
SORIN BURCEA
National Meteorological Administration, Bucharest, Romania

ROXANA CICĂ
National Meteorological Administration, and Faculty of Geography, University of Bucharest, Bucharest, Romania

ROXANA BOJARIIU
National Meteorological Administration, Bucharest, Romania

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ABSTRACT

A climatology and trend of hail events in Romania are presented using hail data spanning the years 1961–2014. Hail observations from weather stations and model reanalysis data were used to document the spatial and temporal distributions, variabilities, and environments of hail events. The results show that hail occurs most frequently in mountainous areas, while the smallest average number of hail days per year is found in the southeast. Herein, the convective season was defined as April–September, given that 94.2% of all mean monthly hail days were identified in this period. During the convective season the hail events prevail with most of these occurring in the afternoon and evening hours between 1000 and 1800 UTC. The severe hail events occur, overall, between 1400 and 1600 UTC, while in the southwest severe hail occurs later between 1600 and 1900 UTC. The spatial distribution of the convective parameters is consistent with the spatial distribution of hail days, revealing that hail is not favored in southeastern Romania, but in the rest of the country. The trend analysis of mean hail days per year disclose that 55.2% of all stations show a statistically significant upward trend, 3.8% show a statistically significant downward trend, while 40.9% show no statistically significant trend. A correlation between the variability of hail days per year and the variability in the occurrence of low pressure systems of Atlantic origin exists, the latter generating low pressure systems over the Mediterranean Sea that supply eastern Europe with the moist air needed for convection.

1. Introduction

Convective storms producing heavy rain, wind gusts, hail, and lightning, have great impact on socioeconomic activities. Moreover, disaster risk management and mitigation processes need to consider not only the activities of stakeholders, but also the issues of various natural hazards if an area is prone to it. Hailstorms carry a high risk for agriculture, infrastructure, and vehicles (e.g., Hohl et al. 2002), causing major losses estimated in certain cases to tens of millions of Euros (Kunz and Puskeiler 2010). Consequently, hail climatologies and trends have been developed, permitting the identification of hail-affected areas, hail frequency, its seasonality, and intensity.

Lately, damaging hailstorms were reported and hail studies have been developed for different regions of the world, including Europe, Asia, Africa, North and South America, and Australia. These studies used data obtained from point measurements such as weather stations and hailpads, but also from insurance loss data and remote sensing (weather radar data). In Europe, hail climatologies or hail-related studies exist for most of the countries. Some of these are mentioned below, with a focus on south-southeast Europe and Romania’s neighboring countries. Nevertheless, a comprehensive review of hail observations and hailstorm characteristics in Europe can be found in Punge and Kunz (2016). The European Severe Storms Laboratory (ESSL) developed a preliminary climatology, based on large hail (>2 cm) reports over
Europe, for the period 2000–07 [Fig. 13 in Hand and Cappelluti (2011)]. Even though this climatology is biased by a very large number of observations over Germany prior to 2005, one may see peaks in frequency near the Pyrenees, over the Alps, and Romania, and a rapid decrease in frequency north of 60°N. Pocakal et al. (2009) analyzed the influence of orography on hail characteristics in Croatia, based on hail data collected in continental parts of the country, for the period 1981–2006. Their results show that the greatest number of hail days is found in the western (hilly) part of the country, while the eastern (generally flat) part is characterized by the smallest number of hail days. For Moldova, within a study focused on hail suppression, Potapov et al. (2007) state that most severe hailstorms occur over the northern plateau and central uplands regions. According to Simeonov (1996), Bulgaria is highly exposed to hail and hail damage to agriculture occurs regularly, on 54–99 days yr$^{-1}$ according to insurance records dating back to 1888. For Serbia, Ćurić and Janc (2016) have found that a hail point frequency maximum (2.4) is found in the hilly region of western Serbia, around the Morava valley, being confirmed by a hail-reporting network of 235 stations. Cića et al. (2015) performed an assessment of severe hailstorms and hail risk for an area in southern Romania using damage data of 52 hail events and radar measurements, results showing that the hail-affected areas were well captured by the footprints and magnitude of the radar variables.

