Report:

Climate and climate change data for Croatia

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(FB8)

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Let's grow up together

DRINK ADRIA

Adriatic IPA
Cross Border Cooperation 2007-2013

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CONTENT:

1. INTRODUCTION

Occurrence of long dry periods, which is becoming more prominent and frequent on the wider regional area covered by DRINK ADRIA project, coincides with the observed global temperature increase on Earth over the past decades. Although there are significant differences in estimations whether mentioned observed recent climate change can be attributed to global climate change or just periodic climate variations, previous projections and manifestations of such possible changes *[1], [2], [3], [4], [5], [6], [7]* show the need to take into account the possible continuation and even increase of those negative climate change trends in water resource management, regardless if those are irreversible changes or normal climate variations. Contemporary approaches to water resource management seek the elaboration of different scenarios of possible long-term changes, to identify risks on time and prepare and optimize protective control measures. This is especially evident because of the relationship of globally present flow decrease trends *[8]*, which are observed especially in the Mediterranean, where at the same time water use increased significantly *[9]*. According to the most commonly cited reports of IPCC (Intergovemmental Panel on Climate Change) which is advocate of global climate change presence, it is predicted that the ocean level could rise between 9 and 88 cm until 2100, where the mean value is 48 cm *[10]*. Such changes, even with less intensity of changes, will certainly result in the need to protect and optimize the use of water resources, where special meaning for the population have water resources for water supply.

For analyzed regional area different scenarios of climate change impact assesment are made also for sea level rise, and ways of slowing down unwanted processes are discussed, as well as adjustment to such changes. In that sense, Croatia took over the obligations of the United Nations Framework Convention on Climate Change in 1996, and brought *First national communication of the Republic of Croatia to the United Nations Framework Convention on Climate Change (UNFCCC), 2001* *[11]*. Since then, several revisions of such national report were brought, in accordance with the general knowledge about possible global climate change scenarios. Therefore, this report is based on the last, the *Sixth National Communication and First Biennial Report of the Republic of Croatia under the United Nations Framework Convention on Climate Change (UNFCCC), 2014* (in further text referenced as *Sixth National Communication, 2014* *[12]*) as well as several previous documents and recent research projects results which considered regional manifestations of climate change/variations in Croatia, different scenarios of possible further changes, as well as possible strategy for responding to them. A part of the report enhasizes the climate and climate change data only for the Adriatic part.

As reference climate period in most of those documents period 1961-1990 was taken. The focus of this report are temperature and precipitation data for the Republic of Croatia, existing as well as estimated for some of the most likely climate change scenarios, which are determined by the application of several standard methodological procedures, which are referenced. Figure 1-1 shows the Republic of Croatia map with marked pilot areas of project DRINK ADRIA.

Figure 1-1. Republic of Croatia map with pilot areas of project DRINK ADRIA [13]

2. EXISTING CLIMATE FEATURES IN CROATIA

According to Köppen classification for a standard period 1961-1990, the largest part of Croatia belongs to the climate type C, a moderately warm rainy climate. The southernmost part of the island of Lošinj, the Dalmatian coast and islands have the Mediterranean climate with dry and hot summers (Csa), whereas the coastal areas of Istria, the Kvarner littoral and the Dalmatia's interior have a moderately warm and humid climate with hot summers (Cfa). The moderately warm and humid climate with warm summers (Cfb) prevails in the major part of Croatia, in the continental Pannonian region and the interior of Istria. Only the regions of Gorski kotar, Lika and the Dinaric Alps above altitude of 1200 m belong to the climate type D, subtype Df, a humid snowy forest climate *[12]*.

The annual mean air temperature in the lowland area of northern Croatia is 10-12 ºC, at altitudes above 400 m it is under 10 ºC and in the mountains it is 3-4 ºC. In the coastal area it is 12-17 ºC. January is the coldest month on average, with the temperature in the Pannonian region ranging from 0 to -2 ºC. Along the Adriatic coast winters are milder;

January temperatures are 4- 6 ºC. In the north and east of Croatia average July temperatures are 20-22 ºC and on the Adriatic coast 23-26 ºC. The absolute minimum temperature of -35.5 ºC was measured in Čakovec on 3 February 1929 and the absolute maximum of 42.8 ºC in Ploče on 5 August 1981 *[12]*.

The least precipitation in Croatia is recorded in the open part of the central Adriatic (Palagruža, 304 mm) and in the eastern Slavonia and Baranja (Osijek, 650 mm). Central Croatia and the coastal zone have annual precipitation between 800 and 1,200 mm. The amount of precipitation in the Pannonian region decreases from the west towards the east. From the coast towards the inland the precipitation increases. Most of the precipitation is recorded on the coastal slopes and peaks of the Dinarides (Risnjak, 3,470 m), from Gorski Kotar in the northwest to the southern Velebit in the southeast *[12]*.
Spatial distribution of selected climate parameters is shown in Figure 2-1.

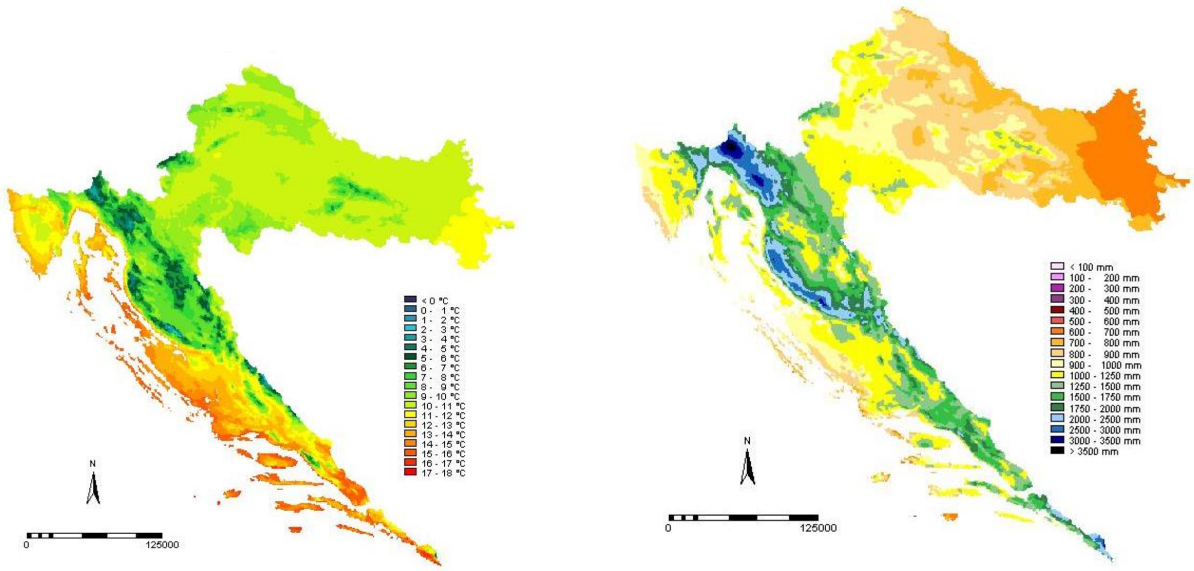

Figure 2-1. Spatial distribution of selected climate parameters for reference climate period 1961-1990. Left: mean annual air temperature; right: mean annual precipitation amount [14]

Climate change in Croatia over the period 1961-2010 has been determined by trends in annual and seasonal mean air temperature, mean minimum and mean maximum temperature; and in indices of temperature extremes; then in precipitation amounts and precipitation indices, as well as in dry and wet spells.
Temperature trends were calculated for the temperature deviations from the associated 1961-1990 means, and expressed in ºC per decade, while trends in indices of temperature extremes are expressed by number of days per decade. Trends in air temperature (mean, mean minimum and mean maximum temperature) in the last 50 years (1961-2010) show warming all over Croatia (Figure 2-2). Annual temperature trends are positive and significant, and the changes are higher on the mainland than at the **coast** and the **Dalmatian hinterland**. The maximum temperature values were exposed to the greatest

changes (Figure 2-2) with the highest frequency of trends in the class of 0.3-0.4 ºC per decade, while trends in the mean and the mean minimum air temperatures mostly range between 0.2 and 0.3 ºC per decade. The overall positive trend in the annual air temperatures comes are mainly caused by the significant positive summer trends, while the trends for the winter and spring gave almost equal contribution to the increasing trends of mean maximum temperature. Autumn temperatures are subjected to small changes and they are mostly positive. Observed warming can be seen in all indices of temperature extremes, with positive trends of warm temperature indices (warm days and nights as well as warm spell duration index) and with the negative trends of cold temperature indices (cold days and nights and cold spell duration index) (Fig. 2-3). At most stations, the increase of the number of SU ranges between 2 and 8 days per decade. Increase in the number of warm days (Tx90) most often accounted 6-10 days and warm nights (Tn90) even 8-12 days per decade. The duration of warm spells at most stations has increased for 4-6 days. Cold days and cold nights (Tx10 and Tn10) have the most significant trends, and their number at most stations is reduced for up to 4 days per decade *[12]*.

