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Relation of El Niño characteristics and timings with rainfall extremes in India and Australia

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सार – चूँकि विश्व के कुछ भागों विशेषकर भारत और दक्षिण पूर्व आस्ट्रेलिया में कुछ एलनिनों वर्ष सूखे के साथ संबंद्ध पाए गए हैं अतः एलनिनों के प्रभाव प्रायिकात्मक होते हैं जो कुछ ही क्षेत्रों को प्रभावित करते हैं, किन्तु सभी एलनिनों समान रूप से प्रभावी नहीं होते हैं। हाल ही में यह ज्ञात हुआ है कि असंदिग्ध एनसों (एलनिनों वर्ष, जिसमें न्यूनतम दक्षिणी दोलन सूचकांक और प्रशांत महासागर सतह का अधिकतम तापमान कलैंडर वर्ष के मध्य में होता है) सूखे के साथ सुसंबद्ध थे। इस विषय में यह जाँच की गई है कि क्या भारत और आस्ट्रेलिया में (प्रधान वर्षा ऋतु के अनुरूप) एलनिनों की प्रभावोत्पादकता एलनिनों की घटनाओं के साथ अनुकूल समय में किसी प्रकार से जुड़ी हैं। सामान्यतः प्रधान वर्षा ऋतु के दौरान सक्रिय एलनिनों सूखे के साथ सुसंबद्ध होते हैं। किन्तु कुछ घटनाएं इस पैटर्न के अनुरूप नहीं होती हैं। एलनिनों अथवा लानिना के अभाव वाले अनेक वर्ष सूखे अथवा बाढ़ों के साथ भी संबद्ध होते हैं। इस प्रकार एलनिनों/वर्षा का संबंध निश्चय ही अस्पष्ट है।

ABSTRACT. Whereas some El Nino years are known to be associated with droughts in some parts of the globe, notably India and south-east Australia, the El Niño effects are probabilistic, affecting only some regions and, not all El Niños are equally effective. Recently, it was observed that Unambiguous ENSOW (El Niño years, in which the Southern Oscillation Index minima and Pacific sea surface temperature maxima occurred in the middle of the calendar year) were better associated with droughts. In this communication, it is checked whether the effectiveness of El Niños was in any way related to suitable timings of the El Niño events (coincident with main rainy seasons) in India and Australia. In general, El Niños active during the main rainy season were associated better with droughts. But some events did not fit this pattern. Also, many years not having El Niños or La Niñas were associated with droughts or floods. Thus, the El Niño/rainfall relationship is rather loose.

Key words – Indian rainfall, Australian rainfall, El Niño, La Niña, Droughts, Floods.

1. Introduction

Along the coast of Peru-Ecuador in South America, there is an ocean current called "Peru or Humboldt" current. The El Niño (The Child) is identified with warming of this ocean current (Hushke, 1959). In some years, the current may extend southward along the coast of Peru to Lat. 12° S, killing plankton and fish in the coastal waters. Quinn *et al*. (1978, 1987) determined the occurrence of El Niño events on the basis of the disruption of fishery, hydrological data, sea-surface temperature and rainfall along and near the Peru-Ecuador coast, defining intensities based on the positive sea-surface temperature anomalies along the coast *viz*. Strong, in excess of 3° C; Moderate, 2.0° - 3.0° C; Weak, 1.0° - 2.0° C. El Niño is the oceanic component of the general El Niño/Southern Oscillation (ENSO) phenomenon, while the Southern Oscillation, generally represented by Tahiti minus Darwin atmospheric pressure difference (T-D), is its atmospheric component. Anomalies in the two may not always occur simultaneously (Deser and Wallace, 1987; Trenberth, 1997).

Several workers have reported links between the ENSO phenomenon and rainfall extremes in India (Pant and Parthasarathy, 1981; Rasmusson and Carpenter, 1983; Khandekar and Neralla, 1984; Kiladis and Diaz, 1989; Ropelewski and Halpert, 1987, 1989; Mooley and Paolino, 1989; Chattopadhyay and Bhatla, 1996; Kripalani and Kulkarni, 1997) and Australia (McBride and Nicholls, 1983; Nicholls, 1988; Wright, 1988a,b; Ropelewski and Halpert, 1987, 1989; Nicholls and Wang, 1990; Evans and

Allan, 1992). Webster and Yang (1992) showed that monsoon and ENSO were selectively interactive systems. The El Niño effects are probabilistic, *i.e.*, significant rainfall anomalies are seen more often in some areas only (McBride and Nicholls, 1983, for Australia, Ropelewski and Halpert, 1987, 1989 for a global scale), and, in any location, not all El Niños are equally effective.

Why are all El Niños not equally effective? Trenberth (1997) refers to different "flavours" of El Niños but does not identify them. Kane (1997a,b) attempted a finer classification of El Niños, in which Unambiguous ENSOW type events were found to be overwhelmingly associated with droughts in India arid some parts of Australia and the globe. These were El Niño (EN) years (Quinn *et al.*, 1987), during which the Southern Oscillation Index SOI (represented by Tahiti minus Darwin atmospheric pressure difference T-D) had a minimum (SO) and the equatorial eastern Pacific sea surface temperatures (SST) had a maximum (W), in the middle of the calendar year. Thus, Unambiguous ENSOW could be a distinguishing characteristic (flavour). Recently, Mooley (1997) attempted a classification of El Niños (as observed on the Peru-Ecuador coast) dividing these into two categories, namely (*i*) EW, where El Niños were associated with a warming phase of the equatorial southeast (ESE) Pacific region (0-10° S, 80° W -180° W), and (*ii*) E, where El Niños were not associated with a warming phase in ESE and reported that the EW category was overwhelmingly associated with droughts in Indian summer monsoon. A comparison showed that the classification used in Mooley (1997) is almost the same as in Kane (1997a, b).