In Asia, Kahraman et al. (2016) performed a severe hail climatology of Turkey for the period 1925–2014, using official severe weather reports from meteorological stations, newspaper archives, and Internet sources. The results show an overall increase of severe hail days for the period 1925–2014, and that almost all of the country is prone to severe hailstorms. Zhang et al. (2008) updated China’s hail climatology using a record of observations from 1961 to 2005, and showed that hail frequency is higher over the central Tibetan Plateau. Xie et al. (2008) documented the trend of hail in China during 1960–2005, results showing no trend in the mean annual hail days from 1960 to the early 1980s, but a significant decreasing afterward. In Africa, Visser and van Heerden (2000) have done a comparison of hail kinetic energy derived from radar reflectivity with crop damage reports over the eastern Free State based on the analysis of three hail case studies from 1995, with the highest crop damage claims. They found a good relationship between the crop damage reports and radar hail kinetic energy.

In North America, Cintineo et al. (2012) published a study on high-resolution hail climatology of the contiguous United States derived from Multi-Radar Multi-Sensor (MRMS) algorithms, leveraging the Multiyear Reanalysis of Remotely Sensed Storms (MYORRSS) dataset at NOAA’s National Severe Storms Laboratory (NSSL). The dataset spans 42 months (2007–10), and the results showed a broad maximum of annual hailfalls in the Great Plains and a diminished secondary maximum in the southeastern United States. In South America, Mezher et al. (2012) constructed the hail climatology of Argentina, for the period 1960–2008, using records of hail data from weather stations; the maximum hail frequency is observed during the summer months, while the trend in the annual number of hail days is increasing in the northwest and northeast of the country. In Australia, the hail climatology for the state of New South Wales (NSW), based on reports of hailstones from 1791 to 2003, was developed by Schuster et al. (2005). Their results show that hailstorms occur most frequently between October and February (Australian spring and summer) in NSW, with peak activity in November and December, and that the majority of NSW hailstorms occur during the late afternoon between 1500 and 1900 local time, with hailstorms in Sydney occurring about 1 h earlier.

The research presented in this paper extends the scientific approach and findings of the above-mentioned studies to Romania, in terms of determining, for instance, the spatial distribution of severe hail days and of time of occurrence of hail events, monthly and hourly distributions, or trends of hail events. Hence, the aim of this article is to contribute to the climatology of hail in Europe, by presenting a comprehensive hail climatology and trend in Romania. The research would also contribute to a better understanding of the importance and possible influence of hailfalls in the current climate of Europe. Although Romania has a long history of meteorological observations, extending back to 1884, a detailed climatological study and trend of hail was not carried out or available to the international research community. The current Romanian hail climatology (Mărcușu 2008) performed using data recorded at the weather stations within the 1961–2000 period is very general, and presents only the map of spatial distribution of the mean hail days per year. This shows that, overall for Romania, the number of mean annual hail days is smaller than 2 days, with a minimum (0.2 days) in southeastern Romania and a maximum (>8 days) in western Romania. Therefore, there was a need to extend the efforts to include more spatial analysis and to use all available observations to update the current hail climatology of Romania, considering also the analysis of additional characteristics of hail (e.g., diameter, time of occurrence). Another objective of this paper is to investigate the relationship between the spatial distributions of hail and convective parameters (e.g., convective
available potential energy, freezing level height), and to assess if a statistically significant long-term trend in hail across Romania is present.

This article is structured as follows. Section 2 describes the datasets and methodology, while the results are presented in detail, in different subsections (hail climatology, hail trends, and physical mechanisms related to hail variability in Romania), within section 3. The conclusions are given in section 4.

