STUDY OF ATMOSPHERIC INSTABILITY OF JUNE IN THE PERIOD 2004-2019 IN THE NORTH-WESTERN REGION OF ROMANIA

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ABSTRACT. The meteorological radar, due to its temporal and spatial resolution, has become an indispensable and necessary tool in the meteorologist's hand in order to create a climatology of the meteorological phenomena, to identify synoptic-orographic mechanisms that lead to their appearance and timely issue of weather alerts. This is observed from the analysis of June between 2004 and 2019 with the help of the WSR-98D radar from Bobohalma near Târnăveni. Using certain radar parameters: reflectivity, hail size, the number of identified storms, the years were ranked according to their atmospheric instability, in order to compare them with climatological data. Thus it was obtained that in the years 2018, 2016 and 2019 the atmospheric instability the highest of, obtaining a good correlation with the average deviations of the geopotential at 500 mb and of the isotherms at 300 mb and 850 mb or with the low values of the LI index (instability index).

Keywords: atmospheric instability, radar, storms, reflectivity, North-Western of Romania

1. INTRODUCTION

The degree of atmospheric instability of a day or a month is often very difficult to estimate because the data from the weather stations are at isolated points which may or may not capture a meteorological phenomenon or its intensity. In order to cover this shortcoming, the weather radar WSR-98D Bobohalma (near Târnăveni) was used, which by its temporal and spatial resolution was able to identify the meteorological phenomena, characteristic of instability, in evolution as well as their intensity. Hence, it is necessary to create a radar climatology using data provided by the Doppler WSR-98D radar. The purpose of this paper is to provide a comprehensive statistical analysis of convective storms from the north-western part of Romania in June between 2004 and 2019. While radar data is widely used for short-term weather forecasting, climate use is still uncommon. An analysis of climatic studies for Europe using meteorological radar data was carried out by Keupp et al. (2017) showing that there are only a few of such studies, the majority of the works being related to hail or precipitation. And yet, radar data

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has many advantages over other sources. Radar-based data allow the study of small-scale atmospheric structures and dynamics (Berg et al. 2015). All in all, radar data has great potential for climatological applications, which is far from being fully exploited. Thus, this paper aims to provide a perspective on the possibilities of the climatological use of meteorological radar data in estimating the degree of atmospheric instability.

2. DATA AND METHODS

The data received from the S-band Doppler Radar, type WSR-98D, installed at Bobohalma (RDBB) were used in analyzing 16 summer seasons, June 2004 - 2019. The coverage area of the RDBB is 166106 km². An application of the WSR radar identifies a possible storm according to certain parameters of the cloud system, such as reflectivity, echo height, liquid composition, or ice etc. Thus, when a cloud or a cloud system that is identified meets these characteristics, it receives a name (e.g. A2) and it is also called "storm core". Data on these storm cores are available every 6 minutes and contain information such as: coordinates of the core (name, radius and azimuth), type of core (Meso or TVS), hail probability (POSH - Probability of Severe Hail and POH-Probability of Hail), hail size, VIL (vertically integrated liquid), maximum reflectivity and the height at which it is found, the height of the cloud top, predicted direction and propagation speed. Polar coordinates were transformed into scalar coordinates to facilitate analysis.

Fig. 1. Radar reception area by Bobohalma WSR-98D

In 16 years, the RDBB radar identified a number of 905624 storms out of which 306361 storms were analyzed, only those located to the north-west of the radar site in the area of Cluj (CJ), Salaj (SJ), Satu Mare (SM), Maramures (MM) and Bistrita Nasaud (BN) counties. (Fig.1) The ranking was made according to the number of storms, so the year with the most storms received rank 16 and the year with the fewest storms received rank 1. The analysis was performed both quantitatively and qualitatively. The average number of storms in a day was about 640, so it was one of the criteria to identify how many days exceeded this average. Then the analysis was made according to the number of days in which were recorded over 1200 storms. The number of storms of 1200 is chosen arbitrarily being almost double than the average

of the day. The ranking was made beginning with the year with the most days with storms that received 16 points. The qualitative analysis was done according to the maximum reflectivity identified by the radar for each storm, taking the threshold of 55 dBZ level from which it is considered that the storm is mature, and the size of the hail determined by the radar taking as the threshold the diameter of 2 cm.

