

Article

Dry Spells in Croatia: Observed Climate Change and Climate Projections

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Abstract: This study performs a systematic analysis of the recent and future changes of dry spells (DS) in Croatia. DS are defined as consecutive sequences of days with daily precipitation less than 5 mm of the precipitation-per-day threshold (DS5). Daily precipitation data come from a dense national rain gauge network (covering seven regions) and span the period 1961–2015. The spatial and temporal changes of the observed mean (MDS5) and maximum (MxDS5) seasonal and annual dry spells were analysed by means of the Kendall tau method and the partial trend method. Future changes of DS5 were assessed by employing the three regional climate models (RegCM4, CCLM4 and RCA4) covering the EURO-CORDEX domain with a 12.5-km horizontal resolution, resulting in a realistic orography and land–sea border over Croatia. The models were forced at their boundaries by the four CMIP5 global climate models. For the reference period 1971–2000, the observed, as well as modelled, DS5 were analysed, and the systematic model errors were assessed. Finally, the projections and future changes of the DS5 statistics based on simulations under the high and medium greenhouse gases concentration scenarios (i.e., RCP8.5 and RCP4.5) with a focus on the climate change signal between 1971–2000 and two future periods, 2011–2040 and 2041–2070, were examined. A prevailing increasing trend of MDS5 was found in the warm part of the year, being significant in the mountainous littoral and North Adriatic coastal region. An increasing trend of MxDS5 was also found in the warm part of the year (both the spring and summer), and it was particularly pronounced along the Adriatic coast, while a coherent negative trend pattern was found in the autumn. By applying the partial trend methodology, an increase was found in the very long DS5 (above the 90th percentile) in the recent half of the analysed 55-year period in all seasons, except in the autumn when shortening in the DS5 was detected. The climate change signal during the two analysed future periods was positive for the summer in all regions, weakly negative for the winter and not conclusive for the spring, autumn and year. It was found that no RCM-GCM combination is the best in all cases, since the most successful model combinations depend on the season and location.

Keywords: dry spells; trends; climate change; climate models; Croatia; EURO-CORDEX



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1. Introduction

Drought is a natural hazard that can cause a wide range of impacts affecting the environment, society and the economy [1]. Since the beginning of the 21st century, different parts of Europe faced several extreme droughts: among others, the drought (accompanied by the heatwave) in 2003 that hit Western and Central Europe; the 2011/2012 drought that affected SE Europe [2]; the extreme drought in 2015 that affected the Central and Eastern parts of Europe [3]; the summer in 2017 that was extremely dry in the Western Balkan Peninsula, particularly in Croatia [4], and Western Europe was affected by severe drought during a whole period from the summer of 2016 to the summer of 2017 [5]. In Croatia, in 2017, there were more than 100 consecutive dry days with a large precipitation deficit and

extremely high air temperature during the summer months [6]. These facts become one of the main motivations to investigate dry spells in Croatia, where there are significant spatial differences in the average precipitation amounts and frequency of occurrence between continental, mountainous and coastal areas [7]. The region of Croatia belongs to the transitional area between Northern Europe with an observed general increase in average precipitation and the drying Mediterranean [8,9]. This region is also characterized by large seasonal variability. The maritime annual cycle of precipitation is a characteristic of the coastal and mountainous region along the Adriatic coast, with the rainiest period in the winter and minima in the summer. On the other hand, the continental annual cycle of precipitation is a characteristic of the inland, with the rainiest period in the early summer with a secondary maximum in November as a consequence of the maritime influence, whereas the minimum occurs in the winter months [7].

A spatial and temporal analysis of the precipitation amounts and the indices of extremes in Croatia have been investigated in several studies. Gajić-Čapka et al. [10] analysed the trends in extreme precipitation indices during the 1961–2010 period. The results revealed a decreasing trend in annual precipitation amounts in the mountainous and central hinterland, whereas a significant positive trend was found in the eastern mainland. A negative annual trend is mainly caused by a decrease in the frequency of very wet days and their contribution to the total precipitation. A tendency of the increasing annual frequency of dry days was encountered all over the country, particularly in the northern Adriatic region, including the mountainous littoral.

In meteorological practice, drought monitoring usually relies on the cumulative precipitation amount on the different time scale (month or season), which may sometimes lead to incorrect conclusions on dryness (or wetness) of a particular month or season [11]. However, dry spell monitoring provides insight into the spatiotemporal distribution of the daily precipitation [12] and, thus, enables the identification of spatial patterns of drought risk [13]. Dry spells may have an impact on many sectors in different ways, but agriculture and water management are mostly affected by long dry spell durations [12,14]. Dry spells are generally defined as consecutive sequences of days with daily precipitation less than a given precipitation-per-day threshold (Rd , in mm). The most commonly used Rd values in practice and the scientific papers are those of 0.1, 1, 5 and 10 mm (e.g., [15–18]). In particular, the maximum duration of dry spells corresponding to the 1-mm threshold was widely analysed across Europe in the context of climate change, since they belong to the core set of indices of extremes recommended by the WMO [19]. There is a large body of studies dealing with long-term trends of dry spells on the local and regional levels (e.g., [17,20–22]) or pan-European level [23] but, also, at the global level (e.g., [14]), employing datasets starting from the middle of the 20th century. Zolina et al. [23] found a rising trend of dry periods (but, also, of wet periods) over the Netherlands and Eastern Europe, especially in the cold season, suggesting a regrouping of the wet/dry days into more prolonged wet/dry episodes. Over France and Central-Southern Europe (including the Balkan states, Romania and Bulgaria) during both (warm and cold) halves of the year, the tendencies in the durations of wet and dry periods have opposite signs. Recently, the trend analysis of extreme dry (and wet) periods by Breinl et al. [14] revealed a shorter DS duration in Scandinavia; a N–S gradient in trends in Western Europe with longer DS lengths was experienced in Central and Southern France, whereas DS have become shorter in the West. Eastern Europe has been facing a general trend toward longer DS durations. From Figure 3c in [14] there are indications for longer DS lengths in continental Croatia and Southern Adriatic and shorter durations along the Middle Adriatic.

Cindrić et al. [11] analysed trends of dry spells for 25 stations in Croatia based on the data from the second half of the 20th century (1961–2000). They analysed the mean and maximum dry spell durations and time trends on seasonal and annual scales, defining the four categories of dry spells according to daily precipitation threshold (0.1, 1, 5 and 10 mm). The results revealed a positive trend of both mean and maximal durations during the winter and spring seasons and a negative trend in the autumn, for all thresholds.

The present study focuses on the mean and maximum dry spells associated with the 5-mm threshold (*DS5*) with two goals in mind. The first one is to extend the previous trend analysis of Cindrić et al. [11] by increasing the station density and extending the time series to the period 1961–2015. The second goal is to analyse the expected changes of the dry spells pattern over Croatia in two future periods (2011–2040 and 2041–2070) with the respect to the 1971–2000 period. For this purpose, three regional climate models, RegCM4 [24], CCLM4 [25] and RCA4 [26], that cover the EURO-CORDEX [27] domain at the 12.5-km horizontal resolution and are forced at the lateral boundaries using four CMIP5 global climate models [28] are employed. The application of the regional climate models with a horizontal resolution higher than the forcing global climate models provides more realistic information on the local process, especially over the complex terrain areas. For future periods, the RCP4.5 and RCP8.5 scenarios [29] are considered.

The overall objective of the study was to make a systematic dry spell analysis in the context of climate change, both for the present and the future. The study was primarily aimed at climate change adaptation in Croatia, particularly in agriculture, as well as in other economic sectors (tourism, water management and energy), but, also, to meet the general framework of the current and expected climate changes in Europe.

2. Data and Methods

2.1. Data

We considered the dry spells corresponding to the daily precipitation limit of 5 mm and denote them by *DS5*. This threshold was chosen since the prolonged periods with daily precipitation amounts less than 5 mm may considerably reduce the soil–water content, with negative impacts on the agriculture [30]. In order to construct dry spells, daily precipitation data must be employed, which puts quite strict requirements on data completeness, because missing values may significantly influence the estimates of event durations and the character of their alternations [23].

The analysis was based on daily rainfall data from 131 (climatological and rain gauge) stations maintained by the Croatian Meteorological and Hydrological Service (DHMZ), spanning the 1961–2015 period. A slightly shorter period of data was available at eight stations that ceased their operation during the 2011–2014 period. Still, those stations were included in the analysis for the spatial completeness and, because the corresponding data, are of good quality. The stations were further divided into seven regions (Table 1) characterised by different precipitation regimes in Croatia (Figure 1). The same set of stations were used in Gajić-Čapka et al. [10], since precipitation data from these stations showed good quality and passed the homogeneity tests [31]. The present paper deals with trends and future long-term changes in *DS* in Croatia. For completeness, a brief description of the *DS5* climatology is included.

Table 1. The list of seven regions (Reg) with the corresponding number of stations (No), and the representative station of each region for climate model validation.

