Characterizing Long Term Rainfall Data for Estimating Climate Risk in Semi-arid Zimbabwe

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1 Introduction

Most of the potential benefits that could be realised from the use of a range of forecasts, including the SCF are yet to be achieved, partly due to failure to fully communicate agriculturally relevant climate information to users (Hansen et al. 2011; Stern and Cooper 2011). There is a mismatch between the farmers' needs and the forecasts, in terms of relevance and their scale (Patt and Gwata 2002; Manatsa and Gadzirayi 2010). There is therefore a need to research into ways of improving dissemination of the weather related information as suggested in various studies (Patt and Gwata 2002; Manatsa and Gadzirayi 2010; Hansen et al. 2011; Stern and Cooper 2011).

Despite the existence and dissemination of SCF amongst many communities, there is still much more information that could be provided by national meteorological services to augment and improve the seasonal forecast information (Hansen et al. 2011). Simple rainfall analyses using long term rainfall records could be able to assist farmers in terms of proving valuable information in relation to climate risk management (Stern and Cooper 2011). This type of analyses, when used with SCF will hopefully be useful to farmers, aiding them in making ex-ante agricultural decisions as well as going a long way in addressing some of the constraints to using

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SCF (Mupangwa et al. 2011; Stern and Cooper 2011). A number of studies in the 1980s (for example, Stern et al. 1982; Sivakumar 1988) have described the importance accessing long-term daily rainfall records to enable "weather-within-climate" analyses that can be tailored to the needs of different groups of users to be done. Mupangwa et al. (2011) notes that the analysis of daily rainfall data in most semi-arid regions shows that the crop moisture related problems are associated with intra-seasonal dry spells during critical stages of crop growth rather than cumulative rainfall.

The importance of increasing temperatures in terms of climate change is however acknowledged; but this paper focuses mainly on rainfall data as under rain fed agriculture, season to season variability in rainfall and possible changes in the pattern and in the variability are likely to be of more immediate concern to farmers (Stern and Cooper 2011). Crops primarily respond to daily climate or sequences of daily climate and in particular daily rainfall is a key parameter in rain-fed agriculture (Stern et al. 1981; Cooper et al. 2006).

The main objectives of the study included (i) using daily rainfall values to examine the risk or probability of getting a number of weather events that would be useful for farmers such as (a) annual rainfall, (b) rainfall onset and cessation, (c) number of rain days, and (d) risks of dry spells during the growing season in different seasons (i.e. in El Nino, Ordinary and La Nina seasons) and (ii) using Markov Modelling to quantify the chance of rain.

2 Methodology

Long term rainfall data from Hwange District (1963–2009) was used for this study. The principal station used was Victoria Falls Airport (17.56° latitude and 25.50° longitude). The dataset had three years of data missing, i.e. from 1981 to 1984. The methods of Stern and Cooper (2011) were used to analyse the rainfall data. The software package used was Instat Statistical programme (University of Reading 2008). The rainfall data were categorised in El Nino, La Nina and Ordinary years (Table 1) based on information from the International Research Institute for Climate and Society (IRI), (http://portal.iri.columbia.edu/).

2.1 The Weather-Induced Risk Analyses

2.1.1 Number of Rain Days

A way of exploring rainfall data in terms of its distribution and amount is to look at the number of rain days. In this study, a rainy day is regarded as a day with measurable rain; i.e. a day yielding 2.95 mm or more. Meteorologically, Mupangwa et al. (2011) notes that 0.85 mm over 1 or 2 days can be classified as a rainy day, but that agronomically the threshold value is too low (Mupangwa et al. 2011; Stern, personal communication). Stern and Cooper (2011) indicate that setting or defining the threshold for rain is usually a complication in rainfall data analysis. This is mainly due to that the smallest amounts recorded are 0.1 mm, and in some countries in the early years, the lower limit was 0.01 inches. Below this value, days could be recorded as having trace rainfall. The ideal would be to record all non-zero values, i.e. to set the limit as 'trace and above'. The daily data, from which the annual totals are calculated, contains a mixture of zero values (dry days) plus those with rain.

