Proc. Indian Acad. Sci. (Earth Planet. Sci.), Vol. 102, No. 1, March 1993, pp. 219–239.

Interannual variability of monsoons in Malaysia and its relationship with ENSO

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Abstract. Interannual variations of the monsoons have been studied utilising homogeneous rainfall records of 41 years (1951–1991) from Malaysia and upper air data of stations in Asia, Australia and Western Pacific. Sources of upper air data are U.S. Department of Commerce and Kuala Lumpur Northern Winter Monsoon Activity Centre. Extreme wet and dry years have been identified and the influence of ENSO on Malaysian annual rainfall has been discussed. Influence of ENSO on the performance of northern summer and winter monsoons has also been studied from Malaysian rainfall data. Further, regional circulation patterns associated with El Nino and La Nina years have also been identified. No linear trend has been found in the annual rainfall of 16 stations in Malaysia. Most El Nino years are associated with below median and La Nina years with above median rainfall at most stations in Malaysia. ENSO has greater influence over East Malaysia than peninsular Malaysia. Interannual variability of rainfall with reference to ENSO conditions has been discussed in details. Also, circulation features have been identified to foresee El Nino/La Nina events.

Keywords. Monsoons; interannual variability; La Nina; El Nino; BMSO.

1. Introduction

Since the early 80s climate change and global warming have become the topic of serious discussion not only within the scientific community but also the general and the international political communities. In view of this development, there have been many research studies on global warming and climate change.

In Malaysia, several studies related to climate change have also been conducted. The more notable studies are by Todovov and David (1982) and Chan and Chong (1989). In the former study, rainfall data of 13 stations from records varying from 48 to 95 years (all ending in 1980) were used. They concluded that annual rainfalls have a high degree of variability, and a decline in annual rainfalls in the 1970 decade had also occurred in the past. In the latter study, a long-term record of temperature in 11 principal meteorological stations in Malaysia was examined. It was found that all the temperature series indicated increasing trends.

Since monsoon is a component of the weather/climate system, it is, therefore, pertinent to examine the interannual variations of the monsoon in the effort to monitor the climate system and it's short term variability. Cheang conducted several studies on this subject relevant to Malaysia in 1984, 1985, 1987, 1988 and 1992. These studies concluded that ENSO was a very important signal in controlling the year to year variation of the northern winter monsoon in south-east Asia. Similar features in the monthly mean circulation patterns over Asia and western Pacific were noted in these studies for the different El Nino years and similarly for the different La Nina years (known as anti El Nino in the above-mentioned studies).

The objectives of this study are:

- To examine the year to year variations of the annual rainfalls in Malaysia during the 41-year period from 1951.
- To identify the extreme wet and dry years during the same period.
- To examine the influence of ENSO on the annual rainfall.
- To examine the influence of ENSO on the rainfall during the northern summer and winter monsoons.
- To examine the monthly mean circulation pattern with respect to El Nino and La Nina years.

2. Data

Validated rainfall data of 16 stations in Malaysia from a homogeneous record of 41 years (1951 till 1991) were used in this study. Rainfall analysis was carried out using percentile values while the median values were used as reference in the computation of annual and monthly deviations.

Monthly mean upper air data of stations in the Asia/Australia/western Pacific for the period from 1968–1984 were taken from the Climatic Statistics published by the U.S. Department of Commerce. The data for the period 1985 till 1991 were taken from the monsoon data set compiled by the Kuala Lumpur Northern Winter Monsoon Activity Centre in Malaysian Meteorological Service. The Centre was established in 1985 in connection with the World Meteorological Organisation Long-term Asian/African Monsoon Project.

3. Interannual variations of rainfall in Malaysia

Annual rainfall data of 16 stations, namely, Alor Star, Bayan Lepas, Ipoh, Sitiawan, Cameron Highlands, Subang, Malacca, Kota Bharu, Kuala Trengganu, Kuantan, Mersing, Kuching, Bintulu, Miri, Kota Kinabalu and Sandakan from a record of 41 years (from 1951 till 1991) were examined to determine whether there was any increasing and decreasing trend during the last 41 years. The location of the stations are shown in figure 1. The yearly deviation from the median value of annual rainfall was computed for each year and each station.

Figures 2a, b, c, d, e and f, show the deviations from median values of annual rainfall for 6 stations in Malaysia. The unshaded bars indicate above median whereas

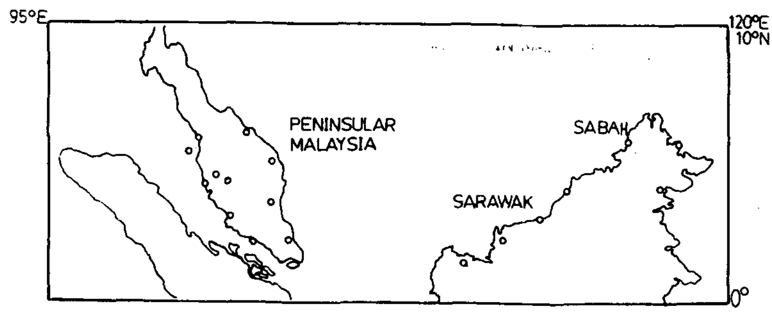


Figure 1. Rainfall stations (○) in Malaysia.

the shaded indicate below median. Figures for the other 10 stations are not shown here. It is difficult to identify any linear increasing or decreasing trend in all the stations during the 41 year period. Nevertheless, the figures reveal the frequent occurrence of a prolonged period (2 to 4 consecutive years) of below or above median annual rainfall. Prolonged periods of above or below median annual rainfall lasting for 5 to 8 consecutive years had also occurred but only in a few stations.

The above analysis shows that there are certain years when many stations recorded similar anomalies, either above or below median annual rainfall. This information is clearly depicted in figures 3a and b which are the spatial and time distribution of extreme annual rainfall of the 16 stations in Malaysia during the 41 year period. This method of presentation follows that of Diaz (1983).

Each box represents total annual rainfall of one station. In figure 3a, the boxes are shaded differently for annual rainfall in three percentile ranges, namely; (i) bottom 5 percentile; (ii) greater than 5 to 10 percentile and (iii) greater than 10 to 20 percentile to show the extremely dry years. An extremely dry year is defined as one when at least two stations recorded annual rainfall in the bottom 20 percentile range.

Similarly, years with annual rainfall in three percentile ranges (i) 80 to less than 90 percentile; (ii) 90 to less than 95 percentile; and (iii) 95 and greater percentile are shaded differently in figure 3b to show the extremely wet years. An extremely wet year in an area is defined as that when at least two stations experienced annual rainfall in the 80–100 percentile range.