Another distinguishing characteristic could be the time of commencement and duration of the El Niño. The purpose of the present communication is mainly to examine the relationship between the El Niño timings and droughts. For India, the All India summer monsoon rainfall (IMR, for Jun - Sep) is considered. For Australia, different regions (*e.g.*, northern, eastern) are reported to have different ENSO relationships, more persistent during the Austral winter to early summer seasons (McBride and Nicholls, 1983). In this communication, 8 regions of Australia selected by Srikanthan and Stewart (1991) are considered.

2. Data

The All India summer monsoon rainfall (IMR) data were obtained from Parthasarathy *et al.* (1992) and rainfall data for Australia were obtained from Srikanthan and Stewart (1991), both updated by further private communication. The Australian data were obtained by grouping data from selected 69 rainfall stations into 8

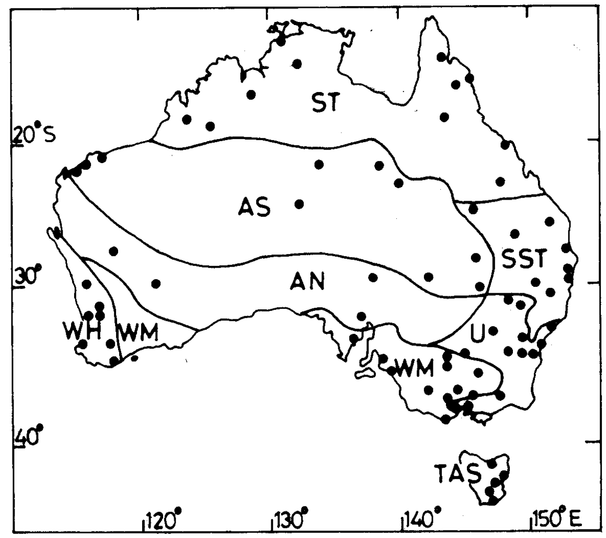

Fig. 1. Map of Australia, showing the locations of the eight major rainfall regions and 69 stations (Srikanthan and Stewart, 1991)

major climatic regions (Fig. 1), based on similar seasonal rainfall patterns. The regions TAS (Tasmania), WM and WH have large rainfalls in the (Austral) winter months (May-Aug), similar to the summer months of India. Hence, TAS, WM, HM are considered as Australian Group 1 (Gr. 1). Other regions AN, AS, U, SST, ST have main rainy seasons either in Austral summer (Nov - Feb) or have uniform rains in all months. These are considered as Australian Group 2 (Gr. 2).

Data for Puerto Chicama (8° S, 80° W, Peru coast) SST anomalies (for 1925 onwards) were obtained from private sources and those for Niño 1 + 2 region (0°-10° S, 90° W-80° W) near Peru-Ecuador coast and Niño 3 region (5° N-5° S, 150° W-90° W) in eastern equatorial Pacific and for Tahiti (18° S, 150° W) minus Darwin (12° S, 131° E) pressure difference (T-D) (for 1950 onwards), from Parker (1983) and the monthly Climate Diagnostic Bulletins of CPC (Climate Prediction Center of NOAA's National Center for Environmental Prediction). The SO index obtained by Wright (1975) based on pressure at a wide spread of stations (Cape Town, Bombay, Djakarta, Darwin, Adelaide, Apia, Honolulu, Santiago) was also examined and found to be very similar to the Tahiti minus Darwin pressure difference (T-D). For Pacific SST, the Wright (1984) Index was also used and refers to the region 6° N - 6° S, 180 - 90° W (central and eastern equatorial Pacific, almost the same as Niño 3 region). A similar SST index developed by Angell (1981, and further private communication) was also used for comparison, specially when Wright SST values were missing.

3. Plots

Plots of SST at Puerto Chicama, Wright SST and SO index indicated the following features :

(*i*) The largest SST fluctuation was at Puerto Chicama. In 1982-83, the temperature anomaly reached almost 10° C.

(*ii*) The Niño 1 + 2 region SST fluctuation was almost similar to that of Puerto Chicama but smoother and smaller in magnitude (about half) with almost similar commencement (within a month). The Niño 3 region SST fluctuations were also roughly similar but with still smaller magnitudes (about one-third) and commenced generally with a delay of 1-2 months. The plots of Wright SST were very similar to those of Niño 3 region.

(*iii*) The SOI evolution was often dephased, starting earlier (1982) and/or lasting longer (1969) or occurring alone (1959, 1974). This explains why ENSO events chosen by different workers on the basis of (*i*) El Niños (Rasmusson and Carpenter, 1983, following Quinn *et al*. 1987), (*ii*) Southern Oscillation Index (T-D) (Kiladis and Diaz, 1989) and (*iii*) Eastern equatorial Pacific SST (Mooley and Paolino, 1989), do not always tally between themselves.

