DRŽAVNI HIDROMETEOROLOŠKI ZAVOD
SEKTOR ZA METEOROLOŠKA ISTRAŽIVANJA I RAZVOJ
Služba za klimatološka istraživanja i primijenjenu klimatologiju
Služba za agrometeorologiju
SEKTOR ZA MOTRENJE VREMENA I KLIME

Šesto nacionalno izvješće Republike Hrvatske prema Okvirnoj konvenciji Ujedinjenih naroda o promjeni klime (UNFCCC)

Izabrane točke u poglavljima:

7. - Utjecaj klimatskih promjena i mjere prilagodbe

8. - Istraživanje, sistematsko motrenje i monitoring

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Selected sections in chapters:

7. – Climate change impacts and adaptation measures

8. –Resarch, systematic observation and monitoring

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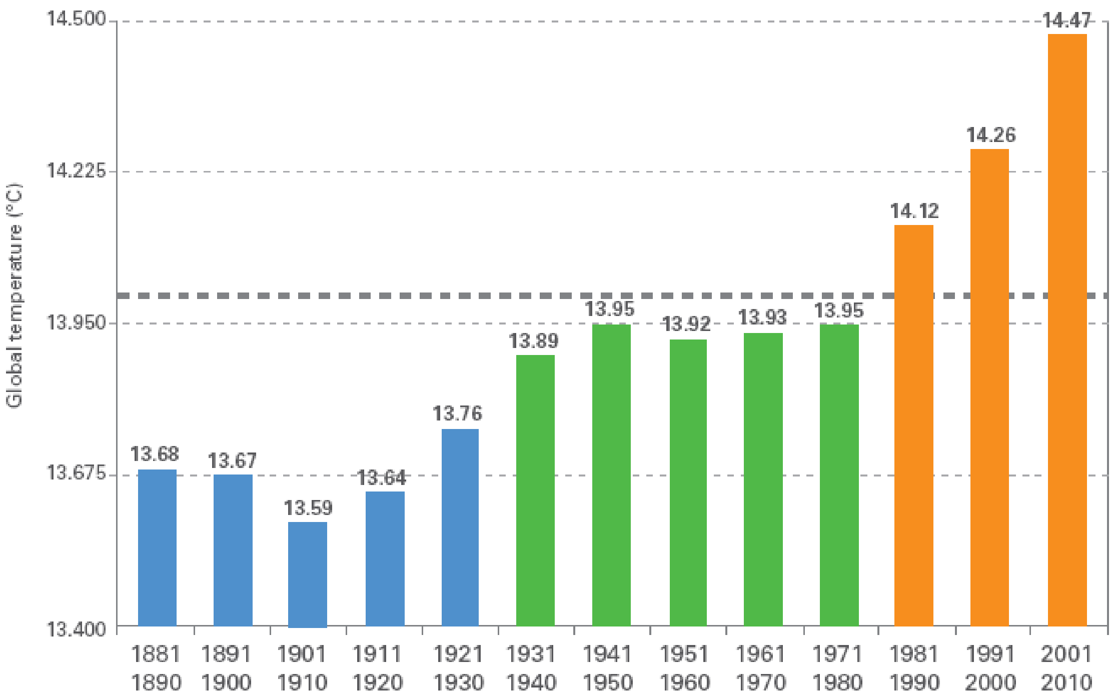
7. - UTJECAJ KLIMATSKIH PROMJENA I MJERE PRILAGODBE

7.1. – Globalne klimatske promjene

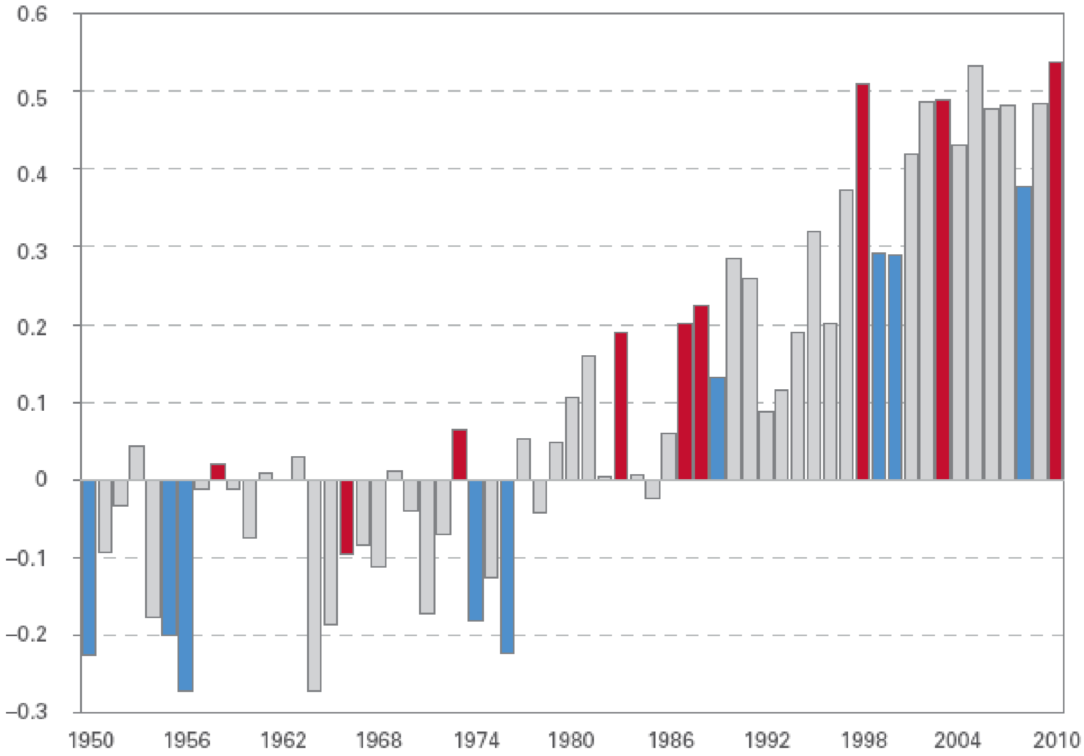
Klima na Zemlji varira tijekom godišnjih doba, dekada i stoljeća kao posljedica prirodnih i ljudskih utjecaja. Prirodna varijabilnost na različitim vremenskim ljestvicama je uzrokovana ciklusima i trendovima promjena na Zemljinoj orbiti (Milanković, 2008), dolaznom Sunčevom ozračenju, sastavu atmosfere, oceanskoj cirkulaciji, biosferi, ledenom pokrovu i drugim uzrocima (WMO, 2013).

7.1.1. - Najtoplija dekada

Proučavanje Svjetske meteorološke organizacije (WMO, 2013) pokazuje da se znakovit porast globalne temperature zraka pojavio tijekom zadnje četiri dekade to jest od 1971. do 2010. godine (Slika 7.1.1-1 i 7.1.1-2). Porast globalne temperature u prosjeku iznosi 0.17°C po dekadi za vrijeme navedenog razdoblja dok je za čitavo promatrano razdoblje 1880-2010. prosječan porast samo 0.062°C po dekadi. Nadalje, porast od 0.21°C srednje dekadne temperature između razdoblja 1991-2000. i 2001-2010. je veći od porasta srednje dekadne temperature između razdoblja 1981-1990. i 1991-2000. (0.14°C) te predstavlja najveći porast u odnosu na sve sukcesivne dekade od početka instrumentalnih mjerenja. Devet od deset najtoplijih godina u čitavom raspoloživom nizu pripadaju prvoj dekadi 21. stoljeća. Najtoplija godina uopće je 2010.



Slika 7.1.1-1 Globalna kombinirana površinska temperatura zraka iznad kopna i površinska temperatura mora (°C). Horizontalna siva crta označava vrijednost višegodišnjeg prosjeka za razdoblje 1961-1990. (14°C) (WMO, 2013).

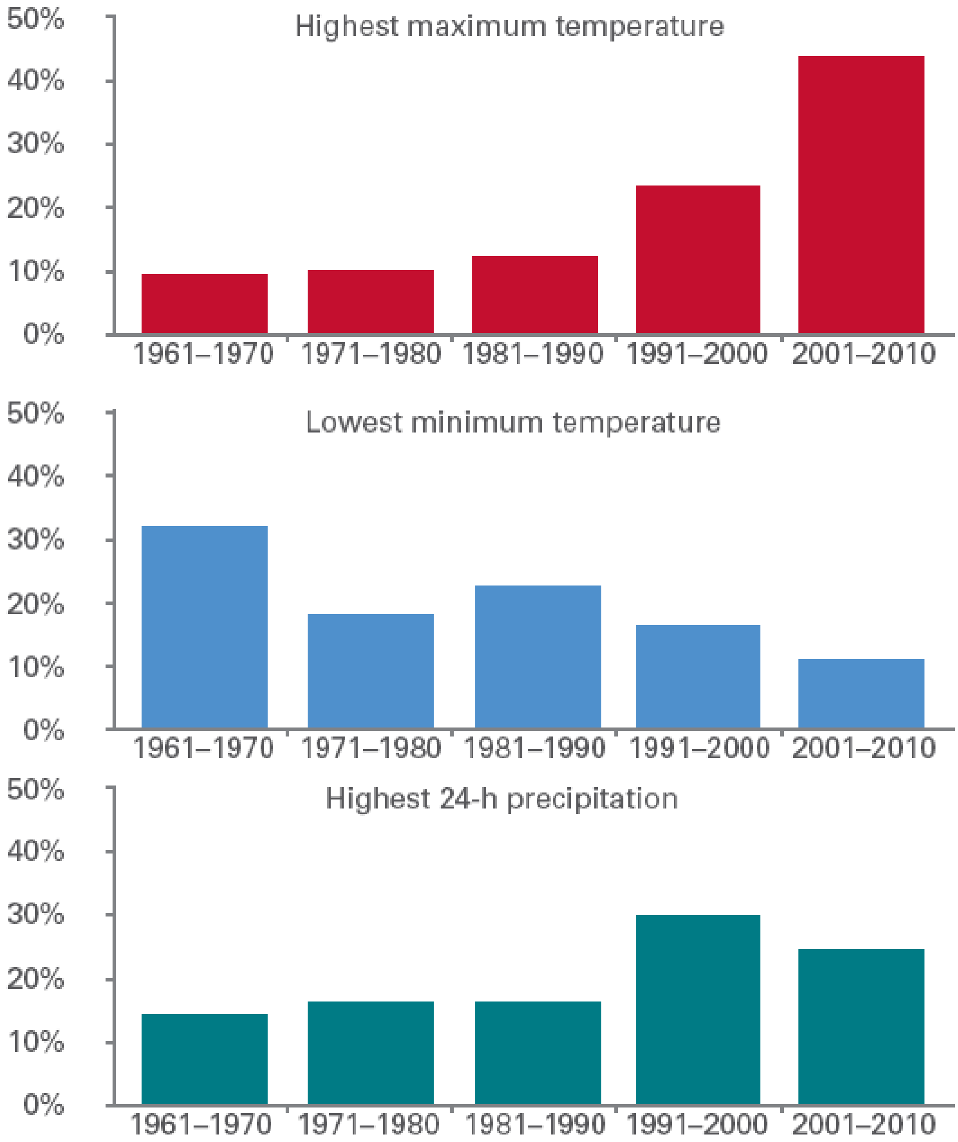


Slika 7.1.1-2 Anomalije globalne površinske temperature (°C) za razdoblje 1950-2010. u odnosu na standardno razdoblje 1961-1990. uz označavanje godina s pojavom La Nina (plavo) i El Nino (crveno) (WMO, 2013).

7.1.2. - "Topli" i "hladni" ekstremi

Iako je srednja godišnja temperatura zraka važan klimatski pokazatelj, temperatura koju osjećaju ljudi može se znatno razlikovati od dana do dana i tijekom godine zbog prirodne varijabilnosti klime. Istovremeno, čovjekov utjecaj je vjerojatno izazvao porast maksimalnih temperature toplih dana i noći kao i minimalnih temperatura hladnih dana i noći. Također je vjerojatnije da postoji nego da ne postoji čovjekov utjecaj na porast rizika za pojavu toplih valova (WMO, 2013).

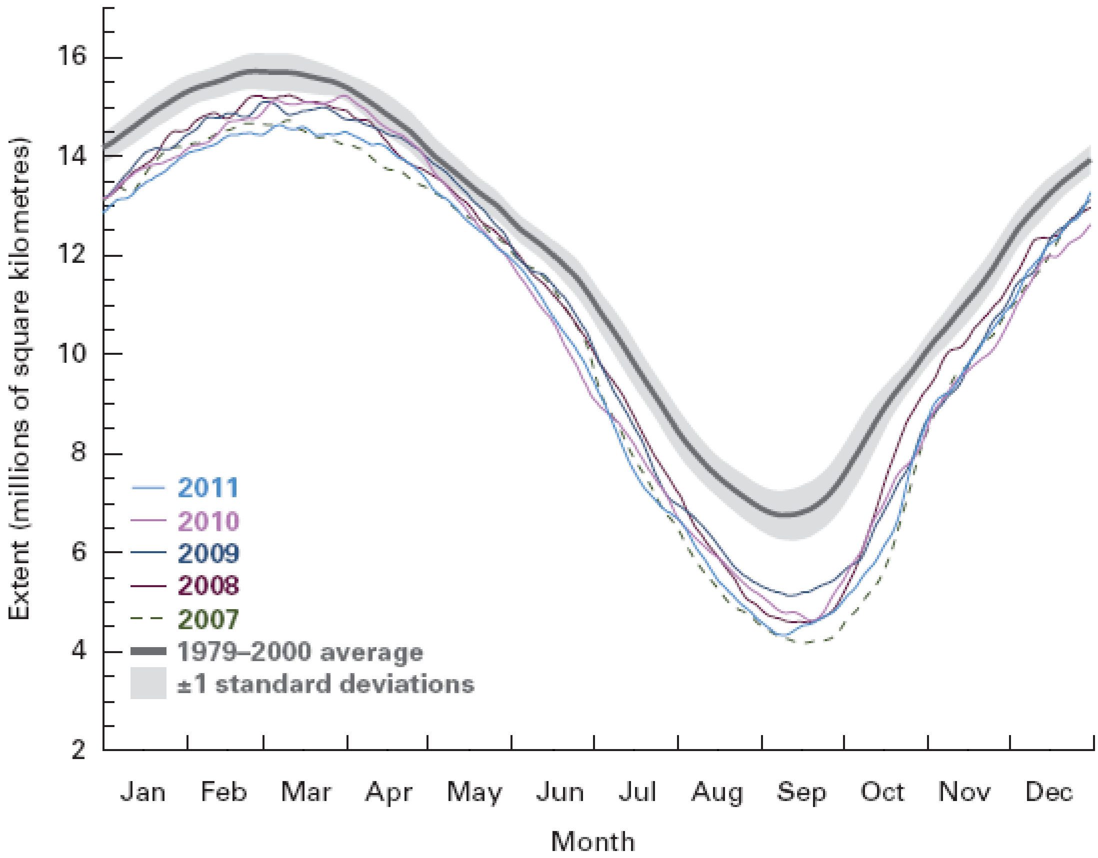
Prema istraživanju WMO-a, ukupno 56 zemalja (44 posto) izvjestilo je da se njihov apsolutni dnevni maksimum temperature za razdoblje 1961-2010. pojavio za vrijeme dekade 2001-2010., dok se u 24 posto zemalja taj maksimum pojavio za vrijeme dekade 1991-2000., ostalih 32 posto zemalja su zabilježile apsolutni maksimum tijekom preostale tri dekade. Nasuprot tome, 11 posto (14 od 127) zemalja zabilježilo je apsolutni minimum temperature tijekom dekade 2001-2010., 32 posto tijekom 1961-1970. i preostalih 20 posto zemalja zabilježilo je apsolutni minimum u preostalim međudekadama (Slika 7.1.2-1).



Slika 7.1.2-1 Apsolutni ekstremi minimalne i maksimalne temperature zraka i 24-satne količine oborine u zadnjih pet dekada. (WMO, 2013)

7.1.3. - Ledeni pokrivač na Arktiku

Arktički ledeni pokrov bio je znatno ispod razine višegodišnjeg prosjeka iz 1979-2000. za 5 godina u razdoblju 2001-2011. (Slika 7.1.3-1). Na primjer, za 2011. godinu mimalna površina ledenog pokrova zabilježena je 9. rujna od 4.33 milijuna km^2, to jest 35 posto manje od prosjeka 1979–2000., prema podacima Nacionalnog centra za snježni i ledeni pokrivač SAD-a. To je drugi po redu minimum ledenog pokrova veći samo za 0.16 milijuna km^2 od rekordnog minimuma iz 2007. godine. Za razliku od 2007. godine, pomorski putevi su bili otvoreni u smjerovima sjever-zapad i sjever istok za vrijeme ljeta 2011. godine. Volumen leda od 4 200 km^3, je bio ispod navedenog višegodišnjeg prosjeka odnosno najnižeg rekorda od 4 580 km^3 iz 2010. godine (WMO, 2012).



Slika 7.1.3-1 Ledeni morski pokrov sjeverne hemisfere za 2011. godinu u usporedbi s prethodnim godinama i prosjekom 1979-2000. godina. (WMO, 2012)

Litaratura

Milanković, M., 2008: *Astronomical theory of climate changes and its application in Geophysics.* Prosvjeta, Zagreb. 192 pp.

WMO, 2012: *WMO statement on the status of the global climate in 2011.*

WMO Note – No 1085. 19 pp.

WMO, 2013 : The global climate 2001-2010 – A decade of climate extremes, summary report

WMO Note – No 1119. 15 pp.

7.2. - Opažene klimatske promjene u Hrvatskoj

Klimatske promjene u Hrvatskoj u razdoblju 1961-2010. analizirane su pomoću trendova godišnjih i sezonskih srednjih, srednjih minimalnih i srednjih maksimalnih temperatura zraka i indeksa temperaturnih ekstrema, zatim godišnjih i sezonskih količina oborine i oborinskih indeksa kao i sušnih i kišnih razdoblja. Analiza se temelji na podacima 41 niza srednjih dnevnih i ekstremnih temperatura zraka i 137 nizova dnevnih količina oborine. Indeksi temperaturnih i oborinskih ekstrema su izračunati prema definicijama koje je dao Ekspertni tim za detekciju klimatskih promjena i indekse (ETCCDI) (Peterson i sur. 2001;. WMO 2004), Komisija za klimatologiju (WMO/CCI) i Svjetski klimatski istraživački program, Klimatska varijabilnost i prediktabilnost (WCRP/CLIVAR). Dugoročni trendovi procijenjeni su metodom linearne regresije, a neparametarski Mann-Kendallov rang test (Gilbert, 1987) primijenjen je za procjenu statističke značajnosti trendova na 95% razini značajnosti. Sveukupna značajnost trenda (*eng. field significance trend*) je ocijenjena pomoću Monte Carlo simulacija (Zhang i sur. 2004).

7.2.1. - Temperatura zraka

Trendovi temperature izračunati su za odstupanja temperature od srednjaka iz razdoblja 1961-1990. i izraženi su u °C po destljeću, dok su trendovi temperaturnih indeksa izraženi u brojevima dana na deset godina.

Tijekom 50 - godišnjeg razdoblja (1961-2010.) trendovi **srednje, srednje minimalne i srednje maksimalne** temperature zraka pokazuju zatopljenje u cijeloj Hrvatskoj (Sl. 7.2.1-1). Trendovi godišnje temperature zraka su pozitivni i signifikantni, a promjene su veće u kontinentalnom dijelu zemlje nego na obali i u dalmatinskoj unutrašnjosti. Najvećim promjena bila je izložena maksimalna temperatura zraka (Sl. 7.2.1-1 gore) s najvećom učestalošću trendova u klasi 0,3-0,4°C na 10 godina, dok su trendovi srednje i srednje minimalne temperature zraka bile najčešće između 0,2 i 0,3°C. Najveći doprinos ukupnom pozitivnom trendu temperature zraka dali su ljetni trendovi, a porastu srednjih maksimalnih temperatura podjednako su doprinijeli i trendovi za zimu i proljeće. Najmanje promjene imale su jesenske temperature zraka koje su, premda uglavnom pozitivne, većinom bile nesignifikantne.

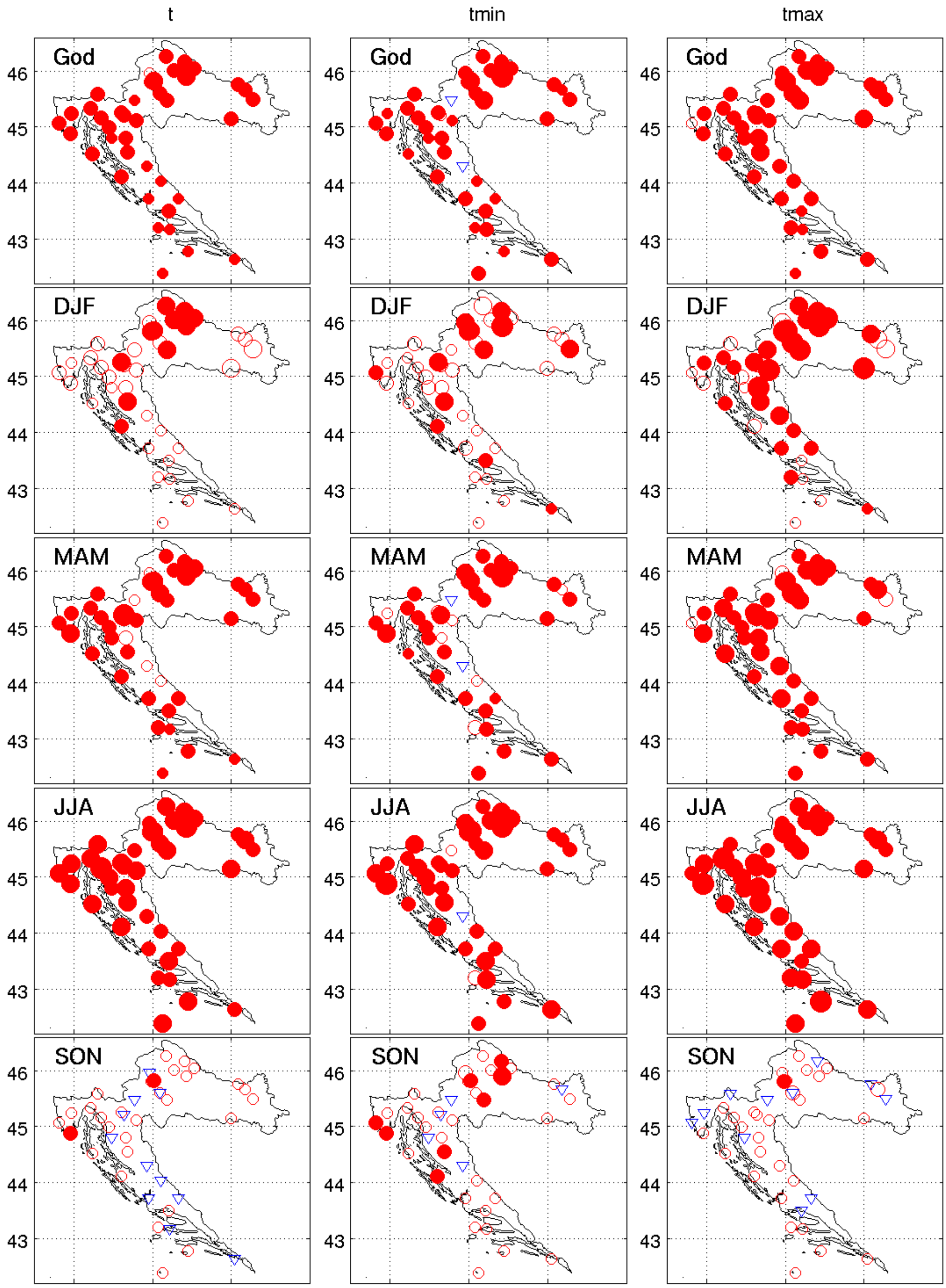
Uočeno zatopljenje očituje se i u svim **indeksima temperaturnih ekstrema** pozitivnim trendovima toplih temperaturnih indeksa (topli dani i noći te trajanje toplih razdoblja) te s negativnim trendovima hladnih temperaturnih indeksa (hladni dani i hladne noći te duljina hladnih razdoblja) (Sl. 7.2.1-2).

Trendovi **indeksa toplih temperaturnih ekstrema** statistički su značajani za sve trendove što potvrđuje i sveukupna značajanost trenda (Sl. 7.2.1-2 lijevo). Najveći je porast toplih dana (**Tx90**) i toplih noći (**Tn90**), a nešto su manji trendovi toplih dana (prema apsolutnom pragu, **SU**) i duljine toplih razdoblja (**WSDI**), ali su i oni gotovo svi signifikantni. Na većini postaja porast broja toplih dana prema apsolutnom pragu (SU) kretao se je između 2 do 8 dana na 10 godina (Tablica 7.2.1-2). Povećanje broja toplih dana (Tx90) najčešće je iznosilo 6-10 dana, a toplih noći čak 8-12 dana na 10 godina. Duljina toplih razdoblja na najvećem je broju postaja povećana za 4-6 dana.

Zatopljenje se očituje i u negativnom trendu **indeksa hladnih temperaturnih ekstrema**, ali su oni manji od trendova toplih indeksa (Sl. 7. 7.2.1-2 desno). Najviše je signifikantnih trendova za hladne dane i noći (**Tx10** i **Tn10**), čiji se je broj na najvećem broju postaja smanjio do 4 dana u 10 godina (Tab. 7.2.1-1). Slično kao i kod toplih ekstrema, trendovi broja hladnih dana prema apsolutnom pragu (**FD**) su manji (najčešće do -2 dana u 10 godina). Najmanja je promjena zabilježena u duljini hladnih razdoblja (**CSDI**) koja su se na više od 90% postaja skratila do 2 dana, a trend je nesignifikantan kako na većini postaja tako i na cijelom području, prema sveukupnom testu za trend.

Tablica 7.2.1-1. Definicija indeksa hladnih i toplih temperaturnih ekstrema. Skraćenice i definicije slijede standardizaciju WMO-CCL/CLIVAR radne grupe za utvrđivanje klimatskih promjena.

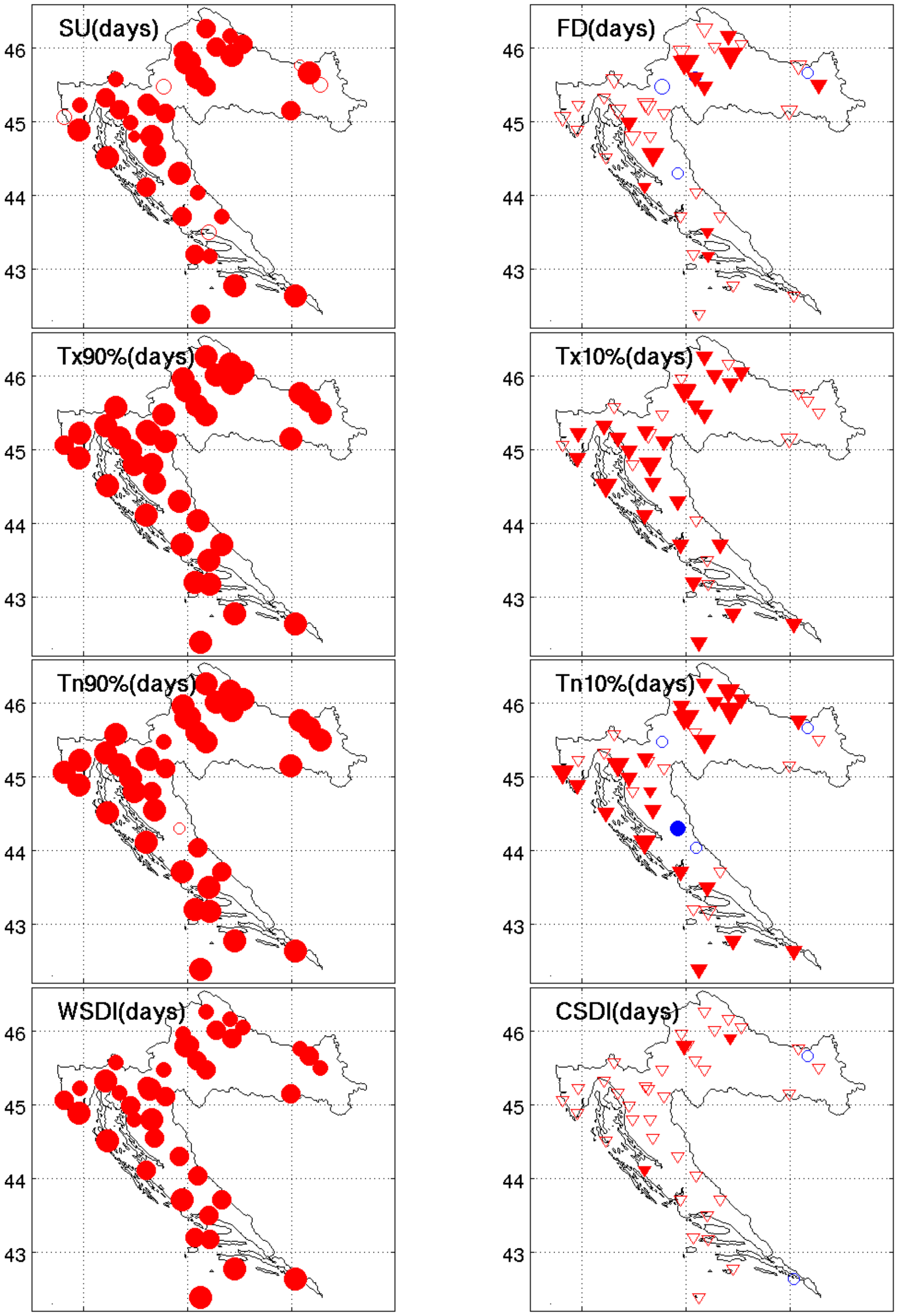
Indeksi hladnih temperaturnih ekstrema		
FD	Hladni dani (apsolutni prag)	Broj dana s minimalnim temperaturama zraka <0°C
Tn10%	Hladne noći (prag prema percentilu)	Broj dana s minimalnom temperaturom zraka nižom od praga, određenog kao 10-ti percentil minimalne temperature zraka za kalendarski dan u razdoblju 1961-1990.
Tx10%	Hladni dani (prag prema percentilu)	Broj dana s maksimalnom temperaturom zraka nižom od praga, određenog kao 10-ti percentil maksimalne temperature zraka za kalendarski dan u razdoblju 1961-1990.
CSDI	Trajanje hladnih razdoblja	Broj dana u razdobljima od najmanje 6 uzastopnih dana s minimalnom temperaturom zraka nižod od TnN10
Indeksi toplih temperaturnih ekstrema		
Tn90%	Tople noći (prag prema percentilu)	Broj dana s temperaturom zraka višom od praga, određenog kao 90-ti percentil minimalne temperature zraka za kalendarski dan u razdoblju 1961-1990.
Tx90%	Topli dani (prag prema percentilu)	Broj dana s temperaturom zraka višom od praga, određenog kao 90-ti percentil maksimalne temperature zraka za kalendarski dan u razdoblju 1961-1990.
WSDI	Trajanje toplih razdoblja	Broj dana u razdobljima od najmanje 6 uzastopnih dana s maksimalnom temperaturom zraka višom od Tn90
SU	Topli dani (apsolutni prag)	Broj dana s maksimalnom temperaturama zraka ≥25°C



Slika 7.2.1-1. Dekadni trendovi (°C/10god) srednje (t), srednje minimalne (tmin) i srednje maksimalne (tmax) temperature zraka za godinu i po godišnjim dobima (DJF – zima, MAM – proljeće, JJA – ljeto, SON – jesen) u razdoblju 1961-2010. Krugovi označavaju pozitivne trendove, trokuti negativne, dok popunjeni znakovi označavaju statistički značajan trend. Četiri veličine znakova su proporcionalne promjeni temperature u °C na desetljeće.

Tablica 7.2.1-2. Relativna učestalost trendova (broj dana na 10 godina) toplih (SU, Tx90, Tx10, WSDI) i hladnih (FD, Tx10, Tn10, CSDI) indeksa temperaturnih ekstrema na 41 meteorološkoj postaji u Hrvatskoj.

Trend	**SU**	**Tx90**	**Tn90**	**WSDI**	**FD**	**Tx10**	**Tn10**	**CSDI**
≤-6.0	0.0	0.0	0.0	0.0	2.4	0.0	2.4	0.0
-5.9--4.0	0.0	0.0	0.0	0.0	7.3	7.3	17.1	0.0
-3.9--2.0	0.0	0.0	0.0	0.0	36.6	**63.4**	**39.0**	2.4
-1.9-0.0	0.0	0.0	0.0	0.0	**43.9**	29.3	31.7	**92.7**
0.1-2.0	4.9	0.0	2.4	0.0	7.3	0.0	7.3	4.9
2.1-4.0	29.3	0.0	2.4	29.3	2.4	0.0	2.4	0.0
4.1-6.0	**36.6**	2.4	12.2	**46.3**	0.0	0.0	0.0	0.0
6.1-8.0	29.3	**29.3**	12.2	14.6	0.0	0.0	0.0	0.0
8.1-10.0	0.0	26.8	22.0	9.8	0.0	0.0	0.0	0.0
10.1-12.0	0.0	17.1	**24.4**	0.0	0.0	0.0	0.0	0.0
12.1-14.0	0.0	19.5	14.6	0.0	0.0	0.0	0.0	0.0
14.1-16.0	0.0	4.9	4.9	0.0	0.0	0.0	0.0	0.0
16.1-18.0	0.0	0.0	2.4	0.0	0.0	0.0	0.0	0.0
18.1-20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
>20.0	0.0	0.0	2.4	0.0	0.0	0.0	0.0	0.0



Slika 7.2.1-2 Dekadni trendovi (dani/10god) indeksa toplih (lijevo – SU, Tx90, Tn90, WSDI) i hladnih (desno – FD, Tx10, Tn90, CSDI) temperaturnih ekstrema u razdoblju 1961-2010. Krugovi označavaju pozitivne trendove, trokuti negativne, dok popunjeni znakovi označavaju statistički značajan trend. Četiri veličine znakova su proporcionalne promjeni broja dana na desetljeće.

7.2.2. - Oborina

Trendovi **godišnjih i sezonskih količina oborine** daju opći pregled vremenskih promjena količine oborine u cijeloj zemlji. Tijekom nedavnog 50 - godišnjeg razdoblja (1961-2010.), godišnje količine oborine (*R)* pokazuju prevladavajuće nesignifikantne trendove, koji su pozitivni u istočnim ravničarskim krajevima i negativni u ostalim područjima Hrvatske (Sl. 7.2.2-1. (a)). Statistički značajno smanjenje (puni simboli) utvrđeno je na postajama u planinskom području Gorskog kotara i u Istri, kao i na južnom priobalju. Izraženo na desetljeće kao postotak odgovarajućih prosječnih vrijednosti, ta smanjenja kreću se između -7% i -2%. Godišnje negativne trendove uglavnom su uzrokovali trendovi smanjenja ljetnih količina (*R - JJA*), koji su statistički značajni na većini postaja u gorskom području i na nekim postajama na Jadranu i njegovom zaleđu (Sl. 7.2.2-1 (b)). Na statističku značajnost godišnjeg trenda smanjenja oborine u Istri i Gorskom kotaru također je utjecala negativna tendencija proljetnih količina (od -8% do -5%; Sl. 7.2.2-1.(c)). Pozitivni (krugovi) godišnji trendovi oborine u istočnom nizinskom području, prvenstveno su uzrokovani značajnim povećanjem oborine u jesen (Sl. 7.2.2-1. (d)) i u manjoj mjeri u proljeće i ljeto. Prostorna raspodjela sezonskih trendova također pokazuje zanimljive značajke. Ljetna oborina ima jasno istaknut negativni trend u cijeloj zemlji, i tu je jedan broj postaja za koje je to smanjenje statistički značajno, s relativnim promjenama između -11% i -6% na desetljeće. U jesen trendovi su slabi i miješanog predznaka, osim u istočnom nizinskom području gdje neke postaje pokazuju značajan trend porasta oborine (8% do 11%). U proljeće rezultati ne pokazuju signal u južnom i istočnom dijelu zemlje, dok je negativni trend prisutan u preostalom području, značajan samo u Istri i Gorskom kotaru (-5% do -7%). Tijekom zime (Sl. 7.2.2-1. (e)) trendovi oborine nisu značajni i kreću se između -11% i 8%. Oni su uglavnom negativni u južnim i istočnim krajevima kao i u Istri. U preostalom dijelu zemlje su mješovitog predznaka.

Regionalna raspodjela trendova **oborinskih indeksa**, koji definiraju veličinu i učestalost oborinskih ekstrema, pokazuje složenu strukturu, kao što je također nađeno u nekim mediteranskim regijama.

Prostorna raspodjela trendova učestalosti suhih i vlažnih oborinskih ekstrema kao što je prikazano **brojem suhih dana (*DD*), umjereno vlažnih dana (*R75*)** i **vrlo vlažnih dana (*R95*)** nalazi se na slici 7.2.2-1. (f, g, h). Trendovi *DD* su uglavnom slabi, ali statistički značajni pozitivni trendovi (1% do 2%) javljaju se na nekim postajama u Gorskom kotaru, Istri i južnom priobalju. Svojstvo trenda *R75* je prostorno vrlo slično onome godišnjih količina oborine. Regionalna raspodjela trendova R95 ne pokazuje signal na većem dijelu zemlje. Statistički značajne promjene su prisutne na nekoliko postaja, pozitivne u sjevernom ravničarskom području i negativne u Gorskom kotaru kao i na krajnjoj južnoj obali (između -22% i 16%). To pokazuje da je povećanje količina oborine u jesen u unutrašnjosti uglavnom uzrokovano porastom broja dana s velikim dnevnim količinama oborine.

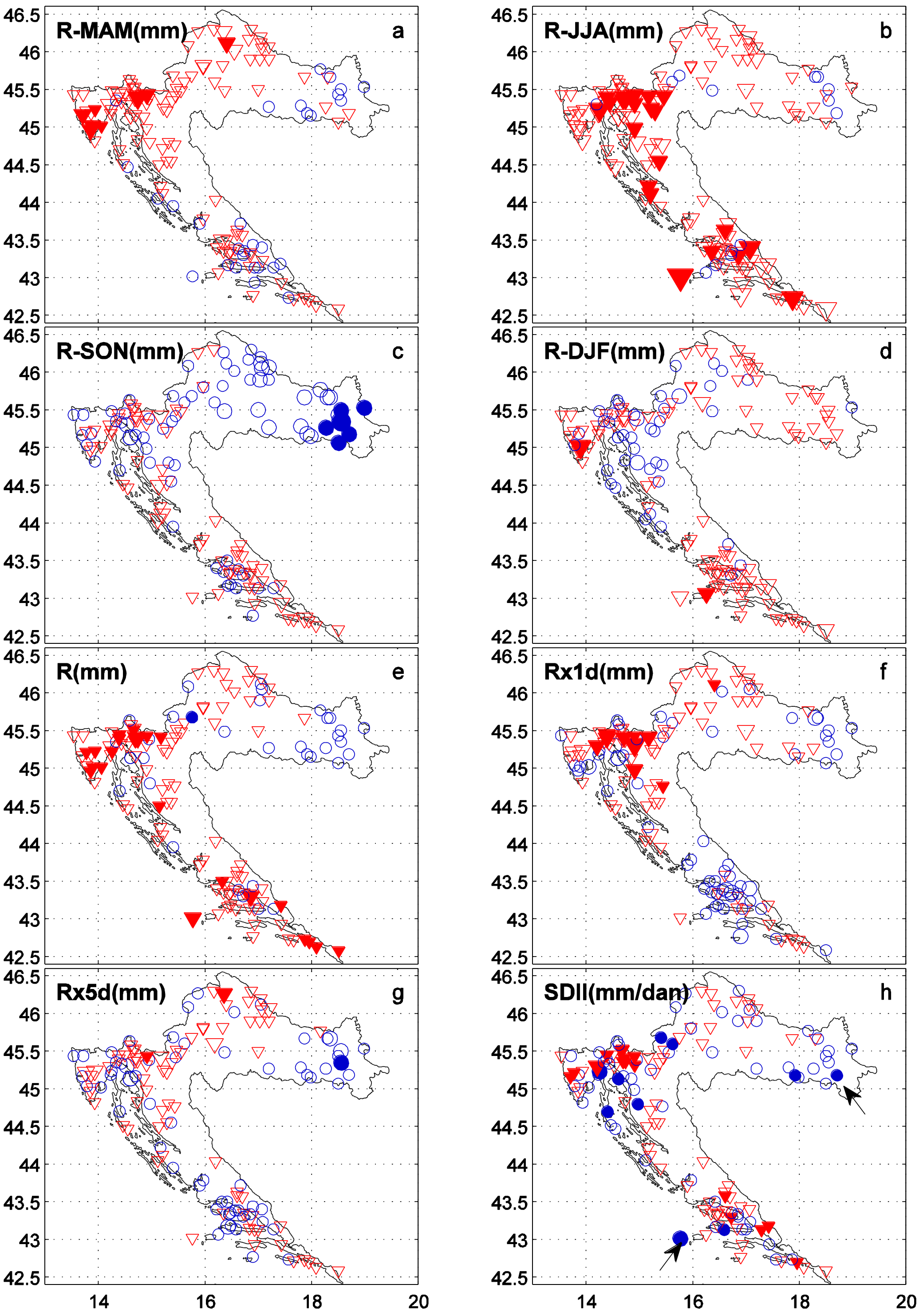
Trendovi intenziteta oborine za oborinske dane (Sl. 7.2.2-1. (i)), definiran **standardnim dnevnim intenzitetom (*SDII*)**, odražava promjene veličine trenda dvije veličine; godišnjih količina oborine i godišnjeg broja oborinskih dana. Na primjer, za dvije postaje u različitim područjima (označeno s dvije strelice na slici 7.2.2-1. (i)) s istom promjenom učestalosti R_d (u tim slučajevima značajno smanjenje, vidi sliku. 7.2.2-1. (f)), ali različitih promjena *R*, *SDII* ima sličan značajan porast na obje postaje. To podrazumijeva da *SDII* nije pogodan za objašnjavanje uzroka promjena *R*. Zbog ove činjenice, ovaj indeks i njegovi trendovi trebaju se koristiti s oprezom u primijenjenim studijama.

Tablica 7.2.2-1. Popis oborinskih indeksa i njihove definicije

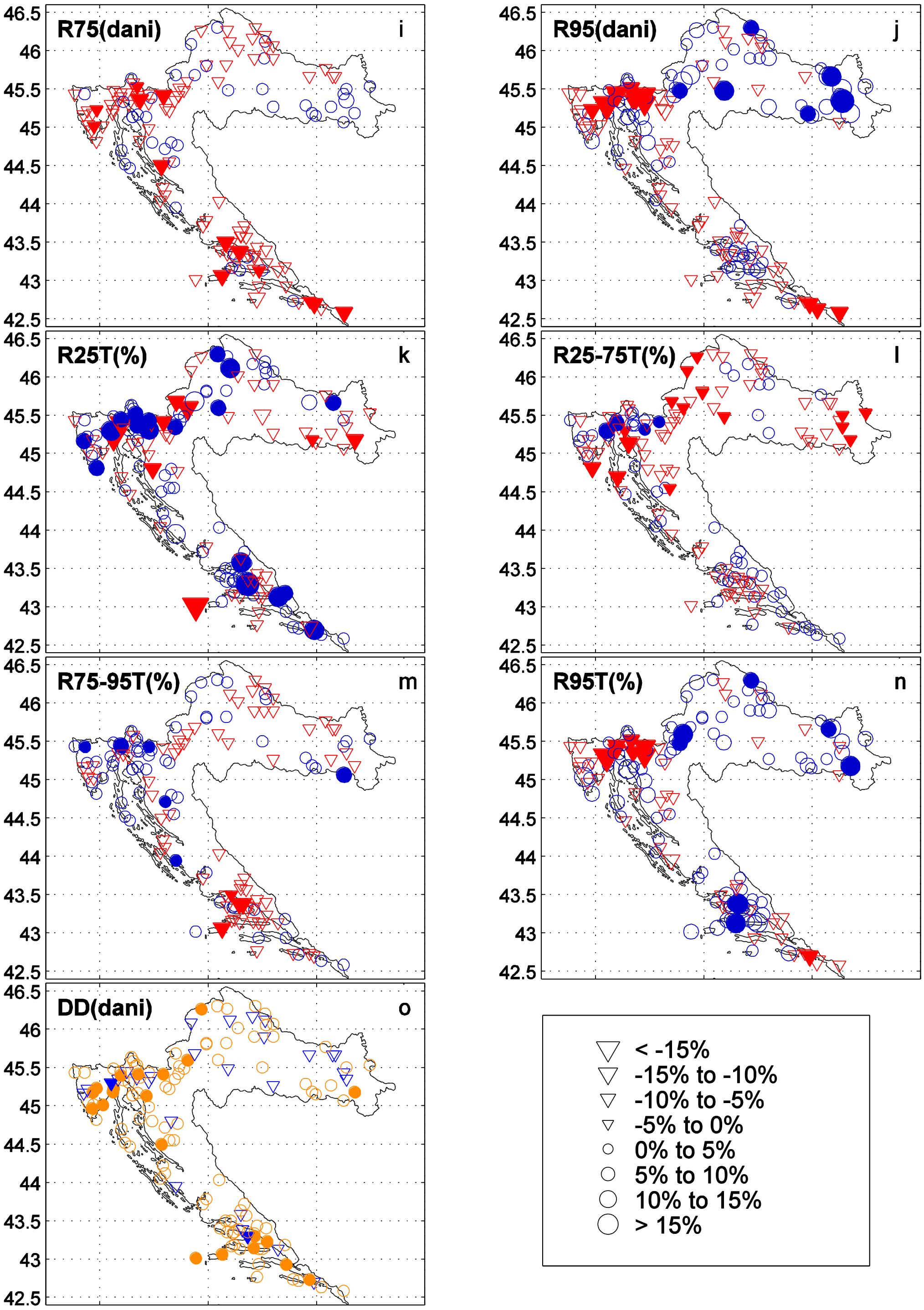
Br.	Indeksi	Jedinice	Definicije
1	DD	days	Suhi dani *(Broj dana s dnevnom količinom oborine R_d<1.0 mm)*
2	SDII	mm/dan	Standardni dnevni intenzitet oborine *(godišnja količina oborine / godišnji broj oborinskih dana (R_d≥1.0 mm)*
3	R75	dani	Umjereno vlažni dani *(Broj dana s količinom oborine $R_d > R_{75\%}$, gdje je $R_{75\%}$ 75. percentil razdiobe dnevnih količina oborine koji je određen iz svih oborinskih dana (R_d ≥ 1.0 mm) u referentnom razdoblju 1961-1990.)*
4	R95	dani	Vrlo vlažni dani *(Broj dana s količinom oborine $R_d > R_{95\%}$, gdje je $R_{95\%}$ 95. percentil razdiobe dnevnih količina oborine koji je određen iz svih oborinskih dana (R_d ≥ 1.0 mm) u referentnom razdoblju 1961-1990.)*
5	R25T	%	Udio oborine u dane s $R_d < R_{25\%}$ *(Udio godišnje količine oborine $\Sigma R_d/R_t$, gdje je ΣR_d suma dnevnih količina oborine manjih od 25. percentila oborine u dane s $R_{25\%}$ u referentnom razdoblju 1961-1990.), a R_t je ukupna godišnja količina oborine*
6	R25-75T	%	Udio oborine u dane s $R_{25\%} \leq R_d \leq R_{75\%}$ *(Udio godišnje količine oborine $\Sigma R_d/R_t$, gdje je ΣR_d suma dnevnih količina oborine jednakih ili većih od 25. percentila oborine u dane s $R_{25\%}$ i jednakih ili manjih od 75. percentila oborine u dane s $R_{75\%}$ u referentnom razdoblju*
7	R75-95T	%	Udio oborine u dane s $R_{75\%} < R_d \leq R_{95\%}$ *(Udio godišnje količine oborine $\Sigma R_d/R_t$, gdje je ΣR_d suma dnevnih količina oborine većih od 75. percentila oborine u dane s $R_{75\%}$ i jednakih ili manjih od 95. percentila oborine u dane s $R_{95\%}$ u referentnom razdoblju 1961-1990.), a R_t je ukupna godišnja količina oborine*
8	R95T	%	Udio oborine u vrlo vlažne dane *(Udio godišnje količine oborine $\Sigma R_d/R_t$, gdje je ΣR_d suma dnevnih oborina većih od 95. percentila oborine u vrlo vlažne dane $R_{95\%}$ u referentnom razdoblju 1961-1990.), a R_t je ukupna godišnja količina oborine*
9	Rx1d	mm	Najveća 1-dnevna količina oborine *(Najveća količina oborine u 1-dnevnim intervalima)*

Udio pojedinih dnevnih količina oborine u ukupnoj godišnjoj količini analiziran je za različite kategorije, koje pokrivaju cijelu skalu razdiobe dnevnih količina oborine. Analizirane su četiri klase s percentilnim pragovima i definirani su sljedeći indeksi: ***R95T***, ***R75-95T***, ***R25-75T*** i ***R25T*** (Tablica 7.2.2-1.). Trendovi tih indeksa prikazani su na slici. 7.2.2-1. (j-m). Dvije nasuprotne kategorije, one vrlo velikih oborinskih ekstrema (*R95T*) i one slabih oborina (*R25T*), pokazuju prevladavajuće slabe trendove koji su vrlo miješanog predznaka u cijeloj zemlji. Ipak, neke lokacije pokazuju signifikantan trend. Značajni pozitivni trendovi *R25T* pojavljuju se uglavnom u zapadnoj Hrvatskoj (uključujući sjeverozapadne krajeve, Gorski kotar i Istru) i duž južne obale Jadrana. U istočnom nizinskom području gdje je prevladavajući pozitivan trend količine oborine *R*, također su prisutni i značajni pozitivni trendovi *R95T*. Doprinos godišnjim količinama oborine od dnevnih oborina, koje pripadaju središnjem dijelu razdiobe (*R25-75T*), pokazuje slabe promjene (-7% do 7%). Slično vrijedi i za trendove dijela godišnje količine oborina zbog oborine u umjereno vlažnim danima (*R75-95T*). Ipak, postoji značajan pozitivan trend na nekoliko postaja u planinskim predjelima, kao i na sjevernom i srednjem Jadranu, unatoč smanjenju učestalosti takvih dana. Na južnom priobalju *R75-95T* pokazuje negativne trendove koji mogu biti u vezi sa smanjenjem broja umjereno vlažnih dana *R75*.

