LONG TERM RAINFALL TRENDS IN THE SOUTH AFRICAN SUGAR INDUSTRY

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Abstract

Records from 18 of the longest and most reliable rainfall stations in the sugar industry were subjected to a spectral analysis which showed significant long-term oscillations with a mean wavelength of 19,2 years. The wavelength varied from 17,7 years in the northern rainfed areas to 22,5 years in the southern part of the cane belt. Shorter oscillations were also found with wavelengths of 2,2, 3,6 and 6,8 years. The last wavelength (6,8 years) is of greater significance in the south. The data are presented graphically following smoothing with a binomial filter which attenuates wavelengths shorter than 5 years. Examination of sunspot records show that the double sunspot series has in recent times had a period of about 20 years and that it appears to be related to the rainfall oscillations. Based on subjective projections, as well as on predictions based on sunspot behaviour there is a probability that the majority of the sugar industry will experience a series of below average rainfall years centred on the mid-1980s.

Introduction and Methods

Attempts have been made over the last forty years to detect cyclic fluctuations from long-term rainfall records in South Africa [6,8]. Much of the earlier work was handicapped by lack of adequate records, but recently considerable evidence of periodicity in rainfall has been provided by Dyer and co-workers [1,2,3,4,7]. These papers show that there has been a marked periodic fluctuation in rainfall over the summer rainfall region of South Africa with an oscillation of 18-22 years (average about 20 years). It was found that the summer rainfall region has recently enjoyed a period of above average rainfall centred on the mid-1970s following a drought in the mid-1960s and predictions were made [3,4] that rainfall will be below average during the early to mid-1980s. These predictions were based on three methods: a subjective method, a trigonometrical regression, and a method based on sunspots. Other oscillations were also observed, the strongest of which is in the range 3-4 years. No evidence was found in this work to support the hypothesis that South African rainfall has decreased progressively over the past 75 years.

Due to the relatively small percentage (15-20%) of the South African sugar industry which is irrigated, sugar production is strongly influenced by rainfall, and the reductions in yield caused by inadequate rainfall during the mid-1960s are well remembered. It is consequently of considerable interest to ascertain to what extent the rainfall trends observed over the summer rainfall region as a whole are representative of the sugar belt in particular.

To this end, data were obtained from S.A. Sugar Association records from the eighteen longest recording stations, all of which had records extending over a period of at least 45 years (1933 to 1977). The oldest records were from Natal Estates, commencing in 1887. The location of these stations is shown on Fig. 1 and details of the stations are given in Table 1.

The stations are reasonably representative of the sugar belt as a whole with the exception of the northern irrigated areas and the Midlands. Spectral analyses were performed on the raw data from each station in order to determine the wavelength of any oscillation present. In order to smooth the data for graphical presentation a low pass binomial filter of the form $(a + b)^4$ was applied. This method of smoothing has certain advantages over the moving average technique.

It does not produce phase changes between the smoothed and unsmoothed series; neither does it have the tendency to turn peaks into troughs which can have the effect of producing spurious oscillations in the smoothed series. All oscillations of wavelength less than 5 years are effectively attenuated by this technique. The data for the first two and last two years for each station cannot be calculated with this technique and have been estimated using binomial equations of lower order.

TABLE 1

Details of Rainfall Stations

Station	Latitude	Longitude	Year Records Commenced
Hluhluwe	28° 08′	32° 18′	1925
Eteza	28° 30′	32° 15′	1926
Mposa	28° 38′	32° 04′	1925
Empangeni Mill	28° 45′	31° 55′	1925
Empangeni West	28° 45′	31° 45′	1913
Amatikulu Mill	29° 03′	31° 32′	1924
Darnall Mill	29° 15′	31° 23′	1933
Gledhow Mill	29° 21′	31° 18′	1920
Upper Tongaat	29° 25′	31° 05′	1924
La Mercy	29° 35′	31° 05′	1898
Inyaninga	29° 36′	31° 05′	1933
S.A.S.A. Expt. Stn.	29° 42′	31° 02′	1927
Natal Estates	29° 42′	31° 02′	1887
Umbumbulu	29° 59′	30° 43′	1930
Illovo Mill	30° 06′	30° 49′	1930
Dumisa	30° 16′	30° 26′	1930
Renishaw	30° 17′	30° 44′	1930
Sezela Mill	30° 25′	30° 40′	1918

Results and Discussion

Wavelength of Oscillation

The wavelengths of all appreciable oscillations have been obtained from computer printouts and are presented in Table 2, together with the relevant variances.