Using data from <https://www.esrl.noaa.gov/> there were analyzed the monthly deviations of the geopotential height from 500 mb and of the isotherms from 300 mb to 850 mb, the top was made according to the size of the negative or positive deviation. The highest score (16 points) was received by the highest positive deviation and the lowest score (1 point) by the highest negative deviation. Also, through the data from [noaa.gov](https://www.noaa.gov/) there was analyzed the monthly evolution of the LI index (lifted index), an instability index. The year with the lowest value of LI received the maximum score of 16 points.

3. ASSESSMENT OF THE ATMOSPHERIC INSTABILITY WITH RADAR DATA

The assessment of atmospheric instability degree was made using data from the Doppler radar from Bobohalma near Târnăveni. The analysis was done quantitatively using the number of storms detected by the radar monthly and daily in June 2004-2019. The analysis for each day was made according to the average value for June of 640 storms and the value of 1200 storms. The qualitative analysis was done taking into account the maximum reflectivity of each storm, and considering only the mature storms with reflectivity greater than 55 dBZ or that had a hail diameter of more than 2 cm.

3.1. Assessment of atmospheric instability based on the number of storms detected by radar per month

WSR-98D radar has identified 306361 storms. At every 6 minutes scan, the radar identifies cloud formations that, depending on their characteristics, can be considered storms. (Fig. 2)

Fig. 2. Number of storms detected by Bobohalma WSR-98D radar in June between 2004 and 2019.

Points from 1 to 16 were given according to the number of storms detected by Bobohalma WSR-98D radar in June between 2004 and 2009. (Table 1)

Table 1. Instability rank according to the number of storms

Year	2018	2016	2013	2019	2011	2008	2006	2015	2010	2007	2009	2017	2012	2005	2014	2004
Number storms	36602	25484	24537	22604	22180	20246	19816	19417	18788	17614	16212	16321	15436	11885	11307	7912
Rank	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1

Thus, from the storms number point of view, the years 2018, 2016, 2013, 2019 have higher ranks and 2005, 2014 and 2004 have lower ranks.

3.2. Assessment of atmospheric instability based on the number of storms detected by radar per day

Only the number of storms is not sufficient to determine the degree of the atmospheric instability of the month. In how many days were the storms present? The average number of storms per day was calculated for the entire considered period obtaining an average number of storms of 640 per day. (Fig.3)

Fig.3. Number of days with more than 640 storms detected by Bobohalma WSR-98D radar in June between 2004 and 2009.

The years 2018, 2019, 2016, 2013 rank among the first in the top when in June are many days with above average atmospheric instability. The year 2018 has 27 days with above average atmospheric instability. But a slight change in the top is observed, and not only in the first 4 years. So, the degree of instability is also given by the number of storms in a day. (Table 2)

Table 2. Atmospheric instability rank according to the number of days with more than 640 storms

Number days	27	20	17	17	16	15	15	14	13	11	11	9	9	8	8	3
Year	2018	2019	2016	2013	2006	2007	2010	2011	2008	2009	2011	2012	2015	2005	2014	2004
Rank	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1

Doing a refining (Fig. 4), ranking was made according to the number days with more than 1200 storms, we get essential changes especially in the middle of the ranking (Table 2, Table 3).

Fig. 4. Number of days in Junewith more than 1200 storms detectedby BobohalmaWSR-98D radarbetween 2004 and 2009.

Fixing an upper threshold, it was sought to establish a ranking of the intensity of the degree of atmospheric instability. The most spectacular jump is observed in the year 2019. If at the first 2 criteria it was in the top, at the criterion of over 1200 storms it falls on the 10th position, decreasing from 20 days to 6.

