MAUSAM, **55**, 1 (January 2004), 73-88

551.577.37 : 551.513 : 551.526.6 (8)

Precipitation anomalies in the United States associated with a finer classification of El Niño events

R. P. KANE

lnstituto Nacional de Pesquisas Espaciais –INPE,

Caixa Postal 515, 12245-970 - São José dos Campos, SP, Brazil

(*Received 2 August 1999, Modified 8 July 2003*)

सार – इस शोध पत्र में एल नीनो की घटनाओं का परिष्कृत वर्गीकरण करने का प्रयास किया गया है। यह जाँच प्रत्येक वर्ष की गई है कि क्या एल निनो (इ.एन.) और/अथवा दक्षिणी दोलन इंडेक्स एस.ओ.आई. न्यूनतम (एस.ओ.) और/अथवा उष्ण (डब्ल्यू.) अथवा ठंडा (सी.) भूमध्यरेखीय पूर्वी प्रशांत समुद्र सतह तापमान (एस.एस.टी.) है। अनेक वर्ष ई.एन.एस.ओ.डब्ल्यू. वाले वर्ष थे जिन्हें आगे दो समूहों में उपविभाजित किया गया नामतः असंदिग्ध ई.एन.एस.ओ.डब्ल्यू. जहाँ जब एस.ओ.आई. न्यूनतम और एस.एस.टी. अधिकतम कलैंडर वर्ष (मई–अगस्त) के मध्य में देखे गए, संदिग्ध ई.एन.एस.ओ.डब्ल्यू. जहाँ ये स्थितियाँ कलैंडर वर्ष के पूर्वाद्ध अथवा उत्तरार्द्ध में पाई गई एल निनो की अन्य घटनाएँ ई.एन.एस.ओ., ई.एन.डब्ल्यू., ई.एन.सी., ई.एन. प्रकार की हैं। जिन वर्षों में एल निनों की घटना नहीं घटी वे एस.ओ.डब्ल्यू., एस.ओ.सी., एस.ओ., डब्ल्यू.,सी. और अंतिम में (सी.) सभी एंटी एल निनो अथवा ला निना वाले हैं।

भारत की पूरी ग्रीष्मकालीन मानसून वर्षा के असंदिग्ध ई.एन.एस.ओ.डब्ल्यू. अनावृष्टि और बाढ़ के साथ शीत (सी.) से काफी जुड़ी होती है। 1900–90 के दौरान संयुक्त राज्य अमरीका में वर्षा के अनेक क्षेत्र विशिष्ट ई.एन. एस.ओ. संबंध दिखाते हैं किंतु ये संबंध अलग–अलग क्षेत्रों के लिए विभिन्न प्रकार के होते हैं। सामान्यतः (*i*) पश्चिमी संयुक्त राज्य अमरीका/ग्रेट लेक अनावृष्टि और संदिग्ध ई.एन.एस.ओ.डब्ल्यू. (*ii*) पश्चिम के मध्य/मध्य संयुक्त राज्य अमरीका की बाढ़ें और असंदिग्ध ई.एन.एस.ओ.डब्ल्यू. (*iii*) दक्षिणी तटीय मैदान/खाड़ी तट/पूर्वी/दक्षिणी पूर्वी अनावृष्टि तथा संदिग्ध और असंदिग्ध ई.एन.एस.ओ.डब्ल्यू. के बीच इनके अच्छे संबंध होते हैं। ला नीना असंदिग्ध ई.एन.एस.ओ.डब्ल्यू. से काफी विपरीत प्रभावों को दिखाता है किन्तु ऐसा सदैव नहीं होता हैं विशेष रूप से सुदूर पश्चिम में। उसी क्षेत्र में इ.एन.एस.ओ. के प्रभाव प्रमुख वर्षा ऋतु तथा वर्षा ऋतु से पहले और बाद में प्रायः महत्वपूर्ण और विभिन्न (विपरीत) होते हैं। यहाँ अनेक प्रकार के अन्य विवरणों की भी चर्चा की गई है।

ABSTRACT. A finer classification of El Niño events is attempted. Each year was examined to check whether it had an El Niño (EN) and or a Southern Oscillation Index SOI minimum (SO) and or warm (W) or cold (C) equatorial eastern Pacific sea surface temperatures (SST). Several years were ENSOW, which were further subdivided into two groups *viz*. Unambiguous ENSOW where SOI minima and SST maxima were observed in the middle of the calendar year (May-Aug) and Ambiguous ENSOW where these conditions were obtained in the early or late part of the calendar year. Other El Niño events were of the type ENSO; ENW, ENC, EN. Years not having El Niño were of the types SOW, SOC, SO, W, C, the last one (C) containing all Anti-El Niños or La Niñas.

For the all India summer monsoon rainfall, Unambiguous ENSOW were overwhelmingly associated with droughts and the cold (C) events with floods. For the rainfall in USA during 1900-90, several regions showed distinct ENSO relationships, but different for different regions. Generally, there were good associations between (*i*) western USA/Great lakes droughts and ambiguous ENSOW, (*ii*) midwest/central USA floods and unambiguous ENSOW, (*iii*) south coastal plain/Gulf coast/eastern/southeastern droughts and both ambiguous and unambiguous ENSOW. La Niñas showed effects mostly opposite to those of unambiguous ENSOW, but not always, especially in the far west. For the same region, ENSO effects were often substantial and different (opposite) for the main rainy season and the pre and or post-rainy season. Many other details are also presented.

Key words – ENSO, ENW, ENC, SOI, El-Niño.

1. Introduction

The interannual variability of worldwide climate is reported to be intimately related to the strong coupling of the ocean and atmosphere across the equatorial Pacific during El Niño/Southern Oscillation (ENSO) events. Quinn *et al*. (1978) demonstrated the relationship between occurrences of El Niños and Indonesian droughts. Several workers have reported similar relationship for India and USA. Andrade and Sellers (1988) reported ENSO effects on precipitation in Arizona and western New Mexico. Karl *et al*. (1994) mentioned that all regions in the extreme west including Pacific northwest are usually drier than normal during ENSO events, though Bell and Janowiak (1995) argued that the excessive rainfall in the spring of 1993 in the north-central and northwest USA had some links with warmer Pacific SST. Douglas and Englehart (1984) investigated the relationship with rainfall in Florida. Kiladis and Diaz (1989) identified global climatic anomalies associated with the Southern Oscillation. Some parts of USA were also included in their analysis. The strong El Niño of 1982-83 received special attention (Quiroz, 1983; Douglas and Englehart, 1984; Norton *et al*., 1985), as many features associated with the same were abnormal. Ropelewski and Halpert (1986, 1989) reported that for southeastern USA and northern Mexico, the rainfall during October of the El Niño year to March of the following year was above normal for ~80% of the El Niño events. A similar excess rainfall was also noticed in the Great Basin area of the western USA, for the April through October season of the El Niño years. These seasonal results were further refined by Richman *et al*. (1991), who used PCA (principal component analysis) to identify monthly SOI-related patterns. Recently, Montroy (1997) made a very detailed analysis using PCA of sea surface temperature (SST) anomalies in the tropical Pacific to correlate with central and eastern North American precipitation on a monthly basis and identified linear relationships between central and eastern Pacific SST and USA rainfalls, positive for November to March rainfall in southeastern USA and Texas and negative for the January to March rainfall in the region Great Lakes to Ohio River Valley and also negative for the July-August rainfall in southeastern USA. Trenberth (1993) had noticed that all El Niños did not produce the same type of effect (in 1940-41 and 1982-83, California experienced floods, but in 1986-87, there were droughts) and surmised that different El Niños had different 'flavors'.

Most of the workers so far have obtained composites of all warm events, *e.g*., all El Niños (Rasmusson and Carpenter, 1983), or all SOI minima (Kiladis and Diaz, 1989) or all warm events in the Pacific (Mooley and Paolino, 1989). Recently, Kane (1997a,b; 1998a,b) attempted a finer classification of El Niños which showed good relationship with All India rainfall. In the present communication, the behaviour of rainfall in different parts of USA is examined to see whether this finer classification reveals better associations. The methodology used is similar to that of Ropelewski and Halpert (1986) except that whereas they used 24 months data (6 months of the previous year, 12 months of the current El Niño year, 6 months of the succeeding year), in the present analysis, 36 months are used (12 of the previous year, 12 of the El Niño year, 12 of the next year).

2. Data

The data used are the United States historical climatology network - National and regional estimates of monthly and annual precipitation, as given in Karl *et al*. (1994). They selected 877 stations, which were partitioned into 23 groups corresponding to the U.S. climatic regions specified by Karl *et al*. (1988) (Fig. 1). The resulting number of stations per region ranges from 12 in the South Pacific Coastal region, to 88 in the Southern Plains region. Area averages were calculated by equally weighting the totals for each station within a region, while values for whole USA were obtained as are ally weighted average of the regional values. For comparison with USA rainfall data, All India rainfall data (Singh and Sontakke, 1996) were used, mainly because these showed very good relationship with the finer classification of El Niños. All the data used were mainly for the period 1900-91.

