CLIMATE PREDICTION ANALYSIS USING AN ENSEMBLE OF REGCM EXPERIMENTS FOR CENTRAL/EASTERN EUROPE

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1. INTRODUCTION

The CORDEX international initiative is the Coordinated Regional Climate Downscaling Experiment (Lake et al., 2017) in the framework of WCRP (World Climate Research Program). The entire Earth is distributed into 14 different domains being defined to run climate models with a fine resolution in the framework of CORDEX. Among these domains, the Mediterranean domain (i.e. region 12 covering 30°-50°N, 10°W-45°E) is in the focus of Med-CORDEX (Ruti et al., 2016). The specific aim of our research group is to contribute to the complex regional climate modeling database with several experiments of one selected model with ~50 km horizontal resolution using the mosaic-type subgridding option in order to take into account subgrid processes (Pieczka et al., 2019). For this purpose, RegCM was selected, which is a 3-dimensional, sigma-coordinate, primitive equation model, originally developed by Giorgi et al. (1993a, 1993b), and currently available from the ICTP (Abdus Salam International Centre for Theoretical Physics, Trieste, Italy). We completed several experiments for the MED-44 domain (Fig. 1) using different Representative Concentration Pathways (RCP) scenarios – both RCP4.5 and RCP8.5 (van Vuuren et al., 2011) – and different global climate models (GCMs) – HadGEM2 (Collins et al., 2011) and MPI-ESM Jungclaus et al., 2013; Stevens et al., 2013) – as initial and lateral boundary conditions (ICBC) driving the regional model.

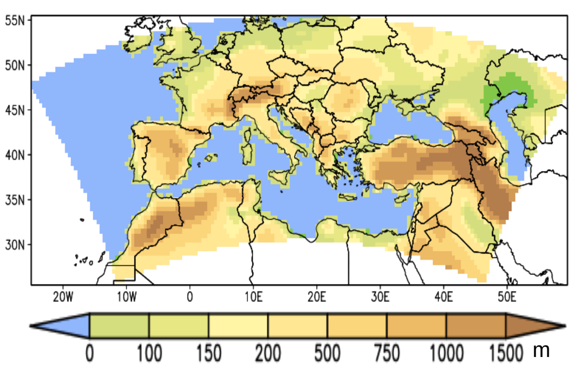

Fig. 1: The topography of the MedCORDEX integration domain (MED-44) for the RegCM4.3 simulation at ~50 km horizontal resolution.

Besides the validation of historical runs (covering 1951-2005), RCP scenarios representing different future conditions are also analyzed for the 21st century (2006-2100). In this study we present an ensemble of 4 simulation members using the same regional climate model with special focus on temperature (section 3.1) and precipitation (section 3.2) conditions.

2. REGIONAL CLIMATE MODEL REGCM

Regional climate model RegCM originally stems from the National Center for Atmospheric Research/ Pennsylvania State University (NCAR/PSU) Mesoscale Model version MM4 (Dickinson et al., 1989; Giorgi, 1989). It is a 3-dimensional, limited-area, hydrostatic, compressible, sigma-p vertical coordinate model maintained at ICTP, Trieste. The description of model equations and possible parameterizations available in the latest version can be found in Elguindi et al. (2011) in detail. In our simulations we used the model settings agreed as default within the Med-CORDEX project (Somot et al., 2012) at 50 km horizontal resolution, with the modification of activating the subgrid Biosphere-Atmosphere Transfer Scheme (BATS). Therefore, the land surface processes are modelled by BATS version 1e (Dickinson et al., 1993) with the treatment for subgrid variability of topography, and land cover is determined using a mosaic-type approach (Giorgi et al., 2003). Each grid cell is divided into 25 subgrid cells. As a result, in our simulation the size of the land surface grid cell is 10 km × 10 km horizontally. The affect of the selection of the cumulus parametrization is discussed in Pieczka et al. (2017).

