Analysis of Climate Change in Croatia Based on Calculation of Temperature Thresholds

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Summary

The equivalent of the phenological data for the beginning of active vegetation and the provision of plant growth stage development with heat is the date when the average daily air temperature exceeds a certain threshold or biological minimum, and is determined from the average annual temperature pattern. The aim of the paper was to calculate occurences of temperature thresholds of 5, 10, 15, 20 and 25 °C for the reference period 1961-1990 and the recent period from 1991 to 2018, at three locations - Osijek, Gospić and Zadar, covering three agricultural regions of Croatia - Pannonian, Mountain and Adriatic region, respectively, and to indicate potential climate change in selected areas through analysis of time series and calculation of trends in the beginning, end and duration period of a certain temperature. Based on the results of the calculation of temperature thresholds in the observed period from 1991 to 2018, warming occurred in all three agricultural regions and the last four years - 2015, 2016, 2017 and 2018 have been the warmest years so far. Furthermore, temperature thresholds on average appear earlier than in the period from 1961 to 1990 and often have later endings. The most significant extension of the number of days is calculated for the temperature thresholds of 5 °C and 10 °C in the area of the Pannonian and Mountain agricultural regions, and in the Adriatic region for the temperature threshold of 10 °C. Results indicate pronounced winter/spring warming which can induce advanced start of active vegetation and extension of warm season in mountainous areas.

Key words

climate change, temperature thresholds, time series, agricultural regions

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Introduction

According to Branković (2014), climate is defined as a set of average weather conditions, ie mean values of meteorological elements and phenomena that are expressed using means, extremes and variability of climate variables over a longer (often 30-year) period. Variations within longer periods of time represent climate change and indicate significant and long-term changes in the manifestation of climatic elements, and such changes are of great importance for human life (Pandžić and Žibrat, 2014). One of the major climate changes is global warming, ie. an increase in average air temperatures (Branković, 2014). Climate change poses a growing threat in the 21st century as it affects all aspects of the environment and the economy, and threatens the sustainable development of society. Climate change affects the frequency and intensity of extreme weather events (extreme rainfall, floods and torrents, erosions, storms, droughts, heat waves, fires) and gradual climate change (rising air, soil and water temperatures, rising sea levels, sea acidification, desertification). The report of the Intergovernmental Panel on Climate Change (IPCC) (2018) states that the global trend of temperature rise is at +1.1 °C and if the concentration of greenhouse gases continues to increase at the current rate, global warming is likely to reach 1.5 °C between 2030 and 2052. There is growing evidence that Croatia is under the influence of climate change, and given that it largely belongs to the Mediterranean region, this change will grow and vulnerability to climate change is assessed as high. According to some forecasts (Urban et al., 2012; Hawkins et al., 2013; Challinor et al., 2014; FAO, 2019), agriculture is the sector that will suffer most from the effects of climate change, mainly in the form of certain yield loss for arable crops with increased yield variability under the influence of raising air temperatures.

When long-term changes in temperature are observed, the period of the past climate 1960-1990 was mostly colder than the old period 1931-1960, and the climatic period 1971-2000 was generally warmer than 1961-1990 (Zaninović et al., 2008). The increase in temperature in the period 1971-2000 is visible during all seasons with the exception of autumn. The differences are greatest between winter temperatures and are greater in the continental part of Croatia than on the coast.

Increasingly long and frequent droughts, as well as the growing vulnerability of crops to heat stress in recent decades, are a clear signal that climate change adaptation measures need to be implemented. In the period from 1980 to 2014, the drought in the summer months was the largest single cause of damage to Croatian agriculture caused by climate variability. Water deficiency in soil and increased air temperatures in the coming period will be two key problems in agriculture's fight against climate change (Official Gazette, 46/2020). However, climate change will probably also have some positive effects in agricultural sector, such as the cultivation of some new crops and varieties in areas where this has not been possible so far.

The change in average temperatures during the year is extremely important for agricultural production (Penzar and Penzar, 2000). The equivalent of the phenological data for the beginning of active vegetation and the provision of plant growth stage development with heat is the date when the average daily air temperature exceeds a certain threshold or biological minimum, and is determined from the average annual temperature pattern. Thresholds of 5 °C are usually calculated as the limit of active vegetation and the beginning of winter crops vegetation and plants of the cold season, 10 °C as the limit of active vegetation of subtropical plants and spring crops, temperature of 15 °C as the level important for generative crop phenophase, and temperature threshold of 20 °C suitable for thermophilic cultures and as level of summer heat. Knowledge of the beginning and end of the periods with temperatures above a certain threshold is important for the application of certain agrotechnical measures and the selection of cultivars and hybrids (Bilandžija, 2019).

