AN ANALYSIS OF LONG-TERM DAILY RAINFALL DATA FROM GROOTFONTEIN, 1916 TO 2008

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INTRODUCTION

In the Karoo, rainfall is the primary driver of primary production, and hence of available fodder. Rainfall during the late summer months is higher than during other times of the year, but daily and seasonal rainfall are highly variable. The consequence that is of agricultural importance here is that there are frequent dry spells and dry seasons, during which animal production is low, sometimes to the extent where animals die or must be sold.

Dry episodes are typically referred to as 'droughts'. A drought may be described as a period of unusually dry weather. Because rainfall can be measured, this allows numerical definitions of drought, such as 'accumulated rainfall, over a particular period, lower than what one would expect 90 % of the time'. Because drought is a period of *unusually* low rainfall, an absence of rain during the winter months would be unlikely to constitute a drought, because dry winters are the norm. In contrast, if a drought began in midsummer, and was relieved through good rains only during the following summer, it would not be sensible to say that there was no drought during the intermediate wintertime. So while many people, especially farmers, may have a good intuitive feeling for what constitutes a drought, defining a drought purely from rainfall records can be more difficult.

Animal production suffers during a drought, not usually because of a lack of water, but owing to a lack of forage, as plants use water to produce edible material. Therefore, rain that falls today could be available for animals to eat in several months' time. Accordingly, a prolonged dry spell may not actually be a drought if there are sufficient forage resources available. Therefore, when defining a drought within the context of livestock production, it is necessary to accommodate the residual amount of available forage, which in turn is a function of previous rainfall. However, rain that fell e.g. a year ago, is only going to have a fraction of the current value of rain that fell e.g. a week ago, because much of the vegetation produced by the earlier rain would likely have been eaten, or senesced.

During the 1980's a conceptual model for defining a drought was developed at Dohne Research Station (Danckwerts, 2006, JE Danckwerts Pers. Comm. Saxfold Park, Adelaide, 5760). When the cumulative total of the past 12 months' rain, discounted according to the 'age' of the rain, dipped below the corresponding long-term cumulative total of unexpectedly-dry years (defined as the 10th percentile), then a drought had started. The end of the drought was when the cumulative total broke though the cumulative total of 'normal' years (50th percentile). This means that droughts began when food availability was low, and ended only after enough rain had fallen to bring food reserves back to normal. The predictions from the model corresponded well with what farmers qualitatively defined as a drought. In this paper, this model is used for defining periods of drought (Figure 1).

The purpose of this report is to describe a variety of parameters of the rainfall data that have been collected at Grootfontein since 1916. As such, this is a description of a population, and any trends that the data reveal may not be in any way indicative of longer-term trends or changes.

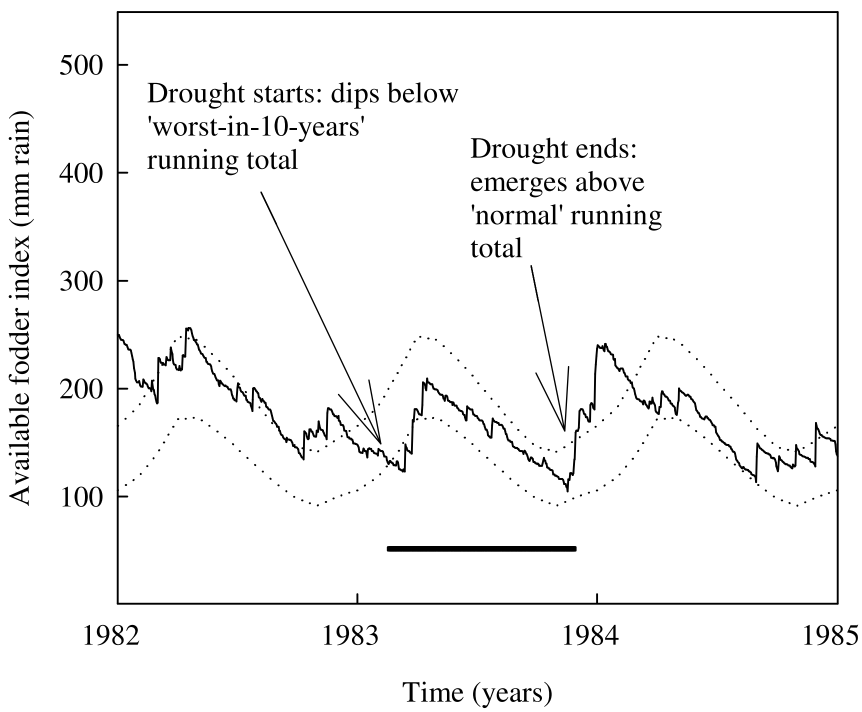


Figure 1. Illustration of how the drought model is used to define the beginning and end of a drought. The upper dotted line is the 12-month cumulative running total of average normal (50th percentile) rainfall discounted linearly according to time since present (current month = 100%, first month = 8.3%, or 1/12). The lower dotted line is the 12-month cumulative running total of average low (10th percentile) rainfall discounted similarly. The solid line reflects the cumulative running total of current rainfall, discounted according to time since present. The horizontal black line reflects the period of the drought.

