Journal of the Meteorological Society of Japan, Vol. 80, No. 2, pp. 285–310, 2002

Spatial and Temporal Variations of the Rainy Season over Indonesia and their Link to ENSO

HAMADA Jun-Ichi

Frontier Observational Research System for Global Change (FORSGC), Japan Marin Science and Technology Center (JAMSTEC), Yokohama, Japan

Manabu D. YAMANAKA

Frontier Observational Research System for Global Change (FORSGC), Japan Marin Science and Technology Center (JAMSTEC), Yokohama, Japan
Graduate School of Science and Technology, Kobe University, Kobe, Japan

Jun MATSUMOTO

Department of Earth and Planetary Science, University of Tokyo, Tokyo, Japan

Shoichiro FUKAO

Radio Science Center for Space and Atmosphere (RASC), Kyoto University, Uji, Japan

Paulus Agus WINARSO

Meteorological and Geophysical Agency (BMG), Jakarta, Indonesia

and

Tien SRIBIMAWATI

Agency for the Assessment and Application of Technology (BPPT), Jakarta, Indonesia

(Manuscript received 29 May 1998, in revised form 7 January 2002)

Abstract

Regional and interannual variations of the rainy season over Indonesia are investigated using *daily* rainfall data during 1961–90. Pentad-mean rainfall data, with a relatively better continuity have been obtained for 46 stations, and the annual and semi-annual cycles of rainfall at these stations have been objectively analyzed by harmonic analysis. The onset of southern-hemispheric spring/summer (SON/DJF) rainy season starts from the Indian Ocean side of Jawa in the middle September, and propagates northward (in Jawa) and eastward (to Nusa Tenggara in middle December). Another route of rainy sea-

---

Corresponding author: Jun-Ichi Hamada, Frontier Observational Research System for Global Change (FORSGC), Japan Marin Science and Technology Center (JAMSTEC), Yokohama, Japan.
E-mail: hamada@jamstec.go.jp

son propagation from Irian Jaya to Nusa Tenggara is observed. The withdrawal of the rainy season starts from western Nusa Tenggara in March, and goes eastward (to eastern Nusa Tenggara), and westward (to Jawa), until late May.

Rainy season onset comes later (earlier) in *El Niño* (*La Niña*) years than the average at most stations (particularly in the south-eastern part of Jawa). Correlations between rainfall amounts at those stations, and the southern oscillation index in SON, are significantly high. However, the rainfall amount throughout a rainy season is not dependent upon the length of the rainy season (between onset and withdrawal) in many areas (except southern Sulawesi). The dominant time scale of interannual variations of rainy season onset during 1961–90 is 2–3 years, which looks somewhat shorter than that during 1910–41.

1. Introduction

The Indonesian region is called "the maritime continent" (Ramage 1968), because this region consists of many islands surrounded by warmer sea water. Convection in general (except for dry season in an *El Niño* year, as will be mentioned later) is more active than in the other tropical regions, which act as the heat engine to drive the east–west circulation. This active convection provides a large amount of rainfall, and geographic and interannual variations of the convection activity, and rainfall, are major evidence of climate variations in the tropics.

Previous studies mainly by Dutch and Australian meteorologists on rainfall variations in the Indonesian maritime continent were based on monthly rainfall data (Braak 1929; McBride 1992). Climatological classification of seasonal rainfall variations was examined by Schmidt and Ferguson (1951). The rainfall atlas of the whole territory of Indonesia was published by the Meteorological and Geophysical Institute (LMG, the predecessor of Meteorological and Geophysical Agency (BMG); see LMG, 1973a, b). They were composed by an averaged annual rainfall, and monthly rainfall maps during 1931–60 (Jawa[1] and Madura) and 1911–40 (others). Based on monthly data during 1879–1941, Eguchi (1983) divided Indonesia (except for Irian Jaya) into mainly three climatic subregions: one rainy season during October–February (Jawa, Bali and Nusa Tenggara), two rainy seasons in a year with the annual maximum during October–February (Sumatera and western Kalimantan), and one or two rainy seasons with the annual maximum during March–July (Eastern Kalimantan, Sulawesi and Maluku). He suggested that geographical, and seasonal variations of Indonesian rainfall, might be governed by the low level westerly wind originated from the Indian Ocean, rather than the location of inter tropical convergence zone (ITCZ).

The rainfall data used in the studies mentioned above were obtained before 1960s, and data after 1960s have seldom been analyzed systematically. The seasonal variations of cloud and wind, such as onset and withdrawal of rainy season, or monsoon over the Indonesia region, have been examined by several authors (Matsumoto 1992b; Tanaka 1994; Murakami and Matsumoto 1994). Other studies by Japanese ecologists examined climatic condition and statistics including those of rainfall (e.g., Inoue and Nakamura 1990; Nakamura 1994), but they were only for selected regions in Sumatera and Jawa without any detailed discussion on meteorological and climatological aspects. Therefore, there are no complete description on climatology over the Indonesia region after 1960s. Some authors have pointed out climate changes, such as temperature and rainfall trend, and their relation with *El Niño* and southern oscillation (ENSO) over the Asia–Australia monsoon region in particular for recent decades (e.g., Nicholls et al. 1996; Shinoda 1998). Since so-called 'global change' is drawing a great interest (both social and scientific), it is important to compare the climatology over Indonesia before and after the 1960s.

It has been well documented that the interannual variability of monthly rainfall in Indonesia is strongly related to ENSO (e.g., Berlage 1957; Berlage 1966; Yasunari 1981; Hackert and Hastenrath 1986; Yasunari and Suppiah 1988; see Allan 1991, for a review concerning

---

[1] In this paper we use the standard spellings in the Indonesian language for geographical names such as Jawa, Sumatera, Kalimantan, Sulawesi and Irian Jaya (corresponding to Java, Sumatra, Borneo, Celebes and New Guinea in English or Dutch spellings).

mainly the Australian region). Nicholls (1981, 1984a) showed a link among surface pressure at Darwin of northern Australia, sea surface temperature around Indonesia, and Indonesian rainfall, from the viewpoint of predictability of the Indonesian climate variations. Ropelewski and Halpert (1987) showed that the rainfall variations all over the world were correlated with ENSO, and that one of the most significant signals of ENSO–related precipitation variation was a rainfall decrease during June–November in the *El Niño* year over Indonesia—Papua New Guinea region. A recent study by Haylock and McBride (2001), based on monthly rainfall data, also shows coherence of interannual variations of seasonal rainfall anomalies in Indonesia, and high correlations with the southern oscillation index (SOI), and those of rainfall during the rainy season (December–February) are clear only in a limited region. Recently, Können et al. (1998) have tried to extend ENSO studies back to the early 19th century, based on old meteorological data such as monthly rainday counts at Jakarta.

Those longer time-scale (seasonal and interannual) variations of Indonesian rainfall must be generated through some modifications of shorter and smaller phenomena which are so-called hierarchical structures, detected in time and space, from satellite cloud observation and/or objective analysis (Nakazawa 1988; Nitta et al. 1992). The Indonesian maritime continent is also the key region for understanding the character and mechanism of hierarchical structure (e.g., McBride 1992; Nitta et al. 1992). The mechanism of organization of cloud clusters may involve effects of complex geographical variations, as well as those of large-scale atmospheric structure and circulation. Nitta et al. (1992) showed that super cloud clusters (SCC), propagating eastward from the Indian Ocean to the western Pacific, were suppressed in the western Indonesia region possibly due to a complex topography in Sumatera. It is also affected by microphysical situations (e.g., Takahashi et al. 1995). Therefore, detailed investigation of temporal and spatial variations of rainfall pattern is strongly required.

However, rainfall characteristics over Indonesia, especially on time-scales shorter than one month, have not been fully studied yet, mainly because of lack of digitized observational data with sufficient reliability, continuity and resolution. Radio Atmospheric Science Center (RASC) of Kyoto University has worked to fill up such a observational gap since 1985 in cooperation with the Agency for the Assessment and Application of Technology (BPPT), and BMG, and the Frontier Observational Research System for Global Change (FORSGC) succeeds to this job since 1999. The present paper focuses on the geographical, and interannual characteristics of seasonal rainfall variations, mainly the southern-hemispheric summer monsoon rainy season, with time-scales less than one month based on *daily* raingauge observations over Indonesia. We also examine the differences of rainfall pattern between *El Niño* and *La Niña* years. The data used in this paper forms a part of a much more complete database of basic meteorological quantities over the whole monsoon region, including the Indonesian maritime continent (see Matsumoto 1992a; Hamada and Sribimawati 1998).

In Section 2, the daily rainfall data and definitions of the rainy season are described. In Section 3, characteristics of mean seasonal rainfall variations over the whole Indonesia region are examined for the recent thirty years (1961–90). In Section 4, we examine the interannual variations of the southern-hemispheric summer monsoon rainy season, and study differences between *El Niño* and *La Niña* years. In Section 5, we compare the climatology of seasonal rainfall variations, and interannual variations of rainy season onset obtained in this study with foregoing studies based on the data before 1960s. In Section 6, conclusions of this study are given.

2. Data and definitions

2.1 Daily rainfall data

Indonesia is one of the first places of scientific meteorological observations in the eastern Asia (see, e.g., McBride 1992; Können et al. 1998). Berlage (1949) collected rainfall data at 4,339 stations in Indonesia, which had been in operation during 1879–1941, from 5 consecutive years. Now BMG is operating or arranging more than 6,000 rainfall stations, and divided them into 39 regions over Indonesia (as of December 1993). Some of the data are collected and recorded in a digital form (since 1980's), at the head office of BMG in Jakarta, but the others are kept only at each provincial offices. We have collected daily rainfall data observed for a thirty-year period from 1961 to 1990, at 157 stations distributed over the whole territory of Indonesia, extending from 95°E to 136°E in longitude and from 5°N to 10°S in latitude (Hamada and Sribimawati 1998).

Because in this study we mainly concern southern-hemispheric summer around which the rainy season in the most parts of Indonesia is known to appear (e.g., LMG, 1973a, 1973b; Eguchi 1983; also see Section 3), we define an *analysis year* starting from 30 June, and ending on June 29, of the subsequent calendar year. We divide one analysis year into 73 pentads; the first pentad (pentad 1) is from June 30 to July 4, and the last pentad (pentad 73) is between June 25–29. Data on February 29 in a leap year has been included into pentad 49 (February 25–March 1).

We have made pentad-averaged daily rainfall amounts, allowing missing data for two days at maximum in each pentad at each station. If any pentad-mean data are lacked in an analysis year at a station, we have omitted all the data in that analysis year from calculations in this study. Finally we have selected 46 stations (as listed in Table 1 and plotted in Fig. 1), at which pentad-mean data have been obtained completely for the 73 pentads, in at least eight analysis years. See Appendix for details.

2.2 *Analysis of annual and semi-annual components of rainfall variations*

In order to obtain mean climatology, the original pentad-mean data described in Subsection 2.1 have been averaged for available years during 1961–90 at each of the 46 stations. The averaged pentad-mean data obtained by this procedure are in general still fluctuated, because the daily rainfall amount is a quite highly fluctuated quantity mainly due to atmospheric disturbances (cloud clusters) with time scales of a few days. In order to obtain smoothed seasonal variations, we apply a running average for every neighboring three pentads.

In this study we fit the smoothed mean pentad data series (obtained by above-mentioned procedure at each station) to an approximated formula defined by a sum of the annual (73-pentad) average, and four harmonics with periods of 73 (annual), 36.5 (semi-annual), 18.25 and 9.125 pentads by the least-square method (cf., Wilks 1995). The difference between the approximated formula, and the original smoothed mean pentad data, is usually sufficiently small in particular for southern-hemispheric stations as shown in the next paragraph, although the location (pentad) of the maximum of the approximated formula is much shifted from the actual one at stations in the vicinity of the equator, which do not have clear seasonal variations. As long as a station has a clear seasonal variation, we may obtain a climatological classification objectively by using amplitudes of the annual and semi-annual components, based on the harmonic analysis mentioned here (see Subsection 2.3).

Figure 2 shows an example of the harmonic analysis mentioned above. This is the case for Jakarta (6°10′S, 106°49′E), Jawa. Because in this case the annual component is dominant in seasonal variations (as will be mentioned in Subsection 3.1), the maximum of the annual component (dashed-dotted curve) looks roughly closely located near that of the running-averaged pentad-mean data (bars). Adding semi-annual (dashed), and much shorter two components, we obtain a (solid) curve fitting well to the pentad-mean data, which is not only for Jakarta but also for the other stations. This implies that contributions by components with periods between 3–9 pentads (15–45 days) are not so important in calculations of the mean seasonal variations of rainfall. In other words, the intraseasonal variations (or super cloud clusters) of rainfall are well canceled by a simple average for longer than 8 years, although they may govern rainfall variations in an individual year, as will be mentioned later.

2.3 *Climatological classification type of seasonal rainfall variations*

We classify the stations into climatological regions based on amplitudes of the annual and semi-annual components (analyzed as mentioned in Subsection 2.2), and maximum rainfall pentad.

First, if the difference between the maximum and minimum of the ‘smoothed’ pentad-mean rainfall variation (defined in Subsection 2.2) at a station is greater than 6.0 mm day^{-1}, it is defined as the station has rainy and dry seasons. The other stations are defined as with no

Table 1. List of observation stations used in this study. Station number, station name, region name, location (degree· minute), number of available years from 1961 to 1990 and numbers of *El Niño* and *La Niña* years are given. Missing shows the percentage of numbers of pentad data which includes missing for one day or two days in each pentad during number of years.

