DELIVERABLE 3.2.3

Climate change projections assessment:

Bias-correction of regional climate models' simulations

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Project key facts

Priority:	2. Safety and resilience
Specific objective:	2.1 Improve the climate change monitoring and planning of adaptation measures tackling specific effects in the cooperation area
Acronym:	**RESPONSe**
Title:	**Strategies to adapt to climate change in Adriatic regions**
ID request:	10175714
Lead Partner:	INFORMEST
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Deliverable information

WP 3	Harmonization of the climate change analysis and monitoring systems
A 2	Analysis of regional climate models' projections and bias adjustment
Issued by:	**Partner n°6 – DHMZ**
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V 0.1	15.10.2019.	DHMZ	Table of content defined, and first contributions included.
Final	15.04.2020.	DHMZ	Numbers check and minor revision done.

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Introduction

For the Activity 2 *Analysis of regional climate models' projections and bias adjustment* in the WP3, the RESPONSe Application Form (AF) plans following activities related to the creation of the bias adjusted (or bias corrected) time-series:

"RCM simulations considered will be subjected to a statistical post-processing through an empirical Quantile Mapping (QM):.(1) regional-based QM, and (2) station-focused QM application, Both the applications will be configured in order to preserve original simulations' climate change signal."

This deliverable is focused to the analysis of the systematic errors of the regional climate models and the description of the bias correction/adjustment method. It is related to other deliverables in the Activity 2 in the WP3 in the following manner. Deliverable D3.2.1 included the analysis of the climate change signal in atmosphere-only and coupled atmosphere-ocean/sea regional climate models (RCM). It was accompanied by the dataset D3.2.2 that included extracted time-series of several climate variables for the locations of the RESPONSe focus areas. Where this deliverable, i.e. D3.2.3, examines the systematic errors in the same RCMs and presents the applied bias correction/adjustment methodology, it is followed by the dataset D3.2.4 that includes extracted and bias corrected/adjusted time-series of mean, minimum and maximum daily near-surface (2 m) air temperature and total precipitation amount also for the locations of the RESPONSe focus areas.

RCM systematic errors

1 Near-surface air temperature

Systematic errors in the seasonal near-surface air temperature *T2m* are analysed in this subsection. We discuss the models' result in each season, depending on the specific combination of the regional climate model (RCM) and forcing global climate model (GCM). We will refer to general dominance of the positive errors (or overestimation) or negative errors (or underestimation). For the specific values in terms of the units please check location of interest. For detailed analysis of models' errors over the parts of the south-eastern Europe and Mediterranean, please consider e.g. Kotlarski et al. (2014) and Güttler et al. (2020).

Winter (DJF) systematic errors are presented in Figure 1.1. Underestimation of the *T2m* dominates over the Adriatic domain. Most notable deviation from this general result is the RCM RegCM4 forced by the GCM HadGEM2-ES, with *T2m* overestimation over almost the whole Italy and Croatia, not limited to the coastal regions only. RCM RCA4 strongly underestimates *T2m* over the Alpine region, with systematic errors more than -6 °C. Part of the *T2m* overestimation in all models in the region of the Velebit mountain is related to the RCM misrepresentations of the orography (this is seen also in other seasons, and other temperature based variables, i.e. *T2min* and *T2max*).

Spring (MAM) systematic errors are presented in Figure 1.2. *T2m* underestimation is found to dominate in all RCM-GCM combinations. Mixed sign of errors is most obvious in case of the RCM CLM and GCM HadGEM2-ES.

Summer (JJA) systematic errors are presented in Figure 1.3. Three aspects of the models' behaviour are detected: (1) general temperature underestimation over the Alpine region, (2) the existence of the temperature overestimation over the Pannonian plain, (3) the strong impact of the GCM HadGEM2-ES where all three RCM show temperature overestimation of the Pannonian plain with values close to 6 °C in case of RCM CLM. Nevertheless, model errors in the coastal Adriatic zone (where all the focus areas are located) are in the acceptable range between -1.5 °C and 1.5 °C.

Autumn (SON) systematic errors are presented in Figure 1.4. Mixed sign of the model errors are found. The model behaviour ranges from the area wide underestimation in RCM RegCM4 and GCM CNRM couple to general overestimation in RCM RegCM4 and GCM HadGEM2 couple. Again, models' systematic errors in the coastal Adriatic zone are not extreme.

Finally, when examining the multi-model ensemble mean in Figure 1.5, following structure of the *T2m* systematic errors is present: (1) underestimation in the spring, (2) dominance of the overestimation during summer, (3) mixed sign of systematic errors in remaining two seasons (winter and autumn), with (4) general good performance of the analysed models in the coastal Adriatic region, where all RESPONSe target areas are located.

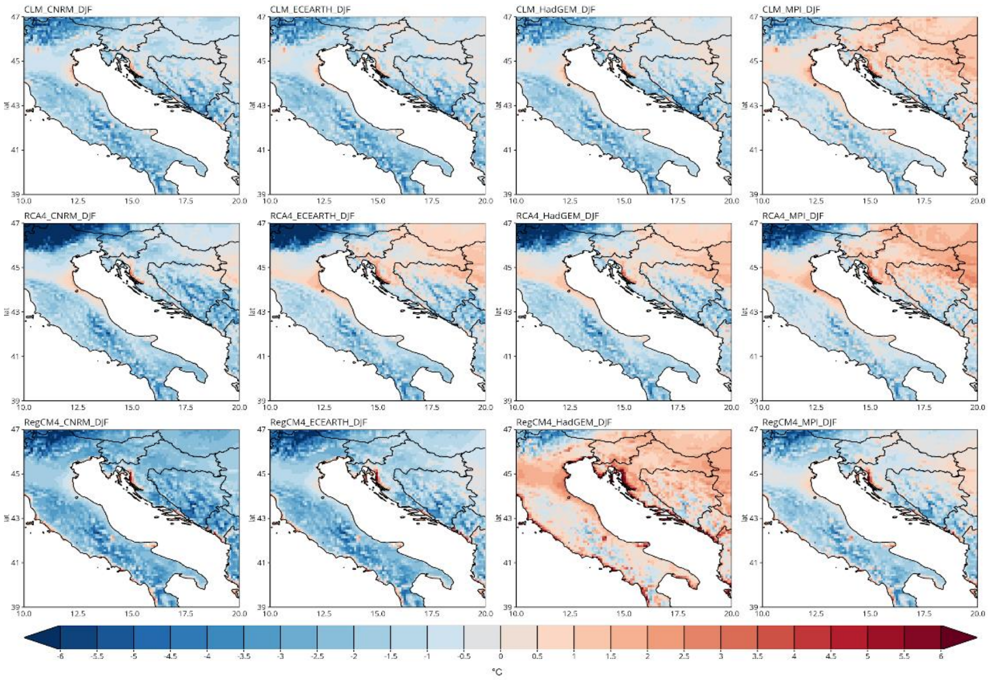

Figure 1.1: Mean winter (DJF) temperature (*T2m*) bias (12 EURO-CORDEX RCMs - EOBS v19.0e; 1971-2000). Rows: RCMs CLM, RCA4, RegCM4. Columns: GCMs CNRM, ECEARTH, HadGEM2-ES and MPI-ESM.