METHODS

Daily rainfall data from Grootfontein from 1916 to 2008 were obtained from the South African Weather Service and the Agricultural Research Council. Data were arranged into a single table headed by a range of columns containing information such as date, day, month, year, rainfall, location, and various others. Each row was a record of a single day's rainfall. Data were managed using Pivot Tables in Microsoft Excel.

Rainfall in most of South Africa is seasonal, with most rain at Grootfontein falling in summer. Therefore, rainfall data were examined on a seasonal basis (1 July – 30 June) rather than on a calendar basis (1 January – 31 December). For example, the 1984 season includes data from 1 July 1984 to 30 June 1985. To calculate further rainfall parameters, data were manipulated arithmetically within additional columns in the table (e.g. whether a day had >20 mm of rain). Seasons with missing data were omitted (1915, 1998 – 2003, and 2008). Statistical analyses were performed in Statgraphics (2006) and SigmaPlot (2001).

RESULTS

Seasonal rainfall

Average seasonal rainfall was 370.2 mm, ranging from 153.8 mm in 1969 to 688.6 mm in 1973. Seasonal rainfall increased slightly over the period, but this trend was not significant ($F_{1,84} = 2.13$, $P = 0.15$) and the linear regression explained very little of the variation ($R^2_{adj} = 1.5\%$). Average rainfall before 1990 was 364.4 mm, and since 1990 was 405.8 mm, but these populations are not statistically different ($t = 1.15$; $P = 0.25$).

Seventy nine percent (68 of 86 years) of the values were between 200 and 500 mm, and 93% between 200 and 600 mm (Figure 2). Fifty eight percent of years had below-average rainfall, while 55% of years were 'normal' or 'good' (defined as being greater than 90% of average rainfall).

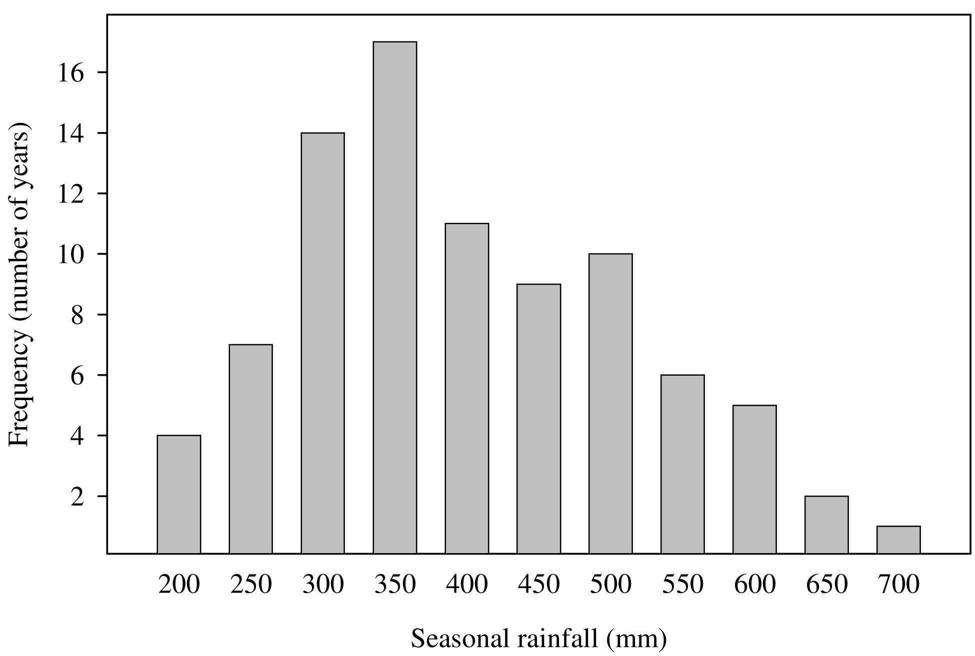


Figure 2. Frequency histogram of seasonal rainfall at Grootfontein.

