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The KENYA INSTITUTE for PUBLIC POLICY RESEARCH and ANALYSIS

Downscaled Climate Analysis on Historical, Current and Future Trends in the East African Community Region

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THE KENYA INSTITUTE FOR PUBLIC POLICY RESEARCH AND ANALYSIS (KIPPRA)

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World Meteorological Organization Regional Office for Eastern and Southern Africa

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Foreword

Climate change and climate change variability is a threat to food production patterns, thus exacerbating food and nutrition insecurity across Africa. Therefore, tackling poverty, hunger and food security is a priority for the Africa Union Agenda 2063 which underscores the right of Africans to live healthy and productive lifes. Further, the African Union has set a target to eliminate hunger and food insecurity by 2025 towards achieving the Sustainable Development Goal (SDG) 2 on ending hunger, achieving food security and improving nutrition. Unfortunately, Africa is not on track in meeting these targets mainly because the region is not producing enough food due to climate change and low adoption of technology. However, climate change has variable impacts on food production, with both production losses and gains across the region. As a result, regional trade is critical for facilitating the distribution of agricultural products to enhance food security in the region.

The East Africa Community (EAC) region is particularly vulnerable to climate change. The region is already experiencing increased climate change impacts, including extreme weather conditions, persistent drought, floods, and landslides and rising sea level which threaten food security and efforts to eradicate poverty. Despite the huge potential to produce enough food, the agricultural production system in the region is mainly rainfed, which consequently leads to high food and nutrition insecurity.

Finding solutions to perennial food security challenges in the EAC is crucial and urgent as climate change impacts intensify in frequency and severity. Looking beyond just agricultural production systems is thus critical in tackling this peril. Thus, there is need to apply other approaches such as the nexus approach which allows for evaluating integrative systems where, for instance, trade facilitates food security in a changing climate environment. Although agriculture production is vulnerable to climate change, food security is not necessary a result of low production but a combination of other factors such as poor food distribution caused by perverse subsidies and other trade barriers. The EAC has been able to attain a common market status, which could facilitate trade in the region and thus mitigate food shortages.

Despite the various measures and programmes adopted in EAC, some parts of the region continue to face food deficits due to restrictive trade policies and barriers to trade. Opportunities exist for adopting existing policy frameworks by member countries to address food security needs.

Preface

The project on Regional Assessment of Climate Change, Agricultural Production, Trade in Agricultural Production and Food Security in East African Community (EAC) was carried with support from the ACPC-CLIMDEV Work Programme. The ClimDev-Africa Programme is an initiative of the African Union Commission (AUC), the United Nations Economic Commission for Africa (UNECA) and the African Development Bank (AfDB). It is mandated at the highest level by African leaders (AU Summit of Heads of State and Government). The Programme was established to create a solid foundation for Africa's response to climate change and works closely with other African and non-African institutions and partners specialized in climate and development.

Over the last few years, our understanding and certainty about how climate is changing and the possible impacts this could have has grown immensely. This notwithstanding, agricultural production systems in the EAC region are highly vulnerable to climate change, consequently affecting food and nutrition security. The region is the most developed regional economic community (REC) in Africa, and cross border trade plays a critical role in facilitating food security. In response, the United Nations Economic Commission for Africa–African Climate Policy Centre (ACPC) is increasing its efforts to improve the capacity of EAC member states for mainstreaming climate change impacts in development policies, frameworks and plans.

The three-year project was launched in May 2014 covering Burundi, Kenya, Rwanda, Tanzania and Uganda. The activities carried in this study were linked to the ClimDev-Africa Programme work stream II, which focuses on solid policy analysis for decision support, and was spearheaded by the Kenya Institute for Public Policy Research Analysis (KIPPRA). The overall objective of the project was to assess whether or not agricultural production systems and trade policies in EAC can be adjusted to alleviate the impact of climate change on food security, and promote sustainable development. The project outputs include pre-project report, country scoping studies, indepth EAC studies on climate change, crop production model, economic policy and trade and finally a comprehensive regional report.

Acknowledgements

The study was conceptualized and commissioned by the African Climate Policy Centre (ACPC), United Nations Economic Commission for Africa (UNECA), under the leadership of Dr Fatima Denton, Director of the Special Initiative Division, UNECA. Dr Tom Owiyo and Dr Johnson Nkem, senior experts at ACPC, guided the conceptual framing and provided oversight during implementation. Regular technical support was provided by ACPC researchers, Dr Wifran Moufouma Okia, Mr Nassirou Ba, Dr Habtamou Adessou, and research fellows Yosef Amha and Rivaldo.

The study was conducted as a part of the activities of the Climate Change and Development in Africa (ClimDev-Africa) Programme supported by the UK Department for International Development (DfID), European Union Commission, Norway, Sweden, France, Nordic Development Fund, and the United States Agency for International Development (USAID).

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The regional Partner Institutions included Economic Policy Research Centre (EPRC)–Uganda team lead by Dr Isaac Shinyekwa, Sokoine University–Tanzania team led by Prof. Siza Tumbo, University of Burundi team led by Dr Alex Ndayiragije, and Kigali Independent University team led by Mr Paul Muzungu. The participation of the stakeholders in various stages of the preparation of the report was highly valuable in enriching the report.

The Economic Commission for Africa and KIPPRA would like to express their appreciation to all the government Ministries, State Departments and Agencies in Burundi, Kenya, Rwanda, Tanzania and Uganda for their active participation and providing the data and information used in preparing the report.

Executive Summary

Understanding and confidence on climate change and its potential impacts have grown greatly over the last few years. While the evidence for climate change grows stronger, uncertainty prevails over the precise nature of these changes and their impacts at local and farm level. This study evaluates the climate variability and change in past, current and future climate in five countries in the East African Community (EAC), namely Kenya, Tanzania, Uganda, Burundi and Rwanda using high resolution regional models under the Coordinated Regional Climate Downscaling Experiment (CORDEX). Trends of mean variability was determined using graphical, regression and Mann-Kendall test approaches for the past (1970-2000), current (2001-2014) and projected future climate change scenarios (Representative Concentration Pathways - RCPs - 4.5 wm^{-2} and 8.5 wm^{-2} for mid (2041-70) and end (2071-00) century.

Over EAC, most of the models are inconsistent in representing spatial precipitation distribution. However, the study notes than ensemble precipitation from CORDEX well represented the rainfall climatology over EAC. Temperature fields are well represented by all the CORDEX models and the ensemble. The study notes that multimodel ensemble mean outperforms the results of individual models in most of the areas and time periods as assessed for both precipitation and temperature fields. Precipitation remained highly variable both in space and time. Temporal pattern of rainfall over EAC had a strong inter-annual rainfal variability associated with extreme events such as floods and droughts. Climate variability and change is expected to result to adverse macro socio-economic implications especially in agriculture and thus affect the livelihoods of populations in the region. Adapting to these changes will require the knowledge of their frequency and severity. Therefore, there is an urgent need for realistic adaptation options aimed at reducing the vulnerability of the environment, wildlife and human and support economic systems to cope with the consequences of recurrent climate extremes, variability and climate change.

Abbreviations and Acronyms

ACMV	African Cassava Mosaic Virus
AEZ	Agro-Ecological Zones
APSIM	Agricultural Production Systems sIMulator
CIA	Central Investigation Agency
CMIP	Coupled Model Inter-Comparison Project
CORDEX	Coordinated Regional Downscaling Experiment
DfID	Department for International Development
EAC	East Africa Community
ECMWF	European Centre for Medium-Range Weather Forecasts
ENSO	El Nino Southern Oscillation
FAO	Food and Agriculture Organization
GCMs	General Circulation Model
IPCC	Inter-governmental Panel on Climate Change
IRI	International Research Institute
RCMs	Regional Circulation Models
SMHI	Sveriges Meteorologiska och Hydrologiska Institut
SRES	Special Report on Emission Scenarios
UNFCCC	United Nations Framework Convention on Climate Change

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1. Introduction

1.1 Background Information and Justification

Understanding and confidence on climate change and its potential impacts have grown greatly over the last few years. The Inter-governmental Panel on Climate Change (IPCC) fifth assessment report (AR5) notes that climate change is unequivocal (IPCC, 2014). Studies by Anyah and Qiu (2012) and Endris et al. (2013) affirm that rainfall in the Eastern Africa region remains highly variable, unreliable and likely associated with changes in the regional climate. Other observed evidence includes but not limited to the shift in the length of growing seasons and increased frequency of extreme events such as drought and floods. Changes in climate coupled with resource-based conflicts in Eastern Africa have significantly affected food security.

Climate models are suitable tools for assessing climate variability and change (Endris et al., 2013). The Global Climate Models (GCMs) have been used to simulate changes in atmospheric circulation (Shongwe et al., 2009). However, its coarse resolution (~100 -150km) makes the GCMs unable to capture the detailed processes at the regional level (Giorgi et al., 2009). The sub-grid scale processes which significantly affect climate include variations in vegetation, topography, soils, and coastlines. Effective adaptation strategies meant to respond to climate variability and change require reliable information at finer spatial and temporal resolution. Therefore, Regional Climate Model output is more suited to support understanding of local climate especially in regions such as Eastern Africa with complex processes (Sun et al., 2006). The Coordinated Regional Climate Downscaling Experiment (CORDEX) provides dynamically downscaled model output and thus high-resolution regional climate projections suitable for impact assessment at regional scales (Giorgi et al., 2009).

Therefore, the study aimed at analyzing downscaled information on historical and projected climate information over the East Africa Community.

1.2 Objective of the Study

The overall objective of the study is to provide downscaled climate change information in East African Community (EAC) for historical, current and future trends. The specific objective are:

(i) To assess the performance of CORDEX regional climate models in simulating climate in EAC

(ii) To determine past and future trends of climate change in EAC

1.3 Scope of the Study

The study focuses on five countries in the East African Community, namely: Kenya, Tanzania, Uganda, Burundi and Rwanda.

Kenya lies between latitudes 5°N and 5°S and between longitudes 34° E and 42°E. The country has climate and environmental extremes, with altitude varying from sea level to over 5000m. Mean annual rainfall ranges from 250mm in the arid and semi-arid areas to 2000mm in highlands. Kenya has a total area of 580,367 square kilometres. Further, only 12 per cent has a high potential for agriculture. A further 5.5 per cent which is classified as medium potential mainly supports livestock, especially sheep and goats. Only 60 per cent of this high and medium potential land is devoted to crops (maize, coffee, tea, horticultural crops) and the rest is used for grazing and forests. Most of the high potential land is found within the highland areas of the Rift Valley, Central, Eastern Nyanza and Western provinces.

Uganda lies between latitudes 4°N to 1°S and longitude 29°E to 36°E. Although temperature variations may be significant especially over high ground areas in western, eastern, south western, and parts of northern Uganda, rainfall, like in many tropical areas, largely determines the climatic sub-regions (agro-climatic zones) of the country. It also determines the spatial patterns of natural resources and land use activities. The spatial climate homogeneity with regard to spatial and temporal rainfall patterns have been identified and highlighted. The homogeneous delineations benefit spatial and temporal zonal evaluations of soil moisture availability for crop production. The climate of Uganda is regarded as its most valuable natural resource and a major determinant of other natural resources, such as water, forests, and wildlife as well as human activities based on these resources such as agriculture and eco-tourism (Republic of Uganda, MWE 2007). Together, these resources provide the means of livelihood for many Ugandans and enhance economic growth, which is predominantly agriculture-based.

Tanzania lies between latitudes 1° 00' S and 11° 48' S and longitudes 29° 30' E and 39°45'. The climate of Tanzania is influenced by its location close to the equator, the Indian Ocean and the physiography (Mkonda and He, 2016). As a result, Tanzania experiences highly variable climatic conditions.

Rwanda (26,300 km^2) is a small-land locked central African country lying between latitudes 1–3° S and longitudes 29–31° E. It borders the Democratic Republic of Congo (DRC), Uganda, Tanzania and Burundi. Although the country is just below the equator, its high altitude (1,000–3,000 m above sea level) moderates the climate. The average annual temperature (17–20°C) varies within the altitude ranges with small variations between the rainy and the dry season. The country enjoys high rainfall (October–June) followed by a short dry period (July–September). The average monthly rainfall of 85 mm supports a broad range of crops and vegetation. Mountain ranges and high land plateaus dominate the relief of the country.

Burundi is a small landlocked country. Topography significantly influences climate. Burundi has two main growing seasons which comprise of the rainy season (September to May) and dry season (June to August). Mean temperatures vary between 15°C and 20°C. The annual mean rainfall is between 700mm and 1600 mm. However, the country is being affected by climate changes with an expanded period of dry season starting from mid-May and ends in October.

2. Literature Review

2.1 Climate Change Modelling in East Africa Community

Climate modeling involves the use of computer models of the climate system to simulate the interactions of the components of the earth's climate system and their response to solar radiation between the top of the atmosphere and the surface of the Earth (Jones et al, 2004). A climate model is a mathematical representation of the climate system, expressed as computer codes and run on a powerful computer to provide a comprehensive and quantitative description of how atmospheric temperature, air pressure, winds, water vapour, clouds, and precipitation respond to the solar heating of the atmosphere (IPCC, 2007; Jones et al, 2004).

The climate and topography of East Africa is diverse, ranging from humid tropical lowlands to high and dry mountain plateaus. Temperatures in lowland plains are warm throughout the year (above 22°C) but decrease in mountainous areas away from the coast. Precipitation regimes in some parts of East Africa are bimodal, resulting in two wet seasons each year. Climatic changes over the latter part of the 20th century is well documented and, since 1960, mean global temperatures have increased and precipitation has become increasingly variable with extreme drought and flood events occurring with increased frequency (Parry et al., 2007; Funk et al., 2008). The rate of polar ice melt has increased and glaciers have retreated or disappeared altogether (Boko et al., 2007). Global circulation models (GCMs) are used to suggest future temperatures and precipitation, and generally they conclude that many regions of the world will become warmer with greater precipitation variation and more frequent climatic extremes (Boko et al., 2007; Doherty et al., 2010).

Many East African households rely on agriculture as a source of income as well as providing food for their families. Agricultural products contribute significantly to the export earnings of many East African countries and, on average, agriculture contributes 21 per cent to African GDP, rising to as much as 70 per cent in some African nations (Mendelsohn et al., 2000). Agriculture will be directly and significantly affected by these future climatic changes (Brown and Funk, 2008). The growth, development and yield of agricultural crops are influenced by many climatic factors. Changes in temperature, precipitation regimes, frequency of extreme events, and atmospheric concentrations of CO_2 resulting from climatic change will inevitably affect the production of agricultural crops (Tubiello et al., 2007). Higher temperatures may lengthen growing seasons, reduce soil moisture, alter plant development and product quality, and affect crop pests and diseases (Downing, 1991). Constructing models to predict crop responses to climatic change and identifying geographical regions most affected by future changes are required to aid adaptation strategies (Lobell et al., 2008). Without adaptation, many regions of the world will be affected by increased levels of hunger, flooding, drought and crop failure (Liu et al., 2008; Lobell et al., 2008; Thornton et al., 2009).

Concerns over the future suitability of commodity crops in the region have arisen, and Downing (1991) suggested that as the climate becomes warmer in Kenya, many of the tea plantations would become uneconomical. Assessing how future climatic change will affect the distribution of commodity crops and yields is critical in assessing the sustainability of the industry in the region. To increase the effectiveness of adaptation processes, and to utilize the financial resources available from aid and donor organizations, an understanding of crop responses to climatic variables, and regional studies highlighting areas most at risk from climatic change are required (Slingo et al., 2005; Lobell et al., 2008; Thornton et al., 2009). Despite the few studies investigating the impact of climatic change on crop production, research is needed to assess how regional changes in temperature and precipitation will affect the suitability and productivity of crops in East Africa.

2.2 Availability and use of the Climate Models

Many of the studies on assessment of impacts and adaptation especially for East Africa, such as for national communications to the UNFCCC, provide results that show how different sectors, systems and communities might be affected by climate change. In these studies, the countries depend on generated climate scenarios based on inputs from General Circulation Models (GCMs) which are designed in developed countries.

Global Climate Models (GCMs) are suitable tools for the assessment of climate variability and change (Endris et al., 2013). The most commonly used global models in vulnerability and adaptation studies are GISS, HadCM2, UKTR, GFDL, CCCM and ECHAM3 (IPCC, 2007). GCM-based climate change scenarios are consistent in predicting temperature rise across Africa, but show considerable uncertainty about both the magnitude and direction of changes in precipitation (IRI, 2006). Appropriate use of a range of such scenarios combined with analysis of trends in historical data can contribute to the understanding of future trends and uncertainties that are crucial for long-term planning horizons.

Washington et al. (2004) outlined a number of characteristics of GCM models that are critical for model prediction performance. These included the ability to capture reasonably well the simulation of mean, large-scale patterns of contemporary climate (e.g. temperatures, wind, precipitation) as well as the broad response to Pacific Ocean forcing (ENSO) and to ocean temperature patterns in the surrounding basins (Indian, Atlantic and Mediterranean). Moreover, these models need to capture, to a lesser extent, the precise positioning, timing and intensity of specific features such as the onset of the Sahel precipitation, the precipitation gradient across southern Africa, and the orientation of tropical convection over East Africa and the interaction of Saharan dust with climate is not included in most models and inadequate information on the coupled land-surface atmosphere feedbacks.

Over East Africa, 12 CMIP-3 general circulation models were assessed and showed wetter climate by the end of the 21st Century. Moreover, it projected less severe droughts and more intense wet seasons during March-April-May (MAM) and October-November-December (OND) (IPCC, 2013; Mikova et al., 2015). These results indicate a reversal of the past seasonal trend (Williams and Funk, 2011) and attributable to cooling in the eastern equatorial Pacific which in turn offsets the SST warming over the equatorial Pacific.

Compared to many parts of the world, scientific understanding of the African climate system as a whole is low, and variations in capacity exist among different African regions (Washington, 2004).

Regional climate model studies suggest drying over Kenya, Uganda and South Sudan in August and September as a result of a weakening Somali jet and Indian monsoon (Patricola and Cook, 2011).

Dynamical downscaling and regional climate models make use of the boundary conditions (e.g. atmospheric parameters from a GCM such as surface pressure, the wind, temperature and vapour) and principles of physics within an atmospheric circulation system to generate small scale (high resolution) datasets. Due to its reliance on high-resolution physical datasets, the approach is useful in the representation, especially of extreme events. However, dynamical downscaling is a computationally and technically expensive method, a characteristic that has limited the number of institutions employing the approach. Key among the dynamical downscaled models in use in Africa is the MM5, WRF, DARLAM and PRECIS models (IPCC, 2007) and thus selected for use in this study.

Over the past decade, several international projects have applied Regional Climate Models (RCMs) to generate high-resolution, multi-model ensembles of future climate projections by downscaling output from AOGCMs. These include PRUDENCE (Christensen et al., 2007) and ENSEMBLES (van der Linden and Mitchell 2009) for Europe; NARCCAP (Mearns et al., 2009) for North America; CLARIS-LPB (Menéndez et al., 2010) over South America and ENSEMBLES-AMMA for West Africa (van der Linden and Mitchell 2009). Each of these projects has made significant contributions to downscaling efforts over their specific regions.

2.3 Climate Change Scenarios

IPCC defines climate scenarios as plausible representations of the future. Unlike weather forecasts, climate scenarios are not predictions. They are consistent with assumptions about future emissions of GHG and other pollutants. A range of scenarios can be used to identify the sensitivity of an exposure unit to climate change. This, in turn, helps policy makers decide on appropriate policy responses to the modification. In 2000, the IPCC published a set of emissions scenarios for use in climate change studies (Special Report on Emissions Scenarios – SRES).

Four narrative storylines were defined by SRES and named A1, A2, B1 and B2. In contrast to the SRES scenarios, RCPs represent pathways of radiative forcing, not detailed socio-economic narratives or scenarios. Central to the process is the concept that any single radiative forcing pathway can result from a diverse range of socio-economic and technological development scenarios. There are four RCP scenarios: RCP2.6, RCP4.5, RCP6.0 and RCP8.5. These scenarios are formulated such that they represent the full range of stabilisation, mitigation and baseline emission scenarios available in the literature (Hibbard et al., 2011). The naming convention reflects socioeconomic pathways that reach a specific radiative forcing by the year 2100.

2.4 Institutional Partners in Climate Modelling in EAC

The key partner institutions for this component were identified as the National Meteorological and Hydrological Services (NMHSs) in the EAC countries due to their main role in providing climate information required in the assessment. Table 2.1 shows NMHSs in EAC region..

Table 2.1: NMHSs institutions in East Africa Community

Institution	Country
Tanzania Meteorological Agency (TMA)	Tanzania
Hydro & Agro-Meteorology Department of Geographical Institute of Burundi (IGEBU)	Burundi
Uganda National Meteorological Authority (UNMA)	Uganda
Kenya Meteorological Service	Kenya
Rwanda Meteorological Agency	Rwanda

3. Data and Methodology

3.1 Data Sources

Climate change and crop modelling data used included observed climate and climate model output.

3.1.1 Observed climate data

Climate and crop modeling utilized daily observed data. These included Precipitation (PPT), Maximum Temperature (TMAX) and Minimum Temperature (TMIN) Model output. These were compared to observed datasets obtained from the National Meteorological and Hydrological service (NMHS) of Burundi (5 stations), Kenya (7 stations), Tanzania (7 stations), Rwanda (8 stations) and Uganda (10 stations) based on representative Agro-Climatic Zones. Moreover, solar radiation, required for crop modelling, was estimated using the Hargreaves and Samani (1982, 1985) equation for each zone. Representative Agro-Climatic Zones were selected to evaluate the performance of the RCM models used as shown in Table 3.1.

Table 3.1: List of selected stations in EAC

Uganda	Kenya	Tanzania	Rwanda	Burundi
Kotido/ Kitgum	Kakamega	Dar es Salaam	Gabiro	Bujumbura
Lira	Kisii	Dodoma	Kamembe	Nyanza Lac
Gulu	Eldoret	Arusha	Gisenyi	Gisozi
Masindi	Thika	Kigoma	Gikongoro	Muyinga
Soroti	Narok/ Nakuru	Mbeya	Byumba	Musasa
Jinja	Garissa	Moshi	Save	
Kabale	Wajir	Morogoro	Ruhuha	
Masaka			Kigali	
Mbarara				
Kasese				

3.1.2 Regional Climate Model (RCM) data

In this study, simulated daily data used included rainfall, Maximum and Minimum temperature and sunshine duration data from 8 CORDEX RCMs. Nikulin et al. (2012) provide detailed information on the CORDEX models which include but not limited to model dynamics, physical parameterisation, its lateral and boundary conditions. Moreover, the output runs in the transient mode for the period 1951-2100. The eight (8) CORDEX models over the Africa domain are

Table 3.2: List of CMIP5 GCMs used in the study

Institute Name	GCM Name	Calendar
CCCma (Canada)	CanESM2	365 days
CNRM-CERFACS (France)	CNRM-CM5	Standard
MOHC (UK)	HadGEM2-ES	360 days
NCC (Norway)	NorESM1-M	365 days
ICHEC (Europe)	EC-EARTH	Standard
MIROC (Japan)	MIROC5	365 days
NOAA-GFDL (USA)	GFDL-ESM2M	365 days
MPI-M (Germany)	MPI-ESM-LR	Standard

analysed for both historical (1971-2000) and future projections (2016 to 2045 and 2071 to 2100) based on RCP4.5 and 8.5 scenarios. All simulations performed are at 50km (0.448) resolution over the project domain. Table 3.2 presents a list of the eight (8) CORDEX models used.

