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# African farmers' perceptions of erratic rainfall

Elisabeth Simelton[1,2], Claire H. Quinn[1], Philip Antwi-Agyei[1,3], Nnyaladzi Batisani[4], Andrew J. Dougill[1], Jen Dyer[1], Evan D. G. Fraser[1,5], David Mkwambisi[6], Staffan Rosell[7], Susannah Sallu[1], Lindsay C. Stringer[1]

## Abstract

Farmers' perceptions of how rainfall is changing is crucial in anticipating the effects of climate change, as only farmers who perceive a problem will adapt to it. However, even within the same location, people may perceive rainfall changes differently. Therefore, how can scientists, practitioners, and farmers ensure that they talk about the same rainfall changes? The overall aim of this paper is to improve the understanding of what people mean when they say rainfall is becoming more erratic. To do this we compared farmers' perceptions of rainfall changes from four semi-arid regions in Botswana, Ethiopia, Ghana and Malawi, and integrated this with meteorological data. A conceptual rainfall matrix was designed to organise the data as perceptions of onset, duration or cessation.

The matrix helped to clarify ways in which rainfall was becoming "more erratic", in particular in identifying that increasing frequency of dry days and reduced amounts of rainfall (i.e. a meteorological definition) were behind perceptions that rainy seasons started later and finished earlier. A common perception that could not be found within meteorological data was that "rainfall used to start earlier than now". Perceptions that could be reproduced across datasets include "it is difficult to know when the rainy season starts". Here, "more erratic rainfall" may refer to increasing inter-annual variability in the timing of onsets (using an agronomic definition), which resulted in less predictable rainy seasons.

Factors confounding perceptions of rainfall include (lack of and existing) institutional support that prevent farmers from responding at the onset of the rainy season. We introduce "access droughts" to denote crop failures that result from institutional support that leads to maladaptation strategies and increased sensitivity of the agricultural system. Access droughts are sometimes mistaken (by farmers, scientists, extension, policy makers etc.) for agronomic or meteorological droughts. The research suggests that top-down climate impact scenarios need to be grounded with farmers' and extension workers' understandings of how weather is changing more carefully in order to improve policy implementation. The graphs presented in this paper are an attempt to contribute to enhanced clarity in such communications.

Keywords: climate variability, access drought, expectation, onset, cessation, precipitation, participatory methods, farmers' perception

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**About the Authors**

Elisabeth Simelton has worked with climate change research since 2002. She has published both qualitative and quantiative studies on impacts and adaptation within the fields of agriculture, drought and food security together with several of the co-authors of this paper. She was a post-doc researcher at SRI and Centre for Climate Change Economics and Policy (CCCEP) at the time for the fieldwork, and is currently a guest researcher at CCCEP and researcher at World Agroforestry Centre in Vietnam.

This research is a collaboration among several of SRIs Africa experts. They include:

Claire Quinn, who is lecturer in natural resources management with previous agroecological research in Tanzania and South Africa. Evan Fraser was a senior lecturer at SRI at the time of the fieldwork, is an associate professor at University of Guelph in Canada since 2010. He has published extensively on food security and climate change. Andy Dougill is professor of environmental sustainability specialising in dryland envrionmental change, with long experience from Botswana. Lindsay Stringer is reader and Susannah Sallu is lecturer in Environment and Development. Both have extensive expertise in African dryland issues. Jen Dyer and Philip Antwi-Agyei are PhD students at SRI and CCCEP working on the potential of jatropha for improving rural livelihoods in Malawi, and farming systems vulnerability and adaptation to climate change in Ghana, respectively.

Elisabeth and Claire’s fieldwork were partly funded by the Delphe project, which enables knowledge and research exchange between universities in the UK, Malawi and Botswana. This programme resulted in the collaboration with Nnyaladzi Batisani, lecturer at University of Botswana who specialises in climate change assessments and David Mkwambisi, lecturer at Bunda College in Malawi who specialises in climate change and agriculture development.

Staffan Rosell is a PhD student at Goteborg University in Sweden, who has specialised on land use and farming systems in central highlands Ethiopia for over a decade.

# 1. Introduction

The most common way to assess how climate is changing is by using meteorological observations. For example, in rainfed semiarid agriculture the onset of the rainy season often determines the length of the growing period and thereby suitable combination of crops (Mugalavai et al., 2008). However, rainfall changes rarely produce the type of significant trends that temperature does. For climatic exposure and impact studies the dominant discourse is defined by quantitative modelers. Outputs, such as the Intergovernmental Panel on Climate Change (IPCC) reports, show that for many parts of Africa the exposure to new climatic conditions is projected to reach beyond previously experienced extreme events (Boko et al., 2007). As more than 95% of sub-Saharan African agriculture is rainfed, the impacts are felt particularly by those who directly depend on reliable weather patterns for a livelihood, and where crop cultivation is already on the threshold, small variations will be more noticeable (Tadross et al. 2009). Climate impacts are often based on crop-model simulations run for biophysical adaptations to water and temperature stress while assuming farmers as either doing none or full adaptation (Challinor et al. 2010). This results in simulations of a farming system that is non-sensitive to the kind of socio-economic factors one often finds in qualitative case studies, such as planting decisions based on access to inputs and perceptions. In addition, crop models with meteorological data do not lend itself for assessing the impact of “erratic rainfall”, which is important for farmers’ decisions and outcomes.

An alternative way to find out how climate is changing is to ask farmers. Qualitative studies often find that the sensitivity of agricultural systems to climate are rarely attributed to solely changes in some exposure or in the adaptive capacities to respond to the exposure, as assumed in crop models; instead sensitivities can be seen as pathways over time (Sallu et al., 2010). For example, Figure 1 highlights that farmers face both bio-physical and socio-economic constraints, and that these may vary with the living standard of the household. Furthermore, the capacity to respond is often constrained by a lack of investments and policy integration, which can exacerbate existing problems and reduce further adaptation options (Fazey et al., 2010; Stringer et al., 2010). This is because institutional and individual adaptations coincide in a context of simultaneous responses to a range of environmental, economic, societal, and political changes, of which changing climate patterns is just one (O'Brien et al., 2007). The important difference compared with most top-down modelling approaches is that contextual analyses recognise that experiences from and perceptions of past events can influence responses to future events.

Ground-truthing of “scientific observations” of changes in climatic patterns with local perceptions has wider applications for adaptation policies. As “perception is a necessary prerequisite for adaptation” (Madisson, 2007, p. 22), the demand for adaptation policies that acknowledge local contexts is rising (Jennings and Magrath, 2009; Twomlow et al., 2008) from both donor and local communities. These communities are becoming increasingly aware that both top-down and bottom-up approaches, each on its own, will overlook whether there is a common understanding among stakeholders of *what* aspect of climate (exposure) is changing, or *how* it is changing. This development require tools that can mix indigenous and scientific knowledge to better illustrate local perceptions of change (Newsham and Thomas, 2011).

One example where there is an apparent need for aligning perceptions and meteorological observations is the frequently stated indication of climate variability and/or change: the “increase in *erratic* rainfall” (Jennings and Magrath, 2009; Twomlow et al., 2008). While terms like “more unpredictable” are also common it is often unclear what “erratic” is synonymous with. In quantitative terms, there is a big difference whether the term “erratic” denotes uncertain, unpredictable, variable or out-of-season rainfall; whether “increase” denotes a trend, a change or more accentuated rains. “Erratic” seems more commonly used by practitioners (possibly citing farmers) and only a few scientists have attempted to quantify what is meant by “erratic” using methods such as coefficient of variation (Parida and Moalafhi, 2008), or associating erratic rainfall with periodic atmospheric phenomena such as El Niño (Tadross et al. 2009). More often the statement “more erratic rainfall” seems a convenient but vague collective description for various combinations of changing weather patterns.

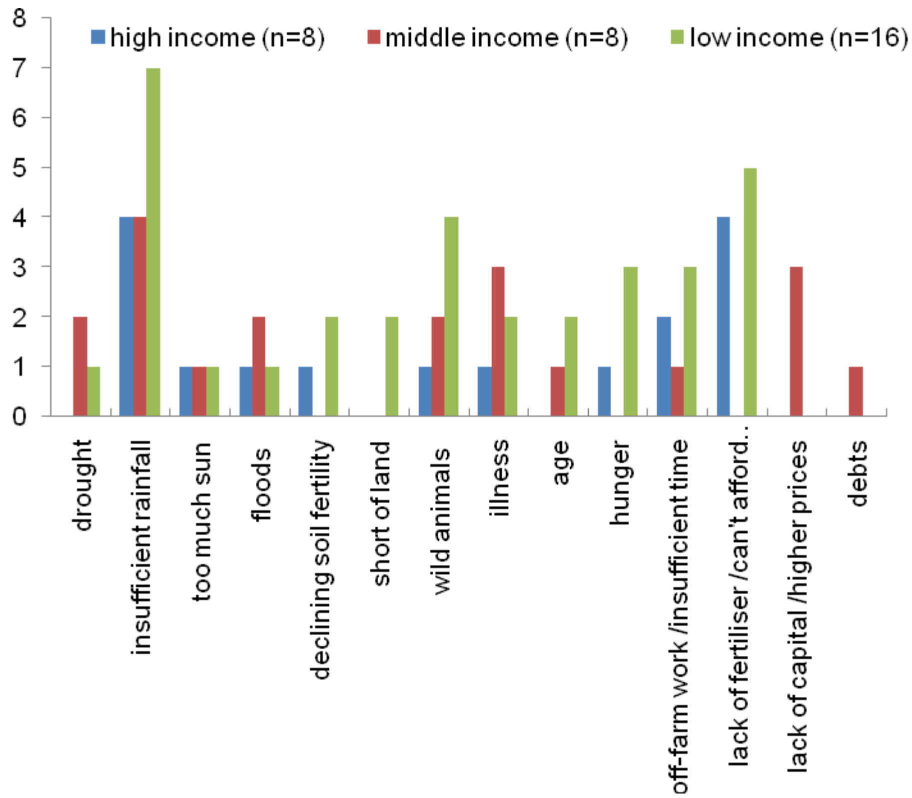



*Figure 1 Example of challenges for a good harvest by income group sorted from the left into natural, social and economic challenges. The example is taken from fieldwork in Malawi and was asked as an open-ended question that allowed multiple answers, i.e. not questionnaire with tick-boxes. The Y-axis shows number of respondents. Note that the low income group is twice as big as the high and middle income groups. Source: Simelton & Quinn, fieldwork 2009 with individual households (n=32).*

This working paper aims to narrow the gap between farmers' perception of changes in rainfall and statistical analyses of meteorological data. Specifically we focus on the concept of "erratic rainfall" and develop a conceptual rainfall matrix to help identify and characterise local representations of this ambiguous concept. We mix local narratives with conventional statistical analyses to explore agreement/disagreement with observed rainfall data and elucidate and explain the gaps. Second, we identify factors that may confound the perception that rainfall has become more erratic. In doing this we draw on case studies from four countries across the African continent (i) which are in different stages of economic development and (ii) where agriculture is rainfed and largely depending on limited rainfall. Since the perceptions are in focus of this research examples from the countries are presented together rather than as four separate cases.

2. Approaches for analysing measured and perceived changes in rainfall

While the literature offers myriad ways to carry out quantitative analyses of meteorological data, and somewhat fewer tools to explore qualitative case studies on farmers' perceptions of climate, the two approaches are rarely used to inform each other. One reason for farmers' and extension workers' observations of weather remaining largely unutilised could be a lack of participatory tools for rainfall analyses, in particular, tools that can be used without formal training in meteorology/climatology. Below we review two distinct approaches to rainfall analysis: the measured and the perceived, and demonstrate why these approaches are complementary.

## 2.1 Measured rainfall changes

There are at least three potential gaps in communication between scientists and farmers: scientists tend to 1) analyse climate data at different timescales than those that are important for farmers and crop growth (Ovuka and Lindqvist, 2000); 2) focus on meteorological droughts while farmers refer to agronomic droughts (Slegers, 2008), and 3) use complex mathematical rules rather than simple practical approximations of available soil moisture to characterise onsets and cessations of rainfall (Mugalavai et al., 2008). Both impact and forecasting studies pose challenges for quantitative scientists.

**I. Scientists correlate rainfall trends with crop yields to show the impacts of climate change on agriculture – but there are few trends**. The IPCC's Fourth Assessment Report Scientific Basis has collated strong scientific evidence to show seasonal annual mean warming of Africa, though few studies actually manage to quantify significant linear trends in rainfall (Cheung et al., 2008). In a similar manner, the summary statistics of rainfall for the four key stations used in this paper also show few linear trends (Table 1). This is because the natural variability is high, and although rainfall commonly exhibits cyclic patterns, traditional statistical models often fail to capture this within the noise of natural variability (Mongi et al., 2010). Nevertheless, some studies using spatially aggregated data analyses have demonstrated significant trends over recent decades, typically with trend breaks in the 1980s. For example, mapping a wide range of meteorological data Funk et al. (2008) find that ten countries in East and Southern Africa had declining growing season rainfall between 1979 and 2005. Using 134 time-series points from meteorological stations in Ethiopia, another study finds a rainfall decline during June-September between 1960 and 2002 (Cheung et al., 2008). Similarly, there is evidence from Botswana of a decrease in rainfall since 1981 (Parida and Moalafhi, 2008) and a decrease in the number of rainy days during 1975-2005 (Batisani and Yarnal, 2009). However, changes in intensity and seasonality are more statistically significant than changes in annual total rainfall, at least in South Africa (Boko et al., 2007).

