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TRAJECTORIES OF HAIL CELLS WITH POTENTIAL OF GENERATING HAILSTORMS IN MOLDOVA IN 2016-2017

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Abstract. Hail is one of the most damaging weather phenomena. Inflicted damage affects mostly agriculture, but also human settlements. The effects produced are mainly due to the size of the hailstones and the amount of fallen ice and, of course, to the vulnerability of the territory in which it occurs. The average number of hail days in Moldova increases from less than 1 day / year in the Barlad Plateau to over 6 days a year on the high mountain peaks. Studies at national or regional level in Romania have not addressed the problem of trajectories of hail cells with potential of generating hailstorms. In addition to literature references, weather data from the ground, synoptic maps and satellite images for the warm seasons of the two years have been used. In the two observation seasons (15 April-15 October) of the years 2016 and 2018 for the analyzed territory, a number of days with similar convective cells were observed, 51, respectively 53. The direction of southwest movement (33%) dominated, followed by the northwest direction.

Introduction

Hail is one of the most damaging weather phenomena. Inflicted damage affects mostly agriculture, but also human settlements. The effects produced are mainly due to the size of the hailstones and the amount of fallen ice and, of course, to the vulnerability of the territory in which it occurs. The average number of hail days in Moldova increases from less than 1 day / year in the Barlad Plateau to over 6 days a year on the high mountain peaks.

Previous studies have not addressed the issue of trajectories of potentially hail-producing cells. The problem of the hail phenomenon in the Romanian climatological bibliography had different directions of approach. The first Romanian scientific paper regarding hail was published by Șt. Hepites in 1882.

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First of all, hail was generated in most cases from central systems, so of a a real use have been studies in dynamic meteorology at continental, national or regional level, such as Doneaud, 1957, 1958; Șorodoc, 1962; Struțu, 1966; Bălescu and Militaru, 1967; Beșleagă and Grimani, 1974; Struțu and Militaru, 1974; Drăghici, 1980; Ion-Bordei Ecaterina, 1983; Apostol, 1997, etc. Aspects of convection and atmospheric instability involved in the process of hail genesis have been addressed by Hârjoabă and Crețu, 1984; Sfăcă et al., 2015; Istrate et al., 2015, 2016. Hârjoabă and Crețu (1984) consider that east of the Eastern Carpathians only a very small amount of rainfall (about 3%) of the annual sums is produced during local convective phenomena, but their importance in the production of hail is decisive. The general characteristics and the spatial distribution of hail in Romania are analyzed in the works of *The Geographical Monography of Romania (1960)*, *Climate of Romania (1962)*, *Geography of Romania, volume I (1983)*, *Climate of Romania (2008)*, *Iliescu and Popa (1983)*, *Istrate et al. (2017)*. Unfortunately, a monograph on hail at the national level has not been written yet. The general characteristics and spatial distribution of hail in different regions of Moldova were analyzed in climate monographs by Mihăilescu, 2001; Apostol, 2002, 2004; Mihăilă, 2006; Rusu (ed., 2007); Machidon, 2009; Sfăcă, 2015 etc. Analyzes of hail are also present in climate monographs on some Moldovan cities, such as those developed by Erhan, 1979; Larion-Precupanu, 1999; Vieru, 2014 and others. Other works on the characteristics of hail and its distribution in different areas were further elaborated by Gugiuman, Chiriac, 1956; Erhan, 1986; Apostol, Machidon, 2009, 2010, 2011, 2011 a, 2011 b and others. Recently, with the construction of the national hail protection and precipitation incentive system, papers have been published on hail avoidance methods by Machidon, 2006; Istrate, 2016; Axinte et al., 2017 and others.

Methodology

The study is based on the multiple analysis of traces of hail-producing cells on the territory of Moldova during the warm (convective) period, for the period 15 April-15 October 2016 and 2017. Hailstones are rarely occurring outside this range. A series of data, satellite imagery, synoptic maps, maps of thunderstorm phenomena, extracts from the websites: www.ogimet.com, www.wetterzentrale.de, <http://eumetsat.int/>, <http://gis.ncdc.noaa.gov/>, http://en.blitzortung.org/live_dynamic_maps.php, www.sat24.com, <http://www.inmh.ro/>, www.lightningmaps.org. The target parameters were followed each year during 183 days of the season. The number of days and trajectories of the convective cells in Moldova were monitored for each month. The study has analyzed the areas of convection of orographic nature, the manifestation

of simple, multicellular and supercellular cell systems, the number of days with convections, the specific trajectories and their frequency.

