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Climate change projections of infrastructure-hazardous phenomena (heavy rainfall and wind) in Bulgaria

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Abstract: Climate change projections of infrastructure-hazardous phenomena (heavy rainfall and wind) are presented for Bulgaria. The change in the number of extreme convective rainfall and wind events are presented according to the warning thresholds from the Meteoalarm program. The largest changes in heavy precipitation events are found along the Black Sea coast and in mountainous regions (the Balkan mountain range and the Rila-Rhodope area). In terms of extreme wind, the largest changes in the number of extreme events are observed in Northern, Northeastern and Southeastern Bulgaria (the Danube Plain, Dobrudzha and the Upper Thracian Lowland), the southwestern parts of the country and the Black Sea coast region.

Keywords: Climate change projections, extreme precipitation, extreme wind, Bulgaria, infrastructure

1. INTRODUCTION

The world has been warming over the past 50 years, and most of the observed warming is very likely due to anthropogenic greenhouse gas emissions (Myhre et al., 2013). According to the Intergovernmental Panel on Climate Change Sixth Assessment Report IPCC AR6 (https://www.ipcc.ch/report/ar6/wg1/), the increase in atmospheric emissions of carbon dioxide CO_2, methane CH_4 and nitrogene dioxide NO_2 during the industrial age is the result of human activity and human influence is the primary driver of many of the changes observed in the atmosphere, ocean, cryosphere and biosphere. Rising global temperatures and related impacts pose one of the greatest threats to humanity. In particular, changes in the magnitude and frequency of extreme events are among the most worrisome (Outten and Sobolowski, 2021; Forzieri et al, 2016; Beniston et

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al., 2007). Extreme winds cause significant damages each year and present a serious problem for multiple industries including construction, forestation, wind energy, and many others (Outten and Esau, 2013). Wind storms are among the most destructive natural disasters in Europe, with annual losses in the EU estimated at around €5 billion (Spinoni et al., 2020). The number of recorded wind storms has increased significantly in recent decades, but there is still no consensus on the climate-induced trend in winds over Europe. Different business sectors rely on knowledge of extreme winds. The proper design and construction of infrastructure and large buildings depends on accurate assessments of extreme winds. Extreme winds regularly cause the largest economic damages in Europe (MunichRe, 2011). Wind power is another sector that relies on a good knowledge of extreme winds to avoid wind turbine failures and minimise disruption to electricity generation. Turbines stop producing electricity if the wind speed is too high. Given the growing needs of these industries, and the damages and losses that extreme wind events can cause, the need for robust and reliable estimates of the frequency and intensity of extreme wind events are of increasing importance.

In modern society, infrastructure is the main pillar of development (Pudyastuti and Nugraha, 2018). Important infrastructures in a region are water infrastructure, transport infrastructure, energy infrastructure, waste infrastructure, communication infrastructures, construction of public facilities like hospitals, schools, shopping centres, offices etc. Water infrastructure includes dams, irrigation networks, drainage networks, sewers and municipal water supply networks. Examples of transport infrastructure are airports, ports, railways, highways, toll roads and others. Extreme weather events due to climate change are likely to increase disruption to infrastructures. When the functioning of infrastructure in a region is disrupted, this will affect other sectors, including the economy and public health.

The extreme winds in Europe were examined in PRUDENCE project (Schwierz et al., 2010; Rockel and Woth, 2007; Beniston et al., 2007). The simulations have a horizontal resolution of 50 km. To identify extreme winds, they look at the 95th, 98th, and 99th percentiles of the 10-meter wind speed. These studies show a projected increase in winds over northern Europe with reduced wind speeds over the Mediterranean. The next studies have reviewed the results of the ENSEMBLES project (Outten and Esau, 2013; Pryor et al, 2012; Donat et al, 2011). The simulations were performed with a horizontal resolution of 25 km, allowing to determine some of the details of the spatial distribution of extreme winds. In Donat et al. (2011) the 98th percentile of wind speed is investigated. In Pryor et al. (2012) and Outten and Esau (2013) were examined the 50-year return levels of wind. These studies show an increase in wind speed over northern Europe. In Donat et al. (2011) and Outten&Esau (2013) a projected extreme wind decreases over the Mediterranean. The largest changes were found in the ocean, while the changes over land were classified as inconsistent (Nikulin et al., 2011). In Outten and Sobolowski, (2021), the predicted changes in extreme winds from the 15-member ensemble of high-resolution simulations of the Euro-CORDEX project at a resolution of about 12 km are investigated. They find that the higher resolution simulations have a clear added value compared to similar simulations at coarser resolution and that the spatial heterogeneity and highly localized nature of the extreme winds are well-captured. Effects such as orographic interactions, drag due to urban areas, and individual storm tracks over the oceans are clearly visible, and that future wind changes are also characterized by strong spatial heterogeneity. They predict more frequent extreme episodes for northern, central and southern Europe in the 21st century. As is clear from the studies reviewed here, extreme winds have been assessed in a variety of ways.

Since the 1950s, extreme precipitation events have increased and become more frequent in many regions of the world (IPCC, 2021). These trends are expected to continue as the planet continues to warm. Warmer air can trap more water vapor. With each degree of warming, the water vapour capacity of the air increases by about 7% (Trenberth, 2011). An atmosphere with more moisture can lead to more intense rainfall. An increase in intense precipitation events does not always lead to an increase in the total amount of precipitation during the season or year. Some climate models predict a decrease in moderate precipitation and an increase in the duration of dry periods, which offsets the increase in precipitation during extreme events. An adverse impact of heavy rainfall is the risk of flooding. This risk is increased in the urban area where impermeable road pavement force water quickly into the drain system. In addition to flooding, heavy rainfall also increases the risk of landslides. When above-normal rainfall raises the water table and saturates the soil, slopes can lose their stability and trigger a landslide. Excessive rainfall can also degrade water quality and harm human health and ecosystems. Heavy rains can cause temporary or permanent flooding of roads, bridges and harbours. Structural damage or increased wear and tear can lead to higher maintenance costs due to failures.

In Bulgaria, the most common natural disasters of meteorological nature are related to extreme rainfalls, extreme temperatures, storms, floods, forest fires, landslides. Previous studies of assessment of extreme precipitation and/or wind for Bulgaria are described in Alexandrov et al. (2004); Bocheva et al (2007); Bocheva et al. (2009); Bocheva et al. (2010); Malcheva (2017); Bocheva and Popchristov (2019); Bocheva and Malcheva (2020); Malcheva et al. (2020). In Bocheva et al. (2009) the variability and trends associated with extreme precipitation events in Bulgaria during the periods 1961-1990 and 1991-2005 were investigated. They found evidence of significant increase (more than 32%) of the days with heavy 24-hour precipitation during the second period. They also found that the frequency of heavy-rain events in the warm half of the year in 1991–2005 is about 60% higher than in 1961–1990. In Bocheva et al. (2010) an increase of mean annual number of days with torrential precipitation (totals ≥ 100 mm/24 h in one station) was found with about 30 % for the period 1991-2007 versus those for 1961-1990. Bocheva and Popchristov (2019) used data for extreme precipitation (totals ≥60 mm/24 h) from the meteorological network of the National Institute of Meteorology and Hydrology for the period 1991–2017. They found an increase of the annual number of days with heavy precipitation for the investigated period and they also found that 78% of all days are during the summer and autumn. In Bocheva and Malcheva (2020) the variability and trends of extreme 24-hour precipitation in Bulgaria during the periods 1931-1960, 1961-1990, 1991-2019 have been presented. They have analyzed potentially dangerous precipitation (≥ 60 mm/24 h) on the base of available daily data from all stations of the national meteorological network. They concluded that the number of days with extreme precipitation increases by 19-42% in the period 1991-2019. They also found that the most considerable change in the number of these events was observed in the regions with transitional-Mediterranean climate and maritime climate (near the Black Sea).