Monthly rainfall

Monthly rainfall reflected a unimodal distribution typical of summer rainfall areas, peaking in March with an average of 63.8 mm from a minimum in June with an average of 10.1 mm (Figure 3). March is usually the last month when good rains can be expected; the average for April is approximately half that of the preceding month at 22.7 mm. Recent (1990 – 2008) and older (1916-1989) seasonal rainfall distributions (Figure 4) indicate that rainfall in December, January and February since 1990 was higher than before.

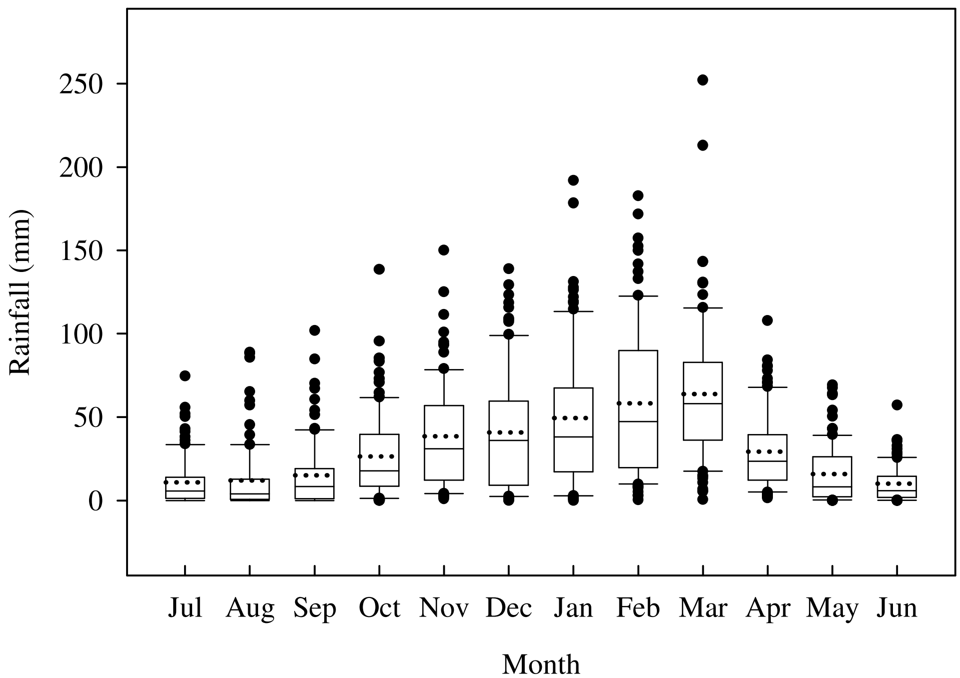


Figure 3. Monthly rainfall at Grootfontein. Mean monthly rainfall is reflected by dotted lines. Boxes include the central 50% of all values, while lower and upper bars demarcate the 10th and 90th percentiles respectively. The solid line within the box is the median. Dots are outliers.

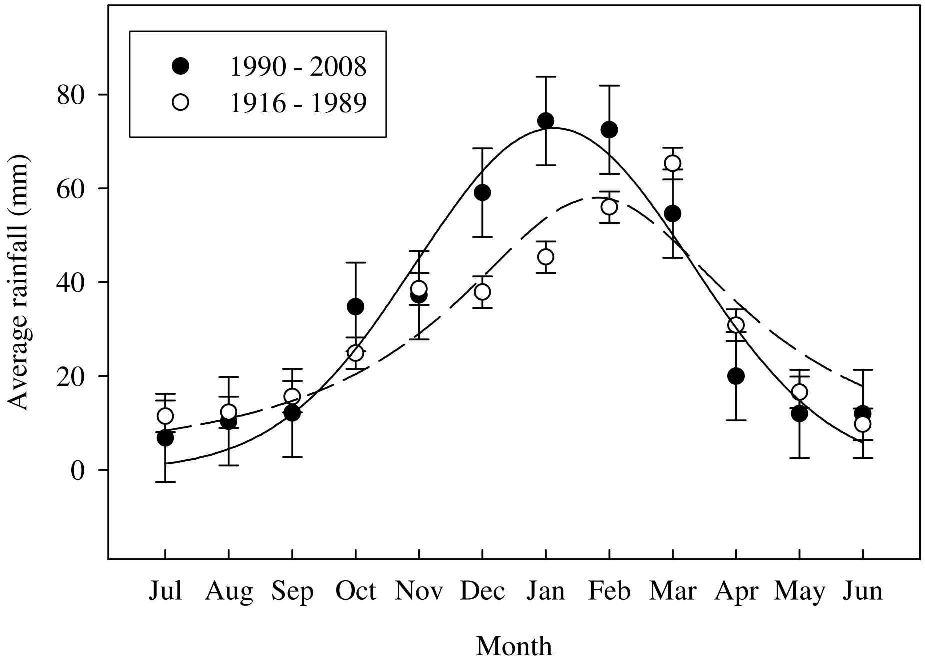


Figure 4. Recent (1990-2008) and earlier (1916-1989) average monthly rainfall at Grootfontein. Lines are Gaussian regressions for 1990-2008 (solid) and 1916-1989 (dashed; all parameters are significant). Bars are standard errors.

