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A re-examination of ENSO/anti-ENSO events and simultaneous performance of the Indian summer monsoon

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सार — दक्षिणी दोलन सूचकांक का प्रयोग करते हुए 1901-1990 की अवधि में प्रशांत क्षेत्र के साथ-साथ सम्पूर्ण भारत में मानसुन वर्षा तथा एंसो/प्रति-एंसो घटनाओं के मध्य संबंध का पुन: परीक्षण किया गया है। परीक्षण के परिणाम से पता चलता है कि शुष्क मानसून वर्षों और एंसो घटनाओं के मध्य अत्यंत घनिष्ठ संबंध है। प्रति-एंसो घटनाओं और नम मानसून के मध्य दुर्बल दूरसंयोजन है जो यह दर्शाता है कि प्रति-एंसो घटनाओं का भारतीय मानसूनी वर्षा पर केवल मध्यम श्रेणी का प्रभाव पड़ता है। मानसून ऋतु के दौरान एंसो (प्रति-एंसो) घटनाओं का विकसित होना अत्यंत विश्वसनीय रूप से वर्षा ऋतु के दौरान बाढ़ (सूखा) के न होने की सूचना देता है। उक्त अवधि के दौरान 70 (50) प्रतिशत सूखा (बाढ़) एंसो (प्रति-एंसो) घटनाओं के दौरान पड़ा। इससे यह पता चलता है कि सूखे (बाढ़) के रूप में मानसुन गतिविधियाँ वर्षा ऋतु के दौरान एंसो/प्रति-एंसो घटनाओं के घटने का महत्वपूर्ण कारण हो सकती है।

ABSTRACT. The relationship between ENSO/anti-ENSO events in the Pacific basin and simultaneous all India monsoon rainfall has been re-examined for the period 1901-1990 using Southern Oscillation Index (SOI). The result shows that there is fairly strong association between ENSO events and dry monsoon years. There exists a weak teleconnection between anti-ENSO events and wet monsoon indicating that anti-ENSO events have only a moderate impact on the Indian monsoon rainfall. Developing ENSO (anti-ENSO) episodes during the monsoon season indicates non-occurrence of simultaneous floods (droughts) with a very high degree of confidence. 70 (50) percent of the droughts (floods) during the above period have occurred during ENSO (anti-ENSO) events indicating that extreme monsoon activities in the form of droughts (floods) might be important factors for the occurrence of simultaneous ENSO/anti-ENSO events.

Key words — ENSO, SOI, El Nino, La Nina, Anomaly, SST, Monsoon rainfall, Drought, Teleconnection.

1. Introduction

The frequent occurrence of large scale droughts and floods has been found to have serious socio-economic impacts in many countries, especially over the tropics. The challenging question is, whether these droughts and floods over different parts of the world occur randomly or appear simultaneously with some large scale atmospheric and/or oceanic phenomenon ? Studies by many workers over the past decade or so have shown that interannual variation in many parts of the world and ENSO (El Nino Southern Oscillation) events (warm events) in the tropics are generally related, for example, droughts in Australia, Indonesia, India and parts of Africa and heavy rain and floods in the Pacific coast of south America (Nicholls 1991, Ropelewski and Halpert 1987). During an anti-ENSO or the cold event, the pattern of climatic anomalies is broadly the reverse of that experienced during an ENSO event (Van Loon and Shea 1985, Meehl 1987, Kiladis and Van Loon 1988, Ropelewski and Halpert 1989). Sikka (1980), for the first time, related monsoon droughts over India with the occurrence of ENSO event. Since then there are several studies relating Indian monsoon rainfall and ENSO/anti-ENSO events (Angell 1981, Rasmusson and Carpenter 1983, Mooley and Parthasarathy 1983, Parthasarathy and Pant 1985, Bhalme *et al.* 1990, Webster and Yang 1992, Mohanty 1993). Although most studies suggest some link between ENSO (anti-ENSO) events and deficient (excess) summer monsoon rainfall over India, the relationship is not necessarily universal.

