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Prediction of Indian droughts with lower stratospheric winds

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सार — ग्रीष्मकालीन मानसून (जून से सितम्बर) बहुत ही कमजोर होने से भारत में भीषण सूखे की स्थिति पैदा हो जाती है, क्योंकि देश के अधिकांश भागों में वार्षिक वर्षा की 75 प्रतिशत वर्षा इसी अवधि में होती है। इस प्रकार पर्याप्त समय रहते मानसून की व्यापक विफलता की प्रागुक्ति भारत में सूखे के पूर्वानुमान में सहायक हो सकती है। अनेक अध्ययनों में संकेत मिला है कि वायुमण्डल की विभिन्न सतहों को परस्पर संबंध रखने में अर्ध द्विवार्षिक दोलन (क्यू० बी० ओ०) की महत्वपूर्ण भूमिका है। हाल ही में थपलियाल (1979) ने यह दर्शाया है कि 50 मि० बार स्तर पर जनवरी के परिसंचरण लक्षणों का माध्य पश्चिमी क्यू० बी० ओ० वर्षों में कमजोर मानसूनी वर्षा का संकेत देते हैं। परन्तु इससे पश्चिमी क्यू० बी० ओ० वर्षों में वर्ष 1979 जैसी बड़े पैमाने पर मानसून की विफलता की पूर्ण व्याख्या नहीं हो पाती। अतः पिछले महीनों के विश्वभर के कुछ परिसंचरण लक्षणों की पहचान के लिए एक प्रयास किया गया है जिसका भारत में बड़े पैमाने पर मानसून की विफलता की प्रागुक्ति में उपयोग किया जा सकता है। इसके लिए हाल के दो विपरीत मानसून वाले वर्षों में निम्न समताप मण्डल में विश्वभर के औसत मासिक परिसंचरण लक्षणों का अध्ययन किया गया है। ये वर्ष हैं —1980, एक अच्छी मानसून वाला वर्ष और 1979, भंयकर सूखे वाला वर्ष। इन दो वर्षों में 50 मि० बार स्तर पर बिल्कुल भिन्न परिसंचरण लक्षण पाए गए। 1980 की शरद ऋतु में पूरे विश्व में तीन महत्वपूर्ण दीर्घमाप के परिसंचरण लक्षण पाए गए। इनमें द्रोणी और कटक का जोड़ा भूमध्य रेखा के समानान्तर था और अधिकाशंतः उत्तरी गोलार्ध के उष्ण क्षेत्र में स्थित था, सर्व प्रमुख था। इसी के साथ 1979 में भूमध्य रेखा के समीप एक द्रोणी और पाई गई, जो दक्षिण गोलार्ध के चारों ओर थी। इस परिणाम से उत्साहित होकर भारत में मानसूनी वर्षा के सापेक्ष पिछले 16 वर्षों के (1965–1980 तक) शीतकालीन परिसंचरण लक्षणों के माध्यों का अध्ययन किया गया। 1980 की शीत ऋतु जैसे परिसंचरण लक्षण समस्त पूर्वी क्यू० बी० ओ० वर्षों में पाए गए और 1979 की शीत ऋतु जैसे परिसंचरण लक्षण सभी पश्चिमी क्यू० बी० ओ० वर्षों में पाए गए। यह देखा गया है कि कटक और द्रोणी की स्थिति और उनका विस्तार भारत में कमजोर मानसूनी वर्षा के संबंध में विश्वसनीय संकेत प्रदान करते हैं। जिन वर्षों में उत्तरी गोलार्ध में कटक और द्रोणी का विस्तार क्षेत्र छोटा होता है, उनमें मानसूनी वर्षा अच्छी होती है और जिन वर्षों में इन परिसंचरण लक्षणों का विस्तार क्षेत्र बड़ा होता है, उन वर्षों में मानसूनी वर्षा कमजोर होती है। इस संबंध को एक विशुद्ध गणितीय मॉडल द्वारा व्यक्त किया गया है। हाल ही के वर्षों की मानसून ऋतु में (1965–1980) बड़े पैमाने पर कमजोर वर्षा के पूर्वानुमान के लिए इस मॉडल का सफलता पूर्वक प्रयोग किया गया है। इन वर्षों में इस पूर्वानुमान मॉडल की कार्यक्षमता बहुत अच्छी रही है। मॉडल से यह अनुमान लगाया गया है कि उन शीत ऋतुओं के बाद, जिनमें द्रोणी और कटक की जोड़ी की औसत अनुदैर्ध्य लंबाई उत्तरी गोलार्ध में 140° देशान्तर से अधिक होती है, ग्रीष्म कालीन मानसूनों के दौरान भारत में भीषण सूखे की स्थिति होती है। अतः भारत मे भीषण सूखा केवल पश्चिमी क्यू० बी० ओ० वर्षों में ही पड़ता है। इस प्रकार इस विधि को आधार बनाकर मानसून शुरु होने से लगभग 3 महीने पहले ही बड़े पैमाने पर मानसून की विफलता से उत्पन्न सूखे का पूर्वानुमान किया जा सकता है।

