

New 1981–2010 climatological normals for Croatia and comparison to previous 1961–1990 and 1971–2000 normals

[full paper]

Irena Nimac and Melita Perčec Tadić
Meteorological and Hydrological Service of Croatia
Zagreb, Croatia
irena.nimac@cirus.dhz.hr

Abstract— Mean values of climate parameters (climatological normals) provide an insight into the climate characteristics of the region. Comparison of climate parameters for different 30-year periods can gain an insight into the stability of climate conditions of some area or their variability may be an indication of climate change. In this paper, daily precipitation amount and daily temperature data from 20 meteorological stations in Croatia are used to calculate climatological normals for three 30-year periods (1961–1990, 1971–2000 and 1981–2010). Although Croatia is relatively small country, large topographic variety, openness towards Pannonian Plain and position along the Adriatic Sea define different regions, so the selection of stations is in accordance with that. Spatial distribution of annual and seasonal climatological normals of temperature and precipitation amounts is shown for each period. Relative changes of temperature and precipitation amounts between three 30-year periods are calculated and presented at annual and seasonal scales. Important temperature and precipitation indices, like number of cold or warm days and number of days above some precipitation threshold are discussed in the climate change context.

Keywords— *climatological normals; temperature; precipitation; indices; climate change.*

I. INTRODUCTION

Climate is defined through the mean or the variability of weather conditions expressed by mean values, extremes and variability of climate variables in a longer period over some area. As defined in [1], climatological normal (CLINO) is the average value of climatological data computed for relatively long period, at least 30 years, while normals calculated for following consecutive 30-year periods, 1901–1930, 1931–1960, etc are called climatological standard normals.

In calculating climatological normal for a station, data record for 30 year period should meet certain requirements like homogeneity and completeness. Regarding homogeneity; changes in location, instruments or observation procedures that would influence result are unwanted, while regarding completeness; records should be complete with no missing values since normals calculated from incomplete datasets can

be biased. In case of missing data it is also mentioned [2] that normals should be calculated only when values are available for at least 80% of the years of record with no more than three consecutive missing years.

A 30-year period is used as long enough to filter out short-term interannual fluctuations or anomalies, but sufficiently short to be able to show long term climatic trends. Besides being a measure to which recent or current observations can be compared, climatological normals also serve as estimate of conditions most likely to be experienced at given location [3]. Heaving in mind those two purposes, it is obvious that when normals are used as a reference it is convenient to have standard period that is not changing frequently. On the opposite, when estimating the most expected value for the climatic element that is experiencing a trend, like e.g. temperature during recent decades, predictive accuracy is improved by updating the averages frequently.

Many studies have shown that 30 year is not optimal averaging period for normals when used for estimation of the most probable value of the climatological element. Optimal period for temperatures is often shorter, while for precipitation is greater than 30 years [3]. In global climate change research [4] where shifts in some teleconnection indexes and shifts in Köppen climates were analyzed, the optimal averaging period of at least 15 years is statistically suggested as representative for climatological mapping. Research was based on CRU monthly mean temperature and precipitation data set on 0.5° spatial resolution. Following that results, the 25-years moving averages were applied to the observed and projected monthly temperature and precipitation data from four emission scenarios producing 176 Köppen-Geiger climatic maps [5] used for estimating the effect of climate change on patterns of climate classes.

Last few decades climate change is important topic, not only among atmospheric scientists, since climate change affects human health, agriculture, industry and tourism. Further on, it is not easy to assess its influence or to validate and compare the different climate models outputs. It has been demonstrated that climate classes can be a used to verify the

