turbulent exchange coefficients (that depend on turbulent kinetic energy and its dissipation rate) and the gradients of corresponding functions (wind speed components and CO2 concentrations).
The clear-cut area selected for the study is situated in the south-western part of Valdai Hills in European Russia. The area of the clear-cut is about 4.5 ha and it is surrounded by a mixed forest stand represented mainly by Norway spruce, White birch and Eurasian aspen species with tree heights ranged between 18 and 22 m (Mamkin et al. 2016, 2019). The vegetation at the clear-cut area is mainly represented by herbaceous species and a small number of juvenile aspen trees.
Results of numerical experiments with the developed 3D model showed that clear-cutting has significant effect on spatial distributions of wind speed components as well as atmospheric momentum and CO2 fluxes. Spatial flux heterogeneity is also enhanced by complex shape of the clear-cut boundary. The largest effect of the clear-cut on the air flows is mainly appeared along the windward forest edge whereas at the leeward forest edge this effect is less pronounced. The leeward part of the clear-cut is characterized by prevailed downward air flows (with negative values of vertical wind component) whereas the upward air flows (with prevailed positive values of vertical wind component) are appeared at its windward part. It is very important to point out that the horizontal gradients of vertical and horizontal wind velocities at the lowest part of the atmospheric surface layer (up to the height 3-4 m above the ground surface) as well as horizontal turbulent and non-turbulent CO2 advection terms in the central part of the clear-cut is relatively small that can be used as important criteria indicating sufficient reestablishing of the air flow in this part of the clear-cut after its disturbance at the leeward forest edge.

Reference

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