Interaction between frontal cloud system and dangerous events in Crimea

Ganna Pirnach[1] Taras Belyi[2]

[1]Ukrainian Hydrometeorological Institute, Kyiv, Ukraine, (hanna@uhmi.org.ua/+380 (44) 525 53 63),
[2]Institute of geophysics NAS of Ukraine, Kyiv, Ukraine, (tbelyi@mail.ru/+380 (44) 450 25 20)

Introduction

Numerical simulation of atmospheric phenomena connected with atmospheric fronts and their cloud systems that caused the damages in frame aircrafts, agriculture, transport etc have been fulfilled for several synoptic situations. Present work continues theoretical studies of heavy precipitation caused floods and damages in mountain regions of Ukraine. In recent years heavy precipitation causes flash floods in Crimea region very frequently. Conditions of formation of high convective cells, supercells, long lasting precipitation and heavy rainfalls, horizontal and vertical rotor cells have been objected for investigation. Theoretical interpretation of atmospheric state by nowcasting numerical models and cloud evolution modeling by forecasting models were conducted and inner structure of modelled cloud at different stage of their development were investigated.

Methodology of the research

The three-dimension diagnostic and prognostic models with non-elastic dynamics at detail microphysics have been adapted for theoretical interpretation of the investigated phenomena. There is proposed research methodology based on numerical integration of dynamic and thermodynamic full equation jointly with kinetic equation for cloud particles distribution function [1, 3–5]. 3-D diagnostic models were used for construction of initial meteorological fields and analyses of current state of atmosphere at target time and space [3]. Initialization of models was performed by rawinsound data from the regular network get up from British Atmospheric Data Centre (BADC).

Diagnostic modeling

Numerical experiments to study the conditions of heavy rainfall in various parts of east Crimea were carried out after detailed study of synoptic situation using synoptic maps of different format and purpose of analysis and different kind of satellite information, allowing to choose the best for the task space and time to build the initial fields. Figure 1 shows the map of south-eastern Crimea where there were heavy rain causing flooding.

Fig. 1. Part of map. The east Crimea region . O is Bogatoe village, epicenter of catastrophic precipitation in August 08, 2002

The cloud processes observed in the Crimea in this period were convective in nature and demanded for his study high-resolution computational grid. Nested grids different scales were used for modeling. For general characteristics of the situation in eastern Crimea the results of simulation with horizontal spacing equal to 5 km nested grid and attached to 100km for stretched grid. With this separation can be seen more or less general description of the distribution of meteorological variables in the south-eastern Crimea where there were dramatic events associated with heavy precipitation. Numerical experiments for study of inter structure and features of evolution convective cloud clusters different mesoscales, and supercells and severe chimney clouds have been carried out. The calculations were carried out both in Cartesian and in the sigma - coordinate system. The 200 m step was used for vertical resolution. Highest *z* is 15 km .

Fig. 2 shows the horizontal distribution of dynamic and thermodynamic characteristics of the cloudness calculated in the sigma-coordinate system for night-time sounding of August 08, 2002 in one of the key periods of maximum precipitation intensity. Pressure, temperature, rotor, entropy have cell structure that caused next formation of the convective cells. A characteristic feature of the distribution of meteorological elements over the east Crimea was a wedge of high temperatures before and part of the mountain in the eastern foothills of Crimea which were preserved even in the night. The cells of increased temperature were visible even in the mountains. The sea-level pressure formed a closed triangular area of high pressure which served as a natural barrier to moisture movement and contributed to its accumulation in the surrounding area and the appearing of mesoscale cloud formations.

Spatial attention was given to stream lines. According to the distribution of stream function at 00 GMT of August 05 the air mass had a cyclonic circulation and weather in the eastern Crimea determined air flows from the north east. After 12 h the flow changed it direction on opposite and the weather over the island was identified the southern and south-west flow to the night of August 06. After circulation of the atmosphere began vary sharply. At August 07 the different flows are meeting. In August 08 in east Crimea flows have countered along $x = 0$ and in August 10 over the peninsula dominated north-eastern cyclonic flows. In Fig.2 there is evolution of stream line structure in August 08 shown.

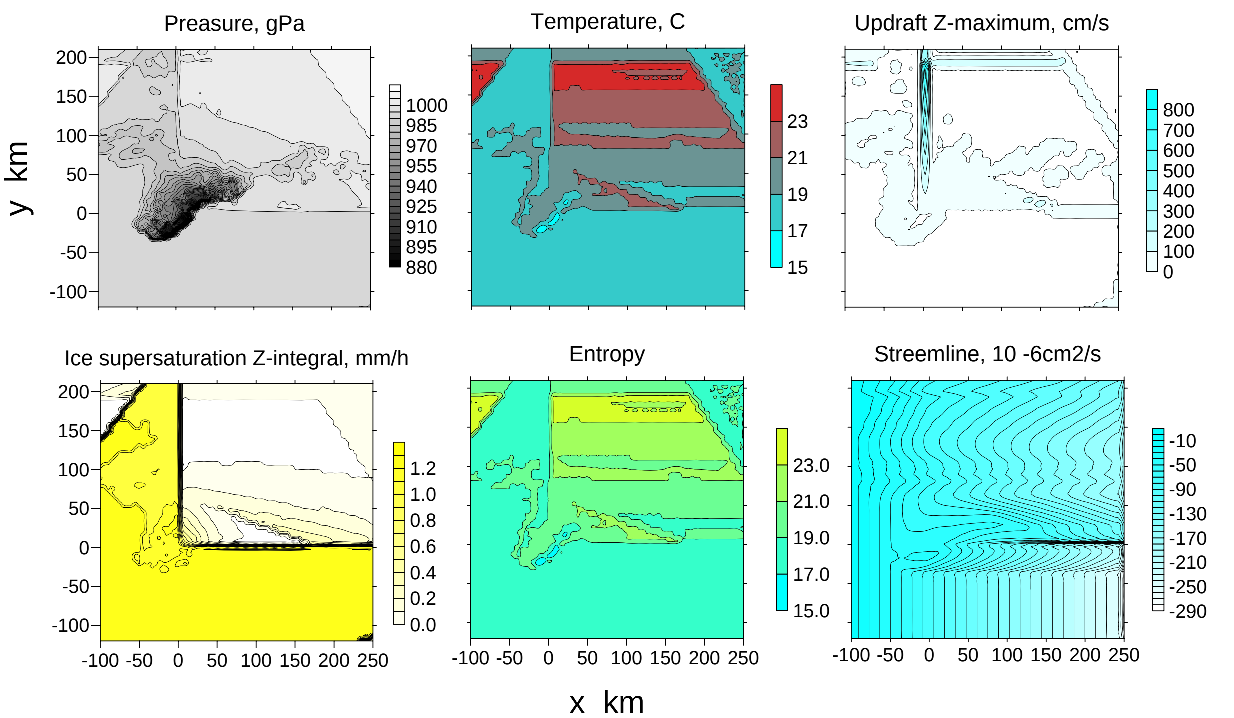

Fig.2. Horizontal distribution of integral and meteorological characteristics of cloudy atmosphere at 00 GMT of August 08, 2002

Chain of maximum vortex velocity, vertical motions and condensation rate indicated places cumulus clouds in a given area. Free for sublimation water vapor accumulated in the south of the triangle. The minimum of the entropy value also was on the edge of the triangle defined, as well as its derivative, testified to the highest intensity of the precipitation formation process location. Contrasts in temperature and pressure in specified region caused the formation of powerful convective cloud formations. Warm air raised to different heights, quickly cooled, condensation rate increased in it, causing the rapid growth of precipitation particles.

