FUTURE CLIMATE FOR AFRICA

COUNTRY CLIMATE BRIEF

October 2017

Future climate projections for Tanzania

Introduction

This brief provides an overview of future climate change in Tanzania, using results from the latest available climate model simulations. The UMFULA research team of the Future Climate for Africa (FCFA) programme has analysed 34 Global Climate Models (GCMs) that provide projections for Tanzania to try to distil robust messages and some key trends that may help planning and decision-making.

We first present a summary of recent observed rainfall and temperature variability. This is followed by an overview of the range of climate projections available from the leading source of climate model results. A detailed annex[1] describes the methods and datasets used in the brief and presents a wider range of figures for further reference. A two-page summary[2] also highlights key findings.

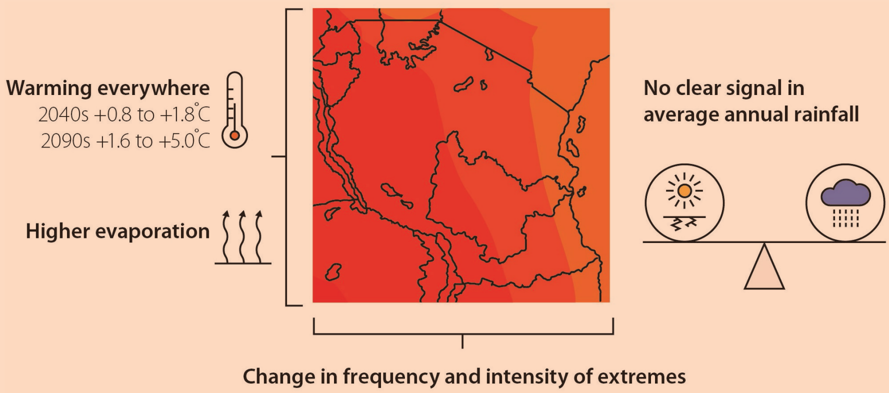
Key messages

Recent trends

- Rainfall in Tanzania is highly variable, with large differences in amounts and seasonality (the timing of wet seasons and dry seasons) from year to year.
- Between 1981 and 2016 there are marked areas of drying in parts of northeast and much of southern Tanzania. In contrast, moderate wetting trends occurred in central Tanzania and stronger wetting trends in the northwest of the country.
- Since the early 2000s, the years 2003 and 2005 were notably dry and 2006 very wet.
- A clear warming trend is apparent in annual temperature.

Future projections

Figure 1: Summary of climate changes in Tanzania
Map shows warming is evenly distributed across Tanzania, with a smaller increase along the coast



- Climate model projections of future rainfall averaged across Tanzania are mixed: out of 34 models roughly one third project lower rainfall and two thirds higher rainfall.
- The range of rainfall change across the 34 models is fairly modest, with 20 models projecting changes of less than +/-5% by the 2040s.

About FCFA

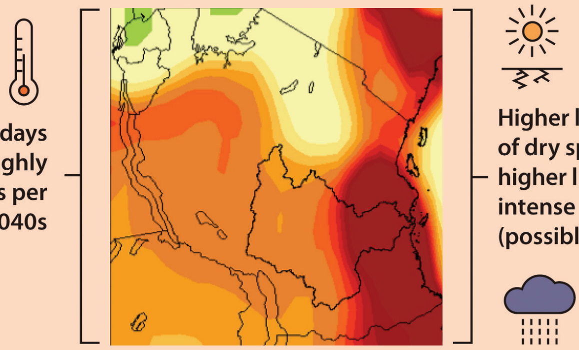
Future Climate for Africa (FCFA) aims to generate fundamentally new climate science focused on Africa, and to ensure that this science has an impact on human development across the continent.

www.futureclimateafrica.org

- Taking an average of 34 climate models, changes in annual rainfall across Tanzania show increases in the north/northeast (around 3 to 4%) and decreases in the south (-1 to -2%) by the 2040s.
- The per cent changes in annual rainfall are very small, but they are larger in specific seasons.
- By the 2090s the changes have similar spatial patterns but are larger, with annual rainfall increasing in the north by more than 9% and decreasing in the south by less than 9%.
- In contrast to rainfall, there is strong agreement on continued future warming throughout Tanzania. Warming is in the range of 0.8 to 1.8°C by the 2040s, evenly distributed across Tanzania.
- By the 2090s projected warming is in the range of 1.6 to 5.0°C, also evenly distributed across the country (Figure 1).

Changes in extremes

Figure 2: Summary of changes in extremes across Tanzania
The map shows the pattern of increase in number of days above 30 °C (darker shading indicates greater increase).



- Changes in climate factors on daily timescales show increases in the mean number of days with temperatures more than 30°C (a threshold sometimes used to examine the sensitivity of maize to heat stress), consistent across all models.
- For rainfall there is strong agreement for decreases in the mean number of rain days and increases in the amount of rainfall on each rainy day (the 'rainfall intensity'). Taken together these changes suggest more variable rainfall, with both higher likelihood of dry spells and a higher likelihood of intense rainfall events (often associated with flooding).