The risks caused by climate change events can lead to loss of life or cause significant damage that affects a country's economic growth and well-being. Extreme weather events pose one of the most visible and immediate dangers to society. In a number of studies, e.g. in Dourte et al. (2015), increasing water content is considered as the main cause of increasing rainfall intensity. In areas with a general decrease in annual rainfall, the increase in the number of intense rainfall events is a consequence of the fact that the conditions for their occurrence become more likely during more months of the year. It is known that heavy rainfall prevails during the warm period of the year and its nature is mainly convective. In Berg et al. (2013) is mentioned that in contrast, convective precipitation exhibited characteristic spatial and temporal scales, and its intensity in response to warming exceeded the Clausius – Clapeyron rate. Convective precipitation responds much more sensitively to temperature increases than stratiform precipitation, becoming dominant in extreme precipitation events. It is also noted that the Clausius-Clapeyron relationship describes the rate of change of saturation vapor pressure of approximately 7% per 1 ºC at typical surface temperatures and thus defines the scale of increase in extreme precipitation. In (Trenberth, 2011) the water-holding capacity of the air increases as the atmosphere warms, leading to an increase in water vapor, as a result, storms cause more intense rainfall. The increase in the number of intense precipitation events is even observed when the total amount of precipitation decreases (Myhre et al., 2019). A statistically significant relationship with global near-surface temperature changes is mentioned in Westra et al. (2013) with clear meridional dependence. According to Hawcroft et al. (2018), an increase in the number of extratropical cyclones is the mechanism that leads to an increase in extreme precipitation events. A moderate increase in total precipitation accompanied by a relatively strong increase in convective precipitation and a concomitant decrease in precipitation is noted in Chernokulsky et al. (2019). The influence of mountains and topography on precipitation and its intensity has been considered by many authors. The mechanism of the impact of mountains is described in Houze (2012). Convective systems are influenced by the direction of air flow. In Kirshbaum et al. (2018) is concluded that moist instability is regulated by the larger-scale background flow, local evapotranspiration, transport of moisture and thermodynamic heterogeneities over the complex terrain. The sensitivity of extreme precipitation to warming in climate simulations is lower over mountains than over oceans and plains (Xiaoming and Durran, 2016). There is likely to be a statistically significant increase in the number of heavy precipitation events in more regions, but there are strong regional and sub-regional differences in trends (IPCC, 2012). Also, there is a high degree of confidence that changes in precipitation intensity will affect landslides in some regions. It is likely that the frequency of heavy precipitation events, or the proportion of heavy precipitation events in total precipitation events, will increase during the 21st century in many regions of the globe. In Jacob et al. (2014) projected future mean seasonal changes in temperature and precipitation intensity in Europe are presented. Projections show an increase in heavy winter precipitation in most parts of Europe by the end of the century and an increase in heavy summer precipitation, except in southern Europe. It is also shown that large parts of Eastern Europe and the Alpine region could be exposed to temperature warming by the end of the century. They find that the high resolution of the simulations is clearly evident in the pattern of change in rainfall intensity and more detailed spatial patterns in high-resolution simulations can be associated with better resolved physical processes such as convection and heavy precipitation.

2. METHODS AND DATA

The main goal of the paper is to present a possible way of estimating expected changes in infrastructure-hazardous phenomena (extreme wind and precipitation). The goal is not focused on model sensitivity and validation or comparison of different models. In this study we use RegCM4 (Giorgi et al.,1993a, Giorgi et al.,1993b, Giorgi et al., 2012) regional climate model to simulate the future changes of extreme wind and precipitation in Bulgaria. The boundary conditions are from HadGEM2-ES global climate model (Collins et al., 2011), which has 38 vertical levels and a horizontal resolution of 1.25° x 1.875° according to RCP4.5 (Thomson et al., 2011) and RCP8.5 (Riahi et al, 2011). Results are presented for two future periods (2021-2050 and 2071-2099), compared with the reference (1975-2004) on spatial maps of extreme wind and precipitation above the Meteoalarm thresholds for the territory of Bulgaria, annually and by seasons. The RegCM4 model has a dynamical core of the fifth-generation mesoscale model (MM5) from the National Center for atmospheric Research (NCAR) and Pennsylvania State University (Grell et al., 1994). It is a hydrostatic model with a horizontal Arakawa B-grid and a vertical σ-coordinate. It uses the National Center for atmospheric Research radiation scheme NCAR CCM3 (Kiehl et al., 1996). The following physics schemes were used in the experiment: an explicit SUBEX moisture scheme (Pal et al., 2000), a BATS scheme (Dickinson et al., 1993) for parameterization of subsurface interaction processes, a Holtslag scheme (Holtslag et al., 1990) for the planetary boundary layer. Experiments on the sensitivity of the model to planetary boundary layer parametrization were performed by Güttler et al., (2014). Many studies have been published on the validation and calibration of numerical models (Torma et al., 2011; Pieczka et al., 2016; Kotlarski et al., 2014; Giorgi et al., 2012). The Grell (1993) scheme with the Arakawa - Schubert (Arakawa and Schubert, 1974) closure assumption (Grell-AS) was used to parametrize convective precipitation for Bulgaria. A sensitivity analysis of five experiments with different convective precipitation schemes found that the model is sensible to the choice of cumulus convection scheme and that the most appropriate convective precipitation scheme in the region covering Bulgaria is Grell scheme with Arakawa-Schubert closure (Valcheva and Peneva, 2014). In Chervenkov et al. (2017) and Gadzhev et al. (2018) were shown sensitivity tests with RegCM with 20 different configurations over South-eastern Europe. They have concluded that Grell scheme gives the smallest biases for this region. More details on the model can be found in Elguindi et al. (2014). The study area is centred at 24°E, 42°N, with a horizontal resolution of 20 km. The results are shown only for the territory of Bulgaria after removing the buffer zone from 12 grid points from each side of the domain. In Valcheva (2019), considering annual mean temperature and precipitation, the RegCM4 model forced with boundary conditions provided from HadGEM2-ES global climate model showed warm temperature bias 0.7 °C and 67% more precipitation for the territory of Bulgaria compared with observational data for the period 1975-2004. In spring and autumn the mean biases are lower than 0.5°C, cold in spring and warm in autumn. In summer and winter the model showed warm temperature biases (1.9°C and 1.1°C, respectively). For precipitation, the model showed overestimation in all seasons except the summer season.

RCP (Representative Concentration Pathways) scenarios were used in this study (Moss et al., 2010). The greenhouse gas concentrations in the RCPs closely correspond to the emission trends discussed in Clarke et al. (2010). For CO_2, RCP8.5 follows the upper range in the literature, rapidly increasing concentrations (van Vuuren et. al., 2011). RCP6 and RCP4.5 show a stabilizing CO_2 concentration, close to the median range in the literature. RCP2.6 has a peak in carbon dioxide concentrations around 2050, followed by a modest decline to around 400 ppm, by the end of the century. The hypothesis accepted here is that the increase in greenhouse gases is the reason for the increase in the number of extreme rainfall and wind. That is why we use RCP4.5 (stabilizing concentration) and RCP8.5 (increasing concentration) scenarios for this study.

We use the extreme precipitation definition given by WMO (WMO, 2016) that precipitation event is considered to be extreme when it exceeds a certain threshold that has a certain associated impact, i.e. a fixed threshold. It is recommended for reporting heavy precipitation events at regional level to use 24 hours time-scale as a period for a common criteria for heavy precipitation. According to (WMO, 2016) an extreme can be identified when a single climate variable (precipitation or wind) exceed its specific thresholds, which can be varying percentile-based values, fixed absolute values and return period.

In this study we apply Meteoalarm criteria. Each country participating in Meteoalarm (http://www.meteoalarm.org/) program has a set of thresholds for hazardous weather, in particular for heavy rainfall and extreme wind. The thresholds depend on both, the climatic norms specific to the country and the infrastructure. The color scale meaning is: yellow - the weather is potentially dangerous; orange - the weather is dangerous; red - the weather is very dangerous.

On Table 1, with accordance with the Meteoalarm program, the thresholds are from 14 m/s to 19 m/s for strong winds or "yellow" code, from 20 m/s to 29 m/s for stormy winds or "orange" code and above 30 m/s for hurricane winds or "red" code. Only the first thresholds, above 14m/s, 20m/s and 30m/s respectively, will be used. For precipitation (Table 1) the thresholds are from 15 to 35mm, from 35 to 65mm and above 65mm per 24 hours for the three codes, respectively. Here we will use only the first thresholds, above 15, 35 and 65 mm/24h.

Table 1. Accepted values by Meteoalarm for Bulgaria.

