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Analogue in the southwest monsoon*

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सार – सन् 1946 से 1975 तक के 30 वर्षों के जुलाई और अगस्त महीनों के समुद्र तल और दो उच्च स्तरों के दैनिक मौसम सचित्रों को सचित्रों के विभिन्न अभिलक्षणों के लिए श्रेणीबद्ध किया गया है। देश के विभिन्न भागों में वर्षा के पूर्वानुमान के लिए समतुल्यों के चयनार्थ कोडेड सूचना को मूल स्रोत मानकर वस्तुनिष्ठ के रूप में उपयोग किया गया है।

देश के मौसम विज्ञान उपखंभागों में वर्षा की प्राप्ति के लिए तुल्यरूपों को आधार मान कर 1978 की मानसून ऋतु की अवधि में किए गए पूर्वानुमान प्रयोगों के परिणामों की चर्चा की गई है। पूर्वानुमान के लिए तुल्यरूपों के कल निष्पादन का प्रचालन पूर्वानुमान और प्रस्थापित्व के संदर्भ में अनुमान लगाया गया है।

श्रेणीबद्ध सूचना को मानसून के सिनाप्टिक-जलवायु की पहलुओं के अध्ययन के लिए भी उपयोग में लाया गया है।

ABSTRACT. Daily weather charts for the sea level and two upper levels for the months of July and August for 30 years (1946-1975) have been categorised for different features of the charts. The coded information is objectively utilised as the basic source for selecting analogues for forecasting rainfall over different parts of the country.

The results of a forecasting experiment conducted during the monsoon season of 1978 based on the analogues for the prediction of rainfall over the meteorological sub-divisions of the country are discussed. The overall performance of the analogues for forecasting purpose is assessed with respect to operational forecasts and persistence.

The categorised information was also utilised to study the synoptic-climatological aspects of monsoon.

1. Introduction

In meteorology, analogue means two states of atmosphere resembling each other very closely. During the peak monsoon months of July and August quasi-steady flow and pressure patterns prevail over India. As such analogous situations in the daily flow and pressure patterns are expected to exist in the historical records for July and August. It is, therefore, expected that these 'weather analogues' may serve as a tool for forecasting rainfall over different parts of India during these months. The analogue technique of forecasting weather is based on the assumption that days of similar synoptic situations experience nearly identical weather. The technique is being used in meteorology by many for the prediction of short-term weather variation (Baur 1951, Elliot 1951). Lorenz (1969) used the naturally occurring analogues to study the atmospheric predictability. Recently the analogue methodology has been further advanced and used by several others for the prediction of short term weather variation and climatic fluctuation (*viz.*, Yacowar 1975, Gruza *et al.* 1976, Gruza and Ranjkova 1977 and Agnew and Alexander 1980). In fact, an operational forecaster under certain situations refers to similar situations in the past records to see the evolution of the subsequent patterns and the weather accompanying them and in doing so he has to depend largely on his experience and memory of the past weather charts. It is, therefore, relevant that analogue charts from the past years are chosen by an objective method, and their utility in forecasting is evaluated. For this purpose, the important synoptic information from the daily weather charts of past several years for the main monsoon months of July and August had been categorised and put in punched cards in a coded

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form which can easily be processed by the computer. Categorised data collected in this way forms a large historical data bank from which appropriate analogue charts can be found out in a short time by modern data processing technique. In this paper we discuss the method of categorisation of synoptic information adopted for the daily weather charts over India and evaluate their use for forecasting daily rainfall over different parts of the country by selecting suitable analogues from the past years. The results of a forecasting experiment conducted during the monsoon season of 1978 based on the analogues for prediction of rainfall over the meteorological sub-divisions of the country, is also discussed. The overall performance of the analogues for forecasting purpose is assessed with respect to operational forecast and persistence. The historical data bank has also been utilised to study the life history of the monsoon lows and informations and statistics thus obtained has been utilised in studying the life history of the analogous monsoon lows.

2. Categorisation scheme

Daily weather charts over the Indian region from 1946 to 1975 for the two main monsoon months July and August were categorised in suitable codes and put on punch cards. The scheme followed for categorisation is discussed below:

2.1. *Area covered*

The area covered for the categorisation of charts extended from equator to 40 deg. N and 40 deg. E to 110 deg. E covering the Indian region and its neighbourhood. This area was divided into 2½ deg. latitude-longitude squares and each square was given an identification number.

