

## Floods and droughts in association with cold and warm ENSO events and related circulation features

MEDHA KHOLE and U.S DE

*Meteorological Office, Pune - 411 005, India*

*(Received 17 April 1997, Modified 14 May 1999)*

सार — प्रायद्वीपीय भारत में, बाढ़ों का आना तथा सूखा पड़ने की घटनाएं ग्रीष्मकालीन मानसून वर्षा के साथ जुड़ी हुई हैं। अब यह स्पष्ट हो गया है कि भारतीय ग्रीष्मकालीन मानसून को दूर से प्रभावित करने वाले तथ्यों में एल निनो-दक्षिणी दोलन (ई एस एस ओ) का स्थान प्रमुख है। ग्रीष्मकालीन मानसून वर्षा से संबंधित प्रलेखों को प्रकाशित साहित्य में भी समुचित स्थान दिया जाता है। मौसम के संबंध में पूर्वानुमान लगाने वाले भारतीयों को मानसून पद्धति और एल निनो दक्षिणी दोलनों के परस्पर संबंधों की जानकारी जी. वॉकर के समय से है। नार्मड (1953) ने मानसून से संबंधित निष्कर्षों का सार प्रस्तुत करते हुए कहा, "भूमंडलीय मौसम प्राचलों के मानसून पर पड़ने वाले प्रभावों की तुलना में भूमंडलीय मौसम पर पड़ने वाला मानसून का प्रभाव दीर्घकालीन होता है।" 1990 से 1994 तक की उष्ण एल निनो दक्षिणी दोलनों की अवधि विश्व के विभिन्न क्षेत्रों में मौसम संबंधी विसंगतियाँ उत्पन्न करने वाली एक लम्बी अवधि थी। तथापि इस अवधि में सम्पूर्ण भारत में हुई वर्षा बिल्कुल सामान्य जैसी ही थी और वस्तुतः वर्ष 1994 में भारत में वर्षा प्रचुर मात्रा में हुई। इस शोध का उद्देश्य, इन विशेषताओं में से कुछ एक की अधिक विवेचनात्मक रूप से जांच पड़ताल करना है।

यह पाया गया है कि एल निनो दक्षिणी दोलनों का परिसंचरण पद्धति के क्षेत्रीय स्तर पर परिवर्तनकारी प्रभाव पड़ता है जो भूमंडलीय स्तर पर परिसंचरण पद्धति के साथ संबद्ध हो कर प्रावस्था अवरोध उत्पन्न करता है जिसके परिणामस्वरूप चरम स्तरीय घटनाओं का घटित होना अथवा घटित नहीं होना सम्भव होता है। इसके अलावा 1960-1990 तक की अवधि का गुणात्मक विश्लेषण वर्षा ऋतु के अंतिम चरण में वर्षा की मध्यावधि न्यूनता की सीमा का पता लगाने के लिए किया गया है। इस बात का पता चला है कि कुछ विचाराधीन मामलों में से काफी मामलों में सूखा वाले वर्षों में भी वर्षा ऋतु के अंतिम चरण में वर्षा की मध्यावधि न्यूनता पाई गई है।

**ABSTRACT.** For the Indian subcontinent, the occurrence of floods and droughts is closely linked with the summer monsoon activity. The phenomenon of El Nino-Southern Oscillation (ENSO) has been established to be one of the major teleconnections of Indian Summer Monsoon. Also the relationship between the circulation features and summer monsoon activity is well documented in the literature. The interaction of ENSO with monsoon system was known to the seasonal forecasters in India from the days of G. Walker. Normand (1953) summarising these results has remarked that 'Monsoon has a prolonged influence on the global weather rather than global weather parameters influencing the monsoon'. 1990-94 was a prolonged period of warm ENSO producing weather anomalies in different regions of the globe. Yet during the same period all India rainfall was very close to normal and in fact, 1994 was a year of abundant rainfall for India. The aim of the study is to examine some of these features more critically.

It is observed that ENSO has a modifying effect on the regional scale circulation pattern and possible interactions and/or phase-locking with the planetary scale circulation pattern, which results into the occurrence or non-occurrence of an extreme event. Also, a qualitative analysis is carried for a period 1960-90 to assess how far the mid-season rainfall deficiency is made up at the end of the season. It is observed that even during drought years, the mid-season rainfall deficiency is made up at the end of the season for a considerable percentage of the total number of cases.

**Key words**—El-nino southern oscillation, Southern oscillation index, Drought, Flood, Warm and cold ENSO, Circulation features.

### 1. Introduction

Occurrence of floods and droughts is a world-wide phenomenon associated with extremes of rainfall. For the

Indian subcontinent, the occurrence of floods and droughts is closely linked with the activity of summer monsoon. The activity of Indian summer monsoon rainfall has many teleconnections, various aspects of the Indian Summer mon-

TABLE 1

Trend of the value of area receiving deficient/scanty rainfall and excess rainfall at the end of the season as compared to its value at the middle of the season (1960-90)

Area of Deficient/Scanty Rainfall				Area of Excess Rainfall			
DW years		DnW Years		DW years		DnW Years	
Trend	% of cases	Trend	% of cases	Trend	% of cases	Trend	% of cases
Decreasing	80%	Decreasing	50%	Increasing	40%	Increasing	50%
Increasing	20%	Increasing	50%	Decreasing	60%	Decreasing	50%

