Georgian Geographical Journal 2023, Vol.3 (2)

The Performance of RegCM4.7.1 over Georgia's Territory Using Two Different Configurations

Mariam Elizbarashvili[1]*, Zurab Seperteladze[1], George Mikuchadze[1]

Abstract

This study utilised the Abdus Salam International Centre for Theoretical Physics (ICTP) Regional Climate Model version 4.7.1, adopting two different configurations. The ability of each configuration to reproduce mean and extreme temperatures and precipitation in different environmental conditions in Georgia was studied. The model conducted simulations over the time frame of 2009–2014, with a horizontal grid spacing of 12 km. The simulations utilised ERA5 data as boundary conditions. Both simulations encompass the whole geographical area of Georgia, as well as the Black and Caspian Seas. The outputs from these high-resolution simulations of mean and extreme precipitation and air temperature were compared with the observational data for 2010–2014 for Georgia's territory. A comparison of existing weather station data with model data showed that the model with both configurations performed better in simulating the monthly mean and extreme values of temperature than those of precipitation. The biases between observed and simulated precipitation are high for both configurations as well. There is no significant difference between the two simulation results. However, it is also important to carry out further analysis and compare the results of these simulations not only with weather station data but also with different reanalysis data, which will allow us to perform not a point analysis but a spatial analysis over the entire area of the domain.

Keywords: Observation, Model simulation, Mean and extreme, Temperature, Precipitation

Introduction

Regional climate modelling is recognised as an important tool for assessing the potential impacts of climate change at local and regional scales. It can be used to predict temperature, precipitation, or extreme weather events [1, 2].

Such information is crucial for policymakers, urban planners, and communities to make informed decisions about infrastructure, land use, and disaster preparedness. Therefore, high-resolution, reliable regional climate modelling is essential for individual countries and regions, for which, first, it is necessary to conduct experiments with the purpose of selecting regional model configurations.

In this study, we apply the Regional Climate Model version 4.7.1 to the Georgian territory and surrounding area. The objective of this study is to evaluate the model's performance and its ability to reproduce observed data.

The model's performance was assessed by conducting sensitivity experiments. The RegCM was configured, and parameters for physical processes such as convection, clouds, radiation, and boundary layers were set. Two simulations with two different settings were performed to understand how changes in the model physics configuration and domain size affect the results. The model simulation results were validated against observational data, and the ability of each configuration to reproduce mean and extreme temperatures and precipitation in different environmental conditions in Georgia was assessed.

Methods and Materials

The regional climate model (RegCM) was developed by the Abdus Salam International Centre for Theoretical Physics (ICTP) and has been widely used for climate simulations for different regions of the world [3-9].

In this study, RegCM4.7.1 simulations for the period of years 2009-2014 at a 12 km horizontal grid spacing were performed over Georgia's territory with:

1. Emanuel Cumulus convection scheme [10] and Explicit Nogherotto-Tompkins moisture scheme [11] (Emanuel 1).
2. Emanuel Cumulus convection scheme with Explicit WSM5 moisture scheme (Emanuel 2).

[1] Department of Geography/Faculty of Exact and Natural Sciences, Ivane Javakhishvili Tbilisi State University, Tbilisi, Georgia

* Corresponding author: mariam.elizbarashvili@tsu.ge

The first simulation (Emanuel 1) was performed over the domain centered in clat = 41, clon = 43 with 252 points in the E/W direction, 172 points in the N/S direction and 41 vertical levels.

The second simulation was performed over the domain (Emanuel 2) centered in clat = 41.5, clon = 41.2, with 200 points in the E/W direction, 128 points in the N/S direction, and 41 vertical levels. Both domains encompass Georgia's territory, the Caucasus mountains, the full Black and Caspian Seas and surrounding areas.

The Community Land Model version 4.5 (CLM) [12] exponential relaxation lateral boundary conditions scheme, stratocumulus clouds simulation, and the rapid radiation transfer model RRTM radiation scheme [13] were used for both simulations.

The hourly ERA5 high-resolution climate data and the weekly sea surface temperature from the National Oceanic and Atmospheric Administration (NOAA) [14] were applied to drive the model. ERA5 is the fifth generation European Centre for Medium-Range Weather Forecasts (ECMWF) atmospheric reanalysis of the global climate.

RegCM simulations are computationally intensive, especially when using high spatial and temporal resolutions and access to sufficient computational resources is essential. For our simulations, we used The Georgian Research and Educational Networking Association GRENA's resources.

Study area

The article discusses the findings of a study that compared weather data from various weather stations in different physical-geographical and climatic conditions in Georgia, including Tbilisi, Tsalka, Poti, and Mta Sabueti (as shown in Table 1). The study also included simulation data generated by two different configurations of a regional climate model. The observational data were compared to the data from the nearest grid point in the model simulation.

Table 1. Meteorological stations

Meteorological Station	Latitude, N°	Longitude, E°	Elevation, m
Tbilisi	41.7	44.83	600
Tsalka	41.6	44.09	1482
Mount Sabueti	42.03	43.48	1248
Poti	42.14	41.68	3

Tbilisi is situated in the eastern part of Georgia, particularly in the Tbilisi hollow. It occupies land on both sides of the Mtkvari River, at an elevation ranging from 380 to 600 metres a.s.l. The city has a dry subtropical climate.

