Chapter 6
Meteorology of the Maritime Continent (Region – III) (Comprising Philippines, Indonesia and Equatorial Western Pacific Ocean)

6.1 Introduction

The region which we are about to study is not really a continent in its usual sense consisting mainly of land, but a continent in which the land surface may be looked upon as fragmented into thousands of islands, large and small, with water masses separating them so as to combine the effects of a continent and an ocean over a vast geographical area lying between the continents of Asia and Australia and between the Indian and the Pacific oceans. It covers a wide area of land and ocean extending longitudinally from about 100°E to the dateline or even beyond, and latitudinally from about 10°S to about 20°N (see Fig. 6.1).

Along its northwestern borders lies a part of Southeast Asia. It has within its borders two great archipelagos, Philippines and Indonesia, and a large number of oceanic archipelagos, such as Micronesia, Polynesia, Melanesia, besides innumerable small islands or island groups in the heart of the Pacific Ocean, both north and south of the equator. The Philippines has more than 7000 islands, of which three (Luzon, Visayas and Mindanao) only are large. Indonesia also has within its borders thousands of islands, spread out along and about the equator between the Indian and the Pacific oceans. Here also there are only a few large islands (viz., Sumatra, Djawa, Borneo, Sulawesi, Moluccas, Timor and Irian Barat) and the rest are all tiny islands. It is estimated that more than two-thirds of the total area of the Maritime continent may be occupied by water masses and only one-third or even less by land. Apart from land-sea configuration, the topography of the Maritime continent plays an important role in determining the climate of the region. High mountain ranges, many of which are volcanic, are strewn all over the region and, depending upon their location and alignment in relation to the heat sources and sinks and prevailing winds, they play important roles in the meteorology of the continent, especially the distribution of fog, clouds, thunderstorms and rainfall.

The Maritime continent occupies a centerstage in the monsoon circulations between Asia and Australia and between the Indian and the Pacific oceans. It experiences a monsoon type of climate, mostly warm and humid, practically throughout the year. Here, the NE monsoon alternates with the SW monsoon in a seasonal cycle, as the intertropical convergence zone moves north and south across the equator. Further, the tradewinds of the two hemispheres meet and

K. Saha, *Tropical Circulation Systems and Monsoons*,
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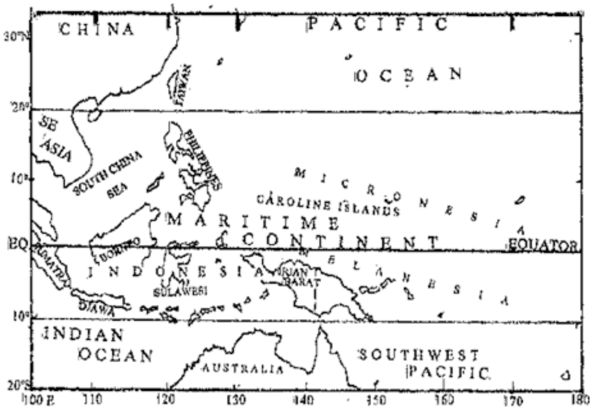

Fig. 6.1 Map of the Maritime continent showing its approximate boundaries and main islands

produce near-equatorial troughs and convergence zones including the South Pacific Convergence Zone (SPCZ). The Maritime continent acts as the principal heat source for the tropical circulation, involving the monsoon, Hadley and Walker-type circulations. It appears to play a crucial role in El Nino years when large-scale shift occurs in the distributions of equatorial heat sources and sinks and associated global climate systems. It is also the region of development of tropical waves into summertime typhoons of the NW Pacific and tropical cyclones of the SW Pacific.

Because of the importance of the Maritime continent as a diabatic heat source for regional and global circulations, the meteorology of this continent has been studied by several workers ever since the colonial days. Historically, climatic studies in the Maritime continent started with two of its largest archipelagos, viz., the Philippines (Flores and Balagot, 1969) and Indonesia (Sukanto, 1969). A brief survey of some of the studies is presented in the sections that follow.

6.2 Climate of the Maritime Continent

The important climatic elements for this continent are: pressure, temperature, humidity and rainfall, besides its wind systems.

6.2.1 Pressure

The annual variation of surface pressure is very small over the Maritime continent, but not quite so over the continents which lie to its north and south.

During northern winter (December–February) when maximum insolation is in the southern hemisphere, a ‘heat low’ develops over the continent of Australia and an extended trough of low pressure over the SW Pacific in the region of New Guinea, while a series of intense high pressure cells develop over the subtropical belt of the continent of Asia. These pressure distributions bring about a pressure gradient across the Maritime continent from northern to southern hemisphere.