**II. Scientists want to forecast rainfall onset to predict harvests – but may overlook two-way communication.** The onsets of rainy seasons are key for examining shifts in rain patterns and at the same time are also important indicators for farmers. First, a number of attempts to relate rainfall to underlying large-scale atmospheric pressure systems indicate that rainfall can be predictable to some extent. For example, Ingram et al. (2002) found that rainfall variability in the Sahel-Sudan region of western Africa could be correlated with sea-surface temperature, while East African rainfall is associated with the movements of the Inter-Tropical Convergence Zone (ITCZ) during the “long rains” in March-May (Mugalavai et al., 2008) and declining rainfall in East and Southern Africa has been linked with warming of the Indian Ocean (Funk et al., 2008). Using historical documents from the Kalahari, Nash and Endfield (2008) showed that droughts have been associated with post-El Niño-Southern Oscillation (ENSO) years at least since the 19$^{th}$ century. More specifically, recent studies from Southeast Africa have linked (i) an increase in high pressure systems with increased number of dry days; (ii) El Niño phases with early rains followed by a dry spell; and (iii) La Niña phases with later onset and increase in rainy days (Tadross et al., 2009). However, due to the increasing frequency in El Niño events it may be difficult to separate the causes. Second, onsets have been analysed using various approaches from simple logical expressions to complex models. These are frequently defined as a formula consisting of the total rainfall produced within a certain period of time restricted by a maximum count of dry days. Using variations of such formulae, Tadross et al. (2009) found delayed rainy season onsets in Zambia and Malawi and earlier cessation in the northern parts of the South African region. Markov chain modelling was used to capture Ghana’s dissected onset trends between 1960 and 2008, with slightly earlier rainfall in the Sudan savannah while onsets were delayed in the Guinea savannah (Armah et al., 2011). While quantitative methods may contribute to improved forecasting, whether the outputs agree with farmers’ perceptions, and whether farmers have access to and trust the forecasts is another matter.

Marin (2010) argues that indigenous knowledge provides a necessary complementary spatial scale of analysis of climate change to those offered by meteorological stations and general circulation models. So-called participatory methods can be used for enhancing farmers’ capacities to perceive and interpret weather signs. For example, crop model simulations have shown that “false onsets” may be due to failure to distinguish local rainfall from the large-scale onsets, hence farmers could obtain higher yields by postponing planting (Marteau et al., 2011). Moreover, Patt & Gwatha (2002) find that farmers who received training and feedback are more successful in interpreting and responding to the information than those who simply received one-way weather forecasts. Their work draws attention to the need for shared interpretations of weather and tools to characterise changes (Newsham and Thomas, 2011; Patt et al., 2005; Roncoli et al., 2009).

## 2.2 Perceived rainfall changes

Participatory approaches that have been used to capture farmers' perceptions of rainfall include semi-structured interviews, key informant interviews or focus groups for confirming meteorological data (Hageback et al., 2005; Patt and Gwata, 2002). Three challenges faced by scientists doing qualitative studies on perceptions of climate include:

**I. Scientists who ask farmers will get many different answers, not one.** Scientists need to pay attention to farmers' responses in groups versus their responses as individuals. Hageback et al. (2005) facilitated a card game where farmers ranked decadal average summer and winter temperatures, rainfall, and wind speed, which resulted in matrix of decade versus climate indicator that satisfactorily agreed with observations. In contrast, while Mongolian herders characterised changes in a number of rainfall markers, such as onset, droughts, patchy rainfall, timing, seasonality, frequency and intensity, not all could be verified with nearby meteorological observations (Marin, 2010). In addition, Marin asked the Mongolian herders to rank the previous eight years into five grades in terms of their own definitions of good and bad years. With the exception of the last two periods, this resulted in non-significant differences between the five gradings and no consistent correlation with the number of dead animals. By asking for good and bad years, these findings illustrate how perceptions of rainfall changes may be confused with how the changes manifest, e.g. more droughts or floods versus their impacts on yields or livelihoods. Evidence from farmers' across Africa links the changes in climatic patterns, in particular increase in rainfall variability, with impacts on crop production, e.g. plummeting crop production in Botswana 1982-85 (Parida and Moalafhi, 2008) and teff cultivation in Ethiopia (Rosell and Holmer, 2007). The examples suggest that when outsiders talk with farmers about their perceptions of rainfall, it is important to distinguish the actual rainfall from its impacts on agriculture.

**II. Not all droughts depend on water inputs.** Droughts can result from lack of rainfall (meteorological droughts), increase in temperature and evaporation (agronomic droughts) or be manmade, e.g. due to farm management or institutional failures that reduce or increase the farming system's sensitivity to drought (Devereux, 2009). For example, structural adjustment programmes and state-supported seed and fertiliser programmes can drive behavioural changes, and while fertiliser inputs can reduce the sensitivity to weather and produce more stable harvests, farmers often simultaneously move from traditional drought resistant grain crops to irrigation demanding crops (Snapp et al., 2010). Ethiopia provides a clear example of how droughts are only are the final trigger while structural and institutional failures are the main cause of famines (Devereux, 2009; Fraser, 2007). The drivers of droughts are context-specific, often interlinked and act over different time scales.

**III. A "bad" year for one farmer may be "good" for another.** A maize farmer may perceive climatic events differently from a cattle rancher because they expect different types of weather. Farmers also tend to base their adaptation strategies on recent years' weather and on extreme events rather than on the average climate (Smit et al. 1997 in Madisson, 2007; Marx et al., 2007). Sallu (2007) interviewed pastoralists in Khawa, Botswana and found that (i) both male and female groups collectively described the post-1970s rainfall scenario as dynamic in contrast to the individually conceived decline expressed during interviews, (ii) over the 30-year period (1974-2004), rainfall dynamics were exaggerated, with peaks overestimated and troughs underestimated by both gender groups, (iii) there was a trend towards pre-1995 overestimation and post-1995 underestimation of rainfall, and (iv) the women's group had a shorter collective memory of events than the men's. Maddison (2007) finds that farmers' adaptation to perceived increases in temperature include altering crops, moves to off-farm activities or the application of shading and water harvesting techniques. For declining rainfall, farmers tend to adapt with the same crop, e.g. by varying planting dates with the onset of the rainy season. Therefore, if they took successful measures and received a good harvest farmers may not consider it being a "dry year" (as synonymous for bad year). Furthermore, the links between perceptions and behaviour ultimately depend on the resources farmers have access to that enable them to respond to particular weather stresses. The number of response strategies also depends on how immediate or severe the problem is perceived to be (Meze-Hausken, 2000). In particular, experienced farmers are more likely to perceive changes in climate and educated farmers are more likely to make at least one adaptation (Maddison, 2007). Categorical groups, such as gender, geographic location, income levels (e.g. Figure 1), farming system etc., are therefore helpful when identifying other factors that may influence or confound farmers' perceptions of rainfall changes.

In summary, when studying why some small droughts result in major crop failures and some major droughts result in minor crop failures (e.g. Fraser, 2007), it is important that the contexts of (perceived and observed) exposure, sensitivity and impacts are fully understood, so that the suggested adaptation strategies address the appropriate changes.

# 3. Material and Methods

## 3.1 Study areas

This research links fieldwork from semi-arid regions with rainfed agriculture in Botswana, Ethiopia, Ghana and Malawi. Figure 2 gives "national level" annual anomalies and Table 1 summary statistics of using available rainfall data. Note that in Figure 2 the meteorological stations in Botswana, Ghana and Malawi are distributed across the country and no spatial effects are considered. Generally the standardised anomalies of annual rainfall for all four countries were strongly positive in the 1960s, negative in the 1980s and more balanced in the 2000s with Malawi and Ethiopia furthermore showing some decadal patterns (Figure 2). Table 2 includes major climate systems and details for the case study locations.

The four countries vary in terms of economic development. The Supplementary Table S1 gives more detail to the national level socioeconomic descriptions summarised below. Despite Botswana's relative wealth and social welfare system, its urban and rural areas remain divided. While staple food cultivation is mainly for household food security, wealth is largely associated with cattle herd size. After severe droughts in the 1980s, the government has continuously introduced various drought-relief programs, such as grants for small stock and livestock. Some policies are controversial, in particular those that favour large cattle ranges, such as subsidised waterholes, leading to overstocking. (Belbase and Morgan, 1994; Reed et al., 2006; Sallu et al., 2010).

Ethiopia's drought early warning system was established in 1974 after the famines earlier in the same decade. However, the system focused on upland cropland and therefore failed to anticipate the combined effects of the drought in 1997-98 and the Rift Valley fever outbreak in 1998, which hit both pastoralists and agriculturalists in 1999-2000. (Devereux, 2009).

*Table 1 Summary statistics for total annual and seasonal rainfall for one key meteorological station near case study locations. Note that the time periods covered vary. Also note the ranges of annual rainfall and the lack of temporal trends and compare with e.g. Table 5. More local data is provided in Table 2.*

| **Rainfall measure** | **Letlhakeng, central E Botswana 1990-2005** | **Hayk, N Ethiopia 1963-2007** | **Navrongo, NE Ghana 1961-2007** | **Bvumbwe, S Malawi 1961-2008** |
|---|---|---|---|---|
| Mean (mm)<br>Median (±range) (mm) | 405<br>337 (+405; -98) | 1162<br>1174 (+470; -599) | 1083mm<br>1045 (+616; -294) | 1150<br>1128 (+782; -393) |
| Trend (mm/yr)[1] | -6 mm ($R^2$=0.02) | -1 mm ($R^2$ <0.001) | 0.5 mm ($R^2$ < 0.001) | 1 mm ($R^2$ < 0.001) |
| Coefficient of Variation (%) | 40 | 18 | 20 | 20 |
| Trend Inter-Annual Variability (mm/yr) | 6 mm ($R^2$=0.01) | -0.1 mm ($R^2$ < 0.001) | -1.6 mm ($R^2$ < 0.001) | 0.5 mm ($R^2$ < 0.001) |
| Rainfall mm/growing season(s) | 200-800 mm (September to May) | 240-340 mm (February to May, *belg*);<br>700-760 mm (June/July to October, *kiremt*) | 1060 mm (April to October) | 650-1100 mm (October to March) |

[1]Trend refers to the annual total rainfall for the period available for respective meteorological station.

Ghana went through structural adjustment programs in the 1980s (Konadu-Agyemang, 2000). The most recent severe drought in 1983 emerged during a period of political instability. The country spans tropical to semiarid agroecozones with vast differences in irrigation amounts and access to inputs. Malawi's structural adjustment programs resulted in well-studied 1990s and 2001/02-famines. Nationwide seed and fertiliser subsidies (1998-2001, 2006 to ongoing in 2011) targeting poor households have boosted maize productivity. HIV, leading to uneven demography, is a challenge for rural development, reducing the agriculture labour force, not only in Malawi (Devereux, 2009; Snapp et al., 2010) but also in Botswana.

*Table 2 Village level statistics for case studies. For rainfall summary see Table 1.*

| | **Botswana** | **Ethiopia** | **Ghana** | **Malawi I** | **Malawi II** |
|---|---|---|---|---|---|
| Field work carried out | June-July 2010 | 2010 | July-August 2010, July 2011 | June-July 2009 | 2010 |
| Where (n villages) | 2 villages in east region (n=2) | 3 villages in northern region (n=3) | 2 villages in northeast and central regions (n= 2) | 8 villages, south and central regions (n=8) | 14 villages in 8 provinces across the country (n=14) |
| Climate system [1] | Arid; Uni-modal, peak in January-February, small amount in June-July (*khogo la moko*). Intense rains via southward moving Zaire Air Boundary (summer, November to April); Prolonged rains from the Indian Ocean (summer) or from the south Atlantic Ocean (winter) | Semi-arid Bi-modal Mediterranean low pressure, ICTZ, Indian ocean monsoon | Tropical (south) to semi-arid (north). Bimodal equatorial rainfall (south) with peaks in June and October; tropical uni-modal monsoon (north) with peak in June | Semi-arid in the Lower Shire Valley (south), to sub-humid on the plateaux and the highlands. Uni-modal with peak in January | |
| Landscape | Sandvelt, Hard velt | Rift Valley | Savannah | Rift Valley | Across the country |
| Focus groups and household interviews (n persons) | 2 Focus groups (n=12) HH interviews (n=63) | HH interviews (n=43) | 2 Focus Groups (n=15) HH interviews (n=28) | 2 Focus groups (n=12) HH interviews (n=81) + extension and NGO staff (n=12) | 2 Focus groups in 9 districts (n = 11-15 people/group) |
| Wealth distribution (%) (rich/middle/poor) | 20/40/40 % | 0/60/40 % | 15/40/45 % | 25/25/50 % | n.a. |
| Main agricultural crops | Maize, sorghum, groundnut, livestock | Teff, sorghum; livestock | Maize, sorghum, millet; yam, groundnut, beans | Maize, beans, millet, cotton, tobacco, sweet potato | |
| Main growing season | November to May/June | February to May (*belg*); June/July to October (*kiremt*) | South: March to July; Upper East: May to September | December to June (August) | |
| Rainfall data used in this study | Daily precipitation 1990-2005 | Daily precipitation 1963-2007 | Monthly precipitation 1961-2007 | Daily precipitation 1961-2009 | Daily precipitation 1961-2009 |
| Main meteorological station | Letlhakeng 1068 masl Lat: 24.1S Lon: 25.0E | Hayk 1900 masl Lat: 11.2N Lon: 39.4E | Navrongo 197 masl Lat: 10.9N Lon: 1.1W | Bvumbwe 1146 masl Lat: 15.9S Lon: 35.0E | Chitedze (1149 masl; Lat: 14.0S Lon: 33.4E), Dedza (1759 masl; Lat: 14.4S Lon: 34.2E), Chileka (767 masl; Lat: 15.7S Lon: 34.6E), Bvumbwe (see left) |