Table 1 The different season types in the study period

La Nina	Ordinary	El Nino
1970 1973 1975 1984 1988 1998–1999 2007	1964 1966–1969 1971 1974 1976–1981 1983 1985 1989–1990 1992–1993 1995–1996 2000–2001 2003–2005 2008	1963 1965 1972 1982 1986–1987 1991 1994 1997 2002 2006 2009

Source International Research Institute for Climate and Society (IRI) (http://portal.iri.columbia.edu/)

2.1.2 Onset of the Rains

The start of the season in this study was modified from the ones defined by Mupangwa et al. (2011) and Stern et al. (2003) and it was defined as the first day after 1 November when the rainfall accumulated over 1 or 2 days is at least 20 mm. Further to this definition, to avoid a false start to the season through long dry spells, a condition that this day (start of the season) should not be followed by 10 consecutive dry days within 21 days of the start date, was set.

2.1.3 Dry Spells

The dry spells were defined as any spells within the season that had 7 days or more without rainfall (less than 2.95 mm) in the season after the 1st of November (Day 124) to the end of the rains which technically occurs by 30 April of each season.

2.1.4 Risks of Dry Spells or Replanting 10, 12 and 15 Days After Planting

The risks of dry spells of 10, 12 and 15 days between 1 November and 15 December (the planting window or possible planting dates) were determined.

2.1.5 Date of the End of the Rains

This was taken as the last day with 10 mm by the end of April, i.e. any day that has 10 mm or more before the end of April. This approach defines a single date for the latest possible end of rains date each year. Hence the dataset gave a set of 44 values in Hwange (1963–2009, with 3 years missing data).

2.1.6 Length of Rains

This was derived as the number of days between the end of the rain and the start of the rains.

2.1.7 Using the El Nino Factor

As already indicated, the data were categorized in El Nino, La Nina and Ordinary years based on information from the International Research Institute for Climate and Society (IRI), (http://portal.iri.columbia.edu/). The weather-induced risk analyses for different events were then conducted and risks of the different weather within climate events in the different El Nino, La Nina or Ordinary seasons were established. For each of the analyses, a test of significance (i.e. one way analysis of variance with the Y variate being the weather aspect of interest for example, number of rain days by factor (El Nino, Ordinary or La Nina) was done to find out if there were significant differences in the El Nino, Ordinary or La Nina seasons.

2.1.8 A Modelling Approach to Rainfall Analyses

The long term daily rainfall was also fitted to simple Markov chain models as outlined by Stern et al. (1982, 2003) and Stern and Cooper (2011). For this study Markov chain models of order one and two were considered. Markov modelling intends to further analyse the rainfall through using a more 'sensitive' and precise method of analysis of the rainfall data that would therefore have a chance of detecting smaller changes in the pattern of rainfall and can therefore be of use in augmenting the current SCF information.

3 Results

3.1 Risk Analysis for Total Rainfall Data

The risk of receiving rainfall in a year of more than 800 mm is low, i.e. 28%, meaning that in only 3 out of 10 years can expect rainfall above 800 mm. The risk of receiving rainfall that is below the mean is relatively low, i.e. 43%, meaning any 6 out of 10 years could receive above 625 mm. The risk of receiving rainfall lower than 400 mm is even lower, at 16%. The risk of receiving rainfall less than 200 mm is non-existent (Table 2).

3.1.1 Risks Associated with Annual Rainfall in El Nino, Normal and La Nina Seasons

There are more Ordinary seasons than El Nino seasons and the least are La Nina seasons (Table 3). However, there are no statistically significant differences in rainfall amounts received in the different season types; El Nino, Ordinary and La Nina years ($p > 0.05$).

