ATMOSPHERIC FEATURES OF HAIL PERIODS IN SERBIA

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Abstract. From 1969 to 1986, there were 222 periods of several successive hail days registered in the target area covered by the hail suppression system in Serbia. In order to have the features of the atmosphere on hail days clearly outlined, a thorough analysis of the synoptic situation and some other important meteorological elements of the periods had to be made. The analysis proved the assumption that Cb cloud development is stimulated by the synoptic situation accompanying a hail period. On the other hand, no direct connection could be found between the occurrence of hail and some other meteorological elements, suggesting that the synoptic-scale conditions studied here are necessary ones, though not sufficient for the development of hailstorms.

1. INTRODUCTION

Ever since the introduction of the hail suppression system in Serbia, it has been noticed that the periods of successive hail days regularly appear in the target area several times a year. That is when widespread hailstorms leave large hail swaths in parts of the target area.

Some of the typically prevailing synoptic situations of the periods are identified, suggesting that such periods could be characterized by some of the specific features of the atmosphere, probably closely connected with the development of hailstorms. This study deals with the synoptic situations and some of the important meteorological elements during hail periods in Serbia.

2. HAIL PERIOD STATISTICS

In the 18-year time period from 1969 to 1986, there were 222 periods with a total of 876 hail days registered in Serbia (Fig. 1).

The annual frequency and duration of the storms during these periods (Table 1) indicate that the annual frequencies and mean length of the hail periods are rather uniform. This is not the case with frequencies at a meteorological station, because a station experiences hail at random, while it is a regular phenomena in an area throughout the year.

Table 2 shows the distribution of the hail periods according to number of days in the period. The frequencies suggest that there are at least three different mechanisms governing the hail processes. The first mechanism corresponds to the hail periods of two- to five-day duration; the second one seems to govern the seven- to nine-day lasting processes; while the third covers the processes exceeding ten-day periods. These possible mechanisms provide a convenient separation of the data for this study.

The data for the distribution of hail periods according to their monthly frequencies are presented in Table 3. More than 50% of all the cases occurred in May and June, which corresponds to the annual thermal and pluviometric regimes. Namely, these months are known to have the greatest increase in surface temperature in Serbia, as well as maximum amount of precipitation. The mean values of the duration of hail periods are very similar, too.

Fig. 1. Territory of Serbia, covered by hail suppression system (full circles, showing main synoptic stations). The insert in the upper right-hand corner shows the region relative to the remaining parts of former Yugoslavia and surrounding countries.

3. SYNOPTIC CONDITIONS

For the purpose of this study, each hail period was extended to include the day before it began and the one after it ended. This enabled us to see the differences in

Table 1. Frequency and duration of hail periods in Serbia.

Year	No. of periods	No. of days	Mean duration (days)	duration (days)
1969	13	47	3.6	8
1970	17	63	3.7	12
1971	8	35	4.4	9
1972	10	42	4.2	11
1973	10	44	4.2	15
1974	10	35	3.5	8
1975	14	67	4.8	17
1976	15	63	4.2	11
1977	16	63	3.9	9
1978	13	46	3.5	9
1979	13	49	3.8	12
1980	12	41	3.4	7
1981	10	43	4.3	9
1982	13	51	3.9	9
1983	14	41	2.9	5
1984	13	40	3.1	6
1985	10	45	4.5	12
1986	11	61	5.5	14

atmospheric features before, during, and after the hail periods. The synoptic conditions for these periods were studied from the series of synoptic charts and the radiosonde observations from Belgrade were used to calculate the mean values for the standard isobaric levels of 1000, 850, 700, and 500 hPa, as well as the mean thickness of the layers between these levels. Mean mixing ratio and the mean values of windshear, vorticity, and static stability were also calculated.

Table 2. Frequency of hail periods according to duration in days.

No. of Days	No. of Periods
2	79
3	61
4	28
5	18
6	4
7	6
8	6
9	10
10	0
11	3
12	3
13	0
14	2
15	1
16	0
17	1

Table 3. Monthly frequencies and duration of hail periods.

Month	No. of periods	No. of days	Mean duration (days)	Maximum duration (days)
April	8	28	3.5	6
May	52	211	4.0	14
June	60	247	4.1	17
July	47	192	4.1	15
August	42	158	3.8	9
September	13	40	3.1	7

Meteorological conditions of the shorter periods, lasting from two to five days, are mostly characterized by a cold front, usually passing from a NW to SE direction.

The hail periods with medium duration of some seven to nine days mostly coincide with large slow-moving upper air trough or depression. It was noticed in some cases that the considered area was in the weak surface gradient field or even on the surface pressure ridge during the first part of the hail period, while the cyclonic circulation prevailed during the second.