Source: [1] FAO country profile, e.g. http://www.fao.org/ag/AGP/agpc/doc/Counprof/Botswana/Botswana.htm

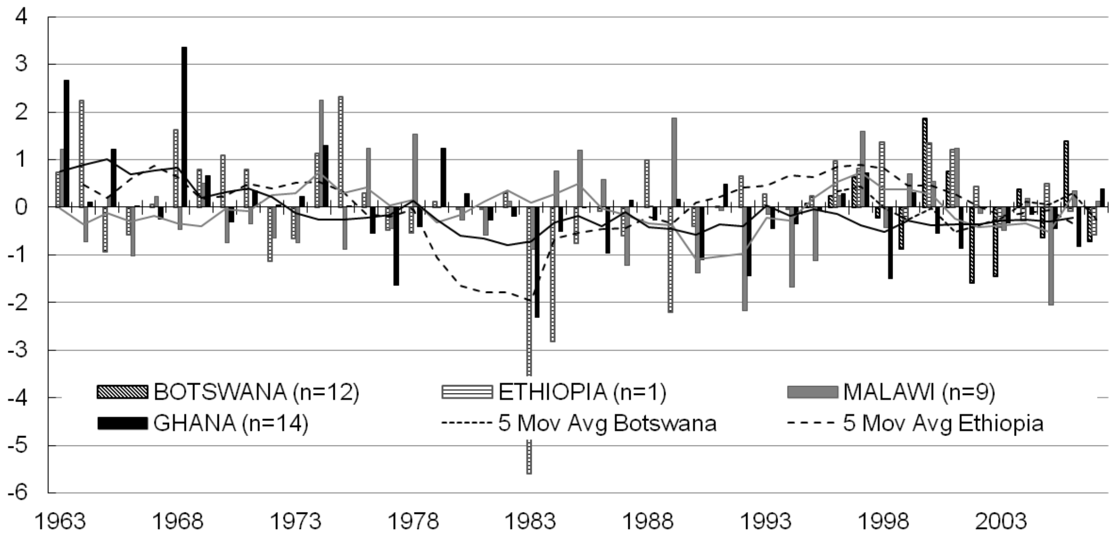



*Figure 2 Anomalies of standardised annual rainfall with five year moving average for available rainfall data from 12 stations in Botswana, one station in Ethiopia, 14 stations in Ghana and 9 stations in Malawi. The overall picture is that rainfall deviated strongly positively in the 1960s, negatively in the 1980s and was more balanced in the 2000s while the moving average show weak decadal patterns. Note that only one station was available for Ethiopia while for the other countries data is distributed across the country and given equal weight. The unit of y-axis is standard deviation.*

## 3.2 Methods

This research was carried out in Botswana, Ethiopia, Ghana and Malawi by four different research teams (Table 2). Farmers' perceptions of rainfall were gathered in addition to or as part of four separate research project activities that all used participatory methods to investigate farmers' adaptive capacity to climate change (Ghana, Malawi I, Botswana, Ethiopia) or farmers' use of indigenous knowledge for adaptation to climate change (Malawi II). The data collection and analysis detailed below covers three steps: fieldwork, meteorological data and meta-analysis.

1. Fieldwork consisted of focus group meetings and semi-structured interviews. The focus group meetings included transect walks, village mapping, establishing local criteria for wealth ranking, farming calendars for wet/dry/"normal" years and general challenges to farming, thereafter leading the discussions into perceptions of rainfall. The semi-structured interviews were conducted with adult household members. While the perceptions were gathered in similar ways, the follow-up questions varied from place to place. A topic guide, rather than structured questions was therefore used to streamline the interviews across the teams while allowing autonomy of the individual research and to avoid climate/drought bias. The questions were open and if farmers brought up climate/drought/rainfall follow-up questions were asked (e.g. Figure 1).

Attempts were made to balance the respondents in terms of income levels, gender and age and where applicable, to include different ethnic origins. Specifically, the number of interviewed households from different wealth groups represented the wealth distribution in the village (Table 2). Focus group meetings lasted between 60 and 180 minutes, while individual conversations lasted generally between 20 and 60 minutes. Preliminary findings were anonymised and reported back to villagers, which allowed for questions and clarifications from both sides.

2. Climate data. Observed daily or monthly total rainfall data were collected for local meteorological stations for available periods from respective National Meteorological Bureaux (Table 2). The data were checked for non-physical and missing values by the authors. The bi-monthly Multivariate ENSO-index, MEI, was downloaded from NOAA http://www.esrl.noaa.gov/psd/enso/mei/rank.html, last updated June 10, 2011; (Wolter and Timlin, 2011).

3. Meta-analysis. To ensure consistency during the course of the meta-analysis we developed a simple framework for organising the quotes on erratic rainfall: a *posterior* flowchart matrix that reads from left to right (Figure 3). Sorting quotes in parallel columns helps to account more systematically for rainfall perceptions that vary with types of farming or access to livelihood assets.

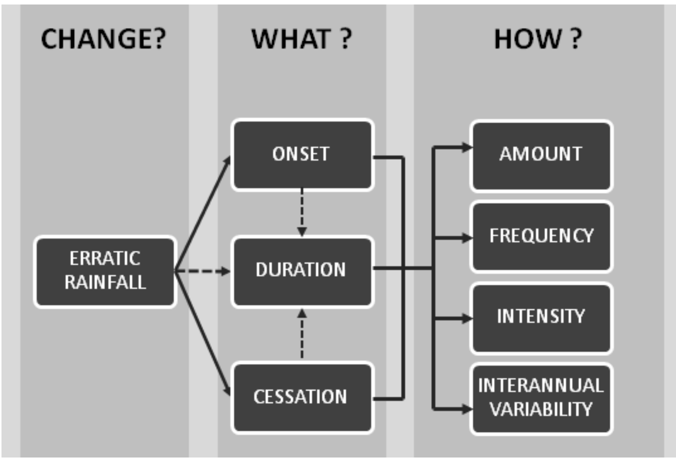



*Figure 3 Analytical flowchart matrix for organizing and categorizing quotes on "erratic rainfall". The first level (left) collates quotes stating the ways in which rainfall is (or is not) changing, the second level categorizes what part of the rainy seasons the quotes and narratives relate to, and the third level (right) aims to specify in detail how this is perceived to change. Note that changes in the onset or cessation may overlap with perceptions of the duration.*

The matrix is built up as a flowchart of three hierarchies. The first level (left column) establishes whether there is a *change*, this includes examples of perceptions relating broadly to any changes in rainfall. At each level the number of respondents not perceiving changes are noted as well. At the second level (middle column) we identify *what* is changing, i.e. the onset, duration, or cessation of the rainy (or dry) season. Changes in the onset and/or cessation may influence the duration. A range of definitions of onset and cessation exist, depending on local agronomic contexts. To visualise the perceived onset, we asked how farmers knew when it was time to plant or when the rainy season had started. This resulted in three simple definitions of onset in this paper: (i) the month the rainfall starts after the dry season (i.e. a meteorological definition); (ii) when the soil horizon is moist to the depth of an underarm's length (i.e. an agronomic definition based on when farmers started planting in Botswana); and (iii) a simpler measure of 40 mm accumulated rainfall, adapted from a combinations of (ii) above and the definition 40 mm in 4 four days taken from Tadross et al. (2009). For Ethiopia we used a more detailed definition of cessation following Rosell (2011) while for the rest of the places it was defined as the month in which rainfall stops. At the third level (right column), common climate statistics may help in identifying exactly *how* any of the three parts within the second level are changing. For example, identifying whether quotes refer to changes in amount of rainfall, frequency (unit time between wet or dry spells) or intensity (amount per unit time) or whether it is possible to detect inter-annual variability when there is no trend. The statistics methods used include: linear trend, moving average, coefficient of variation, percent change between two periods to explore potential proxies for "before" and "now" either as suggested based on interviews or as comparison to perception, standardized anomalies and correlation.

This matrix can be adapted for other locations and is useful for scientists with limited background in climatology to identify in-depth the type of rainfall changes farmers perceive. Different local matrices need to be considered as perceptions of erratic rainfall may be confounded by the impacts it has on various livelihood outcomes, such as rainfed agriculture, livestock keeping or fishing. See Appendix 4 for more information. In the examples below we generalise the local perceptions up to country level as our main concern is to see if "erratic rainfall" is similar across all four countries. Malawi has been given somewhat more space in this paper as we have been able to cross-check more information, thanks to more detailed rainfall data and ongoing fieldwork activities in the country.

Justification and limitations: Although a consistent research methodology was applied, studies at each site were carried out by different teams and under slightly differing research objectives. Although the intention was to start talking about the general challenges farmers face (Figure 1) and then lead the discussion towards their perceptions of changing rainfall, the sub-headings of all studies relate to climate and farmers may therefore have felt obliged to say they have perceived changes in rainfall when in fact they had not (Maddison, 2007). Furthermore, rainfall in arid and semi-arid areas is very local by nature. Local spatial dynamics will not be elaborated in this paper as current meteorological observations are too sparse for meaningful analysis. Instead we compare meteorological trends with farmers' perceptions and assume that verification across both methods indicates "correctness". Lastly, it is important to be aware of language barriers and semantics, as many nuances may be lost in translation (both between sociolects and ethnic languages).

# 4 Results & Discussion

Section 4.1 presents what characteristics of rainfall that farmers perceive are changing. Each heading is a quote mentioned independently by more than three farmers in at least two places. The findings have been organised according to the rain exposure framework (Figure 3) and we use the quotes to explore meteorological data using graphs and statistical analyses. The first level identifies examples relating broadly to "erratic" changes in rainfall (Section 4.1.1). At the next level we focus on what is changing: the onset (Section 4.1.2), duration (Section 4.1.3), and cessation (Section 4.1.4) of the rainy (or dry) season. Section 4.2 discusses factors that may confound the perceptions of rainfall.

## 4.1 Perceptions of change

### 4.1.1 "Rainfall is more erratic"

A clear majority of the interviewed farmers stated that they have observed changes in the rainfall (all interviewed in Malawi and approximately 70-90% for Botswana, Ghana, and Ethiopia). As a first description of those changes, farmers in all four countries said that rainfall was becoming "more erratic" or "more unpredictable" with regard to temporal variations. Occasionally "erratic" would refer to spatial variations, such as in central Malawi, where for the last few years "*rains come on one side of the farm and not the other*." Although some national level studies indicate that this may be the case (e.g. Armah et al., 2011), Table 3 exemplifies the semantic challenge by giving common local words translated as "erratic rainfall" and the term used for climate change. The fact that people have named particular adverse weather events further suggests that they occur with some regularity or frequency. For example, in Ethiopia the *kiremt* rain should start in the end of June, however, if it starts in the middle of July or ends early (before September), this is commonly referred to as *ye zinab meqoraret huneta*, i.e. erratic rainfall.

