CLIMATOLOGICAL ASSESSMENT OF EXTREME 24-HOUR PRECIPITATION IN BULGARIA DURING THE PERIOD 1931-2019

Lilia Bocheva, Krastina Malcheva

National Institute of Meteorology and Hydrology, Bulgaria

ABSTRACT

The object of this study is the variability and trends of extreme 24-hour precipitation in Bulgaria during the period 1931-2019. The regime of potentially dangerous precipitation (≥ 60 mm/24 h) have been analyzed on the base of available daily data from all stations of the national meteorological network with continuous observations at least in half of the study period. We focused our attention on this type of precipitation because it often causes significant economic damage and human casualties.

The advanced tools, embedded in ArcGIS Pro 2.4, have been used to investigate the intra-annual and spatial distribution of extreme precipitation. Also, the number of cases and the number of days with extreme precipitation have been summarized for the regions with different precipitation regimes and compared for three sub-periods (1931-1960; 1961-1990; 1991-2019).

In the regions with temperate-continental and transitional-continental climate, which comprise almost 70% of the territory of Bulgaria, the number of days with extreme precipitation remains almost unchanged in the first two periods while in the last period (1991-2019) it increases by 19-42%. The most considerable change in the number of these events is observed in the regions with transitional-Mediterranean climate and maritime climate (near the Black Sea). In the south-central and eastern parts of the country, the number of days with heavy precipitation is twice more in recent years in comparison with the period 1931-1960, and with 32% higher than those in the period 1961-1990. In contrast, in south-western Bulgaria, which is also strongly influenced by the Mediterranean air masses, these events have even decreased in recent years – with about 25% compared to 1961-1990.

Keywords: Bulgaria, extreme precipitation, climate variability

INTRODUCTION

In recent decades, in the context of the theory of global warming, there has been a sharp increase in the interest in changing the precipitation regime at both global and regional levels ([1], [2], [3]). Most authors conclude that the observed increase of global average air temperature after pre-industrial age (0.8-1.2 ºC) lead to a rise in the amount of water vapor in the atmosphere, to changes in the water cycle and atmospheric circulation, and is the reason for the observed global increase in extreme precipitation. The eastern Mediterranean is one of the most affected areas by climate change in Europe, where the combined effect of warming and drying is expected to increase the regional impact of global warming [4]. In addition to changes in mean climatic conditions, global warming is likely to induce changes in several aspects of extreme rainfall, such as duration and magnitude ([5], [6]).

The climate in Bulgaria became not only warmer but also drier at the end of the 20th century [7]. From the beginning of the 21st century, however, a statistically insignificant increase of annual precipitation totals is observed in our country mainly due to the contribution of heavy rainfall, whose frequency increased significantly ([8], [9]).

The main goals of this study are to present the spatial and temporal distribution of heavy precipitation events in different parts of Bulgaria and also to summarize their climate peculiarities over a longer period. We focus our attention on this group of torrential precipitation because daily amounts above 60 mm are higher than monthly normals for more than 80% of meteorological stations in Bulgaria and often cause damages in affected regions.

DATA AND METHODS

Precipitation data, only for potentially dangerous events (≥ 60 mm/24 h), in the period 1931-2019 for 498 meteorological stations (Fig.1b – all dots) from the meteorological database of the National Institute of Meteorology and Hydrology (NIMH) were processed by program procedures and respective time series were obtained. The threshold of 60 mm/24 h is chosen, because it's similar to those used in forecasting practices in NIMH (extreme event warnings according to the METEOALARM), and also its applicability was confirmed through the approach presented in [9].

In all stations, daily precipitation total is measured at 7.30 a.m. (local time) with classic ground-level precipitation gauges and represented the 24-h amount collected from 7.30 h of the previous day. The data series have been examined with respect to their quality and continuity of records. The regime of extreme daily precipitation is summarized for the whole study period and compared for three sub-periods (1931-1960; 1961-1990; 1991-2019) on the base of all available data from stations with continuous records for at least half of the study period. About 20% of the stations have continuous data for the almost full 89-year period (Fig. 1b – black dots).

