9th International Conference

WATER FOR ALL

19-20 May 2022 Osijek - Croatia

CLIMATE CHANGE IMPACTS ON WATER BALANCE COMPONENTS IN BOSNIA AND HERZEGOVINA AND CROATIA

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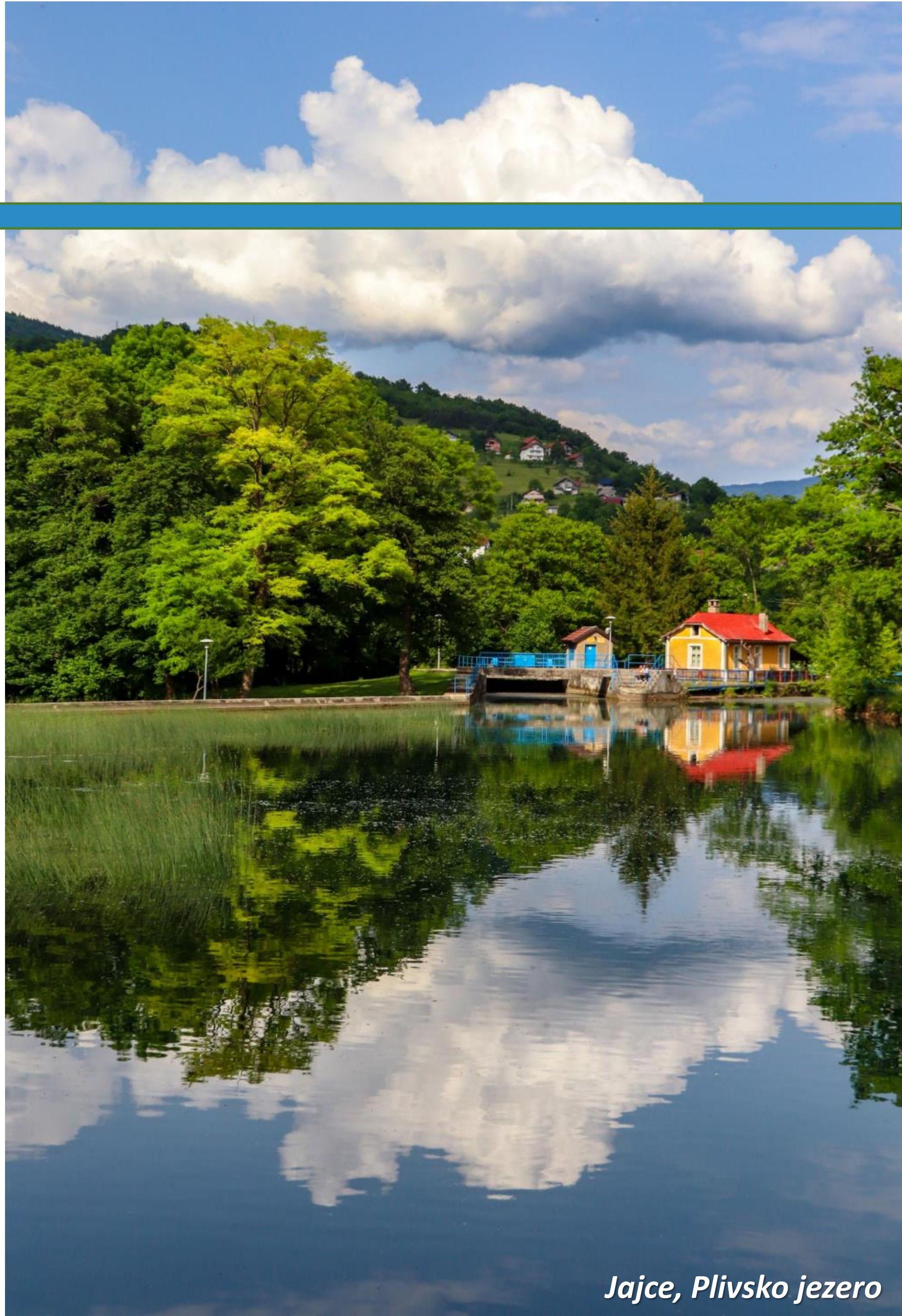
INTRODUCTION

Global climate change and associated impacts on water resources are the most urgent challenges facing mankind today and will have enduring implications for generations to come.

- Timing and magnitude of surface runoff →
- Stream discharge →
- Evapotranspiration →
- Drought occurrence →
- Flood events →

There is an essential need for effective management of water resources



[1]Sharma & Irmak, 2012

INTRODUCTION

The increase in air temperature and changes in precipitation amount has resulted in change of evapotranspiration (ET_0) and soil water balance elements (deficit, runoff, snow, etc.).

Since soil water balance is important for deremination, undertanding and model

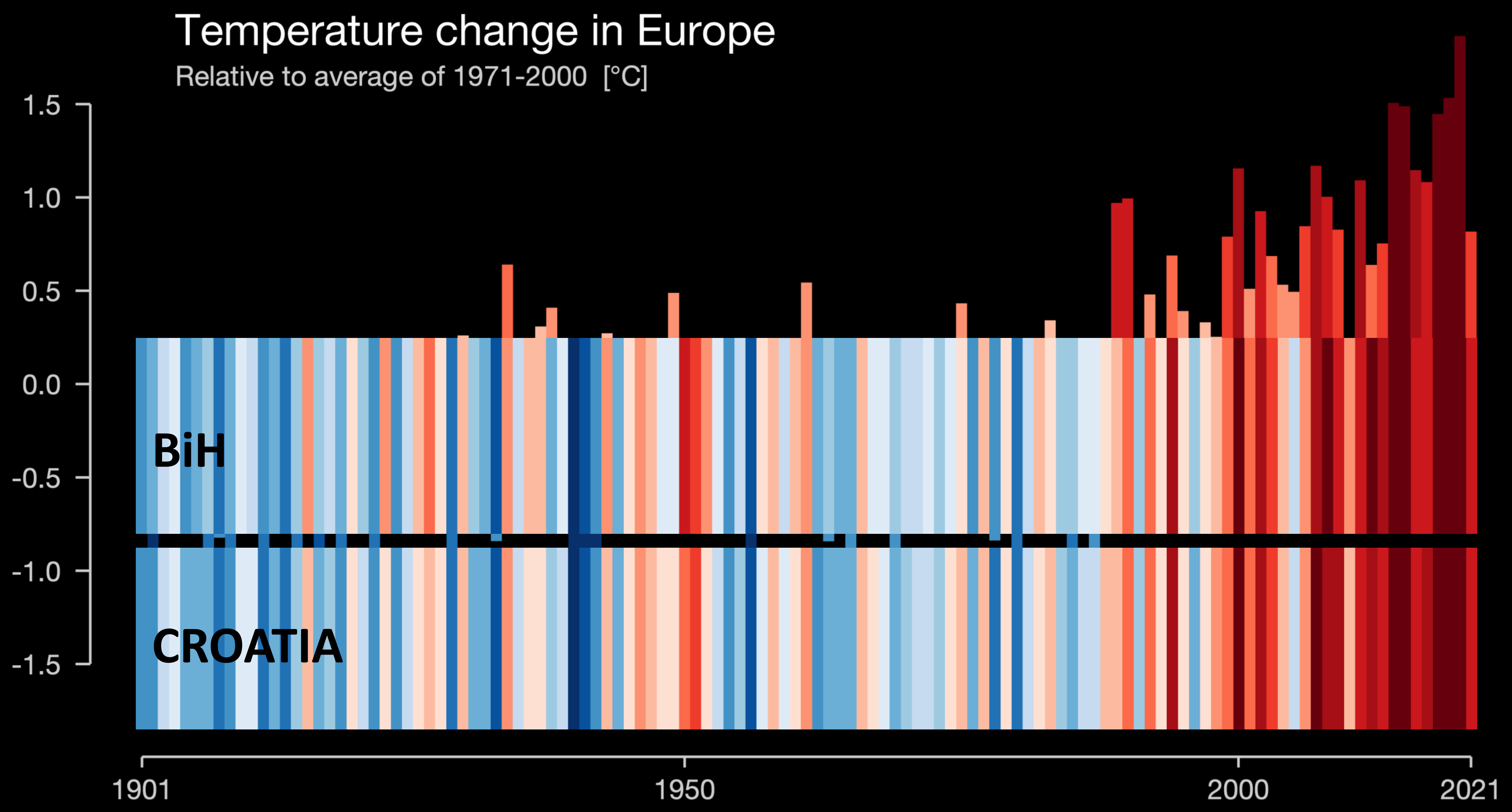
- Water availability
- Crop irrigation requirement
- Flood risk assessment
- Regional water management decision-making
- Drought analyses
- Environmental studies
- Possibilities of organizing agricultural production
- Climate change impacts and design effective adaptation and mitigation measures

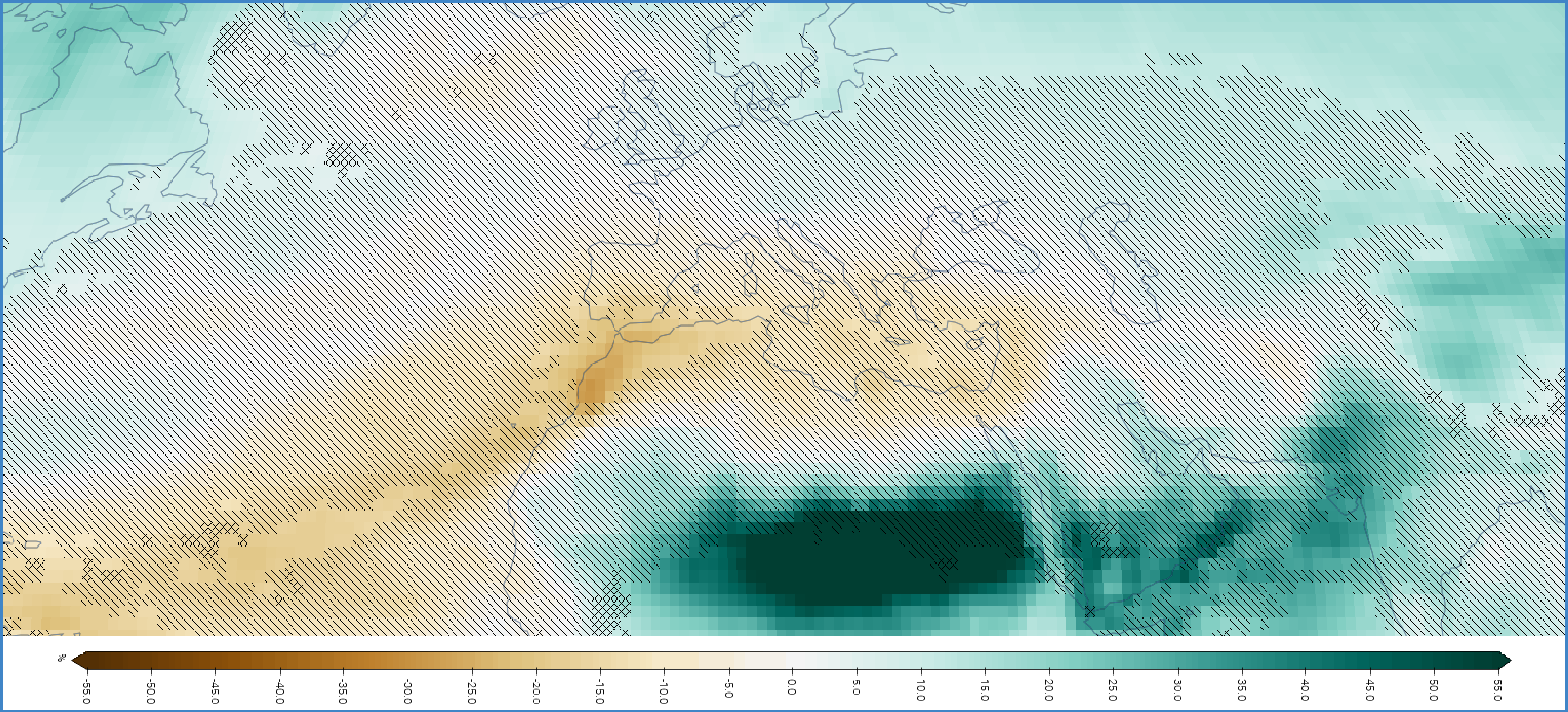
[6]Žurovec, 2012; Pereira et al., 2015; Pandey et al., 2016; Čadro S. et al., 2017; Žurovec et al., 2017.