Key points about climate models and this brief

- Climate model results are not finite predictions. They should always be presented as a range of outcomes – not just one 'forecast of the future'.
- Because of the uncertainties we refer to climate model results as 'projections'.
- The projections presented here are not the only ones available and they are not a final product – there will always be new model results which may be similar or different. Planning based on projections from climate models must include opportunities to update any climate information used. Climate change projections are also available for Regional Climate Models (these are similar to Global Climate Models, but applied to smaller areas and produce results with more spatial detail). Each Regional Climate Model is run with inputs from Global Climate Models and is therefore subject to the same scientific uncertainties.
- The brief is not comprehensive and neither is it the only source of climate model results. It serves as an introduction to non-expert audiences with an interest or need to consider climate change in Tanzania.
- Over time, UMFULA will develop more detailed understanding of regional climate processes and how these are represented in climate models, leading to new guidance on the use of climate projections.
- This brief complements the FCFA Guide *Climate models: What they show us and how they can be used in planning*[3].

Further information on many related topics can be found on the FCFA website: www.futureclimateafrica.org.

Sources of data[4]

Knowledge of past rainfall and temperature in Africa is constrained by sparse weather stations and data gaps. Here we use international data sets which interpolate station data for temperature, and use station and remotely sensed satellite data for rainfall (see Table 1). For future climate we use the 34 models used by the Intergovernmental Panel on Climate Change (IPCC), known as CMIP5, which project variations in temperature and rainfall for different periods in the future compared to the baseline period 1950-2005. We present climate simulations based only on a high greenhouse gas emission pathway (worst case scenario, known as RCP8.5, with other pathways available).

Table 1: Summary of data sources and parameters for past climate
(See annex[5] for full detail, CHIRPS data are v2.0 Climate Hazards group Infrared Precipitation with Stations).

	Rainfall	Temperature
Data source	CHIRPS	Climatic Research Unit
Data availability	1981-2017	1901-2015
Time period	Seasonal and annual	Seasonal and annual

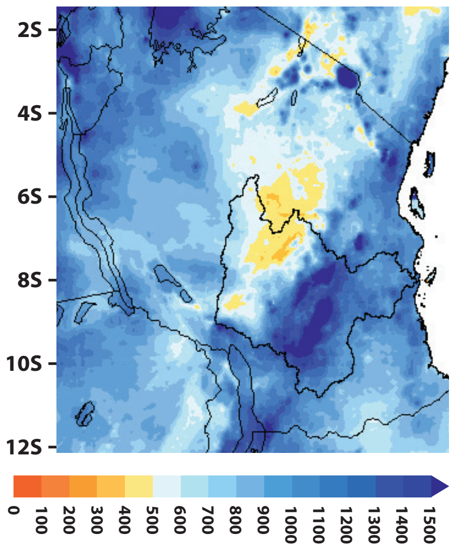
Recent climate variability and extremes from observations

Rainfall

Tanzania's large size, elevation differences and location across the equator gives rise to differences in rainfall amounts (from 300-1200mm per year) and seasonality (the timing of wet seasons and dry seasons), as well as variability over time, for example from year to year (Figure 3). Northern areas generally experience two rainy seasons; the October to December (OND) (short rains) and March to May (MAM) (long rains) seasons. Northern Tanzania experiences a strong, although not only, influence from the El Niño-Southern Oscillation, in which above average rainfall occurs over east Africa during an El Niño event and the reverse during La Niña. Western and southern Tanzania experience a single rainy season from October to April, but the influences on variability are poorly understood.

Figure 4 presents time series of observed annual and seasonal rainfall. Key points are the absence of any strong trend in the series, and since the early 2000s notably dry years in 2003 and 2005 and a very wet year in 2006. Taking a country average may obscure large differences between locations and therefore Figure 5 shows a map of the trend in annual rainfall expressed as mm per year. There are marked areas of drying in parts of northeast and much of southern Tanzania. In contrast, moderate wetting trends appear in central Tanzania and stronger ones in northwest Tanzania. The drying and wetting patterns lead to the lack of trend in the country area average series (Figure 4). Drying is most pronounced from the October to December and October to the following March seasons in southern Tanzania[6]. A prolonged drying trend in March to May (MAM) rainfall in the larger Horn of Africa has been widely observed and is somewhat apparent in northeast Tanzania in Figure 5, but much more pronounced in Kenya[7].

Figure 3: Observed mean annual rainfall (in mm) for 1981-2010
The outline of the Rufiji river basin is shown in black.



CHIRPS Annual rainfall 1981-2010 mm/yr

Figure 4: Observed annual and seasonal rainfall (rainfall totals in mm) for all of Tanzania for 1981-2016
Seasons are March to May (MAM), October to December (OND), and October to the following March (ONDJFM). The dotted straight lines represent the linear negative trend over the whole period.