4. Rainfall relation with ENSOW etc. - A recapitulation

Kane (1997a,b ; 1998), showed the rainfall status of All India summer monsoon rainfall (IMR) and rainfall in the 8 major regions of Australia, for (a) Unambiguous ENSOW, (b) Ambiguous ENSOW and (c) Other types of El Niño events. The meaning of the labels (ENSOW etc.) for each year, used in Kane (1997a,b ; 1998) is restated here, as follows :

In literature, the term ENSO is used for the general phenomenon of El Niño/Southern Oscillation. We will use it generally in the same sense; but for specific years, their literary meaning is used. Thus :

EN = Presence of El Niño at Puerto Chicama (Quinn *et al*., 1978, 1987, updated) and Niño 1 +2 region.

SO = Presence of minimum in the Southern Oscillation Index SOI, Wright SOI Index or Tahiti minus Darwin atmospheric pressure difference (T-D), *i.e*., maximum in (D-T).

W = Presence of maximum (positive anomalies) in the sea surface temperature (SST) in the eastern equatorial Pacific (Niño 3 region and/or Wright SST).

C = Presence of minimum (negative anomalies) in the sea surface temperature (SST) in the eastern equatorial Pacific region (Niño 3 region and/or Wright SST). These are La Niñas.

Various combinations of these were seen. In particular, some prominent events were ENSOW, *i.e*., El Niño (EN) existed (Quinn *et al*., 1987), SOI minima (SO) also existed and, eastern equatorial Pacific SST was warmer (W). The SOI and SST plots (12-monthly running means) were used to check whether the SOI minima or SST maxima occurred in the middle of the calendar-year (May-Aug). If so, the events were termed as ENSOW-U, *i.e*., Unambiguous ENSOW. If the SOI minima or SST maxima occurred in the earlier or later part of the year (not in the middle), the events were termed as ENSOW-A, *i.e*., Ambiguous ENSOW. Years having neither an EN nor SO nor W nor C were termed as non-events. I and II indicate first and second years of double El Niño events (1957-58 etc.). Symbols S (Strong), M (Moderate), W (Weak) indicates strengths of the El Niños involved, as defined by Quinn *et al*. (1987).

Rainfall was represented by symbols: (+ or –) means normal rainfall (within ± 0.5σ); (f) means positive deviations in the range + 0.5σ to +1.0σ (mild floods); (d) means negative deviations in the range –0.5σ to –1.0σ (mild droughts); (D and F) mean severe droughts and floods (deviations numerically exceeding 1.0 σ). The salient features important to the present investigation are :

(*i*) The Unambiguous ENSOW had definite association (16 out of 16 events) with droughts (D, d) or deficient rainfall (–) in All India summer monsoon (IMR). The fraction of positive deviations (F, f, +) to the total, was 0.00 for IMR.

(*ii*) For the Australian regions, this fraction was very small for TAS (Tasmania, 0.06), AS (0.00) and AT (0.00). Thus, these regions also were predominantly drought-prone during Unambiguous ENSOW. Regions WM (0.25), WH (0.30), U (0.19), AN (0.27), SST (0.19) were also drought-prone, but to a lesser extent.

(*iii*) For the Ambiguous ENSOW, the fractions of positive deviations were near 0.50, implying roughly equal probability of droughts and floods, *i.e*., essentially a poor El Niño relationship. For IMR, the fraction was large (0.73), implying a better association with floods rather than with droughts.

Thus, Unambiguous ENSOW had a distinct “flavour”, suitable for producing droughts in IMR and some parts of Australia (particularly, southeastern Australia).

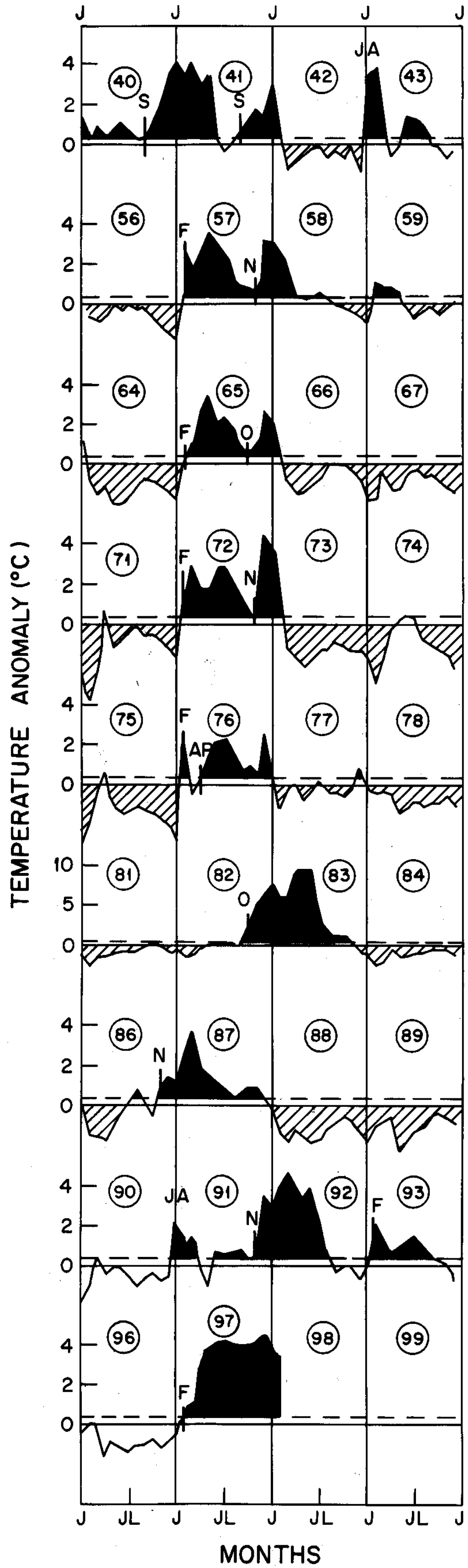

Fig. 2. Monthly values of Puerto Chicama SST anomalies for selected 4-year intervals involving El Niño events. For 1997 (bottom plot), Niño 1+2 region SST anomaly was used

