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INDIA METEOROLOGICAL DEPARTMENT

FORECASTING MANUAL

PART IV

COMPREHENSIVE ARTICLES ON SELECTED TOPICS

17 : MEDIUM RANGE FORECASTING

ISSUED BY

THE DEPUTY DIRECTOR GENERAL OF OBSERVATORIES (FORECASTING)

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FORECASTING MANUAL

Part IV. Comprehensive Articles on Selected Topics

17. Medium Range Forecasting

by

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1. Introduction

1.1 A weather forecast may range in time from a few hours to many days, months, or years. Between the short-range forecast covering a period of say 24 hours to a climatic forecast which may span thousands of years, we have a wide spectrum. In meteorological parlance, a forecast that is valid for a period of about three to seven days is known as a medium range forecast. Forecasts of longer duration go generally under the name of extended-range forecasts. For clarity, it is desirable to specify a medium range forecast by the exact number of days it covers. For example, a forecast valid for five days may be called a five-day forecast; one valid for seven days may be called a seven-day forecast.

1.2 Although scientific weather forecasting commenced almost half a century ago, the emphasis during the years has been, almost exclusively, on issue of short-range forecasts, primarily because of heavy demands for these forecasts for aviation and other operational requirements. Nevertheless, need for medium-range forecasts has been increasingly felt in recent years in connection with agricultural operations, military and economic planning, hydrological warning systems, etc. The importance of medium-range forecasts for a country like India whose economy is vitally dependent upon the vagaries of weather can hardly be over-emphasised.

1.3 Since the methods of medium-range forecasting developed so far are quite involved and require rather elaborate arrangement, not many countries of the world are at present preparing these forecasts. In fact, there may be in all about a dozen countries only which are actually doing so. In general, there have been two main approaches to the study of the problem - one through purely statistical method and the other through physical-cum-statistical method. The purely statistical method aims at evolving suitable regression equations connecting the predictand (the element of weather to be predicted, such as rainfall or temperature) with suitable predictors such as heights of isobaric surfaces, isobaric thicknesses, etc. In the physical-cum-statistical method, an attempt is made to understand the physical or natural evolution of large scale meteorological systems which have a period of their own and during which period they exercise their influence upon the day-to-day weather. Such meteorological systems with a period of natural evolution of their own are known differently in different countries, e.g., "grosswetter" in Germany (Baur, 19.., "long waves in the westerlies" in U.S.A., "macro-homogeneous processes" in Rus.. Early studies in the field of medium-range forecasting were directed towards learning more about the characteristics of this natural evolution of large-scale meteorological systems and the laws that govern such evolution. For this purpose, the Russians used composite charts which traced the day-to-day positions, movement and development of important systems such as troughs, ridges, fronts, etc. whereas the Americans used the five-day mean charts. From the trend of development revealed by these mean charts, long period changes in meteorological systems were predicted and the expected weather was expressed in terms of departures from climatic normals, such as "much below normal", "below normal", "normal", "above normal" and "much above normal".

1.4 In the following sections, it is proposed to present a brief review of methods that have been developed in the field of medium-range forecasting, with particular leaning towards the physical or physical-cum-statistical approach. The statistical approach which has been fairly intensively pursued in India will be reviewed in a later section while reviewing the work done in India.

2. Methods of Medium Range Forecasting

2.1 The following are some of the methods that have been developed and tried for medium-range forecasting of weather :

(i) The typing method
(ii) The analogue method
(iii) The mean circulation method
(iv) The method of natural synoptic periods
and (v) The numerical method

The essential features of these methods are stated in the following paragraphs

2.2 The typing method

In the typing method, past weather situations are classified on the basis of types and the classification is used to select a past weather situation which bears the closest resemblance to the present. The evolution of the selected situation then forms the guideline for the forecast. The success of this method depends upon the correct identification of the type and the ability to forecast its development into succeeding types. Correlation techniques are used for forecasting. Attempts have been made to obtain, i) the probability of one type of map succeeding another and ii) the relationship of subsequent positions of various centres of action to their previous positions. The typing method has been widely used in Germany (Hess et al, 1956; Hoffmann, 1957) and U.S.A. (Krick, 1942; Elliot, 1951).

2.3 The analogue method

2.3.1 The analogue method rests on the belief that similar weather situations evolve in a similar manner so that if we can find a past weather situation which is similar to the present, the evolution will be similar. Although the analogue method has been used in U.S.A. and Britain, there are a number of limitations on the success of this method. Firstly, it is the difficulty of selecting right analogues, and secondly, even if we succeed in picking up the right ones, there is no guarantee that they will evolve the same way. In actual practice, it is extremely difficult to get two charts which are quite similar in all respects. It has, therefore, been suggested that analogues should be used in conjunction with other methods, either as an aid or a check on pressure pattern prognosis.

2.3.2 While the basic approach in the typing and analogue methods is the same, viz. to find past charts similar to the current chart and use these for forecasting, the difference in the two methods lies in the technique adopted for utilising similar past charts for issuing forecast.

2.4 The mean circulation method

2.4.1 Medium-range forecasting by the mean circulation method involves four distinct steps: (a) a quantitative description of the initial state of the general circulation, (b) predicting the changes in the general circulation, (c) interpreting the predicted circulation in terms of weather and (d) deducing the day-to-day sequence of the weather within the forecast period

2.4.2 Namias and collaborators (Namias, 1947; Namias and Clapp, 1951; Jay, 1960) who evolved the mean circulation method used the well-known "index cycle" to represent the general circulation and its changes. A change in circulation indices was usually forecast after due consideration of the physical processes involved and by using statistical relationships. The influence of such factors as "confluence" and "blocking" was given due weightage in assessing changes in circulation indices.

2.4.3 Other methods used to forecast the mean circulation or the five-day mean contour pattern include use of (1) the Rossby wave formula and (2) the trend and kinematic method. Constant Absolute Vorticity (C.A.V) trajectories are also utilised to derive the directions of movement of trough and ridge systems and changes in their amplitudes.

2.4.4 The trend and kinematic method utilises the trend in contour values between the observed five-day mean chart centred two days before the day of the forecast and the five-day mean chart centred on the day of the forecast. The latter mean is obtained by taking observed values for three days and statistically derived values for two days. Petterssen's kinematic equations are then employed to derive the future positions of contour systems. The final forecast is issued after careful examination of products obtained by both the physical method and the trend and kinematic method.