Region	No	Station	Latitude	Longitude
Eastern mainland (Reg 1)	16	Osijek (Stat 1)	45°30'9" N	18°33'41" E
Western mainland (Reg 2)	25	Zagreb Maksimir (Stat 2)	45°49'19" N	16°2'1" E
Central hinterland (Reg 3)	15	Ličko Lešće (Stat 3)	44°48'37" N	15°18'40" E
Mountainous region (Reg 4)	14	Ravna Gora (Stat 4)	45°22'28" N	14°56'22" E
Mountainous littoral (Reg 5)	9	Rijeka (Stat 5)	45°20'13" N	14°26'34" E
North Adriatic coastal (Reg 6)	23	Mali Lošinj (Stat 6)	44°31'57" N	14°28'19" E
Central and South Adriatic coastal (Reg 7)	30	Split Marjan (Stat 7)	43°30'30" N	16°25'35" E

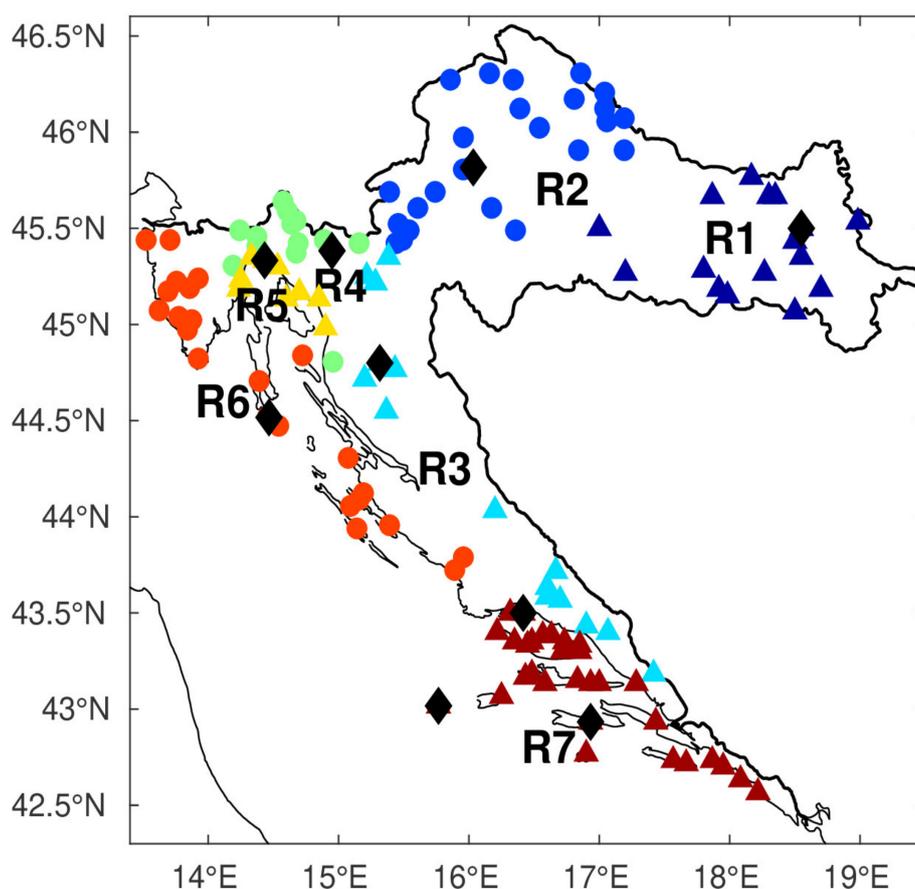


Figure 1. Locations of the meteorological stations used in this study and the regions listed in Table 1. The nine stations selected for the regional climate model validations and climate change projection analysis are highlighted with black diamonds.

In the first part of the study, we focus on the trend analysis of observed dry spells (DS5) in Croatia, considering both the mean (*MDS5*) and maximum durations (*MxDS5*). The analysis is performed on annual and seasonal (winter (DJF), spring (MAM), summer (JJA) and autumn (SON)) bases. A dry spell beginning in one season but extending to the next one is accounted for the season in which it started (see [11] and the references therein). For example, a dry spell beginning in August and ending in September is included in the summer season.

2.2. Methods

Trends in the *MDS5* and *MxDS5* duration on an annual and seasonal basis were estimated using the Kendall tau method [32,33], since this estimator of the slope (also called Sen's slope) is statistically robust and resistant, as opposed to the ordinary least-squares estimator. Statistical significance of the obtained trend is estimated using the nonparametric Mann–Kendall test [34], with a 95% significance level.

Furthermore, the innovative partial trend methodology introduced by Öztopal and Şen [35] is additionally used for detecting changes in dry spells. It provides a comparison of the two periods of equal lengths in which the data are sorted into ascending order. Here, the *DS5* duration series are divided into two periods: 1961–1987 and 1988–2014. The recent period is plotted on the vertical axis against the referent (older) period plotted on the horizontal axis of a Cartesian coordinate system. The straight line drawn at 45° on the same plot indicates no trend in the given series. If the scatter of points is below (above) the 45° line, there is an indication of decreasing (increasing) trend in the given time series. The advantage of this methodology is that it provides information on the trend sign, along with different domains (subgroups) of dry spell durations (see Section 3.2).

To estimate the changes of dry spells in the future climate, three regional climate models (RCMs) are used: RegCM4, CCLM4 and RCA4. The RCMs originate from the EURO-CORDEX initiative, and they are forced at their boundaries by the CMIP5 (Coupled Model Intercomparison Project Phase 5) global climate models (Table 2). In this study, four different global climate models were considered: HadGEM2-ES (hereafter, HA), CNRM-CM5 (hereafter, CN), EC-EARTH (hereafter, EC) and MPI-ESM (hereafter, MP). Those three RCMs have a 12.5-km horizontal resolution, resulting in a realistic orography and coastal line over Croatia. Three 30-year periods are defined for an analysis of the RCM simulations and projections: one present (1971–2000) and two future (2011–2040 and 2041–2070). The projections and future changes of the dry spell statistics are based on the RCM simulations under the medium and high greenhouse gas concentration scenarios (i.e., RCP4.5 and RCP8.5). We employed three regional climate models in order to estimate the uncertainties related to the selection of the combination of regional and global climate models. The model results of *DS5* are validated against the observed *DS5*—for each region, a representative station is selected, and the results are compared to the corresponding model results at the nearest grid box centre. Then, the difference between the two future (2011–2040 and 2041–2070) periods and the historical period (1971–2000) are compared for the two emission scenarios separately, both on a seasonal and annual basis. In Table 1, the list of selected stations in seven regions is given.

Table 2. List of abbreviations and full climate model names and the associated horizontal grid spacing of each model.

Abbreviation	Full Climate Model Name	Horizontal Grid Spacing
EURO-CORDEX regional climate models		
RegCM4	DHMZ-RegCM4-2	12.5 km × 12.5 km
RCA4	SMHI-RCA4	0.11° × 0.11°
CCLM4	CLMcom-CCLM4-8-17	0.11° × 0.11°
CMIP5 global climate models		
HA	MOHC-HadGEM2-ES	1.25° × 1.88°
CN	CNRM-CERFACS-CNRM-CM5	1.40° × 1.41°
MP	MPI-M-MPI-ESM-MR, MPI-M-MPI-ESM-LR	1.87° × 1.88°
EC	ICHEC-EC-EARTH	1.12° × 1.13°

3. Results

3.1. Mean and Maximum Dry Spell Duration

The mean (*MDS5*) and maximum (*MxDS5*) dry spell durations with the 5-mm per-day-threshold are depicted with bars in Figures 2 and 3, respectively. The corresponding regional mean values of *MDS5* and *MxDS5* are given in Table 3. In Figure 2, the empirical frequency distribution is presented by the median (red dots) and interquartile (25th and 75th percentile) ranges for each station. It can be seen that the mean values are much higher than the corresponding median values, implying a positive skewness of the DS distribution. In Table 4, the corresponding *MDS5* for the representative stations of each region are given for the same observed period of 1961–2015. The values are very close to the associated regional mean values.

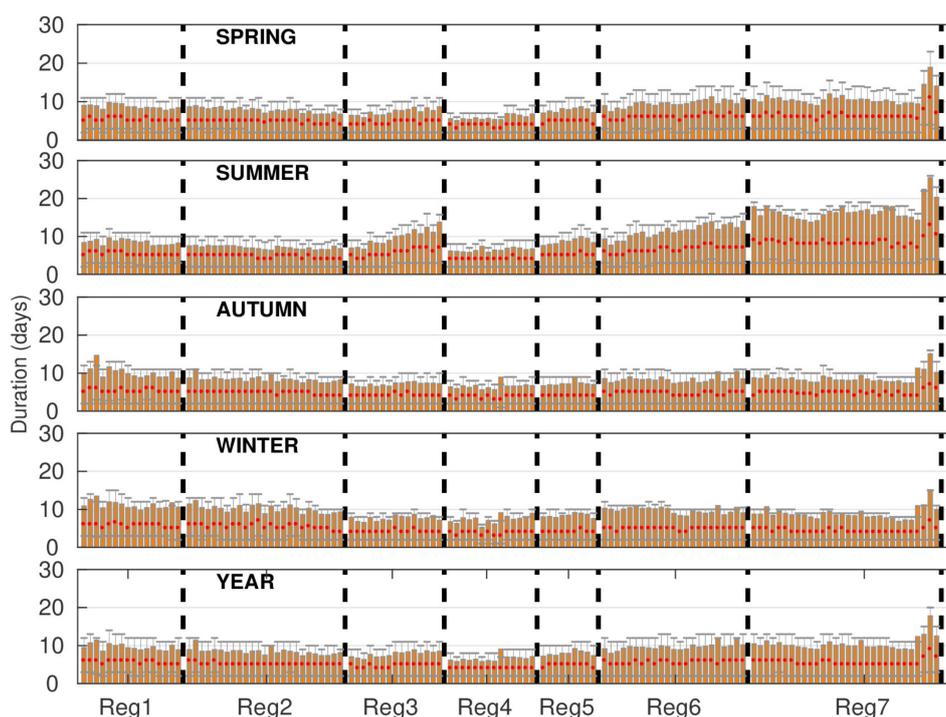


Figure 2. Seasonal (upper four panels) and annual (bottom panel) mean dry spell durations in days (brown bars) for the 5-mm precipitation-per-day thresholds. Red dots indicate the corresponding median values, while the interquartile range (25th and 75th percentiles) for each station is depicted in grey. The seven regions are distinguished by bold dashed vertical lines.

