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TECHNICAL REPORT

IMPACT OF CLIMATE CHANGE ON SELECT VALUE CHAINS IN MOZAMBIQUE

January 2017

This document was produced for review by the United States Agency for International Development. It was prepared by the University of Arizona for the ATLAS Task Order.

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COVER PHOTO: Julio Onofrio Rainde, CGIAR, 2016. Farmers meet with extension service representatives in Dororo district, Mozambique.

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January 2017

Prepared for:

United States Agency for International Development

Climate Change Adaptation, Thought Leadership and Assessments (ATLAS)

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ACRONYMS

AWS	automatic weather station
CHIRPS	Climate Hazards Group InfraRed Precipitation with Stations
CRU	Climate Research Unit
CSA	climate-smart agriculture
CSAG	Climate System Analysis Group
FtF	Feed the Future
GCM	global circulation model
GDP	gross domestic product
INAM	National Meteorology Institute
INGC	National Institute of Disaster Management
INS	National Institute of Health
ITCZ	Intertropical Convergence Zone
PET	Potential Evapotranspiration
USAID	United States Agency for International Development
ZOI	Zone of Influence

EXECUTIVE SUMMARY

Rural livelihoods in Mozambique are primarily agriculturally-based and climate dependent. Food insecurity increases during the rainy season while households await the next harvest. Climate shocks will likely increase poverty and malnutrition for rural households, which are not currently resilient enough to withstand the effects of a changing climate.

Current climate variability, extreme weather events and projected future changes in climate pose a threat to the future of agriculture in Mozambique. Detailed information on how these dynamics manifest at regional and local scales and what can be done to mitigate their impacts has been limited, despite the importance of this information in designing responses.

This report seeks to address that knowledge gap by identifying specific regional climate risks to three value chain crops in Mozambique: soy, pigeon pea and sesame. These crops were selected based on economic importance as well as their priority in USAID's Feed the Future (FtF) Program's Zone of Influence (ZOI). This area includes the provinces of Tete, Manica, Nampula and Zambezia.

Much of the ZOI's agricultural production is already vulnerable to the vagaries of climate because crop production there is primarily rainfed, with cropping cycles defined by the onset of the rains. Farmers typically do not use improved farming practices or inputs, which leaves them less resilient to the impacts of a changing climate. Practices to improve land preparation, such as tractor-based tillage and crop rotation, as well as the use of improved, certified seed, have been promoted. Adoption rates, however, remain low. Without a major shift in the farming system, the situation for poor farmers is expected to worsen as the projections for climate change in Mozambique become reality.

KEY FINDINGS

CLIMATE PROJECTIONS

Temperature

- Mean annual temperatures are expected to rise by 1.5°C to 3°C by 2065, with increases more pronounced in the interior of the country.

Rainfall

- Increased rainfall over most of Mozambique from December to April.
- Increased frequency of intense rainfall events across the entire ZOI, coupled with longer dry periods.
- Continuation of the delayed start and earlier end of the rainy season, especially in northern Nampula Province.

OVERALL CLIMATE RISKS

Principal risks in the FtF-targeted region based on the projections above include:

- ***Shifts in growing seasons***: Increased temperatures could impact soil moisture availability and soil temperature at planting, disrupting typical planting dates. Delayed start and earlier cessation of the rainy season could shorten the typical November to April growing season, with the new start in January and end in March.
- ***Reduced crop productivity***: All crops are sensitive to extreme temperatures to some degree, particularly around the reproductive stage, called antithesis. Average temperatures already hover above critical thresholds for crop heat tolerance, and days above 35°C are starting to occur. They will continue to do so as average temperatures increase.
- ***Loss/damage to crops:*** Extreme events such as extended dry period, intense rainfall events and cyclones pose a risk to production.

CLIMATE SENSITIVITIES OF KEY VALUE CHAINS

Soy: *Overall threat to the soy value chain due to climate change is high*.
It is likely that the negative impacts of climate change due to increased temperature, droughts and floods will offset the potential gain in yield from increased CO_2 in the atmosphere, resulting in an overall decrease in soy yields in Mozambique. Extreme weather is the largest risk factor for crop production, especially from droughts and floods. Drought could lead to a nationwide soy shortage but devastate northern and central Mozambique especially, where most soy is grown and where the market is the largest. Flooding has potential to decrease availability of soy on the domestic market, forcing some farmers to find alternative feed for livestock.

Pigeon Pea: *Overall threat to the pigeon pea value chain due to climate change is low.*
Several varieties of pigeon pea are cultivated in Mozambique and are well-adapted to the current environment. Partially due to its drought tolerance, pigeon pea can be grown multiple times in a single year. Multiple growing seasons create an opportunity to export to India, where seasonal fluctuations in supply fall short of demand. The biggest threat climate change poses on pigeon pea production is due to floods, especially projected increased intensities and frequencies. Increased flooding will limit pigeon pea on the domestic market, put subsistence farmers at risk, and limit the ability of Mozambique to become competitive on the export market.

Sesame: *Overall threat to the sesame value chain due to climate change is medium.*
Several varieties of sesame are native to East Africa and well-suited to Mozambique’s climate. In East Africa, local varieties have performed best historically. Nevertheless, non-native varieties resistant to pests and/or better-suited for extreme rain are under investigation in other countries and could be explored for Mozambique. Floods are the largest climate threat to sesame: they have potential to decrease stocks for export, severely limiting the sesame value chain in Mozambique.

RESPONSES

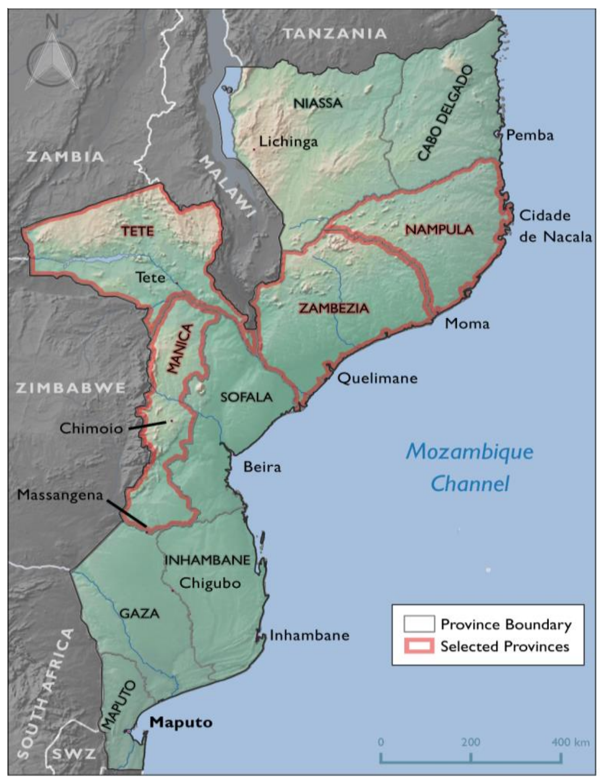
This report demonstrates a strong likelihood of increased temperatures, extreme weather events and changes in rainfall patterns in Mozambique, together with evidence that some of these changes have already begun. In response, the agricultural system must adapt and become more resilient to these changes. The uncertainty associated with future climate is compounded by the fact that climate change is occurring on top of significant existing interannual variability in climate. Therefore, it is impossible to plan for a single future scenario or single set of on-the-ground agricultural interventions that will be effective in all areas of Mozambique in all years. In the end, it will be important to develop robust solutions that build national, community and individual resilience to respond to the entire suite of future climate scenarios.

One approach is to pair a package of locally relevant climate-smart agricultural practices with improved climate and weather information for decision-making. This way, farmers can decide what will be the most effective adaptive strategy in a specific year given their local context and constraints. Examples of existing services are provided in Section 4, Potential Areas of Investment.

1. OVERVIEW

Agriculture accounts for more than 25 percent of Mozambique's GDP and employs more than 80 percent of the country's workforce. The majority of producers are subsistence farmers holding less than 10 hectares (ha) of land. Only an estimated 16 percent of arable land is under cultivation. Given the agriculture sector's potential, the Mozambican government, international donors, NGOs and private sector entities, such as Earth Networks (www.earthnetworks.com), are banking on its future success and investing heavily to improve productivity. Earth Networks, for example, is working with the national government to create decision-support tools that provide information to users across sectors, including agriculture.

Figure 1: Provinces of the Feed the Future Program's Zone of Influence



Rural livelihoods in Mozambique are primarily agriculture-based and climate-dependent. Food insecurity increases during the rainy season while households await the next harvest. Climate shocks will likely increase poverty and malnutrition for rural households, which are not currently resilient enough to withstand the overall effects of a changing climate.

Current climate variability, extreme weather events and projected changes in climate pose a threat to the future of agriculture in Mozambique. (See details in Sections 3 and 4.) Information on how these dynamics manifest at regional and local scales – and what can be done to mitigate their impacts – has been limited, despite the importance of this information in designing responses.

This report seeks to address that knowledge gap by identifying regional climate risks to three value chain crops in Mozambique: soy, pigeon pea and sesame. These crops were selected based on economic importance as well as their priority in USAID's Feed the Future (FtF) Program's Zone of Influence (ZOI). This area includes the provinces of Tete, Manica, Nampula and Zambezia (Figure 1). Other FtF value chains (i.e., common beans, groundnut, cowpea, cashews and banana), though important in Mozambique and within the FtF ZOI, are not included in this analysis. They may warrant attention in subsequent analyses.

Even without considering future climate change, current trends may already have implications for FtF objectives in Mozambique. A 2008 study by Mozambique's National Institute of Disaster Management (known by its Portuguese acronym INGC) and a recent analysis by USAID's ATLAS project highlight several important trends. Based on observational data in the historical record for Mozambique, these trends are described below in order of *confidence derived*:

- ***High Confidence***: Statistically significant changes observed in the historical climate with plausible links to large-scale climatological changes.
  - Rainfall exhibits large interannual variability.
  - Temperatures are increasing.
  - Current mean dry spell length (period within the rainy season with no significant rain) is on average seven days longer than in 1960, increasing by up to 20 days for specific locations such as Zambezia (September to November).

- ***Lower Confidence:*** Important though not statistically significant changes observed in the period 2000-2014 compared to 1981-1999.
  - Zambezia Province and coastal areas of Nampula Province received less precipitation in 2000-2014 when compared to 1981-1999, while most of the rest of the country received more precipitation.
  - Fewer heavy rain days (days with rainfall above 20 mm) in Zambezia Province in the more recent period compared to the earlier period, while the rest of the country received more intense rainfall, especially coastal areas of Sofala and Inhambane provinces.

This report is based on a desk-based assessment of these climate risks and a field visit to Mozambique that include interviews with stakeholders in the Nacala Corridor (including Nampula and Zambezia provinces), donors in Maputo who work in northern Mozambique and key informants working in other areas of northern Mozambique.

The primary areas of climate-related concern for the ZOI are:

- ***Shifts in growing seasons***: The length of time that soil temperature and soil moisture conditions are suitable for crop growth will change, with delayed start and earlier end dates for the growing season. The typical growing season could shift from the current season of November through April to a start in late January and finish in March, in some cases potentially shortening the season significantly.
- ***Increases in extreme events including high temperatures and intense rainfall events or longer dry periods***: All crops are sensitive to extreme temperatures, particularly around the reproductive stage, called antithesis. Nevertheless, as the value chain analyses below suggest, crops such as pigeon pea are more resilient to temperature extremes than others, such as soy. Average temperatures, however, already hover above critical thresholds for heat tolerance. For example, days above

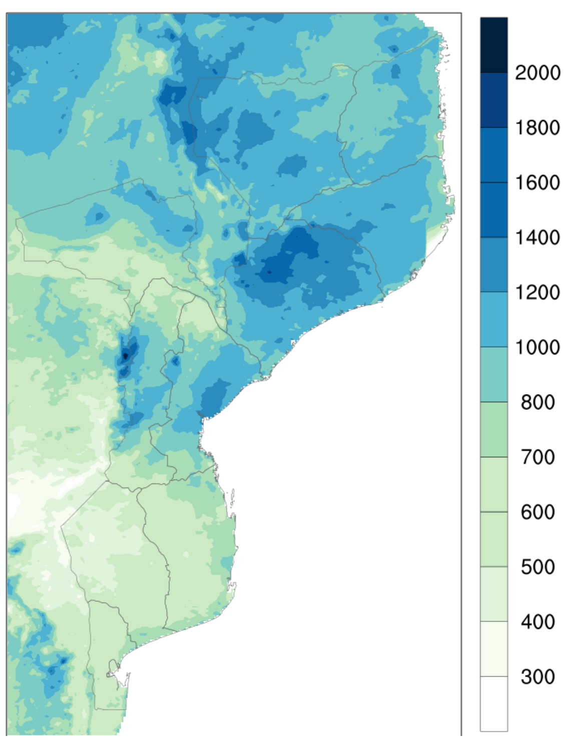
35°C are already occurring. They will continue to do so as average temperatures increase. Droughts, intense rainfall events and cyclones also pose a risk to production.