3. Finer classification of ENSO events

In literature, the term ENSO is used for the general phenomenon of El Niño/Southern Oscillation. Here, following terminology is used :

EN = Presence of El Niño (warmer waters) at Puerto Chicama (Peru-Ecuador coast) (list of Quinn *et al*., 1978, 1987 and later, visual inspection of the plots).

SO = Presence of minimum in the Southern Oscillation Index SOI, Wright Index or Tahiti minus Darwin atmospheric pressure difference (T-D) (Angell, 1981; Parker, 1983; Wright, 1975, 1984).

W = Presence of maximum (positive anomalies) in the sea surface temperature (SST) in the eastern equatorial Pacific (Niño 3 region), exceeding 1.0° C.

C = Presence of minimum (negative anomalies) in the sea surface temperature (SST) in the eastern equatorial Pacific region (Niño 1+2 and Niño 3 region). All La Niñas mentioned by various workers are included here.

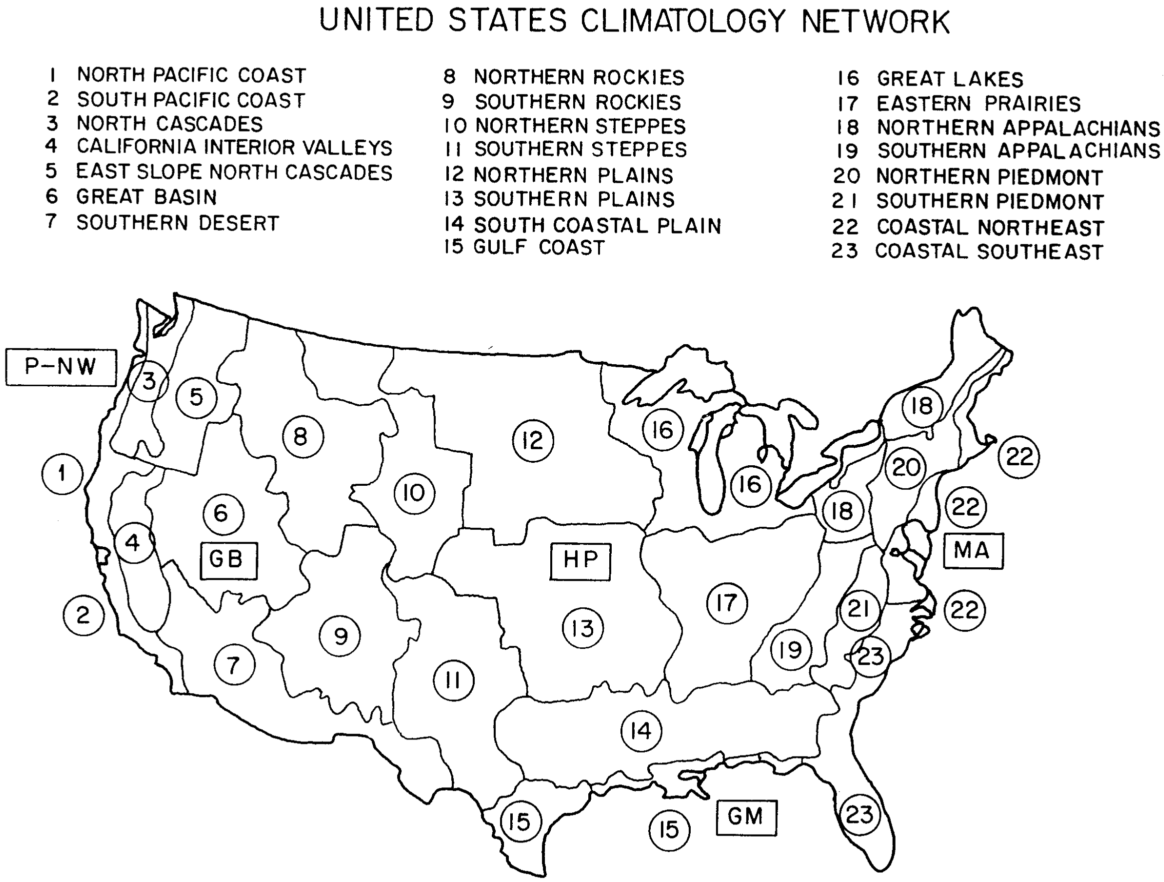


Fig. 1. Map of USA showing the 23 climatic regions (Karl *et al*. 1988). Regions used by Ropelewski and Halpert (1986) *viz*. Pacific-Northwest (P-NW), Great Basin (GB), High Plains (HP), Gulf and Mexican region (GM) and Mid-Atlantic (MA) are roughly indicated

Various combinations of these are considered. Of major interest are events of type ENSOW, where El Niño (EN) existed (Quinn *et al*., 1978, 1987), SOI was minimum and, eastern equatorial Pacific SST was warmer (W). The 12-monthly running means of SOI and SST are 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 extremes SOI and SST were in the earlier or later part of the year (not in the middle), the events were termed as ENSOW-A, *i.e*., Ambiguous ENSOW. Kane (1997a,b) has shown that the Unambiguous ENSOW are overwhelmingly associated with droughts in India and southeastern Australia. Other events were labeled as ENSO, ENW, in which case the El Niño existed at Puerto Chicama, but only one of the conditions SOI minima or W existed, not both (dephasing mentioned by Deser and Wallace, 1987), while ENC meant an El Niño was seen in the earlier part of the year, followed by a C (La Niña, cold event). Other years not involving El Niños were classified as (*i*) SOW, which means SOI minima (SO) existed, equatorial eastern Pacific temperature was warmer (W), but there was no El Niño mentioned in the Quinn *et al*. 1978, 1987, (*ii*) SO, where only SOI minima existed, (*iii*) W, where only central Pacific was warmer, (*iv*) SOC, where SO was in the early part of the year, followed by a C in the later part and (*v*) C, the cold events (La Niñas). Years not classified under any of the categories EN, SO, W or C are termed as non-events.

For the period 1900-90, the classification used is shown in Table 1.

4. Procedure of analysis

The procedure of analysis and the type of results expected are illustrated first by using the Indian rainfall data. In the case of the USA data, values for all months

TABLE 1

Distribution of the years 1900-90 in various categories. Symbols S (Strong), M (Moderate), W (Weak) indicate the strengths of the El Niños involved. I and II indicate first and second years of double events (1957-58, etc.). R, K, P indicate that these were selected as warm events by Rasmusson and Carpenter (1983), Kiladis and Diaz (1989) and Mooley and Paolino (1989). K* and P* indicate that these were selected as cold events by Kiladis and Diaz (1989) and Mooley and Paolino (1989)

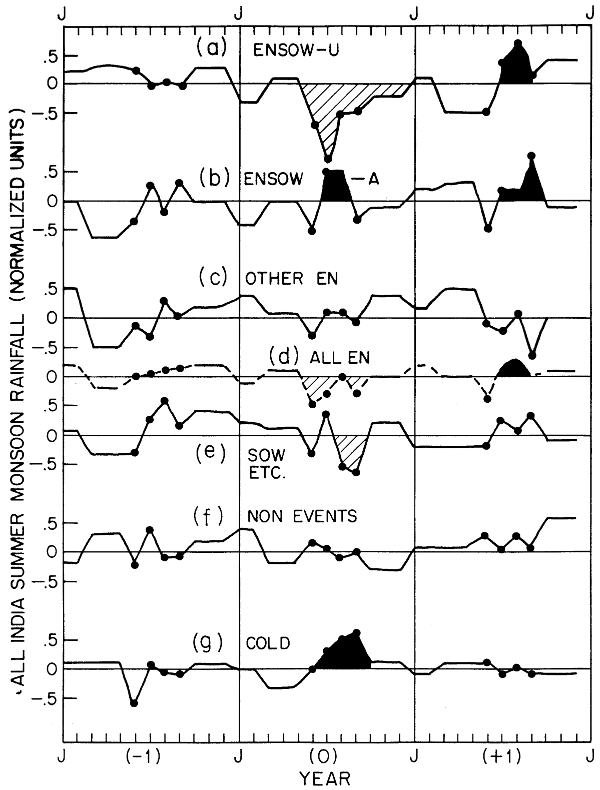
Unambiguous ENSOW	Ambiguous ENSOW	Other El Niños	SOW etc.	Non events	C La Niña
M 1902 RKP	M 1914 R	S 1912 ENSO	1904 SOW KP	1901	1903 K*P*
M 1905 R P	M 1919 II	M 1929 EN	1913 SOW KP	1915	1906 K*P*
S 1911 RKP	M 1923 RK	S 1932 EN	1944 SOW	1937	1908 K*P*
S 1918 I RKP	S 1925 I RKP	M 1939 EN	1977 SOW	1945	1909
M 1930 I RKP	S 1926 II	M 1943 EN	1979 SOW	1947	1910
S 1941 II R P	M 1931 II K*	M 1907 ENC	1920 W K*	1952	1916 K*P*
M 1951 RKP	S 1940 I P	S 1917 ENC	1968 W P	1966	1921
S 1957 I RKP	W 1948 P	S 1927 ENC	1986 W K	1978	1922
M 1965 RKP	M 1953 RK	S 1973 ENC	1959 SO	1980	1924 K*
S 1972 I RKP	S 1958 II	Total = 9 events	1974 SO	1981	1928 K*
S 1982 KP	W 1963 KP		1935 SOC	1984	1933
M 1987	W 1969 RKP		1936 SOC	1985	1934
Total = 12 events	M 1976 RKP		1946 SOC P*	1989	1938 K*
	S 1983 II P*		1949 SOC K*	1990	1942 K*
	Total = 14 events		Total = 14 events	Total = 14 events	1950
					1954 K*
					1955 P*
					1956
					1960
					1961
					1962
					1964 K*P*
					1967 P*
					1970 K*P*
					1971
					1975 K*
					1988
					Total = 27 events

were available. However, for the Indian data, values were available for JF, MAM, June, July, August, September and OND. The major Indian rainfall occurs during the summer months June, July, August, September (average ~900 mm); but year-to-year variations are considerable. Here, deviations from mean are expressed as fractions of the standard deviations (normalized values), separately for each month. The normalised values are indicated by symbols also; +, – indicating positive and negative deviations within 0 and ± 0.5 σ; f, d for ± 0.5 to ± 1.0 σ and F, D for deviations exceeding 1.0 σ, in magnitude.