Area of Deficient/Scanty Rainfall				Area of Excess Rainfall			
FC years		FnC Years		FC Years		FnC Years	
Trend	% of cases	Trend	% of cases	Trend	% of cases	Trend	% of cases
Decreasing	67%	Decreasing	100%	Increasing	100%	Increasing	100%
Increasing	33%	Increasing	0%	Decreasing	0%	Decreasing	0%

soon activity - ENSO relationship have been investigated by several research workers such as Elliot and Angell (1987), Parthasarthy *et al.* (1985), Rasmusson and Carpenter (1983), Sikka (1980), Bhalme *et al.* (1983), Shukla (1987); Shukla and Paolino (1983), Walker (1923) and many others. It has been observed that in general occurrence of El-Nino during the negative phase of Southern Oscillation (SO) proves to be conducive for poor activity of the Indian summer monsoon. However, there are some drought years not associated with ENSO whereas not all El-Nino years are drought years. Similar observation holds good for La-Nina year and flood year for India. For example, Wilby (1993) lists 1974 and 1979 as non-ENSO years though they were years of monsoon failure for India. Also, the relationship of Indian summer monsoon rainfall and tropospheric circulation features is well documented in the literature. Alexander *et al.* (1978), Banerjee *et al.* (1978), Mooley *et al.* (1986), Mooley and Shukla (1972) are a few to name. The present study aims at examining some of these aspects more critically.

## 2. Data and Methodology

Shukla (1991) has studied the Indian summer monsoon rainfall anomalies in associated with warm and cold ENSO events. Various causes are identified as regards occurrences of floods and droughts over India and warm and cold ENSO events, from this anomaly diagram prepared by Shukla (1991). The period covered is from 1870-1990.

In the second part, the anomalous tropospheric circulation features for flood and drought years are examined on a monthly scale. This study is carried out for a period of 1979-90 which constitutes a subset of the long period data set 1870 - 1990; using the monthly anomaly charts of June

to September. These charts are examined for the presence of various circulation features such as trough, ridge, cyclonic or anticyclonic circulation *etc.* The daily wind data obtained from a well distributed network of RS/RW stations over India and the monthly climatological wind normals have been utilised for the preparation of these charts.

Further, a qualitative assessment of the relationship between the rainfall at the middle of the summer monsoon season (June and July) *vis-a-vis* that for the end of the season (June to September) is carried out to examine on the aspects of making up of the mid-season rainfall deficiency at the end of the season. For this purpose the area receiving deficient/scanty rainfall and the area receiving excess rainfall during the mid-season period and at the end of the season have been compared. This analysis is done for a period 1960-90 which again constitutes a subset of the long period data set 1970-90. Table 1 shows the details of this comparative analysis.

## 3. Identification of drought and flood years

As described in data and methodology section following are the various cases of flood and drought years as identified from the anomaly diagram of Shukla (1991). A year with normalised rainfall departure greater than +1 is designated as flood year and a year with normalised rainfall departure less than -1 is designated as a drought year.

- (i) Drought years associated with warm ENSO events (DW): 1877, 1899, 1904, 1911, 1918, 1951, 1965, 1968, 1972, 1982, 1987.

