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Agricultural Drought and Climate Smart Agriculture

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Acronyms

AEZ	Agroecological Zones
AR5	Fifth Assessment Report of IPCC, 2014
CAM3	Community Atmosphere Model version 3
CCAFS	Climate Change, Agriculture and Food Security (CGIAR Research Program)
CGIAR	Consultative Group for International Agricultural Research
ClimDev-Africa	Climate for Development in Africa Programme, African Union Commission
CMIP5	Coupled Model Inter-comparison Project Phase 5
CSA	Climate Smart Agriculture
DFID	Department for International Development – United Kingdom
EEZ	Exclusive Economic Zone
ENSO	El Niño - Southern Oscillation
ESA	Eastern and Southern Africa
FAO	Food and Agriculture Organisation of United Nations (www.fao.org)
FEWSNET	Famine Early Warning System Network (www.fews.net)
GCMs	Global Circulation Models or Global Climate Models
GFCS	Global Framework for Climate Services
GHACOF	Greater Horn of Africa Climate Outlook Forum
GPCP	Global Precipitation Climatology Project (http://precip.gsfc.nasa.gov/)
HadAM3	Hadley Centre Atmospheric Model version 3 (UKMet Office)
IPCC	Intergovernmental Panel on Climate Change (www.ipcc.ch)
NMS	National Meteorological Service in each country
PDSI	Palmer Drought Severity Index
RCOF	Regional Climate Outlook Forums
SADC	Southern African Development Community (www.sadc.int)
SARCOF	Southern African Regional Climate Outlook Forum
SOI	Southern Oscillation Index
SPI	Standard Precipitation Index
SRES	Special Report on Emissions Scenarios (IPCC SRES, 2000)
SST	Sea Surface Temperature
TRMM	Tropical Rainfall Measuring Mission (pmm.nasa.gov/trmm)
UKMet Office	United Kingdom Meteorological Office (http://www.metoffice.gov.uk/)
WMO	World Meteorology Organisation (www.wmo.int)
WRSI	Water Requirements Satisfaction Index

Executive summary

Drought is endemic across Eastern and Southern Africa. According to calculations using a standardised precipitation index, there is a 20-30% chance of drought across much of the region in any given year. This means a drought can be expected at least once every three to five years. This common measure, known as *meteorological drought*, considers only the lack of rainfall in comparison with the mean amount normally received at a specific location. There are two problems with this. First, the measure of normal rainfall masks the high variability of rainfall from year to year. The coefficient of variation (a measure of how much rainfall varies from the annual mean amount) can be more than 45% across Southern Africa. What this means is that receiving “normal” levels of rainfall is not common. The second problem is that changes in annual means do not account for the impacts of seasonal or intra-seasonal shortfalls. Agricultural crops may be suffering from rainfall shortages even if there is no meteorological drought.

Scientists use different definitions of drought that describe lack of rain at different scales and with different effects on physical processes, society, and the economy. *Agricultural drought* considers the impacts of a lack of rainfall on agricultural productivity in an area. This is usually measured in terms of the availability of adequate quantities of water for plant growth with a water satisfaction index. The main difficulty here is that water satisfaction depends on many additional factors such as soil conditions, slope, temperature, and type of crop grown. Much also depends on the timing of rainfall relative to the timing of plant growth.

Similarly, measures of *hydrological drought* consider the relationship between rainfall and water availability at the scale of a catchment or watershed. This considers water flow process (both above and below ground), storage, and evaporation. *Ecosystem drought* is similar to agricultural drought, but considers the impacts of rainfall on natural vegetation. A *socioeconomic drought* considers the effects of a lack of rain on society and the economy.

This paper examines how a better understanding of changing drought risks, including those related to the rise of greenhouse gases and climate change, can guide the prioritisation of interventions for climate smart agriculture. It highlights the importance of the differences in measures of meteorological and agricultural drought, as well as the limitations of the general circulation models (GCM) in forecasting changing drought risks. The paper considers the associated relationship between El Niño-Southern Oscillation (ENSO) and agricultural drought. It concludes by considering the implications for prioritising climate smart agricultural interventions.

Most countries in Southern Africa have a single rainfall season starting in November or December and ending in March or April. There are, however, two rainfall seasons in the region from the northern half of Tanzania and into the equatorial zone. Total annual rainfall ranges from 400 to 1 400 millimetres across the five Vuna countries (Malawi, Mozambique, Tanzania, Zambia, and Zimbabwe). Roughly 75-100% of the precipitation falls during the wet season, but with high spatial and temporal variability. Studies using monthly rainfall data indicate that the timing and amounts of rainfall across the region have not significantly changed over the last century. Rainfall, however, has always been extremely variable, but the likelihood of meteorological drought is not constant each year. The analysis of daily rainfall records is important for agricultural drought, as it is important to consider the timing of the start and end of the rains, as well as the total number of rainy days. Some analysis suggests a trend for seasons to start later, with a declining number of rainy days (Tadross et al., 2009), although other studies do not agree (Stern & Cooper, 2011). Extended dry spells are common in Southern Africa, and can have disastrous effects on agricultural production if they occur during sensitive stages of crop growth such as germination, flowering, and grain-filling. Reductions in frequency of rain days over Zambia, Malawi, and Zimbabwe are particularly linked to El Niño.

The impacts of greenhouse gases on climate change are most commonly assessed with GCMs. These use mathematical equations to describe the general circulation of atmospheric and oceanographic fluid movements around the globe and to make projections of future climates under different scenarios. As there are many GCMs from various climate institutions around the world, most analysts—including the Intergovernmental Panel on Climate Change (IPCC)—now combine the results from ensembles of GCMs to predict expected changes.

IPCC-AR5 projections for rainfall changes show a likely increase in annual amounts over significant parts of Eastern Africa, and a very likely decrease in annual amount over much of Southern Africa under the high greenhouse gas (GHG) scenario. However, these changes are projected to occur only by the end of the century with medium to high confidence. If little increase in GHG occurs, then few changes are expected in the current rainfall variability. Meteorological drought will remain endemic in the region, but it will not increase.

IPCC-AR5 (2014b) reports a much stronger and more consistent relationship between the rise of greenhouse gases and changes in air temperature. The reports highlight the fact that temperatures in much of Eastern and Southern Africa have already increased by 1.5-2 degrees

Celsius, and are likely to increase further if greenhouse gas concentrations are not maintained at current levels. Across inland Southern Africa, minimum temperatures have increased more rapidly than maximum temperatures, mainly due to fewer extremely cold nights, a situation that should allow more rapid crop growth.

GCMs are generally said to be substantially better at forecasting changes in temperature than changes in precipitation. Common reference is made to analyses of historical rainfall data that cite changing trends that may or may not ultimately be proven to be related to the rise of greenhouse gases.

Scientists also use the El Niño phenomenon of higher sea surface temperatures (SST) in the equatorial zone of the central and eastern Pacific Ocean as a method for forecasting rainfall at distant locations around the world. This is possible due to teleconnections to climate events, together with a lag time between changes in SST and climatic consequences. These relationships have been modelled effectively and used SST as a predictor. Much of Southern Africa generally receives lower rainfall under El Niño conditions—which involve higher SSTs and negative Southern Oscillation Index (SOI)—as well as an early start to the rainy season. La Niña conditions generally produce higher seasonal rainfall. The latest IPCC reports (IPCC, 2014a) indicate that the current GCMs do not represent SST variability well enough to accurately project El Niño or La Niña events.

What can we conclude about the changing characteristics and probabilities of agricultural drought? The main contribution of the GCMs is to confirm the significant relationship between rising greenhouse gases and rising temperatures. These increase the evaporation of water from the soil and surrounding watershed, and also increase evapotranspiration rate from plants. Even with no changes in rainfall, crops are likely to be more stressed more often.

The GCMs offer a clear warning of the rising probabilities of drought in Southern Africa and possibly flooding in Eastern Africa in future years. However, the better predictor of drought in the near term is ENSO—and more specifically the warming of SST linked with El Niño. These events appear to be linked with a later start to the rains, longer midseason dry spells, and fewer rainy days—each contributing to higher levels of agricultural drought. Further evaluation of long-term daily climate datasets using a water satisfaction index may clarify our understanding of these relationships. Improvements in the capacity of the GCMs to forecast precipitation will also help.

One key result of such meteorological and climate research is that the quality of seasonal forecasts of agricultural drought has improved. The most immediate challenge for climate smart agriculture is to better use these seasonal forecasts to guide farmer decision-making. If agricultural rains are likely to be more favourable (during La Niña) then farmers may be encouraged to grow crops and varieties making use of the higher rainfall. For example, late-maturing varieties (longer season) can use the additional rain water to achieve higher yields. If an El Niño drought is likely, farmers may be encouraged to plant earlier-maturing varieties and invest more in assuring the capture of water in the field. More work is needed to improve the delivery of information about seasonal forecasts and to encourage "response farming."

The full set of evidence suggests that climate smart agriculture efforts need to place higher priority on improving the capacity of farmers to cope with agricultural drought. Such droughts are already endemic in the region, and they remain the most prevalent and significant climate risk faced. The costs of drought relief and recovery are substantial. Solutions to today's droughts will improve the capacity to cope with future droughts that may become more frequent.

The literature indicates that the most immediate and obvious change in the nature of agricultural drought (in addition to less available rainwater) will be higher rates of evaporation and evapotranspiration caused by rising temperatures. Therefore, research and extension priorities may correspondingly be set on varieties with both greater heat and drought tolerance, as well as farmers' management practices, such as use of improved practical mulches, that reduce soil temperatures and evaporation. Priority may also be high for improved exchange of technologies that improve water harvesting in farmers' fields and retention of the limited rainfall that can fall in fewer days with greater intensity. Such efforts would well complement larger investments in the promotion of response farming, which uses the rainfall forecasts to make agronomic on-farm management decisions.

In sum, the changing risks of drought in Eastern and Southern Africa need to be examined in much detail in order to understand their implications for investments in becoming climate smart. It is not adequate to draw conclusions about meteorological drought; we need to understand the changing prospects for agricultural drought. Assessments of changes in average rainfall need to be refined to examine changes in rainfall timing, intensity and spatial distribution. The GCMs offer better information about temperature than rainfall. But this is made up for by the value of ENSO predictions. Closer assessment of historical data may further clarify the details of trends in various components of agricultural drought. Finally, much work is still needed to make this information useful and relevant to farmers.

> “Rainfall is vital for crop production under the rainfed farming systems of Eastern and Southern Africa.

1 Introduction

Rainfall is vital for crop production under the rainfed farming systems of Eastern and Southern Africa (ESA). However, rainfall is highly variable from season to season, and droughts are commonplace. Agriculture drought is usually described in terms of the rainfall needed to maintain an adequate supply of water to ensure crop growth through the season, as distinct from meteorological drought, which is concerned only with the amount of rainfall received relative to a long-term mean. Thus agricultural drought depends on the type of crop and soil, as well as the amount and timing of rainfall through the season relative to crop growth and development. Both increasing temperatures and erratic rainfall have a negative influence on food production systems in ESA, damaging the livelihoods of many of the vulnerable poor.

This report gives an overview of historical rainfall patterns—including links to the ENSO phenomenon—and discusses projections for future changes. Farmers need ways to cope with variable conditions from season to season. Coping strategies that address the different aspects of agricultural drought in the region will be examined.

This report covers the objectives of this project plan, which are to:

- Conduct a strategic review of available literature examining agricultural drought risks in Eastern and Southern Africa, and how these are changing as a result of climate change, including an assessment of changes in the relationship between ENSO and drought in Southern Africa.
- Compare these results with the breadth of proposals for coping with drought offered under the rubric of CSA.

FAO defines “climate smart agriculture” as follows: “an approach to developing the technical, policy and investment conditions to achieve three main objectives: sustainably increasing agricultural productivity and incomes, adapting and building resilience to climate change, and reducing and/or removing greenhouse gases emissions, where possible” (FAO, 2010a).

This broad definition of CSA has resulted in the inclusion of many technologies and policies not specifically focused on addressing the risk resulting from variable climate conditions. This means that CSA shares common ground with sustainable development and with sustainable intensification. However, CSA should focus on making recommendations for resource-efficient farming systems that will be resilient under a range of future projected climates. Therefore, it appears that this CSA definition is too vague and results in the inclusion of many development issues that are only loosely related to climate. It would be more helpful if CSA was defined in a focused way, where the appropriate responses are directly linked to the risks (changes in temperature and rainfall). Then these proposed interventions (of management, services, and policy) could be evaluated under the projected future climate scenarios against the current or baseline climate conditions.

As the current conditions across ESA include highly variable rainfall and frequent droughts, climate-smart interventions should help farmers cope with agricultural drought both now and in the future. This report considers the effects of higher temperatures, combined with variability and lack of consistent rainfall through a growing season, in evaluating interventions that address both the current situation and climate change. It also recommends some practical interventions to address the joint effects of high temperatures and erratic rainfall on agricultural production.

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> **Farmers need ways to cope with variable conditions from season to season.**

2 Drought and rainfall patterns in Eastern and Southern Africa

At present many different analyses of data from diverse climate databases have been performed across Africa, but they give somewhat differing results. This is probably due to several factors:

a) There is a lack of continuous long-term daily climate data available at a scale that has sufficient spatial detail across all of ESA.

b) Where such data does exist, different analysis methods have been used in different countries, making it difficult to compare results across ESA.

c) Some analyses were performed with secondary or derived data (e.g., remote sensing and/or reanalysis[1] information).

d) Other analyses used monthly data from a single station, which give results that vary from analyses relying on a wider area with daily data.

e) Many weather stations in ESA still use manual instrumentation, and national meteorological services (NMS) often lack good equipment or maintenance standards, resulting in many gaps in datasets.

Therefore, a consistent and thorough analysis needs to be made of daily historical rainfall and temperature observations across Eastern and Southern Africa. Following this, GCMs hind-cast outputs should be compared with these historic trends such that one can select several GCMs that represent ESA climate consistently well so that one can rely on those projections for future climate for the region. This may need to include improvements in the specific equations used by climate modellers to better represent the local observations as well as an enhancement of the way the topography is represented in downscaling actions.

2.1 Definitions of types of drought

A drought is a period of below-average precipitation in a given area. Drought should not be confused with the different climatic types (such as humid or arid), as any type of climate can receive below-average rainfall. It measures not the absolute amount of rainfall received but the amount received relative to the long-term mean. Droughts have a substantial impact on ecosystems, agriculture, and the hydrological water resources of the affected region and thus harm the local economy. If below average rainfall coincides with high temperatures, a drought can worsen because of higher evaporation.

Definitions of drought vary according to disciplinary approaches and scale as well as region and needs. Wilhite and Glantz (1985) categorised drought in terms of four basic measuring approaches. The first three—meteorological, agricultural, and hydrological—measure drought in terms of physical phenomena, while the fourth—socioeconomic—examines how drought affects human activities. Other researchers also consider a fifth approach, ecological, which considers how lack of rainfall affects both natural systems and human societies.

Various indices are available to characterise each type of drought and to measure the severity and expected impacts of drought on livelihoods.