Tsalka is situated in the eastern part of Georgia, particularly in the Kvemo Kartli region. It is located in the Tsalka hollow, on the bank of the Tsalka reservoir and Khrami River. The town is at an elevation of 1482 mm a.s.l. and has a dry subtropical mountain climate.

Mt. Sabueti is situated on the western slopes of the Likhi range, at the headwaters of the Chkhrimela River, with an elevation of 1246 m a.s.l. The Likhi range functions as a climatic barrier separating the western and eastern parts of Georgia. However, the border of the Kolkheti plain and the climatic-botanical regions of eastern Georgia do not align with the watershed, but instead follow the eastern slopes of the range. Thus, Mt. Sabueti is situated inside the geographical area characterised by a hilly terrain and a humid subtropical climate.

Poti is situated in the Kolkheti plain along the Black Sea coastline, at an elevation of 1-3 m a.s.l. This area is known for its humid subtropical marine climate.

Results

Annual air temperature

Fig. 1 presents the annual air temperature variation according to the model simulations and observational data for the selected weather stations in Georgia. It seems that for all stations for both simulations, the model well describes the annual air temperature variation.

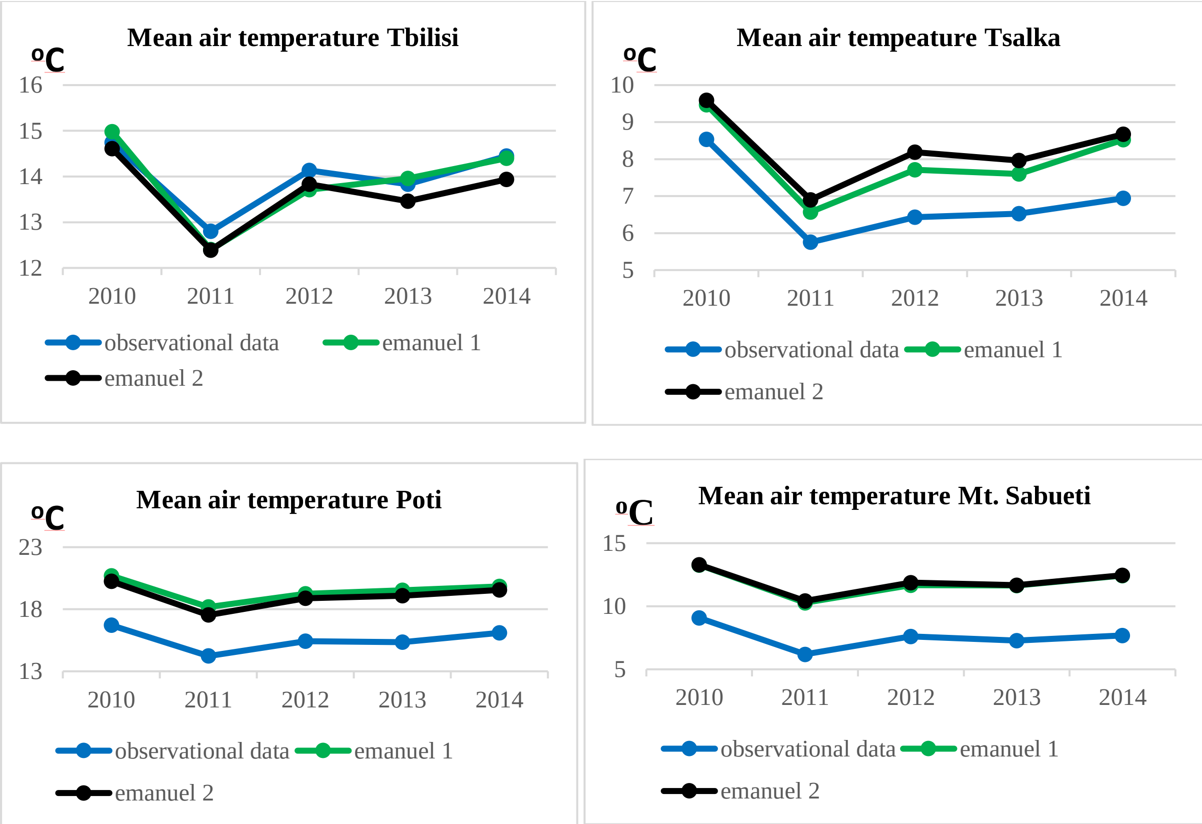
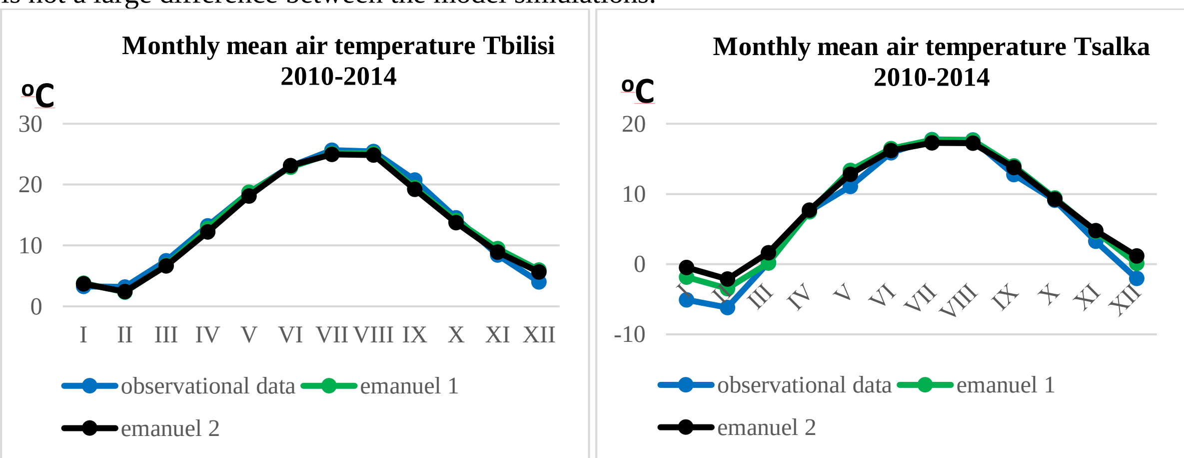


