

COMPARATIVE ANALYSIS OF SEVERE STORMS, CONNECTED WITH EXTREME PRECIPITATION IN BULGARIA (1951-2010)

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Abstract

During the last years there is an evident upward tendency of damages caused by natural disasters. Much of them are caused by extreme events such as torrential precipitation associated with thunderstorms or/and wind storms and they tend to increase.

A comparative analysis of some very extreme precipitation events was carried out using all the available data for torrential precipitation (totals over 100 mm/24 h) from the meteorological network of the National Institute of Meteorology and Hydrology for the period 1951–2010. The annual distribution of extreme precipitation events over different parts of Bulgaria is presented. For the territory of the country as whole an increase of the mean annual number of days with torrential precipitation was found recently. This increment was statistically significant in Eastern Bulgaria and Black sea coast where the number of flood rain events has increased especially during the pick of active tourist season.

Key words: extreme precipitation, annual variability; floods

1. INTRODUCTION

Global warming is suggested to be linked to the recent increase of heavy rainfall events due to the increased atmospheric water vapor and warmer air. Annual precipitation totals also show upward trends in many regions (Dai et al., 1997). In most areas of the world, the trends in rainfall have the same sign as the trends of 1-day heavy rain amounts (Groisman & Coauthors, 1999; Alexander et al., 2006). Contrary to many mid- to upper latitude regions of the world in which the positive trends in precipitation amounts were reported, several studies (Alexandrov et al., 2004; Sahsamanoglou et al., 1997; Sharov et al., 2000) show a dominant downward trend in Balkans. Negative trend in annual and seasonal precipitation sums, associated with increase in the contribution of heavy rainfall events to total precipitation, is observed in some Mediterranean and South European countries (Alpert et al., 2000; Brunetti et al., 2001; Costa, 2007; Nastos & Zerefos, 2008; Croitoru et al., 2013).

The extreme precipitation events in Bulgaria are rare and local phenomena. They are usually registered at one or a few neighbor stations within a couple of days. The precipitation amounts ≥ 100 mm/24 h, measured in a given station correlate with those measured in neighbor stations only to some extend (Gospodinov and Dimitrov, 2010). On the other hand, such events can occur in between the existing meteorological stations. That's why the investigations of torrential precipitation, as well as other climate extreme events, have to be considered with the fact that existing meteorological network are not created for observation of such rare phenomena and some times small-scale phenomena.

The series of hazardous events which affected the Balkans and in particular Bulgaria during the last 10 years are connected with severe convective storms and really heavy rainfall events which had a considerable impact on the Bulgarian economy. For example only in 2005 a series of such extreme events produced floods in more than 80% of the territory of the country and caused significant property damage, (more than half a billion EUR) and loss of life (25 victims). Gathering and analyzing all the available data for such type of weather phenomena is therefore necessary in order to improve their predictability.

The aim of this investigation is to study variability and distribution of extreme precipitation events over Bulgaria (totals ≥ 100 mm/24 h in one station are considered) during the period 1951-2010. A complex analysis of torrential precipitation events over East Bulgaria is carried out.

2. DATA AND METHODS

The study is carried out on the basis of data of torrential precipitation events from the meteorological database of the National Institute of Meteorology and Hydrology (NIMH) of Bulgaria for the period 1951-2010. Extreme

precipitation event is defined as one for which the total measured rainfall per 24 hours is equal or greater than 100 mm, which is almost 2 times above the average monthly precipitation amount for all Bulgarian meteorological stations.

The data from all types of stations (synoptic, climatological and rain-gauge) (Fig.1) are used. For some of them regular observations are available for the whole period and for others – only for a part of it. The period after 1951 is considered because the instruments and methods of measurement of daily precipitation amounts are the same. Furthermore, after the World War II, in many places in Bulgaria new meteorological stations were opened or meteorological observations were restored. This increased the representativeness of the national meteorological network. In all station daily precipitation total is measured in 7:30 a.m. local time (LT) with classic ground-level precipitation gauges. The automatic stations data is not included in this study, because their data records are very short – not more than 15 years of measurements. Expert quality control of the data is performed on the basis of standard Transact-SQL monthly and annual reports from the meteorological database and comparison with meteorological stations – analogues.