Table 2-1. List of the selected indices of temperature extremes and precipitation and their definition. The abbreviations and definitions are according to standardisation of WMO-CCL/CLIVAR working group for climate change [12]

Indices of cold temperature extremes		
FD	Frost days (absoulte treshold)	Number of days with minimum temperature below 0°C
TN10%	Cold nights (percentile treshold)	Number of days with minimum temperature (TN) below the 10th percentile from the 1961-1990 baseline period
TX10%	Cold days (percentile treshold)	Number of days with maximum temperature (TX) below the 10th percentile from the 1961-1990 baseline period
CSDI	Cold spell duration index	Number of days in periods with at least 6 consecutive days with minimum temperature below TN10%
Indices of warm temperature extremes		
TN90%	Warm nights (percentile treshold)	Number of days with minimum temperature (TN) above the 90th percentile from the 1961-1990 baseline period
TX90%	Warm days (percentile treshold)	Number of days with maximum temperature (TX) above the 90th percentile from the 1961-1990 baseline period
WSDI	Warm spell duration index	Number of days in periods with at least 6 consecutive days with minimum temperature above TX90%
SU	Summer days (absolute treshold)	Number of days with maximum temperature 25°C
List of the percipitation indices and their definitions		
Indices	Unit	Definition
DD	days	Dry days (absolute extreme) *(Number of days with daily precipitation amount Rd<1.0 mm)*
SDII	Mm/days	Simple daily intensity index (absolute extreme) *(annual precipitation amount / annual number of wet days (Rd≥1.0 mm)*
R75	days	Moderate wet days (percentible treshold) *(Number of days with precipitation Rd>R75%, where R75% is the 75th percentile of the distribution of daily precipitation amounts at days with 1 mm or more precipitation in the 1961-1990 baseline period)*
R95	days	Very wet days (percentile treshold) *(Number of days with precipitation Rd>R95%, where R95% is the 95th percentile of the distribution of daily precipitation amounts at days with 1 mm or more precipitation in the 1961-1990 baseline period)*
R25T	%	Precipitation fraction due to days with Rd<R25% (percentile threshold) *(Fraction of annual total precipitation ΣRd/Rt, where ΣRd indicatest he sum of daily precipitation less than the 25th percentile of precipitation at days with R25% in the 1961-1990 baseline period. ARt is the total annual precipitation amount.)*
R25-75T	%	Precipitation fraction due to days with R25%≤Rd≤R75% (percentile threshold) *(Fraction of annual total precipitation ΣRd/Rt, where ΣRd indicates the sum of daily precipitation equal to or exceeding the 25th percentile of precipitation at days with R25% and equal to or less than the 75th percentile of precipitation at days with R75% in the 1961-1990 baseline period. Rt is the total annual precipitation amount.)*
R75-95T	%	Precipitation fraction due to days with R75%<Rd≤R95% (percentile threshold) *(Fraction of annual total precipitation ΣRd/Rt, where ΣRd indicates the sum of daily precipitation exceeding the 75th percentile of precipitation at days with R75% and equal to or less than the 95th percentile of precipitation at days with R95% in the 1961-1990 baseline period. Rt is the total annual precipitation amount.)*
R95T	%	Percipitation fraction due to very wet days (percentile treshold) *(Fraction of annual total precipitation ΣRd/Rt, where ΣRd indicates the sum of daily precipitation exceeding the 95th percentile of precipitation at very wet days R95% in the 1961-1990 baseline period)*
Rx1d	mm	Highest 1-day percipitation amount (absolute extreme) *(Maximum precipitation sums for 1-day intervals)*
Rx5d	mm	Highest 5-day percipitation amount (absolute extreme) *(Maximum precipitation sums for 5-day intervals)*

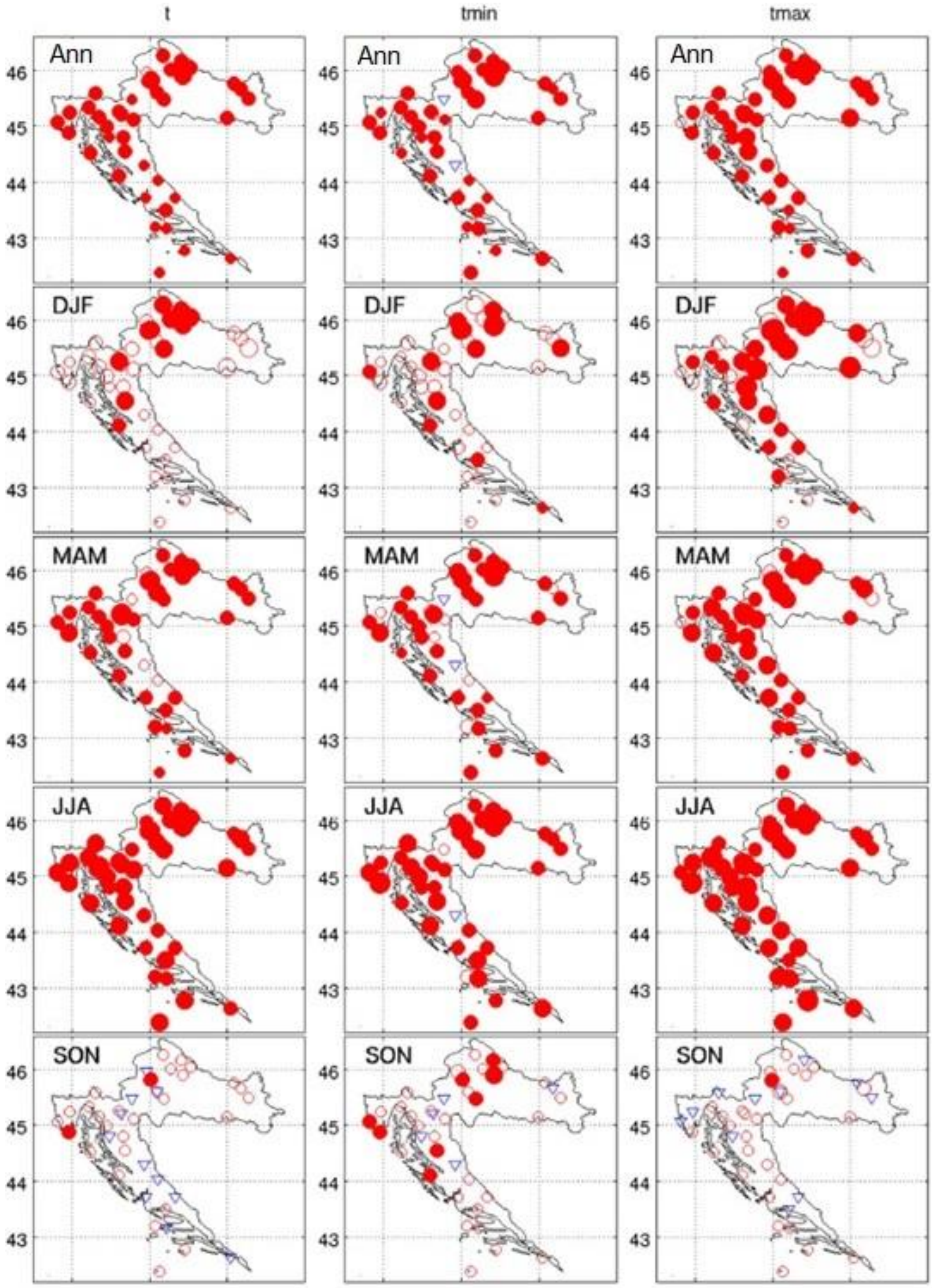

Figure 2-2. Decadal trends (ºC/10yrs) in annual and seasonal (DJF-winter, MAM-spring, JJA-summer, SON-autumn) mean (t), mean minimum (tmin) and mean maximum temperature (tmax) values in the 1961-2010 period. Circles denote positive trends, triangles the negative one, whereas filling means statistically significant trend. Four sizes of symbols are proportional to the absolute value of change (in ºC) per decade relative to the respective average from the period 1961-1990: <0.2, 0.2-0.4, 0.4-0.6 and >0.6, respectively [12]

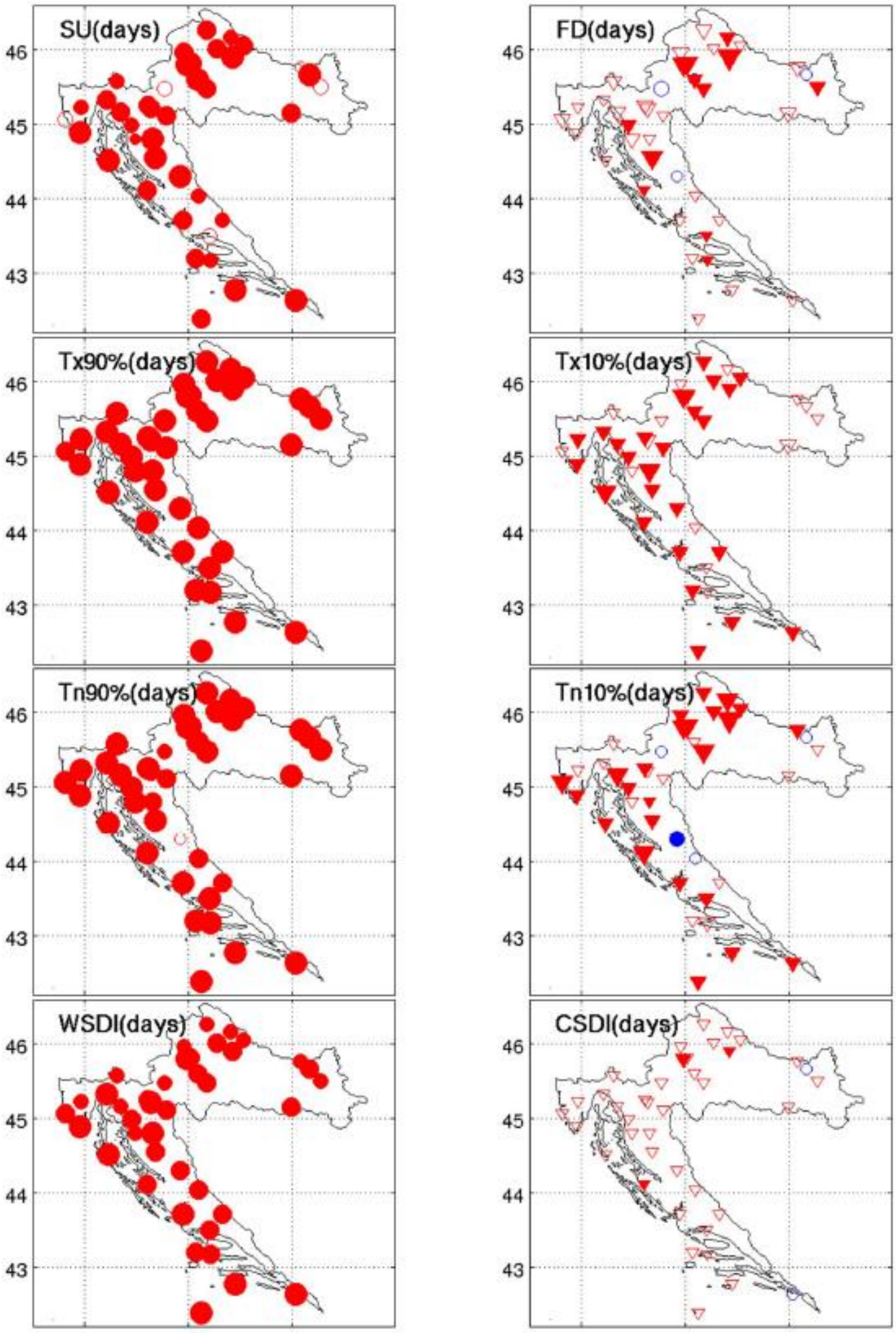

Figure 2-3. Decadal trends (days/10yrs) in annual extreme temperature indices in the 1961-2010 period. Circles denote positive trends, triangles the negative one, whereas filling means statistically significant trend. Four sizes of symbols are proportional to the absolute value of change (in days) per decade relative to the respective average from the period 1961-1990: <2, 2-4, 4-6 and >6, respectively [12]

The positive temperature trends in the continental part of Croatia is mostly due to winter trends (+0.06 °C/10 years in Osijek, +0.13 °C/10 years in Zagreb and Gospić), while on the **Adriatic** to summer trends (+0.13 °C/10 years in **Crikvenica** and +0.07 °C/10 years in **Hvar**), Table 2-2.
In Table 2-2 it is shown that annual amounts of precipitation showed a downward trend in five parts of Croatia. It is more expressed over the **Adriatic** (**Crikvenica**: -1.8% in 10 years, statistically significant and **Hvar**: -1.2% in 10 years), than in the inland (mountainous hinterland– Gospić: -0.8% in 10 years, eastern Slavonija, Osijek: -1.3% in 10 years, north-western Croatia, Zagreb-Grič: -0.3% in 10 years), *[15]*.