2. Data and methodology

a. Data

To reach the goals of this study, hail observations from weather stations and reanalysis data were used. The Romanian National Meteorological Administration has records of hail data as far back as 1884. Therefore, the first step was to collect and to construct a large spatio-temporal dataset, which included data from 149 weather stations over 54 yr (1961–2014). However, some records were incomplete or present a lack of homogeneity due to either change in location of measurement, interruption of measurements for certain periods, or other issues that make the data unreliable.

The observational hail data used in this study were recorded manually and daily, with an hourly resolution, by the observers at the weather stations in the surface observational network in Romania. The hail records include information on time of occurrence, duration, and hailstone minimum and maximum diameter (measured using a ruler). In this study, the diameter refers to the maximum diameter of the hailstone. A minimum hailstone size of 5 mm was used per World Meteorological Organization’s guidance (WMO 2008), resulting in a dataset comprising observations made at 105 weather stations (from a total of 149 stations), in the period 1961–2014. The limitations of hail observations, particularly those regarding the missing data and the human observer bias need to be considered. While the time of occurrence of hail events can be accurate, the diameter measurement can present biases, as larger hailstones could have fallen to the ground and not have been considered by the observer due to various reasons (e.g., melting before the measurement was performed). Such biases arise when attempting to determine the magnitude of particular weather phenomena (e.g., maximum hail size) as the sampling may be inadequate considering the storm-scale variability of hail parameters (Edwards and Thompson 1998; Witt et al. 1998; Morgan and Towery 1975). In the analysis herein, if more than 1 day of observations was missing in a month, then that month was flagged as having missing data. Stations with records with less than 10% missing data have been included in the analysis, for a better spatial coverage. Thus, from the total number of selected stations (105), 18 stations had missing data less than 5%, and 13 stations had missing data between 5% and 10%.

The locations of the 105 weather stations and Romania’s topography are shown in Fig. 1. The lowest elevation (<10 m MSL) is found in the southeast, namely Danube Delta (visible in Fig. 1 near the Black Sea), while the highest mountain peak (2544 m MSL) is located in the Făgăraș Mountains of the Southern Carpathians (south part of the mountains in Fig. 1).

Reanalysis data (Twentieth Century Reanalysis V2) have been used to investigate the physical mechanisms that shape the spatiotemporal variability of hail events within the analyzed period. These data were obtained from the Physical Sciences Division (PSD) of Earth System Research Laboratory (ESRL), National Oceanic and Atmospheric Administration (NOAA), Boulder, Colorado, from their website (http://www.esrl.noaa.gov/psd) (Compo et al. 2011). The parameters analyzed herein are surface-based convective available potential energy (CAPE), specific humidity in the lowest 100 hPa (q), freezing level height (FLH), and cloud precipitable water (CLDWR). These parameters provide information on the atmospheric instability needed for the
occurrence of convection and hail formation (Doswell et al. 1996; Brooks et al. 2007).

b. Methodology

For a single station, a hail day is defined as a day during which at least one hail event was observed and recorded, and the number of mean (severe) hail days per year is defined as the sum of (severe) hail days in 54 years divided by 54. A severe hail day was defined as the day when the hail measured more than 15 mm at a single station at least. The monthly (hourly) hail frequency is equal to the average hail days (events) in a particular month (hour) over the whole 54-yr period, while the mean time of occurrence of severe hail events was calculated by averaging the times of occurrences of hail events. If multiple hail events were present in a day, at a given station, only one event was kept for the trend calculation of hail days per year, to avoid the miscount of hail days recorded at that station.

The spatial distribution of the mean hail days per year was obtained in two steps: first, the number of mean hail days per year was calculated for each station, and second, an inverse distance weighting (IDW) algorithm was used to interpolate the irregularly spaced station data to a 50-km resolution grid. The IDW algorithm (Shepard 1968) is a deterministic method for multivariate interpolation of a scattered set of points, by which values are assigned to unknown points by calculating a weighted average of the known values.