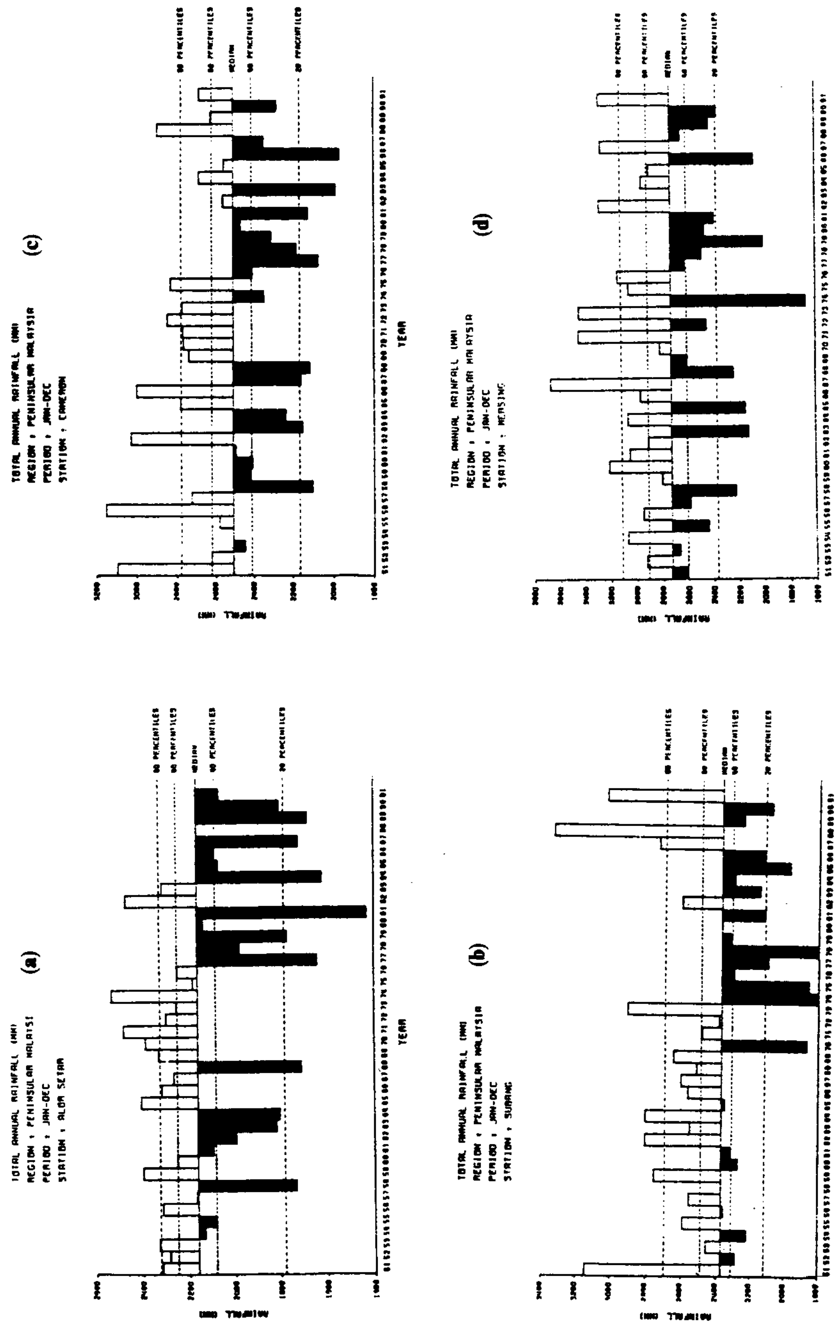
Boxes which are not shaded at all represent annual rainfall values falling outside the above mentioned percentile ranges. It is evident in the figures that the 1951–1956 period was distinctly wet throughout Malaysia with many stations recording extremely wet conditions. From 1957 to 1970, very few stations recorded extremely wet or dry conditions. During the early 70's, wet and dry conditions alternated from one year to the next. From 1977 till 1991, there were more years with many stations recording extremely dry than extremely wet conditions throughout the country. 1984, 1985 and 1988 are the exceptional years during this period. Median annual rainfalls were recorded in 1984 and 1985 at almost all the stations while in 1988 extreme wet conditions were recorded at many stations. It is worth pointing out that during the last 11 years (from 1981 to 1991), there were more dry than wet years in Bayan Lepas, Alor Star, Kota Bharu, Miri and Kota Kinabalu (figure 2). Table 1 shows the extremely wet and dry years and the areas affected.

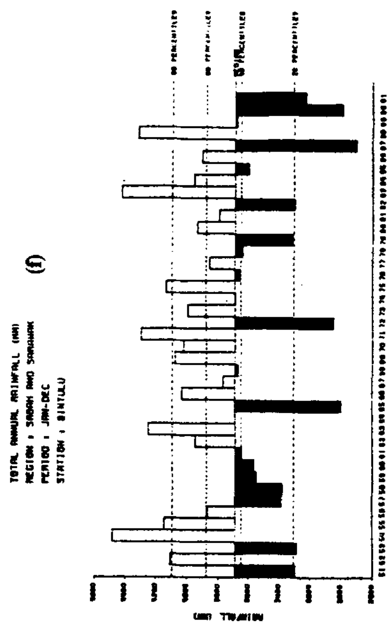
4. Influence of El Nino Southern Oscillation (ENSO) on the annual rainfall

Figure 4 depicts the graph of monthly Southern Oscillation Index (SOI) for the period from 1951 to 1991. The SOI values were obtained from Climate Analysis Centre, U.S.A. The El Nino (with persistent negative monthly SOI values) and La Nina (with persistent positive monthly SOI values) years are indicated as arrows and asterisks respectively in the figure. The historical occurrences of El Nino episodes are taken from Quinn *et al* (1979) while those of La Nina events are based on the work of Zang and Wang (1987).

4.1 *Effect of El Nino on annual rainfall*

It is well known that major ENSO episodes, such as the one which occurred in 1982/83, can lead to massive displacement of rainfall regions in the tropics, bringing


(a)
TOTAL ANNUAL RAINFALL (MM)
REGION : PENINSULAR MALAYSIA
PERIOD : JAN-DEC
STATION : ALOR SETAR
YEAR
(b)
TOTAL ANNUAL RAINFALL (MM)
REGION : PENINSULAR MALAYSIA
PERIOD : JAN-DEC
STATION : SUBANG
YEAR
(c)
TOTAL ANNUAL RAINFALL (MM)
REGION : PENINSULAR MALAYSIA
PERIOD : JAN-DEC
STATION : CAMERON
YEAR
(d)
TOTAL ANNUAL RAINFALL (MM)
REGION : PENINSULAR MALAYSIA
PERIOD : JAN-DEC
STATION : MERSING
YEAR



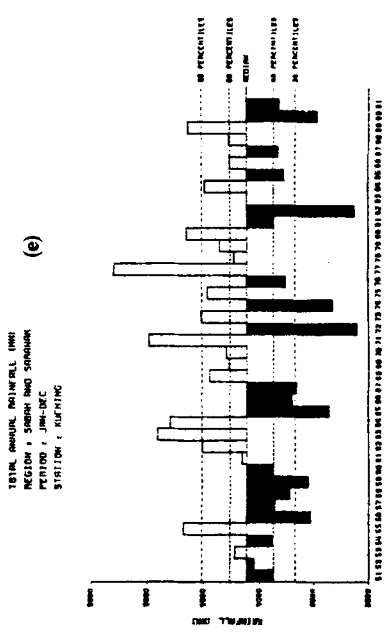


Figure 2. Annual rainfall of 6 stations in Malaysia. Period 1951–1991.

