METEOROLOGICAL AND HYDROLOGICAL SERVICE OF CROATIA

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CLIMATOLOGICAL RESEARCH AND APPLIED CLIMATOLOGY DEPARTMENT
AGROMETEOROLOGICAL DEPARTMENT

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Selected chapters:

Observed climate changes in Croatia

Climate change scenario

Impact of climate variations and changes on plants and wildfire danger

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Content

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1. Observed Climate Changes

Detection of climate variations and changes in air temperature and precipitation over the area of Croatia since the beginning of the 20th century has been performed according to the long-term meteorological measurements that started during the 19th century at meteorological stations in different climate regions: Osijek (continental climate), Zagreb-Grič (continental climate under a mild maritime influence), Gospić (continental climate of highland Croatia under a strong maritime influence), Crikvenica (maritime climate of eastern coast of the northern Adriatic) and Hvar (maritime climate of the Dalmatian area).

Decadal trends during the 20th century as well as those till 2008 were compared in order to determine the differences that appeared due to the changes in temperature and precipitation regimes at the beginning of the 21st century.

1.1. Air temperature

Increase of mean annual air temperature, which in the 20th century was between +0.02°C per 10 years in Gospić up to +0.07°C per 10 years in Zagreb, continued and amplified by the beginning of the 21st century (Table 1-1 and 1-2). In such way, decadal trends were proceeding until 2004 within the range from 0.04°C up to 0.08°C, and by 2008 between 0.05°C and 0.10°C. Prevailing positive trend has become particularly expressed within the last 50 years, even more within the last 25 years (Figure 1-1, Table 1-1). Trends of mean annual air temperature within the 108-year period are statistically significant at all stations except for Osijek, while within the last 50, i.e. 25 years at all observed stations. 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). The greatest trends were recorded in Zagreb; however, it should take into account that such increase is partially a result of the urban heat island.

Consequence of the faster atmosphere warming up during the last period of time is a result that out of ten warmest years since the beginning of the 20th century 7 of them were recorded in Zagreb, 6 in Gospić and Crikvenica, 5 in Hvar and 4 in Osijek (Table 1-3).

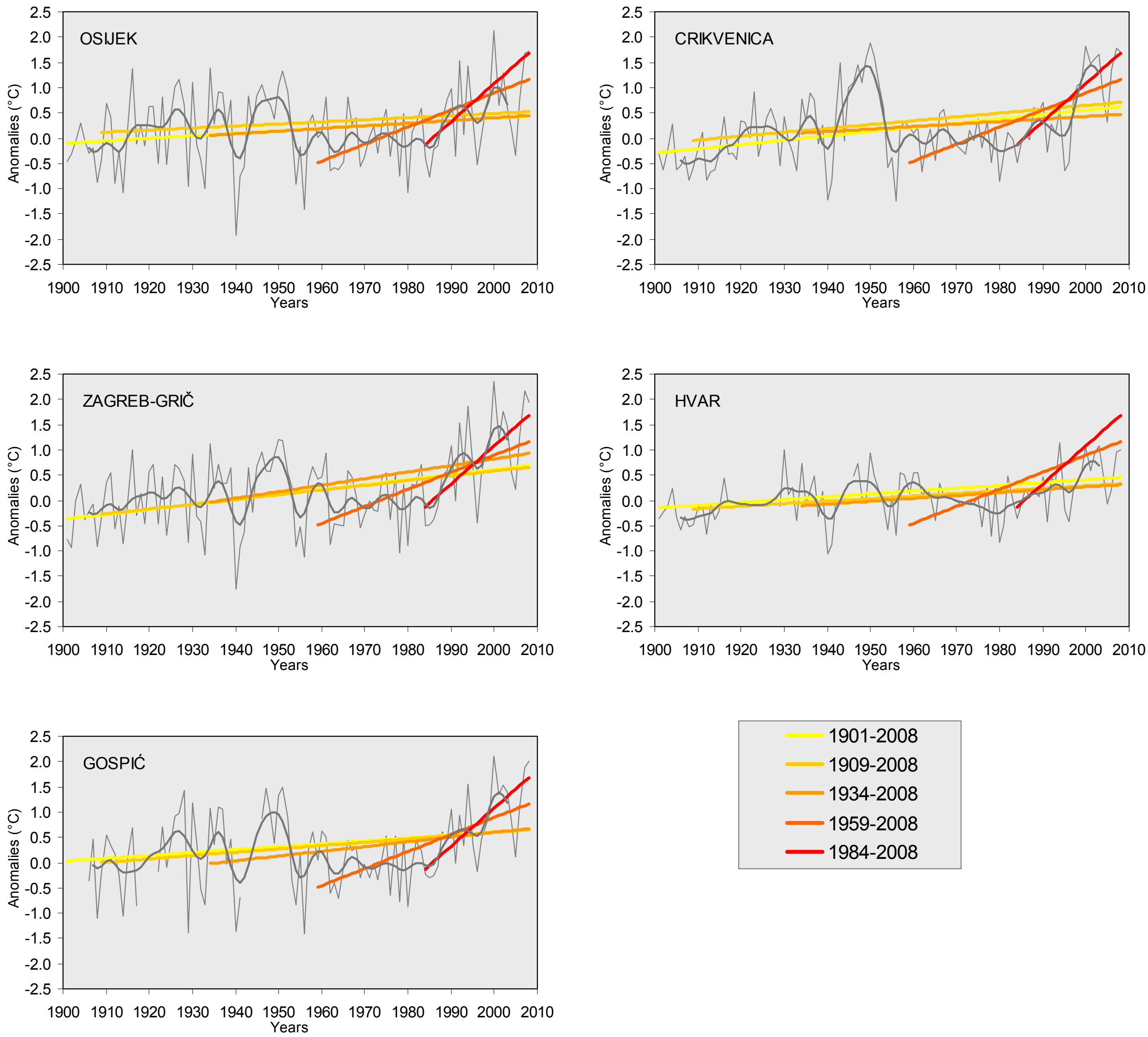

Figure 1-1. Time series for the mean annual air temperature related 11-year binomial moving averages, and trends for 108-, 100-, 75-, 50- and 25-year period. Unit is anomalies (°C) with respect to 1961-1990 average.

Table 1-1. Trends in mean annual air temperature (°C/10 years) for 108-, 100-, 75-, 50- and 25-year period. Trends significant at the 5% level are bolded.

	Osijek	**Zagreb-Grič**	**Gospić**	**Crikvenica**	**Hvar**
1901-2008 (108y)	+0.05	**+0.10**	**+0.06**	**+0.09**	**+0.06**
1909-2008 (100y)	+0.04	**+0.09**	**+0.07**	**+0.08**	**+0.05**
1934-2008 (75y)	+0.05	**+0.13**	+0.09	+0.05	+0.06
1959-2008 (50y)	**+0.23**	**+0.34**	**+0.32**	**+0.28**	**+0.12**
1984-2008 (25y)	**+0.52**	**+0.75**	**+0.69**	**+0.75**	**+0.35**

Table 1-2. Trends in mean annual and seasonal air temperature .(°C/10 years) Trends significant at the 5% level are bolded.

	Osijek	Zagreb-Grič	Gospić	Crikvenica	Hvar
Mean air temperature trend 1901-2000 (°C / 10 godina)					
Winter	+0.04	+0.09	+0.10	+0.06	+0.04
Spring	+0.02	+0.07	+0.00	-0.01	+0.02
Summer	+0.03	+0.05	-0.03	**+0.07**	+0.03
Autumn	+0.03	+0.05	+0.00	+0.07	+0.05
Year	+0.03	**+0.07**	+0.02	**+0.05**	**+0.04**
Mean air temperature trend 1901-2004 (°C / 10 godina)					
Winter	+0.04	+0.10	+0.11	+0.07	+0.04
Spring	+0.04	**+0.09**	+0.03	+0.02	+0.04
Summer	+0.05	**+0.08**	+0.02	**+0.11**	+0.06
Autumn	+0.03	+0.06	+0.02	**+0.08**	+0.06
Year	+0.04	**+0.08**	+0.04	**+0.07**	**+0.05**
Mean air temperature trend 1901-2008 (°C / 10 godina)					
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**

Table 1-3. The ten warmest years. Years from the period 1991-2008 are bolded

Osijek		Zagreb-Grič		Gospić		Crikvenica		Hvar	
year	*°C*	year	*°C*	year	*°C*	year	*°C*	year	*°C*
2000	***12.9***	**2000**	***13.8***	**2000**	***10.5***	1950	*16.0*	1945	*19.2*
2008	***12.5***	**2007**	***13.6***	**2008**	***10.4***	**2000**	***15.9***	**1994**	***17.5***
2007	***12.4***	**2008**	***13.4***	**2007**	***10.3***	**2007**	***15.9***	**2003**	***17.4***
1992	***12.3***	**1994**	***13.3***	**1994**	***9.9***	**2008**	***15.8***	**2000**	***17.4***
1994	***12.2***	**2002**	***13.2***	**2002**	***9.9***	**2003**	***15.8***	1930	*17.3*
1934	*12.2*	**1992**	***13.0***	1951	*9.9*	1951	*15.7*	**2008**	***17.3***
1916	*12.1*	**2003**	***12.9***	1947	*9.9*	1949	*15.7*	**2007**	***17.3***
1951	*12.1*	**2006**	***12.7***	1928	*9.8*	**2002**	***15.7***	1950	*17.3*
2002	***12.1***	**2001**	***12.7***	**2003**	***9.8***	1943	*15.6*	**2002**	***17.3***
1927	*11.9*	1950	*12.7*	**2001**	***9.7***	**2001**	***15.6***	1947	*17.1*

Assuming that the warming observed in mean air temperatures is a result of changes in frequencies of temperature extremes. Analysis of changes in number of days, in which the air temperature exceeds some specific values, does not provide any comparison of observed characteristics in different climate conditions. Namely, frequency of cold (t_{min}<0°C) or warm days (t_{maks}≥25°C) significantly differs between continental climate (Osijek) and maritime climate of Adriatic islands (Hvar). Therefore, The Expert Team on Climate Change Detection Monitoring and Indices of the World Meteorological Organization - Commission for Climatology (WMO-CCl) and Research Programme on Climate Variability and Predictability (CLIVAR) suggested a number of indices of meteorological parameters. Suggested indices are related to days in which the air temperature exceeds the threshold specified by the probability of appearance, i.e. in specific return period. Six indices have been used for the analysis of temperature extremes, four of them with thresholds specified by percentiles and two of them by fixed thresholds. Three warm temperature indices are warm days and warm nights with maximum and minimum air temperature above the 90th percentile of the daily temperature distribution in the 1961-1990 baseline period, as well as summer days with maximum air temperature higher than 25°C. Three cold temperature indices are cold days and cold nights with maximum and minimum air temperatures below the 10th percentile, as well as frost days with minimum air temperature lower than 0°C.

Within the whole analyzed period, a majority of warm temperature indices has a positive trend, while a majority of cold temperature indices has a negative trend (exceptions are warm nights Tn10% in Hvar, and summer days in Gospić and frost days in Osijek) (Table 1-4). Comparison with trends from earlier periods 1901-2000 and 1901-2004 indicates that almost all trends by 2008 has been amplified, some of them have become statistically significant, while changes in trends of warm temperature indices are greater than changes in trends of cold indices. Trends are much more expressed at the Adriatic, than in the inland, except in Zagreb, where they are probably a result of urban heat island impact.

Table 1-4. Trends in indices of temperature extremes (FD, Tn10%, Tx10%, SU, Tn90% and Tx90%) (number of days) according to the reference period 1961-1990, and mean values of number of frost (FD) and summer (SU) days. Trends significant at the 5% level are bolded.

	Osijek	**Zagreb Grič**	**Gospić**	**Crikvenica**	**Hvar**
Trend 1901-2000 (days / 10 years)					
FD	+1.1	-0.9	+0.1	**-0.7**	0.0
Tn10%	-0.3	**-0.3**	-0.3	**-0.3**	**+0.9**
Tx10%	**-1.1**	**-1.4**	-0.5	**-1.9**	**-5.4**
SU	-0.2	0.0	-1.2	+1.0	**+2.6**
Tn90%	-0.5	**+2.7**	+0.6	+0.7	**-0.8**
Tx90%	-0.3	+0.5	-0.1	**+1.4**	**+3.3**
Trend 1901-2004 (days / 10 years)					
FD	+1.0	-0.9	+0.1	**-0.8**	-0.1
Tn10%	-0.4	**-2.7**	-0.6	**-2.9**	+0.5
Tx10%	**-1.2**	**-1.7**	-0.4	**-2.0**	**-5.2**
SU	0.0	+0.1	-0.6	**+0.1**	**+2.6**
Tn90%	+0.1	**+3.2**	**+1.3**	+1.7	+0.4
Tx90%	0.0	+1.2	+1.1	**+1.6**	**+3.8**
Trend 1901-2008 (days / 10 years)					
FD	+0.9	**-0.1**	-0.1	**-0.8**	-0.1
Tn10%	-0.6	**-2.7**	**-0.8**	**-2.9**	+0.2
Tx10%	**-1.2**	**-1.7**	-0.8	**-1.9**	**-5.1**
SU	0.0	+0.3	-0.4	**+1.1**	**+2.6**
Tn90%	+0.6	**+3.5**	**+1.9**	**+2.2**	+1.0
Tx90%	+0.4	+1.8	+1.5	**+1.8**	**+4.1**
Mean number of days in period 1961-1990.					
FD	88	60	120	18	5
SU	90	61	47	84	110

