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THE EXTREMELY RAINY 2014 IN BULGARIA

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Abstract: In 2014 almost all stations of Bulgaria reported annual rainfalls significantly exceeding the norm, especially as far as the warm semester quantities are concerned. In this paper, the situation in the lowlands, plains, hilly areas and mountainous valley is presented. In eight of the 16 stations studied, the annual rainfalls exceeded 1000 mm, when the norm for most stations in the non-mountainous part of the country (lower than 600 m of elevation) was between 500 and 700 mm. Excess above annual norms varied between 177 and 578 mm with average values of about 350-450 mm. First and foremost this was due to a precipitation increase in the warm half of the year. An analysis of typical meteorological situations was made in order to clarify the causes for this anomaly. The number of Icelandic cyclones associated with rainfall situations over the country was slightly smaller than the usual one. The Mediterranean cyclones activity in the warm half of the year marked an untypical upward trend, most likely due to NAO index short time shifting from a positive to a negative phase. It can be suggested that this was the main reason for the substantial growth of rainfalls in Bulgaria during the warm season of 2014.

Key words: annual and monthly precipitation in 2014; heavy rainfall; Mediterranean cyclones activity; warm half of the year.

1. INTRODUCTION

The average annual rainfall in the lowlands, plains and the hilly part of Bulgaria is within the range of 500-700 mm (Topliyski, 2006). The altitudinal zone under 600 m altitude covers 72,5% of the Bulgarian territory. In 2014, the majority of the stations of this area recorded precipitation quantities significantly greater than the normal ones. They either exceeded the maximum annual rainfall ever recorded in the whole history of meteorological observations in this area.

2. OUTPUT DATA

The monthly and annual rainfalls in 2014 for the utilized 16 stations were published in the monthly bulletins of the National Institute of Meteorology and Hydrology (NIMH). They were compared with historical data from the Climate Reference Book "Precipitation in Bulgaria" (Koleva & Peneva, 1990) for the period 1931-1985, accepted as a norm. For some of the stations additional data were included, which concerned daily rainfalls in 2014.

3. ANALYSIS OF PRECIPITATION IN 2014

3.1. Annual and monthly precipitation

Table 1 presents data on the annual rainfalls in 2014, their excess above the norm for all stations under investigation, and the absolute maximum annual rainfall amounts with the year of their occurrence. The absolute maximum precipitation sums, recorded in 2014, are highlighted in bold.

The remarkable fact is that in eight stations, the annual rainfall in the year 2014 was above 1000 mm (and in the other three – between 938 and 996 mm), which is an extremely rare event for the low altitude area of Bulgaria, with probability level far less than 5% ("Precipitation in Bulgaria", 1990, p. 67). The excess in absolute figures above the norms was impressive (between 177 mm and 578 mm) with average values of about 350-450 mm (Fig. 1).

Table 1. Annual quantities of precipitation (Q) in 2014, the norm (Qn) for the period 1931-1985, excess of the 2014 reported at multiannual average and maximum annual quantities (records in 2014 are highlighted in bold)

Station and elevation (m)	Precipitation Q (mm) 2014	Qn (mm) 1931-1985	Q-Qn (mm)	Q/Qn (%)	Maximum annual rainfall	
					(mm)	year
Vidin (34)	**953**	583	372	163	848	1939
Montana (203)	1030	628	403	164	n/a	n/a
Vratsa (311)	**1389**	811	578	171	1289	2005
Pleven (160)	854	578	276	148	947	2005
V.Tarnovo (193)	1042	680	362	153	1158	2005
Ruse (44)	938	586	353	160	1030	2005
Razgrad (345)	1007	556	443	181	1084	2005
Varna (30)	**878**	480	398	183	757	1951?
Burgas (22)	**1034**	543	494	190	962	1931
Sliven (254)	**1037**	587	450	177	978	n/a
Plovdiv (156)	**996**	540	457	184	795	1955
Kardzhali (325)	1091	687	404	159	1196	1940
Sandanski (207)	**710**	533	177	133	647	2010
Blagoevgrad (414)	**863**	560	303	154	799	1960
Kyustendil (520)	802	625	178	128	1046	1937
Sofia (593)	**1070**	621	481	172	970	2005

The relative excess of the annual precipitation in 2014 was from 128% (Kyustendil) up to 190% (Burgas) while the common values are around 150-170% (median 159%).

