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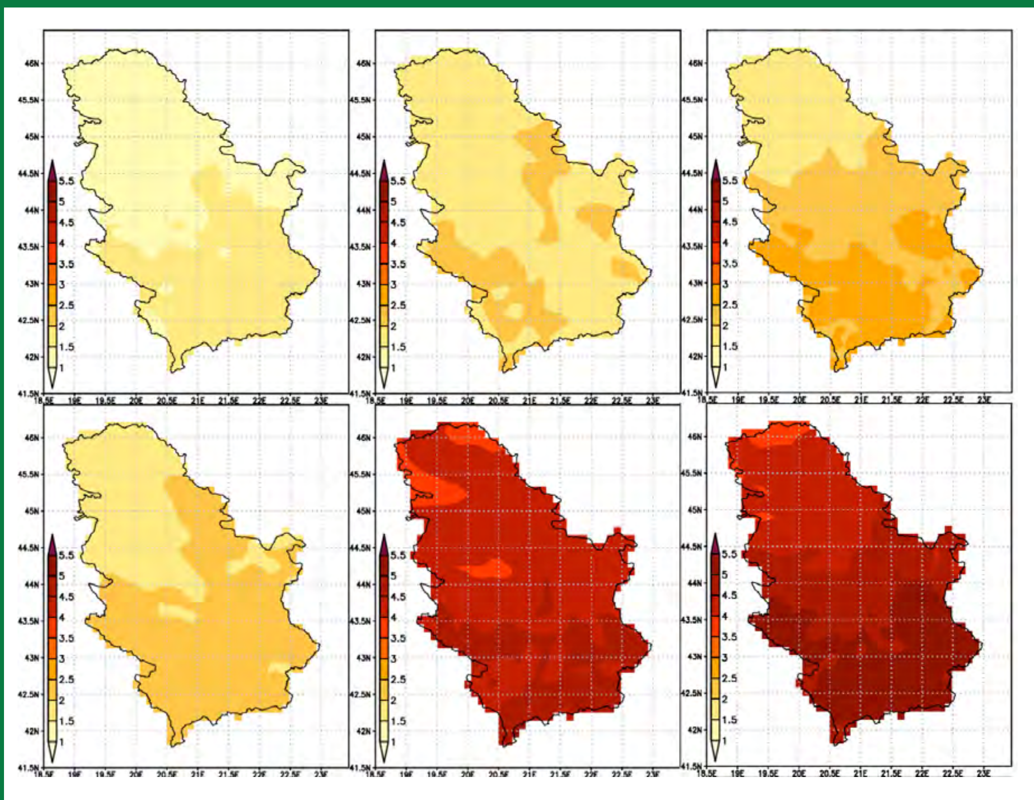

CLIMATE CHANGES OBSERVED IN SERBIA AND FUTURE CLIMATE PROJECTIONS BASED ON DIFFERENT SCENARIOS OF FUTURE EMISSIONS

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CONTENTS

1. INTRODUCTION

Climate changes, which can be clearly detected today in long-term climatic and meteorological data sets, are characterized primarily by an increase in temperatures, but also by changes in the precipitation pattern, their annual distribution and their intensity distribution, as well as by an increased frequency of extreme weather events and periods with extreme climatic conditions. Such changes clearly affect the environment, economy, health and safety of people.

An analysis of the observed climate changes in the territory of the Republic of Serbia shows that the temperature rise trend is increasing over time. In January 2019, the Republic Hydrometeorological Service announced that 2018 was the hottest year since records began in the Republic of Serbia (see appendix). In recent decades, changes in climatic conditions have also been conducive to more frequent droughts, while more precipitation can be related to intensive precipitation events.

The analysis of future climate changes shows the range of possible future climate conditions depending on the future greenhouse gas emissions and the response of the climate system to these changes. On the territory of the Republic of Serbia, temperatures are expected to continue rising until the end of this century to values that are on average 3 to 5°C higher than the temperatures from mid-last century. Such changes cause an even further destabilisation of the climate system and a progressive change in climatic conditions conducive to the onset of extreme heat waves, severe drought episodes and an increase in precipitation accumulations during extreme events.

In the future, we can very likely expect further temperature and precipitation record breaks, both in regions around the world and in Serbia.

2. CLIMATE CHANGES OBSERVED

2.1 Temperature changes observed

For the analysis of observed changes in essential climate variables, temperature and precipitation, in Serbia, three sets of data were used:

1. mean monthly temperature and precipitation values at the meteorological station of the Belgrade Observatory, which has been conducting a series of observations since 1888, when the observatory was established,
2. E-OBS gridded climatology with a 10 km horizontal resolution and daily time resolution, covering the entire territory of Serbia from 1950 to 2017. E-OBS is available through the European Union's Copernicus programme, and
3. DanubeClim gridded climatology with a horizontal resolution of 10 km and daily time resolution which also covers the entire territory of Serbia but for period from 1961 to 2010.