3.1.2 Risk Analysis for the Annual Rainfall Total for El Nino, Normal and La Nina Seasons

The risk of receiving rainfall amount that is less than the mean amount of 625.4 mm significantly decreases in La Nina seasons compared to El Nino and Ordinary

Table 2 General descriptive statistics of total annual rainfall and associated risks

Rainfall summary statistics (Rainfall in mm)	
Minimum	211
Maximum	1043
Mean rainfall	625
Std. deviation	212
Count ≤ 200	0
Count ≤ 400	7
Count ≤ 600	19
Count ≤ 800	32

Table 3 Mean rainfall amounts in the different season types

Season type	Number of seasons	Mean rainfall (mm)	Standard deviation
El Nino	11	598.4	193.9
Ordinary	26	630.7	225.7

La Nina	7	648	213

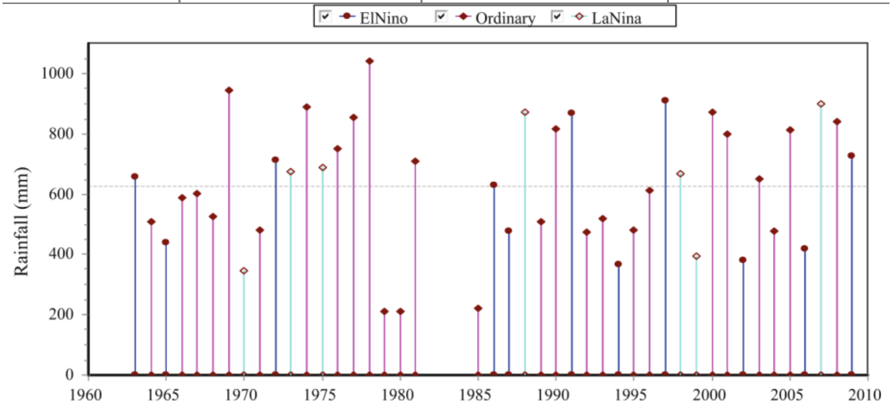

Fig. 1 Occurrence of different season types in comparison to the long term rainfall mean

seasons (Fig. 1). There is a 50% chance that during El Nino seasons rainfall could be below the long term average of 625.4 mm. The risk analysis for the different season types implies that farmers in Hwange may need to take precautionary measures in their farming practices (especially in El Nino and Ordinary seasons that have a high risk of receiving below the mean annual rainfall). However, there is still need for further investigating the in the within season rainfall distribution, which is more important to the farmers than the annual rainfall amount.

3.2 Analysing Number of Rain Days in Different Season Types

The mean number of rain days since 1963–2009 was found to be 36 days (±14.6 days). There are no significant differences in rain days' count for the different season types ($p > 0.05$); 34 days with rain in El Nino seasons; 38 days of rain in Ordinary seasons and 35 days of rain in La Nina seasons. There is about 50% probability of El Nino seasons having less than the mean of 36 rain days. However the risk of less than the mean of 36 rain days in Ordinary and La Nina seasons is relatively low (3 in 10 years or 30%) (Fig. 2).

3.3 Start of Season in Different Season Types

Analysis of the start of the season is very important in semi-arid areas, where seed inputs are expensive and farmers do not really afford replanting. Data analysis revealed that the mean start of the season in Hwange is Day 154 (1 December)

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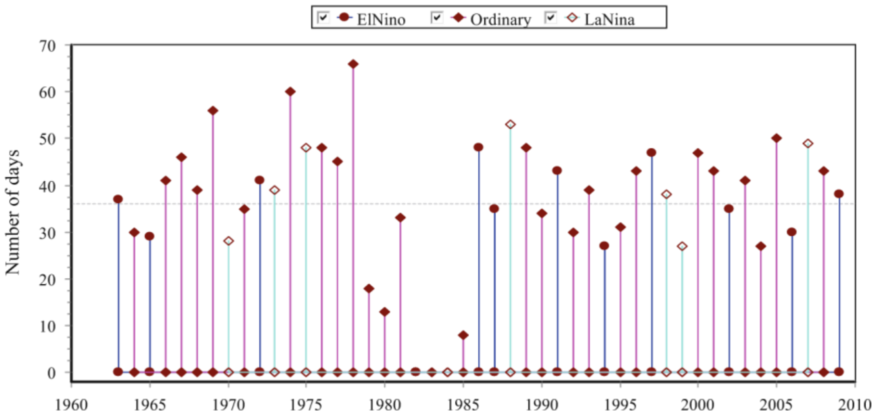

Fig. 2 Number of rain days in the different season types (mean is 36 days)

(±25 days). The earliest start of the season was found to be Day 124 (1 November) and the latest was found to be Day 245 (1 March). There were no significant differences ($p > 0.05$) in the start of seasons for the different season types (El Nino years' mean start day of the season was Day 151–28 November; Ordinary years' was Day 153–30 November; and La Nina was Day 163–10 December).

