MAUSAM,52, 1(January 2001), 57-66

551.526.6 : 551.513.7 : 551.553.21 (540)

El Nino of 1997-1998 and Indian Monsoon

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सार - 1997-1998 के एल नीनो और उसके कारण उत्पन्न हुई भीषण विश्वस्तरीय मौसम विसंगतियों के प्रति विश्व में सभी स्तरों पर विस्तृत रूप से दिलचस्पी उत्पन्न हो गई थी। परिणामस्वरूप संयुक्त राष्ट्र आम सभा ने एक संकल्प (52/200) पारित किया जिसमें मानव समाज और पर्यावरण पर पड़ने वाले एल नीनो के प्रतिकूल प्रभाव को कम करने के लिए समाज और पर्यावरण पर पडने वाले एल नीनो के प्रतिकूल प्रभाव को कम करने के लिए अंतर्राष्ट्रीय सहयोग देने का अनुरोध किया था। यह एल नीनो (उष्ण चरण) अप्रेल-मई 1997 के आस-पास आरम्भ हुआ और दिसंबर 1997 के आस-पास अपनी चरम तीव्रता में पहुँचा तथा मई 1998 के आस-पास यह समाप्त हो गया। लगभग इसी समय ला नीनो (शीत चरण) का आरंभ हुआ जो जनवरी 1999 में अपनी चरम सीमा पर पहुँचा तथा जून- जुलाई 1999 के आस-पास कमजोर पड़ गया और अगस्त 1999 तक जब यह शोध पत्र लिखा गया, इसकी स्थिति मंद बनी रही।

एल नीनो के विकास और उसके क्षीण होने की स्थिति को एस.एस. टी., एस.ओ.आई और समुद्र सतह के नीचे के समुद्र-जल के तापमान के माध्यम से दर्शाया गया है। एल नीनो की चरम अवस्था के लक्षणों को एस.एस.टी., समुद्र स्तर अवदाब, सतह पवन, ओ. एल. आर. और वॉकर परिचालन द्वारा दिखाया गया है। ओ. एल. आर. विसंगति, 850 हेक्टापास्कल क्षेत्रीय पवन विसंगति और समुद्र स्तर अवदाब की विसंगति के पश्चिम से पूर्व की और बढ़ने के स्पष्ट संकेत मिलते हैं। एस.एस.टी. विसंगति की पद्धति से इस प्रकार के क्षेत्रीय आरोह-अवरोह के स्पष्ट संकेत नहीं मिलते हैं।

पूरे एल नीनो की प्रवृत्ति भूमंडलीय है।

1871-1990 तक की 120 वर्षों की अवधि की एल नीनो/ला नीना वर्षों को अखिल भारतीय ग्रीष्मकालीन मानसून वर्षा की विसंगतियों (ए.आई.एस.एम.आर.) सहित तालिकाबद्ध किया गया है। एल नीनो वर्षों में कम वर्षा वाले वर्षों तथा ला नीना वर्षों में भारत में अत्याधिक वर्षा वाले वर्षों के संकेत मिलते हैं। एल नीनों/ला नीना की घटनाओं का 6-12 महीने पहले पूर्वानुमान लगया जा सकता है जिसका उपयोग भारत मौसम विज्ञान विभाग द्वारा जारी किए जाने वाले सरकारी मानसून वर्षा के पूर्वानुमान में किया जा सकता है और इसका उपयोग पूर्वानुमान के एक भाग के रूप में किया भी जा रहा है। केवल एल नीनो पर आधारित अनुमानों के अनुसार यह आशंका व्यक्त की गई थी कि कुछ क्षेत्रों में 1997 का वर्ष अत्याधिक न्यून ग्रीष्मकालीन8 मानसून वर्षा का वर्ष हो सकता है। तथापि जून-सितंबर 1997 के दौरान भारत में वास्तविक वर्षा सामान्य से 2 प्रतिशत अधिक हुई। भारत मौसम विज्ञान विभाग ने "सामान्य" वर्षा (10 प्रतिशत के घट बढ़ के साथ) का अनुमान लगाया था।

ABSTRACT. El-Nino of 1997 – 1998 was accompanied by severe global weather anomalies, which generated widespread interest at all levels in the world. As a result, United Nations General Assembly passed a resolution (52 / 200) urging International co-operation to reduce the adverse impact of El-Nino on human society and Environment. The El-Nino (Warm Phase) commenced around April – May 1997, reached peak intensity around December 1997 and ended around May 1998. La-Nina (Cold Phase) started around this time, reached its peak in January 1999, weakened around June – July 1999 and has continued in its weak phase at the time of writing, August 1999.

Development and decay of the El-Nino are illustrated through SST, SOI and sea-water temperature below the sea-surface. Features during peak period of El-Nino are illustrated through SST, sea-level pressure, surface wind, OLR, and Walker Circulation. There is clear evidence of west-to-east propagation of OLR anomaly, 850 hPa zonal wind anomaly and sea-level pressure anomaly. SST anomaly pattern did not give strong evidence of this type of zonal progression.

El-Nino is global in nature.