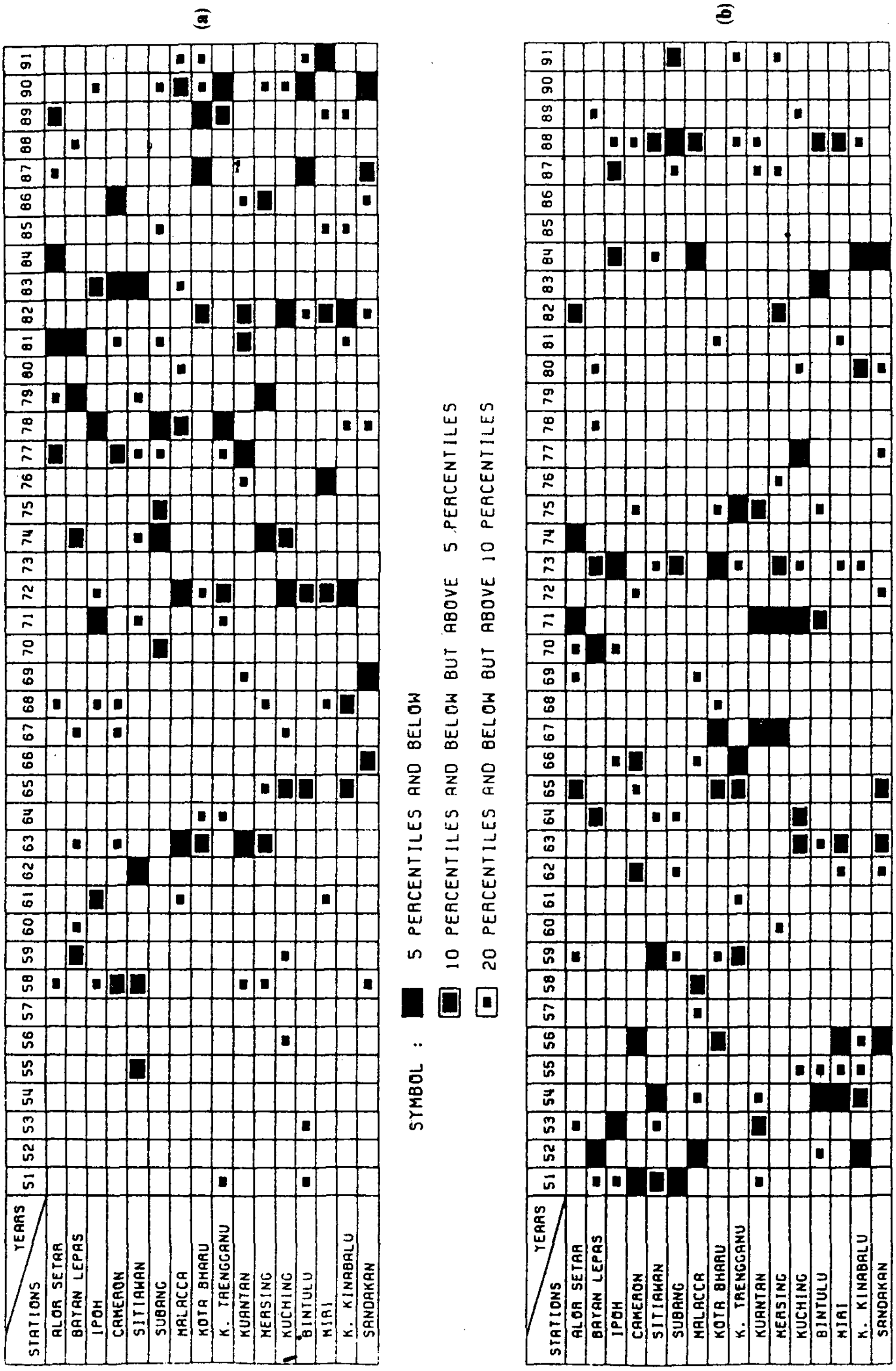


Figure 3. Spatial and time distribution of annual rainfall.

Table 1. Extreme wet and dry years and areas affected.

Areas affected	Extremely wet years	Extremely dry years
Malaysia (both the peninsula and east Malaysia)	1952, 1954, 1956*, 1964*, 1970*, 1971*, 1973*, 1975* and 1988*	1958, 1968, <u>1972</u> 1974, 1978, <u>1982</u> <u>1987</u> and <u>1991</u>
Peninsular Malaysia	<u>1951</u>, <u>1953</u>, 1959 and <u>1965</u>	<u>1963</u> and <u>1977</u>
East Malaysia	1955*, 1963 and <u>1977</u>	<u>1965</u>

*Indicated La Nina years whereas years which are underlined are El Nino years.

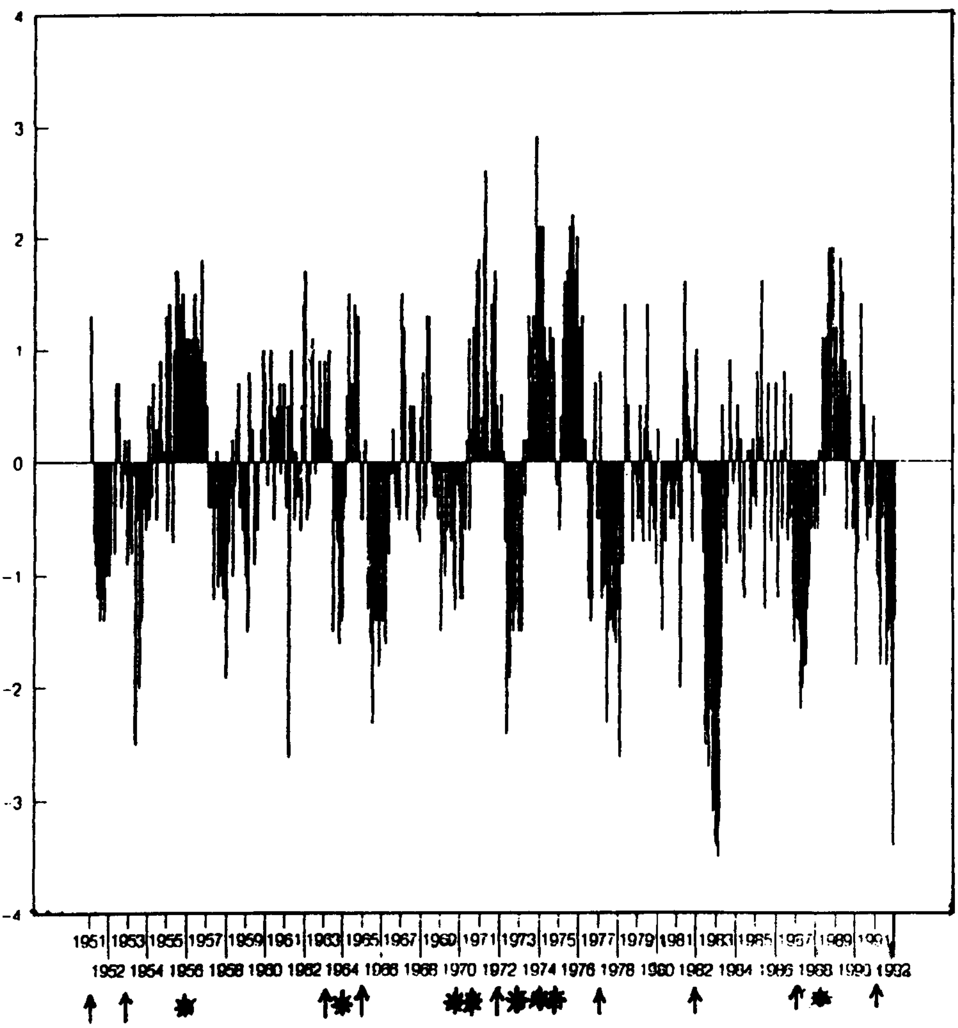


Figure 4. Southern Oscillation Index (SOI).

drought to vast areas and torrential rain to otherwise arid regions. Meehl (1987) and Ropelewski and Halpest (1987) have shown that the El Nino phenomenon is associated with below normal rainfall over northern Australia, Indonesia and Philippines. Since Malaysia is located near this region, it would be interesting to study the effect of ENSO (El Nino and Southern Oscillation) on the rainfall of Malaysia. Of the 12 El Nino years (1951, 1953, 1957, 1963, 1965, 1969, 1972, 1977, 1982, 1986, 1987 and 1991) 7 of them did bring about extremely dry years to many stations over the whole country or peninsular Malaysia or east Malaysia as depicted in table 1. However, 3 other El Nino years, 1951, 1953 and 1957 did not experience extremely dry conditions. In fact, some stations in peninsular Malaysia or east Malaysia recorded, on the contrary, extreme wet conditions during 1951 and 1953 (figures 3a and b and table 1) and almost all the stations did not record any extreme conditions during 1957 (figures 3a and b). In 1965, some stations in peninsular Malaysia recorded extremely wet conditions whereas some stations in east Malaysia recorded extremely dry conditions. In 1977 conditions were contrary to those in 1965.