CODE	YELLOW	ORANGE	RED
PRECIPITATION	Amount of rainfall: 15-35 mm in 24 hours or intense rainfall up to 30 mm in 6 hours	Amount of rainfall: 35-65 mm in 24 hours or intense rainfall over 30 mm in 6 hours	Amount of rainfall: > 65 mm in 24 hours
WIND	Strong wind: speed 14-19 m/s (50-69 km/h) and/or gusts up to 24 m/s (90 km/h)	Stormy wind: Speed 20-29 m/s (70-100 km/h) and/or gusts up to 32 m/s (115 km/h) local wind - Foehn, Bora	Hurricane wind: speed ≥ 30 m/s (>100 km/h); local wind - Foehn, Bora

The E-OBS version 22.0e daily precipitation dataset (Cornes et al., 2018), available in a regular grid of 0.25 deg, was used to properly estimate significant changes. Figure 1 shows the number of cases with a threshold above 15 mm, 35 mm and 65 mm over 24 hours at each grid point. Areas with a change ± 1 are considered uncertain. This interval allows to distinguish compact zones of change in the number of heavy rainfalls. When comparing these cases with hazardous weather warnings in practice, it may seem that the cases of increasing intense rainfall are few, but this is misleading as heavy rain warnings are issued for the whole area even if the risk points are few.

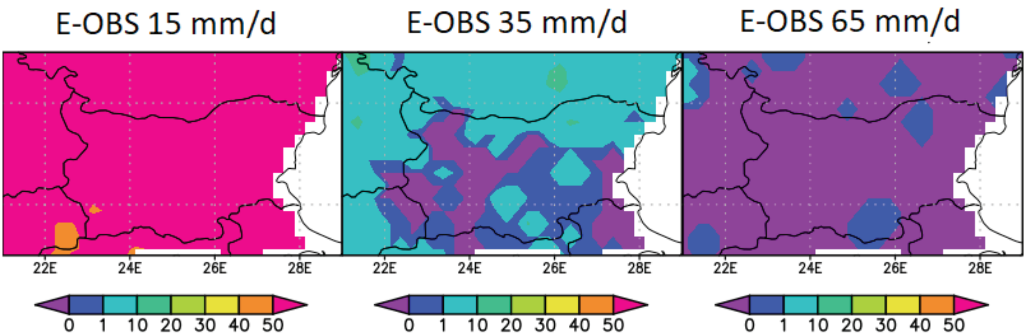

Fig. 1. The number of cases above the thresholds 15, 35 and 65 mm per 24 hours in accordance with the E-OBS rainfall ensemble data with 0.25º x 0.25º resolution for the period 1975-2004.

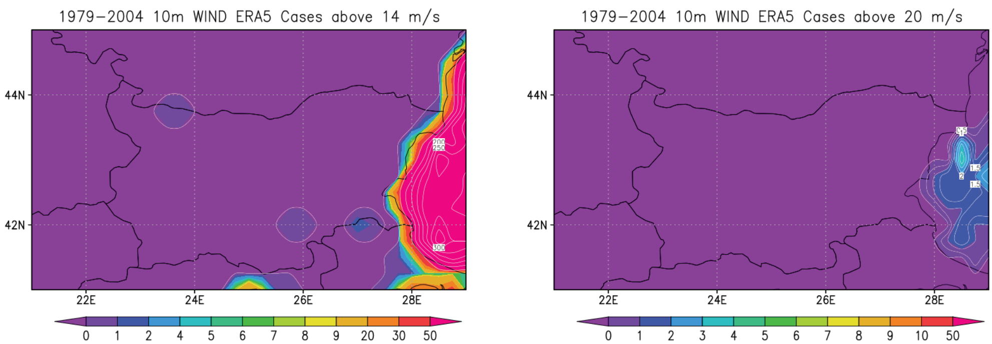

Fig. 2. The number of cases above the thresholds 14 m/s and 20 m/s in accordance with the ERA5 data with 0.25º x 0.25º resolution (~31 km) for the period 1979-2004.

The new ERA5 reanalysis data provided by ECMWF (European Centre for Medium-Range Weather Forecasts) is the latest meteorological analysis datasets. It includes estimates of a range of atmospheric parameters including air temperature, pressure, wind, humidity and ozone at different altitudes, as well as surface parameters such as precipitation, soil moisture, sea surface temperature. The resolution of the data is 0.25° ~31 km and 137 vertical levels (up to about 80 km altitude). This study used hourly time-resolved maximum wind speed data for Europe from 1979 to 2004, https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-singlelevelstab =form. Figure 2 presents the number of cases with strong winds above 14 m/s and stormy winds above 20 m/s based on ERA5 data (Hersbach et al., 2018) for the period 1979-2004 available from 1979 up to now. We show only the winds above 14 and 20 m/s because according to the ERA5 datasets there is no cases of winds above 30m/s for the territory of Bulgaria for the period 1979-2004.

3. RESULTS

3.1. Extreme convective precipitation

Climate change simulations of convective precipitation events above the thresholds of 15, 35 and 65 mm per 24 hours for the territory of Bulgaria by the end of the century are shown in Figure 3, Figure 4 and Figure 5, respectively.

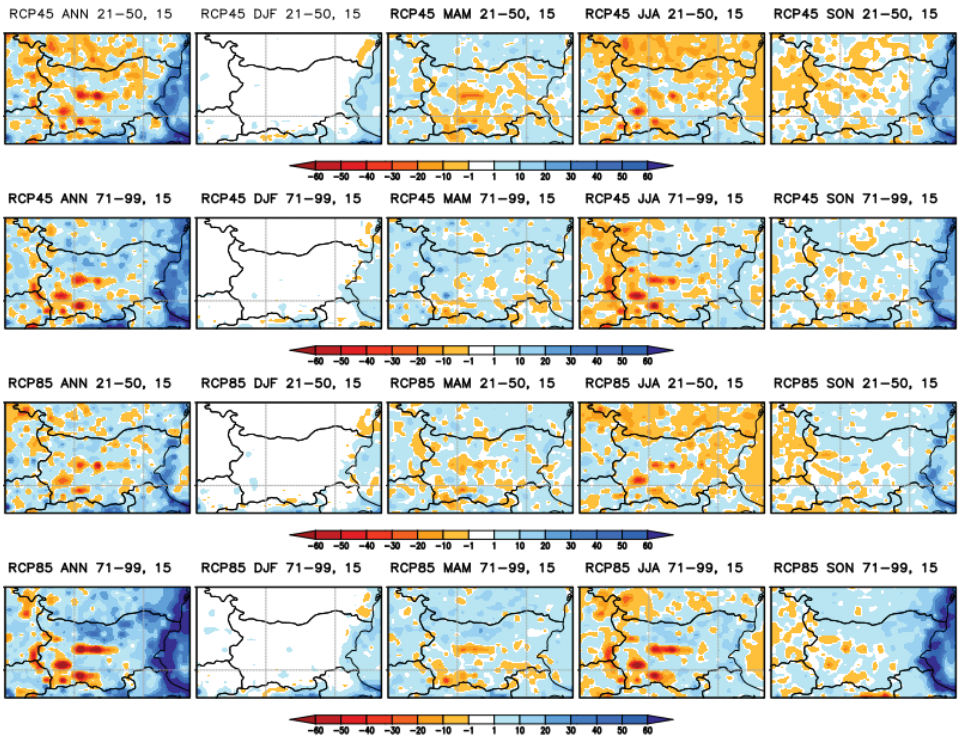

Fig. 3. Simulated annual and seasonal change in the number of cases with convective rainfall above 15 mm per 24 hours for the periods 2021-2050 and 2071-2099 according to RCP4.5 (first two rows) and RCP8.5 (second two rows) for the territory of Bulgaria.

Figure 3 shows the annual and seasonal change in the number of convective rainfall cases above the threshold of 15mm per 24 hours. The first column shows a decrease in the number of annual heavy precipitation events in mountainous regions, especially in the Balkan mountains and the Rila-Rhodope region, by more than 60 events over 30 years, and an increase along the Black Sea coast by 40-60 events over 30 years for both scenarios. According to the RCP8.5 scenario, extreme precipitation events in the Danube plain and Dobrudzha are expected to increase with 40-60 cases by the end of the century and along the Black Sea Coast with more than 80 events in 30 years. The areas exposed to the highest risk of heavy rainfall by the end of the century are the districts of Pleven, Rousse, Silistra, Dobrich, Varna and Burgas. Looking at the seasons, there is an increase in extreme precipitation events along the Black Sea coast in the autumn season by 40-60 events and along the Danube plain and Dobrudzha by 20 events over 30 years. The most significant decrease in extreme precipitation in mountainous regions is observed in the summer season with more than 60 cases in the last 30 years, especially in the high parts of the Rila-Rhodope region and the Balkan mountain.

