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Methods of Foreshadowing Monsoon and Winter Rainfall in India

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1. *Introduction*

THE first official monsoon forecast was issued in 1886, and attempts have been made each year since then to foreshadow the rainfall of the coming season. In these attempts the India Meteorological Department has been a pioneer, being the first among the meteorological services in the world to undertake a systematic and scientific study of world weather for the particular purpose of predicting a season's rainfall in advance.

Although these forecasts have been issued in India for more than half a century and are notified through the medium of newspapers, their scope and significance are not always quite clear to the general public. This paper is intended to explain briefly and simply the methods used in long-range forecasting, the scope of the forecasts issued and also the degree of their reliability, so that the public may have a clearer idea as to how the forecasts are to be interpreted and to what extent they can be depended upon.

2. *Short-range and long-range forecasts,—their respective scope and utility*

Prediction of weather, although it is by no means the only duty of a meteorological department, is the one best known to the general public. These predictions are ordinarily for 24 or 36 hours ahead and describe the kind of weather and especially the rainfall likely to be experienced in different parts of the country during the period specified. These are the short-range forecasts designed to inform sailors and airmen as well as to serve the day to day needs of the general public. It is obvious that other kinds of forecasts would be still more useful, particularly for the farmers especially those in which the kind of weather, the rainfall or temperature is foretold for three days or a week or a month in advance. However, the longer the period a forecast is framed to cover, the more uncertain and vague it tends to become. Thus, while a meteorologist may undertake to predict the likelihood of rainfall and its approximate amount over any particular areas during the next 24 or 36 hours, and would, under certain favourable conditions, be able to say about what time of the day or night the rainfall is likely to occur, it would be impossible for him to predict what the total rainfall at one particular place or in one particular small district will be during the next two or three months, or what will be the daily or weekly distribution of rainfall over a region during the next three months. All that can be achieved in a seasonal forecast is the probable departure from normal of the season's rainfall over a fairly extensive region as, for example, the *Peninsula or northwest India*. A forecast of this kind becomes of less use, the smaller the area in which one is interested, or the more one wishes to know in detail the variations of rainfall from week to week or place to place during any one season. It does, however, give some useful information to those who are interested in the total rainfall of the season over the region as a whole or a large part of the region from the point of view of agriculture, irrigation or water supply.

The scope and utility of a long-range, seasonal forecast are thus very different from those of the daily, short-range forecast. The methods of analysis used in them are also altogether different. The former is drawn up after a careful examination of the full daily weather charts of the region—and its surroundings—with which the forecaster is concerned, the analysis being partly based on an application of meteorological physics and partly on the forecaster's experience of past weather charts. Until recent years these daily "synoptic" charts mainly contained information only of meteorological elements recorded at ground level only, but these are now supplemented by winds and a few temperatures and humidities aloft. The synoptic charts thus furnish a forecaster with a picture of the atmospheric structure of the air over his region, which with his knowledge of its physical properties, enables him to say what the sequence of weather is likely to be. The different masses of air which make up the structure do not remain stationary but are in a state of constant motion. The structure is, therefore, in a state of continual change in its details from day to day, and the weather phenomena associated with the structure accordingly undergo corresponding variations in detail. This is the reason why an analysis of the synoptic charts of any one day does not allow a forecaster to predict the weather for more than a day or two ahead.

The above being the case, one may naturally wonder how it is possible to issue any forecast at all covering a period as long as two to four months, the shortest and the longest period of the seasonal forecasts issued by the India Meteorological Department. That it has been possible to issue such forecasts is due to the following reasons.

In the first place, seasonal forecasts in India deal with only one meteorological element, namely rainfall, which in a country, which is mainly agricultural, is much more important than pressure, or temperature, etc. Secondly, rainfall is caused by rising air; and hence abnormal rainfall over a large area during a season signifies that there has been an abnormal physical phenomenon occurring, namely, the rising of an unusual amount of air. Local individual rainfalls may, however, have but little physical significance. Also, it is well-known that even in a city like, say, Delhi, where the orography is more or less smooth it often happens that on a day when there is rain in New Delhi there is little or no rain in Old Delhi and *vice versa*. During the course of a month however the difference between the total rainfall recorded at these two places becomes proportionately less, the difference becoming still smaller when a whole season or a year is taken into account. Again, if we group together places which are orographically similar, we find that the year to year variation of the rainfall over the area as a whole is much smaller than over individual places. The restriction of the forecast to a single element and the grouping together of a large number of stations simplify the problem to a considerable extent. In India, the seasonal forecasts issued by the meteorological department are limited to a statement of the expected departure from normal of one element only, *viz*., rainfall, and the forecasts are at present issued for two major divisions of the country, *viz*., North-west India and the Peninsula.