Three-dimensional forecasting numerical modeling

Evolution of clouds and precipitation was calculated using a system of integral-differential equations with initial conditions obtained using diagnostic models [4, 5]. Most of the calculations carried out for the most active period of August 6-8. The subject of investigation was as mesoscale precipitation of scale in hundreds of miles as cloud formation of a smaller scale, down to individual cumulus. When modeling nested grids used in step 5 km, 2 km., 1 km, 200 m. In so far as to bring all the results of experiments in the work there is no way, the only limit individual calculations were presented. In Figure 3 the spatial distribution of cloudiness and entropy after 2 hour of development is represented. The step nested grid was 5 km. With this separation it is possible to display a picture of clouds around the studied area. In the above named epicenter the cloud cover did not was continuous. It is approaching to this area from the northeast and southwest, and it has formed some powerful cloud formation in the scale of several kilometers or even hundreds of meters Fig.4-5). As seen from Fig. 3, ice cover and entropy horizontal distribution depicted the cell structure. Strong cloud formation reached tropopause observed in the north, and west, and east of the epicenter of precipitation. Vertical cross sections show presence of deep convective cloud clusters. The powerful convective clouds with the crystalline tops and mixed (water) layers below them were most dangerous. Horizontal distribution of entropy signaled this dangerous by minimum values. Entropy minimum correspond to ice concentration maximum. Availability of minimum entropy and powerful mixed clouds with crystal tops at 100 <x <150 km and y = 65 km can be used as example. The clouds were mixed with crystalline tops, the concentration of crystals reached 10^6 / g. Seeding moist layers below these crystals have been as a powerful factor in building strong and catastrophic fallout.

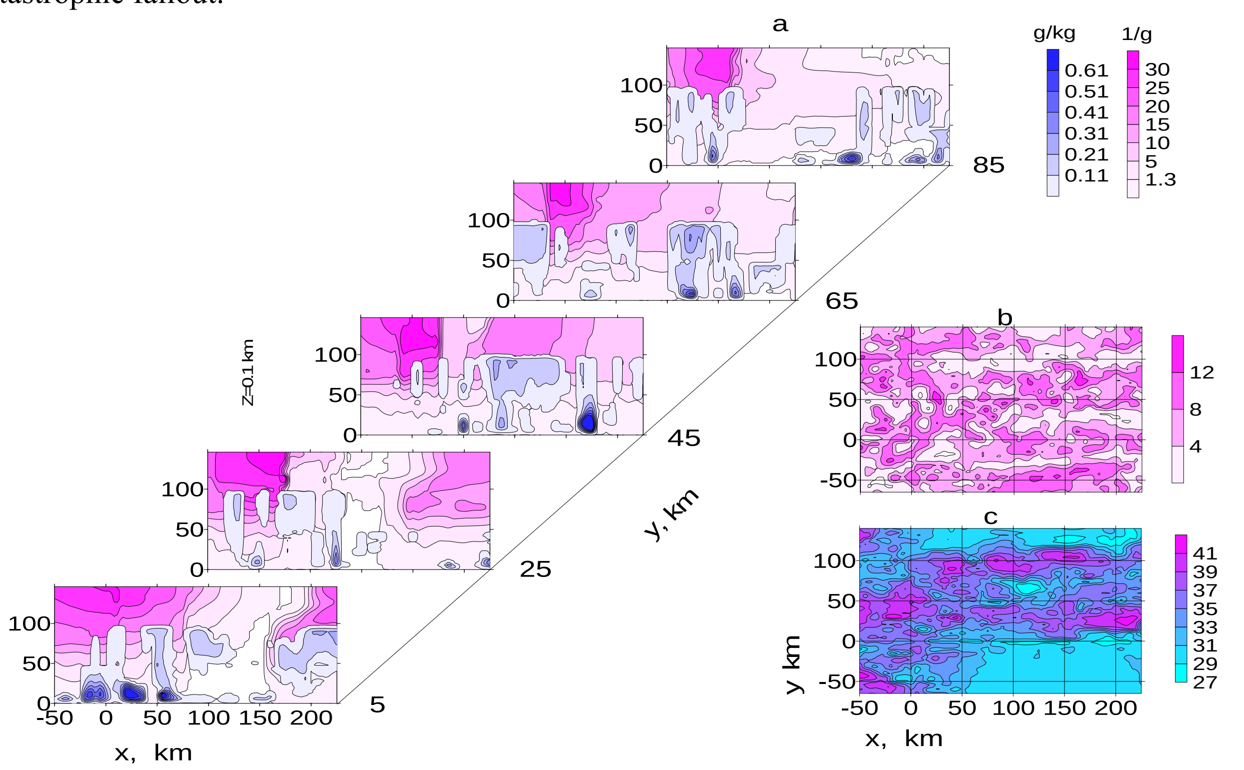

Fig. 3. Spatial distribution of clouds and entropy
a) ice concentration 1/g) and water content (g/kg) vertical cross section at different *y*. b) Ice cover (ice concentration Z-max,1000/g); c) entropy distribution at z=3 km, cal/g.grad, numbers at the scales

The 1km space steps were used for convective cloud clusters (Fig.4). At time from 1 h to 2 h chain of clouds transformed in several clouds and disappears after. The 0.2 km space steps were used for several convective clouds (Fig.5).

