Significance of Early Announcement of Weather Extremes: Case Study - Montenegro

Dragan Burić, Dragoslav Banjak, Miroslav Doderović, Angel Marčev and Jovan Dragojlovic

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Dragan Burić*[1], Dragoslav Banjak*, Miroslav Doderović*, Angel Marčev**, Jovan Dragojlović***

** University of Montenegro, Faculty of Philosophy, Department of Geography, Nikšić, Montenegro*
*** Institute of Hydrometeorology and Seismology of Montenegro, Podgorica, Montenegro*
**** University of Prishtina, Faculty of Natural Sciences and Mathematics, Department for Geography, Kosovska Mitrovica,Serbia*

Abstract: In the last two decades, there has been no year in Montenegro in which some weather extreme has not been registered. The aim of this paper is to highlight the importance of an early announcement of potentially dangerous weather phenomena in the example of one case in Montenegro. The prognostic material including ocassionally storm surges, heavy rainfall and the occurrence of severe local instability in Montenegro on July 28, 2019 was considered. Based on the analysis of the synoptic material, the warning of the expected weather conditions was given two days before. The warnings of the competent institutions should be respected in order to adapt the population to the expected extreme weather situations and thus avoid or mitigate the negative consequences.

Key words: extreme weather event, significance of early warning, Montenegro

[1] dragan.buric@meteo.co.me (corresponding author)
ORCID: https://orcid.org/0000-0003-0905-1915

Introduction

Contemporary climate changes and global warming are increasingly attracting attention. The key questions in relation with this topic (or rather say problems) that scientists are trying to answer are: why is today's climate changing, what is the cause, what consequences for humankind could possible changes in today's climate cause? With very high confidence, the IPCC points out that human influence has been the dominant cause of observed warming since the mid–20th century. Certainly climate change mitigation is impossible without reducing effects of greenhouse gas emissions. A significant form of mitigation is the afforestation and the slowdown of deforestation. "Through afforestation, land could collect CO_2 from the atmosphere" (IPCC, 2021).

There is a general belief that the most striking consequences of contemporary climate changes are the increase in the frequency and intensity of extreme weather phenomena. There are numerous works highlighting the increase in the frequency of extreme climate events in almost all parts of the world (Vose et al., 2005; Alexander et al., 2006; Ahmed et al., 2017; Garreaud, 2018; Faiz et al., 2018; Engström & Keellings 2018). In the Mediterranean Basin of the (European and African part), in the period 1958–2008, there is an increasing trend of both maximum and minimum temperatures, but the tendency is more intense in the Western Mediterranean Region (Efthymiadis et al., 2011). By doing analysis of several extreme climatic indices for the Eastern Mediterranean Region, Kostopoulou & Jones (2005) found that in the period 1958–2000, the most pronounced warming trend is during the summer. Regarding precipitation, the authors point out that there are contrasts, but that the overall picture is such that the western part of the study region (Central Mediterranean Region – Italy) registers significant positive trends of intense rainfall, while the eastern half records negative trends of all rainfall indices, indicating a tendency of aridity. And Brunetti et al. (2006) points out that in the second half of the 20th century, Italy recorded a significant increase in extreme temperatures, while a negative tendency was observed in precipitation. Similar results were obtained by Caloiero et al. (2017) for southern Italy as well as for the central part of this state for the period 1951–2012. In the period 1961–2006, a bigger part of Spain registers a trend of rising maximum and minimum temperatures (Del Rio et al., 2012).

In the last two decades, there has not been a year in Montenegro where no time extreme has been registered – high temperatures, heat waves, floods, prolonged droughts, fires. Some extreme weather phenomena in Montenegro were described in the papers of Ducić et al. (2012) and Burić et al. (2014a, 2021). The extremely high temperatures and a series of heat waves stand out especially in the summer of 2003 and 2007, and 2010 is the record year for heavy rainfall and unprecedented floods in Montenegro (Burić et al., 2011).

By virtue of more reliable products of numerical modeling (prognostic or synoptic material), the degree of accuracy of the short–term weather forecast is very high today. The main aim of the paper is to emphasize the importance of early announcement of potentially dangerous weather disasters ona concrete example. The early warnings given by competent services for such events (hazardous weather events) are of great importance to the local community and should be respected in order to avoid human victims and mitigate material damage. In an era of contemporary climate changes and the increased incidence of extreme weather events, there is no doubt that the role of national meteorological services will be increasingly important in the future.

Area of interest, databases and methodology

The study covers the territory of Montenegro, a country with an area of 13 812 km2. Montenegro is a Mediterranean country, reaching the Adriatic Sea in the length of about 100 km. It is very heterogeneous in relief (Fig. 1), the highest peak in this country is on the mountain range of Prokletije (Zla Kolata) in the northeast of the country, whose altitude is 2534 m, while the lowest point is the level of the Adriatic Sea (0 m). This pronounced relief fragmentation influences the formation of local convective clouds, convective precipitation, the appearance of fog, etc. (Burić et al., 2013). Thus, most of Montenegro has the Mediterranean climate characteristics (Burić et al., 2014b).