*Table 3 Local expressions for "erratic rainfall" and "climate change*

| Country (language) | Botswana (Setswana) | Ghana (Asante Twi) | Ethiopia (Amharic) | Malawi (Chichewa) |
|---|---|---|---|---|
| Erratic rainfall | *pula e e sa ikanyegeng* rainfall which is erratic/unreliable | *ewiem nsakyeraɛ; yɛrentumi nkyerɛ mmerɛ nsuo befiri aseɛ ato ne nna dodo a nsuo beto wo mmerɛ a yɛredua yɛn nnobaeɛ* the unpredictability of the onset and duration of rains during the farming season | *wekitun yaltebeke ye zinab huneata* or *ye zinab meqoraret huneta* rain that falls unexpectedly or irregularly | *Yosadalilika* unpredictable rain |
| Climate change | Setswana does not have a word for *climate change*, but a translation of *global warming*. | *ewiem nsajveraee* changes in the weather patterns | *ye ayer nibret lewt* change of air condition or climatic condition | *kusintha kwa nyengo* the word for climate change, includes short and long-term variability |

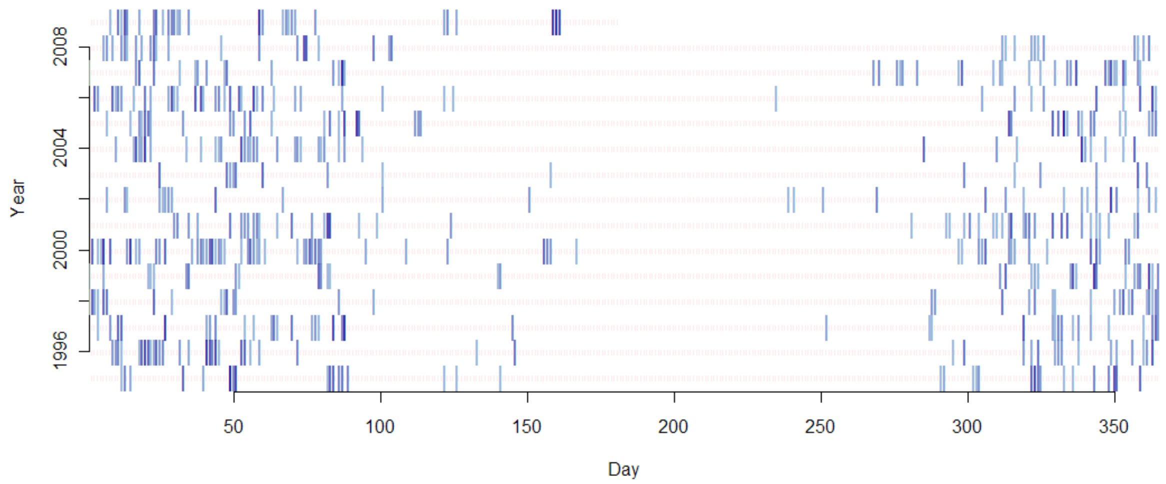



*Figure 4  Distribution of daily rainfall, Letlhakeng, Botswana for 1995-2009. The x-axis shows the day number 1-365 (i.e. January 1 to December 31), the y-axis the years and the shade illustrates daily rainfall intensity (white = < 1mm/d, lightest blue 1-4mm/d, lighter blue = 5-9mm/d, darker blue 10-19 mm/d, darkest blue >19mm/d).*

To identify what was becoming more erratic, we map the daily distribution of rainfall. This alludes to several Botswana farmers, who independently of each other mimicked the sound-effects of rainfall intensity and frequency by drumming their hands to illustrate regularity in the past that now was lost. Assuming that the rainfall data is complete, Figure 4 illustrates both the distribution of rainy days and rainfall amounts during 14 years for Letlhakeng, Botswana. In this example the onset is clearly highly variable and seems to suggest that a comparatively dry onset (day 250-365) is followed by a wet period in January to March (day 1-75) and *vice versa*

### 4.1.2 Onset: "Rain comes later or not at all"

The Ethiopian farmers, with two rainy periods, made no comments on changes of the *belg* rains (February-March); instead they perceived a shift towards an earlier onset of the *kiremt* rainy season around July. Conversely, farmers in Ghana, Malawi and Botswana, all with one rainy season, primarily talked about the rainfall arriving later now compared to some unspecified time in the past. A typical quote is given by a village leader in Ghana:

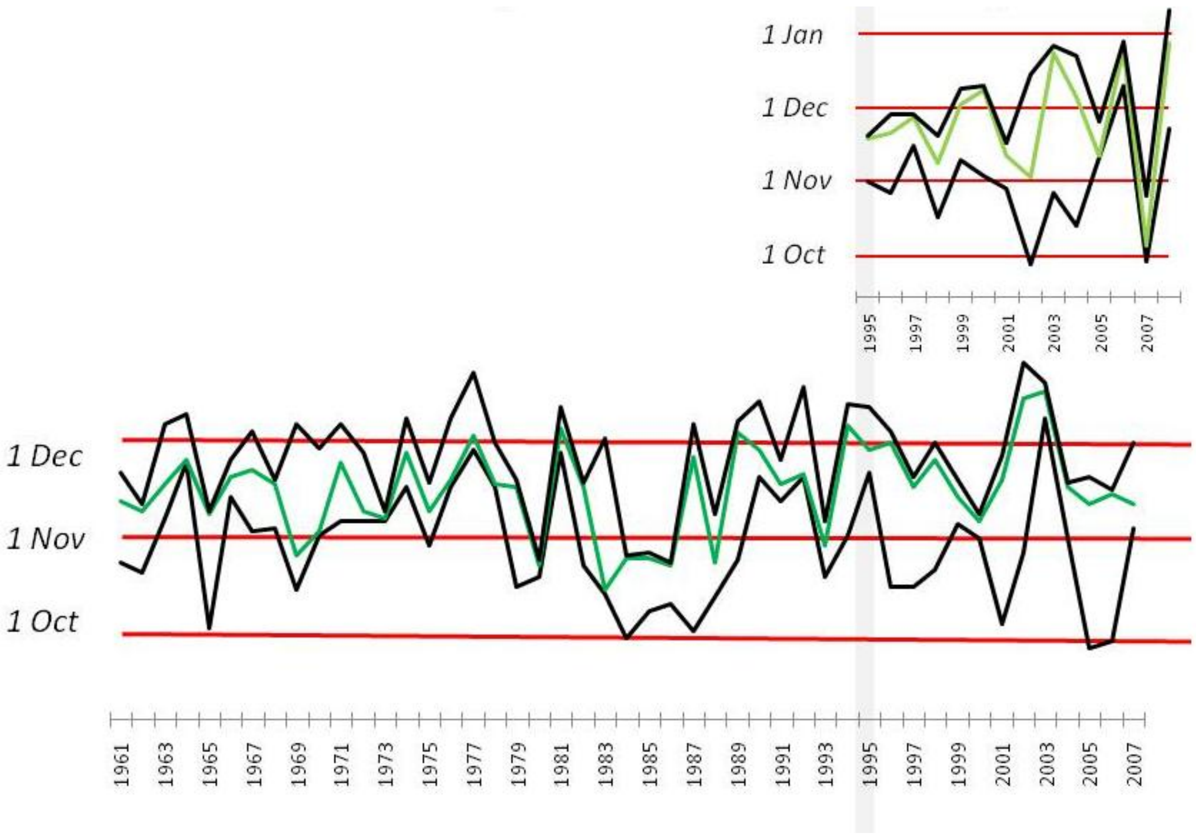
*When I was a young man in this village the rains used to start in March. Now the rains do not come until mid to late May and farmers will have to prepare their lands and wait for the rains*.

Meteorological data for Navrongo, which is near the village this particular respondent leads, does not support the assertion that rains used to start in March every year (Supplementary Figure S1). Meteorological observations do however suggest that before the 1990s there were more frequent rains in March.

Figure 5 shows the onset defined as the first, second and third Gregorian days with 10 mm or more rainfall in one day, i.e. an agronomic onset. Ten millimetres in one day is considered big enough to notice even without a rain gauge and after the third set of 10 mm the accumulated soil moisture will have started to reach the 30 cm soil depth required for planting. While this definition builds on focus group interviews in Letlhakeng, Botswana, less than 30 mm may be necessary for the less sandy soils in Malawi. The time between the first and third rainfall shows the potential duration of the onset. Two changes are noteworthy. First, the inter-annual variability in onset has increased in both locations, and for Botswana this increased from one month in the 1990s to three in the 2000s (Figure 5a). Second, in Botswana the length between first and third rainfall is shorter while in Malawi there seems to be a delay in the second rainfall from about 1980s (Figure 5b). This was explained by two extension workers in central Malawi, who stated that rather than rains coming later they had dry spells after planting. One direct consequence of the erratic onsets was that extension workers and FAO officials found it increasingly difficult to give advice as information provided to farmers has followed the lines of "*when the rain starts this is what you do…"*. During individual interviews farmers explained that rain may fall early (in October) so people plant, but then it is dry again and crops wilt. Rain may then come too heavily in November and then stop again. In contrast, the focus group interviews across Malawi concluded that the rainy season now starts 1-1.5 months later (Table 5).

In Ethiopia the period between the first and third of the ≥10-mm rains typically occur within 3 months for *belg* and less than 2 months for *kiremt*, however the interval between the three rainy days is regular, about two weeks (Figure 5c). The graph confirms farmers' perceptions and other indices (see Rosell 2010) suggesting earlier *kiremt* onset and no change in *belg*. This clearly displays the late *belg* season that resulted in Wollo's two disastrous droughts in 1973 and in 1984/85, and the record low total rainfall in 1984.

In summary, the meteorological data do not confirm that rainfall started as early as the farmers and extension workers stated, i.e. in September (South Malawi), nor that it fell regularly in October (east Botswana) or in March (Navrongo, Ghana). Instead, the graphs illustrate that farmers need to be on standby to start planting, for two months (Malawi, Ethopian *belg*) and up to three months (Botswana) and four months (Ethiopian *kiremt*). In summary, local farmers' and extension workers' perceptions of onsets as "more erratic" or "less predictable" can be illustrated with meteorological data as shifts in inter-annual variability of onsets.



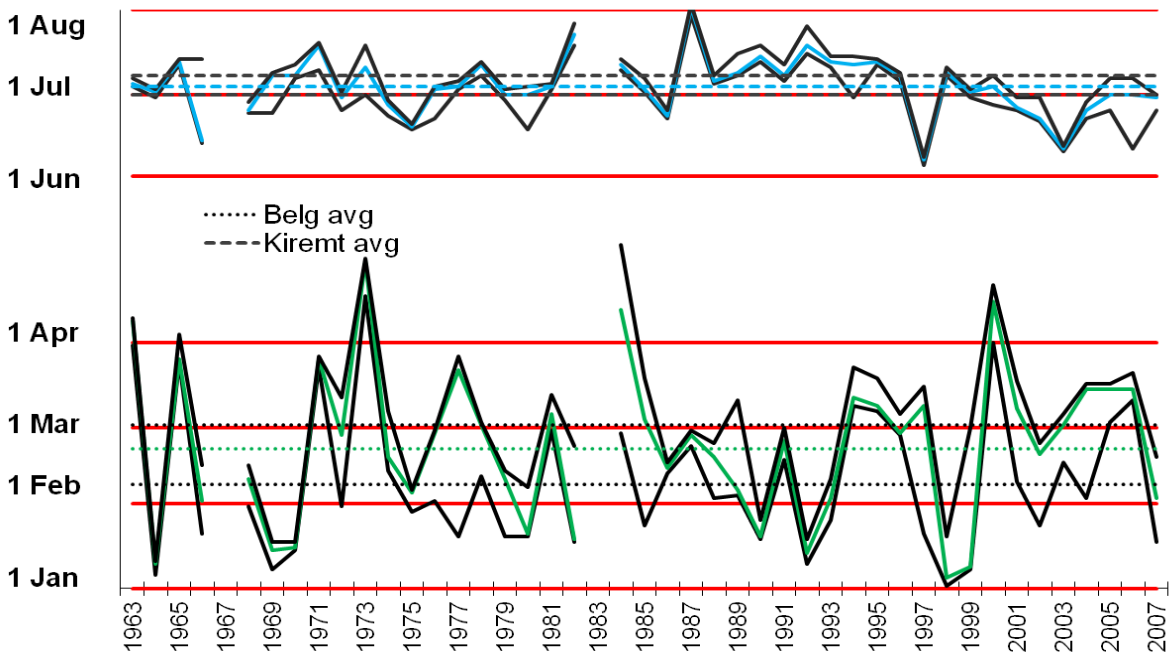




*Figure 5 Changes in onset. Each line denotes the first, second and third day with at least 10 mm in one day, where the total of 3x10mm (and potential showers in between) is assumed to indicate the agronomic onset of the rainy season in a) Letlhakeng, Botswana (upper right), b) Bvumbwe, Malawi (bottom); and c) Hayk, Ethiopia for belg (lower) and kiremt (upper) rain seasons. The straight lines indicate the average first, second, and third day over the full period.*

### 4.1.3 Duration: "The rainy season is shorter with less rain"

Figure 4 gives a preliminary overview of changes in distribution and intensity of daily rainfall. With monthly datasets, data analyses and illustrations focus on quotes relating to amounts and temporal variations, e.g. inter-annual variability.

Ethiopian teff-farmers depend on the short duration and relatively invariable amount rainfall during the *belg* season (February to May). Farmers interviewed in Wollo observed that around the year 2000 the rains lasted longer than 3 months and with more precipitation at each rain event. Now the rains last <1 week and provide less water. Meteorological data support this. Monthly total rainfall declined by 3 to 15% over the past 20 years in each of the *belg* months, except for February when the coefficient of variation instead increased by 47% (Rosell, 2011). These changes could suggest that the increasing frequency of El Niño phases, which are associated with drier than normal December-February and wetter than normal March-May (Tadross et al., 2009), had a stronger overall drying effect on *belg*. Secondly, in Ghana 90% of respondents said that the rainfall amount had reduced compared to their childhood, while a few stated that the amount had not necessarily changed but rather it was the onset of the rains that has altered. This may be explained by local variations however it also mirrors the immense variability across the country, in particular during onset. Ten of the sixteen available meteorological observations show that on average, by the end of May, from as little as 5-30% (Navrongo) to as much as 15-65% (Tema) of the total annual rainfall has fallen, and by the end of September between 40% (Accra) and 95% (Tema). An example for Navrongo is shown in Supplementary Figure S1.

