Evaluation of Global Climate Datasets over Armenia

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***Abstract*—A large number of global climate datasets have been released in recent decades, which are used for climate monitoring and climate change assessment purposes. These global climate datasets are based on global models, or use both observations and model output through data assimilation. It is of great importance to evaluate the available global climate datasets against in-situ observations, especially in mountainous countries such as Armenia, where there is a high spatial heterogeneity in the distribution of climate variables. This paper evaluates historical simulations of monthly temperatures and precipitation from the Community Climate System Model 4 (CCSM4) and the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA5-Land global reanalysis over Armenia against the in-situ observations over the period 1961-2005. Overall, both CCSM4 and ERA5-land global datasets are able to capture the annual cycle of mean temperatures and precipitation over Armenia. The ERA5-Land reanalysis has higher skill in reproducing temperature over Armenia as compared to the coarser resolution CCSM4 model. The CCSM4 model overestimates the warming rates over Armenia in the period 1961-2005 while the ERA5-land reanalysis shows wet biases overestimating precipitation over Armenia.**

***Keywords*— Climate change, CCSM4 Model, ERA5-Land Reanalysis, Armenia.**

I. Introduction

Climate change is one of the most challenging issues for humanity. Nowadays, we are witnessing more frequent extreme weather and climatic events globally. Referring to recent extreme events, it is worth noting the strong heatwaves and unprecedented high temperatures recorded in United States, where a temperature of 54.4 °C was recorded in July, 2021 [1]. At the time, deadly floods occurred in China and Germany causing tens of billions in damages. Furthermore, long-term climatic trends are very concerning as well. The mean global temperature steadily increases, and the recent seven years, 2015 - 2021, were the seven warmest years on record [1]. Armenia and the Southern Caucasus region are also vulnerable to climate change. Previous

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studies have shown significant increases in extreme temperatures and climate in recent decades [2-5]. The Hydrometeorology and Monitoring Center of Armenia reported the three warmest years since the 1930s in 2010, 2018 and 2021, respectively. Climate change projections are not optimistic. Mean annual temperatures can increase by 2.5 – 5.0 in the 21st century under various representative concentration pathway (RCP) scenarios [4].

A large number of various global climate datasets have been released in recent decades for climate monitoring and climate change assessment purposes. These global climate datasets are based on global models, or use both observations and model outputs through data assimilation. Therefore, it is of great importance to evaluate the available global climate datasets against in-situ observations, especially in mountainous countries such as Armenia, where there is a high spatial heterogeneity in the distribution of climate variables. This paper evaluates historical simulations of monthly temperatures and precipitation from the Community Climate System Model 4 (CCSM4) and the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA5-Land global reanalysis over Armenia using in-situ observations.

II. Data and Method

In our study, the global CCSM4 climate model [6] was selected from the Coupled Model Intercomparison Project Phase 5 (CMIP5) dataset. The CCSM4 is an atmosphere-ocean coupled model developed by the National Center for Atmospheric Research (NCAR), United States. Details on dynamic cores and physical parametrization schemes of the model are described in [6]. The spatial resolution of the models for CCSM4 is 1.2° × 0.9° grid for the atmosphere in latitude and longitude. The model took into account spatially averaged temperatures and precipitation over Armenia. The modeled mean values were estimated using the five grid points located over Armenia (Figure 1; large bold crests).

The second “pseudo-observational” global climate dataset used in this study is the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA5-Land reanalysis [7]. Although the ERA5-Land reanalysis assimilates observations from surface stations and upper-air soundings, and most importantly, huge amount of satellite observations are received, this dataset also uses a numerical weather prediction model for producing climate variable fields. It is important for our mountainous area that ERA5-Land reanalysis has a relatively high spatial (~ 9 km) resolution. We used ~300 ERA5-Land grid points located over Armenia (Figure 1; black dots) to estimate the spatial mean temperature and precipitation over Armenia.

In this study, the meteorological stations are selected that have long time series of observations covering the period 1961-2005. The station observations have been checked both for quality control and homogeneity issues in this study. Finally, 45 meteorological stations were selected to provide high-quality time series of observed temperature and precipitation (Figure 1; green triangles).

Thus, observed mean values were estimated considering the selected meteorological stations which have elevations ranging from about 500 to 3300 m above sea-level.