However, different authors selected the ENSO/ anti-ENSO events based on a number of factors, *e.g.*, Sea Surface Temperature Anomaly (SSTA) over eastern Pacific (Quinn *et al.* 1978, Rasmusson and Carpenter 1982), Southern Oscillation Index (SOI) Halpert and Ropelewski (1992) and several other atmospheric and oceanographic parameters like disruption of fishery and marine bird life off the coasts of Peru and Equador. In view of this ambiguity in the definition of ENSO/anti-ENSO years, disagreement prevails among scientists about the listing of the above years. Moreover, ENSO/ anti-ENSO events sometimes continue for two years. A confusion, therefore, prevails as to which

TABLE 1

Comparative statistical properties of all India summer monsoon (June to September) rainfall series

Rainfall series	Period	Mean (cm)	Standard deviation (cm)
Shukla (1987)	1901-1981	89.0	8.4
Thapliyal (1990)	1901-1980	87.6	9.2
Parthasarathy & Mooley (1978)	1881-1980	89.0	8.0
Authors' series	1901-1990	88.2	8.9

TABLE 2

Dry and wet all India monsoon rainfall years

Dry years (Total 17)	Wet years (Total 13)
1901, 1904, 1905*, 1911*, 1918*, 1920*, 1941, 1951*, 1965*, 1966, 1968, 1972*, 1974, 1979*, 1982*, 1985, 1987*	1916**, 1917**, 1933**, 1942**, 1953, 1955, 1956, 1959, 1961**, 1975, 1983, 1988**, 1990

* Drought years
** Flood years

year should be considered as ENSO/anti-ENSO year for its teleconnection study with monsoon rainfall. An error in finding the ENSO years will lead entirely to wrong results. The present authors are of the view that the fixing of the years of the ENSO/anti-ENSO events should be done on the basis of an objective criterion based on a single parameter whose relationship with Indian monsoon rainfall is precisely known from correlation analysis. Before that a discussion on the two important factors of the definition of ENSO/anti-ENSO, *i.e.,* SSTA and SOI would be useful. The Southern Oscillation (SO) is a global scale phenomenon involving out-of-phase relationship for the atmospheric pressure with centres of action over Indonesia and southeast Pacific Ocean. Difference in surface pressure anomaly between any two or more stations in these regions are used as index of southern oscillation as a measure of the strength of SO. Most researchers use Tahiti minus Darwin surface pressure anomaly for the state of the SO circulation.

Bjerknes (1966, 1969) pioneering work on the dynamics of ocean-atmospheric interaction explained for the first time that positive SST anomalies along the equatorial Pacific and the coast of South America, known as El Nino, occur during the negative SO phase. Since then, many researches on the SO related global scale atmospheric anomalies have shown that periods with anomalously warm or cold waters in the central and east Pacific are associated with the negative and positive phases of SO respectively. Hence the expressions ENSO (anti-ENSO) and warm event (cold event) are used to denote periods of positive (negative) SST anomaly over central and east Pacific during the negative (positive) SO phase. However, Caviedes (1985) found that SOI as an indicator of south Pacific anticyclone, reveals better than any other measure the inception, maturity and decline of ENSO events. Deser and Wallace (1987) showed that SSTs in the eastern Pacific and the SO do not always act together. We have, therefore, chosen the ENSO/anti-ENSO events on the basis of SOI and not SSTA. Using SOI as a surrogate for SST in eastern tropical Pacific is also because of the fact that temperature data over a long period are not available.

The objectives of the present study are :

(*i*) To compute an area-weighted all India monsoon rainfall series during the period 1901-90 and to identify the performance of monsoon as deficient (dry) and excess (wet) monsoon rainfall years during this period.

(*ii*) To identify the ENSO/anti-ENSO monsoon years (within a long period ENSO event) on the basis of an objective criterion (SOI) as discussed in section 4.

(*iii*) To examine the association between ENSO/anti-ENSO events on the simultaneous performance of Indian summer monsoon rainfall during 1901-90.

Thus, our approach essentially differs from most of the other studies in two respects. Firstly, we have considered ENSO/anti-ENSO years as those years which occur during the Indian monsoon season irrespective of its occurrence before or after it. Secondly, we have selected ENSO/anti-ENSO years on the basis of one single objective criterion being the magnitude of SOI.

2. Details of data

The summer monsoon rainfall data sets over 31 meteorological sub-divisions of India for the period

1901-80 and over 33 meteorological sub-divisions from 1981-83, were provided by India Meteorological Department (IMD), Pune; while the data for the remaining period of 1984-90 were obtained from the journal 'Mausam'. An area-weighted average of rainfall for each of the 31 (1901-80) and 33 (1981-90) sub-divisions of India, is taken as a measure of all India summer monsoon rainfall. The mean was found from 90 years' data, *i.e.,* 1901-90 as 88.2 cm and standard deviation as 8.9 cm (Table 1). Verma (1983) updated Parthasarathy and Mooley rainfall series (1978) to get 100 years' series from 1881-1980 (from Asnani, Tropical Meteorology, Vol. I, p. 335). It can be seen that mean and standard deviation of all the 4 series are almost same. Then, each year's rainfall from 1901-90 was expressed as standardized rainfall anomaly by dividing each year's departure from normal by the standard deviation. This all India monsoon rainfall series was utilized to identify deficient (dry) and excess (wet) monsoon rainfall years.

