



Brief climate analysis and extreme weather events in Bulgaria in 2021

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Abstract: This review paper presents a brief climate analysis and extreme weather events in 2021 based on data from the meteorological network of the National Institute of Meteorology and Hydrology (NIMH). Other sources of information are also used in the complex assessment of extreme hydrometeorological and agrometeorological events in the country. Our analysis shows that the winter (December 2020 - February 2021) is the second warmest since 1930, while the year 2021 as a whole is the 12th hottest since 1930. At the same time, mean annual precipitation is about 20% above the climate normal. January is the wettest month in 2021, with average precipitation about three times over the monthly normal, but also the wettest January in the last 92 years.

Keywords: climate analysis, extreme events, tornado, drought, floods

1. INTRODUCTION

The presented review summarizes the analyses prepared by NIMH as a country-level contribution to two annual publications supported by the World Meteorological Organization (WMO). The first one, State of the Climate in 2021 (Blunden and Boyer, 2022) is a comprehensive annual summary of the global climate published as a supplement to the Bulletin of the American Meteorological Society (BAMS). The second publication, Annual Bulletin on the Climate in WMO Region VI (<https://www.dwd.de/rcc-cm>), includes the most recent climate information for Europe and the Middle East. Some climatological assessments and extreme events are also presented in the NIMH's Annual Hydrometeorological Bulletin for 2021 (<http://bulletins.cfd.meteo.bg>).

Globally, 2021 year is less warm than some recent years due to the influence of moderate La Niña events (WMO, 2022). The summary of the European State of the

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Climate 2021, compiled by the Copernicus Climate Change Service, ranked the year “just outside the warmest ten on record” (<https://climate.copernicus.eu>). The discharge of many rivers is below average. In spring, a large part of Europe has registered unusually cold temperatures that cause frost damage to agriculture. Summer is the warmest on record and also brings several extreme events. A prolonged and intense heatwave in the Mediterranean, combined with very dry conditions, favored the record-breaking maximum temperatures and intense wildfires. In July, a record level of rainfall caused severe flooding in Western Europe. In the context of this wide variety of climate events on the continental scale, the paper aims to contribute to a clearer understanding of the climate’s state in Bulgaria during 2021.

2. DATA AND METHODS

The brief annual and seasonal climate analysis is prepared on data from the 42 synoptic, 78 climatological and 24 agro-meteorological stations from the meteorological network of NIMH (Figure 1). We consider the period since 1930 because, from this year, the stations in the meteorological network of Bulgaria have a sufficiently good spatial distribution and are representative of all climatic regions of the country. Temperature and precipitation normals are defined as the 1991 - 2020 averages.

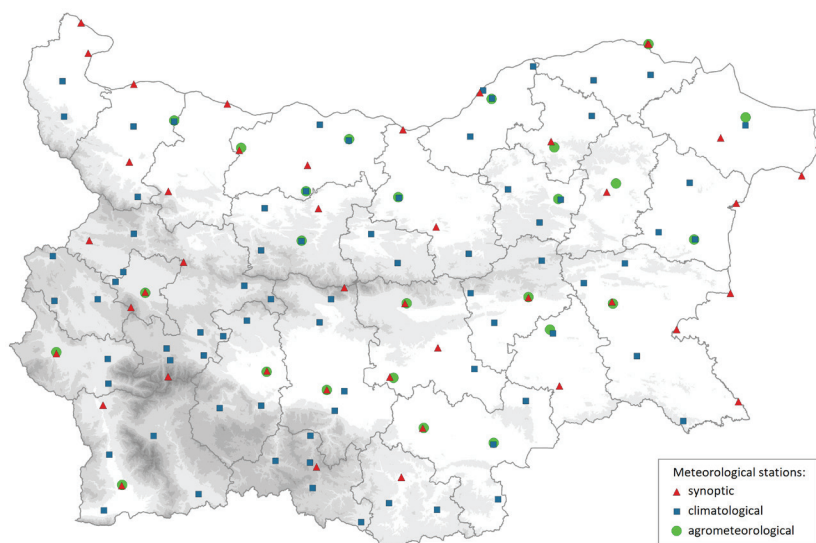


Fig. 1. Spatial distribution of the meteorological stations used in the survey: synoptic (red triangles), climatological (blue squares) and agrometeorological (green circles)

The ranking in the warm/cold or wet/dry categories (at a yearly, seasonal and monthly scale) since 1930 is based on the country-averaged mean air temperature and

precipitation totals, while detailed analysis is focused on averages for the low part of the country (up to 800 m altitude) where are mainly located the populated areas.