ABSTRACT. An extremely deficient summer monsoon (June to September) produces severe drought conditions in India because 75 per cent of the annual rainfall over a large part of the country occurs during this season. The prediction of large scale monsoon failure sufficiently in advance can therefore help to forecast the occurrence of drought over India. A number of studies have indicated that the Quasi Biennial Oscillation (QBO) plays an important role in linking different layers of the atmosphere. Recently, Thapliyal (1979) has shown that mean January circulation features at 50 mb level are able to indicate the deficient monsoon rainfall in westerly QBO years, This, however, does not explain fully the large scale monsoon failure that occurs in westerly QBO years such as 1979. An attempt has therefore been made here to identify a few global circulation features during antecedent months which can be used for predicting large scale monsoon failure over India. For this purpose, the mean monthly global circulation features in the lower stratosphere have been studied for two recent years of contrasting monsoon over India, namely, 1980 — a good monsoon year, and 1979 — a severe drought year. During these two years, completely different circulation features have been found at 50 mb level. In winter 1980 a subtropical ridge is situated over the northern hemisphere around latitude 20 deg. N. On the other hand, in winter 1979 three significant large scale circulation features are situated over the globe. The prominent among them is a pair of trough and ridge which runs parallel to the equator and is mostly situated in the tropical region of the northern hemisphere. Simultaneously a near equatorial trough is also found in 1979 which encircles the southern hemisphere. Encouraged by this result, the mean winter circulation features during the recent 16 years (1965 to 1980) have been studied in relation to monsoon rainfall in India. The circulation features like those of winter 1980 are found in all the easterly QBO years while the features like those of winter 1979 are found in all the westerly QBO years. It has been noted that the location and the extent of the ridge and the trough provide reliable indications regarding the deficient monsoon rainfall in India. Years, when the extent of northern hemispheric ridge and trough is small, are followed by good monsoon rain while years when the extent of these circulation features is large are followed by deficient monsoon rains. This relationship has been expressed by an exact mathematical model which has been successfully used for forecasting the large scale rainfall deficiency during the recent monsoon seasons (1965 to 1980). The performance of the forecast model during recent 16 years has been found excellent. From the model it is inferred that the winters, in which the mean longitudinal length of the pair of trough and ridge over northern hemisphere is more than 140 degrees longitude are followed by severe drought conditions during subsequent summer monsoon over India. Thus, severe droughts have occurred over India in westerly QBO years only. Based on this method the drought conditions due to large scale monsoon failure could, therefore, be forecast about 3 months prior to the start of the season over India.

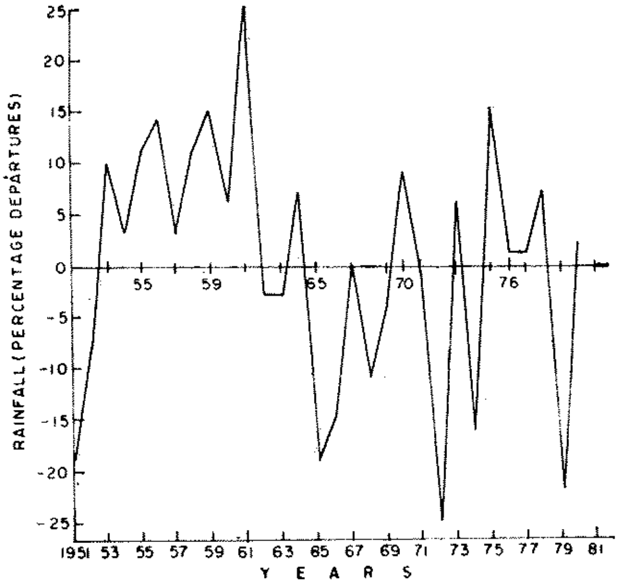


Fig. 1. Indian monsoon rainfall (June to September). Percentage departure from normal (851.8 mm)

1. Introduction

Extreme deficiency in rainfall during the summer monsoon can produce severe drought conditions in India because the 75 per cent of the annual rainfall that occurs during 4 monsoon months, June to September, has to meet the water requirements of the country during the entire year. The problem of forecasting drought over India, therefore, reduces to the prediction of large scale monsoon failure over the country. This indicates that the long range forecasts for extremely deficient monsoon rains given sufficiently in advance, can play a dominant role in mitigating the disastrous effects of the droughts. There is, therefore, a need for developing reliable techniques for long range forecast which could be used for foreshadowing, atleast a season ahead, the large scale deficiency in monsoon rainfall over India.

