The Character of Rainfall in the Indonesian Monsoon *)

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Abstract

Indonesia lies between two continents (Asia and Australia) and two oceans (Pasific and Hindia). The differences in physical properties between ocean and continent cause monsoon circulation. As a monsoonal region, Indonesia suffer heavy rains especially in hemisphere summer and autumn. Orographic effect in monsoonal region able to increase the amount of rainfall in the windward slope.

Monsoonal areas are influenced by monsoon winds. In southern hemisphere Indonesia, west monsoon is more humid than east monsoon, so that the monthly rainfall distribution indicates a maximum in west monsoon season and a minimum in east monsoon season. The Indonesian monsoon is a part of the East and Southeast Asian monsoon. Monsoon can be reinforced by local winds to yield the amount of rainfall abudantly.

Convective cloud, such as cumulonimbus yields heavy rains and sometime hailstones. Convectional rainfall occurs after the maximum insolation. At night the convection is more active over the sea than that over the land. Under the influence of maritime area, the convectional rainfall able to occur in the morning. Heavy rains are frequently occurred in hemisphere summer and autumn compared to in hemisphere winter and spring.

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1. Introduction

The Indonesian region represents the longest island arc in the world that extends from $7^0 20'$N to 14^0S and 92^0E to 141^0E with total coast line length of 43,670 miles or 80,791 km. From meteorological aspects, the Indonesian maritime continent has complexities in weather and climate phenomena. The atmosphere above the Indonesian region is very complex and its cloud formation is unique.

As Indonesia is a mountainous archipelago, its weather and climate are influenced by the local wind systems, like land–sea breeze and mountain–valley breeze. The daily wind system is very important in climatology because it occurs regularly and frequently. This case happens in several places in Indonesian archipelago. The heat change between night and day time is the primary driving force of the daily wind system, on account of a strong difference in the heat between the air over the land and over the sea (land and sea breezes) or between the air over uplands and lowlands (valley and mountain winds). Because the duration is limited, then the daily wind system is usually effective only on relatively small areas, therefore, this wind system mostly causes local weather variations.

Rainfalls are definitely one important factor for all social aspects in agriculture, hydrology, and others. Rainfalls in highlands have a potential energy that can be transformed into other energy such as electric energy. Therefore, a sensible awareness toward the environmental conservation is very craved for in order that every raindrop falling into the ground can be well and appropriately managed.

Indonesia lies in the equatorial region defined as a region bounded by latitude 10^0N and 10^0S or by Earth's vorticity $f = 2\ \Omega \sin \phi = 2 \times 7.29 \times 10^{-5} \times \sin 10^0 = 2.5 \times 10^{-5}\ s^{-1}$, where Ω is the angle velocity of Earth's rotation and ϕ is the geographical latitude. The equatorial region has an energy surplus in all seasons. Figure 1, shows the geographical and meteorological position of Indonesia relative to the surrounding oceans and continents. Symbol ⊗ shows the annual sun migration. On 23 September and 21 March the sun is above the equator, while on 22 June and 22 December the sun is above the latitudes 23.5^0N and 23.5^0S, respectively.

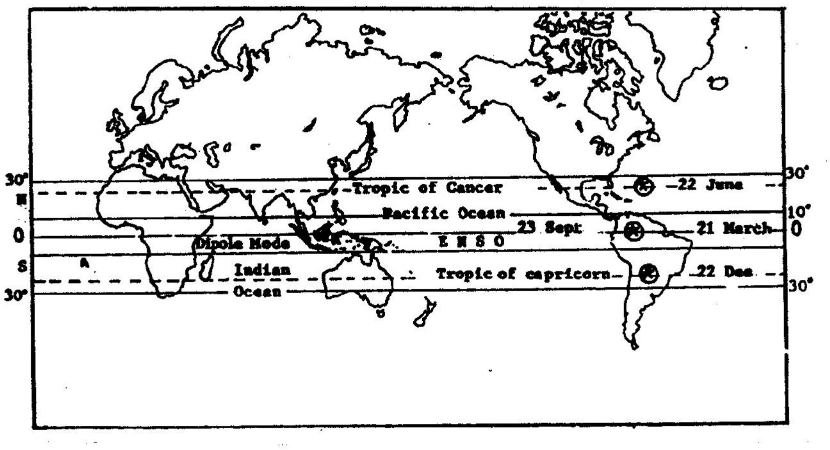

Figure 1. The geographical and meteorological position of Indonesia.