3.3.1 Risk Analysis of Start of Season Date in El Nino, Normal and La Nina Seasons

Six out of the 11 El Nino seasons had their start of the season dates on earlier dates than the mean date of Day 154 (1 December) (Fig. 3). This means that if farmers in Hwange have to decide when to plant, they could be informed that there is about 50% chance that the season starts before 1 December and they would be advised to stagger the sowing dates (before and after 1 December) in El Nino seasons. Approximately 60% of the Ordinary seasons had their season onset before 1 December hence farmers could be advised to plant before the 1st of December. In La Nina seasons, the advice could be that farmers plant after the 1st of December as the probability that the start of the season is going to be then is high (70%).

3.4 Dry Spells and Their Occurrence in Different Season Types

Dry spells were analysed from 1 November and these were defined as any spells within the season that had 7 consecutive days or more without rainfall after the 1st of November of each season. The mean frequency of dry spells in Hwange is

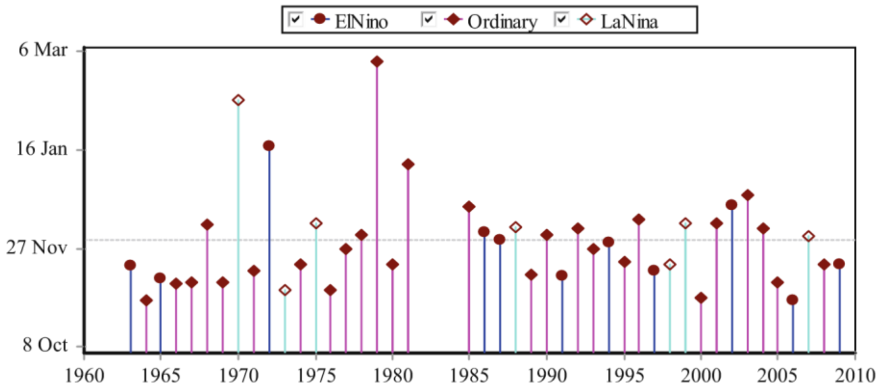

Fig. 3 Dates of the onset of seasons for the different season types (mean is 1 December)

15.4 (±1.5). During El Nino years, the mean frequency of dry spells was found to be 7.7, for Ordinary years, it was 6.5 and in La Nina seasons, it was 6.1. Although there are no statistically significant differences in dry spells in different season types, there is a higher chance (82%) of getting more dry spells in El Nino seasons, i.e. 9 out of the 11 seasons, compared to 46% in Ordinary years and 43% in La Nina seasons.

3.4.1 Risk of Dry Spells Longer Than 10, 12 and 15 Days

Figure 4 gives the proportion of years that had a dry spell longer than 10, 12 or 15 days during the 21 days following planting dates, ranging from the 1st of November to the 15th December, conditional on the initial day being rainy. The top curve show that for a crop planted on 1 November, the risk of a dry spell of 10 days or more, in early November is very high at 60%. The risk of a dry spell of 15-days or more is relatively less, about 30%, or one year in three seasons can farmers encounter a dry spell of more than 15 days in early November. By planting at the end of November, the risk of a 10-day dry spell has considerably decreased to 30%, and shortly after the risk has reached a plateau in Hwange. In terms of extension advice, someone wishing to minimize their risk of dry spells could be advised to wait if they were considering planting in early November, and they could plant in mid-November because the risk does not decrease further, but the chance of a damaging dry spell later in the season might increase. Also, the growing of drought tolerant crops that can withstand a 15 day dry spell after date of planting is recommended. Because of the high risk of dry spells in early November and December there is a high chance of having to replant in the semi-arid areas.

