Linking Drought Forecast Information to Smallholder Farmer's Agricultural Strategies and Local Knowledge in Southern Malawi

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by

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Summary

Most people of Malawi are dependent on rainfed agriculture for their livelihoods. This leaves them vulnerable to drought and changing rainfall patterns due to climate change. Over time, farmers have adopted local strategies and knowledge that help reducing the overall vulnerability to climate variability shocks. One other option to increase the resilience of rainfed farmers to drought, is providing forecast information on the upcoming rainfall season. Forecast information has the potential to inform farmers in their decisions surrounding agricultural strategies. However, significant challenges remain in the provision of forecast information. Often, the forecast information is not tailored to farmers, resulting in limited uptake of forecast information into their agricultural decision-making.

Therefore, this study explores whether drought forecast information can be linked to existing farmers strategies and local knowledge on predicting future rainfall patterns. During a period of three months in Malawi, participatory research approaches are used to create an understanding of what requirements drought forecast information should meet to effectively inform farmers in their decision-making. Consequently, a sequential threshold model was established that relates annually monitored meteorological indicators *before* the rainy season, to the occurrence of dry conditions *during* the season. Dry conditions were expressed in the drought indicators that farmers require for their agricultural decision-making. Additionally, using interviews among stakeholders and a visualisation of the current information flow, further insights on the current drought information system were developed.

Although farmers have their own strategies and timing of decision-making, this research has generalized some of the opinions and strategies to develop the 'requirements' which a contextualized forecast should meet. In August farmers require a prediction of the onset of the rainy season, typically starting mid-November. In addition, an update on the timing of the onset of rains is required in beginning of November. An overall indication of the 'dryness' of the rainy season is required in September. Here, 'dryness' is characterized by the number of dry spells, a composite 'drought index' of associated rainfall variables by the farmers. The forecast should be on a scale that is locally relevant (EPA level).

This research consequently established a forecasting model, based on meteorological variables from local knowledge which can complement the forecast variables from the DCCMS. The results of forecast verification show that meteorological indicators based on local knowledge have a predictive value for forecasting drought indicators. Subsequently, skill analysis of forecasting incorporating all the above dimensions shows that the accuracy of the forecast differs per location with an increased skill to the Southern locations. In addition, it is also location dependent whether the contribution of wind, temperature or ENSO indicators gives the most predictive value. The results show that a combination of all indicators have the best predictive value. In addition, the results show that local knowledge indicators have an increased predictive value in forecasting the locally relevant critical events in comparison to the currently used ENSO-related indicators by the DCCMS.

Additional research is needed to further analyse certain aspects of this research, such as research on the robustness of the model used. Research on the risk farmers are willing to take in their respective decisions could act as another requirement the forecast skill should meet. This highlights the importance of having continuous feedback from the farmers, since farmers may experience adverse impacts from wrongly informed decisions. Despite these limitations, it is argued that the inclusion of local knowledge in the current drought information system of Malawi may improve the provision of forecast information for farmers and shows that it is possible to capture local knowledge in a technical approach. The findings have relevant implications for other stakeholders, such as humanitarian and meteorological organisations, that are implementing drought-risk reduction approaches and climate services.

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Abbreviations

ACPA	Area Civil Protection Committee
AEDEC	Agricultural Extension Development Coordinator
AEDO	Agricultural Extension Development Officers
DCCMS	Department of Climate Change and Meteorological Services
DCPC	District Civil Protection Committee
DEWS	Drought Early Warning System
DADO	District Agricultural Development Officer
DEAS	Department of Agricultural Extension Services
DoDMA	Department of Disaster Management Affairs
DRR	Disaster Risk Reduction
ENSO	El Niño Southern Oscillations
EPA	Extension Planning Area
EWEA	Early Warning Early Action
EWS	Early Warning Systems
FbF	Forecast based Financing
FGD	Focus Group Discussion
FRT	Farm Radio Trust
GDP	Gross Domestic Product
LK	Local Knowledge
MoAIWD	Ministry of Agriculture, Irrigation & Water Development
MoU	Memorandum of Understanding
MRCS	Malawi Red Cross Society
NGO	Non-Governmental Organisation
NLRC	Netherlands Red Cross
NMS	National Meteorological Services
PICSA	Participatory Climate Service for Agriculture
SARCOF	South African Regional Climate Outlook Forum
SST	Sea Surface Temperature
UNDP	United National Development Programme
VCPC	Village Civil Protection Committee
WMO	World Meteorological Organization
WFP	World Food Programme

1 | Introduction

Throughout Sub-Saharan Africa, more than 95% of cultivated land is under rainfed agriculture (FAOSTAT, 2009). This leaves the population vulnerable to an increase in climate variability and droughts which can reduce their crop yield and indirectly lead to food insecurity (Ibrahim & Alex, 2008). Climate change aggravates the effects of this variability, due to more erratic rainfall as well as an overall increase in temperature (Winsemius et al., 2014; Ziervogel et al., 2014).

Malawi is one of the countries in Sub-Saharan Africa of which its population is highly dependent on rainfed agriculture. Agriculture is the country's main practice, supporting most of its rural population (Coulibaly et al., 2015). Malawi is highly vulnerable for food insecurity due to high exposure to climate shocks as well as chronic poverty that heighten risk and limit coping capacities (Shiferaw et al., 2014). Farmers have, however, adopted their own mitigation strategies and local knowledge on weather predictions that helps in reducing the overall vulnerability to drought (Tschakert, 2007).

Organisations consider the provision of forecast information about the upcoming rainy season as one of the options to reduce the impact drought has on rainfed agriculture. Forecast information can help to adapt to the risks at hand and make informed agricultural decisions (Carsell et al., 2004). (Humanitarian) organisations are, therefore, increasingly integrating climate tools and services into Early Warning Systems (EWS) that drive activities and preparedness to forecasted climate hazards (Wilkinson et al, 2018).

Using forecast information in the agricultural sector in Sub-Saharan Africa has shown potential (Hansen et al., 2011). However, significant challenges remain in the provision of forecast information. Often, the forecast is not tailored to farmers, and the uptake of the forecast information into their agricultural decision-making is limited (Patt & Gwata, 2002; Cash & Buizer, 2005; Bruno Soares et al., 2018).

It is argued by various authors that the inclusion of local knowledge is important in the provision of forecast information. The inclusion might lead to forecast information that is better suited and understood by local users, thereby increasing overall climate resilience (Plotz, 2017). Additionally, it may lead to forecast information that is locally relevant and better trusted by the users. Local knowledge of drought predictions may include the occurrence of a certain meteorological phenomenon that can suggest an upcoming drought event (Mugi, 2014). This research aims to incorporate those meteorological indicators into the production of forecast information which is tailored to the agricultural decision-making of farmers. In doing so, this study aims to establish and evaluate locally informed forecast information, that is connected to the farmers forecast requirements and context in Malawi.

1.1 Scope and Relevance

This section further addresses the scope of the study, together with the scientific and societal relevance. Additionally, the context and partners involved in this research are presented in section 1.1.2.

Drought is a globally occurring phenomenon and with climate change, the impacts are expected to increase. However, drought is difficult to grasp due to its unique set of characteristics. The impact of drought differs on a spatial and temporal scale. This research aims to contribute to drought-related research efforts. The research focusses on communities vulnerable to drought; smallholder farmers in Southern Malawi that depend on rainfed agriculture. Maize is the staple crop of the population, which is why it is this crop that is considered in the scope of the study.

(Humanitarian) organisations and governmental institutions are increasingly integrating climate tools and services into Early Warning Systems (EWS) that drive activities and preparedness to forecasted climate hazards (Wilkinson et al, 2018). The efforts include, e.g. 'Disaster Risk Reduction' (DRR) and climate resilience projects. However, there is often limited uptake of forecast information into agricultural decision-making of farmers, which is often the 'target group' of those projects. A better understanding of drought forecast information in relation to vulnerable communities is, therefore, useful for the actors involved.

Several studies have been done on forecast information and local knowledge in Malawi (Kalanda-Joshua et al., 2011; Nkomwa et al., 2014; Trogrlić et al., 2019). All studies state that there is a need to incorporating this knowledge into the provision of climate-related information. However, using local knowledge indicators and long-term historical records to integrate the two forecasts remains unreported in literature. This leaves a gap in this research field and presents the opportunity to scientifically analyse local forecast signs on their predictive value. For this reason, this study explores whether forecast modelling can be linked to local knowledge and the agricultural strategies of farmers. In addition, the 'system' in which the forecast information is disseminated is included in the scope of the study. In doing so, the research bridges gaps between different research fields, both in natural and social sciences.

1.1.2 Partners involved

This work is a thesis for the master specialisation Water Resources at TU Delft while working as a Graduate Intern at 510 | An Initiative of the Netherlands Red Cross. This research coincides with the NERC-SHEAR IPACE Malawi project that 510 is a partner in. The aim of that project is to: (1) identify critical agro-climatic indicators in central and southern Malawi; (2) test the skill of short term to seasonal forecast tools in simulating these indicators; and (3) co-design agricultural climate services and input into early warning early action systems based on these indicators/forecast tools. Other partners in the NERC SHEAR project and who have been involved in this research are the University of Leeds, the UK MET Office, the Data Team of Malawi Red Cross and Department of Climate Change and Meteorological Services.

1.2 Objectives and Research Questions

This thesis aims to approach climate and weather forecasts with smallholder farmers as the central user; forecasts which are tailored to the local agricultural strategies and knowledge of smallholder farming communities in Central and South Malawi. It interacts between science, (meteorological) institutions, NGO's and smallholder farmers in Malawi.

The wider goal of this research is the understand and potentially suggest improvements on the forecast information given to farmers. It aims to establish and evaluate locally informed forecast information, that is connected to end-user forecast requirements and context concerning smallholder farmers in Malawi.

Objectives

- Provide an overview of what forecast information is valuable for farmer's agricultural strategies and how that is currently received though local knowledge and 'technical' forecasts.
- Understand whether local knowledge can be linked to forecast information and potentially inform agricultural strategies.
- Provide recommendations on what could be improved in the current forecast information provision and production in Malawi.

Main research question | Can drought forecast information for smallholder farmers be improved by linking it to agricultural strategies and local knowledge in Southern Malawi?

To answer the main research question, this thesis is further divided into three sub-questions.

1. **What agricultural decisions do farmers make in their drought-related strategies and how can forecast information inform those decisions?**
   - How is drought influencing the agricultural practices of farmers?
   - What drought-related strategies and local knowledge are already in place at the community level?
   - How could forecast information support their agricultural practices? What information do they currently rely on? How is available information received? And what could be improved?
   - How can this be 'translated' and incorporated into the design of drought-related forecasts? What forecast variables, with what lead time, scale and communicated by whom?

2. **How is current drought forecast information produced and disseminated to the smallholder farmers?**
   - How is a 'technical' forecast 'translated' to information, warning and advice to farmers? Is local knowledge included by them?
   - How are forecast information and drought warnings currently disseminated? Channels, frequency, what information
   - From the stakeholder's perspectives, what are the current strengths and weaknesses in the current drought information system?

3. **Can a forecasting model based on meteorological indicators derived from local knowledge deliver the necessary information to support the agricultural decisions?**
   - Are the patterns (memory) of rainfall and local knowledge, in agreement with hydro-meteorological data?
   - It there a correlation between meteorological indicators informed by local knowledge and drought indicators that could inform agricultural decision-making?
   - What information, with what lead time, scale and skill, can be given by a forecast based on local knowledge?
   - Does this comply with the decision-making of farmers, to potentially inform agricultural strategies?

1.3 Reader's Guide

This thesis consists of 8 chapters. In the theoretical background (Chapter 2) an overview of the current scientific literature, relevant approaches and definitions are elaborated on. The background of the research area and methods to answer the research questions are explained in Chapter 3. The results are given in separated chapters; a separate chapter per sub-question (Chapter 4, 5 and 6). In the discussion (Chapter 7), there is a reflection on the results. At last, the conclusions and recommendations are addressed (Chapter 8).

2 | Theoretical Background

The theoretical background elaborates on the concepts and main topics of this research. Section 2.1 describes the term 'smallholder farmer', their livelihood, local knowledge and agricultural strategies. In section 2.2 the definitions, impact and drivers of drought are explained. Subsequently, the drought forecast systems are elaborated on in section 2.3, where the elements which make up a forecasting system are explained, and the current barriers are identified. Lastly, the production of current forecasting systems and key terms in forecasting are explained in Section 2.4.

2.1 Smallholder Farmers in Malawi

In this section more context is given on the smallholder farmers in Malawi. The term 'smallholder farmers' is explained together with their livelihood, local knowledge and strategies.

The government of Malawi distinguishes between smallholder farmers and estate farmers, the latter being large-scale commercial operations (Chirwa, 2007). The smallholder sector is divided into three categories: net food buyers, intermediate farmers and net food sellers, as explained in Table 1.

Table 1: Smallholder Farmer Categories (Chirwa, 2007)

Category	Farm Size (ha)	Percentage of total	Produce
Net food buyers	<0.7	35%	Cannot produce enough food to satisfy their subsistence needs.
Intermediate farmers	0.7-1.5	40%	Produce just enough for their survival but have very little for sale
Net food sellers	>1.5	25%	Produce more than their subsistence needs for survival during the year

On about 70% of the cultivated land, the staple crop maize is grown. Clearly, the agricultural sector in Malawi is critical for the livelihoods of a large population by sustaining them in the food provision for their households (Chirwa, 2007).

Smallholder farmers are however increasingly suffering from the adverse effects of climate variability. This has had a negative impact on agricultural production and is attributed to the fact that most of their agriculture is rainfed. Farmers have, however, adopted their own mitigation strategies and local knowledge on weather predictions which have evolved over time and helps in reducing the overall vulnerability to drought (Tschakert, 2007). For instance, an occurrence of a certain phenomenon (e.g. ecological, meteorological) that can suggest an upcoming rainfall event (Mugi, 2014). Smallholder farmers are able to understand and incorporate such forecast information into their decision-making process (Suarez & Patt, 2004). Alessa et al. (2008) stress that local knowledge and perceptions influence people's decisions both in deciding whether to act or not. In addition, local perceptions of climate variability are deemed important since they reflect local concerns (Danielsen et al., 2005) and focus on the actual impacts of climate variability on people's lives (Laidler, 2006). In this research, the collective term 'local knowledge' is used for historical and predictive knowledge of the smallholder farmers.

Several studies have been done on the local knowledge of communities in Malawi (Kalanda-Joshua et al., 2011; Nkomwa et al.,2014; Trogrlić et al., (2019). All studies state that there is a need for incorporating this knowledge into the dissemination process of climate-related information. Two case studies by Kalanda-Joshua et al. (2011) and Nkomwa et al. (2014) have stated that what farmers have observed and indicated over the past years (rise in temperature, more erratic rainfall) is backed up by science. However, when looking at the predictive capacity of local knowledge instead of historical knowledge, no research has been done on this in relation to drought-related forecasting.

Farmers make several decisions in their agricultural practices that can influence their vulnerability to climate variability. The term 'strategies' is also used for this agricultural decision-making process. A study by (Chidanti-Malunga, 2011) has been done on the 'Adaptive Strategies to Climate Change in Southern Malawi'. It was concluded that when a drought is expected various strategies can be applied. This includes increased management of residual moisture, mulching, pit planting, crop diversity, shifting of planting dates and alternative sources of income.

Mulwa et al. (2017) found that access to climate-related forecast information significantly determines adaptation across most strategies. Pangapanga et al., (2012) state that variables such as temperature and rainfall significantly affect farmer's decisions over various adaptation strategies. This underscores the important role of making climate-related forecast information available to farmers (Mulwa et al., 2017).

2.2 Drought

Firstly, this section elaborates on the definition of drought and its drivers and impacts. Secondly, drought information systems are explained and what components they consist of. It elaborates on how current drought forecasts are made in Malawi and what could be improved in the drought information systems in relation to the uptake of forecast into decisions making of its users.

2.2.1 Drought: impact and definition

Droughts are a persistent and costly hazard impacting human and environmental systems. Drought affects both surface and groundwater resources, crop production, economic and social sectors, water quality and ecological systems. It impacts the livelihood security, personal security, access to education and food security (Wens et al., 2019).

There is not a standard definition of drought in literature. In very general terms, drought can be expressed as "an exceptional lack of water compared with normal conditions" (Van Loon et al., 2016). In literature, however, are some definitions recognized depending on the sector the drought has an impact on (Wilhite & Glantz, 1985):

- Meteorological drought: a period of months to years with a deficit in precipitation or climatological water balance over a given region.
- Agricultural drought: reduced soil moisture that results in reduced crop yields.
- Hydrological drought: when river streamflow and water storages in water bodies fall below long-term mean levels.
- Socio-economic drought: associates the supply and demand of some economic good or service with elements of meteorological, hydrological, and agricultural drought.

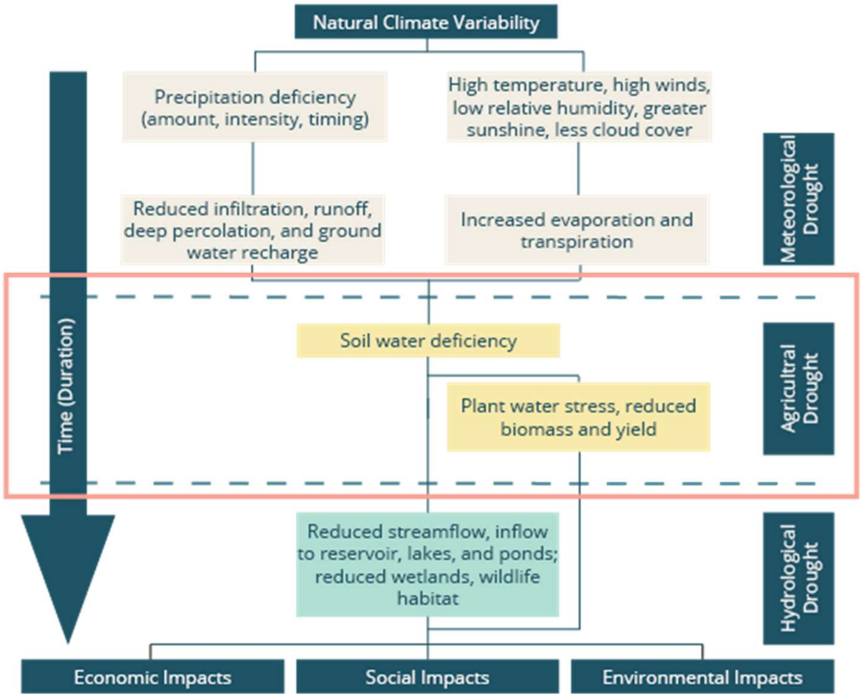

Figure 1: Classification of Drought in Time. Made by Panis (2019). Adapted from Wilhide (2000)

Drought can occur in a form of natural climate variability, whereby there is a deficit of rainfall or higher temperatures for a certain period. There is however a concern that climate change may aggravate the effects of the natural climate variability, resulting in more climate extremes as well as an overall increase in temperature (Zaitchik, 2017). Figure 1 shows how the different types of drought relate to one another in terms of drought duration.

Drought risks and impacts are expected to increase in many parts of the world due to the continuous increase of climate variability and the distribution of wealth and people. Drought is a complex phenomenon which is difficult to grasp due to its unique set of characteristics. Drought has a slow onset, large spatial and temporal extent. In addition, the impacts drought has can be influenced by adaptive decision-making of humans. In this sense, droughts are equally a social and hydroclimatic issue (Wens et al., 2019; Van Loon et al., 2016).

In this research, the focus is on rainfall deficit resulting in crop failure due to the lack of soil moisture in the ground which is defined as **agricultural drought**. It is, however, often not a lower amount of total rainfall over the season that influences the harvest, it is often the poor distribution of rainfall that is the cause for agricultural drought (Winsemius et al., 2014; Barron and Okwach, 2005). In practice, this can be for example; a later onset of the rainfall season, erratic rainfall, dry spells or extreme drought in the season. Agricultural drought can have a severe impact on the food security and nutrition of populations whose lives and livelihoods are highly dependent on rainfed agriculture. The effects are indirect and potentially catastrophic, starting with a failed harvest, then livestock mortality and insufficient access to water which can lead affected populations to adopt negative coping mechanisms and eventually put them in need of emergency assistance (WFP, 2019).

In the remainder of this research, the term 'drought' is used as explained above and can thus refer to any of the variations of agricultural drought.

2.2.2 Drivers of Drought in Malawi

The El Niño Southern Oscillation (ENSO) is one of the most important climate phenomena on Earth due to its ability to change the global atmospheric circulation, which in turn, influences temperature and precipitation across the globe. The ENSO phenomenon takes place at the tropical Pacific Ocean which is bounded to the east (by South America) and west (by the shallow season in the region of Indonesia). ENSO naturally oscillates between three key phases: Neutral, La Niña and El Niño. During El Niño, there is warming of the ocean surface, or above-average Sea Surface Temperatures (SST) in the Pacific Oceans. During La Niña there is a cooling of the ocean surface, or below-average SST. How Africa is generally influenced by La Niña and El Niño events, is illustrated in Figure 2. However, it should be noted that no two events and no two sets of impacts are the same. Some impacts occur as an ENSO event is developing and some will persist even when an El Nino or La Nina never fully forms. Figure 2 highlights the differences in climate patterns from North to South in Malawi. During an El Niño event, the North has a higher likelihood of above-normal rainfall, while the South has a higher likelihood of below-normal rainfall. Conversely, during a La Niña the Southern region has a higher likelihood of having above-normal rainfall.

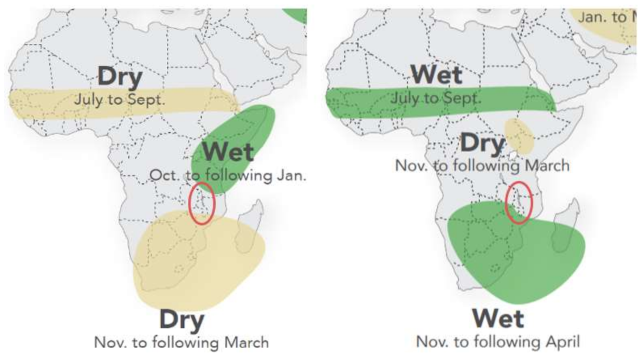

Figure 2: Left: El Niño impacts on rainfall and Right: La Niña impacts on rainfall[1]. Red circle indicates Malawi.

Near the equator is the so-called Intertropical Convergence Zone (ITCZ) which is a low-pressure zone due to the concentrated heat from the sun. This seasonal progression of ITCZ drives Malawi's rainy season. The zonal band of convective and precipitative maxima migrates south in the austral spring (September–November), bringing the first rains and heralding the onset of the wet (agricultural) season, while its equatorward return during the austral autumn (March-May) is associated with the wet season's cessation.

2.3 Drought Information Systems

In this section, the broader concept of drought information systems is explained. In the following two sections, the key elements that are found in research related to an effective drought information system are mentioned. The first section relates the decision-making process of action upon a forecast and reflects on the barriers that can limit the uptake of forecast information to decision-making. In the second section, the current forecast production is explained and how local knowledge could be included in that process. Pulwarty and Sivakumar (2014) describe a drought information system as "an integrated risk assessment, communication and decision support system of which early warning is a central component and output. In turn, an early warning information system involves much more than the development and dissemination of a forecast. It is the systematic collection and analysis of relevant information about and coming from areas of impending risk."

[1] https://iri.columbia.edu/our-expertise/climate/enso/

The UNDRR (formerly known as UN/ISDR) indicated four key elements of an effective, people-centred early warning systems: 1. risk knowledge 2. monitoring & warning service 3. dissemination and communication 4. response capability, as illustrated with the abbreviations of relevant actors for Malawi in Figure 3 (UN/ISDR, 2006). The actors and their role are explained in a later stage in this research, see section 5.2. There is a range of cross-cutting issues that should be considered when designing and maintaining an effective drought information system, especially the involvement of local communities. A local, 'bottom-up' approach to early warning systems enables a multi-dimensional response to problems and needs (UN/ISDR, 2006).

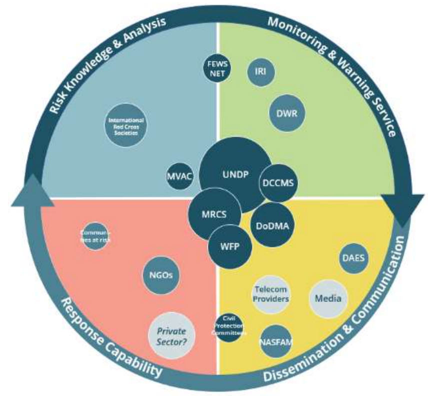

Figure 3: Phases of Early Warning System with relevant Actors in Malawi

In most countries, National Meteorological Services (NMS) either generate or have access to seasonal forecasts and are able to give forecast information on the upcoming season. However, the uptake of these forecasts by local communities can be limited (Plotz & Chambers, 2017). Various studies argue that the production of solely 'scientific' forecast information is not sufficient to support agricultural decisions (Patt & Gwata, 2002; Cash & Buizer, 2005; Bruno Soares et al., 2018). Various barriers have been identified and elaborated on in section 2.3.1.

Instead, it is argued by numerous authors that there is a need to incorporate both technical and local knowledge in the provision of forecast information (e.g. Plotz & Chambers, 2017; Kalanda-Joshua et al., 2011; Nkomwa et al., 2014; Trogrlić et al., (2019). Plotz and Chambers (2017) argue that "the incorporation of local knowledge forecast methods into technical forecast systems can lead to forecasts that are locally relevant and better trusted by the users. This, in turn, could significantly improve the communication and application of forecast information, especially to remote communities". The current technical approach of deriving seasonal forecast for agricultural purposes and the approaches of inclusion local knowledge are elaborated on in section 2.4.2.

2.3.1 Uptake of Forecast Information for Making Agricultural Decisions: process and barriers

As mentioned previously, farmers can make certain decisions concerning their agricultural practices in the field, to minimize the effects of a drought. Forecast information can be helpful in this decision-making process (Dilley, 2000). How well a weather forecast is received and accepted by smallholder farming communities depends on various factors. Molinari and Handmer (2011) developed a decision tree which represents the human behavioural steps in the forecast information process that needs to be satisfied before action occurs. This decisions tree is initially designed for flood hazards but will be used in this research to act as a guideline in which the way decisions are made. The event tree then foresees the following possible behaviours, as defined by (Molinari and Handmer, 2011):

- Receiving: in case of an available forecast (official or not), not everyone receives the forecast information
- Understanding: if the forecast is noticed, not all people understand its meaning
- Target: if people understand the meaning of the forecast, not everyone thinks the forecast applies to them
- Trusting: once people realize that the forecast applies to them, not everyone trusts the forecast
- Confirming: even if people trust the forecast, they usually look for confirmation before acting
- Once a forecast is confirmed or trusted, not everyone takes effective action
- In case of no or ineffective forecast information, people may take some action anyway (i.e. when they realize it does not rain).

Additionally, various other articles state numerous constraints for the uptake of forecast information into decision-making processes. The most relevant article for this study is by Patt and Gwata (2002) and mention six barriers for the uptake of forecast information for smallholder farmers in Zimbabwe. The barriers are credibility, legitimacy, scale, cognitive capacity, procedural and institutional barriers, and available choices. For this research, the six barriers by Patt and Gwata (2002) are reduced to four barriers, combined with the study of Molinari and Handmer (2011) and other relevant studies to provide an overview of the barriers that can limit the uptake of a forecast in decision-making. This overview is the result of an iterative process of the outcomes of the research and acts as a categorisation on which further analysis of this research is based. The 'choice' and 'scale' constrain are merged to the 'application' category which includes both the decision-making of farmers in their agricultural strategies and at what scale the forecast should be to make it applicable to the local circumstances. The 'application' constraint also includes other variables that deal with the applicability of the forecast to the agricultural decision-making. The 'legitimacy' constraint is not included in this study. An overview of the decision framework and the barriers in relation to the early warning system components are illustrated in Figure 4. The feedback loop implies that decisions making of farmers gives the forecast 'requirements' for producing a forecast that is applicable for smallholder farmers and highlights the essence of the research approach.

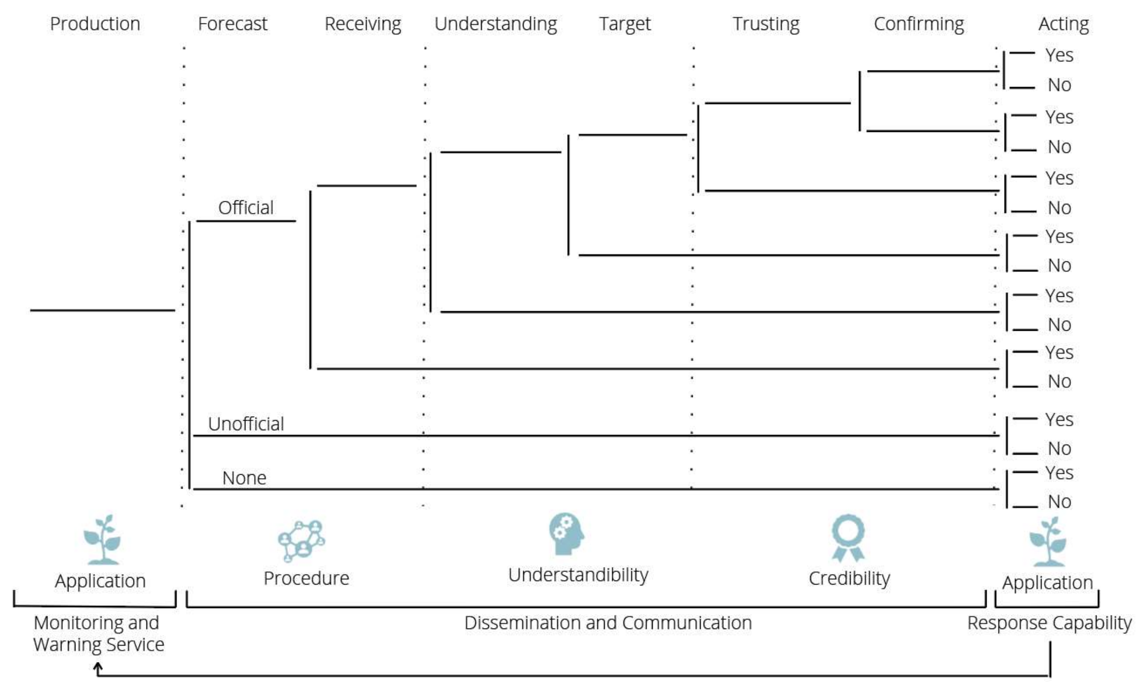

Figure 4: Decision Process of acting upon Forecast Information. Adapted from Molinari and Handmer (2011)

The four categories with the corresponding studies and core findings are presented in the table below. In the consecutive section the four categories are elaborated on. These four categories act as a guideline in which the current dissemination and production of forecast information in Malawi is assessed. Table 2 gives an overview of the barriers that can limit the uptake of forecast information.

Table 2: Four Categories that include Barriers for the Uptake of Forecast Information.

Category	Summary of the Barriers Related to the Category	Source
Application	- Forecast is not useful for agricultural practices and decisions.	Bruno Soares (2018), Hill & Mjelde, 2002, Patt and Gwata (2002)
Procedure	- Forecast arrives at the wrong time, to the wrong people, or is unexpected. - Forecast is not repetitively communicated.	Cash and Buizer (2005), Dilley (2000), Soares (2018), Patt and Gwata (2002)
Understandability	- Forecast is confusing, or not well communicated. - Forecast is not given in an appropriate format.	Bruno Soares (2018), Patt and Gwata (2002)
Credibility	- Communicator or source is not trusted. - Forecast is superseding local knowledge. - Previous forecasts perceived as being wrong.	Bruno Soares (2018), Cash and Buizer (2005), Lemos et al. (2012), Patt and Gwata (2002)

Application

For forecast information to be applied in agricultural decision-making, the forecast should meet certain conditions that deal with the applicability in their farming practices. One of the requirements can be the timing at which forecasts are received. It can determine whether forecast information may align with important agricultural decision-making points (Hill & Mjelde, 2002). It is also argued that providing forecasts into categories that are tailored to specific decisions surrounding their agricultural strategies (ridge making, crop choice etc), can increase the value of the forecast (Bruno Soares, 2018). Furthermore, the type of parameters included within the forecast information also plays a role in determining their value. For example, the spatial and temporal resolution should be locally relevant (scale) and the types of weather parameters predicted (e.g., distribution of rainfall throughout the season, rainfall onset, other parameters like temperature and wind) are key to determining the value of the forecasts for decision-making (Bruno Soares et al., 2018). In the design and production of a forecast, these factors should already be considered.

Procedure

The institutional design of a drought information system can play an important role in influencing the information flow and the uptake of forecast information into decision-making (Orlove & Tosteson, 1999). The institutional linkages in the system should be developed and sustained to ensure an effective communication of forecast information (Dilley, 2000). In turn, sustainable resources play an important role in sustaining those linkages (Bruno Soares et al., 2018).

Patt & Gwata (2002) argue that “it is through repetitive communication that forecasters and farmers learn about each other’s methods, such as who makes decisions, what decisions they make, and through what channels information arrives”. The forecast should be given at the right timing, to the right people in a well-thought-through procedure.

Understandability

If users do not understand forecast information, they may use it incorrectly or not at all (Patt & Gwata, 2002). The meaning of a probabilistic forecast may be a difficult concept to understand and may pose a barrier in the interpretation and uptake of forecasts. Therefore, the way in which probabilistic forecasts are formatted, packaged and communicated matters (Bruno Soares et al., 2018). For example, as Patt and Gwata (2002) describe, a seasonal forecast is often packaged in two halves; from October to December and from January to March. Farmers could interpret this as meaning that there would be two distinct growing seasons.

Credibility

Decision-makers, in this case the smallholder farmers, may be sceptical about the credibility of forecasts the accuracy is not high enough or not well communicated (Hill & Mjelde, 2002). When farmers do not understand the scientific methods used the trust in the forecast may decrease. Especially if they see the forecast as conflicting local knowledge on weather predictions (Lemos et al., 2012). Communicators could gain trust by presenting the official forecast in tandem forecast derived from local knowledge (Patt & Gwata, 2002).

It is argued that the users of forecast information are more likely to trust the information if it comes from sources with which they have existing relationships or already trust (Bruno Soares et al., 2018; Lemos et al., 2012). It is unlikely that communicators are trusted it the users perceive the communicator as having been wrong in the past, unless there is also an existing reputation of being right. The reputation of the communicators can arise not arise not only from personal experience but also from institutional norms when users question the agenda of the communicators. (Patt & Gwata, 2002)

2.4 Forecasting Drought for Agricultural Purposes

In this section, some background will be given in underlying processes in the making of seasonal forecasts and how current seasonal forecasts are performing. Additionally, two approaches on how technical and local knowledge forecasts can be integrated are explained.

Some terms are used throughout this research that is related to the forecasting model:

Lead time: the time between the forecast release and the observed event (drought).

Skill: the measure of how well/accurate a forecast can predict an observed event (drought).

2.4.1 Technical Production of Seasonal forecasts in Malawi

Currently, drought predictions are often a combination of both dynamical and statistical approaches. (Hao et al., 2017). Statistical approaches are mostly based on historical records in which empirical relations are found. Here, the underlying physical mechanisms are not considered. Dynamical approaches are based on those mechanisms which may include processes of e.g. the atmosphere and oceans. Currently, most seasonal forecasts rely on the El Niño Southern Oscillation (ENSO) phenomenon which is explained in section 2.2.2. ENSO can often predict its arrival many seasons in advance of its strongest impacts on weather and climate. Coarse resolutions are often a limitation in seasonal forecasts which may lead to extra procedures such as downscaling, in which the model may be coupled with statistical approaches. (Hao et al., 2017)

African countries often produce their seasonal forecast based on a Regional Climate Outlook Forum, organized by the World Meteorological Organization (WMO). Malawi is part of the South African Regional Climate Outlook Forum (SARCOF). Hyvärinen et al., (2015) found that the probabilistic seasonal precipitation forecast issued by SARCOF has limited skill. It should be noted, however, that this study was done with a dataset of ten years only. Johnston et al., (2004) have assessed the seasonal forecast in Southern Africa and mention that research effort should focus on increasing skill and utility on specific needs of the users.

2.4.2 Integration with Local Knowledge

There is an opportunity to improve seasonal climate forecasting by embracing both the strengths and weakness of the local knowledge and the technical forecasting system. Plotz et al. (2017) argue that it would improve the overall understanding of the problem and potentially produce forecast products that are based on collaborative relationships. The forecast produced would be better suited and understood by local users, thereby increasing overall climate resilience. Plotz et al, (2017) have classified the methods for combining information from local knowledge forecast with those from technical forecasts into two broad categories; labelled as the 'consensus' and the 'science integration' approach as visualised in Figure 5.

The consensus approach includes meetings of experts, usually representatives from the local community group that hold the local knowledge and representatives from the National Meteorological Service (NMS). Together, they discuss their respective forecasts for the coming period and form an agreed (consensus) forecast. Another form of the consensus approach is through the use of local committees who adapt the information provided by National Meteorological Service and local knowledge experts before providing an agreed forecast that is communicated by local radio and/or agricultural extension officers. Plotz et al, (2017)

In the second approach, the local knowledge forecast is formally combined with statistical or dynamical weather or climate models. In this approach, the meteorological-related indicators derived from local knowledge are monitored. Science integration approaches that involve the community and meteorologists in forecasting have been practised in Africa (Plotz et al, 2007). Waiswa et al., (2007) showed that for a dataset of twelve years a strong relationship could be found for the temperature indicator derived from local knowledge and the onset of rains. However, using local knowledge indicators and long-term historical records to integrate forecast systems remains unreported in literature. Plotz et al, (2017)

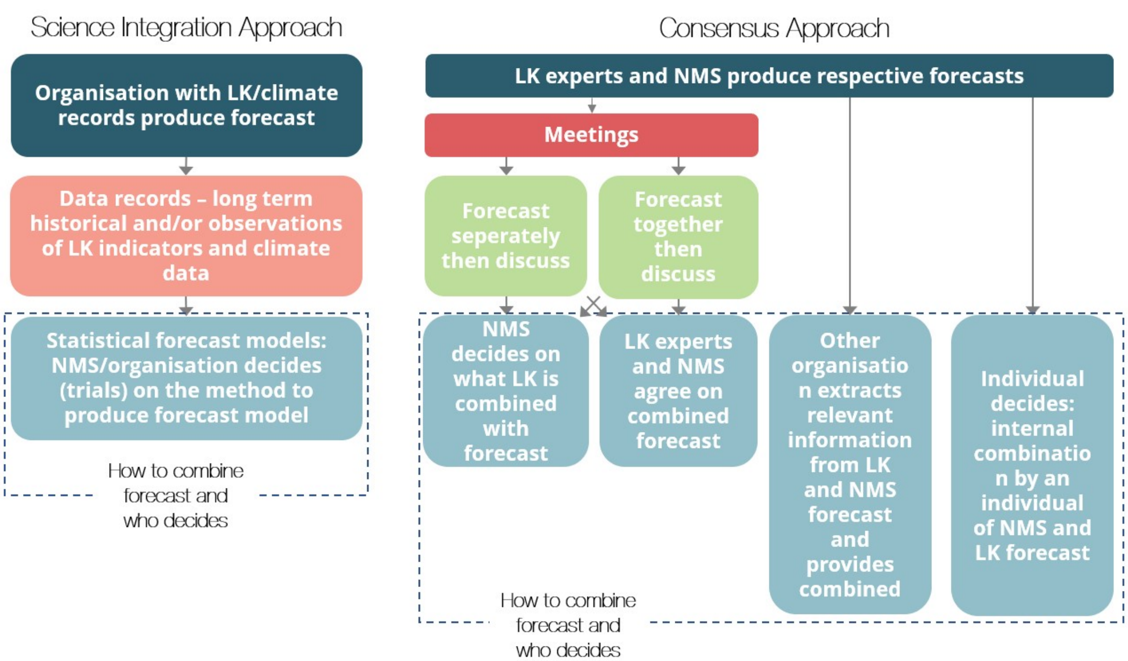

Figure 5: Two Approaches for including Local Knowledge in Forecasts: Science Integration and Consensus Approach. Adapted from Plotz et al. (2017).

3 | Methodology

In this chapter, the methodology is explained by first introducing the context and background of the case study sites, and then describing the methods used to answer the three main questions (see section 1.2). The study was conducted in three phases, of which the first two were during a stay of three months in Malawi. During the first phase, participatory approaches explored the smallholder farmers definitions of drought, the available drought strategies, local knowledge, the current receival of drought information and what could be improved in that process. In the second phase, the current drought information system is explored through key informant interviews throughout differed sectors and administrative levels. In the last phase, an approach of forecasting through meteorological indicators based on local knowledge is explored which could potentially forecast drought indicators that are valuable for the farmers (as explored in the first phase) and improve the current drought information system (as explored in the second phase).

3.1 Background Malawi

Malawi is a country landlocked by Mozambique, Zambia and Tanzania with a population of almost 20 million of which 83% lives in rural areas (World Bank, 2017). Its population size is projected to be more than doubled by 2050, while currently, 71 % of the population lives under the poverty line of PPP which is $1.90 a day (Alkire & Jahan, 2018). Malawi is ranked as 107 out of 113 countries in the 2018 Global Food Security Index. The population density, elevation and poverty index across Malawi is shown in Figure 6.

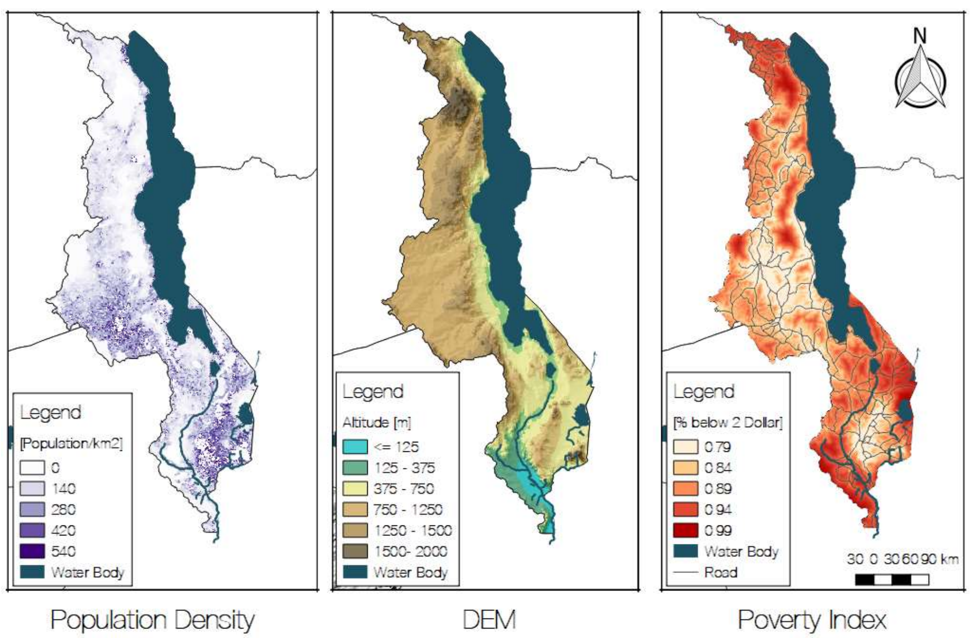

Figure 6: Population Density[2], Digital Elevation Model (DEM)[3], Poverty Index[4] (Percentage of the Population under the 2 Dollar Poverty Line)

[2] Population Density: https://data.humdata.org/dataset/highresolutionpopulationdensitymaps

[3] Digital Elevation Model: http://opendata.rcmrd.org/datasets/malawi-srtm-dem-30meters

[4] Poverty Index: Tatem AJ, Gething PW, Bhatt S, Weiss D and Pezzulo C (2013) Pilot high resolution poverty maps, University of Southampton/Oxford. DOI:10.5258/SOTON/WP00157

3.1.1 Climate

Malawi has a sub-tropical climate which relatively dry and strongly seasonal. The Department of Climate Change and Meteorological Services (DCCMS) has meteorologically divided Malawi into five zones: Northern Areas, Central Areas, Lakeshore Areas, the Southern Highlands and the Shire Valley (Figure 7). For the seasonal forecasting, DCCMS has divided Malawi into two parts; the northern and southern half of the country which are influenced differently by ENSO.

The distribution of annual rainfall and mean minimum and maximum temperatures for Malawi is shown in Figure 7. 95% of the annual rainfall falls within the period of November to April which is the rainy season of Malawi. From May to August a cool, dry winter season is evident with mean maximum temperatures varying between 17 and 27 °C and minimum temperatures falling between 4 and 10 °C. A hot, dry season lasts from September to October with mean maximum temperatures varying between 25 and 37 °C.

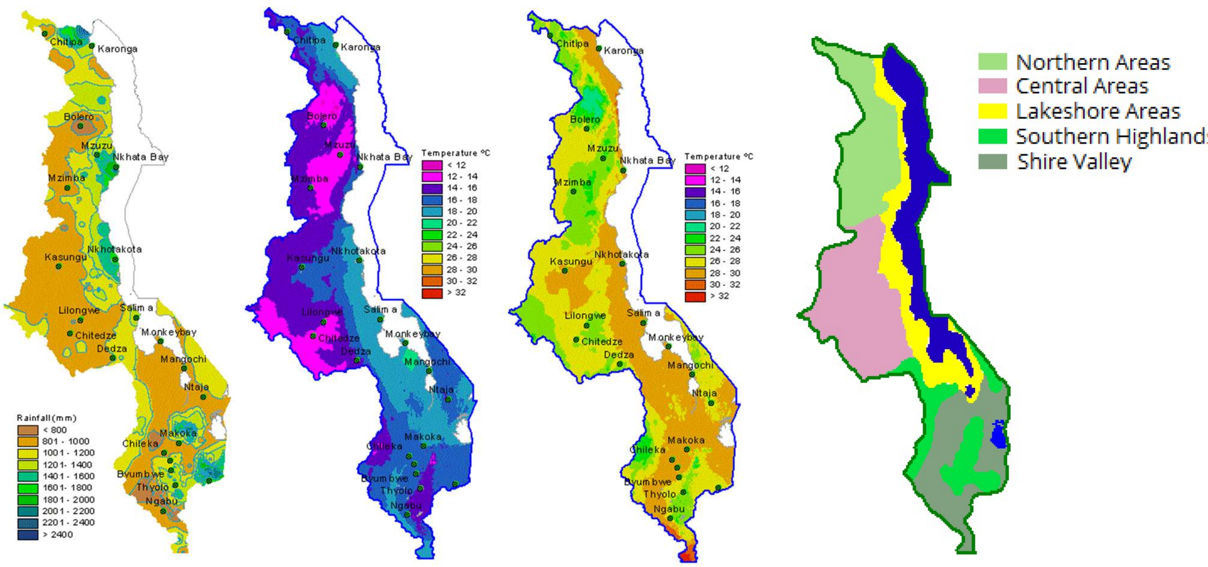

Figure 7: Annual Rainfall, Minimum & Maximum Temperature (DCCMS, n.a.)