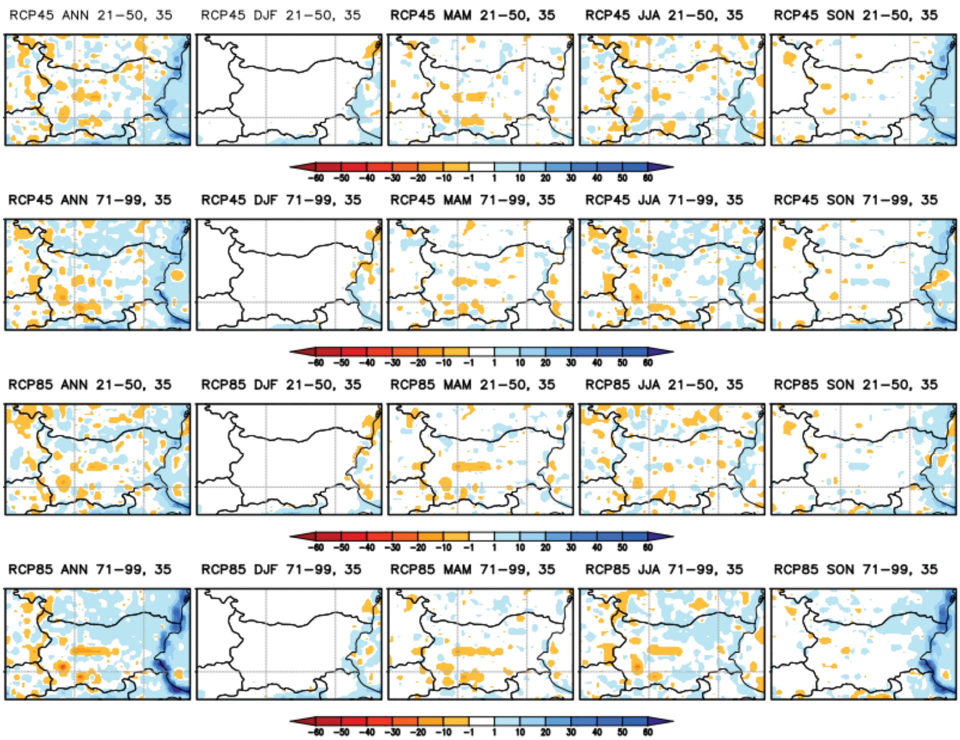

Fig. 4. Same as Fig.3, but for 35 mm per 24 hours.

Figure 4 shows the annual and seasonal change in the number of cases with convective precipitation above the threshold of 35 mm in 24 hours. The first column shows a decrease in the number of annual heavy rains in mountainous areas by 20-40 events over 30 years and an increase in the number of heavy rains along the coast by 40-60 events over 30 years for both scenarios and for both periods. The areas at the greatest risk are Dobrich, Varna and Burgas districts. Considering the seasons, the extreme precipitation in autumn along the Black Sea coast is expected to increase by 20-30 cases in the period 2021-2050 and by 30-40 cases in the period 2070-2099. In summer and autumn seasons can be expected an increase of extreme precipitation in the Dobrudzha region up to 20 cases for 30 years by the end of the century. The extreme precipitation in spring and summer season decreases by 10-20 cases in 30 years in mountainous regions (Rila, Pirin and Balkan mountains).

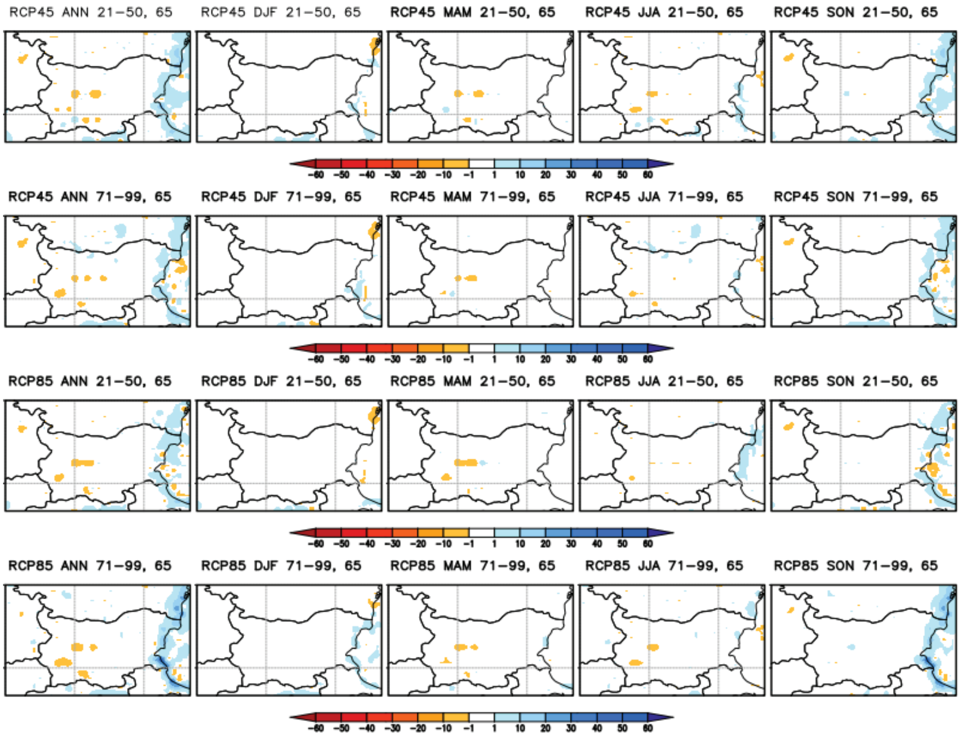

Fig. 5. Same as Fig.3, but for 65 mm per 24 hours.

In Figure 5, the annual and seasonal change in the number of cases with 24-hour convective precipitation above the threshold of 65 mm in 24 hours is shown. The first column shows a decrease in the number of annual heavy rainfalls in mountainous areas by 10-20 cases in 30 years and an increase in the Black Sea area. The biggest increase can be expected in the autumn season along the Black Sea coast with up to 20 cases in accordance with RCP8.5 scenario by the end of the 21st century. The areas at the greatest risk are Dobrich, Varna and Burgas districts.

As we can see, the number of heavy rainfalls in mountainous regions decreased in both climate change simulation periods and for both scenarios. This can be explained by the processes noted in (Xiaoming and Durran, 2016) for these regions due to rising temperatures. The increase in water content is not sufficient to increase the number of intense convective precipitation events. This effect occurs mainly in summer when the number of convective and/or stratiform precipitation events decrease. The decrease in the number of extreme rainfall events does not preclude an increase in the amount of precipitation in these areas due to increased water content according to Clausius-

Clapeyron law. For this reason, Figure 6 shows the annual and seasonal change in convective precipitation under the RCP4.5 and RCP8.5 scenarios in percentages, and Figure 7 shows simulated annual and seasonal mean temperature change (in °C) for the territory of Bulgaria by the end of the century.

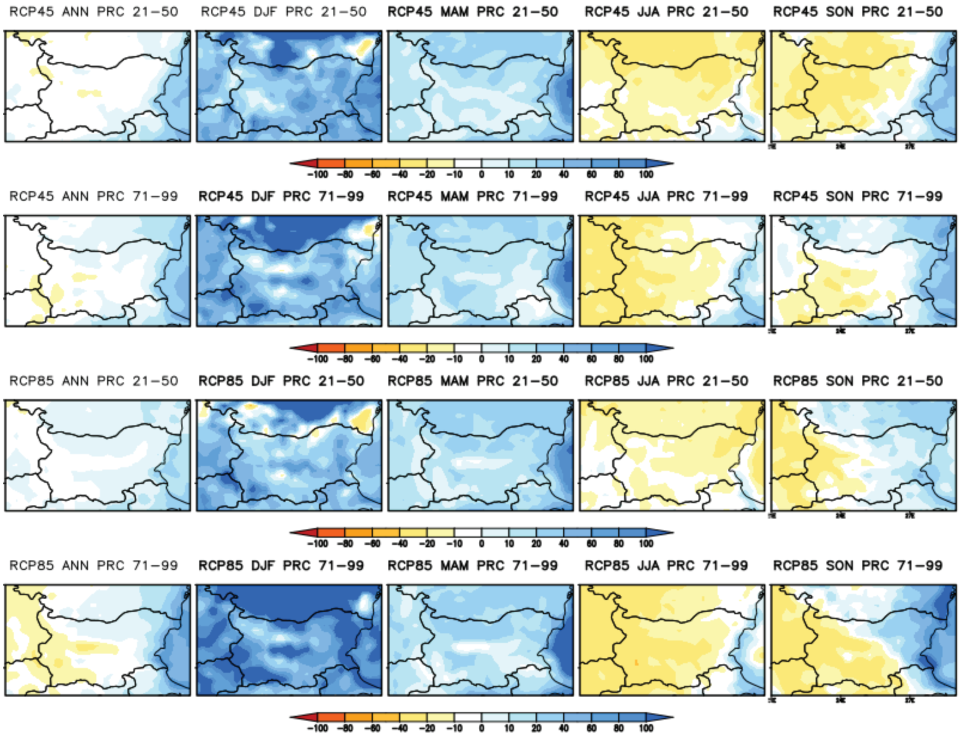

Fig. 6. Simulated annual and seasonal change of convective precipitation (in %) for the periods 2021-2050 and 2071-2099 according to RCP4.5 (first two rows) and RCP8.5 (second two rows) for the territory of Bulgaria.

