Statistical Downscaling of Global Climate Model MIROC_4h Outputs to Precipitation in Rwanda

Nkusi Pearl and Mutabazi Alphonse(✉)

Climate Change Program, Single Project Implementation Unit,
Rwanda Environment Management Authority, KG 7AVE, Kigali, Rwanda
nkusipearl@gmail.com, mutalpho@hotmail.com

Abstract. Statistically downscaled models for precipitation based on multiple linear regression were developed and validated in the four different climatological zones of Rwanda for period, 1961–1990. The validation of these monthly models was majorly based on the ability of the model to reproduce trends of rainfall for an independent period. The downscaled simulations suggest that there will generally be increases in precipitation for majority of the months and increases of over 15% in the known onset months of rain seasons. The dry months are also expected to experience slight variations for the Eastern zone.

Keywords: Statistical downscaling · MIROC_4h · Precipitation
Rwanda

1 Status of Rwanda's Climate

Rwanda is a country in Tropical Eastern Africa whose economy depends mainly on agriculture. It is famously known as 'the land of a thousand hills'. Due to landscape terrain with high slopes and high population density, Rwanda is highly exposed to climate change effect and. There is, therefore, need for availing accurate climate-related information to stakeholders throughout the country mainly for long-term planning purpose. Over the recent pasts, Rwanda has experienced extreme events in various parts of countries such as the destructive floods that affected the entire country in May 2012, and the recent Gakenke flood in May 2016.

In Rwanda, there is a high likelihood that rainfall quantity will increase by the end of 21st century. However, model predictions are averages for long periods; daily, monthly and annual variability are very uncertain. While this rainfall increase is predicted to be between 10 and 20% of observed mean rainfall in 1961–1990, there is no indication whether the temporal rainfall distribution will enough to meet future water requirements (Rwanda Country Situational Analysis 2011).

1.1 Problem Statement

Precipitation in Rwanda and East Africa as a whole is a highly variable climate parameter in space and time; as recently studied in Ongoma and Chen (2017). Due to

C. M. F. Kebe et al. (Eds.): InterSol 2018, LNICST 249, pp. 163–171, 2018.
https://doi.org/10.1007/978-3-319-98878-8_16

this reason, precipitation forecasts and projections require to be at high spatial resolution in order to improve their accuracy. Stake holders in government institutions/agencies and various sectors of the economy also require precise climate related information for short and long periods into the future. Therefore, there is still need for information on climate projections across the country to facilitate national and district-level strategic development plans. The readily available Global Climate Model simulations have very coarse spatial resolution and do not account for local climate aspects. To address this gap in available climate information, statistical downscaling is performed in this study.

1.2 General Objective of Study

To generate downscaled climate projections for the various climatological zones of Rwanda and provide future climate scenarios information on precipitation.

2 Materials and Methods

The observational data (predictand) was monthly precipitation for reference climatological stations of Rwanda; obtained from the National Meteorological Service, METEO Rwanda. This is stationed data collected over time periods, 1961–2014. The stations were selected to represent homogeneous climatological rainfall zones of Rwanda (Prioul and Sirven 1980) The model output data (predictors) was obtained from the data portal of Lawrence Livermore National Laboratory, Department of Energy USA.

MIROC4h, was chosen from WCRP's Coupled Model Intercomparison Project Phase 5 (CMIP5). The model output prepared for CMIP5 historical was used for the 1961–1990 model training period while those prepared for CMIP5 RCP 4.5 were used for development of downscaled projections (2015–2035). The validation period, 1991–2014 made use of both sets of data.

MIROC_4h was chosen based on its high spatial resolution; considering Rwanda's size of 26,338 km^2. High spatial resolution of $(1.0 \times 1.0)^\circ$ or higher allows for more grid points represented for Rwanda. These models present predictor data for 22 vertical levels for the representation of the atmosphere. 4 vertical levels were selected for this study. MIROC_4h simulations for the period 2015–2035 are obtained from esgf.llnl.gov data portal. Representative Concentration Pathways (RCP) scenario that is selected, appropriate for Rwanda is RCP 4.5. The MIROC_4h model has a high spatial resolution of $(0.56^\circ \times 0.56^\circ)$ and the output data sets from which data was extracted for the training period were 1850–2005 (historical) and 2006–2035 (simulations).