2.2. *Information categorised*

With reference to each grid square the following information were collected from various weather charts and coded in suitable card format. The weather charts referred were sea level pressure and auxiliary charts of 0300 GMT and upper air charts of 00 GMT.

(a) Information from sea level pressure chart:

(*i*) Meridional gradient of pressure over peninsular India which we designate as 'Monsoon Zonal Index'. This gives an indication of the general strength of the monsoon westerlies over the peninsula,

(*ii*) Position, intensity, orientation and extent of the monsoon trough,

(*iii*) Position, intensity, orientation and extent of any other troughs, ridges etc.,

(*iv*) Position, intensity and past movement of closed low pressure systems.

(b) Information from auxiliary charts :

(*i*) 24-hour pressure changes,

(*ii*) Pressure departure from normal,

(*iii*) Distribution and character of convective phenomena, such as, thunderstorm, dust storm etc.,

(*iv*) Distribution and character of daily rainfall,

(*v*) Distribution and character of very heavy rainfall (greater than 12 cm in 24-hour).

(c) Information from upper air charts :

1.5 km

(*i*) Position of monsoon trough,

(*ii*) Position of any other troughs or ridges,

(*iii*) Position, intensity and past movement of closed cyclonic circulation,

(*iv*) Areas of well marked convergence/divergence, cyclonic/anti-cyclonic shear and field of deformation (judged subjectively).

9.0 km

(*i*) Position of seasonal anticyclone ridge to the north of India,

(*ii*) Movement and intensity of closed cyclonic circulation.

3. Forecast by Analogue method

3.1. *Procedure for selection of analogue*

During the summer monsoon months of July and August 1978, forecasts of rainfall distribution valid for 24 hours over various meteorological sub-divisions of India were issued daily on an operational basis by using the analogue method. As the 03 GMT sea level and auxiliary charts of the day were not completely ready by the time the forecasts were issued, the morning 00 GMT sea level and upper air charts of the day as well as the previous day, 12 GMT sea level, upper air and auxiliary charts were considered for the purpose. Searches are then made through the historical data file containing 30 years data collected as above to find analogues in respect of some salient features in the current synoptic chart, like a low pressure system/systems in the sea level chart, cyclonic circulation(s) at 1.5 km level, position and orientation of monsoon trough or any other trough at sea level/1.5 km level. The process usually yields a number of analogues (*say* approximately 15 to 20). These analogues were then compared more closely with current situations in respect of overall sea level pressure pattern, meridional pressure gradient, upper air flow pattern at 1.5 km, changes in sea level pressure in 24 hours, pres-