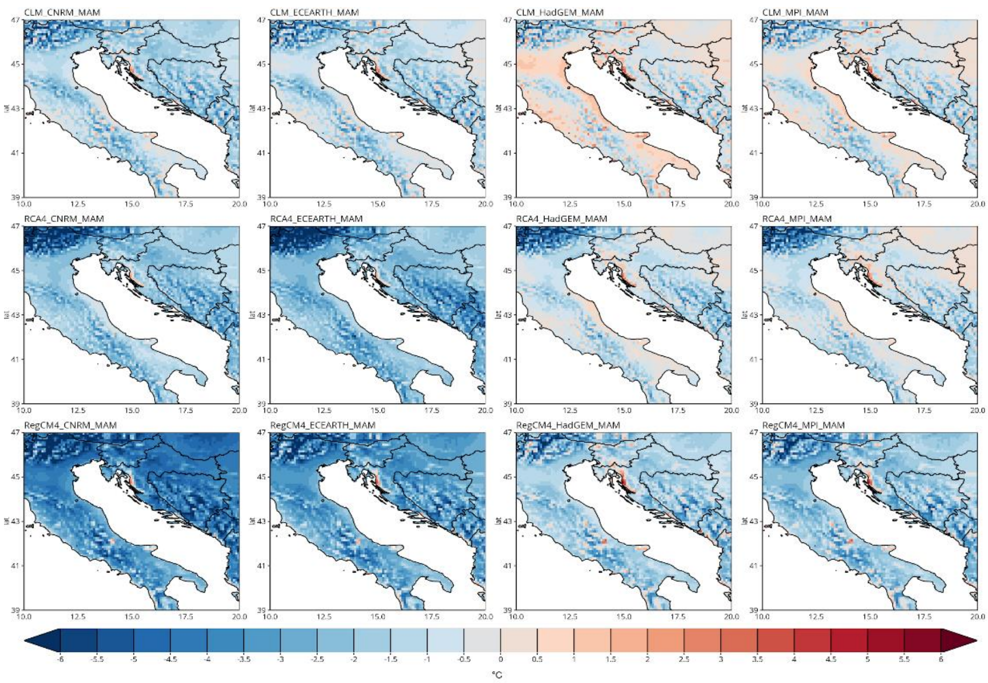

Figure 1.2: Same as Fig 1.1 but for spring (MAM).

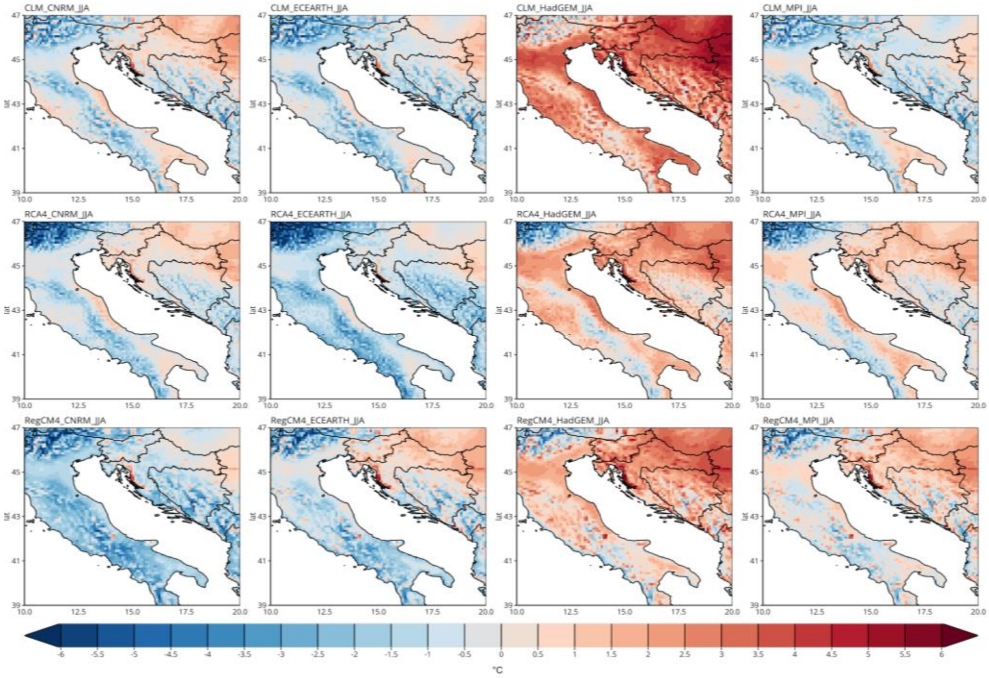

Figure 1.3: Same as Fig 1.1 but for summer (JJA).

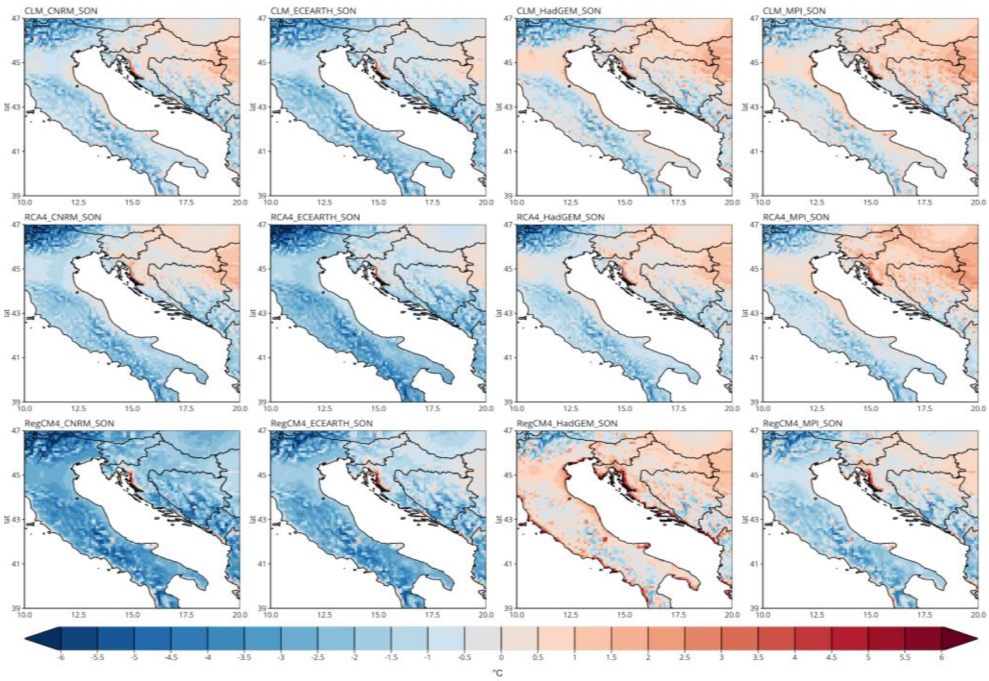

Figure 1.4: Same as Fig 1.1 but for autumn (SON).

