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El Nino, Southern Oscillation, equatorial eastern Pacific sea surface temperatures and summer monsoon rainfall in India

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सार — 120 वर्षों (1871-1990) से, प्रत्येक वर्ष को या तो इल नीनो वर्ष (इ. एन.), या दक्षिणी दोलन न्यूनतम वर्ष (एस. ओ.), अथवा इन दोनों का मिला जुला वर्ष अथवा इनमें से किसी के भी प्रभाव से रहित वर्ष के रूप में निर्दिष्ट किया गया है। अखिल भारतीय ग्रीष्म कालीन मानसून वर्षा (आई. एस. एम. आर.) के अनुसार सुस्पष्ट इ. एन. एस. ओ. डब्ल्यू. वर्षमें कैलेंडर वर्ष के बीच में एस. ओ. और डब्ल्यू. (गर्मी पड़ने की घटनाएं) सूखा पड़ने की अशंका बहुत रहती है और टाइप सी (सर्दी पड़ने की घटनाएं) की घटनाएं घटने पर बाढ़ आने की आशंका बहुत रहती है। तथापि, सूखे की कुछ घटनाएं इ. एन. से संबंधित घटनाएं नहीं घटने पर भी हुई हैं और बाढ़ की कुछ घटनाएं इ. एन. से संबंधित घटनाओं के घटने पर भी हुई हैं। इन मामलों का कारण यूरेशियाई हिमाच्छादन तथा समतापमंडलीय पवन क्यू. बी. ओ. जैसे अन्य प्राचलों का व्यापक प्रभाव हो सकता है।

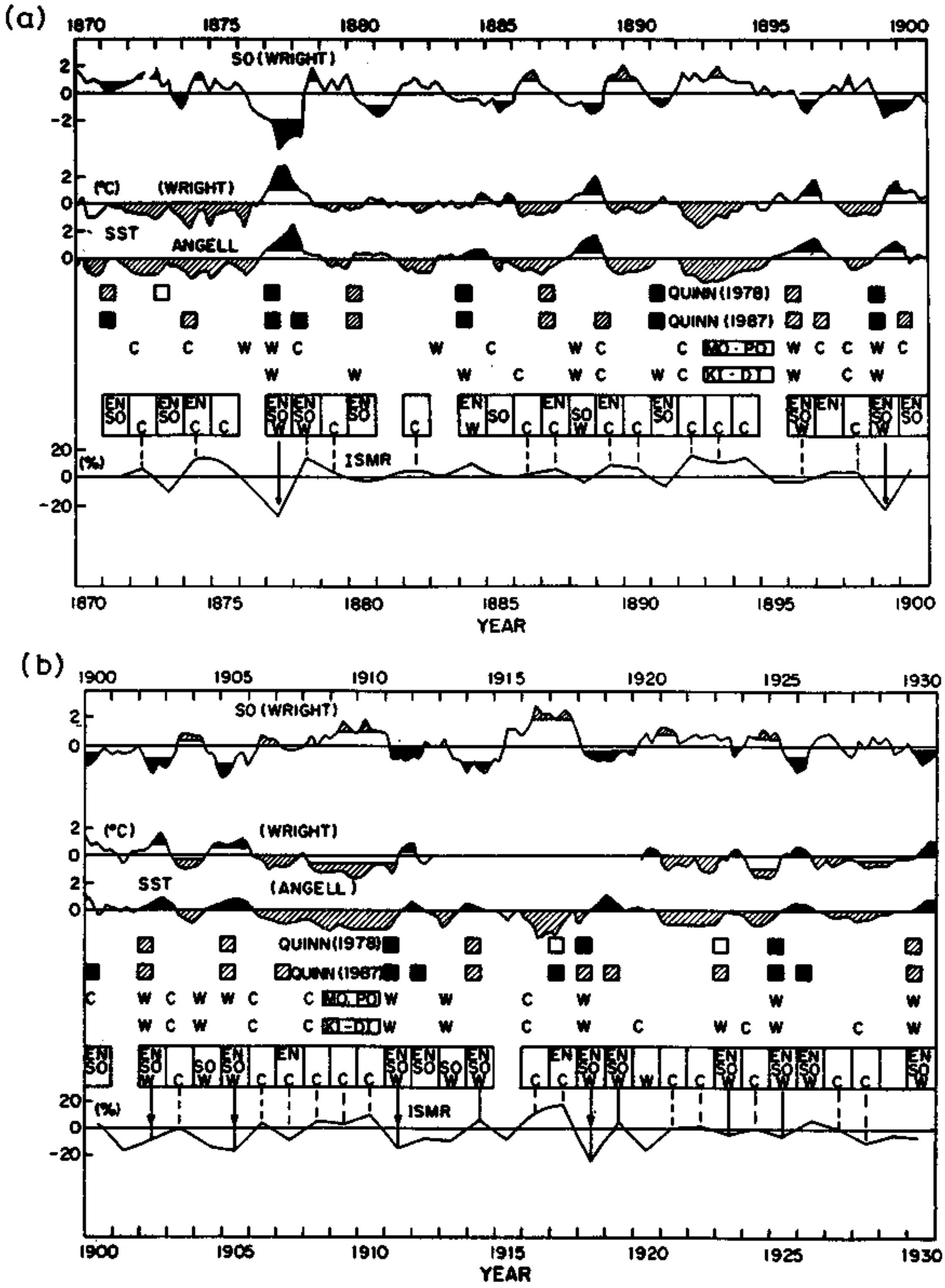
ABSTRACT. For the 120 years (1871-1990), every year was designated as an El Nino (EN), or Southern Oscillation (SO), minimum or a combination of these, or none. For all India summer monsoon rainfall (ISMR), unambiguous ENSOW [SO and W (warm events) in the middle of the calendar year] seemed to be best associated with droughts and events of type C (cold events) were best associated with floods. However, some droughts occurred without the presence of EN related events and some floods occurred even in the presence of EN related events. In these cases, other parameters such as Eurasian snow cover or stratospheric wind QBO might have had a larger influence.

