A modelling study of the effects of species composition changes on radiation, H_2O and CO_2 fluxes in a boreal forest ecosystem

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Climatic changes may have significant impacts on forest ecosystems. They can result in changes of tree species composition, forest productivity and soil carbon sequestration. A global warming which is expected to be particularly large at higher latitudes will affect boreal forests probably more strongly than forests in other latitudinal zones (e.g. IPCC 2001, 2007). It can be expected that the greatest changes may occur at the southern boundary of the boreal forest zone, where the boreal coniferous forest is likely to give way to broadleaf species. How such vegetation changes will affect water and CO_2 budgets of land surface at this area is not known yet.

Objectives:

The main goal of this study to estimate effects of species composition changes on evapotranspiration and Net Ecosystem Exchange (NEE) of CO_2 in boreal forest ecosystems using one- and three-dimensional SVAT (Soil – Vegetation – Atmosphere Transfer) models (Mixfor-SVAT, Mixfor-3D) (e.g. Oltchev et al. 2007). Key scientific questions of this study are to estimate: (*i*) How sensitive are evapotranspiration and NEE of CO_2 of boreal forest ecosystems to changes of tree species composition, and (*ii*) How will the main components of the water and CO_2 balances be changed if due to global warming spruce trees will be replaced by deciduous tree species? In order to describe a sensitivity of the evapotranspiration and NEE of CO_2 to species composition in a forest stand, the fluxes were modelled for a forest stands with different proportions of spruce and broadleaf trees (Fig. 1). Pure spruce forest stand was classified in our study as a reference. As input meteorological parameters in our modelling experiments the measured meteorological air temperature, humidity, wind speed, precipitation rate and global solar radiation data for one year test period were used.

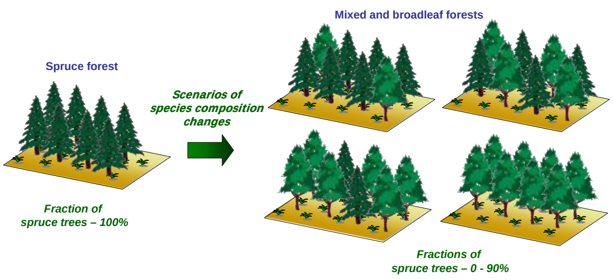

Fig. 1: *The main scenarios of model experiments.*

Model descriptions:

A 1D multi-layer process-based MixFor-SVAT model was developed to describe the turbulent energy, water and CO_2 exchanges within and above mono- or multi-specific forest stands (Olchev et al. 2002, 2008). The main concept used in Mixfor-SVAT is an aggregated description of the physical and biological processes on different spatial scales of a forest ecosystem: from individual leaf, canopy sub-layer and individual tree to entire ecosystem. The vertical H_2O and CO_2 fluxes are calculated taking into account transpiration, root water uptake, photosynthesis and respiration of different tree species in the forest stand, as well as evaporation and respiration of the soil and dead biomass respirations (Fig. 4). The main advantages of Mixfor-SVAT over the other 1D SVAT models are ability to describe the multi-species structure of a forest canopy and to quantify the flux partitioning among different tree species.

A more sophisticated 3D SVAT model Mixfor-3D is focused to quantify micro-scale effects of forest stand heterogeneity on radiation, temperature, H_2O and CO_2 regimes of the forest canopy and soil. It has a very high grid cell resolution ($2m \times 2m \times 1m$) that allow to describe the spatial variability of microclimatic conditions within the forest stand and to estimate contribution of each individual tree to total ecosystem fluxes.