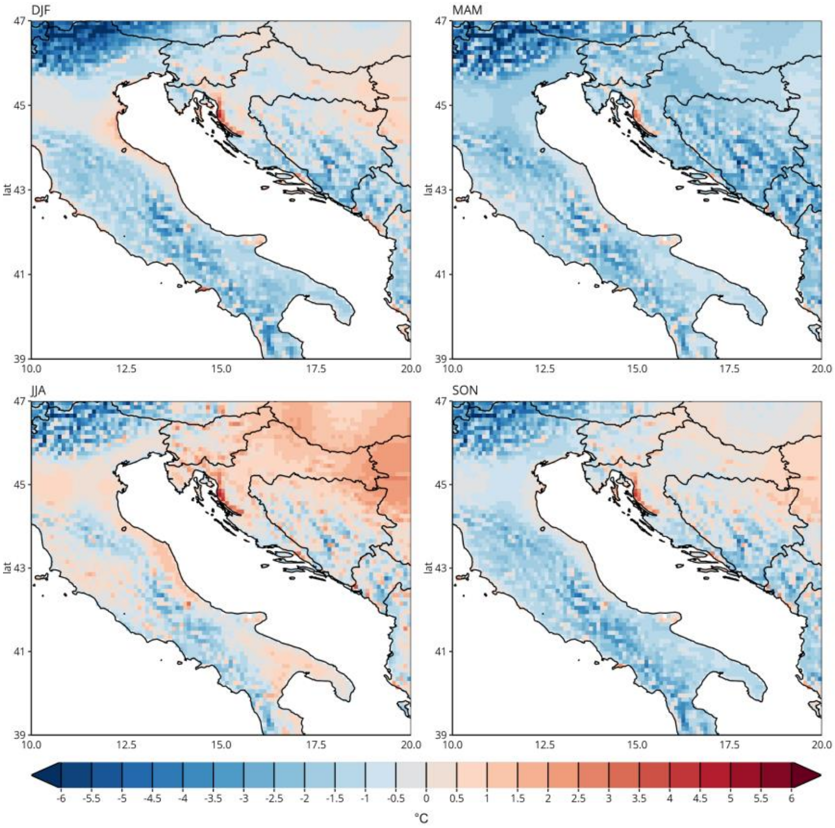

Figure 1.5: Mean seasonal temperature (*T2m*) bias (mean of 12 EURO-CORDEX RCMs - EOBS v19.0e; 1971-2000).

2 Near-surface minimum air temperature

Systematic errors in the seasonal near-surface minimum air temperature *T2min* are analysed in this subsection. Seasonal means are generated based on the daily air temperature minimum as an input. Most results in terms of *T2min* are comparable to *T2m*.

Winter (DJF) systematic errors are presented in Figure 2.1. Underestimation of the *T2min* dominates over the Adriatic domain. Most notable deviations from this general result are the RCM RegCM4 forced by the GCM HadGEM2-ES and RCM CLM forced by the GCM MPI-ESM.

Spring (MAM) systematic errors are presented in Figure 2.2. *T2min* underestimation is found to dominate in RCM-GCM combinations in case of RCMs RCA4 and RegCM4. In case of RCM CLM model the sign of the model errors is more mixed, with CLM & MPI-ESM and CLM & HadGEM2-ES combinations showing overestimation over the most of the broader Adriatic domain.

Summer (JJA) systematic errors are presented in Figure 2.3. Structure of *T2min* errors range from underestimation in RCM RCA4 and GCM ECEARTH to strong overestimation in RCM CLM and GCM HadGEM2-ES. In several cases, substantial model errors are found in the coastal Adriatic region. This strongly motivates the application of the bias correction/adjustment statistical methods before using RCM results in forcing different impact models.

Autumn (SON) systematic errors are presented in Figure 2.4. Structure of the model errors depends on the specific RCM-GCM combination, while the amplitude of the same errors in the coastal Adriatic region is, in general, in the acceptable range from -1.5 °C to 1.5 °C.

Finally, when examining the multi-model ensemble mean in Figure 2.5, following structure of the *T2min* systematic errors is present: (1) underestimation in the spring (similar to *T2m* in Figure 1.5), (2) mixed sign of systematic errors in remaining three seasons (winter, summer and autumn), with (3) general good performance of the analysed models in the coastal Adriatic region, where all RESPONSe target areas are present. Problems along the Velebit Mountain are present as for the case of the *T2m* and discussed in the previous subsection.

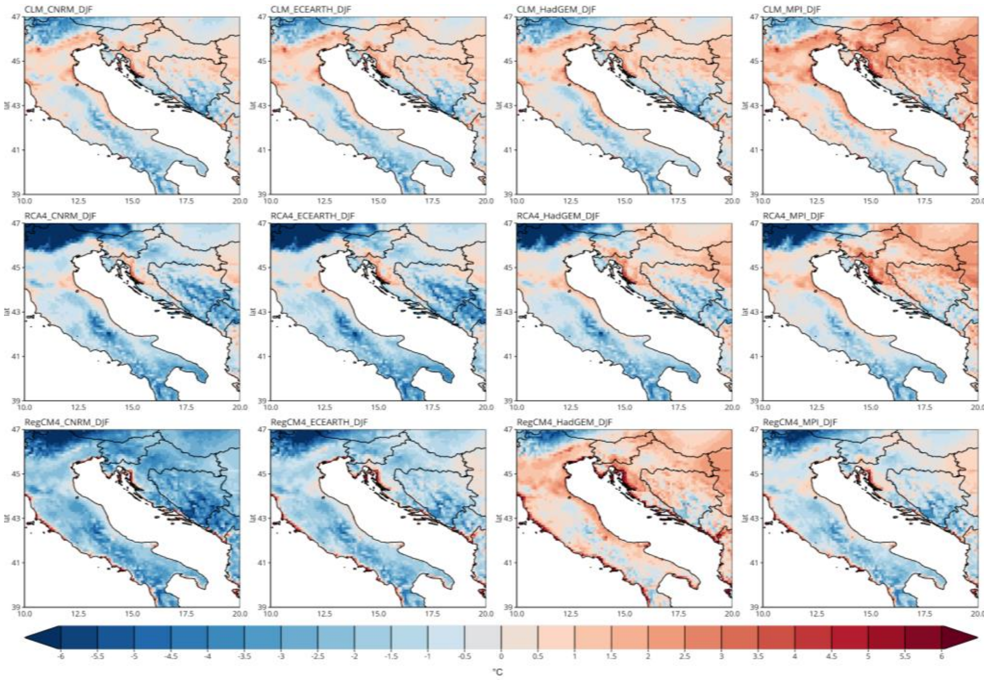

Figure 2.1: Mean winter (DJF) minimum temperature (*T2min*) bias (12 EURO-CORDEX RCMs - EOBS v19.0e; 1971-2000). Rows: RCMs CLM, RCA4, RegCM4. Columns: GCMs CNRM, ECEARTH, HadGEM2-ES and MPI-ESM.

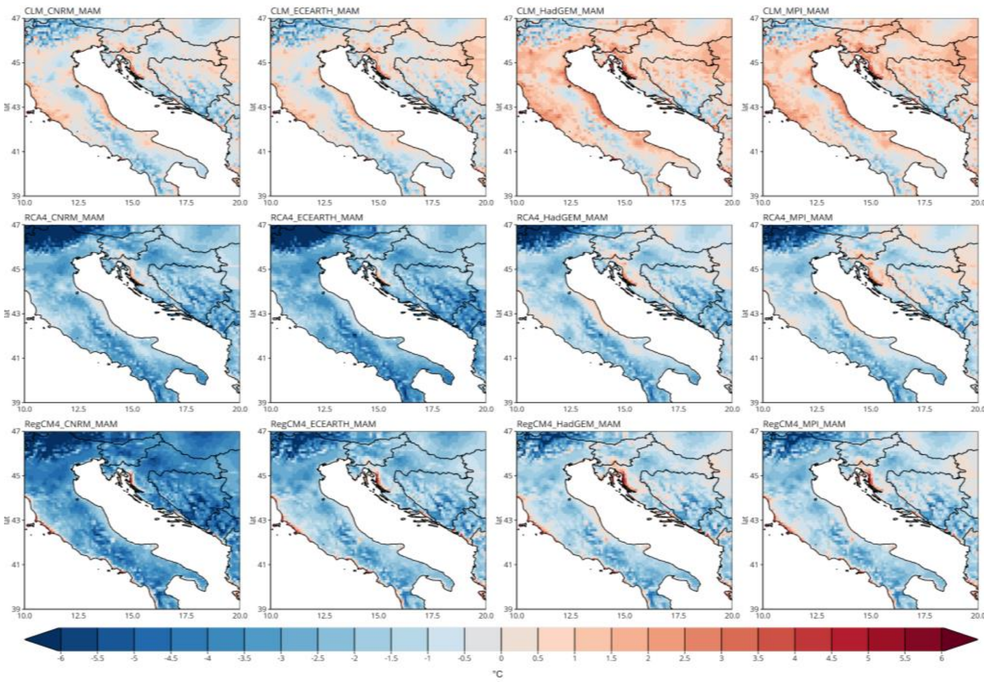

Figure 2.2: Same as Fig. 2.1 for spring (MAM).