INTRODUCTION

Characteristic	Croatia	Bosnia and Herzegovina
Area (km^2)	**56,594**	51,129
Water (%)	1.09	**1.40**
Coastline (km)	**1,777**	20
Mean elevation (m)	331	**500**
Highest point (m)	1,831	**2,386**
GDP (nominal) per capita[7] ($)	**17,337**	7,078
Population	**4,284,889**	3,531,159
Population density (per km^2)	**73.00**	69.06
HDI[8] for 2022	**0.837**	0.769
Köppen climate classification	*Dfc, Dfb, Dfa, Cfb, Cfa, Csb, Csa*	*ET, Dfb, Cfa, Cfb, Csa*
CRI[9] average for 2000–2019	**47,00 (53)**	68,17 (122)

[7]International Monetary Fund (2019); [8]United Nations Development Programme; [9]Global Climate Risk Index Eckstein et al., 2021.


Temperature change in Europe
Relative to average of 1971-2000 [°C]
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
BiH
CROATIA
1901
1950
2000
2021



Total precipitation (PR) - Change (%)

Medium Term (2041-2060) (SSP5-8.5) (rel. to 1961-1990)

CMIP6 - Annual (33 models)

Robust signal

No change or no robust signal

Conflicting signal

http://www.ipcc.ch/copyright

The aim of this study was to determine and compare the severity of changes in annual water balance between two climate periods: 1961-1990 and 1991-2020, in order to analyze the seriousness of climate change's influence on soil water balance and enable better understanding of the impact of climate change to the region of Bosnia and Herzegovina and Croatia.

MATERIALS AND METHODS

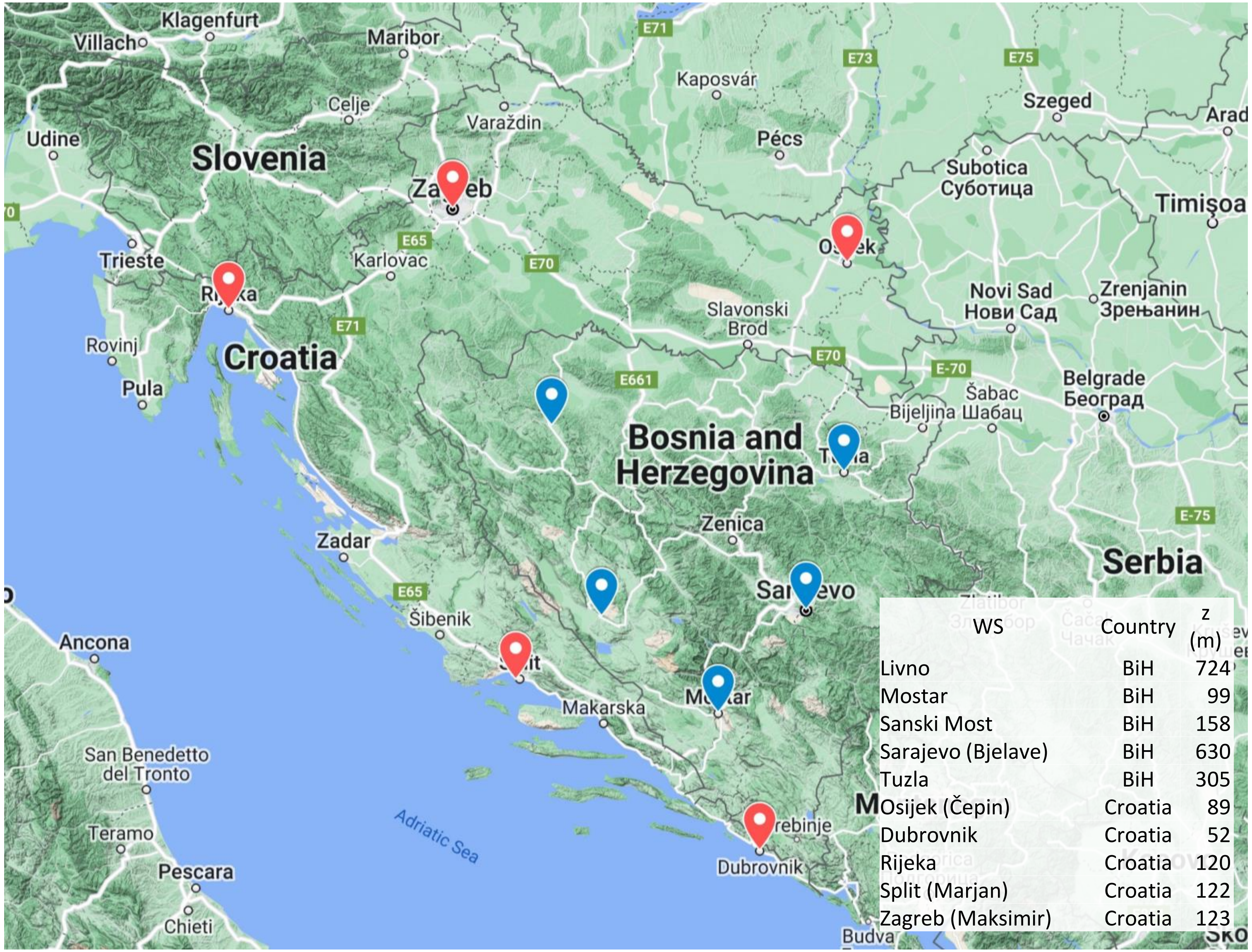
10 weather stations (WS) with long-term continuous climate data records were selected, five in Croatia: Osijek, Dubrovnik, Rijeka, Split, and Zagreb; and five in BiH: Livno, Sanaki Most, Sarajevo, Tuzla and Mostar.

From these WS for the period 1961-2020 (60 years) following parameters were collected and averaged over each month:

- **Mean, max. and min. air temperature (°C)**
- **Precipitation (mm)**
- **Relative humidity (%)**
- **Solar radiation (h day^{-1})**
- **Wind speed (m s^{-1})**

The 60-year period (720 months) is divided into two climatic periods, the climatic period of the reference normal: 1961-1990 and the last climatological standard normal 1991-2020.

Source of data: *Federal Hydrometeorological Institute Sarajevo* and Croatian Meteorological and Hydrological Service



WS	Country	z (m)
Livno	BiH	724
Mostar	BiH	99
Sanski Most	BiH	158
Sarajevo (Bjelave)	BiH	630
Tuzla	BiH	305
Osijek (Čepin)	Croatia	89
Dubrovnik	Croatia	52
Rijeka	Croatia	120
Split (Marjan)	Croatia	122
Zagreb (Maksimir)	Croatia	123

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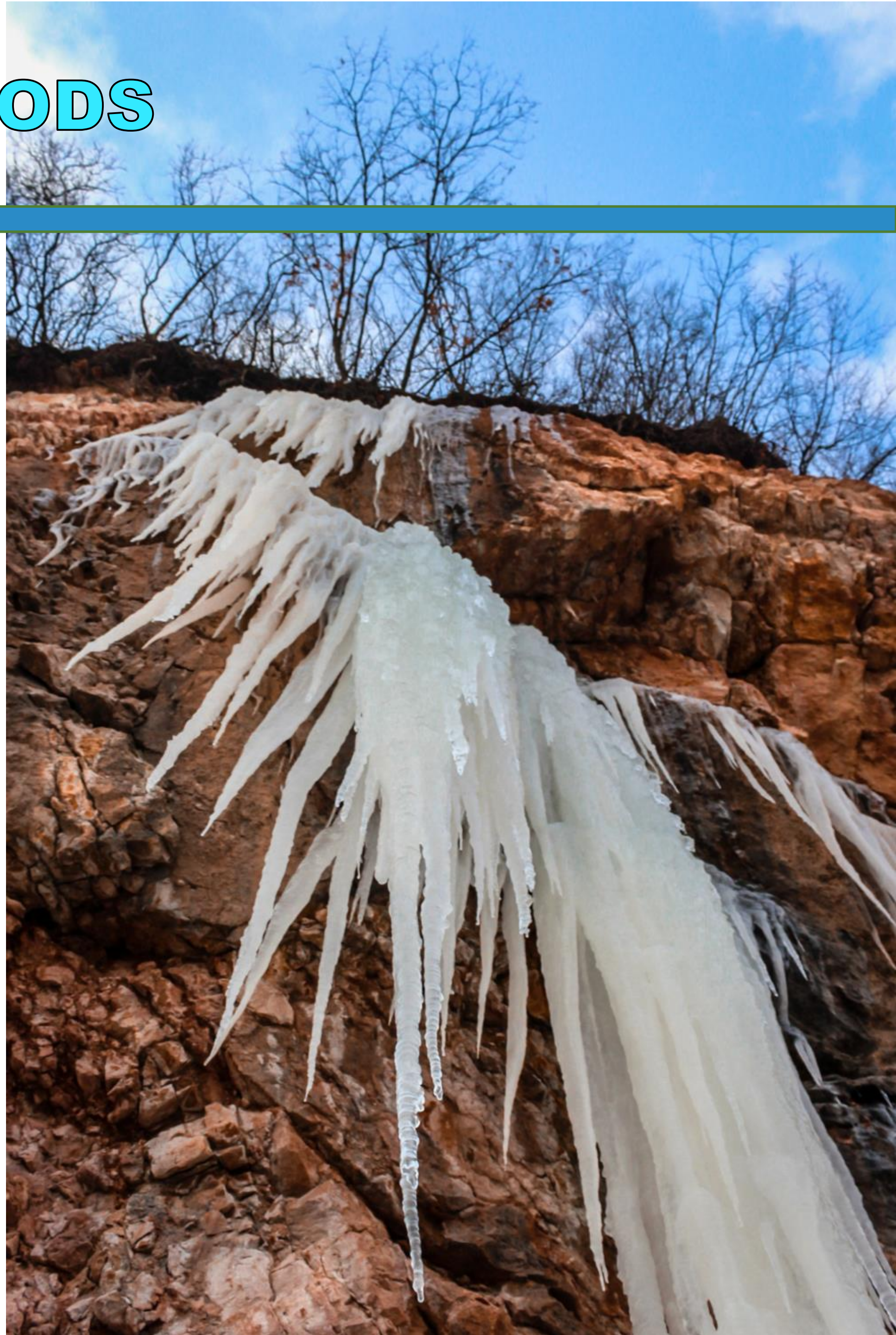
MATERIALS AND METHODS



Reference evapotranspiration (*ET_0*) was calculated using standard FAO-PM equation. All necessary parameters required for calculation of *ET_o* where computed following the procedure developed in FAO irrigation and drainage paper No. 56 and 66.