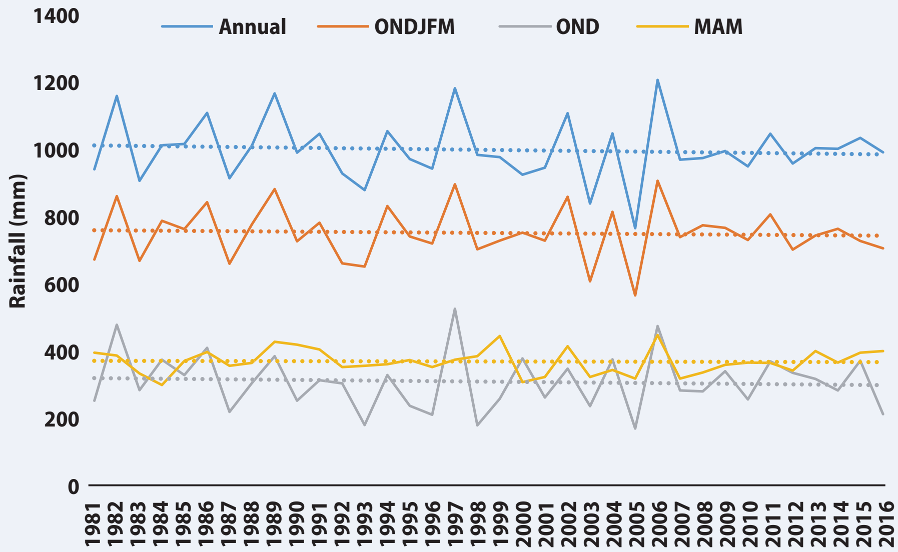
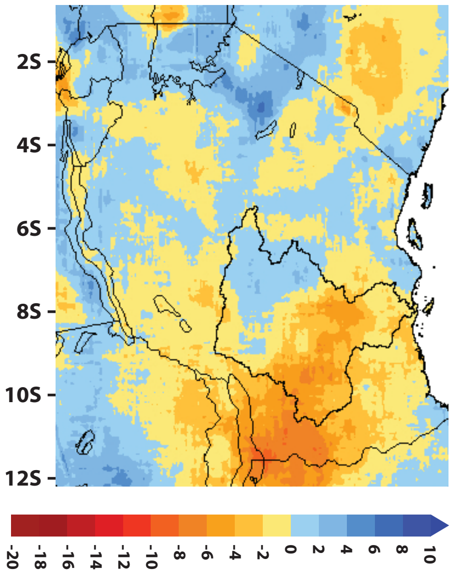


Figure 5: Observed trend in annual rainfall (linear trend for each grid cell in mm per year) for 1981-2016
Seasonal trends are shown in the annex[8].



CHIRPS Annual rainfall trend 1981-2016 mm/yr

When does variability become a trend and does it matter?

We can consider whether trends are present in observations in various ways, with the use of different statistical tests or combinations of the climate variable (e.g. using daily or annual rainfall, for example). The start and end point of a trend analysis can greatly affect whether a trend is detected (this is termed 'sampling variability'). Trends may be expressed as mm or per cent change over time. Both measures can be difficult to interpret in terms of whether they are likely to have had a noticeable effect in real life. A 50mm drying trend in rainfall per decade in a wet location may be insignificant and impossible for local people to notice (1000mm would reduce to 950mm over 10 years), whereas the same trend in a drier location may be significant and noticeable (600mm would reduce to 550 mm, potentially limiting the viability of some rain fed crops).

Trends are generally very irregular, which makes them difficult to detect. A trend during recent years is much more likely to have been noticed by local people, and several dry years occurring close together by chance may easily be mistaken as a trend. The time of year when the trend occurs is also important in terms of perception. A trend becomes relevant from a practical perspective when it leads to either adverse impacts or opportunities affecting the environment or people. From a scientific perspective, trends are also important as they help to confirm whether change is happening and in understanding the causes of such changes, which can often be difficult to determine. Trends may sometimes be a function of variability over multiple years. It is thus not good practice to assume they will continue into the future without strong evidence to support this.

Temperature generally shows much less variability than rainfall in time and space. The variation in mean annual temperature across Tanzania is shown in Figure 6. It is generally warmer nearer to the coast and in parts of the lower Rufiji valley and cooler in areas of higher elevation. A clear warming trend is apparent in annual temperature (roughly 0.03°C per year) and the other three seasons, and these trends are present across most of the country (Figure 7).

