SPECTRAL CHARACTERISTICS OF THE SERIES OF ANNUAL RAINFALL IN ENGLAND AND WALES

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Abstract. Despite the small size of England and Wales, the rainfall there shows large variations, possibly due to geographical and topographical conditions. Spectral analysis shows a large number of periodicities, but many are statistically insignificant, indicating considerable randomness. Significant periodicities are invariably in the low periodicity region (periodicity < 5 yr). Occasionally, high periodicities are also encountered, but are always accompanied by low periodicities. Hence, meaningful predictions are not possible.

1. Introduction

In a recent communication (Kane and Trivedi, 1986) it was shown that for annual rainfall series, meaningful predictions were possible only if the most prominent periodicities were in the high periodicity ($T = 10$ yr or more) region. For many parts of England (Great Britain), rainfall series are available as far back as the 18th century. If prominent periodicities for any of these lie in the high periodicity region, predictions of drought or flood intervals may be possible and could be useful for water managements as also for agricultural planning. In the present communication we present a spectral analysis of some of these series with a view to explore their prediction potentials.

2. Data and Analysis for 11 Districts

The study of rainfall in England began with the work of Symons (1866) and was continued later by many workers (e.g. Nicholas and Glasspole, 1931). Craddock (1976) has given the representative annual rainfall totals, expressed as percentage of appropriate standards, for all the years from 1725 to 1973 for each of 11 regions covering most of England. Since the reliability of data has improved with time, and since spectral characteristics are known to vary with time, we have concentrated only on data of about the recentmost 100 years, viz. 1870–1973 (104 yr). The left half of Table I lists the 11 districts (areas or regions) for which data are given by Craddock (1976). Figure 1 is a map of England and Wales and the locations of these 11 districts are marked by the circled numbers. In most of the cases, only data for a single station seem to be involved (for 1870–1973). When subjected to MESA, the time series for all these 11 districts

Climatic Change **12** (1988) 77–92.

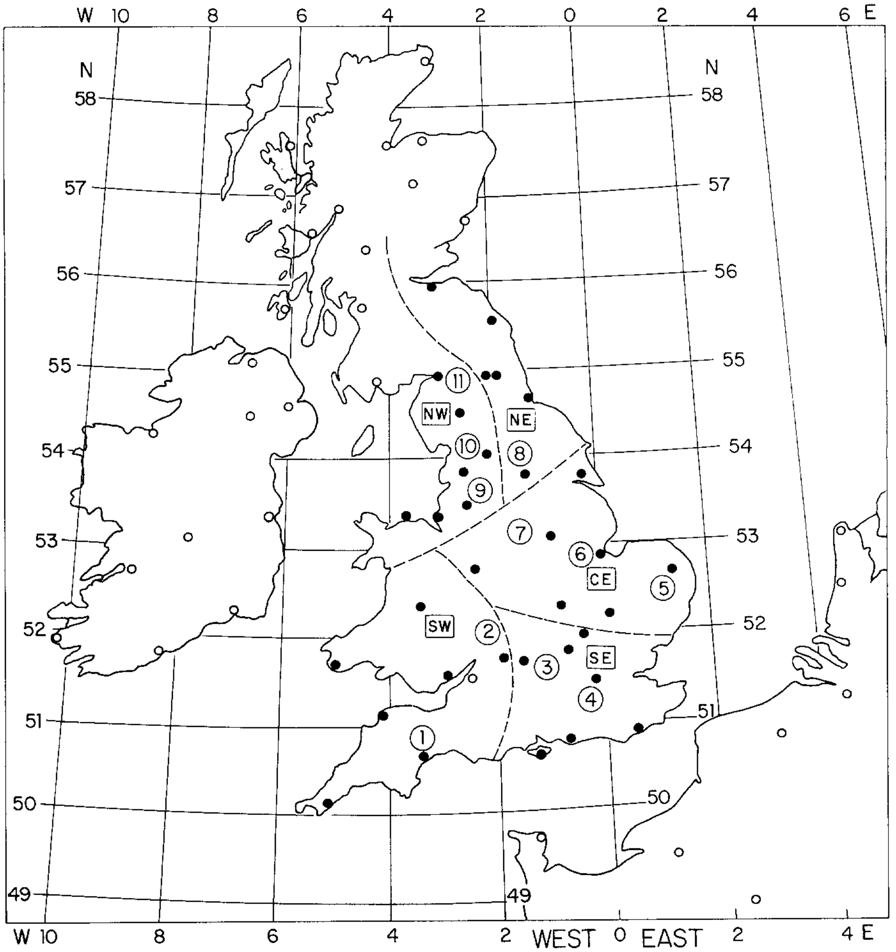

Fig. 1. Map of United Kingdom and parts of surrounding countries. Circled numbers 1 to 11: The 11 districts of Craddock (1976). Open circles and some full circles: The 55 sites used by Wigley *et al.* (1984) for principle component analysis. Dashed lines: Demarcate the five major regions SE, SW, CE, NE and NW. Full circles: Locations of 35 key stations, seven in each of the five regions SE, SW, CE, NE, NW. 25 full circles and open circles are coincident.

indicated more than a dozen periodicities. All these were used for a Multiple Regression Analysis.

Figure 2 shows the various periodicities observed. The shaded portion encloses the 2σ (*a priori*) level and the horizontal line above it marks the 3σ (*a priori*) level. As can be seen, a large number of periodicities are within the 2σ (*a priori*) level and are thus indicative of a random noise. Very few exceed the 3σ

TABLE I: Districts and regions of England and Wales, used for rainfall analysis during 1870–1973.