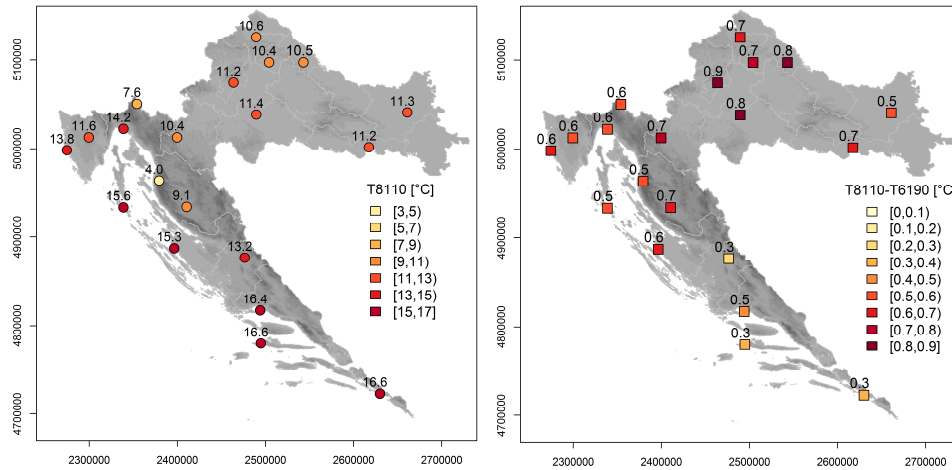


Fig. 1. Temperature climatological normals for latest period 1981–2010 (left) and differences from the standard 1961–1990 period (right). Statistically significant differences at 95 % confidence level are marked with squares.

output of GCM [6] or to serve for model intercomparison to investigate a climate change in Europe [7].

II. DATA AND METHODS

A. Area of interest

Climate in Croatia is determined by its geographical position and medium and large atmospheric circulation systems that does not affect equally all parts of the country [8]. Main climate modifiers are Adriatic and Mediterranean Sea, orography of Dinarids with its shape, altitude and position towards the prevailing flow and openness of the northeastern parts towards Pannonian Plain. Therefore, three main climatic regions in Croatia are continental, mountain and maritime. Mainland of Croatia has moderate continental climate with variety of weather situations and frequent and intensive changes during the year, as it is in a circulation area of mid-latitudes. At higher altitudes climate is mountain and differs from wider area by its lower air temperatures and heavy snowfall. Coastal area is also in mid-latitudes circulation zone, but in summer this area comes under the influence of the subtropical zone as Azorean anticyclone prevents cold air outbreaks to the Adriatic.

According to Köppen climate classification, defined by mean annual temperature course and precipitation amount, most of the Croatia has warm temperate rainy climate with temperature of the coldest month higher than -3°C and lower than 18°C (symbol *C*) [8]. Only highest mountainous areas (>1200 m asl) have a snow-forest climate with average temperature of the coldest month below or equal to -3°C (symbol *D*). Continental part has *Cfbw* climate with average temperature of the warmest month of the year below 22°C (warmer summer, *b*), no extremely dry months during year (*f*) while month with the lowest precipitation amount is in the cold part of the year (*w*) and two maxima in the annual precipitation course (*x*). Lower mountainous areas have climate class *Cfsbx* with the highest monthly precipitation in the cold part

of the year (*s*), while highest areas have *Dfsbx* climate. In accordance with mentioned diversity of climate conditions, selection of the stations used in this study is representative.

B. Data and methods

Data used in this study are daily data from 20 meteorological stations which are part of meteorological network of Meteorological and Hydrological Service of Croatia (DHMZ). Selected stations have time series long enough to cover observed 50-year period. Within activities of DHMZ, regular processing and control of the data is carried out. Daily mean temperature is calculated from measurements at 7 am, 2 pm and 9 pm local time, while precipitation daily amounts are measured at 7 am. Few stations had some missing data which were interpolated according to the records of the nearby representative station.

In this work focus is on the analysis of changes in climatological normals of temperature and precipitation amount for three different 30-year periods: 1961–1990 (6190), 1971–2000 (7100) and 1981–2010 (8110). Statistical significance of the temperature change between latest and first observed period will be tested with two sample Student's *t*-test for differences of mean, while for precipitation significance will be tested with Wilcoxon rank-sum test which is nonparametric [9]. Due to 10-year overlapping between those two periods, one of the assumptions that require independence is not fully satisfied. Beside changes on the annual scale, we will examine the seasonal changes and changes in some temperature and precipitation indices, such as number of cold and warm days and number of days above certain precipitation threshold.