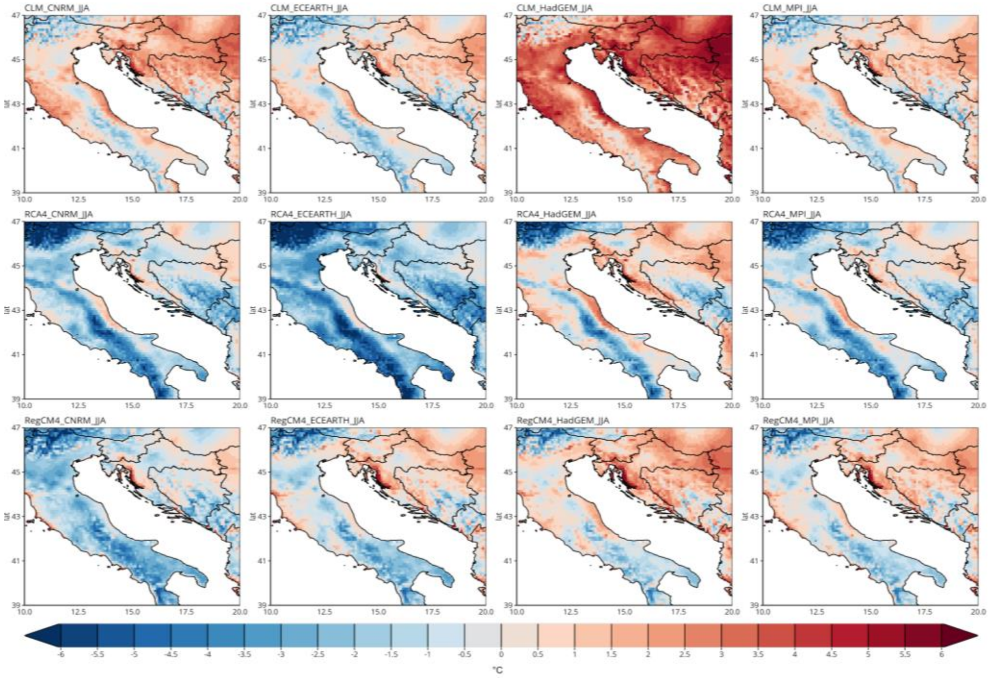

Figure 2.3: Same as Fig. 2.1 for summer (JJA).

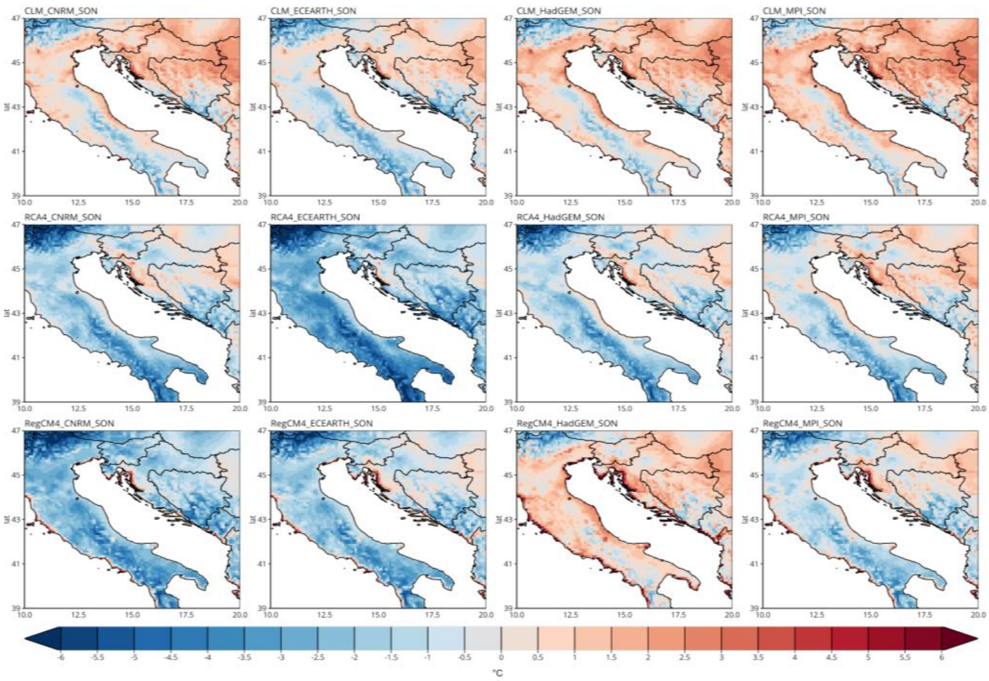

Figure 2.4: Same as Fig. 2.1 for autumn (SON).

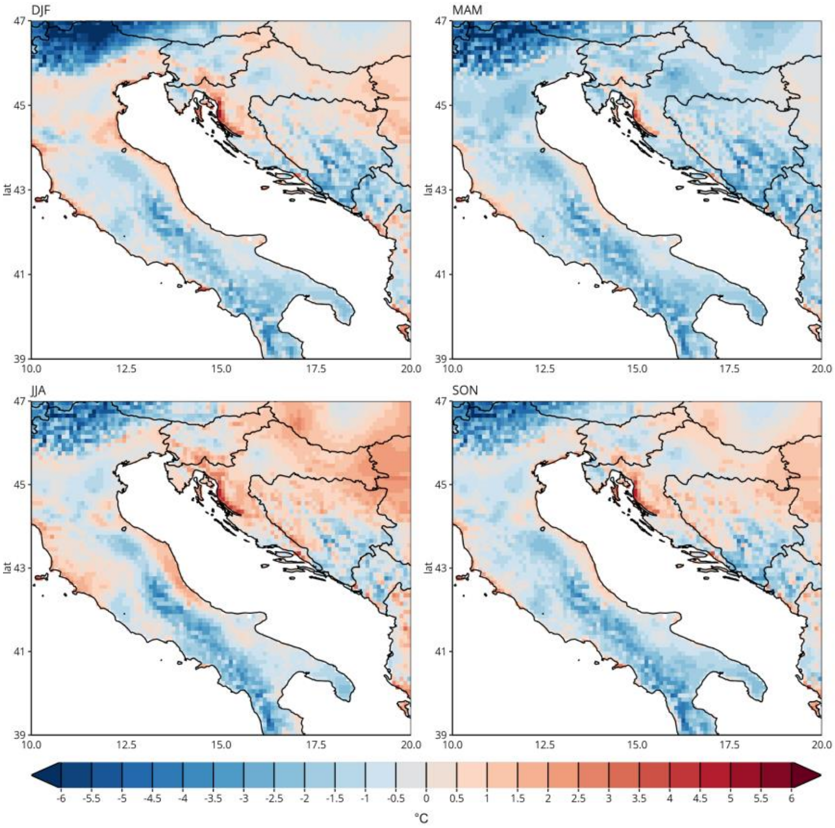

Figure 2.5 Mean seasonal minimum temperature (*T2min*) bias (mean of 12 EURO-CORDEX RCMs - EOBS v19.0e; 1971-2000).

3 Near-surface maximum air temperature

Systematic errors in the seasonal near-surface maximum air temperature *T2max* are analysed in this subsection. Seasonal means are generated based on the daily air temperature maximum as an input. Most results in terms of *T2max* are comparable to *T2m* and *T2min*.