5. Indian rainfall deviations for various types of years

Indian rainfall deviations for various types of years *viz*. Unambiguous ENSOW, Ambiguous ENSOW, Other EN, events not involving El Niños, Non-events and C (La Niña) events were examined, for 3 consecutive years, with the year of event in the middle. Detailed tables are not, shown here but are similar to those shown in Kane (1997a, b). The following characteristics were noted :

(*i*) In the Unambiguous ENSOW group, there was a profusion of (–, d, D) *i.e.*, droughts. The average for this group showed large negative (normalised) deviations, –0.7, –1.3, –0.5, –0.5 for June, July, August, September. Such large negative deviations were not seen in the averages of the groups Ambiguous ENSOW or other EN. Thus, Unambiguous ENSOW have a distinct edge over other types of El Niños, for causing droughts in India. If all types of El Niños are considered together, effects are not so prominent.



Figs. 2(a-g). All India rainfall anomalies, 36 consecutive monthly values, where the middle 12 months refer to the type of event involved, (a) Unambiguous ENSOW, (b) Ambiguous ENSOW, (c) Other El Niños, (d) All El Niños, (e) SOW etc., (f) Non-events and (g) Cold (C) events, La Niñas. Positive anomalies are shown black and negative anomalies, hatched

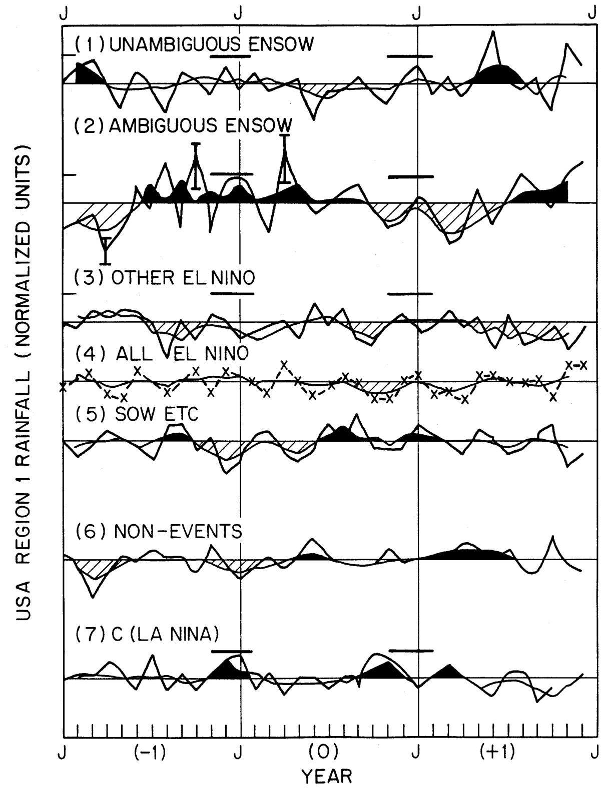


Fig. 3. Same as Fig. 2, for region I (North Pacific Coast) of USA

(*ii*) In the Ambiguous ENSOW group, the symbols were mixed.

(*iii*) In the group SOW etc., there was some indication of significant negative deviations in August-September for some events, which was reflected in the averages being –0.5, –0.6. Thus, some events of this type (El Niño not reported, but SOI negative and or central Pacific SST above normal) can also cause droughts in India.

(*iv*) In Non-events, all types of symbols were seen. Thus, droughts or floods (even severe, F or D) can occur even when ENSO is not involved, indicating the influence of other factors.

(*v*) In C (La Niña) events, there was a profusion of (+, f, F) *i.e.*, floods (excess rains) in August, September, with average values of standardized rainfall deviations +0.5 and +0.6. Thus, C type years are likely to cause excess rains.

Fig. 2 shows the average plots for the for All India rainfall, for various groups (a-g). Large negative deviations (shown hatched) are seen in Fig. 2(a) and Fig. 2(e) in the middle part, indicating occurrence of droughts. There is some indication in Fig. 2(a) that in the following year, excess rains might occur (shown black). Large positive deviations (shown black) are seen in the middle part of Fig. 2(g), indicating occurrence of excess rains during La Niña events.

6. Rainfall anomalies in USA

For some of the 23 regions, the average monthly rainfall was almost equally spread over all the months. However, in many regions, more than 50% rainfall was concentrated in 3-4 consecutive months, termed as the main rainy season, centered mostly in spring or summer or autumn. Only in California, the main rainy season was winter (NDJF). Tables were made for all the 23 regions (Fig. 1) in USA but are not shown here. Only the average plots like those in Fig. 2 are shown. Fig. 3 shows an example, a plot for region 1 (North Pacific Coast) of USA. In some months, the anomalies are large (exceeding 0.5 σ). As mentioned by Montroy (1997), teleconnections can be identified on a calendar monthly basis. However, it

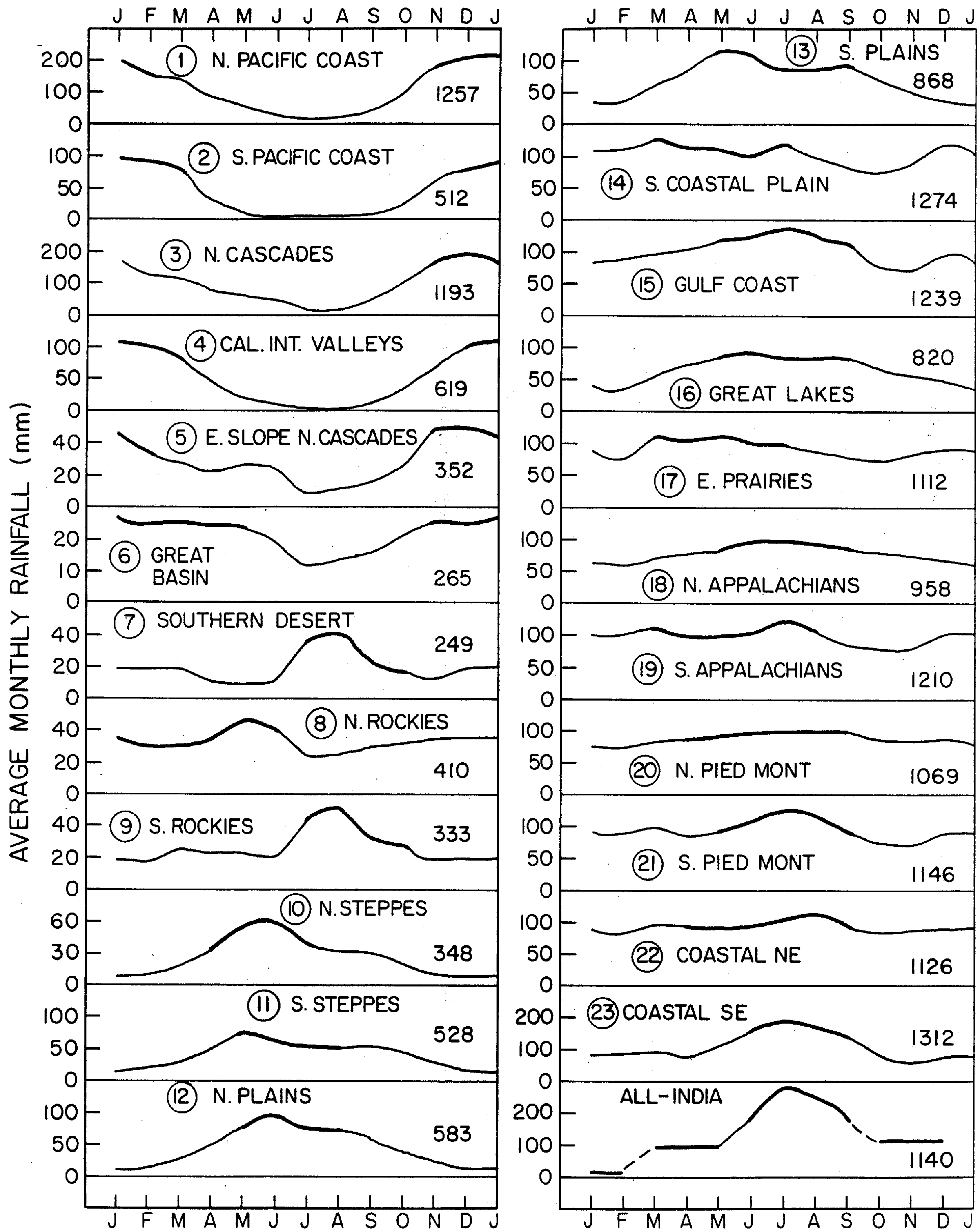


Fig. 4. Climatology (average monthly rainfalls for 1900-91) for regions 1-23 of USA and for All India rainfall