The people of Malawi have established names for certain types of winds:

Chiperoni: "Malawian name for the influx of cool moist air from the south-east, bringing overcast conditions with drizzle on windward slopes along the Northern lakeshore and in particular to many areas in the South of Malawi. This phenomenon can persist for up to a week but the usual duration is two to three days." (DCCMS., n.a.)

Mwera: "Strong South Eastern ly winds occur immediately before and occasionally during a Chiperoni outbreak. Lake Malawi is particularly affected by the Mwera due to the flat and obstruction free nature of its surface, allowing winds of considerable strength to develop. The onset of a Mwera can be quite sudden causing a rapid deterioration in the condition of the late itself." (DCCMS., n.a.)

3.1.2 Cropping season

As mentioned, the rainy season is from November to April, in which 95 % of the annual rain falls. This means that no rainfed-agriculture takes place in the dry season and people are predominantly reliant on the rainy season for their crop production. Maize is the is staple crop of the Malawian population. Figure 8 shows the growing stages of the maize crop, together with the dry and rainy season. The crop stages include sowing, growing and harvesting.

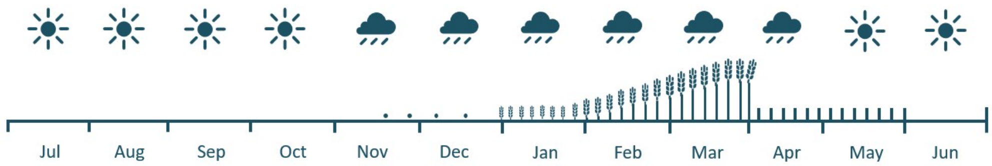

Figure 8: Crop Calendar of Malawi (Rainfed). Adapted from Panis (2019).

3.1.3 Disasters

Malawi is often faced with natural disasters, where drought and floods are among the most severe ones, as observed in Table 3. Increases in temperature and erratic rainfall due to a changing climate cause more frequent and intense droughts, flood and severe weather, which in turn disrupt lives and livelihoods among Malawi most vulnerable communities (DoDMA, 2015). In April 2016, the President of Malawi declared a state of national disaster. About one third of Malawi's population was at that time reported to be in need of humanitarian assistance to help them cope with the food shortages. This emergency occurred due to prolonged dry spells during the 2015/16 season, which greatly affected the crop production (IFRC, 2016).

Table 3: Past Disasters in terms of the total of people affected in Malawi from 1980 to Present (EM-DAT)

Type	Date	Total affected (x10000)
Drought	April 1992	700
Drought	October 2015	670
Drought	October 2005	510
Drought	February 2002	283
Drought	February 1990	280
Drought	August 2012	190
Drought	1987	143
Flood	4-3-2019	98
Flood	1-1-2015	64
Drought	October 2007	52

3.1.4 Administrative levels

Malawi is divided into multiple administrative levels within the government departments which can be seen in Figure 9. Those structures are used throughout the rest of the research, especially in Chapter 5. For the 'Disaster' line, DoDMA stands for the Disaster of Disaster Management Affairs and CPC stand for Civil Protection Committee.

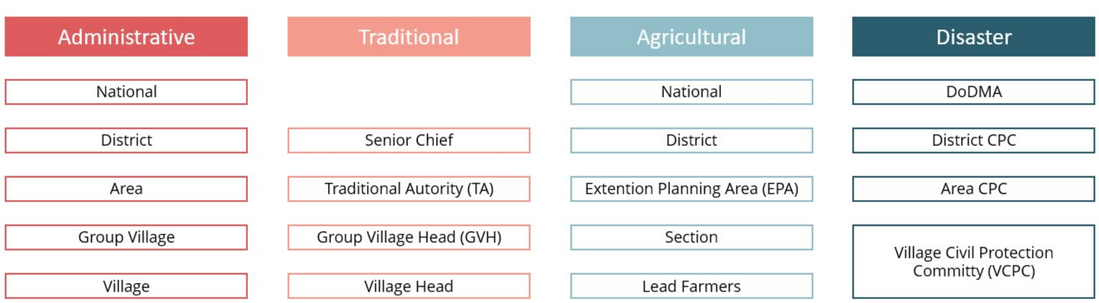

Figure 9: Administrative Levels in Malawi

3.1.5 Research Areas

The research locations coincide with the ones of the NERC SHEAR IPACE project. Three districts in central and south Malawi are selected and indicated by red in the map on the right; Salima, Mangochi and Zomba. These districts are chosen because of its proneness to hazards, its food security risk and the ongoing projects from the World Food Programme (WFP) and Malawi Red Cross Society (MRCS). It is done in consultations with relevant organisations.

The research locations are so-called Extension Planning Areas (EPAs) and chosen due to their close location to the weather stations and which can be seen in Figure 10.

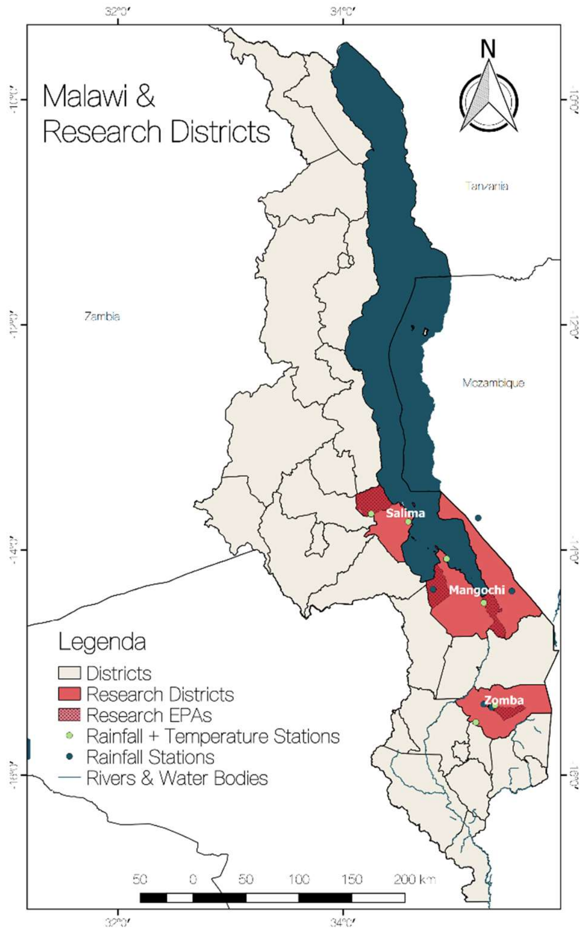

Figure 10: Malawi and Research Districts

3.2 Smallholder Farmers: Agricultural Strategies, Local Knowledge and Forecast Information

The methods for answering the first research question is explained in this section. The aim of the methodology was to get a better understanding of the farmers agricultural strategies, local knowledge and received forecast information. To do so, a local understanding of the smallholders is important, and a fieldwork trip has been conducted. Section 3.2.1 described the two methods that are used during the fieldwork, 1) Focus Group Discussions (FGDs) that included a seasonal calendar and an interview protocol and 2) a sorting exercise. Section 3.2.2 describes how the collected data is analysed. The data collected in FGDs was analysed by thematic analysis and data collected in the sorting exercise was analysed by means of ranking. It is expected that the outcomes of the methods can lead to 'requirements' that forecast information should meet to be applicable to the farmer's agricultural decision-making and existing local knowledge on drought predictions. Additionally, the methodology should lead to an assessment of what the strengths and weaknesses are of the currently received forecast information.

3.2.1 Data collection

The first data collection in Malawi has been held in collaboration with the NERC SHEAR IPACE project in the three districts. A detailed description of the data collection program can be found in Appendix A. In the program, a protocol is included that provides a detailed description of what information should be recorded for every interview to ensure consistent data quality (Tong & Craig, 2007). In the FGDs, the groups can be composed of both male and female and should involve between five and ten participants. Ideally, elderly people within the community are to be included. It should be the case that those invited feel at ease with each other and that they have a similar level of readiness or capacity to talk. The facilitator followed the protocol and recorded the FGD. The facilitator (m) has a journalistic background and had no previous contact with the farmers. During the FGD the facilitator mentioned key words of answers which were written on the seasonal calendars by the researchers. After the FGDs, a photo of the seasonal calendars is made, and the recordings are transcribed word by word.

The second data collection was done in collaboration with MRCS office in Zomba. The data collection program can be found in Appendix B. The facilitator was an employee of MRCS and was already familiar with the participants. During the sorting exercises, the facilitators mentioned key words of answers of the participants that were included in the exercise. After the sorting exercise, a photo was taken of the outcome. It should be noted the presence of both the Red Cross and my own presence could influence the data collection quality. Farmers may associate the Red Cross as a donor and could influence their interpretation of the questions and answers given.

The first data collection program was held in all three research districts. Districts are separated in different Extension Planning Areas (EPAs). The EPAs are chosen due to the close distance from the weather stations. Per EPA two FGDs and an interview with the two AEDOs are held who are responsible for the respective farmers. In Salima, there is one EPA named Khombedza chosen as research EPA. In Mangochi, there are three research EPAs; Nankumba, Mbwadzulu and Maiwa. And in Zomba, there is one research area chosen named Mpokwa.

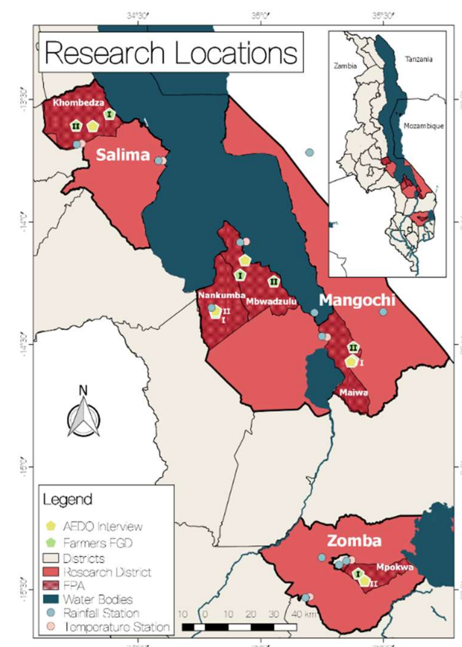

Figure 11: Research Locations

The research location of the second data collection was district Zomba, in the same EPA as the first data collection trip; Mpokwa. This research location is selected due to logistical reasons. See Figure 11 for an overview of the districts and EPAs, the exact research locations and weather stations.

Seasonal Calendar

In Focus Group Discussions (FGDs) two seasonal calendars were made. A seasonal calendar is a participatory tool to explore seasonal changes throughout the year. Ten FGDs were scheduled and conducted by a local radio journalist in the local language Chichewa. The discussions were recorded and translated into English. Some general information on the farmers was gathered to ensure good and structured data quality. This included their gender, farm plot size, purpose of farming, crops grown and yield.

Figure 12: Seasonal Calendar in FGD

The first sheet included four themes: agricultural practices and the weather and field observations in 'good' and 'bad' conditions for agricultural practices. Also, the non-climatic risks were included. An example of the setting of a FGD during the first sheet can be seen in Figure 12.

In the second sheet, the farmers were asked to indicate an extreme year. For that particular year, the agricultural practices, weather and field conditions were described. The output of the FGDs are in the remainder of this research describes as 'the described events'.

Protocol

In the FGDs, questions are asked about weather and climate information that they receive. The protocol included questions what 'dimensions' of forecast information is valued and what could be improved. Example of these 'dimensions' can be the communicator, format and spatial scale of the received forecast information. The answers to the questions can lead to an assessment of what forecast information is preferred and whether the current receival of forecast information can be improved. In addition, questions on local knowledge were included about what observations in the environment could be seen to suggest a certain weather phenomenon. The interviews were conducted by means of a pre-defined protocol, see Appendix A, to ensure consistency in the answers and enable a structured analysis.

Sorting

Sorting is a qualitative method that helps in the determination of the relative priorities, given a certain topic. After an analysis of the findings of the first fieldwork, three topics have been established in which further research was useful to determine the relative importance within these topics. The three topics established are: 'drought' seasons, agricultural decisions and forecast information. The process of the exercise is as follows, and is separately done for every topic:

1. The participants were asked a question related to the topic, to create the cards. For example; "what decisions do you have to make in the field when a drought is expected?". The cards were already pre-made, based on the findings of the first fieldwork, and translated to the local language, Chichewa. This was done to shorten the time span of the exercise. Answers which were not pre-made were written and translated during the exercise itself.

2. After the answers were collected, the participants were asked to sort the answers to one of the three topics.
3. On every topic, the reasoning of why the participants have ranked the way they did, and 'characteristics' of the answers were mentioned. For example, the 'critical events' of the rainfall pattern in the drought years, when the agricultural decisions are being made in the year and what makes forecast information useful.

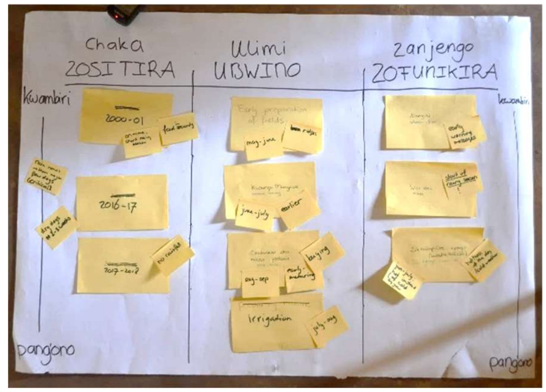

Figure 13: Sorting Exercise

3.2.2 Analysis

The seasonal calendar and semi-structured interviews are analysed with the thematic analysis and the sorting exercise is analysed by means of ranking.

Thematic Analysis

The seasonal calendar and interviews were analysed through thematic analysis. Thematic analysis is a qualitative research method and required to analyse and interpret the output of the interviews. The steps taken in the thematic analysis are described below.

The seasonal calendars were digitized, and the interviews were transcribed by the facilitator and read through by the researcher to familiarize with the answers. Both the calendars and interviews were coded and collected in a database to perform the analysis on. The codes were then categorized in themes that best fitted the collection of codes. Different themes for climatic influences, agricultural practices and local knowledge were created. Though the themes, the codes could be counted and interpreted.

A specific form of thematic analysis is used to analyse the interviews concerning the received forecast information. This type of analysis is called the template technique (King, 1998). Hereby, the technique makes use of a predefined template that guides the analysis. The template used in this analysis encompasses the six barriers in the uptake of forecast information by smallholder farmers in Zimbabwe, by Patt et al. (2002), which represents the given context best. If they are encompassed by one of the themes/categories, the code is attached to the theme. If the codes do not fit in one of the themes, additional themes are to be created or removes. Eventually, four themes have been established which are explained in more detail in section 2.3.1. The codes which have the same meaning are grouped to one keyword. The number of codes which are present in one keyword is counted and a quote which best represents the keyword best is highlighted. Finally, the findings can be interpreted with the help of the categories.

Ranking

The ranking method is applied to analyse the output of the sorting exercise and to give relative importance of the answers given. This can then be further used in the establishment of 'requirements' that forecast information should meet.

Here, the sorting sheets were digitized, and a ranking analysis was done. For every topic, each answer was given a score. Scores of one to four were given, depending on the ranking. If an answer was ranked first, the highest score of four was given. Ultimately, the scores were summed, and the answers were ranked; the higher the score, the higher the ranking.

3.3 Current Drought Information System

Within the study, a method was needed to evaluate, explore and understand the current drought information system. In brief, data was gathered through key informant interviews, for which two protocols have been designed. A flow chart that is based on the output of the interviews is created to assist in the visualisation of the drought information system. Through the template technique, the interviews are analysed to understand the strength and weakness of the current drought information. These methods are further elaborated in the remainder of this section.

3.3.1 Key Information Interviews

Semi-structured interviews with key informants have been held on national and district level to follow the information process. Two types of protocols for the interviews were made; one for stakeholders mostly working with general forecast information and one for stakeholders who are focussed on extreme forecast information. The protocols are designed in such a way that the output of the questions are the input for the flowchart and are objectively formulated. Most questions are in an objective form; "*From who do you receive information*?", "*When do you receive information?*" etc. In this way, little room is given for own interpretation of the farmers.

In the protocols, additional questions have been made that are input for the identification of the strengths and weaknesses of the drought information system. These questions are sensitive for own interpretation and thus reliant on the key informant. This stresses the importance of interviewing the 'right' person who has insights into the process. Table 4 gives an overview of the interviews with the abbreviation of the actors that are interviewed.

Table 4: Overview of the Key Informant Interviews

Interview	#	Protocol (Method)	Information Channel	Administrative Level(s)	Objective
DoDMA	2	Extreme (semi-structured)	Disaster	National, District	Dissemination process
MoAIWD	1	Extreme (semi-structured)	Extension	National	Dissemination process
DCCMS	3	Extreme & General (semi-structured)	Source	National, District	Dissemination process + Forecast Production
FRT	1	General (semi-structured)	Media	National	Dissemination process
LUANAR	1	General (semi-structured)	Source	National	Forecast Production
DAES	1	General (semi-structured)	Extension	National	Dissemination process
MRCS	2	Extreme (semi-structured)	MRCS	National, District	Dissemination process
NASFAM	1	General (semi-structured)	Extension	National	Dissemination process
DoDMA/DCPC	1	Extreme (semi-structured)	Disaster	District	Dissemination process
AEDO/AEDEC	5	General (semi-structured)	Extension	Area	Dissemination process
ACPC/VCPC	2	Extreme (semi-structured)	Disaster	Area, Local	Dissemination process

3.3.2 Analysis

The interviews have been analysed by, firstly, transcribing the interviews word by word. These interviews were held in English and the could be transcribed without the help of a translator. Two types of analysis have been performed; a so-called template technique that is based on pre-defined themes in section 2.3.4 and the creation of a flow chart of the dissemination structure. The results are interpreted after which the understanding of the current drought information systems with its strengths and weakness is created.

Thematic Analysis: Template Technique

A template technique refers to a particular way of thematically analyse qualitative data (King, 1998). To prepare for the analysis, all interviews are transcribed word by word and are read through to familiarize with the answers. The same procedure of analysis is used and described in section 3.2.2 and is therefore not repeated.

Visualisation: Flow Chart

Through visualisation, the 'flow' of forecast information can be better understood. The output of the interviews acts as the input of the visualisation. The interview protocols were made in such a way that the visualisation can be done more easily. The protocols were divided into a receiver or provider of information. During the interviews, initial maps were made to visualise and get an initial understanding of the forecast information received and passed on by the actor. The initial maps were overlaid, analysed and all interviews were transcribed. Based on the answers of the questions the mapping could be finalised and finished into detail. By means of a brainstorm process different symbols, colours, patterns, nodes were established to create a map and categorization. The visualisation process was inspired by an article by Ziervogel (2008): *Stakeholder networks: improving seasonal climate forecasts.* If a party did not get a certain type of information, it was not included in the mapping. This was done to keep the visualisation simpler to read.

3.4 Predictive Value of Local Knowledge for Forecasting Drought Information

The aim of the method is to develop a forecast model based on local knowledge and analyse whether this has predictive value and could potentially support agricultural decisions. A prerequisite to developing this is to understand current farming practices and forecast production. Therefore, the results of the previous two method sections are essential to be able to address this. From Chapter 4 it was found that farmers would like to receive the following drought forecast information, see Table 5. It should be noted that the required lead time is an indication of how many months the forecast should be received before the drought occurs. The occurrence of the numerous dry spells, for instance, can vary from the onset of the rains, around November, to February.

Table 5: Drought Forecast Information Specifics

Drought Indicator	Timing of Onset of Rain	'Dryness' of rainy season / Dry spells
Timing	August and November	September
Required Lead Time	~ 4 months and 1/2 month	~ 3 months
Spatial resolution	EPA	EPA
Supporting Decision	Timing of Land Preparations and Planting	Type of Ridges and Seed/Crop Selection

A schematic overview of the steps that are taken is provided in Figure 14, the numbers correspond with the order of the upcoming sections. The aim of the methodology proposed, is to forecast the drought indicators with meteorological indicators derived from local knowledge. Here, both the drought indicators and meteorological indicators should be computed on a yearly basis and combined in a model. With the use of the model the predictive value can be analysed. Some steps are made in this process and shortly addressed.

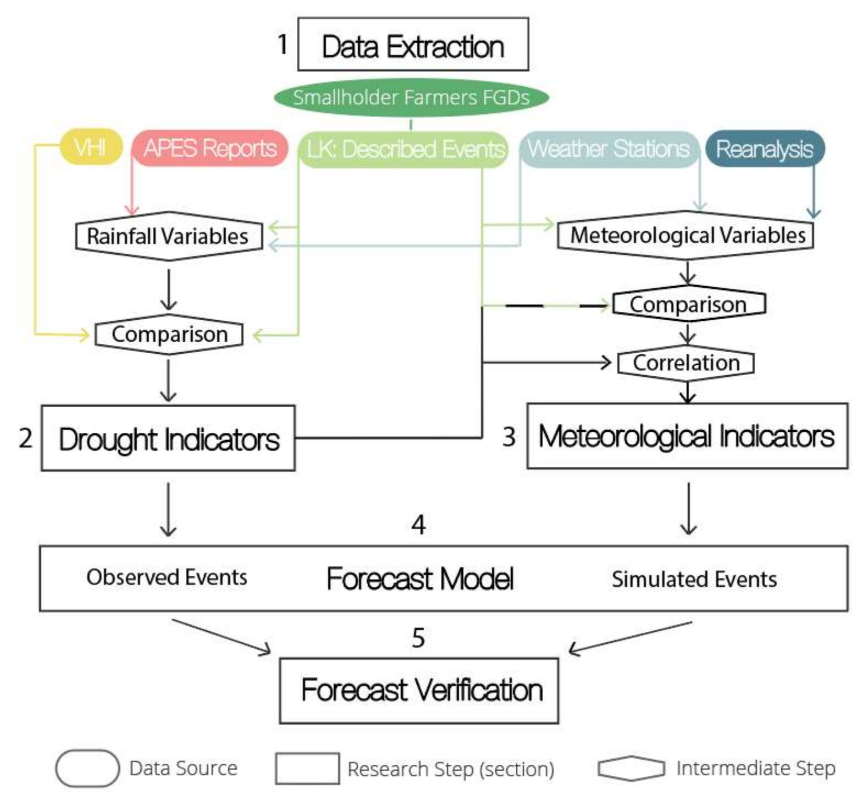

Figure 14: Flow Diagram of Steps taken in the Production and Assessment of the Forecast Model based on Local Knowledge

Firstly, the relevant data is extracted to compute the drought and meteorological indicators. The data includes observation data of weather stations, ERA 5 reanalysis data, described drought events by the farmers, VHI and Agricultural (APES) reports. Secondly, drought indicators are derived through the computation of rainfall variables and, subsequently, compared with described drought events and VHI data. This leads to drought indicators that are 'critical' for agricultural strategies, i.e. those drought indicators that farmers are sensitive to. Thirdly, the meteorological indicators are established by visually comparing time series and spatial and temporal visualisations of meteorological variables with the described drought events and computed drought indicators. Through pairwise correlation analysis between the meteorological indicators and the drought indicators, the significant meteorological indicators are selected which are input for the model. In the next step, a model sets a threshold for the drought indicators to form the observed events and combines a set of thresholds for the meteorological indicators to form the simulated events. In the final step, the performance of the forecast model is analysed through verification metrics which compares the observed and simulated events of the model. The steps are described in more detail in the forthcoming sections.

3.4.1 Data extraction

Different types of sources are used in the data extraction. This includes observed data by DCCMS, ERA 5 reanalysis data, agricultural reports from the agricultural department and Vegetation Health Index (VHI) data. The details of the data extraction are described in the following sections. In addition, the data quality of the rainfall weather station is analysed through a spatial correlation method.

Weather Station Data

Through the IPACE project, DCCMS has shared daily rainfall observations for eleven station locations and daily minimum and maximum daily temperature observations of six stations. The locations of the weather stations are shown in Figure 15. A detailed overview of the weather stations and their location, elevation and the time span of the data can be found in Appendix D.

All rainfall datasets and all but two temperature datasets meet the 30-year climatological standard. None of them is shorter than 15 years, which is sometimes used as a requirement to define a minimum duration over which variability in climate may be evaluated (Dunning, 2016).

Outliers in the data were found by plotting the data and finding abnormal values by conditional formatting, after which the typing errors (e.g. 319 ºC => 31.9 ºC) and zero values (0 ºC => Nan) were adjusted to obtain a cleaner data set.

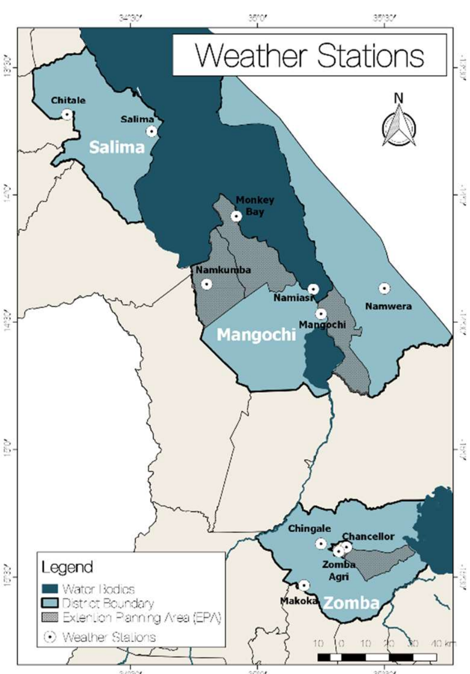

Figure 15: Locations of Weather Stations in the Research Districts

Data Quality | Spatial Correlation

Over the period of 1975 to 2016 the spatial correlation between the rainfall stations is calculated for the rainy season and defined by the correlation coefficient ρ ($0 < \rho < 1$). The analysis will act both as quality control and spatial analysis of the rainfall observation dataset. The correlation coefficient (ρ) is the function of the distance (r) between stations:

$$\rho = \rho_0 \cdot exp\left(-\frac{r}{r_0}\right) \qquad (1)$$

where ρ_0 is a measure for the accuracy of the stations, being the correlation between two stations at zero distance [-] and r_0 is a length scale defining the rate at which the correlation decreases [km] and indicates the distance at which there is no more correlation.

ERA 5 Reanalysis Data

ERA 5 is a climate reanalysis dataset from the European Centre for Medium-Range Weather Forecasts (ECMWF). Dew point temperature, u and w component wind data at 10 pressure levels were obtained from the Copernicus Climate Data Store Toolbox to compute relative humidity, wind speed and direction. The hourly data has a 0.25° x 0.25° resolution and spans from June 1979 to May 2019.

Wind

Wind data is obtained in the form of two vectors u and v in m/s. Hereafter, from the two vector components the wind speed and direction are calculated.

Wind speed is calculated by:

$$|V_{wind}| = \sqrt{u^2 + v^2} \quad (2)$$

The direction is the meteorological wind direction, whereby 0 degrees is north, 90 degrees is East etc. Hereby, u and v component are kept separate until the final step of the wind direction computation:

$$\theta(°) = \frac{180}{\pi} arctan^2(-u, -v) \quad (3)$$

Relative Humidity

Relative humidity (RH) is the ratio of actual vapor pressure (e_a) and the saturation vapor pressure (e_s); derived from the Clausius Clapeyron equations:

$$RH = \frac{e_a}{e_s} \cdot 100\ \% \quad (4)$$

$$e_s = 0.61\ exp\left(\frac{19.9T_{dew}}{273+T_{dew}}\right) \quad (5)$$

$$e_a = 0.61\ exp\left(\frac{19.9T}{273+T}\right) \quad (6)$$

where T_{dew} is the dew point temperature, T the (maximum) air temperature, e_s the saturation vapor pressure and e_a is the actual vapor pressure.

Agricultural Reports

Data of both district agricultural and meteorological office of Zomba has been collected. From the agricultural office, this is the so-called Agricultural Production Estimates (APES) reports from 2011 to 2019 and includes details on the season with the first rains, the onset of effective rains and dry spells.

"The effective planting rains were experienced on 19th December 2014 throughout the district. Most farmers started planting different crops with these rains."

Described Events

Though the seasonal calendar farmers described an extreme event in which they recall the weather and field conditions of a season of choice. The transcriptions of the FGD gives information on local knowledge and the occurrence of dry spells, onset of rain and agricultural practices. This information is linked to weather station and reanalysis data to compute what observed conditions are 'critical' to farmers.

VHI

The computed drought seasons are verified with observed conditions. The verification is done with the VHI dataset which is an index for drought. VHI is a dataset is obtained from the NOAA STAR – Centre for Satellite Application and Research. The weekly data has a 16 x 16 km resolution and spans from 1981 to present.

VHI is an index developed by Kogan (1995) which combines the Vegetation Condition Index (VCI) and the Temperature Condition Index (TCI). VCI is a proxy for soil moisture condition and was designed to separate the weather-related component from the ecological component of NDVI. VCI is scaled by the minimum and maximum of NDVI, while TCI is scaled by the minimum and maximum temperature value of a certain pixel.

VHI data is extracted for the period farmers indicate as 'critical' in the rainy season on the basis of their described events. The drought intensity is based on the VHI values which are below 40, as defined by NOAA STAR. Drought is "Exceptional" if the indices are between 0 and 5; "Extreme" if they are 6-15; "Severe" 16-25; "Moderate" 26-35; "Abnormally dry condition" 35-40. By visualising the dataset, a comparison of 'drought' and 'no drought' season is made that can verify the computed 'dryness' of a season.

3.4.2 Drought Indicators

Several rainy season variables are derived on an annual basis from the weather station observations. The chosen variables are derived from the results of the investigations described in section 4.2. In this section, the methods used to derive the rainy season characteristics are described. In brief, the rainfall variables that are associated with drought are defined based upon the investigations described in section 4.2. Subsequently, the drought indicators, i.e. those that farmers' strategies may be sensitive to (section 4.6), are formed by comparing the rainfall variables with described events by the farmers. These steps are described in more detail below.

Rainfall Variables associated with Drought

From the results of the investigations described in section 4.2, farmers associated drought with a number of rainfall variables: little rainy days (number of rainy days), little rainfall (total rainfall), many dry spells (number of dry spells), a late onset (timing of onset), and short rainy season (length of rainy season). First, these rainfall variables are defined before they are formed to drought indicators that are useful for agricultural decision-making.

Defining those rainfall variables is a very important process since it can influence the conclusions made. Methods for the analysis of the variables of the rainy season should carefully be considered. For instance, the rainy season stretches from November to March and thus straddles calendar years. As such, in the computation of the data, this should be taken into consideration.

A method by Liebmann and Marengo (2001) is used to distinguish the rainy season from the dry season; to eventually calculate the **length of the rainy season**. This method has shown good results in African countries (Camberlin et al., 2009; Boyard-Micheau et al., 2013).

The original formula of this method is transformed in order to use it for a particular season and is defined as follows:

$$C(d) = \sum_{i=Jan\ 1st}^{d} R_i - \bar{R} \quad (7)$$

Where *C* is the cumulative daily rainfall anomaly for a particular day *(d)* for an individual season, calculated by summing the difference between the daily precipitation *(R_i)* and the mean precipitation of that season *($\bar{R}$)* from June to July the following year. The onset of the rainy season is defined as the day on which the minimum of *C(d)* is reached; the rainy season begins at the point after which the daily rainfall exceeds the mean rainfall. The end is defined as the day on which the maximum of *C(d)* is reached; the day on which the daily rainfall drops below the mean rainfall. The length is the difference between the onset and end of the rainy season and expressed as the number of days.

The onset of the rainy season that has been defined above, does not necessarily coincide with the 'agricultural onset'. The 'agricultural onset' is related to the effective planting onset, whereby the onset of rain is not followed by a dry spell so that the seeds can germinate (Kniveton et al., 2009). The most common method of defining the effective onset across Africa is described in Stern et al. (1982), whereby a precipitation threshold measured over a set amount of days must be exceeded, and not followed by a specified number of cumulative dry days (dry spell) over a predetermined period after this initial rainfall event. The definition needs to be tailor-fit and localised. The method described by Stern et al. (1982) is used in this research and was done through an iterative process that evaluated the computed onset of rain with the agricultural reports and the described event of the farmers. The **effective planting onset** of the rainy season was then defined as a period of three days that exceeded the threshold of more than 25 mm. Also, in the next five days, an accumulated rainfall of 10 mm must have fallen as well, meaning there must be no dry spell in the next 5 days. This date was then converted to the number of days from the 1st of October. This was done for every station, after which the (Thiessen) weighted average is taken for every district.

The onset dates of the rainfall stations 'Makoka' in Dzaone EPA, 'Chingale' in Chingale EPA and 'Zomba Agriculture' in Thondwe EPA were compared by APES reports from 2010/11 – 2018/19 of the Ministry of Agriculture in Zomba, which stated the onset dates in different EPA's of Zomba district.

The **number of rainy days** was defined as the sum of the number of rainy days in a particular season. A rainy day was defined as a day that exceeded a rainfall threshold value of 2 mm. This value considers hydrological processes like interception and evaporation (Savenije, 2004). It is compared by APES reports of the Ministry of Agriculture in Zomba, which also states the number of rainy days per season for Zomba district. For every station, the number of rainy days is calculated, after which the (Thiessen) weighted average is taken for every district.

For every station, the **total rainfall** is calculated, by summing up all rainfall in the rainy season. Subsequently, the (Thiessen) weighted average is taken for every district.

A **dry spell** is the cumulative number of days without rain (less than 2 mm). The **number of dry spells** is defined as the number of times the threshold (number of days) of a dry spell is reached in the period between the onset of rain defined in the length of the season and the end of February.

These rainfall variables established by comparing, APES reports, the transcripts of the FGDs and the time series. It is done in an iterative process whereby this comparison is made continuously. A summary of the rainfall variables defined above is given in Table 6.

Table 6: Summary of Defined Rainfall Variables

Rainfall Variable	Definition
Length of rainfall season	The difference in days between the onset and end of the rainy season, as defined by Liebmann and Marengo (2001)
Effective Planting Onset	A period of three days that exceeded the threshold of more than 25 mm, not be followed by a dry spell in the next 5 days
Number of Rainy Days	The sum of the number of rainy days. A rainy day is defined as a day that exceeds a rainfall threshold value of 2 mm
Total Rainfall	The sum of all rainfall in the rainy season
Dry Spells	The cumulative number of days without rain (less than 2 mm).

From Rainfall Variables to Drought Indicators

The rainfall variables are formed to drought indicators by comparing them to the described events of farmers. Here, the drought indicators are formed by setting 'critical thresholds' based on the comparison made. In section 4.6 it was found that the timing of the onset of rain and an overall indication of the dryness of the rainy season can inform agricultural strategies. It was also observed that dry spells in the rainy season can be critical for the farmer's crop production. Therefore, the number of dry spells is taken as an indicator for the dryness of the season. The dryness of the season is also expressed as a composite measure of the rainfall variables associated with drought. Here, the computation of the drought indicators is elaborated upon.

Timing of Onset

The timing of onset is defined as the date of the effective onset of the rainy season. The effective onset is defined in the previous section and computed on a yearly basis for every rainfall station. A comparison is made between the computed effective onset of rain and the described events of the farmers to set a threshold for a 'late' onset of rain. The comparison is made with the closest station in relation to the location of the farmer's group.

Number of Dry Spells

Dry spell information is defined are the number of dry spells as defined in the previous section and computed for every rainfall station on a yearly basis. The number of dry spells can give an indication of the overall state of the season. By comparing the dry spells of the closest station with the described event of the farmers, the number of dry spells (of a certain length) that is critical for agricultural practices is explored.

Dryness of Rainy Season

One quantitative measure is computed to give an overall indication of the dryness of the rainy season which could indicate extreme droughts for the district. Many types of 'Drought Indices' are developed for different purposes and sectors. It could be based on rainfall, hydrological measures (river depth, streamflow), vegetation quality or temperature data (Bayissa, 2018). It this research, no existing drought index is used. Instead, the interpretations of the farmers are used to compute the overall dryness of the rainy season. To do so, an interpolation technique is used to compute station data to district data. Additionally, the farmer's description of a 'dry rainy season' is used to combine into a 'drought index' through the Principle Component Analysis (PCA). The extremes of the drought index are compared to VHI data and thresholds are set to define an extreme drought. The exact computation is described stepwise below.

<u>Interpolation Technique</u>

To compute the dryness of the rainy season at district level for the three districts, the Thiessen Polygons interpolation method is used to compute a regional estimate; lines are drawn to connect the observation point, including those just outside of the district. The connecting lines are bisected perpendicularly to form a polygon around each point. The value of the observation point is assumed valid for the whole of the area of the polygon.

If there are n stations within a region with rainfall values P_1, $P_2 \dots P_n$ and areas A_1, $A_2 \dots A_n$ of the respective Thiessen polygons, the average rainfall over the region P is computed as:

$$P = \sum_1^n P_i \frac{A_i}{A} \qquad (8)$$

$\frac{A_i}{A}$ is called the weighing factor.

Principle Component Analysis

The goal is to express the quality of the season in one quantitative measure, combining the terms of the above-mentioned rainfall variables to a 'dryness' for every district; the 'Drought Index'.

Through findings of section 4.2, farmers describe a dry season as little rainfall (total rainfall), few numbers of rainy days (number of rainy days), a lot of dry spells (number of dry spells), a short season (length of season) and a late onset (date of onset). To what extent those components are related to one another and how the 'dryness' of a rainy season can be quantitively expressed, is explored with the Principle Component Analysis.

PCA is a statistical procedure that uses an orthogonal transformation to convert a set of observations of possibly correlated variables into a set of values of linearly uncorrelated variables called principal components (Wold et al, 1987). The drought index of a season can then be expressed in the different principle components:

$$Drought\ Index = \alpha \cdot Rainy\ Days + \beta \cdot Total\ Rain + \gamma \cdot Length\ Season + \delta \cdot Effective\ Onset + \varepsilon \cdot Number\ of\ Dry\ Spells \quad (9)$$

All the five variables that are analysed in the PCA are first (inverse) normalized, 1 being 'Drought' 0 being 'No Drought': number of rainy days (inverse), total rainfall (inverse), length (inverse), number of dry spells (normal) and the effective onset (normal).

The PCA analysis can be verified by the Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy which indicates the usability of a PCA analysis on this dataset (1 = perfect). Also, it is indicated what percentage of the total variance the principal component explains.

Comparison with VHI

The resulting 'Drought Index' for every district is compared with the farmer's interpretations of a 'bad' and 'good' crop conditions. The typical timings that distinguish 'good' and 'bad crop conditions are taken as the timeframe for which the VHI data is obtained. In this way, it can be verified whether the 'Drought' and 'No Drought' are in accordance with the VHI data.

Since there is no historical data available on the decision-making of the farmers in relation to, for instance, making box ridges and buying drought-tolerant seeds and whether that was the right or wrong decision, the drought index could not be linked to the farmers. For that reason, different percentiles of the drought index were computed. It is assumed that the 25% highest drought indices, so 75 percentile (P75), would be high enough to inform drought management strategies. This is further discussed in Chapter 7.

3.4.3 Meteorological Indicators

Both the farmer's local knowledge and the forecast produced by DCCMS rely on meteorological indicators in forecasting drought (described in section 4.5.1 and section 5.2, respectively). In this research, all these meteorological indicators are used in the prediction of drought. To compute those meteorological indicators, a few steps are taken. Firstly, all meteorological variables are spatially and seasonally analysed. Afterwards, the meteorological variables are visually compared to the previously defined drought indicators to find in which domain the weather shows distinctive patterns.

Meteorological Variables: Climatology

The daily climatologies of meteorological variables are calculated and plotted for every district. A daily climatology is the long-term average of each day in the year of a given variable. This is done for relative humidity, minimum and maximum temperature, wind speed and direction. The climatologies can be used to compute anomalies. Anomalies are created by subtracting climatological values from observed data.

Comparison with Described Events

The meteorological variables are compared to the drought indicators to potentially find distinctive patterns which can be used in the forecast model.

Three 'drought' and 'no drought' seasons are analysed on large scale wind processes. The wind direction and speed are monthly averaged and plotted for the period from July to December. For the described events, the dry spells and onset of rain are indicated in the time series of the meteorological data. The time series are from June to December and plotted for relative humidity, wind speed and direction and anomalies of minimum and maximum temperature. In addition, visualisation of the wind speed and direction are plotted for 1) weekly averages during the two longest dry spells 2) weekly averages for the week before the effective onset of rain 3) daily averages during the onset of rain. It is observed whether spatial or temporal patterns can be seen that resemble the meteorological signs from local knowledge and indicate a drought. By averaging over the regions that show most resemblance, those indicators are taken in to the next step; the correlation analysis. Additionally, it is assessed whether the described events of farmers are in agreement with observation data.

Correlation Analysis

A pair-wise correlation analysis is done to find which of the meteorological indicators can be used in the model to find the predictive value of the forecast. For every year of the datasets, the indicators are monthly averaged in the period of June to December. This period coincides with the temporal occurrence of local knowledge.

The meteorological indicators were correlated with the drought information, to find the best performing indicators. Positive (negative) Spearman Rank correlations of $r > 0.25$ ($r < -0.25$) with a p-value of $p < 0.075$ are selected since they are statistically considered to be significant. The correlated indicators are then used as input for the forecast model.

3.4.4 Forecast Model

A forecast model is built that transforms the chosen set of correlated meteorological indicators (i.e. the predictors) into a prediction of the drought indicators (i.e. the predictand). This is done through a sequential threshold model. In brief, the drought indicators are transformed to the drought and no-drought years which represent the 'observed events'. The forecast model also establishes drought and no-drought years but then using a sequential thresholding procedure on the meteorological indicators selected as predictors (see section 3.4.2). These represent the 'simulated events'. The set of drought and no-drought years are created to be compared in the forecast verification. Such a threshold model is established for each drought indicator of interest. For the predictions of dry spell and onset drought indicators the model predicts for an individual station, while for the drought index the model predicts at district level. The exact process of the forecast model is explained below.

Observed events

The observed events are a set of zeros and ones which is created and can be altered by varying a threshold. For instance, the number of dry spells is altered as a threshold. The model makes a set of zeros and ones for one dry spell or more, two dry spells or more etc for every season. In the dataset, there are more seasons in which there are one or more dry spells than there are years with five or more dry spells. Depending on the threshold used, there are less or more observed events and thus also an alteration in the ratio zeros and ones in the observed events of the model.

Simulated events

The simulated events are a set of zeros and ones as well, in order to make a comparison with the observed events. However, there are several steps taken in computing various meteorological indicators to a binary (zero/one) outcome. The steps are schematized in Figure 16 and elaborated on below.

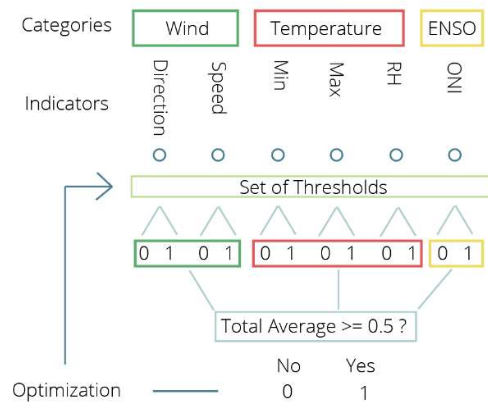

Figure 16: Computation of Simulated Events

Firstly, the meteorological indicators are separated into three categories; wind, temperature and ENSO. Both wind and temperature are associated with the local knowledge and ENSO is a commonly used predictor by DCCMS (see section 3.1.5). In the wind category are wind speed and direction in various spatial regions. The temperature category includes relative humidity, maximum and minimum temperature. The ONI index represents ENSO.

For every individual meteorological indicator, a separate threshold is set. Depending on whether there is a positive or negative correlation with the drought indicator, values above or below the threshold will be set to either a zero or one. When there are two (or more) consecutive significant correlations within one indicator (for example ENSO for June and July), the indicator with the highest correlation is taken.

The resulting zero and ones of the indicators are averaged per category. Afterwards, all categories are averaged; if this is greater or equal to 0.5 the simulated event will be set to 1, otherwise 0.

The best set of combination of thresholds is found by a global optimization method called 'Differential Evolution' in the SciPy environment of Python. This method varies thresholds in the model and minimizes a certain 'Goodness of Fit' metric. The Mean Squared Error (MSE) is such a metric and is computed as follows:

$$MSE = \frac{1}{N}\sum_{i}^{n}(S_i - O_i)^2 \qquad (10)$$

where *S* is the simulated value (zero or one), *O* the observed value (zero or one) and *N* the number of years in the dataset. An MSE value of 0 means there is no difference between the simulated and observed value and thus a perfect score.

The forecast model gives a set of zeros and ones that represent the observed and simulated events for every season. For example, when the dataset of the drought and meteorological indicators of a station spans 50 years, 50 observed and simulated events are created. The length of the dataset, however, differs per station or district. Subsequently, the two sets are compared in the forecast verification. The thresholds of the drought indicators can be varied (see precious section 'Observed Events') to find the predictability of the meteorological indicators for different thresholds.

3.4.5 Forecast Verification

The objective of the forecast verification is to find the predictive value of the meteorological indicators that can forecast drought indicators that could be useful for agricultural strategies. The aim is to find out 1) the predictive value of meteorological indicators informed by local knowledge 2) the forecast skill for predicting critical drought indicators with the required lead time.

This comparison is done by means of forecast verification methods. One of the ways to verify a forecast is using a contingency table which includes the hits, misses, false alarms and correct negatives. A hit is when the forecast model has simulated an event which is also observed. A false alarm occurs when the forecast model has predicted the event, but the event has not occurred. When a forecast model has not predicted an event, but the event did occur it is called a miss. And lastly, when both the forecast model predicted no event and the event does not occur as well it is called a correct negative. This is done for the entire dataset of that location and the contingency table is formed (see Table 7).

Table 7: Contingency Table

		Event Observed	
		Yes (1)	**No (0)**
Event Simulated	**Yes (1)**	Hit	False Alarm
	No (0)	Miss	Correct Negative

From the results of the contingency table, various forecast verification metrics can be calculated. In this research, five metrics are used to assess the predictive value of the forecast. The metrics include the Hit Rates (HR), False Alarm Ratio (FAR), Probability of False Detection (POFD), Probability Correct (PC) and Threat Score (TS). The equations are given in Eq. 11 until Eq. 15.

$$HR = \frac{Hits}{Hits \quad Misses} \tag{11}$$

$$FAR = \frac{False\ alarms}{Hits+Fals \quad Alarms} \tag{12}$$

$$POFD = \frac{False\ Alarms}{Correct\ Negatives+False\ Alarms} \tag{13}$$

$$PC = \frac{Hits+Correc \quad Negatives}{Sum\ of\ all} \tag{14}$$

$$TS = \frac{Hits}{Hits+\ Misses+Fals \quad Alarms} \tag{15}$$

By plotting the Hit Rate (HR) against the FAR and POFD for several thresholds, the predictive value is assessed. The ranges of the scores are between 0 and 1. The perfect score for HR is 1 and for FAR and POFD is 0. By varying the thresholds in the prediction of the drought indicators, different forecast metrics are computed. Figure 17 illustrates how a forecast verification plot can be interpreted. The grey areas of the plots indicate the 'no skill' zone in which the forecast does not have a predicted value. When plotting the HR against the POFD, it is expected when a POFD and HR is low (bottom left of left graph) the forecast model never simulates an observed event. On the contrary, when both the HR and POFD are high, the forecast model always simulates an observed event. A forecast model increases in predictive value (e.g. when new information becomes available that improves the forecast model) when the results (the orange line) move further away from the 'no skill' zone. In the plot of the HR plotted against the FAR, a forecast shows an increased skill when the results have a high HR and low FAR, as indicated in Figure 17 in the right plot.