Since reflected solar radiation (*R_s*) is required for net radiation at the crop surface (*R_n*) calculation and this parameter is not measured on WS, it was estimated from the measured sunshine hours data (The Campbell–Stokes sunshine recorder) with the Ångström (1924) equation.

Actual vapor pressure (*e_a*) was derived from relative humidity data.

When wind speed was not available, the average regional wind speed value was used.

Monthly values of FAO-PM *ET_0* were calculated using *REF-ET: Reference Evapotranspiration Calculator*

Allen et al. (1998)

$$ET_0 = \frac{0.408\Delta \cdot (R_n - G) + \gamma \cdot \frac{900}{T_{mean} + 273} \cdot u_2 \cdot (e_s - e_a)}{\Delta + \gamma \cdot (1 + 0.34 \cdot u_2)}$$

Ångström (1924)

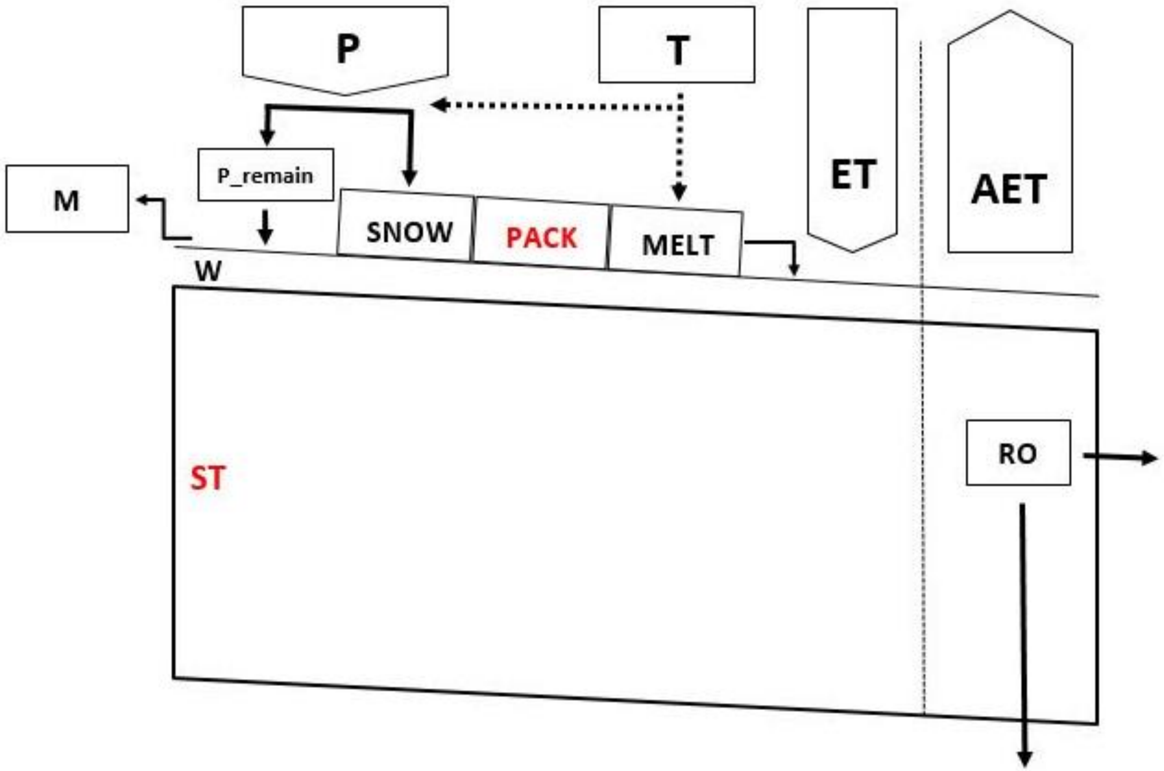
$$R_s = (a_s + b_s \cdot \mathrm{n/N}) \cdot R_a$$

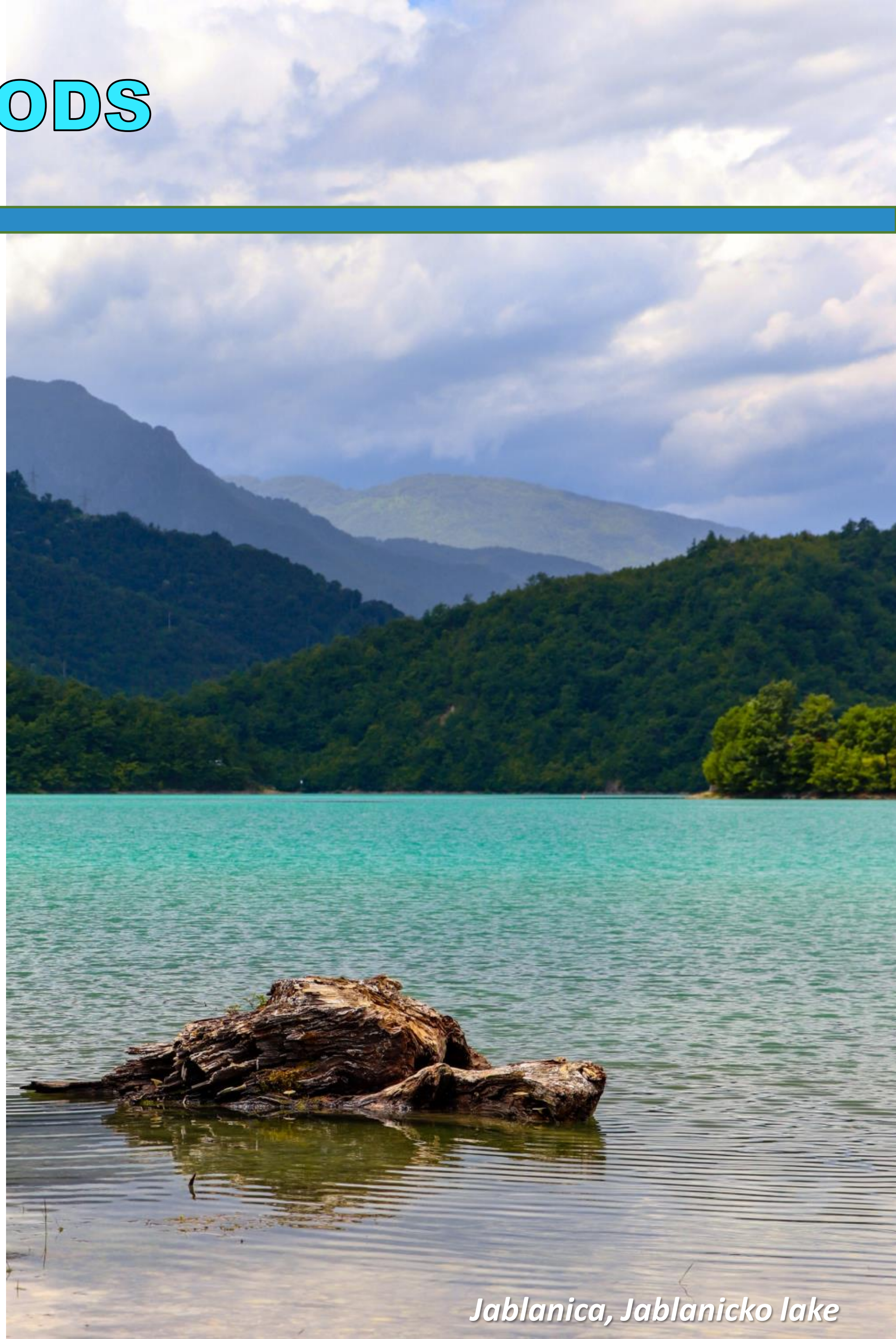
$$e_a = \frac{e^0(T_{min})\frac{RH_{max}}{100} + e^0(T_{max})\frac{RH_{min}}{100}}{2}$$

MATERIALS AND METHODS

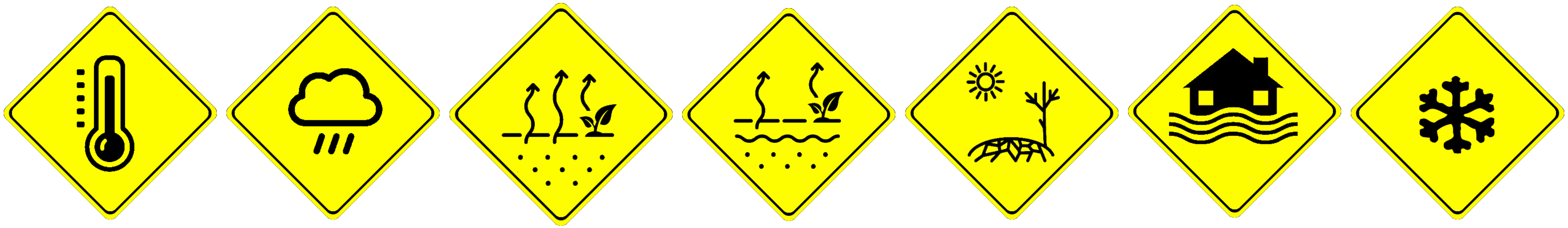
Monthly water balance was calculated using Thornthwaite & Mather method that was later modified and described in Dingman (2002).

The value of available water content in the soil: ST = 100 mm was used.





MATERIALS AND METHODS



Mean annual air temperature (°C)	Annual sum of precipitation (mm)	Annual sum of reference evapotranspiration (mm)	Annual sum of actual evapotranspiration (mm)	Annual sum of soil moisture deficit (mm)	Annual sum of total runoff (mm)	Annual sum of amount of snow (mm)
T_{mean}	**P**	**ETo**	**AET**	**M**	**RO**	**SNOW**

After calculation of annual means (μ) and the standard deviation (σ) for all analyzed water balance components the coefficient of variation (CV) was calculated.