The long-lasting hail periods of more than 10 days duration mostly coincide with stationary deep trough, the top of which, after some time, cuts off and forms an upper depression cold pool over the area.

4. STANDARD ISOBARIC FEATURES

Tables 4, 5, and 6 show the mean monthly values of the standard isobaric surface anomalies in decameters (dkm) in Belgrade, the day before, during, and the day after the hail periods.

Table 4. Mean monthly anomaly (dkm) values of the standard isobaric levels in Belgrade, the day before the hail periods in Serbia.

Month	Level (hPa)			
	1000	850	700	500
April	-1	0	0	-3
May	-2	0	0	-1
June	-1	0	0	-1
July	-1	0	0	1
August	0	1	1	1
September	-1	1	2	1

Table 5. Mean monthly anomaly values (dkm) of the standard isobaric levels in Belgrade, during the hail periods in Serbia.

Month	Level (hPa)			
	1000	850	700	500
April	-3	-2	0	-2
May	-3	-2	-2	-2
June	-2	-1	-1	-1
July	-3	-2	-1	-1
August	-2	-1	-2	-2
September	-2	-1	-1	0

Table 6. Mean monthly anomaly values (dkm) of the standard isobaric levels in Belgrade, the day after the hail periods in Serbia.

Month	Level (hPa)			
	1000	850	700	500
April	0	0	0	-2
May	-2	-1	-3	-4
June	-1	-1	-3	-4
July	-2	-2	-4	-4
August	-1	-1	-3	-4
September	-2	-2	-3	-5

Table 4 indicates that in the first three months, the 1000 and 500 hPa height anomalies were negative, while the 850 and 700 hPa height anomalies were zero. That corresponds to low pressure at the surface and cold advection in the middle of the atmosphere. In the last three months, the anomalies of the isobaric heights were positive except the 1000 hPa, showing that the day before hail occurrence, the atmosphere was somewhat warmer than normal.

Table 5 shows that the values of all the standard isobaric levels are below normal in hail periods. The negative deviations are greatest on the 1000 hPa, indicating that hail periods are characterized by the existence of low pressure in Serbia.

The day after the hail periods, as can be seen in Table 6, the values of all the isobaric levels were below normal. However, comparing the data of the hail periods to data of the day after, we can see that the values for 1000 and 850 hPa increased, while those for 700 and 500 hPa decreased. Accordingly, the pressure in the lower level of the atmosphere rose, while the middle of the atmosphere was cooled by the cold air.

5. THICKNESS FEATURES

Tables 7, 8, and 9 show that the day before and during the hail periods, the surface layer (1000/850 hPa) gets warmer than it normally is. The thickness (or the mean temperature) of the other two layers is mostly normal or below normal. The day after the hail periods, the thickness of the upper layers is mostly normal or below normal. The day after the hail periods, the thickness of the surface layer is more normal, while the thicknesses of the upper layers have become less than normal, showing signs of cooling aloft.

6. ATMOSPHERIC FEATURES OF THE LONGEST HAIL PERIODS

Between 1969 and 1986, there were four hail periods registered in Serbia, lasting two weeks or even more. They are:

i) June 29 - July 13, 1973
ii) May 15 - May 28, 1975
iii) June 16 - July 2, 1975
iv) June 10 - June 23, 1986

A detailed analysis of meteorological conditions and synoptic situations of the periods showed that there was an anticyclone prevailing, with the center situated somewhere over central or northern Europe, covering Serbia with the southeast part of the storm. A northerly stream with cold advection on the eastern side of the anticyclone formed an upper trough which extended meridionally from the north of Europe to the Mediterranean Sea. Associated with that trough, a long-lasting cyclonic circulation (an upper depression) that was established in southern Europe and Serbia came to be under the domination of that cyclonic circulation. This type of synoptic situation proved to be very steady.

The sea level pressure was below normal throughout 40 of the 60 days that formed the lengthier hail periods. Only in 20 out of the 60 was it above normal. The thickness of the layer between the standard isobaric levels was mostly above normal, except for the layer of 1000/850 hPa, which was below that value. The lapse rate during the longest hail periods, according to radiosonde observations performed at Belgrade 00 UTC, was close to average (0.6°C/100 m) in the majority of days, being below normal only in a few.

Table 7. Mean monthly thickness (dkm) anomalies in Belgrade, the day before the hail periods in Serbia.

Month	Layer (hPa)			
	1000/ 850	850/ 700	700/ 500	1000/ 500
April	1	2	-2	1
May	2	0	0	1
June	1	0	-1	1
July	1	0	0	1
August	1	-1	0	0
September	1	1	0	-2

Table 8. Mean monthly thickness anomalies (dkm) in Belgrade during the hail periods in Serbia.