The first column of Figure 6 shows a decrease in the annual convective precipitation by 10-20% in the central and south-western parts of the country and an increase in precipitation by 10-20% over the Danube plain, Dobrudzha, the Upper Thracian Lowland and the Black Sea Coast. In accordance with the RCP8.5 scenario an increase in precipitation in the Black Sea region can be expected with more than 30% by the end of the century. During the spring and winter an increase in precipitation is shown over the whole territory of Bulgaria, the largest increase is in northern Bulgaria and mountains regions with 20-40% in spring and with 80-90% in winter season by the end of the century. On the other hand, during the winter season, there are no apparent changes in the number of extreme precipitation events above the “yellow”, “orange” and “red” codes (Figure 3, Figure 4 and Figure 5). During the summer season, the amount of precipitation decreases by 20-40% in almost entire study area, except in the easternmost parts of the country. During the autumn, convective precipitation decreases by 20-40% in western and southern Bulgaria and increases by 20-40% in Northeastern Bulgaria and over the Black Sea. In accordance with the RCP8.5 scenario in autumn, convective precipitation increases by 60-80% in Dobrudzha and the Black Sea region.

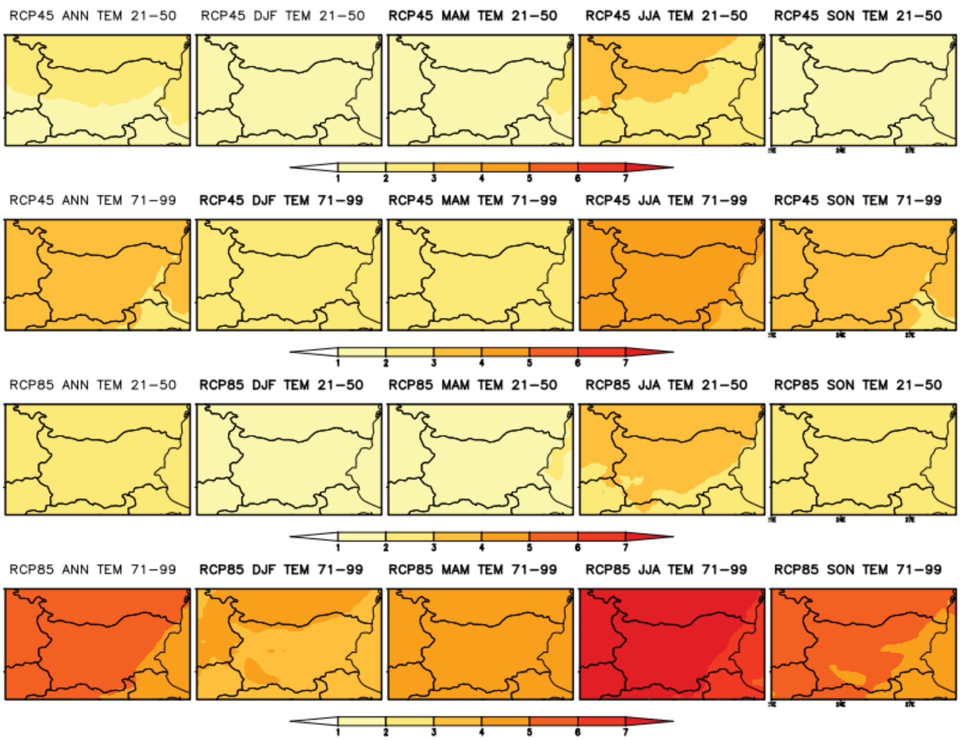

Fig. 7. Simulated annual and seasonal mean temperature change (in °C) for the territory of Bulgaria for the periods 2021-2050 and 2071-2099 according to RCP4.5 (first two rows) and RCP8.5 (second two rows).

According to the RCP4.5 scenario, the annual temperature increase (Figure 7) is between 1.8 and 2.1 ºC for Bulgaria in the first period and between 2.9 and 3.2 ºC in the second period. In the first period 2021-2050, the greatest warming can be expected in the summer season - between 2.6 and 3.2 ºC. In the other seasons, the temperature increase is less - between 1.5 and 1.9 ºC. In the second period 2071-2099, the temperature increases between 2.2 ºC and 2.4 ºC in the winter season and between 2.5 and 3.5 ºC in spring and autumn. Temperature increases in summer can reach 4 - 4.4 ºC. According to RCP8.5 scenario, the annual temperature increase is between 2.1 °C and 2.2 °C in the first period and between 4.5 °C and 5.4 °C in the second period for the territory of Bulgaria. In the first period, 2021-2050, the greatest warming can be expected in the summer season, between 3°C and 3.2 °C. In the other seasons, the temperature increase is less, between 1.6 °C and 2.4 °C. In the second period, 2071-2099, the temperature increase is between 3.5 °C and 4.5 °C except summer season, in which the temperature can increase above 6 ºC.

3.2. Extreme wind

The climatic simulations related to wind as well as other meteorological elements depend on the parametrizations used in the specific model. They may use different schemes of turbulent exchange, roughness, ‘drag’, Richardson number and others affecting the formation of the surface layer and processes in the atmosphere. Bulgaria has a complex and intricate topography with a maritime zone, vast plains, lowlands and high mountains occupying about one third of the country’s territory. This leads to significant differences in the formation of the ground layer and turbulent exchange in different areas. As a result, a specific dependence of wind speed on altitude is formed. Wind velocity is greatest in the plains and over the sea and gradually decreases with increasing altitude. After moving to the higher parts in the mountains, the wind speed starts to increase again (Figure 8). This leads to more cases of strong winds on the plains, a decrease in their number in certain areas and an increase again over the mountains.

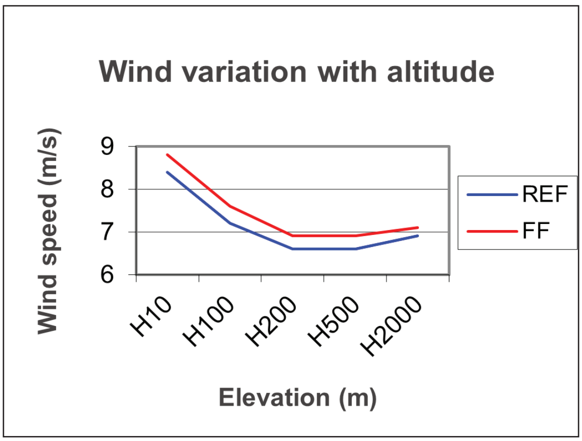

Fig. 8. Variation of wind speed with altitude.

It is observed small differences in wind values between the reference and future period. The wind behaviour for all scenarios and periods remains the same as the reference period, indicating the same mechanism of surface layer formation and turbulent exchange with the rest of the troposphere, which appear to be topography dependent only. For the most extreme winds (above 30 m/s), only a slight change in the number of wind events is observed over the sea. The reason for this is probably the different parametrizations over land and sea.