- *Meteorological drought* is defined by a lack of precipitation (compared to a "normal" or average amount) and the duration of the dry period. It is region-specific because atmospheric conditions that result in deficiencies of precipitation are highly variable from region to region. A relative measure of drought severity is given by calculating either the Standard Precipitation Index (SPI) or the Palmer Drought Severity Index (PDSI) for different time periods.
- *Agricultural drought* measures lack of rainfall as it impacts agricultural production, in terms of precipitation shortages relative to evapotranspiration demands and available soil water. A good agricultural drought definition includes the

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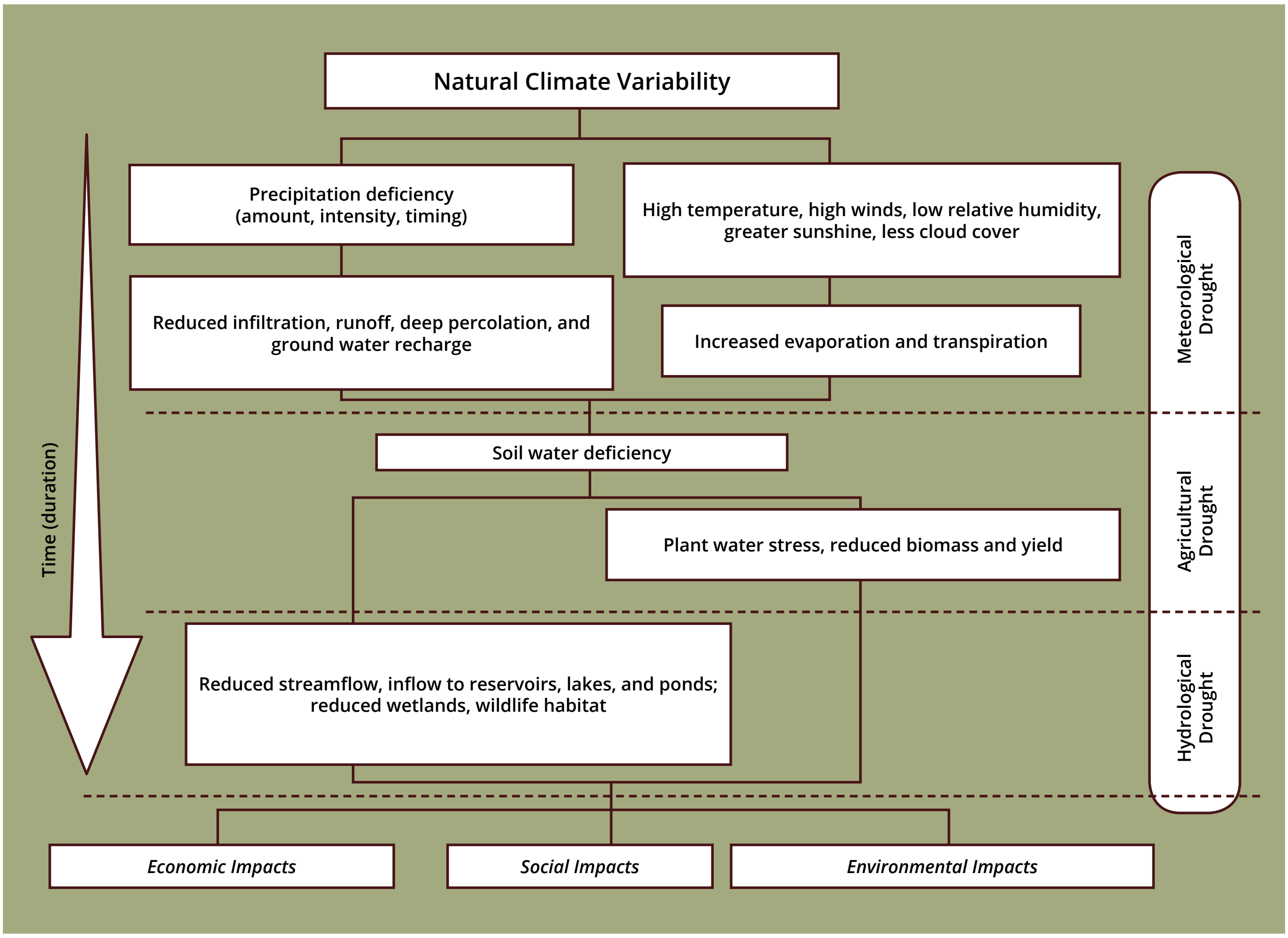
[1] Reanalyses are estimates of historical atmospheric temperature and wind (& other quantities), created by processing past meteorological data using fixed state-of-the-art weather forecasting models. It avoids effects from changing operational analysis systems to improve continuity, but global reanalyses still suffer from changing coverage and biases in observing systems.

variable susceptibility of crops during different growth and/or development stages, and is related to timing of rainy season and dry spells. The Water Requirements Satisfaction Index (WRSI) uses a simple water balance for some combination of crop and soil conditions.

- *Hydrological drought* is the effect of deficit rainfall on a watershed or catchment considering the hydrological system of both surface (streams, reservoirs, etc.) and sub-surface (soil and groundwater) water systems, including both frequency and severity. Hydrological drought lags meteorological and agricultural droughts, due to the buffer effect of stored water. The magnitude and frequency of hydrological droughts are affected by changes in land use and land degradation.
- *Socioeconomic drought* is a response by society to drought as it depends on water supply in time and space or the demand by the economy. It occurs when the demand for an economic good—water—exceeds supply due to a weather-related shortfall related to meteorological drought.
- *Ecological drought* is an effect of rainfall deficits resulting in widespread prolonged lack of sufficient water for natural ecosystems, confounded by multiple hydrological and socioeconomic stresses.

The various types of drought are interlinked and affect different parts of the natural agro-ecosystem at different time intervals (Fig. 1). This diagram illustrates how natural climate variability affects various aspects of the hydrological cycle and helps one to envisage management strategies that can be used in developing practical responses that ultimately have social, economic and ecological impacts. Meteorological drought includes natural climate variability of precipitation (that influences infiltration and runoff), and that of high temperature (that influences evapotranspiration rate). Agricultural drought includes the effect of these on soil water deficit and plant water stress, which both result in reduced crop production (biomass & yield). Management factors that decrease soil evaporation (such as mulch and crop cover) can reduce soil water deficit thus stabilising crop production. Agricultural management factors (like tillage, soil conservation) that reduce runoff and erosion thus help maintain soil and/or ground water balance and influence hydrological drought. Therefore, sustainable systems can be encouraged by a range of interventions in response to different types of droughts at different parts of the system.



Source: National Drought Mitigation Center, 2016

Figure 1: Comparison of types of drought and duration with resultant impacts

From an African agricultural viewpoint, the most important type of drought is the agricultural, which measures the amount and timing of the rainfall required for crop and livestock production. Therefore, agricultural drought and its effect on agricultural production will be discussed in relation to climate forecast systems and advisories provided by NMSs and international climate centres.

Drought is a prolonged event without a clear starting point, as it represents a number of days without rainfall during a period when long-term records show rain is expected. Because historic records are used as the basis for forecasts, it is important to gauge the amount and quality of rainfall information available as well as the resultant degree of uncertainty of forecasts. One method used to represent the likelihood of rainfall occurring involves the probability of receiving a certain amount of rain over a specific area under different conditions. For agricultural drought, these rainfall amounts and dry periods are related to a crop production system at a specific location.

Box 1. Using SPI with satellite rainfall as drought indicator for maize production in Malawi

Standard Precipitation Index (SPI) is a meteorological drought indicator based only on precipitation amounts, which allows comparison of rainfall deficits at multiple time and spatial scales. Jayanthi and the FEWS NET team (2013) calculated monthly SPI from monthly satellite rainfall estimate values (NOAA RFE2) across southern Malawi and related that information to district-level maize yield data for 24 years. SPI was used in this study as a drought hazard index for the months corresponding to the silk, tasselling, milk, grain-filling, and hardening phases, namely January-March. These linear equations for single months and multiple months were compared. The analysis shows that maize yield reductions for three types of varieties—local, hybrid, and composite—are best correlated with SPI drought conditions (less than 0.2) in February and March, probably because this is during the grain formation and filling stages. The February SPI is the most relevant index to use as an early warning of drought, as March SPI would come too late to be useful. Due to the variability in rain onset date and the use of monthly data, this study should be repeated in more detail with actual annual start of rain dates and daily or decadal (10-day period) data. The district-wide relationships of drought (SPI) to maize yield reduction were up-scaled to obtain a regional maize vulnerability model for southern Malawi. The February PSI was chosen as a useful index as it covers the critical maize flowering phase and can be used as an early warning indicator to give decision-makers additional time to assess the seasonal production outcome and identify drought conditions related to food production (Jayanthi et al., 2013). Probably it would have been better to try to use daily or decadal rainfall data with WRSI as an indicator of agricultural drought rather than SPI, which does not include any crop or soil characteristics.

2.2 Long-term observations of Eastern and Southern Africa

Rainfall and temperature observations are made in all countries across ESA, with the monthly datasets of certain stations being collated by WMO in Geneva since its establishment in 1950. However, these monthly datasets do not provide enough detail in either space or time for detailed analysis of agricultural drought. More detailed Information is required, particularly on a daily time scale and in rural areas where agriculture is a dominant means of livelihood. Across much of Africa, the rainfall data has historically been aggregated into 10-day periods or decades, which are more useful for agricultural applications. The occurrence of agricultural droughts was historically determined using decades as there are only 37 periods during a year, and this was easier to work with prior to widespread use of computers. Currently, the rainfall information is collected primarily by using remote sensing equipment, which gives a better spatial perspective but has not always been checked for ground-truth across all parts of Africa (Funk et al., 2003, 2014).

2.2.1 Observed temperature trends

IPCC (2014b) reported a significant increase in temperature in both equatorial and southern parts of Eastern Africa since the early 1980s. FEWS NET (Famine Early Warning System Network) reports show an increase in seasonal mean temperature in many areas of Ethiopia, Kenya, South Sudan, and Uganda over the last 50 years (Funk et al., 2003, 2014). Rising air temperatures will cause increases in daily evaporation rates. This leads to drier soil that heats faster, which results in higher temperatures, particularly in semi-arid areas where the air is drier. This means that the limited water available from lower rainfall will be depleted more quickly. Higher temperatures thus aggravate the agricultural drought conditions, as there will be less water available for use by crops during the growing season, resulting in lower crop production.

Most of Southern Africa has also experienced upward trends in annual mean, maximum, and minimum temperature over large areas during the second half of 20th century, with the most significant warming occurring from 1980-2000 (IPCC, 2014b). Minimum temperatures have increased more rapidly than maximum temperatures over inland Southern Africa (New et al., 2006). However, the diurnal range of temperatures does not have a consistent trend: some stations show temperatures moving in the opposite direction, and a zone across Namibia, Botswana, Zambia, and Mozambique has seen more rapid increases in maximum temperature extremes than in minimum temperature extremes. So extremely cold days and nights have decreased, and hot days and nights have increased (New et al., 2006). This shows that caution is required when considering reports of blanket changes in temperature (and rainfall) across the region.

2.2.2 Observed rainfall trends

Across the African continent, most areas lack sufficient observational data to draw conclusions about trends in annual precipitation over the past century, and in many regions there are discrepancies between different observed datasets. There is high variability in rainfall—of 15-18%—in the observed datasets around the long-term mean (IPCC, 2014a). The average rainfall across the whole African continent is less than 1,000 millimetres per year, and ranges from 250 to 2 500 millimetres across ESA (Fig. 2) (Thornton, 2015). For the five countries (Malawi, Mozambique, Tanzania, Zambia, and Zimbabwe) targeted by the Vuna programme, annual rainfall ranges from 400 to 1 400 millimetres, with 75-100% received during the wet season (Liebmann et al., 2012).

As gridded datasets[2] are currently the most common, Sylla et al. (2013) compared three gridded observed daily rainfall datasets over Africa: FEWS NET, GPCP (Global Precipitation Climatology Project), and TRMM (Tropical Rainfall Measuring Mission). They found that different observation products exhibit substantial systematic differences in mean rainfall, frequency of wet days, precipitation intensity and extremes, and maximum length of wet and dry spells. Liebmann et al. (2012) compared the TRIMM, GPCP, and FEWS NET rain gauge datasets over a 12-year period. They concluded that no immediate preference can be given as to which dataset best represents African precipitation. The GPCP gives higher annual estimates than TRMM. However, although the timing of seasonal cycles and mean onset dates derived from monthly data is usually consistent between datasets, it is not very useful for farmers, who need more detailed information to plan their planting activities. As a result, despite new technologies to obtain rainfall information using remote sensing, the datasets are not useful if the time scale is so long. Some of the remote-sensing techniques were developed and calibrated under different types of rain-producing systems (e.g. orographic) and have not been well calibrated under convective-type rainfall due to lack of good long-term ground-truthing data from the ESA region. These results illustrate the difficulty faced by scientists due to lack of good, consistent, detailed climate datasets across ESA. Therefore, caution is needed when considering conclusions drawn, because one must bear in mind the variability in time and space in observational datasets (both gauged and remote sensing). This high uncertainty in some databases prevents rigorous and unambiguous evaluation of climate models across Africa.

2.2.3 Historic variability

This high variability is reiterated by Thornton (2015), who shows a 25-45+% coefficient of variation (a measure of how much rainfall varies from annual average) across Southern Africa, reflecting the erratic nature of rainfall in this low-rainfall region (WorldClim data, 1960-90) (Figure 3). The prevalence of droughts as calculated using SPI with different time periods is shown across the maize-growing areas of ESA in Figure 4 (Tesfaye et al., 2016).

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[2] Land and ocean gridded datasets contain a value for each squared-off area across the globe, usually on a 5-degree by 5-degree grid (72 longitude by 36 latitude).