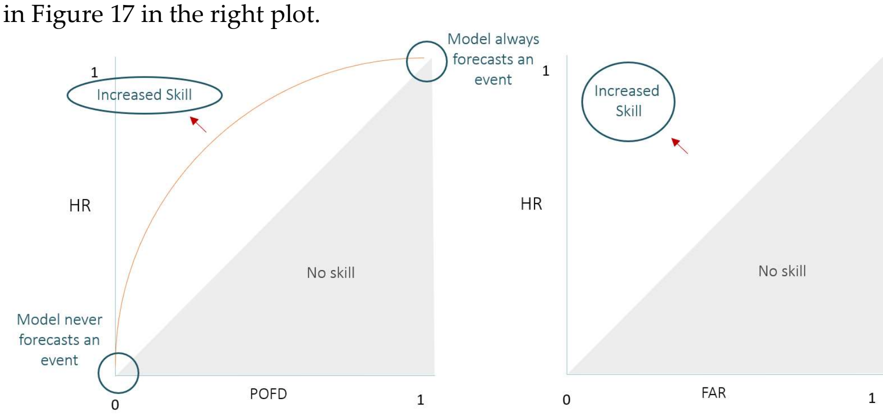

Figure 17: Interpretation of Forecast Verification Graphs

4 | Results – Context of Smallholder Farmers: agricultural strategies, local knowledge and forecast information

In this chapter, a general picture of the smallholder farmer's agricultural context is sketched, and relevant decisions points for drought strategies and their timing has been captured. Section 4.1 provides background information on the collected data and farmers. The farmer's interpretations of drought are elaborated on in section 4.2. In section 4.3, the weather and field conditions for agricultural practices is schematised in the form of a calendar, together with the climatic influences on it. The current receival of forecast information is elaborated on in section 4.5. Additionally, the available local knowledge which is present to predict drought-related events are mentioned and schematised. Eventually, in section 4.6, an assessment is made of the current receival of forecast information by the farmers and the results are linked to requirements for tailored drought forecast information.

4.1 Data Collection | Quality and Background

All ten scheduled FGD have been performed during the first fieldwork in the three district Salima, Mangochi and Zomba. The quality of the FGD progressed along the way, with an increased understanding and structured way of organising the FGD. Fortunately, the outcome of all FGD of adequate quality and well designed to be further used in the analysis and data saturation was reached. Subsequently, the outcomes were analysed, and a second data collection was performed in one of the research districts, Zomba. Due to logistical and time restrictions, the exercise could not be performed in every district. The sorting exercise had a relatively small sample size of ten sorting sheets but was enough to quantify the relative decisions and preferences that could be further used in the research.

Initial questions were asked at the start of each FGD to get the context of the farmer groups. This included the gender, plot size, crops grown, purpose of farming and average yield in good and bad weather conditions. It should be mentioned that there is no such thing as 'the smallholder farmer'. However, for the scope of this study, the farmer's situation has been generalised and formed into a general picture. The answers were similar and no big discussion points, disagreements or large variances were observed.

Out of all the farmers in the FGDs 64 women and 54 men were participating. The crop that was grown most was unanimously answered to be maize. Other crops that were grown included cotton, rice, groundnuts, sweet potatoes, tobacco, sorghum and pigeon peas. The plots were at its smallest one acre and largest six acres. The medium plot size was between 1.5 and 3 acres. Based on the literature found in section 2.2, this would mean most smallholder farmers are 'net food buyers' or 'intermediate farmers'. This was also the most common answer to the question of the purpose of their farms; the maize is mostly for household food consumption. The rest they sell to pay for their children school fees. They also tell that it depends on the season how much they will sell and keep for consumption. Typical yields differ per farmer and depend on their plot size. A good production can be 10 to 20 bags of 50kg of maize per acre, depending on whether it is local or hybrid maize.

4.2 Drought: extremes and interpretation

Table 8: Extreme Rainfall Seasons Mentioned in FGDs

District	EPA	Season
Salima	Khombedza	2008/09
	Khombedza	2000/01
Mangochi	Nankumba	2017/18
	Nankumba	2015/16
	Mbwadzulu	2000/01
	Maiwa	2000/01
Zomba	Mpokwa	2000/01
	Mpokwa	2011/12

During every FGD, the farmers were asked to reach consensus on what the most extreme rainfall season was. It was observed that an extreme year is automatically associated with food insecurity by the farmers. All groups mention a drought season as the most critical season (although floods, for example, could have been answered as well). During the ten FGDs, the most extreme rainfall seasons can be found in Table 8. These described events are used to establish further insights into what the 'critical' events are in the rainfall season and they are compared to observation data in Chapter 6. Additionally, individual farmers mentioned the rainfall patterns associated with drought. Different terms were used to express this and can be summarized as: little rainfall, few rainy days, late onset of rain, dry spells and a short rainy season and are further used in section 3.4.2.

As just mentioned, farmers tend to define an 'extreme drought season' as the year in which there was food insecurity, not necessarily the rainfall season itself. In one of the focus group discussions, an example of this has been encountered. It concerned the seasons 1999/2000/2001. When farmers were asked to give more details on the chosen 'extreme season'. The farmers indicated '2001' as the most extreme season and mention that the 1999/2000 season started relatively early with less harvest than normal. When the rainfall season of 2000/01 effectively started very late due to dry spells, the farmers greatly suffered from food insecurity during 2001 until the produce of the 2000/01 season was harvested (later than normal).

4.3 Weather and Field Conditions

Through the seasonal calendar at the FGDs, the farmers have indicated the 'good and bad' weather and field conditions for their agricultural practices. The bad conditions are associated with the conditions that prevail during a drought season, as indicated above. The 'good' conditions are associated with good crop produce. The results are elaborated on in the following paragraphs. Although the FGDs were held in three different districts, the answers about a typical rainy season were similar and it was chosen not to separate them into different calendars. Figure 18 visualises a summary of the outcome of the seasonal calendar for the 'good' and ' bad' weather conditions. An explanation of the conditions is given below.

When good weather and climate conditions prevail, the farmers mentioned that the rains will fall from half of November to end of March. In October, already some cloud formation and light rains can be expected. Crops will not sustain dry spells longer than one or two weeks depending on what month of the rainy season the dry spells are occurring. It is most critical when the crop is in a growing phase, which is in December and January. Further in the season, three weeks of the absence of the rain is the maximum a crop can endure. In April, there should be no rains anymore (if the onset of rain is half November), since the maize crops have then already matured and are supposed to dry and be harvested.

Both winds and temperature observations are part of the farmer's local knowledge of predicting rainfall patterns and is more elaborated on in section 4.5.1. As generally believed, when Mwera winds are present there will be no rain. Mwera winds are heavy winds from the South East. Most of the time, Mwera winds are not favourable for agricultural practices. Except for March, this is the month in which maize crop should be drying and the Mwera winds can help in that process. Before and during the season - especially in January and February when either dry spells or heavy rains are likely to occur – there is a general belief:

"North Easterly winds keep the rains constant. But it is worrisome when the Mwera winds persist. That dries the soil and crops start to wither."

Temperature is seen as a good indicator for whether good or bad climate conditions prevail. It should be 'cold' from half July to half of August. High temperatures in October and November are present when a good rainy season is coming. Moderate temperature during the rest of the season indicates good conditions. If it is very hot in June, people are already expecting it to be cold in October, which indicates a bad rainy season. Also, when there are dry spells in January or February, high temperatures are present.

Associated with good weather conditions, the soil is still a bit moist in July and August and getting really dry in September and October. Beginning of November, the soil is getting a bit moist due to the initial rains in October. When the good rains start, the soil is getting moist and will remain moist for the rest of the season. During bad weather conditions, a lack of rainfall and the Mwera winds make the soil completely dry from April to June. It will remain dry, until the rains start again, which may only be in February again, due to the delayed rains and lack of infiltration in the hard and cracked soil.

The growing season is parallel with the rainy season; from half November to end of April. In a good season, the seeds are planted with the first good rains in November. By February the crop will be maturing. In March the maize is drying, after which it can be harvested in April.

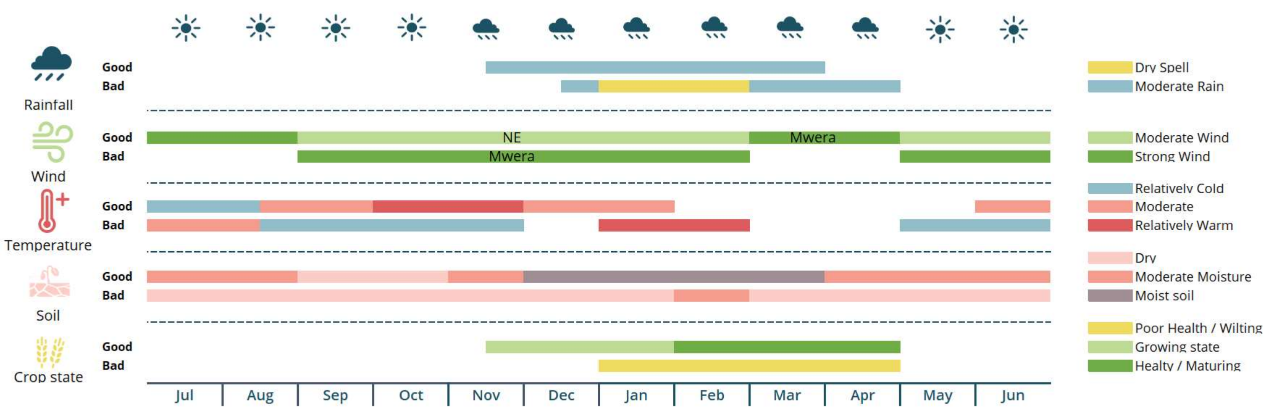

Figure 18: Good and Bad Weather and Field Conditions According to Farmers

4.4 Agricultural Strategies and the Influence of Drought

The agricultural practices that farmers indicated in the focus groups discussion, alongside the seasonal calendar are discussed in this section. The agricultural practices that are mentioned for each month are analysed and summarised in Figure 19. Additionally, some decisions surrounding the agricultural practices are influenced by drought. How drought influences some of the agricultural practices is explained below and indicated in Figure 19 as well.

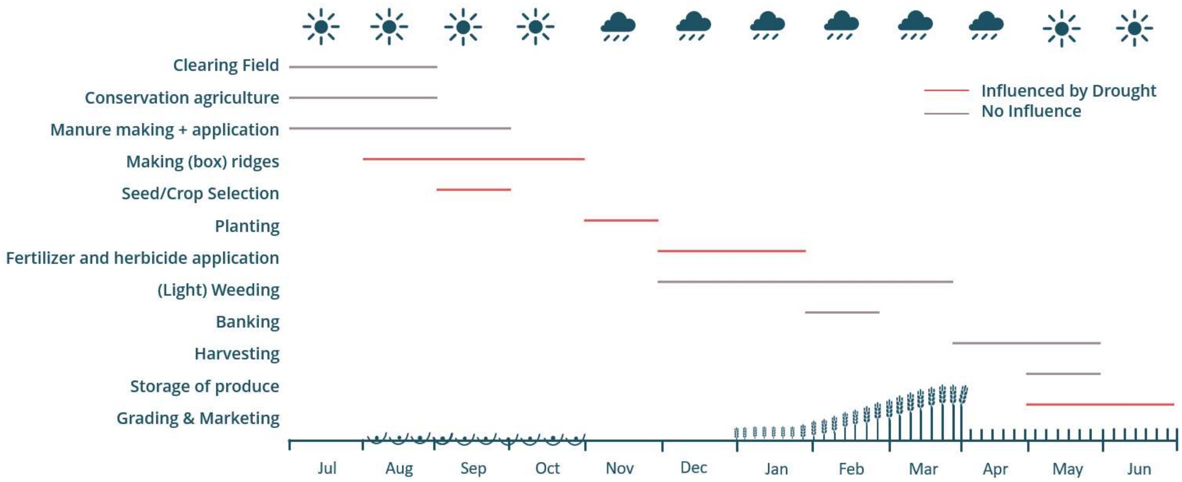

Figure 19: Agricultural Practices during the Season and the Influence of Drought

The agricultural practices for the season begin in July with land preparation. This includes clearing the field and preparing for the so-called conservation agriculture. It is a collective term for mulching, stocks burying to retain moisture and reduce evaporation losses. Mulching is an activity whereby the leftover of harvest, like leaves, are covering the land to give nutrition to the soil, reduce evaporation and retain soil moisture. The leftover stocks of the maize are buried, to retain the moisture as well. Research has shown that conservation agriculture is an effective method resulting in higher crop yields and reducing the risk of armyworms (Hobbs et al., 2007). Mulching can be difficult and energy-consuming when soil is hard and dry. Manure making is done simultaneously with conservation agriculture. The manure is composted which can take up to two months, depending on the plot size, and is applied in September.

Ridge making is a long process which starts around August and ends around October before the rainy season starts. The ridges can be made in different ways; differed heights, different distances apart. Box ridges can be made when a dryer season is expected. There should not be heavy rains when box ridges have been made, because of high chances of waterlogging which causes the crops to rot.

Around September, most farmers select or decide on the type of seeds or crops they would like to plant in the upcoming rainy season. Seed or crop selection often depends on an overall indication of the rainy season. If there will be good rains, the farmers tend to grow their staple food maize. Otherwise, they may also plant alternative crops which are more drought-resistant like sweet potato and cassava. Farmers may also opt for buying more expensive seeds like hybrid or early maturing (maize) seeds.

Planting is done around November when the rains are expected. A decision should be made on the timing of planting. The planting date is influenced by the onset of the heavy rains, when there is already a bit of moisture in the soil and should not to be followed by a dry spell. Some farmers have indicated that there are different techniques available when planting seeds. Although it not commonly done, so-called 'pit making' is one of the options. Pit making is done when the farmers believe it will be a relative dry season. The seeds will be planted in the pits so that with little rain the seeds will germinate relatively easy. The disadvantage is, is that with heavy rainfall the pits can easily be filled which makes the seeds more vulnerable to rotting.

Most farmers have access and the financial capacity to buy fertilizers and herbicides and apply it during around December and January. However, fertilizer application should be done when there are moderate rains and not followed by heavy rains. That will wash away (the costly) fertilizer.

Around April and May, the crop produce is harvested, graded and stored. During this period, the farmers have a decision to make by roughly estimating how much they need for consumption to sustain the family until the next harvest. This estimation determines what portion they should sell on the market to buy new farm inputs or other goods. If it is not a good season and the produce is little, they will keep anything for own consumption.

There are some other non-climatic factors that influence crop production. Among other factors, this includes the availability of markets, limited capacity of governmental institutions, lack of resources to buy farm inputs, illness, exploitation by vendors, no transport to buy input or to sell produce or to get produce from the farm. These factors can form a 'negative loop' in which no investments are made which can be sustained and keeps farmers in poverty. These examples show that drought is one of the challenges farmers face.

4.4.1 Prioritization of Agricultural Strategies

With the use of the sorting exercise, it is explored which of the practices and decisions are most important if farmers would know a drought would come. This is important to know in the development of what forecast information is useful for the most important decision in the farmer's strategies. For all ten sorting exercises, the points are calculated as described in section 3.2.2 and total points were summed and ranked. The results of the ranking are summarized in Table 9. It became clear that making box ridges and starting with early preparations are linked with each other and are important decisions for the farmers. Additionally, the crop and seed choice are important decisions as well. It was found that planting dates were not mentioned as one of the drought strategies, although it was considered an important decision during the seasonal calendar. The choice of irrigation is not further included in this study as it is out of the scope.

Table 9: Ranking of Agricultural Strategies

Ran-king	Points	Strategy	Explanation	Month
1	28	Box Ridges	Making box ridges. It takes extra time, so need to start earlier with field preparations	September
2	*13*	*Irrigation*	*To extend rainy season or provide water during dry spell*	*April*
3	12	Crop Choice	Crops which are more tolerant to drought like cassava, sweet potato, sorghum, millet etc	Prep: April (after harvest) Choice: November
4	11	Early preparations	Need to start early with making manure and ridges	July-August
4	11	Pit Making	Making a hole where seeds are planted in to retain moisture	November
4	11	Seed Choice	Hybrid/early maturing maize seed variations	August/September
5	5	Conservation Agriculture (CA)	Mulching, burying stocks	July
6	4	Diversion of crops	To spread the risk	Preparation: April (after harvest) Choice: November
7	1	Stocking food		June

4.4.2 Investments and Risks

Figure 20: Example of Box Ridge

For most strategies/decisions, an investment is made in terms of time or money. Additionally, the risks surrounding their decisions differ. For example, for the seed and crop choice a financial investment is made when buying hybrid seeds instead of local seeds. The results reveal that farmers find the choice of making box ridges most important. The decision requires a time (and financial) investment. Making box ridges takes longer to construct than normal ridges and thus land preparations should start earlier. Firstly, the normal ridges are made with conservation techniques. Subsequently, an extra box is made around the ridges (see Figure 20). It can be a risky decision since it is time-consuming and can lead to waterlogging when the rains are too heavy. It does conserve a lot of water and is thus very favourable when a dry year comes. One farmer also explains:

"So, if there will be heavy rains that season and we have made box ridges, there will be waterlogging. If there will be a few rains, then we also need advice in advance to make more box ridges to preserve water for moisture in the field."

4.5 Forecast Information

Smallholder farmers receive forecast information on the weather and climate from different sources which can help in supporting their agricultural practices. Two distinctions are made; forecast produced by DCCMS and forecast information based on local knowledge by the farmers themselves. Both forecasts are elaborated on in the following sections.

4.5.1 Forecast Information based on Local Knowledge

Farmers have their local knowledge which can forecast weather and give early warning for the quality and the onset of the upcoming rainy season. All farmers groups mention both wind and temperature related local knowledge signs which indicated that meteorological signs are well known and widely observed in different regions in Malawi. In addition, the local knowledge of the farmers has shown the same indicators for different groups, such as the SE and NE winds. However, in different regions, different months of occurrence are mentioned. The wind indicators often coincide with the temperature signs. When winds are mentioned, mostly the relative temperatures are mentioned as well; *"When there are **cold winds** in October or November, we know that rains will delay."* However, the meteorological indicators are chosen to be categorised in wind and temperature indicators separately. The meteorological indicators are categorized and summarized in Table 10 below. Not all the mentioned indicators are provided. Instead, the best descriptive indicators are selected since there is overlap in the months of occurrence. Other indicators, mainly ecological, were also mentioned. These are summarized in Appendix C.

Table 10: Local Meteorological Indicators for Drought

Wind		
Rainfall Information	Indicator	Month
Season / Onset	*"When in September and October and we have little winds, it is a sign that we will have rain on time. But when it is windy, chances of good rains are minimal."*	September-October
Season	*"If we have Mwera winds blowing heavily in October up to November, we expect a dry spell. And North Easterly winds are a sign of good rains. Mwera winds block the Northeasterly wind."*	October-November

Season	*"Heavy winds in October and November is an indication that there will be erratic rains in that season. Especially when we experience whirlwinds."*	October - November
Temperature		
Rainfall Information	Indicator	Month
Season	*"If we experience high temperatures in June, we start having doubts to say, if it is this hot in June, what will October bring us? Usually in this case, we have low temperatures in October. This is a sign that we will not have adequate rainfall."*	June / October
Season	*"The month of July is normally cold. But when we see that it is sunny and the temperatures are high, we expect the worst."*	July
Onset	*"Early august, it is cold to warm. The temperatures then rise the second half of the month. But when we see that it is cold throughout the month, it is a sign that rains will delay."*	August
Season / Onset	*"When temperatures are high in September and October, it is a sign that we will have rain on time. But when it is cold, chances of good rains are minimal."*	September-October
Dry Spell	*"When we have cold weather in October and November, we look forward to a dry spell. But when we have high temperatures, we know for sure that it will rain."*	October-November
Onset + Season	*"When temperatures are very high, at night and during the day, it is a sign of heavy rains ahead. When it is cold, we know that we will not have much rainfall and it will start late."*	November

It can be observed that the signs of the onset of rain and quality of the season coincide with each other. For farmers, a drought simply means dry days when there actually should be more rain; that includes dry spells, late onset of rain, little rainfall, few rainy days and a short season, as explained in section 4.2. A summary of the local knowledge described in the table above is given in Figure 21. Here, wind and temperature indicators that are observed in the dry season can forecast variables of the rainy season.

Figure 21: Forecast for Rainy Season Based on Local Meteorological Signs Observed in Dry Season

Some farmers have concerns related to their local knowledge. Especially the ecological signs are not well trusted anymore. It is believed that due to climate change, the weather patterns and thus the signs are not as constant as they were before.

"With climate change and the cutting down of trees, some signs don't work."

4.5.3 Forecast Information from Meteorological Services

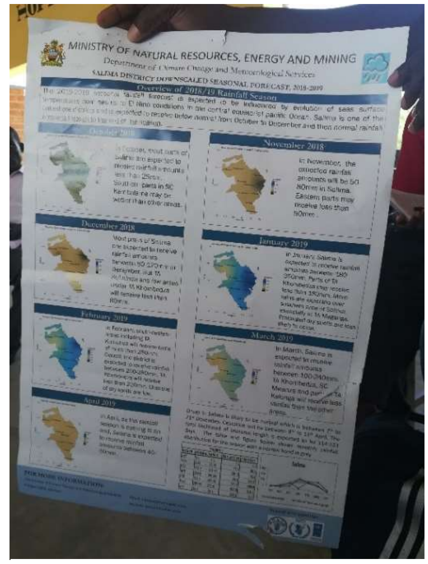

Figure 22: Seasonal Forecast for Salima District

This section explains what forecast information is currently received by the farmers. It explains what information is useful for them and what they wish to receive more. The forecast information received by farmers is ranked in terms of usefulness.

Forecast information is mostly given by the extension officers or through the radio. Through the radio is mostly short-term weather information, whereas the extension officers give the seasonal forecast by means of a poster with verbal explanation, as shown in Figure 22. This poster includes the number of mm per month (October-April) that will likely fall and a range of days for the onset of rains. They also receive information on the onset of the rains and whether they should plant with the first rains or not. Not all farmers receive information in the same frequency and timing. The seasonal forecast is mostly received between September and November, varying between villages. Depending on the location, extension officers may visit once or twice a month.

Information is helping them in many ways to improve their agricultural practices. Table 11 gives an overview of the farmer's preferences of forecast information in Zomba district. The radio is valued as most useful, closely followed by the extension officers. The radio gives agricultural advice on their field practices and updates the farmers on rainfall patterns and the onset of rain. Farmers mention that according to the extension officer's advice on rain distribution for a specific season, they can switch to planting drought-tolerant crops like cassava and sweet potato. When a dry year is expected advice is given to make box ridges, practise conservation agriculture, alter the time of fertilizer application, choose the type of crops to plant, shift planting dates and alter planting method (pit planting). On third place in the local knowledge on temperatures. Others include local knowledge on wind and birds, SMS and social media.

Table 11: Ranking of Forecast Information in Zomba District

Ranking	Score	Forecast Info	Characteristics/Reasons
1	33	Radio (FRT)	Advice on agricultural practices + onset of rains and rainfall patterns
2	32	Extension officer	Early warning messages: advice on what crop to plant
3	9	LK: Temperature	Normal: May-early August cold. Drougth: May-October cold
4	4	NGO/SMS	SMS messages from Farm Radio Trust
4	4	LK: wind	Heavy mwera winds
5	2	LK: Animals	Certain birds that migrate or make noises
6	1	Social Media	Facebook Page of DCCMS

4.6 Requirements for dissemination and forecast

In section 4.6.1, the farmer's perspective on currently received forecast information is elaborated on. Based on those findings, section 4.6.2 gives an overview of what 'requirements' drought forecast information should meet and acts as a baseline in section 3.4.

4.6.1 Assessment of Received Forecast Information

Table 12 shows the results of the thematic analysis, explaining the four categories from the farmer's perspective.

Table 12: Assessment of the Received Forecast Information

Category	Key Word	Count	Example Quote
Procedure	Timing	6	*"But usually the information comes in late."*
	Repetition	9	*"If there can be more trainings for the officers, it can help us also get more information, even recruiting more officers."*
	Communication Format	3	*"It is good to verbally give us the information because that can reach many of us."*
	Communication Channel	5	*"But [extension workers] cannot manage to be available often because of other commitments. While radio reaches millions at one time."*
	Awareness Raising/ Inclusiveness	3	*"I would have loved that we also access what we see at the ministry of agriculture offices. If we can have someone to explain to us from the instrument measures."*
Under-standability	Communicator	4	*"We need more information from the extension officers. We understand them better."*
	Possibility for feedback	3	*"Like how you are doing here, I can ask you a question and you can respond right away because you are here. Even after getting a text message, if I don't understand the information I have no one to ask. So an extension is better."*
	Format	5	*"If we can have it through use of posters so that we can see because you cannot take in all verbal information."*
	Language	5	*"We easily get the information because it comes in our local language."*
Credibility	Usefulness	3	*"It is useful. When we are advised, we know what to do. For example, if we are warned of a coming dry spell, we are advised to plant early."*
	Correct Forecast	9	*"Of course there are cases where the Met services inform us of heavy rains then there are no rains. But most of the times, the give us correct information."*
	Spatial resolution	8	*"I don't trust them 100%. There are times we are informed that the lakeshore area will receive rainfall. So when we talk of lakeshore areas, we have Mangochi, Nkhotakota, and Salima [district]. They do not specify if it is only for Nkhotakota [district]. We wonder when we do not receive rainfall in our area. At least they should specify the area for the information given. Otherwise, they give us false hope."*
	Communicator	2	*"I especially trust the information on radio."*
Application	Forecast Variable	7	*"We need to have information about the onset of rainfall. To know if rainfall will delay or start early."*
	Timing	6	*"And we need information about the onset of rainfall in September and October. These are months when we expect rainfall."*
	Advice/knowledge	17	*"As we go to our fields, we have that knowledge. That if we plant the local maize variety, we will not have a good harvest."*

Procedure

A critical constraint for the forecast information to be useful is the timing of the information. The forecast often comes late and not frequently. Farmers find verbal communication, in combination with posters, a good option as an effective communication channel, because it can reach many. For example, through radio or by training lead farmers which can pass on information to fellow farmers. Not all farmers receive the same amount of information, which is either due to the availability of the extension workers or the number of radios. Furthermore, when new rain gauges are installed, they would like to learn how that works.

Understandability

Extension officers are best understood because the farmers can ask questions immediately and the communication is in Chichewa. The language and feedback components play an important role in understanding. In addition, the format of communication matters. The use of posters helps and should, indeed, be in the local language.

Credibility

The forecast information originated from DCCMS is valued as very useful and is a generally widely accepted and trusted. It is sometimes not fully trusted, mostly due to its spatial resolution. The area for which the information is given is not specific enough. The scale of the forecast given in the five meteorological zones is too large. The spatial resolution should be on district level at minimum, EPA level preferably. The radio and extension officers are the most trusted communicators.

Application

Valuable variables that are applicable for farming purposes include the onset of rains, dry spell information and whether there will be much or little rainfall that season. This information related to decisions is made in the field during different times of the year. Figure 23 visualises what forecasted drought information is required for what type of agricultural decision at what moment in time.

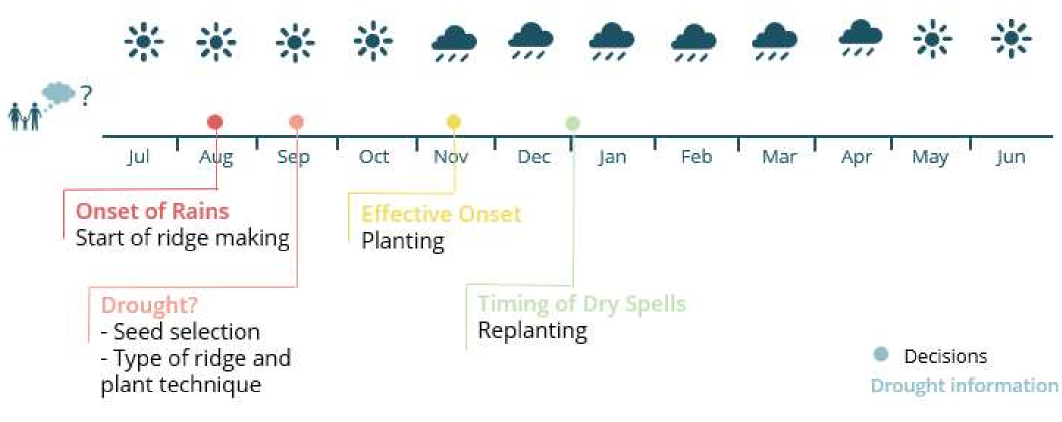

Figure 23: Type of Forecast for Agricultural Decisions in the Season

4.6.2 Preferred Drought Forecast Information

The findings above are summarised into the preferred requirements of drought forecast information for smallholder farmers, which are given in an overview in Table 13. The timing of dry spells is left out of the scope of the study. However, dry spells may be 'critical' events in the season (section 4.2) and included in the prediction on whether there will be a relatively dry rainy season or not.

Table 13: Requirements for Drought Forecast Information

Drought Indicator	Timing of Onset of Rain	'Dryness' of the rainy season / Dry Spells
Decision	Start of Ridge Making and Planting	Type of ridge to make and seeds to plant
Month of Decision	August and November	September
Scale	~EPA	
Communicator	Radio/Extension Officer	
Format	Verbal and Written Communication with possibilities for feedback	

5 | Results – Current Drought Information System

In this chapter, the dissemination flows for three types of forecast information from a national to farmers level are visualised and elaborated on in section 5.2. Additionally, the current forecast information is assessed from the perspectives of the relevant stakeholders in the drought information system (section 5.3).

5.1 Data Collection | Quality

The key informants or groups were identified in consultation with the Malawi Red Cross Society (MRCS) staff members. Through the interview protocols, see Appendix A and B, similar questions were asked during the interviews, allowing for a direct comparison of the answers. In total 20 interviews have been held with key informants or groups. Thereby nearly all planned interviews have been conducted. The ACPC interview has been integrated into the VCPC group discussion due to time constraints. Also, there has been no interview with a MRCS actor on area level. All conducted interviews have been conducted in English and transcribed word by word to capture the nuance of the answers. The protocol was thoroughly designed to capture the desired outputs and data saturation was reached. In general, the data was of adequate quality for exploring the strengths and weaknesses of the current drought information system.

5.2 Flow Diagram

A flow diagram is made, as can be as seen in Figure 24, that visualises how forecast information 'flows' to get a better understanding of the drought information system. First, the results of how the flow diagram is categorised with the use of different symbols, colours, patterns, nodes and arrows is explained. Hereafter, the forecast 'origin' and information 'channels' of the flow diagram are elaborated on. In section 5.2.1, to section 5.2.3 the three types of forecast information in the diagram are explained.

The forecast information was separated into different categories:

- Type of information
- Nodes
- Sub-networks
- Levels
- Channels of information transfer

The different <u>type of forecast information</u> sources is divided into three categories:

Seasonal: seasonal outlook, poster and national workshops

Weather updates: includes short-term weather forecasts like a weekly update from radio, 10-day bulletins, 5-day weather forecast, day-to-day forecast

Local knowledge: meteorological and ecological indicators for rainfall patterns or events

The <u>nodes</u> represent what that actor is doing with the information:

● Add value
◆ Pass on as it is
▼ Receive and do not pass on

The <u>sub-networks</u> were divided into the following categories: the 'extreme climate information' or the 'general climate information' – that coincide with the interview protocol.

Actors dealing with extreme weather/climate information

Actors intended to mostly deal with general weather/climate information

The levels are split into the following categories:

1. Forecast origin: Forecast based on either scientific knowledge by DCCMS or local knowledge
2. National
3. District
4. Area: EPA/TA
5. Local: village/section/GVH
6. Individual: the smallholder farmer

Channels of communication transfer include:

Electronic Communication: SMS, social media, radio and television
Mouth to mouth: verbal communication between individuals
Organised Gatherings: a meeting specially organised by one of the actors
Observations: feelings or observations through local knowledge

The dissemination of the forecast products flows through different 'channels', see Figure 24:

Humanitarian Organisations operate whenever a project is focussing on early warning, or when an official disaster warning has been called upon. Their aim is to give an early warning in case of disaster to reduce the number of people that are affected by that disaster, or to build resilience to it. In this research MRCS, the United Nations Development Programme (UNDP) and the World Food Programme (WFP) are considered in this channel. However, this study has put the focus on the MRCS procedures.

The **disaster** line includes the officers of Department of Disaster Management Affairs (DoDMA). They are mandated with coordinating disaster risk reduction, relief and early warning systems in the country and for the dissemination of warnings once they have been generated from the DCCMS.

The **extension** channel represents the network of the Department of Agricultural Extension Services (DAES) that plays an important role in the dissemination of the climate information. DAES is a part of the ministry of Agriculture and is 'the bridge' between the forecast and the advice for farmers.

The last channel is the **media** structure. The media includes radio, newspapers and TV programmes like Zodiak. There are community radios that only air for a certain area. The content producers are also included in this channel. One of those content producers is Farm Radio Trust which the farmers have often mentioned during the FGDs.

The flow chart that has been created is illustrated in Figure 24. Firstly, the level 'forecast origin' is explained. Subsequently, the flow chart is explained and contextualised through 'following' the three different types of forecast information; seasonal forecast, weather updates and local knowledge (section 5.2.1, 5.2.2 and 5.2.3 respectively)

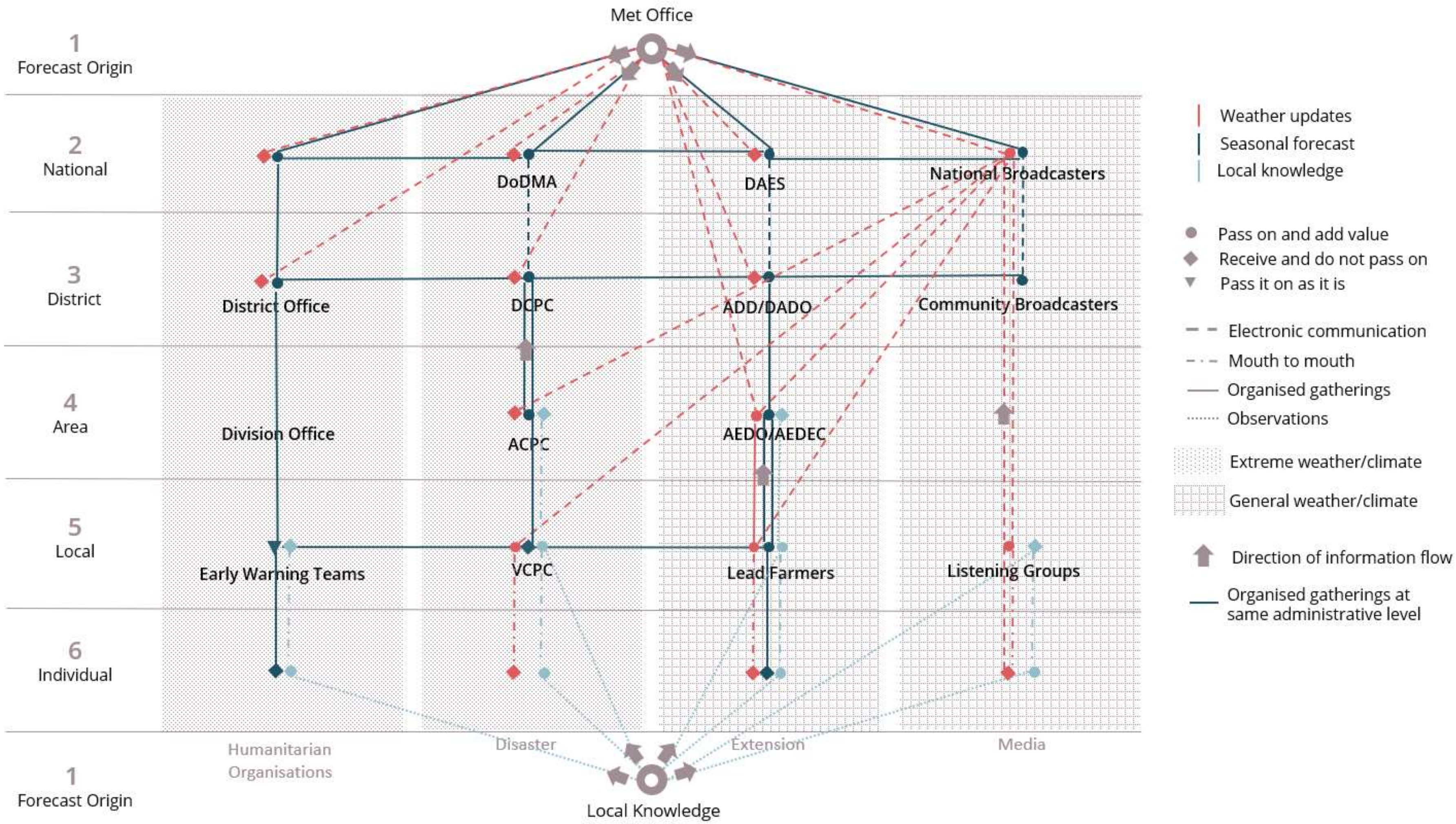

Figure 24: The Flow Diagram of the Forecast Information in Malawi. Abbreviations: Department of Disaster Management Affairs (DoDMA), District Civil Protection Committee (DCPC), Area Civil Protection Committee (ACPC), Village Civil Protection Committee (VCPC), Department of Agricultural Extension Services (DAES), Agricultural Development Division (ADD), District Agricultural Development Officer (DADO), Agricultural Extension Development Officers (AEDO), Agricultural Extension Development Coordinators (AEDEC)

The dissemination of climate and weather information starts at the **forecast origin**. There are two main forecast sources for smallholder farmers; the forecast based on local knowledge and the forecast based on scientific models made by the Malawian Met Office. In section 4.5.1, the forecast based on local knowledge is elaborated on. Now, the process of the production of the forecast products by DCCMS is explained.

An initial seasonal forecast is made by DCCMS in July/August before heading to the Southern African Conference of Forecasting (SARCOF). SARCOF is a yearly conference organised by the World Meteorological Organisation (WMO) in August for SADC countries to provide the seasonal outlook of that year. The seasonal outlooks are based on Sea Surface Temperatures (SST) in the Pacific Ocean (see section 2.2.2). After attending the conference, DCCMS cross-checks whether their forecast coincides with the forecast made by the Southwest Indian Ocean countries at SWIOCOF. Afterwards, DCCMS downscales the initial seasonal forecast product and includes meteorological features for Malawi after which a national outlook for the season is created. This national outlook makes a distinction between Northern and Southern Malawi. Afterwards, the minister responsible has to authorise before the Seasonal Outlook can be announced in September. DoDMA's highest committee, 'National Preparedness and Relief Committee' calls for a meeting for DCCMS to present. The membership of that committee consists of all government principle secretaries and NGOs. Once approved by this committee, the production of the downscaled seasonal forecasts per district can start which takes about two weeks. The seasonal forecast is downscaled to districts level by means of GIS mapping tools and shows variations within the district. For the forecast of the onset of rains, DCCMS is looking at historical records of data by defining certain conditions that should fit the start of the season. By using years which are analogous to the season in consideration, they get the mean of those days as expected start time of rains. After the production and printing of the downscaled seasonal forecast poster, a 'dissemination week' is organised. In this week DCCMS together with DoDMA go to districts and communities to hand out and give presentations on the poster. A summary of this process is illustrated in Figure 25.

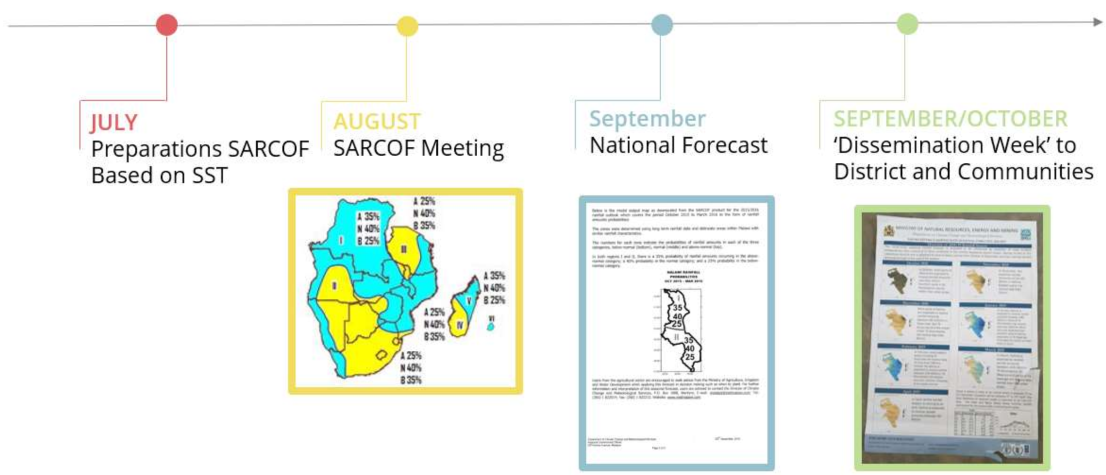

Figure 25: Forecast Production and Dissemination in Time

5.2.1 Seasonal Forecast

As explained above, every year a national meeting is called upon by DoDMA. Besides, DoDMA calls for another meeting with the committee called 'humanitarian response committee' and includes all government departments and ministries and NGOs, including UN agencies. This meeting represents the horizontal line on the national level.

Disaster Channel

In the dissemination week, DoDMA and DCCMS visit all the districts. Thereby, they first go to the district councils after which the communities. During the meeting at district council level, the DCPC organises the meeting which represents the horizontal line on the district level in Figure 24. The DCPC is a committee that includes people from all sectors such as the administrative sector, the media and NGOs. In total, the DCPC consists of approximately 35 to 40 members. In the meeting, DCCMS presents the seasonal forecast and hands out posters for the specific district. They include messages like; the forecast is based on probabilities and should not be taken as given or updates during the season should be followed by means of other dissemination platforms such as the newspaper, radio and social media.

It is now up to the DCPC to take the message down to the communities where there are Area and Village Civil Protection Committees. These are committees set up as 'administrative structures' by the disaster department. The forecast information is disseminated though these 'structures'. For the seasonal forecast, however, the agricultural extension service plays a more important role – since they (should) know how to make the translation from seasonal forecast information to agricultural advice for the farmers.

Extension Channel

The advisories by DEAS are made at national level and disseminated in three forms to the communities: radio, leaflets and the Participatory Integrated Climate Services for Agriculture (PICSA) program. The PICSA program is a temporary program that is developed by the University of Reading and is available in some districts. The aim is to train the extension officers on how to inform their farmers with advice once the seasonal forecast that has been given. The leaflets are distributed throughout the country by means of the agricultural administrative structures. They also work together with radio stations to air their programs. The Agricultural Extension Development Officers (AEDOs) are the ones that disseminate the climate forecasts to the lead farmers by means of written text on the seasonal calendar poster. They may also show agricultural practices by means of demonstrations or drama performances.

Figure 26: Gathering of Extension Officer and Lead Farmers

Media Channel

The media itself does not create content concerning the seasonal forecast. Farm Radio Trust, the biggest player in the content development of agricultural advice, does not use the seasonal forecast to generate the content of their programmes. They do have a meeting before the onset of the rainy season with the 'National Agricultural Content Development Committee' where researchers from universities, stakeholders, DCCMS, DAES, radio stations and farming communities come together and develop content for that particular season. DAES also produces content for the radio. Thereby, the seasonal forecast is used to create applicable content and advice for the upcoming season.

Humanitarian Organisations Channel

Depending on the project which is being implemented, MRCS is involved in the dissemination of the seasonal forecast. Sometimes they are involved in a project which includes climate information. For example, in one of the research districts Zomba, the seasonal forecast was disseminated by MRCS in TA Mwambo. The poster was printed in a big format and translated to the vernacular language. MRCS has so-called Early Warning Teams that were involved in the dissemination process, together with the CPC structures and local DCCMS officers. UNDP is the leading organisation in the project named ‘M-Climes: Scaling up the use of Modernised Climate Information and Early Warning Systems’ which is, currently, the main project running. The project has funded, for example, the production of the seasonal forecast posters. WFP had a drought Forecast-Based-Financing (FbF) project and is involved in the implementation of the PICSA program.

5.2.2 Weather updates

The weather updates include a daily forecast, a 5-day weather forecast and a 10-day agrometeorological bulletin. They are provided for the five climatic zones, as explained in section 3.1.1. They are disseminated through a big WhatsApp group called ‘Weather Chasers’, radio, news, Facebook, email and updated on their website: metmalawi.com.

The WhatsApp group is joined by various stakeholders, and most of them have created new groups where they forward the daily and 5-day weather forecast in. For example, extension officers receive information via these groups. Often, this information is received but not necessarily passed on.

The 10-day agro-bulletins are only available when the rainy season has started and are uploaded on the website and sent by email to the Ministry of Agriculture, both on national and district level. The bulletins not used by any other stakeholder that has been interviewed.

DCCMS has an MoU with different media stations where they provide weekly forecasts for, e.g. with Farm Radio Trust (FRT). They give weekly information for certain districts on rain and temperature and also link some agricultural advice to it. Radio Listening Groups have been established whereby smallholder farmers meet, listen and discuss the weather and advice.

5.2.3 Local Knowledge

Local knowledge is observed by the individual farmers and is communicated and discussed amongst them when they are gathering. Reasons for a gathering can be the initiation of a chief, a meeting of the radio listening groups or the visit of the extension officer. In this way, extension workers are also very aware of the local knowledge that the communities have gathered. There are plans by DoDMA to collect and document the local knowledge signs on district level, but so far this has not happened in the research areas of this thesis.

5.3 Categorisation | Stakeholders

By means of the results of the categorisation, an overview is created that explains the four categories from the perspective of other stakeholders than the smallholder farmers, see Table 12. The results can identify the strengths and opportunities in the current production and dissemination process of forecast information.

Table 14: Current Situation of Forecast and Dissemination from the Perspective of Stakeholders other than Smallholder Farmers.