Table 3. Mean values of MDS5 and MxDS5 (in days) for seven regions (Reg) from the observation period 1961–2015.

	MDS5					MxDS5				
	Spring	Summer	Autumn	Winter	Year	Spring	Summer	Autumn	Winter	Year
Reg 1	8.7	8.5	10.1	11.1	9.6	71.3	58.9	59.5	76.3	92.0
Reg 2	7.8	7.1	8.4	10.1	8.4	50.3	47.2	54.5	80.6	72.8
Reg 3	7.3	9.7	7.1	7.6	7.7	49.5	69.9	51.0	77.5	72.7
Reg 4	5.9	6.5	6.6	7.4	6.6	39.4	53.7	51.6	79.9	62.4
Reg 5	7.8	8.7	7.2	8.3	7.9	46.8	72.9	52.0	81.1	74.1
Reg 6	9.5	11.3	8.3	9.7	9.6	55.2	74.6	56.3	81.3	81.7
Reg 7	10.8	16.7	8.8	8.9	10.4	71.8	99.9	54.6	75.0	110.2

The regional distribution of MDS5 reflects the prevailing continental and maritime precipitation regimes in Croatia, as well as mountainous climate in the transition region (Reg 4). Generally, in all seasons, MDS5 are the shortest in the mountainous region (Reg 4), while the easternmost and southernmost regions (Reg 1 and Reg 7) have the longest MDS5. On an annual scale, in the continental (Reg 1 and Reg 2) and Adriatic regions (Reg 6 and Reg 7), MDS5 are of similar durations. However, in the warm part of the year (spring and summer), the Middle and Southern Adriatic experience the longest sequences of dry days, whereas, in the cold part of the year (autumn and winter), the longest MDS5 occur in the continental regions. Nevertheless, it can be seen that the three southernmost stations situated at distinct Adriatic islands are exceptions, having the longest MDS5 durations in all the seasons.

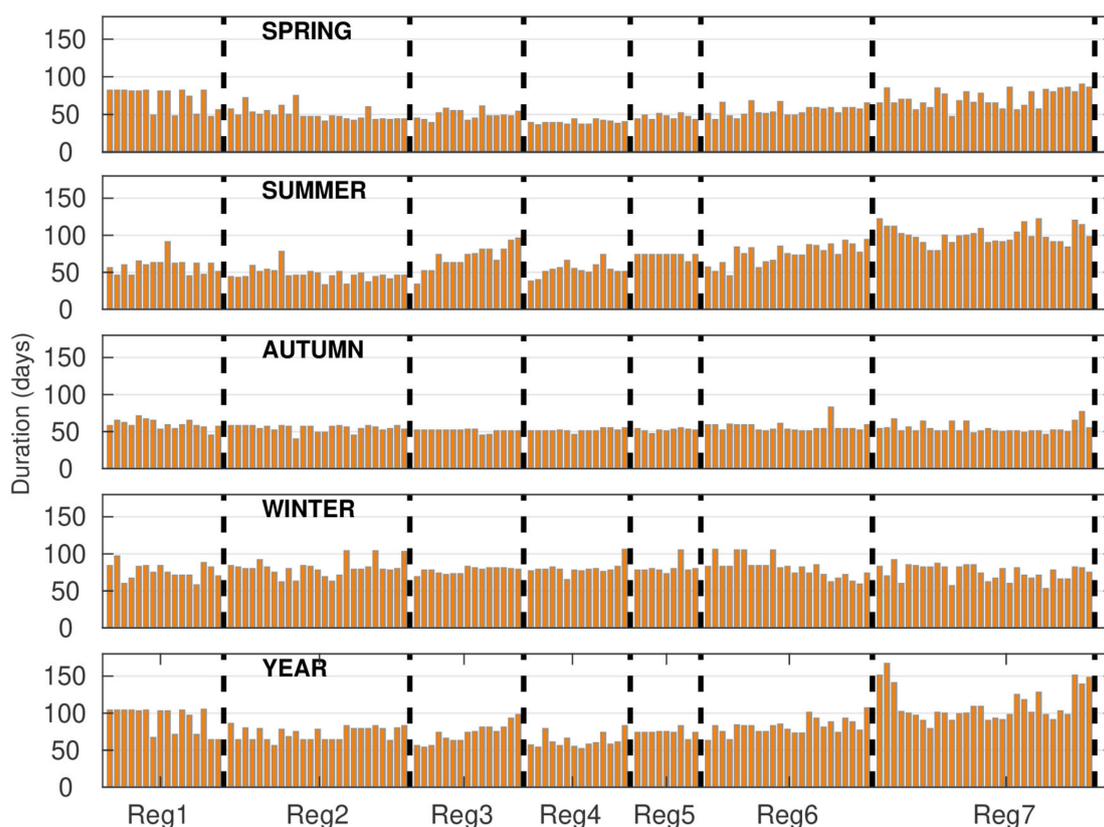


Figure 3. Seasonal (upper four panels) and annual (bottom panel) maximum dry spell durations (MxDS5, in days) for the 5-mm precipitation-per-day thresholds. The seven regions are distinguished by bold dashed vertical lines.

Table 4. MDS5 (in days) at seven representative stations in the regions (from Table 1) from the observational period (1961–2015).

	Spring	Summer	Autumn	Winter	Year
Stat 1	9.6	8.8	10.6	11.8	10.0
Stat 2	8.0	7.0	8.4	11.1	8.5
Stat 3	7.3	8.7	7.1	7.9	7.7
Stat 4	5.1	6.0	5.9	6.3	5.8
Stat 5	7.6	7.9	6.9	8.1	7.6
Stat 6	9.5	11.7	7.7	8.2	9.1
Stat 7	9.9	15.4	8.6	8.7	10.0

On the other hand, MxDS5 did not reveal such a distinctive spatiotemporal pattern as MDS5 (Figure 2). Nevertheless, the shortest MxDS5 durations are still found in the mountainous region (Reg 4), while the longest MxDS5 are the most common in the Central and Southern Adriatic regions (Reg 7). The MxDS5 pattern in Reg 1 closely follows the one of Reg 7, with annual mean durations of 92 and 110 days, respectively. In the spring, the mean MxDS5 in those two regions is 72 days. The Adriatic coastal regions and the hinterland are the driest in the summer, with the average MxDS5 ranging between 70 and 75 days (Reg 3, Reg 5 and Reg 6) and 100 days (Reg 7). In the autumn, the durations of the MxDS5 are pretty similar in all the regions, ranging from 51 to 59 days (Table 3).

3.2. Trends

The trends in the seasonal and annual *MDS5* and *MxDS5* durations are shown in Figures 4 and 5, respectively. The values of Sen's slope are expressed in days per 10 years.

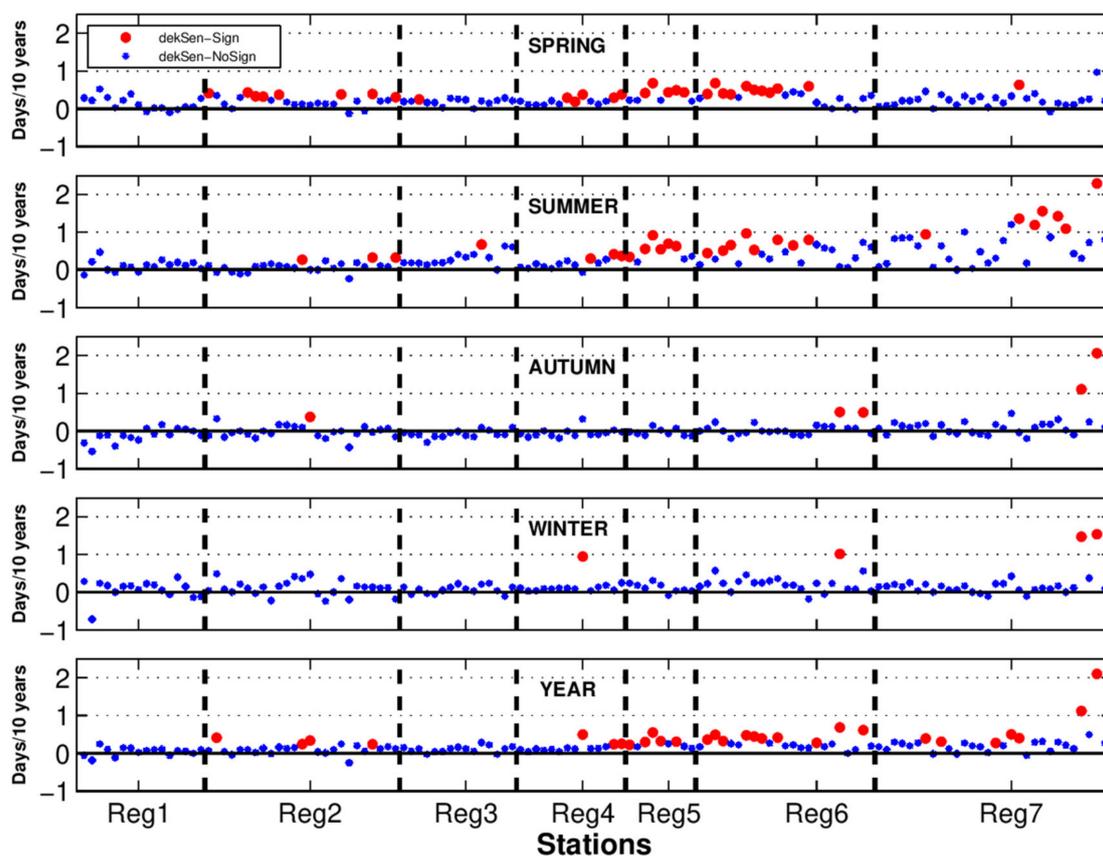


Figure 4. The trends in the seasonal and annual *MDS5* (in days/10 years). Dots refer to trend values (Sen's slope) for each station in the associated region. Blue dots present nonsignificant trends, whereas significant trends are highlighted by red dots.