Thanks to advanced tools, embedded in ArcGIS Pro 2.4 [10], the regionalization of examined events is made based on climate classification of precipitation regime in Bulgaria [12] and five specific regions on the territory of the country are determined (see Fig. 1). The long term variation and the intra-annual regime of days and cases with potentially dangerous precipitation for each of them are analyzed for the whole period and compared for 3 specific periods, mentioned above. The spatial distribution of frequencies of extreme precipitation in Bulgaria (see Fig. 3) is obtained by using the same approach described in [11].

DISTRIBUTION OF EXTREME PRECIPITATION IN BULGARIA

The local and regional precipitation regime in Bulgaria is highly influenced by latitude, altitude, topography, the proximity of large water bodies (the Black Sea and the Aegean Sea), and the prevalent atmospheric circulation. Our country is also located on the transition between two climatic zones (moderate continental and Mediterranean ones) in which the intra-annual precipitation regime is very different. According to the accepted in the NIMH climate classification [12], the territory of Bulgaria is divided into two main climatic areas (European-Continental and Continental-Mediterranean) and four climatic subareas (Moderate-Continental, Transition-Continental, South-Bulgarian and Black-Sea). In Moderate-Continental subarea and part of Transition-Continental

subarea, the maximum precipitation occurs in summer, and the minimum – in winter, and opposite, in the southernmost regions (belonging to South-Bulgarian subarea) and Black-Sea subarea the maximum precipitation occurs in winter or autumn, and the minimum – in summer. The rest part of the territory of Bulgaria falls into a transition zone, where the seasonal precipitation amounts are largely equalized. These peculiarities determine the climate classification according to the annual course of precipitation in the country presented in [12].

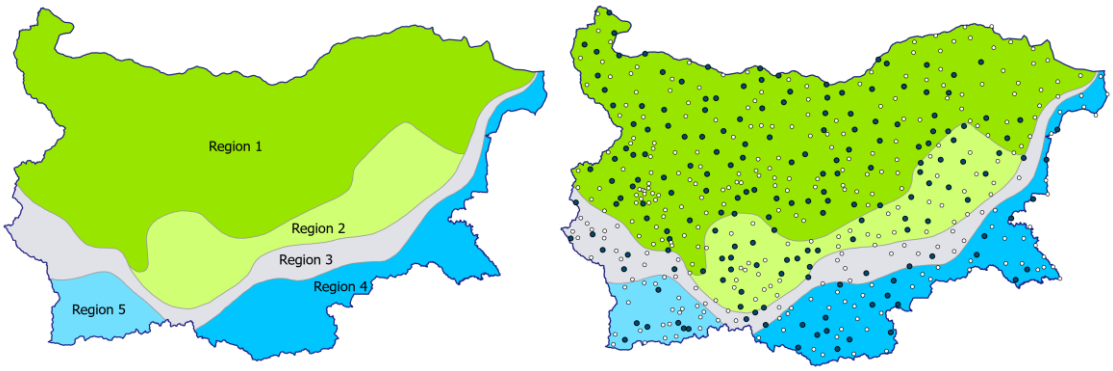


Figure 1. (a) Regionalization of 24-hour extreme precipitation events for the period 1931-2019 based on climate classification of precipitation regime in Bulgaria [12]; (b) Spatial distribution of meteorological stations, used in the study (black dots – stations with continuous data for the almost full study period).