The focus group discussions across Malawi suggested that farmers perceive the rainy period to be shorter now, coming at random compared to the previously longer and more reliable periods with heavy rainfall. Qualitative data with spatial and temporal variations can be complex to display graphically, contrasting farmers' perceptions of rainfall onset and cessation (i.e. duration) between the undefined "now" and "before" with nearby meteorological data that is split in half (to symbolise "now" and "before"). Table 5 contrasts farmers' perceptions of the duration with the difference in average number of dry days and average monthly precipitation for 1990s-2000s (the perceived "now") and 1960s-1980s (the perceived "before"). In the case of Malawi, the farmers generally said that rainfall started up to two months later and ended one to two months earlier than "before". In contrast to annual total statistics (Table 1), when analysing monthly data, almost all months had an increase in the number of dry days and a decline in rainfall particularly from October to December and March to April. These declines reduce the duration of the rainy season from both ends. However, the big drop in rainfall at the onset should be interpreted with caution as the total amounts are small; the average October rainfall in Chileka dropped from 29 to 20 mm (-48%) between the two periods and in Bvumbwe from 32 to 18 mm (-80%) while from November the average monthly rainfall reaches at least 75 mm. Instead, "later onsets" are perhaps better described as the consistent increase in dry days and reduction in monthly rainfall from October to December and "earlier cessation" as the increase in number of dry days and reduction in rainfall in April. In strong contrast to southern Malawi, a majority of the interviewed farmers in the central and northern parts referred to dry spells in the middle of the rainy season as droughts. For example, Table 5 shows that January is the only month with an increase in rainy days and total rainfall. If this rain fails and causes a mid-season drought, it can have severe consequences for agriculture. Data in Table 5 is consistent with the general perceptions of later onset and earlier cessation, nevertheless there is no data to support perceptions that rainfall started earlier in the past. In an attempt to identify two possibilities of "now" and "before", the averages for two periods were compared. The difference of the means of the two "halves" was larger when the dataset was split at 1988/89 than at 1984/85, hence the key "change" appeared to be in the second half of the 1980s. In Malawi this is possibly associated with large spatial and temporal scale atmospheric and oceanic patterns (Richard et al., 2001, Table 6).

#### 4.1.4 Cessation: "The rainy season ends earlier"

In terms of agronomic cessation, the farming calendar suggests that the duration of the rainy season largely determines the timing for harvest. The later the rainy season ends the later harvesting can be carried out. In Malawi, weather impacts include crops drying before maturity or crop damage due to floods, water shortages, land losses and infrastructure destruction (Mkwambisi et al., 2010). (One example from Malawi is shown in Supplementary Table S2). With a meteorological definition, the number of dry days and amounts of rainfall towards the end of the rainy season has increased over past two decades in Malawi (Table 5), hence the earlier cessation.  Figure 4 substantiates the Botswana farmers' views that the light rainfalls after the main rainy seasons, around days 125-160 and referred to as *khogo la moko* (the rain that cleans up the harvest dust), have behaved differently after 2004. Figure 4 shows that *khogo la moko* fell early between 2004 and 2008, and with very high intensity rain in 2009. Botswana farmers associated these changes with changes in temperature, wind direction and wind speed.

Defining duration and cessation is particularly important for matching crop duration with the short planting windows in bimodal rain patterns. In analysing inter-annual variability, it is also vital to associate periodic climate patterns that are known to be linked with rainfall, such as ENSO. A longer elaboration on ENSO is provided in Supplementary material (Figures S2, S3 and S4).

#### 4.1.5 Gaps between perceived changes and meteorological observations of changes in rainfall

Table 4 summarises the collated perceptions of erratic rainfall vis-à-vis meteorological data analyses and attempts to identify the gaps between the two. In particular there are three key questions that arise:

- Were onsets earlier in the past? Unsurprisingly for rain-fed agriculture in semi-arid regions, the fieldwork from Malawi, Botswana and Ghana indicates that the onset of rainfall is one important decision making indicator for both farmers and extension advisors. The perceptions and meteorological data support stronger inter-annual variability of timing and rainfall intensity over the past five decades. Perceptions of onset are intertwined with impacts on crop growth. In Ethiopia and Botswana an early dry spell during the rainy season corresponded with harvest failure: either as a result of no planting or after planting with insufficient plant-available water.

- Were rainfalls more predictable or regular (i.e. frequent) in the past, or what made rains in the past perceived now as more “predictable” or regular? Characterising changes in the duration of rainy seasons becomes particularly important in regions with two short rainy seasons, such as the Ethiopia case, and for finding crops that fit narrowing planting windows that may require a shift from two to one crop per year.
- Perceptions of rainfall changes may be confounded with their impacts, and it is difficult to fully separate cause and effect. Narrowing the gaps involves further developing participatory approaches for making distinctions between meteorological and agronomic characterisations of onset and cessation respectively. Based on the findings, we recommend that the meteorological cessation is defined independently of onset and farming activity.

*Table 4 A summary of identified gaps between farmers' perceptions and meteorological data.*

| Rainfall | Qualitative evidence (perceptions in Malawi, Botswana, Ghana, Ethiopia) | Quantitative evidence (meteorological observations from Malawi, Botswana, Ghana, Ethiopia; scientific literature) | Gaps between farmers' perceptions and scientific evidence | Evidence from this study |
|---|---|---|---|---|
| *Climate* | *Now you can no longer predict the rains in this village. Quotes refer to rainfall being unpredictable in terms of when they start (onset) or how they fall (frequency and amount) during the early phase of rainy season.* | This and other studies show few statistically significant trends in annual total rainfall amounts but in monthly trends, and large natural spatial and temporal variability. | Distinguish between climate and weather, between changes in weather/climate (exposure) and impacts of changing weather/climate, between climatic versus non-climatic drivers of change and impact. Wet/dry/"normal" years preferred for exposure studies, avoid good/bad years as synonymous to good/bad rain. | Table 1: summary statistics<br>Table 3: semantics for erratic vs change<br>Table 5: narratives, monthly trends Table S1: Farming calendar<br>Figure 4 annual distribution of rainy days and amounts. |
| *Erratic* | | This study shows that the inter-annual variability of onset is increasing, especially in Botswana and Malawi. | Clarify if rainfalls truly were "predictable" sometime in the past. If so, in what ways?<br>Identify semantic gaps in terms of the meaning and connotations of "change" versus "variability", e.g. due to language and education. | |
| *Onset* | *Rains used to start in March, now the rains don't come until mid or late May (Navrongo, Ghana). Kiremt starts earlier (Ethiopia). It used to rain in September now it comes in December, January or not at all (*S Malawi*). Rainfall used to start in October, now it starts in December or January* (Botswana).<br>Onsets are more unpredictable with dry spells after planting (Malawi). | Later onset: Little meteorological evidence that rain started to fall earlier in the past 40 years in Malawi and Botswana, instead the time to meet a 40-mm onset criteria takes longer since 1980s. Before 1990s there was more often rain in March (Navrongo, Ghana).<br>Earlier onset: Ethiopian *kiremt* started earlier since mid-1990s.<br>Meteorological onsets: increase in number of dry days.<br>Agronomic onsets: period between first rains and "enough rain for planting" more variable between years.<br><br>Previous studies have linked onsets (DJF) with ENSO in Eastern and Southern Africa (Tadross et al., 2009) and sea surface temperature in Ghana: Delayed onset in Guinea savannah while earlier rains in Sudan savannah 1960-2008 (Armah et al. 2011). | Forecasting onsets and the subsequent month's rainfall correctly is essential for farmers' trust in weather forecasts and climate information.<br><br>Need for in-depth dialogues and tools to illustrate what (climatic and non-climatic) factors constitute references to "now" and "before".<br>Triangulate (using e.g. narratives, planting records, meteorological data) to clarify if and how the onset was earlier "before"? Was "onset" defined differently in the past (change in land use?)?<br><br>How come village narratives and meteorological data show similar gaps in four countries (small gap between farmers, big gap among scientists)? Is it a matter of local versus regional scales of analysis or within-country variations, e.g. Ghana and Malawi? | Suppl. Figure S1: Annual total and monthly distribution<br><br>Figure 5: Timing of agronomic onset<br>Suppl. Figure S2: Accumulated monthly rainfall |
| *Duration* | *Ten years ago the belg rain lasted longer than three months. Now the rains are shorter than one week and bring less rain* (Hayk, Ethiopia) | This paper shows some shifts in the distribution of monthly total rainfall (e.g. from December to January) and the rainiest month (Malawi, Botswana, Ghana).<br>Previous studies show that South African droughts in 1950-60s were associated with regional ocean-atmosphere anomalies over SW Indian Ocean while droughts in 1970-80s associated with ENSO hence more variable JFM rainfall and more intense droughts, (Richard et al., 2001). In Botswana rainfall declined and variability (CV) increased since 1980s (Parida & Moalafhi, 2008). *Belg* rainfall declined each month, except February and | It is possible that the onset month(s) were rainier in the past, now the period between first and third 10-mm rain is longer. This can be perceived as later onset and less frequent more intense rainfall – leading to the perception of shorter duration. | Figure 4 Distribution of rainfall<br>Suppl. Figure S1Annual total and monthly distribution<br>Table 5 Onset before and now |

| | | | | |
|---|---|---|---|---|
| | | variability increased (Rosell, 2011). | | |
| *Cessation* | *The rainy season finishes earlier now* (esp. Malawi and Ethiopia) | This paper shows that monthly rainfall declines towards the end of the rainy season (esp. Malawi).<br>Previous studies of Eastern Africa associated earlier cessation with warming of Indian Ocean (Funk et al., 2008) and cessation (wetter MAM) with El Niño (Tadross et al., 2009). | Definitions of “cessation” are likely to be confounded by onset definitions, planting calendar, i.e. meteorological versus agronomic cessations, and crop/animal water demand, i.e. impacts on the farming system. | Suppl Table S2 Farming calendar<br>Suppl. Figure S2 Accumulated monthly rainfall |
| *Amount* | No/few trends in annual or total rainy season amounts but in certain months (Malawi, Botswana, Ghana).<br>*There is less rain now than in my childhood* (Ghana). | This paper shows changes in decadal cycles (strong positive anomalies in 1960s, negative in 1980s, more balanced anomalies in 2000s) and ENSO effects: more frequent La Niña (El Niño) in 1970s (1980s) associated with higher (lower) *kiremt* rainfall, in Ethiopia.<br>In Letlhakeng, Botswana: negative monthly anomalies (DJF) during El Niño phase.<br>In Malawi: average monthly rainfall at the onset and cessation months declined from 1990s.<br><br>Previous studies for Ethiopia show decline in rainfall June-Sept since 1980s (*kiremt*) (Cheung et al., 2008) and in Ghana rainfall declined since 1970s (Voortman, 1998). | Opposing perceptions of amounts of rainfall calls for more detailed analyses. Rainfall variability overtakes most trends in amounts.<br>Possibly confounded by spatial variability. High future potential to map spatial variability with satellite data. | Figure 2 Anomalies<br>Suppl. Figure S1 Annual distribution of monthly rainfall.<br>Suppl. Figure S2 Accumulated rainfall<br>Suppl. Figure S3 Seasonal rainfall during ENSO<br>Suppl. Figure S4 Seasonal rainfall correlation with ENSO<br>Table 5 Cessation before and now |
| *Frequency* | *There are fewer rainy days now …* | This paper shows increasing number of dry days (especially December, February, April in northern and central Malawi) and decreasing in the south (January). PDF-curves show little trend-shifts.<br>See meteorological onset above. | Urgent to farmers. Relatively easy to measure with daily meteorological data and to set up local and crop specific mathematical rules and adaptation strategies. | Figure 4 Distribution of wet-dry days |
| *Intensity* | *… and more rain when it rains* (Botswana, Malawi) | Where the total rainfall amount shows no or small declining trends and the number of dry days is increasing this leads to more intense rainfall (Bvumbwe, S Malawi). | Urgent to farmers. Difficult to measure without hourly data. May be very local rains and difficult to predict/forecast. Place a network of rain gauges managed by farmers to observe the ranges of intensity. Identify coping strategies and farming systems that withstand a wide range of rainfall. | Suppl. Figure S3 Rainfall during ENSO |
| *Confounding factors* | *When I was younger we could transplant rice right through until April as there was enough rain but since 1991, if you transplant later than January, there will be no harvest. There is less rain than there used to be. My parents used to harvest more. (Chilimba village, Malawi)* | Contextual characteristics that vary from place to place<br>External factors: government policies, information<br>Expectations: (financial, physical, social) access to inputs, social welfare support<br>Experience: behaviour, worst cases versus recency memories<br>This study shows that farmers refer to meteorological and agronomic droughts. In addition, crop failures may be unrelated to both meteorological and agronomic droughts:<br>Access drought, where external inputs bypass farmers' expectations and /or experiences. | Urgent to policy makers. It is crucial to separate, as far as possible, whether perceptions of rainfall are based on changes in the actual exposure or in the impacts on agriculture.<br>Many factors interact to influence the perception of rainfall: external factors influence farmers' expectations and experiences, e.g. farmers expectations of a certain type of rainfall may not meet the expected harvest outcome, farmers' experiences lead to various types of behaviour (planned and autonomous adaptation versus maladaptation). | Figure 7 Rainfall versus yield variability<br>Suppl. Table S2 Farming calendar |