Table 2-2: Trends in mean annual and seasonal air temperature (°C/10 years); trends in annual and seasonal precipitation amounts. Trends significant at the 5% level are bolded. [15]

	Osijek	**Zagreb-Grič**	**Gospić**	**Crikvenica**	**Hvar**
Mean air temperature trend 1901-2008 (°C/10 years)					
WINTER	+0.06	+0.13	+0.13	+0.08	+0.04
SPRING	+0.05	**+0.11**	+0.05	+0.04	**+0.05**
SUMMER	+0.06	**+0.09**	+0.04	**+0.13**	**+0.07**
AUTUMN	+0.03	+0.07	+0.03	**+0.09**	+0.05
YEAR	+0.05	**+0.10**	**+0.06**	**+0.09**	**+0.06**
Percipitation amount trend 1901-2000 (% /10 years)					
WINTER	+0.6	-0.3	-2.7	-1.8	-2.9
SPRING	**-4.1**	-1.1	-2.0	-2.2	-2.0
SUMMER	+0.7	+1.2	+0.9	-2.7	+2.8
AUTUMN	-3.0	-1.4	+0.1	-0.9	-0.4
YEAR	-1.3	-0.3	-0.8	**-1.8**	-1.2

During the recent 50-year period (1961-2010) the annual precipitation amounts (*R*) experienced prevailing insignificant trends that are increasing in the eastern lowland and decreasing elsewhere (Fig.2-4. (a)). The statistically significant decreases (filled symbols) are found for the stations in the mountainous region of Gorski kotar and in the **Istria peninsula** (**northern Adriatic**) as well as in the **southern coastal** region. Expressed per decade as percentages of the respective average values, these decreases range between -7% and -2%. Annual negative trends are mainly caused by decreasing trends in summer amounts (*RJJA*), which are found to be statistically significant at most stations in the mountainous region and at some stations along the **Adriatic and its hinterland** (Fig. 2-4. (b)). The statistical significance of the annual negative trend in **Istria** and Gorski kotar is also influenced by spring negative tendencies (from -8% to -5%; Fig. 2-4. (c)). Positive (circles) annual trends in eastern lowland are primarily caused by the significant increasing trends in autumn (Fig. 2-4 (d)) and to a less extent in spring and summer.

Summer precipitation shows a clear prominence of negative trend estimates all over the country and there is a number of stations for which this decrease is statistically significant, with the relative change between -11% and -6% per decade. In autumn, the trends are weak and mixed in sign, except in the eastern lowland where some locations show significant increasing trend in precipitation (8% to 11%). In spring results suggest no signal in the southern and eastern part of the country, while a negative tendency seems to affect the rest of the country, significantly only in **Istria** and Gorski kotar (-5% to -7%). During winter season (Fig.2-4. (e)), precipitation trends are not significant and they range between -11% and 8%. They are mostly negative at the southern and eastern parts as well as at **Istria** peninsula *[12]*.

Regional distribution of trends in precipitation indices, that define magnitude and frequency of precipitation extremes, shows complex structure. Spatial distribution of trends in frequency of dry and wet precipitation extremes as indicated by number of dry days (*DD*), moderate wet days (*R75*) and very wet days (*R95*) are presented in Fig.2-4. (f, g, h). The trends in *DD* are predominantly weak, but statistically significant positive trends (1% to 2%) appear at some stations in the mountainous region of Gorski kotar, **Istria** peninsula and in the **southern coastal** region. The trend pattern of *R75* is spatially very similar to the annual precipitation one. The regional distribution of *R95* trends shows no signal over the majority of the country. Statistically significant changes are present at few stations; positive over the northern lowlands and negative in the highlands of Gorski kotar as well as at the **very southern coast** *[12]*.

Trends in the intensity of precipitation for wet days (Fig.2-4 (i)), as measured by the simple daily intensity index (*SDII*), reflect changes of trend magnitudes in two variables, annual amounts and annual number of wet days. For example, for two stations in different regions (indicated by two arrows in Fig.2-4. (i)), the same change in frequency of *Rd* (in these cases significant decrease, see Fig.2-4. (f)) but different changes in *R*, resulted in the similar significant increase in *SDII* at both stations. It implies that *SDII* is not suitable for explaining the causes of changes in *R*. Because of this fact, this index and its trends should be used with caution in application studies *[12]*.

Characteristic trends of mean annual temperatures and annual precipitation amounts for selected stations on the Croatian coastal area (station Crikvenica for the northern Adriatic and Hvar for the southern Adriatic) are shown in Figure 2-5.

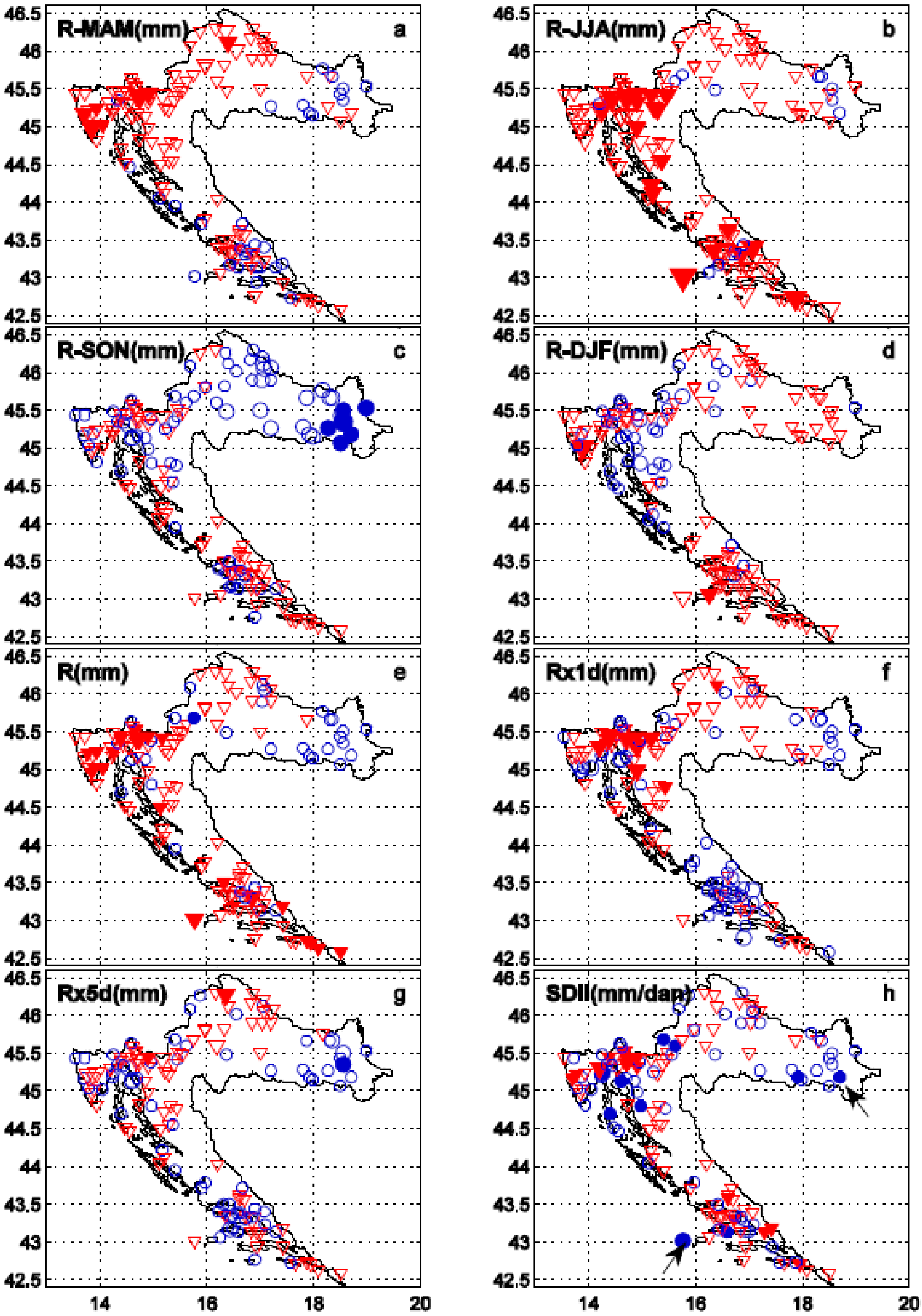

Figure 2-4. Decadal trends (%/10yrs) in seasonal and annual precipitation (R-MAM, R-JJA, R-SON. R-DJF, R) and precipitation indices (Rx1d, Rx5d, SDII, R75, R95, R25T, R25-50T, R50-75T, R75-95T, R95T and DD) in the 1961-2010 period. Circles denote positive trends, triangles the negative one, whereas filling means statistically significant trend. Four sizes of symbols are proportional to the absolute value of change per decade relative to the respective average from the period 1961-1990: <5%, 5-10%, 10-15% and >15%, respectively [12]