2. CLIMATE VARIABILITY AND CHANGE IN MOZAMBIQUE

2.1 OVERVIEW OF CLIMATE VARIABILITY AND TRENDS

Situated in the intertropical zone, Mozambique's climate is strongly influenced by the Intertropical Convergence Zone (ITCZ) as well as the southeast trade winds and the northeastern monsoon. The climate is generally hot and rainy in summer (November to April), when the ITCZ migrates southwards, and cold and dry in winter (May to October). Rainfall varies between 1800 mm a year near the Zambezi Delta to about 300 mm a year in the lowlands of the southern interior (Figure 2). The driest areas of the country lie in the interior of Gaza Province in the southwest. The highlands of the northern and central regions are affected by the northeast monsoon, with a mean annual total rainfall of 1000 mm to 2000 mm. The exception is Tete Province, which typically receives 500 mm to 600mm of annual rainfall, most likely because it is further inland and low-lying in the Zambezi Valley. Generally, the inland section of the Zambezi Valley is drier than other parts of the north and center of the country.

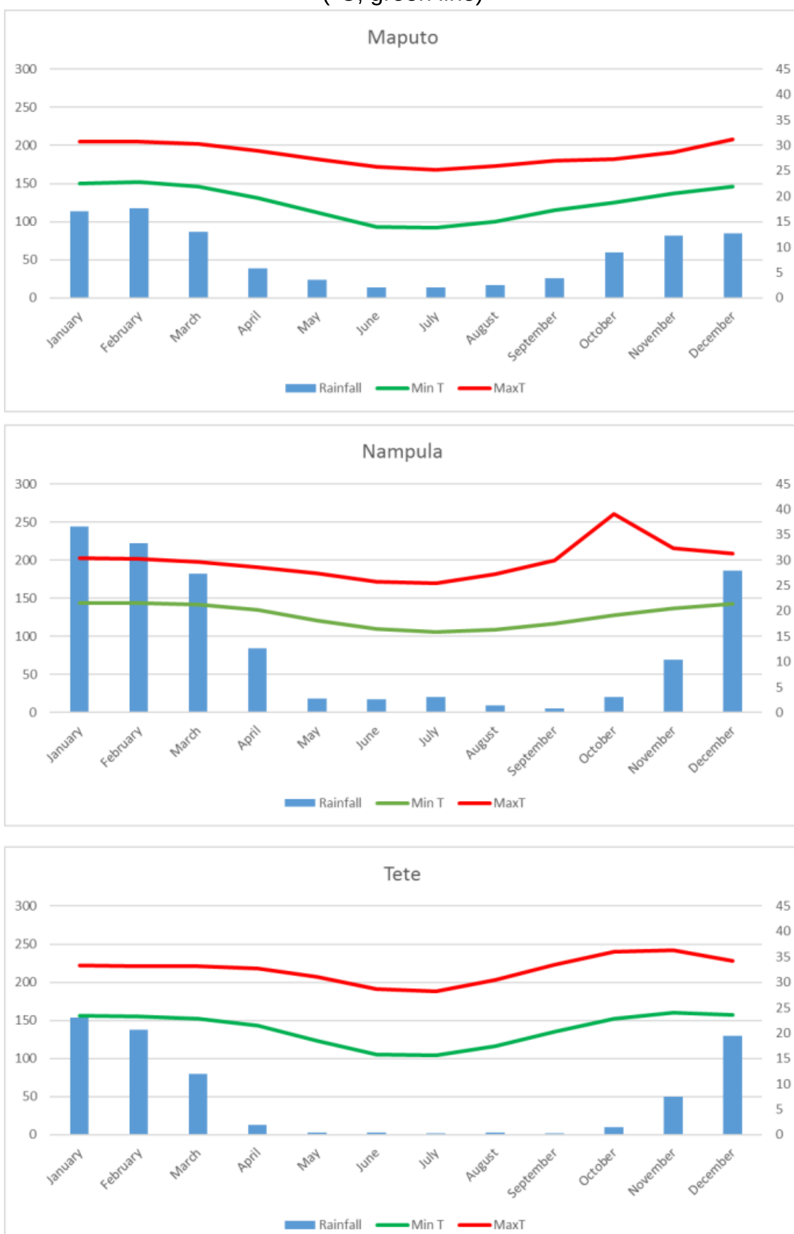
Figure 2: Annual mean precipitation for each grid cell for the period 1981-2014 (in mm)



Source: Climate Hazards Group InfraRed Precipitation with Stations (CHIRPS) dataset.

The seasonality of rainfall and temperature varies by region, as does total monthly rainfall and average monthly minimum and maximum temperatures. Figure 3 shows weather station-scale historical average seasonality at three different observation stations, representing a) South (Maputo), b) Zambezia (Tete) and c) North (Nampula). As illustrated in the figure, northern Mozambique experiences higher rainfall totals than the rest of the country, while Zambezia areas experience the highest maximum temperatures. Further detail on these regional differences is provided in the precipitation and temperature subsections below.

Figure 3: Average monthly rainfall (mm; blue bars), maximum temperature (°C; red line) and minimum temperature (°C; green line)

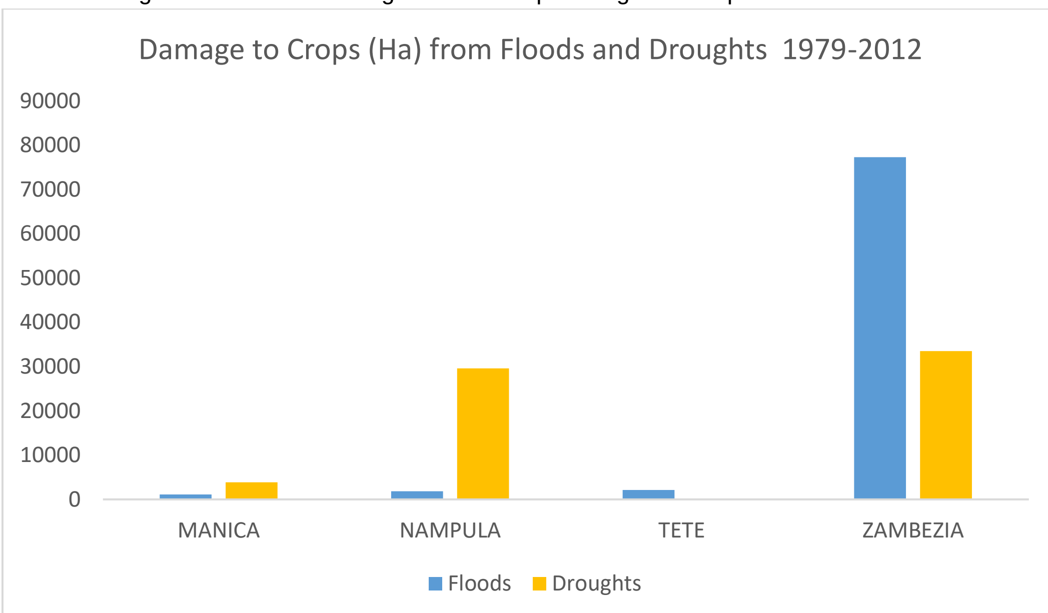


Source: Climate System Analysis Group (CSAG) Climate Information Platform (http://cip.csag.uct.ac.za).

2.1.1 RAINFALL

Considerable interannual variability in rainfall exists across the country, with many examples of intense drought at one extreme and floods from above average rainfall on the other (Figure 4). High temperatures, recurrent droughts and tropical cyclones are important factors to consider when evaluating the climate. In addition, the El Niño Southern Oscillation (ENSO) increases the intensity of droughts and heavy rainfall events in Mozambique.

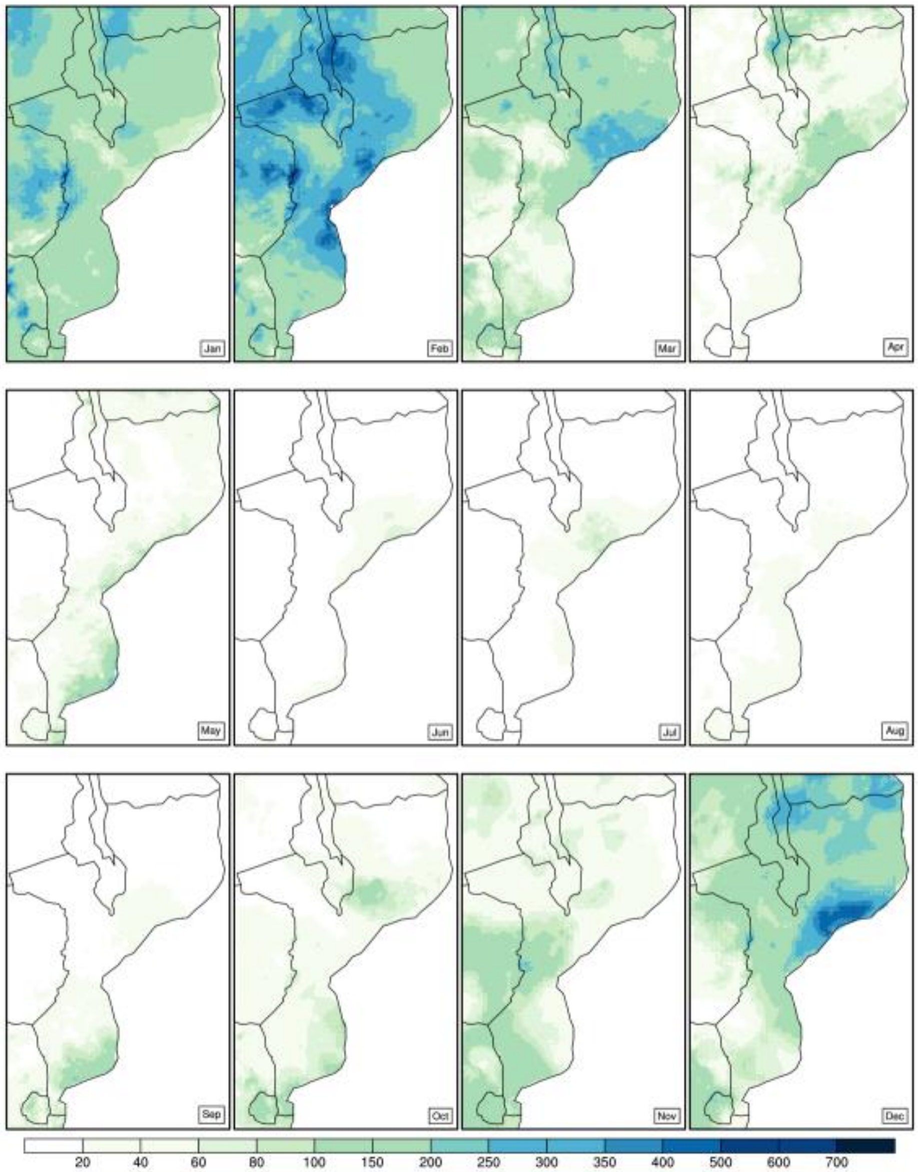
Figure 4: Flood and drought-related crop damage across provinces of the ZOI



Source: Mozambique *Desinventar* Disaster Inventory, http://www.desinventar.net/DesInventar/profiletab.jsp?countrycode=moz

The seasonality of rainfall across the country is shown in Figure 5. Rains typically begin with the southward movement of the ITCZ in November/December and continue south through April, bringing the majority of the country's rain, with peaks in the ZOI in January and February.

