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NUMERICAL MODELLING OF AN ENSAMBLE OF HUMIDITY PROCESSES AND THEIR INTERCONVERSION IN ATMOSPHERE

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Abstract. On the basis of the numerical model of a mesoscale boundary layer of atmocphere (MBLA) developed by us interesting humidity processes series are simulated, among which the special attention is given to modelling of ensemble of clouds and a fog. The accent becomes also on interconversion humidity processes in the above-stated ensemble. In modelling of this phenomenon the special role belongs to turbulent regime of MBLA. The simulated process is unknown to us from materials of meteorological supervision and consequently it is possible to consider it as result of numerical experiment.

Keywords and phrases: A mesoscale boundary layer of an atmosphere, a fog, a cloud, a numerical simulation, a local weather forecast, an ecology, clouds ensemble.

AMS subject classification: 60H10, 60H3X.

Introduction. In the present work the problem of numerical modelling of humidity phenomenon which is taking place in mesoscale boundary layer of atmocphere (MBLA) is considered. It is meant as fogs, stratus clouds, cloudy processes and related by them questions.

We investigate them not only from the point of view of weather forecast, agro-, avia-fnd sea meteorology, but also ecology, as in them there is an intensive accumulation of polluting substances.

It is necessary to notice still that fact, that at formation of fogs and clouds, and, especially, at their simultaneous existence, releasing of the latent warmth of condensation of water vapour takes place in environment because of what the curve of temperature stratification of atmosphere is transformed in polygonal line. This polygonal line of atmospheric temperature stratification creates temperature-inversion layers, so-called "traps", where polluting substances accumulate. As it has been specified above, this effect considerably increases in case of simultaneous existence of fogs and clouds and in horizontal, and a vertical plane. Formation of these above-stated temperature-inversion layers is obligatory accompanying process of fog- and cloudformation.

Given article also is devoted modelling of such processes and their interconversion.

Naturally, there exists corresponding literature [1-3] about similar subjects, but we consider and model some the interesting processes distinct from them and unknown even from meteorological supervision. In our opinion, they are physically quite logical and expected and it is possible to consider them as result of numerical experiment. Probably further we should get corresponding materials of meteorological supervision.

Problem statement. We consider a two-dimensional, non-stationary problem (in a plane (x-z)) over thermally heterogeneous underlying surface. Its horizontal and vertical sizes are equaled about 100 km and 2 km, respectively. Coriolis force can be neglected Because of the small horizontal sizes. As it is accepted by consideration of problems about MBLA it is neglected also by falling of air density with height.If we shall apply Bussinesc free convection simplification, cvasistatic approximation, constancy of turbulence coefficients, the method of taking into account of macrometeoprocesses on mesoprocesses, the initial system of the equations of MBLA (with the account of phase transformations of water vapour) and its boundary-initial conditions will have such view [1,2,4-6]:

$$\frac{\mathrm{du}}{\mathrm{dt}} = -\frac{\partial\pi}{\partial \mathrm{x}} + \Delta'\mathrm{u},$$
$$\frac{\partial\pi}{\partial \mathrm{z}} = \lambda\theta,$$
$$\frac{\partial \mathrm{u}}{\partial \mathrm{x}} + \frac{\partial \mathrm{w}}{\partial \mathrm{z}} = 0,$$
$$\frac{\mathrm{d}\theta}{\mathrm{dt}} + \mathrm{Sw} = \frac{\mathrm{L}}{\mathrm{c_p}}\Phi + \Delta'\theta,$$
$$\frac{\mathrm{dq}}{\mathrm{dt}} + \gamma_{\mathrm{q}}\mathrm{w} = -\Phi + \Delta'\mathrm{q},$$
$$\frac{\mathrm{dv}}{\mathrm{dt}} = \Phi + \Delta'\mathrm{v},$$
$$\frac{\mathrm{d}}{\mathrm{dt}} = \frac{\partial}{\partial \mathrm{t}} + \mathrm{u}\frac{\partial}{\partial \mathrm{x}} + \mathrm{w}\frac{\partial}{\partial \mathrm{z}},$$
$$\Delta' = \mu\frac{\partial^2}{\partial \mathrm{x}^2} + \nu\frac{\partial^2}{\partial \mathrm{z}^2},$$