Fig. 1. Montenegro's position in Southeast Europe

For the purposes of analysis, the data about ground and altitude structure of the atmosphere were used, as well as the outputs of global (GFS and ECMWF) and operational (WRF–NMM) models, then the composite synoptic parameters of instability, an emagram, a SYNOP report from meteorological stations, and other analytical and prognostic material. The sounding and the wind hodograph in the form of emagrams with a resolution of 1.0km were obtained on the basis of the operational WRF–NMM model, which uses ECMWF data from Reading (UK) as input parameters. Standardized deviation and percentile methods were used to categorize precipitation.

Results

On Sunday, July 28, 2019, in the afternoon and evening, Montenegro was hit by a severe storm. The coastal and central parts of Montenegro were particularly affected, where in a short time a large amount of rainfall was emitted, there were storms and strong thunderstorms were recorded. Prognostic material with initialization of as much as three days before the storm indicated the possibility of a dangerous meteorological phenomenon. The following two days, especially the day before (July 27, 2019), prognostic models confirmed the lability of the atmosphere over Montenegro and indicated a higher probability of an extreme weather event. We have done a detailed analysis of the prognostic material with the initialization two days before the storm that hit Montenegro on July 28.

The analysis of the synoptic material from 0:00am UTC (2am according to Central European time) for July 28, 2019, indicates the existence of a shallow cyclone on the ground floor, centered over the Gulf of Genoa. At altitude (AT 500 hPa) wide low pressure area was active, which was extending from the northwest in the direction of the Ligurian and Tyrrhenian seas (Fig. 2a). The area of Montenegro and the southwestern Balkans was located in the front of both pressure areas, both at the ground and at the altitude. The analysis of the synoptic map of the total cloudiness indicated high cirrus clouds (Ci and Cs – Cirrus and Cirrostratus) above Montenegro, which indicated the arrival of a frontal wave. Synoptic material from 6am UTC indicates that the ground cyclone and the elevation valley have shifted eastward. There was also a deepening of the ground cyclone, whose center was then located above northern Italy (Fig. 2b), but there was still no precipitation. Frontal wave (cold front) was indicated by the change of the cloud system, i.e. the appearance of medium (As and Ac – altostratus and altocumulus), and later low clouds (Cu – Cumulus and Sc – Stratocumulus) above Montenegro. Global synoptic material for the mentioned period showed a rain zone west of Montenegro, but after examining the SYNOP report from meteorological stations in Montenegro from 10am UTC, one station in the southwest (Herceg Novi) registers the light rain.

The products of the numerical models from 12pm UTC showed further displacement of the pressure fields toward east and northeast, so during this period the center of the ground cyclone was located above the northern Adriatic, and the axis of the altitude area of the instability was increasingly gaining a general direction from west to east–southeast i.e. toward the Ionian Sea. (Fig. 2c). According to the existing structure of the atmosphere, it was to be expected that the rain zone would move from the west to Montenegro, but the SYNOP report showed that only a few meteorological stations in the coastal and western part of the country registered light rain. For the last 6 hours (06–12 UTC) these few stations registered a negligible amount of precipitation, up to 0.5 mm. So, obviously there was a so–called delay or slower movement of the process from west to east compared to what was simulated by the prognostic material, but this phenomenon (occurrence of process delay) is quite common in weather forecasting, even when analyzing synoptic maps of better (larger) resolution. The next two hours, rain zone spread from the west and southwest to the rest of Montenegro, but still with sporadic and occasional light rain. The analysis further revealed that several stations at the coast and north of the country register intensified strikes of eastern and southeastern wind – up to 11 m/s, which is later more intensified. However, around 3pm UTC (5pm according to the Central European Time), central and most coastal areas record heavy rain, local showers, thunderstorms and wind gusts – up to 23 m/s.

Based on the analysis of the Synoptic material from 6pm UTC, the process was further shifted to the east (Fig. 2d). At that time, the axis of the pressure area was covering the southern parts of Montenegro. In most of Montenegro, the process was weakened, except in the far eastern and southeastern regions, which were then under heavy rain and thunderstorms. In the next term (7pm UTC), in the west, southwest and in the most of central Montenegro, the intensity of rain was already weakened, that is, there was light rainfall only in some places, and an hour or two later, rainfall was weakened in the east and southeast of the country. Thus, around 7pm UTC, weakening of the process started over Montenegro, which was confirmed by the structure of the atmosphere from 00am UTC for July 29, 2019.