Figure 1. Annual temperature variation for selected weather stations according to the model and observational data

In Tbilisi, the observational data exceed the "Emanuel 2" simulation outputs for all years and almost coincide with the "Emanuel 1" simulation outputs for some years. In Tsalka, Poti and Mt. Sabueti, the model data for both simulations exceed the observational data for all years.

The largest difference between the model and observational data of average annual air temperature is observed in Mount Sabueti and Poti, and the difference is 4.78 OC and 4.18 OC, respectively. There is not a large difference between the model simulations.



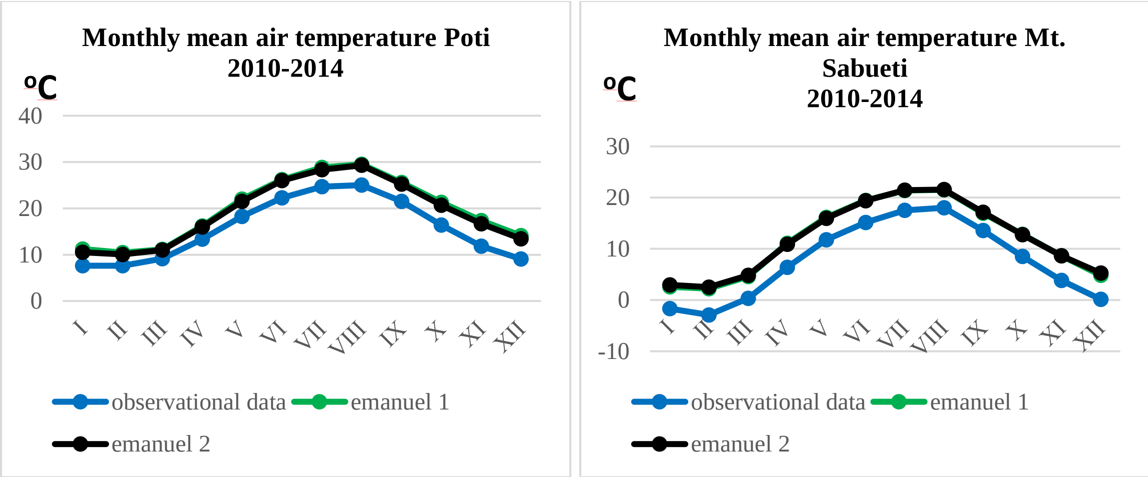


Figure 2. Monthly mean air temperature for selected weather stations according to the model and observational data

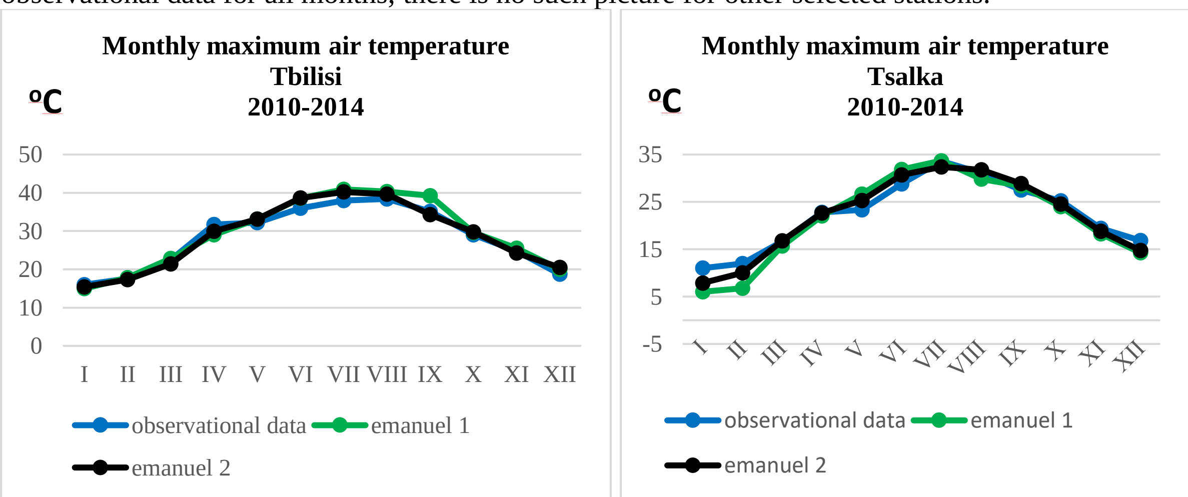
Monthly Mean Air Temperature

Fig. 2 presents the monthly mean air temperature for Tbilisi, Tsalka, Poti and Mt. Sabueti according to the model and observational data for 2010-2014. The model simulation data well reflect the intra-annual trend of the monthly mean air temperature. In Tbilisi, the model simulations and observational data almost coincide with each other throughout the year for both simulations. In Tsalka, the difference between the model simulations and observational data is highest during the winter, and the best agreement is during the summer and in March, April and October.

