CHAPTER II: TRIENNIAL OSCILLATION IN ATMOSPHERE AND OCEAN

2.1 Introduction

2.1.1 In a paper published eight years ago the author reported evidence for the existence of a triennial oscillation in the sub-tropical westerlies and equatorial easterlies of the upper troposphere over south Asia and in the monsoon rainfall of India during the decade 1965-1974 (Joseph-1975). This oscillation was found to be distinctly different from the Quasi Biennial Oscillation (QBO). The triennial oscillation in winds was found to affect the tracks of post-monsoon cyclonic storms of the Bay of Bengal - Joseph (1976). Studies by Angell and Korshover (1975, 1978) showed that during the same decade the monthly mean temperature of the global tropical troposphere also showed a prominent triennial oscillation, distinctly different from the familiar QBO of the equatorial lower stratosphere.

2.1.2 In a recent paper the author suggested that monsoon - north Indian ocean interaction is the probable cause of this triennial oscillation (Joseph - 1981). Subsequent studies by Joseph and Pillai (1981) established that there was a significant 3 year cycle in the Sea Surface Temperature over the north Indian Ocean during the period 1961-1973. An important corollary emerged from these investigations, that India may not have more than 2 major droughts consecutively, as the north Indian Ocean would warm up sufficiently after 2 droughts and make the monsoon rainfall of the third year normal or excess. This corollary, which is supported by the available climatology, could be made effective use of, in planning India's buffer stock of essential food grains.
2.1.3 In this chapter the different aspects of the triennial oscillation will be discussed. An attempt will be made to link the various elements of the observed triennial oscillation in a qualitative way to gain understanding about the processes in the atmosphere and ocean that are responsible for the inter-annual variability of monsoon rainfall, manifested in the triennial oscillation.

2.2 Triennial oscillation in upper tropospheric winds

2.2.1 In the equatorial regions of South Asia, upper tropospheric westerlies and easterlies normally have their levels of maximum wind close to the 150 mb level. Fig. 2.1 gives maps of the monthly mean 150 mb wind field of January of the years 1965, 1966 and 1967, for the tropical areas of Asia and eastern Africa. In January 1967 in the area south of 15°N the wind field in the monthly mean was easterlies of 30 to 40 knots, with the occurrence on a large number of individual days, of well developed easterly jet streams having core wind speeds close to 100 knots. In contrast in January 1966 the mid-latitude westerlies of the northern hemisphere over South Asia extended close to the equator over the Arabian Sea and adjoining Indian longitudes and even crossed over to the southern hemisphere. In January 1965, westerlies were close to the equator over the Arabian Sea and adjoining peninsular India.

2.2.2 The strong easterly jet stream, with core near 150 mb level, occurring during the summer monsoon over south Asia (Koteswaram - 1958) is found to mask these large scale changes in the upper troposphere over South Asia during May to October, but from the monthly mean winds of the remaining months of 1965, 1966 and 1967 it could be inferred that the sub-tropical westerlies (and the equatorial easterlies) of the upper
the troposphere had executed an oscillation of period about 3 years. From a detailed examination of the monthly mean 150 mb wind field of the decade 1965-1974, it is inferred that there was a regular triennial oscillation of the wind field over south Asia during this period. This oscillation was most pronounced over the Arabian Sea and adjoining peninsular India.

2.2.3 The zonal components ($U$) of the monthly mean 150 mb winds of Gan Island (00°41'S, 75°09'E), Minicoy (8°18'N, 73°00'E) and Trivandrum (08°28'N, 76°57'E) for January months of the 9 years 1965 to 1973 were subjected to harmonic analysis. Table 2.1 gives the percentage of variance accounted by the 9 year, 4.5 year and 3 year cycle (first, second and third harmonics). 50 to 60 percent of the variance is accounted for by the triennial oscillation. For Trivandrum a similar analysis was performed on the following 9 year period 1974 - 1982. The results obtained are also given in Table 2.1. During 1974 - 1982 also the three year oscillation is prominent, but it accounts only for 42% of the variance.