*Table 5 Central and South Malawi: Farmers perceptions of the onset and cessation (duration) of rainy season between "now" and "before" with darker grey for great unity among focus groups and lighter grey for differences between groups. Note that in south farmers perceive rainfall to end earlier, but it was not clarified whether early April refers to now or before. The perceptions are contrasted with the change in average number of dry days per month (DD) and monthly rainfall (P) for the periods 1961/62-1988/89 and 1989/90-2007/08. Significant trends in number of dry days per decade are shown (d/10yr).*

| Location | | Period | S | O | N | D | J | F | M | A | M |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Central | Dedza | "before"<br>"now" | | | | | | | | | |
| | Dedza Met station | % change | *DD ± 0%<br>P <5mm* | DD +4%<br>P<11mm | DD +8%<br>P +3% | **DD +27%;<br>+1.3d/10y<br>P -21%** | DD -10%<br>P +8% | **DD +20%;<br>+1.2 d/10y<br>P -9%** | DD +4 %<br>P +6 % | **DD+15%;<br>+0.9d/10yr<br>P -33%** | DD +7%<br>P <12mm |
| | Kasungu<br>Lilongwe | "before"<br>"now" | | | | | | | | | |
| | Ntchisi | "before"<br>"now" | | | | | | | | | |
| | Chitedze Met station | % change | *DD ± 0%<br>P <5mm* | DD +1%<br>P -21% | **DD +8%<br>P -31%** | **DD +19%<br>P -17%** | DD ± 0%<br>P +12% | DD +5%<br>P -4% | DD +8%<br>P -11% | **DD +12%<br>+1d/10yr<br>P -62%** | DD -2%<br>P <16mm |
| South | Chikwawa | "before"<br>"now" | | | | | | | | *nd* | |
| | Bvumbwe Met station | % change | *DD -2%<br>P <11mm* | DD +7%<br>P -80% | DD +6%<br>P -5% | DD +11%<br>P +2% | DD -8%<br>P +22% | DD +19%<br>P +5% | **DD +14%<br>P -12%** | **DD +13%<br>P -48%** | DD +6%<br>P <25mm |
| | Chileka Met station | % change | *DD ± 0%<br>P <5mm* | DD +5%<br>P -48% | DD +4%<br>P -9% | DD +9%<br>P -13% | DD ± 0%<br>P +18% | DD +17%<br>P -6% | DD +10%<br>P -29% | DD +9%<br>P -20% | DD +4%<br>P <10mm |

*% change between mean for 1961/62-1988/89 and 1989/90-2007/08; DD = dry days; P = monthly precipitation; d/10yr = decadal trend in DD (1961-2008)*

*Source: Authors' fieldwork in 2009 and Mkwambisi focus group discussions in 2010; Malawi Meteorological bureau.*

## 4.2 Contextual perceptions – changes in sensitivity of agricultural systems

Answers to questions about *when* the changes in rainfall had occurred varied more than as to *how* the changes were perceived. The focus group discussions carried out independently throughout Malawi showed general agreement that rains became progressively more difficult to predict from the 1990s and 2000s, particularly with more erratic onsets. One forestry officer said

*We used to have abundant rains in the 1970s/80s and early 90s but since 2000 we had some changes in rainfall.*

In Botswana most interviewed farmers mentioned a specific year in which change was noted, while a few gave a range from a couple of years to decades. A majority of those who said there was a change in rainfall patterns also stated that changes have occurred in the most recent decade (see Figure 6). When respondents could not mention a particular year or period for the change, they referred to "before" versus "now", or "in the good old days" when rainfall and impacts typically were better than "nowadays" (see examples in Table 5). In some cases "good" and "bad" years were used to separate transitional changes (trends) from inter-annual variability. However, the "good old days" are also possible examples of nostalgia. For example, a former village chief in Botswana stated that the rainfall changed in 1965, which coincides with the independence period when the village leaders lost their power (new government system). In Balaka, Malawi, farmers related good and bad rainfall to presidential periods: "*During the Kamuzu Banda era rains fell from November to May, in the Muluzi era from October to February or December to April. Both Muluzi and Bingu* *periods gave bad rains while the best rains fell in the Kamuzu Banda era*." In Chileka (near Balaka), the average seasonal rainfall during Malawi's Banda regime (1966-94) was insignificantly higher, 800 mm, while during both the Muluzi (1994-2004) and Bingu (2004-present ) periods it was about 770 mm. Similar references to romanticizing the past were found in Botswana (Sallu, 2007).

The perceptions presented here are in line with Marx et al. (2007). Their research shows that while extreme weather events remain vivid in memory if they coincide with other memorable events (such as presidential eras; referred to as the availability heuristic), farmers' decisions tend to be based on recently experienced events (such as a flood or a drought), which therefore overestimates the likelihood of the same event happening again (the recency heuristic). Consequently, probing questions asking about "good versus bad" and "now versus before" may be misleading if the intent is to investigate perceptions of changes in rainfall. As such, answers will be associated with farming activity outcomes, whereby one year can be "good" for somebody and "bad" for another, irrespective of weather. Both "now versus before" and listing "good versus bad years" are precarious when the recent period is generally more vivid in memory, which is one possible synthesis interpretation of Figure 6. Furthermore, the age of respondents and establishment of their own household may influence when they started paying more attention to rainfall impacts. This study conforms with others that find links between farmers' experience, education and the number of response strategies (Madisson, 2007). Our discussions with farmers in Malawi and Botswana provide some ideas for further investigation with a greater number of respondents. Our preliminary results seem to point to links between households (i) pursuing a greater number of response strategies, (ii) making decisions based on discussions within the household, which allowed decisions to vary from year to year, and (iii) being able to give more detailed and diverse perceptions of past rainfall changes, in particular highlighting the recent one to two decades. In contrast, fewer response options seemed to appear in households with fixed decisions, such as "this is how we always do it and what we know", hence there was less flexible crop variation, where farmers generally gave less vivid but fairly consistent perceptions of rainfall, in particular highlighting the odd extreme weather events. Another reason for low levels of diversity is the combination of poverty and single-headed households. Confirming evidence along this line could suggest that recency heuristics may be more common with adapting farmers while availability heuristics may be more common with less adapting farmers (see Marx et al., 2007).

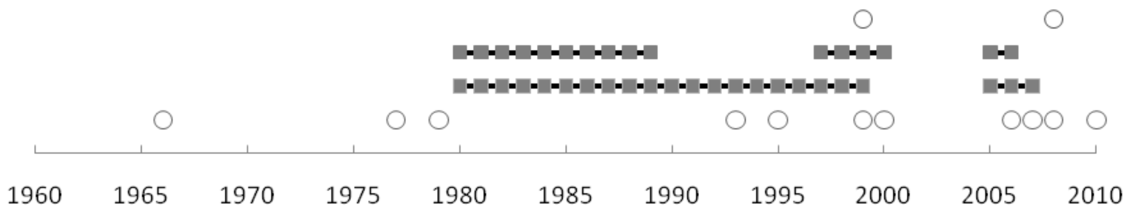



*Figure 6 Years or periods when farmers say there was a change in rainfall. 1999 is the most "popular". Squared lines illustrate a perceived change over a period, circles when one specific year has been mentioned. One reason for this pattern may be the age of farmers, which vary from early 40s to elderly. Source: Quinn & Simelton fieldwork 2010 interviews with individual households in Mogobane and Letlhakeng, Botswana (n=20).*

### 4.2.1 Confounding factors

Some perceptions of rainfall changes could be successfully reconstructed with meteorological data when the gaps between perceptions and scientific approaches are narrow, while others showed inconsistencies. One reason for inconsistency is that perceptions of rainfall can be confounded with impacts on yields, changes in the agricultural system that have made the crops or the farming system more sensitive to rainfall changes, or combinations of both. Impacts on yields may be indirectly associated with, or aggraved by, adverse climatic conditions, such as pests, delayed planting, or totally unrelated to climatic conditions, such as access to farm inputs. Here we discuss how farmers' perceptions of rainfall may be confounded by their access to external factors (e.g. policies, infrastructure, information, forecasts) their expectations or their previous experiences of harvest outcomes. Lastly, we introduce the concept of 'access droughts' which encompasses all three "confounding" factors: external factors, expectations and experiences.

***External factors***

A number of the interviewed Malawi farmers perceived that rainfall changed in the 1990s. Besides the presidential shift, this change coincides with a period of local seed and fertiliser trials (1992-96) followed by the national Starter-Pack policy with composite/hybrid seeds and fertilisers (1997-2000), which was introduced to help increasing yields and ensure national food security (Snapp et al., 2003). However, the first two years of Malawi's Starter Packs produced bumper harvests and coincided with good rainfall while in the third year both the policy changed and rainfall declined, which made it difficult to evaluate the direct cause of the third year's crop failures (*ibid.*). Although these policies were generally considered successful for food security at the national level, the local impacts varied. One village head said:

*People in my village started using hybrid seeds since the agricultural extension workers recommended it due to unpredictable rains. We are benefitting now because even if the rains are bad people still harvest something.*

Farmers in other villages in Malawi were of the opposite opinion and mixed hybrid seeds with lower yielding traditional seeds to be sure of some harvest. Figure 7 shows that the inter-annual variability for standardised rainfall in Malawi is high but fairly constant while the increase in standardised harvest variability coincides with the introduction of hybrid maize. That is an agricultural policy, rather than changes in rainfall, alter the sensitivity of the agricultural system.

***Expectations and Experiences***

The individual household interviews highlighted that their (financial, physical or social) access to inputs influences how they are affected by rainfall changes, how they perceive those changes, and how they believe they can respond to or adapt to the changes. In Malawi changed inputs or management following extension advice or policies raised some farmers' expectations on receiving higher or more stable yields. However those expectations may not be met for various reasons. An elderly, so-called "group headman" in Malawi said

*Particularly from 1993/94, at the turn of the political party, the new administration has given more freedom and producers have no say on prices. So people are hungry and have no energy to work on their fields.*

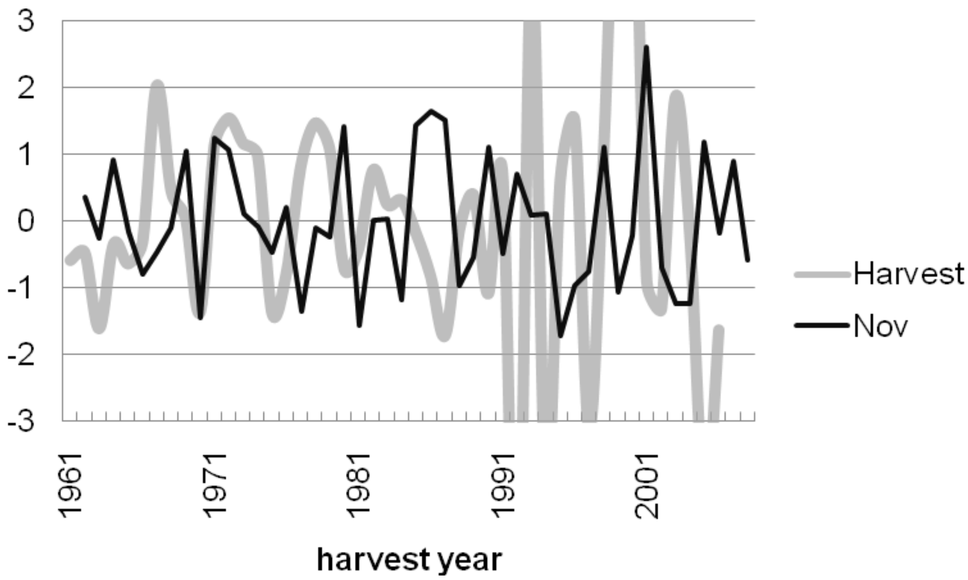



*Figure 7 Inter-annual variability in rainfall and national maize harvest, Malawi. Standardised rainfall for November (significantly correlated with national level harvest, not much difference in inter-annual variability between November and growing season rainfall) and standardised harvest. The graph shows that while farmers say rainfall becomes more unpredictable, harvests are actually becoming far more unpredictable. The big wobbles here coincide with state program for hybrid maize. Note that the y-axis has been cut at ±3 S.D. to illustrate the shift in variability (the maximum extent reaches ±7 S.D.).Source: Malawi Meteorological Bureau, Ministry of Agriculture and Irrigation, Ministry of Agriculture and Food Security*

This quote demonstrates how the Structural Adjustment Programs were felt on ground. Similarly, the 2001/02-famine started with a decline in maize harvests that resulted in domestic food price inflation that the government failed to buffer (Devereux, 2009; Snapp et al., 2010). While making a livelihood consequently becomes more difficult, e.g. due to changes in labour or health (Figure 1), the farming system's sensitivity to changes has increased and small rainfall perturbations may be more easily perceived. If this coincides with a new political regime, it makes it memorable (Marx et al., 2007).

Farmers adjust the planting of different crops depending on (i) experience and indigenous knowledge, (ii) whether they anticipate the rainy season to be drier or wetter than “normal”, or (iii) as a second strategy in the event of natural hazards (see Farming Calendar Supplementary Table S2). A critical indicator of whether a year was good or bad is the timing of planting. Sometimes planting at the first rain was successful; sometimes those who waited for the second shower had a better harvest. The focus group discussions in Malawi and Botswana showed interesting differences during dry onsets: while Malawi farmers continued to mix traditional seeds with new varieties “to get something instead of nothing” when they expected poor rainfall, some, generally the less wealthy farmers in Botswana, decided not to plant at all. The decision to not plant was based on the expectation that their input (time and/or capital) would not be worth the outcome (harvest and/or profit). In the case of Botswana there are several possible reasons for not planting: the annual rainfall is already at the lower limit for cultivation, poor households expect to receive drought relief and in rich households livestock provide an economic safeguard and have higher priority than crops.