2. The Monsoon Regions

Monsoon wind is caused by the differences in physical properties between ocean and continent; the heat capacity of the ocean is higher than continent. The ocean surface reflects solar radiation more than the continent surface, and the solar radiation can enter into the water deeply with the help of water movement (sea current). On the other hand, the heat on the continent can penetrate down to several centimeters only. The results of this physical property difference is that the ocean heats up slowly when there is solar radiation and cools down slowly with the absence of solar radiation, compared to the continent[1]. As a result, the ocean is cooler during summer and warmer during winter compared with the continent. The change from winter to summer or vice versa can turn back the direction of the pressure gradient force so that the monsoon wind experiences an inversion of its direction, see Figure 2. The direction of the pressure gradient force is from the continent to the ocean in winter and from the ocean to the continent in summer.

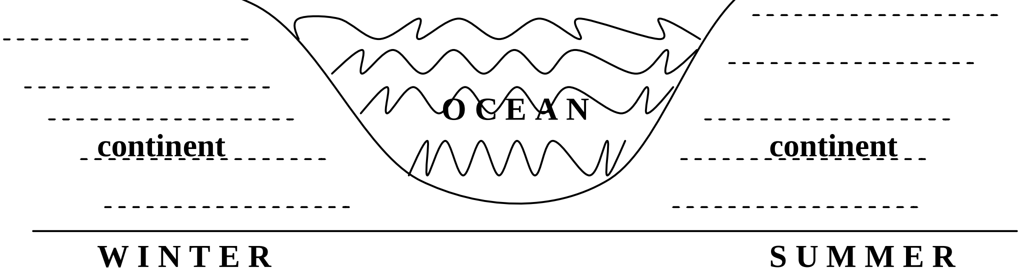

Figure 2. Pressure gradient force (F_p) in winter and summer.

The main characteristics of the monsoon regions are as follows[2] :

- the prevailing wind direction deviates by at least 120^0 between mid winter (January) and mid summer (July).
- the average frequency of prevailing wind direction in mid summer and mid winter is more than 40%.
- the mean resultant winds in at least one of the months exceeds 3 ms^{-1}.
- and less than one cyclone–anticyclone alteration occurs on average every two years in any one month in a 5^0 latitude–longitude rectangle. The monsoon regions of the world according to this set of criteria are shown in Figure 3.

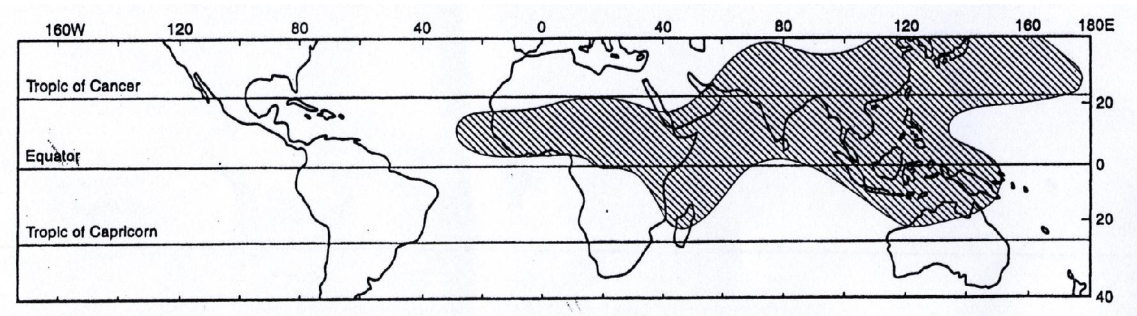

Figure 3. Area with monsoon circulations[2].

