Secular changes in South African rainfall: 1880 to 1972

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SUMMARY

Analysis of time series for 157 stations with records covering the period 1910–1972 and for fewer stations with records extending back to 1880 suggests that the commonly held view that South Africa, as a whole, is undergoing progressive desiccation must be questioned. Instead the data suggest the specific regional occurrence of weak (but nonetheless readily discernible) oscillations of 16–20 and 10–12 years, the ubiquity of 3–4 year fluctuations and the spatially distinctive occurrence of a quasi-biennial oscillation.

1. INTRODUCTION

That South Africa is drying up or alternatively is undergoing some sort of cyclic rainfall variation has been debated for many years. The observations of early explorers and missionaries suggest that in former times periods of heavy rainfall and expanses of standing water occurred in areas now semi-arid (Moffat 1842; Livingstone 1857). Wilson (1865) was firmly of the belief that the Kalahari had become drier. In analysing meteorological records for 10 stations in Bechuanaland, Wallis (1935) came to the same conclusion. In a general review Barber (1910) suggested South Africa as a whole was drying up, a view that was widely held by the public, both lay and informed (Agric. J. Un. S. Afr. 1913), but not by the Union Parliament Senate Select Committee on Droughts, Rainfall and Soil Erosion appointed at the time (Union of S.A. 1914). None the less, in 1918 Schwarz reiterated the idea that South Africa as a whole was undergoing progressive desiccation (Schwarz 1919). His ideas were criticized by Cox (1926), Schumann and Thompson (1934) and Thompson (1936). The fundamental difficulty of refuting the assertion of desiccation lay in the limited length of record available for analysis.

Ideas concerning the possible cyclic nature of rainfall over South Africa were put forward as early as 1888 (Hutchins 1888; Tripp 1888). Using records extending back to the middle of the nineteenth century, Nevill (1908) found evidence for an 18-year periodicity in the rainfall of Natal. Cox (1925) found some evidence for a 14-year period for Cape Town over an 83-year set of observations. This was later refuted by Loor (1948) in the analysis of a 100-year record for the city. Periodicities in South West African rainfall for the interval 1771–1925 were analysed by van Reenen (1925). Likewise Peres (1930) analysed the available record for Lourenco Marques and found evidence of a 20-year periodicity.

More recently, Vorster (1957) has concluded from linear regression analysis of data for 17 stations in the south-western Cape Province that a general decline of rainfall occurred between 1881 and 1950. This finding was not corroborated by Brook and Mametse (1969), who did, however, support the spatial dependence of regression coefficients suggested by Hofmeyr and Schulze (1963). The latest work on rainfall fluctuations suggests the reality of the 18–20 year oscillation reported by Nevill and Peres and shows the distinctive regional distribution of its occurrence (Tyson 1971, 1972; Keen 1971).

In this paper the temporal and spatial oscillations of annual rainfall are examined for the period 1910–1972 at 157 stations in South Africa and for a decreasing number of stations with records extending back to 1880 (see Fig. 1 for location of stations). The years 1910–1972 are taken as a reference period over which the spatial organization of specific
oscillations will be assessed. On the basis of available data it will be shown that it is difficult to conclude that South Africa as a whole is undergoing progressive desiccation. Instead it will be shown that since the inception of meteorological records a weak 16–20 year oscillation has occurred over most of the north-eastern summer rainfall parts of the country. In addition, the occurrence of a weaker 10–12 year fluctuation in the southern Cape coastal and adjacent inland areas experiencing an all-seasons rainfall regime will be suggested.