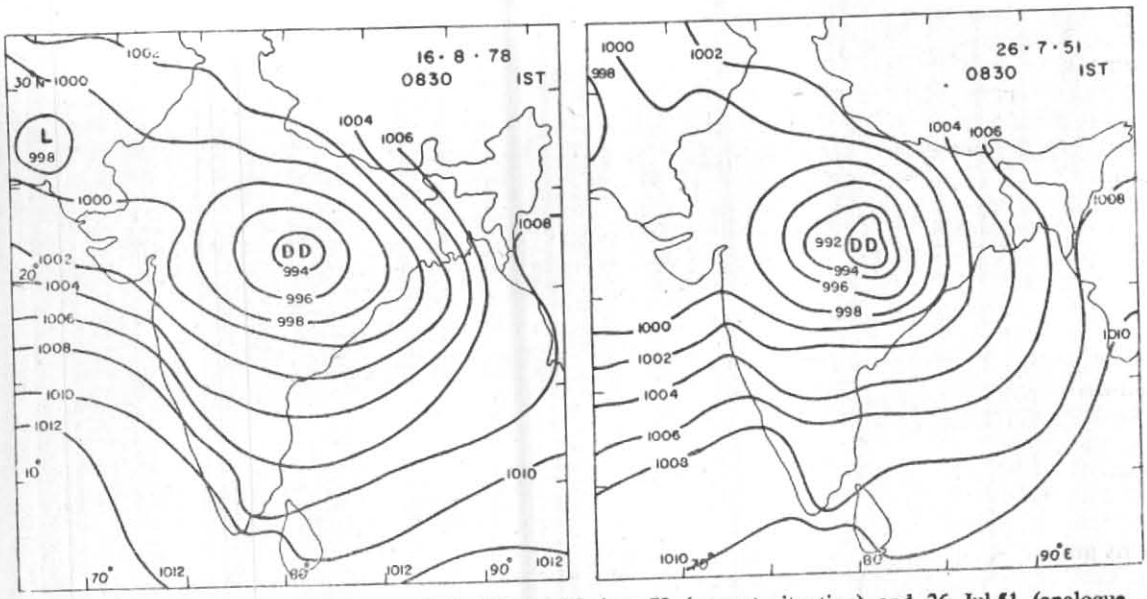

Fig. 1. Sea level pressure pattern at 0830 IST of 16 Aug 78 (current situation) and 26 Jul 51 (analogue situation)

sure departure from normal, weather associated with them, their history of evolution etc. The analogue which was in close agreement in all these aspects with the current situation was selected as the best analogue by subjective assessment. On some occasions more than one analogues were picked up as best analogues. In such cases forecast was decided by the subjective assessment of the various analogues.

Analogues were selected on the basis of lower tropospheric conditions of the atmosphere. The middle and upper tropospheric feature (*e.g.*, mid-tropospheric westerly trough or upper tropospheric easterly jet stream) have not been considered in this study because of non-availability of these informations on day to day basis in the historical data file used in this study. Such information is available only at best for the last 10 years and this length of data is not considered sufficient for determining analogues.

Forecast under the present series were issued on an operational basis on 50 occasions during July and August 1978. It is worth mentioning here that not all the analogues chosen were found to be good, very good or excellent analogues. There were occasions (approximately 25 per cent cases) when the analogues were not found to be very satisfactory from all respects. We termed them as poor analogues. Situations having no well defined monsoonal systems or having two or more co-existing systems, the past records of which were rather few or rare, sometimes causes difficulty in selecting the analogues. On one or two occasions no reasonable analogue was found. Perhaps extension of more years data in the data file may help us to overcome these situations.

3.2. *Analogue forecast*

The weather accompanying the analogue situation in the next 24 hours were considered to be the forecast for next 24 hours following the current situation. In this experiment the distribution of rainfall over various meteorological sub-divisions of India were forecast. Five categories of rainfall distribution as used in Weather Central, Pune of the India Meteorological Department were also used in this experiment for forecasting the rainfall distribution. These are:

Rainfall category	*Areal specification*
Wide spread (W)	more than 75% of area received rain
Fairly wide spread (F)	51 – 75% of area received rain
Scattered (S)	26 – 50% of area received rain
Isolated (I)	1 – 25% of area received rain
Dry (D)	No Rain or Trace (<.25 mm)

The rainfall distribution over various subdivisions, as recorded on the subsequent day of the analogue situation were therefore, considered as the forecast of rainfall distribution over the same sub-divisions on the subsequent day of the current situation.

3.3. *Example of the analogue situation*

An example of an analogous situation selected in respect of a current situation on 16 August