3. TEMPERATURE AND PRECIPITATION

In 2021 the country-averaged annual air temperature increased by 0.4°C , compared to the climate normal, which ranks the year as the 12th hottest since 1930 (Figure 2). According to the monthly temperature anomalies for the low part of the country, the warmest month was January, with a deviation range ($+1.2^{\circ}\text{C}$ to $+3.8^{\circ}\text{C}$), followed by February ($+1.4^{\circ}\text{C}$ to $+4.0^{\circ}\text{C}$) and December (-0.5°C to $+3.3^{\circ}\text{C}$). The coldest months were October (-3.7°C to -0.5°C), April (-3.3°C to -0.1°C) and March (-3.2°C to -0.4°C).

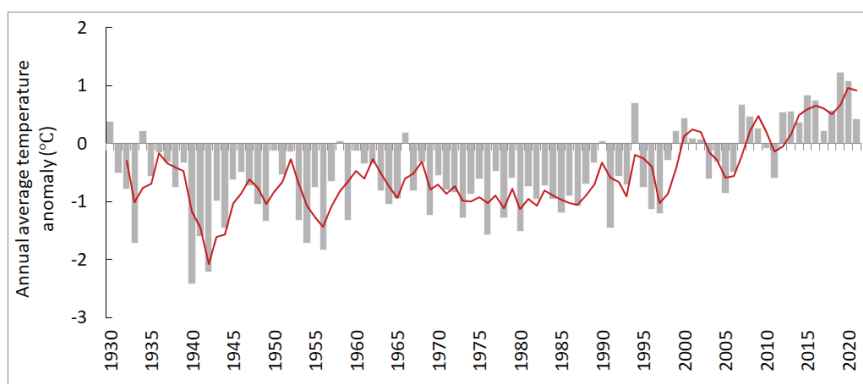


Fig. 2. Deviation from the climate normal of the country averaged mean annual air temperature for the period 1930-2021

The winter was the second warmest since 1930, with a temperature anomaly of $+2.6^{\circ}\text{C}$. December 2020 was the third warmest since 1930, with an average anomaly of $+2.9^{\circ}\text{C}$ in North Bulgaria ($+4.2^{\circ}\text{C}$ in Sevlievo, Gabrovo District) and $+3.5^{\circ}\text{C}$ in South Bulgaria (up to $+4.8^{\circ}\text{C}$ in Sofia District). January 2021 was the 5th warmest, with deviations of $+2.6^{\circ}\text{C}$ on average in North Bulgaria and $+2.4^{\circ}\text{C}$ on average in South Bulgaria. In February 2021, the temperature anomaly was $+1.9^{\circ}\text{C}$ for North Bulgaria and $+2.2^{\circ}\text{C}$ for South Bulgaria ($+4.0^{\circ}\text{C}$ in Kotel, Sliven District). No prolonged cold spells have been observed.

Spring was cold (-1.1°C below the normal). After cold March and April with an average anomaly of -1.6°C and -1.8°C , respectively, the season continued with about normal temperatures in May. The lowest minimum temperatures in March were registered in South Bulgaria during the last decade of the month (down to -16.5°C in Pernik District); in North Bulgaria, the lowest temperatures occurred in the period 8-10 March (-10.0°C in Gabrovo District). Almost to the end of April, negative anomalies

of daily minimum temperature were observed. On 9 - 10 April, minimum temperatures dropped well-below zero in South Bulgaria (-8.2°C in Pernik District) and in some regions in North Bulgaria (-5.6°C in Montana District).

