VUNA

changing farming for
a changing climate

Climate Risks and Trends in Eastern and Southern Africa

Research Report commissioned by Vuna | November 2016

Adam Smith
International

UKaid
from the British people

Please cite this publication as follows:

Mutamba, Manyewu. 2016. Climate Risks and Trends in Eastern and Southern Africa. Vuna Research Report. Pretoria: Vuna. Online: http://www.vuna-africa.com

Project Team

Quality Assurance	David Rohrbach
Project Manager	Vimbai Chasi
Editor	Mark Essig

Date: November 2016 | **Lead Author:** Manyewu Mutamba | **QA'd by:** David Rohrbach

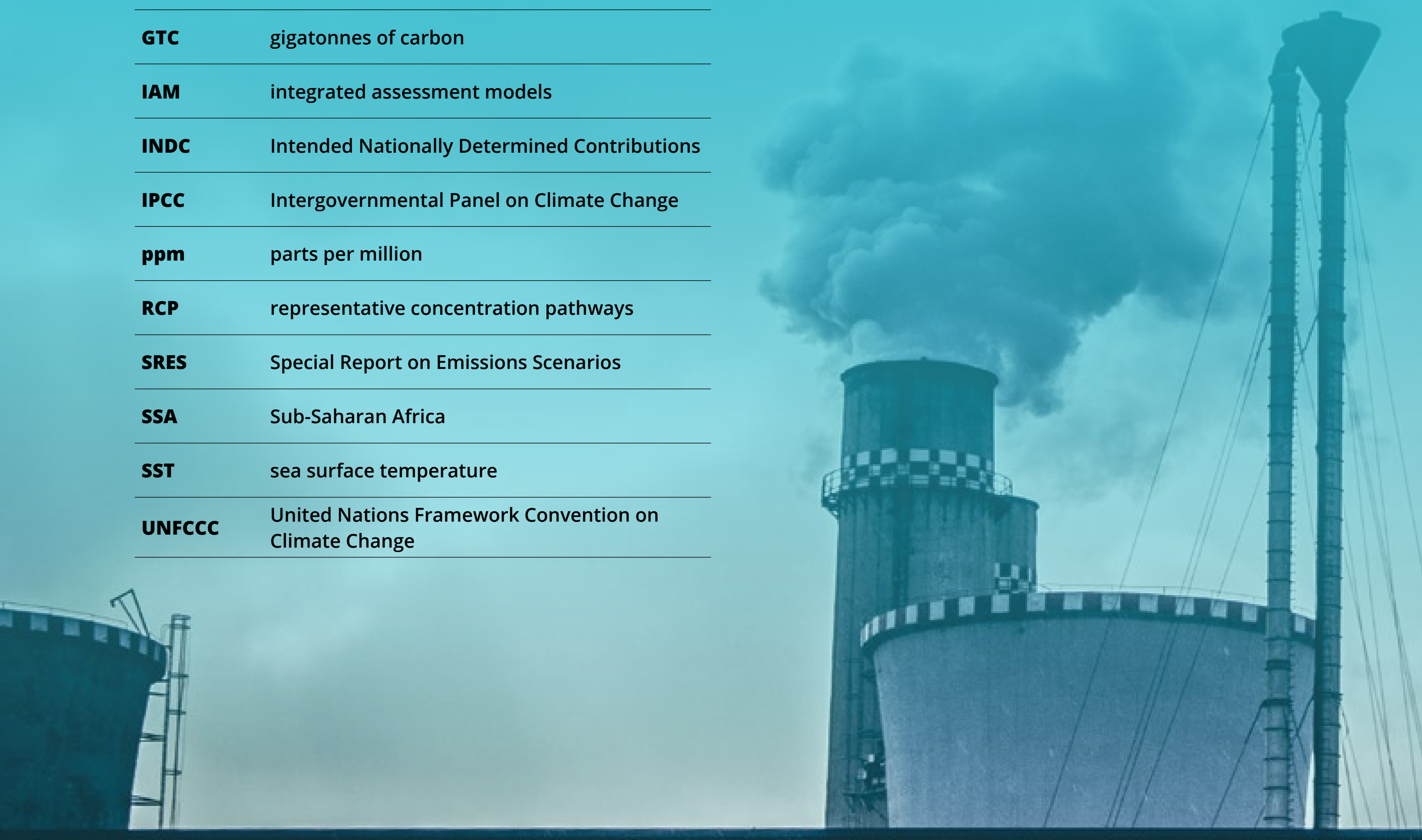
Vuna is a DFID-funded regional Climate Smart Agriculture Programme. The British Government's Department for International Development (DFID) financed this work as part of the United Kingdom's aid programme. However, the views and recommendations contained in this report are those of the consultant, and DFID is not responsible for, or bound by the recommendations made. This material is not to be reproduced, altered, contents deleted or modified in any way without written permission from Vuna.

UKaid
from the British people

TABLE OF CONTENTS

Acronyms

AfricaCSA	Africa Climate Smart Alliance
AR5	Fifth Assessment Report
C	centigrade
CCAFS	Climate Change, Agriculture and Food Security
CO_2	carbon dioxide
COP21	21st Conference of Parties
CSA	climate smart agriculture
DFID	Department for International Development
ENSO	El Niño-Southern Oscillation
ESA	Eastern and Southern Africa
FAO	Food and Agriculture Organization of the United Nations
GACSA	Global Alliance for Climate Smart Agriculture
GCM	general circulation model
GHG	greenhouse gases
GTC	gigatonnes of carbon
IAM	integrated assessment models
INDC	Intended Nationally Determined Contributions
IPCC	Intergovernmental Panel on Climate Change
ppm	parts per million
RCP	representative concentration pathways
SRES	Special Report on Emissions Scenarios
SSA	Sub-Saharan Africa
SST	sea surface temperature
UNFCCC	United Nations Framework Convention on Climate Change



Executive summary

Agricultural production in Eastern and Southern Africa (ESA) is broadly characterised by high climate risks. Rainfall is variable in timing, amount, and intensity. Both drought and flooding are common. These challenges are magnified by the fact that the majority of farmers in this region face severe poverty, resource constraints, and food insecurity. More than 90% of these farmers are dependent on rainfed production. The rise in global greenhouse gases appears to be increasing these climate risks.

This paper briefly summarises available information on current climate risks in ESA, and then shows how these risks are expected to worsen by the middle and end of the century. It discusses the implications of these changing risks for agricultural investment and for prioritising the pursuit of more climate smart agricultural systems. A key theme underlying this discussion is that a better understanding of, and response to, current climate risks will provide a strong foundation for improving resilience to climate change in the future.

> Rising concentrations of CO2 will continue to have varied impacts.

The paper primarily summarises key findings of the Fifth Assessment Report (AR5) by the Intergovernmental Panel on Climate Change (IPCC) for Eastern and Southern Africa. The AR5 is the latest in a series of scientific publications on climate change that are periodically produced by the IPCC. The multiple volumes of the AR5 encompass thousands of pages of discussion of both the science of climate change and the expected impacts. This paper reviews a subset of information most relevant to practitioners and policy makers concerned about climate change and climate smart agriculture in ESA. Emphasis is placed on summarising current and projected changes in five key climate parameters important to agriculture: temperature, precipitation, extreme events such as droughts and flooding, carbon dioxide (CO_2) concentrations, and pest and disease pressures.

Current climate risks in ESA: The AR5 reports highlight the fact that temperatures in much of Sub-Saharan Africa (SSA) are rising faster than in other parts of the world. In most of ESA, temperatures have already increased by 0.5-1.0 degree centigrade over the past 50 years. The largest gains have occurred in average minimum temperatures. Large inter- and intra-annual rainfall variability is already a major challenge for agricultural production in many parts of ESA. Data and model limitations cloud the picture of changes in recent decades, with some findings suggesting greater rainfall variability and others indicating little change in these risks. The general circulation models (GCMs) are not able to consistently model extreme events such as droughts and floods. However, some estimates derived from analyses of sea surface temperatures (SST) suggest these risks have become more frequent in Eastern Africa over the past 30 to 60 years. In Southern Africa the likelihood of extreme temperatures increased in recent decades. The combination of higher temperatures and variable rainfall may be contributing to rising pest and disease pressures. Cumulative CO_2 emissions from 1750 to 2011 are 545 gigatonnes of carbon (GTC). Higher levels of CO_2 are contributing to rising temperatures and greater variability of rainfall. But rising CO_2 concentrations also lead to improvements in agricultural productivity.