Figure 6: Observed annual mean temperature (°C) for 1976-2005

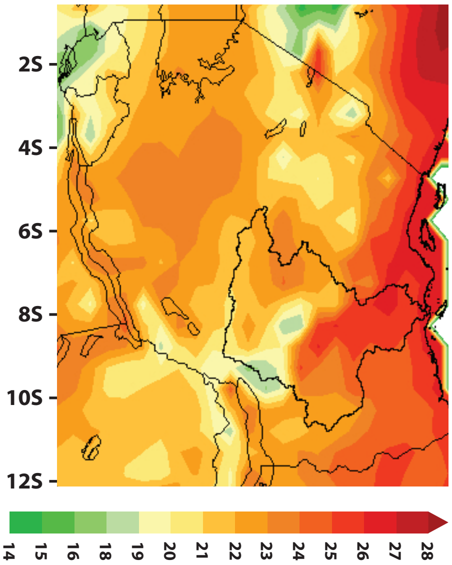
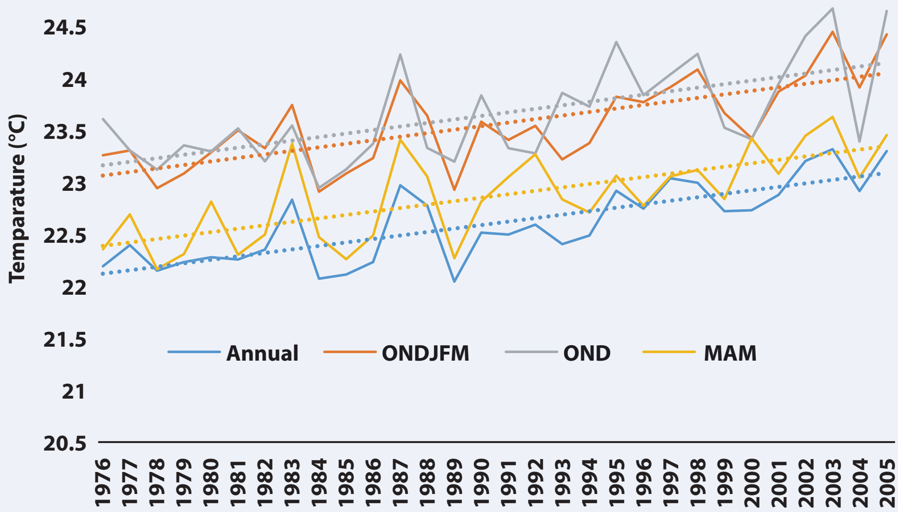


Figure 7: Observed annual and seasonal temperature (°C) for all Tanzania for 1976-2005

Seasons are March to May (MAM), October to December (OND), and October to the following March (ONDJFM). The dotted straight lines represent the linear increasing trend of 0.03°C over the whole period and for all the seasons.



Projections of future rainfall and temperature

Whilst all climate models show warming in most places into the future (particularly towards the interior of Tanzania), different climate models can simulate very different patterns of rainfall. In some cases drier and wetter conditions can be projected for the same location. Most studies of future climate therefore include results from different climate models. There are many sets of Global Climate Models results available to develop climate projections. We show results from 34 climate model experiments[9].

For those new to this topic, appreciating the implications of the points above for interpreting climate model projections can be challenging. Presenting this information in an accessible format requires careful consideration; there are numerous options to show results in tables and diagrams[10].

Climate projections for rainfall in Tanzania are mixed (Figure 8). Out of the 34 models, 11 (32%) project reductions in annual rainfall for the 2030s – and the rest (68%) project wetter conditions. Nine models (26%) project drying by the 2070s (see annex). The size of change in annual mean rainfall is generally modest, from a -12% drying to a +13% wetting. Twenty models project changes less than +/-5% for the 2030s. The changes are larger by the 2070s; a range of -15% decrease to +26% increase and only 10 models produce changes less than +/-5%.

There are too many technical reasons for the spread in climate model results to go into detail here, but we anticipate that scientific advancements through FCFA and UMFULA will improve our understanding of these issues. This may provide us with scientifically defensible reasons to reject some models (e.g. perhaps they have major errors in simulating key aspects of the regional climate) or to give extra weight to others which perform particularly well.

What do the rainfall projections mean for planning?

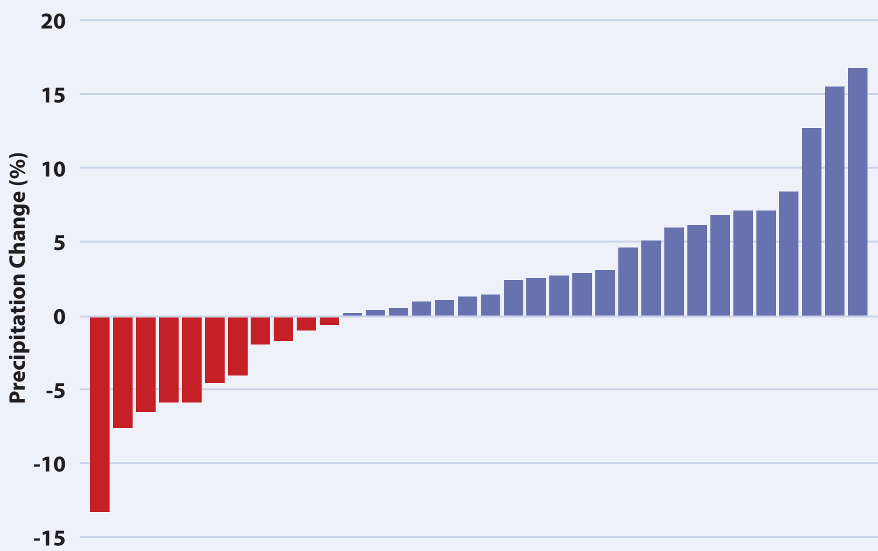
Given that roughly one third of the climate models project drier conditions can we say there is a one in three chance that Tanzania will be drier in the 2030s? Not really, because this set of climate models is not the full population. Other model results exist (e.g. Regional Climate Models) that could give different results and as new climate model results become available they may change the main message.