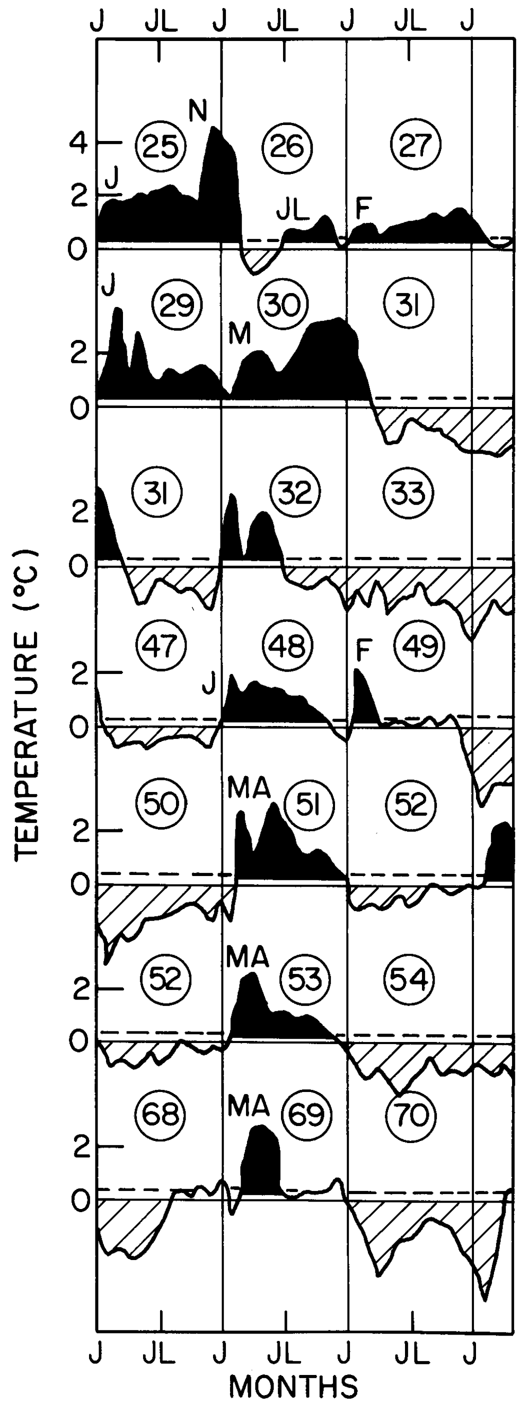

Fig. 3. Same as Fig. 2, for some other El Niño events, for selected 3-year intervals

Is there any physical significance to the category Unambiguous ENSOW? A possible clue comes from the analysis of Ward *et al.* (1994) where years were sorted out depending on whether these were wet (excess rains) or dry (droughts) in Sahel and India and their average

TABLE 1

El Niño events (Year and months of commencement and termination), their characterizations (ENSOW etc.), expected effects (Exp. Gr.1) on rainfall in India and regions TAS, WM, WH of Australia, and their observed rainfalls, expected effects (Exp. Gr. 2) on rainfall in regions U, AN, SST, AS, ST of Australia, and their observed rainfalls

