Project Report: Future Climate for Africa

Near-term climate change in Zambia

What the research tells us

Anton Chilufya, a volunteer with the Zambia Red Cross, escorts a group or orphans for vaccination against measles in 2006. He and his colleagues face a challenging future for human health as climate impacts threaten supplies of safe drinking water, meaning people in rural communities dependent on shallow wells and surface water will have to travel greater distances to get it. (Marko Kokic/IFRC)

By Colin Gannon, Dan Kandy, Josh Turner, Ipsita Kumar, Karoliina Pilli-Sihvola and Flaviour Sisala Chanda

Red Cross/Red Crescent Climate Centre

P.O. Box 28120
2502 KC The Hague
The Netherlands

+31 (0)70 4455666
climatecentre@redcross.nl
www.climatecentre.org

RED CROSS/RED CRESCENT CLIMATE CENTRE

International Federation of Red Cross and Red Crescent Societies

The Netherlands Red Cross

1. Overview

The climate of Zambia, including its precipitation and temperature patterns, is expected to continue to change in the next 5 to 40 years. In the absence of adaptation or disaster risk management, this could affect the agriculture, health, and energy sectors.

Total annual precipitation is expected to decrease slightly, although the frequency of extreme precipitation events (causing flash floods) will probably become greater. The intensity of rainfall events and the time between them may also increase. In other words, this reduction in the frequency of rainy days could lead to longer dry spells interspersed by more intense heavy precipitation events, all without greatly altering total annual precipitation.

The changing precipitation pattern could have negative impacts across many sectors. Agricultural production and hydroelectric power generation could decrease while cholera and malaria may rise.

Daytime and night-time temperatures across all of Southern Africa are expected to gradually increase in coming decades. This would also probably result in higher incidence of extreme heatwaves and also elevate evapotranspiration rates.

The rising temperatures could have a negative impact in the agricultural sector by compromising livestock and crop health and reducing labour productivity, as well as in the human health sector by raising malaria transmission rates and increasing incidence of heat-related illnesses.

These and other likely changes in the medium-term future have implications for decisions currently under consideration for development and humanitarian work in Zambia. Key forms of investment planning, ranging from infrastructure design to capacity building to risk reduction, need to take into account the range of plausible futures for a more robust path to adaptation.

2. Introduction

This Climate Centre project report synthesizes current published information regarding climatology, climate variability, and near-term climate change in Zambia. Country, regional, and climate studies have been integrated into a comprehensive picture of Zambia's current and near-future climate. Additionally, the paper outlines the impact of climate on human health, agriculture, energy, and infrastructure. While climate change has consequences everywhere, the discussion here will focus on the sectors most impacted by the projected changes in precipitation and temperature.

Limitations in projecting the future climate of Zambia, including its quantification and relevant spatial detail, will also be discussed. With consideration of these restrictions, this paper aims to evaluate past impacts of climate and extreme weather in various sectors, and demonstrate whether these events are expected to be more or less common in the future. While some social challenges persist in Zambia regardless of climate, understanding and preparing for expected changes in climate and weather extremes can greatly help reduce risks and abate societal issues.

This paper was produced in the context of the Future Climate for Africa (FCFA) pilot study in Zambia to examine how to make climate science actionable, so decision-makers can make informed adaptation and development investments that are robust to a range of possible outcomes in the near- to medium-term future. The outcomes of this study will be used by the UK Department for International Development (DFID) to assess a new research programme to advance scientific understanding of the Southern African climate on decadal timescales and, working with African stakeholders, help this science inform long-term climate-resilient development strategies.

3. Zambia's climate past

The climate of Zambia can be separated into two seasons. The warmer wet season begins in October and extends through April. Precipitation peaks in December, January and February at around 200mm/month. The colder dry season extends from May through September and sees very little precipitation and long dry spells. Average temperatures peak in October, and lowest average temperatures occur in July.

Variable precipitation

Rainfall averages about 960mm annually, but is variable across the Zambezi river basin, from 1,500mm annually in the northern highlands to 600mm in the south-west (Beilfuss, 2012). The past 40 years has seen a slight reduction in annual precipitation, along with increased variability in rainfall year-to-year, and an increase in extreme precipitation events (IPCC, 2007; Kirtman et al., 2013; Hulme et al., 2001; Reason, Landman and Tennant, 2006).

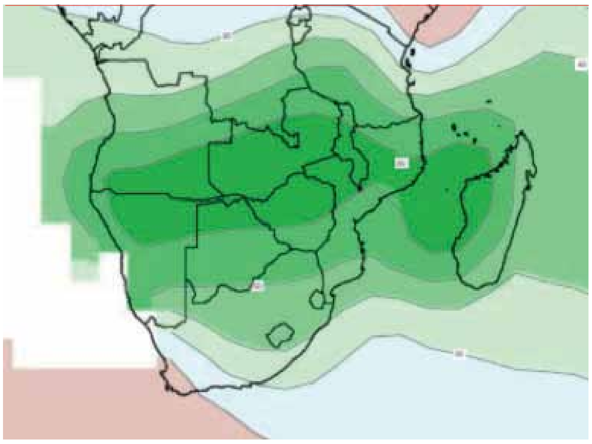

Figure 1. The percentage of annual precipitation that occurs during the Zambian summer, based on climatological precipitation using a 1981–2010 base period. Regions shaded in green receive more than 30 per cent of their annual precipitation, while areas shaded in brown receive less than 20 per cent of their annual precipitation during the indicated 3-month season. (Source: IRI.)