We therefore have to be cautious with our interpretation and recognise that projections still include wetter and drier future climate conditions throughout Tanzania. A major consequence of this situation is that planning should consider a range of future climate conditions.

UMFULA is developing approaches to decision-making that can incorporate such uncertainties.

Figure 8: Per cent change in annual mean rainfall for all Tanzania between the GCM simulated current period (1976-2005) and 2021-2050 for 34 GCMs

Each bar on the x-axis represents one GCM. See annex for GCM details and results for the 2090s.



The country-wide average changes in Figure 8 sometimes obscure considerable sub-national variations. However, there is no simple or correct way to summarise the results of spatial changes across 34 climate models[11]. Here we show the average of all 34 models (sometimes called the Multi-Model Ensemble), noting that the averaging process does not provide a more reliable result; it simply summarises the patterns of change across all the models. Figure 9 illustrates that for the multi-model mean, annual rainfall tends to increase in the north/northeast (around 3 to 4% maximum) and decrease in the south (-1 to -2%). The per cent changes in annual rainfall are very small, but they are larger in the seasons, for example, drying of up to 9% in the October to December rainy season and wetting of 9% in the March to May rainy season.

By the 2090s the changes have similar spatial patterns but are larger, with changes in annual rainfall increasing in the north by more than 9% and decreasing in the south by less than 9%[12].

But, as mentioned above, planning and decisions using climate model projections should always consider a range of outcomes, not just the multi-model mean.

In contrast to rainfall, there is strong consensus on rising temperatures in Tanzania. The climate models project warming, in the range of 0.8 to 1.8°C by the 2040s. In the Multi-Model Ensemble, warming of roughly 1°C is relatively evenly distributed across Tanzania[13]. By the 2090s, all models project warming in the range of 1.6 to 5.0°C, with the Multi-Model Ensemble warming of roughly 3-4°C fairly evenly distributed across Tanzania (slightly less warming nearer to the coast).

Figure 9: Mean annual and seasonal precipitation change (%) for the 2040s (2021-2050) compared to current period 1976-2005 using the multi-model ensemble mean of 34 GCMs for annual, OND, ONDJFM and MAM
See annex for GCM details and results for the 2090s. Results are shown for a high greenhouse gas emission scenario (RCP 8.5)