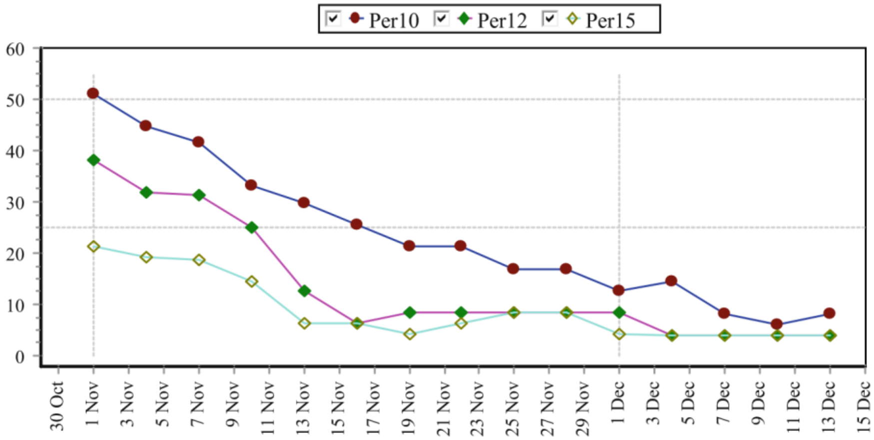

Fig. 4 Risk of dry spells (10, 12 and 15 days)

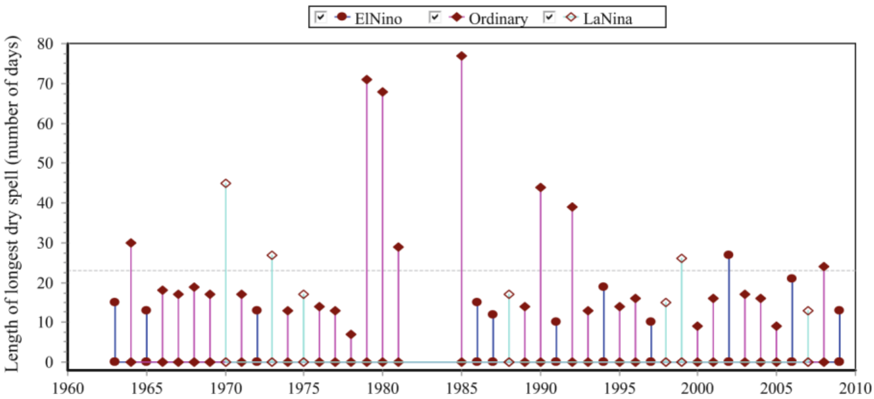

Fig. 5 Length of longest dry spell in different season types (mean is 23 days)

3.4.2 Mean Length of the Longest Dry Spells in El Nino, Normal and La Nina Seasons

The study finds that the length of the longest dry spells is statistically different for the different season types in Hwange district ($p < 0.05$), being longest in Ordinary seasons (26 days) compared to El Nino (15 days) and La Nina seasons (23 days). The risk of very long dry spells in El Nino seasons is not very high (10%), although moisture conservation strategies are necessary (Fig. 5).

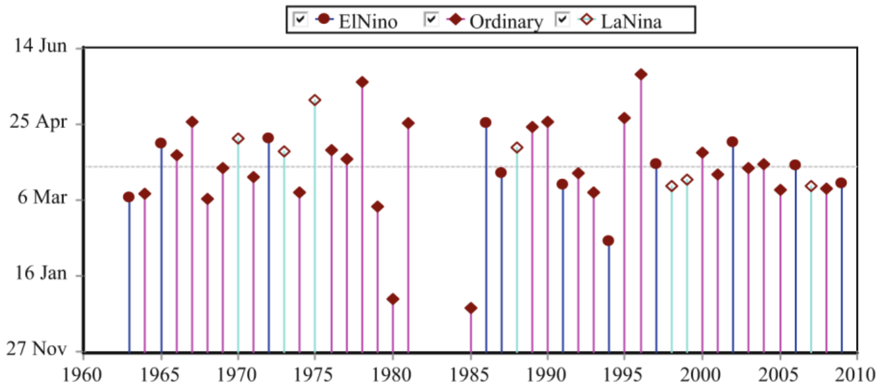

Fig. 6 End of rains in the different season types (mean is 28 March)