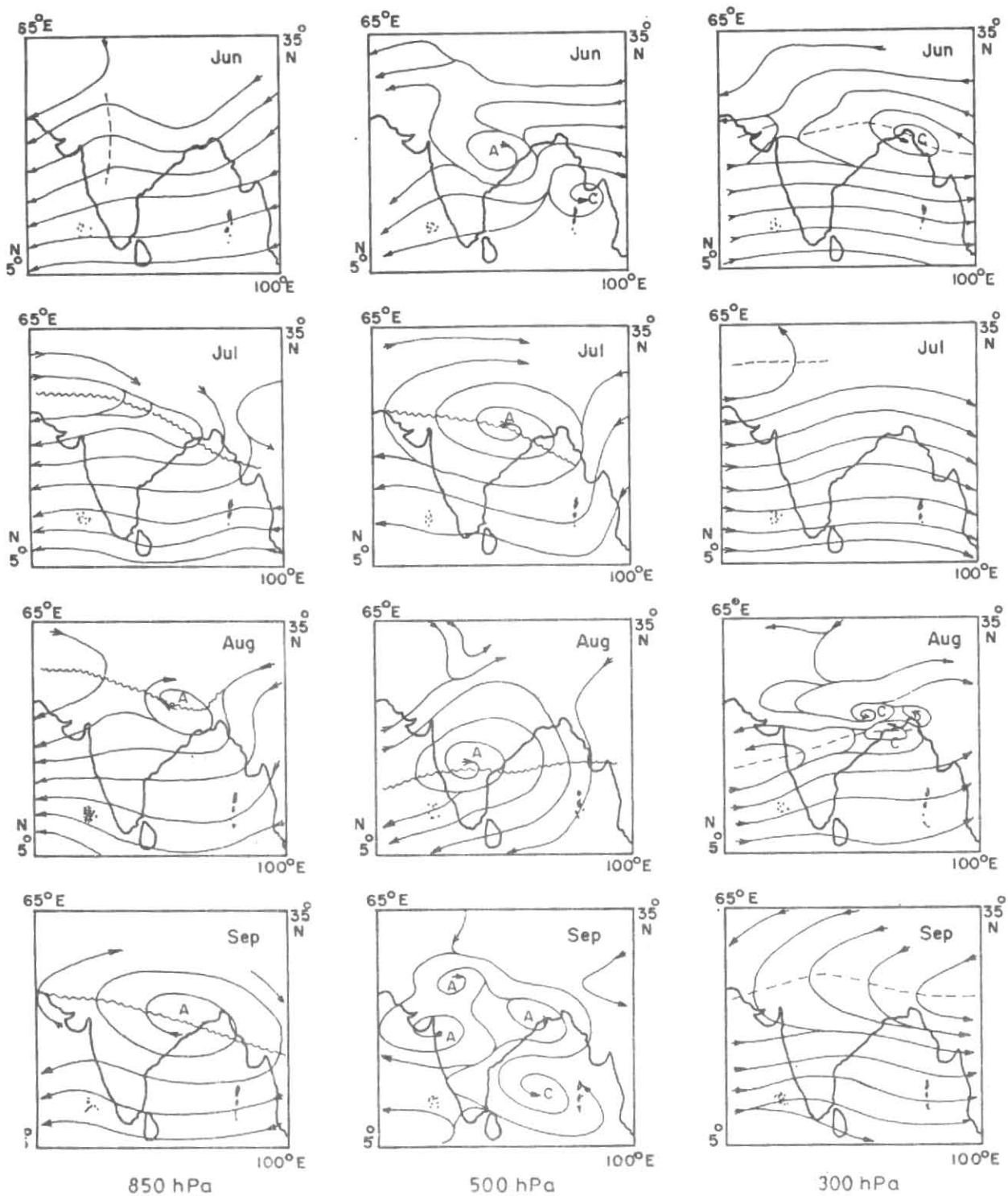


Fig.1. Monthly anomaly circulation maps for 1982

(ii) Drought years not associated with warm ENSO events (DnW) : 1873, 1901, 1905, 1920, 1928, 1941, 1966, 1974, 1979, 1986.

(iii) Flood years associated with cold ENSO events (FC): 1892, 1894, 1910, 1916, 1933, 1970, 1975, 1988.

- (iv) Flood years not associated with cold ENSO events (FnC): 1874, 1878, 1917, 1942, 1956, 1959, 1961, 1983, 1990.
- (v) Warm ENSO events associated with normalised rainfall departure value between 0 and +1: 1900, 1944.
- (vi) Cold ENSO events associated with normalised rainfall departure value between 0 to -1: Nil.

This classification differs from that given by Chatopadhyay and Bhatla (1996) and others in which they have defined an ENSO episode based on Southern Oscillation Index (SOI) during July-August-September (JAS) of an year on the basis of the significant positive correlation between SOI and the all India monsoon rainfall.

### 3.1. Rainfall distribution for drought and flood years (1960-90)

In order to determine the pattern correlation among drought and flood years, the coefficient of rank correlation between the percentage departure of rainfall (from normal) for DW/DnW and FC/FnC years is computed. For this purpose, the mean composite rainfall for DW & DnW and FC & FnC years is considered for each of the 35 meteorological sub-divisions of India. The value of rank CC for DW and DnW years is +0.70 and for FC and FnC years is +0.36. Thus, it can be inferred that, the rainfall pattern for India as a whole, does not exhibit high degree of dissimilarity for DW and DnW years. However, for FC and FnC years, the relatively low value of rank correlation coefficient (CC) indicates a lesser degree of similarity in the rainfall patterns.

The difference was also examined for smaller homogeneous areas in the country. The values of rank CC between mean rainfall percentage departure (from normal) for years for DW and DnW years and for FC and FnC years for five homogeneous regions of India [Parthasarathy *et al.* (1995)] were computed and are as under:

Region	Value of Rank DW and DnW years	CC between FC and FnC years
North West (NW) - India	-0.37	+0.54
West Central (WC) - India	+0.52	-0.62
Central North East (CNE) - India	+0.90	+0.20
North East (NE) - India	-0.80	+0.40
Peninsular India	-0.31	+0.66

It is seen that the regions of NW, NE and Peninsular India exhibit distinct difference in rainfall patterns in case

of DW and DnW years. The highest value of rank CC is observed for NE- India. For CNE India the high value of rank CC indicates a close similarity in rainfall patterns in case of DW and DnW years. As regards FC and FnC years, a high degree of dissimilarity in rainfall pattern is observed for WC-India. For rest of the regions the rank CCs are positive. The highest value for peninsular India indicates a high degree of similarity in rainfall patterns for FC and FnC years and the lowest value of rank CC for CNE India indicates a lesser degree of similarity in rainfall patterns for FC and FnC years. Also, the reversal in the sign of rank CC for DW & DnW years and FC & FnC years is significant for NW, WC, NE and peninsular India.

## 4. Discussion

### 4.1. Circulation features of drought years (1975-90)

From the cases described in section 3, it is evident that during the period 1975-90, there are two DW years *viz.* 1982 and 1987 and two DnW years *viz.* 1979 and 1986. Following are the salient features of anomaly circulation features observed for these years:

#### (a) DW years

(i) 1982—Fig.1 depicts the monthly circulation pattern for 1982. In June, at 850 hPa, easterly flow is observed implying weaker than normal lower tropospheric monsoon westerlies. At 500 hPa, an Anticyclonic Circulation (AC) is observed over central India and at 300 hPa, a trough is observed along 20-23°N which implies that upper tropospheric easterlies are weaker than normal. In July, a similar pattern persisted with a ridge running across the region of monsoon trough at 850 hPa, a ridge along 20-25°N at 500 hPa and westerly flow at 300 hPa. In August, a ridge is observed along 27-30°N at 850 hPa along 15°N at 500 hPa and a trough along 15-20°N at 300 hPa. In September, a ridge is observed along 18-25°N at 850 hPa, along 20°N at 500 hPa and a trough along 24-25°N at 300 hPa.