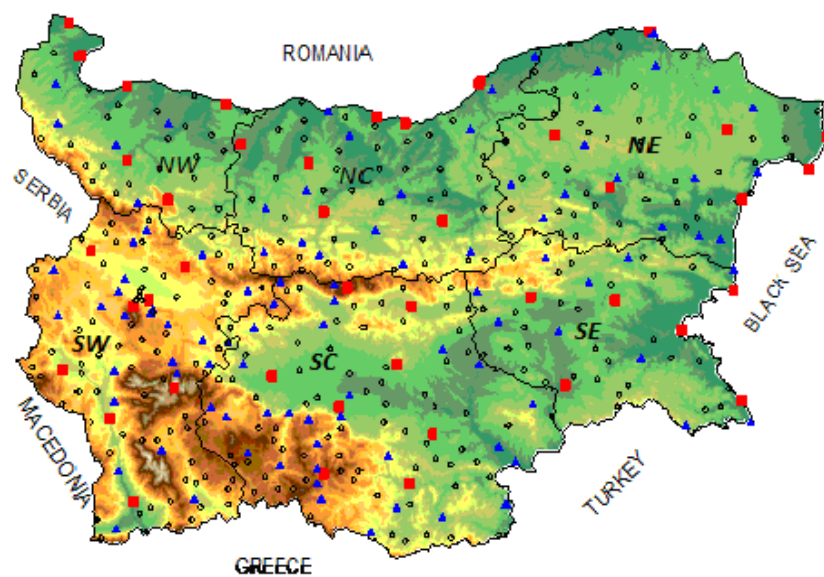


Figure 1. NIMH weather network in Bulgaria: synoptic (squares), climatological (triangles) and rain-gauge (circles) stations.

The monthly and annual distributions of days with torrential precipitation are summarized for the whole country for two 30-years periods 1951-1980 and 1981-2010. The mean annual and mean monthly number of days with extreme precipitation is summarized for the country as a whole, and for each of the 6 considered regions in Bulgaria during the whole studied period. The selected regions are: North-West (NW), North-Central (NC), North-East (NE), South-East (SE), South-Central (SC), and South-West (SW) Bulgaria (BG) - see Fig.1. They are chosen on administrative principle but also match to some extent the different sub-climate zones of the country. Table 1 summarizes the geographical features of the six regions.

Statistical analysis is performed in order to assess the variability and possible differences in the torrential precipitation days for long-term data series. The Poisson distribution and the corresponding nonparametric tests are applicable to such discrete samples of heavy precipitation days (Stat Sof., 2004).

All cases associated with extremely severe weather, which produced abundant torrential precipitation of about 200 mm/24 h in the eastern part of the country at the Black Sea coast or not far from it have been analyzed. For these cases the measured 24-hour precipitation totals exceed seasonal normal of precipitation for the given station. These amounts are among the greatest ever observed in Bulgaria.

The NIMH historical archive of synoptic maps, the monthly bulletin of NIMH and the NCEP/NCAR Reanalysis data and maps (see Kalnay & Coauthors, 1996) were used for the classification of synoptic situations causing torrential precipitation in East Bulgaria. Images in Fig. 4 are provided by the NOAA-ESRL Physical Sciences Division, Boulder Colorado from their Web site at <http://www.esrl.noaa.gov/psd/> and by EUMETSAT.

Table 1. Geographical features for different regions in Bulgaria.