The overall amount of annual rainfall over the low altitude part of Bulgaria in 2014 (for the utilized stations) exceeded the norms for the period 1931-1985 at 9 of 15 stations. In 4 stations, the rainfall amounts in 2014 exceeded the present-day maximum annual precipitation with more than 100 mm and at Plovdiv with 200 mm (Fig. 1).

It is important to draw attention to the relatively even distribution of rainfall throughout the year and its almost permanent excess over the monthly norms for the period 1960-1990 (given as a norm in NIMH monthly bulletin). This applies to 9-10 months of the year, and in five of them (March, May, September, October and December) above-normal monthly precipitation was measured in all monitored stations. Only in February everywhere (except for Razgrad station) the rainfall was below normal. After the first two months of the year, which were predominantly rainless (North East Bulgaria is excluded), a nearly uninterrupted series of 4-8 months followed with rainfalls above the norm for the prevailing number of monitored stations; breaks for some of them occurred in June, July, August, and especially in November.

The greatest excess of monthly rainfall was established in September – from 3 to over 6 times above the norm for twelve out of the sixteen observed stations. Moreover, in nine of the stations the maximum monthly rainfall during 2014 occurred exactly in September, although historically for a large part of the country September is known as one of the months with minimum precipitation (Dimitrov, 1979; Topliyski, 2006; Velev, 2010). This comes only to prove that the established anomaly of the September rainfall increase, especially in North-East Bulgaria has continued in the past 15-20 years (Drenovski & Stoyanov, 2009a; Drenovski & Stoyanov 2009b; Drenovski & Karashtranova, 2011). Obviously this anomaly is of a more extensive regional scope and is in conformity with the aforesaid autumn precipitation increase in part of Romania (Rimbu et al, 2015). It may also be relevant to the significant relative increase of the autumn rainfall on the Iberian Peninsula, determined by Brunetti et al., (2010) for the 1976-2005 periods.

3.2. Seasonal distribution of rainfalls

The seasonal distribution of rainfalls serves to define the precipitation regime (continental, Mediterranean and transitional) in certain parts of the country. According to a lot of authors, including Xoplaki et al., (2004), the wet season in the Mediterranean is from October to March and the dry one – from April to September. Therefore, to characterize the respective type of precipitation regime, the ratio P_w/P_c between the rainfalls during the warm half of the year (IV-IX) and the cold one (X-III), was used (Fig. 2).

The P_w/P_c ratio widely varies in different parts of Bulgaria. In most of North and Western-Central Bulgaria the rainfalls during the warm half of the year (with maximum in May-June) are significantly greater (by 40-50%) than the rainfalls in the cold period. In Bulgarian climatology this phenomenon is known as the Continental rainfall pattern.