Floods and droughts

Zambian society, with 70 per cent of the workforce dependent upon agriculture (World Bank, 2014) and a large portion of the country in the floodplains of the River Zambezi, is highly vulnerable to this precipitation variability. Floods are common and affect many sectors; droughts can also be devastating and have prolonged side effects that touch every facet of Zambian life. Both hazards have become more frequent and severe in recent decades (GRZ, 2007).

Historically, Zambia has been prone to extreme rainfall events resulting in widespread flooding. A recent flooding event during the 2006–7 rainy season saw nearly 1.5 million people affected (GRZ, 2007). Typical impacts from a major flooding event include: collapsed houses and buildings, destruction of infrastructure (roads, sanitation facilities), waterlogged agricultural fields, destruction of crops, contaminated water supplies and an increase in human diseases (GRZ, 2007; Leary, Kulkarni and Seipt, 2007).

Compromised human health is one of the leading concerns associated with floods. Associated diseases include malaria, cholera, dysentery, and bilharzias (schistosamiasis) (GRZ, 2007). The outbreak in water-borne diseases (cholera and dysentery) is a result of Zambians' dependence on surface water for drinking; these sources may become contaminated after a flood. This is a particular concern in areas where pit latrines are commonplace. An example of a recent disaster is the April 2010 floods which hit Lusaka, resulting in 3,381 cases of cholera and 87 deaths (IFRC, 2010).

Vector-borne diseases, particularly malaria, are also associated with these events, as stagnated water serves as a breeding ground for disease-carrying mosquitos (GRZ, 2007). Malaria kills more people than any other disease in Zambia (UNICEF, 2014) and is associated with variations in precipitation.

While floods often result in immediate disaster situations, many longer-term societal threats exist during times of drought, particularly in the agriculture, energy and human health. A 2004–5 drought, during which about two thirds of the country received little or no rainfall during the growing season, resulted in 1.2 million people being affected (GRZ, 2007).

Zambia as a whole is vulnerable to increased frequency of drought. Since 1960, the mean annual precipitation countrywide has been decreasing by 1.9mm per month per decade, most notably in the summer months, and the growing season has been shortening (McSweeney, New and Lizcano, 2010; Tadross et al., 2009). Key crops, which include sorghum, cassava, millet, and the staple crop, maize, cannot mature during this short growing season, and the food security of the country is affected (GRZ, 2011).

Cattle, which are crucial to livelihoods of many Zambians, are stressed during times of extreme drought, a result of reduced plant growth and a shortage of pasture. Consequently, cattle experience poor nutrition and reduced immunity and reproductive capacity (Leary, Kulkarni and Seipt, 2007).

Fish stocks, like cattle, are directly influenced by droughts. Low precipitation results in reduced nutrient levels in lakes and rivers, diminishing water quality and negatively impacting the health of fisheries. The species most vulnerable to such effects in the Zambezi basin are breams and sardines (GRZ, 2007).

With regards to human health, droughts are often associated with malnutrition, diarrhoea, food poisoning, dysentery, and other water-borne diseases. During times of droughts, access to drinking water becomes more limited, and the distance from the source to the household expands; as a result, the water requires extra handling and cases of diarrhoea tend to increase (GRZ, 2007).

Furthermore, this longer walking distance from household to water source results in a higher number of human-wildlife conflicts, particularly in rural areas near game management areas or rivers. During 2002 to 2008, a total of 347 people were killed (49 annually) by five species – crocodile, elephant, hippopotamus, lion and buffalo (Chomba, 2012); exposure to these predators is higher when water is scarce (GRZ, 2007).

While the human health and agriculture sectors suffer during times of drought, the energy sector is almost entirely dependent upon rainfall. Zambia generates over 90 per cent of its power from hydroelectricity, making energy security highly dependent upon precipitation patterns. Reduced power generation in recent years has had a negative impact on the economic productivity as this leads to increased power shortages, forcing industries to reduce their levels of production (GRZ, 2011; Beilfuss, 2012; World Bank, 2010).
It is worth noting that while Zambia may experience periods of flooding or drought, these events can occur roughly simultaneously, depending on the timing of the rain. For instance, during a time of

drought, an extreme precipitation event could result in high run-off (due to low soil absorption), triggering a flash flood. In this scenario, despite relatively low total rainfall totals, flooding can still exist as a threat.

Rising temperatures

A distinct warming trend has been observed in Southern Africa through the 20th century. Surface temperatures have increased by half a degree Celsius or more over most of Africa (Hulme et al., 2001; New et al., 2006; IPCC, 2007, 2014) with the 1995 to 2010 period seeing significantly higher surface temperature anomalies compared to the prior 15 years (Collins, 2005; IPCC, 2014).