The results revealed a generally increasing trend in *MDS5* durations in the warm part of the year (spring and summer). In the mountainous littoral (Reg 5), and along the Adriatic regions (Reg 6 and 7), the trend is statistically significant, with a prevailing significant increase also in Reg 2 during the spring. The largest and, also, the most significant trend is found in the summer at the Southern Adriatic region (Reg 7), particularly at the southernmost islands, showing an increase in *MDS5* duration from one to 2.5 days in 10 years. On the other hand, in the cold part of the year (autumn and winter), there is no clear sign in the trend values for the majority of the stations. Though, a few stations in Reg 6 and Reg 7 pointed out a positive and significant trend (up to two days in 10 years). Consequently, an increasing trend in the annual *MDS5* durations was found that was statistically significant along Adriatic regions (Reg 6 and 7) and in the mountainous littoral (Reg 5).

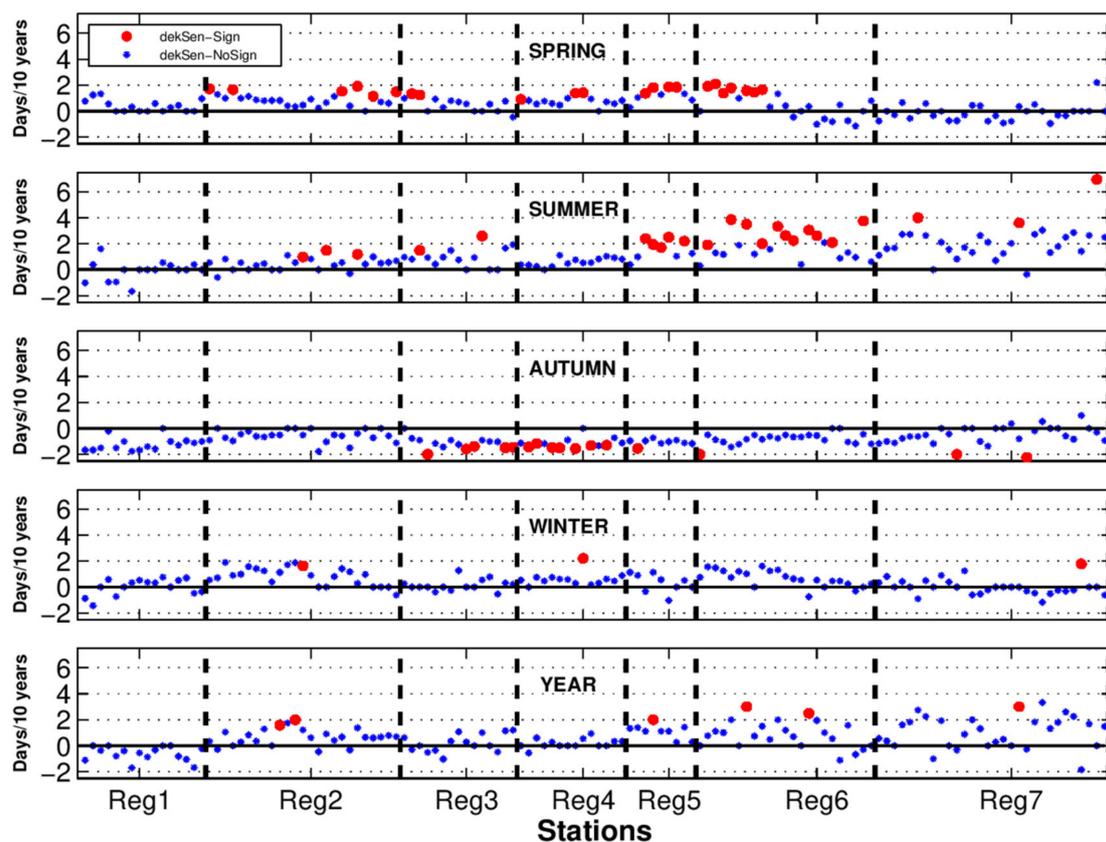


Figure 5. The same as Figure 4 but for $MxDS5$.

The trend results in $MxDS5$ durations for the spring revealed a consistently increasing trend in all the regions from Reg 1 to Reg 5. The trend is also positive (and statistically significant) at half of the stations in Reg 6 (Figure 5), which are located on the Istrian Peninsula, while, at the second half of the stations in Reg 6 (mostly island stations) and the whole of Reg 7, there is no clear sign in the trend values. In the summer, an increasing trend prevailed: at the mountainous littoral and in the Northern Adriatic (Regs 5 and 6), it is statistically significant. An overall decreasing trend is found in the autumn, and it is statistically significant in the mountainous region (Reg 4). In the winter, an increasing trend prevailed in Reg 2 and Reg 6, but generally, it is not pronounced over Croatian territory. A prevailing positive trend is apparent in Reg 2, and in regions 5–7 for the annual $MxDS$, though only at a few stations is the trend significant.

It can be noticed that no trend is detected in Reg 1, neither for $MDS5$ nor for $MxDS5$. On the other hand, most stations with a significant trend are found along the mountainous littoral and Northern Adriatic (Regs 5 and 6) in the warm part of the year. They contributed to the prevailing significant trend on an annual scale. The least number of stations with a significant trend is found in the cold part of the year for $MDS5$ and in the winter for $MxDS5$.

Partial trends for $DS5$ for a selected nine stations are presented in Figure 6. The first seven stations are mentioned earlier (Table 1) as the representatives of each region. Additional Southern Adriatic stations Čara (Stat 8) and Svetac (Stat 9) are included, since they revealed a prevailing significant trend in nearly all seasons. The $DS5$ in the recent period (1988–2014) are plotted on the vertical axis against the $DS5$ from the older period (1961–1987), which are plotted on the horizontal axis. In fact, the percentile values of $DS5$ are employed (curves of different colours) and not the $DS5$ themselves, because the DS series was not recorded with constant sampling intervals, as is needed to produce partial trend plots. The corresponding 95th percentile values representing long $DS5$ durations are indicated by dots in Figure 6. It can be seen that, for short, dry spells, scatter diagrams

are close to 45° line at all the selected stations and for all seasons, thus indicating no trend, while, for long, dry spells, the differences between the seasons and between the two selected periods increased. It should be noted here that, for some stations, the percentile values of the annual DS may overlap with one of the seasons, so not all circles in Figure 6 are clearly distinguished (e.g., the summer 95th percentile at Svetac).

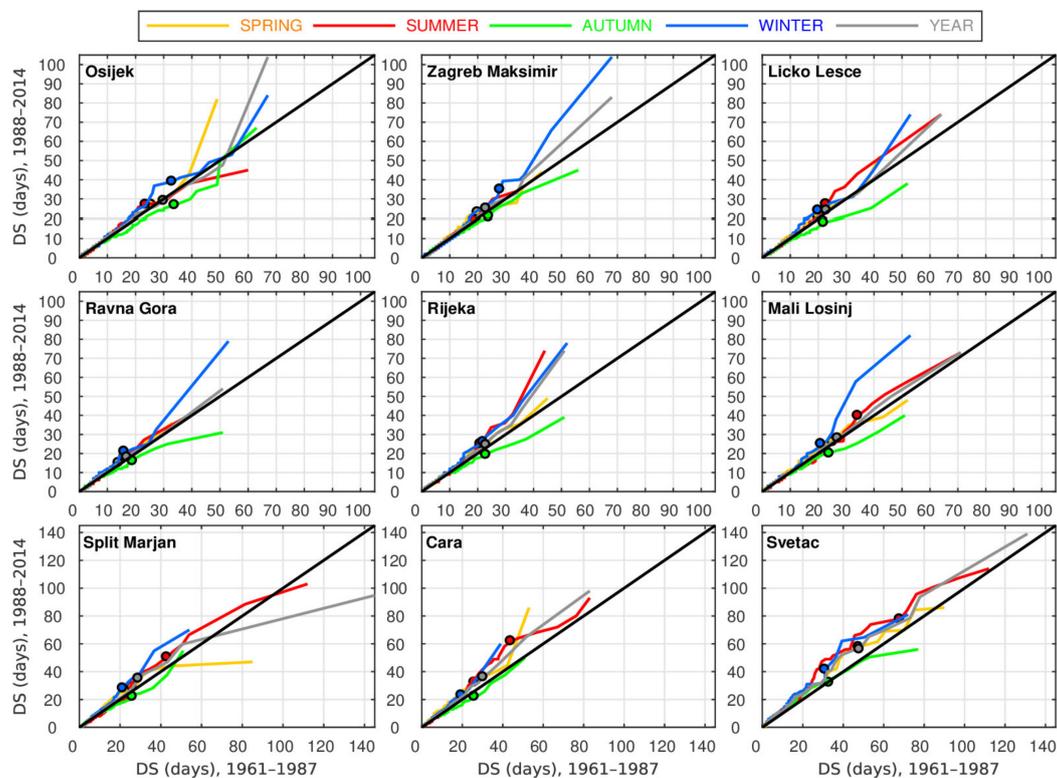


Figure 6. The partial trend scatter diagram for DS5 for nine selected stations in Croatia. Seasons are distinguished by different colours. The 95th percentile values from each period (1961–1987 and 1988–2014) are denoted by circles.