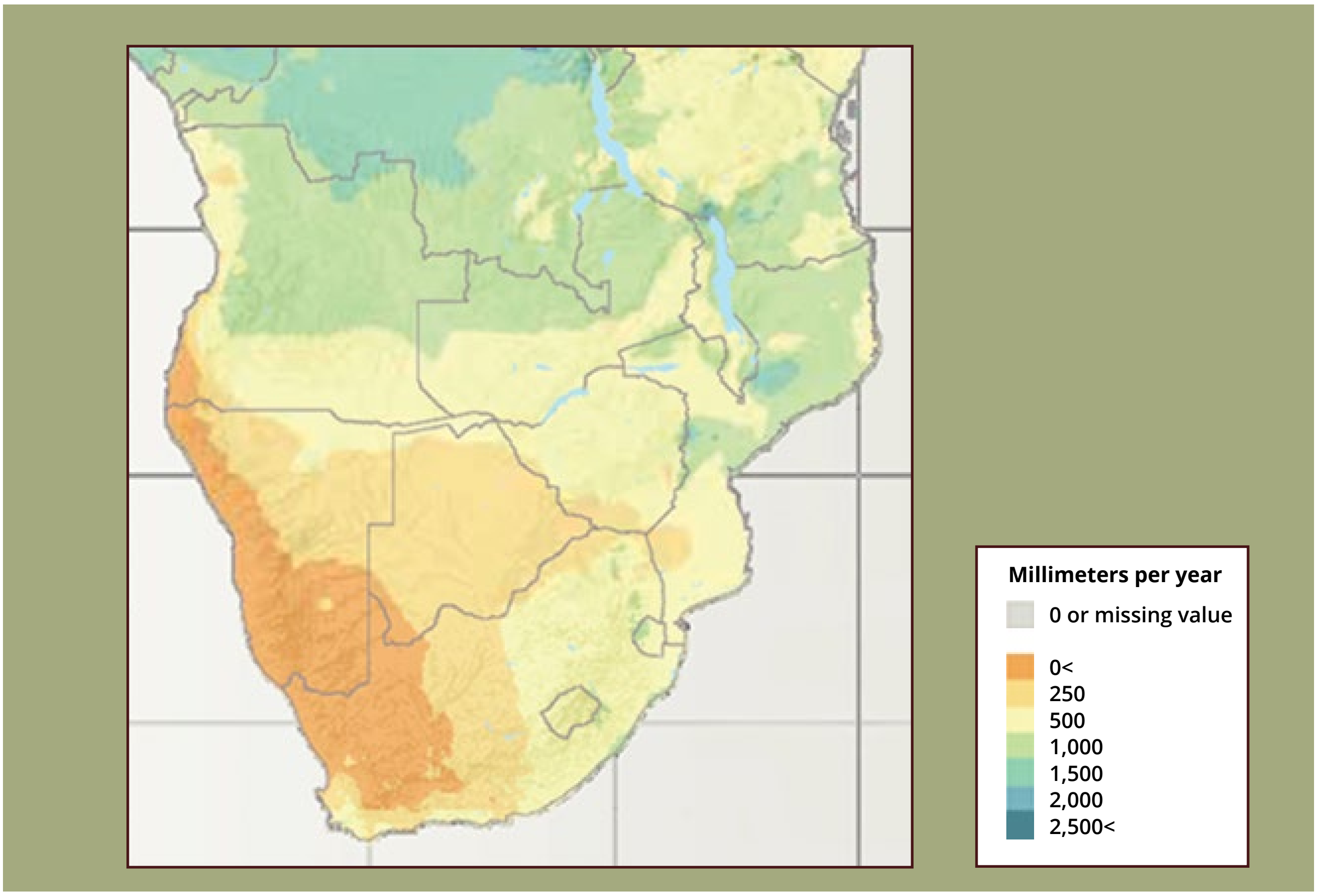

Figure 2: Total annual rainfall across Eastern and Southern Africa (Thornton, 2015, p. 2)

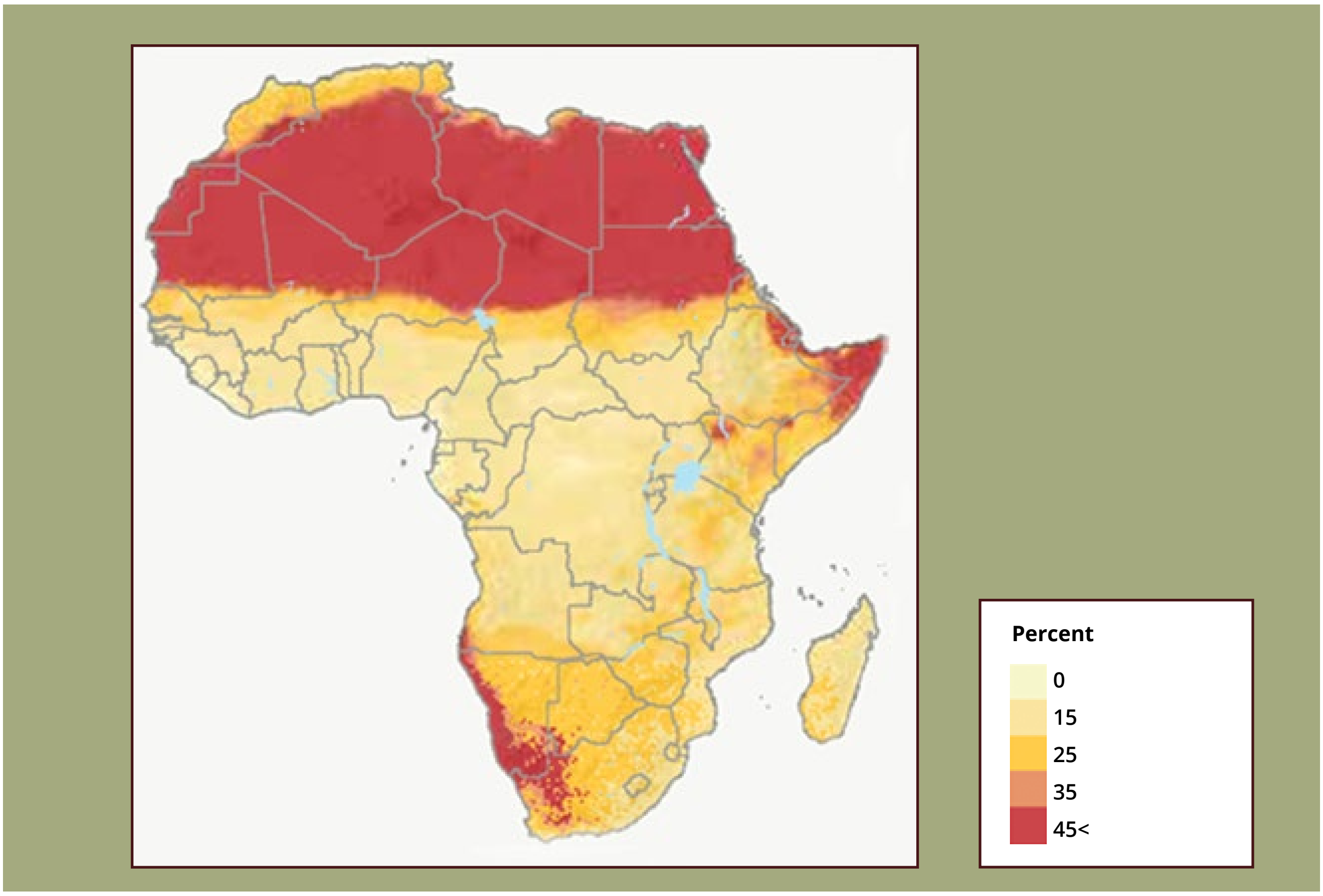

Figure 3: Rainfall variability across Africa using coefficient of variation calculated from standard deviation of annual rainfall simulated for 1 000 years of daily rainfall data for roughly 420000 grid cells (Thornton, 2015, p2)

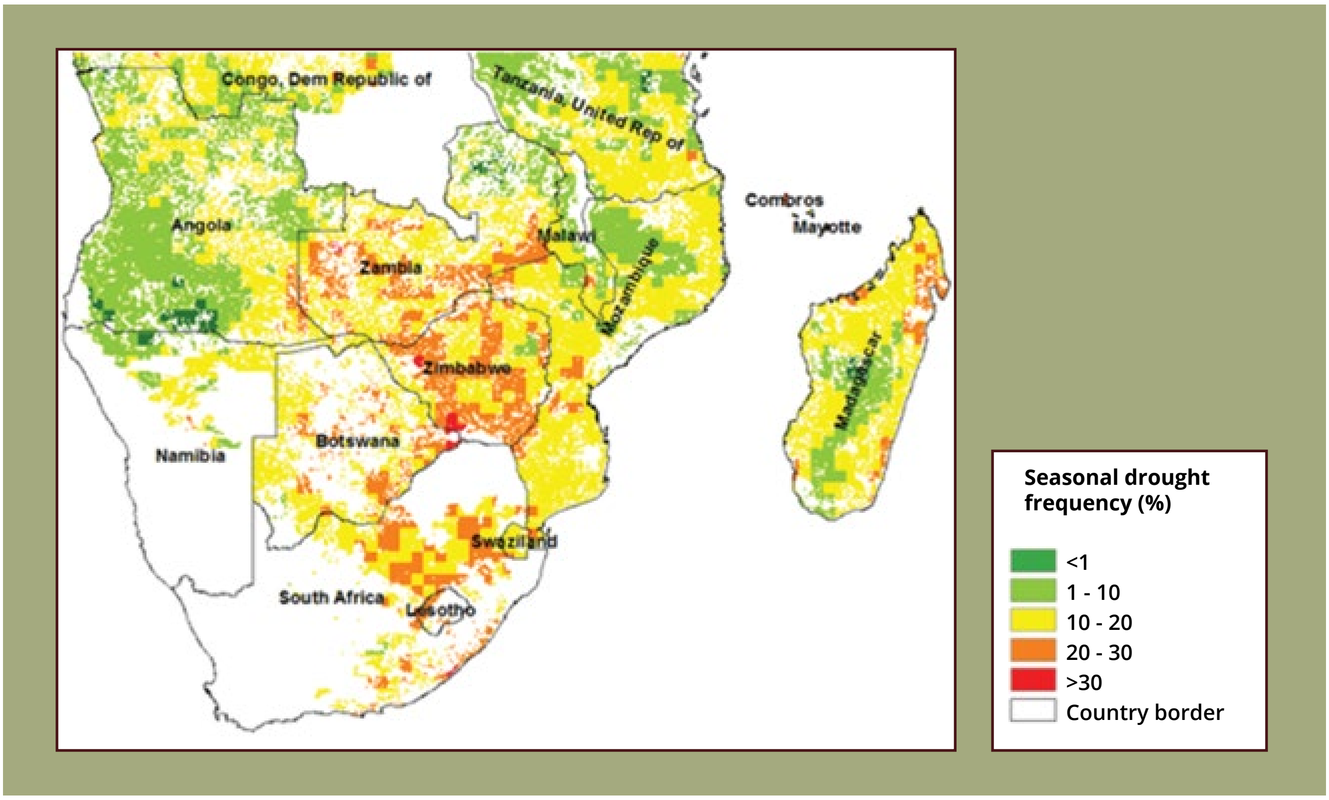

Figure 4: Prevalence of meteorological drought across maize-growing areas of Southern Africa from SPI calculations, 1960-1998 (Tesfaye et al., 2016, p. 81)

Much of ESA experiences a 20-30% chance of drought each year (Fig. 3). This means that one in every three to five years receive lower than normal rainfall or some sort of meteorological drought. One cannot expect to receive the average amount of rainfall every season. This emphasises the importance of considering seasonal rainfall forecasts when planning farming operations, which need to be flexible, with an ability to change some operations to allow for crop production under lower rainfall conditions (see discussion below).

IPCC uses degrees of confidence and attaches likelihood of occurrence to the information, although most scientific articles do not refer to these parameters (IPCC, 2014a). The IPCC-AR5 outlook is for a drier Southern Africa, a very likely lower mean annual amount of rainfall starting in the mid-21st century under the high-GHG scenario, with medium confidence that droughts will be more intense due to the combined effects of less rainfall and higher evaporation. Over parts of Eastern Africa, the mean annual rainfall amount is likely to increase starting in the mid-21st century under the high-GHG scenario, with a high confidence for increase in heavy precipitation. In addition, semi-arid areas are more vulnerable to changes than the humid areas nearer the equatorial zone. Therefore, it is likely that the combined effects of higher temperatures and lower rainfall will mean that farmers in Southern Africa need to cope with more severe and more frequent agricultural drought conditions. This is mainly because crops have optimal temperatures at which they grow well, and if extreme temperatures—such as 34-44 degrees Celsius (Harrison et al., 2011)—are frequently outside this range, then the crop will suffer heat stress. The critical periods include soon after sowing, especially if high temperatures and a dry spell occur simultaneously, thus limiting germination and emergence of seedlings through a hard-crusted soil surface. Another period sensitive to both heat and water stress is flowering, when pollen is released and seeds fertilised. Grain-filling stage also needs an adequate supply of water to maintain high photosynthesis to provide carbohydrates to store in the seeds. As the variability in rainfall between years will continue, farmers need to be able to respond to the seasonal forecast and implement different interventions accordingly each year.

2.3 Timing of rainfall seasons

Different countries in ESA have different rainfall seasons. Table 1 shows the respective months when each country normally has a rainy or wet season. For example, in Malawi and Zambia, the wet season stretches from December to April. By comparison, the normal wet season in Zimbabwe, Mozambique, and Tanzania begins in November, but after that the countries diverge: rains continue until February in Mozambique and until March in Zimbabwe, while in northern Tanzania the short rains end in January, with a period of long rains stretching from March through May (Table 1).

Table 1: Description of seasons based on climate (rainfall and temperatures), by month.

Country	S	O	N	D	J	F	M	A	M	J	J	A
Malawi	Hot & Dry			Hot & Wet					Cool & Dry			
Mozambique			Summer & Wet							Winter & Dry		
Tanzania	Dry		Short Rains			Dry	Long rains			Dry		
Zambia	Hot & Dry			Hot & Wet					Cool & Dry			
Zimbabwe			Summer Rains					Dry Winter				

As most ESA areas have a single dominant rainy season (northern Tanzania is the exception) with high annual variability, both the start (beginning) and the end (cessation) of the wet season are important (Table 1). Farmers do not plant before the rainy season starts, and many delay planting until long after the first rains due to other limitations (such as labour or draft power). The selection of suitable cultivars for an area is dependent on the length of the rainy season and planting date. A range of criteria have been used to define the start of rains or "planting date," when 10, 20, or 30 millimetres fall in a time period of 5, 10, or 20 days (Tadross et al., 2009). There have been many studies done with long-term climate data to assess these parameters at a local and regional scale.

When considering changes over the whole African continent, Kniveton et al. (2009) found that the average start of wet season shifted 9, 12, and 21 days later from 1978 to 2002 (according the 10, 20 and 30 millimetres rainfall thresholds, respectively), with high inter-annual variability. From analysis across SADC region (excluding South Africa), Tadross et al. (2009) found start dates of summer rains (25 millimetres over 10 days) to be on average between about September 10 and October 20 across central and southern Mozambique, parts of Zimbabwe, and northwest Zambia. They found that El Niño conditions (negative SOI) were linked to an earlier start of the season, although not necessarily with continued consistent rain due to an increase in the number of dry days and mean dry-spell length. In general, during El Niño, early cessation also occurs, resulting in a shorter cropping season with less consistent rainfall, as well as regular crop failure (Tadross et al., 2009). Liebmann et al. (2012), using GPCP daily precipitation data, found the earliest start of the season—October 12 (see Figure 5)—on the southeast coast of South Africa and in northwest in Angola. A later start occurs as one moves northwards and westwards across Southern Africa, with starts in mid-November through parts of Zambia and central Mozambique, in agreement with Tadross et al. (2009). On average, the earliest ending of the southern wet season occurs in mid- to end-February in southern Zimbabwe and in northwestern parts of Mozambique (Fig. 5b). The dry season expands in all directions from there, with latest cessation being end-April to beginning May along the Mozambique coast and northeastern Zambia and Malawi (Fig. 5b) (Tadross et al., 2009).