Projected changes in climate risk: If current trends in greenhouse gas emissions persist, temperatures are projected to rise by 2 degrees centigrade by mid-century, and by 3-6 degrees by the end of the century in most of ESA. Models of precipitation are less conclusive. Decreases in rainfall are projected in southwestern parts of Southern Africa by the mid-21st century. By contrast, projections for Eastern Africa suggest an increase in rainfall over this period, with a wetter climate and less severe droughts expected by the end of the century. In most regions, rainfall is expected to be more variable, but much uncertainty remains about the level and speed of these changes. Again, the GCMs do not predict extremes well. However, several background studies suggest that droughts and flooding may become more common. Rising concentrations of CO_2 will continue to have varied impacts, contributing to rising temperatures but also improving plant growth. Depending on the ultimate levels of temperature and rainfall changes, the geographical ranges of some pests and diseases will shift.

Implications for agriculture: In the near term, the adoption of agricultural technologies, production levels, and food security will be affected more by rising population pressures and changing market conditions than by changes in climate. However, given the high costs of droughts and flooding, higher priority needs to be attached to the promotion of climate smart practices that improve resilience to these risks. Over time, the prospect of continuing increases in temperature suggests the importance of investments in crop varieties that are more temperature- and drought-tolerant, and field management strategies that reduce evaporation. The prospect of more erratic rainfall suggests the need for technologies offering improved water-harvesting and water-use efficiency. Continuing improvement in seasonal forecasting offers the prospect of higher payoffs from response farming. More successful responses to current climate risks will significantly improve our capacity to respond to future climate risks.

1 Introduction

In recent years, agriculture has gained increasing prominence in discussions about climate change. This reflects a growing recognition that agriculture is a major contributor to greenhouse gases, but also that crop productivity could decline substantially if farmers do not adapt to changing weather patterns. These concerns led to more substantial discussion of agriculture and climate change in the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), the latest in a series of scientific publications on climate change that are periodically produced by the IPCC. The multivolume report (e.g., IPCC, 2013; IPCC 2014a; IPCC 2014b; IPCC 2014c) provides the most comprehensive review available of trends in climate change and their expected impacts.

The importance of agriculture as both a contributor and a respondent to climate change was also highlighted in the 2015 Paris Climate Conference, officially called the 21st Conference of Parties (COP21). The preface to the Paris Agreement, negotiated under the United Nations Framework Convention on Climate Change (UNFCCC), states that all signatories to the agreement recognise "the fundamental priority of safeguarding food security and ending hunger, and the particular vulnerabilities of food production systems to the adverse impacts of climate change" (UNFCCC, 2015, p. 1). In preparing for this conference, governments drafted Intended Nationally Determined Contributions (INDC) identifying how they would respond to the risks of climate change. More than 80% of these plans prominently feature agriculture (CCAFS, 2016).

Larger levels of national and international funding are correspondingly being allocated to the development and promotion of climate smart agriculture (CSA). This term has been formally defined by the Food and Agriculture Organization of the United Nations (FAO) as consisting of three components: (1) sustainably increasing agricultural productivity and incomes; (2) adapting and building resilience to climate change; (3) reducing and/or removing greenhouse gases emissions, where possible (FAO, 2013; p. ix). The Global Alliance for Climate Smart Agriculture (GACSA) is a multi-stakeholder coalition promoting the incorporation of CSA approaches within food and agricultural systems (United Nations, 2014). Its African affiliate, the Africa Climate Smart Alliance (AfricaCSA), has committed to up-scale the adoption of CSA approaches, targeting six million smallholder farmers in Sub-Saharan Africa by 2021 (AfricaCSA, 2014). In line with the AfricaCSA, the VUNA programme on CSA, funded by the United Kingdom's Department for International Development (DFID), aims to increase the climate resilience of vulnerable farming communities across ESA by supporting the uptake of holistic CSA practices by smallholder farmers (Vuna, 2016). There are many related programmes.

A key challenge is to prioritise the extremely broad array of agricultural technologies, institutional arrangements, and activities now being called "climate smart" (e.g. Rosenstock et al., 2016; Nzuma et al., 2014). In particular, most CSA programmes need to clarify how they are improving the adaptation and resilience of smallholder farmers to climate change. In order to address this issue, it is first necessary to identify what specific changes in climate, and what specific climate risks, agriculture must adapt to.

Unfortunately, changes in climate are difficult to measure in ESA because of the large historical variability in climate patterns and the limited availability and inconsistency of historical climate data. Lay observers easily confuse annual anomalies in weather data (e.g., a later start to rains or a severe drought) with an evolving climate risk. In fact, risks such as drought, flooding, and variable rainfall patterns are endemic in this region. It is not clear that these risks are changing as a result of rising levels of greenhouse gases (GHG). However, if CSA aims to improve adaptation and resilience to current climate risks as well as future risks that may result from climate change, this distinction is less important. The challenge is simply to better demarcate these current risks, and to seek understanding of how these risks are likely to change over time.

The IPCC's AR5 reports highlight the inconsistent and sometimes conflicting evidence of climate change in ESA. Much depends on the models being cited. The findings most prominently discussed are based on a subset of GCMs that highlight the correlation between the rise of GHG and changing climate patterns. Projections of climate change are based on an evolving set of scenario analyses (see Box 1) linked with expectations regarding the continuing growth in atmospheric concentrations of GHG. The AR5 identifies these scenarios as different representative concentration pathways (RCP). A lower RCP of 2.6 refers to a scenario in which GHG will start to rapidly decline. The higher RCP of 8.5 refers to a scenario with a continuing rise in GHG. These models seem to accurately predict rising global and regional temperatures. However, they are less accurate in projecting changing precipitation, and they are currently poor at predicting droughts and flooding. The AR5 correspondingly cites a wider range of literature examining two other measures of climate change: (1) models based on changing sea surface temperatures (SST), and (2) extrapolations of historical temperature and rainfall data. The GCMs do not provide good predictions of SST. However, the SST models seem to offer better predictions of droughts and flooding. The analyses of changes in historical weather data provide more detailed information about changes in rainfall within the agricultural season—including evidence of changes in season timing and length, as well as the incidence of mid-season dry spells. The accuracy of extrapolations from these data, however, is uncertain. Citing the different results based on different scenarios and different models in the AR5 can lead to confusion. But these challenges also highlight the persistent gaps in our knowledge of climate trends. Readers interested in more detail are encouraged to read the original IPCC reports (e.g., IPCC, 2013; IPCC 2014a; IPCC 2014b; IPCC 2014c) and the many additional background texts cited.

Box 1. Scenarios used in AR5

A scenario is a storyline or image that describes a potential future, developed to inform decision-making under uncertainty. Scenarios have been part of IPCC future climate projections since 1990 when four scenarios (Bau = business-as-usual, B, C, and D) were used to project climate change. These have since evolved through the successive assessment reports. In 2001 the IPCC Special Report on Emissions Scenarios (SRES) created many scenarios from four Integrated Assessment Models (IAMs), out of which a representative range of marker scenarios were selected (A1B, A1T, A1FI, A2, B1, B2). In the SRES, scenarios had socioeconomic storylines, but climate-mitigation options were not included. The SRES scenarios carried over into the Fourth Assessment Report (AR4, 2007) and formed the basis for the large number of ensemble climate simulations (Coupled Model Intercomparison Project Phase 3 (CMIP3)), which are still in use for climate-change studies relevant to AR5.