Districts (Craddock, 1976)			Regions (Wigley *et al.*, 1984)		
(1) *Devon and Cornwall*			*Southwest* (Region 2)		
Devon and Exeter Institute	50.7° N	3.5° W	(a) Exeter	50.7° N	3.5° W
			(b) Falmouth	50.2° N	5.1° W
(2) *Southwest Midlands*			(c) Pembroke	51.7° N	5.1° W
Ross	51.9° N	2.6° W	(d) Rhayader	52.3° N	3.6° W
			(e) Bideford	51.0° N	4.2° W
			(f) Cardiff	51.5° N	3.2° W
			(g) Cirencester	51.7° N	2.0° W
(3) *Oxford*			*Southeast* (Region 1)		
Radcliffe Observatory	51.7° N	1.2° W	(a) Kew	51.5° N	0.3° W
			(b) Oxford	51.7° N	1.2° W
(4) *London Area*			(c) Chilgrove	50.9° N	0.8° W
Camden Sq.			(d) Ventnor	50.6° N	1.2° W
Buckingham Palace	51.5° N	0.1° W	(e) Tring	51.8° N	0.7° W
			(f) Uckfield	51.0° N	0.1° E
			(g) Bedford	52.1° N	0.5° W
(5) *East Anglia*			*Central* (Region 3)		
Diss	52.4° N	1.2° E	(a) Spalding	52.8° N	0.1° W
Wymondham	52.6° N	1.1° E	(b) Norwich	52.6° N	1.3° E
			(c) Hull	53.7° N	0.3° W
(6) *East Midlands*			(d) Althorp	52.3° N	0.8° W
Pode Hole (Spalding)	52.8° N	0.1° E	(e) Mansfield	53.1° N	1.1° W
			(f) Shifnal	52.7° N	2.3° W
(7) *Notts and Derby*			(g) Cambridge	52.2° N	0.1° W
Mickleover	52.9° N	1.5° W			
Etwall Reservoir	52.9° N	1.5° W			
(8) *Yorkshire*			*Northeast* (Region 5)		
Leeds	53.8° N	1.6° W	(a) Edinburgh	55.9° N	3.2° W
			(b) Whittledean	54.9° N	1.9° W
			(c) Leeds	53.8° N	1.6° W
			(d) Redmires	53.4° N	1.6° W
			(e) Lilburn Tower	55.5° N	2.0° W
			(f) Hallington Reservoir	55.1° N	2.0° W
			(g) Lockwood Reservoir	54.6° N	1.0° W
(9) *Liverpool Area*			*Northwest* (Region 4)		
Liverpool	53.4° N	3.0° W	(a) Carlisle	54.9° N	3.0° W
			(b) Manchester	53.5° N	2.3° W
(10) *Lancaster-Kendal Area*			(c) Llandudno	53.3° N	3.8° W
Kendal	54.3° N	2.7° W	(d) Kendal	54.3° N	2.7° W
Morecambe	54.1° N	2.9° W	(e) Stonyhurst	53.8° N	2.5° W
			(f) Liverpool	53.4° N	3.0° W
(11) *Carlisle Area*			(g) Malham Tarn	54.1° N	2.2° W
Carlisle	54.9° N	3.0° W			

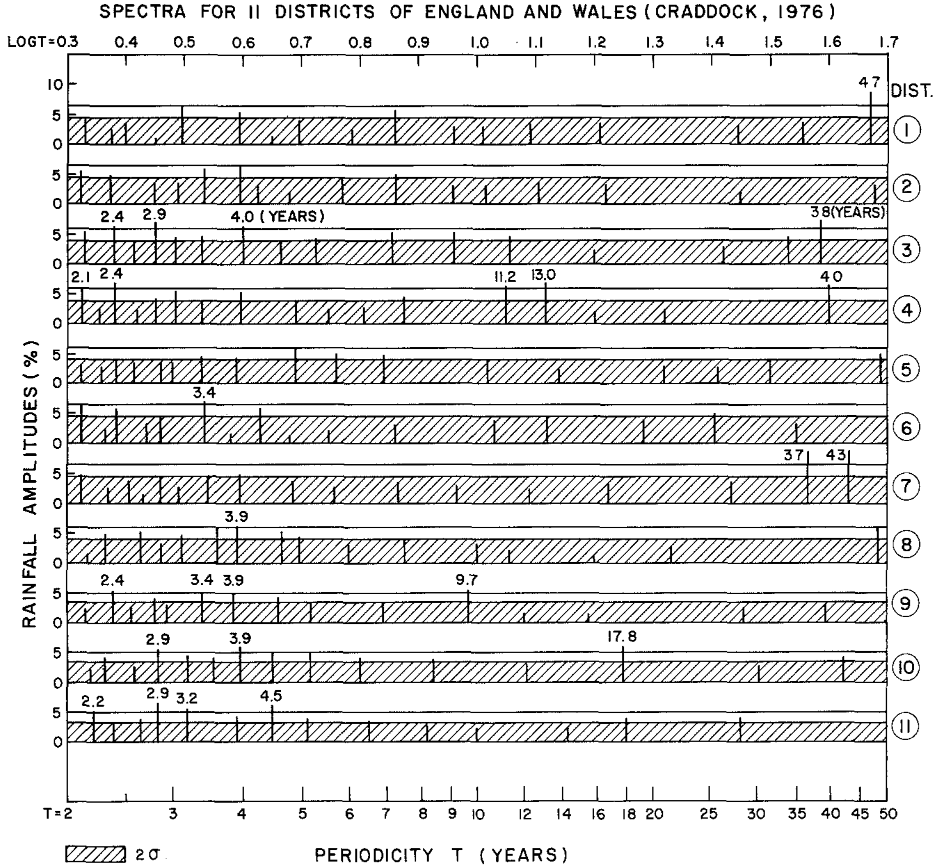

Fig. 2. Amplitudes (%) of the periodicities (years) observed in the spectra of the 11 districts of England and Wales (Craddock, 1976). The hatched portion indicates 2σ limit (*a priori*) and the horizontal line above it indicates 3σ limit (*a priori*). Numbers indicate periodicities T (years) with significance exceeding 3σ (*a priori*).

(*a priori*) level. The periodicities (in years) for these are indicated specifically in Figure 2. In most of the cases, these significant periodicities are in the low periodicity region ($T < 5$ yr). Hence, the criterion mentioned in Kane and Trivedi (1986) for successful prediction is not satisfied. For some districts, there are significant periodicities in the high periodicity region ($T > 10$ yr). These are not similar for all Districts. Districts 4 and 9 have significant periodicities near solar cycle, District 10 at $T = 18$ yr, while Districts 1, 3, 4, and 7 have periodicities near $T = 40$ yr. Gray (1976) found periodicities $T = 40$, 50, and 100 yr for Southeast England, which corresponds to Districts 3, 4. However, in all these cases, there are significant (or near significant) periodicities in the low periodicity region too. Hence, no worthwhile predictions can be expected. Figure 3 shows a plot of the observed values (full lines, for 1950 onwards only, up to 1973) and