<i>Geography of regions</i>	<i>Orography</i>	<i>Relation to sea bodies</i>
NW Bulgaria	Flat, mountain ridge at southwest border	Far from sea
NC Bulgaria	Flat, mountain ridge at south border	Far from sea
NE Bulgaria	Flat, mountain ridge at southwest corner	Borders the Black Sea
SE Bulgaria	Flat, low mountain at south border	Borders the Black Sea, close to Aegean Sea
SC Bulgaria	Flat in the middle, mountainous massive in the south, mountainous ridge in the north	Close to Aegean Sea
SW Bulgaria	Very mountainous	Close to Aegean Sea

3. EXTREME PRECIPITATION IN BULGARIA DURING THE PERIOD 1951 - 2010

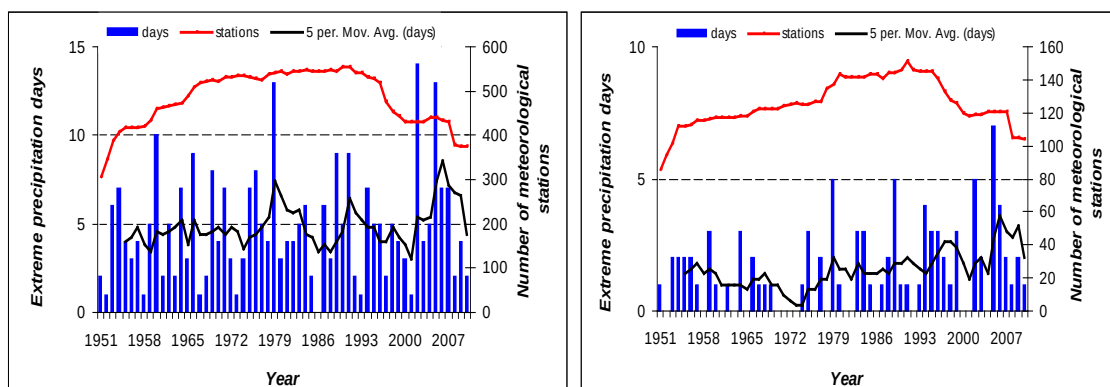
The mean annual number of days with dangerous precipitation during the period (1981-2010) is 4.9 which in comparison with the period (1951-1980) – 4.7 days, represents statistically insignificant increase of mean annual extreme-rainfall days of about 4% for whole country (Table 2). In the same time, the same comparison for each of the 6 studied regions show that the decreasing trends in annual distribution of torrential precipitation are observed in West and NC Bulgaria. This decrement (about 40%) is statistically significant only for SW Bulgaria. In other parts of the country an increasing trend is observed during the second 30-years period, which is statistically significant for stations from NE and SE Bulgaria (Table 2).

During the studied 60-year period the annual distribution of number of days with precipitation ≥ 100 mm/24 h, registered at least in one station (Fig.2a), shows a slight trend of increase for the country as the whole. This increment become more pronounced after 1991, nevertheless that the number of observation stations decreases. The same tendency is observed especially for stations from NE and SE regions in which during the last 20 years the days with extreme precipitation become two times more frequent than in other regions of Bulgaria (Fig.2b). According to these results in the next paragraph we will present more precisely the weather patterns, connected with torrential precipitation in East Bulgaria.

The inter-annual distribution of the mean number of days with extreme precipitation is presented in Fig.3. Difference in monthly maximum of heavy rain days during the two investigated periods is observed (Fig.3a). During the period 1951-1980, the greatest number of heavy rain days is observed in June, September and January. Recently, such type of precipitation events more frequently occur in all summer months and especially in July their increase is about 170%. There is also an increase in the frequency of heavy-rain episodes in almost all months from May to November in the period 1981-2010. In contrary, there is a tendency of decrease of extreme-precipitation days (Fig.3a) in January and especially during the spring months (March and April). This has also been obtained in Cavazos (2000) and Bocheva et al. (2009).