During northern summer (June–October), the pressure field is reversed with development of a series of deep 'heat lows' over Asia and an intense high pressure cell over Australia. The pressure gradient is then from southern to the northern hemisphere.

The impact of the above-mentioned large-scale seasonal changes of pressure, however, appears to be limited to only the northern and southern parts of the Maritime continent. Near the equator, the pressure field is rather flat with only a weak gradient from the winter to the summer hemisphere.

6.2.2 Temperature

The atmosphere over the Maritime continent is generally warm throughout the year. However, some seasonal variations do occur, mostly over the islands which lie in the extreme northern and southern latitudes, which come under the direct influence of the large-amplitude oscillations of temperature from one season to the other.

An example of this influence is given in Table 6.1 which presents the average monthly temperatures during bi-monthly periods of the year in the main islands of the Philippines, viz., Luzon, Visayas and Mindanao.

It may be seen from Table 6.1 that the seasonal variation of temperature in Luzon Island which is closer to East Asia mainland is much larger than that of Mindanao which is farther away.

Similar differences in seasonal variation of temperature may also be seen between Indonesian Islands which are closer to the landmass of Australia than those located farther away.

The seasonal variation of temperature in the Indonesian island of Sumatra is found to be much larger than that of any of the other islands of Indonesia, except, perhaps, Irian Barat for which no data are available. But it is well-known that during northern winter, the island of New Guinea as a whole being near the equator registers very high temperatures, similar to those over Northern Australia.

Table 6.1 Average monthly temperatures (°C) during bi-monthly periods for 42 stations in the Philippines, averaged over the islands of Luzon, Visayas and Mindanao Number of stations averaged in each island is given in bracket

	Month					
Island	J-F	M-A	M-J	J-A	S-O	N-D
Luzon (19)	25.1	27.0	28.2	27.5	27.1	25.7
Visayas (14)	26.3	27.5	28.1	27.5	27.4	26.8
Mindanao (9)	26.3	27.2	27.4	27.0	27.0	26.7

6.2.3 Relative Humidity and Cloudiness

A high level of relative humidity, varying from 75 to 85%, prevails over the Maritime continent throughout the year. The seasonal variations are small. Mean monthly cloudiness over the continent is also moderate to high, varying from 4 to 6 oktas, with little seasonal variation.

6.2.4 Rainfall

Rainfall is by far the most important climatic element of the Maritime continent.

Its space-time distribution depends upon several climatic factors which we shall discuss in the next section. Tables 6.2 and 6.3 show the average monthly rainfall during bi-monthly periods in the main islands of the Philippines and Indonesia respectively.

Table 6.2 Distribution of average monthly rainfall (mm) during bi-monthly periods in the Philippine islands (number of stations averaged for each island is indicated in bracket). Yearly total is given at the end

	Months						
	J–F	M–A	M–J	J–A	S–O	N–D	Year
Luzon (20)	107	89	214	384	315	252	2724
Visayas (14)	149	95	189	240	257	266	2392
Mindanao (10)	167	140	202	215	221	230	2350

Table 6.3 Average monthly rainfall (mm) during bi-monthly periods at selected island/stations in Indonesia, 1931–1960

	Months						
Island/stations	J–F	M–A	M–J	J–A	S–O	N–D	Year
Sumatra/							
Medan	134	140	173	190	232	217	2174
Padang	306	382	315	300	516	563	4764
Palembang	260	297	142	94	144	304	2480
Djawa/							
Djakarta	388	171	105	56	85	175	1760
Surabaja	303	250	104	30	27	203	1837
Borneo/							
Balikpapan	178	234	242	252	174	218	2597
Band-jarmasin	283	264	150	108	135	258	2393
Sulawesi/							
Menado	396	270	255	208	211	336	3352
Timor/							
Kupang	327	176	27	3	5	110	1297
Moluku/							
Ambon	128	193	541	537	210	172	3457

From the above tables, it is found that many of the island stations in Indonesia have more rainfall during southern summer than winter. Notable among these stations are Palembang in Sumatra, Djakarta and Surabaja in Djawa, Bandjarmasin in Borneo, Menado in Sulawesi and Kupang in Timor. Exceptions are Medan and Padang in Sumatra, Balikpapan in Borneo and Ambon in Maluku which experience more rain during southern winter than summer.

An interesting aspect of rainfall at Padang which is located on the western coast of Sumatra facing the Southeastern Indian Ocean and at Palembang located on the eastern coast is that both experience two peaks in rainfall, once during northward movement of the monsoon and the other during the southward movement.