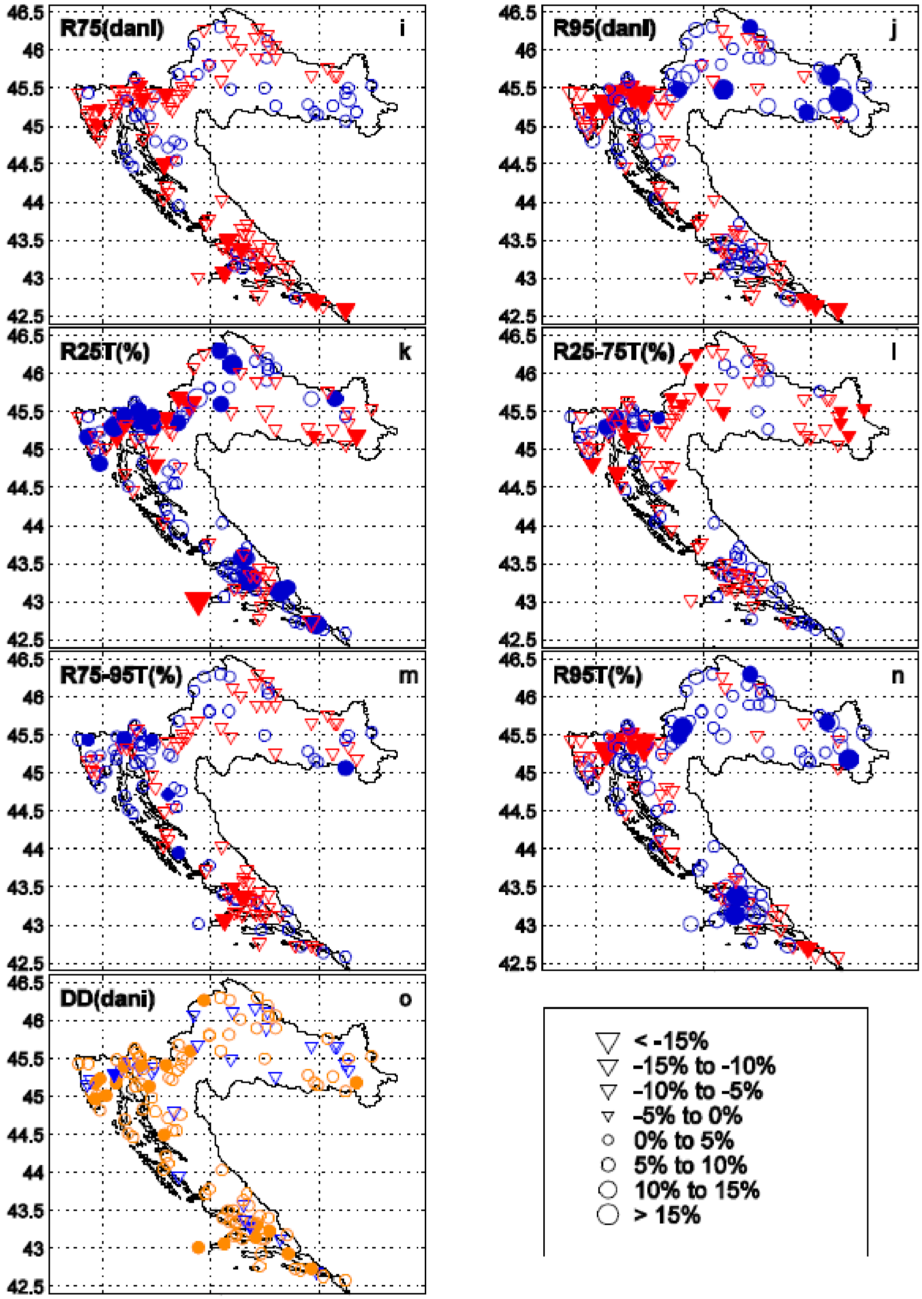

Figure2-4. cont. [12]

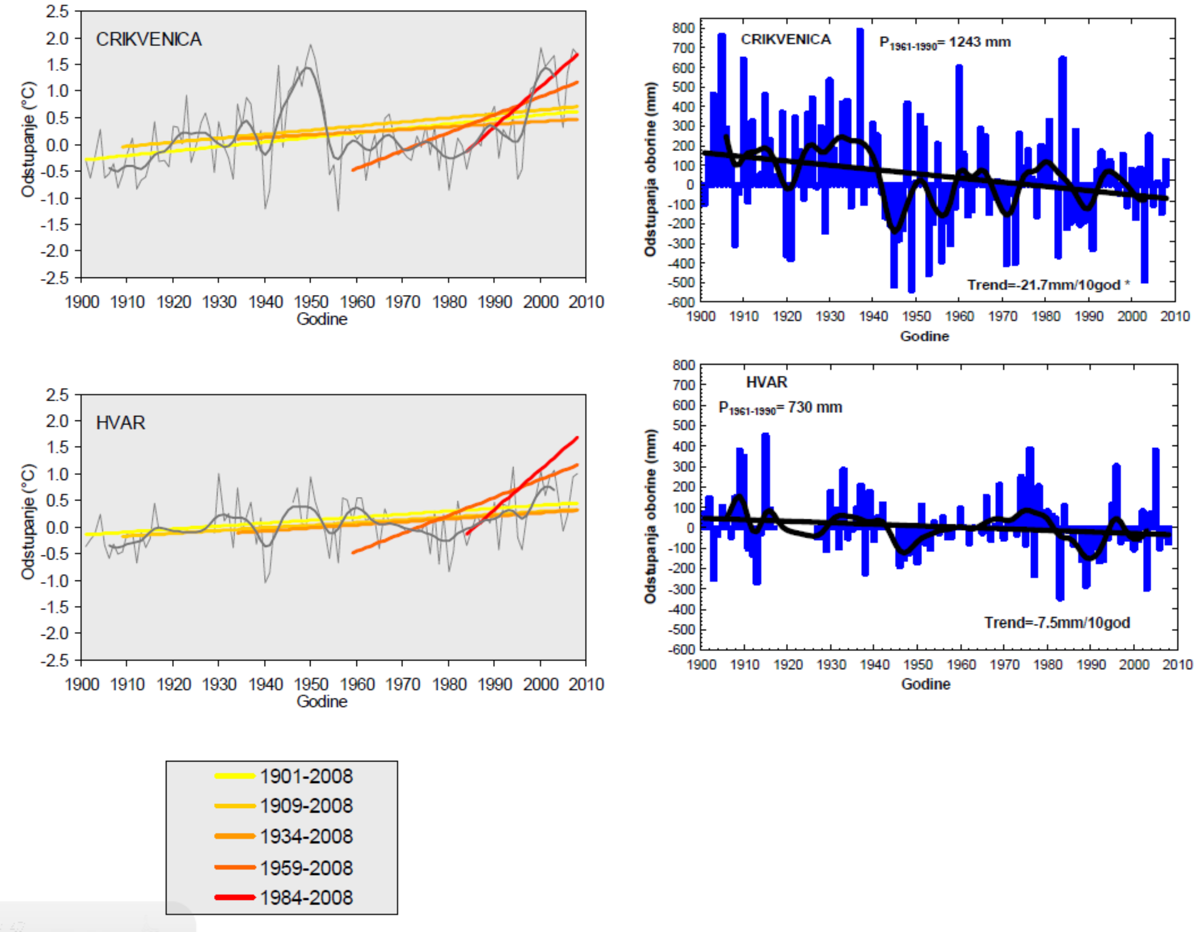

Figure 2-5. Time series of deviations from the mean (1961-1990) for stations Crikvenica and Hvar: left - mean annual air temperatures; right - annual precipitation amounts [16]

3. CLIMATE CHANGE SCENARIOS

On the Croatian area for the assessment of climate change several climate models are used. The most common is climate model RegCM, developed in *International Centre for Theoretical Physics* in Trieste *[17]*, which was used for climate predictions for the period 2011-2040 within the *Sixth National Communication, 2014 [12]*. It is a regional climate model which, for climate change simulations, takes initial and boundary conditions from joint global climate model ECHAM5/MPI-OM *[18], [19]*. For climate change assessment for the period up to the year 2100 in the framework of project CCWaterS *[20]*, with mentioned RegCM, model Aladin was also used *[21]*, and model Promes *[22]* where climate change projections are made until the year 2050.

In (for Croatia) reference *Sixth National Communication, 2014*, the results of the future climate change in a broader region of Croatia are discussed for temperature at 2 m (T2m) and precipitation. The results for each parameter are obtained from the two data sources:

a) from dynamical downscaling by the RegCM RCM made at the Croatian Meteorological and Hydrological Service (DHMZ) for the IPCC A2 scenario (Nakićenović et al., 2000) and
b) from dynamical downscaling of various RCMs that participated in the European project ENSEMBLES (van der Linden and Mitchell 2009, Christensen et al. 2010) for the IPCC A1B scenario [12].

Climate changes in Croatia were analyzed with model RegCM for two 30-year periods:

1. Period from year 2011 to 2040 represents the near future, and is of greatest interest for the users of climate information in long-term planning of climate change adaptation.
2. Period from year 2041 to 2070 represents the middle of the 21st century in which, by the A2 scenario, further increase of the carbon dioxide concentration (CO_2) in the atmosphere is predicted, and the signal of climate change is stronger [23].

In the first period of future climate (2011-2040) in Croatia (Figure 3-1) during winter a temperature increase of 0.6 °C is expected, and 1°C during summer [23].

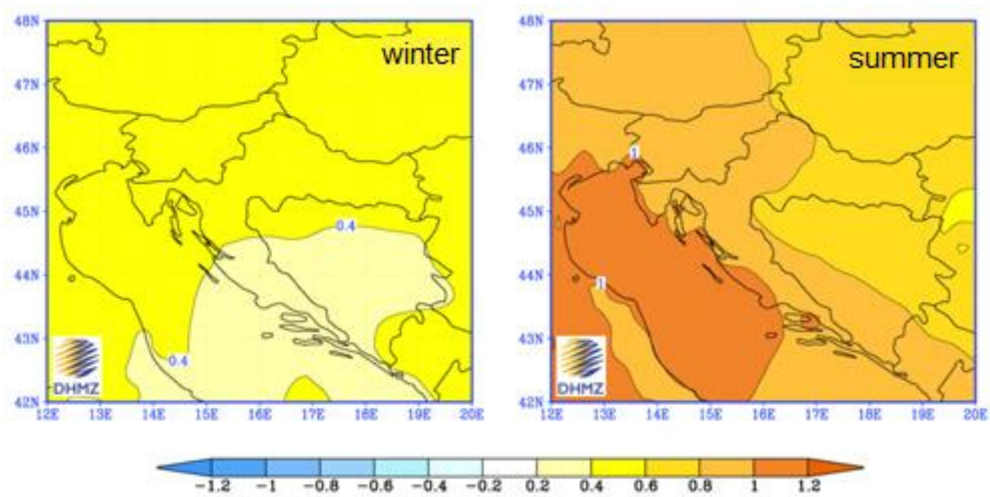

Figure 3-1. Change in ground air temperature (in °C) in Croatia in the period 2011-2040 in respect of the period 1961-1990 according to the results of the ensemble mean of regional climate model RegCM for the A2 scenario of greenhouse gas emissions for winter (left) and summer (right) [23]

In the second period of future climate (2041-2070) the expected increase amplitude in Croatia (Figure 3-2) during winter is up to 2 °C in continental part and up to 1.6 °C in the south, and during summer up to 2.4 °C in the continental Croatia, and up to 3 °C in the coastal zone [23].