4.2 *Effect of La Nina on annual rainfall*

The La Nina years are 1955, 1956, 1960, 1964, 1970, 1971, 1973, 1974, 1975 and 1988. Of the 10 years, 8 of them recorded extremely wet conditions at many stations (table 3). In 1960, 14 out of the 16 stations did not record any extreme condition. Only one recorded extremely dry and one recorded extremely wet years (figure 2a and b). In 1974 more stations recorded extremely dry than wet years.

The above analysis shows the complexity in the influence of ENSO on the annual rainfall in Malaysia. This is in agreement with the results of studies by Meijer and Prakash (1988) and Quah (1988). Nevertheless due to the evidence that from a record of 41 years, 7 out of 12 El Nino years did result in extremely dry conditions and 8 out of 10 La Nina years did record extremely wet conditions, it can be concluded that ENSO did exert a certain influence on the Malaysian rainfall. In order to study the anomalies from the normal influence of ENSO and the difference in the areal extent of the influence on the Malaysian rainfall, one has to examine the variation

Table 2. Exceptional years which did not follow the normal influence of ENSO.

1.	El Nino years (many stations recorded extremely wet years)	1951 and 1953
2.	El Nino years (peninsular Malaysia experienced different extreme conditions from those in east Malaysia)	1965, 1969 and 1977
3.	El Nino year (No extreme condition)	1957
4.	Neither El Nino nor La Nina years (many stations recorded extremely dry years)	1958, 1968 and 1978
5.	La Nina years (more stations recorded extremely dry than wet years)	1974
6.	La Nina years (most stations did not record any extremely dry or wet years)	1960
7.	Neither La Nina nor El Nino (many stations recorded extremely wet years)	1952, 1954, 1959 and 1963

of the seasonal rainfall and the variation in the monthly mean circulation of the region.

As pointed out earlier, there are exceptional years which experienced wet or dry condition not following the normal influence of ENSO. These years are tabulated in table 2.

5. Interannual variations of monsoonal rain

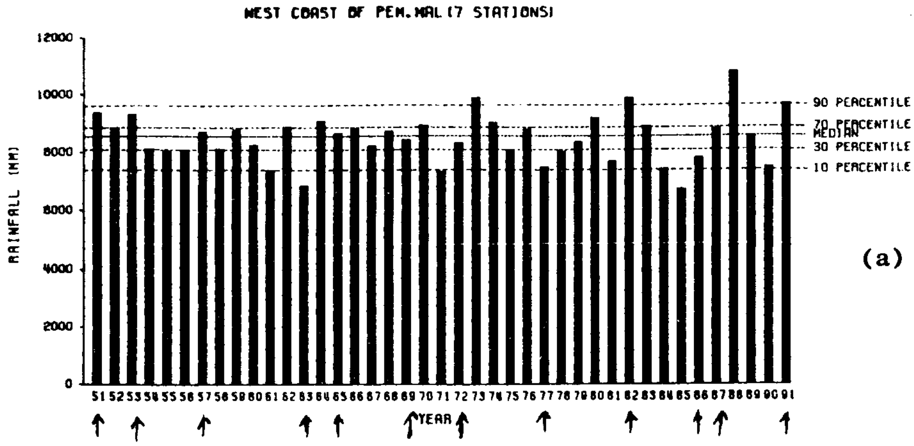
Malaysia experiences two monsoons; namely, the northern summer and winter monsoons (locally known as southwest and northeast monsoons). The former prevails during the period from end of May till September while the latter from November till March (Cheang 1986). The two rainy seasons are from (i) April till May and (ii) October till mid January. In view of this and for the purpose of this study, the total April till September rainfall is considered as the northern summer monsoonal rainfall whereas the total October till March rainfall, the northern winter monsoon rainfall. Figures 5a, b, c, and d are the bar charts for the total summer monsoon rainfall for 7 and 4 stations along the west and east coast of peninsular Malaysia and 2 and 3 stations in Sabah and Sarawak respectively. Similarly figures 6a, b, c and d are the total winter monsoon rainfall for the same stations. In these figures, the 10, 30, 50 (median), 70 and 90 percentile lines are indicated. Values falling within $\pm$ 20 percentiles of median are taken as normal, those greater than 70 and 90 percentiles as above and very much above normal respectively and those below 30 and 10 percentiles are considered as below and very much below normal respectively. Based on these criteria, the states (west coast W, east coast E, Sabah S and Sarawak Sk) represented by the number of stations indicated earlier, affected by above or below normal monsoon during the El Nino and La Nina years are tabulated and discussed in the following sections. States which were affected by very much above and very much below normal monsoon are underlined in the table.

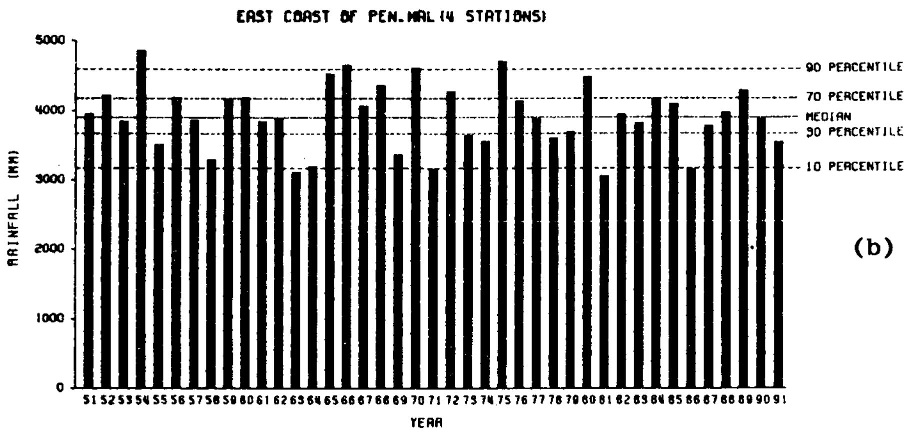
5.1 *Effect of El Nino on winter monsoon rainfall in Malaysia*

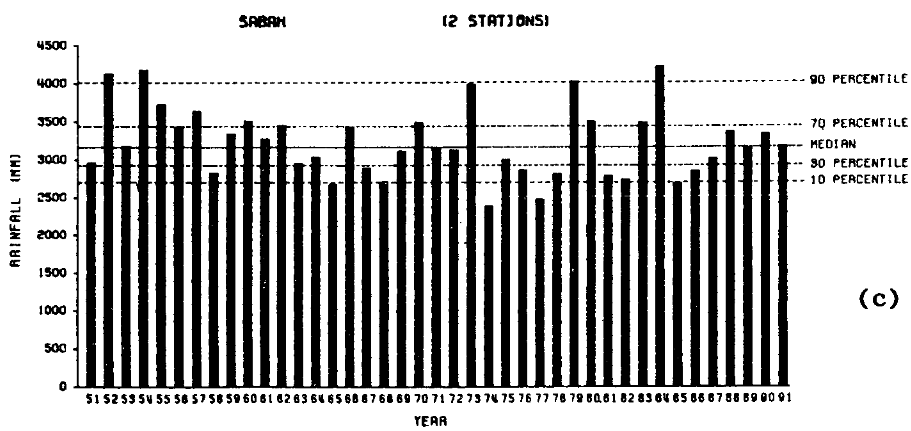
Table 3 below shows that Sabah (S) and Sarawak (Sk) recorded below normal winter monsoon rainfall in almost all the El Nino years except for 1969 and 1987. These two states also recorded below normal summer monsoon rainfall in six out of 12 El Nino years. The other six years 1951, 1953, 1957, 1969, 1987 and 1991 recorded on the contrary, above normal summer monsoon rainfall.