According to Table 6.3, Padang in Sumatra appears to have the highest recorded annual rainfall of 4764 mm at a station in Indonesia. But, of course, no record exists for rainfall in Irian Barat where rainfall may be much higher, since its mountains are affected by the Southwest Pacific Convergence Zone (SPCZ) almost throughout the year. In the Philippines (Table 6.2), more rain falls during northern summer than during winter in all the main islands.

6.3 Factors Affecting the Climate of the Maritime Continent

Several factors appear to affect the climate of the Maritime continent. Important among these are:

1. Geographical location and topography;
2. Ocean currents;
3. Equatorial trough, ITCZ and Monsoons;
4. SPCZ;
5. Depressions and cyclones/typhoons.

6.3.1 Geographical Location and Topography

Geographically, the Maritime continent is located in a more or less NW-SE orientation between the two large continents of Asia and Australia. However, being the larger continent, Asia appears to have somewhat greater influence on the climate of the Maritime continent than Australia during both winter and summer. It is also influenced by conditions in the world's two largest oceans, the Pacific Ocean to the north and east and the Indian Ocean to the west and south.

Almost every large island of the Maritime continent has mountain systems, many of which are volcanic. Through their thermal and mechanical effects, they not only control the direction of airflow but also influence the distribution of rainfall.

6.3.2 Ocean Currents

For a fuller understanding of the climate of the Maritime continent, it is necessary to know the impact of ocean currents on the circulation of the atmosphere over the region. According to oceanographers (e.g., Sverdrup, 1943), the warm North Equatorial ocean current driven by the northeast tradewinds on arriving at the Philippine coastal basin divides itself into two parts: one moving northwestward along the east coasts of Visayas and Luzon islands and turn into the well-known Kuroshio current and the other turning southward around the coasts of Visayas and Mindanao and then eastward to form the eastward-flowing warm Equatorial countercurrent. On the western coasts of these islands also, there is a similar division of the ocean currents driven by the monsoon winds, one turning northward along the coast of Luzon and the other turning south or southeastward along the coasts of Visayas and Mindanao islands.

The above-mentioned ocean currents keep the average ocean surface temperature around the Philippine islands relatively high at 27.3°C, as compared to the average m.s.l. air temperature of 26.9°C at landstations in the area (Selga et al., 1931). Observations also reveal that the variability of water temperature in the area decreases from north to south. For example, the annual range of variation of water temperature in the Bashi and Balintang channels north of Luzon is 7°C, but it drops to 5°C in the South China Sea and about 4°C in all the seas south of Luzon.

The warm sea surface temperature around the Philippine islands maintains high convective activity over the region. It is also believed to be responsible for frequent occurrence of instability thunderstorms, cyclogenesis and high frequency of development of typhoons over the area, and in general increase summer monsoon rainfall over the Maritime continent.

6.3.3 Equatorial Trough, the ITCZ and Monsoons

6.3.3.1 The Equatorial Trough and Its Movement

It is well-known that the equatorial trough of low pressure which acts as a heat source undergoes a seasonal movement following the seasonal movement of the Sun. The seasonal movement of the sun creates differential heating and an isallobaric gradient in the meridional direction. The equatorial trough of low pressure which is usually located over the ocean is forced by the background isallobaric gradient to move in the direction of the gradient. Now, the isallobaric gradient may occur between two neighboring parts of land, or ocean, or between land and ocean.

In the Maritime continent, because of the distribution of land and ocean, the only viable route for movement of the Equatorial trough of low pressure from one hemisphere to the other is across the landmasses of Southeast Asia, i.e., via the western Indonesian islands of Djawa and Sumatra, Malayasia, Thailand, Vietnam and mainland China.

6.3.3.2 ITCZ

Since the tradewinds of the two hemispheres converge into the circulation around the equatorial trough of low pressure, forming the ITCZ on its equatorial side and the TCZ in the poleward side (see Fig. 1.4), the ITCZ and its associated monsoon current will follow the same land route in moving from one hemisphere to the other as the equatorial trough. This is well borne out by Fig. 6.2, due to Flores and Balagot (1969), showing the mean monthly locations of the ITCZ during its northward and the southward movements across the equator.

