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

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Abstract. 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. 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. 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 (adapt) the population to the expected extreme weather situations and thus avoid or mitigate the negative consequences.

1. 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? In the latest Fifth Report of the Intergovernmental Panel on Climate Change [1] it is emphasized that the human impact on climate is clear, primarily in the form of increased concentrations of greenhouse gases effects in the atmosphere. It is further emphasized that the greatest contribution to positive radiation forcing has had increased concentration of CO_2 in the atmosphere since 1750. Thus, with very high confidence, the IPCC points out that human influence has been the dominant cause of observed warming since the mid-20th century.

The IPCC Fifth Report also addresses climate change adaptation and mitigation (reports of Working Group II and Working Group III), but these issues will be discussed in more details in the Sixth Report, which is expected to be published in 2021/2022. 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 CO2 from the atmosphere" [1]. In the Fifth IPCC Report, as well as in the previous ones, it is emphasized that changes in the intensity and frequency of extreme weather events, such as: droughts, floods, extreme temperatures, heat waves, stormy weather with hail, heavy short-term rainfall, have been registered in many regions of the world. etc.

There are numerous works highlighting the increase in the frequency of extreme climate events in almost all parts of the world. Based on the equivalent of about 71% of the world's land surface for the period 1950-2004, Vose et al. [2] point out that there is a positive trend of maximum and minimum temperature in almost all parts of the world, but that the minimum temperature grows faster. Having analyzed the daily extremes of temperature and precipitation, Alexander et al. [3] indicate that significant warming of the Northern Hemisphere occurred during the 20th century. Ahmed et al. [4] point out that in the period 1961-2010. rainfall was increased in Pakistan except in the southwestern part of the country, which became drier. Western Patagonia (Chile-Argentina) was hit by an unprecedented drought in the summer and fall of 2016, with a serious environmental impact [5]. Extreme rainfall and droughts in northeast China are reported in the paper by Faiz et al. [6]. The southeastern United States was repeatedly affected by severe droughts that affected the environment and economy of the region during the period 1950-2005 [7].

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 [8]. By doing analysis of several extreme climatic indices for the Eastern Mediterranean Region, Kostopoulou and Jones [9] 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. [10] 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. [11] 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 [12].

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. [13] and Buric et al. [14]. 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 [15].

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.

2. Research area, database 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 (Figure 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. [16]. Thus, most of Montenegro has the Mediterranean climate characteristics [17].

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 SINOP 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 1.0 km were obtained on the basis of the operational WRF-NMM model, which uses ECMWF data from Redding as input parameters. Standardized deviation and percentile methods were used to categorize precipitation.

Figure 1. Relief map of Montenegro and position in Europe

3. Results of the analysis of synoptic material for Montenegro for July 28, 2019

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. The forecasters of the Institute for Hydrometeorology and Seismology of Montenegro (IHMSM), had announced three days before the storm that dangerous meteorological phenomena could be expected. The day before (July 27, 2019), the forecast models confirm the lability of the atmosphere and the IHMSM declares an orange meteoalarm, that is, a medium level warning of expected weather conditions.

The analysis of the synoptic material from 12 am UTC (2pm 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 (Figure 2 - a). 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. According to the data from SINOP report, there was cirrus cloudness above Montenegro (Ci and Cs - Cirrus and Cirrostratus), which indicated the arrival of a frontal wave - it was a poorly conspicuous cold front. A little later, medium (As and Ac - altostratus and altocumulus) and low clouds (Cu - Cumulus and Sc - Stratocumulus) appeared, but still without rain. Synoptic material from 6am UTC indicates that the ground cyclone and the elevation valley have shifted eastward. There is also a deepening of the ground cyclone, whose center was then located above northern Italy (Figure 2 - b), but there was still no precipitation. After examining the SINOP report from metereological stations in Montenegro from 10am UTC, only one station in the southwest (Herceg Novi) registers the light rain.