With AR5, the development of scenarios fundamentally changed from the IPCC-led SRES process. An ad hoc group of experts built a new structure for scenarios called representative concentration pathways (RCPs) using updated IAMs. It was intended to provide a flexible, interactive, and iterative approach to climate-change scenarios. The four RCPs are keyed to a range of trajectories of GHG concentrations and climate forcing. They are labelled by the approximate radiative forcing (RF, W m–2) that is reached during or near the end of the 21st century (RCP2.6, RCP4.5, RCP6.0, RCP8.5). A stringent mitigation scenario (RCP2.6) represents the best case, in which greenhouse gases are rapidly reduced, while the highest GHG emissions scenario (RCP8.5) is a worst case, with a continuing rise in greenhouse gas emissions.

Source: IPCC, 2014a

It is also important to consider the variation of timeframes considered and the levels of confidence underlying the projected results. Some of the climate changes cited are already occurring. However, many of the largest changes are expected to occur only by the middle or end of the 21st century. Levels of confidence regarding these possible changes vary from low to high. For example, lower levels of confidence are attached to projections of changes in rainfall in the next twenty years, but higher levels of confidence are attached to projections of changes of rainfall by late in the century. Even so, the spatial extent of these projections is not consistently clear.

Drought risks are among the most difficult of climate problems faced by farmers. However, the AR5 does not consistently distinguish the various types of drought being considered (see Box 2). The IPCC reports most commonly discuss the prospects for *meteorological* drought, or a deficit of rainfall relative to some normal or average amount. For agriculture, however, the timing of the deficit relative to plant growth—termed *agricultural* drought—is more important than the absolute level of rainfall. The impact of the deficit also depends on the soil type and its water-holding capacity, as well as the type of crop grown. Farmers in ESA are concerned about when the rainy season starts, the consistency of rainfall, the chances of a mid-season dry spell, and the length of the rainy season. In addition, farmers who are dependent on irrigation are more concerned about the prospects for *hydrological* drought, which depends on the relationship between rainfall and streamflow or groundwater supplies, which in turn depends on topography, evaporation, and the levels of competition for these water resources. In effect, projected changes in precipitation linked with climate change are only indirectly related to the actual incidence of agricultural or hydrological drought.

Box 2. Types of drought

Meteorological drought is defined usually on the basis of the degree of dryness (in comparison to some "normal" or average amount) and the duration of the dry period. Definitions of meteorological drought must be considered as region-specific, because the atmospheric conditions that result in deficiencies of precipitation are highly variable from region to region.

Hydrological drought is associated with the effects of periods of precipitation (including snowfall) shortfalls on surface or subsurface water supply (i.e., streamflow, reservoir and lake levels, groundwater). The frequency and severity of hydrological drought is often defined on a watershed or river-basin scale. Although all droughts originate with a deficiency of precipitation, hydrologists are more concerned with how this deficiency plays out through the hydrologic system. Hydrological droughts are usually out of phase with or lag the occurrence of meteorological and agricultural droughts. It takes longer for precipitation deficiencies to show up in components of the hydrological system such as soil moisture, streamflow, and groundwater and reservoir levels.

Agricultural drought links various characteristics of meteorological (or hydrological) drought to agricultural impacts, focusing on precipitation shortages, differences between actual and potential evapotranspiration, soil water deficits, reduced groundwater or reservoir levels, and so forth. A plant's water demand depends on prevailing weather conditions, the biological characteristics of the specific plant, its stage of growth, and the physical and biological properties of the soil. A good definition of agricultural drought should be able to account for the variable susceptibility of crops during different stages of crop development, from emergence to maturity.

Source: National Drought Mitigation Center, 2016.

This paper aims to promote improved understanding of how agricultural climate risks in ESA are changing as a result of global and regional climate change. It briefly summarises the AR5 findings about current climate risks relating to agriculture. It then discusses the projected changes in these risks in ESA by the end of the 21st century. Finally, it discusses some of the implications of these findings for prioritising investments in CSA.

> "Drought risks are among the most difficult of climate problems faced by farmers.

2 Current climate risks in Eastern and Southern Africa

The East and Southern Africa (ESA) region faces endemic climate risk[1] largely associated with inter- and intra-seasonal variability in precipitation, and the likelihood of drought or flooding. These risks undermine the willingness of farmers to invest scarce resources in new technologies or management practices. The loss of a single harvest can quickly bring a family to the brink of starvation. Key farming assets may have to be sold in order to preserve household livelihoods. In this context, investments offering low but consistent yields may be favoured over investments offering higher average returns, but also a higher probability of catastrophic losses. Average productivity and food security remain low. A key challenge for CSA is the need to help farmers better cope with these current climate risks. Solutions here will contribute to improving climate resilience if these risks worsen as a result of climate change.

The impacts of climate change on food production will largely be transmitted through five key parameters: (1) temperature, (2) precipitation, (3) extreme events, (4) CO_2 concentrations, and (5) pests and diseases incidence. The following discussion reviews the AR5 findings on the recent changes and current incidence of these risks in ESA. This is particularly important for the identification and prioritisation of the most immediate CSA investment needs.

2.1 Current temperature risks

The recent temperature trends cited in the AR5 are unambiguous. More than a dozen studies concur that temperatures over most African regions have increased by 0.5 degree centigrade or more over the past 50 to 100 years (Rosenzweig et al., 2007; Trenberth et al., 2007; Christy et al., 2009; Collins, 2011; Hoffman et al., 2011; Mohamed, 2011; Stern et al., 2011; Funk et al., 2012; Nicholson et al., 2013, as cited in Niang et al., 2014, p. 1206). In Eastern Africa, sub-regional analyses confirm that the equatorial and southern parts of this region experienced significant increases in temperature within the last 30 years (Anyah and Qiu, 2012, as cited in Niang et al., 2014, p. 1206). Many parts of Ethiopia, Kenya, South Sudan, and Uganda witnessed an increase in seasonal average temperatures over the last 50 years (Funk et al., 2011, 2012, as cited in Niang et al., 2014, p. 1206). Countries bordering the western Indian Ocean were also found to have experienced this trend. In Southern Africa, related studies indicate increasing trends in annual average, minimum, and maximum temperatures in the last 60 years, with most of the warming occurring in the last two decades (Zhou et al., 2010; Collins, 2011; Kruger and Sekele, 2012, as cited in Niang et al., 2014, p. 1206). In general, minimum temperatures were found to have increased more rapidly than maximum temperatures (New et al., 2006, as cited in Niang et al., 2014, p. 1206). There was a warming trend between 1961 and 2008, as well as an increase in intensity of temperature extremes (Vincent et al., 2011, as cited in Niang et al., 2014, p. 1206).

The impacts of these rising temperatures on agriculture depend on the timing of these changes (e.g., what part of the year the changes are occurring), the incidence of extremes, and whether the extremes occur as higher minimum or higher maximum temperatures. Higher minimum temperatures may have less impact on most field crops but could severely affect the productivity of fruits that are dependent on a winter cold spell. The impacts of higher maximum temperatures depend on both their timing during the production season (e.g., if they occur during the critical growth stages of germination or flowering) and the likelihood of reaching biological thresholds, which vary by crop. Impacts also depend on variety choice and the crop management practices employed. More analysis is needed to evaluate these agricultural impacts.

2.2 Current rainfall risks

Rainfall risks are endemic in much of Eastern and Southern Africa. Seasons start late and end early. Mid-season dry spells are common. Rainfall varies by year and by intensity within the season. These risks have been identified as the most significant climate-related threat to food production in the near term (FAO, 2016). In combination with higher temperatures, lower rainfall and erratic seasonal patterns result in significant yield losses due to moisture stress,

---

[1] Risk is the potential for consequences where something of value is at stake and where the outcome is uncertain, recognising the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. Risk results from the interaction of vulnerability, exposure, and hazard (IPPC, 2014b; Pg 5).

especially when they occur at critical stages of crop growth such as flowering and grain filling (Iqbal et al., 2009; Lobell et al., 2013; Moriondo et al., 2011, as cited in Porter et al., 2014, p. 497).