All stations showed marked long-term oscillations with wavelengths between 17,7 and 22,5 years (average 19,2 years). While the average length of oscillation is close to the figure of the summer rainfall region as a whole[4], there appears to be a relationship between latitude and wavelength as shown in Fig. 2. In the northern area the wavelength is around 18 years, in the southern area 22 years, while in the central region it is about 19-20 years. A linear regression calculated on the data gave the equation:

Wavelength = -16,38 + 1,21 x Latitude.

The correlation coefficient is r = 0,62 ($P < 0.99$)

In addition to the long-term oscillations, there are a number of short-term oscillations which are detailed for each station in Table 2. These have been commonly found in the spectral analyses of other stations in South Africa [7], and the data may be summarised as follows: there was an ubiquitous oscillation of 2,2 years, while other commonly observed oscillations centred on 3,6 years (13 stations) and 6,8 years (12 stations). The possibility of these being harmonics of the long-term oscillations

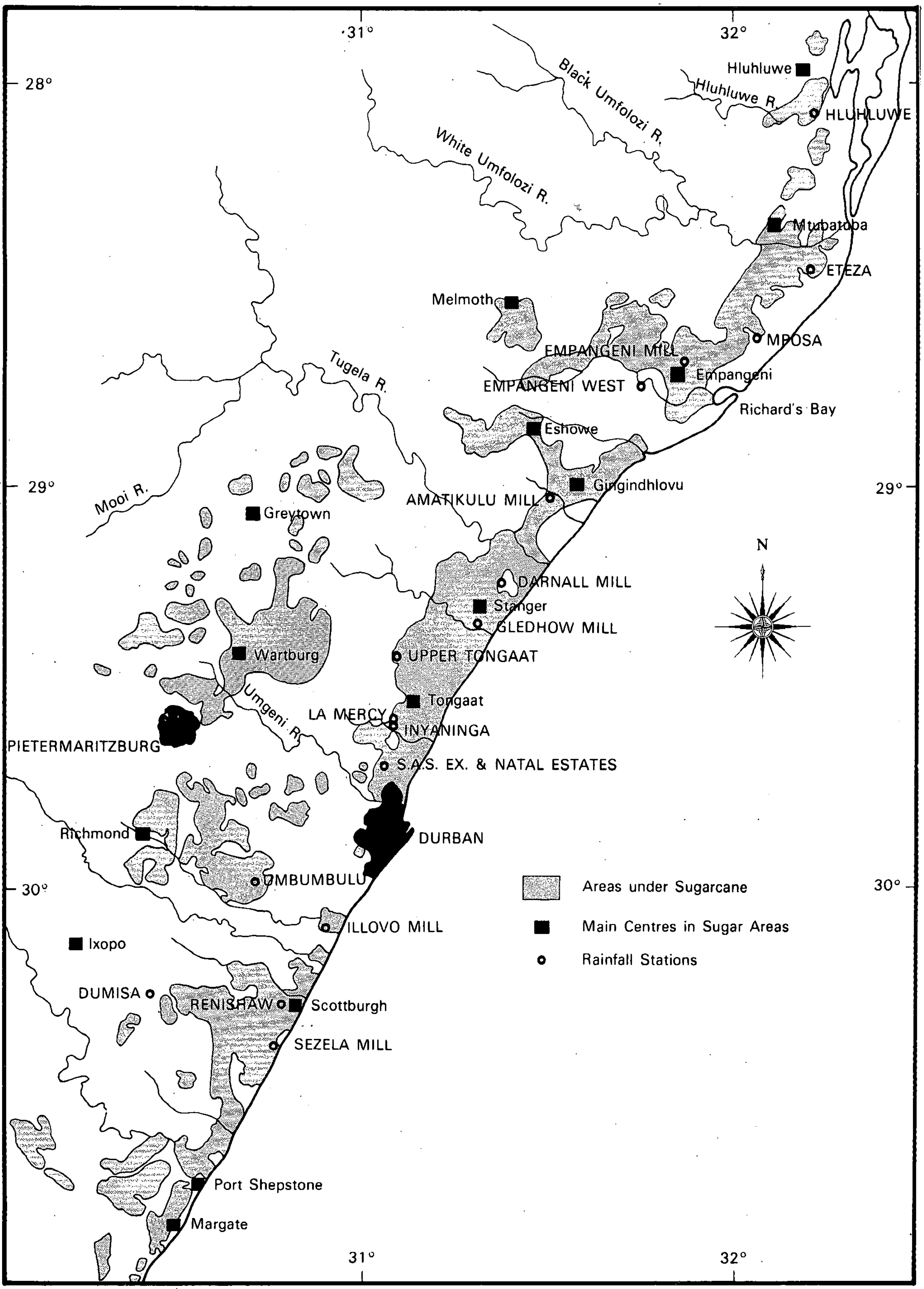

Figure 1: The South African Sugar Industry (excluding the northern areas)

cannot be excluded. Table 2 also gives the variance associated with each oscillation. This indicates the relative magnitude of each oscillation and it can be seen that while the long-term oscillation is the most important in the north, the oscillation of 6,8 years wavelength is more important in the south. This is illustrated in Fig. 3 which shows the spectral analysis of two stations, Amatikulu with a dominant oscillation of 18,8 years and Sezela where the 6,8 year oscillation is of greater magnitude than the long-term one of 22,5 years.