3.1.3 Data limitations

The EAC region lacks high quality observation datasets at suitable temporal and spatial resolution necessary for evaluating RCM simulations. Therefore, the climate change modelling relied on post-processed data available at CORDEX data portal. Endris et al. (2013) presents detailed limitations of CORDEX models for the Africa domain.

3.2 Methodology

3.2.1 Downscaling of CORDEX regional climate

This study utilised dynamical downscaling techniques whereby downscaled climate change models take data from GCMs and interpret them about local climate dynamics (Tadross et al., 2005). The period considered included both historical/past (1971 to 2000) and Future (2016 to 2045 as mid-century and 2071 to 2100 as end century). The future projections use Representative Concentration Pathways (RCPs) scenario 4.5wm^2 and 8.5wm^2. Dynamical downscaling makes use of RCM that are driven by a GCM to simulate regional climate. The ability of the RCMs to model atmospheric processes and land cover changes explicitly is regarded as its main advantage. However, RCMs may have limitations in simulating convective precipitation that is common in the tropics accurately.

3.2.2 Assessment of the skill of climate models

The ability of the climate model to match the long-term historical climate observations was determined through both graphical and error analysis techniques. Error analysis techniques included Normalized root mean square error (NRMSE), Modified Nash-Sutcliffe Efficiency (mNSE) and Mean Absolute Error (MAE) techniques. RMSE evaluates the relative deviation between the simulation and the measurements in a range between 0 for a perfect match of simulation and measurement towards +∞ indicating no match at all. Legates and McCabe (1999) present a detailed description of error analysis techniques. Notably, non-dimensional forms of the RMSE are useful because often one wants to compare RMSE with different units. Therefore, the study adopted the Normalized Root Mean Square Error (NRMSE). The Nash-Sutcliffe model efficiency coefficient (E) is commonly used to describe the accuracy of model outputs quantitatively. E ranges from -□ to 1 with values closer to 1 indicating model accuracy.

3.2.3 Determination of trend of past and future climate

This activity involved determination of spatial and temporal variability of past and future climate over EAC. The presence of a monotonic increasing or decreasing trend was tested with the non-parametric Mann-Kendall test while the slope of a linear trend was estimated with the non-parametric Sen's method (Gilbert, 1987). Furthermore, the true slope of the existing trend (as change per year) was estimated using the Sen's non-parametric method.

Mann-Kendall test is a test that evaluates whether y values tend to increase or decrease over time through what is essentially a non-parametric form of monotonic trend regression analysis. The Mann-Kendall test analyzes the sign of the difference between later-measured data and earlier-measured data. Each later-measured value is compared to all values measured earlier, resulting in a total of n(n-1)/2 possible pairs of data, where n is the total number of observations. Missing values are allowed and the data do not need to conform to any particular distribution. The Mann-Kendall test assumes that a value can always be declared less than, greater than, or equal to another value; that data are independent; and that the distribution of data remains constant in either the original units or transformed units (Helsel and Hirsch, 1992). Because the Mann-Kendall test statistics are invariant to transformations such as logs (i.e., the test statistics will be the same value for both raw and log-transformed data), the Mann-Kendall test is applicable in many situations. To perform a Mann-Kendall test, compute the difference between the later-measured value and all earlier-measured values, (y_j-y_i), where j>i, and assign the integer value of 1, 0, or –1 to positive differences, no differences, and negative differences, respectively. The test statistic, S, is then computed as the sum of the integers:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sign}(y_j - y_i) \qquad (3)$$

Where sign (y_j - y_i) is equal to +1, 0, or -1 as indicated above. When *S* is a large positive number, later-measured values tend to be larger than earlier values and an upward trend is indicated. When *S* is a large negative number, later values tend to be smaller than earlier values and a downward trend is indicated. When the absolute value of *S* is small, no trend is indicated. The test statistic τ can be computed as:

$$\tau = \frac{S}{n(n-1)/2} \tag{4}$$

which has a range of –1 to +1 and is analogous to the correlation coefficient in regression analysis. The null hypothesis of no trend is rejected when *S* and τ are significantly different from zero. If a significant trend is found, the rate of change can be calculated using the Sen slope estimator (Helsel and Hirsch, 1992) given as

$$\beta_1 = \text{median}\left(\frac{y_j - y_i}{x_j - x_i}\right) \tag{5}$$

for all i < j and i = 1, 2, ..., n-1 and j = 2, 3,..., n; in other words, computing the slope for all pairs of data that were used to compute *S*. The median of those slopes is the Sen slope estimator.

The tested significance levels α are 0.001, 0.01, 0.05 and 0.1. A two-tailed test is used for four different significance levels α : 0.1, 0.05, 0.01 and 0.001. The significance level 0.001 means that there is a 0.1 per cent probability that the values x_i are from a random distribution and with that probability we make a mistake when rejecting H_o of no trend. Thus, the significance level 0.001 means that the existence of a monotonic trend is very probable. Respectively, the significance level 0.1 means that there is a 10 per cent probability that we make a mistake when rejecting H_o.

For the four tested significance levels, the symbols used include *** if trend at α = 0.001 level of significance, ** if trend at α = 0.01 level of significance, * if trend at α = 0.05 level of significance and + if trend at α = 0.1 level of significance. If the cell is blank, the significance level is greater than 0.1. The true slope of an existing trend (as change per year) was estimated using the Sen's non-parametric method. The Sen slope was then expressed as a per cent of the mean quantity per unit time (Salmi et al., 2002; Slack et al., 2003). That is:

$$\%\ trend = \frac{[Sen\ Slope\ Estimator\ Q]}{mean\ f(year)} \tag{6}$$

% trend=[Sen Slope Estimator Q]/(mean f(year))

4. Results and Discussion

4.1 Determination and Assessment of the Skill of Climate Models

The study notes that individual models have individual bias in simulating weather and climate especially in EAC due to complex dynamics and topography. Therefore, the skill of CORDEX models in simulating Precipitation, Maximum Temperature and Minimum Temperature were assessed over EAC.

4.1.1 Comparison of observed and CORDEX RCM climatology

CORDEX models were compared to selected stations from Kenya, Uganda, Tanzania, Uganda, Rwanda and Burundi. Error Analysis and graphical plots of observed and simulated precipitation, maximum temperature and minimum temperature for baseline period are presented in Table 4.1 and in Figure 4.1 to Figure 4.6.

In Table 4.1, MAE for precipitation indicated positive values over all stations in EAC and ranged from 0.82 to 2.26. Similarly, the nRMSE showed that CORDEX RCMs over-estimated precipitation over EAC with stations such as Gikongoro showing over-estimation of upto 60 per cent. Assessment of the efficiency of CORDEX RCM using mNSE indicated that the observed mean precipitation was a better predictor than the CORDEX model. However, mNSE values were centred about zero, and thus an indication that the model was accurate. MAE for maximum temperature indicated positive and all values below zero over all stations in EAC and thus an indication of small errors existing between modeled and observed maximum temperature. Similarly, the nRMSE values were all above 100 per cent for maximum temperature and thus showed that CORDEX RCMs over-estimated maximum temperature over EAC. These over-estimation was upto 80 per cent in most stations in Rwanda and Burundi. Assessment of the efficiency of CORDEX RCMs showed that observed mean maximum temperature was a better predictor than the model. However, mNSE values over most stations were noted to be centred around zero and thus an indication of model accuracy. MAE for minimum temperature indicated positive, and all values below zero over all stations in EAC and thus an indication of small errors existing between modeled and observed maximum temperature. Similarly, the nRMSE values were all above 100 per cent for minimum temperature and thus showed that CORDEX RCMs over-estimated maximum temperature over EAC. These over-estimation was upto 76 per cent in most stations in Rwanda and Burundi. Assessment of the efficiency of CORDEX RCMs showed that observed mean maximum temperature was a better predictor than the model. However, mNSE values over most stations were noted to be centred about zero, and thus an indication of model accuracy.

Graphical comparison of observed and modeled precipitation over selected stations in Kenya (Figure 4.1 and Figure 4.2), Uganda (Figure 4.3), Tanzania (Figure 4.4), Rwanda (Figure 4.5) and Burundi (Figure 4.6) showed that observed and model data sets were well comparable.

Table 4.1: Error analysis of observed and simulated precipitation, maximum temperature and minimum temperature for baseline period

	Precipitation			Maximum Temperature			Minimum Temperature		
	MAE	nRMSE (%)	mNSE	MAE	nRMSE (%)	MNSE	MAE	nRMSE (%)	mNSE
Kakamega	1.18	148.80	-0.53	0.73	130.4	-0.33	0.52	112.6	-0.22
Kisii	1.15	151.20	-0.71	0.71	125.1	-0.27	0.55	127.8	-0.46
Eldoret	1.44	118.90	-0.43	0.71	141.8	-0.49	0.53	122.7	-0.46
Thika	1.10	141.80	-0.49	0.52	119.9	-0.31	0.41	118.6	-0.24
Narok	1.18	152.00	-0.41	0.68	138.9	-0.57	0.71	178.7	-1.08
Garissa	0.97	126.00	-0.32	0.49	116.5	-0.19	0.48	132.3	-0.45
Wajir	1.02	145.20	-0.49	0.6	148	-0.74	0.74	176.8	-0.99
Kotido	2.26	115.20	0.00	0.84	127.1	-0.44	0.77	117.6	-0.43
Lira	1.25	153.50	-0.52	0.82	126.5	-0.45	0.75	115.2	-0.39
Gulu	1.12	135.20	-0.35	0.77	129.4	-0.44	0.6	104.8	-0.15
Masindi	1.17	148.50	-0.53	0.74	132.9	-0.44	0.66	121.9	-0.29
Soroti	1.12	140.50	-0.32	0.81	127.2	-0.44	0.76	126.9	-0.5
Jinja	1.20	152.10	-0.49	0.72	129.1	-0.36	0.69	122.3	-0.34
Kabale	1.23	142.40	-0.46	0.76	129.8	-0.42	0.77	169.3	-1.15
Masaka	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mbarara	1.23	141.10	-0.52	0.69	122.8	-0.41	0.8	149	-0.79
Kasese	NA	NA	NA	NA	NA	NA	NA	NA	NA
Dar	NA	NA	NA	NA	NA	NA	NA	NA	NA
Dodoma	1.15	146.30	-0.42	0.63	121.2	-0.19	0.44	110.4	-0.06
Arusha	0.82	107.30	-0.06	0.48	118.4	-0.18	0.4	121.4	-0.27
Kigoma	1.26	142.70	-0.49	0.56	120.3	-0.24	0.4	109.1	-0.08
Mbeya	NA	NA	NA	NA	NA	NA	NA	NA	NA
Moshi	1.05	131.10	-0.31	0.5	124.7	-0.28	0.4	119.2	-0.29
Morogoro	NA	NA	NA	0.59	129.4	-0.3	0.23	76.2	0.22
Gabiro	1.14	141.40	-0.47	1.53	159.5	-0.62	0.72	177.3	-1.09
Kamembe	1.25	147.80	-0.61	1.97	180.2	-0.81	0.76	147.5	-0.57
Gisenyi	2.42	125.90	-0.10	1.74	180.3	-0.92	0.62	145.2	-0.79
Gikongoro	1.26	160.60	-0.76	1.7	179	-0.84	0.57	126.7	-0.42
Byumba	1.26	159.80	-0.63	1.77	175.1	-0.85	0.77	169.5	-1.08
Save	1.38	140.10	-0.32	1.63	158.3	-0.57	0.64	145.5	-0.6
Ruhuha	NA	NA	NA	1.63	156.4	-0.57	0.68	163	-0.88
Kigali	1.20	147.70	-0.56	1.62	170.5	-0.85	0.74	168.2	-1.11
Bujumbura	1.08	137.90	-0.47	1.44	181.6	-0.83	0.47	115.1	-0.12
Nyanza Lac	1.00	124.10	-0.32	1.16	178.6	-0.75	0.44	117.5	-0.22
Gisozi	1.17	146.10	-0.37	1.44	181.6	-0.83	0.47	115.1	-0.12

Muyinga	1.22	148.60	-0.66	1.49	154.1	-0.51	0.55	131	-0.44
Musasa	1.24	149.10	-0.47	1.34	187.7	-0.89	0.37	90.6	0.05

4.2 Spatial and Temporal Variability of Climate Change in East Africa Community

The spatial and temporal analysis of climate change is based on the baseline climate (1971-2000) and RCP scenarios (RCP 4.5 and RCP 8.5) for mid-century (2016-2045) and end-century (2071-2100)

Figure 4.1: Time series of observed and modeled rainfall over Dagoretti and Kericho stations in Kenya

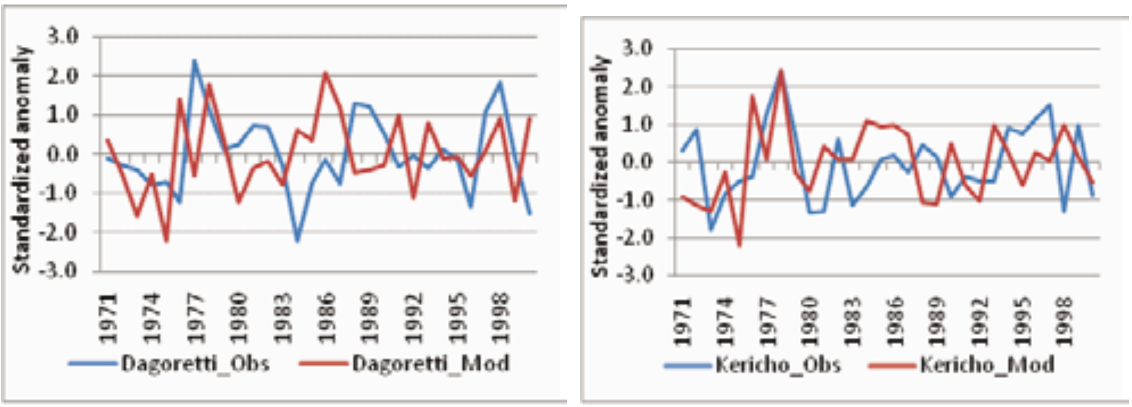


Figure 4.2: Time series of observed and modeled rainfall over Meru and Makindu stations in Kenya

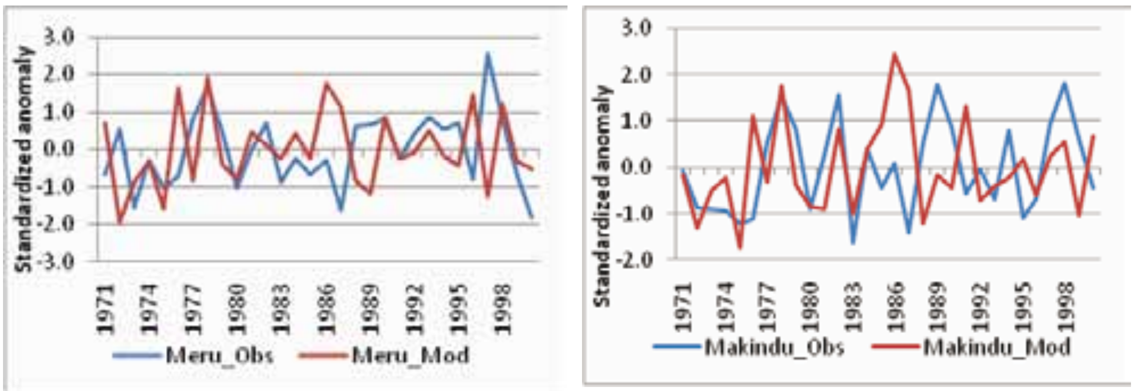
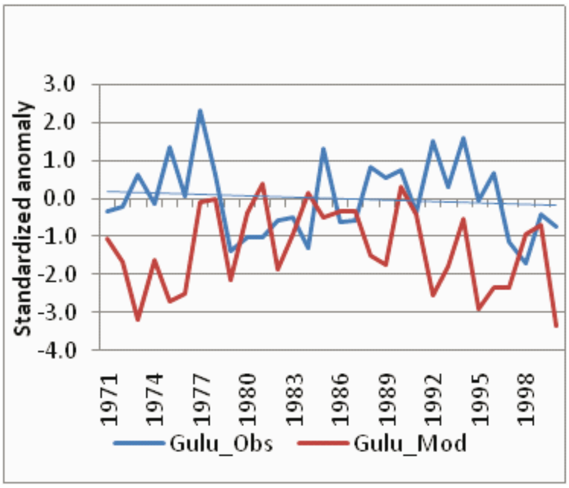


Figure 4.3: Time series of observed and modeled rainfall over Gulu and Kabale stations in Uganda



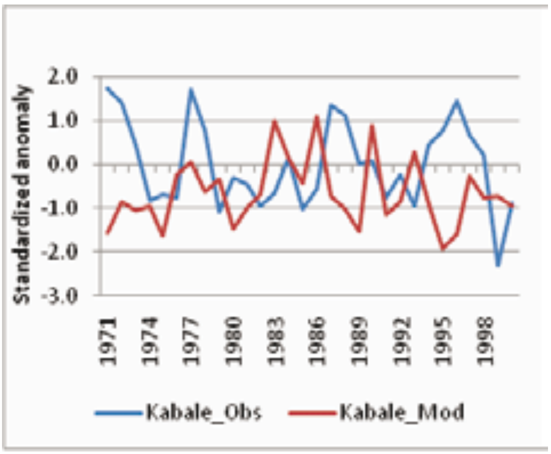
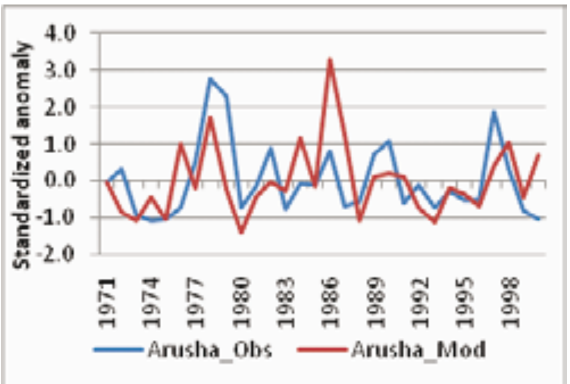


Figure 4.4: Time series of observed and modeled rainfall over Arusha and Dodoma stations in Tanzania



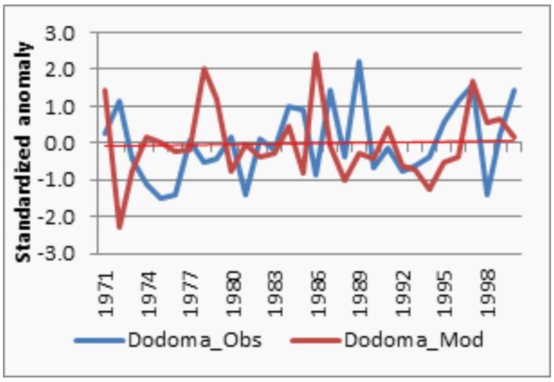
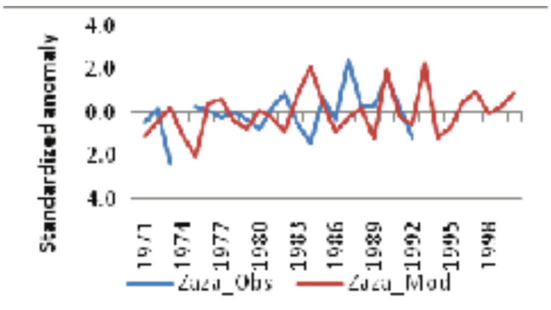


Figure 4.5: Time series of observed and modeled rainfall over Zaza and Kigali stations in Rwanda



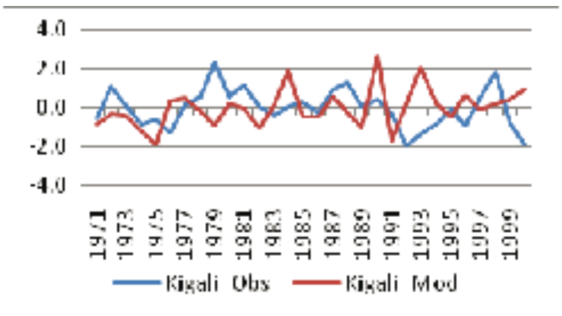
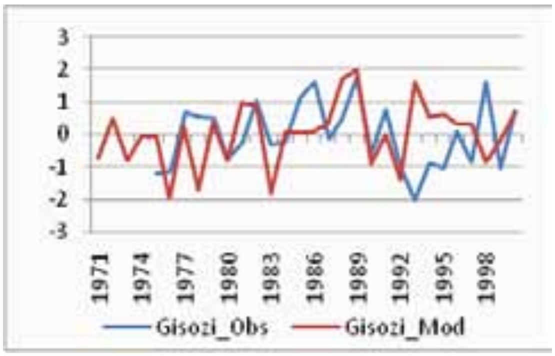
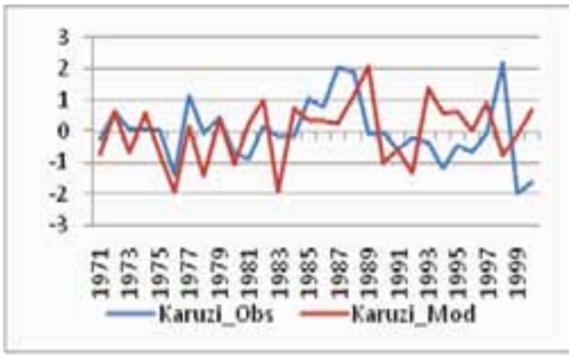


Figure 4.6: Time series of observed and modeled rainfall over Gisozi and Karuzi stations in Burundi





4.2.1 Past climate change analysis

Spatial analysis of baseline climate

Spatial analysis of annual, DJF, MAM, JJA and OND seasons for the baseline climate (precipitation, maximum temperature and minimum temperature) are presented for both individual and ensemble CORDEX RCMS.

