Numerical modeling of cloud and precipitation evolution and its connection with entropy

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A recent work devoted to sources of entropy connected with mesoscale frontal cloudiness. Three-dimensional nowacasting and forecasting numerical models developed in UHRI [Pirnach, 1998; 2008; Belyi et al., 2009] for modeling of the winter and summer frontal cloud systems were adapted for theoretical interpretation of the investigated phenomena.

The integration of full thermodynamic equations, which included equations for air motion, water vapor content, temperature transfer, the continuity and thermodynamic state equations are used in these models. Cloud microphysics is considered explicitly by solving the kinetic equations for the droplet and crystal size distribution. The size distribution function of the cloud and precipitation particles is formed due to cloud condensation nucleation, ice nucleation, growth (evaporation) by deposition, and freezing, riming, collection by raindrops of cloud drops. Droplet and ice nucleation is accounted by parameterization in the model. Cartesian coordinates (x, y, z) and terrain-following sigma coordinates

ξ, η, ζ have been used. In second case the system of equation will be described as follows:

$$\frac{dS_i}{dt} = F_i + \Delta S_i \,, \qquad (1)$$

$$\frac{\partial \rho u}{\partial \xi} + \frac{\partial \rho v}{\partial \eta} + \frac{\partial \rho w}{\partial \zeta} = 0\,,$$

$$\rho = \frac{p}{RT}\,,$$

$$S_i = (u, v, w, T, q, f_k),$$

$$i = 1,2,...,8\,;\; k = 1,2,3\,,$$

u, v, w are components of wind velocity across ζ, η, ζ axis, which are directed on east, north and perpendicular to the ground surface respectively. F_i are describes separate physical processes: F_1—F_3 presented right parts of wind velocity projections, which included Carioles parameter, free-fall acceleration, pressure gradients and etc.; F_4—F_5 describe heat and moisture fluxes; F_6—F_8 represent processes of droplets and crystal nucleation, cloud and precipitation particles falling velocities, their transfer, condensation and coagulation processes etc; ΔS_i is turbulent transfer; p and ρ are pressure and density; T is temperature; q is specific humidity; f_k are cloud particle size distribution functions.

A splitting method had been used for sintegration of the system (1). The solution scheme was described as follows:

$$\frac{\partial S_i}{\partial t} = \sum_{n=1}^{6} F_{in}\,,\; n = 1,2,...,6\,;\; i = 1,2,...,8\,.$$

System (5) to split up on 6 equations as follows:

$$\frac{\partial S_{in}}{\partial t} = F_{in}\,,\; n = 1,2,...,6\,.$$

F_{i1} presented the advection, convection and turbulent transfer; F_{i2} included the pressure gradients; F_{i3} included Carioles acceleration; F_{i4} described a vertical motion solution schemes; F_{i5} presented condensation processes; F_{i6} included coagulation solution schemes.

Entropy S calculated by relationship [Khrgian, 1969]:

$$S = C_p \ln\theta + \text{const}\,,$$

θ is potential temperature, C_p is specific heat capacity at the constant pressure.

Production of entropy calculated by relationship as follows:

$$\frac{dS}{dt} = \frac{d\theta}{dt}\frac{C_p}{\theta}\,.$$

Numerical simulation of atmospheric phenomena connected with atmospheric fronts and their cloud systems that caused the damages events have been fulfilled for several synoptic situations observed in steppe part and mountain regions of Ukraine. Diagnostic and forecast models have been constructed for mesoscale cloud formations followed by high floods in Carpathian region. Numerical experiments are carried out with aim to determine the role of various dynamics and microphisics parameters in formation of strong and catastrophic precipitation. Series of numerical experiments have been carried out with aim to research the key parameters caused features of development of dangerous events and their activity. Special numerical experiments have been carried out with a main goal to research the temporal and spatial distribution of entropy and its production. Numerical study interaction between entropy and cloud and precipitation had been carried out.

It is found, the unlimited growth of water and ice supersaturation is possible if mechanisms of cloud precipitation formation are insufficiently effective for precipitating of whole moisture. In turn, it can cause intensive activation of cloud condensation nuclei and unlimited growth of large drops as well. Therefore the unlimited growth of precipitation intensities may occur.

Some key parameters, meteorological conditions and predictors caused the occurrence of dangerous phenomena were defined. The main features of strong precipitation have been noted as follows: interaction of flows of different physical nature coming from opposite directions; presence of ice supersaturation layers; strong vortical motions in single air mass advanced to mountain ridge; chimney clouds with ice tops and cirrus clouds above; high tropopause achieved 10 km and more, strong ascending and compensative descending motions; the necessary combination of precipitation-forming mechanisms.

Coupling modeling of evolution entropy and precipitation found their perfect agreement. Regions of the low entropy coincided with regions of heavy precipitation. Regions with high entropy located in cloudless space. Regions of the low entropy can to be good predictors of heavy precipitation with a high confidence probability.

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