### 2. Circulation and Precipitation Patterns

Owing to its location between 22° and 35°S, much of South Africa is dominated by anticyclonic circulation patterns and attendant subsidence (Fig. 1). This is particularly so in winter when the frequency of anticyclonic systems exceeds 70% (Vowinckel 1956). In summer, rainfall occurs over north-eastern South Africa as a result of organized thunderstorm activity, inland penetration of cyclonic disturbances, and the large-scale advection of air from the north-east, east and south-east. During this season the south-western Cape receives little rain. In contrast with summer months, when cyclonic activity is most active
sout of the sub-continent, winter cyclogenesis may occur in sub-tropical latitudes (Taljaard, Schmidt and van Loon 1961; Taljaard and van Loon 1962). Travelling cyclonic disturbances produce the winter rainfall of the south-western Cape. Only along the southern Cape coastal belt is rainfall experienced in all seasons (Fig. 1). The net result of the seasonal and daily circulation patterns is to produce a mean annual distribution of rainfall with a characteristic gradient from the wetter east coast to the desert west coast (Fig. 1).

3. METHODS OF ANALYSIS

Annual rainfall series have been analysed for trend, serial correlation and spectral characteristics using the following procedures.

(a) Trend

The presence or absence of trend (either linear or non-linear) in individual rainfall series has been determined using the Mann–Kendall rank statistic $\tau$ (Kendall and Stuart 1961). This is defined as $\tau = (4\sum n_i/N(N - 1)) - 1$, where $n_i$ is the number of values larger than the ith value in the series subsequent to its position in the series of $N$ values. The statistic approximates closely to a normal distribution for $N > 10$, and can be used to assess the significance of a trend by comparison with the values $\tau_\alpha = \pm t_\alpha \sqrt{(4N + 10)/\sqrt{9N(N-1)}}$, where $t_\alpha$ is the desired probability level of the normal distribution for a two-tailed test.

Linear trend has been determined by conventional least squares regression analysis and the significance of regression coefficients tested using a two-tailed $t$-test. In both types of trend determination the 5% level of significance has been taken for the rejection of the null hypothesis of no trend for individual sets of data.

(b) Serial correlation

Serial correlations $r(k)$ have been determined from

$$r(k) = \frac{1}{N} \sum_{i=1}^{N-k} x(t) \cdot x(t+k)/s_x^2$$

where $X(t) = X(t) - \overline{X}$, $x(t) = (X(t) + k) - \overline{X}$, $k$ is the lag number and $s_x^2$ is the variance of the series (Otnes 1972).

(c) Serial analysis

Estimates of smoothed spectral density have been determined from stationary raw data using

$$s(f) = 2\Delta t \left\{ 1 + 2 \sum_{k=1}^{m} r(k) \cdot \lambda(k) \cdot \cos(2\pi k f \Delta t) \right\}$$

for $0 < f < \frac{1}{2\Delta t}$ where $\Delta t$, $r(k)$, $\lambda(k)$ and $m$ are interval between observations, serial correlations, lag window and maximum lag respectively. The window used is that of Parzen (1957) giving estimates of smoothed spectral density as

$$s(f) = 2 \left[ 1 + 2 \sum_{k=1}^{m/2} r(k) \left\{ 1 - \frac{6k^2}{m} \left( 1 - \frac{k}{m} \right) \right\} \cos \frac{\pi lk}{F} ight.$$ 
$$+ 4 \sum_{m/2+1}^{m-1} r(k) \left( 1 - \frac{k}{m} \right)^3 \cos \frac{\pi lk}{F} \right], \quad l = 0, 1, \ldots, F,$$
for frequencies at spacing \( f = l/2F \) where \( F \) was chosen such that \( F = 2m \). The final choice of \( m \) was determined following the suggestions of Jenkins and Watts (1968) for window closing. By comparing spectra for maximum lag values of 10, 20 and 30, a cut-off value of \( m = 20 \) was chosen in an attempt to maximize spectral detail and minimize spectral instability.

Significance of spectral estimates is often determined using the null hypothesis of a first order Markov generating process as outlined by Mitchell et al. (1966). Such an approach has been used by Erat (1973a, b), by Jagannathan and Parthasarathy (1973) and by Parthasarathy and Dhar (1974). In this study, however, the requirement for a simple Markov process that \( r_2 \approx r^2, \ r_3 \approx r^3 \), etc., does not hold. A number of alternative null hypotheses may be postulated and identified by methods suggested by Box and Jenkins (1970). In this paper spectral significance has been determined following the procedure given by Jenkins and Watts (1968) and by assuming the generating process is purely random.