TABLE 2

Average ENSO effects at the 23 locations in USA, during (0) and the pre (–1) and post (+1) rainy seasons of each region, for various types of El Niño events (Unambiguous ENSOW, Ambiguous ENSOW, other EN, SOW etc. and C)

Region number (Rainy season)	Unambiguous ENSOW			Ambiguous ENSOW			Other El Niños			SOW etc.			C La Niños		
	–1	0	+1	–1	0	+1	–1	0	+1	–1	0	+1	–1	0	+1
1 (NDJF)	–		+	–	–	D	–			+			+		
2 (DJFM)	+		f			+	f	–	–	+	+			–	+
3 (NDJ)	–	–	+	–	–	D	–			+			+		–
4 (DJFM)	+	+	+	–	–	–	–		+	F	+		–		+
5 (NDJF)	+			+	d	D	–			–	+	+	+		d
6 (NDJFMAM)	+		–	+	d	d		–			F	+	–		+
7 (JASO)	F	f	F	+		f		+	d	–		f	–		d
8 (JFMAMJ)	F	–	–	d	D	+					+	+	+		–
9 (JASO)	f	F	f	+		F	+	–	D			f	–	–	d
10 (AMJJ)		f	F	–	+	–	f					f	–		
11 (MJJA)	f	f	F	d		+	f		d		F	f	–		d
12 (MJJA)	+	f	F		–	d	f	–	d	f	+	f			–
13 (MJJAS)		+	F	–		+	+		–	+	+	+	–		d
14 (MAMJJ)		d	F		d	f	f	f				f			D
15 (MJJAS)		–	F	–		F	+			+	F	F	–		D
16 (MJJAS)	–	f	F		D	D	f	–	–				+		–
17 (MAMJJ)	–	d	F	–	d	d	f	F	–	+	+	+	+		–
18 (MJJAS)	d	+		f	d	d	+	+	+		+	+			–
19 (MAMJJA)		–	+	–	–	+	f	F			–	+		f	d
20 (AMJJAS)	d	D			d	+			f			+		+	–
21 (MJJAS)	d	–	f	–	d	d	f	f	+	–	+	+		+	d
22 (AMJJAS)		–	F		–	+	+	–	+		–			+	–
23 (JJAS)		d	F		–	F	f	f	d		+				D

seems reasonable to assume that these would extend to 2-3 months at least. Hence, running averages over 3 consecutive months were obtained and are shown as superposed thick lines. Large fluctuations are seen (positives black, negatives hatched), more so in the group of Ambiguous ENSOW (second plot). Thus, this classification indicates a better ENSO relationship with Ambiguous ENSOW for region 1 of USA. The average monthly rainfalls (climatology) for the 23 regions in USA are shown in Fig. 4. In the western part (regions 1-6), the main rainfall occurs during winter months (shown by thicker lines). In Fig. 3, the horizontal lines indicate the main rainy season (NDJF) for region 1. For Ambiguous ENSOW (second plot in Fig. 3), large negative anomalies (hatched markings) are seen in the rainy season and post-rainy season, in agreement with the observation of Karl *et al*. (1994) that the regions in the extreme west of USA are usually drier than normal during ENSO periods. For Unambiguous ENSOW (first plot in Fig. 3) or Other El Niños (third plot in Fig. 3), dry conditions are not seen. As a result, the average plot for all El Niños (fourth plot) does not show discernible dry conditions. Thus, dry conditions occur only for some El Niños, in this case, what we call Ambiguous ENSOW. For La Niñas (cold C events, seventh plot in Fig. 3), there is a slight indication of a reverse effect *viz*. excess rains (black marking) in the rainy season.

In Fig. 4, only regions 1-6 (far west) show winter (November, December, January, February) maxima in rainfall. Regions 7-13 (middle west) and 21, 23 (southeast) show maxima for few months during April-September. All other regions have rainfalls spread more or less over all months. Plots like those in Fig. 3 for north Pacific coast were made for all regions.

6.1. *Specific ENSO effects*

Table 2 shows the average effects observed in the 23 regions of USA, for pre, during and post - rainy season (the rainy seasons are different for different regions, as shown in the first column), for the Unambiguous ENSOW, Ambiguous ENSOW, Other EN, SOW etc. and C events.

The following facts may be noted :

(*i*) The effects for the three groups of El Niños (Unambiguous ENSOW, Ambiguous ENSOW, Other EN) are not alike.

(*ii*) In western USA (regions 1-6, California), the Unambiguous ENSOW and the Other El Niños are not very effective, though the former seem to yield slightly excess rains and the latter slightly negative; but the Ambiguous ENSOW show deficit rains (d, D) during the rainy season, and soon after also. The Unambiguous ENSOW have SOI minima and SST maxima in the middle of the calendar year (MJJA) and their effect probably wanes out by the end of the calendar year. The effects for C (La Niña) are not striking, perhaps because many more events are considered.

(*iii*) In mid-west and central USA (regions 7-13), there is profusion of f and F, indicating a tendency of excess rains during and after the rainy seasons, but only for the Unambiguous ENSOW. For the Ambiguous ENSOW and Other El Niños, the effects are mixed. An exception is region 8 (Northern Rockies) where the prolonged rainy season (January - June) shows deficit rains for both Ambiguous and Unambiguous ENSOW.

(*iv*) In regions 14, 15 (South coastal plain and Gulf coast), both Ambiguous and Unambiguous ENSOW yield deficit rains in the rainy season (summer) and excess rains thereafter.

(*v*) In the vicinity of Great Lakes (regions 16, 17, 18), Unambiguous ENSOW give mixed results in the rainy season (summer) but excess rains thereafter. For the Ambiguous ENSOW, deficit rains occur during and after the rainy season. For other El Niños, results are uncertain, with a slight tendency of excess rains during and before the rainy season.

(*vi*) In the eastern and southeastern part (regions 19, 20, 21, 22, 23), deficit rains occur during and before the rainy season (summer) and excess rains thereafter, for both Ambiguous and Unambiguous ENSOW; but Other El Niños give excess rains before, during and after the rainy season, except for region 23 (coastal southeast) where deficit rains occur after the rainy season.

(*vii*) The events of the SOW type show mostly excess rains throughout USA, especially during and after the rainy season. In contrast, C (La Niña) events show mostly deficit rains, especially after the rainy season.

(*viii*) Most of the large anomalies were associated with ENSOW type events, both Unambiguous and Ambiguous, but different at different regions and could occur during the main rainy season or before or after it.

Summarizing, there are good associations between (*i*) western USA/Great Lakes droughts and Ambiguous ENSOW, (*ii*) midwest/central USA floods and Unambiguous ENSOW, (*iii*) south coastal plain/ Gulf coast/eastern/southeastern droughts and both Ambiguous and Unambiguous ENSOW. La Niñas show effects mostly opposite to those of Unambiguous ENSOW, but not invariably so, especially in the far west.

6.2. *Dependence on the times of commencement and duration of El Niños*

Detailed plots of the SST anomalies at Puerto Chicama during major El Niño events since 1925 were used to locate the commencements and endings of the El Niño events. Some El Niños existed almost throughout the year while some were active only in the first few months and some in the last few months of the calendar year. From these, 3 groups were formed as follows :

Whole year El Niños (13)	:	1925, 1929, 1930, 1940, 1948, 1951, 1953, 1957, 1965, 1972, 1976, 1983, 1987.
First half El Niños (10)	:	1926, 1931, 1939, 1941, 1943, 1949, 1958, 1966, 1969, 1973.
Latter half El Niños (3)	:	1963, 1982, 1986.

Averages for each of 3 successive years were plotted (not shown here). The broad results are listed in Table 3.