The influence of El Nino on the west (W) and east (E) coast states in peninsular Malaysia was more complex. Both E and W were affected by very much below normal winter monsoon rainfall in the record-breaking El Nino year of 1982. Only E was affected by below normal winter monsoon in 1972 and 1977, whereas only W was affected in 1986 and 1991. The effect was not very clear during the summer monsoon. However, it is worth pointing out that both the states experienced below normal summer monsoon in 1963 and 1986.

1951, 1953, 1957, 1965, 1969 and 1987 are the El Nino years when the effect of El Nino (weaker monsoon) in Malaysia was not clear. In fact during the winter monsoon of 1965 (October 1965–March 1966), very wet condition was recorded in peninsular Malaysia, contrary to the below normal condition observed during the other major El Nino years such as 1972, 1977 and 1982.


WEST COAST OF PEN.MAL (7 STATIONS)
RAINFALL (MM)
YEAR
90 PERCENTILE
70 PERCENTILE
MEDIAN
30 PERCENTILE
10 PERCENTILE
(a)


EAST COAST OF PEN.MAL (4 STATIONS)
RAINFALL (MM)
YEAR
90 PERCENTILE
70 PERCENTILE
MEDIAN
30 PERCENTILE
10 PERCENTILE
(b)


SABAH (2 STATIONS)
RAINFALL (MM)
YEAR
90 PERCENTILE
70 PERCENTILE
MEDIAN
30 PERCENTILE
10 PERCENTILE
(c)

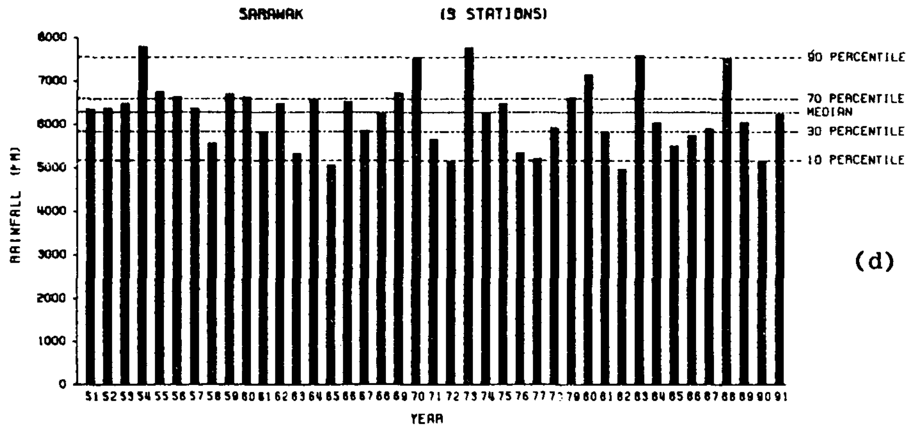
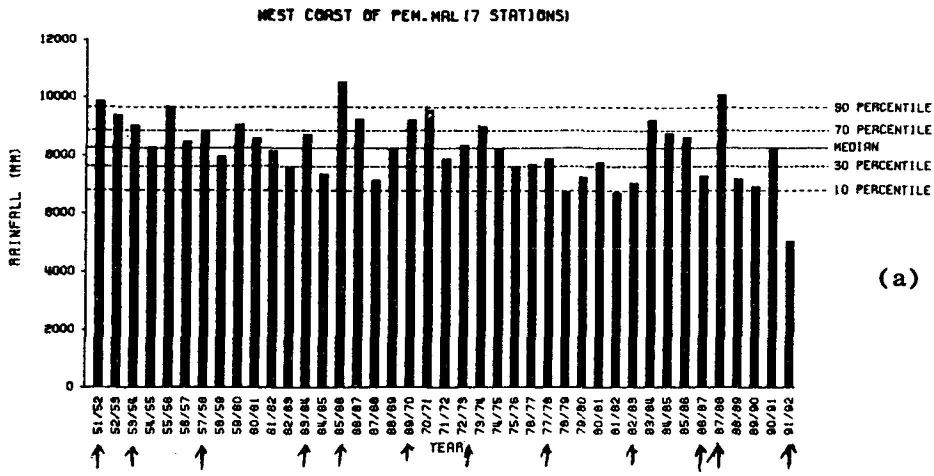
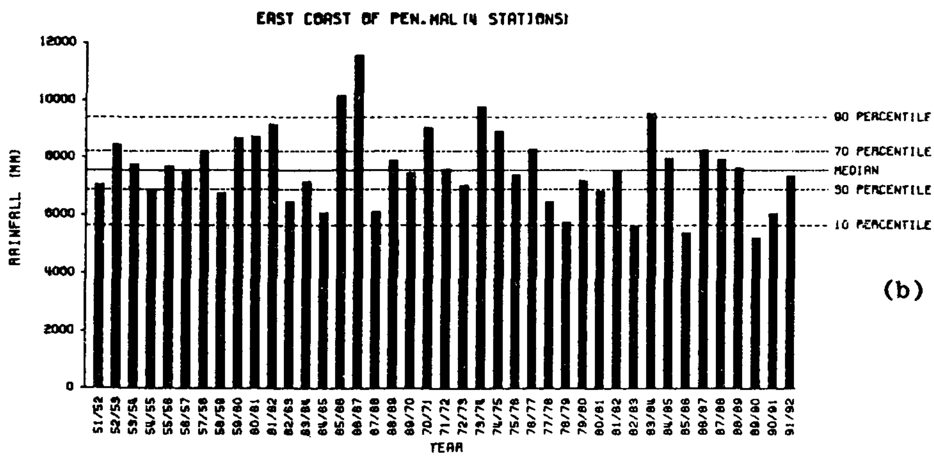
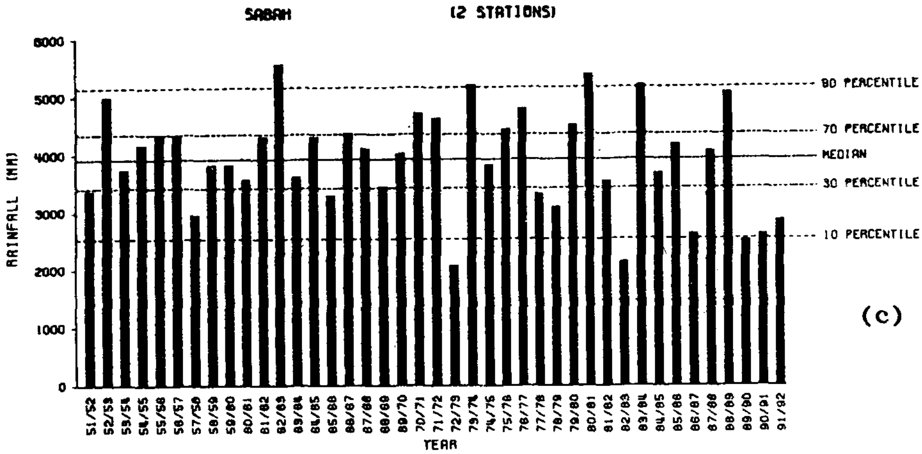


Figure 5. Total seasonal rainfall (MM) Apr–Sep.