El Niño	Duration		Characteristic	Exp.	Observed				Exp.	Observed				
				Gr.	IMR	TAS	WM	WH	Gr.2	U	AN	SST	AS	ST
Q1925 I	Jan	Dec	ENSOW-A	D	d*	D*	D*	-	D	-	-	d*	-	d*
Q1926 II	Jan	Feb	ENSOW-A	+/-	F	+*	-*	F						
	Jul	Nov							d	d*	-	-	d*	+
Q1929	Jan	Dec	EN	D	-	+	d*	-	d	d*	d*	-	-	-
Q1931 II	Jan	Mar	ENSOWA(C)	+/-	+*	+*	f	+*	f	f*	-	d	-	-
Q1941 II	Jan	Apr	ENSOW-U	+/-	D	D	d	+*						
	Sep	Dec							d	d*	F	d*	-	-
Q1943	Jan	Aug	EN	d	+	-	D*	d*	+/-	-*	D	+*	d	+*
Q1948	Jan	Oct	ENSOW-A	D	+	-	+	-	d	-	-	-	f	+
Q1958 II	Jan	Apr	ENSOWA(C)	+/-	+*	F	f	+*	f	+	+	F*	-	-
Q1973 II	Jan	Feb	EN C (Mar)	f	f *	+	F*	f*	f	f*	F*	f*	F*	F*
Q1983 II	Jan	Oct	ENSOW-A	D	F	-	F	+	f	F*	+	F*	f*	F*
Q1987	Jan	Jan	ENSOW-U	D	D*	D*	-	D*	+/-	-*	d	-*	-*	d
1991 I	Jan	Mar	ENSOW-A	+/-	-*	-*								
	Nov	Dec							D					
1992 II	Jan	Aug	ENSOW-A	+/-	- *	- *			+/-					
1927	Feb	Dec	EN	D	-	d*	-	-	D	+	-	+	d*	-
Q1932	Feb	Jun	EN	+/-	d	-*	+*	f	+/-	d	+*	d	-*	d
Q1957I	Feb	Dec	ENSOW-U	D	d*	-	D*	d *	D	d*	d*	D*	-	-
Q1965	Feb	Dec	ENSOW-U	D	D*	-	-	f	D	-	f	-	d*	d*
Q1972I	Feb	Dec	ENSOW-U	D	D*	d*	-	D *	D	-	d*	+	-	-
Q1976	Feb	Dec	ENSOW-A	D	+	f	-	D *	D	-	D*	+	+	+
1993	Feb	Oct	ENW	D	+	-			+/-					
Q1930I	Mar	Dec	ENSOW-U	D	d*	f	+	-	D	+	+	+	-	-
Q1951	Mar	Dec	ENSOW-U	D	D*	-	+	+	d	-	-	D*	-	D*
Q1953	Mar	Nov	ENSOW-A	D	f	+	+	-	+/-	- *	-*	-*	-*	-*
Q1969	Mar	Jun	ENSOW-A	+/-	-*	f	- *	D	+/-	f	d	-*	d	d
Q1940 I	Sep	Dec	ENSOW-A	+/-	-*	D	d	D	D	-	d*	-	-	-
Q1982 I	Oct	Dec	ENSOW-U	+/-	D	d	D	D	D	D*	d*	D*	d*	d*
1986 I	Nov	Dec	W	+/-	D	+*	f	d	D	+	F	-	+	-
27 events														
*					14	10	8	9		11	9	12	9	8
Non *					13	17	16	15		13	15	12	15	16
* / Total					0.52	0.37	0.33	0.38		0.46	0.38	0.50	0.38	0.33

characteristics studied, in terms of SST anomalies in the Pacific. They found that years of Type I which were associated with a near-global rainfall teleconnection including a tropic-wide oscillation, had a strong contrast in SST anomalies between the central/eastern tropical Pacific and western tropical Pacific. Earlier, Fu *et al.* (1986) had identified two distinct patterns in Pacific SST. In one, the Pacific was warmer east of the dateline, warmer in Central Pacific, but slightly below normal west of the dateline (examples: 1957, 1965, 1972, 1982). In another, the Pacific was warmer everywhere (examples: 1963, 1969). In cases like 1976, there was a mixture of the two. These different SST patterns in the Pacific could have different effects on the world climate. Mooley (1997) mentions a large-scale adverse influence of the descending limb of the Walker circulation in EW years (same as Unambiguous ENSOW) in comparison to E years.

Question whether the Unambiguous ENSOW are more effective because these might have occurred during the main rainy season, and the other El Niños are less effective because they might have occurred off-season, has been examined in the next section.

5. El Niño commencement and duration

Figs. 2 and 3 show detailed plots of the SST anomalies at Puerto Chicama during major El Niño events since 1925. These plots are used to locate the commencements and endings of the El Niño events. For double events *i.e.*, events which continued in the next year (1957-58 etc.), each year is considered as a separate event, the first year event considered as ending in December of the first year (marked as I) and the second year event as commencing in January of the second year (marked as II). Table 1 lists the El Niño events starting with those which commenced in January. Rainfall is represented by symbols. Q indicates events mentioned in Quinn *et al.* (1978, 1987).

In Table 1, column 1 gives the year of the event, columns 2 and 3 give the duration and column 4 gives our classification (ENSOW etc.). Column 5 (headed Exp. Gr. 1) gives the expected rainfall for IMR (India), TAS, WM, WH, during May - August Columns 6, 7, 8 and 9 give the rainfall actually observed in these four regions. Column 10 (headed Exp. Gr.2) gives the expected rainfall for U, AN, SST, AS, ST, during November – February. Columns 11, 12, 13 and 14 give the rainfall actually observed in these five regions. If an event commenced and ended before June, it is considered as ineffective for rainfalls for both groups Gr. 1 and Gr. 2 and the expected values are designated as +/– (normal rainfall). If the event is strong during June - September only, the expected value for Gr. 1 is D (Droughts); but for Gr. 2, it is +/– (normal rainfall). If the event remains strong throughout the year, the expected value for both Gr. 1 and Gr. 2 is D. If the event started after August and continued up to the year end, the expected value for Gr. 1 is +/– (normal); but for Gr. 2, it is D. When the expected rainfall tallied with the observed rainfall (+/– expected tallying with + or - observed, D or d expected tallying with D or d observed, F or f expected tallying with F or f observed), the observed values are marked with an asterisk (*). The following may be noted :

In Table 1, there are 22 Q events (present in the list of Quinn *et al.* 1978, 1987) and 5 others equivalent to Q events, making a total of 27 events.

(*i*) For India (IMR), there were 14 events (*) when expected and observed values tallied. From these, 7 were expected and observed drought years, *viz*., 1925 (ENSOW -A), 1987 (ENSOW-U), 1957 (ENSOW-U), 1965 (ENSOW-U), 1972 (ENSOW-U), 1930 (ENSOW-U), 1951 (ENSOW-U), indicating that these ENSOW-U proved effective because of proper phasing with the main rainy season of Gr. 1. Other 7 were El Niño years when there was dephasing and expected rainfall was +/- (normal) and observed rainfalls also were + or –.