2.4.5 The next step is to transform the prognosticated contour chart in terms of mean weather anomalies, such as precipitation or temperature anomalies. For this purpose, statistical relationships are used. These relationships have proved more useful in forecasting temperature anomalies than precipitation anomalies.

2.4.6 The break-up of the five-day mean weather anomalies in the form of the daily sequence is the most difficult process and to date no satisfactory method has been evolved for doing this. Both physical reasoning and statistical considerations are applied but the success is often limited.

2.5 The method of natural synoptic periods

2.5.1 This is more or less the Russian version of the mean circulation method, since the two have many features in common. First evolved by

Khrabrov (1959), the method rests on the findings of Mul'tanovskii that there are natural periods ranging from a few days to a few weeks during which "an orienting process develops in a definite manner with the sign of the field being preserved in the area of the natural region". These periods are the periods of natural evolution of a macro-homogeneous synoptic process. The most important feature of a macro-homogeneous synoptic process is the so-called high-altitude planetary frontal zone (h.p.f.z.), which is identified as the region of maximum pressure gradient or the line of maximum wind at a level. Like the index cycle, the h.p.f.z. undergoes a definite cycle of change during a macro-homogeneous synoptic process and accounts for such changes in circulation features as warm and cold advection, the number of long waves, etc. The different evolutions of the h.p.f.z. have been typed and their relationships with the wave-length of the h.p.f.z. established and these are made use of in forecasting.

2.5.2 From the observations of the behaviour of the h.p.f.z. during the first two days of a macro-homogeneous synoptic process, the future positions of the pressure or contour systems and the evolution of the h.p.f.z. are derived. Typical trajectories of pressure systems connected with a particular position of the h.p.f.z. are also utilized. Weather expected in different quadrants of the pressure systems during movement along the trajectory is then forecast. Analogues are also used for this purpose.

2.6 The numerical method

2.6.1 During the last decade or so, the availability of fast computers has made possible numerical integration of the hydrodynamical equations of motion for periods up to 96 or 120 hours and the computed values are readily available for use for medium-range forecasts of weather. Namias and his collaborators (1958) have given a detailed account of the various numerical methods currently in use in U.S. Weather Bureau. These are known as the trend method, the summation method and the basic current method.

2.6.2 In the trend method, five-day mean 500 mb chart centred on the day of the forecast (the trend map) is constructed automatically on the computer by taking observed height values for three-days and extracting the predicted height values for 24 and 48 hours from the short-range numerical forecasts. A field of 2-day height tendencies of the mean is also computed automatically and superimposed on the mean contours. The resulting fields of height and height tendency enable kinematic computation of the long-wave motion and development and assist in arriving at the forecast for the desired five-day period (which is centred four days in advance of the "trend map"). The numerically produced trend chart, by automatically including 24 - and 48 - hour numerical forecasts has made the procedure faster and more reliable than the earlier statistically-produced trend chart. The trend method permits forecasts to be made of mean state centred each day upto 4 days in advance. While such a forecast series is found to be useful, it should be borne in mind that the real atmosphere is not so simple in its behaviour and that pure extrapolation methods are bound to meet failures.

2.6.3 In the summation method, numerically integrated forecast values for four days and the observed value on the day of the forecast are taken to form a five-day mean chart centred two days in advance of the forecast day. The two-fold purpose of the summation chart is (i) to provide a mean chart two days in advance so that comparison with earlier observed mean maps and the trend charts may enable further inferences to be drawn regarding evolution of the mean state, and (ii) to derive estimates of mean temperature anomalies.

2.6.4 The basic current method constitutes, essentially, an application of the barotropic model to the five-day mean 500 mb chart, instead of the daily chart, to obtain future mean circulation patterns. Experiments carried out in U.S.A. show that the predictions by this method produce rational flow patterns but become out of phase with the observed, after a few days. The failure is attributed largely to neglect of physical processes involved in the actual atmosphere such as ocean-continent contrasts, heat sources and sinks, mountains, etc. Attempts are being made to improve the working of the current numerical model by incorporating some of these important physical factors.

3. Development of Medium-Range Forecasting in India

3.1 A scheme to study and develop methods of medium-range forecasting in India was sanctioned by the Government of India as part of the second Five-Year plan of the India Meteorological Department. In 1957, two units, one under the Deputy Director General of Observatories (Forecasting) and the other under the Deputy Director General of Observatories (Climatology and Geophysics) were set up to pursue the scheme. After the establishment of the Institute of

Tropical Meteorology, these units were transferred to the Institute from 1st April, 1965.

3.2 Methods of approach to the problem

3.2.1 In general, there have been two broad approaches to the problem of medium-range forecasting in India, viz. (a) the synoptic or synoptic-cum-statistical approach, and (b) the contingency or statistical approach.

A. The first approach consists of the following steps :

(i) to obtain useful concurrent relationships between the mean patterns of circulation and the mean anomalies in the weather elements of interest during a specified period;

(ii) to develop a reasonably good method of prognosticating the mean circulation patterns during the period for which the forecast is to be prepared; and

(iii) to forecast the mean anomalies in the weather elements by applying concurrent relationships to the mean prognosticated circulation patterns.

B. The second approach involves the following steps :

(i) to search for parameters which have useful relationships with the anomalies in weather elements in the subsequent period, and to obtain these relationships. These parameters are referred to as the 'predictor parameters' or 'predictors'; and

(ii) to obtain the forecast of the anomalies in weather elements by applying the relationships to the current values of the predictor parameters.

3.2.2 In the first approach, success depends on our ability to obtain useful relationships and to obtain an accurate prognostic chart. In view of the complex nature of the processes and interactions taking place within the atmosphere, it is impossible to obtain a one-to-one relationship and a prognostic chart of high accuracy. Hence, when we pass on from steps A(i) and A(ii) to A(iii), there is a fall in the accuracy of the forecasts since in each of the steps an error is involved. In the second approach, success depends on whether during our extensive search we are able to arrive at the most useful predictor parameters. It is, therefore, possible that we may be able to achieve reasonable success in the above mentioned exploratory steps for some areas and for some periods but not for other areas and periods and, as such, we may develop forecasting techniques for some selected areas and periods only.