3. *History of seasonal forecasting in India*

As has been mentioned already, the ordinary synoptic method used for daily or short-range forecasts cannot yet be applied to seasonal or long-range forecasting, and it is, therefore, necessary to attack the problem in a different way. It has also been mentioned that the scope of seasonal forecasting in India is limited at present to foreshadowing how the actual amount of rainfall in a particular season is likely to differ from the normal of that season. Now, although the normal gives one an idea of the value of the element that is to be expected on the average in any one season, the actuals of different years may vary considerably from this normal. The problem, therefore, is to find out factors which would provide one with a clue as to how the actual of the coming season is going to depart from the normal, or in other words to try to find out meteorological factors here or elsewhere, the preceding values of which bear a relationship with the succeeding values of the element to be forecasted. The first amongst the factors useful for the prediction of Indian rainfall was discovered about sixty years ago when it was observed that some great droughts in India appeared to be preceded by excessive winter or spring snowfalls on the mountains to the North and North-west of India. That is to say, excessive snowfall on the Himalayas has on the subsequent rainfall an adverse effect which lasts for as long as four months. The first few estimates of monsoon rainfall beginning with that in June 1882 made by Mr. H. F. Blanford, the first Director General of Observatories, were based almost entirely on this relationship. A search for similar other meteorological elements or factors was made by Mr. Blanford and later by his successor Sir John Eliot, who extended his search for relationships to Seychelles, Mauritius, Africa and Australia. The methods of forecasting adopted by Blanford and Eliot were, however, not quite satisfactory as these were chiefly based on the method of curve parallels, and past data available at the time being few, the deductions made by them were to a large extent liable to be affected by personal bias. Later, Sir Gilbert Walker who began his work on this problem in 1904 introduced numerical methods of correlation into Meteorology and succeeded in eliminating this personal equation from his forecasts to a very considerable measure; this defect has been completely eliminated in recent years by using the "Performance test," which has also been useful in separating significant factors from insignificant ones, in arranging the significant factors in the order of their reliability, and in the search for fresh factors.

4. *Facts about India's Rainfall*

There is a wide variation in the distribution of rainfall in the different parts of India. For instance, during the South-west monsoon, some parts of the Konkan and Malabar receive rainfall of nearly 100 inches, while some parts of Sind receive less than 2 inches. There are many contributory causes for these variations, and, therefore, for seasonal forecasting it is important to select geographical divisions in such a way that rainfall over each as a whole is effected by the same set of causes or factors. For the monsoon rains (June to September), the three divisions adopted are defined below :—

(*a*) *The Peninsula* — This comprises Gujarat, the Konkan, the Bombay Deccan, the Central Provinces, Hyderabad and the North Madras Coast.

(*b*) *North-west India.*—This includes the United Provinces West, the Punjab, Kashmir, the North-West Frontier Province and Rajputana.

(*c*) *North-east India.*—This comprises Bengal, Assam, Bihar and Orissa.

For August and September rains, the North Madras Coast is omitted from the above definition of "The Peninsula"; and the whole of the "United Provinces" is included and Kashmir is excluded in the definition of north-west India.

For the winter precipitation, north-west India is assumed to comprise the western Himalayas, the United Provinces, the Punjab, the North-west Frontier Province, Sind Rajputana and Gujarat.

The areas included in the different divisions are different in the different seasons and are determined largely by the factors which control a particular distribution of rainfall in a particular season and not by geographical consideration.

Over the different divisions there are hundreds of raingauge stations. The rainfall data of all these stations which extend over periods of 50 years or more have been collected together and analysed statistically. From this analysis, the following important results have been deduced :—

Facts about India's rainfall.