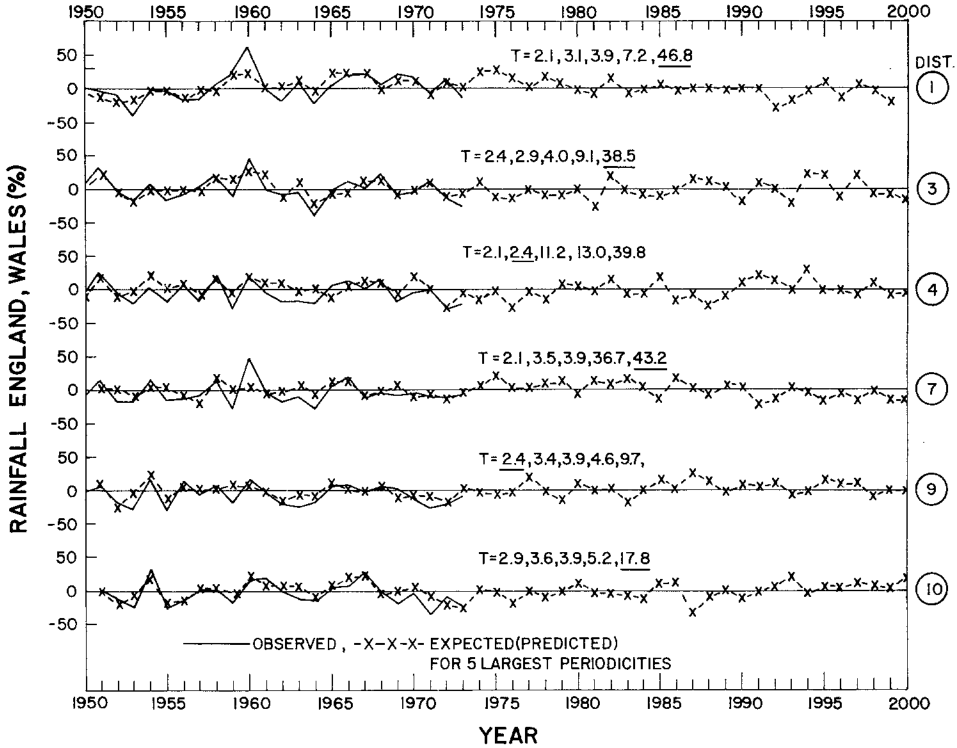

Fig. 3. Observed values (full lines, 1950 onwards only) and expected values (crosses and dashes) using the 5 most prominent periodicities for the rainfall series for Districts 1, 3, 4, 7, 9, and 10 (Craddock, 1976) for which prominent periodicities in the high periodicity region existed.

the expected values (crosses), using the five most prominent periodicities, for the rainfall series for Districts 1, 3, 4, 7, 9, and 10 for which significant high periodicities (also) were observed. As can be seen, frequent ups and downs (indicating the effect of low periodicities) are noticed in all the series and, it is not possible to locate any prolonged intervals of deficit (or excess) rainfall for any region.

The upper part of Table II lists all the periodicities significant at a 2σ (*a priori*) level and periodicities exceeding the 3σ (*a priori*) level are marked by an asterisk (*), for the 11 districts. A large number of periodicities are statistically insignificant. Thus, a considerable amount of randomness is involved in all these series. Craddock (1976) mentions the standard deviation (between years) as about 17% for districts 1 to 8, covering most of England (including Wales, which is district 2), but rather lower in the northwestern area represented by districts 9 to 11. If all these series are fully independent, the standard deviation of their *average* should be roughly $17\%/(11)^{1/2} = {\sim}5\%$. Craddock (1976) has also given the average series and its standard deviation is 12.8%. Craddock concluded, therefore, that there was some *coherence* in the rainfall patterns across the

TABLE II: Periodicities T_n (years), Amplitudes r_n (%) significant at a 2σ level (a priori) and the Percentage Variation explained (PVE). Asterisk (*) indicates significance at a 3σ level (*a priori*) for r_n.

STATION	Periodicities T_n (years), Amplitudes r_n (%) significant at a 2σ level (a priori) and the Percentage Variation explained (PVE). Asterisk (*) indicates significance at a 3σ level (a priori) for r_n																		STANDARD ERROR r_n (a priori)
	T_n	2.1			3.1		3.9					7.2						46.8	
District 1 (Craddock, 1976)	r_n	4.7			6.2		5.5					5.7						8.9*	±2.2
	PVE	3.6			6.3		4.9					5.3						13.0	
	T_n	2.1	2.4		3.4		3.9					7.2							
District 2	r_n	5.5	4.7		5.7		6.0					4.7							±2.2
	PVE	5.0	3.6		5.3		6.0					3.7							
	T_n	2.1	2.4	2.9				4.0		5.3		7.2	9.1	11.4		33.9	38.5		
District 3	r_n	5.2	5.9*	7.2*				5.9*		4.0		5.2	5.4	4.6		4.1	8.1*		±1.9
	PVE	4.5	5.8	8.6				5.8		2.6		4.4	4.9	3.6		2.8	10.8		
	T_n	2.1	2.4	2.8	3.1	3.4	3.9		4.9			7.5		11.2	13.0		39.8		
District 4	r_n	6.1*	7.0*	4.0	5.3	4.1	5.1		3.9			4.5		6.0*	7.0*		6.5*		±1.9
	PVE	6.1	8.2	2.7	4.7	2.7	4.3		2.6			3.3		6.0	8.1		6.9		
	T_n		2.4			3.4	3.9		4.9	5.8	6.9					31.6		49.0	
District 5	r_n		4.1			4.3	4.3		5.6	5.1	4.8					4.3		5.0	±2.0
	PVE		3.2			3.5	3.6		5.8	5.0	4.3					3.5		4.8	
	T_n	2.1	2.4	2.9		3.4		4.3							13.2	25.4			
District 6	r_n	6.3	5.7	4.6		7.0*		5.8							4.4	4.9			±2.2
	PVE	6.3	5.3	3.4		7.9		5.4							3.1	3.8			
	T_n	2.1		2.9		3.5	3.9										36.7	43.2	
District 7	r_n	4.5		4.5		4.6	4.7										9.2*	10.9*	±2.2
	PVE	3.2		3.2		3.5	3.6										13.6	19.0	

TABLE II (*continued*)