3.2.3 Studies conducted so far have used five-day mean or pentad values of meteorological parameters as working tools and the predictand has been mostly five-day rainfall during the summer monsoon season. In most parts of India, 80–90% of the annual rain falls during the southwest monsoon season and the economic life of the country is largely dependent on the rains that fall during this season. Hence it is but natural that most of the studies have been directed towards the problem of forecasting monsoon rain. The problem of forecasting winter precipitation and temperature has also received some attention. A brief account of the studies carried out, following the two approaches mentioned above, is given in the following paragraphs.

3.3 The Synoptic-cum-statistical method

3.3.1 In the synoptic approach, the basic working tool has been the five-day mean 700 mb contour chart, covering an area from 50°E to 140°E and from equator to 50°N. For the portion from 60°E to 100°E and from equator to 35°N, the grid-points are at five-degree latitude-longitude intervals, while for the remaining area they are at ten-degree intervals. From the daily analysed 700 mb contour charts for 00 and 12 GMT, the contour height values are interpolated for grid-points in India and adjoining parts and these are averaged over five-day periods to obtain the mean contour charts. For the remaining area, the five-day mean contour heights are interpolated from the U.S. Weather Bureau 5-day mean 700 mb contour chart for the northern hemisphere. Mean charts are prepared for overlapping five-day periods, e.g., 5-9 July, 7-11 July, as is done in U.S.A. Five-day mean 700 mb contour grid-point charts have been prepared and analysed from 1956 to 1964.

3.3.2 Corresponding to the above charts, contour anomaly (departure from normal) charts have been prepared. These are obtained by utilising the interpolated normal 700 mb height values at the grid-points.

3.3.3 Finally, charts of anomaly of weather elements under consideration have also been prepared for all the 5-day periods under study. In the case of rainfall, charts showing anomalies (A-abnormal, N-normal and S-subnormal) for observatories in India and neighbourhood have been prepared. The five-day rainfall limits used for classifying the pentad rainfall in the three classes are generally obtained from the past 30 years' pentad rainfall data in such a way that the probability of pentad rain falling in each of the three classes is 1/3. Preliminary studies dealing with the different stages of the synoptic approach as enumerated earlier are summarised below.

3.4 Concurrent relationships

3.4.1 Rai Sircar and Lal (1960) have studied the five-day mean sea-level pressure charts and 700 mb contour charts in relation to concurrent 5-day mean precipitation over north India during two winter seasons. They find that the 700 mb charts are more helpful in locating the rainfall producing disturbances and that the mean 700 mb contour pattern of a particular type usually leads to a specific type of rainfall distribution. In general, well-marked centres of negative contour anomaly are associated with good rainfall activity over north India during winter.

3.4.2 Pant (1964) who studied the 5-day mean circulation patterns in relation to 5-day mean precipitation over India during winter has brought out the following concurrent associations :

i) abnormal (i.e. above normal) rainfall over large parts of India is usually associated with 5-day mean trough over Indo-Pakistan region;

ii) maximum spread of abnormal rain over north India also occurs when the high pressure cell over the peninsula is the weakest;

iii) the weakening of the high pressure cell over the peninsula is associated with 5-day mean trough approaching northwest India.

3.4.3 Rai Sircar, Natarajan and Joshi (1961) have examined the concurrent relationship between 5-day mean 700 mb contour height and 5-day mean surface temperature anomalies over India during winter. From the correlation coefficients worked out for 35 stations, they find that the maximum value of 0.60 of the correlation coefficient is over north Gujarat and adjoining parts of Rajasthan. They have given regression equations between 5-day mean surface temperature anomaly and 5-day mean 700 mb contour anomaly for Ahmedabad and Jodhpur.

3.4.4 Mooley (1965) has shown that the position of the axis of monsoon trough along long. 75°E and contour height anomaly along and near west coast are closely related to rainfall anomaly on west coast during July. Axis position south of lat. 25°N and negative contour anomaly are found to be favourable for abnormal rain and axis position north of 25°N and positive contour anomaly are associated with subnormal rain on the west coast. A few typical charts to illustrate these points are given in the figures 1 to 6. For some other areas also, the location of the axis of the monsoon trough appears to be related to rainfall anomaly.

3.5 Prognostication of 700 mb contour chart

3.5.1 Pant, Das and Natarajan (1965) have worked out regression equations for five areas of India, which can be used for prognosticating the 5-day mean 700 mb contour anomaly from the 700 mb contour anomaly on the first day of the 5-day period during January and July. Utilising the normal grid point height, the 700 mb prognostic contour anomaly chart can be converted into 700 mb prognostic contour height chart. The method has been tested in seven cases from July 1963 and appears to give in general, a reasonably good prognostic 700 mb contour charts. The method, however, fails under conditions when rapid changes in contour patterns take place. An extensive testing, however, would be necessary before its definite utility can be asserted.

3.5.2 Shukla and Suryanarayana (1967) have developed a method for forecasting five-day mean 700 mb contour height during July and August by the use of regression coefficients. The method is essentially based on the multiple regression equations, relating the mean height of a pentad at each radiosonde station in India to the mean heights at the 12 radiosonde stations during the pentad just preceding. The method has been tested on independent data for two years and an assessment has been made by computing the rank correlation coefficients between the observed and forecast values of 5-day mean heights of 700 mb surface. The average rank correlation coefficient is 0.64. The authors have stated that the contour height forecast may not be very accurate but the broad synoptic patterns on 5-day mean 700 mb chart can be forecast with good success by this method.

3.6 Forecasting five-day rainfall amount

Shukla (1966) has attempted to evolve a method for forecasting 5-day rainfall amount at Ratnagiri during July under situations when abnormal rainfall is forecast by other considerations. Forecast of abnormal rainfall is indicated when the axis of monsoon trough along long. 75°E is prognosticated to be south of lat. 25°N as per method developed by Mooley (1965).

3.7 Statistical approach - the contingency technique

3.7.1 The basic parameters which appear relevant are :

i) the mean contour height for the preceding non-overlapping pentad, ii) contour height trend during the preceding non-overlapping pentad i.e. the height change from the mean height for the pentad to that on the last day of the pentad and iii) mean contour height on the day preceding the pentad for which forecast is to be issued. If in addition to 700 mb level, 500 mb level also is considered, thickness between these two levels may also be considered as a basic parameter.