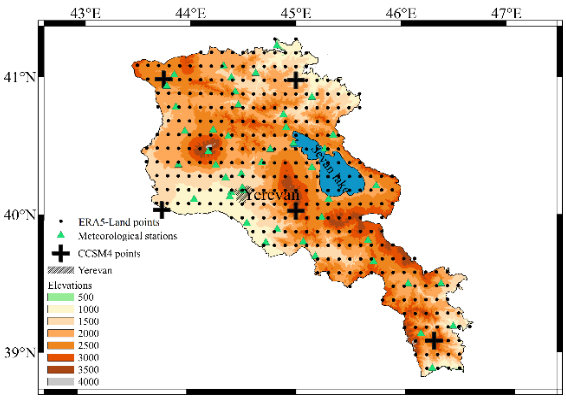

Figure 1: The Topographic map of Armenia overlaid with meteorological stations (green triangles), ERA5-Land reanalysis (black dots) and CCSM4 model (bold black crests) grid-points

III. Results

Figures 2a and b compare mean monthly observed and modeled temperatures and precipitation in Armenia over the reference period 1961-1990. The annual temperature cycle is well captured by both the CCSM4 climate model and the ERA5-land reanalysis. The CCSM4 model overestimates the observed temperatures in the summer months. At the same time, the ERA5-land reanalysis accurately represents the annual temperature cycle in Armenia. The precipitation modeling is a greater challenge for both the CCSM4 model and the ERA5-land reanalysis (Figure 2b). Figure 2b shows that the CCSM4 model better fits the observations reproducing the annual cycle of precipitation quite well, while the ERA5-land reanalysis strongly overestimates the observed precipitation.

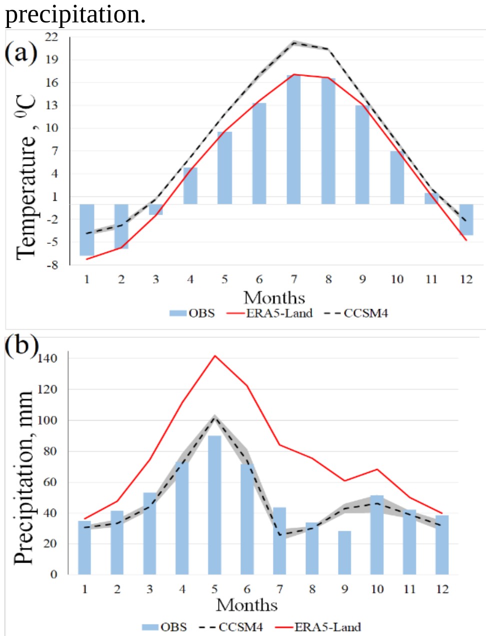

Figure 2: Mean monthly temperatures (a) and precipitation (b) over Armenia for the reference period 1961-1990 derived from observations (blue bars), ERA5-Land (red) and CCSM4 model (dashed black line). The shaded areas around the CCSM4 lines show the model uncertainty range.

We further evaluated the seasonal temperatures modeled by CCSM4 against in-situ observations. The Summer and Winter seasons are characterized by the highest Root Mean Squared Errors (RMSE) when CCSM4 simulates warmer temperatures with mean biases ranging from 3 to 4 °C

(Figure 3a). The correlation coefficients are lower than 0.4 for all seasons (Figure 3b).

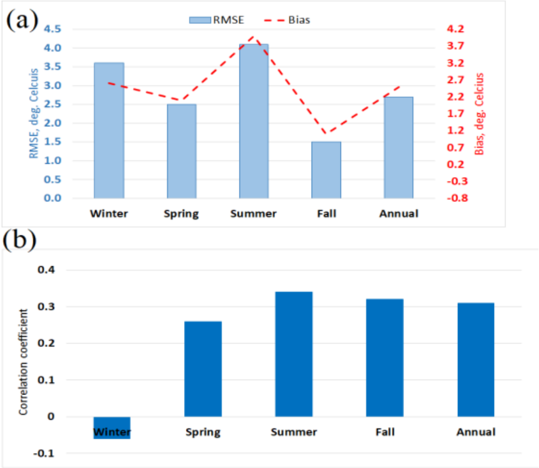

Figure 3: Root Mean Squared Errors (RMSE, bars) and mean biases (dashed line) (a) and correlation coefficients (b) for mean seasonal temperatures in Armenia over the period 1961-2005