Thus, weaker than normal monsoon circulation persisted through the entire monsoon season of 1982.

(ii) 1987—Fig.2 depicts the monthly anomaly circulation pattern for 1987. In June, a ridge is observed along 20-23°N at 850 hPa, a ridge and a trough along 20-22°N and 11°N respectively at 500 hPa and a ridge along 15-18°N and a trough along 12-13°N at 300 hPa, indicating a weaker than normal circulation at all representative levels. In July, a ridge is observed along 12°N at 850 hPa and along 15-20°N at 300 hPa, indicating weaker (stronger) than normal circulation at lower (upper) troposphere. In August, the flow over Indian region, north of 10°N is observed be westerly at 850 hPa, indicating stronger than normal lower tropospheric

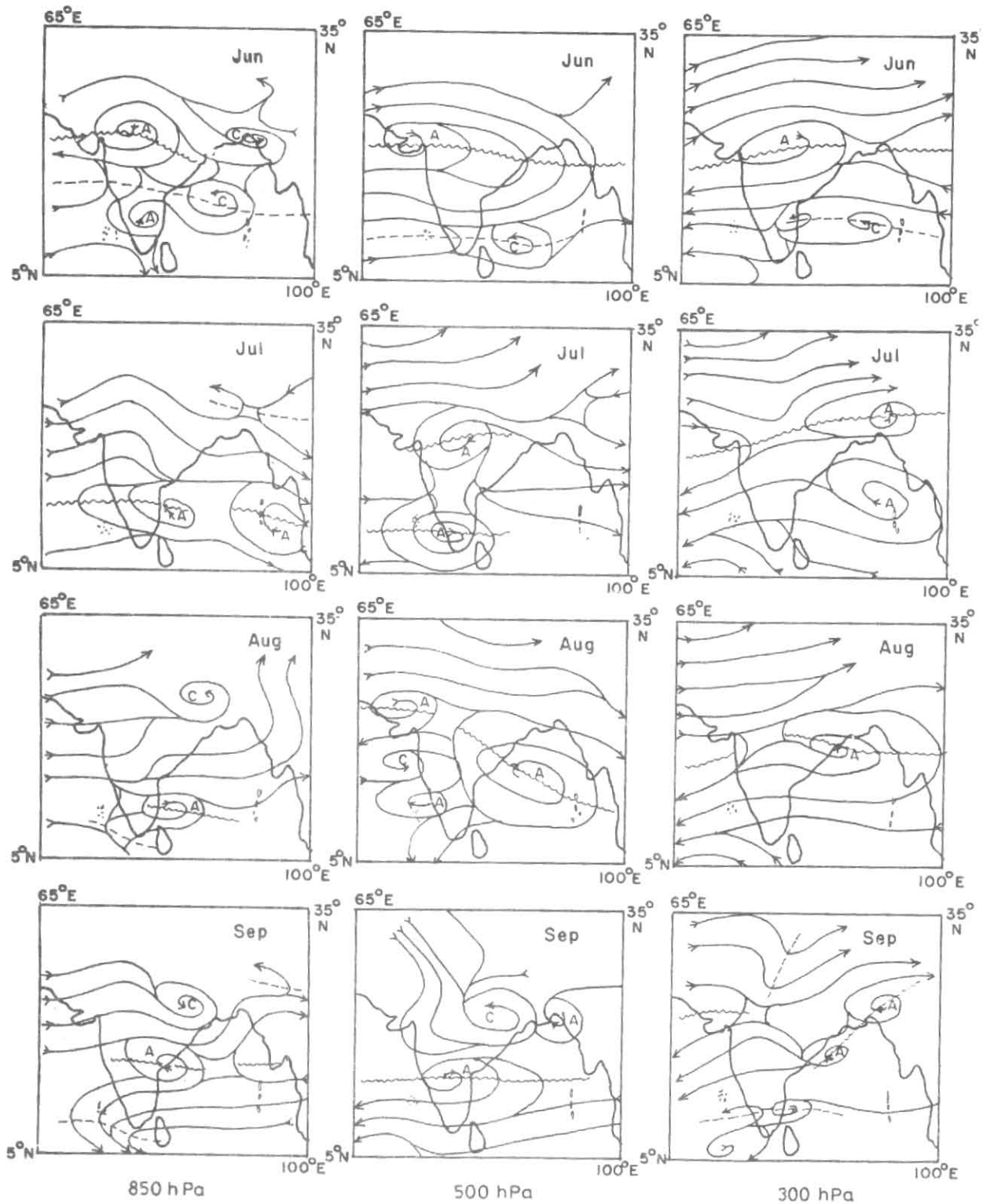


Fig.2. Monthly anomaly circulation maps for 1987

pattern. At 500 hPa, a northwest-Southeast (NW-SE) oriented ridge is observed between the region 10- 25°N and 65-100° E and at 300 hPa, a ridge is observed along 20°N.