2.3 Triennial oscillation in monsoon rainfall

2.3.1 Fig. 2.2 gives the Parthasarathy-Mooley (1976) monsoon rainfall series for the period 1960 to 1975. The three year oscillation in rainfall is clearly seen from this figure. Years of good monsoon rainfall have occurred at intervals of 3 years i.e. 1961, 1964, 1967, 1970 and 1973. In between these, there were many years when monsoon gave poor rainfall. Mooley (1975) calculated the percentage area of India covered by subdivisions having monsoon rainfall less than 19 percent from the normal for the period 1947 to 1974. He found that the years with minimum percentage of the area with monsoon rainfall deficiency were recurring with regularity, once in 3 years from 1953 onwards.
2.3.2 Comparing with the 150 mb wind field, it is found that monsoon rainfall was poor in those years when the westerly wind field, particularly over Arabian Sea, had intruded equatorwards and the equatorial easterlies were weak (or were replaced by westerlies) during the previous winter and pre-monsoon seasons. In those years when the equatorial areas had strong easterlies during winter and pre-monsoon seasons, the monsoon rainfall was normal or above normal in India. Thus the triennial oscillation in monsoon rainfall is intimately linked with the triennial oscillation in the upper tropospheric wind flow over south Asia. In those years when sub-tropical westerlies intruded equatorwards over Arabian Sea during winter and the pre-monsoon seasons, monthly mean wind charts show that in the following monsoon season also westerlies intrude into areas immediately west of India north of latitude 25°N, in the form of a trough at about 65°E longitude, as may be seen from the figure-2.5 for the year 1972. In the year 1973 which had good monsoon rainfall there is a ridge in this area instead of the trough. This aspect would be discussed again in Chapter IV.

2.3.3 That the sub-tropical westerlies when they intrude equatorwards over South Asia could affect large scale changes in the Indian monsoon rainfall for the season as a whole (June to September) is in general conformity with the existing knowledge about the causes of the short period fluctuations in Indian summer monsoon rainfall. They are:

(a) Ramaswamy (1962) has shown that break-monsoon conditions are associated with pronounced low index circulation in the middle latitude westerlies north of the Himalayas causing large amplitude troughs in the upper tropospheric westerlies to affect north India. Similar ideas were expressed by Pisharoty and Dasai (1956). This concept may be extended to
the seasonal scale when we get an intrusion of westerlies as a trough immediately to the west of India in monthly mean charts. It may be noted that in the years of major monsoon failures, prolonged break-monsoon conditions contributed significantly to the observed rainfall deficiencies in central and north-west India and along the west coast.

(b) Monsoon depressions move in more northerly directions when the sub-tropical westerlies move to more southerly latitudes, and such depression movement adversely affect the rainfall distribution over large parts of India, particularly the central and north-western parts.

(c) Abnormal south-ward intrusion of westerlies lead to delay in the onset and advance of the monsoon and to its early withdrawal, thus reducing the duration of monsoon rainfall over the country, leading to seasonal rainfall deficiencies.

2.4 Triennial oscillation in cyclone tracks

2.4.1 The triennial oscillation in winds affected the tracks of the severe cyclonic storms of the Bay of Bengal of the post-monsoon season. There was considerable difference in the tracks of Bay cyclones from year to year during the decade 1965-1974. November is a month when cyclones of the Bay can strike any part of the coastal areas around the Bay of Bengal. Fig. 2.4 gives the tracks of the severe cyclonic storms of the Bay of Bengal of November during the decade 1965-1974. There was no severe cyclonic storm during November in 1965 and 1967, but during the remaining years of the decade there was at least one severe cyclonic storm in each November. In the years 1966, 1969 and 1972, severe cyclones of November moved westwards and hit Tamil Nadu and Andhra coasts. In the remaining years of the decade, severe cyclones had northerly movement and they affected west Bengal, Bangladesh and Burma. A three year
oscillation in the cyclone tracks is clearly seen in figure 2.4.