Key words - El Nino (EN), Southern Oscillation (SO), Sea surface temperatures (SST), Monsoon rainfall, Events.

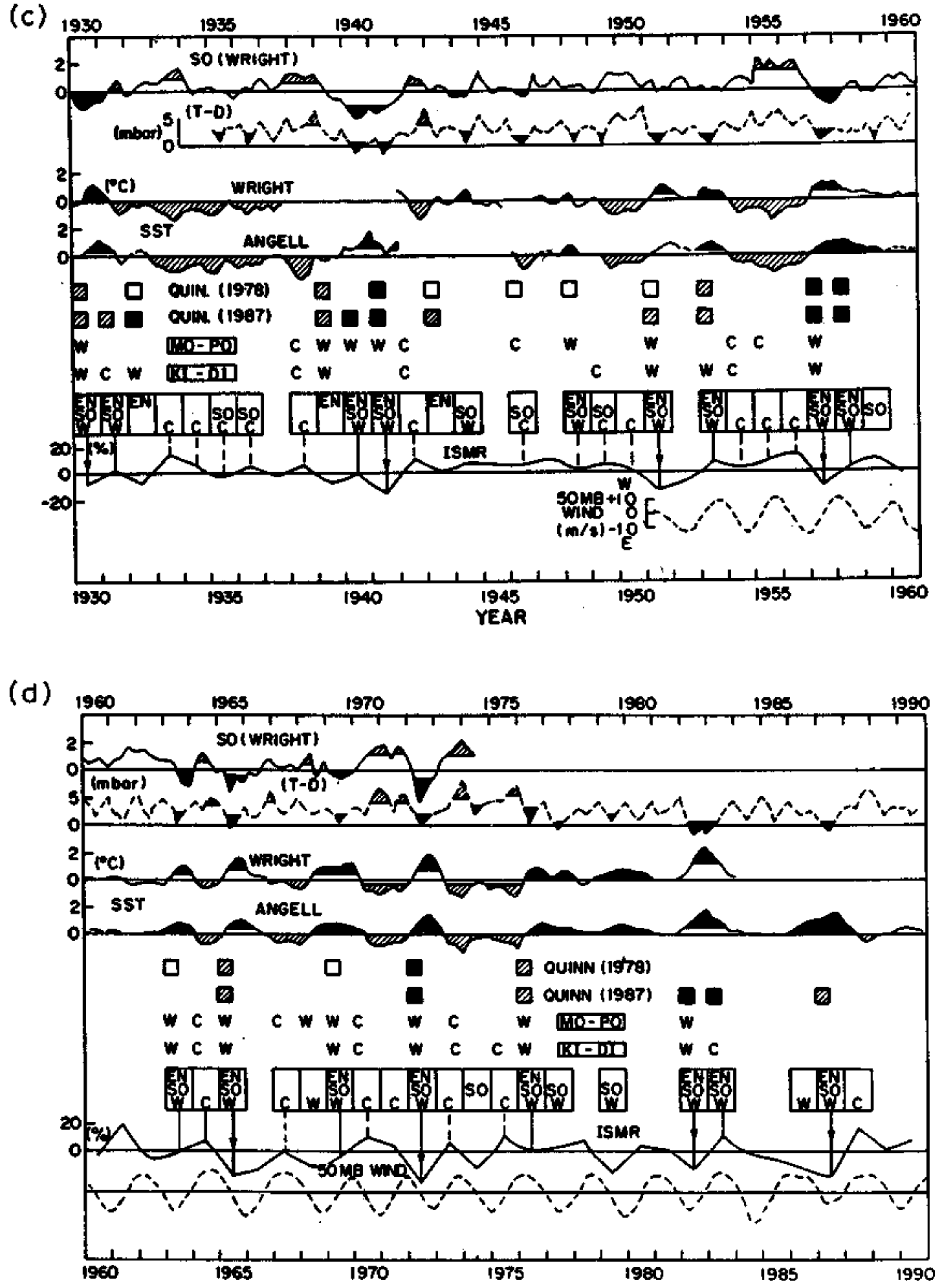
1. Introduction

In some years, anomalously warm surface water invades the southern Ecuadorian and Peruvian coastal regions. As the invasion sets in during December-January, the phenomenon is popularly known as El Nino (EN) (The Child), referring to the birth of Jesus Christ. Within months, these events are followed by warming of the equatorial eastern Pacific (warm events) and are supposed to be intimately connected with the Southern Oscillation (SO), the seesaw in surface pressure anomalies between the Indian ocean-Australian region (*e.g.*, Darwin) and the southeastern tropical Pacific (*e.g.*, Tahiti).

These EN, SO phenomena and/or Pacific warm events are reported to be intimately related with rainfall variations in several regions. There are, however, some disconcerting features about the inventory of these events. For the El Nino events, Quinn *et al.* (1978) provided the first comprehensive documentation. Later, Quinn *et al.* (1987) gave a revised, updated list; but the lists in these two publications do not tally completely. Some events (years) are mentioned as El Nino events in one list but not in the other. Also, the strengths of some events are different in the two lists (strong or moderate in one list, moderate or even weak in the other). Kiladis and Diaz (1989) have given a list of warm episodes which does not coincide completely with the listing of Quinn *et al.* (1978) and the cold and warm episodes mentioned by Kiladis and Diaz (1989) do not coincide with similar episodes used by Mooley and Paolino (1989). Comparing El Nino events and Southern Oscillation minima during 1925-1986, Deser and Wallace (1987) concluded that El Nino events "occurred both in advance of and subsequent to major negative swings of the Southern Oscillation" and further that El Nino events and negative SO could