The aim of this paper was to calculate temperature thresholds of 5, 10, 15, 20 and 25 °C for the reference period 1961-1990 and the recent period from 1991 to 2018, at three locations - Osijek, Gospić and Zadar, covering three agricultural regions of Croatia - Pannonian, Mountain and Adriatic region, respectively, and to indicate potential climate change in selected areas through analysis of time series and calculation of trends in the beginning, end and duration period of a certain temperature.

Materials and Methods

Considering the heterogeneity of geomorphological, lithological and agroecological characteristics of Croatia, three agricultural regions have been differentiated: Pannonian, Mountain and Adriatic region (Bašić, 2014) (Fig. 1). Regions are largely determined on the basis of soil and climate characteristics that define the ecological conditions for crop production, and on the basis of the structures, stability and results of overall agricultural production. The Pannonian region is the largest agricultural region which covers 46.2% of the Croatian land area. The climate is moderately continental with hot summers and cold winters, and precipitation is unevenly distributed throughout the year, which can lead to dry periods and it is necessary to rely on irrigation methods. The Mountainous agricultural region is characterized by a typical mountain climate, with extremely high level of precipitation most often in the form of snow, the vegetation period is short, and spring and autumn frosts are a regular occurrence. The Adriatic agricultural region has a Mediterranean coastal climate, with hot and dry summers and rainy winters that induce erosion. Irrigation systems need to be introduced for agricultural use and maximum production efficiency. The most important climate modifiers in Croatia are the Adriatic and the wider Mediterranean Sea, the orography of the Dinarides with its shape, altitude and position according to the prevailing current, the openness of the northeastern parts to the Pannonian plain, and the diversity of vegetation. Based on this, three main climatic areas have been defined: continental, mountainous and coastal (Zaninović et al., 2008), which almost completely overlap with the three main agricultural regions: the Pannonian, Mountainous and Adriatic regions.

Calculation of temperature thresholds of 5, 10, 15, 20 and 25 °C was based on mean monthly air temperatures of the referent 30-year climatological period 1961-1990 and the representative of the recent climate in period of 1991-2018. Given the categorization on three main agricultural regions in Croatia with specific climatic characteristics, temperature data were collected on main meteorological stations from the regular network of Meteorological and Hydrological Service of Croatia: Osijek for the Pannonian region (h=89 ASL, 45°30´9´´N, 18°33´41´´E), Gospić