In this study, the predictand is monthly rainfall totals from four reference climatological stations for each climatological region of Rwanda. According to Prioul and Sirven (1980), there are four climatologically homogenous zones in Rwanda (Fig. 1).

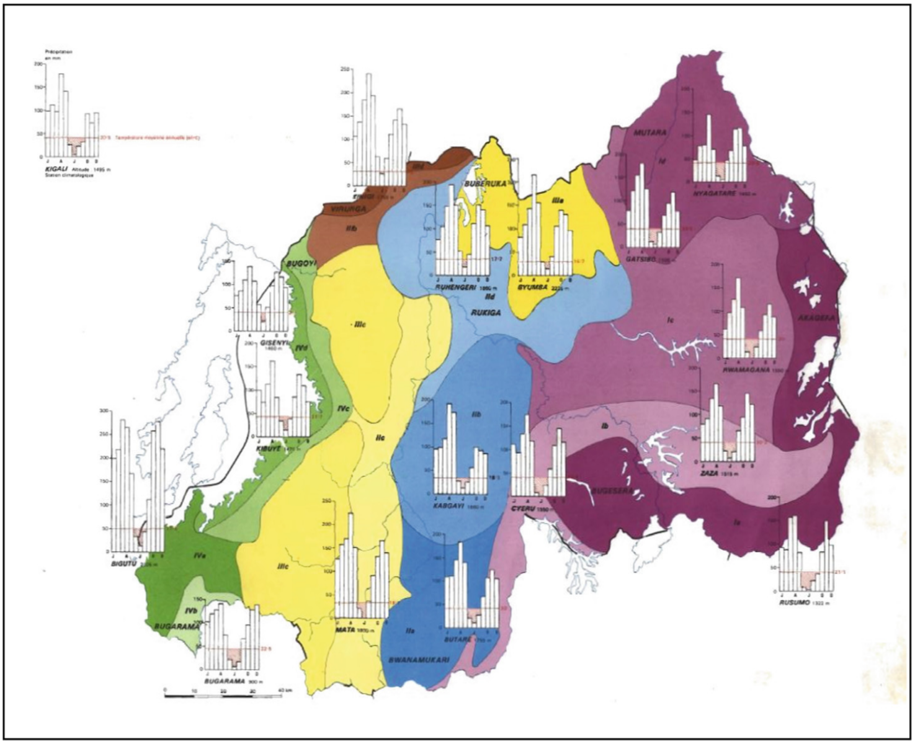


Fig. 1. Map of Rwanda showing climatic regions by colour (Prioul and Sirven 1980)

In this study, we have selected one station for each climatological homogenous zone as indicated below

1. Kanombe station: Warm and dry Eastern Low land
2. Rubona Station: Central Plateau
3. Byumba station: Montane climate
4. Kamembe station: Lake Kivu shores' climate.

There were four main steps taken for this downscaling technique for each reference climatological station:

1. Correlation of predictand (precipitation) and predictors (model output values) to select four best potential precipitation predictors. The empirical relationships are formed based on highest correlation coefficients between potential predictors and predictand
2. stepwise regression to select the best three predictors to yield empirical statistical models

3. Evaluation of statistical models using observations of predictand (precipitation) values for an independent data period
4. Future projections of precipitation.

MIROC_4h historical run, r1i1p1 was used for the period, 1961–1990 and 13 potential rainfall predictors were selected.

They were assigned variable names as follows:

> *Precipitation P, northward wind at surface Vs, eastward wind at surface Us, temperature T at 850* hPa*, temperature T at 700* hPa*, eastward wind U at 850* hPa*, eastward wind U at 700* hPa*, northward wind Vat 850* hPa*, northward wind at V 700* hPa*, relative humidity H at 850* hPam*, relative humidity H at 700* hPa*, geopotential height Z at 850* hPa *and, geopotential height Z at 700* hPa.