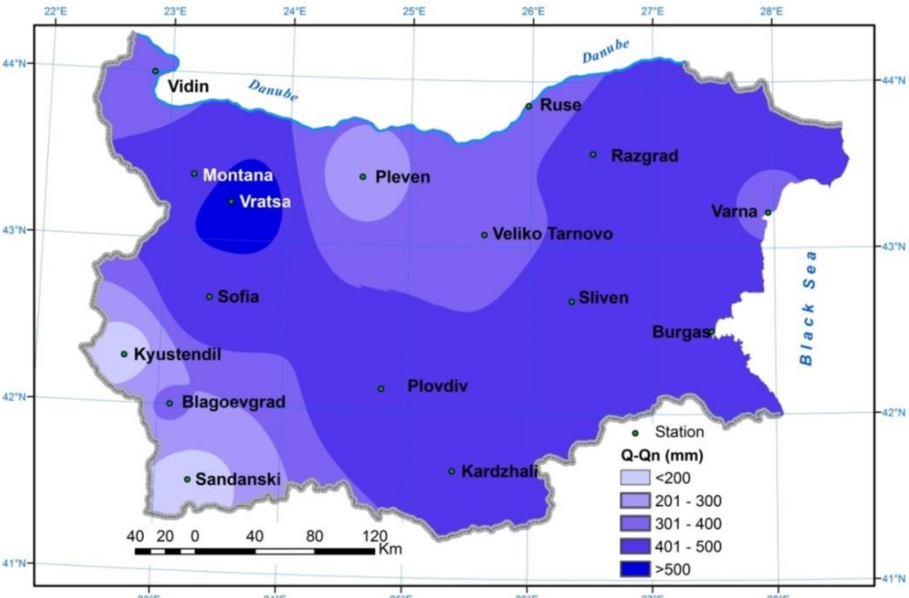

Figure 1. Absolute excess (mm) of the annual precipitation in 2014 (Q) above the norm (Qn) for the period 1931-1985

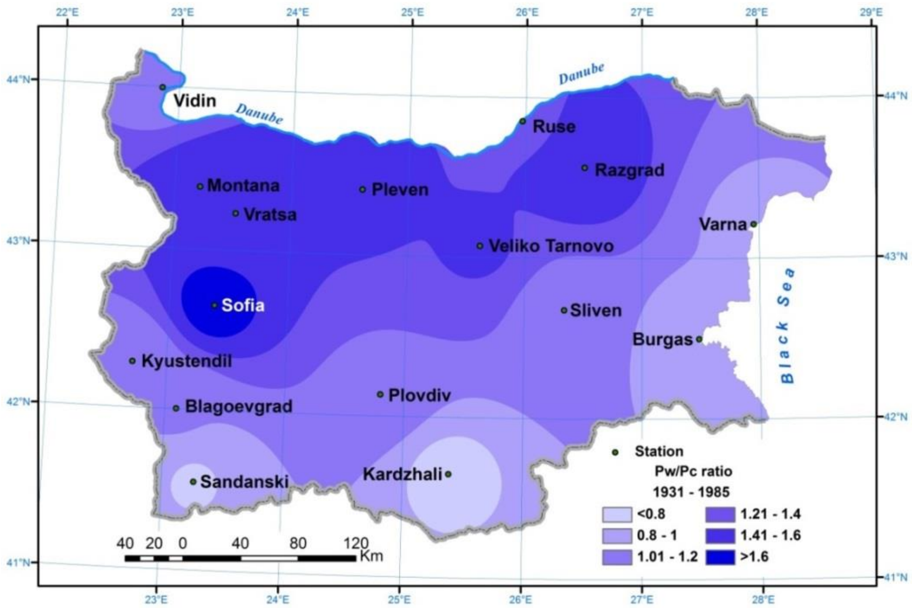

Figure 2. P_w/P_c ratio for the 1931-1985 period, (between the precipitation in the warm and the cold half of the year)

Conversely, in the south and south-eastern parts of the country the cold season precipitation is prevailing with a maximum in November-December, due to the Mediterranean rainfall pattern. Between the above mentioned regions in Bulgaria is situated a transitional area with almost equal precipitation in the warm and in the cold seasons (Fig. 2.).

In 2014 a serious disturbance in the semestral distribution of rainfalls was established for almost all stations. The precipitation amounts in the warm season (April-September) – P_w were much more than those in the cold half of the year (October-March) – P_c, which led to a substantial change in their ratio as shown in table 2.

Practically everywhere during the warm season, and with only one exception in the cold half of the year (Kyustendil station), a considerable absolute precipitation increase was recorded. In almost all stations a much more substantial growth of rainfalls (215-438 mm) occurred in the warm half of the year. The maximum excess in Vratsa station (523 mm) can be explained by the orographic factor and the position towards the Mediterranean cyclones trajectories. In nine of the stations the absolute rainfall amounts in the warm season rose about two or more times above the usual ones (Table 2.) and even surpassed the respective annual norms (Table 1). The warm season precipitation was much more substantial (above 600 mm) in North-West, Central and South-East Bulgaria (Fig. 3).

The growth of the cold season precipitation was much smaller (about 40-150 mm, excluding North-East Bulgaria - up to 200 mm), and between 15% and 55% in relative figures.