Figs. 1(a&b). Plots for (a) 1870-1900 and (b) 1900-1930, of 3 monthly (DJF, MAM, JJA, SON) means of: (*i*) SO index (Wright 1984) (Black = Minima), (*ii*) (T-D) Tahiti minus Darwin (Parker 1983), (*iii*) SST (Wright 1984, Angell 1981) (Black = Maxima), (*iv*) El Ninos (Black = Strong, Hatched = Moderate, Blank = Weak) from Quinn *et al.* (1978, 1987), (*v*) Cold (C) and Warm (W) events from MO.PO (Mooley and Paolino 1989) and KI.DI (Kiladis and Diaz 1989), (*vi*) Our designation EN, SO, W or C (or their combination including none) for each year, (*vii*) ISMR Indian summer monsoon rainfall, and (*viii*) 12-month running means of 50 hPa low latitude zonal wind (Venne and Dartt 1990)



Figs.1(c&d). Plots for (c) 1930-1960 and (d) 1960-1990 of 3 monthly (DJF, MAM, JJA, SON) means of: (*i*) SO index (Wright 1984) (Black = Minima), (*ii*) (T-D) Tahiti minus Darwin (Parker 1983), (*iii*) SST (Wright 1984, Angell 1981) (Black = Maxima), (*iv*) El Ninos (Black = Strong, Hatched = Moderate, Blank = Weak) from Quinn *et al.* (1978, 1987), (*v*) Cold (C) and Warm (W) events from MO.PO (Mooley and Paolino 1989) and KI.DI (Kiladis and Diaz 1989), (*vi*) Our designation EN, SO, W or C (or their combination including none) for each year, (*vii*) ISMR Indian summer monsoon rainfall, and (*viii*) 12-month running means of 50 hPa low latitude zonal wind (Venne and Dartt 1990)

TABLE 1

ENSOW events (S=Strong, M=Moderate) and Rainfall (F=Floods, D=Droughts)

Year	EN	SO	W (Warm)	ISMR Dev.(%)
		(A) Unambiguous events		
1877	S	S	S	-29D
1899	S	S	S	-26 D
1911	S	S	S	-14 D
1918	S	S	S	-24 D
1941	S	S	S	-14 D
1957	S	S	S	-8 Normal
1972	S	S	S	-23 D
1982	S	S	S	-14 D
1896	M	S	S	-3 Normal
1902	M	S	S	-7 Normal
1905	M	S	S	-16 D
1930	M	S	S	-6 Normal
1951	M	S	S	-14 D
1965	M	S	S	-17 D
1976	M	S	S	+1 Normal
1987	M	S	S	-19 D
16 events				15 negative 1 positive
		(B) Ambiguous events		
1878	S	S (early)	S (early)	+14 F
1914	M	S	M (early)	+6
1919	M	M	M(early)	+4
1923	M	M	M	-4
1925	S	S(late)	S(late)	-6
1926	S	S(early)	S(early)	+6
1931	M	M(early)	S(early)	+3
1940	S	S	S(late)	-1
1948	Weak	M	S(early)	+2
1953	M	S	M	+8
1958	S	S(early)	S(early)	+4
1963	Weak	S	S	+1
1969	Weak	M	S	-3
1983	S	S(early)	S(early)	+12F
14 events				4 negative 10 positive

occur separately and these two phenomena "are more loosely coupled than other studies would imply"

For the Indian summer monsoon rainfall (henceforth termed as ISMR), Sikka (1980) made the first attempt to relate ENSO with ISMR. Shukla and Paolino (1983) and Elliott and Angell (1987) reported a good relationship with Southern Oscillation while Rasmusson and Carpenter (1983), Khandekar and Neralla (1984), Mooley and Parthasarathy (1984) and Mooley and Paolino (1989) reported a good relationship with east equatorial Pacific temperatures. Webster and Yang (1992) presented an account of the selectively interactive system of ENSO and monsoon.

In the present communication, we propose to reexamine the El Nino, SO and SST data, characterize each year from 1870 up to 1990 and see which of these are related to what category of rainfall deviations and also, in the reverse way, which rainfall extremes are related to which types of years.

2. Data

El Nino (henceforth EN) represents warm water episodes in Peru-Ecuador coast. For these, both the lists Quinn *et al.* (1978, 1987) were used and comparison made with the lists of Kiladis and Diaz (1989) and Mooley and Paolino (1989). For Southern Oscillation, we used the SO index (Wright 1984) as also Tahiti minus Darwin mean sea level pressure values (Parker 1983, and further values from Meteorological Data Reports). For SST (sea- surface temperatures for equatorial eastern Pacific), data used were from Wright (1984, and further private communication) as also from Angell (1981, and further private communication). Indian summer monsoon rainfall data (ISMR) were obtained from Parthasarathy *et al.* (1992). Stratospheric equatorial zonal wind data were obtained from Venne and Dart (1990).

3. Plots of the various time series

Fig. 1 shows plots of the various parameters for (a) 1870- 1900, (b) 1900-1930, (c) 1930-1960 and (d) 1960-1990. The top plots are for 3 monthly means (for standard seasons DJF, MAM, JJA, SON) of the SO index (Wright 1984) where the black portions represent prominent SO minima. For 1934 onwards, Tahiti minus Darwin mean sea-level pressure difference (T-D) is also plotted. The standard seasons are as follows :

DJF : December - January - February

MAM : March - April - May

JJA : June-July-August

SON : September-October-November

The next two plots are for equatorial eastern Pacific SST (Wright 1984, Angell 1981 and private communications). Here, the maxima represent warm (W) events and are marked black while low values represent cold events (C) and are marked hatched. In general, C events are also associated with La Nina (anti El-Nino), cold water episodes along Peru-Ecuador coast.