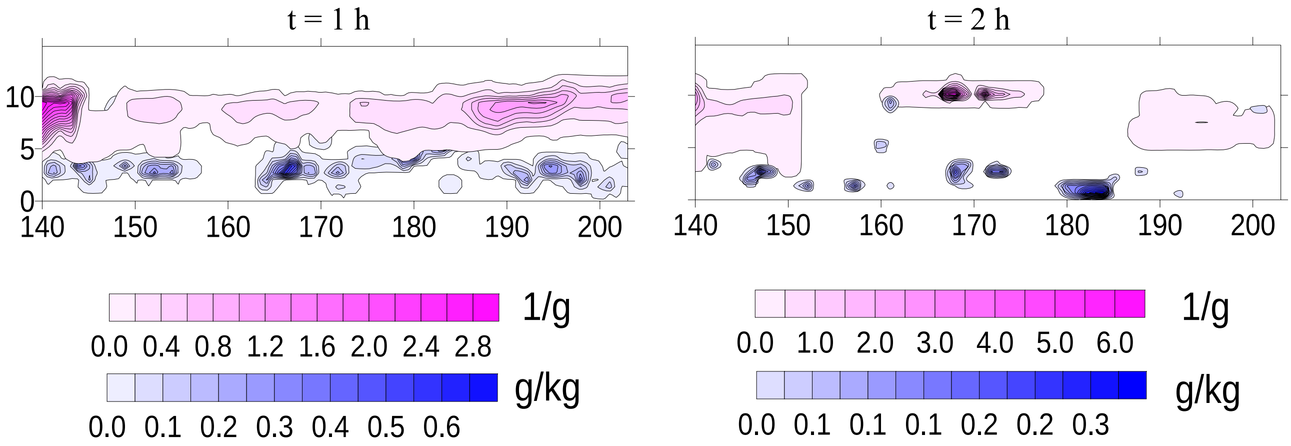

Fig. 4 Vertical cross section ice concentration (1000/g, pink colour) and water content (g/kg, blue) at different *t* and y =33 km. Sim Kolodaziv. Horizontal step 1 km

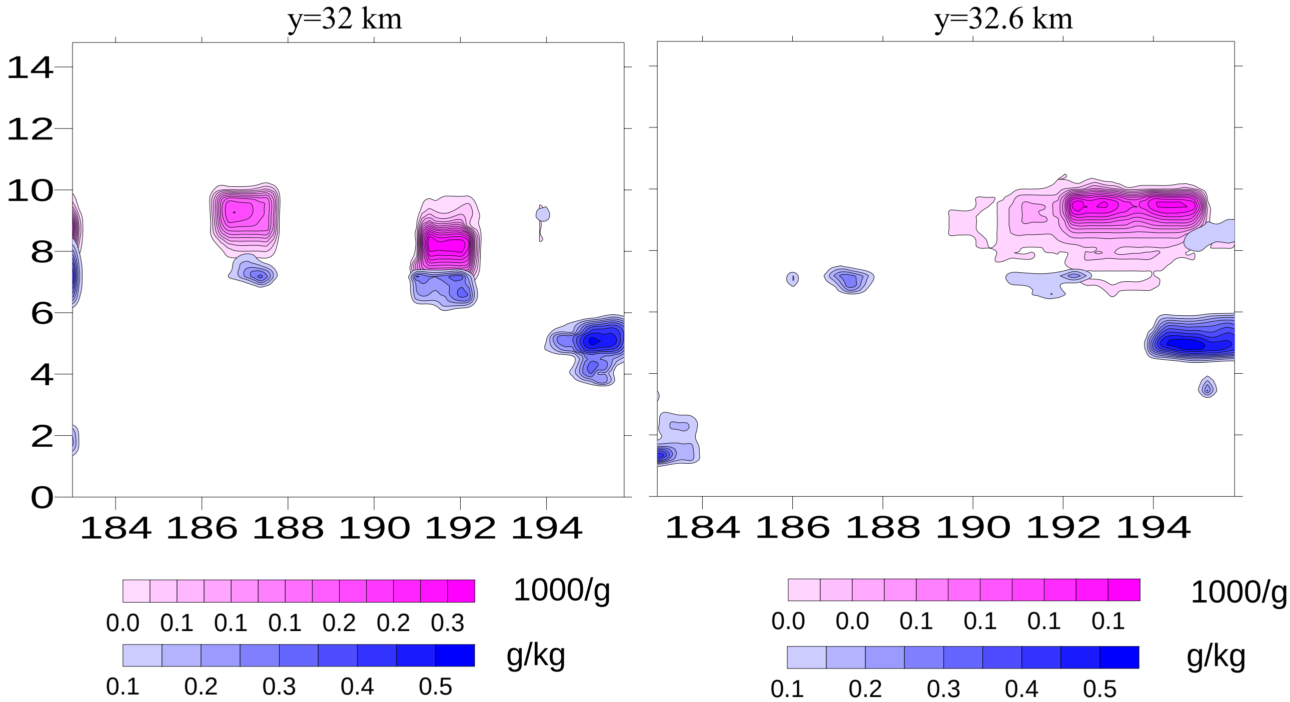

Fig. 5. As 4 at different *y* and *t*=2h. Horizontal step 200 m. Sim Kolodaziv

In Figure 6 depicts the three-hour precipitation sums for the first 12 hours of cloud development after 00 hours of August 08. As seen from this figure, the distribution of rainfall was spotted structure. Cells heavy rain appeared in different places from time to time. The amounts of precipitation and the number of cells are increasing significantly if coagulation processes are taking into account. Near v. Bagate the spot of strong precipitation was seen at *t* = 6 hours. At *t* = 9 hr the precipitation sums and size of spots reached maximum and then declined. This course of process was with the inclusion of coagulation processes of maximal intensity. The maximum amount in this case sometimes exceeded 50 mm/ 3 hr. While intensity of coagulation processes are decreasing (especially large drops with a small drops), the maximum precipitation intensity decreased and largely reduced the duration of the existence of strong precipitation cores. The calculations for flat terrain depicted the least amount of precipitation. In the area of v. Bogate spot with heavy precipitation was not observed. In general, the pattern of precipitation depends on many factors as follows: initial conditions, the intensity of precipitation formation, relief etc. All these factors carefully studied and used in the analysis of the causes of catastrophic formation of precipitation. In the submitted figure is an example of cumulative analysis of impact on amounts of precipitation of the rain drop coagulation with small drops and riming with zero initial conditions for cloud particles. This figure also confirms that recognizing the decisive influence on the precipitation of dynamic factors but microphysical processes can not be neglected. At the same catastrophic formation of precipitation in the summer against the background of favorable dynamic conditions coagulation processes play a crucial role. In epicenter of strong precipitation (20 <x <60 km, 0 <y <50 km, Fig.6) catastrophic precipitation had turned on only when the processes of coagulation were included.