Changes in precipitation amounts **in the near future** (2011-2040) are very small and limited to smaller areas, and they vary in the sign depending of the season (Figure 3-3). The biggest change in precipitation, according to A2 scenario, can be expected in the Adriatic in autumn when RegCM indicates a decrease of precipitation with a maximum of approximately 45-50 mm in the southern Adriatic. However, this reduction of autumn precipitation amount is not statistically significant *[23]*.

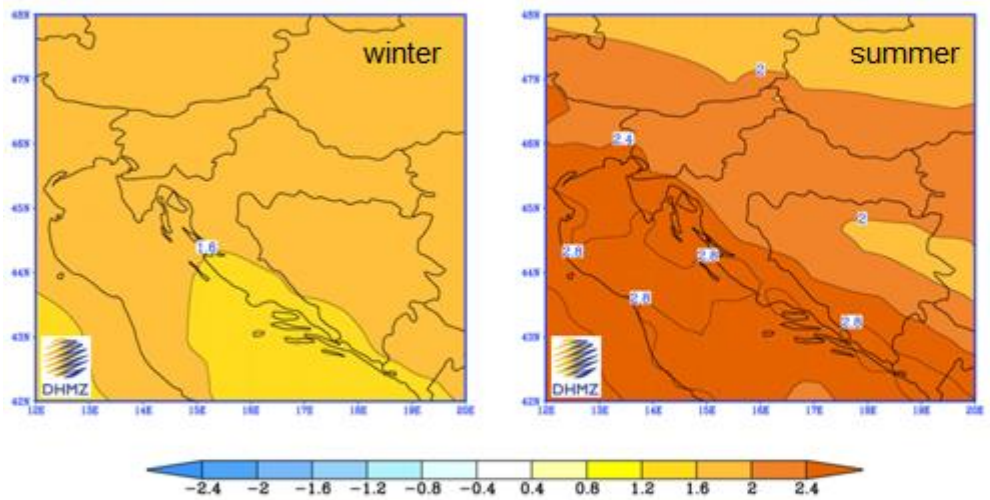

Figure 3-2. Change in ground air temperature (in °C) in Croatia in the period 2041-2070 in respect of the period 1961-1990 according to the results of the ensemble mean of regional climate model RegCM for the A2 scenario of greenhouse gas emissions for winter (left) and summer (right) [23]

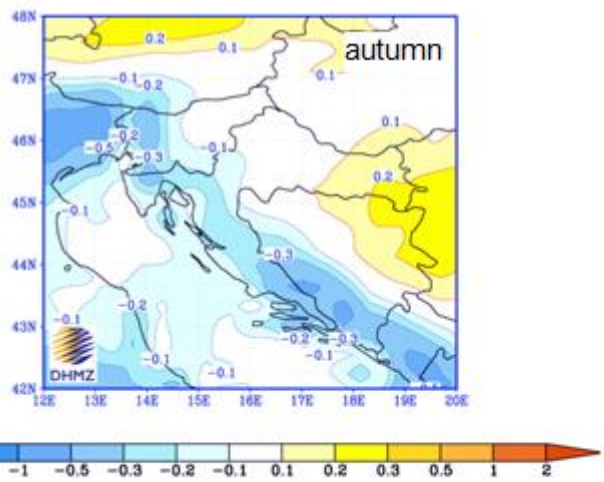

Figure 3-3. Change in precipitation in Croatia (in mm/day) in the period 2011-2040 in respect of the period 1961-1990 according to the results of the ensemble mean of regional climate model RegCM for the A2 scenario of greenhouse gas emissions for autumn [23]

In the second period of future climate (2041-2070) precipitation changes in Croatia are somewhat more expressed (Figure 3-4). During summer in the mountainous Croatia and in the coastal area a decrease in precipitation is expected. Reductions reach value of 45-50 mm and they are statistically significant. During winter an increase in precipitation in north-western Croatia and on the Adriatic can be expected, however that increase is not statistically significant *[23]*.

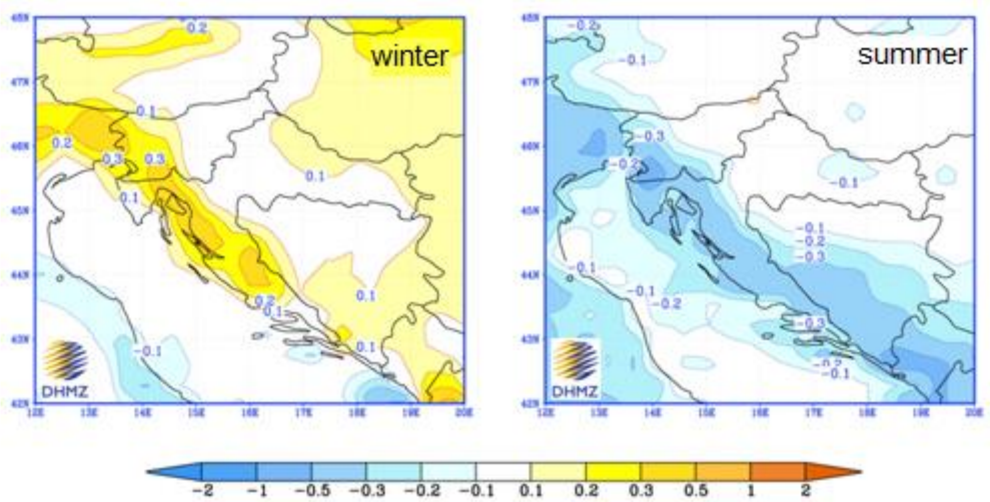

Figure 3-4. Change in precipitation in Croatia (in mm/day) in the period 2041-2070 in respect of the period 1961-1990 according to the results of the ensemble mean of regional climate model RegCM for the A2 scenario of greenhouse gas emissions for winter (left) and summer (right) [23]

For the purpose of project CCWaterS *[20]* realisation on pilot areas in Croatia, DHMZ (2010) made estimates of climate conditions for three pilot areas in Croatia, which were represented by selected climatological stations Cres (North Adriatic), Zadar (Middle Adriatic) and Vela Luka on the island of Korčula (South Adriatic). For illustration, the results of conducted climate change predictions in the temperature (Figure 3-5) and precipitation regime (Figure 3-6) are chosen on station Vela Luka, given that within the project DRINK ADRIA continuation of activities in pilot area Blato on the island of Korčula is predicted (activities started in project CCWaterS). P0 indicates reference 30-year period 1961-1990, P1 (2021-2050), and P2 (2071-2100) *[24], [25]*.

According to the *Sixth National Communication, 2014*, although the Republic of Croatia belongs to a group of countries for which water issues are not a limiting factor of development, climate changes will cause problems in water supply and meeting the evergrowing drinking water requirements. Research show that water resources in Croatia are already under challenge of climate change, as certain impacts and changes occur in regard to water flow, evapotranspiration, groundwater inflow, water level in rivers and lakes, water temperature, etc. Change in precipitation form will influence not only the discharge, but the intensity, time period and frequency of floods and droughts as well. Some sources estimate that discharges in the largest watercourses of the Republic of Croatia will be decreased by 10% to 20%, although in eastern part of the country such change could be less than 10%. This issue requires research, since results of global and regional models of climate change indicate changes in precipitation in Croatia. Moreover, evapotranspiration increase due to temperature rise could also make an impact. The Government of the Republic of Croatia adopted the River Basin Management Plan (OG No. 82/2013) and Croatian Waters prepare the Flood Risk Management Plan. In their measure programmes, documents contain adaptation measures to climate change consequences *[12]*.

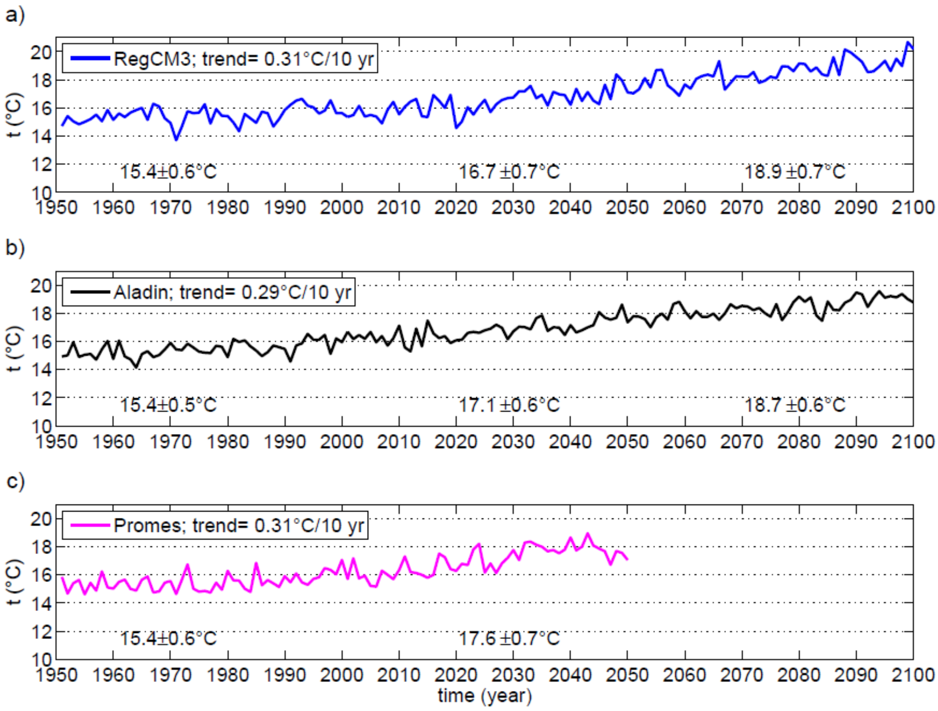

Figure 3-5. The Blato catchment: annual mean temperatures a) RegCM3 b) Aladin c) Promes. In each panel decadal trend based on entire available time series is shown. Additional numbers at the bottom of each panel are mean values and standard deviations during P0, P1 and P2. [24]