3. PROJECTION RESULTS

After completing the validation analysis (Bartholy et al., 2015; Pieczka et al., 2017, 2019) of the different historical experiments using ERA-Interim (Dee et al., 2011) reanalysis data and GCM outputs as ICBC, the GCM simulation driven experiments continued with two different scenario conditions starting from 2006 throughout the entire 21st century. In order to analyze the simulation results, the projected temperature and precipitation changes are presented on annual and seasonal scales for the MED-44 domain. The regional climatic consequences of RCP4.5 and RCP8.5 scenarios (van Vuuren et al., 2011) are compared for

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the coming 2-decade-long periods in the middle and the end of the 21st century (i.e., 2041-2060 and 2081-2100, respectively). The reference period is defined as the last two decades of the 20th century (1981-2000) in the whole study.

3.1 *Temperature*

The projected annual mean temperature changes are shown for the mid- and late-century in Figs. 2 and 3, respectively. The warming signal is clearly seen on the maps, and the GCM providing the ICBC determines the range of the estimated changes. Moreover, the greater increase of radiative forcing (which is greater in the case of RCP8.5 than RCP4.5) is projected to result in greater warming. Furthermore, the estimated mean warming is greater over land than the sea. The projected annual mean temperature increases of all the target periods for both GCM-driven simulations are greater than the inter-annual temperature variability in the reference period.

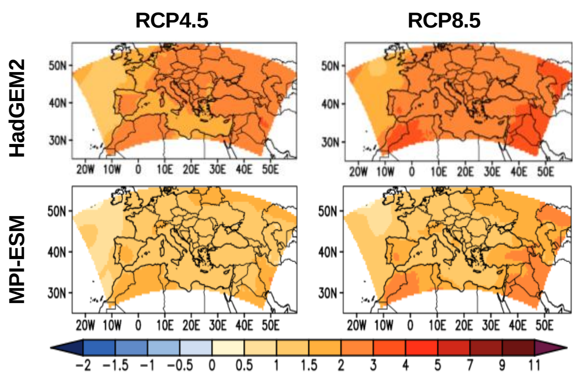

Fig. 2: Projected **annual** mean temperature changes (°C) by **2041–2060** using the RCP4.5 and RCP8.5 scenarios. The projected warming is greater than the inter-annual variability in the reference period (1981–2000).

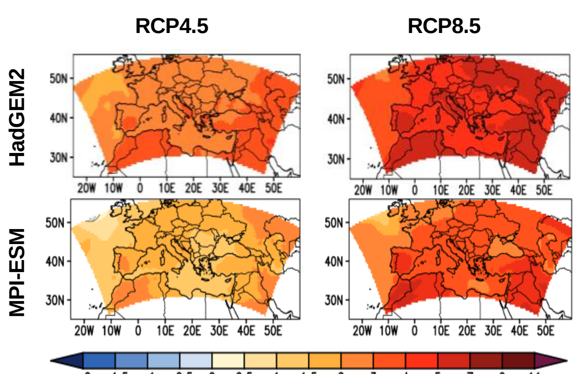

Fig. 3: Projected **annual** mean temperature changes (°C) by **2081–2100** using the RCP4.5 and RCP8.5 scenarios. The projected warming is greater than the inter-annual variability in the reference period (1981–2000).

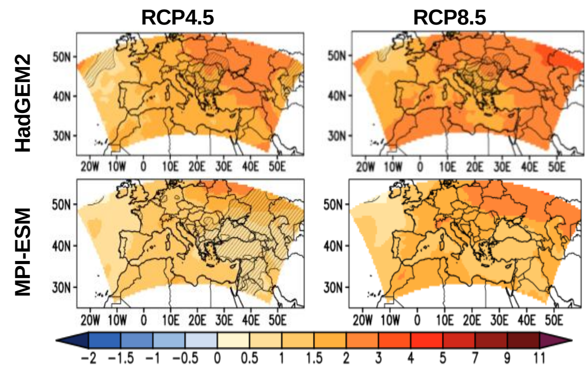

Fig. 4: Projected seasonal mean temperature changes (°C) in **winter** by **2041–2060** using the RCP4.5 and RCP8.5 scenarios. Hatched area indicates where the projected change is smaller than the inter-annual variability in the reference period (1981–2000).