(i) Precipitation

In Figure 4.7, CORDEX models show high annual total rainfall in excess of 2,000mm in most parts of EAC except North Eastern Kenya. ICHEC model (Figure 4.7c) showed wet conditions compared to MOHC model (Figure 4.7e), which showed dry conditions for the same period. During DJF (Figure 4.8), North of EAC recorded minimum rainfall ranging between 0 and 5mm whereas the south of EAC especially in Tanzania and Burundi recorded rainfall in excess of 600mm. During MAM season, rainfall was noted to undergo highest variations with the western Kenya, South Eastern Uganda and parts of Tanzania showing more rainfall compared to other parts of EAC. MOHC (Figure 4.9e) and NCC (Figure 8g) showed dry conditions compared to ICHEC (Figure 4.9c) and MPI (Figure 4.9f). Worth noting, all models showed that Eastern Kenya, Central and western Tanzania were generally drier compared to western Kenya and Uganda recording enhanced rainfall over EAC. During OND (Figure 4.11), most regions over EAC showed enhanced rainfall except Northern Kenya and Uganda with NOAA model (Figure 4.11h) indicating rainfall while MIROC (Figure 4.11d) indicated less rainfall. The Figure 6 to Figure 16 show that CORDEX models have individual bias in simulating precipitation, with ICHEC and MPI models indicating higher values compared to MOHC and MIROC models. Although CORDEX models simulations of annual rainfall were comparable, notable biases were observed in individual models' ability to simulate seasonal rainfall. However, both seasonal and annual rainfall patterns are well captured by the CORDEX models. The study notes that Ensemble CORDEX RCMs under CORDEX capture fairly well compared to individual models.

Previous studies have shown that the inter-annual rainfall variability is strongly associated with perturbations in the global SSTs, especially over the equatorial Pacific and Indian Ocean basins (Ogallo, 1988; Nicholson and Kim, 1997; Indeje et al., 2000; Saji et al., 1999; Black et al., 2003; Clark et al., 2003; Nyakwada, 2009; Omondi et al., 2013). The influence of global SST on eastern Africa rainfall depends on the season and the region. Generally, during JJAS *El Nino* conditions produce deficit rainfall and *La Nina* conditions produce excess rainfall over the northern parts of East Africa, whereas during OND the equatorial and southern parts of East Africa get below average rainfall during *La Nina* and above average during *El Nino*. As CORDEX RCMs are forced by ERA-Interim reanalysis, this would suggest that downscaling coarser model output improves rainfall representation at the regional scale. In general, most of the RCMs over-estimated rainfall while temperature fields were comparable. The multimodel ensemble mean outperforms the results of individual models in most of the areas and time periods as assessed. This is likely because of the cancellation of opposite signed biases across the models. Similar results have been shown by Paeth et al. (2011) and in the CORDEX context by Nikulin et al. (2012). At the level of individual models, it is of concern that many models produce good results in one region and poor results in another over the same time period. This would suggest that some models may be getting correct results in particular regions for the wrong reasons. Despite this, it has been demonstrated that the multimodel ensemble mean simulates eastern Africa rainfall adequately and can therefore be used for the assessment of future climate projections for the region. This can be affirmed by similar studies using different assessment critiria, e.g. Endris et al. (2013).

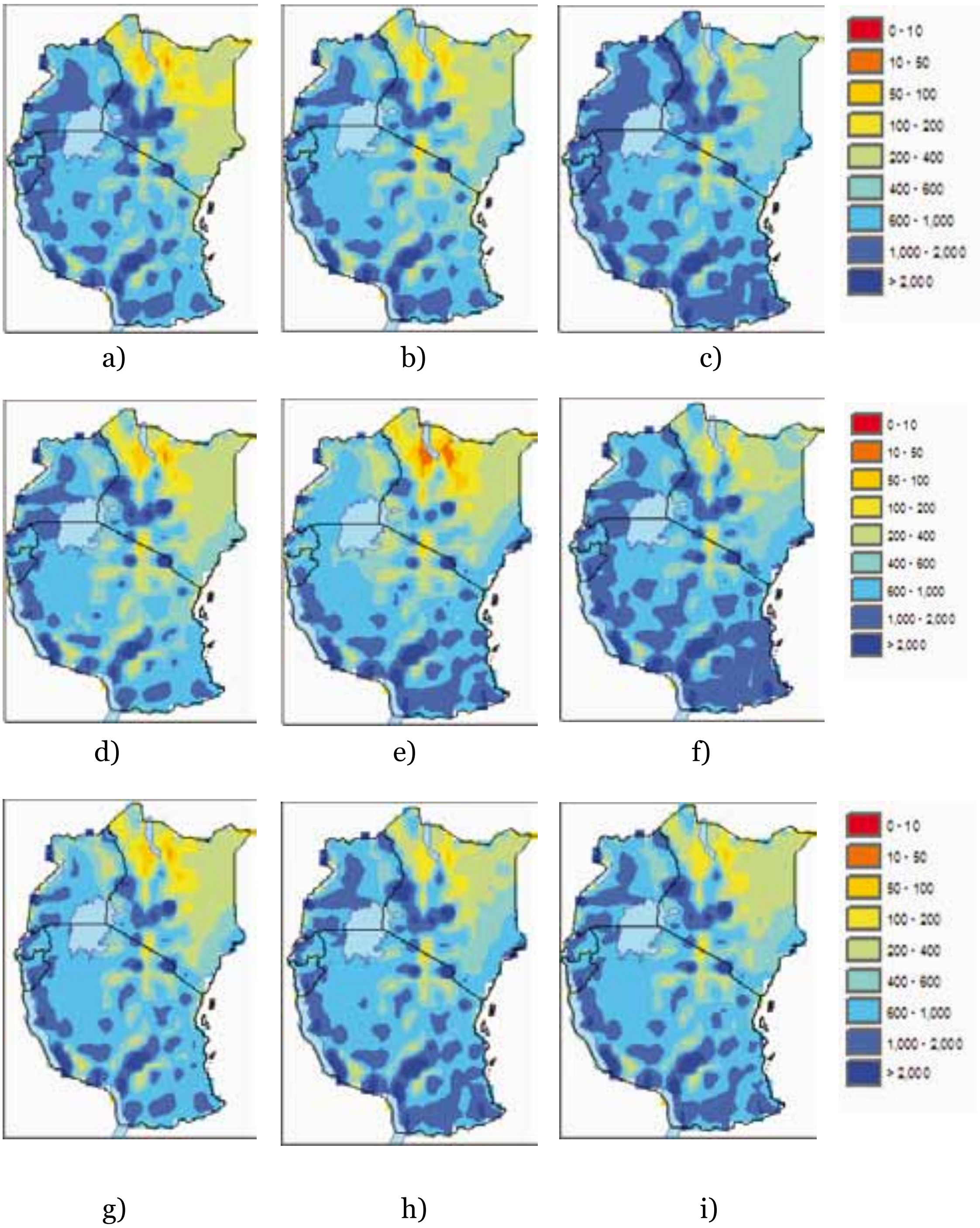
(ii) Maximum temperature

Based on CORDEX RCMs, the annual maximum temperatures (Figure 4.12) indicated higher temperatures of above 35°C over north-east of EAC, which includes north Uganda, north-east Kenya and sections of Tanzanian Coast. Similar patterns of Maximum temperature were observed for DJF (Figure 4.13), MAM (Figure 4.14), JJA (Figure 4.15) and OND (Figure 4.16). The location of intense maximum temperatures were noted to shift slightly during the season. The inter-seasonal shift in locations of intense maximum temperatures could be attributed to the location of ITCZ, which indicates the position of the sun. Notably, the central Kenya and parts of central Tanzania recorded lowest Maximum temperatures compared to the rest of EAC and this could be attributed to presence of high topographical features such as Mt Kenya in central Kenya and Mt Kilimanjaro in Tanzania.

(iii) Minimum temperature

Over EAC region, CORDEX RCMs (Figure 4.17-4.21) showed that minimum temperatures were lowest over the west compared to east. CNRM (Figure 4.17b) and ICHEC (Figure 4.17c) indicated lowest temperatures over central and eastern EAC. During DJF (Figure 4.18), lowest temperatures were recorded in Central Kenya and eastern L. Victoria. It was noted that the lower minimum temperature pattern during DJF extended to the south of EAC in Tanzania during MAM (Figure 4.19). JJA (Figure 4.20) assessment indicated lower minimum temperatures over

Figure 4.7: Comparison of a) CCCma b) CNRM c) ICHEC d) MIROC e) MOHC f) MPI g) NCC h) NOAA and i) ENSEMBLE CORDEX RCMs in Simulating annual precipitation over EAC (1971 -2000)



south of EAC especially in Tanzania. CCCma (Figure 4.19a) and NCC (Figure 4.19g) showed very high minimum temperatures of about 25°C around Lake Turkana during MAM season and, thus resulting to huge biases relative to other CORDEX RCMs

Figure 4.8: Comparison of a) CCCma b) CNRM c) ICHEC d) MIROC e) MOHC f) MPI g) NCC h) NOAA and i) ENSEMBLE CORDEX models in Simulating DJF seasonal precipitation over EAC (1971 -2000)

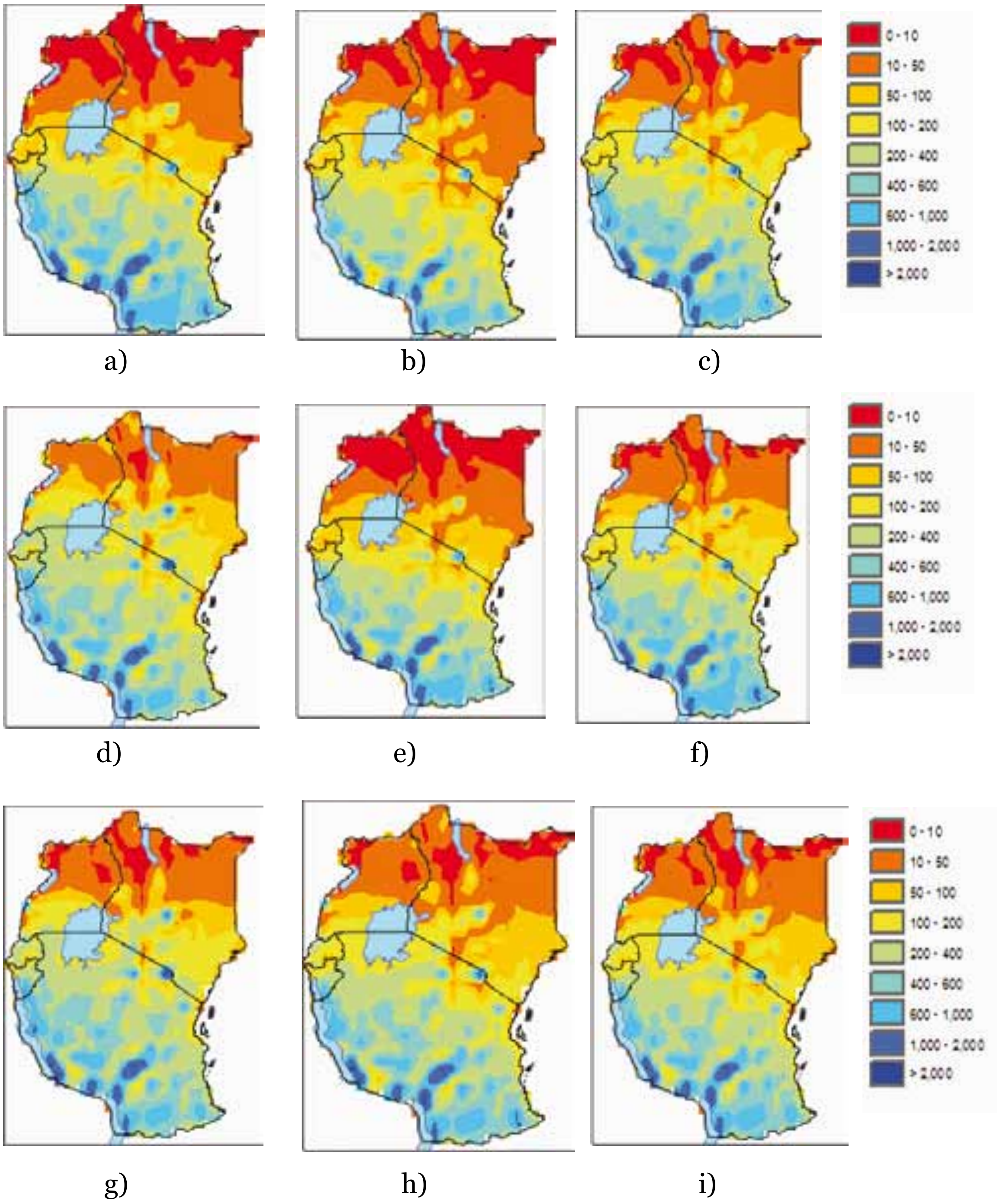


Figure 4.9: Comparison of a) CCCma b) CNRM c) ICHEC d) MIROC e) MOHC f) MPI g) NCC h) NOAA and i) ENSEMBLE CORDEX models in Simulating MAM seasonal precipitation over EAC (1971 -2000)

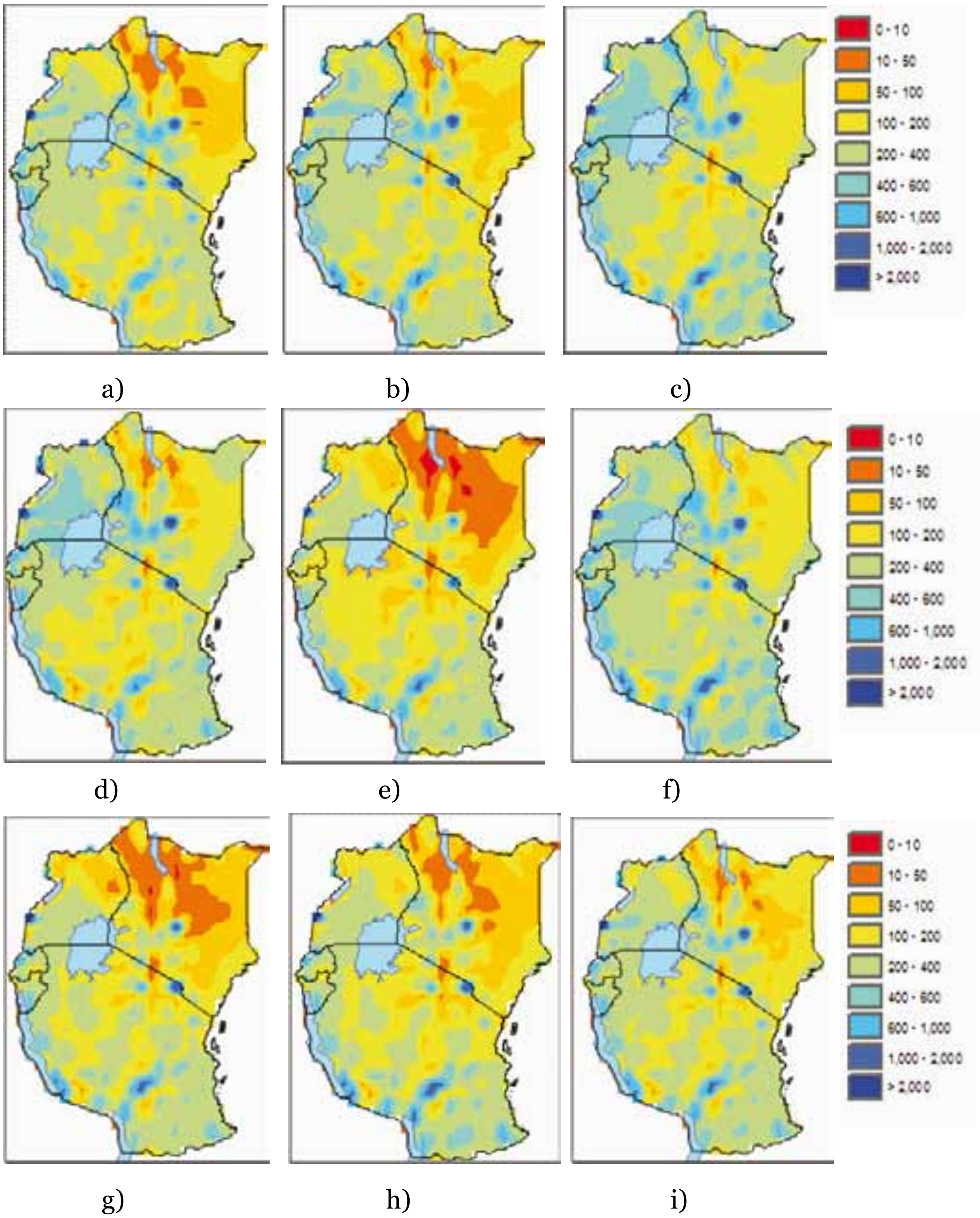


Figure 4.10: Comparison of a) CCCma b) CNRM c) ICHEC d) MIROC e) MOHC f) MPI g) NCC h) NOAA and i) ENSEMBLE CORDEX models in Simulating JJA seasonal precipitation over EAC (1971 -2000)

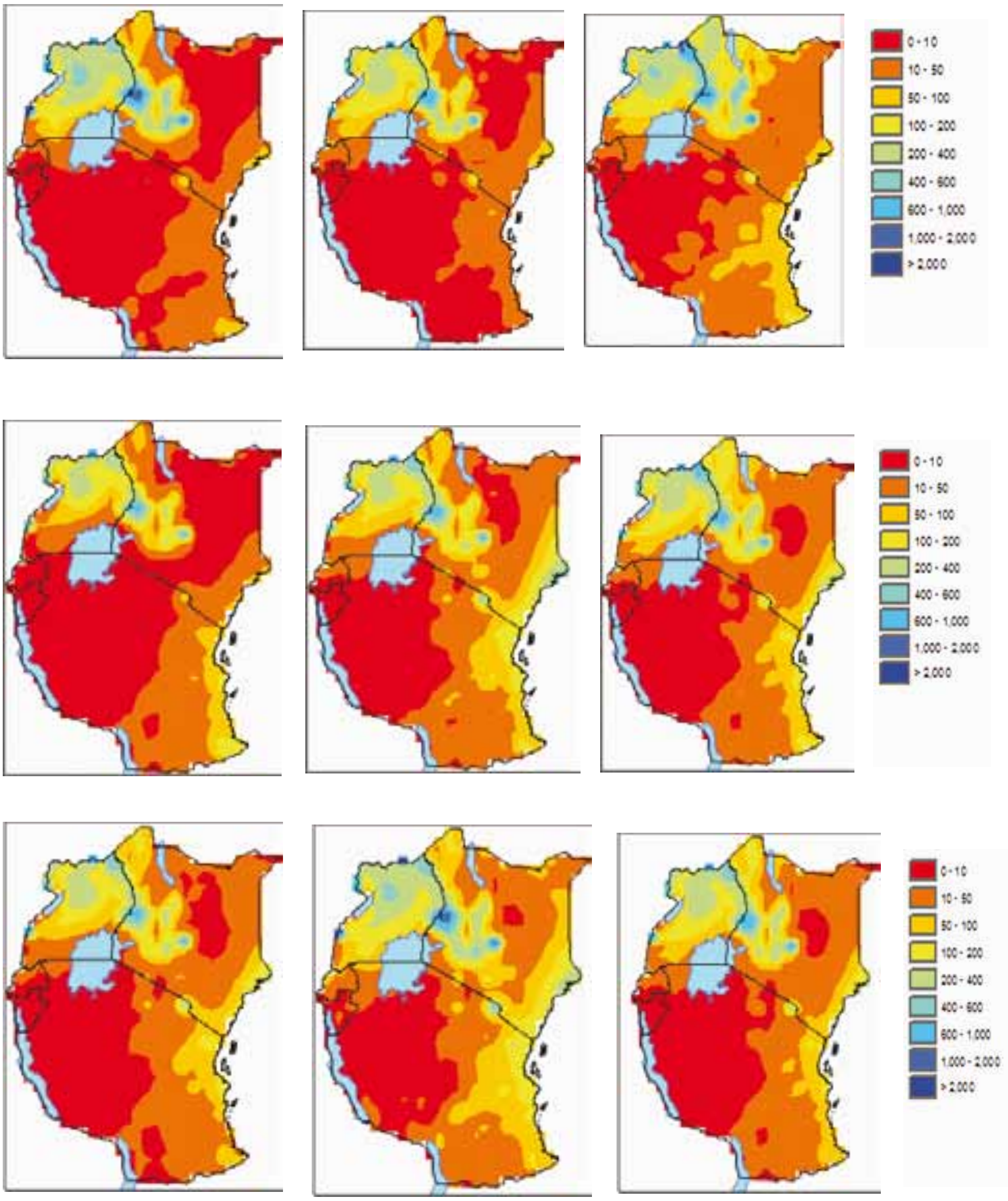


Figure 4.11: Comparison of a) CCCma b) CNRM c) ICHEC d) MIROC e) MOHC f) MPI g) NCC h) NOAA and i) ENSEMBLE CORDEX models in Simulating OND seasonal precipitation over EAC (1971 -2000)