3.7.2 To obtain the locations at which one or more of the above parameters are significantly related to pentad rainfall anomaly during the next 5-day period, the principle of selection by contrast is used. Two types of composite charts are prepared and contrasted, one for markedly abnormal rain and the other for markedly subnormal rain. About 10 to 15 pentads with markedly abnormal rainfall in the area under consideration are selected. Contour charts, contour trend charts, contour anomaly charts for pentad just preceding these pentads of markedly abnormal rain are added and averaged to get composite charts for abnormal rainfall. In a similar way composite charts for subnormal rain are prepared. These composite charts are prepared for the area 60-100°E and equator to 35°N. Significant predictor parameters are tentatively selected from this area. The two composite charts for the two types of contrasting rainfall anomaly reveal the locations where significant differences exist. Such differences are tested for statistical significance by the t-test, the level of significance adopted being 5% level.

3.7.3 After tentative selection of significant prediction parameters, pairs of predictor parameters are graphically correlated with the rainfall anomaly of the pentad just following by means of scatter diagrams. The two predictor parameters forming a pair should as far as possible be independent. The points on each of the scatter diagrams may be divided by smooth curves into three classes α, β and γ such that the points in class α are mostly cases which fall in class 'abnormal' of the predictand, those in class β, mostly cases falling in the predictand class 'normal' and those in class γ, mostly falling in the predictand class 'subnormal'. If there are 5 predictand classes, the scatter diagram may be divided by smooth curves into 5 classes. For each of the scatter diagrams, a 3 x 3 or 5 x 5 (as the case may be) contingency table is prepared by obtaining frequency for each of the cells. Once these contingency tables have been prepared, contingency technique, as given by Wahl and White (1952), Lund and Wahl (1955), is applied to the area in question for evolving a scheme for forecasting the predictand class for the area.

3.7.4 Contingency technique may be briefly described as follows :
After the contingency tables have been prepared, it should be checked whether these contain any useful information i.e. information over and above that existing in the climatology of the predictand alone. This is done by computing Shannon Information Ratio (I_c (X)) for predictor pair X, as adapted by Holloway and Woodbury (1955).

$$I_c(X) = 1 + \frac{\sum_{i=1}^{k}\sum_{j=1}^{l} O_{ij}\log_e O_{ij} - \sum_{i=1}^{k} S_i \log_e S_i}{N\log_e N - \sum_{j=1}^{l} S_j \log_e S_j}$$

where O_{ij} is the observed frequency in the cell defined by the ith row and jth column of the contingency table,

- S_i is the marginal total of the ith row,
- S_j the marginal total of the jth column,
- N is the total frequency,
- K is the number of rows and l the number of columns in the contingency table

3.7.5 Even when no relationship exists between the predictor pair and the predictand random influences affecting I_c are possible. Hence I_E the expected information ratio on the basis of non-existence of relationship has to be computed from the formula

$$I_E = \frac{\frac{1}{2}(k-1)(l-1)}{N\log_e N - \sum_{j=1}^{l} S_j \log_e S_j}$$

3.7.6 Holloway and Woodbury (loc. cit.) have shown that confidence limits for I_E can be obtained from the following formula by utilizing χ^2 value for (k - 1) (l - 1) degree of freedom.

$$L(I_E) \text{ i.e. confidence limit for } I_E = \frac{\frac{1}{2}\chi^2}{N\log_e N - \sum_{j=1}^{l} S_j \log_e S_j}$$

The denominator is the function of the climatology of the predictand. Contingency tables for which I_S is significant at 5% or 1% level of confidence may be accepted. Out of these, three best tables may be finally selected.

3.7.7 The three selected contingency tables are converted into tables of normalised contingency ratios. R'_{ij} the normalised contingency ratio in the cell defined by the ith row and jth column, is given by the formula

$$R'_{ij} = 1 + \left(\frac{O_{ij}}{E_{ij}} - 1\right)\sqrt{\frac{k\,l\,E_{ij}}{N_o}}$$

where E_{ij} is the expected frequency in the cell defined by ith row and jth column on the basis of no relationship between the predictor pair and the predictand, and No is the largest N in the three tables.

3.7.8 Let the three 3 x 3 tables of normalised contingency ratios be as shown below :

Predictor class	For predictor pair I Predictand class A	 N	 S	For predictor pair II Predictand class A	 N	 S	For predictor pair III Predictand class A	 N	 S
α	$(R'_{11})_I$	$(R'_{12})_I$	$(R'_{13})_I$	$(R'_{11})_{II}$	$(R'_{12})_{II}$	$(R'_{13})_{II}$	$(R'_{11})_{III}$	$(R'_{12})_{III}$	$(R'_{13})_{III}$
β	$(R'_{21})_I$	$(R'_{22})_I$	$(R'_{23})_I$	$(R'_{21})_{II}$	$(R'_{22})_{II}$	$(R'_{23})_{II}$	$(R'_{21})_{III}$	$(R'_{22})_{III}$	$(R'_{23})_{III}$
γ	$(R'_{31})_I$	$(R'_{32})_I$	$(R'_{33})_I$	$(R'_{31})_{II}$	$(R'_{32})_{II}$	$(R'_{33})_{II}$	$(R'_{31})_{III}$	$(R'_{32})_{III}$	$(R'_{33})_{III}$

3.7.9 The table of normalised contingency ratios gives the probabilities of the 9 combinations of the predictor and predictand classes. Let us suppose that in an actual case, predictor class for the first pair is α that of the second pair is β and that for the third pair is γ. Then the combined probabilities for the three predictand classes A, N, S are

$$\left\{(R'_{11})_I\,(R'_{21})_{II}\,(R'_{31})_{III}\right\},\ \left\{(R'_{12})_I\,(R'_{22})_{II}\,(R'_{32})_{III}\right\},\ \left\{(R'_{13})_I\,(R'_{23})_{II}\,(R'_{33})_{III}\right\}$$

respectively, on the assumption of independence of predictor pairs. The predictand class corresponding to the largest of these combined probabilities is forecast. It is inconvenient to multiply three quantities. Hence, $10 + \log_{10} R'_{ij}$ where R'_{ij} are normalised contingency ratios, are tabulated, 10 being added to avoid negative logarithms. Quantities from the respective cells in these tables are added to find out the largest combined probability. In practice it is not necessary to refer to the tables if all the three predictor classes are identical. For example, if the identical predictor class is α , then the predictand class to be forecast is A. If the assumption of independence of predictor pairs does not hold, then in the critical case when all the three predictor classes are different the forecast of the predictand class is likely to be vitiated, the extent of vitiation depending on the extent of departure from the assumption of independence. One of the main advantages of the contingency technique is that it can deal with nonlinear relationships which are mostly found to exist between meteorological parameters.