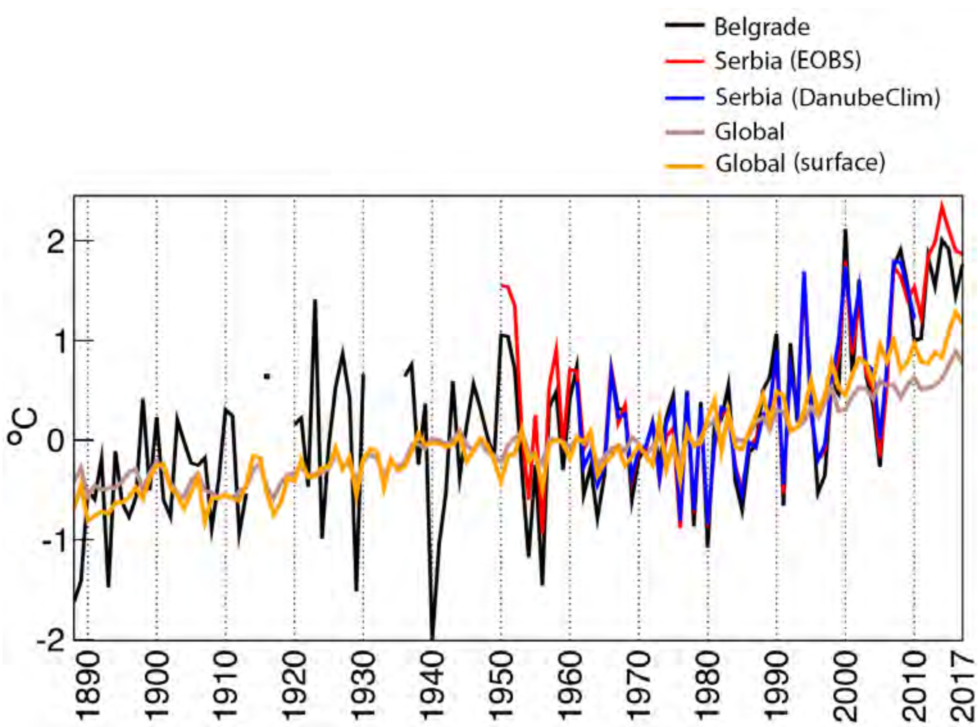

Figure 1. Anomaly of the mean annual temperature (°C) relative to the mean reference period value (1961-1990). The values for Belgrade were obtained from observations at the Belgrade Observatory meteorological station which has the longest observations sequence (since 1888). Average values for the whole of Serbia were obtained from two sets of data: E-OBS (database with interpolated daily temperature and precipitation values at a resolution of 10 km since 1950) and DanubeClim (database of daily interpolated data with a resolution of 10 km for the 1961-2010 period).

In order to quantify the temperature change, the 1961-1990 period was taken as the reference climatological period against which the changes are calculated. The anomaly of the mean annual temperatures relative to the mean reference period values are shown in Figure 1. According to the presented results, it is clear that the average annual temperature upward trend in Serbia is higher than the trend of the average global temperature increase, which has been especially noticeable after 1980. Also, the trend of rising temperatures in Serbia is higher than the trend of mean global air surface temperature over land, which is higher than the global temperature trend[1]. The average trend of temperature change on average in the territory of Serbia in the 1961-2017 period was 0.36°C per decade, while, during the 1981-2017 period, this trend of temperature increase was 0.60°C per decade.

According to E-OBS data, which form the most comprehensive set in terms of both spatial and temporal coverage, in the 1950-2017 period, 9 out of the 10 warmest years were observed after the year 2000[2]. The warmest year on average was 2014 when the anomaly of the mean annual temperature from the reference period was 2.33°C. The second warmest year was 2015 with a anomaly of more than 2°C, while the remaining eight had a temperature anomaly over 1.5°C (Table 1).

	Year	Anomaly
1	2014	2.33
2	2015	2.11
3	2013	1.98
4	2016	1.90
5	2017	1.86
6	2012	1.84
7	2000	1.79
8	2007	1.73
9	2008	1.65
10	1994	1.61

Table 1. List of warmest years on average for the territory of Serbia in the 1950-2017 period with a given anomaly (°C) compared to the average value for the 1961-1990 reference period (9.44°C); the values shown are obtained from E-OBS data.

[1] The difference in the trend between mean global temperature and mean surface temperature over land is mainly the result of a higher heat capacity of the ocean compared to the heat capacity of the land.

[2] By using data from meteorological stations in Serbia only, without their interpolation to the entire territory (http://www.hidmet.gov.rs/podaci/meteorologija/ciril/2018.pdf), or another data set, the exact sequence may be somewhat changed, however, all available data show that by far the largest number of warmest years has been observed after the year 2000. See also the appendix at the end of the publication.

The analysis of the spatial distribution of the observed temperature changes is shown through the anomaly of the mean annual temperatures for the 1998-2017 period (last 20 years, at the time of preparation of this study) and for the 2008-2017 period (last 10 years, at the time of preparation of this study) relative to the reference period. During the 20-year observation period, 1998-2017, the mean annual temperature anomaly was positive throughout the territory, ranging from 0.5 to 1.5°C, while the anomaly was over 1°C in eastern parts of central Serbia as well as in northern Vojvodina. Over the last ten years, the anomaly of the average annual temperature was over 1.5°C in most of the territory of Serbia, while in the western and eastern parts the anomaly was over 2°C. The analysis of changes in mean, maximum and minimum temperatures by seasons for both periods showed that the highest temperature increase over the last 10 years was observed during the summer season, specifically the mean maximum temperature, with an anomaly of over 2.5°C in most of Serbia. The change of the mean minimum temperatures by seasons for both periods is less than the change in maximum temperatures, except during the last decade in the winter period. The selected results of this analysis are shown in Figure 2.

Figure 2. Selected results of the spatial analysis of the observed temperature changes in the territory of Serbia: anomaly of the mean temperature (°C) for the 1998-2017 period (left panel) and the 2008-2017 period (central panel) from the mean temperatures values for the 1961-1990 reference period; anomaly of the mean maximum temperature (°C) for the summer season (June-August) for the 2008-2017 period from the mean maximum temperature value for summer for the 1961-1990 reference period (right panel); the values shown have been obtained from E-OBS data.

2.2 Precipitation changes observed

Accumulated precipitation does not have a clear and unambiguous trend in the spatial and seasonal analysis as is the case with temperature changes. For Belgrade, this trend is +0.8% per decade (6 mm per decade), while the average trend throughout Serbia is +1.1% per decade (7 mm per decade), but neither trend is statistically significant. The year with the highest amount of precipitation in the territory of Serbia during the analysed period was 2014 with an anomaly of about +40%, and the year with the least amount of precipitation was 2000 with an anomaly of approximately -40% compared to the 1961-1990 reference period.

The analysis of the spatial change of accumulated annual and seasonal precipitation for both selected periods (1998-2017 and 2008-2017) shows an increase in most of Serbia (0-10%) relative to the reference period, especially during the last 10 years in the south of the country (over 10%). The change in the precipitation redistribution during the year stands out among the analyses of precipitation seasonal cycle, revealing particularly pronounced reduction of accumulated precipitation during the summer season (June-August). Over the last 10 years, the summers had predominantly below average amount of precipitation. The maximum precipitation deficit is in the central and southern parts, with a -20% to -30% negative change. The selected precipitation analysis results are shown in Figure 3.