First rains of the season

All seasons since 1916 had at least 10 mm of rain on a single day, and 96% of years had at least 20 mm. Approximately three-quarters of the seasons had at least 30 mm on one day, while in only one-quarter of the years did it rain as much as 50 mm on one day. Light rains (<10 mm) fell by November in 75% of seasons, while larger rains (20-30 mm) usually fall between October and February. Heavy rains (50 mm) occur seldom and usually between January and March (Figure 5).

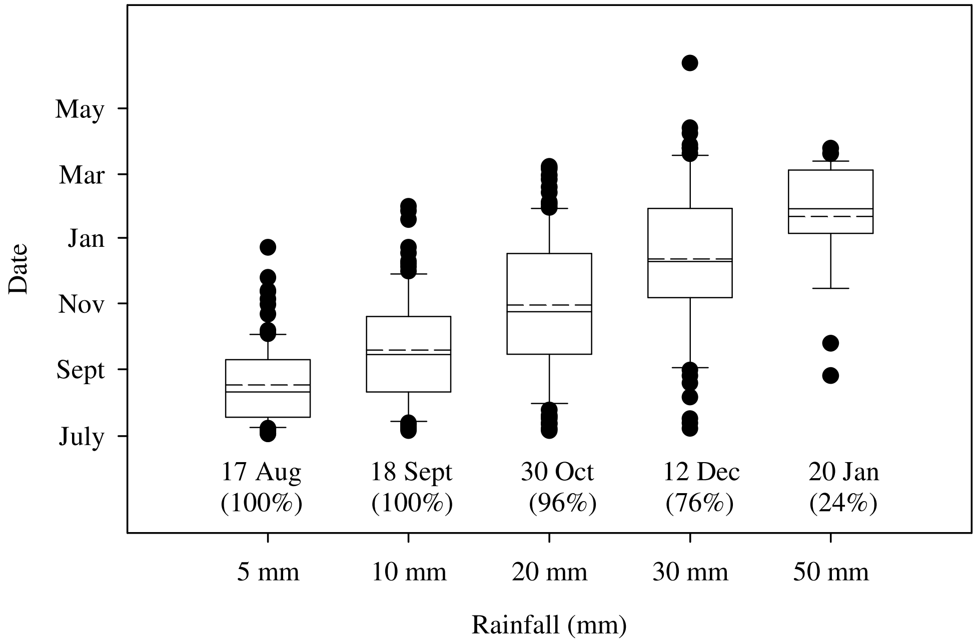


Figure 5. Date of first rainfall for rains of different magnitudes. Dates above the x-axis enumerate the mean (dashed line) values, while parenthesised values are the proportion of years from 1916-2008 for which an event of that size occurred. Boxes surround the central 50% of values; the horizontal line within the boxes is the median; the upper and lower bars indicate the 90^{th} and 10^{th} percentiles, respectively, and dots are outliers.

Dry spells

The longest period without any rain was a period of 104 days during the winter of 1958, from 1 June to 12 September. The longest spell without any large rainfalls (>20 mm in a single day) was from 24 January 2002 to 20 November 2003 – a period of 613 days. However, small rainfalls accrued 385 mm. The longest dry spell without any significant cumulated rainfall (20 mm cumulative rainfall over a 5-day period) was from 7 Oct 1992 to 15 Oct 1993, a period of 367 days, when only 148 mm fell. This was preceded by a dry spell of 186 days (starting at the end of March 1992) during which there was 43 mm of rain. The combined periods spanned one and a half years, during which 213 mm of rain fell, at an equivalent rate of 123 mm per year, which is below the long-term seasonal minimum of 154 mm in 1969.

The maximum dry period per year over time (1916-2008) decreased slightly, but the relation was not significant ($F_{1,85}$ = 2.3; P = 0.13) and allowed almost no predictive capability (R^2_{adj} = 0.015).

Drought

Droughts have punctuated the climate at Grootfontein throughout the period under review (Figure 6 and Figure 7). Over 90% of droughts are shorter than 14 months, 50% are shorter than 7 months, and 25% shorter than 3 months. There have been two unprecedentedly long droughts – the first started in 1926 and continued for nearly 3½ years, and the other started in 1968 and continued for over 2½ years.