Monthly Maximum Air Temperature

Figure 3 shows the monthly maximum air temperature for 4 weather stations in Georgia according to the model and observational data for 2010-2014. The intra-annual movements of monthly maximum temperatures are in good agreement with each other according to the observational data and model data. There is no difference between the outputs of the two simulations.

The largest difference between the monthly maximum air temperature observational data and model data is observed at the high mountainous station on Mt. Sabueti. This difference is relatively small in eastern Georgia's high mountain station – Tsalka, in Tbilisi and in western Georgia on the Black Sea coast - in Poti (Fig. 3). Moreover, for Mt. Sabueti, both model simulations significantly exceed observational data for all months; there is no such picture for other selected stations.



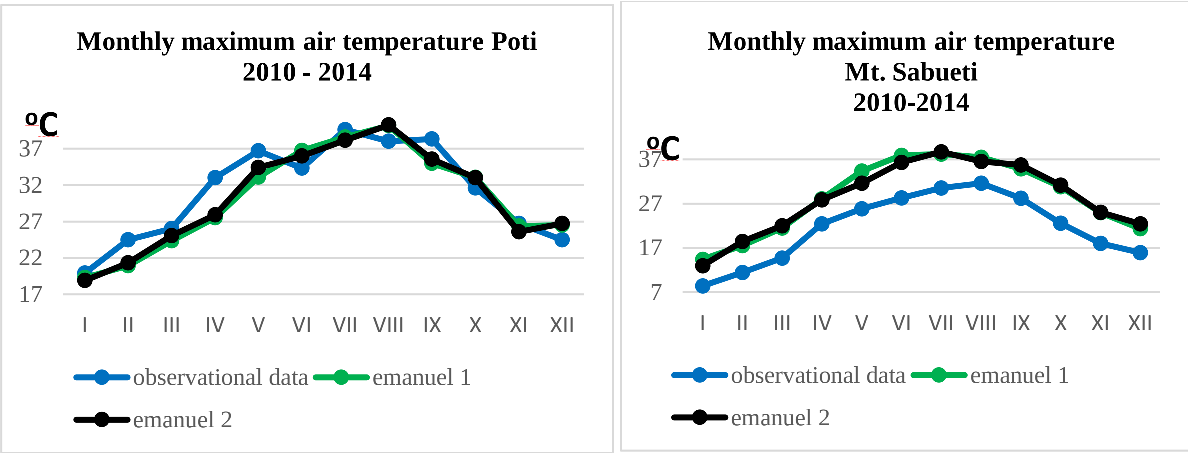


Figure 3. Monthly maximum air temperature for weather stations according to the model and observational data, 2010-2014

Monthly Minimum Air Temperature

Fig. 4 shows the monthly minimum air temperature for Tbilisi, Tsalka, Poti and Mt. Sabueti weather stations for 2010-2014 according to the model and observational data. The intra-annual course of monthly minimum air temperature is in good agreement with each other according to observational data and model data. Both the "Emanuel 1" and "Emanuel 2" simulations depict monthly minimum air temperature observational data for Tbilisi well.