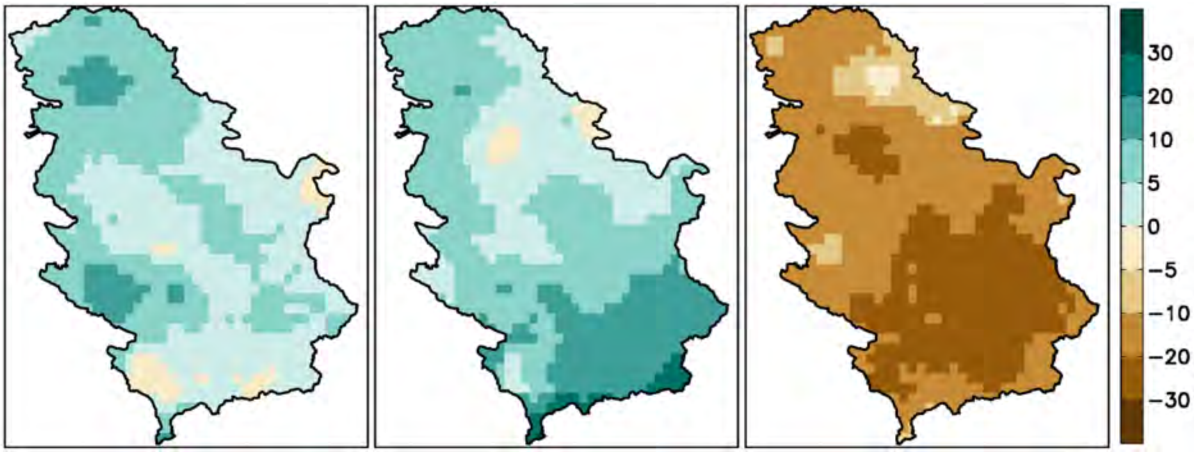

Figure 3. The selected results of the spatial analysis of the observed precipitation changes in the territory of Serbia: the anomaly of the mean annual precipitation sum (%) for the 1998-2017 period (left panel) and 2008-2017 (central panel) from the mean annual precipitation values for the 1961-1990 reference period; the anomaly of the mean precipitation sum (%) for the summer season (June-August) for the 2008-2017 period from the mean summer precipitation sum for the 1961-1990 reference period (right panel); the values shown have been obtained from the E-OBS data.

2.3 Changes in climate indices observed

2.3.1 Heat indices

The analysis of heat indices shows the extent to which the stated increases in temperature affect the decrease in the intensity and duration of cold periods, and how much an observed increase in temperature has led to an increase in warm periods with potentially adverse effects.

During the analysed 1998-2017 period, the largest part of the territory of Serbia had a decrease in the number of frost days (a day with minimum temperature below 0°C) by 5 to 10 days. During the last ten years in most of the country this decrease exceeded 10 days. The most pronounced decrease was observed in the east and southwest of the country, where the change is greater than 30 days. Ice days (days when the maximum temperature below

0°C is observed) are less frequent than frost days, so anomalies from the reference period are smaller. It is clear, however, that the number of these days is also decreasing with more distinct anomaly values at higher altitudes, where a decrease of more than 10 days was obtained for the last ten years, with over 15 days in some parts of the country.

The change in the number of summer days (days when the maximum observed temperature was above 25 °C) shows that, on average, over the last 20 years, there is an increase by over half a month of these days. However, over the past 10 years, in most of Serbia, there were, on average, more than 25 hot days over the year compared to the values of the reference period. Tropical days (days when maximum observed temperature is above 30°C) are less frequent than hot days and their observed increase over the last decade in the lowlands of Serbia is over 20 days on average per year.

Particularly important in the analysis of high temperature risks is the duration of very warm periods and the number of occurrences of hot period events of sufficient duration to affect the increased vulnerability of nature's ecosystems, the economy and human health. The climate indices that indicate such increased vulnerability to high temperatures are the duration and number of occurrences of **heat waves** and **extreme heat waves**.

A heat wave is a period of not less than 6 days during which the maximum daily temperature was higher than the expected maximum temperature for the time of year in which the heat wave was observed. Expected maximum daily temperatures are defined as the mean maximum daily temperatures for each day of the year, based on the values of maximum temperatures in a five-day window, around the respective day, and based on values during the 1961-1990 period. An extreme heat wave is a period of not less than 6 days during which the maximum daily temperature was higher than 90% of the maximum temperatures for the time of year during which the extreme heat wave was observed.

On average, over the past 10 years, there were over 20 days more per year during which heat waves were observed. An increase of more than 30 days was observed in western Serbia and the lowlands of central Serbia, south of the lower Danube, where the number of occurrences of heat waves per year increased by 3. In the 2008-2017 period, the average number of extreme heat waves increased by 2-3 occurrences annually compared to the reference period, with an even higher proportion of occurrences in western and southwestern Serbia (increase by over 4). The selected values of the heat indices are shown in Figure 4.

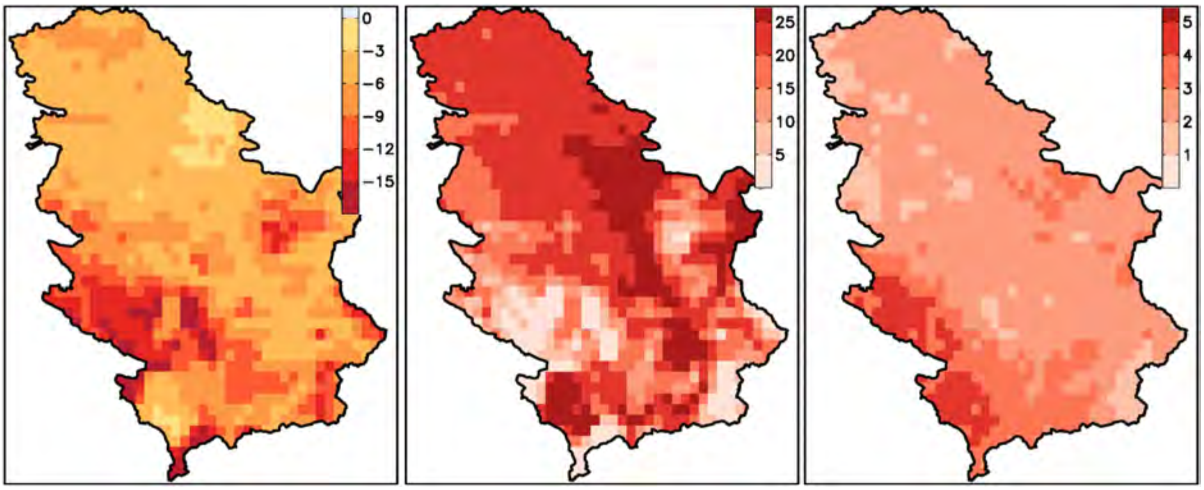

Figure 4. Selected results of the analysis of heat climate indices: changes in the average annual occurrence of ice days (left panel), tropical days (central panel) and the number of extreme heat waves (right panel) during the 2008 -2017 period compared to the 1961-1990 reference period; the advantages shown have been obtained from the E-OBS data.