There is no obvious relation between droughts and years of good rainfall (Figure 7). For example, droughts in the 1950's occurred between years of average rain, while the drought of 1996 was between two very wet seasons.

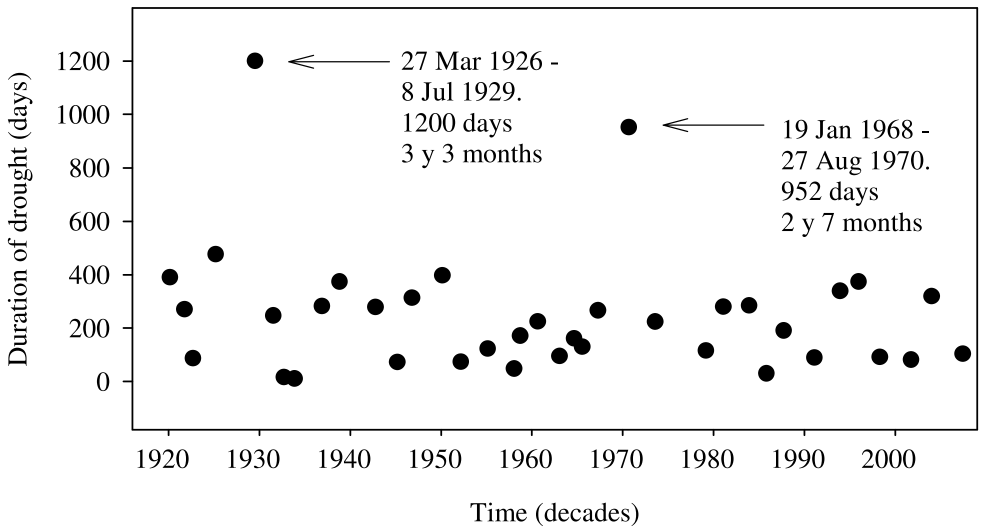
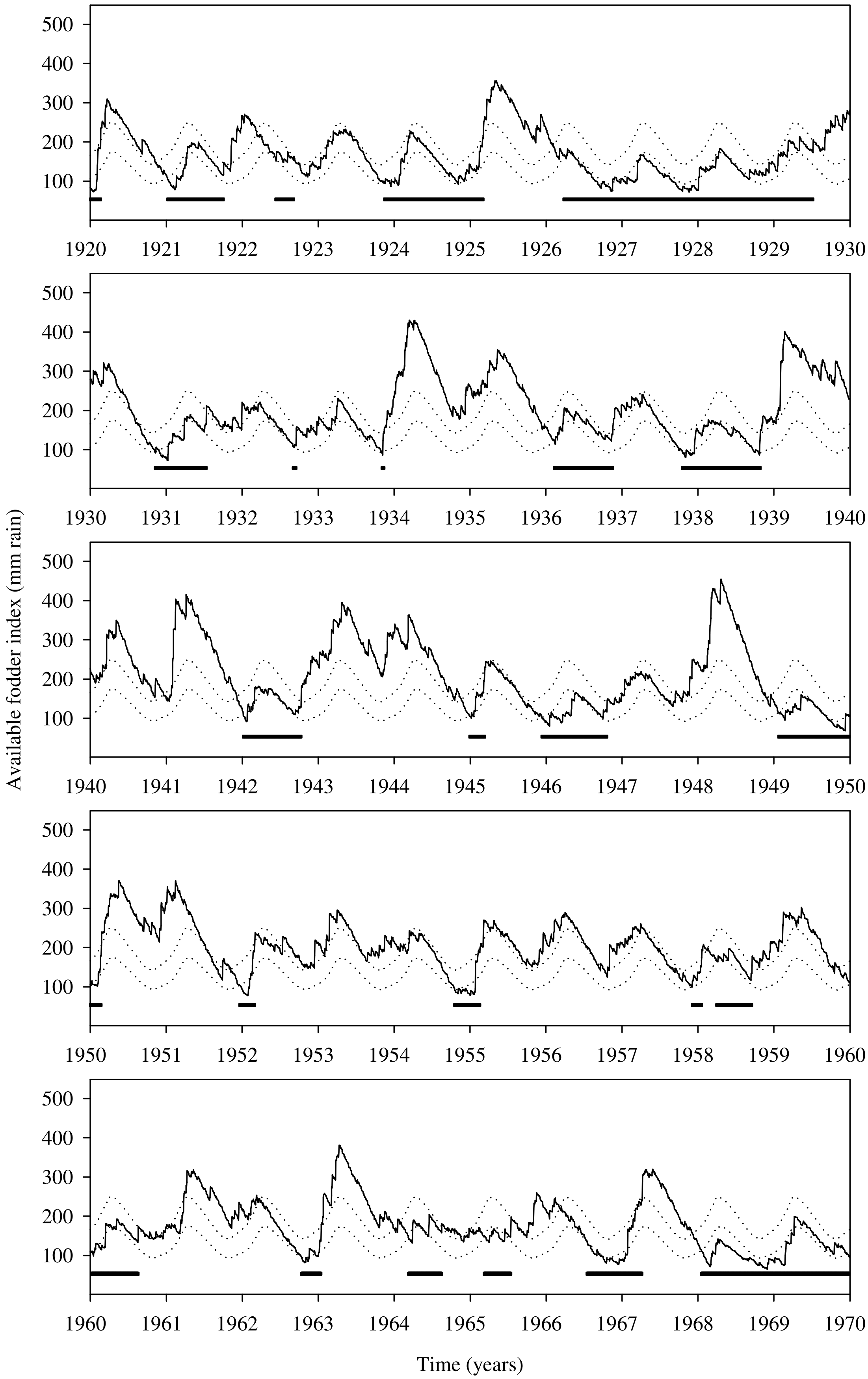