Smoothed Temporal Series

Figs 4 and 5 shows the temporal series for some stations with the rainfall data smoothed using the binomial filter and expressed as a percentage of the mean for each station. A visual examination of the graphs for all stations showed a marked periodicity with wavelength around 18-20 years in most areas except in the south where a 6,8 year wavelength is dominant.

The majority of stations showed periods of high rainfall centred on the late 1930s/early 1940s, mid/late 1950s and mid-1970s with intervening periods of below average rainfall during the late 1920s/early 1930s, mid-late 1940s and mid-1960s.

Sunspots

Regular oscillations in sunspot numbers have been observed for centuries[5]. This periodicity has varied considerably in amplitude and slightly in wavelength; in spite of this, the double

TABLE 2

Wavelengths of Main Oscillations

Rainfall Stations	Long-term Oscillation		Short Term Oscillations (Years)							
	Years	P	2,0 – 2,3	2,4 – 2,3	2,9 – 3,8	3,9 – 4,2	4,3 – 4,6	4,7 – 5,9	6,0 – 6,9	>7,0
Hluhluwe	17,7	,95	2,2		2,9	3,9	4,3	4,7	6,4	
variance	*(3,6)*		*(2,2)*		*(4,0)*	*(2,0)*	*(2,3)*	(3,3)	*(2,7)*	
Eteza	19,6	,95	2,2	2,6	3,6*					
variance	*(3,5)*		*(2,5)*	*(2,4)*	*(2,2)*					
Mposa	17,7	,90	2,2	2,4	3,5	3,9				7,5
variance	*(3,0)*		*(3,5)*	*(3,0)*	*(2,9)*	*(2,3)*				*(2,2)*
Empangeni Mill	18,0	,80	2,2	2,4	3,6	3,9				7,4
variance	*(2,3)*		*(4,8)*	*(3,2)*	*(4,0)*	*(2,5)*				*(2,5)*
Empangeni West	18,0	,90	2,2	2,4	3,6	4,0			6,8	
variance	*(3,5)*		*(2,6)*	*(3,1)*	*(3,1)*	*(2,0)*			*(2,3)*	
Amatikulu Mill	18,8	,99	2,2		3,6*	4,1			6,8	
variance	*(6,0)*		*(2,2)*		*(2,4)*	*(2,2)*			*(2,3)*	
Darnall Mill	19,2	,95	2,2		3,6	4,1	4,6		6,6	
variance	*(3,7)*		*(3,9)*		*(3,2)*	*(2,9)*	*(2,6)*		*(2,5)*	
Gledhow Mill	19,9	,99	2,2	2,4	3,6		4,7		6,6	10,5
variance	*(7,4)*		*(2,1)*	*(2,5)*	*(3,2)*		*(2,3)*		*(3,2)*	*(2,5)*
Upper Tongaat	19,6	,95	2,2	2,4	3,6		4,7			
variance	*(5,4)*		*(5,6)*	*(2,2)*	*(4,3)*		*(3,2)*			
La Mercy	19,2	,90	2,2	2,6	3,6					
variance	*(3,3)*		*(4,3)*	*(3,8)*	*(5,2)*					
Inyaninga	18,4	,95	2,2		3,6		4,6	5,7	6,8	
variance	*(3,9)*		*(3,3)*		*(4,3)*		*(2,2)*	*(2,2)*	*(2,4)*	
S.A.S.A. Expt. Stn.	19,2	,95	2,2	2,6	3,7		4,6		6,8	
variance	*(3,9)*		*(1,6)*	*(2,8)*	*(3,4)*		*(3,4)*		*(3,1)*	
Natal Estates	18,8	,95	2,2	2,6*	3,6		4,7		6,8	
variance	*(3,5)*		*(4,1)*	*(4,2)*	*(3,0)*		*(2,9)*		*(3,2)*	
Umbumbulu	18,0	,90	2,2*			4,1		5,7	6,8	
variance	*(3,1)*		*(2,0)*			*(3,2)*		*(2,5)*	*(2,8)*	
Illovo Mill	19,6	,80	2,2			4,1	4,6	5,5	6,8	
variance	*(1,7)*		*(2,8)*			*(2,4)*	*(3,2)*	*(3,0)*	*(4,0)*	
Dumisa	18,9	,90	2,2		3,7	4,1	4,6	5,7	6,9	
variance	*(3,0)*		*(2,7)*		*(2,2)*	*(2,7)*	*(2,1)*	*(3,3)*	*(2,6)*	
Renishaw	22,0	,95	2,2	2,6		4,1	4,6		6,8	
variance	*(3,3)*		*(3,3)*	*(2,1)*		*(2,2)*	*(2,1)*		*(3,1)*	
Sezela Mill	22,5	,80	2,2	2,6		4,2		5,8	6,8	
variance	*(2,0)*		*(4,1)*	*(2,5)*		*(2,7)*		*(3,5)*	*(4,7)*	
Mean	19,2									