In Table 3, the rainy season for regions 1-6 is around NDJF and normally, the end part of the event year is considered. However, for the second group in Table 3 (middle portion referring to El Niños occurring in the first half of the year Jan-Jun), the rainy season considered is the NDJF or DJFM at the beginning of the event year. The first column gives the region number and the main rainy season months (in parenthesis). In other columns, the

TABLE 3

Average ENSO effects at the 23 locations in USA, during (0) and the pre (–1) and post (+1) rainy seasons of each region, for El Niño events lasting during the whole year, first half, and second half of the year

Region number (Rainy season)	Whole Year			First half			Second half		
	–1	0	+1	–1	0	+1	–1	0	+1
1 (NDJF)		–			f		+	f	F
2 (DJFM)	+		+		f	d	F	f	f
3 (NDJ)	+	d			d	+	F	+	f
4 (DJFM)	+				+	–	F	f	f
5 (NDJF)	+	d			d	+	F	f	F
6 (NDJFMAM)	f	d		F	–	d	F	f	F
7 (JASO)	f	f	F	F	f	d		F	D
8 (JFMAMJ)		f	D	F	D	f	f	F	F
9 (JASO)		f	f	F		–	–	F	f
10 (AMJJ)		+	d	–	d		+	f	F
11 (MJJA)		–	f	F	+	–	D	f	F
12 (MJJA)	+	–	+	D			F	F	F
13 (MJJAS)	+	–	+	F	+		D	f	F
14 (MAMJJ)	f	d	F	F			D	–	F
15 (MJJAS)	+	–	F	F		d	D	D	F
16 (MJJAS)	f		+	D			–	f	D
17 (MAMJJ)		d	f	–	f	+	D		d
18 (MJJAS)	f	d		D		–	D	f	D
19 (MAMJJA)	f	d	f		+	d	D	D	F
20 (AMJJAS)	+	d		F	d	–		D	d
21 (MJJAS)		d	F		+	D	D	D	F
22 (AMJJAS)	+	D	F	+		d	D	D	F
23 (JJAS)	f	d	F	+	+	d	d	d	F

ENSO effects are given (droughts d, D; floods f, F; near-normal rainfall +, –) for the corresponding rainy seasons of each region, for the year of El Niño (0), for the year previous to the El Niño year (–1) and for the year next to the El Niño year (+1). The following may be noted :

(*i*) For the first group (El Niños operative throughout the whole year), the rainy season has deficit rains (d, D) in most of the regions and excess rains (f) only in a few regions; but the following year shows mostly excess rains. Thus, single patterns (droughts or floods) are rarely seen; always there are droughts in the rainy season, followed and / or preceded by floods in the pre and post-rainy seasons (or *vice versa*).

(*ii*) For the second group (El Niños in the first half of the year), patterns are mixed. Many two year events (*e.g.*, 1958 in El Niño of 1957-58) are in this group and these yielded excess rains rather than droughts in India.

(*iii*) For the third group (El Niños in the latter half of the year), results are very striking, with a profusion of (f, F) *i.e.*, excess rains in many regions during and after the rainy season. However, this group has only 3 events (1963, 1982, 1986), each with very strong ENSO effects. Trenberth (1993) mentions that California experienced wet conditions in 1940-41, 1982-83 and droughts in 1986-87. Thus, according to Trenberth, this third group contains El Niños of different flavors and hence, the group is not homogenous. The same may be true of the first and second groups as well.

6.3. *Effects during some well-known large El Niño events*

Some well-known large El Niño events (1939-40-41, 1981-82-83 and 1986-87-88) are examined separately. The following was noted :

(*i*) During the event of 1939-40-41, though the main event occurred in 1940, the previous year was not eventless. In 1939, an El Niño occurred in the first half (Jan-Jun). This was associated with deficit rains in many regions. The main El Niño started in January 1940 and

TABLE 4

Years showing positive (+, f, F) and negative (-, d, D) rainfall anomalies in all the regions (1-6)

Positive anomalies				Negative anomalies			
Year	Type	Year	Type	Year	Type	Year	Type
1903	C	1955	C	1907	ENC	1946	SOC
1906	C	1957	ENSOW-U	1911	ENSOW-U	1947	Non-event
1909	C	1966	Non-event	1919	ENSOW-A	1954	C
1913	SOW	1968	W	1923	ENSOW-A	1959	SO
1915	Non-event	1977	SOW	1925	ENSOW-A	1962	C
1931	ENSOW-A	1981	Non-event	1927	ENC	1967	C
1937	Non-event	1982	ENSOW-A	1928	C	1976	ENSOW-A
1942	C			1929	EN	1984	Non-event
				1930	ENSOW-U	1986	ENW
				1938	C	1987	ENSOW-U
						1989	Non-event

lasted up to June 1941 (18 months). In regions 1-11, mostly excess rains occurred, though often interspersed with intervals of deficit rains. In regions 12-15, effects were negligible; but in regions in the east (16-21), deficit rains occurred. In region 22, excess rains occurred and in region 23, patterns were obscure. Thus, in the 1940-41 event, ENSO effects were, excess rains in the west and deficit rains in the east.

(*ii*) During the event of 1981-82-83, 1981 and most part of 1982 were eventless. El Niño started in October 1982 and lasted upto 1983 end (15 months). Yet, the winter of 1981-82 showed considerable excess rains in California, indicating that ENSO is not a necessary condition for excess rains there. In the main event (1982 end and whole of 1983), there were excess rains in almost all regions, though some regions (7, 11, 13, 14, and 17-23) had intervals of deficit rains interspersed. Thus, years of excess rains may be confined to a part of USA, or could be widespread.

(*iii*) During the event of 1985-86-87, 1985 and most of 1986 were a non-event and the main event started only in November 1986, lasting upto November 1987 (13 months). Yet, excess rains occurred in 1985-86 in almost all regions (in some cases, wet followed by dry), indicating again that ENSO was not necessary for excess (or deficit) rains. In the main event of 1987, dry conditions occurred in California (1-6) and in regions 7, 8 and wet, or wet followed by dry conditions in other regions.

Karl *et al*. (1994) mention that all regions in the extreme west including Pacific northwest are usually drier than normal during ENSO periods. This was not invariably true. Glaring exceptions of excess rains like 1940-41 and 1982-83 did occur. For region 2 only (South Pacific Coast), which is nearest to the equatorial eastern Pacific, the following was noted :

(*i*) For Unambiguous ENSOW, from the 12 events, most showed excess rains excepting 1911, 1930, 1987, which showed deficit rains. Thus, Unambiguous ENSOW did seem to pick up excess rains in the South Pacific Coast.

(*ii*) For Ambiguous ENSOW, most of the 9 events showed deficit rains, a glaring exception being 1925. The end part of 1940 showed excess rains; but this was related to the Unambiguous ENSOW of 1941. Thus, Ambiguous ENSOW did not pick up deficit rains in the South Pacific Coast.

7. Events of extreme rainfalls, and inter-region correlations

Whereas the classification Unambiguous ENSOW and Ambiguous ENSOW does seem to pick up categories of differing characteristics, the relationship is not perfect. The problem can be addressed other way round to see what are the characteristics of the years when extreme rainfalls occurred in the different regions. The rainfall status of each region in each year during 1900-91 was examined. Some general features were as follows :

(*i*) The regions 1-6 (far-western USA) had distinctly different characteristics, including the climatology which showed the main rainy season in winter (Fig. 4). In many years, these 6 regions did not show similar anomalies between themselves. In some years, regions 1, 3, 5 were similar to each other and regions 2, 4, 6 were similar to each other; but the two groups showed opposite anomalies. However, in some years all the 6 regions showed similar anomalies. Years showing positive or negative anomalies in all the 6 regions are as shown in Table 4.

(*ii*) In Table 4, from the 15 years of positive anomalies in California as a whole, 5 were C (La Niñas), 4 were Non-events, 3 ENSOW (2 A, 1 U), 2 SOW and 1 W. Thus, cold as well as warm events (including non-events) were associated with excess rains. From the 21 years of negative anomalies, 5 were C (La Niñas), 3 were Non-events, 2 were ENC, 1 was SOC, 1 was EN, 1 was ENW, 1 was SO and 7 were ENSOW (4 A, 3 U). Thus, cold as well as warm events (including non-events) can be associated with deficit rains, though a slight bias for ENSOW events is noticed. Thus, our classification ENSOW etc. is only partially successful in picking the flavors for rainfalls anomalies in California.

(*iii*) In other regions of USA, rainfall was varied and only some nearby regions seemed to have similar anomalies. In regions 7-18 (total 12 regions), 10 or more regions had excess rainfalls in the years 1905 (ENSOW-U), 1907 (ENC), 1908 (C), 1912 (ENSO), 1923 (ENSOW-A), 1935 (SOC), 1957 (ENSOW-U), 1958 (ENSOW-A). Most of these had an El Niño and / or SO and a relationship between warm events and excess rains in regions 7-12 is indicated. There were deficit rains in the years 19.10 (C), 1913 (SOW), 1930 (ENSOW-U), 1933 (C), 1934 (C), 1937 (Non-event), 1952 (non-event), 1956 (C), 1988 (C). Most of these had a C (La Niña) or were non-events and a relationship between cold events and deficit rains in regions 7 -12 is loosely indicated.

(*iv*) In regions 19-23, there was good coherence. In years 1900 (ENSO), 1911 (ENSOW-U), 1914 (ENSOW-A), 1921 (C), 1925 (ENSOW-A), 1926 (ENSOW-A), 1930 (ENSOW-U), 1932 (EN), 1936 (SOC), 1944 (SOW), 1951 (ENSOW-U), 1966 (Non-event), 1968 (W), 1970 (C), 1981 (Non-event), 1988 (C), all these regions had deficit rains and a bias (11 out of 16) towards warm events was indicated, though the association with some La Niñas (C) (3) and non-events (2) also, is disconcerting.