STATION	Periodicities T_n (years), Amplitudes r_n (%) significant at a 2σ level (a priori) and the Percentage Variation explained (PVE). Asterisk (*) indicates significance at a 3σ level (a priori) for r_n																				STANDARD ERROR r_n (a priori)
	T_n		2.3	2.7	3.1	3.4	3.9		4.6	5.0		7.5								50.0	
District 8	r_n		4.7	5.1	4.8	5.8	6.0*		5.3	4.2		4.0								5.8	±2.0
	PVE		3.9	4.6	4.1	6.0	6.5		5.1	3.2		2.8								5.9	
	T_n		2.4	2.8		3.4	3.9		4.6	5.2				9.7						50.0	
District 9	r_n		5.4*	3.9		5.2*	5.1*		4.2	3.8				5.4*						3.9	±1.7
	PVE		7.2	3.8		6.6	6.4		4.3	3.6				7.1						3.8	
	T_n		2.3	2.9	3.2	3.6	3.9		4.5	5.2	6.3		8.4				17.8			42.2	
District 10	r_n		4.2	5.5*	4.6	4.7	5.8*		4.7	4.9	3.9		3.9				6.7*			4.2	±1.7
	PVE		3.4	5.8	4.1	4.3	6.6		4.3	4.7	2.9		3.0				8.6			3.3	
	T_n	2.2	2.7	2.9	3.2		3.9		4.5	5.1	6.5						18.0	28.2			
District 11	r_n	4.8*	3.7	6.8*	5.2*		4.4		6.4*	3.6	3.2						4.1	4.3			±1.6
	PVE	5.4	3.2	10.7	6.1		4.4		9.4	2.9	2.4						3.8	4.3			
District (1, 2)	T_n	2.1	2.4		3.1		3.9					7.2			10.5					47.3	
SW (Region 2)	r_n	4.4	6.0*		5.7		5.7					5.0			4.4					5.7	±2.0
	PVE	3.7	6.6		6.0		6.0					4.7			3.6					6.0	
Cirencester	T_n	2.1	2.4	2.9	3.1		3.9			5.3		7.0			10.7	12.3			38.0		
SW (Region 2)	r_n	4.7	5.2	6.2*	5.7*		6.3*			4.1		4.4			6.5*	4.7			3.9		±1.9
(Jones, 1980)	PVE	3.9	4.6	6.7	5.4		7.0			2.9		3.4			7.5	3.8			2.7		
District (3, 4)	T_n	2.1	2.4	2.8	3.1	3.4	3.9					7.2	8.2		11.2			27.9	36.7		
SE (Region 1)	r_n	5.7*	6.3*	4.4	4.4	4.1	5.5					4.9	3.8		5.9*			4.7	6.8*		±1.9
	PVE	5.9	7.3	3.5	3.5	3.1	5.5					4.3	2.7		6.3			4.0	8.3		
Kew	T_n	2.1	2.4	2.8	3.0	3.4		4.0		5.3					10.4	12.7			36.3		
SE (Region 1)	r_n	4.2	5.8	4.2	6.7*	4.6		5.0		4.6					4.6	8.3*			4.6		±2.0
(Wales-Smith, 1971)	PVE	2.7	6.2	2.8	7.8	3.6		4.0		3.6					3.8	12.0			3.6		

TABLE II (*continued*)

STATION	Periodicities T_n (years), Amplitudes r_n (%) significant at a 2σ level (a priori) and the Percentage Variation explained (PVE). Asterisk (*) indicates significance at a 3σ level (a priori) for r_n																		STANDARD ERROR r_n (a priori)
District (5, 6, 7)	T_n	2.1	2.4	2.9		3.4	3.9										37.6		
CE (Region 3)	r_n	4.5	4.1	5.6		6.2*	4.7										5.0		±1.9
	PVE	4.3	3.5	6.8		8.3	4.8										5.4		
Spalding (Pode Hole)	T_n	2.1	2.4	2.9		3.4		4.3						13.2		26.0			
CE (Region 3)	r_n	6.1	5.1	6.3		6.3		5.4						4.9		5.5			±2.2
(Tabony, 1980)	PVE	5.6	3.9	6.0		6.0		4.5						3.6		4.6			
Norwich	T_n	2.1	2.4		3.0	3.4	3.9	4.1		5.7				12.9				42.7	
CE (Region 3)	r_n	3.8	4.0		4.5	4.8	5.3	3.8		5.5				4.9				5.3	±1.9
(Craddock, 1977)	PVE	2.9	3.3		4.1	4.7	5.7	2.9		6.2				4.8				5.7	
District (8)	T_n		2.3	2.7	3.1	3.4	3.9		4.6	5.0	7.5							50.0	
NE (Region 5)	r_n		4.7	5.1	4.8	5.8	6.0*		5.3	4.2	4.0							5.8	±2.0
	PVE		3.9	4.6	4.1	6.0	6.5		5.1	3.2	2.8							5.9	
District (9, 10, 11)	T_n			2.9	3.2	3.4	3.9		4.5	5.2		9.7			17.0	27.2			
NW (Region 4)	r_n			5.6*	3.5	4.0	4.9*		4.7*	3.6		3.1			3.7	3.0			±1.5
	PVE			9.2	3.6	4.7	7.1		6.4	3.9		2.9			4.1	2.7			
England and Wales	T_n	2.1	2.4	2.9	3.1	3.4	3.9		4.7		7.2		10.7	12.3			39.4	46.8	
Average (1870–1973)	r_n	3.2	4.4*	5.6*	3.0	4.5*	4.7*		3.8		3.7		3.1	3.2			3.8	4.9*	±1.3
(Craddock, 1976)	PVE	3.1	5.8	9.3	2.7	6.1	6.6		4.3		4.1		2.8	3.0			4.3	7.1	
England and Wales	T_n	2.1	2.4	2.9		3.4	3.9		4.6		7.0		10.7					50.0	
Average (1870–1980)	r_n	2.8	3.5	5.8*		3.5	4.3*		3.7		3.2		3.4					3.7	±1.4
(Wigley *et al.*, 1984)	PVE	2.4	3.9	10.7		3.8	5.7		4.4		3.2		3.6					4.2	

country and suggested that, taking account also of the regions in Scotland etc., a total of three or four independent parameters should be enough to represent the annual rainfall patterns of Britain. He also suggested that a principal component analysis could estimate these parameters.

3. Analysis for Regions

Gregory (1975) defined regionally coherent rainfall areas for England, Wales and Scotland using a number of methods, but the regions depended upon the used method. Tabony (1980a) compiled a set of homogeneous European rainfall series for 182 stations covering the whole of Europe. For England and Wales, he conducted a principal component analysis, but used a network of only 7 sites. Wigley *et al.* (1984) used 55 stations taken from the compilation of Tabony (1980a). These are shown in Figure 1 as mostly open and some full circles. Only about half of these are in the England-Wales region. The others are in Eire, Northern Ireland, Scotland, Belgium, The Netherlands, and France and were included to counteract possible edge effects. A principal component analysis suggested five main regions into which rainfall variations over England and Wales could be divided, viz. south-east (SE), south-west (SW), central (CE), north-west (NW), and the north-east (NE). These broad regions are demarcated by dashed lines in Figure 1. To check the coherence of rainfall variations within these five regions, a long station record was chosen from each and cross-correlated with the remaining stations. The stations chosen were Kew (SE), Exeter (SW), Spalding (CE), Carlisle (NW) and Edinburgh (NE). For each of the five regions, seven key stations were selected to obtain the regional average precipitation series. These 35 key stations are shown as full circles in Figure 1. Out of these 25 were a part of the 55 stations used for the principal component analysis and hence 25 open circles and 25 full circles are coincident. The right half of Table I lists these 35 key stations. Finally, the five regional series were combined to yield a homogeneous England and Wales precipitation series.

