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MODELLING OF REGIONAL CLIMATIC EXTREMES BASED ON STATISTICAL AND DYNAMICAL DOWNSCALING TECHNIQUES *

Teimuraz Davitashvili   Lika Megrelidze   Meri Sharikadze

Abstract. Characterizing present climate conditions and providing future climate projections at a regional scale is an extremely difficult task as it involves additional uncertainties while reducing, a spatial scale of Global Climate Models (GCMs) simulated climate parameters. Decreasing in spatial accuracy of GCMs simulated climate variables occurs from continental to local scale using statistical downscaling (SD) or dynamical downscaling (DD) techniques [1]. There is a gap in most studies, specifically focused on estimating the uncertainty of downscaling results due to different statistical methods, as well as in creating ensembles from different GCM and SD methods at several sites in Georgia [2]. In this article, a climate change parameter such as temperature has been investigated by SD and DD methods with an emphasis on SD.

Keywords and phrases: Modelling, climate, statistical and dynamical downscaling.

AMS subject classification (2010): 62P12, 68U20.

1 Introduction. Uncertainties in regional climate predictions come from various sources, including initial and boundary conditions, incomplete formulations of the model, methods of its solution, uncertainties in current and future emission scenarios [1,3]. Model estimates are usually performed by comparing model outputs with reference observational data or reanalyzing using suitable metrics, and the results can be further used to improve the model and / or correct bias [1-4]. This study evaluates the results of 4 RCMs and a high-resolution global model for Georgia using the Regional Climate Model Evaluation System (RCMES). Namely, this study evaluates the simulation results obtained from 2 RCMs (RegCM v 4.7.0 and WRF-ARW v3.9.1.1) centered for the Georgia domain, and 2 RCM simulations from the CORDEX program developed for different areas (namely RCA4 for MENA (Middle East and North Africa) and HadRM3P for CAS (Central Asian domain)). This choice (RCA4 and HadRM3P) was driven by the fact that only these two areas overlap our target area and evolutionary modeling is only available for these two models in the ESGF (Earth System Grid Federation) -CORDEX archive. Finally, High resolution GCM - MRI-AGCM3.2 output was provided from the Meteorological Research Institute of Japan Meteorology agency. Due to the challenging climatic regime of Georgia, the territory was divided into 8 sub-regions to test the effectiveness of modeling in different sub-regions. Comparison of the simulated annual cycle with the CRU analysis for sub-regions shows that the multi-model ensemble generally agrees well with the observed

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climatology in these regions, and all five simulations have nearly identical annual cycles and a similar range of mean monthly temperatures. However, despite reasonable results, model biases vary noticeably across regions and seasons (Fig.1).

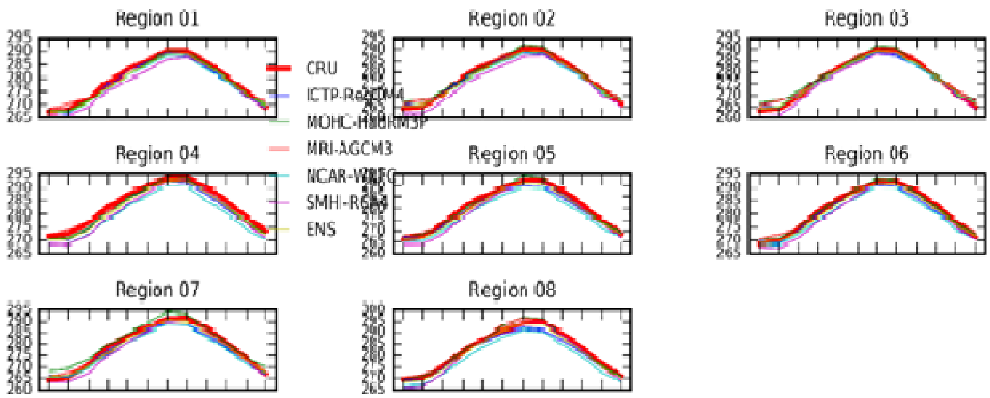

Figure 1: Simulated and observed (CRU, thick red) temperature annual cycle ($^{\circ}C$) for the 8 sub-regions. The thin yellow line indicates the multi-model ensemble temperature.

Fig. 1 shows the dependence of temperature deviations on time. One (RCA4) out of five KMs has a constant negative temperature offset throughout the year, for the other four models, the temperature is usually overestimated in winter (January and February). Seasonal variations in the magnitude of the deviation of the area average temperature indicate that the ENS models have a less extreme annual cycle than the annual observation cycle. During the transitional seasons (spring, autumn), all areas of the study area have a cold slope. It seems to be the largest in the lowlands of western Georgia. The deviation towards an increase in the average temperature in the area is the greatest in winter. In this season, warm biases extend over entire mountainous regions including the Greater and Lesser Caucasus.