(*v*) All regions 1-23 rarely showed similar anomalies in the same year. Years when 16 or more regions showed excess rains were: 1905 (ENSOW-U), 1906 (C), 1909 (C), 1935 (SOC), 1942 (C), 1958 (ENSOW-A), 1969 (ENSOW-A), 1979 (SOW), 1981 (Non-event), 1982 (ENSOW -U). As can be seen, there are no particular biases for El Niño or C events. Years when 16 or more regions showed deficit rains were: 1910 (C), 1911 (ENSOW-U), 1917 (ENC), 1918 (ENSOW-U), 1925 (ENSOW-A), 1930 (ENSOW-U), 1936 (SOC), 1954 (C), 1956 (C), 1962 (C), 1976 (ENSOW-A), 1984 (Non-event), 1988 (C), again indicating no particular biases for El Niño or C events. Thus, widespread excess rains or droughts in whole USA do not seem to be necessarily related to the ENSO phenomenon as such.

(*vi*) In some years, regions 1-6 showed anomalies similar to regions 19-23 and opposite to regions 7-18.

To check the teleconnections and coherence between the various regions, a correlation analysis was carried out. Based on good intercorrelations, the final groups chosen were :

Region A (1+3+5); B (2+4+6); C (8+10); D (7+9); E (11+12+13); F (14+15); G (16+18+20); H (17+19); I (21+22+23). These were averaged with equal weight, to give the rainfall characteristics of whole USA. The rainfall anomalies for these groups for various types of years (ENSOW etc.) were examined. The following was noted :

(*i*) For the 12 Unambiguous ENSOW, All India summer monsoon rainfall (AI) showed a very good ENSO relationship. However, for the USA regions, only regions E, H, I showed a barely significant relationship with Unambiguous ENSOW, E (Central USA) bias for excess rains and H, I (southeastern USA) bias for deficit rains.

(*ii*) For the 14 Ambiguous ENSOW, AI did not show any significant relationship. For USA, only regions B, C (southwestern USA), showed a slight bias for excess rains.

(*iii*) For 27 C events (La Niñas), AI showed an overwhelming bias for excess rains. For USA, only region C (southern desert and rockies) showed a bias for deficit rains during cold events. Other regions had no significant relationship with cold events.

Since the ENSO relationships for ENSOW etc. are not very strong, extreme rainfall events in each region were examined individually. Table 5 shows the years of ten largest droughts and ten largest floods.

In Table 5, the following may be noted :

(*i*) For the 10 severest events considered when the anomalies are mostly exceeding 1.0 normalised units, a few exceeding even 2.0. For whole USA, the anomalies are between 0.5 and 1.0 units.

(*ii*) In each group of years, all types of events are encountered, indicating that droughts or floods are not confined to ENSO years alone.

TABLE 5

Years of ten largest droughts and ten largest floods with their types (ENSOW etc.), for various broad regions of USA

Region	Drought years	Flood years	Region	Drought years	Flood years
A	1976 ENSOW-A	1973 ENC	B	1976 ENSOW-A	1977 SOW
	1943 EN	1955 C		1923 ENSOW-A	1982 ENSOW-U
	1930 ENSOW-U	1964 C		1930 ENSOW-U	1906 C
	1928 C	1981 Non-event		1975 C	1937 Non-event
	1956 C	1937 Non-event		1912 ENSO	1940 ENSOW-A
	1936 SOC	1915 Non-event		1933 C	1968 W
	1978 Non-event	1942 C		1938 C	1979 SOW
	1919 ENSOW-A	1968 W		1947 Non-event	1951 ENSOW-U
	1914 ENSOW-A	1950 C		1960 C	1905 ENSOW-U
	1923 ENSOW-A	1945 Non-event		1965 ENSOW-U	1913 SOW
	7 EN 3LN	2EN 8LN		5EN 5LN	8EN 2LN
C	1956 C	1941 ENSOW-U	D	1924 C	1915 Non-event
	1924 C	1919 ENSOW-A		1931 ENSOW-A	1908 C
	1973 ENC	1984 Non-event		1985 Non-event	1905 ENSOW-U
	1948 ENSOW-A	1907 ENC		1919 ENSOW-A	1957 ENSOW-U
	1979 SOW	1914 ENSOW-A		1934 C	1975 C
	1952 Non-event	1972 ENSOW-U		1966 Non-event	1967 C
	1922 C	1911 ENSOW-U		1960 C	1923 ENSOW-A
	1934 C	1921 C		1939 EN	1927 ENC
	1953 ENSOW-A	1957 ENSOW-U		1910 C	1982 ENSOW-U
	1910 C	1990 Non-event		1977 SOW	1907 ENC
	4 EN 6 LN	7 EN 3 LN		4 EN 6 LN	6 EN 4 LN
E	1934 C	1915 Non-event	F	1925 ENSOW-A	1975 C
	1976 ENSOW-A	1902 ENSOW-U		1954 C	1900 ENSO
	1936 SOC	1951 ENSOW-U		1917 ENC	1973 ENC
	1901 Non-event	1905 ENSOW-U		1918 ENSOW-U	1946 SOC
	1988 C	1908 C		1924 C	1928 C
	1910 C	1950 C		1930 ENSOW-U	1919 ENSOW-A
	1922 C	1965 ENSOW-U		1962 C	1989 Non-event
	1931 ENSOW-A	1903 C		1902 ENSOW-U	1923 ENSOW-A
	1952 Non-event	1944 SOW		1931 ENSOW-A	1957 ENSOW-U
	1913 SOW	1957 ENSOW-U		1915 Non-event	1979 SOW
	4 EN 6 LN	6 EN 4 LN		6 EN 4 LN	7 EN 3 LN
G	1930 ENSOW-U	1945 Non-event	H	1930 ENSOW-U	1973 ENC
	1963 ENSOW-A	1938 C		1925 ENSOW-A	1989 Non-event
	1964 C	1972 ENSOW-U		1988 C	1920 W
	1939 EN	1902 ENSOW-U		1914 ENSOW-A	1928 C
	1966 Non-event	1989 Non-event		1986 W	1912 ENSO
	1913 SOW	1990 Non-event		1926 ENSOW-A	1909 C
	1923 ENSOW-A	1986 ENW		1954 C	1964 C
	1936 SOC	1975 C		1966 Non-event	1935 SOC
	1988 C	1924 C		1902 ENSOW-U	1961 C
	1910 C	1905 ENSOW-U		1987 ENSOW-U	1901 Non-event
	6 EN 4 LN	4 EN 6 LN		7 EN 3 LN	4 EN 6 LN
I	1925 ENSOW- A	1928 C	US	1930 ENSOW-U	1906 C
	1980 Non-event	1945 Non-event		1954 C	1945 Non-event
	1914 ENSOW-A	1901 Non-event		1925 ENSOW-A	1905 ENSOW-U
	1930 ENSOW-U	1989 Non-event		1956 C	1908 C
	1954 C	1924 C		1976 ENSOW-A	1942 C
	1986 W	1906 C		1988 C	1957 ENSOW-U
	1900 ENSO	1979 SOW		1934 C	1973 ENC
	1911 ENSOW-U	1975 C		1936 SOC	1975 C
	1963 ENSOW-A	1919 ENSOW-A		1910 C	1981 Non-event
	1968 W	1935 SOC		1918 ENC	1982 ENSOW-U
	8 EN 2 LN	3 EN 7 LN		5 EN 5 LN	4 EN 6 LN

(*iii*) The events are divided into two parts. One involves warm events (ENSOW-A or U; ENSO; ENW; EN; SOW; SO; W; even SOC; ENC, though these contain C), and is termed as EN. The other involves cold event (C), but non-events are also included in this part, termed as LN (La Nina). The numbers are given at the bottom of every ten events in Table 5. By these criteria, following relationships are noticed :

(a) Predominantly warm events (7, 8 EN; 3, 2 LN): Droughts in A, H, I; and floods in B, C, F.

(b) Predominantly cold events (3, 2 EN; 7, 8 LN): Droughts in no region; but floods in A, I.

Thus, in regions A (northern California) and I (southeastern USA), droughts are associated with warm events and floods are associated with cold events (including non-events) preferentially. But in regions B (southern California), C (southern desert and southern rockies) and F (south coastal plain and Gulf coast), whereas floods are associated with warm events (opposite to regions A, I, which showed association with droughts), droughts were not associated well with cold events. Thus, some nonlinearity (cold events not showing results opposite to warm events) is probably indicated. In any case, northern and southern California have often dissimilar ENSO effects. Only 1923, 1930, 1976 had common severe droughts and 1937, 1968 had common severe floods in A and B.