No.	Station		Region	Location		Year		
	Number	Name		Lat.	Lon.	Total (Missing)	*El Niño*	*La Niña*
1	02026	Tanjung Priok	Jawa	−6·06	106·52	18 (0.6 %)	4	3
2	02027	Jakarta	Jawa	−6·10	106·49	17 (0.5 %)	2	4
3	02033C	Halim	Jawa	−6·16	106·53	17 (0.3 %)	3	3
4	02068	Cikopo	Jawa	−6·42	106·54	9 (0.0 %)	2	3
5	03230	Tasik Malaya	Jawa	−7·29	108·35	13 (4.6 %)	4	4
6	05035A	Tegal	Jawa	−6·51	109·09	9 (0.9 %)	2	1
7	06016	Cilacap	Jawa	−7·44	109·01	10 (0.0 %)	2	3
8	07053	Kedung Ptri	Jawa	−7·40	110·03	11 (0.0 %)	2	1
9	10210	Karang Asem	Jawa	−7·00	111·07	12 (0.0 %)	1	1
10	12192	Bawean	Jawa	−5·51	112·38	11 (2.0 %)	3	2
11	13028C	Madiun	Jawa	−7·37	111·31	12 (2.2 %)	4	3
12	15190	Tempeh	Jawa	−8·14	113·15	9 (0.2 %)	2	2
13	15216	Kalijeruk	Jawa	−8·03	113·20	14 (0.1 %)	3	4
14	16191	Dadapan	Jawa	−8·15	114·19	11 (0.1 %)	2	4
15	20113A	Sigli	Sumatera	5·23	95·57	8 (0.2 %)	2	3
16	21127I	Medan	Sumatera	3·34	98·41	11 (2.2 %)	1	4
17	22267A	Tarempa	Sumatera	3·12	106·15	8 (3.1 %)	1	2
18	23175B	Jambi	Sumatera	−1·38	103·39	11 (3.9 %)	2	3
19	24257	Pangkal Pinang	Sumatera	−2·08	106·07	14 (0.3 %)	4	2
20	26273	Pontianak	Kalimantan	−0·01	109·23	15 (0.5 %)	4	4
21	28308B	Banjarmasin	Kalimantan	−3·27	114·45	14 (1.6 %)	4	4
22	29313D	Balikpapan	Kalimantan	−1·17	116·50	13 (1.8 %)	4	2
23	29318	Kotabaru	Kalimantan	−3·26	116·21	10 (1.9 %)	2	3
24	29324	Muara Muntai	Kalimantan	−0·20	116·22	13 (0.1 %)	3	4
25	29327A	Tarakan	Kalimantan	3·50	117·37	9 (0.8 %)	3	1
26	30330	Taruna	Sulawesi	3·35	125·27	8 (0.0 %)	1	3
27	30330C	Naha	Sulawesi	3·43	125·22	9 (8.5 %)	1	0
28	30331E	Manado	Sulawesi	1·32	124·55	22 (0.2 %)	5	4
29	30334B	Kayuwatu	Sulawesi	1·33	124·55	14 (0.3 %)	3	2
30	30352	Gorontalo	Sulawesi	0·31	123·03	8 (2.1 %)	0	2
31	31364E	Palu	Sulawesi	−0·41	119·44	11 (2.4 %)	1	2
32	31367	Luwuk	Sulawesi	−0·45	122·47	11 (0.2 %)	2	0
33	33415D	Panakukang	Sulawesi	−5·11	119·28	18 (0.2 %)	4	3
34	34440	Tabanan	Bali	−8·33	115·08	14 (0.0 %)	2	4
35	34445B	Denpasar	Bali	−8·45	115·10	8 (3.3 %)	2	1
36	36461	Waingapu	Nusa Tenggara	−9·40	120·20	17 (0.1 %)	5	4
37	36470G	Kupang	Nusa Tenggara	−10·10	123·40	8 (2.2 %)	2	1
38	37479	Saumlaki	Nusa Tenggara	−7·59	131·18	10 (6.8 %)	2	0
39	37481A	Geser	Nusa Tenggara	−3·48	130·50	8 (0.2 %)	3	2
40	37487	Amahai	Maluku	−3·22	128·53	10 (0.1 %)	2	1
41	37490	Ambon	Maluku	−3·42	128·05	18 (0.6 %)	4	2
42	37495B	Labuha	Maluku	−1·48	127·24	8 (0.7 %)	2	3
43	37496	Ternate	Maluku	0·50	127·25	8 (8.6 %)	1	2
44	37510	Tual	Nusa Tenggara	−5·41	132·48	17 (0.4 %)	3	3
45	381010	Biak	Irian Jaya	−1·11	136·07	14 (0.0 %)	4	3
46	383054	Babo	Irian Jaya	−2·30	133·25	11 (0.1 %)	3	2

rainy and dry seasons, which are in very good agreement with the non-wet/dry region defined from outgoing long-wave radiation (OLR) by Murakami and Matsumoto (1994). Next, as for the stations with rainy and dry seasons, we classify types I and II depending upon whether annual (C_1) or semi-annual (C_2) component has the larger amplitude, and also types A and B depending upon whether the maximum rainfall of 'smoothed' pentad-mean rainfall amount ap-

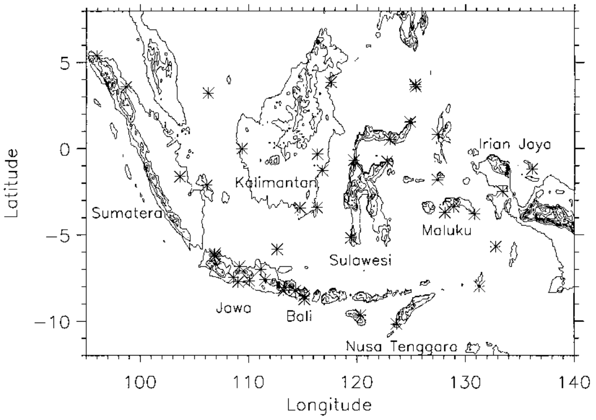

Fig. 1. Map of the rainfall observation stations in Indonesia and the topography. An asterisk ('$*$') shows observation station. Contour shows elevation of topography. The contour interval is 500 meter.

pears during September–February or during March–August. By these procedures, we define the following five types as the climatological classification:

- A-I: Annual cycle is dominant ($C_1 > C_2$), and the maximum rainfall occurs during September–February (during pentads 14–49);
- A-II: Semi-annual cycle is dominant ($C_2 > C_1$), and the maximum rainfall occurs during September–February (during pentads 14–49);
- B-I: Annual cycle is dominant ($C_1 > C_2$), and the maximum rainfall occurs during July–August or March–June (during pentads 1–13 or 50–73);
- B-II: Semi-annual cycle is dominant ($C_2 > C_1$), and the maximum rainfall occurs during July–August or March–June (during pentads 1–13 or 50–73); and
- C: Rainy and dry seasons do not clearly exist.

This classification is not significantly different from previous classifications (e.g., Eguchi 1983), but more objective. The example shown in Fig. 2 (Jakarta) is classified into A-I, because the maximum–minimum difference is 12.9 mm day^{-1}, amplitude of annual component (4.37 mm day^{-1}) is larger than semi-annual component (2.28 mm day^{-1}), and the maximum rainfall is in the pentad 42.

2.4 Definition of onset and withdrawal of the southern-hemispheric summer rainy season

As for the southern-hemispheric summer (during December–February: DJF) rainy season at the stations which have the A-I type climate, we define the onset (withdrawal) time of the rainy season, as the first pentad when the three-pentad running-mean rainfall amount exceeds (lowers) annual-mean pentad-mean rainfall amount in at least three consecutive pentads after lowering (exceeding) it in more than three consecutive pentads. This definition follows Matsumoto (1995), who applied it to the rainfall data over the Indo-China Peninsula. Tanaka (1994), and Murakami and Matsumoto (1994) also applied similar definitions to the satellite cloud data. We have compared their results with DJF rainy season, based on rainfall data as will be described in subsection 3.2. As for Jakarta (see Fig. 2), the rainy season exists from early December (onset: pentad 32) to late March (withdrawal: pentad 54).

We also define rainy season onset dates in individual years to show the correlations among rainy season onset, rainfall amount and southern oscillation index (SOI) (Subsubsection 4.1b). The definition is the same as the climatological one, but we put an additional criterion that the onset date must be in, or after, September. Though heavy rainfall sometimes occurs before September, we regard it as rainfall not due to the seasonal variations but due to a cloud cluster, with a time scale shorter than the intraseasonal variations.

2.5 Definition of El Niño and La Niña years

Because we focus ourselves on the DJF rainy season, we employ the definition of Suppiah (1993) who studied the contrast of intraseasonal rainfall variations during the DJF rainy season over northern Australia between *El Niño* and *La Niña* years, based on SOI and eastern equatorial Pacific sea-surface temperature variations during this season[2]. Table 2 shows the *El Niño* and *La Niña* years in Suppiah's definition during 1961–90. Right-hand side columns in Table 1 show total numbers of *El Niño* and *La*

---

[2] Suppiah (1993) called *El Niño* and *La Niña* years as ENSO and anti–ENSO years.

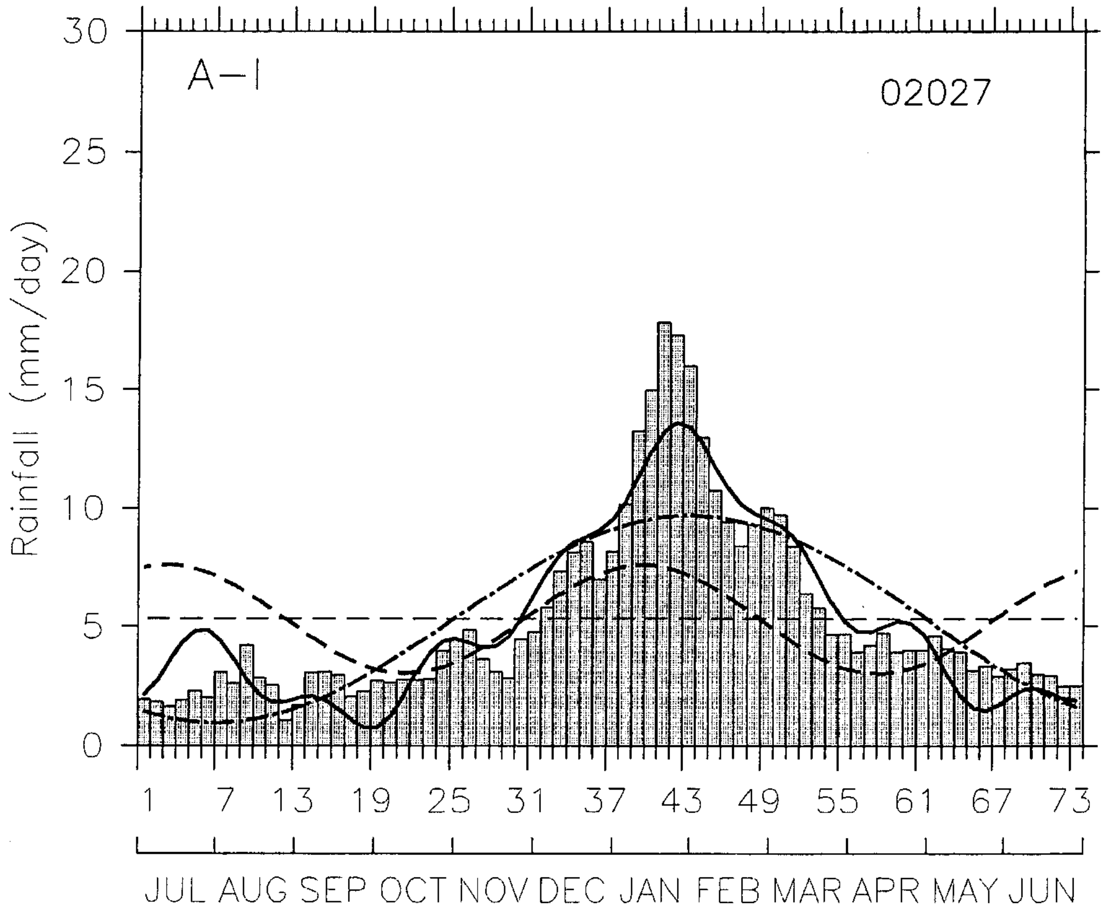

Fig. 2. Three-pentad running-averaged pentad-mean rainfall amount (bars) at Jakarta (02027; 6°10′S, 106°49′E). Dashed-dotted and dashed curves show 73-pentad (annual) and 36.5-pentad (semi-annual) components, respectively, which are fitted to the averaged seasonal variation (bars). A solid curve shows "smoothed" pentad rainfall variation, which is defined by the summation of the four components of 73, 36.5, 18.25 and 9.125-pentad periods. Upper right number shows the station number. The climatological classification described in Subsection 2.3 is labeled in upper left.

Table 2. List of *El Niño* years and *La Niña* years during the periods of 1961–90 and 1910–41 (after Suppiah 1993).