Prvu informaciju o vremenskim promjenama godišnjih ekstrema koju pružaju podaci o maksimalnim 1-dnevnim količinama oborine (***Rx1d***) i višednevnim oborinskim epizodama, i to maksimalne 5-dnevne količine oborine (***Rx5d***) prikazano je na slici 7.2.2-1. (n-o) relativnim promjenama linearnih trendova. Smjer trenda oba indeksa je općenito usklađen po područjima. Trend je slab i prevladavajuće pozitivan u istočnom ravničarskom području i duž obale, dok je uglavnom negativan u sjeverozapadnom području i u planinskim predjelima (značajan za *Rx1d*).



Slika 7.2.2-1. Dekadni trendovi (%/10god) sezonskih i godišnjih količina oborine (R-MAM, proljeće; R-JJA, ljeto; R-SON, jesen; R-DJF, zima; R, godina) i oborinskih indeksa (Rx1d, Rx5d, SDII, R75, R95, R25T , R25-50T, R50-75T, R75-95T, R95T i DD) u razdoblju 1961-2010. Krugovi označavaju pozitivne trendove, trokuti negativne, dok popunjeni znakovi označavaju statistički značajan trend. Četiri veličine znakova su proporcionalne relativnim vrijednostima promjena na desetljeće u odnosu na odgovarajući srednjak iz razdoblja 1961-1990: <5%, 5-10%, 10-15% i >15%.



Slika 7.2.2-1. nastavak

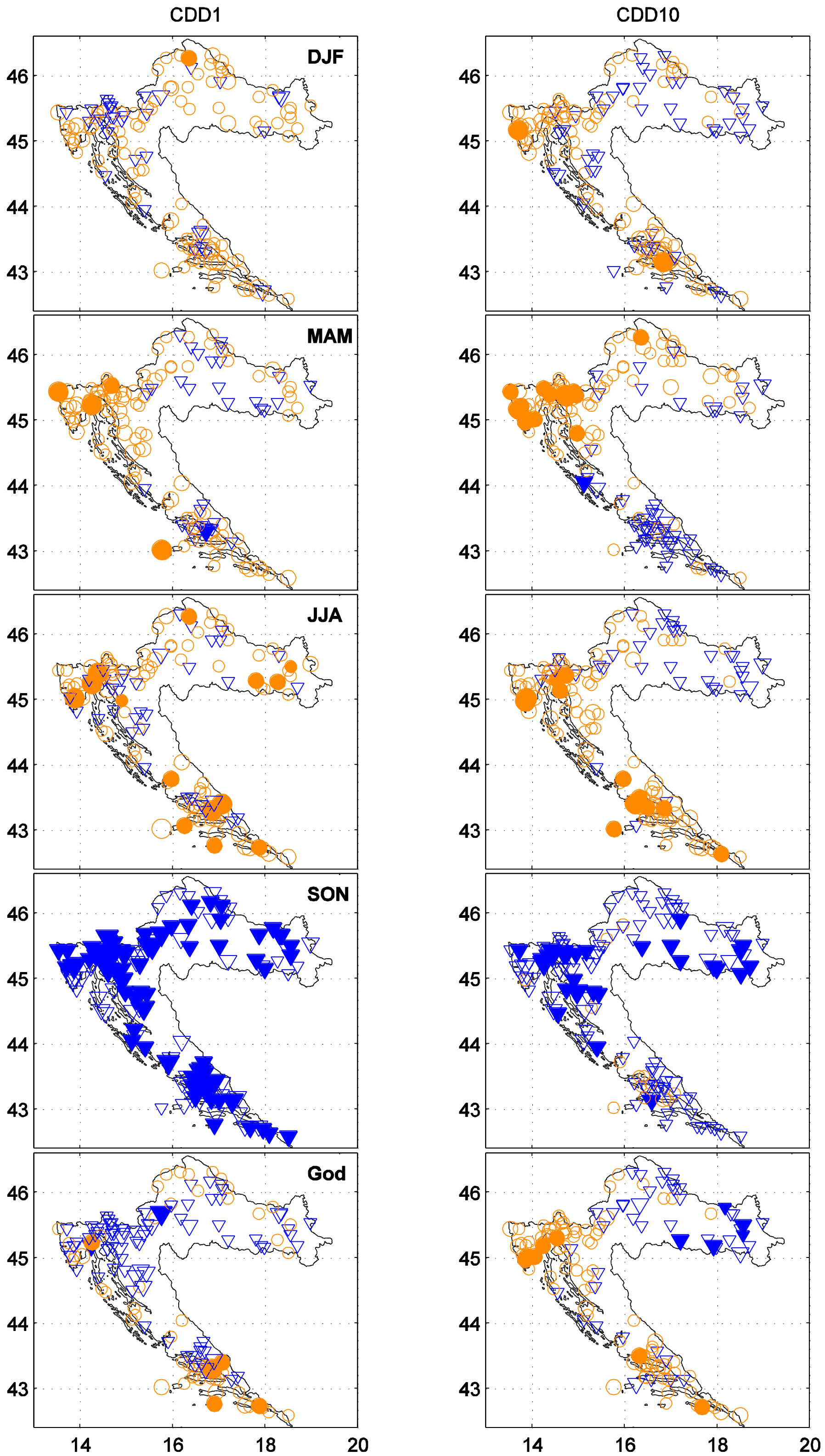
7.2.3. - Sušna i kišna razdoblja

Vremenske promjene sušnih i kišnih razdoblja u Hrvatskoj prikazane su pomoću godišnjeg i sezonskog trenda njihovih maksimalnih trajanja. Sušno (kišno) razdoblje je definirano kao uzastopni slijed dana s dnevnom količinom oborine manjom (većom) od određenog praga: 1 mm i 10 mm. Te kategorije će u narednom tekstu biti označene s CDD1 i CDD10 za sušna razdoblja (od engl. *consecutive dry days*) odnosno s CWD1 i CWD10 za kišna razdoblja (eng. *consectuive wet spell*). Razdoblja koja počinju u jednoj sezoni, a nastavljaju se u drugu, pridružena su onoj sezoni u kojoj su započela. Trend je izražen kao odstupanje po dekadi u odnosu na srednjak iz klimatološkog razdoblja 1961-1990. (%/10god).

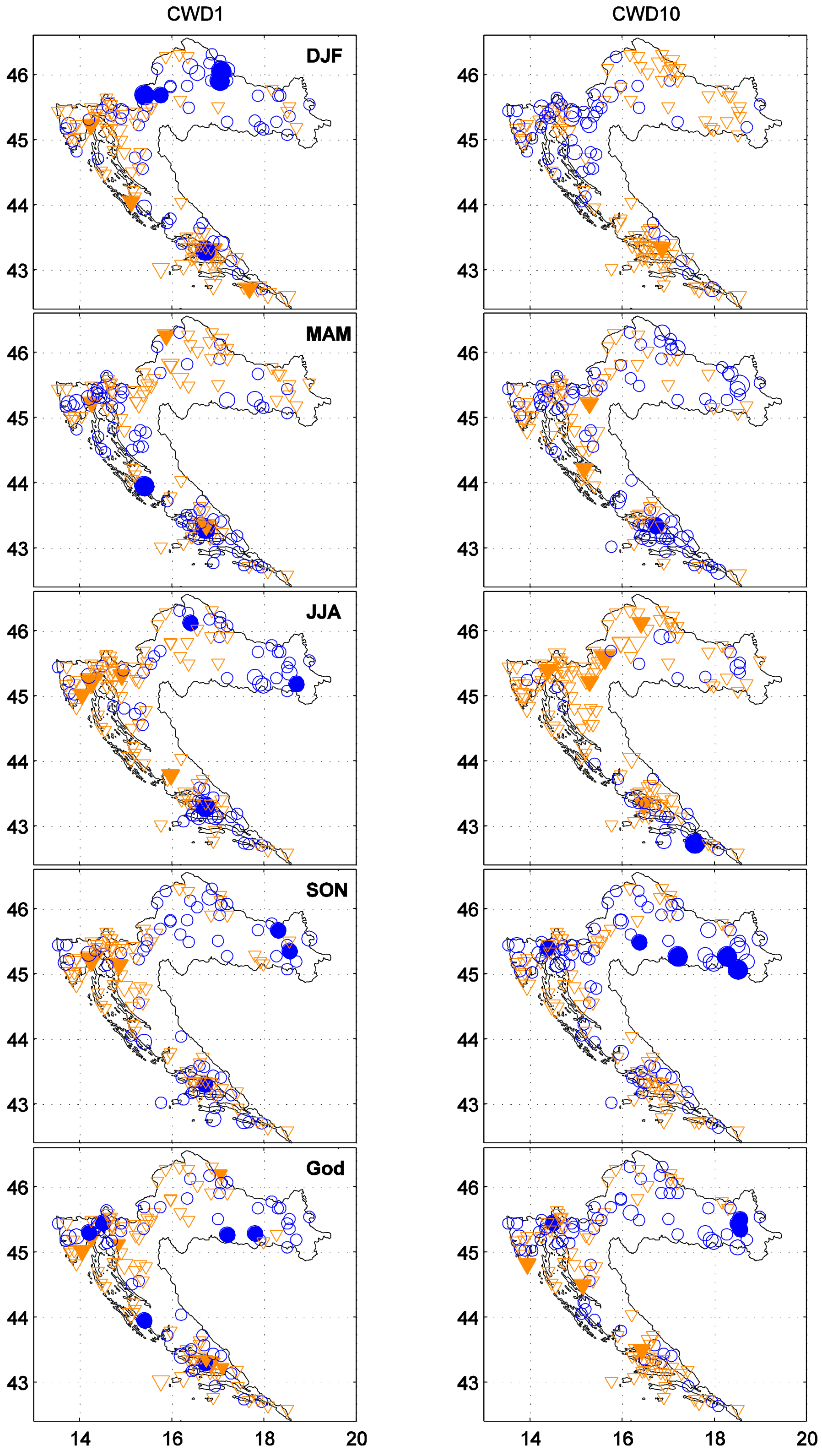
Prema rezultatima trenda (Slika 7.2.3-1.) najizraženije su promjene **sušnih razdoblja** u jesenskim mjesecima (SON) kada je u cijeloj Hrvatskoj uočen statistički značajan negativan trend. To smanjenje se kreće od -14%/10god do -1%/10god za kategoriju CDD1 odnosno od -11%/10god do 5%/10god za CDD10. U ostalim sezonama je trend sušnih razdoblja za obje kategorije slabije izražen od jesenskog. Ipak, uočava se produljenje sušnih razdoblja u proljeće (MAM) na sjevernom Jadranu (od 7%/10god do 12%/10god), dok se ljeti takva tendencija uočava i duž južne jadranske obale dosežući vrijednosti do 24%/10god. Ljeti se uočava statistički značajan trend sušnih razdoblja prve kategorije (CDD1) i u istočnoj Slavoniji (od 4%/10god do 7%/10god). Zimi nema značajnog prostornog trenda, ali se uočava tendencija povećanja CDD1 u cijeloj Hrvatskoj, osim u Gorskom Kotaru i Lici gdje prevladava negativan trend, te smanjenje CDD10 u kontinentalnom dijelu Hrvatske. Godišnje duljine sušnih razdoblja prve kategorije (CDD1) pokazuju tendenciju smanjenja u južnom dijelu kontinentalne Hrvatske i na sjevernom Jadranu, te statistički značajan porast na južnom Jadranu. S druge strane, sušna razdoblja kategorije CDD10 imaju tendenciju povećanja duž Jadrana i u gorju, a smanjenja u unutrašnjosti, osobito u istočnoj Slavoniji. Takav predznak trenda CDD10 može se povezati s uočenim porastom vrlo vlažnih dana (R95) u unutrašnjosti odnosno smanjenjem u gorju i na Jadranu (vidi poglavlje 7.2.2).

Za razliku od sušnih razdoblja, **kišna razdoblja** ne pokazuju prostornu konzistentnost trenda niti u jednoj sezoni (Slika 7.2.3-2.). Ipak, može se uočiti tendencija povećanja CWD1 u istočnoj Slavoniji i sjeverozapadnoj Hrvatskoj ljeti (do 9%/10god) i u jesen (do 6%/10god). U isto vrijeme uočava se smanjenje kišnih razdoblja CWD1 na sjevernom Jadranu i u Gorskom kotaru (do -12%/10god). Zimi je trend CWD1 uglavnom miješanog predznaka, a samo u sjeverozapadnoj unutrašnjosti Hrvatske prevladava statistički značajan pozitivan trend (do 15%/10god).

Rezultati trenda kišnih razdoblja kategorije CWD10 ukazuju na statistčki značajan pozitivan jesenski trend u području doline rijeke Save (11%/10god). Zajedno s opaženim jesenskim smanjenjem sušnih razdoblja iste kategorije ovi rezultati ukazuju na općenito vlažnije prilike na području istočne Hrvatske. Ljeti je uočen negativan trend CWD10 duž sjevernog i srednjeg Jadrana te u gorju (8%/10god do -11%/10god), a pozitivan na južnom Jadranu (do 15%/10god). Općenito, velika je prostorna heterogenost u predznaku trenda kišnih razdoblja ove kategorije.



Slika 7.2.3-1. Dekadni trendovi (%/10god) maksimalnih sušnih razdoblja za kategorije 1mm i 10 mm (CDD1, CDD10), po sezonama i za godinu u razdoblju 1961-2010. Krugovi označavaju pozitivne trendove, trokuti negativne, dok popunjeni znakovi označavaju statistički značajan trend. Četiri veličine znakova su proporcionalne relativnim vrijednostima promjena na desetljeće u odnosu na odgovarajući srednjak iz razdoblja 1961-1990.: <5%, 5-10%, 10-30% and >30%



Slika 7.2.3-2. Dekadni trendovi (%/10god) maksimalnih kišnih razdoblja za kategorije 1mm i 10 mm (CDD1, CDD10), po sezonama i za godinu u razdoblju 1961-2010. Krugovi označavaju pozitivne trendove, trokuti negativne, dok popunjeni znakovi označavaju statistički značajan trend. Četiri veličine znakova su

proporcionalne relativnim vrijednostima promjena na desetljeće u odnosu na odgovarajući srednjak iz razdoblja 1961-1990.: <5%, 5-10%, 10-30% and >30%

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7.2.4. - Komponente vodne ravnoteže

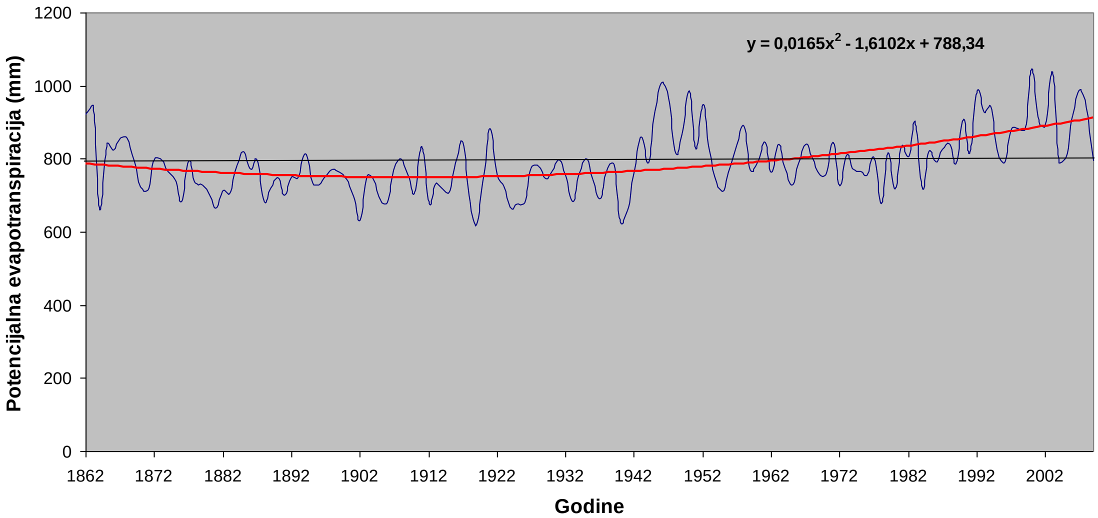
Može se ramatrati šest komponenata vodne ravnoteže: količina oborine, potencijalna i stvarna evapotranspiracija, gubitak vode iz tla i procjeđivanje vode u tlo, otjecanje i količina vlage u tlu dubine do jedan metar. Kako je opisano u Pandžić et al. (2008), 10-dnevne komponente vodne ravnoteže izračunate su prema modificiranoj Palmerovoj (1965) proceduri gdje je korištena modificirana Eaglemanova (1967) procedura za izračunavanje 10-dnevne potencijalne evapotranspiracije. Sve komponente vodne ravnoteže izražene su milimetrima što je brojčani ekvivalent litri po četvornom metru.

Iz slike 7.2.4-1 je vidljivo da postoji trend godišnjih vrijednosti potencijalne evapotranspiracije, a on je vrlo sličan trendu temperature. Navedena sličnost se može objasniti jakom povezanošću temperature zraka i potencijalne evapotranspiracije. Prema trendu, tijekom 21. stoljeća može se očekivati daljnji porast potencijalne evapotranspiracije za 30%. To znači, u slučaju da će količina oborine ostati nepromijenjena u odnosu na postojeće stanje porast potencijalne evapotranspiracije može utjecati na značajno smanjenje drugih komponenata vodne ravnoteže. Trend stvarne evapotranspiracije i procjeđivanja u tlo su slabije izraženi od trenda potencijalne evapotranspiracije. Ekstrapolacija rezultata potencijalne evapotranspiracije dobivenih za Zagreb-Grič na druge meteorološke postaje, uključujući obalno područje, moguća je zahvaljujući razmjerno izraženoj korelaciji između vremenskih nizova potencijalne evapotranspiracije za šire područje Hrvatske (Pandžić et al., 2008).

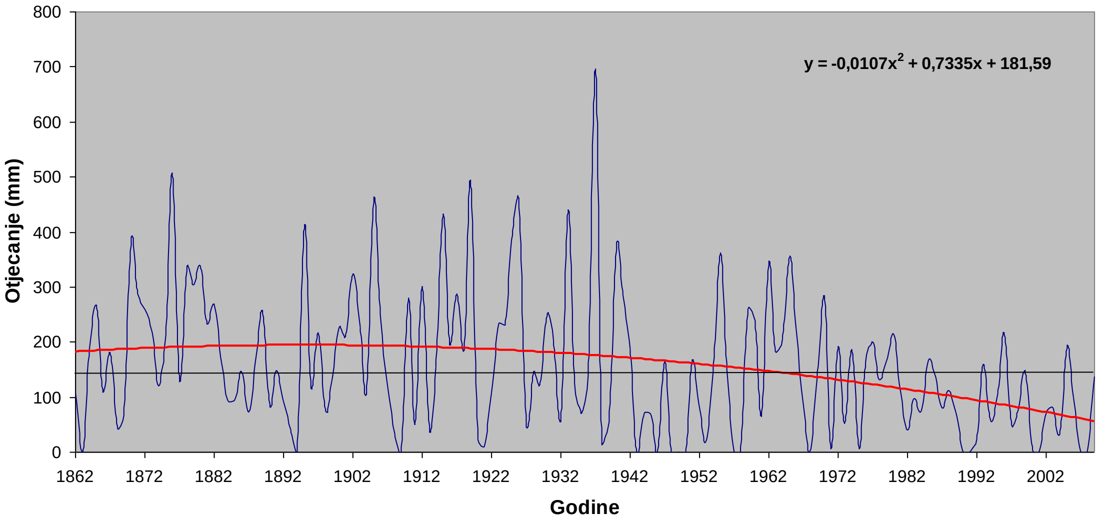
Očigledno je iz slike 7.2.4-2 da postoji izražen negativni trend otjecanja za meteorološku postaju Zagreb-Grič. Prema tom trendu do sredine stoljeća bi otjecanje izračunato Palmerovom metodom trebalo iščeznuti. Rezultat je uzbunjujući iako je "prognostička" moć trenda slaba i nadamo se da se to neće dogoditi. Postoji izražena korelacija između izračunatog otjecanja za Zagreb-Grič i onog za druge meteorološke postaje što je pokazano u Pandžić et al. (2008). Tako, na neki način, rezultati dobiveni za Zagreb-Grič mogu se ekstrapolirati na meteorološke postaje s kraćim vremeskim nizovima otjecanja od onog za Zagreb-Grič. Također je pokazano da su neka područja u Hrvatskoj osjetljivija na globalno zatopljenje od drugih što ovisi o omjeru između potencijalne evapotranspiracije i količine oborine. Općenito, u područjima gdje je količina oborine znatno veća od iznosa potencijalne evapotranspiracije porast potencijalne evapotranspiracije neće znatno utjecati na druge komponente vodne bilance uključujući i otjecanje. Osjetljivija područja bit će ona na kojima su količine oborine slične potencijalne evapotranspiracije.

Godišnja razdioba količine oborine je vrlo važna za druge komponente vodne ravnoteže. Kako je potencijalna evapotranspiracija osjetljivija na promjenu temperature zraka u toplom nego u hladnom dijelu godine, područja s maksimalnom količinom oborine u toplom dijelu godine bit će osjetljivija na globalno zatopljenje nego ona s maksimalnom količinom oborine za vrijeme hladnog dijela godine.

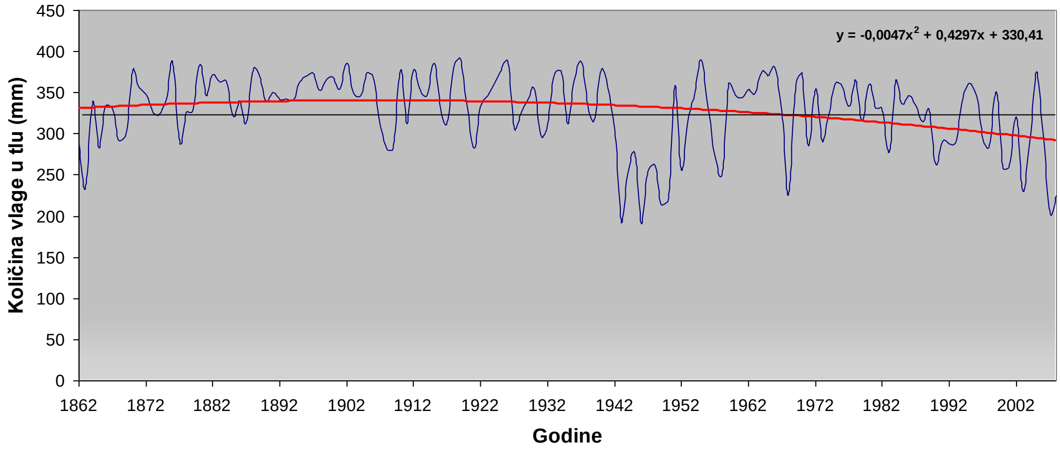
Trend količine vlage u tlu pokazuje smanjenje u idućih pola stoljeća (Slika 7.2.4-3). Regionalna osjetljivost na varijabilnost količine vlage i njezin trend ovisi o vrsti tla to jest njegovom poljskom kapacitetu koji je općenito prilično mali u obalnom pojasu.



Slika 7.2.4-1. Vremenski niz godišnje potencijalne evapotranspiracije (mm) za meteorološku postaju Zagreb-Grič za razdoblje 1862-2008. Tanka crta predstavlja prosjek za razdoblje 1961-1990. godina (Pandžić i Trninić, 2010).



Slika 7.2.4-2 Vremenski niz godišnjeg otjecanja (mm) za meteorološku postaju Zagreb-Grič za razdoblje 1862-2008. godina. Tanka crta predstavlja prosjek za razdoblje 1961-1990.godina (Pandžić i Trninić, 2010).



Slika 7.2.4-3. Vremenski niz godišnje količine vlage u tlu (mm) za meteorološku postaju Zagreb-Grič za razdoblje 1862-2008. godina. Tanka linija predstavlja prosjek za razdoblje 1961-1990. godina (Pandžić i Trninić, 2010).

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7.2.5. - Sažeti prikaz dekadne klime za Hrvatsku

Za WMO istraživanje 2013. godine korišteni su podaci 11 meteoroloških postaja s područja Hrvatske (Osijek, Varaždin, Zagreb-Grič, Ogulin, Gospić, Knin, Rijeka, Zadar, Split-Marjan, Dubrovnik i Hvar). Razdioba postaja razmjerno ujednačeno pokriva područje Hrvatske. Analizirano je 5 dekadnih razdoblja počevši od 1961-1970. do posljednjeg 2001-2010. Razmatrane su dnevne minimalne i maksimalne temperature zraka kao i dnevne količine oborine. Iz Tablice 7.2.5-1 je vidljivo da je Knin najtopliji grad u Hrvatskoj, a Gospić najhladniji. Tako je apsoluni minimum temperatire zraka od -28.9°C zabilježen u Gospiću, a apsolutni maksimum od 41.4°C u Kninu. Treba spomenuti da je na području Hrvatske zabilježena maksimalna temperatura zraka viša od 42°C, a minimalna niža od -30°C na postajama koje nisu razmatrane u predmetnoj analizi. Najniža minimalna temperature zabilježena je u dekadi 1961-1970, a najviša maksimalna temperature u deckadi 1991-2000. Najveća dnevna količina oborine od 352.2 mm zabilježena je u Zadru 1986. godine.

Prostorni srednjak dekadne temperature zraka je izračunat kao aritimetički srednjak srednjih dekadnih temperatura zraka za 11 meteoroloških postaja. Rezultati su prikazani u Tablici 7.2.5-2. Iz tablice je vidljivo da je najniža srednja dekadna temperatura za područje Hrvatske ona za razdoblje 1971-1980. i, samo je za 0.1°C niža od one za dekadu 1961-1970., koja je na razini prosjeka za standardno razdoblje 1961-1990. U razdoblju 1981-1990. dolazi do blagog porasta srednje "prostorne" temperature u odnosu na prethodne dekade. Tijekom posljednje dvije dekade porast je još izraženiji i iznosi 0.6°C odnosno 1.0°C u odnosu na srednjak za razdoblje 1961-1990. što je u skladu s globalnim trendom.

U Tablici 7.2.5-3 prikazano je rangiranje godišnjih prostornih srednjaka za razdoblje 2001-2010. Najtoplija 2007. godina je bila za 1.5°C toplija od srednjaka standardnog razdoblja 1961-1990., a najhladnija 2005. godina je bila za 0.1°C hladnija. Tijekom dekade 2001-2010. prostorni srednjak temperature zraka je u 9 godina bio viši od odgovarajućeg standardnog višegodišnjeg srednjaka

Tablica 7.2.5-1 Dekadni dnevni ekstremi za Hrvatsku za razdoblje 1961-2010.

Razdoblje	**Parametar**	**vrijednost**	**datum**	**Ime postaje**	**Koordinate**	
					g.š.	**g.d.**
1961-1970	Najviša maksimalna temperatura (°C)	38,6	11.7.1968.	Osijek	45° 28` 24``	18° 48` 23``
	Najniža minimalna temperatura (°C)	-28,9	15.1.1963.	Gospic	44° 33` 2``	15° 22` 23``
	Maksimalna 24-satna oborina (mm)	189,2	15.9.1967.	Rijeka	45° 20` 13``	14° 26` 34``
1971-1980	Najviša maksimalna temperatura (°C)	38,4	5.8.1980.	Knin	44° 2` 27``	16° 12` 25``
	Najniža minimalna temperatura (°C)	-24,8	21.2.1978.	Osijek	45° 28` 24``	18° 48` 23``
	Maksimalna 24-satna oborina (mm)	210,3	1.9.1976.	Rijeka	45° 20` 13``	14° 26` 34``
1981-1990	Najviša maksimalna temperatura (°C)	39,6	3.8.1981.	Knin	44° 2` 27``	16° 12` 25``
	Najniža minimalna temperatura (°C)	-27,3	12.1.1985.	Gospic	44° 33` 2``	15° 22` 23``
	Maksimalna 24-satna oborina (mm)	352,2	11.9.1986.	Zadar	44° 7` 48``	15° 12` 21``
1991-2000	Najviša maksimalna temperatura (°C)	41.4	22.8.2000.	Knin	44° 2` 27``	16° 12` 25``
	Najniža minimalna temperatura (°C)	-26,4	26.1.2000.	Gospic	44° 33` 2``	15° 22` 23``
	Maksimalna 24-satna oborina (mm)	200	19.10.1998.	Rijeka	45° 20` 13``	14° 26` 34``
2001-2010	Najviša maksimalna temperatura (°C)	40,9	19.7.2007.	Knin	44° 2` 27``	16° 12` 25``
	Najniža minimalna temperatura (°C)	-27,6	13.1.2003.	Gospic	44° 33` 2``	15° 22` 23``
	Maksimalna 24-satna oborina (mm)	161,4	23.11.2010.	Dubrovnik	42°3 8` 41``	18° 5` 6``

Tablica 7.2.5-2 Srednje dekadne prostorne temperature zraka za Hrvatsku za razdoblje 1901-2010.

DEKADA	Srednja temperatura (°C)	Anomalija u odnosu na prosjek 1961-1990. godina (°C)
1901-1910	NA	NA
1911-1920	NA	NA
1921-1930	NA	NA
1931-1940	NA	NA
1941-1950	NA	NA
1951-1960	NA	NA
1961-1970	12,7	0
1971-1980	12,6	-0,1
1981-1990	12,8	0,1
1991-2000	13,3	0,6
2001-2010	13,7	1,0

Tablica 7.2.5-3 Rangiranje godina prema srednjoj prostornoj temperaturi zraka za razdoblje 2001-2010

RANG 2001-2010	GODINA	Temperatura (°C)	Anomalija (°C)
Najtoplija	2007	14,23	1,53
2	2008	14,2	1,5
3	2009	14,1	1,4
4	2002	14,0	1,3
5	2003	13,9	1,2
6	2001	13,7	1,0
7	2006	13,5	0,8
8	2004	13,23	0,53
9	2010	13,22	0,52
Najhladnija	2005	12,6	-0,1

7.3. - Scenariji klimatskih promjena

7.3.1 - Uvod

Regionalni klimatski modeli s relativno visokom prostornom rezolucijom od 10 do 50 km koriste se za analizu lokalne i regionalne klime te čine osnovu za istraživanje budućih klimatskih promjena. U usporedbi s globalnim klimatskim modelima, uobičajene prostorne rezolucije od 100 do 300 km, regionalni klimatski modeli detaljnije opisuju klimu malih prostornih skala (kao što je slučaj Hrvatske) koja je uvelike ovisna o lokalnoj topografiji, razdiobi kopna i mora, te udaljenosti od mora. Međutim, opis stvarnog stanja klime i (projiciranih) klimatskih promjena regionalnim modelima ne mora biti nužno bolji od onoga u globalnim klimatskim modelima. Dakle, rezultati nekog regionalnog modela ovise o kvaliteti početnih i rubnih uvjeta u procesu *dinamičke prilagodbe*, odnosno u procesu forsiranja regionalnog modela s podacima nekog globalnog modela ili s podacima reanalize. Sustavni pregled metodologije dinamičke prilagodbe dan je u, primjerice, Giorgi i Mearns (1999) i Rummukainen (2010).

U ovom izvještaju opisani su rezultati budućih klimatskih promjena za područje Hrvatske za dva osnovna meteorološka parametra: temperaturu na visini od 2 m (T2m) i oborinu. Za svaki od ovih parametara rezultati se odnose na dva izvora podataka: a) dinamičku prilagodbu regionalnim klimatskim modelom RegCM urađenu u Državnom hidrometeorološkom zavodu (DHMZ) po IPCC scenariju A2 (Nakićenović i sur. 2000) i b) dinamičke prilagodbe raznih regionalnih klimatskih modela iz europskog projekta ENSEMBLES (van der Linden i Mitchell 2009, Christensen i sur. 2010) po IPCC scenariju A1B.

DHMZ simulacije budućih klimatskih promjena modelom RegCM (detalji modela dani su u Pal i sur. 2007) rađene su za područje Europe na horizontalnoj rezoluciji od 35 km (Branković i sur. 2012). RegCM model je svakih 6 sati forsiran rubnim uvjetima preuzetim iz globalnog modela ECHAM5/MPI-OM (Roeckner i sur. 2003).

Rezultati ENSEMBLES projekta odnose se kako na različite regionalne tako i na različite globalne klimatske modele. Na taj način mogu se istražiti izvori nepouzdanosti u projekcijama buduće klime (Hawkins i Sutton 2009**,** Déqué i sur. 2012). U ovom izvještaju analizirano je 18 kombinacija regionalnih i globalnih klimatskih modela iz projekta ENSEMBLES (Tablica 7.3-1). Detalji modela te prikaz pripadajućih domena dostupni su u Christensen i sur. 2010 (njihova Tablica 1 i Sl. 1) i Déqué i sur. 2012.

7.3.2.- Metodologija

Klimatske promjene za T2m i oborinu u DHMZ RegCM simulacijama analizirane su iz razlika sezonskih srednjaka dobivenih iz dva razdoblja: klima 20. stoljeća (“sadašnja“ klima) definirana je za razdoblje 1961-1990 (u tekstu i slikama označeno kao razdoblje P0). P0 predstavlja standardno 30-godišnje klimatsko razdoblje prema naputcima Svjetske meteorološke organizacije (WMO 1988). Promjene klime promatrane su za (neposredno) buduće razdoblje 2011-2040 (P1). Obje klime, sadašnja i buduća, izračunate su usrednjavanjem tri člana RegCM ansambla koji se međusobno razlikuju u početnim uvjetima dobivenim iz globalnog modela ECHAM5/MPI-OM. Premda je u ovoj analizi korišten ansambl

RegCM simulacija, ona je donekle manjkava jer uključuje rubne i početne uvjete iz samo jednog globalnog modela.

U ENSEMBLES simulacijama "sadašnja" klima (P0) također je definirana za razdoblje 1961-1990 u kojem su regionalni klimatski modeli forsirani s globalnim klimatskim modelima i mjerenim koncentracijama plinova staklenika. Za buduću klimu (21. stoljeće) rezultati simulacija podijeljeni su u tri razdoblja: 2011-2040 (P1; dakle isto kao i za DHMZ RegCM simulacije), 2041-2070 (P2), te 2071-2099 (P3). Promjena klime u tri buduća razdoblja izračunata je kao razlike 30-godišnjih srednjaka P1-P0, P2-P0 i P3-P0, a promatramo razlike između srednjaka skupa svih modela - u svakom razdoblju se klimatološka polja usrednjavaju po svim modelima a zatim se analizira razlika između razdoblja. U ENSEMBLES projektu je u razdobljima P2 i P3 na raspolaganju bio manji broj simulacija (modela) nego za P1, tako da pripadni srednjaci za P0 sadržavaju samo one modele koji uključuju razdoblja P2 i P3. Dodatno, u svakoj točki zajedničke računalne mreže (približno svakih 25 km) određena je suglasnost među modelima tako da se ispitalo da li dvije trećine modela daje isti predznak klimatske promjene kao što je predznak razlika između srednjaka skupova modela (npr. IPCC 2007). Diskusija ENSEMBLES rezultata za područje obalne Hrvatske poziva se na rad Branković i sur. (2013) u kojem je analiziran podskup ENSEMBLES simulacija (pet regionalnih klimatskih modela forsiranih s globalnim modelom ECHAM5/MPI-OM). U Branković i sur. (2013) statistička značajnost klimatskih promjena je procijenjena koristeći Wilcoxon-Mann–Whitney neparametarski test (Wilks 2006).

I za DHMZ RegCM i za ENSEMBLES modele, analiza je prikazana i diskutirana za četiri klimatološke sezone: zima (prosinac, siječanj, veljača; DJF), proljeće (ožujak, travanj, svibanj; MAM), ljeto (lipanj, srpanj, kolovoz; JJA) i jesen (rujan, listopad, studeni; SON).

7.3.3.- Rezultati

7.3.3.1.- Temperatura na 2 m (T2m)

(a) DHMZ RegCM simulacije

Očekuje se da će sezonski osrednjena temperatura zraka T2m na području Europe u razdoblju P0 porasti u rasponu između 0.2°C i 2°C (Sl. 7.3.3.1-1). Međutim, ovaj raspon porasta T2m neće biti jednako zastupljen u svim sezonama. Najmanji porast, 0.2°C–0.4°C iznad većeg dijela središnje Europe te nešto veći na Pirinejskom poluotoku (do oko 0.6°C) i na istočnim rubovima domene (do 0.8°C), očekuje se u proljeće (Sl. 7.3.3.1-1b). Jednoliki se porast temperature od 0.4°C iznad većeg dijela domene integracije očekuje zimi, uz porast temperature do 1°C na sjeveroistoku Europe i u sjeverozapadnom dijelu Afrike (Sl. 7.3.3.1-1a). Najveći porast temperature se očekuje ljeti (Sl. 7.3.3.1-1c), uz najveće vrijednosti na Pirenejskom poluotoku (gotovo do 2°C) i u zapadnoj Africi. U jesen će porast temperature imati sličan oblik promjene kao i u ljeto, ali se očekuje manja amplituda temperaturne promjene (maksimalno do 1.4°C, Sl. 7.3.3.1-1d). Promjene temperature su u svim sezonama statistički značajne za 95%-tni nivo signifikantnosti na gotovo cijelom području domene, osim u proljeće (kada promjene iznad sjevernog dijela središnje Europe i iznad Atlantika nisu statistički značajne).

Za područje Hrvatske može se izdvojiti sljedeći zaključak: najveće promjene srednje temperature zraka očekuju se ljeti kada bi temperatura mogla porasti do oko 0.8°C u Slavoniji, 0.8°C-1°C u središnjoj Hrvatskoj, u Istri i duž unutrašnjeg dijela jadranske obale, te na srednjem i južnom Jadranu. Najveća promjena, oko 1°C, očekuje se na obali i otocima sjevernog Jadrana. U jesen očekivana promjena temperature zraka iznosi oko 0.8°C, a zimi i u proljeće 0.2°C-0.4°C.

Promjene amplituda ekstremnih temperatura zraka na 2 m u budućoj klimi (Sl. 7.3.3.1-2) bit će izraženije u odnosu na promjenu srednjih sezonskih temperatura zraka (Sl. 7.3.3.1-1). Zimi se na većem dijelu domene može očekivati porast srednjih minimalnih temperatura oko 0.4°C, u nekim dijelovima alpskog područja do 0.6°C, a na sjeveroistoku domene minimalna temperatura zraka može porasti do 1.4°C. Porast minimalnih temperatura zraka do oko 0.6°C može se očekivati na južnim rubovima domene (Sl. 7.3.3.1-2a). Promjena srednje maksimalne temperature zraka u ljeto (Sl. 7.3.3.1-2b) prostorno će imati sličan oblik kao i promjena srednje ljetne temperature na 2 m (Sl. 7.3.3.1-1c), ali će odstupanja biti izraženija. Najveće promjene se očekuju u središnjem dijelu Pirenejskog poluotoka gdje srednja maksimalna temperatura zraka može biti veća za 2°C u odnosu na srednje maksimalne temperature zraka u klimi 20. stoljeća. Očekivane promjene minimalne temperature zimi i maksimalne temperature ljeti su statistički značajne na cijelom području integracije za 95%-tni nivo signifikantnosti.

Zimske minimalne temperature zraka u većem dijelu Hrvatske mogle bi porasti do oko 0.5°C, a samo na području dalmatinskog zaleđa porast bi mogao biti nešto blaži (Sl. 7.3.3.1-2a). Ljetne maksimalne temperature zraka porast će oko 0.8°C u unutrašnjosti, te nešto više od 1°C duž jadranske obale (Sl. 7.3.3.1-2b).

Iz RegCM simulacija sadašnje klime analizirani su i brojevi hladnih i toplih dana, te uspoređeni s podacima motrenja na postajama DHMZ-a. Općenito su ekstreme pojave posljedica lokalnih geofizičkih karakteristika te ih regionalni model, zbog njegove relativno grublje horizontalne rezolucije, često nije u mogućnosti primjereno simulirati.

Iz Sl. 7.3.3.1-3a vidi se da RegCM model podcjenjuje broj hladnih dana zimi (to je broj dana kad je minimalna temperatura manja od 0°C) u unutrašnjosti Hrvatske a precjenjuje na obali. U sjevernom dijelu Hrvatske, u sadašnjoj klimi opaženi srednji broj hladnih dana na postajama prelazi 60 dana u zimi, dok je modelom dobiveno manje od 50 dana. Najveće neslaganje modeliranih i opaženih podataka može se uočiti u području uz jadransku obalu. Naime, strma orografija i lokalne karakteristike reljefa nisu adekvatno predstavljene u modelu s rezolucijom od 35 km pa tako dolazi do razlika u odnosu na mjerene podatke. Unatoč tome, ipak se može zaključiti da model razmjerno dobro prikazuje opažene razlike u broju hladnih dana u kontinentalnom i obalnom dijelu Hrvatske. Broj hladnih dana će se u budućoj klimi smanjiti za 10% na sjeveru, odnosno 5% u obalnim područjima (Sl. 7.3.3.1-3b). Ovo je u skladu s porastom minimalne temperature zraka na cijelom području Hrvatske.

Model također podcjenjuje srednji broj toplih dana ($T2max \geq 25$°C) u sadašnjoj klimi (Sl. 7.3.3.1-3c). Općenito je broj toplih dana dobiven modelom upola manji od izmjerenog broja toplih dana na hrvatskim postajama. Razlog razlikama u broju toplih dana je djelomično u sistematskoj pogrešci modela, a djelomično u manjkavom prikazu vegetacije područja koje je blizu obale. U bliskoj se budućnosti može očekivati porast broja toplih dana, i to između 3-4 u sjevernoj Hrvatskoj pa do 10 uz obalu (Sl. 7.3.3.1-3d). U odnosu na sadašnju klimu ovaj porast iznosi 10-15% i u skladu je s očekivanim porastom maksimalnih temperatura zraka.

(b) ENSEMBLES simulacije

Simulacije ENSEMBLES modela za prvo 30-godišnje razdoblje (P1) ukazuju na porast T2m u svim sezonama, uglavnom između 1°C i 1.5°C. Nešto veći porast, između 1.5°C i 2°C, je moguć u istočnoj i središnjoj Hrvatskoj zimi (Sl. 7.3.3.1-4a) te u središnjoj i južnoj Dalmaciji tijekom ljeta (Sl. 7.3.3.1-4c). Na srednjoj mjesečnoj vremenskoj skali moguć je pad temperature do -0.5°C i to prvenstveno kao posljedica unutarnje varijabilnosti klimatskog sustava (Hawkins 2011; Branković i sur. 2013; njihova Sl. 10).

Za razdoblje oko sredine 21. stoljeća (P2) projiciran je porast temperature između 2.5°C i 3°C u kontinentalnoj Hrvatskoj te nešto blaži porast u obalnom području tijekom zime (Sl. 7.3.3.1-5a). Ljeti je porast u središnjoj i južnoj Dalmaciji između 3°C i 3.5°C, te nešto blaži porast između 2.5°C i 3°C u ostalim dijelovima Hrvatske (Sl. 7.3.3.1-5c). U ostale dvije sezone je porast T2m prostorno ujednačen kao i u projekcijama za prvi dio 21. stoljeća te iznosi između 2°C i 2.5°C (nije prikazano). Ovi rezultati slični su zagrijavanju dobivenom direktno iz srednjaka ansambla globalnog modela ECHAM5/MPI-OM za isto razdoblje P2, 2041-2070 (Branković i sur. 2010). Najveće razlike u porastu T2m između globalnog i regionalnog modela nalazimo u ljetnoj sezoni kad globalni model daje izraženiji porast T2m (preko 3.5°C) iznad sjevernog Jadrana, a manji porast T2m iznad srednjeg i južnog dijela.

Projekcije za kraj 21. stoljeća (razdoblje P3) upućuju na mogući izrazito visok porast T2m te na veće razlike u proljeće i jesen u odnosu na projicirane promjene u ranijim razdobljima 21. stoljeća. U kontinentalnoj Hrvatskoj zimi projicirani porast T2m je od 3.5°C do 4°C te nešto blaži porast u obalnom području - između 3°C i 3.5°C (Sl. 7.3.3.1-5b). Ljetni, vrlo izražen, projicirani porast T2m u južnoj i središnjoj Dalmaciji iznosi između 4.5°C i 5°C, a u ostalim dijelovima Hrvatske između 4°C i 4.5°C (Sl. 7.3.3.1-5d). U nekim modelima na srednjoj mjesečnoj skali mogući su porasti temperature u obalnom području ljeti i veći od 5°C (npr. modeli RACMO2 i REMO u Branković i sur. 2013; njihova Sl. 10). Porasti T2m u ostale dvije sezone (proljeće i jesen) su prostorno ujednačeni na cijelom području Hrvatske, slično kao u P1 i P2, i projekcije za P3 upućuju na porast između 3°C i 3.5°C tijekom proljeća te između 3.5°C i 4°C tijekom jeseni (nije prikazano).

Više od dvije trećine modela se slaže sa smjerom projiciranih promjena te iznosom porasta od barem 0.5°C u svim sezonama i u cijelom 21. stoljeću. Standardne mjere statističke značajnosti također upućuju na značajne promjene u temperaturi zraka već u prvom dijelu 21. stoljeća.