***additional minor oscillations occurred in these groups.**

sunspot series shown in Fig 6 shows a remarkably regular behaviour since 1700. There is however evidence that it was absent for a spell prior to this[5].

The wavelength of the double sunspot cycle has reduced from some 22 years to 20 years in recent times (this corresponds to a single sunspot cycle of 11 and 10 years). Using a cross-spectral analysis, Dyer [2,3] has shown a coherence between the double sunspot series and the temporal series for the summer rainfall region as a whole with a phase difference of 0,5 years in a period of 20 years. Figs 4 and 5 show visually that a similar coherence exists with some of the series in the sugar belt. This applies particularly to the central and northern stations and least to the southern stations.

Rainfall Forecasts

No attempt can be made to predict rainfall for short periods with the above techniques since oscillations with wavelengths shorter than the order of the filter (5 years) are effectively at-

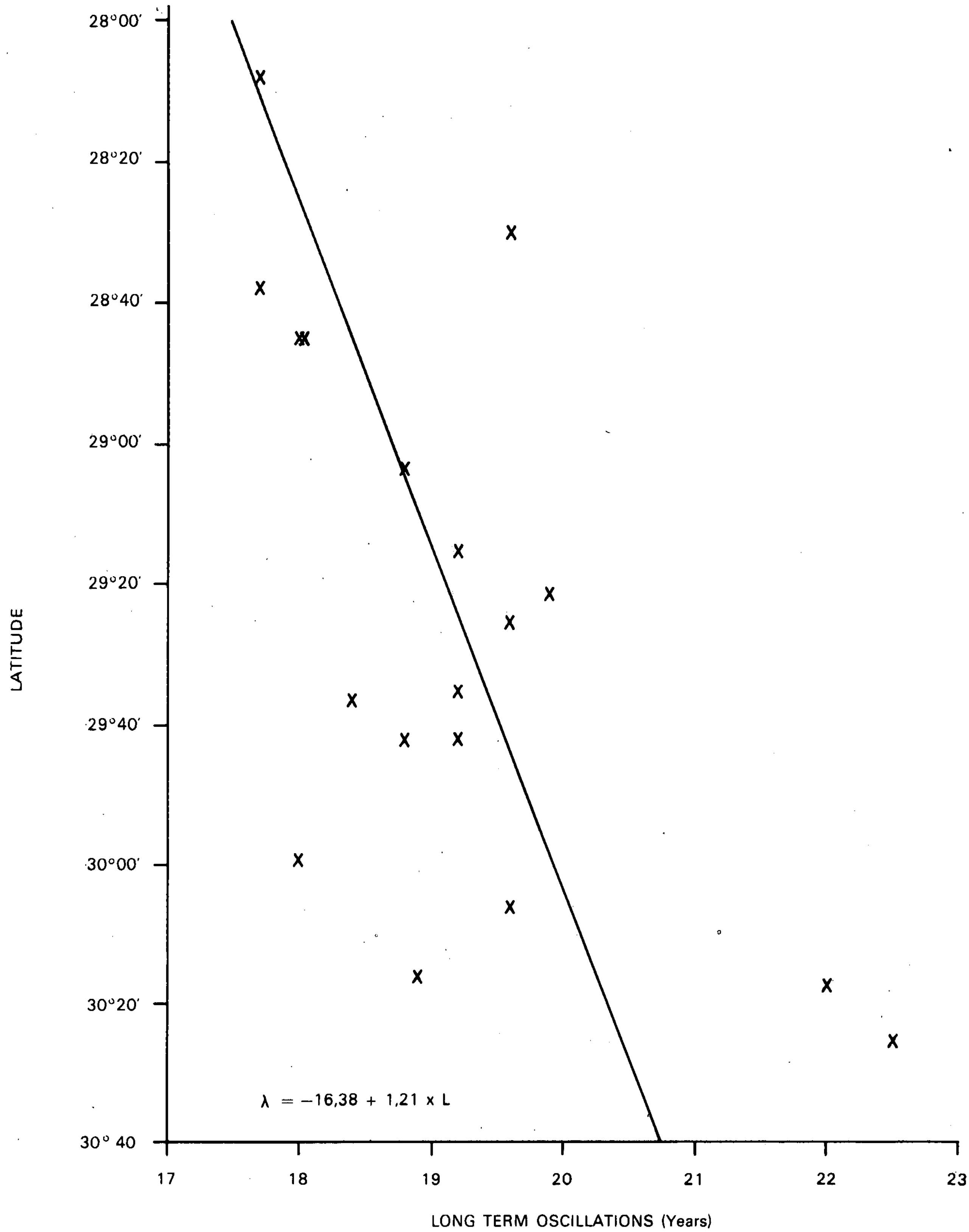

Figure 2: Relationship between Latitude and Wavelength of long term oscillations

tenuated. However, it is possible using either the sunspot correlation or subjective observations to make predictions of future rainfall trends over periods longer than five years. Such predictions are fraught with hazards, since for example they are based

