BLACK SEA INFLUENCE ON FORMATION OF HAIL-HAZARDOUS CUMULONIMBUS CLOUDS IN SOUTH MOLDOVA

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The space-time structure of hail-hazardous cumulonimbus clouds evolving on the sea-breeze fronts in northwestern Black Sea coast for the period of 1996-1999 is investigated with the help of MRL-5. A chart of number of days with radio echo of cumulonimbus clouds with radar reflectivity more than 65 dBZ in days with evolution of sea-breeze fronts is obtained. Statistic characteristics of sea-breeze fronts are presented.

Introduction

South part of the Republic of Moldova is located in close proximity to the Black Sea at the distance 70-100 km. It is known that vicinity of two heterogeneous underlying surfaces, for example land-sea, always leads to appearance of various mesometeorological processes, including evolution of hail-hazardous cumulonimbus clouds (Cb) which are connected with such dangerous weather phenomena as showers, thunderstorms, hail, squall [2,8].

Knowledge of conditions for formation and dynamics of evolution of these Cb is of direct interest for solution the problems of weather modification with the purpose of both decrease of losses from hail and artificial increase of precipitation.

North-western regions near the Black Sea (territory of the south-western part of Odessa province of the Ukraine and South of Moldova) in warm period of the year are characterized by high recurrence of breezes [2]. The breezes are the local mesometeorological processes evolving in coastal regions of oceans, seas, large reservoirs and rivers. Above the land, at a distance from the coast line, a convective instability line, so called sea-breeze front (SBF) is often formed. This is a convergence zone located parallel to the coast line formed as a result of interaction with the day (sea) breeze and weakened and moisty large-scale background flow from the land, where in the presence of unstable stratification cumuli and cumulonimbus clouds are evolved. The sea-breeze front is distinguished by space-time image of TV and IR pictures obtained from meteorological satellites of the Earth or by structure of field of radio-echo of cumulonimbus clouds found by radar. The sea-breeze front penetration depth defined as a distance from the coast line to the external boundary of radio-echo of cumulonimbus clouds (RECC) may reach from 50 to 200 km, covering south regions of the Republic of Moldova, including those where works on protection of agricultural products from hail are constantly carried out [6].

The purpose of the given work is to investigate space-time structure of hail-hazardous cumulonimbus clouds evolving on mesoscale sea-breeze fronts in the north-western regions of the Black Sea on the basis of radar and aerosynoptic data.

For the period (April-September) of 1996-1999 there were analyzed 139 days with evolution of breeze fronts, in 32 cases (days) radio-echo from cumulonimbus clouds with radar reflectivity more than 65 dBZ (η>65 dBZ) was observed, and besides several cases of RECC with η>65 dBZ were stated during one day.

The observations were carried out with the help of radar MRL-5 in the Kahul special department of the Special service on active influences on hydrometeorological processes of the Republic of Moldova. Photoregistration of all the radar information was carried out in the radius of 300 km in every 15-20 minutes, in the radius of 100 km - in every 10-15 minutes. For the analysis the data of radio-soundings of Odessa and Chisinau stations and charts of baric topography were used.

Main results

In works [2, 3, 6] it is shown that the sea-breeze fronts evolve in weakened field of general circulation of the atmosphere, in unstably stratified and moisty air mass, and in 56% cases come on small-gradient baric fields of high and low pressure. The large-scale background flow is characterized by weakened westerly, north-westerly and northerly winds with the modal velocity 4-7 m/s in the stratum of 850-500 hPa, i.e. by seaward winds that provided divergence of air flows and intensification of convection in the zone of sea-breeze front. In work [3] there was estimated the value of horizontal divergence of wind velocity while sea-breeze front evolving for north-western regions of the Black Sea on the basis of radar measurements of RECC area in the grid 30x30 km from the plan-position indicator (PPI) of the radar MRL-5. The divergence order appeared to equal 10^{-4} s^{-1} being comparable with its value at macroscale atmospheric frontal passage. In the convergence regions (negative divergence) maximal values of radar parameters of RECC are determined.

For the north-western coast of the Black Sea the penetration depth of sea-breezes averages 20-25 km [2, 3]. Average number of days with breezes is 58, but it may oscillate from 50 to 78 [2]. Table 1 shows recurrences of time of RECC appearance on the sea-breeze fronts (A) and time of appearance on them of RECC with radar reflectivity η>65 dBZ (B). It is seen from Table 1 that sea-breeze fronts most often evolve in the period from noon to 2 p.m. (50.4%), i.e. in the period of maxima evolution of the day (sea) breeze. Hail-hazardous cumulonimbus clouds most often evolve from 4 p.m. to 6 p.m. (50.5%).

