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Prediction of the date of establishment of southwest monsoon along the West Coast of India

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1. Introduction

In India where agriculture is the major industry and the problem of raising enough food for her millions is of vital importance, the success or failure of the crops in any year is closely linked with the behaviour of the monsoon. The southwest monsoon is indeed the biggest meteorological event of the year. The prediction of the date and nature of its establishment along the West Coast of India and its subsequent behaviour during its advance into the different parts of the country, of the total precipitation during the monsoon season which extends roughly from June to September and of the manner of its withdrawal from the country later has been a challenge to the Indian meteorologist.

Even from the days of Blanford and Eliot the Government of India became interested in a forecast of the expected total precipitation during the monsoon season as a whole, and seasonal or long-range forecasting in India originated in 1886. These annual forecasts were based upon rather empirical and perhaps subjective considerations in the earliest days but soon took a more objective shape in the hands of Walker (*vide references*) who developed the correlation technique for predicting the total precipitation in India during the southwest monsoon, from the world-weather factors in the pre-monsoon period which foreshadowed the subsequent weather in India. These methods underwent further extension and revision later by Normand* (1932), Savur (*vide references*), Doraiswamy and others (*vide references*). The monsoon forecasts which are of great interest to the Government as well as to the people of India and which are issued every year about the commencement of the monsoon season, attempt to predict only the expected total precipitation of the season over wide areas like peninsular and northwest India, without indicating when exactly the monsoon rains will start, how it will be distributed in time and space, when breaks in the rainfall may be expected and when the monsoon is likely to withdraw from the different parts of the country.

These other aspects of the monsoon problem which are of vital interest to the Indian farmer naturally drew the attention of the senior author many years ago when he made a beginning with a detailed study of the date of establishment of the southwest monsoon in India over a series of years and began to explore the possibility of forecasting this date with the aid of such pre-monsoon factors of world-weather which may be exercising any significant influence on the time and the character of the ' burst of the monsoon ' over India.

2. The Date of Establishment of the Monsoon

The weather forecaster, who bases his predictions mainly on the synoptic situation day by day, usually indicates the onset of the monsoon. For the purpose of our present studies we have fixed the dates in accordance with the procedure described below.

*For a critical review of Monsoon Seasonal Forecasting in India please see also Sir Charles Normand's Presidential address delivered before the Royal Meteorological Society, London, on 17 June 1953, which has appeared in *Quart. J. R. met. Soc.*, October, 1953.