To detect the trends within time series of water balance components (annual precipitation, reference evapotranspiration, actual evapotranspiration, soil moisture deficit, total runoff and snow) linear regression was used.

Coefficient of variation

$$CV = \frac{\sigma}{\mu}$$

Linear regression method

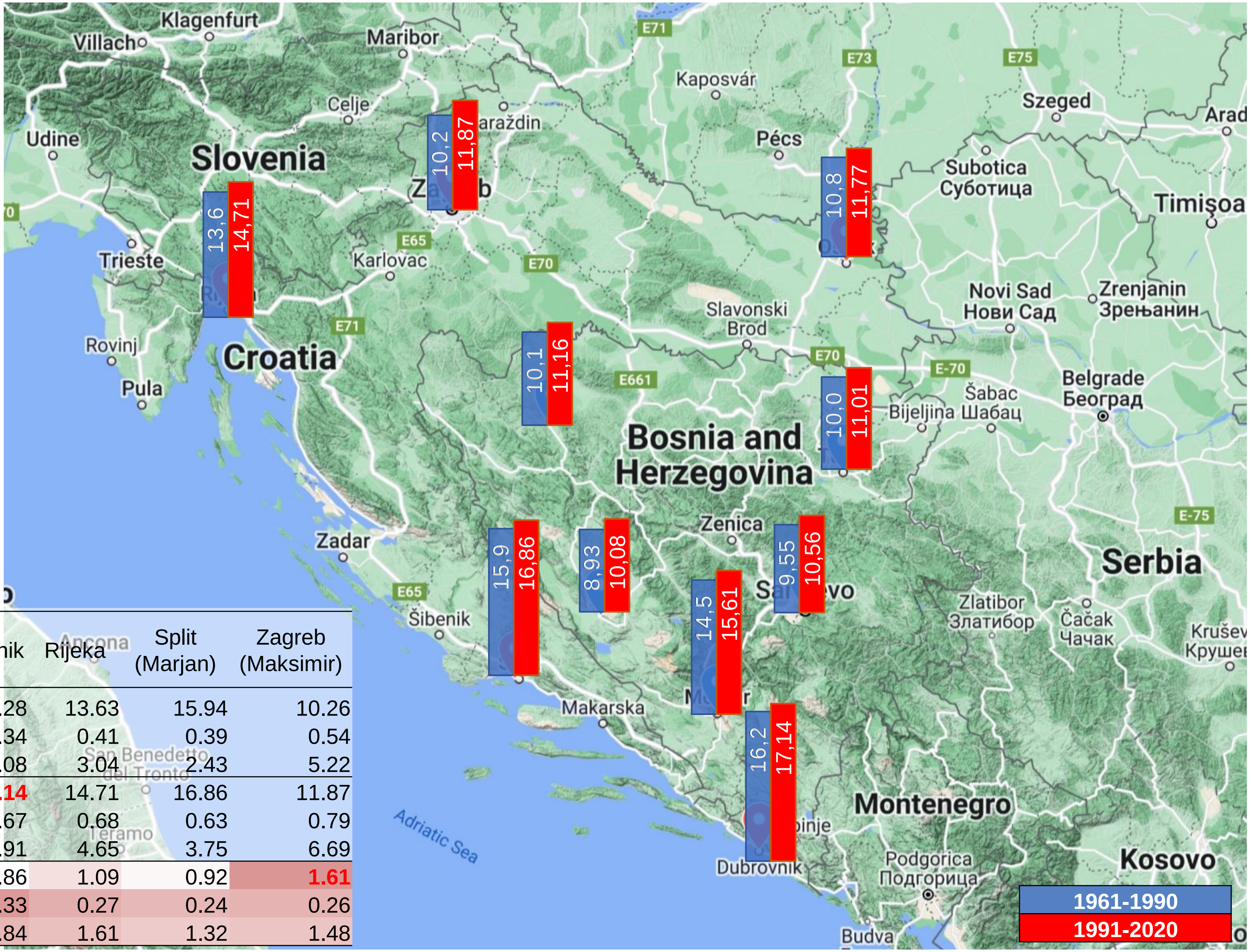
$$y = a + b \times x$$

RESULTS

Mean annual air temperature (°C)

- The highest mean monthly temperature is in Dubrovnik (17.14 °C), and the lowest in Livno (10.08 °C).
- The coefficient of variation (CV) shows the largest temperature variations in the area of Tuzla and Sarajevo.
- An increase in temperature was found in all WS, ranging from 0.86 °C in Dubrovnik to 1.61 °C in Zagreb.
- In addition, an increase in variations in monthly air temperatures was found at all locations.

Tmean		Livno	Mostar	Sanski Most	Sarajevo (Bjelave)	Tuzla	Osijek (Čepin)	Dubrovnik	Rijeka	Split (Marjan)	Zagreb (Maksimir)
1961-1990	$\bar{x}$	8.93	14.57	10.12	9.55	10.01	10.82	16.28	13.63	15.94	10.26
	σ	0.41	0.44	0.52	0.42	0.47	0.71	0.34	0.41	0.39	0.54
	CV	4.62	3.05	5.15	4.43	4.69	6.59	2.08	3.04	2.43	5.22
1991-2020	$\bar{x}$	10.08	15.61	11.16	10.56	11.01	11.77	17.14	14.71	16.86	11.87
	σ	0.61	0.59	0.69	0.73	0.81	0.76	0.67	0.68	0.63	0.79
	CV	6.02	3.77	6.22	**6.96**	**7.35**	6.47	3.91	4.65	3.75	6.69
Difference	$\bar{x}$	1.15	1.05	1.04	1.01	1.00	0.95	0.86	1.09	0.92	**1.61**
	σ	0.19	0.14	0.17	0.31	0.34	0.05	0.33	0.27	0.24	0.26
	CV	1.40	0.72	1.07	2.53	2.65	-0.12	1.84	1.61	1.32	1.48



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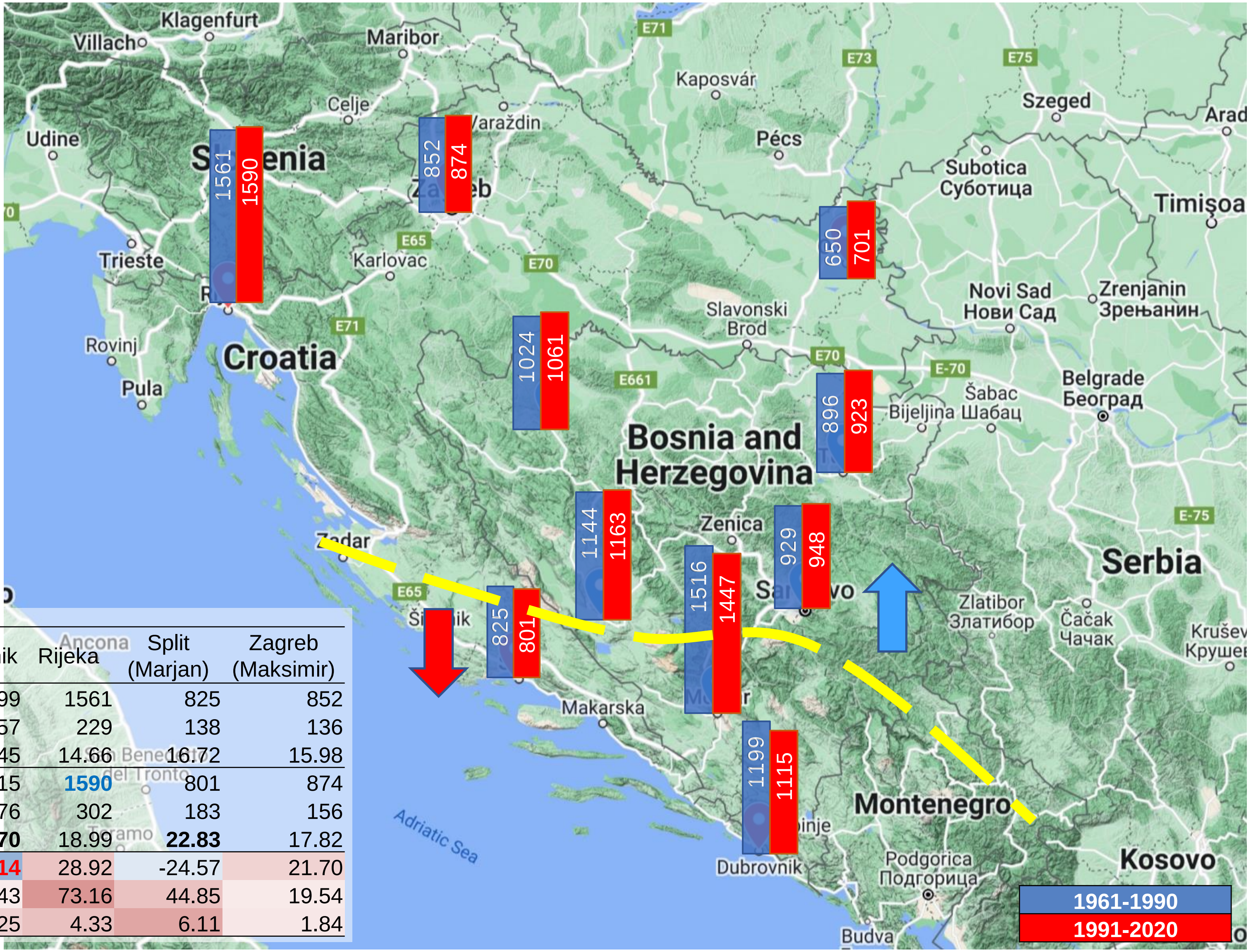
RESULTS

Mean annual precipitation (mm)

- The highest annual amount of precipitation is in Rijeka with 1590 mm, followed by Mostar with 1447 mm. The least precipitation is in Osijek, annual average is only 701 mm.
- The largest variations in precipitation are in the Mediterranean part, ie in Mostar, Dubrovnik and Split. The area where the annual amount of precipitation decreased, the highest decrease is in Dubrovnik 83 mm.
- The biggest positive change in sum of precipitation is in Osijek, where the average annual rainfall has increased by 51 mm.
- **It is interesting to note that the coefficient of variation increased at all investigated locations.**