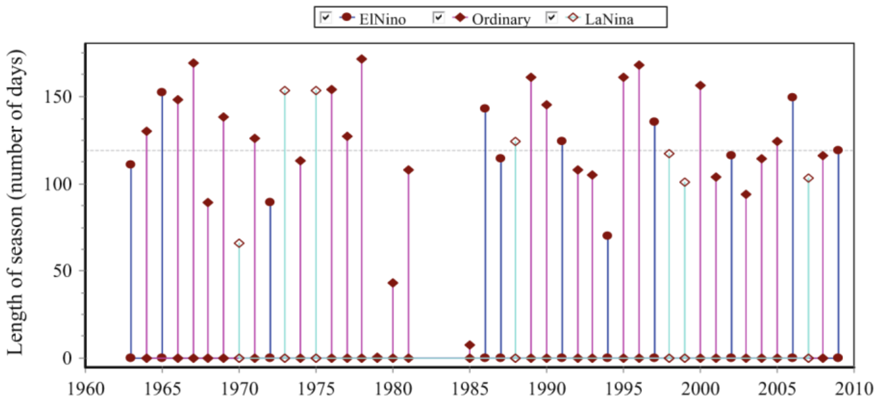

Fig. 7 Season length in El Nino years (mean is 119 days)

3.5 End of the Rains and Its Occurrence in Different Season Types

The mean last day of the season is Day 272; the 28th of March. The latest day of the end of the season recorded was Day 333 (28th May) and the earliest was Day 179 (26th December). There are no statistically significant differences in the end of season dates in different season types ($p > 0.05$). In the El Nino and Ordinary seasons, the mean end of rains is on Day 271 or 27th March, with the mean end of rains in La Nina seasons being on Day 279 (4th April). However, there is a high risk that the rainfall cessation dates across the different season types occur before the mean date of the 28th March (Day 272) (60% in El Nino and Ordinary seasons and 40% in La Nina seasons) (Fig. 6).

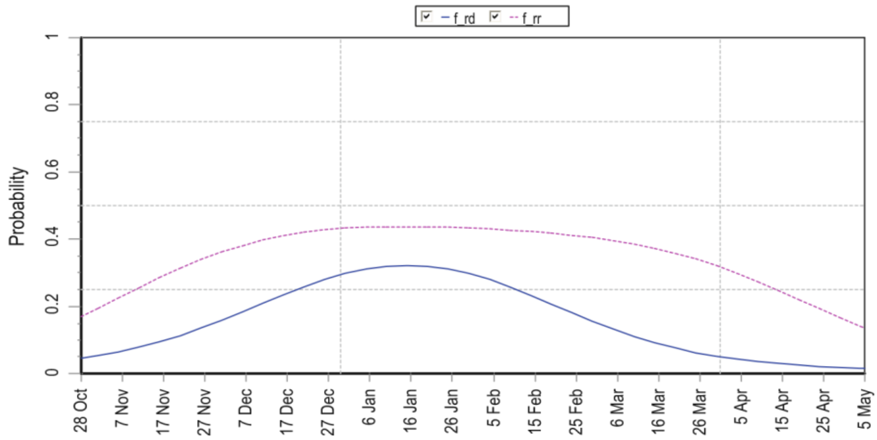

Fig. 8 First order chance of rain

3.6 Length of the Season (Season Length in El Nino, Normal and La Nina Seasons)

The mean season length was found to be 119 days (±38). There are no significant differences in the season lengths for the different season types ($p > 0.05$); 120 days in El Nino years, 114 and 107 days in Ordinary and La Nina years respectively. There is a high risk that the season length across the different season types is less than the mean length of 119 days (Figs. 7 and 8).