Wigley *et al.* (1984), updated in Wigley and Jones (1987), have published only the final England and Wales series. The five regional series have not yet been published. Privately (courtesy P. D. Jones), we could get the regional series for a limited period of 55 years (1931–1985). We will use these for a limited comparison.

To match with the five regions, Craddock's (1976) data could be combined as follows:

District 1, 2	= SW region
3, 4	= SE
5, 6, 7	= CE
8	= NE
9, 10, 11	= NW

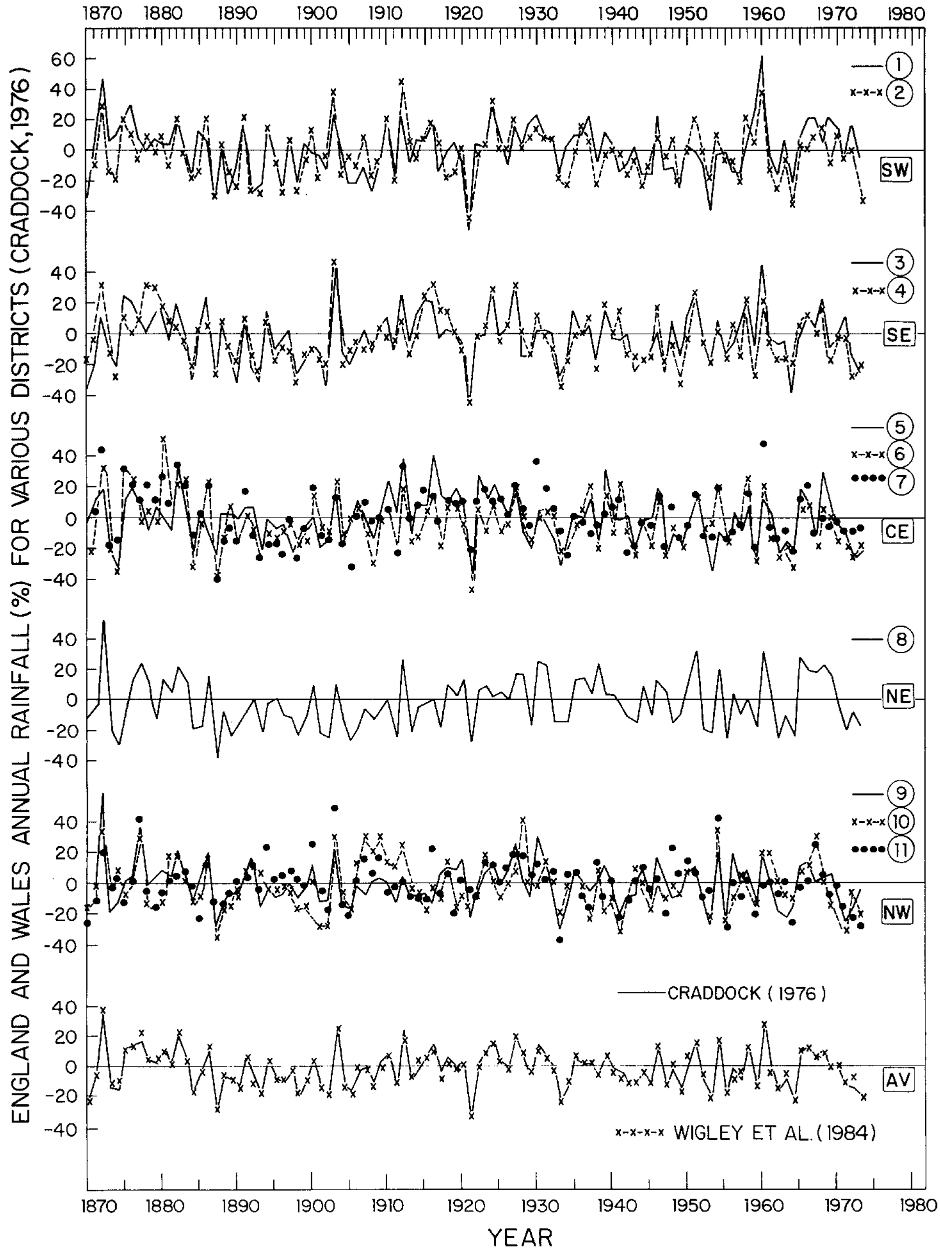

Fig. 4. Plots of the annual rainfall series for 11 districts (Craddock, 1976). Series in the same region (SW, SE, CE, NE, NW) are superposed. The bottom curves are for the average (AV) for England and Wales, obtained by Craddock (1976) (full lines) and Wigley *et al.* (1984) (crosses).

To check the coherence between stations of the same region, a correlation analysis was conducted between District 1 and District 2 rainfalls. The correlation coefficient was about +0.7, indicating that about 50% of the variance was of random origin. Similarly, District 3 was compared with District 4, District 6 with District 5 and District 7 and District 10 with District 9 and District 11. In all cases, correlation coefficients were about +0.7, thus indicating about 50% variance of random origin. Figure 4 is a plot of the annual rainfall series for the 11 districts for 1870–1973, with series in the same region superimposed. There are considerable dissimilarities between districts in the same region, indicating some lack of coherence. However, the final average curves for England and Wales obtained by Craddock (1976) and Wigley *et al.* (1984) are remarkably similar, as can be seen in the bottom plot of Figure 8, in spite of the fact that Craddock's series is essentially for England only. Figure 5(a) shows a plot of the Craddock values for the five regions (Districts 1 + 2; 3 + 4; 5 + 6 + 7; 8 and