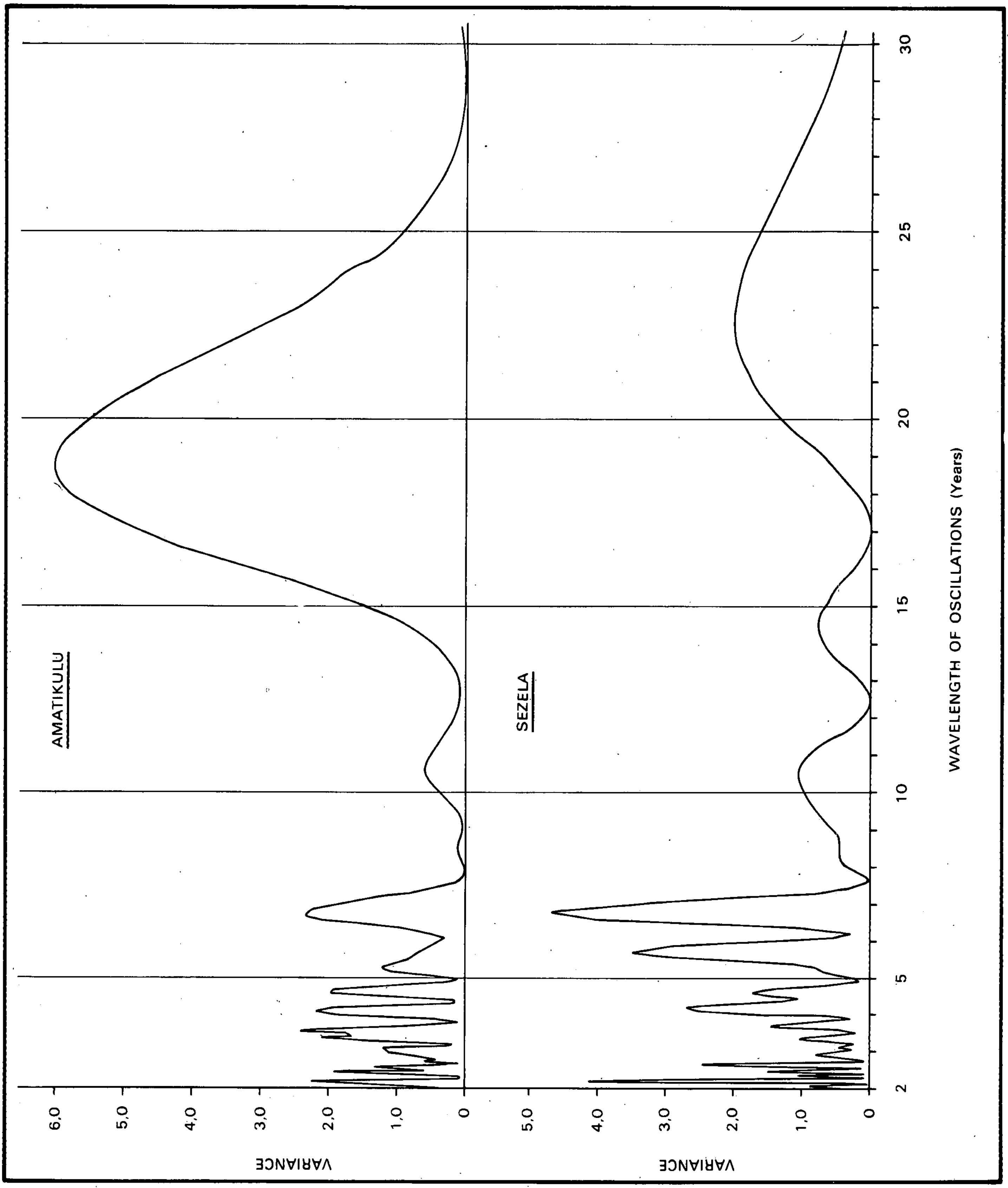

Figure 3: Spectra of Amatikulu and Sezela

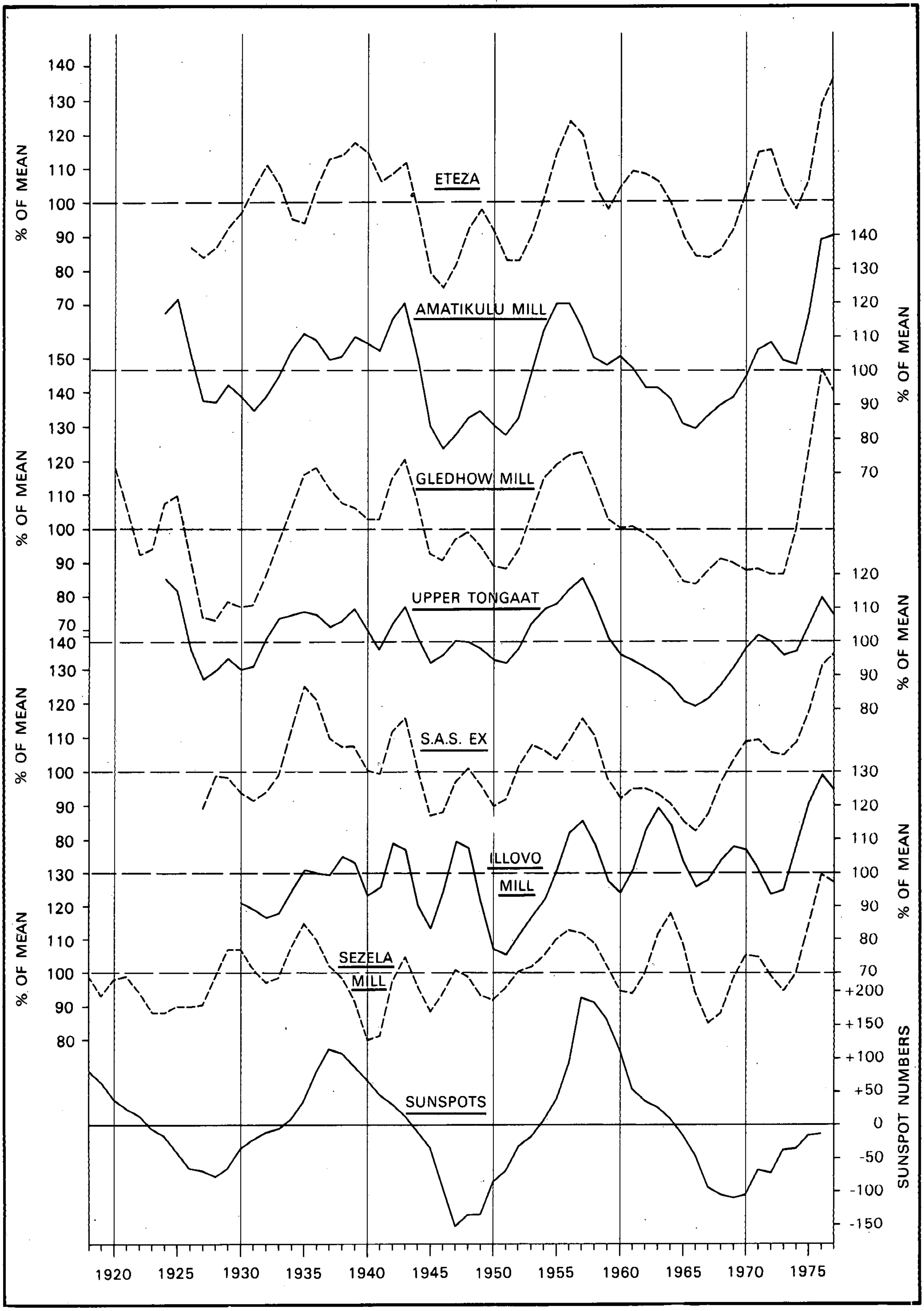

Figure 4: Filtered rainfall series of Eteza, Amatikulu Mill, Gledhow Mill, Upper Tongaat, S.A.S.Ex., Illovo Mill & Sezela Mill