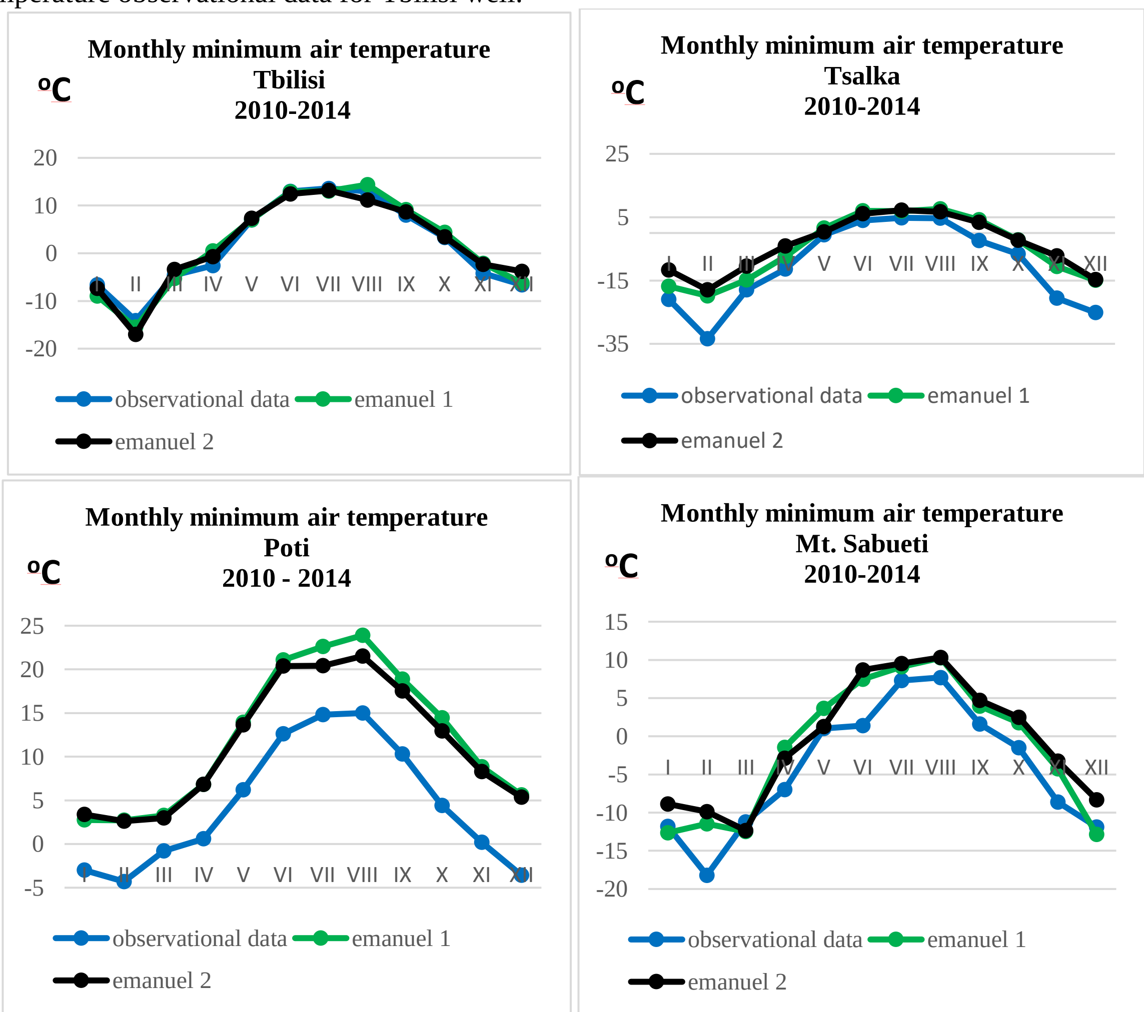


Figure 4. Monthly minimum air temperature for the weather stations of Georgia according to the model and observational data, 2010-2014

The largest difference between the monthly minimum air temperature observational data and the model data is observed for Tsalka in February - -13.55 OC, and -15.38 OC for the Emanuel 1 and Emanuel 2 simulations, respectively (Figure 4).

The large difference between the monthly minimum air temperature observational data and model data is also observed in all months at the weather station on the Black Sea coast – Poti (Figure 6). For Poti, the model data exceed the observational data for both simulations. In the high mountain weather station of western Georgia – Mt Sabueti, the gap between the monthly minimum air temperature's observational data and model data is relatively small.

Annual precipitation

Figure 5 shows the variation in annual precipitation according to the model and observational data for Tbilisi, Tsalka, Poti and Mt. Sabueti weather stations for 2010-2014. As we can see, in most cases of all stations, the model data differ significantly from the observational data.