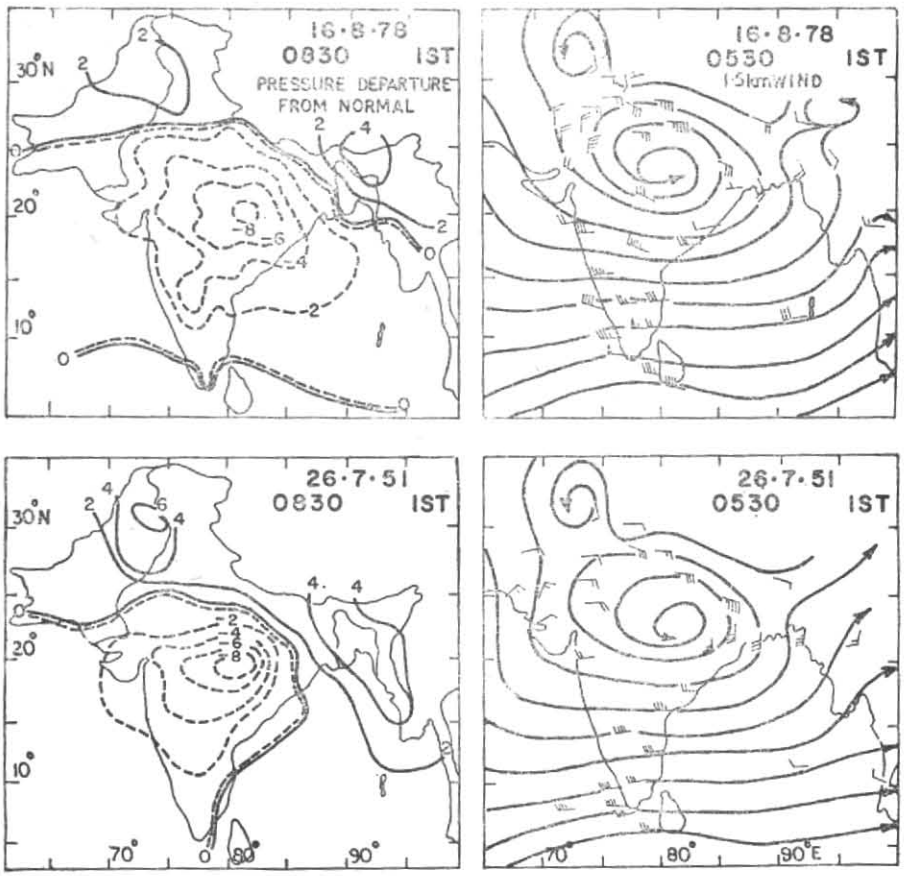

Fig. 2. Pressure departure from normal at 0830 IST and flow pattern at 1.5 km level at 0530 IST of 16 Aug 78 and 26 Jul 51

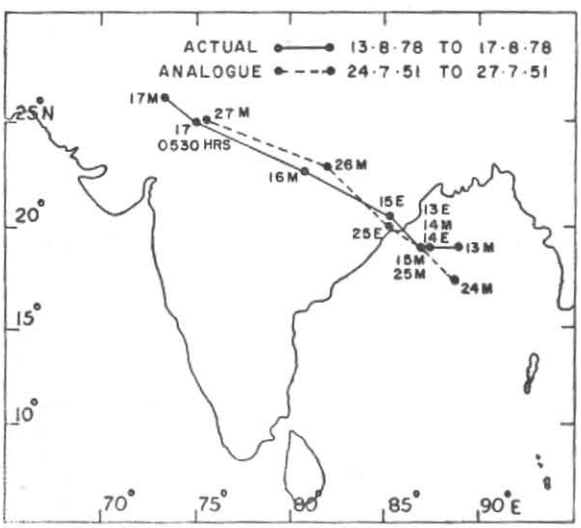

Fig. 3. Tracks of the two depressions-actual (13-17 Aug 78) and analogue (24-27 Jul 51)

1978 is shown in Figs. 1 to 4. A deep depression which formed over northwest Bay of Bengal on 14 August 1978, lay over east Madhya Pradesh at 03 GMT on 16 August 1978 and the 03 GMT chart of 26 July 1951 was found to be a perfect analogue of this situation in respect of its surface pressure pattern (Fig. 1), pressure departure from normal and upper air flow pattern at 1.5 km level (Fig. 2), and movement of the two systems (Fig. 3). Fig. 4 shows the rainfall distribution over various sub-divisions at 03 GMT on the subsequent day of the analogue data as the forecast of rainfall distribution valid till 03 GMT of 17 August 1978 and the rainfall distribution actually realised over the same subdivisions on the day.

4. Verification of forecast

Forecasts thus issued were verified against the actual rainfall realised at 03 GMT of the verifying day. If the same category of rainfall distribution occurred in a sub-division as that of the forecast, the forecast was said to be absolutely correct and if the realised rainfall distribution for the subdivision agreed within one category on either side of the forecast category the forecast was considered to be fairly satisfactory. Percentage of the total number of subdivisions for which the forecast lay under different verification categories were worked out on each day. The operational forecast issued by the Weather Central, Pune (based on experience and subjective assessment of the synoptic situations) as