Khromov computed the monsoon index by expression as follows[2] :

$$I_m = \frac{F_{jan} + F_{jul}}{2} \qquad (1)$$

where F_{jan} and F_{jul} are frequencies of prevailing wind in January and July, respectively. The deviation of wind direction in January and July at least 120^0. When the monsoon index (I_m) equals 40 percents or more, the area is monsoonal and the rest is nonmonsoonal.

By using equation (1) it is obtained that average monsoon index are 64 and 51 percents for Bandung and Jakarta areas, respectively. These values of monsoon index show that Bandung (6.92^0 S, 107.60^0 E) and Jakarta (6.17^0 S, 106.82^0 E) are monsoonal areas[3].

3. Indonesian Monsoon

Three main monsoon systems have been recognized, these are the African, Asian and Australian monsoon systems. The Asian monsoon is divided into two separate subsystems, namely an Indian monsoon and an East Asian monsoon. The monsoon over East Asia is not simply an eastward extension of the Indian monsoon, but a separate component of the large Asian monsoon system. The important factor for driving the East Asian monsoons is the existence of heat source and sink region over the South China Sea and Australian region. The East Asian monsoon has a very strong cold winter signature, a characteristic not possessed by the Indian monsoon system[4].

The Indonesian monsoon is a part of the East and Southeast Asian monsoon. The direction of wind over the Indonesian region in boreal mid winter (January) and mid summer (July) may be seen in Figure 4. This figure shows paterns of average wind at altitude 2000 ft. In northern hemisphere winter (December, January, February), monsoon wind blows from Siberia region toward Australian continent. During this period go on west to northwest winds over southern hemisphere Indonesia, such as southern Sumatera, Java, Bali, Lombok, Nusa Tenggara up to Papua. Boreal winter monsoon is called west monsoon and the season is called **west monsoon season**, while over northern hemisphere Indonesia, such as northern Sumatera and West Kalimantan, monsoon wind come from northeast direction called northeast monsoon and the season is called **northeast monsoon season**.

In boreal summer, on the contrary wind blows from Australian continent toward Asian continent. In the region extends from the end of southern Sumatera, Java, Bali, Lombok, Nusa Tenggara up to Papua, wind direction from east to west called east monsoon and the season is called **east monsoon season**, while over northern hemisphere Indonesia, wind blows from southwest toward northeast called southwest monsoon and the season is called **southwest monsoon season**, see figure 4.

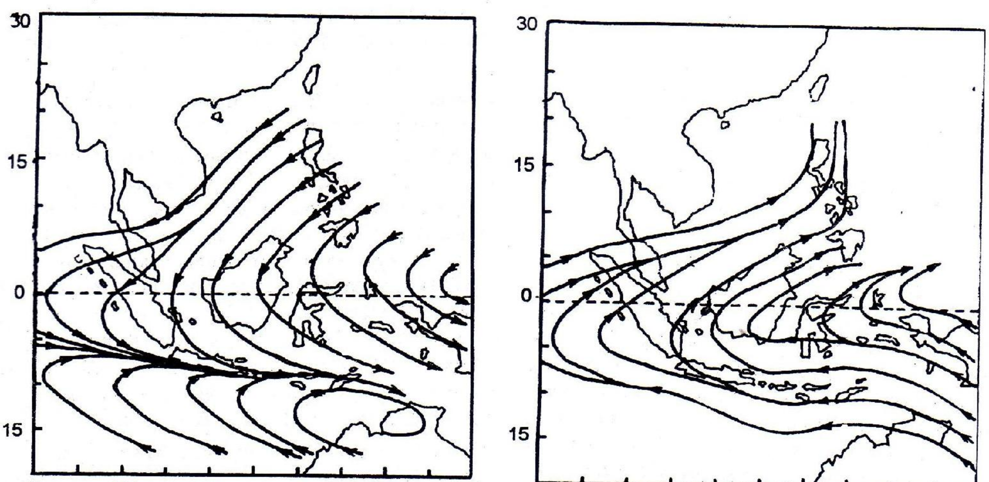

Figure 4. Mean wind patterns in January (left) and July (right)[5].

Table 1. Division of season based on the monsoon in Indonesia[5].