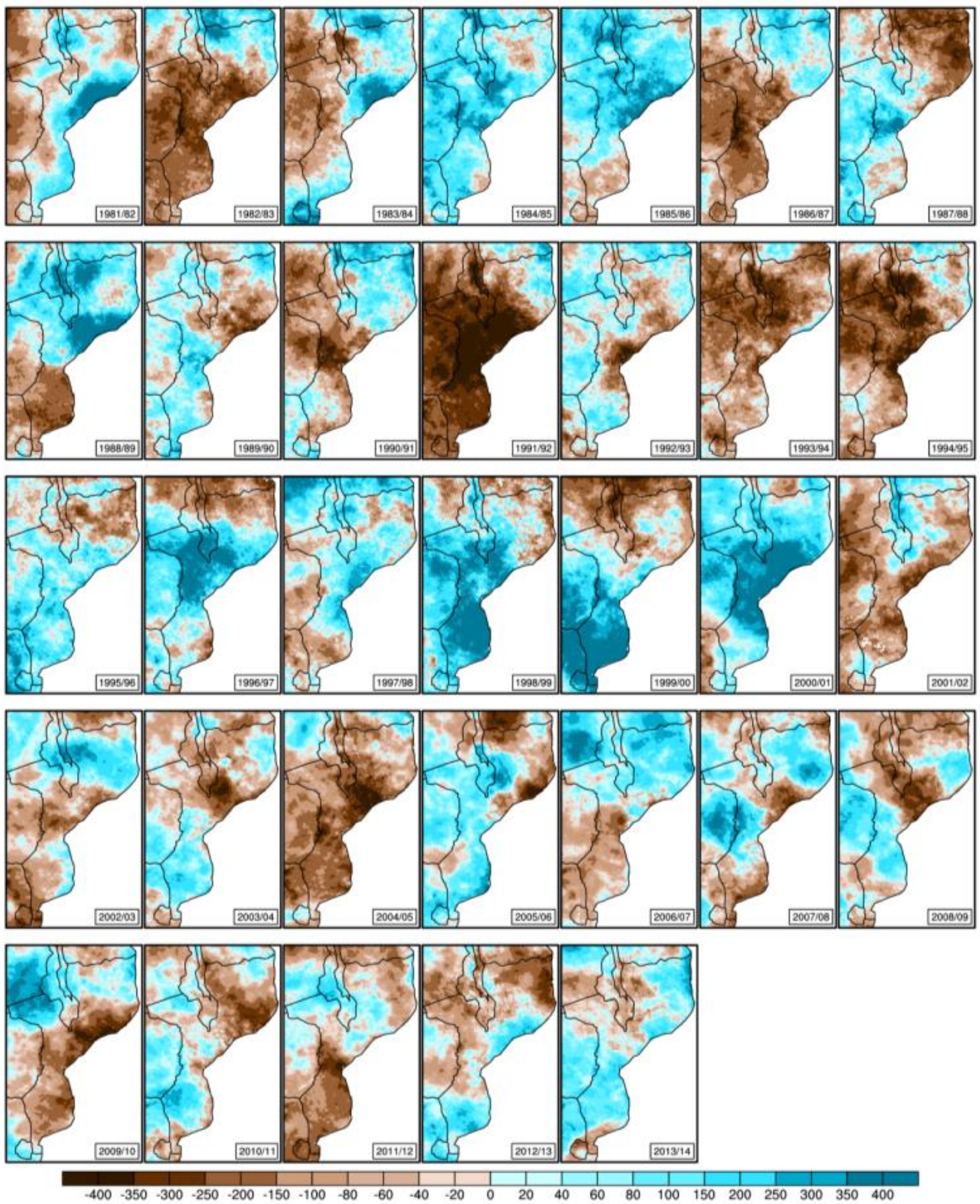
Figure 5: Seasonal cycle of monthly rainfall across Mozambique (in mm)



Note: The month is indicated at the bottom right corner of each panel.
Source: CHIRPS.

Annual rainfall patterns in Mozambique vary both spatially and temporally, as shown in Figure 6. For the scale, zero represents the annual average rainfall, with negative numbers in brown showing below average rainfall and positive numbers in blue showing above average rainfall. The center and south experience higher variability than the rest of the country, with many occurrences of intense drought as well as above average rainfall. The north, on average, experiences lower variability and more consistent rainfall. Below-average rainfall that can lead to drought tends to occur mostly in the south, while intense storms and floods are more frequent in the central and northern areas. Droughts appear to be cyclical, driven by El Niño patterns, which bring warmer and drier conditions.

Figure 6: Change in year to year average rainfall (in mm) from 1981-2014 across Mozambique when compared to average values for this period

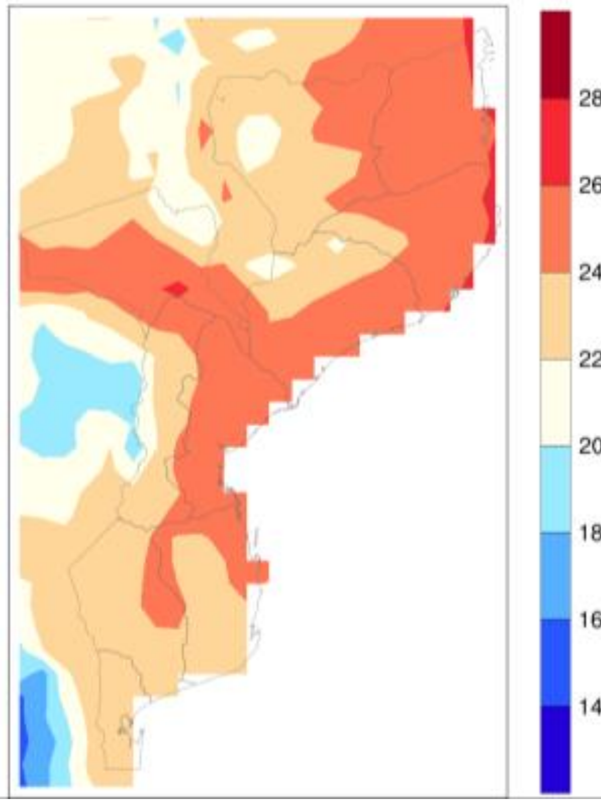


Note: The years compared are indicated the bottom right corner of each panel. Browns denote areas with reduced rainfall and blues areas where rainfall increased over the comparison period.
Source: CHIRPS.

2.1.2 TEMPERATURE

Annual mean temperatures across Mozambique for the period 1981-2014 (Figure 7) exhibit some spatial variability. Ranging from 24°C to 28°C, mean temperatures in the northern and central interior (Zambezi Valley) are generally higher than in the south, where the range is 22°C to 26°C.

Figure 7: Annual mean temperature for each grid cell for the period 1981-2014 (in °C)

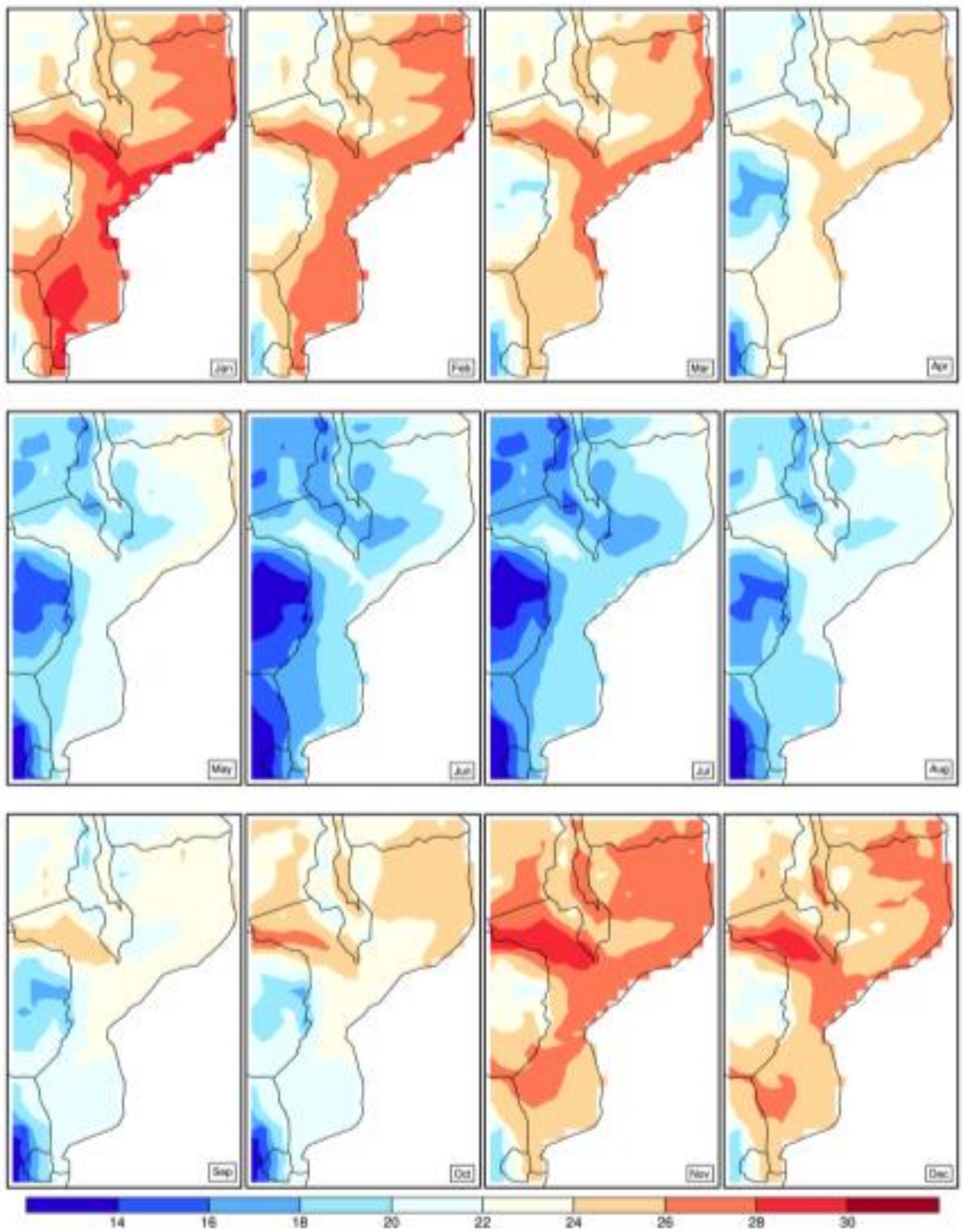


Note: As shown in the figure, the south of the country experiences a mean temperature range of between 22 and 26°C. The northern and central interior (Zambezi valley) regions of the country generally experience higher average temperatures, with an annual mean of 24 to 28°C. The coldest temperatures recorded were in one of the western mountain ranges of Manica, where frost conditions are common during winter.

Source: CRU TS3.23.

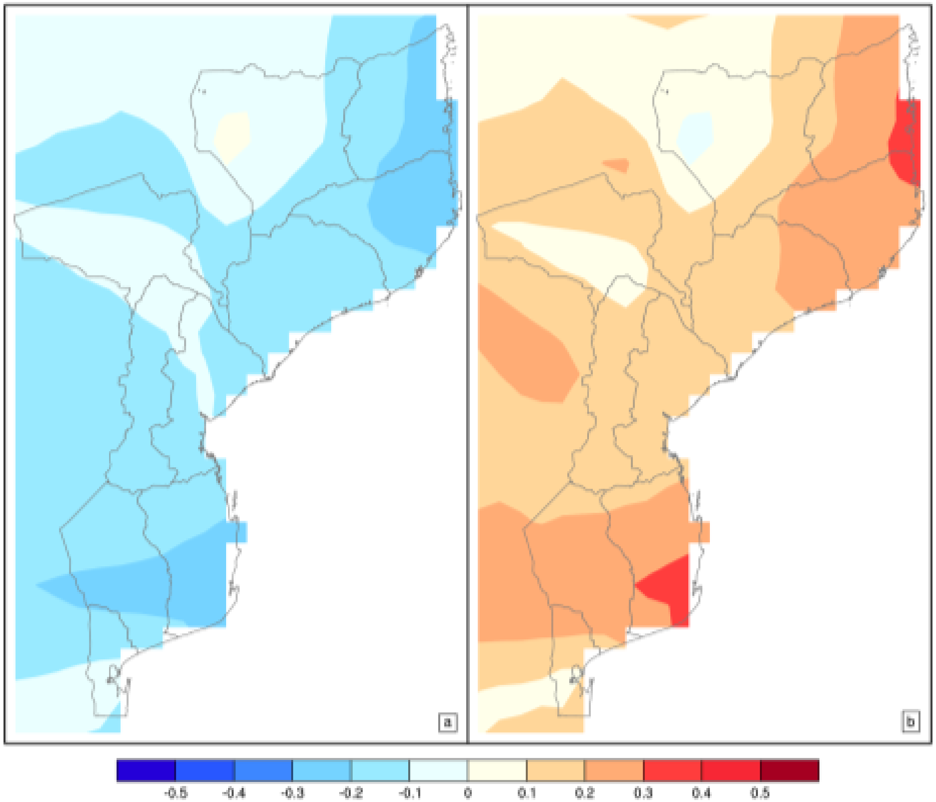
Monthly mean temperatures across Mozambique vary (Figure 8) but peak during the summer (November to April) with the hottest months being January and February. The coldest months occur during the winter (May to August), when monthly mean minimum temperatures often drop below 20°C. Average temperatures are already on the rise, as the comparison between temperatures in 1981-1999 and 2000-2014 shown in Figure 9 suggests.