	Normal Rainfall (Inches).	Extremes of variations. Amount and Year.	Standard Deviation. (Inches)	Limits (in % of normals) within which rainfall is expected to lie on a 4 to 1 chance of success.	Lowermost limit below which rainfall is not expected to fall on a 4 to 1 chance of success.
				%	%
Monsoon Rainfall— June to Sept.					
Peninsula (1875-1940)	34·1	−16·6, 1899 +10·3, 1878	5·1	±19	87
North-west India	19·4	−11·6, 1877 +14·0, 1917	4·6	±30	80
North-east India (1875-1929 only)	52·6	− 9·9, 1884 + 8·0, 1922	4·1	±10	93
Monsoon Rainfall— August and Sept.					
Peninsula	16·9	− 8·9, 1899 +10·8, 1878	3·9	±30	81
North-West India	11·0	− 9·2, 1877 +10·4, 1917	3·8	±44	71
Winter Precipitation— Jan. to March.					
North-West India.	2·8	− 2·1, 1902 + 3·7, 1911	1·3	±58	63

Taking the data for the years 1875-1940, the average value of the monsoon rainfall (June to September) over the Peninsula taken as a whole is 34·1 inches. There is, however, a large variation from year to year. In 1899, the rainfall was as low as 17·5 inches, and in 1878 it was as high as 44.7 inches. A measure of the dispersion in the different years from the normal value is given by the statistical quantity, known as the "standard deviation," which in the case of the peninsula rainfall, June to September, comes out to be ± 5·1 inches or ± 15% of the normal. For northwest India, the average value of rainfall during June to September obtained from the data of the years 1875-1940, is 19·4 inches. In 1877, the rainfall over this area was as low as 7·8 inches and in 1917, it was as high as 33·4 inches. In this area, the variability of rainfall from year to year is greater, and the standard deviation is ± 4·6 inches or ± 24% of the normal.

The normal value of the winter precipitation, January to March, in North-west India, is 2·8 inches. The rainfall was, however, as low as 0·7 inches in 1902 and as high as 6·5 inches in 1911. The variation from the normal from year to year is considerable, and the standard deviation is ±1·3 inches or ±46% of the normal.

In the case of monsoon rainfall, June to September, over north-east India, the variation from year to year is small. The normal value is 52·6 inches; the lowest value was 42·7 inches in 1884, and the highest 60·6 inches in 1922. The standard deviation is only ±4·1 inches or only about 8% of the normal.

5. *Standard 80% expectation based on past behaviour of season's rainfall, or an intelligent layman's forecast*

The climatological data based on past events, particularly when these are expressed in the form of a frequency table or a frequency diagram to show the percentage of observations falling within definite limits, give one a rough indication of what is ordinarily to be expected in a season. For instance, an examination of the records of 55 years (1875-1929) of June to September rainfall in north-west India shows that the departure from normal exceeded $\pm 30\%$ in only 12 out of 55, *i.e.*, in about 22% cases. A more detailed statistical calculation based on actual departures during the above period of 55 years shows that there is only a 20% chance that the departure of rainfall may fall outside the limits of 33%. A knowledge of the past rainfall alone, without any information at all about associated meteorological factors, would, therefore, enable one to foreshadow with an 80% chance of success that "June to September rainfall in north-west India will be within 33% of the normal". Yet another form of forecast based on the past history of rainfall which would also be correct in 80% cases would read.—

"Rainfall in north-west India during the period June to September will not be less than 79% of the normal".

We may call these "an intelligent layman's forecasts", or the "standard 80 per cent. expectations". Similar forecasts or expectations with 4 : 1 chance of success in the case of seasonal rainfall in other areas would be as follows :—

Peninsula rain .. (*June-September*)	.. "June to September rainfall in the Peninsula will be within $\pm 20\%$ of the normal", or "June to September rainfall will not be less than 87% of the normal".
Peninsula rain .. (*August-September*)	.. "August-September rainfall in the Peninsula will be within $\pm 31\%$ of the normal", or "August-September rainfall will not be less than 80% of the normal".
North-west India rain (*August-September*)	.. "August-September rainfall in north-west India will be within $\pm 46\%$ of the normal", or "August-September rainfall will not be less than 71% of the normal".
North-west India rain (*January-March*)	.. "January-March precipitation in north-west India will be within $\pm 58\%$ of the normal", or "January-March precipitation will not be less than 63% of the normal".
North-east India rain (*June-September*)	.. "June-September rainfall in north-east India will be within $\pm 10\%$ of the normal", or "June-September rainfall will not be less than 93% of the normal".