Category	Key Word	Cou nt	Example Quote
Procedure	Challenges due to lack of resources at lower administrative levels	7	*“Now at district level for example my office, I don't receive any funding.”*
	Communication channels	17	*“Of course, with the use of the radio it is effective.”*

Procedure	Institutional procedures	4	*"Yes in fact, it takes long. That happens in this bureaucracy. Sometimes you send it for clearance and the minister is not around and then you have to wait until he comes back."*
	Partnerships	2	*"Also, we need to incorporate for example, the media, the journalist. We should include them. So when we give the information, they can be interpreted."*
	Repetitive communication	6	*"After this [seasonal] forecast we don't receive any information in between. The only information we receive is on the radio."*
	Inclusiveness	5	*"We just disseminate based on the partners suggestion – the one who is helping us with resources and helping is us to disseminate. At time, they only target the district they are interested in."*
	Inclusion of Local Knowledge	2	*"When we are doing the forecast dissemination, we also ask them to match it with the indigenous knowledge and see if they are complementary to each other."*
Under-standability	Participatory approach (PICSA)	6	*"Before the PICSA training it was hard to understand. But having been oriented and taught what the parameters mean, it is so easy these days to understand."*
	Local Language	7	*"We do teach the farmers in our vernacular language which is Chichewa. But sometimes the weather forecast is in English. So it takes ones time to study."*
	Technical Terms	7	*"Some parameters we cannot understand. Only the Met officials can."*
	Repetitive training/ communication	2	*"Of course, we have understood the information we are given. But there are some terminologies that we do not understand. So we would like to have another training to remind and teach us what we do not understand."*
Credibility	Need for scientific approach in LK / Distrust in LK	6	*"[Indigenous knowledge] is helpful, but it needs to be backed by scientific data. Because with climate change things are changing. We cannot rely on the indigenous knowledge. I think the best way is scientific, because things have changed with climate change."*
	Participatory (PICSA) approach	5	*"And now with the PICSA approach, I'm quite sure it will still be more effective."*
	Spatial Resolution	4	*"We produce the advice based on EPAs, but what we get now from DCCMS is based on the zones."*
	Local Language	4	*"But what is lacking is the transition from English to Chichewa, so that people know what is expected."*
	Awareness raising	1	*"But awareness! It is very important, because the people destroy the infrastructure [weather stations]."*
Applicability	Variables in Forecast	6	*"Would still want more information on weather in general, because in many cases their forecast is mostly on rainfall. Yeah but in agriculture it's not just rainfall that we need."*
	Timing of Forecast (repetition)	4	*"January – February the information is crucial because either there are dry spells or there are floods."*
	Translation into Farming Practices through (PICSA)	9	*"To say, we are going to have a dry spell maybe in January so let us prepare for that one. How? It's when our friends would say, can you plant early maturing varieties, can you*

			construct these rain water harvesting structures and the like."
	Spatial Resolution	5	*"The problem we had in the past is that the MET department had forecasts for the region, maybe for the whole district. But there were variations from one EPA to another, one area to another."*

Procedure

The Malawian government is highly dependent on international development funding (Hendriks & Boersma, 2019). NGOs often operate project-based and may fund projects that include the dissemination of forecast information. Thereby, a few districts are targeted and not every district might receive forecast information. Last season, 2018/19, was the first year that the seasonal forecast was distributed to all the districts, due to funding of an NGO. Thus, the distribution of the seasonal forecast is dependent on sustainable resources. In terms of other partnerships, it is suggested that journalists could be included in the dissemination process to inform and train them in translating information into usable products which can be given on other media platforms.

It is also pointed out that the 'last mile' of the dissemination is a challenge; extension workers are sometimes not able to reach the farmers due to transport or resources issues. This might result in that the forecast does either not reach at all or not on time the end-user to be useful. An identical problem is observed for the weather updates, which are disseminated mostly via email and WhatsApp. Extension workers do not always have enough credit to receive those messages. The weather updates therefore only reach the farmers by radio or SMS. Other methods of dissemination on improving current dissemination and networks might be a solution. Radio is seen as a very effective method on which a lot of people rely; it is repetitive communication with possibilities for feedback. Other communication channels might be useful, such as the usage of cars driving with billboard information or theatre performances.

The institutional, bureaucratic and non-efficient procedures might cause a delay in the approval of the seasonal forecast. Also, more participatory approaches could be incorporated in the procedures of, for example, installing a weather station. Currently, there is not enough awareness about the value of the weather stations and there is a lot of vandalism. An approach that is mentioned is to include the communities before installing to create a feeling of ownership.

Some stakeholder mention that local knowledge should be included in the forecast dissemination since it can help in understanding the forecast. Additionally, it was mentioned that the advantage of local knowledge is that it has a longer lead time than 'scientifically' produced weather forecast. Many stakeholders mention that local knowledge should be documented and backed up by science. Others prefer the use of scientific forecast only. The variations in the answers given shows that there is a discussion among stakeholders on the inclusion of local knowledge in forecasting.

Understandability

It can be difficult for extension workers and farmers to interpret the forecast. The three categories (above-normal, normal, below-normal) forecast in the seasonal outlook can be interpreted wrongly by decision-makers and are considered too complex, because of the usage of technical terms. The PICSA program assists extension workers and farmers with the interpretation, by explaining historical data, probabilities and the nature of forecasts. Such training might be necessary to make sure that forecasts are well understood, and the decisions are taken accordingly. It is suggested by extension officers that the training should be given on a regular basis, to make sure the knowledge is kept up to date.

The seasonal posters are printed in both Chichewa and English versions. However, it would have been more convenient when more versions were printed in Chichewa. The suggestion of one of the stakeholders is to distribute additional posters in gathering places like churches and schools. The national seasonal outlook and weather updates are disseminated through Whatsapp and other channels in English.

Credibility

The weather updates are generally accepted in terms of credibility by all stakeholders. The seasonal forecast is less trusted in terms of accuracy since the seasonal forecast sometimes changes within the rainy season. There is no clear communication of this change. There is limited feedback from the 'lower' administrative levels back to DCCMS. The current downscaled forecast is considered to be a great improvement to the previous versions, especially in terms of the spatial resolution. The PICSA approach is very effective and valued, however, it is only available in certain regions. The PICSA approach is a participatory approach which increases the trust users have in the seasonal forecast due to the explanation of the probabilistic nature of forecasts. Not all seasonal forecasts are translated to vernacular language or Chichewa. This has negative consequences for the uptake of the forecasts since farmers cannot read English decreasing the credibility (and understandability) of the forecast.

Application

It is mentioned that not only (total) rainfall parameters are needed. Other parameters like humidity, temperature and wind also affect agriculture. Furthermore, not just total rainfall is of interest, but especially the onset of rains and dry spells. Also, the spatial resolution is of utter importance. There are different opinions, some say EPA level would be sufficient, others say GVH level would be. Some also mention that it should be reliable enough in terms of neighbouring EPAs. Neighbouring EPAs should not be significantly different to the adjacent EPA. Especially if extension workers are responsible for different regions which do not coincide with the spatial variation in the forecast.

In previous years, the seasonal forecast arrived in the districts by November. By that time, farmers had already made decisions in terms of land preparations and seed selection. Thus, the forecast did not have any further implications for the farmers. Thereby, they could not apply it in their agricultural practices.

Until two years ago, the PICSA approach was not implemented. That meant, according to DAES, that the farmers were getting the information from either radio or DCCMS, but they were not able to translate that into their farming practices. The PICSA program also helps in budgeting, which underpins the decisions making process.

6 | Results – Prediction of Drought Information with Local Knowledge

From the findings of Chapter 3 it became apparent the forecast information could be improved on various aspects. A distinction is made between short-term forecast information and seasonal forecast information. What the farmers would like to receive on seasonal forecast information is 1) drought indicators that include the timing of the onset and the 'dryness' of the rainy season or dry spells, 2) available in August and September, respectively, 3) preferably on EPA level and 4) communicated by the extension officers and radio. The short-term forecast information should include a more accurate timing of the onset of the rains and alerts if a dry spell is coming, communicated by radio and given for the EPA. In this chapter, all drought information, except the timing of a dry spell, is further investigated.

This chapter shows the results of the prediction of drought indicators through meteorological indicators based on local knowledge of the farmers. It is argued that the inclusion of local knowledge in drought information systems can lead to a forecast locally relevant and better trusted by the users. This, in turn, could significantly improve the communication and application of forecast information.

Firstly, the findings of the computed drought indicators are provided in section 6.1. In section 6.2 the climatologies of the meteorological indicators for the three districts are compared. Section 6.3 gives the results of the comparison of drought indicators and the local knowledge indicators. Section 6.4 elaborates on the correlation analysis. Finally, section 6.5, shows the results of the forecast verification of the model.

6.1 Date Extraction | Quality

The spatial and seasonal correlations of the eleven rainfall stations are plotted to give an indication of the quality of the data set and an understanding of the spatial and temperature differences of rainfall patterns. The result of the distance-correlation plot is shown in Figure 27. Daily and monthly averaged data from the 11 rain gauge stations show a good station characteristics coefficient ρ_0 of 0.91 for the monthly rainfall and a ρ_0 of 0.61 for the daily rainfall dataset over a period of 1975 to 2016. This indicates a fair quality of the rainfall dataset and means they can be used in further analysis of this work. The decline in the trendline indicates that the further the stations are apart from each other, the lower the correlation of the rainfall data. This decline is stronger for monthly rainfall data than for daily rainfall data. The distance at which there is no more correlation between stations (d_o) for daily rainfall is around 140 km and shows that there is no more correlation between Salima stations and Zomba Stations. Since Salima and Mangochi stations are more closely located, the rainfall events in Salima and Mangochi show more correlation.

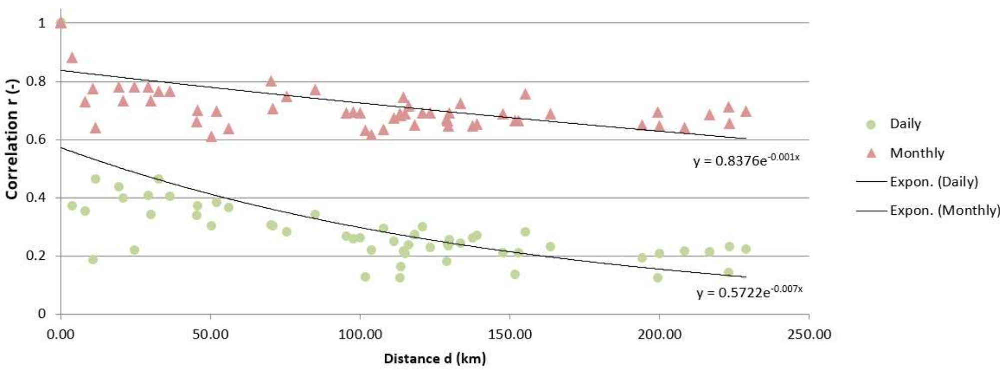

Figure 27: Distance-Correlation of Daily and Monthly Rainfall Data

6.2 Drought Indicators

The rainfall observation data is spatially and temporally analysed, after which the results of the conversion from rainfall variables to drought indicators which are to be predicted in the forecast are shared.

6.2.2 From Rainfall Variables to Drought Indicators

The results in Chapter 3 show what drought indicators are important for the farmer's agricultural strategies. The rainfall variables, as defined in section 3.4.2, are further analysed to form drought indicators which is, eventually, what needs to be predicted with the forecast model. The indicators are: 'dryness', dry spells and timing of onset. How the indicators are computed is elaborated in the next sections.

'Dryness of the rainy season': Drought Index

Table 15: Results of PCA

	Salima	Mangochi	Zomba
α	0.918	0.894	0.897
β	0.844	0.888	0.888
γ	0.719	0.312	0.227
δ	0.690	0.505	0.475
ε	0.383	0.520	0.593
%	46.1	47.0	46.9
KMO	0.56	0.52	0.57

In Table 11 the **first** principle components with the factors are summarized for every district. Here, α represents the number of rainy days, β total rainfall, γ length of the season, δ effective onset of rain, and ε the number of dry spells, as explained in section 3.4.2. The percentages that the principal component of the total variance explains are also given, together with the KMO values. The percentage of explained variance together with the KMO is not very high, but acceptable. Adding a second or more principle components would include negative factors. This would be contrary to what is expected. For example, if the number of dry spells (ε) would increase, the lower the drought index would be, instead of being higher. Drought is, however, more extreme with higher values (1= drought, 0 = no drought). The resulting drought index for the three districts can be found in Appendix E. The three most dry seasons are 1991/92, 1993/94 and 2015/16 and the least dry seasons are 2000/01, 2005/06 and 2008/09. These seasons are verified with the VHI dataset. Figure 28 shows the results with 0 being extremely dry (low health of vegetation), 100 being not dry (high health of vegetation). The results show a good correspondence with low VHI values for extremely dry years and high VHI values for the least dry years.

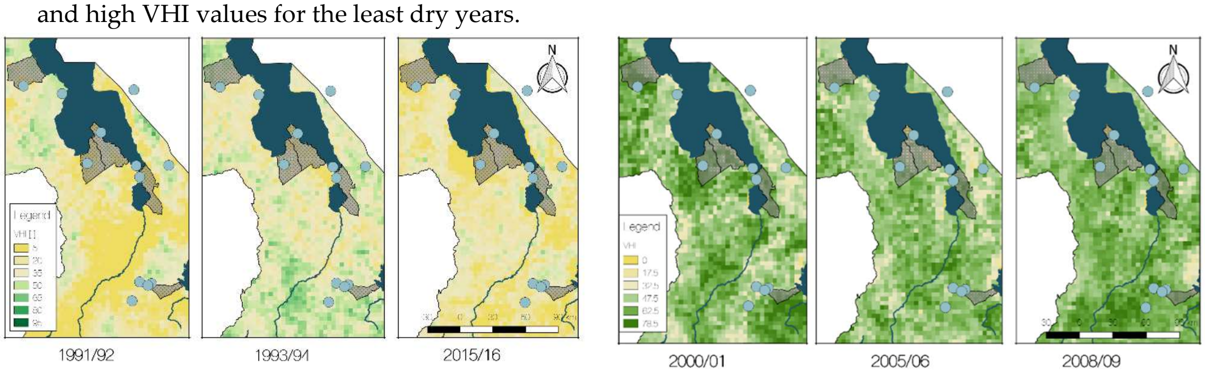

Figure 28: Left: VHI of Extremely Dry Season. Right: VHI of Least Dry Seasons

Timing of Onset and Dry Spells

The computed dry spells, effective onset and the rainfall patterns are plotted and compared to the described events of the farmers. They are compared to find 'critical thresholds' that could potentially inform agricultural decisions. The assumption made in this comparison is that the memory of the farmers is correct. This could, however, be compared to the observation data. One example is shown in Figure 29, the rest of the comparisons can be found in Appendix E. In this particular season, the onset and dry spells have been computed. The entire rainfall pattern and the dry spells patterns (consecutive dry days) are illustrated. The effective onset is marked in grey with the exact date of 25 December 2011.

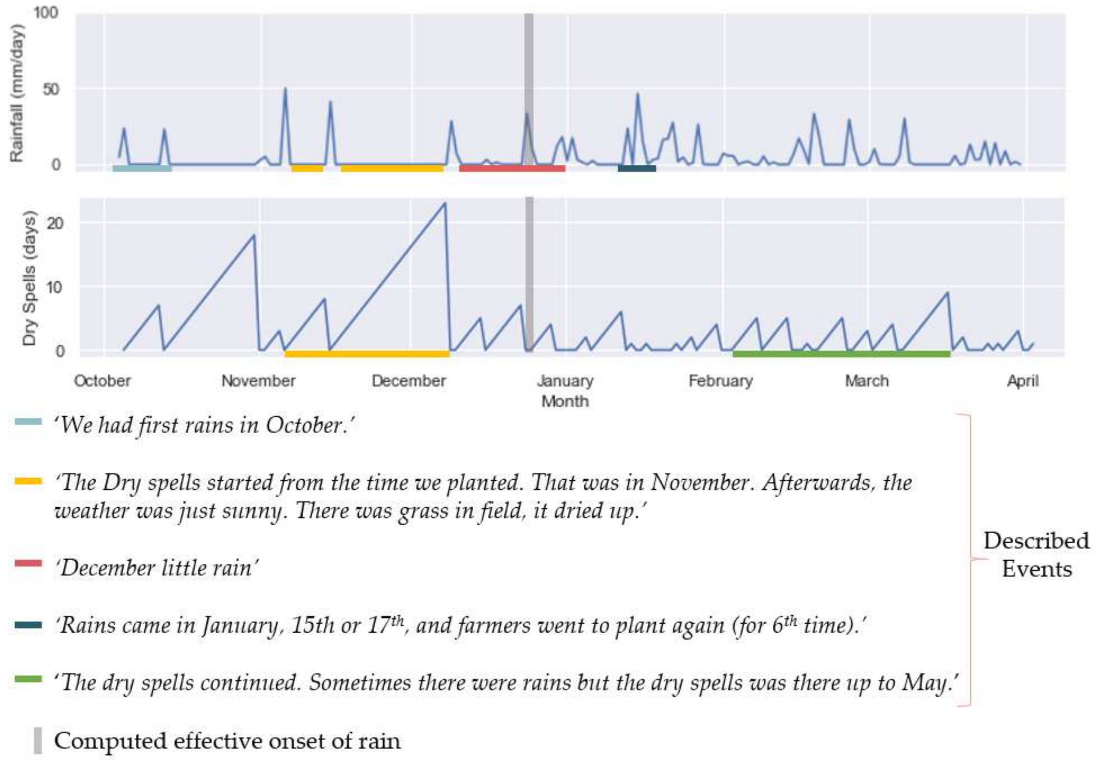

Figure 29: Rainfall and Dry Spell Pattern for Zomba Agriculture Station Season 2011-12

It can be seen that the farmer's memory of the season and its timing of events coincide, in most cases, with the rainfall observation data and its computed onset and dry spell information. The memory went as far as the season of 2000/01. This agreement in memory and observations data allows us to link the critical thresholds that could lead to drought indicators that can be forecasted. It leads to the definition of a dry spell which is an event after the first rains for a period of no rain for 5 days. Also, the critical period for dry spells seem to be from the first onset of rains to the end of February and the critical number of dry spells for the crop within that period is three times. This information is used for the forecast model in section 6.4.

6.3 Meteorological Indicators

This section provides the results of the computation and analysis of the meteorological indicators that are based on local knowledge. Firstly, section 6.3.1 provides the climatologies of the computed meteorological variables. Secondly, section 6.3.2 visually compares the variables with the drought indicators established in section 6.2 to potentially find spatial and temporal meteorological patterns that could indicate a drought event. Lastly, in section 6.3.3, the results of the pair-wise correlation analysis are provided. The significant correlations are the meteorological indicators eventually used in the prediction of the drought indicators.

6.3.1 Climatologies

A spatial and temporal understanding of the meteorological variables of the research areas are explored through climatologies. The climatologies of the months June to December of the meteorological indicators, except ONI, are plotted and shown in Figure 30. It shows the results for the three different districts, in which spatial and temporal variations can be observed. The following main observations are drawn.

- District Zomba has a lower **maximum temperature** during the year. This could be explained by a higher altitude of the district. Mangochi and Salima are quite similar compared to one another, except during August, September and October when there is a slight difference in which Salima has a higher maximum temperature.
- **Minimum temperature** shows a similar pattern compared to maximum temperature with Zomba having lower temperatures throughout the year.
- From June to September the **wind speed** in the districts differ quite substantially and converge towards each other when reaching December.
- In the months June and July the **wind direction** is similar for every district (coming from South-Eastern directions) and slowly increases in variation in the different districts. Towards November, December (when rain is expected), the wind turns more Easterly. A 'decline' in wind direction can be seen at the end of December when the wind has turned in North Eastern directions.
- The **relative humidity** follows a pattern which is *mirrored to* the maximum temperature, with a peak around December and a minimum around October. This can be explained by the fact that the relative humidity is a computation of the dew temperature and the maximum temperature, as explained in section 3.4.1.

Figure 30: Climatologies of Meteorological Variables

6.3.2 Comparison of Local Knowledge with Drought Indicators

A comparison is made of the drought information with the meteorological indicators of local knowledge to explore meteorological patterns. In this section, the distinctive patterns and examples are elaborated on.

The computed drought indices of 'drought' and 'no drought' seasons are compared with meteorological indicators and shown in Appendix F. The orange squares represent the locations of the districts, where Mangochi is divided into two parts. Based on the local knowledge, regions with distinctive patterns of wind direction and speed for North-Eastern and South-Eastern regions were selected. These regions are illustrated in Figure 31, representing monthly means of wind speed (colour) and direction (arrows). The regions are now called 'Zone NE' and 'Zone SE' and are, together with the orange regions, included in the correlation analysis and forecast model.

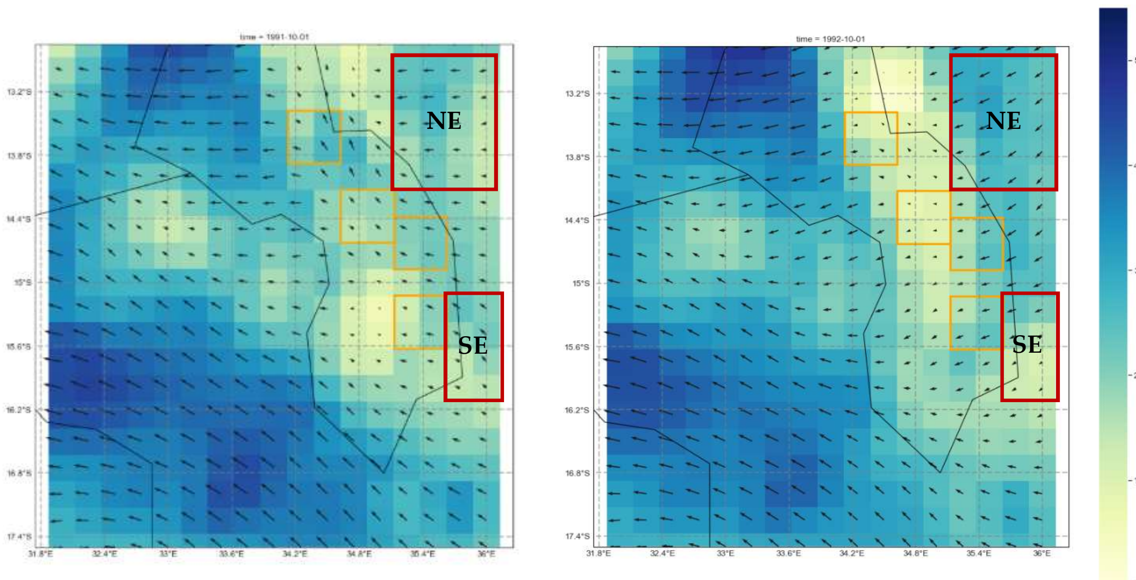

Figure 31: Patterns in Wind Direction for 'Drought' (1991-92) and 'No Drought' (1992/93) Season in October

The meteorological variables are analysed by the creation of time series of wind, temperature, relative humidity. The plots are compared with the described events by the farmers and the computed effective onset and dry spells. An example the comparison this is given in Figure 32. Additionally, wind direction and speed are visually compared to look for patterns a week before and during the onset and during dry spells. All comparisons and visualisation can be found in Appendix F. However, no clear links were observed in the comparison between observation data and the described events. This means that no additional temporal or spatial patterns of the meteorological model were taken into account in the correlation analysis and model.

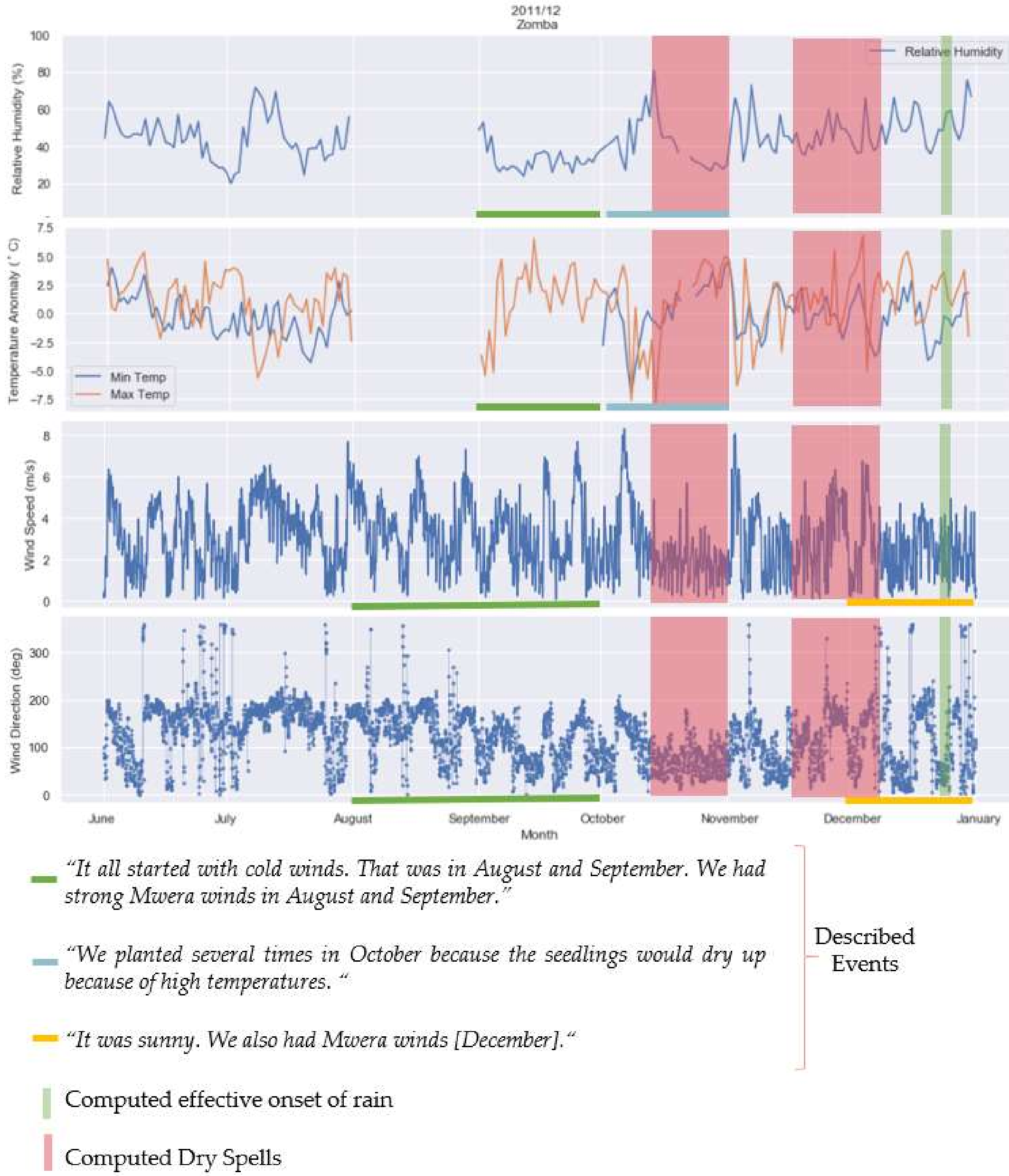

Figure 32: Time Series of Relative Humidity, Wind Speed and Direction for Zomba Agriculture Station Season 2011/12

6.3.3 Correlation Analysis

The three drought indicators for every district or station, are correlated to the meteorological indicators for the months June to December. The results of the Spearman Rank correlations, with corresponding p-values, are shown in Appendix G. The significant correlations ($p<0.75$) are included in the forecast model.

The results show that it differs per observation station how many indicators show a significant correlation. Additionally, different types of indicators (temperature/wind/ENSO) are dominant for different stations. Some stations show little or no correlations.

From the findings of local knowledge in section 4.5.1, it was expected that anomalies in wind and temperature-related variables *before* the dry season are related to anomalies of drought indicators *during* the rainy season. This implies that either positive or negative correlations were expected for the wind and temperature-related indicators in relation to the drought indicators. A negative correlation for temperature-related indicators was expected during June to half August, while a positive correlation during half August to November was expected. A positive correlation was expected for wind-related indicators during the months August to November. Here, positive correlation would mean, for example, that a positive wind direction anomaly (more North-Easterly) gives an increased chance of an increased number of dry spells.

Figure 33 has been created to illustrate and compare what was expected from local knowledge (thin coloured bars in dry season) and what was observed in the significant correlations for different months (thick coloured bars in dry season). On the right side of the graph (rainy season) it can be seen for what drought indicators that significant correlations are be observed.

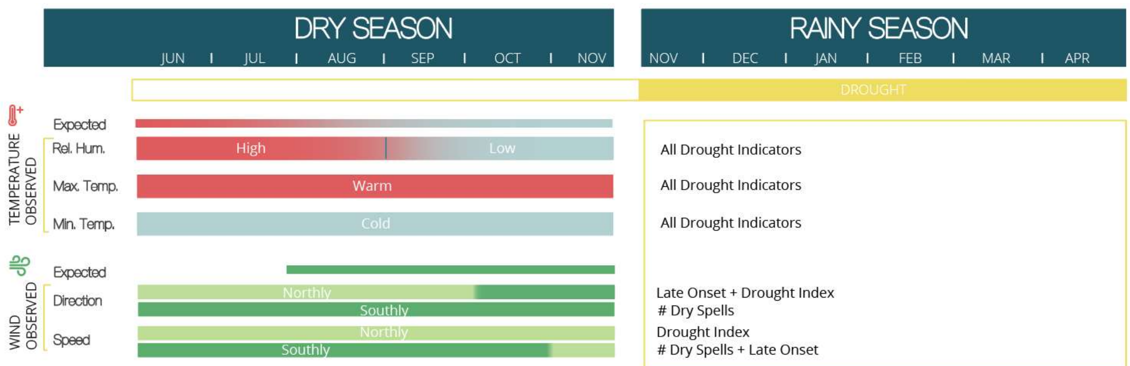

Figure 33: Expected vs Observed Correlations for the Wind and Temperature Indicators

For the temperature-related indicators, the relative humidity indicator shows the expected correlations. However, the maximum and minimum temperature show different results. The observed significant correlations indicate that positive anomalies of maximum temperature during June to November, increase the chance on the occurrence of drought (i.e. a greater number of dry spells, a later onset of rain and a higher drought index). On the contrary, negative anomalies of minimum temperatures give a higher chance of drought.

Wind indicators do not show similar correlations with all drought indicators to what is expected by local knowledge. Different correlations are observed, depending on what drought indicators the meteorological indicator is correlated with. For dry spells, quite similar correlations in comparison to the expected comparisons are seen.

For the ENSO indicator, positive correlations are observed for two out of three districts in the prediction of the number of dry spells. In addition, for all months and all three districts, a positive correlation is seen with the drought index. This implies that a positive ONI gives an increase chance of more dry spells of the severity of the drought index. The exception is Chancellor College Station where a negative correlation with the onset of rain is seen.

6.4 Forecast Verification

This section shows the results of the verification of the forecast model, as explained in section 3.4.5. In section 6.4.1, the predictive value of the meteorological indicators is analysed by varying the thresholds of the drought indicators. In addition, it is explored what type of meteorological indicators (wind/temperature/ENSO) give the forecast its most predictive value. The aim is to analyse whether the meteorological indicators based on local knowledge have an increased predictive value compared to ENSO indicators. In section 6.4.2, the skill of predicting drought indicators that meet all requirements of the farmers, is analysed. This means that only the critical drought indicators are predicted by meteorological indicators that are within the required months of prediction. Additionally, the results of the analysis are spatially visualised.

6.4.1 Predictive Value of Local Knowledge

For different thresholds that are set on the drought indicators, the forecast verification is performed. In this way, the predictive value across different thresholds can be determined, without yet considering the critical thresholds and month of prediction (established in section 6.2 and 4.6.2, respectively). Additionally, it is tested what type of meteorological indicators (i.e. wind, temperature or ENSO related) give the forecast its predictive value.

As explained in section 3.4.4, the thresholds for the drought information are altered to find the predictive value for different thresholds. For dry spell information, the number of dry spells is altered as the threshold. For instance, the model makes predictions for one dry spell or more, two dry spells or more etc. For onset information, since the climatological onset is different for every station due to geographical locations, the onset of rain is interpreted as a relative measure. The mean onset is the 0 threshold, and for every station the + 10, +20 and -10, -20 days of the mean is computed. For example, the model tries to predict an onset later than -20 days from the onset. The 25, 50 and 75 percentile values of the drought index are computed and for every district the model predicts for higher than the 'low', 'medium' or 'high' drought index, respectively. It is expected that with low thresholds the drought indicators can be well predicted, but with many false alarms (high HR, high POFD). Predicting drought indicators with a low threshold, however, does not have much value since it does not give meaningful information. On the contrary, prediction drought indicators with a high threshold gives meaningful information, but it is expected that the results give low hit rates since it difficult to predict. The critical thresholds are meaningful to predict and is further elaborated on in section 6.4.2, since in this section the predictive value of the meteorological indicators is assessed first. In the forecast verification, the metrics are calculated with the same samples as have been used for calibration of the model. This is further discussed in Chapter 7.

From the contingency tables and the corresponding metrics, the HR is plotted against the POFD and FAR. As described in section 3.4.5, the further the results are from the 'no-skill' line the better the predictive value is. Figure 34 shows that all indicators show a good skill across all thresholds. This indicates that the meteorological data has predictive value and confirms existing local knowledge. For the plots of the HR versus FAR is can be observed that when the thresholds are increased and thus more extreme drought information is predicted, e.g. more than five dry spells, the HR decreases and the FAR increases and no reliable forecast can be given. In addition, in the plot of the HR versus POFD for predicting three or more dry spells, more points are observed towards the no skill area. This indicates that the predictive value decreases for the prediction of three dry spells or more.

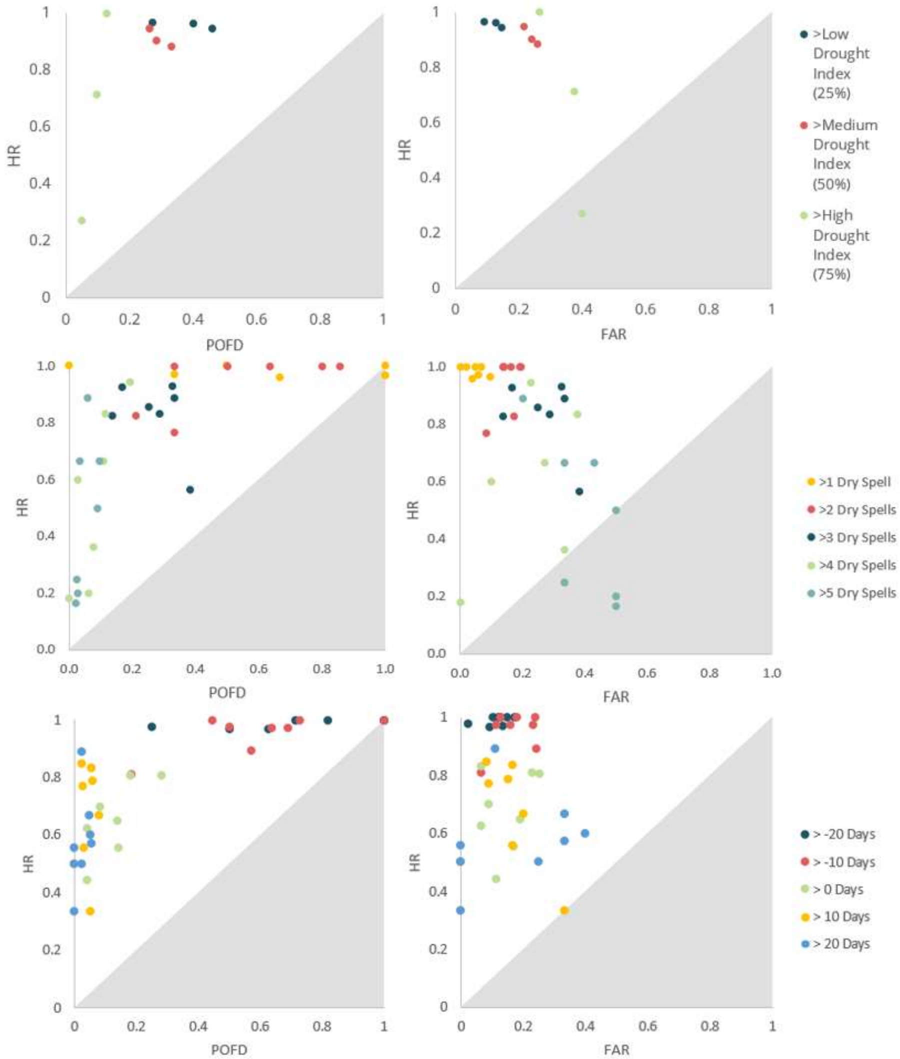

Figure 34: Hit Rate (HR) plotted against the Probability of False Detections (POFD) and False Alarm Rates (FAR) for different thresholds of the a) Onset (deviation from mean in days) b) Number of Dry Spells c) Drought Index (percentile). The grey area represents the 'no skill' zone.

Predictive Value of Indicators

For the critical drought indicators, the performance is tested by varying the indicators that are used. The critical drought indicators are established in section 6.2 and reflects the drought conditions that farmer's agricultural strategies are sensitive to. The robustness of the meteorological indicators in the model is tested by sequentially leaving out one or two predictors. The test is done for all indicators, including those that do not meet the lead time requirements. The aim is to analysis whether there are indicators that are dominant in giving the local knowledge its predictive value. The predictive value is assessed by comparing the total of misses and false alarms. The results can be found in Appendix H and the main findings are summarised here.

For the drought index, a combination of all indicators as predictors gives the best predictive value. Although Salima's drought index predictions are not skilful, the best set of indicators is the combination of wind and temperature. For the drought index in Mangochi and Zomba, the predictive value is mostly dependent on wind indicators.

For Namwera Station (Mangochi District), when only temperature indicators are taken in the prediction of the number of dry spells better values are observed. In all other cases, a combination of all indicators as predictors gives the best values.

The onset of the rainy season is best predicted, when all indicators are combined. Exceptions are Monkey Bay and Nankumba Station (Mangochi District). When only wind indicators are included and the temperature indicators are excluded, a slight improvement can be seen.

From the results above it is observed that the ENSO indicator is never the best predictive indicator. Instead, when wind or temperature indicators were not taken into the analysis the skill decreased. Depending on the location, either the wind, temperature or a combination of both or all gave the best results. In most cases a combination of all indicators shows the highest skill. This is further discussed in Chapter 7.

6.4.2 Forecast Skill for Predicting Critical Drought Indicators

In this section, the forecast skill for the prediction of the 'critical' drought indicators with the required month of prediction is explored. These predictions meet the requirements of the farmers. The aim of this section is to explore whether the forecast model can potentially forecast drought indicators that can inform farmers in their agricultural decision-making. The results are shown through contingency tables and forecast verification metrics for the drought index, number of dry spells and the timing of onset, respectively. Additionally, the forecast verification results are visualised in terms of its spatial variation.

Drought Index

The 75-percentile threshold is assumed to be the 'critical' threshold that could indicate an extreme drought which could potentially inform drought strategies in the month September, as explained in section 4.6.2. The contingency tables for the three districts are illustrated in Table 16. It should be noted that there are relatively few observed events which can influence the validity in the forecast verification metrics since slight changes in the contingency table can change the metrics significantly. By observing the various verification metrics and graphs, the forecast for Salima shows no skill, because of its low HR and TS and high FAR. For Zomba and Mangochi, the results show that the forecast has a good skill for predicting the drought index. The question remains, however, whether the skill for predicting drought for Mangochi and Zomba district is high enough to accurately inform agricultural strategies. This is further discussed in Chapter 7.

Table 16: Contingency Tables for Prediction of Drought

Salima (50)		Observed (11)	
		Yes	No
Sim	Yes	3	2
	No	8	37
		PC	0.8
		FAR	0.4
		TS	0.23
		HR	0.27
		POFD	0.05

Mangochi (38)		Observed (10)	
		Yes	No
Sim	Yes	8	2
	No	2	25
		PC	0.90
		FAR	0.2
		TS	0.67
		HR	0.8
		POFD	0.07

Zomba (42)		Observed (11)	
		Yes	No
Sim	Yes	11	3
	No	0	28
		PC	0.93
		FAR	0.21
		TS	0.79
		HR	1.0
		POFD	0.10

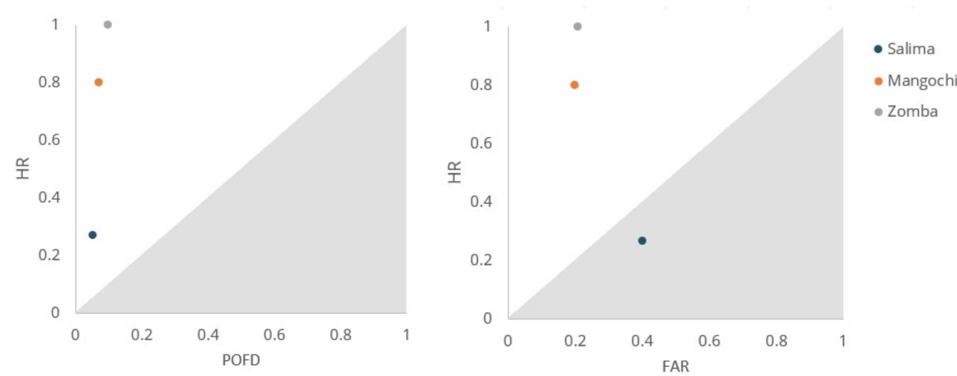

Figure 35: HR plotted against POFD and FAR for the prediction of Drought Index (P75) in September

Number of Dry Spells

From the previous analysis in section 6.2.2, three dry spells of five days seem critical for the farmer's agricultural practices and are therefore chosen as the critical threshold for dry spell information which could inform agricultural decisions in September. Only five out of eleven stations meet the lead time requirements of having significant correlated indicators before September. The corresponding contingency tables and graphs of those stations are presented in Figure 36. It can be observed that there are relatively many observed events which indicates that having three dry spells in the period between the effective onset and February is quite a common phenomenon. This differs however per station and might also indicate that it differs per station what is the critical number of dry spells. When looking at the predictive value, all stations give skill for predicting three dry spells as can also be seen in Figure 36. The ratio of non-and observed events gives an increase of the validity in the forecast verification metrics since it is less influenced by a slight change in the contingency table.

Table 17: Contingency Tables for Prediction of Number of Dry Spells (3) in September

Namwera

		Observed (13)	
		Yes	No
Sim	Yes	18	9
	No	0	10

PC	0.76
FAR	0.33
TS	0.67
HR	1.00
POFD	0.47

Makoka

		Observed (29)	
		Yes	No
Sim	Yes	27	13
	No	2	9

PC	0.71
FAR	0.33
TS	0.64
HR	0.93
POFD	0.59

Chancellor

		Observed (18)	
		Yes	No
Sim	Yes	15	5
	No	3	19

PC	0.75
FAR	0.25
TS	0.65
HR	0.83
POFD	0.36

Chingale

		Observed (27)	
		Yes	No
Sim	Yes	20	3
	No	7	15

PC	0.78
FAR	0.13
TS	0.67
HR	0.74
POFD	0.17

Zomba Agri

		Observed (23)	
		Yes	No
Sim	Yes	20	6
	No	3	11

PC	0.78
FAR	0.23
TS	0.69
HR	0.87
POFD	0.35

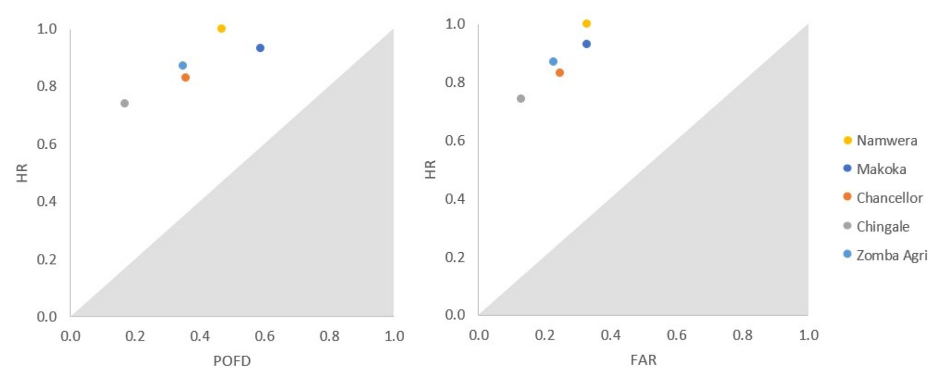

Figure 36: HR plotted against POFD and FAR for the prediction of Number of Dry Spells (3) in September

Timing of Onset

The farmers like to know in August and November whether the (effective) onset will be late or not. This can inform the start of the land preparations and the planting dates, respectively. About 10 days from the mean is seen as late and thus taken as critical threshold, as explained in section 6.2.2. The resulting contingency tables for the forecast in August are presented below. Six stations out of eleven stations meet the requirement of delivering a skillful forecast in August. It can be observed that all stations, with the exception of Salima Station, give a skillful forecast.

Table 18: Contingency Tables for Prediction of Onset in August

	Salima (12)	Namwera (13)	Monkey Bay (12)	Nam-kumba (12)	Chingale (23)	Zomba Agri (23)
Sim Yes / Obs Yes	2	11	7	6	9	10
Sim Yes / Obs No	1	9	4	2	4	4
Sim No / Obs Yes	10	2	5	6	5	2
Sim No / Obs No	36	32	21	28	30	34
PC	0.78	0.80	0.76	0.81	0.81	0.88
FAR	0.33	0.45	0.36	0.25	0.31	0.29
TS	0.15	0.50	0.44	0.43	0.50	0.63
HR	0.17	0.85	0.58	0.50	0.64	0.83
POFD	0.03	0.22	0.16	0.07	0.12	0.11

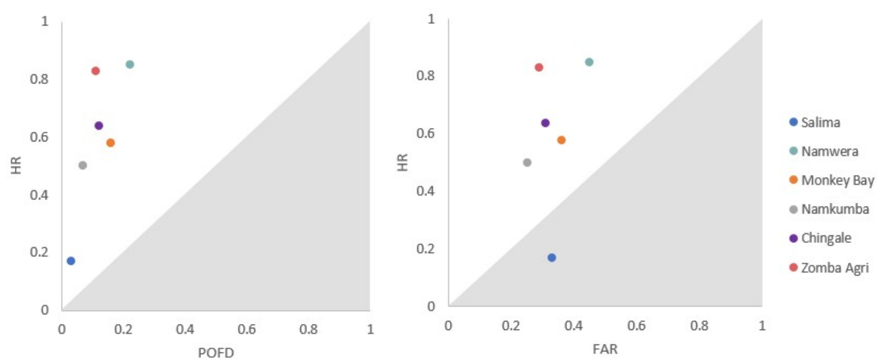

Figure 37: HR plotted against POFD and FAR for the prediction of Timing of Onset (later than 10 days) in August

When the forecast should inform the planting dates in November, more stations (eight) meet that requirement. The resulting contingency tables can be found in Table 19 and Figure 38: HR plotted against POFD and FAR for the prediction of Timing of Onset (later than 10 days) in November. It can be observed that the overall forecast skill is improved compared to the forecast given in August. Again all stations, with the exception of Salima Statin, show some degree of skill. It differs per station how forecast performs.