The next two rows show the presence of El Ninos as given in Quinn *et al.* (1978) (upper row) and Quinn *et al.* (1987) (lower row). Strong (or very strong) events are marked as black squares, moderate (or near moderate) events as hatched squares and weak event as blank squares. The strengths are defined by Quinn *et al.* (1978) as repre-

TABLE 2

ENSO (S=Strong, M=Moderate) events and rainfall (F=Floods, D=Droughts)

Year	EN	SO	ISMR Dev.(%)
1871	S	M	-1
1873	Weak	S(late)	-12 D
1880	M	S(late)	-4
1891	S	S	-7
1900	S	S(early)	+4
1912	S	S(early)	-6
6 events			5 negative 1 positive

TABLE 3

EN (S=Strong, M=Moderate) and SST (C=Cold, W=Warm, X=non-event) and rainfall (F=Floods, D=Droughts)

Year	EN	SO	ISMR Dev. (%)
1884	S	W	+9
1897	M	X	+4
1932	S	X	-6
1939	M	X	-7
1943	M	X	+2
1874	M	C	+14F
1887	M	C	+5
1889	M	C	+9
1907	M	C	-9
1917	S	C	+18F
10 events			3 negative 7 positive

senting temperature anomalies along the Peru-Ecuador coast as >2.9°C (strong S), 2.0- 2.9°C (moderate M) and <2°C (weak W). As can be seen, the two rows are not completely identical. The next two rows show the warm (W) and cold (C) events mentioned in Mooley and Paolino (1989) (labeled as MO.PO) and Kiladis and Diaz (1989) (labeled as KI.DI). The next plot shows our designation of each year as having an El Nino (EN) and/or Southern Oscillation minimum (SO) and/or a warm (W) or cold (C) event as judged from the SO and equatorial eastern Pacific SST plots. The SO minima and Pacific SST maxima (W) could be in any part of the calendar year, early, middle or late. Later on, we will be making a distinction as to whether SO, W occurred in the middle of the year or early or late. As can be seen, some of the MO.PO events do not make the grade (*e.g.*, W events of 1976 and 1983).

The next plots show the ISMR as one value per year. The ISMR series has a mean value of 852 mm with a standard deviation of 83 mm (*i.e.*, ~10%), and a deviation range from -29% to +19%. For 1951 onwards, the dashed plot below ISMR shows the 50 mb low latitude zonal wind velocities (Venne and Dartt 1990) as 12-month running means, 3 months apart (4 values per year).

4. Rainfall deviations corresponding to events of various types

We now examine the rainfall deviations during years of events of different types.

(a) *Events of ENSOW type*

Some years have an El Nino (along Peru-Ecuador coast) as well as SO minimum and an equatorial eastern Pacific SST increase (W). The strength of El Nino was considered as given by Quinn *et al.* (1978, 1987) lists (strong of the two lists) as S (Strong), M (Moderate) or W (Weak). For SO minima and equatorial eastern Pacific SST maxima, strengths were given by us (by inspecting the plots) as S or M. If the SO and SST extremes were weak,, these were considered as non events (not to confuse with W-Warm).

Table 1 lists 30 ENSOW events and the corresponding ISMR values. Negative ISMR deviations <-9% are designated as droughts and positive deviations >+9% as floods. The ENSOW events are divided into two categories. Both have EN along the Peru-Ecuador coast. But for 16 unambiguous ENSOW (upper part of Table 1), the SO minima and equatorial eastern Pacific SST maxima (W) occurred in the middle of the calendar year (May-September, simultaneously with ISMR). For 14 ambiguous ENSOW (lower part of Table 1), SO minima and W occurred earlier than June or later than September, *i.e.*, outside ISMR interval.

(*i*) For the 16 unambiguous events (Table 1A), the ISMR deviations are mostly large negative, indicating that in such years, droughts in India should be expected. Among the 16 events, 11 have droughts (D). From the other 5, 1957 (-8%), 1902 (-7%) and 1930(-6%) have small negative deviations and 1896 (-3%) and 1976 (+1%) have very small deviations. Thus, for these 5 years, the rainfall was near normal, probably because the El Nino involved was moderate (M), except for 1957 (-8%) for which El Nino was strong (S).

(*ii*) For the 14 ambiguous events (Table 1B), the El Nino was S for 6, M for 5 and Weak for 3 events. But the SO minima and SST maxima (W) were *not in the middle of the year*. For almost all the events, ISMR deviations are low and rarely negative. Some of these are second years of double EN events (*e.g.*, 1957-58, 1982- 83). Thus, even when El Nino along Peru-Ecuador coast is strong or moderate, SO minima and equatorial eastern pacific SST maxima displaced from the middle of

TABLE 4

EN absent, SO and/or SST (Warm=W or Cold=C, X=non-event) and rainfall (F=Floods, D=Droughts)

Year	SO	SST	ISMR Dev.(%)
1888	S(late)	W	-5
1904	S(late)	W(early)	-12 D
1913	S(late)	W(late)	-8
1944	M	W	+8
1977	M	W	+3
1979	M	W	-17D
1920	X	W	-16D
1968	X	W(late)	-12D
1986	X	W(late)	-12 D
1885	M	X	-1
1974	M	X	-12 D
1959	M	X	+10 F
1935	M	C	-1
1936	M	C	+6
1946	S	C	+6
1949	M	C	+6

the year (monsoon season) (both earlier or later) and moderate in strength seem to nullify or minimize the drought intensities.

(b) *Events of the ENSO type*

For these 6 events listed in Table 2, EN existed and so did SO minima; but equatorial eastern Pacific SST was normal (neither warm nor cold). Almost all the ISMR deviations were low indicating that such events do not have a capacity to cause severe droughts. For the one event in which the deviation exceeded 10%, *viz.*, 1873 (-12%), the El Nino was weak and the SO minimum strong but late, almost at the end of 1873.