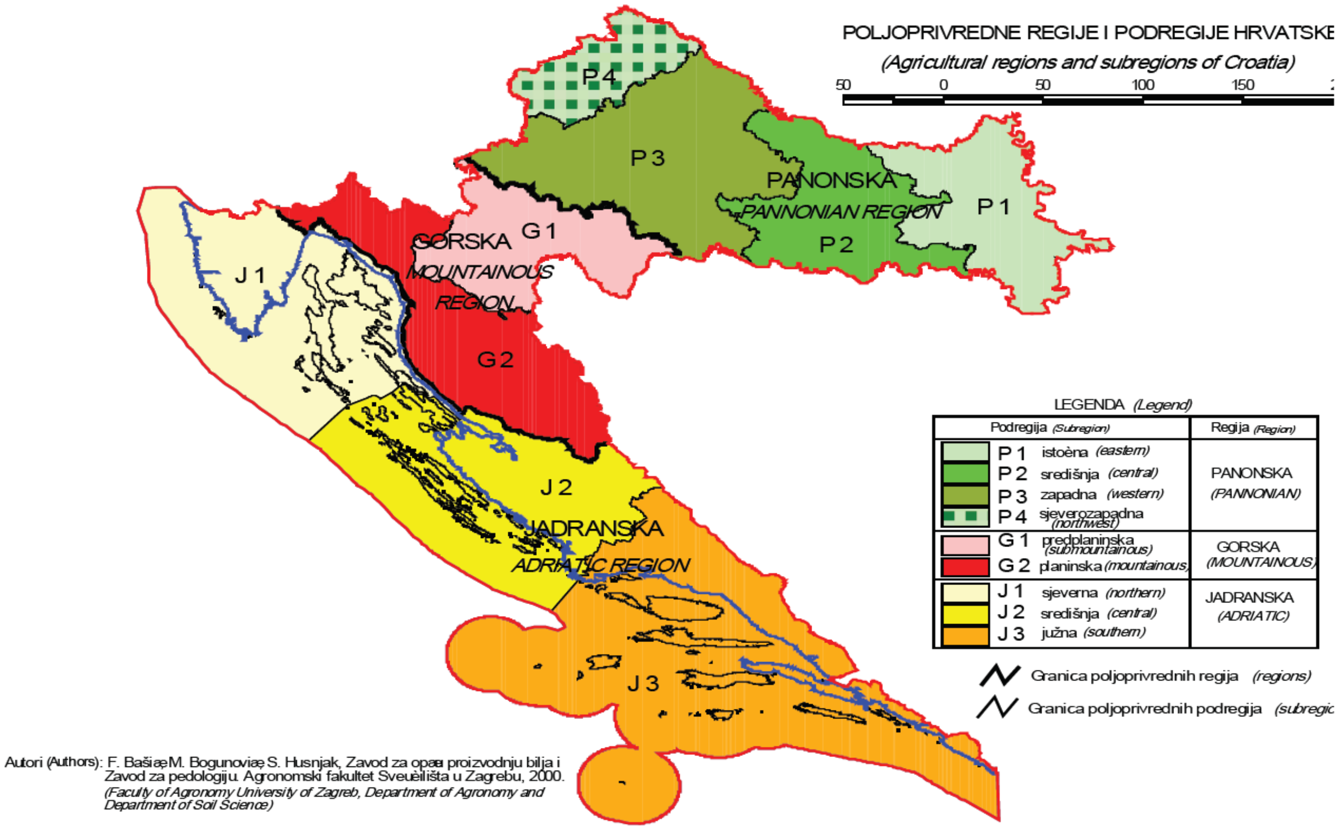

Figure 1. Agricultural regions and subregions of Croatia (Source: Bašić, 2014)

for the Mountainous region (h=564 ASL, 44°33'2"N, 15°22'23"E) and Zadar for the Adriatic region (h=5 ASL, 44°7'48"N, 15°12'21"E).

The dates of occurrence of an individual threshold are determined from the average annual pattern of air temperature for an individual meteorological station. Two calculations are used: one for the part of the year in which the values of the average monthly air temperature increase and the other for the part of the year in which the values of the average monthly air temperature decrease (Zaninović et al., 2008).

Temperature thresholds for the beginning and the end of vegetation periods with the temperatures above 5, 10, 15, 20 and 25 °C are calculated according to Butorac (1976).

Calculation of the beginning period above a given temperature T:

$$n = \frac{b - a}{30} \qquad x = \frac{(T°C - a)}{n}$$

Calculation of the end period above a given temperature T:

$$n = \frac{b - a}{30} \qquad x = \frac{(b - T°C)}{n}$$

where:

a – mean monthly temperature closest to the temperature threshold but lower than it

b - mean monthly temperature closest to the temperature threshold but higher than it

T - temperature thresholds of 5, 10, 15, 20 and 25 °C

x - number of days to be added to the middle of the month with temperature a (for the beginning of the period) or with temperature b (for the end of the period).

Trend analyses of beginning, end and duration period of temperature thresholds were carried out on long-term (1991–2018) data series of monthly climate dana ($p < 0.05$), in Statistica 12 (StatSoft Inc., 2014).

Results

The beginning, end and duration in days of the vegetation periods with temperatures above temperature thresholds of 5, 10, 15, 20 and 25 °C in the reference period 1961-1990 and recent period 1991-2018 for meteorological stations Osijek, Gospić and Zadar are presented in Table 1.

Comparison of the calculations for the periods 1991-2018 and 1961-1991 indicates increase in the number of days with all temperature thresholds in Osijek, Gospić and Zadar, while the dates of threshold occurrence appear earlier, and end later in the period 1991-2018 compared to the period 1961-1990. The period with temperatures above 5 °C is prolonged by 9 days in the Pannonian region (Osijek) and 17 days in the Mountain region (Gospić) in the recent period compared to reference period.

Table 1. Dates of occurrence of temperature thresholds and their duration in days for the former period 1961-1990 and recent period 1991-2018 (locations Osijek, Gospić and Zadar)

Osijek															
period	5 °C			10 °C			15 °C			20 °C			25 °C		
	B	E	D	B	E	D	B	E	D	B	E	D	B	E	D
1961-1990	10-Mar	18-Nov	254	6-Apr	21-Oct	198	7-May	24-Sep	140	25-Jun	18-Aug	54	-	-	-
1991-2018	5-Mar	23-Nov	263	2-Apr	25-Oct	206	1-May	26-Sep	148	8-Jun	26-Aug	79	-	-	-
Gospić															
period	5 °C			10 °C			15 °C			20 °C			25 °C		
	B	E	D	B	E	D	B	E	D	B	E	D	B	E	D
1961-1990	24-Mar	9-Nov	230	27-Apr	9-Oct	165	5-Jun	3-Aug	59	-	-	-	-	-	-
1991-2018	16-Mar	18-Nov	247	20-Apr	14-Oct	177	23-May	9-Sep	109	15-Jul	15-Jul	1	-	-	-
Zadar															
period	5 °C			10 °C			15 °C			20 °C			25 °C		
	B	E	D	B	E	D	B	E	D	B	E	D	B	E	D
1961-1990	-	-	-	20-Mar	28-Nov	253	30-Apr	23-Oct	176	6-Jun	12-Sep	98	-	-	-
1991-2018	-	-	-	12-Mar	5-Dec	268	23-Apr	26-Oct	186	26-May	18-Sep	115	14-Jul	25-Jul	11