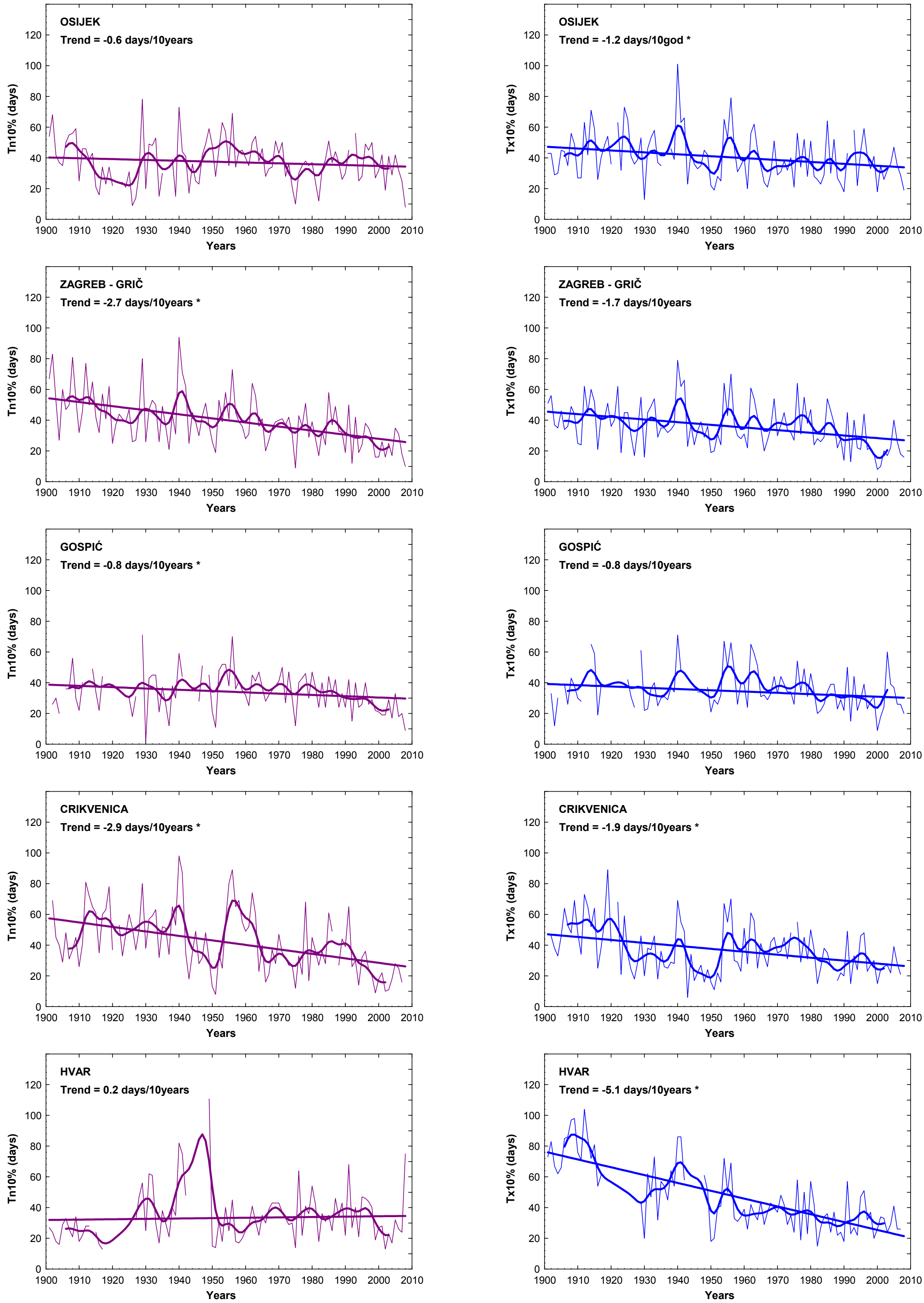

Figure 1-2. Time series for the number of days with minimum (Tn10% - left) and maximum (Tx10% - right) air temperatures below the 10th percentile, related binomial moving averages and trends (* - trends significant at the 5% level). Period: 1901-2008

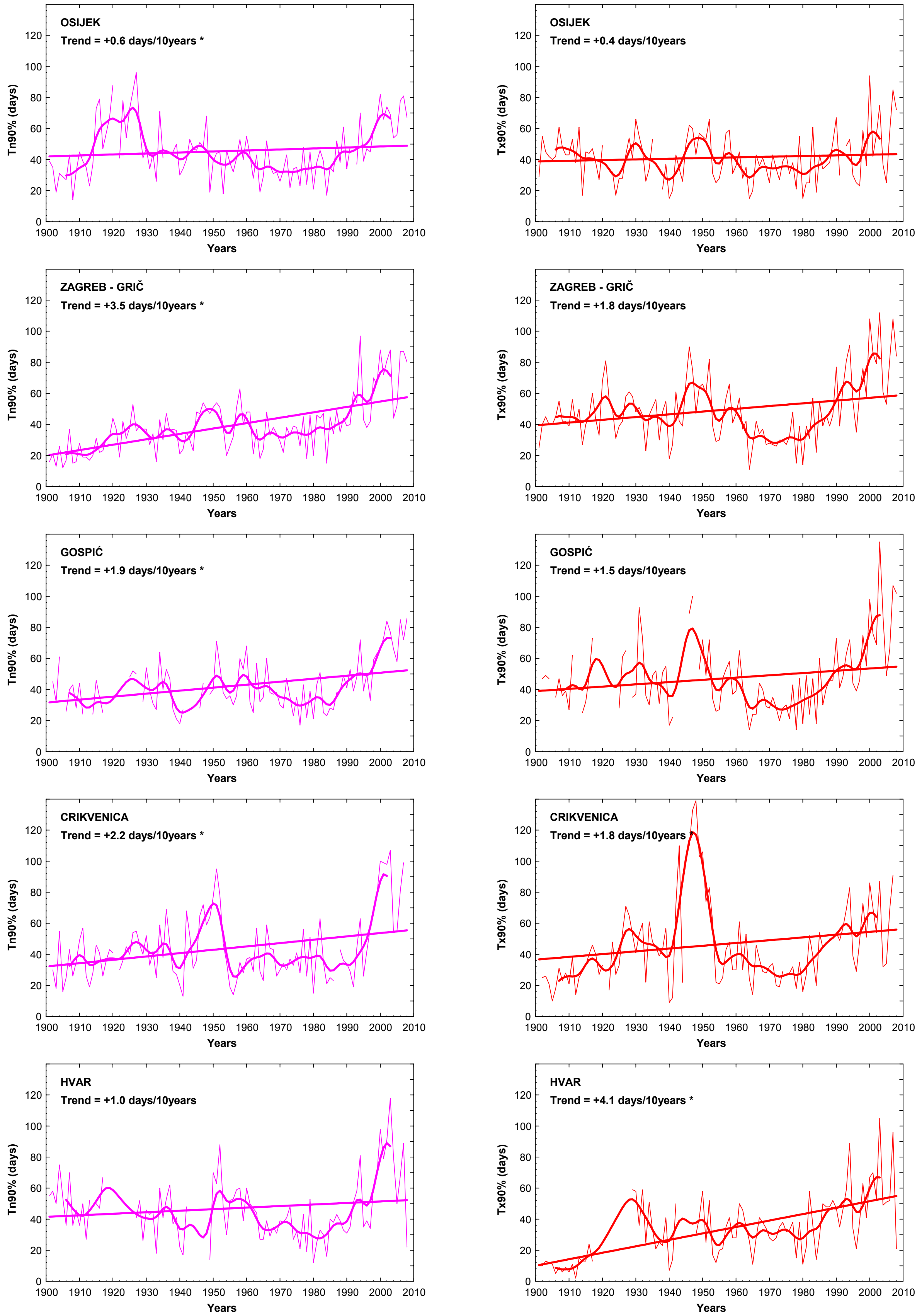

Figure 1-3. Time series for the number of days with minimum (Tn90% - left) and maximum (Tx90% - right) air temperatures above the 90th percentile, and related binomial moving averages and trends (* - trends significant at the 5% level). Period: 1901-2008.

1.2. Precipitation

During the 20th century annual amounts of precipitation showed a downward trend in all parts of Croatia, thus joining the trend of drying across the Mediterranean (Figure 1-4 and Table 1-5). 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 hinterlan– Gospić: -0.8% in 10 years, eastern Slavonija, Osijek: -1.3% in 10 years, north-western Croatia, Zagreb-Grič: -0.3% in 10 years). These are the results of the seasonal precipitation trends which differ among regions. In the area of northern Adriatic (Crikvenica) decrease in all seasonal precipitation amounts has been observed, mostly expressed during summer (-2.7% in 10 years), then in spring (-2.2% in 10 years) and winter (-1.8% in 10 years). On Dalmatian islands (Hvar) decrease in annual precipitation amounts is a result of decline in winter (-2.9% in 10 years) and spring (-2.0% in 10 years) precipitation amounts. In the mountainous hinterland (Gospić on the Lika plateau) a decrease in winter (-2.7% in 10 years) and spring (-2.0% in 10 years) precipitation amounts is mostly expressed. The decline in annual amounts of precipitation over the area north of the Sava River results from decrease in spring (Osijek: -4.1% in 10 years and Zagreb-Grič: -1.1% in 10 years) and autumn (Osijek: -3.0% in 10 years and Zagreb-Grič: -1.4% in 10 years) precipitation amounts.

Decadal trends in annual and seasonal precipitation amounts have not been significantly changed according to data series prolonged by 2008 (Table 1-5). Less changes are present with Osijek, where attenuation of negative spring precipitation trend was observed, but still remaining statistically significant, as well as weakening of negative autumn precipitation trend and strengthening of positive summer trend. Negative spring precipitation trend weakened in the area of Hvar.

Precipitation amounts have large interannual variability, both on annual and seasonal scales. Therefore, in order to find out position of 10 driest years in the observed 108-year period, it can be seen that they do not occur grouped in some period. During the last 18 years, i.e. since the beginning of 1990's, there was only one out of three driest years. 2003 is one of 10 driest years at all locations. Beside this year, there was 2000 in Osijek, 2007 and 1994 in Gospić and 1992 in Hvar. (Table 1-6).

Variability of annual precipitation amounts in the period 1901-2008, expressed by time series of coefficients of variability, calculated for 30-year periods with one year shift, indicates a decrease in Zagreb, Gospić and Crikvenica (Figure 1-4 right). Such a decrease was present in Osijek by the end of the 20th century as well, but the changes since the beginning of the 21st century contribute to an increase of variability. In Hvar there was an increase of variability in a period from the middle of the 20th century.

Change in precipitation regime patterns, which can result in precipitation decrease in Croatia, can be also indicated by tendency in frequency and intensity of precipitation extremes defined by number of days in which the precipitation amount R_d exceeds defined thresholds (dry days, wet days and very wet days), i.e. part of annual precipitation amount occurring during very rainy days, annual maximum 5-day and 1-day precipitation amounts. Dry days are defined as days in which R_d<1.0 mm, wet days have $R_d \geq 75^{th}$ percentile and very wet days $R_d \geq 95^{th}$ percentile of daily amounts, determined by the sample of all precipitation days (R_d≥1.0 mm) within standard reference period 1961-1990.

In the period 1901-2008 there was statistically significant increase of annual number of dry days (R_d<1.0 mm) in the whole area of Croatia, mostly negative trend of wet days (Rd≥R75%), significant in Osijek and Crikvenica, while in the number of very wet days (Rd≥R95%) there was no change (Table 1-7). Fraction of annual total precipitation due to very wet days (R95%T) is almost unaltered. Absolute annual 1-day and 5-day maxima indicate large interannual variability, with weak positive trend only on Dalmatian islands, while in the inland and Littoral there is a decrease of precipitation amounts during heavy precipitation events, statistically significant for 5-day maxima in Osijek (-1.0mm/10years) and 1-day maxima in Gospić (-1.4mm/10years).

As seen from above, in the area of drying such as Croatia there is no signal of major secular changes in extremes related to the high amounts of precipitation and frequency of wet and very wet days over the larger part of Croatia. The reduction in the annual amounts of precipitation can be attributed to changes in the frequency of low-intensity rain days and significant increase in incidence of dry days all over Croatia.

Table 1-5 Trends in. annual and seasonal precipitation amounts. Trends significant at the 5% level are bolded.

	Osijek	**Zagreb-Grič**	**Gospić #**	**Crikvenica**	**Hvar**
Precipitation 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
Precipitation amount trend 1901-2004 (% / 10 years)					
Winter	+0.2	-0.4	-2.6	-1.9	**-2.4**
Spring	**-3.6**	-0.9	-2.0	-2.1	-2.0
Summer	+0.8	+0.9	-0.1	**-3.4**	+2.9
Autumn	-1.8	-1.0	+0.6	-0.7	-1.0
Year	-1.0	-0.3	-0.8	**-1.8**	-1.3
Precipitation amount trend 1901-2008 (% / 10 years)					
Winter	-0.0	-0.4	-2.9	-1.6	**-2.9**
Spring	**-3.2**	-0.9	-1.8	-1.9	-1.3
Summer	+1.3	+1.1	+0.1	**-2.9**	+2.9
Autumn	-2.0	-1.3	-0.2	-1.1	-0.5
Year	-0.8	-0.3	-1.0	**-1.7**	-1.0

since 1924.

Table 1-6. Ten driest years. Years from the period 1991-2008 are bolded.

Osijek		Zagreb-Grič		Gospić #		Crikvenica		Hvar	
year	*mm*	year	*mm*	year	*mm*	year	*mm*	year	*mm*
2000	***316***	1949	*581*	1983	*910*	1949	*704*	1983	*384*
1921	*422*	1973	*607*	1953	*973*	1945	*726*	**2003**	***431***
1983	*467*	1971	*616*	1949	*1085*	**2003**	***752***	1989	*444*
1947	*494*	1927	*624*	1971	*1091*	1953	*786*	1913	*461*
1953	*500*	**2003**	***624***	**2003**	***1099***	1971	*835*	1903	*479*
1949	*505*	1921	*651*	**2007**	***1109***	1973	*842*	1977	*496*
2003	***517***	1946	*665*	1989	*1119*	1956	*850*	1938	*505*
1971	*519*	1942	*671*	**1994**	***1121***	1921	*861*	1946	*542*
1928	*522*	1938	*688*	1975	*1135*	1983	*877*	1950	*557*
1924	*523*	1911	*691*	1946	*1136*	1920	*882*	**1992**	***563***

since 1924.

Table 1-7. Trends in indices of precipitation extremes (DD – dry days, R75% - wet days, R95% - very wet days, R95%T – annual precipitation fraction due to very wet days, Rx1d – annual 1-day precipitation maxima, Rx5d – annual 5-day precipitation maxima). Trends significant at the 5% level are bolded .

	Osijek	**Zagreb-Grič**	**Gospić #**	**Crikvenica**	**Hvar**
Trend 1901-2000 (in 10 years)					
DD (dani)	+0.9	**+1.5**	+1.6	**+2.1**	**+1.1**
R75% (dani)	-0.3	+0.0	-0.2	-0.5	-0.3
R95% (dani)	-0.1	+0.1	+0.1	-0.1	-0.0
R95%T (%)	-0.3	+0.4	+0.5	+0.1	+0.3
Rx1d (mm)	-0.4	+0.0	-1.3	+1.4	+0.5
Rx5d (mm)	**-2.2**	-0.4	-0.3	-2.7	-0.7
Trend 1901-2008 (in 10 years)					
DD (dani)	**+1.0**	**+1.4**	+1.4	**+2.3**	**+1.1**
R75% (dani)	**-0.2**	+0.1	-0.2	**-0.5**	-0.2
R95% (dani)	-0.1	+0.1	+0.0	-0.1	-0.0
R95%T (%)	-0.2	+0.3	+0.1	-0.0	+0.3
Rx1d (mm)	+0.2	-0.2	**-1.4**	+0.8	+0.9
Rx5d (mm)	**-1.0**	-0.6	+0.3	-2.4	+0.6
# od 1924.					