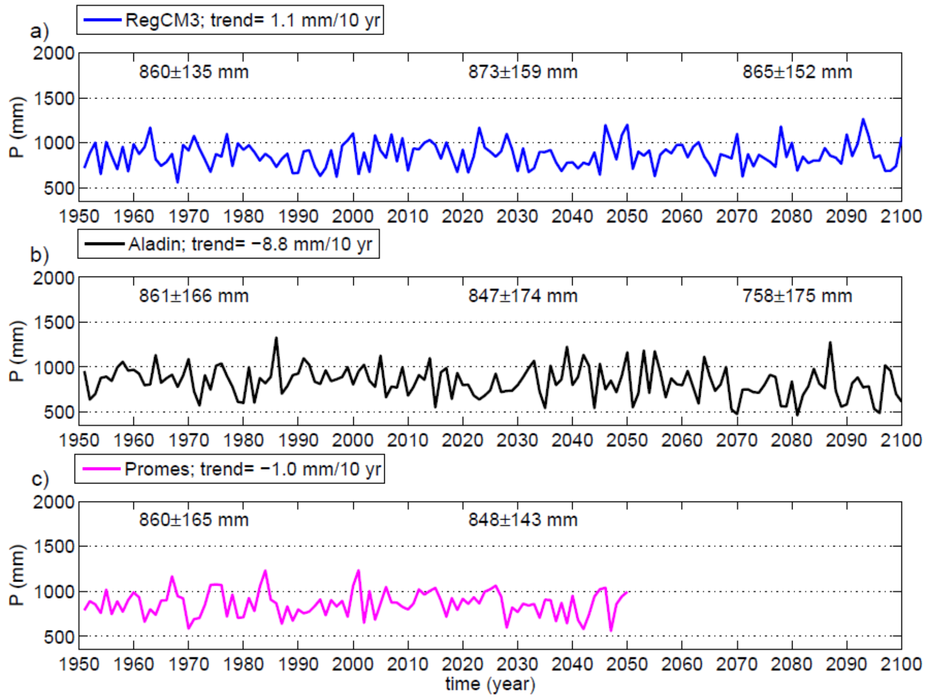

Figure 3-6. The Blato catchment: annual precipitation amounts a) RegCM3 b) Aladin c) Promes. In each panel decadal trend based on entire available time series is shown. Additional numbers at the bottom of each panel are mean values and standard deviations during P0, P1 and P2. [24]

4. CLIMATE AND CLIMATE CHANGE OVER THE CROATIAN ADRIATIC

Following content is extracted from the report [26] in order to highlight the features of the Adriatic part of Croatia.

4.1. Introduction

Climate of the two meteorological parameters, 2m air temperature (*T2m*) and total precipitation (*R*), over the Croatian Adriatic region for the reference period 1961-1990 and the projection of the near-future climate in the 21st century will be described in the following text. These two climatological parameters will be analysed in detail for the two Croatian pilot areas: Mirna River and Prud wellspring catchments within the DRINKADRIA project. The future climate projections for the Croatian Adriatic are based on the downscaling simulations of regional climate models (RCMs). Owing to their relatively high horizontal resolution (between 10 and 50 km), RCMs are normally used to study regional climate and climate change. They are more appropriate than global climate models (GCMs) for describing climate at relatively small spatial scales where local topography and the land-sea distribution are important. However, in the process of dynamical downscaling the RCM results strongly depend on the quality of the boundary conditions which are typically provided either by GCMs or by reanalysis data (e.g. *[27]*; *[28]*). In this report, the analysed projections of the 21st century air temperature and precipitation are obtained from various RCMs that participated in the EU FP6 project ENSEMBLES (*[29]*, *[30]*) using the IPCC[1] A1B scenario of the greenhouse gases concentrations *[31]*. More details are given in the *Sixth National Communication, 2014 [12]*[2].

4.2. Data and methodology

The average climate conditions shown and discussed here for the Croatian Adriatic in the reference climate period 1961-1990 are based on the data from the Climate Atlas of Croatia *[14]* and on an analysis of the climate conditions over the Adriatic catchments regions *[32]*. In this overview the average annual cycle of air temperature and precipitation is discussed and their seasonality, that would be used to calculate the water balance components, is emphasised. The data series are obtained from the Croatian Meteorological and Hydrological Service (DHMZ), where a routine operational quality control recommended by WMO (*[33]*, *[14]*), is carried out. The long-term changes in the observed annual and seasonal air temperature and precipitation are analysed for the 1961-2010 period. Most results presented and discussed here are described in *[12]* and in *[34]*. Trends are estimated by the Kendall's tau method and the non-parametric Mann-Kendall test was applied to determine statistical significance of trends at the 95% confidence level *[35]*.
From the ENSEMBLES database, 18 combinations of various RCMs, all available at a 25-km horizontal resolution, and forced by various GCMs are analysed (Table 4.2-1). The RCMs results of the future climate are discussed only for the period 2011-2040 (denoted as P1). For other future periods of the 21st century the results are presented in *[12]*. The climate change in the future period is computed as the differences between the 30-year

[1] Intergovernmental Panel on Climate Change (http://www.ipcc.ch)

[2] Available from http://unfccc.int/national_reports/annex_i_natcom/submitted_natcom/items/7742.php

means of the P1 and P0 periods. Additionally, the agreement in the sign of the projected changes among different RCMs is determined.

Table 4.2-1: Analysed regional climate models (RCMs), organisations which performed the simulations and the sources of the boundary conditions (see [12] for more details) [

	Regional climate model	Organisation	Global climate model providing the boundary conditions
1.	RCA3	C4I	HadCM3Q16
2.	RM5.1	CNRM	HadCM3Q1
3.	HIRHAM5	DMI	ARPEGE
4.	HIRHAM5	DMI	ECHAM5
5.	HIRHAM5	DMI	BCM
6.	CLM	ETHZ	HadCM3Q0
7.	RegCM3	ICTP	ECHAM5
8.	RACMO2	KNMI	ECHAM5
9.	HadRM3Q0	MetoHC	HadCM3Q0
10.	HadRM3Q16	MetoHC	HadCM3Q16
11.	HadRM3Q3	MetoHC	HadCM3Q3
12.	REMO	MPI-M	ECHAM5
13.	RCA3	SMHI	BCM
14.	RCA3	SMHI	ECHAM5
15.	RCA3	SMHI	HadCM3Q3
16.	HIRHAM	Met.No	BCM
17.	HIRHAM	Met.No	HadCM3Q0
18.	PROMES	UCLM	HadCM3Q0

4.3. Croatian Adriatic climate in the reference period

Climate of the Croatian Adriatic is primarily determined by circulation of the northern mid-latitudes weather systems with frequent and often intense changes of the local weather during the most part of the year *[14]*. In the summer, this area is influenced by the ridge of the Azorean high with prevailing dry and warm weather and with regular daily wind circulation from the sea and the night circulation down the hill slopes towards the sea. Local factors - the land/sea contrast and high and steep orography of the Dinarides - together with the north-Adriatic cyclogenetic effect, strongly affect climate of the Croatian Adriatic. In calm weather, which normally prevails during the cold part of the year and at night, the local geophysical conditions are dominant and relatively large differences in the values of meteorological parameters can occur even at nearby stations. Cyclonic activity, typical for winter, early spring and late autumn, affects cloudiness and precipitation regime of both coastal areas and the hinterland.

The Croatian Adriatic river catchments (Figure 4.4-1) cover the coastal area and its hinterland, including the mountainous regions of Gorski kotar and Lika, where the mountainous climate is present. Over the Croatian Adriatic catchments, July is the hottest and January is the coldest month in the annual cycle of the mean monthly air temperature (see Figures 2a and 2b in *[32]*). Such annual cycle is under a strong influence of the sea and has typically maritime characteristics with the autumn season (SON) being warmer than the spring (MAM). The effect of the sea on the climate of the Adriatic islands and in a wider coastal zone of Istria is manifested as a moderation of the minimum air temperature. However, in the mountainous areas of the coastal basin, due to strong winter radiative cooling, the minimum temperatures attain their lowest values, especially at the Lika plateau (-28.9ºC in Gospić) as well as in the interior of the Istrian peninsula (-18.7ºC in Pazin). The influence of the sea is also manifested in a reduction of the amplitude of the extreme temperatures on the Dalmatian islands (Lastovo: tmax=36.2ºC, tmin=-6.8ºC) and at the coast (Zadar: tmax=35.7ºC, tmin=-9.1ºC). Away from the coast, in the karst fields of the Dalmatian hinterland, the impacts of winter cooling and of summer warming are, on the other hand, enhanced, resulting in higher absolute maxima and lower absolute minima (e.g. Sinj: tmax=39.3ºC, tmin=-22.2ºC) than at the coast.

The entire area has a maritime precipitation regime with larger amounts of precipitation in the cold (October to March) than in the warm part (April to September) of the year, and with the minimum in summer (see Figures 3a and 3b in *[32]*).

The maximum in the precipitation annual cycle occurs in November (on the Dalmatian islands in December), but with different amplitudes at different locations (Pazin: 134 mm, Rijeka: 175 mm, Gospić: 179 mm, Cres: 136 mm, Split–Marjan: 108 mm, Knin: 122 mm, Opuzen: 180 mm, Hvar: 91 mm). The monthly minimum appears in July (Pazin: 72 mm, Rijeka: 81 mm, Gospić: 66 mm, Cres: 53 mm, Split-Marjan: 28 mm, Knin: 46 mm, Opuzen: 36 mm, Hvar: 25 mm). Interannual variability of monthly amounts is largest in October in Primorje-Istrian basin (70-90% of the total precipitation for that month) and in the Dalmatian hinterland (about 80%), and in July in the southern part of the Croatian Adriatic - on the Dalmatian islands and in the Neretva River valley (120%) and in the Dubrovnik area (100%). The least variable (most stable) on the year-to-year basis are the precipitation amounts in April (31-62%) over the whole area of the Adriatic catchments.