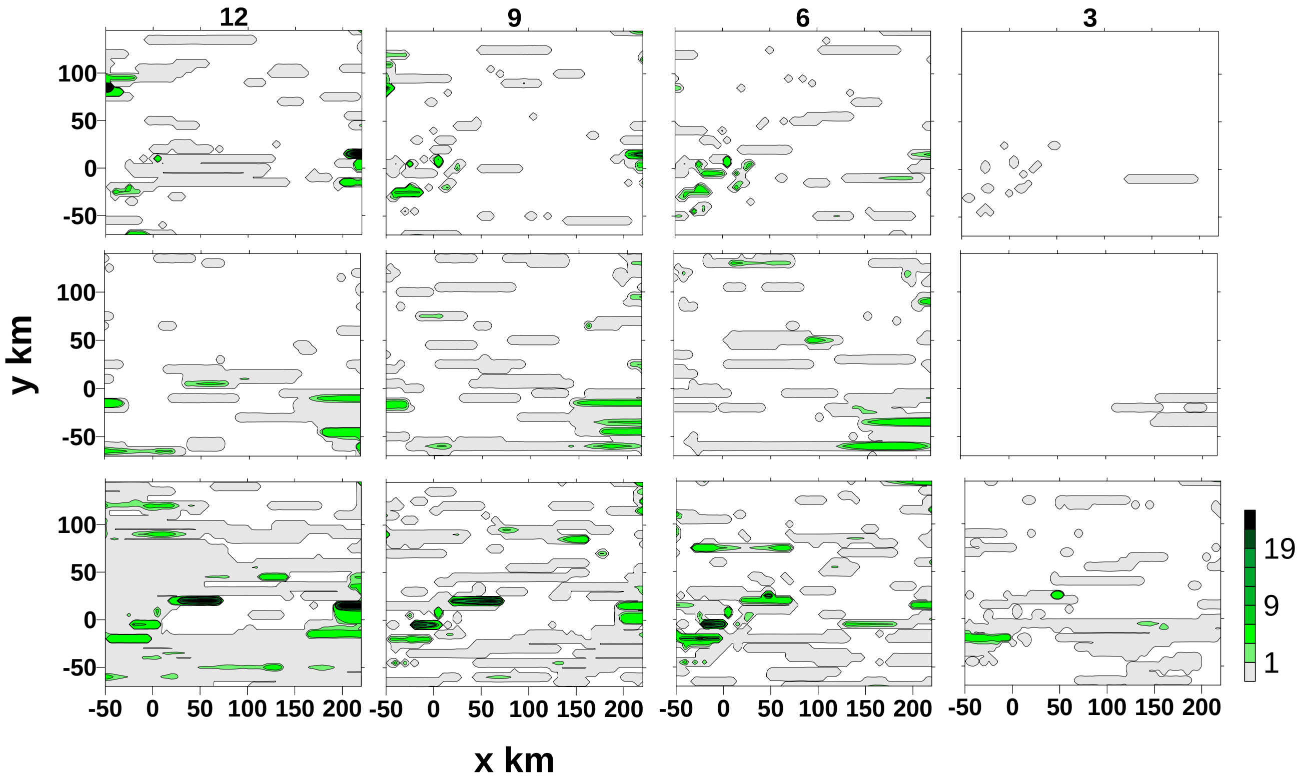

Fig. 6. The amounts of precipitation during the first 12 hours of cloud development after 00 GMT of August 08, 2002
First line is calculations without coagulation processes; the second row is it for flat relief; the third row is it with a maximum intensity of coagulation processes for complex terrain. The numbers at the top are the time deadline, hrs; figures near scale are precipitation sums, mm.

The most detail we will discuss the modeling of cumulus in the area of Bogate village, in the epicenter of the heavy precipitation core near the point (x, y) = (50, 30 km). In Figure 7 shows the spatial distribution of integral and meteorological characteristics in the area of v. Bogate. According to the distribution of sea level pressure, temperature, entropy, flow lines. Any special excitations in the atmosphere were not observed. Pressure increased slowly from southwest to northeast as entropy increased. Updrafts and condensation rate signaled some disturbance shown on the grid diagonal.

Simulation results for the complex terrain had a somewhat different picture. Almost all properties marked spotty structure. Stains reduced entropy can be clearly distinguished at the center point and the north-east of it. Lines of streamlines depicted cyclonic circulation. Ice supersaturation isolines not so noticeable. In both cases the amount of free sublimation of water vapor slowly increases from southwest to northeast. Condensation rate and its ascending motion spots with maximum values indicate the centers of the clouds and precipitation activity. Spotted structure of meteorological characteristics over time caused the spotted structure of clouds and precipitation (Fig. 8–9) and the formation of a strong precipitation cells.

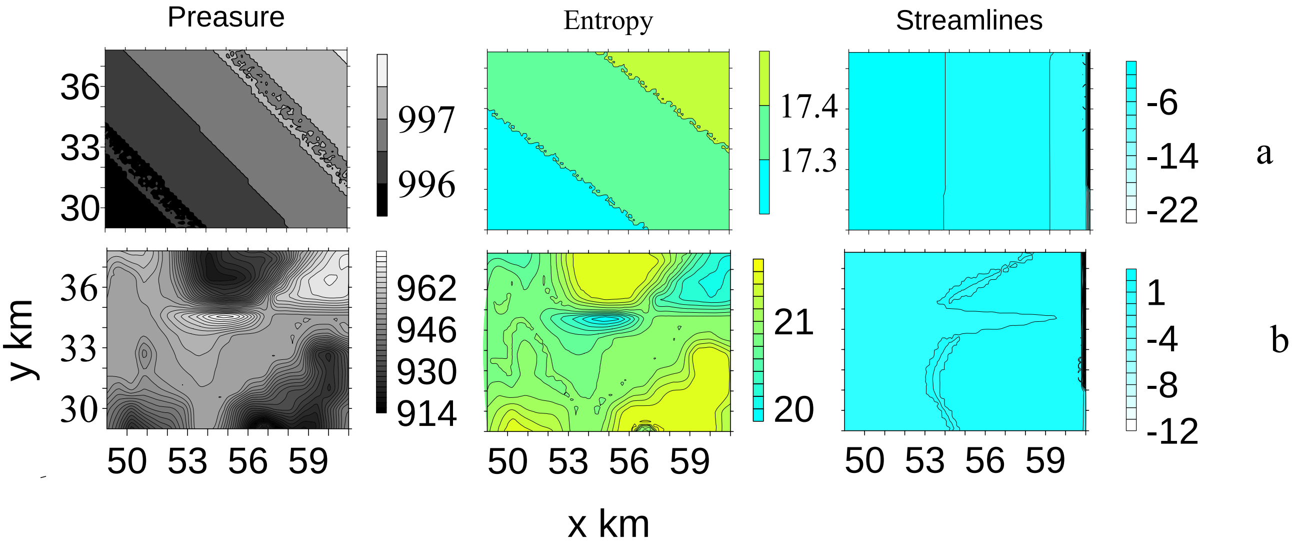

Fig.7. Initial conditions for Village Bogatoe for pressure, hPa; entropy, cal/kg.grad; streamlines, 10^6 cm^2/s . First line presented run for sea-level. Second line is complex relief.