2.4.2 A comparison with the 150 mb wind charts revealed that the Bay cyclones moved north during periods when equatorial easterlies were weak and sub-tropical westerlies intruded southward into the tropics and the westward motion occurred in years when the equatorial easterlies were strong, in agreement with the existing steering concepts. Although in the years 1965 and 1967 there were no severe cyclones in November, the severe cyclones that occurred in October or December in both these years had northerly movement, in accordance with the triennial oscillation in winds. The movement of November cyclones of the decade 1965 - 1974 clearly shows the large scale changes in the wind circulation over south Asia from year to year, in the form of a 3 year cycle. The contrasting cyclone tracks of November 1966 and November 1968 have been discussed in detail by Ramaswamy (1972), who finds that in November 1966 sub-tropical westerly jet streams were confined mostly to latitudes north of 25°N, whereas in November 1968 jet streams were observed on many days even at latitude 19°N and westerly winds of 50 knots speed were noticed even at latitude 14°N.

2.5 Change from westerly to easterly phase in the triennial cycle

2.5.1 One factor noticed was that just after the second consecutive monsoon failure, equatorial easterlies at 150 mb strengthened and spread to latitudes as far north as 15°N over the Indian seas, particularly the east Arabian Sea and Bay of Bengal. This may be seen from the select 150 mb monthly mean wind charts presented in figure 2.5 for the period 1965 to 1967. This figure may be seen along with figure 2.1. In January 1966 westerlies over Arabian Sea and peninsular Indian longitudes reached almost up to the equator. The sub-tropical anticyclone was
noticed only over the Andaman Sea and to its south-east. There was large scale monsoon failure in India during 1965. November 1965 shows almost the same wind flow at 150 mb except that westerlies have further moved south. This pattern of wind flow persisted in January 1966; in fact westerlies became stronger over the equatorial regions south of Arabian Sea and peninsular India, where the westerly belt is seen to have crossed over to the southern hemisphere. Wind flow of April 1966 is similar to that of November 1965. Monsoon failed a second time in 1966. Immediately after the monsoon failure of 1966, the wind flow changed completely. In November 1966 a strong easterly belt was noticed over the equatorial area. The sub-tropical anticyclone is seen prominently over the Bay of Bengal, peninsular India and East Arabian Sea. The post monsoon severe cyclones of 1966 moved predominately westwards. This pattern of wind flow persisted for many months as may be seen from the wind flow of January 1967 in figure 2.5. The monsoon of 1967 was near normal and immediately after that the wind flow reverted back to that which existed in 1965. Major changes in wind flow took place across the monsoons of 1966 and 1967.

2.5.2 In 1971, monsoon had below normal rainfall and in 1972 there was a major monsoon failure. In the triennial cycle 1971 to 1973 wind flow changed from westerly phase to easterly phase across the monsoon of 1972 as may be seen from figure 2.6. It reverted back soon after the good monsoon of 1973. Monsoon rainfall and cyclone tracks were affected, as discussed before, by the changes in wind flow in the triennial cycle. The triennial cycle 1968-1970 had also a similar manifestation of wind flow change from westerly to easterly across the monsoon of 1969 as may be seen from figure 2.7.
2.5.3 Thus there seems to be considerable persistence in the upper
tropospheric flow over South Asia and the large scale circulation features,
monsoon rainfall of India and tracks of post-monsoon cyclones of Bay of
Bengal appear to be causally linked with each other. Since the atmosphere
does not have a memory of more than one to two weeks, such a persistence
can come only from its linkage with features like Sea Surface Temperature
(SST), snow cover over land, moisture over land etc. In the following
section, the SST over North Indian Ocean is examined to see if it is
linked with the triennial oscillation in the atmosphere.