Besides statistical measures applied on the temporal series, the long-term temperature and precipitation series are the basis for determining of Köppen-Geiger climate classes. This has been done in R statistical framework [10] using the ClimClass library [11].

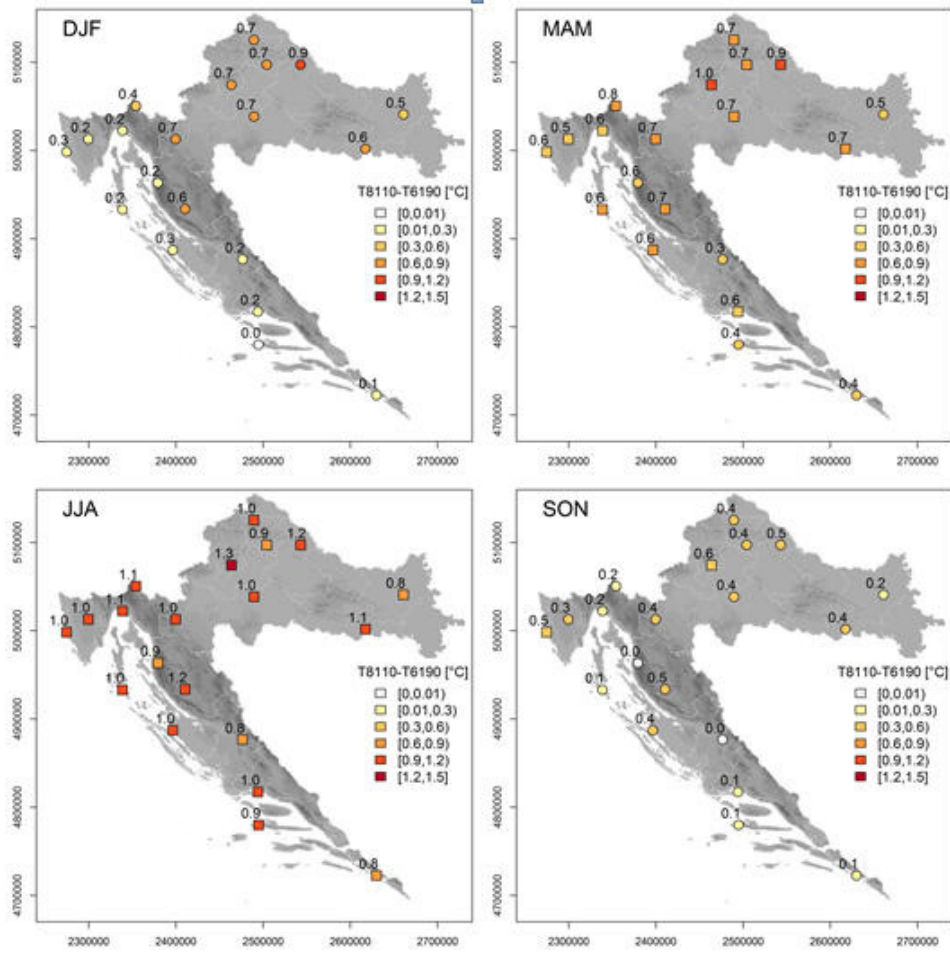


Fig. 2. Seasonal changes in temperature climatological normals between latest 1981–2010 and standard 1961–1990 period for winter (DJF), spring (MAM), summer (JJA) and autumn (SON). Statistically significant differences at 95 % confidence level are marked with squares.

III. RESULTS

A. Temperature

The factors that mostly influence air temperature are the ground surface by either warming or cooling the air, as well as heat radiation of the air itself. Therefore, beside general atmospheric circulation and geographical latitude, spatio-temporal characteristics of air temperature in Croatia are mainly influenced by land-sea distribution because of the difference in heat accumulation, and by elevation. Hence, the highest average 30-year values of temperature, up to 16.6°C, occur at southern coastal area where sea is warming the air in the winter, while the lowest temperatures (4°C) are in the mountains because of temperature decrease with height (Fig. 1 left).