It may be noted that the ITCZ reaches its southernmost position near the north coast of Australia sometime in February and northernmost position in the East China Sea in July. Starting from the south, its movement is slow till about April when it lies evenly poised along the equator. From May onward, however, a dramatic change appears to occur in its location. Its western part (west of about 120°E) comes under the influence of a series of ‘heat lows’ over southeast Asia and moves rapidly northward through Thailand and Vietnam to the southern part of China, while the eastern

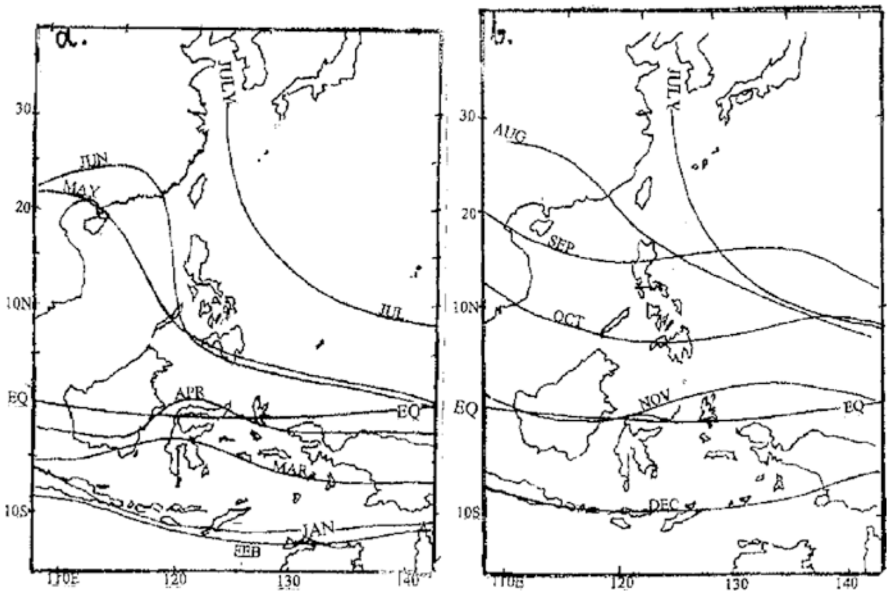

Fig. 6.2 Mean monthly locations of the ITCZ over the Maritime continent and neighborhood during its (**a**) northward advance between January and July, and (**b**) southward retreat between July and December (after Flores and Balagot, 1969)

part moves slowly over the ocean toward the Philippine Islands. The differential movement continues till July when the ITCZ on the two fronts reaches its northernmost location. The return journey appears to be traversed very much by the same route, though somewhat tardily. It is back to its equatorial location in November. From there, its western part moves rapidly across the Indonesian islands to converge into the circulation around the 'heat low' over the Australian continent during January-February.

6.3.3.3 Monsoons

The Maritime continent experiences monsoon wind systems almost throughout the year, with wind directions reversing between winter and summer, as shown in Fig. 6.3(a) and (b) respectively.

(a) Northern Winter Monsoon: During northern winter, N/NE-ly winds diverging from the strong anticyclonic circulation around the Siberian high pressure area, converge into the northeasterly tradewinds which blow over the tropical North Pacific Ocean along a line oriented in a NE-SW direction in the vicinity of the Philippine Islands. However, over most parts of the western North Pacific Ocean, diverging winds from the Asiatic anticyclone appear to cross the equator and blow as the NW-ly tradewinds and converge into the heat low circulations over Northwestern Australia and New Guinea area.

On account of their long travel over warm equatorial oceans, both the aircurrents pick up enough heat and moisture from the underlying ocean surface before they arrive at the convergence zones. At the convergence zones they produce penetrative convection, heavy clouding and precipitation, which are easily detectable in satellite visible and infrared cloud imagery. Islands of the Maritime Continent with large mountain ranges facing these winds experience heavy rainfall on their windward sides.

(b) Northern Summer Monsoon: From about late-April onward, a series of 'heat lows' develop over the landmasses of Southeast Asia, from Malayasia north-northeastward via Indo-China peninsula to Southern China. A heat low also develops over the Philippine islands area. The aircurrents which converge into these heat low circulations are basically from the equatorial Indian Ocean, both north and south of the equator and the western Pacific Ocean. They travel over the Maritime Continent to converge into these heat low circulations and produce intense rainfall along the ITCZ and light to moderate rainfall along the TCZ.