Period	*El Niño* and *La Niña*	Year
1961–1990	*El Niño*	1963, 1965, 1969, 1972, 1976, 1982 and 1986
	La Niña	1964, 1970, 1973, 1975 and 1988
1910–1941	*El Niño*	1911, 1913, 1918, 1923, 1925, 1930, 1932, 1939 and 1941
	La Niña	1916, 1920, 1924, 1928, 1931, 1933 and 1938

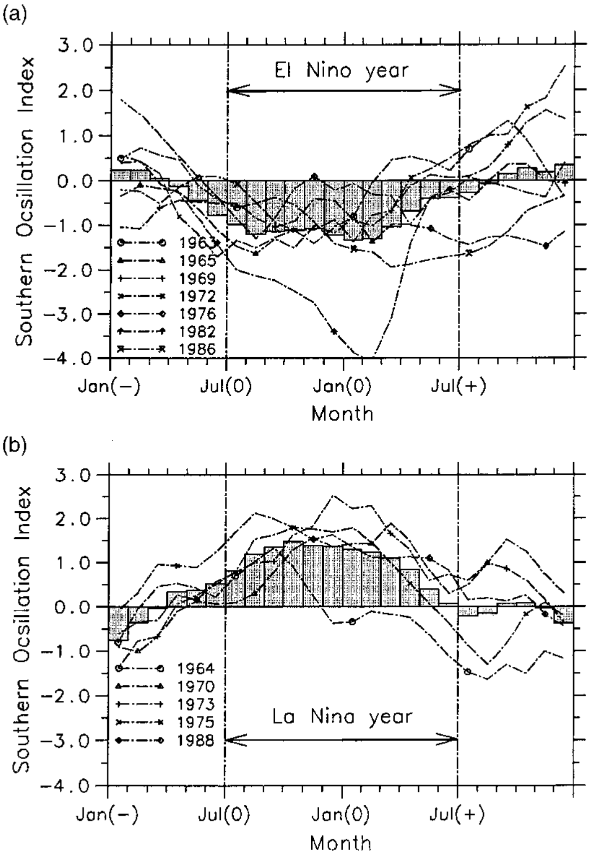

Fig. 3. Three month running averaged southern oscillation index (SOI) variations in (a) *El Niño* and (b) *La Niña* years during 1961–90.

Niña years in which the data were obtained at each station used in this study.

The average for the period during 1961–90, negative SOI indicating *El Niño* continues from April to August of the subsequent year, whereas positive SOI corresponding to *La Niña* starts from April and ends in October of the subsequent year (see Fig. 3). We have compiled pentad-mean rainfall amount variations for *El Niño* and *La Niña* years defined for one-year (73-pentad) periods just as the same definition as an analysis year defined in Subsection 2.1. We also calculated correlation coefficients for interannual variations of rainy season onset date, rainfall amount and SOI (Section 4).

Table 2 also shows *El Niño* and *La Niña* years during 1910–41. During this period, de Boer (1947) studied interannual variations of rainy season in and around Jawa. We analyzed ENSO–rainfall relationship during early 1900s using his results so as to compare it with that of the period during 1961–90 (Subsection 5.2).

3. Mean characteristics of rainy season in 1960s–80s

The mean characteristics of geographical distributions of yearly and monthly rainfall amounts calculated by ourselves from the daily rainfall data during 1961–90, are almost consistent to foregoing studies based on monthly rainfall data before 1960s. However, as will be mentioned in Section 5, there are some differences of rainy season between our analysis and foregoing studies, suggesting interdecadal variabilities of the climate over Indonesia. In this section, we summarize climatology of rainy season, averaged for 1960s–80s.

3.1 Annual and semi-annual components

Mean yearly total rainfall amounts are larger than 3000 mm in the western part of Indonesia (western and northern Kalimantan, eastern Sumatera, northern Sulawesi and some stations in Jawa), and are decreased eastward in the southern islands (Jawa, Bali and Nusa Tenggara). Smaller rainfall (less than 2000 mm) regions also exist in the northern islands (central Sulawesi, from the eastern side of Kalimantan central mountains to Maluku).

Concerning seasonal variations, as shown in Fig. 4(a), the annual cycle (73-pentad component) is dominant in the southern side of 5°S, and the amplitude is especially large around the Jawa Sea. The maximum phase comes between January–March, and delays eastward. The active rainfall also comes earlier in the southern Jawa, than in northern Jawa. However, a different annual cycle appears in Maluku Islands, of which the maximum phase appears in the opposite season (May–July) for southern Indonesia. Near the equator, the amplitude of annual component is very small, and the phase of annual cycle is changed at around 115°E. In the western side of 115°E the maximum phase is between September–November, whereas in the eastern side it is between December–January, which is similar to that in southern Indonesia. Figure 4(b) shows the semiannual (36.5-pentad) component. It is found that large amplitude appears in Sumatera, western Kalimantan and the south-western coast of Jawa with maximum phases in October and April. The semi-annual component is small in the eastern Indonesia. In the southern side of 5°S, it is also small, and the maximum appears apparently in January, and around July.

Figure 5 shows the map of geographical distributions of seasonal rainfall variation types defined in subsection 2.3. The A-I type climate appears in the southern side of 5°S (Jawa and Nusa Tenggara; for example Jakarta shown in Fig. 2), and the rainfall amount decreases (and duration of dry season increases) eastward. This climate is also seen at the northern-hemispheric stations such as Sigli, northern Sumatera (see Fig. 6(a)) and Manado, northern Sulawesi (see Fig. 6(b)). However, in the northern Sumatera (e.g., Medan), the semi-annual component is as large as the annual component, and the maximum phase of annual component appears in November, which is earlier than that in the southern-hemispheric side. In northern Sulawesi, rainfall amounts are large even during June–August (≥ 5.0 mm day^{-1}).

The A-II type climate appears at equatorial stations in the western side of Kalimantan central mountains (western Kalimantan and equatorial Sumatera). Figure 6(c) shows seasonal

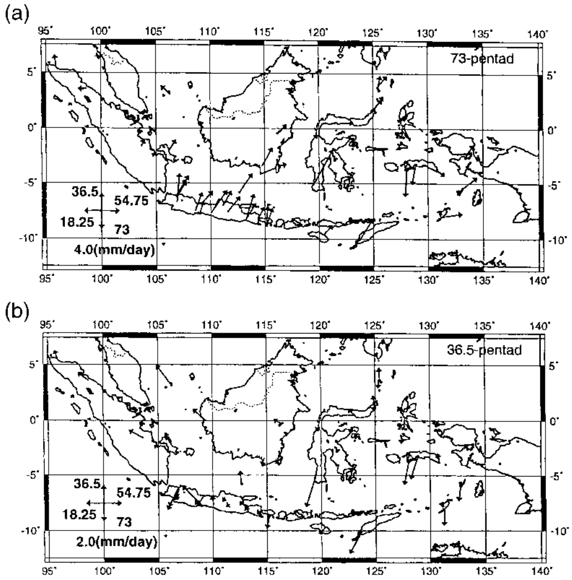

Fig. 4. (a) 73-pentad (annual) and (b) 36.5-pentad (semi-annual) components of averaged pentad-mean rainfall variations based on harmonic least-square fitting. Direction and length of arrow indicate the phase and amplitude of each component. Scales of arrows of the 36.5-pentad component are twice as long as those of the 73-pentad component.

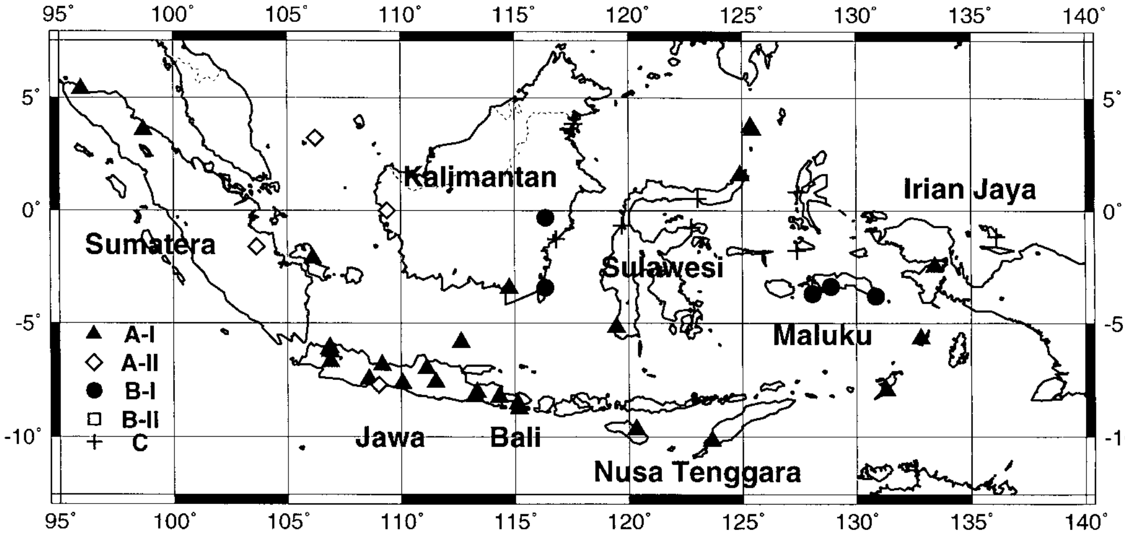

Fig. 5. Climatological classification map. Type-A (type-B) means that maximum rainfall occurs during September–February (March–August). Type-I (type-II) means that annual (semi-annual) component is dominant. Plus symbols denote stations at which seasonal variations are not clear (type-C). Detailed explanation is in the text (Subsection 2.3).

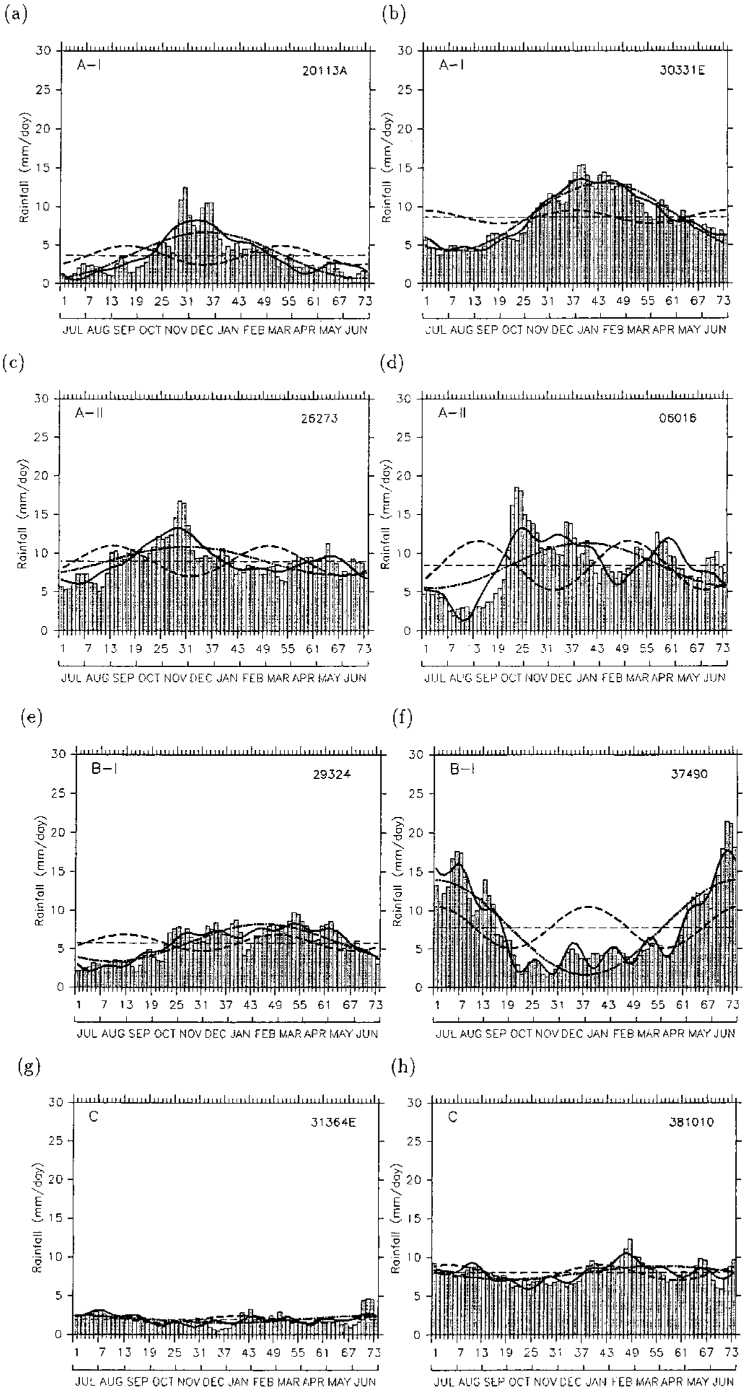

Fig. 6. Same as Figure 2 but for stations of A-I, A-II, B-I and C types of rainy season. A-I type stations at (a) Sigli (20113A; 5°23′N, 95°57′E), north-eastern Sumatera and (b) Manado (30331E; 1°32′N, 124°55′E), northern Sulawesi, A-II type stations at (c) Pontianak (26273; 0°01′S, 109°23′E), western Kalimantan and (d) Cilacap (06016; 7°44′S, 109°01′E), southern Jawa, B-I type stations at (e) Muara Muntai (29324; 0°20′S, 116°22′E), eastern Kalimantan and (f) Ambon (37490; 3°42′S, 128°05′E), Maluku and C type stations at (g) Palu (31364E; 0°41′S, 119°44′E), central Sulawesi and (h) Biak (381010; 1°11′S, 136°07′E), Irian Jaya are shown.

variation at Pontianak, western Kalimantan. Rainfall is abundant throughout the year, and the peaks appear twice during September–January and during April–May. The A-II type also appears at Cilacap, south-western Jawa (see Fig. 6(d)), and the peaks appear twice during October–January and during March–April. Onset of the September–November(SON)/December–February(DJF) rainy season at Cilacap is more abrupt than at the equatorial stations.

The B-I type climate is distributed in eastern Kalimantan and Maluku. In eastern Kalimantan, such as at Muara Muntai shown in Fig. 6(e), the rainfall peak appears in March, but the difference between maximum and minimum rainfall amount is small. At stations in Maluku, such as at Ambon shown in Fig. 6(f), the rainfall peak appears between June–August (JJA) which may be caused by an orographic effect in windward slope of steep mountains for south-easterly during JJA.