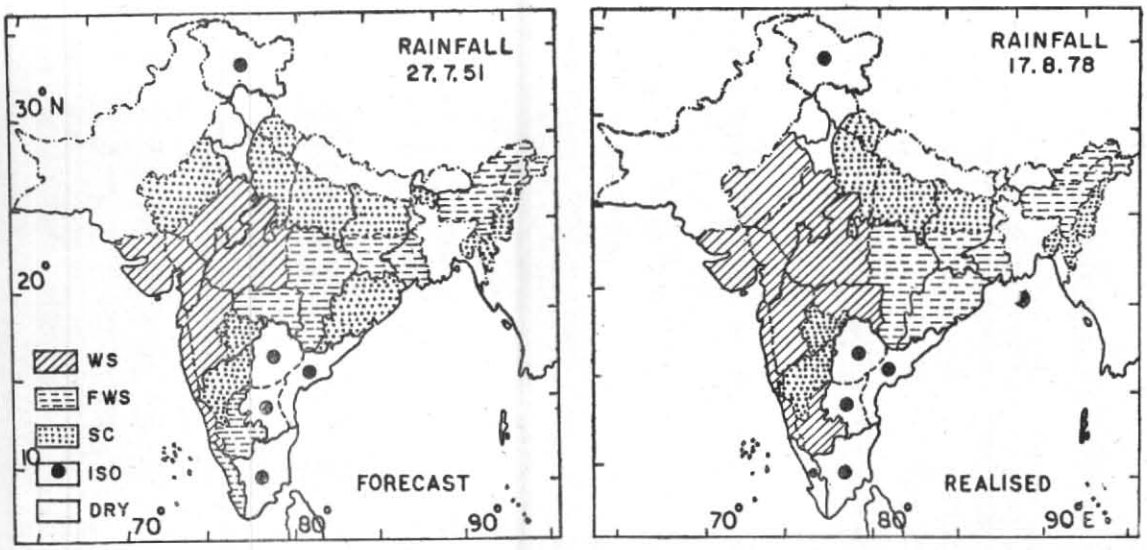

Fig. 4. Forecast of rainfall distribution over different sub-divisions by analogue technique and the realised rainfall distribution

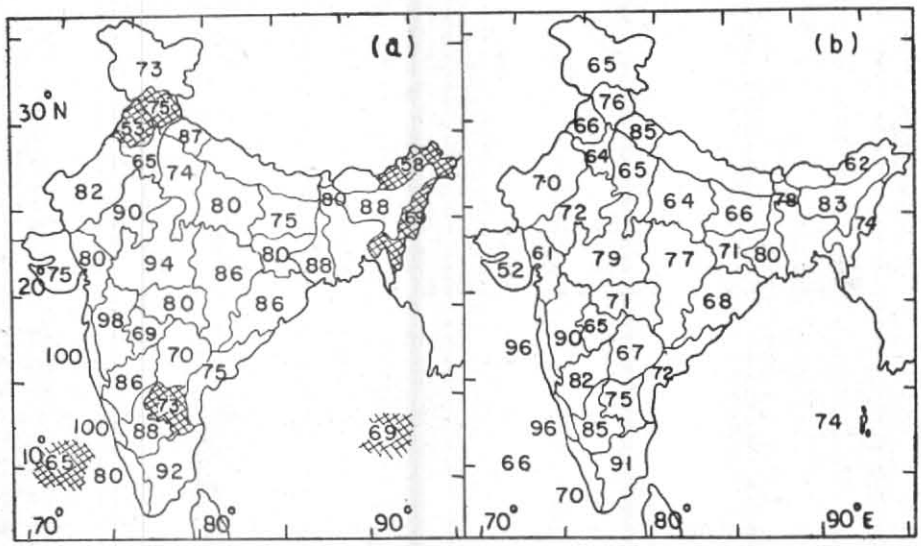

Fig. 5. (*a*) Percentage of success of analogue forecast under fairly correct category over different sub-divisions and (*b*) percentage of success expected on random basis (shaded sub-divisions in Fig. (a) shows the analoguetechnique scored less success over the success expected on random basis over these sub-divisions)

TABLE 1

Comparison of forecasts based on analogue technique. operational forecasts and persistence forecasts

Technique	Average percentage of sub-divisions for which forecast were	
	Absolutely correct	Fairly correct
Analogue	37	80
Operational	32	74
Persistence	40	78