> "Farmers do not plant before the rainy season starts, and many delay planting until long after the first rains due to other limitations.

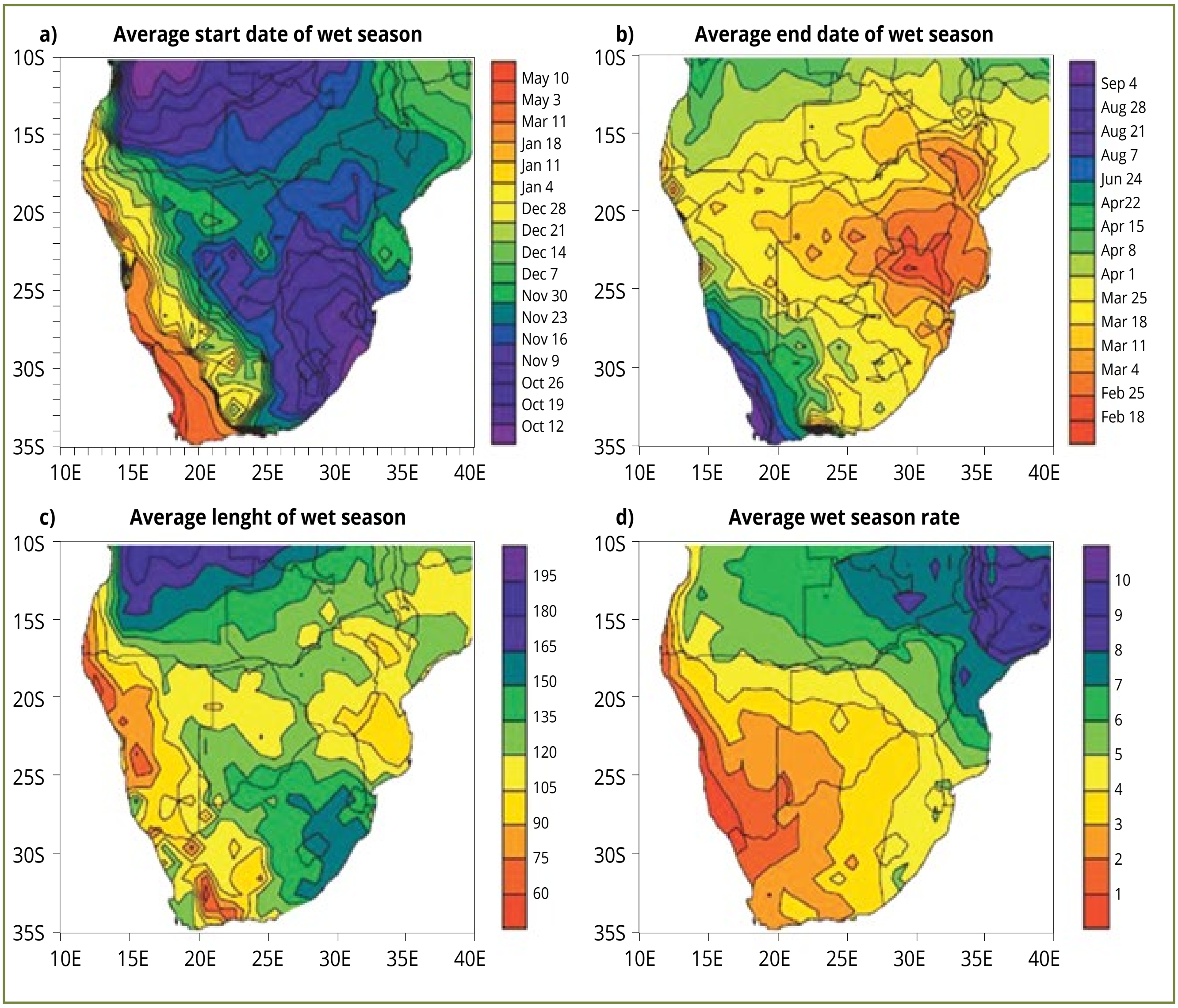

Figure 5: Mean (a) start date, computed from individual years, and (b) end date of wet season for Southern Africa (note differing contour intervals); (c) mean length of wet season in days; and (d) mean daily rain rate during wet season (mm/day). From (Liebmann et al., 2012, pp. 4311-2).

During the short rains, the end date also differs widely across northern Tanzania, and daily mean rainfall amounts above (below) 10 millimetres per day are more (less) frequent during anomalously wet (dry) seasons (Philippon et al., 2014). For southern Zimbabwe the relationship between the start and end of growing season is stronger as aridity increases (Mupangwa et al., 2011). This is in agreement with an analysis of rainfall data from northern, more humid areas of Zimbabwe, indicating that length of growing season increases when the start of rains is earlier (Chiduza, 1995). The farming systems across ESA have adjusted according to these variations in start and end of rainy seasons, resulting in different minor crops grown alongside the major crop of maize.

The length of wet seasons varies across Eastern and Southern Africa ranging from 90 to 180 days (Fig. 5c). The shortest wet seasons are across the western part of Zimbabwe and extending into the southwestern part of Zambia, as well as patches in southwestern Mozambique. The longest rainy seasons (150 days) occur in northern Zambia and the middle region of Mozambique (Fig. 5c) (Liebmann et al., 2012; Tadross et al., 2009). The daily rain rate also differs across ESA, giving a range of wet season durations and rainfall amounts (Fig. 5d). The variation in length of the rainy season and thus the growing season across ESA means that a range of crops with life cycles of different lengths are grown in different areas. It also has an influence on the choice of varieties or cultivar (e.g., for maize), as taller, longer-growing varieties with a higher production (commonly called "late-maturing") can be grown in areas with longer rainy season. The choice of variety is an adaptation strategy used when drought conditions with a shorter, drier rainy season are predicted.

Box 2. Trends from daily rainfall analysis in Zambia

Stern and Cooper (2011) used an example from Zambia (Moorings, Southern Province) with 89 years of daily rainfall data to illustrate the characteristics of rainfall patterns and variability both between and within seasons, as these are of importance to farmers. They calculated weather-induced risk associated with the inter- and intra-seasonal variability of rainfall. They found no simple trends at this Moorings station in daily rainfall data, but monthly rainfall analysis gives good indications of four important points: (1) there is no evidence of climate change that would suggest farmers should change practices; (2) this means that long-term records can be used to compare the probability of success of different cropping strategies; (3) calculations of standard deviation for three successive 30-year periods indicated that there is no change in variability of monthly rainfall; (4) when using a fitted statistical model the trend was not statistically significant. This lack of evidence of a trend suggests either that there is no change or that the large variability makes it difficult to detect, even using this long-term dataset. The observed variability of monthly rainfall totals is due to variability in the number of days with rain as well as variability of rainfall amounts on those days. Thus, when there is high variability in rainfall amounts across years, it can be perceived as changing even when there is no statistical trend present. Stern and Cooper conclude that the chance of rain has not remained constant over 89 years, but the trend cannot be explained in a simple manner, as there is no evidence that it was seasonally dependent. When considering the amount of per rain day, there was some indication (though still inconclusive) of a slight increase in mean per rain day ($p = 0.015$) over the past 40 years. Secondly, almost all the variability in rainfall is inter-annual, so rainfall has always been extremely variable from year to year, and the possible trends may not be new. Therefore, farmers have always had to cope with this variability and adapt their cropping systems. This means that it is vitally important that they are assisted in making farming decisions that are based on good scientific evidence and predictions for each cropping season.

Using the South African daily rainfall dataset, Tennant and Hewitson (2002) found that caution is needed when making extrapolations, because seasons with a high total rainfall generally have a higher number of heavy rain days (more than 20 millimetres) and not necessarily an increase in days of light rains. They also found that seasons with a high total rainfall may still contain prolonged dry periods, as there was a low correlation of dry spell length with season totals, suggesting that wet seasons had predominantly heavier rainfall events, not numerous light rain events. These relationships probably also hold across other SADC countries. Because crops need a consistent supply of water through the growing season to limit water stress, a seasonal outlook for above-normal rainfall does not mean that dry spells cannot occur during the season. Receiving larger amount of rain (more than 20 millimetres) on a single day can be an advantage to farmers, as that water can penetrate deeper into the soil profile, where the roots are, and also be stored for use later in the season, particularly if water-harvesting is used. When rain comes in smaller daily amounts (less than 10 millimetres), a higher proportion of the total annual rainwater is lost by evaporation into the atmosphere, because after each rainfall, evaporation dries the soil surface, making absorption more difficult.

Therefore, when considering agricultural drought and CSA interventions, it is of vital importance to have a good analysis of the daily rainfall that provides the long-term start and cessation dates of the rainy season (and thus length of season), as well as the amount of rainfall received per day and the length of dry spells. CSA interventions can be evaluated by matching these rainfall characteristics at a specific location to projected rainfall trends and possible changes in the future conditions, as is discussed in a later section. Due to the continued large variability and uncertainty surrounding projections, it will be important to have seasonal rainfall forecasts with added agricultural advisories about specific interventions related a particular crop and location.

2.4 Duration of wet and dry spells

The length of the dry spell is critical, because without additional water most crops can continue with good growth only for a certain length of time, which varies according to crop species. The number of dry days and number of dry spells occurring during a season at a specific place, as well as the frequency of recurrence of certain dry-spell durations, can assist in planning agronomic operations by farmers. Secondary indices are able to consider a specific crop and soil in a water balance calculation and therefore give an indication of when water stress and yield reduction will occur. In this way, it is often better to work with derived indices that use rainfall amounts and soil-crop characteristics to calculate a water stress factor or water requirement index such as WRSI. As the WRSI calculation uses rainfall amounts received on specific days, it integrates the effect of dry spells into the water balance and thus calculates an index of water stress experienced by the crop.

In Tanzania, the length of dry-spell occurrence is highly variable in space, even over relatively short distances (Fischer et al., 2013). In Equatorial East Africa (northern Tanzania and Kenya) over the period 1961-2001, during the long rains, anomalously wet ones showed earlier onsets and more wet spells with higher daily mean rainfall amounts (more than 14 millimetres per day). In southern Zimbabwe no significant change in the number of wet days per season was found over the past 50 to 74 years (Mupangwa et al., 2011). There was a high probability of 14- and 21-day dry spells during the peak rainfall months. In the analysis (using 104 climate stations, most with 50 years through 2005 but one dating back to 1900), Tadross et al. (2007) found increases in mean dry spell length as well as reductions in frequency of rain-days over Malawi, Zambia, and Zimbabwe during rainfall season.

In order to evaluate the effect of changes in rainfall patterns on agricultural drought, one can use a water balance at a crop field scale with measured rainfall. Estes et al. (2014) use a meteorological dataset (corrected for possible biases) to analyse changes in precipitation (as supply of water), potential evapotranspiration (E*p*, as demand), and water availability (expressed as the ratio P/E*p*) in 20 countries (focusing on maize-growing regions and seasons), between 1979 and 2010. For Tanzania and Malawi, they found declines in water availability mostly due to decreased rainfall, which was aggravated by increasing demand by the maize cropping systems. Much of the reduced water availability in East Africa occurred during the more sensitive middle part of the maize-growing season, suggesting negative consequences for maize production (Estes et al., 2014). Similar studies have been carried out by CYMMIT for different cultivars and by FEWS NET using remotely sensed data.

Tennent and Hewitson (2002) found that the length of the period between rain days has a low correlation to season totals, demonstrating that seasons with high total rainfall may still contain prolonged dry periods. Over Zambia, Malawi, and Zimbabwe, increases in mean dry-spell length and reductions in rain-day frequency through the 20th century were also confirmed during the rainfall season (as defined from planting date to rainfall cessation), especially when the planting date was at its earliest (ignoring false starts). This implies that changes were occurring during the beginning of the season, which reinforces evidence of a later start of consistent rainfall. All such information must be considered when evaluating agricultural droughts. In the light of past frequent occurrence of the dry spells during the rainy season and the delay in the start of the season, it is clear that drought is not a new but a regular occurrence across Southern Africa.

These short-duration dry spells are generally not considered as a meteorological drought due to their shorter duration (up to 14 days). Usually rain continues in a consistent manner following a dry spell and plants can recover. What is important about dry spells is their timing, relative to crop growth stage, and their duration, together with soil water conditions prior to them. If WRSI is calculated as an indicator of agricultural drought, then the degree of crop water stress expected can help to determine the effect on crop production. Therefore, dry spells and their timing relative to the crop age need to be taken into consideration when making estimates of the crop production.

Dry spells across ESA are variable in both space and time during the rainy season. From station data across four countries it was shown that the mean dry spell length has increased during the 20th century, or it can alternatively be stated that the frequency of the rainy days have decreased (Tadross et al., 2009). However, the rainfall data is highly variable across the region due to the occurrence of scattered thunderstorms and some individual stations even give opposite trends. Therefore, it is important to do detailed analysis of specific locations and use a water balance or WRSI to determine the agricultural drought effect on crop production. This is necessary because dry spells can be critical if they occur during the flowering and grain-filling periods, or if they become linked together into an extended drought.

Box 3. Likelihood of dry spells in Tanzania

Barron et al. (2003) related the likelihood of dry spells to the maize production at Same, Same District, Tanzania (37◦43E, 4◦5S, 872 meters above sea level) from 1970 until 1992. They found that the likelihood of a dry spell of more than five consecutive days is high during any time of the year, although slightly less during the expected rainy seasons. At Same, the probability of dry spell occurrence (P = 75%) is lower during the long rains that the short rains (P = 86%), indicating that long rains have a more reliable distribution. This was confirmed by farmers' experience. However, when relating rainfall to crop production, a water balance approach is better as it takes into consideration crop and soil characteristics (comparing sandy and clay), via evapotranspiration (ET), together with the rainfall. Effects of dry spells on crop growth are strongly dependant on soil type and development stage of the crop that is included in seasonal progression of ET. This study showed that maize on sandy soil (particularly during short rains) experienced more and longer water stress periods compared to that grown on a clay soil where there were fewer stress periods during both flowering and grain-filling stages due to available stored soil water. The negative impact of dry spells on yields proved to be higher when analysed on the basis of crop development stages than when analysed on a seasonal basis only, as the occurrence of dry spells affecting yields negatively were highly dependent on soil water storage capacity (Barron et al., 2003).

3 ENSO-rainfall relationships and seasonal forecasts

Firstly, we provide a brief explanation of ENSO and GCMs as an introduction and basis for discussion of the relationships between ENSO and rainfall in ESA. This is followed by a discussion on how GCMs predict ENSO events and the use of seasonal forecasts in ESA.

El Niño is local warming of surface waters (measured as higher sea surface temperature (SST)) across the entire equatorial zone of the central and eastern Pacific Ocean off the Peruvian coast, which affects worldwide atmospheric circulations. As it often peaks around Christmas time, the phenomenon was given the name *El Niño* (Spanish for Christ Child), with La Niña referring to a cooling of ocean surface water (lower SST) (Gommes, 1998). As with most atmospheric phenomena, it occurs at more or less regular intervals (pseudo-cycles), averaging every four to five years but with a range of two to eleven years. As such, it is not an "abnormal" occurrence. El Niño triggers so much interest for three reasons: it influences climate across the globe via teleconnections;[3] it can be modelled, and thus forecast; and the presence of a time lag between El Niño itself and many of its most important climatic consequences. Therefore, it is used for forecasting seasonal climate.