3.7.10 So far, contingency techniques have been applied to forecast rainfall at Bombay by Jagannathan and Ramamurthi (1961), Calcutta by Sajnani (1964), New Delhi by De (1967), Bangalore by Bedi and Kulandaidasan (1967), in Kerala by Mooley (1967), Konkan by Shukla (1967), coastal Andhra Pradesh by Shukla et al (1966) and Gomti catchment by Bedi and Kulandaidasan (1967). Table 1 gives details in respect of these studies including the skill scores defined by the relation : skill score = (C - E) / (T - E), where C is the number of correct forecasts, T is the total number of forecasts issued, and E is the number of forecasts expected to be correct by chance or on climatological basis. Success of the method described depends largely on the efficiency and the statistical stability of the predictor parameters used. It is, therefore, necessary to test from time to time the statistical stability of the selected parameters, to reject parameters which have been found to be unstable and to select some useful parameters to replace the rejected parameters.

4. Conclusion

In recent years rapid strides have been made in our studies of the general circulation of the atmosphere by the numerical method (see for example, Mintz, 1964) and it may be hoped that further progress in the field of medium range forecasting might take place along these lines, fast replacing or supplementing the other methods. The day-to-day integration will bring out the evolution of the meteorological systems over extended periods but for this the existing numerical methods will have to be improved by making them more realistic and concurrent relationships will have to be developed for forecasting the weather elements in any detail.

Table 1.

Details of studies based on the contingency technique for various cities/ areas in India.

Forecast Technique for city/area	Data used			Period when technique can be used.	Period of independent data used for verification of technique.	Skill score of the technique.
	Type	level	period			
Bombay	Indian radiosonde stations.	700 mb and 500 mb	1950-57	June-September	3 years	0.46
Calcutta	,,	,,	1950-58	,,	3 years	0.46
New Delhi	,,	,,	1950-62	July- August	3 years	0.55
Bangalore	,,	,,	1950-62	July-September	3 years	0.45
Kerala	Grid point within the area 60°-100°E and 0°-35°N	700 mb	1957-61	July	3 years	0.44
Konkan	,,	,,	1957-61	July	2 years	0.51
Coastal Andhra Pradesh	,,	,,	1957-61	July	2 years	0.50
Gomati catchment	Indian radiosonde stations.	700 mb and 500 mb	1950-60	June-September	3 years	0.57

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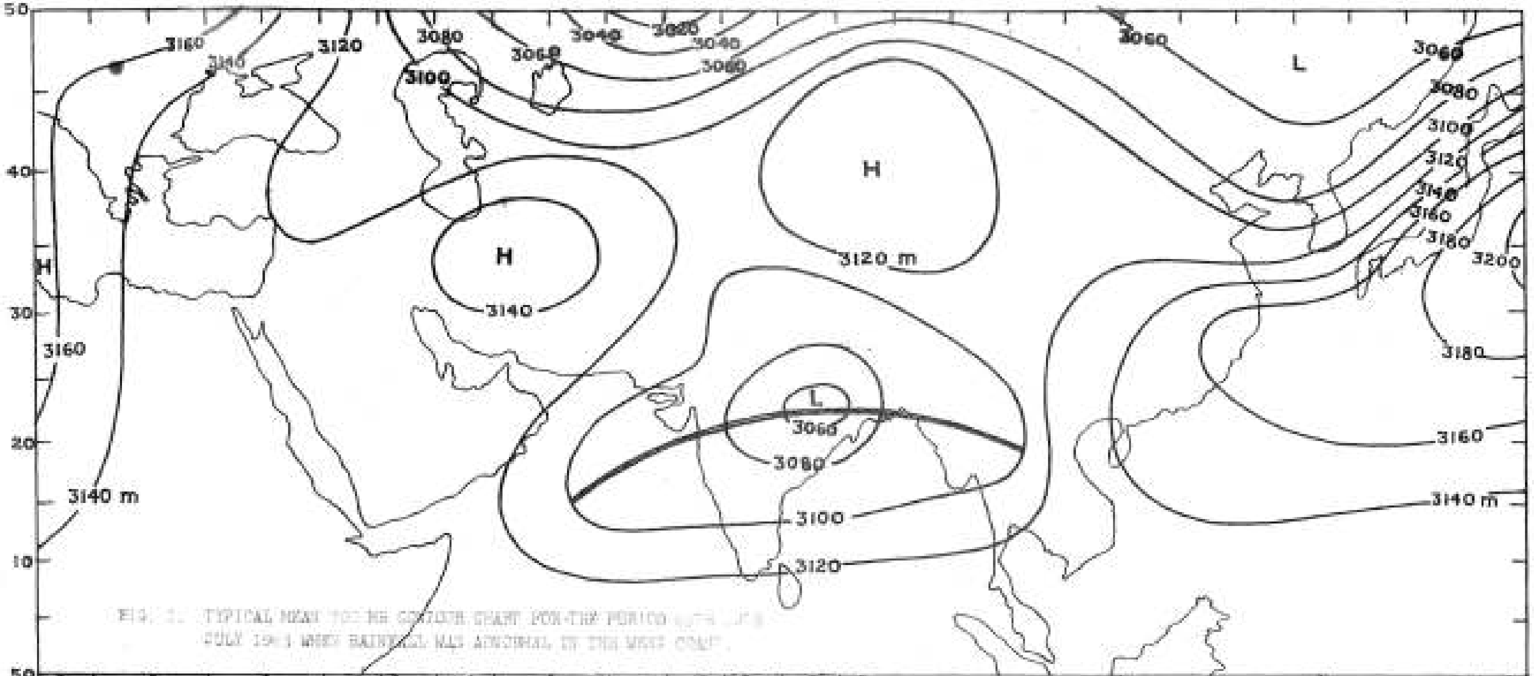

FIG. 1. TYPICAL MEAN 700 MB CONTOUR CHART FOR THE PERIOD [illegible] JULY 19[illegible] WHEN RAINFALL WAS ABNORMAL IN THE WEST COAST.