(c) *Events of EN with SST (W or C) type*

For these events listed in Table 3, El Ninos (strong or moderate) existed but no SO minima were observed while the equatorial eastern Pacific SST was warm (W) or cold (C) or neither of these (X). For 5 events of strong or moderate El Ninos (upper half of Table 3), one (1884) was a warm event (ENW) while the others were only EN events. For other 5 events (lower half of Table 3) of moderate or strong El Ninos, equatorial eastern Pacific SST were cold (C). These were ENC events, where the warmth of the Peru-Ecuador coast did not reach far in equatorial eastern Pacific. The ISMR deviations were low, indicating normal rainfall. However, for 1874 and 1917 (ENC), rainfalls were excess (+14 and +18%), indicating that C overpowered EN.

(d) *Events of SO and/or SST (Warm or Cold) type*

For these events listed in Table 4, El Ninos were absent. There is no doubt about it as these do not appear in Quinn *et al.* (1978, 1987). However, as seen from Fig.1(a), for some of these, SO minima or W did occur and these events were used by MO.PO and KI.DI as warm episodes. For the first 6 events (SOW), strong or moderate SO minima existed along with warm (W) events. For 4 of these, ISMR deviation were -5%, -12%, -8%, -17%. But for the other 2, the rainfall deviations were positive (+8%, +3%). Thus, a W (warm equatorial eastern Pacific SST) did not guarantee a deficient rainfall year. However, for 3 events (1920, 1968, 1986), there were no prominent SO minima (nor El Ninos), and these were isolated W (Warm Pacific) events with large negative rainfall deviations (-16%, -12%, -12%). For another 3 events (1885, 1974, 1959), only moderate SO minima (only SO events) existed and the ISMR deviations were mixed (-1%, -12%, +10%). For another 4 events (1935, 1936, 1946, 1949), there were moderate or strong SO accompanied by cold SST (SOC events) and for these, ISMR deviations were low (-1%, +6%, +6%, +6%). Thus, the relationship between ISMR deviations and SO and/or W or C is not always as expected (droughts for SO, W; floods for C).

(e) *Cold events*

Table 5 lists years when El Ninos and prominent SO minima were absent, while eastern equatorial Pacific SST showed cold (C) temperatures. Most of these are extended events, covering the whole year. But for a few (1967, 1975, 1988), Pacific SST turned cold only in the end of the year. For ISMR, almost all deviations were positive (34 out of 36 events). Eleven events were floods. Only two years (1927, 1928) showed negative deviations (-1% and -10%). Thus, for such (C) events, rainfall above normal seems to be almost assured. There were no El Ninos, and at least some of these years should be La Ninas.

Thus a general conclusion would be that warm water episodes along Peru-Ecuador coast (El Ninos) in conjunction with SO minima and equatorial eastern Pacific SST maxima (warm events), with SO and W *in the middle of the calendar year*, seem to lead to deficit rainfalls in Indian summer monsoon, while exclusively cold events C (equatorial eastern Pacific SST minima) tend to lead to excess rainfall. In all other cases, mixed results are obtained and single El Ninos or SO minima or equatorial eastern Pacific warm SST events W by themselves do not guarantee rainfall deficits.

TABLE 5
EN and SO minima absent (X). Only SST, C(Cold) events and rainfall (F=Floods, D=Droughts)

Year	EN	SO	ISMR (Dev.(%)
1872	X	C	+7
1875	X	C	+9
1879	X	C	+5
1882	X	C	+6
1886	X	C	+2
1890	X	C	+6
1892	X	C	+16F
1893	X	C	+12 F
1894	X	C	+14 F
1898	X	C	+3
1903	X	C	+1
1906	X	C	+4
1908	X	C	+5
1909	X	C	+4
1910	X	C	+10 F
1916	X	C	+12 F
1921	X	C	+1
1922	X	C	+2
1924	X	C	+1
1927	X	C	-1
1928	X	C	-10
1933	x	C	+14 F
1934	X	C	+7
1938	x	C	+7
1942	X	C	+12 F
1950	X	C	+3
1954	x	C	+4
1955	X	C	+9
1956	X	C	+15 F
1964	X	C	+8
1967	X	C(late)	+1
1970	x	C	+10 F
1971	X	C	+4
1973	X	C	+7
1975	X	C(late)	+13 F
1988	X	C(late)	+16 F
36 events			34 positive 2 negative

5. Types of events associated with extreme rainfalls

Let us now examine which type of events are associated when rainfall has extremes (deficient or excess).

Table 6 lists the ranked deficient rainfall (drought) years for ISMR with the status of El Ninos, SO minima and SST indicated for each one of these years. As can be seen, 7 of the 10 very severe droughts (1-10) and 4 of the 10 mild droughts (11-20) were associated with strong or moderate El Ninos and prominent SO minima and SST maxima (warm events), *i.e.*, ENSOW. However, there were some notable exceptions. For 1979 (SOW), there was no El Nino and yet rainfall deficit was -17%. The same was true for 1920, 1901, 1966, 1986, 1974, 1968. Thus, severe or moderate rainfall deficit could occur even without El Ninos and/or SO minima or even without SST maxima (W).

Fig. 2 shows a plot of SO index and SST (Wright 1984) 3-monthly averages for seven seasons, three pre-monsoon, three post-monsoon and the monsoon season (JJA) in between, for the first 17 years of ISMR ranked deficient rainfall. So is shown in the left half (minima shaded black), SST in the right half (maxima shaded black) and years and their rainfall deviations as well as El Nino status (Strong S, Moderate M or Weak) and group designation (ENSOW etc.) are indicated. The *average* SO and SST patterns are also shown in the bottom part (crosses). For two events 1982 and 1979 shown at the bottom, (T-D) values are used instead of SO index (Wright). The averages show SO minima and SST maxima at or soon after the monsoon (JJA) months. However, the averages are largely influenced by a few events, specially the most severe droughts of 1877, 1899, 1918, 1972, 1965 and 1905. For many others, notably 1920, 1901, 1966, 1951, 1873, 1968, the SO and/or SST patterns are very different from the average patterns.