The Southern Oscillation is an East-West alternating balancing movement of air masses between the Pacific and the Indo-Australian areas. It is associated (roughly synchronised) with typical wind patterns and El Niño, and it is monitored by the SOI, which is calculated using ratios of pressure differences at Darwin and Tahiti. Thus, El Niño is the oceanic component, while Southern Oscillation is the atmospheric component. This combination gives rise to the term ENSO. There is limited correlation between minor variations in Southern Oscillation and SST, but there are stronger relationships under conditions with larger changes in SST and SOI (i.e., stronger El Niño and La Niña events), providing better predictability of future patterns (Gommes, 1998).

A general circulation model or global climate model (GCM) is a mathematical model that describes the general circulation of atmospheric and oceanographic fluid movements around the globe. GCMs use Navier-Stokes equations on a rotating sphere with thermodynamic terms for various energy sources (radiation, latent heat) in computer programmes to simulate the Earth's atmospheric and oceanographic movements. The equations are solved for many time intervals in grids across the surface of the earth, stretching into many atmosphere and ocean layers. GCMs also include sea-ice and land-surface components. There are many GCMs developed by different research centres around the world, and they are used for weather forecasting, understanding the climate, and generating projections for climate change scenarios.

3.1 Relationships between ENSO and ESA rainfall

El Niño has different impacts on different parts of the world. Therefore, the specific consequences in a particular region have been documented from empirical and statistical relationships developed under the extreme ENSO conditions. Over much of the Southern Africa region, higher SSTs (El Niño) and a negative SOI is associated with drought conditions during the October to March normal rainy season (Gommes, 1998). It has also been associated with an early start to the rainy season but then a lack of consistent rain through the rest of the season, with an increased number of dry days (or fewer rainy days) and longer mean dry spells (Tadross et al., 2007, 2009). Thus in Southern Africa under El Niño conditions, the season has lower rainfall amounts and less consistent rain, which regularly results in crop failure. In Eastern Africa, El Niño (warmer SST & negative SOI) is associated with unusual high rainfall or wetness from October to December, coinciding with the short rainy season (Gommes, 1998).

The relationship between rainfall and extreme El Niño conditions have been used to formulate seasonal forecasts for ESA that are used to help farmers and governments prepare for the seasons and particularly for international NGOs to prepare to take preventative actions. Therefore, additional response mechanisms should also be developed continually at different levels in order to be able to respond to the seasonal forecasts and develop alternative strategies to cope with the changes in a broad context. This would also allow them to make interventions and take the opportunity to change some agronomic practices in order to prepare for drought conditions or benefit from good rainfall conditions

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[3] Teleconnection in atmospheric science refers to climate anomalies or atmospheric circulations having a causal connection to each other in widely separated parts of the globe (typically thousands of kilometres).

(under La Niña). Thus the necessary tools should include alternative options and interventions to address climate-sensitive decisions in the agricultural systems.

3.2 ENSO: global relationships

Stevenson et al. (2012) explain the main drivers of the relationship between ENSO and temperature increases as related to a number of aspects, namely sampling length, physical adjustments to climate changes, errors in model physics, and uncertainties in forcing projections. They go on to assess the current state of knowledge about such relationships with information from GCMs, stating that it would be wise not to place too much weight on such results until the climatologists have improved their methodology. Therefore, in order to make meaningful conclusions about ENSO-climate change responses, one needs large ensembles of models that include dynamic causes of teleconnection difference (Stevenson et al., 2012). They state that at present, given their detailed study with current models in CMIP5, it is not possible to draw good conclusions about relationships between ENSO and long-term climate change. Similarly, Kim et al. (2014) reported no consensus on the magnitude of changes in SST variability, which are commonly used to represent the ENSO amplitude. They show, by consensus from the nine most realistic models, that it varies in a cyclic manner with time, with an increasing trend in ENSO amplitude until 2040, followed by a decreasing trend towards the end of the century. Li et al. (2011) stated that the ability to detect and predict changes in ENSO amplitude is limited by the relatively short record of observations, making it impossible to characterise the natural variability. Li et al. (2013) showed, with unprecedented accuracy, that ENSO activity in the late 20th century was anomalously high compared to the previous seven centuries, suggesting a response to global warming. However, climate models disagree about the ENSO response to global warming, probably due to an underestimate of the sensitivity to solar radiation variations. These studies show that this is an active field of research, and various climatologists have different opinions about the performance of various GCMs.

Klutse et al. (2015) presented results from an evaluation of two GCMs against reanalysis datasets (best estimate of observed state of atmosphere &independent of instruments) showing that both GCMs simulate circulation features and seasonal cycles of rainfall and temperature fairly well. The maximum error in simulated temperature fields is about 2 degrees Celsius, and for rainfall 8 millimetres per day. Both CAM3 and HadAM3 GCMs gave reasonable simulations of a significant relationship between regional rainfall and SST in the central equatorial zone Pacific Ocean (Niño 3.4 region) and show that in these two GCMs, ENSO strongly drives the climate of Southern Africa (Klutse et al., 2015).

Yeh et al. (2014) point out that despite significant progress, unresolved questions still remain, including ENSO diversity and extreme events, decadal modulation, predictability, teleconnections, and interaction of ENSO with other climate phenomena. It appears that progress can be made if two types of El Niño are distinguished by the conditions of SSTs. DelSole et al. (2014) show that by 2095 the North Atlantic will become the dominant area for seasonal predictability as ENSO becomes less variable and teleconnection patterns expand into the Atlantic.

However, the ENSO frequency is not well captured by almost any models (especially five- to six-year periods), nor is the spatial pattern of SSTs, but they can reproduce the global averaged SST low-frequency variations since the1970s (Jha et al., 2014). This highlights the need for caution with GCM outputs, as one can assume the dynamics and spatial pattern of SST trends are correct when global averages are well represented, but this was not the case here. Therefore, one needs to remember these warnings from the climatologists when trying to relate climate change scenarios via ENSO to the expected occurrence of droughts in the future.

In conclusion, it appears that according to the opinion of climate science experts, the current GCMs do not represent SST variability well enough to draw good conclusions about the likelihood of ENSO occurrence in long-term climate change. No doubt, the climatologists are continually improving the GCMs and, with time, the projections may improve. However, currently, it is difficult to use the GCMs to predict future ENSO events in the medium to long term, through to the end of this century, with much accuracy.

3.3 Seasonal forecast systems in ESA

The African seasonal predictions have mainly been driven via the Regional Climate Outlook Forums (RCOFs) which were initiated in Southern, Eastern, and West Africa in 1997-98 (Hansen et al., 2011). Essentially, in ESA they are based on ENSO connections to rainfall, but it should be noted that actual predictability of seasonal climate fluctuations is considerably more complicated than the cycle of El Niño and La Niña, which span different time periods with a high year-to-year variability. During the initial RCOFs, rainfall forecasts were made only using statistical models with SST and SOI as drivers; later, however, they combined GCM outputs to provide skilful forecasts of seasonal rainfall over large agriculturally important regions and seasons (Hansen et al., 2011). Currently, seasonal outlooks have increased in skilfulness (accuracy and/or degree that prediction represents observation) and are available more than a month before the start of summer rains in Southern Africa and the short rains in Eastern Africa.

Annual RCOFs were held together with training for the national meteorological services (NMS) and a range of users in each region. They develop, distribute, and discuss potential applications of a consensus seasonal rainfall forecast for the coming season. In Southern (SARCOF) and Eastern (GHACOF) Africa, they have received international funding and brought stakeholders from climate-sensitive sectors together to discuss the impacts and develop tailor-made, practical, user-friendly applications. The media has played an important role in this process, addressing dissemination strategies and challenges. RCOFs initially did not provide information about amounts of rainfall and frequencies, but as the process matured, these aspects have been addressed. More recently, the RCOFs have worked together under CCAFS, Global Framework for Climate Services (GFCS), and ClimDev-Africa to promote the use of this information by agricultural stakeholders such as farmers, agricultural extension officers, public and non-governmental agricultural research and development organisations, ministries of agriculture, and agribusiness. Dissemination methods have received much attention, although they vary across countries, including translation into multiple local languages and across different media types—radio, TV, newspaper, internet, e-mail, etc. Training of users has also been a priority, including the training of trainers and hands-on applications for on-farm decision-making.

The usefulness of seasonal forecasts is limited in some countries by delays in distribution via the government channels and thus lack of timely availability. In some ESA countries, value-added advisories with specific agricultural information have received much work and are distributed to smallholders via pre-season community meetings. A good example is in Zambia’s Southern Province, where meteorologists from Livingstone go annually to farming communities to explain the use of the probabilistic rainfall information as provided in the seasonal outlook (Nanja & Walker, 2011). A series of radio programmes were broadcast on a local radio station each week to explain climate-crop interactions and to suggest possible changes in farming practices.

There are a number of constraints, including access to reliable information and resources (such as finance, land, seed, draught power, and marketing channels) to act on the information received (Patt & Gwata, 2002). Some common errors have emerged, such as a tendency to hedge forecasts towards higher probabilities in the near-normal rainfall range, as this seems to be a “safer” forecast. However, the RCOFs have begun to correct this tendency (Hansen et al., 2011). A common language is being developed to enable effective communication of forecast skill, including forecast uncertainty, as well as assessment of forecast quality, for regular evaluations of progress in the usefulness and value of the forecasts (Kirtman & Pirani, 2009). Benefits also emerge as the climate-change and seasonal forecast communities interact and learn from each other, and integrate products to benefit society and build resilience and coping mechanisms.

New developments are expected, such as alternate data analysis and tools to update forecasts for the current season. Husak et al. (2013) developed a technique to characterise the seasonal rainfall by combining rainfall to date in a current season with a few potential scenarios based on the satellite rainfall estimates from FEWSNET. These predictions can be updated throughout the season—something currently only done in a few SADC counties—to show a narrowing envelope of seasonal totals, which converge on the actual final seasonal rainfall amount. During each season, scenario information about rainfall expectations can thus provide users a decision-making tool to quantify uncertainty in seasonal rainfall totals and provide earlier warning of agricultural drought.

It can be seen that the ESA seasonal rainfall forecast system is well developed and operational in most SADC countries. There is, however, potential for expansion to include information in terms of agricultural drought (such as WRSI) and supplementary tailored advisories with specific information about specific crops, in addition to rainfall and temperature outlooks. These could use the current rainfall information and be based on AEZ or farming systems and the type of farmer, thus stretching across countries in the region. There are many opportunities to formulate the additional value according to the needs of the community and their own local seasonal farming practices (e.g., resource levels, crop, or variety choice), where typical interventions could be modelled across a range of ENSO type years (Walker et al., 2009). With some adaptation and adjustment, seasonal forecasts could also serve the agribusiness sector with tools for planning distribution of seed of different varieties according to the forecast, fertiliser, and other agro-chemical inputs according to supply and demand. Preliminary work done by Climate Systems Analysis Group at Univeristy of Cape Town shows potential and can be expanded to other countries (Johnson, 2008).

Box 4. Smallholder farmers and seasonal climate forecasts in Zimbabwe

Smallholder farmers in southwestern Zimbabwe are dependent on rainfed agriculture despite variable, low, erratic annual rainfall. Chagonda and a team from Midlands State University in Zimbabwe engaged with smallholders in Gweru and Lupane districts concerning the use of seasonal forecasts and their farming decisions. Farmers have their own local indicators that they use to predict seasonal rainfall. These indigenous signs are based on generations of past experience and include environmental, biological, and traditional beliefs. They use changes in fruits, trees, butterflies, and frogs, as well as the direction of the winds and the presence of haze. The scientific seasonal climate forecasts were obtained from the Zimbabwean meteorological department and the Southern African Regional Climate Outlook Forum (SARCOF). The farmers' methods predict only either a "wet" or "dry" rainy season, and they were consistent with scientific forecasts and the amount of rainfall received during the two seasons in the study.

Farmers selected differences in tillage, fertility, selection of varieties, and number of weeding actions as responses that they can make to seasonal forecast information. The experiments were conducted over only two seasons, so they do not give conclusive results about the benefits of interventions, as some treatments were destroyed by heavy rainfall. Therefore, recommendations for interventions according to seasonal rainfall forecasts cannot be made.

The farmers' perceptions about changes in the local rainfall patterns do not all agree with the climate data analysis results. Farmers claimed that the rains were starting later and finishing earlier, whereas the Lower Gweru rainfall record showed that rains started 9 days earlier and at Lupane they had been five to ten days later in the last five years. The climate data showed that the rainy season was not ending earlier. This suggests that farmers might have poor memories of rainfall variability over the longer term, as they make almost no measurement of rainfall themselves (Chagonda et al., 2015).

> **"There are a number of constraints, including access to reliable information and resources.**

4 Climate-change projections for ESA

This section about climate change is included in order to bring the above discussion about agricultural drought conditions into perspective relative to the climate change projections for the rest of the 21st century. As the key issue in this paper is agricultural drought, it is important to assess whether the information available about the projected changes in temperature and rainfall can be used to assess variations in agricultural drought in the future. The impacts of greenhouse gases as computed by the GCMs are mainly expressed as the changes in temperature and rainfall on a monthly basis. Together with the fact that GCMs are better at predicting temperature variations than rainfall, it is more difficult to extrapolate and convert these projections to represent agricultural drought in the future. As the projections show continued high rainfall variability in the future, one can expect that the erratic rainfall will continue and translate into continued regular droughts. For clarity, firstly the method of using scenarios is briefly described, followed by the IPCC-AR5 outlook for changes in temperature and rainfall across ESA.

4.1 Explanation of representative concentration pathways (RCPs)

Groups of scientists under IPCC have worked out several scenarios making a range of assumptions about the near future and changes in human influence on the environment. Constructed scenarios describe plausible trajectories of different aspects of the future that can then be used to investigate potential consequences of anthropogenic climate change. Major driving forces are represented—including processes, impacts (physical, ecological, and socioeconomic), and potential responses—in order to inform climate change policy (Wayne, 2013). The usefulness of these scenarios is that the impact of changes on climate with time can be compared across the globe under the same assumptions. IPCC changed the method of representing scenarios in AR5 (Fifth Assessment Report, IPCC, 2014a&b). Scenarios are now represented by RCPs that provide time-dependent projections of atmospheric GHG concentrations and different trajectories of radiative forcing over time through 2100 (Table 2). These replace the older IPCC Special Report on Emission Scenarios (SRES) (IPCC- SRES, 2000) and show increased understanding of anthropogenic effects.