General aspects

Genetic factors involved in the genesis of convective cells are the same as those

of the climate: solar radiation, the active surface and the general circulation of the atmosphere.

The dynamics of the atmosphere brings changes in the state of time from one moment to the next, so different aspects of the weather over the region of Moldova, as well as the trajectories of the convective cells, are given by the position that the baric centers have in relation to it. Thus, if the dorsals of the two anticyclones are located to the north, they contribute to cold air coming from the north and northeast. If located south, the territory is invaded by hot and humid air from the south and southwest.

The main factors influencing the active area are the relief and the presence in the south-west of the Mediterranean Sea. First of all, the Eastern Carpathians have a role as a barricade for western cyclonic trajectories. The high-altitude relief located west of them (the Apuseni Mountains, the Alps and the mountainous chains of Central and Western Europe) block the Atlantic trajectories from the west, their influence being lower, being present on the trajectories north of the Carpathian chain. Cyclones formed in the Central and Western Mediterranean move generally to the northeast, and their trajectories are influenced by the mountainous systems of the Balkan Peninsula and the Carpathians. The Black Sea is the area of regeneration of some Mediterranean cyclones who reach this area, some of them receiving retrograde trajectories that cross Moldova. Rarely, small-scale retrograde cyclones are also generated in the ponto-caspian steppe.

Altitude is a feature of the relief strongly involved in the genesis of hail, through orographic convection. In local convection phenomena are involved both the major relief as a barrier to wet air masses and the local active surface characteristics, such as altitude, slope orientation with respect to the position of the Sun and the displacement of air masses, slope degree and landform shape type (concave, convex, flat).

Results

In the studied region, located in the temperate climate zone between the 45° and 48°N parallels, the occurrence of convective cells is approximately half of the total number of days a year. The convective orographic areas are mainly in the Eastern Carpathians and east of them, up to the Siret Corridor.

After analyzing data from the two years, a high frequency of days with hail generating cells has been observed in the May and June seasons of season change, with an average of approximately 13 days for each of the two months of convective activity. As an average for the two "convective" seasons analyzed from 2016 and 2017, an average of 52 days with potentially hail generating cells was recorded.

In the case of trajectories, the general western circulation influences the movement of thunderstorm cells, along with the cyclonic trajectories and the position of the frontal systems within the respective cyclones. The two main directions of travel are on western components, SW-NE with an average of 34%, especially in the case of Mediterranean cyclones, and NW-SE, with a frequency of 24%, situation present especially for the Atlantic cyclones. The frequency of circulations on the W-E trajectory is largely influenced by the Eastern Carpathians, positioned perpendicular to this direction, the mountain chain influencing the formation, discharging and dissipation of the cells in most situations. Thus immediately east of the Eastern Carpathians, in most of the situations the convective systems have a local character and are discharged up to Siret River. The western direction has the frequency of 18%. In some situations, cellular systems are reloaded up to the Siret valley, and can be diverted from the original trajectory by the nordic currents arising from the deflection of the western movement north of the Carpathians, through the Coandă effect, which diverts the western currents along the Northern Carpathian curvature (Bordei-Ion, 1983; Apostol, Sfică, 2011). In the other situations, they are based on synoptic circumstances specific to retrograde Mediterranean depressions or to the situations of altitude cold air depressions (cut-off low) in the south of Moldova, situations that can generate heavy rainfalls on large surfaces and retrograde trajectories of the convective systems.

In the warm season of 2016, there were 51 days of potentially hail-producing convective cells, accounting for 27.9% of the total days of the interval, the highest percentage being registered at the end of spring and early summer, with 7.6% both in May and June (Table 1).