7.3.3.2.- Oborina

(a) DHMZ RegCM simulacije

Promjene oborinskih prilika na području Hrvatske u bližoj budućnosti (2011-2040; razdoblje P1) u odnosu na sadašnju klimu (1961-1990; P0) analizirane su za srednje količine oborine i indekse oborinskih ekstrema po sezonama i za godinu slično kao što je prikazano u radu Patarčić i sur. 2013. (rad poslan u Climate Research). Korišteni su sljedeći indeksi oborinskih ekstrema (Peterson i sur. 2001; WMO 2004):

1. suhi dani (*DD*) – broj dana u sezoni (godini) u kojima je dnevna količina oborine (R_d) manja od 1.0 mm

2. standardni dnevni intenzitet oborine (*SDII*) – ukupna sezonska (godišnja) količina oborine podijeljena s brojem oborinskih dana ($R_d \geq 1.0$ mm) u sezoni (godini)
3. vlažni dani (*R75*) – broj dana u sezoni (godini) u kojima je količina oborine veća od 75. percentila dnevnih količina oborine koji je određen iz svih oborinskih dana ($R_d \geq 1.0$ mm) u sezoni (godini) u referentnom razdoblju 1961-1990.
4. vrlo vlažni dani (*R95*) – broj dana u sezoni (godini) u kojima je količina oborine veća od 95. percentila dnevnih količina oborine koji je određen iz svih oborinskih dana ($R_d \geq 1.0$ mm) u sezoni (godini) u referentnom razdoblju 1961-1990.
5. *R95T* – udio sezonske (godišnje) količine oborine koja padne u vrlo vlažne dane u ukupnoj sezonskoj (godišnjoj) količini oborine. Ovaj indeks pokazuje udio ekstremnih količina oborine u sezoni/godini.

Ukupna oborina i indeksi oborinskih ekstrema najprije su izračunati za svaki član ansambla u svakoj godini (i sezoni), a zatim je izračunat 30-godišnji srednjak za godinu (i sezone) te srednjak svih članova ansambla. Prikazani rezultati promjena količine oborine i indeksa oborinskih ekstrema odnose se na srednjak ansambla. Statistička značajnost promjena oborine i indeksa oborinskih ekstrema u budućoj klimi ocijenjena je neparametarskim Wilcoxon-Mann-Whitney statističkim testom (npr. Wilks 2006) na 95% razini povjerenja.

Najveće promjene u sezonskoj količini oborine u bližoj budućnosti (razdoblje P1) su projicirane za jesen kada se u većem dijelu Hrvatske može očekivati smanjenje oborine uglavnom između 2% i 8% (Sl. 7.3.3.2-1d). Međutim, na području Slavonije oborina će se povećati između 2% i 12%, a na krajnjem istoku predviđeno povećanje iznosi i više od 12% i statistički je značajno. U ostalim sezonama model projicira povećanje oborine (2%-8%) osim u proljeće (Sl. 7.3.3.2-1b) na Jadranu gdje se na području Istre i Kvarnera te srednjeg Jadrana može očekivati smanjenje oborine od 2% do 10%. Ove promjene, osobito zimi i u ljeto, nisu prostorno rasprostranjene i manjeg su iznosa nego u jesen te nisu statistički značajne. Smanjenje oborine na Jadranu u jesen i proljeće odražava se na promjene oborine na godišnjoj razini – na dijelovima sjevernog i srednjeg Jadrana u bližoj budućnosti može se očekivati 2%-4% manje oborine (Sl. 7.3.3.2-1e). U istočnom dijelu kontinentalne Hrvatske model daje povećanje godišnje količine oborine između 2% i 6% koje je u istočnoj Slavoniji statistički značajno.

Promjena broja suhih dana (*DD*) zamjetna je samo u jesen kada se u većem dijelu Hrvatske, osim istoka kontinentalnog dijela, u bližoj budućnosti može očekivati jedan do dva suha dana više nego u razdoblju 1961-1990 (Sl. 7.3.3.2-2a) što čini između 1% i 4% više suhih dana u odnosu na referentno razdoblje P0. U ostalim sezonama promjene su manje od jednog dana (nije prikazano). Na godišnjoj razini promjene uglavnom prate najveće jesensko povećanje suhih dana, ali s većom amplitudom porasta (Sl. 7.3.3.2-2b) što ukazuje da i druge sezone doprinose povećanju godišnjeg broja suhih dana. Tako se u sjevernom dijelu Istre i Dalmatinskog zaleđa može očekivati i do 4 suha dana više, a u sjeverozapadnoj Hrvatskoj porast od 3 dana godišnje što odgovara promjenama do 2%. U istočnoj kontinentalnoj Hrvatskoj model predviđa godišnje jedan do tri (1%) suha danje manje nego u sadašnjoj klimi. Budući da su promjene broja suhih dana male ili zanemarive (od -1% do 4%), a to znači da su i promjene oborinskih dana male, dnevni intenzitet oborine (*SDII*) u budućem razdoblju uglavnom slijedi promjene sezonske, odnosno godišnje količine oborine. Tako se povećanje *SDII* može očekivati zimi (Sl. 7.3.3.2-3a) u gotovo cijeloj Hrvatskoj (1%-

6%), a u proljeće (Sl. 7.3.3.2-3b) u kontinentalnom području (od 1% do više od 6%). Statistički značajno smanjenje proljetnog indeksa *SDII* može se očekivati u dijelu sjeverne i u središnjoj Dalmaciji. Ljeti (Sl. 7.3.3.2-3c) promjene *SDII* zahvaćaju manja područja s povećanjem ovog indeksa u istočnoj Slavoniji (1% do 3%), dijelovima Istre i sjevernog Jadrana te na krajnjem jugu (1% do 6%). Na području južne Dalmacije ljeti je projicirano smanjenje dnevnog intenziteta uglavnom između 1% i 4%, a u gorskim predjelima još i više. U jesen (Sl. 7.3.3.2-3d) se, slično promjenama ukupne oborine (Sl. 7.3.3.2-1d), u južnoj Hrvatskoj može očekivati smanjenje *SDII* (uglavnom između 1% i 4%), a u istočnoj Slavoniji povećanje od 1% do više od 6%. Na godišnjoj razini promjene *SDII* su po iznosu manje nego u sezonama (Sl. 7.3.3.2-3e). U sjevernom dijelu Hrvatske one iznose od 1% do 3%, a u istočnoj Slavoniji od 3% do 5%. Na Jadranu povećanja odnosno smanjenja *SDII* zahvaćaju manja područja i povezana su sa smanjenjem broja oborinskih dana odnosno smanjenjem godišnje količine oborine. Povećanje *SDII* je statistički značajno u istočnoj Slavoniji u jesen i za godinu, te u dijelu sjeverne Hrvatske u proljeće i na godišnjoj razini.

Projicirane sezonske promjene učestalosti vlažnih (*R75*) i vrlo vlažnih (*R95*) dana su zanemarive. Jedino se na godišnjoj razini uočava porast *R75* od jednog do tri dana u istočnoj kontinentalnoj Hrvatskoj, koji je u većem dijelu i statistički značajan, te smanjenje *R75* (1-2 dana) u dijelu Like i dalmatinskog zaleđa (Sl. 7.3.3.2-4). Iako je promjena učestalosti vrlo vlažnih dana (*R95*) nezamjetna, udio sezonske (godišnje) količine oborine koja padne u te dane u ukupnoj sezonskoj (godišnjoj) količini oborine (indeks *R95T*) mijenja se u budućoj klimi. Porast *R95T* između 1% i 4% nalazimo u zimi (Sl. 7.3.3.2-5a) duž Jadrana i zaleđa te u sjeverozapadnim krajevima Hrvatske. Velike dnevne količine oborine na Jadranu u hladnom dijelu godine rezultat su dugotrajnih oborina (Zaninović i sur. 2008) pa zimsko povećanje *R95T* ukazuje na njihovu intenzifikaciju. U proljeće je povećanje *R95T* predviđeno u sjevernoj Hrvatskoj, u dijelovima sjevernog Jadrana te na krajenjm jugu (Sl. 7.3.3.2-5b). Ljeti su promjenama obuhvaćena manja područja nego u ostalim sezonama i promjenjivog su predznaka (Sl. 7.3.3.2-5c), a nešto jače je izražen porast *R95T* u istočnoj Slavoniji (1%-5%) što ukazuje na veće količine pljuskovitih oborina koje ovdje dominiraju ljeti. U jesen duž Jadrana bi prevladavalo smanjenje *R95T* (Sl. 7.3.3.2-5d), a povećanje je vidljivo u sjeverozapadnoj Hrvatskoj te na području istočne Slavonije (više od 6%) gdje je i statistički značajno. Na godišnjoj razini (Sl. 7.3.3.2-5e) *R95T* može se povećati u istočnoj Slavoniji (povećanje je i statistički značajno) te duž sjevernog i srednjeg Jadrana. Budući da je u svim sezonama i za godinu promjena učestalosti ekstremnih oborina (*R95*) zanemariva, povećanja *R95T* su uglavnom povezana s povećanjem količina ekstremnih oborina, a u manjem dijelu i sa smanjenjem ukupne sezonske odnosno godišnje količine oborine.

Dosadašnja istraživanja promjena oborine na području Europe i Sredozemlja, koja su uglavnom usredotočena na promjene prema kraju 21. stoljeća kada je signal klimatskih promjena jači, ukazuju na povećanje oborine u sjevernoj Europi i smanjenje u južnoj Europi i na području Sredozemlja. Pri tome je granica između ta dva područja ljeti pomaknuta više na sjever tako da osušenje zahvaća veći dio Europe (primjerice Giorgi i Lionello 2008). Branković i sur. (2012) pokazali su da je prema rezultatima modela RegCM, koji su korišteni i u ovom izvješću, podjela europskog područja na vlažniji sjever i sušniji jug zimi djelomice vidljiva već u ranijem razdoblju 2011-2040, ali s manjom amplitudom od one koja je predviđena za kraj 21. stoljeća. U ovom bližem klimatološkom razdoblju (P1) ljetno osušenje još nije uspostavljeno. Iako prikazani rezultati upućuju na statistički nesignifikantne promjene ekstremnih oborina, postoje sličnosti s projekcijama promjena oborinskih ekstrema zimi krajem 21. stoljeća. Primjerice, Kendon i sur. (2010) su na temelju simulacija globalnog modela HadAM3P prema A2 scenariju pokazali da zbog zagrijavanja atmosfere i povećanja vlage u atmosferi zimi u većem dijelu Europe dolazi do povećanja ne samo srednje količine oborine već i dnevnog intenziteta te ekstremnih količina oborine. Međutim, smanjenje učestalosti oborinskih dana zimi (tj. povećanje broja suhih dana), koje je prema njihovim rezultatima predviđeno u južnoj Europi, ne uočava se u našim simulacijama u bližoj budućnosti. Isto tako ljetno osušenje na Sredozemlju koje je krajem 21. stoljeća popraćeno većim brojem suhih dana čak i pod "slabijim" A1B scenarijem (Lehtonen i sur. 2013) nije dobiveno našim simulacijama za razdoblje 2011-2040. Iz prikazanih rezultata vidljivo je da su u Hrvatskoj promjene vlažnih ekstrema (*SDII*, *R95T*) prostorno i po iznosu jače izražene od promjena suhih ekstrema (*DD*). Također se uočava da su u bližoj budućnosti promjene srednjih i ekstremnih oborina podjednake po prostornoj rasprostranjenosti i iznosu u svim sezonama osim u jesen kada dominiraju promjene srednje sezonske oborine.

(b) ENSEMBLES simulacije

U prvom dijelu 21. stoljeća, projicirani porast količine oborine zimi iznosi između 5% i 15% u dijelovima sjeverozapadne Hrvatske te na Kvarneru. Smjer ovih promjena podudara se u barem dvije trećine svih modela (Sl. 7.3.3.2-6a). Za ljeto u istom periodu projicirano je smanjenje količine oborine u velikom dijelu dalmatinskog zaleđa i gorske Hrvatske u iznosu od -5% do -15% (Sl. 7.3.3.2-6c). Ovo smanjenje oborine također nalazimo u barem dvije trećine modela. Smanjenje oborine u istom iznosu projicirano je za južnu Hrvatsku tijekom proljeća (Sl. 7.3.3.2-6b), dok su tijekom jeseni sve projicirane promjene unutar intervala -5% i +5% (Sl. 7.3.3.2-6d). U obalnim i otočnim lokacijama projicirani signal klimatskih promjena je prostorno i vremenski vrlo promjenjiv i rijetko statistički značajan na srednjoj mjesečnoj razini (Branković i sur. 2013; njihova Sl. 11).

Za razdoblje oko sredine 21. stoljeća (P2) projicirane su umjerene promjene oborine za znatno veći dio Hrvatske u odnosu na prvo 30-godišnje razdoblje, osobito za zimu i ljeto. Međutim, projicirani zimski porast količine oborine između 5% i 15% ne premašuje iznose iz razdoblja P1 (Sl. 7.3.3.2-7a). Osjetnije smanjenje oborine, između -15% i -25%, očekuje se tijekom ljeta gotovo na cijelom području Hrvatske s izuzetkom krajnjeg sjevera i zapada gdje bi smanjenje bilo između -5% i -15 % (Sl. 7.3.3.2-7c). U proljeće je projicirano smanjenje oborine u čitavom obalnom području i zaleđu između -15% i -5 % , dok je za jesen projiciran porast oborine od 5% do 15% u praktički cijeloj središnjoj i istočnoj nizinskoj Hrvatskoj (nije prikazano). Iako na srednjoj mjesečnoj razini lokalno može i dalje biti prisutna zamjetna promjenjivost u projiciranom signalu klimatskih promjena sve navedene promjene su velikom većinom prisutne u barem dvije trećine modela.

I u zadnjem 30-godišnjem razdoblju 21. stoljeća (P3) promjene u sezonskim količinama oborine zahvaćaju veće dijelove Hrvatske. Kao i u P2, tijekom zime projiciran je porast količine oborine između 5% i 15% na cijelom području Hrvatske osim na krajnjem jugu (Sl. 7.3.3.2-7b). Dakle, ENSEMBLES modeli ne predviđaju značajnije razlike u porastu oborine zimi između razdoblja P2 i P3. Međutim, projekcije za ljeto u razdoblju P3, ukazuju na veće smanjenje oborine nego u P2. Tako, u središnjoj i istočnoj Hrvatskoj i Istri projicirano smanjenje oborine bilo bi od -15% do -25%, a u gorskoj Hrvatskoj te u većem dijelu Primorja i zaleđa između -25% do -35% (Sl. 7.3.3.2-7d). U nekim modelima nalazimo projekcije još izraženijeg smanjenja ljetne količine oborine i to oko -60% (npr. modeli RACMO2 i HIRHAM5 u Branković i sur. 2013; njihova Sl. 11). Smanjenje oborine u iznosu od -5% do -15% u priobalnom području i zaleđu projicirano je i za proljeće i jesen (nije prikazano). Kao i za prethodno razdoblje, promjene su prisutne u barem dvije trećine modela.

7.3.4.- Diskusija i zaključci

Prema analiziranim projekcijama klimatskih promjena iz ENSEMBLES regionalnih klimatskih modela, porast temperature na području Hrvatske bio bi sve izraženiji do kraja 21. stoljeća. Ovaj porast temperature za A1B scenarij prisutan je u svim ENSEMBLES regionalnim klimatskim modelima bez obzira na različite formulacije samih modela.

Usporedba projekcija klimatskih promjena za područje Hrvatske iz DHMZ RegCM simulacija i iz ENSEMBLES simulacija za neposredno klimatsko razdoblje 2011-2040 (P1) ukazuje da se najveći porast temperature T2m u oba skupa simulacija očekuje u ljetnoj sezoni duž obale hrvatskog dijela Jadrana i u njegovu zaleđu (Sl. 7.3.3.1-1c i Sl. 7.3.3.1-4c). Međutim, detalji projiciranog porasta T2m se sasvim ne podudaraju: prema DHMZ RegCM rezultatima najveći porast od oko 1ºC očekuje se na sjevernom dijelu Jadrana, a prema ENSEMBLES modelima to će biti od 1.5-2ºC na srednjem i južnom dijelu. Ovakav rezultat može izgledati neočekivan jer je u DHMZ RegCM simulacijama model forsiran prema A2 scenariju u kojem je djelovanje stakleničkih plinova jače nego u A1B scenariju koji je korišten za ENSEMBLES modele. No, u bliskoj budućnosti, kao što je razdoblje P1, forsiranje stakleničkih plinova se značajnije ne razlikuje u različitim IPCC scenarijima; razlike među scenarijima postaju izraženije tek u drugoj polovici 21. stoljeća (Meehl i sur. 2007). Iz prikazanih rezultata za različite scenarije i različite modele važno je ustvrditi da podudarnost sezone (ljeto) i podudarnost regije (Jadran i zaleđe) ukazuju na vjerojatnost projiciranog porasta u temperaturi T2m.

S druge strane, u sezonskim i mjesečnim srednjacima ukupne količine oborine postoji veća raznolikost u projiciranom smjeru promjene oborine, ovisno o regiji Hrvatske i/ili sezoni. Tako je, primjerice, u klimatskom razdoblju P1 ljetno smanjenje oborine u zaleđu Jadrana prostorno raširenije i nešto intenzivnije u ENSEMBLES modelima nego u DHMZ RegCM integracijama (usporedi Sl. 7.3.3.2-1c i Sl. 7.3.3.2-6c). Prema kraju ovog stoljeća sve veći dijelovi Hrvatske bili bi zahvaćeni izraženijim promjenama u budućoj količini oborine. Jasan signal klimatske promjene u oborini je umjerena do visoka mogućnost povećanja srednje ukupne količine oborine zimi, te smanjenje ukupne količine oborine ljeti.

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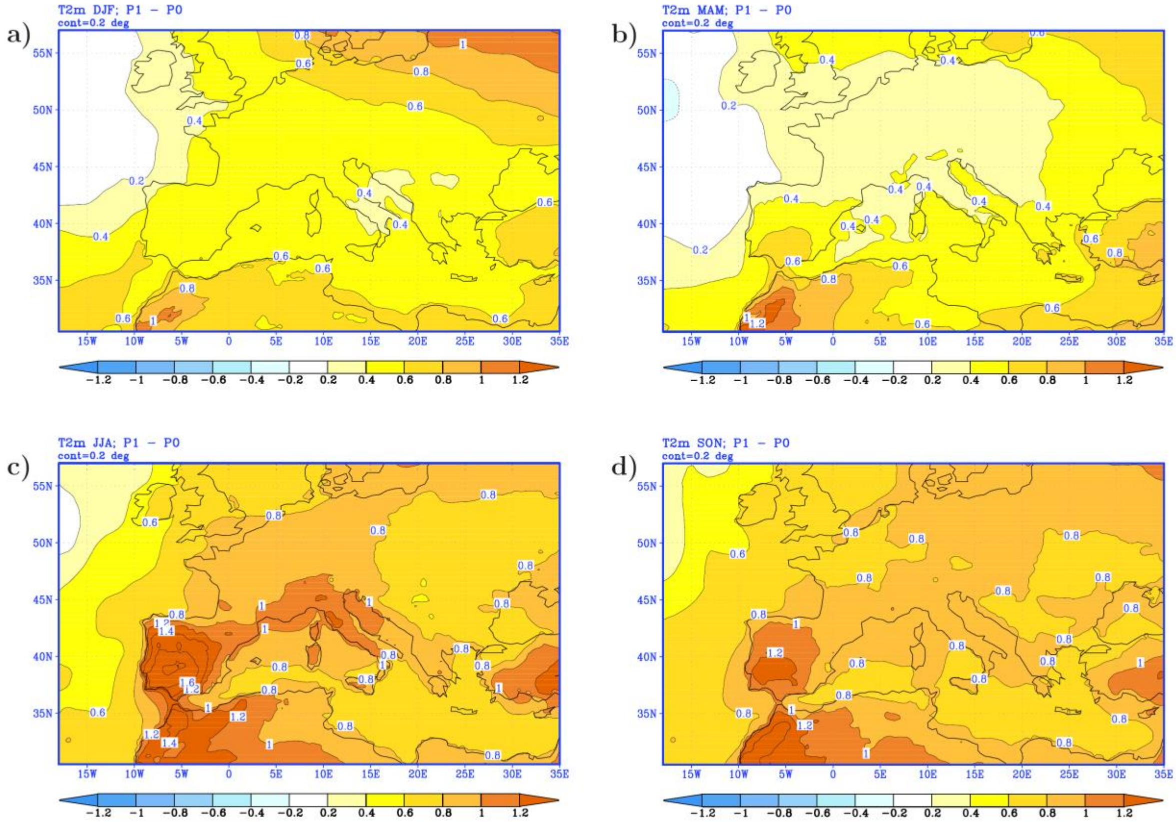
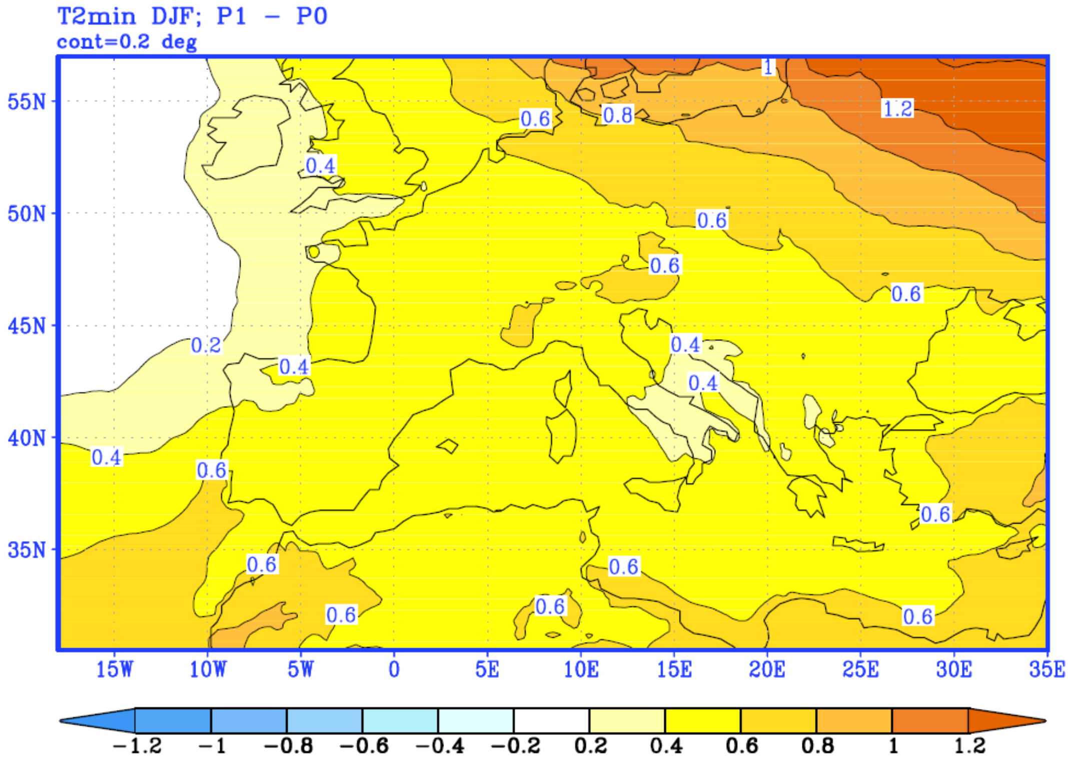
Tablica 7.3-1. Analizirani regionalni klimatski modeli, institucije na kojima su obavljene simulacije te rubni uvjeti. Svi modeli sudjeluju u usporedbi perioda P0 i P1. Modeli u kurzivu ne sudjeluju u usporedbama P0 i P2, te P0 i P3. Podebljane skraćenice označavaju modele koji su analizirani u Branković i sur. (2013). Za opis skraćenica pogledati Christensen i sur. 2010 te Déqué i sur. 2012.

	Regionali klimatski modeli	Organizacija	Globalni klimatski modeli koji daju rubne uvjete regionalnim modelima
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*

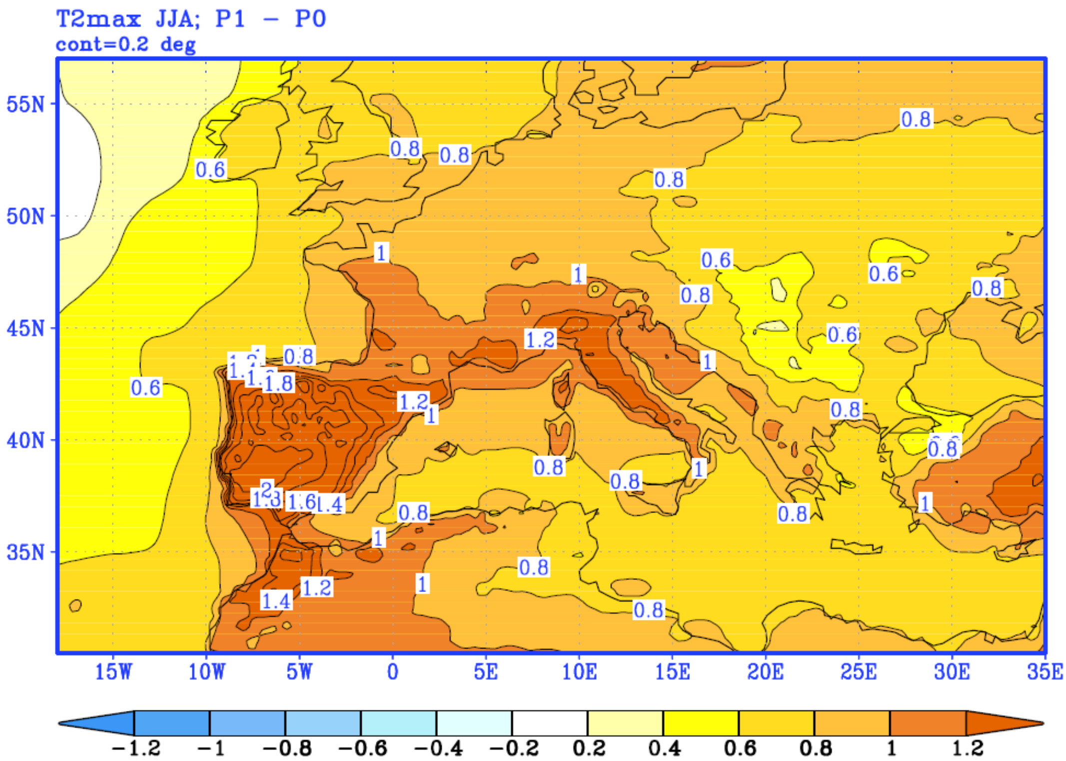


Slika 7.3.1-1. Srednjak ansambla temperature na 2 m (T2m), P1 minus P0: a) zima, b) proljeće, c) ljeto, d) jesen. Izolinije svaka 0.2 °C.

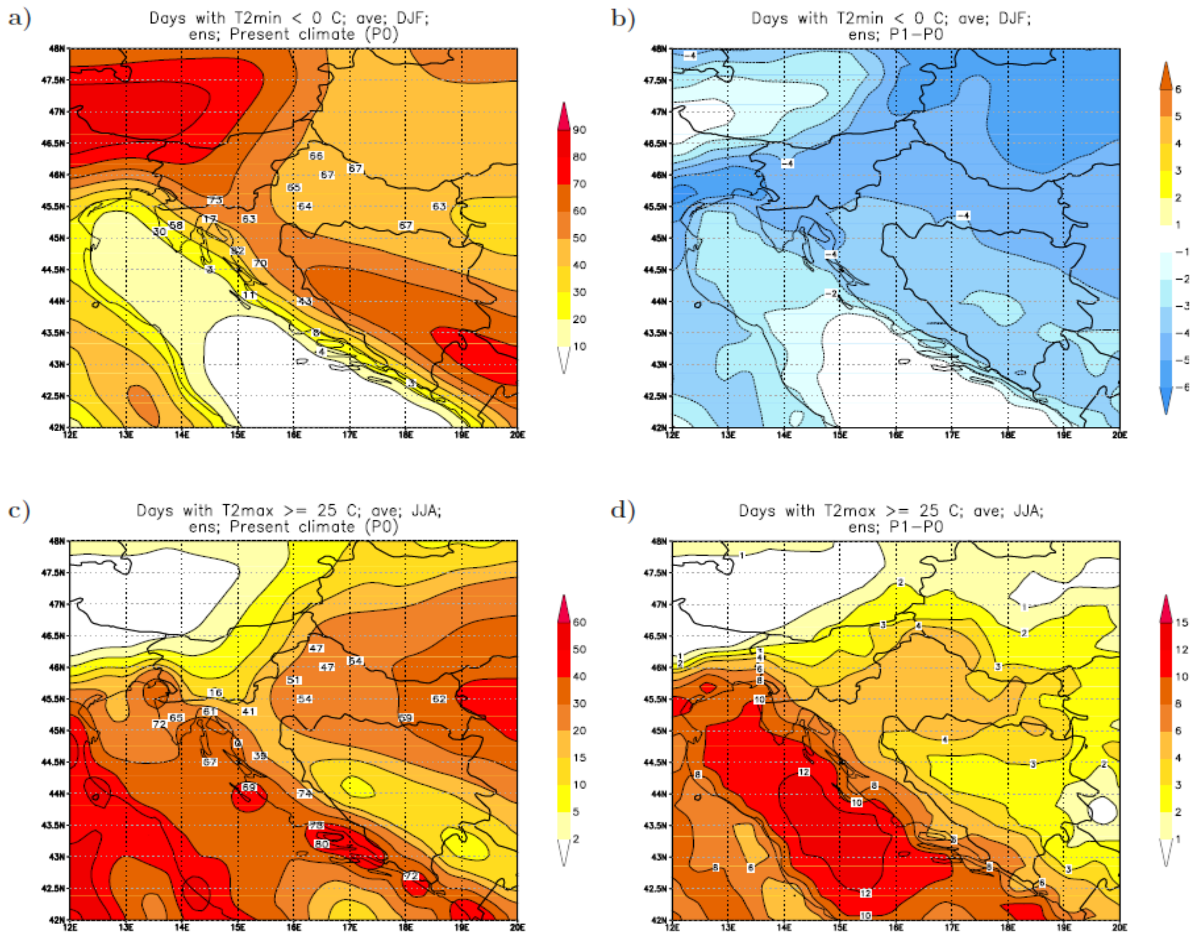
a)



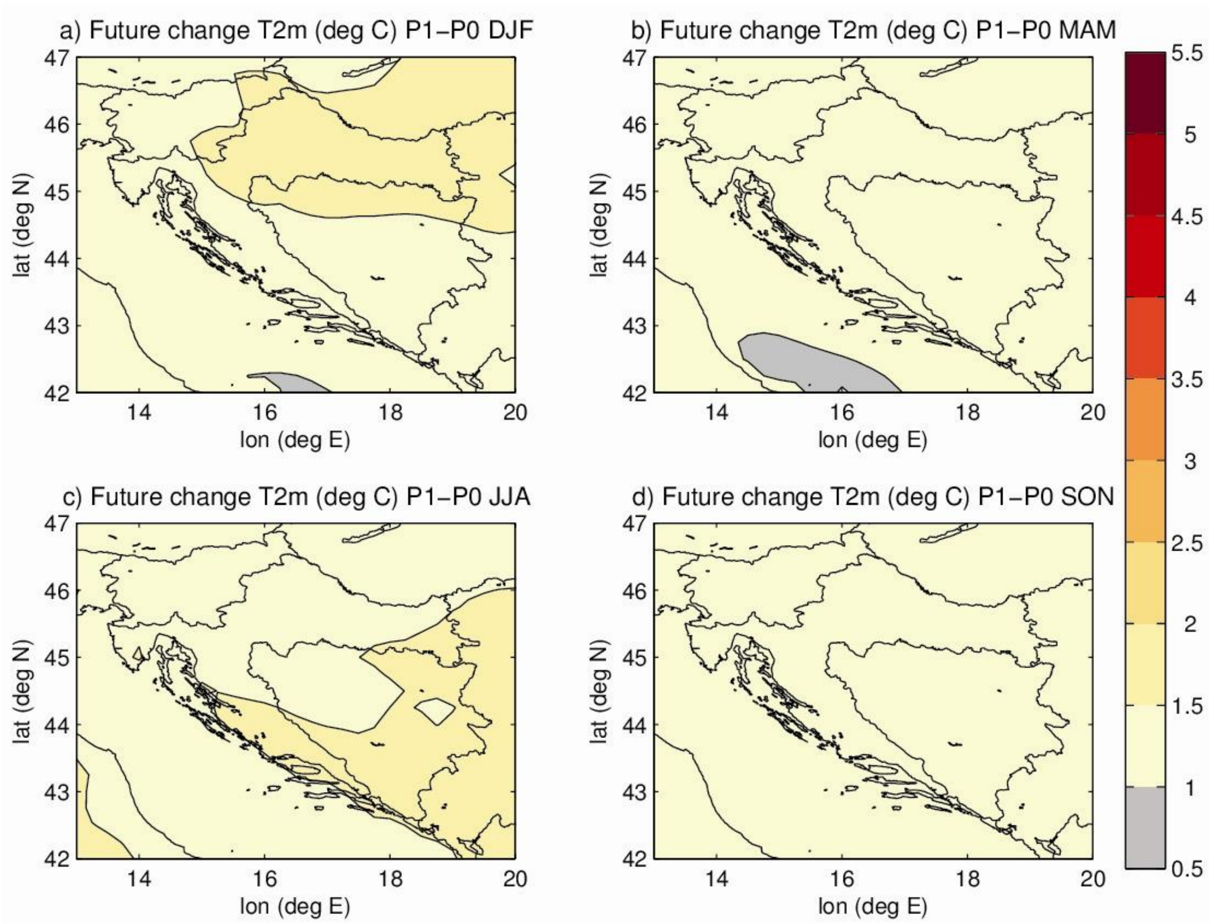
b)



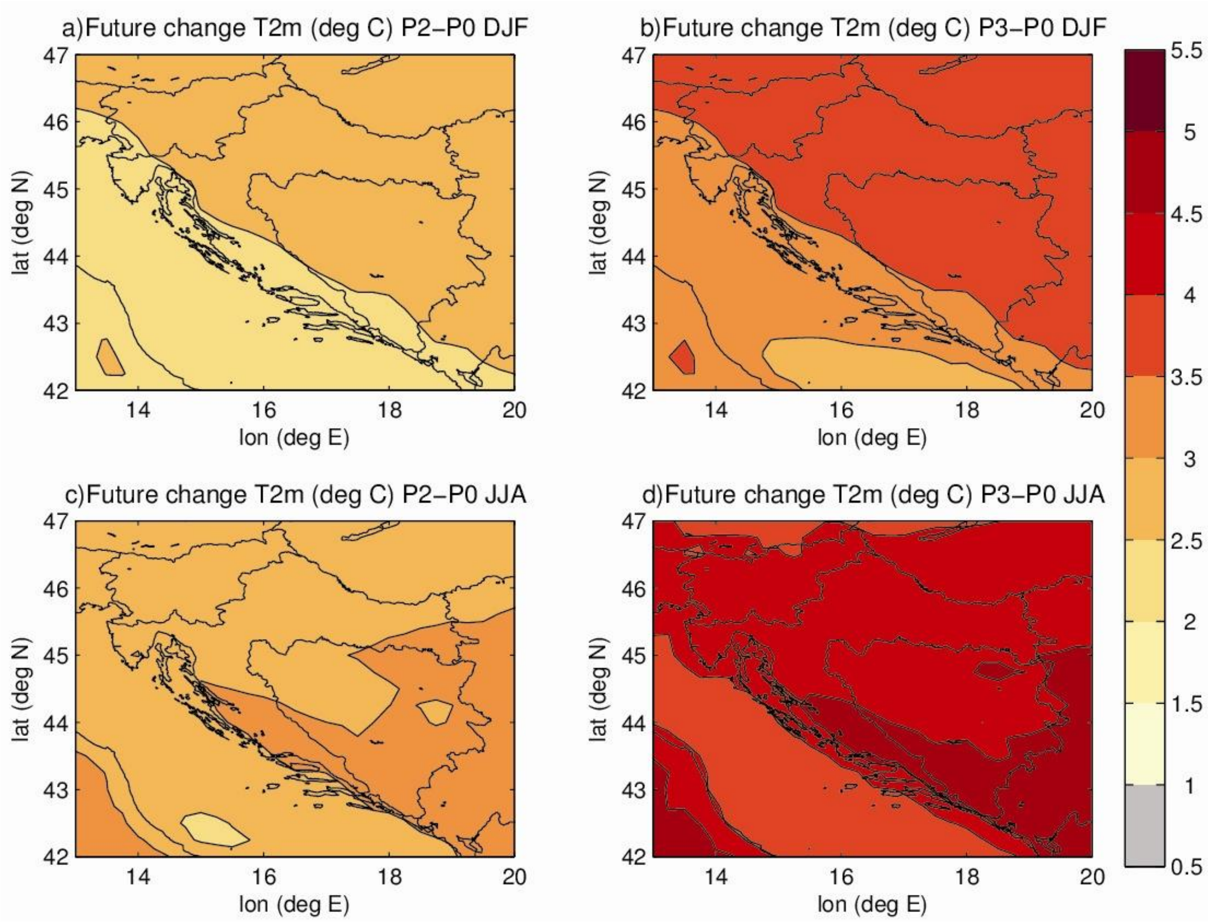
Slika. 7.3.1-2. Srednjak ansambla a) minimalne T2m zimi i b) maksimalne T2m ljeti, P1 minus P0. Izolinije svaka 0.2 °C.



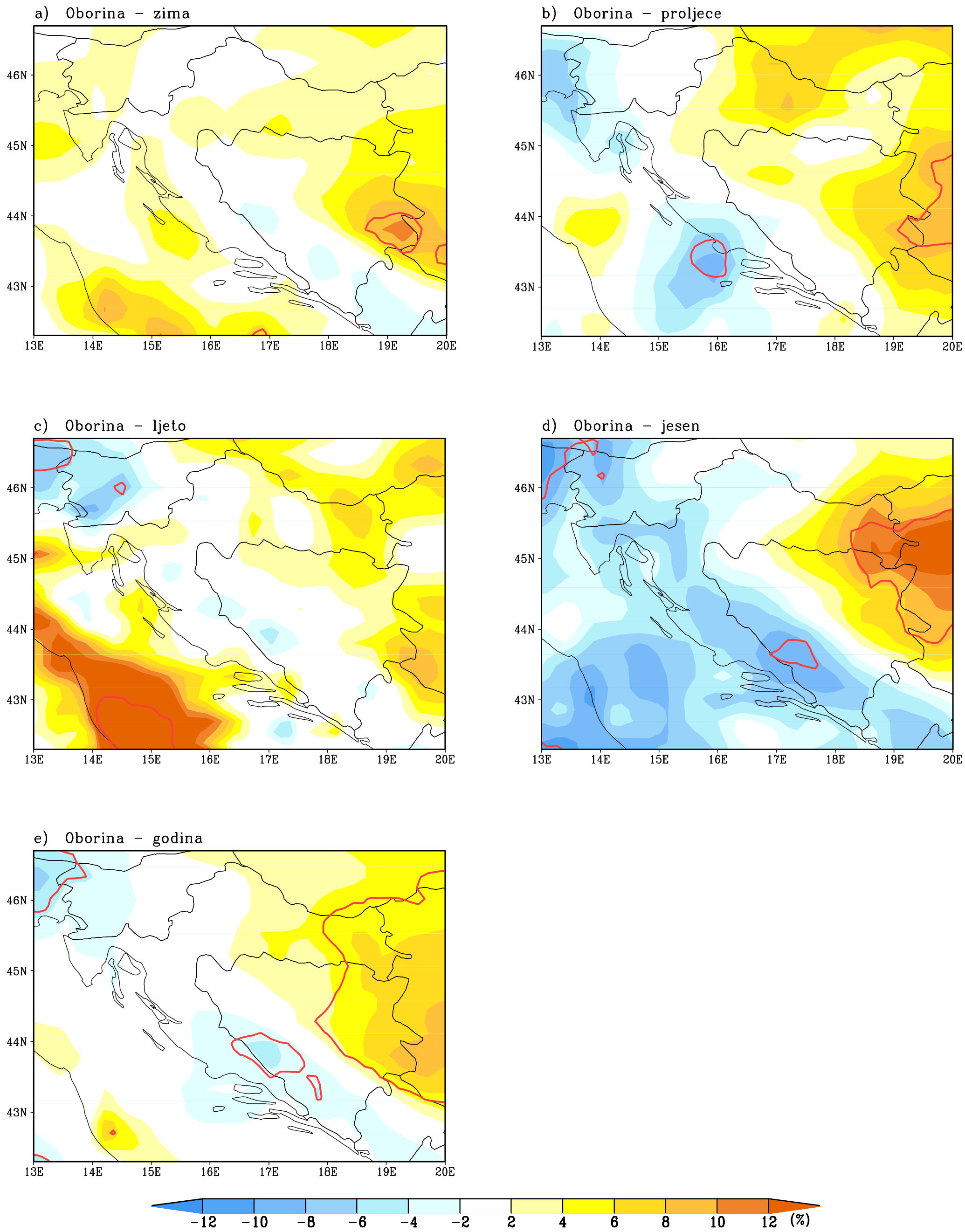
Slika 7.3.1-3. Srednji broj hladnih dana zimi za a) sadašnju klimu (P0) i b) promjena broja hladnih dana (P1 minus P0). Srednji broj toplih dana ljeti za c) sadašnju klimu (P0) i d) promjena broja toplih dana (P1 minus P0). Izolinije u a) svakih 10 dana; u b) 1 dan; u c) 2, 5, 10, 15, 20, 30, 40, 50, 60 i u d) 1, 2, 3, 4, 6, 8, 10, 12, 15 dana.



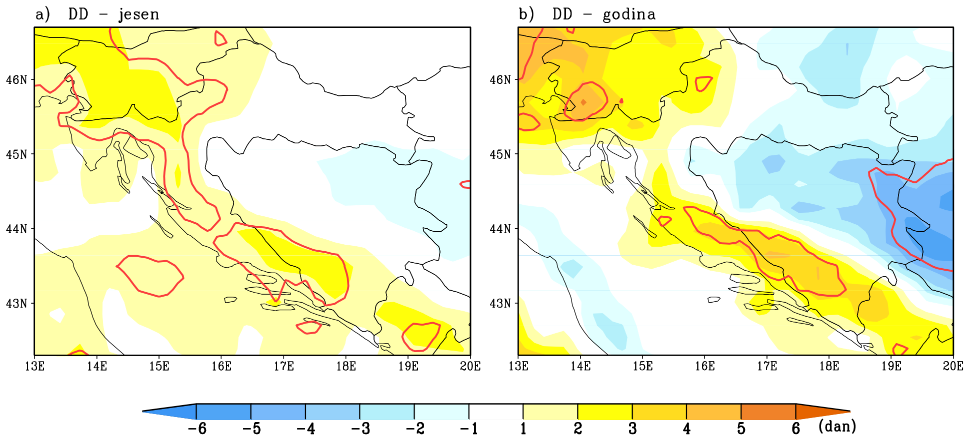
Slika 7.3.1-4. Razlika srednjaka skupa u T2m između perioda P1 i P0: a) zima (DJF), b) proljeće (MAM), c) ljeto (JJA) i d) jesen (SON). Mjerene jedinice su °C. U svim točkama dvije trećine modela daje isti predznak promjene kao srednjak skupa svih modela.



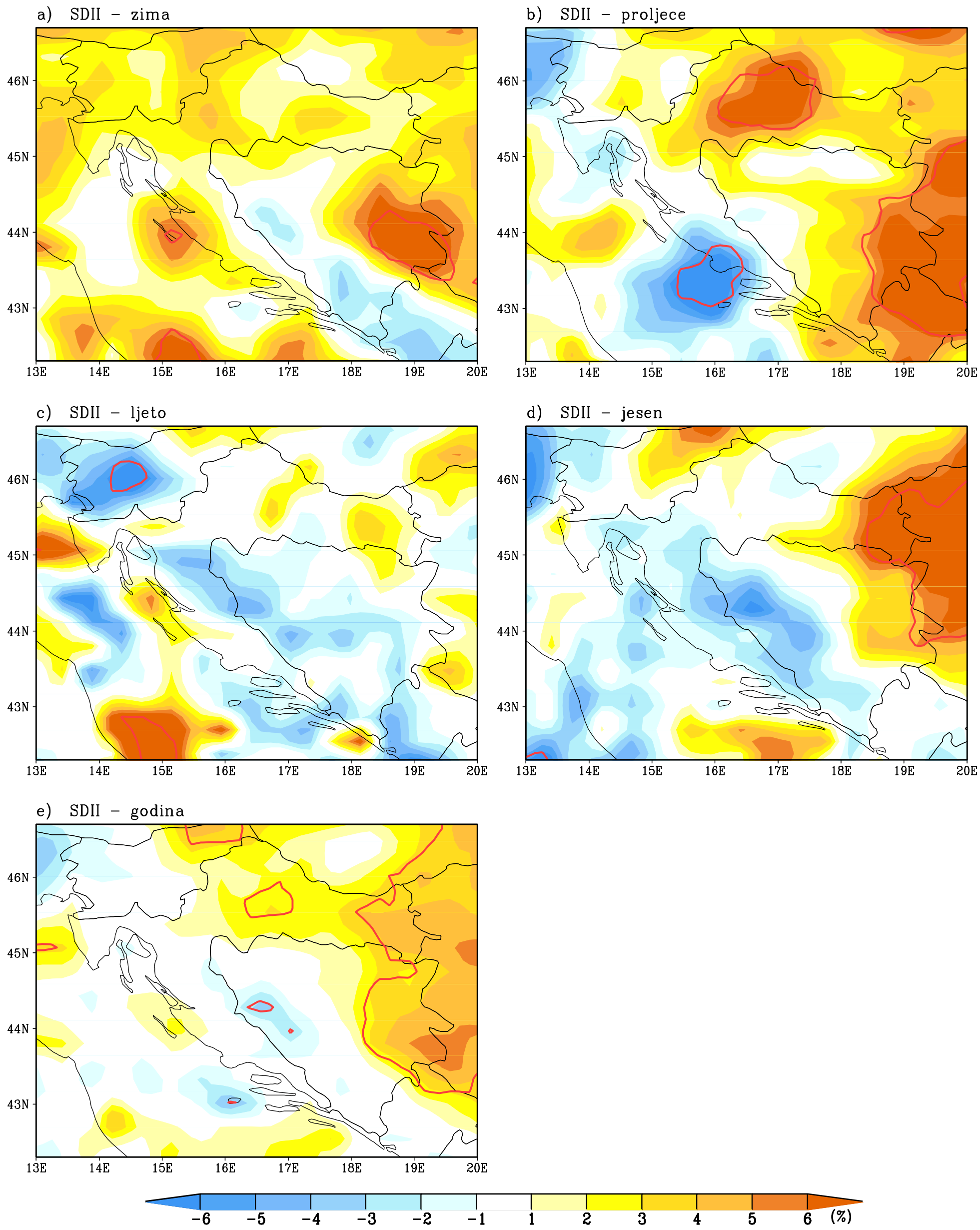
Slika 7.3.1-5. Razlika srednjaka skupa u T2m: zima (DJF) a) P2-P0 i b) P3-P0 te ljeto (JJA) c) P2-P0 i d) P3-P0. Mjerene jedinice su °C. U svim točkama dvije trećine modela daje isti predznak promjene kao srednjak skupa svih modela.