2.6 Triennial oscillation in SST over North Indian Ocean

2.6.1 WMO Congress-IV in 1964 decided to apportion the world ocean
areas among nine member countries for processing the large number of ship
weather observations, made at main synoptic hours by the Voluntary
Observing Fleet (VOF) of about 40 maritime nations. The area of
responsibility given to India is shown in Figure 2.3. India is responsible
for preparing monthly climatological tables for 17 'Selected
Representative Area' (SRA) marked in Figure 2.8 for the years from
1961. Details regarding this scheme are given by Khorkao and Nana (1972).
Data in the form of monthly mean values of SST for these SRAs were made
available to the author by India Meteorological Department for the period
1961 to 1967. These years include 5 good monsoon years 1961 to 1964 and

2.6.2 10 year (1961 - 1970) averages of monthly mean SST of Selected
Representative Areas of Western North Pacific Ocean have been obtained
from Japan Meteorological Agency (1979). Using the 7 year averages for
the Indian Ocean area and the 10 year averages for the West Pacific Ocean
the annual variation of SST was studied. Figure 2.9 gives the annual
variation of monthly mean SST at a few locations (re-numbered) in both the oceans. Locations 1, 5 and 9 are mainly responding to the annual variation of solar radiation. Location 4 on the equator shows very small annual variation. Locations 2, 3, 6 and 7 show the effect of monsoon cooling. These areas cool from May to August, while the other oceanic areas of the northern hemisphere warm. The amplitude of the monsoon cooling, May to August, is largest at 2 and decreases towards east as may be seen from the cooling at 3 and 6. At location 7, in tropical west Pacific, the curve is flat from June to October.

2.6.3 To examine if there is a triennial oscillation in SST over north Indian Ocean a longer series than 7 years was generated. Monthly mean SST were calculated with the data available under the WMO scheme described in para 2.6.1, for the period 1968 to 1973 (Joseph and Pillai 1981) for three SRAs 7, 6 and 17 of Figure 2.8, hereafter called A, B and C respectively (locations also shown in figure 2.13). Each of these SRAs is 3 degrees longitude by 2 degrees latitude. Thus for these 3 SRAs monthly mean SST series were available for 15 years 1961 to 1975. The number of SST observations available in a typical year at each of these SRAs is given in table 2.2.

2.6.4 Twelve month moving average (to remove the annual cycle) of the monthly mean SST of A, B and C shows a pronounced 3 year cycle. Figure 2.10 shows this for area A. Even after applying a 12-month moving average, the amplitude is considerable - about 0.7°C for the first two cycles and about 1°C for the third and fourth cycles. Figure 2.10 also gives the Parthasarathy - Moolay monsoon rainfall series for the same period. The triennial oscillation is seen clearly in both SST and monsoon rainfall during the entire period.
2.6.5 To see the real amplitude for the 3-year cycles in SST at A, the normal SST for each month was calculated as an average of 13-years and monthly anomalies were obtained as departures from monthly normals. To have some smoothing the four 36 month cycles beginning January 1962, January 1965, January 1968 and January 1971 were averaged and the mean cycle thus obtained for A is shown in figure 2.11. The thick line marked is the five month moving average of these values. It is seen that the mean amplitude of the 3-year oscillation in SST at A during the period 1961 - 1973 is about 1.5°C (Maximum SST - Minimum SST). The thick line shows that SST increased during 2 consecutive years and decreased during the third year, thus giving a saw-tooth type of wave. Detailed examination of the SST data showed that the increase and decrease of SST anomalies occurred across the monsoon months June to September and that the anomaly generated by a monsoon persisted till the next monsoon. It may be noted that a 3-year periodicity in the heat storage in the top 100 metre layer of the north Indian Ocean during the period 1964 to 1974 has been reported by Golavastov (1980).