El-Nino / La-Nina years during the 120-year period 1871 – 1990 are tabulated along with All India Summer Monsoon Rainfall (AISMR) anomalies. There is evidence of El-Nino years tending to become years of deficit rainfall and La-Nina years being years of excess rainfall over India. El-Nino / La-Nina events, which can be predicted 6-12 months in advance, can be used and are being used as part of the prediction formulae, in the issue of official monsoon rainfall forecast by India Meteorological Department. Based on El-Nino considerations alone, it had been feared, in some quarters, that 1997 might become a year of extreme deficit summer monsoon rainfall. However, the actual rainfall over India during June – September 1997 was 2 % above normal. India Meteorological Department had predicted "normal" rainfall (±10 % of the rainfall).

Key words -El Nino, Monsoon of India, La Nina, ENSO, U.N.concern, Climate predictability, Climate variability.

1. Introduction

El-Nino of 1997-1998 has been one of the severest during the last few decades, comparable in intensity, if not more intense, than the well-known El-Nino of 1982-1983. El-Nino (Warm Phase) started around April-May 1997, reached peak intensity around December 1997 and ended around May 1998. La- Nina (Cold Phase) started around that time, reached its peak in January 1999, weakened around June – July 1999 but has continued at the time of writing (August 1999).

Instrumental records of temperature started in the world, in an organized manner, in 1860. 1998 was the warmest year since 1860, the global temperature anomaly becoming 0.57° C above normal, the normal being calculated on the basis of mean values during the climatological normal period of 1961-1990.

The highlights of global anomalous weather during the warm phase of El-Nino (April 1997-May 1998) taken from WMO (1998, 1999) are briefly given below:

(*i*) The temperatures in the tropical belt were about the highest in the historical instrumental record period since 1860. In Northwestern Coastal Peru and Western Coastal Ecuador, record warm surface temperatures, 3 – 6° C above normal, prevailed during May – December 1997 over most places, nearly missing the cold season altogether. Middle-latitude temperatures were also above normal over a large part of central and western Russia, western Europe, Alaska and the western coastal belts of North, Central, and Southern American Continent.

(*ii*) Indonesia had less than 50 % of its normal rainfall from March through December 1997, dry conditions persisting through early 1998. By July 1997, the drought conditions had become severe, contributing to vast uncontrolled wild fires in Sumatra and Borneo. By mid-August, large areas of tropical rain forests were completely engulfed in fire, lasting for nearly three months. It was an ecological disaster destroying rain-forests and forest creatures. The fire-smoke reduced visibility over large areas, sometimes to less than 100 m, stopping traffic by land, sea and air. Serious respiratory problems attacked a number of persons; these fires resulted in widespread smoke pollution in Southeast Asia, the severest being around Indonesia. This smoke pollution is lingering on till the time of writing (August 1999). Very dry conditions also occurred over Australia and New Zealand, with widespread bush-fires in New South Wales during November 1997. Rainfall deficits were also recorded across northern Brazil and parts of the Amazon basin during June, July and August 1997. Over northern Brazil, rainfall deficits of 180-360 mm were recorded during this period. This deficit rainfall caused reduction in the level of many rivers of the region and also forest fires in the Amazon Basin.

(*iii*) In central Chile (30° S - 40° S) during the May - October 1997 winter rainy season, there was excess rainfall, the total precipitation ranging from 300 - 400 mm in the north to 900 - 1000 mm in the south, giving an excess of 100 - 300 mm throughout the region. Santiago received nearly 700 mm of precipitation compared to a normal of 290 mm; nearly half of the total 1997 rainfall occurred during late May and June 1997 in association with five major winter storms.

(*iv*) From June to October 1997, there was ENSO-related increase and eastward extension of Jet Stream winds and storminess across the Central and Eastern South Pacific to Southern South America. This caused wetter-than-normal conditions throughout parts of Central and Southern South America. ENSO-related strong low level easterly winds across the Central Equatorial Indian Ocean resulted in exceptionally heavy rainfall in Equatorial Eastern Africa during October to December 1997; the three months of heavy precipitation caused flooding, water-logging, crop-damage and disease in the region covering Tanzania, Somalia, Kenya and Ethiopia. The floods also continued in January and February 1998. Extremely heavy precipitation also occurred in

July 1997 throughout Central and Southern Europe, especially over South Poland, Austria, Czech Republic, Slovakia and Eastern Germany. The resulting floods were the worst of the century in the eastern Czech Republic and adjoining areas.

(*v*) Heavy rains and widespread flooding occurred throughout Southern China from July to August 1997; the Yangstze River was in spate. In Hongkong, the monthly rainfall total reached 700 mm figure. During each of the three months June, July and August 1997, with the three-month total rainfall exceeding 2400 mm, which is more than-twice-the-normal rainfal l for the period June to August. South Eastern Asia continued to have above-normal rainfall during August 1997 when five tropical cyclones moved across the region. These systems caused widespread floods in South Eastern China, particularly in its coastal districts. There was also extreme precipitation and significant flooding in the Republic of Korea, in Vietnam, Bangladesh and the Philippines.

(*vi*) In Southern Africa, the rainy season gave normal to above-normal rainfall during October and November 1997, but rainfall during December 1997 was substantially below normal with practically no rainfal l in parts of Southern Mozambique, Zimbabwe and Eastern parts of South Africa.

(*vii*) During 1997, Global Ozone amounts continued to decline with pronounced depletion in the middle and polar latitudes of the Northern Hemisphere. The Ozone Hole during the Antarctic spring (September - October, 1997) was similar in magnitude to those of the recent past years.