The C type climate appears in the eastern equatorial region, and rainfall is abundant throughout the year (Biak, Irian Jaya; see Fig. 6(h)) or poor (see Fig. 6(g), Palu, Sulawesi). There are no stations classified into the B-II type climate.

3.2 Onset and withdrawal of southern-hemispheric summer rainy season

Figure 7 shows the rainy season durations at stations with A-I type seasonal rainfall variations. Some stations in the northern hemisphere are excluded, because the dominant low level wind direction at these stations is different from that in the southern part of Indonesia. The rainy season starts from south-western Jawa in middle September (Cikopo, pentad 16), and arrives in eastern Nusa Tenggara in middle December (Saumlaki, pentad 34). There is another route of the progression of the rainy season from Irian Jaya to eastern Nusa Tenggara during early November–middle December. Rainy season starts from Babo (pentad 26), and progresses through Tual (pentad 30) to Saumlaki (pentad 34). On the other hand, the rainy season withdrawal starts after middle March from stations in a region covering western Nusa Tenggara, Bali and north-western Jawa, and finishes within April for most stations in Jawa. Besides, the rainy season continues till May or July in eastern Nusa Tenggara and Irian Jaya.

Figure 8 shows distributions of onset and withdrawal times of rainy season over Jawa, Bawean and Bali islands. The rainy season starts before November at southern Jawa stations facing on the Indian Ocean (from west to east, Cikopo: pentad 16; Tasik Malaya: 19; Kedung Ptri: 27; Tempeh: 23; Kalijeruk: 20; Dadapan: 18; Tabanan: 19 and Denpasar: 23). On the other hand, the rainy season begins in late November at northern Jawa stations in the Jawa Sea side (from west to east, Jakarta: 32; Tanjung Priok: 33; Halim: 25; Tegal: 32; Karang Asem: 30; Madiun: 31 and Bawean: 30). In western Jawa the onset period progresses from south (middle September) to north (middle December): Cikopo (6°42′S; pentad 16), Halim (6°16′S; 25), Jakarta (6°10′S; 32) and Tanjung Priok (6°06′S; 33). The seasonal march in west-east direction is not so clear in the present analysis averaged for 30 years in a limited region in/around Jawa.

The rainy season withdrawal starts in middle March from Bali (Denpasar: pentad 53; Tabanan: 56) and western Jawa (Tanjung Priok: 53; Jakarta: 54; Cikopo: 54). The rainy season finishes at most stations before the end of April, except for the southern coast of Jawa (Kedung Ptri: pentad 63; Tempeh: 66; Kalijeruk: 63) and an island in Jawa Sea (Bawean: 65). The rainy season period is longer at stations in the southern coast than in the northern coast of Jawa, although the rainfall amount is greater in the north-western Jawa.

Besides, we examine rainy season onset dates in individual years. Average and standard deviations of the rainy season onsets of individual years have been shown in Table 3, and Fig. 7. Eastward progress (from Jawa to Nusa Tenggara) of the average onset calculated here is almost similar to that of onset calculated from the averaged seasonal rainfall variation. This suggests that such eastward progress of onset occurs similarly every year. However, difference between the southern and northern coasts of Jawa is small for the onset calculated here, suggesting occurrence of strong rainfall in few years governs mainly the northward progress (from the Indian Ocean side to the Jawa Sea side) in Jawa in the averaged seasonal rainfall variations. Namely, the first strong rainfall in a

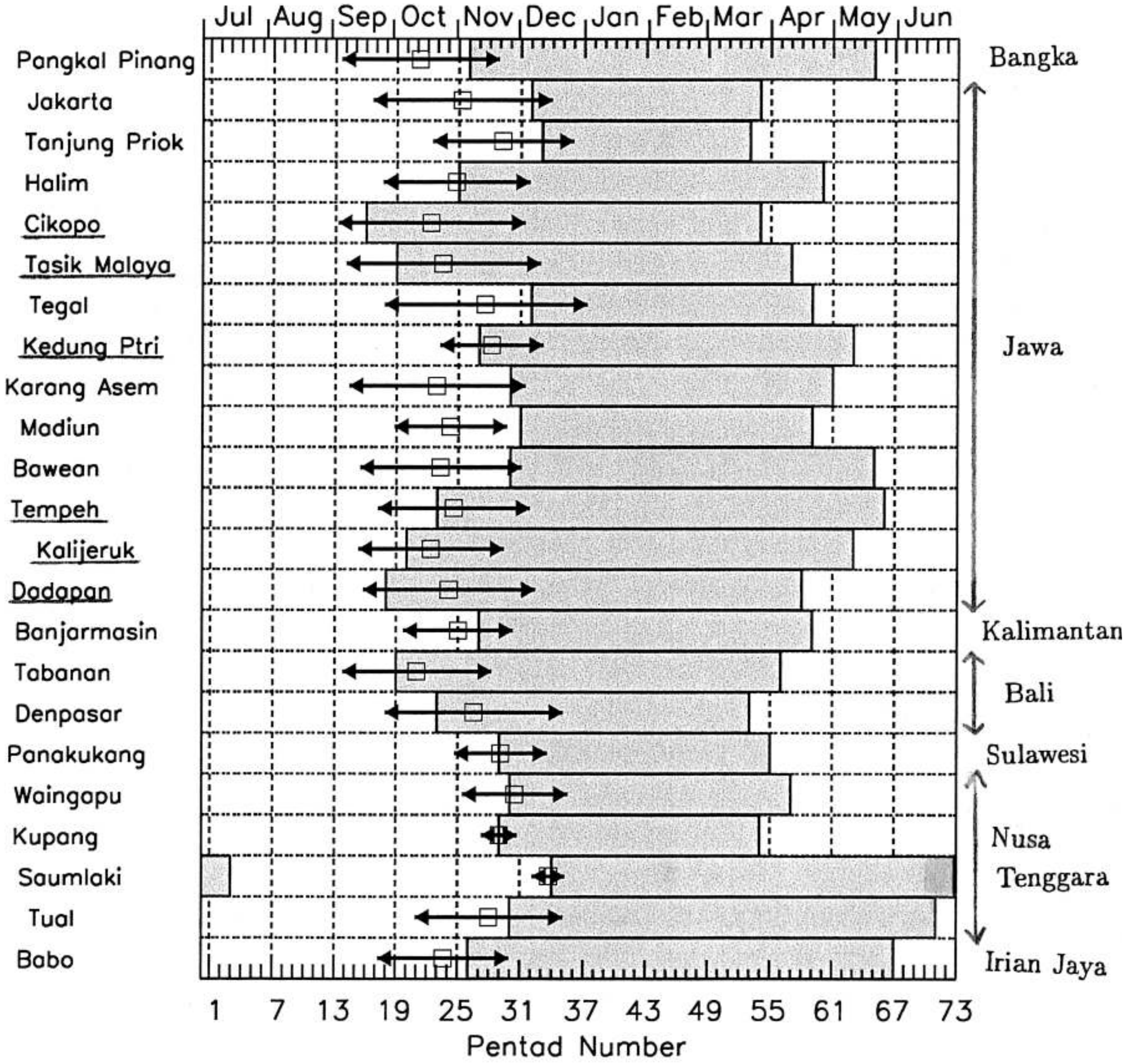

Fig. 7. Rainy season periods obtained from the seasonal variations averaged for available years during 1961–90 at 22 southern-hemispheric Indonesian stations of A-I type. Squares (arrows) indicate averages (standard deviations) of rainy season onsets determined in individual years. In the left-hand side axis, underlined station name shows its location is in the southern extremity of Jawa.

rainy season tends to occur somewhat earlier in the southern (Indian Ocean side) coast than in the northern (Jawa Sea) coast.

The correlation between the rainy season onset and three month accumulated rainfall amount is shown in Table 3. They are negatively correlated (earlier onset corresponds to more rainfall amount) during August–December at almost all stations especially in the eastern part of Jawa. However, their correlation during January–May is low. Therefore, earlier rainy season onset corresponds to larger rainfall activities before, and just at, the beginning of rainy season, but they are not related with total rainfall amounts in rainy season.

Based on satellite cloud observations, Murakami and Matsumoto (1994) have shown that one route of the onset over Indonesia and northern Australia region starts from southern Sumatera as early as pentad 20 (early October)

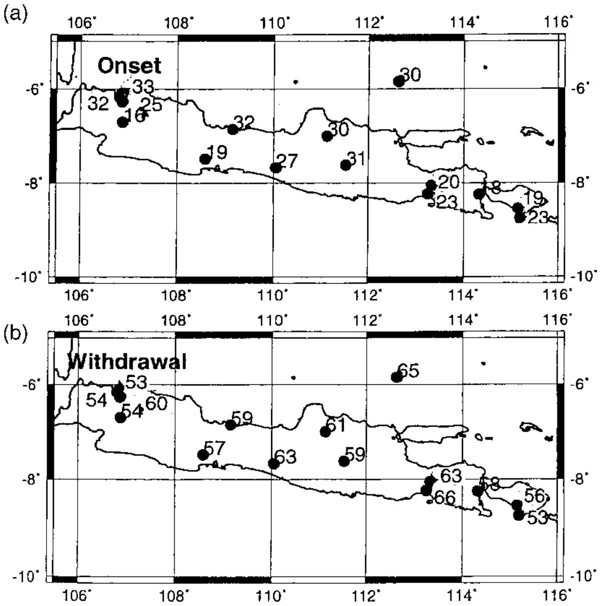

Fig. 8. Distributions of (a) rainy season onset dates (pentad number) and (b) withdrawal dates in/around Jawa and Bali Islands.

and passes the Indonesian Seas around pentad 28 (middle November). Another route starts from the south-western side of Irian Jaya before pentad 30 (late November), and ends up in the Coral Sea on pentad 31 (early December) with the phase curve of onset running roughly from north-east to south-west. The rainy season withdrawal proceeds from Nusa Tenggara and northern Australia region in pentad 55 (late March), through Jawa in pentad 61 (late April) to Irian Jaya in pentad 63 (early May). Tanaka (1994) has presented similar results, except for somewhat slower seasonal march from Jawa to Nusa Tenggara. The present results show that south-north seasonal march is more remarkable than west-east migration in Jawa. The onset determined by rainfall is similar or a few pentad later than that by cloud. In Panakukang (southern Sulawesi) and Banjarmasin (southern Kalimantan) onset (withdrawal) time by rainfall is a few pentad later (earlier) than by cloud.

The differences between rainfall and cloud mentioned above may be caused by structures of SCC. Holland (1986) showed statistically that rainfall peak is about 5 days later than cloud amount peak in northern Australia. Hendon and Liebmann (1990a) indicated that a relation between rainy season onset and passage of eastward moving SCC. As a case study in 1992/93 rainy season, Hashiguchi et al. (1995) also showed that the rainy season onset came from west to east, associated with an eastward moving super cluster at Serpong, near Jakarta. Furthermore, rainy season onset by rainfall is several pentads earlier (later) in the Indian Ocean (Jawa Sea) side than by cloud. This difference between rainfall and cloud in Jawa may be caused by inhomogeneity of rainfall inside SCC and also by higher variability of rainfall due to the complex topography. It should be noted that the analysis based on satellite observations (horizontal resolution is larger than 1° × 1°) can hardly show such local variations as have been shown for Jawa.

4. Interannual variations of rainy season

In this section, we examine the interannual variations of rainy seasons. We focused ourselves on the differences between the climatological region of A-I (Subsection 4.1) and the others (A-II, B-I and C, in Subsection 4.2) for the influence of ENSO on rainy season. We select 12 stations at which data have been collected for both more than two *El Niño* years and more than two *La Niña* years (defined in Subsection 2.5; see Table 2). There are 9 stations of A-I type (5 in Jawa, 1 in Kalimantan, 1 in Sulawesi and 2 in Nusa Tenggara), which are located in the southern part of Indonesia. We exclude Manado in Sulawesi Island which has A-I type because it is located in the northern-hemisphere (1°32′N). The other 3 stations are A-II type (Pontianak, western Kalimantan), B-I type (Muara Muntai, eastern Kalimantan) and C type (Biak, Irian Jaya).

4.1 Stations which have A-I type seasonal rainfall variations

a. Differences between El Niño and La Niña years

Figures 9(a)–(c) show three typical examples of the differences between *El Niño* and *La Niña* years which were obtained at three stations. In the first example obtained at Kalijeruk in eastern Jawa (see Fig. 9(a)), the rainy season does not change the duration length so much, but is

Table 3. Average and standard deviation of rainy season onset dates (pentad number) calculated for each years. Correlation coefficient between onset date anomaly and three-months accumulated rainfall amount (SON: September–November; DJF: December–February; MAM: March–May) are also shown. ∗ (∗∗) shows 95 (99)% confidence levels. Star (⋆) shows the station which is located in the southern part of Jawa.