Southern Hemisphere Indonesia		Northern Hemisphere Indonesia	
Season	**Period**	**Season**	**Period**
West monsoon	Dec – Jan – Feb	Northeast monsoon	Dec – Jan – Feb
First transition	Mar – Apr – May	First transition	Mar – Apr – May
East monsoon	June – July – Aug	Southwest monsoon	June – July – Aug
Second transition	Sept – Oct – Nov	Second transition	Sept – Oct – Nov

4. Rainfall in the Indonesian Monsoon

a. Orographic Effect

Monsoons can be reinforced by sea and valley breezes to rise by orographic effect, such as in the Mt. Muria, area, central Java. Stations in this area show the amount of rainfall abudantly, such as at Jepara and Bangsri located in windward slope when in northwest monsoon (December, January, February) and in leeward slope when in southeast monsoon (June, July, August), see Table 2 and Figure 5.

Table 2. Seasonal rainfall in Mt. Muria (1604 m) area, Central Java.

Station	a.s.l.	DJF	JJA	DJF / JJA
Jepara	3 m	1919 mm	107 mm	17.9
Bangsri	80 m	2367 mm	141 mm	19.8

Note : a.s.l : above sea level
DJF : December, January, February
JJA : June, July, August

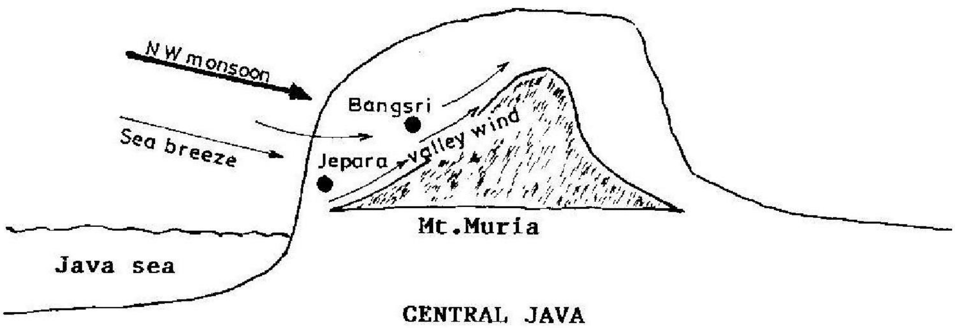

Figure 5. Reinforcement of northwest monsoon by local winds (sea breeze and valley wind) and orographic effect.

b. Convective Cloud and Convectional Rainfall

The troposphere over the Indonesian equatorial region is convectively unstable for all seasons. This case is shown by vertical profiles of equivalent potential temperature (θ_e) from the surface up to the layer of 700 mb. Vertical profiles of θ_e are warmer in the convective clouds compared to in the clear atmosphere condition or in the non convective clouds. Figure 6 shows the vertical profiles of equivalent potential temperature (θ_e) in midsummer (January) and midwinter (July) of southern hemisphere.