Falling water levels, greater health risks

Temperature variability plays a crucial role in various aspects of Zambian society. The agricultural and human health sectors are impacted by temperatures; extreme heat results in loss of human and animal life and damages crop output (GRZ, 2007).

Indirectly, warmer temperatures tend to correlate with higher evaporation rates, leading to declining water levels. The falling water levels and subsequent reduced oxygen and increased salinity levels strain the fish stocks and other river and lake fauna (Bond, Lake and Arthington, 2008). There is also evidence of increased disease incidence among livestock, particularly cattle, during times of extremely high temperature (Leary, Kulkarni and Seipt, 2007).

Human health is also highly correlated with temperature regimes. Disease transmission tends to be higher with warmer temperatures. This is particularly true with malaria, which is regulated in part by cold temperatures; rainfall, however, is the primary driver of malaria (GRZ, 2007).

4. The drivers of seasonal weather

The Inter-Tropical Convergence Zone

Annual climate is largely governed by the shifting of the Inter-Tropical Convergence Zone (ITCZ) and the Pacific Ocean’s El Niño-Southern Oscillation (ENSO). However, the influence of the Atlantic and Indian Oceans cannot be ignored in analysing the country’s climate. While most variability in the region’s climate occurs season-to-season and year-to-year, there is evidence that some variability is linked to decadal and multi-decadal patterns.

Decadal changes in the north-south sea surface temperature (SST) differential have an effect on the regional climate of southern Africa (Reason, Landman and Tennant, 2006). These changes affect air circulation patterns in the southern hemisphere and alter the strengths of nearby sub-tropical high-pressure systems (Reason, Landman and Tennant, 2006). However, the impacts of these decadal SST patterns in the region are little studied and deserve further exploration.

The ITCZ, a band of clouds that encircles the globe at the equator and brings high levels of precipitation, shifts northwards and southwards depending on the season, and sits over West Africa during the southern hemisphere winter and over south-east Zambia during the southern hemisphere summer (Reason, Landman and Tennant, 2006). The timing and magnitude of ITCZ and its movements over Africa are associated with ENSO, solar insolation, and local SSTs (Goddard and Graham, 1999).

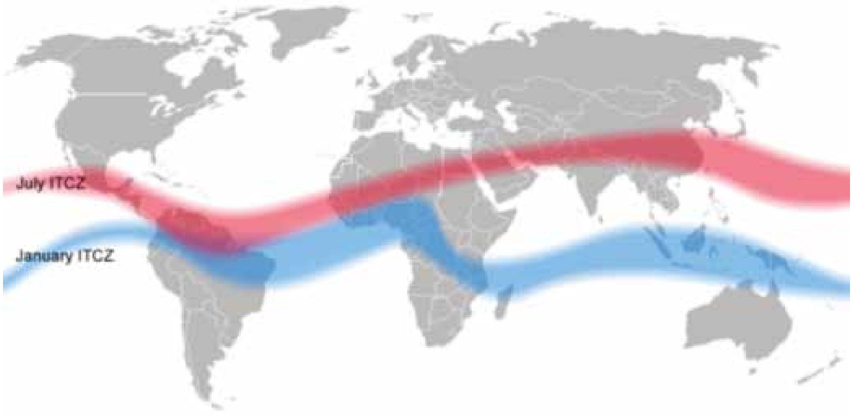

Figure 2. The Intertropical Convergence Zone in July (red) and February (blue). (Image by Mats Halldin.)

The 'Angolan Low', 'Benguela Niños' and the Atlantic

High surface temperatures over Angola produce a low-pressure zone during the Zambian rainy season. This 'Angolan Low' sets up moisture circulation in the region by drawing in warm moist air from the tropical Atlantic toward Zambia. This influences the amount of moisture transported from the Atlantic Ocean and consequently the rainfall received. Zambia also sits at the nexus of low-level moisture transport from both the Indian and Atlantic Oceans; this convergence of moisture is responsible for much of the rainfall in the rainy season in Zambia (Reason, Landman and Tennant, 2006).

Studies have yet to investigate what will happen to the Angolan Low as the climate warms. Benguela Niños and Niñas are so named after the cold water current off south-west Africa; events where surface water is anomalously warm – Benguela Niños – or anomalously cool – Benguela Niñas (Reason, Landman and Tennant, 2006). The events take place generally from February through April, which coincides with the maximum Angolan Low strength and the location of the ITCZ over Zambia.

Generally speaking, Benguela events can influence the strength of the Angolan Low and thus the moisture transport from the Atlantic and Indian Oceans. Warm Benguela Niño events lead to increased evaporation and convection over south-west Africa (Reason, Landman and Tennant, 2006), yet they tend to produce above average rainfall in Zambia only when the atmospheric circulation changes enough to draw in additional moisture from the Indian Ocean while simultaneously reducing the amount of moisture transported away from the region (Rouault et al., 2003).