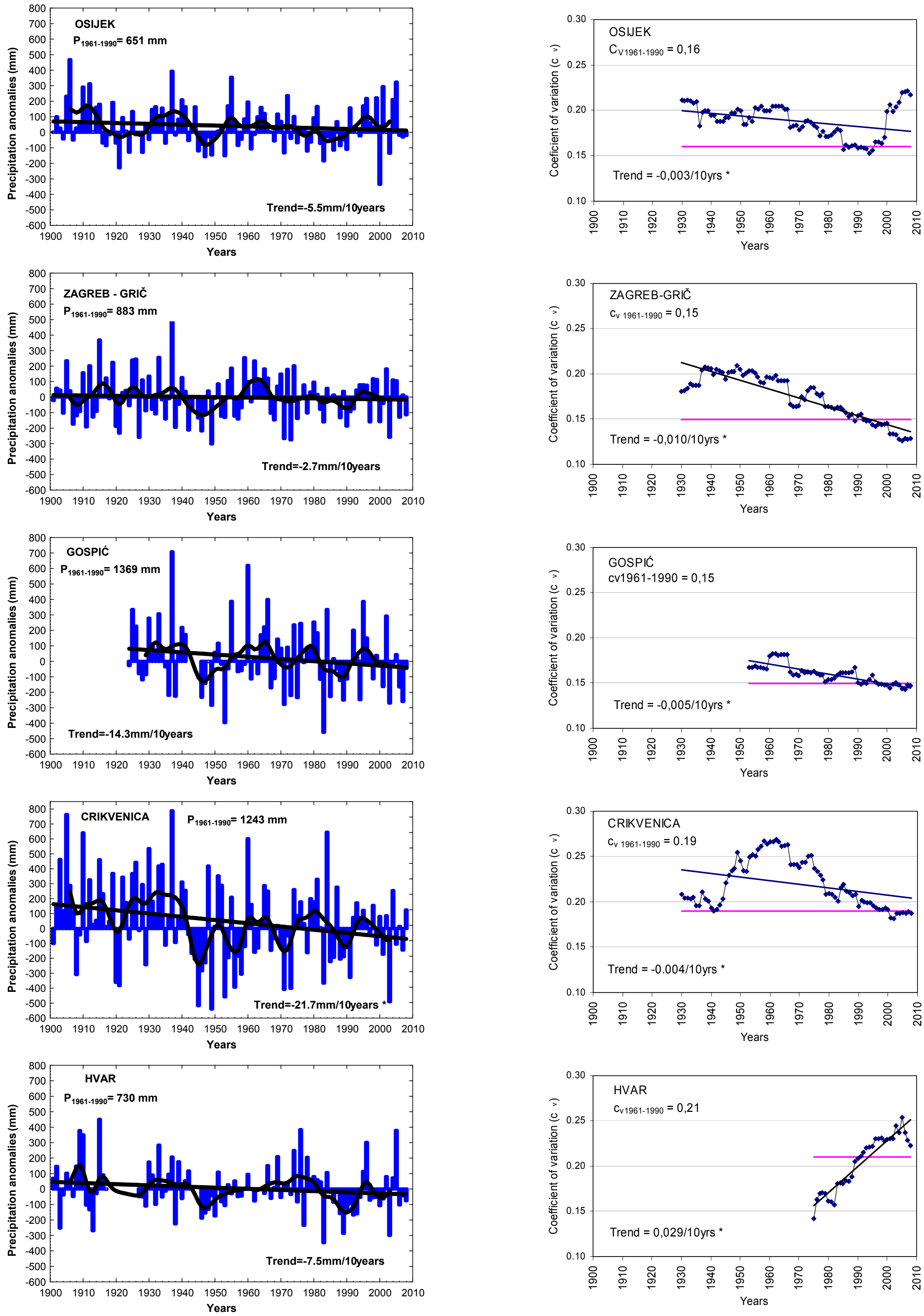

Figure 1-4. Time series for the annual precipitation amounts, related 11-year binomial moving averages and trends (left), unit is anomalies (mm) with respect to 1961-1990 average). Time series for the coefficients of variation for 30-year periods with one year shift and trends (right). (* - trends significant at the 5% level). Period: 1901-2008 (Gospić: 1924-2008).

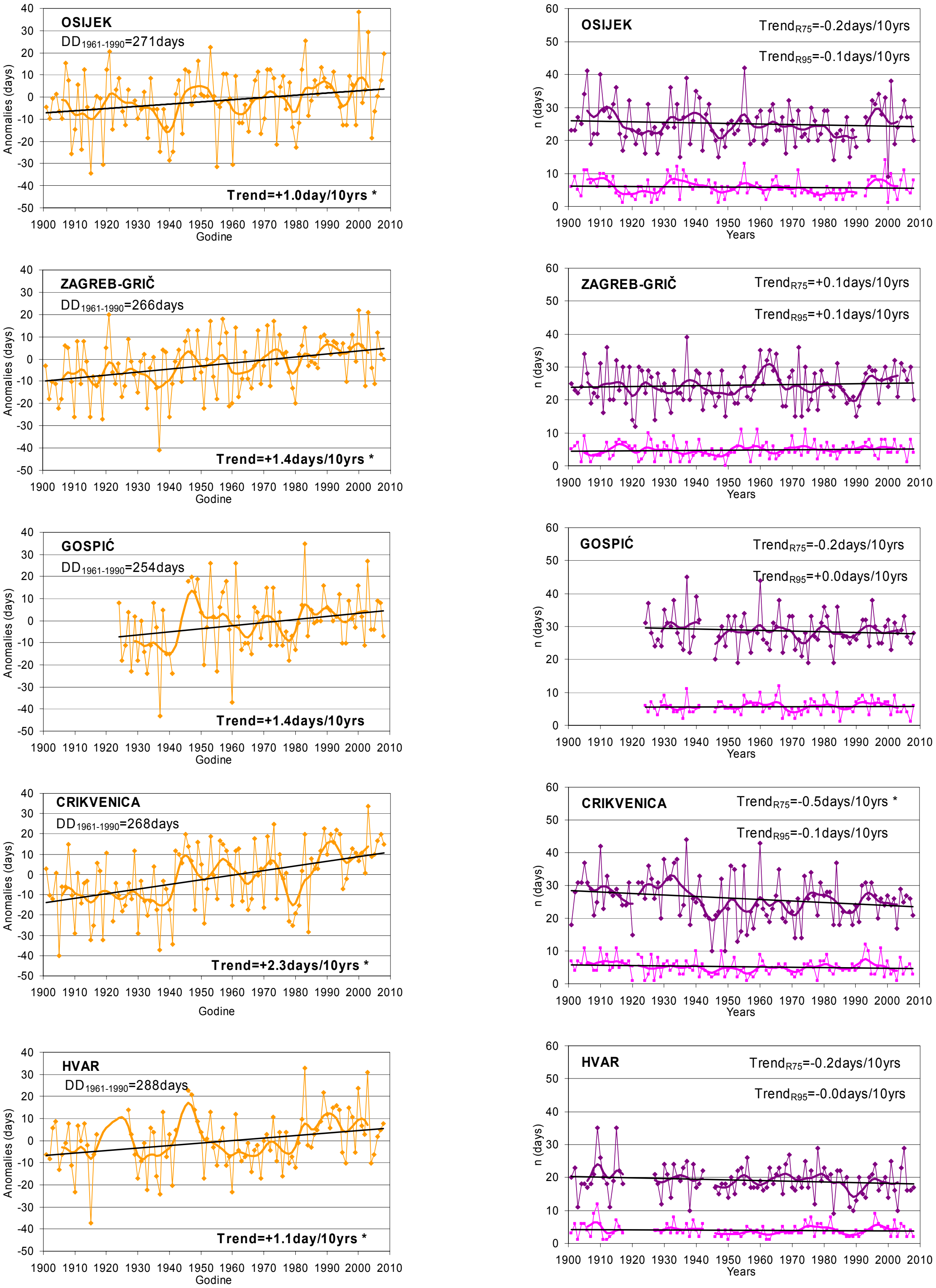

Figure 1-5. Time series for the number of dry days (left), unit is anomalies (days) with respect to 1961-1990 average. On the right time series for the number of moderate wet days (Rd>R75% - above) and very wet days (Rd>R95% - below), related 11-year binomial moving averages and trends (* - trends significant at the 5% level). Period: 1901-2008. (Gospić: 1924-2008).

1.3. **Dry spells**

Detected significant positive trend in number of dry days in the area of Croatia raises the question on frequency of consecutive dry days. Variations of dry sequences are analysed imploying daily precipitaiton data from the period 1961-2000 at 25 meteorological stations, which uniformly comprise main climate zones in Croatia (continental, mountain and maritime). Dry spell is defined as a sequence of days with daily precipitation amount (Rd) less than defined threshold. Seasonal and annual mean and maximum durations of dry spells have been analyzed for precipitation threshold of 1 mm and 10 mm. Trend is expressed as depature per decade in relation to the respective long-term mean value.

Results of trend analysis indicate prevailing increase of mean annual duration of dry spells with Rd < *1 mm* . It is statistically significant in Istria (5 to 6%/10years) and on southern islands (Hvar and Lastovo 5%/10years) (Figure 1-6). Increase of dry spells on annual basis is a result of prevailing increase in all seasons, except in autumn, when negative trend has been observed. The most significant changes have been detected in spring, especially in northern Adriatic (8 to 11%/10years). Analysis of annual maximum dry spells with Rd < 1 mm does not reveal any significant positive or negative trend in Croatia (Figure 1-6). Positive trend prevails in spring and it is statistically significant in northern Adriatic (9 to 11%/10years), while negative trend prevails in autumn, which is significant only in Rijeka, Šibenik and Osijek (9 to 12%/10years).

Analysis of annual mean durations of dry spells for daily precipitation threshold of *10 mm* indicates prevailing positive trend in Croatia, significant in Istria and Dubrovnik (6 to 8%/10years) (Figure 1-6). Negative, but statistically insignificant trend has been observed only in lowlands of Croatia. Statistical significance of trend at annual scale is mostly forced by winter and summer significant increase of mean dry spells. Still, positive trend, statistically the most significant one, has been observed in spring; while in autumn, durations of mean dry spells with Rd < 10 mm decline, especially in the area of Slavonija (10 to 11%/10years). Maximum dry spells have being increased along the coast (10 to 11 %/10years), while reduced in the inland (8 %/10years) (Figure 1-7). Such annual trend of maximum dry spells is mostly contributed by summer variations. Prevailing increase of dry spells at the Adriatic, as well as poorly expressed trend in the continental area contribute to the fact that Croatia remains within the transitional area between the northern Europe with general tendency of precipitation increase, and the drying Mediterranean.

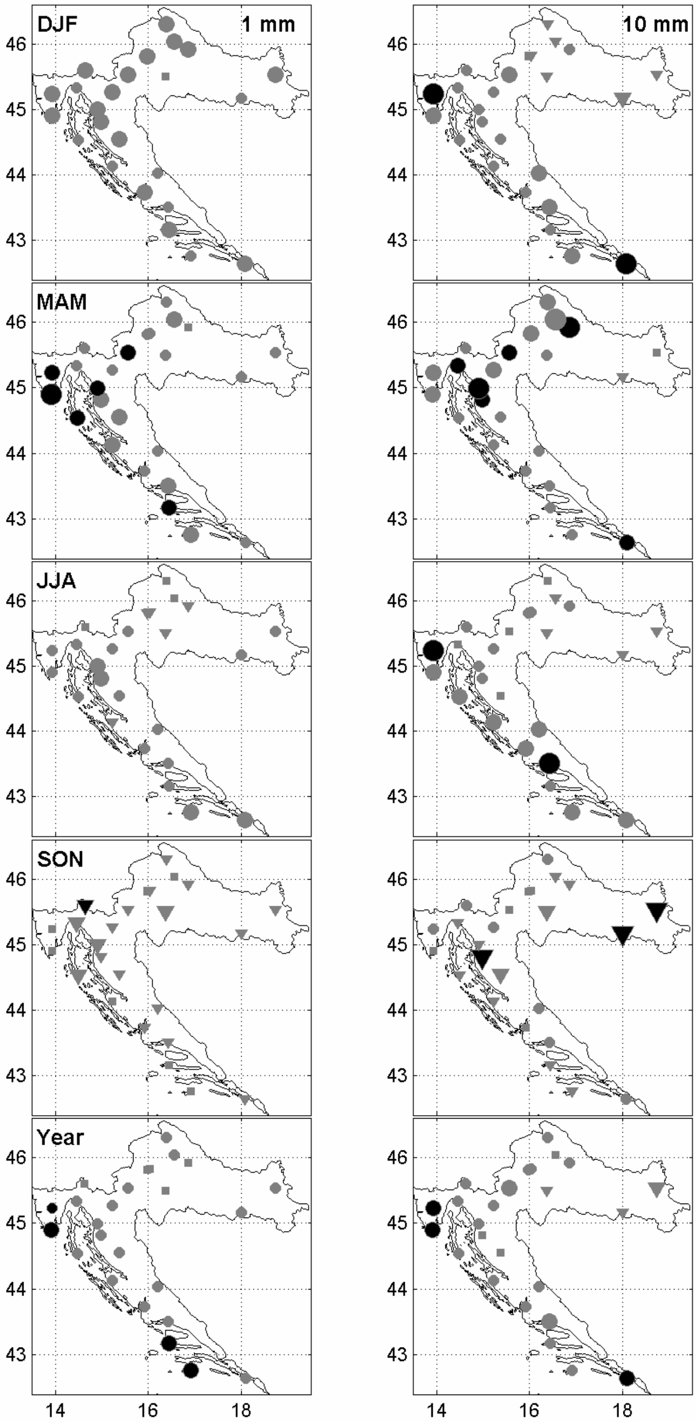

Figure 1-6. Trend results of mean dry spells for the precipitation threshold of 1 mm (left column) and 10 mm (right column), for seasons (upper four rows) and a year (lower row). Circles indicate positive trend, triangles negative trend, while symbols in bold type indicate statistically significant trend. Size of symbols is proportional to the absolute value of change per decade relative to the respective average: 1-5%/10years, 5-10%/10 years and larger than 10%. Squares indicate trend between +/- 1%/10years.