These laws obtained from a statistical analysis of the past data give valuable information but if a forecast is made of the probable rainfall based on these laws alone, it will not be of much practical value, because the range between the two limits within which the amount of rainfall may be expected to be is considerable, except in the case of north-east India. Moreover, the forecast from year to year will remain the same and, therefore, no previous indication will be obtained of the tendency of the coming rainfall to deviate from the normal.

It is possible to bring the two limits, within which the amount of rainfall in a season may be expected to be nearer each other, and also to get information regarding the position of the two limits with respect to the normal rainfall, if we are able to determine any significant relationship between previously existing meteorological conditions over any part of the world and the rainfall over the three divisions. With this object in view a world-wide search was made of factors which may have relations with India's rainfall, and hundreds of correlation coefficients were worked out.

6. *Method in use for preparation of seasonal forecasts*

The method of forecasting developed by Sir Gilbert Walker and at present followed by the India Meteorological Department is based on the above principle, and it seeks to determine a few major factors that have significant relationships with the element to be forecast, to determine their correlations with the latter and among themselves, and thence to deduce the multip'e regression equation of best fit, and the multiple correlation coefficient.* The extensive and intensive searches carried on over a number of years yielded a large number of factors, local as well as extra-Indian, which appeared to show certain relationships with Indian rainfall. A selection out of the numerous factors so found was made by applying a test of significance, now known as "Walker's test," and 28 factors were ultimately chosen for the six forecasting formulae,—2 for the rainfall of the Peninsula, 3 for that of northwest India and 1 for that of north-east India, which were finally worked out by Sir Gilbert Walker in 1924 shortly before his retirement. A few of these factors were, on being tested in subsequent years, found to have become insignificant and were omitted from the formulae, and one or two new factors added to the lists. Also, owing to certain reasons which will be explained later, the issue of forecasts of monsoon rainfall in northeast India was discontinued after some time. The factors in use at present in connection with the remaining 5 forecasting formulae are as follows :—

Element forecasted	Factors used.	
(A) Winter (January-March) precipitation in north-west India, comprising the western Himalayas, the United Provinces, the Punjab, the North-West Frontier Province, Sind, Rajputana and Gujarat.	1. Western rain (December)	(I)
	2. Agra west upper winds, $\frac{1}{2}$ (second half of Sept and first half of October).	(IV)
	3. Port Blair rain (December)	(III)
	4. South America pressure (December).	(II)
(B) Monsoon (June-September) rainfall in the Peninsula, comprising Gujarat, the Konkan, the Bombay Deccan, the Central Provinces, Hyderabad and the North Madras Coast	1. South Rhodesia rain (October-April)	(I)
	2. South America pressure. $\frac{1}{2}$ (April and May)	(II)
	3. Dutch Harbour temperature 1/5 (Dec.-April).	(III)
	4. Java rainfall (October-February).	(IV)
(C) Monsoon (June-September) rain in north-west India, comprising the United Provinces West, the Punjab, Kashmir, the North-West Frontier Province and Rajputana.	1. South America pressure, $\frac{1}{2}$ (April and May).	(II)
	2. South Rhodesia rain (October-April)	(I)
	3. Snowfall accumulation on the Western Himalayas (May).	(V)
	4. Equatorial pressure, i.e., pressure at Zanzibar and Seychelles, $\frac{1}{3}$ (February and March), Batavia $\frac{1}{4}$ (Jan.-April) and Port Darwin $\frac{1}{3}$ (March-May).	(III)
	5. Dutch Harbour temperature, $\frac{1}{2}$ (March and April).	(IV)
(D) Rainfall (August-September) in the Peninsula, comprising Gujarat, the Konkan the Bombay Deccan, the Central Provinces and Hyderabad.	1. Local pressure (July)	(I)
	2. Mauritius pressure (July)	(III)
	3. Java rain (October-February)	(IV)
	4. South Rhodesia rain (October-April)	(II)
(E) Rainfall (August-September) in north-west India, comprising the United Provinces, the Punjab, the North-West Frontier Province and Rajputana.	1. Local pressure (July)	(III)
	2. Mauritius pressure (July)	(IV)
	3. South Rhodesia rain (October-April)	(II)
	4. South America pressure, $\frac{1}{2}$ (June and July).	(I)