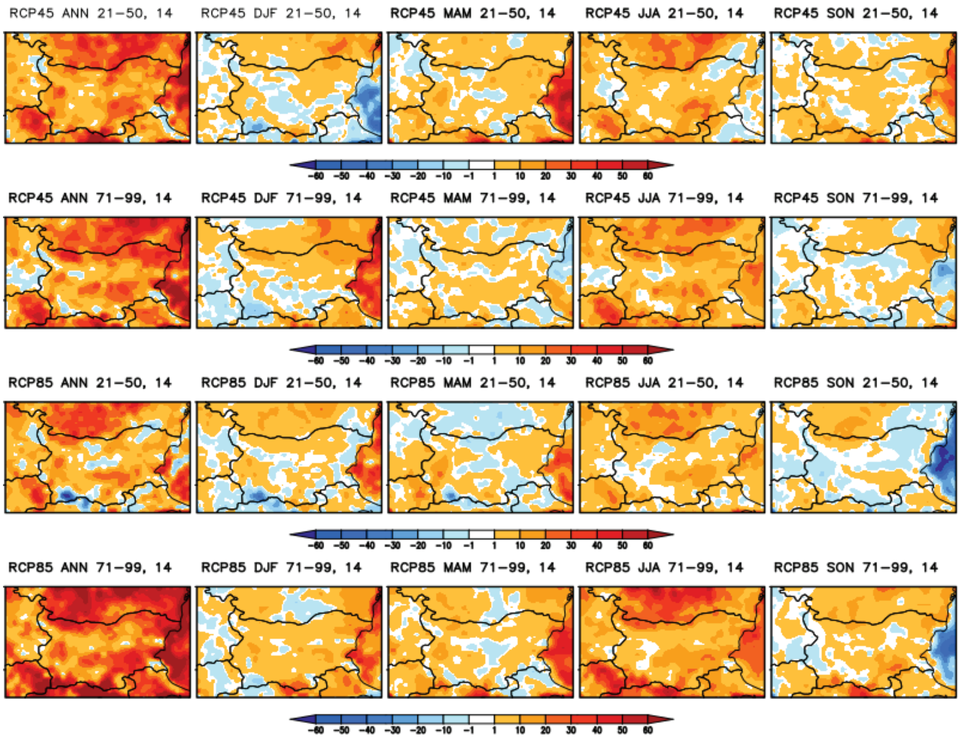

Fig. 9. Simulated annual and seasonal change in the number of cases of 10m maximum wind speed above 14 m/s for the periods 2021-2050 and 2071-2099 according to RCP4.5 (first two rows) and RCP8.5 (second two rows) for the territory of Bulgaria.

The annual change of strong winds above 14 m/s is shown in Figure 9. The number of cases under both scenarios is expected to increase by about 20 cases in the period 2021-2050 and up to 40-60 cases in the period 2071-2099 under RCP4.5 scenario over the Danube Plain, Dobrudzha, Upper Thracian Lowland and the Black Sea Coast, as well as for the southernmost parts of Rila and Pirin mountains. In the RCP8.5 scenario for the period 2070-2099, the increase in winds above 14 m/s is for the whole country, with 40 cases to the northwest, 40-80 cases along the Black Sea Coast and up to 100 cases in Central and Southern Bulgaria. The areas exposed to the highest risk of strong winds, in accordance with the numerical simulations by the end of the century, are the districts of Montana, Vratsa, Pleven, Rousse, Silistra, Dobrich, Varna, Burgas, Sofia, Blagoevgrad, Kardzhali, Yambol and Sliven. For all seasons, an increase in the number of high wind events is expected for the most parts of the country, mainly in the plains and lowlands and the coastal zone.

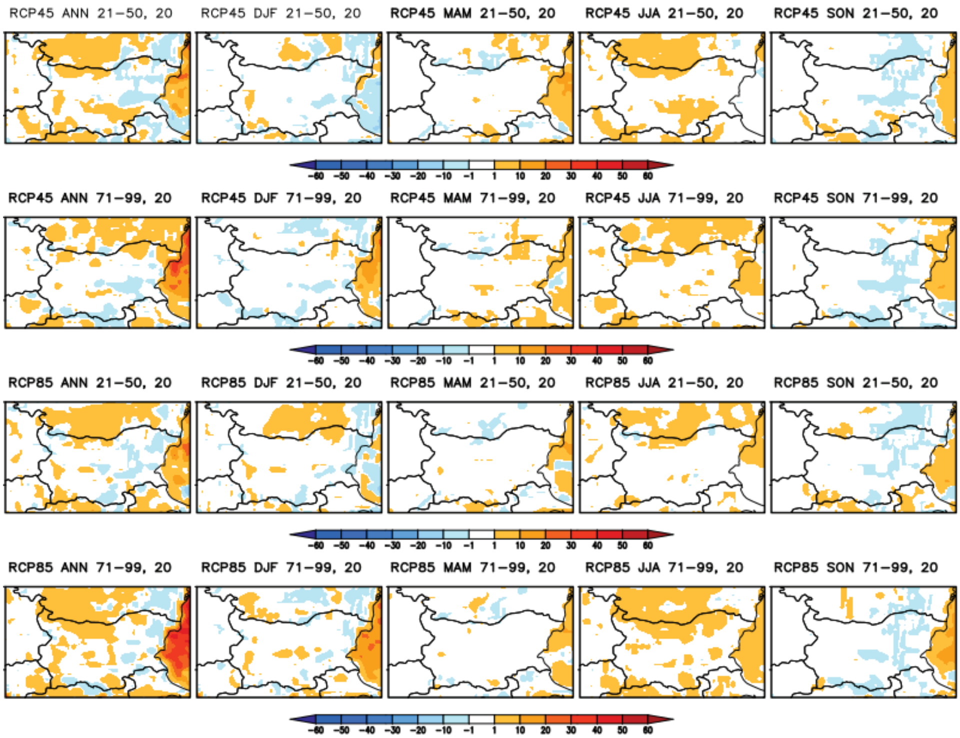

Fig. 10. Same as Fig.9, but for 20 m/s**.**

In the case of stormy winds above 20 m/s, an increase of 20-25 cases in the Black Sea area can be expected under the RCP4.5 scenario and up to 30 cases under RCP8.5 by 2099. In the Danube plain and Dobrudzha there is an increase of about 10 cases in 30 years. The most risky areas are the districts of Vratsa, Pleven, Sofia, the easternmost parts of Dobrich and Varna districts and the southernmost parts of Blagoevgrad and Kardzhali districts. Notable is the increase in stormy winds over the sea on both annual and seasonal maps (Figure 10).

For the most extreme winds (above 30 m/s), little change in the number of cases is observed only over the sea (not shown here) in the range of ±2 cases over 30 years. The reason for this is probably due to the different parametrizations of the numerical model over land and sea. For the territory of Bulgaria, there is no visible change in the simulated annual and seasonal variation of the number of cases above 30 m/s.

4. CONCLUDING REMARKS

The objects of study in this work are the infrastructure-hazardous phenomena (heavy rainfall and wind) in Bulgaria. In general, it can be concluded that it is possible to identify areas at increased risk of heavy rain and extreme wind in Bulgaria using the Meteoalarm criteria. In the case of wind, above 14 m/s, the areas exposed to the highest risk, according to the numerical simulations by the end of the century, are the districts of Montana, Vratsa, Pleven, Rousse, Silistra, Dobrich, Varna, Burgas, Sofia, Blagoevgrad, Kardzhali, Yambol and Sliven. For winds above 20m/s, the most risky areas are the districts of Vratsa, Pleven, Sofia, the easternmost parts of Dobrich and Varna districts and the southernmost parts of Blagoevgrad and Kardzhali districts. For winds above 30 m/s, the numerical simulations do not predict changes for the territory of Bulgaria. In the case of extreme precipitation, above 15mm/24h, the areas exposed to the highest risk are the districts of Pleven, Rousse, Silistra, Dobrich, Varna and Burgas. For rainfall, over 35mm/24h and 65mm/24h, the areas at the greatest risk are Dobrich, Varna and Burgas districts. The results confirm the theoretical studies for reducing convective precipitation in mountainous regions and their increase in coastal and plain areas. This is a consequence of both, the increases in water content, according to the law of Clausius - Clapeyron, as well as the extension of the period in which convective precipitation occurs. The modelled temperature changes in the different seasons, as well as the annual ones, show a relevant response to the dynamics of the processes on the intensive precipitation. The wind behaviour remains the same as the reference period for all scenarios and periods, indicating the same mechanism of surface layer formation and turbulent exchange with the rest of the troposphere, which appear to be topography dependent only. The wind velocity is the greatest on the plains and over the sea and decreases with increasing altitude. After moving to the higher parts in the mountains, the wind speed starts to increase again, which leads to more cases of strong winds on the plains, a decrease in their number in certain areas and an increase again over the mountains.