2.6.6 To study the amplitude and phase of the 3-year wave in SST, the 144 monthly values of SST anomaly of each area A, B and C from January 1962 to December 1973 were subjected to harmonic analysis. The series was expressed as
where \( P \) is the total period (144 months) and \( N \) is the number of observations (144). The amplitude of the \( i^{th} \) harmonic is

\[
C_i = \left( A_i^2 + B_i^2 \right)^{1/2}
\]

and the time at which the \( i^{th} \) harmonic reaches maximum (phase) is

\[
t_i = \frac{P}{2\pi} \arctan \left( \frac{A_i}{B_i} \right)
\]

The fractional variance accounted for by the \( i^{th} \) harmonic is

\[
\frac{C_i^2}{2S^2}
\]

where \( S \) is the standard deviation. Data in respect of the first 12 harmonics are given in table 2.3. At all the three areas A, B, and C, the fourth harmonic (36 month wave) has the maximum amplitude and it accounts for the highest percent of variance. For all other harmonics the variance is very low. This shows that the only prominent oscillation (other than the annual variation which has been removed from the data) is the triennial oscillation. The phase of maximum SST at A is 22 (August of the 2nd year of the triennial cycle), at B is 21 (September of second year) and C is 26 (February of the third year).

2.6.7 Power spectrum analysis of the series of 156 monthly mean anomalies of SST at A, B, and C for the period 1961 - 1975 with lag of 54 months was also carried out as per the method outlined in WMO technical note No. 79 (1966) on 'Climatic Change.' Figure 2.12 shows the spectrum for area A. The 3 year cycle is significant at 99% level. There is no other periodicity except a 3 month cycle. Areas B and C also show the 3 year cycle, but it is significant at 95% level at C and only at 90% level at B.

2.6.8 The area affected by the 3 year oscillation in SST was examined. For this, 5 degree latitude longitude square average of SST were
calculated for each month of the period 1965 to 1973 (108 months) for the north Indian Ocean area north of 15°S. The average monthly number of SST observations in each 5 degree square during this period are as given in figure 2.15. With a stipulation of at least 5 observations of SST for a monthly average, the data series (of 108 monthly values) of many of the squares outside the thick line boundary of figure 2.13 were not complete and so could not be used. The average 3 year cycle of SST anomalies were worked out using the data of 3 cycles beginning January 1965, January 1968 and January 1971. The amplitude (maximum-minimum SST) of the mean 3 year cycle for each 5 degree square is given in figure 2.14. The triennial oscillation is found to have amplitude of 1°C and more over a large area of the north Indian Ocean.

2.6.9 The 108 monthly SST anomaly value time series of each five degree square was subjected to power spectrum analysis with lag of 36. Practically all the squares show a 3 year wave. The 3 year wave is significant at levels 80%, 90% and 95% as shown in figure 2.15. The X mark shows that the level of significance is less than 80%. It is seen that a large area of the Indian Ocean north of 5°S has a triennial oscillation in SST significant at 95% level. (The values given in brackets in figures 2.14 and 2.15 are for squares where one value of the 108 value series is an average with less than 5 SST observations).

2.6.10 Harmonic analysis of the 108 month SST series of each 5 degree square was done. In all the squares, the 36 month wave (third harmonic) is the only prominent wave. The phase of maximum SST of the 36 month wave is as shown in figure 2.16, with isolines marked in months, July of second year (Phase 19) to January of third year (Phase 25).
The progression of phase from west to east is interesting. The phase propagation is fast along central Arabian Sea and slow over south Arabian Sea and the equatorial regions.

2.7 Quasi Biennial Oscillation and the Triennial Oscillation

2.7.1 Quasi Biennial Oscillation (QBO) seen prominently in the equatorial lower stratosphere is a well known mode of the atmosphere and many atmospheric features have been correlated with the QBO, like wind in the lower troposphere (Ananthakrishnan and Trivengadathan - 1966), rainfall (Koteswaram and Alvi - 1970), the annual frequencies of cyclonic disturbances in the Bay of Bengal (Bhalme - 1972) etc. It has been examined whether there is any relation between the QBO and the triennial oscillation discussed in this chapter. Figure 2.17 (Joseph - 1975) gives the 50 mb zonal winds of Singapore (U component with the annual variation removed). The QBO, that is the alternation between easterly and westerly zonal winds, can be clearly seen in the figure. The location of the monsoon months and of January are marked in the figure.