Table 19: Contingency Tables for Prediction of Timing of Onset in November

	Salima (12)	Namwera (13)	Monkey Bay (12)	Nam-kumba (12)	Makoka (13)	Chancellor (9)	Chingale (23)	Zomba Agri (23)
Sim Yes / Obs Yes	4	11	8	6	6	5	11	10
Sim Yes / Obs No	2	1	3	0	0	1	2	4
Sim No / Obs Yes	8	2	4	6	7	4	3	2
Sim No / Obs No	35	40	22	30	37	32	32	32
PC	0.80	0.94	0.81	0.86	0.86	0.88	0.90	0.88
FAR	0.33	0.08	0.27	0	0.00	0.17	0.15	0.29
TS	0.29	0.79	0.53	0.5	0.46	0.50	0.69	0.63
HR	0.33	0.85	0.67	0.5	0.46	0.56	0.79	0.83
POFD	0.05	0.02	0.12	0	0.00	0.03	0.06	0.11

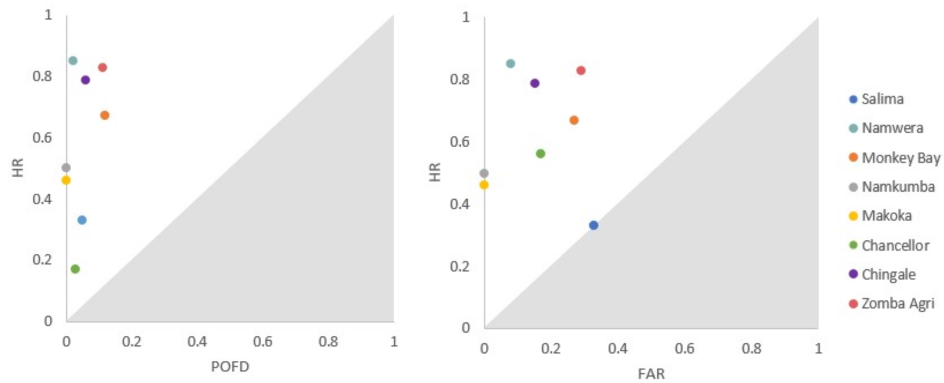

Figure 38: HR plotted against POFD and FAR for the prediction of Timing of Onset (later than 10 days) in November

Spatial Differences

For all drought indicators, excluding the forecast for the timing of onset in August, the results are spatially visualised in Figure 39. The hit rates and false alarm ratios were chosen as forecast metrics. To further explain this, the practical meaning of HR and FAR are explained. When including the HR, you would like to know how often the forecast has predicted the drought (=hit) in relation to when the forecast has not predicted a drought, but a drought was observed (=miss). In relation to the FAR, you would like to know how often the prediction is false when a drought is forecasted (=false alarm) in comparison to the number of correct forecasts (=hits). In Figure 39, it can be observed that some stations have grey values which indicate that there are no significant correlated indicators for that stations and month of prediction. The uncorrelated stations are mostly in Salima and Mangochi districts. In contrary, the stations located in Zomba have an increased prediction value for the drought indicators.

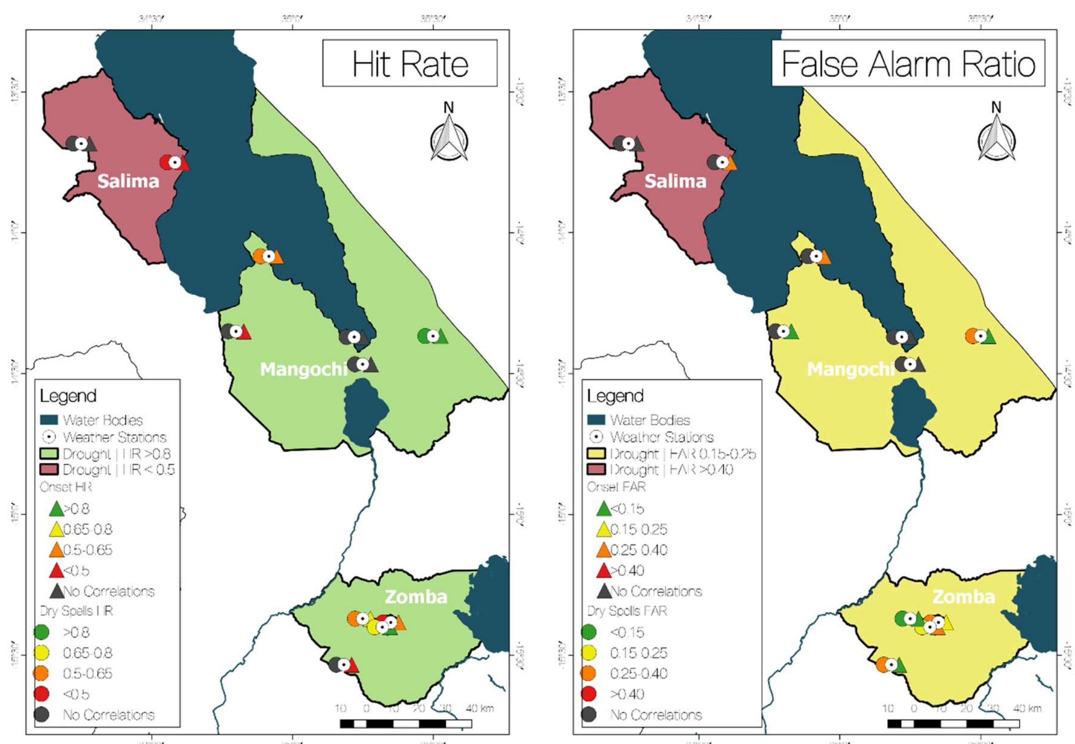

Figure 39: Spatial Overview of the Hit Rates and False Alarm Ratios for Forecast of Drought Indicators

7 | Discussion

By approaching the drought information from the smallholder farmers needs and perspective, the findings of this study suggest that certain drought indicators may inform the decision-making of the farmers in their agricultural strategies and could potentially be forecasted through local knowledge. This chapter provides a discussion on the findings of the forecast model informed by local knowledge (Chapter 6) in relation to the farmer's context (Chapter 4). Furthermore, the current forecast system (Chapter 5) is discussed in perspective to the farmers (Chapter 4).

7.1 Forecast model linked to agricultural strategies and local knowledge

This section provides a discussion on various aspects concerning the findings of the forecast predictions informed by local knowledge and the application of the forecast to farmers in relation to adverse impact and the drought indicators produced. In doing so, it reflects on research questions one and three.

7.1.1 Local knowledge: Meteorological Indicators

Based on the results of the predictive value of local knowledge, local knowledge indicators used in this study could be valuable for forecasting in South Malawi. Some observations are made concerning the local knowledge indicators and are discussed here.

It was observed that relative humidity shows the same trends to how farmers explained their local knowledge. This could be explained by the fact that farmers 'feel' temperature (thermal sensation) and that for example 'hot' is interpreted by high relative humidity (Berglund, 1998). In turn, although the maximum temperature is relatively high but the relative humidity low, it might still be felt as relatively cold. For indicators in the wind category, no similar trends were observed. Within this study, only limited spatial regions have been explored for the wind indicators. This might explain the variances among the results. In addition, wind direction, speed and temperature have been analysed separately. However, farmers have indicated, for example, 'cold Mwera winds' which implies a combined indicator of both wind speed, direction and temperature. Exploring those combined indicators can lead to new findings on the predictive value of meteorological indicators informed by local knowledge.

Farmers across the different research locations explained their meteorological predictions through local knowledge on a different temporal scale (section 4.5.1). This is in agreement with the results from Chapter 6, where the local knowledge is analysed through observation data. The results of both correlation analysis (section 6.3) and the influence of the indicator analyses (section 6.4) suggested that local knowledge varies on a temporal and spatial scale. Some areas had 'stronger' and more variations in the indicators on different time scales (section 6.3, Appendix G). In addition, it differs per location which local knowledge indicator was most important in giving the forecast its predictive value. Comparing the local knowledge indicators with the ONI indicators, revealed that the local knowledge indicators are more dominant in giving the forecast its predictive value than the ONI indicator. Local knowledge indicators could be a more local representation of larger ENSO influenced processes. It is therefore argued, as in agreement with Briggs (2005) and Trogrlić et al., (2019), that local knowledge varies between different localities in time and space and that its local character is what gives it power and relevance.

Current seasonal forecasts mostly rely on large processes in the atmosphere and oceans like the ENSO. This study, however, focusses on district or EPA (station) level and tries to focus on local processes relevant for farmers. The results from the correlation and forecast verification analysis (section 6.3 and section 6.4) suggest that the ENSO phenomenon has a predictive value for predicting a more extreme drought, but limited value for more local, small scale processes such as the onset of rain or dry spells.

It is therefore argued that the use of wind and temperature related indicators, and not just ENSO, should be further investigated when (seasonally) forecasting locally relevant agricultural drought indicators.

The results from the spatial variation analysis suggest that the stations in Zomba district have the best predictive value for predicting the drought indicators. Indeed, other stations in Salima and Mangochi show less predictive value or inconclusive results, due to limited correlated meteorological indicators that met the month of prediction requirements. This spatial variation could be explained by geographic features that could influence meteorological processes. The prominent winds in Malawi is easterly (from the Indian ocean). Salima and Mangochi are, in contrary to Zomba, neighbouring districts of Lake Malawi. The lake may well influence the atmospheric conditions and influence the wind conditions in the region. Other conditions such as differences in altitude of the stations or the quality of the observations data and limited occurring drought condition therein may possibly also have influenced the findings. In addition, it was found that Mangochi and Zomba districts have an increased predictive value for the forecast of the drought index and may be explained by the influence of the El Ñino Southern Oscillations (ENSO). During an El Niño, Southern regions in Malawi are more likely to experience droughts than central and northern regions. This phenomenon may be reflected in the decreased predictive value of the most northern district (Salima district), as was observed in Figure 39.

From the results in Chapter 4, it became clear that farmers would like to receive information on EPA scale. The size of an EPA is roughly 30 to 50 km in length or width and would mean that the forecast should be given on that scale. The density of the current observations network does not reach the required density to accurately predict at EPA scale in most of the country. Currently, only a small amount of stations shows a predictive value for the prediction of drought indicators. This would imply that information could only be given to farmers closely located to the station with predictive value and could not reach many farmers. Either increasing the density of the observations network or using well-validated reanalysis data as complementary data source could be a solution to reaching EPA scale. The results of the forecast verification (section 6.5) suggest that the ERA5 reanalysis dataset with a resolution of 0.25 x 0.25° (~ 30 x 30 km) which is used for the wind direction, wind speed and relative humidity indicators are of good enough quality since the forecast model gives skill in predicting drought indicators.

In predicting the onset of rain in section 6.4.2, the month of prediction was varied and included the months of August and November. This gives different lead times of the forecast and some observations were made in the forecast verification results. It was observed that with an increase in lead time, fewer station could provide a forecast that meets the requirement of having significant correlated indicators in or before the month of August. Additionally, the skill of the forecast decreased with the increase in lead time. This is expected since the longer the lead time the higher the uncertainty is for the prediction of an event. It should be noted, however, that the lead times used in this research do not yet consider the duration of the forecast dissemination. Potentially, the inclusion of available temperature and wind forecast products of various meteorological institutions in the forecast model could be valuable to extend the lead time. Here, (dynamical) forecasts products of temperature and wind can be coupled to statistical models (e.g. regression models) that informs its drought predictions on local knowledge. In brief, a set of local knowledge informed forecast productions (wind and temperature) may be combined with a statistical model that predicts the drought indicators.

The results of the forecast verification are not analysed on its robustness, which is so far a major limitation in the research. Further analysis, such as a bootstrapping analysis, is needed to further investigate the robustness of the model and the corresponding skill analysis. This would reveal how robust the forecast verification metrics are as a result of the relatively small sample size.

7.1.2 Application to farmers: Drought indicators and Impact

This research aimed to produce a forecast that is in coherence with the farmer's agricultural decision-making. Some challenges in producing such a forecast are discussed in this section. Further research should be done on varying the critical thresholds for drought indicators, in combination with the farmer's willingness to take 'risky' decisions. This should be done in a continuous and repetitive process with the farmers.

Comparison of the described event by the farmers and the observations data, together with the APES reports and literature, have contributed to the definition of the predicted drought indicators. Even still, the computation of the drought indicators remains sensitive to defining the critical threshold and its implementations can locally differ. Further research should be done that verifies whether the farmers agree with the established three drought indicators.

The drought index is based on the farmer's interpretation of a rainfall season that is associated with drought. There are, however, limitations in the computation of the drought index. This reflects in both the 'linkage' from a drought index to the agricultural strategies and the applicability a PCA. In the PCA results, the percentage of explained variance of the first principle was not high, but acceptable. The PCA method may not be the best suited method to compute an overall drought index. The possible reason being that the PCA method can capture linear correlations between features, but fails when this assumption is violated (Shlends, 2014). Since there is no historical data on impact or decision data, no link could be established between when a drought index is 'high enough' to opt for certain strategies, such as the decisions for making box ridges. Most importantly, farmers may not relate to one composite index. Single informative rainfall variables such as the onset and dry spells might better inform farmers because these are indicators that can be directly understood by farmers. This also indicates that drought can be caused by different types of critical events like confirmed in various studies, including Barron and Okwach (2005), Allen and Ingram (2002) and Rockström and Falkenmark (2000). As was encountered in this research, the season might seem reasonable by observing rainfall totals, but the season before might be the critical factor. Other critical events might be a long dry spell that could destroy the whole crop, or a late effective onset because of small dry spells. This was also observed in the described events by the farmers in section 4.2. The season 2000/01 had a late effective onset due to a dry spell at the beginning of the season and led to high food insecurity even though the total seasonal rainfall was not very low. As a result, although this season led to food insecurity, the season 2000/01 was labelled as 'no drought' in the composite drought index.

For that reason, the overall state of the season was also indicated through the number of dry spells and the effective onset of rain was computed as drought indicators. This is in agreement with another case study in Burkino Faso which stated that smallholder farmers show the most interest in receiving forecasts of the start of the rainy season, and whether there would be interruptions in rains (Ingram et al., 2002). However, there should be additional research that could verify whether this is actually the information the farmers in Malawi wish to receive. This highlights the importance of having continuous feedback with the farmers. For instance, providing short-term forecast on upcoming dry spells within the season might inform the timing of replanting. Predicting this information is, however, not further studied in this research.

Ziervogel et al. (2005), suggests that if forecasts are not correct 60-70% of the time, then they are unlike to benefit farmers and may do more harm than good. In the forecast verification metrics, the Probability Correct (PC) metric is indicating this percentage. All the critical thresholds for the drought indicators meet this standard. However, one metric (or more) cannot inform whether a forecast may be beneficial for farmers. It remains up to the farmers whether they are willing to adapt their decisions making and accept wrong forecast. For this to happen, they should be well informed and the potential risk of acting on a forecast should be communicated and if possible mitigated e.g. by social security safety nets such as insurance. For making a decision, an investment has to made which can be in the form of financial investments, like buying hybrid seeds, or time investment for extra preparations. Some decisions might have more positive impact than others and the adverse impact of making the decision wrongfully might also differ per decision. For instance, the decisions of making box ridges to capture soil moisture in the field was an important decision that takes a relatively large time investment but can possibly lead to a substantial reduction of a poor rainy season. However, the adverse impacts are also substantial. The box ridges give an increased risk of having waterlogging in the field in times of floods and heavy rain. When a forecast is given, the farmers should be well informed how accurate that forecast is and what this means to their farming practices and risks. This should be carefully considered and communicated by stakeholders providing forecast information. In this way, farmers can decide for themselves what kind of decision they might take. This is in line with the ready-set-go approach of the Red Cross (Bazo et al., 2019). Here, a highly accurate forecast may inform high impact decisions with potentially high investment, while less accurate forecasts may inform 'no-regret' decisions which will improve the crop production no matter the climatic conditions. This research has not explored what risks farmers are willing to take for different decisions in their agricultural strategies, although this may add important findings to the research. Participatory research methods like serious games maybe useful tools to explore this and could help find further requirements of what the accuracy of the forecast should be at different decision moments (Suarez et al, 2014).

This study has generalised the strategies of farmers. However, no single farmer makes the same decisions and the factors that influence those decisions differ from farmer to farmer. In addition, certain strategies like buying hybrid seeds may not be available for everyone due to e.g. accessibility or financial issues. Despite that limitation, Mulwa et al. (2017) found that making climate-related related information can still motivate farmers to adapt.

7.2 Communication and Dissemination in The Current Drought Information System

This study highlights the importance of including and understanding the dissemination process when researching (seasonal) forecast that is tailored to a certain user. An understanding of the current drought information flow is formed, together with the farmer's preferences and the predictive value of local knowledge. By comparing the findings some topics are discussed in this section.

7.2.1 Strengths and Weaknesses

The findings on the current drought information system and the preferred received forecast information of the farmers illustrate that the systems could be improved and better tailored to the farmers. This study, therefore, highlights the importance of designing forecast information that best fits the end-users, in this case the smallholder farmers. This means that the end-user and their needs need to be better understood such that their needs are built into the design and dissemination of the forecast system, as in agreement with Johnston et al. (2004).

Depending on the district and location, farmers receive different frequencies and types of forecast information, being it from the radio, extension officers, NGO's etc. Stakeholders mention that it is due to the funding structure that not all districts are receiving the same amount of funding. The Malawian government is heavily dependent on the funding of NGOs with each NGO having their own 'target districts' and funding schemes (Hendriks & Boersma, 2019). This reflects in the inequal inclusion, frequency and type of provided forecast information for farmers in different districts. Not all forecast communications to farmers and extension officers are in the local language, which hinders understandability of the forecast information. Most trusted communicators by the farmers are the extension officers and the radio. The short-term forecasts are well received through the radio. The establishment of farmer listening groups enables farmers to ask questions and to discuss the implementations of the information with fellow farmers. However, not all farmers receive information via the radio due to the limited amount of radios and in some area's extension officers visit unregular or infrequent due to lack of resources. It is, however, important that the timing of the receival of information aligns with the decision points (Hill & Mjelde, 2002). Moreover, some forecasts have a scale of the five meteorological zones which is too large for the farmers to be locally relevant and decreases both the applicability and credibility of the forecast. A forecast with the scale of an EPA would be better. The seasonal forecast poster was first received by farmers for the 2018/19 season and included a forecast on EPA scale. The poster included an indication of the date of the onset of rains which is highly appreciated. However, the results suggest that although the forecasted total rainfall amounts alone do not support the farmers in their strategy-making, if it is combined with advice that is applicable to their farming practices it can be useful. Extension officers and the radio both make a translation from forecast to agricultural advice. Participatory training (like PICSA) are, in turn, highly appreciated by the extension officers to make that translation. The seasonal forecast is best appreciated if it is communicated by extension officers that include the explanations of the forecast, its meanings, potential strategies and management of resources. This suggests that the dissemination process can influence the effectiveness of forecast information, especially concerning seasonal forecast information. It highlights the importance of training the extension workers on interpreting the forecast to relevant advice. This is in agreement with various other studies, such as Soares et al. (2018) and Ingram et al. (2002).

This research demonstrated that visualisation of this system helps to better understand the dense and complex process, as mentioned by Ziervogel and Downing (2004). Although the method and analysis applied in this thesis (see sections 3.3 and 5.2) has provided insight into how the drought information system could be improved, it has limitations. The underlying processes and causes of gaps in this system, such as the finance structure and sustainability of projects remain hard to resolve. The timestep between 'nodes' is difficult to determine due to the intrinsic process in which the seasonal forecast is disseminated. At different locations and for different stakeholders, the information may be received at different times. It was observed that the dissemination of the forecast is often reliant on the funding of external parties which in turn determine the 'speed' of the dissemination process and thus the timestep between the different administrative levels and channels. The limitations of the visualisation of the stakeholder networks are in agreement with Ziervogel (2002), who mentions that it has a limited ability to pick up some of the institutional and cultural factors that may constrain improved dissemination.

7.2.2 Opportunity: Inclusion of Local Knowledge

This study argues for inclusion and integration of local knowledge in forecasting for climate-related issues, which is in line with other studies (Kalanda-Joshua et al., 2011; Nkomwa et al.,2014; Trogrlić et al., 2019). It is expected that it will improve the understandability, credibility and applicability of the forecast in communities where local knowledge on meteorological indicators is available. Among others, Patt et al., (2002) state that the seasonal forecast should agree with local knowledge before there is an uptake of the forecast into agricultural decisions. When looking at the approach established by Plotz et al. (2017), as explained in section 2.4.2, this study would argue that a combination of both approaches would best fit the drought information system of Malawi. Both the 'scientific approach' could be integrated through including meteorological indicators into forecasting and the 'consensus approach' structure is already in place to some extent through extension services. However, this study found limited integration of local knowledge in the current procedure. Farmers often do not mention local knowledge in the question related to forecast information. On the contrary, other stakeholders do mention that the uptake of the seasonal forecasts is limited when it is not in agreement with the local knowledge signs. As described by Plotz et al. (2017), the value of local knowledge is being eroded by two main challenges: first, the rapid loss of local knowledge due, in part, to rapid urbanization and emphasis on conventional science; and second, the reduction of value of local knowledge for forecast methods due to apparent changing reliability and loss of the traditional indicators. There are growing concerns among many communities that the effectiveness of some biological indicators for forecasting have reduced due to changes in the climate (Plotz et al., 2017). This second challenge is a concern that was also indicated by the farmers and other stakeholders, as explained in section 4.5.1 and 5.3. These factors could constrain the integration of local knowledge in the current drought information system. This study, however, found that with a recent dataset the meteorological indicators have predictive value. These findings suggest that, despite climate change, local knowledge based on meteorological signs are not decreasing in its reliability. On the contrary, it could even create opportunities in a changing and more unpredictable environment.

Based on the predictive value of the local knowledge and its possibility to inform agricultural decisions, it is argued that organisations that deal with either the production or the dissemination of forecast information to farmers, should tailor the information to their needs. This is, however, most relevant to farmer communities who have existing knowledge on drought predictions. When scaling up the approach, meteorological indicators should be locally established. More robust and extensive meteorological models that combine both dynamical and statistical approaches could be of use in producing such drought forecasts.

8 | Conclusions & Recommendations

The agricultural practices of smallholder farmers and decisions surrounding their strategies are influenced by drought. Farmers explain drought as (a series of) critical events in the rainy season that destroy their crop and eventually leads to food insecurity. These critical events mostly include a late onset of rain or dry spells during the growing phase of their crop. Drought forecast information can inform farmers to adapt their strategies in time. The decisions made in their drought-related strategies are made at various moments, both before and during the rainy season. The timing of the onset of rain can inform the timing of ridge making and planting. An overall indication of the 'dryness' of the rainy season can inform farmers to opt for the type of ridges to construct or to plant alternative seeds or crops. Preferably, the forecast should be given at a local relevant scale and communicated in their local language via the radio or extension officers. Farmers currently receive forecast information that originates from local knowledge and the Department of Climate Change and Meteorological Services (DCCMS). In addition, farmers make their own predictions of drought indicators in the upcoming rainy season by using temperature and wind observations as signs.

Although farmers have their own strategies and timing of their decision-making, this research has generalized some of the opinions and strategies to develop 'requirements' which a forecast should meet. Based on the findings above, this includes information on the onset of rain in August and November and an overall indication of the 'dryness' of the rainy season in September. The forecast should be on a scale that is locally relevant (EPA level). By comparing the described events of the farmers and observation data, the drought indicators and meteorological indicators have been established. Here, drought is characterized by the number of dry spells, a composite 'drought index' of associated rainfall variables by the farmers and the timing of the onset of rain that is effective for planting.

This research consequently established a forecasting model, based on meteorological variables from local knowledge which can complement the forecast variables from the DCCMS. A sequential threshold model was established that relates annually monitored meteorological indicators based on wind direction and wind speed, temperature and relative humidity anomalies and ENSO *before* the rainy season, to the occurrence of dry conditions *during* the season. Dry conditions were expressed in the drought indicators that farmers require for their agricultural decision-making.

A skill analysis of forecasting incorporating all the above dimensions shows that the accuracy of the forecast differs per location with an increased skill to the Southern locations, geographically further away from Lake Malawi. In addition, it is also location dependent whether the contribution of wind, temperature or ENSO indicators gives the most predictive value. The results show that, for almost all stations and districts, a combination of all indicators have the best predictive value. In addition, the results show that local knowledge indicators have an increased predictive value in forecasting the locally relevant critical events in comparison to the currently used ENSO-related indicators by the DCCMS.

The current forecast information that smallholder farmers receive in Southern Malawi can be more adapted to the farmer's needs. This research argues that the inclusion of local knowledge can potentially improve the current forecast information to farmer's requirements and context. Thereby, it could potentially increase trust and understanding of forecast information.

The findings may be insightful and relevant for actors or research fields involved in drought forecasting in relation to, e.g. Disaster Risk Reduction (DRR) approaches and designing user-specific forecast information.

Recommendations

Some recommendations for further research are made for both this research and other fields, together with the implications for relevant stakeholders in the drought information system of Malawi.

Future Research

It is recommended to further analyse the model used in this research on the robustness of the forecast verification scores related to the sample size of the datasets. The datasets only capture a limited amount of drought events. This could be done through bootstrapping techniques in which new sample sets are generated by random sampling from the existing dataset. In addition, a set of available (seasonal) forecast products that are related to local knowledge (temperature and wind-related products) may be explored. These forecasts can be combined with a statistical model that predicts the drought indicators. Also, more sophisticated models like machine learning models can be explored.

In addition, by collecting historical data on agricultural decisions a link may be established between what decision has been made in the past and which of those decisions are 'regret' decision for those historical rainfall seasons. In this way, the thresholds in the model can be linked to decisions and be more applicable to the farmer's strategies. Participatory research methods, such as serious games, could explore the required skill of the forecast for every decision made. Results of the games may be incorporated in the forecast model and hence adapt it even more to the farmer's decision-making process. In any case, there should be a continuous 'feedback loop' with the farmers to ensure the forecast information is best tailored to the farmers. These recommendations fit within a range of interdisciplinary fields, such as a combination of natural (e.g. meteorological) and social (e.g. behavioural and communication) sciences.

Implications for Stakeholders

For the relevant stakeholders within the drought information system of Malawi, some implications and suggestions are made based on its strengths and weaknesses found. The recommendations are elaborated on per 'information channel', as described in section 5.2.

Forecast Production

Few weather observation stations are present in Malawi, resulting in less accurate forecasts that largely rely on large-scale processes like ENSO (Pulwarty & Sivakumar, 2014). Increasing the density of the observation network could enhance forecast products. In addition, the inclusion of meteorological indicators used in this method could be incorporated into existing models of DCCMS, to forecast locally relevant drought phenomena. During one of the interviews, it was mentioned that people often destroy the observations stations. Involving communities when installing new weather station could be helpful since some farmers have shown interest in how the weather stations work. For example, schools could be involved in the maintenance of the stations as part of an educational program. Furthermore, by encouraging other (inter)national partnerships, capacity and opportunities can be created. For instance, by partnering up with the media, private (agricultural) sector and other (international) meteorological institutions. For example, journalists could be trained to 'translate' weather and climate forecast to agricultural advice or seeds suppliers could promote drought-tolerant seeds when a drought is expected. In addition, DCCMS could explore the use of forecast products of other meteorological institutions.

Humanitarian Organisations

With the increase of forecast applications in humanitarian and developing organisations that implement projects related to disaster risk reduction and climate services, the approach and results of this study could be insightful. Organisations should carefully consider the provision of seasonal forecasts with limited skill to farmers since it could have adverse impacts of the farmer's livelihoods.

In addition, valuable resources could be 'wasted' when there is limited uptake of the forecasts into the decision-making of smallholder farmers. This research emphasizes that organisations use existing communication channels and formats with a forecast that includes local knowledge. Alternatively, organisations could consider taking 'no-regret' actions, such as distributing (drought-tolerant) sweet potato vines and keep the risk of acting upon seasonal forecast to themselves. Another option that could be considered is the introduction of financial safety nets (e.g. microloans) that may allow farmers to make decisions that are less risk-averse. This would make the forecast information easier to use even if they are sometimes incorrect. It is key that farmers are included and trained (e.g. budgeting, marketing) in the project implementations. As was pointed out before, humanitarian organisations have a big financial role in Malawi and may influence the funding received by different actors. It remains important that funding is reached at lower administrative levels to ensure that forecast information is received timely by the farmers.

Disaster Department

The disaster department is mandated to disseminate and communicate the forecast produced. The forecasts could be more effectively issued by focussing on what communication channels are best appreciated by the farmers. For drought, extension officers and the radio are the valued communicators and their service should be made widely available across the country. Here, funding structures play an important role as they influence the timing, frequency and availability of the forecast information provided to farmers. Better collaboration between the disaster department, agricultural extension services, (humanitarian) organisation and radio could, therefore, be established.

Extension Department

The extension department has a key and important role to play in translation of forecasts to agricultural advice. The extension officers are well trusted by the farmers and, in turn, the extension officers highly appreciate training (like PICSA) on the interpretation of the forecast to relevant agricultural advice. Drought forecast information should be one of the components of that advice, as currently being done. Farmers have indicated that the general explanations and demonstrations on their agricultural practices, and knowledge transfer on, for example, healthy cooking methods are very helpful in their lives.

Media

The radio is a highly valued media channel by the farmers since it is well accessible, effective and has the possibility to ask feedback. However, not all farmers receive information via the radio due to limitations in the distribution of radios. Media channels could look for new opportunities to incorporate the agricultural advice, including forecast information, on the shows and work together with relevant partners to make the radio even better accessible to all farmers.

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Appendix A | First Data Collection Program

In the period of 23th of April to 10th of May, a fieldwork data collection will take place in Zomba, Mangochi, Salima and Lilongwe. A graduation internship at Malawi Red Cross Society is done afterwards.

Type of information to collect

National and District Level (KII):

➢ Information on existing drought forecast models and early warning early actions systems in Malawi

➢ Understanding the dissemination of information flow and content from forecast to smallholder farming communities

➢ Understanding of ODSS system and current usage of that system (crop calendar, drought monitor and rainfall forecasts)

➢ Get feedback from partners

Area level (KII):

➢ Understanding information dissimilation from extension worker to farmer

➢ Understand the current gaps and opportunities of the climate service

Community level (FGD):

➢ Information on local knowledge

➢ Received forecast information

➢ Understanding the agricultural strategies and climate-related risks of smallholder farming communities

Locations

Data collection will take place at the following locations.

National Level	Area level (EPA officers)	Community level
Lilongwe	Salima	Khombedza
	Mangochi	Nankumba, Mbwadzulu, Maiwa
	Zomba	Mpokwa

Preliminary program

The first three weeks will be in collaboration with the NERC SHEAR IPACE project on community and district level:

- 1 Extension Planning Area (EPA) each in Zomba and Salima, and 3 EPAs in Mangochi
- 2 Farmers Focus Group Discussions (FGD) + 1 Agricultural Extension Officers meeting / FGD in each EPA
- For each EPA Agricultural Extension Officers FGD can be done on the same day as farmers FGD based on their availability.

A graduation internship is then planned whereby a pilot serious game will be developed to gain data on agricultural strategies and decision-making and perceived forecast information. A preliminary itinerary can be found below.

WEEK OF **22.04.2019 (NERC SHEAR IPACE)**						
District	Mon	Tue	Wed	Thu	Fri	Sat/ Sun
Lilongwe / Salima	**Lilongwe -** Planning field activities	**Salima -** Khombedza EPA - Farmers FGD	**Salima -** Khombedza EPA - Farmers FGD	**Mangochi -** Nankumba EPA - Farmers FGD	**Mangochi -** Nankumba EPA - Farmers FGD	x
WEEK OF **29.04.2019 (NERC SHEAR IPACE)**						
District	Mon	Tue	Wed	Thu	Fri	Sat/ Sun
Mangochi	**Mangochi -** Mbwadzulu EPA - Farmers FGD	**Mangochi -** Mbwadzulu EPA - Farmers FGD	**Labour Day**	**Mangochi -** Maiwa EPA - Farmers FGD	**Mangochi -** Maiwa EPA - Farmers FGD	x
WEEK OF **06.05.2019**						
District	Mon	Tue	Wed	Thu	Fri	Sat/ Sun
Zomba / Lilongwe	**Zomba -** Mpokwa EPA - Farmers FGD	**Zomba –** Mpokwa EPA - Farmers FGD	**Return to Lilongwe**	**Lilongwe**	**Lilongwe**	x
13.05.2019 – 20.07.2019 (Graduation Internship at MRCS)						

Strategy Community Level

Focus group discussions (FGD) in the five EPA research areas are held in collaboration with the NERC SHEAR IPACE project. The procedure of the FGDs has been adapted from the researchers at University of Leeds, since it has been done in collaboration with them.

Who to interview

- Groups of Smallholder Farmers

FGD can be composed of both male and female and should involve between 5 and 10 participants. Ideally, elderly people within the community are to be included. It should be the case that those invited feel at ease with each other and that they have a similar level of readiness or capacity to talk. Should this not be the case, for example when a chief is participating, we might opt for having separate discussions with the quieter people, because being silent does not necessarily mean that you do not having anything to say. Some triangulation or cross-checking of information may be needed. This can be done by comparing what different focus groups, for example a group of women and a group of men, have said about the topic or by observation (Bolt, 2001).

Procedure FGDs

The research team should be composed of one facilitator, one translator and the discussion should be audio recorded. The audio files need to be fully transcribed into English by a translator. Observations about the nature of responses and group dynamics should also be noted (for example, if responses are being dominated by one individual; that there doesn't appear to be consensus; that participants do not appear to understand the question etc.). All outputs should be photographed and coded.

Initiation

Seek and follow advice from key informant (District Officer or village head, for example) about appropriate ways of beginning the interview, e.g. with introductions from seniors, allowing everyone to introduce themselves, opening prayer etc.

Brief introduce research and purpose

Thank you for accepting to participate in and contribute to this exercise which is being conducted as part of the IPACE-Malawi project.

This exercise and discussion is designed to build an understanding of agricultural systems and the influence of drought, as well as to understand the weather information that you currently receive and how it is used. You will be asked to collectively build a typical agricultural calendar and think about how practices/field/weather conditions change in extreme years.

The exercise will take about two hours. You are reminded that you do not have to answer any questions that you do not feel conformable with, and that you are free to withdraw at any time.

Record the following

Interview information:

- Date of Interview
- Start Time
- End Time

Participant's information:

- Participant's names
- Districts
- EPA
- Village Name
- GPS Coordinates

Background Information

Ask participants to discuss and agree between them a rough average farm size for the farms that they represent and the size of the smallest and largest farms represented. Also ask them to list the crops that they grow between them and rank the top three most important in terms of area cultivated. Record these answers.

Constructing a Seasonal Calendar

Using a large (A2) pre-prepared sheet (sheet 1) discuss the five pre-prepared rows and ask participants to describe agricultural practices, weather and field conditions in a good and bad year, and key non climate-related risks that are encountered.

These can be anything that participants believe to be significant, but there may be a need for clarification. The following is provided as examples:

Agricultural practices	Land preparation (specific techniques), planting (by crop), weeding, fertiliser/top-dressing application, drying , storage
Description of weather and field during good/bad conditions	Presence/absence of rain, rainfall quantities (specify – 1-2mm) and durations, dry spells (absence of rain over specified duration), temperatures, winds, rainfall intensity, timing of rains, excess rainfall, soil moisture

Other non-climatic conditions affecting their agricultural practices	Crop insurance, accessibility to seeds, availability of labour, availability of fertilizers

The facilitator should capture these points (in English or Chichewa) on post-it notes and where necessary recorded the span of time (in days/weeks/months) and dates/days of relevance of any description. Where a description is relevant across several months, post-it notes can be combined to indicate this spread.

This sheet should be discussed until all of the group members are satisfied that it represents a complete picture of the typical crop/farm calendar. In addition, arrows should be drawn in the sheet in order to identify the linkages between the agricultural practices and the other aspects discussed: description of field/crop in good conditions, climate related risks, description of field/crop when those climate risks occur and other non-climate factors influencing their agricultural practices.

Sheet 1

	July	August	September	October	November	December	January	February	March	April	May	June
What are your main agricultural practices/decisions												
How much time does it take to make preparations to implement these decisions?												
How are these agricultural decisions affected by weather condition during these months?												
What do you expect to see on the field/what weather do you observe when there are good conditions?												
What do you expect to see on the field/what weather do you observe when there are bad conditions?												
What other non-climate factors affect these agricultural practices?												

Use of forecast information (for farmers)

- Do they use/receive weather/climate information? Separate them into groups based on 'they receive' and 'they don't'.

If <u>they receive</u> weather/climate information:

- What information do they use?
- How does that information help them with their crop-related decisions?
- From where do they get this information from (the source of the information)?
- How do they receive this information (through which mechanisms e.g. extension officer?)

If <u>they don't</u> receive weather/climate information:

- Why don't they use it?
- If they had access, what information would be useful for them to have?
- How would that information help them with their crop-related decisions? What of these would be the critical decisions to them?
- How would they like to receive this information (through which mechanisms e.g. extension officer)?

• In what format do they receive it (e.g. information on the radio, piece of paper, etc)?	• In what format would they receive to it (e.g. information on the radio, piece of paper, etc)?
• How often do they receive the information?	• How often would they like to receive it?
• Is the information they receive useful to inform your decisions? Why/why not?	• What conditions would need to be place for allowing them to use the information? e.g. access to the information, help understanding it, receiving it at the right time of the year. (Please ask them to describe these conditions in detail)
• Do you trust the information? Why/why not? • What other information would be useful to have? Why/why not? • How would you like to receive the information (e.g. extension officer, radio, etc) and in what format (e.g. verbal message, text message, etc)? Why? • Would it be more useful for you to receive this information at different times of the year? Why? • What else would you change about how this information so it would be more useful to help you manage your agricultural practices?	• Any other comments they would like to add to this?

Recalling and Describing Extreme Season

Ask the participants (both farmers and extension officers in separate FGDs) to recall that season/year and think about how: (1) practices, (2) the description of the weather and field.

The facilitator/translator should use a different sheet (sheet 2) to add other post-its to it.

This sheet should be discussed until all of the group members are satisfied that it represents a complete picture of an extreme season/year (a bad year for their crop) seasonal calendar.

Sheet 2

	July	August	September	October	November	December	January	February	March	April	May	June
What were your main agricultural practices? What did you see on your field/ observe in the weather during that season?												

Using **Sheet 2** developed above, ask participants to discuss:

- What was the most critical weather risk/event affecting their crops (probe to try and make these as specific as possible (i.e. ‘consistent rainfall every day for the first three weeks after planting’, rather than just ‘rainfall’)?

- Did they use weather/climate information? If yes, what information did they use?
- From where did you receive it? How did you receive it? When did you receive it?
- Did it help with their crop-related decision-making? If so, how?
- Would you like to improve that information (e.g. type of information, source, format for receiving, timing)? If so, how?
- Do you observe something in the environment (like wind, temperature, animals, trees) that give a sign that a dry period/year is coming?

Close the Session

Thank participants for their time. Explain that this information will be combined with that collected in other locations and that we will use it as a basis of exploring how forecast information can be improved. Explain that this will be a long term process (to manage expectations about immediate benefits). Give seniors/district officer/village head opportunity to give final closing words, as appropriate.

Strategy at Area level

At area level, Key Informant Interviews (KII) will be held with EPA Officers and representatives of institutions.

Who to interview

- Extension Planning Area (EPA) Officers

Questions EPA Officers

The interviews with EPA Officers should also be audio-recorded and afterwards fully transcribed (word by word) into English.

- How long have you been working as an (extension) officer?
- Are you responsible for a particular EPA or village?
- What type of support/information do you provide to the EPA/villages you work with?
- Do you provide weather/climate information to the farmers?
- Have you received training under PICSA program? If so, please describe the type of training.

If they provide weather/climate information:

- What type of information do you provide (e.g. forecasts for the next 5 days, seasonal forecast, etc)
- From where do you receive this information (please describe the whole chain from whoever produces the information down to getting to you)?
- How do you receive this information? E.g. text message, radio, etc
- In what format do you receive that information? (e.g. a text describing the weather/climate conditions for that period)?
- Do you work on that information before passing it on to the farmers? (e.g. do you change it in a way so that the farmers understand it better?). If so, what do you do?

If they don't provide weather/climate information:

- Can you explain why you don't provide weather/climate information to the farmers?
- In your opinion, are the farmers with whom you work interested in receiving this type of information? Please explain why/why not?
- If the farmers are interested in receiving this type of information would you be able to provide them with that information? Please explain why/why not?
- What would you require to be able to provide them with that information?
  e.g. having access to the weather/climate information, having training on how to understand the information, more resources to be able to reach the villages, etc.
- Would you be interested in providing that information to the farmers if you had the right conditions for doing it?

- How frequently do you receive this information?
- How frequently do you give this information to the farmers?
- Are there critical periods in the cropping calendar when this information is very relevant to the farmers? If so, why and when are those periods?
- Do the farmers use this information to help them make decisions about how they manage their agricultural practices? If so, can you give us a few examples of how farmers have used it e.g. what type of decisions did they made based on this information and when?
- In your opinion, how could this process of providing weather/climate information to the farmers be improved?
- What else could be improved to help you better deliver this information to the farmers?

Strategy at National level

In the period of the 6th till the 10th of May meetings can be scheduled in Lilongwe in cooperation with Thirza Teule (ECHO-II). The aim is to follow the climate service & drought early warning in its full dissemination. The priority institutions to talk to are DoDMA, DCCMS, and DAES.

Who to interview

<u>Specific objectives of National interviews on extreme climate information</u>

- MRCS
- DODMA
- DCCMS

<u>Specific objectives of National interviews on general climate information</u>

- Farmers Radio Trust: Understanding weather forecast dissemination and advise. How is advise and information reached, what source?
- NASFAM
- DEAS

<u>Specific objectives of National interviews on droughts</u>

- LUANAR : Knowledge on specific drought impact on the growing season of rainfed agriculture. Strategies and coping capabilities of farmers.
- WFP: in what district is this climate service available? What are the lessons learned?

Protocol National Level | Extreme climate information

Initiation

Let everybody introduce themselves: name, organisation, role. Thank the interviewer for their time. Ask for permission to record the interview.

We are doing this interview for our master thesis research at the Netherlands Red Cross. I'm a MSc Hydrology student at the VU University in Amsterdam (Thirza). My thesis research is on assessing the flood early warning system of Malawi, as part of the ECHO-II project of the Netherlands Red Cross in cooperation with the Malawi Red Cross Society.

My name is Ileen and I am a MSc Watermanagement at the TU Delft in the Netherlands. My research is on drought early warning systems targeted on agricultural practices and decisions, linked to the NERC SHEAR IPACE project of the University of Leeds in cooperation of the Netherlands and Malawi Red Cross. I am currently based at Malawi Red Cross as an intern, also doing other activities concerning Early Warning Systems in the ECHO-III project.

Brief introduce research and purpose of this interview

We are aiming to find out how the weather forecast information flows; from the forecast that has been given by DCCMS or another source eventually to the communities. We are focusing especially on the years when drought or flood event occurred.

Interview Questions

The interview should be recorded and fully transcribed into English.

- What is your role in the organisation? Could you briefly describe your responsibilities?
- Are you involved in any projects/programmes linked to early warning systems?
- What type of climate/weather information are you working with (E.g. droughts, flash floods, riverine floods etc.)
- Do you receive or provide climate information / warnings? Or both?

It might be that they are both a receiver of information and a provider of information. Then ask both columns

<u>Receiving</u> extreme weather/climate information	**<u>Providing</u> extreme weather/climate information**
From where do you receive this information (please describe the whole chain from whoever produces the information down to getting to you)?	To who do you provide that information (please describe the whole chain from who you deliver next and thereafter)?
What type of information do you receive? (e.g. forecasts for the next 5 days, seasonal forecast, spatial scale etc)	What type of information do you provide? (e.g. forecasts for the next 5 days, seasonal forecast, spatial scale etc)
	Do you produce this information? If so, how do you produce the information?
	Do you tailor the information before distributing it to other stakeholders? If so, what do you add or change?
How do you receive this information? E.g. text message, radio, email etc	How do you send out/communicate this information? E.g. text message, radio, email etc

Who else is involved when you receive information? (in the Whatsapp group, meeting, workshop etc)	Who else is involved when you provide information? (in the Whatsapp group, meeting, workshop etc)
In what format do you receive that information? (e.g. a text/graphs/charts describing the weather/climate conditions for that period)?	In what format do you provide that information? (e.g. a text/graphs/charts describing the weather/climate conditions for that period)?
How frequently / when do you receive this information? (How many days/weeks/months before the extreme event do you receive this information?)	How frequently / when do you provide this information? (How many days/months before the extreme event do you provide this information?)
In your opinion, how could this process of receiving weather/climate information be improved?	In your opinion, how could this process of delivering weather/climate information be improved?
Communities have also developed a lot of local knowledge over the years on forecasting floods and droughts. They are able to see signs in the environment that indicate an upcoming extreme event.	
Do you receive this type of information from local communities? If so, do you combine this information with "official forecast information" and how? If not, do you think it is useful and possible to combine this information?	
Do you know if any other efforts are taken to involve the local knowledge of communities in early warning systems for extreme weather events? If so, how?	

Protocol National Level | General climate information

Initiation

Let everybody introduce themselves: name, organisation, role. Thank the interviewer for their time. Ask for permission to record the interview.

My name is Ileen and I am a MSc Watermanagement at the TU Delft in the Netherlands. My research is on forecasts and early warnings targeted on agricultural practices and decisions, linked to the NERC SHEAR IPACE project of the University of Leeds in cooperation of the Netherlands and Malawi Red Cross.

Brief introduce research and purpose of this interview

The aim of the IPACE project is to improve the weather forecast in three pilot districts: Salima, Mangochi and Zomba. We have been in the field, talking to farmers about their agricultural practices, how climate is affecting their farming practices and what climate information they are receiving. We have also spoken to the extension officers about what climate information they receive and how they deliver that to the farmers. The aim is to pilot the improved forecast in the upcoming season (if everything goes as planned) in the three districts and the reflect on that afterwards. Otherwise, we will target September 2020.

With this interview we are aiming to find out how the climate or weather information flows; from the forecast that has been given by the DCCMS eventually to the communities.

Interview Questions

The interview should be recorded and fully transcribed into English.