(*ii*) For IMR, there were 13 events when expected and observed values did not tally. Thus, the phase criterion succeeded or failed in almost equal number of cases. The numbers 14/13 and the fraction of success 14/27 = 0.52 are given at the bottom of Table 1. In 3 cases, *viz.*, 1941 (ENSOW-U), 1982 (ENSOW-U) and 1986 (W), the events terminated before April or started in October or later (as judged by SST anomalies reaching almost zero) and hence, were not expected to give droughts; but severe droughts were observed in India (also in Australia). The 1982 event is particularly curious. In all other events, the SST anomalies started first at Puerto Chicama and within a month or two at Niño 1+2 and Niño 3 regions; but in 1982, the SST anomalies started 2-3 months earlier at Niño 3 region. The 1982-83 event was the most intense El Niño till then and Quiroz (1983) has mentioned several unusual, extraordinary aspects of this event.

(*iii*) In Australia, the fraction of asterisks (*) is ~0.50 or less. Thus, less than half of the events conform to the expectations of droughts when El Niño was active. Here, 1982 also conformed. The late El Niño was conducive to droughts and did yield droughts all over Australia.

In conclusion, though the phasing of El Niño duration relative to the main rainfall season did matter in some cases, in more than half the cases, it did not matter.

Lough (1991) studied the rainfall variations in Queensland, a state extending from 10° S to 29° S and encompassing 22 percent of Australia (roughly similar to SST) and the eastern part of ST (Fig. 1) and gave the rainfall anomalies for 1891-1986 for the local summer (October, November, December of one year and January, February, March of the next year), during which ~70% of the yearly rainfall occurs. We used these summer values to see their ENSO relationships. For Unambiguous ENSOW, 11 out of 13 events were associated with droughts, a good relationship. In the years 1925, 1930, 1941, 1951, 1957, 1965, 1982 when El Niños lasted throughout the whole calendar year, the succeeding summer rainfalls (1925-26, 1930-31 etc.) were observed to be all deficient, as expected. In 1943, 1969, 1973, 1983, the El Niños were operative only in the early part of the calendar year and the rainfalls were observed to be normal or excess (not deficient), again as expected. However, in 1926, 1927, 1929, 1931, 1932, 1940, 1948, 1953, 1958, 1972, 1976, the succeeding summer rainfalls (1926-27, 1927-28 etc.) were not as per expectation. Floods (droughts) occurred when droughts (floods) or normal rainfalls were expected. Thus, phase relationship is only partially observed even when seasonal rainfall is considered. Lough (1991) had noticed the loose relationship between rainfall extremes and SOI extremes. Using the list of warm and cold events based on SOI as given in Kiladis and van Loon (1988), Lough (1991) reported that 1901-02, 1922-23, 1934-35, 1964-65 were drought years, and 1895-96, 1953-54, 1976-77 were wet years, both with no corresponding extremes (low or high) in SOI. On the other hand, years of SOI negative extremes (warm events) 1913, 1923 were not followed by rainfall deficits during the summers 1913-14 and 1923-24. Only normal rainfalls were observed. We also observed that years of positive SOI extremes (cold events La Niña) 1892, 1903, 1906, 1920, 1928, 1938 were not followed by rainfall excesses during the summers 1892-93, 1903-04 etc. Only normal rainfalls were observed. In a later paper, Lough (1997) prepared simpler normalised rainfall indices using data from only 17 stations in Queensland, which were found to have an interannual variability very well correlated (correlation +0.97) with the earlier series. Lough (1997) reported that both summer and winter rainfall anomalies were generally well related to ENSO phenomena; but the relationships broke down during 1931-50 for summer rainfalls and during 1911-30 for the winter rainfalls. Earlier, McBride and Nicholls (1983) had also mentioned that the SOI-rainfall correlations vary with time (pattern different in 1932-53 as compared to 1954-73). Thus, the variation of the relationship between El Niño duration and droughts as reported above by us seems to be observed by other workers also.

6. Droughts and floods in India and Australia

(a) *Droughts in India*

Let us examine the years when droughts occurred in India during 1925-94. These are listed below, with the designations of years used in Kane (1997a,b; 1998).

1925	d	ENSOW-A (Jan-Dec)
1928	D	C (La Niña)
1930	d	ENSOW-U (Mar-Dec)
1932	d	EN (Feb-Jun)
1939	d	EN (Jan)
1941	D	ENSOW-U (Jan-Jun)
1951	D	ENSOW-U (Mar-Dec)
1952	d	Non-event
1957	d	ENSOW-U (Feb-Dec)
1962	d	Non-event
1965	D	ENSOW-U (Mar-Dec)
1966	D	Non-event
1968	D	W
1972	D	ENSOW-U (Feb-Dec)
1974	D	SO
1979	D	SOW
1982	D	ENSOW-U (Oct-Dec)
1985	d	Non-event
1986	D	W
1987	D	ENSOW-U (Jan-Nov)
1991	d	ENSOW-A (Jul-Sep)
1992	d	ENSOW-A (Jan-Aug)

Thus, from the 22 droughts (10 mild, d; 12 severe, D) in All India summer monsoon, 8 were associated with Unambiguous ENSOW and 3 with Ambiguous ENSOW, indicating that ENSOW (especially, ENSOW-U) is a combination favourable for droughts. However, it is neither necessary nor sufficient. In 11 cases (50%), droughts occurred in other categories of years. It may also be noted that the interactions between El Niño/La Niña and the climate anomalies (droughts, floods etc.) are non-linear in nature. As such, the distinction d, D or f, F may not be very meaningful. Hence, no importance will be given to the relative proportions of d, D or f, F.