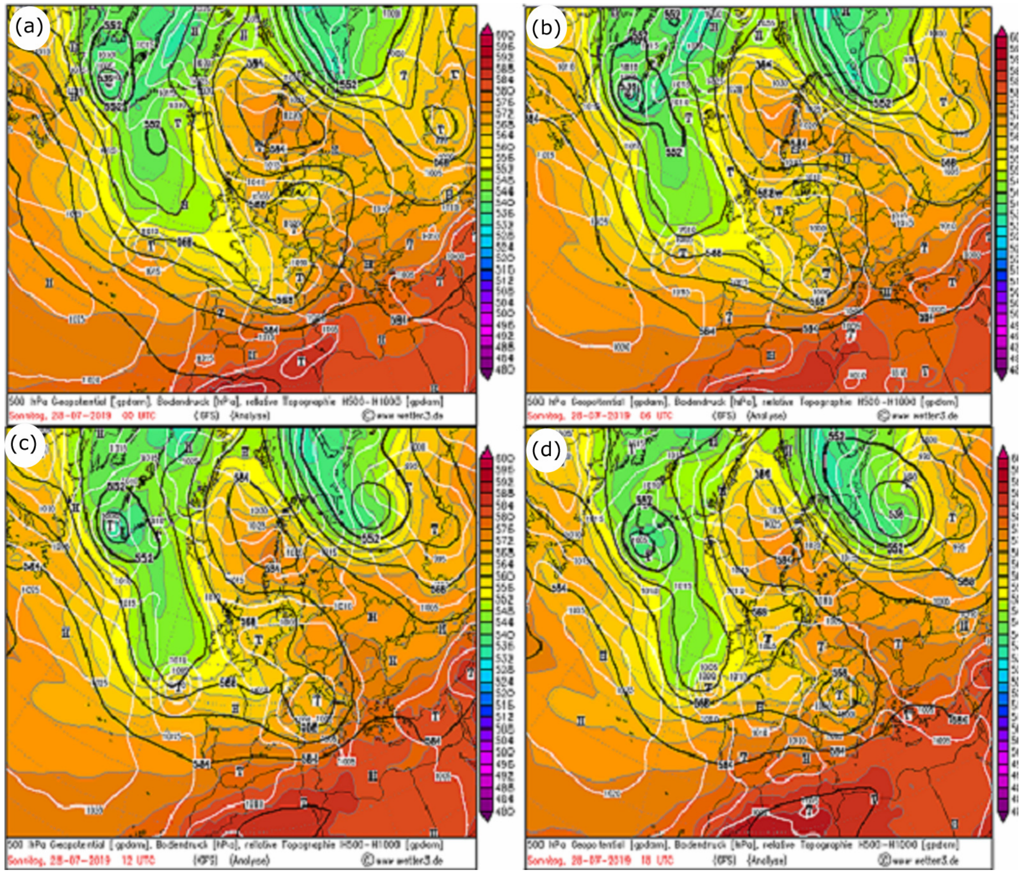

Fig. 2. Structure of the atmosphere at ground level and at 500 hPa at:
12am (a), 6am (b), 12pm (c) and 6pm (d) UTC

Thus, the analysis of synoptic maps of global models, which cover the whole of Europe, North Africa and parts of the Atlantic, indicated that the process should be most turbulent in the early afternoon (around 13–14 UTC). It has already been mentioned that process delays are a common occurrence in weather forecasting. In order to more accurately estimate the terms of expectation of the most turbulent process, generally announce the best possible weather forecasts, the analysis of additional synoptic material and prognostic maps of better (larger) resolution is approached. Since it was determined that the main deterioration of the weather was related to the afternoon hours, the analysis for the periods of 12 and 18 UTC is given below. The AT 700 hPa map at 12pm and 6pm UTC (Fig. 3) shows an area of extremely high relative humidity in the west and northwest of the Balkans, in the north of Italy and in the Alps region – about 80–90%, and humidity above Montenegro was between 90–95%, which indicated a pronounced lability of the atmosphere.

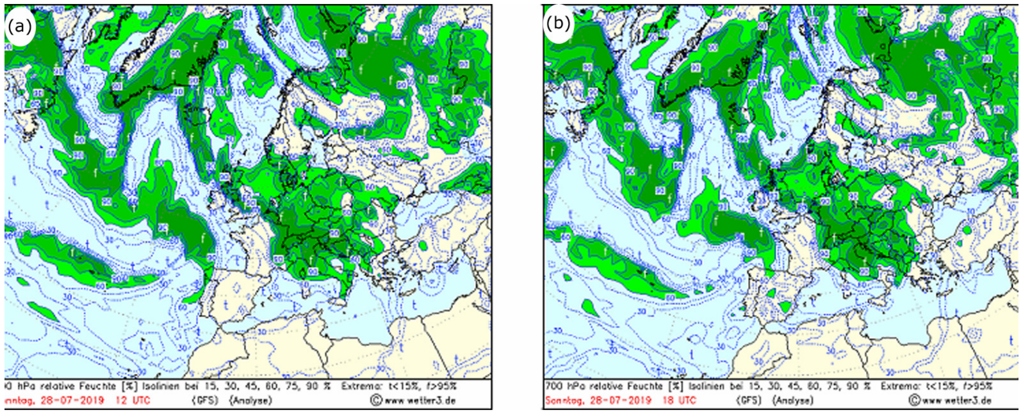

Fig. 3. Relative humidity at 700 hPa at 12pm (a) and 6pm (b) UTC July 28, 2019

On the analytical charts of the ground pressure from 12 pm and 6pm UTC (Fig. 4), there is a low pressure field above Western and most of southern Europe, and a vast discontinuity surface (frontal wave) extends from Iceland, via Britain, to the Benelux States, part of Central Europe and it turns in the direction of the Ligurian Sea. The northwestern part of the Balkans is influenced by the occluded front and the center of the shallow cyclone is above the northern Adriatic Sea. After 6pm the UTC frontal system continues to move eastward and gradually weakens, and to the west of it, the pressure begins to grow.