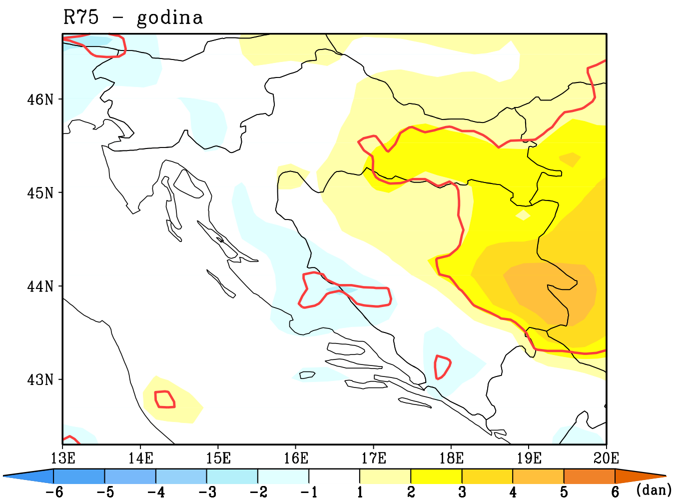
Slika 7.3.2-1. Promjena sezonske (a-d) i godišnje količine oborine (e) u bližoj budućnosti (2011-2040; razdoblje P1) u odnosu na referentno razdoblje (1961-1990; P0). Promjene su izražene u postocima količina oborine u referentnom razdoblju. Statistički značajne promjene na 95% razini povjerenja označene su crvenom krivuljom.



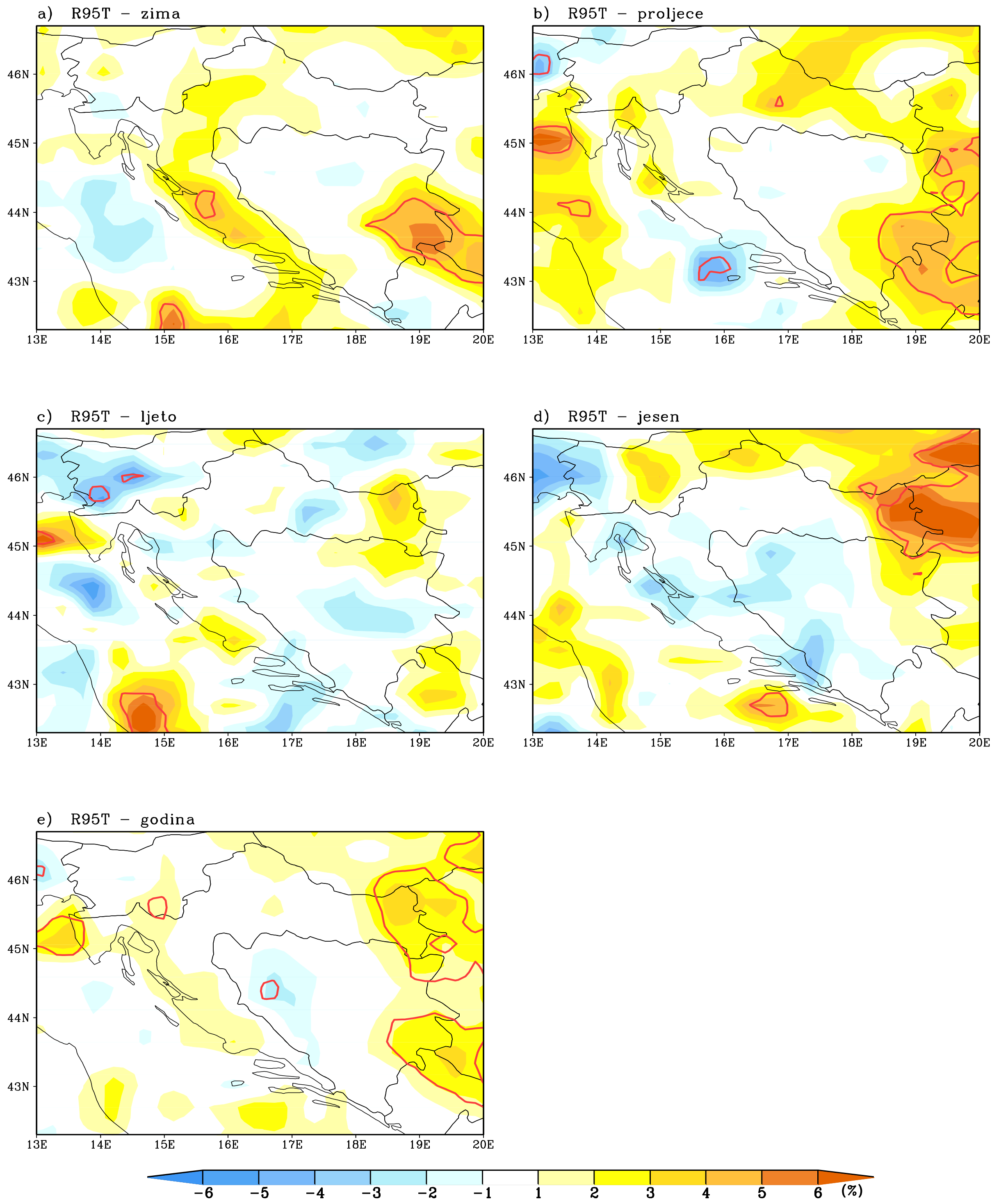
Slika 7.3.2-2. Promjena broja suhih dana (DD) u bližoj budućnosti (2011-2040) u odnosu na referentno razdoblje (1961-1990) u jesen (a) i za godinu (b). Statistički značajne promjene na 95% razini povjerenja su označene crvenom krivuljom.



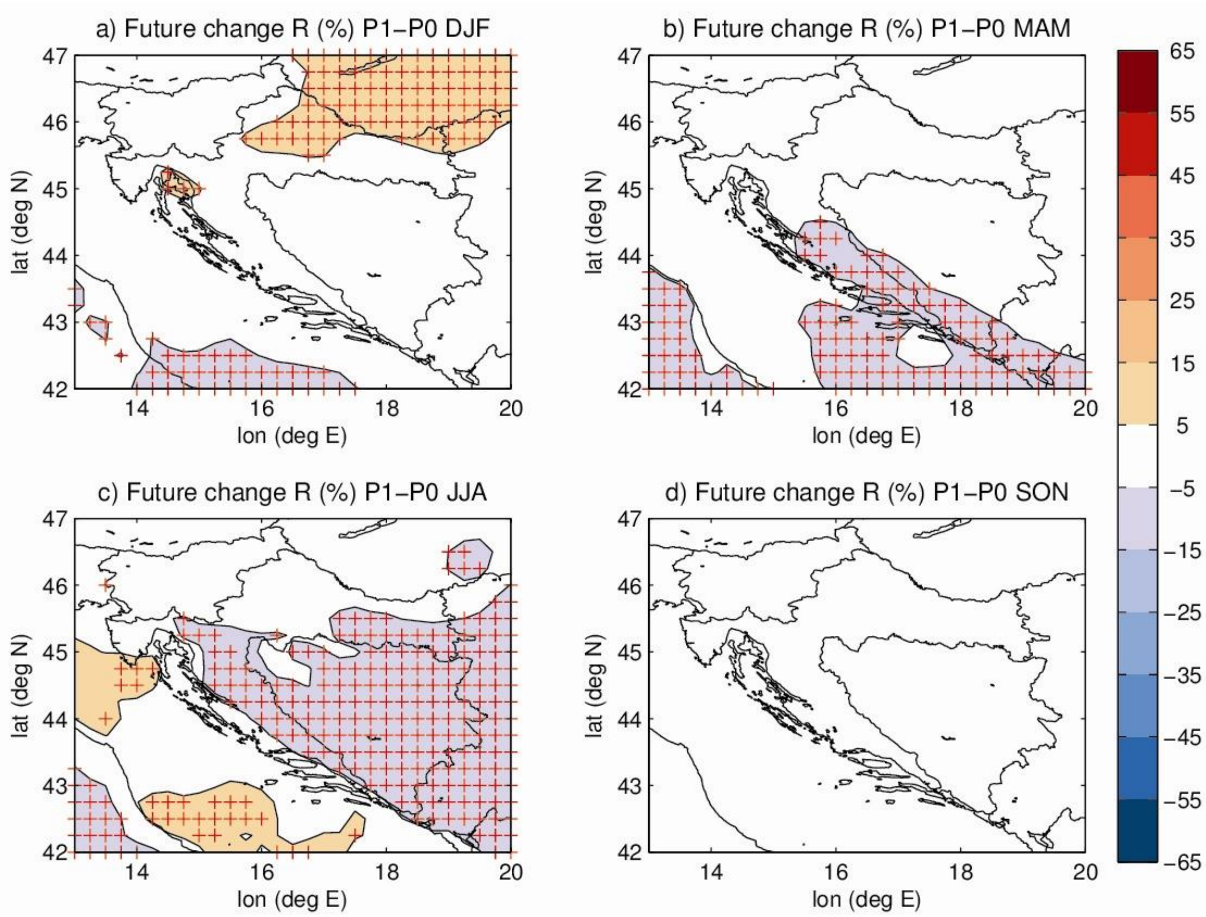
Slika 7.3.2-3. Promjena dnevnog intenziteta oborine (SDII) po sezonama (a-d) i za godinu (e) u bližoj budućnosti (2011-2040; P1) u odnosu na referentno razdoblje (1961-1990; P0). Promjene su izražene u postocima intenziteta u referentnom razdoblju. Statistički značajne promjene na 95% razini povjerenja su označene crvenom krivuljom.



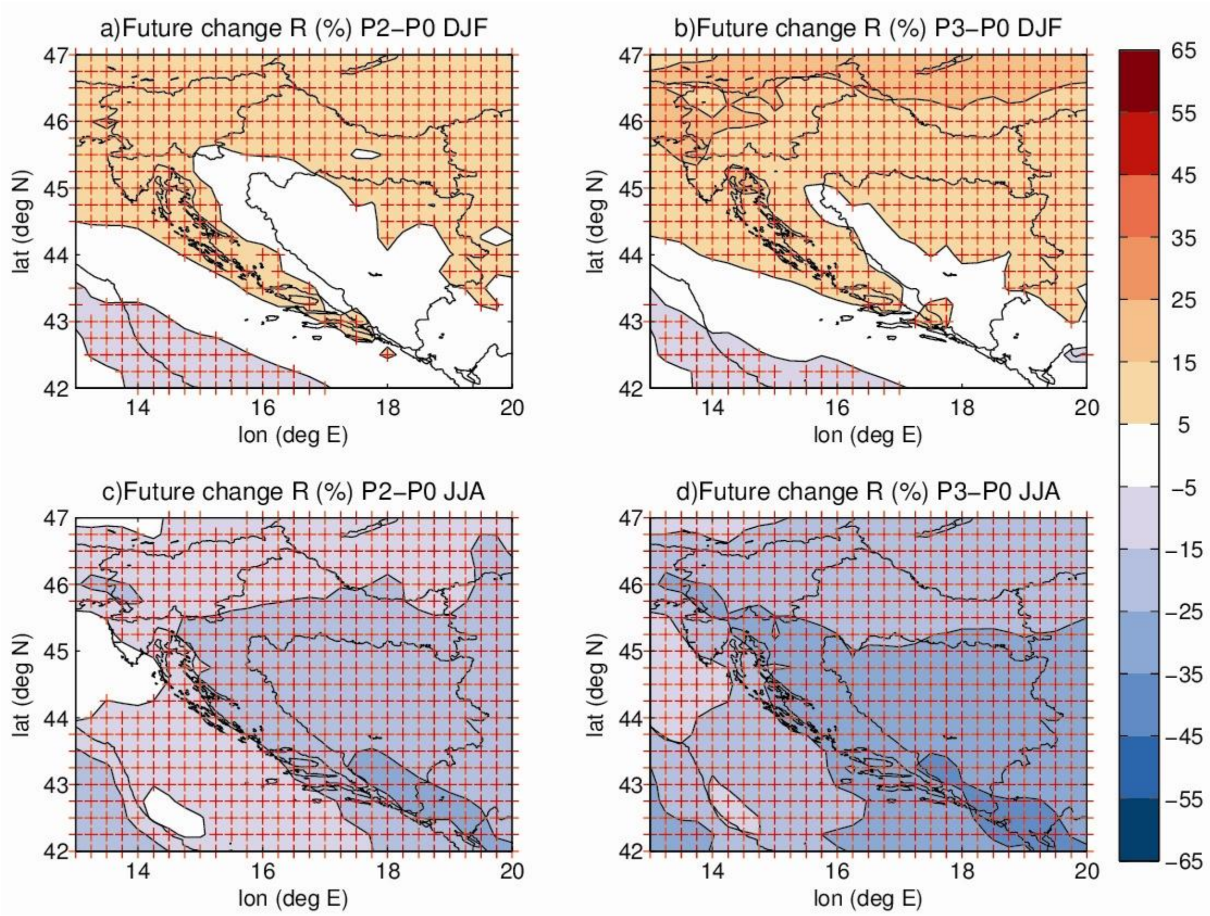
Slika 7.3.2-4. Promjena vlažnih dana (R75) u godini u bližoj budućnosti (2011-2040; P1) u odnosu na referentno razdoblje (1961-1990; P0). Promjene su izražene kao razlike vrijednosti indeksa u budućoj i sadašnjoj klimi. Statistički značajne promjene na 95% razini povjerenja su označene crvenom krivuljom.



Slika 7.3.2-5. Promjena udjela sezonske (a-d) i godišnje (e) količine oborine koja padne u vrlo vlažne dane u ukupnoj sezonskoj odnosno godišnjoj količini oborine (R95T) u bližoj budućnosti (2011-2040; P1) u odnosu na referentno razdoblje (1961-1990; P0). Promjene su izražene kao razlike vrijednosti indeksa u budućoj i sadašnjoj klimi. Statistički značajne promjene na 95% razini povjerenja su označene crvenom krivuljom.



Slika 7.3.2-6. Relativna razlika srednjaka skupa za ukupnu količinu oborine R između razdoblja P1 i P0: a) zima (DJF), b) proljeće (MAM), c) ljeto (JJA) i d) jesen (SON). Mjerene jedinice su %. S oznakom + su označene točke u kojima dvije trećine modela daje isti predznak promjene kao srednjak skupa svih modela te je relativna razlika srednjaka skupa izvan intervala ±5%.



Slika 7.3.2-7. Relativna razlika srednjaka skupa za ukupnu količinu oborine R: klimatološka zima (DJF) a) P2-P0 i b) P3-P0 te ljeto (JJA) c) P2-P0 i d) P3-P0. Mjerene jedinice su %. S oznakom + su označene točke u kojima dvije trećine modela daje isti predznak promjene kao srednjak skupa te je relativna razlika srednjaka skupa izvan intervala ±5%.

7.4. - Utjecaj klimatskih promjena na biljke i zaštitu šuma od požara

7.4.1. - Utjecaj klimatskih promjena na opasnost od požara raslinja

Najugroženije područje u Hrvatskoj s obzirom na požare raslinja je dalmatinska obala s otocima ljeti. Razlog tome su lako zapaljivi biljni pokrov i dugotrajna sušna razdoblja. Tu potencijalnu opasnost od šumskih požara svakako povećava i ljudski čimbenik zbog povećanog broja turista u ljetnim mjesecima. Za procjenu potencijalne opasnosti od šumskih požara primjenjuje se kanadska metoda *Fire Weather Index*. Jedan od njezinih indeksa je srednja mjesečna žestina (*Monthly Severity Rating*, MSR) iz koje se procjenjuje srednja sezonska žestina *(Seasonal Severity Rating*, SSR). Pod sezonskom ocjenom žestine smatra se procjena potencijalne ugroženosti od šumskih požara za vrijeme požarne sezone od lipnja do rujna, a pod mjesečnom procjena za pojedini mjesec. Povoljni vremenski uvjeti postoje za nastanak velikih požara ako je SSR $\geq$ 7.

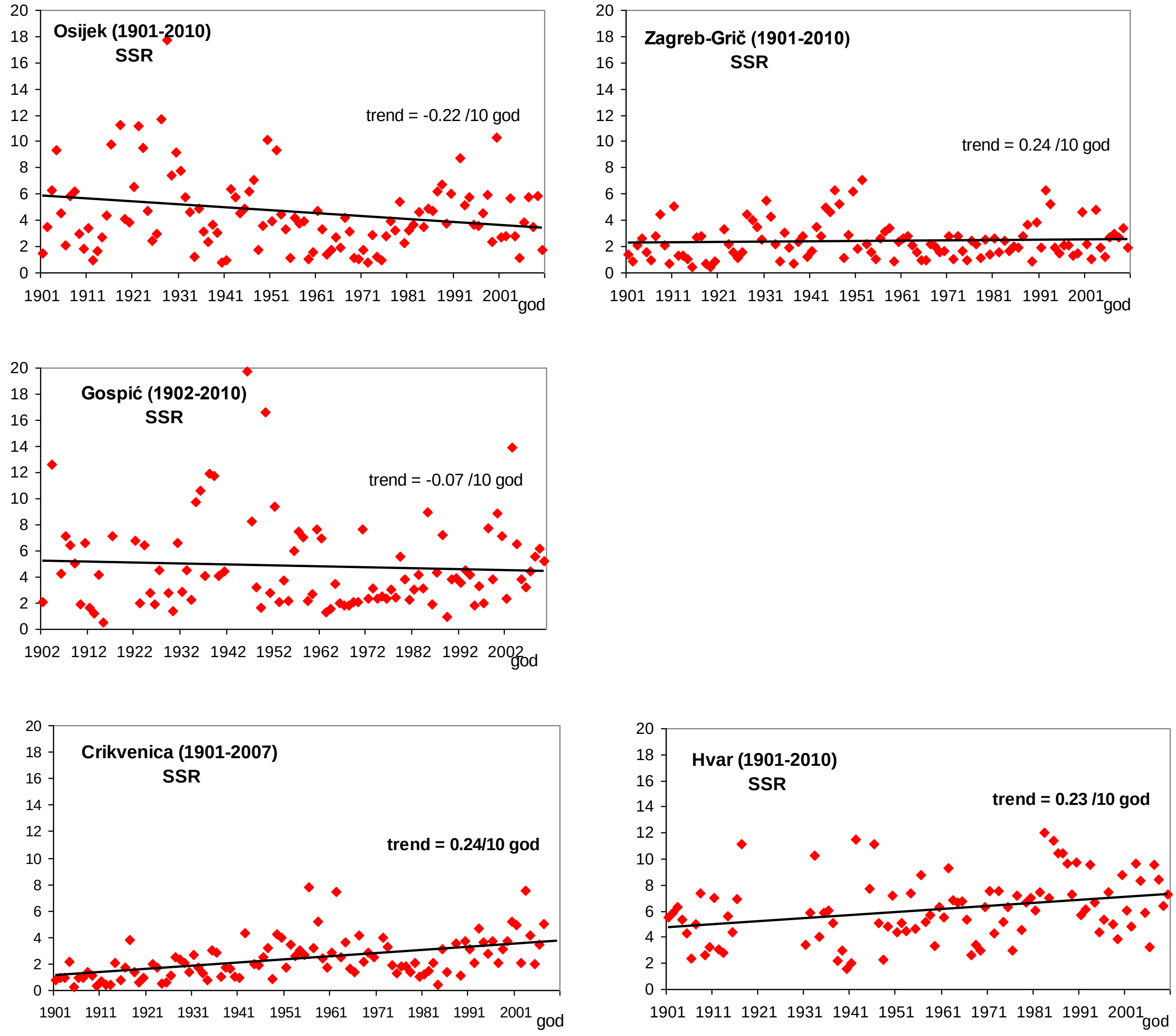
Analiza MSR i SSR je pokazala da se u posljednjih 30 godina područje velike potencijalne opasnosti od požara raslinja širi od dalmatinskog priobalja i otoka prema njenoj unutrašnjosti (tablica 7.4.1.–1). Od promatranih pet postaja, koje pokrivaju različite klimatske zone, najveću srednju vrijednost SSR ima postaja Hvar koja je porasla od 6.9 u razdoblju 1961.–1990. na 7.5 u razdoblju 1981.–2010. Porast ugroženosti od požara zapaža se na sjevernom Jadranu, ali i u istočnoj Slavoniji u odnosu na razdoblje 1961.–1990. Najveća potencijalna opasnost javlja se u kolovozu, a zatim u srpnju.

Analiza linearnih trendova MSR i SSR je u suglasju s prethodnom usporedbom između dva promatrana razdoblja. Ona potvrđuje širenje područja s povećanom potencijalnom opasnošću od srednjeg prema sjevernom Jadranu prema podacima posljednjih 110 godina (tablica 7.4.1.–2 i slika 7.4.1–1). Kako bi se vidjelo koliko su dobiveni rezultati s pet postaja reprezentativni za pojedina područja, analizirani su linearni trendovi MSR i SSR za još sedam postaja za koje postoje meteorološki podaci u kraćem razdoblju 1951–2010. Postaje Lastovo i Knin, koje se nalaze u Dalmaciji, pokazuju daleko najviše vrijednosti linearnih trendova MSR i SSR koje su uglavnom i statistički signifikantne. Tako Lastovo ima najveći porast SSR od promatranih postaja (2.0/10 god), a u Kninu iznosi 1.0/10 god. Na postaji Lastovo su ostvareni i najveći trendovi MSR (u srpnju 3.0/10 god i kolovozu 2.3/10 god). Tako visoke vrijednosti spomenutih veličina na tim postajama potvrđuju činjenicu do koje smo već došli prilikom analize postaje Hvar. Naime, dalmatinsko područje u proteklih 60-ak godina pokazuje i vrlo visok porast opasnosti od požara raslinja, ali i produljenje požarne sezone. Međutim, posljednjih 60 godina primijećen je statistički signifikantan trend u unutrašnjosti Hrvatske (Lika i istočna Slavonija). S time požarna problematika nije više vezana isključivo za jadransku obalu i otoke nego i za druge dijelove Hrvatske. Utjecaj klimatskih promjena na opasnost od požara raslinja pokazuje tendenciju ranijeg početka požarne sezone u svibnju, ali i mogućnost produljenja sezone požara u jesen do listopada, osobito na jadranskom području.

Istaknimo da se rezultati istraživanja na području Hrvatske uvelike podudaraju s onima drugih zemalja. Tako se požarni režim u našoj zemlji dobro uklapa u širu sliku povećanja područja velike ugroženosti od šumskih požara na Sredozemlju i u istočnoj Europi u ljetnim mjesecima.

Tablica 7.4.1–1 Srednja (SRED), maksimalna (MAKS) i minimalna (MIN) mjesečna (MSR) i sezonska (SSR) žestina uz standardnu devijaciju (STD) za Osijek, Zagreb-Grič, Gospić, Crikvenicu i Hvar u razdobljima 1961.–1990. i 1981.–2010.

Mjeseci	**Svibanj**	**Lipanj**	**Srpanj**	**Kolovoz**	**Rujan**	**Listopad**	**SSR**
	MSR						**lip-ruj**
Osijek							
SRED1961-90	2.14	2.11	3.61	4.14	3.20	2.18	3.26
STD	1.56	1.56	2.40	2.91	2.48	1.79	1.66
MAKS	6.52	8.25	9.14	11.63	9.61	7.61	6.70
MIN	0.06	0.29	0.40	0.44	0.33	0.00	0.75
SRED1981-10	3.22	3.22	5.59	5.96	3.60	2.29	4.59
STD	2.13	2.59	2.73	3.69	2.70	2.12	1.99
MAKS	8.37	12.52	11.93	15.52	11.43	9.11	10.34
MIN	0.94	0.65	1.33	0.26	0.54	0.25	1.17
Zagreb-Grič							
SRED1961-90	1.98	1.70	2.72	2.41	1.28	0.73	2.03
STD	1.61	1.14	1.87	1.98	1.18	0.71	0.78
MAKS	5.82	5.49	6.77	8.72	5.69	3.30	3.86
MIN	0.14	0.43	0.77	0.60	0.23	0.01	0.83
SRED1981-10	2.42	2.09	3.12	3.64	1.39	0.56	2.56
STD	1.74	1.33	1.79	3.30	1.24	0.64	1.31
MAKS	8.19	5.52	7.31	13.89	5.51	3.30	6.30
MIN	0.50	0.43	0.81	0.39	0.05	0.06	0.83
Gospić							
SRED1961-90	1.39	1.89	4.65	5.22	2.36	1.08	3.53
STD	1.24	1.71	2.87	4.12	2.98	1.87	2.14
MAKS	5.75	9.49	11.31	15.87	12.64	10.33	8.96
MIN	0.14	0.44	1.27	0.42	0.15	0.00	0.97
SRED1981-10	1.94	2.90	5.93	7.79	2.31	0.91	4.73
STD	1.73	2.20	3.21	6.25	2.34	1.86	2.70
MAKS	9.04	10.04	13.34	27.75	10.90	10.33	13.88
MIN	0.14	0.38	1.27	0.90	0.12	0.00	0.97
Crikvenica							
SRED1961-90	0.94	1.43	3.31	3.45	1.51	1.20	2.42
STD	0.76	1.25	2.20	2.68	1.55	1.25	1.39
MAKS	3.55	4.79	8.32	14.37	6.31	4.63	7.41
MIN	0.04	0.12	0.91	0.30	0.07	0.00	0.39
SRED1981-10	1.50	2.20	4.41	4.58	1.36	0.81	3.14
STD	1.53	1.79	3.14	2.99	1.17	1.05	1.57
MAKS	6.22	6.46	13.22	10.74	3.85	4.18	7.51
MIN	0.04	0.23	0.91	0.30	0.07	0.01	0.39
Hvar							
SRED1961-90	3.07	4.79	8.60	8.82	5.29	3.34	6.87
STD	1.76	2.61	2.89	3.63	3.71	2.58	2.46
MAKS	7.10	11.30	13.53	17.64	15.22	10.41	12.01
MIN	0.59	0.80	2.79	2.93	0.76	0.12	2.60
SRED1981-10	3.08	5.17	9.44	9.31	5.94	2.88	7.46
STD	1.40	2.71	3.02	3.82	3.69	2.53	2.29
MAKS	7.10	11.30	15.95	17.64	15.22	10.41	12.01
MIN	0.87	1.78	3.94	1.76	0.36	0.45	3.28



Slika 7.4.1–1. Vremenski nizovi sezonske žestine (SSR) i linearni trendovi za postaje Osijek, Zagreb-Grič, Gospić, Crikvenica i Hvar uglavnom u razdoblju 1901.–2010.

Tablica 7.4.1–2 Linearni trendovi mjesečne (MSR) i sezonske (SSR) žestine za odabrane postaje u Hrvatskoj uglavnom u razdobljima 1901.–2010. i 1951–2010. Signifikantni linearne trendovi na razini ≤ 0.05 su podebljani.

Mjeseci	**Svibanj**	**Lipanj**	**Srpanj**	**Kolovoz**	**Rujan**	**Listopad**	**SSR lip-ruj**
1901.-2010.	**MSR**						
Osijek	-0.03	-0.18	-0.29	-0.24	-0.18	**0.06**	-0.22
Zagreb-Grič	**0.12**	-0.01	0.04	0.09	-0.03	-0.01	0.02
Gospić	-0.01	-0.14	-0.13	0.07	-0.08	0.03	-0.07
Crikvenica	**0.14**	**0.18**	**0.38**	**0.34**	0.06	**0.07**	**0.24**
Hvar	**0.10**	0.14	**0.42**	0.28	0.09	**0.14**	**0.23**
1951.-2010.							
Osijek	**0.03**	**0.20**	**0.47**	0.16	-0.12	0.00	**0.18**
Zagreb-Grič	0.17	0.10	0.11	0.17	-0.12	-0.05	0.06
Gospić	0.17	0.18	**0.46**	0.64	-0.18	-0.02	**0.28**
Rovinj	**0.32**	**0.55**	**1.02**	**0.87**	**0.46**	0.15	**0.67**
Rijeka	0.19	**0.30**	**0.66**	**0.67**	-0.17	-0.18	**0.36**
Crikvenica	0.08	0.25	0.41	0.24	-0.55	-0.21	0.09
Šibenik	-0.03	0.26	**1.06**	0.56	-0.25	-0.36	0.41
Knin	0.35	**0.72**	**1.73**	**1.44**	0.09	-0.08	**0.99**
Split-Marjan	-0.45	-0.15	**0.04**	0.99	0.19	-0.13	-0.33
Hvar	0.00	0.24	0.72	**0.21**	0.20	-0.02	**0.41**
Lastovo	**0.74**	**1.43**	**2.95**	**2.29**	**1.42**	0.44	**2.02**

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7.4.2. - Utjecaj klimatskih promjena na vinovu lozu

Uzgoj vinove loze i proizvodnja vina u Hrvatskoj imaju dugu tradiciju pa je važno utvrditi kako klimatske promjene utječu na njezin razvoj i urod. Za praćenje promjene početka nastupa pojedine razvojne faze od godine do godine korišteni su fenološki podaci poznatih sorata vinove loze: graševine, malvazije istarske i plavca malog u razdoblju 1961.–2010. Istraživanja u svijetu pokazuju da utjecaj budućih klimatskih promjena neće biti ujednačen za sve sorte i sva vinorodna područja. Tako će se pojaviti neka nova područja s optimalnim uvjetima za uzgoj nekih sorata vinove loze koja to do sada nisu bila. No, očekuje se da će se na postojećim vinorodnim područjima uzgajati i širi sortiment vinove loze čime bi se izgubio regionalni karakter vina.

Početak vegetacije vinove loze prvenstveno ovisi o temperaturnim prilikama, a aktivna temperatura za vinovu lozu je kad je srednja dnevna temperatura zraka iznad 10°C. U prosjeku se pojava prvih mladica na Jadranu javlja posljednjeg tjedan ožujka i traje sve do kraja drugog desetodnevlja travnja, a na kopnenom dijelu traje od sredine do kraja travnja (tablica 7.4.2.–1). Posljednja razvojna faza je berba, čiji nastup nije vremenski tako ujednačen kao pojava mladica jer ovisi o ranoj ili kasnoj sorti vinove loze. U prosjeku berba nastupa od kraja srpnja do početka listopada na Jadranu i od sredine kolovoza do sredine listopada u kontinentalnom dijelu zemlje. Na dalmatinskim postajama su za pojedine sorte vinove loze u razdoblju 1981.–2010. za početak zrenja i puno zrenje, te berbu primijećene velike vrijednosti standardne devijacije (12–18 dana) što ukazuje na veliku varijabilnost nastupa ovih fenofaza od godine do godine. Usporedba duljine trajanja vegetacijskog razdoblja vinove loze (od početka tjeranja mladica do berbe) posljednja tri desetljeća sa standardnim razdobljem 1961.–1990. pokazuje u novijem razdoblju da vegetacija u prosjeku traje kraće za sve promatrane sorte vinove loze.

Duljina trajanja zrenja grožđa definirana je kao razlika između srednjeg datuma nastupa punog i početka zrenja. Posljednjih 30-godina došlo je do kraćeg trajanja zrenja i do 2 tjedna (tablica 7.4.2.–2). Skraćenju vegetacijskog razdoblja više doprinosi veći pomak berbe prema ljetu nego raniji početak vegetacije u proljeće. To utječe na odnos šećera i kiseline u grožđu, a time i na kvalitetu vina i povećanje alkohola u vinu čime se onda gubi prepoznatljivost pojedinih vrsta vina.

Linearni trendovi fenofaza na postajama u unutrašnjosti Hrvatske pokazuju raniji početak proljetnih fenofaza graševine, a u Istri malvazije za 2–3 dana/10 god (tablica 7.4.2.–3 i slika 7.4.2.–1). U Dalmaciji plavac mali samo za postaju Hvar pokazuje signifikantno raniji početak tjeranja mladica, listanja i cvjetanja. Trendovi su pozitivni za početak zrenja graševine u Križevcima i Daruvaru, te plavca malog u Hvaru i Orebiću za 2–6 dana/10 god. Puno zrenje i berba pokazuju signifikantno raniji početak u kontinentalnoj Hrvatskoj i Istri nego na srednjem Jadranu. To potvrđuju iskustva vinogradara da se izraženije promjene u ranijem nastupu fenofaza vinove loze događaju u unutrašnjosti Hrvatske nego u Dalmaciji. Tako primjerice u ekstremno toplim godinama početkom 21. st. rane i kasne sorte dozorile su gotovo istovremeno. Posljedica toga je bila prevelika koncentracija šećera u grožđu, a time i preveliki postotak alkohola u vinu. Takva vina više podsjećaju na dalmatinska vina te vinogradari su počeli više uzgajati crne sorte grožđa u unutrašnjosti Hrvatske.

Tablica 7.4.2–1. Srednji (SRED), najkasniji (MAKS) i najraniji (MIN) datumi fenofaza za vinovu lozu uz standardnu devijaciju (STD) na odabranim postajama u Hrvatskoj uglavnom u razdoblju 1961.–2010. BS: Početak tjeranja mladica, UL: Pojava prvih listova, BF: Početak cvatnje BR: Početak zrenja, EF: Završetak cvatnje, FR: Puno zrenje, RP: Berba

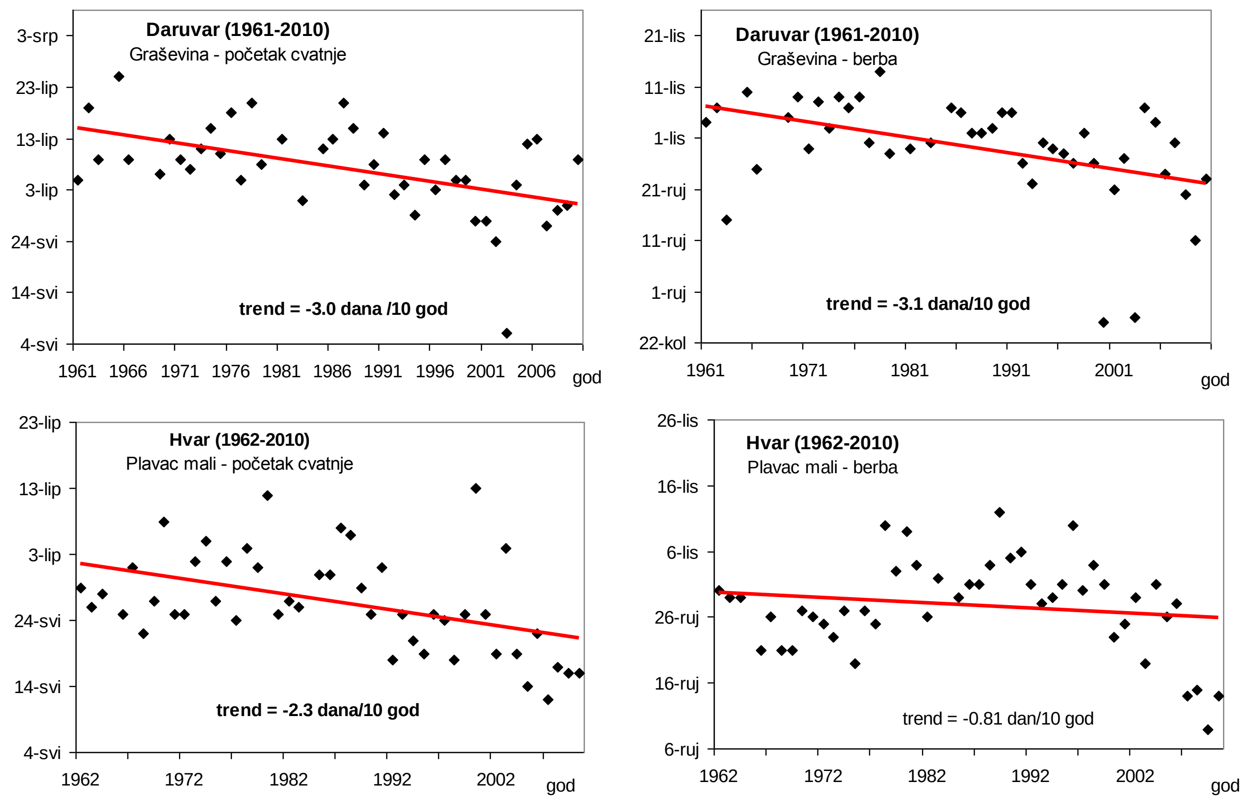
Fenofaze			BS	UL	BF	EF	BR	FR	RP
Graševina	Daruvar	SRED1961-90	25.4.	3.5.	12.6.	21.6.	22.8.	26.9.	5.10.
		STD	9	9	6	6	5	5	6
		MAKS	9.5.	16.5.	26.6.	4.7.	1.9.	3.10.	15.10.
		MIN	4.4.	15.4.	2.6.	12.6.	11.8.	14.9.	16.9.
		SRED1981-10	22.4.	30.4.	6.6.	17.6.	27.8.	17.9.	27.9.
		STD	8	9	9	8	9	14	11
		MAKS	9.5.	14.5.	21.6.	29.6.	10.9.	3.10.	8.10.
		MIN	3.4.	9.4.	7.5.	22.5.	29.7.	7.8.	27.8.
	Križevci	SRED1961-90	27.4.	4.5.	11.6.	19.6.	24.8.	2.10.	13.10.
		STD	8	9	6	6	8	7	7
		MAKS	10.5.	20.5.	26.6.	3.7.	10.9.	22.10.	27.10.
		MIN	12.4.	16.4.	4.6.	12.6.	13.8.	23.9.	1.10.
		SRED1981-10	22.4.	29.4.	6.6.	17.6.	28.8.	25.9.	3.10.
		STD	8	8	10	6	8	6	8
		MAKS	4.5.	12.5.	22.6.	29.6.	16.9.	5.10.	17.10.
		MIN	5.4.	12.4.	11.5.	6.6.	16.8.	15.9.	20.9.
Malvazija istarska	Čepić	SRED1961-90	26.4.	1.5.	9.6.	18.6.	19.8.	19.9.	25.9.
		STD	9	9	6	6	5	7	10
		MAKS	6.4.	10.4.	28.5.	9.6.	11.8.	1.9.	15.9.
		MIN	28.3.	3.4.	15.5.	25.5.	5.8.	20.8.	5.9.
		SRED1981-10	18.4.	26.4.	31.5.	12.6.	20.8.	12.9.	22.9.
		STD	10	10	8	7	9	12	6
		MAKS	5.5.	12.5.	13.6.	25.6.	10.9.	27.9.	2.10.
		MIN	28.3.	3.4.	15.5.	25.5.	5.8.	20.8.	5.9.
Plavac mali	Hvar	SRED1961-90	12.4.	18.4.	31.5.	9.6.	15.8.	16.9.	30.9.
		STD	7	7	5	5	8	14	6
		MAKS	29.3.	4.4.	23.5.	30.5.	3.8.	20.8.	20.9.
		MIN	22.4.	29.4.	13.6.	21.6.	31.8.	7.10.	13.10.
		SRED1981-10	5.4.	11.4.	26.5.	5.6.	20.8.	14.9.	29.9.
		STD	11	10	8	5	6	15	8
		MAKS	18.3.	25.3.	13.5.	28.5.	10.8.	25.8.	10.9.
		MIN	22.4.	26.4.	14.6.	15.6.	31.8.	7.10.	13.10.
	Orebić	SRED1961-90	15.4.	21.4.	30.5.	7.6.	17.8.	24.9.	30.9.
		STD	10	10	8	7	9	10	10
		MAKS	29.3.	4.4.	12.5.	20.5.	1.8.	26.8.	29.8.
		MIN	30.4.	5.5.	17.6.	24.6.	7.9.	8.10.	16.10.
		SRED1981-10	16.4.	21.4.	28.5.	6.6.	29.8.	26.9.	1.10.
		STD	8	8	5	5	11	8	7
		MAKS	4.4.	13.4.	14.5.	23.5.	23.7.	20.8.	20.9.
		MIN	27.3.	2.4.	20.5.	26.5.	13.8.	3.9.	13.9.
	Lastovo	SRED1961-90	19.4.	25.4.	31.5.	9.6.	13.8.	23.9.	2.10.
		STD	7	7	8	7	12	12	7
		MAKS	29.4.	4.5.	20.6.	25.6.	5.9.	16.10.	16.10.
		MIN	4.4.	13.4.	14.5.	23.5.	23.7.	20.8.	20.9.
		SRED1981-10	19.4.	24.4.	30.5.	9.6.	13.8.	17.9.	30.9.
		STD	9	9	6	6	15	18	10
		MAKS	4.5.	8.5.	11.6.	19.6.	5.9.	16.10.	16.10.
		MIN	28.3.	3.4.	17.5.	27.5.	17.7.	18.8.	9.9.

Tablica 7.4.2–2. Srednja duljina trajanja (dani) zrenja graševine i plavca malog od početka do punog zrenja na postajama Daruvar i Hvar u razdobljima 1961.–1990., 1971.–2000. i 1981–2010.

Sorta	**Postaje**	**Duljina trajanja zrenja grožđa (dani)**		
		1961.–1990.	1971.–2000.	1981.–2010.
Graševina	Daruvar	35	30	22
Plavac mali	Hvar	32	33	26

Tablica 7.4.2–3. Linearni trendovi fenofaza (dan/10 god) za vinovu lozu na odabranim postajama u Hrvatskoj uglavnom u razdoblju 1961.-2010. Signifikantni linearne trendovi na razini ≤ 0.05 su podebljani.

Trend (dan/10 god)	**Fenofaze**	**BS**	**UL**	**BF**	**EF**	**BR**	**FR**	**RP**
Graševina	**Daruvar** 1961.-2010.	**-1.55**	-1.49	**-3.01**	**-1.88**	**2.34**	**-3.73**	**-3.10**
	Križevci 1961.-2010.	**-2.22**	**-2.40**	-2.36	-0.35	**1.95**	**-4.43**	**-5.24**
Malvazija istarska	**Čepić** 1968.-2010.	**-3.23**	**-1.92**	**-5.03**	**-2.90**	-0.49	**-4.88**	-2.29
Plavac mali	**Hvar** 1962.-2010.	**-3.87**	**-3.85**	**-2.35**	**-1.50**	**2.41**	-0.20	-0.81
	Orebić 1962.-2010.	0.19	-0.25	-0.27	-0.34	**6.23**	0.98	0.53
	Lastovo 1961.-2010.	-0.30	-0.67	-0.20	0.15	-0.64	-3.70	-1.02



Slika 7.4.2–1. Vremenski nizovi fenoloških faza vinove loze i linearni trendovi za Daruvar i Hvar u razdoblju 1961–2010.

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8. - ISTRAŽIVANJE, SISTEMATSKO MOTRENJE I MONITORING

8.1. - Globalni klimatski motriteljski sustav

Globalni klimatski motriteljski sustav (engl. Global Climate Observation System - GCOS) ustanovljen je 1992. godine i Republika Hrvatska, koju predstavlja Državni hidrometeorološki zavod, je njegova članica od osnutka. Taj sustav uključuje motrenja u svim dijelovima klimatskog sustava: atmosferi, moru i kopnu. Nakana GCOS-a je definirati i pokriti motrenjima sve potrebne zahtjeve monitoringa klimatskog sustava uključujući satelitska motrenja na globalnoj, regionalnoj i nacionalnoj razini i stvoriti uvjete za unapređenje sustava motrenja.

Globalni sustav svih sustava motrenja Zemlje (Global Earth Observation System of Systems - GEOSS) je razmjerno nova inicijativa za koordinaciju i poboljšanje postojećih sustava motrenja na globalnoj razini s ciljem zadovoljenja zahtjeva korisnika na temama: prirodne katastrofe, zdravstvo, energija, klima, voda, vrijeme, ekosustavi, poljoprivreda i bioraznolikost. Hrvatska se pridružila GEOSS-u 2004. godine.

8.2. - Prikupljanje podataka i sustavna motrenja u Hrvatskoj

8.2.1. - Postojeće motriteljske mreže

Republika Hrvatska ima dugu tradiciju u praćenju segmenata klimatskog sustava. Državni hidrometeorološki zavod (DHMZ) je nacionalna ustanova za meteorologiju i hidrologiju koja provodi meteorološka motrenja za operativne potrebe od 1851. godine.

Hrvatske institucije koje održavaju motriteljske sustave u segmentima atmosfere, mora i kopna jesu:

- Državni hidrometeorološki zavod;
- Ministarstvo prometa;
- Ministarstvo za zaštitu okoliša i prirode;
- Institut za medicinska istraživanja;
- Institut za javno zdravstvo;
- Institut za oceanografiju i ribarstvo;
- Hrvatski hidrografski institut;
- Institut "Ruđer Bošković"
- Geofizički zavod "Andrija Mohorovičić”.

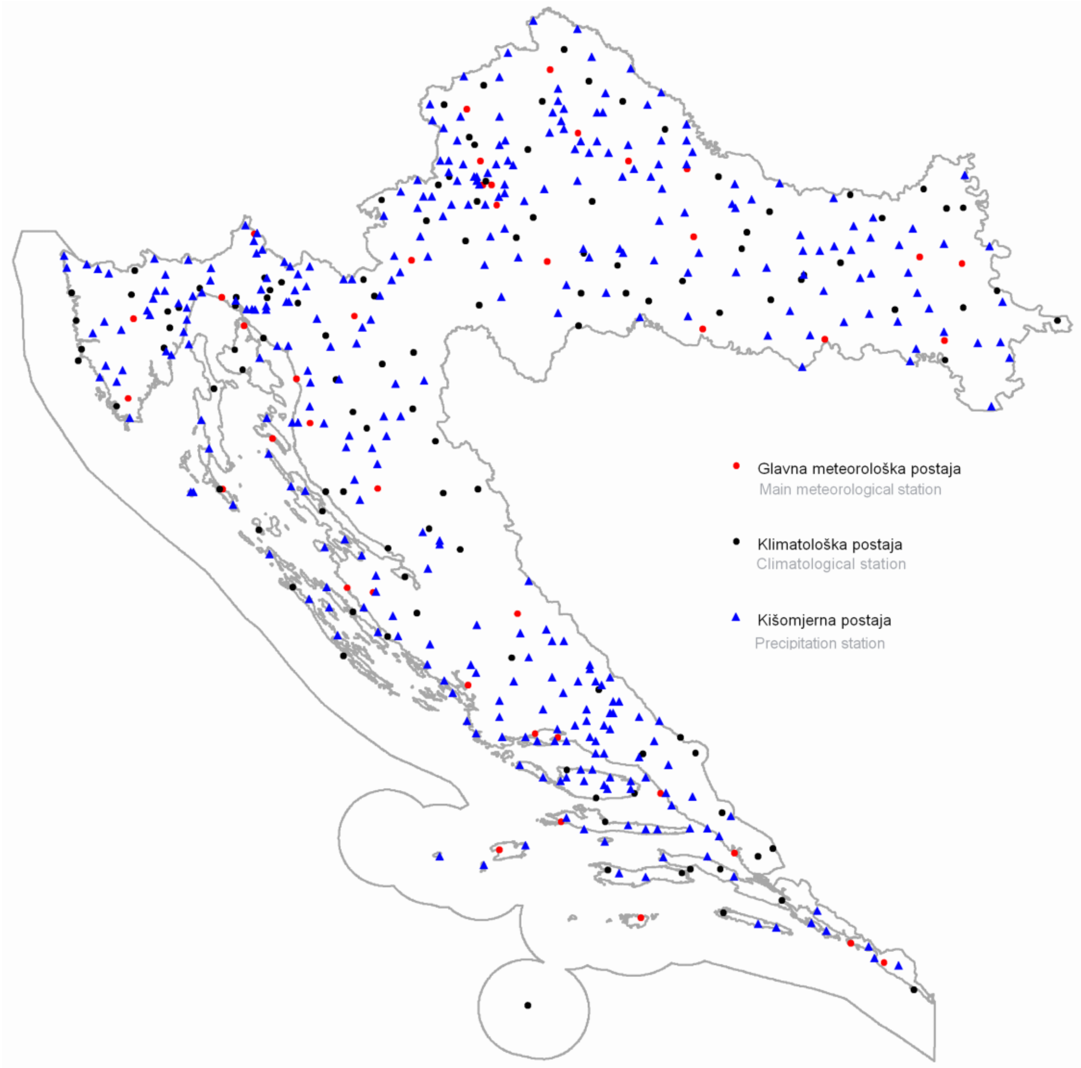
Pored navedenih institucija, različite institucije i sektori gospodarstva provode vlastita sustavna ili sporadična motrenja. Tablica 8.2.1-1 prikazuje sve postaje u Hrvatskoj za motrenje segmenata klimatskog sustava.