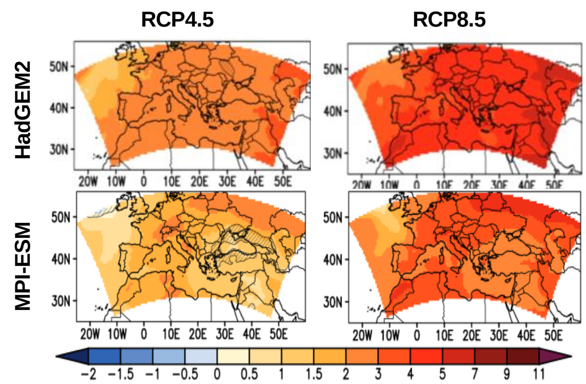

Fig. 5: Projected seasonal mean temperature changes (°C) in **winter** by **2081–2100** using the RCP4.5 and RCP8.5 scenarios. Hatched area indicates where the projected change is smaller than the inter-annual variability in the reference period (1981–2000).

Seasonal estimations are also calculated, from which winter and summer projected changes are shown in Figs. 4-5 and Figs. 6-7, respectively. The projected warming is greater in summer than winter. Nevertheless, similar conclusions can be drawn from the seasonal maps to the annual maps with respect to the difference between RCP8.5 and RCP4.5. Considering the ensemble members from the point of view of driving GCMs, the overall regional warmings projected by the HadGEM2-driven RegCM simulations are greater than the MPI-ESM-driven RegCM simulations, which can be explained by the projected global warming rates of the GCMs.

According to the climate model simulations, the European regional warming slows down in the second part of the 21st century in the case of RCP4.5, which consequently results in small differences between the projected temperature increases in 2041-2060 and 2081-2100. Since RCP8.5 does not assume such change neither in the radiative forcing, nor in the warming, the regional temperature increase is projected to continue throughout the whole 21st century.

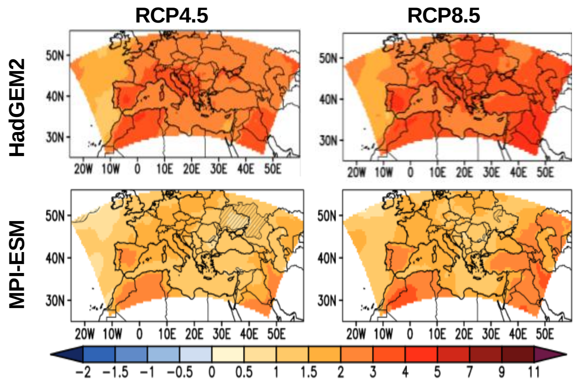

Fig. 6: Projected seasonal mean temperature changes (°C) in **summer** by **2041–2060** using the RCP4.5 and RCP8.5 scenarios. Hatched area indicates where the projected change is smaller than the inter-annual variability in the reference period (1981–2000).

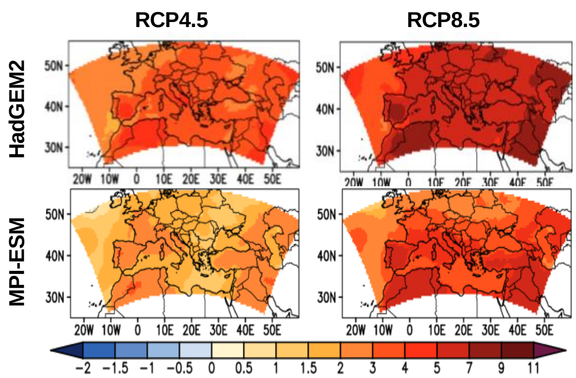

Fig. 7: Projected seasonal mean temperature changes (°C) in **summer** by **2081–2100** using the RCP4.5 and RCP8.5 scenarios. The projected warming is greater than the inter-annual variability in the reference period (1981–2000).