Table 7 lists the ranked excess rainfall (flood) years for ISMR. For most of the years, El Ninos and SO minima are missing (X) and cold SST (C) are indicated. Notable exceptions are 1917, 1878, 1874, 1983, 1884 when strong or moderate El Ninos occurred and yet the rainfall was excess. Fig.3 shows the plots of SO and SST. The SO patterns are mostly maxima and SST patterns are mostly minima (cold events), notable exception being 1878 and 1959 when SO and/or SST patterns were different from average. However, on the whole, an absence of SO minima and presence of SST minima (cold events) seem to be adequate to cause excess rainfall in ISMR, even in the presence of El Ninos, which should have favoured droughts.

6. Models and predictions

The influence of large-scale atmospheric anomalies like EN and SO and equatorial eastern Pacific SST on the Indian monsoon has been known since long and investigated recently also in several studies (*e.g.*, Sikka 1980, Shukla and Paolino 1983, Rasmussen and Carpenter 1983, Mooley and Parthasarathy 1984, Khandekar and Neralla 1984, Elliot and Angell 1987). The Walker circulation is now recognized as the dynamical link between ENSO and the weather and climate over the whole Indo-Pacific region (see for example, Ropelewski and Halpert 1987). However, some local factors also come into the picture for every region. For example, Hahn and Shukla (1976), Dey and Banukumar (1983), show an inverse relationship between Eurasian snow cover and the Indian monsoon. Another parameter is the equato-

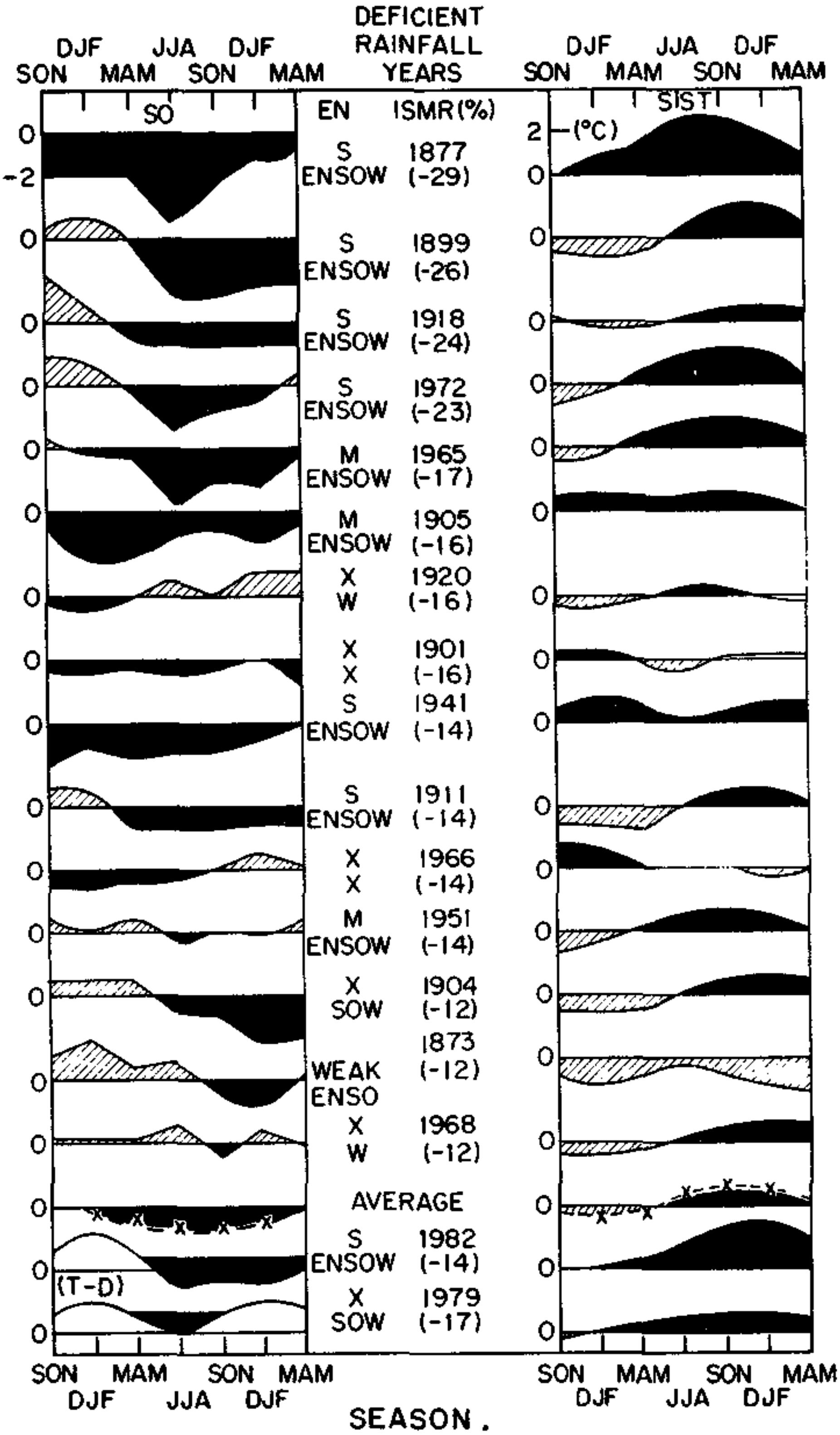


Fig.2. SO (left half) and SST (right half) variations for seven seasons, three pre-monsoon (SON, DJF, MAM), monsoon season (JJA) and three post-monsoon seasons (SON, DJF, MAM) for 17 years of largest deficient rainfall (droughts) for Indian monsoon. Black = SO minima and SST maxima. Hatched = SO maxima and SST minima. For each year, the strength of the El Nino (S, M, Weak) and the general status (ENSOW etc.) is also indicated

