P1.18 THE DETAILED MODEL OF NONSTATIONARY ENERGY AND MATTER TRANSPORT AND TURBULENCE IN INHOMOGENEOUSE FOREST AND IN ATMOSPHERIC BOUNDARY LAYER OVER IT

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1. INTRODUCTION

The model presented to discussion has been developed as the result of special attempts to achieve the compromise settlement between the completeness of the natural processes description, simplicity of its numerical realization and practical usefulness. The model developed is the nonstationary 3-D coupled model for energy and matter turbulent transport in the forest canopy and in the planetary boundary layer over it. The model has been tested using the experimental data obtained from three forest sites of European Russia and Siberia in the frames of the Russian-European "EUROSIBERIAN CARBONFLUX" project carried out during last five years.

2. MODEL DESCRIPTION

2.1 *Basic Equations*

The model developed is based on the Reynolds hydrodynamic equations for turbulent motion. According to the classical conceptions the turbulent flux of each substance are approximated as the multiplication of the gradients of each substance mean concentration and the coefficient of turbulent diffusion for each substance. So for description of horizontal components of the wind speed the 3D nonstationary hydrodynamic equations are used. Contrary to the case of the turbulent flow over vegetation these two equations include the additional terms describing the friction interaction between leaves and interleaf air. As the third equation for the calculation the vertical velocity the continuity equation is used.

In natural conditions the phytoelements are differentially illuminated by the incoming solar radiation. Some of them are shaded, whereas other ones are exposed to direct radiation. Caused by this phenomenon the leaf temperature is mosaic, therefore two temperatures and two characteristic of leaf water potential are included to the corresponding equations for heat and water exchange in vegetation. The model nonstationary 3-D equation for carbon dioxide transfer and absorption also contains two instomata concentrations.

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2.2 *Turbulence Closure Technique*

The equations mentioned above are not comprised the closed set of mathematical equations. For this purpose three additional equations have been included to the model. They are the transfer equation for turbulent energy, semi-empirical equation describing the vertical profile of the scale of turbulence and the formula represented of the Kolmogorov's self-similarity hypothesis. For approximation the spatial distribution of horizontal turbulent coefficients the model uses the semi-empirical Smagorinsky's formula.

2.3. *Radiation Equations*

For description of the short-wave radiation fields in the model the following hypotheses have been used. (i) The forest canopy is represented as locally horizontally homogeneous turbid medium and isotropic turbid medium. (ii) The canopy impact on radiation fluxes accomplished by the foliage, which leaf area density (LAD), is changed from one gridcell to another. (iii) The leaf and soil reflection coefficients independents on incident angle of incoming radiation. (iv) The optical properties of the both sides of leaf are identical. (v) The model considers separately the direct solar and diffuse sky component of radiation subdivided into two spectral bands - near-infrared and photosynthetic active radiation. Other than the direct sun radiation and diffusive sky one are the most powerful components of the total radiation in the vegetation canopy it also contains the additional radiation fluxes which associated with the scattering of direct sun and diffusive sky radiations by phytoelements. The corresponding equations for upward and downward fluxes of this kind of radiation as well as the equation of the thermal radiation penetration are also included to the model developed.

3. DESCRIPTION OF THE TEST SITES

The model results were tested using the experimental data obtained from three forest sites. The first site is located on the western side of the Yenesey River, 35 km west of Zotino village in Central Siberia (61^{o}N, 90^{o}E). This is a forest of Scots Pines; trees are about 20 m tall and 120 years old. The measurements were carried out from June 24, 1999 until July 15 1999 with using the eddy-correlation system. Three days (June 28, 29, 30) at morning, noon and afternoon air temperature, humidity and CO_2 concentration at several layers of atmospheric boundary layer over this site were measured using airborne instruments.

The second experimental site as the first one is also located on the western side of Yenisey River about 40 km southwest Zotino village. This is a forest about 200-year-old and 16 meters tall of *P.Sylvestris.* During 18 days (July 8-25, 1996) the total evapotranspiration flux were measured by eddy correlation instruments. In this site the measurements of air temperature and humidity as well as the carbon dioxide concentration using airborne instruments have also been carried out. The third experimental site is situated in the Central Biosphere Forest Reserve located about 300 km North-West Moscow (56^{o}27N, 32^{o}55E). The dominated tree types on this area are spruce and pine. The structure and spatial distribution of vegetation in this site are well studied and documented. Such information together with the experimental data of surface fluxes and meteorological parameters are very valuable for model validation.

4. RESULTS AND DISCUSSION

4.1 *Experiments with the 1-D Model*

Model validation and testing was undertaken in several stages. Initially the capability of the model to simulate correctly the daily trajectory of the main meteorological parameters was tested. Following this purpose the numerical experiments with 1-D version of the model have been carried out. In this calculations the experimental data obtained from the first site in June 1999 are used. The results of these numerical experimentations illustrate the ability of the model to reconstruct the vertical profile of meteorological parameters in the atmospheric boundary layer as well in the forest stand under the assumption of its horizontal homogeneity. At the same time the numeric experiments with 1-D model indicate that for more detailed description the meteorological conditions in atmospheric boundary layer the detailed data are required. Besides others it concerns with the cloudiness parameters, which determine the solar weather within forest canopy.

4.2 *Experiments with 2-D and 3-D Models*

These numerical experiments were focused on the questions of the tracers transport in inhomogeneous forest canopy and atmospheric boundary over it. First of all carbon dioxide regime was attracted the special attention. Among other interesting questions concerned with carbon dioxide transport the model gives the possibility to investigate the "footprint" effects above the forest. According this purpose the area around the monitoring station in Central Biosphere Forest Reserve near Moscow has been chosen.

The calculations were shown that the regularities of footprint effect remain principally the same as those established by the analytical methods. The model is able correctly reconstruct the tendency of the "footprint" maximum to shift when changing the height and time of the measurement. So the position of "footprint" maximum shifts to the measurement point when decreasing of the height as well as when increasing of turbulence in afternoon time. For example, after noon the fraction from all CO_2 sources and sinks that are within 800m distances upwind the tower into the total CO_2 flux measured at the 34 m height is about 92%. Whereas it is only about 50% into the flux measured at the 95m heights. Unlike the analytical "footprint" models technique the method implemented in the model developed allows to take into account the surface heterogeneity associated with dynamic factors as well as with spatial distribution of carbon dioxide sources and sinks.

5. CONCLUSION

The tested version of model developed has demonstrated a reasonable agreement of model and experimental data under different weather conditions. Low requirements to computing time make the model a useful tool for solution of many tasks. Among them: (i) the estimation of diurnal trajectory of CO_2 concentration in atmospheric boundary layer, (ii) evaluation of the canopy heterogeneity on CO_2 fluxes; (iii) investigation of the influence of broken clouds on the vegetation illumination, the photosynthesis intensity and on the spatial distribution of CO_2 concentration. Other applications of the model developed could be: (iv) the investigation of the problem of spatial aggregation of energy fluxes, (v) the calculation the footprint for different tracer and different weather conditions, (vi) the assessment of the effect of spatial variations of illumination on energy and CO_2 fluxes above the canopy.

The solutions of such problems are of great interest for a wide range of forest meteorology problems.