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AIR-TEMPERATURE VARIATIONS AND ENSO EFFECTS IN INDONESIA, THE PHILIPPINES AND EL SALVADOR. ENSO PATTERNS AND CHANGES FROM 1866–1993

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Abstract—The major features in development of the "El Nino-Southern Oscillation" (ENSO) involve oscillation of the Pacific ocean-atmosphere in an essentially unpredictable (chaotic) fashion. The system moves between extremes of the so-called "warm events" lasting one or two years and involving movement of warm sea water from the western Pacific along the equator to impact on the west coast of the American continent and "cold-events" associated with easterly trade-wind-induced flows of colder water from the eastern Pacific towards the west. Historical data indicate that ENSO years as experienced by the Island of Java are either much warmer than non-ENSO years or only slightly, if at all, warmer than normal (non-ENSO) years. Hot-dry years within the ENSO warm event cycle are almost always followed by cooler wet years and *vice versa*. This pattern also extends to include the year immediately following the terminal year of an ENSO warm event set. The initial year of an ENSO warm event set may be either hot with a long dry season or relatively cool (nearer to the temperature of a non-ENSO year) and having a short dry season. In recent years, since 1950, of the 9 ENSO warm events, the initial year tends to have been hot and dry for 6 (1951, 1957, 1963, 1972, 1982, 1991) and neutral or cool and wet for 3 (1968, 1976, 1986).

An area of 88,000 ha burned in 1991 (Jakarta Post 30 November 1991) largely in Kalimantan in association with the 1991–1992 ENSO event, an extensive pall of smoke developed over Kalimantan, Singapore and Malaysia during September–October of 1991. Surface vegetation-based fires continued to burn in East Kalimantan as of 29 April 1992 and extended into the 1992 dry season, in response to the ENSO conditions carrying forward from 1991.

The increasing annual trend in air-temperature exhibited by the mean monthly values over the period 1866–1993, for the Jakarta and the Semarang data taken together is 1.64°C (0.0132°C per year from 25.771 to 27.409°C). The major industrial development in infrastructure for Jakarta has been significant only since 1980 or so and was not apparent before 1970 when the city had the aspect of an extended village with few large buildings (greater than 3–4 stories) and no extensive highways. The 1.65° difference between 1866 and 1991 can presumably be partitioned into: (1) urban heat-island effect, (2) effect of deforestation, (3) effect of secular micro-climate shift, (4) influence of general global warming with particular reference to the tropics.

When the blocks of non-ENSO years in themselves are considered, the deviations from the secular trend for warmest month mean temperatures in successive years are correlated with that of the next immediate year deviation so that either continual warming or cooling appears to take place from the termination of one ENSO to the initiation of the next. When the deviations around the secular trend shown by the warmest month average temperatures are summed for the inter-ENSO intervals (the separate non-ENSO years) the resultant "heat-loading" index is positively correlated with the following (initial) ENSO warmest month deviation from the overall ENSO warmest month secular trend. This provides an immediate predictive mechanism for the likely strength of an ENSO, in terms of the dry season impact to the Island of Java, should one occur in the next year to break a non-ENSO sequence. The length of the build-up and the build-up achieved seems not to be related. The relationship does not in itself however, predict the occurrence of the "next" ENSO.

The data show that a consistent structure underlies ENSO events for the last century and a quarter. However, as a process monitored by mean monthly air-temperature measurements at Jakarta–Semarang, the system is changing in character with time in association with an overall atmospheric temperature increase in a way that involves increased intra-annual temperature fluctuations. In general ENSO years are associated with higher temperatures than non-ENSO years, with a significant negative correlation between subsequent years which are thereafter systematically cooler. This may be because the ENSO event actively mixes excess heat energy into the ocean-sink to an extent that is in direct proportion to the outstanding positive temperature deviation. A weak ENSO, preceded by a relatively modest temperature build-up in the lead-up non-ENSO years, then results in limited mixing which leads to a relatively warm subsequent year while a strong event leads to extensive mixing and so generally results in a following very much cooler year. Atmospheric temperature build-up possibly associated with the greenhouse effect may be coupled to an increasingly wider temperature swing in west and central Java associated with the warm pool influence but anchored by the ocean-sink.