Various statistical equations were used to conceive a computer program that finds the best possible correlation coefficients, among the selected predictors that represents the physical relationship between the predictors and predictand. According to Sachindra et al. (2014) and Osman and Mawada (2016), selection/screening of potential predictors is the most important step in statistical downscaling. Four main potential predictors were selected from model outputs of MIROC4h to be run by the program and considered appropriate to characteristics of Rwanda's climate:

> *Wind Velocity, W at 850, 700* mb *levels and surface; Wind direction D at 850, 700* mb *levels and surface; Relative Humidity H at 850 and 700* mb *levels; Air temperature T at 850 and 700* mb *levels.*

The generated model equations are then assessed against observational values of precipitation and temperature for an independent time period, 1991 to 2016. The main objective of this process is to determine to what percentage of accuracy, the models developed can reproduce the precipitation values observed in this period. The validation process shows the potential of the statistical model developed to make future projections of precipitation. Both graphical and statistical methods are used to validate the models' performance (Sachindra et al. 2014). The methods that are used in the study include: Model evaluation using graphical representation, Model evaluation and assessment of accuracy of empirical statistical models using contingency tables, development of terciles for both predicted and observed climate parameters as per each climatological region. The developed, evaluated and verified statistical models are used for simulations to generate future projections over Rwanda from 2015 to 2035 for precipitation.

3 Results and Discussion

3.1 Screening of Predictors and Development of Statistical Models

The following predictors were selected using step wise regression and the models developed by multiple linear regression techniques. Example of coding used to name variables: *HJY4 where*

H: Humidity;
J: MIROC_4h (Japan);
Y: Grid Point Y;
4: 4th Vertical level (700 hPa).

A FORTRAN program that performs multiple linear regression equivalent to statistical and graphical analysis software (SYSTAT). However, the advantage of the program is its ability to run correlation and multiple linear regressions on hundreds of predictors and is limitless on the number of predictors to include in the model equation. The predictor with the highest frequency of selection included humidity predictors at 700 hPa, and wind direction at the surface. Below is a table of selected predictors for each station (Table 1).

Table 1. Selected Predictors for each month for the period of 1961 to 1990 at each reference station

	Selected precipitation predictor per month											
	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
KIGALI	HJY4	HJY4	HJY4	HJU4	HJV4	HJV4	TJY4	HJU4	HJX4	HJY4	HJA4	HJY4
	DJA4	DJD0	DJG4	DJX3	WJK0	WJU0	TJN3	DJK0	DJW4	TJN3	WJJ0	DJA0
KAMEMBE	HJU4	HJY4	DJO4	HJY4	HJY4	HJO4	HJY4	HJY4	HJY4	HJY4	DJR0	HJX4
	DJB0	DJG0	DJR4	HJQ4	WJN0	HJJ3	WJT3	DJU4	DJO0	HJU4	DJY3	TJK4
RUBONA	HJU4	HJY4	HJL4	HJG4	HJY4	HJY4	TJY4	HJX4	HJY4	HJY4	HJD4	HJO4
	DJD3	TJK4	DJG0	DJY0	HJA4	DJO3	TJN3	DJX4	DJG0	HJS3	DJS0	WJP4
BYUMBA	HJW4	HJV4	HJY4	HJY4	HJY4	HJY4	HJY4	HJE4	HJY4	HJS4	HJX4	HJW4
	HJH4	WJN0	DJS0	TJN3	DJK4	TJA4	TJN3	DJU0	DJX0	DJT3	DJI3	TJN3

3.2 Statistical Model Evaluation and Development of Future Projections

The MIROC4h model projections that are downscaled in this study depict variability in precipitation anomalies for the next two decades (upto 2035). In reference to similar studies on East Africa Shongwe et al. (2010), the trends of precipitation changes tend to agree especially with the general trend across the known MAM and SON rainy seasons. In reference to the year, 2015, the downscaled projections of MIROC_4h suggest that by 2035, there will be an increasing trend in precipitation during majority of the months apart from January, March, July and November for Kanombe station. Validation was based on the model's ability to graphically reproduce trends of rainfall for the validation period, 1991–2014.

