Carbon dioxide and water budget of boreal forest ecosystems of the South-European Taiga: results of field measurements and modelling experiments .

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The main goal of this study is to quantify the energy, water and carbon budgets of a boreal forest area at the Upper Volga region (about 3412 km^2 between 56°20'-57°20'N and 32°00'-33°20'E) in Russia (Fig. 1) at local and regional scales using field measurements and model estimations. The H_2O and CO_2 fluxes were described by eddy-covariance flux measurements (at several experimental sites) and using local-scale Mixfor-SVAT and regional-scale SVAT-Regio models.
Continuous eddy-covariance flux measurements were carried out in two spruce forest stands in the Central Forest Biosphere Reserve continuously since 1998 (Fig. 2). Equipment for EC measurements was installed in meteorological towers and includes of 3D-ultrasonic anemometer (Gill Solent, UK) combined with a close-path H_2O/CO_2 analyser LI-6262 (Li-Cor, USA).

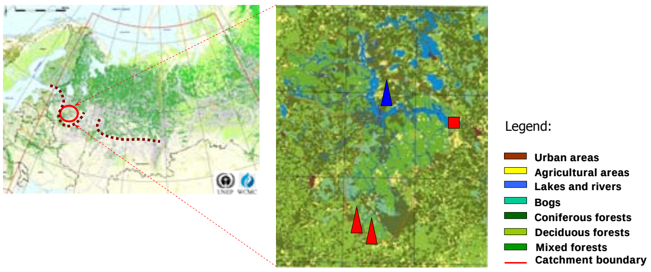

Fig. 1: *Geographical location of a study area in the Upper Volga region and positions of experimental sites (present and former) for long-term EC flux (triangles) and runoff (square) measurements.*

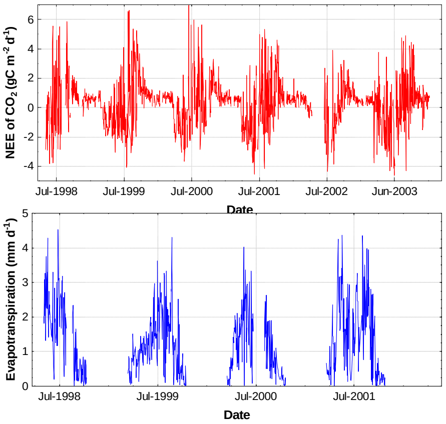

***Fig. 2:** Examples of annual variability of NEE of CO_2 and evapotranspiration in a spruce forest ecosystem in the Central Forest Biosphere Reserve (Nelidovo) measured by Eddy Covariance technique.*

An one-dimensional multi-layer process-based MixFor-SVAT model was developed to describe the turbulent energy, water and CO_2 exchanges within and above mono-specific and mixed (both coniferous and deciduous) forest stands. In our study it was used: to fill out missing EC data as well as EC data observed during the period with weak turbulent exchange; to describe the flux partitioning (different tree species and canopy layers) within a forest stand; and to quantify possible response of entire forest ecosystem and different tree species to environmental changes and especially to anomalous weather conditions. Model was tested against field data at different experimental sites and showed well agreement (Olchev et al., 1996, 2002, 2006; Vygodskaya et al. 2004). The main advantage of Mixfor-SVAT is ability to describe the multi-species structure of forest canopy (Fig. 3) and to quantify accurately the flux partitioning among different species using 1D modelling approach, only (Fig. 4).

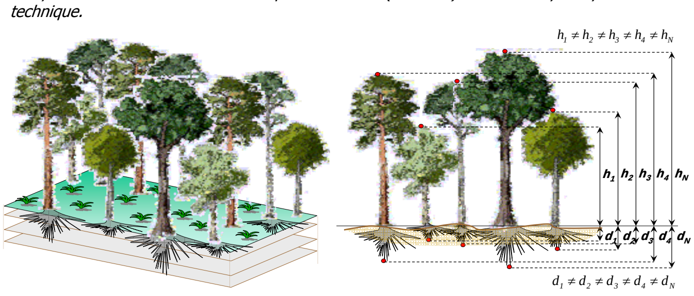

Fig. 3: *Representation of different tree species within a mixed tree stand. It is assumed that different tree species can have a different height, crown structure, stem diameter, root structure and depth.*

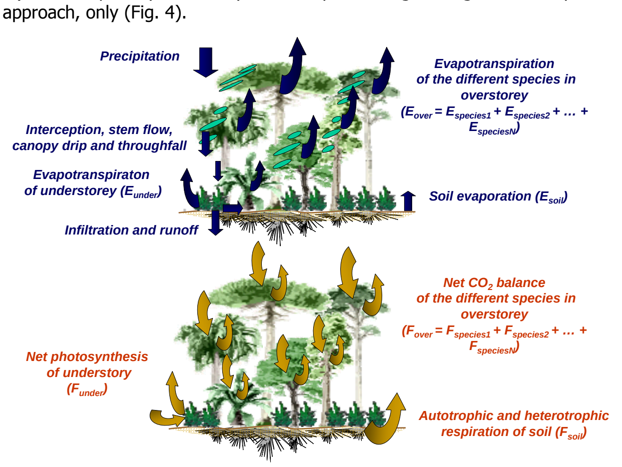

***Fig. 4:** H_2O and CO_2 fluxes between multi-species forest ecosystem and the atmosphere described by the MixFor-SVAT model.*