(*viii*) The average CO_2 concentration increase at Mauna-Loa (Hawaii, USA) during the 1980s and early 1990s had been about 1.4 to 1.5 ppmv per year. The very strong El-Nino of 1997 appears to have slowed down the increase rate of CO_2 by the middle of 1997.

(*ix*) In January 1998, Canada experienced 80-100 hrs of freezing rain, nearly double the normal number of hours for a whole year.

UN Resolution on El Nino Studies

As the El-Nino (warm event) progressed during 1997 and reports of disastrous weather events came in from different parts of the world and the scientists began to attribute the disasters to the El-Nino, the high-level administrators throughout the world felt concerned. In December 1997 the United Nations General Assembly passed a Resolution (52 / 200) urging international co-operation to reduce the impact of El -Nino phenomenon. In response to that Resolution, a task force of several UN Agencies, led by the secretariat for the International Decade for Natural Disaster Reduction (IDNDR) organised an "International Seminar on El-Nino; Evaluation and Projections". This Seminar was held in Guayaquil, Ecuador, during 9-13 November 1998, It may be mentioned that about a year before the beginning of the El-Nino event, the US Meteorologists had predicted the beginning of the warm El-Nino phase around April-May 1997 (see US Climate Diagnostic Bulletin of April 1996, p. 46). This international Seminar provided a first international platform for a scientific and technical retrospective analysis of the 1997-1998 El-Nino event. This analysis included a global description of the El-Nino/Southern Oscillation phenomenon, an overview of the climate anomalies and their regional impacts, the then prevailing state of climate predictability and application of seasonal prediction to decision-making at government level. Around the time of the Guayaquil International Seminar, Central America, large areas of China, and Bangladesh were reeling from the effects of severe flooding events. During the Seminar, the retreat of the El-Nino (Warm phase) and the onset of the La-Nina (Cool phase) also received some attention. As stated earlier, La-Nina phase started around May 1998, reached its peak in January 1999, weakened around June-July 1999, but has continued in August 1999.

2. Development and Decay of El-Nino of 1997-1998

There are a number of recognized features indicating the beginning, peak, and decay of an El-Nino event. We have used the following three features in determining the start (April-May 1997), the peak (December 1997) and the end (June 1998) of this El-Nino event :

(a) SST

(b) Tahiti-Darwin Pressure Anomaly standardized by the mean annual standard deviation (SOI).

(c) Sea-water temperature below sea-surface.

(a) *SST*

We followed Trenberth's (1997) definition of El-Nino that SST anomaly in region Nino 3.4 (5° N - 5° S, 170° W - 120° W) be +0.4° C or more for at least six consecutive months. By this definition, El-Nino