Comparing the 1961–1987 and the 1988–2014 periods, it can be seen that generally the duration of the longest DS5 was prolonged in the recent period in all seasons, except in the autumn, where a dominantly negative trend is found. On the other hand, changes in short and medium DS5 duration are not particularly expressed. However, if one looks at the extreme DS5 values (longer than 95th percentile), the summer maxima in the easternmost region (Osijek station) and maxima in the warm part of the year at the Southern Adriatic coast (Split Marjan Station) were recorded in the earlier period.

3.3. Simulations of Dry Spell Durations in Historical and Future Climate

3.3.1. Evaluation of Regional Climate Models: General Overview

Regional climate model simulations of the dry spell durations depend on the specific combination of the global and regional climate model, the chosen historical and future period and the selection of the greenhouse gas concentration scenarios. Therefore, the seasonal and annual *MDS5* durations are calculated from the three regional climate models forced at their boundaries by the four global climate models, for three different time periods and two different scenarios, as described in Section 2.2.

The mean duration of dry spells for the historical period 1971–2000 obtained from observations and the RCMs are compared (Figure 7 and Table 5). Observed values present 30-year average values of *MDS5*, while the model values refer to the median of twelve different model combinations in total (four global and three regional models) of 30-year average values of *MDS5* in each specific RCM run. The median of all model combinations is used to limit the impact of the outliers in the ensemble of the twelve model simulations

(these values are given in Ensemble in Table 5), while the mean value for each RCM is equivalent in computation to approach applied in the analysis of the observed values. The observed values (O) can be compared with the model ensembles of the simulated *MDS5* for the simulated historical period (M) with respect to the seasons (Figure 7) or with the results of an individual model (Table 5). For the latter, the comparison can be done regarding seasons or regarding the different model combinations. In the following, the difference between the *MDS5* of three RCMs forced by each GCM is discussed.

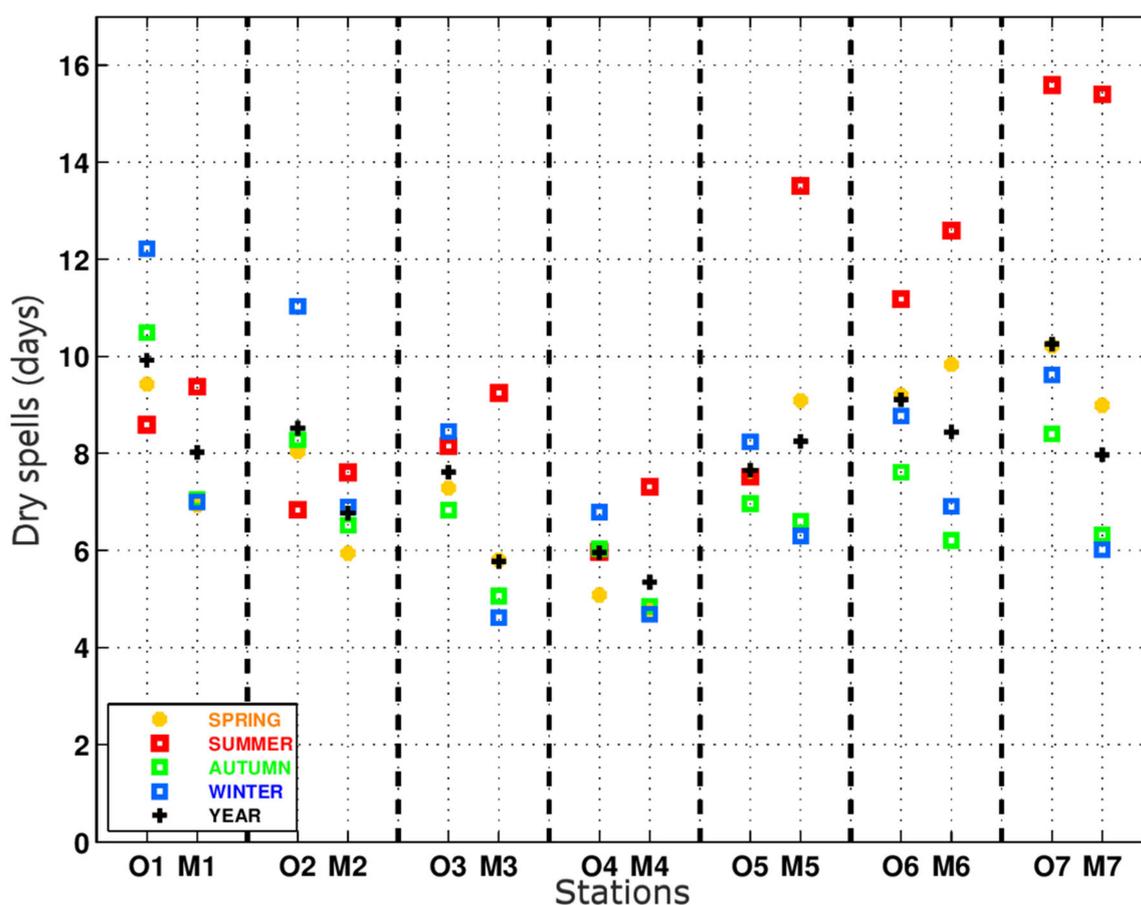


Figure 7. Average *MDS5* from observations (O) and the median of 30-year average *MDS5* from the models (M) for seven stations on the annual and seasonal time scale. Seasons are distinguished by different colours.

3.3.2. Evaluation of Regional Climate Models: Seasonal Variability

In the spring, the observed *MDS5* duration is close to the simulated one at the mountainous station (Stat 4) and is well-simulated in all model combinations (Table 5). At Stat 5 and Stat 6, the *MDS5* are overestimated by one and two days, respectively, while at the rest of the stations, *MDS5* are underestimated by one to almost three days (Figure 7). According to the individual model results, the best estimation of *MDS5* at all stations is found for the model combination HA-CCLM4. The largest underestimation (4 days) is found at the continental Stat 1 for CN-RCA4, while the largest overestimation (9 days) is found at Stat 5 (which is located within the very complex topography) for the HA-RegCM4 combination (Table 5).

Table 5. The difference in *MDS5* between each model simulation and observations for seven stations on the annual and seasonal time scales. Negative and positive values are highlighted with blue and orange colours, respectively.