6.3.3.4 SPCZ

The Southwest Pacific Convergence Zone (SPCZ) is a narrow but prominent convergence zone between the SE tradewinds of the southern hemisphere and the heat low circulation over the New Guinea area, extending eastsoutheastward across the Coral Sea in equatorial SW Pacific Ocean region (see Fig. 6.3). It is associated with a warm trough of low pressure over the oceanic area. It appears as a prominent

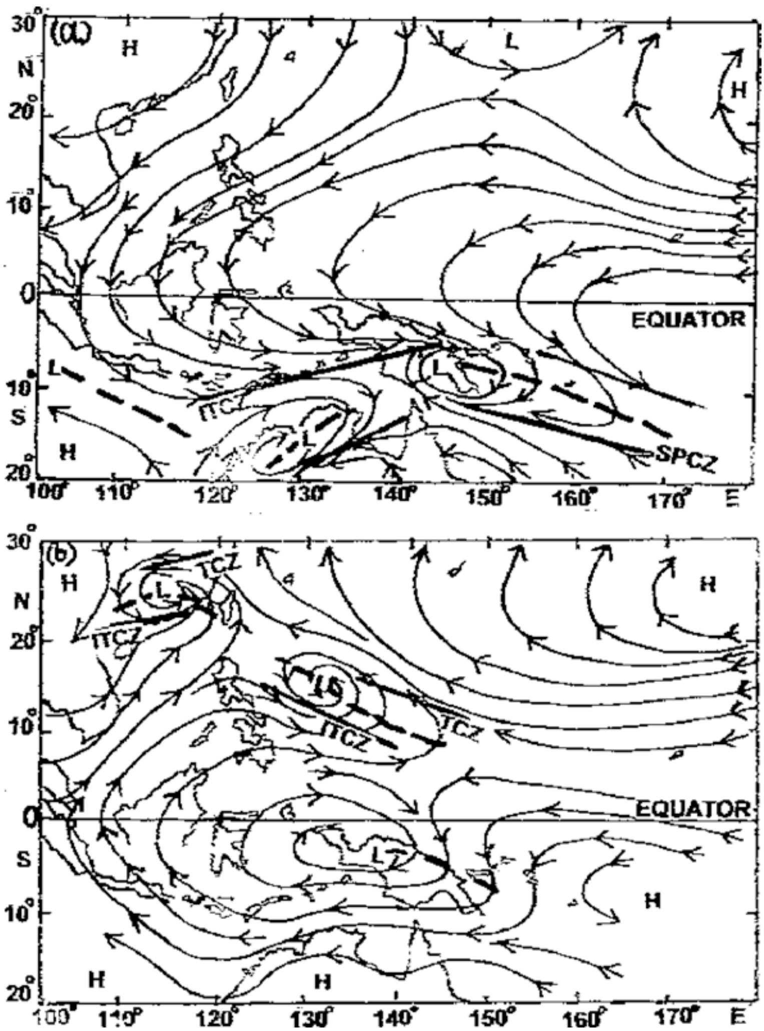

Fig. 6.3 Low level tradewind circulations and convergence zones over the Maritime continent and neighborhood during northern (**a**) winter, and (**b**) summer

cloud band in satellite cloud imagery almost throughout the year and constitutes a quasi-permanent heat source for the tropical circulation. However, its location and intensity vary with season, being in a more southerly location and more intense and active during southern summer. As of to-day, no completely satisfactory explanation has been offered regarding the origin and movement of this convergence zone. Kiladis et al. (1989) who carried out a GCM experiment on the origin of the SPCZ using the ECWMF T21 model found that the removal of the Australian or the South American continent or both had no effect on the location and orientation of the

SPCZ, though it caused a loss of intensity of the convergence when the continental influences were removed. A plausible explanation offered by them regarding its orientation was that ‘the eastsoutheastward orientation of the SPCZ into the SW Pacific Ocean is primarily due to its interactions with the midlatitude circulation rather than to the presence of continental boundaries or oceanic upwelling in the eastern South Pacific’.

6.3.3.5 Tropical Cyclones/Typhoons

Every summer, a number of tropical cyclones/typhoons develop in the ITCZ which lies close to the Philippines over the western North Pacific and affect the climate of the Maritime continent. Easterly waves moving into this area undergo explosive cyclogenesis/development for the reasons discussed in 2.10 and 2.11. After development, most of them move northwestward towards the east coast of China. But a large number of them recurve northeastward from near the island of Taiwan and affect Korea and the islands of Japan and North Pacific Ocean. Some cyclones developing over the South China Sea move westward across Vietnam and countries of Southeast Asia where they cause high winds and extremely heavy rain. Storm surges associated with most of these disturbances inundate large coastal belts and floods in many areas.

The word ‘typhoon’ in Chinese means the ‘Big wind’. It is the typhoons that cause maximum loss of life and damage to property by their hurricane-speed winds, torrential flood-producing rain and coastal inundation by storm surge. Several accounts of the ferocity and dangers associated with these typhoons are available (e.g., Algue, 1904; Gherzi, 1930). For example, according to Tannehill (1927), the number of people who died at Haiphong in the typhoon that hit the East coast of China in 1881 was 300,000.