\((d)\) Filtering

Except in the cases of the trend and spectral analyses the data \( X(t) \) for \( 1 \leq t \leq n \) have been smoothed using a 5-termed binomial low-pass filter of the type recommended by Mitchell et al. (1966) in which the smoothed series is given by

\[
S(t) = 0.06X(t - 2) + 0.25X(t - 1) + 0.38X(t) + 0.25X(t + 1) + 0.06X(t + 2)
\]

for \( 3 \leq t \leq (n - 2) \). The first two and last two terms have been estimated as

\[
S(1) = 0.54X(1) + 0.46X(2);
S(2) = 0.25X(1) + 0.50X(2) + 0.25X(3);
S(n - 1) = 0.25X(n - 2) + 0.50X(n - 1) + 0.25X(n);
\]

and

\[
S(n) = 0.54X(n) + 0.46(n - 1)
\]

The frequency response for the series \( S(t) \) for \( 3 \leq t \leq (n - 2) \) is approximately \( R(f) = \cos p\pi f/\Delta t \), where \( p \) is the order of the binomial expansion. This function gives ratios of smoothed to unsmoothed amplitudes of 0.952, 0.925, and 0.813 for periods of 20, 16, and 10 years.

4. RESULTS

\((a)\) Trends in rainfall

The occurrence of trend of any kind within South African rainfall data for the period of meteorological record is a function of the length of that record (Table 1). In general it appears that as the length of record increases so the tendency for the occurrence of trend decreases. For example, of the 30 stations with records extending back to 1880, five show negative trend through the periods 1910 and 1900–1972. Of these five stations, four show

<table>
<thead>
<tr>
<th>Number of stations for given observation periods</th>
<th>Number of stations showing significant trend over different intervals during the observation period</th>
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trend between 1890 and 1972 and only three between 1880 and 1972. In some cases, e.g., stations 49 and 53 in Fig. 2(b), negative trend is introduced only by a wet interlude in the 1880–1890 decade. Of the 157 stations with records for the period 1910–1972, 26 (17%) show significant trend. Of these stations two show positive trend, 24 negative.

If the rainfall records are independent, then four of the 157 stations with 1910–1972 data may be expected to show positive trend and four negative trend at approximately the 5% level of significance (two-tailed). Instead 24 showed negative trend. Likewise two out of the 30 stations with data going back to 1880 may be expected to show trend; one positive, the other negative. Instead three showed negative trend.

In this way it may be concluded that South Africa as a whole has undergone a progressive decline in rainfall over the period of meteorological record. Two considerations mitigate against this view. In the first place the data do not consist of 157 series of independent records. Instead the results presented hereafter show that a high degree of spatial association does exist between series for adjacent stations. Thus statistical hypothesis testing becomes extremely difficult. In the second place the distribution of stations exhibiting trend shows no spatial clustering (Fig. 2(a)). The stations showing negative trend are evenly distributed among about seven times as many stations showing no trend. If, notwithstanding the lack of independence of the data, it is accepted that statistical evidence exists for assuming declining rainfall, then it is impossible to give a physical, climatological explanation for why only about one-seventh of the stations show this decline.

(b) Oscillations in rainfall

Inspection of stationary rainfall series* filtered with a 5-term binomial low-pass filter, shows that at many stations in the northern and eastern parts of South Africa, a fluctuation with a period of about 20 years is apparent (group A stations in Fig. 3). In the southern Cape Province this oscillation is less distinct and appears to break down into a quasi 10-year oscillation (group B stations). In some parts of the country, notably central areas, organized fluctuations appear to be absent altogether (group C stations). In the case of the group A

* The basic data that have been examined for oscillations have in all cases been the series made up of either deviations from mean annual rainfall, when no trend is present, or deviations from the least squares regression line, in those cases where trend is present.
Figure 3. Superimposed deviations from mean annual rainfall smoothed by taking 5-year weighted averages for selected stations in northern and eastern South Africa (group A), in the southern Cape Province (group B) and in remaining areas (group C). The group A stations are 85, 86, 103, 130, 139, and 48. Those given in group B are 27, 34, 39, 46, and 47, and those in group C are 53, 68, 79, 120 and 121.