In September, at 850 hPa, a ridge is observed along 18°N with westerly winds over the region, north of 18°N (indicating stronger than normal lower tropospheric monsoon west-



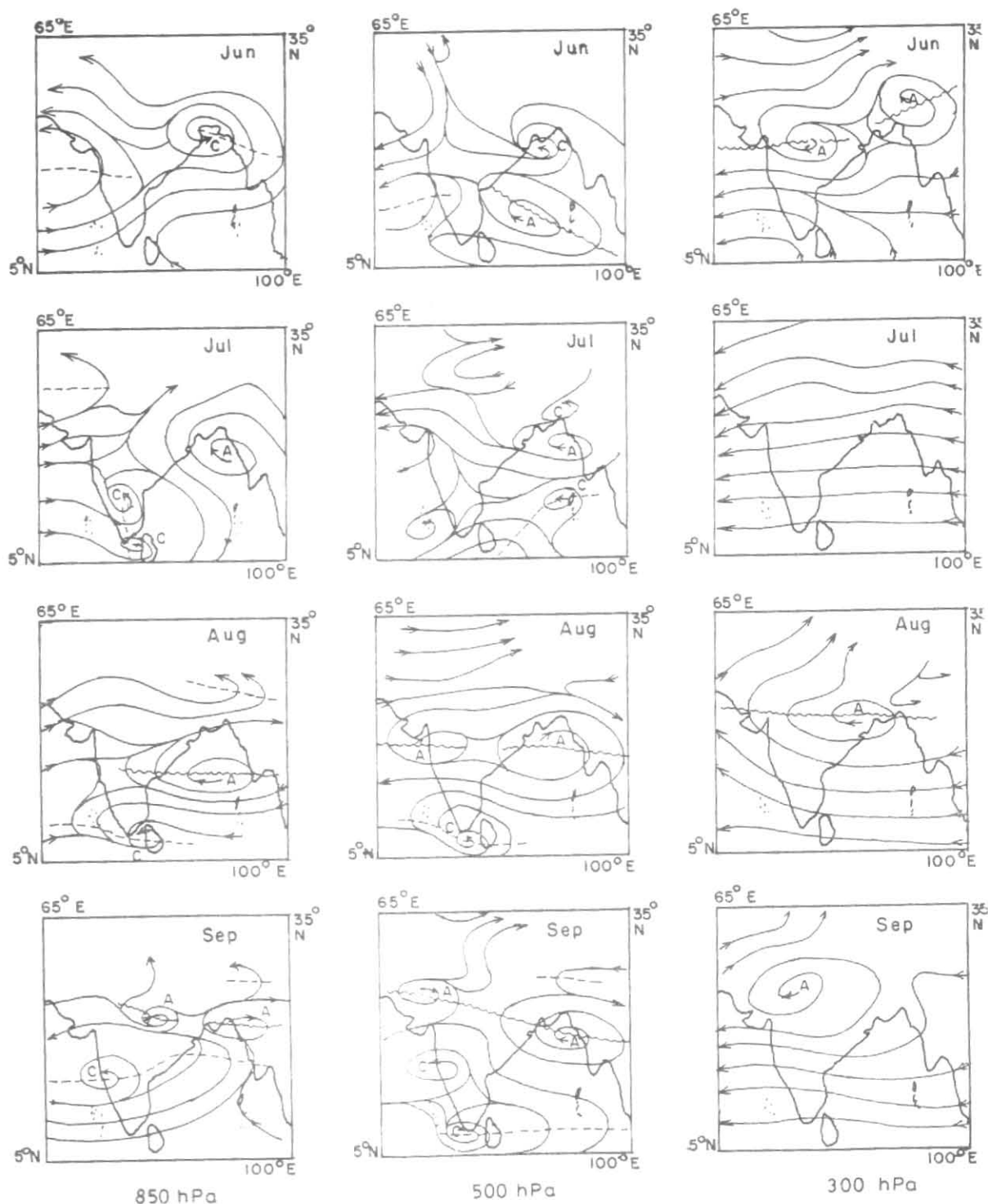


Fig.3. Monthly anomaly circulation maps for 1988

erlies), at 500 hPa, a ridge is observed along  $15^{\circ}\text{N}$  at 200 hPa, a trough is observed along  $10^{\circ}\text{N}$  indicating weaker than normal upper tropospheric easterlies.

Thus, in June, the monsoon circulation at all representative levels is observed to be weaker than normal. In

July, the lower tropospheric circulation is weaker than normal whereas the upper tropospheric circulation is stronger than normal. In August, lower and upper tropospheric circulations are stronger than normal and in September, an overall mixed circulation pattern is observed.

(b) *DnW* years

(i) 1979—In June, at 850 hPa and 500 hPa, the anomaly winds are easterly over Indian region indicating weaker than normal lower and middle tropospheric monsoon westerlies. At 300 hPa, a trough is observed along 25°N implying weaker than normal upper tropospheric easterlies, especially over peninsular region. In July, at 850 hPa, a ridge is observed along 25–30°N and at 500 hPa, a ridge is observed along 20–25°N. These features indicate weaker than normal monsoonal circulation in lower and middle troposphere. At 300 hPa, the wind flow is observed to be mainly westerly. In August, a ridge is observed over 20–30°N at 850 hPa and along 20°N at 500 hPa and a trough along 27–30°N at 300 hPa, indicating weaker than normal circulation throughout the entire troposphere. In September, a ridge is observed between 18–25°N at 850 hPa, along 20°N and at 500 hPa, and a trough is observed along 28°N at 300 hPa. Thus, it can be inferred that in 1979, a weaker than normal circulation persisted over the entire troposphere for all the four monsoon months of June to September.

(ii) 1986—In June, at 850 hPa, a North-South oriented ridge is observed along 86°N and at 300 hPa, a ridge is observed along 22–24°N. In August, at 850 hPa, a trough is observed along 15–20°N at 500 hPa, along 12–23°N with a ridge along 13–14°N. At 300 hPa, a ridge is observed along 25–28°N. This circulation pattern is indicative of a stronger than normal circulation, especially over the Indian region, south of 15°N. In September, the lower tropospheric circulation pattern is indicative of weaker than normal monsoon circulation. At 500 hPa, a ridge is observed along 21–22°N.