2.7.2 It is seen that during the period 1964 to 1968, QBO was unusually longer, almost a triennial oscillation, but the three cycles from 1968 to 1973 had period around two years. In contrast during this entire period 1964 to 1973 the upper tropospheric winds, monsoon rainfall, cyclone tracks and the North Indian Ocean SST exhibited a very regular 3 year cycle. There appears to be no direct relation between the essentially tropospheric phenomenon of the 'Triennial Oscillation' and the essentially Stratospheric phenomenon of 'Quasi Biennial Oscillation'.
2.3 Triennial Oscillation: an important mode of the troposphere

2.3.1 More than 50 years ago Kidson (1925) pointed out that the atmosphere over the Indian Ocean had a periodicity of 36 months. In the preceding sections of this chapter it was shown that during the 1960s and early 1970s the north Indian Ocean and the atmosphere above had experienced a regular triennial oscillation in Sea Surface Temperature, upper tropospheric winds, monsoon rainfall and cyclone tracks. In Chapter-III we will see how these features are inter-related through monsoon - Indian Ocean interaction on a seasonal scale. Thus the triennial oscillation may be taken as a major mode of the Indian Ocean and the troposphere aloft. The climate of the area is controlled by it much more than by the Quasi Biennial Oscillation of the equatorial lower stratosphere. Angell and Karshovar (1975, 1978) found a triennial oscillation in the tropospheric (surface to 100 mb) mean temperature of the global tropics during the decade 1965 - 1974 of amplitude 0.3°C. They considered this oscillation as distinctly different from the QBO. Yonamoto and Hoshinda (1979) found a triennial oscillation in the global surface temperature of the tropics. Gordon (1982) has found a highly significant three year period in the zonally averaged geopotential heights of the 50 mb pressure surface at 10°N. Gordon et al (1982) concluded from a detailed analysis that the quasi-triennial spectral peaks are more likely to be of physical origin than a result of Quasi Biennial Oscillation - Southern Oscillation interaction.

2.3.2 Examining longer time series of data (of the order of 100 years) as described in Chapter-I, Parthasarathy and Noclay (1978) and Raghavendra (1975) found significant periodicity around 2.7 years. Although these
authors have associated this periodicity with the QBO mode. 2.7 years appears to be too long a period for the QBO. In fact for the rainfall series of 'Peninsular India', Raghavendra (1973) found a spectral peak at 95% significance level with a periodicity of 2.3 years, as may be seen from figure-1.5 of Chapter-I. This may represent the QBO component. Pan (1978) as quoted by Krishnamurty (1979) found an oscillation in the planetary scale circulation of the upper troposphere over the tropics with a period around 2.6 years.

2.8.3 Commenting on the 2.7 year spectral peak in long term rainfall records, Krishnamurty (1979) writes: 'It is a little difficult to understand what a 2.7 year period really is, when data for June to September are averaged and used as a unit here. If one were to state that after a year of maximum rainfall the next one would be most likely to occur 2.7 year later, this would place that next maximum in a late winter season. This, of course is an absurd interpretation. Our interpretation of the long term record is that there probably exists a 2.7 year mode that excites monsoon rainfall whenever its phase occurs during the monsoonal months of June to September. Since the results are averages for a large area and therefore based on a large number of observations, the 2.7 year mode deserves very careful study.'
REFERENCES


5. Golavastov, V.A. (1990) - 'Peculiarities of ocean thermodynamics in the tropical Indian Ocean during the Southwest monsoon 1979,' Results of Summer MONEX field phase research (Part B), FGGE operations report, Vol.9, WMO, p 186-192


15. Kotawar, P. (1956) - 'The easterly jet stream in the tropics,' TELLUS, 10, p 43-57


18. Mooly, D.A. (1975) - 'Vagaries of the Indian monsoon during the last 10 years,' Vayu Mandal, 5, p 65

19. Pan, H.L. (1978) - 'Upper tropospheric tropical circulations during a recent decade,' Ph.D. dissertation, Department of Meteorology, Florida State University, Tallahassee, Florida, U.S.A.