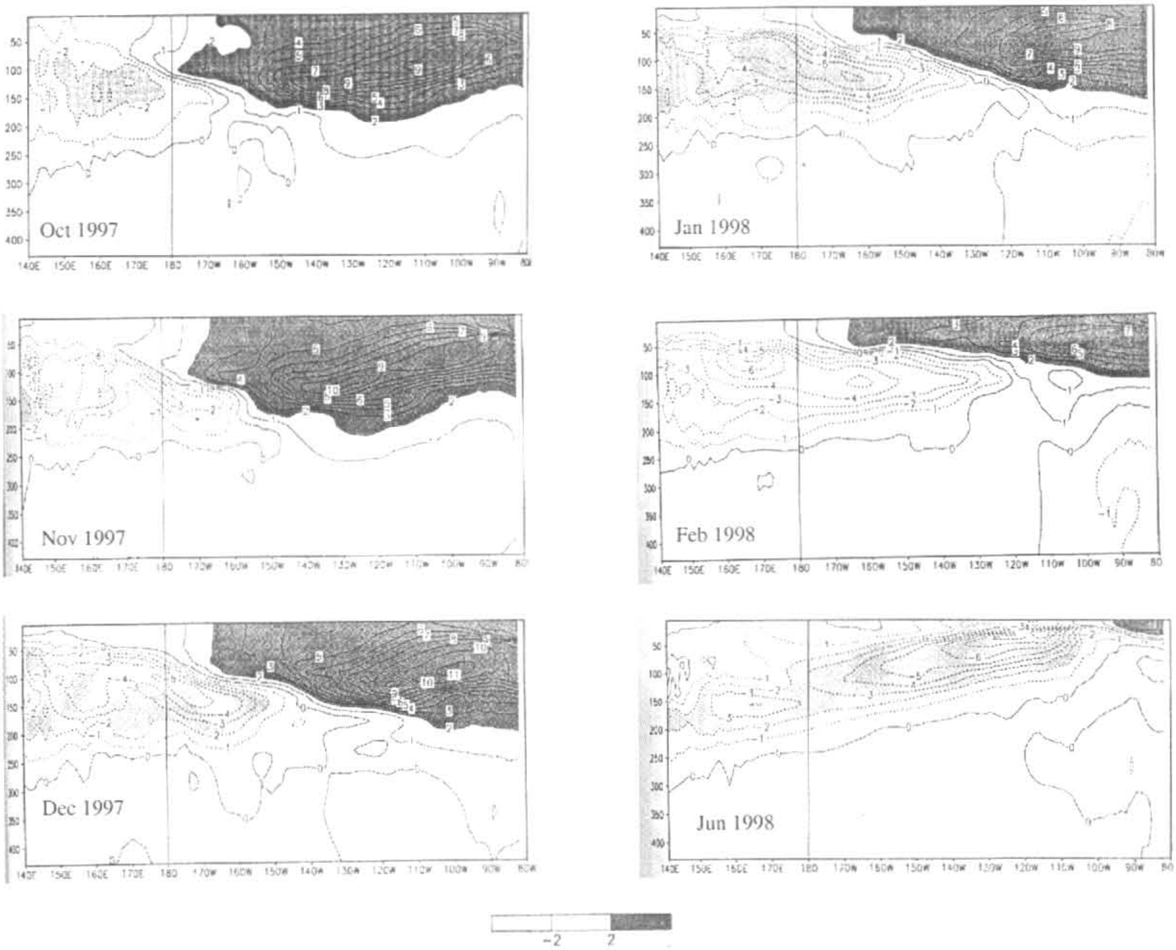


Fig. 1. Depth-longitude section of the Pacific in the equatorial region with temperature anomalies for the months Oct., Nov., Dec. 1997 and Jan., Feb. and June 1998 (USA., Clim. Diag. Bull.)

commenced in April 1997. SST anomaly in Nino 3.4 reached maximum value of 2.9 in November and December 1997; the ano- maly was+0.9 in May 1998 and became -0.7 in June 1998.

(b) *SOI*

Negative values of SOI are indicative of the warm phase of the El-Nino. SOI was positive during January and February 1997. It became negative in March 1997 and remained negative up to and including April 1998. It became positive in May 1998 and remained positive during July, August and September 1998. During the regime of negative values of SOI, the largest negative value (-3.3) occurred in January 1998.

(c) *Sea-water temperature below sea-surface*

Fig. 1, taken from monthly Climate Diagnostic Bulletin of USA, (U.S. Deptt. of Commerce; 1997,1998) shows the sea-water temperature anomalies at and below the sea-surface up to a depth of about 300 m for the months October, November, December 1997 and January, February, June 1998.

The following features are noteworthy: –

(*i*) While the anomalies of the water temperature at the sea-surface were of the order of 3° C, the anomalies of water temperature below the sea-surface were much larger, being of the order of8° C around the depth of 100 m below the sea-surface. During the period January 1997 to August 1998 (not all the months are shown here), the largest value of temperature anomaly between 11° C and 12° C had occurred during December 1997 at a depth of about 100 m below the sea-surface.

(*ii*) Some sea-saw pattern is seen in the depth and intensity of warm and cold water temperature anomalies between east equatorial and west equatorial Pacific. 0° C anomaly line slopes down from west equatorial Pacific to east

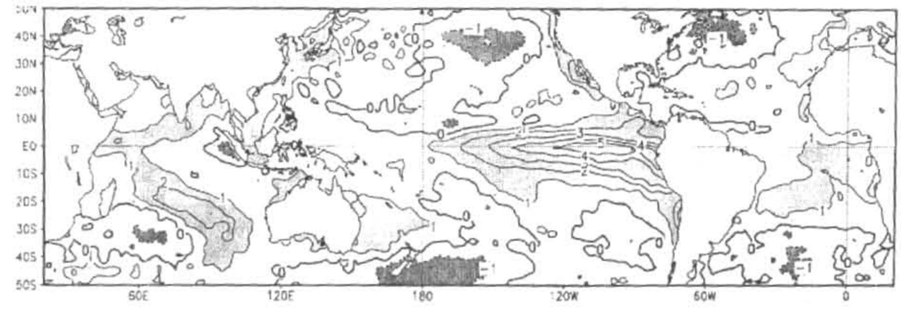


Fig. 2. Anomalous sea surface temperature for December 1997. Contour interval is 1° C. Dashed contours indicate negative anomalies. SST analysis is the OI analysis, while anomalies are departures from the adjusted OI climatology (Reynolds and Smith 1995, J. Climate, 8, 1571-1583. (USA. , Clim. Diag. Bull.)

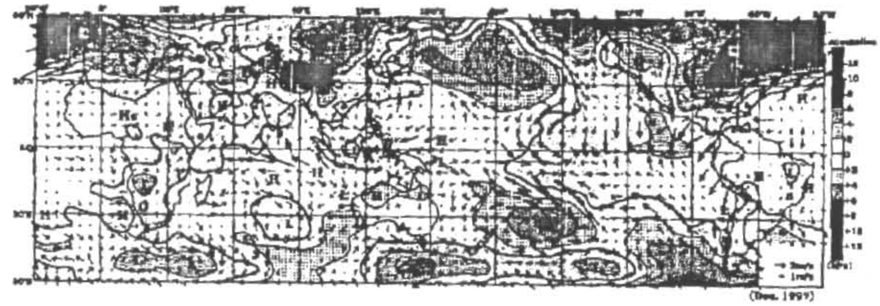


Fig. 3. Monthly mean Sea-level pressure anomaly and surface wind anomaly vector; Contour interval is 2 hPa. for sea level pressure anomalies. Base period for normal is 1988-1996 (Mon. Rep. on Clim. Sys., Japan Met. Ag.)