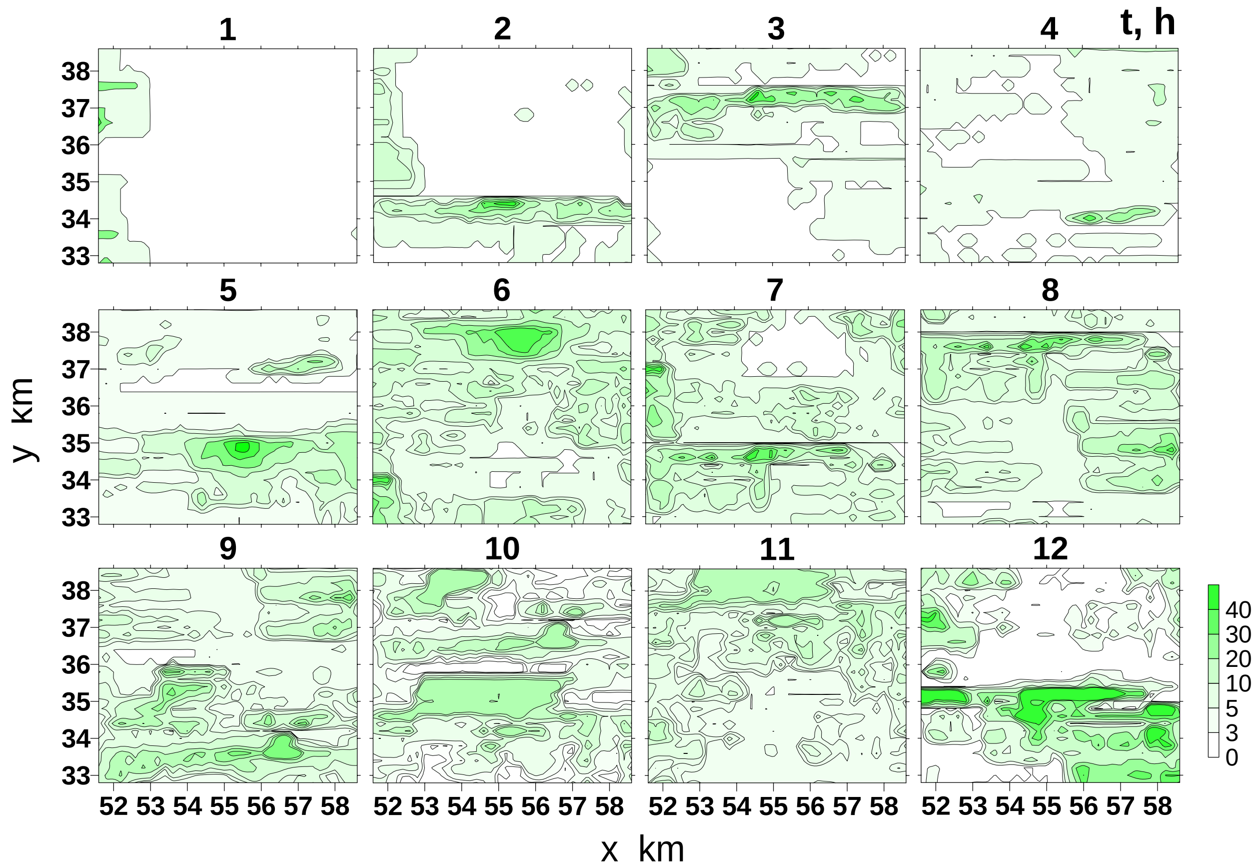

Fig. 8. Modeled evolution of precipitation intensity for v. Bogatoe.
Numbers near tops is time, h; Numbers near scale precipitation intensity, mm/h

The main feature of the distribution of microphysical properties during their evolution was the absence of crystal clouds and partially water clouds in the area in which there appeared some cumulus. Over time, these clouds, during development imbibed with a free environment for condensation and sublimation moisture turned in powerful dense formation which gave heavy precipitation. These schools get involved in a free for sublimation of water vapor stimulate grew precipitation intensity rapidly.

Fig. 8,9 shown evolution of rainfall intensity and sums in the first 12 hr. Simulated clouds limited by coagulation of crystals with drops of maximal intensity. Amounts and intensity of precipitation reached catastrophic values were determined no long-term rainfall but short-lived separate convection clusters with strong showers. Characteristic for this region is that the cloud systems were advancing on him from the east, and west, and in between them was clear air. Clouds appeared regularly in different places and gave the storm precipitation. Merging with large cloudy arrays these clouds can dissolve in them, and could intensify depending on the thermodynamic conditions of air masses over a given territory.

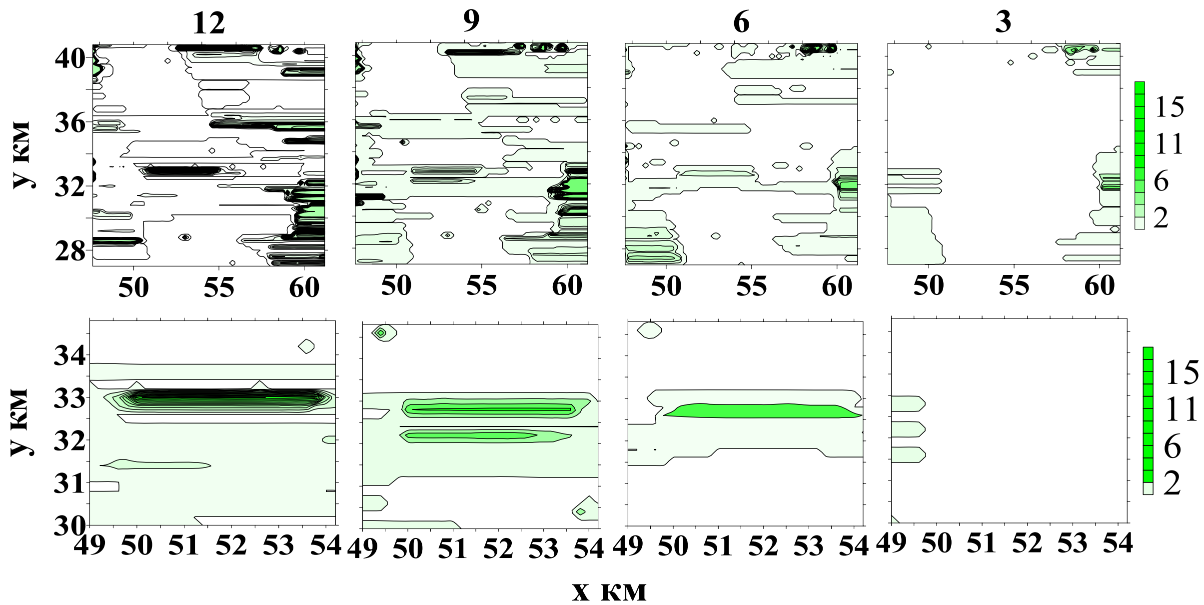

Fig. 9. The 3h amounts of precipitation during the first 12 hours of cloud development after 00 GMT of August 08, 2002 for v. Bogatoe. The numbers at the top are the deadline, hrs; figures near-scale are sums, mm.

