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

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ABSTRACT. For the Indian subcontinent, the occurrence of floods and droughts is closely linked with the summer monsoon activity. The phenomenon of E1 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 — E1-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)

### (A) Drought Years

<table>
<thead>
<tr>
<th>Trend</th>
<th>% of cases</th>
<th>Trend</th>
<th>% of cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decreasing DW years</td>
<td>67%</td>
<td>Increasing DW years</td>
<td>44%</td>
</tr>
<tr>
<td>Increasing DW years</td>
<td>33%</td>
<td>Decreasing DW years</td>
<td>56%</td>
</tr>
</tbody>
</table>

### (B) Flood Years

<table>
<thead>
<tr>
<th>Trend</th>
<th>% of cases</th>
<th>Trend</th>
<th>% of cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decreasing FC years</td>
<td>83%</td>
<td>Increasing FC years</td>
<td>100%</td>
</tr>
<tr>
<td>Increasing FC years</td>
<td>17%</td>
<td>Decreasing FC years</td>
<td>0%</td>
</tr>
</tbody>
</table>

soon activity - ENSO relationship have been investigated by several research workers such as Elliot and Angell (1987), Parthasarthy et al. (1985), Rasmussen 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 conductive 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 association 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.

Fig. 1. Monthly anomaly circulation maps for 1982


(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 Chattopadhyay 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:

<table>
<thead>
<tr>
<th>Region</th>
<th>Value of Rank DW and DnW years</th>
<th>CC between FC and FnC years</th>
</tr>
</thead>
<tbody>
<tr>
<td>North West (NW)</td>
<td>-0.37</td>
<td>+0.54</td>
</tr>
<tr>
<td>West Central (WC)</td>
<td>+0.52</td>
<td>-0.62</td>
</tr>
<tr>
<td>Central North</td>
<td>+0.90</td>
<td>+0.20</td>
</tr>
<tr>
<td>East (CNE) - India</td>
<td>-0.80</td>
<td>+0.40</td>
</tr>
<tr>
<td>North East (NE) - India</td>
<td>-0.31</td>
<td>+0.66</td>
</tr>
</tbody>
</table>

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 throughout 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
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-
erlies), at 500 hPa, a ridge is observed along 15°N at 200 hPa, a trough is observed along 10°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.
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. 199 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 E1-Nino and non-E1-Nino years.

<table>
<thead>
<tr>
<th>E1-Nino and drought/flood occurrence over India (1875-1987)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drought</td>
</tr>
<tr>
<td>E1-Nino</td>
</tr>
<tr>
<td>Non-E1 Nino</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

(After Gadgil and Mishra, 1995)

This data brings out the following

An E1-Nino year being a drought year is observed in a less percentage of total cases (43%) than an E1-Nino year being a normal year (57%). However, there is no E1-Nino year being a flood year.

A non-E1Nino year being a normal year is observed in 75% of cases, which is much larger a percentage than that of an E1-Nino year being a normal year (57%). A non-E1-Nino year can be a drought year as well, though with a low chance of 6% of the cases only. Unlikely, an E1-Nino year being a flood year is not observed in a single case in the sample.

A non-E1-Nino year being a flood year is observed in 18% of cases which is very less compared to the case of an E1-Nino year being a drought year (43%). A non-E1 Nino year has, therefore, a greater probability of being a normal monsoon year.

This is in conformity 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 manyfold 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 its 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 patterns 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.

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References