Tab 1. Number of days with convective cells and their percentage during 2016

2016	April	May	June	July	August	September	October	Total
Nr. days	3	14	14	7	9	3	1	51
% of 183	1.64%	7.65%	7.65%	3.83%	4.92%	1.64%	0.55%	27.88%
% of 51	5.88%	27.45%	27.45%	13.73%	17.65%	5.88%	1.96%	

Dominating are the SW-NE (33%) and NW-SE (24%) trajectories, the high percentage being given by Mediterranean cyclones and the lack of a major

orography on this route of moving atmospheric fronts. The situation of the E-W and especially NE-SW trajectories is attributed to the retrograde depressions from the Black Sea area (Figure 1).

In the 2017 season were registered 53 days with potentially hail-generating cells, compared to 51 in 2016. The western sector has grown a bit more, with an 18% percentage of the W-E circulation, 10% higher than in 2016. The same thing can be seen in the SW-NE trajectories, with a 35% value, the highest frequency being recorded on this direction, of 2% compared to the 2016 season. The circulations in the NW sector remain the same, but we notice a reduced oscillation of trajectories involving retrograde cyclones, with values reaching 0 for S-N and E-W trajectories (Table 2 and Figure 1).

Tab. 2. Number of days with convective cells and their percentage during 2017

2017	April	May	June	July	August	September	October	Total
Nr. days	2	11	12	13	8	6	1	53
% of 183	1.09%	6.01%	6.56%	7.10%	4.37%	3.28%	0.55%	28.96%
% of 53	3.77%	20.75%	22.64%	24.53%	15.09%	11.32%	1.89%	

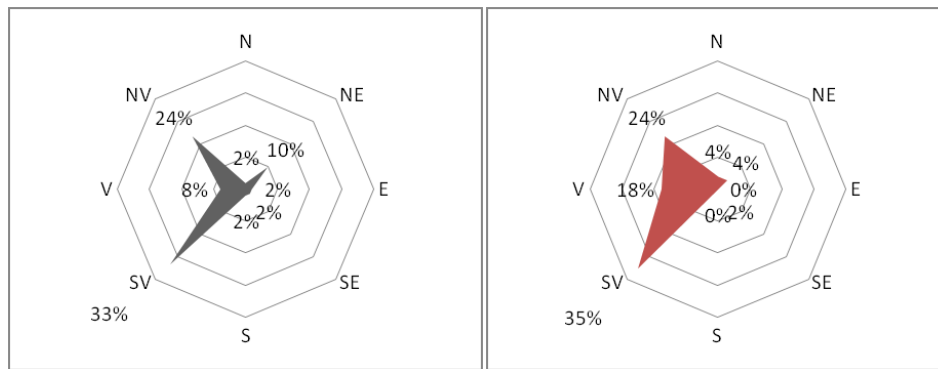


Fig. 1. The trajectories of potentially hail-generating convective cells during the warm seasons of 2016 (from 51 days recorded, a) and 2017 (from 53 recorded days, b).

The situation in the warm seasons of the two years presents similar aspects in the territory, any part of it having the same hail production chances and of being crossed by convective cells with hail potential. The situation also occurred in the mountainous area, but here the frequency of the episodes increased directly in relation to altitude. Even though the mountainous area has a high percentage of

hail-days, the phenomenon is not a major risk, since the more frequent hail episodes do not cause major damage than in localities, the arable land being reduced in surface, and in the high areas, where the hail frequency exceeds 5 days a year, there are no crops nor localities.

Some different situations of potentially hail-generating cells' behaviour

The convective episode from 15-16 August, 2016. The days of 15 and 16 August 2016 were characterized by a generally unstable weather in Romania and, implicitly, over the territory of Moldova. At European level, the Azores High peak expanded northward, covering the British Archipelago, while over the center and east of the continent were active low pressure areas, detached from the polar lows (Figure 2).