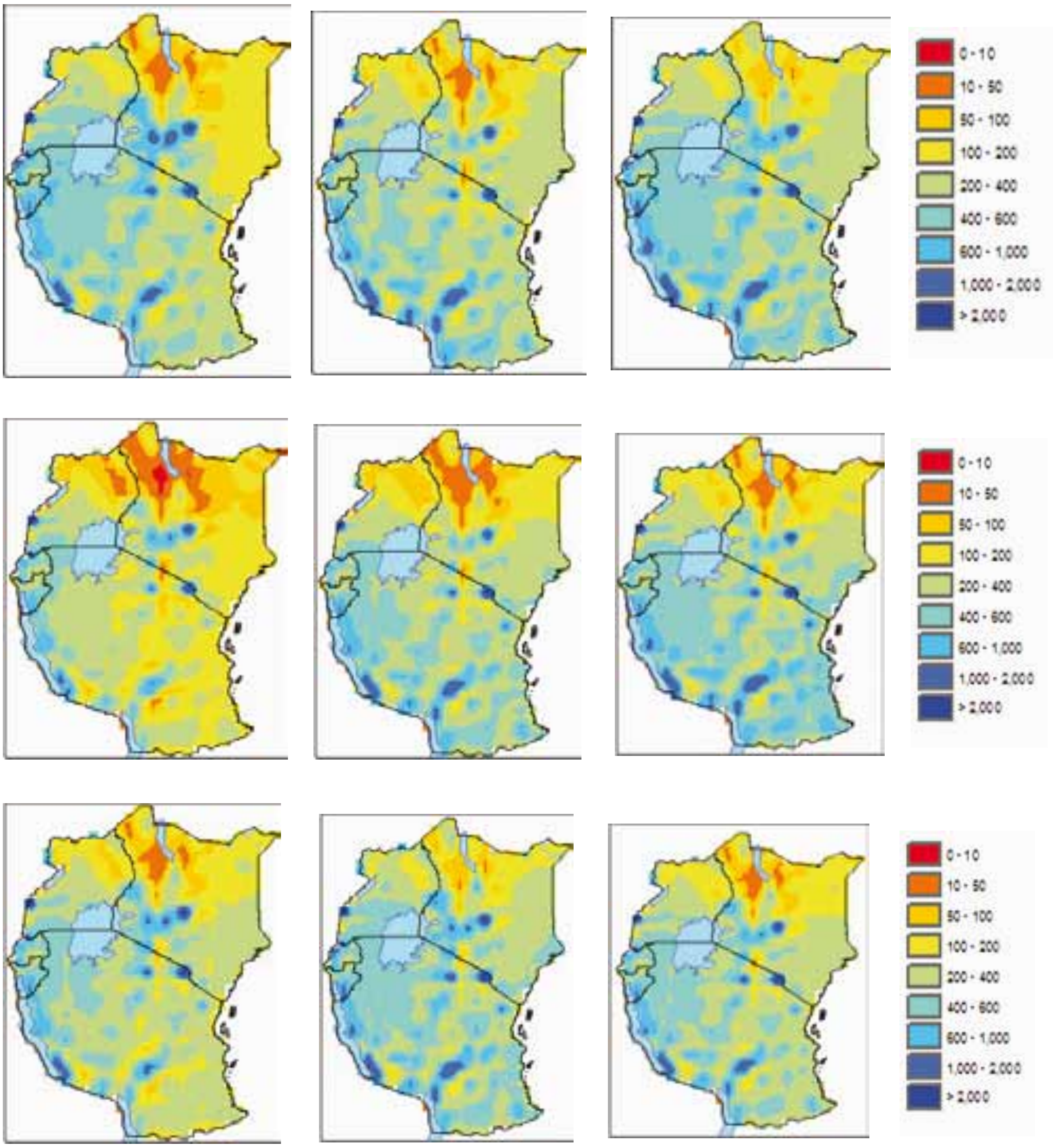


Figure 4.12: Comparison of a) CCCma b) CNRM c) ICHEC d) MIROC e) MOHC f) MPI g) NCC h) NOAA and i) ENSEMBLE CORDEX models in simulating annual maximum temperature over EAC (1971 -2000)

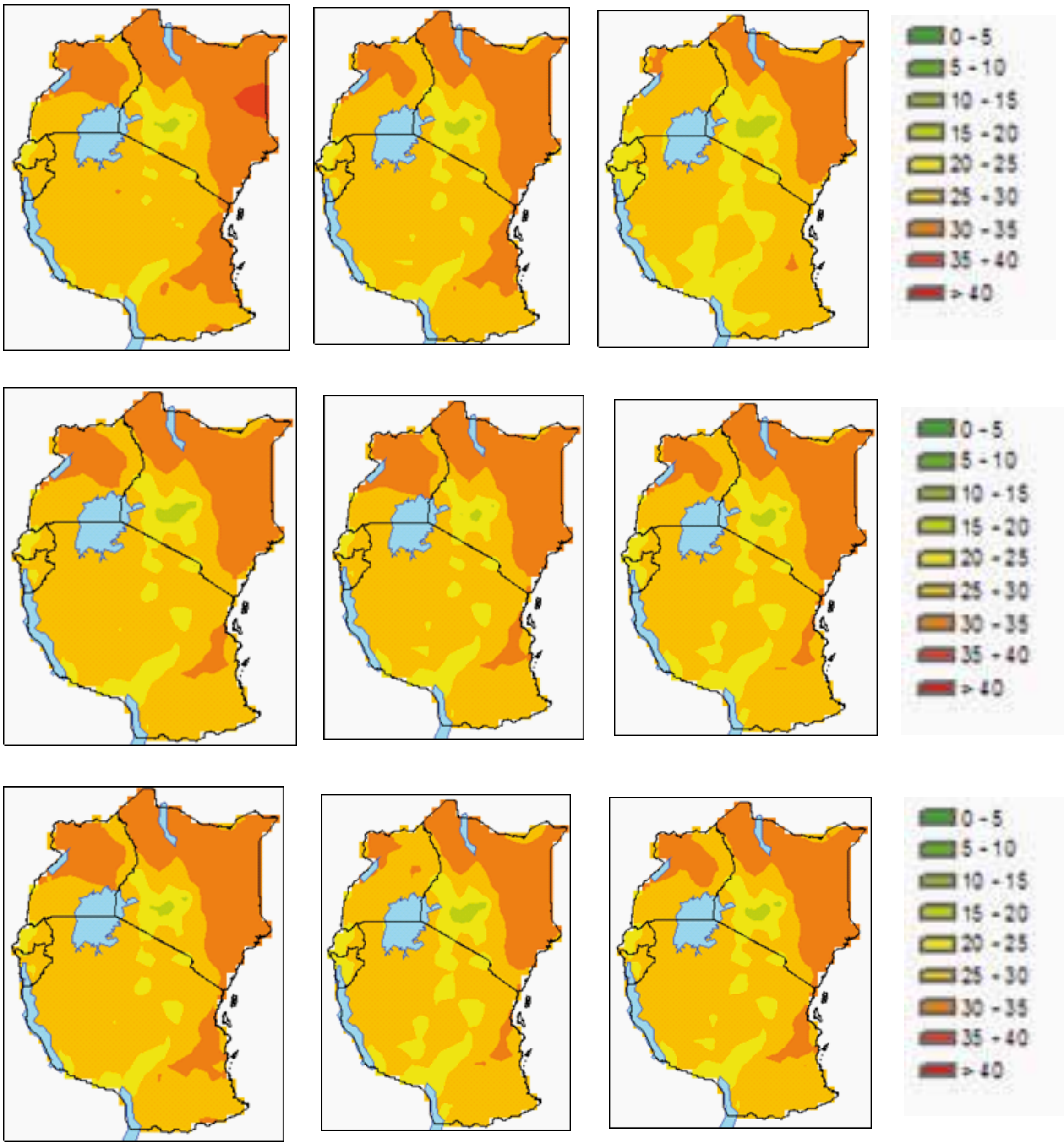


Figure 4.13: Comparison of a) CCCma b) CNRM c) ICHEC d) MIROC e) MOHC f) MPI g) NCC h) NOAA and i) ENSEMBLE CORDEX models in Simulating DJF Maximum Temperature over EAC (1971 -2000)

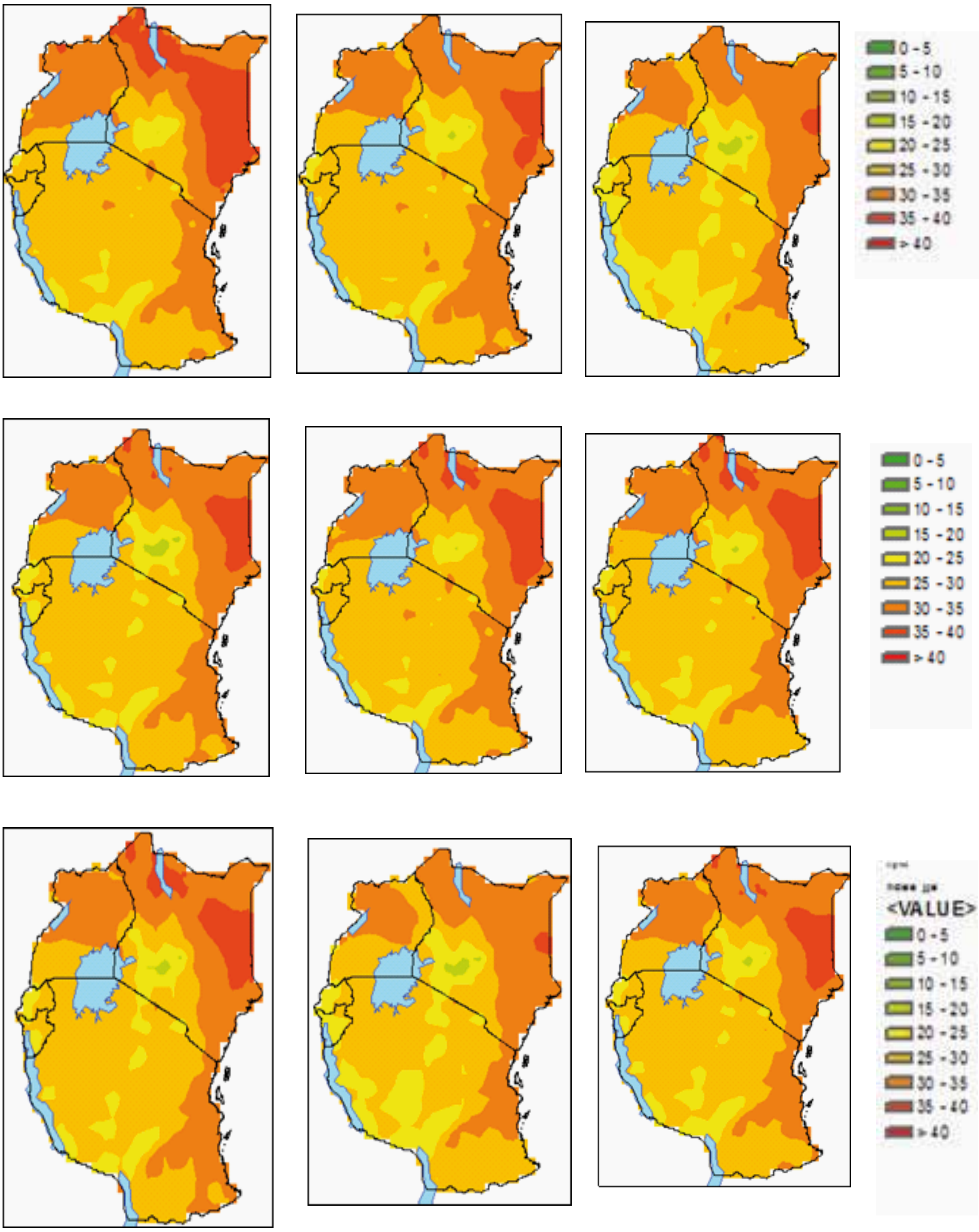


Figure 4.14: Comparison of a) CCCma b) CNRM c) ICHEC d) MIROC e) MOHC f) MPI g) NCC h) NOAA and i) ENSEMBLE CORDEX models in Simulating MAM seasonal Maximum Temperature over EAC (1971 -2000)

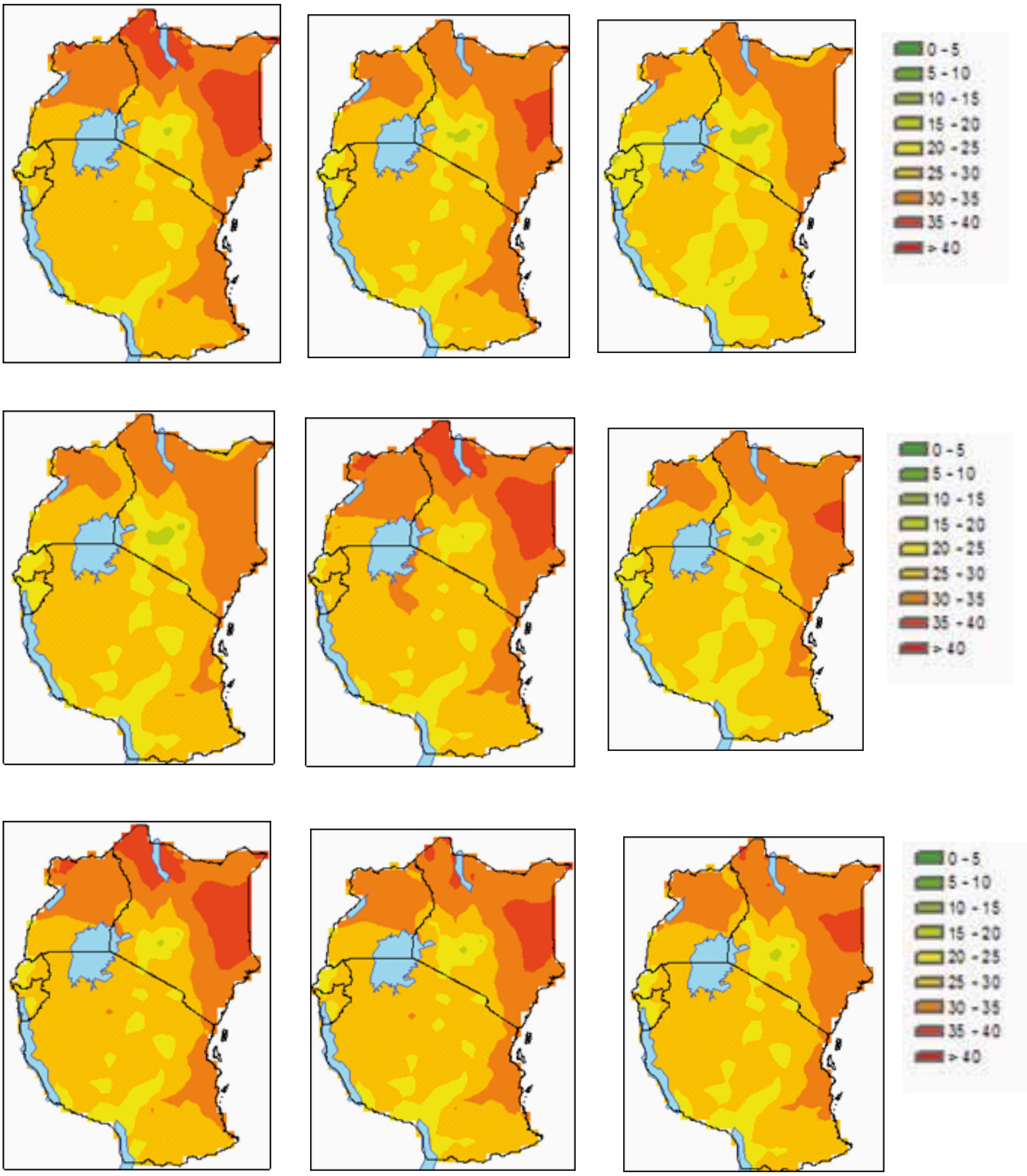


Figure 4.15: Comparison of a) CCCma b) CNRM c) ICHEC d) MIROC e) MOHC f) MPI g) NCC h) NOAA and i) ENSEMBLE CORDEX models in Simulating JJA seasonal Maximum Temperature over EAC (1971 -2000)

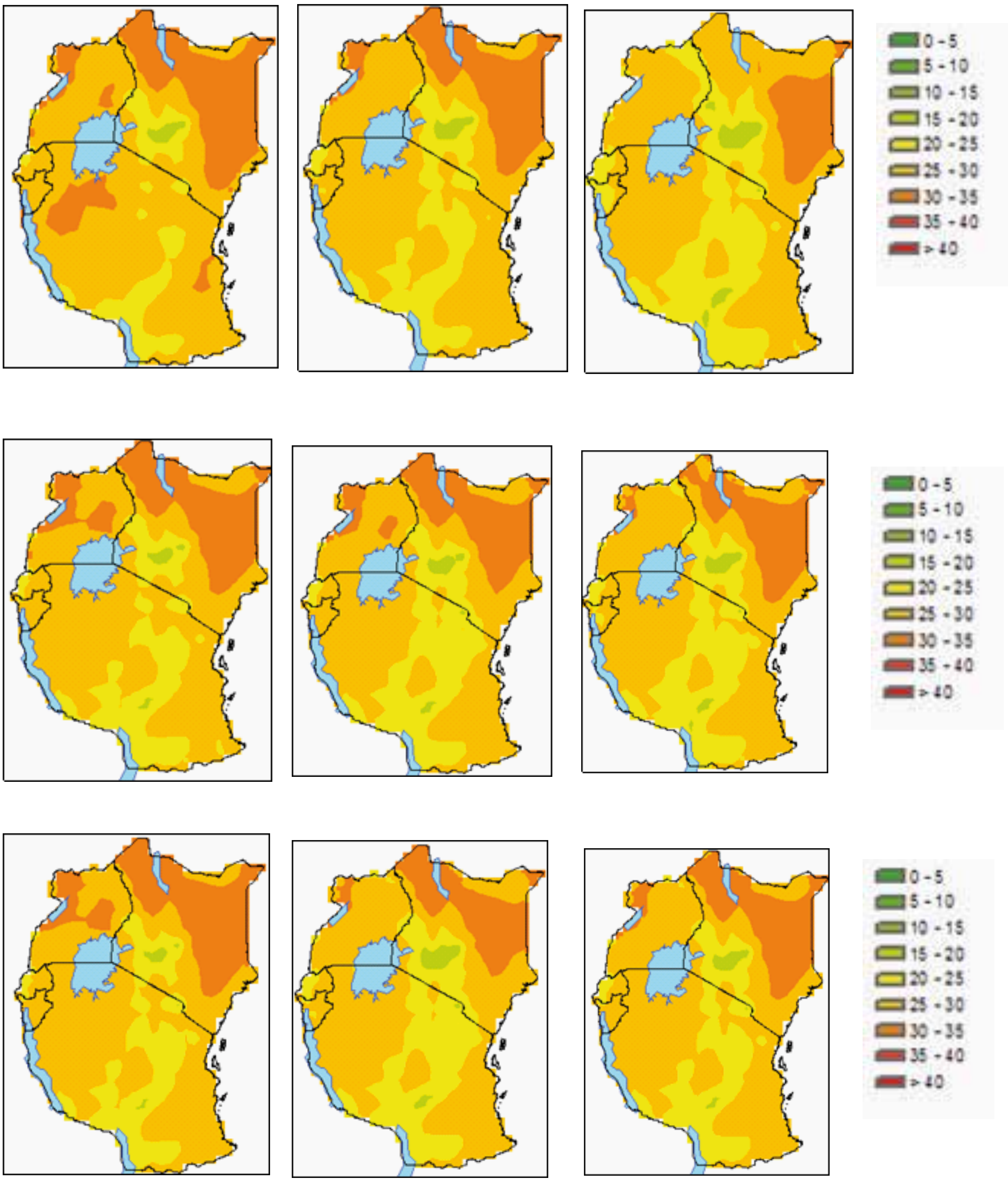


Figure 4.16: Comparison of a) CCCma b) CNRM c) ICHEC d) MIROC e) MOHC f) MPI g) NCC h) NOAA and i) ENSEMBLE CORDEX models in Simulating OND seasonal Maximum Temperature over EAC (1971 -2000)

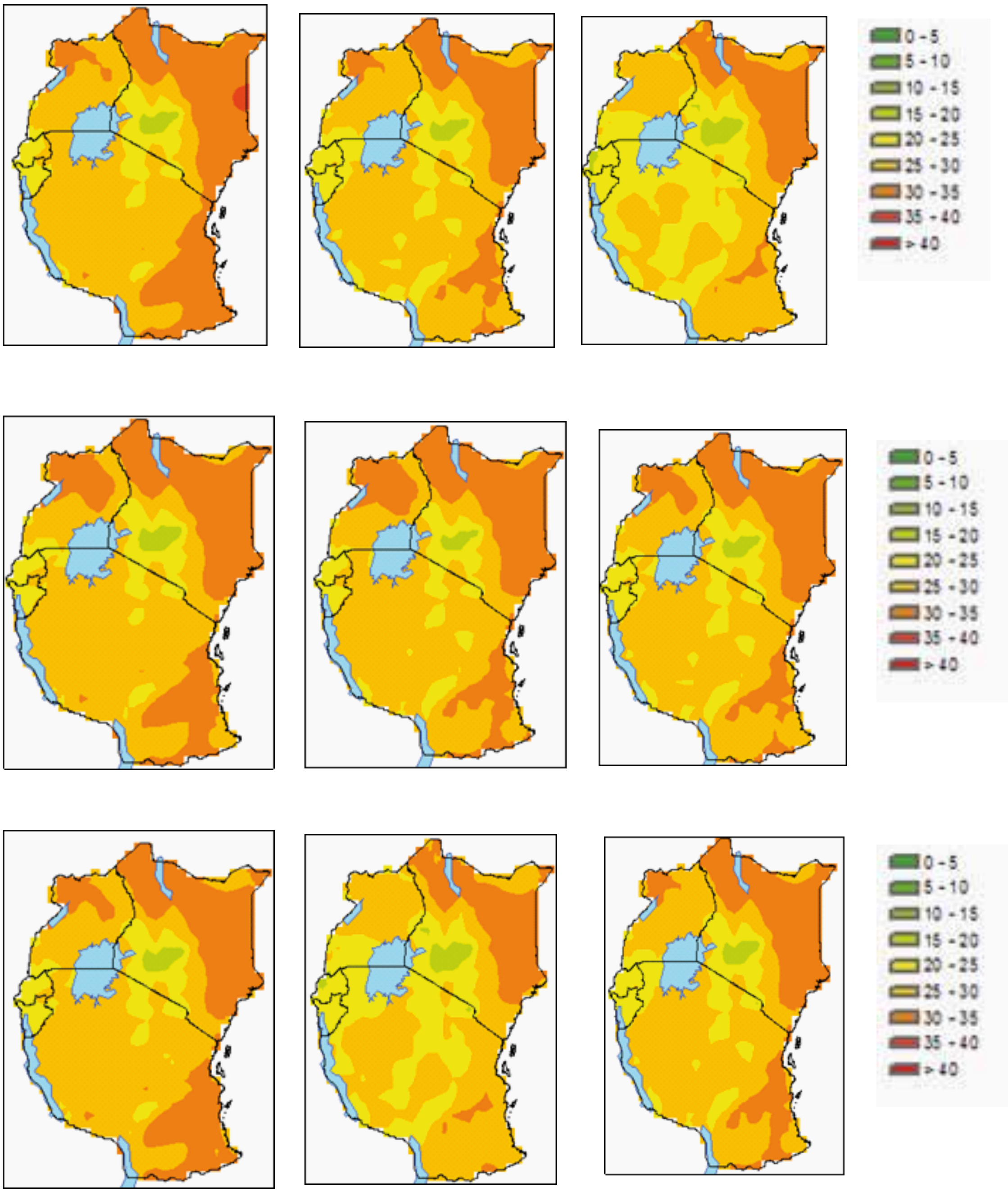
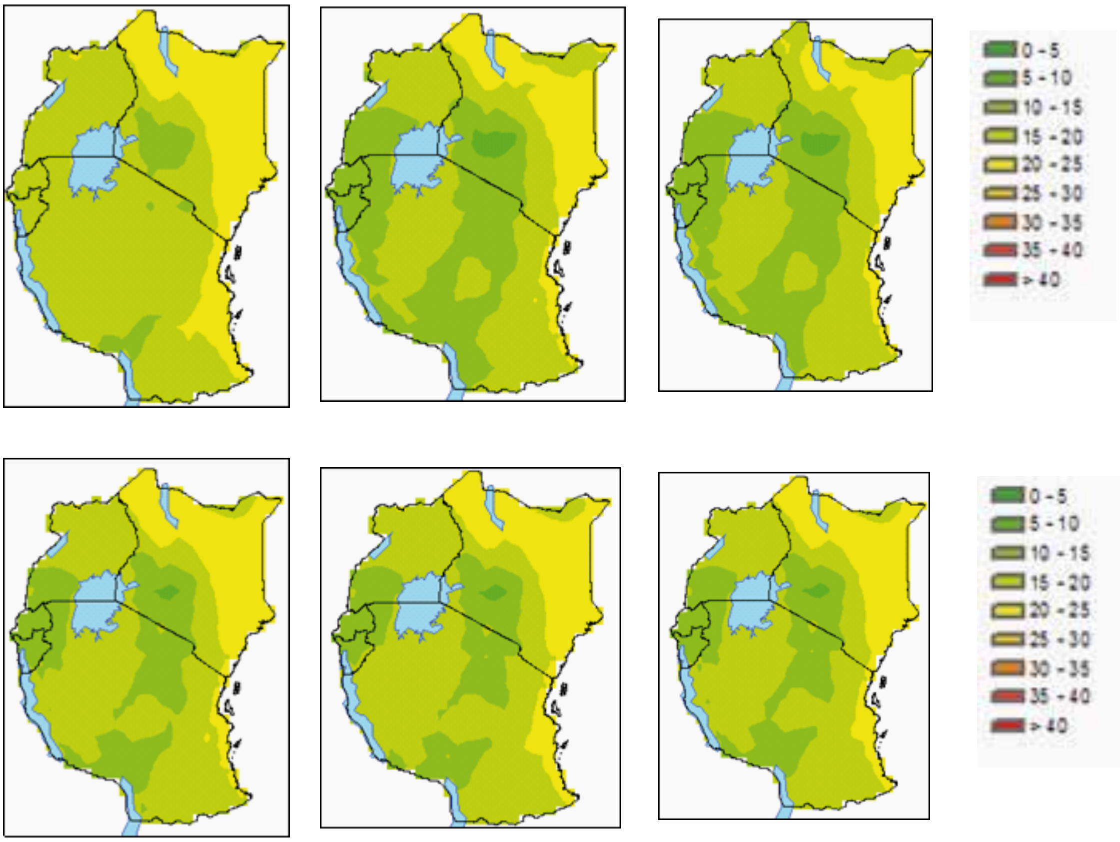