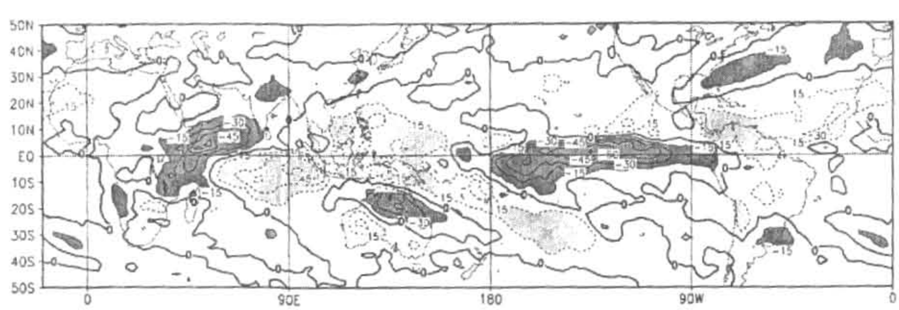


Fig. 4. Anomalous outgoing longwave radiation for Dec. 1997 (NOAA 12 VHRR IR window channel measurement by NESDIS/SRL). Anomaly contour interval is 15 Wm^{-2} with positive values indicated by dashed contours and light shading. Anomalies are departures from the 1979 – 1995 base period monthly means (USA, Clim. Diag. Bull.)

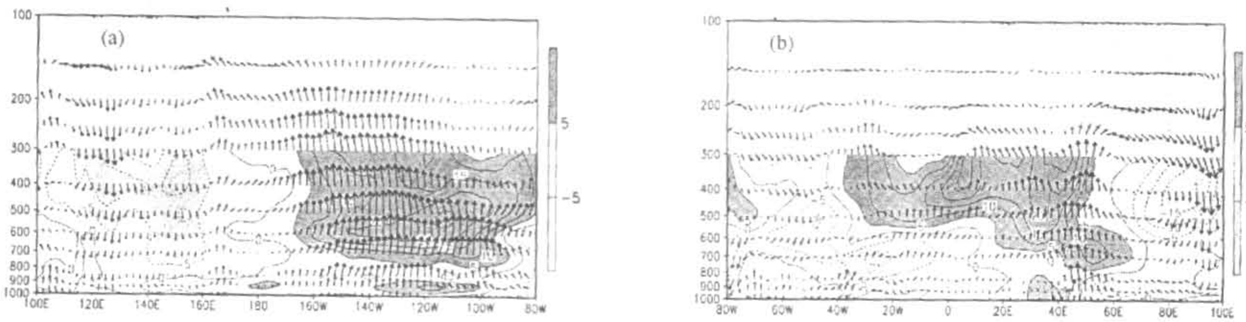
equatorial Pacific during December 1997 (peak of El-Nino) and slopes down in the opposite direction from east equatorial Pacific to west equatorial Pacific during June 1998.

3. Features during peak period of El-Nino around December 1997

Figs. 2, 3, 4 and 5 respectively show the anomaly features during December 1997 in respect of SST, sea-level pressure and surface wind, OLR and Walker Circulation. The following features are noteworthy :

(*i*) *SST*

There is a marked positive SST anomaly along the equatorial east Pacific with maximum contour value of 5° C. This positive anomaly is extending southward and northward along the west coasts of South America and of North America. There are also positive SST anomalies, though very weak of the order of 1° C, along equatorial east Atlantic with extensions along the west coasts of South and North African Continent.



Figs.5 (a&b). Walker circulation anomaly for Dec. 1997: shadings and contours denote relative humidity. (US, Clim. Diag. Bull.)

(*ii*) *Sea level pressure and surface wind (Fig. 3, taken from Japan Met. Agency, 1997)*

Surface pressure anomaly is positive over North Australia and along a belt extending from North Australia to extreme South America across the South Pacific Ocean. There is also another region of positive pressure anomaly extending from northeastern parts of South America to African Sahara across the Atlantic. In between these two positive pressure anomaly regions, there is region of negative pressure anomaly over east equatorial Pacific and central parts of South America. Pressure anomaly pattern suggests that the subtropical anticyclone in the south-east Pacific Ocean, which anticyclone drives the cold Peru current from south, has shifted away southwestwards from the Chile-Peru Coast. That would weaken the cold ocean water advection as well as the cold upwelling along the Chile-Peru coast, leading to warm SST anomalies along Chile-Peru coast. This is supported by both surface wind anomaly and SST anomaly patterns; there is anomalous northerly surface wind along the Chile-Peru coastline. *The southwestward shifting of the seasonal sub-tropical anticyclone away from the Chile-Peru Coast appears to be the immediate principal cause of warm SST anomaly near the Chile-Peru-Ecuador Coasts.*

Also in the near-equatorial region of eastern Pacific, we see confluence of anomalous northerly and southerly surface winds. By themselves, these anomalous winds would produce accumulation of ocean surface waters and downwelling in the near-equatorial region. In the presence of seasonal surface easterly winds, which cause the seasonal upwelling and cooling in the near-equatorial region of the eastern Pacific, this anomalous confluence of surface winds will cause positive SST anomaly in this near-equator region of the eastern Pacific.

(*iii*) *OLR anomaly pattern*

The OLR anomaly pattern shows negative values of considerable magnitude over equatorial central and eastern Pacific, indicating enhanced convection over this area which also has large positive SST anomaly. There is also negative OLR anomaly over extreme North Australia and adjoining ocean region indicating enhanced convective activity. Between these two regions of negative OLR anomaly (equatorial central and eastern Pacific on one side and extreme North Australia and adjoining ocean on the other side), there is a strip of positive OLR anomaly over what may be called SPCZ region.