Table 2: Description of representative concentration pathways (RCPs) used for IPCC-AR5 scenarios

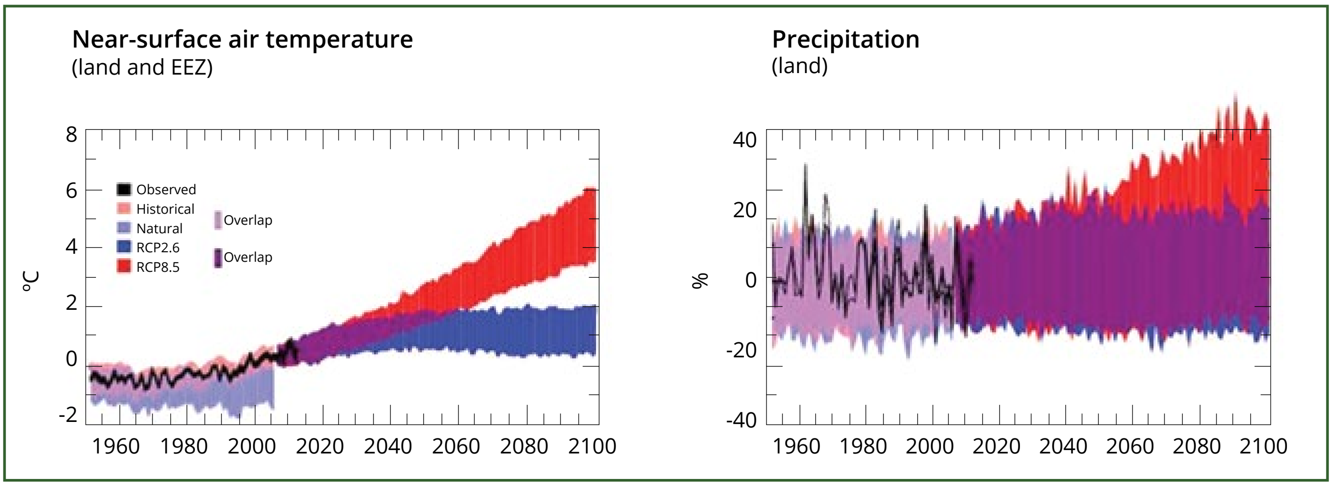
Scenario	Description	CO_2 equiv. ppm	Temp anomaly °C	SRES equivalent
RCP8.5	High: radiative forcing continues to rise and reaches >8.5 W/m^2 by 2100; represents increasing greenhouse gas emissions over time	1370	4.9	SRES A1F1
RCP6	Intermediate stabilisation pathway: radiative forcing is stabilised at approximately 6 W/m^2 after 2100 without overshoot; using a range of technologies and strategies for reducing greenhouse gas emissions	850	3.0	SRES B2
RCP4.5	Intermediate stabilisation pathway: radiative forcing stabilises at approximately 4.5 W/m^2 after 2100 without overshooting	650	2.4	SRES B1
RCP2.6	Low: radiative forcing peaks at approximately 3.1 W/m^{2}by mid-century, and returns to 2.6 W/m2 by 2100; leads to very low greenhouse gas concentration levels	490	1.5	None

Source: IPCC (2014a); Wayne (2013).

4.2 Future climate variations

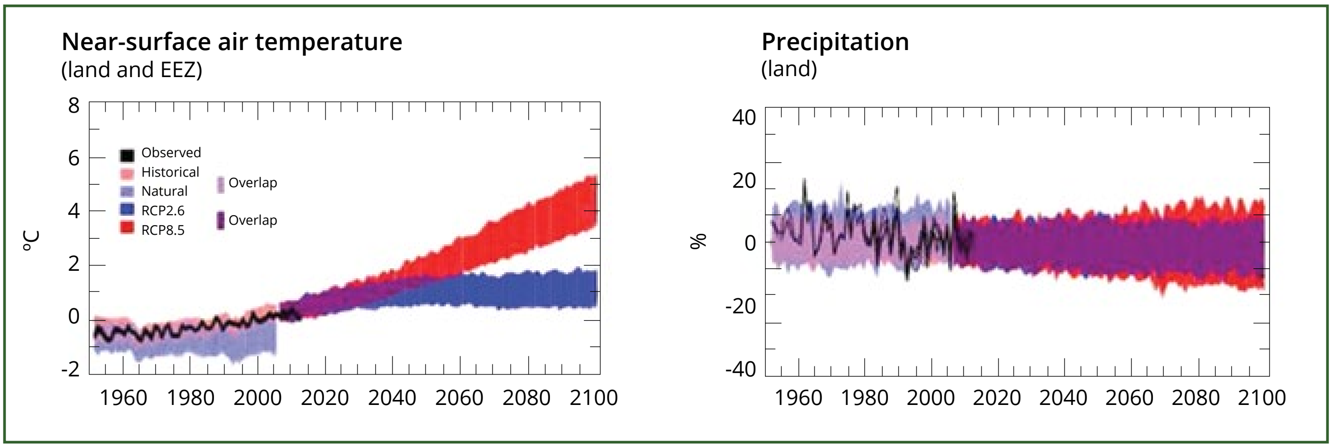
4.2.1 Projected temperature trends

Mean warming of land surface across Southern Africa is likely to be higher than the global mean land surface temperature increase in all seasons (IPCC, 2014b). Across ESA, the constrained scenario (low GHG, maintained at current levels), RCP2.6, shows surface temperatures that do not exceed 2 degrees Celsius above the 1986-2005 baseline. However, for the high GHG or unconstrained scenario, RCP8.5, projections for temperature increase across Eastern Africa are very likely to reach 3.8-6.0 degrees, while for Southern Africa they are 3.2-5.2 degrees above baseline (IPCC, 2014b Fig. 6&7) across these regions by the end of 21st century.



Black lines show estimates from observational measurements. Shading denotes 5-95 percentile range of climate model simulations driven with historical changes in anthropogenic and natural drivers (63 simulations), historical changes in "natural" drivers only (34), RCP2.6 scenario (63), and RCP8.5 (63). Data are anomalies from 1986-2005 average of individual observational data time series or of corresponding historical all-forcing simulations (IPCC, 2014a, from Fig. 22-2, p. 1208).

Figure 6: Observed and simulated variations in past and projected future annual average temperature for East African community.



Black lines show estimates from observational measurements. Shading denotes 5-95 percentile range of climate model simulations driven with historical changes in anthropogenic and natural drivers (63 simulations), historical changes in "natural" drivers only (34), RCP2.6 scenario (63), and RCP8.5 (63). Data are anomalies of average individual observational data time series (1986-2005) or corresponding historical all-forcing simulations (IPCC, 2014a, from Fig. 22-2, p. 1208).

Figure 7: SADC observed and simulated variations in past and projected future annual average temperature.

These higher temperatures will mostly have negative effects on agricultural productivity, with an increasing likelihood of declining yield potential of major crops across these regions of Africa. Therefore, agriculture in Africa will face significant challenges in adapting to projected climate change by mid-century. In Southern Africa, the maize mixed systems will be most vulnerable to climate change, with estimated losses by mid-century of 18% (Zinyengere et al., 2013). In Eastern

Africa, the opposite may occur: with rising temperatures, maize may be cultivated at altitudes above 1 700 meters, thus shifting areas where it can be grown (Thornton et al., 2009). The climate impacts on non-cereals vary by crop and area, with possible gains and losses. For instance, as cassava is more tolerant to high temperatures and sporadic rainfall than many cereals, it may be an option as a crop substitute (Jarvis et al., 2012; Liu et al., 2008). Common beans can experience reduced yields, and groundnuts and bambara groundnuts will benefit from the warmer climates (Jarvis et al., 2012, Karunaratne et al., 2015). Banana and plantain production will probably shift to the higher latitudes because it is sensitive to extreme temperatures (IPCC, 2014a). The use of agroecological zone in determining suitable areas for specific crops (with temperature and water requirements) will become more important with the rising temperatures.

Box 5. Temperature effects on maize in Mozambique

Harrison et al. (2011) examined historical changes in heat stress across the major maize-growing areas of Mozambique. They identified changes in maize phenology and heat stress exposure through the summer rainfall growing seasons from 1979-80 until 2008-09 for two maize varieties, one open-pollinated and the other late-maturing. They used the long-term mean start-of-rains date for each agroecological region and daily maximum and minimum temperatures to compute thermal time and a range of indices representing the growing season temperature and maize phenology.

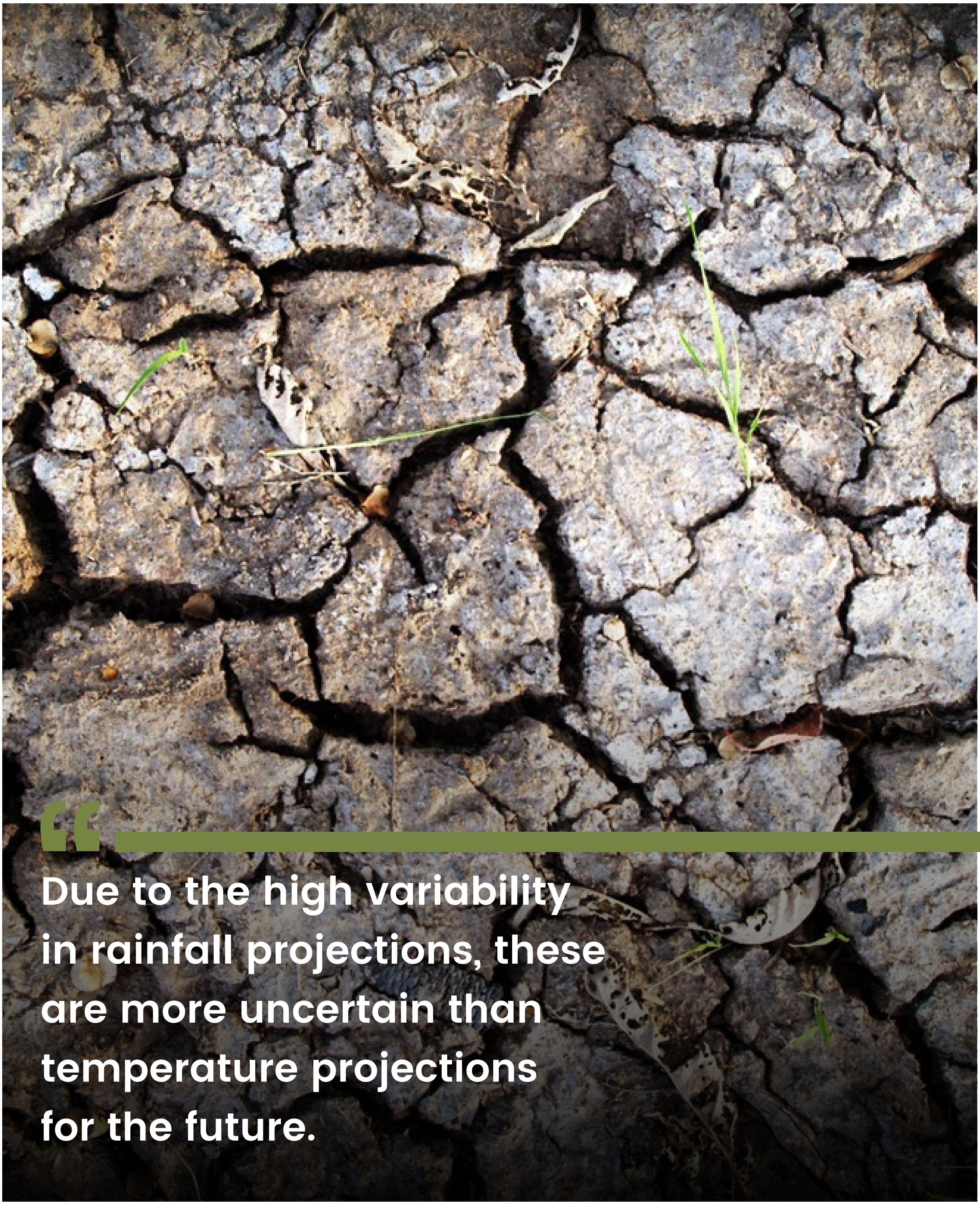
They identified phenological trends caused by temperatures occurring during part of a season that resulted in specific impact on yield. For example, an increase in early season temperatures caused shortening of the vegetative growth period from planting to start of the reproductive stage and so the plant cannot develop to an optimal size. This shifted the maximum crop water requirements occurring to earlier in the season, which increased yield risk if consistent rainfall does not fall early. This harsher thermal environment, also caused the maize reproductive period to start earlier, which increased the risk of heat and water stress. If the temperatures are higher during mid- to late season, then the reproductive period is shorter. This means that there is limited time for photosynthesis to accumulate starch to store in the grains, resulting in smaller grains and lower yield. Heat stress during initial reproductive phases of silk elongation and tasselling phase easily causes water stress and can result in poor seed set and lower yields. For seasons with higher mean temperatures throughout, the total duration of time to maturity is shortened, with consequently lower biomass and reduced yield. Hot summers resulted in 5-7% shorter growing period over the 30-year period in central Mozambique, as the most affected areas.

Farmers could respond by delaying the planting date to allow the flowering to coincide with the peak rainfall period to escape the heat and drought stress. Another potential adaptation would be to plant varieties with longer growth duration to maximise use of available radiation and rain water. However, further experimentation is needed with these late maturing varieties under farm conditions. The good linkages between yield and season length and duration of grain-filling suggest that increasing temperatures are a threat to maize production in Mozambique (Harrison et al., 2011).

4.2.2 Projected rainfall variability

Due to the high variability in rainfall, these are more uncertain than temperature projections for the future. Rainfall projections are also more variable in both space and time than temperature projections (as can be seen in Figures 6 and 7) (IPCC, 2014a). It is very likely that there will be increases in rainfall variability, with likely increases in annual amounts over Eastern Africa and very likely decreases in annual values across Southern Africa under the CMIP5-RCP8.5 scenarios by the mid-21st century (IPCC, 2014a). For Eastern Africa, the increases can be up to twice those recorded in the past, ranging from -10% to +40% of the baseline under RCP8.5 by 2100. Across Southern Africa, the trend is more likely to be toward a lower rainfall, but under RCP8.5 the variability still straddles the baseline from -15% to +10% (IPCC, 2014a Fig. 6&7). Under the RCP2.6, constrained scenario, the variability is projected to remain similar to that in the historical record in both Eastern and Southern Africa (Figures 6 and 7). Therefore, one can conclude that the existing high variability in rainfall from season to season across ESA can at least be expected to continue if GHG emissions remains constant and worsen if they increase. Consequently, for the agricultural sector, it seems best to prepare for a worst-case scenario of more meteorological droughts across Southern Africa and more flooding across Eastern Africa.

Across the equatorial zones of Eastern Africa, one can expect higher rainfall with increased variability. Thus there could be fewer meteorological droughts and a higher frequency of local flooding, but the variability remains. Across Southern Africa, given the projection of slightly lower rainfall, one can expect the existing regular meteorological droughts to be aggravated, especially as these projections have high uncertainty. However, agricultural drought includes more than just the assessment of the amount of rainfall received. Because GCMs are not easily used to make good predictions of the variations in rainfall-season starting dates and dry spells, by mid-century the effect of climate change on the finer aspects of agricultural drought remains unknown and uncertain. Higher temperatures in the future would increase the evaporation and thus also affect the WRSI, so one can expect more frequent agricultural droughts. Therefore, food production across ESA will continue to be among the world's most vulnerable, as most food crops are cultivated in rainfed farming systems where growing seasons are confined to rainy seasons with both high intra- and inter-seasonal variability. The continued occurrence of agricultural droughts is thus expected to persist, with negative effects on both crop and livestock production. This may be accompanied by an increased frequency of crop failure due to the expected higher temperatures (Thornton et al., 2009).