Thus, in 1986, the circulation pattern indicates weaker than normal strength in June, August and September at lower tropospheric levels and stronger than normal strength of upper tropospheric easterlies, over the Indian region south of 20°N.

4.2. *Circulation features for flood years (1975-90)*

It is evident from section 3, that during the period 1975-90, 1988 in FC year and 1983 and 1990 are the FnC years. The anomaly circulation features observed during these years are as described below:

(a) *FC* year

(i) 1988—Fig.3 depicts the anomaly circulation pattern for 1988.

In June, a trough is observed along 20°N at 850 hPa and the upper - tropospheric ridge is observed over 20–25°N. Thus, lower and upper tropospheric circulation features are suggestive of stronger than normal monsoon circulation. This pattern is observed to be persisting in July, with a

North-South oriented trough over peninsular region south of 15°N at 850 hPa and easterly flow at 300 hPa. In August at 850 hPa, a trough is observed along 10°N and a ridge along 17°N. At 500 hPa, a trough is observed along 10°N with a northward shift in the position of ridge which is observed along 20°N. At 300 hPa, a ridge is observed along 25°N, indicating a stronger than normal upper tropospheric easterlies. In September, a similar circulation pattern is observed. At 850 hPa, a trough is observed along 17°N and ridge along 22°N, whereas, at 300 hPa, a trough is observed at 8–9°N and a ridge along 20–25°N indicating stronger than normal upper tropospheric easterlies over the peninsular region.

Thus, in 1988, generally, stronger than normal monsoon circulation is observed in June. In July, August and September, the lower and middle tropospheric circulation is indicative of weaker than normal circulation but upper tropospheric circulation is stronger than normal.

(b) *FnC* years

(i) 1983—Fig.4 depicts the anomaly circulation pattern for 1983.

In June, at 850 hPa, a ridge is observed along 25–30°N and at 500 hPa, the location of ridge is along 20–30°N. At 300 hPa, a trough is observed along 28–29°N. These features indicate a weaker than normal monsoon circulation throughout the entire troposphere. This pattern did persist during the rest of the three monsoon months *viz.* July, August and September. In July, a ridge is observed along 20–30°N at 850 hPa and along 20–22°N at 500 hPa whereas a trough is observed along 30–33°N. In August, a ridge is observed along 26–28°N at 850 hPa and along 20–30°N at 500 hPa with a trough along 30°N at 300 hPa. In September, the circulation pattern at 850 hPa is characterized by mainly southerly components of winds. At 500 hPa, a trough is observed at 15–23°N and a ridge along 10–16°N, whereas at 300 hPa, a trough is observed along 20–25°N.

(ii) 1990—In June, at 850 hPa, a ridge is observed along 17°N. At 500 hPa and 300 hPa, a trough is observed along 25°N. In July, at 850 hPa, a ridge is observed along 10°N and a trough along 23°N; at 500 hPa, a ridge is observed along 13°N and a trough along 20°N, whereas, at 300 hPa, the winds are mainly easterly over central and southern India. In August, at 850 hPa, a ridge is observed along 22°N; at 500 hPa, a trough is observed along 12°N. In September, a ridge is observed along 15°N at 850 hPa and a trough along 25°N at 500 hPa. The upper tropospheric circulation pattern is observed to be ill-defined for August and September.