In a zone extending from coastal eastern Africa to the southern tip of India, there is negative OLR anomaly indicating enhanced convection. As stated earlier, the region of coastal eastern Africa had persistent unusually heavy rains towards the end of 1997 and beginning of 1998.

(*iv*) *Walker Circulation*

The wind data in this section are averaged for the latitudinal belt 5°N-5°S. Shaded areas denote relative humidity anomalies. Broadly speaking, there is anomalous upward motion in east Equatorial Pacific between 160° W and 180° W. This upward limb of the anomalous Walker Circulation splits up into two streams, one to the east and the other to the west. The eastern part descends down near longitude60° W (Amazon Basin in Brazil) while the western part descends down near longitude 120° E (Indonesia). Relative humidity anomalies are positive in the region of

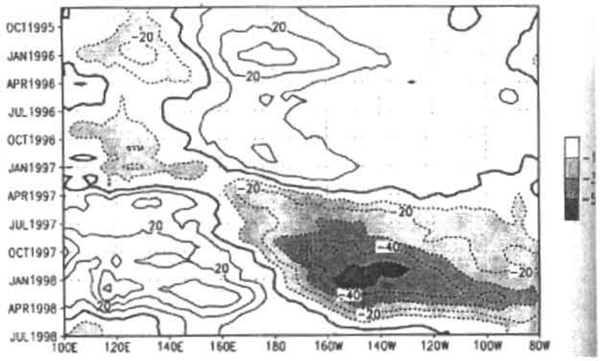


Fig. 6. Time-longitude section of anomalous OLR for 5° N- 5° S. The data are smoothed temporally by using a 3-month running average. Contour interval is 10 Wm^{-2}. Dashed contours indicate negative OLR anomalies. Anomalies are departures from the 1979-1995 base period monthly means (USA,Clim. Diag. Bull.)

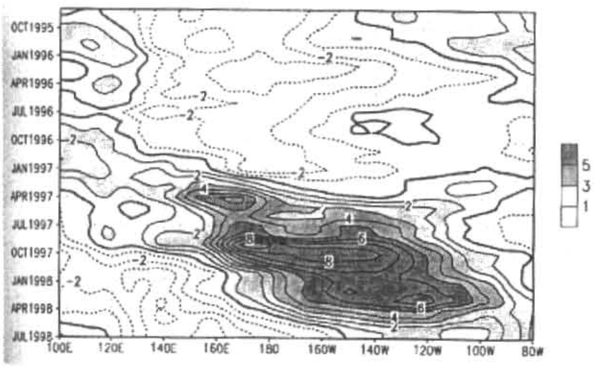


Fig. 7. Time-longitude section of 850 hPa zonal wind (CDAS/Reanalysis) for for 5° N- 5° S. The data are smoothed temporally by using a 3-month running average. Contour intervals is 1 ms^{-1}. Dashed contours indicate easterly anomalies. Anomalies are departures from the 1979-1995 base period monthly means (USA, Clim. Diag. Bull.)

anomalous upward motion and negative in the region of anomalous downward motion. This pattern is quite consistent with the patterns of SST anomaly and OLR anomaly. Weather was also unusually dry in Amazon Basin and in Indonesia during December 1997, accompanied by devastating forest fires. *Thus the anomalies in Walker Circulation give a very clear physical picture connecting SST anomalies, OLR anomalies and weather anomalies.*

There is also anomalous upward motion over the region 30° E - 60° E matching with anomalous heavy rains over Coastal Eastern Africa.

4. East-west progression of El-Nino anomalies

Figs. 6, 7 and 8 taken from US monthly Climate Diagnostic Bulletin, show the time-longitude sections of

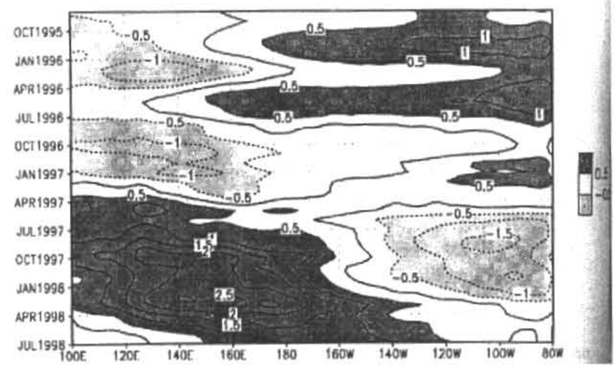


Fig. 8. Time–longitute section of anomalous sea level pressure (CDAS/Reanalysis) for . 5° N- 5° S. The data are smoothed temporally by using a 3-month running average Contour interval is 0.5 hPa. Dashed contours indicate negative anomalies. Anomalies are departures from the 1979-1995 base period monthly means (USA, Clim. Diag. Bull.)

monthly mean anomalies of OLR, 850 hPa zonal wind, and sea-level pressure respectively. Theses sections give mean values for 5° N - 5° S after smoothing of the data by using a 3-month running average. The *x*-axis covers the entire Equatorial Pacific from 100° E – International Date Line – 80° W. *y*-axis is the time co-ordinate from October 1995 – July 1998. Anomalies are departures from 1979 – 1995 base period monthly means. The following features are noteworthy :

(*i*) OLR anomaly pattern (Fig. 6) shows clear evidence of eastward progression of negative anomalies followed by positive anomalies from April 1997 to January 1998.