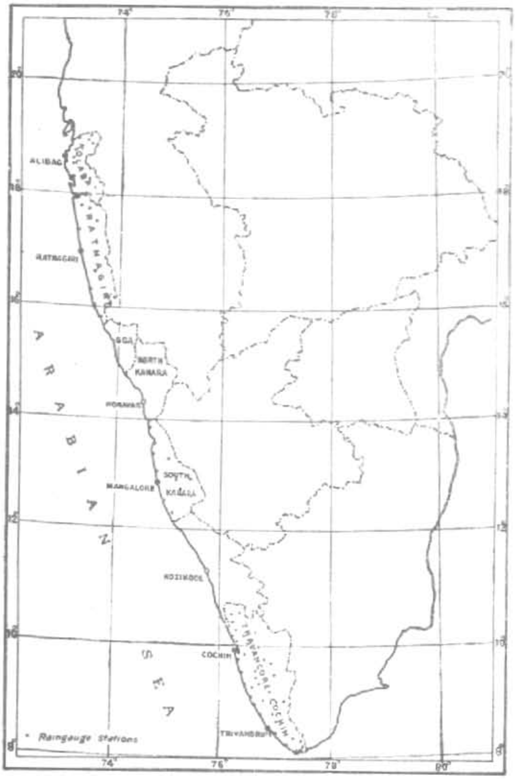

Fig. 1. Map of Peninsula showing the west coastal areas

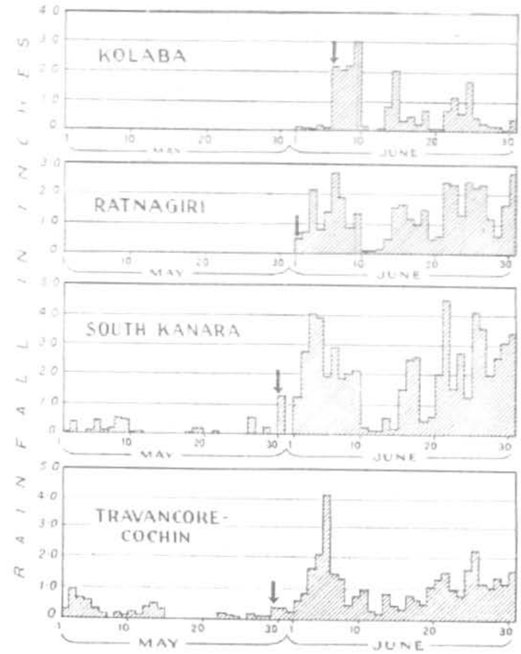

Fig. 2. Daily rainfall in the west coastal areas (1929)

Attention was confined to the Arabian Sea branch of the southwest monsoon which hits the Malabar coast early in June and then travels northwards along the West Coast, the actual dates of establishment as well as the speed of travel varying from year to year. For fixing the actual date of establishment of the southwest monsoon in different areas, the mean daily rainfall was plotted day by day for the months of May and June for each year for the following four areas along the West Coast (Fig. 1)—

(1) Travancore-Cochin,

(2) South Kanara,

(3) Ratnagiri and

(4) Colaba.

An inspection of these daily rainfall graphs (please see typical example given in Fig. 2) makes it possible to fix the date of actual commencement of the persistent rainfall which is characteristic of the monsoon. Owing to the incidence of pre-monsoon rainfall, often in the form of thundershowers, the wet season starts earlier in the southern areas like Travancore-Cochin and South Kanara and merges into the later monsoon rainfall without an abrupt or sudden increase in some years. Nevertheless, it is possible to fix the date of establishment of the monsoon even in these areas. As one moves northwards, the pre-monsoon rains decrease rapidly and in the areas near the Ratnagiri and Kolaba districts the rains begin in most years with the onset of the monsoon itself.

Table 1 gives the dates of establishment of the monsoon over the above four areas for the years 1891 to 1950 reckoned as number of days from 1 May (1 May itself taken as 1). In our present studies, we have fixed the date of commencement of the monsoon by looking at the charts showing the mean daily rainfall over the 4 areas referred to earlier (Fig. 2). The commencement of persistent heavy rainfall has been our main criterion so that the dates given in Table 1

TABLE 1

Dates of establishment of southwest monsoon, reckoned from 1 May

Year	Travancore-Cochin	South Kanara	Ratnagiri	Kolaba	Year	Travancore-Cochin	South Kanara	Ratnagiri	Kolaba
1891	27	34	50	52	1921	32	34	41	43
92	22	24	29	31	22	25	31	41	43
93	22	35	41	41	23	35	42	43	44
94	32	33	38	38	24	31	34	41	43
95	39	43	45	46	25	27	28	29	29
1896	30	31	32	32	1926	28	36	40	41
97	30	36	38	38	27	23	27	41	41
98	33	34	39	39	28	31	31	36	38
99	23	38	40	41	29	29	30	32	37
1900	37	39	40	40	30	21	38	39	40
1901	32	35	38	38	1931	23	29	45	45
02	31	37	38	43	32	14	33	34	34
03	39	42	43	43	33	22	28	32	32
04	29	32	38	39	34	37	37	41	41
05	37	39	40	41	35	41	41	43	45
1906	34	37	38	39	1936	20	22	29	32
07	31	36	42	42	37	34	41	42	43
08	39	41	42	42	38	32	33	33	35
09	32	33	34	34	39	37	37	38	40
10	28	33	34	34	40	38	44	47	49
1911	32	33	35	35	1941	23	34	45	47
12	35	37	43	43	42	35	39	43	44
13	24	32	37	38	43	12	14	21	21
14	28	36	44	44	44	29	30	40	41
15	34	43	48	49	45	32	33	42	44
1916	26	27	31	32	1946	29	32	32	33
17	26	29	35	36	47	31	34	38	39
18	7	15	22	25	48	25	37	39	39
19	16	26	35	37	49	23	23	25	25
20	27	33	37	37	50	26	27	41	41