In 2014 a very significant relative increase in P_w/P_c ratio was established almost throughout the country (Fig. 4) compared to the common values for the period 1931-1985 (Fig. 2). In some stations (Burgas & Kyustendil) this coefficient doubled its values because of different reasons.

3.3. Causes for observed anomaly

The cause of these situations was the increased frequency of strong (over 30 mm), heavy and torrential rainfall situations during the warm half of the year. Simeonov et al., (2009) report of about 42% increase of the mean number of days with precipitation of over 30 mm during the warm season (April-September) in Bulgaria for the period 1991-2006 compared with 1961-1990. Moreover, "the frequency of heavy-rain events in the warm half of the year in 1991–2005 is about 60% higher than in 1961–1990" (Bocheva et al., 2009).

In each month during the period May-October there was at least one rain-gauge station with maximum 24-hour rainfall above 100 mm. In many cases such extreme events caused floods and loss of human lives (Dobrich, Varna and Veliko Tarnovo – 19-20.06.2014, Burgas and Vratsa – 06.09.2014, etc.).

There, in seven distinct days within the period from May to October, a total of 490 mm of precipitation was registered (almost the half of the annual amount in 2014) with 24-hour maximum rainfall on 6 th September, 2014 – 176 mm. In the gauge station of Veselie (Burgas region) only in two days (16th July and 26th October) an aggregated sum of over 400 mm was reported. Bocheva et al. (2010) note that "in the recent decades (1991-2007) such type of precipitation more frequently occurs in July and September". In spatial aspect, according to Bocheva et al., (2014) "for East Bulgaria and the Black Sea coast there is a statistically significant increase of the mean annual heavy precipitation days during the period 1981-2010 versus the previous one (1951-1980) by about 60-75%". The same authors point out that about 40% of all torrential precipitation episodes over East Bulgaria are associated with Mediterranean cyclones and may be linked to the change of their routes across the Balkan Peninsula. This is in correlation with the Pfahl & Wernli (2012) conclusion that more than 80% of the precipitation extremes in the Mediterranean region are directly related to cyclones and shifts of the storm tracks. That is why an analysis of meteorological situations has been made.

Table 2. Precipitations in the warm (IV-IX) and the cold (X-III) half of the 2014 year and their ratio P_w/P_c, compared with the common ratio for the 1931-1985 period

Stations	P_w - warm season rainfall (mm)			P_c – cold season rainfall (mm)			P_w/P_c ratio 2014	Common P_w/P_c ratio 1931-1985
	2014	1931-1985	difference	2014	1931-1985	difference		
Vidin	600	306	+294	353	277	+76	1,70	1,11
Montana	711	380	+331	319	248	+71	2,23	1,53
Vratsa	1011	488	+523	378	323	+55	2,67	1,51
Pleven	516	342	+174	338	236	+102	1,53	1,45
V.Tarnovo	614	399	+215	428	281	+147	1,43	1,42
Ruse	484	339	+145	454	247	+207	1,07	1,37
Razgrad	587	342	+245	420	224	+196	1,40	1,53
Varna	497	235	+262	381	245	+136	1,30	0,96
Burgas	659	254	+405	375	289	+86	1,76	0,88
Sliven	619	306	+313	418	281	+137	1,48	1,09
Plovdiv	607	288	+319	389	252	+137	1,56	1,15
Kardzhali	575	294	+281	516	393	+123	1,11	0,75
Sandanski	365	235	+130	345	298	+47	1,06	0,79
Blagoevgrad	520	283	+237	343	277	+66	1,52	1,02
Kyustendil	536	314	+222	266	311	-45	2,02	1,01
Sofia	807	368	+437	263	220	+43	3,07	1,68