Comparison of mean temperature for latest normal period (T8110) to the standard climatological period 1961–1990 (T6190) shows significant increase in mean temperature at all observed stations (Fig. 1 right). Changes are larger in continental mainland, while lower differences occur at the coast, especially at southern part. Such result is in agreement with stronger heating of the land, while response on the coast is

weaker due to more inert changes of the sea temperature. Comparing average temperatures differences between two consecutive periods (7100-6190 and 8110-7100), it is obtained that warming during the latter period was stronger (Tab. 1).

TABLE I. AVERAGE DIFFERENCES IN MEAN ANNUAL AND SEASONAL TEMPERATURE, MEAN MAXIMAL AND MINIMAL TEMPERATURE AND AVERAGE CHANGES IN NUMBER OF DAYS WITH TEMPERATURE ABOVE OR BELOW CERTAIN TRESHOLD

	Comparing periods		
	7100-6190	8110-7100	8110-6190
$\Delta T_{ANN} [^{\circ}C]$	0.2	0.4	0.6
$\Delta T_{DJF} [^{\circ}C]$	0.5	0.0	0.4
$\Delta T_{MAM} [^{\circ}C]$	0.2	0.4	0.6
$\Delta T_{JJA} [^{\circ}C]$	0.4	0.6	1.0
$\Delta T_{SON} [^{\circ}C]$	-0.1	0.4	0.3
$\Delta t_{max} [^{\circ}C]$	0.3	0.4	0.7
$\Delta t_{min} [^{\circ}C]$	0.2	0.4	0.6
$T_{min} \leq -10^{\circ}C$	-1.3	0.3	-1.0
$T_{max} < 0^{\circ}C$	-1.9	0.0	-1.8
$T_{min} < 0^{\circ}C$	-1.2	-1.9	-3.1
$T_{max} \geq 25^{\circ}C$	3.6	6.4	10.0
$T_{max} \geq 30^{\circ}C$	2.8	5.9	8.7
$T_{min} \geq 20^{\circ}C$	1.8	3.5	5.2

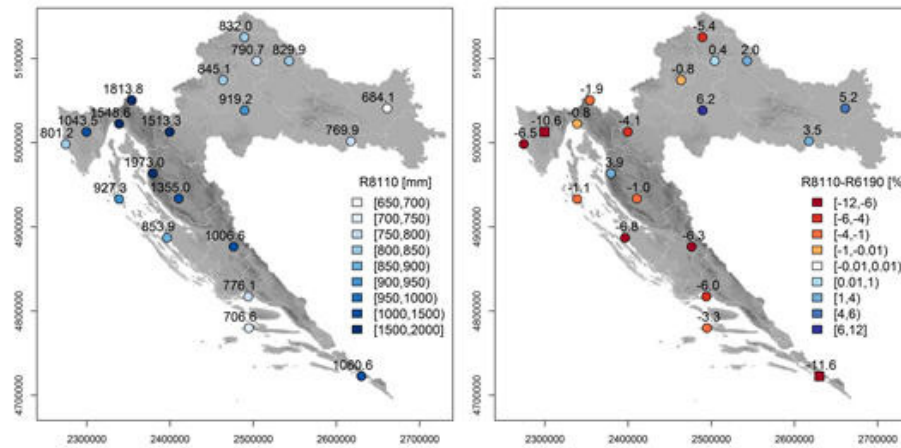


Fig. 3. Precipitation climatological normals for latest period 1981–2010 (left) and relative differences comparing to standard 1961–1990 period (right). Statistically significant differences at 95 % confidence level are marked with squares.

Such result is in accordance with [12] where decadal temperature trends in period 1961–2010 from 41 daily temperature and 137 daily precipitation series were examined. The increase in mean annual temperature was shown significant at all stations, with stronger warming in continental area than along the coast.

Looking at seasonal changes of T8110 comparing to T6190, the temperature increased in all seasons and at almost all stations (Fig. 2). Temperature change is the largest in summer, around 1°C, and significant at all stations. Spring temperature increase is also significant at most of the stations, but weaker than in summer, from 0.4–1.0°C. Such increase is result of successive warming, stronger in later periods (Tab. 1).

