Wide-spread severe convective storm events in Bulgaria (1991-2010)

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I. INTRODUCTION

During the last years there is an evident upward trend of the amount of damage caused by natural disasters (UN/ISDR, 2008). Much of it is caused by extreme events such as torrential precipitation associated with thunderstorms or/and wind storms. The number of these atmospheric events also tends to increase. This change has often been attributed to the effects of climate change. Some authors (Easterling et al., 2000; Kothavala, 1997) point out that they occur with greater frequency, especially northward of 35°N. The same tendency is observed in Bulgaria during the last decade of the 20th century (Bocheva et al., 2006).

The objective of this work is to give an overview of the spatial and temporal distribution of the occurrence of severe convective storms (SCS) simultaneously in a large part of the country. The covered period is 1991-2010. All days in which there is thunderstorm activity combined with 24-hour precipitation amount above 30 mm are selected and analyzed. Detailed investigation is carried out on the part of these SCS which are observed in at least 4 out of 27 administrative regions of the country (see Simeonov et al., 2009). These large-scale SCS events have become more frequent in Bulgaria during the last 10 years. Most of them (96 % of all) have also been documented as being the cause of floods and economic loss in the affected regions. They are more often found in Central and East Bulgaria than in the western part of the country. 80% of them occur in the second half of summer and the first half of autumn.

An attempt is made to classify the synoptic situations leading to such type of massive SCS in Bulgaria and to further investigate the frequency distribution of the derived synoptic types on annual and monthly basis.

Analysis of the available aerological data for all cases is currently under work. For the most recent 10–year period (2000–2010) we try to investigate from a climatological point of view the frequency distribution of a selected number of instability indices to evaluate the thermodynamic environmental potential over large part of Bulgaria for the occurrence of potentially dangerous SCS.

II. DATA AND INVESTIGATION METHOD

The study is based on data of heavy and torrential precipitation events from the meteorological database of the National Institute of Meteorology and Hydrology (NIMH) of Bulgaria for the period 1991–2010. We consider 128 synoptic and climatological stations (Fig.1) in which regular observations are completed for the whole period. In all stations the daily precipitation total is measured at 7:30 a.m. local time with classic ground-level precipitation gauges. The data series have been examined with respect to their quality and continuity of records. Expert quality control of data has been carried out. The automatic stations data is not included in this study because of their short period of exploitation and different sensors. The distribution of 2 groups of stormy days for each station is analyzed and then summarized for each of the 6 considered regions in Bulgaria during the whole studied period. The chosen groups are: ***group I*** – days with heavy precipitation (59.9 ≥Q≥ 30 mm/24 h) and thunderstorm (Ts) at least in one station; ***group II*** - days with torrential precipitation (Q≥ 60 mm/24 h) and Ts at least in one station. 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 extend the different sub-climate zones of the country. Table I summarizes the geographical features of the six regions.

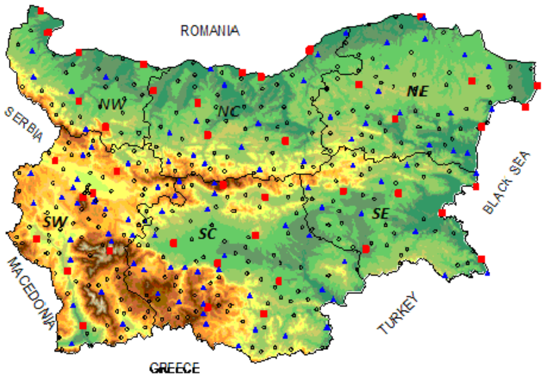


FIG.1. The present NIMH weather stations network: synoptic (squares), climatological (triangles) and rain-gauge (circles) stations

Geography of regions	***Orography***	***Relation to sea bodies***
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	Closest to Aegean Sea
SW Bulgaria	Very mountainous	Close to Aegean Sea

Table I: Geographical features for different regions in Bulgaria.

All days with thunderstorm occurrence in all synoptic and climatological stations within the studied period are considered. Thunder day is defined as follows:

- a day when at least one thunderstorm occurred between 00:00 and 24:00 h local time;
- even distant thunderstorms are taken into account;

- if a thunderstorm occurred at the turn of 2 days it is taken into account for both

The aim of the present study is to continue the investigation over potentially dangerous SCS that lead to abundant precipitation. This is the reason why the same method as the one in Simeonov et al., 2009, has been used. The chosen thresholds for heavy 24–hours precipitation amount is similar to the one accepted in Sharov&Tomova, 1987. They define the threshold as being the daily precipitation total, which is at least 30% of mean monthly precipitation sum for a given station.