The annual precipitation totals are highest in the Primorje-Istrian catchment: in Gorski Kotar (Parg 1849 mm) and Lika (Zavižan 1899 mm and Gospić 1369 mm) and over a broader area of Rijeka (Rijeka 1561 mm). The amounts decrease from the coast towards the outer islands (Cres 1053 mm), and from the interior of the Istrian Peninsula (Pazin 1167 mm) to the coast (Pula 847 mm). Over the Dalmatian basin, the largest annual amounts are found in the hinterland and increasing from the northwest (Knin 1074 mm) to the southeast (Opuzen 1308 mm). The lowest amounts are at the Dalmatian islands and they increase from the outer islands towards the coast (Lastovo 691 mm, Hvar 730 mm, Split-Marjan 825 mm). Interannual variability of the annual precipitation amounts is smaller than that for monthly amounts (c_v is from 10% to 24%).

4.4. Observed trends

Observed trends in the annual and seasonal quantities of climate parameters indicate their temporal change over the area of interest. Temperature trends are calculated for deviations (anomalies) of air temperature from the 1961-1990 mean and expressed in °C per decade. In three seasons, JJA, MAM and DJF, trends in the mean air temperature show warming all over Croatian Adriatic while trends in SON are of the mixed sign (Figure 4.4-2). The annual temperature trends are all positive and significant, and they range mostly between 0.2°C and 0.3°C per decade.

During the recent 50-year period (1961-2010) the prevailing trends in the annual precipitation amounts indicate a decrease in precipitation which, at most stations, is statistically insignificant (Figure 4.4-3). The trend values go down to the 7% of the respective climate means. Generally, when negative trends are observed for the whole year, they are mainly caused by decreasing trends (drying) in the summer; the summer trends, in turn, are found to be statistically significant at most stations in the mountainous region and at some stations along the Adriatic and its hinterland.

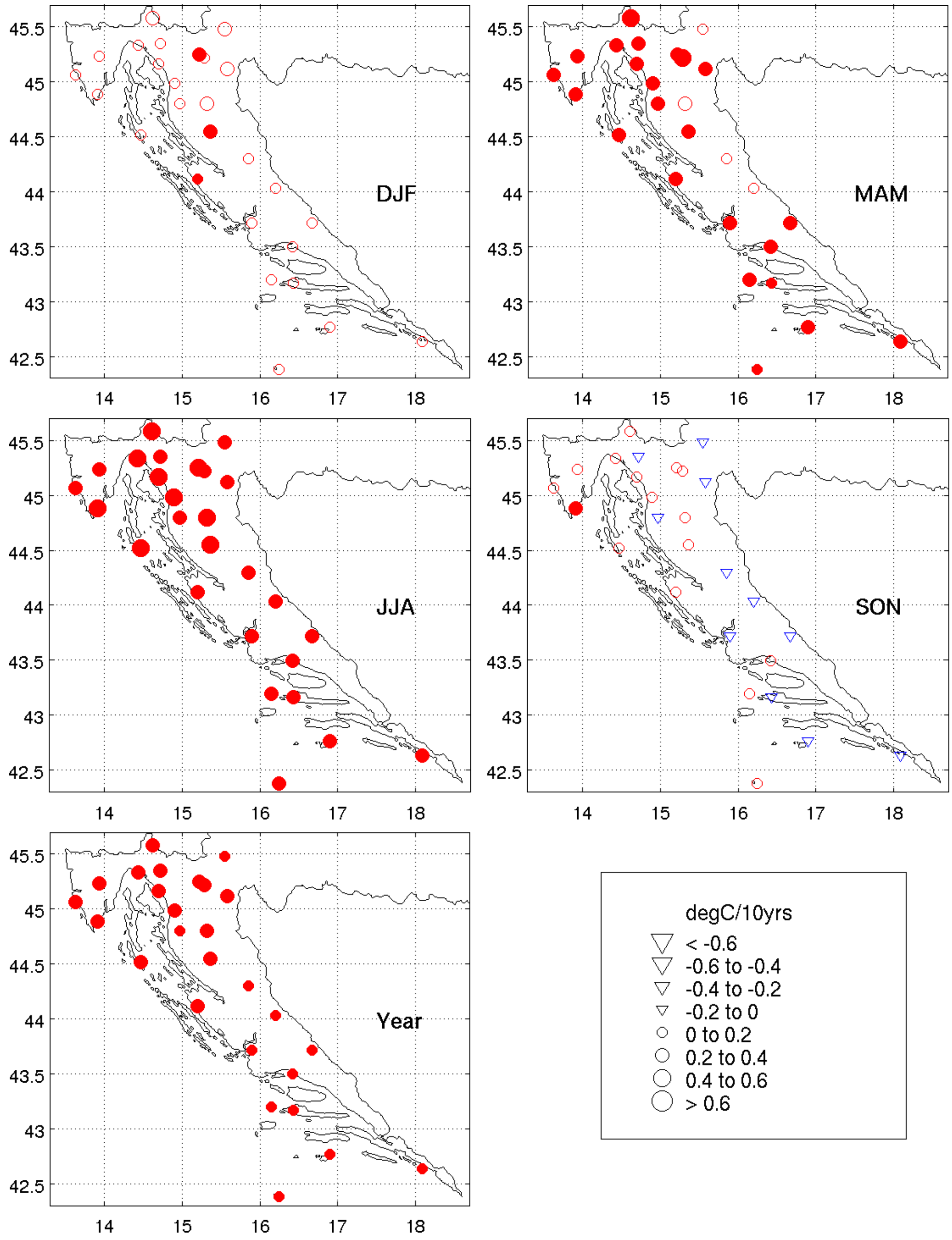

Figure 4.4-2. Decadal trends (°C/decade) in the annual and seasonal (DJF-winter, MAM-spring, JJA-summer, SON-autumn) mean air temperature in the 1961-2010 period. Circles denote positive trends, triangles the negative ones; solid symbols indicate statistically significant trend at the 5% confidence level. The symbol size is proportional to the magnitude of change (in °C) per decade. [26]

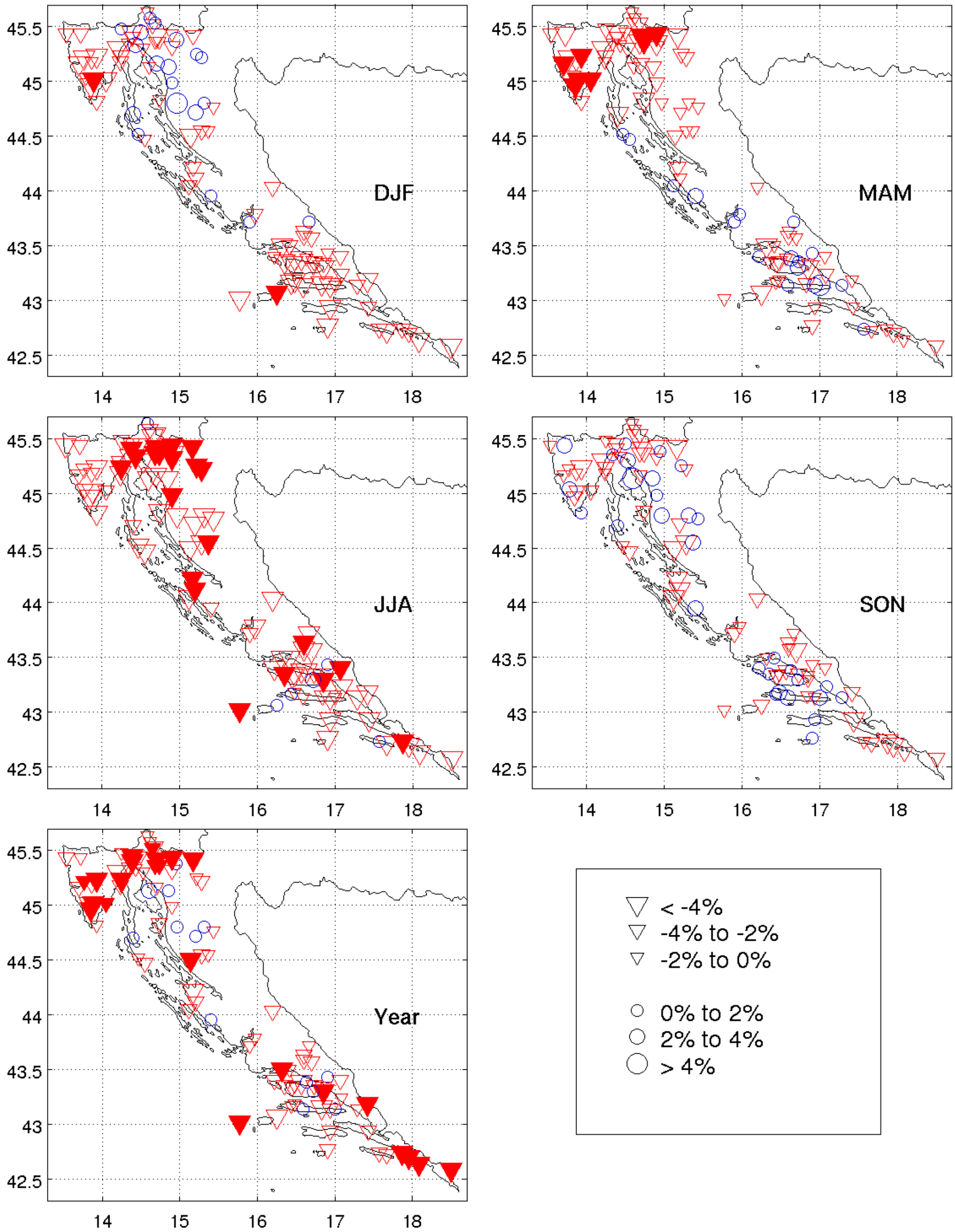

Figure 4.4-3. Decadal trends (%/10yrs) in annual (R) and seasonal precipitation (R-MAM, R-JJA, R-SON, R-DJF) in the 1961-2010 period. Circles denote positive trends, triangles the negative one, whereas filling means statistically significant trend at 5% level. Three sizes of symbols are proportional to the absolute value of change per decade relative to the respective average from the period 1961-1990: <2%, 2-4%, and >4%, respectively. [26]

Annual and seasonal long-term precipitation trends for the period 1961-2010, expressed as absolute changes (in mm/decade), are calculated for five regions which belong to the Croatian Adriatic catchments (Table 4.4-1). During the recent 50-year period, trends in the annual precipitation amounts are negative (indicating a reduction in precipitation) in all regions; only in Gorski kotar this trend is statistically significant (-50.6 mm/10yrs). In spring and summer, drying occurred in all regions, but it is statistically significant only during summer in three regions. In other seasons a decreasing trend prevails but it is not statistically significant *[36]*.