A lack of sufficient historical data, coupled with significant discrepancies in those rainfall records that are available, limits the ability to draw conclusions regarding recent trends in annual precipitation in ESA over the past century. Based on the review of historical records, analysts (Rosell and Holmer, 2007; Hession and Moore, 2011, as cited in Niang et al., 2014, p. 1209), found a high degree of temporal and spatial variability in precipitation across East Africa. The months of March, May, and June were found to have received reduced precipitation over the last three decades (Williams and Funk, 2011; Funk et al., 2008, as cited in Niang et al., 2014, p. 1209). This has been attributed to the rapid warming of the Indian Ocean. The last 60 years (1948-2009) have also seen a decline in monsoonal precipitation across much of the Horn of Africa region due to changes in sea level pressure between the southern Mediterranean and the northern Indian Ocean (Williams et al., 2012, as cited in Niang et al., 2014, p.1209).

In Southern Africa, historical rainfall records indicate a reduction in late summer precipitation during the second half of the 20th century, particularly over the region's western half, from Namibia to Angola and Congo. This similarly has been attributed to a rising trend in surface temperatures of the Indian Ocean (Hoerling et al., 2006; New et al., 2006 as cited in Niang et al., 2014, p. 1209). A modest decline in rainfall has been observed for the western parts of South Africa, Zimbabwe, and Botswana. Some observers cite intra-seasonal changes to the onset of the rainy season, increasing intensity of dry spells, and increasing intensity of daily rainfall (Tadross et al., 2005, 2009; Thomas et al., 2007; Kniveton et al., 2009, as cited in Niang et al., 2014, p.1209). However, Stern and Cooper (2011) identify no such change.

Overall, it has proven difficult to distinguish changes in rainfall risks in the context of the natural variability of precipitation patterns. These difficulties are multiplied by the lack of consistent historical data and intraregional variation of findings. While the variability of rainfall levels and timing may have increased, it is not known whether these trends can be extrapolated into the future. The most accurate conclusion may be that rainfall risks remain significant for a large proportion of farming households in ESA.

2.3 Current extreme event risks

Droughts and flooding are common hazards in ESA. In recent decades, the southern parts of the region have been struck by five major, widespread droughts (1991-1992, 1994-1995, 2000-2001, 2005-2006, and 2015-2016) and numerous smaller droughts. These have resulted in crop failure, degradation of rangelands, and depletion of water sources, and they often have led to significant loss of crop harvest and livestock. FAO (2016) cites 20-60% losses in animal numbers during serious drought events in the past two or three decades.

Floods have been commonly caused by two factors. First, persistently heavy rainfall caused by cyclonic storms periodically causes widespread flooding in the eastern regions bordering the Indian Ocean, including large parts of Mozambique, Zimbabwe, and Malawi. Second, localised flooding in many inland areas is associated with sudden, high-intensity rainfall falling over generally flat terrain, leading rivers to burst their banks and dams to overflow.

The AR5 cites a number of studies that show that droughts and floods have become more frequent in ESA (Funk et al., 2008; Williams and Funk, 2011; Shongwe et al., 2011; Lyon and DeWitt, 2012, as cited in Niang et al., 2014, p. 1211). However, it remains unclear whether these changes are the result of human influence on the climate or are part of the natural variability in weather patterns. More reports of drought may also result from the combination of rising populations in drought- and flood-prone regions, as well as better communications in previously isolated areas.

Predictions of floods and drought are most closely related to changes in SST. For example, most of the recent droughts in Southern Africa have been linked to the occurrence of the El Niño-Southern Oscillation (ENSO) phenomenon in the Pacific Ocean. La Niña events are correlated with higher-than-average rainfall. Changes in SST in the Indian Ocean are linked with the likelihood of cyclonic activity. None of these changes have been empirically linked, however, with the global rise in greenhouse gases.

In line with upward trends in average temperatures, the last two decades of the 20th century saw an increase in the likelihood of heat waves in South Africa compared to the period 1961-1980 (Lyon, 2009, as cited in Niang et al., 2014, p.1211). These have been correlated with dry conditions that are typical of El Niño events.

2.4 Current carbon dioxide risks

GCMs—representing physical processes in the atmosphere, ocean, cryosphere, and land surface—are the most advanced tools currently available for simulating the response of the global climate system to increasing greenhouse gas concentrations (IPCC, 2014a). Human activities are the dominant cause of the observed increase in GHGs since 1750 and of the consequent global warming (IPCC, 2014a). AR5 reports that GHGs (made up of mainly carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O)) have increased more rapidly since 1970 than during prior decades (IPCC, 2014a). Present-day (2011) abundances of GHGs exceed the range over the past 800,000 years. Annual emission of CO_2 from fossil fuels and cement production was 9.5 gigatonnes of carbon (GTC) in 2011, 54% above the 1990 level (IPCC, 2014b). More than 20% of this added CO_2 will remain in the atmosphere for longer than 1000 years (IPCC, 2014a).

On a global basis, farming and forestry, including deforestation, contribute approximately 24 percent of annual GHG emissions, and together are the second-largest emitter after the energy sector (IPCC 2014c). The largest shares of these emissions are derived from cattle production, fertilisation, and deforestation. Smaller quantities of emissions come from rice production, the burning of crop residues, and fuel use on farms. While the aggregate contribution of Sub-Saharan Africa to global emissions is currently small, it is expected to increase sharply with population and income growth (World Resources Institute, 2014).

Climate smart agriculture encompasses efforts to reduce greenhouse gases emissions. However, it is also important to note that CO_2 concentrations above 100 parts per million can increase the rate of leaf photosynthesis and improve water-use efficiency, especially in C3[2] crops like wheat and rice (Porter et al., 2014, p. 488). The highest yield benefits from elevated CO_2 concentration were observed in tuber crops like cassava, due to their ability to store extra carbohydrates in their roots. This factor is expected to partially offset any possible decline in yields associated with rising temperatures and the decline of rainfall (Porter et al., 2014).

Unfortunately, elevated levels of CO_2 also favour the growth of weeds, increasing competition for water and nutrients in crop fields. The combination of changes in climate and rising CO_2 concentrations will likely enhance the distribution, and increase the competitiveness, of agronomically important and invasive weeds. Without improvements in management, weeds could potentially cause yield losses of 10-36% (FAO 2016). There is also evidence that elevated CO_2 concentrations will have negative impacts on the nutritional quality of food and fodder, particularly the protein and micronutrient content (Porter et al., 2014, p. 488). Lower levels of protein and decreased edible portions in food crops such as rice, wheat, barley, and potato have been reported (Taub et al., 2008, as cited in Porter et al., 2014, p. 501).

2.5 Current pest and disease risks

Pest and diseases already pose significant risks to agricultural production. Average yield losses due to pests and diseases have been estimated at about 16-18% for major crops (Porter et al., 2014, p. 500). The FAO estimated the yield loss to pests alone at about 10-16% of the global harvest each year. The cost of these losses was estimated to be at least $220 billion per year (FAO, 2016).

No data are available measuring changes in pest and disease incidence overall in ESA. However, it is known that changes in precipitation and temperature are likely to change and extend the geographical range of species habitation. This could take pests and diseases into areas that are not prepared for them, potentially causing catastrophic yield losses. Higher minimum temperatures, in particular, will enable overwintering by pests, increasing populations and allowing then to appear earlier in the season when crops are most vulnerable.

---

[2] C3 plants (e.g., rice, wheat, barley, and legumes) fix and reduce inorganic CO_2 into organic compounds using only the C3 pathway in photosynthesis. This is the most basic type of photosynthesis, employed by approximately 85% of earth's plants. C4 plants (e.g. maize, sorghum, and millet) employ the C4 photosynthesis, a more complex adaptation that allows them to survive in hot and dry areas, and they can, therefore, out-compete C3 plants in these areas. See http://www.cropsreview.com/c3-plants.html

3 Projected climate trends in Eastern and Southern Africa

3.1 Temperature projections

The strongest and most unambiguous climate projections cited by the AR5 relate to temperature. These are expected to continue rising under both the best case (RCP 2.6) and worst case (RCP 8.5) emissions scenarios. In the coming decades, Africa as a whole is projected to experience faster warming than the rest of the world (Christensen et al., 2007; Joshi et al., 2011; Sanderson et al., 2011; James and Washington, 2013, as cited in Niang et al., 2014, p. 1209). If current trends in GHG emissions are not arrested (i.e., the RCP 8.5 scenario), an additional increase in average temperature exceeding 2 degrees centigrade is projected by 2050. By 2100, this increase is projected to exceed 4 degrees. Southern Africa is projected to experience larger temperature increases than northern parts of the continent (Sillmann and Roeckner, 2008; Watterson, 2009; Mariotti et al., 2011; Orlowsky and Seneviratne, 2012; James and Washington, 2013, as cited in Niang et al., 2014, p. 1209).