A large number of studies has shown that the QBO (Quasi-Biennial Oscillation) plays an important role in linking the different layers of the atmosphere. The QBO slowly descends from middle stratospheric levels and after a few months it affects several tropospheric and surface parameters. This suggests that the global wind circulation in the lower stratosphere can, after a few months, produce some effects on the major weather events that occur over the world. Since the monsoon circulation over the Indian sub-continent is a part of global general circulation, it may be worthwhile to study the influence of the lower stratospheric winds on the performance of the monsoon and also to identify a few global circulation features that can be used for forecasting, sufficiently in advance, the large scale monsoon failure over India. Recently Thapliyal (1979) has shown that some features in the mean January circulation at 50 mb level are able to indicate the monsoon rainfall in the years when QBO has a westerly phase. This method, however, does not fully explain the large scale monsoon failure that had occurred in 1979. Recently, Pisharoty (1981) has suggested that the monsoon is a delayed response to the inadequacy of the poleward transport of heat during the preceding winter. For relating the lower stratospheric winter conditions with the monsoon rainfall it is, therefore, felt that the circulation features during the months of January and February should be viewed together and not those occurring in January circulation alone. In relation to monsoon rainfall the 50 mb winter (January and February) circulation patterns for recent 16 years (1965 to 1980) have, therefore, been studied here in detail.

2. Monsoon performance

The performance of monsoon has been judged by the actual total precipitation it gives over the entire country. Since the World Meteorological Organisation has recommended that the 30-year period is sufficient for computing normal, the monsoon rainfall data for 1951 to 1980 have been collected from the National

TABLE 1

Group 'A' years (easterly QBO years winter patterns similar to that of 1980) and corresponding monsoon rainfall departures in percentage of normal

	1980	'77	'75	'73	'71	'69	'66
Rainfall departures	+2	+1	+15	+6	—1	—4	—15

TABLE 2

Group 'B' years (westerly QBO years winter patterns similar to that of 1979) and corresponding monsoon rainfall departures in percentage of normal

	1979	'76	'74	'72	'70	'68	'67	'65
Rainfall departures	—22	+1	—16	—25	+9	—11	0	—19

Data Centre of the India Meteorological Department and used for calculating the normal (85.18 cm) and standard deviation (12.14 per cent of normal). For recent 30 yr (1951-80), the monsoon rainfall has been shown as percentage of departure from normal in Fig. 1. It is seen from the figure that recent 16 years (1965 to 1980) are characterised by large scale year to year variation in the rainfall. During the 30-year period large scale monsoon failures have occurred in 1951, 1965, 1972, 1974 and 1979 and in all these years more than 50 per cent area of the country has been affected (Dhar *et al.* 1979) by significant rainfall deficiency (— 20% of normal or less). It is also noted from the figure that during all these five years the deficiency of rainfall has been more than 15 per cent of the normal. This indicates that the magnitude of the drought can be measured by the deficiency of the rainfall and the year in which the monsoon deficiency is more than 15 per cent can be termed as severe drought year. It can, therefore, be inferred that severe drought conditions during recent 30 years have occurred on five occasions (1951, 1965, 1972, 1974, and 1979) only. A detailed study of the mean monthly circulation patterns during these five years, therefore, may provide some clue for predicting the occurrence of drought over India.