Table 4.4-1: Decadal trends in annual and seasonal precipitation amounts for five sub-regions in the Croatian Adriatic catchments in the period 1961-2010. Statistically significant trends at the 95% confidence level are in bold. [36]

Regions	MAM	JJA	SON	DJF	YEAR
Lika and Dalmatian hinterland	-3.6	**-16.0**	-3.6	-6.0	-24.6
Gorski kotar	-12.5	**-21.0**	-15.5	-7.9	**-50.6**
Littoral of Kvarner bay	-4.0	**-22.6**	4.0	2.9	-7.7
Istria and Northern coastal region	-7.9	-10.8	-7.9	-5.9	-24.7
Central and Southern coastal region	-1.4	-7.1	-1.7	-15.9	-28.9

4.5. Simulated climate change

Projected differences between P1 and P0 periods according to ENSEMBLES simulations are presented in this section. Additionally, agreement in the sign of the projected changes is determined by evaluating if the same sign of simulated climate change as in the difference between the entire ensemble means is simulated by the two thirds of all ENSEMBLES RCMs considered here.

The RCM simulations from the ENSEMBLES project indicate for the P1 period an increase of 2m air temperature (*T2m*) in all seasons with the amplitude typically between 1°C and 1.5°C (Fig. 4.5-1). A somewhat higher warming, between 1.5°C and 1.75°C, is projected over central and southern Dalmatia during the summer (Fig. 4.5-1 c). For the P1 period, more than the two-thirds of all ENSEMBLES models agree in the sign of projected changes (warming) when compared to the P0 period. A weak decrease of the mean *T2m* amounting to -0.5°C may be possible in some months during P1, mostly as the consequence of internal variability of the climate system. However, in the rest of the 21st century and for the IPCC A1B scenario all ENSEMBLES simulations indicate only warming, on both seasonal and monthly timescales (e.g. *[38]*; *[12]*).

In the first part of the 21st century (P1), the total precipitation amount *R* during winter is projected to increase over parts of the Kvarner region with the amplitude between approximately 5% and 15% relative to the reference period P0, 1961-1990 (Fig. 4.5-2 a). The sign of these changes agrees in at least the two thirds of all models.

For the summer season in the same period P1, *R* is projected to decrease from approximately -5% down to -15% over large parts of the Dalmatian hinterland, the mountainous region of Gorski kotar and the Lika highlands (Fig. 4.5-2 c). This decrease in precipitation is also found in at least the two-thirds of the models. A reduction of precipitation of the same amplitude is projected for the southern Croatia during spring (Fig. 4.5-2 b), while during autumn the projected changes are almost negligible, between approximately -5% and +5% (Fig. 4.5-2 d). For more details and similar analysis of the later periods of the 21st century see *[12]*.

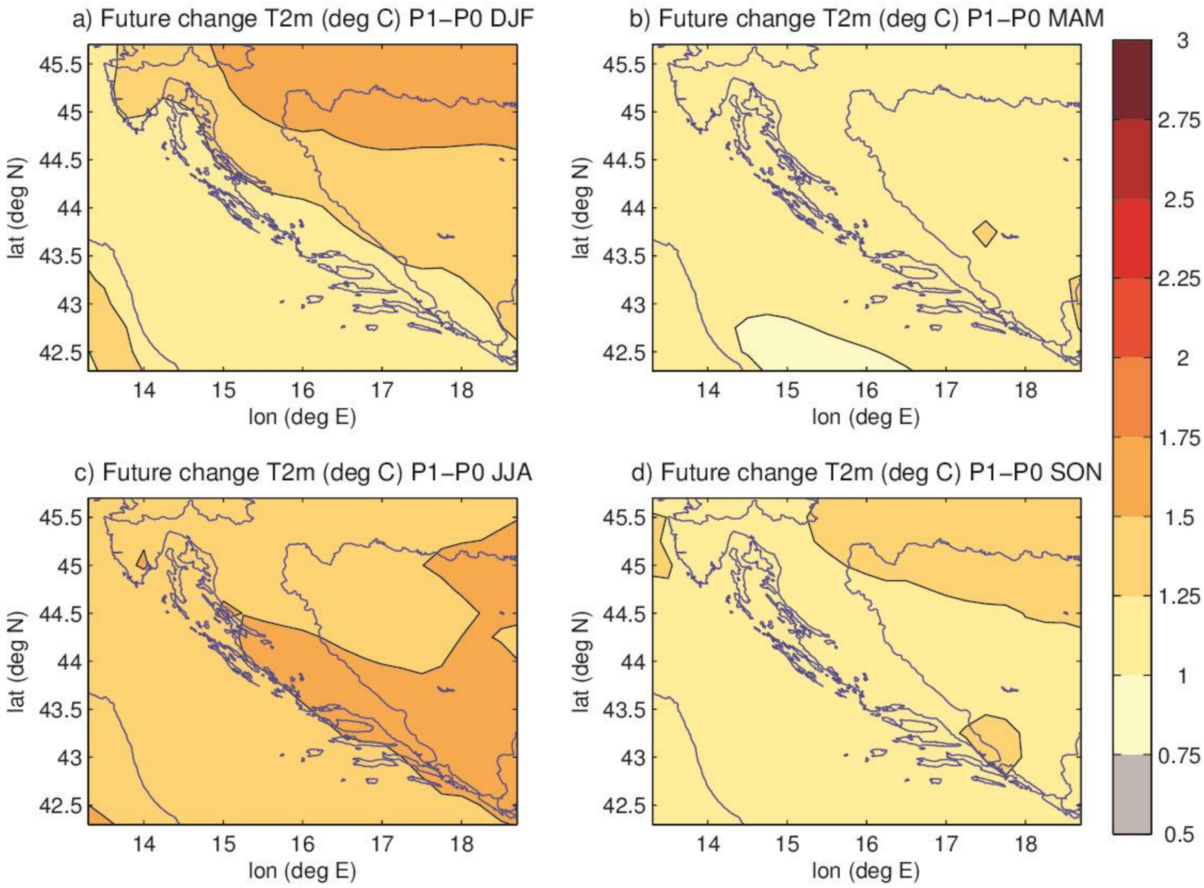

Figure 4.5-1. The air temperature ensemble-mean difference between the periods P1 (2011-2040) and P0 (1961-1990): a) winter (DJF), b) spring (MAM), c) summer (JJA) and d) autumn (SON). Units are °C. In all grid points, the sign of change in at least the two-thirds of the models agrees with the sign of change in the ensemble mean.[26]

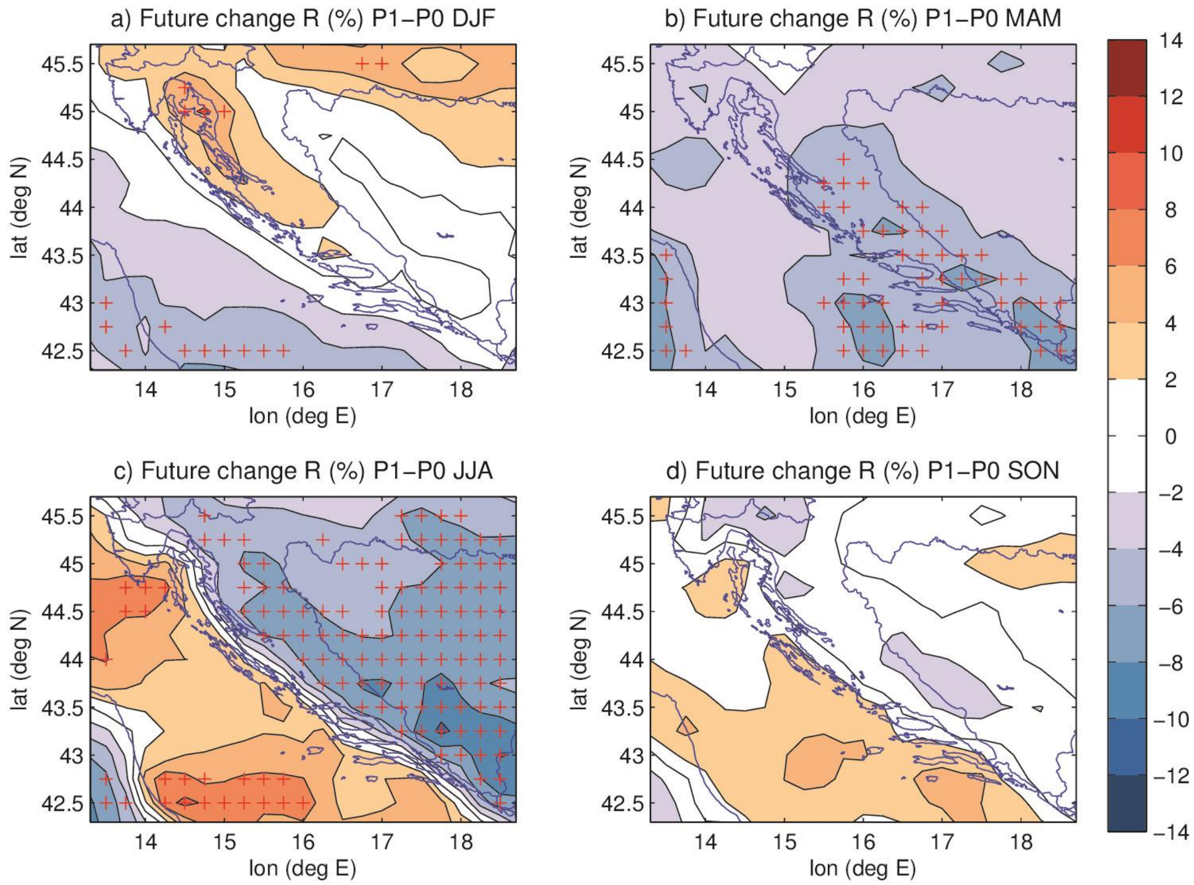

Figure 4.5-2. Ensemble-mean relative difference (in %) of the total precipitation between the periods P1 and P0 in: a) winter (DJF), b) spring (MAM), c) summer (JJA) and d) autumn (SON). The + marker denotes grid points where the sign of change in at least the two-thirds of the models agrees with the sign of change of the ensemble mean difference and when the relative difference of ensemble means is outside the interval ±5%.

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