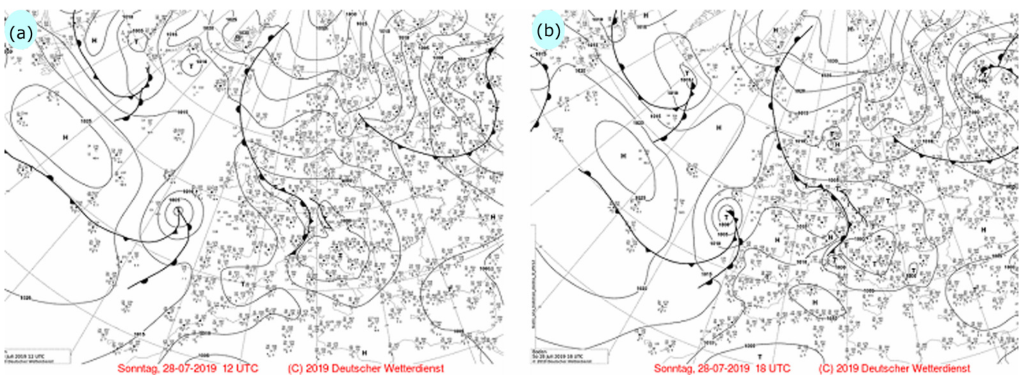

Fig. 4. Ground analytic chart above Europe at 12pm (a) and 6pm (b) UTC on July 28, 2019

Previously considered prognostic and analytical charts clearly indicate that Montenegro is located in the front part of the cyclone and altitude pressure field, that is to say, under the influence of moist and unstable south–southwest current, but they do not indicate such a tumultuous development of weather which was indicated by additional prognostic material. Namely, on the 12pm UTC instability chart, an increased value of the CAPE index is observed above the southern Adriatics – about 2000 J/kg. This zone with increased convective energy of instability up to 6pm UTC is moving towards the coastal and central part of Montenegro (Fig. 5), just in the period when heavy rainfall, strong wind and thunderstorms are registered.

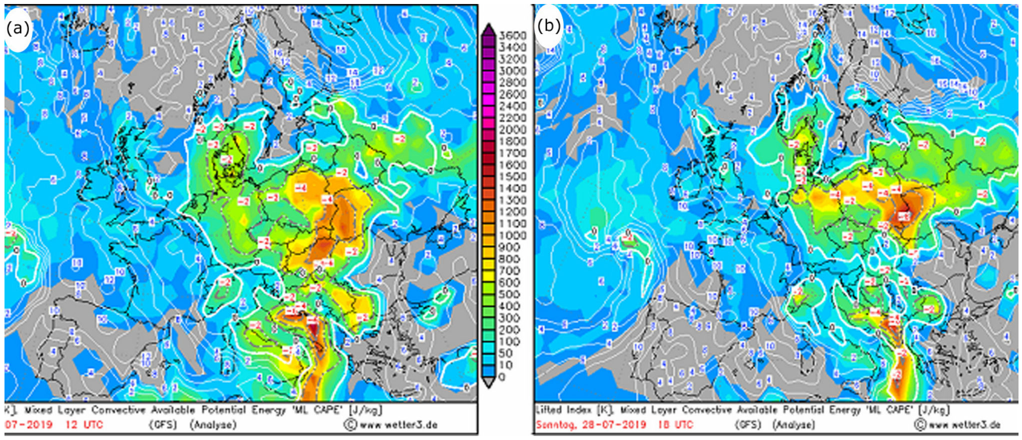

Fig. 5. CAPE instability index at 12pm (a) and 6pm (b) UTC on July 28, 2019

The strength of the process is also indicated by the composite chart, and the instability was recorded by the Gematronik–type radar from a radar center on Jastrebac Mountain in central part of Serbia. The products of the global GFS model are only available in the main sinoptic periods (12am, 6pm, 12pm and 6pm), while the outputs of the operating WRF–NMM model are hourly available. By analyzing the maps of better resolution of maximum reflection, where the initialization started two days before (from 26.7.2019), a rapid development of cumulonimbus (Cb) cloudiness can be seen first in the southwestern part of Montenegro at 4pm and 5pm UTC on July 28, 2019, where the maximum intensity of reflectivity is at a radar reflection of about 45 dbZ (decibels). In the next period (6pm UTC) Cb reflection spreads and intensifies, reaching up nearly to 50 dbZ (Fig. 6). From 7pm UTC onwards, the zone of high instability moves towards east and reaches only the very eastern parts of Montenegro at 8pm and 9pm UTC. After 9pm the UTC zone of severe instability disappears completely. Therefore, based on this analysis, it can be concluded that the culmination of the instability process started between 4pm and 5pm UTC, first in southwestern and western part of Montenegro, and then the zone with heavy rain, showers, storm wind and thunderstorms moved east to 8–9pm UTC. The analysis of SYNOP weather station reports for July 28, 2019 confirmed the forecast which had been given two days before, when during this period (4pm – 7pm UTC on July 28, 2019) the strongest wind gusts were registered, reaching up to 23 m/s (about 83 km/h) at the coast and in the central part of Montenegro.