P		Livno	Mostar	Sanski Most	Sarajevo (Bjelave)	Tuzla	Osijek (Čepin)	Dubrovnik	Rijeka	Split (Marjan)	Zagreb (Maksimir)
1961-1990	$\bar{x}$	1144	1516	1024	929	896	650	1199	1561	825	852
	σ	161	297	125	143	123	102	257	229	138	136
	CV	14.08	19.58	12.22	15.40	13.79	15.77	21.45	14.66	16.72	15.98
1991-2020	$\bar{x}$	1163	1447	1061	948	923	701	1115	1590	801	874
	σ	224	362	180	148	193	157	276	302	183	156
	CV	19.30	**25.01**	16.98	15.64	20.88	22.40	**24.70**	18.99	**22.83**	17.82
Difference	$\bar{x}$	18.73	-68.26	37.76	19.00	27.37	51.34	-83.14	28.92	-24.57	21.70
	σ	63.40	64.99	55.16	5.35	69.73	54.61	18.43	73.16	44.85	19.54
	CV	5.23	5.43	4.75	0.24	7.10	6.63	3.25	4.33	6.11	1.84



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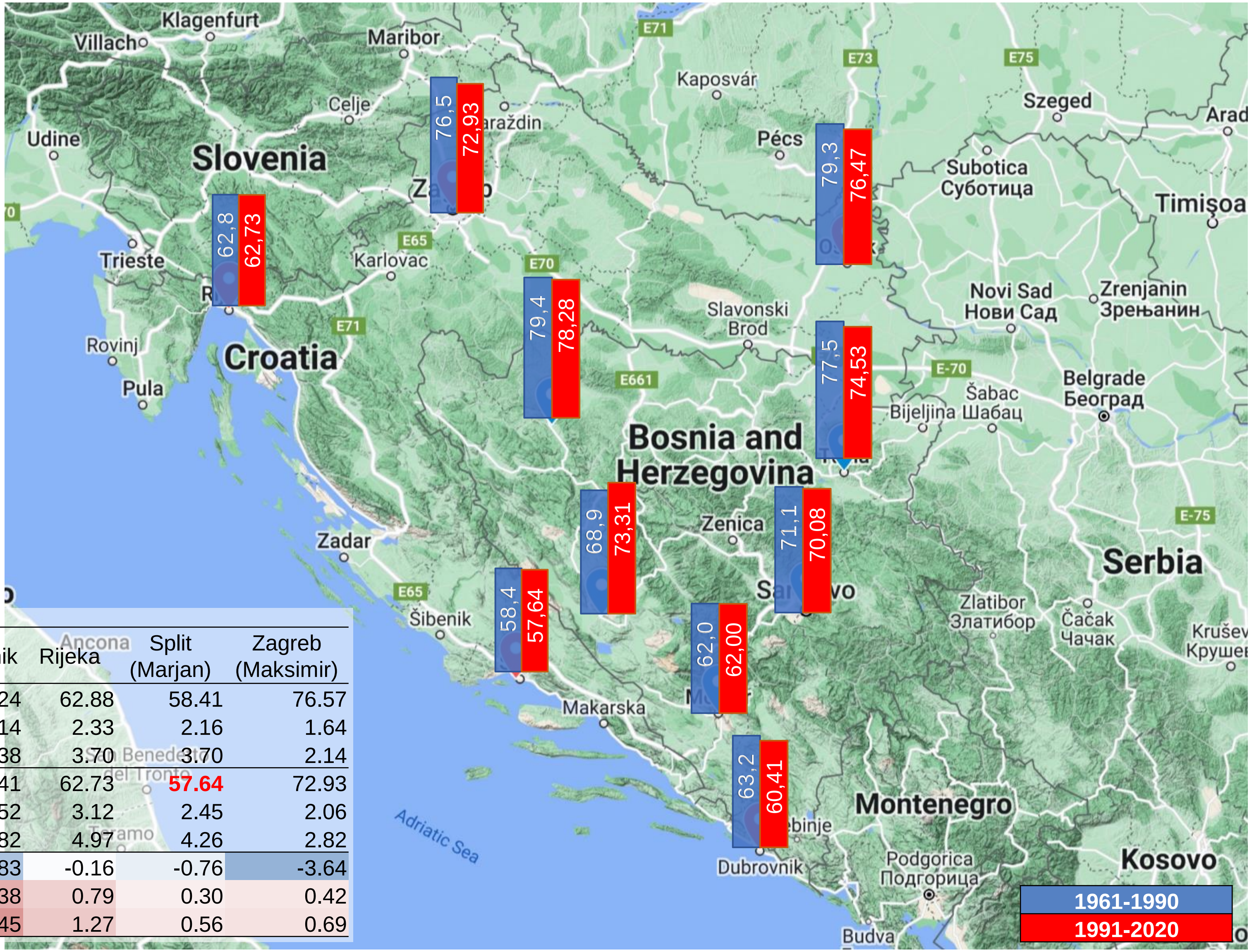
RESULTS

Mean annual relative humidity (%)

- The lowest values of mean relative humidity (RH_{mean}) are in the southern parts of the region (Split, Dubrovnik, Mostar, Rijeka), and the highest in the continental part (Sanski Most, Osijek, Tuzla).
- The Livno area stands out as the location with the greatest variations in RH_{mean}, however, and the only location where there was an increase in humidity in the period 1991-2020 compared to the previous climate normal.
- Reduction of RH_{mean}, in other locations ranges from 0.05 in Mostar to 3.64 in Zagreb.
- As with T_{mean}, this parameter also records a smaller CV only at the location of Osijek.



RH_{mean}		Livno	Mostar	Sanski Most	Sarajevo (Bjelave)	Tuzla	Osijek (Čepin)	Dubrovnik	Rijeka	Split (Marjan)	Zagreb (Maksimir)
1961-1990	$\bar{x}$	68.99	62.04	79.48	71.19	77.58	79.35	63.24	62.88	58.41	76.57
	σ	6.24	3.13	1.33	2.76	2.65	4.18	2.14	2.33	2.16	1.64
	CV	9.04	5.04	1.67	3.88	3.42	5.27	3.38	3.70	3.70	2.14
1991-2020	$\bar{x}$	73.31	62.00	78.28	70.08	74.53	76.47	60.41	62.73	57.64	72.93
	σ	8.02	3.96	2.04	3.05	2.69	2.76	3.52	3.12	2.45	2.06
	CV	**10.94**	6.39	2.60	4.35	3.61	3.61	5.82	4.97	4.26	2.82
Difference	$\bar{x}$	4.32	-0.05	-1.20	-1.11	-3.05	-2.88	-2.83	-0.16	-0.76	-3.64
	σ	1.78	0.83	0.71	0.29	0.04	-1.42	1.38	0.79	0.30	0.42
	CV	1.90	1.35	0.93	0.47	0.19	-1.66	2.45	1.27	0.56	0.69

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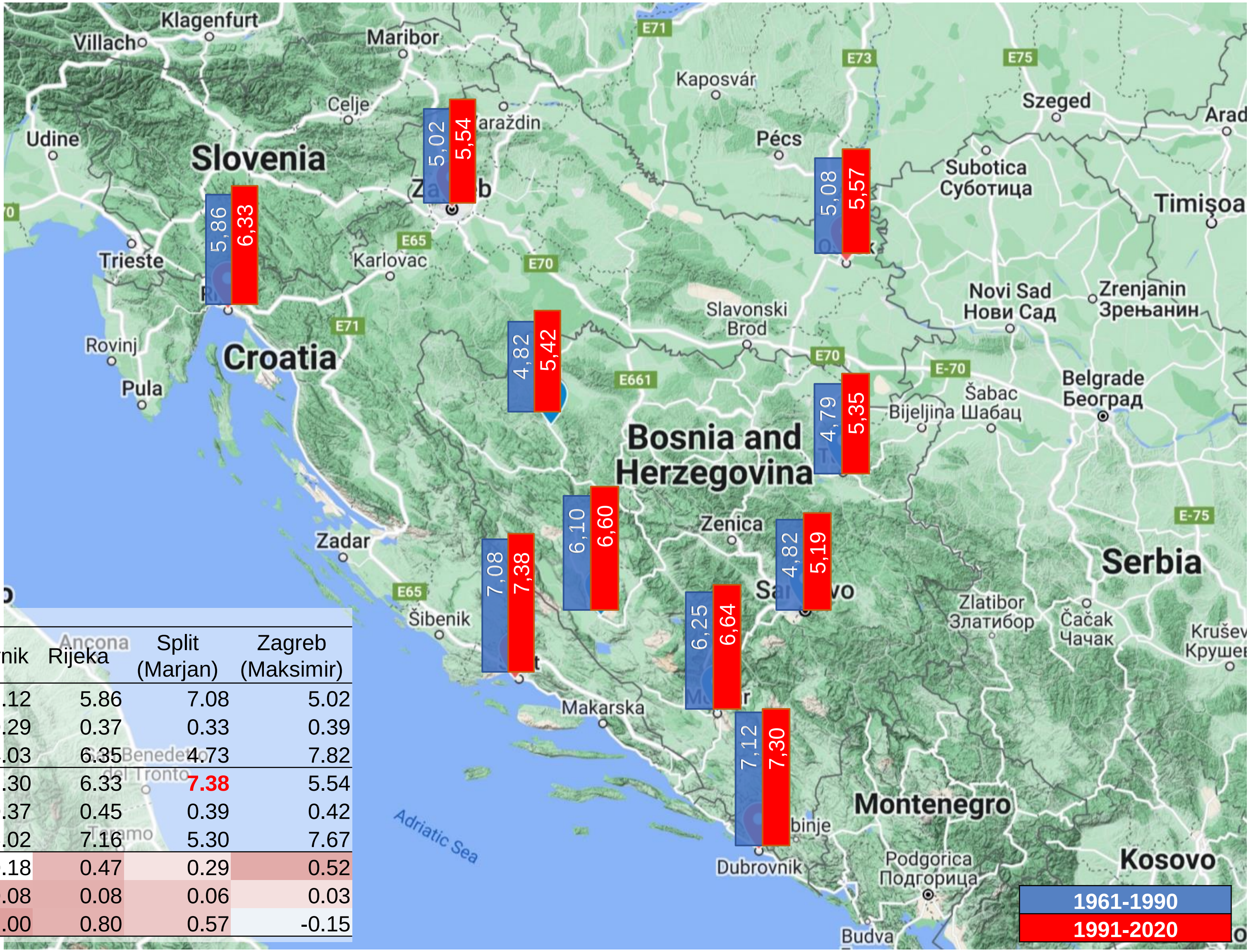
RESULTS

Mean annual solar radiation (h/day)

- We have the most hours of sunshine in Split and Dubrovnik (more than 7.3 hours per day), and the least in Sarajevo (5.19 hours per day).
- As is the case with air temperatures, this parameter also records an increase in all investigated locations, ranging from 0.18 to 0.6. The biggest increase is in Sanski Most.