The products of the numerical models from 12pm UTC show further displacement of the pressure fields toward east and northeast, so during this period the center of the ground cyclone is located above the northern Adriatic, and the axis of the altitude area of the instability is increasingly gaining a general direction from west to east-southeast, that is, toward the Ionian Sea. (Figure 2 - c). According to the SINOP report, several stations at the coast and in the western part of the country register light rain, with negligible rainfall - up to 0.5 mm.

Over the next two hours, rain zone spreads from the west and southwest to the rest of Montenegro, but it is still sporadical 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 (Figure 2 - d). 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 12am UTC for 29.7.2019.

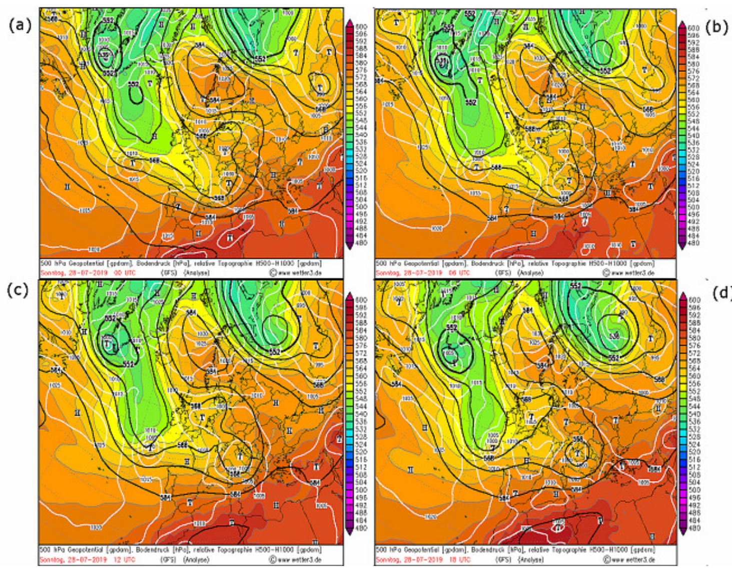

Figure 2. Structure of the atmosphere at ground level and at 500 hPa at: 12am (a), 6am (b), 12pm (c) and 6pm (d) UTC

The AT 700 hPa map at 12pm and 6pm UTC (Figure 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 he Alps region - about 80-90%. In the period from 3pm to 6pm UTC, humidity above Montenegro was between 90-95%, which indicated a pronounced lability of the atmosphere.

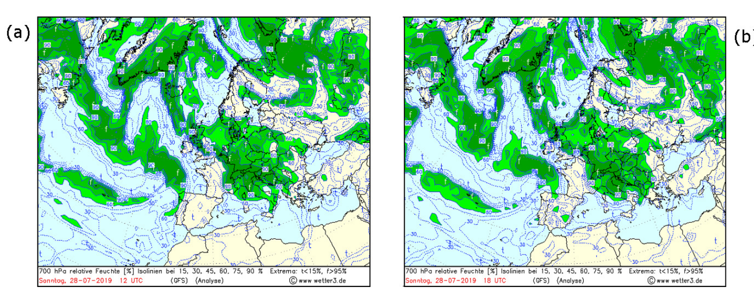

Figure 3. Relative humidity at 700 hPa at 12pm (a) and 6pm (b) UTC July 28, 2019

On the analytical charts of the ground pressure from 12 pm and 6pm UTC (Figure 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.

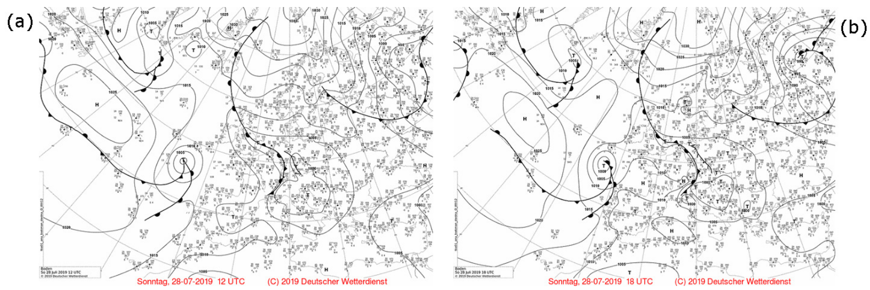

Figure 4. Ground analytic chart above Europe at 12pm (a) and 6pm (b) UTC on July 28, 2019

Previously considered prognostic and analytical charts clearly indicate that Montenegro is located in the front part of the cyclone and altutude 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 (Figure 5), just in the period when heavy rainfall, strong wind and thunderstorms are registered.