TABLE 2

Technique	Average percentage of sub-division in which forecast were absolutely correct when analogue chosen was	
	Poor	Very good or excellent
Analogue	29	46
Operational	31	33
Persistence	39	41

published in the *Indian Daily Weather Report* were also verified on day to day basis, based on the scheme outlined above. Besides, the forecasts were also verified against persistence, *i.e.,* the rainfall category as obtained on the current day chart is the forecast for the next day. For this verification the rainfall reports as received by the Weather Central, Pune including the late reports have been considered. Table 1 shows the average performance of three methods which occurred during the series of experiment.

Table 1 suggests that the score of the three methods is almost identical to each other. This is understandable as the rainfall over the scale of the subdivisions is by and large controlled by the large scale monsoon flow/pressure pattern which evolve rather slowly and the synoptic scale disturbances which have a life span of a few days.

However, it appears that the average performance of the analogue technique for the absolutely correct category is encouraging compared to the average performance of the operational technique, but it is not so when compared with that of persistance forecast. This is because the success of analogue technique depended solely on the quality of the analogue chosen. A poor analogue (*See* Sec. 3.1) consequently yielded poor prediction success, whereas the percentage of success of persistance forecast maintained an average success of 40 per cent irrespective of the quality of the analogue. Table 2 shows the average percentage of sub-divisions in which analogue forecasts were absolutely correct for cases when the analogues chosen were rather poor and also for cases when analogues chosen were very good or excellent. The corresponding performance of the other two techinques are also shown.

The percentage of success of analogue forecast under fairly correct category were assessed for different subdivisions of India and also compared with the percentage of success expected on random basis over different subdivisions (Fig. 5). To obtain percentage of success expected on random basis. 5×5 contingency tables, based on 5 category of rainfall distribution [*e.g.,* W, F, S, I and D (*see* Sec. 3.2)] between the observed and forecast rainfall distribution were prepared for each subdivision. The marginal totals of column and rows are used to obtain the expected frequencies of each cell in the contingency table which is given by Maxwell (1961):

$$f_{ij} = C_i R_j / T$$

where, C_i is the frequency in the ith column

R_j is the frequency in the jth row

f_{ij} is the frequency in the cell corresponding to ith column and jth row.

T is the total number of forecast.

In the present case of 5 × 5 contingency table, the procedure is expanded to calculate the frequencies of observed rainfall distribution within one category of forecast rainfall distribution and the number of forecasts expected to be correct (E) within one category are calculated as follows :

$$E = (f_{DD} + f_{DI}) + (f_{ID} + f_{II} + f_{IS}) + \\ + (f_{SI} + f_{SS} + f_{SF}) + (f_{FS} + f_{FF} + f_{FW}) + \\ + (f_{WF} + f_{WW})$$

where the first and second subscripts in the right hand side refer to forecast and observed category of rainfall distribution.

It is seen from Fig. 5 that but for few subdivisions, *i.e.,* Arunachal, Nagaland, Punjab, Himachal Pradesh, Rayalaseema, Bay islands and Lakshadweep the analogue technique exhibits more success for rest of the sub-divisions.

We have also classified the success in four categories according to the percentage of number of days of fairly correct forecast in each subdivision. These categories are (*i*) very good (when the percentage of success was 80 per cent and above), (*ii*) good (70-79 per cent), (*iii*) Poor (60-69 per cent) and (*iv*) extremely poor (below 60 per cent. Table 3 shows the break up of the number of subdivisions in each of these categories as well as the percentage of area of India covered by these subdivisions, for the three types of forecast.

Table 3 shows that the success of analogue forcast under very good categories is higher compared to the operational and persistence forecasts.

5. Special features of analogue study

It is of interest to know the persistency of an analogous situation in time or in other words whether subsequent calender days of an analogous situation are the analogue for the subsequent calendar days of the current chart also. The length of this period would determine the persistency of similar development or evolution of synoptic situation. Table 4 shows the frequency distribution of the persistence of analogues for two days and above.