TABLE 2

Area	Mean date of establishment	Standard deviation (in days)	Earliest date	Latest date	Range earliest minus latest date
1. Travancore-Cochin	May 29	7·2	7-5-1918	10-6-1935	34 days
2. South Kanara	June 3	6·3	14-5-1943	13-6-1940	29 days
3. Ratnagiri	June 7	6·0	21-5-1943	19-6-1891	29 days
4. Kolaba	June 8	6·1	21-5-1943	21-6-1891	31 days
(Combining the areas 1 and 2 as "West Coast South" and 3 and 4 as "West Coast North" and 1 and 4 as "West Coast", we have the following information)					
5. West Coast South (1 and 2)	May 31	6·4	11-5-1918	10-6-1903 10-6-1935 10-6-1940	30 days
6. West Coast North (3 and 4)	June 8	6·0	21-5-1943	18-6-1915	28 days
7. West Coast (1 and 4)	June 3	6·0	16-5-1918	13-6-1940	28 days

often occur a few days later than the date which the weather forecaster is tempted to indicate in his forecasts, based on the synoptic situations and the lie of the air masses and their movements. We shall hereafter refer to the dates given in Table 1 as the "dates of establishment" of the southwest monsoon.

Table 2 gives the mean date of establishment, its standard deviation (in days), and the earliest and latest dates of establishment and the years in which they occurred.

While the mean dates of establishment and their standard deviations are as in columns 2 and 3 of Table 2, the monsoon did set in as early as 7 May in Travancore-Cochin in 1918 and as late as the 21 June in Kolaba district in 1891. The range between the earliest and the latest dates is of the order of a month in all the areas referred to.

Obviously, the range of these variations is sufficiently large to justify attempts to forecast them from year to year. It is no wonder that the Indian farmer is so keen and anxious to know when the monsoon rains will set in during any given year as his agricultural operations are so dependent on the commencement of these rains.

It will be of interest to study the frequency distribution of the dates of establishment of the southwest monsoon. Fig. 3 shows the frequency distribution of these dates in respect of the West Coast South, West Coast North and West Coast respectively. These show some negative skewness as confirmed by the g values given below.

	g_1	S.E. of g_1	g_2	S.E. of g_2
West Coast (South)	—0·888	·309	1·090	·614
West Coast (North)	—0·839	,,	0·656	,,
West Coast	—1·065	,,	1·258	,,

g_1 indicates the asymmetry of the distribution; the negative values show that values higher than the mean are slightly more frequent. g_2 is a measure of the kurtosis; the positive values of g_2 indicate higher frequency of extreme and modal values than in a normal distribution.

3. Search for factors which may be influencing the date of establishment of the southwest monsoon along the West Coast of India

The main features of the atmospheric circulation over India associated with the southwest monsoon have been discussed by many workers, notably Blanford (1889), Harwood (1924), Simpson (1921), Wagner (1931), Ramanathan and Ramakrishnan (1938) and Banerji (1950). The strong "north to south" pressure gradient over India during winter weakens rapidly in the pre-monsoon or summer months, March to April, before developing into a strong "south to north" pressure gradient over the country associated with the monsoon season. Early in summer the meridional pressure gradient weakens. The early reversal of the pressure gradient in any year may indicate an earlier onset of the monsoon. This factor is adequately represented by the date of equalisation of pressure at Lahore in the north and Bangalore in the south. Owing to ambiguity of dates in some years, however, we have later substituted for this factor the difference of pressures between Cochin and Jaipur in April.