Winter (DJF) systematic errors are presented in Figure 3.1. Underestimation of the *T2max* dominates over the Adriatic domain. Most notable deviations from this general result are the RCM RegCM4 forced by the GCM HadGEM2-ES and RCM RCA4 forced by the GCM MPI-ESM and HadGEM2-ES. Area of the largest *T2max* overestimation include the Pannonian Basin and River Po catchment.

Spring (MAM) systematic errors are presented in Figure 3.2. *T2max* underestimation dominates in all RCMs, and is independent on the forcing GCM. In the RCM RegCM4 and GCM CNRM large parts of the domain are facing *T2max* underestimation more than -5 °C. However, the same RCM shows the best performance in the 12-member ensemble when forced by the GCM HadGEM2-ES.

Summer (JJA) systematic errors are presented in Figure 3.3. When forced by the GCM HadGEM2-ES, all three RCMs show major errors, with strong overestimation over most of the region. Even in the coastal zone, errors of more than 3 °C are found in some RCM-GCM couples. Again, this strongly motivates the application of the bias correction/adjustment statistical methods before using RCM results in forcing different impact models, as indicated before for *T2min*.

Autumn (SON) systematic errors are presented in Figure 3.4. Structure of the model errors depends on the specific RCM-GCM combination, while the amplitude of the same errors in the coastal Adriatic region is in general in the acceptable range from -1.5 °C to 1.5 °C. As for MAM, largest underestimation is found in RCM RegCM4 and GCM CNRM couple, while models often overestimate air temperature over the Pannonian Basin and River Po catchment (in these cases, systematic errors between 2°C and 3°C can be found in e.g. RCM RCA4 and GCM MPI-ESM couple).

Finally, when examining the multi-model ensemble mean in Figure 3.5, common structure of the *T2max* systematic errors is documented as for the case of *T2m* and *T2min*. The use of the multi-model ensemble mean is beneficial, partly because of the systematic error compensation.

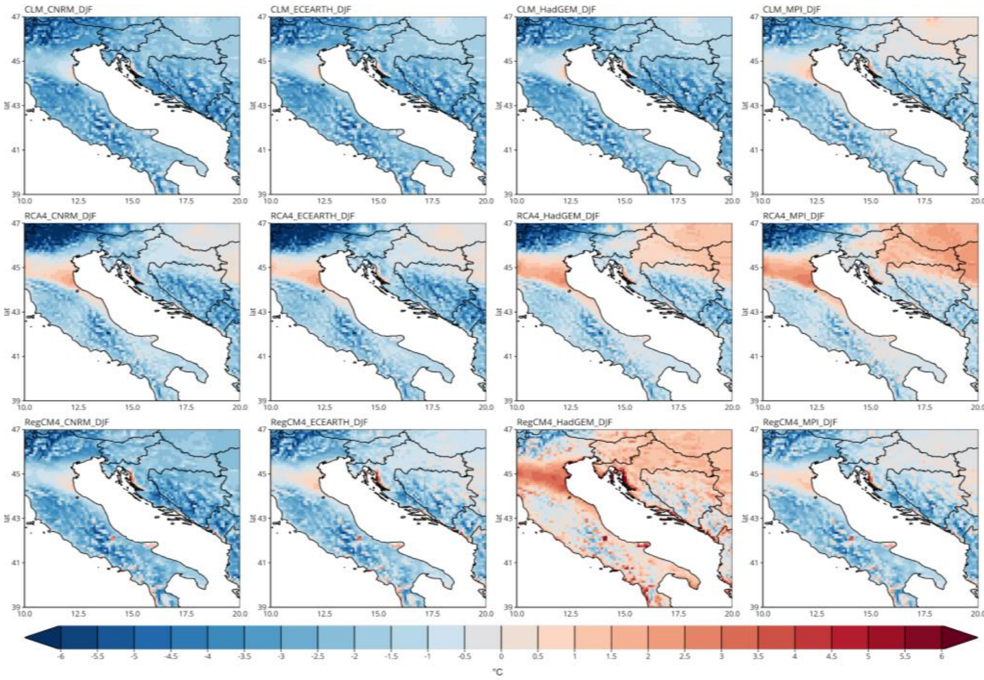

Figure 3.1: Mean winter (DJF) maximum temperature (*T2max*) bias (12 EURO-CORDEX RCMs - EOBS v19.0e; 1971-2000). Rows: RCMs CLM, RCA4, RegCM4. Columns: GCMs CNRM, ECEARTH, HadGEM2-ES and MPI-ESM.

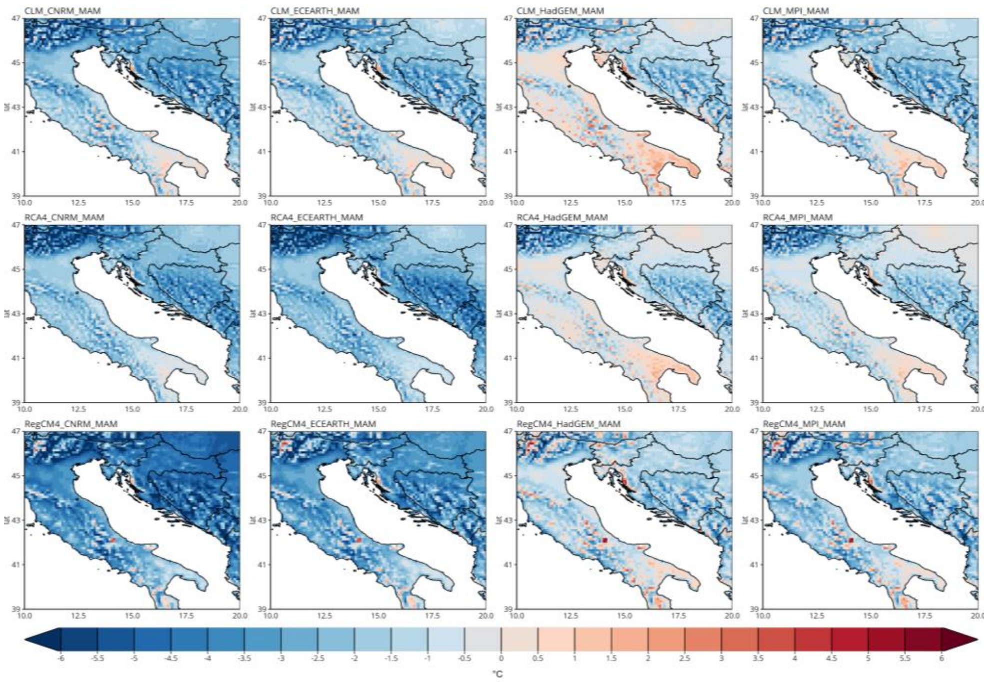

Figure 3.2: Same as Fig. 3.1 for spring (MAM).