Station		Rainy Season Onset		Correlation Coefficient		
No.	Name	Average	SD	SON	DJF	MAM
24257	Pangkal Pinang	21.23	7.64	−0.61*	−0.12	−0.22
02027	Jakarta	25.29	8.63	−0.65**	−0.31	0.02
02026	Tanjung Priok	29.22	6.73	−0.68**	0.12	0.34
02033C	Halim	24.76	7.08	−0.58*	−0.16	−0.06
02068	Cikopo⋆	22.33	9.06	−0.60	−0.19	0.15
03230	Tasik Malaya⋆	23.46	9.41	−0.72**	−0.15	0.36
05035A	Tegal	27.56	9.71	−0.82**	−0.41	−0.20
07053	Kedung Ptri⋆	28.18	4.95	−0.86**	−0.62*	0.62*
10210	Karang Asem	22.92	8.53	−0.68*	−0.23	0.22
13028C	Madiun	24.25	5.43	−0.92**	0.22	0.59*
12192	Bawean	23.27	7.79	−0.66*	−0.04	0.50
15190	Tempeh⋆	24.56	7.32	−0.95**	0.13	−0.06
15216	Kalijeruk⋆	22.36	7.04	−0.81**	−0.23	0.22
16191	Dadapan⋆	24.09	8.32	−0.91**	−0.03	0.10
28308B	Banjarmasin	25.00	5.28	−0.86**	0.29	−0.21
34440	Tabanan	21.00	7.23	−0.86**	−0.09	0.01
34445B	Denpasar	26.50	8.54	−0.88**	0.06	−0.48
33415D	Panakukang	29.11	4.45	−0.79**	−0.39	−0.30
36461	Waingapu	30.47	5.03	−0.89**	0.25	0.13
36470G	Kupang	29.00	1.73	−0.85**	0.34	−0.42
37479	Saumlaki	33.70	1.55	0.29	−0.30	−0.27
37510	Tual	28.00	7.06	−0.82**	−0.10	0.30
383054	Babo	23.64	6.33	−0.70*	−0.16	0.42

shifted between *El Niño* year (late onset) and *La Niña* year (early onset). As for the *El Niño* year, the rainy season onset delays 8 pentads (pentad 28, middle November) and withdrawal also delays 6 pentads (pentad 69, early June). Duration of rainy season is 2 pentads shorter than average, and rainfall amount in the rainy season is 14.4% smaller than the average. As for the *La Niña* year, the rainy season onset starts in pentad 15 (middle September; 5 pentads earlier than the average) and ends in pentad 53 (middle March; 10 pentads earlier). Duration of rainy season is 5 pentads shorter than in the average year, and rainfall amount in the rainy season is almost similar (+0.3%) to that for the average year. The rainy season onset (withdrawal) is 13 (16) pentads later in the *El Niño* year than in the *La Niña* year.

In the second example (see Fig. 9(b)) obtained at Panakukang in southern Sulawesi, duration and rainfall amount in the rainy season are both smaller in the *El Niño* year than in the *La Niña* year, although the center of the rainy season is not so different between *El Niño* and *La Niña* years. As for the *El Niño* year, the rainy season onset delays 4 pentads (pentad 33, early December) from the average, and the withdrawal is 6 pentad (pentad 49, late February) earlier than the average; therefore, the rainy season is 10 pentads shorter than in the average year. Rainfall in the rainy season decreases 46.2%. As for the *La Niña* year, the rainy season starts in pentad 28 (middle November) and ends in pentad 54 (late March). Rainfall is 20.8% greater than in the average year.

In the third example (see Fig. 9(c)) obtained at Tanjung Priok in north-western Jawa, the relationship between the rainy season and ENSO is not clear. As for the *El Niño* year, the rainy season onset and withdrawal are similar to those in the average year. Besides, the rainy season onset delays 1 pentad, and duration is 1 pentad shorter in the *La Niña* year. Rainfall amounts during the rainy season increase 16.1% and 13.3% in the *El Niño* and the *La Niña* years, respectively.

As a summary, Figure 10 shows comparisons among rainy season durations of average, *El Niño* and *La Niña* years at 9 stations. As for the *El Niño* year, the rainy season onset delay is recognized at many stations (as described in the first and second examples above). The delays are 4 pentads in southern Sulawesi (Panakukang), 8–11 pentads in Jawa (Halim, Tasik Malaya and Kalijuruk), and 4–7 pentads in Nusa Tenggara (Waingapu and Tual). The withdrawal delays longer than 4 pentads at 5 stations (Tasik Malaya, Madiun, Kalijeruk, Banjarmasin and Waingapu), but earlier (thus the duration is shorter) than the average at Tual and Panakukang. The withdrawal date is not so different from the average at Tanjung Priok and Halim in north-western Jawa. Rainfall amounts in the rainy season decrease remarkably (about 10% or more) at 4 stations, Halim, Kalijeruk, Tual and Panakukang, but it rather increases (about 10%) at the other stations.

As for the *La Niña* year, the rainy season onset is distinctly earlier (4–12 pentads) than for the average year, especially at stations in south-eastern Jawa and at Banjarmasin. Besides, they are only different for 2 pentads or less from the average at Tasik Mayala, Waingapu, Tual, Panakukang and Tanjung Priok.

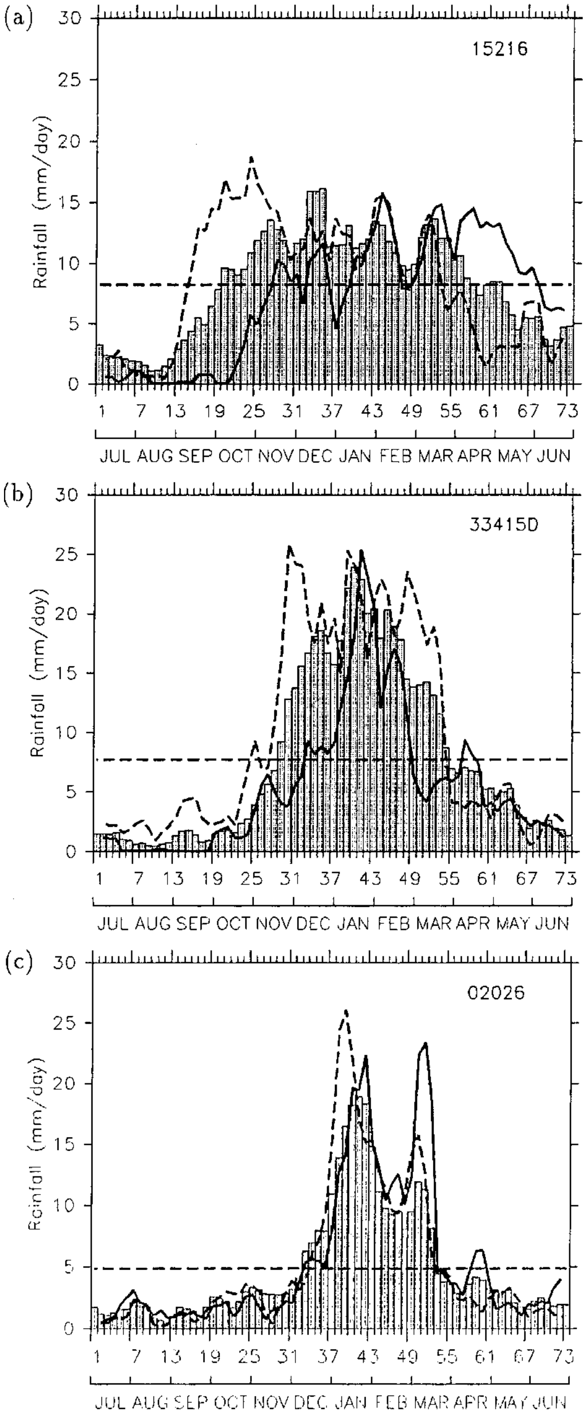

Fig. 9. Pentad-mean rainfall variations composed for the *El Niño* (solid curve) and *La Niña* (dashed curve) years at (a) Kalijeruk (15216; 8°03′S, 113°20′E), (b) Panakukang (33415D; 5°11′S, 119°28′E) and (c) Tanjung Priok (02026; 6°06′S, 106°52′E). The pentad-mean rainfall amount averaged for all the years is shown by bars. Horizontal dashed line shows annual-mean pentad-mean rainfall amount averaged for all the years.

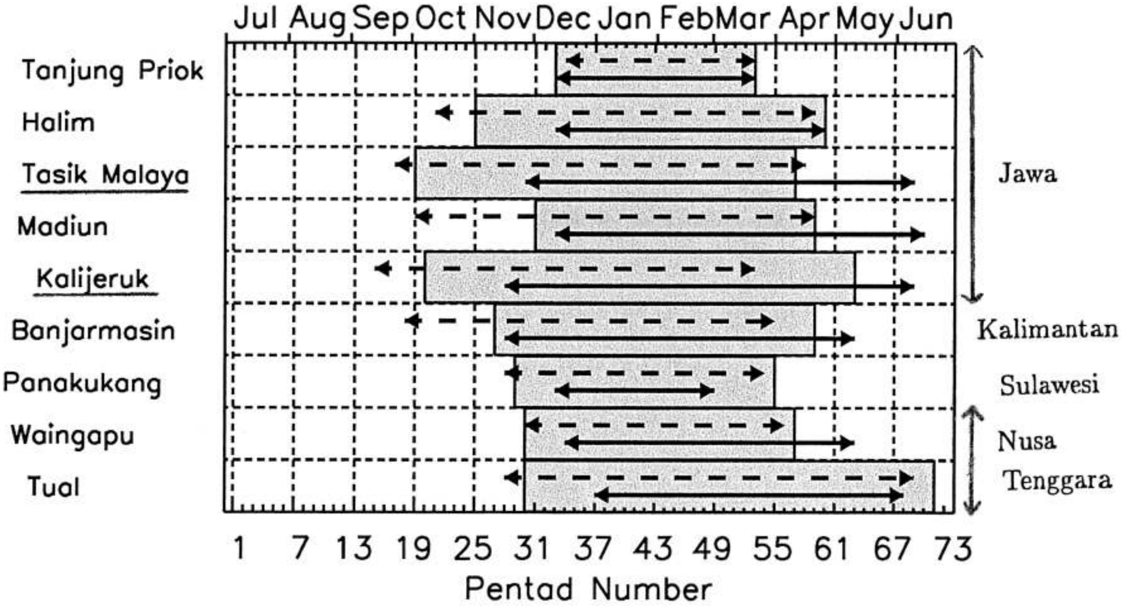

Fig. 10. Comparison of the southern-hemispheric summer rainy season periods between *El Niño* (thin arrow) and *La Niña* (dashed arrow) years at 9 stations. Stick shows the averaged rainy season period. In the left-hand side axis, underlined station name shows its location is in the southern extremity of Jawa.

The rainy season withdrawal dates are similar to, or a few pentads earlier, than the average at almost all the stations, but 4 or more pentads earlier at Kalijeruk and Banjarmasin. Rainfall amounts in the rainy season increase at all stations except for Tual, which is clear in particular at Panakukang and Halim (greater than 20%).

Figure 11 shows variations of normalized rainfall anomaly in the *El Niño* and *La Niña* years at 4 stations along the southern extremity of Indonesia from west to east: Tasik Malaya (108°35′E), Kalijeruk (113°20′E), Waingapu (120°20′E) and Tual (132°48′E). As for the *El Niño* year, negative anomaly appears during August–February, and rainfall anomaly turns to positive after February in these stations. The pentads when rainfall anomaly turns from negative to positive are 33, 48, 42 and 46 at those stations from west to east. In the *La Niña* year, rainfall anomalies are positive during August–January, and turns into negative after January. The pentads when the anomaly changes from positive to negative are 31, 34, 42 and 37 at those stations from west to east. From these results, rainfall anomalies appear earlier in the western part than in the eastern part of the southern territory of Indonesia. Rainfall decrease is well correlated with *El Niño* mainly during September–November.

As mentioned in Section 1, seasonal and interannual variations of rainfall over Indonesia may be generated, through some modifications of shorter and smaller weather disturbances such as cloud clusters. It is found that there are intraseasonal variations in rainfall in the rainy season at some stations in Indonesia, and in the surrounding regions (e.g., Inoue and Nakamura 1990; Hendon and Liebmann 1990b; Rutledge et al. 1992; Suppiah 1993). Differences of rainfall amount and onset of the rainy season over these regions are also closely related to behaviors of hierarchical structures of clouds, such as eastward moving super cloud cluster originated from Indian Ocean to western Pacific. (e.g., Hendon and Liebmann 1990a; Nitta et al. 1992; Hashiguchi et al. 1995).

Effects of the intraseasonal variations are also found in the three typical examples described in the beginning of this subsection. As shown in Fig. 9(c), active rainfall periods appear in January and early March and inactive

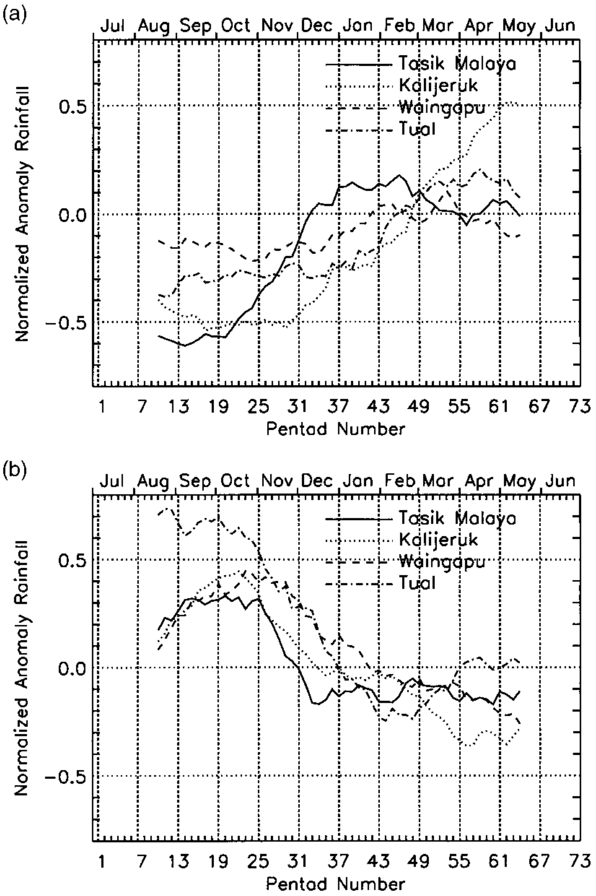

Fig. 11. Normalized anomalies of rainfall variations at four A-I type stations, Tasik Malaya (03230; 108°35′E), Kalijeruk (15216; 113°20′E), Waingapu (36461; 120°20′E) and Tual (37510; 132°48′E) in the southern most part of Indonesia in the (a) *El Niño* and (b) *La Niña* years. 19-pentad (95 days) running mean is applied.

rainfall period appears in February in both *El Niño* and *La Niña* years at Tanjung Priok, which suggest that the intraseasonal variations have time scales of about 50-days with a phase-lock to the seasonal variations. However, rainfall maxima occur a few pentads later in *El Niño* year than in *La Niña* year, and the rainfall amount in March is larger (that in January is smaller) in *El Niño* years than in *La Niña* years, suggesting some differences of structures of the intraseasonal variations between *El Niño* and *La Niña* years.