Note :—Roman figures within brackets in the last column indicate the latest order of reliability of the factors

**Note* —A mathematical measure of the relationship between the variations of two changing quantities is given by what is called the *correlation coefficient* between the two quantities. The greatest numerical value which the correlation coefficient can have is 1 and this is obtained when the correlation is *perfect*. *i e*, when the deviation of one quantity from its mean is always exactly proportional to the deviation of the other quantity from its mean. An example of perfect correlation is that between the mass and volume of different quantities of water at the same temperature. In the opposite extreme is *zero correlation* which obtains when the change in the two quantities is entirely unrelated An example of this would be the rainfall in a certain area and the average height of individuals in that area. Between these extremes come the usual correlations, as for instance the correlation between the height of a father and the height of the son at a certain age.

Let us consider the factors used in connection with (A) above. It is well-known that the winter precipitation in north-west India is associated with a series of disturbances which enter India from the west. Tracing these disturbances backwards, one finds that a number of them are continuations of depressions which previously affected the Mediterranean and south-west Europe. The paths of these disturbances lie across the extreme north of India in the autumn months, but tend to move to more southerly latitudes as the season advances. Their activity becomes evident in the regions to the west of India (like the Persian Gulf coast, Iran and Baluchistan, etc.), at an earlier date than in the plains of India, and therefore, the rainfall in December in the western regions, *i.e.*, the "western rain (December)" serves as an indication of their activity in India in the subsequent months. The correlation coefficient between this factor and the winter rains in north-west India is, *according to the latest computation*, +.36.

Again, it was found that the westerly current over Northern India, which is the distinguishing characteristic of the major circulation of the atmosphere over Northern India in winter, makes its appearance at the higher levels even as early as the close of September and the beginning of October. The late Mr. J. H. Field, who was the pioneer in the measurement of upper winds over India generally and over Agra in particular, showed that the strength of these westerly winds over Agra in the later half of September and the first fortnight of October gave a good indication of the coming intensity of the winter rains. The data so far collected shows that this factor has a correlation coefficient of +·48 with January to March precipitation in north-west India.

On the other side, the December rainfall in the south-east of the Bay, as measured at Port Blair, indicates how the monsoon current is retreating southwards from Indian Waters. The later the monsoon withdraws than normally, *i.e.*, the higher the excess of the December rainfall at Port Blair above the normal, the poorer is likely to be the winter rainfall in the north-west India. This is indicated by the negative sign of the correlation coefficient which is −·21.

While the above factors give indications of development over India and its neighbourhood, South American pressure in December has been found to give an indication of the magnitude of the major oscillation between the two hemispheres, and this has been found to have an influence on the winter precipitation over north-west India. The correlation coefficient of the factor is +·41.

With the help of the above four correlation coefficients and also the inter-correlation coefficients between each pair out of these four factors one can form a regression equation which gives the departure from normal of the winter rains in north-west India in terms of the known departures from normal of the four different factors. The latest equation in use in connection with the forecasting formulae (A) is as follows :—

$$\left.\begin{array}{l}\text{Winter precipitation in north-}\\ \text{west India (in inches).}\end{array}\right\} = \left\{\begin{array}{ll}+.602\ \text{(South America pressure)} & +\cdot418\ \text{(Western rain)}\\ -\cdot056\ \text{(Port Blair rain)} & +\cdot151\ \text{(Agra West Upper Winds.)}\end{array}\right.$$

where the expressions in brackets indicate the "proportional departures," *i.e.*, the ratio of the actual departures to their standard deviations.