Summer was the 5th warmest since 1930, with deviations of $+0.6^{\circ}\text{C}$ on average in North Bulgaria and $+0.9^{\circ}\text{C}$ on average in South Bulgaria. June was -0.6°C cooler than normal. The largest negative anomalies were registered in the central and eastern parts of the country (-2.5°C in Elena, Veliko Tarnovo District); the largest positive anomalies were registered in Northwest Bulgaria ($+1.5^{\circ}\text{C}$ in Belogradchik, Montana District). July was the third warmest since 1930, with deviations of $+0.6^{\circ}\text{C}$ on average in North Bulgaria and $+0.9^{\circ}\text{C}$ on average in South Bulgaria. August was the 4th warmest since 1930, with an average deviation of $+1.0^{\circ}\text{C}$ in North Bulgaria ($+2.0^{\circ}\text{C}$ in Belogradchik, Montana District) and $+1.4^{\circ}\text{C}$ in South Bulgaria ($+4.2^{\circ}\text{C}$ in Velingrad, Pazardzhik District).

Autumn was cool, with an average deviation of -0.4°C in North Bulgaria and -0.5°C in South Bulgaria. September was cooler than normal, with an average temperature anomaly of -0.4°C . The largest negative anomalies were registered in October, mainly in the central and western parts of the country (-3.7°C in Elena, Veliko Tarnovo District). November was warmer than normal, with $+1.2^{\circ}\text{C}$.

December 2021 was warm, with an average temperature anomaly of $+1.9^{\circ}\text{C}$ in North Bulgaria ($+3.3^{\circ}\text{C}$ in Krushari, Dobrich District) and $+1.8^{\circ}\text{C}$ in South Bulgaria ($+3.0^{\circ}\text{C}$ in Elhovo, Yambol District).

The country-averaged annual precipitation is around 120% of the normal, which ranks the year as the 10th wettest since 1930 (Figure 3). For the areas below 800 m, there is no considerable difference between North and South Bulgaria.

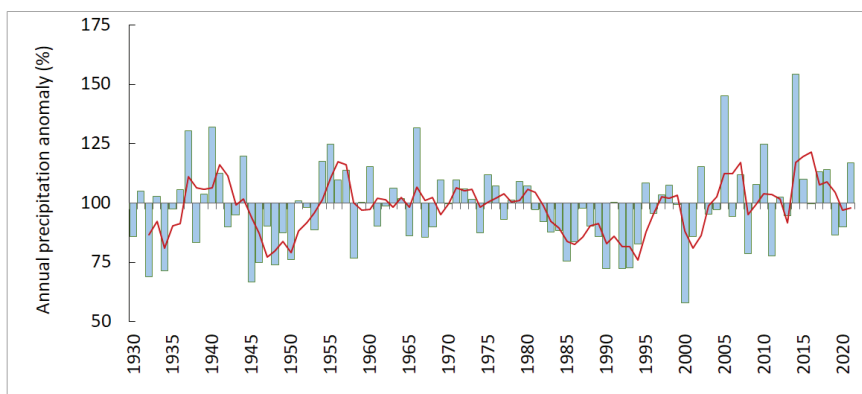


Fig. 3. Deviation from the climate normal of the country-averaged annual precipitation for the period 1930-2021

Seasonal precipitation amounts were: 175% of the normal in the winter, 118% in the spring, 88% in the summer, and 97% in the autumn. The winter was the 4th wettest

since 1930. The rainiest month of 2021 was January, the wettest in the last 92 years, with average precipitation about three times over the monthly normal (up to 577% in Iskrets, Sofia District). Wetter months were also October (4th wettest since 1930) with an average anomaly of 201%, and December (9th wettest since 1930) with an average anomaly of 185%. The driest months were September and July, with 33% and 49% from the normal, respectively. Low rainfall in September exacerbates the rainfall deficit accumulated in July and August.

4. EXTREME WEATHER EVENTS

4.1. Hot and cold spells, frost, drought and agrometeorological impact

The cold spell in the period 8 - 12 April 2021 (at some places, minimum daily temperatures dropped down to 8 - 9° C below zero) led to frost damages at the orchards in districts of Pleven, Razgrad, Targovishte, Silistra, Stara Zagora, Pazardzhik, Blagoevgrad and Kyustendil. The affected areas were about 6000 km². In the area of Silistra, apricot fruit bud damage reached 60-80% at the end of the first decade of April. During the next 10 days, additional damages to fruit trees were reported – up to 25-30% in the flowers of the early cherry varieties and over 90% to the apricot in the Kyustendil region and up to 50% to the apricot in the Pazardzhik region.