Figure 4.17: Comparison of a) CCCma b) CNRM c) ICHEC d) MIROC e) MOHC f) MPI g) NCC h) NOAA and i) ENSEMBLE CORDEX models in Simulating annual minimum temperature over EAC (1971 -2000)



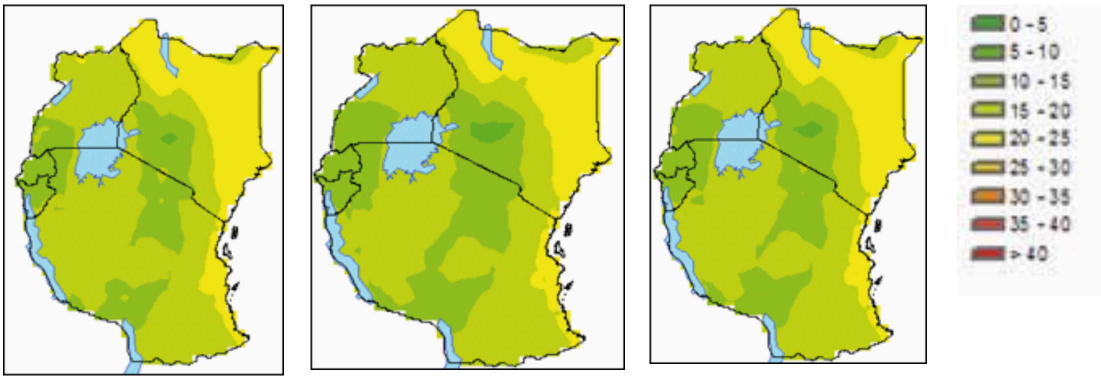
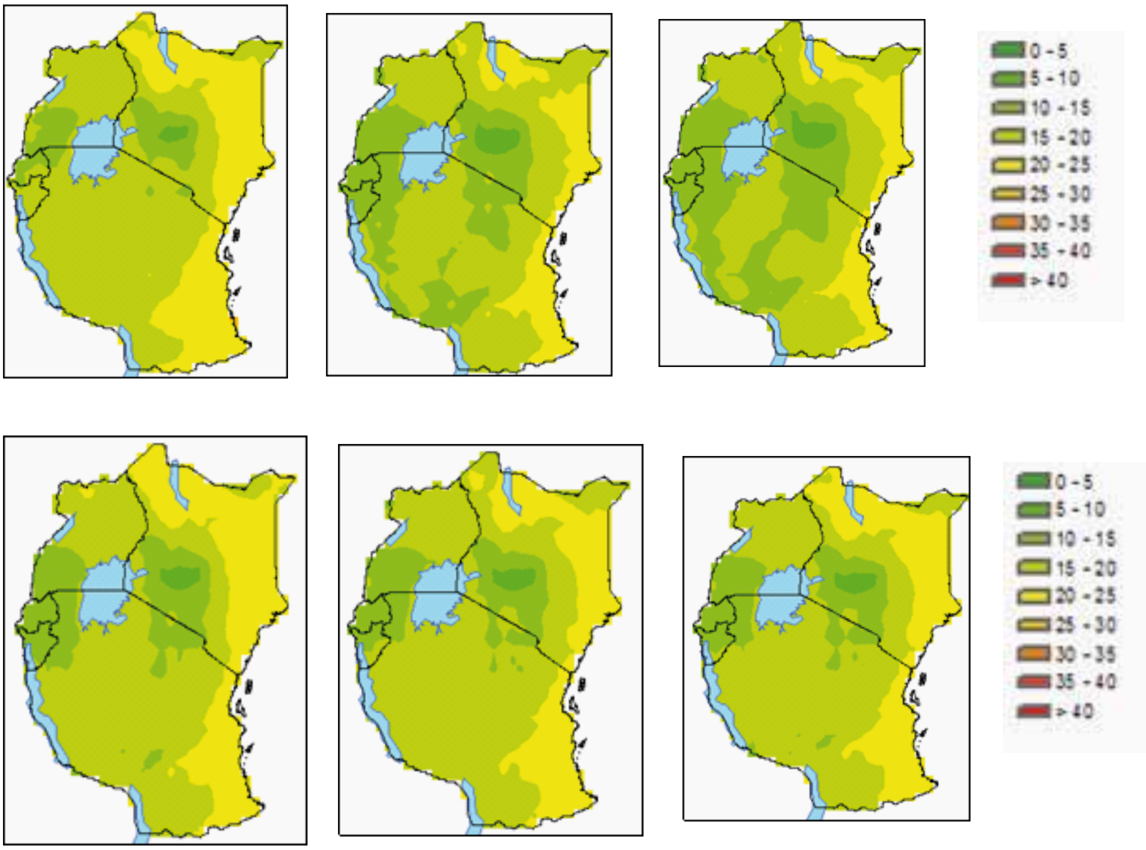


Figure 4.18: Comparison of a) CCCma b) CNRM c) ICHEC d) MIROC e) MOHC f) MPI g) NCC h) NOAA and i) ENSEMBLE CORDEX models in Simulating DJF seasonal Maximum Temperature over EAC (1971 -2000)



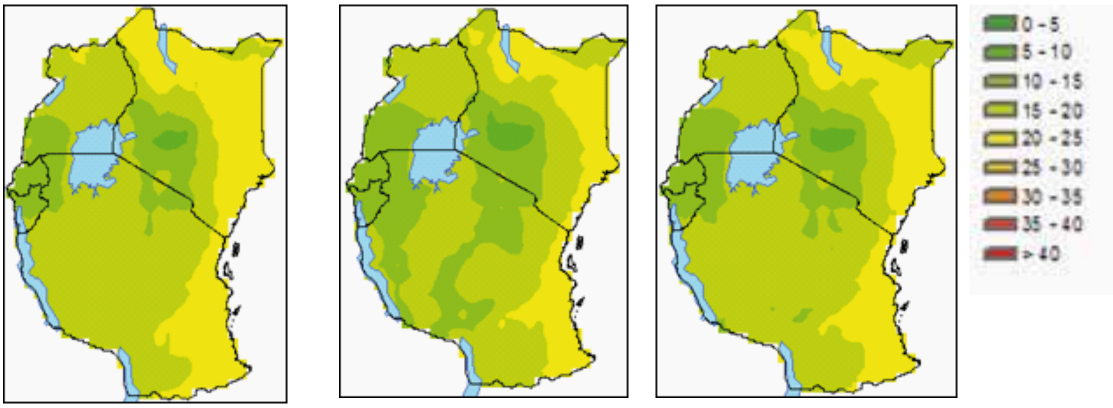


Figure 4.19: Comparison of a) CCCma b) CNRM c) ICHEC d) MIROC e) MOHC f) MPI g) NCC h) NOAA and i) ENSEMBLE CORDEX models in Simulating MAM seasonal Maximum Temperature over EAC (1971 -2000)

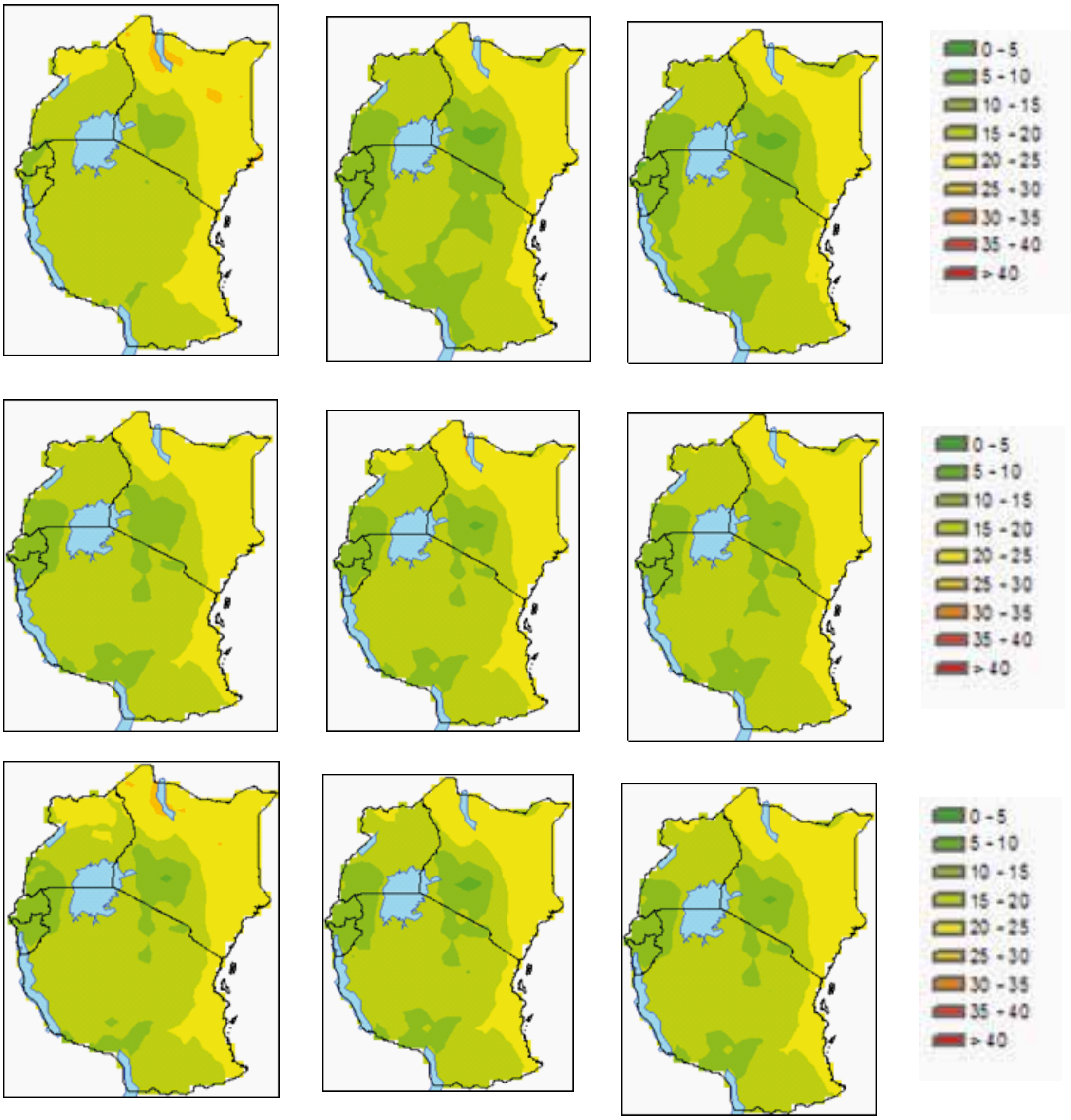


Figure 4.20: Comparison of a) CCCma b) CNRM c) ICHEC d) MIROC e) MOHC f) MPI g) NCC h) NOAA and i) ENSEMBLE CORDEX models in Simulating JJA seasonal Maximum Temperature over EAC (1971 -2000)

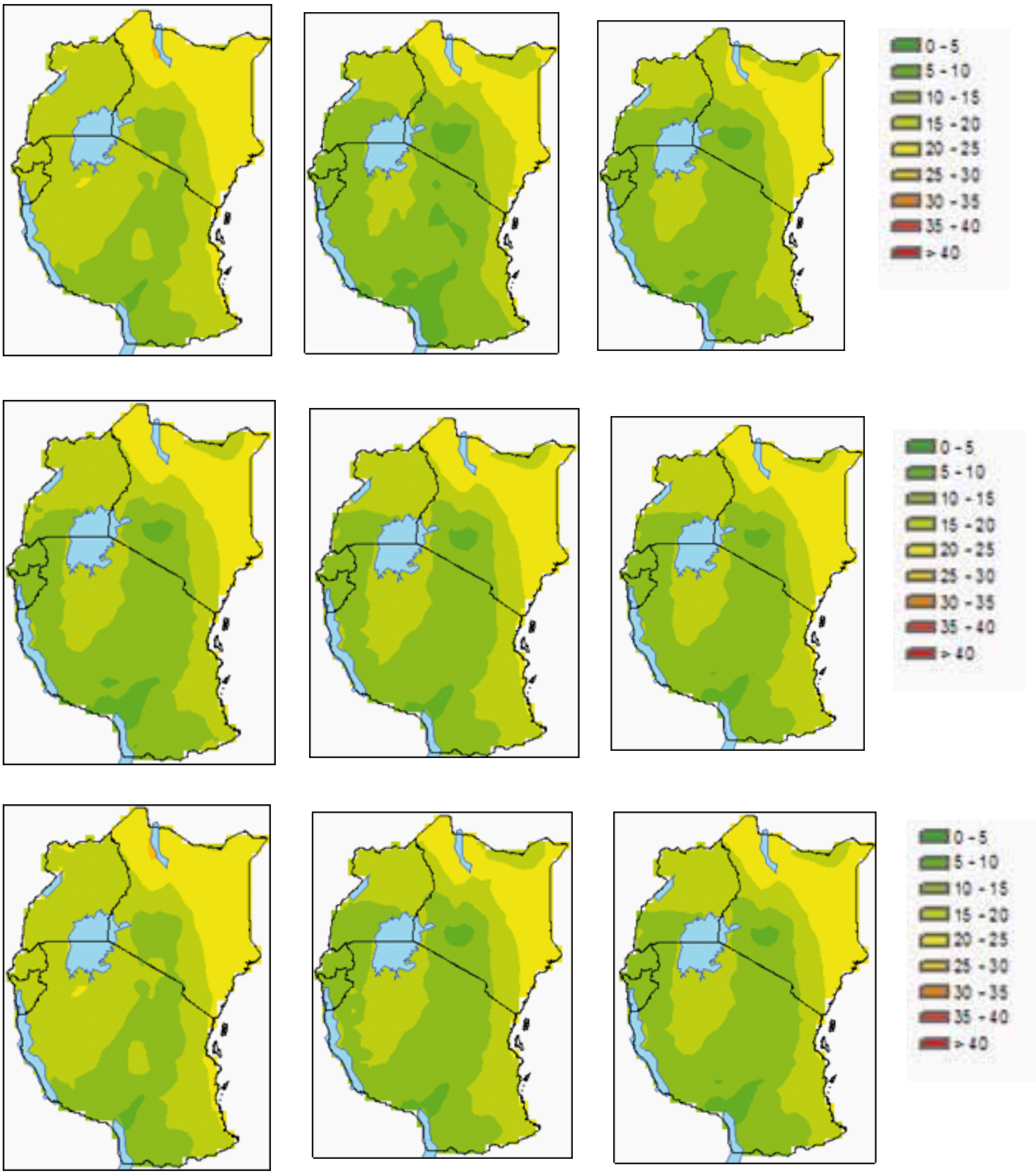
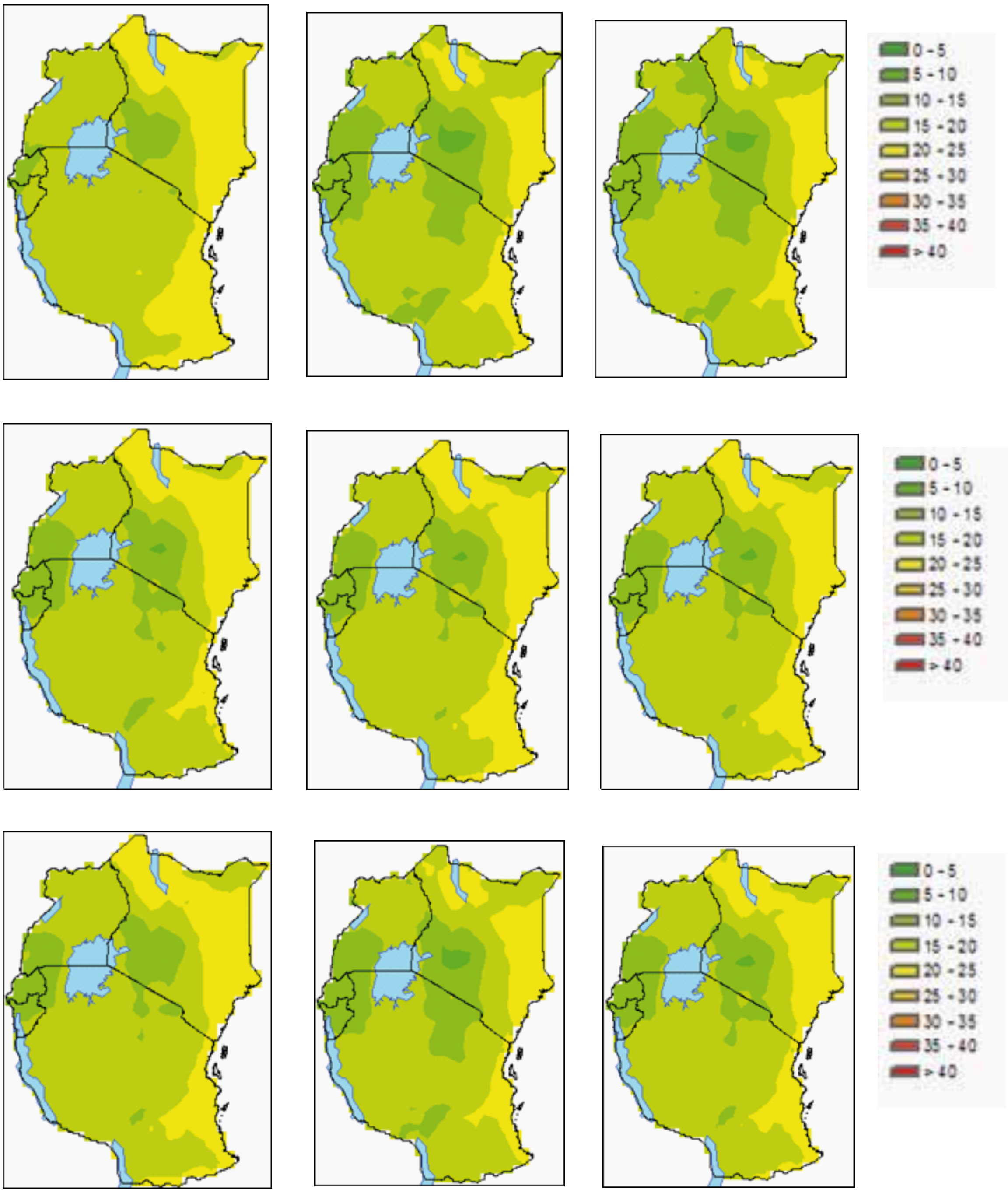


Figure 4.21: Comparison of a) CCCma b) CNRM c) ICHEC d) MIROC e) MOHC f) MPI g) NCC h) NOAA and i) ENSEMBLE CORDEX models in Simulating OND seasonal Maximum Temperature over EAC (1971 -2000)



Temporal Analysis of Baseline Climate

The results of trend of baseline climate based on Mann Kendall test and Sen's estimate at 0.001, 0.01, 0.05, 0.1 level of significance (α) are presented in Table 4.2. The Sen slope was also expressed as percent of mean quantity per unit time (% Δ)

Table 4.2: Trend analysis of maximum temperature (1971-2000)