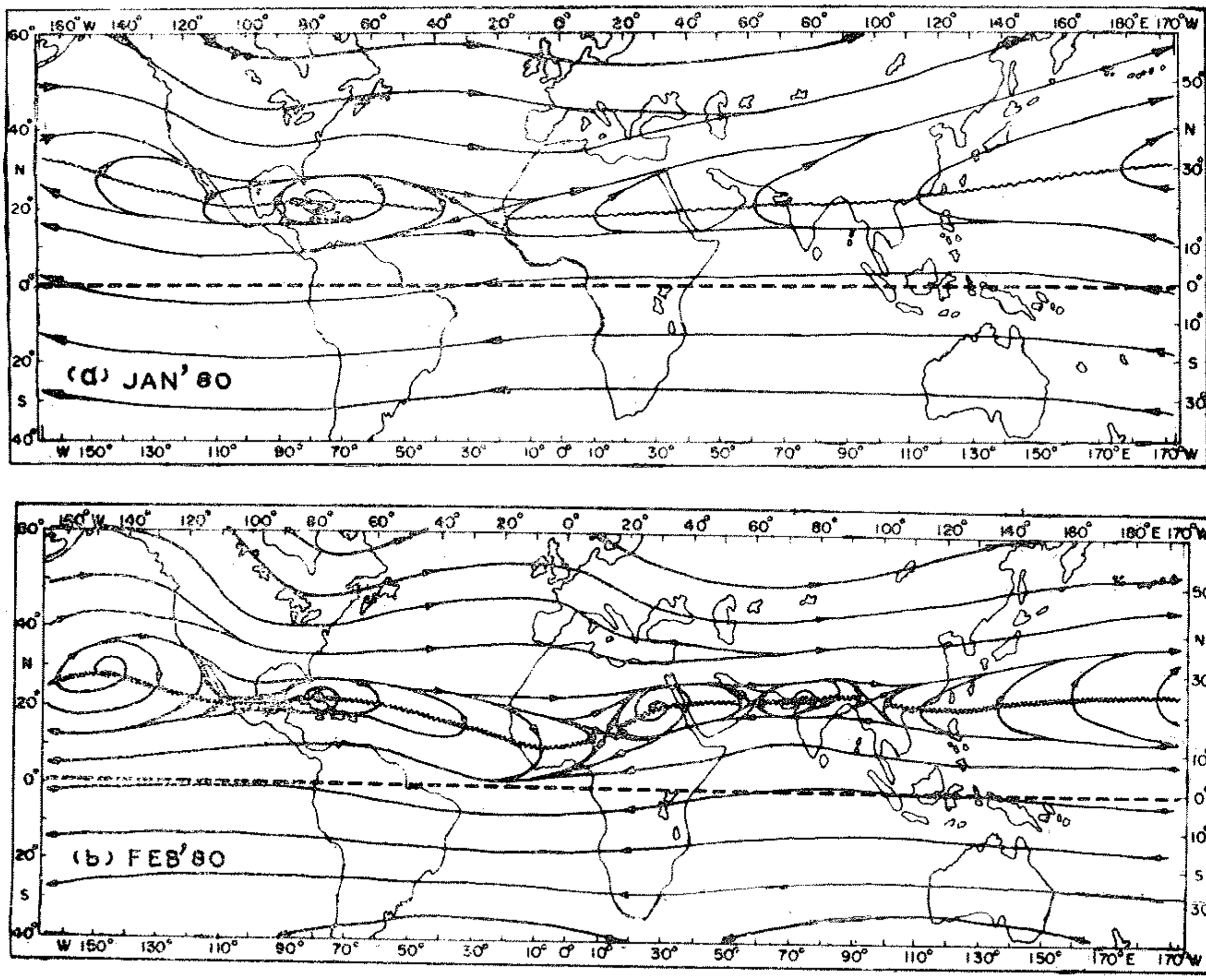
3. Monsoon performance in relation to stratospheric winds

Evidence is slowly accumulating that the studies of the interaction between the stratosphere and of the general downward propagation of the phase of QBO might lead to development of techniques for forecasting weather over large areas of the globe. For examining the relationship between the mean monthly wind circulation patterns in the lower stratosphere during winter months and the performance of the subsequent monsoon, the 50 mb mean monthly wind charts for the globe for all the 12 months of two recent contrasting monsoon years 1979 (a severe drought year) and 1980 (a good rainfall year) have been prepared. In 1979 the drought conditions prevailed over many parts of the country while in 1980 good monsoon rainfall occurred in India. From the *"Monthly Climatic Data of the World"* the mean monthly winds at 50 mb level have been collected and plotted on global charts which cover both hemispheres from latitude 40 deg. S to 60 deg. N. In recent years a large number of wind observations have been collected from the lower stratospheric levels and the global coverage of data particularly at 50 mb level (20.5 km) is adequate for studying the different circulation features that occur at this level.

On comparing the mean monthly charts of the two contrasting years it has been found that by and large the circulation features in a drought year differ considerably from those of good monsoon year. During the winter months (January and February) a significant difference has been noted between the mean monthly circulation features of two contrasting years. The analysed charts of mean January winds of two contrasting years 1980 and 1979 are respectively presented in Figs. 2(a) and 3(a). In addition, the mean February charts for these two contrasting years are also given in Figs. 2(b) and 3(b). It is noted from the figures that the broad scale circulation features during the winter months of a good monsoon year differ considerably from those found in a severe drought year. The most prominent circulation feature in a good year is the well marked subtropical ridge over the northern hemisphere around latitude 20 deg. N covering the entire globe. On the other hand, in a severe drought year (1979) this extensive sub-tropical ridge around 20 deg. N gets broken and appears over a limited region of the globe. Among three prominent features of the circulation in a drought year the most salient one is the near equatorial trough which encircles the southern hemisphere. Simultaneously a pair of trough and ridge which runs almost parallel to equator is also found over the large part of tropics in the northern hemisphere. Thus the winter circulation features in a severe drought year are completely different from those of a good monsoon year and are unique in nature.