At Kalijeruk (see Fig. 9(a)) which has a shift of rainy season between *El Niño* and *La Niña* years, the time scales of rainfall variations are about 30-days both in *El Niño* and *La Niña* years, which suggest again the existence of seasonal-lock intraseasonal variations. In *El Niño* years, inactive rainfall periods with rainfall amounts less than average appear even in the rainy season.

At Panakukang (see Fig. 9(b)), it is suggested that there are intraseasonal variations with time scales of 30–60 days, in *El Niño* years. In the *La Niña* years, rainfall variations during the rainy season are relatively weak, at least in this 3-year average. From these results, intraseasonal rainfall variations (about 30 to 60 days) exist during every rainy season, though each station has different characteristics of interannual variations of rainy season. The spatial, and temporal variations of intraseasonal rainfall variations and their relationships with rainy season onset and rainfall amount during rainy season in more details are beyond the scope of this paper.

b. Correlations among rainy season onset, rainfall amount and SOI

As introduced in Section 1, some earlier studies (e.g., Ropelewski and Halpert 1987; Können et al. 1998) have shown that A-I region rainfall in particular, in the dry season is well correlated with SOI. They mainly used monthly rainfall amounts and rainday counts. In this study, we use pentad-mean rainfall records and examine correlations between the rainy season onset and SOI.

Figure 12(a) shows interannual variations of the rainy season onset in and around Jawa during 1961–90. We have standardized anomaly of rainy season onset at each station in Jawa and Madula, and have obtained the average and standard deviation so as to indicate general aspects. It is found that characteristic time scales of the interannual variations of onset are changed in the early 1970s. Biennial variations are dominant before 1970s, and late (early) onset well corresponds to *El Niño* (*La Niña*) year. Besides, 3–5 year variations are recognized after 1970s. Interannual variations of onset is related with the time interval of *El*

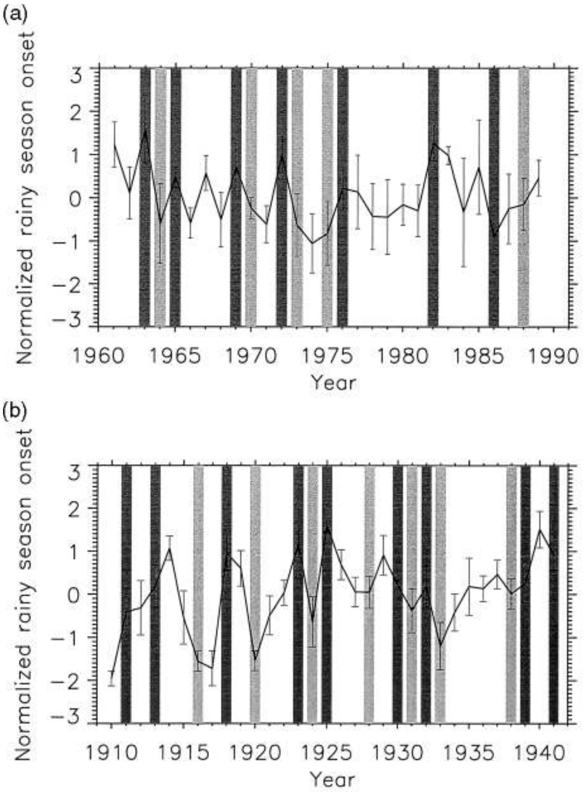

Fig. 12. Interannual variations of rainy season onset in Jawa Island during the period of (a) 1961–90 and (b) 1910–41, using the data of de Boer (1947). Thin line shows average of normalized rainy season onsets calculated for each station in and around Jawa Island, and vertical line shows standard deviations of them. Black (gray) bar shows *El Niño* (*La Niña*) year.

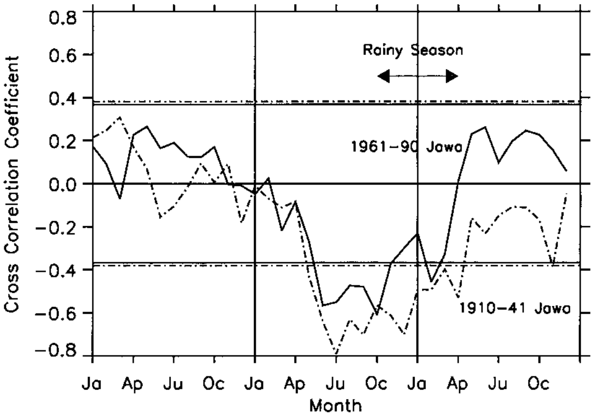

Fig. 13. Lag correlations between rainy season onset in Jawa and SOI during 1961–90 (solid line) and 1910–41 (dashed line). The reference rainy season is shown as a double-head arrow. Horizontal solid (dashed) line shows 95% confidence level of 1961–90 (1910–41) case.

Niño/La Niña occurrence, though, the relation rainy season onset with ENSO is weaker after the 1970s than before the 1970s.

Figure 13 shows the lag correlation between the averaged rainy season onset in and around Jawa (see Fig. 12) and SOI. During 1961–90, their correlations are significantly negative during June–December of reference year in general, but they have local differences (not shown). Thus the rainy season onset, is influenced by situation of ENSO in JJA/SON before rainy season. Correlations are not so strong at some stations mainly in the eastern part of Jawa, and the correlation is relatively high during JJA/SON of the proceeding and subsequent years. Furthermore, some stations outside Jawa (such as Banjarmasin and Waingapu) show significantly positive correlations in June–October of the subsequent year (not shown). SOI becomes negative (occur *El Niño* condition) in June–October of the subsequent year, when rainy season onset is earlier than average. Therefore, the characteristic time scales of interannual variations of the rainy season onset and SOI are shorter than 3 years.

4.2 The other stations (A-II, B-I and C types of seasonal rainfall variations)

Figure 14 is the same as Fig. 11 but for the stations other than A-I type. There are 3 stations at Pontianak (109°23′E, A-II type), Muara Muntai (116°22′E, B-I type) and Biak (136°07′E, C type) along the equator from west to east. It should be noted that interannual variations at these stations were not studied in foregoing studies cited in the previous subsection. In the *El Niño* year, rainfall anomalies are negative during August–December, and are changed to positive after November/December at Pontiank and Biak. The onset time of positive anomaly is 10 pentads earlier at Pontianak (pentad 27) than at Biak (pentad 37). At Muara Muntai, a negative anomaly continues till March.

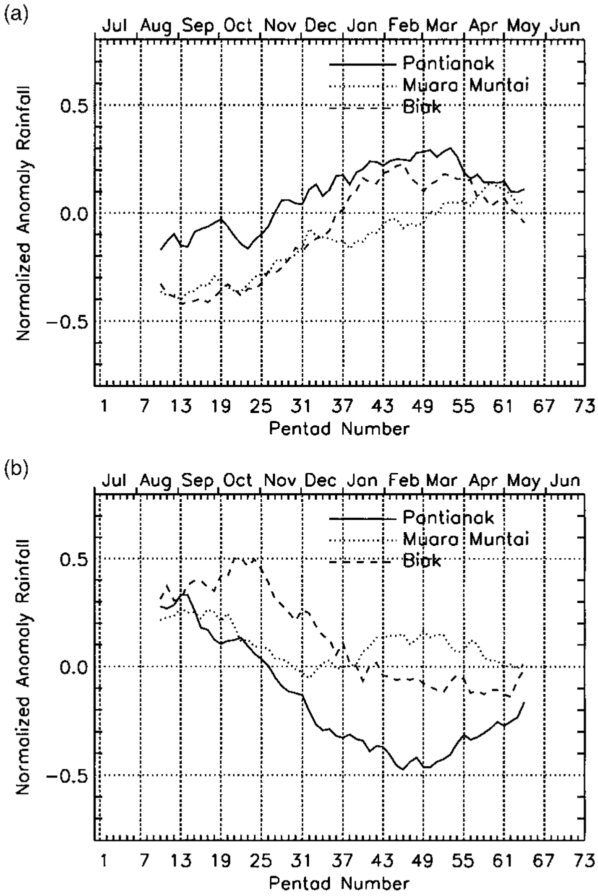

Fig. 14. Same as Figure 11 such as Pontianak (A-II, 26273; 109°23′E), Muara Muntai (B-I, 29324; 116°22′E) and Biak (C, 381010; 136°07′E) along the equator.

In the *La Niña* year, rainfall anomaly variations have opposite signs to those in the *El Niño* year. Rainfall anomalies at Pontianak and Biak are positive during August–January, and they turn negative after January. The withdrawal of positive anomaly occurs 13 pentads earlier at Pontianak (pentad 27) than at Biak (pentad 40). At Muara Muntai, a positive anomaly continues from August to May (anomaly takes a negative value at once in pentad 30 but turns into positive), which is well correlated with SOI.

From these results, interannual differences of rainy season at A-II-, B-I- and C-type stations near equator show similar patterns, but there are longitudinal differences (lags) of the seasonality and strength of the correlation between rainfall amount and SOI. Such longitudinal differences appear also in the A-I stations in southern Indonesia (shown in Fig. 11). A relation between topography and interannual variability of rainy seasons (A-II, B-I and C types) in Sumatera, Kalimantan, Sulawesi and Irian Jaya might be studied (just as Jawa Island) (described in Subsection 4.1), after collecting data at many more stations in these islands.

5. Comparison between rainy seasons before and after 1960s

5.1 Changes of seasonal rainfall variations

The characteristics of rainy season before 1960s are basically similar to our results after 1960s. Our A-I type dominant over the most part in the south of 5°S corresponds to Eguchi (1983)'s subregion A-I, although our A-I type appears also in the northern hemisphere such as northern part of Sumatera. Our A-II type distributed in the western side of Kalimantan central mountains corresponds to, but is not exactly the same as, Eguchi's subregion A-II (e.g., A-I type stations appear at Pangkal Pinang and in northern Sumatera), probably because our definition is more objective on estimation of the semi-annual component (see Subsection 2.3). Our B-I type also corresponds to Eguchi's subregion B-I. Eguchi described that there were regions with two rainfall peaks (the maximum in/around March–July) in the most part of the eastern side of Kalimantan central mountains, but these regions are not B-II type but C type (no clear rainy season) in our definition based on more objective analysis. He also indicated that there were regions with similar seasonality (two rainy season and maximum in/around March–July) in the southern hemisphere such as southern part of Bangka Island (near the south-east coast of Sumatera Island), central and south-eastern part of Jawa and eastern Nusa Tenggara, but they are not confirmed in our results.

It must be noted that, as shown in Subsection 4.1, A-I type stations have significant shifts of rainy season between *El Niño* and *La Niña* years. This suggests that two peaks (rainy sea-

Table 4. Average (standard deviation in parenthesis) of rainy season onset dates (based on 10-day data) of 12 old regions in and around Jawa during 1910–41 (after de Boer 1947). Difference (10-day) between onset in the *El Niño* (*La Niña*) year that in the average year is also shown. Plus (minus) shows late (early) onset.

Station	Region	Rainy Season Onset		
		Average	*El Niño*	*La Niña*
1: Batavia	North West	1st Oct (2.6)	+2.2	−1.7
2: Cheribon	North West	2nd Oct (2.2)	+1.8	−1.5
3: Djombang	North East	3rd Oct (2.4)	+1.4	−1.7
4: Klaten	South Central	3rd Oct (2.5)	+1.4	−1.8
5: Pasuruan	North East	3rd Nov (1.7)	+1.4	−1.5
6: East-Madura	North East	2nd Nov (2.0)	+1.6	−2.2
7: Djember	South East	2nd Oct (2.2)	+1.1	−1.0
8: Dampit	South East	3rd Oct (2.3)	+1.4	−1.8
9: Blitar	South Central	1st Nov (2.3)	+1.3	−1.8
10: Bandjar	South West	2nd Oct (2.3)	+1.6	−1.3
11: Bodjonegoro	North East	3rd Oct (2.0)	+1.8	−1.7
12: Semarang	North Central	2nd Oct (2.1)	+1.9	−1.7

sons) of averaged seasonal rainfall variations in the southern-hemispheric regions may be caused by interannual variations of rainy season. A change of ENSO behaviors (occurrence of *El Niño*) may occur between the former and later periods, and this may induce differences of rainfall peaks at A-I stations between these two periods. According to Shinoda (1998), yearly rainfall amounts tend to be decreasing since 1960s in the sub-tropics and tropics over north-Africa, south-eastern Asia. It is considered that this rainfall decreasing tendency in the last few decades was partly influenced by frequently occurred strong *El Niño* events. In the southern neighbor region, Shinoda (1998) have shown that yearly Australian rainfall was decreasing since 1980s, although rainfall amounts during 1975–94 over the most part of Australia were more abundant than during 1955–74. Nicholls et al. (1996) have also shown that Australian rainfall is less affected by *El Niño* after 1970s than before 1970s, probably due to increased Indian Ocean sea surface temperature since the early 1970s. Such interannual differences of seasonal rainfall variations in each sub-region may become complex due to topography of the Indonesian maritime continent, but this must be studied after collecting continuous data at many more stations.