Figure 6. The duration of droughts at Grootfontein from 1916 to 2008.



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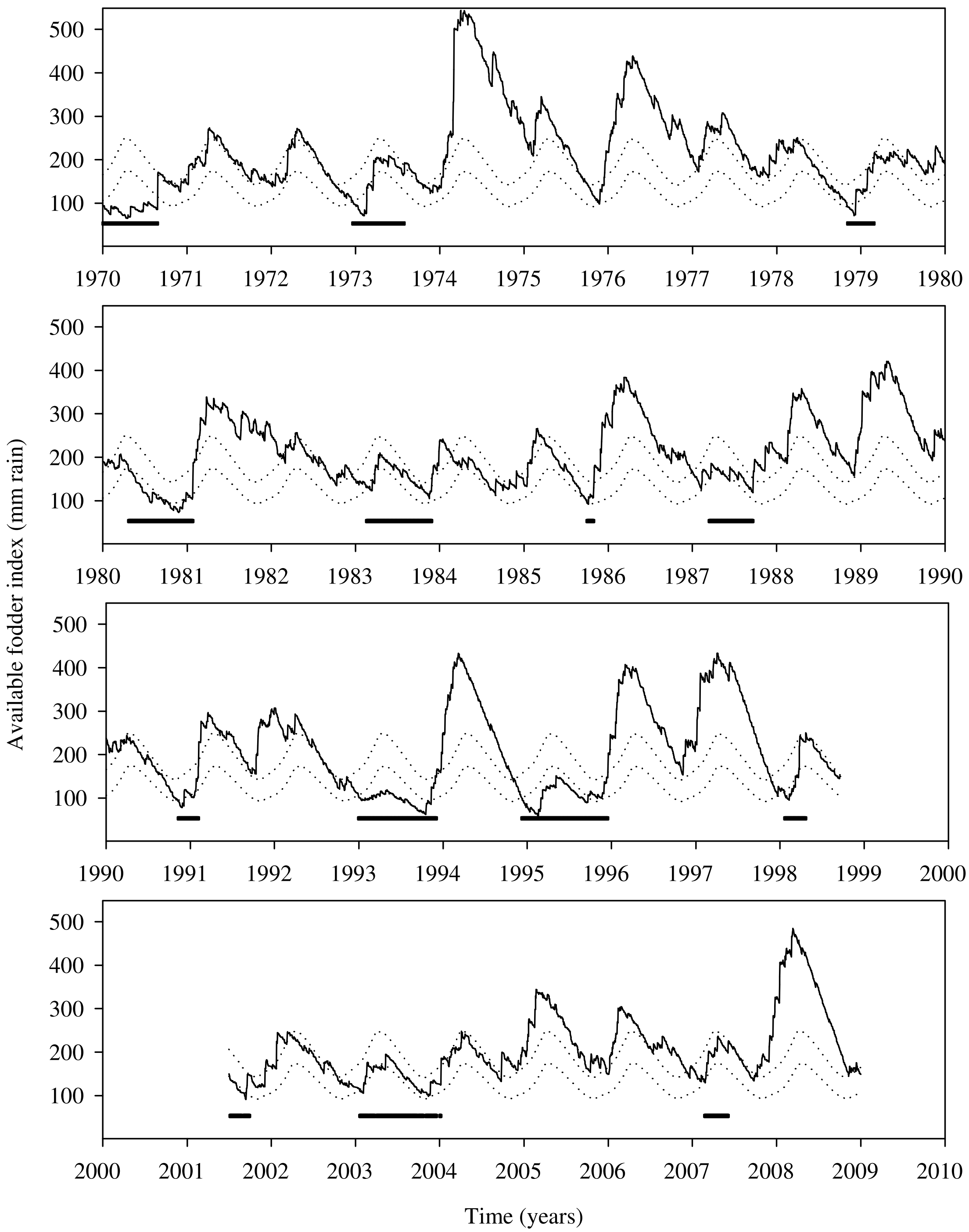