In addition, a large number of world weather factors in March, April and May and sometimes as early as the preceding October was examined. Among them those which appeared to be associated with the date of establishment of the southwest monsoon are listed below—

1. Seychelles rainfall in April
2. Mean westerly component of upper winds over Agra* during 1st half of May from 1 to 3 km
3. Darwin pressure in April
4. Cochin pressure minus Jaipur pressure in April
5. South Rhodesian rainfall during October to April
6. South Rhodesian rainfall in April
7. Java rainfall during October to February.

* As Agra upper winds are not available after 1941, the average of Delhi and Gwalior upper winds at corresponding heights during the overlapping period 1938 to 1941 were compared and found to be a suitable substitute for Agra winds. The series after 1941 refer to (*Delhi* + *Gwalior*)/2 and hereafter we will be referring to this as "Agra winds"

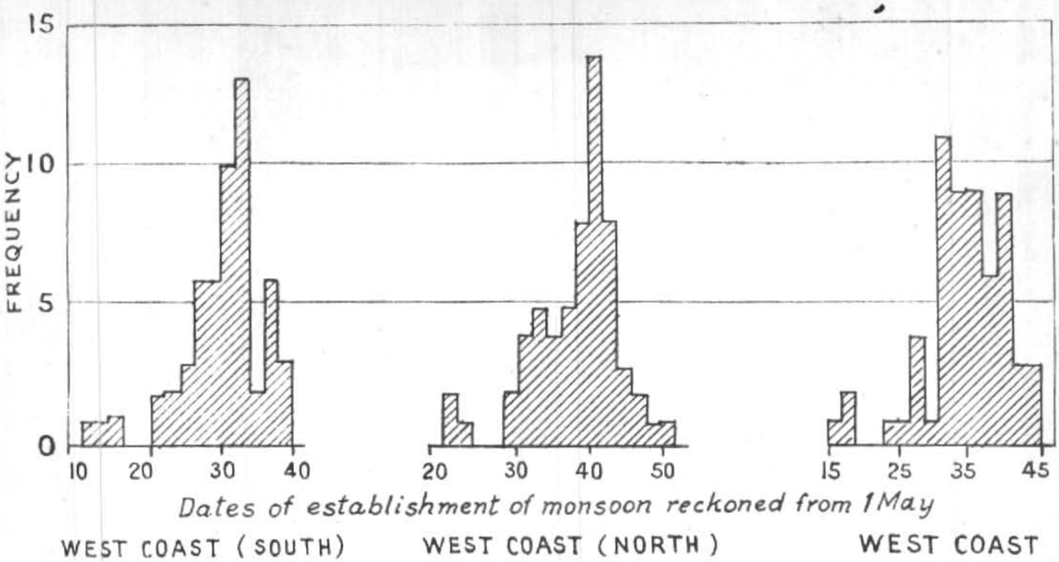

Fig. 3. Frequency diagrams of dates of establishment of Southwest monsoon

TABLE 3

Correlation coefficients

Factor	Date of establishment of monsoon (A) in :							
	Travan-core-Cochin	South Kanara	Ratna-giri	Kolaba	West Coast South	West Coast North	West Coast	Period for which data utilised
Seychelles rain in April (B)	·4155	·3191	·3602	·3494	·3886	·3565	·4300	1899-1950
Agra mean west winds 1 to 3 km, May 1st half (C)	·2782	·3278	·2506	·2613	·3142	·2568	·2967	1914-1929 1931-1950
Darwin pressure in April (D)	·1107	·2705	·2470	·2830	·1953	·2658	·2114	1891-1950
Cochin pressure *minus* Jaipur pressure in April (E)	−·2614	−·3354	−·2851	−·2825	−·3083	−·2845	−·2975	1899-1950
South Rhodesian rainfall October to April (F)	−·1670	−·1589	−·3371	−·3143	−·1646	−·3304	−·3024	1906-1950
South Rhodesian rainfall April (G)	−·2797	−·1584	−·2080	−·2434	−·2339	−·2239	−·2908	1899-1950
Java rain October-February (H)	−·1284	−·2188	−·2974	−·2962	−·1791	−·2983	−·2237	1899-1950

Table 3 gives the product-moment correlation coefficients between the " date of establishment of the southwest monsoon " (A) and all the seven factors mentioned on p. 308.