Summarizing the data on extreme precipitation for the 89-year study period, we also grouped them according to the peculiarities of their monthly distribution. The following division into 5 main regions, presented on Fig. 1, is obtained. These regions almost completely coincide with the areas described in [12]. The annual distribution of the number of days and cases with potentially dangerous precipitation for each region, as well as their monthly and quantity frequency, are presented on Fig. 2. The largest Region 1, where the climate is predominantly moderate-continental, is characterized by a pronounced maximum of extreme precipitation during the summer (over 60% of all cases are in period June-August) and by a winter minimum (about 3% in the period February-March). In Region 2 and Region 3, which are in a transition zone between continental and Mediterranean air masses, the days with potentially dangerous precipitation have a more even distribution in the individual months without such clear peaks. However, in Region 2 the influence of continental climate is still dominant. Typically the maximum number of cases is registered in the warm half of the year (about 65% of all cases are between May and September), and the minimum is during the winter and spring (about 19% between December and April). Region 3 has a relatively uniform monthly distribution of extreme precipitation in the second half of the year with maximum in late autumn and second maximum in July. Region 4, which includes the Rhodope Mountains, Strandzha-Sakar mountainous region and narrow area near Black sea coastline, as well as Region 5, covering the south-western corner of the country, are the zones with well-expressed Mediterranean precipitation regime with autumn maximum (in October or November) and spring minimum (in April or May).