In addition to the indicated heat indices, the length of the vegetation period is also important for the normal growth and development of plant species, both in natural and agricultural systems. The standard in calculating this index is that the vegetation period is considered to start when the average daily temperatures during the year become higher than 5°C (the first 5 consecutive days that meet this criterion) and continue until temperatures drop below this value (also the first 5 consecutive days that meet this criterion but in the second half of the year). On average, over the last 20 years (1998-2017), the vegetation period was extended by more than 5 days, and in some areas, at generally lower altitudes, as much as 10 days compared to the reference period. This change during the last 10 years of the analysed period includes values of as much as 25 days in a large part of the territory, with a maximum in central Serbia where an average longer vegetation period of over 40 days was observed.

2.3.2 Precipitation indices

The analysis of precipitation indices shows that, in addition to small (statistically non-significant) trends of change in accumulated annual precipitation, there is a change in precipitation pattern and a different redistribution by intensity.

The results obtained from the analysed periods show that there has been an increase in the intensity of heavy precipitation compared to the reference period, with more pronounced changes over the last decade. During the year, precipitation in the territory of Serbia occurs in about 35-40% of days, during which an average accumulation is 5-6 mm. Days with very heavy precipitation are considered to be days during which accumulation is higher than

20 mm, while days with extremely heavy precipitation are those during which accumulation is higher than 40 mm. The number of days with very heavy precipitation has increased on average by 1-2 times. However, the frequency of more extreme weather events, with more than 40 mm of precipitation in some parts of Serbia, has increased by more than 5 times with respect to the reference period. Maximum daily values during the year of observed accumulated precipitation has increased almost in the entire territory of Serbia, and in most parts of the country by over 5% (in some parts by over as much as 10%). The values of the selected precipitation indices are shown in Figure 5.

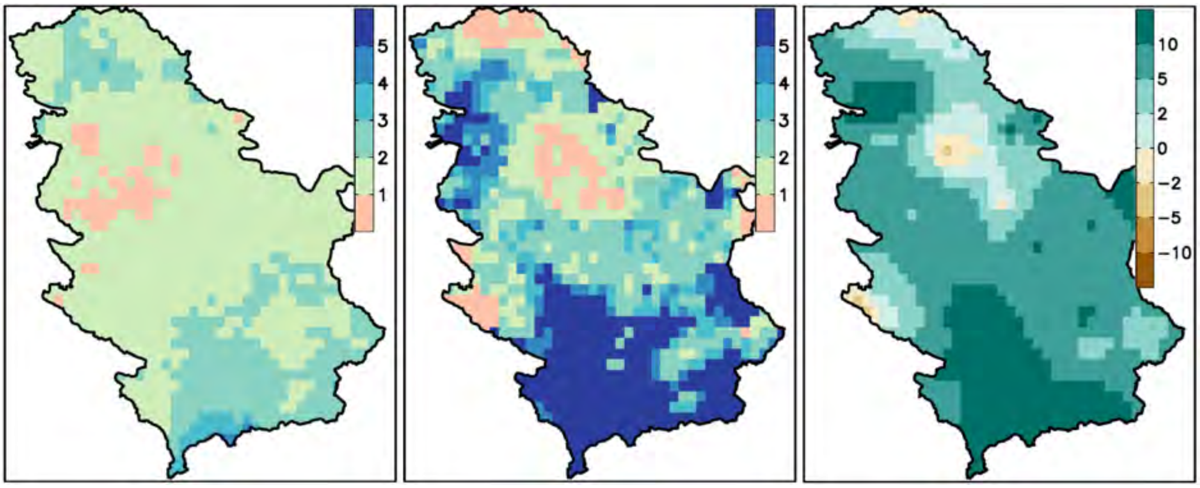

Figure 5. Selected results of the analysis of precipitation climate indices: changes in the mean annual number of days with precipitation higher than 20mm (left panel) and higher than 40 mm (central panel) obtained for the 2008-2017 period in relation to the average value of the 1961-1990 reference period (the presented results show how many times the occurrence of these events has changed); changes in maximum daily precipitation (%) in the 2008-2017 period relative to the values observed during the reference period 1961-1990 (right panel); the benefits presented have been obtained from the E-OBS data.

2.3.3 Drought analysis

3For the analysis of the consequences of the observed changes in climate variables, an index indicating the frequency and intensity of droughts was selected, an event which, according to the previously published analyses (e.g. **Intended Nationally Determined Contribution of the Republic of Serbia**), is causing the highest material damage in Serbia. The occurrence of the dry season is affected by the deficit in precipitation but also by increased temperatures, which affect the increase of evapotranspiration. The SPEI (**Standardized Precipitation-Evapotranspiration Index)** includes both effects and values lower than -1 indicate dry periods, while values higher than 1 indicate wet periods. SPEI6 is a value of this index that relates to the selected six-month period. As the analysis of changes in accumulated seasonal precipitation showed a decrease in precipitation during the warmer part of the year accompanied by significant positive changes in temperature, **SPEI6** was calculated for the month of August (SPEI6 for the March-August period). The obtained results explain the increased vulnerability of the agricultural sector, as it is during this period that phenological stages such as growth, development and maturation of crops cultivated on the territory of Serbia occur.

The results of the SPEI6 index for August for the territory of Serbia for each year during the 1950-2017 period are shown in Figure 6. After 2000, the frequency of droughts increased. The years in which the index was lower than -1 were 2000, 2003, 2007, 2011, 2012 and 2015 and 2017. Prior to 2000, only three years had an index of less than -1.