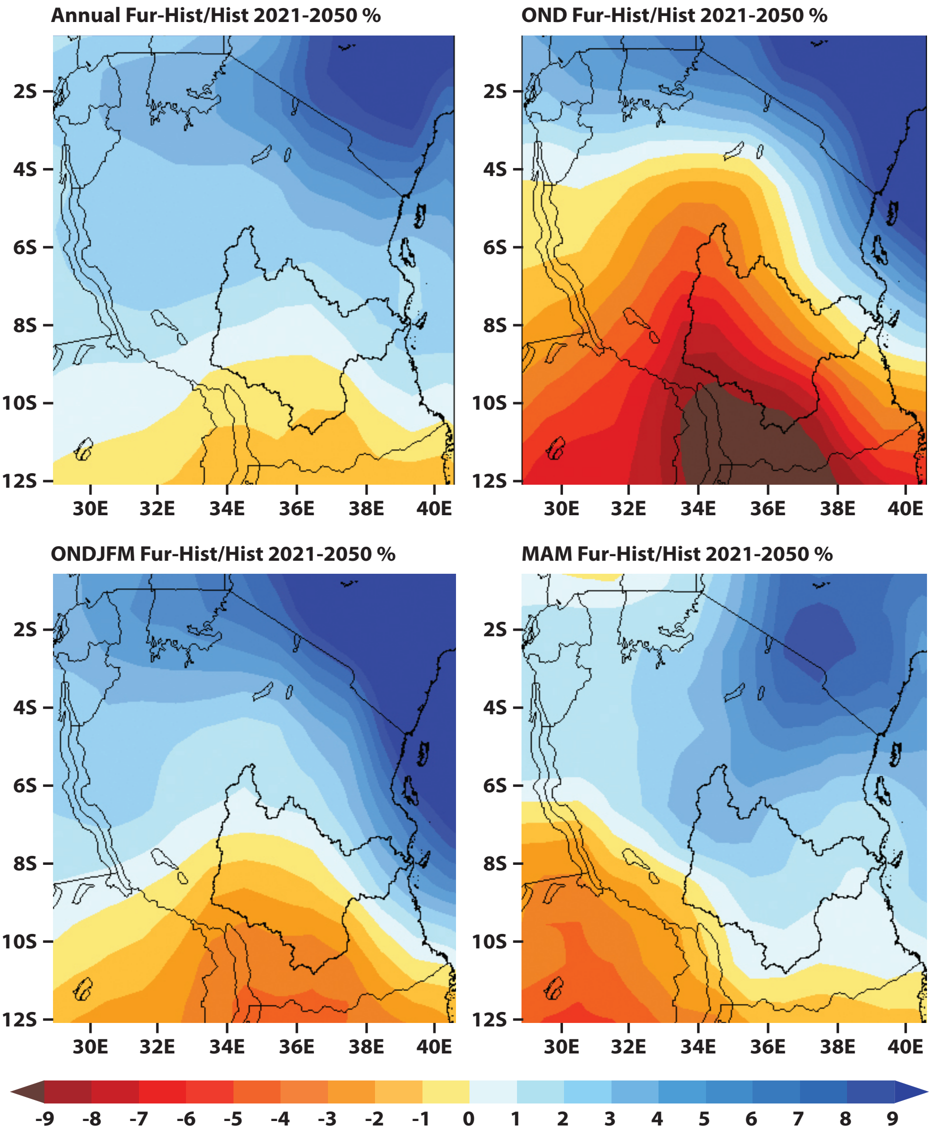


Table 2: Annual and seasonal mean changes for the near future (2040s) and longer-term future (2090s) periods
Results are shown for a high greenhouse gas emission scenario (RCP 8.5).

	Rainfall		Temperature	
	2021-2050	2070-2099	2021-2050	2070-2099
Annual	2.4	0.1	1.3	3.9
OND	-0.5	-1.7	1.3	3.9
ONDJFM	2.8	8.2	1.3	3.8
MAM	1.5	6.9	1.3	3.9

The East African rainfall paradox[14]

Future rainfall patterns in the Greater Horn of Africa have received significant attention because of an apparent paradox: there is an observed drying trend in the short rains (March to May), whereas most climate models project increasing rainfall in much of the region (primarily in northern Tanzania, see Figure 9). Rowell et al. (2015) consider six hypotheses to explain the paradox but cannot fully account for it. They recommend three priorities for further investigation: to undertake a more comprehensive climate science assessment of the reliability of climate model projections; to assess the suggestion that dust particles released through human activities may have driven the rainfall decline; and to examine the role of natural rainfall variability in the decline.

Table 2 summarises the annual and seasonal mean changes averaged for all Tanzania for the near future and longer-term future periods.

Change in extremes

Changes in climate factors on daily timescales can provide a useful guide to the potential magnitude and frequency of extreme weather events in the future. The map in Figure 10 shows for the Multi-Model Ensemble increases in the mean number of days with temperature more than 30°C (a threshold sometimes used to examine the sensitivity of maize to heat stress) across the whole of Tanzania. Figure 11 shows that all the climate models project increases in this parameter, ranging from roughly 10 to 80 days per year by the 2040s.

Figure 10: Multi-Model Ensemble annual mean change in the number of days with temperature more than 30 °C for the 2040s (2021-2050) compared to current period 1976-2005

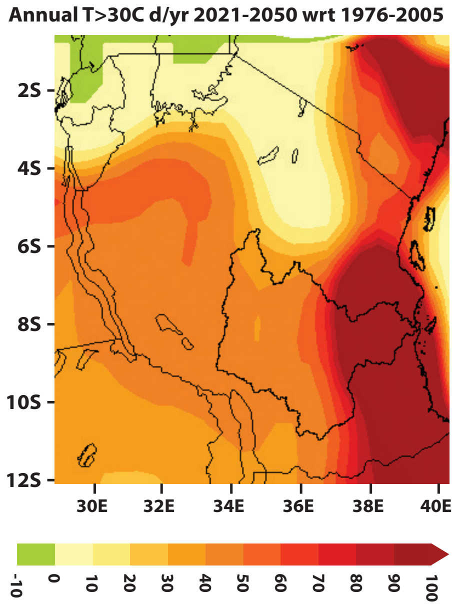


Figure 12 shows that for rainfall there is strong agreement between models that the mean number of rain days is projected to decrease (29 models project decrease, five project increase). Figure 13 shows that there is also strong agreement that the amount of rainfall on each rainy day (the 'rainfall intensity') is projected to increase. Taken together, these changes suggest more variable rainfall, with both higher likelihood of dry spells and higher likelihood of intense rainfall events (often associated with flooding).

Figure 11: Change in the annual mean number of days with temperature more than 30°C for all Tanzania between the GCM simulated current period (1976-2005) and 2021-2050

Each bar on the x-axis represents one GCM

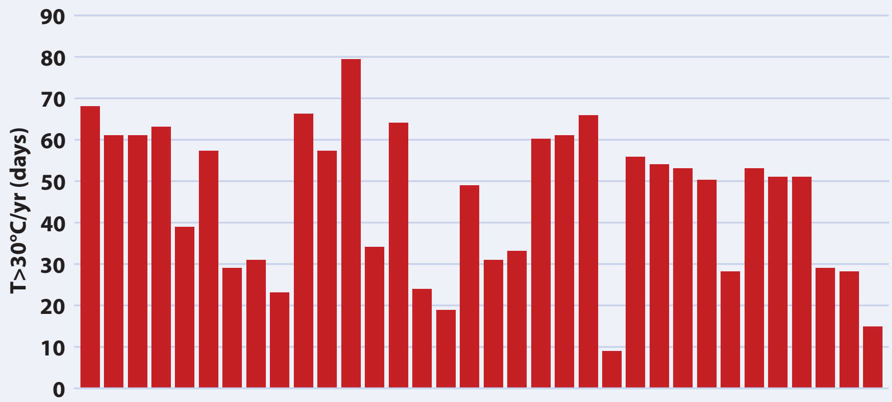


Figure 12: Per cent change in annual mean number of rainy days (i.e. days with rainfall more than 0.1 mm) for all Tanzania between the GCM simulated current period (1976-2005) and 2021-2050