Tropical cyclones usually weaken after landfall and few persist after moving beyond about 500 km from the coast. However, remnants of a few westward-propagating ones may survive to emerge over the Bay of Bengal.

An interesting study by Chin (1958) compiled the statistics of the number of tropical cyclones that passed through each square of 2.5° latitude–longitude over the northwest Pacific and the China seas during August of a 70-year period, 1884–1953, presented in Fig. 6.4.

A monthly breakup of the average number of tropical cyclones within 5–30°N and 105–150°E during the same 70-year period is given in Fig. 6.5.

Figure 6.5 which includes tropical cyclones of varying intensity, ranging from weak depressions to mature cyclones (or typhoons), shows that annually about 22 tropical cyclones form over the region of northwestern Pacific and the China seas. Of these, most occur between July and October. With improvement in observation, a more reliable statistics has been available in recent years. For example, during the period 1947–1964, the average number of cyclones detected per year over the same area was found to be 31 with a maximum of 45 in 1961 and a minimum of 20 in 1951.

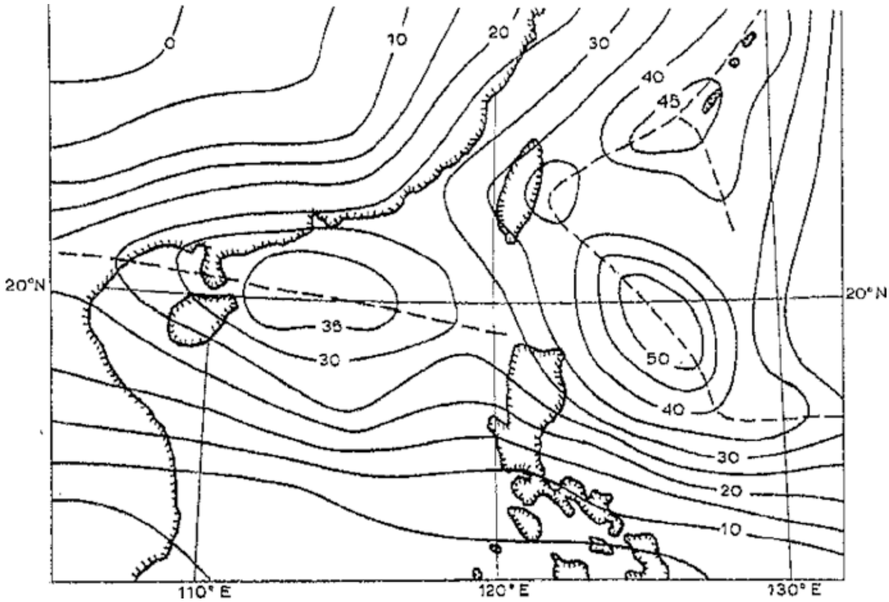

Fig. 6.4 Number of tropical cyclones passing through each square of 2.5° latitude–longitude over the northwest Pacific and the China seas during August in a 70-year period, 1884–1953. *Broken lines* are axes of maxima (after Chin, 1958)

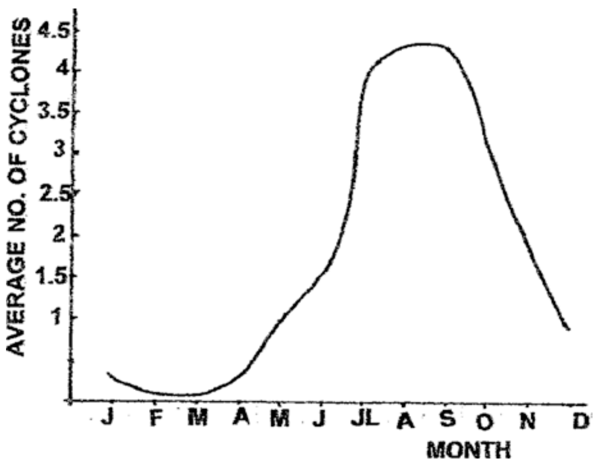

Fig. 6.5 Monthly distribution of the average number of tropical cyclones

6.4 The Maritime Continent – A Heat Source

Attempts have been made to identify the Maritime continent as a heat source or sink by using one or more of the well-known characteristics associated with the ITCZ. Flores and Balagot (1969) used the low-level convergence of airflow and precipitation for the purpose. Upper level divergence derived from computed fields of velocity potential has been used by a number of workers (e.g. Ding and He, 1984; Krishnamurti and Surgi, 1987; Murakami, 1987a).