Prolonged hot weather in Bulgaria is most often associated with the advection of tropical air masses over the Balkan Peninsula and additional radiative overheating in a low-gradient surface baric field. Maximum temperatures above 42-43° C are comparatively rare but possible temperature extremes. In accordance with the obtained statistical estimates of high temperatures characteristic of the country's low part climate during the warm half-year, hot spells can be defined as periods with maximum air temperature $\geq 32, 34, 36, 38$ and 40° C, and a relevant duration of 6, 5, 4, 3 and 2 consecutive days at least (Malcheva et al., 2021; 2022). This climate indicator describes well the extreme heat events in the country, providing a combined assessment of their intensity and duration.

Although Copernicus Climate Change Service announced the summer of 2021 as the hottest in Europe for the entire history of meteorological measurements (<https://climate.copernicus.eu/>), in Bulgaria, it is generally comparable to the summer of 2017, far from the extreme heat of 2000, 2007 and 2012. The average number of hot days for the low part of the country is 34, and the average maximum number of consecutive hot days is 11. The maxima for both indicators (67 and 27 days, respectively) are reached in the region of Sandanski and Petrich (Figure 4a). The aggregate duration of hot periods with temperatures above 38° C is 3 - 6 days in the central part of the Danube Plain and the Eastern Rhodopes, 3 - 12 days in the Upper Thracian lowland, and 7 - 16 days along the Struma Valley. Only in the area of Sandanski and Petrich, the aggregate duration of hot periods with temperatures above 40° C is 8 - 9 days (Figure 4b).

From late June to the second decade of August, prolonged hot spells (up to 16 days in North Bulgaria and 29 days in South Bulgaria) with a maximum temperature $\geq 32^\circ\text{C}$ were registered. In many regions, the total number of days in hot spells exceeded 35 (over 55 days in Sandanski District). Extreme heat with maximum temperatures above 34°C gripped the country from 26 July to 5 August 2021. On 2 August, temperatures above 42°C were measured in Stara Zagora, Haskovo and Blagoevgrad districts (43°C in Kresna, Blagoevgrad District).

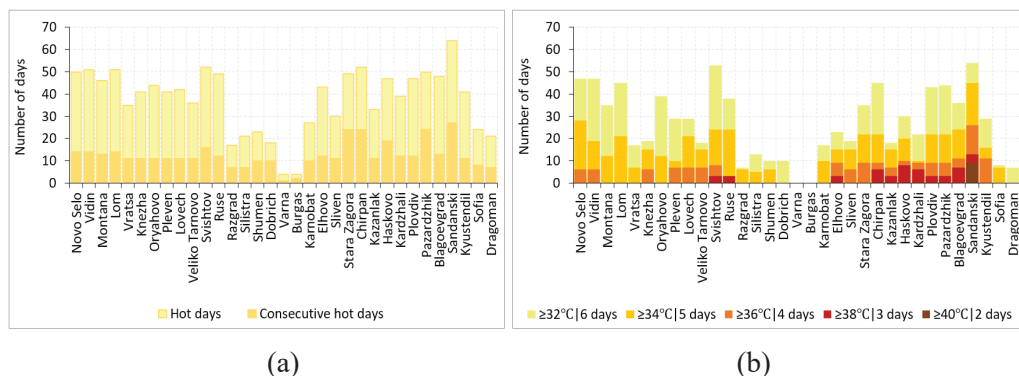


Fig. 4. Hot weather indicators calculated on data from 33 synoptic stations, representative of the low part of Bulgaria: (a) number of hot days and maximum number of consecutive hot days; (b) hot spells duration at different thresholds

Two periods of severe agrometeorological drought were registered in 2021, during which the available soil water supplies in the top 1 m soil layer were depleted. The first one corresponds to the prolonged hot period from late June to the second decade of August; the second period begins on average from 6 - 10 September and lasts until 8 October. The longest dry period in North Bulgaria (83 days, from 10 July to 30 September) was registered in the agricultural stations of Varna. The longest dry period in South Bulgaria (78 days, from 3 July to 18 September) was registered in the agricultural stations of Stara Zagora. In September, rainfall amounts below the normal were recorded in the country. The depletion of soil moisture reserves and drying processes continued in the whole territory of Bulgaria. In the middle of the month, the Soil Moisture Index (SMI) showed extreme drought values in most of the country (Figure 5b).

The Standardized Precipitation Index calculated for a 3-month accumulation period outlines the central and eastern parts of the country as the mainly affected by drought from July to September (Figure 5a).