Table 1. Recurrence (%) of time of appearance of RECC (A) and RECC with radar reflectivity η>65 dBZ (B) on the sea-breeze fronts for the period of 1996-1999

		Gradation, hour						Sum
		10-12	12-14	14-16	16-18	18-20	20-22	
A	Number of cases	31	70	30	7	1	-	139
	Recurrence, %	22.3	50.4	21.6	5.0	0.7	-	100
B	Number of cases	-	18	44	79	49	5	195
	Recurrence, %	-	9.2	22.6	40.5	25.2	2.5	100

Note. Discrepancy of number of cases of RECC with η>65 dBZ and number of days with the sea-breeze fronts is explained by the presence of several cases of RECC with η>65 dBZ in the same day.

Table 2 presents the results of radar observations of the sea-breeze fronts for the mentioned period. Table 2 data show that in the breeze period for the north-western regions of the Black Sea coast on the average in 59.9% cases RECC evolution on the sea-breeze fronts is observed, in 23.5% cases of them evolution of RECC with radar reflectivity η>65 dBZ is registered.

It follows from tables 1 and 2 that not all breeze circulations are accompanied by formation cloudy band of RECC. It is obvious in this case that there is absent one of the mentioned conditions: the ascending branch in the breeze cell, instability of the atmosphere and convergence of air flows in the sea-breeze front zone.

Table 2. Results of radar observations of the sea-breeze fronts in the north-western region of the Black Sea for the period of 1996-1999

Years / Denomination	1996	1997	1998	1999	Sum	Average
Number of days with SBF	36	38	35	30	139	34.7
Number of days with RECC on SBF with η>65dBZ	5	6	12	9	32	8.0
Recurrence (%) of ratio of number of days with RECC on SBF with η>65dBZ to number of days with SBF	13.9	15.8	34.3	30.0	94.0	23.5
Recurrence (%) of ratio of number of days with SBF to average number of days with breezes	62.1	65.5	60.3	51.7	239.6	59.9

In work [6] a chart of number of days with RECC in the radius of 300 km in days with evolution of the sea-breeze fronts with the value of radar reflectivity above 12 dBZ with resolution 30x30 km is obtained. However, practice of anti-hail protection requires construction of a chart of number of days with radar reflectivity above 65 dBZ, but with higher space resolution in order to reveal general regularities of distribution of hail-hazardous cumulonimbus clouds evolving on the sea-breeze fronts. Taking into account the fact that radar parameters of hail-hazardous cumulonimbus clouds for MRL-5 are most representatively measured in the radius 100-150 km, this chart was constructed in the radius of 100 km from the radar location. The investigated territory of the north-western regions of the Black Sea was divided into squares 10x10 km. In the coordinates "azimuth-range" all cases with radio-echo from the hail-hazardous cumulonimbus clouds with radar reflectivity η>65 dBZ were plotted and they were summed up in each square for the period of four years. Then isolines of equal values of number of days with RECC were drawn (Fig.1).

The chart analysis shows that distribution of the number of days with RECC with the radar reflectivity η>65 dBZ is characterized by high spotted in both directions perpendicular and parallel to the coast line. It is seen from Fig.1 that the sea breeze penetration depth averages 20-25 km, and the distance between the maxima centers is multiple by 25 km, i.e. by the sea-breeze penetration depth.

If one unites the maxima centers, the obtained picture will resemble meso-scale cellular structure of thunderstorm-hail processes, in the units of which maxima of number of days of RECC with η>65 dBZ are registered (Fig.1-b).

Thunderstorm-hail process (THP) is a process of evolution of cumulonimbus clouds (scale of several hundreds kilometers) of frontal or air-mass character in the atmosphere leading to formation of thunderstorms, showers, hail, squall. Methods for obtaining and analysis of thunderstorm-hail processes are given in [5, 6].

In works [3, 6] it is shown that the convergence zone formed in result of interaction between seaward background flow with breeze circulation varies in time and covers the coast strip (100-150 km), where in the presence of unstable stratification Cb evolve. The convergence zone width and its value depend on characteristics of both large-scale background flow and breeze [8]. In this zone there are formed meso-scale circulation systems of movement of the Benar open cell type (meso-β-scale), which exist during several hours. Appearance of new Cb and evolution of already existing Cb on the sea-breeze fronts occur in the zones of updrought of regular structures with characteristic size of mesocells in the RECC field 30-40 km horizontally [6]. In work [5] there is made a conclusion on determinacy of atmospheric processes of meso-γ-scale, i.e. cloud-scale, by circulations of meso-β-scale. Existence of these circulations against the background of larger scale determines limits of predictability of meso-γ-scale processes [5]. Meso-scale movements are classified according to [9].