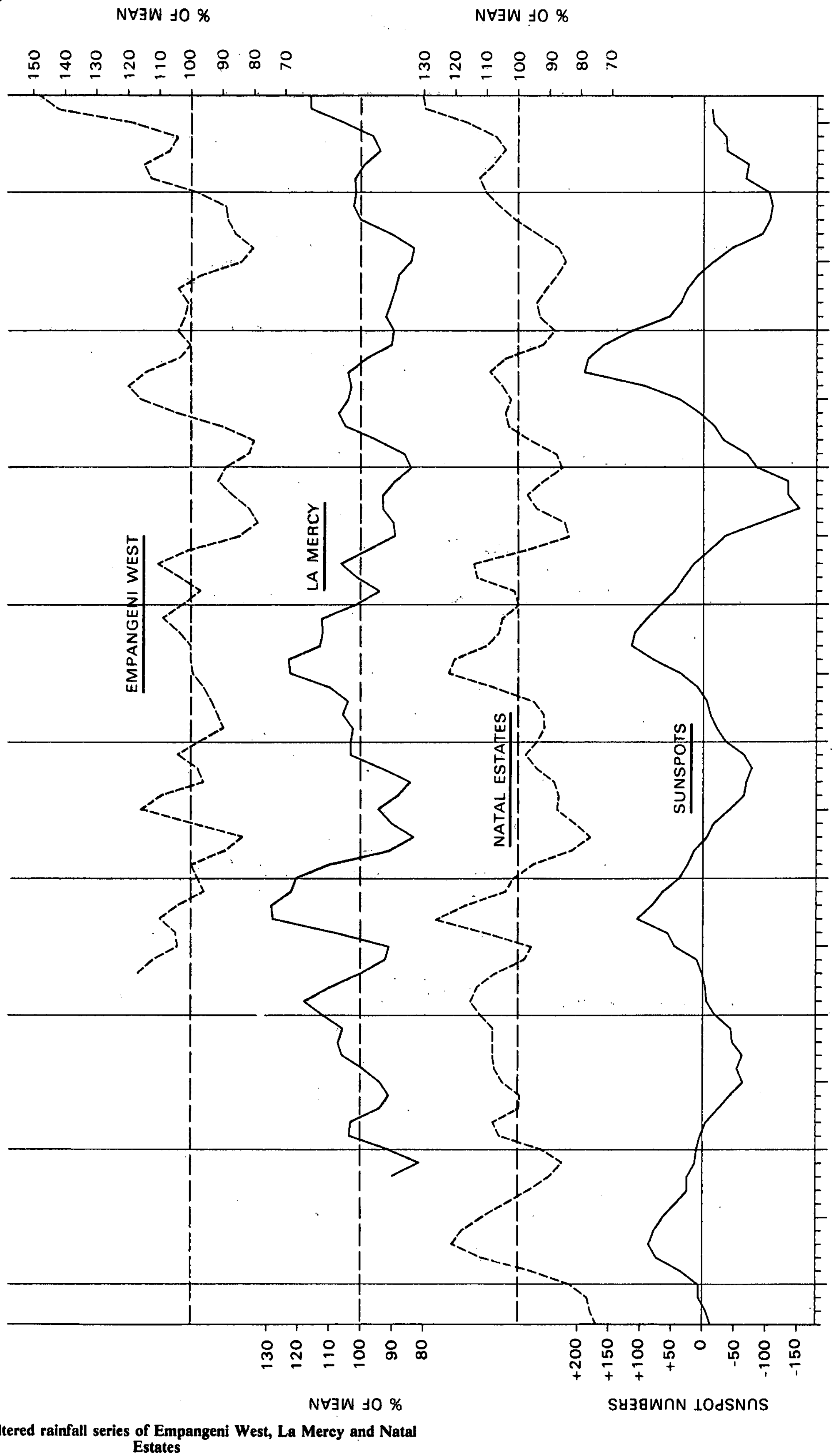

Figure 5: Filtered rainfall series of Empangeni West, La Mercy and Natal Estates

on the assumption that the general circulation over South Africa and the surrounding ocean will continue to behave in a manner similar to that observed during the last 75 years. Nevertheless it should be of value to venture such a prediction, viz that a period of below average rainfall can be expected over most of the sugar belt during the mid-1980s followed by a period of above average rainfall during the mid-1990s.