Between the 10 and 21 August, the Lebnitsa River (a tributary of the Struma River) dried up in its lower course. Between the 1 and 11 October, the Fakiiska River dried up in its lower course.

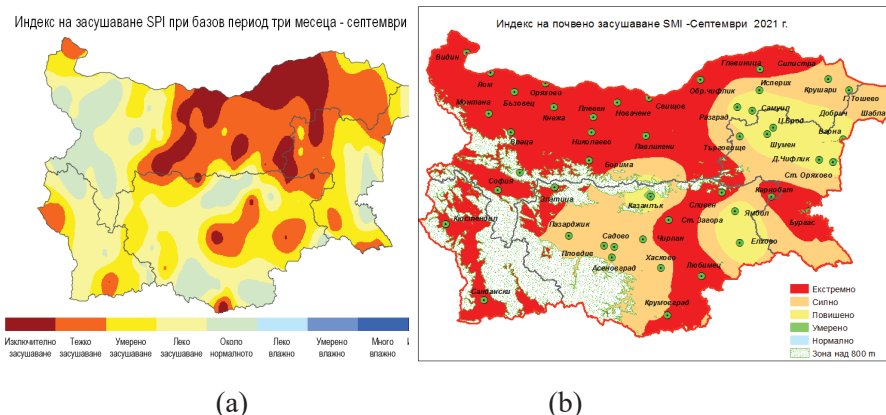


Fig. 5. Spatial distribution of drought indices on the territory of the country for September 2021: (a) 3-month SPI; (б) SMI (more information and archive of drought indices maps for recent 12 months is available at: www.hydro.bg)

4.2. Heavy precipitation and floods

In the period 8 - 12 January, due to heavy rainfall, combined at some places with snowmelt, flash and fluvial floods were registered in many parts of the country – mainly in West and Southeast Bulgaria: along the rivers Struma, Mesta and their tributaries; in the region of Sofia valley; along Fakiiska River and some small rivers in Burgas District. A state of emergency due to floods, destroyed bridges and broken roads was announced in 8 districts. By preliminary assessment, the peak of the flood wave along the middle and lower course of the Mesta River has a return period slightly greater than 20 years. The accumulated precipitation sums in almost the whole country exceeded the monthly climate normal. In Sofia, Blagoevgrad, Yambol and Burgas districts, precipitation sums for 72 hours exceeded three times the monthly normal. Heavy snowfall led to a break in the electricity in many places in Northwest Bulgaria.

At the beginning of February, heavy rains continued in various areas of Bulgaria, especially in the southern half of the country. On 2 February, a state of emergency was declared for some villages in Burgas District (Figure 7), where the Veleka River overflowed and flooded houses, roads and arable lands. Landslides intensified in many places in the Rhodopes.

On March 15 - 17, heavy rain and snow precipitation, more significant in the western and southern parts of the country, led to landslides in some places and interrupted roads. In the mountain regions of Western Bulgaria, snow drifts of over 2 m were formed. The next significant mixed precipitation in the period March 20 - 24 caused the intensification of landslides in different parts of the country.

Successive significant rain and snow precipitation in April also caused the activation of landslides. Some roads were temporarily closed to traffic because of landslides (Belovo - Yundola on 5 April, Sofia - Samokov and Mikhalkovo - Devin on 20 April).

During the period October 7 - 16, significant precipitation amounts fell in different parts of the country, and the first snow cover was observed in the mountains of western Bulgaria. Heavy rains caused damage, especially in Smolyan District.

A slow-moving Mediterranean cyclone passed through the Balkan Peninsula, leading to a rainy situation between the 10 and 14 December. At the beginning of the period, heavy rainfall (25-35 mm) occurred in southern Bulgaria and the Rila - Rhodope Massif, accompanied by thunderstorm activity. On the 11 and 12 December, the rainfall covered the whole country, with thunderstorm activity again in the mountain regions. Along with the penetration of cold air in the rear part of the cyclone, the rain in the mountains and high valleys, later also along the Struma River, turned into snow. On 13 December, the precipitation continued over almost all the country; the snowfalls were significant in the Rhodopes, where a snow cover of 30-60 cm was also formed in the low part. In the Rhodope Mountains, strong wind gusts and heavy wet snow further complicated the situation by knocking down branches and whole trees. The largest precipitation amounts were measured in Zlatograd - 252 mm, Rozhen - 161 mm, Raikovo - 157 mm and Chepelare - 153 mm (Artinyan et al., 2021). The snow cover reached a height of 80 cm in the village of Manastir, Smolyan District, on 14 December. Due to heavy rain and snowfall, many districts (mostly in South Bulgaria) have registered floods and landslides, which caused serious damage to infrastructure and water supply problems. Several rivers in South Bulgaria (Arda, Vacha, Mesta and Struma) and many of their tributaries have overflowed (Paralska et al., 2022). Many municipalities declared an emergency situation. Due to destroyed roads, many villages remained without connections with neighboring settlements. By preliminary assessment, the peak discharges have a return period between 20 and 200 years at the different hydrometric stations.