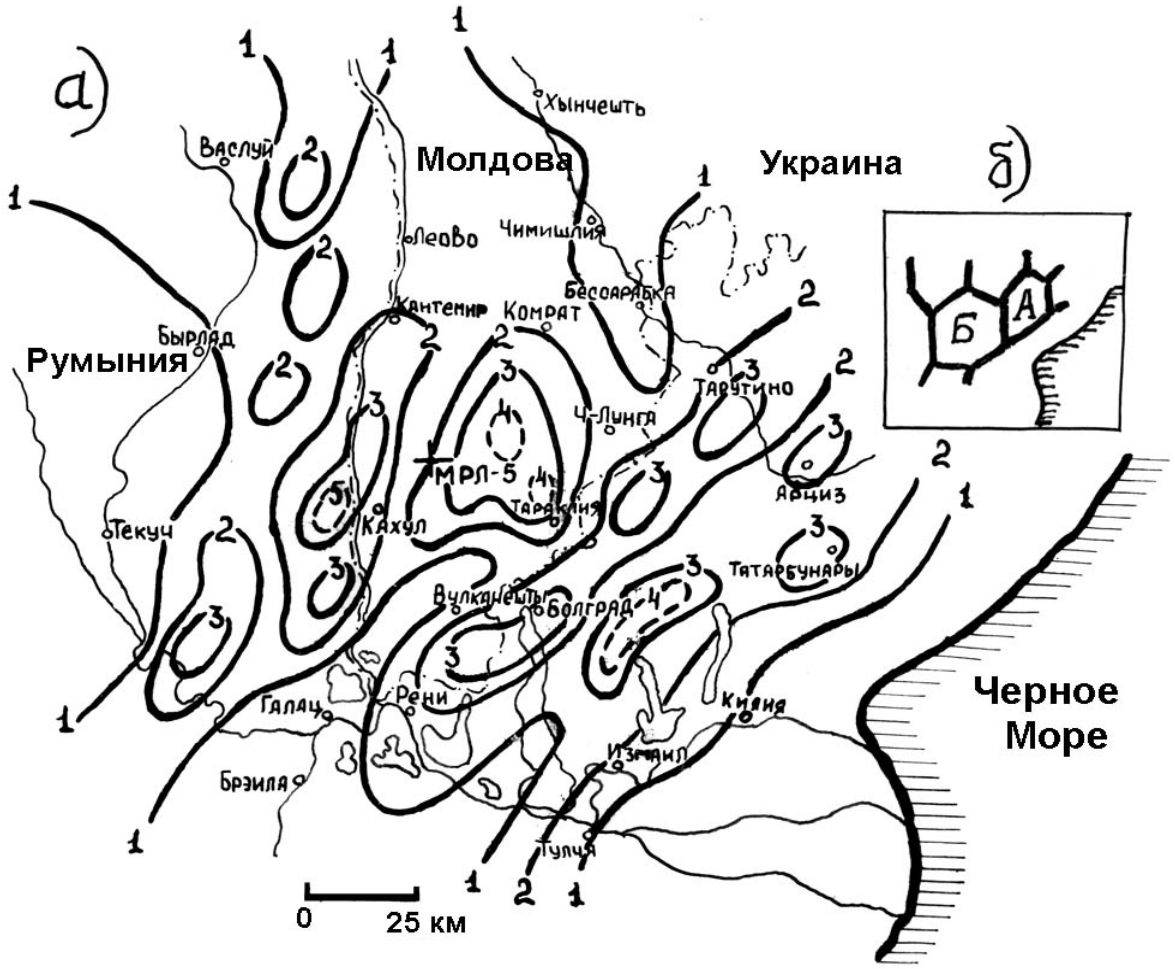

Fig.1. Chart of number of days of RECC with radar reflectivity η>65 dBZ in the days with evolution of the sea-breeze fronts for the period of 1996-1999 in the radius 100 km (a) and scheme of meso-scale cellular structure of maxima of number of days of RECC with η>65 dBZ (b). Average diameter of mesocell A is 40 km, of mesocell B - 60 km. Location of the radar МРЛ-5 is marked by cross.

Meso-scale cellular structure of cumulonimbus clouds evolution is the most obviously pronounced at weaken background flow characterized by small values of velocity of steering flow and vertical shear of wind with height (no more than 1 m/s per kilometer all over the troposphere) [7], this being typical for aerologic structure of the sea-breeze fronts [2, 3, 6].

In this case average diameter of mesocell A is 40 km, and that of mesocell B - 60 km (Fig.1-b). In central parts of mesocells number of days of RECC with η>65 dBZ is less than along the sides and in units of the meso-scale net, i.e. for meso-scale processes of this type, regions of maxima of number of days of RECC with η>65 dBZ are geographically determined by higher recurrence of hail-hazardous cumulonimbus clouds than in neighboring regions. This property must be taken into account for planning of anti-hail protection system and for estimation of efficiency of active influences. In the South of the Republic the maxima distribution of number of days of RECC with η>65 dBZ is located in its central part between the towns Kahul, Taraklia, Chadyr-Lunga and in the lower part of the near-Prut lowland.