So far, we considered events from 1925 onwards only, as Puerto Chicama data were available only since then. However, Indian summer monsoon rainfall data are available since 1871 and the Wright SST index representing W, is also available since then. The mild and severe droughts in India during 1871-1924 are listed below :

1873	D	ENSO (W not seen)
1876	d	Non-event
1877	D	ENSOW-U (Feb-Dec)
1888	d	ENSOW-U (Jan-Dec)
1891	d	ENSO (Apr-Aug)
1899	D	ENSOW-U (Jul-Dec)
1901	D	Non-event
1902	d	ENSOW-U (Jan-Dec)
1904	D	SOW (Ju1-Dec)
1905	D	ENSOW-U (Jan-Dec)
1907	d	ENC (W not seen)
1911	D	ENSOW-U (Aug-Dec)
1912	d	ENSO (Jan-Feb)
1913	d	SOW (No data for W)
1915	d	Non-event
1918	D	ENSOW-U (No data for W)
1920	D	W (Jun-Oct)

In some cases, the El Niño started late (August), but this was for the Niño 3 region. In Niño 1 + 2 region or at Puerto Chicama, it must have started earlier. Thus, in all cases where El Niño was involved, the timing was concurrent with Indian summer monsoon. From the 17 drought events (9 severe, 8 mild), 7 were associated with ENSOW-U, but 10 were associated with other types of events, again confirming the favourableness but not exclusiveness of ENSOW type events for causing droughts.

(b) *Droughts in Australia*

A table (not shown here) was made listing the droughts which occurred during 1871-1989 in the various regions of Australia. Droughts common to 5 or more regions were marked. The following was noted :

(*i*) In each region, about one-third or more droughts were related to ENSOW-U or ENSOW-A. But about the same number was related to other categories. Thus, relationship with ENSOW (U or A) is by no means predominant.

(*ii*) The most disconcerting aspect was the occurrence of droughts even during Non-events and still worse, during C events (La Niñas).

(*iii*) Many of these droughts were confined to one or two regions and hence, must be of very local origin. However, some were common to more than four regions. Amongst these, there were many ENSOW-U (1888, 1896, 1899, 1902, 1911, 1957, 1982), but there were two ENSOW-A (1914, 1919), one EN (1897), two SOW (1944, 1977), two non-events (1901, 1937) and one C event. Thus, widespread droughts can occur not only during ENSOW (U or A) events but even during other type of events. Droughts during El Niño years get lot of publicity, and those occurring in other years are ignored.

(c) *Floods in India*

Following is the list of floods (f = mild; F = severe) in India during 1871-1996 :

1872	f	C	1938	f	C
1874	F	ENC	1942	F	C
1875	f	C	1944	f	SOW
1878	F	ENSOW-A	1945	f	Non-event
1879	f	C	1946	f	SOC
1882	f	C	1947	F	Non-event
1884	f	ENW	1949	f	SOC
1887	f	ENC	1953	f	ENSOW-A
1889	f	ENC	1955	f	C
1890	f	C	1956	F	C
1892	F	C	1959	F	SO
1893	F	C	1961	F	Non-event
1894	F	C	1964	f	C
1908	f	C	1970	F	C
1910	F	C	1973	f	ENC
1914	f	ENSOW-A	1975	F	C
1916	F	C	1978	f	Non-event
1917	F	ENC	1983	F	ENSOW-A
1926	f	ENSOW-A	1988	F	C
1933	F	C	1990	f	Non-event
1934	f	C	1994	F	SOW
1936	f	SOC			

From the 43 events of floods, 21 were associated with C (basically La Niña), 8 with ENC or SOC (EN or SO in a part of the year, C in the rest), 5 with ENSOW-A (mostly II year El Niño events, active in January but disappearing soon after, leaving the rest of the year as C), 5 Non-events and 4 other types (ENW, SO, SOW). Thus, La Niñas seem to be better associated with floods than El Niños are with droughts, probably because, as commented by Trenberth (1997), La Niñas run smoothly and last longer.

(d) *Floods in Australia*

A table was made listing the years of floods which occurred in different regions of Australia during 1871-1989. Events common to five or more regions were marked. The following was noted :

(*i*) In each region, about half or more floods were related to the C events (La Niña). Thus, the relationship of floods with La Niña is better than the relationship of droughts with El Niños. Some floods were associated with ENSOW also, but more with ENSOW-A than with ENSOW-U, probably because some ENSOW-A (many II year events) were short lived, active only in the early part of the calendar year, followed by a C event in the latter part of the same year.

(*ii*) The most disconcerting aspect was the occurrence of floods even during Non-events and still worse, during some El Niño events.

(*iii*) Many of these floods were confined to one or two regions and hence, must be of very local origin. However, some were common to more than four regions. Amongst these, there were many C events (La Niñas, 1890, 1893, 1903, 1916, 1955, 1975); but there were three) ENC (1889, 1917, 1973) and one ENSOW-A, again because the El Niño was in the earlier part of the year and there was C in the later part. There was one SO too. Thus, widespread floods can occur not only during C events but even during other type of events.