It can be summarized that 66 floods were recorded on the territory of Bulgaria in 2021 following the methodology described in Balabanova et al., 2019. Most of them were registered during January (23 flood events), June (13 events) and December (20 events). They are divided by type into three groups: river floods - 43 cases (blue dots on Figure 6), torrential floods - 6 cases (red dots on Figure 6) and rain floods - 17 cases (green dots on Figure 6). A large number of river floods were recorded in the middle of January and December in the southern parts of the country, which were caused as a result of heavy rainfall combined with snowmelt.

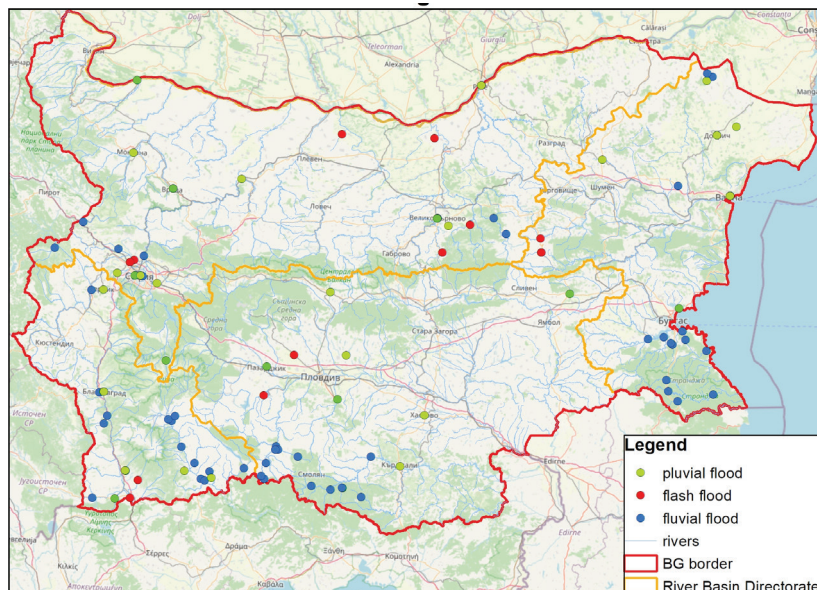


Fig. 6. Recorded floods in Bulgaria in 2021.

4.3. Strong wind events, severe convective storms and tornadoes

In the meteorological stations of NIMH, days with strong winds in a large part of the territory of the country were registered in almost all months of 2021. The damages were significant in several cases during the spring and autumn months.

A Mediterranean cyclone passed through the country from west to east from March 15 - 17. When it came from the west on 15 March, in some places in Eastern Bulgaria, along the Struma valley and in the northern foothills of the mountains, sensitive to foehn, a strong southerly wind was blowing. When the cyclone passed to the east on March 16 - 17, a strong wind (with gusts over 22-24 m/s) blew from the west-northwest, mainly in the Danube plain, the Upper Thracian lowland, along the Struma Valley, as well as in the Sofia field area. The greatest wind damages were caused in some districts from Southwestern and Southcentral Bulgaria. Fallen trees, damaged cars, downed billboards, and partially destroyed roofs were reported.

On November 29 - 30, a cold atmospheric front was passing through the country, it rained in many places, and thunderstorm activity developed along the front line. A strong, south-westerly wind was blowing mainly in Eastern Bulgaria and in the Rhodopes before the front. According to media reports, 40 settlements in the Smolyan region were left without electricity due to broken transmission lines caused by the strong wind. The hurricane wind broke branches and uprooted trees in Sliven, Yambol

and Burgas. Damages to vehicles, buildings and roads were reported. In Sliven, a dozen villages were left without a power supply.