8. Predictions : Effects of the 1997-98 El Niño

The Climate Prediction center, NCEP (National Centers for Environmental Predictions), NOAA, Washington, USA issues official operational long-lead seasonal forecasts for temperature and precipitation. The year 1996 was a quiet year. In the February of 1997, an El Niño started and the temperature anomalies in the Peruvian coast soon assumed gigantic proportions, exceeding those of all previous El Niños, including the 1982-83 event which was the strongest till then. For this El Niño, several predictions were made (as given in Barnston, 1996, 1997; Unger, 1996, 1997). Some of these predictions came true, but not all. A major lacuna was about the prediction of the El Niño itself. Glantz (1998) mentions the key points about prediction of the 1997 El Niño as follows: (a) The performance in forecasting the onset of the 1997-98 El Niño was largely mediocre. (b) Dynamical models as yet do not outperform the statistical ones, with respect to forecasting El Niño. Regarding rainfall and other parameters in USA, many abnormal features are attributed to El Niño; but the most obvious symptoms of the recent El Niño, about which there is little doubt, are (1) winter storms along California coast and (2) lots of winter rainfall in Florida. California suffered from heavy rains and some deserts there flowered. In northeast and southeast, heavy snowstorms and rainfalls occurred. Record temperature extremes were noted. In their climate assessment for 1997, Bell and Halpert (1998) mention two features, (*i*) below normal rainfall during March-December, 1997 in central America and the Caribbean Sea and (*ii*) widespread flooding in the Red River Valley of the north-central United States during April 1997, following an abnormally cold and snowy winter. Whether all these could be attributed exclusively to the El Niño, is a moot question. From newspaper and television reports, the striking features reported were the stormy conditions and heavy rainfalls in the South Pacific coast of USA. In the El Niño/Southern Oscillation (ENSO) Diagnostic Advisory 98/2 (11 February 1998) issued by Climate Prediction Center/NCEP of NOAA/National Weather Service, Washington, it is mentioned that the strong ENSO conditions in the tropical Pacific caused pronounced departures from normal in the position and intensity of the jet stream over the North Pacific and North America during January 1998. Storminess increased in intensity and frequency over the eastern North Pacific and over the west coast of USA, causing very heavy precipitation over most of California and later, along the Gulf Coast, over Florida and throughout the Southeast and Mid-Atlantic. A curious question is, why is this pattern not seen in every strong El Niño event? Excess rainfalls were observed in 1940-41 winter in South Pacific Coast but not in the North Pacific Coast, in 1982-83 winter in both North and South Pacific Coast, but in 1986-87, in none of these two.

9. Conclusions and discussion

This work relates to a study of the monthly rainfall values for 1900-91, for 23 regions of United States Climatology Network as given by Karl *et al.* (1994). Using a finer classification of El Niño events, the following was observed :

(a) For each region in USA, 36 consecutive monthly values were considered, 12 for the pre-event (–1) year, 12 for the event (0) year and 12 for the post-event (+1) year. All values were expressed as normalized units (deviations from monthly mean in millimeters divided by the standard deviation for that month in millimeters). To minimize the effect of single monthly erratic values, 3-monthly running averages were calculated.

(b) For AI (All India), the Unambiguous ENSOW (El Niño years in which SOI minima or SST maxima occurred in the middle of the calendar year) composite of 12 events showed a large negative anomaly in the rainy season (JJAS) of the (0) year, indicating a good association with droughts. The C event composite of 27 events showed a large positive anomaly, indicating a good association with excess rains. Similar plots for the 23 regions in USA indicated substantial anomalies, not only in the main rainy season but in the pre and post-rainy seasons also (El Niños causing excess rains in the normally dry months), often of opposite signs. Different regions showed different patterns for Unambiguous and Ambiguous ENSOW (El Niño years in which SOI minima or SST maxima occurred in the beginning or end of the calendar year, not in the middle), indicating different response to different flavors (or mixture of flavors). In a general way, there were good associations between (*i*) western USN Great Lakes droughts and Ambiguous ENSOW, (*ii*) midwest/central USA floods and Unambiguous ENSOW, (*iii*) south coastal plain/Gulf coast/eastern/southeastern droughts and both Ambiguous and Unambiguous ENSOW. La Niñas showed effects mostly opposite to those of Unambiguous ENSOW, but not invariably so, especially in the far west.

(c) From the 26 El Niño events considered, 13 were operative for almost the whole year, and from the other 13, 10 were operative in the first half of the calendar year (Jan-Jun) and 3 in the second half (Jul-Dec). The response of rainfall was not related to these El Niño timings. In fact, in the group of El Niños starting and ending in the latter half, for 2 among the 3 events, the effects were opposite to each other (1986-87 associated with droughts and 1982-83 with floods, in California), indicating that this group certainly did not have a unique flavor.

(d) Even the Unambiguous ENSOW and Ambiguous ENSOW do not have exclusive, unique, separate flavors, though the former is biased to excess rains and the latter, to droughts, in California (regions 1-6).

(e) Based on good intercorrelations between the 23 regional rainfall series, 9 broad regional groups were made as A (Region 1+3+5, Northern California), B (2+4+6, Southern California), C (7+9, Southern Desert and Rockies), D (8+ 10, Northern Rockies and Steppes), E (11+12+13, central USA), F (14+15, South coast and Gulf), G (16+18+20, Great Lakes and Northern Appalachians), H (17+19, Eastern Prairies and Southern Appalachians), I (21+22+23, southeast USA). Only, their main seasonal rainfall was considered. Floods in E; C, D ; C, H were associated with Unambiguous ENSOW, Ambiguous ENSOW, Other El Niños, respectively. Thus, different regions responded to this classification differently. Droughts in H, I were associated with Unambiguous ENSOW only.

(f) Years of ten severest droughts and ten severest floods in each of these 9 broad regions indicated that El Niños were conducive to give droughts in regions A, H, I and floods in regions B, C, F. Note that, A and B (northern and southern California) responded to El Niños generally in an opposite way. La Niñas were conducive to give droughts nowhere in particular but floods in region A, I, opposite to El Niño effect (droughts in A, I).

Thus, some regions showed reasonably good ENSO effects (some droughts, some floods) while others did not show significant relationships. A disconcerting feature was the occurrence of severe droughts or floods in some regions during some non-events, indicating strong effects of origin other than ENSO.

How do the present results compare with those of other workers? In most of the earlier-works, composites are obtained for warm events and cold events and compared with each other; but no further classification is done among the warm or cold events. Hence, the results of the present investigation can be compared only for the group of All El Niños and the C events.

(*i*) Kiladis and Diaz (1989) obtained SOI related composites for cold (SOI maxima) and warm (SOI minima) events. Apart from the results for the Caribbean region, they reported dry conditions over western USA in the SON (-1) season, *i.e.*, of the year previous to the event year. In the present case, from the regions 1-6 of California, the Unambiguous ENSOW showed a negative anomaly for region 2 only, and Ambiguous ENSOW did not show a negative anomaly (instead, shows positive anomalies). Thus, the results of Kiladis and Diaz (1989), an average of such events, are in partial agreement with our findings. For the event year, they reported dry conditions in DJF over southeastern USA. In general, our results differ considerably for the Unambiguous and Ambiguous ENSOW. Hence, whereas some similarities with the results of Kiladis and Diaz (1989) are seen, in details, our results are sometimes different.

(*ii*) Ropelewski and Halpert (1986) formed 24 monthly composite values for several El Niño events (~13) as given by Rasmusson and Carpenter (1983), for several hundred locations in USA. The 24-month series were subjected to a harmonic analysis. The amplitude of the first harmonic indicated the strength of the ENSO signal and the phase indicated the months of strongest response. They identified Gulf and Mexican (GM), Oct. (0) to Mar. (+) and Great Basin (GB), Apr. (0) to Oct. (0) as the regions and seasons which showed positive rainfall anomalies during El Niños. Some indication of a relationship with High Plains (HP) was also there; but Pacific northwest (P-NW) and Mid-Atlantic (MA) did not show significant relationships. Their results agree with ours, especially for Unambiguous and Ambiguous ENSOW.

(*iii*) Montroy (1997) identified some regions in central and eastern USA as having good relationship with tropical Pacific SST. Thus, southeastern USA rainfall, Nov-Mar was reported to have a positive relation with SST. In our case, the positive relationship was confirmed, more so for Unambiguous and Ambiguous ENSOW. For the same region for Jul-Aug, a negative relation was reported. A positive relation was reported for Texas, Nov.-Mar. In our case, Ambiguous ENSOW show a pattern agreeing with that reported by Montroy, while Unambiguous ENSOW agree partially. There is general agreement with the results of Montroy; but more, finer details are revealed.