Abbreviations: B - beginning; E - end; D – duration in days

Considering the period with temperatures above 10 °C, it is prolonged by 8 days in Osijek, 12 days in Gospić and 15 days in the Adriatic region (Zadar) in the recent period compared to reference period. The period with temperature threshold of 15 °C is prolonged by 8, 50 and 10 days in Osijek, Gospić and Zadar, respectively. Regarding the change in the duration of vegetation period with temperatures above 20 °C, it is prolonged by 25 days in Osijek and 17 days in Zadar, while in the Mountain region it occurred for 1 day in the recent period and it was not detected in the reference period 1961-1990. For the first time, average daily temperatures above 25 °C were recorded for Zadar in duration of 11 days. The greatest average change in duration of all temperature thresholds was detected in the Mountain region with extreme 50 days duration of 15 °C, followed by the Adriatic region. In the Pannonian region, the most pronounced change in duration of temperature thresholds was recorded in the warmest period of the year for temperatures above 20 °C. Similar results were obtained by Bilandžija et al. (2019), who observed longer vegetation periods with temperatures above 5, 10 and 15 °C in the north east part of Croatia.

Our next step was to analyse temporal trends of beginning, end and duration period with certain temperature threshold during the last 28 years. Time series correlation analysis determined a linear trend of change of beginning, end and duration in days of the period with temperature threshold of 5, 10, 15 and 20 °C for the meteorological station Osijek (Fig. 2). An earlier beginning of the period with temperature equal to or higher than 5 °C accounts for 3 days per decade. The end of the period with temperature equal to or greater than 5 °C occurs 4 days later/10 years. The annual duration of the temperature threshold of 5 °C increases by about 8 days/10 years. The calculated trends are not statistically significant ($p < 0.05$).

Non-significant linear trends at the 0.05 level were calculated for the beginning, end and duration period with temperature threshold of 10 °C: -6 days/10 years, +1 day/10 years and +7 days/10 years, respectively, as well as for temperatures above 15 °C: -4 days/10 years, -4 days/10 years and -2 days/10 years, respectively. Considering temperature thresholds and duration of temperatures above 20 °C, linear trends were not significant for the time series for Osijek (-6 days/10 years for the beginning, no trend for the end period, and +6 days/10 years for duration).

The trend analysis has shown that the linear trends significant at the 0.05 level exist in the time series of Gospić for the beginning and duration of the period with temperatures above 5 °C: -8 days/10 years and +13 days/10 years, respectively, while the end period with later occurence of about 8 days/10 years has no significant trend (Fig. 3). The earlier occurrence of temperature threshold of 10 °C is -10 days/10 years, while the trend for end period is +3 days/10 years. However, the annual duration of the temperature threshold of 10 °C increases significantly by about 13 days/10 years for the period 1990–2018 ($p < 0.05$). Linear trends calculated for temperature thresholds of 15 °C and 20 °C for Gospić are not statisticaly significant. The linear trends for the beginning, end and duration period for temperatures above 15 °C recorded small changes (-3 days, 0 days and +2 days per decade, respectively).

