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Influence of spatial heterogeneity on solar radiation transport in vegetation cover: estimation using a 3D model

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Effects of spatial heterogeneity of vegetation cover on transmission, reflection and absorption of photosynthetically active solar radiation were described using three-dimensional (3D) and one-dimensional (1D) modeling approaches. The widely used 1D models in respect of 3D approaches consider the vegetation cover as a horizontally homogeneous turbid medium that is obviously can result in some uncertainties in radiation flux estimates. For our numerical experiments a uniform ground surface area with regularly planted spruce trees of different density was taken. Two main model experiments were provided. In the first experiment the solar radiation transfer was simulated for actual 3D plant canopy structure. The second experiment imitated 1D plant canopy structure. The plant canopy in this experiment was considered as a horizontally uniform turbid medium. It was also assumed that the Leaf area index (LAI) of the trees in the experiment is dependent on vertical coordinate only. The values of LAI averaged for entire experimental plot for both modeling experiments were identical. The solar radiation transmission, reflection and absorption within each model experiment were calculated under different sun heights and a range of LAI of the forest stand (from 1 to 5). For calculations of radiative fluxes we used a key system of equations describing the three-dimensional solar radiation transfer within a plant canopy proposed by Y.Ross (Ross 1977) and further developed by Muneni and Kniazikhin (Ross, Myneni 1991; Kniazikhin et al. (1997). According to this approach the function of solar radiation with the wavelength λ and intensity $I_\lambda(r,\Omega)$ at each point of space $\mathbf{r} = \{x, y, z\}$ inside the vegetation canopy is depended on the solid angle $\Omega = \{\varphi, \theta\}$ (θ is a zenith angle of the sun) and estimated as the sum of the direct $I_{m,\lambda}(r,\Omega)$ and the diffuse $I_{d,\lambda}(r,\Omega)$ solar radiation. To calculate the scattered direct solar radiation, it is necessary to take into account the structure of each individual tree in the forest stand. In the study we assume the vertical and horizontal heterogeneity of phytomass within each tree crown. The scattering within tree crowns is derived by solving the three-dimensional integro-differential equation of radiative transfer (Ross, Myneni 1991; Knyazikhin et al., 1997). The transmission and reflection coefficients of vegetation elements (leaves, branches, stems) were taken from the results of field experiments (Knyazikhin et al 1997).

Comparison of the results of solar radiation transfer for 3D and 1D forest canopy structures showed significant differences in radiation fluxes obtained in 3D and 1D experiments. The difference in forest canopy absorption, reflection and transmission are influenced by openness of forest canopy, forest density, sun elevation, proportion of direct and diffuse radiation, and many other factors.

The developed model can be used as part of aggregated CO_2 and H_2O exchange models describing also the plant canopy photosynthesis, respiration and water uptake, as well as the processes of turbulent transport within and above the vegetation cover.

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