The analysis shows that majority of the analogues are valid for only 1 day. However, there were 16 occasions out of 50 days of the experiment when the analogy was retained for two to four days. However, only twice the analogous sequence was retained for 4 days. The longer period persistency occurs when a well marked synoptic scale feature like a monsoon depression is present on the current chart. An

TABLE 3

Category of success	Range of percentage of successful days (%)	No. of sub-divisions for different methods			Percentage of area of India covered by the sub-divisions		
		Analogue	Operational	Persistence	Analogue	Operational	Persistence
Very good	80 and above	20	8	15	63	26	54
Good	70-79	8	14	13	27	42	37
Poor	60-69	3	6	2	6	21	4
Extremely Poor	Below 60	2	5	3	4	11	5

TABLE 4

Frequency distribution of persistence of analogues

	No. of days of persistence of analogy			
	2 days	3 days	4 days	more than 4 days
No. of occasions	10	4	2	0

TABLE 5

Life duration of low pressure systems

	Life duration (in days) of lows										
	1	2	3	4	5	6	7	8	9	10	>10
No. of lows formed	196	84	47	41	35	28	17	5	5	5	7
Percentage of total	42	18	10	9	7	6	4	1	1	1	1

TABLE 6

Frequency distribution of the formaton of low pressyure systems

	No. of lows formed			
	Below 10	10 to 14	15 to 19	20 and above
No. of occassions	3	8	15	4

TABLE 7

Frequency distribution of formation of lows in different major areas

Duration	Total No. and % of lows in the areas			
	India	N. Bay & adj. land	Land locked monsoon trough	N. Arabian Sea & land
1 day	196 (42%)	60 (31%)	86 (44%)	11 (6%)
> 1 day	274 (58%)	128 (47%)	81 (30%)	14 (5%)
Total	470	188 (40%)	167 (35%)	25 (5%)

example of one such case was the system which formed at 03 GMT on 14 August 1978 in which a deep depression was found to lie over north Bay of Bengal and for which the analogue chosen was the 03 GMT situation on 25 July 1951. Thereafter the analogy was found to retain for 4 days till 17 August 1978.

The track which the August 1978 depression followed was also similar to the track of the analogue depression (Fig. 3) for which reason the analogy could be retained for 4 days.

In some cases the analogy was short lived even in cases which were dominated by monsoon depression due to differences in movement/development of the system.

6. Synoptic climatological aspects of monsoon lows

The categorised data would also serve as important reference material for study of synoptic climatological aspects of monsoon.

Information about monsoon depressions have been compiled by India met. Dept. (1964 and 1972). As low pressure systems are of frequent occurrence and are also responsible for a good amount of rainfall it may be worthwhile to compile and study statistics about low pressure systems which might or might not have intensified into depression. Sikka (1980) has suggested that the performance of monsoon season rainfall is related to the frequency of formation of lows rather than depression. The

TABLE 8

Frequency distribution of percentage of disturbed days

	Percentage of disturbed days					
	30-39%	40-49%	50-59%	60-69%	70-79%	80%
No. of occasions	2	5	7	8	6	2

following synoptic-climatological aspects about monsoon lows are obtained based on the information contained in the data used for the present study.

During the 30 years period (1946 to 1975) a total number of 470 lows formed over the Indian region during July and August, out of which 265 (56 per cent) formed in July and 205 (44 per cent) in August. Of these 470 lows 113 (24 per cent) intensified into tropical depressions or higher stage of intensity. Thus on an average 16 lows form every year during the period July and August of which nearly 4 intensify to at least the tropical depression stage. A large number of these lows are rather short lived, *i.e.*, those whose life did not exceed two days representing nearly 60 per cent of the total systems. Low pressure systems living more than five days are rather infrequent. Table 5 shows the life duration of the low pressure systems.

Table 6 shows the frequency distribution of the formation of low pressure systems over the Indian region during July and August. There is considerable year to year fluctuation in the formation of lows in July and August. There are quite a few years (1959, 1970, 1973, 1975) when more than 20 lows formed in the month of July and August. In some of the years (1953, 1968, 1972) the number of lows in these months were less than 10.

Table 7 shows the distribution of formation of low pressure systems and their percentage of total in different major areas like (*i*) north Bay of Bengal and the adjoining land area (17.5-25 deg. N and 85-92.5 deg. E), (*ii*) land-locked part of the monsoon trough area (75-90 deg. E and 20-30 deg. N) excluding the Bay area, and (*iii*) north Arabian Sea and the adjoining land area (17.5-25 deg. N and 65-72.5 deg. E).