Figure 8: Seasonal cycle of monthly mean temperature (in °C)



Note: The month is indicated in the bottom right corner of each panel.
Source: CHIRPS.

Figure 9: Observed change in annual temperature over Mozambique for 1981-1999 and 2000-2014 compared to the long term mean 1981-2014 (in °C)



Note: Left: 1981-1999 changes. Right: 2000-2014 changes. Changes are calculated differences between these time periods and the long term mean 1981-2014.
Source: CRU TS3.23.

2.2 PROJECTED CHANGES IN CLIMATE

The available evidence on projected changes in the ZOI of relevance to the FtF program is summarized in Table 1. A detailed analysis follows.

Table 1: Projected changes in climate across the ZOI

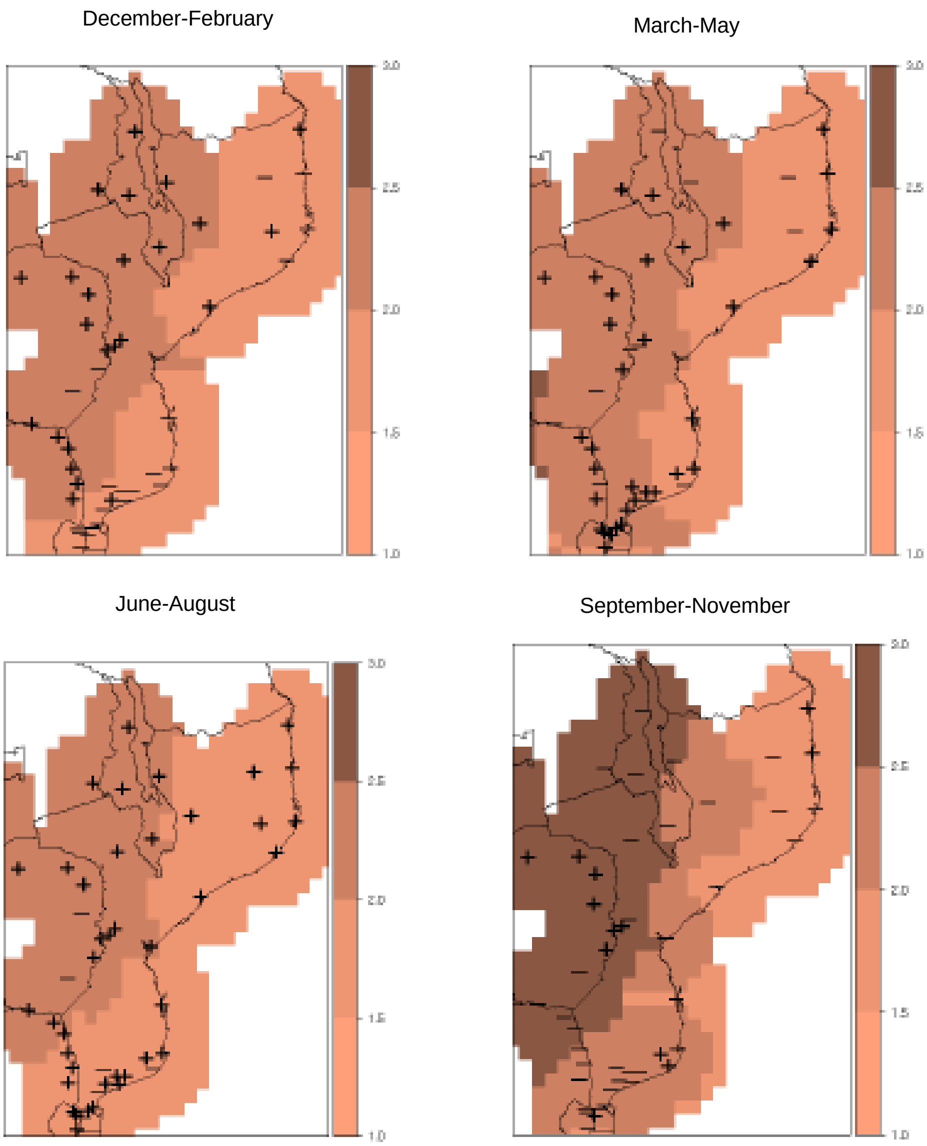
Rainfall
While projected rainfall changes are subject to large uncertainties, a majority of models suggest: • Increased rainfall over most of Mozambique from December to April, offset partly by increases in temperature. These increases raise evapotranspiration rates during the dry season, resulting in soil moisture deficits. • Increase in length of dry spells, defined by the number of days during the rainy season receiving less than 1 mm of rain. • Increased frequency of intense rainfall events across the entire ZOI. • Continuation of the delayed start and earlier end of the rainy season, especially in northern Nampula Province.
Temperature
• Mean annual temperatures are expected to rise by 1.5°C to 3°C, with higher values more likely based on current emissions by the 2046-2065 period. Increases will be more marked in the interior of the country. • Increases in evapotranspiration will likely exceed projected increases in rainfall during winter and early summer, resulting in a drier season, especially in the center of the country. • The largest increases in temperature will likely occur from September to November, before the onset of rains over much of the country. This could impact soil moisture availability at planting and disrupt typical planting dates. • Over all regions, the likelihood of extreme maximum daily temperatures above 35°C will increase.

2.2.1 TEMPERATURE

With increased greenhouse gas concentrations, both minimum and maximum temperatures in Mozambique are projected to continue to warm across all seasons. Projections derived from global circulation models (GCMs) suggest:

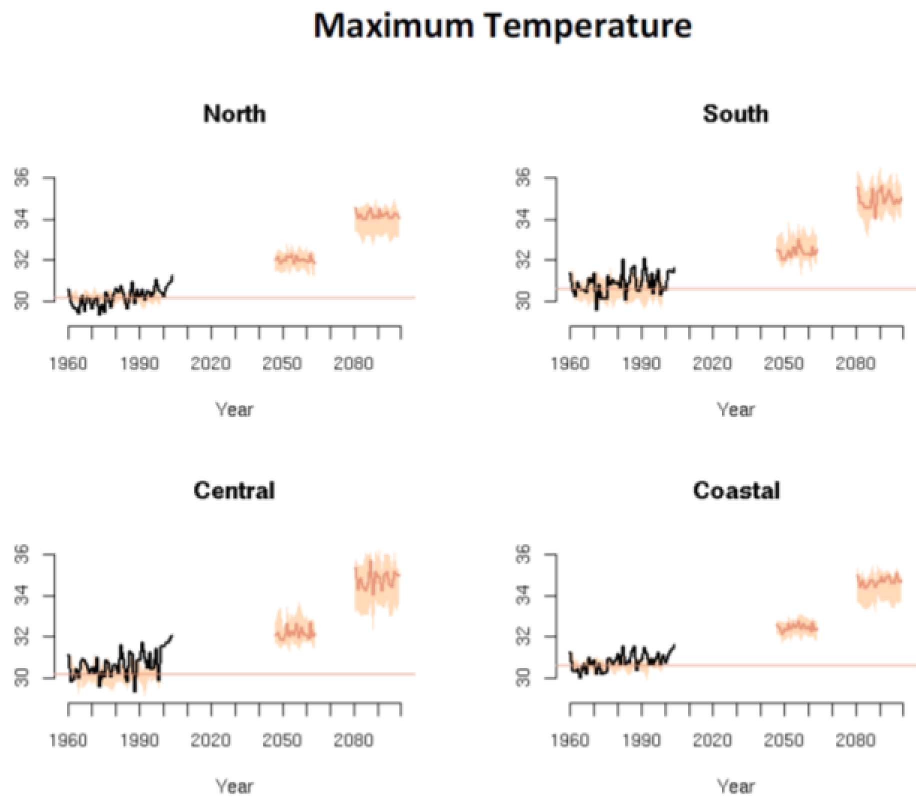
- Increase of mean annual temperatures by 1.5°C to 3°C by the 2046-2065 period (Figure 10).
- Maximum temperatures will increase more in the interior and less on the coast, partly due to the moderating influence of the ocean (Figure 11).
- The number of days above 35°C – already increasing – will continue to do so as average temperatures increase.

Figure 10: Median projected changes in maximum temperature from seven GCMs, 2046-2065 (in °C) across quarters in the year



Note: Darker brown areas indicate projected warming of 2.5°C to 3°C. In all four seasons, maximum temperatures rise more towards the interior and less at the coast, partly due to the moderating influence of the ocean
"+"/"- "indicates whether seasonal variability is expected to increase/decrease in the future.
Source: INGC 2009.

Figure 11: Historical interannual variability and projected changes in maximum temperatures by 2045-2065 in Mozambique, from November to April (in °C)



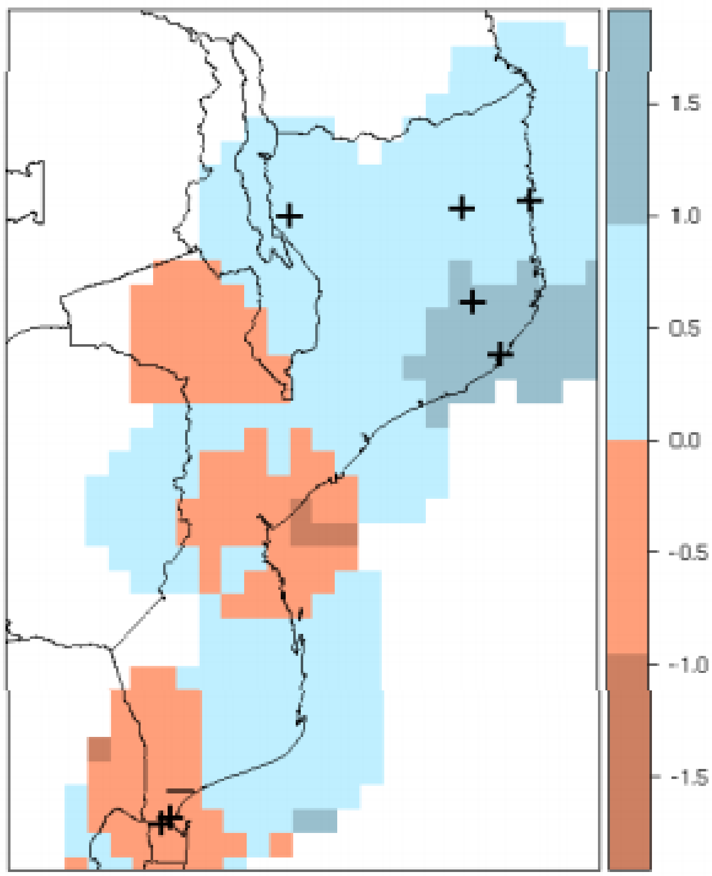
Notes: Orange shading: GCM inter-model range. Dark orange: median of the models. Black line: actual meteorological station observations. Horizontal orange line: mean of the seven GCM control climate simulations.
Source: INGC 2009.