Table3. Instability rankaccording to the number of days with more than 1200 storms in June

Number days	13	9	7	7	7	6	6	5	5	5	5	5	4	4	2	0
Year	2018	2016	2009	2011	2013	2008	2019	2006	2010	2012	2015	2017	2005	2007	2017	2004
Rank	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1

3.3. Assessment of atmospheric instability based on the maximum reflectivity > 55 dBZ

By analyzing the storms qualitatively, i.e. we use the intensity of the storms, it is observed that out of the total number of storms, only 14.8% become mature and can cause damage. A mature storm is considered to have a reflectivity greater than 55 dBZ. (Fig. 5)

Fig. 5. Number of storms with reflectivity> 55 dBZ detected by Bobohalmathe WSR-98D radarin June between 2004 and 2009.

A new ranking is made according to the number of storms with reflectivity > 55 dBZ detected by Bobohalma the WSR-98D radar in June between 2004 and 2009. (Table 4). Again the ranking of the unstable years keeps in the top the years 2018, 2019.

There are differences from the other charts. The year 2009 goes to the end of the ranking with 11 positions when considering only mature storms. Analyzing the storms, it is obtained that there were years when in June there were many storms but not all were intense and years with fewer storms but with a higher frequency of mature storms (Table 3). For example, the 2019 year goes from the 6th position to the 2nd one, which shows us that the storms were generally more intense.

Table 4. Atmospheric instability rank according to the number of storms with reflectivity > 55 dBZ

Year	2018	2019	2013	2016	2006	2012	2011	2010	2017	2008	2007	2015	2009	2014	2005	2004
Rank	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1

3.4. Assessment of atmospheric instability based on the detected hail diameter > 2 cm

Also, in the qualitative analysis is the study of storms with a hail potential of more than 2 cm in diameter. (Table 5)

Table 5. Atmospheric instability rank according to the number of storms with detected hail diameter > 2 cm

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total	%
error	0	0	9	24	18	17	5	7	5	25	0	15	33	25	23	22	228	0,07
<1,3 cm	529	965	2752	2841	2348	2159	1777	3267	1912	3931	1627	2408	3418	2425	7375	4505	44239	14,44
1.3 cm	161	304	1446	1323	1285	890	990	1369	1139	2157	613	1058	1792	1386	4143	2956	23012	7,51
1.9 cm	71	102	658	450	548	337	461	529	567	948	219	413	914	627	1866	1573	10283	3,36
2.5 cm	32	30	294	139	189	127	308	214	338	461	85	172	468	352	830	864	4903	1,60
3.2 cm	15	21	146	55	98	53	140	123	200	236	21	77	257	195	400	471	2508	0,82
3.8 cm	9	9	68	23	33	29	81	45	118	170	3	49	177	105	215	265	1399	0,46
4.5 cm	4	0	35	13	28	10	45	32	87	105	4	17	105	66	133	172	856	0,28
5.1 cm	0	0	20	8	15	6	27	16	76	62	1	8	73	30	61	87	490	0,16
5.7 cm	1	0	15	7	3	4	15	7	58	33	0	9	53	32	41	64	342	0,11
6.4 cm	0	0	5	2	5	2	15	6	43	16	0	1	33	15	29	37	209	0,07
7.0 cm	0	0	5	0	3	0	9	5	28	16	0	0	31	17	11	21	146	0,05
7.6 cm	0	0	6	0	1	0	10	2	28	11	0	2	22	6	7	21	116	0,04
8.3 cm	0	0	1	0	1	0	7	2	12	6	0	0	22	7	5	6	69	0,02
8.9 cm	0	0	0	0	1	0	3	1	6	3	0	0	13	3	2	5	37	0,01
9.5 cm	0	0	1	0	1	0	1	0	4	1	0	0	12	7	1	2	30	0,01
10.2 cm	0	0	1	0	0	0	3	3	5	2	0	0	24	9	3	4	54	0,02
Without hail	7090	10454	14354	12729	15669	12578	14891	16552	10810	16354	8734	15188	18037	11014	21457	11529	217440	70,98
Total	7912	11885	19816	17614	20246	16212	18788	22180	15436	24537	11307	19417	25484	16321	36602	22604	306361	100

Of the total number of storms detected by the weather radar, only 7% are storms that contain hail with the diameter greater than 2 cm (Table 5).