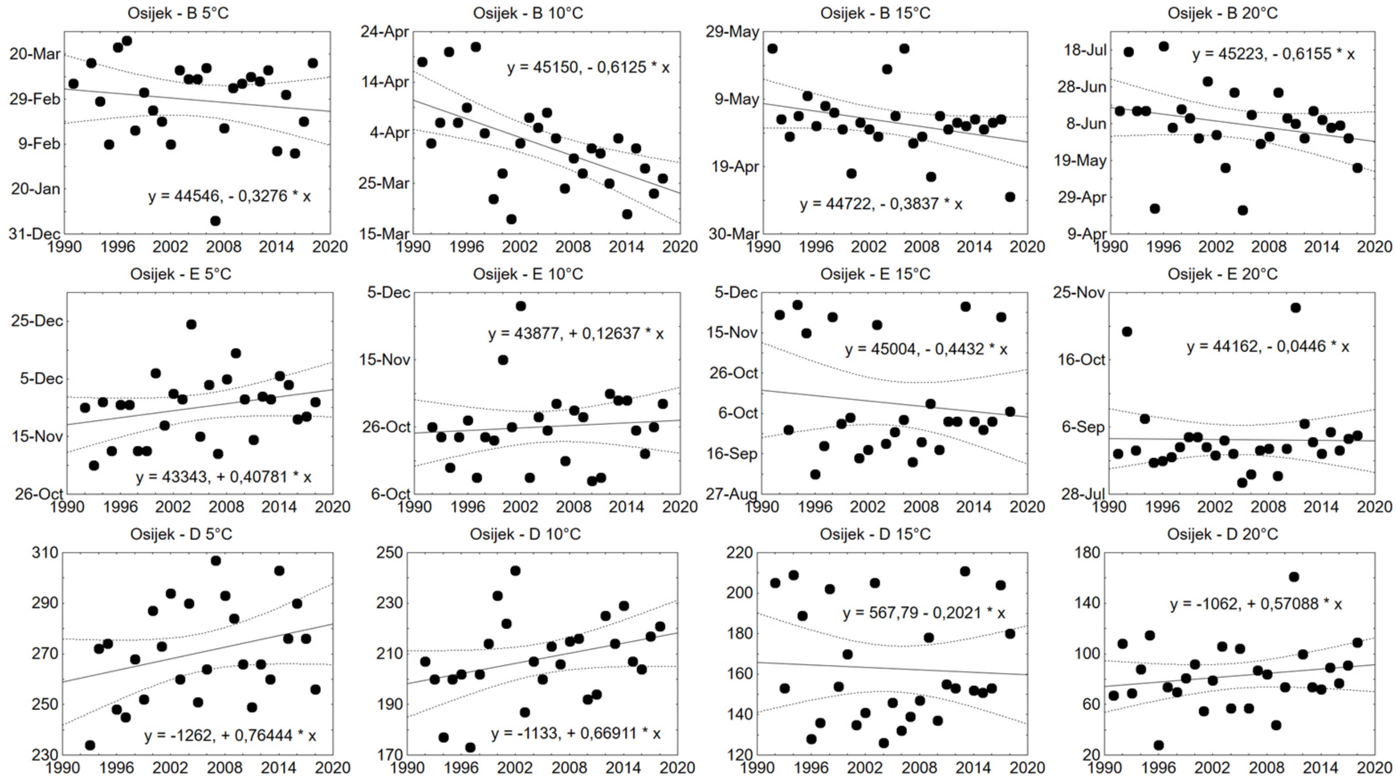

Figure 2. Linear trend analysis for the beginning, end and duration period with temperatures above 5, 10, 15 and 20 °C in the time series 1990-2018, Osijek (Pannonian region) (B – beginning; E – end; D – duration in days)