Multiple studies cited in the AR5 project a higher frequency of heat waves and higher rates of evaporation in parts of East Africa (Niang et al., 2014). By 2050-2100, countries along the equator are projected to have a significant number of days warmer than 2 degrees centigrade above the late-20th century average (Anyah and Qiu, 2012, as cited in Niang et al., 2014, p. 1209). By the end of the century, areas around the upper Blue Nile are projected to experience temperature increases of 2-5 degrees centigrade compared to a 1961-1990 baseline (Elshamy et al., 2009, as cited in Niang et al., 2014, p. 1209).

Temperature increases in Southern Africa are projected to exceed global average increases in all seasons. Projections suggest that temperature increases could reach 3.4-4.2 degrees by the end of the century compared to averages for 1981-2000 (Moise and Hudson, 2008 as cited in Niang et al., 2014, p. 1209). A number of studies (Moise and Hudson, 2008; Engelbrecht et al., 2009; Shongwe et al., 2009; Watterson, 2009, as cited in Niang et al., 2014, p. 1209) have projected high warming for the southwestern half of the sub-region, including northwestern South Africa, Botswana, and Namibia. If emission levels continued to rise at current levels (RCP 8.5), a number of studies project (with high confidence) that by the end of the 21st century annual average temperatures for most African regions would be 3-6 degrees hotter than averages for 1986-2005 (Niang et al., 2014, p. 1209).

This generic discussion of temperature trends needs to be matched by a closer assessment of the timing of these increases—for example, whether minimum temperatures are likely to continue to rise faster than maximum temperatures. The consequences for crop growth also depend on the timing of extremes during the year (e.g., whether these are more likely during the planting season or during crop flowering). There may be a need for alternative crops and crop varieties that have greater heat tolerance. However, the largest impacts of rising temperatures may appear in rising rates of evaporation associated with agricultural drought.

3.2 Precipitation projections

Projections of future precipitation trends are less certain than those for temperature. These trends have proven difficult to model, and they exhibit larger spatial and seasonal variations. AR5 findings suggest that most areas of the African continent are unlikely to see any changes in average annual precipitation by the middle to end of the 21st century (Niang et al., 2014, p. 1210). However, parts of Eastern Africa are projected to see a reversal of a drier historical trend by the end of the 21st century, with wetter and more intense rainy seasons and less-severe droughts. In contrast, projections for Southern Africa show a decline in average annual rainfall in the dry southwest, encompassing Namibia and Botswana. Large parts of the summer rainfall areas of Southern Africa are projected to have dryer spring months, signalling delays in the onset of seasonal rainfall. Winters across much of Southern Africa are also projected to be drier by the end of the 21st century. However, wetter conditions are projected for the southeastern areas of South Africa and along the Drakensberg Mountains (Niang et al., 2014, p. 1210).

The main conclusion is that GCM models do not yet predict changes in precipitation well. At best, these models suggest more rain in parts of Eastern Africa and less rain in parts of Southern Africa by the end of the century. Some assessments of historical trends suggest changes in the timing of rainfall or the length of growing seasons, but others find no significant changes. Continuing improvements in the GCMs may be required to resolve these uncertainties.

Again, the main immediate conclusion for agricultural systems is the need for continuing improvements in the capacity of farmers to cope with rainfall variability. This implies the need for greater improvement in water management practices within the field, as well as within the watershed.

3.3 Extreme temperature and rainfall projections

The extreme warm indices—used to measure extremely hot days and nights—are projected to increase over Southern Africa. This is consistent with a decrease in extreme cold indices that measure cold days and cold nights, confirming a general warming trend (New et al., 2006, as cited in Niang et al., 2014, p. 1211).

The AR5 notes that the forecasts of changes in drought and flood incidence lack confidence. The GCMs cannot model these. However, several SST-based studies cited in AR5 project a high risk of severe droughts in the southwestern areas of the Southern Africa sub-region during the 21st century and beyond (Hoerling et al., 2006; Shongwe et al., 2011, as cited in Niang et al., 2014, p. 1211). The continued warming in the Indian-Pacific warm pool is cited as the cause of droughts in the sub-region.

In Eastern Africa, more frequent instances of heavy precipitation (Seneviratne et al., 2012, as cited in Niang et al., 2014, p. 1211) and an increase in the number of extreme wet days by the mid-21st century have been projected with high certainty (Vizy and Cook, 2012, as cited in Niang et al., 2014, p. 1211), pointing to an increasing risk of flooding. These trends are linked with the incidence of tropical cyclones associated with warmer SST in the Indian Ocean.

Scientists continue to search for ways to integrate models of SST into the GCM. If successful, projections of extreme events may improve. In the meantime, improvements in seasonal forecasting offer the prospect for early warning linked with early advice to farmers about the likelihood of flooding or drought.

3.4 Pest and disease projections

Projections of the relationships between temperatures, precipitation, and pest and disease pressures remain rudimentary. Nonetheless, scientists believe pest and disease pressures are likely to worsen and merit closer monitoring. Epidemics of significant diseases—like stem and stripe rusts in wheat—that are problematic in East and Northern Africa have been flagged as potentially responsive to higher temperatures and wetter conditions (Porter et al., 2014). Higher temperatures in the Arabica coffee-producing East African highlands could favour the outbreak of the coffee berry borer in Ethiopia, Kenya, Uganda, Rwanda, and Burundi (Jaramillo et al., 2011, as cited in Niang et al., 2014, p. 1220). The highly destructive burrowing nematode could also move into banana-producing regions of Eastern Africa with rising temperatures. Rising minimum temperatures are also likely to favour the expansion of banana black leaf streak in Angola. The prevalence of tick vectors for East Coast fever disease in cattle is likely to shift southwards with temperature increases above 2 degrees centigrade and projected changes in precipitation (Olwoch et al., 2008, as cited in Niang et al., 2014, p. 1220).

4 Changes in crop suitability

The AR5 cites evidence of "a large negative sensitivity of crop yields to extreme daytime temperatures above 30 degrees centigrade" (Porter et al., 2014, p. 488) if more climate smart technologies are not adopted. For example, certain studies (Asseng et al., 2011; Lobell et al., 2012, as cited by Porter et al., 2014, p. 497) report accelerated senescence in wheat from extended exposure to temperatures above 32-34 degrees after the flowering stage. Higher temperatures also trigger increased demand for water by crops—as well as by any weeds competing with these crops—and will lead to higher rates of evaporation (FAO, 2016; Niang et al., 2014). Higher temperatures are also linked to earlier flowering and maturity observed in grapes, apples, and other horticultural crops. Müller and Elliott (2015) caution that more frequent and intense heat events, especially during flowering, may lead to earlier maturity and a reduction in biomass production. This implies a reduction of both grain and stover yields. High temperatures during flowering were also linked to a decline in grain filling. A continuing decline in winter chill units (due to rising minimum temperatures) required by many fruit and nut trees was projected to have negative impacts on apples, cherries, and other fruits. Rising temperatures are also projected to have negative impacts on most regions that now produce grapes for wine, coffee, and tea. However, the effect of rising temperature on cassava and sugarcane is projected to be positive as higher temperatures and elevated CO_2 levels improve conditions for photosynthesis and growth (Porter et al., 2014; Thornton et al., 2015).