In this study, long-term trends have been analyzed for each of the 105 weather stations covering Romania. The trend significance has been determined using the non-parametric Mann–Kendall’s statistical test (Mann 1945; Kendall 1975), performed with a 95% confidence level setting. Then the trend was classified as 1) an upward trend, 2) a downward trend, and 3) a flat (no) trend. The return periods have been computed based on the generalized extreme value (GEV) distribution fitted to the histogram of annual maximum hail diameter selected for the whole country (105 stations) in each year. Extreme value theory enables the analysis of the tail behavior of distributions in hydrology and climatology. The GEV distribution spans the three main classes of tail behavior associated with the Fréchet, Weibull, and Gumbel distributions. Here, the return periods were computed based on the GEV distribution fitted to the histogram of maximum annual hail diameter selected for the whole country (105 stations) in each year. Extreme value theory enables the analysis of the tail behavior of distributions in hydrology and climatology. The GEV distribution spans the three main classes of tail behavior associated with the Fréchet, Weibull, and Gumbel distributions. Here, the return periods were computed based on the GEV distribution fitted to the histogram of maximum annual hail diameter (selected for whole country, in each year), with the parameters \( k = -0.03255, \sigma = 13.469, \) and \( \mu = 26.986. \) Mapping the return periods at the locations of meteorological stations is not possible with the available standard measurements due to the extent of missing observations of hail diameter.

The reanalysis data were processed to obtain the spatial distribution of the mean values of the above-mentioned convective parameters, within the period 1961–2012. From the complete reanalysis dataset, only those grids corresponding to the days when hail was recorded were kept for the analysis. For each hail day, all grid points were saved, but not only the grid point that contained the hail event. As the majority of hail events occur during April–September and around 1200 UTC (see Figs. 7–8), for each day within this monthly interval when at least one hail event with a hail diameter larger than 15 mm occurred, reanalysis values were retained and averaged, in each grid cell, only for 1200 UTC. The CAPE and CLDWTR fields were available, while \( q \) in the lowest 100 hPa and FLH were calculated. The specific humidity was extracted from the grids corresponding to the 1000-, 950-, and 900-hPa levels followed by averaging of these layers, resulting a single grid. The FLH was calculated by reverse interpolation of the vertical profile of temperature, in each grid point, to find the geopotential height of the 0°C isotherm (Harris et al. 2000).

3. Results and discussion

a. Climatology and trend of hail events

The spatial distribution of the mean hail days per year over Romania, for the 54-yr period (1961–2014), is illustrated in Fig. 2. Given the methodology (i.e., spatial interpolation) used to construct the spatial distribution of hail days, the pattern in Fig. 2 should be considered only as indicative of large-scale distribution as the interpolated values are not necessarily valid at particular locations (other than those where observations were performed).

The spatial distribution of mean hail days per year shows the lowest values in the southeastern and eastern
parts of Romania, while the average number of hail days increases in the rest of the country and as the altitude of the terrain increases. The plains from south, east, and west, and some mountainous areas are characterized by average values of 0.5–1.5 hail days, while on the mountain slopes and peaks the average multiannual hail days ranges between 2 and 11. The minimum value is 0.3 in the southeast, near the Black Sea, and the maximum value is 11.8, found in the mountains from northwestern part of Romania. These point values are not clearly visible in Fig. 2 because of the 50-km grid interpolation. The distribution shows high gradients in mountainous areas, indicating a terrain-related geographical distribution.

The spatial distribution shows an increasing mean hail size from the southeast to the northwest (Fig. 3), with southeastern Romania being characterized by mean hail sizes between 5 and 9.5 mm, while in the rest of the country the mean hail diameter ranges from 9.5 up to 14 mm over large areas, with a maximum of 18.5–20 mm in some isolated areas. The maximum hail diameter and mean hail diameter spatial distributions (Fig. 4) are similar. A spatial division between the southern and northern part of the country is observed. Maximum hail sizes between 10 and 30 mm are depicted in the south, with isolated areas in the southwest where the maximum size can reach 40–45 mm. In the north the maximum hail diameter ranges from 25 to 45 mm over large areas, with an isolated maximum of 55–60 mm in the mountainous areas in the northwest.