Annual and monthly distributions of large-scale SCS are presented and results for two 10–year periods 1991–2000 and 2001–2010, are compared.

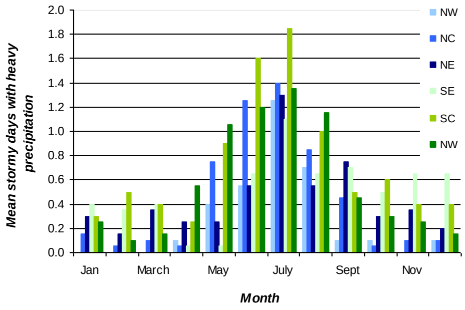
The NIMH historical archive of synoptic maps and NCEP/NCAR Reanalysis data and maps (see Kalnay and Coauthors, 1996) were used for the analysis and classification of synoptic situations causing severe convective weather events at least in 15% of the territory of Bulgaria. Maps are produced on http://www.esrl.noaa.gov/psd/ (NOAA/ESRL Physical Sciences Division, Boulder Colorado) and are based on NOAA Reanalysis (Kalnay et al. 1996).

The strongest convective activity in Bulgarian takes place mainly during the afternoon and early evening hours (Simeonov et al., 1990). This fact helps to motivate us to choose the day-time sounding data (06:00 or 12:00 UTC) from the nearest to the SCS occurrence station for the aerological analysis under work.

III. DISTRIBUTION OF SCS

III.1. Distribution of SCS, connected with different precipitation types

Frequently, the heavy rain episodes are attended by thunderstorm activity or/and strong winds and this “combination” commonly causes big economic losses. Half of all heavy precipitation events belong to this group of events (Fig. 2).



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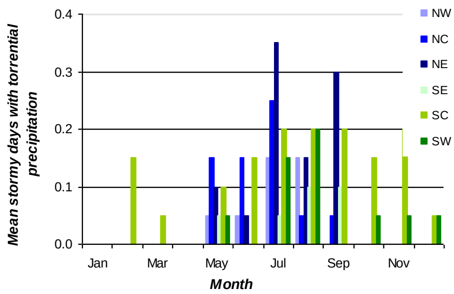


b)

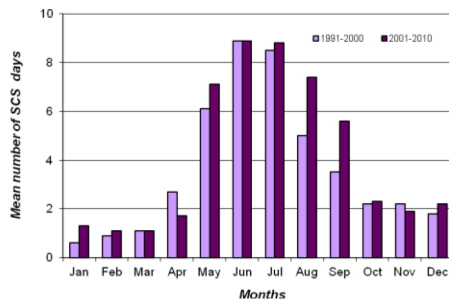
FIG. 2. Monthly distribution of stormy days for different regions in Bulgaria: a) I group; b) II group.

The maximum in the annual distribution of stormy days is at the height of the summer season in July for all regions in Bulgaria. For cases from group I (Fig. 2a) this result coincides with the observed maximum in the monthly distribution of thunderstorm days for East Bulgaria. It takes place a month later than for other parts of the country (Bocheva et al., 2013).

Stormy days in the southern regions of the country, especially those connected with torrential precipitation over 60 mm/24h, are evenly distributed by month. For regions from North Bulgaria all days from group II occur only during the warm half of the year during the studied period. In the same time, the potentially dangerous precipitation events, attended by thunderstorms during the cold half of the year, are typical for SC Bulgaria (about 40% of all cases). Some cases from group II (Fig. 2b) are observed in SW Bulgaria from October to December (first half of the cold season).

III.2. Distribution of wide-spread SCS

The inter-annual distribution of the mean number of days with SCS is presented on Fig.3. There is difference in the number of thundery heavy-rain days during the two investigated periods. While during the first decade (1991–2000) the greatest number of SCS days in one station is observed in June, July and May (see Fig.3a), in the second decade (2001–2010) such type of events more frequently occur in all summer months. In August and September their increment is statistically significant (about 50–60%). It can be said that as a whole SCS days increase during the second period with about 14%. Only in April statistically significant decrease of SCS days with 37% is observed.



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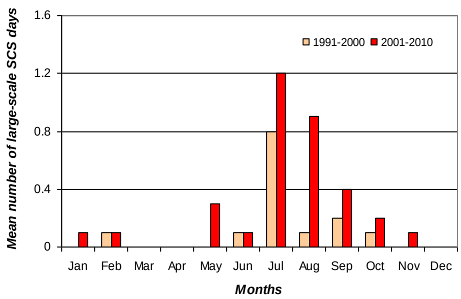

b)

FIG. 3. Monthly distribution of SCS in Bulgaria: a) all cases; b) wide-spread SCS only

For the whole contry there is observed increase of the frequency of the large-scale SCS episodes in almost all months during the 2001–2010 period (Fig.3b). There is growth of about 140% on annual basis. It is most significant in August (8 times more than during the period 1991–2000). August is followed by September and October in which there have recently been observed two times more massive SCS.