In colder part of the year, autumn and winter, increase is stronger inland but those changes are not statistically significant. In [12], seasonal analysis of decadal trend showed that in summer and spring warming is significant at most of the stations, while winter increase is significant only in central inland and at few stations of coastal hinterland.

Another indicator of warming is increase in mean maximal and minimal air temperature (Tab. 1), larger between two more recent 30-year periods, 8110-7100. Spatial distribution of changes (not shown) suggests larger amplitudes in inland and mountains, and lower at coastal region, which is also in accordance with results from [12].

Some of temperature indices were also examined such as number of tropical nights ($T_{\min} \geq 20^\circ\text{C}$), warm days ($T_{\max} \geq 25^\circ\text{C}$), hot days ($T_{\max} \geq 30^\circ\text{C}$), icy days ($T_{\min} < 0^\circ\text{C}$), frosty days ($T_{\max} < 0^\circ\text{C}$) and days with minimal temperature below or equal -10°C . Due to larger occurrence of tropical nights and hot days along the coast, and icy and frosty days in mountainous and continental area, amplitudes of changes follow that pattern. Analysis of changes of different temperature indices between latest and standard 30-year period shows increase in warm and decrease in cold indices (Tab. 1). Comparison of consecutive periods shows that for warm indices such positive changes are result of successive increase,

larger between latest periods, while for some cold indices slight increase occurred at few stations comparing last two 30-year periods.

B. Precipitation

Precipitation in Croatia is mostly result of passing cyclones and related atmospheric fronts which does not affect equally all parts of country [8]. Occurrence, amount and location of precipitation depend of humidity of the air mass, intensity and direction of the air current, and of the vertical component of its movement. Formation of the clouds and development of precipitation can be significantly intensified by some local factors such as distance from the sea and orography. While orography of the Dinarids represents an obstacle for maritime air masses moving toward mainland and for continental masses moving toward the coast, at the same time it can enhance convection and formation of clouds and intensified precipitation. In [13], they analyzed daily precipitation amount of wider Alpine region with purpose of making high resolution maps (5 km). Large area of Croatia was included in analysis, except most southern Dalmatia and eastern part of Slavonia.

TABLE II. AVERAGE RELATIVE DIFFERENCES IN ANNUAL AND SEASONAL PRECIPITATION AMOUNT AND AVERAGE CHANGES IN NUMBER OF DAYS WITH DAILY PRECIPITATION AMOUNT ABOVE CERTAIN TRESHOLD

	Comparing periods		
	7100-6190	8110-7100	8110-6190
ΔR_{ANN} [%]	-2.1	-0.2	-2.2
ΔR_{DJF} [%]	-6.2	3.1	-3.2
ΔR_{MAM} [%]	-4.8	-1.7	-6.4
ΔR_{JJA} [%]	-5.2	-3.3	-8.2
ΔR_{SON} [%]	6.0	0.6	6.7
$Rd \geq 0.1$ mm	-3.3	-1.6	-5.0
$Rd \geq 1$ mm	-3.0	-1.4	-4.3
$Rd \geq 5$ mm	-2.0	-0.7	-2.6
$Rd \geq 10$ mm	-1.0	-0.1	-1.1
$Rd \geq 20$ mm	-0.4	0.5	0.1
$Rd \geq 50$ mm	0.1	0.0	0.1

The largest mean precipitation amount for days with precipitation is estimated for the peaks of Dinarids and larger