TABLE 6

ISMR, Deficient rainfall (drought) years (ranked), SST, EN, SO (S=Strong, M=Moderate, X=non-event)

Rank	Year	Dev. (%)	EN	SO	SST (Warm=W) (Cold=C)	Group Designation
Severe						
01	1877	-29	S	S	S(W)	ENSOW
02	1899	-26	S	S	S(W)	ENSOW
03	1918	-24	S	S	S(W)	ENSOW
04	1972	-23	S	S	S(W)	ENSOW
05	1987	-19	M	S	S(W)	ENSOW
06	1965	-17	M	S	S(W)	ENSOW
07	1979	-17	X	M	S(W)	SOW
08	1905	-16	M	S	S(W)	ENSOW
09	1920	-16	X	X	M(W)	SOW
10	1901	-16	X	X	X	X
Mild						
11	1941	-14	S	S	S(W)	ENSOW
12	1911	-14	S	S	S(W)	ENSOW
13	1966	-14	X	X	X	X
14	1982	-14	S	S	S(W)	ENSOW
15	1951	-14	M	S	S(W)	ENSOW
16	1986	-13	X	X	S(W)	W
17	1974	-12	X	M	X	SO
18	1904	-12	X	S(late)	S(W) (late)	SOW
19	1873	-12	Weak	S(late)	X	ENSO
20	1968	-12	X	X	S(W) (late)	W

rial stratospheric wind QBO (Quasi Biennial Oscillation) wherein the easterly phase of the QBO was seen to be related to deficit monsoon (*e.g.*, Bhalme *et al.* 1987 and references therein). The plot of 12 monthly running means of 50 hPa equatorial zonal winds at the bottom of our Fig.1 gives some indication. The latitudinal location of the axis of the 500hPa ridge along 75°E also seems to be related to Indian monsoon (*e.g.*, Krishna Kumar *et al.* 1992 and references therein).

Whereas the models based on these are gratifying, their value for prediction purposes becomes sometimes limited, for various reasons. For prediction, the parameters need to be precursors. The Eurasian winter snow cover does satisfy this condition as it occurs several months before the Indian summer monsoon. El Ninos can probably be predicted several months in advance, using trends in SO index. The El Nino itself is a precursor (occurring in January). However, as shown in this communication, El Nino alone (even strong) does not seem to guarantee anything. Tables 1,2,3 listed 46 El Nino events out of which only 27 gave negative deviations for Indian summer monsoon. However, the best score (15 out of 16) was for the unambiguous ENSOW events of Table 1A. So, one needs to ensure that an El Nino in January is followed later by an SO minimum and SST maximum (W). Is there some indication, say, at least one season earlier than summer, that SO minima and SST maxima would occur? In Fig.2 for the 17 severest drought years of ISMR, the *average* patterns (bottom part, crosses) shows that the DJF and MAM (pre-monsoon) values of SO were slightly negative while those of SST were almost zero. However, for individual events for SO, for 11 events (out of 17), the DJF and MAM values were either already negative or on a downward gradient from DJF to MAM (Shukla and Paolino, 1983). Similarly, for 11 events (out of 17), the SST values were either already positive or on an upward gradient from DJF to MAM. Thus, when El Nino was noticed, in about 60% cases, an examination of the pre-monsoon DJF, MAM values could give an indication of whether SO minima and SST maxima would occur in the following Indian monsoon summer season (JJA). Whether 60% is a good score is a matter of subjective opinion. The other 40% events were unpredictable, which we consider rather unsatisfactory.

7. Conclusions

All years from 1870 to 1990 were characterized as El Nino (EN), or Southern Oscillation minima (SO) or equatorial eastern Pacific sea surface temperature maxima (Warm events W) or minima (Cold events C) or combinations of these and the percentage rainfall deviations for Indian Summer Monsoon Rainfall (ISMR) were studied for each type. The following was noticed:

(*i*) For ISMR, from 16 unambiguous events of type ENSOW (El Ninos, with SO minima and equatorial eastern Pacific SST maxima in the middle of the year), 15 were very well related to deficit rainfall. Thus, unambiguous ENSOW seems to be a sufficient condition for producing droughts in India. There were 14 ENSOW of the ambiguous type where EN were strong or moderate but SO minima and/or SST maxima (W) occurred earlier or later than ISMR season (JJA). For these, ISMR had low negative as well as positive deviations.

(*ii*) From 36 events when there were no EN or SO minima and SST showed minima (Cold events C), 34 events showed positive deviations for ISMR. Thus, cold SST was well associated with excess rainfall.

(*iii*) From 46 events involving El Nino, omitting 16 unambiguous ENSOW, the rest 30 events showed poor relationship (both positive and negative deviations for ISMR), indicating that El Ninos by themselves do not guarantee anything.