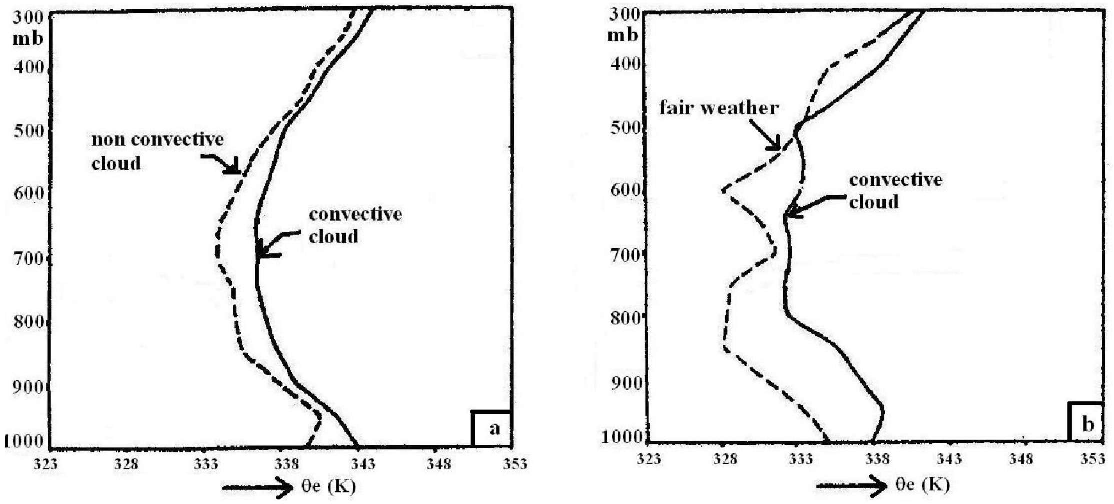

Figure 6. The vertical profiles of equivalent potential temperature (θ_e) over Jakarta in January (a) and July (b).

Convectional rainfall generally occurs over a limited spatial scale, it is therefore characterized by large spatial variability. The spatial scale of convectional rainfall usually depends on convectional cells or thunderstorms form individually, or become organized into weather systems such as squall lines. Convective cloud, because it is formed by rapid updraft, often to great heights in the atmosphere, the precipitation particles are usually in the solid form of hail, see Figure 7.

Figure 7. Cumulonimbus and hailstones in Wamena, Papua (eastern Indonesia), 3 December 2007 (Photo : Metro TV).

Most of convectional rainfall occurs after the maximum insolation or after 12.00 o'clock local time. Convectional rainfall come from convective cloud of cumulus due to unstability of the troposphere through the convectional bouyancy force. Figure 4 shows average amount of 3 hourly rainfall from 00.00 to 24.00 o'clock local time. Convectional rains generally run about one hour or less.

At night, sea is warmer than land, so that the convection is more active over the sea than that over the land. Figure 8 shows the distribution of convectional rainfall in Bandung and Jakarta.