n		Livno	Mostar	Sanski Most	Sarajevo (Bjelave)	Tuzla	Osijek (Čepin)	Dubrovnik	Rijeka	Split (Marjan)	Zagreb (Maksimir)
1961-1990	$\bar{x}$	6.10	6.25	4.82	4.82	4.79	5.08	7.12	5.86	7.08	5.02
	σ	0.45	0.35	0.38	0.35	0.44	0.41	0.29	0.37	0.33	0.39
	CV	7.40	5.54	7.89	7.28	9.14	8.10	4.03	6.35	4.73	7.82
1991-2020	$\bar{x}$	6.60	6.64	5.42	5.19	5.35	5.57	7.30	6.33	7.38	5.54
	σ	0.46	0.38	0.49	0.37	0.48	0.40	0.37	0.45	0.39	0.42
	CV	7.04	5.66	8.98	7.04	9.00	7.16	5.02	7.16	5.30	7.67
Difference	$\bar{x}$	0.50	0.40	0.60	0.36	0.56	0.49	0.18	0.47	0.29	0.52
	σ	0.01	0.03	0.11	0.01	0.04	-0.01	0.08	0.08	0.06	0.03
	CV	-0.37	0.12	1.09	-0.24	-0.14	-0.94	1.00	0.80	0.57	-0.15



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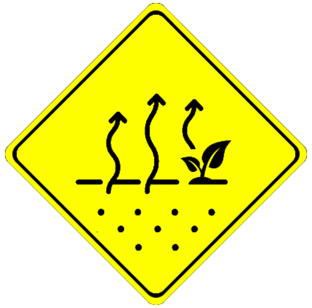
EVAPOTRSPIRATON AND WATER BALANCE


Čapljina, River Trebižat

RESULTS

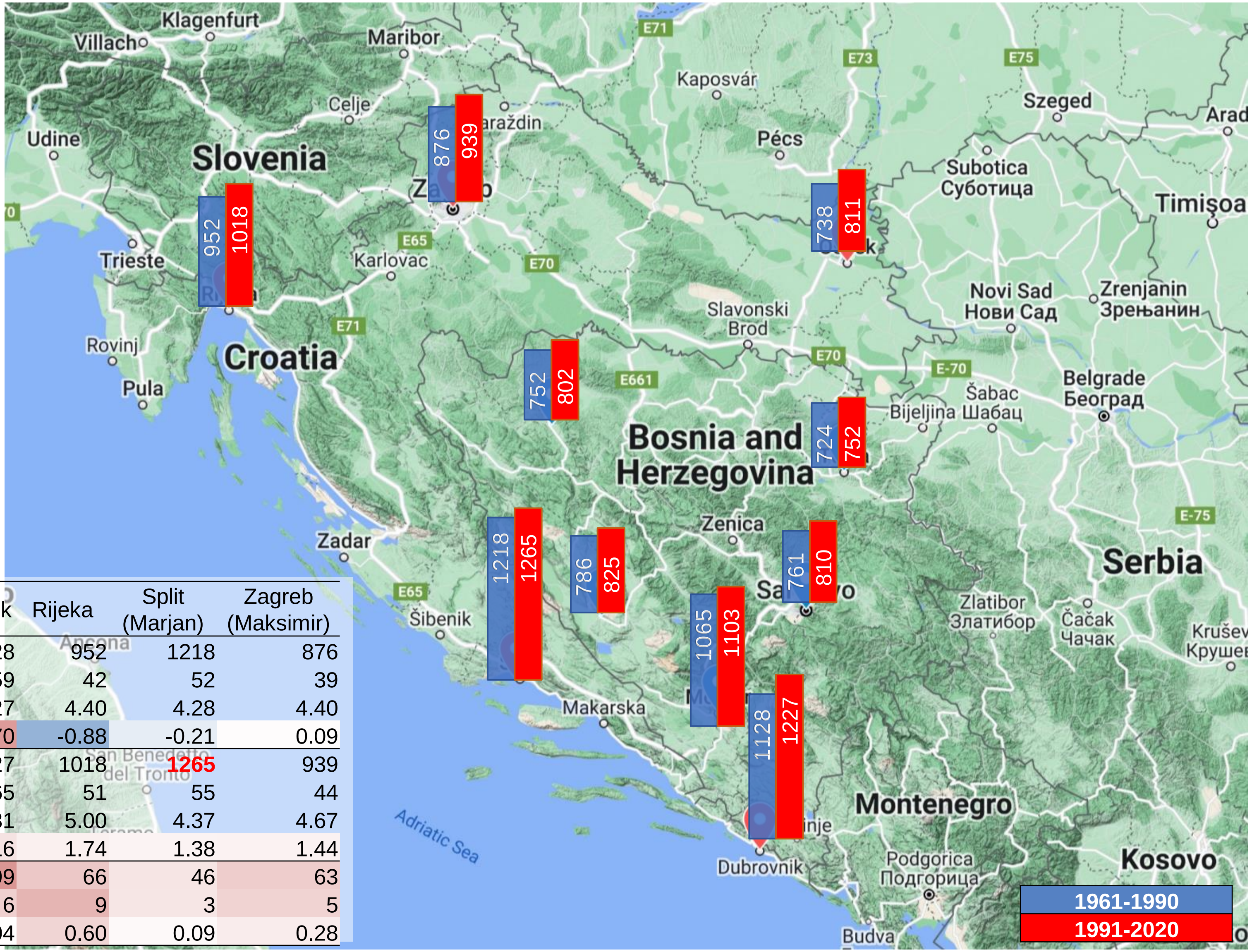


Mean annual Reference Evapotranspiration (mm)

- The highest ETo values were determined for Split (1265 mm), followed by Dubrovnik (1227 mm) and Mostar (1103 mm). The lowest values are in Tuzla, where they amount to 752 mm per year.

- In all locations, for the climate period 91-2020, an increase in ETo was determined, which is most pronounced in the area of Dubrovnik.
- The analysis of the trend of these two climatic periods shows significant differences both between the periods and the locations. The biggest positive trend was recorded in Tuzla, where it is 11.55 mm / year.
- It is interesting to note that two locations show a negative trend of this parameter: Livno and Mostar.

ETo		Livno	Mostar	Sanski Most	Sarajevo (Bjelave)	Tuzla	Osijek (Čepin)	Dubrovnik	Rijeka	Split (Marjan)	Zagreb (Maksimir)
1961-1990	$\bar{x}$	786	1065	752	761	724	738	1128	952	1218	876
	σ	40	64	43	41	39	34	59	42	52	39
	CV	5.15	5.98	5.78	5.41	5.33	4.65	5.27	4.40	4.28	4.40
	b	2.83	-0.33	1.23	0.25	-0.52	1.68	2.70	-0.88	-0.21	0.09
1991-2020	$\bar{x}$	825	1103	802	810	752	811	1227	1018	1265	939
	σ	39	66	44	44	51	46	65	51	55	44
	CV	4.67	6.00	5.45	5.47	6.81	5.68	5.31	5.00	4.37	4.67
	b	-0.37	-2.58	0.35	1.79	11.55	2.17	3.16	1.74	1.38	1.44
Difference	$\bar{x}$	39	38	50	49	28	73	99	66	46	63
	σ	-2	3	0	3	13	12	6	9	3	5
	CV	-0.48	0.02	-0.33	0.06	1.49	1.03	0.04	0.60	0.09	0.28



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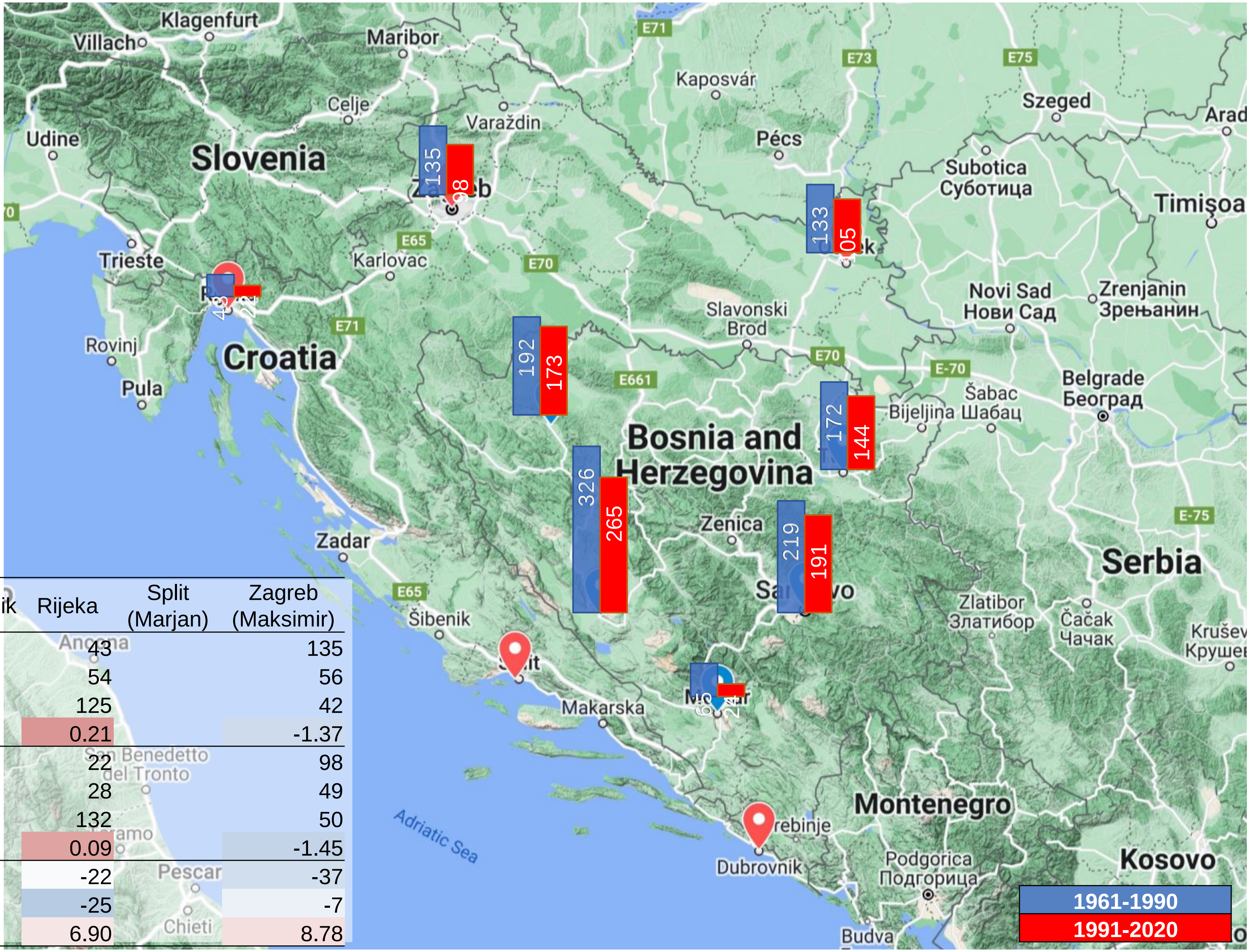
RESULTS

Mean annual amount of snow (mm)

- The highest amount of snowfall is in Livno: 265 mm per year, while in Dubrovnik and Split the snow hardly falls.
- The reduction of snowfall at all research sites. This reduction ranges from 19 mm in Sanski Most to 61 mm in Livno.
- The decrease is accompanied by a negative trend in both analyzed periods, with the exception of Mostar and Rijeka, where we have a stable trend.

