A MATHEMATICAL MODEL OF MICROCLIMATE

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Abstract. Climatologists will be interested in a mathematical model of microclimate which is being developed by the fluid-mechanics group at the Institute of Limnology (Leningrad). The model is designed for two main types of application: microclimatic simulations; and microclimatic interpretations of large-scale weather forecasts.

The model which has been developed by the fluid-mechanical group in the Institute of Limnology (Leningrad) is designed for two main types of application:

1. Simulation of microclimate of future man-made landscapes and of natural landscapes for which there are no local hydrometeorological historical data. The model is used to predict alterations of temperature, humidity, wind velocity and other meteorological parameters in the lower boundary layer produced by various transformations of the environment: the creation of reservoirs, their elimination, changing their area or depth; irrigation of arid lands or drainage of bogs; forestation or forest cutting; large-scale construction work. Numerical experiments based on the proposed model will provide answers, for instance, to such questions as: What will be the evaporation losses from a projected reservoir? What will be its temperature regime and vertical mixing conditions? What will be the evaporation losses from lands planned for irrigation? What will air pollution conditions be like above a proposed town?

2. Interpreting large-scale weather forecasts issued by hydrometeorological services in terms of a particular landscape. Such local forecasts are based on the same physicomathematical model as the microclimate simulation. However, instead of using large-scale climatic data as initial conditions, synthetic data obtained from the evolution of the meteorological fields in the free atmosphere is derived from the general forecast. In practice, the proposed mathematical model of the lower active layer of the atmosphere appears to be an independent part which, being connected to a general weather forecast model, adapts it for the locality of peculiar interest. In this way it is possible, for instance, to forecast morning fogs over aerodromes, convective clouds and associated thunderstorms and damage done by hail to vineyards, and the like.

From the physical point of view, the model is based first of all on the similarity theory for planetary boundary layers (PBL), atmospheric and hydrospheric, the first having the thickness of the order of a kilometre, the second – of the order of a few tens of metres. The theory has been intensively
developed during the last twenty years. In short, its main idea is that the turbulent, well-mixed layer is considered as a whole, its evolution is characterized by changes in integral characteristics (i.e., average values of temperature, velocity components and certain admixtures such as humidity in the atmosphere or salinity in the water basin); while the internal structure is considered self-similar, and thus the thermodynamic interaction with the surface is described by some universal laws. In mathematical terms the key elements of the theory are as follows: self-similarity of the PBL with time-dependent thickness (Zilitinkevich and Deardorff, 1974), equations for this thickness (Zilitinkevich, 1972, 1975b, 1987) and resistance and heat/mass transfer laws (Zilitinkevich et al., 1967; Zilitinkevich, 1970, 1975a, 1989a). Empirical verification of formulas for the thickness of a steady-state PBL under neutral and stable stratification and of prediction equations for the thickness of the growing convective PBL (so-called entrainment equations) as well as empirical determination of universal functions in the resistance and heat/mass laws (so-called A, B, C and D-functions) is discussed in many papers which have recently been summarized (see, for instance, Zilitinkevich, 1989a,b).

The second essential element of the model is the similarity theory for the thermocline, a region with supercritical stability where turbulence can exist only intermittently. The use of the approach developed by Kitaigorodsky and Miropolsky (see Kitaigorodsky, 1970), Mälkki and Tamsalu (1985), Zilitinkevich et al. (1988), Zilitinkevich and Rumyantsev (1990) leads to a very simple parameterization of the vertical temperature profile through the whole depth of a water basin, which is extremely convenient from the computational point of view and at the same time quite realistic and well-founded physically.

Of course, in addition to the above-mentioned non-traditional or not quite traditional approaches, some perfectly traditional ones are used in the model, in particular, in determining the wind and temperature roughness parameters of the land and water surfaces, in calculations of the radiation heat exchange in the PBL, etc. (see, for instance, Brutsaert, 1982; Liou, 1980).

Using the approach based on the similarity theories for the PBL and the thermocline allowed us to overcome a number of difficulties insurmountable in the framework of any traditional eddy-diffusivity or even much more complicated second-order closure theories. In the course of transition from convectively unstable to stably stratified conditions, the PBL thickness sharply decreases, the layer of supercritical stability appearing outside the new PBL, where well-developed turbulence (which degenerates very quickly) is replaced by intermittent, spotty turbulence originating in internal waves. Until now there has been no theory of mixing due to such turbulence. In fact, this has been a dead end for traditional eddy-diffusivity and second-order closure theories. (In the framework of the purely phenomenological Kitaigorodsky–Miropolsky parameterization, there is no apparent dead end, but neither is there a physical theory which could explain the mixing mechanism.) The proposed model combines the new physical