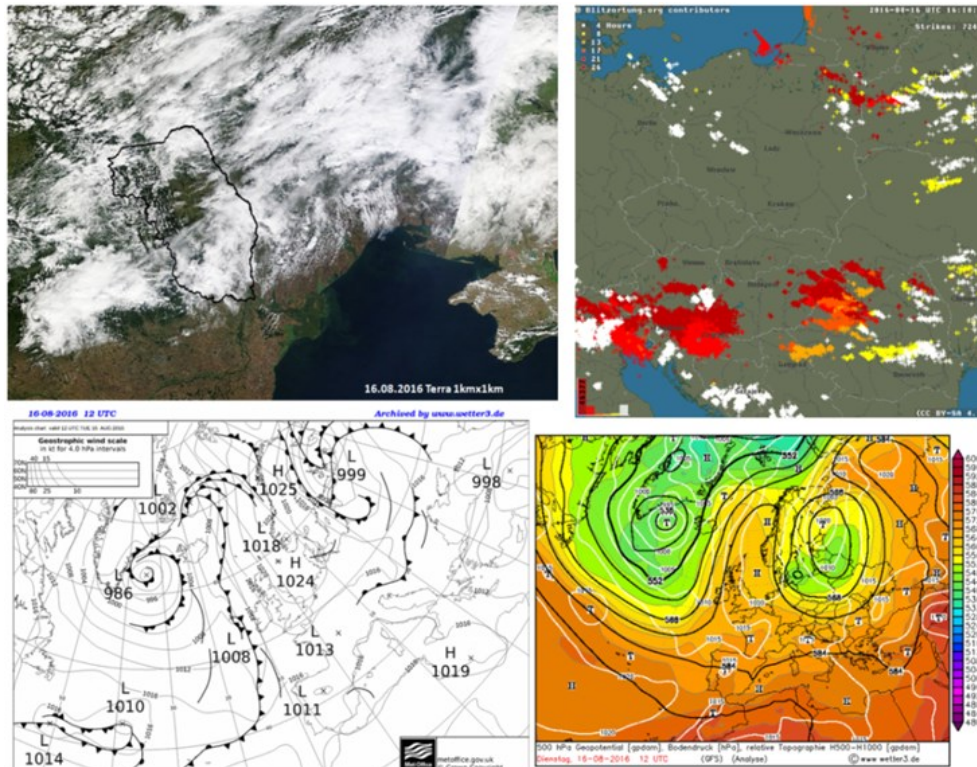


Fig. 2. System of ordonated cells; the synoptic context and the position of the convective systems and thunderstorms in Europe and Moldova, 16.08.2016

This weather-synoptic context favored Moldavia for an unstable time, especially during the afternoons. Atmospheric circulation during the two days was a predominantly Western-North-Western one, which also trained a sea-polar air mass (mP). As a result, in such a mass of cold and unstable air, some convective cellular systems have obviously materialized. Over Moldova, the arrangement of these convective structures was one from the west to the east, an important factor being represented by the Carpathian chain (fig.6), by those orographic initiations, since the masses of air had a predominantly western, even north-west circulation.

The convective episode from 21-22 August, 2016. In the south-eastern and even central-eastern part of Europe, the reference interval was under the domination of a Mediterranean depression system, which later regenerated itself in the Western Black Sea basin (Figure 3). Because over the Russian Plain and the central part of Europe were active high-pressure areas, the mentioned depression core had a retrograde trajectory. On that synoptic component, the direction of air mass movement was dominantly east-north-eastern, on a cyclonic characteristic.