Tablica 8.2.1-1 Tipovi i broj postaja za motrenje klimatskog sustava u Hrvatskoj

Tip postaje	**Broj postaja**
Glavne meteorološke postaje	41
Klimatološke postaje	117
Oborinske postaje	366
Automatske meteorološke postaje	58
Radiosondažne postaje	2
Radarske postaje	8
Postaje za mjerenje sastava atmosfere	50
Postaje za mjerenje razine mora	10
Postaje za mjerenje temperature mora	20
Hidrološke postaje	300
Postaje za mjerenje temperature tla	30
Fenološke postaje	30

8.2.2. - Modernizacija meteorološke motriteljske mreže DHMZ-a

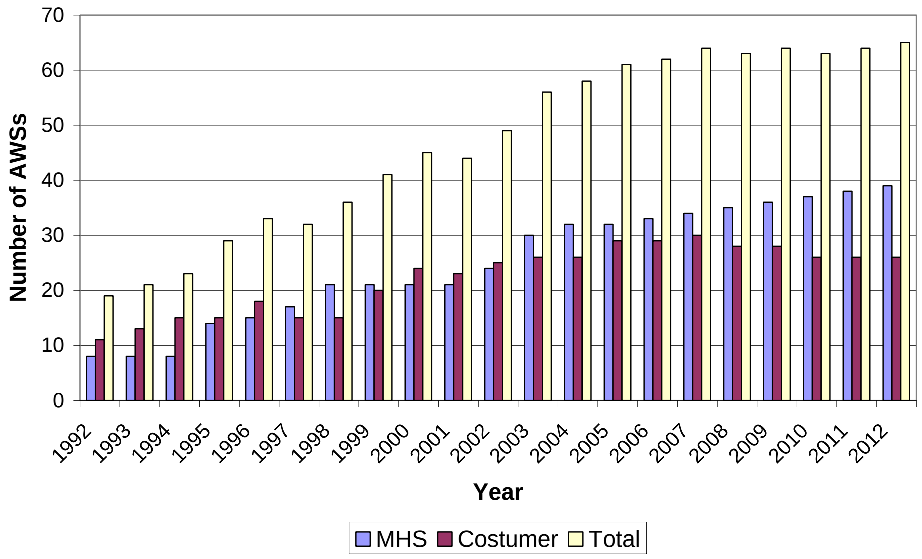
Meteorološka motrenja se bave s dvije vrste podataka: vizualnih opažanja vremenskih pojava i instrumentalnih mjerenja. Sporadična motrenja u Hrvatskoj započela su početkom 19. stoljeća. U DHMZ-u se provode uglavnom manualna motrenja koja obavljaju motritelji na: 41 glavne, 117 klimatoloških, 336 kišomjernih postaja i 23 totalizatora (Slika 8.2.2-1). Djelomično automatizirane postaje (Automated Weather Stations – AWS) kolociraju s 32 glavne meteorološke postaje dok je ostalih 26 instalirano na drugim mjestima. Prostorna razdioba AWS je predstavljena na slici 8.2.2-2a, a vremenski razvoj AWS-a je prikazan na Slici 8.2.2-2b. Sandardna vremenska rezolucija AWS-a je 10 minuta s istom rezolucijom dostave podataka. Mjerenja stanja tla (temperature i vlažnosti tla) te Sunčeva dozračenja i isparavanja obavljaju se na 19 glavnih meteoroloških postaja DHMZ-a, radisondaže se obavljaju u Zagrebu i Zadru, raspoloživi su 2 Dooplerova S-band +6 small S-band meteoroloških radara i jedan sodar.



Slika 8.2.2-1. Razdioba konvencionalnih meteoroloških postaja u Hrvatskoj

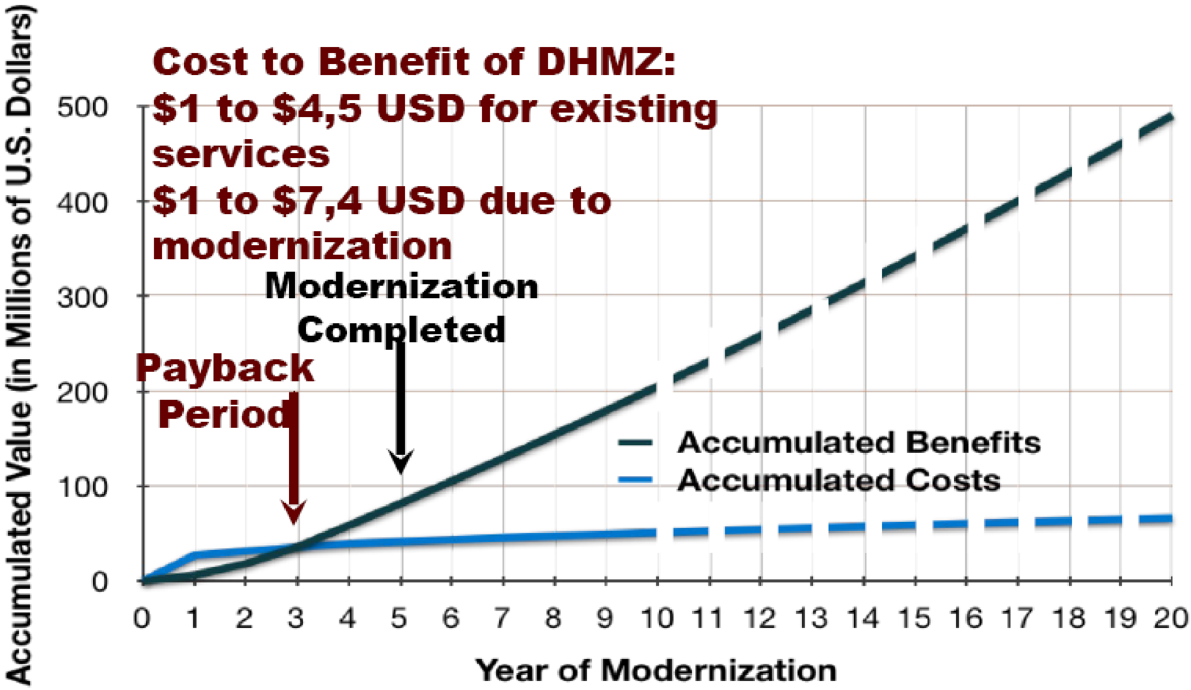
a)

b)



Slika 8.2.2-2 a) Razdioba AWS u Hrvatskoj i b) razvoj AWS mreže u Hrvatskoj

Cost-benefit analiza, koju je provelo Svučilište u Oklahomi, pokazuje da je daljnji razvoj meteorološke motriteljske mreže jekonomski opravdan, to jest investiranje 1 USD rezultira 7 USD dobiti za društvo (Slika 8.2.2-3).

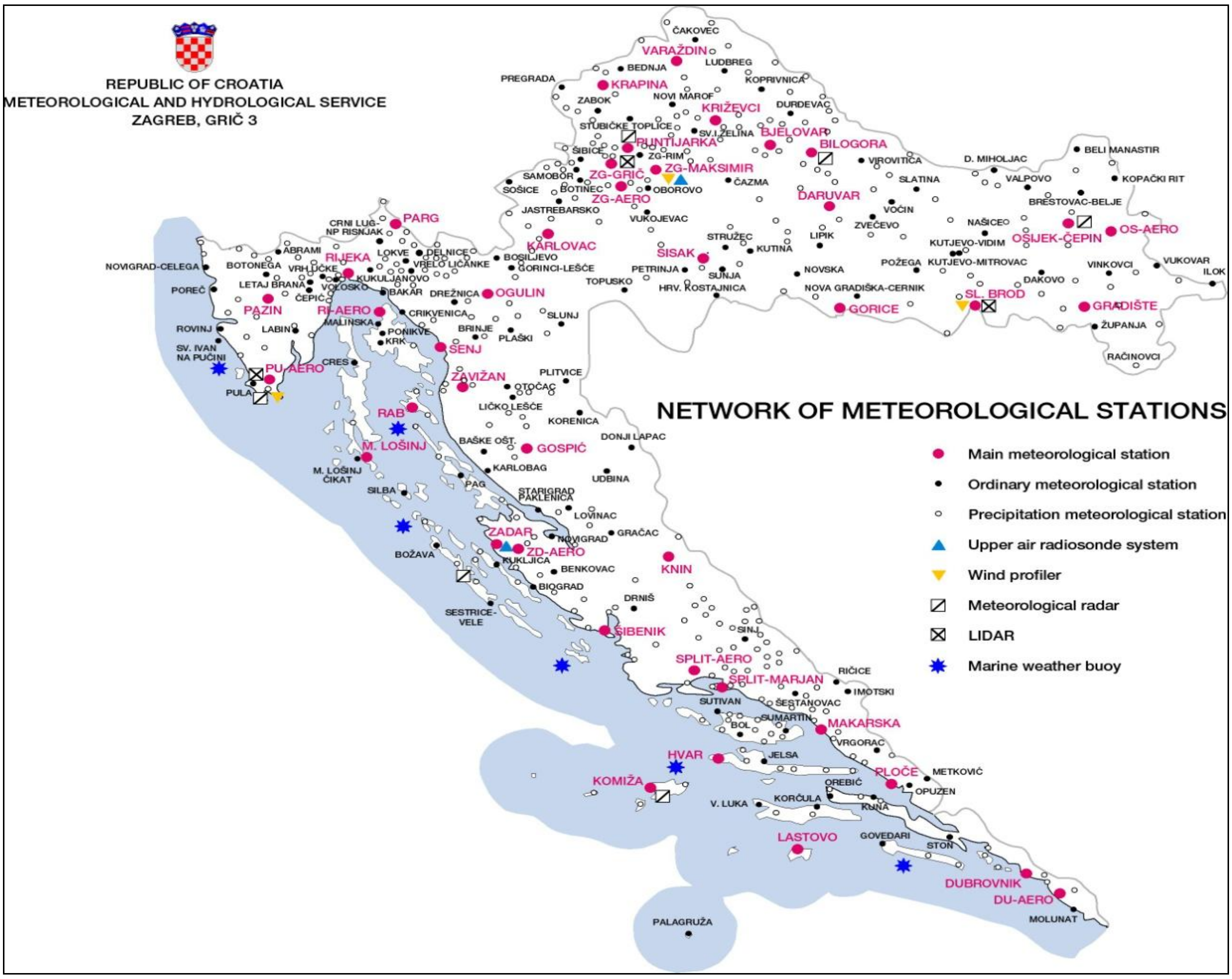


Slika 8.2.2-3 Cost-benefit analiza Sveučilišta u Oklahomi

Usprkos respektabilnom broju meteoroloških postaja i podataka koji se prikupljaju postoji potreba za temeljitom modernizacijom postojeće motriteljske mreže što uključuje modernizaciju postojećih i instalaciju novih postaja: 36 glavnih, 116 klimatoloških, 320 oborinskih, 5 postaja na moru, 2 radiosondažne postaje, 3 wind-profilera, 3 lidara i 6 meteoroloških radara (Slika 8.2.2-4).

Podaci dobiveni od, na navedeni način, modernizirane mreže meteoroloških postaja (prizemnih i visinskih) služit će za mnoge svrhe: monitoring i procjenu daljinskog prekograničnog zagađenja, analizu i primjenu tehnika modeliranja geografske distribucije koncentracija (emisije) zagađivača osiguravajući tako potrebne informacije za suzbijanje rizika od opasnosti za zdravlje ljudi zbog izloženosti zagađenju, posebno za osjetljive skupine; za praćenje klime i kalibraciju modela za klimatske promjene i adekvatno planiranje i upravljanje okolišem i za održive aktivnosti sektora gospodarstva; pribavljajući detaljnija mjerenja s ciljem boljeg razumijevanja utjecaja zagađivača na okoliš; razvoj odgovarajuće politike za prilagodbu i ublažavanje klimatskih promjena uključujući smanjenje rizika od elementarnih nepogoda (na primjer poplava ili suša) kao i civilizacijskih katastrofa; za svrhu proizvodnje obnovljive energije itd.

Realizacija modernizacije je izgledna s obzirom da je projekt *Modernizacije meteorološke i hidrološke motriteljske mreže* predviđen kao jedan od prioritetnih projekata Ministarstva zaštite okoliša i prirode u tematskom cilju adaptacije na klimatske promjene Europske Unije u financijskom razdoblju 2014-2020. godina iz kojeg se očekuje sufinaciranje projekta.



Slika 8.2.2-4. Očekivana modernizirana meteorološka motriteljska mreža u Hrvatskoj uz očekivano sufinaciranje iz fonda Europske unije za financijsko razdoblje 2014-2020.

7. - CLIMATE CHANGE IMPACTS AND ADAPTATION MEASURES

7.1. - Global climate change

The Earth's climate fluctuates over seasons, decades and centures in responnse to both natural and human variables. Natural climate variability on different timescales is caused by cycles and trends in the Earth's orbit (Milanković, 2002), incoming solar radiation, the atmosphere's chemical composition, ocean circulation, the biosphere, cryosphere and much more (WMO, 2013).

7.1.1. - The warmest decade

A study of World Meteorological Organization (WMO, 2013) indicates that a pronounced increase in the global air temperature occurred over the four decades i.e. during period 1971-2010 (Figure 7.1.1-1 and 7.1.1-2). The global temperature increased at an average estimated rate of 0.17°C per decade during that period while during the whole period 1880-2010 was only 0.062 °C per decade. Furthermore, the increase of 0.21°C in average decadal temperature from 1991-2000 to 2001-2010 is larger than the increase from 1981-1990 to 1991-2000 (0.14°C) and larger than between any other two successive decades since the beginning of instrumental records. Nine of the decade's years were among the 10 warmest on record. The warmest year ever recorded was 2010.

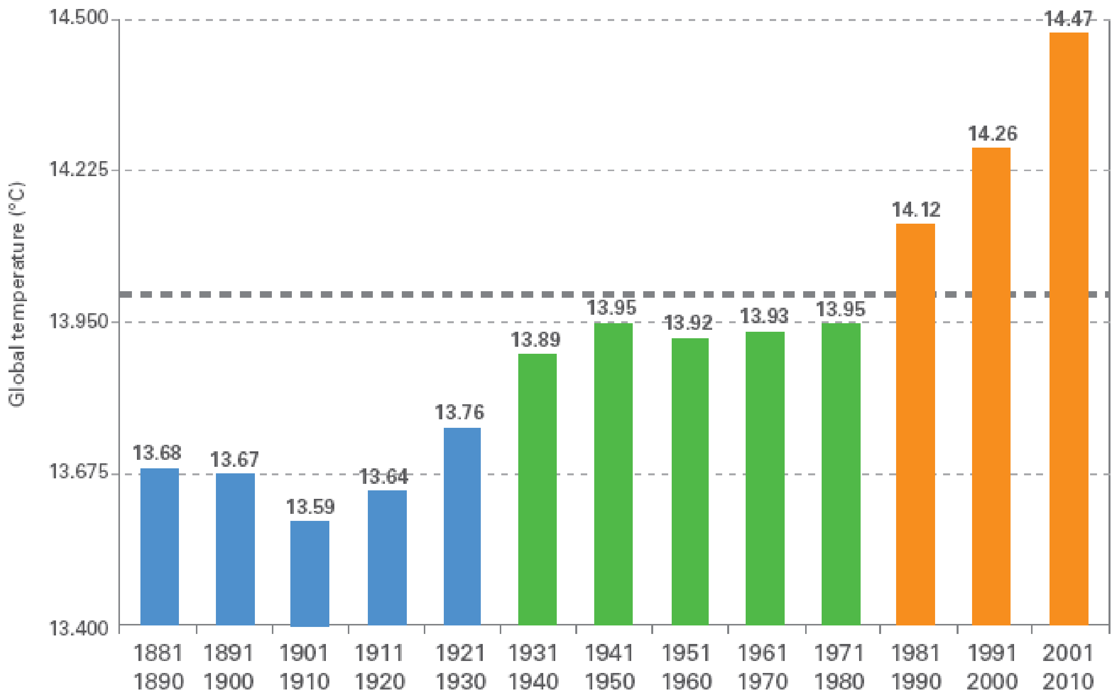


Figure 7.1.1-1 Decadal global combined surface air temperature over land and sea-surface temperature (°C). The horizontal grey line indicates the long-term average value for the period 1961-1990 (14°C). (WMO, 2013)

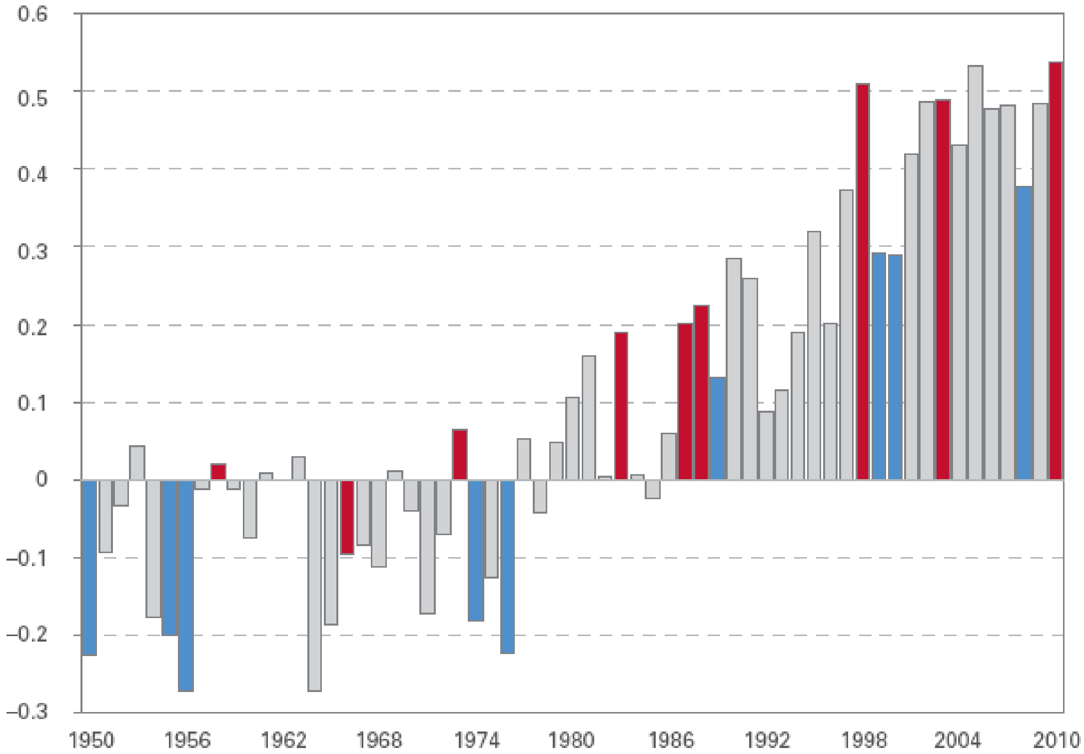


Figure 7.1.1-2 Annual global surface temperature anomalies (°C) for the period 1950-2010 with reference to the 1961-1990 base period, indicating the years with La Nina events (blue) and those with El Nino events (red). (WMO, 2013)

7.1.2. - "Hot" and "cold" extremes

While the average annual air temperature is an important climate indicator, the temperatures that people experience can differ greatly from day to day and over the course of a year because of natural climate variability. At the same time, human influence has probably increased the maximum temperatures of the most extreme hot nights and days and the minimum temperatures of cold nights and cold days. It is also more likely than not that human-induced climate change has increased the risk of heatwaves (WMO, 2013).

According to the WMO survey, a total of 56 countries (44 per cent) reported their highest absolute daily maximum temperature record over the period 1961–2010 being observed in 2001–2010 compared to 24 per cent in 1991–2000, with the remaining 32 per cent spread over the earlier three decades. Conversely, 11 per cent (14 out of 127) of the countries reported their absolute daily minimum temperature record being observed in 2001–2010, compared to 32 per cent in 1961–1970 and around 20 per cent in each of the intermediate decades (Figure 7.1.2-1).

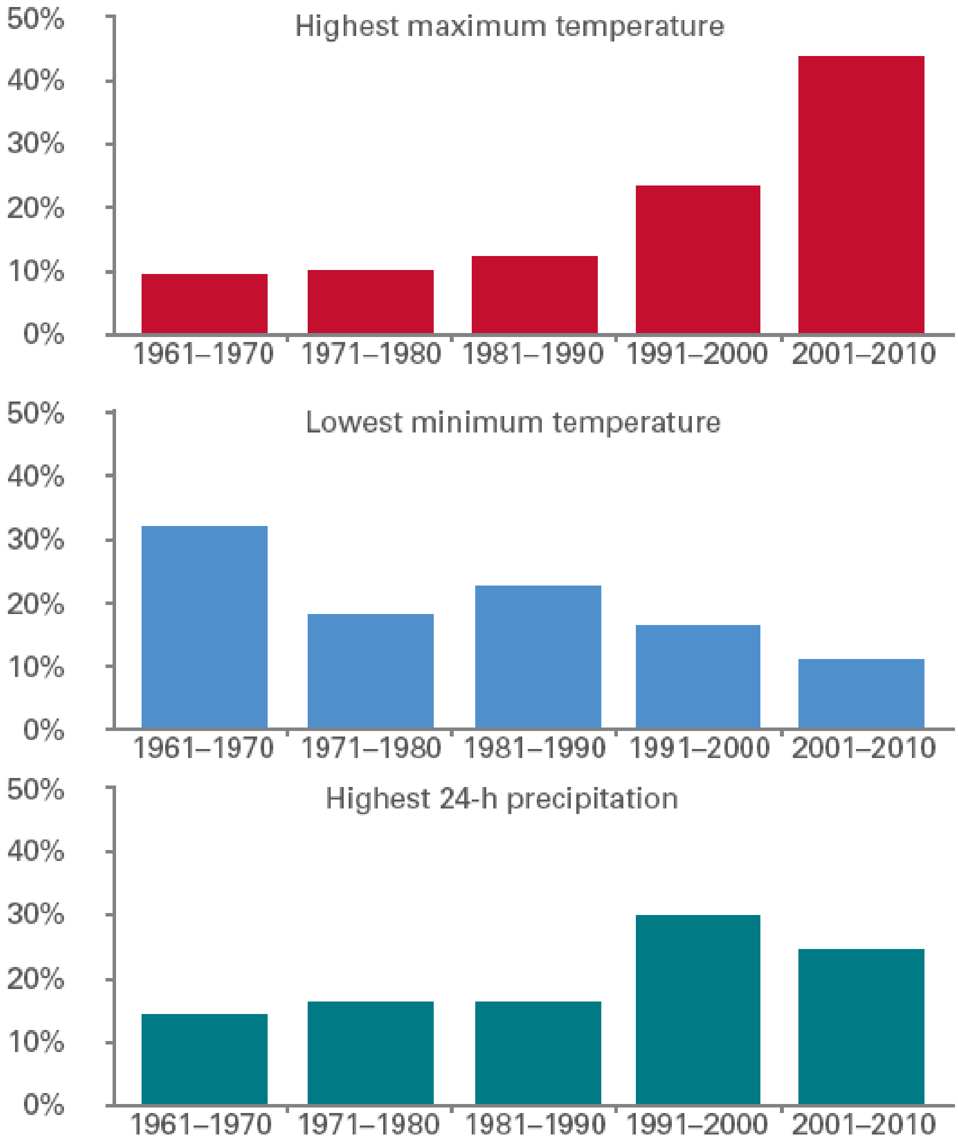


Figure 7.1.2-1 Absolute country records of the daily maximum and minimum air temperature and 24-hour precipitation in the last five decades (WMO, 2013)

7.1.3. - Ice cover on Arctic

Arctic sea-ice extent was well below multiannual average for the period 1979-2000 in 5 years during period 2001-2011 (Figure 7.1.3-1). After tracking at record or near-record low levels for the time of year through the first half of 2011, the seasonal minimum extent, reached on 9 September, was 4.33 million km^2, 35 per cent below the 1979–2000 average, according to the United States National Snow and Ice Data Center. This was the second-lowest seasonal minimum on record, 0.16 million km^2 above the record low set in 2007. Unlike the 2007 season, both the North-West and North-East Passages were ice-free for periods during the 2011 summer. Sea-ice volume was even further below average and was estimated at a new record low of 4 200 km^3, surpassing the record of 4 580 km^3 set in 2010 (WMO, 2012).

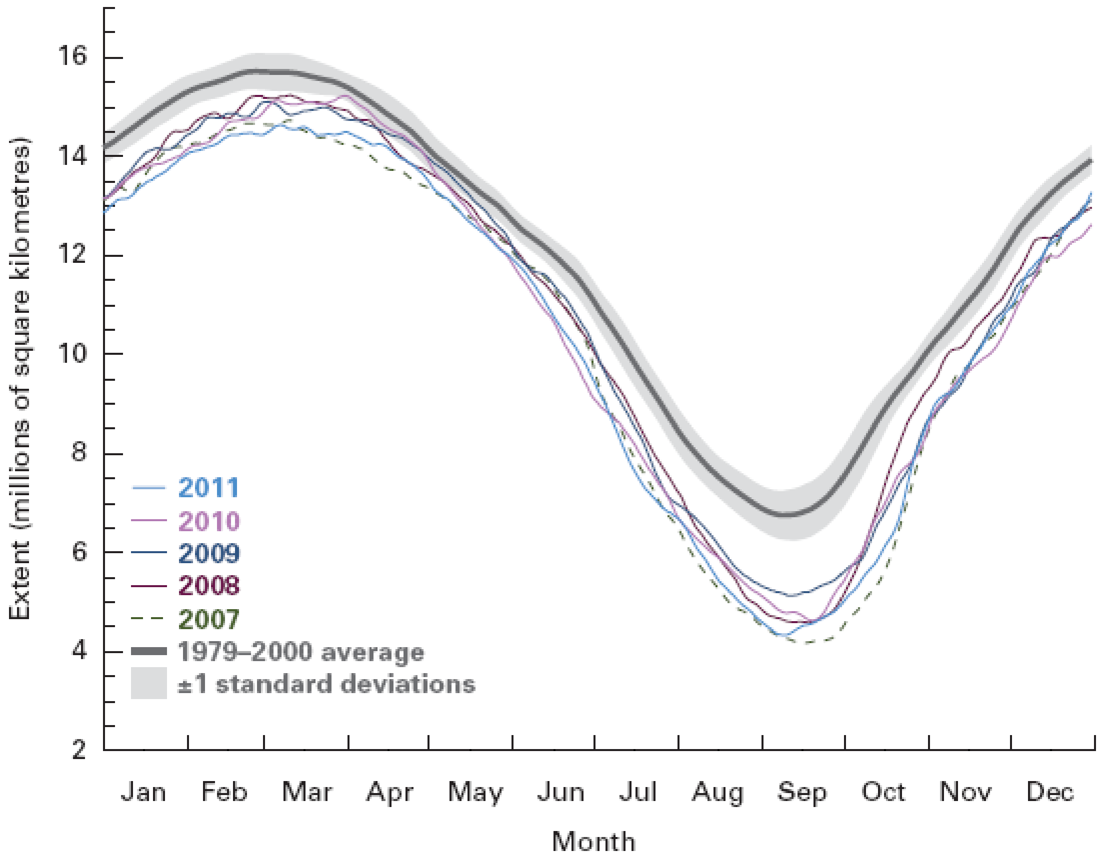


Figure 7.1.3-1 Northern hemisphere sea-ice extent in 2011, compared with previous years and the 1979–2000 average (WMO, 2012).

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7.2. - Observed Climate Change in Croatia

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. The analyses are based on data from 41 mean, minimum and maximum daily temperature series and 137 daily precipitation series. The indices of temperature and precipitation extremes are calculated according to the definitions given by ETCCDI (Expert Team on Climate Change Detection and Indices) (Peterson et al. 2001; WMO 2004), Commission for Climatology (WMO/CCL) and World Climate Research Programme, Climate Variability and Predictability (WCRP/CLIVAR). The non-parametric Mann-Kendall rank test (Gilbert, 1987) was applied to assess statistical significance of trends at the 95% confidence level. The field significance test is based on the Monte Carlo simulation (Zhang et al. 2004).

7.2.1. - Air Temperature

Temperature trends were calculated for the temperature deviations from the associated 1961-1990 means, and expressed in °C 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**) show warming all over Croatia (Figure 7.2.1-1). 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 7.2.1-1) with the highest frequency of trends in the class of 0.3-0.4 °C per decade, while trends in the mean and the mean minimum air temperatures mostly range between 0.2 and 0.3°C 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, though mainly insignificant.

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. 7.2.1-2).

All trends of indices of warm temperature extremes are statistically significant which is confirmed with the field significance trend (Figure 7.2.1-2 left). The most prominent increases are found in the number of warm days (**Tx90**) and warm nights (**Tn90**), and slightly lower trends are found in summer days (**SU**, absolute thresholds) and warm spell duration (**WSDI**). At most stations, the increase of the number of SU ranges between 2 and 8 days per decade (Table 7.2.1-2). 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.

Warming is also evident in the observed negative trend in the indices of cold temperature extremes, but they are less expressed than the trends of warm indices (Figure 7.2.1-2 right). 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, while the trends in the number of cold days (**FD**, absolute thresholds) are smaller and are mostly reduced for up to 2 days per decade (Table 7.2.1-2)..The smallest changes are observed in the cold spell duration index (**CSDI**) which show a decrease by 2 days per decade at the majority of stations (more than 90% of stations). Nevertheless, the trend is not statistically significant.

Table 7.2.1-1. List of the indices of temperaturne extremes and their definition. The abbreviations and definitions are according to standardisation of WMO-CCL/CLIVAR working group for climate change.

Indices of cold temperature extremes		
FD	Frost days (absolute threshold	Number of days with minimum temperature below 0°C
TN10%	Cold nights (percentile threshold)	Number of days with minimum temperature (TN) below the 10th percentile from the 1961-1990 baseline period.
TX10%	Cold days (percentile threshold)	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 threshold)	Number of days with minimum temperature (TN) above the 90th percentile from the 1961-1990 baseline period
TX90%	Warm days (percentile threshold)	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 threshod)	Number of days with maximum temperature ³25°C

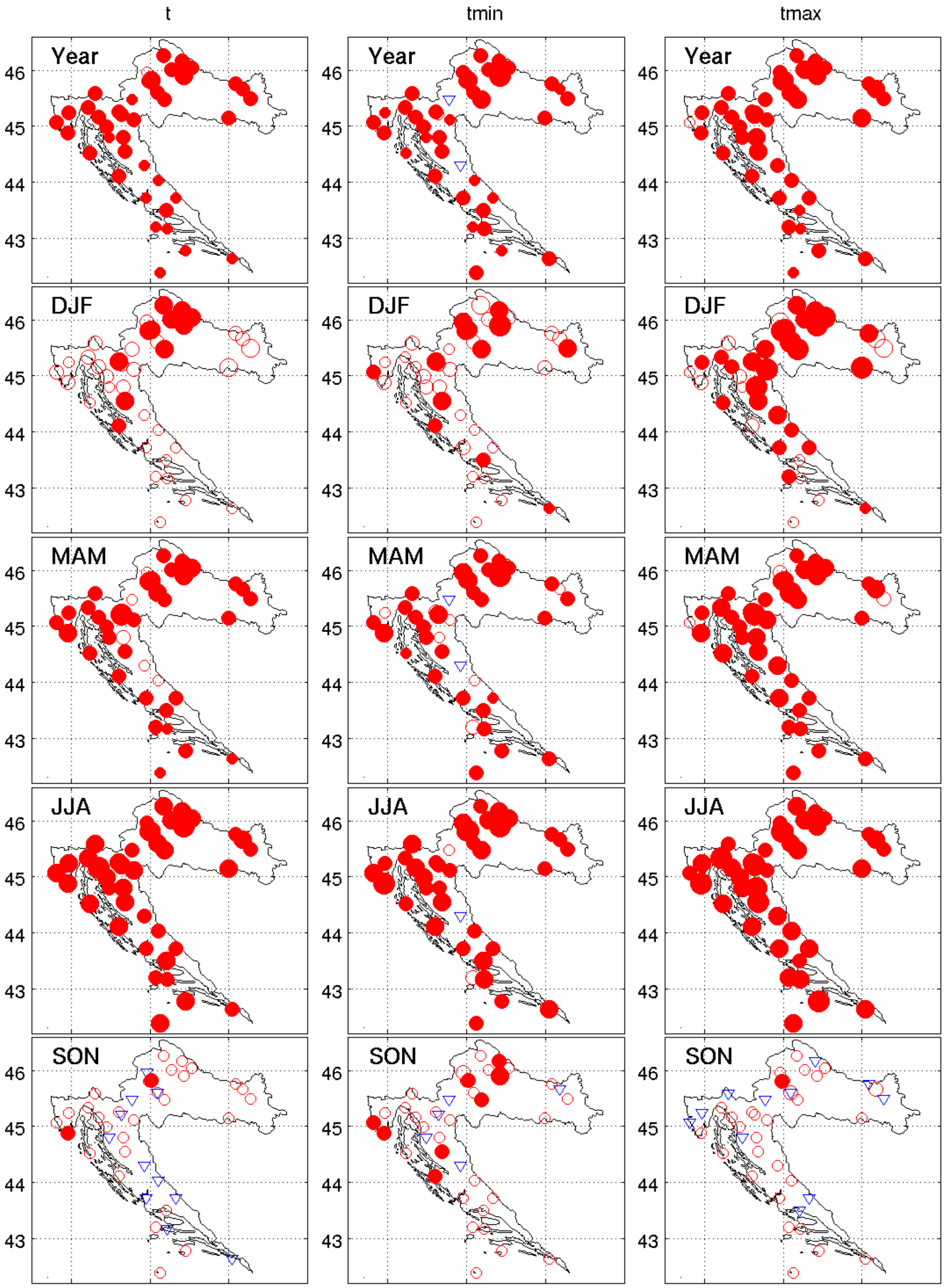

Figure 7.2.1-1. Decadal trends (°C/10yrs) in annual and seasonal (DJF-winter, MAM-spring, JJA-summer, SON-autumn) mean (t), mean minimum (tmin) and mean maximum temperature (tmax) values in the 1961-2010 period. Circles denote positive trends, triangles the negative one, whereas filling means statistically significant trend. Four sizes of symbols are proportional to the absolute value of change (in °C) 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.

Table 7.2.1-2. Relative frequency of trend values (number of days in 10 years) in warm (SU, Tx90, Tx10, WSDI) and cold (FD, Tx10, Tn10, CSDI) temperature indices at 41 meteorological stations in Croatia.

Trend	**SU**	**Tx90**	**Tn90**	**WSDI**	**FD**	**Tx10**	**Tn10**	**CSDI**
≤-6.0	0.0	0.0	0.0	0.0	2.4	0.0	2.4	0.0
-5.9--4.0	0.0	0.0	0.0	0.0	7.3	7.3	17.1	0.0
-3.9--2.0	0.0	0.0	0.0	0.0	36.6	**63.4**	**39.0**	2.4
-1.9-0.0	0.0	0.0	0.0	0.0	**43.9**	29.3	31.7	**92.7**
0.1-2.0	4.9	0.0	2.4	0.0	7.3	0.0	7.3	4.9
2.1-4.0	29.3	0.0	2.4	29.3	2.4	0.0	2.4	0.0
4.1-6.0	**36.6**	2.4	12.2	**46.3**	0.0	0.0	0.0	0.0
6.1-8.0	29.3	**29.3**	12.2	14.6	0.0	0.0	0.0	0.0
8.1-10.0	0.0	26.8	22.0	9.8	0.0	0.0	0.0	0.0
10.1-12.0	0.0	17.1	**24.4**	0.0	0.0	0.0	0.0	0.0
12.1-14.0	0.0	19.5	14.6	0.0	0.0	0.0	0.0	0.0
14.1-16.0	0.0	4.9	4.9	0.0	0.0	0.0	0.0	0.0
16.1-18.0	0.0	0.0	2.4	0.0	0.0	0.0	0.0	0.0
18.1-20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
>20.0	0.0	0.0	2.4	0.0	0.0	0.0	0.0	0.0

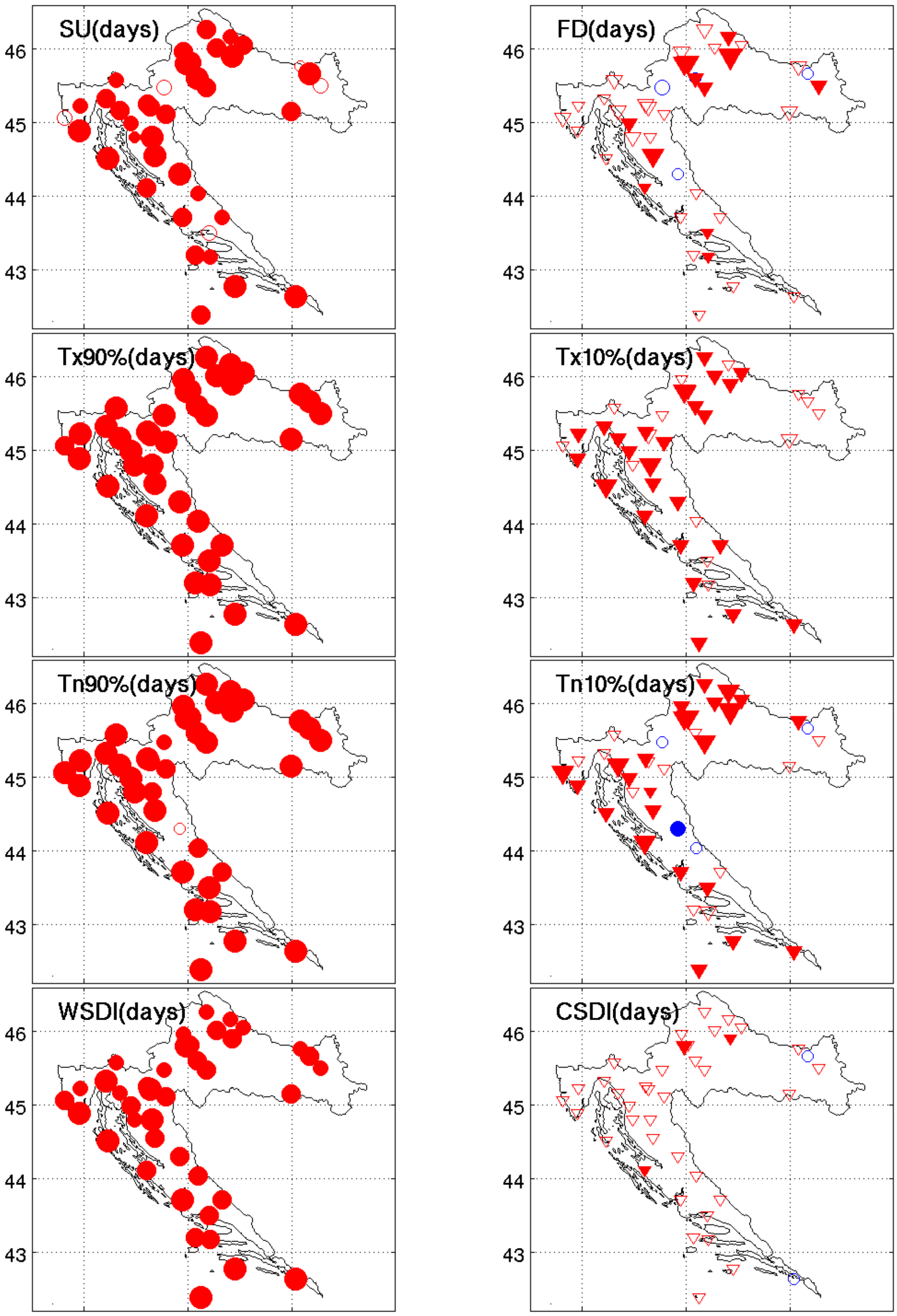

Figure 7.2.1-2 Decadal trends (days/10yrs) in annual extreme temperature indices in the 1961-2010 period. Circles denote positive trends, triangles the negative one, whereas filling means statistically significant trend. Four sizes of symbols are proportional to the absolute value of change (in days) per decade relative to the respective average from the period 1961-1990: <2, 2-4, 4-6 and >6, respectively

7.2.2. - Precipitation

Trends in **annual and seasonal precipitation amounts** give a general overview of the temporal change in precipitation over the country. 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. 7.2.2-1. (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 (*R-JJA*), 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. 7.2.2-1. (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. 7.2.2-1. (c)). Positive (circles) annual trends in eastern lowland are primarily caused by the significant increasing trends in autumn (Fig. 7.2.2-1.(d)) and to a less extent in spring and summer. The geographical distribution of trends for seasons also shows interesting features. 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. 7.2.2-1. (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. The trends of mixed signs are found in the rest of the country.

Regional distribution of trends in **precipitation indices**, that define magnitude and frequency of precipitation extremes, shows complex structure, as it is also found for some Mediterranean regions.

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. 7.2.2-1. (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.

Table 7.2.2-1. List of the precipitation indices and their definitions.

Nr.	Indices	Unit	Definition
1	DD	days	Dry days (absolute extreme) *(Number of days with daily precipitation amount R_d<1.0 mm)*
2	SDII	mm/day	Simple daily intensity index (absolute extreme) *(annual precipitation amount / annual number of wet days (R_d≥1.0 mm)*
3	R75	days	Moderate wet days (percentile threshold) *(Number of days with precipitation $R_d>R_{75\%}$, where $R_{75\%}$ 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*
4	R95	days	Very wet days (percentile threshold) *(Number of days with precipitation $R_d>R_{95\%}$, where $R_{95\%}$ 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*
5	R25T	%	Precipitation fraction due to days with $R_d<R_{25\%}$ (percentile threshold) *(Fraction of annual total precipitation $\sum R_d/R_t$, where $\sum R_d$ indicates the sum of daily precipitation less than the 25th percentile of precipitation at days with $R_{25\%}$ in the 1961-1990 baseline period. a R_t is the total annual precipitation amount.*
6	R25-75T	%	Precipitation fraction due to days with $R_{25\%}\leq R_d\leq R_{75\%}$ (percentile threshold) *(Fraction of annual total precipitation $\sum R_d/R_t$, where $\sum R_d$ indicates the sum of daily precipitation equal to or exceeding the 25th percentile of precipitation at days with $R_{25\%}$ and equal to or less than the 75th percentile of precipitation at days with $R_{75\%}$ in the 1961-1990 baseline period. R_t is the total annual precipitation amount.*
7	R75-95T	%	Precipitation fraction due to days with $R_{75\%}<R_d\leq R_{95\%}$ (percentile threshold) *(Fraction of annual total precipitation $\sum R_d/R_t$, where $\sum R_d$ indicates the sum of daily precipitation exceeding the 75th percentile of precipitation at days with $R_{75\%}$ and equal to or less than the 95th percentile of precipitation at days with $R_{95\%}$ in the 1961-1990 baseline period. R_t is the total annual precipitation amount.*
8	R95T	%	Precipitation fraction due to very wet days (percentile threshold) *(Fraction of annual total precipitation $\sum R_d/R_t$, where $\sum R_d$ indicates the sum of daily precipitation exceeding the 95th percentile of precipitation at very wet days $R_{95\%}$ in the 1961-1990 baseline period*
9	Rx1d	mm	Highest 1-day precipitation amount (absolute extreme) *(Maximum precipitation sums for 1-day intervals)*
10	Rx5d	mm	Highest 5-day precipitation amount (absolute extreme) *(Maximum precipitation sums for 5-day intervals)*

Trends in the intensity of precipitation for wet days (Fig. 7.2.2-1. (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. 7.2.2-1. (i)), the same change in frequency of R_d (in these cases significant decrease, see Fig. 7.2.2-1. (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.

Fraction of annual total precipitation due to different classes of daily precipitation was analysed over the full-scale of daily precipitation categories. Four classes with percentile thresholds define the following indices: ***R95T*, *R75-95T*, *R25-75T*** and ***R25T*** (Table 7.2.2-1.). The trend patterns of these indices are presented in Fig. 7.2.2-1. (j-m). Two opposite categories, that of very high precipitation extremes (R95T) and that of light precipitation extremes (R25T), show prevailing weak trends that are quite mixed in sign over the country. Only some locations seem to be affected by significant trends. Significant positive trend in R25T is found in the western Croatia (including NW region, Gorski kotar and Istria) and along the southern Adriatic coast. In the eastern lowland of Croatia a positive trend in annual precipitation amount is associated with a significant positive trend in R95T. Contribution to annual amounts of daily precipitation from the central part of the distribution (*R25-75T*) shows weak changes of mixed sign (-7% to 7%). The similar is true for trends in the fraction of annual precipitation due to moderate wet days (*R75-95T*). Though, there is a significant positive trend found at few stations in the mountainous regions, as well as at the northern and middle Adriatic, despite the reduction in frequency of such days. Over the southern coastal region the *R75-95T* shows negative trends that can be related to the negative tendency in *R75*.

The first information about temporal changes in annual extremes as defined by **maximum 1-day precipitation (*Rx1d*)** and multi-daily precipitation episode as defined by **maximum 5-day precipitation (*Rx5d*)** is presented by relative changes in their linear trends in Fig. 7-xx(n-o). Trend direction of both indices is generally in agreement along the respective regions. Trend is weak in magnitude and predominantly positive in the eastern lowland and along the coast; while it is mostly negative in NW area and in the mountainous regions (significant for *Rx1d*).

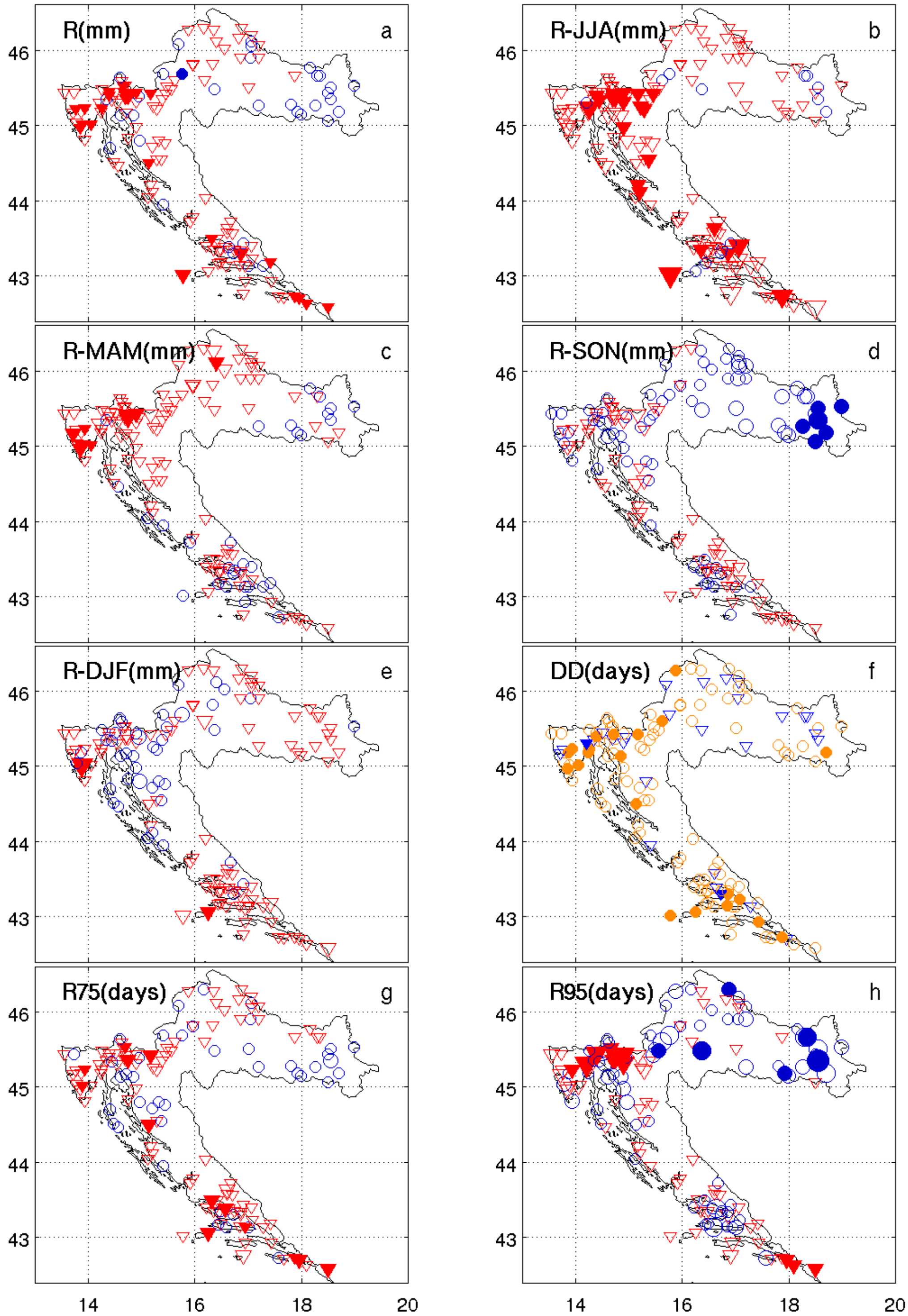

Figure 7.2.2-1. Decadal trends (%/10yrs) in seasonal and annual precipitation (R-MAM, R-JJA, R-SON. R-DJF, R) and precipitation indices (Rx1d, Rx5d, SDII, R75, R95, R25T, R25-50T, R50-75T, R75-95T, R95T and DD) in the 1961-2010 period. Circles denote positive trends, triangles the negative one, whereas 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.