4. Identification of unique circulation features during severe drought years

The inference, that the above unique circulation pattern in winter months occurs in severe drought year is based only on the study of patterns for only two contrasting years. Before arriving at a final conclusion, it is very necessary to confirm that the same circulation pattern, as is found in 1979, occurs in all the severe drought years and it does not occur in any other year. For establishing this result, the 50 mb, mean January, February, March and December winds for recent 16 years (1965 to 1980), for which adequate observations are available, have been analysed. While examining the winter circulation patterns, these four months have been considered because the winter conditions start in late December and continue upto early March. On examining the wind circulation during these four months, it has been found that the mean monthly winter circulation pattern for each of these years in the recent period is either similar to 1979 or to 1980. On the basis of the winter circulation patterns, the recent 16 years (1965 to 1980) have, therefore, been divided in two groups namely 'A' and 'B'. In group 'A' those years have been selected whose winter circulation patterns are similar to that of 1980 (Table 1).



Figs. 2 (a & b). 50 mb mean monthly winds for (a) January 1980 and (b) February 1980

The years whose winter circulation patterns are similar to that of 1979 have been classified under group 'B' (Table 2). It is seen from the tables that the year 1978 does not appear in either of the groups because the mean monthly circulation patterns during its four winter months are not same. The circulation pattern during December 1977 resembles that of group 'A' while that of the subsequent January, February and March resembles that of group 'B'. In view of this, the year 1978 has not been placed in either of the groups. But it may be mentioned here that the monsoon rainfall during 1978 monsoon has been good (+7 per cent of the normal). Since the mean monthly circulation patterns during all the winter months of 1978 do not belong to either of the groups it can be inferred that the winter circulation features in a drought year are different from those that are found in 1978.

It is seen from Table 1 that the large scale monsoon failure (having deficiency more than 15 per cent of the normal) has not occurred during group 'A' years even on a single occasion. In all these years as can be seen from Fig. 3, the easterly QBO phase has been present at 50 mb level. This suggests that no large scale monsoon failure has occurred during the easterly QBO years. Since the mean monthly circulation pattern during the winter of all group 'A' years is different from that of a drought year, it can be inferred that the circulation features found in group 'A' years do not lead to drought conditions over India.

During the winter of group 'B' years listed in Table 2 three large scale circulation features are noticed.

It is seen from the table that severe drought conditions have occurred during group 'B' years on four occasions. In the rest of the years, the rainfall has been normal or slight defect. In all these years the significant circulation features are a tropical trough line running parallel to equator over entire southern hemisphere and a pair of ridge and trough over a large portion of the northern hemisphere. In the present section, each of these circulation features has been critically studied in relation to the monsoon rainfall over India, with a view to examine whether the degree of variations in these features can provide some clue for forecasting the occurrence of drought.

The largest circulation feature that is found during the winter months of all the group 'B' years, is a

TABLE 3

Longitudinal extent of northern hemispheric trough and ridge during winter

Year	Mean extent in degrees longitude of			Monsoon rainfall (percentage of normal)
	Trough	Ridge	Mean of trough and ridge	
1979	185	160	172.5	78
1976	100	81	90.5	101
1974	147	136	141.5	84
1972	238	222	230.0	75
1970	27	28	27.5	109
1968	139	135	137.0	89
1967	68	55	61.5	100
1965	172	152	162.0	81

TABLE 4

Performance of forecast formula

Severe drought years	Magnitude of the drought as percentage departure from the normal		
	Actual	Predicted	Difference
1979	—22	—20	2
1974	—16	—16	0
1972	—25	—25	0
1965	—19	—19	0

tropical trough line that runs in east-west direction and covers the entire southern hemisphere (Figs. 3 & 5). The trough line separates the QBO westerly winds from the southern hemispheric easterly winds. The position of the trough at 50 mb level may thus indicate the relative strength of QBO in relation to the seasonal lower stratospheric circulations and if so it may have some influence on the monsoon rainfall in India. To examine this aspect the location of the trough line during all the group B years has been studied. In all these years, the location of the trough has been found between the equator and 10 deg. S latitude. On comparing the mean location of the trough with the rainfall of the corresponding year it has been found that when the trough is located in more southerly position during the winter, the subsequent monsoon gets more deficient rainfall. However, the difference between the mean location of the trough in any two years is very small and may not be very useful for foreshadowing the occurrence of drought in India.