5.2 *Changes of SON/DJF rainy season onset*

De Boer (1947) studied the SON/DJF rainy season in Jawa and Madura during 1910–41, using a definition that the beginning of the rainy season is the first 10-day after which the rainfall is more than 50 mm. He divided the Jawa-Madura region into 12 sub-regions (each region has several stations), and obtained rainy season averaged for each sub-region. Such averaged rainy season started from the western side of Jawa and proceeded to the eastern side during early October–late November (see Table 4). Rainy season ends up during May–June from eastern Jawa. On the other hand, our analysis suggests that seasonal march from the southern part of Jawa to the northern part is dominant during 1961–90. It must be pointed out that de Boer's definition did not consider difference of rainfall amounts between individual stations (it is usually more rainfall at stations in western Jawa than in eastern Jawa), so that west-east variations should be emphasized in de Boer's analysis.

We re-analyzed interannual variations of rainy season onset using his results so as to show the ENSO–Jawa rainfall relationships. As for the spatial variations of them, onset time in the *El Niño* (*La Niña*) years during 1910–41 were 10–20 days later (earlier) than average for these years at each sub-region (see Table 4). Delay of onset associated with an *El Niño* event was shown especially in north-eastern Jawa such as Bodjonegoro, Semarang and east Madura. Onset date delay in *El Niño* year in the north-western Jawa is more obvious during 1910–41 (about 20 days) than during 1961–90 (same as average at Tanjung Priok) (see Fig. 10).

Figure 12(b) shows interannual variations of rainy season onset averaged in and around Jawa during 1910–41. 4–5 year variations are dominant, and early onsets are well related with *La Niña* years. Figure 13 shows the lag correlation between rainy season onset averaged in Jawa (see Fig. 12(b)) and SOI during 1910–41, compared with that during 1961–90. We find strongly negative (with more than 95% confidence) correlations appearing almost for one year (during May and subsequent April) during 1910–41, which is clearly lasting longer than those (a half year during June–November) for 1961–90. Almost all the sub-regions in Jawa showed similar tendency (not shown). These features suggest that interannual variations of the rainy season onset due to ENSO had a time scale longer than 3 years, which are consistent with the occurrence of *El Niño*.

6. Conclusions

In this study, we have investigated the geographical and interannual variations of rainy season over the Indonesian maritime continent on the basis of *daily* rainfall data at 46 stations during 1961–90. We have also compared them with those before 1960s. The results obtained in this study are summarized as follows:

1. Indonesia is classified into four climatological regions, based on analysis of the amplitude and phase of annual oscillation from the pentad-mean rainfall amounts averaged for years of available data. The annual cycle with a rainfall maximum in SON/DJF is dominant in the greater part of Indonesia, which is mainly in the southern-hemispheric side. Near the equator, and in the northern-hemispheric side, the semi-annual cycle is predominant but maximum rainfall (total maximum of a superposition of annual, semi-annual and shorter components) occurs in September–November in the western side of the Kalimantan central mountains. In the eastern part, a different annual cycle with a maximum during March–August is found, but the rainfall is relatively small. The other areas do not have clear rainy and dry seasons.
2. Geographical variations of the onset and withdrawal of SON/DJF rainy season in the annual-cycle dominant region around Jawa have been studied on the basis of the averaged pentad-mean database mentioned above. In Jawa the onset starts from the Indian Ocean side and goes northward. The rainy season propagates eastward and then finally starts in Nusa Tenggara. Another route from Irian Jaya to Nusa Tenggara also exists. The rainy season ends up from western Nusa Tenggara, Bali and north-western Jawa to southern Jawa, and eastern Nusa Tenggara.
3. Differences of rainy season between *El Niño* and *La Niña* years have been studied on the basis of composite analyses of the pentad-mean data. Rainy season onset becomes later (earlier) in *El Niño* (*La Niña*) year than the average at the most stations, except for a few stations in northern Jawa. Relationships between rainy season onset, and the pentad-mean rainfall *amount* during the rainy season are not so clear. This suggests that the precipitation mechanism (cloud cluster) during the rainy season itself is not so different between *El Niño* and *La Niña* years. However, the shift (or shortening at some stations) of the rainy season in *El Niño* year may induce a decrease of rainfall in a calendar year, because the rainy season in Indonesia and also the *El Niño* appear generally in the latter half of a year and continue until the subsequent year.
4. *El Niño* influences to the rainfall activity in the eastern part (in particular in Sulawesi) rather than in the western part. Duration and rainfall amount of the rainy season are both decrease (increase) than average in the *El Niño* (*La Niña*) year in Sulawesi. The most significant correlation between SOI and the rainfall amount appears in SON. However, rainfall anomaly changes sign earlier than SOI so that correlations in DJF/MAM are small or negative. Besides, rainfall anom-

aly pattern tends to appear earlier in the western part of Indonesia than in the eastern part.

5. Interannual changes of rainy season have much more considerable localities in Jawa during 1961–90 (this study) rather than during 1910–41 (de Boer 1947), though definitions are somewhat different from each other. The dominant time scale of interannual variations of rainy season onset in Indonesia during 1961–90 (2–3 years) is shorter than during 1910–41 (more than 3 years), which is consistent with that of occurrence of *El Niño*.

The interannual and interdecadal variations of rainfall described in the items 3–5 above may be related to those of activities of super cloud clusters or intraseasonal variations. The super cloud clusters are made up of smaller cloud clusters and individual cloud systems which must be highly affected by local (topographic and thermal) conditions. Such effects and systematic seasonal-latitudinal variations of radiative forcing may induce the geographical variations of seasonal rainfall summarized as the items 1 and 2. Therefore, investigations on intraseasonal rainfall variations and their geographical and interannual differences are necessary to explain all the items 1–5 completely. In order to do them, we still continue to collect *daily* rainfall data at many other stations over the Indonesian maritime continent.

Acknowledgments

We thank all the operators who engage in constructing Indonesian meteorological database, and colleagues of BMG, BPPT, RASC and FORSGC. We also thank Dr. Ryuichi Kawamura of the University of Toyama and two anonymous reviewers for their quite constructive and informative suggestions. The first author (Hamada) started this work at RASC (as of April 1,2000, Radio Atmospheric Science Center became Radio Science Center for Space and Atmosphere), Kyoto University, which was supported by a grant (6002) of the Japan Society for the Promotion of Science (JSPS) under the Fellowships for Japanese Junior Scientists during 1996–99. The present study was financially supported also by Grants-in-Aids (08041107 and 10041117) of the Japanese Ministry of Education, Science and Culture, and by FORSGC Project of Japan Marine Science and Technology Center (JAMSTEC).

Appendix

As mentioned in Subsection 2.1, we have used data collected from 46 stations over Indonesia which are listed in Table 1. Actually we have collected daily rainfall data obtained at 157 stations for the thirty-year period (1961–90) which have been listed in Hamada and Sribimawati (1998). We have selected the 46 stations, considering the number of years for which pentad-mean data have been obtained completely, as shown in Tables A1 and A2 in details.

Table A1 shows an example of the collection of complete pentad-mean data which does not include missing daily data at Jakarta (02027; 6°10′S, 106°49′E). Minimum number of complete pentad-mean rainfall data in every pentad number is 16 at pentad 49 (February 25–March 1) (see right column). Number of years with complete (73-pentad) sets of pantad-mean rainfall data is 12 (see bottom line). We used 17 years data at Jakarta in this study (see Table 1), hence we allowed missing data for two days at maximum in each pentad in 5 years. Percentages (numbers) of the pentad-mean data with missing daily rainfall data were less than 10% (8 pentad) in each year so that the influence of missing data were not so large in this study.

Table A2 shows the list of the collection of rainfall data at all 46 station used in this study. Number of years and minimum number of years in every pentad number as shown in Table A1 are indicated in left-middle column.

Table A1. List of pentad-mean rainfall amount data at Jakarta (02027; 6°10′S, 106°49′E) at 1–73 pentad from 1961–90. In the middle column, an asterisk ('∗') shows the complete pentad rainfall data and a slash ('/') shows pentad data which includes missing data. Number of complete data at each pentad number is shown in the right column. At the bottom line, an asterisk (a slash) shows complete (incomplete) 73-pentad data sets in each year. Number of years with complete (73-pentad) sets (*i.e.,* count of '∗') of pentad rainfall data is shown in bottom-left, and minimum number of complete data in every pentad is shown in bottom-right.

Pentad Number		Analysis year						Total
		61–65	66–70	71–75	76–80	81–85	86–90	
1:	Jun 30 – Jul 4	*****	/////	//***	*****	*//**	*****	21
2:	Jul 5 – Jul 9	*****	/////	//***	*****	*//**	*****	21
3:	Jul 10 – Jul 14	*****	/////	//***	*****	*//**	*****	21
4:	Jul 15 – Jul 19	*****	/////	//***	*****	*//**	*****	21
5:	Jul 20 – Jul 24	*****	/////	//***	*****	*//**	*****	21
6:	Jul 25 – Jul 29	*****	/////	//***	*****	*//**	*****	21
7:	Jul 30 – Aug 3	*****	/////	//***	*****	*//**	*****	21
8:	Aug 4 – Aug 8	*****	/////	//***	*****	*//**	*****	21
9:	Aug 9 – Aug 13	*****	/////	//***	*****	*//**	*****	21
10:	Aug 14 – Aug 18	*****	/////	//***	*****	*//**	*****	21
11:	Aug 19 – Aug 23	*****	/////	//***	*****	*//**	*****	21
12:	Aug 24 – Aug 28	*****	/////	//***	*****	*//**	*****	21
13:	Aug 29 – Sep 2	*****	/////	//***	*****	*//**	*****	21
14:	Sep 3 – Sep 7	*****	/////	//***	*****	*//**	*****	21
15:	Sep 8 – Sep 12	*****	/////	//***	*****	*//**	*****	21
16:	Sep 13 – Sep 17	*****	/////	//***	*****	*//**	*****	21
17:	Sep 18 – Sep 22	*****	/////	//***	*****	*//**	*****	21
18:	Sep 23 – Sep 27	*****	/////	//***	*****	*//**	*****	21
19:	Sep 28 – Oct 2	*****	/////	//***	*****	*//**	*****	21
20:	Oct 3 – Oct 7	*****	/////	//***	*****	*//**	*****	21
21:	Oct 8 – Oct 12	*****	/////	//***	*****	*//**	*****	21
22:	Oct 13 – Oct 17	*****	/////	//***	*****	*//**	*****	21
23:	Oct 18 – Oct 22	*****	/////	//***	*****	*//**	*****	21
24:	Oct 23 – Oct 27	*****	/////	//***	*****	*//**	*****	21
25:	Oct 28 – Nov 1	*/***	/////	//***	*****	*//**	*****	20
26:	Nov 2 – Nov 6	*****	/////	//***	*****	*//**	*****	21
27:	Nov 7 – Nov 11	*****	/////	//***	*****	*//**	*****	21
28:	Nov 12 – Nov 16	*****	/////	//***	*****	*//**	*****	21
29:	Nov 17 – Nov 21	*****	/////	//***	*****	*//**	*****	21
30:	Nov 22 – Nov 26	*****	/////	//***	*****	*//**	*****	21
31:	Nov 27 – Dec 1	*****	/////	//***	*****	*//**	*****	21
32:	Dec 2 – Dec 6	*****	/////	//***	*****	*//**	*****	21
33:	Dec 7 – Dec 11	*****	/////	//***	*****	*//**	*****	21
34:	Dec 12 – Dec 16	*****	/////	//***	*****	*//**	*****	21
35:	Dec 17 – Dec 21	*****	/////	//***	*****	*//**	*****	21
36:	Dec 22 – Dec 26	*****	/////	//***	*****	*//**	*****	21
37:	Dec 27 – Dec 31	*****	/////	//***	*****	///**	*****	20
38:	Jan 1 – Jan 5	****/	/////	//***	/****	/****	****/	19
39:	Jan 6 – Jan 10	****/	/////	//***	/****	/****	****/	19
40:	Jan 11 – Jan 15	****/	/////	//***	/****	/****	****/	19
41:	Jan 16 – Jan 20	****/	/////	//***	/****	/****	****/	19
42:	Jan 21 – Jan 25	****/	/////	//***	/****	/****	****/	19
43:	Jan 26 – Jan 30	****/	/////	//***	/****	/**/*	****/	18
44:	Jan 31 – Feb 4	****/	/////	//***	*****	/**/*	****/	19
45:	Feb 5 – Feb 9	****/	/////	//***	*****	/****	****/	20
46:	Feb 10 – Feb 14	****/	/////	//***	*****	/****	****/	20
47:	Feb 15 – Feb 19	****/	/////	//***	*****	/****	****/	20
48:	Feb 20 – Feb 24	****/	/////	//***	*****	/****	****/	20
49:	Feb 25 – Mar 1	**/*/	/////	//**/	*****	//***	*/**/	16
50:	Mar 2 – Mar 6	****/	/////	/****	*****	//***	****/	20
51:	Mar 7 – Mar 11	****/	/////	/****	*****	//***	****/	20
52:	Mar 12 – Mar 16	****/	/////	/****	*****	//***	****/	20
53:	Mar 17 – Mar 21	****/	/////	/****	*****	//***	****/	20
54:	Mar 22 – Mar 26	****/	/////	/****	*****	//***	****/	20
55:	Mar 27 – Mar 31	****/	/////	/****	*****	//***	****/	20
56:	Apr 1 – Apr 5	****/	/////	/****	*****	//***	****/	20
57:	Apr 6 – Apr 10	****/	/////	/****	*****	//***	****/	20
58:	Apr 11 – Apr 15	****/	/////	/****	*****	//***	****/	20
59:	Apr 16 – Apr 20	****/	/////	/****	*****	//***	****/	20
60:	Apr 21 – Apr 25	****/	/////	/****	*****	//***	****/	20
61:	Apr 26 – Apr 30	****/	/////	/****	*****	//***	****/	20
62:	May 1 – May 5	****/	/////	/****	*****	//***	****/	20
63:	May 6 – May 10	****/	/////	/****	*****	//***	****/	20
64:	May 11 – May 15	****/	/////	/****	*****	//***	****/	20
65:	May 16 – May 20	****/	/////	/****	*****	//***	****/	20
66:	May 21 – May 25	****/	/////	/****	*****	//***	****/	20
67:	May 26 – May 30	****/	/////	/****	*****	//***	****/	20
68:	May 31 – Jun 4	****/	/////	/****	*****	//***	****/	20
69:	Jun 5 – Jun 9	****/	/////	/****	*****	//***	****/	20
70:	Jun 10 – Jun 14	****/	/////	/****	*****	//***	****/	20
71:	Jun 15 – Jun 19	****/	/////	/****	*****	//***	****/	20
72:	Jun 20 – Jun 24	****/	/////	/****	*****	//***	****/	20
73:	Jun 25 – Jun 29	****/	/////	/****	*****	//***	****/	20
Number of years: 12		*//*/	/////	//**/	/****	////*	*/**/	16

Table A2. List of rainfall data used in the present study. Percentage of complete pentad data which does not have missing daily data in each year, is indicated in right-hand side columns by a number (percentage is divided by ten). An asterisk ('*') and a slash ('/') indicate complete 73-pentad data sets and no data in each year. Number of years with complete (73-pentad) sets (*i.e.,* count of '*') of pentad rainfall data is shown in left-middle column, and minimum number of years in every pentad number is attached in a bracket.