***Access drought***

By “access” drought we refer to an illusionary drought, where i) external factors confound the perceptions of the exposure, and ii) where climate impacts are inferred from resource dependency, i.e. reliance of a narrow range of resources that adds stresses within livelihoods (Adger, 1999) or maladaptation. For example, one feature of Malawi’s current support targeting the poor is the seed and fertiliser coupons. In two of the interviewed villages the poorest farmers stated that actually, the better-off received the coupons for fertilisers and seeds, or that the packages had run out. In these cases the majority belonged to the poorest category, while the middle group said that the government and charity NGOs targeted the poorest of the poor while there was no help for the ”common poor”, other than loans through farmer groups (see last four bars in Figure 1). National seed and fertiliser programmes thus meant that a number of farmers, who could not afford to buy appropriate seeds, planted the distributed seeds, regardless of local suitability, expecting a good yield. In Botswana a policy on free ploughing of 5 ha led to a queue for draught power, hence the access to equipment and its timing determined planting, not individual decision making. In south Malawi, even though the village is situated within five kilometers from Mwanza river, the water is not used for irrigation due to lack of pumping equipment. In another village only those who can afford the membership of the irrigation scheme receive water. Crop failures under these circumstances obviously depend on lack of access to tools and inputs, rather than droughts. In both Botswana and Ethiopia, the consequence is that even if farmers knew when they should plant, their harvests are destroyed due to their inability to take pro-active and reactive measures. In summary, lessons can be learned from the impacts of policies that run the risk of undermining farmers’ capacity to fully utilise their experiences in agriculture. Interpretations of weather patterns should be carefully studied in adaptation studies.

# 5 Conclusions

***Perceptions of rainfall and meteorological evidence***

Using farmers' perceptions of rainfall from four countries across Africa we have identified some characteristics of the term "erratic" rainfall. The immediate perception of erratic appears to be synonymous to unpredictable, however, when looking in depth there are several characteristics.

- More specifically, the onset is perceived to be later "now" than "in the past". Meteorological evidence to support this includes increasing number of dry days and declining rainfall at the normal time for onset (Table 5). Increasing rainfall two or three months after the "normal" onset may further accentuate the perception of a later onset. The term "erratic" mirrors the fact that the inter-annual variability and the spread of the onset (a total of at least 30 mm based on accumulating rainfall ≥10mm/day) has increased (Figure 5). This onset graph (when animated and presented in three steps) conveys the importance of the timing of onset, however, there is no meteorological data to indicate that rainfall used to arrive earlier over the past 40 years. Missing data may be a problem for this type of illustration.
- The cessation is perceived to arrive earlier. Meteorological evidence to support this includes an increasing number of dry days, declining monthly total rainfall (Table 5) or premature cessation (Figure S2).

The duration of the rainy season is perceived to be shorter with fewer rainy days but high intensity rainfall, i.e. lower effective rainfall. Meteorological evidence to support shifts in rainfall distribution includes graphs of daily rainfall intensity (Figure 4), variations in monthly distribution of the annual total rainfall (Figure S1), an increasing number of dry days and no or small changes in total rainfall with occasional changes in certain months (Table 5). The daily rainfall distribution and intensity graph (Figure 4) is intuitive but provides little analysis and therefore, depending on the findings, may not convey a clear message, such as that lower effective rainfall has considerable consequences on agriculture production, as harvests may be reduced when water is lost through overland flow rather than infiltrated.

- Meteorological evidence that may contradict the concept of erratic rainfall as being irregular includes periodicity in annual rainfall anomalies (Figure 2), correlations with ENSO (Figure S3, Figure S4) and other large scale phenomena.
- The timings of the changes were perceived to happen over a 5-10 year period, in most cases during the recent two decades (Figure 6). The meteorological evidence to support a combination of events leading to changing patterns in the 1980s and 1990s include changes in the timing of onsets, change in average rainfall amounts and frequency at onsets and cessations before and after 1989 (e.g. Figure S3). Other studies imply that this period coincided with warming of the Indian Ocean and increasing ENSO intensity.

- Perceptions of rainfall may be confounded by the impacts of rainfall, farmers memorising more recent or extreme events respectively, as well as external non-climatic factors. Non-climatic factors that coincided with the perceived timing of the changes in rainfall include structural adjustment programs, national agricultural and food security policies and living standards, affecting farmers' access to subsidies and agricultural inputs resulting in more unstable yields (Figure 7). Asking farmers about “good” and “bad” years may lead the conversation into perceptions of impacts rather than weather.

***Reducing gaps for adaptation***

The farming calendar (Supplementary Table S2) serves many purposes and is easy and intuitive to develop with farmers. The farming calendar shows that farmers experience and adapt to a range of weather scenarios, hence their perceptions that rainfall is becoming unpredictable needs to be taken seriously by scientists and policymakers. The key gaps between farmers' perceptions and the scientific evidence appear in terms of onsets in the past, shifts in rainfall during the rainy season and characterising the cessation (Table 4). We argue that the gaps between traditional qualitative and quantitative discourses need to be narrowed by exploring synergies that eventually may lead towards more appropriate adaptation policies (Challinor et al., 2009; Fraser et al., 2008). Typically the access to a combination of social, human, financial and natural capitals influences the individual's capacity to take advantage of institutional support. Scientists need to be aware that changed farming practises also influences perceptions of rainfall rather than the other way around. For successful adaptation to changes in climatic patterns, the roles of indigenous knowledge and semantic challenges should not be underestimated. It is essential to identify what external inputs (e.g. policies, subsidies): 1) are provided that raise farmers' and scientists' expectations of yield (agricultural sensitivity) but bypass farmers' abilities to interpret and respond to weather stress, 2) are provided but not accessed by all farmers and which prevent them from gaining experiences of agriculture and weather forecasting. Furthermore, the same amount of rainfall can result in a good year for some and a bad year for others – perceptions therefore are closely associated with (expected and previously experienced) impacts, not only the actual rainfall. In terms of impacts and adaptive capacity it is important to separate re-active and pro-active behaviour; some plant early others late or not at all - this may shape the way in which farmers' perceive rainfall. Unless stakeholders distinguish between exposure (rainfall change), impact (yield change) and sensitivity to exposure (changes in agricultural systems) adaptation policies are unlikely to lead to success.

We introduced the concept of “access droughts” to denote crop failures that result from institutional support that leads to maladaptation strategies and increased sensitivity of the agricultural system. We have shown that access droughts are sometimes mistaken (by farmers, scientists, extension, policy makers etc.) for agronomic or meteorological droughts.

This research brings us to hypothesise that understanding local perceptions of changes in the climatic patterns, such as rainfall changes, could enhance local adaptive capacity. This hypothesis will be tested further in the next phase of this research.

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# Supplementary Material

# Appendix 1 – Socioeconomic data for the four countries

*Table S1 Country-level climate and socio-economic statistics for Botswana, Ethiopia, Ghana and Malawi*

| | Botswana | Ethiopia | Ghana | Malawi |
|---|---|---|---|---|
| Population 2009[1] | 1.95 million | 82.82 million | 23.84 million | 15.26 million |
| Economically active in agriculture 2008 | 0.30 million | 30.63 million | 5.79 million | 4.92 million |
| GNI/capita current US$ 2009[1] | Middle income 6240 | Least income 330 | Low income 700 | Least income 280 |
| Structural adjustment programs | No | 1992-97 | 1983-90 | 1981-98 |
| Prevalence of undernourishment % of population 2007[2] | 25 | 41 | 5 | 28 |
| Famine/drought history | 1982-87, 1992 | 1970s, 1984/85, 1999/2000, 2011 | 1981-83 | 1990s, 2001/02 |
| Value, total agricultural | Net importer | Net exporter | Net exporter | Net exporter |
| -Import | 518 million | 525 million | 1044 million | 151 million |
| -Export current US$ 2007[3] | 151 million | 1038 million | 1482 million | 773 million |
| % irrigated area of total agr land 2003[2] | 0.3 | 2.5 | 0.5 | 2.2 |

Source: [1] The World Bank http://data.worldbank.org/indicator/NY.GNP.PCAP.CD; http://data.worldbank.org/indicator/SP.POP.TOTL;

http://data.worldbank.org/indicator/EN.AGR.EMPL ; [2]Africa Development Indicators (World dataBank, 2010); [3]The Economist Intelligence Unit (The Economist, 2010)

## Appendix 2 – Farming calendar

*Table S2 Farming calendar for Kamwendo village, Machinga district in the northeast of South Malawi.*

| | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul |
|---|---|---|---|---|---|---|---|---|---|
| Rain (wet year) | | 1w heavy | | | | | | | |
| Likwenu river | | | Flood risk | | | | | | |
| Rain ("normal" year) | Rains 1/3 days | | | | | | | | |
| Rain (dry year) | | | | | | | | | |
| ***Crops for household consumption*** | | | | | | | | | |
| MAIZE (wet, normal) | P | | F | | H | | | | |
| MAIZE (dry) | | P | | F | | H | | | |
| PIGEON PEA (wet) | P | | F | | H | | | | |
| PIGEON PEA (normal) | P | | | | F | | | H | H H H – mid Aug |
| ***Crops for sale*** | | | | | | | | | |
| GROUNDNUT (wet, normal) | P | Fh Fl | | | H | | | | |
| GROUNDNUT (dry) | | Ph Pl** | | Fh | | Hh | | | |
| TOBACCO (wet) | P | H H H | H H H | H H H | H H | | | | |
| TOBACCO (normal) | P | H H H | H H H | H H H | H H | | | | |
| TOBACCO (dry) | | P*** | H*** | | | | | | |
| SW POTATO (wet) | | | P P | | F | H | | | |
| SW POTATO (normal) | | | P P | | F H | | | | |
| SW POTATO (dry) | | | P+ | | F H | | | | |
| CHILI (wet, normal) | P* P* P* | | F | | | H H | H H H | H H H | H H H |

P=Plant, F=Flower, H=Harvest; h=hybrid, l=local variety. *Plant when rainy season starts. ** If no rain until Dec 15, use local variety. *** If rain starts in Dec, plant in Dec. If no rain, don't plant. + Plant 15 days after rain. Source: Simelton & Quinn, fieldwork July 17, 2009. Focus group of six key informants (3 women and 3 men).

## Appendix 3 – Supplementary graphs

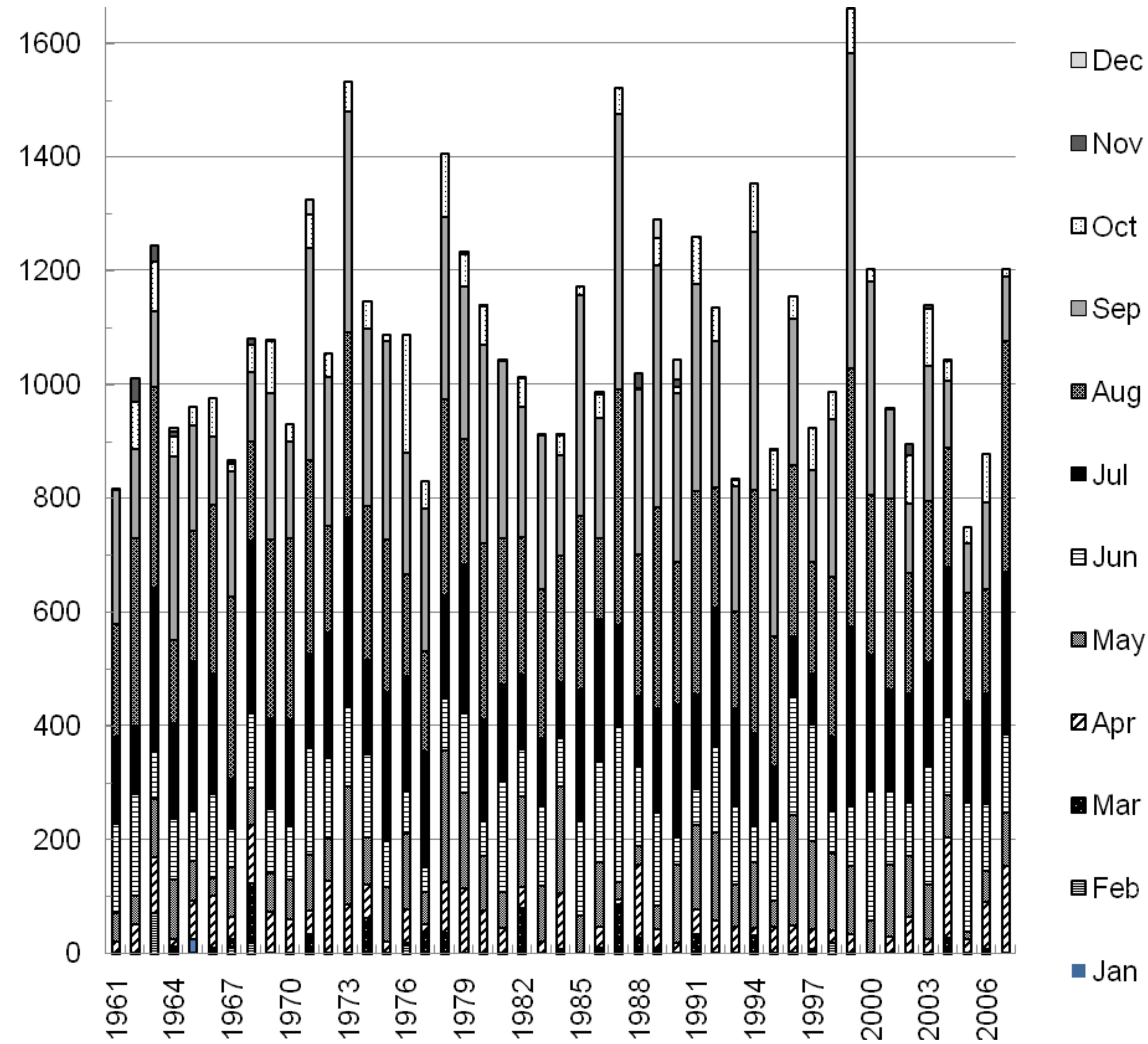


*Figure S1 Rainfall distribution and total rainfall in Navrongo, Upper East Ghana 1961-2007. Here the growing season starts in May, which with few exceptions reaches 50 mm each year. The distribution graph shows that by July-August about 50% the of rainfall used to have fallen, whereas increasingly in later years by the same time about 60% of rains fell, which in part is explained by that September gets a smaller share of the total rainfall.*