In interpreting the above correlation coefficients it should be remembered that a positive correlation indicates that a high value of the factor is associated with a delayed monsoon while a negative correlation indicates that a high value of the factor is associated with an early monsoon. Thus factors B, C and D belong to the 1st category while E, F, G and H belong to the latter.

While excessive rains in April in Seychelles indicate a late arrival of the monsoon, an excessive rainfall in South Rhodesia and Java indicates an early monsoon. A weakening of the westerly component of upper winds at Agra (1 to 3 km) in the first half of May also suggests an early monsoon and so does a negative departure of April pressure at Darwin. It may be mentioned that the correlation coefficients in Table 3 are sufficiently high to justify their use further in this investigation. The inter-correlations between the factors is shown in Table 4.

TABLE 4

Inter-correlation coefficients

	C	D	E	F	G	H
B	−·0713	.0815	−·2108	−·0479	−·0500	−·3003
C		.0012	−·0858	−·1983	−·2233	.1767
D			−·1041	−·1813	−·1654	−·2663
E				−·0884	.2 19	·0878
F					·2521	·4310
G						·2311

From the above we see that Java rainfall (H) is associated with rainfall in South Rhodesia (F, G) as well as in Seychelles (B), indicating that the factors above mentioned are not essentially *all different* or independent of each other and that a proper choice of the factors from amongst these can be made to provide the best multiple correlation coefficient.

4. Formation of Regression Equations

Using the correlation coefficients in Tables 3 and 4, the normal equations for the various combinations of the factors with the date of establishment (A) of the southwest monsoon over the different areas were formed and the regression coefficients calculated. Table 5 gives the regression coefficients in the different regression equations and their multiple correlation coefficients (R). The departure from mean of the element to be forecasted can be calculated by the addition of the proportionate departures of the independent variates, *e.g.*, the expected departure of the date of establishment of the monsoon over, say, West Coast in a particular year can be calculated from the equation :

$$[A]=0\cdot528\,[B]+0\cdot467\,[C]-58.482[E]-0\cdot312\,[F]$$

with a multiple correlation coefficient $R=0\cdot69$. Departure from mean of the variates are indicated by enclosing the symbol for the variate in square brackets.

The significance of the R has been tested with the aid of Wishart's Table (1928) and the values which are significant at the 5 per cent and 1 per cent levels are indicated in Table 5 by single and double asterisks respectively. It may be seen that except formula No. 5·4 which is significant only at the 5 per cent level, all others are significant at the 1 per cent level.

Seychelles (4°37′S, 55°27′E) rain in April, the westerly components of upper winds over Agra (27°10′N, 78°02′E) in the first half of the month of May, have been found to be important factors influencing the date of establishment of the monsoon on the West Coast. The south to north pressure gradient in the month of April over the Indian sub-continent as measured by the difference of pressure over Cochin (9°58′N, 76°14′E) and Jaipur (26°55′N, 75°50′E) has also been another sensitive factor though its influence is slightly less. The equatorial pressure as measured by pressure over Port Darwin (12°28′S, 130°51′E) has also given useful indication of the probable date of establishment of the southwest monsoon over the West Coast. South Rhodesian rain (mean of about 360 stations) during the period October to April is another factor influencing the date of the establishment of the monsoon particularly over the West Coast North ; April rain alone, appears to have a controlling influence so far as West Coast South is concerned.