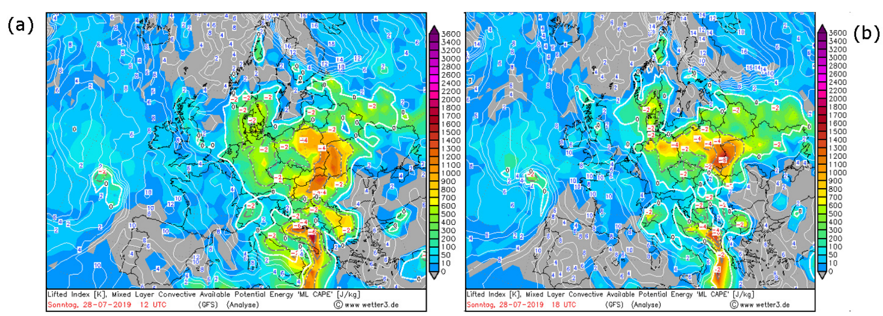

Figure 5. CAPE instability index at 12pm (a) and 6pm (b) UTC on July 28, 2019.

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 southern 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 (Figure 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 SINOP 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.

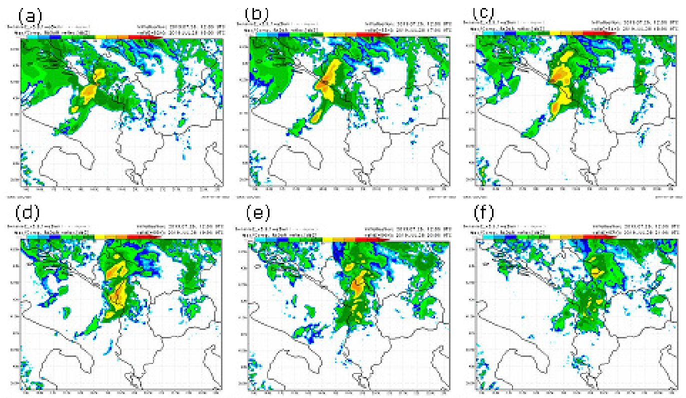

Figure 6. Radar image of maximum reflection of cumulonimbus instability at:
4pm (a), 5pm (b), 6pm (c), 7pm (d), 8pm (e) and 9pm (f) UTC on July 28, 2019

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 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 (Figure 7).

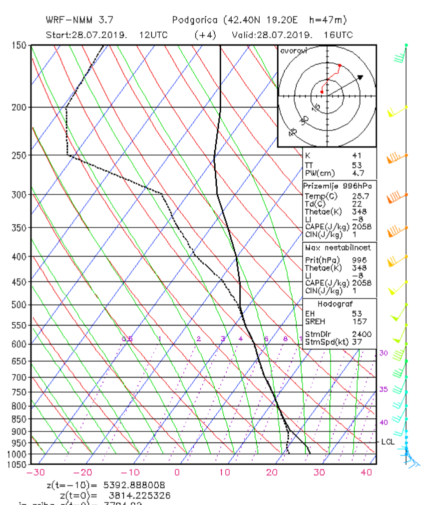

Figure 7. Emagram and hodograph of wind WRF-NMM resolution model
of 1.0 km for 4pm UTC on July 28, 2019

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 25.7^0C and dew point temperature is around 22^0C, 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 mb. 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.

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, 63 mm of rain were measured in Podgorica (Figure 8).