IV. WEATHER PATTERNS ASSOCIATED WITH HEAVY CONVECTIVE RAIN IN LARGE PART OF BULGARIA

IV.1. Classification

The synoptic situations that match the heavy rain with thunder cases have been examined and classified. Thunder activity in Bulgaria is typical for the warm season from mid April to mid October. It reaches its maximum in June (Bocheva et al., 2013). However the data suggest that heavy rain on a large part of the country and associated with thunder occurs more frequently in July, August and even September than in June. Occasionally heavy rain with thunder may occur in the cold season from mid October to mid April too.

We define 5 different periods as it concerns heavy rain with thunder: spring (May-June); early summer (July), late summer (August); autumn (September-October); and cold season (November-April). Table 1 summarizes the geographical features of the regions if Bulgaria. The land surface conditions, the near-sea water conditions and the atmosphere conditions are summarized in Table II.

Seasonal thermodynamics	*Land*	*Sea*	*Air*
Spring	Moist/warm	Relatively cold	Warm/warming up
Summer	Relatively dry/warm	Warm	Warm
Autumn	Relatively dry /cooling	Relatively warm	Cooling down
Cold season	Moist/cold	Cold	Cold

Table II: The land surface, the near sea water and the atmosphere conditions by season.

Table III summarizes the distribution of the seasonal occurrence of heavy rain with thunder in the 6 regions of Bulgaria. One date may concern more than one region and that is why the total number by month or season in Table III may exceed the total number of days (Fig. 2b). From Table III it can be seen that the most endangered regions in spring are the southwest and south-central ones. In summer the most endangered regions are in West and Central Bulgaria while the eastern part is relatively protected. In autumn there are more cases with heavy rain and thunder in East Bulgaria but also in Southwest and South-central. The few cases from the cold season are almost exclusively in the Southeast and South-central.

Region/Season	*Spring*	*Early summer*	*Late summer*	*Autumn*	*Cold season*
NW Bulgaria	1	**13**	**5**	3	0
NC Bulgaria	1	**11**	**7**	3	0
NE Bulgaria	1	7	2	**6**	0
SE Bulgaria	2	8	1	**5**	**2**
SC Bulgaria	**4**	**11**	**4**	**5**	**2**
SW Bulgaria	**4**	**10**	**6**	**6**	**1**

Table III: Distribution of the seasonal occurrence of heavy rain with thunder in the 6 regions of Bulgaria (one date may concern more than one region).

IV.2 Most typical weather patterns

IV.2.1 Cold season

Typically the weather pattern providing heavy precipitation in the cold season is a classic Mediterranean cyclone passing by the country in different trajectories. Mediterranean cyclones are well studied and detailed description can be found for example in Marinova et al., 2005. When it leads to heavy rain with thunder though we need 2 conditions: **I** - the cyclone should be positioned to the southwest of the country and the southeast of Bulgaria should be in the warm air where temperature at 850 hPa geopotential surface should be above 0ºC (Fig. 4b). Warm air is needed in order convection to take place in this unfavorable season; **II** - the cyclone may move along its usual way to the northeast, however it should pass rather to the northwest of Bulgaria or occasionally through the country. This provides continuous southwestern flow over southeastern Bulgaria which is to guarantee the influx of warm and humid air from the Aegean Sea into Southeast Bulgaria. Fig. 4 illustrates the case of 18 November 2007. The low is cut off the Polar front and it is to the west of Bulgaria. There is southern flow over southeastern Bulgaria that brings there relatively warm and humid air from the Aegean Sea.

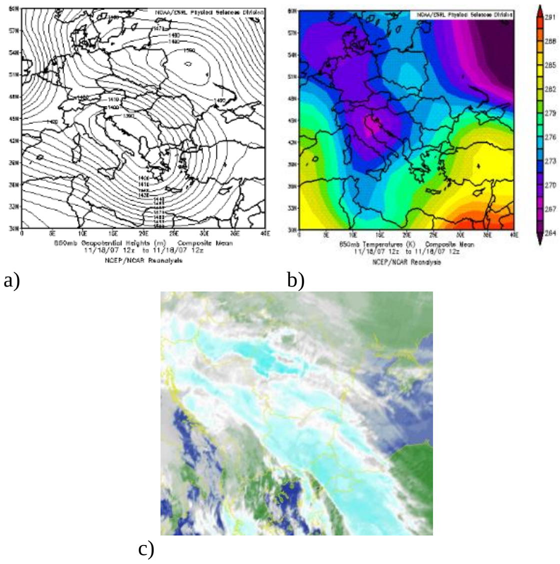

FIG. 4. Maps and images on 18.11.2007 12:00 UTC: (a) 850 hPa geopotential height (m); (b) 850 hPa air temperature (K); IR satellite image.