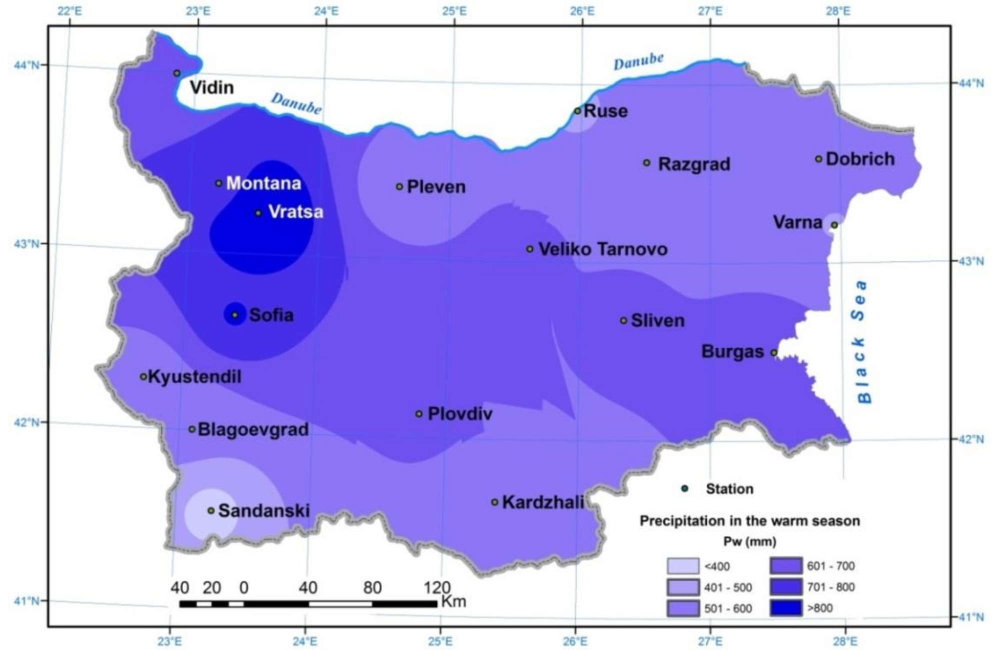

Figure 3. Precipitation in the warm half of the year 2014 (mm)

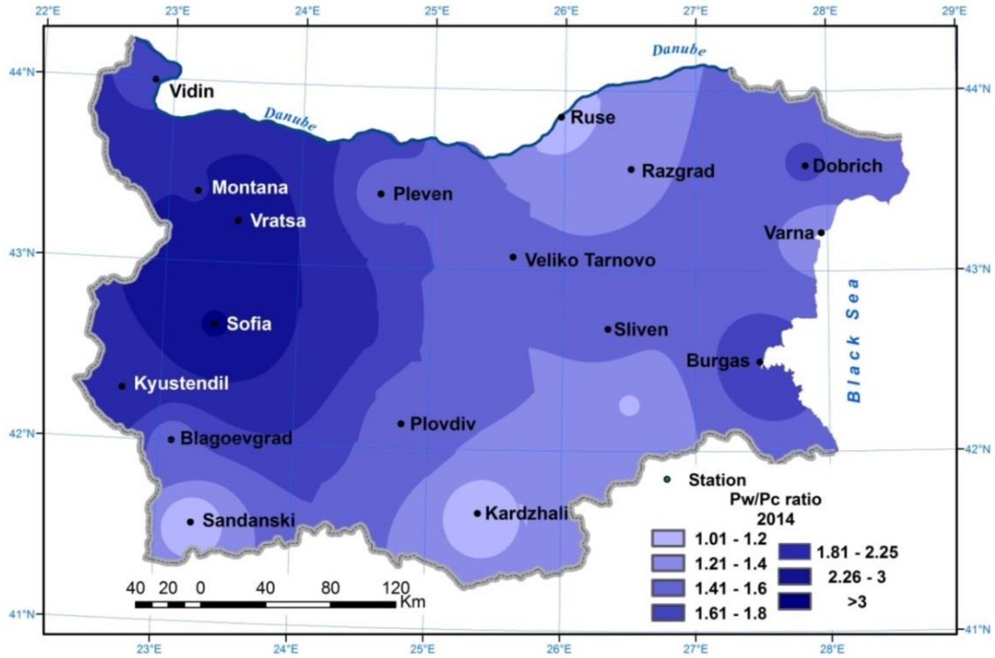

Figure 4. P_w/P_c ratio for 2014 (between the precipitation in the warm and the cold half of the year)

4. ANALYSIS OF METEOROLOGICAL SITUATIONS

The analysis of meteorological situations is based on a weather conditions review in NIMH monthly bulletin for 2014. For the purpose of this analysis 6-hourly archive maps of SLP and 500 hPa geopotential height, 850 hPa temperature, 2M temperature, 700 hPa relative humidity and precipitation rate have been used from the web-site wetter3.de. The results are summarized in table 3.