Station	Precipitation				Maximum Temperature				Minimum Temperature			
	Mann Kendall	Sig	Sen slope	% Δ	Mann Kendall	Sig	Sen slope	% Δ	Mann Kendall	Sig	Sen slope	% Δ
Kakamega	0.96		1.17	21	2.57	*	0.01	3	3.21	**	0.02	9
Kisii	0.39		1.24	10	2.64	**	0.01	5	3.89	***	0.02	11
Eldoret	1.61		2.76	16	3.46	***	0.02	7	3.71	***	0.02	13
Thika	0.93		1.12	15	2.75	**	0.01	5	3.57	***	0.02	11
Nakuru	0.86		2.21	17	3.53	***	0.02	8	3.78	***	0.02	16
Makindu	0.68		0.73	20	2.96	**	0.01	5	3.50	***	0.02	11
Meru	0.54		0.38	11	3.53	***	0.01	6	3.96	***	0.02	13
Dar	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Dodoma	-0.04		-0.10	-1	3.25	**	0.02	6	3.96	***	0.02	11
Arusha	1.00		0.84	25	3.21	**	0.01	5	3.93	***	0.02	13
Kigoma	0.89		0.24	16	3.82	***	0.01	5	3.71	***	0.02	9
Mbeya	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Kia	0.54		0.22	9	3.10	**	0.01	5	4.00	***	0.02	11
Morogoro	-0.36		-0.74	-4	3.14	**	0.02	5	3.93	***	0.02	9
Kitgum	-0.57		-0.42	-7	3.57	***	0.02	5	3.85	***	0.02	12
Lira	-0.36		-0.43	-4	3.53	***	0.02	5	3.78	***	0.02	11
Gulu	0.25		0.29	2	3.75	***	0.02	4	3.75	***	0.02	11
Masindi	-0.46		-0.43	-4	4.00	***	0.01	5	3.60	***	0.02	13
Soroti	0.36		0.36	5	3.25	**	0.01	5	3.35	***	0.02	11
Jinja	0.11		0.13	1	3.18	**	0.01	4	3.03	**	0.02	12
Kabale	1.68	+	2.90	12	3.28	**	0.01	6	3.50	***	0.02	16
Masaka	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mbarara	1.39		1.13	10	3.25	**	0.01	5	3.50	***	0.02	15
Kasese	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Gabiro	2.85	**	1.92	22	1.11		0.01	5	3.50	***	0.02	13
Kamembe	0.61		0.28	6	0.96		0.01	4	4.17	***	0.02	16
Gisenyi	1.89	+	2.46	13	1.22		0.01	4	3.78	***	0.02	16
Gikongoro	0.75		1.31	9	0.77		0.01	4	4.03	***	0.02	16
Rwaza	2.28	*	2.49	17	1.22		0.01	4	3.75	***	0.02	16
Save	1.68	+	0.81	15	0.88		0.01	3	4.10	***	0.02	17
Ruhuha	2.43	*	0.94	21	1.11		0.01	3	4.21	***	0.02	16
Kigali	2.21	*	1.63	15	0.99		0.01	4	3.60	***	0.02	16
Bujumbura	-0.54		-0.45	-5	1.39		0.01	3	4.10	***	0.02	14
Nyanza Lac	0.89		0.19	14	2.00	*	0.01	5	4.39	***	0.02	10
Gisozi	-0.54		-0.45	-5	1.39		0.01	3	4.10	***	0.02	14

Muyinga	1.39		1.07	14	0.96		0.01	3	3.64	***	0.02	14
Musasa	-0.68		-1.38	-6	2.14	*	0.01	5	3.57	***	0.02	13

In Kenya, the trend of precipitation, maximum and minimum temperature are increasing. These increases are significant at α level greater than 0.1 for precipitation and α level less than 0.1 for both maximum and minimum temperature. Notably, the magnitude of the slope were all positive and ranged from 0.38 to 2.76, 2.57 to 3.53 and 3.21 to 3.96 for precipitation, maximum temperature and minimum temperature, respectively. Computed percentage change in trend varied from 10 to 20 per cent for precipitation, 3 to 8 per cent for maximum temperature and 9 to 16 per cent for minimum temperature. In Uganda, the trend of precipitation, maximum and minimum temperature was noted to either increase (Gulu, Soroti, Jinja, Kabale and Mbarara) or decreased (Kitgum, Lira and Masindi). Increases/decreases in precipitation were significant at α level greater than 0.1 for selected stations, except Kabale, while maximum temperature and minimum temperature were significant at α level less than 0.1. The absolute magnitude of the slope ranged from 0.13 to 2.9, 0.01 and 0.02 for precipitation, maximum temperature and minimum temperature, respectively. Computed percentage change in trend varied from -7 to 12 per cent for precipitation, 4 to 6 per cent for maximum temperature and 11 to 16 per cent for minimum temperature.

In Tanzania, the trend of precipitation, maximum and minimum temperature noted increase in all stations except precipitation in Dodoma and Morogoro. The increasing trends were significant at α level greater than 0.1 for precipitation and at α level less than 0.1 for both maximum and minimum temperatures. The absolute magnitudes of the slope ranged from 0.1 -0.8, 0.01 to 0.02 and 3.71 to 4.0 for precipitation, maximum and minimum temperatures, respectively. The percentage change in trend varied from -4 to 25 per cent for precipitation, 5 to 6 per cent for maximum temperature and 9 to 13 per cent for minimum temperature. In Rwanda, the trend of precipitation, maximum and minimum temperature were all increasing and significant at α level greater than 0.1 for precipitation and less than 0.1 for both maximum and minimum temperatures. The magnitude of slope ranged from 0.18 to 2.49, 0.01 and 0.02 for precipitation, maximum and minimum temperature.

In Burundi, the trend of trend of precipitation either increased/decreased while temperatures increased. These trends were significant at α level greater than 0.1 for precipitation and less than 0.1 from maximum and minimum temperature. The absolute magnitude of the trend ranged from 0.45 to 1.39, 0.01 and 0.02 for precipitation, maximum and minimum temperature. The percentage change in trend varied from -6 to 14 per cent for precipitation, 3 to 5 per cent for maximum temperature and 10 to 14 per cent for minimum temperature.

4.2.2 Climate change projection

Temporal analysis of projected precipitation

The results of Mann Kendall test, Sen Slope estimator (Q) and percentage change in mean are presented for projected precipitation under RCP 4.5 and RCP 8.5 scenario in Table 4.3 and Table 4.4, respectively, during the mid century (2016-2045)

Table 4.3: Time series analysis of mid century (2016-2015) projected precipitation in EAC

	RCP 4.5 Scenario				RCP 8.5 Scenario			
	Mann Kendall	Sig	Sen slope	% Δ	Mann Kendall	Sig	Sen slope	%Δ
Kakamega	-0.5		-0.85	-12	0.46		0.69	10
Kisii	0.25		0.87	6	1.39		3.94	26
Eldoret	-0.93		-3.83	-20	1.03		4.27	23
Thika	0.18		0.27	3	1.57		3.42	40
Nakuru	-0.46		-1.47	-10	1.21		4.18	28
Makindu	0.11		0.09	2	1.57		1.82	44
Meru	-0.79		-0.75	-18	0.64		0.84	20
DAR	NA	NA	NA	NA	NA	NA	NA	NA
Dodoma	2.43	*	3.23	34	2.57	*	3.12	33
Arusha	1.68	+	1.87	43	2.11	*	3.24	71
Kigoma	-0.21		-0.12	-7	-0.46		-0.26	-15
Mbeya	NA	NA	NA	NA	NA	NA	NA	NA
Kia	0.36		0.39	15	0.21		0.27	10
Morogoro	1.82	+	6.23	34	-0.14		-0.49	-3
Kitgum	-0.68		-0.71	-10	2.46	*	3.29	47
Lira	-0.25		-0.67	-6	1.14		2.75	24
Gulu	-1.21		-3.19	-22	0.86		1.61	11
Masindi	-1.21		-2.08	-19	-0.14		-0.2	-2
Soroti	-0.25		-0.4	-5	1.61		2.47	30
Jinja	-0.68		-1.43	-11	0		0.04	0
Kabale	-0.43		-1.17	-5	-0.79		-1.67	-7
Mbarara	0.29		0.6	5	0.39		0.44	4
Gabiro	0.25		0.52	5	0		-0.04	0
Kamembe	-1.82	+	-1.77	-36	0.96		1.29	27
Gisenyi	-0.93		-3.32	-16	-0.25		-0.64	-3
Gikongoro	-1.57		-4.05	-25	0.07		0.14	1
Rwaza	-0.71		-1.2	-10	0		-0.15	-1
Save	-0.21		-0.27	-4	-0.39		-0.38	-6
Ruhuha	0.07		0.04	1	-0.25		-0.33	-7
Kigali	-0.71		-1.2	-10	0		-0.15	-1
Bujumbura	-1.18		-2.29	-22	0.21		0.15	1

Nyanza Lac	-1.43		-0.38	-26	-0.29		-0.13	-8
Gisozi	-1.18		-2.29	-22	0.21		0.15	1
Muyinga	0.18		0.2	2	-0.5		-0.96	-12
Musasa	-1.75	+	-4.28	-17	-0.68		-3.47	-14

Table 4.4: Time series analysis of end Century (2071-2100) projected precipitation in EAC

	RCP 4.5 - End Century				RCP 8.5 End Century			
	Mann Kendall	**Sig**	**Sen slope**	**%Δ**	**Mann Kendall**	**Sig**	**Sen slope**	**% Δ**
Kakamega	0.5		0.55	8	0.89		1.63	21
Kisii	-0.04		-0.07	0	0.29		0.89	5
Eldoret	0.21		0.64	3	1.03		2.13	11
Thika	-0.68		-0.82	-9	0.79		1.27	13
Nakuru	0.86		2.56	17	0.11		0.4	3
Makindu	-1.93	+	-2.24	-52	0.14		0.15	3
Meru	-0.82		-1.24	-28	-0.14		-0.14	-3
DAR	NA	NA	NA	NA	NA	NA	NA	NA
Dodoma	-0.36		-0.88	-9	2.32	*	4.41	42
Arusha	0.04		0.05	1	2.96	**	2.95	51
Kigoma	0.93		0.39	24	1		0.52	33
Mbeya	NA	NA	NA	NA	NA	NA	NA	NA
Kia	-0.18		-0.22	-8	0.61		0.48	17
Morogoro	-0.93		-4.17	-22	1.46		6.19	32
Kitgum	1.21		1.19	17	0.86		1.22	17
Lira	-0.11		-0.19	-2	1.61		2.57	22
Gulu	0.43		0.78	5	0.64		1.51	10
Masindi	1.03		1.91	18	1.03		1.94	19
Soroti	0.07		0.24	3	1.53		2.75	30
Jinja	0		-0.03	0	1.57		3.68	29
Kabale	-0.14		-0.59	-2	1.5		7.45	30
Mbarara	0.39		0.61	5	1.53		4.35	33
Gabiro	-0.68		-0.81	-8	1.46		2.06	20
Kamembe	-1.14		-1.09	-23	0.75		1.1	23
Gisenyi	-0.79		-2.39	-12	1.21		5.53	27
Gikongoro	-0.43		-1.33	-8	1.07		4.5	28
Rwaza	-0.29		-0.44	-4	1.11		2.69	24
Save	-0.18		-0.23	-4	1.5		2.21	35
Ruhuha	0.11		0.05	1	1.25		1.34	27
Kigali	-0.29		-0.44	-4	1.11		2.69	24
Bujumbura	-0.71		-0.92	-9	0.71		1.69	17
Nyanza Lac	0.68		0.13	9	0.68		0.32	23
Gisozi	-0.71		-0.92	-9	0.71		1.69	17

Muyinga	-0.54		-0.6	-7	1.57		2.37	27
Musasa	-0.18		-1.04	-4	-0.18		-0.56	-3

In Kenya (Table 4.3), projected precipitation in RCP 4.5 (2016-2045) scenario showed increased trend in Kisii, Thika and Makindu and decreased trend in Kakamega, Eldoret, and Nakuru. These increasing/decreasing trends were all significant at α level greater than 0.1. The magnitude of the slope ranged from -3.83 to 0.27 and its corresponding percentage change ranged from -20 to 6 per cent. On the contrary, precipitation in RCP 8.5 (2016-2045) scenario showed increasing trend in all stations and significant at α level greater than 0.1. The corresponding magnitude of the slope ranged from 0.69 to 4.18 while percentage change in the trend was noted to be between 0 to 40 per cent.

In Tanzania (Table 4.3), precipitation in RCP 4.5 (2016-2045) scenario showed increasing trend in all selected stations except Kigoma. These trends were significant at α level less than 0.1 except Kigoma and KIA. The magnitude of the slope ranged from 0.12 to 6.23 while the corresponding percentage change ranged from -7 to 43 per cent. Comparison to RCP 4.5 (2016-2045) scenario showed increasing trend in Kigoma and Morogoro and all significant at α level less than 0.1 except KIA, Morogoro and Kigoma. The magnitude of the slope ranged from -0.26 to 3.24 with corresponding percentage change of between -15 to 71 per cent.

In Uganda (Table 4.3), all stations indicated a decreasing trend for RCP 4.5 (2016-2045) scenario in all stations except Mbarara. However, the decreasing/increasing trends were significant at α level greater than 0.1. The magnitude of these slopes ranged between -3.19 to 0.6 and corresponding percentage change ranging from -22 to 5 per cent. On the contrary, the trends of precipitation for RCP 8.5 (2016 -2045) were all increasing except Masindi and Kabale. However, these trends were noted to be significant at α level greater than 0.1, except Kitgum. The magnitude of these slopes ranged between -1.67 to 3.29 and corresponding percentage change ranging from -7 to 47 per cent.

In Rwanda (Table 4.3), all stations showed decreasing trend in precipitation for RCP 4.5 (2016-2045) scenario except Gabiro and Ruhuha. However, only Kamambe showed significant trend at α level less than 0.1 with their magnitudes ranging from -4,05 to 0.52. Their corresponding percentage change ranged from -36 to 5 per cent. On the contrary, the trend of precipitation for RCP 4.5 (2016 -2045) were noted to increase in selected stations except Gisenyi, Save and Ruhuha. However, they were all significant at α level greater than 0.1 with corresponding magnitude of the slope ranging from -0.64 to 1.29 while percentage change ranged from -7 to 27 per cent.

In Burundi (Table 4.3), the RCP 4.5 (2016-2045) scenario indicated that all stations had decreasing trend in projected precipitation except Muyinga. The trend of these increase/decrease were all significant at α level greater than 0.1 except Musasa. The magnitude of the slope varied from -4.28 to 0.2 while percentage change in the trend varied from -26 to 2 per cent. Similarly, for RCP 8.5 (2016-

2045) scenario, only Bujumbura and Gisozi indicated positive trend. Notably, the trends in all stations were significant at α level greater than 0.1. The magnitude of the slope ranged from -3.47 to 0.15 while percentage change in trend varied from -14 to 1 per cent.

In Kenya (Table 4.4), for RCP 4.5 (2071-2100) scenario, all stations showed decreasing trend except Kakamega, Eldoret and Nakuru. Only Makindu station indicated significant trend at α level less than 0.1. The magnitude of the slope varied from -2.24 (Makindu) to 2.56 (Nakuru). The percentage change ranged from -52 to 17 per cent. For RCP 8.5 (2071-2100) scenario, trend in precipitation increased except Meru. However, they were noted to be significant at α level greater than 0.1. The magnitude of these slopes ranged from -0.14 to 2.13 while the corresponding percentage change varied from -3 to 21 per cent.

In Tanzania (Table 4.4), for RCP 4.5 (2071 -2100) scenario, increasing trend of precipitation were noted only in Arusha and Kigoma. However, both increasing/ decreasing trends were significant at α level greater than 0.1. The magnitudes of the slope ranged from -4.17 to 0.39 with corresponding percentage change varying from -22 to 24 per cent. During RCP 8.5 (2071-2100) scenario, the trend in all stations were increasing with only Dodoma and Arusha being significant at α level less than 0.1. Similarly, the magnitude of the slope ranged from 0.48 to 6.19 while computed percentage change varied from 17 to 51 per cent.

In Uganda (Table 4.4), for RCP 4.5 (2071 -2100) scenario, all stations indicated increasing trend except Lira and Kabale. However, the trend in all stations were significant at α level greater than 0.1. The magnitude of the slope ranged from -0.59 to 1.91 while percentage change varied from -2 to 18 per cent. For RCP 8.5 (2071-2100) scenario, all stations indicated increasing trend and significant at α level greater than 0.1. The magnitude of the slope ranged from 1.22 to 7.45 while the percentage change varied from 10 to 33 per cent.

In Rwanda (Table 4.4), for RCP 4.5 (2071-2100), the trend in precipitation were all decreasing except in Ruhuha. Notably, these trends were all significant at α level greater than 0.1. The magnitude of the trend ranged from -2.39 to 1 per cent. For RCP 8.5 (2071-2100) scenario, the trend in all stations increased and was significant at α level greater than 0.1. The magnitude of the slope ranged 1.1 to 5.53 with its computed percentage change varying from -20 to 35 per cent.

In Burundi (Table 4.4), for RCP 4.5 (2071-2100) scenario, all stations indicated decreasing trend in precipitation except Nyanza Lac. However, these trends were significant at α level greater than 0.1. The magnitude of the slope ranged from -1.04 to 0.13 with computed percentage change in the trend ranging from -9 to 9 per cent. For RCP 8.5 (2071-2100), trend in all stations showed increasing trend except Musasa. These trends were significant at α level greater than 0.1. The magnitude ranged from 0.56 to 2.37 with percentage change ranging from -3 to 23 per cent.

Spatial Analysis of Projected Precipitation

Projected climate change using rainfall was based on RCP 4.5 and RCP 8.5 scenarios. The results of the ensemble models are presented in Figure 4.22 to Figure 4.25

Spatial analysis of projected rainfall based on RCP 4.5 scenario for mid-century (2016-2045) showed that during DJF (Figure 4.22a), high amounts of about 1,000mm are expected in the south of EAC while the north is expected to have a depressed annual rainfall of up to 100mm. During MAM season (Figure 4.22b), most areas are expected to receive high precipitation. The JJA season (Figure 4.22c) indicate limited amount of precipitation expected in the region except Uganda and western parts of Kenya. During OND (Figure 4.22d), only northern Kenya around Lake Turkana are expected to receive depressed rainfall. Figure 4.22(e) indicates that annual totals precipitation received will be high in most parts of EAC of above 2,000mm, with the north and eastern Kenya being the only areas expected to receive less than 400mm of rainfall per year. Similar patterns

Figure 4.22: Spatial analysis of rainfall during a) DJF b) MAM c) JJA d) OND seasons and e) annual precipitation based on RCP 4.5 scenario (2016-2045)

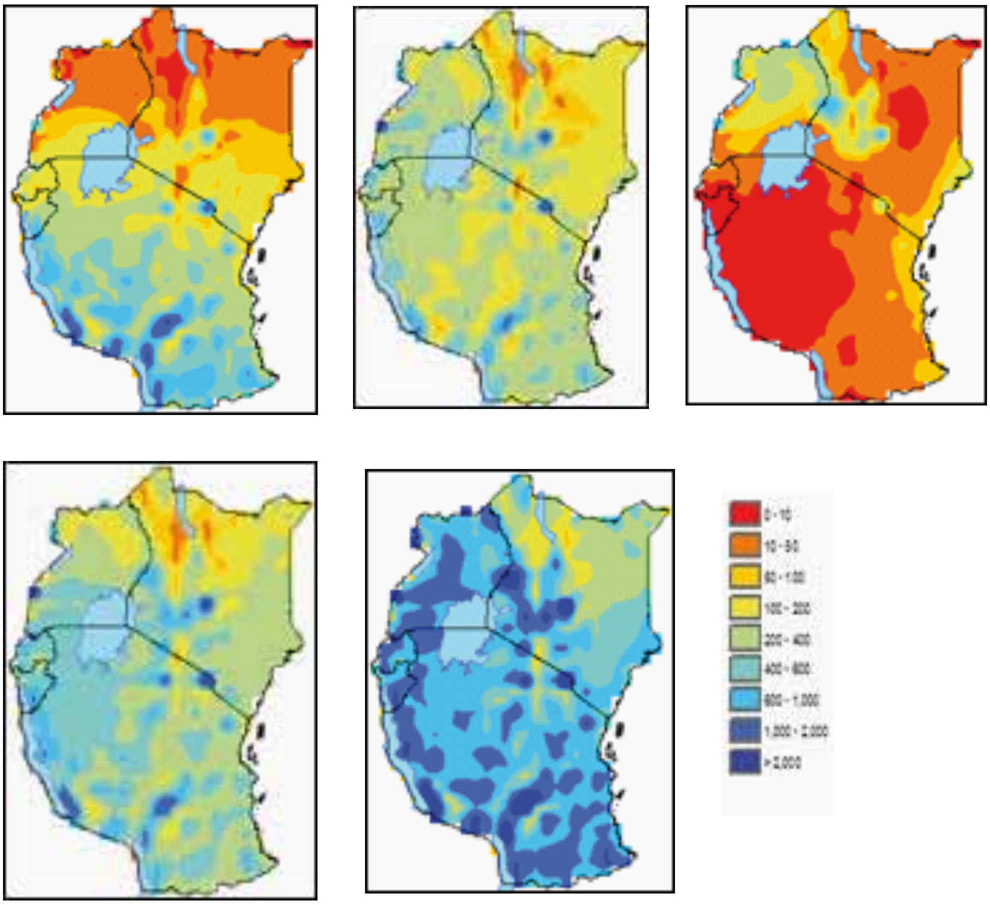


Figure 4.23: Spatial analysis of rainfall during a) DJF b) MAM c) JJA d) OND seasons and e) annual precipitation based on RCP 4.5 scenario (2071 -2100)