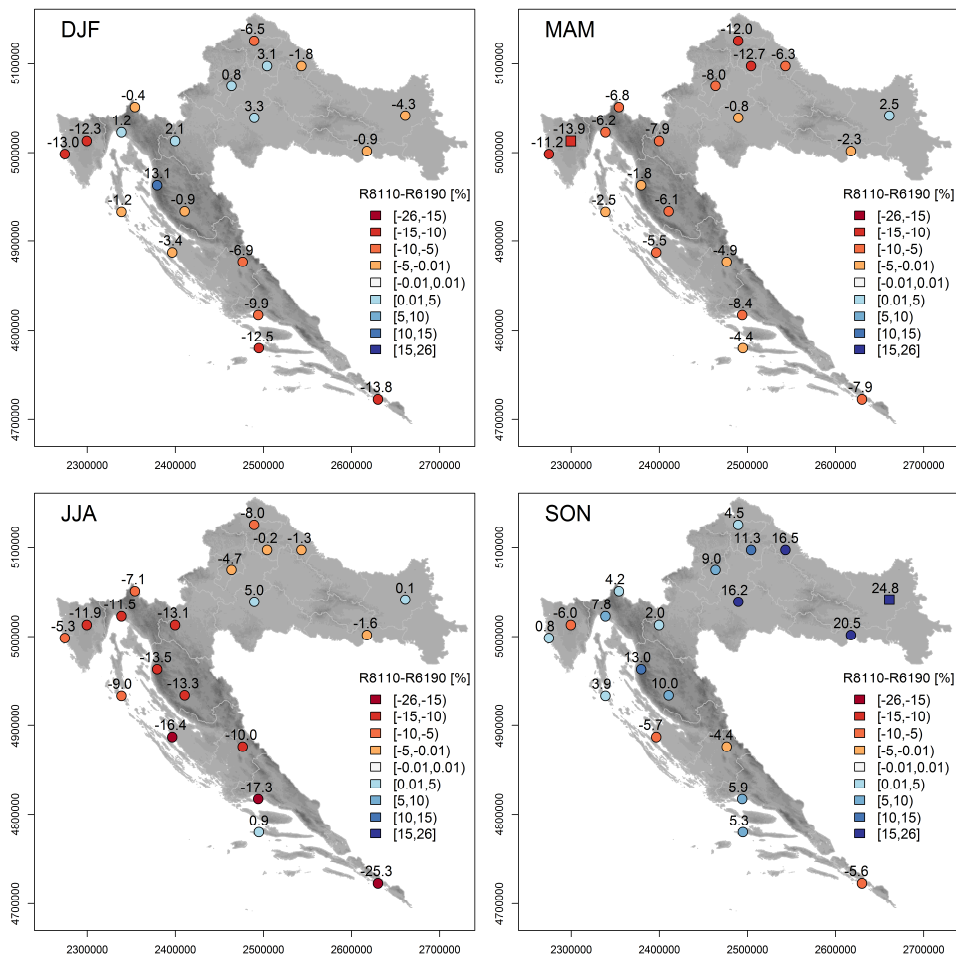


Fig. 4. Seasonal changes in precipitation climatological normals between latest 1981–2010 and standard 1961–1990 period for winter (DJF), spring (MAM), summer (JJA) and autumn (SON). Statistically significant differences at 95 % confidence level are marked with squares.

along the coast compared to inland. Accordingly, the highest values of precipitation amount are at the high mountain stations along the Dinarids with an average 30-year amount over 1500 mm at the selected stations (Fig. 3). Even though it is not possible to appreciate the full spatial variability of precipitation from the 20 selected stations, by keeping in mind the precipitation maps in [8] it is noticeable that precipitation values in the mainland are decreasing eastward as moist air from south-west loses humidity on the way, while those air masses from north-east direction are dry. Looking at coastal area, the distinguished is the most southern station Dubrovnik with the highest precipitation amount due to impact of topography and flow of moist air from the sea with the southern wind. Analysis of changes between precipitation for latest period (R8110) and the first one (R6190), suggests precipitation increase in eastern continental area and mountains and decrease in rest of the area, significant only at most southern station Dubrovnik and in central Istria (Fig. 3). Same results were shown in [14] where they analyzed long-term decadal trends in regional time series for period 1961–2010 from 132 stations. They obtained positive trend in eastern mainland and negative trends in other regions, significant only in mountainous region. Comparing consecutive periods shows that average changes are

larger between first two periods (Tab. 2) which is result of larger decrease at the coast between those two and stronger continental increase between latest periods (not shown). Annual course of precipitation in Croatia has bimodal shape. For continental area, maximums occur in summer and autumn as a result of stronger ground base warming, which enhances convection, and the advection of cold and moist air from northwest direction [15]. Along the coast, larger amount of precipitation are in colder part of the year, in autumn and winter. Comparison of R8110 and R6190 shows various changes for each season (Fig. 4). In warmer part of the year, spring and summer, the precipitation decreased at most of the stations, but significant is only at central Istria in spring. For both mentioned seasons, decrease between first two periods (7100-6190) is larger and occurs at almost all stations (Tab. 2), while between last two periods increase is obtained at few stations in eastern part of country (not shown). For winter, decrease in precipitation appears along the Adriatic coast and in eastern Croatia, while on few continental and mountain stations the precipitation increased. Changes between successive periods show for winter different pattern (Tab. 2). While comparing first two periods shows decrease in precipitation all over the country, comparison of last two gives increase at