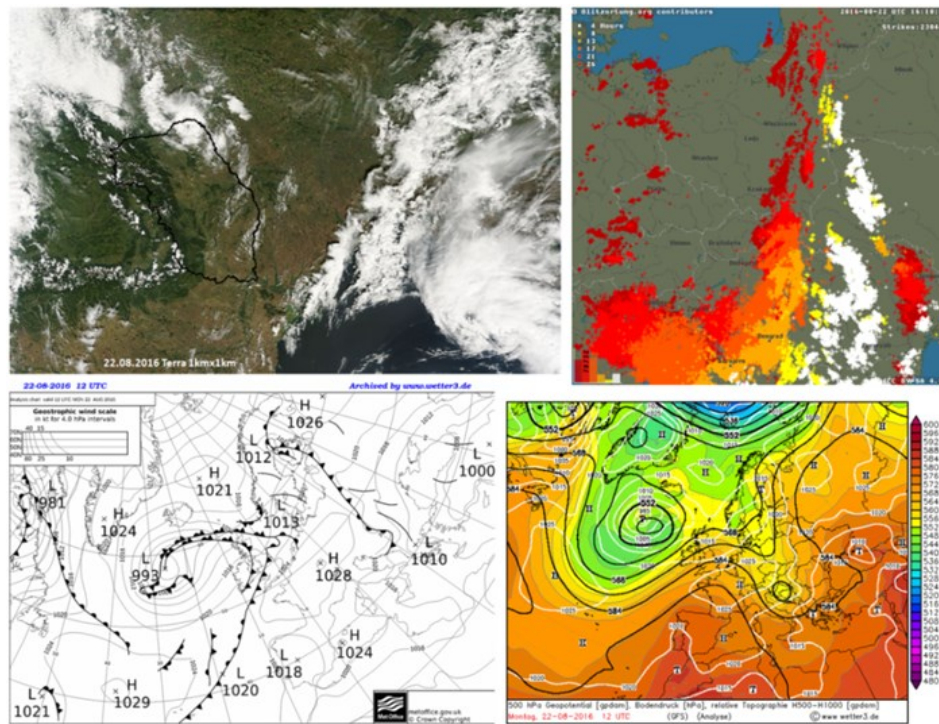


Fig. 3. Complex cells with multi-cellular character; synoptic context, the position of the convective and thunderstorm system in Europe and Moldova, 22.08.2016

Since the advected air was warm and rich in moisture, the degree of instability was quite high during the days of August 21 and 22. Moreover, overlapping the electric discharges and the satellite image, the presence of pronounced convective manifestations over most of Moldova can easily be seen. Definitely, the degree of instability was even higher in the contact area between the plateau areas and the eastern part of the Eastern Carpathians, with significant amounts of water being recorded. The first convections started from the NE of the region (see the satellite image), due to the convergence lines in front of the cold front that was to cross the region. In the image of the thunderstorm events' recordings, one can observe the large number of potentially hail-producing convective cells that crossed the territory simultaneously with the synoptic situation by moving the cold front towards the SE (Figure 3).

The convective episode from 2-3 September 2016. The first days of the fall of 2016 were characterized by an anticyclonic regime in the lower and middle troposphere. This has been proven by both the geopotential maps at 1000 hPa (valid for the lower troposphere, near the surface of the soil) as well as those from 850 hPa and 700 hPa (valid for the middle troposphere, between 2500 and 4500 m altitude for the latitude of Moldova). Instead, in the upper part of the troposphere have been present nuclei of cold air, cut-off lows, detached from the baric lows in the subpolar area. Since at the soil level dominated an anticyclonic regime, the first part of the days of 2 and 3 September 2016 was characterized by a high degree of radiation heating. The territory of Moldova was at that time on the northeast of that anticyclonic system, the air mass circulation being quite slow, on a west-north-western component (Fig. 4).

Once the ground air mass was heated, it showed a convective motion, encountering the cold air portions associated with those cold air nuclei detached from the subpolar low depressions. Once this process has been accomplished, convective cloudy systems have been felt in Moldova. Still, on the background of previously rainfall-lacking days, the degree of saturation in moisture of the volume of air that exhibited convective movements was poor in most parts of Moldova. As illustrated in fig. 4, which represents the arrangement of thunderstorm phenomena in Moldova, a segment with some electrical activity is identified on the eastern frame of the Eastern Carpathians. There were two key factors: a more satisfactory water supply and the proximity of mountain areas, ideal for orographic initiations, since the air mass circulation in those days was one of the Northwestern sector.

The convective episode from 23 June 2017. This instability episode was one of the most representative during the entire convective season of 2017. Its manifestation took place in a period characterized by episodes of instability in Moldova, namely, the last decade of June. In fact, June is climatically characterized as the most unstable month of the year.