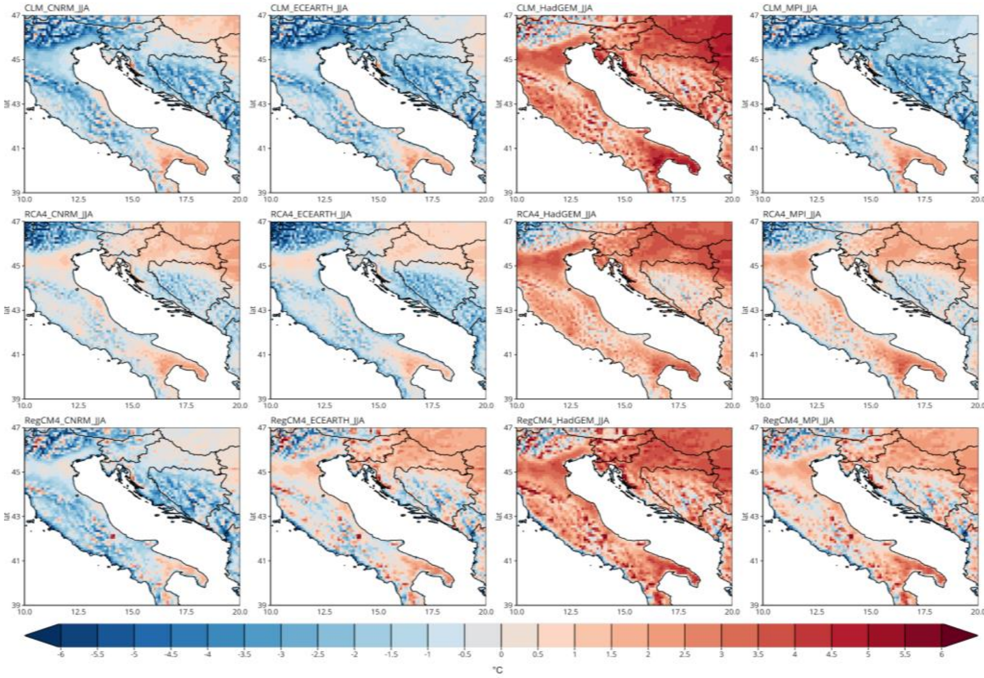

Figure 3.3: Same as Fig. 3.1 for summer (JJA).

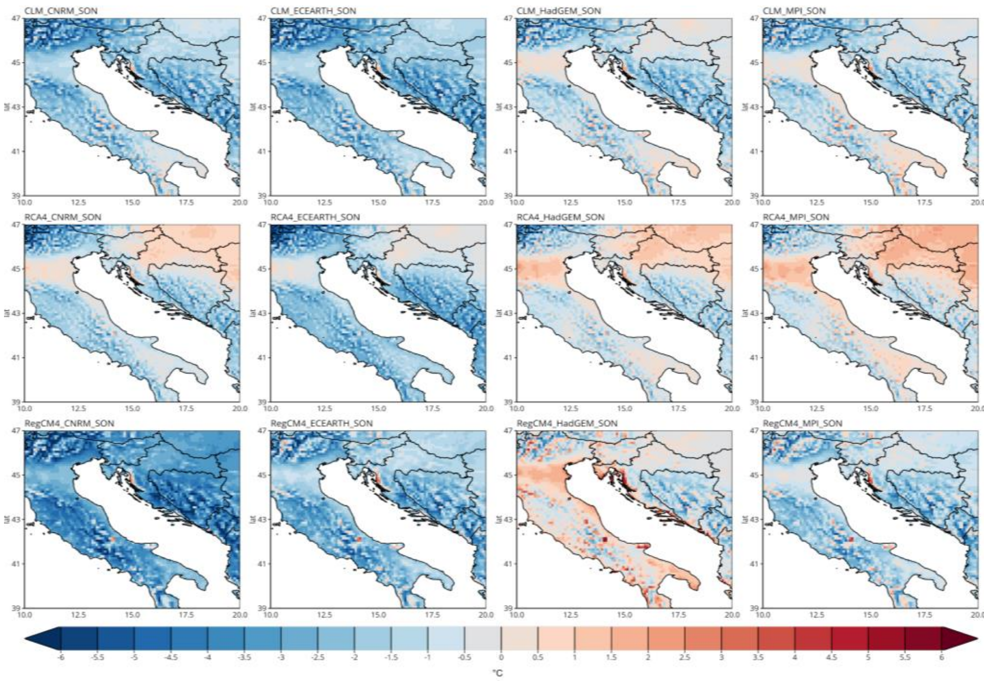

Figure 3.4: Same as Fig. 3.1 for autumn (SON).

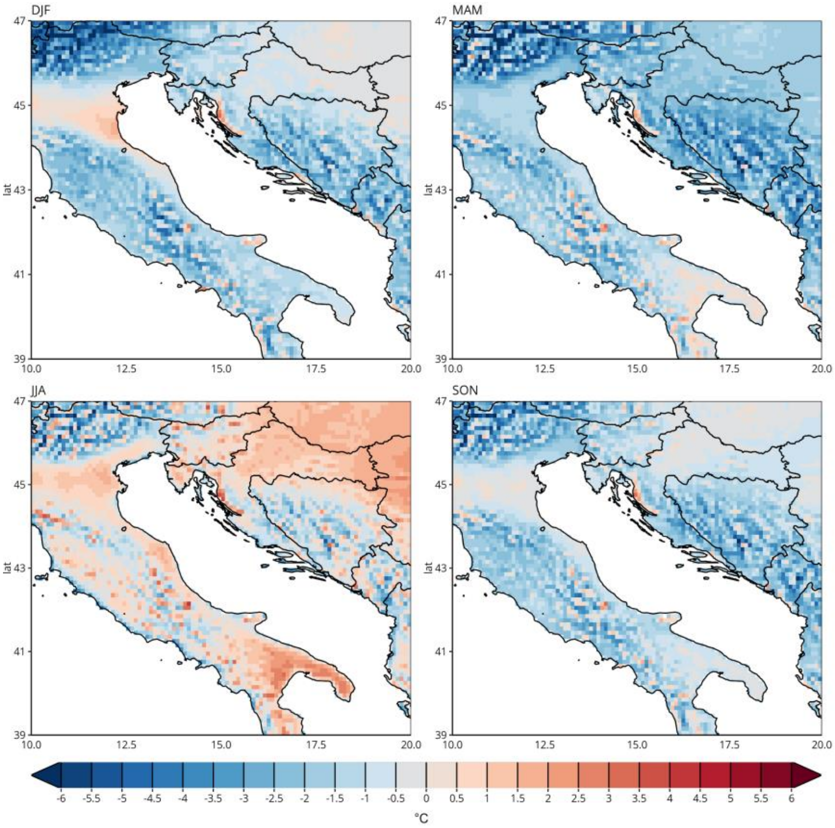

Figure 3.5 Mean seasonal maximum temperature (*T2max*) bias (mean of 12 EURO-CORDEX RCMs - EOBS v19.0e; 1971-2000).

4 Total precipitation amount

Relative systematic errors in the seasonal total precipitation amount *R* are analysed in this subsection.

Winter (DJF) relative systematic errors are presented in Figure 4.1. RCMs CLM and RCA4 show similar structure of errors. It includes moderate overestimation over the Alps, southern Croatia and central Italy. Overestimation in RCM RegCM4 is very strong. This issue was analysed in detail in e.g. Güttler et al. (2020). However, performance of all three RCMs is very good in the northern Croatia and along the Italian Adriatic coast, with relative systematic errors generally between -20% and 20%.

Spring (MAM) relative systematic errors are presented in Figure 4.2. RCM CLM shows the best performance in terms of the systematic errors. In case of RCM RCA4 sporadic strong overestimation is found scattered all over the domain. In RCM RegCM4, again strong overestimation is present in the southern parts of the domain, but with the amplitude a bit lower than in the winter case. Again, performance in the Italian Adriatic coast in encouraging, with the acceptable level of the model errors. Nevertheless, the need for the bias correction/adjustment procedure is required for the most of the region.