Two weak tornado events (F0 by Fujita scale; Fujita and Pearson, 1973; Fujita, 1981), each with a duration of about 15 minutes, were registered in 2021 in Bulgaria. Fortunately, both events were much weaker in occurrence and duration compared to the strong and deadly long-track tornado that struck several villages in the South Moravian Region, Czech Republic, on 24 June 2021, killing six people, injuring the most some 200 others and damaging or destroying 1202 buildings in 7 municipalities (Pucik et al., 2021). The first was observed on 7 June between the village Zlatiya and the town Vulchedram, Montana District (Figure 7), and did not cost any damage. The second was on 20 September in the village of Orlov dol, Haskovo District, and caused damages to roofs, fallen trees and broken electricity poles. The nearby villages of Vladimirovo, Svetlina and Kamenna Reka are also affected by strong convective winds.

From the beginning of the second decade of May to the end of the second decade of July 2021, the weather was extremely dynamic, with frequent thunderstorms, hail and intense rainfall leading to local floods and damages in many parts of the country. On 13 May, an intense hailstorm caused significant damage in some settlements in Northwest Bulgaria. The villages Dobri dol and Yakimovo, Montana region, were the most affected, where the severe hailstorm formed a cover of ice particles with a thickness of more than 20 cm. On 16 May, after torrential rain, the river passing through the town of Kotel overflowed and flooded streets, yards and buildings, causing damage to road infrastructure. Heavy rain also flooded the main streets and boulevards of Ruse. On the evening of 26 May, a powerful thunderstorm with strong wind gusts, intense precipitation and hail led to flooding and power outages in some regions of Sofia city. On the same day, hail caused considerable damage to orchards, grain crops, rose gardens and vineyards near Karlovo, Plovdiv district, where the villages of Iganovo, Karnare and Pevtsite were the most affected.

More significant damages, mainly in central parts of the country, were caused by severe convective storms registered on 26 June. As a result of the intense rainfall, dozens of flooded houses and shops, broken power lines and damage to the road infrastructure in the Veliko Tarnovo region were reported. In the town of Zlataritsa, a man died after a broken electric wire fell on him. Torrential rainfall was also recorded in Ruse, Targovishte, Stara Zagora, Sliven and Yambol regions. The most significant damage from the storm was in Kotel and in the municipality of Antonovo, Targovishte district, where a partial state of emergency was declared.

Severe thunderstorms accompanied by strong winds and intense precipitation caused significant damages, mainly in Northwestern Bulgaria, on 18 - 19 July. Rainfall of 50-60 mm was recorded in some places. Local floods were reported in the regions of Vratsa Montana, Knezha and some areas of Sofia. In many places, some hailstorms have damaged agricultural produce, cars, etc. On 19 July, a strong wind storm was recorded in the village of Gubesh, municipality of Godech. It uprooted trees in the forest

above the village and caused significant damage to the roofs of some of the houses in the village. Additionally, the ensuing torrential rain flooded the roofless buildings. The measured amount of precipitation in the municipality of Godech during this process is close to 50 mm.



February 3rd – Flooded village
Dimchevo, Burgas district

(Todor Stavrev, BTA)

7 June – Tornado near Vulchedram, Montana
district

*(photo – Facebook; Maximum radar reflectivity –
Hail Suppression Agency)*

Fig. 7. Severe weather in different months

4. CONCLUDING REMARKS

This article is aimed at a wide range of readers interested in the meteorological features of 2021 for Bulgaria. The analyses show that although 2021 is another warm year since the beginning of the 21st century, with an average annual temperature of 0.4 degrees above the normal, it is far from the warmest in the ranking. Annual precipitation is about 20% above normal. As in previous years, the number of extreme weather events in 2021 is moderately high. They were observed in all seasons. The most dangerous heavy precipitation and flood events were registered during the cold part of the year in January, March and December, while the damages from strong wind events were more significant in several cases during the spring and autumn months. Two weak tornado events were registered in 2021 in Bulgaria – one in June (in Northwest Bulgaria) and one in September (in Southeast Bulgaria). There were cold spells again in April. During the late spring and summer, severe convective storms often led to local floods and other damages in different regions of the country.

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