(a) above normal conditions

- 1918–1922: anomalous stations: 4.5%
- 1938–1942: anomalous stations: 2%
- 1958–1962: anomalous stations: 7%

(b) below normal conditions

- 1928–1932: anomalous stations: 4%
- 1948–1952: anomalous stations: 2.5%
- 1968–1972: anomalous stations: 5.7%

Figure 4. Cumulative filtered positive and negative deviations from mean annual rainfall (in mm) to show decades of above and below normal rainfall conditions. Stations not conforming to the generalized contours are indicated by means of dots.
stations rainfall peaks occur at about 1918–1922, 1938–1942 and 1958–1962, whereas troughs occur at about 1928–1932, 1948–1952 and 1968–1972. Mapping cumulative positive and negative deviations for these quinquennial periods reveals the areal extent to which the country as a whole experienced the suggested 20-year rainfall oscillation (Fig. 4). The number of the anomalous stations, i.e. those not conforming to the contours of cumulative deviation, at no time exceed 8% of the 157 analysed. The extent to which regular periodicities may account for observed rainfall changes between 1910–1972 may be crudely assessed by fitting appropriate sine waves to the filtered data (Fig. 5). Over the interval 1910–1972 the combined variance associated with waves having periods in the range between 16 to 22 years delimits those parts of the country experiencing a rainfall fluctuation of about 20 years. Both the range of the fluctuation, and the percentage variance it accounts for, increase towards the north-east. In this region the range of the fluctuation exceeds 150mm over a wide area. By contrast the quasi 10-year wave suggested in group B of Fig. 3, is confined to the southern Cape, and in few areas has a range greater than 75mm.

Before the results of Fourier analysis can be accepted it is essential they be confirmed by independent methods of analysis, since as Mitchell et al. (1966) point out, climatic change is more likely to be quasi-periodic than truly periodic. A straightforward method

**WAVES WITH PERIODS 16–22 YEARS**

![Map showing variance and range with 16-22 year periods]

**WAVE WITH PERIOD 10–11 YEARS**

![Map showing variance and range with 10-11 year periods]

Figure 5. Variance and range associated with Fourier waves having periods in the intervals 16 to 22 and 10 to 12 years: 1910–1972 data.
of doing this is to examine each rainfall series, filtered by taking 5-year weighted means, for intervals when both positive and negative cumulative deviations from the mean or trend are maximized. By tabulating the years showing maximum and minimum rainfall, and mapping the positions of stations showing similarities, it is possible to assess the regularity of a suspected fluctuation in both the time and space domains. This has been done for the time domain in Fig. 6. A 16 to 20-year fluctuation is evident from the spacing of 9-yearly maxima and minima in the group A stations numbered 94 to 157. Highest rainfall periods centre about the years 1920–22, 1940–42 and 1958–60. In the cases of stations 59–92 the maximum centred about 1922 is variable. Within group B the oscillation is much more variable, but is still discernible. In group C no clearly discernible pattern is evident. The peaks and troughs based on 5-year cumulative deviations for the group B stations show the extent to which a weak quasi 10-year oscillation is present. In particular it is worth noting, by comparison of the stations near the boundary of groups A and B in the tabulation, how the 5-year peaks in group A at about 1940–42 and 1958–60 break into two sets of peaks in group B. This tends to support the contention that the fluctuation with a period of about 10 years is real, rather than being an harmonic of the fluctuation with a period of about 20 years.