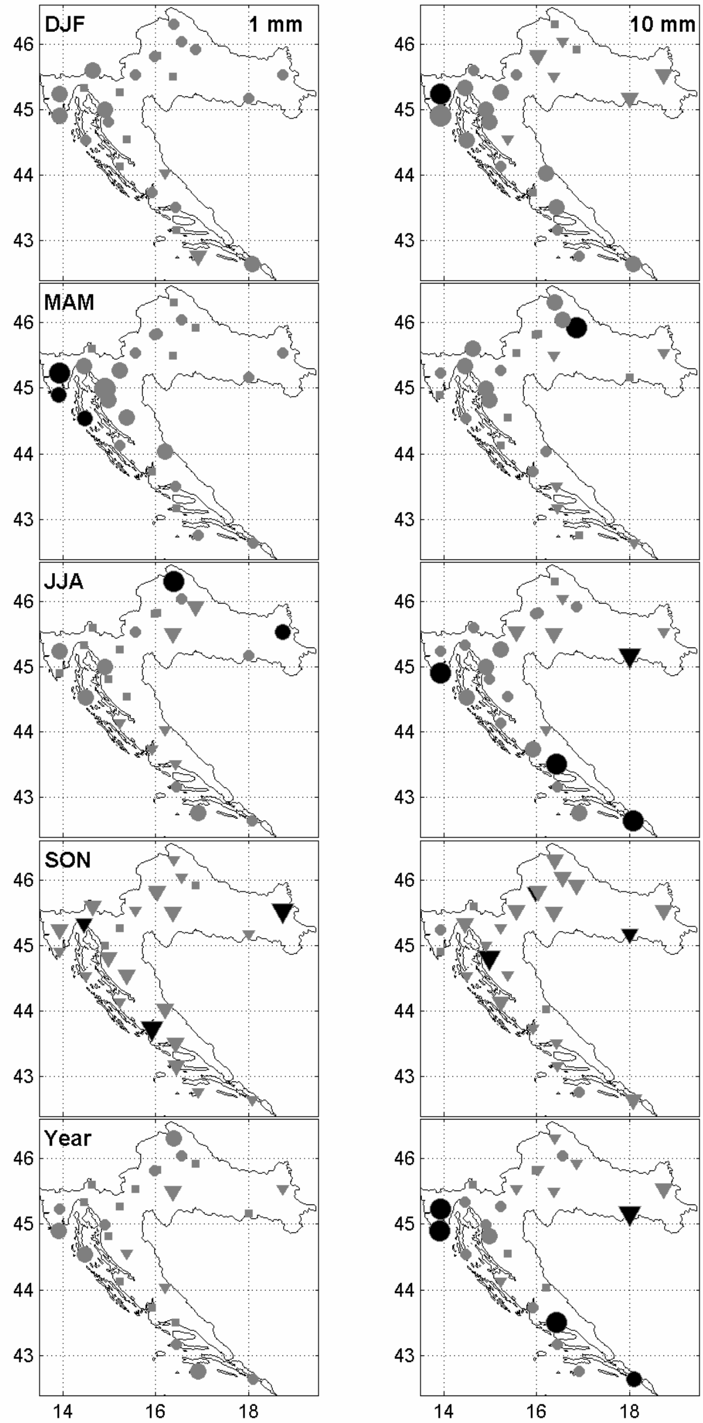

Figure 1-7. Trend results for maximum durations of dry spells for precipitation threshold of 1 mm (left column) and 10 mm (right column), for seasons (upper four rows) and a year (lower row). Circles indicate positive trend, triangles negative trend, while symbols in bold type indicate statistically significant trend. Size of symbols is proportional to the absolute value of change per decade relative to the respective average: 1-5%/10years, 5-10%/10 years and larger than 10%. Squares indicate trend between +/- 1%/10years.

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2. Climate Change Scenario

2.1. Introduction

2.1.1 General remarks

Information on global climate change of the mean value of some climatological parameter, temperature for example, is not sufficient to estimate climate change at regional or local level. The intensity of local climate change can differ from the change of global mean value because of specific latitude, topographic features, distribution of land and sea, etc. However, local climate change should be viewed within the context of global change modulated by local impacts. In this report the results of dynamical downscaling by a regional climate model for the two 30-year periods are described and discussed – for the climate of the 20th century and the future climate from the 21st century, according to the A2 scenario of Intergovernmental Panel on Climate Change (IPCC).

Dynamical downscaling is the method that adjusts the output of a global climate model to a smaller area by the help of a regional climate model. Thus, the results of climate change at a relatively coarse resolution (200-300 km) are being adjusted to much finer space resolution (20-50 km). In this process a regional model defines its “own” hydro- and thermo-dynamical processes at smaller scales, adjusting to the boundary forcing from a global model. In such a way, dynamical consistency in the modelled atmosphere is being achieved. Space variations of climate parameters are better represented at smaller scales by dynamical downscaling, especially extreme events, whose intensity in global models is usually weakened as the smallest grid box of few hundred kilometres can cover the whole region of interest. The alternatives to dynamical downscaling are statistical downscaling methods, but they do not take into account the dynamical connection between global and regional scales.

Although defined for smaller areas and finer resolution, regional climate models cannot improve possible poor results of global models. Of course, vice versa is valid as well – dynamical downscaling by a poor regional climate model cannot improve the global model simulation regardless of the resolution improvement. In other words, the quality of dynamical downscaling results depends on the quality of regional model used for dynamical downscaling as well as on the quality of global model results.

It should be pointed out that the results of a regional climate model cannot accurately describe observational data at regional (local) scale. Of course, it is important that the difference between model results and observations would be as small as possible, but, as model offers only approximation of the actual situation, it inevitably contains errors. Accordingly, a good model is the one with relatively small (systematic) errors. After comparing the model results with observations, by which the modelled climate “state” of the atmosphere for the 20th century is determined, differences between the future model climate and 20th century climate have been analysed. Such differences primarily point out to qualitative assessment of climate change. Due to a number of uncertainties, quantitative climate change assessments should be taken with caution. However, they are necessary in order to execute concrete adaptation and mitigation measures to climate change effects. For example, one of key uncertainties in climate change is the definition of future scenarios given by IPCC (see chapter 2.1.4). This uncertainty is not a result of our lack of understanding of climate system, but a fact that human activities and their possible impact on a future climate should be observed through complex and unpredictable interactions.

2.1.2 Global model, regional model and dynamical downscaling

Dynamical downscaling has been applied to the results of the EH5OM global model, included in the IPCC Fourth Assessment Report (AR4). EH5OM is a coupled atmospheric and oceanic model developed at Max Planck Institute for Meteorology, Hamburg, Germany. Details of EH5OM are given in Roeckner et al. (2003). The EH5OM simulation of the 20th century climate was performed for three different realisations, which differ in a definition of initial conditions. In such a way, sensitivity of climate model to initial conditions is accounted for. For the A2 scenario there are also three model realisations available, each of them being the continuation of the current climate.

The IPCC scenarios for some future period (see Nakićenović et al. 2000) define general assumptions, which climate models should take into consideration after they have been adapted to a model. The A2 scenario assumes the growth of global population to 15 billion by 2100, a moderate economic growth, very high energy consumption and variable hydrocarbons (gas, oil, coal) consumption, as well as moderate to significant arable land usage. These projections are then adapted to a model as the concentrations of greenhouse gases and ozone. The A2 scenario is also called the strong forcing scenario because it predicts the most unfavourable conditions that could occur to the environment – it represents the upper limit of anthropogenic impact to the atmosphere and climate in this century.

For this report, the results of dynamical downscaling by so-called Regional Climate Model of the third generation (RegCM3), have been used. RegCM was developed by Dickinson et al. (1989) and Giorgi (1990). The detailed description of the model version used here is given in Pal et al. (2007). In our experiments the Grell convection scheme (Grell 1993) has been applied along with the Fritsch-Chappel closure (Fritsch and Chappel, 1980). The model horizontal resolution is 35 km in the area with 126 X 88 points centred at 46ºN, 7.5ºE and cover central and eastern Europe and a large part of the Mediterranean. In the vertical, there are 23 levels with the highest level at 100 hPa. Boundary conditions, taken from the EH5OM model, were updated every 6 hours. Dynamical downscaling is performed for all three realisations of the EH5OM global model for 20th century climate and for future climate according to the IPCC A2 scenario.

2.1.3 <u>Selection of periods and seasons</u>

Seasonal mean values for all climatological seasons have been used in the analysis of climate change, while for upper-air fields only the results for winter and summer have been shown. For winter, seasonal mean values were calculated for December-January-February (DJF) period, for spring for March-April-May (MAM) period, etc. Mean values of the 30-year period of future climate (2041-2070) have been compared with mean values of the 30-year period of the 20th century climate (1961-1990). For each parameter and season, statistical significance of the change in the mean value between future and 20th century climate has been calculated. It is based on the testing of the null-hypothesis where the mean values of future and current climate “populations” do not differ. The null-hypothesis is accepted or rejected at the 95% confidence level. In addition to mean values, interannual variability within each 30-year period has been calculated as well. The change in variability is expressed as a difference in standard deviation between future and 20th century climate, calculated from all three model realisations. From the change in mean value and variability, the change of extreme values for the given parameter can be indirectly assessed.

2.1.4 <u>Uncertainties in climate modelling</u>

An estimate of uncertainty in the assessment of future climate change, in particular at regional scale, is an important aspect of the climate change analysis. Uncertainty can be attributed to the following factors: firstly, uncertainty due to inherent (internal) variability of climate system; secondly, uncertainty in defining the future climate scenarios; and thirdly, modelling uncertainty because of approximations in representing processes in the atmosphere and oceans. Relative significance of each of the above factors varies on how far we reach into the future, as well as on spatial and time averaging scales (Hawkins and Sutton 2009). For example, at the regional level, for multi-decade time scales, dominant source of uncertainty is uncertainty in modelling and uncertainty of the given scenario. For smaller time scales, model and inherent variability of climate system represent the main cause of uncertainty. This report does not include explicit assessment of uncertainties of climate integrations by regional model. However, some results of regional model were compared with the results of global model, thus enabling to evaluate, at least partly, to what extent the uncertainty of climate change could be attributed to different modelling approaches.

2.2. Upper-level fields

Climate change of the large-scale circulation, analyzed from the EH5OM global climate model, is discussed in, for example, Branković et al. (2010). We briefly summarize some of general features of global change, as climate change for a wider region of Croatia should not be analysed separately from global change. Here, the comparison with the results of EH5OM climate model is appropriate, as these results are used to define initial and boundary conditions in dynamical downscaling by RegCM.

Global warming in EH5OM model is relatively uniform in the upper troposphere and it is associated with the strengthening of the upper-air westerlies within the jet stream core. The largest increase of surface temperature in Europe is in winter in the north-eastern part (over 3 °C), while in summer is larger than 3.5 °C in the southern Europe and the Mediterranean. The amplitude of warming is larger than model systematic error, whereas the spread within the three model realisations is smaller than the amplitude of climate change. For precipitation, however, such a conclusion is not valid, indicating a large uncertainty in the assessment of future hydrological balance.

Similar to global warming, an increase in temperature in future climate by the middle of the 21st century, i.e. the warming throughout the entire troposphere is evident in RegCM (Fig. 2-1). In south Europe and the Mediterranean warming is larger in summer than in winter, while the largest inter-seasonal difference is in the south-western Europe. In summer, at the 850-hPa level (T850, at approx. 1.5 km altitude) the Mediterranean and south Europe (particularly the Iberian Peninsula) are clearly identified with warming larger than in the other areas of the integration domain (Fig. 2-1d). In winter, a uniform warming is seen through the entire troposphere, while in summer the warming is slightly larger at the lower than at higher layers. The differences between the future and the 20th-century climate in Fig. 2-1 are statistically significant even at the 99% confidence level within entire integration domain.

In accordance with temperature increase, an increase in geopotential is found throughout the troposphere. The meridional gradients in temperature differences at 200 hPa (Fig. 2-1 a,b) indicate that high-altitude wind above Europe will be intensified in future climate in both seasons. This strengthening of the high-altitude wind in winter will occur practically over the entire Europe, but it will be strongest in the western part along with the Atlantic. These changes are statistically significant in the entire integration domain. Similar situation, but with a reduced increase in the wind amplitude, can be found in the lower troposphere. Pinto et al. (2007) associated such an intensified wind in the Atlantic storm path during winter with an increased cyclonic activity in future climate. In summer, the intensification of the upper-level winds is more pronounced in the northern part of the domain, whereas above our areas the northern wind component will be strengthened, although the westerly wind will still prevail.

2.3. Surface fields

2.3.1 Temperature at 2 m (T2m)

In all seasons temperature at 2 m will be increased in future climate (Fig. 2-2); this is statistically significant even at the 99% confidence level. However, warming of the European continent is not the same across the seasons. For example, in winter and spring, the warming is larger in the north-eastern part of Europe than in the Mediterranean (Fig. 2-2 a,b). Such a differential field in T2m is reflected on the Croatian region as well, where a temperature increase in winter is slightly higher in the northern part (for approximately 1.8 °C), and less pronounced in the southern parts of the country (about 1.5 °C; Fig. 2-2a). The warming in future climate, indicated in Fig. 2-2a, is smaller, on average, for about 0.5-1.0 degree than the warming obtained by EH5OM global model (Branković et al. 2010). In spring, an increase in temperature is relatively uniform throughout Croatia (Fig. 2-2b), and, with the amplitude of warming of about 1.5 °C, it is quite similar to winter warming.

In summer and autumn, warming is more pronounced in south Europe and along the coastal part of the Mediterranean (Fig. 2-2 c,d), and significantly exceeds the warming from colder part of the year. For example, above the Iberian Peninsula, amplitude exceeds 4 °C in summer, while in Croatia the warming is between 2 °C in the northern and almost 3 °C in the southern part of the country. In autumn, the T2m increase will be between 1.5 °C in a larger portion of the continental Croatia and slightly above 2 °C in the coastal zone, as well as in Istria and the Dalmatian hinterland. In summer, the warming is similar to that from the winter period (Fig. 2-2c), and for approximately 1 °C smaller than in EH5OM global model. The differences in the future T2m warming between global and regional model can be the consequence of various factors or of their combination. Probably the main source of largest differences between the models is differently defined parameterization of unresolved physical processes. However, the differences could be also attributed to a more detailed (better) orography resolution in the regional model.

The above warming is calculated as the mean value of the three-member ensemble. Unlike the ensemble mean, change in temperature interannual variability, expressed by standard deviation, indicates only a slight increase of temperature variability in future climate (not shown). The T2m standard deviation has a maximum a little higher than 0.3 °C in summer in the eastern and southern Croatia – that is much lower than mean values from Fig. 2-2. In autumn and winter, the change in variability is even smaller, with no change at all in spring.

Such a result indicates that in future climate interannual variation of extreme temperature (usually quantified as the sum of mean value and interannual variation) will mostly depend on change/increase of mean temperature, while it will depend significantly less on the year-to-year temperature variation. Räisänen (2002) came to a similar conclusion analyzing results for the globe from 19 global models.

Increased greenhouse gases concentration according to the A2 scenario will cause relatively larger warming of near-surface atmosphere in summer, which may have a negative impact on human activities and health (see e.g. Srnec i Zaninović 2008). However, global warming should not have damaging consequences if adequate adaptation measures are taken. A higher average temperature in spring can cause an earlier beginning of the vegetation period, while higher temperature in autumn could bring, for example, a prolonged tourist season at the Adriatic coast. However, positive consequences in one season can be "counterbalanced" by negative consequences in another season (for example, a possible reduction of energy consumption for heating in winter is being compensated by increased energy consumption for cooling in summer).

2.3.2 Surface pressure and wind

The increase of geopotential above south Europe in winter is reflects as an increase in mean surface pressure in future climate (not shown). This increase in surface pressure is statistically significant for southern Croatia, but not for other areas. A tendency towards increased pressure can result in an increased frequency of anticyclonic weather types. In summer our regions will be affected by relatively insignificant change of mean pressure – the pressure will be slightly higher in northern areas and slightly lower in south Croatia. However, regardless of the small change in amplitude, the pressure decrease in south Croatia is statistically significant. Therefore, the middle and southern Adriatic will be exposed to an increased cyclonic activity in summer, which will cause more frequent unstable weather types.