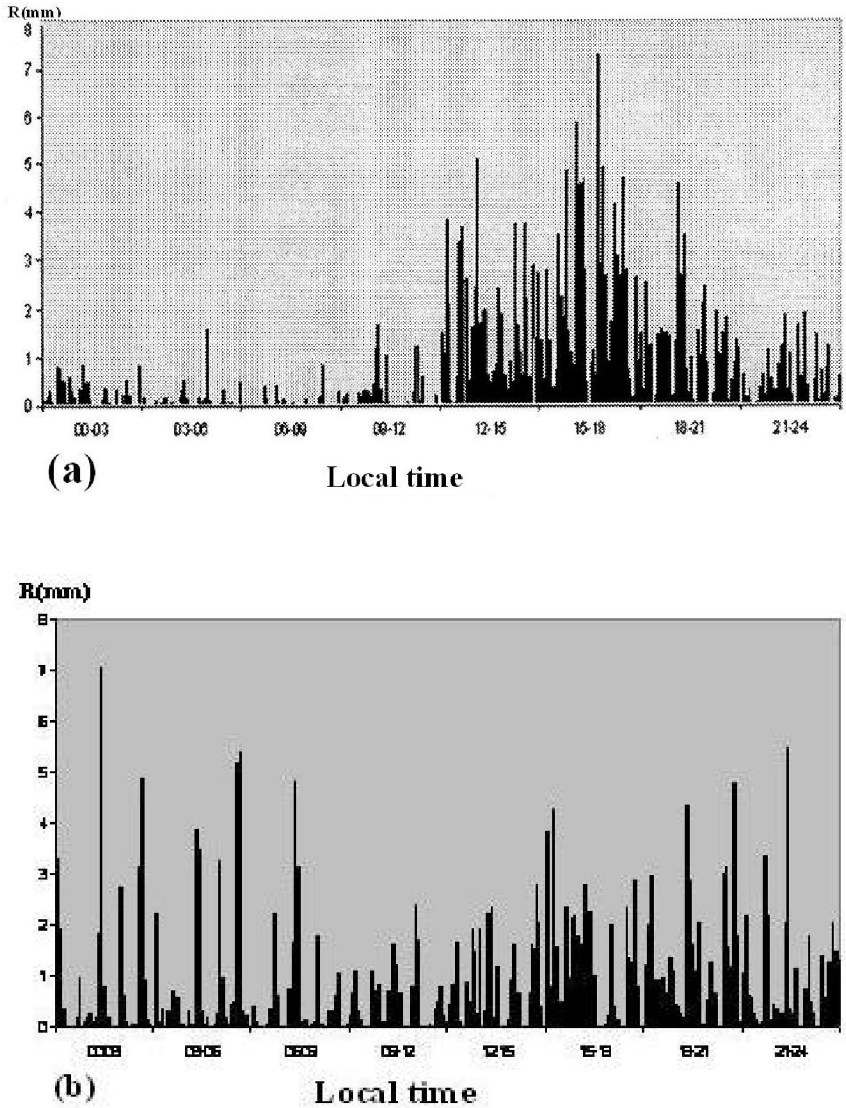

Figure 8. Distribution of 3 hourly rainfall from 00.00 to 24.00 LT in Bandung (a) and Jakarta (b).

Without consider the characteristics of rainfall (from very light rains to heavy rains), the distribution of rainfall shows that rain is frequently occured in summer and autumn compared to in winter and spring of the hemisphere.

Table 3. Frequency distribution of rainfall in Bandung (Southern Hemisphere)

Rainfall Intensity (mm/h)	**D J F summer**	**M A M autumn**	**J J A winter**	**S O N spring**
Year : 2003	F r e q u e n c i e s			
Very light rain (0,1 – 1,0)	9	3	0	2
Light rain (1,1 – 5,0)	37	21	2	34
Normal rain (5,1 – 10,0)	25	11	1	17
Heavy rain (10,1 – 20,0)	8	12	7	10
Very heavy rain (> 20,0)	2	16	1	6
Year : 2004	F r e q u e n c i e s			
Very light rain (0,1 – 1,0)	4	2	1	2
Light rain (1,1 – 5,0)	45	20	5	12
Normal rain (5,1 – 10,0)	18	22	7	11
Heavy rain (10,1 – 20,0)	19	6	4	5
Very heavy rain (> 20,0)	5	13	0	5

c. Monthly rainfall distribution

There are three main types of rainfall pattern over Indonesia, namely : i). Monsoonal type, the distribution of monthly rainfall is influenced by monsoon Asia. ii). Equatorial type, the distribution of monthly rainfall is affected by equinoxes, so the distribution shows double maxima. iii). Local type, rainfall pattern is influenced by local condition and monthly rainfall distribution is the opposite of monsoonal type[2]. Figure 9 shows the distribution of monthly rainfall in Semarang, Pontianak and Ambon as monsoonal, equatorial and local types, respectively.

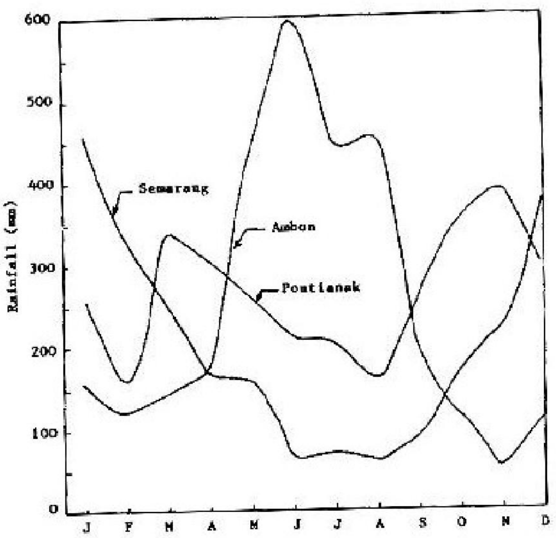

Figure 9. Monthly rainfall distribution for Semarang, Pontianak and Ambon.

d. Daily extreme rainfall in Bandung basin

In general, the amount of daily extreme rainfall is less than 100 mm, only a few months have the amount of daily extreme rainfall more than 100 mm, such as March 1991, March 2003, and February 2005. In east monsoon season, several months have zero rain days, such as in 1987, 1991, 1994, 1995, 2006, and 2007, see Figure 10. From rainfall data, it is applied to predict the following daily extreme rainfall by ANFIS : adaptive neuro fuzzy inference system model[6,7].