In Ghana nearly all respondents had observed changes in the rainy season during their lifetimes. An example for Navrongo is shown in Figure S1. In particular, throughout the investigated time period the onset was particularly variable in six of the stations, the cessation in one station, and both the onset and cessation in three stations (data not shown). Moreover, rather than consistently starting later, rainfall variability was particularly high in April and June while the total rainfall during the rest of the growing season was lower after the 1980s compared to before. It is worth noting that Ghana's 1983 famine occurred in a year with normal distribution within the rainy season but with record low total rainfall, in particular less than normal rain in March (the early onset month). Furthermore, the meteorological observations for the upper East District of Ghana (Figure S1) show a weak cyclical pattern of total growing season rainfall and strong inter-annual variability of up to 300-400 mm in some years. Hence, similarly to most of the 16 stations there were no significant linear trends for monthly rainfall, except that the total rainfall in May (the onset month for late rains) declined during the last decade (1997-2007). In response to the variable onset, farmers say that they now plant later.

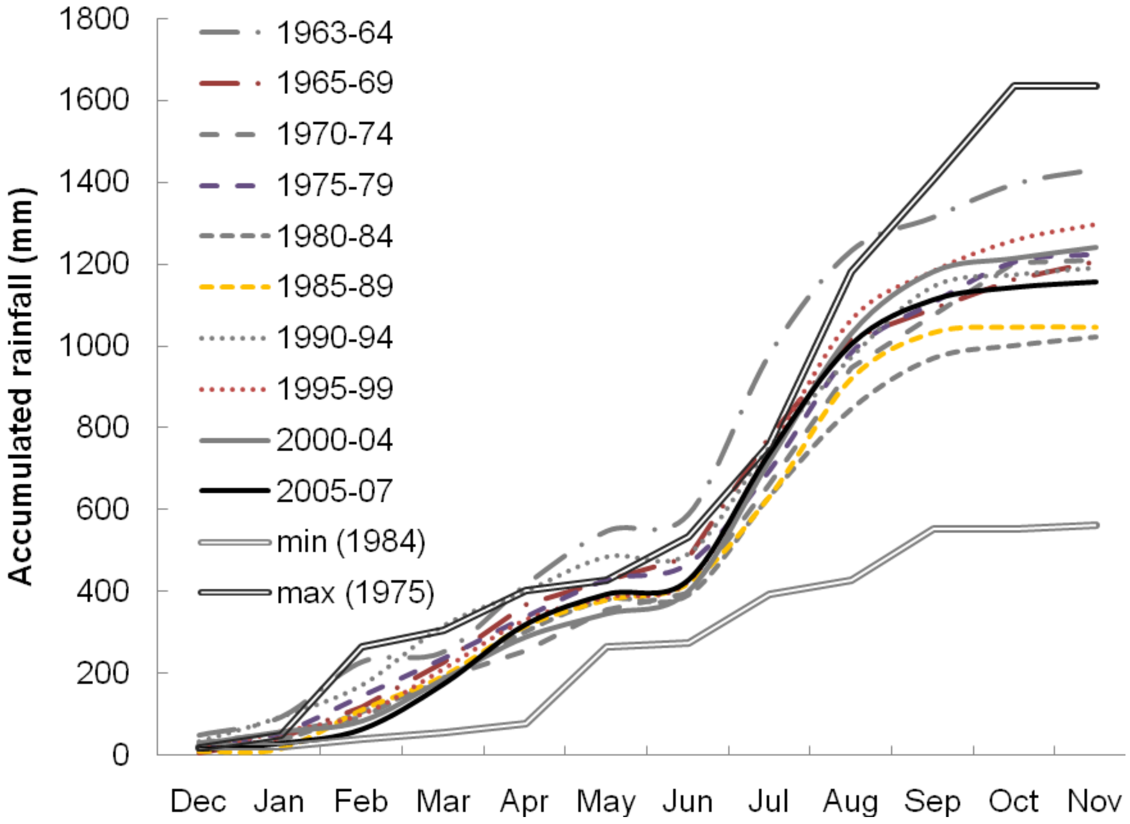


*Figure S2 The maximum spread of the accumulated rainfall and 5-year average accumulated rainfall in Hayk, Wollo, Ethiopia between 1963 and 2007.*

Figure S3 shows the years with most extreme ranges in accumulated rainfall as well as the spread of cessation for Ethiopia. This clearly captures the disastrous year 1984 with late onset, early cessation and low total rainfall which was followed by 1985, which was a rather "average" year. Averages, which scientists typically use to quantify change between two periods (see also Table S2), would clearly mask the variability that is important to farmers. For example, the period 2005-2007 would be considered "average" in terms of total amount, but has both later onset than in the 1980s and a fairly early cessation (Figure S2). In Ethiopia (Figure S3) more frequent La Niña (El Niño) phases during the 1970s (1980s) were associated with higher (lower) *kiremt* rainfall. During the 1990s *kiremt* and *belg* rainfall diverged considerably compared to previous decades. Although in this case harvest and rainfall are not correlated, forecasting ENSO-cycles could help extension and farmers adjust crop selection and management, such as irrigation, stocking herds, during El Niño phases when rainfall is likely to be lower than in other years (Figure S3, Figure S4).

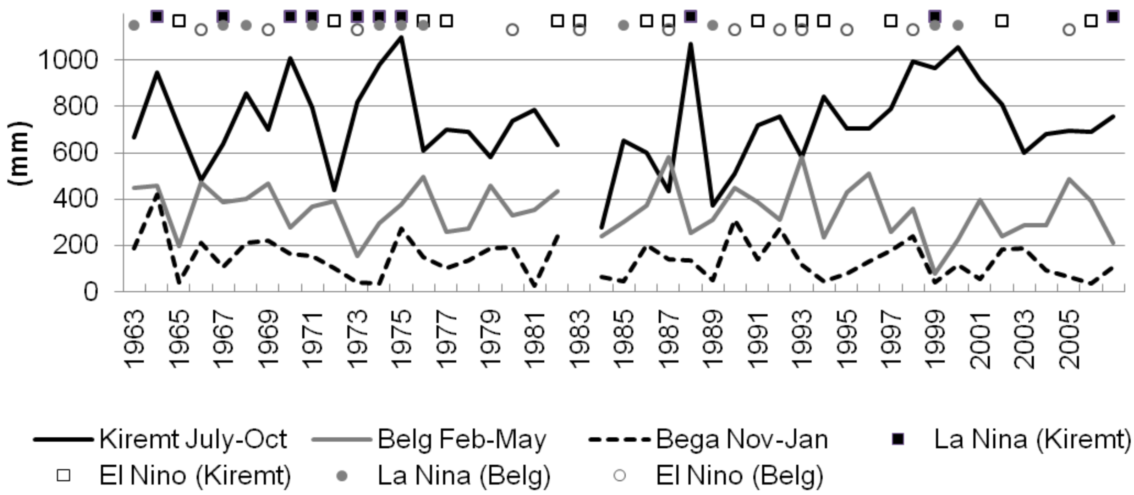


*Figure S3 Ethiopian Bega, Belg and Kiremt rainfall during ENSO phases (average Multi-variate ENSO Index, MEI <19 is classified as a La Niña phase, >44 as El Niño phase) Hayk, 1963-2007. The graph shows that ENSO influenced kiremt rainfall more significantly than Belg. Source: MEI http://www.esrl.noaa.gov/psd/enso/mei/rank.html*

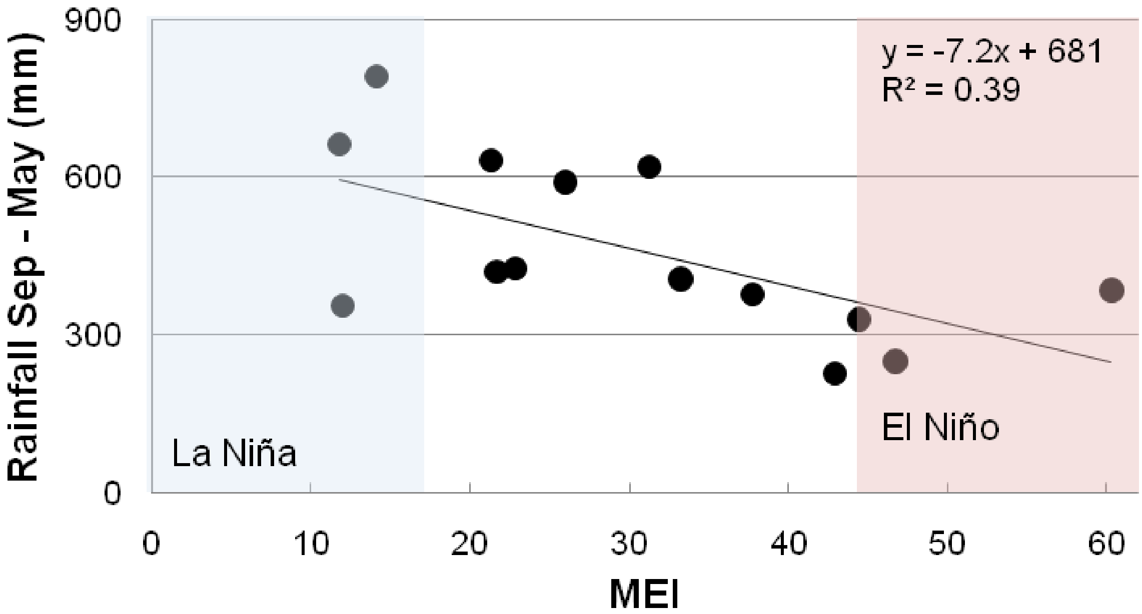


*Figure S4 The relationship between Multi-variate ENSO Index (MEI) and average growing season rainfall of five meteorological stations in Botswana. MEI is calculated as the average for September to May and total rainfall over the same period. Lower MEI index indicates La Niña and higher MEI stronger El Niño. Source: http://www.esrl.noaa.gov/psd/enso/mei/rank.html*

## Appendix 4 – Rapid guide on rainfall data

Daily meteorological data is the preferred resolution for agricultural analyses and are necessary for counting wet and dry days, specifying onset, calculating frequency and intensity etc. Some common statistical tests are given in Table S3.

Quality check. When obtaining meteorological data from meteorological bureaus ask (i) how it was quality controlled (checking for non-physical values, such as 1200 mm in one day), and (ii) how to can tell missing data from the value "zero".

Not all data is meteorological. Sudden step changes, especially notable in temperature records, may indicate that the meteorological station has moved, changed or repaired, or the surrounding has changed. For example in rapidly urbanising environments meteorological stations can have been built in between houses. It is usually impossible to know, although there should be registers on this at the meteorological bureau. Sometimes it can be helpful to check if both rainfall and temperature data show similar step changes.

*Table S3 The first statistics for rainfall analysis and data requirements*

| **Analysis** | | **Graph or type of analysis** | **Daily data** | **Monthly data** |
|---|---|---|---|---|
| | | | x | x |
| Climatology | long-term monthly mean vs long-term mean monthly temperature | Bar graph (rainfall, primary y-axis) with lines (temperature, secondary y-axis), year (x-axis) | | |
| Time series trends | monthly total, growing season total, annual total, decadal averages | Bar graphs (or lines) with linear and non-linear trends (10-year running mean); Mann-Kendall test | x | x |
| Geographic trends | Large-scale onset patterns | Composite time (x-axis)-latitude (y-axis) amount of rainfall (z-axis) maps of onset days | x | |
| Cyclic patterns | annual or seasonal total rainfall, (onset), monsoon/ENSO phases | Moving average (e.g. 5, 10 years); identify ENSO years | (x) | x |
| Variability | inter-annual variability | % coefficient of variation | x | x |
| Density | number of wet/dry days | Scatter plot, density plot | x | |
| Shares | share annual total in respective month | Bar graph with actual (mm) or relative total (100%) | x | x |
| Onset/ Cessation | dates, duration, based on local agronomic requirements | Formulae: *x* mm within *n* days after *date* and *m* consecutive dry days | x | |