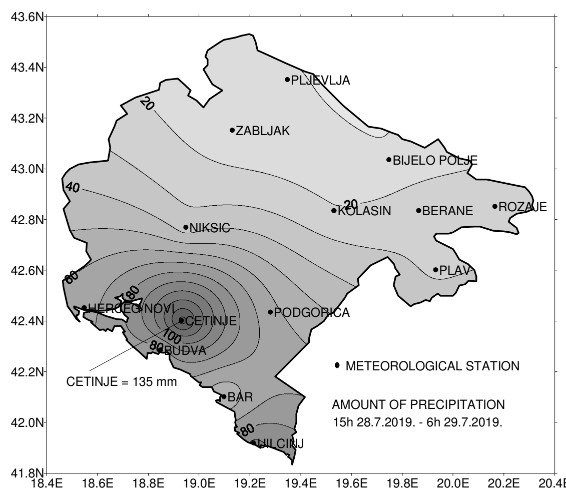

Figure 8. Precipitation in Montenegro for the period of 15 hours
(fro 3pm on July 28 to 6am on July 29, 2019)

Standardized deviation and percentile methods were used to categorize precipitation. Both methods revealed that rainfall in the coastal and central part of Montenegro was in the category of extreme rainfall - above 3 standard deviations, i.e. deviations higher than the 98th percentile of the normal distribution. EUMETSAT satellite images were also used in the analysis, which also indicated the presence of stormy thunderstorms (cumulonimbus). Other prognostic material, such as the development and trajectory of movement of high, medium and low clouds, atmospheric structures on the AT 850 hPa map, etc., indicated pronounced instability in the afternoon and evening on July 28, 2019 in the territory of Montenegro.

The analysis conducted in this paper aimed to point out the importance of early announcement of potentially dangerous weather events. Based on the warnings provided by the forecasters of the

IHMSM, the Emergency Sector, which operates within the Ministry of Internal Affairs of Montenegro as well as local rescue services, undertakes certain protection measures. In the specific case, during the afternoon of the July 28, 2019, Maritime Security officers rescued 7 persons from the sea, because strong wind generated large waves, 2-3 m high.

Therefore, over the last two decades, this small Mediterranean country has been increasingly affected by the weather. To name a few extreme cases. A strong cyclone activity, i.e. deep terrestrial pressure depression centered over the southern Adriatic and a vast altitude valley of instability, extending from northwest Europe to the Ionian Sea, on December 4, 2008 in the Boka Kotorska region (southwest of Montenegro) caused occasional heavy afternoon rainfall and locally hurricane-force wind gusts. The Herceg Novi Meteorological Station registered a gust of 65 m/s or 234 km/h that afternoon - the strongest wind gust ever measured in Montenegro. Also noteworthy is the summer of 2017, when Montenegro was hit by a series of heat waves, and in the capital (Podgorica), it was 11 days in a row with a maximum temperature of over 400C (from July 31 to August 10), which has never happened in the instrumental period (since 1949). In some extreme situations there were also human victims. In early February 2019 (February 3, 2019), Montenegro was hit by a severe storm. In the afternoon, as a result of stormy winds, large waves were formed on Skadar Lake which overturne a boat with nine persons. Unfortunately, a family of three members and one man failed to cope with the massive waves and storm. In this case, too, it was warned that a storm was expected.

Recently, in a very large number of cases, numerical modeling products have almost exactly been interpreting the structure of the atmosphere, with the initialization of 5 or more days of forecast in advance. Thanks to more reliable numerical modeling products (prognostic or synoptic material), the degree of accuracy of the short-term weather forecast is very high today. Such and similar situations remind that the warnings of the competent services should be respected. This is simply necessary for the population to adapt (adapt) their activities to the expected extreme weather situations and thus avoid or mitigate the negative consequences.

4. Conclusion

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 28th July 2019.

Synoptic numerical models with initialization indicated potentially dangerous weather phenomena in Montenegro in the afternoon and evening for 28th July 2019, two days before the storm. The prognosis was almost completely accurate. There were brief periods of heavy rain, stormy winds, strong thunderstorms, sea waves of over 2 m in height. In just 2-3 hours in many places. The precipiration was above the average of the whole July. There were torrential flows, with wind gusts reaching up to 23 m / s (83 km / h) on the slopes of the mountains in the hinterland and in the central part of Montenegro. Due to the early warning that potentially dangerous weather events were expected, there were no human casualties or material damage, as the competent services responded in a timely manner.

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