21. Pisharoty, P.R. and B.N. Desai (1956) - 'Western disturbances and Indian weather,' Indian Journal of Meteorology and Geophysics, 7, p 333-338

22. Ramaswamy, C. (1962) - 'Breaks in the Indian summer monsoon as a phenomenon of interaction between the easterly and the sub-tropical westerly jet stream,' TELLUS, 24, p 337-349

Table 2.1: Percentage variance accounted for by the first 3 harmonics in the 9 year series of January mean zonal wind at 150 mb level of a few stations

<table>
<thead>
<tr>
<th>Station and length of series of January Zonal Wind</th>
<th>Percentage Variance Accounted for by First Harmonic (Period 9 years)</th>
<th>Second Harmonic (Period 4.5 years)</th>
<th>Third Harmonic (Period 3 yrs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gan Island (1965 - 1973)</td>
<td>11</td>
<td>9</td>
<td>51</td>
</tr>
<tr>
<td>Minicoy (1965 - 1973)</td>
<td>5</td>
<td>4</td>
<td>58</td>
</tr>
<tr>
<td>Trivandrum (1965 - 1973)*</td>
<td>1</td>
<td>15</td>
<td>61</td>
</tr>
<tr>
<td>Trivandrum (1974 - 1982)*</td>
<td>15</td>
<td>9</td>
<td>42</td>
</tr>
</tbody>
</table>

* Please see the note given on the following page .......
* Harmonic analysis of the combined 18 year series (1965-1982) of monthly mean January zonal wind of Trivandrum was performed. The results are given below. Here the variance accounted for by the harmonic cycle of period 3.6 years is the highest (not 3 years), followed by a period of 2.5 years which is close to the QBO.

<table>
<thead>
<tr>
<th>Harmonic</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period (in years)</td>
<td>18.0</td>
<td>9.0</td>
<td>6.0</td>
<td>4.5</td>
<td>3.6</td>
<td>3.0</td>
<td>2.6</td>
<td>2.3</td>
<td>2.0</td>
</tr>
<tr>
<td>Percentage variance accounted</td>
<td>6</td>
<td>3</td>
<td>8</td>
<td>2</td>
<td>45</td>
<td>8</td>
<td>4</td>
<td>23</td>
<td>2</td>
</tr>
</tbody>
</table>
Table 2.2: Number of SST observations in A, B, C during 1964

<table>
<thead>
<tr>
<th>SRA</th>
<th>JAN</th>
<th>FEB</th>
<th>MAR</th>
<th>APR</th>
<th>MAY</th>
<th>JUN</th>
<th>JUL</th>
<th>AUG</th>
<th>SEP</th>
<th>OCT</th>
<th>NOV</th>
<th>DEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>107</td>
<td>105</td>
<td>105</td>
<td>118</td>
<td>100</td>
<td>133</td>
<td>81</td>
<td>89</td>
<td>93</td>
<td>84</td>
<td>101</td>
<td>95</td>
</tr>
<tr>
<td>B</td>
<td>25</td>
<td>50</td>
<td>44</td>
<td>38</td>
<td>45</td>
<td>28</td>
<td>38</td>
<td>45</td>
<td>33</td>
<td>34</td>
<td>23</td>
<td>40</td>
</tr>
<tr>
<td>C</td>
<td>28</td>
<td>23</td>
<td>36</td>
<td>31</td>
<td>22</td>
<td>26</td>
<td>21</td>
<td>27</td>
<td>14</td>
<td>20</td>
<td>12</td>
<td>21</td>
</tr>
</tbody>
</table>
Table 2.3: Amplitude and phase of and variance accounted by the first 12 harmonics of the monthly SST Series 1962 to 1973