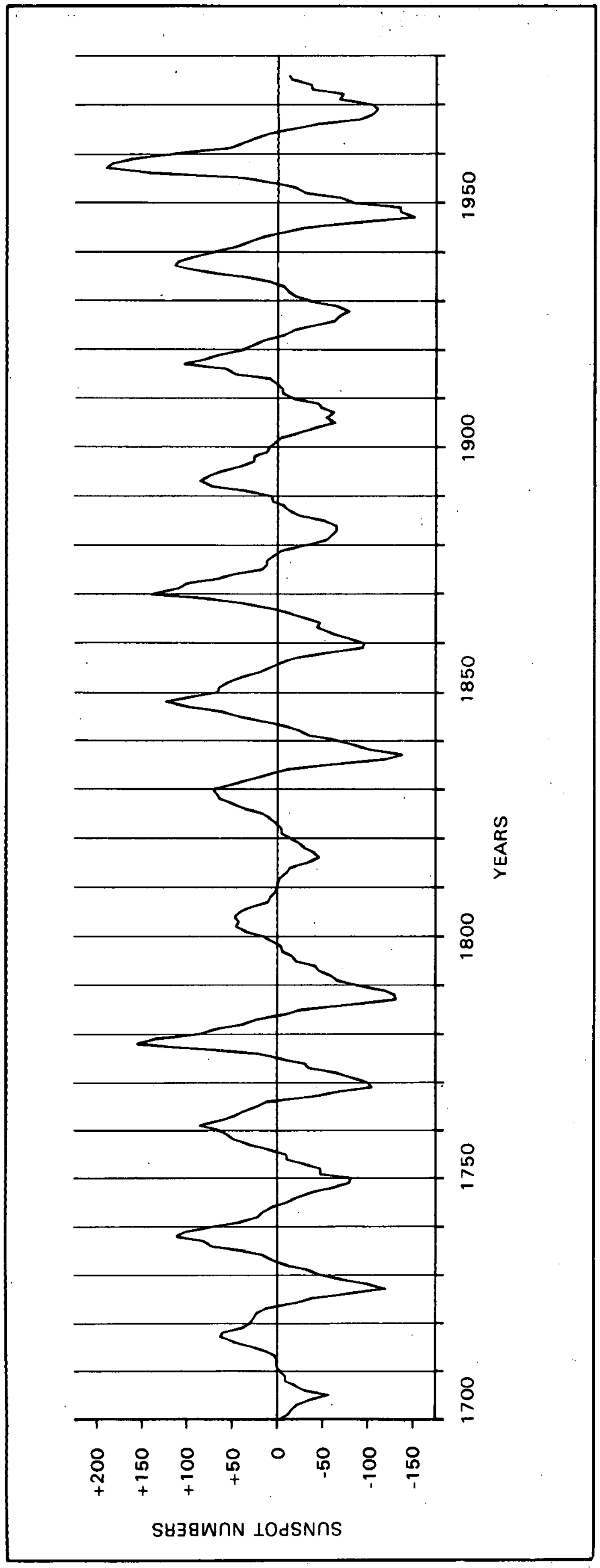

Figure 6: Sunspot behaviour since 1700

Examination of the smoothed rainfall trends for all stations shows that a discernible mid-point of the low rainfall period during the 1960s can be detected for all stations except Illovo. If the wavelength of the long-term oscillation is added to this year, an estimate may be obtained of the mid-point of the expected low rainfall period of the 1980s. This has been done in Table 3, from which it can be seen that the expected average mid-point is 1985.

TABLE 3

Mid points of last and expected periods of low rainfall

	Wavelength Long-term Oscillation* (Years)	Mid Point of Low Rainfall Period	
		Last	Expected
Hluhluwe	17,7	1965	1983
Eteza	19,6	1967	1987
Mposa	17,7	1966	1984
Empangeni Mill	–	1966	–
Empangeni West	18,0	1966	1984
Amatikulu Mill	18,8	1966	1985
Darnall Mill	19,2	1965	1984
Gledhow Mill	19,9	1967	1987
Upper Tongaat	19,6	1967	1987
La Mercy	19,2	1966	1985
Inyaninga	18,4	1966	1984
SASA Expt. Stn.	19,2	1966	1985
Natal Estates	18,8	1965	1984
Umbumbulu	18,0	1969	1987
Illovo Mill	–	–	–
Dumisa	18,9	1968	1987
Renishaw	22,0	1967	1989
Sezela Mill	–	1966	–
Mean	19,0	1966	1985

* Oscillations of which the variance has a probability of less .90 are excluded.

Examination of the sunspot data for all stations shows that there is a moderate coherence between sunspot and rainfall oscillations for most stations over most of the period of records. Visual projections suggest another sunspot minimum in the late 1980s, which would bear a similar lagged relationship to a rainfall minimum in the mid-1980s as it did during the 1960s.

These predictions refer to the average of periods spanning several years during which of course individual years of opposite trends may well occur. Should the magnitude of the low rainfall period during the 1980s be similar to that experienced in the 1960s, effects on sugar yields could be very substantial.

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