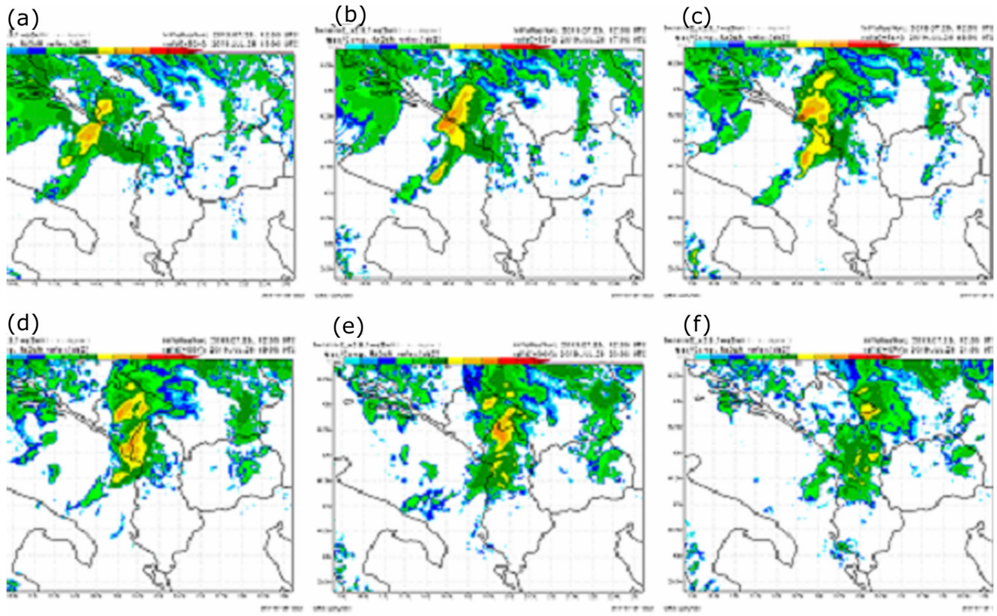

Fig. 6. Radar image of maximum reflection of cumulonimbus instability at: 4pm (a), 5pm (b), 6pm (c), 7pm (d), 8pm (e) and 9pm (f) UTC on July 28, 2019

Finally, the analysis of the emagram confirmed the previously stated. Namely, on the basis of the WRF–NMM model, which uses the data of the global ECMWF model as input data, an emograph and a holograph were made for Podgorica (the capital of Montenegro) at a resolution of 1 km for the time of 4pm UTC, when the maximum turbulence of the process began. The increased vertical gradients of meteorological parameters are observed on the emagram – decrease in temperature with altitude, increased air humidity at the ground area and a sudden increase in wind speed with altitude and its shear (Fig. 7).

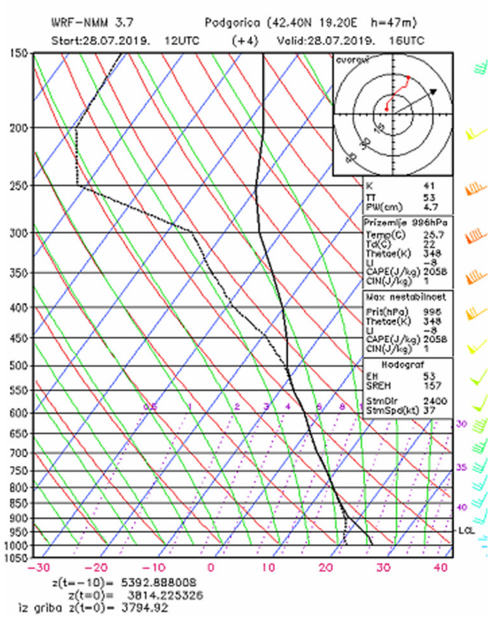

Fig. 7. Emagram and hodograph of wind WRF–NMM resolution model of 1.0 km for 4pm UTC on July 28, 2019

The vertical atmospheric profile above Podgorica in the observed term indicates adiabatic instability from the lowest layers (LCL), through the entire vertical profile, to the highest layers of the troposphere. The ground air temperature is over 25.7^{0}C and dew point temperature is around 22^{0}C, while air pressure is around 996 hPa. The zero isotherm height is at H_0 = 3.8 km and the isotherm height of –10^{0}C is H_{-10} = 5.4 km. The maximum instability is on the ground area, at an altitude of 996 hPa, where the CAPE index value is about 2058 J/kg. Also, other indices indicate strong instability, so the K index (41) and the TT index (53) on the emagram show that there is convective potential and conditions for storm–thunderstorm processes.

The hodograph (polar diagram in the upper right corner of the Figure 7) shows an increase in wind speed with height, as well as wind shear in the cumulonimbus at an altitude of about 900 hPa. The storm is moving at a speed of 37 knots and the direction of the storm is about 240 degrees, that is, from southwest to northeast. Indicators of rotation within the storm, EH (53 m^2/s) and SREH (157 m^2/s), indicated values of thunderstorms by their values. Based on the mentioned parameters, there was a high probability for the occurrence of leeches or waterspouts; the truth is that meteorological stations did not register it, which does not mean that it did not actually happen, because it is an exclusively local vortex.