| HARMONIC | AREA 'A' | | | AREA 'B' | | | AREA 'C' | | |
|----------|---------|---|---|---------|---|---|---------|---|
|          | AMP (°C) | PHASE (month) | VAR. (%) | AMP (°C) | PHASE (month) | VAR. (%) | AMP (°C) | PHASE (month) | VAR. (%) |
| 1        | 0.03    | 50 | 0  | 0.18    | 58 | 11 | 0.07    | 105 | 1  |
| 2        | 0.10    | 11 | 2  | 0.13    | 8  | 5  | 0.06    | 49  | 1  |
| 3        | 0.14    | 40 | 4  | 0.07    | 0  | 2  | 0.21    | 43  | 10 |
| 4        | 0.35    | 20 | 25 | 0.25    | 21 | 20 | 0.26    | 26  | 15 |
| 5        | 0.11    | 19 | 2  | 0.05    | 16 | 1  | 0.02    | 24  | 0  |
| 6        | 0.02    | 23 | 0  | 0.05    | 7  | 1  | 0.07    | 16  | 1  |
| 7        | 0.06    | 10 | 1  | 0.12    | 8  | 5  | 0.14    | 7   | 5  |
| 8        | 0.11    | 8  | 3  | 0.08    | 8  | 2  | 0.10    | 6   | 2  |
| 9        | 0.08    | 0  | 1  | 0.05    | 0  | 1  | 0.09    | 14  | 2  |
| 10       | 0.16    | 13 | 5  | 0.09    | 2  | 2  | 0.04    | 11  | 0  |
| 11       | 0.11    | 9  | 2  | 0.08    | 3  | 2  | 0.06    | 9   | 1  |
| 12       | 0.03    | 9  | 0  | 0.03    | 8  | 0  | 0.03    | 10  | 0  |
Fig. 2.1 - Triennial cycle of the 150 mb wind field during 1965-1967
Fig. 2.2 - The triennial oscillation of monsoon rainfall of India during 1960-1974. Please note the peaks at regular 3-year intervals. (Monsoon rainfall series by Parthasarathy and Mosley - 1978).
Fig. 2.3 - Monthly mean winds and isolines of geopotential of 150 mb level for July 1972 and July 1973.

(Thick arrow shows direction of meridional wind there.)
Fig. 2.5 - Wind flow at 150 mb during 1965-1967. (Please see also Fig. 1.1). The change across the monsoon of 1966 may be noted.
Fig. 2.6 - Wind flow at 150 mb during 1972 and 1973. The change across the monsoon of 1972 may be noted.
Fig. 2.7 – Wind flow at 150 mb during 1968 and 1969. The change across the monsoon of 1969 may be noted.
Fig. 2.8 - The 17 'Selected Representative Areas' of Indian Ocean north of 15°S.
Fig. 2.10 Top figure gives the twelve month moving average of SST at location A. Bottom
tfigure gives the monsoon rainfall of India as derived by Parthaśarathy and Mooley
(1978). The 3 year oscillation is clearly seen in both figures.
Fig 2.11. Average SST anomaly in a 3 year cycle at location A
(average of 4 cycles during 1962 to 1973)
Average monthly frequency of SST observations (1965 to 1973)

FIG. 2.13
Phase of maximum SST of the 3 year harmonic (1965 to 1973)

FIG. 2·16
FIG. 2.17. MONTHLY MEAN E-W COMPONENT (m/s) OF SINGAPORE WINDS AT 50 MB, WITH ANNUAL VARIATION REMOVED. 'J' DENOTES JANUARY.