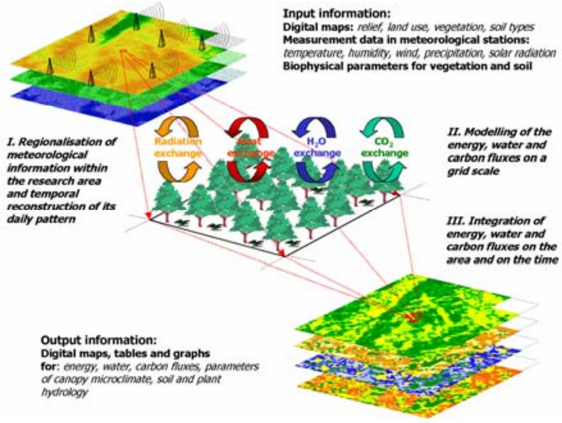

Fig. 5: *The main scheme of the energy, water and carbon dioxide flux simulations in the SVAT-Regio model.*

The regional SVAT model SVAT-Regio was used to describe the spatial patterns of the energy, H_2O- and CO_2 fluxes in regional (catchment) scale (the Upper Volga area). The main concept used in the SVAT-Regio model is aggregated description of energy, H_2O- and CO_2-exchanges in different scales from canopy (leaf, plant/tree, ecosystem) levels to entire landscape (Oltchev et al. 2002, 2006). Multi-layer representation of plant canopy and soil allows to couple the penetration of solar radiation within a plant canopy, the turbulent transfer of sensible heat, H_2O and CO_2 between soil, canopy and the atmosphere, the canopy microclimate, and the plant and soil hydrology with meteorological conditions of the atmospheric boundary layer, canopy architecture, soil morphology, and biological properties of overstorey and understorey vegetation.
As input parameters the SVAT-Regio model uses (Fig. 5):
1. the mean daily or hourly meteorological data measured at meteorological stations located inside and around the modelled area;
2. digital maps of relief, land-use, vegetation and soil;
3. morphological properties of vegetation canopy (species composition, leaf area index, canopy height) determined for each individual grid cell;
4. biological properties of vegetation canopy (e.g. stomatal conductance, photosynthesis and respiration parameters) determined for each plant species;
5. physical properties of soil layers (structure and texture of different soil layers, hydraulic and heat conductivity) determined for each soil type.

The modelling procedure in SVAT-Regio consists of several consecutive steps including (Fig. 5):
1. Spatial interpolation of the meteorological data from nearest meteorological stations to individual grid cells to which the entire study area is divided. SVAT-Regio assumes that the land surface, soil and vegetation within each grid cell are spatially uniform.
2. Temporal reconstruction of the daily meteorological pattern for each grid cell with time step of 1 hour using results of spatial interpolation of the mean daily meteorological data (if the mean daily data as model input parameters are used, only).
3. Simulation of energy, water and carbon dioxide fluxes, canopy microclimate, canopy and soil hydrology for each grid cell. Reciprocal influence of neighbouring cells is taken into account through estimation of horizontal advection.
4. Integration of energy, water and carbon fluxes on the area (e.g. catchment areas, entire area) and on the time (e.g. day, month, season, year) (Fig. 6).

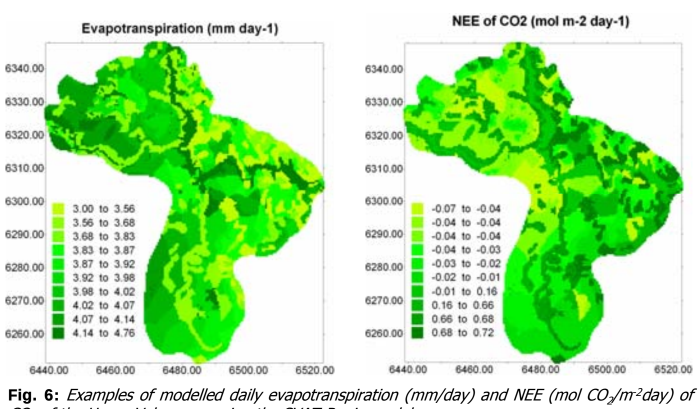

Fig. 6: *Examples of modelled daily evapotranspiration (mm/day) and NEE (mol CO_2/m^{-2}day) of CO_2 of the Upper Volga area using the SVAT-Regio model.*

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