where u, w are horisontal and vertical components of an air velocity, respectively, π, θ, q - deviations of a pressure analog, a potential temperature and a water-vapor mixing ratio from their undisturbed fields, respectively, v - a liquid-water mixing ratio, μ, ν - horisontal and vertical coefficients of turbulence, respectively;

$$\begin{array}{llllll}
\text{at } z = 0 & u = 0, & w = 0, & \theta = F(x,t), & q = 0, & v = 0, \\
\text{at } z = Z & u = 0, & \pi = 0, & \theta = 0, & \dfrac{\partial q}{\partial z} = 0, & \dfrac{\partial v}{\partial z} = 0, \\
\text{at } x = 0, X & \dfrac{\partial u}{\partial x} = 0, & \dfrac{\partial \theta}{\partial x} = 0, & \dfrac{\partial q}{\partial x} = 0, & \dfrac{\partial v}{\partial x} = 0, & \\
\text{at } t = 0 & u = 0, & \theta = 0, & q = 0, & v = 0, &
\end{array}$$

where X, Z horizontal and vertical sizes of MBLA, and temperature of MBLA underlying surface which we take from meteoexperiments [2, 4]:

$$F(x,t) = \begin{cases} 0 & 0 \le x \le 32\mathrm{km}, \quad 48\mathrm{km} < \mathrm{x} \le 80\mathrm{km}, \\ 5\sin\omega\mathrm{t} & 32\mathrm{km} \le \mathrm{x} \le 48\mathrm{km}, \end{cases}$$

here ω is an angular velocity of daily rotation of the Earth.

Thus, we consider local circulation over thermal "island" at its heating by a periodic, daily course of temperature.

The sense and value of other constants and parametres are in detail given in [6]. As to physical and numerical methods of the problem decision they are given in our early works [5,7].

Discussion of results. As a result of the problem decision it has been simulated a number of such abnormal meteorological processes, as simultaneous existence of a stratus and a fog; formation of a vertical complex stratus - fog, but we will in detail stop only on ensemble simulation humidity processes in MBLA.

Varying turbulent regime of MBLA we have received rather interesting, from the point of view of our subjects, simultaneous formation and interconversion various on genetics humidity processes.

At f = 0.98, $\nu = 10\ m^2/sec$, $\mu = 9000\ m^2/sec$ it was possible to receive 4 clouds simultaneously, that is the whole ensemble of clouds has been received. Because of economy of a place it is resulted only "verbal animation" of the process.

At t = 6 h. we have stratus over thermal "island". Its width = 8 km (It in all following cases does not change), maximal liquid-water content $(v_{max}) = 0.44\frac{g}{kg}$, a bottom of the cloud $(z_{min}) = 1000m$, a top of the cloud $(z_{max}) = 1800m$.

At =18 h. it is observed simultaneously a cloud and a fog. Parameters of the cloud are $(v_{max}) = 1.20\frac{g}{kg}$, $(z_{min}) = 1000m$, $(z_{max}) = 1800m$, and parameters of the fog are $(v_{max}) = 1.44\frac{g}{kg}$, $(z_{max}) = 400m$, Its width = 40 km.

At = 23 h. and 15 min. the fog has gradually developed horizontally, along the edges he has risen, because the bottom of a fog is warmer, than a surface of "island" and in due course has turned in 2 independent stratuses along the edges of an "island". That is we have obvious transformation of a part of one powerful fog into 2 independent clouds. It is as a result had the basic cloud, a fog and 2 lateral clouds along the edges of "island", i.e. 4 humidity objects - an ensemble of three clouds and one fog. Corresponding isolines are given in fig. 1. Parameters of the basic cloud are $(v_{max}) = 0.51\frac{g}{kg}$, $(z_{min}) = 1200m$, $(z_{max}) = 1800m$; parameters of the fog are $(v_{max}) = 0.18\frac{g}{kg}$, $(z_{max}) = 400m$, Its width = 32 km; parameters of the lateral cloud are $(v_{max}) = 0.05\frac{g}{kg}$, $(z_{min}) = 400m$, $(z_{max}) = 1000m$, its width = 16 km.