ENSO is basically a tropical forcing and could itself be complicated. Its effect on the extra tropics would be still more complicated. Trenberth (1993) mentions that in the tropical forcing ENSO, small changes in SST considerably alter the atmospheric convection distribution. Changes in location, extent, and time of year of SST anomalies result in different flavors of El Niño, which may cause differences in tropical rainfall. These are projected onto the changes in tropical heating, causing differences in vertical motion, large-scale overturning, upper tropospheric convergence and divergence, differences in Rossby wave forcing and propagation characteristics of the Rossby waves. Further, these waves propagate through the atmosphere to higher latitudes (extratropics) in a medium which varies with the time of the year, with location (convection relative to planetary waves), and with transients (synoptic eddy activity). Thus, even with the same tropical forcing, extratropical responses could be varied. In addition, a large random component could be added in the tropics. Trenberth (1993) asserts that the extratropical patterns cannot be reliably determined by statistical averages, as the number of examples is not large enough to stratify the ENSO events into subtypes, and the best hope for predicting extratropical effect of any El Niño is from better models (linear planetary wave models or atmospheric GCMs). Recently, Livezey *et al*. (1997) made such an attempt by examining teleconnections between moderate to large SST anomalies (separate composites for positive and negative anomalies) in the central equatorial Pacific Ocean and monthly mean Northern Hemisphere 700 hPa heights and US surface temperature and precipitation. Almost year-round teleconnections were found, with substantial nonlinearity between positive and negative-SST anomalies for 700 hPa heights and US temperatures, but linearity for US precipitation. However, usefulness of these results for individual events is doubtful. Much would depend on the exact location and strength of the ENSO-related PNA (Pacific-North America) or other circulation patterns (Yarnal and Diaz, 1986). According to Bell and Janowiak (1995), the midwest USA floods in June-July 1993 were due to 3 major circulation features, for which ENSO was only an indirect contributor. However, even though extratropical circulation patterns may evolve independently, the inter-El Niño variability may still play an important role (Kumar and Hoerling, 1995). In practical terms, it seems very difficult, if not impossible, to predict exactly how any region of USA will respond during the evolution of any particular El Niño.

Acknowledgements

This work was partially supported by FNDCT Brazil under Contract FINEP-531/CT.

References

Andrade, E. R. Jr. and Sellers, W. D., 1988, “El Niño and its effect on precipitation in Arizona and western New Mexico”, *J. Climatol*., **8**, 403-410.

Angell, J. K., 1981, “Comparison of variations in atmospheric quantities with sea surface temperature variations in the equatorial eastern Pacific”, *Mon. Wea. Rev*., **109**, 230-243.

Barnston, A. G., 1996, “Summary of NCEP's Canonical Correlation Analysis (CCA)”, Optimal Climate Normals (OCN), and coupled model forecasts for U .S. climate. Climate Prediction Center, NOAA/NCEP, Washington, Bulletin 5, Nos. 1, 2, 3, 4.

Barnston, A. G., 1997, “Summary of NCEP's Canonical Correlation Analysis (CCA)”, Optimal Climate Normals (OCN), and coupled model forecasts for U.S. climate. Climate Prediction Center, NOAA/NCEP, Washington, Bulletin 6, Nos. 1, 2, 3, 4.

Bell, G. D. and Janowiak, J. E., 1995, “Atmospheric circulation associated with the Midwest floods of 1993”, *Bull. Amer. Meteor. Soc*., **76**, 681-695.

Bell, G. D. and Halpert, M. S., 1998, “Climate assessment for 1997”, *Bull. Amer. Met. Soc*., **79**, S 1 - S 50.

Deser, C. and Wallace, J. M., 1987, “El Niño events and their relation to the Southern Oscillation : 1925-1986”, *J. Geophys. Res*., **92**, 14189-14196.

Douglas, A. V. and Englehart, P. J., 1984, “Factors leading to the heavy precipitation regimes of 1982-83 in the United States”, In Proceedings of the Eighth Annual Climate Diagnostics Workshop, Downsview, Ontario, 52-54.

Glantz, M. H., 1998, A La Niña Summit : A review of the Causes and consequences of cold events, Executive summary of the workshop held 15-17 July 1998 in Boulder, Colorado, Environmental and Societal group, NCAR, Boulder.

Kane, R. P., 1997a, “On the relationship of ENSO with rainfall over different parts of Australia”, *Aust. Met. Mag*., **46**, 39-49.

Kane, R. P., 1997b, "Relationship of El Niño-Southern Oscillation and Pacific sea surface temperature with rainfall in various regions of the globe", *Mon. Wea. Rev*., **125**, 1792-1800.

Kane, R. P., 1998a, "Extremes of the ENSO phenomenon and the Indian summer monsoon rainfall", *Int. J. Climatol*., **18**, 775-791.

Kane, R. P., 1998b, "El Niño, Southern Oscillation, equatorial eastern Pacific sea surface temperatures and summer monsoon rainfall in India", *Mausam*, **49**, 103-114.

Karl, T. R., Diaz, H. F. and Kukla, G., 1988, "Urbanization: Its detection and effect in the United States climate record", *J. Climate*, **1**, 1099-1123.

Karl, T. R., Easterling, D. R. and Groisman, P., Ya., 1994, "United States historical climatology network-national and regional estimates of monthly and annual precipitation", 830-905. In Boden T. A., Kaiser D. P. Sepanski R. J. and Stoss F. (eds.), Trends'93: A compendium of data on global change. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U. S. A.

Kiladis, G. N. and Diaz, H. F., 1989, "Global climate anomalies associated with extremes in the Southern Oscillation", *J. Climate*, **2**, 1069-1090.

Kumar, A. and Hoerling, M. P., 1995, "Prospects and limitations of seasonal atmospheric GCM predictions", *Bull. Amer. Meteor. Soc*., **76**, 335-345.

Livezey, R. E., Masutani, M., Leetmaa, A., Rui, H., Ming, Ji. and Kumar, Arun, 1997, "Teleconnective response of the Pacific-North American region atmosphere to large central equatorial Pacific SST anomalies", *J. Climate,* **10**, 1787-1820.

Montroy, D. L., 1997, "Linear relation of central and eastern North American precipitation to tropical Pacific sea surface temperature anomalies", *J. Climate,* **10**, 541-558.

Mooley, D. A. and Paolino, D. A., 1989, "The response of the Indian monsoon associated with the change in sea surface temperature over the eastern south equatorial Pacific", *Mausam*, **40**, 369-380.

Norton, J., McLain, D., Brainard, R. and Husby, D., 1985, "The 1982-83 El Niño event off Baja and Alta, California, and its ocean climate context", El Niño North; Niño effects in the eastern subarctic Pacific Ocean. Wooster and Fluharty eds., Washington Sea Grant Program, College of Ocean and Fishery Sciences, University of Washington.

Parker, D. E., 1983, "Documentation of a Southern Oscillation Index", *Meteor. Mag*., **112**, 184-188.

Quinn, W. H., Zoff, D. G., Short, K. S. and Kuo Yang, R. T. W., 1978, "Historical trends and statistics of the Southern Oscillation, El Niño and Indonesian droughts", *Fish. Bull*., **76**, 663-678.

Quinn, W. H., Neal, V. T. and Antunes de Mayolo, S. E., 1987, "El Niño occurrences over the past four and a half centuries", *J. Geophys. Res*., **92**, 14449-14461.

Quiroz, R. S., 1983, "The climate of the 'El Niño' winter of 1982-83 - A season of extraordinary climate anomalies", *Mon. Wea. Rev*., **111**, 1685-1706.

Rasmusson, E. M. and Carpenter, T. H., 1983, "The relationship between eastern equatorial Pacific sea surface temperatures and rainfall over India and Sri Lanka", *Mon. Wea. Rev*., **111**, 517-528.

Richman, M. B., Lamb, P. I. and Angel, J. R., 1991, "Relationships between monthly precipitation over central and eastern North America and the Southern Oscillation", Preprints. Fifth Conf. on Climate Variations, Denver, CO, *Amer. Meteor. Soc*., 151-158.

Ropelewski, C. F. and Halpert, M. S., 1986, "North American precipitation and temperature patterns associated with the El Niño/Southern Oscillation (ENSO)", *Mon. Wea. Rev*., **114**, 2352-2362.

Ropelewski, C. F. and Halpert, M. S., 1989, "Precipitation patterns associated with the high index phase of the Southern Oscillation", *J. Climate*, **2**, 268-289.

Singh, N. and Sontakke, N. A., 1996, "The instrumental period rainfall series of the Indian region : A documentation", Res. Report No. RR-067. Contributions from Indian Institute of Tropical Meteorology, Pune - 411 008, India, p79.

Trenberth, K. E., 1993, "The different flavors of El Niño", Proc. 18th Annual Climate Diagnostics Workshop, Boulder, CO, 50-53.

Unger, D., 1996, "Forecasts of surface temperature and precipitation anomalies over the U. S. using Screening Multiple Linear Regression", Climate Prediction Center, NOAA/NCEP, Washington, Bulletin 5, Nos. 1, 2, 3, 4.

Unger, D., 1997, "Forecasts of surface temperature and precipitation anomalies over the U. S. using Screening Multiple Linear Regression", Climate Prediction Center, NOAA/NCEP, Washington, Bulletin 6, Nos. 1, 2, 3, 4.

Wright, P. B., 1975, "An index of the Southern Oscillation", Climatic Research Unit CRU RP4, University of East Anglia, Norwich, p22.

Wright, P. B., 1984, "Relationship between indices of the Southern Oscillation", *Mon. Wea. Rev*., **112**, 1913-1919.

Yarnal, B. and Diaz, H. F., 1986, "Relationships between extremes of the Southern Oscillation and winter climate of the Anglo American Pacific coast', *J. Climatology*, **6**, 197-219.