These events are predictable, based on their connection to trade-wind anomalies in the tropical Atlantic that occur two or three months prior (Florenchie et al., 2003; Florenchie et al., 2004; Hurrell et al., 2006). However, no literature is available on the predictability of the anomalous circulation pattern that allows Benguela events to extend inland over Zambia.

5. What governs Zambia’s climate?

The tropical Pacific and El Niño Southern Oscillation

El Niño-Southern Oscillation (ENSO) is a see-sawing of sea surface temperatures in the Pacific Ocean, and has two distinct phases, commonly known as El Niño and La Niña. ENSO has substantial impacts on local climates throughout the world, and significant on inter-annual precipitation variations in Zambia.

It is worth noting, however, that ENSO phases will not necessarily correlate explicitly with local conditions. The regional and local climate systems predominantly guide the climatic conditions, while ENSO may serve only to shift these conditions in one direction or another (Plisnier, Serneels and Lambin, 2008). During El Niño years, Zambia tends to see an increase in dry spells during December, January, and February, the primary rainy season (Hachigonta and Reason, 2006). During La Niña years, Zambia tends to see decreased dry-spell frequency and increased wet-spell frequency (Hachigonta and Reason, 2006). In this context, a dry spell is defined as a five-day period with less than 5mm of rainfall and a wet spell as a five-day period with more than 20mm of rainfall.

While precipitation in the region is correlated with ENSO, surface temperatures are less correlated with ENSO. However, anomalously warm land surface temperatures during El Niño years have been observed in parts of north-east Zambia (Plisnier, Serneels and Lambin, 2008).

The Indian Ocean Dipole

Despite Zambia’s proximity to the Indian Ocean, there is minimal correlation between Zambia’s climate and the phase of the inter-annual oscillation known as the Indian Ocean Dipole (IOD). There does appear to be a trend between the IOD index and dry-spell frequency in southern Zambia (Hachigonta and Reason, 2006). There are, however, multiple instances of ENSO dominating this relationship, so it may be said that the ENSO influence is stronger than that of the IOD (Hachigonta and Reason, 2006).

6. What will Zambia’s climate look like in 40 years?

Erratic precipitation, less rain

Compared to temperature simulations, predicting future precipitation is relatively difficult and inconclusive; different models tend to produce notably different results. However, a majority of studies using Global Climate Models (GCMs) predict a drying trend (Hulme et al., 2001) through the next 100 years, with a “very likely” decrease in annual mean precipitation over southern Africa by mid-century (IPCC, 2014; Christensen et al., 2013). The difference between models, however, indicates significant uncertainty in these results (Giannini et al., 2008; Hulme et al., 2001).

In addition to a general drying trend, global warming is likely to change the onset of the rainy and dry seasons. For example, decreases in austral spring rainfall imply a delay in the onset of the rainy season (IPCC, 2014).

Patterns and extremes are also likely to change. General rainfall events will tend to become less frequent, while more intense rainfall events, separated by a large number of dry days, will tend to become more frequent (Kay and Washington, 2008; Shongwe et al., 2009). Additionally, the proportion of total rainfall coming from extreme precipitation events is expected to increase (McSweeney, New, and Lizcano, 2010).

Risks to health, agriculture and energy generation

Without adaptation, the societal consequences of this general drying trend, with more frequent intense rainfall events, could be profound. The agricultural sector can be expected to suffer greatly from the decline in total precipitation and the shortening of the growing season; as a result, production is likely to decrease. When precipitation does come, the quantity and run-off may be so great that it will benefit the crops only minimally, potentially even doing more harm than good, inundating fields and destroying crops.

Similarly, access to safe drinking water is likely to diminish, putting stress on both cities and rural areas. Cities which currently rely on boreholes and shallow wells risk depleting their sources, while rural communities dependent upon shallow wells and surface water will have to travel greater distances to collect drinking water, increasing incidences of water-borne diseases (cholera and dysentery) and human-wildlife conflicts.

More frequent extreme precipitation events may also result in a rise in water-borne diseases. Flash flooding events could result in more frequent contamination of the water supply, and communities already stressed with limited water supply may see a rise in the number of cholera cases.

The energy sector is also very threatened by this expected trend. A 2010 World Bank assessment of hydropower in Southern Africa, including Zambia, simulated a reduction in annual average energy production of 21 per cent. Reservoir levels behind the hydroelectric generation dams are expected to decrease on an annual basis as a result of more frequent and prolonged drought conditions. This combined with increased surface water evaporation, especially from upstream reservoirs and flood plains, could result in reduced energy generation capacity throughout Zambia (Beilfuss, 2012).

Rising temperatures

In coming decades, the temperature across Zambia, along with the entire southern African region, is widely expected to increase (Hulme et al., 2001; Tyson, 1991; Christensen et al., 2013), and probably at a faster rate than the global average for all seasons (Christensen et al., 2007; IPCC, 2014). The 2013 Intergovernmental Panel on Climate Change (IPCC) AR5 Working Group I report states that temperature is "very likely" (a more than 90 per cent chance) to increase, across Africa throughout the next century. This result has also been observed in several other climate models which show large temperature increases across southern Africa for 2020–40 (Tyson, 1991).