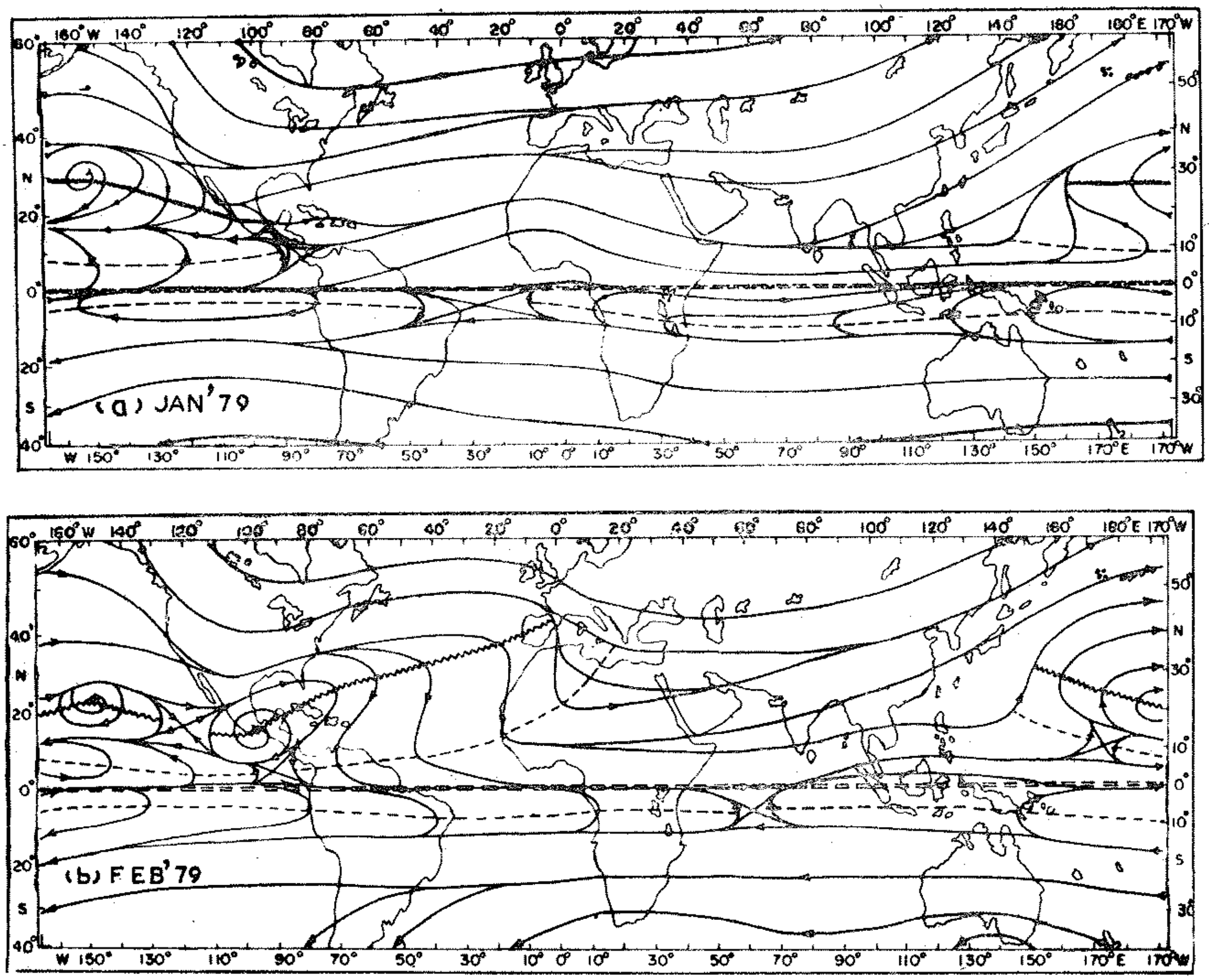
The second prominent circulation feature that is found in all the group 'B' years is a northern hemispheric trough which runs in east-west direction. To estimate the influence of this global feature on the rainfall, the winter circulation patterns of two severe drought years 1972 and 1979 have been examined. The analysed charts for 1979 and 1972 are respectively presented in Figs. 3 and 5. It is noted from Fig. 1 that the most severe drought has occurred in 1972. This is also the year when the longitudinal extent of the northern hemispheric trough in the winter months was found to be maximum. This suggests that the longitudinal extent of the northern hemispheric trough may be associated with the monsoon rainfall in India. For establishing this association, the mean longitudinal extent of the trough during winter has been determined for all the group 'B' years. The winter extent of the trough has been calculated by taking the average of its longitudinal lengths that are found in the months of January and February. The winter extent of the trough in degrees longitude and the rainfall during subsequent monsoon in percentage of normal are presented in Table 3.

From Table 3, it is seen that maximum length of the trough is found in winter 1972 (most severe drought year) and minimum length is found in winter 1970 (most excess rainfall year). Even during the remaining years, the length of the trough increases as the monsoon rainfall in India decreases. To determine an exact relationship, the longitudinal extent of the trough during winter and the rainfall in subsequent monsoon have been plotted on a semi-log graph which is reproduced in Fig. 4. It is seen from the figure that the line joining all the points is a straight line. It can, therefore, be concluded that the relationship between the east-west length of the trough during winter and the subsequent monsoon rainfall in India, is logarithmically linear.