The instability of 23 June 2017 followed some long, warm and humid days that characterized the territory of Moldova. At that time, hot, humid air advections mainly from the south-western sector, on the warm sector of some Atlantic depressions, were present (Figure 5). Thus, the volume of transported air was warm and damp, ideal both for mass instability, where the mountainous areas had also an influence, through orographic initiations. Thus, during the days of 22-23 June 2017, the Atlantic depression system migrated to the central part of Europe. In the first phase the baric gradient increased, as well as the movement velocity of the air masses from the southwest, being involved a higher hot and humid air volume, on a Southwest component. However, on the afternoon of June 23, 2017, the depression system in question was centered on the East of the German-Polish Plain. The positioning of the depression system near the Baltic Republics led to a sudden change in the movement

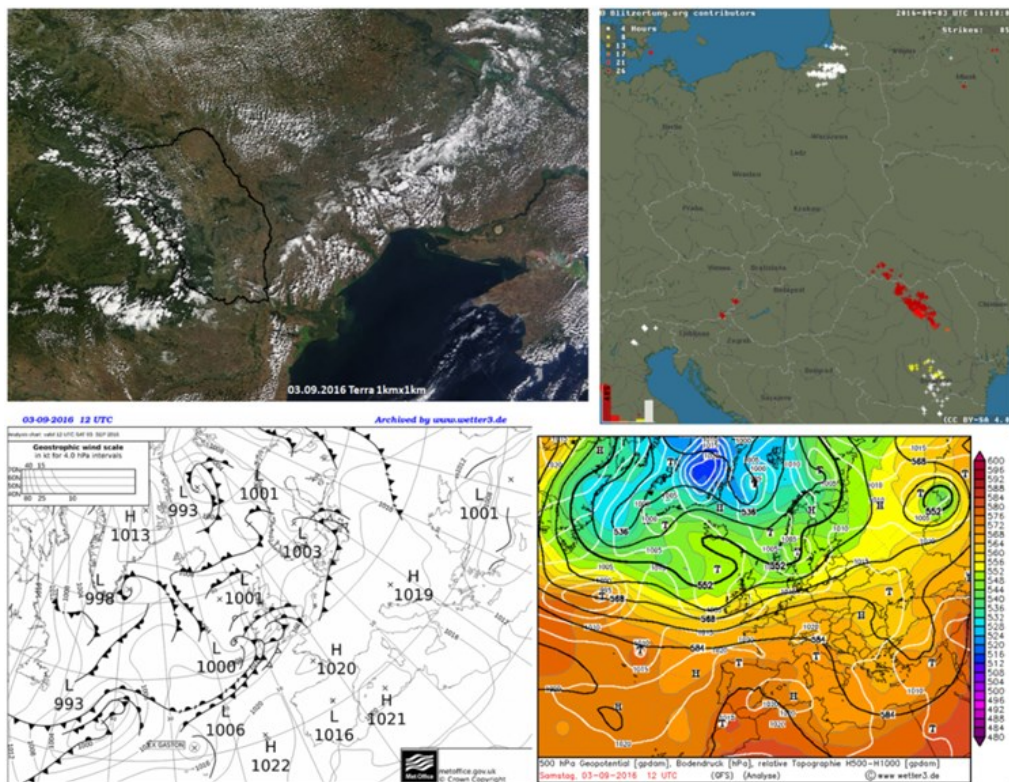


Fig. 4. Local orographic convections; the synoptic context, the position of the convective systems and of the thunderstorms in Europe and Moldova, 03.09.2016

of air masses in Moldova and its surroundings from the northwest. With this change in the direction of movement of the air masses, a cold air was also conveyed, associated with a cold, second-order atmospheric front. The rapid advancing of the cold front to the east and southeast entered very easily over the north of Moldova, as there are no mountain areas to stop or slow down the advent of cold air. As a result, the dislocation of the pre-existing warm and humid air was realized very quickly and was also materialized by intense and very intense thunderstorm manifestations on vast areas (Figure 5).

Besides, the convective systems that covered the entire northern half of Moldova during the afternoon of June 23, 2017 can be very well observed. They were well organized convective systems, their peak reaching altitudes of 13,000-15,000 m. Moreover, the influence of the Eastern Carpathians was clear through the contribution of orographic initiations to all those cumuliform systems.