In chapter 2.2, it has been ascertained that in future climate, associated with an intensification of the Atlantic storm path, westerly upper-level winds will become stronger, in particular in winter within free atmosphere above the north-western Europe. Similar is true for wind at 10 m (surface wind), which will be intensified in winter to the north of the Alps and weakened at its southern slopes (Fig. 2-3a). Above our areas differential wind (the difference between mean wind in future climate and mean wind in the 20th century climate) will retain similar intensity as in the 20th century, but it will slightly turn to the north-east direction, i.e. it will get a somewhat stronger south-western component. Such a differential surface wind will bring to our areas a slightly increased humidity from the western Mediterranean and the Adriatic (not shown), causing a slight increase in winter precipitation in the littoral and mountain areas (see Fig. 2-4a).

In spring and autumn surface wind will remain unchanged in future climate, while in summer north-eastern component will be intensified (Fig. 2-3b). Related to this intensified wind from the inland of the Balkan Peninsula (where in summer humidity in the near-surface layer is smaller than humidity above the Adriatic Sea) is the associated precipitation decrease, at the coastal part of Croatia (cf. Fig. 2-4c).

2.3.3 Precipitation

At regional and local scale the precipitation may have large spatial variability even in climatological mean. It primarily depends on physical features of the surface – altitude and relief indentation. These features are better represented in regional than in global models, so it can be expected that precipitation will be better represented as well. In addition to the representation of precipitation, a better resolved orography has a more appropriate impact on physical processes - for example, in triggering summer convection.

(i) <u>Total precipitation</u>

Change in total precipitation in future climate relative to the 20th century climate, is shown in Fig. 2-4 for all four seasons. The structure of change – an increase of future total precipitation in north Europe and a decrease in the south – is similar in all seasons and it is associated with the path of storm disturbances from the Atlantic into the European continent. The region of the precipitation increase is moved to the north in summer as storm paths are located further north. Giorgi and Coppola (2007) noticed such a "transition" of climate change in precipitation through year analysing the results from 22 global climate models. Clearly, our results for regional adaptation bear semblance to global models.

From Fig. 2-4 it can be seen that total precipitation is decreased in three seasons (spring, summer and autumn), primarily in the coastal, southern and mountainous Croatia. The decrease is less than 0.5 mm day^{-1} (or 45 mm in a season), except in autumn in southern areas, when it is slightly higher than 0.5 mm day^{-1}. Only in winter (Fig. 2-4a) there will be a slight precipitation increase, mainly in the littoral and mountainous part of Croatia, as well as in the northern and eastern parts.

Total precipitation change, especially in winter and spring (Fig. 2-4 a,b), is concentrated in relatively narrow zone along the Adriatic, whereas for a major part of the Adriatic Sea there is small or no change in total precipitation. Considering quite a complex orography of our Adriatic coast (steep rise of high mountains), such a structure of climate change in precipitation (narrow and elongated) indicates the need of dynamical downscaling with even finer horizontal resolution than the current 35 km.

In summer, a *relative* decrease of total precipitation along the eastern Adriatic coast and its inland is larger than in spring and autumn, as total precipitation is smallest in summer. For a major part of our Adriatic coast and its inland a relative decrease of total precipitation in summer is over 20%, while in autumn and spring deficit is lower than 15%. This is indirectly confirmed in Fig. 2-5, where shaded areas of t-test indicate statistical significance in total precipitation change at the 95% confidence level. In summer, a decrease of total precipitation along the eastern Adriatic coast and inland is statistically significant (Fig. 2-5c), while in spring (Fig. 2-5b) and autumn (Fig. 2-5d) precipitation decrease in future climate is significant only in the southern part of the eastern Adriatic coast. It is interesting to notice that precipitation increase in winter is not significant. It could be concluded therefore that in future climate in most of the year there will be a deficit in precipitation in western and southern Croatia, while the increase in winter is not reliable. In northern parts of the country there will be no significant change in total precipitation in future climate. Change in interannual variation of precipitation described by the variation coefficient, indicates an increase in variability in future climate. It is pronounced mainly in the Mediterranean (mostly in summer, least in winter) and it is very weak north of 45 °N (not shown).

The comparison of climate change in total precipitation in Fig. 2-4 with the results of global model indicates the following: the structure of anomaly fields in Fig. 2-4 generally coincides with those from global model (compare with Giorgi and Coppola, 2007, and Branković et al. 2010); however, in Fig. 2-4 there are clearly details at a finer scale, which cannot be seen in global model. In winter, the amplitude of positive anomaly (increase of total precipitation) in the littoral Croatia is slightly higher in RegCM (Fig. 2-4a), than in global model, where the result is mostly neutral. In summer, a decrease of total precipitation is slightly more evident in the littoral Croatia and its hinterland in RegCM model, while in global model it is more pronounced in the northern Croatia. Therefore, model results should be interpreted cautiously, as they could indicate the opposite effects, particularly in the analysis at smaller scales (see comment in 2.1.4).

(ii) Snow

It is expected that the change in the coverage (spatial distribution) and height of snow cover in Europe will occur in association with global warming in winter (Fig. 2-2a). A large decrease of snow cover in future climate, more than 30 mm (but less than 50 mm) of equivalent water, can be found in the Alps (Fig. 2-6a). In other mountainous areas of middle and southern Europe (the Carpathians, the Balkan mountains, the Pyrenees) there will be a reduction of snow cover as well, and also in the lowlands of Germany, Poland and Russia. In our areas, the reduction is 1 mm in northern Croatia, up to slightly more than 2 mm in mountainous areas. Although such a reduction of snow cover in Croatia may seem irrelevant, compared, for example, with the Alps, in relative terms it is quite significant. Except in the north-western Croatia and Istria, the reduction of snow cover by the middle of this century is statistically significant (Fig. 2-6b). The reduction of snow cover will generally bring a decrease in interannual variability (not shown); only in the areas with relatively small snow reduction, for example in the Pannonian lowland, variability will be slightly increased.

From the RegCM model results, the number of days with snow cover for the 20th century has been calculated and compared with the data from the Croatian meteorological and climatological stations (Fig. 2-6c). Model results underestimate observational data, because the model is not capable to distinguish horizontal and vertical scales of climatological stations. For example, the isoline indicating 15 days with snow borders with Gorski Kotar in the north, while data from Sisak and Slavonski Brod indicate 21 and 20 days with snow. In the south, the same isoline is moved too far inland due to an inadequate resolution of a quite sharp gradient in number of days with snow between the littoral and mountainous Croatia, e.g. the Zavižan station in the northern Velebit sticks out with 39 snowy days. However, more relevant is the relative change of number of days with snow in future climate relative to the 20th century climate (Fig. 2-6d). The number of days with snow in future climate is significantly reduced, in many parts, and even halved relative to the 20th century. Regardless to the errors in the representation of present climate, such a decrease is a significant indicator of what to be expected by the middle of this century.

2.3.4 Some significant or extreme occurrences

As for days with snow (Fig. 2-6 c,d), similar statistics is considered for some climatological parameters describing significant or extreme values of surface atmosphere (temperature and precipitation). For climatological stations many extreme events are processed and shown in Zaninović et al. (2008). Fig. 2-7a shows a comparison of stations data and regional model for hot summer days, i.e. when maximum temperature is higher or equal to 30 °C. Although model generally underestimates a number of hot days, still the model results are acceptable for many areas. The number of hot days in model is increased from mountainous areas of the western Balkan, northwards to the Pannonian lowland and towards the Adriatic coast. The largest discrepancy is found at the Knin station, where the number of observed hot days (37) is the largest in Croatia and significantly exceeds the model value (4). Model orography, which is much higher at the location of the Knin station than in reality, effects a general decrease of temperature, as well as frequency of hot days. Also, vegetation cover has an impact on temperature. Namely, in the model in each grid box only one vegetation type is represented (usually the prevailing one), while in reality in the area of 35 X 35 km various types of vegetation could be found. Generally, deficiencies and approximations in model contribute to differences between measured (observed) values and simulated climate.

Difference between future climate and the 20th century climate indicates to an increase of hot days; in many areas the number of hot days will be doubled by the middle of this century. For example, the increase will be from 6 days in mountainous areas up to almost severe 20 days at the Adriatic (Fig. 2-7b). Such an increase of the number of hot days could greatly influence social-economical circumstances in south Europe and the Mediterranean.

Average number of winter days with precipitation larger than 10 mm is shown in Fig. 2-7c. For a major part of Croatia, particularly in the north, model relatively successfully simulates this type of statistics, even some details such as precipitation decrease in Zadar and Split relative to adjacent areas. In mountainous Croatia (Parg, Ogulin) precipitation is underestimated in the model, while in inland Dalmatia (Knin) and southern Croatia (Dubrovnik) it is overestimated. This is probably the result of the southern Croatia orography being higher in model than in reality. It can be concluded that in extremely orographically complex areas of the littoral Croatia it is very hard to reproduce detailed spatial variation of observed number of days by a model.

In future climate, in a major part of the coastal Croatia and its hinterland average number of days with precipitation larger than 10 mm will be increased from 0.5 up to 1 day (Fig. 2-7d). Such a change is consistent with results in Fig. 2-4a, indicating an increase of total precipitation in winter in the coastal Croatia. According to Fig. 2-7d only on the southern Dalmatian islands the number of days with precipitation larger than 10 mm will remain unchanged or slightly decreased relative to the 20th century climate.

In summer model generally underestimates a number of days with precipitation larger than 10 mm (not shown), probably due to showery nature of summer precipitation, which is relatively difficult to reproduce. However, consistent with Fig. 2-4c, in future climate the number of days with such significant precipitation in coastal area and hinterland is decreased (for more than 1.2 days), while in continental Croatia it will be slightly increased.

2.4. Conclusions

The results of the RegCM regional climate model integrations have been analysed for all seasons from the two 30-year periods: 1961-1990, representing the present climate, and 2041-2070, representing the projection of future climate according to the IPCC A2 scenario. By comparing climatological mean values from both periods, it is possible to conclude on possible climate change in the integration domain. Changes of climatological means have been tested by objective statistical method. Interannual variations of some meteorological parameters within selected periods have been compared from which it can be concluded on the change of variability in future climate in relation to the present one.

In all seasons, RegCM predicts temperature increase within the entire integration domain, as well as throughout the depth of the model atmosphere. In the cold part of the year, the warming will be slightly increased in the northern (continental) Croatia, while in warm periods the warming will be increased in the littoral Croatia. Warming in RegCM integrations is in agreement with warming in EH5OM global model, whose data were used to force RegCM via initial and boundary conditions; however, the amplitude of the warming is generally a little lower in RegCM, than in EH5OM model.

The decrease of total precipitation in future climate is expected in a large part of the year, primarily in the littoral Croatia and its hinterland. Such a decrease is, in relative terms, highest in summer because of pronounced climatological minimum in the annual cycle for total precipitation in this part of Croatia. In winter there will be a slight increase of precipitation, again in a narrow littoral zone, but such an increase is not statistically significant. In the northern Croatia no significant precipitation change in future climate is expected.

Analysis of the modelled number of days for some significant and extreme events (number of days with snow, hot days and days with precipitation larger than 10 mm) for the 20th century climate broadly matches observational data, although not in all details. The largest differences between the model and the observations could be attributed to inadequate orography representation regardless of the fact that regional model has relatively fine horizontal resolution. Future changes indicate a decrease in the average number of days with snow, an increase in the number of hot days, as well as slight increase in the number of days with significant precipitation in winter. This statistics agrees well with climate change of the mean values for near-surface temperature and total precipitation.

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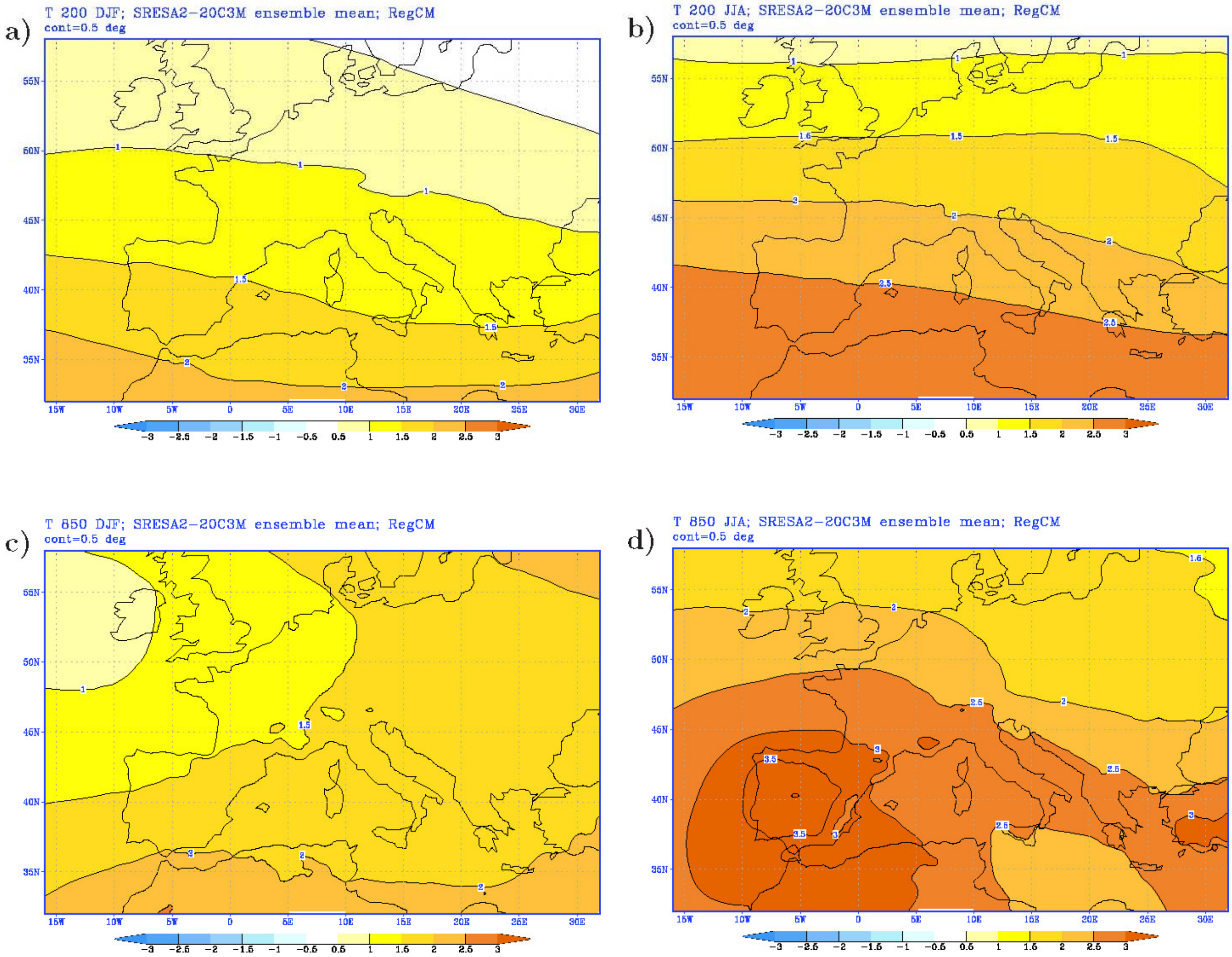


Figure 2-1. Altitudinal temperature, future climate minus the climate of the 20th century: a) winter 200 hPa, b) summer 200 hPa, c) winter 850 hPa, d) summer 850 hPa. Isolines 0,5 degree.