Month	Layer (hPa)			
	1000/ 850	850/ 700	700/ 500	1000/ 500
April	1	0	-3	-2
May	2	0	0	1
June	1	0	-1	0
July	1	0	0	2
August	1	-1	0	1
September	2	1	-1	2

Table 9. Mean monthly thickness (dkm) anomalies in Belgrade, the day after the hail periods in Serbia.

Month	Layer (hPa)			
	1000/ 850	850/ 700	700/ 500	1000/ 500
April	0	0	-2	-2
May	1	-1	-2	-2
June	0	-1	-2	-3
July	0	-1	-2	-3
August	0	-2	-1	-3
September	-1	-1	-1	-3

The analysis of vorticity of the isobaric surface, obtained by the Laplacian with 50 km distance and centered in Belgrade, was negative in all the standard levels, in the majority of days. It was more pronounced at the surface and less in the upper levels. During the longest hail periods, the wind was mostly light and variable in all the standard isobaric levels, while the mixing ratio throughout the atmosphere for the corresponding months was about or even below normal in a majority of days.

7. VORTICITY FEATURES OF HAIL PERIODS

The mean vorticity values, calculated for the days before the hail periods throughout the entire warm half of the year, show the greatest negative value at 850 hPa, and a positive one at 500 hPa only, which indicates that apart from the high pressure on the surface, the lowest layer of the air also had a high mean temperature.

An anticyclonic vorticity which decreased with the altitude showed that cold air advection was taking place in the middle of the troposphere. That advection caused a decrease of thickness as well as a decrease of static stability in the upper layer of the air.

The mean hail periods' vorticity values compared to values for the day before hail periods show that anticyclonic vorticity was decreasing, while the cyclonic one was increasing in all standard levels. The mean vorticity values of the day after the hail periods show that anti-cyclonic vorticity was increasing in lower levels, just as the cyclonic one was in the higher levels.

The above-derived analyses of the mean vorticity values for the day before, during, and the day after the hail periods in Serbia indicate that in the standard isobaric levels, vorticity is in accordance with the general conditions corresponding to the hail periods. However, if we analyze some individual cases, it can be seen that every combination of cyclonic and anticyclonic vorticity is possible in different levels, during different hail periods. Thus the conclusion is that the vorticity of surface pressure and geopotential fields is not a determinant factor for the appearance of hail periods. In other words, it seems that the cyclonic vorticity is a necessary, although at the same time is not a sufficient, condition for the occurrence of hail.

8. STATIC STABILITY OF THE ATMOSPHERE

The static stability changes are usually caused by cold or warm advection in different layers of the atmosphere. The relations between thicknesses of the layers 1000/700, 700/500 and 1000/500 hPa (Radinović, 1966) during the hail periods, as well as for the day before and the day after each hail period, provide the necessary data for the study.

In about 75% of the hail cases, the static stability values of the atmosphere in hail periods were between the values of the day before and the days after the hail periods.

If so, it can be concluded that the static stability of the atmosphere, considered this way, showed no specific features during the hail periods.

9. RICHARDSON NUMBER

In order to estimate the effect of the application of the Richardson number in the forecast of Cb cloud development in Serbia, Ćurić and Janc (1988, 1989) selected 28 days, from the different hail periods, for which they calculated the Richardson number. These studies showed that the criteria for the forecast of Cb clouds based on the Richardson number (Ludlam, 1980), as well as on the modified Richardson number (Setter and Kuo, 1983), proved inapplicable in Serbia. According to Ćurić and Janc, the reason is a rather pronounced orography which directs the spilling of the cold air masses along the valleys.

10. SUMMARY AND CONCLUSIONS

After thorough analyses of the characteristics of hail periods in Serbia consisting of several successive days of hailfall, it was possible to summarize the following:

1) There are several types of synoptic situations which cause the occurrence of hail periods and determine their duration, such as cold front, thermal trough, and upper air depression.

2) Before the appearance of the hail periods, the surface pressure is, on the average, usually below normal, while the values of the upper-air isobaric levels are above normal. This relation is just the opposite of the one from the end of the hail periods.

3) The studies of the cold and warm air mass outbreaks and the advection show that a warm advection usually appears before the occurrence of hail periods.

4) A study on the vorticity of geopotential fields before, during, and after the hail periods shows that every combination of cyclonic and anticyclonic vorticity in different levels and during different hail periods is possible.

5) The mixing ratio in the standard isobaric levels during the hail periods is close to the normal ones for the corresponding months.

6) The studies of the Richardson number in days of the hailfall in Serbia show that these numbers cannot be successfully used in prediction of the hailstorm developments.

Having taken into consideration all of these features of the atmosphere during the hail periods, it may be concluded that they represent a necessary condition, though not a sufficient one, for the development of hailstorms in Serbia. However, the formation of hail and hailfall is a phenomenon of a local nature, being decisively influenced by the local conditions whose scale is considerably less than the synoptic one.

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