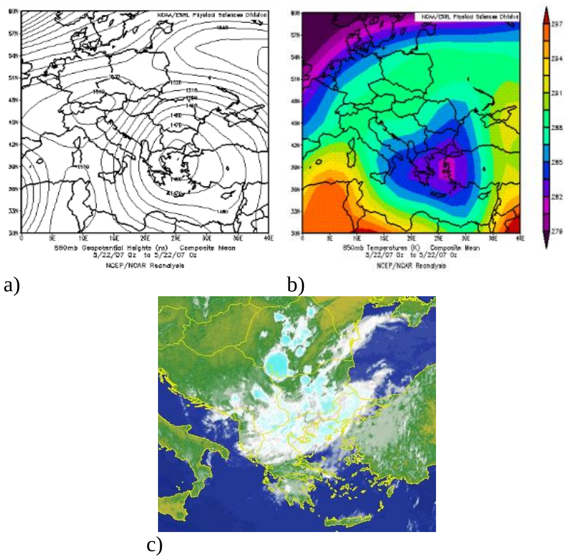

FIG. 5. Maps on 22.05.2007 00:00 UTC: (a) 850 hPa geopotential height (m); (b) 850 hPa air temperature (K). (c) IR satellite image 21.05.2007 12:00 UTC.

IV.2.2 Spring (May-June)

When large area of the country is hit by heavy rain with thunder in spring this is typically associated with general unstable conditions. In spring the soil and vegetation are still moist and provide sufficient amount of moisture at place to feed convection. Therefore complex large-scale synoptic weather patterns are not needed to supply moisture from the Mediterranean. Large and smooth area of relatively low pressure at height together with relatively cool air is enough to provide conditions for wide-spread convection in the country. Thus the accumulated precipitation amounts may reach the target in more than 3 administrative regions. Often however there is an upper low positioned to the south or southeast of Bulgaria. In addition it provides so that the convective systems flush themselves out easier when trying to overcome an orographic obstacle from the northeast. The southwest and south-central parts of the country are the most mountainous and provide such obstacles. This is the case of 21-22 May 2007. Fig. 5 illustrates the case. There is a low centered over the Aegean Sea. The most endangered regions in this case are the southwest and south-central ones.

IV.2.3 Summer (July-August)

During summer the soil and vegetation dry up (Table 2). Therefore only smooth conditions of instability over Bulgaria are not enough to bring heavy rain with thunder over a big part of the country. Some more synoptic-scale dynamism is necessary to provide so that moisture from the Mediterranean comes over Bulgaria. This is why when relatively small cyclonic systems, born in the Mediterranean to the south of the Alps and cut off the Polar front, move into the West Balkans and become stationary they produce powerful meso-scale convective systems, particularly over the mountainous central Balkans including West and Central Bulgaria. The convection feeds back the cyclonic circulation with fresh energy and thus sustains the strong precipitation for a couple of days. The low should be positioned either to the west of Bulgaria or over the country. This is illustrated in Fig. 6 with the case of 6 August 2007. Such cyclone eventually moves eastwards and provides conditions for heavy rain there too. However Eastern Bulgaria suffers from heavy rain with thunder in summer less frequently than the rest of the country.

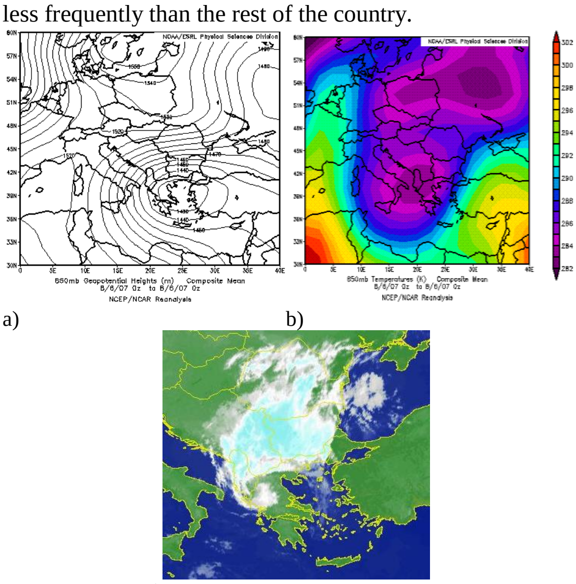

FIG. 6. Maps on 06.08.2007 00:00 UTC: (a) 850 hPa geopotential height (m); (b) 850 hPa air temperature (K). (c) IR satellite image 06.08.2007 03:00 UTC.