No.	Station		Count of Years	Analysis year during 1961–90					
	Number	Name		61–65	66–70	71–75	76–80	81–85	86–90
1	02026	Tanjung Priok	12 (19)	5///0	//6/4	***9*	**9**	**9*9	*9962
2	02027	Jakarta	12 (16)	*99*5	/////	/3**9	9****	4149*	*9**5
3	02033C	Halim	14 (20)	61767	69839	477**	*****	**9**	*9**5
4	02068	Cikopo	9 (11)	***85	78***	34***	5////	/////	/////
5	03230	Tasik Malaya	9 (13)	8****	9**76	*9*9*	51464	2/21/	/////
6	05035A	Tegal	7 (11)	**99*	*6**5	/////	/8*96	40762	65513
7	06016	Cilacap	10 (15)	**9*8	8****	**99*	5////	//3/2	65323
8	07053	Kedung Ptri	11 (13)	*****	**772	/////	4****	43576	734//
9	10210	Karang Asem	12 (17)	****8	***95	/////	4****	*8776	465//
10	12192	Bawean	7 (15)	39*88	7***5	/39**	9*998	30321	32423
11	13028C	Madiun	8 (15)	9**9*	*****	98678	98665	1/2//	17552
12	15190	Tempeh	8 (12)	***94	4*9**	*56*9	5////	/////	/////
13	15216	Kalijeruk	13 (14)	****9	*****	****9	5////	/////	/////
14	16191	Dadapan	10 (13)	**9*7	9*99*	*****	5////	/////	/////
15	20113A	Sigli	7 (10)	3////	///4*	****9	**989	2672/	/////
16	21127I	Medan	2 (11)	66888	99*43	/3*99	1//49	40883	99995
17	22267A	Tarempa	4 (9)	454*9	*9**5	/3049	95869	40500	00310
18	23175B	Jambi	3 (14)	78889	99989	9***9	89889	40400	000//
19	24257	Pangkal Pinang	10 (19)	4*9*8	88***	9*999	9****	40623	54642
20	26273	Pontianak	10 (12)	*****	****9	99*99	5////	/////	/////
21	28308B	Banjarmasin	10 (15)	**9**	548**	*9***	99994	/03/1	43300
22	29313D	Balikpapan	8 (16)	99*9*	79*88	****9	*9978	4/143	67762
23	29318	Kotabaru	7 (13)	**524	*8***	99*99	5////	//243	76631
24	29324	Muara Muntai	12 (18)	****4	//099	*****	*54**	94653	484//
25	29327A	Tarakan	6 (10)	99***	*9**5	/////	2/33/	4760/	134//
26	30330	Taruna	8 (10)	**5//	///4*	*****	54652	/////	0////
27	30330C	Naha	3 (9)	/////	/////	/////	/6*98	7989*	9*741
28	30331E	Manado	20 (22)	*****	*****	****9	9****	*7*93	461//
29	30334B	Kayuwatu	12 (13)	/////	/////	0***9	*9***	*****	5////
30	30352	Gorontalo	5 (12)	/////	/////	45842	9****	54664	69*95
31	31364E	Palu	6 (18)	99**9	8*952	977*9	9*87*	50652	64473
32	31367	Luwuk	9 (13)	/////	////4	91///	/4***	*****	*9995
33	33415D	Panakukang	16 (17)	/////	/////	49**9	*****	*****	****5
34	34440	Tabanan	14 (18)	849**	***9*	*****	9**98	/4*62	013//
35	34445B	Denpasar	5 (10)	/////	/////	//4**	***98	5///4	99862
36	36461	Waingapu	16 (21)	/9***	*****	*****	**549	06764	8*5//
37	36470G	Kupang	3 (15)	74434	5453/	289*9	999**	50887	98752
38	37479	Saumlaki	3 (17)	4788*	996*5	///05	79898	89889	656*5
39	37481A	Geser	7 (11)	9**5/	//1*7	9****	5/45/	//252	25332
40	37487	Amahai	9 (10)	/////	/////	/////	///4*	*****	**9*4
41	37490	Ambon	12 (20)	75***	89*71	/2436	9****	9*99*	99**5
42	37495B	Labuha	5 (8)	1/044	48*9*	99***	5////	/////	/////
43	37496	Ternate	2 (10)	**984	////3	54889	99875	30552	64421
44	37510	Tual	13 (16)	/////	/////	/4**9	*****	***9*	*9*95
45	381010	Biak	14 (14)	*****	*****	****5	/////	//3/0	321//
46	383054	Babo	10 (13)	*9*88	*****	*9**5	/////	/////	/////

References

Allan, R.J., 1991: *Australasia. Teleconnections Linking Worldwide Climate Anomalies: Scientific Basis and Societal Impact*. Cambridge University Press, 73–120.

Berlage, H.P., 1949: Rainfall in Indonesia. *Verhandelingen*, **37**, 212pp.

———, 1957: Fluctuations in the general atmospheric circulation of more than one year, their nature and prognostic value. *Verhandelingen*, **69**, 152pp.

———, 1966: The southern oscillation and world weather. *Verhandelingen*, **88**, 152pp.

Braak, C., 1929: The climate of the Netherlands indies. *Verhandelingen*, **8**, 1602pp.

de Boer, H.J., 1947: On forecasting the beginning and the end of the dry monsoon in Java and Madura. *Verhandelingen*, **32**, 20pp.

Eguchi, T., 1983: Rainfall distribution and air streams over Indonesia. *Geographical Review of Japan*, **56**, 151–170, (in Japanese).

Hackert, E.C. and S. Hastenrath, 1986: Mechanisms of Java rainfall anomalies. *Mon. Wea. Rev.*, **114**, 745–757.

Hamada, J.-I. and T. Sribimawati, 1998: *Catalogue and sample plotting of daily rainfall data for 1961–90 at 157 stations in Indonesia. Climatology of Indonesian Mritime Continent.* Radio Atmospheric Science Center, Kyoto University, 17–90.

Hashiguchi, H., S. Fukao, M.D. Yamanaka, T. Tsuda, S.W.B. Harijono and H. Wiryosumarto, 1995: Boundary Layer Radar observations of the passage of the convection center over Serpong, Indonesia (6°S, 107°E) during the TOGA COARE intensive observation period. *J. Meteor. Soc. Japan*, **73**, 535–548.

Haylock, M. and J.L. McBride, 2001: Spatial coherence and predictability of Indonesian wet season rainfall. *J. Climate*, **14**, 3882–3887.

Hendon, H.H. and B. Liebmann, 1990a: A composite study of onset of Australian summer monsoon. *J. Atmos. Sci.*, **47**, 2227–2240.

——— and B. Liebmann, 1990b: The intraseasonal (30–50 day) oscillation of the Australian summer monsoon. *J. Atmos. Sci.*, **47**, 2909–2923.

Holland, G.J., 1986: Interannual variability of the Australian summer monsoon at Darwin: 1952–82. *Mon. Wea. Rev.*, **114**, 594–604.

Inoue, T. and K. Nakamura, 1990: *Physical and biological background for insect studies in Sumatra. in Natural History of Social Wasps and Bees in Equatorial Sumatra.* Hokkaido University Press, 1–11.

Können, G.P., P.D. Jones, M.H. Kaltofen and R.J. Allan, 1998: Pre-1866 extensions of the southern oscillation index using early Indonesian and Tahitian meteorological readings. *J. Climate*, **11**, 2325–2339.

LMG, 1973a: *Rainfall atlas of Indonesia. Vol. I: Java and Madura (1931–1960). in Meteorological Note No. 9*. Department of Communications Meteorological and Geophysical Institute Republic of Indonesia, 30pp.

———, 1973b: *Rainfall atlas of Indonesia. Vol. II: Sumatra, Kalimantan, Sulawesi, Nusatenggara, Maluku, Irian Jaya (1911–1940). in Meteorological Note No. 9*. Department of Communications Meteorological and Geophysical Institute Republic of Indonesia, 47pp.

Matsumoto, J., 1992a: *Climate over East and Australian monsoon regions. Part II: Distribution of 5-day mean precipitation and OLR*. Dept. of Geography, 1–78.

———, 1992b: The seasonal changes in Asian and Australian monsoon region. *J. Meteor. Soc. Japan*, **70**, 257–273.

———, 1995: Rainfall climatology over Asian monsoon region. *Toward global planning of sustainable use of the Earth*, **Elsevier**, 419–422.

McBride, J.L., 1992: The meteorology of Indonesia and the maritime continent. *Fourth Int. Symp. Equatorial Atmos. Obs. over Indonesia*.

Murakami, T. and J. Matsumoto, 1994: Summer monsoon over the Asian continent and western north Pacific. *J. Meteor. Soc. Japan*, **72**, 719–745.

Nakamura, K., 1994: Regional difference and seasonality of rainfall in Java, with special reference to Bogor. *Tropics*, **4**, 93–103.

Nakazawa, T., 1988: Tropical super clusters within intraseasonal variations over the western Pacific. *J. Meteor. Soc. Japan*, **66**, 823–839.

Nicholls, N., 1981: Air-sea interaction and the possibility of long-range weather prediction in the Indonesian archipelago. *Mon. Wea. Rev.*, **109**, 2435–2443.

———, 1984: The southern oscillation and Indonesian sea surface temperature. *Mon. Wea. Rev.*, **112**, 424–432.

———, B. Lavery, C. Frederiksen and W. Drosdowsky, 1996: Recent apparent changes in relationships between the El Niño-southern oscillation and Australian rainfall and temperature. *Geophys. Res. Lett.*, **23**, 3357–3360.

Nitta, T., T. Mizuno and K. Takahashi, 1992: Multiscale convective systems during the initial phase of the 1986/87 El Niño. *J. Meteor. Soc. Japan*, **70**, 447–466.

Ramage, C.S., 1968: Role of a tropical "maritime continent" in the atmospheric circulation. *Mon. Wea. Rev.*, **96**, 365–369.

Ropelewski, C.F. and M.S. Halpert, 1987: Global and regional scale precipitation patterns associated with the El Niño/southern oscillation. *Mon. Wea. Rev.*, **115**, 1606–1626.

Rutledge, S.A., E.R. Williams and T.D. Keenan, 1992: The Down-Under Doppler and Electricity Experiment (DUNDEE): overview and preliminary results. *Bull. Amer. Meteor. Soc.*, **73**, 3–16.

Schmidt, F.H. and J.H.A. Ferguson, 1951: Rainfall types based on wet and dry period ratios for Indonesia with western New Guinee. *Verhandelingen*, **42**, 77pp.

Shinoda, M., 1998: Climate variations of observation age: Asia–Australia transect. *Meteor. Res. Notes*, **191**, 85–105, (in Japanese).

Suppiah, R., 1993: ENSO phenomenon and 30–50 day variability in the Australian summer monsoon rainfall. *Int. J. Climatol.*, **13**, 837–851.

Takahashi, T., K. Suzuki, M. Orita, M. Tokuno and R. Mar, 1995: Videosonde observations of precipitation processes in equatorial cloud clusters. *J. Meteor. Soc. Japan*, **73**, 509–534.

Tanaka, M., 1994: The onset and retreat dates of the Austral summer monsoon over Indonesia, Australia and New Guinea. *J. Meteor. Soc. Japan*, **72**, 255–267.

Wilks, D.S., 1995: *Statistical methods in the atmospheric science*. Academic Press, 325–341.

Yasunari, T., 1981: Temporal and spatial variations of monthly rainfall in Java, Indonesia. *Southeast Asian Studies*, **19**, 170–186.

——— and R. Suppiah, 1988: *Some problem on the interannual variability of Indonesian monsoon rainfall. in Toropical Rainfall Measurement*. A DEEPAK Publishing, 113–121.