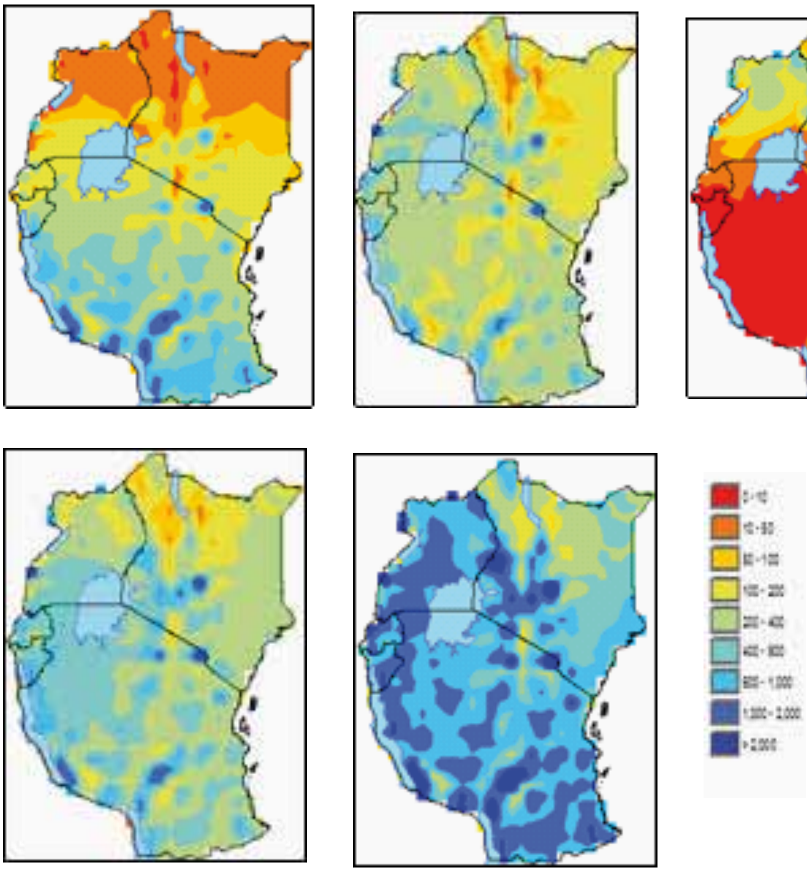
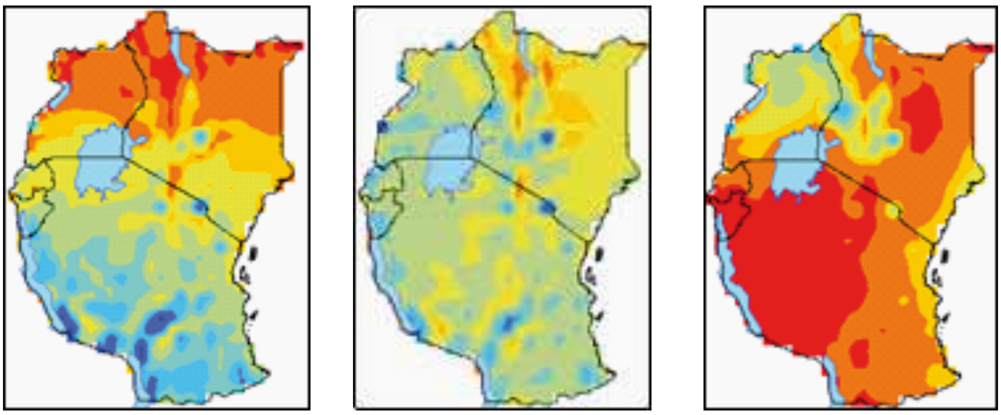


Figure 4.24: Spatial analysis of rainfall during a) DJF b) MAM c) JJA d) OND seasons and e) annual precipitation based on RCP 8.5 scenario (2016 -2045)



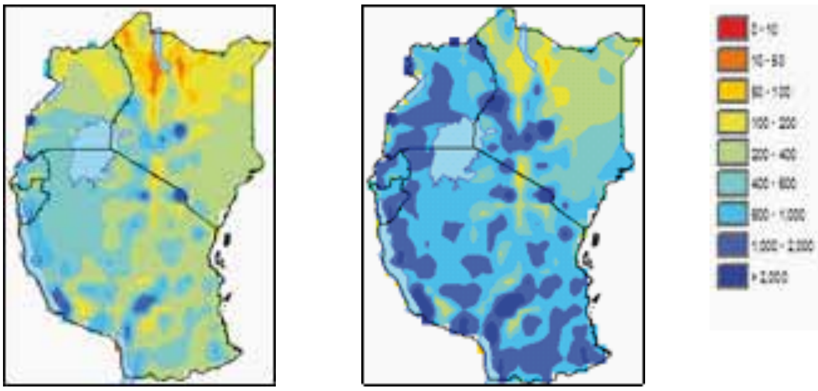
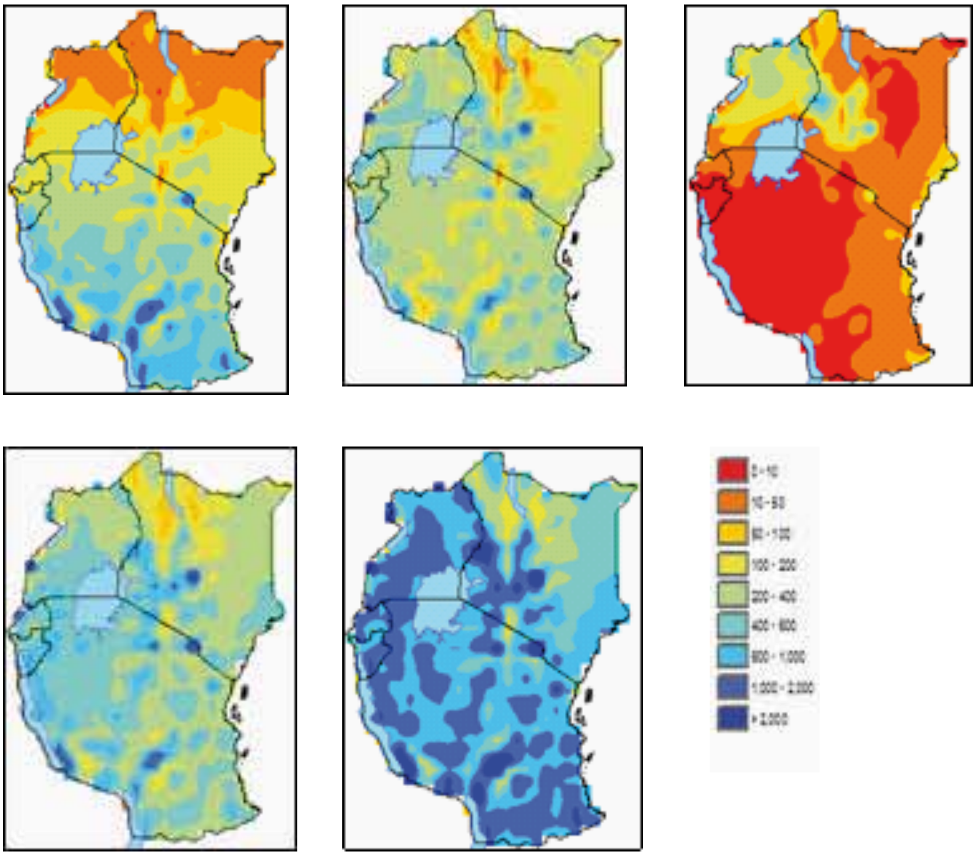


Figure 4.25: Spatial analysis of rainfall during a) DJF b) MAM c) JJA d) OND seasons and e) annual precipitation based on RCP 8.5 scenario (2071 -2100)



are expected for the end century in all seasons, which include DJF (Figure 4.23 a), MAM (Figure 4.23b), JJA (Figure 4.23c) and OND (Figure 4.23d) and annual total rainfall (Figure 4.23e). Notably, the magnitude of expected precipitation was observed to decrease at the end of the century (2071-2100) compared to mid-century (2016-2045).

For RCP 8.5 scenario, the mid-century period showed that DJF precipitation (Figure 4.24a) were concentrated in the south of EAC with northern areas expecting less precipitation of up to 10mm. During MAM (Figure 4.24b), the western parts of EAC were observed to receive more rainfall compared to eastern parts of EAC. Moreover, most parts of WAC are expected to receive depressed rainfall during JJA (Figure 4.24c) except western Kenya and Northern Uganda. During OND (Figure 4.24d), most of the southern parts of EAC are expected to receive more rainfall compared to the north. Overall, annual precipitation are expected to be high in excess of 2,000mm in Tanzania, Uganda, Rwanda, Burundi and western Kenya. Similar precipitation patterns are expected at the end of the century for all seasons including DJF (Figure 4.25a), MAM (Figure 4.25b), JJA (Figure 4.25c) and OND (Figure 4.25d) and annual total rainfall (Figure 4.25e). Both RCP 4.5 and RCP 8.5 scenarios indicate presence of enhanced extreme events during both mid and end century.

Temporal Analysis of Projected Maximum Temperature

The results of time series analysis to detect trend is presented in Table 4.5 and Table 4.6.

Analysis of mid-century maximum temperature for both RCP 4.5 and RCP 8.5 scenario (Table 4.5) indicated an increasing trend in temperature in all selected stations in EAC. These trends were all noted to be significant at α level equal to 0.001. Notably, the magnitudes of slopes were found to be 0.03 for both RCP 4.5 and RCP 8.5 scenario. For RCP 4.5 scenario, the percentage change in maximum temperature ranged from 9-13 per cent, 6-10 per cent, 9-13 per cent, 12-15 per cent and 9-13 per cent in Kenya, Tanzania, Uganda, Rwanda and Burundi. Similarly, for RCP 8.5 scenario, the percentage change in maximum temperature ranged from 9-15 per cent, 11-12 per cent, 9-15 per cent, 14-16 per cent and 11-14 per cent in Kenya, Tanzania, Uganda, Rwanda and Burundi.

Analysis of end century maximum temperature for both RCP 4.5 and RCP 8.5 scenario (Table 4.6) indicated an increasing trend in temperature in all selected stations in EAC. For RCP 4.5 scenario, this increasing trend was significant at α level greater or less than 0.1. However, for RCP 8.5 scenario, the increasing trend in maximum temperature were all significant at α level equal to 0.001. For RCP 4.5 scenario, the magnitude of slope was found to be 0.01 while the magnitude of slope was for RCP 8.5 scenario was found to vary between 0.05 and 0.06. The percentage change in maximum temperature were all below 5 per cent for RCP 4.5 scenario. For RCP 8.5, the percentage change varied from 16-25 per cent, 15-17 per cent, 15-21 per cent, 18-22 per cent and 17-20 per cent in Kenya, Tanzania, Uganda, Rwanda and Burundi.

Table 4.5: Time series analysis of mid-century (2016-2045) maximum temperature in EAC

	RCP 4.5 Mid Century (2016-2045)				RCP 8.5 Mid Century (2016-2045)			
	Mann Kendall	Sig	Sen slope	% Δ	Mann Kendall	Sig	Sen slope	% Δ
Kakamega	4.39	***	0.03	10	5.14	***	0.03	10
Kisii	4.42	***	0.03	11	5.28	***	0.03	12
Eldoret	5.00	***	0.03	13	5.39	***	0.03	14
Thika	4.03	***	0.03	10	4.92	***	0.03	11
Nakuru	5.03	***	0.03	14	5.35	***	0.03	15
Makindu	4.78	***	0.03	9	5.00	***	0.03	9
Meru	5.00	***	0.03	12	5.50	***	0.03	11
DAR	NA	NA	NA	NA	NA	NA	NA	NA
Dodoma	4.28	***	0.02	8	4.75	***	0.03	11
Arusha	4.10	***	0.02	8	5.32	***	0.03	11
Kigoma	5.10	***	0.03	10	4.89	***	0.03	11
Mbeya	NA	NA	NA	NA	NA	NA	NA	NA
Kia	4.35	***	0.03	9	5.21	***	0.03	12
Morogoro	3.39	***	0.02	6	5.07	***	0.04	12
Kitgum	4.50	***	0.03	9	4.10	***	0.03	10
Lira	4.28	***	0.03	9	4.03	***	0.03	9
Gulu	4.50	***	0.03	10	4.35	***	0.03	9
Masindi	4.96	***	0.03	10	4.53	***	0.03	10
Soroti	4.32	***	0.03	10	4.21	***	0.03	10
Jinja	4.85	***	0.03	10	5.42	***	0.03	11
Kabale	5.00	***	0.03	13	5.10	***	0.04	15
Masaka	NA	NA	NA	NA	NA	NA	NA	NA
Mbarara	5.10	***	0.03	10	4.89	***	0.03	12
Kasese	NA	NA	NA	NA	NA	NA	NA	NA
Gabiro	4.60	***	0.03	12	5.28	***	0.04	14
Kamembe	4.67	***	0.03	13	4.89	***	0.04	14
Gisenyi	4.82	***	0.03	15	4.82	***	0.04	16
Gikongoro	4.67	***	0.03	13	4.82	***	0.04	14
Rwaza	4.92	***	0.03	13	5.03	***	0.04	14
Save	4.71	***	0.04	12	5.14	***	0.04	14
Ruhuha	4.64	***	0.04	12	5.17	***	0.04	14
Kigali	4.92	***	0.03	13	5.03	***	0.04	14
Bujumbura	4.71	***	0.03	13	5	***	0.04	14
Nyanza Lac	5.00	***	0.03	9	4.96	***	0.03	11
Gisozi	4.71	***	0.03	13	5.00	***	0.04	14
Muyinga	4.46	***	0.03	12	5.39	***	0.04	13
Musasa	4.57	***	0.03	12	5.03	***	0.04	14

Table 4.6: Time series analysis of end century (2071-2100) maximum temperature in EAC

	RCP 4.5 End Century (2071-2100)				RCP 8.5 End Century (2071-2100)			
Time series	**Mann Kendall**	**Sig**	**Sen slope**	**% Δ**	**Mann Kendall**	**Sig**	**Sen.slope**	**% Δ**
Kakamega	1.43		0.01	2	5.67	***	0.06	16
Kisii	1.86	+	0.01	3	5.99	***	0.06	20
Eldoret	1.86	+	0.01	3	6.1	***	0.06	22
Thika	1.61		0.01	3	6.03	***	0.05	19
Nakuru	1.96	*	0.01	3	6.39	***	0.06	25
Makindu	2.28	*	0.01	5	5.78	***	0.05	16
Meru	1.32		0.01	2	6.57	***	0.06	20
DAR	NA	NA	NA	NA	NA	NA	NA	NA
Dodoma	1.64		0.01	3	5.78	***	0.05	17
Arusha	2.07	*	0.01	4	5.96	***	0.05	16
Kigoma	2.25	*	0.01	3	6.21	***	0.06	17
Mbeya	NA	NA	NA	NA	NA	NA	NA	NA
Kia	1.86	+	0.01	4	6.03	***	0.05	16
Morogoro	1.32		0.01	3	5.53	***	0.05	15
Kitgum	1.21		0.01	3	5.82	***	0.06	17
Lira	1.18		0.01	3	5.64	***	0.05	16
Gulu	1.36		0.01	3	5.85	***	0.06	16
Masindi	1.43		0.01	2	5.82	***	0.05	16
Soroti	1.21		0.01	2	5.78	***	0.05	15
Jinja	2.25	*	0.01	3	5.82	***	0.05	16
Kabale	2.25	*	0.01	4	5.96	***	0.06	21
Masaka	NA	NA	NA	NA	NA	NA	NA	NA
Mbarara	1.82	+	0.01	2	5.46	***	0.06	18
Kasese	NA	NA	NA	NA	NA	NA	NA	NA
Gabiro	2.11	*	0.01	4	5.60	***	0.06	18
Kamembe	2.03	*	0.01	4	5.96	***	0.06	19
Gisenyi	2.32	*	0.01	4	5.96	***	0.06	22
Gikongoro	2.39	*	0.01	5	5.96	***	0.06	21
Rwaza	2.14	*	0.01	5	5.67	***	0.06	20
Save	2.18	*	0.01	4	5.67	***	0.05	18
Ruhuha	2.43	*	0.01	4	5.82	***	0.05	18
Kigali	2.14	*	0.01	5	5.67	***	0.06	20
Bujumbura	2.43	*	0.01	4	5.85	***	0.06	20
Nyanza Lac	2.5	*	0.01	3	6.10	***	0.05	17
Gisozi	2.43	*	0.01	4	5.85	***	0.06	20
Muyinga	2.32	*	0.01	4	5.57	***	0.05	18
Musasa	2.14	*	0.01	3	5.96	***	0.06	19

Spatial analysis of projected maximum temperature

Projected climate change using maximum temperature was based on RCP 4.5 and RCP 8.5 scenarios. The results of the ensemble models are presented in Figure 4.26 to Figure 4.29.

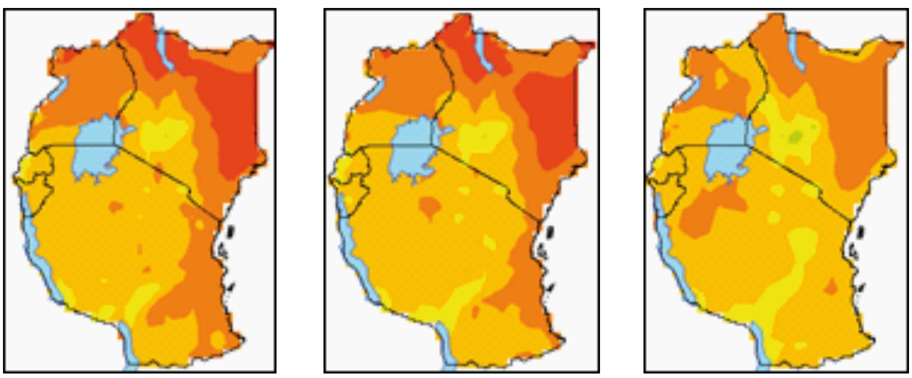
Spatial analysis of projected maximum temperature for RCP 4.5 scenario for mid century (Figure 4.26) indicated higher temperatures in north and eastern Kenya, northern Uganda and along the coast of Kenya and Tanzania while western Kenya, eastern Tanzania, Rwanda and Burundi were observed to have lower temperatures. Lowest temperatures in both seasonal and annual means were recorded in central Kenya. Similar patterns were observed for RCP 8.5 scenario (Figure 4.27). The magnitude of maximum temperature had increased from RCP 4.5 to RCP 8.5 scenario.

Spatial analysis of projected maximum temperature for RCP 8.5 scenario for mid century (Figure 4.28) indicated higher temperatures in most parts of EAC, including Uganda, north, east and coast of Kenya and coast of Tanzania. However, for RCP 8.5 scenario for end century (Figure 4.29), most areas are expected to experience higher temperatures of above 30°C, with northern Uganda, north and eastern Kenya showing maximum temperatures greater than 35°C.

Temporal analysis of projected minimum temperature

Detecting and estimating trends in time series was based on the non-parametric Mann-Kendall test (detection of a monotonic trend of a time series with no seasonal or other cycle) for the trend and the non-parametric Sen's method for the magnitude of the trend. The results of time series are presented in Table 4.7 and Table 4.8

Figure 4.26: Spatial analysis of maximum temperature during a) DJF b) MAM c) JJA d) OND seasons and e) annual based on RCP 4.5 scenario (2016 -2044)



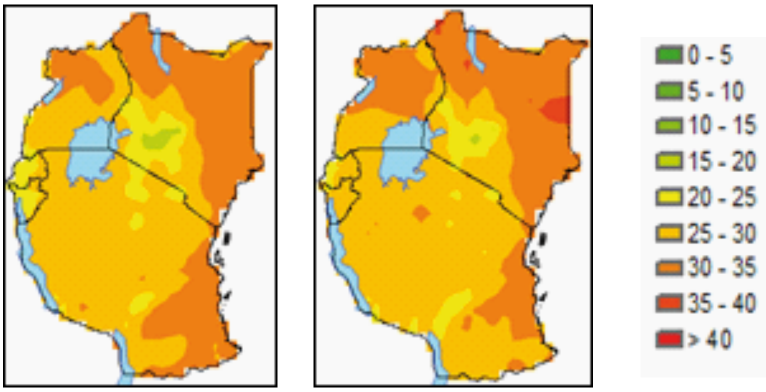


Figure 4.27: Spatial analysis of maximum temperature during a) DJF b) MAM c) JJA d) OND seasons and e) annual based on RCP 4.5 scenario (2071 -2100)

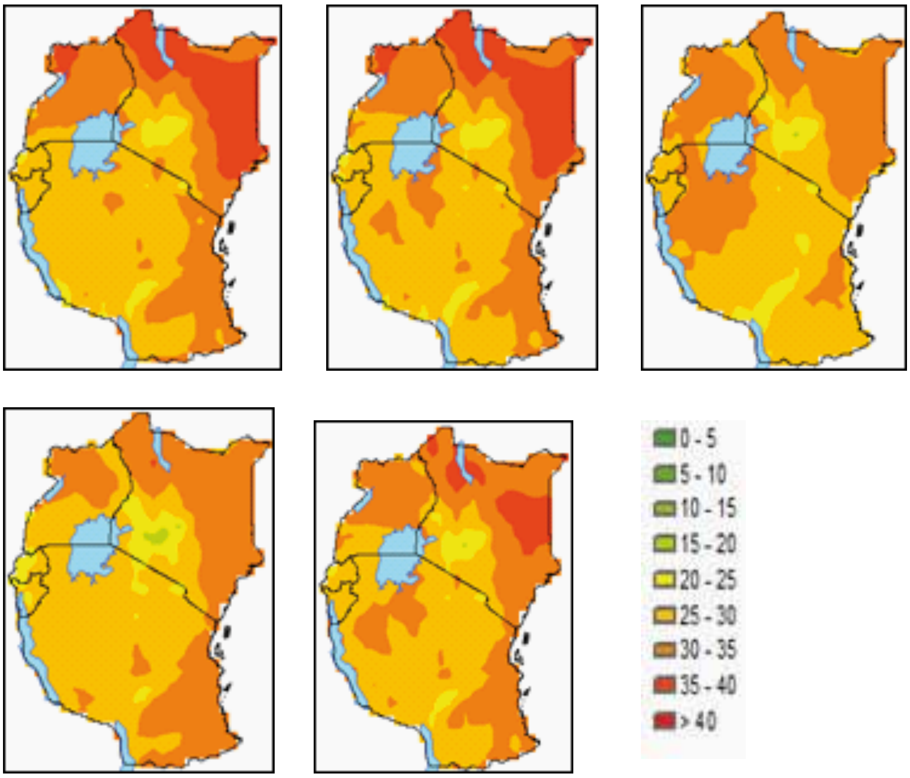


Figure 4.28: Spatial analysis of maximum temperature during a) DJF b) MAM c) JJA d) OND seasons and e) annual based on RCP 8.5 scenario (2016 -2045)