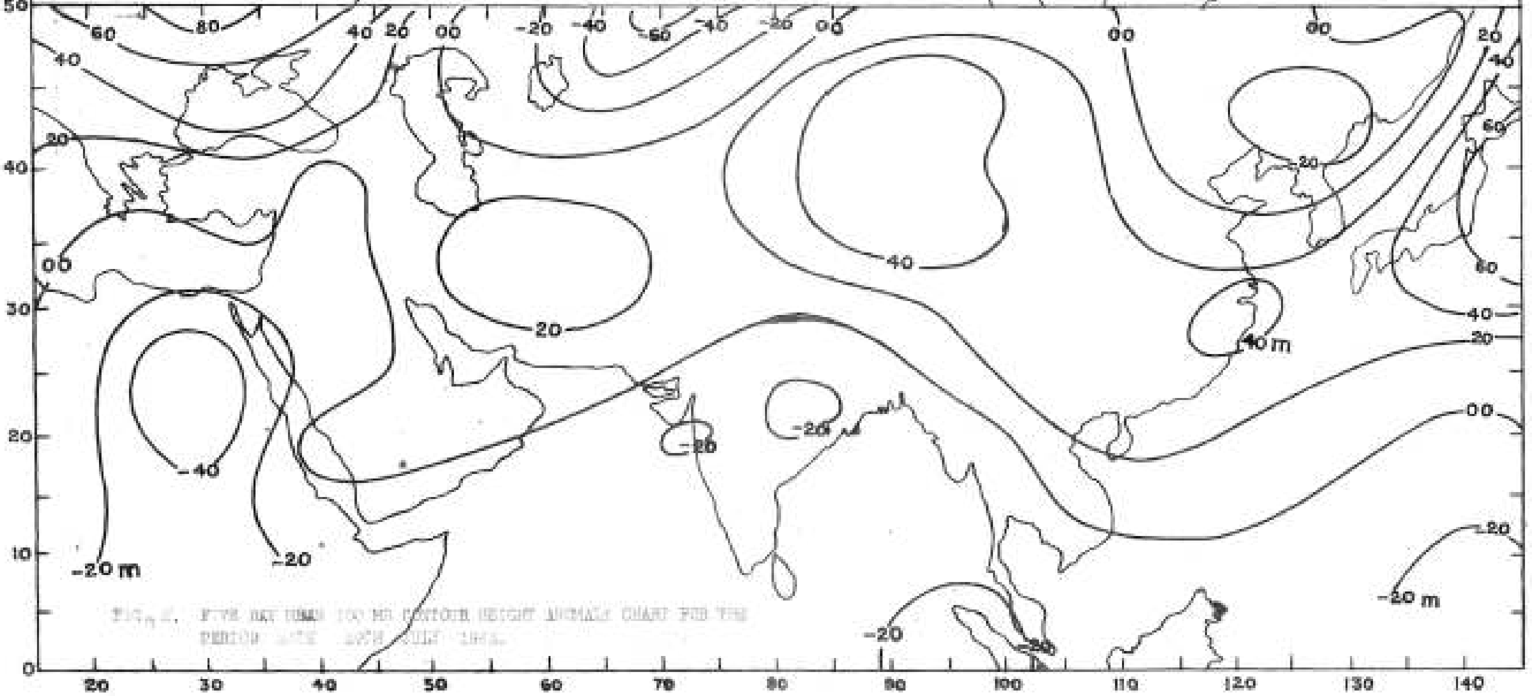

FIG. 2. FIVE DAY MEAN 700 MB CONTOUR HEIGHT ANOMALY CHART FOR THE PERIOD [illegible] JULY 19[illegible].