An analysis of crop models with 20 GCMs by Lobell and colleagues (2008, as cited in Porter et al., 2014, p. 505) found that, without adaptation, Southern Africa and South Asia are the two regions at greatest risk of suffering the most negative yield impacts for several important crops. A synthesis of projections from 52 studies by Knox and colleagues (2012, as cited in Porter et al., 2014, p. 505) found average yield losses of 8%—with wheat, maize, sorghum, and millet affected more than rice, cassava, and sugarcane (Thornton et al., 2015).

A complementary question is whether, as climate changes, existing crops will simply no longer be viable in certain zones. Coffee, tea, and fruit production may need to move to higher elevations. In the absence of technological changes, large areas of maize production may need to shift to sorghum, millet, or cassava. In marginal areas, crop production may simply become secondary to livestock production. And if droughts become frequent enough, farmers may need to migrate out of agriculture.

The main problem with most of these assessments is that they do not take into account potential changes in agricultural technologies and production practices. Yet the adoption of more drought- and heat-tolerant varieties—as well as the use of mulch—may largely offset the impacts of rising temperatures (Cooper et al., 2009). In addition, many technologies are available to improve water-use efficiency, and to capture and utilise a larger percentage of limited amounts of rainfall. One of the most common means to achieve major changes in crop suitability is to expand irrigation. In effect, many of the technologies needed to offset current climate risks and the changes projected over the next 50 or so years are already available. The challenge for CSA is to improve adoption rates.

> **"Southern Africa and South Asia are the two regions at greatest risk of suffering the most negative yield impacts for several important crops.**

5 Implications for building a more climate smart agriculture

Over the next 20 to 40 years, technology adoption and crop choice by farmers in ESA will be shaped less by changes in climate than by market incentives and opportunities. Continuing efforts will be needed to strengthen markets and value chains in order to improve farmers' access to new technologies and the incentives to invest in and apply these technologies. If farmers are well integrated into markets, they are more likely to adjust their farming and broader livelihood strategies as climate risks increase.

The largest climate challenges currently facing much of ESA are the risks of drought and flooding. These risks are already extremely costly to national economies, and may become more frequent over time. As a first priority for achieving climate smartness, larger investments need to be allocated to drought and flood preparedness relative to the costs of food aid, and the costs of supporting the reestablishment of farming operations after a climate disaster.

There are many opportunities for improving resilience in the face of agricultural drought. One of the easiest changes for farmers to make is to switch their seed to a more drought-tolerant variety. Priority needs to be placed on breeding varieties with the capacity to tolerate or escape drought (e.g., by means of a shorter maturity period). But more investment is also needed to assure that all smallholder farmers in drought-prone regions have access to these seed varieties. National seed markets tend to favour commercial producers in higher rainfall zones. Public-private partnerships may be needed to support the dissemination of less profitable open-pollinated seeds of drought-tolerant varieties in drier areas with lower population and market densities.

Complementary investments can promote the adoption of technologies and management practices that help farmers make more efficient use of limited rainfall. These include water harvesting technologies (e.g., infiltration pits or bunds) that keep more water in the field and reduce runoff. Limited or no-tillage systems and the use of mulch reduce the evaporation of limited water supplies. Better weed control reduces the competition for water, leaving more for the crop. A key challenge is that many of these technologies require more labour or capital. Stronger commercial value chains can improve the incentives and capabilities of farmers to adopt these technologies. In less commercialised areas, however, public support for adoption may be justified as a means to reduce the future demands for food aid while strengthening the resilience of the farm household.

Public investments in building irrigation schemes are prioritised by many countries as a means for offsetting the risks of drought. The challenge is that irrigation systems are very expensive both to build and to maintain. Only a small proportion of farmers facing water-access constraints gain access to these systems. These investments must be complemented by a wider range of efforts to improve water-use efficiency in non-irrigated systems. Where irrigation investments are pursued, greater attention must be paid to siting these schemes where water supplies are likely to remain more reliable, and to using technologies that minimise evaporation.

In order to offset the risks of floods, countries need to allocate larger investments to various technologies for flood control (e.g., dams and levees) relative to their otherwise rising investments in flood relief. Otherwise, farming populations need to be moved out of flood-prone areas.

Another path to climate smartness can be found in the use of more accurate seasonal forecasts made possible by improved GCMs, and better understanding of the links between SST and extreme rainfall. The challenge remains to convert these seasonal forecasts into advice of practical usefulness to the affected farmers. This implies the need to help farmers understand these forecasts and to improve their capacity to choose alternative technologies, such as different varieties of crops that are suited to the expected season. The better use of seasonal and short-term forecasts can also improve early warning systems for drought and flood.

Priorities for responding to rising temperatures largely overlap with the interventions needed to improve responsiveness to agricultural drought. These include efforts to develop and disseminate temperature- and drought-tolerant varieties, as well as technologies for reducing water evaporation. In addition, better scouting of shifting pest and disease pressures must be linked with targeted programmes of integrated pest management.

Finally, current and anticipated climate risks imply greater variability of agricultural production and food supplies, which in turn highlight the importance of climate smart trade and stockholding strategies. Better seasonal forecasts can help governments and agribusinesses track and prepare for disruptions in commodity supply. Improved early warning systems can help verify the levels and locations of need early enough to organise timely imports. In complement, countries dependent on agricultural commodity imports need to monitor regional and global supplies and prices in order to better prepare for supply constraints and possible spikes in commodity prices.

In sum, climate risks in ESA are not new. There are many technologies already available for responding to current and evolving risks. The larger challenge is to assure that farmers gain better access to these technologies, and that they have both the capacity and the incentive to apply them. In much of ESA, these goals can be achieved through the continued strengthening and broadening of commercial agricultural markets. However, in outlying areas affected by rising temperatures and erratic rainfall, climate smartness may be achieved only through more deliberate public programmes to strengthen resilience to floods and drought.

Finally, there is a need for continuing investments in improving the evaluation and modelling of climate risks. While a further rise in temperatures appears certain, regional precipitation patterns remain difficult to predict. In the meantime, efforts to improve the resilience of farmers to existing climate risks need to be strengthened. Many of the solutions to these risks are well known. The larger question for CSA is why more farmers are not already using these climate smart technologies and management practices. Practitioners of CSA also need to more consistently measure the levels of improvement achieved in building resilience to climate risks. Ultimately, improved adaptation to today's climate risks will provide a stronger foundation for coping with future climate risks.

> **Complementary investments can promote the adoption of technologies and management practices that help farmers make more efficient use of limited rainfall.**

Bibliography

AfricaCSA, 2014. White paper about the Africa CSA Alliance. Available online at http://africacsa.org/wp-content/uploads/2015/09/White-Paper-About-the-Africa-CSA-Alliance-30.10.14.pdf.

Anyah, R.O. and W. Qiu, 2012. Characteristic 20th and 21st century precipitation and temperature patterns and changes over the Greater Horn of Africa. International Journal of Climatology, 32(3), 347-363.

Asseng, S., I. Foster, and N.C. Turner, 2011. The impact of temperature variability on wheat yields. Global Change Biology, 17, 997-1012.

CCAFS, 2016. Agriculture is integrated into the Paris agreement. Available online at: https://cgspace.cgiar.org/rest/bitstreams/81034/retrieve.

Christensen, J.H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. 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, 2007. Regional climate projections. In Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 847-940.

Christy, J.R., W.B. Norris, and R.T. McNider, 2009. Surface temperature variations in east Africa and possible causes. Journal of Climate, 22(12), 3342-3356.

Collins, J.M., 2011. Temperature variability over Africa. Journal of Climate, 24(14), 3649-3666.

Cooper, P., K.P.C. Rao, P. Singh, J. Dimes, P.S. Traore, K. Rao, P. Dixit, and S.J. Twomlow. 2009. Farming with current and future climate risk: Advancing a Hypothesis of Hope' for rainfed agriculture in the semi-arid tropics. SAT eJournal. 7, 1-19.