In comparison with the organized patterns of rainfall maxima and minima shown by
the groups A and B, and to a negligible extent by group C, stations in Fig. 6, random series produce no discernible pattern at all. Simulating the random series was based on procedures suggested by Tocher (1963) and Whittlesey (1968). One hundred normally distributed random series, with the same order of variance as the observed series, were generated per

**Figure 7.** Frequency occurrence of the observed and simulated periods of rainfall maxima and minima for 1910 to 1972. The histograms in the upper part of the figure are based on Fig. 6, those in the lower part on simulated random series.
station and the means submitted to identical smoothing and sorting procedures to those used in the preparation of Fig. 6.

By determining the frequency with which both the rainfall maxima and minima shown in Fig. 6 occur within specific time intervals, the inverse correlation between periods of above and below normal rainfall in group A and group B stations can be demonstrated (Fig. 7). Likewise the lack of correlation in the case of the group C stations and random series is at once evident. The product moment correlation between 9-yearly maxima and minima, for group A stations with 1910-1972 data, is \(-0.97\), that between the 5-yearly maxima and minima for Group B is \(-0.93\), whereas for the group C stations the correlations are \(+0.03\) and \(-0.29\) for 9- and 5-yearly totals respectively. No stations in group A have data extending back to 1880. The group B stations with data covering the 1880-1972 period show a correlation between 5-yearly maxima and minima of \(-0.84\).

Having established the similarity of rainfall in the various groups of stations in the time domain, it is necessary to show their spatial variation. The group A stations showing the 16-20-year oscillation all occur to the north-east of the country; the group B stations in which both 16 to 20 and 10 to 12-year oscillations can be discerned occur in the southern Cape, (Fig. 8). With the exception of a few outliers, the group C stations fall into three sub-groups: those in the south-western Transvaal and north-western Orange Free State; those in a south-east to north-west corridor running from the eastern to the north-western Cape; and those in the south-western Cape.

Further alternative methods for determining the nature of the apparent oscillations in South African rainfall are the use of serial correlations and spectral analysis. Correlograms for raw data have been determined for all stations. Group A stations exhibit correlograms of the type illustrated by station 148 in Fig. 9; group B stations those of the type illustrated by station 27; and group C stations those of the type illustrated by station 79.

Spectra based on stationary raw data show common characteristics for the three groups of stations (Fig. 10). The group A stations show peaks in the bandwidth of 16-20 year. All these peaks, except that for station 130, are significant at the 5\% level (one-tailed
Figure 10. Examples of rainfall spectra for the periods 1910–1972 and 1880–1972 for some group A, group B and group C stations. Stippling indicates the 16 to 20 and 10 to 12-year peaks in groups A and B respectively.

test) when tested against the null hypothesis of a random generating process. In the case of station 130 the peak is significant at the 10% level. However, many of the peaks for the 63 group A stations are not significant at the 10% level. In view of the opinions of Jenkins (1961) and Granger and Hatanaka (1964) regarding spectral significance, this does not necessarily mean they are not real. The reality of the peaks is suggested by the similarity of large numbers of spectra and is confirmed by the analysis of actual rainfall maxima and minima presented in Figs. 4 and 6.

The group B spectra given in Fig. 10 illustrate peaks in the 10 to 12-year spectral band. Only the peak for station 27 is significant at the 5% level, the rest are significant at the 10% level. None the less, the reality of the oscillation is again supported by independent analysis. The stability of the 10 to 12-year peak is evident from the comparison of the 1910–1972 and 1880–1972 spectra.

The group C stations do not possess common spectral characteristics. In some spectra maximum power is concentrated at high frequencies, in others at low frequencies. In almost all spectra, irrespective of whether from group A, B, or C stations, peaks tend to occur in the 3–4 and 2–3 year ranges. In most instances the 1910–1972 and 1880–1972 spectra show few differences.*

*In order to assess the regional organization and the spatial gradients of specific spectral components, the relative variance associated with integrated frequency bands has been mapped, Fig. 11. The only area of the country in which more than 20% of total variance results from rainfall oscillations with periods greater than 20 years is the south-western Cape Province (one of the sub-group regions of group C stations). Oscillations with periods

* In the case of station 53 in Fig. 10 the differences in low frequency spectral power for the two periods of observation are the result of the wet 1880–1890 decade (see Fig. 2(b)).
Figure 11. Percentage cumulative spectral density associated with rainfall oscillations greater than 20 years, greater than 8 years, in the range 16 to 20 years and the range 10 to 12 years: 1910-1972 data. Stippled areas are for visual impression only.