For the IPCC higher-emissions scenario, the ensemble mean annual temperatures are projected to increase by over 2° C, compared to the late 20th century climatology over the African continent.

Only for the IPCC's lower emissions scenario, which assumes ambitious mitigation, are the ensemble mean annual temperature changes less than 2° C, compared to the late 20th century in both the near and long term over Africa.

Human and livestock health

Although not as economically or socially devastating as the expected changes in precipitation variability, the expected temperature rise has several key consequences in the Zambian agriculture and human health sectors. Most notably, overall warmer temperatures can foster elevated disease transmission rates among livestock and aquaculture, exacerbating the stress caused by reduced pasture health and water quality respectively. Expected warmer temperatures during the cold season could result in a higher number of malaria cases, although this could be offset by elevated rates of evapotranspiration and the subsequent reduction in stagnant water.

Increased annual variability

There is some debate as to whether the future, particularly in the tropical Pacific, will look more like El Niño (warm SST) or La Niña (cool SST). Some model studies and the IPCC's AR3 report argued that the mean state of the tropical Pacific will look more like El Niño as the climate warms (Timmermann et al., 1999; IPCC, 2007). This shift is congruent with projections for widespread drying across southern Africa shown in some models, though these projections have a great deal of uncertainty (Giannini et al., 2008). Other studies predict no change in the mean state of the tropical Pacific (Collins, 2005).

One of the major takeaways from studies of changes in ENSO is that not only is there significant model disagreement, but the errors in producing ENSO in many of these models are too large to make a definitive statement on precise intensity increases in the future (Van Oldenborgh et al., 2005). Nevertheless, it has been argued that there will be stronger inter-annual variability in Zambian precipitation stemming from more frequent El Niños and La Niñas (Fauchereau et al., 2003), and more intense La Niña events, which can lead to extremely above average rainfall and flooding (Timmermann et al., 1999; Fauchereau et al., 2003).

The increasing variability in Zambian rainfall throughout the 20th century is notable and related to more spatially widespread and intense droughts associated with El Niño (Fauchereau et al., 2003). The connection between El Niño/La Niña and Zambian rainfall has been increasing in strength over time (Fauchereau et al., 2003; Christensen et al., 2013). This increasing influence has been linked to reduced local Indian Ocean influence due to anthropogenic warming dampening the effect of variability of local SSTs. This has led to increasing drought potential and wet spells in both severity and extent because of ENSOs increasing dominating influence (Fauchereau et al., 2003).

Consequently, understanding how ENSO will change in the future remains an important endeavour for knowing how the climate of Zambia will change in both the near and long term; studies agree that Zambia has felt the growing effect of ENSO; a shift in the mean state to more El Niño-like could result in drying over southern Africa and more frequent intense La Niña events could lead to intense precipitation and flood. Even if there ends up being no change in the mean state of the equatorial tropical Pacific, due to its increasing importance ENSO will continue to influence the variability of rainfall in Southern Africa and Zambia.

7. Simulating near-term climate change in Zambia

A process known as "downscaling" is used in order to model climate at a regional scale. These downscaled models either rely on observed data (known as "statistical downscaling" because they utilized statistical modelling of observed data to project and predict regional climate patterns), or use knowledge of local climate dynamics to bring global climate models down to the regional level (known as "dynamical downscaling"). These downscaled models are referred to as Regional Climate Models (RCM).

A lack of long-term, extensive, and complete observed data in the region means that most downscaling models for the region use dynamical downscaling models. Recent efforts at producing regional dynamical downscaled models include the Coordinated Regional Climate Downscaling Experiment (CORDEX) as well as Fifth-Generation Pennsylvania State University–National Center for Atmospheric Research Mesoscale Model, the Weather Research and Forecasting model, and the Regional Climate Network model. Dynamical downscaling in Southern Africa is in its infancy and presents a number of challenges.

Because convective activity is the major source of precipitation in the region, the parameterization of this activity is a major source of variability within and between models. Difficulty modelling large-scale circulation pattern, complex topography (such as the presence of Lake Malawi), biases in observational data, and difficulties modelling large circulation patterns, introduce biases into RCMs, producing contradicting estimates of precipitation patterns and amounts.

A lack of understanding of regional climate factors described above, as well as challenges modelling large-scale circulation features (the Hadley circulation, for example), creates difficulties in producing skilled models. The very deep low-pressure bias associated with the Angola Low and the cyclonic circulation anomaly in upper tropospheric winds over the region may account for part of the wet bias seen in the models. However, it is difficult to quantify the degree to which large-scale circulation models and parameterization of local climate factors are introducing biases into GCMs because of a lack of relevant observational data (Kalagnomou et al., 2013). Continued work in this field is likely to improve the skill of RCMs for Southern Africa, but improved knowledge of the role of local climate factors is necessary.