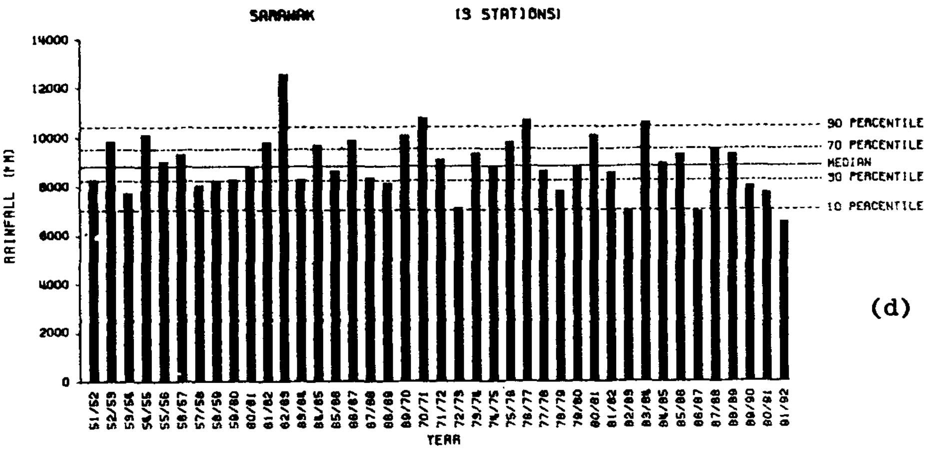


Figure 6. Total seasonal rainfall (MM) Oct–Mar.

5.2 *Effect of La Nina on summer and winter monsoon rainfall in Malaysia*

Table 4 below is similar to table 3 except that it shows the effect of La Nina on the monsoonal rainfall in Malaysia.

In East Malaysia SK recorded above normal summer monsoon rainfall in almost all the 10 La Nina years except for 1971, 1974 and 1975. During the northern winter, S experienced above normal monsoon in almost all the 10 La Nina years except for 1960 and 1974.

In peninsular Malaysia, the effect is again more complex. During the northern summer, there was no consistent picture. As regards to winter monsoon, although above normal rainfall were recorded by both E and W in only 2 out of 10 La Nina years, normal rainfalls were recorded by E in almost all the remaining cases except for 1964 (table 4).

Table 4 depicts clearly that the effect of La Nina on both the summer and winter monsoon in Malaysia was strongest in 1970 and 1973.

Table 3. States affected by below or above normal summer and winter monsoon during El Nino years.

I = Below normal II = Above normal

	Summer (April to September)		Winter (October to March)	
Year	I	II	I	II
*1951	—	(W)	S	(W)
*1953	—	(W)	SK	(—)
1957	—	(S)	SK, S	(E)
1963	W, E, SK	(—)	SK	(—)
*1965	SK, S	(E)	S	(W, E)
*1969	E	(SK)	—	(W, SK)
1972	SK, S	(E)	E, SK, S	(—)
*1977	W, SK, S	(—)	E, S	(—)
1982	SK, S	(W)	W, E, SK, S	(—)
1986	E, W, S, SK	(—)	W, SK, S	(E)
1987	—	(—)	—	(—)
1991	E	(W)	W, SK, S	(—)

(—) Indicates that all states were not affected by above or below normal monsoon.
*The exceptional years from table 2.
Letters which are underlined indicate states recorded very much above or below normal rainfall.

Table 4. States affected by above or below summer and winter monsoon during La Nina years.

I = Above normal II = Below normal

	Summer (April to September)		Winter (October to March)	
Year	I	II	I	II
1955	SK, S	(W, E)	W, S	(—)
1956	SK	(W)	S	(—)
*1960	E, SK, S	(—)	E	(—)
1964	W, SK	(E)	S	(W, E)
1970	W, E, SK, S	(—)	W, E, SK, S	(—)
1971	—	(W, E, SK)	S	(—)
1973	W, SK, S	(E)	W, E, S	(—)
*1974	W	(E, S)	E	(—)
1975	E	(W)	SK, S	(W)
1988	W, SK	(—)	S	(W)

(—) Indicates that all states were not affected by above or below normal monsoon.
*The exceptional years taken from table 2.
Letters which are underlined indicate states recorded very much above or below normal rainfall.

1955, 1971 and 1974 were the three years when anomalous effect of La Nina (below normal rainfall) was experienced during the summer in two or more states. Similarly 1964 was the only anomalous year as regards to winter monsoon.

The above analysis shows that the effects of El Nino and La Nina are stronger over East Malaysia than peninsular Malaysia. Nevertheless intense El Nino and La Nina years did affect both the monsoons in the whole country. Anomalous effects were noted in some of the El Nino and La Nina years. It is worth pointing out that 1976 and 1983, even though neither El Nino nor La Nina years experienced very much above normal winter monsoon rainfall whereas 1978 experienced very much below normal winter monsoon rainfall in almost the whole country (figure 3a and b, 5 and 6). It is therefore necessary to examine the regional circulation to look for explanation for these anomalies.

6. Regional circulation pattern during the El Nino and La Nina years

Rasmussen and Carpenter (1982) and Arkin (1982) have examined the global circulation pattern associated with ENSO. Cheang (1984, 1985 and 1988) has examined the pattern for the Asia and western Pacific region associated with the same phenomenon. Based on upper air data from a record of 19 years (1968 till 1986), monthly mean circulation patterns were analysed in the three studies. The results are summarised as below:-

- During the El Nino years, the northern summer monsoon was characterised by westerlies extending eastward from the South China Sea to about 165° E longitude in equatorial western Pacific in the low levels (850 hPa) and the upper level (200 hPa) circulation was characterised by tropical upper tropospheric trough (TUTT) extending southward to only 15° N latitude in central Pacific.
- During summer monsoon of the La Nina years, the westerlies from South China Sea extended eastward to only about 140° E over the western Pacific in the low levels and the upper level circulation was characterised by TUTT extending southward to the equatorial region in the central Pacific.
- During the fall season (October) of the El Nino years, the low-level circulation was characterised by two areas of cyclonic activity; one over western and central Pacific, the other over Bay of Bengal, and winds over Malaysia were mainly southeasterlies, while the upper-level circulation was characterised by southward expansion of westerlies to central India (south of Bombay) and the TUTT in the central Pacific extended southward to latitude 15° N only.
- During the La Nina years the low-level circulation of October was characterised by broad zonal easterlies over the equatorial Pacific and double troughs straddling the equator over south-east Asia while the upper-level circulation was characterised by the southward expansion of westerlies to northern India (north of Bombay) and the southward extension of the TUTT to equatorial western and central Pacific.
- During the El Nino years the low-level circulation of the winter months (November till March) was characterised by cross-equatorial flow over Malaysia while the upper-level circulation was characterised by the southeastward expansion of the westerlies from India to Malaysia (particularly during January till March).

- During the La Nina years, the low-level circulation of the winter months was characterised by double troughs straddling the equator over south-east Asia (this was noted earlier by Tanaka 1982) while the upper-level circulation was characterised by the TUTT over western and central Pacific and the westerlies over India extended southeastward to only Thailand.

The above-mentioned features are schematically depicted in figures 7 and 8.

6.1 *Regional circulation pattern for 1986, 1988 and 1991*

After the study of Cheang (1988), 5 more years (1987–1991) of upper air data are available. During this 5 year period, 2 major El Nino and one major La Nina events occurred. The El Nino which started in 1986 continued till early 1988 and it was