Similarly, the regression equations in use for the other forecasting formulae (B), (C), (D) and (E) are :—

$$\left.\begin{array}{l}\text{(B) Peninsula rain (June—September)}\\ \text{(in inches)}\end{array}\right\} = \left\{\begin{array}{l}-\cdot258\ \text{(South Rhodesian rain)}\\ +1\cdot93\ \text{(South American Pressure)}\\ -\cdot527\ \text{(Dutch Harbour Temperature)}\\ -\cdot015\ \text{(Java rain).}\end{array}\right.$$

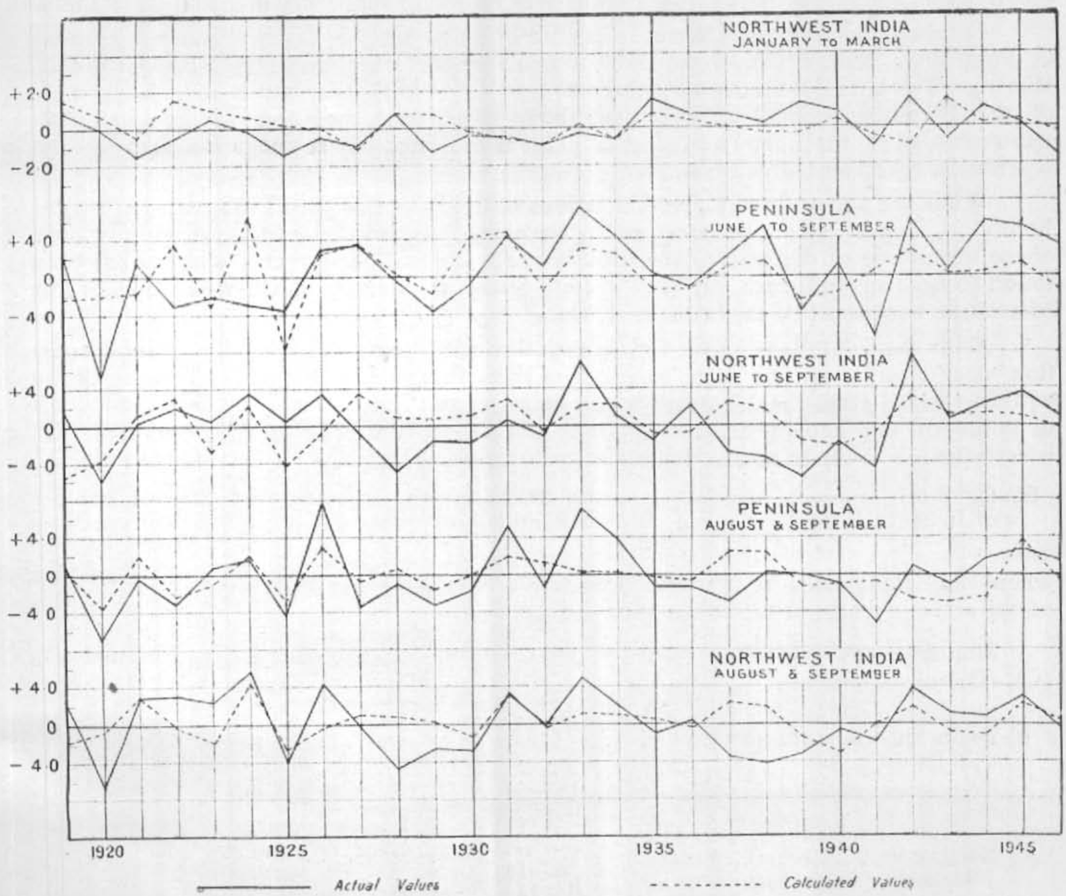
$$\left.\begin{array}{l}\text{(C) North-west India rain (June—}\\ \text{September) (in inches)}\end{array}\right\} = \left\{\begin{array}{l}-\cdot216\ \text{(South Rhodesian rain)}\\ +1\cdot68\ \text{(South American pressure)}\\ -\cdot153\ \text{(Dutch Harbour temperature)}\\ -14\cdot8\ \text{(Equatorial pressure)}\\ -\cdot754\ \text{(Snow accumulation).}\end{array}\right.$$

(D) Peninsula rain (August and September) (in inches) $\Big\} = \Bigg\{$ −35·6 (Mauritius pressure)
+22·3 (Local pressure)
−·062 (South Rhodesian rain)
−·009 (Java rain).

(E) North-west India rain (August—September) (in inches) $\Big\} = \Bigg\{$ −30·2 (Mauritius pressure)
+1·14 (South American pressure)
−3·38 (Local pressure)
−·157 (South Rhodesian rain).