2.2.2 RAINFALL

Drawn from the INGC 2009 study, the figures below show spatial and temporal variability of both past and projected rainfall changes to rainfall. These suggest:

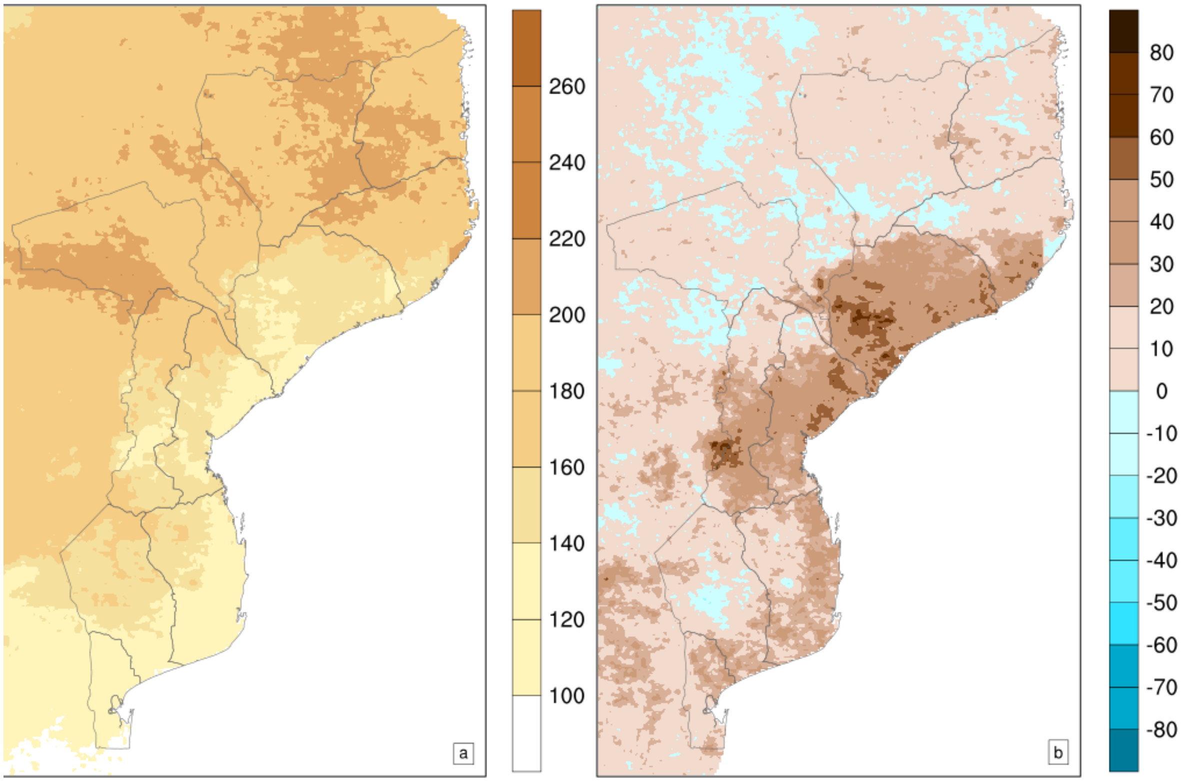
- *A delayed start in the rainy season*, already recorded up to 45 days later in 2005 than in 1960 in northern regions (Figure 12). Although less obvious and consistent, changes in the end and duration of the rainy season are also apparent in other parts of Mozambique.
- *Increase in length of dry spells*, defined by the number of days during the rainy season receiving less than 1 mm of rain. In northern Mozambique, the current mean dry spell length is on average seven days longer than in 1960, increasing by up to 20 days in certain northern areas (Figure 13).

Figure 12: Trends in the start of the rainfall season (days per year) between 1960 and 2005.



Note: Trends in some northern regions suggest that the start of the rains comes up to 45 days later in 2005 than in 1960, such as in Nacala, where the data show a 1 to 1.5 day delay in the start of the rains every year, which, over the 45-year period, suggests a 45 day delay.
Source: INGC 2009.

Figure 13: Change in consecutive dry days across Mozambique, 1981-1999 and 2000-2014



Note: Left: mm. Right: days. Brown areas on the right figure represent an increase in the number of consecutive dry days. The 2000-2014 period shows more consecutive dry days, particularly across Zambezia Province, as well as Sofala Province. In areas of Zambezia this difference is as high as 60 days.
Source: CHIRPS.

Climate projections for Tete and Quelimane, located near the ZOI, are presented in Table 2. The graphs reinforce the points summarized in the preceding discussion.

Table 2: Example historical climatology and projected rainfall changes for Tete station

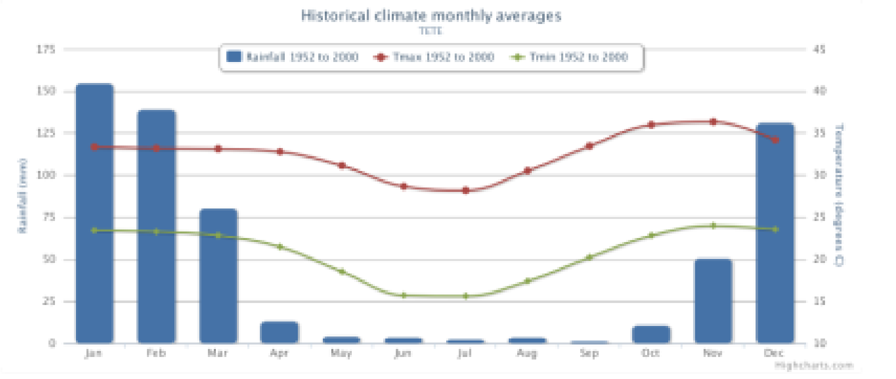
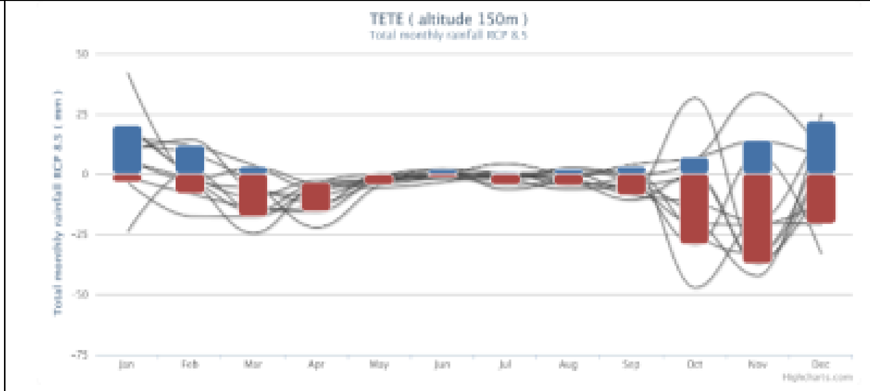
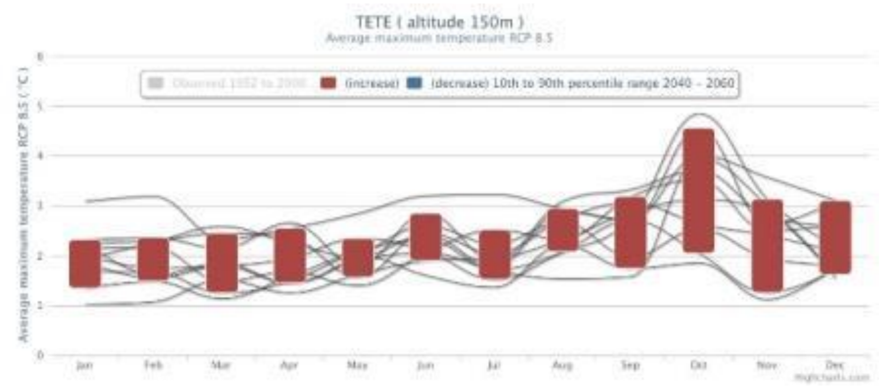
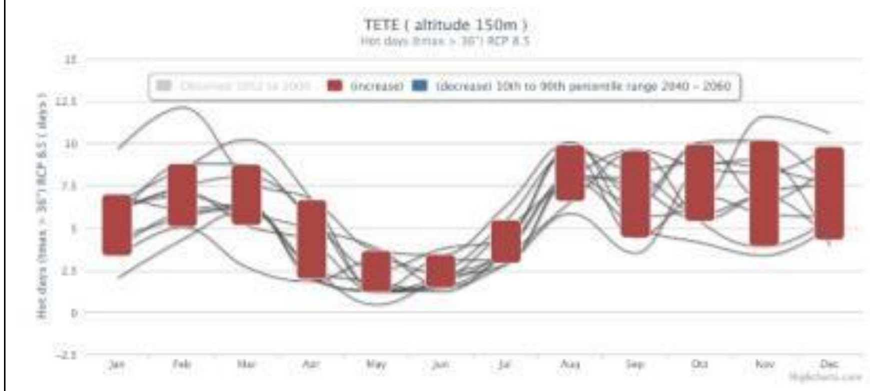
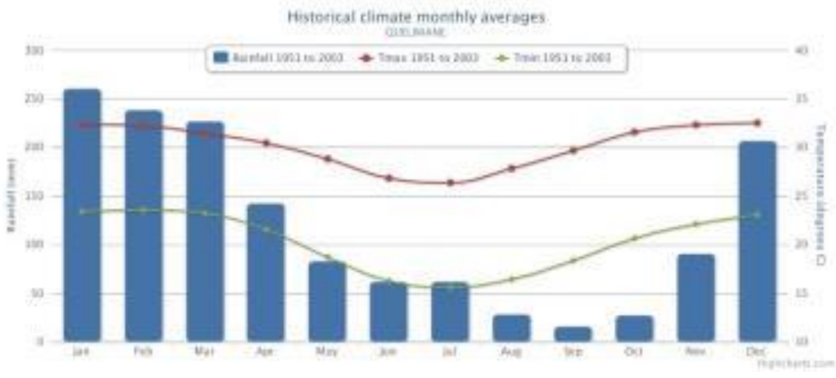
<table>
<tr><th colspan="2">TETE (altitude 150m)</th></tr>
<tr><th>MONTHLY HISTORICAL CLIMATOLOGY</th><th>MONTHLY PROJECTED CHANGES IN RAINFALL UNDER WORST CASE SCENARIO</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Shows typical distribution of rainfall (bars with values on left axis) and minimum (green line) and maximum (red line) temperature, with values on right axis for the station across the year.</td><td>Suggests changes in rainfall across the rainy season of +/- 5–10%, with limited changes projected during the dry season in terms of rainfall. Red bars indicate reduced rainfall projected, blue bars indicate increased rainfall projected within 10th and 90th percentile of projections. Lines are individual GCM values. These changes will, however, be amplified with projected increases in temperature, reducing available soil moisture.</td></tr>
<tr><th>PROJECTED CHANGES IN MAXIMUM TEMPERATURE</th><th>PROJECTED CHANGES IN DAYS ABOVE 36°C</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td colspan="2">Red bars capture 10th and 90th percentile of model projections and suggest increases in temperate, lines are individual model projections.</td></tr>
</table>

Table 3: Example historical climatology and projected rainfall changes for Quelimane station

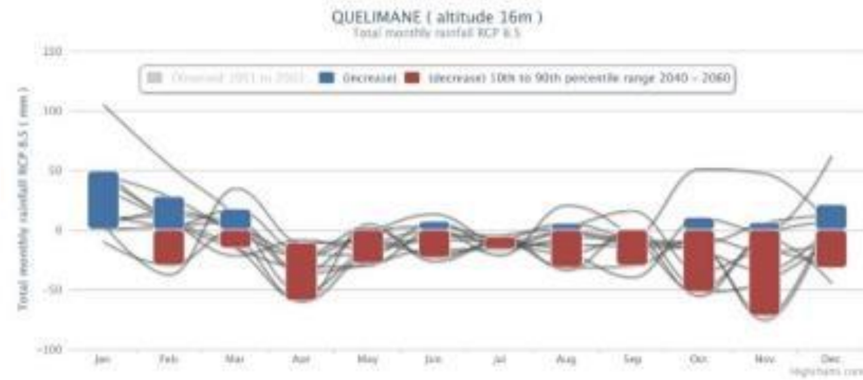
QUELIMANE

HISTORICAL CLIMATOLOGY



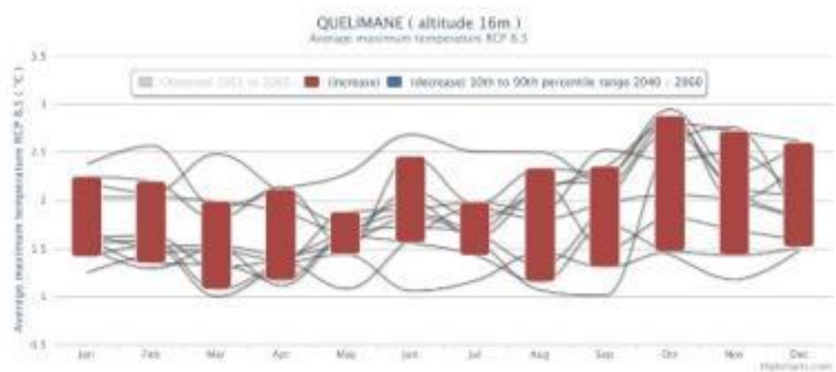
Shows typical distribution of rainfall (bars with values on left axis) and minimum (green line) and maximum (red line) temperature, with values on right axis for the station across the year.

PROJECTED CHANGES IN RAINFALL UNDER WORST CASE SCENARIO



Red bars indicate reduced rainfall projected, blue bars indicate increased rainfall projected within 10th and 90th percentile of projections. Lines are individual GCM values. Suggests changes in total rainfall less pronounced around coast, nevertheless, it is clear that daily rainfall intensity may increase.

PROJECTED CHANGES IN MAXIMUM TEMPERATURE



PROJECTED CHANGES IN DAYS ABOVE 36°C

Red bars capture 10th and 90th percentile of model projections and suggest increases in temperate, lines are individual model projections.

Source: CSAG Climate Information Platform (http://cip.csag.uct.ac.za).