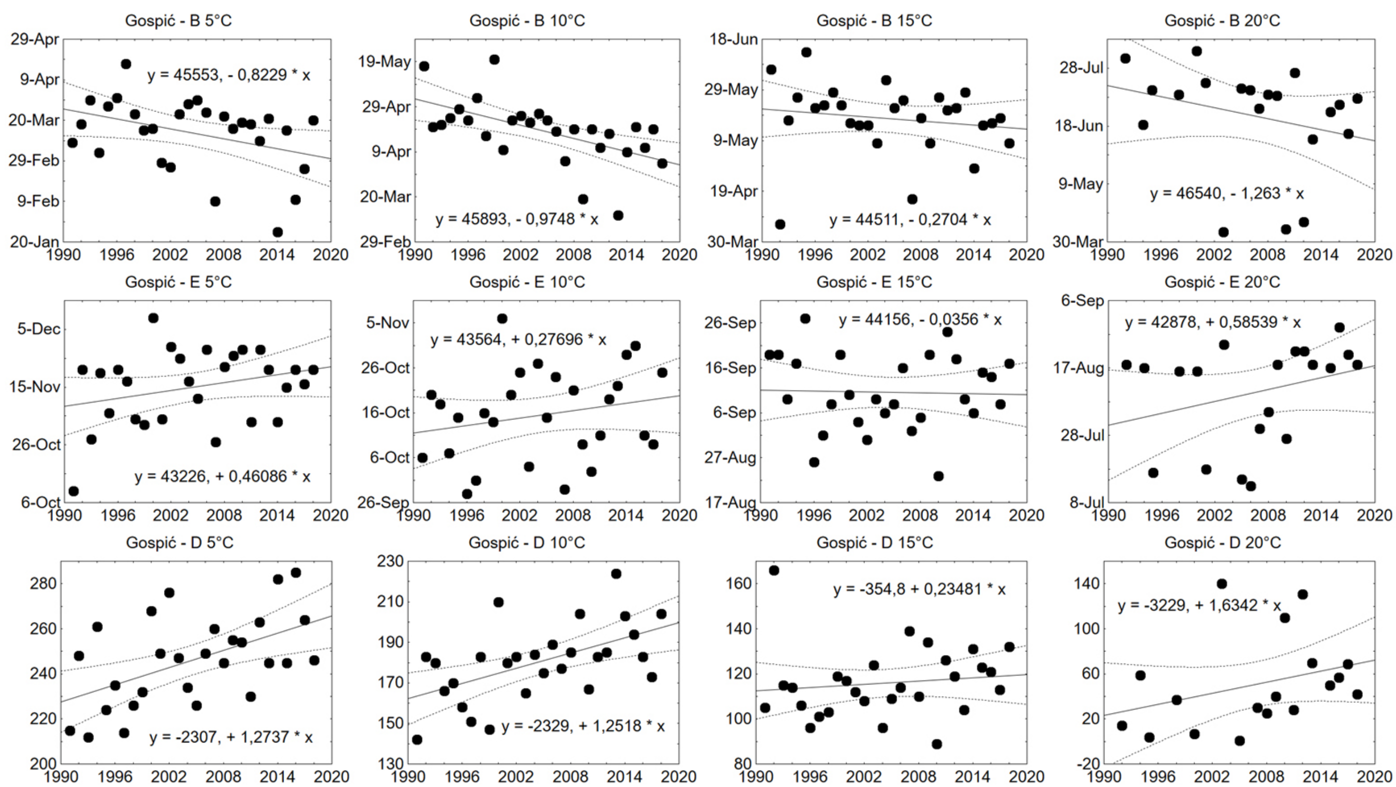

Figure 3. Linear trend analysis for the beginning, end and duration period with temperatures above 5, 10, 15 and 20 °C in the time series 1990-2018, Gospić (Mountain region) (B – beginning; E – end; D – duration in days)

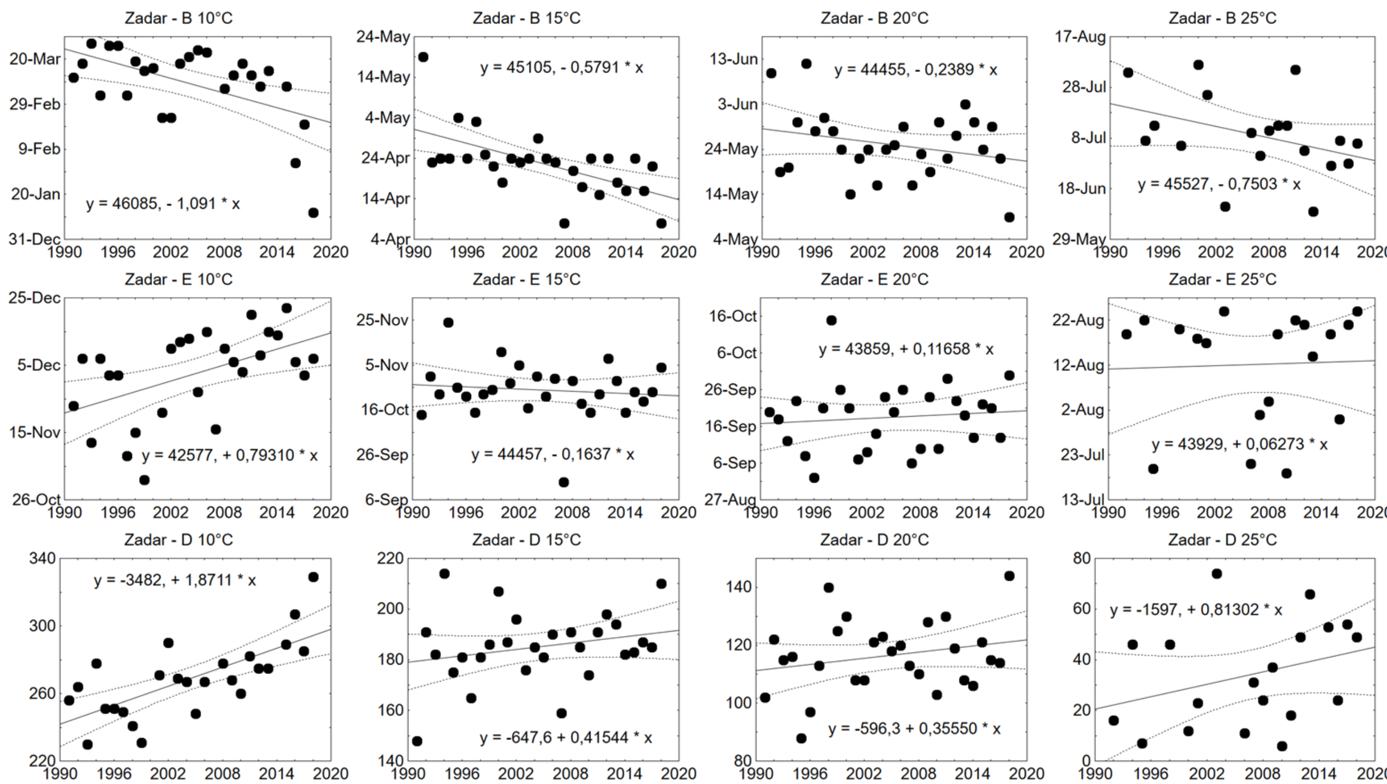

Figure 4. Linear trend analysis for the beginning, end and duration period with temperatures above 10, 15, 20 and 25 °C in the time series 1990-2018, Zadar (Adriatic region) (B – beginning; E – end; D – duration in days)

Although time series for temperatures above 20 °C show pronounced changes in dates of occurrence and their duration due to the high variability in occurences through the 28-year period, the calculated trends were not significant at the 0.05 level (-13 days/10 years, +6 days/10 years and +16 days/10 years for annual duration period, respectively).