We analyze the time series of annual temperature and precipitation anomalies over Armenia from CCSM4 simulations and the ERA5-Land dataset (Figures 4a and b). Overall, the three datasets clearly show warming trends in annual temperatures over Armenia for 1961-2005. However, the CCSM4 model strongly overestimates the warming rates (0.4 °C per decade) compared to the observations and ERA5-Land data (0.1-0.17 °C per decade). The CCSM4 model shows low performance in the 1960s and at the beginning of the 1970s failing to capture the warmest temperature anomaly observed in 1966 (~2 °C), leading to stronger warming trends in simulations. Warm temperature anomalies have been better simulated since the 1990s. The correlation between the observed and CCSM4 temperature anomalies consists of 0.4, which is statistically significant at a 0.05 significance level based on a two-sided p-value (0.04). It is worth noting the strong correlation between the observations and ERA5-land reanalysis (0.97), which is promising for using this dataset to study climate change in Armenia. The model uncertainty range for annual temperature anomalies in the CCSM4 model on average consists of ±0.6 °C (shaded area in Figure 4a).

Turning to the time series of precipitation anomalies, we note that there is high interannual variability making it difficult to reveal any significant precipitation trend in Armenia (Figure 4b). Both observations and ERA5-Land reanalysis show that precipitation decreased by 12–25 mm per decade, while the CCSM4 model shows precipitation increase by 10 mm per decade. The CCSM4 model clearly has difficulties in proper representation of interannual variability of precipitation anomalies in Armenia, as the correlation coefficient (0.23) is not significant at a 0.05 significance level (the two-sided p-value consisted of 1.55). This is expected given the coarse resolution of the model and the high spatial and temporal variability of precipitation induced by the atmospheric circulation and mountainous orography of Armenia [8-9]. However, the high-resolution ERA5-Land reanalysis performs quite well, and the correlation between the observations and reanalysis is 0.88 and statistically significant. Note that the ERA5-Land reanalysis accurately reproduces the wettest year (1963) in the observational records of Armenia when ~350 mm excessive precipitation was observed.

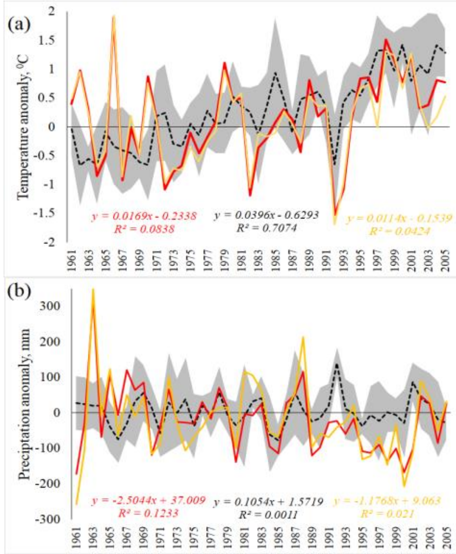

Figure 4: Annual temperature (a) and precipitation (b) anomalies in Armenia for the period 1961-2005 derived from observations (red), ERA5-Land (gold) and CCSM4 model (dashed black). The gray shaded area shows the CCSM4 model uncertainty range. The squared correlation coefficients and equations of linear regressions are presented on the plots.

IV. Conclusions

Overall, both CCSM4 and ERA5-land global datasets are able to capture the annual cycle of mean temperatures and precipitation over Armenia. The ERA5-land reanalysis has higher skill in reproducing temperature over Armenia as compared to the coarser resolution CCSM4 model. This is expected, considering that the ERA5-land reanalysis has ~10 times higher spatial resolution and this dataset assimilates a significant number of ground and satellite observations. Therefore, this is very important for mountainous countries such as Armenia. The CCSM4 model overestimates the warming rates over Armenia in the period 1961-2005 compared to the in-situ observations and ERA5-land reanalysis. The representation of precipitation is more challenging for both the ERA5-land reanalysis and the CCSM4 model. ERA5-land reanalysis produced significant wet biases in Armenia. This is related to the challenges of adequate modeling of orographic precipitation and convection. [9] mentioned that to capture orographic convection over Armenia, convection-permitting modeling is required (with a spatial resolution of less than 4 km). Therefore, even the relatively high-resolution ERA5-land global reanalysis shows significant precipitation biases over Armenia.

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