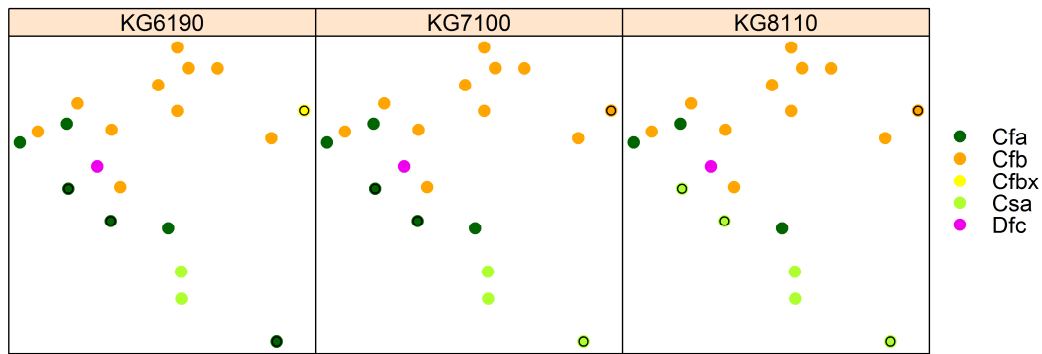


Fig. 5. Köppen-Geiger climate classes for 1961–1990 (KG6190), 1971–2000 (KG7100) and 1981–2010 (KG8110) period. Stations where climate class changed are circled.

relatively all stations. In autumn, increase occurs at most of the stations, with the largest amplitude and only one significant is in most eastern continental part. Analysis of consecutive periods showed successive increase in inland, with larger differences between first two, and decrease in precipitation in the coastal area for latest periods. Such results indicate equalization of summer and autumn maximum in continental area and increase in differences between autumn and winter maxima along the coast. Obtained seasonal changes are in accordance with [8] where they found prevailing decreasing trend in almost all seasons, significant in summer in central hinterland, mountainous and mountainous littoral region. In autumn they found increase in mainland being statistically significant in most eastern parts.

It is interesting to mention that at seven coastal and mountainous stations minimal annual precipitation amount was registered for the same year, 1983. The largest registered daily precipitation amount (352.2 mm) is registered at the station Zadar in 1986.

The highest occurrence of days with precipitation over 0.1 mm, 1 mm and 5 mm is in high mountains, decreasing toward east, and the lowest along the coast (compare with Fig. 7a in [13]). For number of days with stronger precipitation (more than 20 and 50 mm) largest values are also in Dinarids, while the lowest are now in continental part. While in the mainland the days with greater daily precipitation amount are often result of short-term convective precipitation that occurs more often during summer, in the highest areas and along the coast strong precipitation is result of long-term precipitation usually during cold part of the year. Comparing latest and first 30-year period, at almost all stations decrease in number of days with daily precipitation amount above 0.1, 1 and 5 mm is occurred. Such distribution is result of successive decrease with larger amplitudes between first two periods (Tab. 2), except for number of days with precipitation above 5 mm where comparing last two periods increase in mainland occurs. Number of days with precipitation amount above 10 and 20 mm is increased in continental inland and relatively decreased in the coastal area, also as result of successive increase/decrease comparing consecutive periods.