8. Limitations and opportunities for research

This review of the current state of knowledge surrounding near-term climate change in Zambia suffers from multiple limitations and gaps that could be addressed by future DFID projects. Perhaps the largest and most obvious limitation in this study stems from the lack of information addressing Zambia. Much of the literature concerning climate phenomena and climate change deal with Southern Africa as a whole; this limits the applicability of some of the features described above to Zambia specifically, as the climates across Southern Africa are not homogeneous. By the same measure, some studies address climate change in general or in the longer term, and had to be interpolated for relevance to the near-term temporal scale.

A lack of local expertise in regional climate processes and model interpretation, as well as limited access to existing climate information from external research organizations, generally increases uncertainty among local decision-makers and stakeholders, depressing the initiative to act upon projections. More local participation in the development and analysis of climate information could positively result in action to adapting to projected climate change. Through this study, decision-makers will have a more robust understanding of these topics and be empowered to act with greater climate consciousness.

There is uncertainty in the future of the ENSO phenomena, in terms of both changes in frequency and intensity of La Niña and El Niño events as well as changes in the mean state of the tropical Pacific Ocean. As a result of the large effect ENSO has on Southern Africa, this uncertainty translates to uncertainty for projections of Southern African rainfall. Moreover, the augmenting strength of the ENSO teleconnection in this region provides an additional form of uncertainty for projections of near-term as well as long-term climate change for Zambia. ENSO, however, is a reasonably well-understood phenomenon, especially in relation to the other dynamical factors influencing the climate of Zambia.

For some climate factors that influence the climate of Zambia, there is little, if any, information on how they will change in a warming world. No information was found to address how the Angola Low or Benguela Niños will change due to warming. Consequently, model studies and/or downscaling exercises could be used to fill this gap. As far as dynamical downscaling is concerned, there are current efforts to address this shortcoming, like the CORDEX experiment referenced earlier; additionally, as time goes on, spatial resolutions have been improved by way of more computing power; but this is, and cannot be, the only solution. At the time of this study however, little useful downscaled information could be gleaned from the literature. Additionally, many dynamical downscaling attempts are plagued with parameterization issues (IPCC, 2014).

As described above, downscaling in this region presents many difficulties. The choice of model can lead to differing sign and magnitude for changes in precipitation. Statistical methods of downscaling, as mentioned before, have suffered from insufficient observational records; as time goes on, especially with improvements in remote sensing, observational data is becoming more robust and hopefully can translate to some useful statistical methods in the future.

Importantly, data is not always freely accessible. There are observations from Zambia, but those datasets are limited and not available for use for outside organizations or research. Access to this observation data could prove valuable for many reasons, including increased potential for statistical methods for seasonal forecasting and statistical downscaling of climate models. Finally, there was no information found concerning how low frequency climatological phenomena, decadal or multi-decadal, will change in the near or long term.

9. Conclusions

Future research of value to Zambia should include more robust understanding and less uncertain projections of ENSO in the future, further efforts to increase spatial resolution, and additional downscaling exercises for more country and regional information. Ideally, downscaling would be able to individually assess each of the agro-ecological zones, which have distinct climates and will change variably under future scenarios. Perhaps more difficult, but still valuable, will be efforts to understand lesser-known phenomena like low frequency variability, Benguela Niños and the Angola Low. However, additional research with respect to these phenomena could alleviate this gap in knowledge and improve climate change projections for Zambia.

The FCFA pilot study and workshops will help to abate many of the societal threats outlined above by strengthening climate adaptation strategies and developing disaster risk management in Zambia. Given the uncertainties in projected climate trends, adaptation strategies that are robust to a variety of possible futures can reduce the need for certainty in the projections. As climate information provided by DFID becomes more precise and predictability increases, its dissemination to vulnerable populations will become increasingly valuable. Actors within Zambia, having a better understanding of near-term climate change, can then engage in "no-regrets" actions that can help the country to better understand and address climate-related hazards, thus leading to improved humanitarian and development outcomes. Having contingency plans that can be acted upon based on improved climate information will greatly reduce the risks posed to the agriculture, human health and energy sectors.

ACKNOWLEDGEMENTS

This document is an output from a project commissioned through the Climate and Development Knowledge Network (CDKN). CDKN is a programme funded by the UK Department for International Development (DFID) and the Netherlands Directorate-General for International Cooperation (DGIS) for the benefit of developing countries. The views expressed and information contained in it are not necessarily those of or endorsed by DFID, DGIS or the entities managing the delivery of the Climate and Development Knowledge Network, which can accept no responsibility or liability for such views, completeness or accuracy of the information or for any reliance placed on them. Additional funding support was provided by the Norwegian Research Council, through the project "Courting Catastrophe? Humanitarian Policy and Practice in a Changing Climate". The Zambian Red Cross Society played a key role in engaging stakeholders and facilitating research activities in country.
The authors are grateful to the peer reviewers for this paper, Arielle Tozier de la Poterie, and George Kasali, as well as to Richard Jones, Erin Coughlan, Bettina Koelle, Carina Bachofen, Pablo Suarez and Alex Wynter for their helpful comments and guidance. The Climate Centre gratefully aknowledges Patricia Nambuka for valuable institutional support and Wisford Mudenda for assistance with logistics.