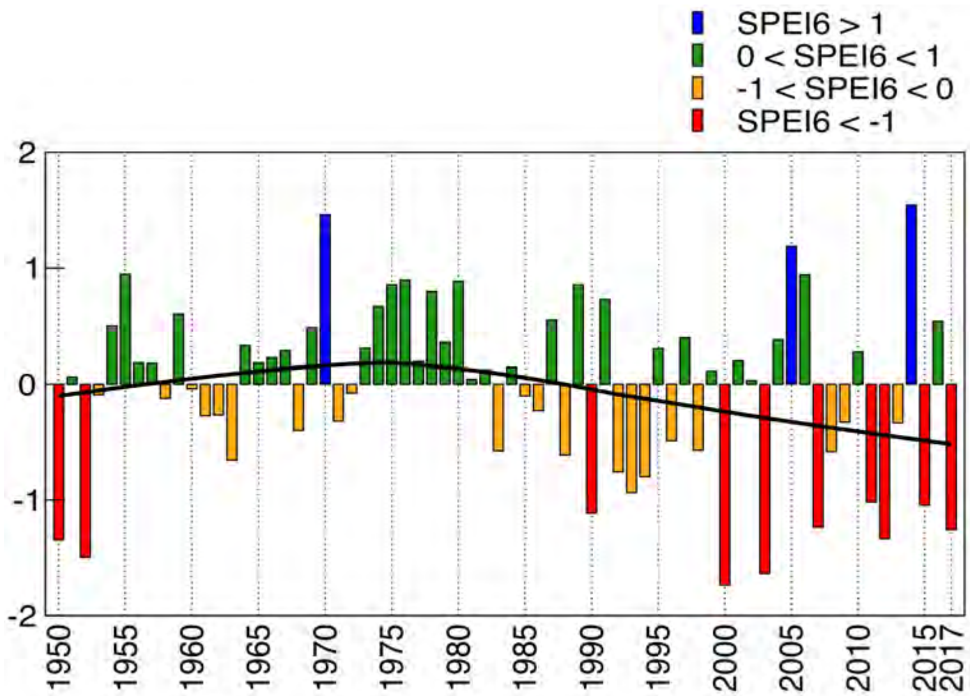

Figure 6. SPEI6 Augurst values for the territory of Serbia and the trend indicator (black line) obtained as the curve that best fits the results using the LOWESS (Locally Weighted Scatterplot Smoothing) method; the presented values have been obtained from E-OBS data.

The analysis of the **SPEI6 index for August,** using the longest series of observed data on the territory of Serbia (the Belgrade Observatory), shows that the trend of increased drought frequency started in the late 1980s and that since the end of the 19th century the drought frequency especially increased during the last decades (Figure 7).

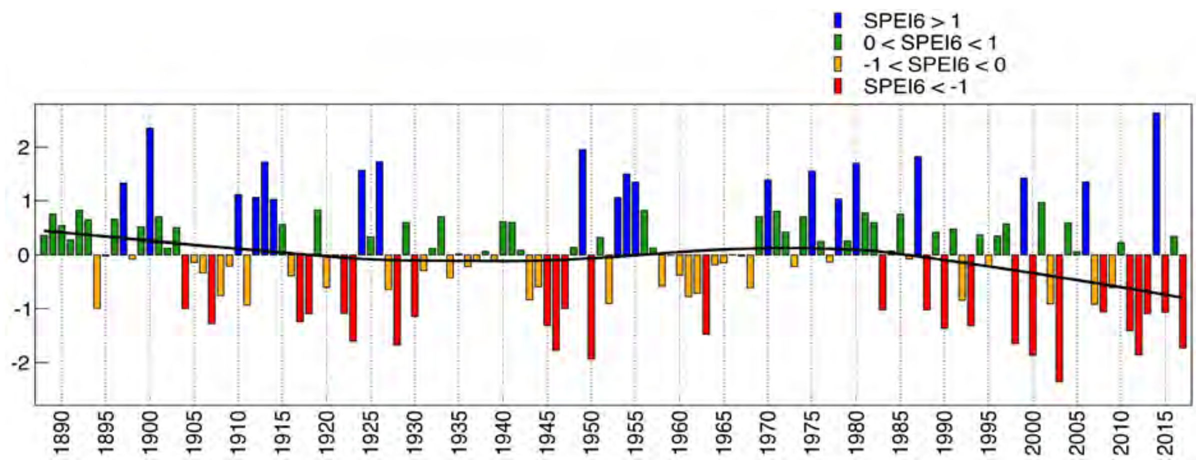

Figure 6a. SPEI6-August values for the Belgrade Observatory station and the change trend indicator (black line) obtained as the curve that best fits the results using the LOWESS (Locally Weighted Scatterplot Smoothing) method.

3. FUTURE CLIMATE CHANGES

The analyses of future climate change are aligned with the latest, Fifth Assessment Report of the Intergovernmental Panel on Climate Change. The results presented here represent the most likely value from the set (ensemble) of solutions obtained using daily values of temperatures and precipitation from nine regional climate models that can be downloaded from the EURO-CORDEX database. The reference period with respect to which the change in future climatic conditions is analysed is 1986-2005 and the analysed future periods are: 2016-2035 (**near future**), 2046-2065 (**mid-century**) and 2081-2100 (**end of century**). The analyses were performed according to two selected greenhouse gas emission scenarios: RCP4.5 (stabilization scenario, which anticipates the stabilisation of emissions from 2040) and RCP8.5 (constant growth scenario), which are assumed to cover the likely range of possible future outcomes.

3.1 Future temperature changes

Over the future periods, an increase in temperature is expected in both scenarios compared to the 1986-2005 reference period. A more intense increase in temperature is anticipated according to RCP8.5, which is expected due to the more intense emissions of greenhouse gases and their impact on the energy balance in the climate system. In this scenario, the mean annual temperature, on average for the territory of Serbia, will increase by 1°C in the near future compared to the reference period, in the period attributed to the mid-21st century, it will rise to 2°C, and, by the end of the century, the average annual temperature will be higher by as much as 4.3°C compared to the reference period. The stabilisation scenario, RCP4.5, shows a slightly less increase in mean annual temperature by about 0.5°C compared to RCP8.5 during the first two analysed periods. However, in this scenario, the greenhouse gas emissions will be stabilised, which in turn affects the temperature stabilisation. In this scenario, by the end of the 21st century, the increase in the average annual temperature in the territory of Serbia will reach a much lower value than the value obtained under the RCP8.5 scenario, which is 2°C higher than the value of the reference period.