3. CLIMATE SENSITIVITIES OF KEY VALUE CHAINS

Much of the ZOI's agricultural production is already vulnerable to the vagaries of climate because crop production there is primarily rainfed, with cropping cycles defined by the onset of the rains. Farmers typically do not use improved farming practices or inputs, which leaves them less resilient to the impacts of a changing climate. Practices to improve land preparation, such as tractor-based tillage and crop rotation, as well as the use of improved, certified seed, have been promoted. Adoption rates, however, remain low. Without a major shift in the farming system, the situation for poor farmers is expected to worsen as the projections for climate change in Mozambique become reality.

The following sections examine the climate sensitivities of key target crops (soy, pigeon pea, and sesame) and their value chains. The impacts of increased temperature and changes in rainfall, including droughts and flooding events, are examined for each crop's value chain. Also included are analyses of the overall risks to each crop's value chain due to the combination of climate impacts (temperature and rainfall). Last, the analysis considers 1) aspects of these value chains that are similarly affected by climate change, such as transportation, and 2) important information gaps.

4.1. SOY

Soy is primarily grown in the ZOI as animal feed for domestic and regional use. Imports supplement domestic supplies, which only meet 40 percent of the country's demand. In addition, demand for soy in Mozambique is growing by about 60 percent annually (USAID 2016). Climate and soil conditions point to the highlands in central and northern Mozambique as areas with the highest yield potential.

Temperature

In Mozambique, increased temperatures due to climate change are unlikely to impact soy seed availability, germination rates, or early growth and development, except under extreme circumstances, such as when temperature exceed 35°C. Temperatures above 35°C lead to poor germination and emergence (Gibson and Mullen 1996). Soy germinates best between about 21°C and 32°C (Kahlil et al. 2010). While projections suggest a greater number of days when temperatures exceed this 35°C threshold, it is difficult to pinpoint specific locations where this will occur. This is due to the low resolution of available temperature datasets and projections, which are only available in 1 kilometer grid cells.

After germination and early development, optimal growing temperature for soy is around 22°C, with a linear decline in yield as average temperatures rise above 30°C (Schlenker and Roberts 2009). The sensitivity of soy to temperature will likely push its production to areas that have cooler average temperatures during the growing season, such as higher elevations. Once soy is harvested, its seeds are susceptible to high humidity because of their high oil content. Assuming seeds are not stored in a controlled environment, the combination of high humidity and high temperature could impact their quality.

Rainfall

Currently, the ideal sowing time for soy in Mozambique is early November. A delayed start to the rainy season can alter sowing dates. Dias and Amane (2011) suggest that soy crops sowed in December in Mozambique may have lower yields. Nevertheless, additional research is required to understand the potential impact of a delayed rainy season on future production. Soy requires at least 400 mm of rain in the three months following planting. It is unlikely that rainfall will fall below this amount under a future climate, even under conditions of high interannual variability. However, an altered rainfall regime, with more dry spells during the growing season, is likely to decrease yields.

Drought and floods pose the greatest climate change risk to soy production in the ZOI. During germination, seeds absorb up to 50 percent of their weight in water. During periods of drought, emergence rates and yields decline. As a result of soy's shallow root system, with maximum root depth at 0.60 meters to 1.30 meters, soy is vulnerable to changing soil moisture conditions. In addition, soy is particularly sensitive to drought during the final stages of growth, when producing seeds. Extreme drought conditions, such as those experienced during El Niño events or when rain falls below 30 mm per month during the rainy season, will decrease yields and potentially cause large-scale crop failure.

Soy is most sensitive to flooding during early growth (Ciampiti et al. 2015). Soy can survive waterlogging and flooding for 48 hours, but such conditions for a period of four days or more can sharply decrease yields (Scott et. al. 1989). In addition, higher temperatures during flooding cause soy to deplete stored energy faster, further putting the crop's survival at risk (Wuebker et. al. 2001). Floods that cause prolonged waterlogging and submergence can reduce yield by 17 to 45 percent at the vegetative stage and 50 to 56 percent at the reproductive stage (Conley and Shannon 2013).

Overall threat to the soy value chain due to climate change - HIGH

While soy yields are highly dependent on temperature and rainfall, CO_2 is another factor. The precise impacts of climate change on the soy value chain are difficult to understand because of the interaction of these factors. For example, a study conducted by researchers from Brazil and the United States using a model that primarily considered CO_2 concentrations and increased temperatures (but ignoring other climate drivers) projected an *increase* of about 11 to 15 percent in soy yields in Mozambique (Talacuece et al 2016). Meanwhile, a study by INGC projected an overall *decrease* of 6.4 percent in soy yields based on scenarios of future climate conditions that considered increased CO_2 concentrations, temperature and changes in rainfall patterns (INGC 2009). It is likely that the negative impacts of climate change due to increased temperature, droughts and floods offset the potential gain in yield from increased CO_2 in the atmosphere, resulting in overall decrease in soy yields in Mozambique.

Extreme weather, such as droughts and floods, will likely have the biggest impact on soy production. Drought could lead to a nationwide soy shortage but be especially devastating to northern and central Mozambique, where most soy is grown and where the market is the largest. Flooding has the potential to decrease availability of soy on the domestic market, which will force some farmers to find alternative feed for livestock.

4.2. PIGEON PEA

Pigeon pea, a hardy species that grows in a variety of environments, is an economically important crop with high potential for improving incomes, particularly for small farmers. An excellent source of protein, dietary fiber, vitamins and minerals (including magnesium, phosphorus, potassium, copper and manganese), pigeon pea offers significant nutritional benefits. One hundred grams of mature, raw pigeon pea provide 114 percent of the daily requirement of folate (76 percent for pregnant women). A nitrogen-fixing legume, pigeon pea is ideal for intercropping, particularly with crops that demand high levels of bioavailable nitrogen, such as maize. In the ZOI, pigeon pea is a critical domestic grain, with potential to expand production for the export market, particularly to India.

Temperature

Increased temperatures are unlikely to impact seed development but could impact germination rates in extreme cases. Increases in temperature below 40°C will likely improve germination. However, daily temperatures above 40°C would reduce germination rates significantly (Schibairo 1993). After germination, optimal growing temperatures are between 18°C and 30°C. Increased temperatures in Mozambique are unlikely to impact plant growth in the near term (Valenzuela 2011). If more heat waves occur, with multiple days above 30°C, production could decrease. In addition, increased temperature in the long term (2080-2100) could decrease yield. This could potentially change the distribution of pigeon pea in the ZOI, in particular limiting productivity in the low-lying inland areas of Zambezia and Nampula, which are projected to warm faster than coastal and highland areas. During storage, the combination of high humidity and high temperature increases the risks of aflatoxin and other fungi to seeds. Proper drying and storage is important to ensure sustainable inputs into value chain.

Rainfall

Optimal rainfall for most varieties of pigeon pea ranges from 600 mm to 1000 mm a year. Overall increased rainfall in Mozambique will likely increase plant growth. Pigeon pea is very sensitive to flooding and waterlogging, making it susceptible to increased frequency of intense rainfall events. Flooding decreases plant growth and production and could lead to plant mortality. Increased flooding during production or maturation could lead to decreased yield and seed availability.

Drought, particularly low soil moisture content during planting, could lead to low germination rates and poor seed development. Some cultivars, however, are more resistant to drought during germination than others. After germination and initial growth, pigeon pea is a drought-tolerant species that can withstand low rainfall (average rainfall of 400 mm annually). Its deep roots (up to 2 meters) offer a comparative advantage over plants with limited root systems that rely on surface soil moisture (Odeny 2007). Reduced rainfall during maturation, however, decreases yields (Lopez et. al. 1996).

Overall threat to the pigeon pea value chain due to climate change - LOW
Several varieties of pigeon pea are cultivated in Mozambique and are well-adapted to the current environment. Partially due to its drought tolerance, pigeon pea can be grown multiple times in a single year. The ability to take advantage of multiple growing seasons creates an opportunity to expand exports to India, where seasonal fluctuations in supply fall short of demand.

An increase in intensity and frequency of floods is the biggest climate change threat to pigeon pea. Increased flooding will limit pigeon pea on the domestic market, put subsistence farmers at risk, and limit the ability of Mozambique to become competitive on the export market.

4.3. SESAME

Native to Sub-Saharan Africa, sesame is well-adapted to Mozambique's climate. It is primarily grown by small farmers in Nampula, Manica and Zambezia provinces. More than 98 percent of production is exported; approximately 75 percent is destined for Asian markets. The global market and demand for sesame continues to grow; currently more than 70 percent of sesame demand is met by production from African countries, primarily Ethiopia, Nigeria and Tanzania. Mozambique has an opportunity to increase production and overseas exports. Recent evidence suggest that yields can be doubled by practices such as the use of improved seed, improved sowing spaces, better drainage and optimized sowing times. Although climate variability and change could increase risks to sesame production, many of its characteristics, such as drought tolerance and high thermal tolerance, can help offset these risks.

Temperature
Sesame is native to tropical and subtropical regions in Africa and has adapted to temperatures found in these regions. Temperatures around 30°C do not impact seed germination and initial growth. Some varieties can tolerate temperatures as high as 40°C during this period (Carvalho et. al. 2001). Ideal temperatures during most of the growth stage for sesame range between 26°C and 30°C. Most varieties tolerate temperatures as high as 33°C. Due to East Africa's warm temperatures, sesame can be grown between sea level and 1500 meters (El-Lattief 2015). Sesame needs constant high temperatures for ideal growth. There is little evidence that the change in temperature likely to occur in Mozambique will decrease sesame production.

Rainfall
Increased overall rainfall will likely have little impact on seed viability and availability but a delayed start of the rainy season and/or increased dry spell length during the growing season could negatively impact yields. Sesame grows well when rainfall is between 300 mm and 600 mm and distributed evenly throughout the growing season – conditions similar to Mozambique's current rainy season. The anticipated increases in overall annual rainfall are unlikely to impact sesame production.

Sesame is a drought-tolerant crop, but studies indicate the crop is sensitive to drought during the germination stage, and soil moisture deficits negatively impact growth. False starts to the rainy season could negatively impact production and increase costs to farmers.

The greatest climate risk to sesame production is the increased frequency and intensity of extreme rain events, as the crop is very sensitive to waterlogging. More than 50 percent of yield is lost when plants are waterlogged for as little as 36 hours (Sarkar et al 2016). Flooding shortly after planting could cause crop failure and reduce seed availability in subsequent years. Several practices could address these impacts, such as diversification of varieties and proper drainage.

Overall threat to the sesame value chain due to climate change - MEDIUM

Several varieties of sesame are native to East Africa and well-suited to Mozambique's climate. In East Africa, local varieties have performed best historically. Nevertheless, non-native varieties resistant to pests and/or better-suited for extreme rain are under investigation in other countries and could be explored for Mozambique. Floods are the largest climate threat to sesame: they have potential to decrease stocks for export, severely limiting the sesame value chain in Mozambique.

4.4. CROSS-CUTTING RISKS

Alongside productivity, climate change is also likely to affect a range of factors related to the value chains of these three crops. The discussion below highlights these impacts.

Transportation and seed storage

Climate change poses risks during post-production through potential impacts on transportation and seed storage. Mozambique lacks quality roads, particularly in rural areas, limiting access to crops during floods. This fact was evident in early 2015, when flooding damaged key bridges on main roads in the north, leading to large-scale shortages of goods. Improving infrastructure, particularly road quality, can help to build value chain resilience.

Temperature and humidity pose a risk to seed storage and quality. As temperatures increase, potentially in combination with increased humidity, seeds are more susceptible to fungi and pathogens. Promoting proper drying and storage techniques can mitigate these risks.

4.5. INFORMATION GAPS

The impacts of climate change on Mozambique and Sub-Saharan Africa generally, and with respect to agricultural value chains, specifically, is understudied. The majority of available research focuses on production risks to the value chain, and even there, the research is limited. A full value chain approach to research could help to identify and prioritize investments to build value chain resilience in light of climate risks. More research in the following areas will improve our understanding of how climate change impacts value chains in Mozambique:

- **Impact of climate change on pests and pathogen outbreaks among specific crops, particularly during crop storage**. The role of climate change on the distribution of pests and pathogens, and their potential impact on germination, production and seed storage is an emerging field. Climate plays a role in pest and pathogen dynamics, but little evidence is available on how the potential distribution of these will change under a changing climate. For example, pests such as the flea beetle can decrease sesame yield by as much as 90 percent (Tanzania Forest Conservation Group 2012; Global Agriculture and Food Security Program 2016), but little is known about how temperature changes will affect their distribution and prevalence.