Interaction between cloud and entropy

In Figure 10 the spatial distributions of fields of specific entropy of dry air, clouds and temperature are given (step nested grid 200 m). Time and spatial distribution of clouds agree well with the distribution of entropy and temperature. Field of minimum entropy on the ground at 158 $<x<160$ (Fig. 10b) is under strong convective clouds reached 12 km (Fig. 10 c-d). The region of maximum concentration of crystals in crystalline top coincided with the minimum entropy on earth. The sharp shift and rise of isotherms that are traced in the temperature to a height of 15 km corresponded to the powerful cloud (Fig. 10d). In these boundaries the temperature distribution has a large shift in the tropopause.

For representation of several cells or clouds necessary decrease grid spatial step. Chimney-clouds have place at x=158 km and y=10 km and caused heavy precipitation. Near this point located entropy minimum. They have high ice tops and mixed under layer. This condition let to grow ice crystal and rain drops to large size and get up to surface.

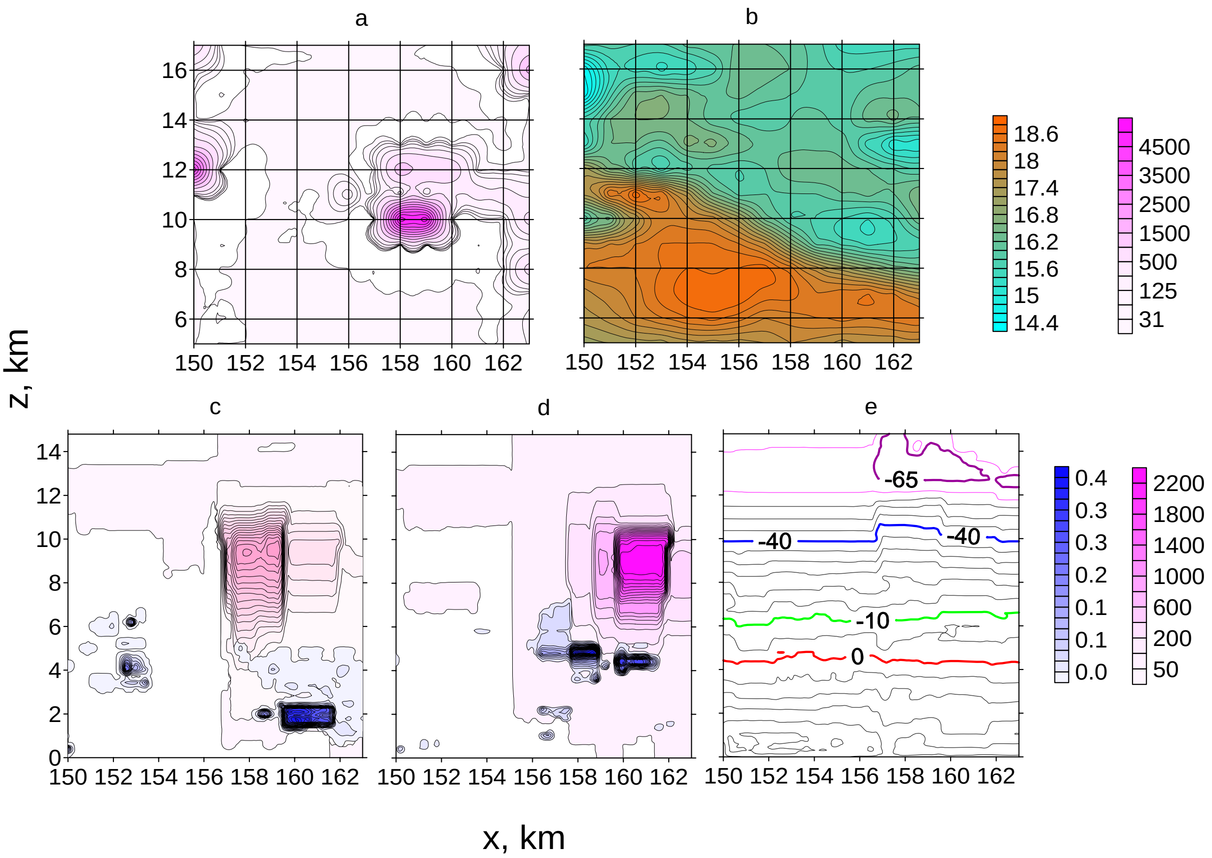

Fig. 10. Spatial distribution of clouds entropy and temperature. Horizontal step 200 m.
a) Ice cover (z-max of ice concentration 1/g); b) entropy (z=3 km, cal/g.grad, number near scale); c) ice concentration (1/g, pink color) and water content (g/kg, blue color) vertical cross sections, y= 9.8 km; d) as *c* y= 10 km; e) temperature C^{o} , number near line, y=9.8 km

Evolution of cloud and precipitation evolution in period seismic activity in Crimea region

Spatial investigations have been fulfilled with aim to study of cloud and precipitation development during seismic activity in August and September 2002 characterized by high seismic activity. A series of numerical experiments was performed to investigate the effect of anomalies of the gravitational field on the development of clouds. Including of the gravitational field anomalies is taken into account in the form of additional terms in the equations. The calculations showed, the addition of the gravity $\boldsymbol{\delta g_a}$ in the equations was the order of 10^{-2}-10^{-3} cm/s^2. It is comparable with the pressure gradient. Examples of calculations are shown in Figures 15-16 and Table. This study was devoted to response on clouds and precipitation of gravity variations (anomalies of the gravitational field).

In Figs 11–12 presented material of gravimetric survey of the Crimean peninsula [2]. A map of Bouguer's anomalies at the density (σ) of the intermediate layer of 2,3 g/cm^3 (Fig. 11) and map of residual anomalies (Fig. 12) received after their averaging in a sliding square window of 24×24 km was built. The Figs 11–.-12 show the inhomogeneous structures of presented fields. Anomalies of gravity fields (Fig. 11) varied from -200 to 120 mGal (10^{-3} cm/s^2) [2].