[3] The mean temperature for the territory of Serbia in the 1986-2005 reference period is higher by about 0.7°C than the mean temperature for the 1961-1990 period, which was used as the reference period in the analysis of climate change observations and in previous national reports to the UNFCCC.

Seasonal analyses and changes in mean maximum and minimum temperatures have shown that in the future climate the temperature increase during the colder part of the year may be slightly less than the temperature increase during the warmer part of the year, but during the second half of the century according to the RCP8.5 the warming of the colder part of the year becomes more intense and catches up with the warming up of the warmer part.

The increase in maximum temperatures are slightly higher than the increase in minimum temperatures. The largest increase will be in the RCP8.5 scenario of the mean maximum temperature during the June-August period for the period at the end of the 21st century, with an average value of as much as 4.7°C higher than the 1986-2005 reference period.

A spatial analysis of changes in temperatures over future periods indicates an increase in warming from north to south. The selected results obtained from the analysis of future temperature changes are shown in Figure 7.

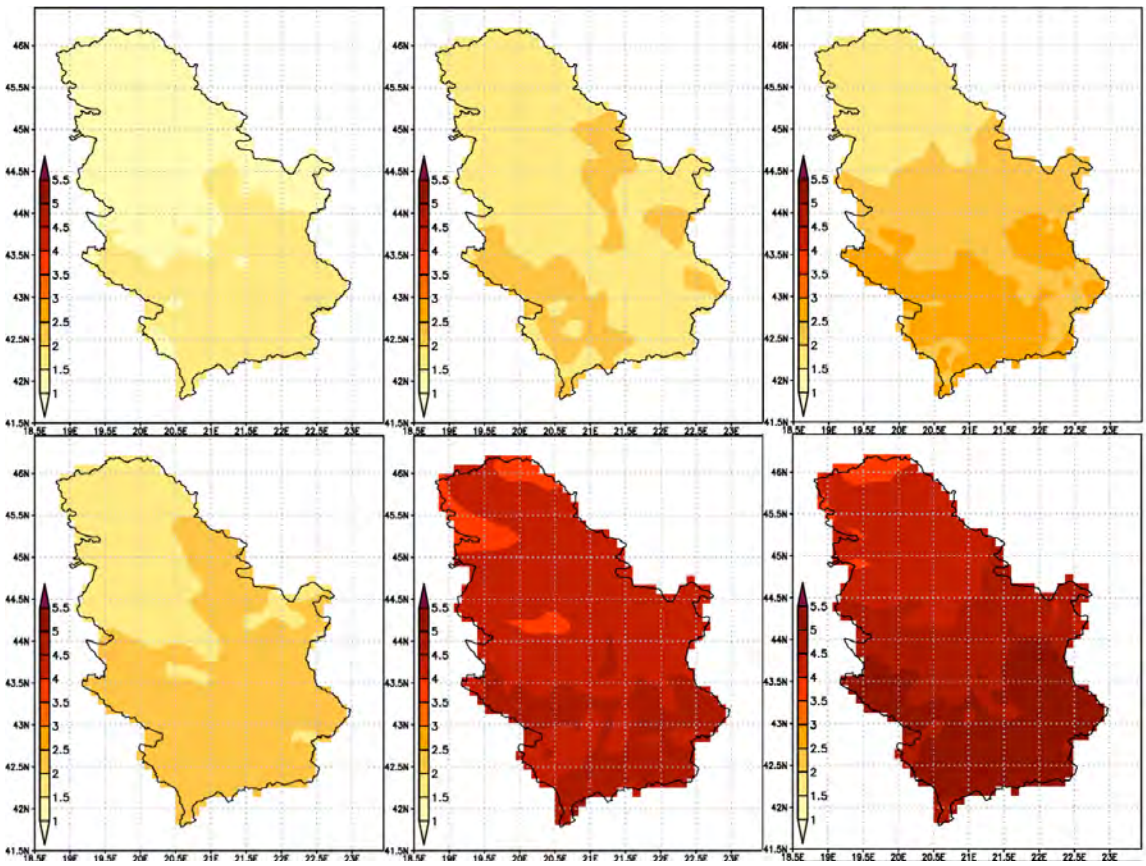

Figure 7. Anomaly of the mean annual temperature (°C) for the 2046-2065 period (left panel) and for the 2081-2100 period (central panel) relative to the values for the 1986-2005 reference period; anomaly of the mean maximum temperature (°C) obtained for the June-August 2081-2100 period compared to the mean maximum temperature values of this period for 1986-2005 (right panel); the results obtained according to the RCP4.5 scenario are shown in the top panels and the results obtained according to the RCP8.5 are shown in the bottom panels.

3.2 Future precipitation changes

The future changes in mean annual accumulated precipitation, averaged for the territory of Serbia, will not have a pronounced trend in the future periods, as is the case with temperature. However, in the second half of the 21st century, according to the RCP8.5 scenario, the average annual precipitation will start to decrease and in the period at the end of the 21st century, central and especially southern Serbia will experience the largest precipitation decrease, even exceeding 10% with respect to the 1986-2005 reference period. The spatial distribution of change in precipitation shows positive trends in the northern parts of the country, with declining towards the south, changing its sign in the central and southern regions.

Precipitation decrease during the June-August period has already been observed and it will continue during future periods according to both scenarios. In the period at the end of the 21st century, according to RCP8.5, the average precipitation decrease in the territory of Serbia will be 20.5%, with a much larger decrease in the southern regions, of as much as 40%. The selected results obtained from the analysis of future precipitation changes are shown in Figure 8.