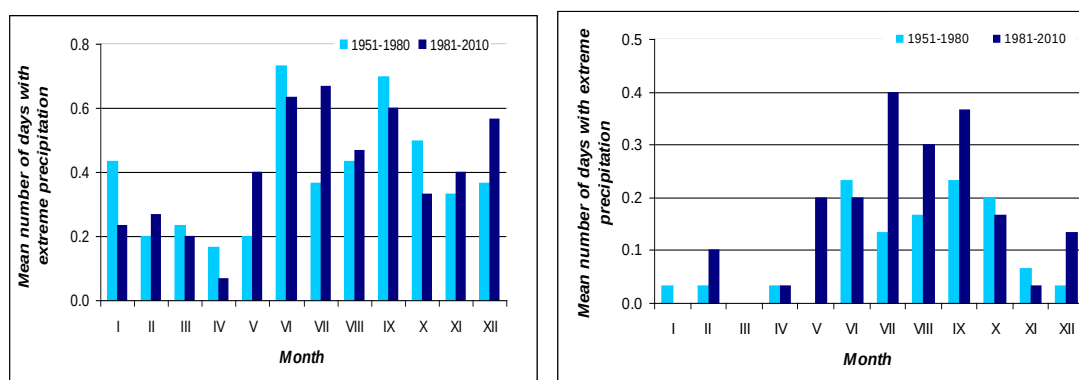
Table 2. Statistical comparison of the average number of torrential precipitation days ($Q \geq 100$ mm/24h) in Bulgaria as a whole and in the eastern part of the country in particular. Poisson distribution for the 1951 – 1980 (1) and 1981 – 2010 (2) data sets is used.

<i>No. of samples</i>	1	1	1	2	2	2	1, 2	<i>tail</i>	$(\mu_2 - \mu_1)/\mu_1$
<i>Precipitation days</i>	<i>mean</i>	<i>min</i>	<i>max</i>	<i>mean</i>	<i>min</i>	<i>max</i>		<i>probability</i>	
≥ 100 mm	μ_1			μ_2			χ^2	<i>p</i>	%
NW Bulgaria	0.27	0	2	0.17	0	2	0.698	0.403	-0.38
NC Bulgaria	0.67	0	2	0.47	0	6	1.064	0.302	-0.30
NE Bulgaria	0.53	0	5	0.93	0	4	3.315	0.068	0.75
SE Bulgaria	0.63	0	3	1.00	0	4	2.491	0.114	0.58
SC Bulgaria	1.63	0	6	2.10	0	6	1.754	0.185	0.29
SW Bulgaria	1.27	0	5	0.77	0	3	3.726	0.053	-0.39
ALL BULGARIA	4.67	1	13	4.87	0	14	0.126	0.723	0.04



a) for all meteorological stations in Bulgaria b) for the stations in Eastern Bulgaria

Figure 2. Annual number of days with precipitation totals ≥ 100 mm/24 h, compared with the number of meteorological stations for the period 1951 - 2010.



a) for all meteorological stations in Bulgaria b) for the stations in Eastern Bulgaria

Figure 3. Inter-annual distribution of the mean number of days with extreme precipitation.

4. WEATHER PATTERNS CONNECTED WITH EXTREME PRECIPITATION IN EAST BULGARIA

Sixty nine synoptic situations, connected with 79 days with torrential precipitation during the whole period 1951-2010, are examined and classified. Rough distribution of such events in 4 typical synoptic situations is presented in Table 3. For many of these situations it is difficult to specify the synoptic feature, leading to more than 100 mm/24 h in one point.

Table 3. Distribution of extreme precipitation events in East Bulgaria (1951 – 2010) according to synoptic situation type.

<i>Synoptic situation</i>	<i>Number of extreme cases</i>	<i>% of total number</i>
<i>Mediterranean cyclone</i>	30	43
<i>Cold front</i>	19	28
<i>Unstable air mass</i>	14	20
<i>Weak depression</i>	6	9
<i>TOTAL</i>	69	100

East Bulgaria is mostly endangered by extreme precipitation in late summer and early autumn - more than 80% of all cases take place between July and October. When cyclonic systems with Mediterranean origin move into the Balkans they often block over, suppressed by a well developed anticyclone over Eastern Europe. This provides conditions for convergence of wind near the surface which favors convection. It is combined with strong mid-troposphere flow from southeast in the general circulation of the cyclonic system. On the other side, in late summer and early autumn, the sea water is relatively warm compared to the land surface and the thermal force is available over sea rather than over land. The air over sea is humid by default and thus moisture is also available in the air that undergoes convection. These three conditions ensure that convection systems mostly generated over sea and then transported inland by the dominant mid-troposphere flow. The fact that the dynamics is stationary provides so that the convection structures move into one and the same area inland for as long as 12 to 48 hours. In other words, the above-described synoptic conditions give birth to a continuous in time and stationary in space convective systems that generate strong precipitation at one and the same place. The cumulative precipitation therefore can be significant. An example about such type of event is given on Fig.4 - the case of 21-22 September 2005 when many villages and towns from 6 districts in East Bulgaria were flooded. The most endangered was town of Shabla at the northern coast of Black Sea. The reported cumulative amount of precipitation in Shabla for that process is about 3 times more than the monthly normal. Above 200 houses was flooded, 8 of all 9 bridges in the town was destroyed, and about hundred domestic animals was drown. Figure 4a,b show the dynamic structure which matches the above given description. Figure 4c is an infra-red satellite image (by MSG EUMETSAT) that shows the convection system that is generated over sea and then transported over land.