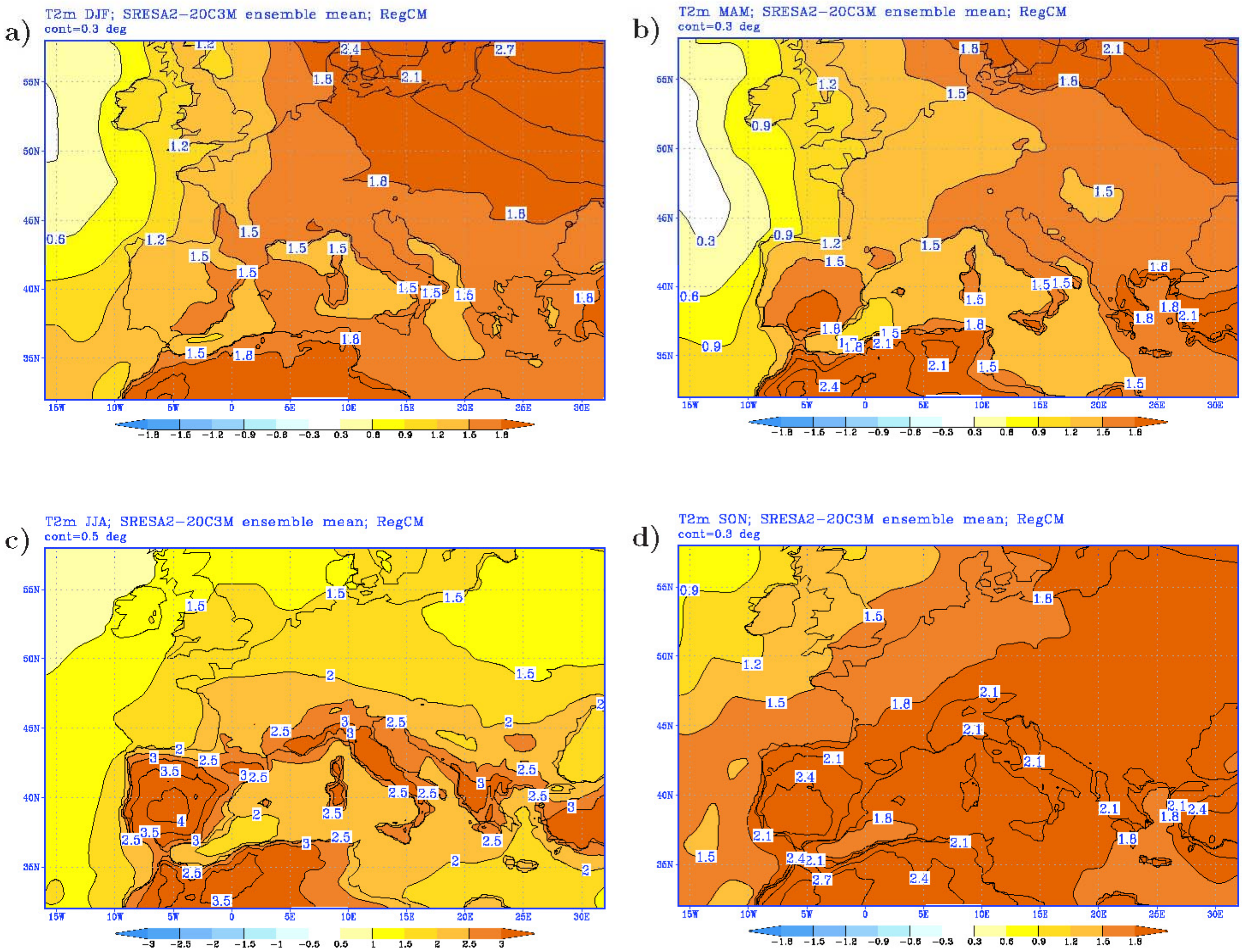
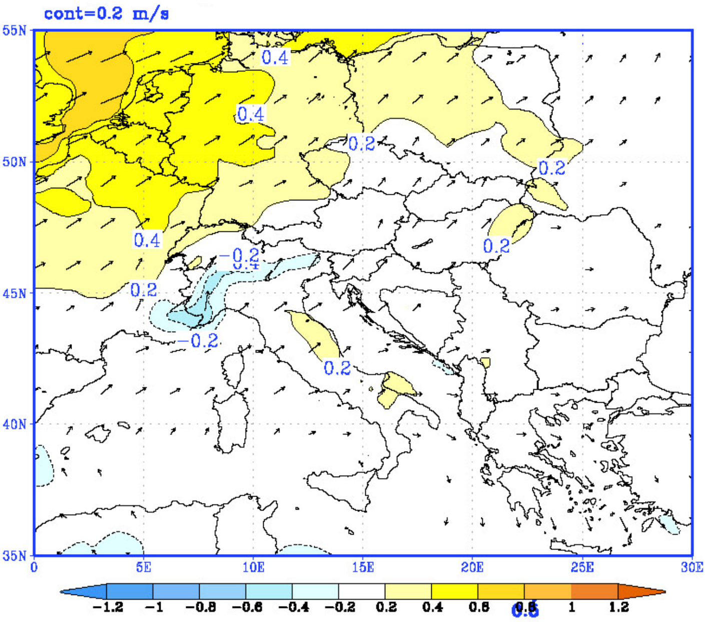


Figure 2-2. Temperature at 2 m, future climate minus the climate of the 20th century: a) winter, b) spring, c) summer, d) autumn. Isolines every 0.3 degrees in a), b) and d), and every 0.5 degrees in c).

a)



b)

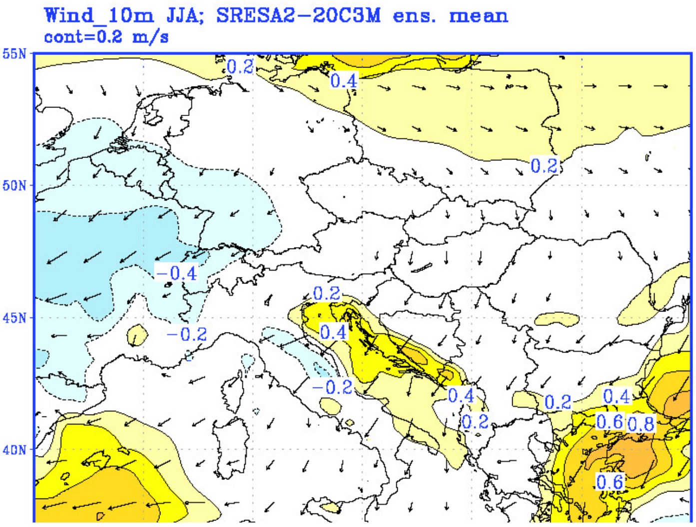


Figure 2-3. Wind at 10 m, future climate minus the climate of the 20th century: a) winter, b) summer. Isolines every 0.2 m/s.

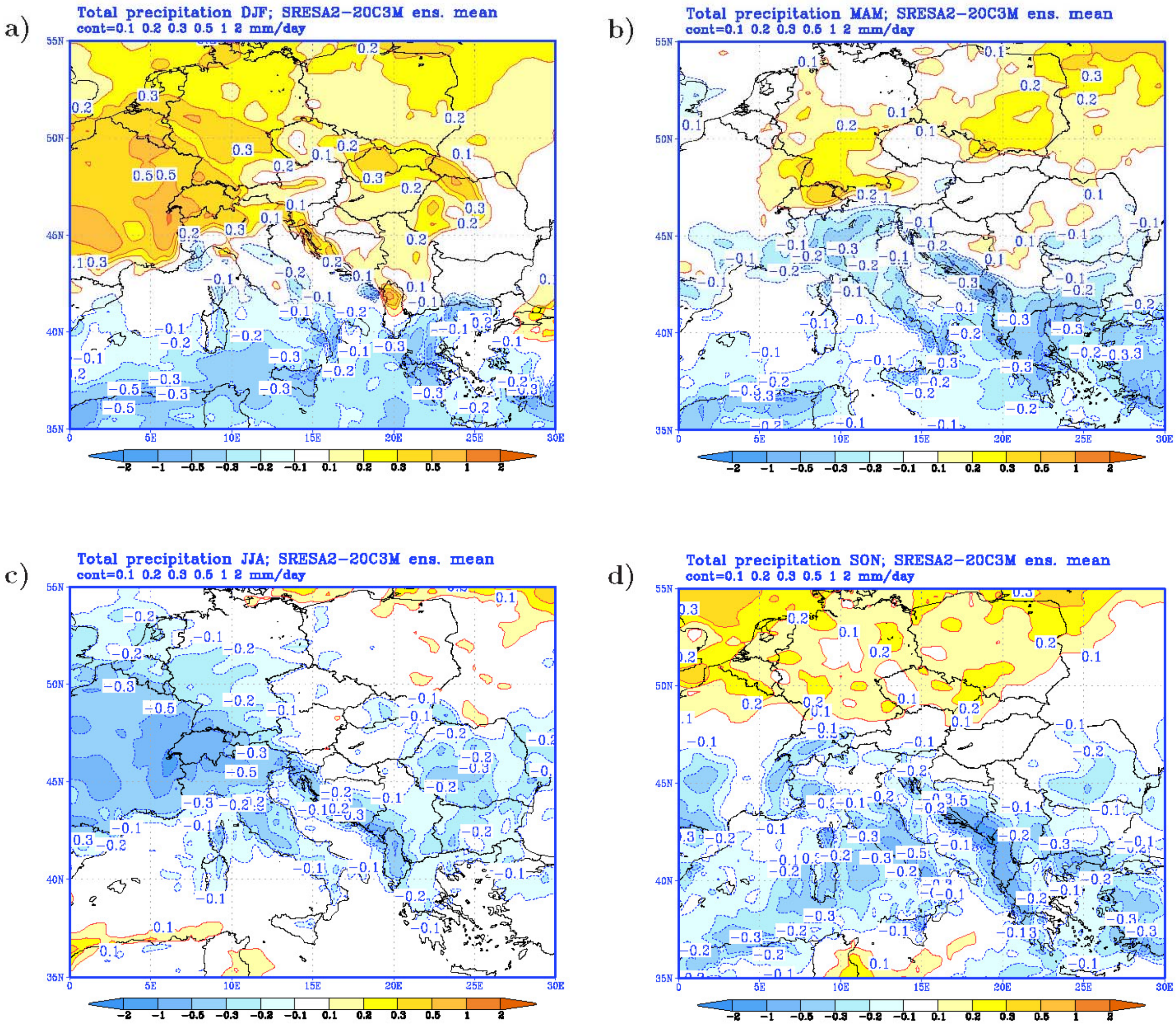


Figure 2-4. Total precipitation, future climate minus climate of the 20th century: a) winter, b) spring, c) summer, d) autumn. Isolines 0.1, 0.2, 0.3, 0.5, 1, 2 mm/day; bold lines positive values, dashed lines negative values.

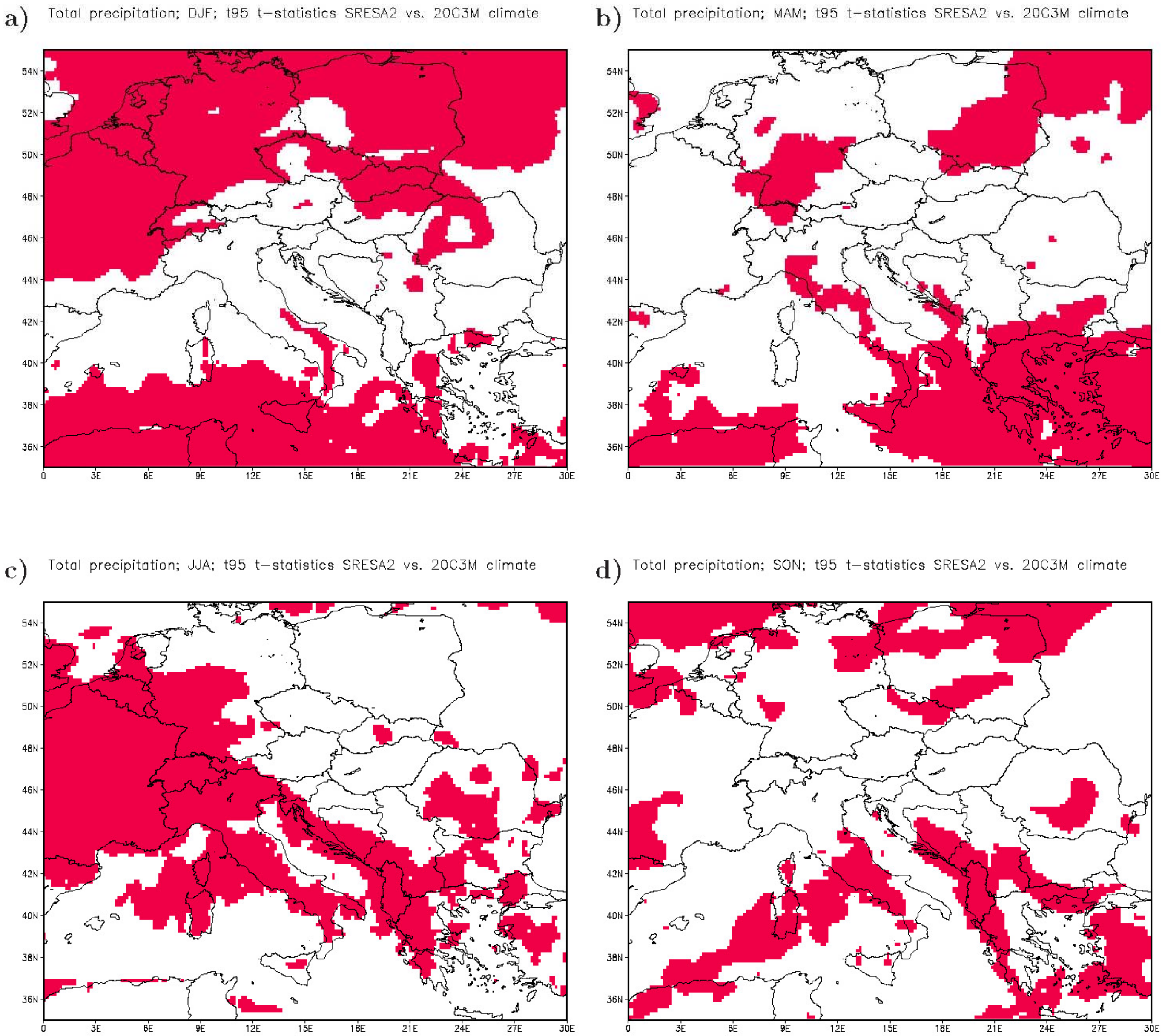


Figure 2-5. t-test significancy of the differences in total precipitation, future climate minus the climate of 20th century with a 95% level of confidence: a) winter, b) spring, c) summer, d) autumn.