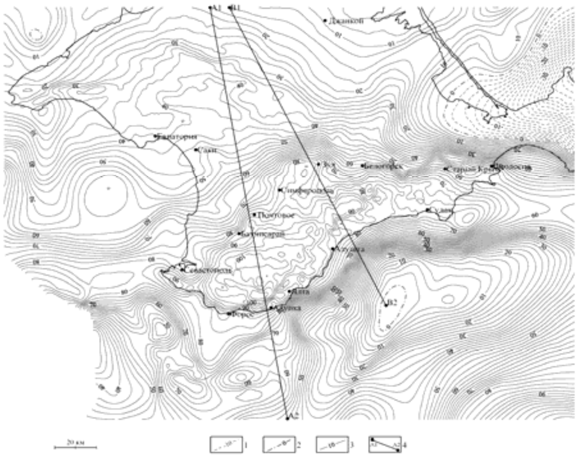

Fig. 11 Anomaly gravity field (Bouguer's) Crimean peninsula and part of the Black Sea area. 1–3 is isonomals gravity field δg_a (1 presented negative values; 2 are zero; 3 are positive value). 4 are lines computer profiles.

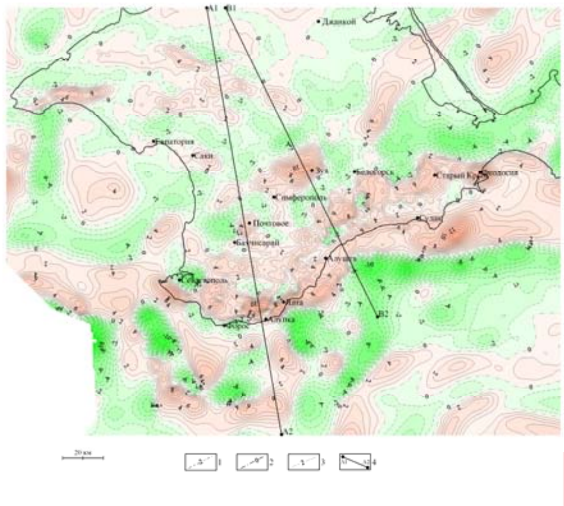

Fig. 12 Local anomalies δg_a (averaging in a sliding square window of 24×24 km). 1–3 are isoline gravity field $\boldsymbol{\delta g_a}$ (1 presented negative values; 2 are zero; 3 are positive value). 4 are lines computer profiles.

Fig. 13 presented a state of atmosphere in east Crimea at time 2002 09 28 2330 GMT near epicenter of earthquake (x= 192 km, y = 10 km) that occurred at 2002 09 29 03 h 08 min GMT.

Distributions of pressure, temperature, entropy etc shown the sharply grows of their gradients in x direction and a sharp band of *z*–maxima updrafts in *y*-direction near epicenter. In a more distant environment the pressure and temperature were more homogenous, especially in sea area.

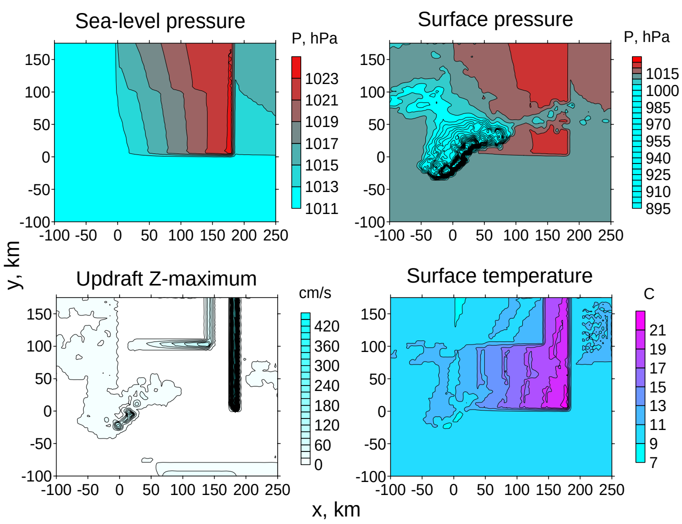

Fig. 13. Initial condition of meteorological futures near of epicenter of earthquake (x= 192 km, y = 10 km) at 2002 09 28 23 30 GMT

Table

Maxima in area ($-100 < x < 250$; $-100 < y < 150$) of the 3h sums of precipitation at different $\boldsymbol{\delta g_a}$.

Case	Time, h				$\boldsymbol{\delta g_a}$, cm/s^2
	3	6	9	12	
1	0.9	2.5	10.1	9.9	0
2	0.4	1.1	5.6	6.0	0.2
3	1.0	15.1	5.0	7.6	0.02
4	1.0	4.5	3.6	1.9	0.002
5	1.0	2.8	4.7	11.2	0.001

*Time presented the final hour of precipitation sum. $\boldsymbol{\delta g_a}$ is parameter defined homogenous distribution of gravity derivation along *x* and *y* direction

In Table the area maxima of precipitation sums for different cases presented. Size of grid selected as in Figs.13 – 15. Time *t* presented the final hour of precipitation sum. $\boldsymbol{\delta g_a}$ is parameter defined homogenous distribution of gravity derivation along *x* and *y* direction. Maximal values in Table was received for Case 3 for $\boldsymbol{\delta g_a}$ with mean value at *t* = 6 h that was the fastest**.** Cases 2, 4 provided the minimal precipitation sums. But even Case 5 with minimal $\boldsymbol{\delta g_a}$ provided the noticeable changing of precipitation.