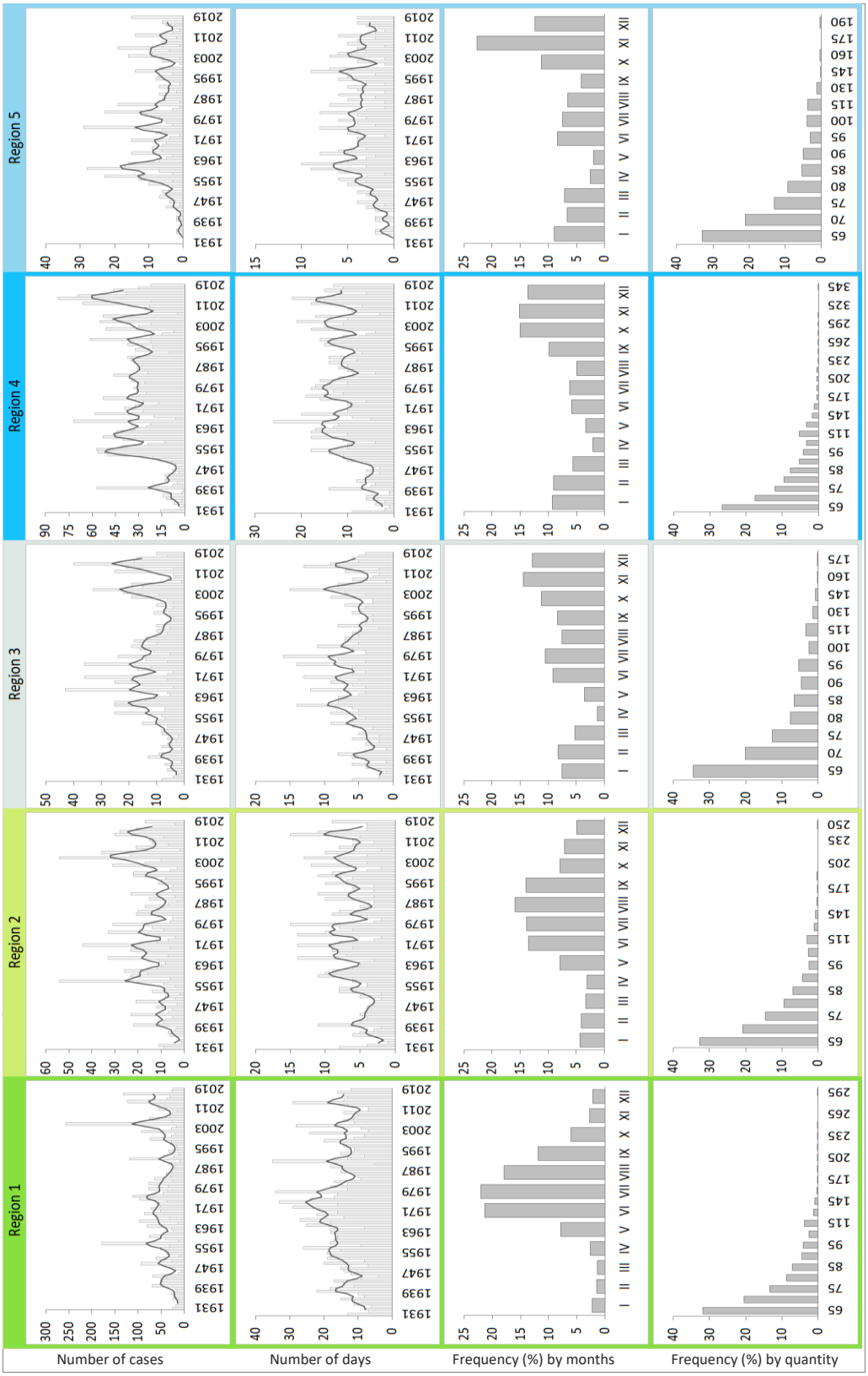


Figure 2. Long-term variation and intra-annual regime of days and cases with potential dangerous precipitation for 5 specific regions, presented on Fig. 1, for the period 1931-2019; on the abscissa of the last row are shown upper bin boundaries in mm.

Although Region 4 and Region 5 are in the same sub-area when it comes to the variation of the annual amount of precipitation [12], there are some differences in the intra-annual regime of extreme 24-hour precipitation, therefore we considered them as two separate regions. In Region 4, the frequency of extreme precipitation is more evenly distributed in autumn and winter when more than 70% of all cases are observed, while in Region 5, there is a well-defined maximum in November when a quarter of all cases is registered. In both regions, a well-pronounced minimum in April and May is seen (Fig. 2), but in June, the frequency of extreme precipitation rises in Region 5, in which about 22% of all cases are observed in summer.

Daily amounts of extreme precipitation between 60 and 85 mm represent about 75-80% of all cases (Fig.2). The frequency of registered quantities over 85 mm/24h is gradually decreasing for almost all regions. The cases over 200 mm are an exception, and in Region 3 and Region 5 they are completely absent. The situation is not the same in Region 4, where high precipitation extremes not only are significantly more common (over 1/3 of all cases), but a secondary maximum also is observed for quantities between 100 and 115 mm (5% of cases). The absolute maximum 24-hour precipitation amount in Bulgaria was measured in this region (Varna, August 21, 1951 – 342 mm).

The number of meteorological stations varies in the study period, so the trend analysis is performed only for stations with continuous data (Fig. 1b – black dots) using the R-package 'trend' [13]. In Region 2 and Region 4, the aggregate number of days with extreme precipitation shows a statistically significant (at a 5% level of significance) positive trend of 0.24 days/dec and 0.45 days/dec, while the number of cases increases with 0.59 days/dec and 0.98 days/dec, respectively. Although in the other regions we don't find any significant tendency in the period 1931-2019, the polynomial curves fitted to the number of days and cases with extreme precipitation, smoothed with 5-year binomial filter, reveals some interesting results (Fig. 3). Except Region 5, where both the number of cases and the number of days with extreme precipitation decreases over time, a relatively rapid increase of extreme events occurs in the rest part of the country in the late 1990th. Moreover, the number of cases rises faster than the number of days, which is in agreement with the worldwide surveys about increasing the spatial range and frequency of precipitation extremes.