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REFERENCES

Alexander L.V. (2016), Global observed long-term changes in temperature and precipitation extremes: a review of progress and limitations in IPCC assessments and beyond, Weather and Climate Extremes 11, 4–16.

Alexandrov, V., Schneider, M., Koleva, E. et al. (2004) Climate variability and change in Bulgaria during the 20th century. Theor Appl Climatol 79, 133-149 https://doi.org/10.1007/s00704-004-0073-4

Arakawa, A. and Schubert, W.H. (1974), Interaction of cumulus cloud ensemble with the largescale environment, Part I. J. atmos. Sci., 31, 674-701.

Beniston, M., Stephenson, D.B., Christensen, O.B., Ferro, C.A.T., Frei, C., Goyette, S., Halsnaes, K., Holt, T., Jylha, K., Kofli, B., Palutikof, J., Scholl, R., Semmler, T., Woth, K. (2007), Future extreme events in European climate: an exploration of regional climate model projections, Clim. Change 81, 71–95.

Berg, P., Moseley, C., Haerter, J. O. (2013), Strong increase in convective precipitation in response to higher temperatures, Nature Geosci. 6, 181–185, doi:10.1038/ngeo1731.

Bocheva L., Georgiev Ch., Simeonov P. (2007), A climatic study of severe storms over Bulgaria produced by Mediterranean cyclones in 1990-2001 period. Atmospheric Research, vol. 83(2-4), pp. 284-293

Bocheva, L., T. Marinova, P. Simeonov, I. Gospodinov (2009), Variability and trends of extreme precipitation events over Bulgaria (1961-2005). Atmospheric Research, 3, 4909497.

Bocheva L., Gospodinov I., Simeonov P., Marinova T. (2010) Climatological Analysis of the Synoptic Situations Causing Torrential Precipitation Events in Bulgaria During the Period 1961-2007. Global Environmental Change: Challenges to Science and Society in Southeastern Europe. Alexandrov V., Gajdusek M., Knight C., Yotova A. (eds), pp. 97-108, https://doi.org/10.1007/978-90-481-8695-2_9

Bocheva L., Pophristov V. (2019), Seasonal analysis of large-scale heavy precipitation events in Bulgaria. 10th Jubilee Conference of the Balkan Physical Union (BPU10), August 2018, Sofia, Bulgaria, Editors: T. M. Mishonov and A. M. Varonov, AIP Conference Proceedings, vol. 2075(1), 200017 (2019); https://doi.org/10.1063/1.5099023

Bocheva L., Malcheva K. (2020), Climatological assessment of extreme 24-hour precipitation in Bulgaria during the period 1931-2019. SGEM2020 Conference Proceedings, vol. 20(4.1), pp. 357-364, DOI: DOI:10.5593/sgem2020/4.1/s19.045

Chernokulsky, A., Kozlov, F., Zolina, O., Bulygina, O., Mokhov, I., Semenov, V. (2019), Observed changes in convective and stratiform precipitation in Northern Eurasia over the last five decades, Environ. Res. Lett. 14 045001.

Chervenkov, H., Ivanov, V., Gadzhev, G., Ganev, K., (2017), Sensitivity Study of Different RegCM4.4 Model Set-Ups – Recent Results from the TVRegCM Experiment CYBERNETICS AND INFORMATION TECHNOLOGIES Vol. 17, No 5 Special issue with selected papers from the workshop "Two Years Avitohol: Advanced High Performance Computing Applications 2017" DOI: 10.1515/cait-2017-0051 pp. 17-26

Clarke L, Edmonds J, Krey V, Richels R, Rose S, Tavoni M (2010), International climate policy architectures: overview of the EMF 22 international scenarios. Energ Econ 31(suppl 2):S64–S81.

Collins WJ, Bellouin N, Doutriaux-Boucher M, Gedney N, Halloran P, Hinton T, Hughes J Jones CD, Joshi M, Liddicoat S, Martin G, O'Connor F, Rae J, Senior C, Sitch S, Totterdell I, Wiltshire A, Woodward S (2011), Development and evaluation of an Earth-system model – HadGEM2, Geosci. Model Dev. Discuss., 4, 997-1062, doi:10.5194/gmdd-4-997-2011.

Cornes, R., G. van der Schrier, E.J.M. van den Besselaar, and P.D. Jones. (2018), An Ensemble Version of the E-OBS Temperature and Precipitation Datasets, J. Geophys. Res. atmos., 123. doi:10.1029/2017JD028200.

Dourte, D. R., Fraisse, C. W., & Bartels, W.L. (2015), Exploring changes in rainfall intensity and seasonal variability in the Southeastern U.S.: Stakeholder engagement, observations, and adaptation, Climate Risk Management, 7, 11–19. doi:10.1016/j.crm.2015.02.001.

Dickinson, R., Henderson-Sellers, A., and Kennedy, P. (1993), Biosphere-atmosphere Transfer Scheme (BATS) version 1 as coupled to the NCAR community climate model, NCAR Technical Note NCAR/TN-387 + STR, 72p.

Elguindi, N.; Bi, X.; Giorgi, F.; Nagarajan, B.; Pal, J.; Solmon, F.; Rauscher, S.; Zakey, A.; O'Brien, T.;Nogherotto, R.; et al. (2014), Regional Climate Model RegCM User Manual Version 4.4, International Centre for Theoretical Physics (ICTP), Trieste, Italy.

Forzieri, G., Feyen, L., Russo, S., Vousdoukas, M., Alfieri, L., Outten, S., Migliavacca, M., Bianchi, A., Rojas, R., A., C. (2016), Multi-hazard assessment in Europe under climate change. Clim. Change 137, 105–119. http://dx.doi.org/10.1007/s10584- 016-1661-x.

Gadzhev G., Ivanov V., Ganev K., Chervenkov H. (2018) TVRegCM Numerical Simulations -

Preliminary Results. In: Lirkov I., Margenov S. (eds) Large-Scale Scientific Computing. LSSC 2017. Lecture Notes in Computer Science, vol 10665, pp 266-274 Springer, Cham DOI 10.1007/978-3-319- 73441-5_28.

Giorgi F, Bates GT, Nieman S (1993a), The multi-year surface climatology of a regional atmospheric model over the Western United States. J Clim 6: 75–95.

Giorgi F, Marinucci MR, Bates GT (1993b), Development of a second generation regional climate model (RegCM2). Part I: Boundary layer and radiative transfer processes. Mon Weather Rev 121: 2794–2813.

Giorgi, F, Coppola, E, Solmon, F, Mariotti, L, Sylla, MB, Bi, X, Elguindi, N, Diro, GT, Nair, V, Giuliani, G, Turuncoglu, UU, Cozzini, S, Güttler, I, O'Brien, Ta, Tawfik, AB, Shalaby, A, Zakey, AS, Steiner, AL, Stordal, F, Sloan, LC & Brankovic, C. (2012), RegCM4: Model description and preliminary tests over multiple CORDEX domains. Climate Research, vol 52, no. 1, pp. 7-29. doi:10.3354/cr01018"10.3354/cr01018.

Giorgi, F., et al. (2012), RegCM4: Model description and preliminary tests over multiple CORDEX domains, Clim. Res., doi:10.3354/cr01018.

Grell G, Dudhia J, Stauffer DR (1994), A description of the fifth generation Penn State/NCAR Mesoscale Model (MM5). NCAR Tech Note NCAR/TN-398 + STR, NCAR, Boulder, CO.

Güttler, I., Branković, Č., O'Brien, T.A. et al. (2014), Sensitivity of the regional climate model RegCM4.2 to planetary boundary layer parameterisation. Clim Dyn 43, 1753–1772 https://doi.org/10.1007/s00382-013-2003-6.

Hawcroft M, Walsh E, Hodges K and Zappa G (2018), Significantly increased extreme precipitation expected in Europe and North America from extratropical cyclones Environ. Res. Lett. 13 124006, doi.org/10.1088/1748-9326/aaed59.

Hersbach, H., Bell, B., Berrisford, P., Biavati, G., Horányi, A., Muñoz Sabater, J., Nicolas, J., Peubey, C., Radu, R., Rozum, I., Schepers, D., Simmons, a., Soci, C., Dee, D., Thépaut, J-N. (2018), ERA5 hourly data on single levels from 1979 to present. Copernicus Climate Change Service (C3S) Climate Data Store (CDS), 10.24381/cds.adbb2d47.