Correlation analysis determined a linear trend of change in occurences and annual duration of the period with temperature thresholds of 10, 15, 20 and 25 °C for the station Zadar (Fig. 4). The linear trends significant at the 0.05 level were determined for the beginning, end and duration of the period with temperatures above 10 °C: -11 days, +8 days and +19 days per decade, respectively. The trend for the earlier occurence of the temperature threshold of 15 °C is significant (-6 days/10 years), compared to the end period and duration which have linear trends of -2 days/10 years and +5 days/10 years, respectively. Considering temperatures above 20 °C and 25 °C, trends in occurences and duration are not significant. The earlier occurrence of temperature threshold of 20 °C is -2 days/10 years, the trend for end period is +1 days/10 years, while annual duration was prolonged for 4 days per decade. Temperatures above 25 °C appeared 8 days earlier/10 years, while the end period occurred around the time of mid-date (19.8.) for 28 years. Annual duration was prolonged for 8 days/10 years.

Discussion

Based on the results of the calculation of temperature thresholds in the observed period from 1991 to 2018, warming occured in all three agricultural regions and the last four years - 2015, 2016, 2017 and 2018 have been the warmest years so far. Furthermore, temperature thresholds on average appear earlier than in the period from 1961 to 1990 and often have later endings. Number of days with higher temperature thresholds is increasing as well. There is a trend of increasing the number of warmer days from year to year, each subsequent year usually has a longer period of warm days than the previous one. The most significant extension of the number of days is calculated for the temperature thresholds of 5 °C and 10 °C in the area of the Pannonian and Mountain agricultural regions, and in the Adriatic region for the temperature threshold of 10 °C. Temperature thresholds of 5 and 10 °C appear earlier in all parts of Croatia. Moreover, there is an increasing occurrence and longer duration of the temperature thresholds of 20 °C and 25 °C in the Adriatic region, during which the greatest droughts occur. Trend analysis has shown that not all of these changes are statistically significant. In various parts of Croatia, the increases are significant only for certain temperature thresholds, mostly 5 and 10 °C: beginning of the temperature threshold of 10 °C in Osijek, beginning and end of the temperature threshold of 5 °C in Gospić, beginning and end of the temperature threshold of 10 °C and 15 °C in Zadar, and duration period with a temperature threshold of 10 °C in Gospić and Zadar. Results indicate pronounced winter/spring warming which can induce advanced start of active vegetation and extension of warm season in the mountainous area.

Similar findings were concluded by Jelić and Vučetić (2011) who recorded earlier occurence of the beginning of leafing and flowering of the common lilac at 31 phenological stations in Croatia during the period 1961-2010, starting from temperature threshold of 5 °C. The analysis of the linear trends of the phenological phases of different apple varieties for selected stations in Croatia showed a significantly earlier starting of leafing and blooming most expressed in mountainous region (3-6 days/decade) (Krulić and Vučetić, 2011). Vučetić and Vučetić (2005) determined earlier beginnig of olive flowering across the Adriatic region (2-4 days/10 years) during the period 1956-2003. According to Funes et al. (2021), for Catalonia region in Spain, growth cycles modelled until 2050 will begin earlier (from -1 days to -12 days for crops with a base temperature of 10 °C). Another connection with temeprature change and plant phenology was discovered by Templ et al. (2017) in comprehensive analysis of occurence of flowering across biogeographical regions of Europe between the period 1970–2010. According to their findings, temperature increased significantly during the first half of the spring across the Mediterranean and the Pannonian region, where flowering of different species generally started earlier in the latest period (1991–2010) compared to the earlier years (1970–1990). Based on the comprehensive analysis conducted by Menzel et al. (2006), the spring phenological signal is a perfect indicator for climate change impacts as it was advanced for −4.6 days/°C for average European circumstances.

Climate change data in Croatia follow some global trends and existing knowledge. The World Meteorological Organization (WMO, 2014) reports that in the period from 1981 to 2010 the most significant increase in global temperature was 0.17 °C per decade. The increase in mean temperature of 0.21 °C between 1991 and 2000 and 2001 to 2010 was higher than any previous measurements. Moreover, nine out of ten years in the 2001-2010 decade were the warmest in the observed years (Patarčić, 2018). According to WMO (2019), 2018 is considered the fourth warmest year in a row since 2015. Therefore, there is a global trend of a constant increase in average annual temperatures.