3.2 *Precipitation*

Similar analysis is carried out for precipitation than for temperature. The projected changes of precipitation are less robust due to the high spatial and temporal variability of precipitation. The estimated changes are overall greater by the end of the 21st century than by the mid-century period. The corresponding annual scale maps are shown in Figs. 8 and 9, respectively. In general, wetter climatic conditions are expected in the northern part of the domain, whereas it will tend to become drier in the vicinity of the Mediterranean Sea. The estimated changes by the late-century exceed the inter-annual variability of annual precipitation in the reference period in the case of the RCP8.5 scenario in a greater spatial extension than in the case of RCP4.5.

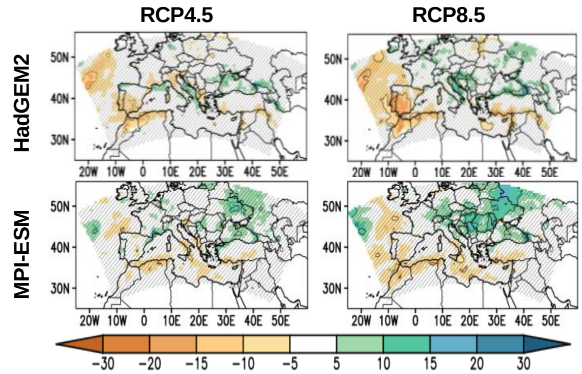

Fig. 8: Projected **annual** mean precipitation changes (%) by **2041–2060** using the RCP4.5 and RCP8.5 scenarios. Hatched area indicates where the projected change is smaller than the inter-annual variability in the reference period (1981-2000).

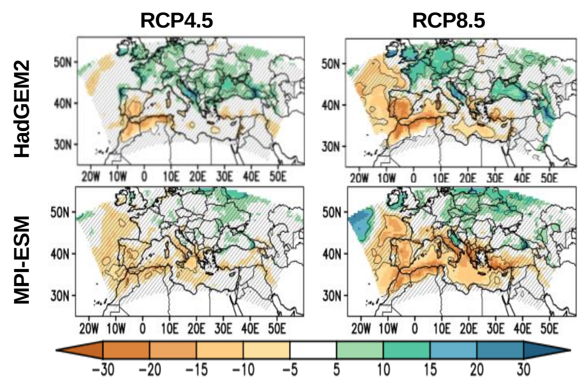

Fig. 9: Projected **annual** mean precipitation changes (%) by **2081–2100** using the RCP4.5 and RCP8.5 scenarios. Hatched area indicates where the projected change is smaller than the inter-annual variability in the reference period (1981–2000).

The seasonal analysis is shown for winter (Figs. 10-11) and summer (Figs. 12-13) in this study. The 4-member RegCM ensemble projects wetter winters in a great part of the continent. The projected precipitation increases are greater by the end of the 21st century than the mid-century, especially, in case of the HadGEM2-driven simulations and the RCP8.5 scenario. The estimated changes exceed the inter-annual variability of winter precipitation in most part of both Central and Eastern Europe (as shown in the upper right map of Fig. 11). The Mediterranean region is likely to become drier in winter, especially, in case of the MPI-ESM-driven simulations, among which the estimated precipitation decrease exceeds the inter-annual variability of winter precipitation in the greatest substantial area of the entire domain when using the RCP8.5 scenario.

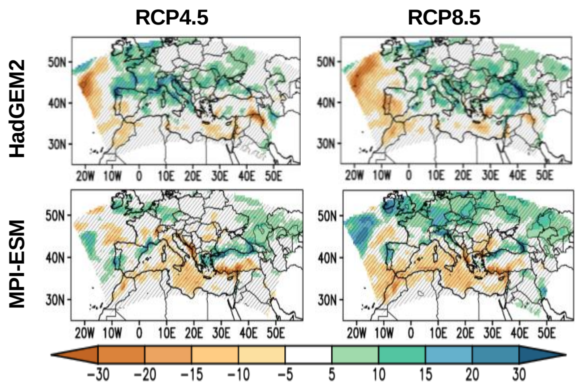

Fig. 10: Projected seasonal mean precipitation changes (%) in **winter** by **2041–2060** using the RCP4.5 and RCP8.5 scenarios. Hatched area indicates where the projected change is smaller than the inter-annual variability in the reference period (1981–2000).