Houze, R. A., Jr. (2012), Orographic effects on precipitating clouds, Rev. Geophys., 50, RG1001, doi:10.1029/2011RG000365.

IPCC (2012), Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)], Cambridge University Press, Cambridge, UK, and New York, NY, USA, 582 pp.

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.

Jacob, D., Petersen, J., Eggert, B. et al. (2014), EURO-CORDEX: new high-resolution climate change projections for European impact research. Reg Environ Change 14, 563–578. https://doi.org/10.1007/s10113-013-0499-2.

Kirshbaum, Daniel; Adler, Bianca; Kalthoff, Norbert; Barthlott, Christian; Serafin, Stefano (2018), Moist Orographic Convection: Physical Mechanisms and Links to Surface-Exchange Processes. Atmosphere, 9(3), 80 doi:10.3390/atmos9030080

Kotlarski S, Keuler K, Christensen OB, Colette A, Déqué M, Gobiet A, Goergen K, Jacob D, Lüthi D, van Meijgaard E, Nikulin G, Schär C, Teichmann C, Vautard R, Warrach-Sagi K, Wulfmeyer V (2014), Regional climate modeling on European scales: A joint standard evaluation of the EURO-CORDEX RCM ensemble. Geosci Model Dev 7:1297–1333.

Malcheva K. (2017) Climatology of intense rainfall in Bulgaria in the recent decades. Bul. J. Meteo & Hydro 22/1-2: 27-40

Malcheva K., Marinova T., Bocheva L. (2020), Statistical Assessment of Annual Maximum Daily Precipitation over Bulgaria in the Period 1892-2018. Proceeding of 1st International Conference on Environmental Protection and Disaster RISKs, vol. 2, pp. 452-466.

Moss, R.H., Edmonds, J.A., Hibbard, K.A., Manning, M.R., Rose, S.K., van Vuuren, D.P., Carter, T.E., Emori, S., Kainuma, M., Kram, T., Meehl, G.A., Mitchell, J.F.B., Nakicenovic, N., Riahi, K., Smith, S.J., Stouffer, R.J., Thomson, A.M., Weyant, J.P., and Wilbanks, .J., (2010) The next generation of scenarios for climate change research and assessment. Nature 463, 747–756. https://doi.org/10.1038/nature08823.

MunichRe (2011), Topics GEO, Natural Catastrophes 2011 Analyses Assessments Positions. Munich Reinsurance Company Publications, Munich, pp. 1–49.

Myhre, G., Shindell, D., Bréon, F.-M., Collins, W., Fuglestvedt, J., Huang, J., Koch, D., Lamarque, J.-F., Lee, D., Mendoza, B., Nakajima, T., Robock, A., Stephens, G., Takemura, T., Zhang, H. (2013), Climate change (2013) The physical science basis. In: Stocker, T.F., Qin, D., Plattner, G.K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M. (Eds.), Contribution of Working Group I to the Fifth assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 659–740. http://dx.doi.org/10.1017/CBO9781107415324.018.

Myhre, G., K. Alterskjær, C. W. Stjern, Ø. Hodnebrog, L. Marelle, B. H. Samset, J. Sillmann N. Schaller, E. Fischer, M. Schulz, A. Stohl (2019), Frequency of extreme precipitation increases extensively with event rareness under global warming, Scientific Reports, 9:16063, https://doi.org/10.1038/s41598-019-52277-4.

Nikulin, G., Kjellstrom, E., Hansson, U., Strandberg, G., Ullerstig, A. (2011), Evaluation and future projections of temperature, precipitation and wind extremes over Europe in an ensemble of regional climate simulations. Tellus, 63A, 41–55. http://dx.doi.org/10.1111/j.1600-0870.2010.00466.x.

Outten, S., Esau, I. (2013), Extreme winds over Europe in the ENSEMBLES regional climate models. Atmos. Chem. Phys. 13, 1–10. http://dx.doi.org/10.5194/acp-13- 1-2013.

Outten, S. and Sobolowski, S., (2021), Extreme wind projections over Europe from the Euro-CORDEX regional climate models, Weather and Climate Extremes 33, 100363.

Pal, J. S., E. E. Small, and E. A. B. Eltahir (2000), Simulation of regional-scale water and energy budgets: Representation of subgrid cloud and precipitation processes within RegCM, J. Geophys. Res.-Atmospheres, 105(D24), 29,579–29,594.

Pieczka, I., Pongrácz, R., André, K., Kelemen, F.D., Bartholy, J. (2016), Sensitivity analysis of different parameterization schemes using RegCM4.3 for the Carpathian Region. Theoretical and Applied Climatology, DOI 10.1007/s00704-016-1941-4.

Pudyastuti and Nugraha (2018), Climate change risks to infrastructures: A general perspective, AIP Conference Proceedings 1977, 040030; https://doi.org/10.1063/1.5043000.

Riahi K, S Rao, V Krey, C Cho, V Chirkov, G Fischer, G Kindermann, N Nakicenovic, P Rafaj (2011), RCP8.5 scenario of comparatively high greenhouse gas emissions. Climatic Change. 109:33-57.DOI 10.1007/s10584-011-0149-y.

Rockel, B., Woth, K. (2007), Extremes of near-surface wind speed over Europe and their future changes as estimated from an ensemble of RCM simulations. Clim. Change 81, 267–280.

Spinoni J., Formetta G. , Mentaschi L., Forzieri G., and Feyen L. (2020), Global warming and windstorm impacts in the EU, EUR 29960 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-12955-4, doi:10.2760/039014. JRC118595.

Schwierz, C., Kollner-Heck, P., Mutter, E., Bresch, D., Vidale, P., Wild, M., Schär, C. (2010), Modelling European winter wind storm losses in current and future climate. Clim. Change 101, 485–514.

Thomson, A.M., Calvin, K.V., Smith, S.J. et al. RCP4.5: a pathway for stabilization of radiative forcing by 2100. Climatic Change 109, 77 (2011), https://doi.org/10.1007/s10584-011-0151-4

Torma C, Coppola E, Giorgi F, Bartoly J, Pongracz R (2011), Validation of a high resolution version of the regional climate model RegCM3 over the Carpathian basin. J Hydrometeorol 12:84–100.

Trenberth, K. (2011), Changes in precipitation with climate change. Climate Research, 47(1), 123–138. doi:10.3354/cr00953.

Valcheva R. (2021), Climate Change Projections for Bulgaria According to RCP45 Scenario Until 2099. In: Mensink C., Matthias V. (eds) Air Pollution Modeling and its Application XXVII. ITM 2019. Springer Proceedings in Complexity. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-662-63760-9_19.

Valcheva R. and E. Peneva (2014), Sensitivity to the parametrization of cumulus convection in the RegCM4.3 simulations focused on Balkan Peninsula and Bulgaria, Annual of Sofia University Sofia "St. Kliment Ohridski", Faculty of Physics, Vol. 107, 113-131.

van Vuuren, D.P., Edmonds, J., Kainuma, M. et al. The representative concentration pathways: an overview. Climatic Change 109, 5 (2011), https://doi.org/10.1007/s10584-011-0148-z

Westra, S., Lisa V. Alexander, Francis W. Zwiers (2013), Global Increasing Trends in Annual Maximum Daily Precipitation, JOURNAL OF CLIMATE 3904-3918, Vol. 26, doi: 10.1175/JCLI-D-12-00502.1.

WMO – World Meteorological Organization (2016) Guidelines on the definition and monitoring of extreme weather and climate events. http://www.wmo.int/pages/prog/wcp/ccl/opace/opace2/documents/DraftversionoftheGuidelinesontheDefinitionandMonitoringofExtremeWeatherandClimateEvents.pdf

Xiaoming, S. and Dale Durran (2016) Sensitivities of Extreme Precipitation to Global Warming are Lower over Mountains than over Oceans and Plains, Journal of Climate, AMS, Vol. 29, 4779- 4791, doi: 10.1175/JCLI-D-15-0576.1.

https://www.ipcc.ch/report/ar6/wg1/

http://www.meteoalarm.org/

https://www.ipcc.ch/report/ar5/wg1/

https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-single-levelstab=form.https://www.ipcc.ch/report/ar6/wg1/