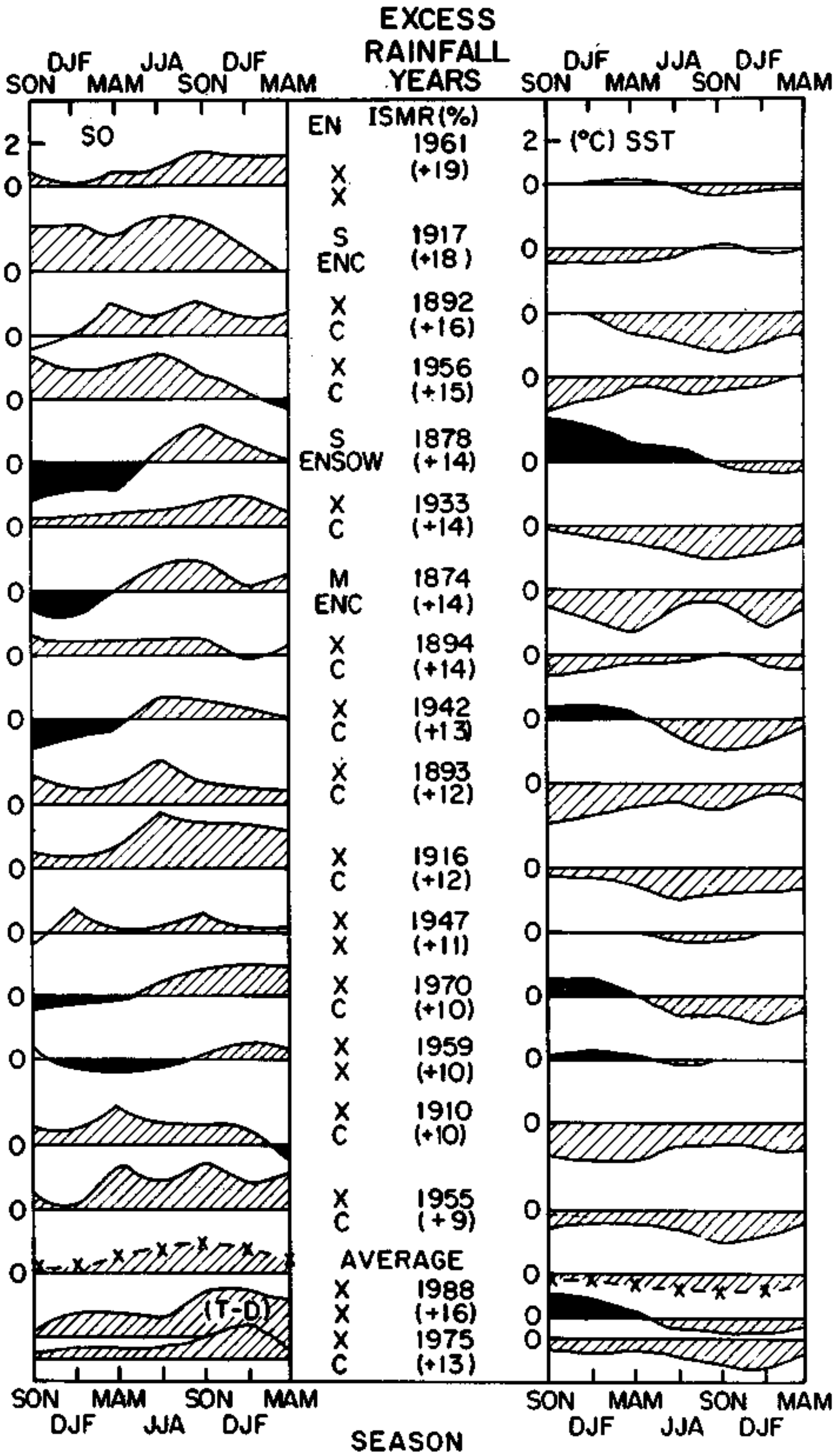


Fig.3. Same as Fig.2, for 17 years of largest excess rainfall (floods) for Indian monsoon

TABLE 7

ISMR, excess rainfall (flood) years (ranked) SST, EN, SO (S=Strong, M=Moderate, X=non-event)

Rank	Year	Dev. (%)	EN	SO	SST (Warm=W) (Cold=C)	Group Designation
Severe						
01	1961	+19	X	X	X	X
02	1917	+18	S	X	C	ENC
03	1988	+16	X	X	C	C
04	1892	+16	X	X	C	C
05	1956	+15	X	X	C	C
06	1878	+14	S	S(early)	W(early)	ENSOW
07	1933	+14	X	X	C	C
08	1874	+14	M	X	C	ENC
09	1894	+14	X	X	C	C
10	1975	+13	X	X	C(late)	C
Mild						
11	1942	+13	X	X	C	C
12	1983	+12	S	S(early)	W(early)	ENSOW
13	1893	+12	X	X	C	C
14	1916	+12	X	X	C	C
15	1947	+11	X	X	X	X
16	1970	+10	X	X	C	C
17	1959	+10	X	X	X	SO
18	1910	+10	X	X	C	C
19	1955	+9	X	X	C	C
20	1884*	+9	S	X	W(late)	ENW

(*iv*) From the point of view of extreme ISMR deviations, from the 10 events of largest rainfall deficiency (severe droughts), 7 were ENSOW, again indicating that ENSOW is a powerful combination to cause ISMR droughts. However, considering 20 events (mild and severe droughts), only 11 were ENSOW, I was ENSO, 2 SOW, 1 SO, 3 W, and 2 non-events. Thus, mild droughts could be associated with other type of events, including cold or non-events. For these years, other factors like Eurasian winter snow cover, stratospheric wind QBO etc. must have had a deciding influence.

(*v*) For excess rainfall (flood) years of ISMR, among the first 10 severe flood events, there was 1 ENSOW, 2 ENC, 5 C and 2 non- events. Thus, the presence of a C seems to be an important factor. For the first 20 mild and severe flood events, there were 2 ENSOW (both had displaced SO and W), 2 ENC, 1 ENW (with W displaced), 1 SO, 11 C and 3 non-events. Thus, EN alone were ineffective in preventing excess rainfall while cold events C had the largest influence in causing floods.

For Indian monsoon, there are two more aspects which need scrutiny. Firstly, the monsoon has its onset over Kerala, the southwestern meteorological sub-division of India. The mean date is near about 1 June but varied considerably, from 7 May to 22 June, in the last 100 years or so. Joseph *et al.* (1994) have shown in their exhaustive analysis that MOK (Monsoon onset over Kerala) delays are related to delays in the seasonal transition of the equatorial convective cloudiness maximum as also with El Ninos. It would be interesting to check whether MOK delays are related preferentially to any particular type of events that we have characterized. Secondly, the behaviours of monsoon rains in different sub-divisions of India are different and the regional rainfalls may react differently to our various categories of events. This needs further exploration.

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