C. Köppen-Geiger climate classes

The presented changes in temperature and precipitation regimes can result in change of Köppen-Geiger climate classes

[5]. During the 1971–2000, climate class changed at first at the most southern station Dubrovnik where *Cfa*, warm temperate climate with hot summers, changed from fully humid (*f*) to dry summer precipitation regime, *Csa* (Fig. 5). The most eastern continental station Osijek lost its slightly wettest beginning of the summer compared to the summer's end of the warm temperate fully humid climate, experiencing a change from *Cfbx* to *Cfb*. In the next period 1981–2010 northern Dalmatian island station Mali Lošinj and coastal station Zadar, experienced a change from fully humid *Cfa* to dry summer precipitation regime, *Csa*, like Dubrovnik already did before.

Not shown in this article, but available from the connected study, is the signal on the Puntijarka mountain near Zagreb, with mean temperature of the coldest month slightly below -3°C , where the increase in temperature resulted in change from snow-forest climate *Dfb* to warm-temperate climate *Cfb*.

IV. CONCLUSION

The analysis of climatological normals of temperature and precipitation for different time periods has given various results depending on region and season. Comparing latest and the standard climatological period significant increase in temperature is observed at all selected stations. Largest warming occurs in continental part while the lowest amplitudes of changes are in southern Adriatic. Seasonal analysis of temperature changes between recent and first 30-year period shows increase for all seasons, significant only in warmer part of the year. While spring and summer increase is result of successive warming, relatively larger between recent periods, autumn and winter increase is moderated with relative temperature decrease between first two, i.e. last two periods. Increase in mean minimal and maximal temperature and warm indices as well as decrease in cold indices confirms warmer climate in Croatia for recent period.

Precipitation response shows dual nature; increase in eastern part of the country and decrease along the coast. Main contribution to eastern continental precipitation increase is in autumn, when most of the selected stations observe positive changes. This will be discussed further in connection to change in climate classes in eastern continental region. Precipitation is increased in winter at highest station Zavižan and at few central inland stations. In spring and summer at almost all stations precipitation amount is decreased, especially summer precipitation in middle and southern Adriatic. This affected also

the change in climate classes in this region. Also, decrease in Istria is expressed in all season except autumn. Such seasonal changes indicate increase in differences between two maximums, autumn and winter on the coast and autumn and summer in the inland. Analysis of number of days with precipitation amount above some threshold gave decrease in number of days with daily precipitation amount above 0.1 mm, 1 mm and 5 mm at almost all stations. For number of days with daily precipitation above higher threshold, increase occurred in continental inland, while along the coast precipitation is relatively decreased.

Changes in Köppen-Geiger climate classes happened mainly due to changes in precipitation regime. These changes are consistent with decrease in precipitation, especially along Dalmatian coast during summer, resulting in change from warm temperate climate with hot summers and fully humid precipitation regime to dry summer precipitation regime (change from *Cfa* to *Csa*). This was confirmed on several other stations not included in this study. Further on, there are several eastern continental stations, including Osijek, with characteristic more humid May and July than August and September (x letter in *Cfbx* comes from $R_{\text{May}} + R_{\text{July}} \geq 1.3 R_{\text{August}} + R_{\text{September}}$) during 1961–1990 period. Due to increased precipitation in autumn in this region, those stations lost this characteristic wettest beginning of the summer compared to its end and became more similar to the rest of the Croatian stations where these precipitation amounts are more similar in those two periods.

Not shown in this article, but available from the previous study, is the signal on the Puntijarka mountain with mean temperature of the coldest month slightly below -3°C where the increase in temperature resulted in change from snow-forest climate to warm-temperate climate, due to change in temperature regime.

The presented analysis indicates significant changes in climatological normals of temperature and precipitation in Croatia. Spatial dependency of climate response due to different climate factors is noticeable. Köppen-Geiger climate classes, as one of the indices that can describe the climate patterns associated with global circulation [4], showed to be able to recognize the climate change signal. The most prominent change is from fully humid to summer dry warm temperate climate with hot summer in Dalmatia. Noticeable change is losing more humid beginning of the summer compared to the end in eastern continental Croatia. For a comparison with a global picture, the digital Köppen-Geiger world map [16] on climate classification, valid for the second half of the 20th century is available from <http://koepfen-geiger.vu-wien.ac.at/>.

ACKNOWLEDGMENT

This work has been supported in part by Croatian Science Foundation under the project 2831 (CARE).

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