The spatial distribution of the mean severe hail days per year (Fig. 5) reveals the smallest values (<0.05 days) in the southeast, while over large areas of the country the mean number of severe hail days per year is 0.05–0.15. The largest number (0.45–0.5 days) is observed in the mountainous areas from the northwest, while local large values are observed in northern and central Romania.

This maximum is located in the same area where the mean number of hail days per year and maximum hail diameter are observed. The spatial distribution of the average time of occurrence of severe hail events (Fig. 6) shows that in most of the country, severe hail occurred between 1400 and 1600 UTC, while in the southwest severe hail occurred later between 1600 and 1200 UTC.

The monthly hail distribution (Fig. 7) reveals that hail can occur all during the year, but with very low frequency during the cold season. The hail events prevail during April–September (94.2% of the total mean monthly hail days), reaching the maximum during the summer (14.1 hail days in June). The monthly distribution is, therefore, related to the atmospheric convection characteristic of the warm season.

The total (for all 105 stations) mean multiannual hourly hail events was calculated and plotted against UTC hours to investigate the diurnal variation of hail occurrence (Fig. 8). The majority of hail events (78%) occur in the afternoon and evening hours, between
1000 and 1800 UTC, while the rest of the hail events (22\%) occur in the interval 1900–1000 UTC. During the night, between 1900 and 0000 UTC, hail occurs more frequently than in the early morning and morning.

The frequency of hail size (Fig. 9a) shows that during 83.4\% (2011 events from 2410) of the total events the hail size ranges from 5 to 15 mm, revealing also that the majority of hail events were not severe. The frequency of occurrence of severe weather events tends to follow approximately a log-linear decrease with increasing intensity (Brooks and Doswell 2001; Brooks and Stensrud 2000). Based on this approach, the severe hail spectrum was divided into ranges of hail size, and plotted versus their percentages from the total severe events (Fig. 9b). The graph shows a decrease of the number of severe hail events with increasing hailstone diameter. Of the total severe hail events (399), 81.9\% (327 cases) are associated with a hailstone diameter between 1.5 and 3 cm, 10.5\% (42 cases) are associated with a hailstone diameter between 3 and 4.5 cm, 4\% (16 cases) are associated with a hailstone diameter between 4.5 and 6 cm, while 1.2\% (5 cases) of all severe hail events involve very large hail (diameter equal to or larger than 6 cm).

The return periods of annual maximum hail diameter in Romania, for the interval 1961–2014, suggests an occurrence of 1 in 100 years for the case of hail diameter equal or larger than 85 mm, 1 in 50 years of diameter equal or larger than 76 mm, 1 in 10 years of diameter equal or larger than 56 mm, and 1 in 2 years of diameter equal or larger than 32 mm.

The trends of the number of mean hail days per year, for the period 1961–2014, calculated for each of the 105 weather stations, are plotted in Fig. 10. Only 4 stations (3.8\% from all stations) show a statistically significant downward trend, while 58 stations (55.2\% from all stations) show a statistically significant upward trend. The remaining 43 stations (40.9\% from all stations) show no significant trend. About 40\% (17 stations) of the stations with a flat trend are located in the southeastern and eastern parts of the country, being consistent with the areas where the smallest number of hail days per year is found.