Five graphs showing the values of departures from normal as calculated from the five regression equations given above, and also the actual values of departures during the twenty-eight years 1919 to 1946 are shown in the plate below. It is seen from these graphs that although the differences between the calculated and actual values were in general small, and the departures as calculated gave in most cases a correct indication of the trend of rainfall in the coming season, the two values were by no means quite the same. These differences are, however, to be expected, for all the factors governing the season's rainfall are obviously not known yet, and the maximum total correlation that we have been able to obtain between rainfall and other factors is only 0·60. As the unknown factors always have a share, the exact amount of rainfall cannot

RAINFALL DEPARTURES



possibly be obtained from the equation. Forecasts of great precision cannot, therefore, be given, and they must be allowed some latitude. That was why Sir Gilbert Walker very appropriately suggested a few years ago to replace the phrase "forecasting of rainfall" by "foreshadowing of rainfall."

7. *Cases in which the calculated value of the probable rainfall shows a large departure positive or negative, from the normal*

On those occasions when the calculated value of the probable rainfall from the regression equation shows a large excess or a large deficit a useful forecast can always be made. For instance in 1915, the calculated value of June to September rain for north-west India was -5·9 inches and actual was -7·4 inches and in 1920, the calculated value was – 4·3 inches, while the actual was -5·9 inches. In 1925 the calculated value of June to September rain over the Peninsula was -5·8 inches, while the actual was -3·6 inches; in 1931, the calculated value was +4·6 inches, while the actual was +4·2 inches; in 1942 calculated value was +4·0 inches and the actual was +6·1 inches. The following are further examples of this kind :—

Area		Year	Period	Calculated value of rainfall (inches)	Observed value of rainfall (inches)
N. W. India	..	1918	August and Sept.	–6·4	–4·8
Peninsula	..	1920	,, ,,	–3·6	–7·1
N. W. India	..	1924	,, ,,	+4·3	+5·1
Peninsula	..	1926	,, ,,	+3·5	+7·5
N. W. India	..	1927	January—March	–1·3	–1·0
N. W. India	..	1935	,, ,,	+0·8	+1·5

In all these cases the calculated value not only did agree with the sign of the actual, but did also foreshadow the large deficit or excess which was actually experienced. In those years in which the forecasting factors are mutually conflicting so that the calculated value of the rainfall does not differ appreciably from the normal, it is not possible to obtain reliable indication as to whether the actual rainfall will be above or below the normal.

8. *Standard of accuracy and the degree of latitude of seasonal forecasts*

The standard of accuracy aimed at by the Meteorological Department in issuing the seasonal forecasts is that they should be correct at least 4 times out of 5, and the latitude referred to above consists in indicating a limit below which the rainfall is not expected to fall, or limits between which the rainfall is expected to lie. The limit or limits are chosen so as to allow usually an 80 per cent chance for the forecasts being correct. An example will make the point more clear. Let us consider, for instance, the forecast that was issued in January, 1936 regarding winter (January—March) precipitation in north-west India for that year. The departure from normal, as was obtained from the regression equation was +0·6″, the normal rainfall for the season being 2·8″. Now, knowing this calculated value of the departure and certain other simple facts, one finds from statistical calculation that the chance of the rainfall of the season falling below normal by .28″ or more, *i.e.*, by 10 per cent. or more, is 16 in 100, that is, 16 per cent. only or, in other words, there was an 84 per cent. chance that winter precipitation in north-west India would not fall below 90 per cent. of the average in the year 1936. The following forecast was, therefore, issued :—

> "Rainfall and snowfall (combined) is not likely to be less than 90 per cent. of the average,"

and this forecast had an 84 per cent. chance of being correct.

A forecast as above is by no means as precise as one would like to have, and there can also be the further criticism that, while the lower limit is indicated in the forecast, no mention is made of the probable higher limit. It may, however, be added that the forecast could have been issued in a different form also, for instance, in this case the forecast might have been given as—"Rainfall and snowfall will be between 80 and 146 per cent. of the normal," and the chance of this being correct would also be about 80 per cent. The first form has the advantage that it gives an assurance that rainfall will not be below a certain specified amount (which is higher than given by the second form) and, therefore, from an utilitarian point of view is probably more helpful than the information given by the second. It is true that the forecasts in either of these forms would not be as precise as could be desired, but considering the fact that the forecast as issued would give the agriculturists and others a helpful indication that no appreciable deficiency of rainfall was to be expected in that year, it was considered useful to publish the forecast.