The relationship between a changing climate and crop susceptibility to herbivore and pathogen attacks is also poorly understood. For example, *Fusarium* wilt already reduces yields of pigeon pea crops, but it is unclear how this wilt will behave with changes in temperature and rainfall. Similarly, aflatoxins, potent mycotoxins that cause developmental and immune system suppression in humans, are found in pigeon pea. Their concentrations could increase with higher temperatures, especially when they occur in conjunction with higher humidity, as is expected in a warmer, wetter future (Vales et al 2014).

Overall, herbivore attacks are likely to increase during crop development under hotter conditions (Ju et.al. 2015). The impacts on specific crops in Mozambique, however, is poorly understood. Typically, Mozambican farmers lack the resources to purchase pesticides or implement other pest control techniques, which makes them vulnerable to changes in pest outbreaks due to weather or climate. Despite the likelihood of temperature and rainfall patterns altering pest and pathogen outbreaks in Mozambique, little research has been conducted in this area.

- **The impact of increased CO_2 in the atmosphere on plant growth and nutrition**. To grow, plants fix CO_2 during photosynthesis. In many cases, increased atmospheric CO_2 resulting from burning fossil fuels, which causes climate change, will increase plant growth. As plant species fix CO_2 differently, the benefits of increased CO_2 in the atmosphere will benefit them in different ways. Many crop species fix nitrogen using the C3 pathway (called C3 plants, as opposed to CAM or C4 plants, which fix nitrogen differently). C3 plants will enjoy the highest rate of increased growth as a result of increased atmospheric CO_2. Some studies suggest that soy, a C3 plant, could increase yield by as much as 24 percent in Mozambique due to increased concentrations of CO_2 in the atmosphere when excluding other climate factors. However, most studies agree that the negative impacts of climate change associated with increased temperatures and extreme weather will likely decrease any benefits plants receive from increased atmospheric CO_2. For example, in the case of soy, when other climate drivers are considered in addition to CO_2, yield is projected to decrease by 6.4 percent in Mozambique (INGC, 2009). Other factors to consider are how increased CO_2 in the atmosphere will 1) increase the presence of weeds and, therefore, competition among plants for resources, and 2) how the nutrition of crops will be affected. Some studies suggest that protein and micronutrients in crops decrease as atmospheric CO_2 increases.

4. POTENTIAL AREAS OF INVESTMENT

This report demonstrates a strong likelihood of increased temperatures, extreme weather events and changes in rainfall patterns in Mozambique, together with evidence that some of these changes have already begun. In response, the agricultural system must adapt and become more resilient to these changes. Unfortunately, these changes often compound existing structural problems in the agricultural system in Mozambique, such as a lack of access to quality, certified seeds and poor infrastructure to move products to markets. Some potential responses already exist through better agricultural practices, such as investing in higher yielding seed varieties or fertilizer. However, it is also important to note that some problems in agricultural systems have little to do with climate change but are equally important, nonetheless. For example, certified seeds are often promoted in order to increase yields and productivity in agricultural systems. Nevertheless, while these seeds may offer advantages to traditional varieties, farmers are unlikely to invest in certified seeds if no market exists for their crops.

While it is fairly certain that Mozambique's climate is changing, and will continue to change, it is impossible to project the future climate exactly. The uncertainty associated with future climate is compounded by the fact that climate change is occurring on top of significant existing interannual variability in climate. Therefore, it is impossible to plan for a single future scenario or single set of on-the-ground agricultural interventions that will be effective in all areas of Mozambique in all years. In the end, it will be important to develop robust solutions that build national, community and individual resilience across the entire suite of future climate scenarios.

One approach is to pair a package of locally relevant climate-smart agricultural practices with improved climate and weather information for decision-making. This way, farmers can decide what will be the most effective adaptive strategy in a specific year given their local context and constraints. This concept of climate services, that is, the provision of climate and weather information on decision-relevant time scales, is further outlined below. It should be noted that climate services will only be effective if farmers have the resources and knowledge to act on the information.

The development of appropriate climate-smart agriculture practices requires more detailed research than was conducted here; future research should consider biophysical changes, geographical differences, and local socio-cultural and economic constraints and incentives.

4.1 CLIMATE SERVICES

Significant uncertainty not only exists around long-term changes in climate in Mozambique, but also around any given farming season. This is because of high interannual variability.

Unfortunately, the level of uncertainty around current and future climate is unlikely to decrease in the near term (i.e., five to 10 years). To make decisions on what to plant, when to plant, what inputs to purchase, etc., farmers currently use a range of traditional and modern methodologies. An approach to improved agricultural decision-making that has sparked interest and shown signs of success in other regions of Africa (e.g., Mali, Senegal, Ethiopia, Ghana) is the provision of climate and weather information to farmers and other stakeholders within the value chain at decision-relevant time-scales. In developed countries, such as the United States, farmers have access to real-time weather forecasts, which allow them to target interventions to specific crop needs, thereby increasing productivity and avoiding climate-related crop losses. “Climate services” apply to a wide range of weather and climate-related information intended to help inform decision-making. For example:

- *Seasonal forecasts* issued three to six months prior to the rainy season can help farmers decide which crops and varieties to plant, and about when to plant. They can help input providers understand and prepare for farmer needs, for example, stockpiling varieties of seeds likely to be in demand.
- *Daily to 10-day forecasts* can help farmers identify what inputs to use and when, as well as whether to supplement soil moisture conditions using simple irrigation during prolonged dry periods.
- *Longer-term projections* can help research agencies better understand the general trends in climate, allowing them to develop new crop varieties or agricultural practices more appropriate for the future climate. In the most extreme scenarios, it can help countries begin to move away from certain crops in the most vulnerable areas.

Perhaps the longest running example of the provision and use of climate services in Sub-Saharan Africa outside of South Africa is in Mali, where the National Meteorological Agency (the *Météo*) has been providing rural farmers with seasonal and 10-day weather forecasts and agro-meteorological advisories since the 1980s. This program, prompted by drought in the 1970s, has become the template for several other national programs, including those in Senegal and Rwanda. These programs, as well as others in countries such as Ethiopia, tend to follow a governmental model, where the national meteorological agency (or analogous agency within the national government) develops a downscaled climate/weather forecast relevant at the country scale and then works with other national ministries and agencies, such as the agriculture ministry, to develop sector-based advisories. In Mali, agro-meteorological advisories provided over the radio, in combination with local measurements of rainfall, help farmers decide when to plant and what variety to plant. In Ethiopia, water and flooding advisories help support water resource and disaster management planning at the national level. Most of these programs are still in early stages; peer-reviewed evidence of their impact is being developed. Even though the Mali program has been in place for more than 30 years, there has been no systematic evaluation of its impact other than a pilot scale assessment in the early 1980s.

Even with the growing interest in climate services programs, there is recognition of the barriers to their effective implementation in Sub-Saharan Africa. These relate to the accuracy of the forecasts, which is dependent on capable staff, adequate modeling and computing resources, and an observation system that is sufficient temporally and spatially resolved. Additionally, most programs seek to incorporate forecasts into an actionable advisory, which requires coordination across ministries as well as both the collection of and dissemination of information at decision-making scales. These advisories then need to be communicated effectively to rural farmers, who may or may not have the resources or abilities to act upon the information. Climate services operate along a value chain from production to use, and each link needs to function for the information to translate into improved decisions and livelihood outcomes. To better identify the barriers to implementing these programs, understand sustainable business models, and develop an evidence base on their effectiveness, USAID's Africa Bureau recently established a two-year learning agenda that is being implemented through a pair of cooperative agreements.

Another interesting effort is that of a private company called Ignitia, which has recently begun providing daily 1- and 2-day forecasts in West Africa for a small fee. This program, started in northern Ghana, has now spread to several other West African countries. Ignitia's program is based on improved real-time tracking of weather events in the tropics and provides users with insight into whether they can expect rainfall over the next two days. Ignitia says it has more than 100,000 paying members. While the business model and product are still new, anecdotal evidence in several countries indicates growing interest in their product, which costs about $6 per season ($0.04 per daily forecast). Although more time is needed to determine the effectiveness and sustainability of this model and the potential to expand or replicate the model beyond West Africa, it offers an interesting complement to government-based models.

The development and use of climate services in Mozambique are currently hindered by a number of factors, including the accuracy of weather and climate forecasts issued by the country's National Meteorology Institute (INAM), which itself is constrained by the country's limited network of observation stations and staff. It is unclear where the resources would come from to improve both INAM's observation system and staff capacity. Mozambique also lacks an effective agriculture extension service, an institution that in other countries effectively communicates climate information to farmers. Nevertheless, these problems are not unique to Mozambique. Although the existing observational data have obvious limitations, an early warning and climate services system to support informed choice in building value chain resilience could offer important information to key stakeholders, diminishing losses due to climate variability and extreme events, and potentially enhancing productivity. Developing and testing such a service could begin at the farm level but would require further investigation and access to available meteorological information on the ZOI.

Several donor and private companies such as Earth Networks and the World Bank through the Pilot Program for Climate Resilience (PPCR), and the WMO through the Global Framework for Climate Services, are already engaging with the Government of Mozambique on improving the observation network and developing a more effective climate services system. Earth Networks, for example, is working with the national government to create decision-support tools that provide information to users across sectors, including agriculture. The World Bank, through the

PPCR is funding the establishment of new automatic weather stations for the National Meteorological Institute (INAM). The WMO, through the GFCS is providing technical advice and expertise to strengthen health service provision using climate information. Ideally, climate services could be made available across all regions in Mozambique, with spatially explicit forecasts provided to farmers. Such a program could help farmers address increased flooding while at the same time supporting improved decision-making in the drought-stricken south. While such information is unlikely to replace more traditional methods for developing a cropping calendar, it can supplement those methods as climate less and less resembles historical patterns.

REFERENCES

Carvalho PG, Borghetti F, Buckeridge MS, Morhy L, and Filho EXF. (2001). Temperature dependent germination and endo-mannanase activity in sesame seeds. Brazilian Journal of Plant Physiology. 13: 139-148.

Ciampitti I, Jardine D, and Shoup D. (2015). Soybean response to standing water and saturated soils. Retrieved from: http://www.agprofessional.com/news/soybean-response-standing-water-and-saturated-soils

Conley S, and Shannon G. (2013). Assessing flood damage to soybean. Retrieved from: http://ipcm.wisc.edu/blog/2013/06/assessing-flood-damage-to-soybean/

Dias D, and Amane M. (2011). Yield response of soybean genotypes to different planting dates in Mozambique. African Crop Science Conference Proceedings. 10: 539-541.

El-Lattief EAA. (2015). Cultivation of Sesame in Egypt. International Journal of Research in Engineering and Applied Sciences. 5: 162-166.

Gibson LR, and Mullen RE. (1996). Soybean seed quality reductions by high day and night temperature. Crop Science. 36: 1615-1619.

Global Agriculture and Food Security Program. (2016). Agribusiness country diagnostic – Mozambique. Retrieved from: https://www.ifc.org/wps/wcm/connect/f633ff804b5f05adbc3afd08bc54e20b/GAFSP_CountryDiagnostic_MOSAMBIQUE_Full_rev.pdf?MOD=AJPERES

INGC. (2009). Main report: INGC Climate Change Report: Study on the impact of climate change on disaster risk in Mozambique. INGC, Mozambique.

Ju RT, Zhu HY, Gao L, Zhou ZH, and Li B. (2015). Increases in both temperature means and extremes likely facilitate invasive herbivore outbreaks. Scientific Reports. 5: 15715.

Khalil SK, Mexal JG, Rehman A, Khan AZ, Wahab S, Subair M, Khalil IH, and Mohammad F. (2010). Soybean mother plant exposure to temperature stress and its effect on germination under osmotic stress. Pakistan Journal of Botany. 42: 213-225.

Lopez FB, Johansen C, and Chauhan YS. Effects of timing of drought stress on phenology, yield and yield components of short-duration pigeon pea. Journal of Agronomy and Crop Science. 177: 311-320.

Odeny DA. (2007). The potential of pigeon pea (Cajanus cajan) in Africa. Natural Resources.

Sarkar PK, Khatun A, and Singha A. (2016). Effect of duration of water-logging on crop stand and yield of sesame. International Journal of Innovation and Applied Sciences. 14: 1-6.

Scott HD, Deangulo J, Daniels MB, and Wood LS. (1989). Flood duration effects on soybean growth and yield. Journal of Agronomy. 81: 631-636.

Schlenker W, and Roberts MJ. (2009). Nonlinear temperature effects indicate severe damages to U.S. crop yields under climate change. Proceedings of the National Academies of Science. 106: 15594-15598.