3.7 A Modelling Approach

The results in the Markov modelling of the chance of rain in Hwange in the First-order-Markov chain are presented in Fig. 8. The top curve in Fig. 8 is the chance of rain when the previous day also had rain (f_rr; representing the chance of rain when the previous day had rain). This is therefore the chance that a rainy spell continues for a further day. In January this is about 0.45, i.e. about 45% of rainy days continued and had rain on the next day. The chance of rain after a rain day earlier in the season (in November) is low, at 0.25, meaning only 25% of the days had rain on the next day. The bottom curve in Fig. 8 is the chance of a rainy day if yesterday had no rain, i.e. the chance of rain after a single dry day (f_rd; representing the chance of rain when the previous day had rain). The results indicate that the chance of a rainy day after a dry day is low during the peak of the season, in January, at 0.25, i.e. 25% of the days have rain after a dry day.

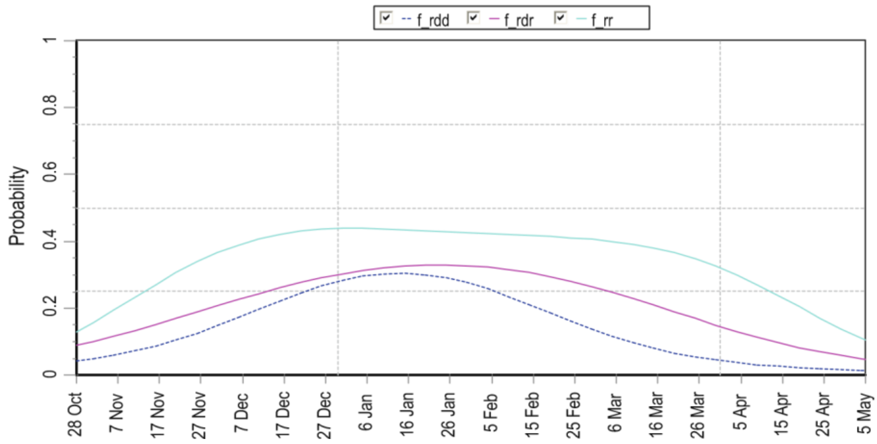

Fig. 9 Second order chance of rain

3.7.1 Second-Order Markov Chains

The top curve in Fig. 9 is the chance of rain when the previous two days also had rain (f_rr). This is therefore the chance that a rainy spell continues for a further day. The chance of rain after 2 rain days is highest in December, and this is over 0.5, i.e. about half of the rainy days continued and had rain on the next day. The middle curve in Fig. 9 shows the chance of rain after a dry spell is in between rain days (f_rdr). The chance of rains when a dry day is sandwiched between rain days is lower than when the previous 2 days were raining. Lastly, the bottom curve in Fig. 9 shows the chance of rain after a dry spell of two or more days. This is therefore the chance that a dry spell (of longer than one day) is broken. This is a smaller probability than the chance of a rain spell continuing, rising to about 0.2 or 20% in January. The chance of rain ‘returning’ is greater after just a single dry day, than if a dry spell has been in experienced for two days or more.

4 Discussion

The analysis of the daily rainfall data was done so as to investigate how it could help farmers (together with the SCF). This type of analyses, when used with SCF will hopefully be useful to farmers, aiding them in making ex-ante agricultural decisions such as what crop varieties to plant, when to plant, weed and apply fertilisers, as well as going a long way in addressing some of the constraints to using SCF.

The information on season length is vital for farmers so that they can choose crops and varieties that mature within the season, whilst moisture is still available.
The rainfall onset and cessation dates are of use to farmers as they help determine the planting time and early planting is usually encouraged to ensure successful

establishment and early survival of the crop, as well as ensuring that harvesting problems do not occur. It is of importance that farmers get to know the onset dates of any given season as these help farmers plan accordingly, to secure inputs on time so that they are not "surprised" by the rains. Since the characterization of the rainfall finds that it is possible to estimate risk for El Nino, Ordinary and La Nina seasons, these could be used together with the SCF to inform farmers of when the season is likely to start.

Crop and livestock management practices are encouraged in the semi-arid areas, irrespective of season types. Staggering of planting irrespective of season types (El Nino, Ordinary or La Nina) is advisable to farmers in the semi-arid areas due to the high risk associated with the start of the rainy season. It would also be wise for farmers in the semi-arid areas to diversify and grow a variety of cereal crops to spread the risk associated with the rainfall distribution in these areas. However as Stern and Cooper (2011) rightly point out, the start of the season is also influenced by several factors such as the farmers' degree of risk aversion, the frequency and amounts of early rainfall events as well as the texture of their soil which will determine how deep any sequence of rainfall events will penetrate and be stored in the soil.