The rank assigned to each year does not have essential changes in the ranking, fixing on the positions especially the years at the top of the ranking (Table 6).

Table 6. Atmospheric instability rank according to the number of storms with the detected hail diameter >2 cm

Year	2018	2019	2016	2013	2012	2017	2006	2010	2011	2008	2015	2007	2009	2014	2005	2004
Storms with hail>2 cm	3604	3592	2204	2070	1570	1471	1255	1125	985	926	748	697	568	333	162	132
Rank	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1

3.5. Assessment of atmospheric instability

The degree of atmospheric instability was obtained by summing radar characteristic products (hail diameter, reflectivity over 50 dBZ etc.) and storms characteristics. After that, a rank for each sum was given, according to the methodology used (Table 7). The most unstable years using the parameters of the weather radar are: 2018, 2019, 2016, and the most stable are: 2004, 2005 and 2014.

Table 7. Atmospheric instability rank obtained from radar data

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
No cores	1	3	10	7	11	5	8	12	4	14	2	9	15	6	16	13
No days with>640 storms	1	2	12	11	8	7	10	9	5	13	3	4	14	6	16	15
No days with>1200 storms	1	3	9	4	10	12	8	13	7	14	2	6	15	5	16	11
Hail diameter >2cm	1	2	9	4	6	5	11	8	12	13	3	7	15	10	14	16
Reflectivity>55dBZ	1	2	12	6	7	4	9	10	11	14	3	5	13	8	16	15
TOTAL	5	12	52	32	42	33	46	52	39	68	13	31	72	35	78	70
Rank	1	2	12	5	9	6	10	11	8	13	3	4	15	7	16	14

4. ASSESSMENT OF INSTABILITY BASED ON METEOROLOGICAL PARAMETERS

In order to validate the method of establishing the degree of atmospheric instability using radar data, these were correlated with some meteorological parameters that are used in the forecast of atmospheric instability situations. As a result, with the help of the reanalysis data from <https://www.esrl.noaa.gov/>, the average monthly deviations were evaluated against the climatological norms, attributed to the north-western part of Romania, of the isotherms at the standard isobaric levels of 300 mb respectively 850 mb and of the geopotential at 500 mb. At the same time, an index of instability LI (lifted index) was analyzed.

4.1. Estimation of the degree of instability according to the deviation of the average monthly isotherms at geopotential height of 300 mb and at 850 mb

The years with positive deviations of the isotherms from at geopotential height of 300 mb and 850 mb in June are generally the most unstable. (Table 8)

Positive deviations imply a warmer weather and therefore, during the daytime warming, an increase in the intensity of convective processes, as a result of the overlapping years with warmer June over unstable years (2018, 2019, 2016), and years with negative deviations over low instability (2004, 2005). In general, the ranks obtained from atmospheric instability and thermal deviation are generally close as values. There are some exceptions such as the years 2006 and 2017. The year 2006 with negative deviations is influenced by a period in which the cyclonic activity predominated in comparison with 2017 in which the anticyclones predominated. (Table 8).