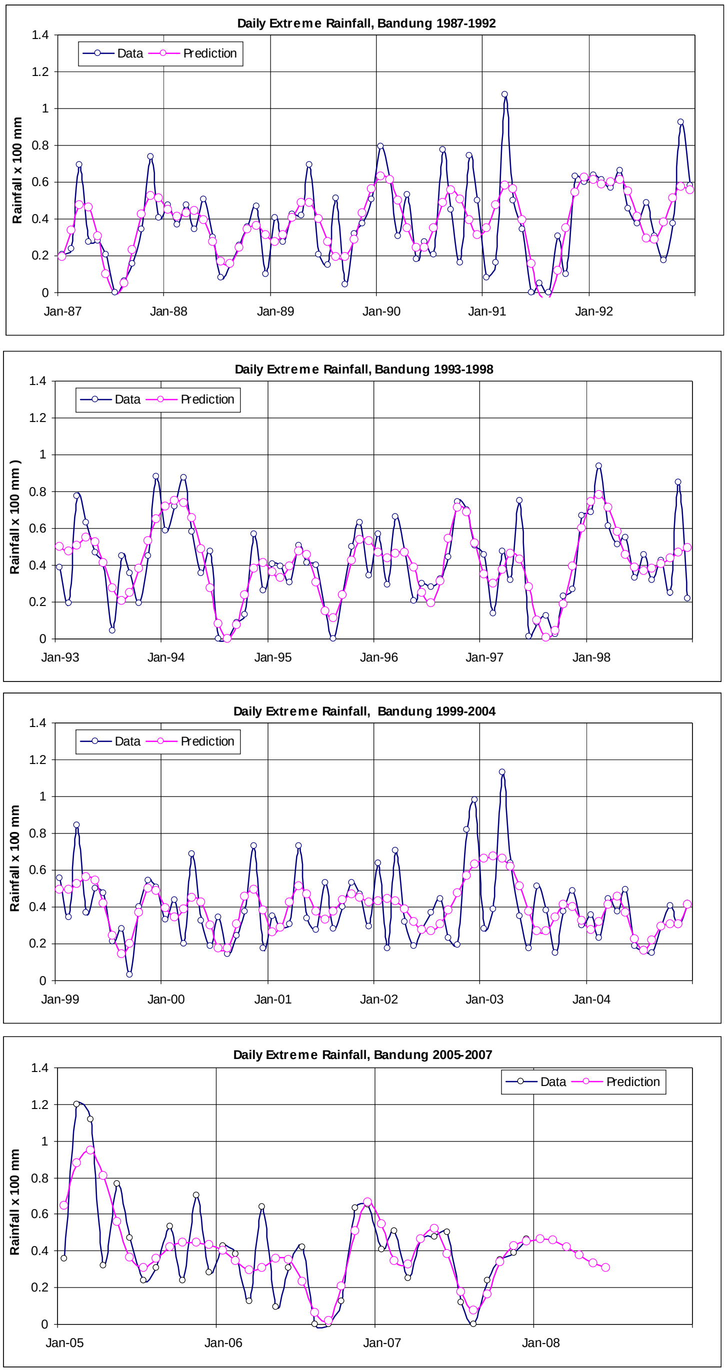

Figure 10. The amount of daily extreme rainfall (1987 – 2007) in Bandung.

Conclusions

The differential seasonal heating of the ocean and continent produce atmospheric pressure changes which yield seasonal wind reversals called the monsoon. The mixture of sea, land and the montainous character of most Indonesian islands, creats a large variety of local climate.

Due to the Earth's rotation, air mass in monsoon moves in curved paths. Northeast monsoon in northern hemisphere Indonesia become northwest or west monsoon in southern hemisphere Indonesia. On the contrary southeast monsoon become southwest monsoon.

Convective clouds and convectional rains are dominant in Indonesian monsoon. Convective clouds yield heavy rains, sometimes hailstones and lightning. Most of convectional rainfall occurs after the maximum insolation (12.00 o'clock local time). Under the influence of maritime area, convectional rainfall able to occur in the morning. The amount of daily extreme rainfall in Bandung basin is usually les than 100 mm, only a few months is greater than 100 mm.

Acknowledgements

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