- What is your role in the organisation? Could you briefly describe your responsibilities?
- Are you involved in any project or activity linked to generate or provide climate information or any of the on-going climate services projects?
- Do you receive or provide climate information? Or both? - It might be that they are both a receiver of information and a provider of information. Then ask both columns ('rowwise')

<u>Receiving</u> weather/climate information	**<u>Providing</u> weather/climate information**
What type of information do you receive? (e.g. forecasts for the next 5 days, seasonal forecast, etc). What is the spatial scale of each type of information - regional or district?	What type of information do you provide? (e.g. forecasts for the next 5 days, seasonal forecast, etc). What is the spatial scale of each type of information - regional or district?
Could you elaborate/list the dates during a month or a season when you receive the weather information? Any reason behind that?	Could you elaborate/list the dates during a month or a season when you deliver the weather information? Any reason behind that?
From where do you receive this information (please describe the whole chain from whoever produces the information down to getting to you)?	To who do you provide that information (please describe the whole chain from who you deliver next and thereafter)?
	Do you produce this information? If so, how do you produce the information?
	Do you tailor the information before distributing it to other stakeholders? If so, what do you add or change?
	What additional information or support do you use to translate the weather information into planning decisions?
How do you receive this information? E.g. text message, radio, email etc	How do you send out/communicate this information? E.g. text message, radio, email etc
Who else is involved when you receive information? (in the Whatsapp group, meeting, workshop etc)	Who else is involved when you provide information? (in the Whatsapp group, meeting, workshop etc)

In what format do you receive that information? (e.g. a text/graphs/charts describing the weather/climate conditions for that period)?	In what format do you provide that information? (e.g. a text/graphs/charts describing the weather/climate conditions for that period)?
How frequently / when do you receive this information?	How frequently / when do you provide this information?
In your opinion, how could this process of receiving weather/climate information be improved?	In your opinion, how could this process of delivering weather/climate information be improved?

Appendix B | Second Data Collection Program

In the period of 24th of June to 28th of June, a fieldwork data collection will take place in Zomba. It is a done by Ileen Streefkerk, doing her master thesis at the Technical University of Delft in the Netherlands, currently interning at Malawi Red Cross.

The main objectives are:

- To understand the dissemination flow of forecast information
- What decisions of the smallholder farmers are most important and which decisions can be influenced by forecast information.
- To find out how smallholder farmers take decisions; if they prefer their local knowledge or the forecast given by the extension officers/radio
- Historical data on drought years

Type of information to collect per level

<u>Community level</u>:

- Decision-making of smallholders concerning agricultural practices for dry years and the influence of climate information in that decision-making

- Local knowledge; the most useful signs and the inclusion of that in climate information

- Received climate information

- Experienced dry season and its characteristics

<u>Area/EPA level (KII):</u>

- Understanding climate information dissimilation from area level to the farmers

- Inclusion of local knowledge in information dissemination

<u>District level</u> (KII):

- Understanding climate information dissimilation from district to eventually the farmers

- Understand the current gaps and opportunities of the climate service

- Data collection: yields and wind data (if possible)

Locations

Data collection will take place at the following locations.

District level	Area Level (EPA)	Community
Zomba	Mpokwa	TA Mwambo

Schedule

The proposed schedule is as follows.

WEEK OF **24.06.2019**						
District	**Mon**	**Tue**	**Wed**	**Thu**	**Fri**	**Sat/ Sun**
	District Level	Local Level	Individual level	Individual level		
Morning	District level interviews MRCS, DCCMS	EPA/TA level interview: ACPC	1 group of 6 smallholder farmers	1 group of 6 smallholder farmers	*Buffer – room for flexibility or extra FDG or interviews*	
Afternoon	District level interviews DoDMA	Interview VCPCs	1 group of 6 smallholder farmers	1 group of 6 smallholder farmers		

Strategy

Who to interview

<u>Local interviews/sorting exercise:</u>

- Village Civil Protection Committee (VCPC)
- Smallholder farmers

<u>Area/EPA interviews:</u>

- Agricultural Extension District Officer (AEDO)
- Area Civil Protection Committee (ACPC)

<u>District level interviews:</u>

- Agricultural Officer
- DoDMA District Officer
- DCCMS District Officer
- MRCS District Officer
- District Civil Protection Committee (DCPC)

Procedure | Sorting Exercise

Initiation

Let everybody introduce themselves: gender, age, how long they have been living in this village. Thank the participators for their time. *If a prayer is usually done before a meeting, that can be done at this point as well.*

Brief introduce research and purpose of this interview

We are doing these interview for my thesis research at the Netherlands Red Cross. I'm a MSc Water management student at the Technical University of Delft, Netherlands. My thesis research is on assessing the drought early warning system of Malawi.

This aim of this discussion is to provide knowledge on what drought forecast information you as a community receive and use.There are no wrong or right answers and all your answers will be treated confidential.

Explanation of Method of Questioning

The question done in pairs is all done by means of sticky notes. The options are already written down on sticky notes in both Chichewa and English. The options that are already pre-made is based on the previous fieldwork. Extra notes can be added it they are not already written down. The sticky notes are not showed, until they have discussed in pairs and have answered. Photos will be made of all the sticky notes rankings. The discussion afterwards will be translated and recorded. The key 'characteristics' answers will be added on the sticky notes.

1.Dry years — Least impact ... Most impact

2.Decisions — Least important ... Most important

3.Forecast — Least useful ... Most useful

1. Previous drought years

In pairs or individually:

a. Can you list the bad years you had on you farm which were due to lack of rainfall from 2000 onwards? (this may be a late onset, dry spell, erratic rainfall etc)
b. Can you rank them from small to big impact on the paper?

2000-2001 | 2001-2002 | 2004-2005 | 2009-2010 | 2012-2013 | 2014-2015 | 2015-2016

Follow-up questions:

a. *Characteristics*:
- What made that year 'bad': #dry days, late onset of rains, short rainy season?
- Why did you rank them the way you did (based on food insecurity, crop production, low income etc)?

2. Agricultural Decisions

In pairs or individually:

a. If you would know that a bad year (like you just listed) was coming upcoming season; what decisions do you have to make in the field in the upcoming season? (seeds, when to plant etc)
b. Can you put the decision from most important to least important? (seeds, when to plant etc)

Crop Choice *Chisankho Cha Mbeu Yodzala*

Seed Choice *Kusankha Mbeu*

Planting Date *Tsiku Lodzala*

Ridge Making *Kupanga Mizele*

Manure Making *Kupanga Manyowa*

Pit Making *Kupanga Mapando*

Fertilizer Application

Produce for Market vs Consumption *Kusankha kugulitsa kapena kugwiritsa ntchito pakkomo*

Follow-up questions:

c. *Characteristics*: When do you do that activity in the year? (seed selection, planting etc). Can you explain why you have put the notes in this order?

3. Forecast information (Both SK and IK)

In pairs or individually:

a. What *weather information/forecast* do you get (radio, extension officers, sms) that helps in those most important decisions?
b. What forecast based on your *indigenous knowledge* can help (animals, winds, temperature)?
c. Can you rank the information sources to which you find least and most useful to support in that decision?

Extension Officers *Alangizi*	Radio *Wailesi*	*NGOs* *Uthenga wa pafoni yammanja*	SMS *Mabungwe*
LK: wind *Zikhulupiliro: Mphepho*	IK: temperature (warm/cold) *Zikhulupiliro: Nyengo (Kutentha/Kuzizira)*	LK: Animals *Zikhulupiliro: Ziweto*	LK: trees *Zikhulupiliro: Mitengo*

Follow-up questions:

a. Why did you rank it the way you did?

b. When and how long before the event (dry year/spell, onset) do you receive that information? *Which source is received first?*

c. How does that information help? *For what decision? (agricultural practice; planting, seeds etc)*

d. Which source(s) do you combine and use to get to those most important decisions (in 2)?

e. How do you combine that?

f. Do you discuss indigenous knowledge with your fellow farmers?

g. Do you think indigenous knowledge should be included in the forecast information you receive?

Questions ACPC / VCPC

General questions about the VCPC/ACPC (can be answered by one person)

- How long ago was this VCPC/ACPC established?
- Would you describe this VCPC/ACPC as an active VCPC/ACPC?
- Did an organization (like the Red Cross) started this VCPC/ACPC and is it still supporting the VCPC/ACPC in any way?

- What type of climate/weather information are you working with (E.g. droughts, flash floods, riverine floods etc.)

- Do you receive or provide climate information / warnings? Or both?

It might be that they are both a receiver of information and a provider of information. Then ask both columns

<u>Receiving</u> extreme weather/climate information	**<u>Providing</u> extreme weather/climate information**
From where do you receive this information (please describe the whole chain from whoever produces the information down to getting to you)?	To who do you provide that information (please describe the whole chain from who you deliver next and thereafter)?
What type of information do you receive? (e.g. forecasts for the next 5 days, seasonal forecast, spatial scale etc)	What type of information do you provide? (e.g. forecasts for the next 5 days, seasonal forecast,spatial scale etc)
How do you use this information?	Do you produce this information? If so, how do you produce the information?
Do you tailor the information you receive before using it? If so, how and why?	Do you tailor the information before distributing it to other stakeholders? If so, what do you add or change?
How do you receive this information? E.g. text message, radio, email etc	How do you send out/communicate this information? E.g. text message, radio, email etc
Who else is involved when you receive information? (in the Whatsapp group, meeting, workshop etc)	Who else is involved when you provide information? (in the Whatsapp group, meeting, workshop etc)
In what format do you receive that information? (e.g. a text/graphs/charts describing the weather/climate conditions for that period)?	In what format do you provide that information? (e.g. a text/graphs/charts describing the weather/climate conditions for that period)?
How frequently / when do you receive this information? (How many days/weeks/months before the extreme event do you receive this information?)	How frequently / when do you provide this information? (How many days/months before the extreme event do you provide this information?)
In your opinion, how could this process of receiving weather/climate information be improved?	In your opinion, how could this process of delivering weather/climate information be improved?

2a. <u>VCPC</u>: Do you make use of drought forecasts based on local knowledge from your community? (local knowledge indicators can be for example: looking at weather patterns or at different behaviour of animals or plants to predict floods) **If not: Why not? If yes:**

a. Do you produce your own forecast information?
b. Do you receive forecasts based on local knowledge indicators, if yes how?
c. What is the main indicator you use to predict a dry spell/year?
d. Do you discuss this information during (VCPC) meetings? If yes, how do you discuss this?

e. Do you share this information again with other community members? If yes, how and when do you share it?
f. Did you used local knowledge for forecasting the last drought in 2015/16? If yes, how long before the drought were you able to predict it?

2b. <u>ACPC</u>: Do you make use of drought forecasts based on local knowledge from communities? (local knowledge indicators can be for example: looking at weather patterns or at different behaviour of animals or plants to predict floods) **If not: Why not? If yes:**

a. From who do you receive this local knowledge and how do you receive it?
b. Which indicators do you trust and use?
c. How long before a flood event do you receive this information?
d. Do you discuss this information during (ACPC) meetings?
e. Do you share this local based information again with other communities?

3 How are the VCPCs structured?

a. Who are the members of the VCPCs/ACPCs?
b. How and by whom are they chosen?
c. How often do you meet and what topics do you discuss?
d. Do you communicate with your community, other VCPCs/ACPCs and other higher level organizations (governmental levels for example). If yes, what information do you communicate with them?
e. What is documented from the meetings, is any local drought forecast information documented?
f. Is anything digitized?
g. Was any information about the last flood documented or digitized?

4 Do you think drought forecasts produced by local communities should be integrated into the official forecasts? If not: Why not? If yes: How should this be integrated?

5 Do you have any further comments to improve the overall drought early warning system?

6 Measures against drought

a. Which measures do you take against droughts?
b. Would you take any different actions (compared to the actions you took), if you knew a drought was coming? If yes, what other actions would you take?
c. If you could advice the government, what measures you would you implement to take action against droughts?

Questions District

See protocol in the First Data Collection Program for extreme and general climate information.

Appendix C | Ecological and Celestial Local Knowledge

Table 20 shows the celestial and ecological indicators of farmer's local knowledge.

Table 20: Celestial and Ecological Local Knowledge Indicators

Categories of Local Indicators	Example signs	Period of occurrence
Celestial		
Sun/moon	*They'd [the ancestors] also predict a good harvest from observing the sun. If they see an oval shape inside the figure of the sun, that was a sign for good harvest.*	
Ecological		
Quality of Rains	*When mango trees have a lot of flowers, it is a sign of good rains. If not, we know the season will not have much rainfall.* ***Salima***	
Onset of Rain	*When Mango trees and India shed leaves, it means the rainy season is nearby.* ***Zomba***	
Onset of Rain	*From May to August, the trees have shed their leaves and around November, when they start budding, we know we will have rains.* ***Mangochi***	November
Quality of Rains	*Our ancestors also taught us this belief, that when a certain black bird (Name not known) starts humming, from October up to November, it is a sign of good rains.* ***Salima***	October-November
Onset of Rain	*We have a type of local bird (Nanzeze) which appear around October and September. It is a sign that the rains are coming.* ***Zomba***	September-October
Onset of Rain	*Remember we have Lake Chilwa to our south. So we have these birds called Njeza flying from the Lake side to the land. If this happens, it also means rains are near to come.* ***Zomba***	
Quality of Rains	*Back then, we had trees like the Kachere tree. When the leaves shed and the tree is budding, it was a sign that there will be good rains. But these days, even when the tree sheds its leaves and starts budding, it is uncertain to experience good rains.* ***Zomba***	
Onset of Rain	*I have a sign that tells me if the rains are near or we will have late rains. Animals like the Guinea fowl. When they start laying eggs, it is a sign that rains will soon start. If we will have late rains, they don't lay eggs.* ***Zomba***	
Onset of Rain	*Our ancestors would predict good rains when they'd see some birds migrating to the lakeside in groups.* ***Mangochi***	
Onset of Rain	*Our ancestors would observe some trees, Baobab trees and some we call Mitwana, in the hills that would bud when the rains were approaching. If they were not budding, it was a sign that rains would delay.* ***Mangohci***	November
Quality of Rains	*We have a certain type of bird. If it hums, tit is a sign of rains. If we don't hear it then we won't have enough rains that season.* ***Mangochi***	October-November
Onset of Rain	*We also have Nsangu trees (Faidherbia abida). When they shade leaves, rains will soon start.* ***Mangochi***	October-November

Appendix D | Weather Station Specifics

The specifics of the weather stations for daily rainfall and daily minimum and maximum temperature observation data is provided in Table 21 and Table 22 respectively.

Table 21: Weather Station Specifics for Rainfall Observations

District	Station Name	Long (deg)	Lat (deg)	Elev (m)	Data Period
Salima	Chitale	34.25	-13.68	606	1948 - 2012
Salima	Salima Airport	34.58	-13.75	512	1954 - 2016
Mangochi	Nankumba	34.80	-14.35	518	1953 - 1997
Mangochi	Monkey Bay Met	34.92	-14.08	482	1979 - 2018
Mangochi	Mangochi Met	35.25	-14.47	482	1961 - 2018
Mangochi	Namwera	35.50	-14.37	899	1977 - 2018
Zomba	Chancellor College	35.35	-15.38	886	1975 - 2016
Zomba	Makoka	35.18	-15.53	1029	1965 - 2019
Zomba	Namiasi	35.22	-14.37	488	1980 - 2018
Zomba	Chingale	35.25	-15.37	610	1952 - 2016
Zomba	Zomba Agric	35.32	-15.4	915	1898 - 2016

Table 22: Weather Station Specifics for Minimum and Maximum Temperature

District	Station Name	Long (deg)	Lat (deg)	Elev (m)	Data Period
Salima	Salima	34.58	-13.75	512	1961 - 2005
Salima	Chitale	34.25	-13.68	606	1983 - 2015
Mangochi	Monkey Bay	34.92	-14.08	482	1979 - 2005
Mangochi	Mangochi	35.25	-14.47	482	1961 -2015
Zomba	Makoka	35.18	-15.53	1029	1968 - 2019
Zomba	Chancellor College	35.35	-15.38	886	1982 - 2006

Appendix E | Drought Indicators

In this appendix, the results of the Drought Index are given. In addition, it shows the results of the comparison is made between the eight described events and the dry spell and onset of rain.

Drought Season

The resulting drought index after the PCA analysis is summarized in Table 23. It states the drought index for the available years and the three districts. For every district, the three highest (=Drought) and lowest (= No Drought) are marked in orange and green, respectively.

Table 23: Drought Index of Districts

Year	Salima	Mangochi	Zomba		Year	Salima	Mangochi	Zomba
1963/64	2.00				1990/91	2.03	1.51	1.88
1964/65	1.90				1991/92	2.52	2.38	2.34
1965/66	2.18				1992/93	1.54	1.35	1.65
1966/67	1.64				1993/94	2.66	2.33	2.32
1967/68	2.03				1994/95	2.51	2.49	2.40
1968/69	1.44				1995/96	2.31	1.36	1.29
1969/70	2.55				1996/97	1.92	1.01	0.75
1970/71	1.56				1997/98	1.52	1.22	1.17
1971/72	1.41				1998/99	1.61	1.37	1.46
1972/73	2.07				1999/00	2.43	1.56	2.46
1973/74	1.26				2000/01	1.25	0.32	0.75
1974/75	2.16		1.79		2001/02	1.82	1.33	1.61
1975/76	1.27		0.78		2002/03	1.73	0.87	1.41
1976/77	1.91		1.38		2003/04	2.22	1.72	1.67
1977/78	1.06		0.27		2004/05	2.46	1.26	1.72
1978/79	1.45		1.82		2005/06	1.25	0.89	0.82
1979/80	1.23		1.83		2006/07	1.73	0.84	0.99
1980/81	1.34	1.73	1.85		2007/08	1.04	1.19	1.62
1981/82	2.18	1.58	1.86		2008/09	0.99	0.98	1.21
1982/83	2.36	2.07	2.19		2009/10	1.19	1.42	2.04
1983/84	2.08	1.4	1.68		2010/11	1.37	1.3	1.59
1984/85	1.75	1.45	0.64		2011/12	1.19	1.24	2.24
1985/86	1.39	1	0.92		2012/13	2.84	1.85	1.61
1986/87	2.05	1.77	1.54		2013/14		1.31	1.77
1987/88	1.92	1.78	1.41		2014/15		1.33	1.56
1988/89	2.16	1.13	1.20		2015/16		1.92	2.43
1989/90	2.45	1.7	1.76		2016/17		1.08	
					2017/18		1.06	

Dry Spells and Onset

The described events are compared with the observations data and the described events by the farmers. Green indicates the computed onset from the analysis. Red indicates dry spells of five days or larger in the period up to and including February.

Event 1

The rainfall and dry spell patterns of season 2008/09 for Salima Station are illustrated in Figure 40.

The farmers descriptions included:

"We planted maize in December when the rains came. Then the rains stopped. We had to weed our maize crop. The whole month of January had no rains. End February the rains came and destroyed our maize crop. This is when our extension workers made arrangements that organizations should provide us sweet potato vines and cassava to plant in the gardens"

Computed Onset: 05/12/2008

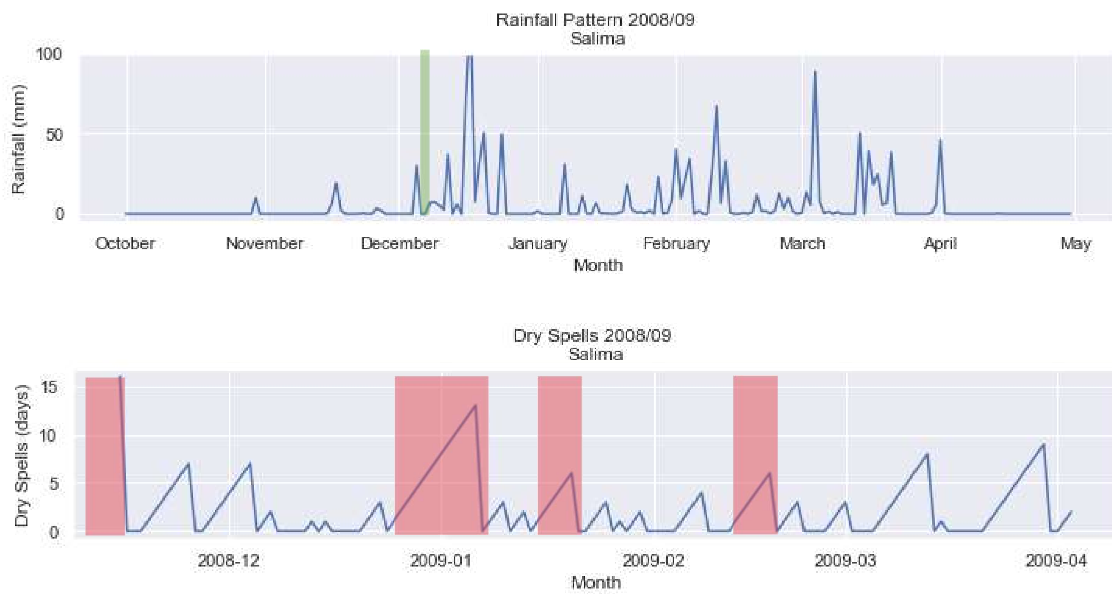

Figure 40: Rainfall and Dry Spell Patterns of Event 1

Event 2

The rainfall and dry spell patterns of season 2000/01 for Chitale Station are illustrated in Figure 41.

The farmers descriptions included:

"But it [the rains] stopped mid-January."

"We had no rains from mid-January up to February. "

Computed Onset: 17/11/2000

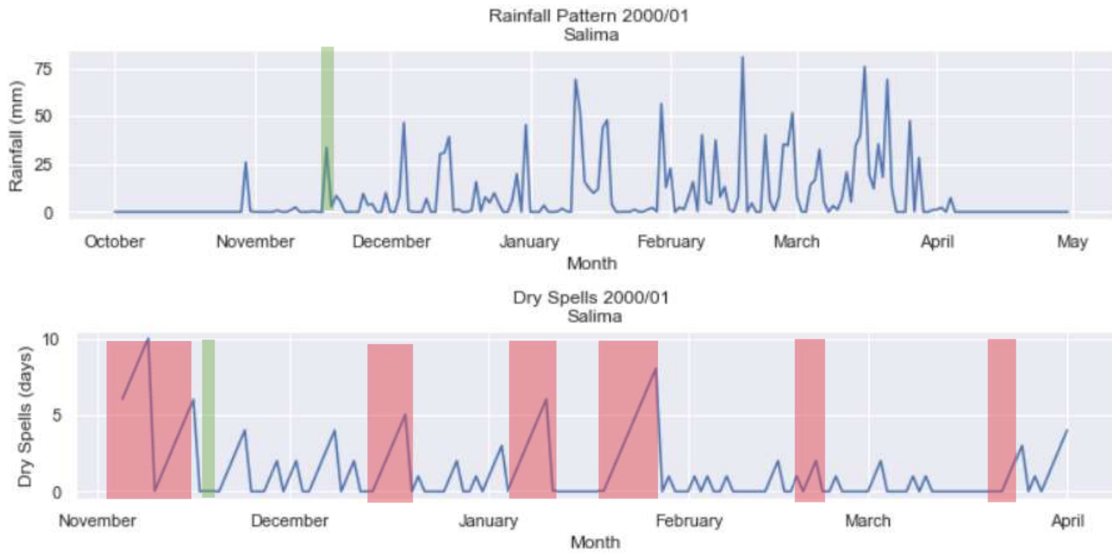

Figure 41: Rainfall and Dry Spell Patterns of Event 2

Event 3

The rainfall and dry spell patterns of season 2017/18 for Namkumba Station are illustrated in Figure 42.

The farmers descriptions included:

"I remember we had no sign of rain in October and November. And at the end of December, 27th to be exact, we received rains which stopped in January. We had no rains the rest of January. The rains came in February between the 10th and 15th. According to how the season go here, that year we had nothing to harvest."

Computed onset: 25/11/2017

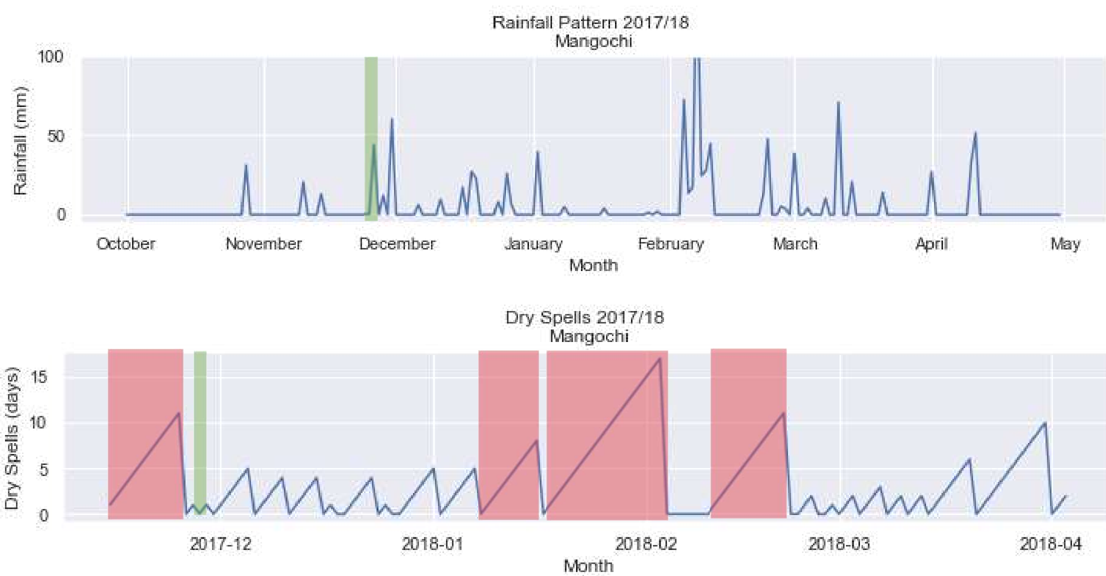

Figure 42: Rainfall and Dry Spell Patterns of Event 3

Event 4

The rainfall and dry spell patterns of season 2015/16 for Namkumba Station are illustrated in Figure 43.

The farmers descriptions included:

"No rains in November and December"

"We received heavy, isolated rainfall. We planted between 4 and 5 January. **"**

"The rains stopped in the same month. It rained for 2.5 weeks. For a month we had no rainfall"

"The maize seed had germinated, and the seedlings were green and healthy, but when the rains stopped and there was a dry spell, the crop withered."

Computed Onset: 10/01/2016

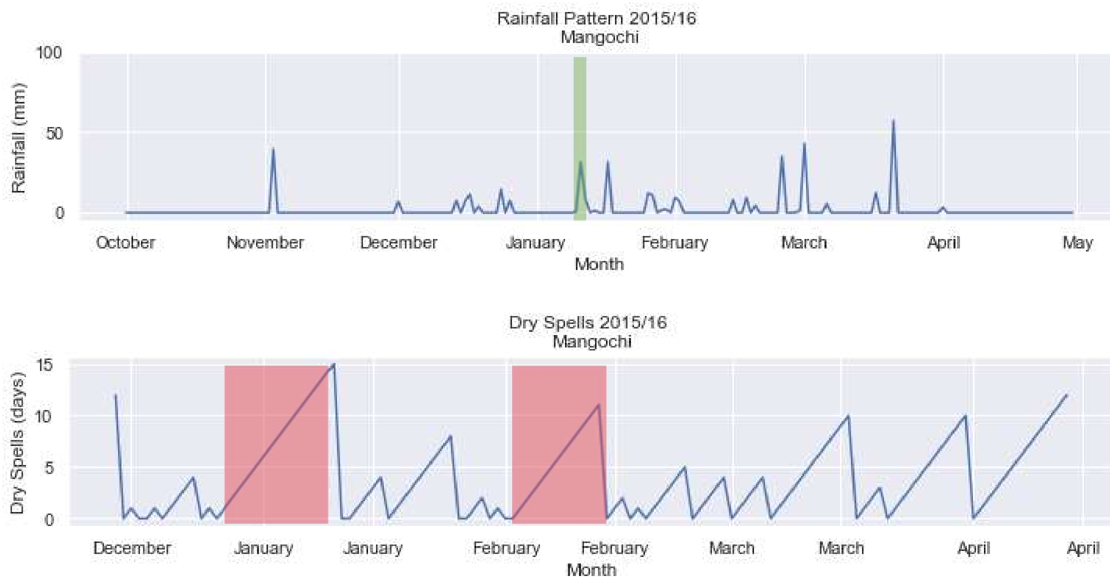

Figure 43: Rainfall and Dry Spell Patterns of Event 4

Event 5

The rainfall and dry spell patterns of season 2000/01 for Monkey Bay Station are illustrated in Figure 44.

The farmers descriptions included:

"The rains came early January for a week then stopped. They were not enough for planting. We had some rains end of February just one day.'

Computed Onset: 11/01/2001

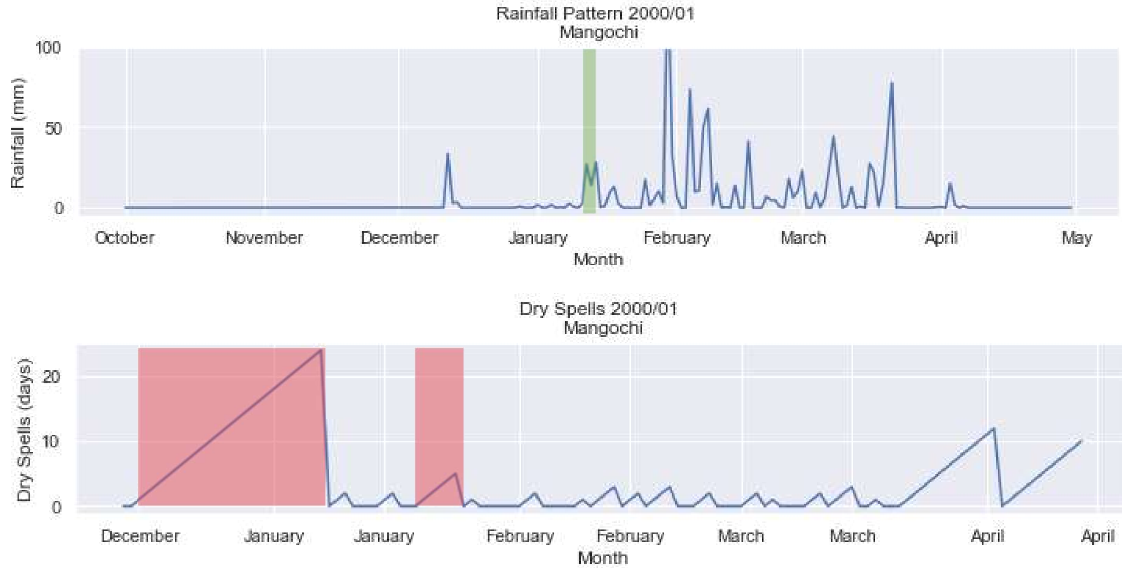

Figure 44: Rainfall and Dry Spell Patterns of Event 5

Event 6

The rainfall and dry spell patterns of season 2000/01 for Mangochi Met Station are illustrated in Figure 43.

The farmers descriptions included:

"We received the first rains end of December and we planted early December."

"The rains would come 2 to 3 days in a week, then there were no rains for 3 weeks, even a month. We would still have heavy clouds forming, but then the wind disturbed the rains"

"We planted maize in December and in the middle of the month the rains stopped. The rains came back after some of the maize plants withered. Farmers were uprooting the withered plants and in those stations, they were sowing again. That was in January."

" Yes January. And for those who did not uproot the withering plants, they had a better harvest. Because the seeds that were sown after uprooting did not do well. The plants withered because the rains stopped again."

Onset from analysis: 09/12/2000

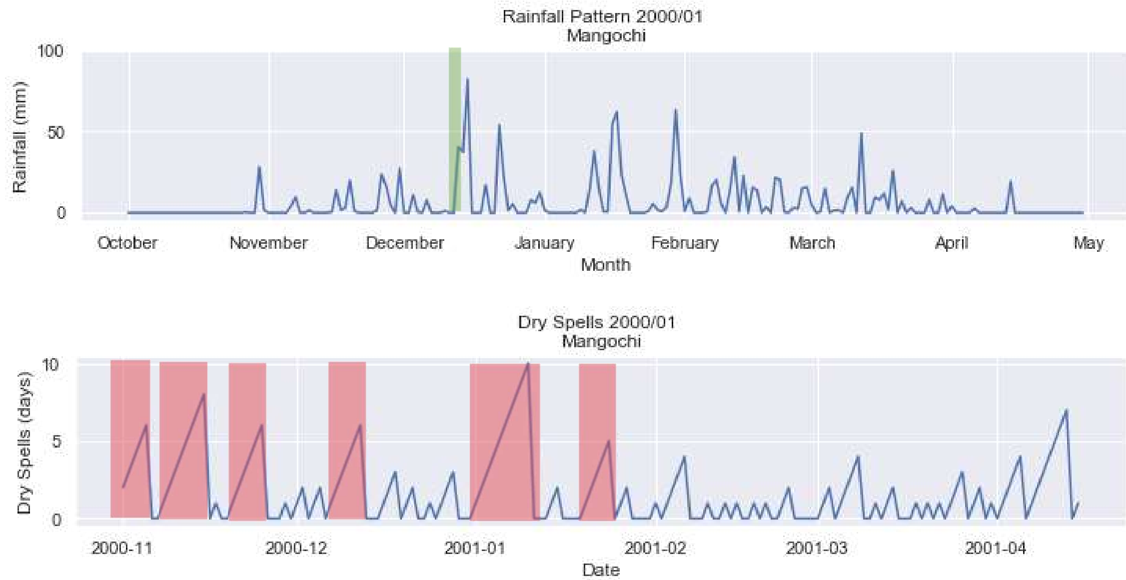

Figure 45: Rainfall and Dry Spell Patterns of Event 6

Event 7:

The rainfall and dry spell patterns of season 2000/01 for Zomba Agri Station are illustrated in Figure 43.

The farmers descriptions included:

"In 2000, the rains came early. People planted and it went well. They harvested even earlier. But for the next season, we received the rains late."

"Rains started end of January. We had rains up to March. The rains were heavy. "

"We planted in January"

"The maize was growing well with the rains. The only issue was that the rains delayed. But after it started, all was well. We had a good harvest."

"The weather was just as usual. Then with climate change we had from November, we were taken by surprise."

"It all started from the previous season into this particular season. We had rains earlier than expected and we planted and harvested early. The next season, the rains delayed. We used up all that we had harvested in the previous season and as we were planting in January, most of us had run out of food supply by December."

"From November to December we had a dry spell and food shortage. "

Onset from analysis: 17/11/2000

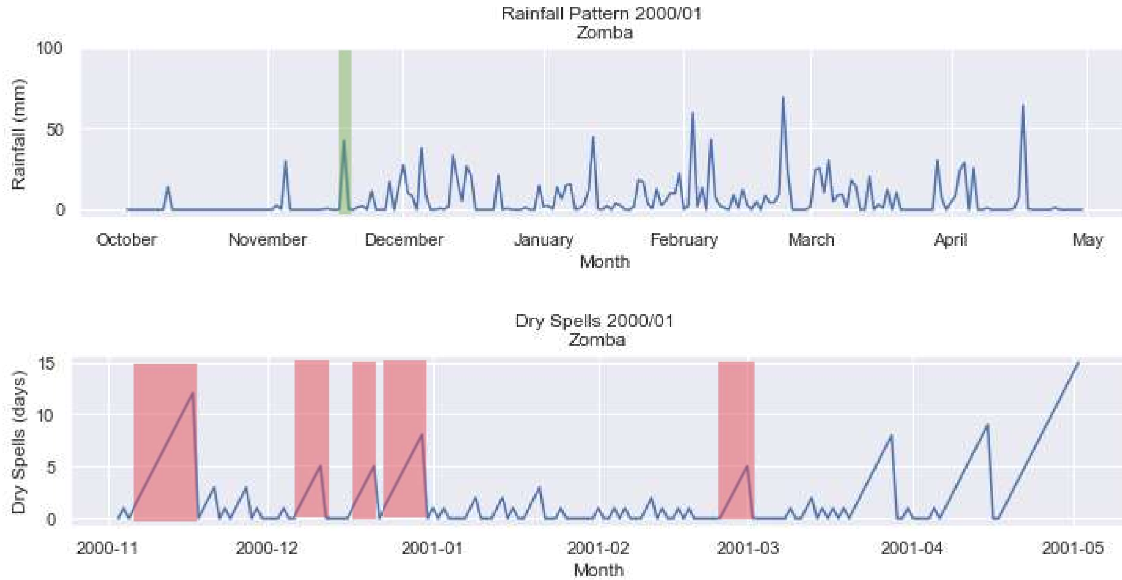

Figure 46: Rainfall and Dry Spell Patterns of Event 7

Event 8

The rainfall and dry spell patterns of season 2011/12 for Zomba Agri Station are illustrated inFigure 47.

The farmers descriptions included:

"There was a serious dry spell. Farmers would harvest a bucket of maize from a big field."

"We had first rains in October."

"The dry spells started from the time we planted. That was in November. Afterwards, the weather was just sunny. There was grass in field, it dried up."

"December little rain."

"Rains came in January, between the 15th and the 17th, and the farmers went to plant again (for the 6th time). "

"The dry spells continued. Sometimes there were rains but the dry spells were there up to May."

Onset from analysis: 25/12/2011

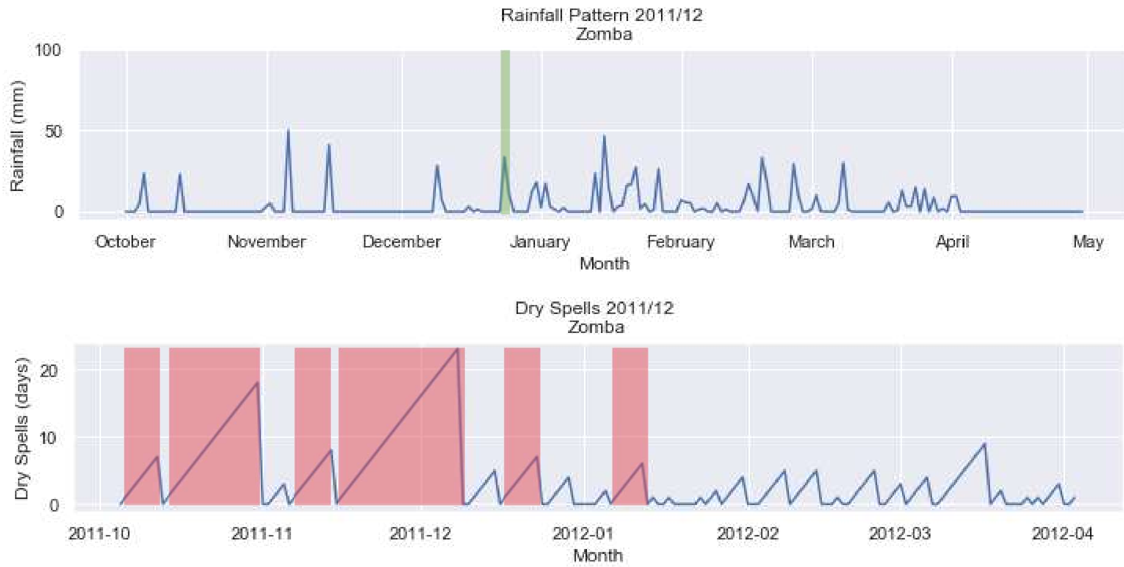

Figure 47: Rainfall and Dry Spell Patterns of Event 8

Appendix F | Comparison Drought and Meteorological Indicators

Eight described events are analysed whereby a comparison is made between the meteorological variables and the drought indicators. Additionally, the large-scale wind processes are analysed for the computed ‘drought’ and ‘no drought’ seasons.

Described Events

The eight events are compared with the time series and maps of the meteorological variables. In the time series, red indicates a dry spell and green the computed onset of rain.

Event 1

The time series and maps of the meteorological variables of season 2008/09 for Salima Station are illustrated in Figure 48, Figure 49 and Figure 50. No temperature data is available for this period.

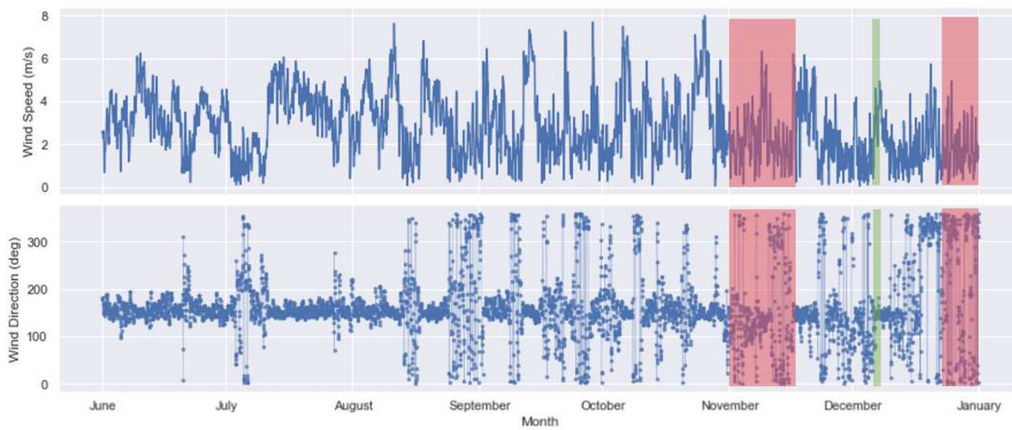

Figure 48: Time Series of Wind Speed and Direction of Event 1

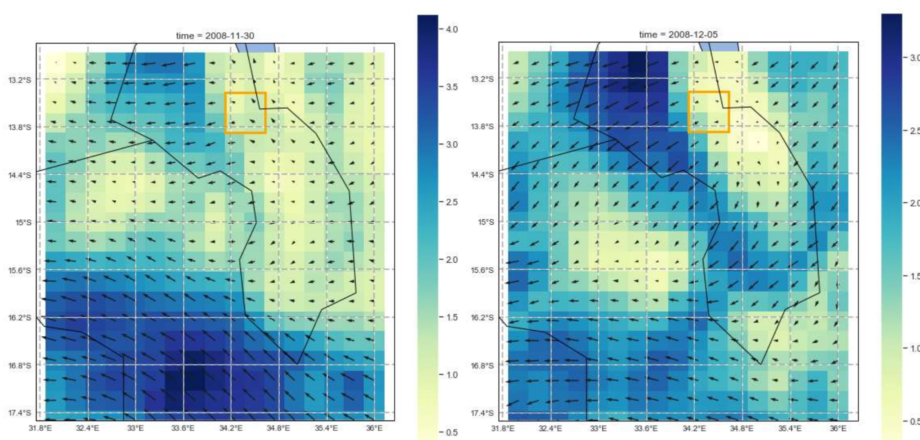

Figure 49: Left: Weekly Average of Wind Direction (arrows) and Speed (colours) one week before Onset. Right: Daily Wind Direction (arrows) and Speed (colours) during Onset

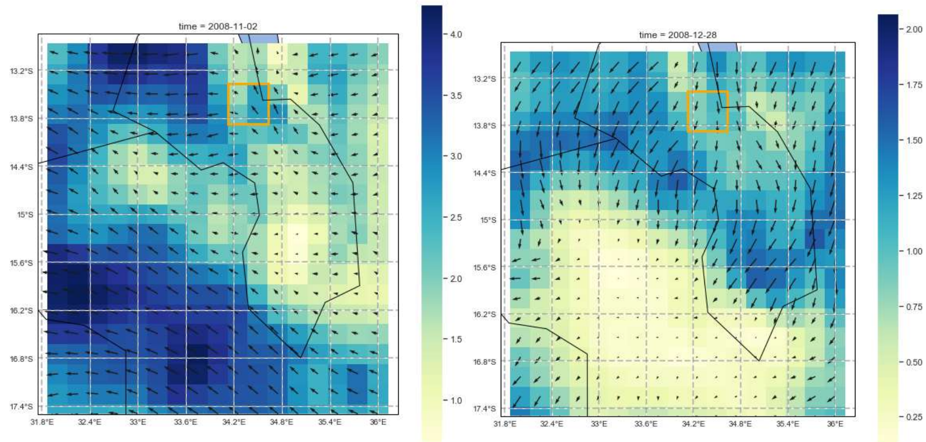

Figure 50: Weekly Average of Wind Direction (arrows) and Speed (colours) during Two Longest Dry Spells

Event 2

The time series and maps of the meteorological variables of season 2000/01 for Chitale Station are illustrated in Figure 51, Figure 52 and Figure 53 .