REFERENCES

Beilfuss, R. A Risk Climate for Southern African Hydro: Assessing Hydrological Risks and Consequences for Zambezi River Basin Dams. In: *International Rivers.* Berkeley, USA, 2012.

Bond, N. R., P. S. Lake, and A. H. Arthington. 'The impacts of drought on freshwater ecosystems: an Australian perspective', in *Hydrobiologia*, Vol. 600 (1), pp. 3-16, 2008.

Chomba, C. 'Patterns of human wildlife conflicts in Zambia, causes, consequences and management responses', in *Journal of Ecology and The Natural Environment*, Vol. 4, pp. 303-313, 2012.

Christensen, J. H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. M. Held, R. Jones, R. K. Kolli, W.-T. Kwon, R. Laprise, V. Magana Rueda, L. Mearns, C. G. Menendez, J. Raisanen, A. Rinke, A. Sarr, and P. Whetton. *Regional Climate Projections*. In: S. Solomon, D. Qin, M. Manning, et al. (editors). *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, United Kindgom and New York, NY, USA, 2007.

Christensen, J. H., K. Krishna Kumar, E. Aldrian, S.-I. An, I. F. A. Cavalcanti, M. de Castro, W. Dong, P. Goswami, A. Hall, J. K. Kanyanga, A. Kitoh, J. Kossin, N.-C. Lau, J. Renwick, D. B. Stephenson, S.-P. Xie, and T. Zhou. *Climate Phenomena and their Relevance for Future Regional Climate Change Supplementary Material.* In: T. F. Stocker, D. Qin, G.-K. Plattner, et al. (editors). *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, United Kingdom and New York, NY, USA, 2013.

Collins, M. 'El Nino- or La Nina-like climate change?', in *Climate Dynamics*, Vol. 24 (1), pp. 89-104, 2005.

Fauchereau, N., S. Trzaska, M. Rouault, and Y. Richard. 'Rainfall variability and changes in southern Arica during the 20th century in the global warming context', in *Natural Hazards*, Vol. 29 (2), pp. 139-154, 2003.

Florenchie, P., J. R. E. Lutjeharms, C. J. C. Reason, S. Masson, and M. Rouault. 'The source of Benguel Ninos in the South Atlantic Ocean', in *Geophysical Research Letters*, Vol. 30 (10), 2003.

Florenchie, P., C. J. C. Reason, J. R. E. Lutjeharms, and M. Rouault. 'Evolution of Interannual Warm and Cold Events in the Southeast Atlantic Ocean', in *Journal of Climate*, Vol. 17 (12), pp. 2318-2334, 2004.

Giannini, A., M. Biasutti, I. M. Held, and A. H. Sobel. 'A global perspective on African climate', in Climatic Change, Vol. 90 (4), pp. 359-383, 2008.

Goddard, L., and N. E. Graham. 'Importance of the Indian Ocean for simulating rainfall anomalies over eastern and southern Africa', in *Journal of Geophysical Research*, Vol. 104 (D16), pp. 19099-19116, 1999.

GRZ-Government of Republic of Zambia. *The National Adaptation Programme of Action (NAPA).* Ministry of Tourism, Environment and Natural Resources (editor). Lusaka, Zambia, 2007.

GRZ-Government of Republic of Zambia. *Sixth National Development Plan (SNDP) 2011-2015*. Ministry of Finance (editor). Lusaka, Zambia, 2011.

Hachigonta, S., and C. J. C. Reason. 'Interannual variability in dry and wet spell characteristics over Zambia', in *Climate Research*, Vol. 32, pp. 49-62, 2006.

Hulme, M., R. Doherty, T. Ngara, M. New, and D. Lister. 'African climate change 1900-2100', in *Climate Research*, Vol. 17 (145-168), 2001.

Hurrell, J. W., M. Visbeck, A. Busalacchi, R. A. Clarke, T. L. Delworth, R. R. Dickson, and W. E. Johns. 'Atlantic climate variability and predictability: A CLIVAR perspective', in *Journal of Climate*, Vol. 19 (20), pp. 5100-5121, 2006.

IFRC-International Federation of Red Cross and Red Crescent Societies. *Zambia: Floods. DREF Operation Final Report. 2010*. Available at http://www.ifrc.org/docs/appeals/10/MDRZM007fr.pdf.

IPCC-Intergovernmental Panel on Climate Change. *Climate Change 2007: The Physical Science Basis.* Contribution of Working Group 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. S. Solomon, D. Qin, M. Manning, et al. (editors). Cambridge, United Kingdom and New York, NY, USA, 2007.

IPCC-Intergovernmental Panel on Climate Change. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* T. F. Stocker, D. Qin, G.-K. Plattner, et al. (editors). Cambridge, United Kingdom and New York, NY, USA, 2013.

IPCC-Intergovernmental Panel on Climate Change. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects.Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* V. R. Barros, C. B. Field, D. J. Dokken, et al. (editors). Cambridge, United Kingdom and New York, NY, USA, 2014.