To compute the SOI, data over Tahiti and Darwin were obtained from Climate Analysis Centre, USA and monthly climatic data of the world published by National Climate Data Centre, NOAA, Ashville. The monthly series of SOI from 1901-90 were computed following the operational version of Climate Analysis Centre (Chen 1982). This monthly SOI series was further analysed to identify ENSO/anti-ENSO years and used in our study. However, a few years' Tahiti data, between 1901-32 (1907, 1908, 1914, 1915, 1931 and 1932), were missing for which the ENSO/anti-ENSO years were obtained from Halpert and Ropelewski (1992) in which the gaps filled in by Jones (1988) are reported. Jones generated values that were missing in the Tahiti record using regression between Tahiti and Apia and between Tahiti and Santiago. Because of the missing Tahiti data and pre 1935 data than the post 1935 data (Ropelewski and Jones 1987), the normals and standard deviations for both Tahiti and Darwin surface pressure were computed using 1935-90 data.

3. Identification of deficient/excess monsoon rainfall years

The identification of abnormal monsoon rainfall years is done on the basis of specified percentage points of the standardized all India monsoon rainfall series which is Gaussian distributed (Mooley and Parthasarathy 1983, Shukla 1987). The years, when the standardized rainfall anomaly value is below the 15th percentile (-1) and above the 85th percentile ($+1$) of the standard normal distribution fitted to long homogeneous rainfall series of India, are considered deficient and excess monsoon years respectively. When the rainfall is below the 10th percentile (-1.28) and above the 90th percentile ($+1.28$), the monsoon rainfall performance is considered as drought and flood respectively. Although, theoretically the long term mean is supposed to be the so called "normal" monsoon rainfall, this is an idealised concept in which rainfall over all the regions of India at all times of the season has the same idealised normal value. In actual situations, the rainfall is more than normal at some region/period, while it is less than normal at some other region/period. Hence, a reasonable departure of the time-averaged and area-averaged rainfall, is considered as 'normal' rainfall. IMD considers standardized all India monsoon rainfall anomaly within ± 1 below and above the long term mean as the normal monsoon rainfall. We have, thus, used the following criterion to categorise the monsoon rainfall as drought, deficient, normal, excess and flood years on the basis of the following criterion applied to the standardized rainfall anomaly :

(*i*)	Drought	< -1.28
(*ii*)	Deficient	< -1 but > -1.28
(*iii*)	Normal	$\geqslant -1$ but $\leqslant +1$
(*iv*)	Excess	> 1 but < 1.28
(*v*)	Flood	> 1.28

For the purpose of teleconnection studies both deficient and the drought years have been combined together as bad, dry or poor rainfall years. While both excess and flood years have been combined together as good or wet monsoon years. Following this criterion, there are 17 dry monsoon years during the period 1901-90 out of which 10 are drought years. There are 13 wet rainfall years also during the above period out of which 6 are flood years. Table 2 shows the dry and wet rainfall years. The remaining 60 years were all normal monsoon years.

Fig. 1 shows standardized all India summer monsoon rainfall for the period 1901-90. The wet and dry monsoon years can be easily recognised from their occurrences above 1 or below 1 standard deviation lines.

4. Identification of ENSO/anti-ENSO monsoon years

Usually ENSO/anti-ENSO events are a long duration (12-18 months) phenomenon. Hanawa