Figure 7. Twelve-month cumulative running total (upper dotted line) of average normal (50th percentile) rainfall discounted linearly according to time since present (current month = 100%, first month = 8.3%, or 1/12) and 12-month cumulative running total (lower dotted line) of average low (10th percentile) rainfall discounted similarly. The solid line reflects the cumulative running total of current rainfall, discounted according to time since present. The horizontal black line reflects the period of the drought.

Large rainfall events

The largest single-day rainfall was 93 mm on 3 March 1974. This signalled the end of the wettest short-term rainy spell, when 248 mm fell over a 5 day period. (As a comparison, 425 mm fell in 2 days in the Laingsburg district in 1981, leading to the devastating floods (Anon 2009). During that time, Middelburg experienced 80 mm over 2 days.)

The mean and median maximum single-day rainfall for each month for early (1916 to 1989) and recent (1990 to 2008) years did not differ, indicating that the magnitude of individual rainfalls did not change over time. The same holds for annual maxima.

The largest single-day rainfall of a season contributes between 5 and 15% (mean = 11%) of the total season's rainfall, and the largest two rainfalls between 10 and 33% (mean = 20%). For 50% of seasons, 50% of the total seasonal rainfall derives from the highest 6 to 9 individual rainfall events (Figure 8).

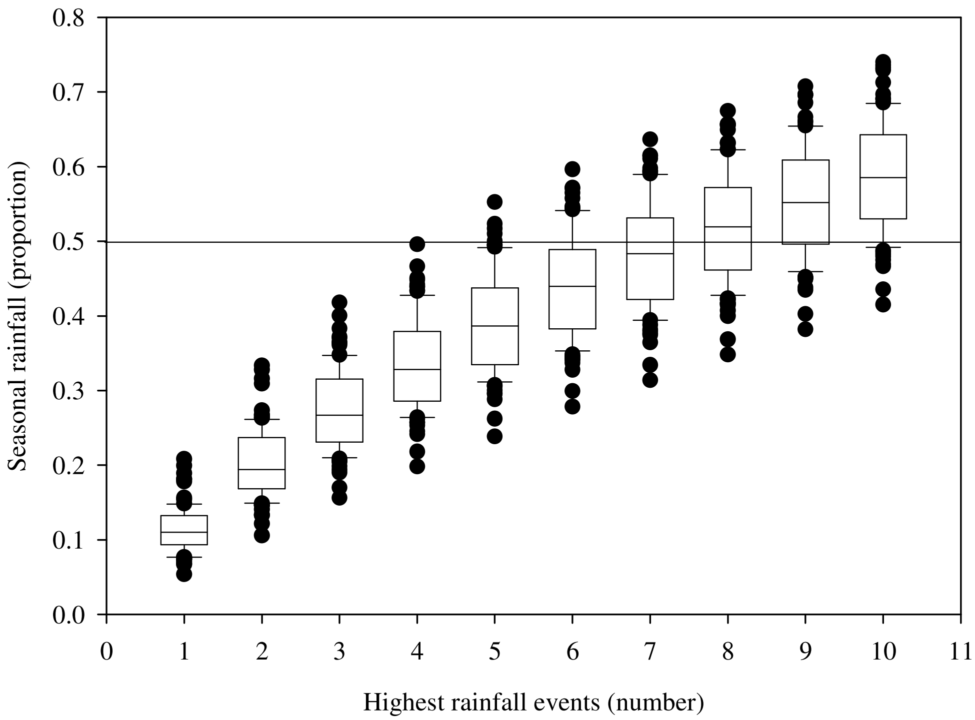

Figure 8. Proportion of total seasonal rainfall derived from the number of highest-ranked individual events.

Effective rainfall

'Effective rainfall' is the term given to rain that is likely to infiltrate soil, become available to plants, and allow plants to produce an agriculturally-meaningful amount of forage. Here, effective rainfall is defined as being a single day's rainfall greater than 5 mm (less than this is unlikely to produce significant plant growth) and less than 40 mm (more than this is likely to result in runoff).