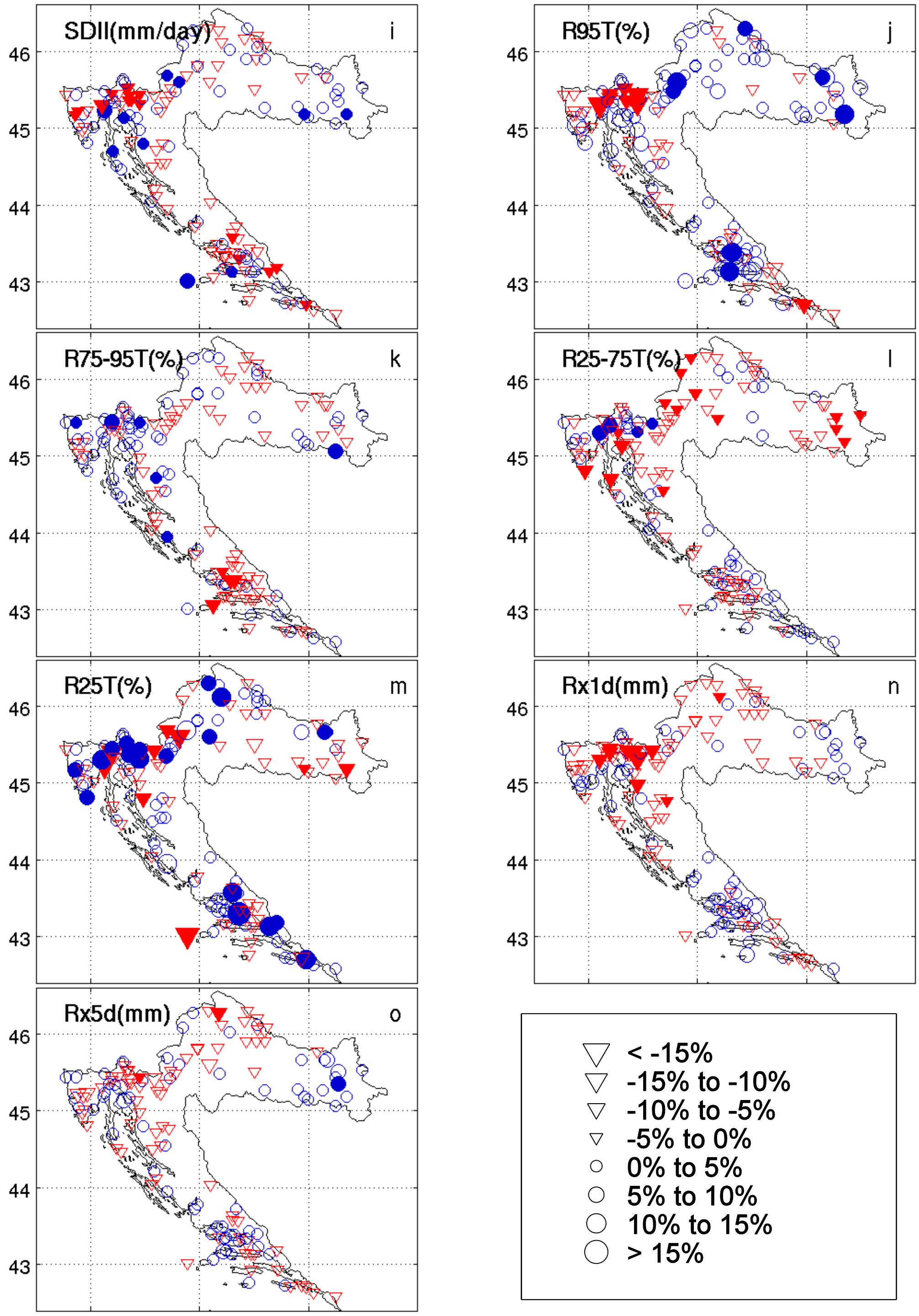

Figure 7.2.2-1. continue

7.2.3. - Dry and wet spells

In this section the annual and seasonal time trends in maximum lengths of dry and wet spells in Croatia are presented. They are defined as consecutive dry/wet days (CDD, CWD) having daily precipitation less/higher than the given threshold: 1 mm and 10 mm. These categories will be abbreviated in the rest of the text with CDD1, CDD10, CWD1 and CWD10 respectively for dry and wet spells. Daily data set comprises the 50-years time period 1961-2010. Spells beginning in one season but extending to the next one are accounted for in the season in which they started. The obtained trends are quantified as changes per decade, expressed as percentages of the associated 1961-1990 means (%/dec).

The most prominent feature of time trend is found for **dry spells** during autumn (SON) for which a spatially consistent statistically significant negative trend is found (Fig. 7.2.3-1). Decrease ranges from -14%/dec to -1%/dec of associated mean length in CDD1; and from -11% to 5% of CDD10.

For the rest of the seasons trends in dry spells of both categories are less consistent in magnitude and direction. Nevertheless, an increase in their lengths is particularly expressed in spring (MAM) at northern Adriatic and its hinterlands (from 7%/dec to 12%/dec); while in summer (JJA) this feature is extended to the southern Croatian coast reaching the increase up to 24% of the climatological mean value for the CDD1. There is also an evidence of increase in CDD1 duration in the eastern Slavonia (4%/dec to 7%/dec) during summer. Winter season (DJF) does not reveal significant changes in dry spell durations. The seasonal trend patterns of CDD1 result with a heterogeneous distribution of the associated annual trend. Though, annual maximum dry spell durations of CDD10 are prone to increase along Adriatic coast and highlands, and to decrease in the continental inland. It my be associated by the significant increase in very wet days (R95) that is found in the inland of Croatia thus breaking duration of dry spells (see chapter 7.2.2).

Regarding the **wet spell** durations there is not found a consistent spatial trend feature as for CDD (Fig. 7.2.3.-2). There is yet a tendency to CWD1 increase during summer (up to 8%/dec) and autumn (up to 6%/dec) in the eastern lowland and NW region. In the same seasons the CWD1 in northern Adriatic are prone to decrease (up to -12%/dec). In winter season the trend results are mainly mixed in signs and only in the Nw inland there is an evidence of the significant CWD1 increase (up to 15%/dec).

Trends in CWD10 show statistically significant positive trend in the eastern lowland during autumn (11%/dec). Together with the observed significant decrease in CDD10 these results reveal the overall tendencies to the wetter conditions in that region. During summer there is a negative tendeny of CWD10 duration along northern and middle Adriatic and the highlands (-8%/dec to -11%/dec), but positive on the southernmost region (up to 15%/dec). Generally, there is a high spatial heterogeneity found in trend signs of CWD10.

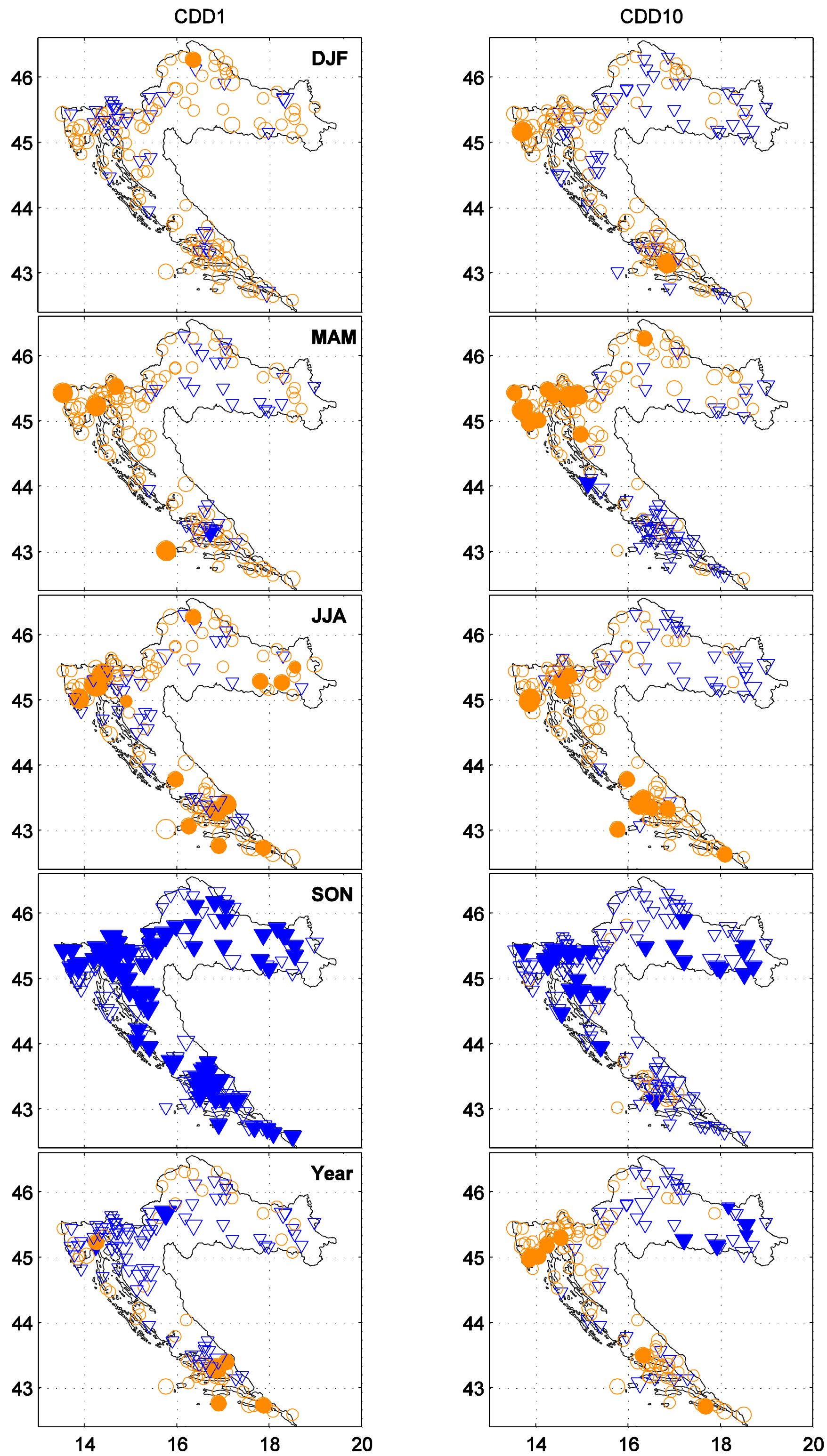

Figure 7.2.3-1. Trend results for maximum dry spell durations for 1 mm and 10 mm thresholds (CDD1, CDD10), for four seasons (upper four rows) and for whole year (bottom row). Circles denote positive trends, triangles the negative one, whereas solid symbols depict statistically significant trend. Blue colour indicates wetter conditions and orange drier. Three sizes of symbols are proportional to the absolute

value of change per decade relative to the associated 1961-1990 mean durations: 1-5%, 5-10% 10-30% and >30%, respectively.

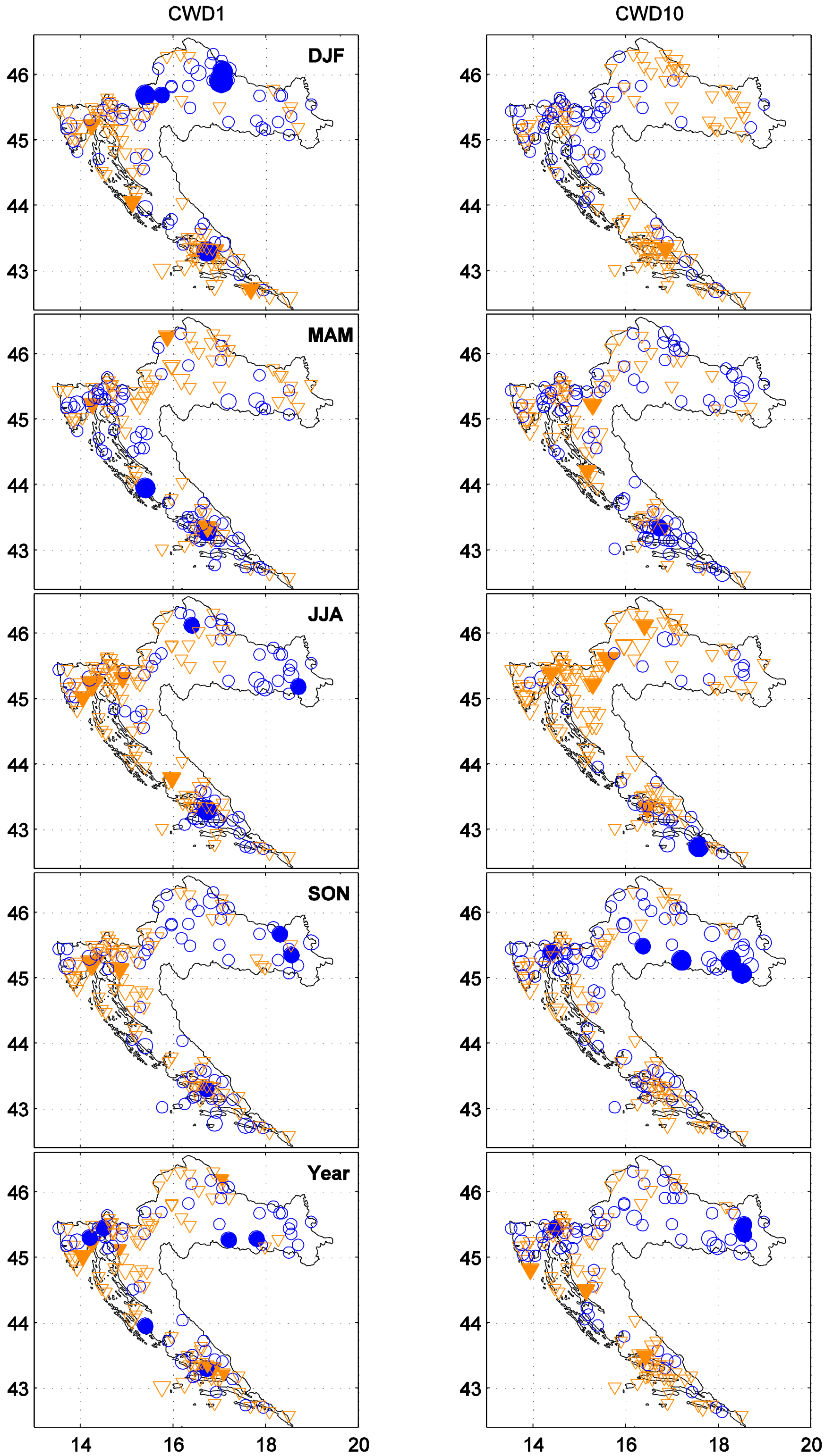

Figure 7.2.3-2. Trend results for maximum wet spell durations for 1 mm and 10 mm thresholds (CWD1, CWD10), for four seasons (upper four rows) and for whole year (bottom row). Circles denote positive trends, triangles the negative one, whereas solid symbols depict statistically significant trend. Blue colour indicates wetter conditions and orange drier. Three sizes of symbols are proportional to the absolute

value of change per decade relative to the associated 1961-1990 mean durations: 1-5%, 5-10% 10-30% and >30%, respectively.

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7.2.4. - Water balance components

Six water balance components can be considered: precipitation amount, potential and real evapotranspiration, loss from and recharge moisture into the soil, run-off and soil moisture amounts within a surface of one metre deep layer of the soil. As described in Pandžić et al. (2008), 10-day water balance components have been calculated according to modified Palmer's (1965) procedure, where modified Eagleman's (1967) procedure has been applied for calculation of 10-day potential evaporation. All water balance components are represented in the same units i.e. in millimetres (mm) what is a equivalent to a litre per square metre.

From the Figure 7.2.4-1 it is visible that there are increasing trends for annual potential evapotranspiration with patterns very similar to those of air. This can be explained by a strong relationship between air temperature and potential evapotranspiration. According to trend lines an increase of annual potential evapotranspiration up to 30% can be expected until middle of 21 century. It means, even in the case that precipitation amounts will stay at the same level as nowadays an increase of potential evapotranspiration can reduce other water balance components for a significant amount. Real evapotranspiration amount trends as well as trend of recharge into the soil are weaker than that for potential evapotranspiration. An extrapolation of the of potential evapotranspiration results for Zagreb-Grič on other meteorological stations, including those on coastal region, can be made thanks to a rather high correlation between time series of potential evapotranspiration for the wider territory of Croatia (Pandžić et al., 2008).

It is obvious from the Figure 7.2.4-2 that there is very strong negative trend for the run-off calculated by Palmer's procedure for Zagreb-Grič meteorological station. According to trend line estimation until the mid-21st century, run-off calculated by Palmer's procedure, will disappear. The results are alarming although “prognostic” power of the trend line is poor and we hope this will not happened. A high correlation exists between calculated run-off for Zagreb-Grič and those for other meteorological stations in the area what has been shown by Pandžić at al. (2008). Thus, somehow results for meteorological stations with shorter time series of run-off can be extrapolated in the past according to the results for Zagreb-Grič meteorological station. It was also shown that some areas in Croatia are more sensitive to global warming than other, which depends on the ratio between potential evapotranspiration and precipitation. In general, in the areas where the precipitation amount is much higher than potential evapotranspiration, an increase in potential evapotranspiration will not considerably affect other water balance components including run-off. More sensitive will be the areas where precipitation amounts are similar to those of potential evapotranspiration.

Annual distribution of precipitation amounts is also very important for other water balance components. As potential evapotranspiration is more sensitive on air temperature changes during warmer than colder part of a year, the areas with maximum precipitation amounts during warmer part of a year will be more sensitive on global warming than those with maximum precipitation during colder part of the year.

Soil moisture trend indicates a reduction of soil moisture in next half century (Figure 7.2.4-3). Regional sensitivity on soil moisture variability and trends depends also on soil type i.e. its field capacity which is in general in coastal region rather small on average.

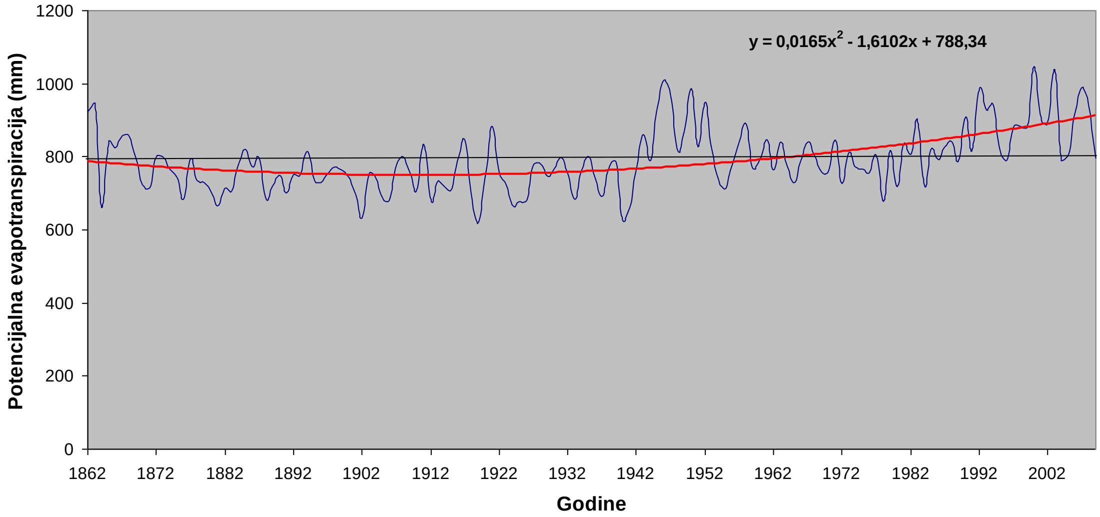

Figure 7.2.4-1. Annual potential evaporation (in millimetres) for Zagreb-Grič meteorological station for the period 1862-2008. Thin line represents an average for the period 1961-1990 (Pandžić and Trninić, 2010).

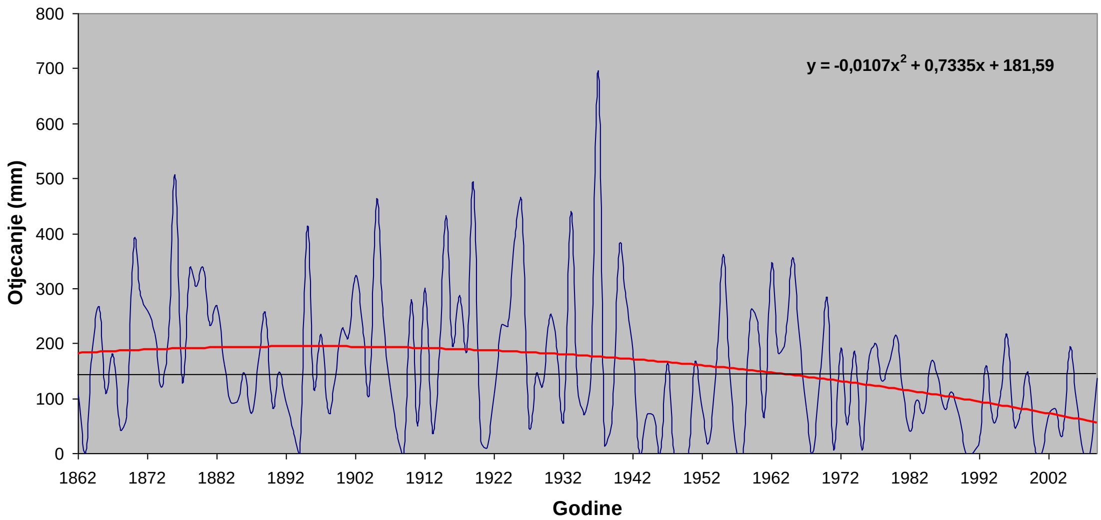

Figure 7.2.4-2. Calculated annual run-off (in millimetres) for Zagreb-Grič meteorological station for the period 1862-2008. Thin line represents an average for the period 1961-1990 (Pandžić and Trninić, 2010).

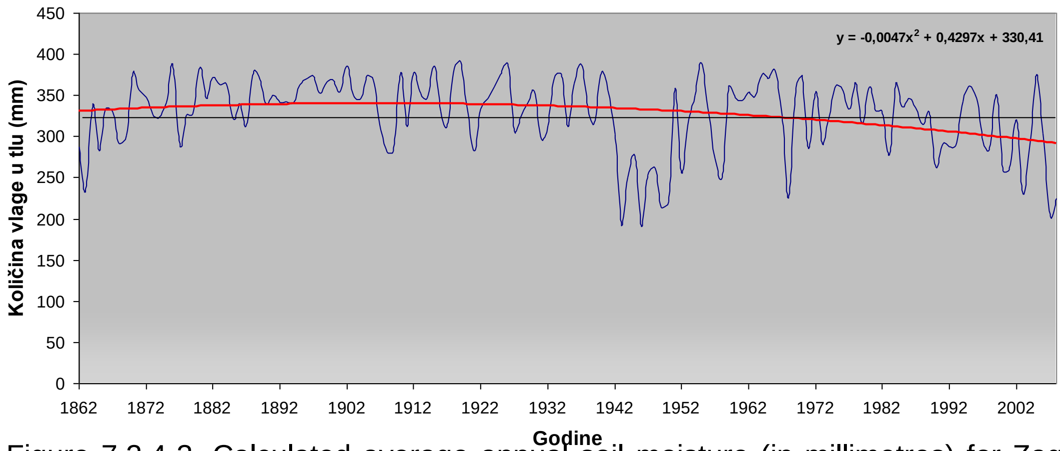

Figure 7.2.4-3. Calculated average annual soil moisture (in millimetres) for Zagreb-Grič meteorological station for the period 1862-2008. Thin line represents an average for the period 1961-1990 (Pandžić and Trninić, 2010).

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7.2.5 . - Decadal climate summary for Croatia

For WMO study in 2013 is used a data set of 11 meteorological stations (Osijek, Varaždin, Zagreb-Grič, Ogulin, Gospić, Knin, Rijeka, Zadar, Split-Marjan, Dubrovnik and Hvar). Distribution of meteorological stations is rather homogeneous over territory of Croatia. Five decadal periods are analyzed, beginning with the decade 1961-1970 until the last 2001-2010. Absolute daily maximum and minimum air temperatures and daily precipitation amounts have been considered. From the Table 7.2.5-1 is visible that Knin is the warmest town in Croatia and Gospic the coldest. Thus, in the period considered absolute minimum temperature of -28.9°C was observed in Gospić, while maximum air temperature of 41.4 °C was observed in Knin. It should be mentioned that at meteorological stations that are not considered here slightly higher maximum, above 42°C, and lower minimum, less than -30°C, have been observed. The lowest minimum temperature is registrated in decade 1961-1970 while the highest maximum temperature is registrated during decade 1991-2000. The highest daily precipitation of 352.2 mm has been observed in Zadar in 1986.

Spaceous decadal averages of air temeparture have been calculaed as arithmetic means of decadal air temeparatures for 11 meteorological. The results are shown in table 7.2.5-2. It is visible that the lowest average decadal spaceous air temperature is for decade 1971-1980 only for 0.1 lower than that for decade 1961-1970 when the air temperature was the same as 1961-1990 average. For the period 1981-1990 a slight increase of temperatue appeared, while during the next two decates an increase have been considerable, i.e. 0.6 °C and 1.0°C respectively, in respect to referent period 1961-1990, which is in accordance with globale decadal averages.

Table 7.2.5-3 shows the ranking of annual spatial averages for the period 2001-2010. The hottest year 2007 was for 1.5 ° C warmer than the mean of the standard period 1961-1990., the coldest year 2005 was 0.1 ° C colder. During the decade 2001-2010, spatial mean air temperature in nine years was higher than the corresponding referent averages

Table 7.2.5-1 Daily extremes per decade for Croatia for the period 1961-2010

Period	Parameter	value	date	Station name	Coordinates	
					Lat	Lon
1961-1970	Highest Maximum Temperature (°C)	38,6	11.7.1968.	Osijek	45° 28` 24``	18° 48` 23``
	Lowest Minimum Temperature (°C)	-28,9	15.1.1963.	Gospic	44° 33` 2``	15° 22` 23``
	Maximum 24-hr rainfall (mm)	189,2	15.9.1967.	Rijeka	45° 20` 13``	14° 26` 34``
1971-1980	Highest Maximum Temperature (°C)	38,4	5.8.1980.	Knin	44° 2` 27``	16° 12` 25``
	Lowest Minimum Temperature (°C)	-24,8	21.2.1978.	Osijek	45° 28` 24``	18° 48` 23``
	Maximum 24-hr rainfall (mm)	210,3	1.9.1976.	Rijeka	45° 20` 13``	14° 26` 34``
1981-1990	Highest Maximum Temperature (°C)	39,6	3.8.1981.	Knin	44° 2` 27``	16° 12` 25``
	Lowest Minimum Temperature (°C)	-27,3	12.1.1985.	Gospic	44° 33` 2``	15° 22` 23``
	Maximum 24-hr rainfall (mm)	352,2	11.9.1986.	Zadar	44° 7` 48``	15° 12` 21``
1991-2000	Highest Maximum Temperature (°C)	41.4	22.8.2000.	Knin	44° 2` 27``	16° 12` 25``
	Lowest Minimum Temperature (°C)	-26,4	26.1.2000.	Gospic	44° 33` 2``	15° 22` 23``
	Maximum 24-hr rainfall (mm)	200	19.10.1998.	Rijeka	45° 20` 13``	14° 26` 34``
2001-2010	Highest Maximum Temperature (°C)	40,9	19.7.2007.	Knin	44° 2` 27``	16° 12` 25``
	Lowest Minimum Temperature (°C)	-27,6	13.1.2003.	Gospic	44° 33` 2``	15° 22` 23``
	Maximum 24-hr rainfall (mm)	161,4	23.11.2010.	Dubrovnik	42°3 8` 41``	18° 5` 6``

Table 7.2.5-2 Decadal air temperature for Croatia for the period 1901-2010

DECADE	Mean Temperature (°C)	Anomaly with respect to 1961-1990 (°C)
1901-1910	NA	NA
1911-1920	NA	NA
1921-1930	NA	NA
1931-1940	NA	NA
1941-1950	NA	NA
1951-1960	NA	NA
1961-1970	12,7	0
1971-1980	12,6	-0,1
1981-1990	12,8	0,1
1991-2000	13,3	0,6
2001-2010	13,7	1,0

Table 7.2.5-3 Temperature ranking 2001-2010

RANKING 2001-2010	YEAR	Temperature (°C)	Anomaly (°C)
Warmest	2007	14,23	1,53
2	2008	14,2	1,5
3	2009	14,1	1,4
4	2002	14,0	1,3
5	2003	13,9	1,2
6	2001	13,7	1,0
7	2006	13,5	0,8
8	2004	13,23	0,53
9	2010	13,22	0,52
Coldest	2005	12,6	-0,1

7.3. - Climate change scenario

7.3.1. - Introduction

Local and regional climate and climate change can be analysed from the results of regional climate models (RCMs) with relatively high horizontal resolution, usually between 10 and 50 km. When compared with global climate models (GCMs) with a coarser horizontal resolution between 100 and 300 km, RCMs allow a detailed description of climate at small scales (like in case of Croatia) which largely depends on local topography, land and sea distribution and the distance from the sea. However, the description of climate and projected climate change by RCMs may not be necessarily better than with GCMs. The results of a RCM depend on the quality of the initial and lateral boundary conditions in the process known as *dynamical downscaling*, whereby a RCM is forced by a GCM or by reanalysis data. A detailed description of the downscaling methods is given in e.g. Giorgi and Mearns (1999) and Rummukainen (2010).

In this report, 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.

The DHMZ downscaling simulations with the RegCM model (model details are given in Pal et al. 2007) are made for the European region at a 35-km horizontal resolution. RegCM was forced every 6 hr by the lateral boundary conditions obtained from the ECHAM5/MPI-OM GCM (Roeckner et al. 2003).

The results from the ENSEMBLES project relate to different RCMs forced by different GCMs. Such a multi-model approach allows an analysis of sources of uncertainty in projections of the future climate (Hawkins and Sutton 2009, Déqué et al. 2012). In this report, the 18 combinations of various RCMs forced by various GCMs are analysed (Table 1). The description of the ENSEMBLES models and experiments are available from Christensen et al. (2010; their Table 1 and Fig. 1) in and from Déqué et al. (2012).

7.3.2. - Methodology

The climate changes for T2m and precipitation in the DHMZ RegCM downscaling simulations are analysed as the differences of seasonal means from the two periods: the period 1961-1990 represents the climate of the 20th century or the “present” climate (from now on in the text and in figures this period is denoted as P0) and the near future period 2011-2040 (denoted as P1). P0 represents a standard 30-year climatic period according to the World Meteorological Organisation standards (WMO 1988). The climate change is defined as a difference between the future and present climate. Both present and future climates are computed as ensemble means of the three different RegCM realisations that differ only in the ECHAM5/MPI-OM initial conditions. Despite having at our disposal three-member ensembles, the deficiency of this analysis is the use of the initial and boundary conditions from only one GCM.

In the ENSEMBLES downscaling simulations, the present climate is also defined for the period 1961-1990 (P0) in which the RCMs were forced by the GCMs that included the observed concentrations of the greenhouse gases (GHGs). For the future climate (in the 21st century) the RCMs results are split into three periods: 2011-2040 (P1; same as the DHMZ simulations), 2041-2070 (P2) and 2071-2099 (P3). The climate change in the three future periods is computed as the differences between the 30-year means: P1-P0, P2-P0 and P3-P0. We discuss the differences of the ensemble means – in each period, the climatological fields are first averaged across the ensemble of all models and then the averages from the two different periods are subtracted. Since in the periods P2 and P3 fewer model simulations were available than for P1, the corresponding P0 contains only those models that are present in P2 and P3. Additionally, the consistency among models in every grid point on the common grid (approximately 25 km) is ascertained if the same sign of climate change as in the difference between the ensemble means is simulated by the two thirds of all the models considered (e.g. IPCC 2007). When discussing the results for the Croatian coast we refer in addition to the results of Branković et al. (2013) where the subset of the ENSEMBLES simulations was analysed (five RCMs forced by the ECHAM5/MPI-OM GCM; Roeckner et al. 2003). Statistical significance of the climate change in Branković et al. (2013) study was determined using the Wilcoxon-Mann-Whitney nonparametric test (Wilks 2006).

For both the DHMZ and ENSEMBLES models, the results for four climatological seasons are presented and discussed: winter (December-February; DJF), spring (March-May; MAM), summer (June-August; JJA) and autumn (September-November; SON).

7.3.3. - Results

7.3.3.1 - Temperature at 2 m (T2m)

(a) The DHMZ RegCM simulations

The mean seasonal near-surface temperature (T2m) over Europe is projected to increase in the period 2011-2040 (P1) in the range between 0.2°C and 2°C (Fig. 7.3.1-1). This increase will not, however, be uniform in all seasons. The smallest increase, between 0.2 – 0.4°C, is expected in spring (Fig. 7.3.1-1b) over a large part of central Europe with a little larger warming over the Iberian Peninsula (up to 0.6°C) and at the eastern border of the integration domain (up to 0.8°C). A relatively uniform increase of

T2m of around 0.4°C is expected in winter over a large part of the integration domain, but over northeastern Europe and northwestern part of Africa the temperature increase is projected to be up to 1°C (Fig. 7.3.1-1a). The largest warming of around 2°C is expected in the summer over the Iberian Peninsula and western Africa (Fig. 7.3.1-1c). The temperature increase in the autumn is projected to have similar pattern as in the summer but with smaller amplitude (maximum up to 1.2°C, Fig. 7.3.1-1d). The above temperature changes are statistically significant at the 95% confidence level in all seasons and in almost entire domain; the only exception is the T2m rise in spring over central Europe and the Atlantic.

From the simulated climate changes over Europe, the following projection for the Croatian region can be inferred: the largest change in T2m is expected to be in the summer with an increase around 0.8°C in Slavonia, 0.8-1°C in the central part of Croatia, the Istrian Peninsula and across the interior of the Adriatic coast and at the central and southern Adriatic. The largest temperature increase, around 1°C, will be at the Adriatic coast and the northern Adriatic islands. The expected warming will be around 0.8°C in the autumn, and between 0.2-0.4°C in winter and spring.

The change in the amplitude of extreme temperatures in the future climate (Fig. 7.3.1-2) will be more pronounced than the change of the mean seasonal T2m (Fig. 7.3.1-1). In the winter, the increase of the mean minimum T2m is projected to be around 0.4°C over a larger part of the domain, in some parts of the Alpine region and in the southern parts of the domain up to 0.6°C, whereas in the northeastern part of domain (Russia) the mean minimum T2m may increase even up to 1.4°C (Fig. 7.3.1-2a). The change of the mean maximum temperature in the summer (Fig. 7.3.1-2b) will have the pattern similar to the change of the mean summer T2m (Fig. 7.3.1-1c), but the amplitude of warming is expected to be larger than that for the mean T2m. The largest warming is expected over the central Iberian Peninsula where the mean maximum temperature in the period P1 could be 2°C higher than the mean maximum temperature in the present climate. The projected changes in the mean minimum T2m during the winter and in the mean maximum T2m during the summer are all statistically significant at the 95% confidence level over the whole integration domain.

In large part of Croatia, the winter minimum T2m is expected to increase up to 0.5°C, however, a smaller increase may be expected only in the Dalmatian hinterland (Fig. 7.3.1-2a). The summer maximum temperature may increase up to around 0.8°C in the continental Croatia and a little more than 1°C along the Adriatic coast (Fig. 7.3.1-2b).

The number of cold and warm days was analysed from the RegCM simulations of the present climate and compared with the observational data at the Croatian meteorological stations. However, since extreme events are largely influenced by local small-scale geophysical characteristics, the regional climate models may have difficulties in simulating extreme parameters because models' horizontal resolution may be too coarse.

Figure 7.3.1-3a shows that during the winter the RegCM model underestimates the number of cold days (that is the number of days when the minimum temperature is colder than 0°C) in the continental Croatia but overestimates at the coast. In the northern part of Croatia, the observed mean number of the winter cold days for the present climate is over 60 days, whereas the model estimate is less than 50 days. The largest discrepancy between the simulated and observed data is seen in the area close to the Adriatic coast. Here, the steep orography and the local geophysical characteristic are not well represented by the model's 35-km resolution and cause the differences with respect to the observational data. In spite of such a deficiency in our model simulations, it can be concluded that the model was able to represent reasonably well the observed differences in the number of cold days between the continental and coastal parts of Croatia. The number of cold days in the future climate is projected to decrease for about 10% in the northern parts of Croatia and about 5% in the coastal area (Fig. 7.3.1-3b). This decrease is consistent with an increase of the minimum T2m over the whole of Croatia.

The RegCM model also underestimates the mean number of warm days in the present climate (Fig. 7.3.1-3c). Generally, the simulated number of warm days is halved when compared with the observed number of warm days at the Croatian stations. This discrepancy is partly due to the model systematic errors and partly due to misrepresentation of vegetation in the areas close to the coast. In the near future, an increase in the number of warm days is expected: by 3-4 days in the northern Croatia and up to 10 days at the coast. (Fig. 7.3.1-3d). This increase is between 10-15% relative to the number of warm days in the present climate and it is consistent with the expected increase of maximum T2m.

(b) The ENSEMBLES simulations

The ENSEMBLES RCM simulations of the first future 30-year period (P1) indicate an increase of T2m in all seasons with the amplitude typically between 1°C and 1.5°C. A somewhat higher warming, between 1.5°C and 2°C, is projected over the eastern and central parts of Croatia during winter (Fig. 7.3.1-4a) and over central and southern Dalmatia during summer (Fig. 7.3.1-4c). On the monthly timescale, even a decrease of the mean temperature amounting to -0.5°C may be possible, primarily as a consequence of internal variability of the climate system (Hawkins 2011; Branković et al. 2013; their Fig. 10).

For the period around the middle of the 21^{st} century (P2), the projected winter warming over the continental Croatia is between 2.5°C and 3°C and a slightly reduced increase of T2m is projected over the coastal areas (Fig. 7.3.1-5a). In the summer, the increase of T2m over central and southern Dalmatia is expected to be between 3°C and 3.5°C, but for the other parts of Croatia a T2m increase of between 2.5°C and 3°C is projected (Fig. 7.3.1-5c). In other two seasons the expected T2m increase is spatially homogeneous

similar to projections for the first part of the 21st century and equals to between 2°C and 2.5°C (not shown). These results are similar to those obtained directly from the ensemble mean of the ECHAM5/MPI-OM GCM for the period P2, 2041-2070 (Branković et al. 2010). The largest differences in the temperature increase between the global and regional models is seen in the summer over the northern Adriatic when the ECHAM5/MPI-OM GCM indicates the warming of over 3.5°C; a somewhat weaker warming is expected in the central and southern parts of the Adriatic.
For the end of the 21st century (period P3), the projections by ENSEMBLES' RCMs include very high T2m increase. Also, the differences between the spring and autumn seasons are higher than in the earlier periods of the 21st century. During the winter, the T2m increase between 3.5°C and 4°C is projected over the continental Croatia and a somewhat reduced T2m increase is simulated for the coastal area – between 3°C and 3.5°C (Fig. 7.3.1-5b). The projected summer warming is very high and equals to between 4.5°C and 5°C over the southern and central Dalmatia and between 4°C and 4.5°C over other parts of Croatia (Fig. 7.3.1-5d). In some models, the increase of the monthly mean temperature higher than 5°C may be possible in the coastal area during the summer (e.g. the RACMO2 and REMO RCMs in Branković et al. 2013; their Fig. 10). In other two seasons, the T2m increase is spatially homogeneous over the whole Croatia and equals to between 3°C and 3.5°C during spring and between 3.5°C and 4°C during autumn (not shown).
More than the two thirds of all ENSEMBLE models agree in the sign of projected changes and simulate the T2m increase in all seasons to be at least 0.5°C higher in the whole 21st century than in the present climate. Standard measures of statistical significance suggest a possibility of significant T2m change even in the first part of the 21st century (Branković et al. 2013).

7.3.3.2 - Precipitation

(a) The DHMZ RegCM simulations

Precipitation changes in Croatia in the near future climate (2011-2040; period P1) relative to the reference climate (1961-1990, P0) are analysed for the mean precipitation and indices of precipitation extremes on the seasonal and annual basis, similar to Patarčić et al. 2013 (submitted to Climate Research). The following indices of precipitation extremes are used (Peterson et al. 2001; WMO 2004):

1. dry days (*DD*) – the number of days in a season (year) with daily precipitation (R_d) less than 1.0 mm
2. simple daily intensity index (*SDII*) – seasonal (annual) precipitation amount divided by seasonal (annual) number of wet days ($R_d \geq 1.0$ mm)

3. moderate wet days (*R75*) – the number of days per season/year with precipitation $R_d>R_{75\%}$, where $R_{75\%}$ is the 75th percentile of the distribution of seasonal (annual) daily precipitation amounts in wet days during the 1961-1990 reference period
4. very wet days (*R95*) – same as *R75* but for the 95th percentile of the distribution of seasonal (annual) daily precipitation
5. *R95T* – fraction of seasonal (annual) precipitation occurring during very wet days.

Total precipitation and indices of precipitation extremes from RegCM3 integrations were first calculated from each individual ensemble member for each year (season) and then the average was computed over 30 years (seasons) and over all members. Thus, the results presented in this report refer to the ensemble mean precipitation and indices of precipitation extremes. Statistical significance of the differences between the near-future and reference climate was tested by the Wilcoxon-Mann-Whitney nonparametric rank sum test (Wilks, 2006) at the 95% confidence level.

The largest near-future change in seasonal precipitation is expected in the autumn, when a decrease of precipitation between 2% and 8% is seen over the larger part of Croatia (Fig. 7.3.2-1d). However, in Slavonia, precipitation is projected to increase between 2% and 12%, and more than 12% in the eastern Slavonia where the increase is statistically significant. In other seasons, the model results indicate an increase in precipitation (2%-8%) except in spring (Fig. 7.3.2-1b) over the Istrian Peninsula, Kvarner Bay and the central Adriatic where precipitation is projected to decrease between 2% and 10%. These changes, particularly in the winter and summer, are not spatially consistent, they are smaller in magnitude than in autumn and they are not statistically significant. The decrease in precipitation at the Adriatic coast in the autumn and spring has an overall impact on the annual amounts – over the northern and middle Adriatic precipitation is projected to decrease by 2% to 4% (Fig. 7.3.2-1e). In the eastern part of the continental Croatia, model results indicate an increase of annual precipitation between 2% and 6% which is statistically significant over eastern Slavonia.

An increase in the number of dry days (*DD*) in autumn (1-2 days) is evident over most of Croatia except in the eastern continental parts (Fig. 7.3.2-2a). This increase corresponds to a 1-4% change relative to the reference climate (P0) values. In other seasons, *DD* changes are less than one day (not shown). On the annual basis, changes in *DD* are larger in magnitude than in autumn due to small increases in the number of *DD* in other seasons that contribute to the annual mean (Fig. 7.3.2-2b). Over the northern part of the Istrian Peninsula and in the Dalmatian hinterland, the model results indicate an increase of *DD* up to 4 days and over the northwestern part of Croatia up to 3 days which corresponds to 2% change. In the eastern continental Croatia, however, a decrease from one to three DD (1%) is projected. Since the changes in *DD* (and consequently in wet days) are very small in all seasons (from -1% to 4%), spatial distribution of the changes in *SDII* (Fig. 7.3.2-3) is mostly determined by the future changes in the seasonal and annual total precipitation. An increase in *SDII* is expected in the winter (Fig. 7.3.2-3a) over a larger part of Croatia (1%-6%) and in the spring (Fig.

7.3.2-3b) in the continental part (from 1% to more than 6%). A statistically significant decrease in the spring *SDII* is seen in the northern and central Dalmatia. Changes in the summer *SDII* (Fig. 7.3.2-3c) affect smaller areas than in other seasons with an increase in the eastern Slavonia (1% to 3%), parts of Istria and the northern Adriatic and in the southernmost part of Croatia (1% to 6%). A decrease in the summer *SDII* is projected over southern Dalmatia (1% to 4%) and over the mountainous part of Croatia (more than 4%). Changes in the autumn *SDII* (Fig. 7.3.2-3d) are consistent with the changes in the total precipitation (Fig. 7.3.2-1d) – in the southern part of Croatia a decrease between 1% and 4% is projected, while an increase is seen in eastern Slavonia (from 1% to more than 6%). On the annual basis (Fig. 7.3.2-3e), the *SDII* changes are generally smaller in magnitude than for seasons, ranging from 1% to 3% in the northern Croatia, and from 3% to 5% in the eastern Slavonia. At the Adriatic coast, the changes in *SDII* are associated with the decreases in the number of wet days or with the decreases in the annual precipitation. The increases in *SDII* are statistically significant in the eastern Slavonia in the autumn and for the year, and also in the part of northern Croatia in the spring and for the year.

The projected changes in the number of seasonal moderate and very wet days (*R75* and *R95*, respectively) are negligible. It is only on the annual basis that a statistically significant increase in *R75* is seen in the eastern continental part of Croatia (1-3 days), and a decrease (1-2 days) is projected over parts of Lika and Dalmatian hinterland (Fig. 7.3.2-4). Although changes in the frequency of *R95* are negligible, the fraction of seasonal and annual precipitation from the very wet days (*R95T*) may change in the near-future climate. The increase in *R95T* between 1% and 4% is projected in the winter (Fig. 7.3.2-5a) along the Adriatic coast and its hinterland, and in the northwestern parts of Croatia. Since the large daily precipitation amounts at the Adriatic coast in the cold part of the year are the result of the long-term precipitation (Zaninović et al. 2008), the winter increase in *R95T* indicates their intensification. In the spring, an increase in *R95T* is projected in the northern Croatia, over parts of the northern Adriatic and in the southernmost part of the coast (Fig. 7.3.2-5b). In the summer, changes in *R95T* are variable in sign and they are spatially less uniform than in other seasons (Fig. 7.3.2-5c). A somewhat larger increase is seen in eastern Slavonia (1%-5%), thus indicating an increase in the short-term heavy precipitation (showers) which dominates over this (continental) region during summer. In the autumn, a decrease in *R95T* is projected along the Adriatic coast (Fig. 7.3.2-5d), while an increase is seen in the northwestern Croatia and eastern Slavonia (more than 6%) where it is statistically significant. On the annual basis (Fig. 7.3.2-5e), *R95T* may significantly increase in eastern Slavonia and along the northern and central Adriatic. Since changes in the frequency of very wet days (*R95*) are generally negligible in all seasons and for the year, the increase in *R95T* is related to the increase in extreme precipitation, and to a lesser extent to the decrease in the total seasonal or annual precipitation.