7. The 1997-98 El Niño

During 1997, an El Niño started in February (Fig. 2, bottom plot) and soon strengthened and continued strong in the latter part of 1997 and the first four months of 1998. Thus, the timing was suitable for severe droughts in India as well as in Australia in 1997. Actually, rainfall was only marginally deficit in 1997 in some parts of India and normal or even excess in some other parts. As such, severe droughts did not occur and the El Niño of 1997 seems to have proved innocuous for India, quite unlike the 1982 El Niño which started in October and yet resulted in severe droughts in India. Since the El Niño ended before the monsoon season, normal or excess rainfall was expected in India in 1998. The summer monsoon (Jun-Sep) rainfall in India in 1998 was normal or above normal, with severe floods in many parts, as also in adjacent Bangladesh. For Australia, the Bureau of Meteorology mentions that from 1 March 1997 to 30 April 1998, severe deficiencies in rainfall occurred across southern and eastern Victoria and eastern Tasmania, and these were relieved at least partially by heavy rainfalls in August and September of 1998. Thus, Australian droughts, at least in the southeastern part, were as per expectation in 1997. Since El Niño weakened after April 1998, the rainfall in succeeding months was excess, as expected.

For India as also for Australia, several workers have noticed effects of factors unrelated to the ENSO phenomenon. In case of India, Himalayan and Eurasian snow covers are reported to have an inverse relationship with IMR (Hahn and Shukla, 1976; Dey and Bhanukumar, 1983; Dickson, 1984). A recent study by Kripalani *et al*. (1996) suggests that the Indian monsoon is better related to snow depth over Russia than to Eurasian snow cover. Shukla and Misra (1977) examined relationships with SST and wind speed over the central Arabian Sea. Relationships with stratospheric wind QBO (Bhalme *et al*., 1986) and with the latitudinal location of the axis of the 500 hPa ridge along 75° E (Krishna Kumar *et al*., 1992) are also reported. Presently, attempts are made to apply statistical models using three types of predictors *viz*., upper air flow over India, heat low development over southern Asia and meridional pressure gradient and cross-equatorial flow over the Indian Ocean and, the Southern Oscillation (Thapliyal and Kulshrestha, 1992). Long range seasonal forecasts for the southwest monsoon rainfall for Indian summer (June to September) are issued by the India Meteorological Department (IMD) sometime in May. For the last few years, this scheme is giving very good predictions for the June-September Indian summer monsoon rainfall.

In Australia, several empirical and modeling studies link SST anomalies in the waters around Australia with rainfall regimes, as seen in "The Australian Bureau of Meteorology Seasonal Climate Outllooks". Wetter years for whole Australia are linked to warmer SSTs in middle and low latitudes and variations of SSTs in the north Australia/Indonesian region are related to rainfalls in eastern Australia (Streten, 1981, 1983; Meehl, 1987; Simmonds, 1990; Allan *et al*., 1990; Lough, 1992 and references therein). Many of these SST relationships, for example for eastern Australia, are related to ENSO influences (Ropelewski and Halpert, 1987, 1989). For rainfall in Queensland, Lough (1992) examined the seasonal SST anomalies off NE Australia (0-30° S, 130° - 180° E) and concluded that the western Pacific cannot be considered as a single region. Part of the area (north-eastern part) varied in association with the central equatorial Pacific (Niño 4 region) and even in the rest of the region, there were spatial differences. Winter rainfall in Queensland was linked more closely with SST variations than with summer rainfall, but both were closely related to ENSO. Earlier, Streten (1983) had reported that cold (warm) SST in the eastern Indian Ocean and SW Pacific in Australasia were related to droughts (excess rains) in Australia. Whet ton (1990) showed a relationship between Australian region SST and Victorian rainfall. Smith (1994) showed from a PCA analysis that the SST in the Indian Ocean was related to the winter rainfall in Australia. For nearby New Zealand, Mullan (1998) found that the SST in the immediate vicinity was correlated to the SST in the Tasman Sea and south Australia and warmer Indian Ocean waters in autumn were followed by wetter conditions in west South Island and drier conditions in other parts of New Zealand.

It seems, therefore, that whereas some El Niño effects have been seen in India and Australia in a spectacular way in the past, there is no guarantee that such effects will always be seen. Trenberth (1997) mentions "flavours" of El Niños. Our classification Unambiguous ENSOW (or the EW of Mooley, 1997) seems to pick a distinct flavour for droughts in India and some parts of Australia. The month of commencement and ending of the El Niño also seem to be of some relevance, as El Niños not coinciding with the rainfall season may not be effective. However, many droughts and floods seem to be unrelated to the ENSO phenomenon and are related to other factors. As such, the anxiety and dramatization showed by the media during El Niño occurrences is not justified.

8. Conclusions

Though El Niños are reported to be associated with droughts in several parts of the globe, notably India and some parts of Australia, the relationship is not one-to-one. Recently, Kane (1997a,b; 1998) noticed that events of the type Unambiguous ENSOW (El Niño years in which the Southern Oscillation Index minima and eastern equatorial Pacific Sea surface temperature maxima occurred in the middle of the calendar year) were associated overwhelmingly with droughts in India and some parts of Australia. Mooley (1997) also reported similar results. In this paper, it is examined whether such events had any connection with the months of commencement and durations of the El Niños themselves. In general, El Niños which were active during the main rainy season were better associated with droughts. However, many other years not having El Niños were also found to be associated with droughts. Thus, the El Niño/rainfall connection seems to be loose.

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