Effective rainfall increased slightly over the period 1916-2008, but the trend was not significant ($F_{1,84} = 2.3$; $P = 0.13$), and the linear regression captured very little of the variation in the data ($R^2_{adj} = 1.53\%$). Monthly values for the months May – October were similar to the average total monthly rainfall, and were lower than average total monthly rainfall for the remaining months (Figure 9). Effective rainfall mimicked total rainfall regarding each month's position in relation to other months. Average effective rainfall for January was similar to that of November and December, while the corresponding average total value was much higher.

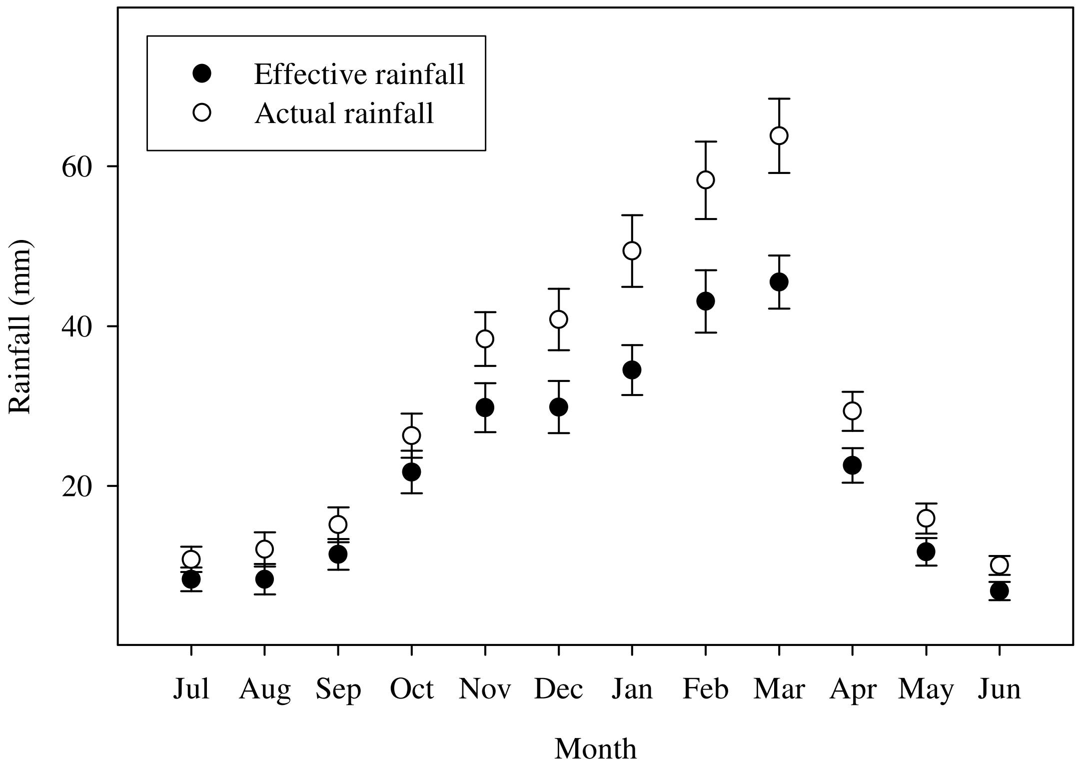

Figure 9. Average effective monthly rainfall (5 mm < single day's rainfall < 40 mm) and average total monthly rainfall from 1916 to 2008 at Grootfontein. Bars are standard errors.

Interesting facts

- Rain has fallen on nine Christmas Days, the most being 34 mm in 1933, followed by 20 mm in 2007.
- Drought spanned the entire year in 1924 and 1928.
- The 1920s experienced the most drought (2084 days), and the 1950s the least (470 days). However, the 1950s are commonly regarded as being a dry decade, owing to the absence of any particularly good years,

DISCUSSION

Rainfall over the period from 1916-2008 was, as expected, highly variable, but showed no significant trends that could be interpreted as being important within the context of climate change. The positively-skewed seasonal rainfall distribution is typical of dry areas in general.

Monthly values confirmed that the area receives mid- to late-summer rain. The three-month period from December to February has experienced higher rainfall in recent years, meaning that since 1990 this period has recently been wetter, and the season has been earlier. Effective rainfall from December to February is considerably lower than the actual rainfall – this implies that the value of the high rainfall during the midsummer months may be slightly misleading, because much of it is probably lost as runoff.

Droughts continue to be a feature of the local climate, but there is no evidence from these results that they are becoming worse – indeed, the two longest droughts during the period under review occurred at the ends of the 1920's and the 1960's.

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