Although the risk of getting a 15 day dry spell was found to be low, it is recommended that farmers grow crops (or varieties) that could withstand a 15 day dry spell. The growing of drought tolerant crops is one decision that farmers could take or the use of simple moisture conservation measures such as soil surface mulching could also help increase the risk of successful crop establishment. Due to the high risk of encountering 10 days long dry spells, the farmers would be advised to implement soil moisture conservation techniques irrespective of season quality. There is also considerable advantage to planting early in semi-arid areas, but this opportunity has often been offset because early planting might have a higher risk of being followed by a long dry spell resulting in seedling death and the need to replant. Because of the high risk of dry spells in early November and December there is a high chance of having to replant in the semi-arid areas and information on risks of dry spells at the start of the season could really assist poor smallholders. The economic cost of replanting is high, so if the planting window has been characterized and is known, farmers could make informed decisions on when to plant. The choice of crop could also be determined by knowledge on the frequency of dry spells and the risks of encountering dry spells after the onset of the rains.

Further rainfall analysis using Markov modelling helps in detecting smaller changes in the pattern of rainfall. Such type of analysis will be beneficial to farmers so that they can make decisions especially on when to plant, apply dressing fertilizer and when to weed. Cooper et al. (2006) have indicated that farmers may be risk averse in using fertility amendments, mainly because of fear that if they do not have information on how rains would fare might lead to inappropriate application

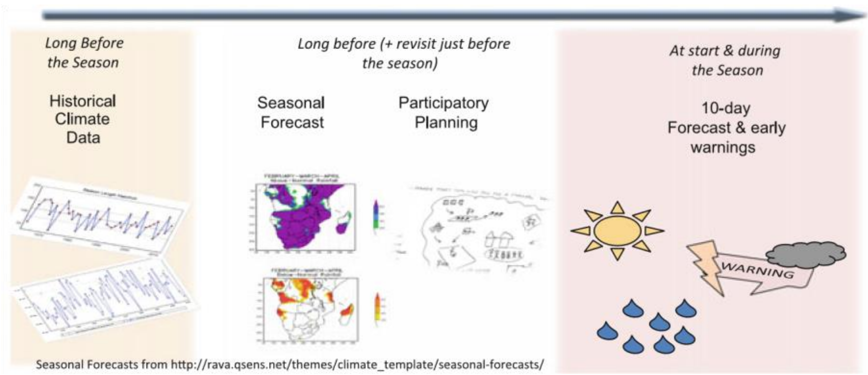

Fig. 10 A schematic plan for introducing the use of weather within climate information with SCF and weather related information to smallholders. Source Adapted from CCAFS (2012)

rates and times. However if the chance of rain in a given season has been determined, it makes it possible for better decision making in terms of when farmers could apply the fertility amendments and how much could be applied.

5 Conclusions and Recommendations

The results from the study do help in answering some of the farmers' concerns in terms of rainfall distribution within the seasons, and helps in showing risks associated with different season types. There are difficult risks in the semi-arid areas of Zimbabwe in terms of dry spells, and since the amount of rainfall cannot be influenced, technologies that enhance water use efficiency could also be one of the major areas of research that should be integrated into the semi-arid farmers' existing strategies to cope with climate variability and ultimately change.

Lastly, one key question that also needs to be answered is how best the characterized climate information could be introduced to the farmers to help them make crop management decisions. Answers to this question lie within suggestions that facilitating smallholders to make better plans and decisions and utilise climate and weather information could be done through some participatory methods (CCAFS 2012). Enhanced communication of climate-related information is an option that could assist in adaptation strategies and timely decision-making by farmers. Packaging SCF with historic climate data as well as bringing in the shorter range forecasts, together with the experience of the season as it develops is a way in which value could be added to climate information dissemination (Fig. 10).

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