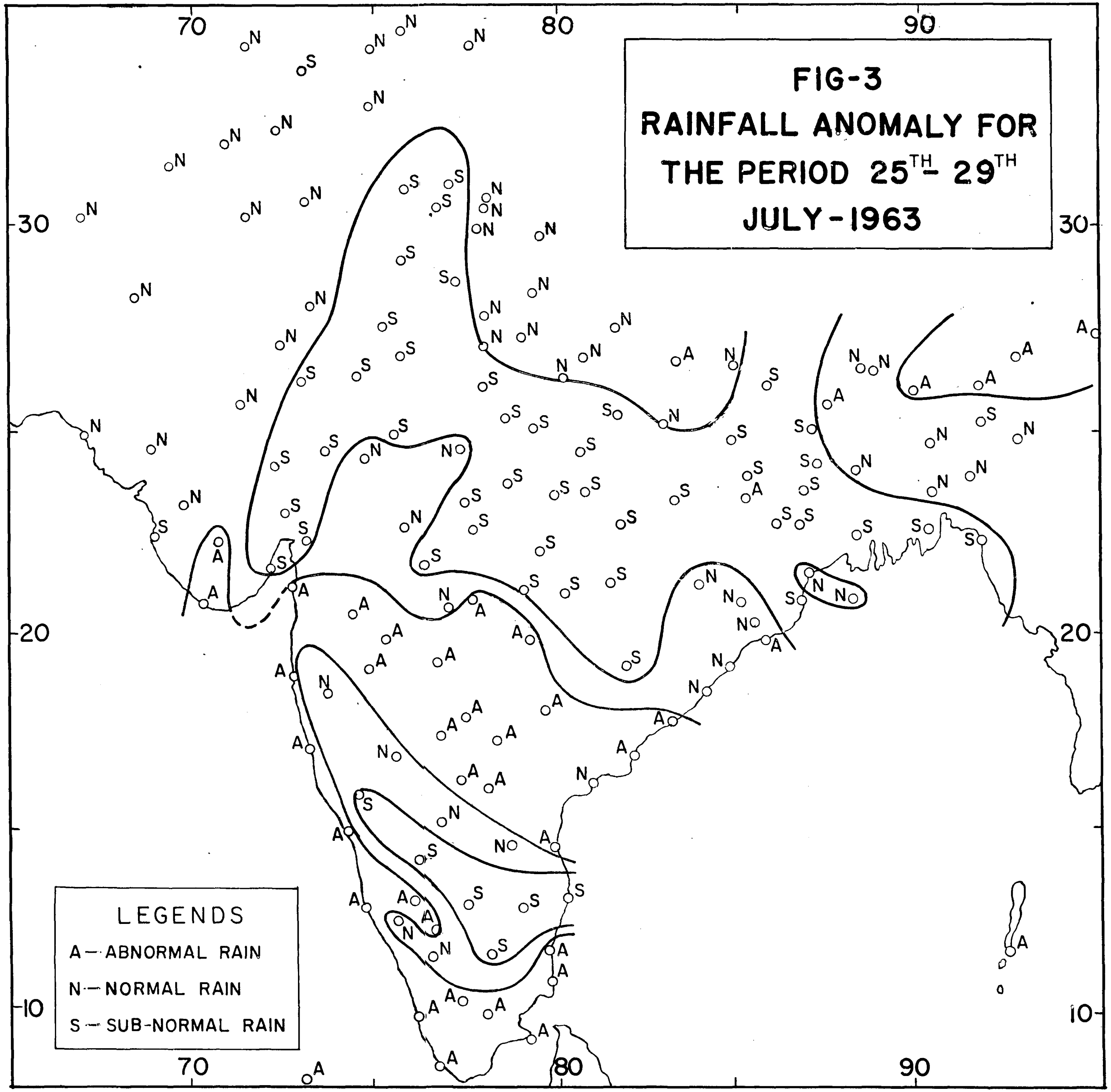

FIG-3
RAINFALL ANOMALY FOR THE PERIOD 25TH – 29TH JULY-1963

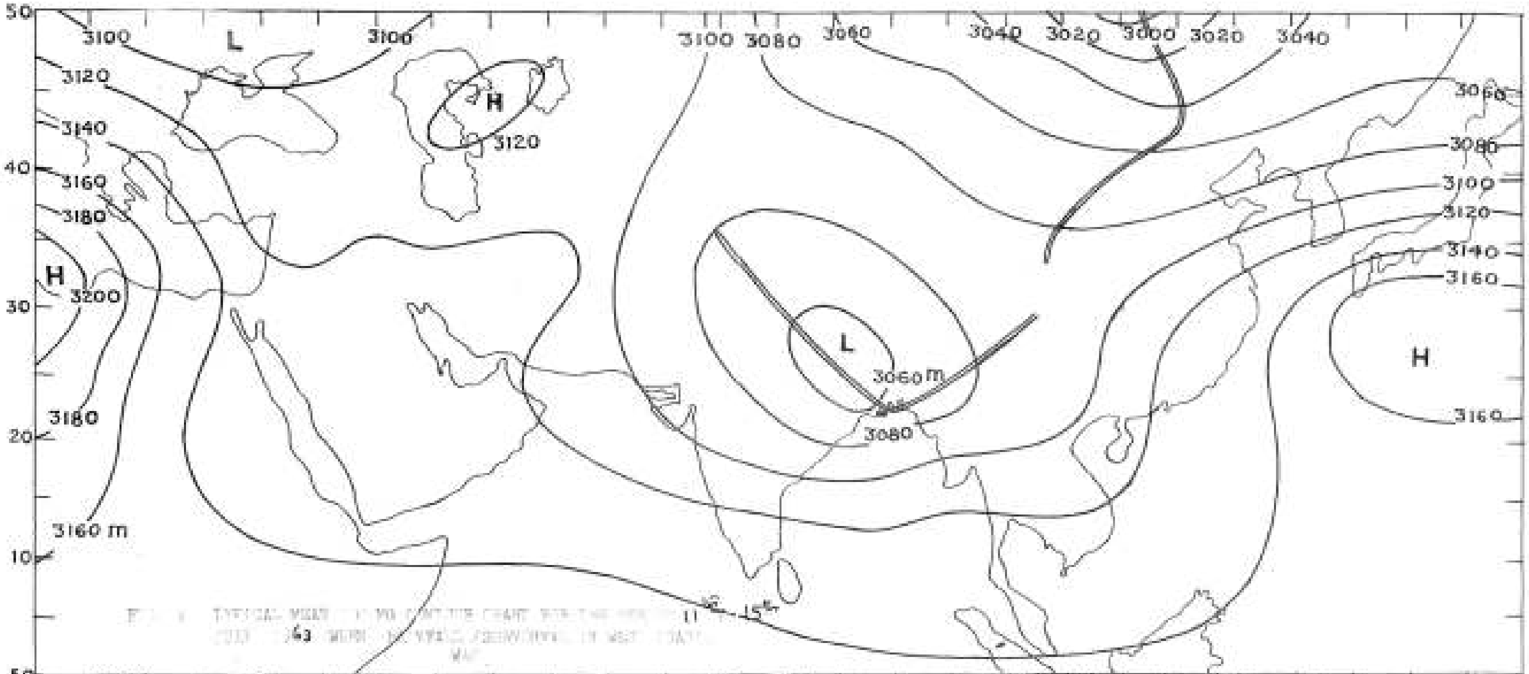

FIG. [illegible] TYPICAL MEAN [illegible] MB CONTOUR CHART FOR THE PERIOD [illegible] 11 [illegible] JULY [illegible] 63 [illegible] WEAK [illegible] CIRCULATION IN WEST COAST [illegible] MAP [illegible]