Figure 12. Percentage cumulative spectral density associated with rainfall oscillations having periods in the 3 to 4-year and 2 to 3-year ranges: 1910-1972 data. The stippled area is for visual impression only.
greater than 8 years occur in two regions, the north-eastern and southern. The 16 to 20-year oscillation is noticeably weaker and is confined to the southern Cape Province.

At the high frequency end of the rainfall spectrum the 3 to 4-year peak is ubiquitous. Oscillations in this band of frequencies show little regional organization and spatial gradients of the spectral component are weak (Fig. 12). The quasi-biennial oscillation contributes maximum relative variance in the 2–3 year range and shows a highly distinctive spatial organization with maximum spectral power being observed in central areas of the country.

5. Discussion

The analysis of rainfall series at 157 stations in South Africa shows that, owing to the lack of independence of the data, no conclusive evidence can be assembled to demonstrate that rainfall has declined generally over the country during the period 1880–1972. Although the number of stations showing negative trend is larger than might be expected by chance, assuming independent data, the impossibility of providing any physical explanation for why only a small fraction of stations should experience this decline mitigates against accepting the suggestion that South Africa as a whole is undergoing progressive desiccation.

Instead of a steady decline, it appears that South African rainfall has oscillated during the period 1880–1972. Independent techniques of analysis suggest the reality of clearly discernible but weak fluctuations with periods 16–20 and 10–12 years; the ubiquity of oscillations of 3–4 years; and the distinctive spatial occurrence of a quasi-biennial oscillation.

The quasi-biennial oscillation occurs almost exclusively in that area of the country having a six-monthly seasonal rainfall regime. The 16–20 year oscillation can be discerned over thousands of square kilometres of the northern, eastern and southern sub-continent having a summer rainfall régime. It is weakest to the south and predominates in the north-east. Though weak, the 10 to 12 year fluctuation shows a distinctive spatial distribution in the coastal and adjacent inland area of the southern Cape Province experiencing an all-seasons rainfall. That this oscillation is more than simply a harmonic of its 16 to 20 year counterpart is suggested by the fact that it fails to account for much variance in areas where the 16 to 20 year fluctuation is most pronounced, and is confirmed by the analysis of actually observed periods of rainfall maxima and minima.

Each of the three techniques used to determine the nature of the rainfall oscillations is individually open to criticism. The arbitrary choice of a fundamental period for the fitting of sine curves to the data and the fact that the observed fluctuations are quasi-periodic, rather than truly periodic, are just two factors mitigating against the use of Fourier analysis. In the case of the sorting of filtered data into periods of maxima and minima rainfall there is the danger that the filtering procedure itself may introduce pseudo-periodicities into the data. It would appear from the simulation exercise mentioned earlier that not only is it difficult to reproduce the correct temporal similarities for many stations from random data, but it is impossible to reproduce the high degree of observed spatial clustering for the stations that do show appropriate temporal similarities. In the case of spectral analysis the short length of record makes it difficult to show the reality of specific spectral peaks in many cases (notably the 16 to 20 year) using tests of statistical significance. However, Granger and Hughes (1968) do suggest that series of the length used can produce meaningful spectral estimates. In addition, the fact that records for many different stations show similar spectra, and the fact that spectral components show such a noticeable, cohesive and in-phase spatial organization, offsets to some extent the doubts one may have concerning the validity of individual spectra.

Notwithstanding these and other objections, the fact that curve fitting, simple sorting of filtered data into periods of maximum and minimum rainfall, and spectral analysis give
independently derived results in substantial agreement, suggests the physical reality rather than the possible statistically spurious nature of the observed fluctuations.

Yet further support for the physical reality of the 16 to 20 year rainfall oscillation is to be found in the similar but inverse oscillation in temperature that has been observed over the country (Table 2).