(*ii*) Fig. 7 shows pattern of 850 hPa zonal wind anomaly. Dashed contours represent easterlies while continuous contours represent westerlies. Anomaly pattern clearly shows eastward progression of westerly wind anomaly from October 1996 up to February 1998. Westerly wind anomaly increased to a maximum intensity of about 8ms^{-1} over Central Equatorial Pacific around October 1997.

(*iii*) Sea Level Pressure anomaly pattern (Fig. 8) does give a suggestion of west-to-east progression particularly over Central Equatorial Pacific.

OLR anomaly, 850 hPa zonal wind anomaly, and sea-level pressure anomaly all show good evidence of their progression from west to east during the build-up of warm phase of El-Nino of 1997-98. SST anomaly pattern, not presented here, did not give strong evidence of zonal progression during this event. Similar were the results of Ji *et al.* (1996) in their observational and model simulations of El-Nino events during 1980s and early 1990s.

TABLE 1

Normalized AISMR during El-Nino / La-Nina years (period : 1871 – 1990) (Source: Kripalani and Kulkarni, 1997)

El-Nino Year		La-Nina Year	
Year	AISMR	Year	AISMR
1877	-3.0	1886	+0.3
1880	-0.4	1889	+0.9
1884	+1.0	1892	+1.7
1887	+0.6	1898	+0.4
1891	-0.7	1903	+0.1
1896	-0.3	1906	+0.4
1899	-2.7	1908	+0.5
1902	-0.7	1916	+1.2
1905	-1.6	1920	-1.6
1911	-1.4	1924	+0.1
1914	+0.5	1931	+0.3
1918	-2.4	1938	+0.7
1923	-0.3	1942	+1.3
1925	-0.6	1949	+0.6
1930	-0.6	1954	+0.4
1932	-0.6	1964	+0.8
1939	-0.7	1966	-1.3
1941	-1.5	1970	+1.0
1951	-1.3	1973	+0.7
1953	+0.8	1975	+1.3
1957	-0.8	1978	+0.7
1965	-1.7	1983	+1.2
1969	-0.3	1988	+1.3
1972	-2.4		
1976	+0.1		
1982	-1.4		
1987	-1.9		

5. Summer monsoon rainfall of India in relation to El-Nino of 1997-1998

(a) *Association between El-Nino and Indian summer monsoon rainfall*

El-Nino/Southern Oscillation is known to have association with Indian summer monsoon rainfall with restricted prediction value. Some of the El-Nino elements are used as parameters in the 15-parameter model (Gowariker *et al.*, 1989) in the official long-range forecast of monsoon rainfall in India by India Meteorological Department. Strong El-Nino (Warm Phase) over East and Central Equatorial Pacific is popularly associated with weak monsoon conditions over India. Kripalani and Kulkarni (1997) reviewed the earlier work published on the subject of association between El-Nino / La-Nina events in the Equatorial Pacific and the Indian summer monsoon rainfall during the 120 – year period 1871 – 1990. Table 1 taken from Kripalani and Kulkarni (1997) shows the years of El-Nino and La-Nina events during the 120 – year period and also anomalies of All–India–Summer–Monsoon – Rainfall (AISMR) normalized in units of standard deviation of the rainfall.

It will be seen that there is some relationship but not one-to-one correspondence between El-Nino / La-Nina events and the Indian monsoon rainfall. In fact, we do not and should not expect one-to-one correspondence. The reasons are given below :

(*i*) El-Nino warm episode has the period of the order of 1 – year from its beginning to its end.

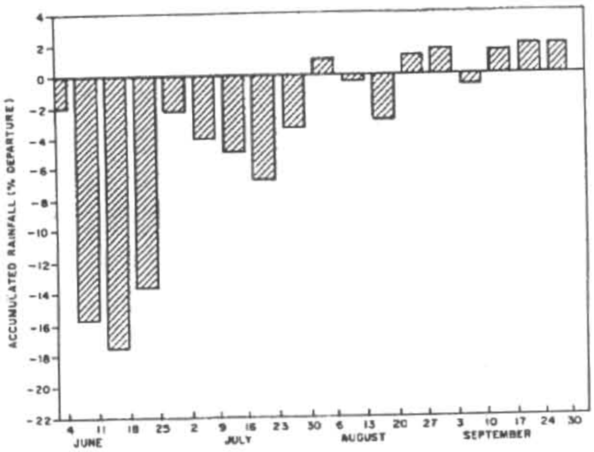


Fig. 9. Weekly accumulated percentage departure of area weighted rainfall of India, June-Sept. 1997. (India Met. Deptt. Clim. Diag. Bull.)

Indian summer monsoon rainfall is counted over a period of four months (June - September) The peak periods of El-Nino and of Indian summer monsoon rainfall do not coincide; they may have no common overlapping period even.

(*ii*) It is now known that in addition to 3 – 4 year El-Nino Oscillation in Equatorial Pacific, there are also inter-decadal oscillations (Zhang *et al.*, 1997) and perhaps even centennial oscillations in oceanic and atmospheric conditions over the Equatorial Pacific. They are all interacting with one another, in a way not yet understood.