	SPRING			HA			EC			MP			CN			Ensemble
	RCA4	CCLM4	RegCM4	RCA4	CCLM4	RegCM4	RCA4	CCLM4	RegCM4	RCA4	CCLM4	RegCM4	RCA4	CCLM4	RegCM4	
SPRING																
Stat 1	-2.7	1.1	0.6	-3.1	-1.9	-2.6	-3.2	-2.3	-1.5	-3.8	-2.4	-2.8	-2.5	-2.5	-2.5	-2.5
Stat 2	-2	0.6	0.3	-2.4	-1.4	-2.1	-2.4	-2.1	-1.6	-3.2	-2.1	-2.4	-2.1	-2.4	-2.1	-2.1
Stat 3	0.5	-0.7	-1	-1.1	-2.1	-2.3	-0.7	-2.4	-1.5	-1.4	-2.6	-2.6	-1.5	-2.6	-2.6	-1.5
Stat 4	0.3	0.8	1.5	-0.4	-0.4	-0.1	-0.2	-0.6	0.4	-0.9	-0.9	-0.4	-0.3	-0.9	-0.4	-0.3
Stat 5	5.8	-0.5	9.2	0.9	-1.6	4	1.6	-2.3	3.5	1.4	-2.6	2.2	1.5	-2.6	2.2	1.5
Stat 6	4.2	1.6	5.2	0.7	-0.5	1.9	0.6	-1.4	1.2	0.5	-1.8	-0.6	0.6	-1.8	-0.6	0.6
Stat 7	3.1	-1.1	3	0.9	-2.2	-1.9	0.4	-3.1	-1.4	-0.2	-3	-2.5	-1.2	-3	-2.5	-1.2
SUMMER																
Stat 1	1.1	13.4	10.8	0.4	2	6.2	-0.7	-0.4	3.8	-1.8	0.2	-0.1	0.8	-1.8	-0.1	0.8
Stat 2	0.9	7.7	6.8	0.7	0.8	3.9	-0.4	-0.6	2.8	-1	0	-0.2	0.8	-1	-0.2	0.8
Stat 3	6.4	4	1.9	3.4	-0.8	0.3	2.6	-1.8	-0.3	2.1	-2	-3	1.1	-2	-3	1.1
Stat 4	2	4.8	4.6	1.7	0.3	2.9	1.1	-0.7	1.6	0.2	-0.6	-0.6	1.3	-0.6	-0.6	1.3
Stat 5	14.7	3.9	27.2	6.1	-0.5	16.4	4.8	-1.9	10.4	6.3	-1.6	5.9	6	-1.6	5.9	6
Stat 6	5.5	5.2	6.3	2.6	-0.6	6.4	0.2	-2.7	2.7	-0.5	-2.9	-2.3	1.4	-2.9	-2.3	1.4
Stat 7	4.8	1	6	2.8	-4	1.7	0.7	-6.2	-1.4	-1	-6.4	-5.9	-0.2	-6.4	-5.9	-0.2
AUTUMN																
Stat 1	-2.4	-3.4	-3.7	-2.3	-2.2	-3.5	-3.1	-3.5	-3.4	-3.1	-3.8	-4.8	-3.4	-3.1	-3.8	-4.8
Stat 2	-1	-1.6	-2	-0.2	-1.1	-2	-1.3	-1.9	-2	-1.2	-2.4	-3.1	-1.8	-2	-1.2	-2.4
Stat 3	-1.1	-1.9	-2.1	-0.9	-1.6	-2	-1.6	-2	-1.5	-1.5	-2.4	-2.7	-1.8	-1.5	-2.4	-2.7
Stat 4	-0.6	-1.3	-1.5	-0.5	-0.9	-1.1	-1	-1.2	-1.3	-1.1	-1.7	-1.8	-1.2	-1.3	-1.1	-1.7
Stat 5	0.8	-1.4	3.7	-0.1	-1.5	0.5	-0.7	-1.9	1.6	-0.7	-2.6	0.8	-0.4	-0.7	-2.6	0.8
Stat 6	-0.3	-1.6	-2.4	-0.6	-0.7	-0.8	-1.3	-1.5	-0.2	-1.5	-2.6	-1.8	-1.4	-0.2	-1.5	-2.6
Stat 7	-0.4	-2.8	-2.9	-0.9	-1.8	-2.6	-1.5	-2.3	-1.3	-1.8	-2.9	-3.4	-2.1	-1.3	-1.8	-2.9
WINTER																
Stat 1	-2.4	-4.7	-6	-2.7	-3.7	-6.4	-4.8	-5.8	-6.3	-4.3	-5.7	-5.6	-5.2	-6.3	-4.3	-5.7
Stat 2	-0.8	-3.4	-5	-1.6	-3	-5.5	-3.5	-4.8	-5.7	-3.4	-4.7	-5.1	-4.1	-5.7	-3.4	-4.7
Stat 3	-2.6	-3.8	-4.2	-2.5	-3	-4.3	-3.8	-4.4	-4.2	-3.5	-4.3	-3.7	-3.8	-4.2	-3.5	-4.3
Stat 4	-1	-2	-1.8	-1.6	-1.7	-2.7	-2.1	-2.7	-2.6	-2.1	-2.8	-2.2	-2.1	-2.6	-2.1	-2.7
Stat 5	-0.7	-2.2	1.4	-1.1	-2.2	-2	-1.9	-3.3	-1.7	-2.3	-3.9	-0.4	-1.9	-1.7	-2.3	-3.9
Stat 6	1	-1.4	-2.3	-0.1	-0.2	-2.1	-1.8	-2.7	-2.5	-1.9	-2.6	-1.5	-1.9	-2.5	-1.9	-2.6
Stat 7	-1.1	-3.2	-3.8	-1.9	-2	-4.5	-3.4	-4.3	-4.6	-3.4	-4	-3.8	-3.6	-4.6	-3.4	-4.3
YEAR																
Stat 1	-1.3	0.1	-1.2	-1.4	-1.1	-1.9	-2.5	-2.5	-1.9	-2.9	-2.4	-3.5	-1.9	-2.5	-2.5	-1.9
Stat 2	-0.9	0	-0.9	-0.7	-1.1	-1.7	-1.8	-2.2	-1.9	-2.2	-2.2	-2.9	-1.8	-2.2	-2.2	-2.9
Stat 3	-0.1	-1.4	-1.9	-0.5	-1.8	-2.2	-1.3	-2.7	-2	-1.5	-2.7	-3	-1.8	-2	-1.5	-2.7
Stat 4	0.2	0	0.2	-0.2	-0.6	-0.6	-0.5	-1.4	-0.7	-1	-1.4	-1.3	-0.6	-1	-1.4	-1.3
Stat 5	3	-0.7	6.4	0.8	-1.6	2.1	0.3	-2.5	1.9	0.1	-2.7	1.2	0.6	-2.7	1.2	0.6
Stat 6	1.3	-0.5	-0.5	0.3	-0.8	0	-1	-2.2	-0.6	-1.3	-2.5	-2	-0.7	-0.6	-1.3	-2.5
Stat 7	0.7	-2.2	-1.7	-0.4	-2.4	-2.5	-1.4	-3.6	-2.4	-1.8	-3.5	-3.8	-2.3	-2.4	-1.8	-3.5

For the summer, models overestimated the observed *MDS5* at all stations, except at the Southern Adriatic Station (Stat 7), where *MDS5s* are almost the same. The largest overestimation of *MDS5* reaches six days at mountainous littoral (Stat 5), while, for the rest of the stations, an overestimation of one day is found (Figure 7). The longest/shortest *MDS5* are simulated by regional climate models forced by HA/CN, while the most successful simulation was performed by EC-CCLM4. The largest overestimated values of *MDS5* are found in the mountainous littoral (Stat 5) for all RCA4 and RegCM4 combinations (up to 27 days), and the largest underestimation is found at the South Adriatic station (Stat 7) for all CCLM4 combinations (up to six days) (Table 5).

In the autumn, the *MDS5* durations are generally underestimated with model simulations, most at the continental Stat 1 (by three days), while the best estimation is found at the Stat 5 (Figure 7). Regarding the GCM-RCM combination, the largest underestimation is also found at Stat 1 (up to five days) for HA/EC/CN-RegCM4 and CN-CCLM4. However, an overestimation is found only at Stat 5, with the largest deviations obtained by HA-RegCM4 (4 days) (Table 5).

Finally, the largest differences between the models and observations are found for the winter season, with the simulated ensemble *MDS5* underestimation ranging from two (Stat 4–6) to five days (Stat 1) (Figure 7 and Table 5). The smallest deviations are found for HA-RCA4, and the largest are found for all RegCM4 combinations (for Stat 1 about six days) (Table 5).

Annual *MDS5s* are underestimated by the models by up to two days at all selected stations, except at the station of Rijeka (Stat 5) where, in total, *MDS5* are only slightly overestimated (Figure 7). The smallest deviations are found for the EC-RCA4 combination. Further, the best estimation is simulated for Stat 4, while the worst simulation is obtained for Stat 5 (6 days overestimation for HA-RegCM4 combination) (Table 5).

Focusing only on the model results, it can be seen that the driest season at all stations is summer (red symbols in Figure 7) with the longest *MDS5* duration along the Adriatic coast

(Stat 6 and 7) and mountainous littoral (Stat 5). On the other side, the autumn and winter are the wettest seasons at all stations. At the continental and mountainous stations (Stat 1, 2 and 4), the *MDS5* in the spring and in the cold part of the year are of similar duration (Figure 7). Although models show limitations in reproducing the details of the local dry spell duration characteristics when compared to the observations, they do reproduce the main seasonal and spatial differences over the domain.

3.3.3. Evaluation of Regional Climate Models: The Effects of the RCM and GCM Combination

In this subsection, we will briefly discuss the behaviour of specific regional models (RC4, CCLM4 and RegCM4) and the impact of boundary forcing by the CMIP5 global models (HA, EC, MP and CN).

- *RCMs Forced by HA*

Generally, the smallest deviation in the spring and a year are simulated by CCLM4, and in the autumn and winter by RCA4. However, in the summer, continental stations (Stat 1 and 2) are better simulated by RCA4 and Adriatic stations (Stat 5–7) by CCLM4. The smallest deviation and the smallest differences between RCM simulations are found at Stat 4, while the largest are at Stat 5 (Table 5).

- *RCMs Forced by EC*

The smallest deviation for most of the stations is simulated by CCLM4 in the summer, and by RCA4 in the autumn, winter and for a year. In the spring, half of the stations are better simulated by CCLM4 and half with the RCA4, though the CCLM4 slightly underestimates the *MDS5*. The smallest deviation and the smallest differences between RCM simulations are found at Stat 4 in the spring, at Stat 2 in the summer and at Stat 6 in the cold seasons and a year, while the largest are found at Stat 5 (Table 5).

- *RCMs Forced by MP*

RCMs forced by MP show a similar simulation pattern to one simulated by RCMs forced by EC, though deviation values are generally lower. While CCLM4 underestimates the *MDS5* in all seasons and at all stations, RCA4 and RegCM4 overestimate them at most stations in the warm part of the year, and at Stat 5 in the autumn and a year (Table 5).

- *RCMs Forced by CN*

CCLM4 and RegCM4 show similar simulation patterns of underestimation of *MDS5* in all seasons and at all stations, except at Stat 5, where RegCM4 shows overestimation. In the cold part of the year and for a year, RCA4 also shows underestimation at all stations but with a smaller amplitude than the other two RCMs. However, in the warm part of the year, no clear pattern of the errors was found. The smallest deviations and the differences between RCM simulations are generally found at Stat 4 and 6 in all seasons. Furthermore, *MDS5* at continental stations (Stat 1 and 2) in summer are very well-simulated by CCLM4 and RegCM4 (Table 5).

In summary, we document that the quality of the RCM results depends on several factors: (1) the selection of the RCM with its specific parameterizations and dynamical core implementations, (2) the selection of GCM boundary condition and underlying strength in the climate change signals, (3) season within the year and (4) the location in space within our domain of analysis with its specific topographic setup and distance from the coast and sea impacts. In this analysis, no single RCM-GCM combination was superior in terms of low systematic errors in all cases, and the use of the ensemble is supported as the appropriate approach when estimating the local historical climate from the regional climate models.