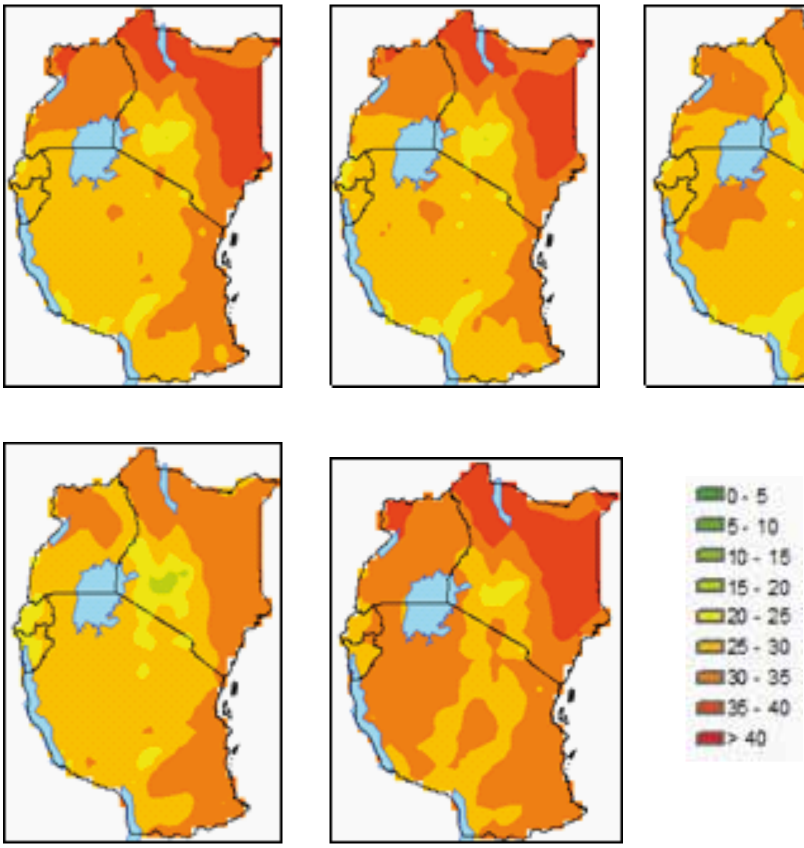
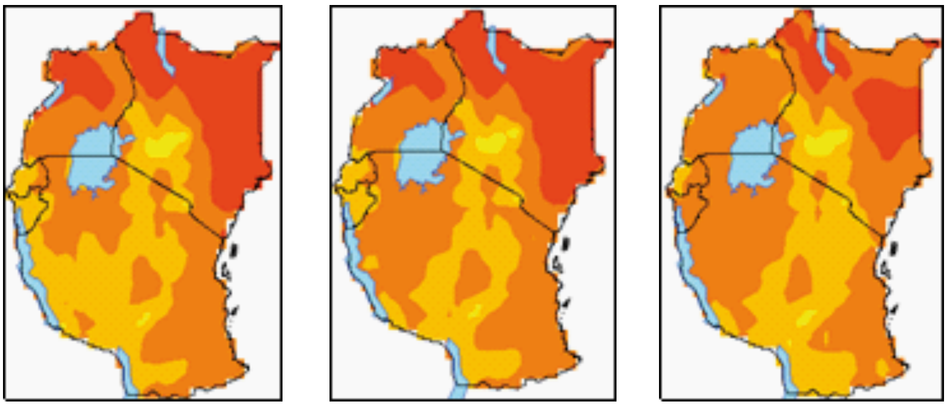
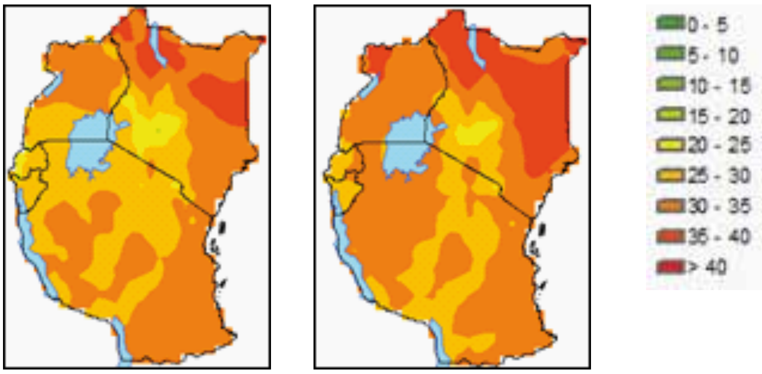


Figure 4.29: Spatial analysis of maximum temperature during a) DJF b) MAM c) JJA d) OND seasons and e) annual based on RCP 8.5 scenario (2071 -2100)





Times series of mid-century projected minimum temperature under both RCP 4.5 and RCP 8.5 scenarios (Table 4.7) showed that the trend in all selected stations were increasing. Notably, these trends were all significant at α level equal to 0.001. For RCP 4.5 scenario, the magnitude of the slope was found to vary between 0.03 and 0.04, with corresponding percentage change varying from 14-26 per cent. For RCP 8.5, the magnitude of the slope was found to vary between 0.03 and 0.05 with corresponding percentage change varying from 16-35 per cent.

Times series of end century projected minimum temperature under both RCP 4.5 and RCP 8.5 scenarios (Table 4.7) showed that the trend in all selected stations were increasing. Worth noting, these trends were found to be significant at α level greater or less than 0.1. However, for RCP 8.5, these trends were all significant at α level equal to 0.001. The corresponding slope was found to vary from 0-0.01 and 0.06-0.07 for RCP 4.5 and RCP 8.5 scenarios, respectively. Consequently, the percentage varied from 0-7 per cent and 28-43 per cent for RCP 4.5 and RCP 8.5 scenarios, respectively

Table 4.7: Time series analysis of mid-century (2016-2045) projected minimum temperature

Station	RCP 4.5 Scenario				RCP 8.5 Scenario			
	Mann Kendall	Sig	Sen slope	% Δ	Mann Kendall	Sig	Sen slope	% Δ
Kakamega	5.28	***	0.03	17	5.78	***	0.04	22
Kisii	5.21	***	0.03	17	6.17	***	0.04	23
Eldoret	5.85	***	0.03	19	5.99	***	0.03	25
Thika	5.64	***	0.03	19	6.07	***	0.04	21
Nakuru	5.96	***	0.03	26	5.89	***	0.04	29
Makindu	5.78	***	0.03	18	5.64	***	0.04	22
Meru	6.03	***	0.03	21	5.92	***	0.04	25
Dar	NA	NA	NA	NA	NA	NA	NA	NA
Dodoma	5.10	***	0.03	16	5.46	***	0.04	20
Arusha	5.32	***	0.03	19	5.74	***	0.04	24
Kigoma	5.71	***	0.03	18	5.96	***	0.04	20

Mbeya	NA	NA	NA	NA	NA	NA	NA	NA
Kia	5.53	***	0.03	19	5.96	***	0.04	25
Morogoro	5.10	***	0.03	14	5.89	***	0.03	17
Kitgum	5.14	***	0.03	16	4.89	***	0.03	17
Lira	4.92	***	0.03	17	4.46	***	0.03	16
Gulu	4.92	***	0.03	14	4.71	***	0.03	17
Masindi	4.89	***	0.03	18	5.32	***	0.04	20
Soroti	4.89	***	0.03	15	5.1	***	0.03	17
Jinja	4.92	***	0.03	18	5.35	***	0.04	23
Kabale	4.89	***	0.03	23	5.5	***	0.05	34
Masaka	NA	NA	NA	NA	NA	NA	NA	NA
Mbarara	5.46	***	0.04	24	5.92	***	0.05	31
Kasese	NA	NA	NA	NA	NA	NA	NA	NA
Gabiro	5.42	***	0.04	24	5.82	***	0.05	30
Kamembe	4.71	***	0.03	22	5.71	***	0.05	30
Gisenyi	4.21	***	0.03	19	5.53	***	0.05	33
Gikongoro	4.50	***	0.03	21	5.6	***	0.05	34
Rwaza	5.25	***	0.03	24	5.6	***	0.05	35
Save	5.17	***	0.03	22	6.1	***	0.05	33
Ruhuha	5.35	***	0.03	23	6.1	***	0.05	33
Kigali	5.25	***	0.03	24	5.6	***	0.05	35
Bujumbura	4.75	***	0.03	21	5.89	***	0.04	30
Nyanza Lac	5.67	***	0.03	17	6.07	***	0.04	23
Gisozi	4.75	***	0.03	21	5.89	***	0.04	30
Muyinga	4.96	***	0.03	22	6.24	***	0.05	29
Musasa	4.75	***	0.03	20	5.78	***	0.04	24

Table 4.8: Time series analysis of mid century (2071-2100) projected minimum temperature

Station	RCP 4.5 Scenario				RCP 8.5 Scenario			
	Mann Kendall	Sig	Sen slope	% Δ	Mann Kendall	Sig	Sen slope	% Δ
Kakamega	1.28		0.01	3	6.35	***	0.06	30
Kisii	1.78	+	0.01	5	6.35	***	0.06	33
Eldoret	1.50		0.00	0	6.17	***	0.06	36
Thika	1.53		0.00	3	6.42	***	0.06	32
Nakuru	1.71	+	0.01	4	6.42	***	0.06	43
Makindu	1.82	+	0.01	3	6.39	***	0.06	29
Meru	1.64		0.01	4	6.6	***	0.07	35
Dar	NA	NA	NA	NA	NA	NA	NA	NA
Dodoma	1.61		0.01	4	6.42	***	0.06	28
Arusha	1.82	+	0.01	3	6.46	***	0.06	30
Kigoma	2.28	*	0.01	4	6.49	***	0.07	28
Mbeya	NA	NA	NA	NA	NA	NA	NA	NA

Kia	1.86	+	0.01	3	6.60	***	0.06	30
Morogoro	1.32		0.01	2	6.78	***	0.06	26
Kitgum	1.61		0.01	4	6.14	***	0.07	31
Lira	1.36		0.01	3	6.03	***	0.07	30
Gulu	1.75	+	0.01	5	6.35	***	0.07	31
Masindi	1.21		0.01	4	6.35	***	0.07	32
Soroti	1.14		0.01	4	6.03	***	0.07	29
Jinja	0.54		0.00	0	6.28	***	0.07	33
Kabale	1.50		0.01	4	6.32	***	0.07	39
Masaka	NA	NA	NA	NA	NA	NA	NA	NA
Mbarara	1.75	+	0.01	3	6.53	***	0.07	39
Kasese	NA	NA	NA	NA	NA	NA	NA	NA
Gabiro	2.07	*	0.01	5	6.39	***	0.07	37
Kamembe	1.93	+	0.01	7	6.35	***	0.07	38
Gisenyi	1.11		0.01	4	6.35	***	0.06	37
Gikongoro	1.82	+	0.01	7	6.42	***	0.07	39
Rwaza	2.00	*	0.01	5	6.39	***	0.07	39
Save	1.68	+	0.01	3	6.57	***	0.07	37
Ruhuha	1.82	+	0.01	6	6.64	***	0.07	38
Kigali	2.00	*	0.01	5	6.39	***	0.07	39
Bujumbura	1.89	+	0.01	6	6.35	***	0.06	36
Nyanza Lac	2.53	*	0.01	5	6.46	***	0.07	31
Gisozi	1.89	+	0.01	6	6.35	***	0.06	36
Muyinga	1.43		0.01	4	6.46	***	0.06	34
Musasa	1.75	+	0.01	5	6.21	***	0.06	29

Spatial analysis of projected minimum temperature

Projected climate change using minimum temperature was based on RCP 4.5 and RCP 8.5 scenarios. The results of the ensemble models are presented in Figure 4.30 to Figure 4.33.

Projected minimum temperature have been noted to remain slightly variable under all scenarios. However, projected minimum temperatures were noted to be higher towards 2100 for RCP 8.5

Figure 4.30: Spatial analysis of minimum temperature during a) DJF b) MAM c) JJA d) OND seasons and e) annual based on RCP 4.5 scenario (2016 -2045)

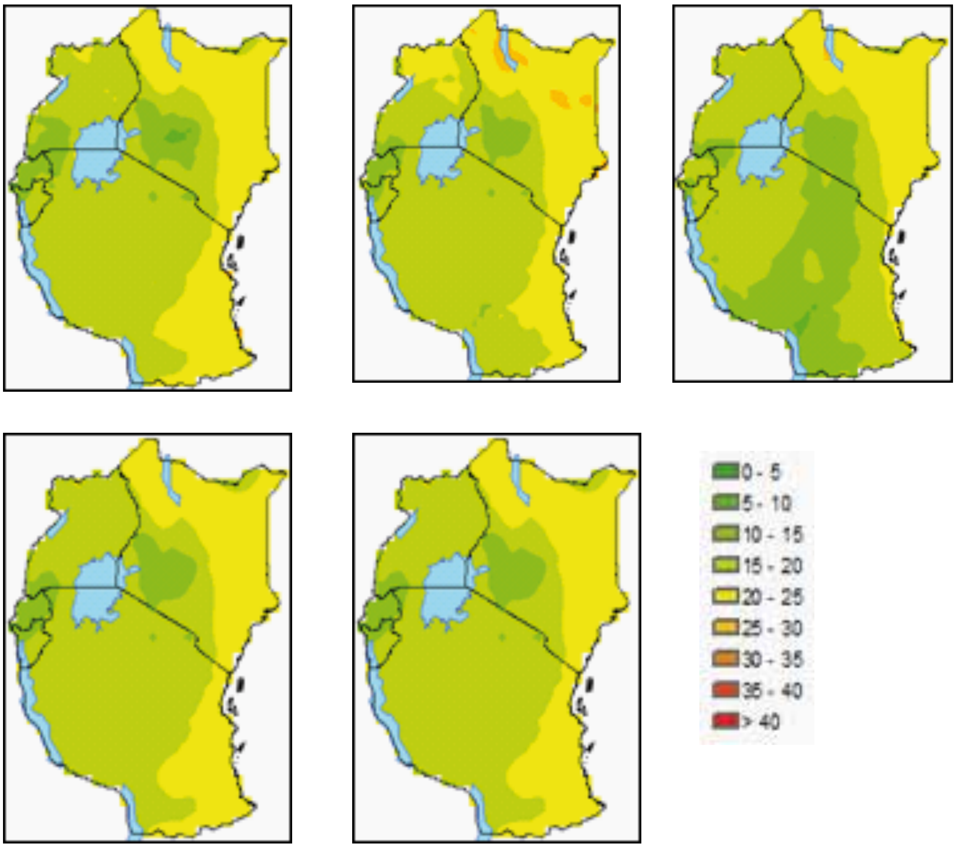


Figure 4.31: Spatial analysis of minimum temperature during a) DJF b) MAM c) JJA d) OND seasons and e) annual based on RCP 4.5 scenario (2071 -2100)

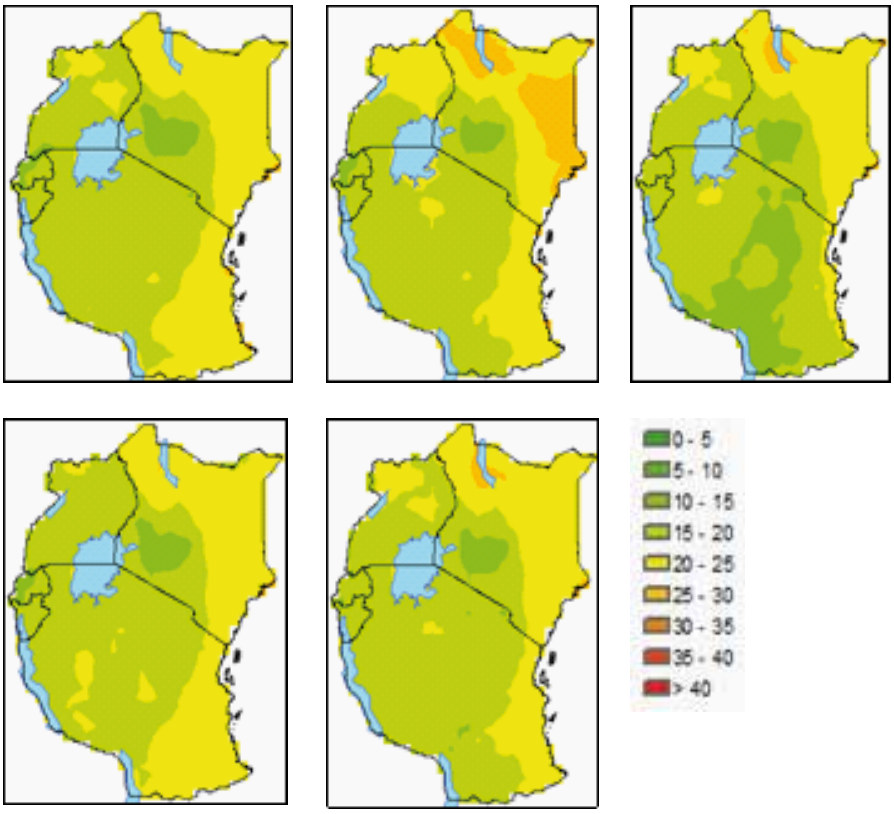
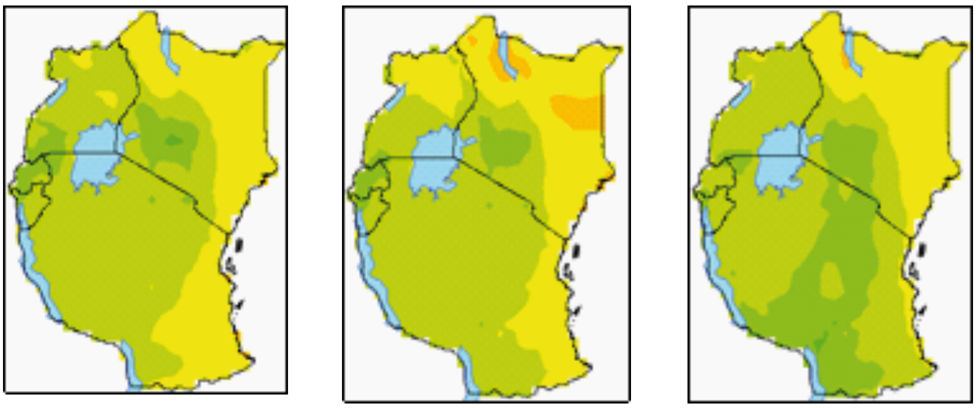


Figure 4.32: Spatial analysis of minimum temperature during a) DJF b) MAM c) JJA d) OND seasons and e) annual based on RCP 8.5 scenario (2016 -2045)



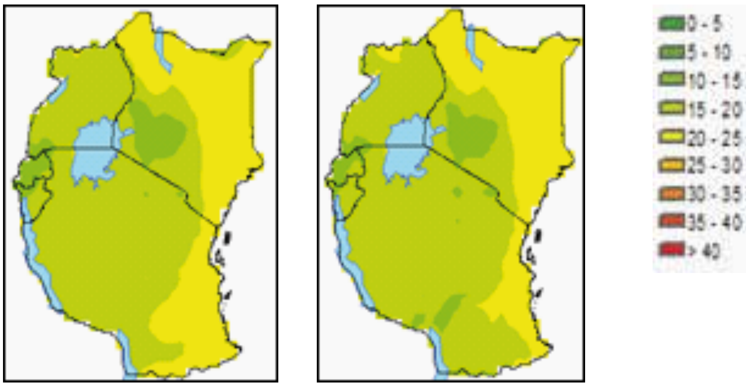
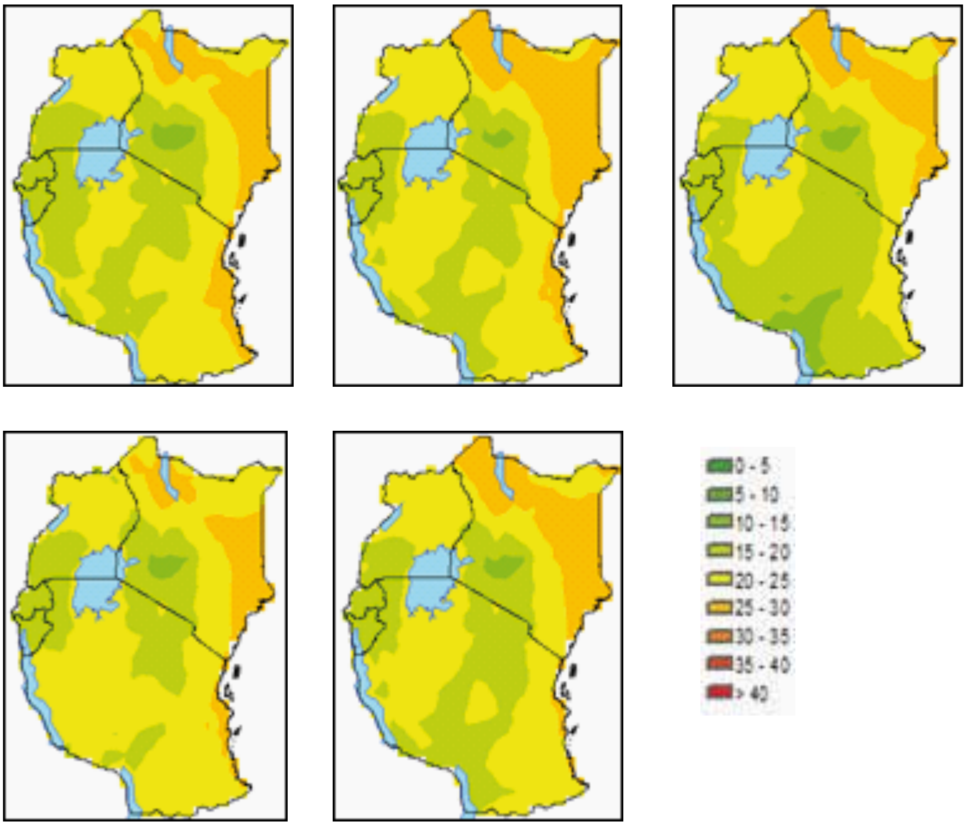


Figure 4.33: Spatial analysis of minimum temperature during a) DJF b) MAM c) JJA d) OND seasons and e) annual based on RCP 4.5 scenario (2071 -2100)



5. Conclusion

Over EAC, most of the models are inconsistent in representing spatial precipitation distribution. However, the study notes that ensemble precipitation from CORDEX well represented the rainfall climatology over EAC. Temperature fields are well represented by all the CORDEX models and the ensemble. The study notes that multimodel ensemble mean outperforms the results of individual models in most of the areas and time periods as assessed for both precipitation and temperature fields. This is likely because of the cancellation of opposite signed biases across the models. At the level of individual models, it is of concern that many models produce good results in one region and poor results in another over the same time period. This would suggest that some models may be getting correct results in particular regions for the wrong reasons. Despite this, it has been demonstrated that the multimodel ensemble mean simulates eastern Africa rainfall adequately and can therefore be used for the assessment of future climate projections for the region.

Precipitation was noted to remain highly variable both in space and time. Worth noting, the temporal pattern of rainfall over EAC has a strong inter-annual rainfall variability associated with extreme events such as floods and droughts. The influence of global SST on eastern Africa rainfall depends on the season and the region. Generally, during JJAS *El Nino* conditions produce deficit rainfall and *La Nina* conditions produce excess rainfall over the northern parts of East Africa, whereas during OND the equatorial and southern parts of East Africa get below average rainfall during *La Nina* and above average during *El Nino*.

Small precipitation gains will largely be offset by high temperatures due to increasing atmospheric demand resulting into unproductive high soil evaporation rather than the productive transpiration and shortening of growing period. CORDEX model-based predictions of future greenhouse gas-induced climate change for the continent clearly suggest that this warming will continue and, in most scenarios as noted in both RCP 4.5 and RCP 8.5 scenarios.

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