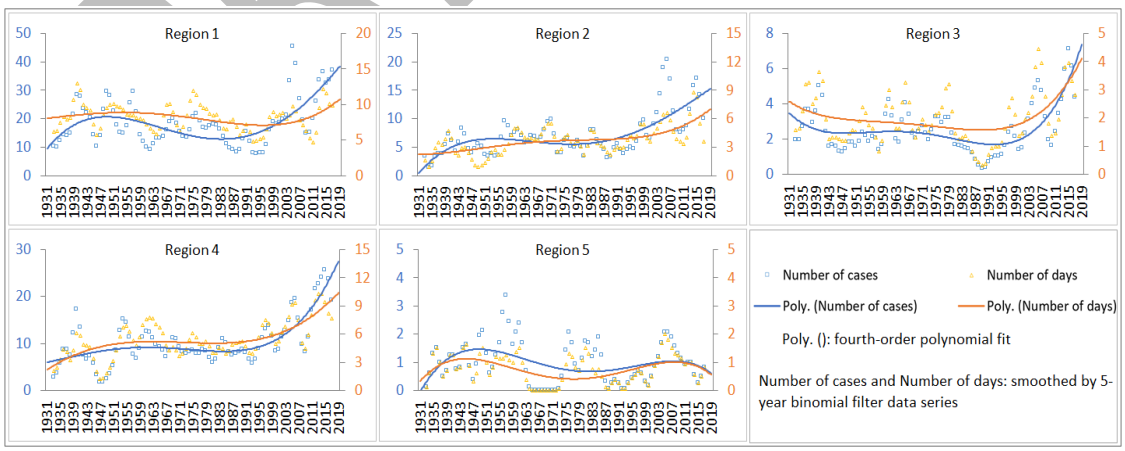
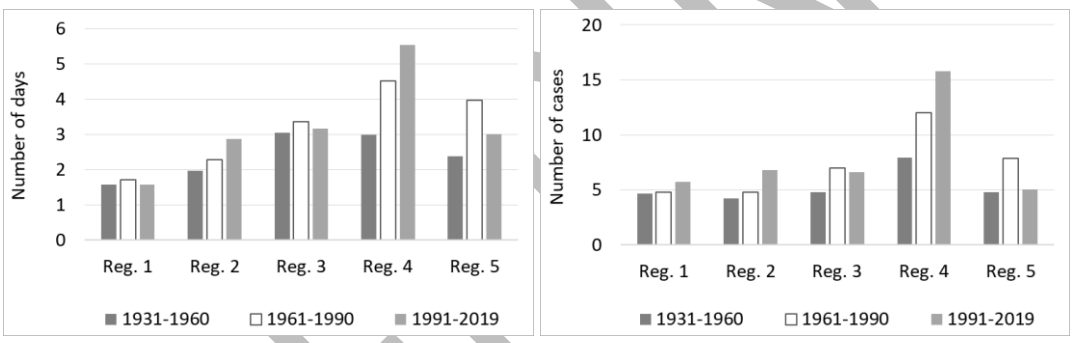


Figure 3. Long-term variation of the smoothed number of days and cases with extreme precipitation on the basis of continuous records in the period 1931-2019.

The multi-year regime of precipitation is characterized by great variability and in order to better assess the observed trends, the average long-term number of days and

cases with extreme events for 3 equal periods for each of the defined regions have been calculated (Fig. 4). In the first two regions (covering more than 70% of the territory of Bulgaria), where the continental climate is dominant, the number of cases with extreme precipitation in the first two periods (1931-1960 and 1961-1990) remains almost unchanged while in the last period (1991-2019) it increases by an average of about 19-42%. In Region 3, where the Mediterranean influence is more pronounced, there are no significant differences in the number of days and number of cases with heavy precipitation over time. The most considerable change in the behaviour of these extremes appears in the regions with a Transitional-Mediterranean climate and near the Black Sea. In the south-central and eastern parts of the country, the number of days with torrential precipitation is twice more in recent years in comparison with the first 30-year period (1931-1960) and with 32% higher than those in the second period of investigation (1961-1990). In contrast, in south-western Bulgaria (Region 5), which is also strongly influenced by the Mediterranean air masses, these events have decreased by about 25% compared to those during the period 1961-1990. In general, the increase in the number of cases is more significant than the increase of the number of days with extreme precipitation, which is an indicator of increasing the spatial range and frequency of this phenomenon, especially during the last period.



(a) (b)

Figure 4. Mean number of days (a) and cases (b) with extreme precipitation for each region for 3 periods (1931-1960; 1961-1990; 1991-2019).

Spatial distribution of the mean annual number of days with extreme precipitation in Bulgaria for the period 1931-2019, obtained by using the Empirical Bayesian Kriging Regression Prediction tool in ArcGIS Pro 2.4, is presented on Fig. 5. (See [11] for details about used interpolation technics.)