However, such trends are also known and expected for Croatia. The trend of increasing air temperature in the 20th century was recorded at meteorological stations throughout the country (Gajić-Čapka et al., 2010). The series of measurements of air temperature over the centuries show an increase between 0.02 °C and 0.07 °C every 10 years (Patarčić, 2018). According to Climate Change Adaptation Strategy (NN 46/20), in the period 1961-2010 the trends of mean, mean minimum and mean maximum air temperatures show a trend of warming over the entire territory of Croatia. The trends of annual air temperature are positive and statistically significant, and the changes are greater in the continental part of the country than on the coast and in the Adriatic hinterland. The largest contribution to the overall positive trend in air temperature was made by summer trends, and the increase in mean maximum temperatures was equally driven by winter and spring trends. The smallest changes occurred in autumn air temperatures (DHMZ, 2013), which is consistent with this study and the completion of the autumn temperature thresholds. Regarding projections in Croatia, Branković et al. (2012) expect an increase in temperature in winter by 0.6 °C in the first period of future climate (2011 - 2040) and by 1 °C in summer. In the second period of future climate (2041-2070), the expected temperature increase is up to 2 °C in the continental part and up to 1.6 °C in the south in winter. Additionally, the increase up to 2.4 °C in the continental part and up to 3 °C on the coastal belt of Croatia in summer is expected.

In light of existing research and the results of this study, we conclude that climate warming is occurring in Croatia and we expect these trends to continue. Therefore, it is necessary to take measures to reduce the human impact on climate by monitoring the ecological strategies in agricultural production (Zgorelec and Bilandžija, 2018). In addition, agricultural strategies for soil management, as well as crop production need to be adapted in order to create a sustainable food production system to alleviate the potential negative consequences of climate change. The main expected impacts of climate change leading to high vulnerability in the agricultural sector are: change in crop growing season with emphasis on cereals and oilseeds (e.g. maize, sugar beet, soybean, etc.); lower yields for all crops; higher water demand; longer growing season that will allow for the cultivation of new varieties and hybrids (NN 46/20). Possible responses and measures to reduce the high vulnerability of the agricultural sector include cultivation of varieties, hybrids and breeds more resilient to climate change, cultivation of early maturing varieties, optimization of sowing dates, increasing the water holding capacity of the soil, conservation tillage and other methods of reduced tillage, proper water management (irrigation and drainage), monitoring of weather and climate prediction models, crop forecasting, conservation of agrobiodiversity, application of agricultural crop rotation practices and cultivation of intercrops (NN 46/20; Butorac, 1999; Jug, 2016; Branković 2014; MZOE, 2018). These measures cannot be introduced and implemented all at once. However, it is necessary to define priorities for the introduction of individual measures in a gradual and sustainable manner and to harmonize them with specific agricultural conditions at the local level (Jug, 2016).

Conclusion

Time series trend analysis of the beginning, end and duration period for temperature thresholds of 5, 10, 15, 20 and 25 °C for the reference (1961-1990) and recent period (1991-2018) indicate a warming trend in all three agricultural regions of Croatia (Pannonian, Mountain and Adriatic). Although there are certain differences between regions, temperature thresholds on average appear earlier in the period 1991-2018 compared to the previous climate period, and often have later endings. Moreover, the number of days with higher temperature thresholds (15 °C and 20 °C) is increasing. There is a trend of increasing the number of warmer days from year to year. Changes in the recent period 1991-2018 compared to the reference period 1961-1990 are most pronounced in the Mountain and Adriatic regions. In the Pannonian region, the most pronounced change in duration of temperature thresholds was recorded in the warmest period of the year for temperatures above 20 °C. Statistically significant trends were determined for Osijek station for the beginning of the period with a temperature threshold of 10 °C (-6 days/10 years), for Gospić station for the beginning of the period with temperatures above 5 °C (-8 days/10 years) and duration of the period with temperature threshold of 5 °C and 10 °C (+13 days/10 years), and for Zadar for both temperature thresholds and a period duration of 10 °C (-11 days/10 years, +8 days/10 years, +19 days/10 years, respectively) and the beginning of a period with a temperature threshold of 15 °C (-6 days/10 years). Due to the earlier onset of active vegetation in continental Croatia and the extension of the vegetation period, there are opportunities for adaptation of agriculture to new climatic conditions such as crop rotation changes and the cultivation of new varieties and hybrids, as well as measures to reduce high vulnerability of agricultural sector to extreme climate conditions, especially drought and heat stress.

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