The farmers descriptions included:

"We had moderate winds. [June]"

"The soil was hard, dry with no moisture. [July]"

"It was very hot. There was also cloud formation. [November]"

"We had good moderate winds. The weather was ok. [December]"

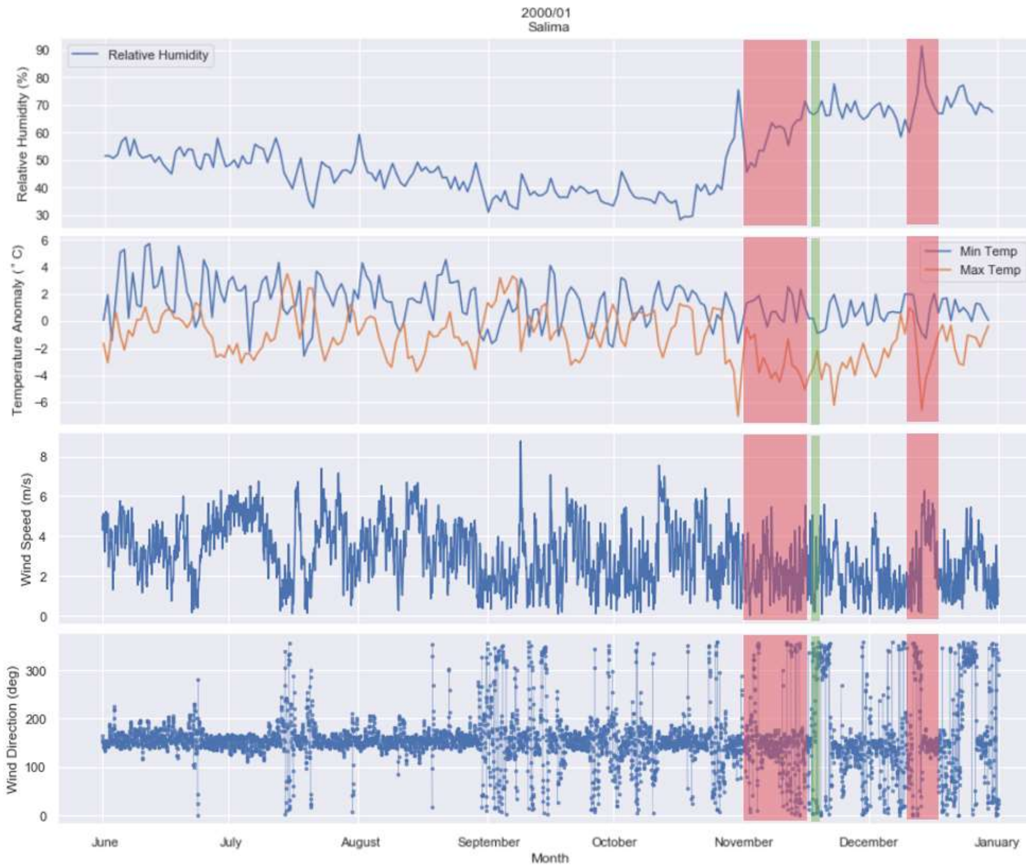

Figure 51: Time Series of Relative Humidity, Wind Speed and Direction of Event 2

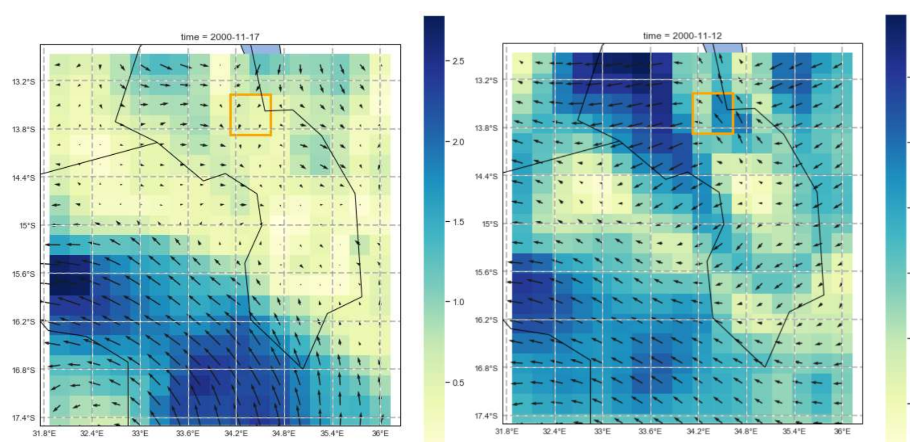

Figure 52: Left: Weekly Average of Wind Direction (arrows) and Speed (colours) one week before Onset. Right: Daily Wind Direction (arrows) and Speed (colours) during Onset

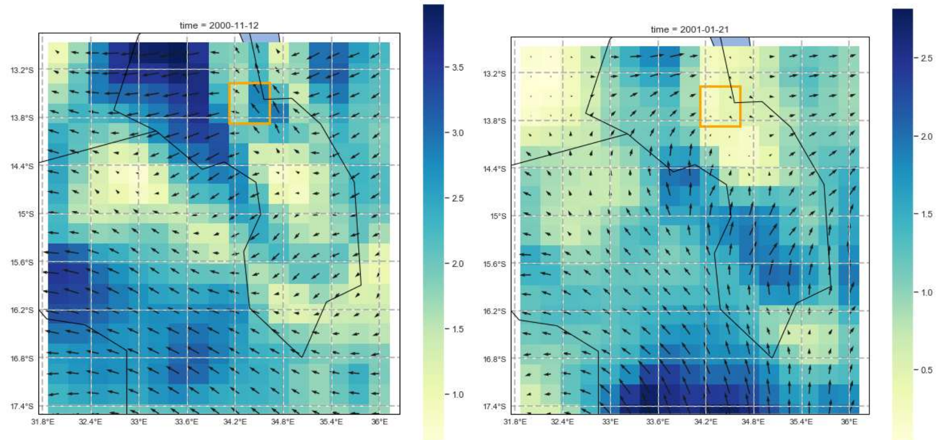

Figure 53: Weekly Average of Wind Direction (arrows) and Speed (colours) during Two Longest Dry Spells

Event 3

The time series and maps of the meteorological variables of season 2017/18 for Namkumba Station are illustrated in Figure 54, Figure 55 and Figure 56. No temperature data is available for this period.

The farmers descriptions included:

"The soil was light and dusty. It was blown away by heavy winds." "It was really cold." [July]

"Cold weather continued. Normally, we expect temperature to rise from mid-August." [August]

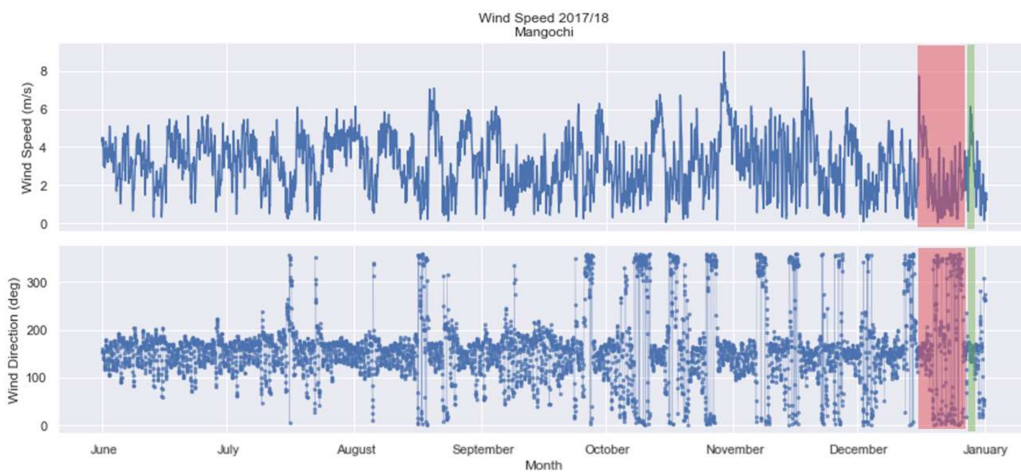

Figure 54: Time Series of Wind Speed and Direction of Event 3

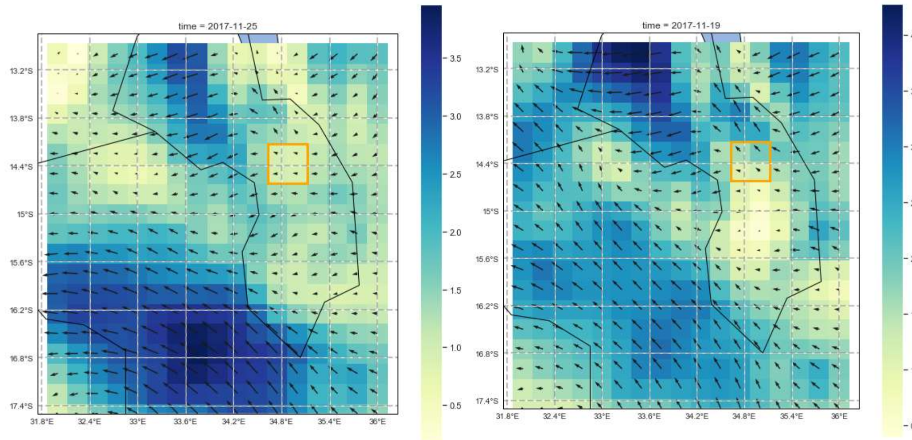

Figure 55: Left: Weekly Average of Wind Direction (arrows) and Speed (colours) one week before Onset. Right: Daily Wind Direction (arrows) and Speed (colours) during Onset

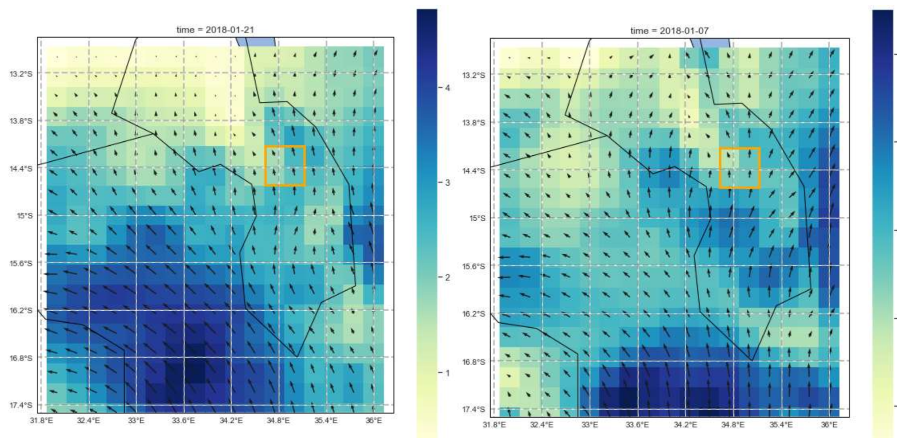

Figure 56: Weekly Average of Wind Direction (arrows) and Speed (colours) during Two Longest Dry Spells

Event 4

The time series and maps of the meteorological variables of season 2015/16 for Namkumba Station are illustrated in

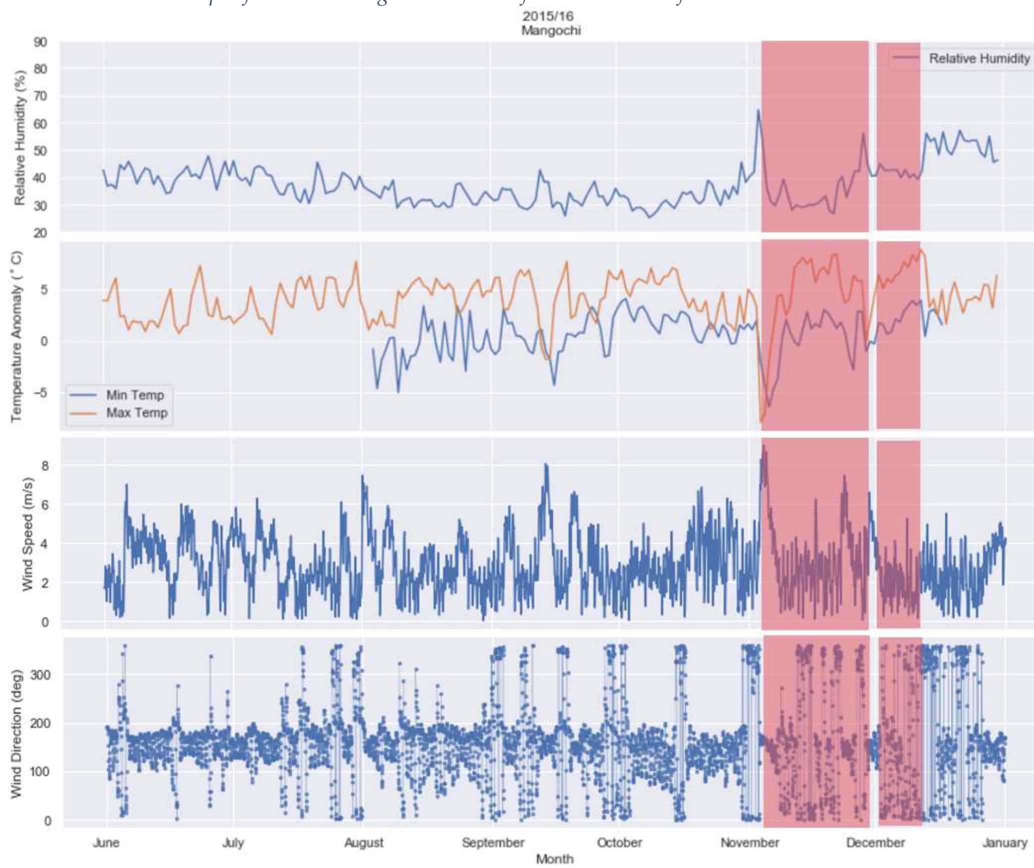

Figure 57, Figure 58 and Figure 59.

The farmers descriptions included:

"It was cold as usual with moderate wind." [July]

"It was cold that year. Up to October."

"We had cold winds. Mwera, our enemy" [September]

"We had Mwera winds." [November]

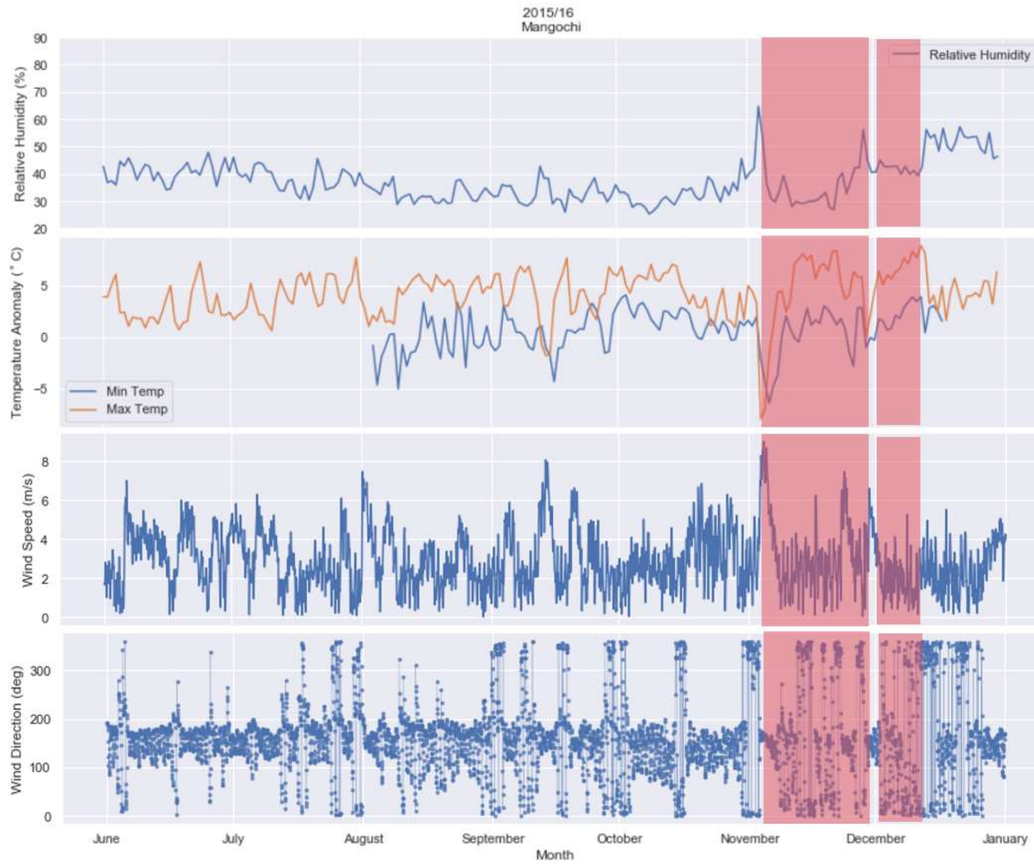

Figure 57: Time Series of Relative Humidity, Wind Speed and Direction of Event 4

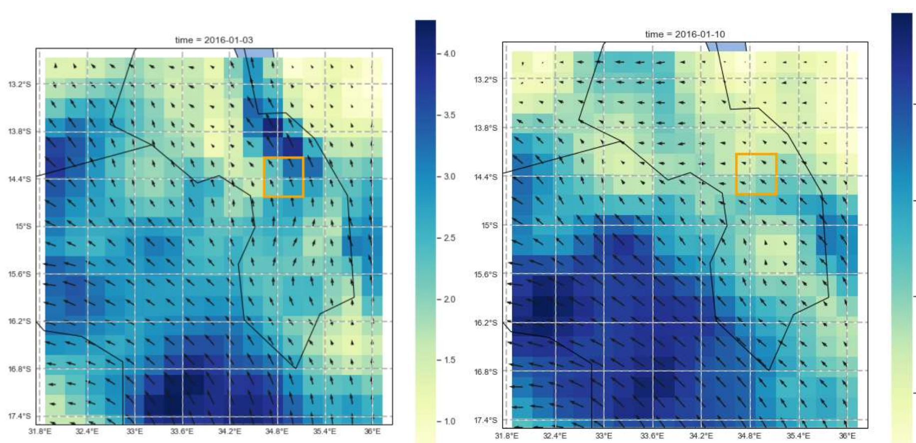

Figure 58: Left: Weekly Average of Wind Direction (arrows) and Speed (colours) one week before Onset. Right: Daily Wind Direction (arrows) and Speed (colours) during Onset

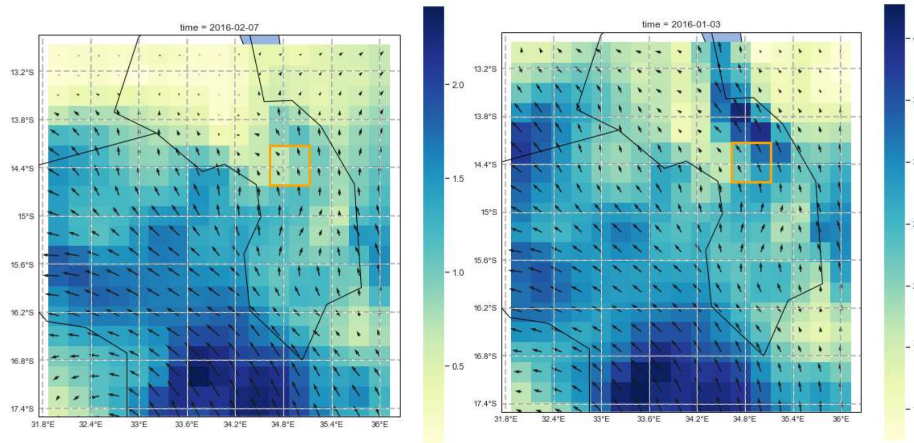

Figure 59: Weekly Average of Wind Direction (arrows) and Speed (colours) during Two Longest Dry Spells

Event 5

The time series and maps of the meteorological variables of season 2000/01 for Monkey Bay Station are illustrated in Figure 60, Figure 61 and Figure 62.

The farmers descriptions included:

“There were Mwera winds.” “Temperatures were so cold that some birds would drop dead because of the cold weather.“ [July]

“The temperatures were high.” [November]

“There was no cloud formation. We were experiencing Mwera winds.” [December]

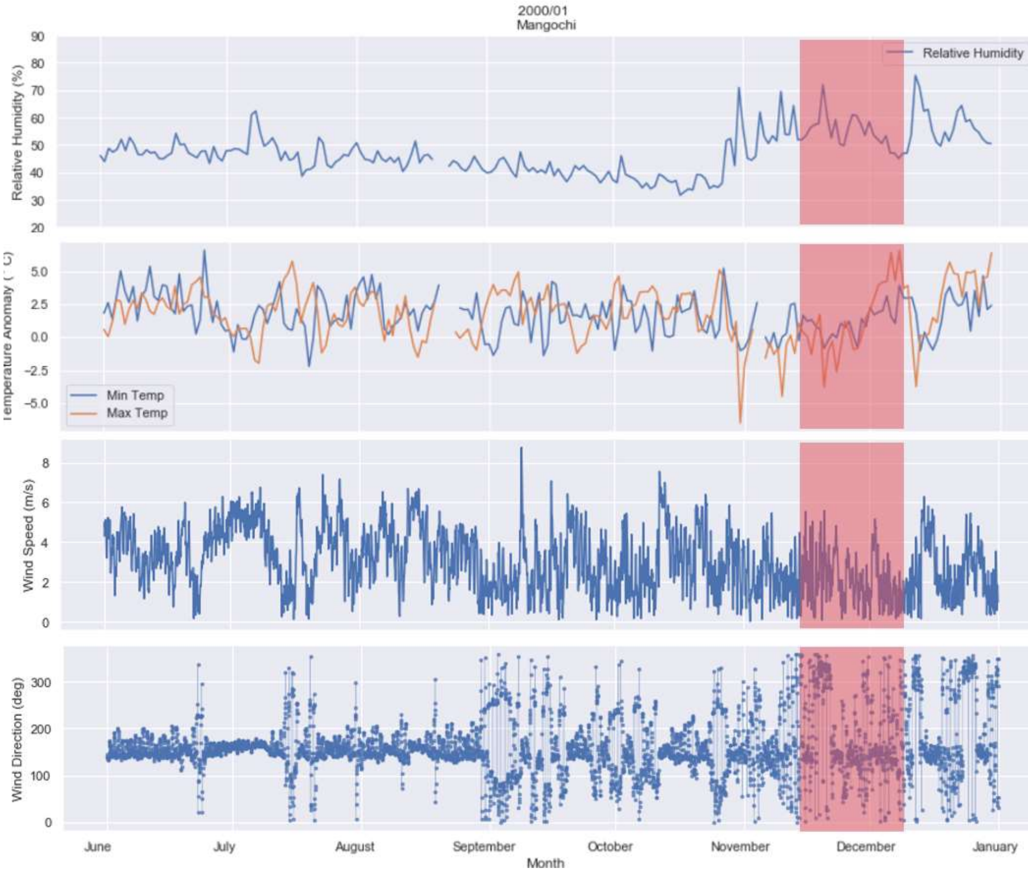

Figure 60: Time Series of Relative Humidity, Wind Speed and Direction of Event 5

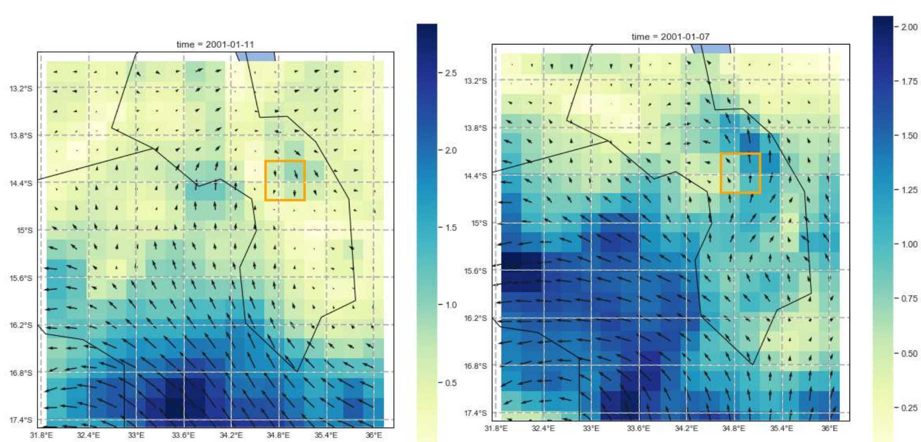

Figure 61: Left: Weekly Average of Wind Direction (arrows) and Speed (colours) one week before Onset. Right: Daily Wind Direction (arrows) and Speed (colours) during Onset

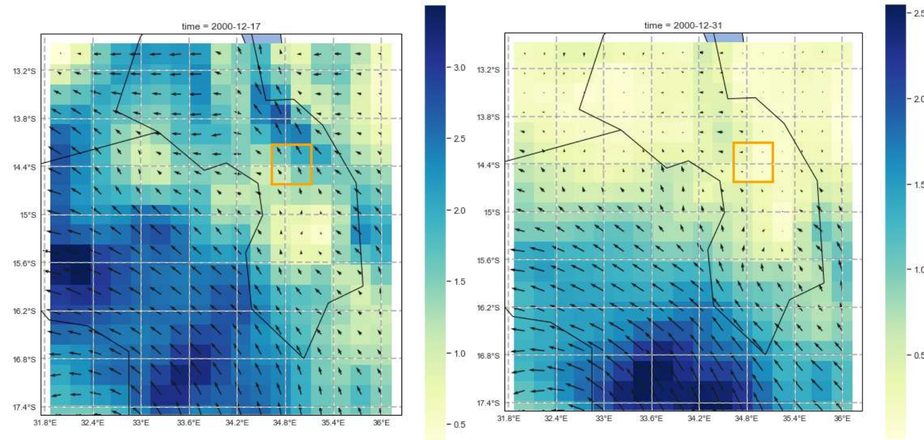

Figure 62: Weekly Average of Wind Direction (arrows) and Speed (colours) during Two Longest Dry Spells

Event 6

The time series and maps of the meteorological variables of season 2000/01 for Mangochi Met Station are illustrated in Figure 63,Figure 64 and Figure 65

The farmers descriptions included:

"It all started in end of October. We would see huge clouds forming and we thought there will be heavy rains. Then all of a sudden, there were heavy winds which cleared the clouds. There were heavy Mwera winds from October to December. "

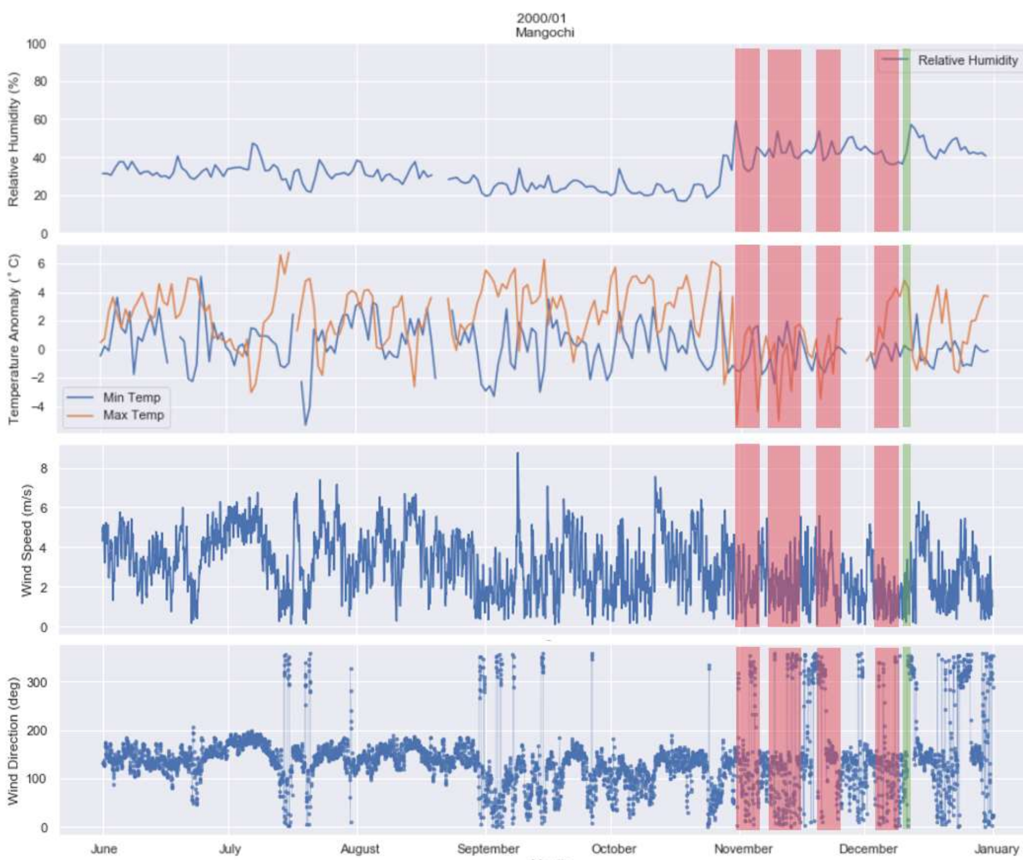

Figure 63: Time Series of Relative Humidity, Wind Speed and Direction of Event 5

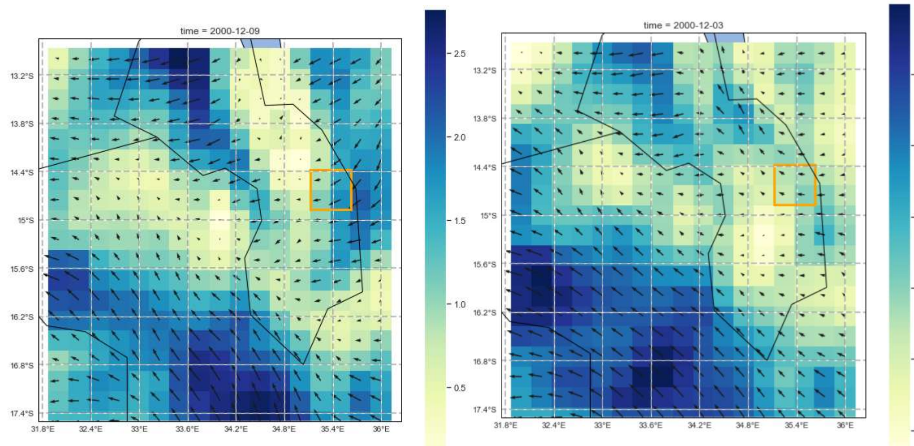

Figure 64: Left: Weekly Average of Wind Direction (arrows) and Speed (colours) one week before Onset. Right: Daily Wind Direction (arrows) and Speed (colours) during Onset

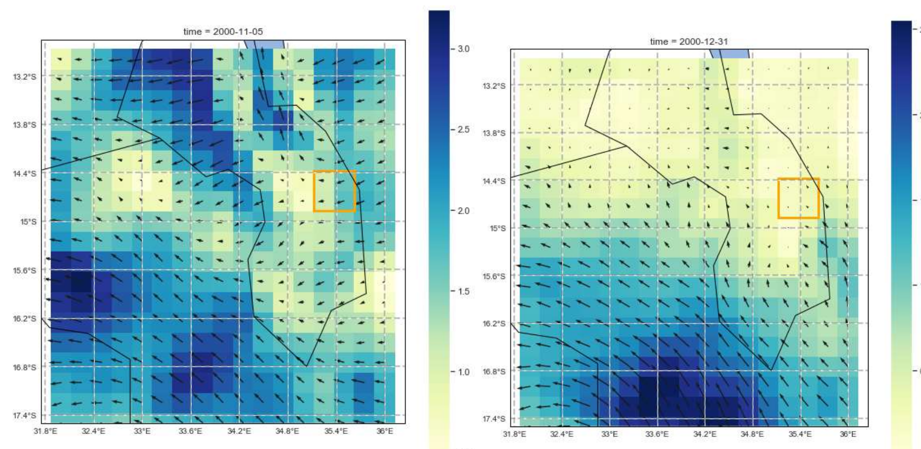

Figure 65: Weekly Average of Wind Direction (arrows) and Speed (colours) during Two Longest Dry Spells

Event 7

The time series and maps of the meteorological variables of season 2000/01 for Zomba Agriculture Station are illustrated in Figure 66, Figure 67 and Figure 68.

The farmers descriptions included:

"The weather was just as usual. Then with climate change we had from November, we were taken by surprise."

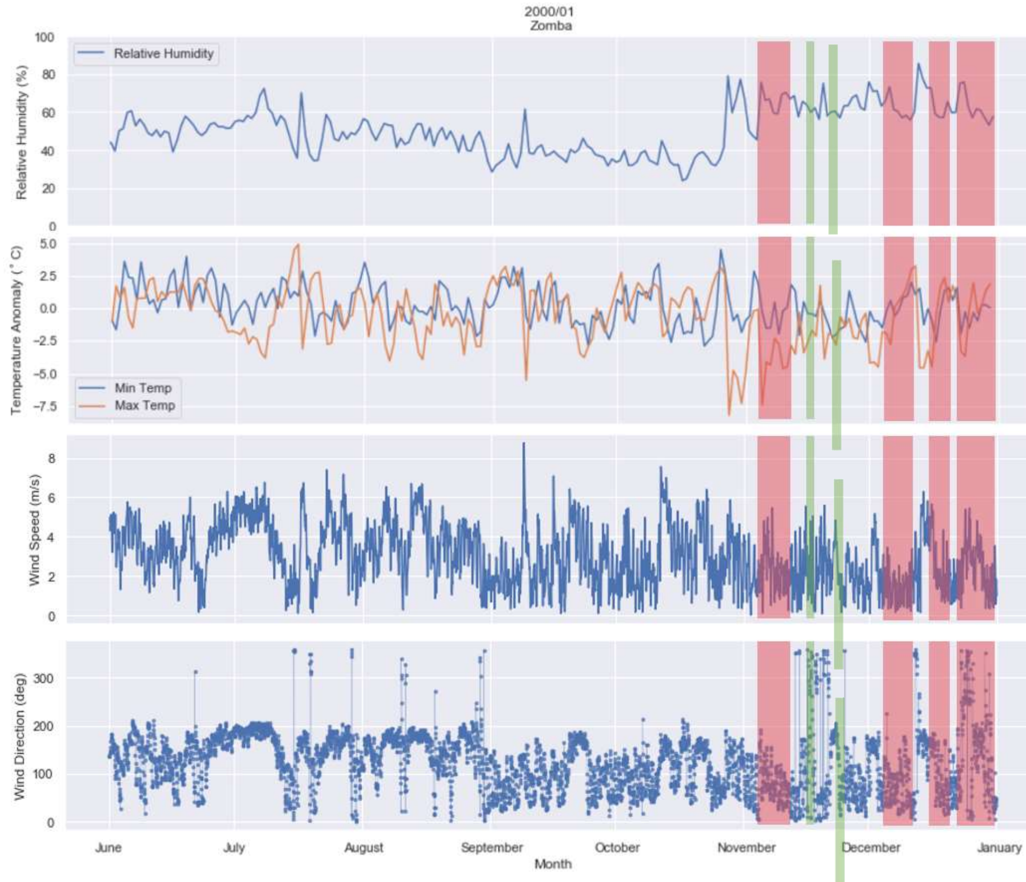

Figure 66: Time Series of Relative Humidity, Wind Speed and Direction of Event 7

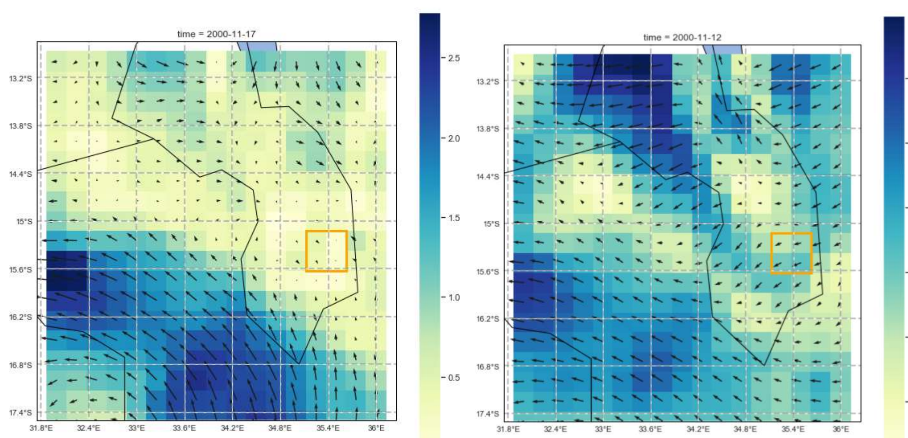

Figure 67: Left: Weekly Average of Wind Direction (arrows) and Speed (colours) one week before Onset. Right: Daily Wind Direction (arrows) and Speed (colours) during Onset

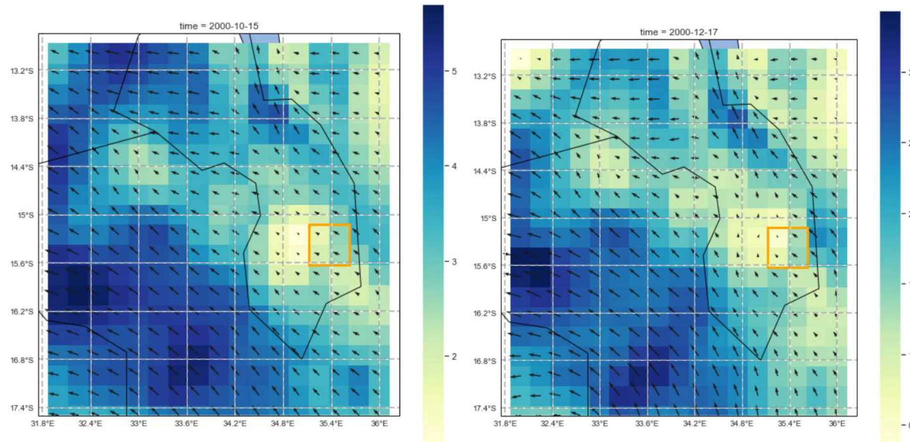

Figure 68: Weekly Average of Wind Direction (arrows) and Speed (colours) during Two Longest Dry Spells

Event 8

The time series and maps of the meteorological variables of season 2011/12 for Zomba Agriculture Station are illustrated in Figure 66, Figure 67 and Figure 68.

The farmers descriptions included:

"It all started with cold winds. That was in August and September. We had strong Mwera winds in August and September."

"We planted several times in October because the seedlings would dry up because of high temperatures. "

"It was sunny. We also had Mwera winds [December]."

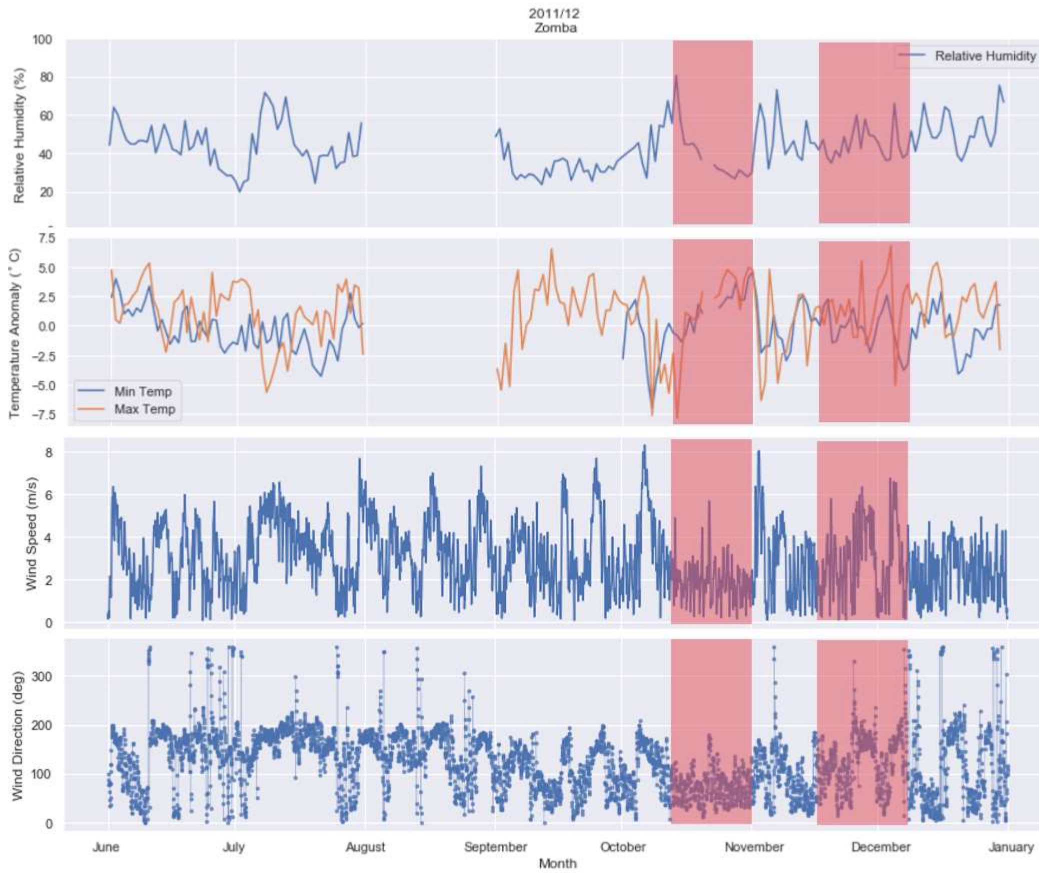

Figure 69: Time Series of Relative Humidity, Wind Speed and Direction of Event 8

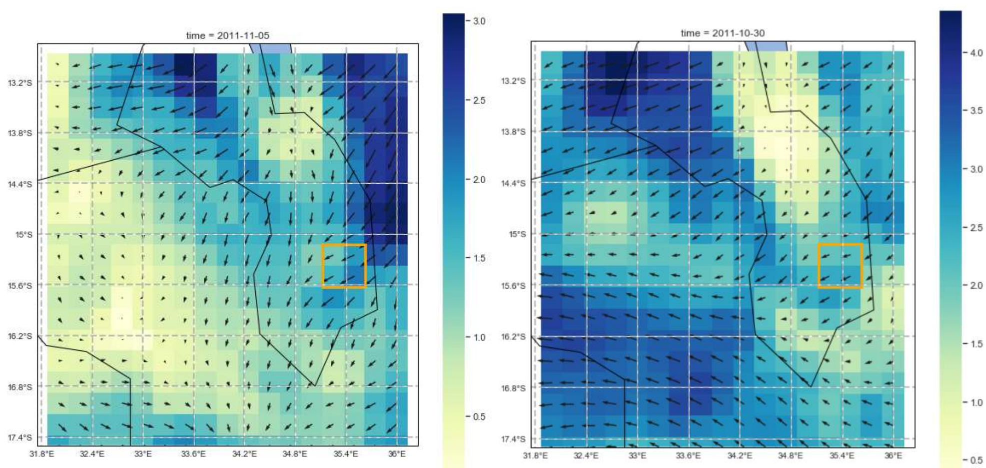

Figure 70: Left: Weekly Average of Wind Direction (arrows) and Speed (colours) one week before Onset. Right: Daily Wind Direction (arrows) and Speed (colours) during Onset

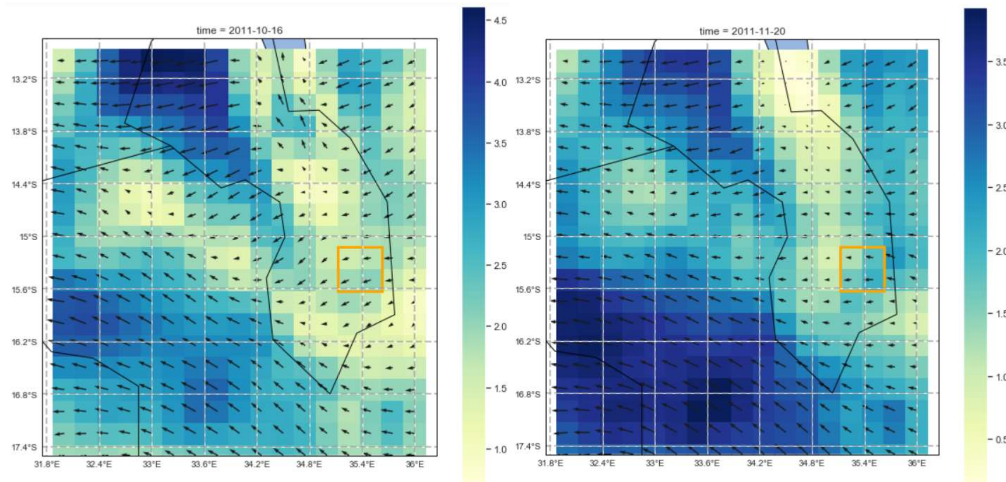

Figure 71: Weekly Average of Wind Direction (arrows) and Speed (colours) during Two Longest Dry Spells

Large Scale Wind Processes

For the three drought and no drought seasons, the large-scale wind processes of monthly averages are visualised for the months July to December.