Each bar on the x-axis represents one GCM

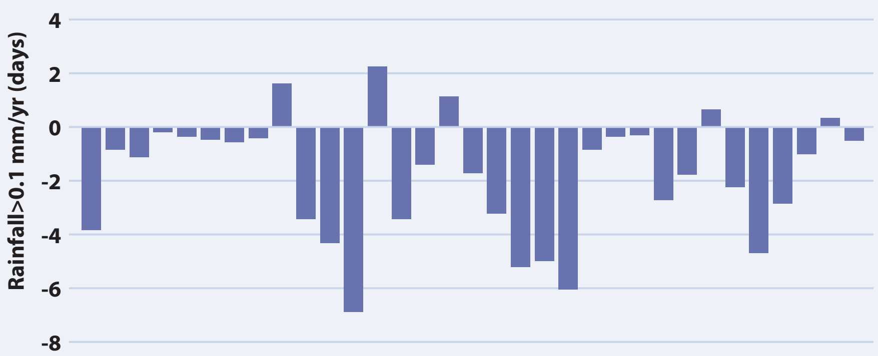
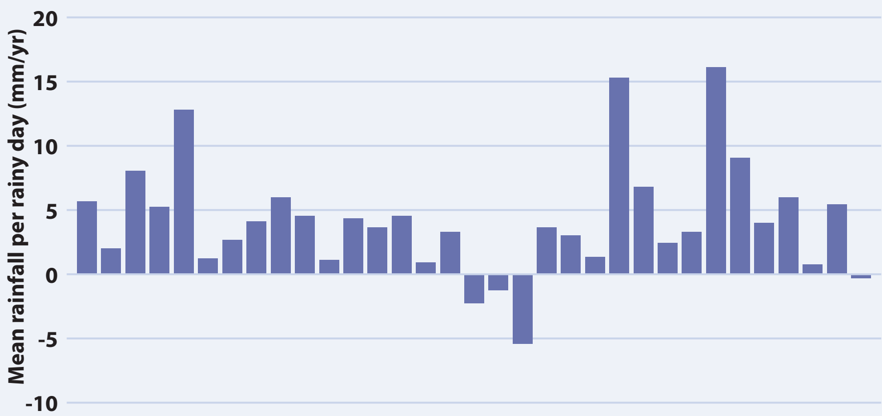


Figure 13: Per cent change in annual mean wet day amount (the mean rainfall per rainy day) for all Tanzania between the GCM simulated current period (1976-2005) and 2021-2050

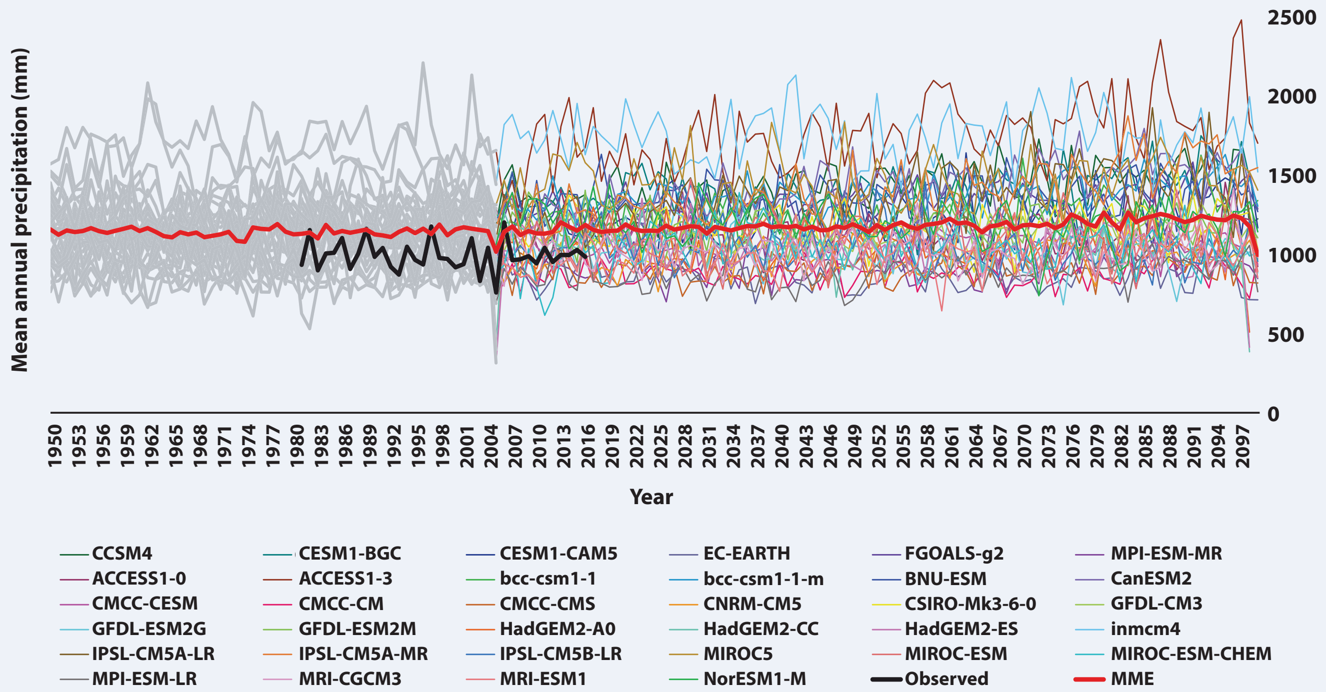
Rain days here are defined as days with rainfall more than 0.1 mm. Each bar on the x-axis represents one GCM