KIGALI:
There will generally, be wetter April-May months of the long rain season and a slight increase in precipitation changes over the dry December-January-February. They also suggest that there will be a general increase in precipitation anomalies for months January-February, April-May, July-August and September-October-December. March, June and November show a decreasing trend (Fig. 2).

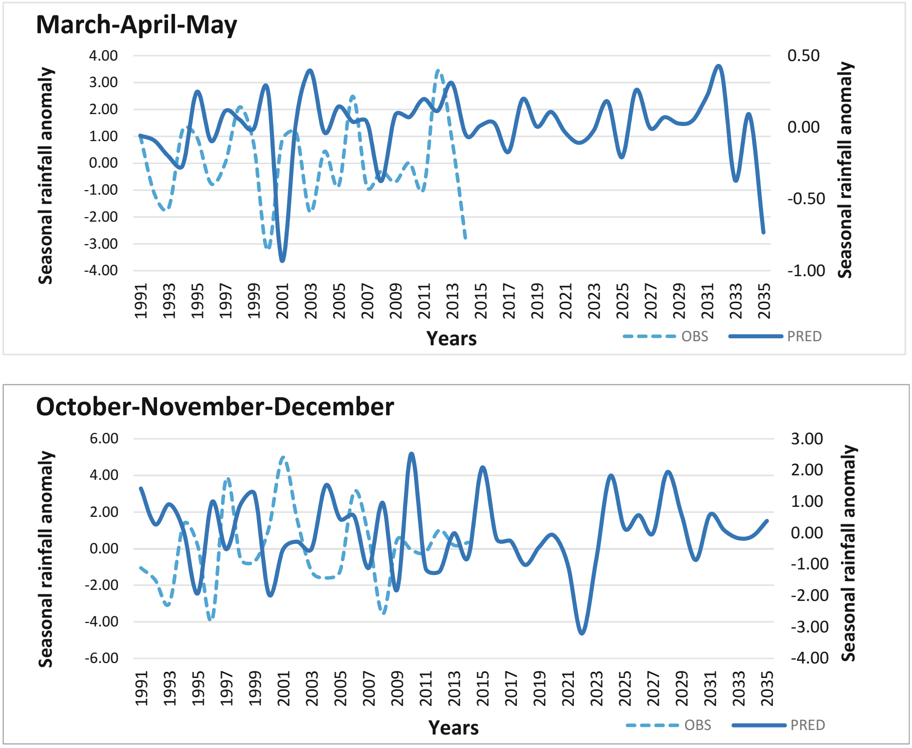
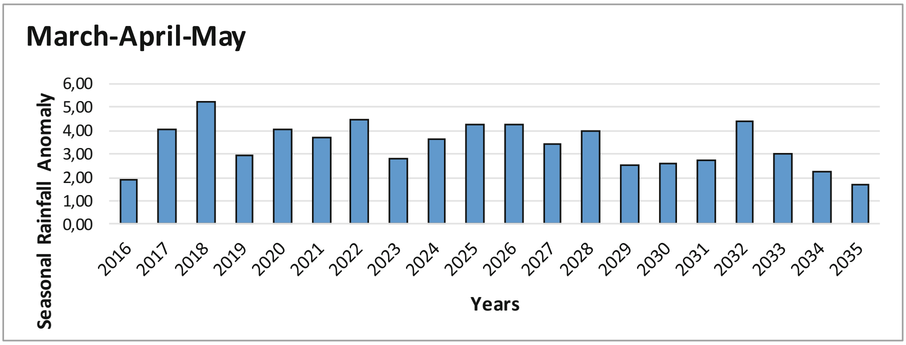