Summer (JJA) relative systematic errors are presented in Figure 4.3. Several distinct features are present: (1) the application of GCM CNRM as a forcing model, induces strong overestimation in the southern Italy, while acceptable level of errors in the northern parts of the analysed domain; (2) again, in RCM RCA4 results one can notice the scattered structure of the precipitation errors with strong overestimation locations all around the domain; (3) there is tendency to underestimate precipitation amount in RCMs when forced by the GCM HadGEM2-ES; in this case underestimation over e.g. Pannonian Basin and northern Italy can go above 40%. The variety of the models' errors is consequence of more internal variability during the summer season, with some examples of boundary conditions pushing the different regional models towards the common state.

Autumn (SON) relative systematic errors are presented in Figure 4.4. For this season, similar structure and amplitude of the model errors is found as in the spring. In most of the cases, large parts of the Croatian and Italian Adriatic coast have model performance at the appropriate level, with model errors between -20% and 20%.

Finally, multi-model ensemble means of the mean seasonal relative systematic errors in *R* are presented in Figure 4.5. The ensemble mean shows good performance with the model errors between -20% and 20%, except at the south of Croatia during winter and spring. The need for the bias correction is more obvious than for the case of the air temperature (*T2min, T2max, T2min*). While there may be regions with the low amplitude of the models' errors, in order to prepare the consistent set of the model projections, the use of the bias corrected/adjustment time-series for the impact models is strongly encouraged.

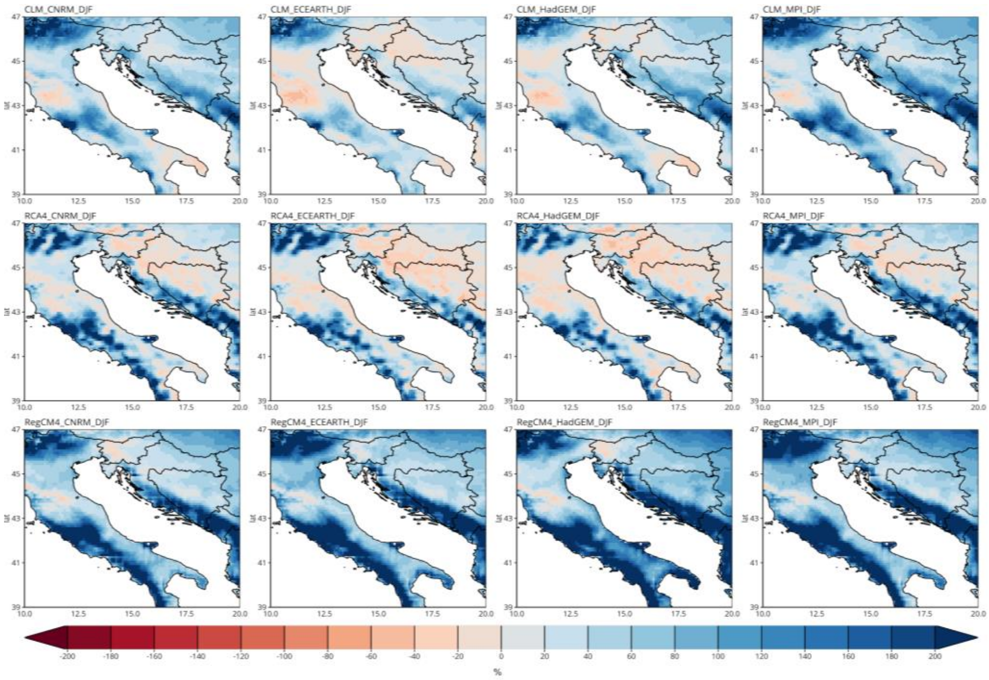

Figure 4.1: Mean winter (DJF) total precipitation amount *R* relative bias (12 EURO-CORDEX RCMs - EOBS v19.0e; 1971-2000). Rows: RCMs CLM, RCA4, RegCM4. Columns: GCMs CNRM, ECEARTH, HadGEM2-ES and MPI-ESM.

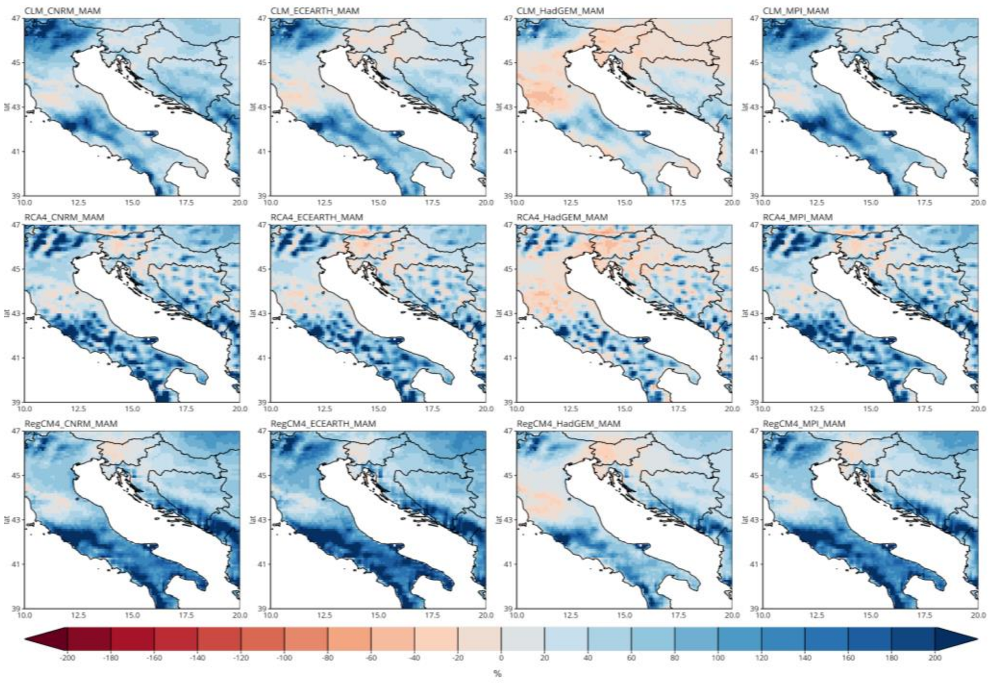

Figure 4.2: Same as Fig. 4.1 for spring (MAM).

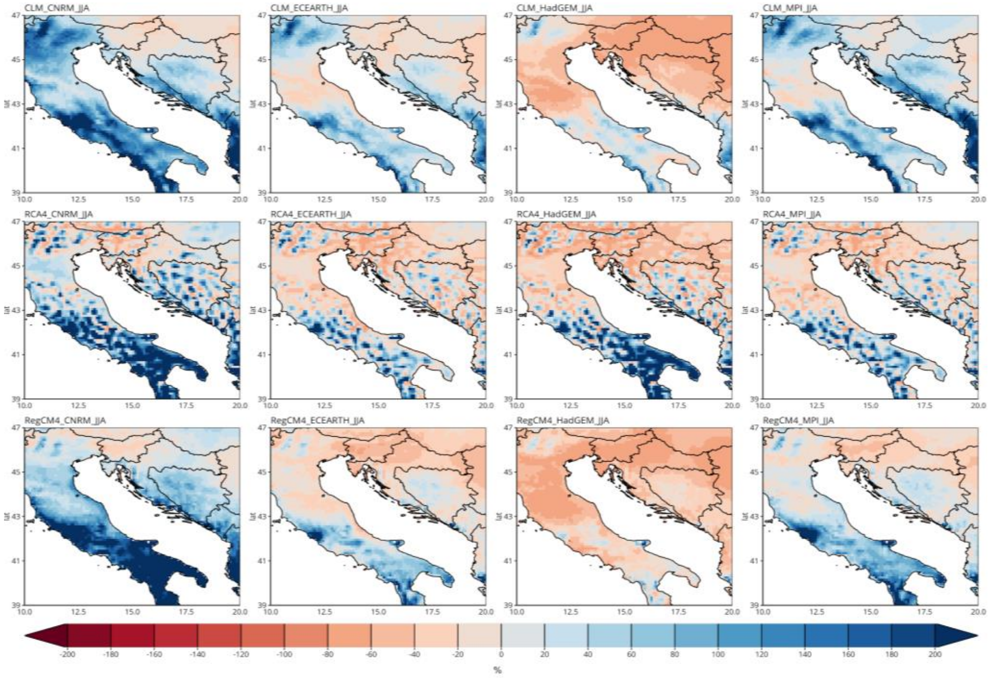

Figure 4.3: Same as Fig. 4.1 for summer (JJA).