Previous studies of precipitation changes in Europe and the Mediterranean area, which are mainly focused on changes at the end of the 21st century when the signal of climate change is stronger, suggest an increase in precipitation in northern Europe and a decrease in southern Europe and the Mediterranean area. In the summer, the border line between the above two areas with different sign of changes is shifted more to the north so that the drying affects most of Europe (e.g. Giorgi and Lionello 2008). Branković et al. (2012) showed that, according to the results of the RegCM simulations which were used in this report, the division on the European wetter north and drier south in the winter was already visible in the near-future climate, but with a smaller amplitude than the one that is projected for the end of the 21st century. On the other hand, they concluded that the summer drying in the P1 climatic period over southern Europe and the Mediterranean area was not yet established. Although our results indicate statistically insignificant changes in extreme precipitation, there are some similarities with projected changes in precipitation extremes in the winter for the late 21st century. For example, Kendon et al. (2010) showed that, based on the global model HadAM3P simulations under the A2 scenario, the warming of the atmosphere and the related increase in the atmospheric moisture in winter in most parts of Europe would result in an increase not only in the mean precipitation, but also in daily intensity and extreme precipitation. However, the reduction in the frequency of wet days in the winter (i.e. increase in the number of dry days), which, according to their results, is projected for southern Europe, is not observed in our simulations in the near future. Moreover, the summer drying in the Mediterranean area in the late 21st century, which is associated with an increase in the number of dry days even under the weaker A1B scenario (Lehtonen et al. 2013), is not seen in our simulations for the period 2011-2040. Our results suggest that the future changes in wet extremes (*SDII* and *R95T*) over Croatia would be more pronounced in terms of magnitude and spatial extent than the changes in dry extreme (*DD*). The described changes in the mean and changes in the extreme precipitation indicate that their spatial extent and magnitude is similar in all seasons except in autumn when the changes in the mean seasonal precipitation dominate.

(b) The ENSEMBLES simulations

In the first part of the 21st century, the total precipitation amount *R* is projected to increase during the winter with the amplitude between 5% and 15% over parts of the northwestern Croatia and the Kvarner region. The sign of these changes agrees in at least the two thirds of all models (Fig. 7.3.2-6a). During summer in the same period, *R* is projected to decreases from -5% down to -15% over large parts of the Dalmatian hinterland and the Croatian highlands (Fig. 7.3.2-6c). This decrease in precipitation is also found in at least the two thirds of the models. The precipitation decrease of the same amplitude is projected for the southern Croatia during spring (Fig. 7.3.2-6b), while during autumn the projected changes are between -5% and +5% (Fig. 7.3.2-6d). Over the coastal and island locations, the projected signal of climate change is spatially and temporally variable and is rarely statistically significant on the monthly timescale (Branković et al. 2013; their Fig. 11).

For the period around the middle of the 21st century (P2), the moderate precipitation changes are projected over a much larger part of Croatia than for the first 30-year long period (P0), especially for the winter and summer seasons. However, the projected winter precipitation increase between 5% and 15% does not exceed the projected changes for the P1 period (Fig. 7.3.2-7a). Somewhat stronger precipitation decrease, between -15% and -25%, is projected for the summer season over almost entire Croatia except the northernmost and westernmost parts where the reduction in precipitation could amount between -5% and -15% of the reference period (Fig. 7.3.2-7c). The projected decrease in precipitation between -15% and -5% during spring is found over the entire coastal area and its hinterland, while during autumn the projected precipitation increase between 5% and 15% is projected over the central and eastern northern lowlands (not shown). Although on the mean monthly timescale and local spatial scales a substantial variability of the projected climate change signal can be expected (Branković et al. 2013; their Fig. 11), the projected changes are present in at least the two thirds of the models.

Changes in seasonal precipitation amounts cover large parts of Croatia also in the last period of the 21st century (P3). As for the P2, the projected increase in the total precipitation during winter between 5% and 15% is seen all over Croatia except the southernmost parts (Fig. 7.3.2-7b). Thus, the ENSEMBLES models do not indicate a substantial difference in the projected winter precipitation increase between the periods P2 and P3. However, the projected decrease in the total precipitation during summer in P3 points to a larger precipitation reduction than in P2. Over the central and eastern parts of Croatia and Istria, the projected precipitation decrease is expected to be between -15% and -25%, while in the Croatian highlands and in the most parts of the northern Adriatic and its hinterland the projected decrease could be between -25% and -35% (Fig. 7.3.2-7d). In some models even stronger reduction of the projected summer precipitation is found (to approximately -60% in RACMO2 and HIRHAM5 RCMs in Branković et al. 2013; their Fig. 11). The reduction in precipitation between -5% and -15% in the coastal area and in the hinterland is projected also for spring and autumn (not shown). As for the previous period, the projected changes are present in at least the two thirds of the models.

7.3.4. - Discussion and conclusions

An analysis of the climate change projections from the ENSEMBLES RCMs indicates a pronounced temperature rise in Croatia towards the end of the 21st century. For the IPCC A1B emission scenario, such a temperature increase is intrinsic to all RCMs irrespective of their physical formulations and differences among the models.

A comparison of climate change projections for Croatia in the near-future period 2011-2040 (P1) from the DHMZ RegCM simulations and from those of the ENSEMBLES project reveals that the largest warming of T2m in both sets of experiments could be expected in the summer season along the Croatian Adriatic coast and in its hinterland (Fig. 7.3.1-1c and Fig. 7.3.1-4c). The details of such a projected warming, however, differ: according to the DHMZ RegCM results, the strongest warming of about 1ºC is expected in the northern Adriatic region, whereas the ENSEMBLES models indicate the warming of 1.5-2ºC in the central and southern Adriatic. This may seem surprising since the emission scenario used in the DHMZ RegCM simulations was the A2 scenario which inherently includes a stronger forcing of the GHGs than in the A1B scenario which was used by the ENSEMBLES models. In the near future (P1), however, the forcing of GHGs does not differ significantly among various scenarios; the differences in forcing between A2 and A1B scenarios are becoming more pronounced only in the second half of the 21st century (Meehl et al. 2007). From our results for different scenarios and different models, it is important to identify the agreement (or consistency) in the season (summer) and in the region (the Adriatic and the hinterland) that points out to the most probable projected warming of the near-surface temperature.

On the other hand, in the seasonal and monthly averaged total precipitation, a much larger diversity of the projected changes are found, depending on the region of Croatia or/and season. Thus, for example, in the period P1, the summer decrease in precipitation in the Adriatic hinterland is spatially more extended and more intense in the ENSEMBLES than in the DHMZ RegCM integrations (Fig. 7.3.2-1c and Fig. 7.3.2-6c). Towards the end of this century a larger parts of Croatia may be exposed to a more distinct changes in precipitation amounts. A clear emerging signal of climate change, relative to the present climate, is a moderate to high possibility of the precipitation increase in the winter and a reduction of the total precipitation in the summer.

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Table 1: Analysed regional climate models (RCMs), organisations which performed simulations and sources of the boundary conditions. All models take part in the comparison between the periods P0 and P1. In the italics are the models that are not compared for the periods P0 and P2 and for the periods P0 and P3. In the bold print are the models that have been analysed in Branković et al. (2013). For acronyms and detailed description of models see Christensen et al. (2010) and Déqué et al. (2012).

	Regional climate model	Organisation	Global climate model that provides 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*

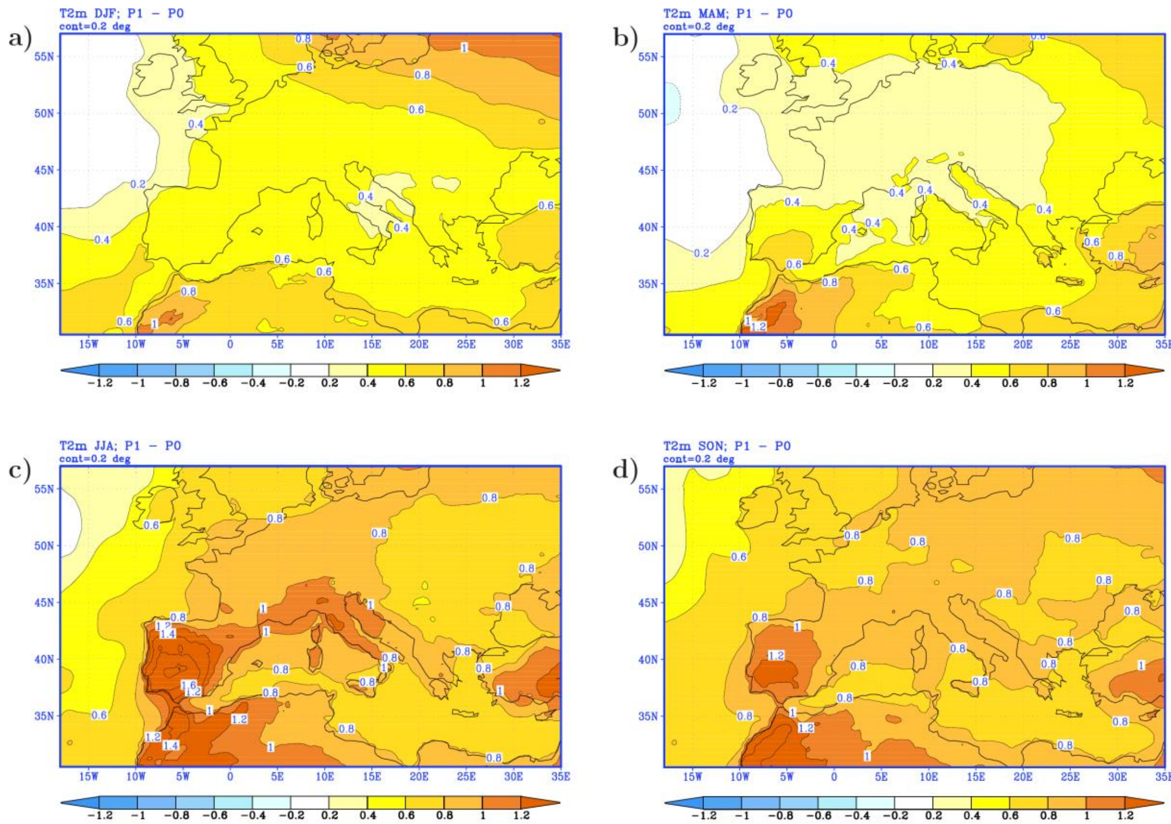
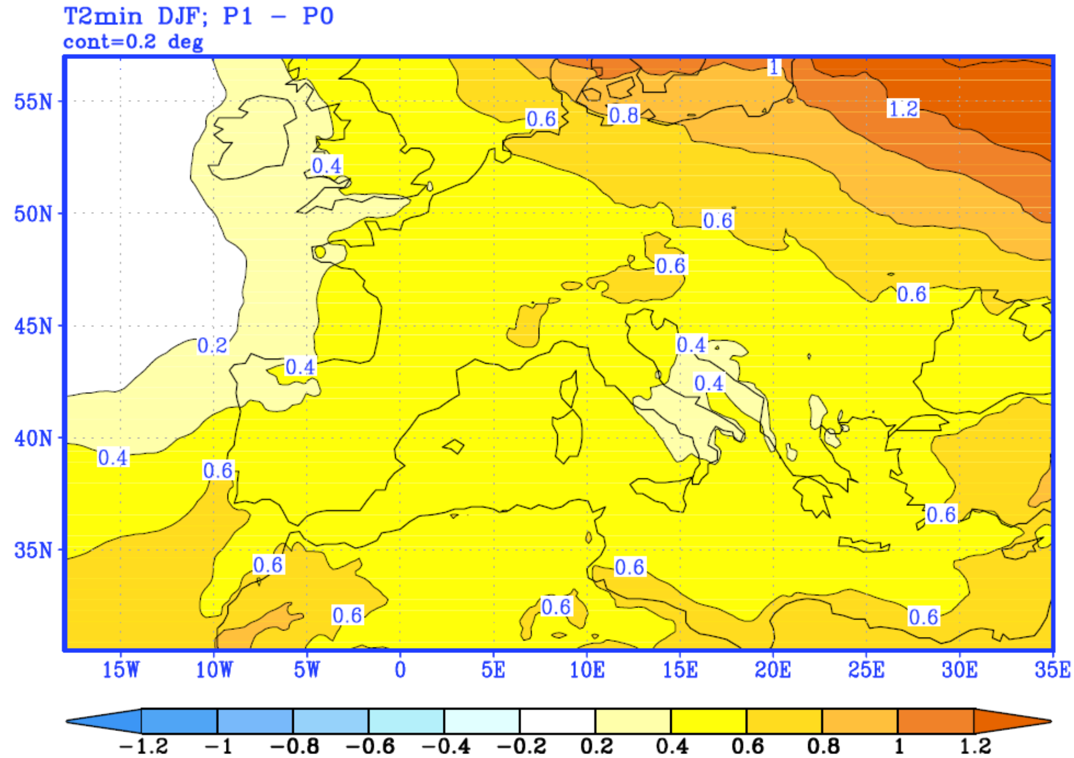


Fig. 7.3.1-1. Ensemble-mean difference of temperature at 2 m (T2m), P1 minus P0: a) winter, b) spring, c) summer, d) autumn. Contours every 0.2 °C.

a)


T2min DJF; P1 – P0
cont=0.2 deg
55N
50N
45N
40N
35N
15W
10W
5W
0
5E
10E
15E
20E
25E
30E
35E
−1.2
−1
−0.8
−0.6
−0.4
−0.2
0.2
0.4
0.6
0.8
1
1.2

b)

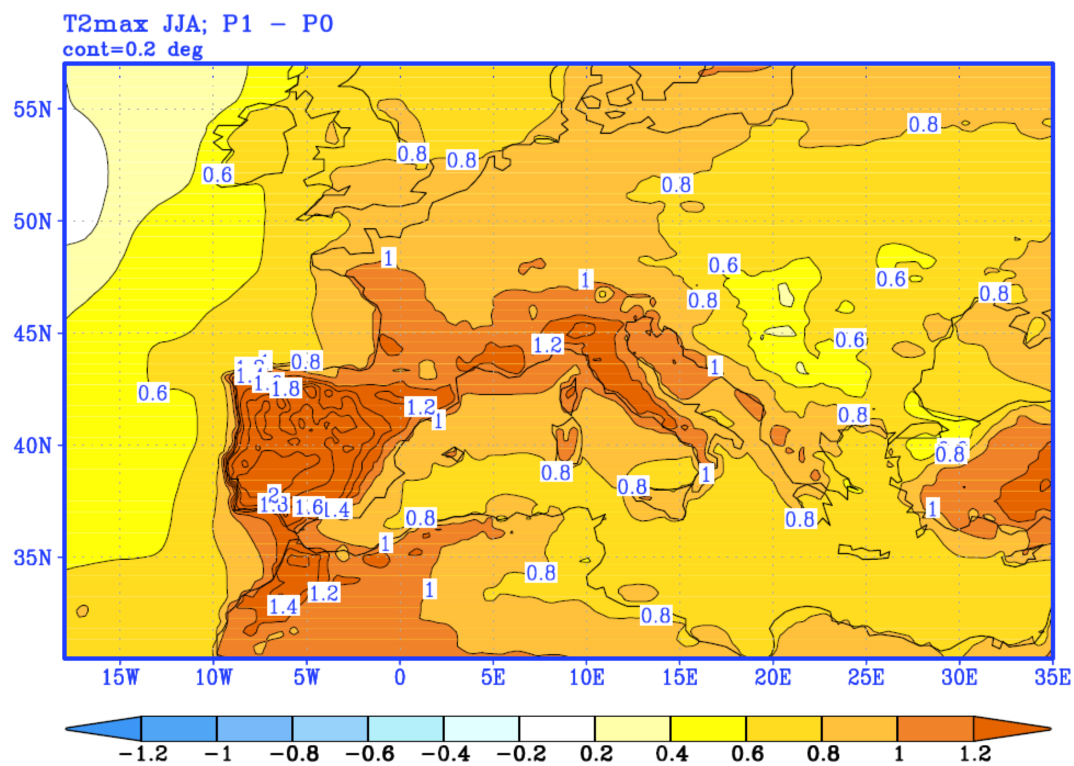

T2max JJA; P1 – P0
cont=0.2 deg
55N
50N
45N
40N
35N
15W
10W
5W
0
5E
10E
15E
20E
25E
30E
35E
−1.2
−1
−0.8
−0.6
−0.4
−0.2
0.2
0.4
0.6
0.8
1
1.2

Fig. 7.3.1-2. Ensemble-mean difference for: a) minimum T2m in the winter, b) maximum T2m in the summer, P1 minus P0. Contours every 0.2 °C.

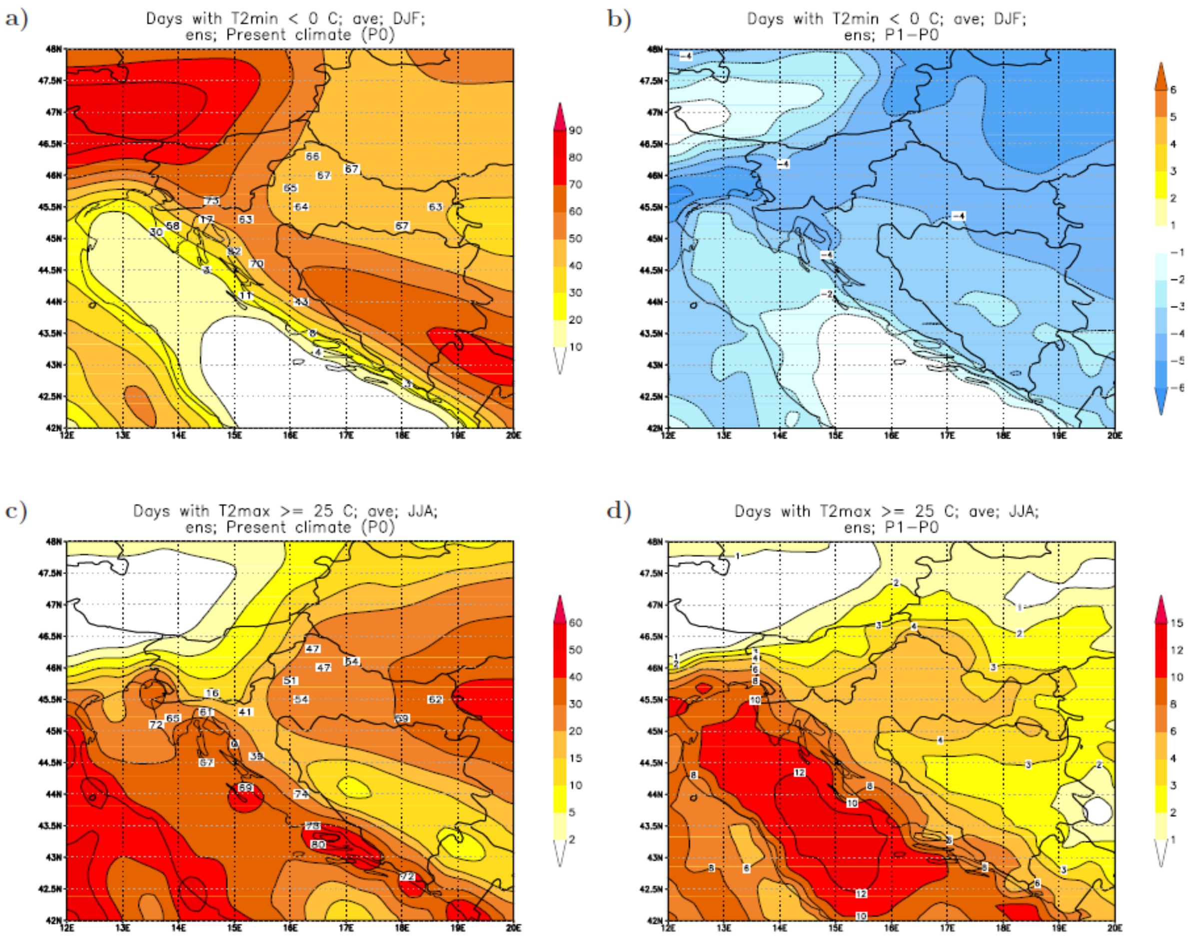


Fig. 7.3.1-3 Mean number of cold days in winter for: a) present climate (P0) and b) change in the number of cold days (P1 minus P0). Mean number of warm days in summer for: c) present climate (P0) and d) change of the number of warm days (P1 minus P0). Contours in a) every 10 days; in b) 1 day; in c) 2, 5, 10, 15, 20, 30, 40, 50, 60 and in d) 1, 2, 3, 4, 6, 8, 10, 12, 15 days.

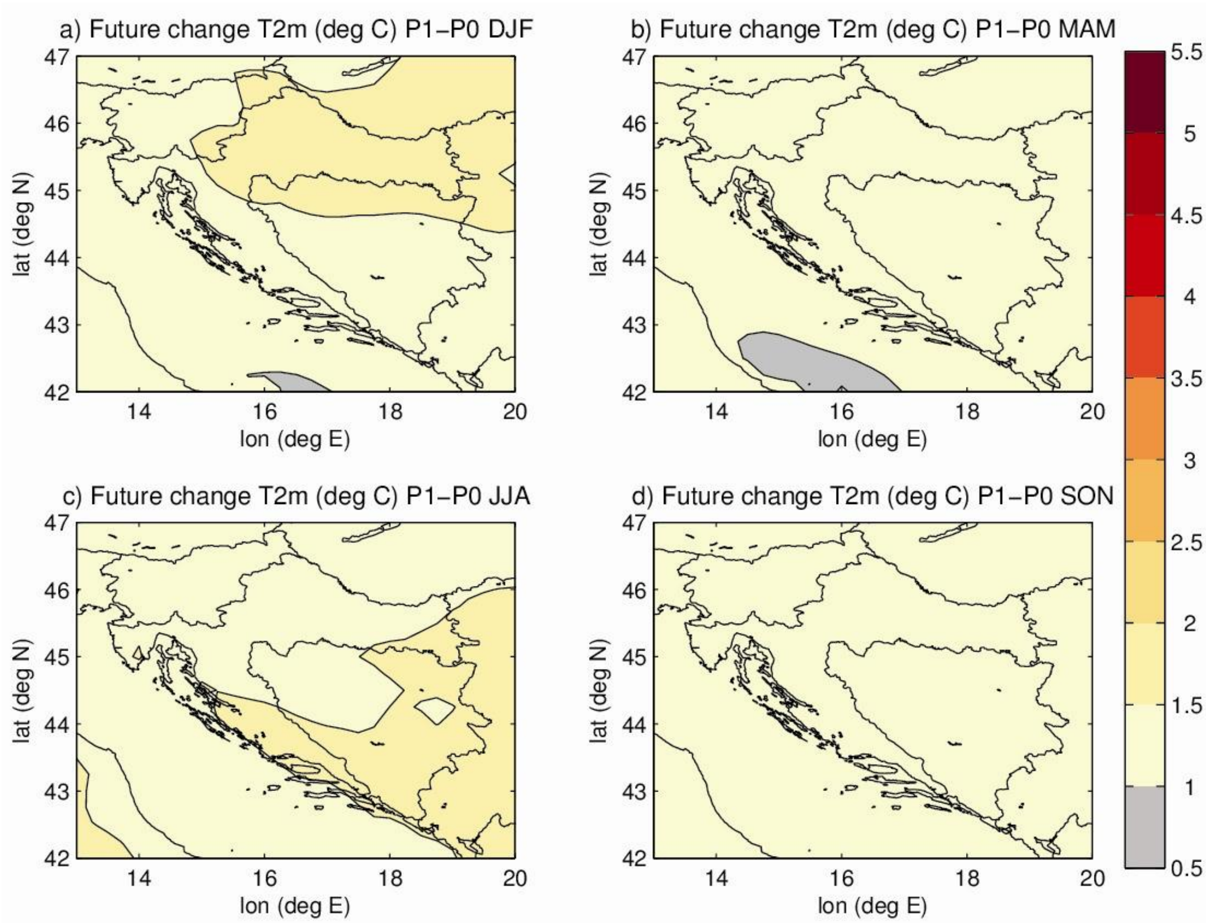


Fig. 3.1.4 The T2m ensemble-mean difference between the periods P1 and P0: a) winter (DJF), b) spring (MAM), c) summer (JJA) and d) autumn (SON). Units are °C. In all grid points, the sign of change in at least the two thirds of the models agrees with the sign of change in ensemble means.

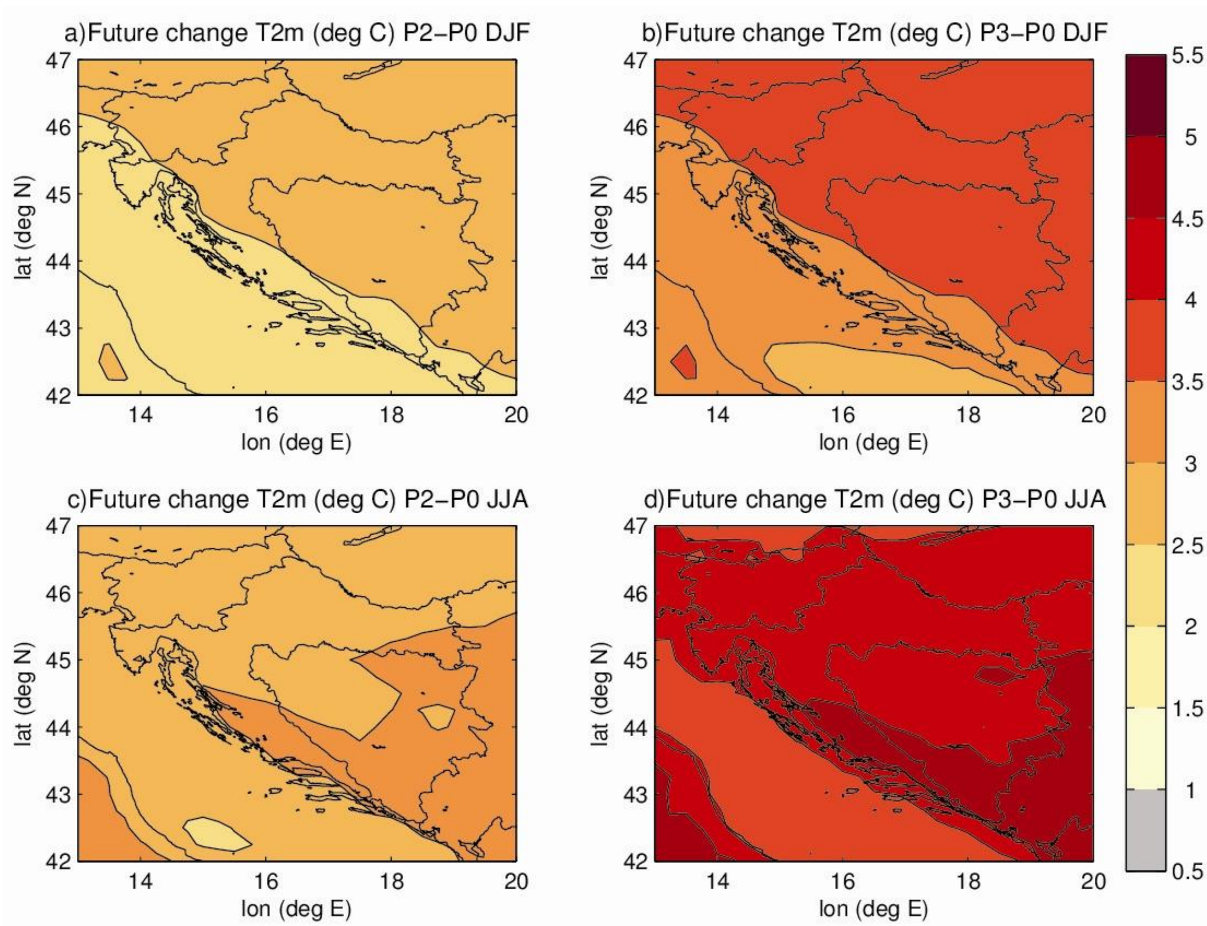


Fig. 7.3.1-5 The T2m ensemble-mean difference in winter (DJF) for: a) P2-P0 and b) P3-P0, and in summer (JJA) for: c) P2-P0 and d) P3-P0. Units are °C. In all grid points, the sign of change in at least the two thirds of the models agrees with the sign of change in ensemble means.

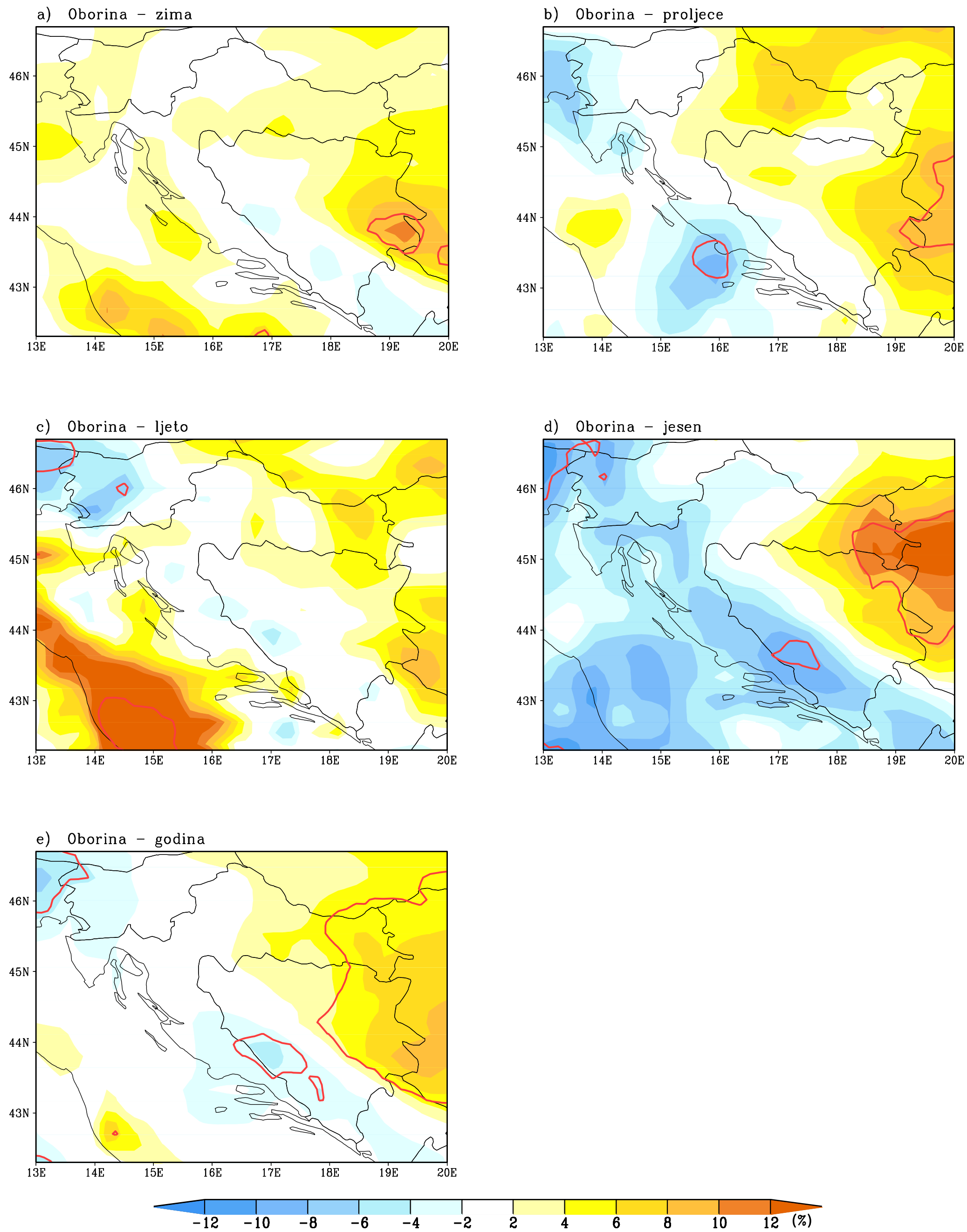


Fig. 7.3.2-1 The near-future (2011-2040; period P1) change in seasonal (a-d) and annual (e) total precipitation relative to the reference period (1961-1990; P0). Changes are expressed as the percentages of precipitation in the reference period. Statistically significant changes at the 95% confidence level are denoted by red contour.

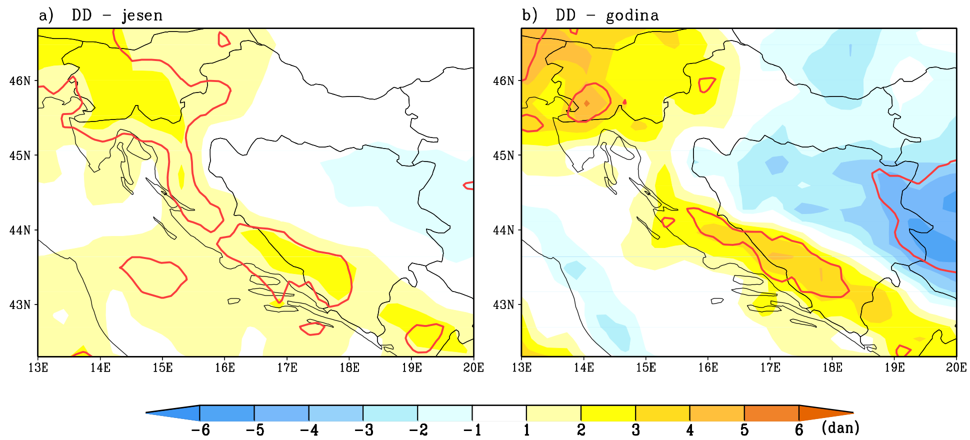


Fig. 7.3.2-2. The near-future (2011-2040) change of the number of dry days (DD) with respect to the reference period (1961-1990) in: (a) autumn and (b) year. Statistically significant changes at the 95% confidence level are denoted by red contour.

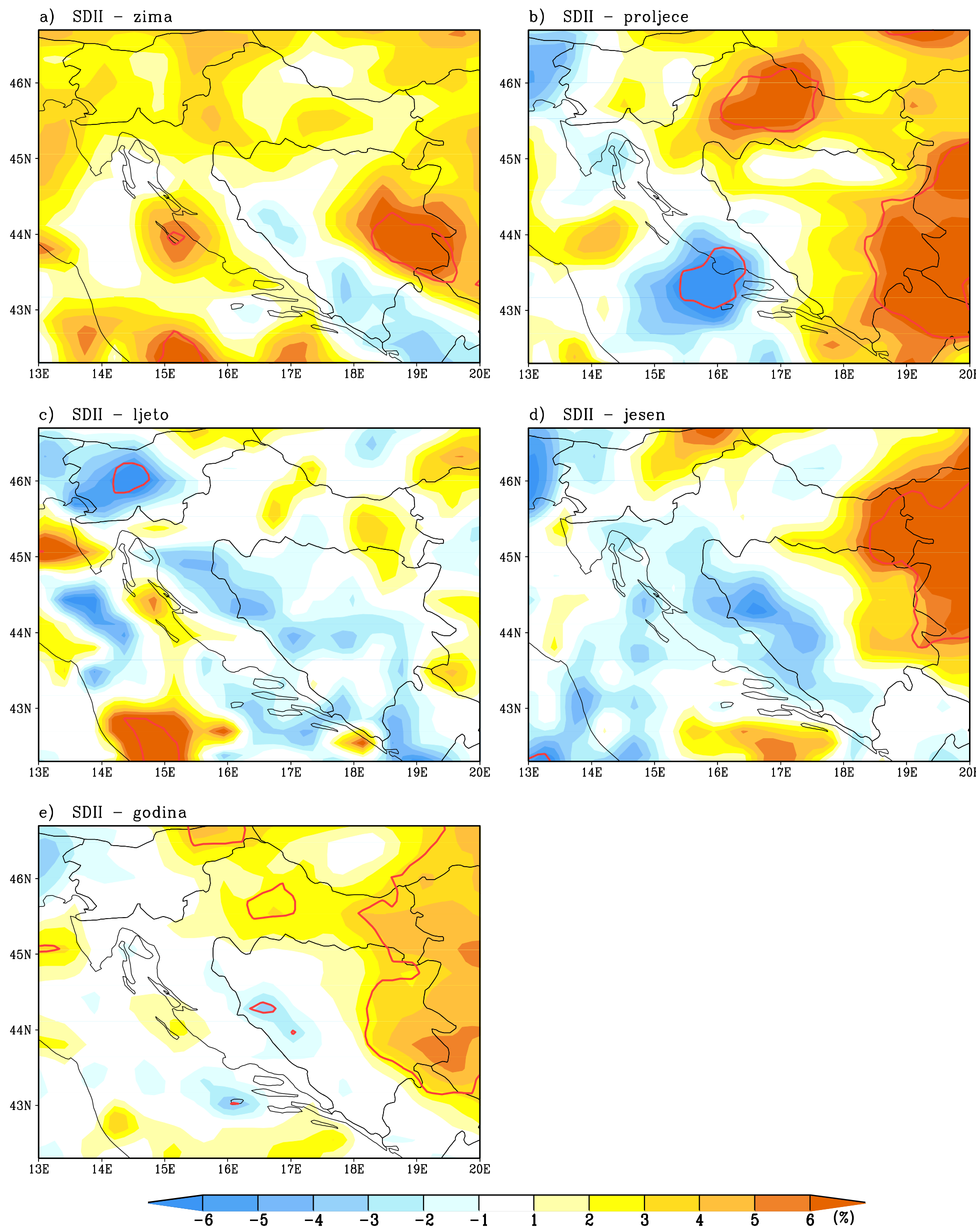


Fig. 7.3.2-3. The near-future (2011-2040; P1) change in the simple daily intensity index (SDII) in (a-d) seasons and in (e) year relative to the reference period (1961-1990; P0). Changes are expressed as the percentages of SDII in the reference period. Statistically significant changes at the 95% confidence level are denoted by red contour.

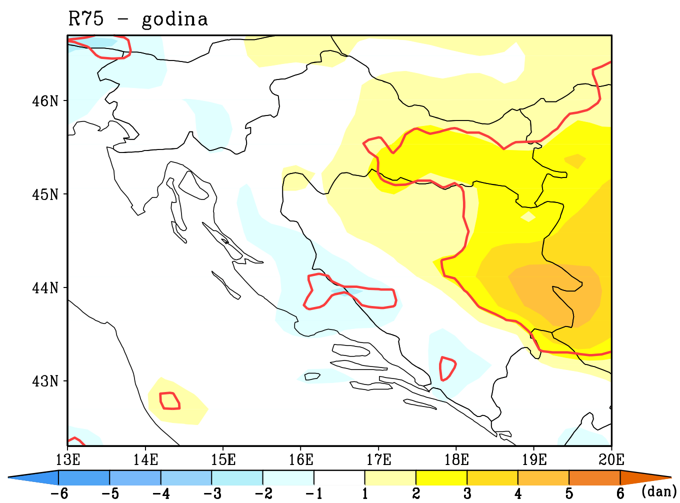


Fig. 7.3.2-4. The near-future (2011-2040; P1) annual change of the moderate wet days (R75) with respect to the reference climate (1961-1990; P0). Changes are expressed as the differences in the index value between the future and the reference period. Statistically significant changes at the 95% confidence level are denoted by red contour.

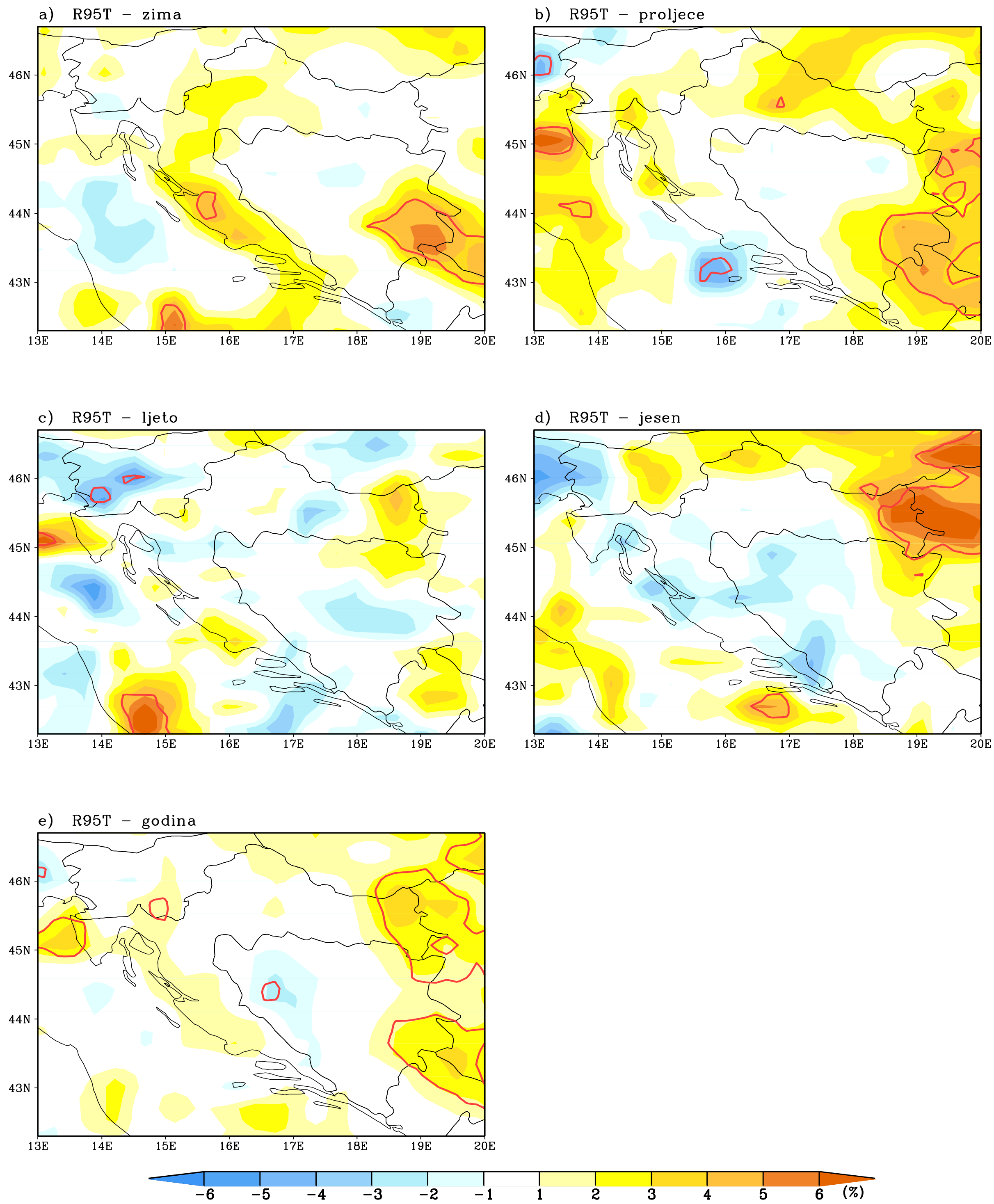


Fig. 7.3.2-5. The near-future (2011-2040; P1) seasonal (a-d) and annual (e) change of the fraction of precipitation occurring on very wet days (R95T) relative to the reference period (1961-1990; P0). Changes are expressed as the differences in the index value between the future and the reference period. Statistically significant changes at the 95% confidence level are denoted by red contour.

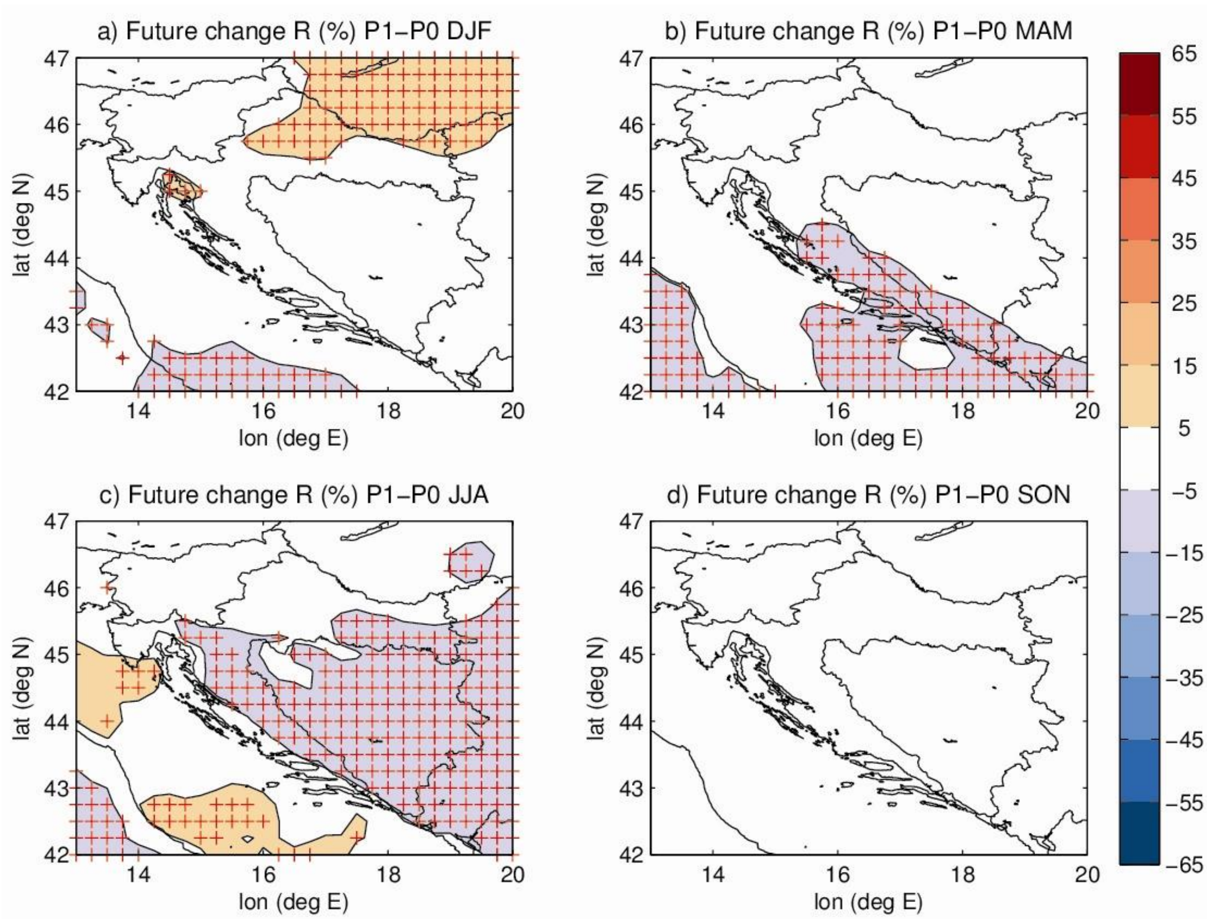


Fig. 7.3.2-6 Ensemble-mean relative difference (in %) of the total precipitation between the periods P1 and P0 in: a) winter (DJF), b) spring (MAM), c) summer (JJA) and d) autumn (SON). The + sign denotes grid points where the sign of change in at least the two thirds of the models agrees with the sign of change of the ensemble mean difference and when the relative difference of ensemble means is outside the interval ±5%.