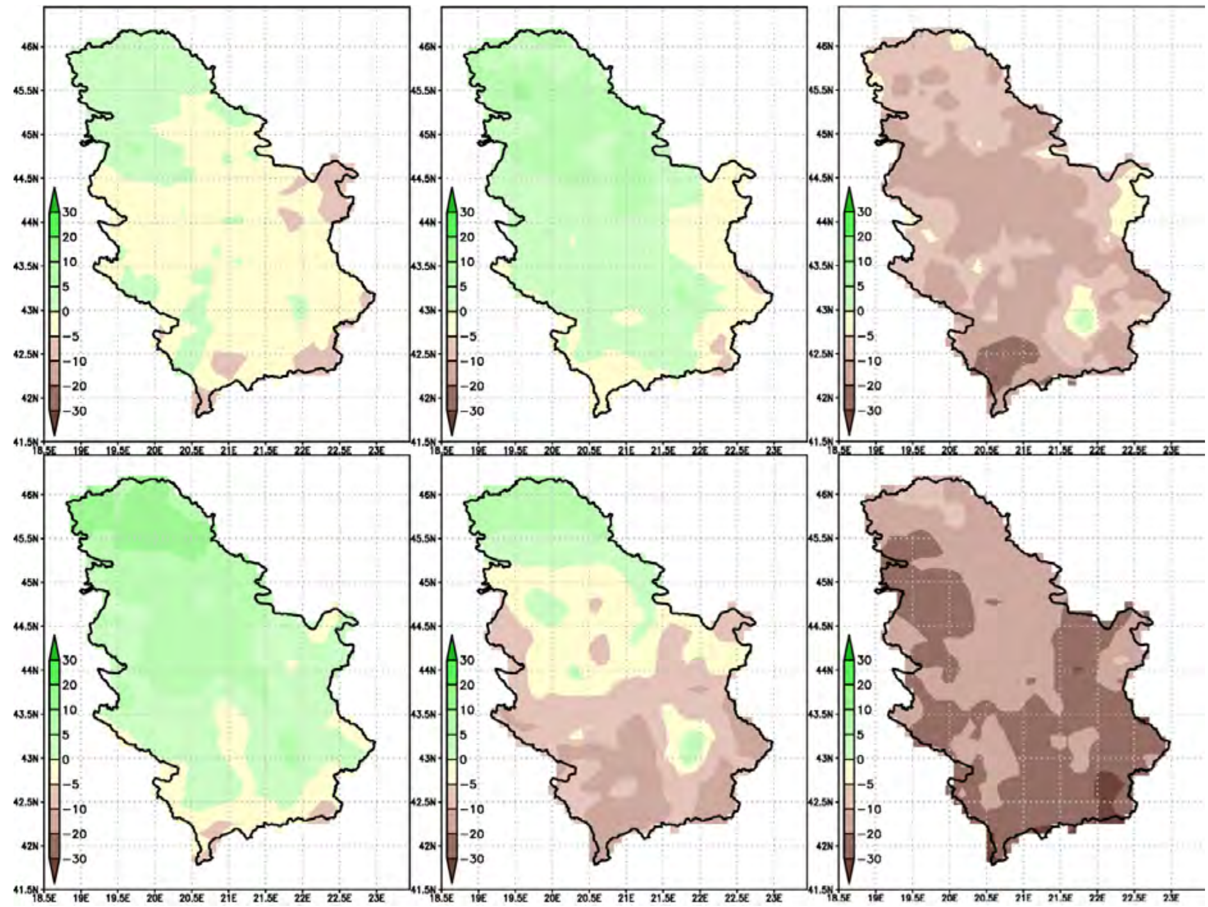

Figure 8. The anomaly of the mean annual precipitation sum (%) for the 2046-2065 period (left panel) and for the 2081-2100 period (central panel) relative to the values for the 1986-2005 reference period; anomaly of mean precipitation sum (%) for the June-August season for the 2081-2100 period compared to the mean seasonal value for the 1986-2005 period (right panel); the results obtained according to the RCP4.5 scenario are shown in the top panels, while the results obtained according to the RCP8.5 are shown in the bottom panels.

3.3 Future changes in climate indices

3.3.1 Heat indices

The number of frost and ice days will progressively decrease in the future due to the temperature increase. Their trend of change is more pronounced at higher altitudes. In the near future, there will be almost 10 days less frosty days on average annually in the territory of Serbia compared to the values of the 1986-2005 reference period. During the mid-21st century climatic period, according to the RCP8.5, there will be almost one month less frosty days and according to the RCP4.5 there will be about half a month less of them. Although the climate will begin to stabilise according to RCP4.5, by the end of the 21st century there will be on average one month less frosty days, while according to RCP8.5 the average decrease in the territory of Serbia is expected to be almost two months, in which case frost days will become a rare event in Serbia. Ice days in the case of the RCP8.5 scenario will only be possible in the highest mountain areas.

The number of hot and tropical days will continue to increase in the future climate conditions. In the climate of the near future, relative to the reference period, changes indicate an extension of summer season conditions by almost half a month, and in the second half of the 21st century, an extension of almost a month may occur, after which the change will stabilise according to the RCP4.5 scenario, while according to RCP8.5, by the end of the century, summer conditions will be on average nearly two months longer than during 1986-2005 period. By the end of the 21st century, the expected increase in the average annual number of tropical days will be in the range between 20, according to RCP4.5, up to almost 50 days in the RCP8.5 scenario. The analysis of the spatial distribution of the results has shown that tropical days will become a relatively regular event in mountainous areas as well.

Heat waves will become more intense and more frequent during future climate periods. Extreme heat waves in the future climate will occur on average at least 2-3 times a year, while during the 1986-2005 reference period these were very rare events. According to the RCP8.5 scenario, by the end of the 21st century, their average occurrence in the territory of Serbia will be as high as 7 occurrences during the year, and in some areas even more than 10. The analysis has shown that in this case, for over two months annually the thermal conditions on the territory of Serbia will be like during the rare occurrences of extreme heat waves in the current climate, but with record high temperatures that have not yet been observed in these regions.

Selected results from the analysis of future values of heat indices are shown in Figure 9.