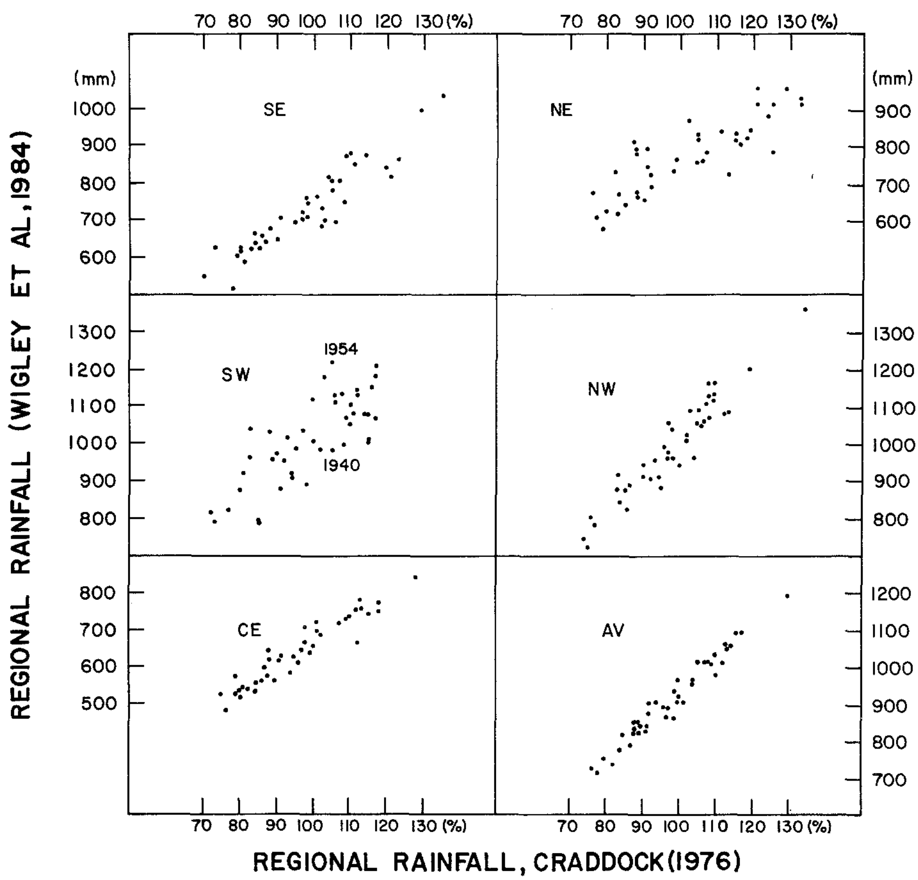

Fig. 5(a). Regional rainfall for 1931–1973, Craddock (1976) versus Wigley *et al.* (1984), for Southeast (SE), Southwest (SW), Central (CE), Northeast (NE), and Average (AV).

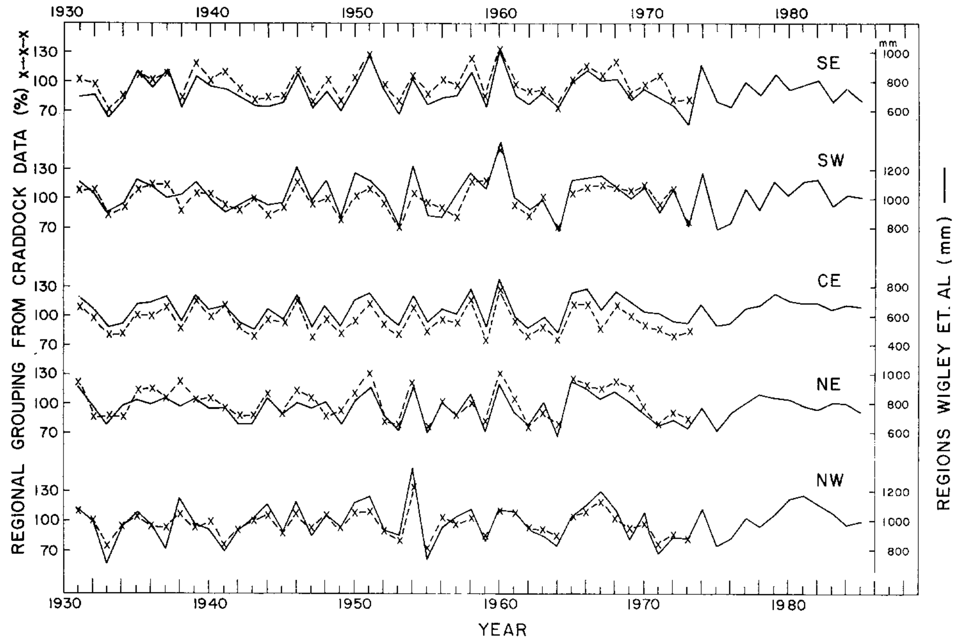

Fig. 5(b). Plots of the regional rainfalls for 1931–1985. Full lines – Wigley *et al.* (1984); crosses and dashes – grouping of Craddock data.

9 + 10 + 11) *versus* the regional values sent to us privately by P. D. Jones. Whereas the matching is reasonably good for SE, CE, and NW, the scatter is large for NE (where Craddock has used only one station, viz. Leeds). The scatter is still larger for SW, where Craddock has used 2 stations versus 7 of Wigley *et al.* (1984). This does not necessarily imply that the SW region is less coherent than others. Craddock did not use gauges in Cornwall-North Devon nor in Wales. The three Welsh gauges used by Wigley *et al.* (1984) seem to make a lot of difference. It may be noted that some Districts of Craddock are composed only of single stations. For the *average*, the scatter is very small. Figure 5(b) shows the actual plot of the annual values for 1931–1985. For SW and NE, the Craddock groupings deviate from the Wigley *et al.* (1984) groupings for some years. However, the nature of the variation from year to year is similar. Since the Wigley *et al.* data with us were very short (55 yr only) and not enough for MESA, we carried out a MESA and Multiple Regression Analysis for the five regional series obtained by combining the Craddock data. The results are given in the lower half of Table II and are plotted in Figure 6. From the literature, we could also obtain long series for Cirencester (Jones, 1980), Kew (Wales-Smith, 1971), Spalding (Tabony, 1980b) and Norwich (Craddock, 1977) and the results for these are also given in Table II and shown in Figure 6, in the appropriate regions. As can be seen, all the regions show several periodicities; but most of these are either insignificant or occur in the low periodicity region ($T < 5$ yr),