SNOW		Livno	Mostar	Sanski Most	Sarajevo (Bjelave)	Tuzla	Osijek (Čepin)	Dubrovnik	Rijeka	Split (Marjan)	Zagreb (Maksimir)
1961-1990	$\bar{x}$	326	65	192	219	172	133		43		135
	σ	130	71	84	91	69	74		54		56
	CV	40	110	44	41	40	56		125		42
	b	-2.69	-1.87	-2.96	-2.63	-2.08	-2.81		0.21		-1.37
1991-2020	$\bar{x}$	265	24	173	191	144	105		22		98
	σ	127	34	82	98	79	52		28		49
	CV	48	138	47	51	55	50		132		50
	b	-0.21	0.11	-2.27	-2.58	-1.95	-2.24		0.09		-1.45
Difference	$\bar{x}$	-61	-40	-19	-28	-28	-29		-22		-37
	σ	-2	-38	-2	7	11	-22		-25		-7
	CV	8.20	27.85	3.44	9.77	15.20	-6.11		6.90		8.78



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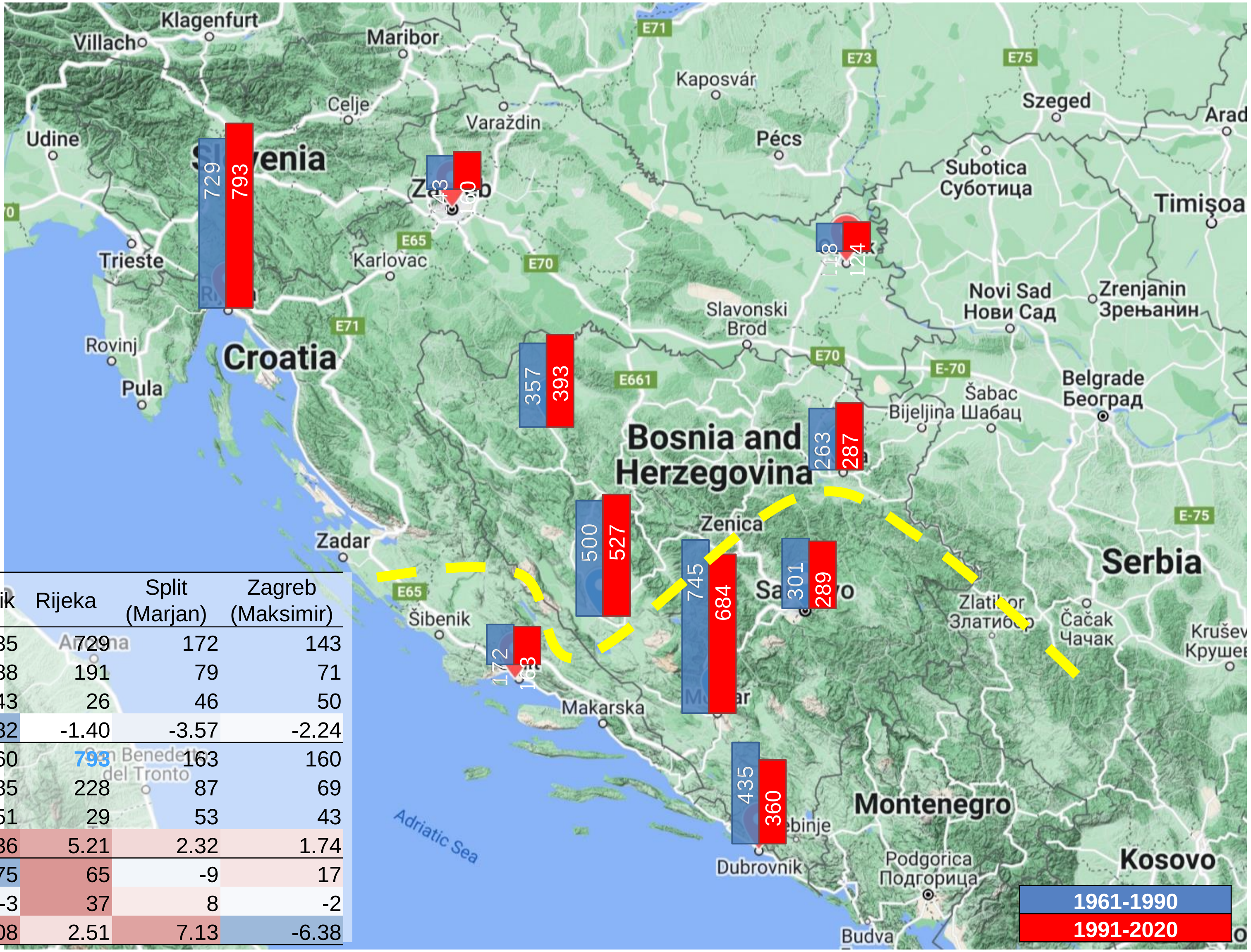
RESULTS

Mean annual runoff (mm)

Blue water

- There are big differences between locations. the highest value of RO is in Rijeka (793 mm) and Mostar (684), and the lowest in Osijek (124 mm).
- Differences between the two climatic periods indicate a decrease in RO in the southern locations, ie in Dubrovnik, Mostar, Sarajevo and Split. On the other hand, a significant increase is recorded at the location of Rijeka (by 65 mm).
- However, by analyzing the trend, the earlier negative trend has been replaced by a positive one. This is especially true of Mostar, Livno and Dubrovnik.

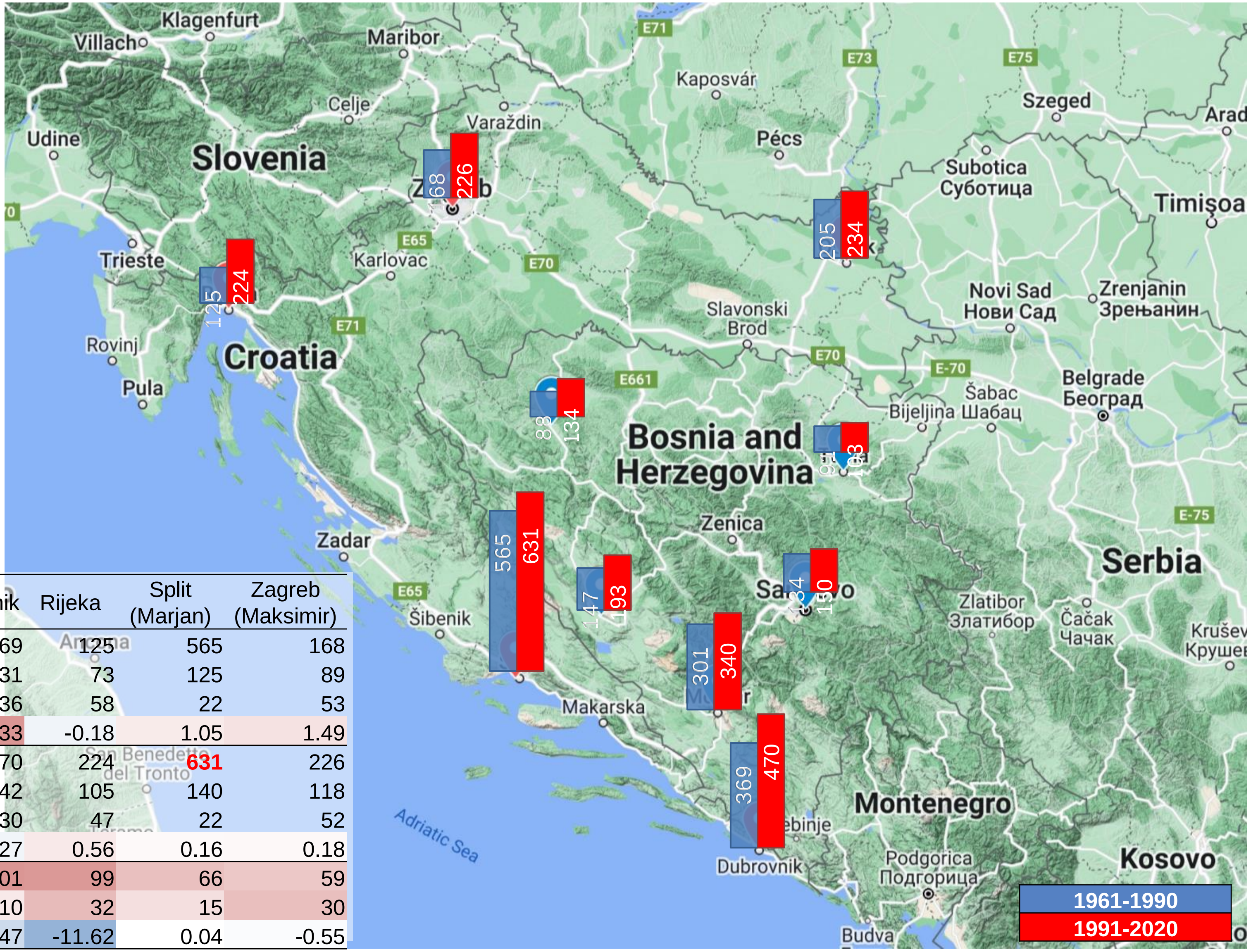
RO		Livno	Mostar	Sanski Most	Sarajevo (Bjelave)	Tuzla	Osijek (Čepin)	Dubrovnik	Rijeka	Split (Marjan)	Zagreb (Maksimir)
1961-1990	$\bar{x}$	500	745	357	301	263	118	435	729	172	143
	σ	158	258	92	113	89	62	188	191	79	71
	CV	32	35	26	38	34	52	43	26	46	50
	b	-6.11	-10.28	-2.23	-1.67	-1.85	-2.20	-13.82	-1.40	-3.57	-2.24
1991-2020	$\bar{x}$	527	684	393	289	287	124	360	793	163	160
	σ	149	273	116	88	118	66	185	228	87	69
	CV	28	40	29	31	41	53	51	29	53	43
	b	5.20	5.76	0.73	-1.30	1.48	-0.95	6.36	5.21	2.32	1.74
Difference	$\bar{x}$	27	-62	36	-12	24	6	-75	65	-9	17
	σ	-9	15	23	-25	29	4	-3	37	8	-2
	CV	-3.36	5.29	3.56	-6.96	7.17	0.68	8.08	2.51	7.13	-6.38



RESULTS

Mean annual Soil mositure deficit (mm)

- As well as RO and M show large differences between the analyzed locations. the highest values are in Split (631 mm) and the lowest in Tuzla (103 mm).
- The values of this parameter are higher in the period 1991-2020 at all locations. In Dubrovnik and the Rijeka, a huge jump is noticeable, amounting to about 100 mm.
- The analysis of the trend indicates an increase in water shortages in Tuzla and Osijek, and their reduction in Mostar.