CropsReview. 2016. http://www.cropsreview.com/c3-plants.html

Elshamy, M.E., I.A. Seierstad, and A. Sorteberg, 2009. Impacts of climate change on Blue Nile flows using bias-corrected GCM scenarios. Hydrology and Earth System Sciences, 13(5), 551-565.

Engelbrecht, F.A., J.L. McGregor, and C.J. Engelbrecht, 2009. Dynamics of the conformal-cubic atmospheric model projected climate-change signal over Southern Africa. International Journal of Climatology, 29(7), 1013-1033.

FAO. 2013. Climate-Smart Agriculture Sourcebook. Rome: FAO. Available online at: http://www.fao.org/docrep/018/i3325e/i3325e00.htm

FAO, 2016. Climate change and food security: risks and responses. Rome. Food and Agriculture Organization.

Fay, J. 2015. Climate Smart Agriculture Program, Design Report. The British Government's Department for International Development (DFID). London, UK.

Funk, C., G. Eilerts, J. Verdin, J. Rowland, and M. Marshall, 2011. A Climate Trend Analysis of Sudan. USGS Fact Sheet 2011-3072, U.S. Department of the Interior, U.S. Geological Survey (USGS), Reston, VA, USA, 6 pp.

Funk, C., J. Michaelsen, and M. Marshall, 2012. Mapping recent decadal climate variations in precipitation and temperature across Eastern Africa and the Sahel. In Remote Sensing of Drought: Innovative Monitoring Approaches [Wardlow, B.D., M.C. Anderson, and J.P. Verdin (eds.)]. CRC Press, Boca Raton, FL, USA, pp.331 358.

Funk, C., M.D. Dettinger, J.C. Michaelsen, J.P. Verdin, M.E. Brown, M. Barlow, and A.Hoell, 2008. Warming of the Indian Ocean threatens Eastern and Southern African food security but could be mitigated by agricultural development. Proceedings of the National Academy of Sciences of the United States of America, 105(32), 11081-11086.

Hession, S.L. and N. Moore, 2011. A spatial regression analysis of the influence of topography on monthly rainfall in East Africa. International Journal of Climatology, 31(10), 1440-1456.

Hoerling, M., J. Hurrell, J. Eischeid, and A. Phillips, 2006. Detection and attribution of twentieth-century northern and Southern African rainfall change. Journal of Climate, 19(16), 3989-4008.

Hoffman, M.T., M.D. Cramer, L. Gillson, and M. Wallace, 2011. Pan evaporation and wind run decline in the Cape Floristic Region of South Africa (1974-2005): implications for vegetation responses to climate change. Climatic Change, 109(3-4), 437-452.

IPCC. 2013. 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, M. Tignor, S.K. Allen, J., Boschung, A., Nauels, Y., Xia, V., Bex & P.M., Midgley, eds. Cambridge, UK, and New York, USA, Cambridge University Press. 1535 p.

IPCC. 2014a. Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Core Writing Team, R.K. Pachauri & L.A. Meyer, eds. Geneva, Switzerland, IPCC. 151 p.

IPCC. 2014b. Climate change 2014: impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. C.B. Field, V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea & L.L. White, eds. Cambridge, UK, and New York, USA, Cambridge University Press. 1132 p.

IPCC. 2014c. Climate Change 2014: Mitigation of Climate Change. Exit Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Iqbal, M.M., M.A. Goheer, and A.M. Khan, 2009. Climate-change aspersions on food security of Pakistan. Science Vision, 15(1), 15-23.

James, R. and R. Washington, 2013. Changes in African temperature and precipitation associated with degrees of global warming. Climatic Change, 117(4), 859-872.

Jaramillo, J., E. Muchugu, F.E. Vega, A. Davis, C. Borgemeister, and A. Chabi-Olaye, 2011: Some like it hot: the influence and implications of climate change on coffee berry borer (Hypothenemus hampei) and coffee production in East Africa. PLoS ONE, 6(9), e24528, doi:10.1371/journal.pone.0024528.

Jarvis, A., J. Ramirez-Villegas, B.V.H. Campo, and C. Navarro-Racines, 2012. Is cassava the answer to African climate change adaptation? Tropical Plant Biology, 5(1), 9-29.

Joshi, M., E. Hawkins, R. Sutton, J. Lowe, and D. Frame, 2011. Projections of when temperature change will exceed 2°C above pre-industrial levels. Nature Climate Change, 1(8), 407-412.

Kniveton, D.R., R. Layberry, C.J.R. Williams, and M. Peck, 2009. Trends in the start of the wet season over Africa. International Journal of Climatology, 29(9), 1216-1225.

Kruger, A.C. and S.S. Sekele, 2012. Trends in extreme temperature indices in South Africa: 1962-2009. International Journal of Climatology, 33(3), 661-676.

Lobell, D.B., M.B. Burke, C. Tebaldi, M.D. Mastrandrea, W.P. Falcon, and R.L. Naylor, 2008. Prioritising climate change adaptation needs for food security in 2030. Science, 319, 607-610.

Lobell, D.B., G.L. Hammer, G. McLean, C. Messina, M.J. Roberts, and W. Schlenker, 2013. The critical role of extreme heat for maize production in the United States. Nature Climate Change, 3, 497-501.

Lyon, B. and D.G. DeWitt, 2012. A recent and abrupt decline in the East African long rains. Geophysical Research Letters, 39(2), L02702, doi:10.1029/2011GL050337.

Lyon, B., 2009. Southern Africa summer drought and heat waves: observations and coupled model behavior. Journal of Climate, 22(22), 6033-6046.

Mariotti, L., E. Coppola, M.B. Sylla, F. Giorgi, and C. Piani, 2011. Regional climate model simulation of projected 21st century climate change over an all-Africa domain: comparison analysis of nested and driving model results. Journal of Geophysical. Research D: Atmospheres, 116(D15), D15111, doi:10.1029/2010JD015068.

Mohamed, A.B., 2011. Climate change risks in Sahelian Africa. Regional Environmental Change, 11(Suppl. 1), 109-117.

Moise, A.F. and D.A. Hudson, 2008. Probabilistic predictions of climate change for Australia and Southern Africa using the reliability ensemble average of IPCC CMIP3 model simulations. Journal of Geophysical Research D: Atmospheres, 113(15), D15113, doi:10.1029/2007JD009250.

Moriondo, M., C. Giannakopoulos, and M. Bindi, 2011. Climate change impact assessment: the role of climate extremes in crop yield simulation. Climatic Change, 104, 679-701.

Müller, C. & Elliott, J. 2015. The Global Gridded Crop Model intercomparison: approaches, insights and caveats for modelling climate change impacts on agriculture at the global scale. In A. Elbehri, ed. Climate change and food systems: global assessments and implications for food security and trade. Rome, FAO.

National Drought Mitigation Center, University of Nebraska-Lincoln. 2016. http://drought.unl.edu/DroughtBasics/TypesofDrought.aspx

New, M., B. Hewitson, D.B. Stephenson, A. Tsiga, A. Kruger, A. Manhique, B. Gomez, C.A.S. Coelho, D.N. Masisi, E. Kululanga, E. Mbambalala, F. Adesina, H. Saleh, J. Kanyanga, J. Adosi, L. Bulane, L. Fortunata, M.L. Mdoka, and R. Lajoie, 2006. Evidence of trends in daily climate extremes over Southern and west Africa. Journal of Geophysical Research D: Atmospheres, 111(D14), D14102, doi:10.1029/2005JD006289.

Niang, I., O.C. Ruppel, M.A. Abdrabo, A. Essel, C. Lennard, J. Padgham, and P. Urquhart, 2014. Africa. In 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 [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1199-1265.

Nicholson, S.E., D.J. Nash, B.M. Chase, S.W. Grab, T.M. Shanahan, D. Verschuren, A. Asrat, A.-M. Lezine, and M. Umer, 2013. Temperature variability over Africa during the last 2000 years. Holocene, 23(8), 1085-1094.