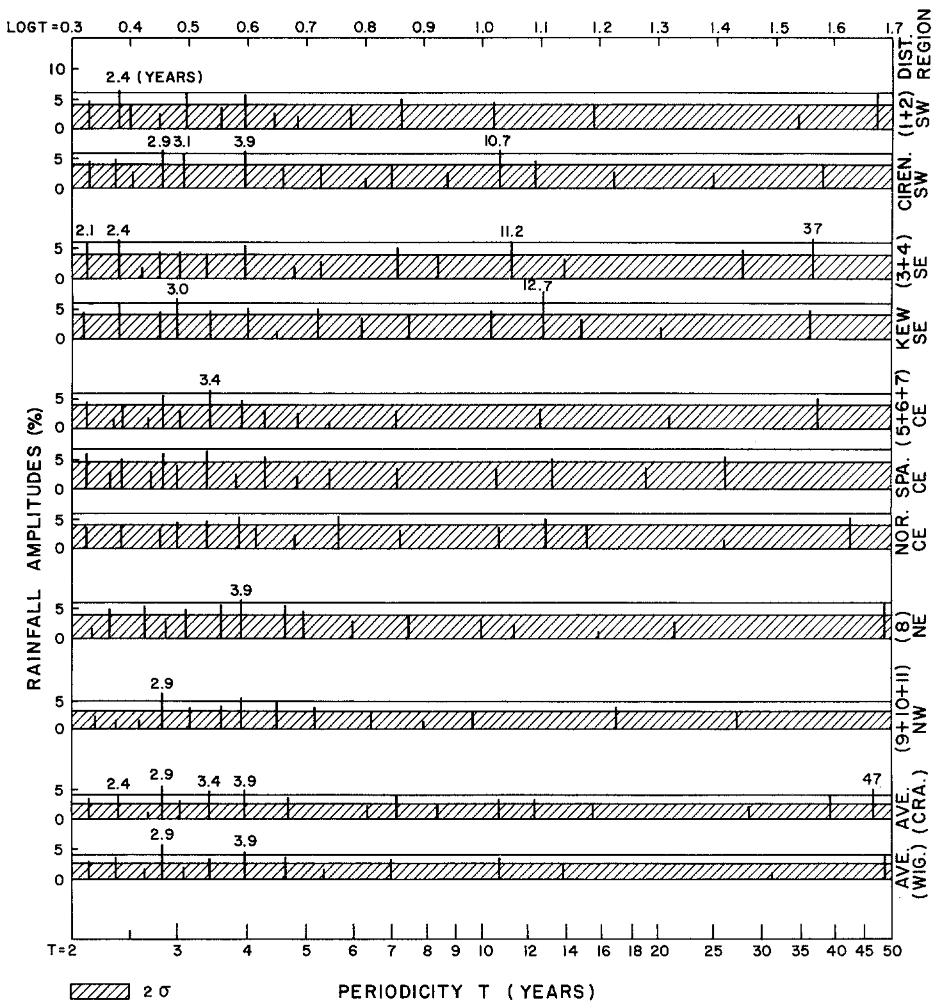

Fig. 6. Amplitudes (%) of the periodicities (years) observed in the spectra of the 5 regions SW, SE, CE, NE and NW by combining the Craddock (1976) data for Districts 1–11, as also for the individual locations Cirencester (SW), Kew (SE), Spalding (CE) and Norwich (CE) and for the overall average (AVE) obtained by Craddock (1976) (CRA) and Wigley *et al.* (1984) (WIG). The hatched portion indicates 2σ limit (*a priori*) and the horizontal line above it indicates 3σ limit (*a priori*). Numbers indicate periodicities T (years) with significance exceeding 3σ (*a priori*).

though in some cases high periodicities are also seen. In no case, there are prominent high periodicities *only*. The same applies to the average series for England and Wales, results for which are given at the bottoms of Figure 6 and Table II. Thus, the potential for prediction is almost nil. The results for the average curve agree well with those of Tabony (1979), who reported $T = 2.1$, 2.4, 3.9, 5, and 6 yr, by using MESA, but did not mention their amplitudes. Gray (1976) found $T = 40$, 50, 100 yr for southeast England (1840–1970) but gave predictions only for *decadal* averages for the next few decades.

4. Attempting Prediction for Kew

Amongst the various series studied, the rainfall series at Kew has the most prominent peak in the high periodicity region ($T = 12.7$ yr, amplitude 8.3%, Percentage Variance Explained = 12%). However, the next largest amplitude is for $T = 3.0$ yr (amplitude 6.7%, PVE = 7.8%). Figure 7 illustrates the results of an attempt to predict. In the first row, the full lines represent the observed values for 1870–1946, while the crosses and dashes represent the expected values using all the 15 periodicities, which were obtained using MESA for 1870–1969 (100 yr). The matching is reasonably good, mainly because so many periodicities are used. In the second row, the full lines represent observed values for 1940–1969. The crosses and dashes represent the expected values using all the 15 periodicities and these have been extrapolated up to year 2000. The big dots represent the observed values for 1970–1980. These were not included in MESA and hence can be used for testing the validity of prediction. As can be seen, the matching is not very good. In particular, there is a major discrepancy in 1974, when the expected value was far below average and the observed value turned out to be well above average! Since the observed values before and after 1974 were below normal, the excess rainfall in 1974 is clearly an anomaly