Table 8. Estimation of the degree of atmospheric instability according to the deviation of the average monthly isotherms at 300 mb and at 850 mb

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Deviation at 300 mb °C	<-0.7	<-0.7	<-0.7	<0.2	>0.5	>0.6	>2.4	>0.8	>2.0	=0.0	<-0.4	>0.3	>1.0	>2.5	>2.0	>3.5
Deviation at 850 mb °C	<-0.6	<-1.2	=0	>2.3	>1.0	>0.7	>1.0	>0.7	>1.5	>1.0	<-0.6	>0.6	>2.0	>2.0	>1.5	>2.5
Thermal deviation rank	2	1	4	5	10	7	11	8	12	9	3	6	14	15	13	16
Instability rang obtained from radar data	1	2	12	7	9	5	10	11	8	13	3	4	15	6	16	14

4.2. Estimation of the degree of instability according to the deviations of the average monthly geopotential height of 500 mb

The average positive or negative deviations of the geopotential height at 500 mb are related to cyclonic or anticyclonic activity. It was expected to have a correlation with the instability related to the negative deviations of the geopotential, so the most unstable years are the years with positive deviations 2019 (70 mgp), 2018 (30 mgp) and the least unstable years 2004, 2005 (-5 mgp) (Table 9).

Table 9. Estimation of the degree of atmospheric instability according to the deviations of the average monthly geopotential height at 500 mb

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
The geopotential height deviation average at 500 mb (m)	<-5	<-5	>10	>15	>22	=0	>10	>5	>40	>10	<-7	>20	>30	>35	>30	>70
Geopotential height rank	2	3	8	9	11	4	7	5	15	6	1	10	12	14	13	16
Instability rank obtained from radar data	1	2	12	7	9	5	10	11	8	13	3	4	15	6	16	14

4.3. Estimation of the degree of atmospheric instability according to the value of LI index

It is a stability index used to determine the potential of the atmosphere to produce storms. Higher negative LI values indicate additional energy for the ascending particle. There are some average values of LI:

- > 2 = atmosphere is stable;
- [0,2) = atmosphere is weakly stable;
- [-2,0) = atmosphere is weakly unstable;
- <-2 = atmosphere is moderately unstable.

It is observed that the years in which the value of LI is <-2 are the most unstable: 2018, 2016, 2019, 2013 and in the years with the lowest instability: 2004, 2005, 2014 the value of LI is > 1. The LI index proved to be a good indicator for establishing instability. (Table 10)

Table10. Estimation of the degree of atmospheric instability according to the value of LI index

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
LI value	>1	>1	(-2;0)	(-2;0)	(-2;0)	(0;1)	(0;1)	(-2;0)	(-2;0)	<-2	>1	(0;1)	<-2	(0;1)	<-2	<-2
LI rank	1	2	11	12	10	6	7	9	8	15	3	4	14	5	13	16
Instability rank obtained from radar data	1	2	12	5	9	6	10	11	8	13	3	4	15	7	16	14

5. CONCLUSIONS

Compared to other data sources, the great potential of meteorological radar data for applied climatology results from its spatial and temporal resolution and coverage. Even if some specific problems arise when analyzing radar data for the purpose of climate study (systematic errors, lack of data, etc.), they can be managed through proper processing.

The results obtained from the study show a satisfactory correlation, especially at the interval ends. The most unstable years resulting from radar data are also the most unstable at the analysis of atmospheric instability (2019, 2016, 2018) and the most stable (204, 2005, 2014). (Table 11)

The differences appear in the middle area of the ranking and are the result of the monthly analysis. An analysis for each day could bring much better correlations, especially in the geopotential height field from 500 mb.

The analysis of the storms detected by the Doppler meteorological radar, both quantitatively and qualitatively, led to a refinement of the degree of instability of June from 2004 to 2019.

Table 11. Correlation of the degree of instability obtained from radar data with the one that derived from the analysis of the atmospheric parameters considered

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Instability rank from atmospheric analysis	1	2	7	9	11	4	8	6	13	10	3	5	15	12	14	16
Instability rank obtained from radar data	1	2	12	5	9	6	10	11	8	13	3	4	15	7	16	14

Thus, in the years with a close number of storms the difference was made by the intensity of the storms, several storms with reflectivity greater than 55dBZ or with hail.

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