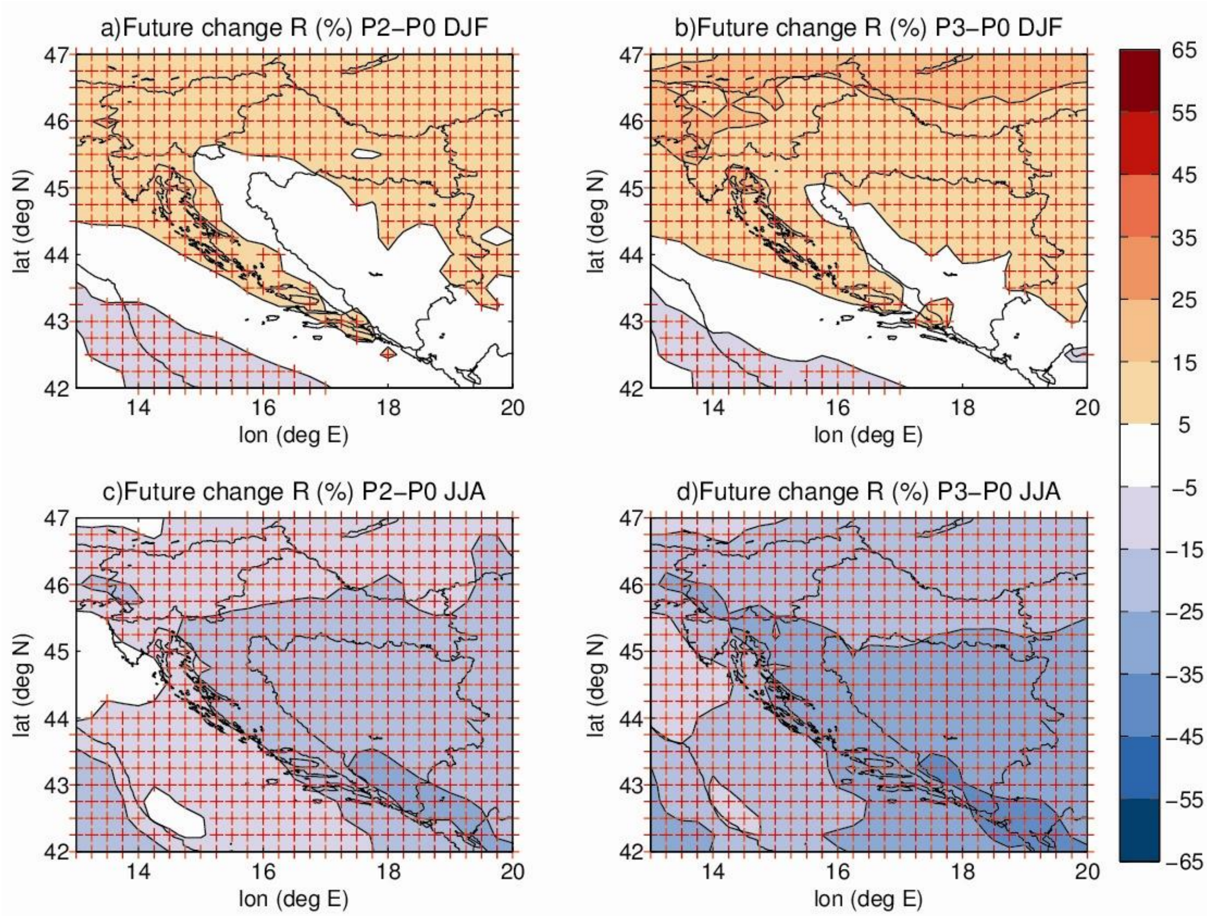


Fig. 7.3.2-7. Ensemble-mean relative difference (in %) of the total precipitation in winter (DJF) for a) P2-P0 i b) P3-P0 and summer (JJA) for c) P2-P0 i d) P3-P0. The + sign denotes grid points where the sign of change in at least the two thirds of the models agrees with the sign of change of the ensemble mean difference and when the relative difference of ensemble means is outside the interval ±5%.

7.4. - Impact of climate change on plants and wildfire risk

7.4.1. - Impact of climate change on wildfire risk

The Dalmatian coast and islands in the summer months run a higher risk of wildfire than any other area in Croatia. This is due to the highly flammable plant cover and extended periods of drought. The human factor, i.e. an increase in tourists in the summer months, also adds to the potential danger. The Canadian *Fire Weather Index* is used to determine the potential danger of wildfire. One of the indices used is the *Monthly Severity Rating* (MSR), which in turn allows the *Seasonal Severity Rating* (SSR) to be estimated. The SSR refers to the estimation of potential wildfire risk during the fire season, from June to September, while the MSR refers to a particular month. Weather conditions conducive to the eruption of large fires prevail if the SSR $\geq$ 7.

An analysis of the MSR and SSR indicates that over the last 30 years the area which is at high risk of wildfire has spread from the Dalmatian coast and islands to include the interior (Table 7.4.1–1). The five stations which were observed represent different climate zones. Out of these, the Hvar station had the highest mean SSR, which rose from 6.9 in the period 1961–1990 to 7.5 in the period 1981–2010. An increased danger of wildfire has been noted in the northern Adriatic, as well as in eastern Slavonia in comparison with the period 1961–1990. August poses the greatest potential risk, followed by July.

An analysis of the linear trends of the MSR and SSR is in accordance with the previous comparison of the two observed periods. Based on data from the last 110 years (Table 7.4.1–2 and Figure 7.4.1–1), the analysis confirms that the area which is at higher potential wildfire risk is spreading from the mid-Adriatic to the northern Adriatic. To determine the extent to which results from the five stations are representative of particular areas, linear trends of the MSR and SSR were analysed for a further seven stations where meteorological data was available for the shorter period 1951–2010. The Lastovo and Knin stations in Dalmatia recorded the highest values in linear trends of the MSR and SSR, which are generally statistically significant. Out of the observed stations Lastovo has had the biggest increase in SSR (2.0/decade), while in Knin this amounted to 1.0/decade. The Lastovo station also recorded the highest MSR trends (3.0/ decade in July and 2.3/decade in August). These high values confirm the conclusion reached in the analysis of the Hvar station. Over the last 60 years, Dalmatia has recorded a steep increase in wildfire risk, as well as an extended fire season. However, the last 60 years have also seen a statistically significant trend in the Croatian interior (Lika and eastern Slavonia). This means that wildfire is no longer an issue only relevant to the Adriatic coast and islands, but to other parts of Croatia as well. The impact of climate change on wildfire risk is reflected in the tendency of the fire season to start earlier (in May), as well as the possibility for the fire season to extend until October, particularly along the Adriatic.

It should be emphasised that the results for Croatia are very much in line with those obtained in other countries. Thus the fire regime in Croatia fits into the bigger picture, which indicates that areas running a higher potential wildfire risk in the Mediterranean and eastern Europe in the summer months are expanding in size.

Table 7.4.1–1 Mean (MEAN), maximum (MAX) and minimum (MIN) monthly (MSR) and seasonal (SSR) severity ratings with standard deviation (STD) for Osijek, Zagreb-Grič, Gospić, Crikvenica and Hvar in the periods 1961–1990 and 1981–2010.

Months	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**SSR**
	MSR						**Jun-Sep**
Osijek							
MEAN1961-90	2.14	2.11	3.61	4.14	3.20	2.18	3.26
STD	1.56	1.56	2.40	2.91	2.48	1.79	1.66
MAX	6.52	8.25	9.14	11.63	9.61	7.61	6.70
MIN	0.06	0.29	0.40	0.44	0.33	0.00	0.75
MEAN1981-10	3.22	3.22	5.59	5.96	3.60	2.29	4.59
STD	2.13	2.59	2.73	3.69	2.70	2.12	1.99
MAX	8.37	12.52	11.93	15.52	11.43	9.11	10.34
MIN	0.94	0.65	1.33	0.26	0.54	0.25	1.17
Zagreb-Grič							
MEAN1961-90	1.98	1.70	2.72	2.41	1.28	0.73	2.03
STD	1.61	1.14	1.87	1.98	1.18	0.71	0.78
MAX	5.82	5.49	6.77	8.72	5.69	3.30	3.86
MIN	0.14	0.43	0.77	0.60	0.23	0.01	0.83
MEAN1981-10	2.42	2.09	3.12	3.64	1.39	0.56	2.56
STD	1.74	1.33	1.79	3.30	1.24	0.64	1.31
MAX	8.19	5.52	7.31	13.89	5.51	3.30	6.30
MIN	0.50	0.43	0.81	0.39	0.05	0.06	0.83
Gospić							
MEAN1961-90	1.39	1.89	4.65	5.22	2.36	1.08	3.53
STD	1.24	1.71	2.87	4.12	2.98	1.87	2.14
MAX	5.75	9.49	11.31	15.87	12.64	10.33	8.96
MIN	0.14	0.44	1.27	0.42	0.15	0.00	0.97
MEAN1981-10	1.94	2.90	5.93	7.79	2.31	0.91	4.73
STD	1.73	2.20	3.21	6.25	2.34	1.86	2.70
MAX	9.04	10.04	13.34	27.75	10.90	10.33	13.88
MIN	0.14	0.38	1.27	0.90	0.12	0.00	0.97
Crikvenica							

MEAN1961-90	0.94	1.43	3.31	3.45	1.51	1.20	2.42
STD	0.76	1.25	2.20	2.68	1.55	1.25	1.39
MAX	3.55	4.79	8.32	14.37	6.31	4.63	7.41
MIN	0.04	0.12	0.91	0.30	0.07	0.00	0.39
MEAN1981-10	1.50	2.20	4.41	4.58	1.36	0.81	3.14
STD	1.53	1.79	3.14	2.99	1.17	1.05	1.57
MAX	6.22	6.46	13.22	10.74	3.85	4.18	7.51
MIN	0.04	0.23	0.91	0.30	0.07	0.01	0.39
Hvar							
MEAN	3.07	4.79	8.60	8.82	5.29	3.34	6.87
STD	1.76	2.61	2.89	3.63	3.71	2.58	2.46
MAX	7.10	11.30	13.53	17.64	15.22	10.41	12.01
MIN	0.59	0.80	2.79	2.93	0.76	0.12	2.60
MEAN	3.08	5.17	9.44	9.31	5.94	2.88	7.46
STD	1.40	2.71	3.02	3.82	3.69	2.53	2.29
MAX	7.10	11.30	15.95	17.64	15.22	10.41	12.01
MIN	0.87	1.78	3.94	1.76	0.36	0.45	3.28

Table 7.4.1–2 Linear trends of monthly (MSR) and seasonal (SSR) severity ratings at selected stations in Croatia mostly in the periods 1901–2010 and 1961–2010. Significant linear trends at the level ≤ 0.05 are marked in bold.

Months	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**SSR**
1901-2010	**MSR**						**Jun-Sep**
Osijek	-0.03	-0.18	-0.29	-0.24	-0.18	**0.06**	-0.22
Zagreb-Grič	**0.12**	-0.01	0.04	0.09	-0.03	-0.01	0.02
Gospić	-0.01	-0.14	-0.13	0.07	-0.08	0.03	-0.07
Crikvenica	**0.14**	**0.18**	**0.38**	**0.34**	0.06	**0.07**	**0.24**
Hvar	**0.10**	0.14	**0.42**	0.28	0.09	**0.14**	**0.23**
1951-2010							
Osijek	**0.03**	**0.20**	**0.47**	0.16	-0.12	0.00	**0.18**
Zagreb-Grič	0.17	0.10	0.11	0.17	-0.12	-0.05	0.06
Gospić	0.17	0.18	**0.46**	0.64	-0.18	-0.02	**0.28**
Rovinj	**0.32**	**0.55**	**1.02**	**0.87**	**0.46**	0.15	**0.67**
Rijeka	0.19	**0.30**	**0.66**	**0.67**	-0.17	-0.18	**0.36**
Crikvenica	0.08	0.25	0.41	0.24	-0.55	-0.21	0.09
Šibenik	-0.03	0.26	**1.06**	0.56	-0.25	-0.36	0.41
Knin	0.35	**0.72**	**1.73**	**1.44**	0.09	-0.08	**0.99**
Split-Marjan	-0.45	-0.15	**0.04**	0.99	0.19	-0.13	-0.33
Hvar	0.00	0.24	0.72	**0.21**	0.20	-0.02	**0.41**
Lastovo	**0.74**	**1.43**	**2.95**	**2.29**	**1.42**	0.44	**2.02**

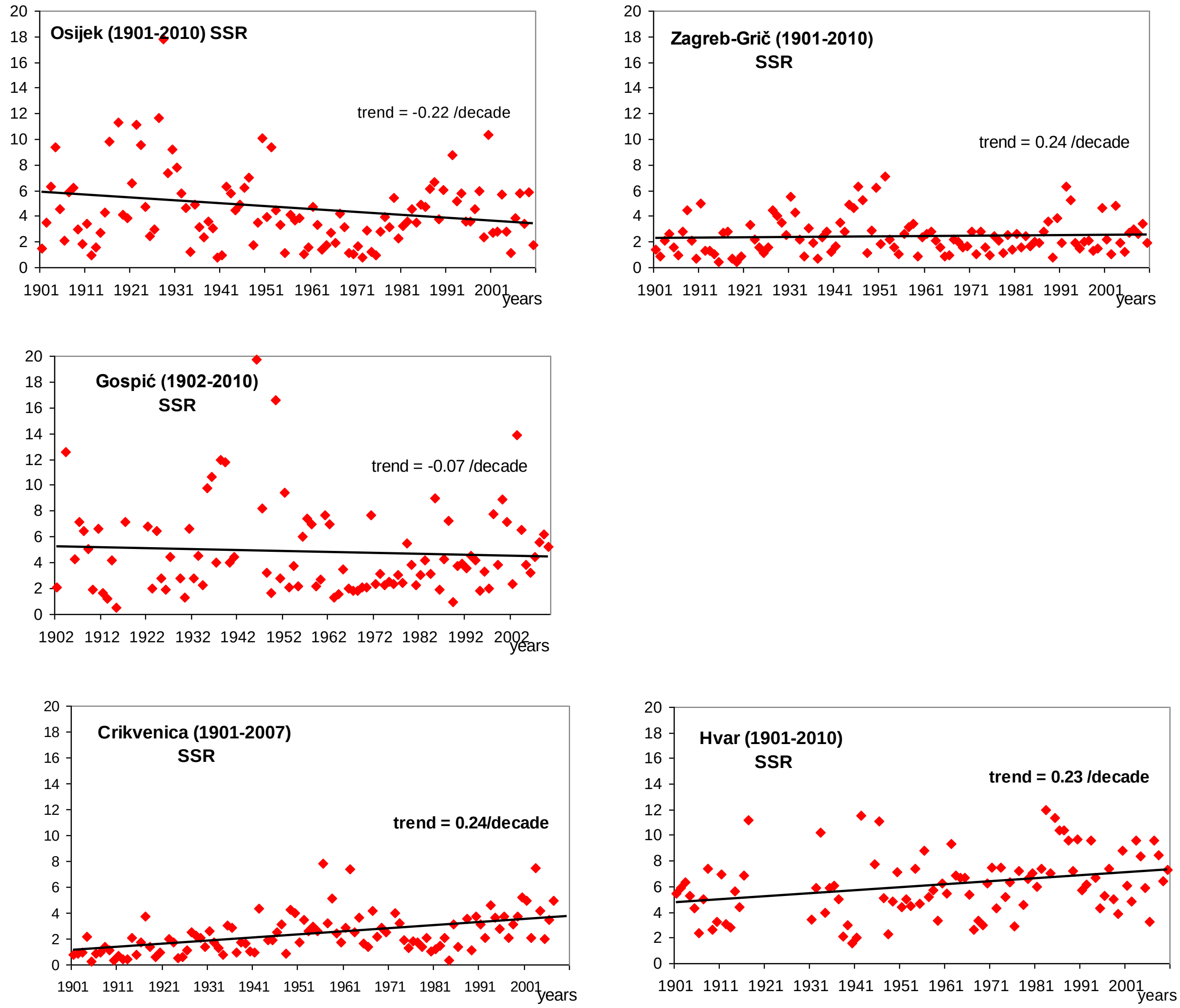


Fig. 7.4.1–1 Time series of seasonal severity rate (SSR) and linear trends for the following meteorological stations: Osijek, Zagreb-Grič, Gospić, Crikvenica and Hvar in the period 1901–2010.

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7.4.2. - Impact of climate changes on grapevines

Grapevine cultivation and wine production have had a long tradition in Croatia, which is why it is important to determine the impact of climate changes on cultivation and crop yield. In order to observe the changes in the beginning of development stages over the years, an analysis was made of phenological data for the well-known grapevine varieties *Riesling Italico*, *Malmsey* and *Plavac Mali* in the period 1961– 2010. Research worldwide indicates that future climate changes will not have an identical impact on all varieties and cultivation areas. Consequently, certain new areas will acquire optimum conditions for cultivating certain grapevine varieties. However, it is also expected that areas currently known for grapevine cultivation will expand their range of varieties, which will ultimately lead to wines losing their regional character.

The onset of the vegetation period in grapevines depends primarily on the temperature. Active temperature is achieved when the mean daily air temperature is above 10°C. On average, on the Adriatic coast sprouts begin to appear in the final week of March and this phase lasts until the end of the second ten-day period of April, while in the continental area this phase spans the second half of April (see Table 7.4.2–1). The final development stage is fruit picking, whose onset is not as uniform as that of the beginning of sprouting since it depends on whether grapes belong to an early or late variety. On average, fruit picking begins anywhere from the end of July until mid-October on the Adriatic coast, and from mid-August until mid-October in the continental region. A high standard deviation (12–18 days) was noted for some grapevine varieties at Dalmatian stations in the period 1981–2010. This was observed in the following phases: beginning of ripening, full ripening and fruit picking, which indicates a great variability in the onset of these pheno-phases from year to year. A comparison of the duration of the grapevine vegetation period (from beginning of sprouting to fruit picking) over the last three decades with the referent period 1961–1990 indicates that vegetation lasts shorter on average for all the observed varieties.

The duration of the ripening period in grapes is defined as the difference between the mean date of the onset of full ripening and the beginning of ripening. Over the last 30 years the ripening period has been reduced by as much as 2 weeks (Table 7.4.2–2). The shortening of the vegetation period is more due to the fruit picking phase beginning earlier in the summer than to the earlier onset of vegetation in the spring. This affects the sugar-acid ratio in grapes, as well as wine quality, and results in higher alcohol content, which in turn makes certain varieties harder to identify. Linear trends indicate an earlier onset of spring pheno-phases in *Riesling Italico* at stations in continental Croatia, as well as in *Malmsey* in Istria, by 2–3 days/10 years (Table 7.4.2–3 and Figure 7.4.2–1). In Dalmatia, *Plavac Mali* shows a significantly earlier beginning of sprouting, leaf unfolding and flowering only at the Hvar station. Trends are positive for the beginning of ripening of *Riesling Italico* in Križevci and Daruvar, as well as *Plavac Mali* in Hvar and Orebić by 2–6 days/decade. The onset of full ripening and fruit picking comes significantly earlier in continental Croatia and Istria than in the mid-Adriatic. This is confirmed by winegrowers whose experience indicates that there are greater changes in the earlier onset of pheno-phases in continental Croatia than in Dalmatia. For instance, the extremely hot years at the beginning of the 21st century saw earlier and later varieties experience ripening at practically the same time. Consequently, the grapes had a very high sugar content, which resulted in wines with a high alcohol content. Such wines resemble Dalmatian wines, so cultivation of red grape varieties has become more frequent in continental Croatia.

Table 7.4.2–1 Mean (MEAN), the latest (MAX) and the earliest (MIN) dates of pheno-phases for grapevine with standard deviation (STD) for selected stations in Croatia mostly in the period 1961–2010. BS: Beginning of sprouting (2-3 cm); BR: Beginning of ripening; UL: Leaf unfolding (2x3 cm); FR: Full ripening; BF: Beginning of flowering/ First flowers open; RP: Fruits ripe for picking;EF: End of flowering

PHENO-PHASES			BS	UL	BF	EF	BR	FR	RP
RIESLING ITALICO	Daruvar	MEAN1961-90	25.4.	3.5.	12.6.	21.6.	22.8.	26.9.	5.10.
		STD	9	9	6	6	5	5	6
		MAX	9.5.	16.5.	26.6.	4.7.	1.9.	3.10.	15.10.
		MIN	4.4.	15.4.	2.6.	12.6.	11.8.	14.9.	16.9.
		MEAN1981-10	22.4.	30.4.	6.6.	17.6.	27.8.	17.9.	27.9.
		STD	8	9	9	8	9	14	11
		MAX	9.5.	14.5.	21.6.	29.6.	10.9.	3.10.	8.10.
		MIN	3.4.	9.4.	7.5.	22.5.	29.7.	7.8.	27.8.
	Križevci	MEAN1961-90	27.4.	4.5.	11.6.	19.6.	24.8.	2.10.	13.10.
		STD	8	9	6	6	8	7	7
		MAX	10.5.	20.5.	26.6.	3.7.	10.9.	22.10.	27.10.
		MIN	12.4.	16.4.	4.6.	12.6.	13.8.	23.9.	1.10.
		MEAN1981-10	22.4.	29.4.	6.6.	17.6.	28.8.	25.9.	3.10.
		STD	8	8	10	6	8	6	8
		MAX	4.5.	12.5.	22.6.	29.6.	16.9.	5.10.	17.10.
		MIN	5.4.	12.4.	11.5.	6.6.	16.8.	15.9.	20.9.
MALMSEY	Čepić	MEAN1961-90	26.4.	1.5.	9.6.	18.6.	19.8.	19.9.	25.9.
		STD	9	9	6	6	5	7	10
		MAX	6.4.	10.4.	28.5.	9.6.	11.8.	1.9.	15.9.
		MIN	28.3.	3.4.	15.5.	25.5.	5.8.	20.8.	5.9.
		MEAN1981-10	18.4.	26.4.	31.5.	12.6.	20.8.	12.9.	22.9.
		STD	10	10	8	7	9	12	6
		MAX	5.5.	12.5.	13.6.	25.6.	10.9.	27.9.	2.10.
		MIN	28.3.	3.4.	15.5.	25.5.	5.8.	20.8.	5.9.
PLAVAC MALI	Hvar	MEAN1961-90	12.4.	18.4.	31.5.	9.6.	15.8.	16.9.	30.9.
		STD	7	7	5	5	8	14	6
		MAX	29.3.	4.4.	23.5.	30.5.	3.8.	20.8.	20.9.
		MIN	22.4.	29.4.	13.6.	21.6.	31.8.	7.10.	13.10.
		MEAN1981-10	5.4.	11.4.	26.5.	5.6.	20.8.	14.9.	29.9.
		STD	11	10	8	5	6	15	8
		MAX	18.3.	25.3.	13.5.	28.5.	10.8.	25.8.	10.9.
		MIN	22.4.	26.4.	14.6.	15.6.	31.8.	7.10.	13.10.
	Orebić	MEAN1961-90	15.4.	21.4.	30.5.	7.6.	17.8.	24.9.	30.9.
		STD	10	10	8	7	9	10	10
		MAX	29.3.	4.4.	12.5.	20.5.	1.8.	26.8.	29.8.
		MIN	30.4.	5.5.	17.6.	24.6.	7.9.	8.10.	16.10.
		MEAN1981-10	16.4.	21.4.	28.5.	6.6.	29.8.	26.9.	1.10.
		STD	8	8	5	5	11	8	7
		MAX	4.4.	13.4.	14.5.	23.5.	23.7.	20.8.	20.9.
		MIN	27.3.	2.4.	20.5.	26.5.	13.8.	3.9.	13.9.
	Lastovo	MEAN1961-90	19.4.	25.4.	31.5.	9.6.	13.8.	23.9.	2.10.
		STD	7	7	8	7	12	12	7
		MAX	29.4.	4.5.	20.6.	25.6.	5.9.	16.10.	16.10.
		MIN	4.4.	13.4.	14.5.	23.5.	23.7.	20.8.	20.9.
		MEAN1981-10	19.4.	24.4.	30.5.	9.6.	13.8.	17.9.	30.9.
		STD	9	9	6	6	15	18	10
		MAX	4.5.	8.5.	11.6.	19.6.	5.9.	16.10.	16.10.
		MIN	28.3.	3.4.	17.5.	27.5.	17.7.	18.8.	9.9.

Table 7.4.2–2 Mean duration (days) for ripening of Riesling Italico and *Plavac Mali* from beginning to full ripening at the Daruvar and Hvar stations in the following periods: 1961–1990, 1971–2000 and 1981–2010.

Variety	**Stations**	**Ripening duration of grape vine (days)**		
		1961.–1990.	1971.–2000.	1981.–2010.
Riesling Italico	Daruvar	35	30	22
Plavac mali	Hvar	32	33	26

Table 7.4.2–3 Linear trends of phenophases (day/decade) for grapevines at selected stations in Croatia mostly in the period 1961-2010. Significant linear trends at the level ≤ 0.05 are marked in bold.

Trend (day/decade)	**Pheno-phases**	**BS**	**UL**	**BF**	**EF**	**BR**	**FR**	**RP**
RIESLING ITALICO	**Daruvar** 1961-2010	**-1.55**	-1.49	**-3.01**	**-1.88**	**2.34**	**-3.73**	**-3.10**
	Križevci 1961-2010	**-2.22**	**-2.40**	-2.36	-0.35	**1.95**	**-4.43**	**-5.24**
MALMSEY	**Čepić** 1968-2010	**-3.23**	**-1.92**	**-5.03**	**-2.90**	-0.49	**-4.88**	-2.29
PLAVAC MALI	**Hvar** 1962-2010	**-3.87**	**-3.85**	**-2.35**	**-1.50**	**2.41**	-0.20	-0.81
	Orebić 1962-2010	0.19	-0.25	-0.27	-0.34	**6.23**	0.98	0.53
	Lastovo 1961-2010	-0.30	-0.67	-0.20	0.15	-0.64	-3.70	-1.02

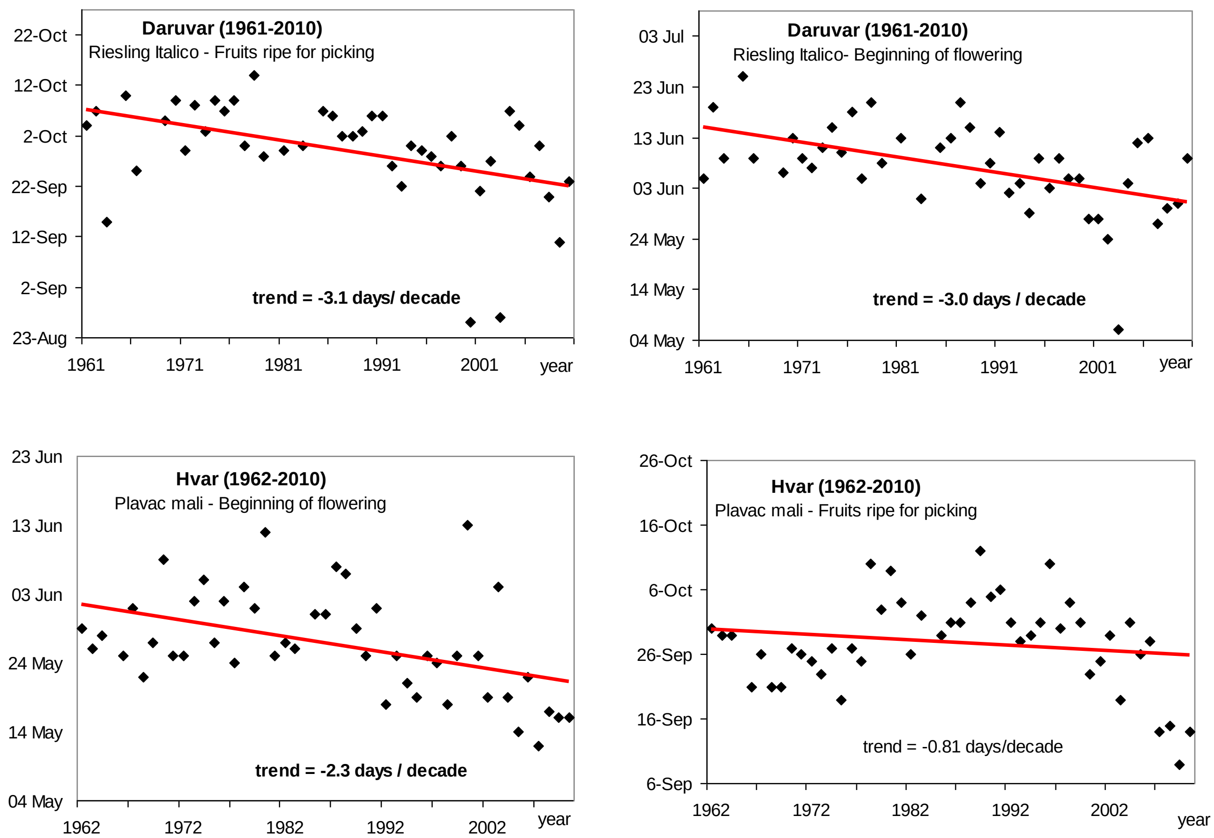

Fig. 7.4.2–1 Time series of phenological phases of grapevines and linear trends for Daruvar and Hvar in the period 1961–2010.

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8. - RESEARCH, SYSTEMATIC OBSERVATION AND MONITORING

8.1. - Global Climate Observation System (GCOS)

Global Climate Observation System (GCOS) was established in 1992 and the Republic of Croatia, represented by the Meteorological and Hydrological Service, has been its member since then. This system includes observation in all parts of the climate system – in the atmosphere, ocean, sea and land. It is intended to define and cover all the observations required for monitoring the climate system including satellite observations at the global, regional and national levels, and to create conditions for observation enhancement.

Global Earth Observation System of Systems (GEOSS) is a new initiative taken with the objective to co-ordinate and enhance all current observing systems at the global level in support of the requirements of user areas: natural disasters, health, energy, climate, water, weather, ecosystems, agriculture and biodiversity. The Republic of Croatia joined the GEOSS in 2004.

8.2. - Data collection and systematic observations in Croatia

8.2.1. - Existing observation networks

The Republic of Croatia has a long tradition in monitoring of all segments of the climate system. The Meteorological and Hydrological Service (DHMZ – Državni hidrometeorološki zavod) is a national institution for meteorology and hydrology and has been carrying out meteorological observations for operational needs since 1851.

Croatian institutions that maintain observing systems in the climate segments of atmosphere, sea and land are:

Meteorological and Hydrological Service;

Ministry of Transport;

Ministry of Environmental and Natural Protection;

Institute for Medical Research;

Public Health Institute;

Institute of Oceanography and Fisheries;

Croatian Hydrographic Institute;

"Ruđer Bošković" Institute

"Andrija Mohorovičić" Geophysical Institute.

Apart from the institutions listed, numerous institutions and sectors of economy run their own systematic or sporadic observations. Table 8.2-1-1 shows all stations in Croatia for obseration of climate system segments.

Table 8.2.1-1: Types and number of stations for climate system observation in Croatia

Type of stations	**Number of stations**
Main meteorological stations	41
Climatological stations	117
Precipitation stations	366
Automatic meteorological stations	58
Radio-sonde stations	2
Radar stations	8
Atmospheric composition - chemistry stations	50
Sea level stations	10
Sea temperature stations	20
Hydrological stations	300
Soil temperature statiins	30
Phenological stations	30

8.2.2. - Modernization of DHMZ meteorological observation network

Meteorological observations deal with two kinds of data - visual observations of weather phenomena and instrumental data. Some observations began in Croatia in the first quarter of 19th century. Currently, DHMZ is operating mainly manually, i.e. by observers at: 41 main meteorological, 117 climatological, 336 precipitation and 23 rain storage stations (Figure 8-2-2-1). Partially automated weather stations (AWS) are co-located at 32 main meteorological station sites, and 26 non-completed AWS are installed at other locations. Spatial distribution of AWS network is represented in Fig. 8.2.2-2a and temporal evolution of AWS network is represented in Fig. 8.2.2-2b). Standard measurement time resolution at existing AMS is 10 minutes with the same potential of transmission. Terrestrial observations (such are: soil temperature, soil moisture, pan evaporation, and solar radiation measurements) are co-located at 19 main meteorological stations. DHMZ still takes care of the two radio-sounding systems in Zagreb and Zadar, 2 Doppler S-band + 6 small S-band weather radars and one sodar.

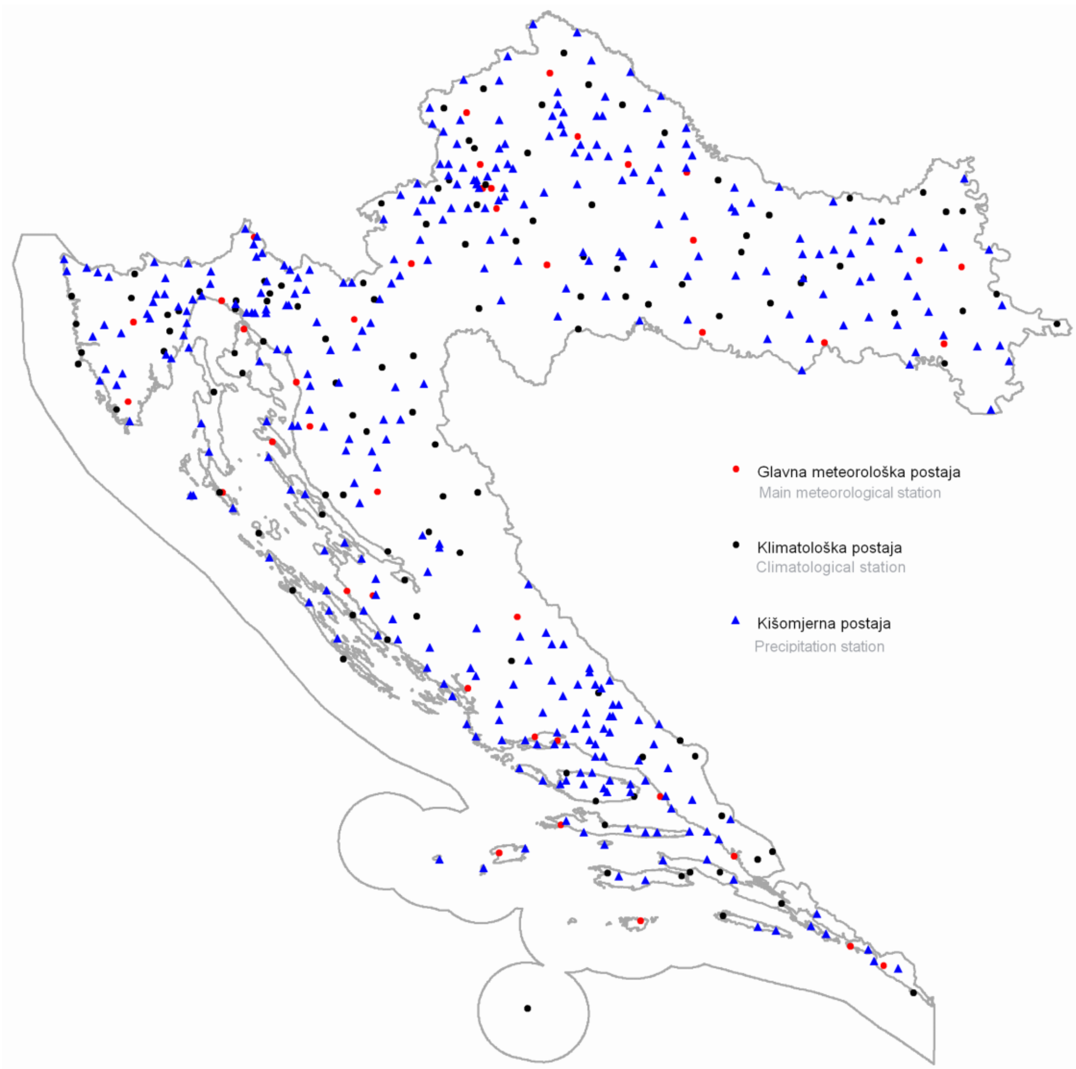

Figure 8.2.2-1. Distribution of conventional meteorological stations in Croatia

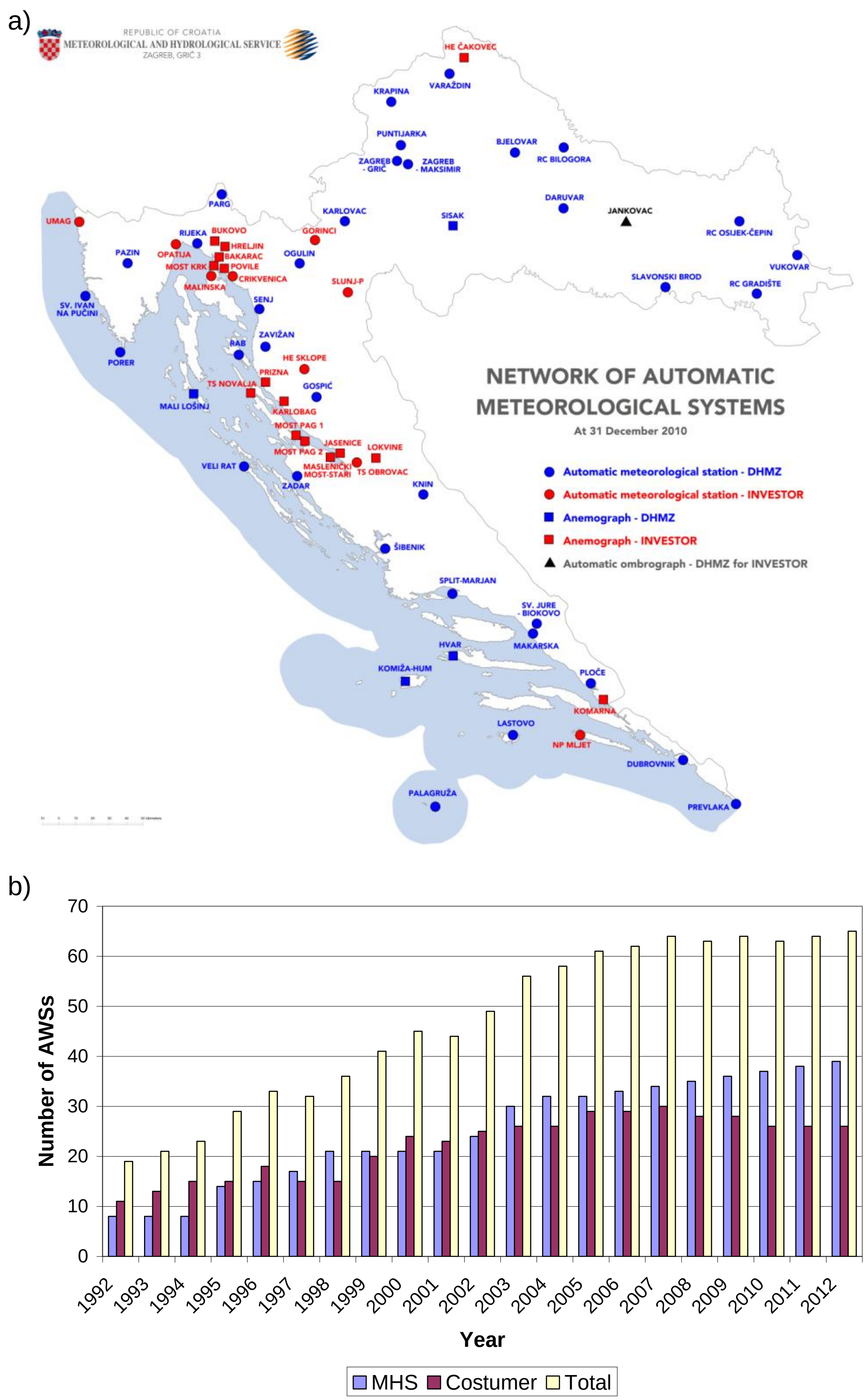

Figure 8.2.2-2 a) Distribution of AWS in Croatia and b) Development of AWS network in Croatia

Cost benefit analysis, made by Oklahoma University, indicates that futher development of is justified as investment of 1USD results up to 7USD benefit for society (Figure 8.2.2-3).

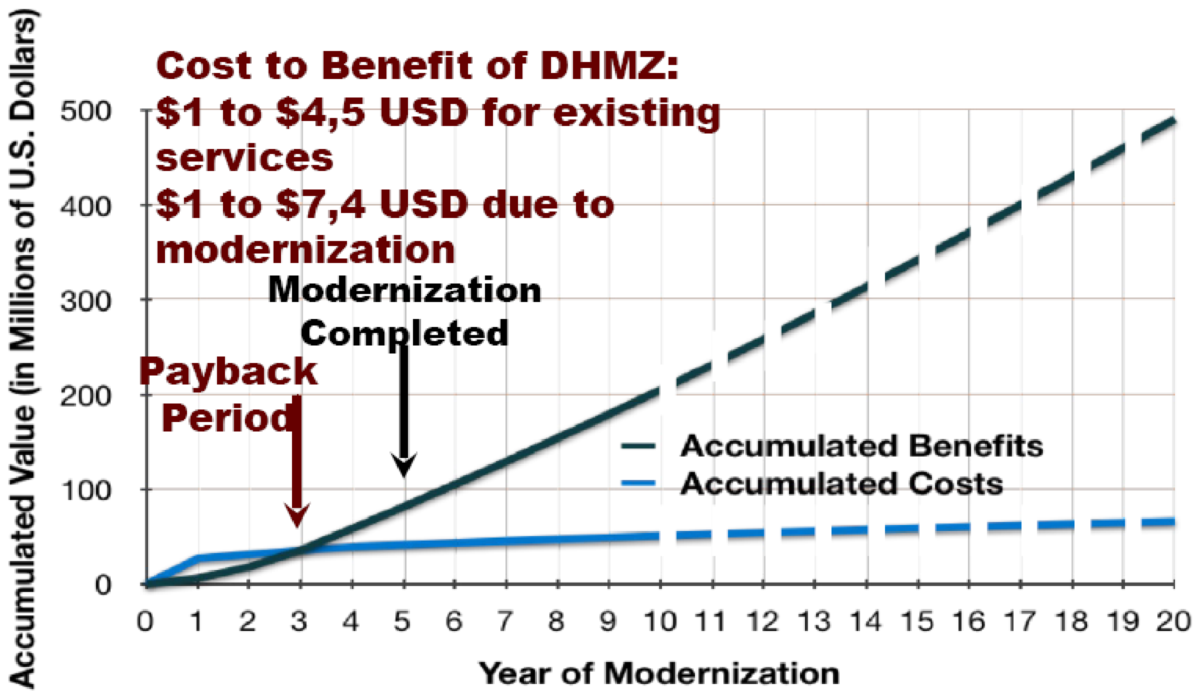

Figure 8.2.2-3 Oklahoma University cost benefit analysis

In spite a respectable number of meteorological stations cited and data collected there is necessity for serious modernization of existing surface and upper air meteorological network what includes modernization existing and installation of new ones: 36 main meteorological stations, 116 climatological stations, 320 rainfall stations, 6 marine stations, 2 radio-sounding stations, 3 wind profilers, 3 lidars as well as 6 weather radars (Figure 8.2.2-4).

Data obtained from the meteorological stations network modernised in this way (both surface and upper air) would serve the numerous purposes such as: monitoring and evaluation of long range transboundary pollutions; analysis and implementation of modelling techniques in terms of geographical distribution of concentration (of emissions) aiming to secure the issue of warning and immediate and appropriate information if necessary when there is a risk to human health from exposure to air pollution, particularly for sensitive groups of the population; climate monitoring and climate change model calibration and testing in order to enable adequate planning and management of human environment and sustainable activity sectors; performing detailed measurements in order to understand better the impact of pollutant and to develop appropriate policies for climate addaptation and mitigation including natural (e.g. floods and drouts) and human disaster risk reduction; renewable energy production purposes etc.

Realization of meteorological observation network modernization is realistic as the project *Modernization of meteorological and hydrological observation networks* has been recognized as priority by Ministry for Environmental and Natural Protection in its operative programme for environment, within thematic objective adaptation on climate changes of European Union within financial period 2014-2020 from which a cofinancing is expected.

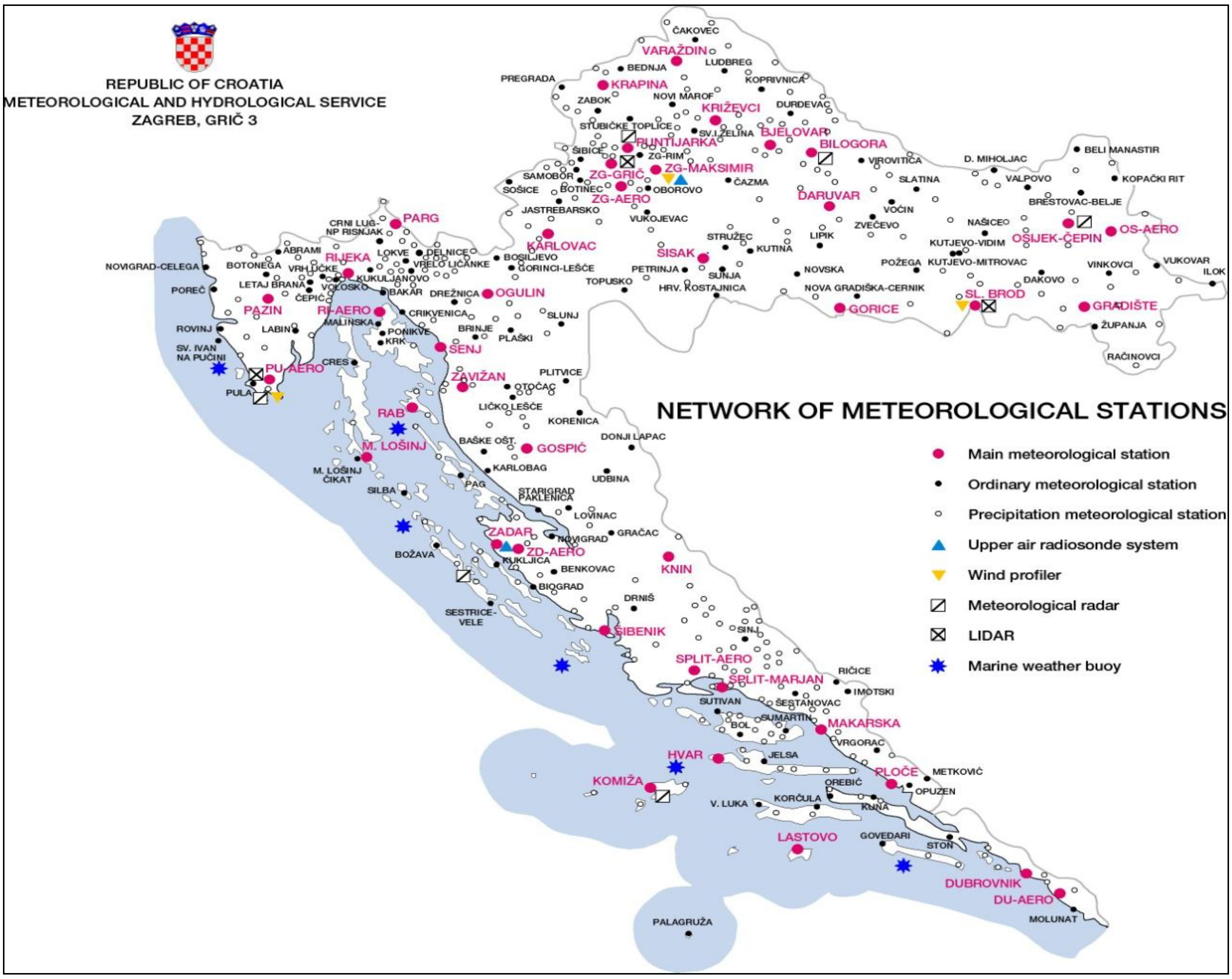

Figure 8.2.2-4 Expected modernized meteorological observation network in Croatia expected to be cofinanced by European Union fund for the period 2014-2020