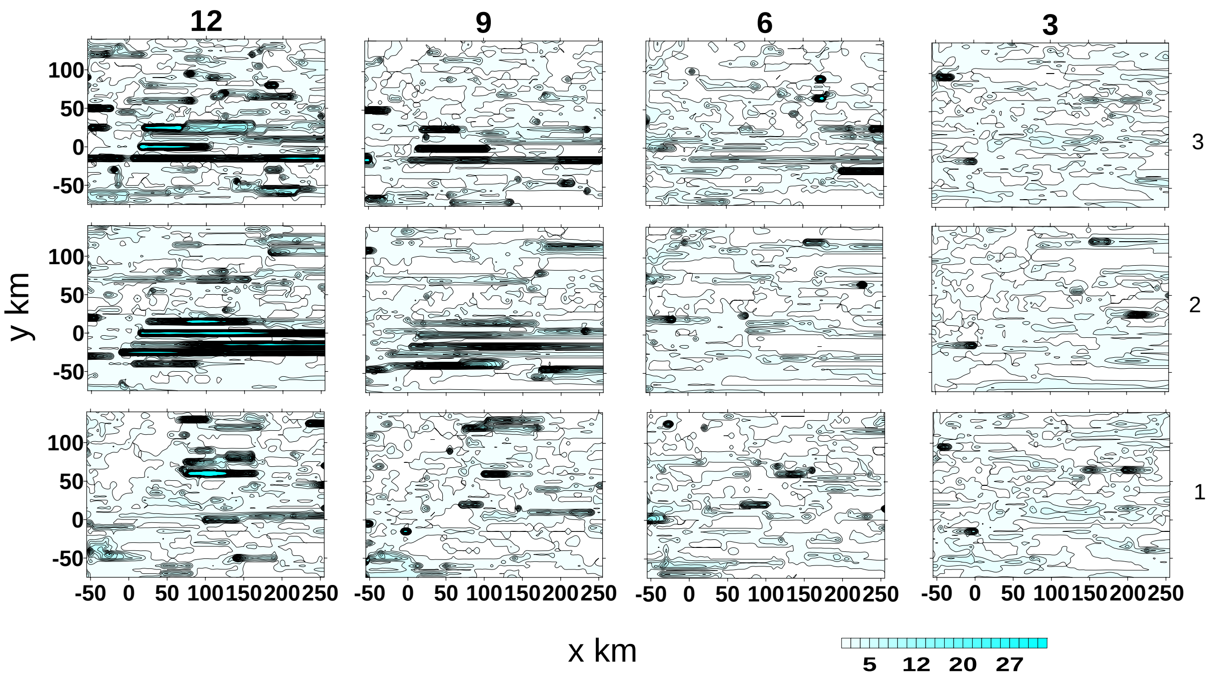

Fig 14. Evolution of clouds at different δg_a. Cloud cover is presented by sums of ice and water content z-integrals.

Numbers rows of figures correspond to rows of Table. Number near scale present the probable precipitation sums, mm. Numbers near tops are time of cloud development.

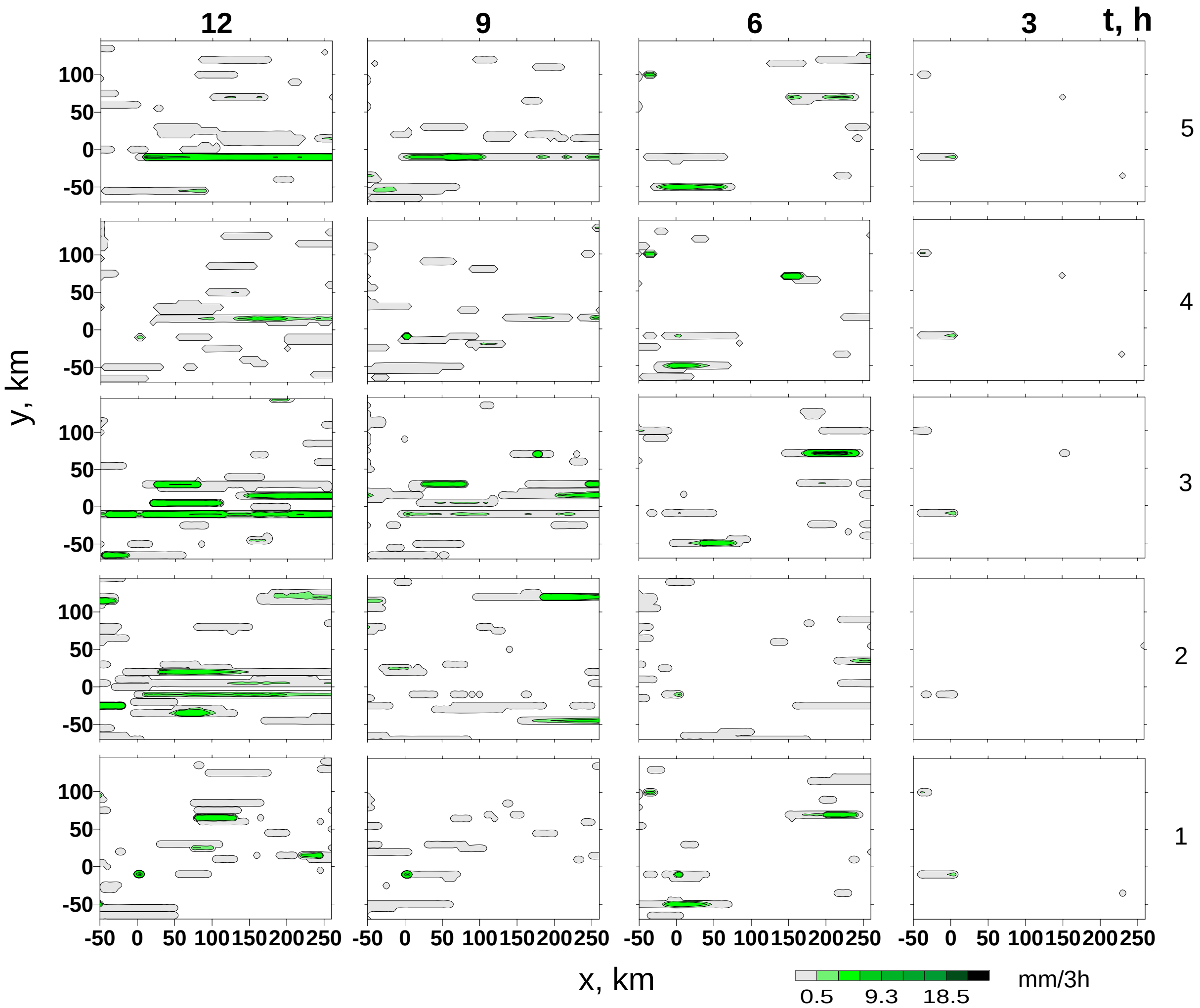

Fig 15. Evolution of the 3h precipitation sums at different δg_a

Numbers rows of figures correspond to rows of Table. Numbers near tops are dedline of sums.

Evolution of cloud and precipitation at different $\boldsymbol{\delta g_a}$ depicted band structure of cloud and precipitation at $\boldsymbol{\delta g_a}$ no equal 0. Maximal precipitation intensity was found for Case 2. In Case 3 and Case 5 bands appeared in more fast time. They have clearly defined location and small width. Certainly, homogeneous distribution $\boldsymbol{\delta g_a}$ defined rectilinear direction of band formation.

Conclusion

Numerical experiments are carried out with main goal to determine the role of various dynamics and microphysics parameters in formation of strong and catastrophic precipitation.
Some key parameters, meteorological conditions and predictors caused the occurrence of dangerous phenomena were defined as follows: interaction between flows of different physical nature coming from opposite directions; strong vortex motions in air mass advanced to study region; presence of ice supersaturation layers; special distribution of heat flows and entropy; chimney clouds with ice tops and cirrus clouds above; tropopause shear, very strong ascending and compensative descending motions; necessary combinations of precipitation-forming mechanisms.

Series of numerical experiments have been carried out with aim to research the temporal and spatial distribution of entropy and its production. Interaction between entropy and cloud and precipitation had been estimated. Response of gravity variations on clouds and precipitation was display by appearance of additional cloud and rainbands.

Some features of meteorological of cloud atmosphere in period seismic activity were discussed.

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