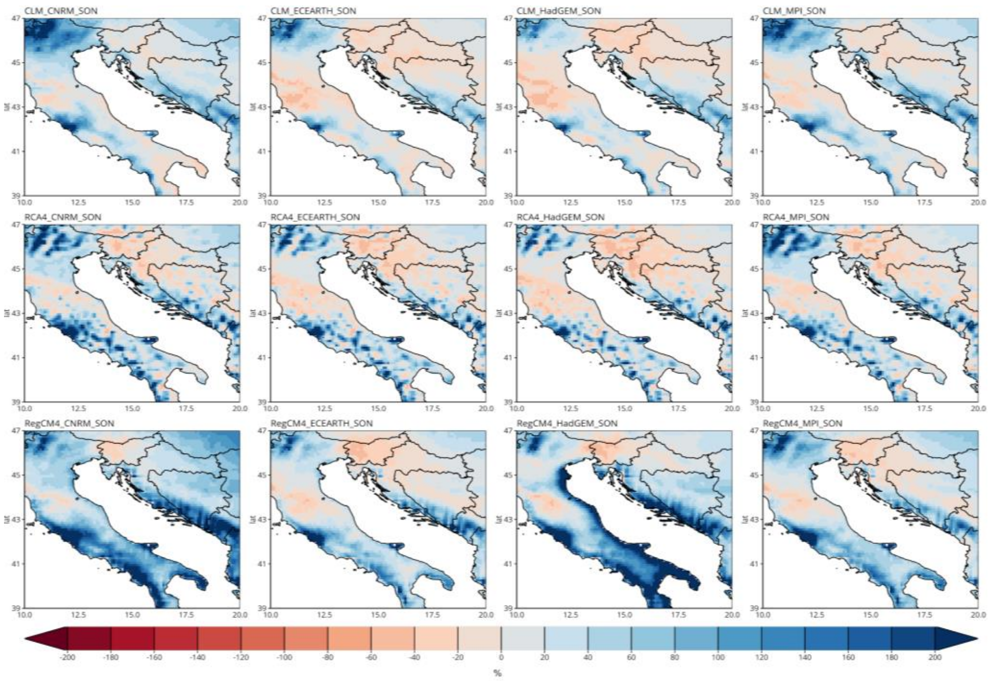

Figure 4.4: Same as Fig. 4.1 for autumn (SON).

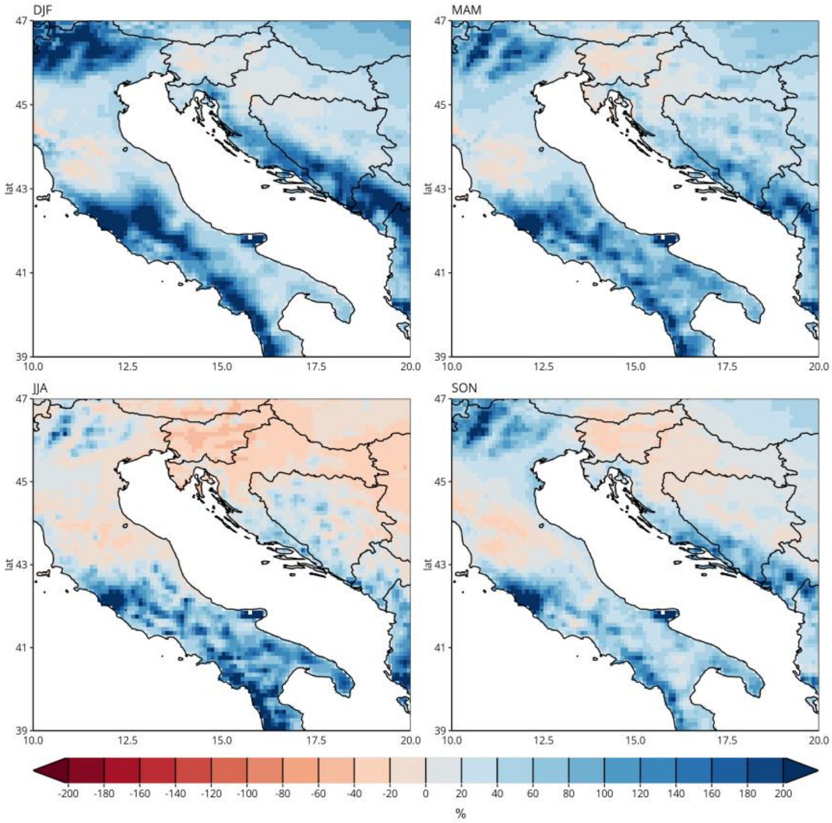

Figure 4.5 Mean seasonal total precipitation *R* relative bias (mean of 12 EURO-CORDEX RCMs - EOBS v19.0e; 1971-2000).

Bias-correction of the RCMs raw output

Biases in daily precipitation and temperature data at 7 stations on Croatian and Italian coast were corrected. Prior to bias correction procedure, data from 12 regional models were extracted at 15.897231 °E 43.750008 °N (Šibenik), 17.929318 °E 40.628807 °N (Brindisi), 13.081274 °E 45.675771 °N (Lignano), 18.099025 °E 42.652195 °N (Dubrovnik), 14.403324 °E 44.862034 °N (Cres), 17.629437 °E 43.045246 °N (Metković), 13.306987 °E 43.639331 °N (Montemarcianino). The Same grid points were extracted from the E-OBS dataset.

No regridding was done between the E-OBS grid and RCM grid but the nearest grid point was used. Due to the HadGEM2-ES 360-days calendar, few days from observations were excluded to get the Same number of data. Considering that no unique method of adjusting 365 days to 360 days calendar and excluding days, a method that keeps as much as possible daily observations were implemented (Stoner, 2011). Firstly, 31st of May, July, August, October, and December were excluded and then in leap years also 31st of March. In standard calendar all leap days were excluded.

The bias correction method used in this study is based on quantile mapping and is described in detail in Sangelantoni et al, 2017. Cases with 365- and 360-days calendar were applied accordingly. Bias correction was conducted for two periods. Firstly, the historical period 1971-2000 was corrected and after, future simulations in the period 2001-2070 were corrected at once.

Acknowledgements

We acknowledge the World Climate Research Programme's Working Group on Regional Climate and Working Group on Coupled Modelling, the former coordinating body of CORDEX, and the responsible panel for CMIP5. The simulations used in this work were also downloaded from the Med-CORDEX database. We want to acknowledge the climate modelling groups for producing and making available their model output.

We also acknowledge the Earth System Grid Federation infrastructure, an international effort led by the U.S. Department of Energy's Program for Climate Model Diagnosis and Intercomparison, the European Network for Earth System Modelling, and other partners in the Global Organisation for Earth System Science Portals (GOESSP).

RegCM4 simulations analysed in this study have been performed as a part of the "Strengthening the Capacity of the Ministry of Environment and Energy for Climate Change Adaptation and Development of the Draft Strategy for Climate Change Adaptation (contract number TF/HR/P3-M1- O1-010)" project funded by the EU Transition Facility.

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