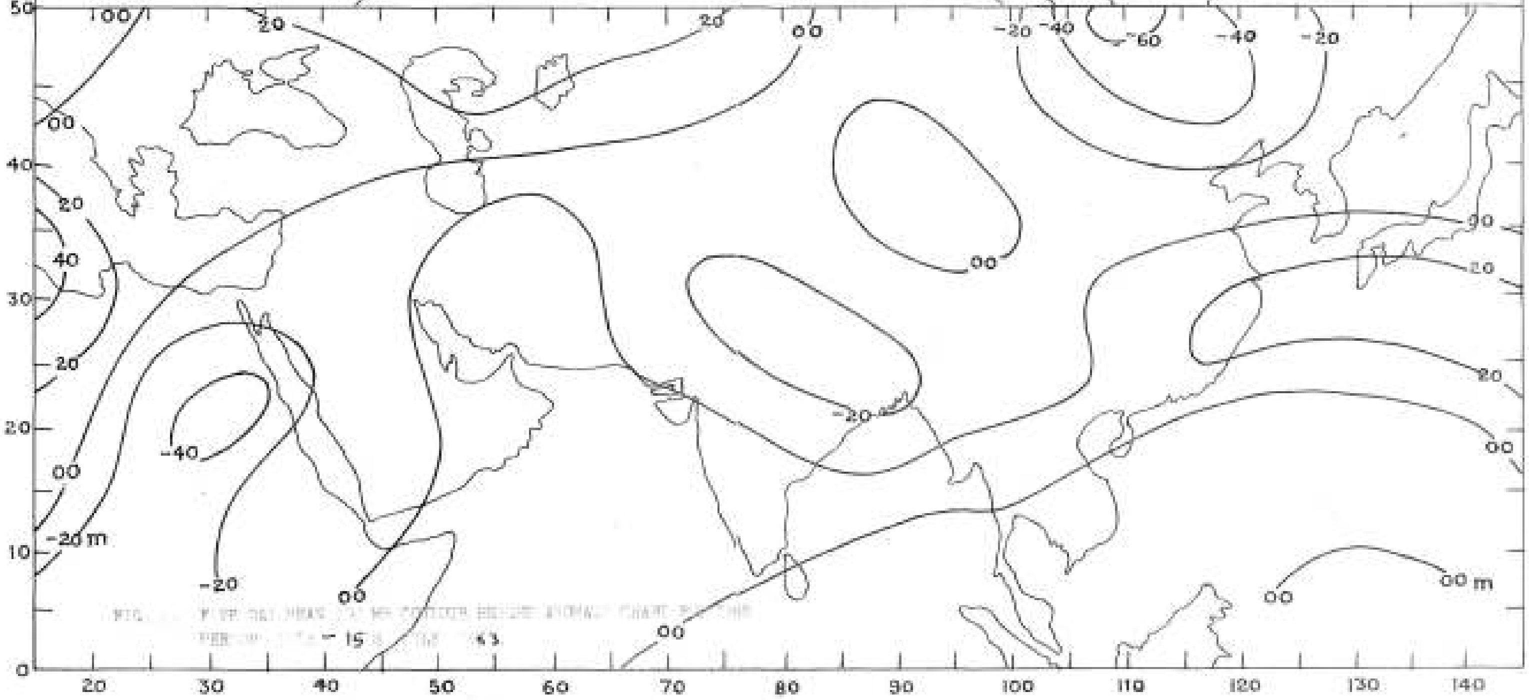

FIG. [illegible] FIVE DAY MEAN [illegible] MB CONTOUR HEIGHT ANOMALY CHART FOR THE PERIOD [illegible] – 15 [illegible] 63

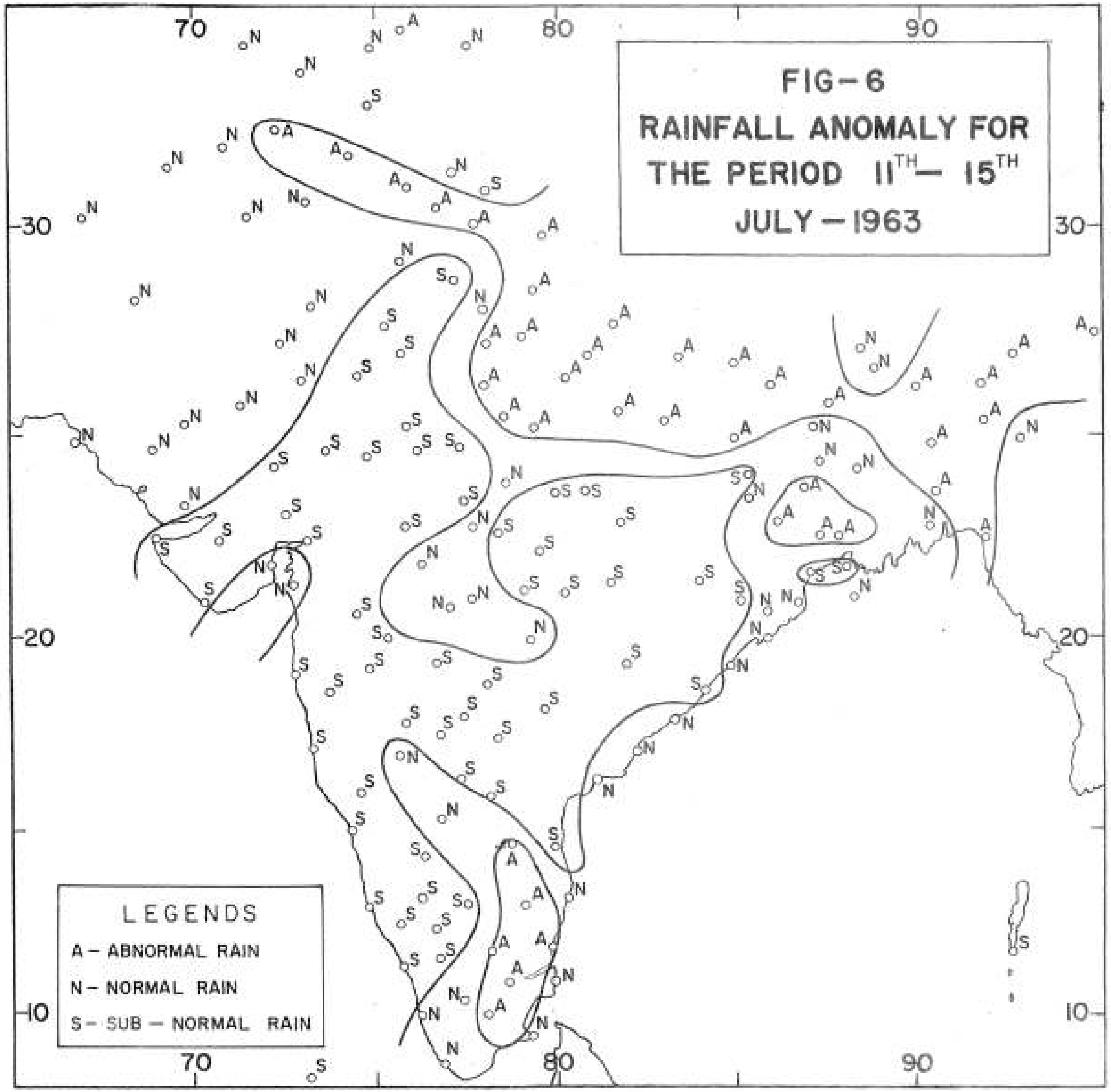
FIG-6
RAINFALL ANOMALY FOR
THE PERIOD 11TH – 15TH
JULY – 1963
LEGENDS
A – ABNORMAL RAIN
N – NORMAL RAIN
S – SUB – NORMAL RAIN