The prevailing part of rainfalls occurs on cold or occluded fronts associated with Mediterranean (from SW) or Icelandic cyclones (from NW), passing over Bulgaria. Rarely precipitation is related with troughs and indistinct cold fronts moving generally from the west across the Balkan Peninsula. Other untypical situations are connected with invasions of cold air from N-NE in the rear of the Mediterranean cyclones, continuing its way eastward over the Black Sea or Asia Minor Peninsula.

Table 3. Number of rainfall situations in 2014

Situations \ Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	all
Cold fronts, associated mainly with Icelandic cyclones			1	2	2	1	5		1	1	1	1	15
Associated with Mediterranean cyclones	4	3	5	5	5	4	2	2	2	2	2	2	38
Mediterranean cyclones from S-SW blocked by anticyclones from N-NE			1	1			1		1	1		1	6
Other untypical situations					2	2	2	4	2	1	1	1	15
Overall:	4	3	7	8	9	7	10	6	6	5	4	5	74

In some cases convectional rainfalls are formed. The average duration of precipitation situations is 1-2 days, but if the Mediterranean cyclones are blocked by a high pressure area, which is located to the NE of Bulgaria, the rainfalls may last longer – up to 4-5 days or even more.

In 2014 there were identified 59 typical rainfall meteorological situations, 44 of which were related to Mediterranean cyclones and 15 – to Icelandic cyclones. At least other 15 untypical situations, associated with considerable precipitation, took place.

The frequency of rainfall situations related to Icelandic cyclones was definitely smaller than normal, with a reduced number from April to June and late maximum in July (5 per month). Untypical situations reached about 1-2 per month with a maximum in August (4 per month).

The average frequency of rainfall situations, connected with Mediterranean cyclones was ranging around the mean values, pointed by Velev (2010) – 3-4 per month. Their maximum, however, was not in the autumn and winter as usual. There was an increased activity of the Mediterranean cyclones during the warm half of 2014, with an atypical maximum between March and June (5-6 per month) and an expected minimum in August (2 per month). The maximum correlates with the NAO index shifting from a positive to a negative phase in the beginning of the warm season (Fig. 5.).

The warm half of 2014 is distinguished by the short-term negative NAO phase, which can be seen in the official site of NOAA. It probably causes the corresponding negative phase of the Mediterranean Oscillation (MO) index. According to Criado-Aldeanueva et al., (2014b) the MO and NAO indices are positively correlated. The same authors (Criado-Aldeanueva et al., 2014a) point out that during the negative MO phase intense cyclogenesis over the central/western Mediterranean takes place and significant rainfall anomalies of up to 250 mm are observed in the Ionian and North Adriatic. Hurrell (1995) and Lionello et al., (2006), find out that during the negative NAO months over the Northern and Western Mediterranean raises the frequency of strong cyclones and above normal precipitation amounts are observed. Eshel & Farrell (2000) suggest that Eastern Mediterranean "rainfall variability is caused by subsidence anomalies associated with NA". Krichak et al., (2014) summarize that teleconnection indices (especially NAO) "affect the interannual variation of the frequency of days with extreme precipitation over a large part of the Euro-Mediterranean region".