Chen and Li (1981) used the energy balance equation to compute the distribution of heat sources and sinks over the Asia-Australia region. They used the expression,

$$HS = R_{\infty} - R_0 - SC + LH$$

where *HS* denotes heat source, R_{∞} is the net radiation at the top of the earth's atmosphere, R_0 is the radiation balance at the earth's surface, *SH* is sensible heat and *LH* is latent heat. Their results for the month of July are shown in Fig. 6.6.

Murakami (1983) used the 3-hourly infra-red radiation data from a GMS-1 geostationary satellite which was positioned directly over the Maritime continent (0, 140°E). The IR data were compiled in terms of equivalent blackbody temperature, T_{BB}. They were further edited on every 1° latitude-longitude square mesh so that a histogram could be prepared to yield a mean value and a standard deviation, σ_{B}, to take account of the spatial variability of the original T_{BB} observation (about 5 km in resolution) within the mesh. He empirically proposed that a value of σ_{B} larger than 5 K can be regarded as a convective area. To measure convective activity, he used an intensity index I_{c}, based on cloud-top temperature and temperatures at two standard atmospheric levels. This index enabled him to distinguish between the radiation emitted from tops of large convective clouds and that from low level clouds or cloud-free areas.

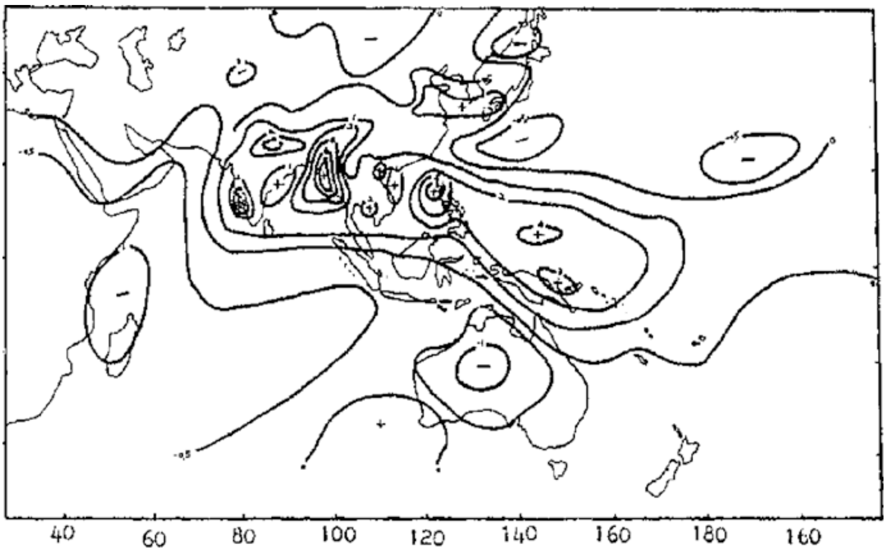

Fig. 6.6 Distribution of mean July heat sources (+) and sinks (–) over the Maritime Continent and adjoining continents and oceans (Chen and Li, 1981)

He defined the index, I_c, by

$$I_c = (T_c - T_{400}) \times 10/(T_{trop} - T_{400})$$

where T_c denotes the mean cloud-top blackbody temperature, and T_{400} and T_{trop} are atmospheric temperatures at 400 mb and tropopause level respectively.

It is easy to see that the value of I_c is zero at 400 mb but increases directly with the height of the cloud top above the 400 mb surface.

The horizontal distributions of monthly mean values of I_c for December 1978 and June 1979, as computed by Murakami (1983, 1984), are shown in Figs. 6.7 and 6.8 respectively.

Murakami's computed values of I_c for December 1978 (Fig. 6.7) reveals three prominent heat sources over the Maritime Continent, one in the near-equatorial region between longitudes 110 and 120°E, the second in the Irian Jaya area between 130 and 140°E, and the third over the Southwestern Pacific Ocean east of about 160°E. It appears that these heat sources may be related to the three regions of cross-equatorial monsoon flows into the southern hemisphere in December (see Fig. 7.8).

The distribution of Murakami's computed values of mean heat sources and sinks for June, 1979, appears to be in substantial agreement with that computed by Chen and Li for July. Further, Murakami's results show the seasonal migration of heat sources and sinks between Australia and Eastern Asia.