Discussion

In most parts of Montenegro, July has the lowest rainfall on average during the year. For example, in Podgorica in July, it rains on average 38 mm of rain. During the mentioned day (July 28, 2019), 43 mm of rain fell in less than 3 hours (between 3pm–6pm UTC), hence a greater amount of precipitation than the average for the whole month. It was raining during the night and the following day (July 29, 2019), but with less intensity. In July, the Cetinje station in the southwest of Montenegro registers a total of 66 mm of rain on average, and 135 mm of rain fell in this place in the period from 3pm on July 28, 2019 to 6am UTC on July 29, 2019, or twice the monthly average. For the same period of 15 hours, 62 mm of rain were measured in Podgorica (Fig. 8).

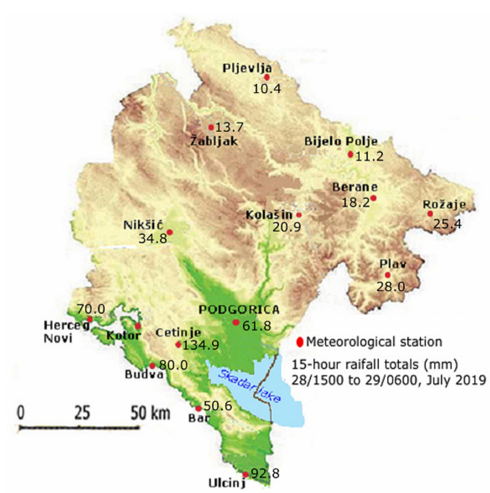

Fig. 8. Precipitation in Montenegro for the period of 15 hours (from 3pm on July 28 to 6am on July 29, 2019)

The research presented in this study is in support of the fact that modern climate change and extreme weather events have not bypassed Montenegro. During the previous 20 years, records of temperature, precipitation, wind and other potentially dangerous weather events were registered in Montenegro (Burić et al., 2011; Burić, 2014; Burić et al., 2015, 2021). In the paper Mihajlović et al. (2021) gives an exhaustive description of an extreme weather situation in Montenegro (water leech in Tivat). Burić et al. (2021) point out that " In early February 2019, Montenegro was hit by a severe wind storm. During the afternoon, as a result of stormy winds, large waves formed on Skadar Lake which overturned a boat and caused the loss of four lives. Fortunately, during the potentially dangerous weather phenomenon analyzed in this paper, apart from minor material damage, there were no human casualties. Climate projections for the south (Podgorica) and north (Kolašin) of Montenegro indicate that a further trend of rising temperatures and more frequent weather extremes should be expected by the end of the 21st century (Burić & Doderović 2020, 2021; Doderović et al., 2020).

The other parts of the Balkan Peninsula are also getting warmer with more frequent extreme weather events, such as high temperatures, heat waves, droughts, and heavy rainfall (Stagge et al., 2017). In Serbia, during the second half of the 20th and the beginning of the 21st century a negative trend of seasonal and annual precipitation, more frequent droughts, a positive trend of extreme daily temperatures and precipitation (Stanojevic et al., 2014; Arsenovic et al., 2015; Bajat et al., 2015; Luković et al., 2015; Pecelj et al., 2020). Croatia is not set aside from the more frequent potentially dangerous weather phenomena (Mihajlović et al., 2016). Also in Bosnia and Herzegovina there is a trend of rising temperatures and increasing extreme weather and climate events (Trbic et al., 2018; Popov et al., 2019). Changes in temperature and precipitation also occur in Slovenia (Milošević et al., 2016, 2017).

Conclusions

During each year in the last two decades, Montenegro recorded weather extremes – high temperatures, heat waves, floods, prolonged droughts, fires. In an era of contemporary climate change and the increasing frequency of weather extremes, the early predictions of potentially dangerous weather events will be increasingly significant. The purpose of this research was to highlight the importance of early warning of dangerous weather events, the necessity of observing the warnings given by the competent services in order to preserve human lives and to avoid consequences, based on a specific weather disaster, which occurred on July 28, 2019.

Analysis of synoptic material with initialization two days before the storm showed that potentially dangerous weather phenomena can be predicted in time. Numerical models clearly indicated that in the afternoon of 28th July 2019, stronger rain showers, thunderstorms, stormy winds and sea leeches were possible. Subsequent data from the SYNOP report showed that in the afternoon of the mentioned day, in just 2–3 hours in the southern and western part of Montenegro, a higher amount of precipitation than the average for the whole month of July was measured. Torrential currents have appeared in the coastal and central part of the country, wind gusts of up to 23 m/s (83 km/h) have been registered locally, and waves about 3 m high have been recorded along the coast (during the bathing season). There is no doubt that the described weather phenomenon had the character of an extreme event, but thanks to the warning of the competent services, which were communicated by the media, there were no human victims.

References

Ahmed, K., Shahid, S., Chung, E.S., Ismail, T. & Wang, X.J. (2017). Spatial distribution of secular trends in annual and seasonal precipitation over Pakistan. *Climate Research*, 74(2), 95–107. https://doi.org/10.3354/cr01489.