During all the group 'B' years the third largest circulation feature is the northern hemispheric ridge which runs in east-west direction, and is nearly parallel to the northern hemispheric trough. An analysis similar to that of the northern hemispheric trough has also been carried out for the ridge. This has revealed that the relationship between the length of ridge in winter and subsequent monsoon rainfall is also logarithmically linear, as has been found earlier in case of the trough.

5. Long range forecasts of severe drought over India

In recent 29 years (1952 to 1980) the severe drought conditions (rainfall deficiency more than 15 per cent of the normal) have occurred over India in four years (1965, 1972, 1974 and 1979) as can be noted from Fig. 1. It has been seen that the winter circulation patterns in all these years are similar to that of group 'B' years (like 1979). In all these years three significant circulation features have been noted. Out of these, the pair of the trough and ridge has shown a linear logarithmic relation with the monsoon rainfall in India. Since both the features, the trough and the ridge, run nearly parallel to each other, they have been combined and used here for predicting the occurrence as well as the magnitude (rainfall deficiency) of the severe drought over India. It is seen from Table 3 that severe drought conditions occur in India when the pair of trough and ridge covers a length in degrees longitude about 140 degrees or more. During all the



Figs. 3 (a & b). 50 mb mean monthly wind patterns for (a) January 1979 and (b) February 1979

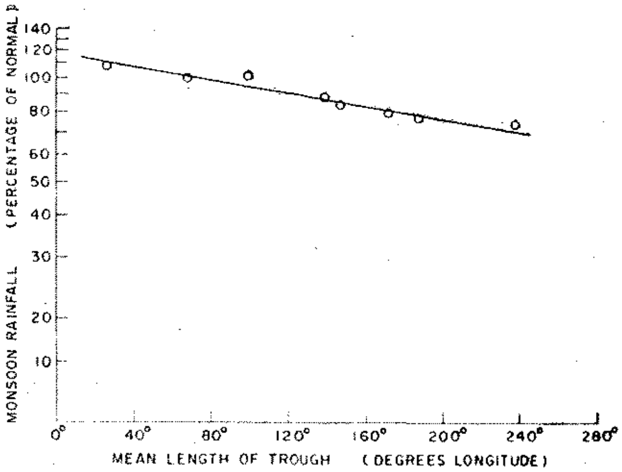
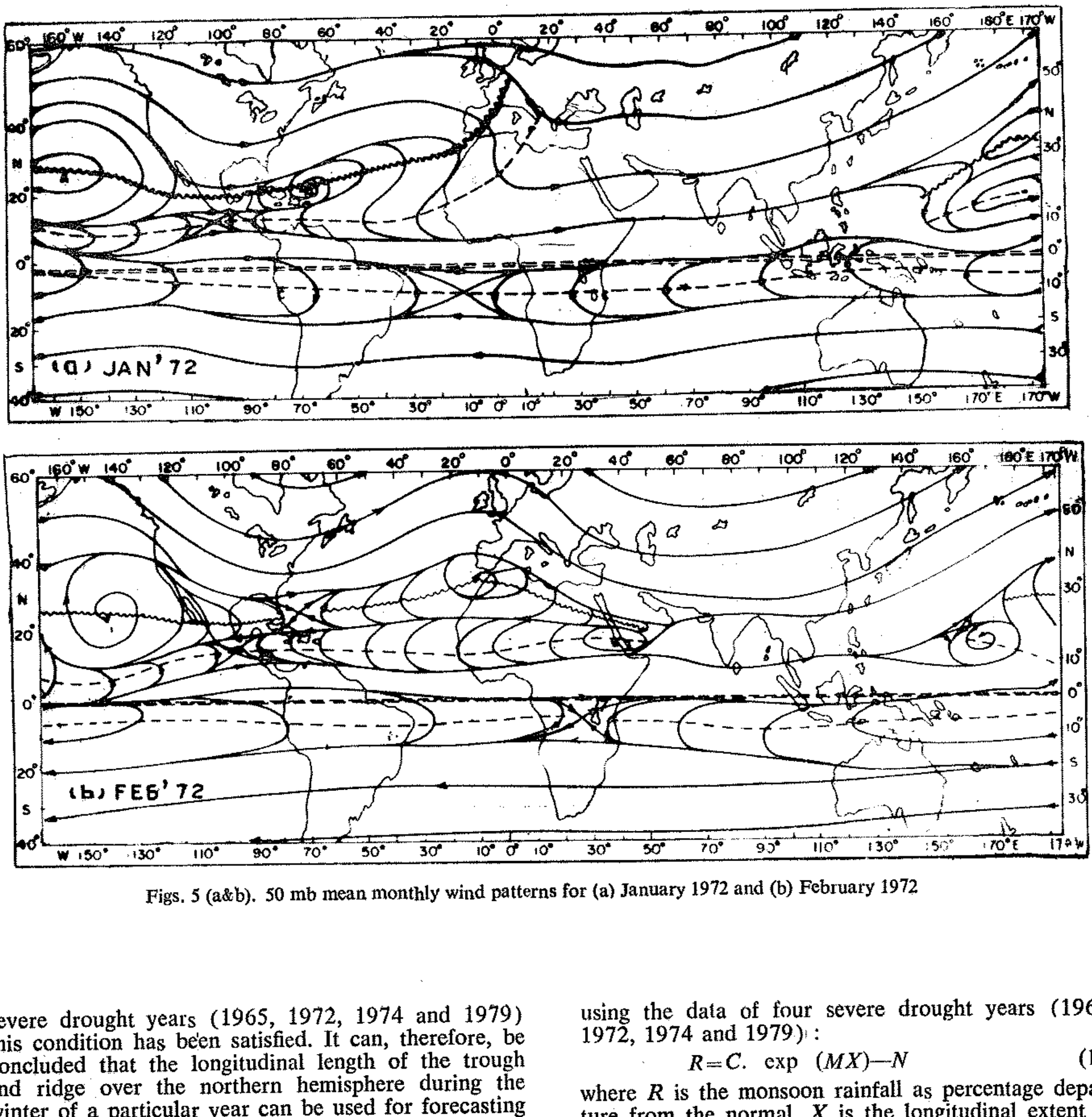