In this study, the decrease in spatial accuracy of the modeled climate variables GCM occurs from continental to Caucasian and Georgian scales using SD or DD methods. Namely, in this study, monthly air temperature extremes from three GCMs of the CMIP5 database were statistically downscaled for the territory of Georgia using the RCMES package with four different methods. These methods were trained for the period 1961-1985, tested for the period 1986-2010, and then used to construct time series of future extreme events for the period 2021-2070 using the RCP4.5 and RCP8.5 scenarios. Validation of SD methods showed that all methods had some advantages and disadvantages on a temporal and spatial scale. The Coupled Model Intercomparison Project (CMIP) is a standard experimental framework for examining the results of coupled atmosphere-ocean general circulation models. CMIP5 is the most current and extensive of the CMIP experiments, which is used in this study. CMIP5 database provides outputs of approximately 60 GCMs with various historical experiments and future emission scenarios. In this study, the outlet temperature was reduced for only three of them: The Geophysical Fluid Dynamics Laboratory's (GFDL-CM3) is one of the leading climate models in CMIP5 includes aerosol–cloud and chemistry–climate interactions; The Hadley Center's Earth System Model (HadGEM2-ES) focuses on how the climate system can respond to anthropogenic disturbances and takes into account greenhouse gas concentrations, aerosol progenitors; The new Max Planck Institute Earth System Model (MPI-ESM) is used in CMIP5 for either an idealized CO2-only exposure or forcing based on observations and the Representative Concentration Pathway (RCP) scenarios. In this study temperatures were downscaled from the above 3 GCMs output using 4 different methods: Delta method (addition); Delta method (bias correction); Quantile mapping and Asynchronous linear regression method.

Table 1. Mean seasonal changes in observed and projected minimum (a) and maximum (b) temperatures under RCP4.5 and RCP8.5 scenarios simulated by the subset of CMIP5 multi-model ensemble between four 25-years periods. Differences are shown as: Δ, indexes indicate comparable periods, corresponding to: 1- 1961-1985, 2 -1986-2010, 3- 2021-2045, 4- 2046-2070.

	Season	$\Delta_{21}OBS$	$\Delta_{32}RCP4.5$	$\Delta_{32}RCP8.5$	$\Delta_{42}RCP4.5$	$\Delta_{42}RCP8.5$
$T_{min}, °C$	DJF	0.32	3.82	4.12	4.36	5.09
	JJA	0.60	0.15	0.14	1.28	2.37
	MAM	0.27	1.01	1.12	2.15	2.62
	SON	0.08	1.65	190	2.67	3.30
	Year	0.32	1.66	1.82	2.62	3.35
$T_{max}, °C$	DJF	0.40	3.73	3.99	4.29	5.19
	JJA	0.69	0.90	1.03	2.53	3.80
	MAM	0.34	0.41	0.56	1.80	2.46
	SON	0.08	-0.13	2.60	3.05	3.96
	Year	0.32	1.91	2.15	3.14	4.01

The results of calculations regarding the seasonal pattern, show that the past trends for Tmin and Tmax persist and will enhance in the future. The most significant increases are projected for winter throughout the future under both scenarios, making summer the least warming season for the year. However, for Tmax in the late 2060s, a minimum increase of around $2°C$ is expected in the spring. The largest increase in Tmin and Tmax up to $5°C$ is expected in winter under the RCP8.5 scenarios in the period 2046-2070 (Table 1). The future time series Tmin and Tmax were constructed for the period of 2021-2070 under RCP4.5 and RCP8.5 scenarios by RCMES. We used delta correction method to produce desired future scenarios. The Future change tendencies have been assessed in comparison of the period of 1986-2010 but were also compared with previous 25-years period (1961-1985) to compare future changes with the magnitudes of past tendencies. According to the simulations the mean annual minimum (maximum) temperature will increase by $1.66°C$ $(1.91°C)$ and $2.62°C$ $(3.14°C)$ in the 2060s under the RCP4.5 scenarios, that are significantly higher than the past 2000s increments ($0.32°C$) with regard to 1980s, for both targeted variables. As expected, the changes under RCP8.5 are greater than under RCP4.5 and mean annual minimum (maximum) temperature will increase by $1.82°C$ ($2.16°C$) and $3.35°C$ ($4.01°C$) in the 2040s, and 2060s, respectively

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Author(s) address(es):

Teimuraz Davitashvili, Meri Sharikadze
I. Vekua Institute of Applied Mathematics of I. Javakhishvili Tbilisi State University
University str. 2, 0186 Tbilisi, Georgia
E-mail: tedavitashvili@gmail.com, meri.sharikadze@tsu.ge

Lika Megrelidze
The Ministry of Environment Protection and Agriculture of Georgia
National Environmental Agency
David Agmashenebeli Ave. 150, 0012 Tbilisi, Georgia
E-mail: megrelidze22@gmail.com