Shibairo SI, Nyabundi JO, Otieno W. (1993). Effects of temperature on germination of seeds of three pigeon pea (Cajanus cajan) genotypes. Retrieved from: https://profiles.uonbi.ac.ke/shibairo/publications/effects-temperature-germination-seeds-three-pigeonpea-cajanus-cajant-genotypes

Talacuece MAD, Justino FB, Rodrigues RA, Flores MEP, Nascimento JG, and Santos EA. (2016). Modeling of soybean under present and future climates in Mozambique. Climate. 4: 31.

Tanzania Forest Conservation Group. (2012). Improving agricultural practices in the context of REDD readiness in Lindi Rural District, Tanzania: a review of current agricultural practices and recommendations for project interventions. Retrieved from: http://www.tfcg.org/pdf/Agricultural%20Review%20and%20Recommended%20Interventions%20for%20Lindi%20FINAL.pdf

USAID. (2016). Mozambique Agricultural Value Chain Analysis.

Valenzuela H. (2011). Pigeon peas: A multipurpose crop for Hawaii. Retrieved from: http://www.ctahr.hawaii.edu/sustainag/news/articles/V7-Valenzuela-cajanus.pdf

Vales, M. I., Ranga Rao, G. V., Sudini, H., Patil, S. B., & Murdock, L. L. (2014). Effective and economic storage of pigeon pea seed in triple layer plastic bags. Journal of Stored Products Research, 58, 29-38.

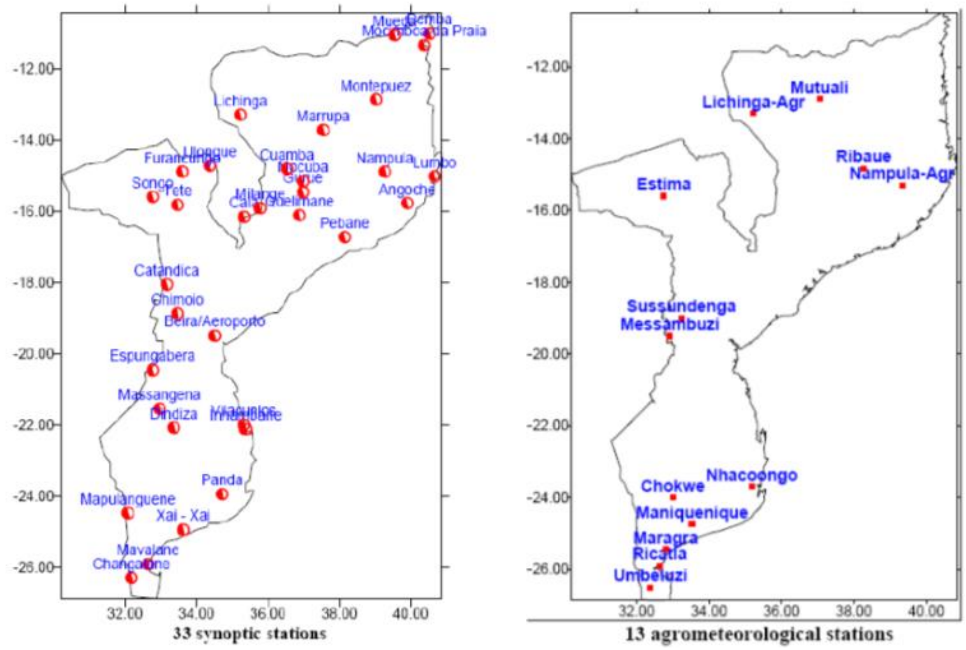
Wuebker EF, Mullen RE, and Koehler K. (2001). Flooding and temperate effects on soybean germination. Crop Science. 41: 1857-1861.

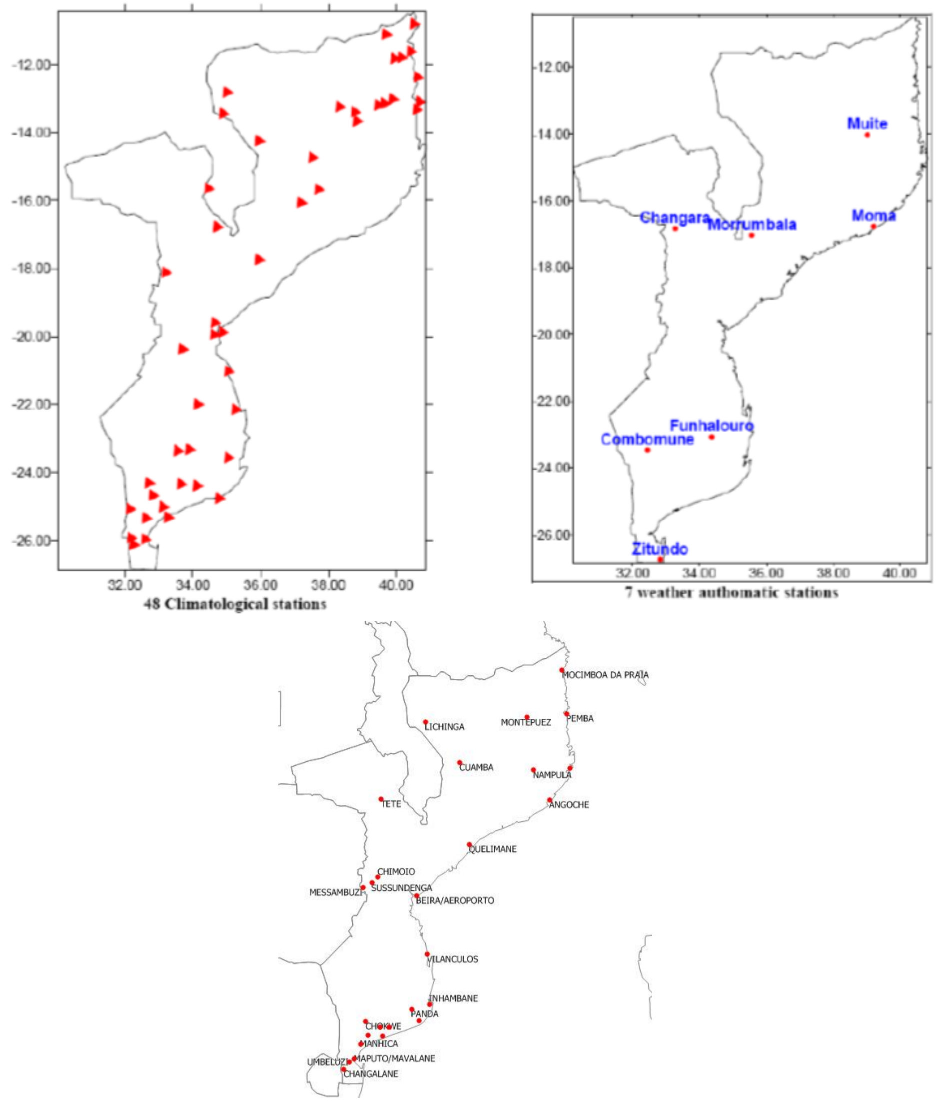
ANNEX: AVAILABLE METEOROLOGICAL INFORMATION

OBSERVATION NETWORK IN MOZAMBIQUE

Figure A2.1 shows the location of relevant meteorological stations across Mozambique, while Table A2.1 summarizes the station types. The variables these stations measure and an initial assessment of record length and quality are provided in Table A2.1. While providing reasonable coverage, the station network over Mozambique has major geographical gaps, especially in Gaza and Tete provinces, as well as in the north, the southern inland regions and, to a lesser extent, the central inland regions, all of which have large areas without station measurements.

Figure A2.1: Location of meteorological stations across Mozambique





Note: Top left: location of synoptic stations (33). Top right: agro-meteorological (AgMet) stations (13). Middle left: 48 climatological stations. Middle: right: seven automatic weather stations (AWS). Center bottom: stations used for downscaling purposes under INGC 2009 study.

Table A2.1: Station types and functions

STATION TYPE	MEASUREMENTS	QUALITY EVALUATION
Climatological stations	Daily rainfall	Many of these have records that finish during the 1990s or earlier, which suggests use of less reliable (manual) data collection.
Synoptic stations	Daily minimum and maximum temperatures, daily rainfall	At least 10 years of good quality data from 1960-2005.
Automatic weather stations (AWS)	Daily minimum and maximum temperatures, daily rainfall, wind speed and direction, and solar radiation	Unclear
Agrometeorological stations	Unknown	Their status and measurements are unclear.

POTENTIAL TO EXPAND THIS AVAILABLE INFORMATION IN THE NEAR FUTURE

Currently under negotiation, a memorandum of understanding (MOU) between the National Meteorology Institute (INAM) and the Mozambique National Institute of Health (INS) would open the way to updating the INGC station dataset from 2005 to the present, allowing for more detailed analysis of current climate variability and trends. Nevertheless, it is unclear whether the agreement would extend the spatial coverage of stations.

QUALITY ASSESSMENT

Despite these maps suggesting high spatial coverage of intervention areas with weather stations, the available data until 2000 (the last year meteorological station data were received from INAM[1]) indicate that:

- Areas suffered from incomplete and inaccurate records during the country's civil war (1975-1992).
- Many stations have records that ended during the 1990s or earlier.
- Many stations lack site security and it is not clear that the data are of sufficient quality.
- It is not clear how long a record exists for each of the seven AWS.
- Of the remaining synoptic and agrometeorological stations, it is unclear how many are still reporting. The data to be obtained from INAM through the INS MOU may allow for a more proper assessment.

This is not to say that the data are not useful, as they may help to fill in missing data (e.g., through spatial interpolation) or be used as a quality control check for nearby stations. Whether or not these quality issues are critical to the design of new projects depends on the crop and the specifics of the locations of intervention. Furthermore, there are ways to estimate missing data in Mozambique by examining data from nearby stations in Malawi for regions where geographic coverage in Mozambique is sparse. In fact, a study conducted by INGC in 2010 on responses to the impacts of climate change in Mozambique shows nearby stations across Southern Africa that could help fill some gaps in station coverage in intervention areas (Figure A2.2). Examination of Malawi information could be undertaken, given agreement with the Malawi meteorological services to access its data.

[1] The possibility exists to obtain additional data from INAM to extend the analysis beyond that available for 1980-2005.

Figure A2.2: Meteorological stations used in the 2010 INGC study on responding to the impacts of climate change in Mozambique

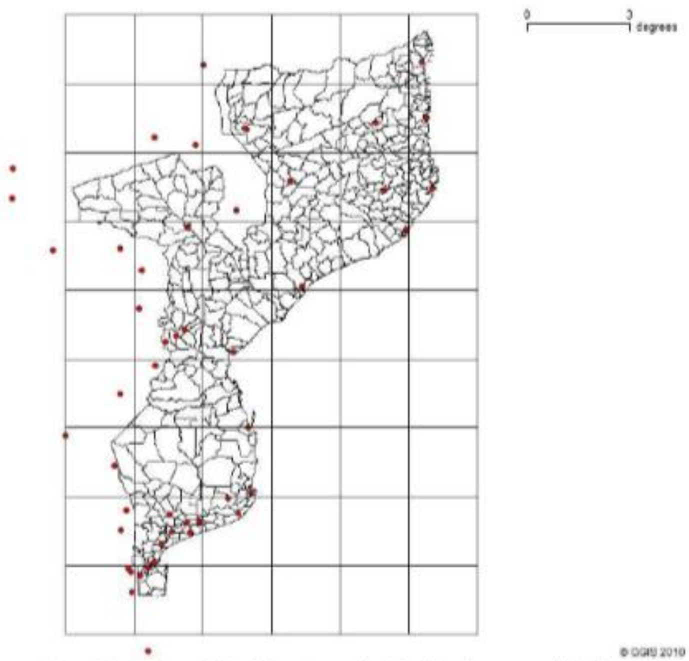


Figure 7: ***Location of the 47 meteorological stations used in this study.***

USING PUBLICLY AVAILABLE INFORMATION TO FILL IN OBSERVATIONAL GAPS

Two sources of information used in this report can help to fill in some of the existing spatial and temporal gaps in Mozambique's observation network. These include:

- *Rainfall:* Climate Hazards Group InfraRed Precipitation with Stations (CHIRPS; Peterson et.al. 2013). The CHIRPS data comprise daily rainfall data only. They are a combination of satellite and weather station rainfall data and are available for the period 1981-2014, gridded to 0.05 x 0.05-degree spatial resolution.

- *Temperature:* Climate Research Unit (CRU TS 3.21; Harris et al. 2014). The CRU TS data comprise monthly time series of various climate variables, which include maximum and minimum temperatures, and rainfall. The data are based on more than 4,000 global weather stations are available for the period 1901-2012, and are gridded to 0.5 x 0.5-degree spatial resolution.

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