It will now be necessary to examine the values of the date of establishment (A) as calculated by the regression formula as against the actual series of dates. In Fig. 4 are shown comparatively the actual dates of establishment of the southwest monsoon over the West Coast as a whole, over the West Coast South and West Coast North and the dates as calculated by the use of the regression formulae Nos. 7·3, 5·2 and 6·2 respectively (see Table 5). It will be seen that there is a fairly close agreement between the calculated and the actual dates except in a few of the years.

If we represent the actual series of dates by A_r, their deviations from the mean date by a_r and the deviation as calculated by the use of the regression formulae as C_r then $a_r = C_r + \varepsilon_r$. Here ε_r is the residual portion of the departure which has not been accounted for by the regression equation. This may partly be due to random variations and perhaps also to causes yet to be discovered. Obviously, the mean value of ε_r is zero since $\Sigma a_r = \Sigma C_r = 0$. The series of residuals ε_r indicate the variation in the unpredictable portion of the element. In order that our forecast may be useful, it is essential that $\sigma_\varepsilon < \sigma_c$ where σ_ε is the standard deviation of the residuals and σ_c is the standard deviation of the dates of establishment calculated. The reduction in the variability of the residuals from that of the element forecasted measures the efficiency of the regression equation.

TABLE 5

Regression Equations

Area for which forecast is required	S. No. of formula	Seychelles rain in April	Mean west winds over Agra during 1-15 May 1km+2km + 3 km	Darwin pressure in April	Cochin pressure *minus* Jaipur pressure in April	South Rhodesian rain October to April	South Rhodesian rain April	Multiple C.C.
		B	C	D	E	F	G	R
Mean		7″·39	14·9 mps	29″·861	0″·060	26″·94	0″·97	
Standard deviation		4″·46	4·9 mps	0″·028	0″·022	7″·22	0″·72	
Travancore-Cochin	1·1	·645	·379		—39·046		—1·764	·56**
South Kanara	2·1	·458	·433	62·102	—62·080			·60**
Ratnagiri	3·1	·460	·410	40·165	—55·585	—·310		·66**
Kolaba	4·1	·459	·420	49·579	—53·354	—·287		·66**
West Coast South	5·1	·561	·410	45·097	—48·765		—·694	·60**
	5·2	·566	·431	47·779	—52·702			·59**
	5·3	·529	·396		—54·522		—·978	·56**
	5·4	·473		41·497	—54·581		—1·311	·50*
West Coast North	6·1	·459	·416	44·632	—54·420	—·302		·64**
	6·2	·521	·435	50·611		—·284		·63**
	6·3	·424		46·116	—62·232	—·248		·57**
West Coast	7·1	·554	·463	34·544	—51·932	—·285		·70**
	7·2	·553	·449	33·652	—49·500	—·275	—·364	·70**
	7·3	·528	·467		—58·482	—·312		·68**
	7·4	·515		36·222	—60·665	—·225		·59**