> “Due to the high variability in rainfall projections, these are more uncertain than temperature projections for the future.

5 Implications for agricultural production

Most food production in ESA is within mixed farming systems, meaning that individual farms commonly encompass multiple crops as well as livestock. Many farmers also participate in off-farm endeavours that complement their farming activities. When they are facing drought, they need to make decisions according to their risk profile and the choices available to them. These will depend upon their income class (and whether they have debt); position in society; relationship to land and land tenure (landowner, labourer, share-cropper, etc.); and range of activities (commercial, subsistence farmer, trader, processor) (Walker & Stigter, 2010). It is logical that farmers in different circumstances will have different opportunities and options to address drought conditions. One first needs to understand the current farming and cropping systems, with their flexibility and choices in the seasonal operations, before developing alternatives. Below are brief descriptions of the most important farming systems in ESA, followed by interventions to cope with the risks of drought.

5.1 Farming systems in Eastern and Southern Africa

Resilient cropping systems should be built within farming systems to offer a range of benefits to producers, the environment, and the surrounding community. Interventions to decrease the impact of drought should be adapted for the existing farming and cropping systems that vary across ESA according to agroecological zones (AEZ). The operations and decisions in different farming and cropping systems should be considered particularly according to scale and purpose of cropping system— household use, cash crops, or small- or large-scale production. African farming systems can broadly be divided into the following: small-scale (traditional, mostly unimproved management, mainly for subsistence, with little fallow); large-scale commercial farms with improved management; irrigation (mainly high-value commodity crops like sugar, tobacco, and coffee); shifting cultivation (slash and burn); livestock farming (dependent on natural or cultivated pastures); agro-forestry systems; and collection of wild fruits or other products from natural vegetation (Nanthambwe, 2003). A range of interventions will be applicable for each of these types of farming systems.

In most African rain-fed farming systems, the productivity depends on natural resources available within the agroecological context (Sebastian, 2014). Therefore, the traditional spatial distribution of African farming systems have been closely aligned to the regional pattern of agroecological zones (AEZs) (Figure 8). This pairing of the two indices could be expected because they are both linked to the climatological conditions, soil and landscape, altitude and latitude. As agroecological conditions are usually seen over a longer time scale, they can help to predict the feasibility and effectiveness of improved technology as an alternative production intervention (Sebastian, 2014). This is why information such as that presented by Engelbrecht and Engelbrecht (2015) on shifts in Köppen-Geiger climate zones over Southern Africa (Africa south of 22 °S) under climate scenarios is useful as a basis from which to work on assessing alternative interventions as adaptations to climate change. They show that semi-arid and arid areas will move steadily eastwards from the Namib Desert, along the west coast of Southern Africa, replacing the grasslands in the central parts of the continent by 2100.

5.1.1 Mixed cereal and legume systems

The dominant cropping systems in both Eastern and Southern Africa are rain-fed mixed cropping systems, as there are relatively few irrigated areas due to the scarcity of water resources. This means that production or growing seasons are limited to rainfall seasons, and planting can only begin after the first rains are received, although it usually takes place even later due to limited availability of animal draught power and labour. These systems (see Figure 8) include mixed cropping agropastoral systems; mixed cereal and root crop systems that involve maize, sorghum, millet, cassava, yam, and legumes (beans, pigeonpea, cowpea, chickpea, groundnut, etc.); and tobacco and cotton as cash crops (AGRA, 2014; Mabhaudhi et al., 2016). The cereals need different amount of water, so usually their distribution varies according to rainfall, with maize grown in higher rainfall regions (greater than 500 millimetres), sorghum with less (400-500 millimetres), and millet in the driest areas (less than 400 millimetres) (Swaraj Foundation, undated; Van Heerden, & Walker, 2016.). These alternative grains can be introduced, but adoption will depend on sociocultural acceptance by the communities.

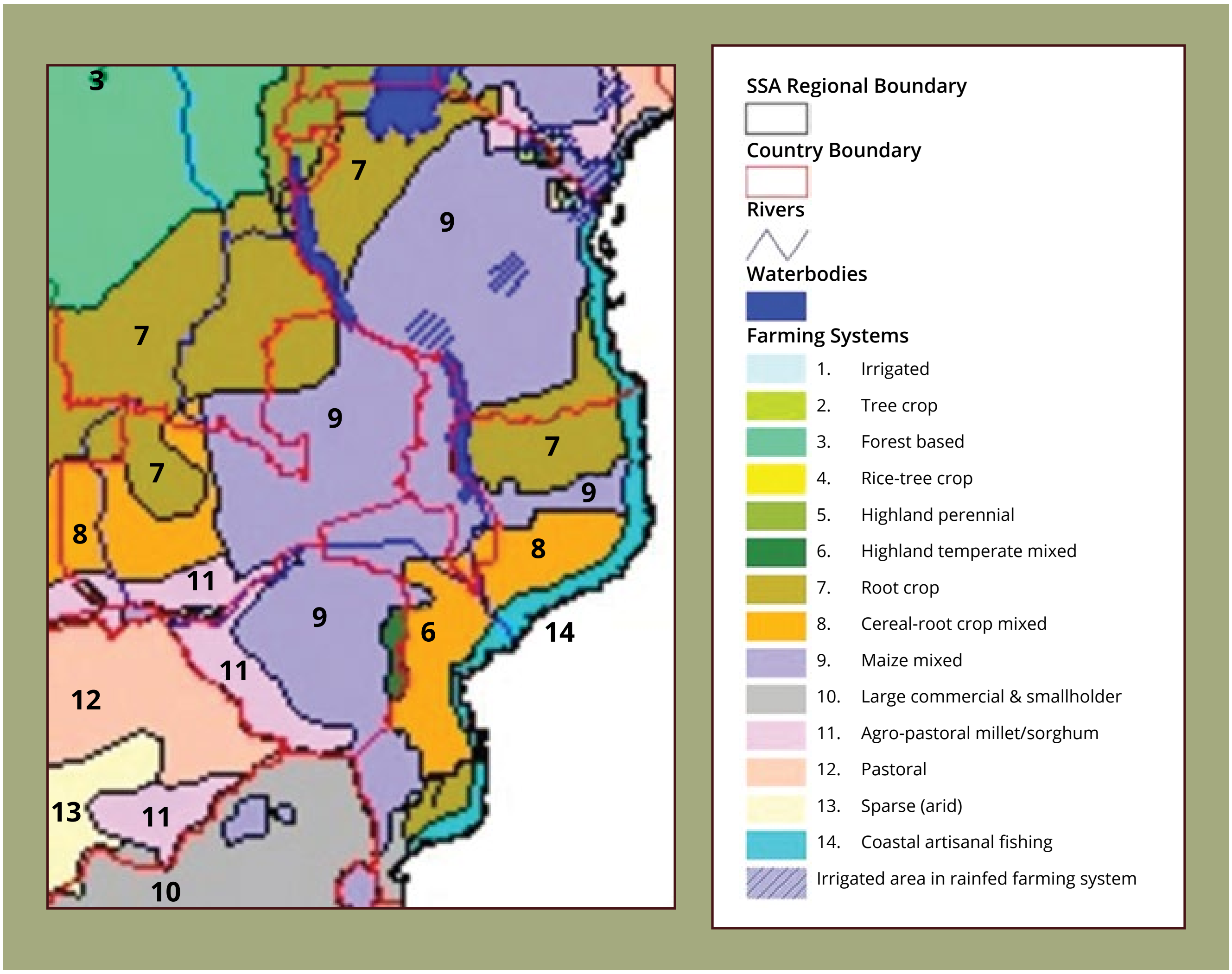


Figure 8: Farming systems distribution across the Eastern and Southern African region (FAO, 2016, http://www.fao.org/farmingsystems/maps_SSA_en.htm)

5.1.2 Alternative and underutilised crops (including root crops)

The cropping systems are called “mixed” because they include a number of other minor crops that increase overall productivity. Most smallholders across Africa grow a large variety of crops, including so-called traditional crops, also known as orphan, indigenous, neglected, and underutilised. These minor crops—which include roots, leaves, cereals, legumes, and trees—are grown throughout ESA in all AEZs, from arid to semi-arid to sub-humid to humid areas (Mabhaudhi et al., 2016). More diverse cropping systems are more productive, less dependent on external inputs (because, for example, legumes fix atmospheric nitrogen), more energy efficient (i.e., they capture more sunlight), and more adaptable and resilient (Doré et al., 2011). Thus agrobiodiversity can provide an index to measure changes in the sustainability, health, and resilience of farming systems (Smith et al., 2015). Such systems provide a broader base for household food supply because various crops mature at different times, and some are more drought-tolerant than the main crop of maize.

5.1.3 Agroforestry systems (including perennials)

Legume trees are part of natural vegetation across many parts of semi-arid Africa, and thus are part of the traditional farming systems. Agroforestry incorporates the cultivation and conservation of trees as a land-use management system in which trees, shrubs, or perennial plants are grown around or among other crops or pastures, providing up to 50 different uses. Integration of trees on farms diversifies the productive farming system and provides ecosystem services, while yielding staple foods and other marketable tree products (Carsan et al., 2014). The FAO’s “Guidelines on Sustainable Forest Management in Drylands of Sub-Saharan Africa” (FAO, 2010b) give information on species and their uses—for products, for ecosystem services, for water and soil conservation, and to stabilise or decrease global carbon emissions (FAO, 2010b).

5.2 Coping with drought risk

Agricultural drought occurs when a lack of rainwater affects crop production, as evapotranspiration by the crop exceeds rainfall received. This can occur due to several variations in the normal rainfall pattern that result in insufficient water being available to produce a harvest. It can be due to a lower amount of rain, a late start and/or early end of rains, or extended and/or more frequent dry spells within the rainy season. Therefore, interventions to help farmers cope with drought should provide alternatives to address all of these possibilities.

Due to high seasonal variability in rainfall, the best intervention options consider and depend on the prevailing conditions, and therefore include information about the current situation and the rainfall forecast for the next 3-6 months. In this way, the interventions can be a response to the current conditions and provide alternative interventions. This also allows farmers to make their own decisions and retain control over their own activities. They react to the actual situation and do not become helpless. The interventions are described below, arranged according to the aspect of agricultural drought that they are addressing.

5.2.1 Lower amount of rainfall

Water available for crop production is dependent on the balance between input (mostly rainfall, with some supplementary irrigation—and extraction, mainly by evapotranspiration and runoff. The useful or "green" water that goes through the plant as transpiration can generate biomass that is available for storage and harvest as grains. Non-productive water—that lost as evaporation directly from the soil surface—should be limited as much as possible. Soil evaporation is reduced by using mulch, which retains water within the soil profile for use by plants. Another method of shifting the balance between soil evaporation and transpiration is to plant more than one crop on the land at the same time, known as intercropping. Usually one of the crops grows quickly so that its leaves shade and protect the soil surface from direct sunlight, thus reducing soil evaporative losses. Under intercropping both the crops, produce a harvest, thus increasing the productivity of the land. A common problem is weeds, which use the water supply but do not contribute to the harvest. One drought intervention is to remove weeds early in the season and keep them under control throughout, especially in the period before the crop has reached full canopy cover. This will save water for the main crop and delay onset of water stress conditions.

The amount of water available in the soil profile for cropping increases under rainwater harvesting. This is where water that would have left a field area and been lost to a crop is saved to infiltrate into the soil profile and be stored. There are many methods, both in-field or micro-catchment and ex-field or macro-catchment, that are used in African farming systems (Biazin et al., 2012). The in-field methods include planting basins, pitting, ripping, contour basins (with or without bunds), tied ridges, terracing and dead-level furrows (with or without collection pits). All help to retain rain water on a field and so promote permeation, even on marginal soils with low infiltration rates. The macro-catchments include open ponds or dams, cisterns or underground tanks, micro-dams, sand dams, and overland flow or spate-irrigation systems. All these types of systems require planning and construction prior to a planting season. They have high initial labour investment costs and are a semi-permanent intervention system. They can improve the water storage by 30% in the long term and improve production up to six-fold (Biazin et al., 2012). Water-harvesting techniques are used as an intervention where drought is a frequent occurrence, and thus become a more permanent part of the tillage system and a long-term response to drought.

Two other interventions that can be implemented prior to the start of the season are the choice of crop or variety and diversification of the cropping system. It is well known that certain crops (e.g., sorghum and millet) require less water to complete their growth cycle and can be good choices when a low-rainfall season is predicted. The different varieties of maize also have different final heights and different lengths of growing season. The short stature and early maturing varieties generally use less water through until maturity and so can be a wise choice for a low rainfall season. The newer drought-tolerant maize varieties can produce higher yields than other commercially available varieties under varying levels of water-stressed conditions (Tesfaye et al., 2016). Therefore, they provide a good opportunity prior to planting to reduce the drought risk during the upcoming season.