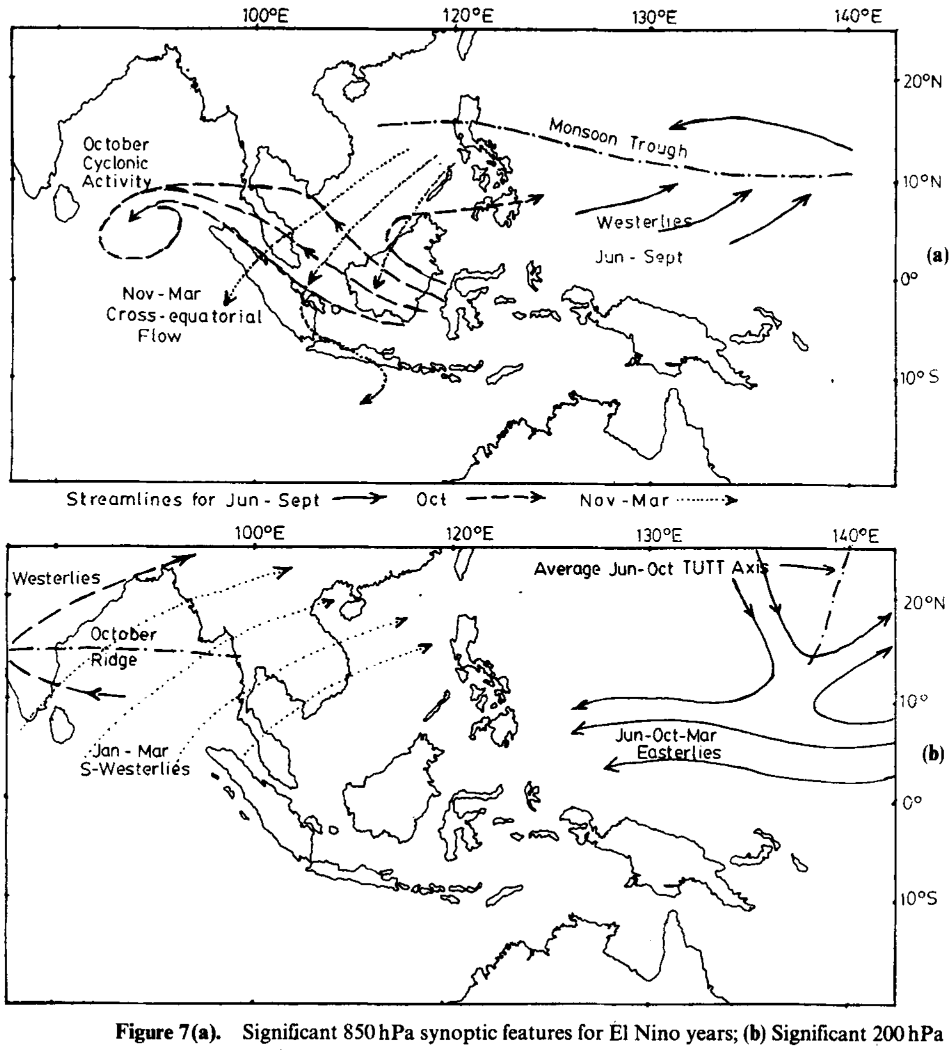


Figure 7(a). Significant 850 hPa synoptic features for El Nino years; **(b)** Significant 200 hPa synoptic features for El Nino years.

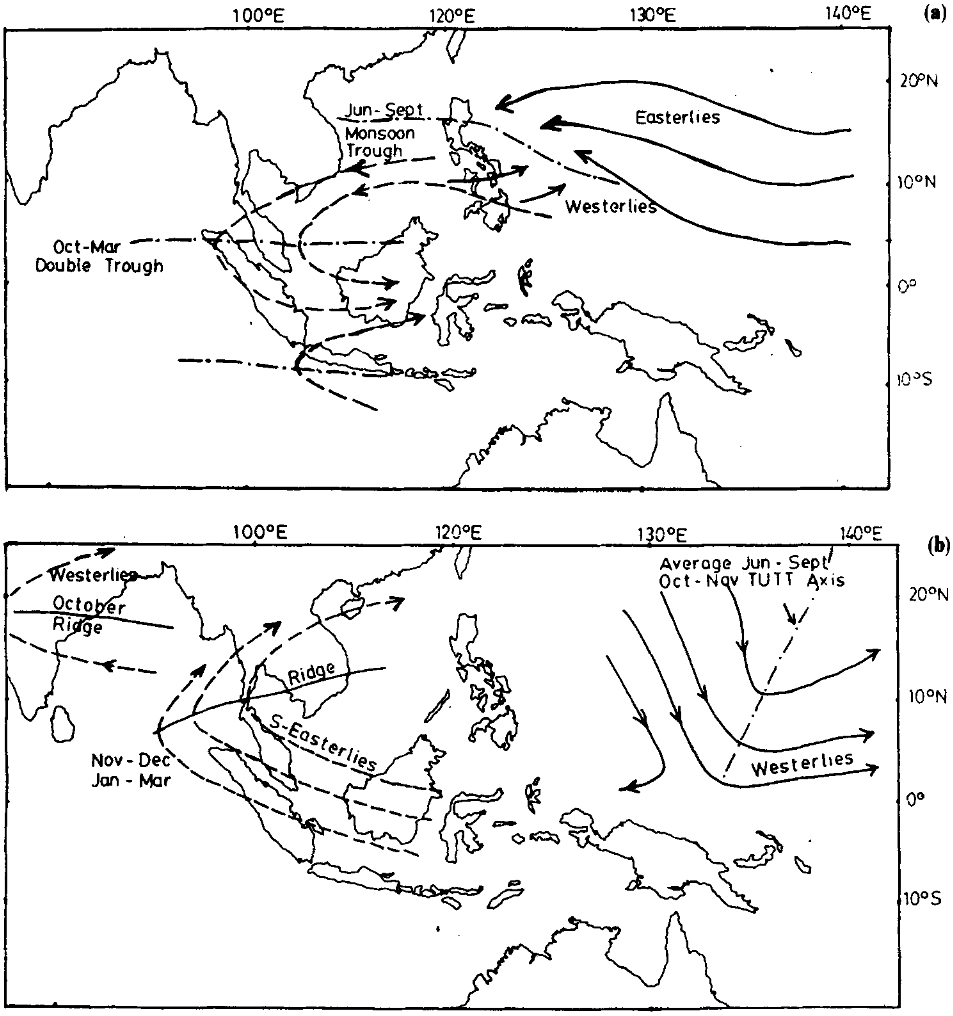


Figure 8(a). Significant 850 hPa synoptic features for La Nina years; **(b)** Significant 200 hPa synoptic features for La Nina years.

followed by one major La Nina from mid 1988 till early 1989. One major El Nino occurred from mid 1991 till mid 1992.

Cheang (1992) compared the monthly mean circulation patterns at 850- and 200-hPa levels of 1986/87, 1987/1988 and 1991/92 with those of the other earlier major El Nino years and found some differences which will be presented in section 6·2. For the 1988/89 La Nina, there was no major difference when compared with those of other major La Nina years.

6.2 *Regional circulation pattern for the anomalous years*

In this section, comparison of the features described in section 6 of the El Nino and La Nina years with those of the anomalous years identified in section 5·1 and 5·2 is presented. The comparison is shown in table 5. Owing to the reason that grid-point

Table 5. Comparison of certain synoptic features of the anomalous years with those of the El Nino years and La Nina years from 22-year (1968–1991) record.

(i) Nothern summer (June–September)

	(A) El Nino years (1972, 1977 and 1982)	(B) La Nina years (1970, 1971, 1973, 1974, 1975 and 1988)	Similarity to synoptic conditions stated in columns (A) for El Nino years or (B) for La Nina years						
			Anomalous El Nino years				Above normal winter monsoon years		Below normal winter monsoon years
			1969 / 70	1986 / 87	1987 / 88	1991 / 92	1976 / 77	1983 / 84	1978 / 79
850 hPa Longitudinal extent of monsoon trough from South China Sea to Western Pacific	From South China Sea to longitude 145°/170°E	From South China Sea to longitude 140°E	(B)	(A)	June–August (B) September (A)	June–July (B) August–September (A)	June (B) July–September (A)	(B)	(B)
200 hPa TUTT over Central Pacific	The axis of the trough extends southwards to only 15°N	The axis of the trough extends southwards to the equatorial region	(A)	(A)	(A)	June (B) July–September (A)	(A)	June (B) July–September (A)	June (B) July–September (A)
(ii) October 850 hPa Near-equatorial trough over western Pacific/ South China Sea/ Indonesia region	Near-equatorial trough not present; easterlies over Malaysia	Double near-equatorial troughs are present	(A)	(B)	(A)	(B)	(B)	(B)	(B)
200 hPa a) TUTT over Western/Central Pacific	The axis of the trough extends to only 15°N	Axis extends to the equatorial region with northwesterlies over western Pacific	(B)	(A)	(A)	(A)	(B)	(B)	(A)
200 hPa b) Upper Westerlies over India/ Bay of Bengal	Extends southwards reaching Bombay (upper wind over Bombay is westerlies)	Extends southwards not reaching Bombay (upper wind over Bombay is easterlies)	(A)	(A)	(A)	(A)	(A)	(A)	(A)