9. *Limitation of the methods*

It should be mentioned here that despite the use of factors in connection with these forecasts it may not in some cases be possible to indicate the probable limit or limits of rainfall of a coming season any more definitely than what is possible to do by merely studying the behaviour of the season's rainfall during the last 40 or 50 years and it is in these circumstances that the Meteorological Department withholds the issue of an official forecast.

It is, however, possible in most cases to issue a forecast which is definitely of greater value than the one which an intelligent layman could obtain by studying the variation of rainfall for 50 or 60 years. To make the point clear let us consider the forecast which was issued in January 1936 regarding winter rains in north-west India, which stated that the winter precipitation in that year was not likely to be less than 90 per cent. of the average. This forecast was obviously more precise and informative than the standard 80 per cent. expectation or an intelligent man's forecast which, in the case of winter rains in north-west India, indicates that there is an 80 per cent. chance that the total precipitation of the season in any year will not fall below 63 *per cent.* of the average. Also, it can be shown from statistical calculation that a knowledge of the past rainfall alone would allow one to issue a forecast like the one issued in January 1936 with only 59 per cent. chance of success, as against the 84 per cent. chance for the forecast based on regression equation. It is thus clear that the use of factors is as a rule, of definite help in issuing forecasts with a greater confidence of success, and that the forecasts issued in this way are generally more informative than those based on random chance. It, however, happens sometimes that the Meteorologist's forecast, inspite of the use of all the known meteorological factors, differs little from the standard 80 per cent. expectation. For instance, in connection with the issue of forecast of winter rains in north-west India in January 1938, it was found that the calculated departure as obtained from the regression equation was—0.2" With this value of the calculated departure one could only say with an 80 per cent. chance of success that the winter precipitation in 1938 was not likely to be less than 72 per cent. of the normal. But as such a forecast would have conveyed little more information than what one gathers from the study of past rainfall alone, no forecast was issued by the Meteorological Department on this occasion. Fortunately, such occasions have not been frequent in the recent past; in fact only 5 such cases arose out of a total of 38 forecasts prepared since 1931. This, however, has been an exceptionally favourable series of years, and it is expected that occasions of no forecast will be more frequent in future, as they were before 1931.

10. *Non-issue of seasonal forecasts in respect of North-east India*

It was mentioned in a previous paragraph that owing to certain reasons the issue of forecast of monsoon rainfall in north-east India was discontinued sometime ago. The reason for this discontinuance is as follows :—

A study of the past rainfall data of north-east India during the monsoon season shows that the variations of rainfall over this region from year to year are small, and, as has been stated above, the behaviour of the past rainfall figures alone would enable an intelligent layman to forecast with an 80 per cent. chance of success that rainfall in any one year would not be below 93 per cent. of the average. As the forecasting factors hitherto discovered do not enable the meteorologist usually to issue forecasts for north-east India with any greater precision than the above the practice of issuing forecasts for this area has been given up in recent years.

11. *Desired future developments*

It has been mentioned above that the seasonal forecasts are issued for large areas and cover seasons of length varying from 2 to 4 months. It has been the aim of the Meteorological Department to investigate the possibility of issuing these forecasts for smaller divisions and for smaller intervals of time. Some progress has been made, but from the very nature of the problem, progress is necessarily slow. Despite the enormous amount of labour which the Meteorological Department put into this problem during the last thirty years, the results obtained so far are still far from satisfactory. We know very fully the frequency distribution of rainfall over the different areas. We know also some of the very important pre-existing factors which control the rainfall over the two major divisions of India, namely, the Peninsula and the north-west India. All these constitute important contributions to knowledge. We do not, however, know yet all the factors which control India's rainfall. It is the aim of the department to make the forecasts more precise than they are at present. This, however, means discovery of fresh significant factors and naturally involves intensive research, while such researches may lead to an improvement here and there in the forecasting formulae, it seems unlikely that complete solution will be achieved in the near future. It is possible that part of the variation of a season's rainfall is not predictable in advance.