**Significant at the 1% level *Significant at the 5% level

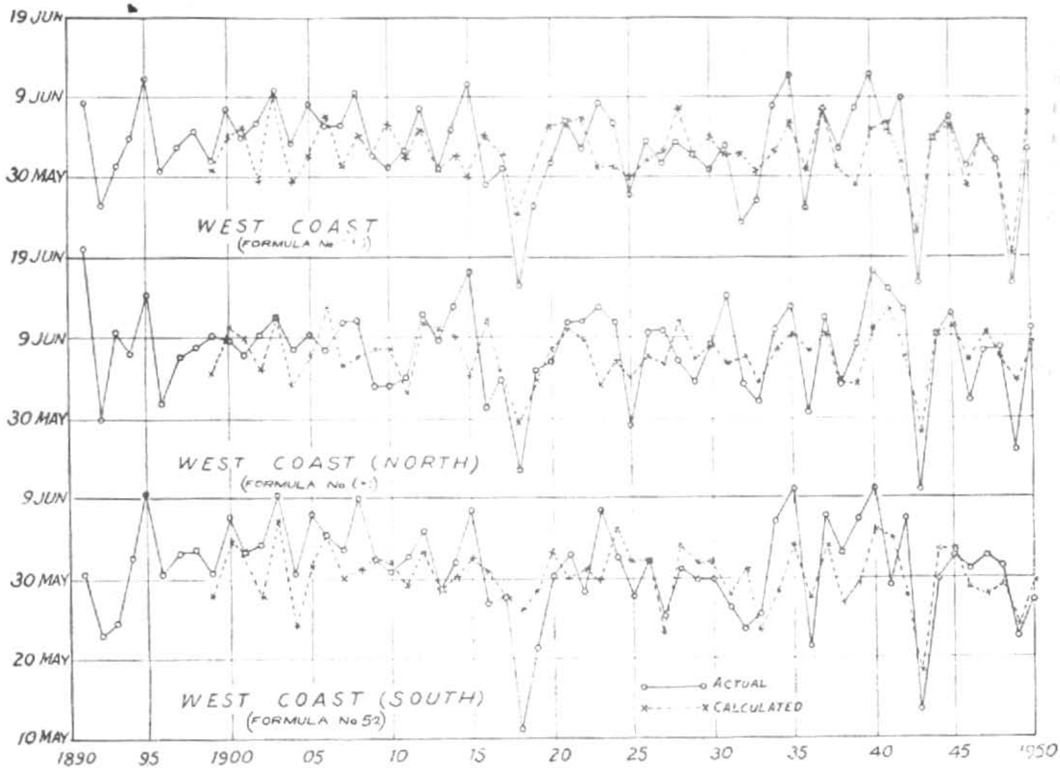

Fig. 4. Date of establishment of monsoon year by year

As exact predictions are not possible, we have necessarily to be content with certain specified probabilities of occurrence. If the distribution of ε population is known, the limits within which ε will lie for the specified probability, can be calculated and with the same probability the limits for the dates of establishment of the monsoon can be stated as

$$A + C + l \text{ and } A + C_r + l'$$

5. Normality of the residuals

As may be seen from the values of g_1 and g_2 given below, the residuals can be considered to be distributed according to the normal law of error.

	g_1	SE (g_1)	g_2	SE (g_2)
West Coast	0·3803	·3304	−0·1835	·6500
West Coast South	0·2930	,,	−0·3734	,,
West Coast North	0·2730	,,	−0·3386	

The sequence of residuals were also tested for randomness in the order of their distribution in the usual manner and no evidence against randomness was forthcoming.

Now with this series of residuals which is distributed normally and occurring in a random order, we will be able to set the limits for the dates of establishment in a particular year with a calculated value of the departure of C_r, the limits being chosen from the table of frequencies in a normal distribution.

It will be interesting to examine the years in which high deviations have occurred. Table 6 gives the years in which the southwest monsoon established itself earlier or later by more than a week than the calculated deviations could indicate.

Now, if we look up a table of probability integrals for normal frequency distribution, we can find that in the case of West Coast, we can expect 5·6 per cent of the occasions

TABLE 6

	Years in which monsoon established over		
	West Coast	West Coast (North)	West Coast (South)
Earlier than anticipated by more than a week	1918, 1932	1916, 1936, 1949	1918, 1919, 1932
Later than anticipated by more than a week	1902, 1915, 1923, 1939, 1942	1915, 1923, 1931	1908, 1923, 1934, 1939, 1942

when positive deviations greater than 7 days can occur (*i.e.*, in about 3 years out of 52 years) and an equal proportion of negative deviations greater than 7 days. The normal figures for West Coast (North) and West Coast (South) are 6·7 per cent (*i.e.*, in about 3 to 4 out of 52 years) and 8·8 per cent (*i.e.*, in about 4 to 5 out of 52 years) respectively. Thus we see that deviations as have been observed are in no way abnormal as there is good agreement between the expected and actual frequencies. Further, it may be mentioned that deviations of 2 weeks or more can still occur on 1 to 2 out of 1000 occasions in the West Coast and West Coast North and about 3 in 1000 in the case of West Coast South. In fact a deviation of 16·0 days has occurred in 1918, *i.e.*, the monsoon established itself on the West Coast (South) more than a fortnight earlier than could have been anticipated from the regression equation.