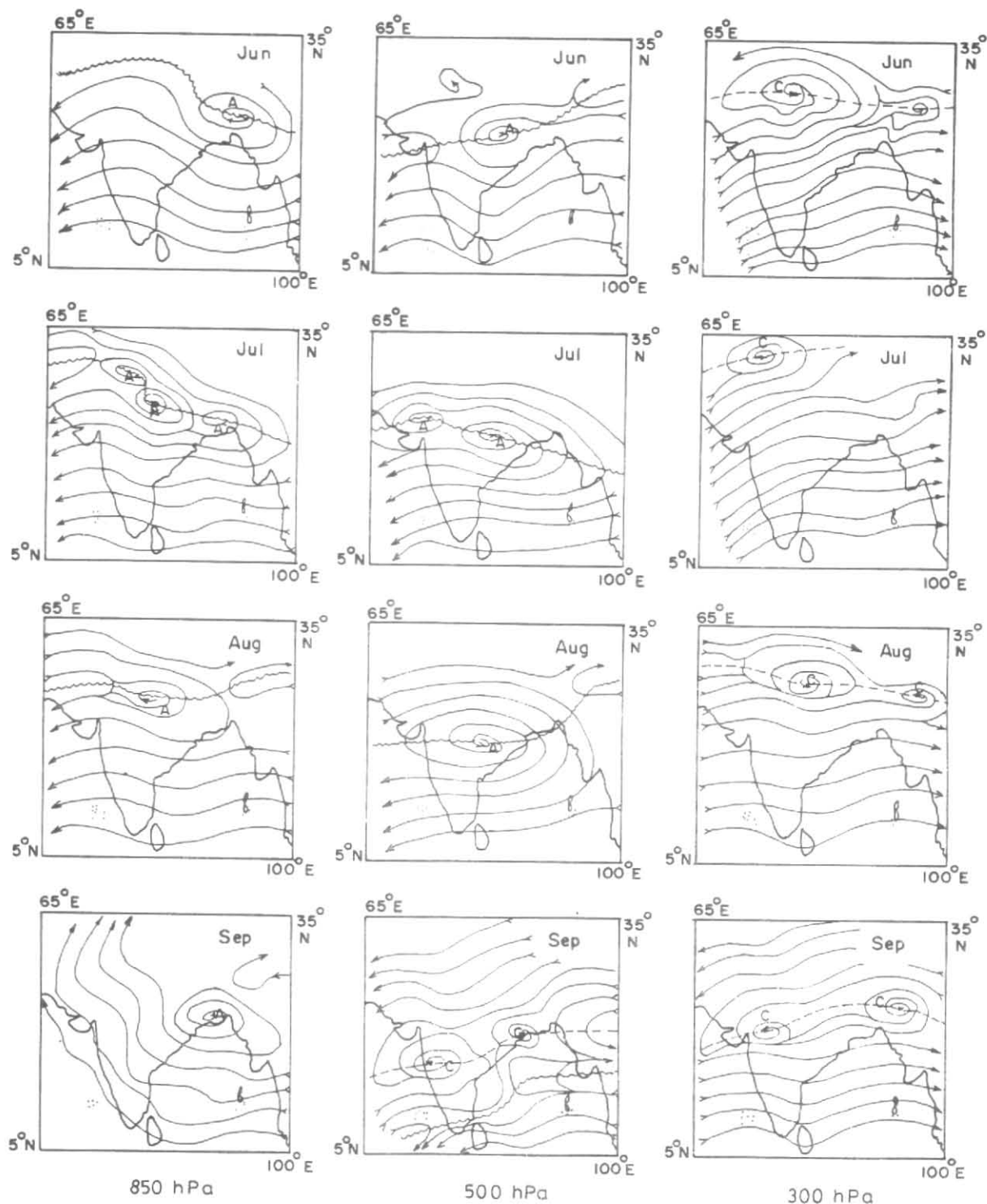


Fig.4. Monthly anomaly circulation maps for 1983

Thus, in case of flood years, the circulation pattern for 1983 is a peculiar one in the sense that, it is indicative of weaker than normal monsoon circulation at all representative levels of troposphere. Moreover, this pattern did

persist during all the four monsoon months. Despite of the fact, 1983 is a flood year. In case of other FnC year viz. 1999 a weaker than normal monsoon circulation prevailed at representative tropospheric levels in June. In July and A



gust, the circulation pattern is observed to be of mixed nature, whereas in September, the circulation pattern is indicative of stronger than normal circulation in lower and middle troposphere. In case of FC year of 1988, in June the circulation is observed to be stronger than normal. In July and August, through the upper-tropospheric circulation was stronger, a weaker than normal circulation prevailed in lower and middle troposphere. In September, stronger than normal circulation is observed in lower and upper troposphere.

#### 4.3. Association between an extreme event (drought or flood) over India and ENSO

The earlier studies have attempted to examine the extreme events (drought or flood) over India and ENSO and it is established that, in general, drought (flood) over India is associated with warm (cold) ENSO event. Quoting from Sikka (1980) and updating the information, Gadgil and Mishra (1995) have found the following distribution of floods and droughts associated with El-Nino and non-El-Nino years.

**El-Nino and drought/flood occurrence over India (1875- 1987)**

	Drought	Neither drought nor flood	Flood	Total
El-Nino	12 (43%)	16 (57%)	0	28
Non-El Nino	6 (7%)	64 (75%)	15 (18%)	85
Total	18	80	15	113

(After Gadgil and Mishra, 1995)

This data brings out the following

An El-Nino year being a drought year is observed in a less percentage of total cases (43%) than an El-Nino year being a normal year (57%). However, there is no El-Nino year being a flood year.

A non-ElNino year being a normal year is observed in 75% of cases, which is much larger a percentage than that of an El-Nino year being a normal year (57%). A non-El-Nino year can be a drought year as well, though with a low chance of 6% of the cases only. Unlike, an El-Nino year being a flood year is not observed in a single case in the sample.

A non-El-Nino year being a flood year is observed in 18% of cases which is very less compared to the case of an El-Nino year being a drought year (43%). A non-El Nino year has, therefore, a greater probability of being a normal monsoon year.

This is in confirmity with the observation from section 3 that there are some years of extreme events not associated with ENSO and some ENSO years are not the years of extreme events over India. Thus, it seems that, ENSO may have an impact to modify the circulation pattern over India, of which the rainfall activity is a manifestation. This must

be different than that of the zonal Walker circulation cells. Also, a probability of interaction (may be nonlinear) between the planetary scale and regional scale circulation changes can not be ruled out. Any extreme event in association with ENSO may occur through the effect of ENSO to modify the circulation pattern over India to make it a typical of an extreme event. Some extreme events may also occur without being associated with ENSO. This may be due to some other factors (some of which may even be independent of ENSO) to make the circulation pattern over India a typical of an extreme. Moreover, some ENSO events may not be the years, of extreme events if in those years, the interaction and/or phase locking between the planetary and the regional scale circulation changes have resulted into wiping off the effect of ENSO and/or the other factors competing with ENSO to modify the Indian circulation pattern are more dominant. Thus, the regional scale circulation pattern which is embedded in the planetary scale circulation seems to be the key feature. The rainfall activity is just a manifestation of this circulation pattern. This pattern gets modified due to manifold factors, of which ENSO is quite dominant. Hence, as brought out by earlier studies, it is possible to say about non-occurrence of a drought (flood) over India in association with a cold (warm) ENSO event. However for further and more conclusive inferences, the relationship between ENSO and Indian monsoon activity must be studied with assessment of following of its important aspects:

- (i) How does ENSO act to modify the regional scale circulation over India and its probable interaction with the changes brought out by ENSO on the planetary scale and phase locking between the two.
- (ii) Factors, other than and competing with ENSO to modify the circulation over India and the situations under which they dominate over ENSO.
- (iii) Interaction and phase locking between the modifying effects of ENSO and of the factors other than ENSO.