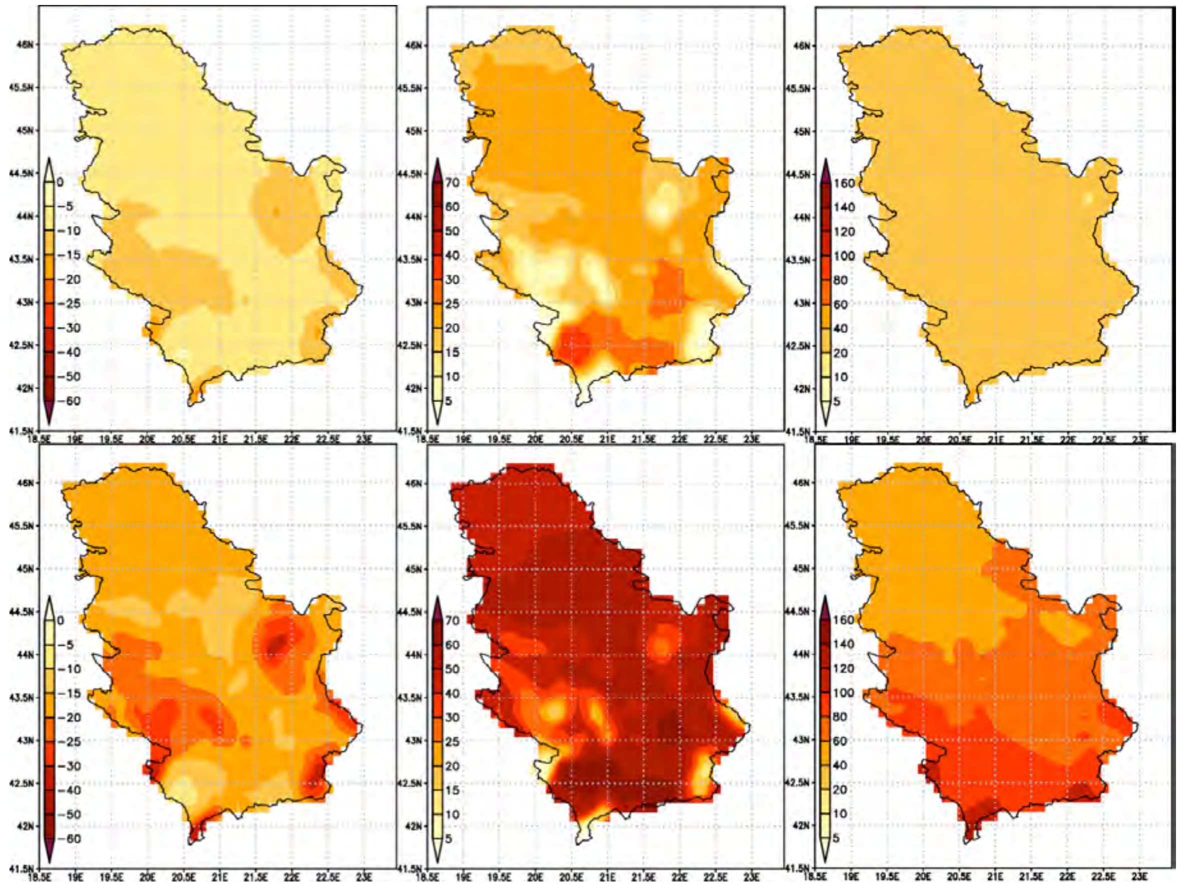

Figure 9. Selected results of analysis of change in heat indices in future climates: change in the average annual occurrence of ice days (left panel), tropical days (central panel) and extreme heat waves (right panel) for the 2081-2100 period relative to the average occurrence during the 1986-2005 reference period; the results obtained according to the RCP4.5 scenario are shown in the top panels and the results obtained by the RCP8.5 are shown in the bottom panels.

The length of the vegetation period will increase by an average of 10 days during the near future compared to the average duration during the 1986-2005 reference period. During the mid-21st century climate period, the duration of this period will be half a month to a month longer, depending on the realisation of future emission scenarios. By the end of the 21st century, the length of the vegetation period will, on average, be at least one month longer in Serbia, but in the case of the RCP8.5 scenario, as much as up to two months.

For crops entering the vegetation period at lower temperatures, minimum thermal conditions for vegetative development will be met throughout the year. Of course, due to the considerable warming, the mountainous areas in this case will have favourable thermal conditions for the cultivation of agricultural crops currently present in the lowlands of Serbia.

3.3.2 Precipitation indices

The changes in precipitation indices indicate a further intensification of the already observed changes in the precipitation distribution intensity towards more frequent heavy precipitation events and higher precipitation accumulations during intense precipitation events. An interesting result was obtained in the analysis of the change in the percentage share of precipitation falling during heavy precipitation days: the change in the amount of precipitation during extreme precipitation events in future climatological periods will progressively increase as a result of more frequent extreme precipitation events but also more intense precipitation.

By the end of the 21st century, according to RCP4.5, as much as 40% more precipitation, accumulated during year, will occur during the days when precipitation is extremely high compared to the precipitation events of the 1986-2005 reference period. According to RCP8.5, these accumulations will increase by 60%.

4. ADDENDUM: 2018, THE HOTTEST YEAR IN SERBIA

In January 2019, the Republic Hydrolometeorological Service of Serbia officially declared 2018 the hottest year in Serbia[4], since records began. Figure 10 shows the mean annual temperature anomaly for Belgrade since 1888.

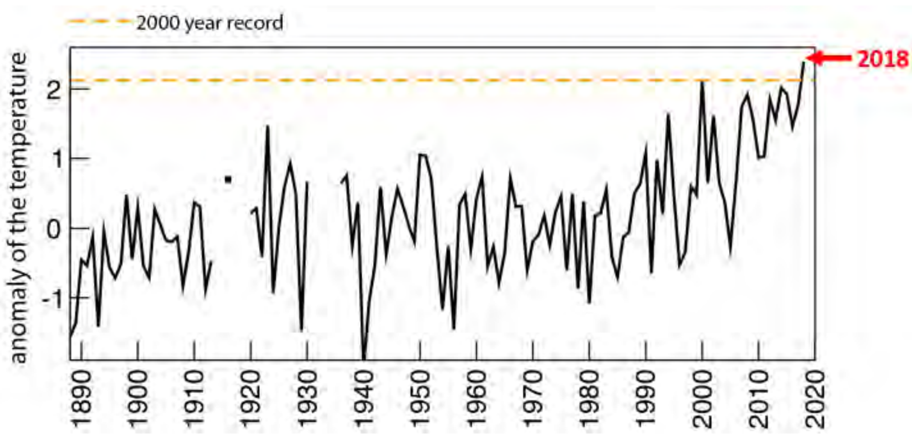

Figure 10. The anomaly of the mean annual temperature (°C) at the Belgrade Observatory meteorological station, since 1888, compared to the mean value from 1961-1990. The data were taken from the Global Historical Climatology Network database, which collects meteorological and climatological observations from around the world, as part of an international data exchange programme. The urban heat island effect has been removed from the time series.

4 http://www.hidmet.gov.rs/podaci/meteorologija/ciril/2018.pdf

СРБИЈА И КЛИМАТСКЕ ПРОМЕНЕ: *Време за акцију*

SERBIA AND CLIMATE CHANGE: *Time for Action*