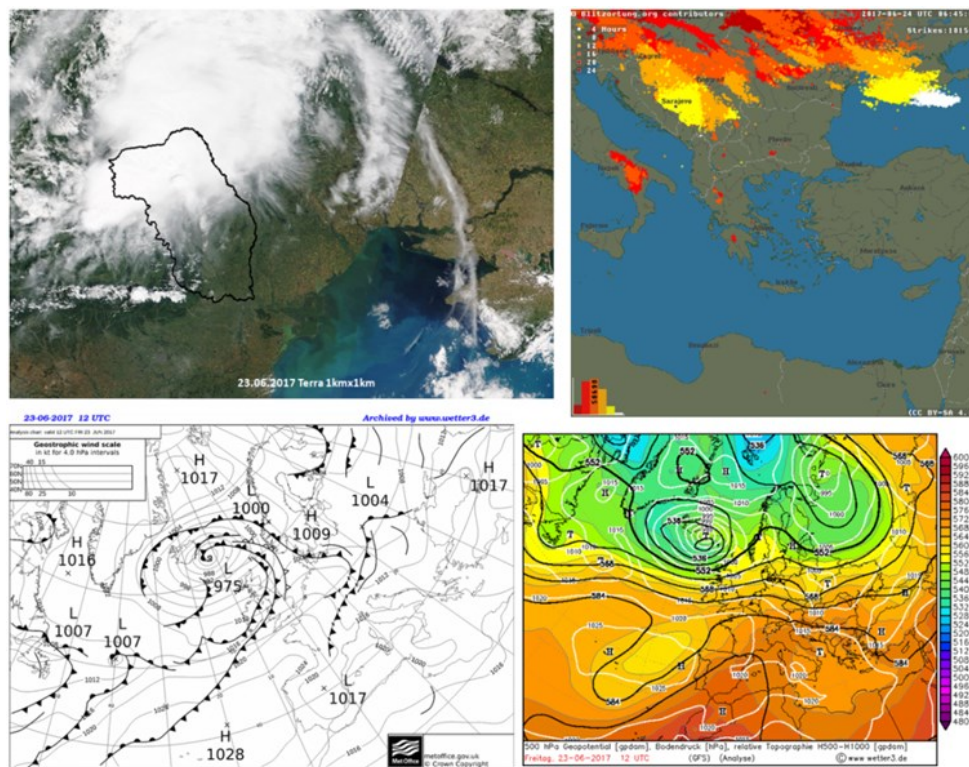


Fig. 5. Supercellular system crossing over the Moldavia region; Synoptic context, the position of the convective systems and thunderstorms in Europe and Moldova, 23.06.2017 – supercell system

The convective episode from August 6th, 2017. The summer of 2017 was characterized by many extreme weather events. Thus, after about 10-12 days when the weather was extremely hot, towards August 6, 2017 over the geographical area of Moldova was present a very unstable hot air mass (Figure 6).

Moreover, a vast anticyclonic area, associated with the Azores high, was active across the west of the continent. Obviously, a transport of cold air was facilitated from the north in the upper part of the troposphere. In the lower and middle parts of the troposphere, even on August 6, 2017, a hot and humid air mass continued to be transported across the south-south-western part.

The combination of the two different volumes of air in the troposphere, as well as a strong convection, favored the presence of very well-organized convective cloud systems for this day. The most exposed parts of Moldova at the convective