<table>
<thead>
<tr>
<th>Station number</th>
<th>Phase lag (years)</th>
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<tr>
<td>157</td>
<td>9</td>
<td>135</td>
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<td>36</td>
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<tr>
<td>136</td>
<td>10</td>
<td>53</td>
<td>10</td>
<td>17</td>
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At 80% of the stations for which annual temperature data were available the 20-year rainfall and temperature oscillations were out of phase by approximately 180°.

The fact that the 16 to 20 year temperature and rainfall fluctuations vary inversely suggests that the fluctuations in the two parameters reflect similar persistent changes in the general circulation of the atmosphere over the sub-continent, since similar but inverse fluctuations may be expected if the controlling mechanism is the general circulation. Periods of higher temperature and lower rainfall are likely to be brought about by persistent anti-cyclonic conditions favouring subsidence, clear skies, dry air and optimum insolation. Similarly, lower temperature and higher rainfall are likely to be due to persistently greater cyclonic activity, increased convergence and cloud cover accompanied by decreased insolation (Schulze 1965). Such a relationship holds over a timescale of months, when a close correlation exists between seasonal anomalies of precipitation and pressure departures over southern Africa (Rubin 1956). Thus an abnormally wet summer over the eastern part of the sub-continent is associated with a general negative departure of pressure, stronger cyclonic activity in the westerlies and a deeper continental trough. By contrast, dry summers coincide with positive pressure anomalies over and to the east of the continent.

To test and elucidate the relationship between the general circulation and the rainfall-temperature oscillations it will be necessary to analyse changes in frequency of rainfall occurrence over extended periods of time, to carry out extensive cross-spectral analyses of pressure and other variables and to use techniques such as that of Dickson (1971) for establishing the relationship between specific spectral peaks and changes in general circulation. All this falls beyond the scope of this paper and must await further investigation.

6. Conclusions

Most studies of climatic change during the period of meteorological record have been concerned with the detailed analysis of observations at relatively few and often widely separated stations taken to be representative of the regions within which they fall. Few studies have been concerned with detailed regional climatic change based on the analysis of data for a dense network of stations. In this paper an attempt has been made, first, to isolate specific components of climatic change; and secondly, to establish the regional gradients of those changes over South Africa. A large number of stations has provided the data for analysis.

Mapping the variance of rainfall spectra integrated over specific frequency intervals
SOUTH AFRICAN RAINFALL
definitely appears to offer a useful means of determining the spatial gradients of the components of change.

Results indicate that there is little conclusive evidence to support the view that South Africa has undergone progressive desiccation over the period 1880–1972. On the other hand, evidence does exist to suggest the occurrence of two weak oscillations in rainfall in some areas. The 16 to 20 year oscillation is most pronounced and most in-phase over the north-eastern convective thunderstorm, summer rainfall areas dominated by the continental anticyclone centred over those parts. The range of the fluctuation in places exceeds 175mm. The 10 to 12 year oscillation is much weaker and occurs almost exclusively in the southern Cape area of all-season rainfall affected by cyclonic disturbances in the westerlies. The range of the fluctuation seldom exceeds 75mm. Likewise the quasi-biennial oscillation shows a restricted region of occurrence coinciding largely with the semi-arid part of the country experiencing a weak equinoctial seasonal cycle of rainfall. The similarity between the distribution of seasonal rainfall regimes, being the manifestations of different rainfall producing systems in different parts of the country, and the distribution of the dominant regional oscillations is striking (Fig. 13).

![Figure 13. Comparison between the spatial incidence of seasonal rainfall regimes and predominant oscillations.](image)

There is as yet no direct evidence, by way of long-period variations in pressure anomalies or circulation indices, that the circulation of the atmosphere over southern Africa and adjacent oceans has undergone oscillatory changes between 1880 and 1972. None the less, the indirect evidence of rainfall and temperature changes supports the contention that such changes did in fact occur and suggests that further investigation into possible circulation changes, both of an impulse or more regular kind, may be profitable.

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