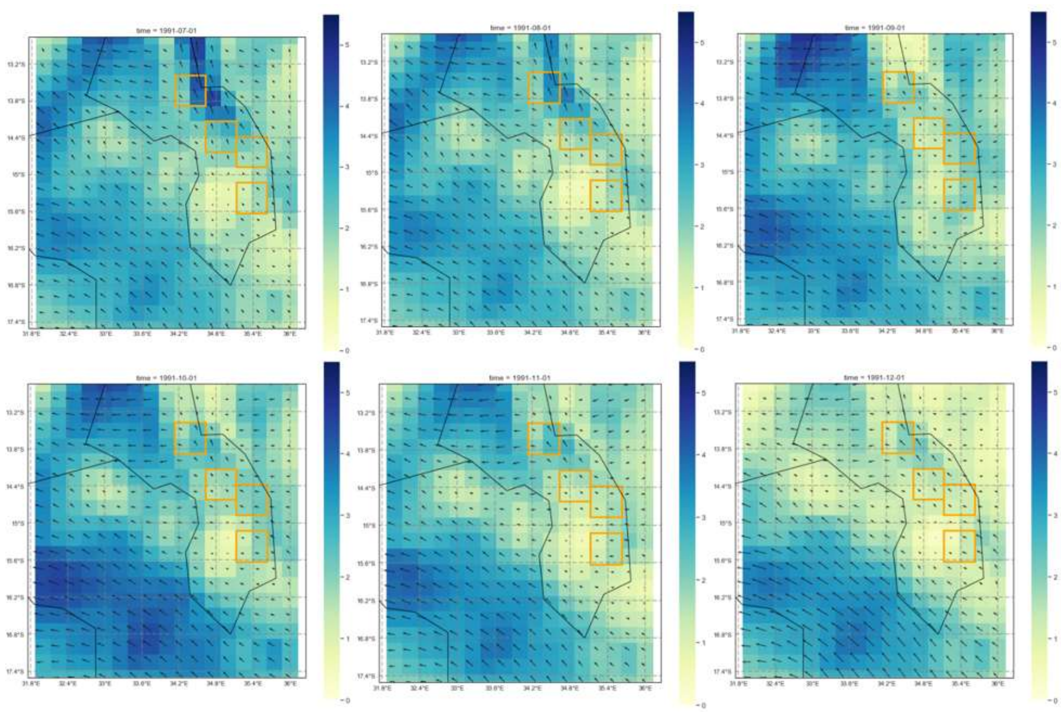

Figure 72: Wind Speed and Direction from July to December in 1991 (from left top to right bottom)

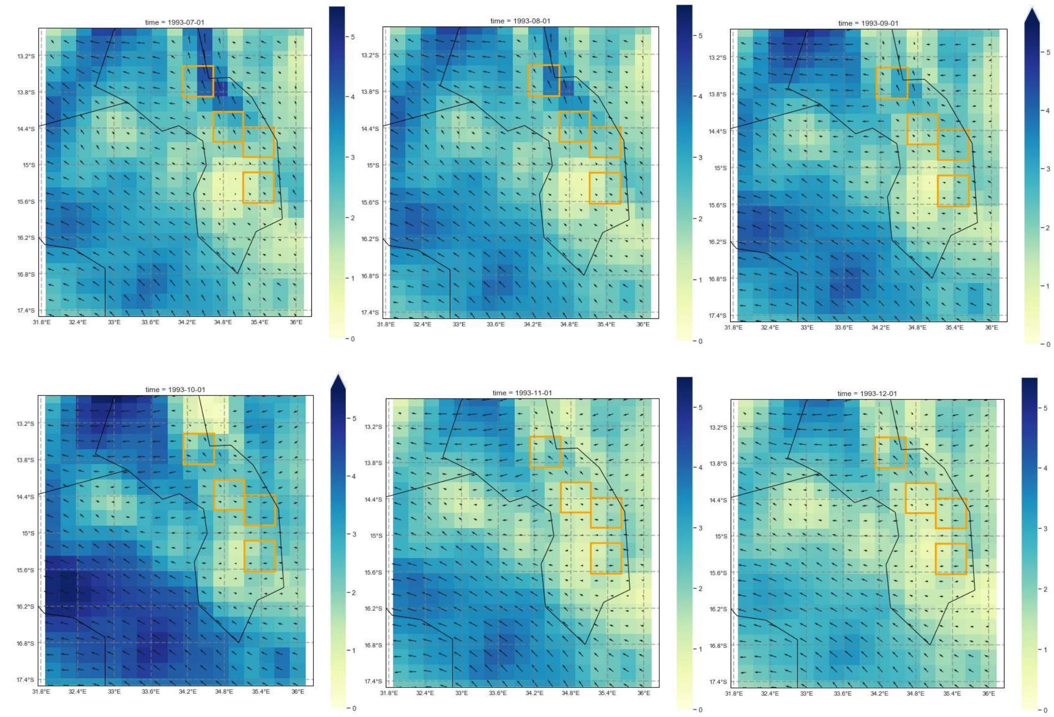

Figure 73: Wind Speed and Direction from July to December in 1993 (from left top to right bottom)

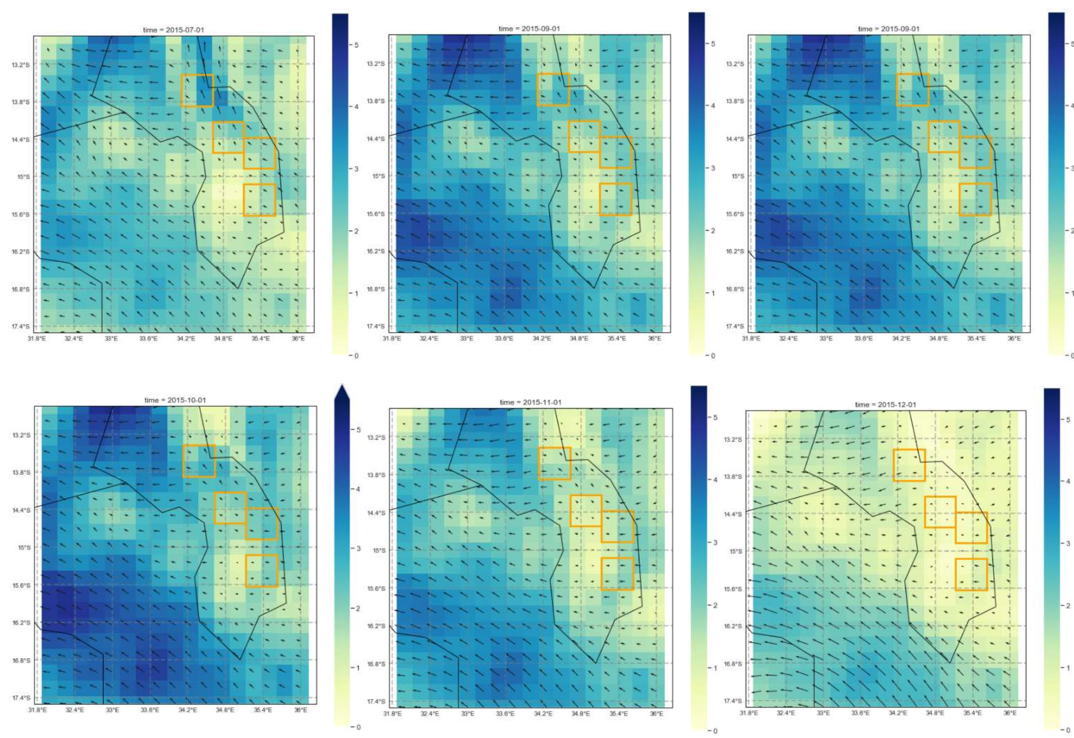

Figure 74: Wind Speed and Direction from July to December in 2015 (from left top to right bottom)

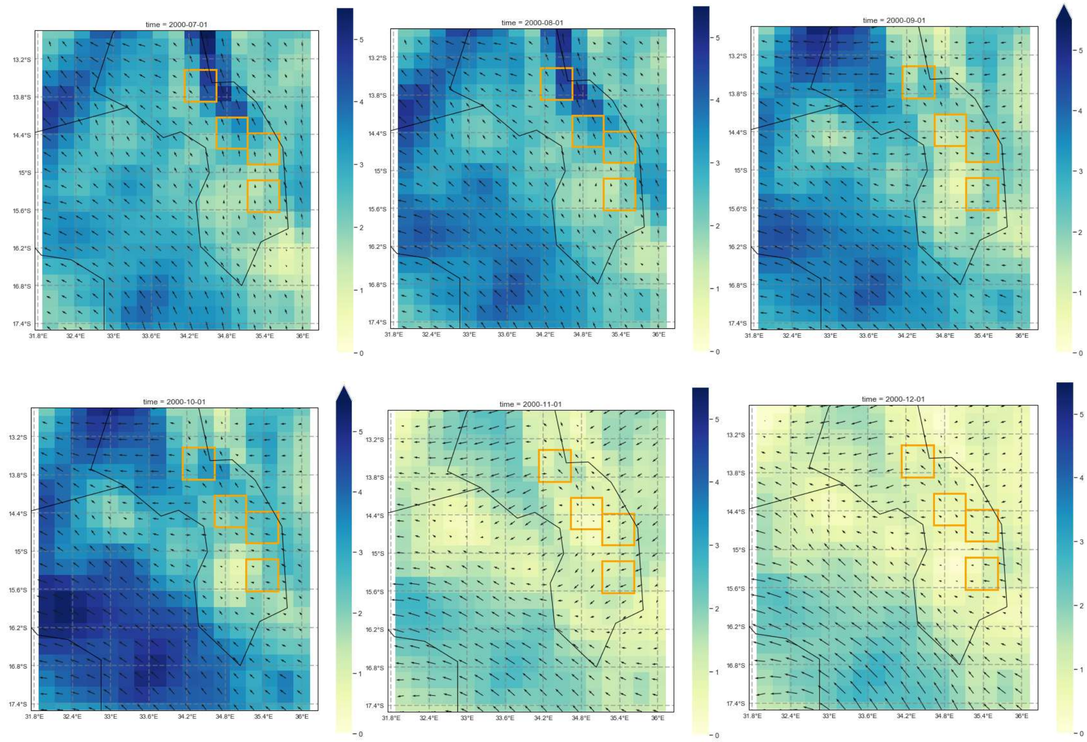

Figure 75: Wind Speed and Direction from July to December in 2000 (from left top to right bottom)

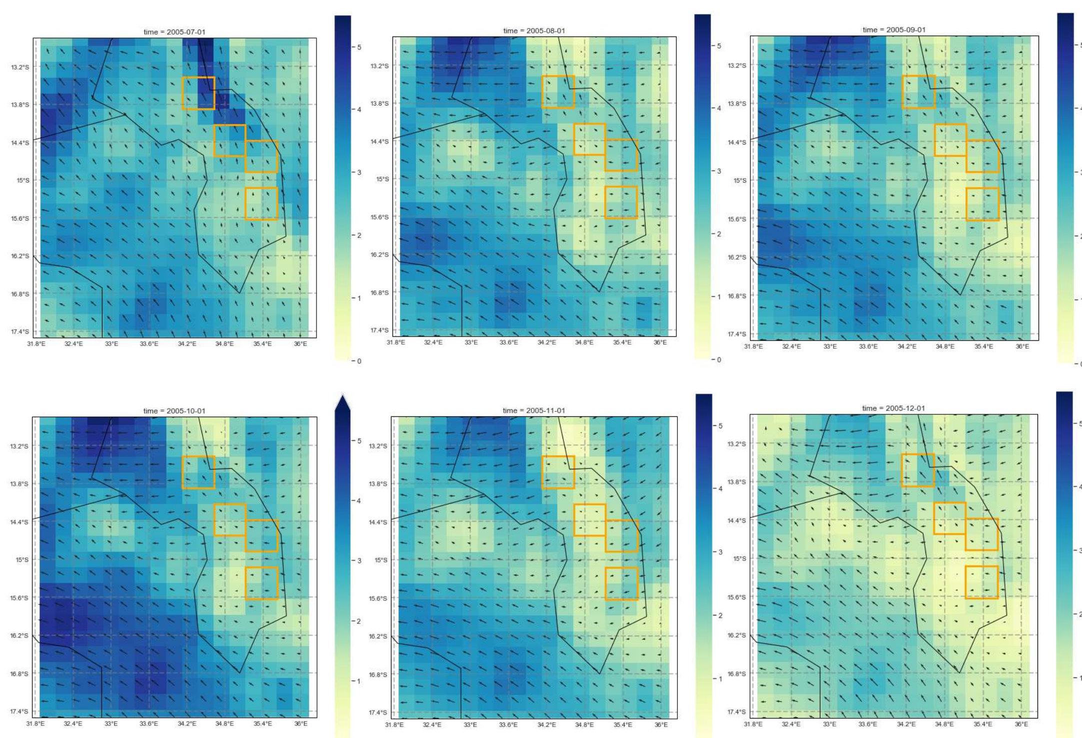

Figure 76: Wind Speed and Direction from July to December in 2005 (from left top to right bottom)

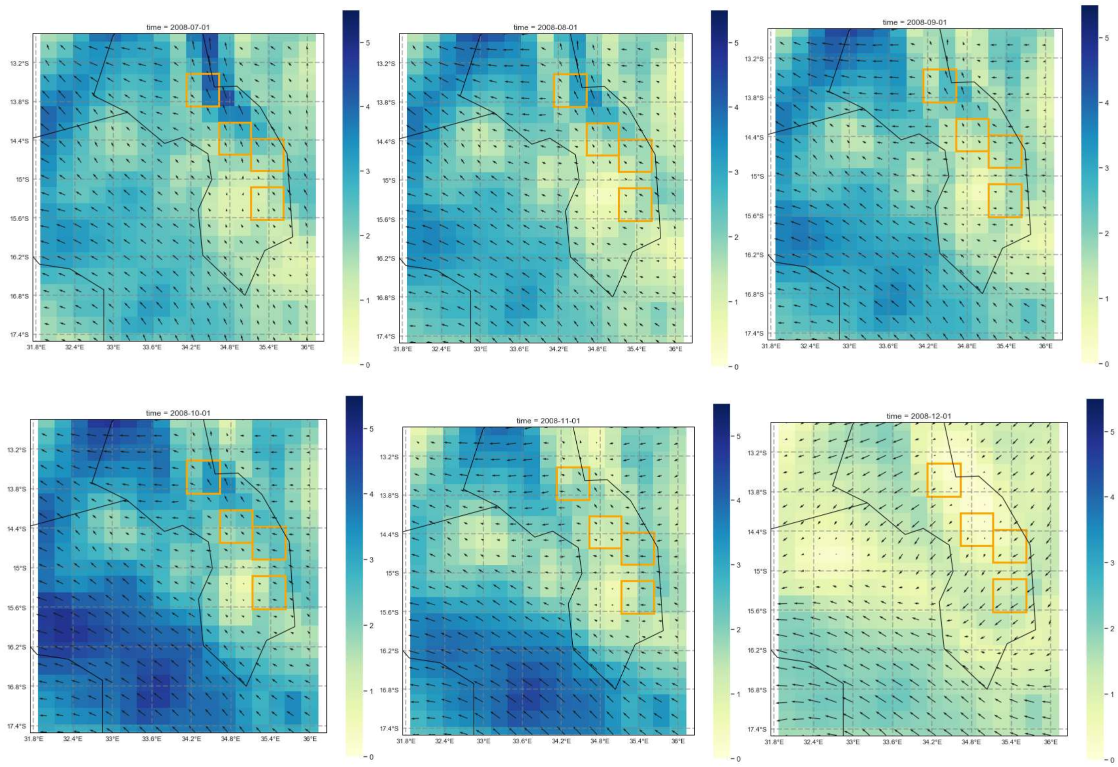

Figure 77: Wind Speed and Direction from July to December in 2008 (from left top to right bottom)

The results of the correlating analysis are presented in the Table 24, Table 25 and Table 26 for drought, dry spells and onset respectively. Orange marks the correlations with a p-value <0.075 and yellow the correlations with a p-value < 0.1.

Table 24: Spearman Rank Correlations of Drought

Salima	Speed Zone NE		Direction Zone NE		Speed District		Direction District		Speed Zone SE		Direction Zone SE		Min Temp		Max Temp		RH		ONI	
	r	p	r	p	r	p	r	p	r	p	r	p	r	p	r	p	r	p	r	p
June	-0.12	0.51	0.04	0.82	-0.11	0.51	-0.34	0.05	-0.20	0.26	0.07	0.70	0.00	0.99	-0.04	0.78	0.02	0.91	0.27	0.06
July	0.32	0.06	-0.42	0.01	-0.22	0.22	0.24	0.16	-0.30	0.09	-0.41	0.02	0.08	0.71	-0.04	0.80	0.03	0.87	0.31	0.03
Aug	0.26	0.13	-0.34	0.05	-0.22	0.21	-0.05	0.79	-0.26	0.13	-0.24	0.17	-0.12	0.70	-0.13	0.36	-0.08	0.65	0.33	0.02
Sep	0.01	0.95	-0.02	0.91	0.00	0.99	-0.10	0.56	0.07	0.68	-0.03	0.86	-0.04	0.64	-0.33	0.02	-0.24	0.18	0.31	0.03
Oct	-0.11	0.52	0.09	0.61	-0.01	0.94	0.02	0.00	0.07	0.70	0.17	0.35	-0.01	0.83	-0.19	0.18	-0.13	0.45	0.29	0.04
Nov	0.09	0.61	0.18	0.31	0.32	0.06	0.16	0.36	0.12	0.49	0.11	0.54	-0.19	0.26	-0.03	0.83	-0.01	0.93	0.28	0.05
Dec	0.08	0.67	0.14	0.41	0.20	0.24	0.16	0.36	0.10	0.57	0.13	0.47	-0.05	0.73	0.11	0.44	0.19	0.29	0.27	0.06
Mangochi																				
June	-0.12	0.20	0.14	0.41	-0.21	0.19	0.13	0.44	-0.26	0.11	0.09	0.58	-0.14	0.42	0.19	0.18	0.31	0.07	0.39	0.02
July	0.03	0.97	-0.17	0.31	0.07	0.67	-0.16	0.34	-0.01	0.94	-0.20	0.22	0.05	0.99	0.22	0.10	0.27	0.09	0.43	0.01
Aug	-0.15	0.37	-0.08	0.62	-0.13	0.42	-0.09	0.61	-0.05	0.78	0.00	0.99	-0.16	0.60	0.28	0.12	0.40	0.03	0.42	0.01
Sep	0.09	0.60	-0.09	0.58	0.14	0.41	-0.11	0.53	-0.04	0.79	-0.13	0.42	-0.22	0.16	0.16	0.24	0.24	0.21	0.40	0.01
Oct	-0.29	0.08	0.24	0.15	-0.35	0.03	0.22	0.19	0.14	0.30	0.28	0.09	-0.28	0.05	0.24	0.40	0.22	0.23	0.40	0.01
Nov	-0.08	0.62	0.10	0.54	-0.05	0.77	0.11	0.50	-0.05	0.75	0.07	0.66	-0.14	0.40	0.03	0.54	0.11	0.47	0.40	0.01
Dec	0.11	0.52	0.06	0.74	0.10	0.54	0.12	0.49	0.05	0.79	0.00	0.98	0.20	0.43	-0.05	0.98	-0.02	0.88	0.42	0.01
Zomba																				
June	-0.30	0.07	-0.12	0.47	-0.37	0.02	-0.17	0.30	-0.33	0.05	0.07	0.70	-0.08	0.57	0.02	0.81	-0.05	0.76	0.26	0.09
July	0.21	0.20	0.05	0.77	0.24	0.15	0.03	0.87	0.13	0.44	-0.41	0.02	-0.09	0.75	-0.24	0.20	0.13	0.11	0.24	0.13
Aug	0.06	0.73	0.10	0.53	0.06	0.70	0.16	0.35	0.09	0.58	-0.24	0.17	-0.14	0.38	-0.22	0.63	0.36	0.04	0.21	0.19
Sep	0.06	0.72	0.13	0.46	0.20	0.23	-0.01	0.97	0.05	0.78	-0.03	0.86	-0.27	0.05	-0.15	0.31	0.03	0.13	0.18	0.27
Oct	-0.35	0.03	0.26	0.11	-0.27	0.10	0.29	0.07	0.10	0.55	0.17	0.35	-0.25	0.11	-0.21	0.20	0.29	0.05	0.22	0.16

Nov	-0.05	0.75	0.09	0.59	0.02	0.91	0.00	0.99	-0.09	0.60	0.11	0.54	0.06	0.75	0.15	0.86	-0.16	0.92	0.24	0.13
Dec	0.01	0.95	0.05	0.75	0.06	0.74	0.07	0.67	0.11	0.50	0.13	0.47	-0.10	0.40	0.30	0.13	-0.49	0.01	0.28	0.07

Table 25: Spearman Rank Correlations of Dry Spells

	Salima		Chitale		Mangochi Met		Namwera		MonkeyBay		Namiasi		Namkumba		Makoka		Chanco		Chingale		Zomba Agri	
	r	p	r	p	r	p	r	p	r	p	r	p	r	p	r	p	r	p	r	p	r	p
Minimum Temperature																						
June	-0.17	0.28	-0.28	0.20	-0.09	0.51	0.01	0.98	-0.09	0.71	0.04	0.82	-0.10	0.46	0.10	0.57	-0.23	0.17	0.02	0.93	-0.05	0.71
July	-0.04	0.47	0.00	0.98	0.06	0.40	-0.01	0.99	0.05	0.78	0.18	0.19	-0.13	0.29	-0.08	0.71	-0.29	0.08	0.00	0.76	0.13	0.30
Aug	0.05	0.52	-0.08	0.71	0.04	0.40	0.00	0.88	-0.31	0.10	0.05	0.64	-0.04	0.76	-0.15	0.30	-0.26	0.21	-0.33	0.09	-0.29	0.12
Sep	-0.08	0.24	-0.15	0.49	-0.11	0.46	-0.10	0.37	-0.37	0.02	-0.18	0.21	0.01	0.73	-0.28	0.09	-0.27	0.02	-0.17	0.34	-0.09	0.62
Oct	-0.19	0.08	-0.12	0.57	0.25	0.08	-0.08	0.20	0.04	0.86	0.23	0.13	0.05	0.89	0.00	0.94	-0.20	0.24	-0.18	0.37	-0.10	0.56
Nov	-0.10	0.18	-0.42	0.05	0.06	0.62	-0.18	0.09	-0.02	0.98	0.14	0.41	-0.06	0.43	-0.26	0.07	-0.12	0.38	-0.30	0.12	-0.29	0.13
Dec	0.07	0.91	-0.30	0.16	0.10	0.52	-0.11	0.25	-0.02	0.65	0.26	0.16	-0.06	0.40	-0.08	0.53	-0.21	0.09	-0.05	0.70	-0.04	0.93
Maximum Temperature																						
June	-0.09	0.50	-0.04	0.80	0.08	0.77	-0.32	0.06	-0.14	0.43	0.04	0.80	-0.10	0.53	0.12	0.67	-0.20	0.26	-0.11	0.70	-0.08	0.46
July	-0.03	0.82	-0.06	0.70	0.03	0.97	-0.32	0.05	-0.26	0.20	-0.10	0.67	0.02	0.83	-0.19	0.18	-0.47	0.00	-0.68	0.00	-0.32	0.08
Aug	-0.04	0.78	-0.10	0.48	0.02	0.89	-0.30	0.08	-0.16	0.40	-0.06	0.92	-0.22	0.19	0.01	0.77	-0.04	0.92	-0.12	0.57	-0.40	0.03
Sep	0.08	0.57	-0.15	0.31	0.03	0.94	-0.27	0.13	0.05	0.98	-0.08	0.54	-0.14	0.35	-0.11	0.30	-0.10	0.89	-0.21	0.42	-0.12	0.24
Oct	0.12	0.31	-0.20	0.16	0.16	0.32	-0.18	0.27	0.00	0.79	0.12	0.53	-0.02	0.58	-0.04	0.59	-0.28	0.07	-0.18	0.47	-0.13	0.44
Nov	0.04	0.80	-0.21	0.15	0.05	0.93	-0.35	0.04	-0.04	0.75	0.10	0.61	-0.10	0.45	-0.33	0.02	-0.20	0.33	-0.34	0.09	-0.24	0.18
Dec	0.09	0.51	0.06	0.70	0.08	0.83	-0.24	0.18	0.01	0.90	0.30	0.11	0.01	0.85	0.01	0.88	-0.17	0.55	0.08	0.50	0.25	0.25
Speed																						
June	0.27	0.10	0.01	0.96	0.13	0.42	0.14	0.39	0.03	0.88	0.08	0.65	-		-0.08	0.60	0.03	0.88	0.01	0.95	0.16	0.19
July	0.12	0.46	-0.09	0.62	-0.13	0.42	-0.29	0.08	-0.07	0.69	0.27	0.10	-		0.13	0.42	0.06	0.72	0.11	0.53	0.34	0.02
Aug	0.07	0.70	-0.14	0.44	0.00	0.93	-0.08	0.64	-0.01	0.10	0.01	0.95	-		-0.25	0.12	-0.21	0.22	0.03	0.84	0.54	0.01
Sep	-0.02	0.92	0.07	0.70	0.08	0.63	0.30	0.06	-0.13	0.04	0.14	0.39	-		0.06	0.73	0.12	0.47	0.31	0.06	0.27	0.01
Oct	-0.03	0.88	-0.01	0.97	0.06	0.72	0.08	0.62	-0.13	0.44	-0.06	0.72	-		-0.20	0.22	-0.24	0.15	-0.11	0.50	0.23	0.04
Nov	0.14	0.40	0.02	0.90	0.04	0.81	-0.27	0.10	0.01	0.96	0.11	0.51	-		-0.36	0.02	-0.23	0.16	-0.42	0.01	0.24	0.22
Dec	0.02	0.92	0.10	0.56	0.03	0.87	-0.18	0.26	-0.11	0.48	-0.06	0.71	-		-0.25	0.11	-0.05	0.77	-0.22	0.19	-0.13	0.27

	Salima		Chitale		Mangochi Met		Namwera		MonkeyBay		Namiasi		Namkumba		Makoka		Chanco		Chingale		Zomba Agri	
	r	p	r	p	r	p	r	p	r	p	r	p	r	p	r	p	r	p	r	p	r	p
Direction																						
June	-0.12	0.48	0.16	0.36	0.17	0.30	0.31	0.06	0.14	0.41	-0.12	0.45	-		-0.21	0.19	0.10	0.56	-0.02	0.92	0.12	0.46
July	-0.07	0.67	-0.05	0.80	0.01	0.95	-0.26	0.11	-0.16	0.31	0.18	0.29	-		0.06	0.72	0.04	0.81	-0.02	0.91	-0.11	0.52
Aug	0.14	0.42	-0.17	0.34	0.07	0.69	0.05	0.78	-0.04	0.82	0.10	0.53	-		0.25	0.12	0.08	0.64	0.12	0.49	0.21	0.21
Sep	0.02	0.93	-0.08	0.64	0.12	0.48	0.22	0.18	-0.20	0.22	0.16	0.33	-		0.31	0.05	0.12	0.48	0.09	0.61	-0.06	0.71
Oct	0.01	0.95	0.10	0.60	0.11	0.50	0.00	0.98	-0.03	0.87	0.21	0.21	-		0.07	0.67	0.21	0.20	0.25	0.14	0.13	0.43
Nov	0.05	0.75	0.08	0.67	0.25	0.12	0.26	0.11	-0.15	0.37	-0.14	0.40	-		0.16	0.31	0.16	0.33	0.14	0.41	0.11	0.51
Dec	0.06	0.74	0.17	0.34	0.20	0.22	0.22	0.18	-0.06	0.71	0.37	0.02	-		0.29	0.06	0.11	0.52	0.13	0.45	0.14	0.41
RH																						
June	-0.20	0.24	-0.04	0.83	-0.05	0.79	-0.23	0.25	0.17	0.41	-0.11	0.59	-0.21	0.56	-0.12	0.56	0.14	0.58	0.01	0.64	0.15	0.41
July	-0.18	0.30	0.08	0.67	0.13	0.54	-0.01	0.95	0.17	0.40	0.07	0.79	-0.24	0.85	0.03	0.08	0.51	0.00	0.36	0.05	0.14	0.39
Aug	-0.17	0.31	0.31	0.08	0.25	0.22	0.20	0.33	0.31	0.12	0.22	0.31	-0.24	0.82	0.11	0.90	0.11	0.81	0.07	0.92	0.54	0.00
Sep	-0.26	0.12	0.23	0.20	0.13	0.56	-0.19	0.33	0.18	0.38	0.02	0.87	-0.15	0.76	-0.19	0.35	0.09	0.67	0.19	0.45	0.45	0.02
Oct	-0.34	0.04	0.37	0.04	0.09	0.65	0.16	0.42	0.43	0.03	-0.05	0.80	0.01	0.60	0.08	0.81	0.22	0.04	0.19	0.16	0.27	0.06
Nov	0.07	0.67	0.24	0.18	0.27	0.19	0.20	0.32	0.43	0.03	-0.09	0.63	0.10	0.54	0.31	0.03	0.20	0.16	0.29	0.04	0.31	0.14
Dec	-0.20	0.24	-0.21	0.24	0.14	0.48	-0.13	0.53	0.16	0.38	-0.23	0.24	-0.11	0.80	-0.14	0.95	0.09	0.91	0.09	0.73	-0.08	0.37
ONI																						
June	0.04	0.76	0.20	0.18	0.26	0.05	0.09	0.48	0.09	0.58	-0.04	0.79	0.08	0.56	0.02	9.00	0.08	0.61	0.18	0.15	0.24	0.07
July	0.10	0.46	0.16	0.26	0.27	0.04	0.09	0.46	0.08	0.62	-0.09	0.58	0.07	0.60	0.08	0.56	0.14	0.38	0.21	0.10	0.23	0.08
Aug	0.15	0.29	0.17	0.23	0.31	0.02	0.11	0.37	0.05	0.77	-0.07	0.65	0.11	0.44	0.17	0.24	0.21	0.18	0.25	0.05	0.24	0.06
Sep	0.14	0.30	0.18	0.22	0.29	0.03	0.11	0.38	0.05	0.78	-0.08	0.63	0.12	0.40	0.16	0.26	0.20	0.20	0.27	0.03	0.21	0.11
Oct	0.15	0.30	0.19	0.19	0.23	0.08	0.10	0.43	0.05	0.78	-0.07	0.69	0.12	0.37	0.18	0.20	0.22	0.17	0.29	0.02	0.23	0.08
Nov	0.14	0.34	0.21	0.16	0.22	0.10	0.09	0.45	0.05	0.75	-0.07	0.70	0.14	0.33	0.20	0.16	0.23	0.15	0.32	0.01	0.26	0.04
Dec	0.13	0.35	0.18	0.22	0.21	0.11	0.10	0.41	0.08	0.63	-0.06	0.73	0.15	0.29	0.21	0.13	0.24	0.13	0.33	0.01	0.27	0.04

Table 26: Spearman Rank Correlations of Onset

	Salima		Chitale		Mangochi		Namwera		MonkeyBay		Namiasi		Namkumba		Makoka		Chancellor		Chingale		Zomba Agri	
Wind Speed	r	p	r	p	r		p	r	p	r	p	r	P	r	p	r	p	r	p	r	p	r
June	-0.26	0.12	-0.16	0.36	-0.14	0.40	-0.18	0.27	0.01	0.97	-0.11	0.50	-0.46	0.02	-0.05	-0.75	-0.18	0.28	-0.17	0.30	-0.44	0.01
July	-0.01	0.96	0.07	0.71	0.00	0.98	0.20	0.22	0.04	0.81	0.22	0.19	0.02	0.91	0.01	0.94	0.16	0.34	-0.03	0.86	0.20	0.23
Aug	-0.05	0.77	-0.17	0.33	-0.08	0.62	-0.19	0.26	0.10	0.53	-0.07	0.67	0.23	0.27	-0.04	0.80	-0.06	0.71	0.10	0.56	0.04	0.83
Sep	-0.09	0.58	-0.01	0.96	-0.20	0.21	0.11	0.51	-0.06	0.72	0.17	0.30	-0.10	0.62	0.16	0.33	0.01	0.97	-0.53	0.00	0.14	0.40
Oct	0.13	0.44	0.14	0.43	0.01	0.96	0.01	0.95	-0.13	0.43	-0.04	0.83	0.01	0.95	0.16	0.30	-0.05	0.78	-0.14	0.42	0.10	0.55
Nov	0.13	0.46	0.13	0.48	0.02	0.92	0.35	0.03	0.20	0.22	0.15	0.38	-0.24	0.24	-0.01	0.97	0.33	0.04	0.25	0.15	0.07	0.68
Dec	0.22	0.19	0.25	0.16	0.26	0.11	0.38	0.02	0.45	0.00	-0.10	0.57	0.01	0.96	-0.02	0.90	0.30	0.08	0.18	0.28	0.18	0.27
Wind Direction																						
June	0.22	0.20	-0.05	0.78	0.16	0.32	-0.20	0.24	-0.08	0.62	0.04	0.80	0.28	0.17	0.11	0.50	0.07	0.67	0.04	0.83	-0.19	0.27
July	-0.18	0.28	0.07	0.67	-0.09	0.60	0.09	0.58	0.30	0.07	0.18	0.27	-0.03	0.88	-0.01	0.97	0.30	0.08	0.09	0.61	0.15	0.39
Aug	-0.21	0.21	-0.17	0.32	-0.04	0.80	-0.12	0.47	0.09	0.27	0.03	0.87	0.05	0.81	0.03	0.87	0.07	0.67	-0.14	0.41	0.24	0.16
Sep	-0.15	0.37	-0.07	0.70	-0.19	0.24	-0.08	0.63	-0.21	0.20	0.13	0.43	0.15	0.46	-0.21	0.19	0.00	0.98	0.31	0.06	-0.09	0.60
Oct	0.04	0.82	0.19	0.26	0.17	0.29	0.33	0.04	-0.10	0.55	0.09	0.59	-0.20	0.33	-0.19	0.23	0.15	0.36	-0.08	0.63	0.10	0.56
Nov	-0.18	0.26	0.01	0.98	0.04	0.80	-0.11	0.50	0.01	0.94	0.01	0.96	0.28	0.17	0.08	0.60	-0.08	0.65	-0.19	0.25	-0.20	0.22
Dec	0.10	0.55	0.17	0.33	0.07	0.66	0.06	0.74	0.25	0.13	0.08	0.64	-0.11	0.60	-0.11	0.51	-0.13	0.44	-0.25	0.13	0.06	0.72
Minimum Temperature																						
June	-0.34	0.03	-0.10	0.53	-0.32	0.31	0.12	0.34	0.07	0.64	0.03	0.80	0.17	0.31	0.22	0.13	-0.13	0.40	-0.10	0.50	0.08	0.65
July	0.20	0.21	-0.16	0.31	0.04	0.63	0.09	0.68	0.12	0.44	0.25	0.16	-0.06	0.65	0.13	0.17	-0.18	0.25	-0.14	0.52	0.00	0.71
Aug	0.04	0.80	0.10	0.53	-0.15	0.71	0.18	0.50	0.14	0.39	0.01	0.95	-0.06	0.65	-0.09	0.27	-0.11	0.32	-0.04	0.85	-0.05	0.39
Sep	0.14	0.37	0.08	0.61	-0.14	0.91	0.16	0.33	0.00	0.99	-0.25	0.19	0.15	0.44	0.01	0.97	-0.03	0.73	-0.17	0.20	0.00	0.64
Oct	-0.14	0.37	-0.07	0.66	-0.45	0.03	0.05	0.43	0.16	0.15	-0.19	0.35	-0.05	0.30	0.22	0.19	-0.09	0.56	-0.03	0.95	-0.13	0.31
Nov	0.02	0.89	0.24	0.12	-0.23	0.78	0.46	0.00	0.09	0.51	0.09	0.54	0.22	0.21	0.13	0.27	-0.01	0.99	0.25	0.11	0.05	0.74

Dec	0.08	0.61	0.11	0.47	-0.05	0.17	0.53	0.00	0.24	0.11	0.15	0.26	0.38	0.09	0.34	0.04	-0.07	0.74	0.31	0.04	0.14	0.27
Maximum Temperature																						
June	-0.05	0.72	0.04	0.80	-0.04	0.79	0.48	0.00	0.33	0.05	0.03	0.86	0.30	0.08	0.28	0.10	-0.07	0.50	0.16	0.26	0.35	0.04
July	0.00	0.98	-0.16	0.26	-0.03	0.89	0.48	0.00	0.29	0.75	-0.05	0.82	0.29	0.10	0.25	0.10	-0.11	0.43	0.14	0.40	0.08	0.73
Aug	0.04	0.77	-0.17	0.24	-0.07	0.76	0.43	0.00	0.25	0.11	-0.03	0.90	0.23	0.19	0.14	0.55	-0.13	0.42	0.11	0.25	0.00	0.61
Sep	0.09	0.50	-0.16	0.26	-0.02	0.96	0.41	0.00	0.26	0.12	-0.08	0.71	0.22	0.28	0.33	0.04	0.08	0.87	-0.17	0.13	0.03	0.60
Oct	0.02	0.89	-0.14	0.35	-0.07	0.78	0.45	0.00	0.35	0.02	-0.02	0.99	0.32	0.10	0.43	0.00	-0.01	0.96	0.01	0.69	0.01	0.97
Nov	0.34	0.01	0.17	0.25	0.03	0.84	0.69	0.00	0.23	0.19	0.13	0.46	0.38	0.03	0.25	0.13	0.16	0.34	0.35	0.01	0.22	0.24
Dec	0.39	0.00	0.14	0.32	0.08	0.63	0.63	0.00	0.38	0.03	0.13	0.47	0.38	0.03	0.45	0.00	0.09	0.76	0.38	0.01	0.49	0.00
RH																						
June	0.11	0.58	0.16	0.43	0.35	0.08	0.15	0.68	0.07	0.76	0.02	0.96	0.08	0.84	-0.03	0.95	-0.07	0.92	0.13	0.30	0.04	0.70
July	0.09	0.68	-0.01	0.97	0.13	0.51	0.01	0.90	-0.03	0.81	-0.27	0.12	-0.01	0.92	0.05	0.97	-0.09	0.99	-0.19	0.28	-0.22	0.29
Aug	0.22	0.28	0.05	0.80	0.29	0.15	0.35	0.04	0.24	0.18	0.03	0.90	0.01	0.91	0.05	0.66	0.11	0.43	0.03	0.93	0.25	0.09
Sep	-0.25	0.21	-0.19	0.35	0.21	0.30	0.06	0.83	-0.17	0.39	0.16	0.40	-0.40	0.05	0.00	0.66	0.01	0.76	0.09	0.53	0.08	0.98
Oct	-0.18	0.38	0.01	0.95	0.11	0.60	-0.05	0.50	-0.43	0.00	0.10	0.68	-0.37	0.23	-0.33	0.02	0.02	0.77	0.12	0.76	-0.09	0.33
Nov	-0.41	0.04	-0.41	0.04	0.31	0.11	-0.49	0.00	-0.08	0.69	-0.26	0.15	-0.28	0.33	-0.26	0.28	-0.46	0.00	-0.30	0.07	-0.07	0.83
Dec	-0.22	0.28	-0.14	0.49	0.22	0.27	-0.65	0.00	-0.25	0.15	-0.21	0.23	-0.56	0.02	-0.18	0.25	-0.51	0.01	-0.36	0.06	-0.50	0.01
ONI																					Zomba Agri	
June	0.24	0.06	-0.13	0.30	0.03	0.84	0.21	0.09	0.14	0.37	0.00	0.97	0.18	0.20	0.15	0.28	-0.25	0.09	0.11	0.40	-0.08	0.56
July	0.23	0.07	-0.14	0.26	0.06	0.65	0.12	0.35	0.06	0.73	-0.02	0.92	0.13	0.37	0.13	0.33	-0.29	0.06	0.08	0.52	-0.16	0.21
Aug	0.23	0.07	-0.15	0.24	0.09	0.51	0.08	0.53	-0.03	0.87	-0.03	0.87	0.08	0.56	0.10	0.45	-0.31	0.04	0.08	0.53	-0.20	0.11
Sep	0.21	0.09	-0.13	0.31	0.11	0.39	0.08	0.54	-0.08	0.63	0.02	0.91	0.07	0.62	0.09	0.53	-0.31	0.04	0.09	0.47	-0.22	0.09
Oct	0.21	0.10	-0.13	0.29	0.12	0.37	0.08	0.53	-0.09	0.69	0.05	0.78	0.06	0.58	0.07	0.63	-0.30	0.05	0.08	0.52	-0.20	0.11
Nov	0.22	0.09	-0.12	0.37	0.13	0.32	0.09	0.49	-0.06	0.70	0.09	0.61	0.06	0.58	0.05	0.70	-0.30	0.52	0.07	0.56	-0.19	0.14
Dec	0.22	0.09	-0.12	0.36	0.14	0.30	0.11	0.39	-0.03	0.84	0.08	0.65	0.08	0.56	0.05	0.72	-0.29	0.54	0.09	0.50	-0.15	0.23

Appendix H | Forecast Verification

In this appendix results are shown of the influence of the category of meteorological indicators, can be found for the drought indicators separately in Table 27, Table 28 and Table 29.

Table 27: Contingency Tables for Drought Index

Salima		All Indicators		Leaving out Temperature		Leaving out Wind		Leaving out ENSO		Temperature Only		Wind Only		ENSO Only	
	Obs	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Sim	Yes	3	2	1	0	1	0	3	2	0	0	1	0	0	0
	No	8	37	10	39	11	38	8	37	11	39	10	39	11	39
	PC	0.80		0.80		0.78		0.80		0.78		0.80		0.78	
	FAR	0.40		0.00		0.00		0.40		-		0.00		-	
	TS	0.23		0.09		0.08		0.23		0.00		0.09		0.00	
	HR	0.27		0.09		0.08		0.27		0.00		0.09		0.00	
	POFD	0.05		0.00		0.00		0.05		0.00		0.00		0.00	

Mangochi		All Indicators		Leaving out Temperature		Leaving out Wind		Leaving out ENSO		Temperature Only		Wind Only		ENSO Only	
	Obs	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Sim	Yes	7	2	6	2	1	0	6	2	0	0	1	0	2	0
	No	4	25	5	25	10	27	5	25	11	27	10	27	9	27
	PC	0.84		0.82		0.74		0.82		0.71		0.74		0.76	
	FAR	0.22		0.25		0.00		0.25		-		0.00		0.00	
	TS	0.54		0.46		0.09		0.46		0.00		0.09		0.18	
	HR	0.64		0.55		0.09		0.55		0.00		0.09		0.18	
	POFD	0.07		0.07		0.00		0.07		0.00		0.00		0.00	

Zomba		All Indicators		Leaving out Temperature		Leaving out Wind		Leaving out ENSO		Temperature Only		Wind Only		ENSO Only	
	Obs	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Sim	Yes	11	4	10	1	5	1	2	0	1	0	8	2	4	1
	No	0	27	3	28	6	30	9	31	10	31	3	29	7	30
	PC	0.90		0.90		0.83		0.79		0.76		0.88		0.81	
	FAR	0.27		0.09		0.17		0.00		0.00		0.20		0.20	
	TS	0.73		0.71		0.42		0.18		0.09		0.62		0.33	
	HR	1.00		0.77		0.45		0.18		0.09		0.73		0.36	
	POFD	0.13		0.03		0.03		0.00		0.00		0.06		0.03	

Table 28: Contingency Tables for Timing of Onset

Salima		All Indicators			Temperature Only			ENSO Only	
	Obs	Yes	No		Yes	No		Yes	No
Sim	Yes	4	2	Yes	1	0	Yes	2	1
	No	8	35	No	11	37	No	10	36
	PC	0.80		PC	0.78		PC	0.78	
	FAR	0.33		FAR	0.00		FAR	0.33	
	TS	0.29		TS	0.08		TS	0.15	
	HR	0.33		HR	0.08		HR	0.17	
	POFD	0.05		POFD	0.00		POFD	0.03	

Namwera		All Indicators			Temperature Only			Wind Only	
	Obs	Yes	No		Yes	No		Yes	No
Sim	Yes	7	3	Yes	2	9	Yes	6	2
	No	6	38	No	0	43	No	7	39
	PC	0.83		PC	0.83		PC	0.83	
	FAR	0.30		FAR	0.82		FAR	0.25	
	TS	0.44		TS	0.18		TS	0.40	
	HR	0.54		HR	1.00		HR	0.46	
	POFD	0.07		POFD	0.17		POFD	0.05	

Monkey Bay		All Indicators			Temperature Only			Wind Only	
	Obs	Yes	No		Yes	No		Yes	No
Sim	Yes	8	2	Yes	6	1	Yes	7	1
	No	4	23	No	6	24	No	5	24
	PC	0.84		PC	0.81		PC	0.84	
	FAR	0.20		FAR	0.14		FAR	0.13	
	TS	0.57		TS	0.46		TS	0.54	
	HR	0.67		HR	0.50		HR	0.58	
	POFD	0.08		POFD	0.04		POFD	0.04	

Namkumba		All Indicators			Temperature Only			Wind Only	
	Obs	Yes	No		Yes	No		Yes	No
Sim	Yes	6	0	Yes	4	0	Yes	3	0
	No	6	30	No	8	30	No	9	30
	PC	0.86		PC	0.81		PC	0.79	
	FAR	0.00		FAR	0.00		FAR	0.00	
	TS	0.50		TS	0.33		TS	0.25	
	HR	0.50		HR	0.33		HR	0.25	
	POFD	0.00		POFD	0.00		POFD	0.00	

Chancellor		All Indicators			Leaving out Temperature			Leaving out Wind			Leaving out ENSO			Temperature Only			Wind Only			ENSO Only	
	Obs	Yes	No		Yes	No		Yes	No		Yes	No		Yes	No		Yes	No		Yes	No
Sim	Yes	5	1	Yes	1	0	Yes	5	1	Yes	4	0	Yes	4	0	Yes	0	0	Yes	1	0
	No	4	32	No	8	33	No	4	32	No	5	33	No	5	33	No	9	33	No	8	33
	PC	0.88		PC	0.81		PC	0.88		PC	0.88		PC	0.88		PC	0.79		PC	0.81	
	FAR	0.17		FAR	0.00		FAR	0.17		FAR	0.00		FAR	0.00		FAR	#DIV		FAR	0.00	
	HR	0.56		HR	0.11		HR	0.56		HR	0.44		HR	0.44		HR	0.00		HR	0.11	
	POFD	0.03		POFD	0.00		POFD	0.03		POFD	0.00		POFD	0.00		POFD	0.00		POFD	0.00	

Chingale		All Indicators			Temperature Only			Wind Only	
	Obs	Yes	No		Yes	No		Yes	No
Sim	Yes	11	2	Yes	9	2	Yes	9	5
	No	3	32	No	5	32	No	5	29
	PC	0.90		PC	0.85		PC	0.79	
	FAR	0.15		FAR	0.18		FAR	0.36	
	TS	0.69		TS	0.56		TS	0.47	
	HR	0.79		HR	0.64		HR	0.64	
	POFD	0.06		POFD	0.06		POFD	0.15	

Zomba Agri		All Indicators			Temperature Only			Wind Only	
	Obs	Yes	No		Yes	No		Yes	No
Sim	Yes	10	2	Yes	10	2	Yes	10	4
	No	2	34	No	2	34	No	2	32
	PC	0.92		PC	0.92		PC	0.88	
	FAR	0.17		FAR	0.17		FAR	0.29	
	TS	0.71		TS	0.71		TS	0.63	
	HR	0.83		HR	0.83		HR	0.83	
	POFD	0.06		POFD	0.06		POFD	0.11	

Table 29: Contingency Tables for Number of Dry Spells

Namwera		All Indicators			Temperature Only			Wind Only	
	Obs	Yes	No		Yes	No		Yes	No
Sim	Yes	16	8	Yes	16	9	Yes	18	10
	No	2	11	No	2	10	No	0	9
	PC	0.73		PC	0.70		PC	0.73	
	FAR	0.33		FAR	0.36		FAR	0.36	
	TS	0.62		TS	0.59		TS	0.64	
	HR	0.89		HR	0.89		HR	1.00	
	POFD	0.42		POFD	0.47		POFD	0.53	

Makoka		All Indicators			Temperature Only			Wind Only	
	Obs	Yes	No		Yes	No		Yes	No
Sim	Yes	27	13	Yes	24	12	Yes	15	4
	No	2	9	No	5	10	No	14	18
	PC	0.71		PC	0.67		PC	0.65	
	FAR	0.33		FAR	0.33		FAR	0.21	
	TS	0.64		TS	0.59		TS	0.45	
	HR	0.93		HR	0.83		HR	0.52	
	POFD	0.59		POFD	0.55		POFD	0.18	

Chingale		All Indicators			Leaving out Temperature			Leaving out Wind			Leaving out ENSO			Temperature Only			Wind Only			ENSO Only	
	Obs	Yes	No		Yes	No		Yes	No		Yes	No		Yes	No		Yes	No		Yes	No
Sim	Yes	25	5	Yes	17	2	Yes	23	3	Yes	26	9	Yes	19	4	Yes	20	4	Yes	20	5
	No	2	12	No	10	14	No	4	14	No	1	8	No	8	13	No	7	13	No	7	12
	PC	0.84		PC	0.72		PC	0.84		PC	0.77		PC	0.73		PC	0.75		PC	0.73	
	FAR	0.17		FAR	0.11		FAR	0.12		FAR	0.26		FAR	0.17		FAR	0.17		FAR	0.20	
	TS	0.78		TS	0.59		TS	0.77		TS	0.72		TS	0.61		TS	0.65		TS	0.63	
	HR	0.93		HR	0.63		HR	0.85		HR	0.96		HR	0.70		HR	0.74		HR	0.74	
	POFD	0.29		POFD	0.13		POFD	0.18		POFD	0.53		POFD	0.24		POFD	0.24		POFD	0.29	

Zomba Agri		All Indicators			Leaving out Temperature			Leaving out Wind			Leaving out ENSO			Temperature Only			Wind Only			ENSO Only	
	Obs	Yes	No		Yes	No		Yes	No		Yes	No		Yes	No		Yes	No		Yes	No
Sim	Yes	19	3	Yes	20	8	Yes	19	4	Yes	20	6	Yes	18	4	Yes	11	3	Yes	16	7
	No	4	14	No	3	9	No	4	13	No	3	11	No	5	13	No	12	14	No	7	10
	B	0.96		B	1.22		B	1.00		B	1.13		B	0.96		B	0.61		B	1.00	
	PC	0.83		PC	0.73		PC	0.80		PC	0.78		PC	0.78		PC	0.63		PC	0.65	
	FAR	0.14		FAR	0.29		FAR	0.17		FAR	0.23		FAR	0.18		FAR	0.21		FAR	0.30	
	TS	0.73		TS	0.65		TS	0.70		TS	0.69		TS	0.67		TS	0.42		TS	0.53	
	HR	0.83		HR	0.87		HR	0.83		HR	0.87		HR	0.78		HR	0.48		HR	0.70	
	POFD	0.18		POFD	0.47		POFD	0.24		POFD	0.35		POFD	0.24		POFD	0.18		POFD	0.41	