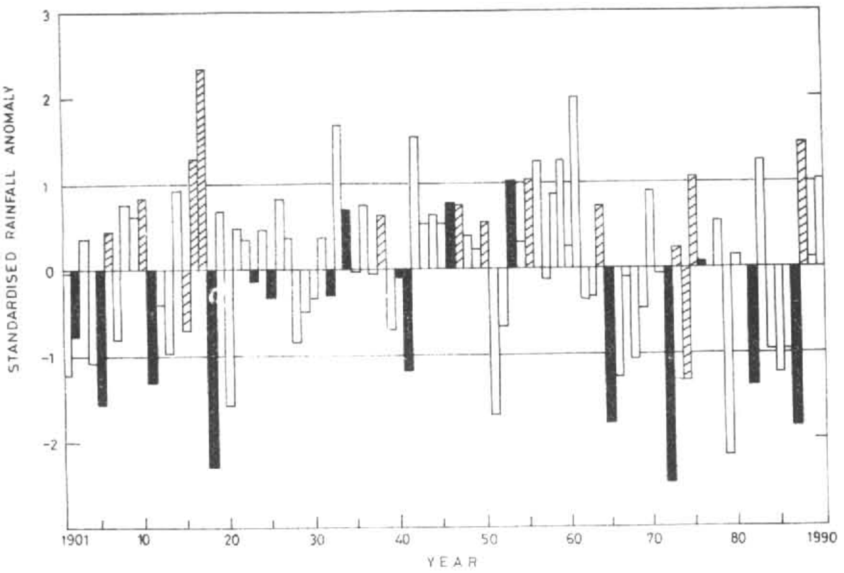

Fig. 1. Standardized all India monsoon (June-September) rainfall anomaly from 1901 to 1990. ENSO and anti-ENSO monsoon events are shown as solid and stipled bars respectively

et al. (1988) defines an ENSO year winter within an ENSO event as the three months of January to March. Yang and Webster (1990) define El Nino and La Nina winters and summers as the three months of December to February and June to August respectively. To identify the appropriate season for defining ENSO/anti-ENSO monsoon, a correlation analysis of the all India monsoon rainfall was first done with 6 seasonal SOI series, namely, previous DJF (December to February) lagging 2 seasons behind monsoon season, previous MAM (March to May) lagging 1 season behind monsoon season, JJA (June to August), JAS (July to September) both concurrent with monsoon season, succeeding SON (September to November) leading monsoon season by 1 lag and succeeding DJF leading monsoon season by 2 lags. The results on the basis of 1933 to 1990 data are shown in Table 3.

It can be seen from the Table 3 that the correlations when SOI lags by either 2 seasons (previous DJF) or 1 season (previous MAM), are not significant, while simultaneous and succeeding correlations are all significant. The insignificant correlation with antecedent SOI means that, if ENSO develops anytime prior to the monsoon season, but if it ends by May, it will not likely to have any impact on the coming monsoon rainfall. The simultaneous significant correlation shows that ENSO will have some impact, if and only if it continues during the simultaneous monsoon season. It might have started since previous October or even earlier itself and continued during the monsoon or it might have developed and ended during the monsoon season only. But in the later case it should continue for at least 3 months JJA or JAS. Table 3 also shows that out of the 2 combinations of concurrent seasons, SOI of JAS gives higher correlation (0.44) than SOI of JJA (0.40). That is why, in the present investigation, ENSO/anti-ENSO monsoon years were selected on the basis of SOI of JAS season.

TABLE 3

Correlation coefficients (CC) between all India monsoon rainfall and SOI

Season	Lag	CC
Dec-Jan-Feb	− 2	− .21
Mar-Apr-May	− 1	.23
Jun-Jul-Aug	0	.40*
Jul-Aug-Sep	0	.44**
Sep-Oct-Nov	+ 1	.54**
Dec-Jan-Feb	+ 2	.50**

* and ** indicate significance at 1 and .1% levels respectively

We could as well consider SOI of succeeding SON, or DJF to see if ENSO/anti-ENSO is present but that would mean considering the effect of monsoon on ENSO/anti-ENSO and not the effect of ENSO/anti-ENSO on monsoon. The point that we

TABLE 4

Years of occurrences of ENSO/anti-ENSO monsoon events (JAS |SOI| ⩾ 0.84) and their association with dry, normal and wet monsoon in India

ENSO monsoon events (Total 18)	Characteristics of Indian monsoon year	Anti-ENSO monsoon events (Total 15)	Characteristics of Indian monsoon year
1902	Normal	1906	Normal
1905*	Dry	1910	Do.
1911*	Do.	1916**	Wet
1918*	Do.	1917**	Do.
1923	Normal	1938	Normal
1925	Do.	1947	Do.
1932	Do.	1950	Do.
1934	Do.	1955	Wet
1940	Do.	1964	Normal
1941	Dry	1971	Do.
1946	Normal	1973	Do.
1953	Wet	1974*	Dry
1965*	Dry	1975	Wet
1972*	Do.	1981	Normal
1976	Normal	1988**	Wet
1977	Do.		
1982*	Dry		
1987*	Do.		