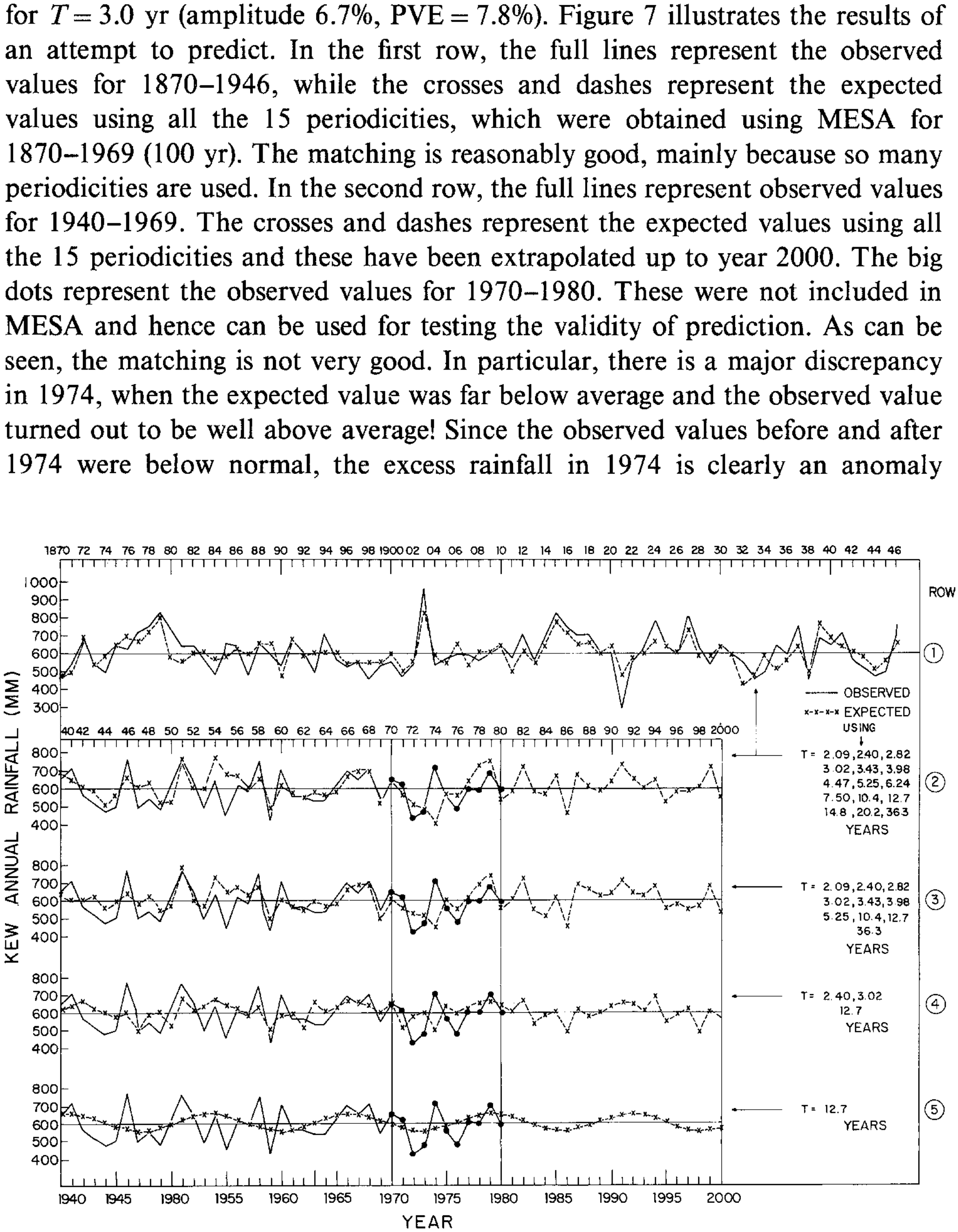

Fig. 7. Observed values for Kew (full lines for 1870–1969 and big dots for 1970–1980) and the values expected (crosses and dashes) using various groups of observed periodicities, as indicated.

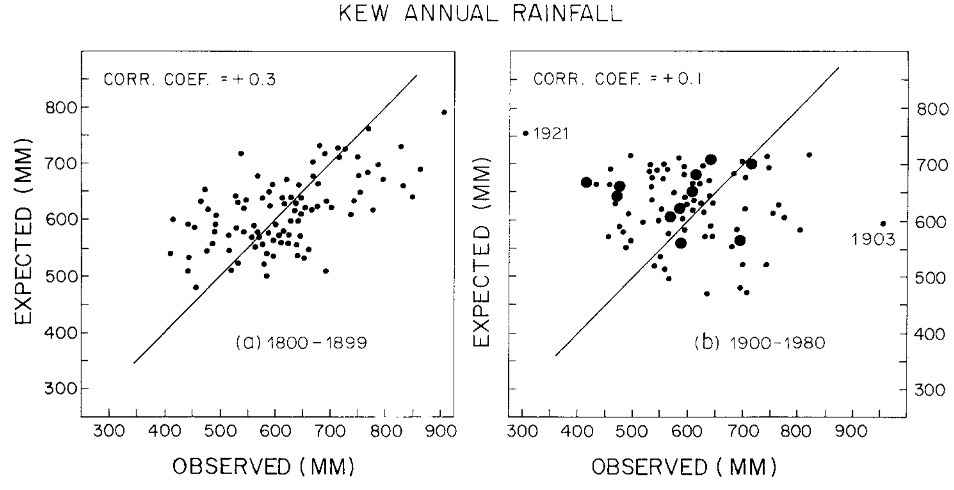

Fig. 8. (a) Observed values of Kew, versus expected values using $T=2.24$, 2.43, 3.47, 6.1, 7.1, 13.5, and 47.3 yr, for 1800–1899 (100 yr). (b) Observed values of Kew, versus expected values using the same periodicities extrapolated for 1900–1980. Big dots represent the last 11 yr (1970–1980).

beyond the reach of the present type of analysis. In succeeding rows, the observed values are the same as in row 2 (for 1940–1969 as full lines and for 1970–1980 as big dots), but the expected values (crosses and dashes) are obtained by using lesser numbers of more significant periodicities. In the fifth row, only $T = 12.7$ yr (amplitude 8.3% ± 2.0%) is used for prediction. As can be seen, very frequent ups and downs, indicating the overwhelming effect of low periodicities, vitiate the prediction possibilities.

To check predictions over longer periods, Kew data for 1800–1899 (100 yr) were subjected to MESA. Seventeen periodicities were located. A Multiple Regression Analysis showed that only 7 periodicities viz. $T=2.24$, 2.43, 3.47, 6.1, 7.1, 13.5, and 47.3 yr were significant at a 2σ (*a priori*) level. However, all these together explained only 36% of the Variance, thus implying a very large (64%) random component. Combining these 7 periodicities, the expected values were calculated. Figure 8(a) shows a plot of observed versus expected values. Many values are far away from the 45° regression line, indicating poor matching (correlation +0.3). Expected values were extrapolated for 1900 onwards. Figure 8(b) shows the plot of independent data i.e. observed versus expected values for 1900–1980, the bigger dots representing 1970–1980. The scatter is very large indeed, indicating an utter lack of correlation (+0.1), because of the presence of transient QBO ($T = 2$–3 yr) as well as a very large random component.

5. Conclusions

A Maximum Entropy Spectral Analysis and Multiple Regression Analysis of the annual rainfall series for the various parts of England and Wales indicate a large number of periodicities. However, many of these are statistically insignificant, indicating a considerable degree of randomness. Among those which are significant, many are in the low periodicity ($T < 5$ yr) regions. In a few cases where significant periodicities exist in the high periodicity region, significant low periodicities are also present. Hence, attempts at prediction, as outlined in Kane and Trivedi (1986), do not succeed in case of these rainfall series in England and Wales.

Acknowledgments

Thanks are due to Dr. P. D. Jones for supplying the regional series as also recent data for Kew. This work was partially supported by FNDCT, Brazil under contract FINEP 537/CT.

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(Received 12 October, 1986; in revised form 18 August, 1987)