M		Livno	Mostar	Sanski Most	Sarajevo (Bjelave)	Tuzla	Osijek (Čepin)	Dubrovnik	Rijeka	Split (Marjan)	Zagreb (Maksimir)
1961-1990	$\bar{x}$	147	301	88	134	91	205	369	125	565	168
	σ	71	118	62	84	78	69	131	73	125	89
	CV	48	39	70	63	85	33	36	58	22	53
	b	0.77	1.74	1.12	0.75	-1.31	3.24	5.33	-0.18	1.05	1.49
1991-2020	$\bar{x}$	193	340	134	150	103	234	470	224	631	226
	σ	79	132	84	81	86	117	142	105	140	118
	CV	41	39	63	54	84	50	30	47	22	52
	b	-0.58	-2.10	0.53	0.47	2.40	2.60	-0.27	0.56	0.16	0.18
Difference	$\bar{x}$	46	39	45	17	12	29	101	99	66	59
	σ	8	14	22	-3	8	49	10	32	15	30
	CV	-7.17	-0.54	-7.29	-9.13	-1.80	16.65	-5.47	-11.62	0.04	-0.55

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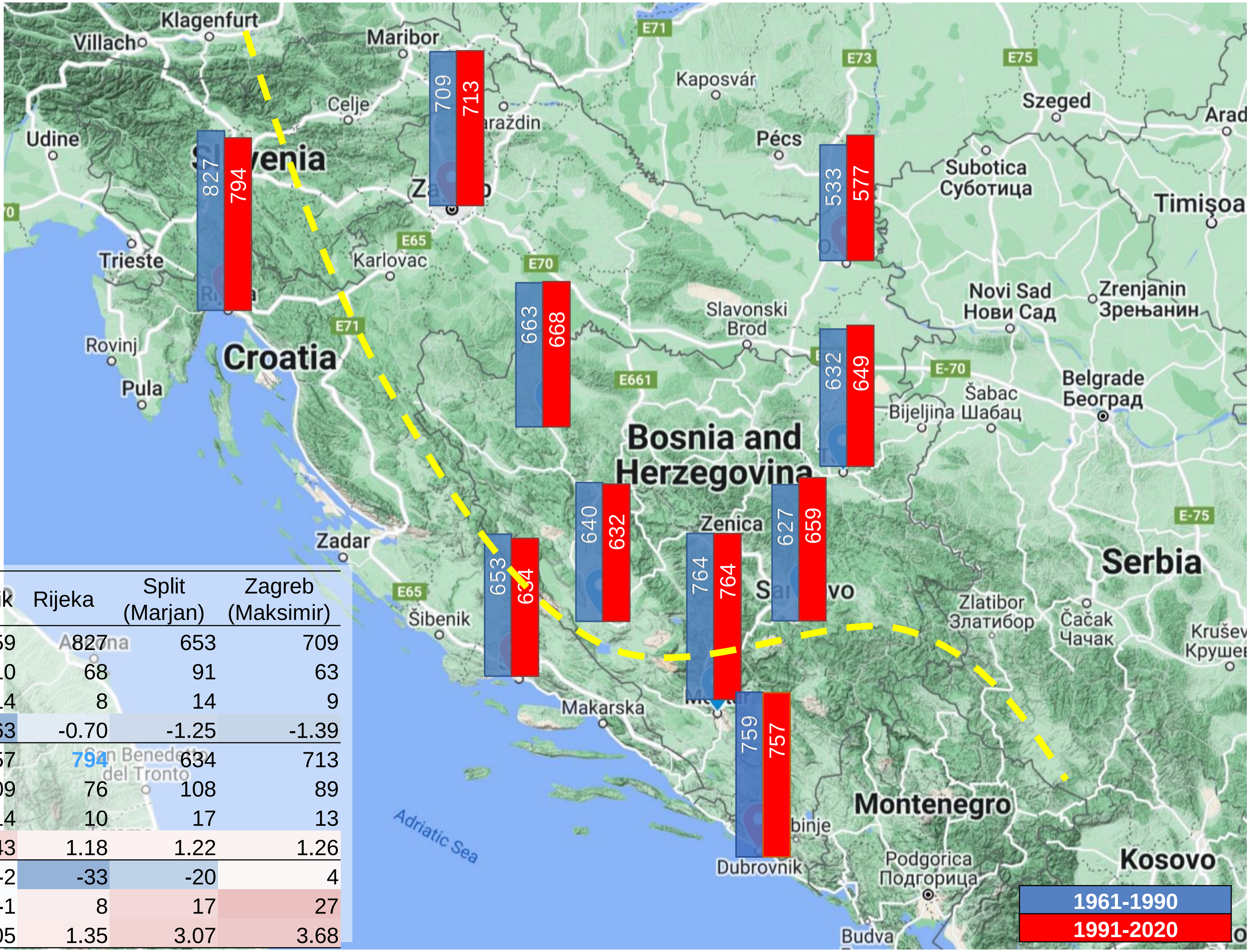
RESULTS

Mean annual Actual Evapotranspiration (mm)

Green water

- Perhaps the most important parameter of the water balance is AET.
- The highest values are in Rijeka (794 mm) and the lowest in Osijek (577 mm).
- The differences between the two climatic periods show an increase in the continental part (up to 44 mm in Osijek) and a decrease in the Mediterranean part (up to 33 mm in Rijeka).
- Trends between the two climate periods do not differ significantly, the most interesting trend is in the area of Tuzla, which shows an increase in AET of 9.15 mm / year.

AET		Livno	Mostar	Sanski Most	Sarajevo (Bjelave)	Tuzla	Osijek (Čepin)	Dubrovnik	Rijeka	Split (Marjan)	Zagreb (Maksimir)
1961-1990	$\bar{x}$	640	764	663	627	632	533	759	827	653	709
	σ	69	86	47	64	55	41	110	68	91	63
	CV	11	11	7	10	9	8	14	8	14	9
	b	2.06	-2.07	0.11	-0.50	0.78	-1.56	-2.63	-0.70	-1.25	-1.39
1991-2020	$\bar{x}$	632	764	668	659	649	577	757	794	634	713
	σ	52	86	54	52	67	86	109	76	108	89
	CV	8	11	8	8	10	15	14	10	17	13
	b	0.21	-0.48	-0.18	1.32	9.15	-0.43	3.43	1.18	1.22	1.26
Difference	$\bar{x}$	-7	-1	5	32	17	44	-2	-33	-20	4
	σ	-16	0	8	-12	12	45	-1	8	17	27
	CV	-2.47	0.00	1.10	-2.34	1.70	7.20	-0.05	1.35	3.07	3.68

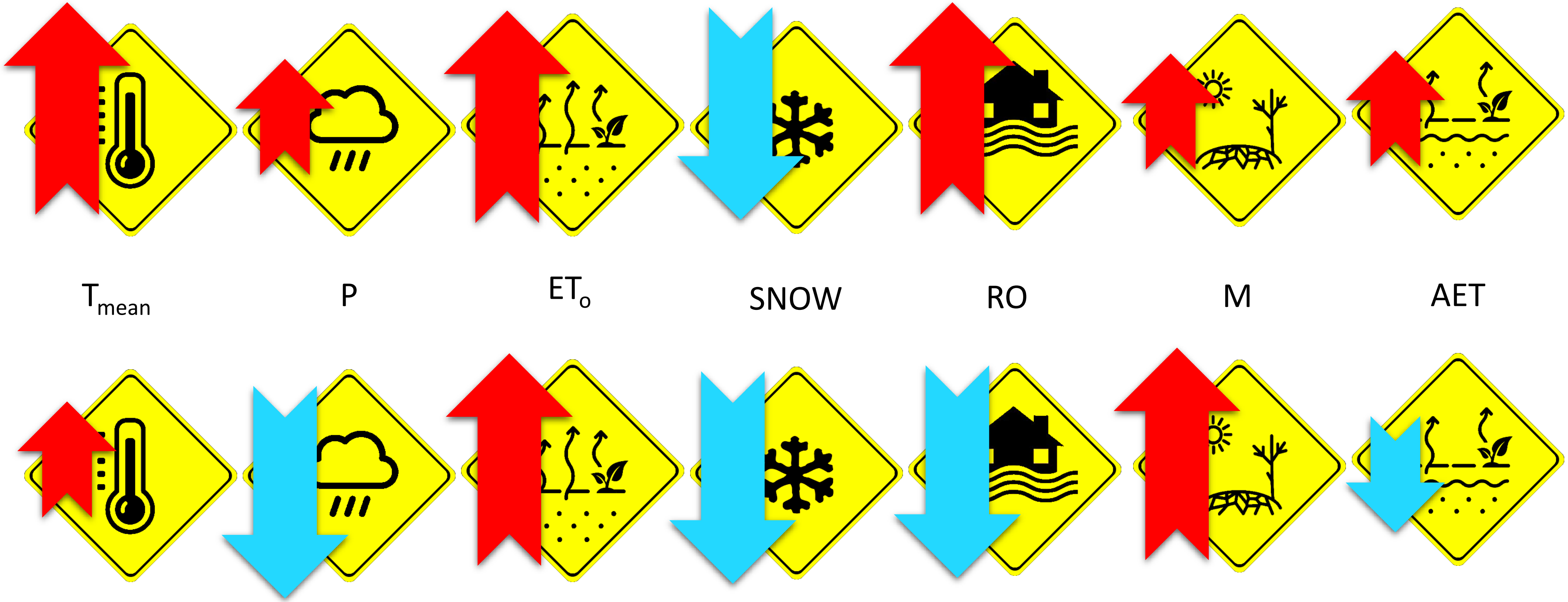


CONCLUSION

Instead of a conclusion

NORTH
(Continental)

SOUTH
(Mediterranean)



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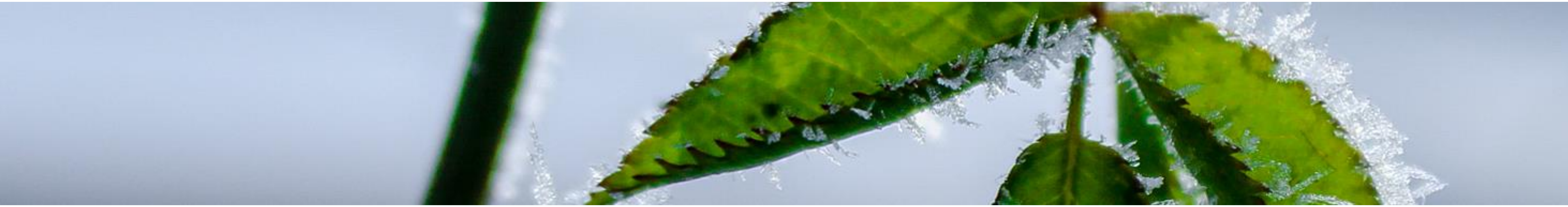

THANK YOU FOR YOUR ATTENTION