Nzuma JM, Radeny M, Kinyangi J, Cramer L. 2014. A Review of Agricultural, Food Security, Food Systems and Climate Change Adaptation Policies, Institutions and Actors in East Africa. CCAFS Working Paper no. 82. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Copenhagen, Denmark

Olwoch, J.M., B. Reyers, F.A. Engelbrecht, and B.F.N. Erasmus, 2008: Climate change and the tick-borne disease, Theileriosis (East Coast fever) in sub-Saharan Africa. Journal of Arid Environments, 72(2), 108-120.

Orlowsky, B. and S.I. Seneviratne, 2012. Global changes in extreme events: regional and seasonal dimension. Climatic Change, 110(3-4), 669-696.

Porter, J.R., L. Xie, A.J. Challinor, K. Cochrane, S.M. Howden, M.M. Iqbal, D.B. Lobell, and M.I. Travasso, 2014. Food security and food production systems. In Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 485-533.

Ramirez-Villegas, J and Thornton, P K, 2015. Climate change impacts on African crop production Working Paper No. 119 CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) https://cgspace.cgiar.org/bitstream/handle/10568/66560/WP119_FINAL.pdf

Rosenstock TS, Lamanna C, Chesterman S, Bell P, Arslan A, Richards M, Rioux J, Akinleye AO, Champalle C, Cheng Z, Corner-Dolloff C, Dohn J, English W, Eyrich AS, Girvetz EH, Kerr A, Lizarazo M, Madalinska A, McFatridge S, Morris KS, Namoi N, Poultouchidou N, Ravina da Silva M, Rayess S, Ström H, Tully KL, Zhou W. 2016. The scientific basis of climate-smart agriculture: A systematic review protocol. CCAFS Working Paper no. 138. Copenhagen, Denmark: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

Rosenzweig, C., G. Casassa, D.J. Karoly, A. Imeson, C. Liu, A. Menzel, S. Rawlins, T.L.Root, B. Seguin, and P. Tryjanowski, 2007. Assessment of observed changes and responses in natural and managed systems. In Climate Change 2007. Impacts, Adaptation and Vulnerability" Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Parry,M.L., O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 79-131.

Rosell, S. and B. Holmer, 2007. Rainfall change and its implications for Belg harvest in South Wollo, Ethiopia. Geografiska Annaler, Series A. Physical Geography, 89(4), 287-299, doi. 10.1111/j.1468-0459.2007.00327.x.

Sanderson, M.G., D.L. Hemming, and R.A. Betts, 2011. Regional temperature and precipitation changes under warming. Philosophical Transactions of the Royal Society A, 369(1934), 85-98.

Seneviratne, S.I., N. Nicholls, D. Easterling, C.M. Goodess, S. Kanae, J. Kossin, Y. Luo, J. Marengo, K. McInnes, M. Rahimi, M. Reichstein, A. Sorteberg, C. Vera, and X. Zhang, 2012. Changes in climate extremes and their impacts on the natural physical environment. In Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 109-230.

Shongwe, M.E., G.J. van Oldenborgh, B. van den Hurk, and M. van Aalst, 2011. Projected changes in mean and extreme precipitation in Africa under global warming. Part II: East Africa. Journal of Climate, 24(14), 3718-3733.

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, 2009. Projected changes in mean and extreme precipitation in Africa under global warming. Part I: Southern Africa. Journal of Climate, 22(13), 3819-3837

Sillmann, J. and E. Roeckner, 2008. Indices for extreme events in projections of anthropogenic climate change. Climatic Change, 86(1-2), 83-104.

Stern, D.I., P.W. Gething, C.W. Kabaria, W.H. Temperley, A.M. Noor, E.A. Okiro, G.D. Shanks, R.W. Snow, and S.I. Hay, 2011. Temperature and malaria trends in highland East Africa. PLoS ONE, 6(9), e24524, doi:10.1371/journal.pone.0024524.

Stern, RD & Cooper, PJM, 2011. Assessing climate risk and climate change using rainfall data – a case study from Zambia. Expl. Agric. 47(2), 241–266. doi:10.1017/S0014479711000081.

Tadross, M., P. Suarez, A. Lotsch, S. Hachigonta, M. Mdoka, L. Unganai, F. Lucio, D. Kamdonyo, and M. Muchinda, 2009. Growing-season rainfall and scenarios of future change in southeast Africa: implications for cultivating maize. Climate Research, 40(2-3), 147-161.

Tadross, M.A., B.C. Hewitson, and M.T. Usman, 2005. The interannual variability on the onset of the maize growing season over South Africa and Zimbabwe. Journal of Climate, 18(16), 3356-3372.

Thomas, D.S.G., C. Twyman, H. Osbahr, and B. Hewitson, 2007. Adaptation to climate change and variability: farmer responses to intra-seasonal precipitation trends in South Africa. Climatic Change, 83(3), 301-322.

Thornton, P.K., Boone, R.B. & Ramirez-Villegas, J. 2015. Climate change impacts on livestock. CCAFS Working Paper No. 120. Copenhagen, CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) (available at: www.ccafs.cgiar.org).

Trenberth, K.E., P.D. Jones, P. Ambenje, R. Bojariu, D. Easterling, A. Klein Tank, D. Parker, F. Rahimzadeh, J.A. Renwick, M. Rusticucci, B. Soden, and P. Zhai, 2007. Observations: surface and atmospheric climate change. In Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 236-336.

UNFCCC, 2015. Paris Agreement. Available online at: http://unfccc.int/files/essential_background/convention/application/pdf/ english_paris_agreement.pdf

United Nations, 2014. Global Alliance for Climate-Smart Agriculture Action Plan. Available online at: http://www.un.org/climatechange/summit/wp-content/uploads/sites/2/2014/09/AGRICULTURE-Action-Plan.pdf.

Vincent, L.A., E. Aguilar, M. Saindou, A.F. Hassane, G. Jumaux, D. Roy, P. Booneeady, R. Virasami, L.Y.A. Randriamarolaza, F.R. Faniriantsoa, V. Amelie, H. Seeward, and B. Montfraix, 2011. Observed trends in indices of daily and extreme temperature and precipitation for the countries of the western Indian Ocean, 1961-2008. Journal of Geophysical Research D: Atmospheres, 16(D10), D10108, doi:10.1029/2010JD015303

Vizy, E.K. and K.H. Cook, 2012. Mid-twenty-first-century changes in extreme events over northern and tropical Africa. Journal of Climate, 25(17), 5748-5767.

Vuna, 2016. Briefing Note. Pretoria

Watterson, I.G., 2009. Components of precipitation and temperature anomalies and change associated with modes of the Southern Hemisphere. International Journal of Climatology, 29(6), 809-826.

Williams, A.P. and C. Funk, 2011. A westward extension of the warm pool leads to a westward extension of the Walker circulation, drying Eastern Africa. Climate Dynamics, 37(11-12), 2417-2435.

Williams, A.P., C. Funk, J. Michaelsen, S.A. Rauscher, I. Robertson, T.H.G. Wils, M. Koprowski, Z. Eshetu, and N.J. Loader, 2012. Recent summer precipitation trends in the Greater Horn of Africa and the emerging role of Indian Ocean Sea surface temperature. Climate Dynamics, 39(9-10), 2307-2328.

Williams, T.O., Mul, M., Cofie, O., Kinyangi, J., Zougmore, R., Wamukoya, G., Nyasimi, M., Mapfumo, P., Speranza, C.I., Amwata, D., Frid-Nielsen, S., Partey, S., Girvetz, E., Rosenstock, T., Campbell, B., 2015. Climate Smart Agriculture in the African Context. Background paper. Feeding Africa Conference. Economic Commission for Africa. Adakar.

World Resources Institute, 2014. http://www.wri.org/print/41752.

Zhou, L., R.E. Dickinson, A. Dai, and P. Dirmeyer, 2010. Detection and attribution of anthropogenic forcing to diurnal temperature range changes from 1950 to 1999: comparing multi-model simulations with observations. Climate Dynamics, 35(7), 1289-1307.

Scan the code to read more on Vuna's work in East and Southern Africa

Contact Us:

T: +27 12 342 3819
E: contact@vuna-africa.com
W: www.vuna-africa.com

Search for **Vuna Africa**