It may be noted that the contribution of Bay of Bengal sector is maximum (40 per cent) to the total frequency of cyclogenesis and majority of them have life duration of two days or more. The landlocked part of the monsoon trough also contributes significantly (35 per cent) to the frequency of formation of lows which are, however, short lived.

TABLE 9

Frequency distribution of mean zonal index

	zonal index (mb)			
	4.0-5.9	6.0-7.9	8.0-9.9	≥10
Jul	0	9	21	0
Aug	4	17	9	0

if we define a disturbed day as a day when at last one low pressure system existed in the monsoon area the statistics shows that nearly 60 per cent of the days in July and August can be classified as disturbed days. Table 8 shows the frequency distribution of the percentage of disturbed days during the months July and August.

During the monsoon season large meridional pressure gradient exists across most of India. Sea level pressure difference between Colombo (7 deg. N, 80 deg. E) and Nagpur (21 deg. N, 79 deg. E) is considered to give a fair measure of this pressure gradient south of the monsoon trough. This is called in our study as 'Monsoon Zonal Index' and would give an indication of the general strength of the westerlies over the peninsula. The strengthening of the westerlies are usually associated with the formation of lows and depressions over the Bay of Bengal. Even in absence of low or depression in the Bay, strong westerly winds are noticed when the monsson trough is well marked and is positioned in its normal position. Table 9 shows the frequency distribution of mean zonal index for July and August.

It may be noted that the month of August had a lower value of zonal index than July in most of the years. In some of the years (1965, 1966, 1969, 1971) the month of August has considerable low value of zonal index (below 6 mb).

7. Concluding remarks

The results of the prediction experiment to forecast the distribution of 24 hour rainfall over different parts of India have been assessed and compared against the operational and persistence forecast. The results show that analogue method of forecasting can be utilised with sufficient accuracy in forecasting the 24-hour rainfall distribution during monsoon season over most parts of the country particularly when we consider the areawise distribution of fairly correct forecasts. However, there are pockets where the performance is not found to be highly satisfactory. These areas are Punjab and Haryana in NW India, Arunachal Pradesh, Nagaland, Manipur, Mizoram, Tripura in NE India and Marathwada over Peninsular India. The

area of these sub-divisions, however, comprise only about 10 per cent of the total area of India. It is also seen that the performance of the operational forecasts and the persistence forecast was also not satisfactory over the same sub-divisions. Whether this was peculiar to the year 1978 or is a general feature cannot be assessed with the data of present experiment. However, some explanations can be given to the failure of analogue technique over Punjab and Haryana, Arunachal and Nagaland etc. Apart from monsoonal systems, the rainfall over Punjab and Haryana are also considerably influenced by the eastward moving western disturbances across northwest India and under such situations analogues which were chosen based mainly on monsoonal systems might not be good enough for these regions. Past records of rainfall data in respect of Arunachal Pradesh and Nagaland etc. were rather not satisfactory which caused the failure of the technique over these regions.

The study also shows that a particular analogue is generally not retained for more than a day unless the situation is dominated by a well defined synoptic scale system, *e.g.*, monsoon depression.

The paper also documents some aspects of the life history of monsoon lows from a study made by utilising the historical data bank which served as an important reference material for the study of analogues.

The study suggests that analogues of synoptic situations from the present data bank of 30 years can be objectively determined and the analogue method of forecasting rainfall can be used as an objective technique for short-range prediction over India. Perhaps better results may be expected if the data bank is extended to cover more years so that while determining the analogues suitable weightage depending upon the quality of the analoques is introduced.

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P. S. :

The experiment of finding the analogues during the monsoon months of July and August, and utilising them in forecasting the rainfall distribution over different sub-divisions of India on an operational basis and also issuing the same to the operational forecaster for their use as a forecast guide, were also carried out during 1979 and 1980. The result shows that while analogue technique maintained more or less the same success as that of 1978, the operational forecast have improved from 32 per cent (for absolute correct) and 74 per cent (for fairly correct) in 1978 to 39 and 83 per cent respectively in 1979 and 41 and 82 per cent respectively in 1980.

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