Alexander, L.V., Zhang, X., Peterson, C., Caesar, J., Gleason, B., Klein Tank, A.M.G., Haylock, M., Collins, D., Trewin, B., Rahimzadeh, F. Tagipour, A., Rupa Kumar, K., Revadekar, J., Griffiths, G., Vincent, L., Stephenson, D.B., Burn, J., Aguilar, E., Brunet, M., Taylor, M., New, M., Zhai, P., Rusticucci, M. & Vazquez–Aguirre, J.L. (2006). Global observed changes in daily climate extremes of temperature and precipitation, JGR: Atmospheres, 111, D05109. https://doi.org/10.1029/2005JD006290.

Arsenović, P., Tošić, I. & Unkašević, M. (2015). Trends in Combined Climate Indices in Serbia from 1961 to 2010. *Meteorology and Atmospheric Physics,* 127(4), 489–498. https://doi.org/10.1007/s00703-015-0380-6.

Bajat, B., Blagojević, D., Kilibarda, M., Luković, J. & Tošić, I. (2015). Spatial analysis of the temperature trends in Serbia during the period 1961–2010. Theoretical and Applied Climatology 121(1–2), 289–301. https://doi.org/10.1007/s00704-014-1243-7.

Brunetti, M., Maugeri, M., Monti, F., Nanni, T. 2006: Temperature and precipitation variability in Italy in the last two centuries from homogenised instrumental time series. *International Journal of Climatology*, 26(3), 345-381. https://doi.org/10.1002/joc.1251.

Burić, D., Ducić, V. & Luković, J. (2011). *Kolebanje klime u Crnoj Gori u drugoj polovini XX i početkom XXI vijeka*. Crnogorska akademija nauka i umjetnosti. Pogorica br.str. 270. https://canupub.me/kzsi.

Burić, D. (2014). *Dinamika i mogući uzroci temperaturnih i padavinskih ekstrema na teritoriji Crne Gore u periodu 1951–2010*. Ph.D. thesis, Geografski fakultet Univerzitet u Beogradu, Beograd.

Burić, D., Ducić, V. & Mihajlović, J. (2013). The climate of Montenegro: Modificators and types – part one. *Bulletin of the Serbian Geographical Society,* 93(4), 83–102. https://doi.org/10.2298/GSGD1304083B.

Burić, D., Luković, J., Ducić, V., Dragojlović, J. & Doderović, M. (2014a). Recent trends in daily temperature extremes over southern Montenegro (1951–2010). *Natural Hazards and Earth System Sciences*, 14(1), 67–72. https://doi.org/10.5194/nhess-14-67-2014.

Burić, D., Ducić, V. & Mihajlović, J. (2014b). The climate of Montenegro: Modificators and types – part two. *Bulletin of the Serbian Geographical Society,* 94(1), 73–90. https://doi.org/10.2298/GSGD1401073B.

Burić, D., Doderovi,ć M., Dragojlović, J. & Penjišević, I. (2021). Extreme weather and climate events in Montenegro – case study, November 2019. *Weather*, 76(11), 383–388. https://doi.org/10.1002/wea.3885.

Burić, D., Luković, J., Bajat, B., Kilibarda, M. & Živković, N. (2015). Recent Trends in Daily Rainfall Extremes over Montenegro (1951–2010). Natural Hazards and Earth System Sciences, 15(9), 2069–2077. https://doi.org/10.5194/nhess-15-2069-2015.

Burić, D. & Doderović, M. (2020). Projected Temperature Changes in Kolašin (Montenegro) up to 2100 According to EBU–POM and ALADIN Regional Climate Models. *Időjárás*, 124(4). 427–445. http://doi.org/10.28974/idojaras.2020.4.1.

Burić, D. & Doderović, M. (2021). Changes in Temperature and Precipitation in the Instrumental Period (1951–2018) and Projections up to 2100 in Podgorica (Montenegro). *International Journal of Climatology*, 41(S1), E133-E149. https://doi.org/10.1002/joc.6671.

Caloiero, T., Coscarelli, R., Ferrari, E. & Sirangelo, B. (2017). Trend analysis of monthly mean values and extreme indices of daily temperature in a region of southern Italy. *International Journal of Climatology*, 37(S1), 284-297. https://doi.org/10.1002/joc.5003.

Del Rio, S., Cano–Ortiz, A., Herrero, L. & Penas, A.P. (2012). Recent trends in mean maximum and minimum air temperatures over Spain (1961–2006). *Theoretical and Applied Climatology*, 109(3–4), 605–626. https://doi.org/10.1007/s00704-012-0593-2.

Doderović, M., Burić, D., Ducić, V. & Mijanović, I. (2020). Recent and Future Air Temperature and Precipitation Changes in the Mountainous Nort of Montenegro. *Journal of the Geographical Institute "Jovan Cvijić" SASA*, 70(3), 189–201. https://doi.org/10.2298/IJGI2003189D.