#### 4.4. How far the mid-season rainfall deficiency is made up at the end of the season

From Table 1 it is evident that the mid-season rainfall deficiency is made up at the end of the season for a reasonably good percentage of total number of years, which includes nine drought years also. The percentage is obviously higher for flood years compared to that for drought years. Nonetheless, it is seen that even in the case of drought years; the decrease in the value of area of deficient/scanty rainfall or increase in area of excess rainfall at the end of the season as compared to it value at middle of the season is observed for a considerable percentage of total number of cases.

The percentage of total number of cases in which the mid-season rainfall deficiency is made up at the end of the season is higher for DW years as compared to DnW years.

The case is opposite for flood years; the percentage being higher for FnC years as compared to FC years.

## 5. Conclusions

- (i) The impact of ENSO on Indian summer monsoon rainfall seems to be through the modification of regional circulation pattern and/or its interaction with the planetary scale influence such as shifting of the branches of Walker circulation, which occurs in association with ENSO event. The effect of ENSO to modify the regional scale circulation and phase locking between regional and planetary scale circulation alterations need further investigation.
- (ii) The effect of ENSO to modify the regional scale circulation pattern over India and interaction between planetary scale and regional scale circulation alterations finally result into the circulation pattern of any year. The rainfall activity is a manifestation of this pattern. Thus the effect of ENSO on Indian monsoon can be studied with this aspect.

### Acknowledgement

The authors express their thanks to Mrs V.V. Patekar for her assistance, Shri A.R. Murudkar and Shri B.S. Hirve for preparing the diagrams and Shri S.J. Gove for neatly typing the Mss.

### References

- Alexander, G., Keshavamurthy, R.N., De, U.S., Chellappa, R., Das, S.K. and Pillai, P.V., 1978, "Fluctuations of monsoon activity", *Indian J. Met. Hydrol. Geophys.*, **29**, 26-87.
- Banerjee, A.K., Sen, P.N. and Raman, C.R.V., 1978, "On foreshadowing SW monsoon rainfall over India with mid-tropospheric circulation anomaly of April", *Indian J. Met. Hydrol. Geophys.*, **29**, 425-431.
- Bhalme, H.N., Mooley, D.A. and Jadhav, S.K., 1983, "Fluctuations in drought/flood area over India and relationships with the southern oscillation", *Mon. Wea. Rev.*, **111**, 86-94.
- Chattopadhyay, J. and Bhatia, R., 1996, "A re-examination of ENSO/anti-ENSO events and simultaneous performance of the Indian summer monsoon", *Mausam*, **47**, 1, 59-66.
- Elliot, W.P. and Angell, J.K., 1987, "The relation between Indian monsoon rainfall, the southern oscillation and hemispheric air and sea temperature 1884-1984", *J. Climate Appl. Meteor.*, **26**, 943-948.
- Gadgil, S. and Mishra, S.K., 1995, 'The Indian Climate Research Programme', *Science Plan*, 11p.
- Mooley, D.A., Parthasarthy, B. and Pant, G.B., "Relationships between Indian summer monsoon rainfall and location of the ridge at 850 hPa level along 75°E", *J. Climate Appl. Meteor.*, **25**, 633-640.
- Mooley, D.A. and Shukla, J., 1972, "Concurrent association between 700 hPa, 5-day mean contour patterns and 5-day rainfall anomaly over India during July", *Indian J. Met. Hydrol. Geophys.*, **23**, 29-34.
- Normand, C.W.B., 1953, "Monsoon Seasonal Forecasting", *Quart. J. Roy. Met. Soc.*, **79**, 463-473.
- Parthasarthy, B. and Pant, G.B., 1985 "Seasonal relationships between Indian summer monsoon rainfall and the southern oscillation", *J. of Climatol.*, **7**, 57-70.
- Parthasarthy, B., Munot, A.A. and Kothawale, D.R., 1995, "Monthly and seasonal rainfall series for All India homogeneous regions and meteorological subdivisions: 1871-1994", IITM Res. Report No. RR- 065.
- Rasmusson, E.M. and Carpenter, T.H., 1983, "The relationship between eastern equatorial Pacific sea surface temperatures and rainfall over India and Sri Lanka", *Mon. Wea. Rev.*, **111**, 517-528.
- Shukla, J., 1987, "Interannual variability of monsoons"; In *Monsoons*, J.S. Fein and P.L. Stephenes., Eds; John Wiley and Sons, 339-463.
- Shukla, J., 1991, "CLIVAR-A study of climate variability and predictability", WMO/TD No.690, 35p.
- Shukla, J. and Paolino, D.A., 1983, "The southern oscillation and long range forecasting of the summer monsoon rainfall over India", *Mon. Wea. Rev.*, **111**, 1830-1837.
- Sikka, D.R., 1980, "Some aspects of the large-scale fluctuations of summer monsoon rainfall over India in relation to fluctuations in the planetary and regional scale circulation parameters", *Proc. Indian Acad. Sci. (Earth and Planet Sci.)*, **89**, 179-195.
- Walker, G.T., 1923, "Correlation in seasonal variations of weather VIII". *Memories Indian Meteorological Dept.*, **24**, 75- 131.
- Wilby, R., 1993, "Evidence of ENSO in the synoptic climate of the British Isles since 1880", *Weather*, **48**, 234-239.