IV.2.4 Autumn (September-October)

East Bulgaria is mostly endangered by extreme precipitation in late summer and autumn. 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 (see Table II).

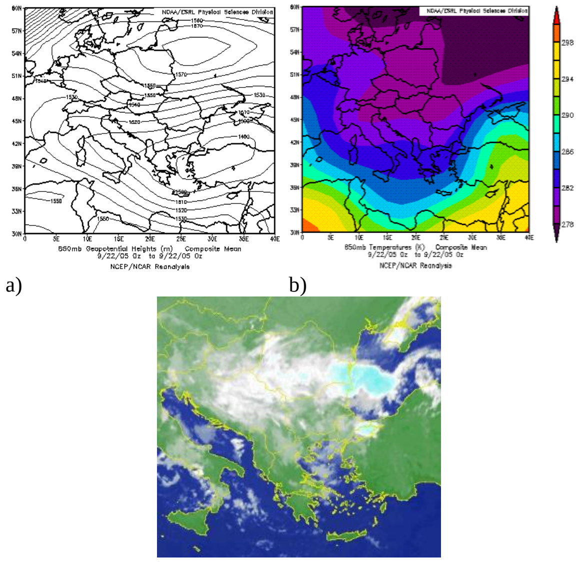

FIG. 7. Maps on 22.09.2005 00:00 UTC: (a) 850 hPa geopotential height (m); (b) 850 hPa air temperature (K). (c) IR satellite image 22.09.2005 01:30 UTC.

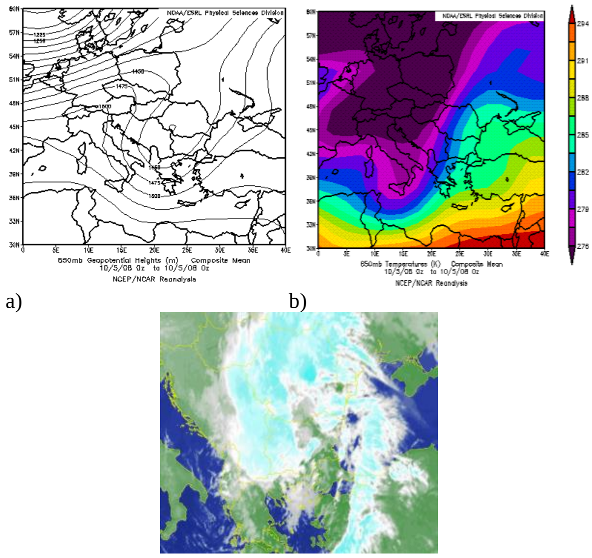

FIG. 7. Maps on 05.10.2008 00:00 UTC: (a) 850 hPa geopotential height (m); (b) 850 hPa air temperature (K). (c) IR satellite image 05.10.2008 04:30 UTC.

The air over sea is by default humid and thus moisture is also available in the air that undergoes convection. All these three conditions provide so that convection systems a mostly generated over sea and then transported inland by the dominant mid-troposphere flow. The low can be positioned either to the west or over Bulgaria. But it should best be over the eastern part of the country or over the Black Sea. This position favors the development of convection over the warm sea. The convective systems then move inland and flush the eastern regions of Bulgaria. In Fig. 7 we give as an example the case of 21-22 September 2005 when the town of Shabla, at the northern coast of Black Sea, is hit by a flood.

The southwest and south-central regions are also menaced by heavy rain in autumn. This however happens differently than the case for Eastern Bulgaria. In autumn the frequency of Mediterranean cyclone increases and the days with heavy rain in a large part of the country become more frequent too. However if they are to be associated with thunder they should be rapid and passing through the country rather than to the south. This is the case of 5 October 2008 which is illustrated in Fig. 8.

V. CONCLUSIONS

The results from the analysis of SCS, registered in the meteorological network of NIMH for the period 1991-2010 can be summarized as follows:

- The month of June is the one with most frequent thunder activity. However it is the month of July when the thunder activity is the most associated with heavy rain in large part of the country.
- The different regions of Bulgaria are endangered by heavy rainfall with thunder in different seasons. Our classification of weather patterns and dangerous seasons can be used as input information for decision making to improve preparedness for heavy precipitation events with thunder.

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