The higher frequency of the extreme precipitation events can be attributed to the widely accepted recent global climate trend. The global warming is expected to end-up with less precipitation in our geographical area. However, the storms may become more violent and as a consequence the extreme precipitation events more frequent. It seems to be the reality already.

The presented below extreme precipitation cases (accumulated precipitation amount above 200 mm/24 h) are very rare events in Bulgaria. For the last 60 years there have been registered 19 such events in the country as a whole, 12 of which in Eastern Bulgaria at the Black Sea coast or not far from it. In Table 4 some characteristics of all cases, which took place in NE and SE regions are presented. All these cases caused at least local floods and had a big effect on the regional and national economy, because all of them took place in a pick of active tourist season between July and October. It can be found in this list the biggest ever registered in Bulgaria precipitation amount from the meteorological records of NIMH (Varna-Druzhdza, 21 August 1951 – 342 mm/24h), and also the really biggest 24-hour precipitation amount ever measured in Bulgaria (Ahtopol 2, 06-07 October 1994 – 463 mm/24h). The difference between the two cases comes from the methodology of measurement of precipitation amount in climate and rain-gauge stations – once a day at 7:30 a.m. LT. In the year 1994 in Ahtopol there is almost 24 hours of uninterrupted heavy rain. The process starts at 02:30 a.m. LT on 06 October and ends at 02:00 a.m. LT on 07 October. So the total of 463 mm is the sum of two measurements during this precipitation event – 200 mm/24h (06 October 1994) and 263 mm/24h (07 October 1994) – see Table 4, line 11 and 12.

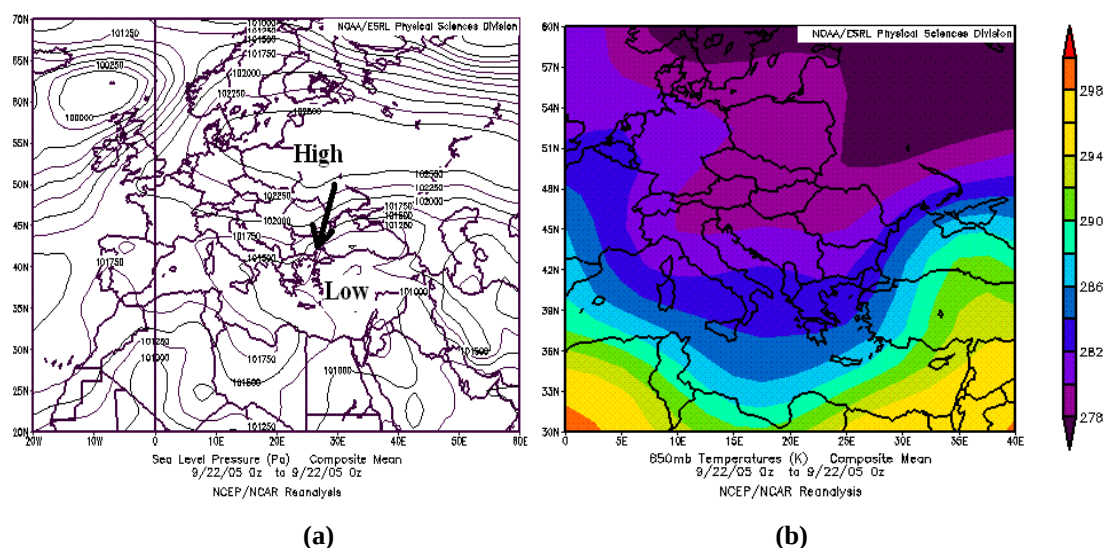




Figure 4.¹ Case of 22 September 2005: (a) Sea level pressure (Pa); (b) Air temperature (K) at 850 hPa; (c) IR satellite image; (d) After flood in Shabla