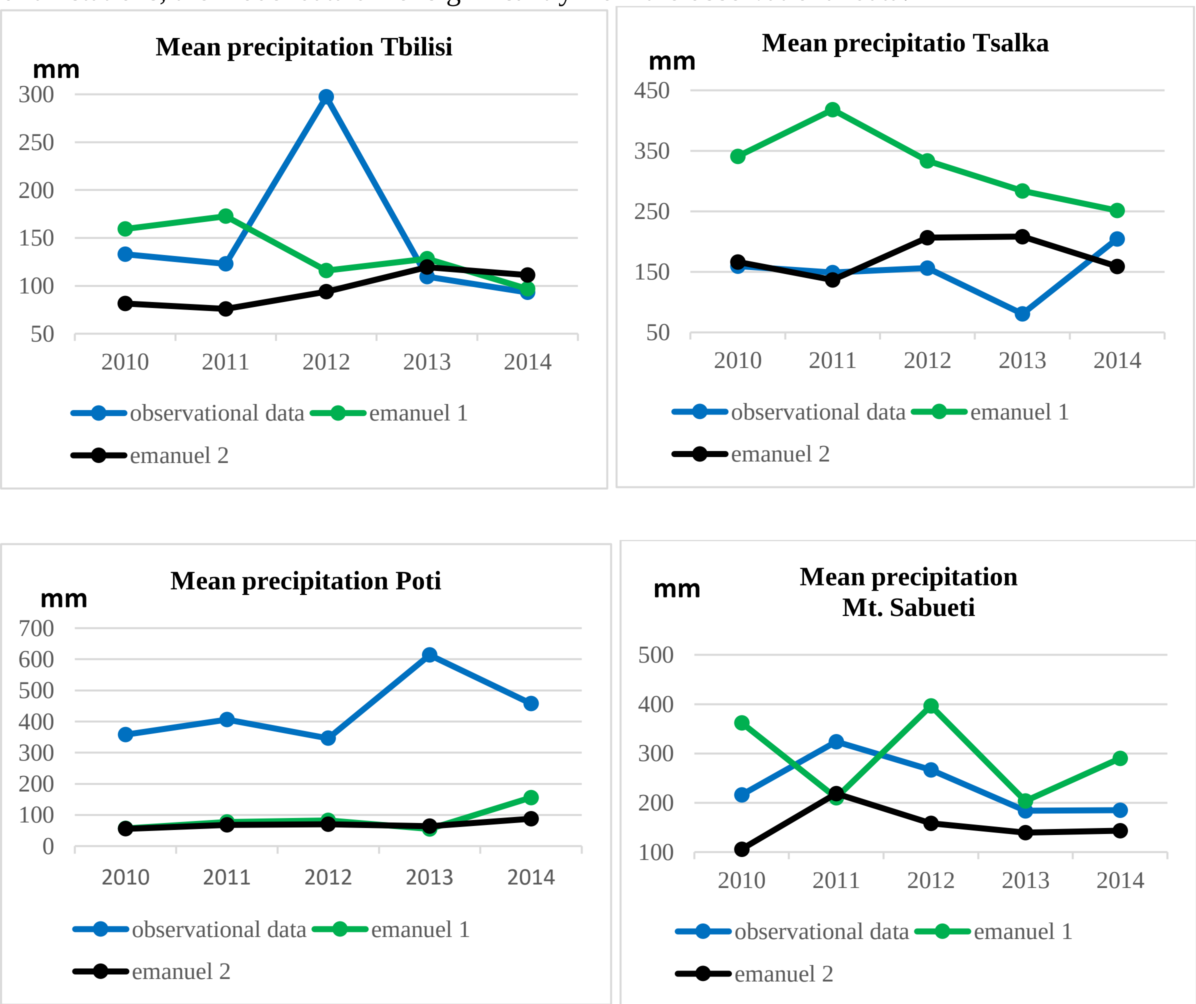


Figure 5. Annual precipitation variation for weather stations according to the model and observational data

For Poti station, the Emanuel 1 and Emanuel 2 simulation outputs almost coincide with each other, and the observational data significantly exceed the model data for both simulations in all years (Fig. 5).

For Mt. At the Sabueti station, the annual precipitation observational data significantly exceed the Emanuel 2 simulation data in all years, and the Emanuel 1 simulation data exceed the observational data in all years except 2011, where the Emanuel 1 and Emanuel 2 simulation outputs coincide with each other.

Monthly mean precipitation

Fig. 6 presents the monthly mean precipitation for Tbilisi, Tsalka, Poti and Mt. Sabueti weather stations for 2010-2014. As we can see, the intra-annual movement of average monthly precipitation mainly differs from each other according to observational data and model data.

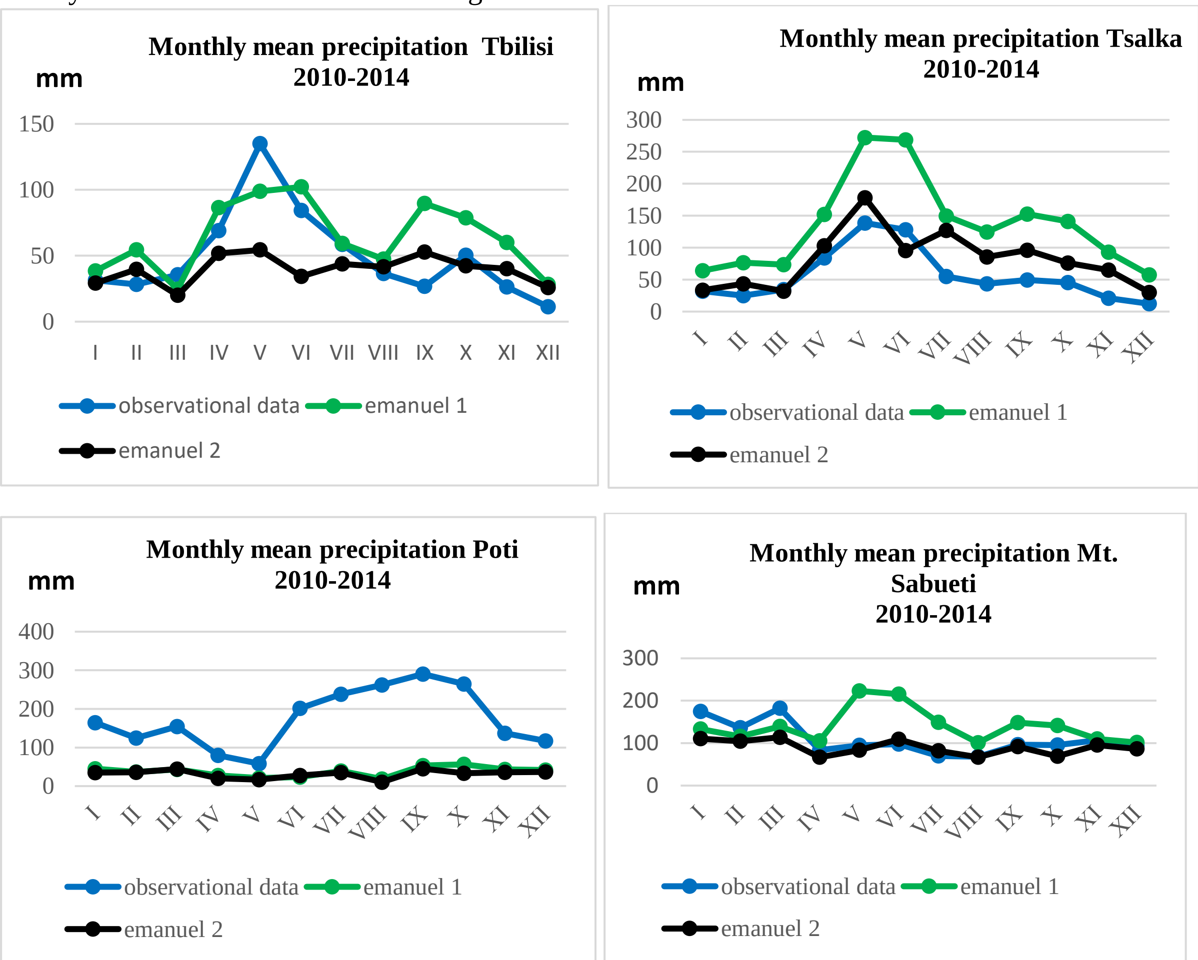


Figure 6. Monthly mean precipitation according to the model and observational data for weather stations, 2010-2014

For Tbilisi, the Emanuel 1 and Emanuel 2 simulation outputs differ from each other, although the model and observational data of some months coincide with each other.