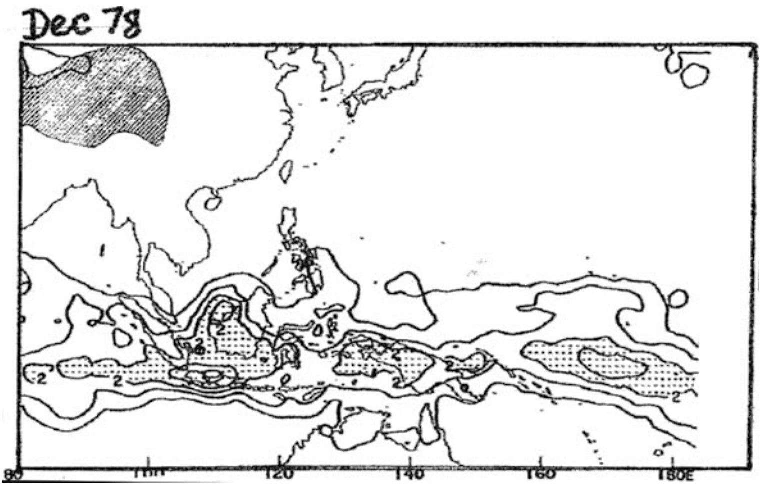

Fig. 6.7 Mean monthly distributions of I_c over the Maritime continent and neighborhood for December 1978. Contours are drawn every 0.5 unit, starting from 1.0. Values greater than 2.0 are *shaded*. The hatched area roughly denotes the plateau above 3000 m (after Murakami, 1983, 1984)

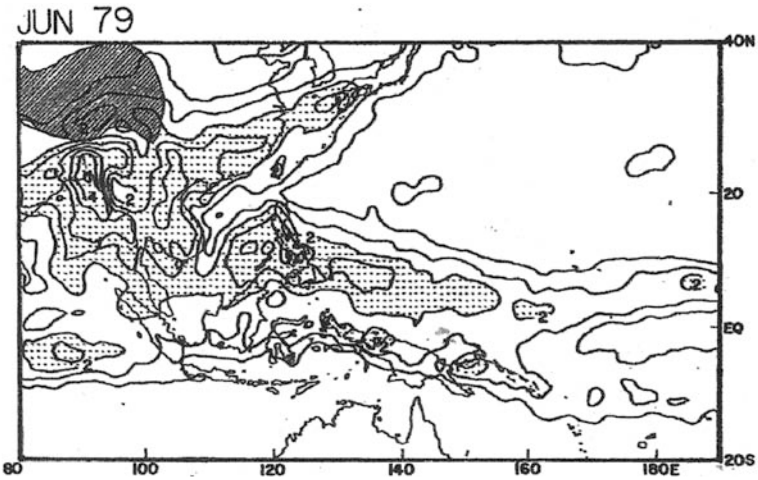

Fig. 6.8 Mean monthly distributions of I_c over the Maritime continent and neighborhood for June 1979. Contours are drawn every 0.5 unit, starting from 1.0. Values greater than 2.0 are *shaded*. The hatched area roughly denotes the plateau above 3000 m (after Murakami, 1983, 1984)

Murakami's study reveals a prominent heat source in the region of the SW Pacific Convergence Zone (SPCZ) during both summer and winter. Another such heat source appears over the South Equatorial Trough (SET) area of the eastern Indian Ocean. The most intense heat source appears to be located over the northeastern part of the Bay of Bengal during the northern summer.

6.5 The Maritime Continent and the ENSO

It is not always that the Maritime continent and the adjoining equatorial eastern Indian Ocean act as a heat source with a positive zonal SST anomaly, while the equatorial eastern Pacific Ocean or the equatorial western Indian Ocean acts as the heat sink. In an El Nino year, which comes usually after every 2–7 years, the roles are reversed and the Maritime continent acts as a heat sink with a negative SST anomaly, while the region of positive SST anomaly switches over to the eastern side of the Pacific ocean near the coast of South America and the western side of the equatorial Indian Ocean. The southern oscillation index over the Maritime continent and neighboring regions becomes highly negative in such a year. The change has disastrous effects on atmospheric circulation and associated rainfall over a vast region of the western Pacific and adjoining Australia, India and China where large deficiencies of rainfall lead to widespread droughts and famine conditions. Such reversals in temperature anomaly between the western and the eastern parts of the equatorial ocean are observed in other equatorial ocean basins as well.

In an interesting study using the IIOE (1963–1965) data, Ramage (1968) found that in January 1963, the Maritime continent served as an active heat source as indicated by excessive rainfall and thunderstorm activity over the continent. The heat generated over the continent was efficiently transported by the Hadley circulation to cause an unusually strong subtropical jetstream over East Asia. By contrast, January 1964 was a drought year for the continent with deficient rainfall, inefficient poleward transport of heat and a weaker meridional circulation. According to him, 'most winters over the western Pacific and southeast Asia fluctuate between situations typical of January 1963 and January 1964.'