(iii) November–December

	(A) El Nino years (1972, 1977 and 1982)	(B) La Nina years (1970, 1971, 1973, 1974, 1975 and 1988)	Similarity to synoptic conditions stated in columns (A) for El Nino years or (B) for La Nina years						
			Anomalous El Nino years				Above normal winter monsoon years		Below normal winter monsoon years
			1969 / 70	1986 / 87	1987 / 88	1991 / 92	1976 / 77	1983 / 84	1978 / 79
850 hPa Near–equatorial trough over Southern South China Sea/ Malaysia/Indonesia region	Near–equatorial troughs are not present mainly cross–equatorial flow	Double near–equatorial troughs are present	(B)	November (B) December (A)	(B)	November (B) December (A)	(B)	(B)	November (B) December (A)
200 hPa a) TUTT over Western/Central Pacific	same as for October	same as for October	(A)	(A)	(A)	(A)	(A)	(B)	(A)
200 hPa b) Upper Westerlies over India/ Bay of Bengal/ Malaysia	Extends to Bay of Bengal/ Peninsular Malaysia	Extends to Southern India/ Nothern Bay of Bengal/ Central Thailand	(A)	(A)	November (B) December (A)	November (B) December (A)	November (B) December (A)	(B)	(A)
(iv) January–March									
850 hPa Near–equatorial trough Southern South China Sea/ Malaysia/Indonesia region	Near–equatorial trough are not present ; mainly cross–equatorial flow over Malaysia	same as for October, November and December	(A)	(A)	(B)	(A)	January (B) February–March (A)	January–February (B) March (A)	January (B) February–March (A)
200 hPa a) TUTT over Western/Central Pacific	TUTT moves further eastwards to central Pacific	same as in (A)	(A)	(A)	(A)	(A)	(A)	January–February (B) March (A)	(A)
200 hPa b) Upper Westerlies over India/ Bay of Bengal/ Malaysia	Same as for November and December	Same as for November and December	(A)	(A)	(A)	(A)	(A)	January–February (B) March (A)	(A)

monthly mean upper air data are not available in Malaysian Meteorological Service, composites of monthly mean wind fields for the El Nino and separately for the La Nina years were not carried out. Furthermore, there were only a few El Nino and La Nina years during the 41-year (1951–1991) period, therefore composite mean wind field may not have much meaning especially if there are significant differences. In table 5, the features which are identified in section 6 are compared. They are:-

- The low-level monsoon trough over the western Pacific during the northern summer.
- The tropical upper tropospheric trough (TUTT) over the western and central Pacific during the northern summer.
- The low-level near-equatorial trough over the South China Sea during the fall (October) and the winter seasons (November through March).
- The TUTT over the western Pacific during the fall and the winter seasons.
- The southward extension of the upper westerlies to southern India/equatorial Bay of Bengal/Malaysia region during the same season.

Table 5 shows the main anomalies in the synoptic conditions by comparing those of the anomalous El Nino years with those of major El Nino years, 1972, 1977 and 1982 are as follows:-

- During the summer monsoon of the anomalous El Nino years, 1986, and 1987, the low-level monsoon trough did not extend from South China Sea to western Pacific as far east as those in the major El Nino years, 1972, 1977 and 1982–this had resulted with the low-level trades from the Pacific to be able to penetrate further westwards.
- During the fall and winter seasons, of 1986/87 and 1987/88 double troughs straddling the equator over south-east Asia, a significant feature of the La Nina years, were present.
- For the 1991/92 winter monsoon the same anomaly as stated in (ii) appeared only in the October month.

The years, 1976 and 1983, though neither El Nino nor La Nina years, recorded very much above normal winter monsoonal rainfall in Malaysia. Synoptic conditions experienced during these two years resembled those during the La Nina years. Similarly, 1978, which recorded very much below normal winter monsoonal rainfall experienced synoptic conditions resembling those during the major El Nino years, 1972, 1977 and 1982.

7. Summary

The results of the above study can be summarised as below:-

- During the 41-year period (1951 till 1991), there was no clear indication of linear decreasing or increasing trend in the annual rainfall of 16 stations in Malaysia.
- Many stations recorded prolonged periods of below or above median annual rainfall lasting for 2–4 consecutive years. A few stations recorded these prolonged conditions as long as 5–8 years.
- Record of annual rainfall shows that short-term variability is evident. The 1951–1956 period was found to be distinctly wet. From 1957 to 1970, very few stations

recorded extreme wet or dry condition. During the early 1970's, wet and dry conditions alternated from one year to the next. From 1977 till 1991, many stations were found to have recorded more extreme dry than extreme wet conditions.

- During the 41-year period, 7 out of 11 El Nino years were found to have recorded very much below median annual rainfall at many stations and 8 out of 10 La Nina years recorded above median annual rainfall.
- East Malaysia is more prone to the influence of ENSO than peninsular Malaysia; it recorded below median rainfall during both the summer and winter monsoons in 6 out of the 12 El Nino years rainfall during both the monsoons.
- The influence of El Nino on the monsoonal rainfall in peninsular Malaysia is weaker. There was not a single case when both the east and west coast states together were affected during both the monsoons. In 1986, both the states were affected during the summer monsoon whereas in 1982, both the states were affected during the winter monsoon. The influence of La Nina had brought about above winter monsoonal rainfall in only 2 out of the 10 cases. Nevertheless most of the remaining cases recorded normal rainfall.
- 1972, 1977, 1982, 1986 and 1991 are the 5 El Nino years when the effect was more significant over the whole country.
- There were anomalous El Nino and La Nina years when rainfall pattern differed from those associated with the influence of ENSO events. As far as monsoonal rainfall is considered, 1951, 1953, 1957, 1965, 1969, 1986 and 1987 are the anomalous El Nino years, whereas 1955, 1964 and 1971 are the anomalous La Nina years.
- There were years which were neither El Nino nor La Nina years and yet extremely wet or dry winter monsoonal rainfall was recorded. 1978 and 1983 are the two of them.
- During the last 16 years since 1977, winter monsoonal rainfall throughout Malaysia was more frequently very much below median (30 percentile and below) than above median (70 percentile and above) (figure 6). During the same period, there were more El Nino than La Nina episodes. Altogether there were 5 episodes of El Nino (1972/73, 1977/78, 1982/83, 1986/87, 1987/88 and 1991/92) and only one episode of La Nina (1988/89). This observation indicates the importance of the ENSO signal in influencing the monsoonal rainfall.
- During the anomalous El Nino years, some of the synoptic features resembled those of La Nina years.
- The eastward extension of the low-level monsoon trough from the South China Sea to western Pacific and the southward extension of TUTT during the summer monsoon over the western/central Pacific to the equatorial region are the two earlier indicators in the regional circulation to monitor the occurrence of El Nino/La Nina events. During the fall (October) and winter monsoon the low-level double trough straddling equator, the TUTT over western Pacific and the south-eastward expansion of upper westerlies from India to Malaysia are the other indicators to monitor. These features play important roles in bringing about active or weak monsoon influencing the short-term climate variability.

Acknowledgements

The author wishes to express his sincere thanks to the Director General of Malaysian Meteorological Service for his permission to publish this paper and to Mr Tan Huvi Vein and Mr Kwan Kok Foo for their assistance in computer programming.

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