Kalagnomou, E.-A., C. Lennard, M. Shongwe, I. Pinto, A. Farve, M. Kent, B. Hewitson, A. Bosio, G. Nikulin, H.-J. Panitz, and M. Buchner. 'A Diagnostic Evaluation of Precipitation in CORDEX Models over Southern Africa', in *Journal of Climate*, Vol. 26, pp. 9477-9506, 2013.

Kay, G., and R. Washington. 'Future southern African summer rainfall variability related to a southwest Indian Ocean dipole in HadCM3', in *Geophysical Research Letters,* Vol. 35 (12), pp. L12701, 2008.

Kirtman, B., S. B. Power, J. A. Adedoyin, G. J. Boer, R. Bojariu, I. Camilloni, F. J. Doblas-Reyes, A. M. Fiore, M. Kimoto, G. A. Meehl, M. Prather, A. Sarr, C. Schar, R. Sutton, G. J. van Oldenborgh, G. Vecchi, and H. J. Wang. *Near-term Climate Change: Projections and Predictability.* In: T. F. Stocker, D. Qin, G.-K. Plattner, et al. (editors). *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, United Kingdom and New York, NY, USA, 2013.

Leary, N., J. Kulkarni, and C. Seipt. *Assessment of Impacts and Adaptation to Climate Change* (AIACC). Washington, D.C., USA, 2007.

McSweeney, C., M. New, and G. Lizcano. 'UNDP Climate Change Country Profiles: Zambia', 2010.

McSweeney, C., M. New, G. Lizcano, and X. Lu. 'The UNDP Climate Change Country Profiles Improving the Accessibility of Observed and Projected Climate Information for Studies of Climate Change in Developing Countries', in *Bulletin of the American Meteorological Society*, Vol. 91 (157-166), 2010.

New, M., B. Hewitson, D. B. Stephenson, A. Tsiga, A. Kruger, A. Manhique, B. Gomez, C. A. S. Coelho, D. Ntiki Masisi, E. Kululanga, E. Mbambalala, F. Adesina, H. Saleh, J. Kanyanga, J. Adosi, L. Bulane, L. Fortunata, M. L. Mdoka, and R. Lajoie. 'Evidence of trends in daily climate extremes over southern and west Africa', in *Journal of Geophysical Research*, Vol. 11 (D14102), pp. 1-11, 2006.

Plisnier, P. D., S. Serneels, and E. F. Lambin. 'Impact of ENSO on East African ecosystems: a multivariate analysis based on climate and remote sensing data', in *Global Ecology and Biogeography*, Vol. 9 (6), pp. 481-497, 2008.

Reason, C. J. C., W. Landman, and W. Tennant. 'Seasonal to decadal prediction of southern African climate and its links with variability of the Atlantic Ocean', in Bulletin of the American Meteorological Society, Vol. 87 (7), pp. 941-955, 2006.

Rouault, M., P. Florenchie, N. Fauchereau, and C. J. C. Reason. 'South East tropical Atlantic warm events and southern African rainfall', in Geophysical Research Letters, pp. 9-1 to 9-4, 2003.

Shongwe, M. E., G. J. van Oldenborgh, B. J. J. M. van den Hurk, B. de Boer, C. A. S. Coelho, and M. K. van Aalst. 'Projected Changes in Mean and Extreme Precipitation in Africa under Global Warming. Part I: Southern Africa', in *Journal of Climat*e, Vol. 22 (13), pp. 3819-3837, 2009.

Tadross, M., P. Suarez, A. Lotsch, S. Hachigonta, M. Mdoka, L. Ungani, F. Lucio, D. Kamdonyo, and M. Muchinda. 'Growing-season rainfall and scenarios of future change in southast Africa: implications for cultivating maize', in *Climate Research*, Vol. 40, pp. 147-161, 2009.

The World Bank. *The Zambezi River Basin: A Multi-Sector Investment Opportunities Analysis.* Water Resources Management, Africa Region (editor). Washington, D.C., USA, 2010.

The World Bank. ‘Zambia Overview.’ *Countries*. 2014. Available at http://www.worldbank.org/en/country/zambia/overview.

Timmermann, A., J. Oberhuber, A. Bacher, M. Esch, M. Latif, and E. Roeckner. ‘Increased El Nino frequency in a climate model forced by future grenhouse warming’, in *Nature*, Vol. 398 (6729), pp. 694-697, 1999.

Tyson, P. D. ‘Climatic Change in Southern Africa: Past and Present Conditions and Possible Future Scenarios’, in *Climatic Change*, Vol. 18, pp. 241-258, 1991.

UNICEF-United Nations Children’s Fund. ‘Malaria.’ *UNICEF Zambia Fact Sheets. 2014*. Available at http://www.unicef.org/zambia/5109_8454.html.

van Oldenborgh, G. J., G. Jan, S. Philip, and M. Collins. ‘El Nino in a changing climate: a multi-model study’, in *Ocean Science Discussions*, Vol. 2 (3), pp. 267-298, 2005.