The physical intensity of precipitation (mm/min) is given in the last column of Table 4. Taking into consideration the definition of intensive precipitation (with physical intensity equal or more than 0.18 mm/min) it can be seen that in almost all given cases the mean precipitation intensity for whole process is greater than the threshold. The most extreme was precipitation in Ahtopol during the first 5 hours of event. All region of the town was flooded. This continuous dangerous event caused landslide activation near the coast area and damages on the roads between Ahtopol and Rezovo. The second one was the case from 04 September 1999, after which many towns and villages from 7 districts from eastern part of the country were flooded. There was a great damage on the infrastructure, hotels and beach, 13 people lost their life.

Table 4. Characteristics of extreme precipitation events

<i>Data</i>	<i>Station</i>	<i>Daily precipitation, mm (l/m²)</i>	<i>Duration, hours(h) and minutes(min)</i>	<i>Mean precipitation intensity, mm/min</i>
21.08.1951	Varna - Druzhiba	342	21h and 10 min	0.27
21.08.1951	Varna	258	21 h and 10 min	0.20
10.08.1975	Kosti	215	20 h and 20 min	0.17
24.10.1975	Zidarovo	212	23 h	0.15
25.09.1977	Rezovo	217	20h	0.18
21.09.1983	Vizitza	246	16 h and 50 min	0.24
21.09.1983	Sredets	210	20 h	0.18
21.09.1983	Bogdanovo	204	17 h	0.20
05.07.1987	General Toshevo	231	20 h and 30 min	0.19
06.10.1994	Ahtopol 1	212	5 h	0.71
06.10.1994	Ahtopol 2	200	5 h	0.66
07.10.1994	Ahtopol 2	263	18 h and 30 min	0.24
04.09.1999	Staro Oryahovo	269	13 h and 20 min	0.34
04.07.2005	Vrani kon	249	24 h	0.17
03.07.2006	MalkoTarnovo	301	18 h	0.28
07.08.2007	Tsar Kaloyan	291	18 h	0.27
09.07.2010	Shabla	201	16 h and 45 min	0.20

¹ Source: 4(a), (b) - NOAA-ESRL Physical Sciences Division, Boulder Colorado (<http://www.esrl.noaa.gov/psd/>); 4(c) – EUMETSAT (<http://www.eumetsat.int/>); 4(d) – Foto from BTA

5. CONCLUSIONS

The annual distribution of number of days with precipitation ≥ 100 mm/24 h, registered in at least one station, for the whole territory of Bulgaria shows a slight trend of increase, but without clear statistical significance. For the regions from western and north-central parts of the country the number of torrential precipitation days decrease during the second 30-years periods of observations and this trend is statistically significant for SW Bulgaria. Contrary, for East Bulgaria and the Black Sea coast there is statistically significant increase of mean annual heavy precipitation days during the period 1981-2010 versus the previous one 1951-1980 with about 60-75%.

An increase of frequency of the heavy rain events from May to November for the period 1981-2010 is observed for eastern regions. In opposite, there is a recent trend of decrease of extreme precipitation days in winter and especially in the spring months (like March and April).

Brief synoptic classification of all torrential precipitation episodes over eastern Bulgaria has been given. About 40% of all cases are associated to the development of Mediterranean cyclones over the region of the Balkan Peninsula. The above given evidences of increase of the frequency of torrential precipitation days over Eastern Bulgaria can be linked to the change of the trajectories of the Mediterranean cyclones over the Balkans (see Marinova et al., 2005).

The most extreme precipitation events for each month from July to October, which are observed in Eastern Bulgaria during the studied period, have been presented in this paper.

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