b. Physical mechanisms related to hail variability in Romania

The assessment of the atmospheric instability, during the considered period, was performed using the re-analysis data described in section 2.
The spatial distributions of the mean values of CAPE, \( q \) in the lowest 100 hPa, FLH, and CLDWTR (Figs. 11 and 12) are consistent with the one of mean hail days per year, mean and maximum hail diameter, and severe hail days per year (Figs. 2–5). Average CAPE and \( q \) in the lowest 100 hPa have the smallest values in southeastern Romania and the highest toward the western part of the country. The mean CAPE values range from 90 J kg\(^{-1}\) in the southeast to 530 J kg\(^{-1}\) in the western part. The average \( q \) distribution follows the CAPE pattern, with the lowest values (6.5 g kg\(^{-1}\)) in the southeast, and the largest values (9.5 g kg\(^{-1}\)) in the western part. The same patterns are observed in the FLH and CLDWTR spatial distributions. Average FLH present the largest values (around 3700 m) in the southeastern part of Romania, and the smallest values (around 3300 m) in the north and northwest. Also, the smallest average CLDWTR values (around 25 g kg\(^{-2}\)) are observed in southeastern Romania, while the largest average values (around 60–70 g kg\(^{-2}\)) are observed in the north and northwest. Consequently, comparing Figs. 2–5 with Figs. 11–12, one observes that hail formation was not generally favored in the southeast, resulting in the lowest values of mean hail days. In the rest of the territory the convection was much more favored, where intense updrafts, that can sustain hail embryos in environments with high liquid water and low freezing levels (so that significant melting does not occur), can develop, as being depicted by the distributions of hail days and convective parameters.

In addition, correlation maps between mean hail days per year and CAPE and between mean hail days per year and \( q \) in the lowest 100 hPa, for the period April–September 1961–2012, indicate that also large-scale atmospheric circulation patterns are related to the spatial variability of hail occurrence in Romania (Fig. 13). The patterns in Fig. 13 show that the variability of annual hail frequency in Romania could be related mainly to Atlantic low pressure systems. The mean hail days per year, in Romania, is positively correlated with an enhanced convective activity (yellow and red shaded in Fig. 13a) that follows the large-scale shape of an extratropical cyclone moving eastward from the Atlantic over the European continent. The correlation coefficients between the hail days per year and specific air humidity indicate that the cyclone tail moves the humid air masses from the Mediterranean area to the higher latitudes (yellow and red shades in Fig. 13b) leaving room for dry air masses (blue shades in Fig. 13b) coming from the north.

c. Discussion

Brief discussions on the approach of this study and similarities with other research on hail, as well as
limitations of the datasets will be presented in the following. Thereby, it is noteworthy to mention that the spatial distribution of hail frequency (hail days per year) in Romania (Fig. 2), calculated using observations at the weather stations, is similar with the normalized density of hail days per year per degree square identified with the Convective Diagnosis Procedure (CDP) developed by the Met Office and presented in Fig. 12 in the study of Hand and Cappelluti (2011). In their study, Hand and Cappelluti (2011) used an algorithm, based on a paper by Fawbush and Miller (1953), to diagnose the hail from numerical model vertical profiles of temperature and humidity. The CDP has been applied to the results of global model fields for 0000, 0600, 1200, and 1800 UTC obtained for every day between the beginning of 2004 and the end of 2008. Over Europe, Hand and Cappelluti (2011) found high densities of hail days, for instance, over the Alps, Italy, Romania, the Balkans, and Greece. Thus, numerical models or reanalysis datasets provide useful information on the areas where convective storms associated with hail may develop.

The gradients in hail days per year spatial distribution in Romania (Fig. 2) is similar to the findings of other studies conducted, for example, in the United States (Changnon 1977), Canada (Etkin and Brun 1999, 2001), Argentina (Mezher et al. 2012), and China (Zhang et al. 2008). These high gradients are visible also over the Alps (Nisi et al. 2016) and other mountainous regions of Europe (Pociakal et al. 2009; Punge and Kunz 2016), revealing a relationship between hail formation and topography (e.g., orographic enhancement of convection).

Regarding severe hail, although some studies discussed the issue of defining it (Webb et al. 2009; Sioutas et al. 2009; Dotzek et al. 2009; Eccel et al. 2012), hail severity is commonly defined by hail diameter. Herein, severe hail was defined as hail with diameters equal to or
greater than 1.5 cm, as crop damages were largely reported with this size (Cică et al. 2015). The same criteria were used, for instance, by Kahraman et al. (2016) to define the hail that produces severe damage in Turkey.