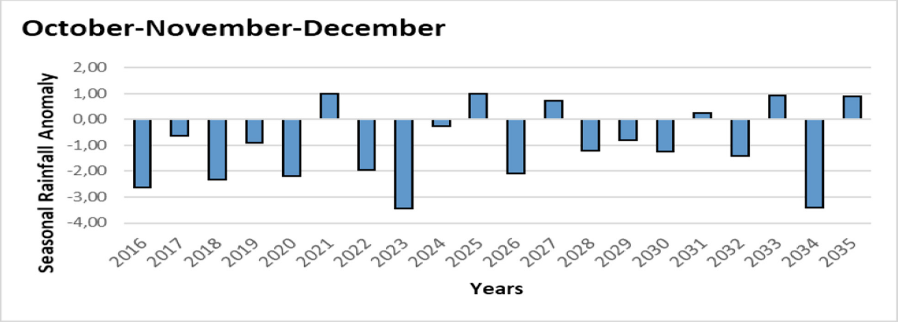
Fig. 2. Seasonal validation (1991-2014) and projections of precipitation (standardized anomalies) from MIROC_4h; Kanombe station (2015 to 2035)

The trends depict a generally wet October-November-December season and a slight increase in precipitation changes over the usually dry January-February and July-August period; showing consistence with projections of mean and extreme precipitation in Africa region under global warming (Shongwe et al. 2010).

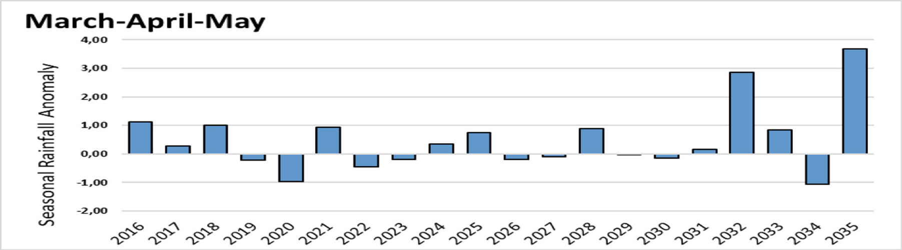
Trends in precipitation changes are relatively in agreement with projections of future climate over the Albertine Rift Valley region upto the year 2030 under the SRES A2 scenario. Seimon and Phillipps (2011) reported an approximate increase in precipitation of about 3–9 mm in Rwanda (as part of the Albertine rift) for the months; January, February, May, November and December in the year 2030, relative to 1990. Downscaled MIROC_4h projections from this study suggest an average decrease ranging from 10–13 mm within the Eastern dry climatic region.

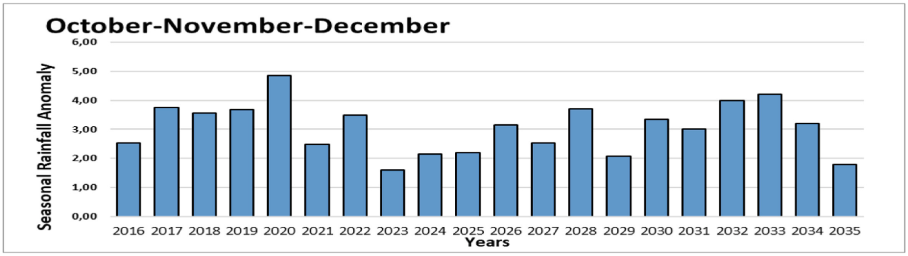
BYUMBA:



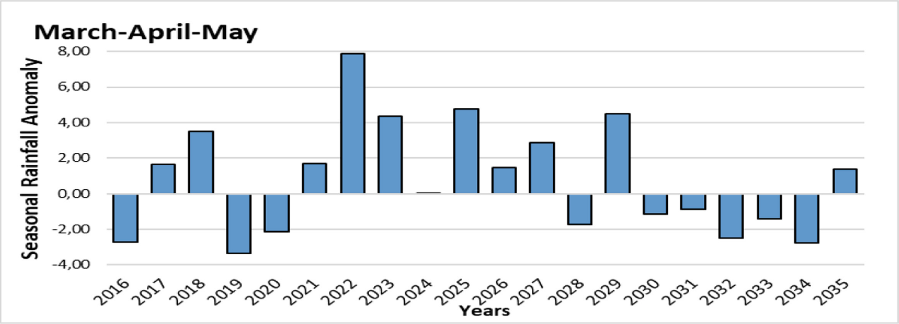


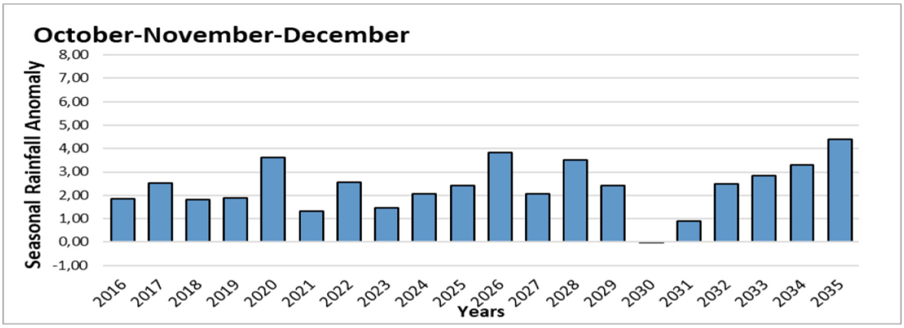
KAMEMBE:





RUBONA:





Throughout the country, the reference stations used in this study show relatively varying future changes in precipitation. An average increase of 14%, 12% and 35% increase is expected for stations Kanombe, Rubona and Kamembe. The long dry months of June-August will experience a slight increase in precipitation in Kigali and a decrease for other stations (Table 2).

Table 2. Percentage change of monthly projected precipitation changes by 2035 with reference to 2015

Stations				
Months	KIGALI	RUBONA	BYUMBA	KAMEMBE
January	−17.0	1.0	19.0	0.25
February	18.0	−22.0	−3.0	−1.0
March	−9.0	−3.0	14.0	−49.0
April	3.0	−63.0	−24.0	−8.0
May	0.05	−1.0	−2.0	1.0
June	−13.0	−29.0	−11.2	−1.2
July	−42.0	−18.0	−6.0	−2.0
August	56.0	−6.0	75.0	36.0
September	23.0	2.0	−11.0	4.0
October	2.0	−4.0	13.0	−14.0
November	−1.0	−1.0	8.0	13.0
December	18.0	15.0	96.0	−42.0

4 Conclusion and Recommendations

From the simulations now tailored to local climate characteristics of Rwanda using observational data, we expect that there will be a general increase in monthly totals of precipitation across the country and significant increases in the onset months of rainfall seasons, MAM and SON. Downscaling of GCM simulations before use in impact assessment studies, or their consideration in national strategies and plans is highly recommended. More GCMs need to be used by climate researchers in Rwanda to increase on the base of information on future climate scenarios.

References

Prioul, Ch., Sirven, P.: Atlas du Rwanda (1980)

Sachindra, D.A., Huang, F., Barton, A., Perera, B.J.C.: Statistical downscaling of general circulation model outputs to precipitation – Part 2: bias-correction and future. Int. J. Climatol. Banner **34**, 3282–3303 (2014). https://doi.org/10.1002/joc.3915

Seimon, A., Phillipps, G.: Regional climatology of the Albertine Rift in “Long Term Changes in Africa”s Rift valley: impacts on biodiversity and ecosystems (2011). https://www.researchgate.net/profile/Michael_Wilson3/publication/216460597_Longterm_changes_in_the_ecological_factors_surrounding_the_chimpanzees_of_Gombe_National_Park/links/02e7e51ded180402e1000000/Long-term-changes-in-the-ecological-factors-surrounding-the-chimpanzees-of-Gombe-National-Park.pdf

Shongwe, M.E., Van Oldenborgh, G.J., Van Den Hurk, B.: Projected changes in mean and extreme precipitation in Africa under global warming, Part II: East Africa, p. 40 (2010)

Ongoma, V., Chen, H.: Temporal and spatial variability of temperature and precipitation over East Africa from 1951 to 2010. Meteorol. Atmos. Phys. **129**, 131 (2017). https://doi.org/10.1007/s00703-016-0462-0

Rwanda Country Situational Analysis: Compiled by Alphonse Mutabazi Climate Change Consultant for Camco, Nairobi, Kenya, May 2011. http://rema.gov.rw/rema_doc/Climate%20change/Situational%20Analysis%20-%20RWANDA%20Final.pdf