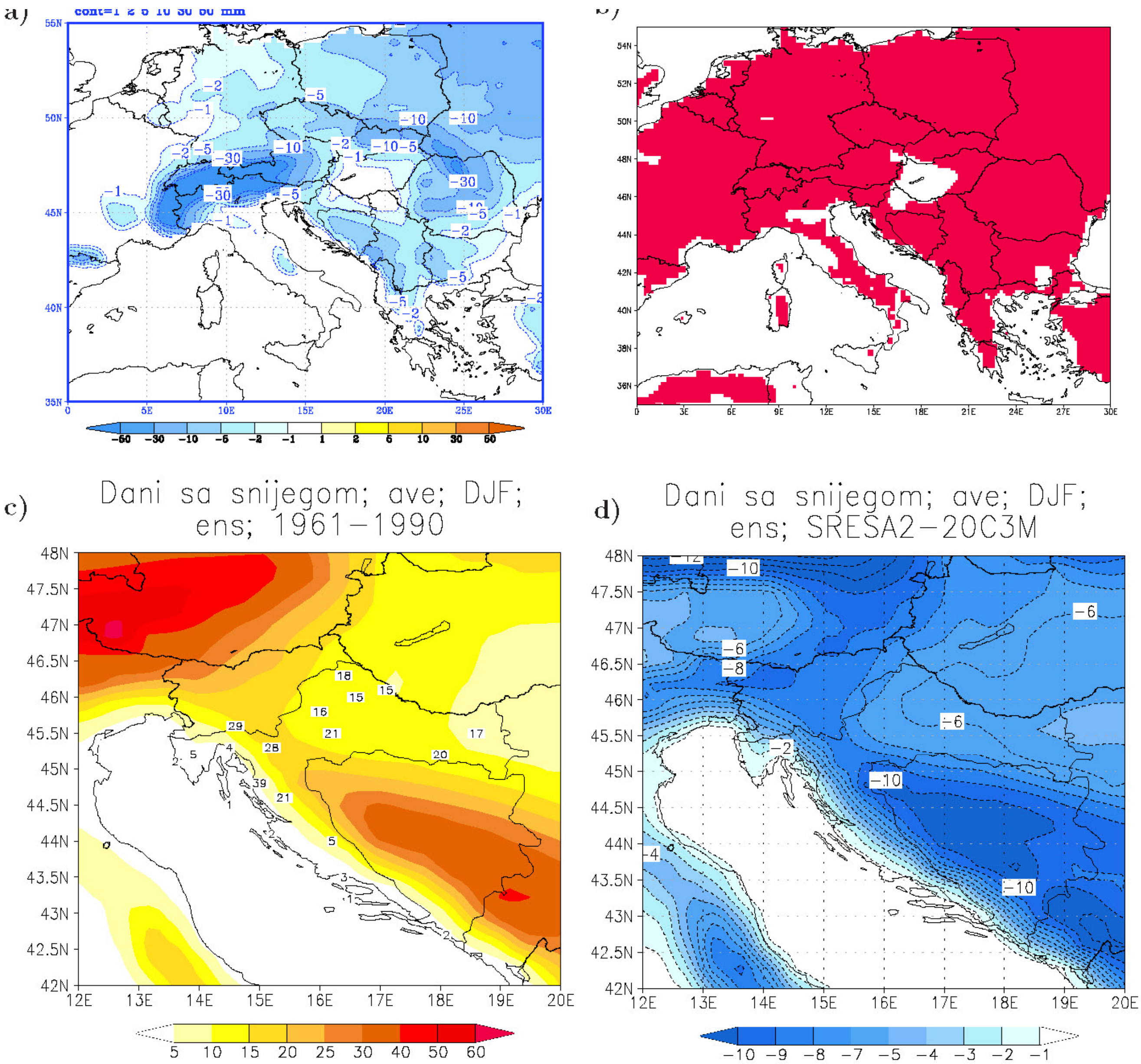


Figure 2-6. Snow in winter, future climate minus the climate of the20th century: a) difference in mean values, b) t-test significancy of the difference of mean values with a 95% level of confidence. Mean number of days with snow in winter c) model and climate stations for the period 1961-1990, d) change of the number of days future climate minus the climate of the 20th century. Isolines in a) 1, 2, 5, 10, 30, 50 mm of equivalent water. Isolines in c) 5, 10, 15, 20, 25, 30, 40, 50 days, in d) 1 day.

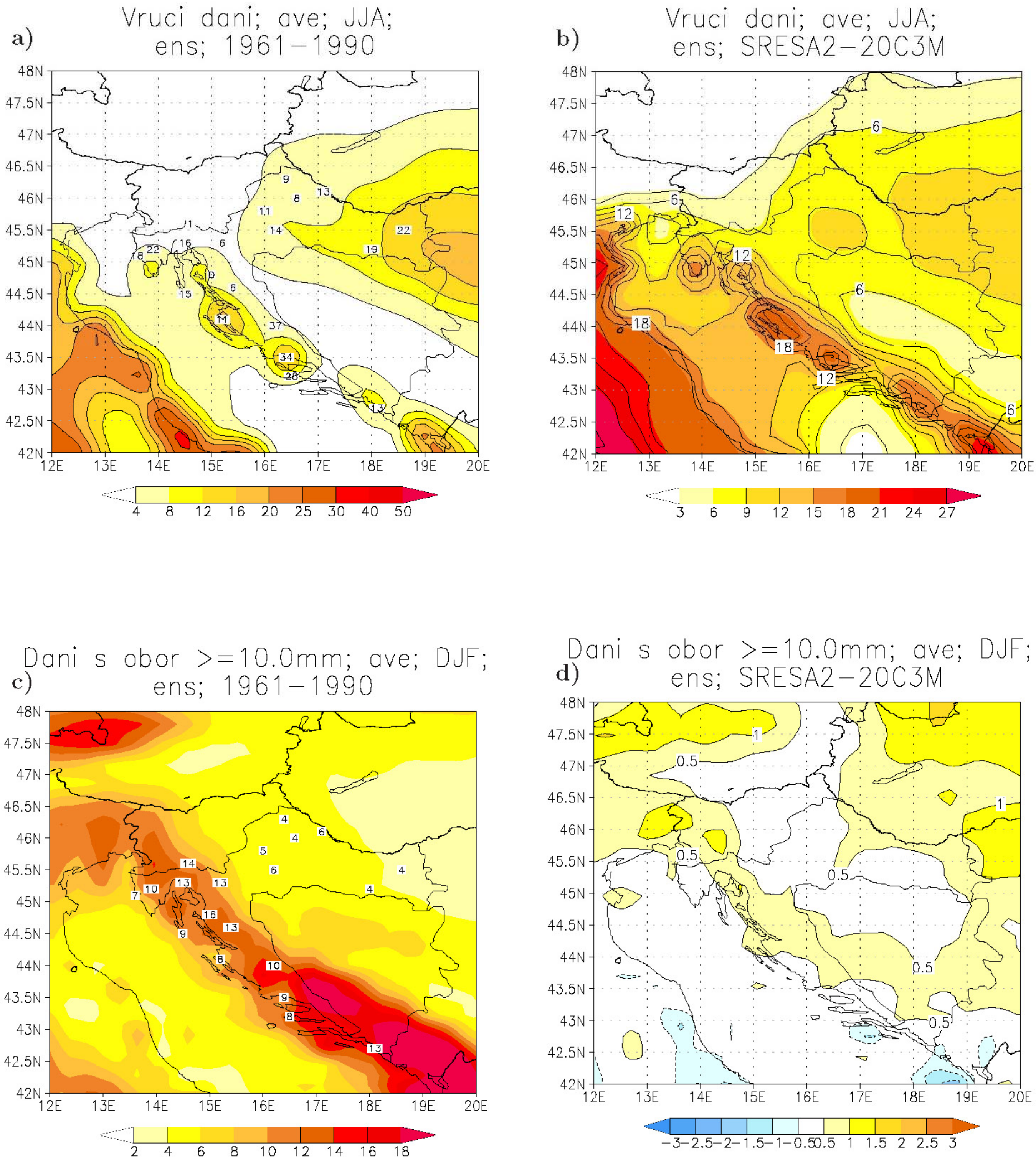


Figure 2-7. Median number of hot days a) model and climate stations for the period 1961-1990, b) change of the number of days minus the climate of the 20th century. Mean number of days with precipitation larger than 10 mm c) model and climate stations.

3. Impact of climate variations and change on plants and on wildfire danger

3.1. Impact of climate variations and change on plants

Research of climate change impact on plants is based on an idea that plants are the first that react to weather and climate change, for which purpose the phenological data are suitable for monitoring development phases of certain plant species. Results of linear trends of long-term phenological phases of common lilac, apple and olive trees from phenological stations Daruvar, Zagreb, Gospić, Rab and Hvar (Fig. 3-1), mostly from the period 1961.-2008., are indicated below. The stations were chosen in order to cover basic climate types in Croatia: continental, mountainous and Mediterranean, as well as the city of Zagreb.

Weather conditions of the last years less and less follow known annual and seasonal cycles and there are more and more extreme weather events not following average states. Thus, for example, during 2007, due to extremely warm winter and spring, phenophases occurred much earlier. Analyses of linear trends of olive tree phenophases along the Adriatic coast and islands, as well as forest trees and fruit trees phenophases in mountainous Croatia within the last 50 years indicated significant earlier beginning of their flowering (2–4 days/10 years) as a result of significant increase of spring air temperature values in this area.

Figure 3-1. Position of selected meteorological and phenological stations in Croatia

In the Croatian inland vegetation period for the majority of plants begins in March or April. The beginning of common lilac leaf unfolding in Zagreb is on 26 March in average, while in Daruvar on 1 April 1st (Table 3-1). Naturally, the periods are changed from year to year, so the range between the latest and the earliest date can be even month and a half.

The flowering usually starts three weeks after the leaf unfolding, while its fully flowering the common lilac achieves a week after the flowering start. High values of standard deviation (8-12 days) also indicate to a great annual variability of common lilac leaf unfolding and flowering from year to year.

In mountainous Croatia the beginning of vegetation is moved to April and May, so in Gospić the common lilac is usually leaf unfolding on 15 April and flowering on 6 May. It is exactly a month later than in Hvar. Naturally, a limit of vegetation beginning is earlier as it moves to the south of Croatia. Comparison between northern and middle Adriatic shows 4-5 days earlier start of common lilac leaf unfolding and flowering in Hvar than in Rab.

In average, apple tree is leaf unfolding and flowering two weeks earlier in Daruvar (9 and 17 April) than in Gospić (25 April 25th and 2 May). Apple maturation also starts two weeks earlier in Daruvar (6 September) than in Gospić (22 September). Such vegetation period of apple tree in the Croatian inland lasts for seven months, while in mountainous Croatia for six months due to an earlier beginning of colouring and leaves falling.

Appearance of the first flowers, full flowering and end of olive tree flowering is a week earlier in Hvar than in Rab. However, first ripe fruits are usually by the middle of October, while the picking is in the first 10-day period in November at both locations.

In order to estimate a tendency of delay/earliness of phenophases in Croatia, linear trends of their appearance have been calculated for observed long-time period (Table 3-1. and Fig. 3-2). Linear trends values in Table 6.4.2 are reduced to 10-year period. One of the methods providing the evaluation of statistical significance of limit change, around which the members of time series are distributed, i.e. evaluation of linear trend existence is non-parametric Mann-Kendall rank test.

Statistically significant trend at the level of 0.05 is noticed in earlier flowering of observed plants (2-4 days/10 years) in all climate zones, except in city of Zagreb. Air temperature rise in Zagreb cannot be just a result of global warming, but in rapid expansion of Zagreb in the last hundred years.

Earlier apple tree flowering (3-4 days/10 years) is more expressed in the mountainous Croatia than in the inland (2 days/10 years). Significant trend of apple tree ripe fruits and picking is noticed only in the inland of Croatia, as well as a tendency of vegetation extension (leaves falling is later 2 days/10 years). On the contrary, in the mountainous Croatia a negative trend of apple tree colouring and leaves falling (3 days/10 years) has been observed, which indicates to shortening the vegetation period in autumn.

Table 3-1. Mean (MEAN), maximum (MAX) and minimum (MIN) phenophase dates for common lilac, apple and olive trees along with related standard deviation (STD) and amplitude (AMPL = MAX - MIN) at selected stations in Croatia mostly within the period 1961–2008.

PHENO-PHASES			UL	BF	FF	EF	RF	RP	CL	FL
COMMON LILAC	MEAN	DARUVAR	4/1	4/21	4/28					
	STD		12	10	9					
	MAKS		4/23	5/7	5/13					
	MIN		3/8	3/30	4/9					
	AMPL		46	38	34					
	MEAN	ZAGREB	3/26	4/20	4/26					
	STD		12	8	8					
	MAX		4/15	5/2	5/10					
	MIN		3/8	4/1	4/9					
	AMPL		38	31	31					
	MEAN	GOSPIĆ	4/15	5/6	5/12					
	STD		11	9	9					
	MAX		5/2	5/20	5/26					
	MIN		3/24	4/10	4/17					
	AMPL		39	40	39					
	MEAN	RAB	3/22	4/11	4/18					
	STD		8	9	8					
	MAX		4/3	4/28	5/6					
	MIN		2/27	3/22	3/30					
	AMPL		36	37	37					
	MEAN	HVAR	3/17	4/6	4/14					
	STD		9	8	9					
	MAX		3/31	4/22	5/1					
	MIN		2/21	3/19	3/24					
	AMPL		39	34	38					
APPLE TREE	MEAN	DARUVAR (1969-2008)	4/9	4/17	4/23	5/2	9/6	9/22	10/22	11/8
	STD		9	9	8	7	7	6	11	11
	MAX		4/25	5/3	5/9	5/16	9/18	10/9	11/11	11/25
	MIN		3/19	3/23	3/31	4/19	8/24	9/9	9/29	10/7
	AMPL		37	41	39	27	25	30	43	49
	SRED	GOSPIĆ (1968-2008)	4/25	5/2	5/8	5/14	9/22	10/5	10/19	10/29
	STD		9	8	8	9	6	7	9	9
	MAX		5/8	5/19	5/23	5/29	10/7	10/18	11/4	11/11
	MIN		4/3	4/17	4/20	4/27	9/7	9/24	10/1	10/6
	AMPL		35	32	33	32	30	24	34	36
OLIVE TREE	MEAN	RAB		5/27	6/3	6/14	10/14	11/7		
	STD			8	8	7	10	10		
	MAX			6/14	6/18	6/30	11/3	11/25		
	MIN			5/6	5/13	5/31	9/9	9/30		
	AMPL			39	36	30	55	56		
	MEAN	HVAR		5/21	5/28	6/6	10/16	11/9		
	STD			10	10	11	11	8		
	MAX			6/5	6/15	6/26	11/5	11/25		
	MIN			4/4	4/8	4/14	9/9	10/20		
	AMPL			62	68	73	57	36		

LEGEND:
UL – Beginning of leaf unfolding
BF – Beginning of flowering
FF – Full (general) flowering
EF – End of flowering
RF – First ripe fruits
RP – Fruit ripe for picking
CL – Colouring of leaves
FL – Leaf fall

Olive tree flowering is earlier 2 days/10 years in northern Adriatic, while in Dalmatia 3 days/10 years. Earlier olive ripe 2 days/10 years is observed in Dalmatia, while earlier picking is not just a result of weather conditions, but it depends on available olive oil processing plants, amount of yield that can be processed at defined moment, as well as on market demand for certain oil quality.