* Drought years

** Flood years

want to stress is that ENSO/anti-ENSO may continue for a long time but if it has ended by May, it will not likely have any impact on the coming monsoon as it happened in 1992. It has to continue during the monsoon season. Thus, while studying ENSO/anti-ENSO monsoon relationship, we are skeptical of accepting ENSO years (as defined in various literatures) and find its relationship with monsoon without critically seeing if those ENSO years are continuing or not during the monsoon season. We like to stress that continuance of ENSO during the monsoon season is necessary to see its effect on monsoon. The significant simultaneous positive correlation with SOI of JAS indicates that Indian summer monsoon rainfall are stronger when SOI > 0 and weaker when the SOI is < 0. This implies that the Indian summer monsoon rainfall is weaker during ENSO years (SOI < 0) and stronger during anti-ENSO years (SOI > 0).

Yang and Webster (1990) selected El Nino/La Nina winter (DJF) and summer (JJA) years on the basis of seasonal |SOI| being ⩾ 0.50. However, in the present investigation, we have defined ENSO monsoon years on the basis of the SOI of JAS season as ⩽ −0.84, being the 20th percentile point of the standard normal distribution. Similarly, anti-ENSO monsoon years are defined on the basis of the SOI of JAS season as ⩾ 0.84 being the 80th percentile point of standard normal distribution. Thus, we have considered ENSO/anti-ENSO events on the basis of seasonal JAS |SOI| being ⩾ 0.84. Table 4 shows the years of occurrences of ENSO/anti-ENSO monsoon years. Thus, there are 18 ENSO events and 15 anti-ENSO events persisting during the monsoon season (July to September) in this century during 1901-90. It may, however, be mentioned here that SOI of JAS may not give any indication about the peak in SOI, the peak may occur in the following DJF. However, as stated earlier, considering peaks in succeeding SON or DJF would mean studying the effect of monsoon on ENSO/anti-ENSO (and not simultaneous relationship) which can form a separate study. Hence, we feel that our method of defining ENSO/anti-ENSO, following Yang and Webster (1990) but on the basis of SOI of JAS, is highly appropriate in view of the significant simultaneous correlation of the two phenomena.

However, developing of an ENSO episode during the monsoon season here means that SOI could have either persisted or could not have persisted in the earlier season, but SOI has crossed the limit set in JAS season. The correlation study by many authors including our study has shown that persistence of ENSO/anti-ENSO in the earlier season is not likely to have any impact on monsoon (correlation weak and insignificant) unless it continues during the JAS season.

5. The relationship between ENSO/anti-ENSO monsoon events and abnormal monsoon rainfall

In Table 4, we have grouped the 18 ENSO and 15 anti-ENSO monsoon years into dry, normal and wet monsoon categories. In Fig. 1 showing the all-India standardized rainfall anomaly, the ENSO monsoon years have been shaded with solid bars, anti-ENSO monsoon years have been stipled, while blanks show normal years.

5.1. *Association of ENSO monsoon events with abnormal monsoon rainfall*

We can see from Table 4 that out of the 18 ENSO monsoon years, 8 (44%) years are associated with dry monsoon, 9 years (50%) are associated with normal monsoon, while only 1 year (6%) is even associated with a wet monsoon. However, there is no example of any ENSO monsoon year being associated with flood year. We can also see from Tables 2 and 4 that out of the 17 dry monsoon years, 8 cases (47%) were associated with ENSO monsoon years while 9 cases (53%) were not associated with ENSO monsoon years. The two alternative being almost same. Thus, the result is inconclusive. However, if we consider the drought years only, the result is very encouraging, out of 10 drought years 7 cases are associated with ENSO monsoon events (1905, 1911, 1918, 1965, 1972, 1982, 1987) and only 3 cases are not associated with ENSO monsoon events (1920, 1951, 1979). It may be mentioned here that the above three years were neither ENSO nor anti-ENSO monsoon years. Thus 70% of the droughts are associated with ENSO monsoon events probably suggesting that extreme monsoon activity in the form of drought may be an important factor for the occurrence of ENSO event. This result is quite in keeping with what Normand (1953) and Shukla and Paolino (1983) said that Indian monsoon rainfall may have active rather than a passive role in world climate anomaly.

The re-examination of the ENSO monsoon relationship suggests that based on the objective technique used by us, slightly less than half (44%) of the ENSO monsoon events can be linked with dry monsoon, a majority of which are, in fact, drought years, while exactly half of the ENSO monsoon events (50%) are more likely to produce normal monsoon. The present evidence does support the view that there exists a reasonably strong relationship between ENSO monsoon events being characterised by deficient monsoon rainfall. The probability of an ENSO monsoon event to be associated with a wet monsoon is, however, very small being 6% only, while that with a flood year is nil.