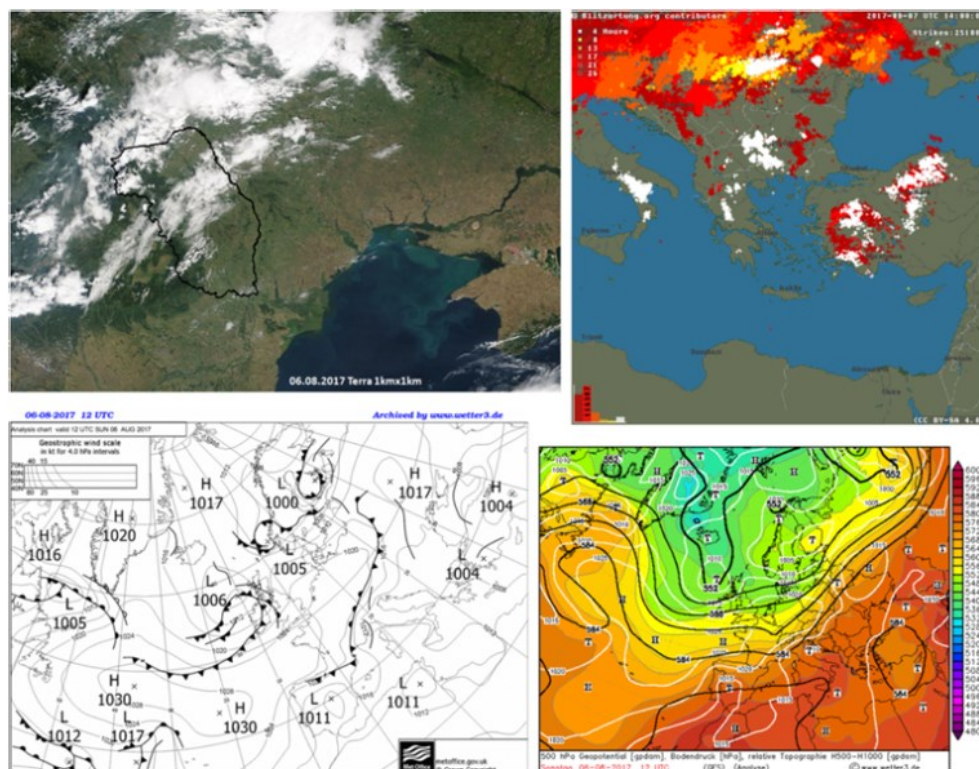


Fig. 1 Multicellular systems; Synoptic context, the position of the convective systems and of the thunderstorms, Europe and Moldova, 06.08.2017

manifestations of the time were the ones from the west and from its center. All these sectors have been affected by frequent electric discharge, torrential rains that favored the occurrence of floods, hailstorms and winds, which also took the shape of squalls, especially in the central part of Moldova.

Conclusions

The main objectives of the chosen theme were the formation and manifestation characteristics, the trajectories and the frequency of the convective cells in Moldova during the warm season of 2016 and 2017. The synoptic and mesoscale conditions, on the basis of which they are produced, were analyzed in order to identify structures favorable for the genesis of potential hail-generating convective systems and the specific displacement directions. Of course, with the climate change, some changes in the general circulation of the atmosphere over the Euro-North Atlantic territory and in Romania also took place, and a synthesis of the research in this direction was needed, on the basis of which the foundation of such research would be more solid. After analyzing the two-year data, a high frequency of hail-generating cells days was observed in May and June, when the western circulation increases, with an average of 13 days for each month from the average for the entire warm season, of 52 days.

A high frequency of the contact of the air masses with different temperatures is registered in the Curvature Subcarpathians and the piedmontan plain in Vrancea County, where a large number of days with the probability of hail cells formation occurs, in the case of large areas of vineyards and fruit trees plantations, vulnerable to hailstorms. However, there is a risk that every area will be crossed by hail-producing cells, it is enough to record only one day for a certain area in a vegetation season so major damage may occur in the case of supercell systems.

In the case of trajectories, the western general circulation also influences the movement of the thunderstorm cells, especially on the SW and NW components, from the south and north of the Carpathian chain. From the SW were recorded 34% of the trajectories, and from the NW 24%. Systems crossing the Eastern Carpathians are largely unloaded and dissipated. The rest those entering Moldova have mainly a local character, reaching down to Siret valley, after which some can regenerate. The trajectories in this direction had the frequency of 18%. Other situations are based on synoptic circumstances specific to the retrograde Mediterranean depressions or to the situations of cold air (cut-off low) depressions in the south of Moldova, situations that can generate heavy rainfall on large surfaces and retrograde trajectories of convective systems.

Future research will take into account elements that influence the rate of displacement of hail generation cells, changes occurring on the cell start

trajectories, the life of each cell in a multicellular system and their layout, elements that complement the results up to now.

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