3.3.4. Future Climate: General Overview

After examining the model systematic errors during the historical period, the climate change signal in *MDS5* duration is presented. It is determined as the differences in

MDS5 duration between the first future period, P1 (2011–2040), the second future period, P2 (2041–2070) and the historical period, P0 (1971–2000). The results are presented as a median difference between the two mentioned periods for twelve different GCM–RCM combinations of 30-year mean values of *MDS* for the two emission scenarios separately (Figure 8).

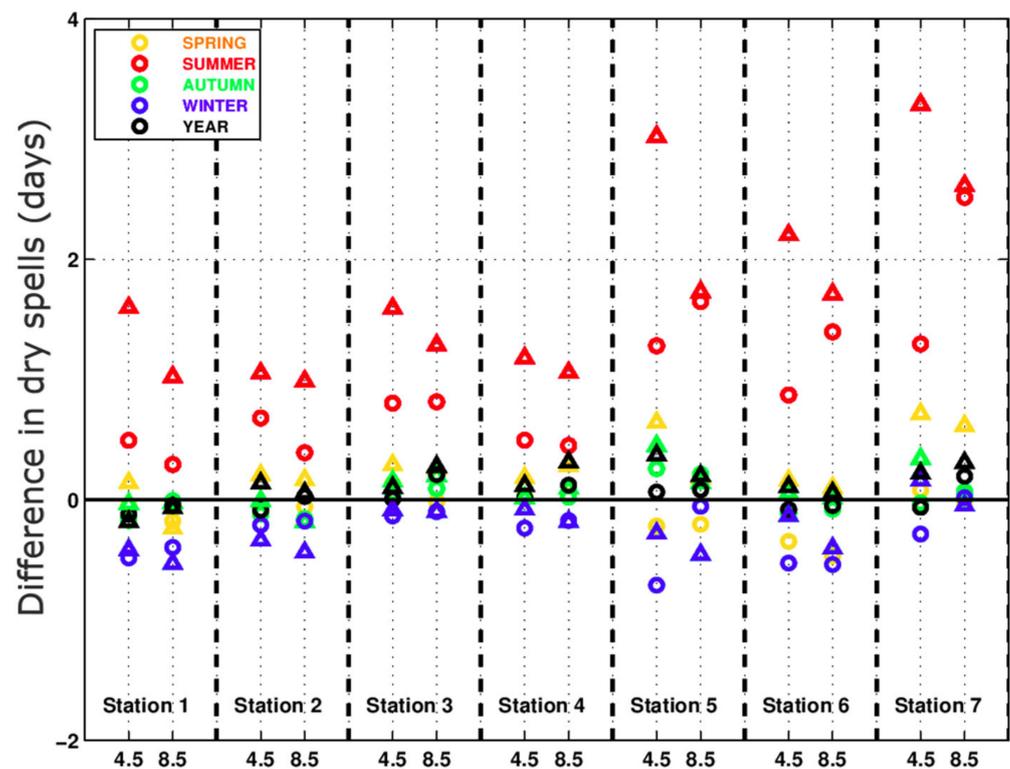


Figure 8. The median difference in *MDS5* duration between two future periods and historical period for RCP4.5 and RCP8.5 scenarios, for seven stations. The circles refer to the period P1 (2011–2040) vs. P0 (1971–2000) and triangles refer to the second period P2 (2041–2070) vs. P0. Seasons are distinguished by different colours. For each station, left symbols present results for RCP4.5, while right symbols present results for RCP8.5 scenario. The corresponding differences in *MDS5* (in days) are given on the vertical axis.

The climate change signal of the simulated *MDS5* is analysed in two ways. In the first subsection, the focus is on the difference in *MDS5* duration between the first future period and historical period (P1–P0) and between the second and first future period (P2–P1) for each scenario, while in the second subsection, the focus is on the difference in *MDS5* duration between two scenarios (RCP8.5–RCP4.5) for each future period. The differences between -0.5 and 0.5 are considered very low in both cases.

3.3.5. Future Climate: The Amplitude of the Climate Change Signal in Different Future Periods

- *Differences between P0 and P1*

The difference in *MDS5* duration between P1 and P0 in spring is very small, mostly around 0, and slightly negative for both scenarios at Stat 5 and 6 (Figure 8). *MDS5* duration increase for summer is very pronounced in simulations for all stations and is around one day for RCP4.5 and up to 2.5 days for RCP8.5 scenario (Figure 8, Table 6). The largest increase in *MDS5* for RCP4.5 is simulated by HA-RegCM4, around six days, and for RCP8.5 by MP-RegCM4, almost nine days. Nevertheless, a negative signal is found for RCP4.5 simulated by HA-RCA4 at Stat 5–7 for up to three days (Table 6). On the other hand, no signal is found in autumn for neither scenario. Decreasing signal in *MDS5* duration for

the winter is generally weak but slightly more negative for RCP4.5 scenario. On an annual time scale, the results are similar as for the autumn (Figure 8).

Table 6. The difference in MDS5 duration between first future period and historical period (P1–P0), and between second and first future period (P2–P1) for RCP4.5 and RCP8.5 scenarios, for seven stations for the summer.

SUMMER	HA			EC			MP			CN			Ensemble
	RCA4	CCLM4	RegCM4										
RCP4.5, P1–P0													
Stat 1	-0.8	0.3	4.1	-0.6	0.8	4.2	0.1	0.4	1.6	0.5	0.3	0.8	0.5
Stat 2	-0.4	1.5	4.9	-0.1	0.3	3.3	0.2	0.9	1.9	0.4	0.1	1.0	0.7
Stat 3	-0.5	1.5	4.1	0.9	-0.2	2.1	0.1	1.0	2.4	0.7	0.3	0.5	0.8
Stat 4	-0.2	1.0	4.0	-0.1	-0.1	2.2	0.0	0.8	1.6	0.5	0.1	0.5	0.5
Stat 5	-2.4	1.3	3.3	3.9	0.0	4.6	0.6	0.6	5.7	2.0	0.3	1.3	1.3
Stat 6	-3.0	2.3	4.7	1.3	0.6	2.0	1.0	0.8	3.5	-0.2	0.0	0.1	0.9
Stat 7	-1.3	0.2	6.3	1.4	-0.1	1.4	1.2	1.5	4.4	1.7	0.4	0.5	1.3
RCP8.5, P1–P0													
Stat 1	0.7	6.5	0.9	-0.1	0.1	2.5	0.3	-0.2	1.8	0.0	0.3	-0.3	0.3
Stat 2	0.5	3.4	3.1	-0.2	0.4	3.1	0.3	0.2	2.4	0.1	0.4	0.3	0.4
Stat 3	1.8	3.6	2.9	1.0	0.6	2.4	0.3	0.2	1.3	-0.2	0.4	0.3	0.8
Stat 4	1.2	3.0	2.0	0.2	0.3	2.2	0.2	0.3	1.7	0.1	0.6	0.1	0.5
Stat 5	6.4	2.8	4.6	4.9	0.3	5.8	0.5	-0.1	8.8	-1.5	0.2	-0.4	1.7
Stat 6	1.7	6.8	5.4	2.4	1.1	3.4	0.5	-0.2	3.1	-1.0	-0.1	-0.5	1.4
Stat 7	2.7	4.4	3.7	4.1	0.7	3.3	2.3	-0.2	3.8	-0.4	1.2	-0.8	2.5
RCP4.5, P2–P1													
Stat 1	2.3	8.4	6.3	1.1	0.9	-1.7	0.2	0.8	-1.6	-0.1	1.4	1.0	1.0
Stat 2	0.8	7.8	5.8	0.3	1.6	-1.4	0.5	0.3	-0.8	-0.5	0.9	-0.4	0.4
Stat 3	3.4	7.2	0.3	1.5	1.9	-0.4	1.4	0.5	-1.5	-0.8	0.7	0.1	0.6
Stat 4	0.9	5.3	2.4	0.5	1.4	-0.2	1.3	0.3	-0.1	-0.3	0.4	-0.1	0.5
Stat 5	7.0	5.9	9.8	4.0	2.1	4.7	2.0	0.0	-2.3	-1.3	0.1	-1.1	2.1
Stat 6	3.8	7.0	6.0	4.3	2.4	1.0	0.7	0.5	-0.8	-0.5	0.5	-0.1	0.9
Stat 7	3.8	5.4	1.7	6.0	4.4	3.6	2.5	0.6	-1.5	-0.9	0.6	0.2	2.1
RCP8.5, P2–P1													
Stat 1	0.4	1.0	5.2	0.3	0.4	1.5	1.0	1.1	0.5	-0.4	0.0	0.6	0.6
Stat 2	0.4	3.7	2.3	0.0	0.7	-0.8	0.4	1.0	-0.8	-0.3	-0.2	-0.2	0.2
Stat 3	1.3	5.0	1.6	1.1	0.6	-1.2	1.4	1.1	-0.1	-0.8	0.4	-0.1	0.9
Stat 4	0.3	2.5	2.7	0.4	0.7	-0.4	0.6	0.8	0.0	0.0	-0.2	0.0	0.4
Stat 5	-5.4	3.0	6.0	1.9	0.8	2.4	1.9	1.0	-4.4	1.0	0.2	1.5	1.3
Stat 6	-2.7	1.8	7.0	1.0	-0.6	0.0	1.9	1.2	0.3	-0.3	0.3	0.3	0.3
Stat 7	0.4	1.3	3.5	0.7	0.3	-2.2	3.6	2.4	0.3	0.3	-0.4	0.1	0.4

• Differences between P1 and P2

In the spring, the largest prolongation in MDS5 duration of almost one day is found at Stat 5 and 7 for the RCP4.5 scenario. MDS5 durations at the rest of the stations are expected to be similar in both periods and scenarios (Figure 8). An increase in MDS5 duration for the summer is very pronounced for all stations. The difference between P1 and P2 for RCP4.5 is from one to two days for all stations except at the continental Stat 2, where it is lower. For RCP8.5 the prolongation is around one day at Stat 1, 3 and 5, while at other stations it is close to 0. Generally, the largest MDS5 prolongation in P2 compared to P1 is simulated by HA for all stations, and by HA-RegCM4 combination the difference reaches 10 days at Stat 5 for RCP4.5 and seven days at Stat 6 for RCP8.5. Nevertheless, the largest shortening of MDS5 is found at Stat 5 (by around five days) for RCP8.5 and HA-RCA4 (Table 6). On the other hand, in autumn and winter (except at Stat 5–7 for RCP4.5), and as well on the annual basis, there are no significant differences in MDS5 duration between two future periods for neither station nor scenario (Figure 8).