5.2. *Association of anti-ENSO monsoon events with abnormal monsoon rainfall*

Table 4 also shows that out of the 15 anti-ENSO monsoon years, a majority of 9 (60%) are associated with normal monsoon. Of the remaining, only 5 (33%) anti-ENSO monsoon years are associated with wet monsoon of which 3 (20%) are flood years, and only 1 (7%, 1974) is associated with dry monsoon also. However, there is no example of any anti-ENSO monsoon year being associated with a drought year.

Fig. 1 also shows that out of the 13 wet monsoon years, only 5 cases (38%) are associated with anti-ENSO monsoon years while 8 cases (62%) were not associated with anti-ENSO monsoon years. The analysis shows that the wet monsoon may be caused due to anti-ENSO conditions during the monsoon season on 38% cases only, while 62% of the wet monsoon are caused by reasons which are regional in nature. If we consider flood years only, 3 (50%) (1916, 1917, 1988) of the 6 flood years are associated with anti-ENSO monsoon years while the remaining 3 cases (50%) are not associated with anti-ENSO. It may be mentioned here that the above 3 cases were not ENSO monsoon years either but normal years.

The re-examination of anti-ENSO monsoon relationship suggests that a majority (60%) of the anti-ENSO monsoon events are not associated with either wet or dry monsoon. Although the anti-ENSO monsoon events have reasonable teleconnection with wet monsoon showing 33% association, the probability of an anti-ENSO monsoon event being associated with the occurrence of extreme monsoon activity, in the form of flood is weak. However, whenever floods have occurred, 50% of them are associated with simultaneous anti-ENSO conditions probably suggesting that extreme monsoon activity in the form of flood is an important factor for the occurrence of anti-ENSO monsoon event. The probability of an anti-ENSO monsoon event to be associated with dry monsoon is, however, very small being 7% only, while that with a drought year is nil.

6. Conclusions

In this paper, we have re-investigated the simultaneous relationship between the Indian summer monsoon and ENSO/anti-ENSO events occurring during the monsoon season (ENSO/anti-ENSO monsoon events) based on an objective assessment during the period 1901-90. Although some of these findings reported here are known from previous studies, however, since the selection of ENSO/anti-ENSO events in the present study are based on simultaneous and objective assessment of a single parameter, our conclusions may be considered as an improvement over the other similar studies. Our main findings are as follows :

(*i*) There exists a reasonably strong teleconnection between ENSO monsoon events and poor performance of monsoon, although the majority of ENSO monsoon years are associated with normal monsoon. Poor or deficient monsoon years show a tendency to be associated with simultaneous ENSO events with 44% correspondence. On the other hand, the re-examination indicates that whenever deficient monsoon has occurred, 47% of them are associated with the occurrence of simultaneous ENSO events. However, whenever extreme poor monsoon (droughts) have occurred, 70% of them are associated with the occurrence of an ENSO monsoon event. Probability of ENSO monsoon events to be associated with wet monsoon is poor. There is not a single example of ENSO monsoon event being associated with a flood year.

(*ii*) Deficient monsoon rains or droughts could be caused by several factors other than ENSO monsoon events as there are years of deficient monsoon rains or droughts not linked with ENSO monsoon events. Of course, ENSO monsoon events appear to be quite an important signal.

(*iii*) Anti-ENSO monsoon events are associated with wet monsoon years only in 33% of the cases while a majority (60%) are associated with normal monsoon, showing that anti-ENSO conditions are weakly tele-connected to wet monsoon and are not necessarily related to wet monsoon. The correspondence is weaker than that between simultaneous ENSO events and dry monsoon. The probability of anti-ENSO events and simultaneous occurrence of dry monsoon activity is also very weak. Flood monsoons occur frequently in the presence of anti-ENSO monsoon events with 50% correspondence, showing that there is a reasonable teleconnection between flood years and anti-ENSO monsoon events, although there is no one-to-one correspondence between them.

(*iv*) If ENSO (anti-ENSO) episodes are developing during the monsoon season, it indicates non-occurrence of floods (droughts) with a fairly high degree of confidence.

(*v*) The strong teleconnection between drought years and simultaneous ENSO events and fairly strong teleconnection between flood years and simultaneous anti-ENSO events probably suggests that extreme monsoon activity in the form of droughts (floods) may be causative factors for the occurrence of ENSO (anti-ENSO) monsoon events.

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