At =23 h. and 40 min. because of heating of a underlying surface the fog gradually rises transformating to obvious stratus, lateral clouds on each side "weaken", distance between the transformed and lateral stratuses increases. As a result we have received ensemble from four clouds. Corresponding isolines are given in fig. 2. Parameters of the basic cloud are $(v_{max}) = 0.47\frac{g}{kg}$, $(z_{min}) = 1200m$, $(z_{max}) = 1800m$; parameters of the transformed stratus from a fog are $(v_{max}) = 0.09\frac{g}{kg}$, $(z_{max}) = 400m$, $(z_{min}) = 200m$, its width = 24 km; parameters of the lateral cloud are $(v_{max}) = 0.04\frac{g}{kg}$, $(z_{min}) = 400m$, $(z_{max}) = 1000m$, its width = 12 km.

At =24 h. the fog disappears and is had only the basic cloud and 2 lateral stratuses on each side of an "island". Parameters of the basic cloud are $(v_{max}) = 0.43\frac{g}{kg}$, $(z_{min}) = 1200m$, $(z_{max}) = 1800m$; parameters of the lateral cloud are $(v_{max}) = 0.04\frac{g}{kg}$, $(z_{min}) = 400m$, $(z_{max}) = 1000m$, its width = 12 km.

At = 25 h. lateral stratus resolve and there is only a basic cloud. Its parameters are $(v_{max}) = 0.40\frac{g}{kg}$, $(z_{min}) = 1200m$, $(z_{max}) = 1800m$. Actually we have daily continuous overcast, what is a source of continuous precipitation.

From the numerical experiments received by us it is possible to conclude, that two "lateral" isolated clouds are simulated by increase μ and decrease ν. It promotes expansion of a fog and then to reception of "lateral" clouds.

Interconversion of humidity processes is interesting not only from the point of view of weather forecast, but also in ecological sense: the successful forecast of this process causes a choice of a right moment of emission in atmosphere of polluting substances from a different sort of sources.

Let's notice also, that interconversions in an ensemble of humidity processes rather actually from the point of view of the forecast of a precipitation and artificial influence on clouds for the purpose of calling or prevention of precipitation.

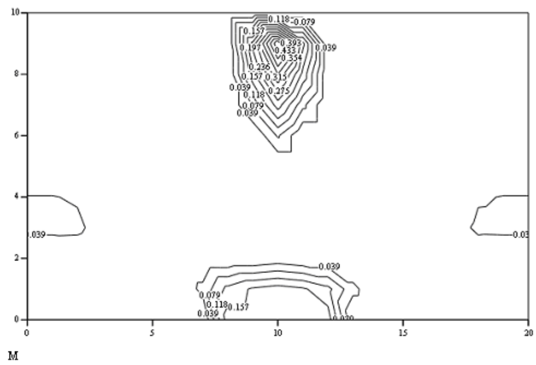

Fig.1.

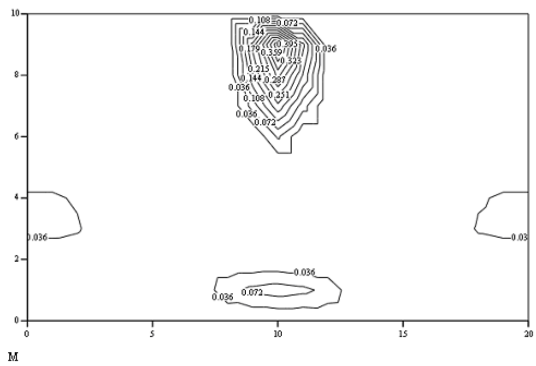

Fig.2.

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