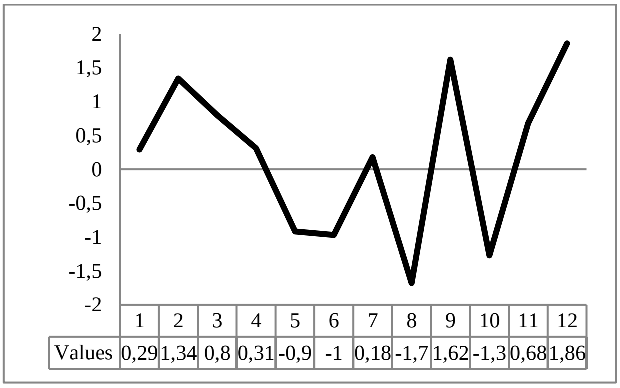

Figure 5. NAO index variability in 2014 (source official NOAA web site)

There are only a few investigations on the NAO and MO indices variation and the Mediterranean cyclone activity in the warm half of the year and their correlation with the precipitation over the central/northern Mediterranean. Dunkeloh & Jacobeit (2003) determine one main typical circulation-rainfall pattern during the summer. According to them its positive mode is characterized by enhanced cyclonic activity and increased precipitation amounts especially in the Northern Mediterranean. Criado-Adeanueva et al., (2014a) confirm such a correlation for winter precipitation, but for summer precipitation they consider it to be rather uncertain, due to prevailing convective events. Rimbu et al., (2015) establish links between the blocking circulation and the precipitation extremes over Romania in summer, partially associated with an enhanced cyclone activity in the Mediterranean region.

Blocking circulation episodes are absolutely usual and occur frequently (more than 2-3 times) over the eastern part of the Balkan Peninsula during the cold season. For example, the first considerable early snow cover in the non-mountainous part of North Bulgaria was registered in the late October of 2014 in analogous situation. One heavy snowfall event in December and one extremely rainy situation in September were caused by the same reason.

5. CONCLUSIONS

The analysis of meteorological situations does not give evidence to conclude that the recorded precipitation, significantly higher than the average annual precipitation amounts throughout the country, is a result of an increased cyclonic activity as a whole. The number of rainfall situations associated with the Icelandic cyclones is slightly smaller on an annual basis. In contrast, the number of Mediterranean cyclones is considerable greater, especially in the warm half of the year, when its minimum is supposed to be.

It can be suggested that the main reason for the substantial growth of rainfalls in Bulgaria during the warm season of 2014 was the increased number of Mediterranean cyclones and their consecutive movement in series through the central or eastern part of the Balkan Peninsula. Untypical maximum of Icelandic cyclones, affecting Bulgaria in July, also contributes to the rainfall growth in summer.

It must be highlighted that in 2014 the number of rainfall situations, associated with strong and heavy precipitation, was greater than the normal one. This can be explained with the increased capacity of the air masses in the Mediterranean cyclones to hold water vapour, especially in summer, late spring and early autumn, when they are much warmer than these in the Icelandic cyclones. The relation between the lower tropospheric moisture content and the temperature is well examined (DelGenio et al., 1991; Bony et al., 1995) and described by the Clausius-Clapeyron equation. It is specified that the air water holding capacity increases by about 7% per 1^{o}C warming. Moreover, advection of these air masses with great precipitable water content over a relatively warmer ground surface during the warm season contributes to the strengthening of vertical movements across the frontal surfaces causing thunderstorms. In the following days after such events subsequent convective rainfalls take place.

The distance which moisture-laden air masses, carried by Icelandic cyclones, must cover to reach Bulgarian territory is at least 3-4 times longer than that covered by Mediterranean cyclones. During the long journey they lose most of their moisture content. That is why an increased number of Mediterranean cyclones instead of Icelandic ones in the warm half of the year can be pointed out as a major reason for the swollen rainfall amounts.

The more significant increase of the cold season precipitation in the eastern part of the country is most likely connected with the prevailing south-eastern trajectories of the Mediterranean cyclones, which is normal for this time of the year, and with regeneration over the Black Sea in some cases. The weak mobility and stationing of some Mediterranean cyclones over the eastern part of the Balkan Peninsula, due to the anticyclonic regime upon the Black Sea, was a crucial factor for heavy rainfall situations due to the prolonged contact and higher temperature contrast between marine and continental air masses. The considerable number of prolonged precipitation situations, associated with the blocking of Mediterranean cyclones over the eastern part of the Balkan Peninsula, resulted in the rainfall increase during the spring and autumn of 2014.

All of the above mentioned analyzed factors made their contribution to the final result – the extremely high precipitation amounts over Bulgaria in 2014.

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