Fig. 4. Relation between the extent of the northern hemispheric trough during winter and the subsequent monsoon rainfall over India



Figs. 5 (a&b). 50 mb mean monthly wind patterns for (a) January 1972 and (b) February 1972

severe drought years (1965, 1972, 1974 and 1979) this condition has been satisfied. It can, therefore, be concluded that the longitudinal length of the trough and ridge over the northern hemisphere during the winter of a particular year can be used for forecasting the severe drought conditions that occur due to large scale monsoon failure over India.

It may be mentioned here that the mean length of the trough and ridge can be used for forecasting the monsoon rainfall that occurs during the group 'B' years. Since, westerly QBO phase has been found in all the group 'B' years, it can be concluded that the longitudinal length of the pair (trough and ridge) can be used for predicting monsoon rainfall in all the westerly QBO years. In this article an attempt has, however, been made to derive an exact mathematical expression which can be used for forecasting the magnitude of severe droughts that occur due to large scale failure of monsoon in India. Since the extent of the trough and ridge shows a linear logarithmic relation with the rainfall, the following expression has been fitted by using the data of four severe drought years (1965, 1972, 1974 and 1979) :

$$R = C.\ \exp\ (MX) - N \quad (1)$$

where R is the monsoon rainfall as percentage departure from the normal, X is the longitudinal extent of the pair of trough and ridge during the winter (January and February), N is the normal rainfall (100%), C and M are constants given below :

$$\left.\begin{aligned} C &= 100.58 \\ M &= -.0013 \end{aligned}\right\} \quad (2)$$

By using Eqn. (1), the magnitude of severe drought has been predicted for the recent 4 years (Table 4).

It is seen from the above Table that Eqn. (1) provides good forecast for the magnitude of the severe droughts, that occur due to large scale monsoon failure over India. From the equation it has been found that the severe drought occurs over India when the mean extent of the trough and ridge is more than 140 degrees of the longitude. In Eqn. (1) the maximum value of X can be assumed as 360 degrees of the longitude which means the pair of trough and ridge is covering the entire northern hemisphere. On using this extreme value of X in Eqn. (1), the value of maximum rainfall departure has been found equal to —37 per cent of the normal. The value seems to be reasonable as it has not been exceeded even once during the recent hundred years (1875-1981).

6. Conclusions

It is possible from this study to forecast the severe drought conditions that occur due to large scale monsoon failure over India. The winters, in which the mean longitudinal length of the pair of trough and ridge over the northern hemisphere is more than 140 degrees, are followed by severe drought conditions during the subsequent summer monsoon over India. Based on this criterion it is possible to forecast, 3 months in advance, the occurrence of severe drought in India. By using Eqn. (1) the highest magnitude of severe drought that can ever occur over India has been found equal to *minus* 37 per cent of the normal. The fact that this limit has not been exceeded even once during recent history of monsoon, lends confidence to the technique and methodology discussed above and the mathematical expression developed to predict severe drought in India. Thus, it is possible to predict, sufficiently in advance, the occurrence of severe droughts over India.

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