Some final technical points: better understanding regional climate

Figure 14 separately shows annual rainfall observations for Tanzania for 1981-2016 (bold black line), as well as the ensemble mean of 34 CMIP5 models for 1950-2099 (bold red line). The figure highlights that there are substantial differences between the observed and climate model simulated rainfall (mean and variability), with the Multi-Model Ensemble roughly 10% too wet. The causes of these differences require further study and we expect it should become feasible to reject some models where they are shown to perform poorly in their simulation of regional climate. The smoothing effect of taking a Multi-Model Ensemble mean is also clear. It reduces the variability shown by individual climate models (including extreme dry or wet years) and it misses the spread in future changes (the variability in the Multi-Model Ensemble never exceeds what has already occurred in the observations). The equivalent figure for temperature is shown in the annex[15] (temperatures rapidly exceed the range experienced in the observations).

Figure 14: Time series of annual rainfall for all Tanzania for 34 CMIP5 models and their ensemble mean (bold red line) for the period 1950-2099 and observations (bold black line) for the period 1981-2016



Final messages for planners

In conclusion, we stress that these climate model projections are not final. There will always be new model results, which may be similar or different. Planning based on projections from climate models must therefore include opportunities to update any climate information used.

For many parts of Africa GCM projections of rainfall remain highly divergent, underscoring the need to test adaptation plans and infrastructure design against a range of future conditions, and where appropriate to introduce approaches to decision-making under uncertainty.

Endnotes

1 FCFA (2017a) *Annex: Future climate projections for Tanzania.* Cape Town: Future Climate for Africa. www.futureclimateafrica.org/resource/future-climate-projections-for-tanzania/

2 FCFA (2017b) *Summary: Future climate projections for Tanzania.* Cape Town: Future Climate for Africa. www.futureclimateafrica.org/resource/future-climate-projections-for-tanzania/

3 FCFA (2016) *Climate models: what they tell us and how they can be used in planning.* Cape Town: Future Climate for Africa. www.futureclimateafrica.org/resource/climate-models-what-they-show-us-and-how-they-can-be-used-in-planning

4 FCFA (2017a) Op. cit.

5 Ibid.

6 Ibid.

7 Ibid.

8 Ibid.

9 FCFA (2017a) Op. cit.

10 FCFA (2017c) *How to understand and interpret global climate model results.* Cape Town: Future Climate for Africa. www.futureclimateafrica.org/resource/how-to-understand-and-interpret-global-climate-model-results/

11 Ibid.

12 FCFA (2017a) Op. cit.

13 Ibid.

14 FCFA (2016) East African climate variability and change. In *Africa's climate: Helping decision-makers make sense of climate information.* Cape Town: Future Climate for Africa. www.futureclimateafrica.org/wp-content/uploads/2016/11/africas-climate-final-report-4nov16.pdf

15 FCFA (2017a) Op. cit.

About Future Climate for Africa

Future Climate for Africa (FCFA) aims to generate fundamentally new climate science focused on Africa, and to ensure that this science has an impact on human development across the continent. This brief was written by members of the UMFULA research team: Declan Conway, Neha Mittal, Emma Archer van Garderen, Joanna Pardoe, Martin Todd, Katharine Vincent and Richard Washington. You can find out more about their work under 'research teams' on www.futureclimateafrica.org. The authors thank the individuals and organisations in Tanzania who have commented on early versions of this brief.

FUTURE CLIMATE FOR AFRICA

Climate & Development Knowledge Network

Funded by: UKaid from the British people; NERC Science of the Environment

www.futureclimateafrica.org e: info@futureclimateafrica.org t: +2721 4470211

Front cover photo: A. Eitzinger, International Centre for Tropical Agriculture (CIAT)/Flickr | Front inside cover: G. Smith, CIAT/Flickr | Back inside cover: H. Lawson/Flickr