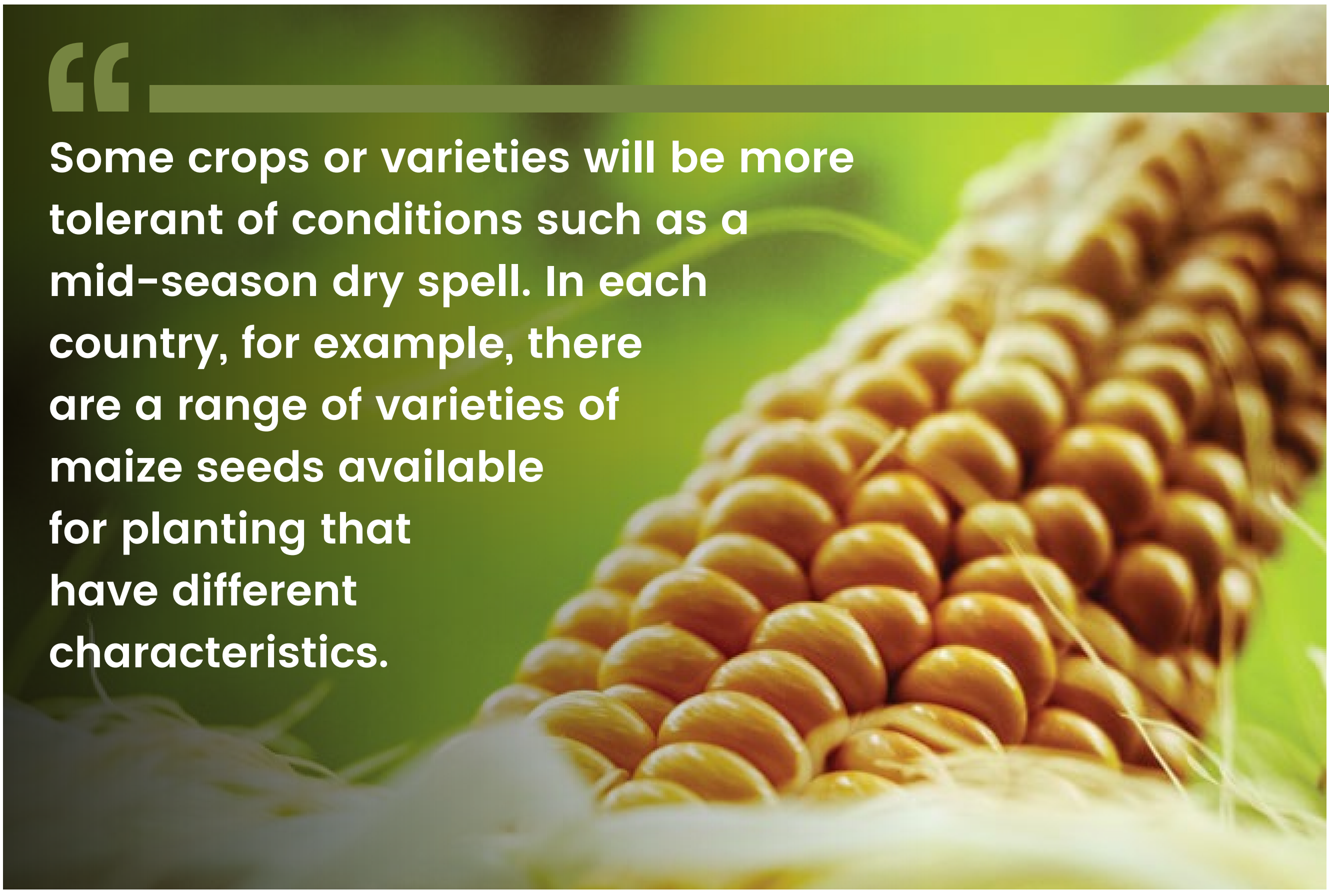
A number of practical interventions have been discussed that can be made to address the lower total rainfall amount received during the rainy season. The decision to take such an intervention could be made on receiving the rainfall forecasts and considering the amount of soil water already stored in a certain field or soil profile. The choice will depend on the availability of the desired seed and the availability of labour to prepare the land and store rainwater.

5.2.2 Shorter rainy season

A late start or early end of the rains (or both) will result in a shorter rainy season. A farmer must decide which crops—and which cultivars—to plant in which fields, and when to plant them. These choices must be made prior to the start of the season, and the planting of the selected crop or variety is a decision that cannot be reversed. Some crops or varieties will be more tolerant of conditions such as a mid-season dry spell. In each country, for example, there are a range of varieties of maize seeds available for planting that have different characteristics, such as shorter time to maturity, plants with shorter stature, more erect leaves that do not flop over, different size and number of maize cobs, etc. Some crops (such as Bambara groundnuts and common beans) are indeterminate, which means that they continue to produce flowers and seed over an extended period of time through the season and do not have a terminal seed production system (as maize does, for example). These are useful for drought avoidance as they can continue to produce seed at intervals over a long period of time, even recovering after short dry spells, and do not simply cut their life cycle under severe water stress conditions. If one receives a seasonal outlook that predicts a shorter rainy season, then one can choose to plant an early-maturing or short-stature crop that will require less water to produce a good yield. These varieties and crops will be able to complete their life cycle in a short time period and thus limit the effects of the drought.

5.2.3 Frequent or prolonged dry spells

In one type of agricultural drought, the rains begin and then are interrupted by an extended dry spell, or frequent short dry spell with little rain received between them. The water balance is important in this situation too, because the amount of water available in the soil profile will determine whether the crop reaches flowering and maturity to produce a crop. The critical growth and development phases are germination, flowering, and grain-filling. Dry spells during germination and emergence can result in poor plant population, which often requires replanting. If there is a prolonged dry spell during the flowering period, then there can be poor fertilisation due to little or wrongly timed pollen releases. If early-maturing, short-stature varieties are serial-planted at stepped intervals after the start of rains, then flowering is spread over a longer period, decreasing the risk of crop failure due to a midseason dry spell. Drought-tolerant crops (such as sorghum and millet) also have different mechanisms and water-stress levels when their stomata close, so they can produce a yield while using less water through to maturity. The water-harvesting methods described above also will help to accumulate more water during the rainy periods, allowing the crop to continue longer between the rains and into the dry spells. All of these interventions, used alone or in combination, can limit the effects of dry-spell droughts during a growing season.



> “Some crops or varieties will be more tolerant of conditions such as a mid-season dry spell. In each country, for example, there are a range of varieties of maize seeds available for planting that have different characteristics.

5.2.4 Higher evaporation rates

The driving forces for evaporation are the temperature of the surrounding air, solar radiation (which supplies the energy), and low water-vapour content in the air (which causes water to evaporate). As temperature rises under changing climate conditions, it will also increase the evaporation rates. Both parts of evapotranspiration from a cropping system—evaporation from exposed soil surfaces and transpiration from plant leaves—are affected by the rise in temperature. There is also a feedback loop: greater heating of dry soil surfaces results in higher temperatures and higher evaporative demand. Because there is a limited amount of soil water available, this demand of water from the atmosphere will cause additional stress on the agricultural systems, particularly when rainfall has decreased. A number of heat- and/or drought-tolerant maize varieties have been bred, but some of the widely grown African hybrids are susceptible to drought stress at elevated temperatures (Cairns et al., 2013). Therefore, it is best to grow varieties that are tolerant to both drought and heat stress.

The use of mulches helps to limit water loss directly from the soil surface under these higher evaporative demand conditions. A mulch covering will limit the amount of direct radiation reaching the soil surface and thus maintain a lower soil surface temperature, limiting evaporation. It will also provide a barrier to free movement of water vapour away from the surface and restrict evaporation and soil water depletion. Using mulch in conjunction with rainwater harvesting within the cropped field gives advantages by increasing crop production, as rainfall collected and stored on the field is available to the crop. Such interventions should be introduced into cropping systems on a routine basis in order to optimise the use of the available rainwater and counter the influence of the higher evaporative demand due to higher temperatures.

5.3 Response farming

Response farming, originally conceived in Kenya, uses the start of rains to predict the upcoming rainy season (Stewart & Hash, 1982). The concept has since been expanded into a flexible system of farming in which key decisions affecting water utilisation and crop yield are modified each season in response to pre-season and early-season predictions of rainfall (Admassu et al., 2014). It uses available historical information (on rainfall and farming systems) together with the current seasonal forecast to make recommendations concerning decisions related to a cropping system (Walker, 2006). The system, however, requires some capacity-building, such as field schools to help farmers better understand seasonal forecasts and the cropping options available (e.g., the differences between early- and later-maturing varieties and different water-harvesting methods).

This can be achieved by establishing a database with the necessary climate, soil, and cropping information. Agrometeorologists can build predictive models to generate meaningful information regarding the best crop choices for farmers, given the current seasonal forecast. Extension workers can then deliver the message to farmers. In this way agricultural advisories can be developed in an operational, location-specific system to add value to seasonal climate forecasts, which normally include only rainfall probabilities. These advisories can be improved with feedback from the farmers on their weather-sensitive decisions, and an evidence-based tool can be developed using data-based decision-making principles. The interventions proposed above that address various aspects of agricultural drought can be included to provide alternatives to optimise water use and crop production under drought situations. The input can include farmers' preferences, locally important cropping-system variations, and seasonal forecasts from several sources, in order to generate tailor-made agricultural seasonal advisories.

5.4 Climate services

If farmers are to implement response farming, they need information about both the local climate and their farming systems. Such information includes long-term climate information, current forecasts, and data about the specific farming systems and possible options for interventions. This would be available via climate or agrometeorological services. Climate services are the provision (including production, translation, and transfer) and use of climate knowledge, data, and information to address climate-informed decision-making and planning at both operational and policy-planning time scales and levels. For farmers, NGOs, and extension workers, these services should be provided together with additional pertinent agricultural information tailor-made to address users' requirements. Climate services make the best available climate science and information available in an effective way to a range of sectors—agriculture, water, tourism, health, energy, etc. (Climate Services Partnership, 2016). Aspects that need to be addressed include communication, technical capabilities, and active communication and exchange between producers, translators, and user communities. For the communication part, it is important to have timely, easily accessible, decision-relevant, scientifically correct information that can be distributed in local non-technical language to the users. The main objective of such climate services is to help society cope with climate risks and make use of opportunities, while strengthening the cooperation between climate sciences and different interested parties that rely on climatic and scientific information (Beierlein & Sheward, 2013). All segments of society can benefit from climate services—governments, industry, economy, businesses, agriculture, media, educators, and the general public.

Good daily climate datasets stored in accessible databases form the foundation of climate or agrometeorological services and should be available to researchers and extension workers. Then local-scale analysis pertinent to the needs of smallholder farmers can be performed. The agricultural drought situation can be evaluated using long-term analysis of the WRSI for a range of typical crops and soils combinations in a specific region (Moeletsi et al., 2013). If these are used to construct frequency curves that can be segregated into different groups according to El Niño and La Niña years, then they are ready to develop recommendations (Tsubo & Walker, 2007). This information, stored in a database decision system, can be used by skilled agrometeorologists in conjunction with annual seasonal rainfall forecasts to generate tailor-made advisories for each region. Information about the interventions to address the low rainfall amounts and shorter rainy growing seasons can be included in such an advisory system. Then recommendations could include a selection of cultivars or other crops, as well as land preparation technologies for water harvesting, according to the upcoming climate forecast.

In order for this type of information to reach the farmers, routine climate services need to be in place. Intermediaries should receive training in climate field schools about the climate and ENSO and their influence on crop production. If they are informed about the current forecasts and the probability of drought for the current season, then they can pass the information along to the farmers. Much effort has been made in ESA to disseminate the seasonal rainfall outlook forecasts to the farming communities. However, the addition of pertinent agricultural information has become a routine process in only in some countries. Many aspects of the dissemination need further work, including the communication channels, content of message, methods of obtaining feedback, and frequency of transmission. Detailed development is needed for translation into local language, explanation of technical terms, use of local radio and print media, and adaptation to local information about crops and technologies. If intermediaries have been training in the basics of climate and weather interaction with the farming systems, then they can assist the farmers in interpreting the current season's information and in developing a plan of action from the available technologies (Stigter et al., 2013).

Farmer climate field schools should be instituted to train extension staff (World Bank Group, FAO & IFAD, 2015) as intermediaries to understand this information and make necessary local adjustments for the communities that they serve, in order to align it with local farmers' preferences (Winarto & Stigter, 2013). On a regular basis the intermediaries should examine and formulate advisories in response to the climate forecast, as they understand the effects of available drought-coping interventions. In this way, farmers can be assisted to make adequate preparation for upcoming seasonal droughts. These tailor-made forecasts with added agricultural information will then form a part of the early warning schemes currently operating in ESA, and can become operational via the combined effort of the meteorological services and agricultural departments, together with NGOs.

> **"In order for this type of information to reach the farmers, routine climate services need to be in place.**

6 Conclusion: options for coping with agricultural drought

The distinction between agricultural drought and meteorological drought has been emphasised in this paper. Agricultural drought refers to more than just the amount of rainfall received, but also the timing of the start of a rainy season and the occurrence of dry spells within it. This additional information is of vital importance to the agricultural sector, as crops can develop water stress during a long dry spell or if planted before the rains begin. The timing of the start of rains helps farmers to make decisions concerning which crop or cultivar to plant on which soils. The WRSI can be used as an indicator of agricultural drought and water stress conditions as it includes information about the crops and soils together with the rainfall.

It is common in Southern Africa to experience extended dry spells (10-14 days) which can have devastating effects on crop production if they occur during susceptible stages of crop growth and development including germination, flowering, and grain-filling. Daily rainfall records suggest that changes in rainfall amounts and patterns may be occurring, particularly in the timing and intensity of precipitation. For example, across Southern Africa reports found a trend for seasons to start later, with a declining number of rainy days (Tadross et al., 2009). However, analysis from individual stations in other studies contradict these claims (Stern & Cooper, 2011).

The rainfall in both Eastern and Southern Africa is linked to ENSO, although in opposite ways. ENSO indices, sea surface temperatures, and pressure differences across the equatorial zone of the Pacific Ocean are used as predictors of the upcoming rainfall season across ESA due to global teleconnections and lag time of effects. In Southern Africa, El Niño conditions (higher SSTs, negative SOI) are associated with less rainfall as well as an early start to the rainy season; in Eastern Africa, El Niño is associated with more rainfall. However, it should be noted that the IPCC-AR5 report (IPCC, 2014a) indicates that the current GCMs do not represent SST variability well enough to accurately project El Niño or La Niña events into the middle and latter parts of the 21st century. GCMs predict that under the high GHG scenario, the annual rainfall amount is very likely to increase over significant parts of Eastern Africa, and very likely to decrease over much of Southern Africa.

Over the past few decades, climate scientists have used GCMs to generate seasonal rainfall forecasts for different regions across Africa. These outlooks give a probabilistic prediction about the prospect of receiving rainfall in a subsequent three-month period relative to long-term mean amounts. This information is combined with contextual information about the climate-sensitive decisions in farming operations in a specific area, to give options to farmers according to the current rainfall outlook. This enables the farmers to use a flexible response farming method to make operational decisions according to the available weather and climate forecasts and information, such as which cultivar or crop to plant at what time. There are still some constraints facing the optimal use of seasonal forecasts and response farming, such as timely distribution of easy-to-understand, practical information. However, even farmers who have access to the seasonal forecasts still need to have viable practical alternatives to choose from in order to make use of the information.

In order to help farmers, cope with agricultural drought due to lack of rainfall, a late start or early end of rains, or more frequent dry spells, one needs to consider a range of options depending on the prevailing conditions. There are a number of water conservation techniques available to accumulate and store more of the rainfall in order to make more efficient use of the limited rain received. These include a range of rainwater harvesting methods to keep the water on the field and to store it in the soil profile for later use. As different crops have different water requirements, it can also help to select a crop or variety that uses less water if the forecast is for a below-normal rainfall season. To facilitate the reduction of wasteful soil-surface water evaporation due to higher temperatures, one can use a soil surface covering such as mulch, intercropping, or regular weeding. One can also use some interventions to address the shorter rainy seasons and dry spells by selecting early maturing varieties and selecting a planting date so as to minimise the risk of a dry spell occurring during the critical flowering stage.

Because there is high seasonal variability in rainfall, the best intervention will use the current seasonal forecasts while considering the prevailing conditions, including available soil water. Then the proposed interventions will be a response to prevailing conditions and provide alternative operations that help cope with the forecast agricultural drought conditions. This will help farmers to make wise decisions based on current seasonal forecasts and available resources, thus retaining control over their own activities. This type of response farming allows farmers to react to the actual situation and prospects of future rainfalls and not remain helpless in the face of recurring agricultural droughts across the Eastern and Southern African region.

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