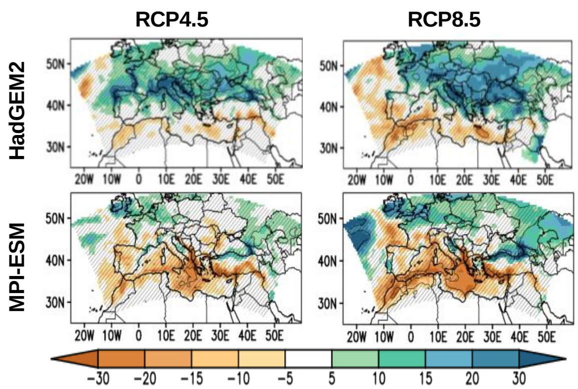

Fig. 11: Projected seasonal mean precipitation changes (%) in **winter** by **2081–2100** using the RCP4.5 and RCP8.5 scenarios. Hatched area indicates where the projected change is smaller than the inter-annual variability in the reference period (1981–2000).

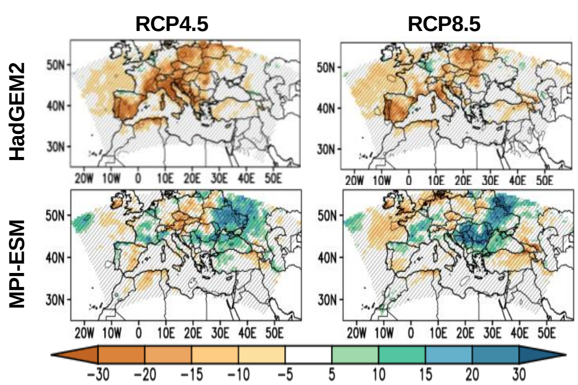

Fig. 12: Projected seasonal mean precipitation changes (%) in **summer** by **2041–2060** using the RCP4.5 and RCP8.5 scenarios. Hatched area indicates where the projected change is smaller than the inter-annual variability in the reference period (1981–2000).

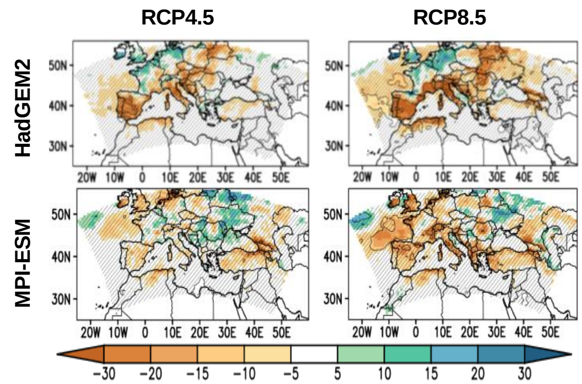

Fig. 13: Projected seasonal mean precipitation changes (%) in **summer** by **2081–2100** using the RCP4.5 and RCP8.5 scenarios. Hatched area indicates where the projected change is smaller than the inter-annual variability in the reference period (1981–2000).

The summer precipitation projections are shown in Figs. 12 and 13 for the middle and the end of the 21st century, respectively. The overall ensemble leads to contradictory estimations in summer precipitation change in many regions within the domain, although they mostly do not exceed the inter-annual variability of summer precipitation, which indicate statistically not justified or significant changes. Substantially drier climatic conditions are projected for summer in the European continental regions around the western Mediterranean Sea when HadGEM2-driven RegCM simulations are taken into account using the RCP8.5 scenario.

4. THE FURTHER USE OF SIMULATION RESULTS

The presented 50-km resolution RegCM-outputs serve as input for further downscaling using a horizontal resolution of ~10 km for a smaller domain covering Central/Eastern Europe including Hungary. These further experiments aim to become the basis of the Hungarian national climate and adaptation strategies by using RegCM results for detailed regional scale climatic projections and specific impact studies (e.g., agriculture, hydrology, health issues, etc.). Some of the impact studies (e.g., Kis et al., 2018) require the bias-correction of simulation outputs taking into account the validation results.

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