It should be noted one more ecological peculiarity concerning the problems of the sea-breeze fronts. Contaminants carried by night (coast) breeze to the sea area, in the day-time with day (sea) breeze evolving may be carried back to the coast zone, where being drawn into the processes of cloud-precipitation formation, may deposit on the surface of the Earth. In the zones of maximum of number of days of RECC with η>65 dBZ level of contamination is expected to be higher than in neighboring territories.

The results given in Fig.1 are in a good agreement with the data presented in [4], where a chart of average annual number of days with hail in the south-western Odessa region was obtained taking into account all types of thunderstorm-hail processes evolving in this region.

Table 3. Recurrence (%) of time of RECC existence with radar reflectivity η>65 dBZ on the sea-breeze fronts for the period of 1996-1999

Denomination	Gradation, min					Sum
	1.0-3.0	3.5-5.0	5.5-7.0	7.5-9.0	> 9	
Number of cases	94	37	27	20	17	195
Recurrence, %	48.2	19.0	13.8	10.3	8.7	100

Note. Discrepancy of number of cases of RECC with η>65 dBZ and number of days with the sea-breeze fronts is explained by the presence of several cases of RECC with η>65 dBZ in the same day.

Table 3 presents recurrence of time of existence of RECC with radar reflectivity η>65 dBZ on the sea-breeze fronts. It is seen from Table 3 that the highest recurrence of existence of RECC with η>65 dBZ falls on gradation 1.0-3.0 minutes (48.2%). Only 8.7% cases fall on gradation >9 minutes. Area of the RECC with radar reflectivity η>65 dBZ near the Earth changes within the limits of $1 \div 10$ km^2 (100-1000 ha), and the longer existence of RECC with η>65 dBZ the larger the area.

For practice it is very interesting to reveal direction of evolution of hail-hazardous cumulonimbus clouds relative to the steering flow, i.e. the direction wherein new hail convective cells appear. For the steering flow the velocity and direction of wind per 600 hPa was taken [7]. For this purpose 20 of hail-hazardous cumulonimbus clouds with convective cells reaching η>65 dBZ were studied. The results are given in Table 4.

Table 4. Recurrence (%) of directions of evolution of hail-hazardous cumulonimbus clouds relative to the steering flow

Denomination	To the left of the flow	To the right of the flow	Upflow	Downflow	Sum
Number of cases	3	5	10	2	20
Recurrence, %	15	25	50	10	100

It is seen from Table 4 that direction of evolution of hail-hazardous cumulonimbus clouds may occur in any direction relative to the steering flow; however prevailing evolution (50%) is found at upflow evolution.

Analysis of 139 studied the sea-breeze fronts has shown that in all the cases one-cell (8%) and multi-cell disordered (92%) thunderstorm-hail processes (THP) are evolved on them. Super-cell and ordered multi-cell THP have not been found in the studied cases. This is connected with a certain thermobaric structure of the atmosphere in days with evolution of the sea-breeze fronts, when there are absent vertical wind shears with height both in direction and velocity typical for super-cell and multi-cell ordered THP. The classification of THP is given by [1].

Conclusions

The results of the carried out investigations allow us to make the following conclusions:

1. The sea-breeze fronts are the most frequently shown in the period from noon to 2 p.m. (50.4%), and hail-hazardous cumulonimbus clouds evolving on them from 4 p.m. to 6 p.m. (40.5%).
2. In the breeze period for the north-western regions of the Black Sea in average in 59.9% cases RECC evolution on the asea-breeze fronts is observed, in 23.5% cases of them evolution of RECC with radar reflectivity η>65 dBZ is registered.
3. The chart of number of days of RECC with radar reflectivity η>65 dBZ in the days with evolution of the sea-breeze fronts for the period of 1996-1999 in the radius 100 km is obtained. The chart has meso-scale cellular structure with characteristic linear horizontal size of 40 and 60 km, in its units maxima of number of days of RECC with η>65 dBZ are observed.
4. The highest recurrence of existence of RECC with η>65 dBZ falls on gradation 1.0-3.0 minutes (48.2%). Only 8.7% cases fall on gradation >9 minutes.
5. Direction of evolution of hail-hazardous cumulonimbus clouds may occur in any direction relative to the steering flow, however prevailing evolution (50%) is found at evolution up flow.
6. On the sea-breeze fronts in the north-western regions of the Black Sea one-cell (8%) and multi-cell disordered (92%) THP are evolved. Super-cell and ordered multi-cell THP have not been found in the studied 139 cases.
7. In the south of the Republic the maxima distribution of number of days with RECC with η>65 dBZ is located in its central part between the towns Kahul, Taraklia, Chadyr-Lunga and in the lower part of the near-Prut lowland.

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