When we examine in closer detail the departures contributed by the different factors in the above exceptional years, it is seen that in the years 1902, 1908, 1916, 1919, 1923, 1931, 1932, 1934, 1936, 1939 and 1942, the factors were giving conflicting indications and as such in those years all that could have been indicated was that the date of establishment of the monsoon would not differ very much from the average and in fact this was the case in the above years.

In the years 1918 and 1949 three of the factors, *viz.*, Seychelles rain, winds over north India and Darwin pressure were indicating an early monsoon while south to north pressure gradient over India and rain in South Rhodesia were pointing towards a late one. In the aggregate, the factors did indicate an early monsoon, but the monsoon established much earlier than anticipated from these factors.

In 1915 Darwin pressure, Seychelles rain and south to north pressure gradient over India were pointing towards a late monsoon while winds over north India and South Rhodesian rain were favourable for an early monsoon. There were indications for the establishment of the monsoon by the normal date but it took another fortnight for the next stronger pulse to push the monsoon up the West Coast.

6. Forecasts based on the formulae

In computing the forecast formulae that are referred to above, use has already been made of the data up to 1950. We may now see what would have been the predictions relating to the date of establishment of the southwest monsoon in the later years, *viz.*, 1951, 1952, 1953 and 1954.

In 1951 : " Agra winds and South Rhodesian rain are both strongly indicative of a late monsoon in the West Coast North and West Coast as a whole while Darwin pressure is strongly in favour of an early monsoon both in West Coast North and West Coast South and Seychelles rain and south to north pressure gradient over India are indifferent. As the factors are conflicting, all that could be stated is that the date of establishment of the monsoon over the West Coast is not likely to be far from normal. "—Actually the monsoon established a day later in the West Coast South and four days earlier in West Coast North and for the West Coast as a whole it was practically on the normal date.

In 1952 : " Agra winds are strongly indicative of a late monsoon over West Coast South as well as West Coast North, Seychelles rain and Darwin pressure also favouring the same. South Rhodesian rain is suggesting an early monsoon over West Coast and strongly pointing to the same as regards West Coast North, the south to north pressure gradient over India remaining indifferent. The factors are somewhat conflicting and the statistical indications are that the monsoon is likely to establish along the West Coast not far from the normal date."—Actually the monsoon established itself on the West Coast on 2 June.

In 1953 : "Agra winds and Seychelles rainfall are indicating a late monsoon while South Rhodesian rain and Darwin pressure are indicating an early one and south to north pressure gradient over India is indifferent. The factors are conflicting but there is a 4 to 1 chance of the monsoon establishing itself later than 3 June"—Actually the monsoon established itself on 8 June on the West Coast South and in West Coast North on the 13 June.

In 1954 : "Seychelles rain and Darwin pressure are very favourable for early monsoon, south to north pressure gradient over India slightly unfavourable. South Rhodesian rain unfavourable and upper winds over North India very unfavourable. Indication of the forecasting factors are conflicting but it appeared that with a four-to-one chance it can be predicted that in

(*i*) the West Coast South comprising of Travancore-Cochin and South Kanara, the monsoon will establish earlier than 1 June and

(*ii*) the West Coast North comprising of Ratnagiri and Kolaba, the monsoon will establish earlier than 9 June.

Actually the monsoon established on the West Coast South about 1 June and in the West Coast North by 8 June 1954.

7. Conclusion and acknowledgements

Further investigation of this problem as well as the exploration of the possibilities of predicting the breaks that occur during the monsoon season are in progress.

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