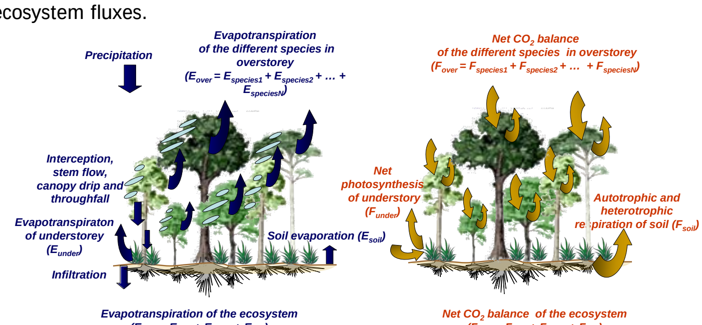

Fig. 4: *H_2O and CO_2 fluxes between a multi-species forest ecosystem and the atmosphere described by the SVAT models.*

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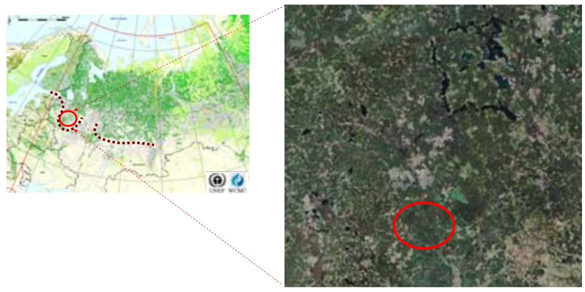

Fig. 2: *Geographical location of a study area in the Central Forest Biosphere Reserve (red cycles). Braun dotted lines in the left map show a smoothed boundary between forest zones with dominating coniferous and deciduous tree species.*

Experimental site:

The area selected for the modelling study is located in the Central Forest Biosphere Reserve CFBR (56°30'N, 32°50'E) in the southern part of Valday hills in Russia at watershed of two large European rivers: Volga and Daugava (Fig. 2). Relief of the area is characterized by relatively flat topography with gentle slope that doesn't usually exceed 2-4°. Area elevation is vary between 230 and 270 meters above a see level. High precipitation amount and peat and clay soils with low hydraulic conductivity result in soil overmoistening and local swamping of the area. Vegetation cover of the CFBR is very heterogeneous. It is represented by different forest types including both typical boreal forest communities and secondary mixed and deciduous forest stands (Fig. 3).

Fig. 3: *Forest stands at a study area in the Central Forest Biosphere Reserve.*

Results:

Results of modelling experiments showed that changes of species composition in a boreal forest stand may have significant effects on evapotranspiration, transpiration, GPP and NEE of CO_2. The main influencing factors are: different rates of transpirations and photosynthesis for coniferous and broadleaf species and different duration of their vegetation periods. Moreover, dynamics of H_2O and CO_2 fluxes for the forest stands are strongly depended on local environmental and weather conditions, soil and vegetation properties. Annual evapotranspiration, transpiration, GPP and NEE of CO_2 of a broadleaf forest is actually higher than in a monospecific spruce forest stand. At the same time, evapotranspiration and transpiration of a mixed forest is some higher than even in a broadleaf forest. On the other hand, NEE of CO_2 of mixed forest some smaller than in both monospecific spruce and broadleaf forest stands. Species composition changes may results in increase by up to 11% of annual evapotranspiration, by up to 14% of annual transpiration, by up to 13 % of annual GPP. Moreover, it may results in both decrease by about 4% and increase by up to 6% of annual NEE of CO_2 (Fig. 5).

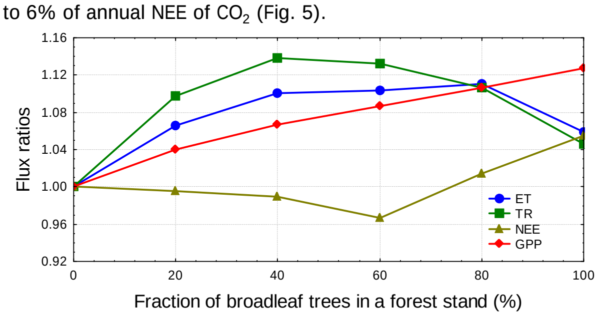

Fig. 5: *The ratios between annual NEEs (NEEyear), GPPs (GPPyear), evapotranspirations (ETyear) and transpirations (TRyear) of a forest stand with different admixture of broadleaf tree species and a monospecific spruce forest plotted as a function of the fraction (%) of broadleaf tree species in the forest stand.*