Ducić, V., Luković, J., Burić, D., Stanojević, G. & Mustafić, S. (2012). Precipitation extremes in the wettest Mediterranean region (Krivošije) and associated atmospheric circulation types. *Natural Hazards and Earth System Sciences*, 12(3), 687–697. https://doi.org/10.5194/nhess-12-687-2012.

Engström, J. & Keellings, D. (2018). Drought in the Southeastern USA: an assessment of downscaled CMIP5 models. *Climate Research*, 74(3), 251-262. https://doi.org/10.3354/cr01502.

Efthymiadis, D., Goodess, C.M. & Jones, P.D. (2011). Trends in Mediterranean gridded temperature extremes and large–scale circulation influences. *Natural Hazards and Earth System Sciences*, 11(8), 2199–2214. https://doi.org/10.5194/nhess-11-2199-2011.

Faiz, M.A., Liu, D., Fu, Q., Wrzesiński, D., Baig, F., Nabi, G., Khan, M.I, Li, T. & Cui, S. (2018). Extreme precipitation and drought monitoring in northeastern China using general circulation models and pan evaporation–based drought indices. *Climate Research*, 74(3), 231-250. https://doi.org/10.3354/cr01503.

Garreaud, R.D. (2018). Record–breaking climate anomalies lead to severe drought and environmental disruption in western Patagonia in 2016. *Climate Research*, 74(3), 217-229. https://doi.org/10.3354/cr01505.

IPCC. (2021). Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson–Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press. In Press.

Kostopoulou, E. & Jones, P.D. (2005). Assessment of climate extremes in the eastern Mediterranean. *Meteorology and Atmospheric Physics*, 89(1–4), 69–85. https://doi.org/10.1007/s00703-005-0122-2.

Luković, J., Blagojević, D., Kilibarda, M. & Bajat, B. (2015). Spatial Pattern of North Atlantic Oscillation Impact on Rainfall in Serbia. Spatial Statistics, 14(A), 39–52. https://doi.org/10.1016/j.spasta.2015.04.007.

Mihajlović, J., Burić, D., Ducić, V. & Milenković, M. (2021). Synoptic Characteristics of an Extreme Weather Event: The Tornadic Waterspout in Tivat (Montenegro), on June 9, 2018. *Geographia Polonica*, 94(1), 69–90. https://doi.org/10.7163/GPol.0194.

Mihajlović, J., Ducić, V. & Burić, D. (2016). Tornadic Waterspout Event in Split (Croatia) – Analysis of Meteorological Environment. *Journal of the Geographical Institute "Jovan Cvijic" SASA*, 66(2), 185–202. https://doi.org/10.2298/IJGI1602185M.

Milošević, D., Savić, M., Stankov, U., Žiberna, I., Pantelić, M., Dolinaj, D. & Leščešen, I. (2017). Maximum Temperatures over Slovenia and Their Relationship with Atmospheric Circulation Patterns. *Geografie*, 122(1), 1–20. https://doi.org/10.37040/geografie2017122010001.

Milošević, D.D., Savić, S.M., Pantelić, M., Stankov, U., Žiberna, I., Dolinaj, D. & Leščešen, I. (2016). Variability of Seasonal and Annual Precipitation in Slovenia and Its Correlation with Large–Scale Atmospheric Circulation. *Open Geosciences*, 8(1), 593–605. https://doi.org/10.1515/geo-2016-0041.

Pecelj, M.M., Lukić, Z.M., Filipović, J.D., Protić, M.B. & Bogdanović, M.U. (2020). Analysis of the Universal Thermal Climate Index During Heat Waves in Serbia. *Natural Hazards and Earth System Sciences*, 20(7), 2021–2036. https://doi.org/10.5194/nhess-20-2021-2020.

Popov, T., Gnjato, S. & Trbić, G. (2019). Changes in Precipitation over the East Herzegovina Region. Bulletin of the Serbian Geographical Society, 99(1), 29–44. https://doi.org/10.2298/GSGD1901029P.

Stagge, J.H., Kingston, D.G., Tallaksen, L.M. & Hannah, D.M. (2017). Observed Drought Indices Show Increasing Divergence Across Europe. Scientific Reports 7, 14045. https://doi.org/10.1038/s41598-017-14283-2.

Stanojević, G., Stojilković, J., Spalević, A. & Kokotović, V. (2014). The Impact of Heat Waves on Daily Mortality in Belgrade (Serbia) During Summer. *Environmental Hazards,* 13(4), 329-342. https://doi.org/10.1080/17477891.2014.932268.

Trbic, G., Bajic, D., Djurdjevic, V., Ducic, V., Cupac, R., Markez, Đ., Vukmir, G., Dekic, R. & Popov, T. (2018). Limits to Adaptation on Climate Change in Bosnia and Herzegovina. Insights and Experiences. In: Leal Filho W, Nalau J (eds) Limits to Climate Change Adaptation. Climate Change Management. Springer, Cham, 245–259. https://doi.org/10.1007/978-3-319-64599-5_14.

Vose, R.S., Easterling, D.R. & Gleason, B. (2005). Maximum and minimum temperature trends for the globe: an update through 2004. Geophysical Research Letters, 32(23), L23822. https://doi.org/10.1029/2005GL024379.