(*iii*) The summer monsoon rainfall over India is related to a number of geophysical phenomena like SST over the Indian ocean, temperatures over Eurasian land mass, snow cover over Central Asia, Circulation Index over the northern hemisphere, sun-spots, etc. El-Nino of the equatorial Pacific is only one of these geophysical phenomena.

(*iv*) Logically, we should find physical relationships in addition to statistical relationships, between El-Nino over Equatorial Pacific, summer monsoon rainfall over India and other associated geophysical phenomena.

(b) *Long range forecast of 1997 summer monsoon rainfall over India*

Occurrence of a strong El-Nino event during 1997 had been predicted by US scientists about a year in advance. Going by general impression that strong El-Nino is associated with weak monsoon conditions in India, a fear had arisen in some quarters that India might suffer from extreme deficit rainfall during June – September 1997. As stated earlier, India Meteorological Department includes some of the elements of El-Nino for long-range monsoon rainfall forecasting. Keeping these and other conventional prediction methods in view, India Meteorological Department issued the following forecast for Indian Summer Monsoon (June – September 1997) rainfall, on 25 May 1997, on the basis of Parametric and Power Regression Models :

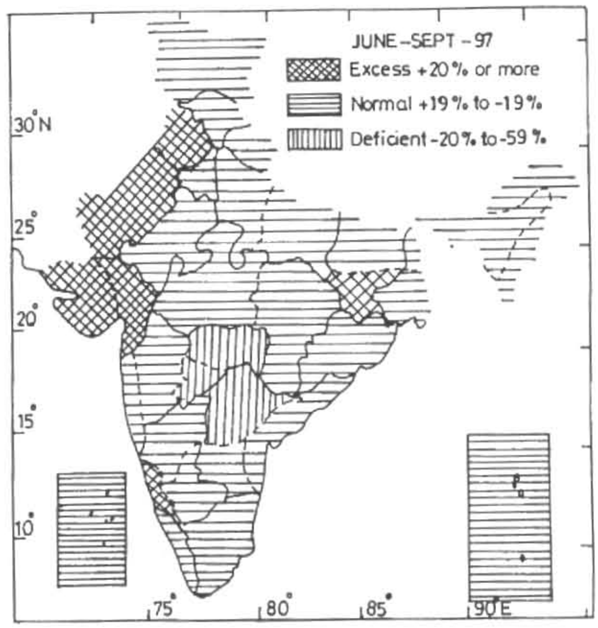


Fig. 10. Sub-divisionwise seasonal rainfall percentage departure for June-Sept. 1997. (India Met. Deptt. Clim. Diag. Bull.))

(*i*) In 1997, the southwest monsoon rainfall over the country is likely to be normal, the normal being defined as rainfall within ±10 % of its long period average value making the year 1997 the tenth normal monsoon year in succession.

(*ii*) Quantitatively, the rainfall for the country as a whole for the entire monsoon season (June to September) is likely to be about 92% of its long period average value within the model forecast error limit of ± 4 %. Thus it will be on the negative side of the long period average.

The actual rainfall for June to September 1997 was 102 % of the normal rainfall, details given below.

(c) *Actual rainfall over India*

Fig. 9 taken from India Meteorological Department (1997) shows the Cumulative Area Weighted Rainfall

(CAWR) of India, week by week, during the period June – September 1997.

The following feature is noteworthy :

During the first three weeks of June, the cumulative rainfall remained 10 – 13% below normal. Rainfall peaked up in the end of 3 June 1997 and recovered substantially to remain only 2% below normal in the beginning of July. It remained 2 – 5 % below normal throughout the month of July. It remained nearly normal during August and slightly above normal during September. At the end of September 1997, June – September rainfall closed at 2% above normal. Fig. 10 taken from India Meteorological Department shows sub-division-wise rainfall over India during the season 1 June to 30 September 1997.

6. Conclusions

(*i*) El-Nino of 1997 – 1998 excited considerable widespread interest in the world for special studies on El-Nino, Climate Variability and Climate Prediction.

(*ii*) El-Nino (Warm Phase) commenced around April – May 1997, reached its peak intensity around December 1997 and ended around May 1998, which was immediately followed by La-Nina, which had continued in its weak phase in August 1999.

(*iii*) Development and decay of this El-Nino event could be clearly seen through SST, SOI, sea-water temperature below the sea-surface, sea-level pressure, lower tropospheric zonal wind, OLR, and Walker Circulation. West – east propagation of anomalies could be seen in most of the indicator parameters.

(*iv*) Years of El-Nino (Warm Phase) tend to be years of less-than-normal summer monsoon rainfall over India, while the reverse happens for La Nina years. Other geophysical phenomena also influence Indian summer monsoon rainfall.

(*v*) While El-Nino is identified by warm temperature anomalies of 2 – 3° C at the sea-surface along relatively narrow strip of Central and Eastern Equatorial Pacific, this is only a small – scale weak manifestation of a deeper and more intense form of warm anomaly in sea-water temperature a few hundred meters deep. This oceanic anomaly appears to be intimately connected with the atmospheric anomaly in position and intensity of the quasi-stationary sub-tropical anticyclones, particularly the one in the lower troposphere, over Southeast Pacific oceanic region. Although seen prominently over the Equatorial Pacific, the phenomenon of El-Nino is global in nature.

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