There is a significant difference in the weather station of Tsalka (1482 m) located in the high mountainous areas of eastern Georgia, where the model data significantly exceed the observational data in all months. For the Emanuel 1 simulation and for the Emanuel 2 simulation, the gap between the model and the observational data is relatively small, and in January and March, the Emanuel 2 simulation data almost coincide with the observational data. For Poti station, the Emanuel 1 and Emanuel 2 simulation outputs coincide with each other, and the observational data significantly exceed the model data for both simulations in all months (Figure 6). For Mt. At the Sabueti station, the gap between the Emanuel 1 simulation output and observational data is larger than the gap between the Emanuel 2 simulation output and observational data for each month.

Daily maximum precipitation

Fig. 7 presents daily maximum precipitation for Tbilisi, Tsalka, Poti and Mt. Sabueti weather stations for 2010-2014. As we can see, the annual movement of maximum daily precipitation differs from each other according to observational data and model data. In Tbilisi and Poti, the daily maximum precipitation model data are less than the observational data.

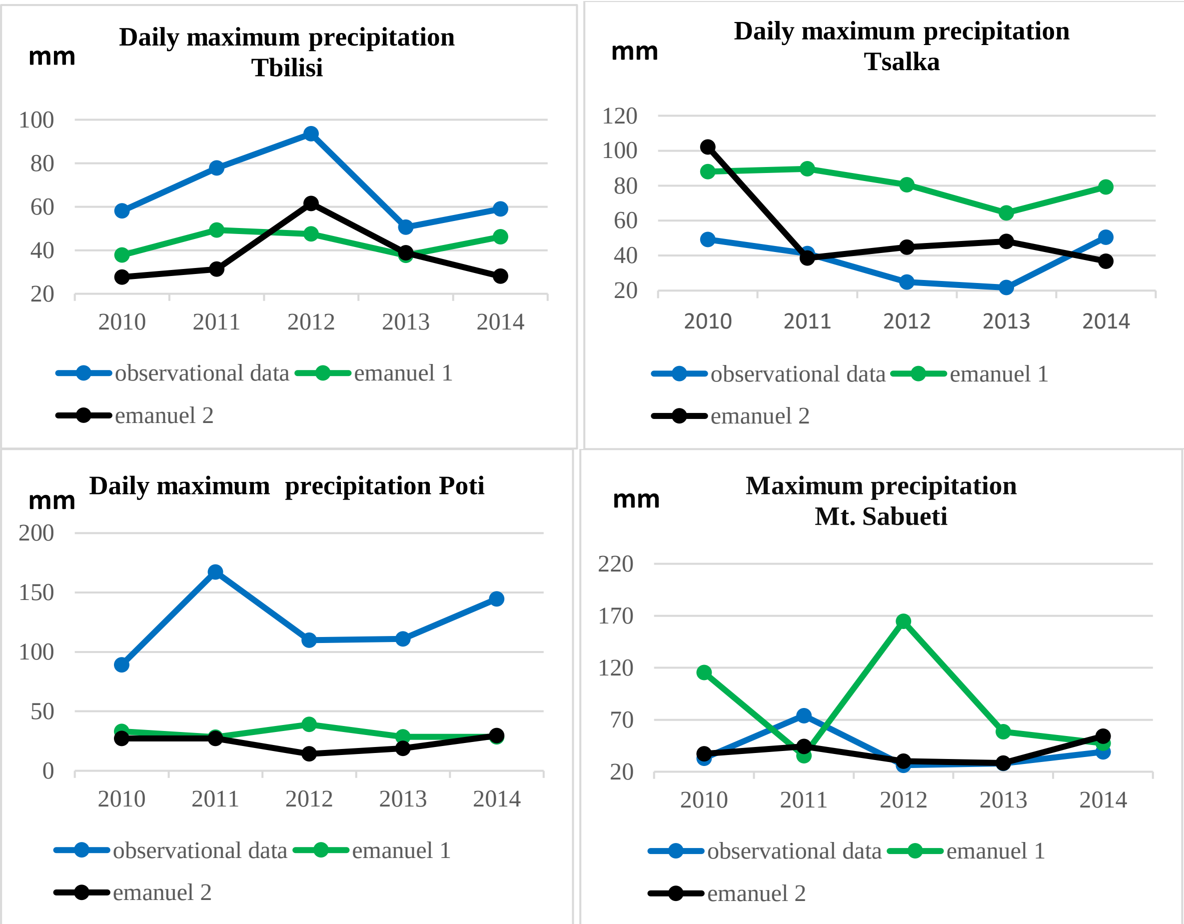


Figure 7. Daily maximum precipitation for Georgia's weather stations for 2010-2014

Discussion

Comparing regional climate model results with observational data is a fundamental step in assessing the reliability and accuracy of the models. It informs our understanding of past and current climate conditions, helps identify model deficiencies, and supports the use of these models for making future climate projections and informed policy decisions.