Analysis of climate change impacts on plants indicated in all climate zones an earlier beginning of flowering t of observed plants in spring, which is a result of warmer winter and spring. In autumn there is no such unambiguous delay in colouring and leaves falling in all climate zones, i.e. vegetation period extension is observed in the inland, but not in the mountainous Croatia. These results are in accordance with observed more expressed mean air temperature rise in spring than in autumn.

Table 3-2. Linear trends of phenophases (day/10 years) for common lilac, apple and olive trees at selected stations in Croatia mostly in the period 1961-2008. Significant linear trends at the level ≤ 0.05 are in bold.

TREND (day/10 ys)	**PHENO-PHASES**	**UL**	**BF**	**FF**	**EF**	**RF**	**RP**	**CL**	**FL**
COMMON LILAC	DARUVAR	0.7	**-2.1**	**-2.8**					
	ZAGREB	-3.4	0.2	0.3					
	GOSPIĆ	**-3.5**	**-2.2**	**-2.4**					
	RAB	-0.6	**-2.7**	**-2.3**					
	HVAR	-1.6	**-1.9**	**-2.3**					
APPLE TREE	DARUVAR (1969-2008)	-0.8	**-2.2**	**-2.2**	**-1.7**	**-1.8**	**-2.1**	-0.2	1.7
	GOSPIĆ (1968-2008)	**-2.4**	**-3.0**	**-3.8**	**-4.5**	-0.6	-0.7	**-2.7**	**-2.9**
OLIVE TREE	RAB		**-1.8**	**-2.2**	0.0	0.0	-1.7		
	HVAR		**-2.9**	**-2.9**	**-2.9**	-2.6	-2.0		

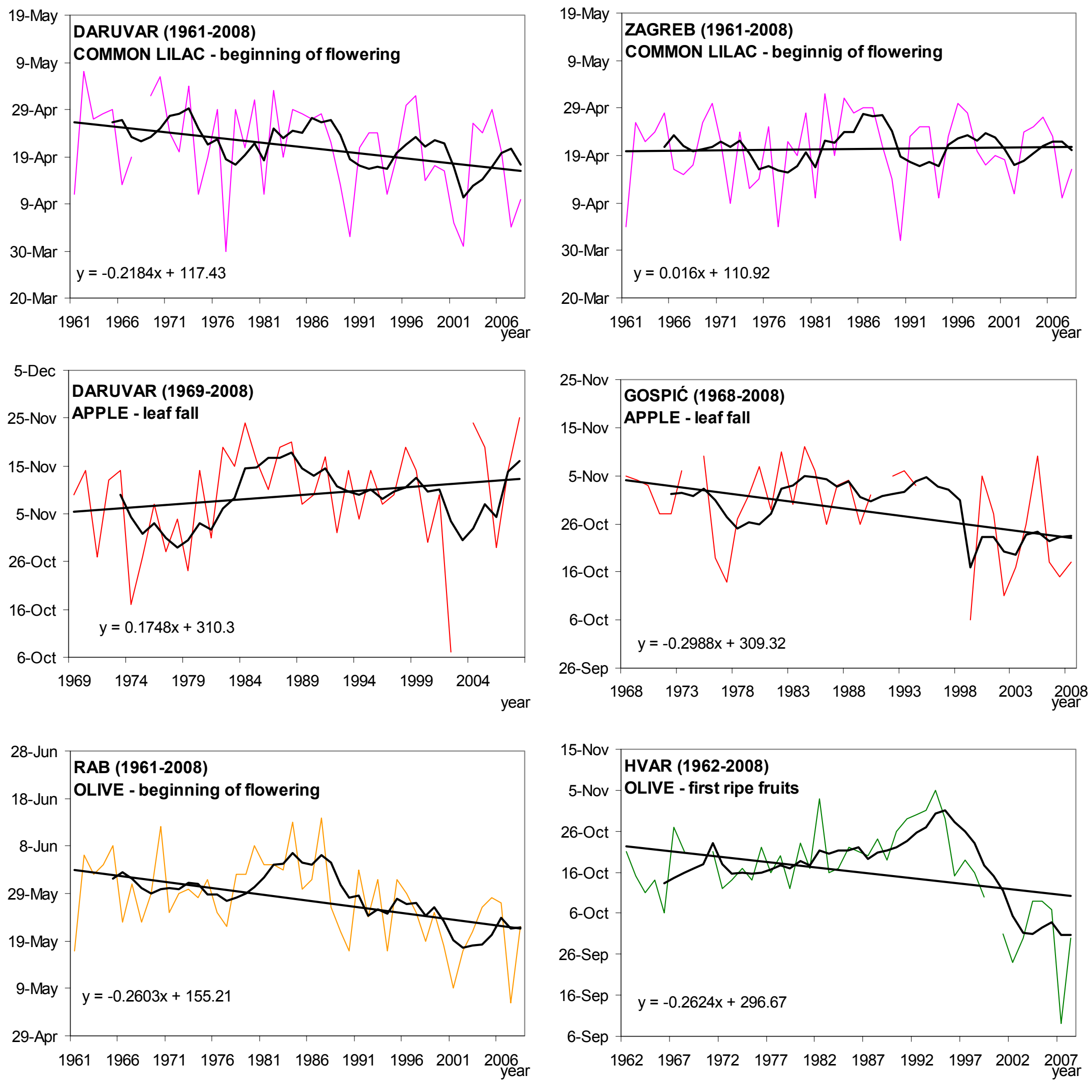


Figure 3-2. Time series of phenological phases of common lilac, apple and olive trees, 5-year flexible mean values and linear trends for Daruvar, Zagreb, Gospić, Rab and Hvar mostly within the period 1961–2008. x is a number of years (1,2…n).

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3.2. Climate change impact on wildfire danger

Croatian Adriatic coast, particularly islands, is a typical example of area where the common interconnection between water (precipitation) and fire is fully expressed. Generally it can be said that in summer a number of fires and burned areas grow from the north to the south, as well as from the inland to the coat and islands, while in winter and early spring is vice versa. Even the precipitation amount is decreased from north to south and from inland to islands. Due to its specificity, the most endangered areas considering forest fires are islands, among them particularly middle Dalmatian islands. Results of global and regional models indicate that the largest changes could be expected in coastal southern part of Adriatic.

In Croatia there are 450 fires in average per year and burned area of 9000 ha. In the last 10 years the largest number of forest fires, total of 730, was recorded in 2000, when 27400 ha burned out. In extremely hot and dry years, such as 1998, 2003 and 2007, above average number of forest fires was recorded in the Adriatic area.

For already 30 years The Meteorological and Hydrological Service has been applying the Canadian method *Fire Weather Index* (*FWI*) to assess a danger of forest fires at the Adriatic. By means of *FWI* daily severity rating *(DSR)* is determined, i.e. assessment of potential danger according to relation:

$$DSR = 0.0272\ FWI^{1.77}$$

Mean *Monthly Severity Rating (MSR)* or mean *Seasonal Severity Rating (SSR)* are calculated from *DSR*. Generally, SSR values above 7 indicate extreme potential danger, values between 3 and 7 are large to very large, values between 1 and 3 are moderate, while values less than 1 are equal to small potential danger.

As severity assessment contains meteorological conditions, as well as moisture dead fuel , *MSR* and *SSR* serve for climate-fire review of average state in certain area per months and fire season. *DSR* daily values could be indicator of change of state from hour to hour for fast acting and distribution of fire brigades in endangered area.

For the analysis of MSR secular variations, long-term time series of meteorological stations Crikvenica (1891–2005) and Hvar (1867–2005) as representatives for climate conditions of northern and middle Adriatic (Fig. 3-1). Due to a higher mean monthly air temperature and lower precipitation amount in Hvar than in Crikvenica, *MSR* is 2-3 times larger than in middle Adriatic in relation to the northern (Table 7-3).

In order to determine possible danger increase of forest fires at Adriatic, linear trends for MSR and non-parametric Mann-Kendall rank test have been analyzed for Crikvenica and Hvar within the season from May to September (Table 3-4 and Fig. 3-3). Significant increase of potential danger is notified in Crikvenica in all months of fire season, while in Hvar in June and July. Progressive test indicates a beginning of *MSR* increase in early 1980's, while trends became significant by the beginning of the 21st century.

Comparison of mean *MSR* secular values with an average from the period 1961.–1990. indicates similar values in Crikvenica and less in Hvar for long-time period in relation to a normal.

Table 3-3. Mean (MEAN), maximum (MAX) and minimum (MIN) monthly severity rating MSR along with related standard deviation (STD) and amplitude (AMPL = MAX - MIN) for Crikvenica (1891–2005) and Hvar (1867–2005), as well as a comparison with a normal 1961–1990.

MONTHS	May	June	July	August	September
CRIKVENICA (1891-2005)					
MEAN	0.9	1.3	3.2	3.8	1.7
STD	0.8	1.1	2.3	3.6	2.1
MAX	3.3	4.4	7.8	16.9	10.5
MIN	0.0	0.0	0.6	0.3	0.1
AMPL	3.3	4.4	7.2	16.6	10.5
CRIKVENICA (1961-1990)					
MEAN	0.8	1.3	2.6	3.2	1.8
STD	1.3	1.3	2.2	3.2	2.0
MAX	5.6	6.4	10.9	23.7	19.8
MIN	0.0	0.0	0.1	0.0	0.0
AMPL	5.6	6.4	10.8	23.7	19.8
HVAR (1867-2005)					
MEAN	2.5	4.1	6.9	7.1	4.4
STD	1.9	2.8	3.3	3.2	3.4
MAX	10.1	12.5	22.2	17.8	18.0
MIN	0.1	0.5	1.2	1.8	0.0
AMPL	10.1	12.0	21.0	16.0	18.0
HVAR (1961-1990)					
MEAN	3.0	4.5	8.0	8.2	4.9
STD	1.7	2.4	2.9	3.6	3.6
MAX	7.0	10.6	13.2	16.8	14.7
MIN	0.5	0.7	2.5	2.8	0.6
AMPL	6.4	9.9	10.6	14.0	14.1

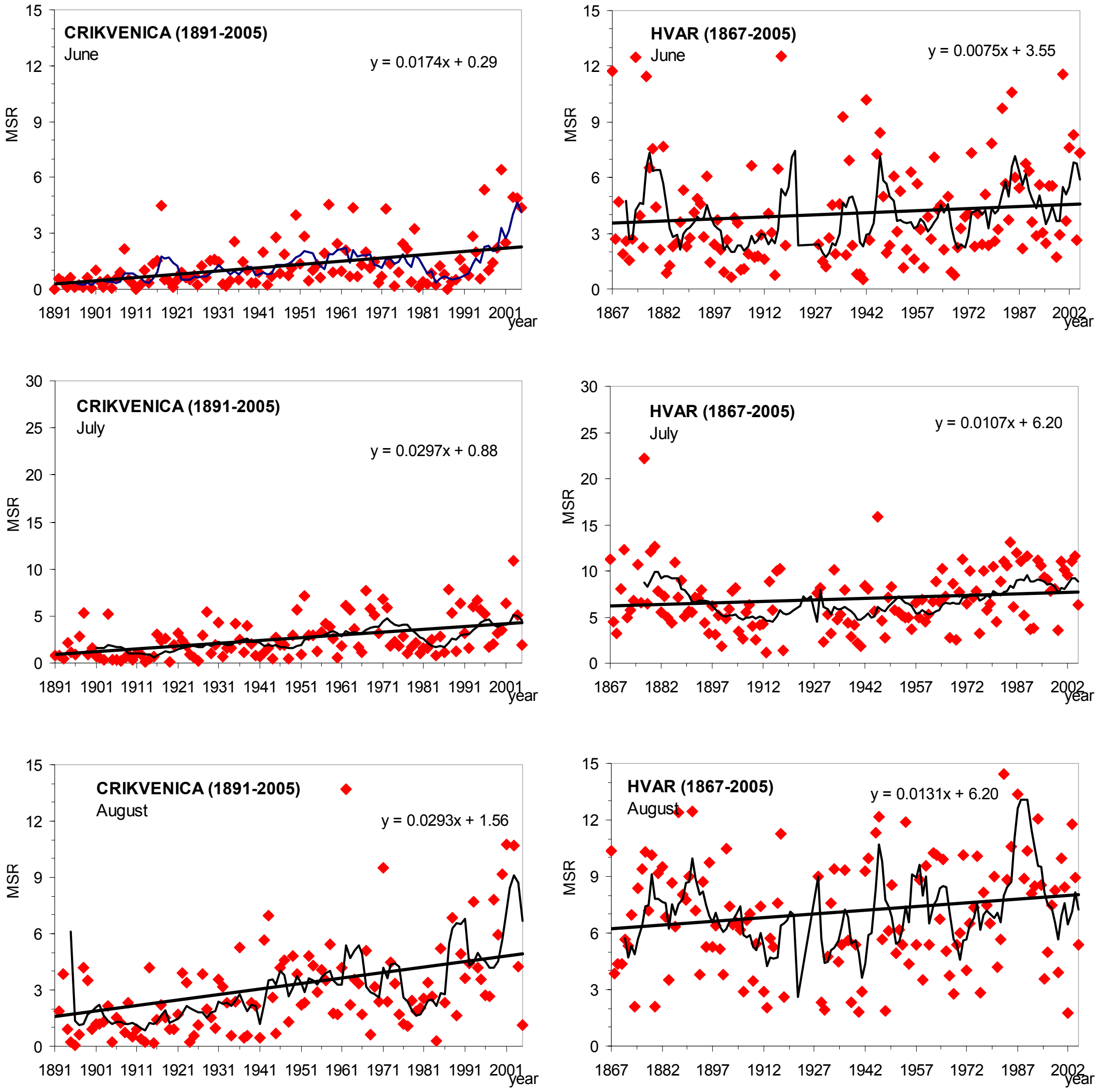

Figure 3-3. Time series of monthly severity rate MSR, 5-year moving average and linear trends for meteorological stations Crikvenica (1891–2006) and Hvar (1867–2005). x is a number of years (1,2…n).

Increased forest fire risk, notified in June, is particularly important as it indicates to earlier beginning of fire season at Adriatic. However, the analysis also shows the expansion of the area with increased forest fire risk from the middle to northern Adriatic, especially in July and August. Reason of increased forest fire risk at northern Adriatic is due to a significant increase of mean air temperature and significant decrease of precipitation in summer.

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