The trend of hail events calculated for each of the 105 stations (Fig. 10) shows a large difference between the number and geographical placement of stations with a statistically significant upward trend (58 stations, all areas of Romania) and those with a statistically significant downward trend (4 stations, western Romania). Similar results were found, for instance, by Xie et al. (2008), who calculated the trend of the mean hail days for 523 weather stations in China, for the period 1960–2005. They found that only one station in the northwest of China shows an upward trend, and that most of the stations with a flat trend are located in the south of China, while about 25% (131 stations) with a distinct downward trend are located in the northwest and northeast of China.

Hailstorms present high spatiotemporal variability and are not always captured accurately and uniquely by a single observation system. It is likely that localized hail events are not recorded at weather stations or by hailpads. In contrast to point measurements (used in this study), the intensity, track, and spatial extent of hailstorms can be derived from radar data, as weather radars provide the advantage of 3D measurements performed at high spatiotemporal resolutions. Merging the ground observations with remote sensing datasets, the type of analysis presented herein can be significantly improved.

4. Conclusions

This study presents the hail climatology and trends in Romania between 1961 and 2014 (54 yr), based on a dataset of observations collected at 105 weather stations. The main conclusions can be summarized as follows:

1) Convective storms that produce hail are common in Romania. The highest hail frequency is found in the country’s mountainous areas, where the average number of hail days per year can reach up to 11.8 (northwestern Romania). The lowest hail frequency occurs in southeastern Romania, near the Black Sea.

2) The monthly distribution of hail events shows that most of these occur during the convective season (April–September). As the year progresses, the number of hail events starts to increase in late spring (April–May), peaks in June, and decreases during autumn (September–October).

3) Most hail events (78%) occur in the afternoon and evening hours, between 1000 and 1800 UTC, while
the rest (22%) occur in the interval between 1800 and 1000 UTC.

4) The spatial distribution of the mean and maximum hail diameter, and severe hail days per year reveals a spatial division between the southeastern and southern parts of Romania (smaller hail and less severe hail days) and the rest of the country (larger hail and more severe hail days).

5) The spatial distributions of the average daily values of CAPE, $q$ in the lowest 100 hPa, FLH, and CLDWR are consistent with the distributions of the mean hail days per year, mean and maximum hail diameter, and mean severe hail days per year. Therefore, convective storms producing hail are less favored in southeastern Romania, where freezing levels are higher and the cloud water content is smaller than in the rest of the country.

6) The spatial distribution of the average time of occurrence of severe hail shows that severe hail occurs, overall, between 1400 and 1600 UTC. In the southwest, severe hail occurs later between 1600 and 1900 UTC.

7) The trend analysis of the mean number of hail days per year at each of the 105 weather stations, during 1961–2014, reveals a statistically significant upward trend at 58 stations, while 4 stations show a significant downward trend (95% confidence level for both the upward and downward trend). The rest of the stations (43) show no significant trend.

8) The return period analysis of the maximum hail diameter, recorded at the weather stations, suggests an occurrence of 1 in 100 years in the case of diameter equal or larger than 85 mm, 1 in 50 years of diameter equal or larger than 76 mm, 1 in 10 years of diameter equal or larger than 56 mm, and 1 in 2 years of diameter equal or larger than 32 mm.

9) Some evidence indicates that the variability of the mean hail days per year in Romania is also related to the variability in the occurrence of low pressure systems of Atlantic origin, which can further generate low pressure systems over the Mediterranean Sea, moving the low-level moist air toward eastern Europe.

The results of this study contribute to the climatology of hail in Europe, and to a better understanding of the hail variability in the current climate of Europe by presenting a comprehensive hail climatology and trend analysis in Romania. However, identifying and validating the causes behind the hail variability and trends over Romania require more studies including numerical experiments with climate models at a very high spatial resolution.

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