There is no significant difference between the model simulation results on two different size domains with two different configurations. A comparison of the model and observational data showed us that both configurations of the model describe the average and extreme values of air temperature and atmospheric precipitation for different weather stations with different accuracies. The discrepancy between the model data and the observational data is particularly obvious when it comes to precipitation. This can be explained by the complex terrain of Georgia and the resolution of the model, which leads to a significant difference between the model points and the actual locations of the meteorological stations [6]. Usually, the observational data from the meteorological stations are compared to the data in the nearest grid of the model simulation. It is important to conduct further analysis and compare the results of these simulations not only with the weather station data but also with different reanalysis data, which will allow us to conduct not a point but spatial analysis over the entire area of the domain.

Conclusions

Observational data from weather stations located in the different physical-geographical conditions of Georgia are compared with the results of simulations conducted with two different configurations of the regional climate model, which showed us that model's both simulations reproduce better the monthly mean and extreme values of temperature than precipitation.

Both simulations capture the variation in the annual, monthly mean and extreme values of air temperature better in the stations located in eastern Georgia – in Tbilisi and Tsalka – than in the stations located in western Georgia – in Poti and Mount Sabueti.

The smallest bias between the observational and model monthly mean and extreme values of temperature for both simulations is in Tbilisi.

There are many uncertainties in yearly, monthly and extreme precipitation. The biases between the observations and simulated precipitation are high, which may be explained by the model resolution, which causes a significant inconsistency between the model points and the locations of weather stations.

Competing interests

The authors declare that they have no competing interests.

Authors' contribution

M.E., Z.S., and G. M. conceived the presented idea. G. M. performed the analytic calculations. M.E. and Z.S. took the lead in writing the manuscript. All authors provided critical feedback and helped to shape the research, analysis and manuscript.

Acknowledgements

This research has been supported by the Shota Rustaveli National Science Foundation of Georgia (SRNSFG) № FR-19-8110.

References

[1] Giorgi, Filippo (2019). Thirty years of regional climate modelling: Where are we and where are we going next? *Journal of Geophysical Research: Atmospheres*, 124, 5696–5723. https://doi.org/10.1029/2018JD030094

[2] Rummukainen, Markku (2010). State-of-the-art with regional climate models, WIREs Climate Change, Volume 1, Issue 1, page numbers: 82-96 https://doi.org/10.1002/wcc.8

[3] Giorgi, Filippo., Marinucci, Maria Rosaria., Bates, Gary T (1993) Development of a second-generation regional climate model (regcm2) i: boundary layer and radiative transfer processes. Monthly Weather Review 121:2794– 2813

[4] Giorgi, Filippo., Marinucci, Maria Rosaria., Bates, Gary T., De Canio, Gerardo (1993). Development of a second-generation regional climate model (regcm2) ii: convective processes and assimilation of lateral boundary conditions. Monthly Weather Review 121:2814–2832

[5] Elizbarashvili, Mariam., Kalmár, Timea., Tsintsadze, Magda., Mshvenieradze, Tsezari (2022). Regional climate modeling for Georgia with RegCM4.7. EGU General Assembly Conference Abstracts, EGU22-2065

[6] Elizbarashvili, Mariam., Mikuchadze, George., Kalmár, Timea., Pal, Jeremy (2023). Comparison of Regional Climate Model Simulations to Observational Data for Georgia. EGU General Assembly Conference Abstracts, EGU23-3828

[7] Elizbarashvili, Mariam., Tsintsadze, Magda., Mshvenieradze, Tsezari (2021). High-resolution Climate Simulation Using Double-nesting Method for Georgia - AGU Fall Meeting Abstracts, A55Q-1638

[8] Giorgi, Filippo., Bi X., Pal, Jeremy (2004). Mean, interannual variability and trends in a regional climate change experiment over Europe. I. Present-day climate (1961–1990). *Climate Dynamics* **22**, 733–756. https://doi.org/10.1007/s00382-004-0409-x

[9] Giorgi, Filippo., Bi X., Pal, Jeremy (2004). Mean, interannual variability and trends in a regional climate change experiment over Europe. II: climate change scenarios (2071–2100). *Climate Dynamics* **23**, 839–858 (2004). https://doi.org/10.1007/s00382-004-0467-0

[10] Emanuel, Kerry A (1991). Scheme for Representing Cumulus Convection in Large-Scale Models. *Journal of Atmospheric Sci*ences, 48, 2313–2329.

[11] Nogherotto, Rita., Tompkins, Adrian Mark., Giuliani, Graziano., Coppola, Erika., Giorgi, Filippo (2016). Numerical framework and performance of the new multiple-phase cloud microphysics scheme in RegCM4. 5: precipitation, cloud microphysics, and cloud radiative effects. *Geoscientific Model Development*, 9(7), 2533-2547

[12] Brunke, Michael A., Broxton, Patrick., Pelletier, Jon., Gochis, David., Hazenberg, Pieter., Lawrence, David M., Leung, L. Ruby., Niu, Guo-Yue Niu, Troch, Peter A., Zeng, Xubin (2016). Implementing and Evaluating Variable Soil Thickness in the Community Land Model, Version 4.5 (CLM4.5). *Journal of Climate.* 29, 3441–3461

[13] Mlawer, Eli., Taubman, Steven., Brown, Patrick., Iacono, Michael., Clough, Shepard (1997). Radiative transfer for inhomogeneous atmospheres: RRTM, a validated correlated-k model for the longwave. *Journal of Geophysical Research*, 102, 16663–16682

[14] Reynolds, Richard W., Rayner, Nick A., Smith, Thomas M., Stokes, Diane C., Wang, Wanqiu (2002). An Improved in Situ and Satellite SST Analysis for Climate. *Journal of Climate*, 15, 1609–1625