In general, there is no clear signal in the change of MDS5 duration in the future for spring and autumn, for summer an increasing signal is substantial, while for winter it is slightly negative. As a result, the signal for the whole year is neutral on the level of the RCM ensemble. The tendency of the dry spell duration increases during the summer season and duration decrease during the winter season is generally consistent with the mean summer precipitation decrease over southern Europe in climate model projections [27].

3.3.6. Future Climate: The Impacts of the RCP Scenario Selection

The results of the ensemble for spring show that there is no significant difference between the two scenarios for neither future period (Figure 8). The situation in summer is not straightforward and it differs for each period. For the first period (P1), MDS5 duration

is around one day longer for RCP8.5 than RCP4.5 at the Adriatic coastal stations (Stat 6 and 7), while for other stations no significant changes were detected. In the second period (P2), *MDS5* duration is from one (Stat 5 and 6) to two days (Stat 7) shorter for RCP8.5 than RCP4.5 (Figure 8, Table 6). The largest difference is found for Stat 5 and HA-RCA4 for which the *MDS5* duration is expected to be nine days longer for RCP8.5 than RCP4.5 in the first period, and around 12 days shorter in the second period compared to the historical period. The smallest differences in *MDS5* duration between P1/P2 and P0, as well as between scenarios are simulated by CN (Table 6). The difference between scenarios in autumn is not significant for neither period. In winter, an increase of around one day is marked for the first period at Stat 5. Besides that, no notable difference is recorded. Generally, on the annual basis, no significant differences in *MDS5* durations between the two scenarios period is found in the future (Figure 8).

4. Discussion and Conclusions

The analysis of mean and maximum dry spells defined with the 5 mm daily precipitation threshold was performed on a seasonal and annual basis for seven regions in Croatia during the period 1961–2015. Generally, the shortest *MDS5* occur in the mountainous region (Reg 4), and the longest *MDS5* in the continental region in the cold part of the year (autumn, winter), and in the Adriatic region in the warm part of the year (spring, summer). While the distribution of *MDS5* is generally uniform within each region, for *MxDS5*, the larger differences between stations within each region are apparent, emphasizing the spatial and temporal variability of precipitation pattern. The reason for that lies mostly in the prevailing circulation patterns which pose a different influence on the dry spell's duration [7,36].

An increasing trend in the observed *MDS5* was found in the warm part of the year (spring and summer), which is significant in the mountainous littoral (Reg 5) and North Adriatic coastal region (Reg 6). On the other hand, no clear trend in *MDS5* was found in the cold part of the year. Consequently, on the annual basis, an increase of *MDS5* prevailed, being statistically significant in Reg 5 and Reg 6. These results suggest that positive trends in *MDS5* found in spring for the period 1961–2000 by Cindrić et al. [11] continued in the following 15 years. However, the pronounced summer increase of *MDS5* along the Adriatic coast detected here was not observed in the previous period. It confirms drying tendencies in the Mediterranean region [9,37].

An increasing trend in *MxDS5* was also found in the warm part of the year, and it was particularly pronounced along the Adriatic coast (Reg 5–7). A coherent negative trend pattern of *MxDS5* during autumn was found here similarly as in Cindrić et al. [11]. In the recent period, the autumn negative trend is significant in the mountainous region (Reg 4) suggesting an increase in the frequency of wet days with cumulative precipitation reaching 5 mm. A negative trend in *MxDS* in autumn was also found at 98% of the stations in the Rhine basin with a large number of significant trends [38]. In winter there was no clear trend. Overall, the obtained results support the estimates of Heinrich and Gobiet [39] that southern Europe is most probably facing an increased risk of longer, more frequent, severe and, also, widespread droughts.

Breinl et al. [14] analysed the trends in annual extreme dry (and wet) spells with a daily precipitation threshold of 0.1 mm on a global scale. From their results for Europe, there is no clear sign in the trend of DS in Croatia but there are indications of longer DS along Adriatic and shorter durations in the continental region, which is in accordance with our results, even though the definitions of DS are different.

The results of partial trend methodology revealed an increase in the very long *DS5* (above 90th percentile) in the recent half of the analysed 55-year period in all seasons, except in autumn. The largest prolongation is found in winter at continental stations (Stat 1, 2, 4 and 5) and in summer along the Adriatic coast (Stat 6–9) and the Central hinterland (Stat 3), while the largest shortening is found in autumn. One can also notice that *DS5* duration tend to be generally longer at Southern Adriatic stations (Stat 7–9). On the other

hand, large differences in short and medium *DS5* duration between the two analysed periods were not detected. These prolongations and shortening in a particular season are in line with the trend results for *MDS5* and *MxDS5* for the whole 55-year period, pointing that the pronounced trends are mainly affected by the longest *DS5* duration. Since the station of Svetac is located on a small, isolated island Svetac in the Middle Adriatic, it reflects a typical decreasing precipitation trend found in the Mediterranean basin [37]. Furthermore, a positive trend of the maximum *DS5* implies a long absence of precipitation which leads to an increase in atmospheric evaporation and soil water demand causing an increase in drought severity and its impact on various environmental systems ([9] and reference therein).

MDS5 simulated by the RCM ensemble is the closest to the observations at the mountainous station (Stat 4) in spring and a year, at Southern Adriatic station (Stat 7) in summer, at the mountainous littoral (Stat 5) in autumn and Northern Adriatic station (Stat 6) in winter. Although the seasonality of each region is apparent in the observations, the climate model simulations present summer as the driest season at all stations with the longest *MDS5* duration along the Adriatic coast (Stat 6 and 7) and mountainous littoral (Stat 5). On the other side, autumn and winter in models are the wettest seasons at coastal stations, confirming the level of realism in applied models.

The most successful model combination depends on season and location, and no RCM-GCM combination outperforms in all cases. The smallest differences between RCMs are found for central hinterland and mountainous region (Stat 3 and 4) for all seasons and a year, while for the mountainous littoral (Stat 5) results vary the most. One of the reasons for that is the fact that mountainous littoral (Stat 5), and as well Adriatic coastal region (Stat 6 and 7) are directly connected to the Adriatic Sea. Since the model resolution is 12.5 km, the models' results are definitely influenced by the complex orography and land-sea contrast.

The projected summer increase of *MDS5* duration is pronounced for all stations (Figure 8), especially in the simulations of the HA-CCLM4 and HA-RegCM4 model combinations, with the largest increase in *MDS5* being six and seven days in the first future period (P1–P0) and ten and seven days in the second future period (P2–P1; Table 6). The longest *MDS5* are in both cases simulated by HA, which is one of the generally dry and warm CMIP5 models in terms of the systematic errors during summer [40,41]. The increase in *MDS5* in summer between two 30 years periods (1961–1990 and 2070–2099) for the entire southern part of Europe and much of central Europe as well as the fact that the length of hot and dry spells is particularly strong and statistically significant for southern Europe is also found in Kundzewicz et al. [42]. An increase in *MDS5* durations in summer is also in agreement with the general reduction of the summer total precipitation amount in projections in these regional models [27]. However, it can be noticed that the summer increase depends more on the selection of future periods than on the scenario at the selected locations. Decreasing signal in *MDS5* duration for winter is weak (Figure 8), but it is likely connected with an increase in the total mean daily precipitation projections for winter (e.g., [43]). For spring, autumn and year there is no clear climate change signal during the two analysed future periods, although results generally show a small increase in *MDS5* duration for the second period (Figure 8).

One of the key issues of simulating precipitation in climate models is the representation of cloud and precipitation processes since they occur at scales smaller than the resolution of current GCMs and RCMs and therefore are very difficult to simulate [44]. Differences between observations and different GCM–RCM simulations are larger in the warm part than in the cold part of the year (Table 5). Differences in future periods between simulations of a single RCM (forced by different GCMs) are smaller in summer than in winter when the smaller differences are found between RCMs forced by a single GCM choice (not shown). This suggests that the RCM's formulation and parameterizations of small-scale processes are more important in the warm part of the year, especially in summer, while the large-scale processes in GCMs are more dominant in the cold part of the year, especially in winter [43].

In some regions, e.g., in the Alps, a connection between a decreasing trend in the length of very long (above 95th percentile) DS and the increasing number of all DS was found [27]. On the other hand, in the Mediterranean, some regions (e.g., Iberian Peninsula) are affected by an increase both in the number and the duration of the very long dry spell events by the end of the twenty-first century, while other sub-regions (e.g., Balkans) are affected by an increase in the number of the very long dry spell events, but not in their duration [12].

These results motivate and encourage us to further analyse a connection between changes in the length and frequency of DS in Croatia. In future studies, an analysis of a connection between governing weather types and the length of dry spells would also be of great interest.

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