As expected, the highest frequency of this dangerous phenomenon occurs in the regions of the Rhodope Mountains and Strandzha Mountain, where the average annual number of extreme precipitation days even may exceed 2 days/year in the southernmost parts. The mountain areas (above 1000-1200 m altitude) are well-outlined with an annual frequency of 0.5 to1 days. In the same interval ranges the number of days with heavy precipitation in Northeast Bulgaria, near the Black sea coast (Fig. 5). In the other regions of the country, the frequency of studied events is below 0.5/year. The obtained spatial distribution of the annual frequencies of potentially dangerous precipitation largely coincides with the presented in [11] spatial distribution of the annual precipitation (the larger precipitation totals, the higher frequency of extreme events). The biggest difference appears in northeastern Bulgaria, where the frequency of extreme precipitation is relatively high, while the average annual precipitation is one of the lowest in the country.

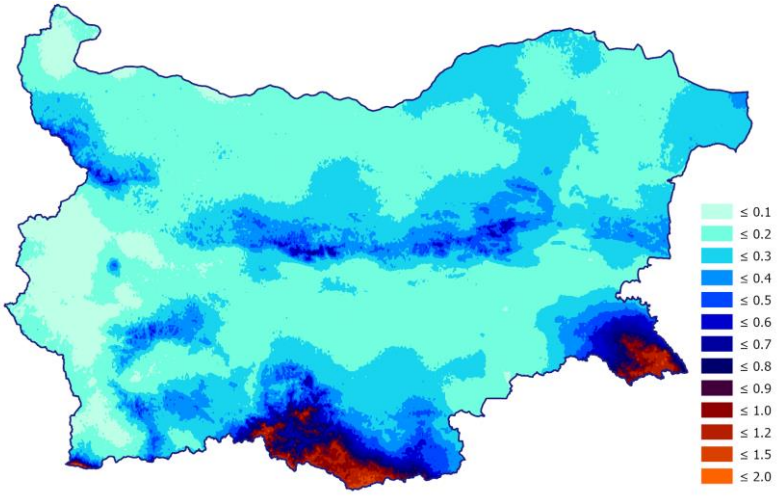


Figure 5. Spatial distribution of mean annual number of days with extreme precipitation in Bulgaria for the period 1931-2019.

CONCLUSION

Long-term variation, trends and spatial distribution of extreme 24-hour precipitation sums (≥ 60 mm) for the period 1931-2019 are presented in this study. The grouping of these dangerous phenomena according to the peculiarities of their monthly distribution is also presented and the obtained 5 regions almost completely coincide with climatic areas in Bulgaria, which present the annual course of precipitation. The most significant differences in extreme precipitation frequency and trends in the zones with well-expressed Mediterranean precipitation regime is received.

The frequency distribution by quantity of all observed extreme precipitation show that most cases are between 60 and 85 mm (75-80% of all). Only in Region 4, the high precipitation extremes are one quarter of all cases. As expected, the highest annual frequency of days with this dangerous phenomenon occurs in the regions of the Rhodope Mountains and Strandzha Mountain - with average annual number in the southernmost parts over 2 days/year. The mountain areas are well-outlined with an annual frequency of 0.5 to 1 days, as well as Northeast Bulgaria, near the Black sea coast. The biggest difference appears in northeastern Bulgaria, where the frequency of extreme precipitation is relatively high, while the average annual precipitation is one of the lowest in the country.

In general, the increase in the number of cases in all regions is more significant than the increase in the number of days with extreme precipitation, which is an indicator of an increase in the frequency of these phenomena. Except Region 5, where both the number of cases and the number of days with extreme precipitation decreases recently (25% compared to those during the period 1961-1990), a relatively rapid increase of extreme events occurs in the rest part of the country in the late 1990th. Statistically significant positive trend of 0.24 days/dec and 0.45 days/dec shows the aggregate number of days with extreme precipitation in Region 2 and Region 4, while the number of cases increases with 0.59 days/dec and 0.98 days/dec, respectively. In Region 4, the number of days with torrential precipitation is twice more in recent years in comparison with period 1931-1960 and with 32% higher than those in period 1961-1990. In

contrast, in south-western Bulgaria (Region 5), which is also strongly influenced by the Mediterranean air masses, these events have decreased by about 25%.

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