Key word index: El Nino, southeast Asia, drought, global change, warm events.

INTRODUCTION

The major features in development of the "El Nino-Southern Oscillation" (ENSO) are discussed by Wyrkti (1982) and later by Enfield (1988). In brief, the system oscillates in an essentially unpredictable (chaotic) fashion between extremes of the so-called "warm events" involving movement of warm sea water from the western Pacific along the equator to impact on the west coast of the American continent and "cold-events" associated with easterly trade-wind-induced flows of colder water from the eastern Pacific towards the west. An atmospheric pressure relationship described by the difference in sea-level air pressure between Tahiti and Darwin, reverses as the two extremes are approached. This pressure difference is termed the "Tahiti-Darwin Index" (T-D Index) or "Southern Oscillation Index" (SOI). A strong downward trend with a consequent low index value takes place with progressive development of a "high" over Darwin and a "low" over Tahiti indicating development of an ENSO warm event condition. This condition coincides with the release of pooled warm water in the region of the western Pacific around eastern Papua New Guinea and the subsequent west to east transmission in the form of a "Kelvin Wave" channeled along the equator, and often with the establishment of drought conditions over much of Indonesia. Wyrkti (1982) and Enfield (1988) provide detailed explanations of Kelvin wave formation together with the related Rossby wave responses.

INDONESIA AND SOUTHEAST ASIA

Indonesia lies on the western margin of the ENSO interaction and for the most part enjoys a humid tropical climate except in the eastern most regions. Indonesia presently supports extensive tracts of tropical rain forest apparently amounting to some 117.9 million ha in 1990 which accounts for some 6.4% of the global total estimated as 1838 million ha in 1982 (Brown and Lugo, 1982). For Indonesia, the ENSO-associated warm event drought of 1991 led to the failure of 190,000 ha in paddy with an overall 843,000 ha affected. This event caused unprecedented losses in rice production to Indonesia resulting in 600,000 tons being imported to the previously self-sufficient archipelago. In 1982–1983 the ENSO-associated drought of that time, resulted in 420,000 ha of paddy being affected and failure of 158,000 ha and was also accompanied by forest fires which burned 3.7 million ha of generally second-growth timber, mainly in Kalimantan (Borneo), Murdiyarso (1993). An area of 88,000 ha burned in 1991 (Jakarta Post 30 November 1991) largely in Kalimantan in association with the 1991–1992 ENSO event. An extensive pall of smoke developed over Kalimantan, Singapore and Malaysia during September–October of 1991 and in 1994. The maximum mean monthly air temperature for data obtained from the cities of Jakarta and Semarang (Java, Indonesia) in 1991 was 29.1°C.

AIR TEMPERATURE

Air-temperature records from Jakarta (Pusat) 06° 11 min south, 106° 50 min east, population 8.8 million in 1991, exist since 1866 with missing years confined to 1943, 1946, 1947 and 1958. These have been combined, "pooled" with records from Semarang 07° 00 min south, 110° 25 min east, a smaller city (population 1.1 million in 1989) 450 km to the east, from the year 1982–1991 inclusive. Figure 1 shows the secular trend of the mean annual temperature (degrees Centigrade) together with regression lines representing the mean temperatures for the warmest and coldest months for ENSO and non-ENSO years, respectively. The slopes of the regression lines representing the coldest and the warmest months differ significantly from each other. When the Jakarta–Semarang temperature records for ENSO warm event years (Kiladis and Diaz, 1989; Brookfield and Allen, 1991; Wang, 1991) are separated from "non-ENSO years", that is all other years, the former are significantly warmer than the latter on average by 0.16°C throughout the time covered by the data, but the trend towards increasing temperature is consistent for both groups so that each appears to increase in temperature at the same rate. The relationship between temperature of warmest months for ENSO and non-ENSO years is shown in Fig. 2.

The secular change in the mean temperature of the warmest month in the year throughout the record is also shown in Fig. 3 which uses different symbol-sets to depict succeeding ENSO-blocks. An ENSO-block is defined as starting immediately after the last year of an ENSO (warm) event running through to include the next year or years involving a warm event. Warm events thus terminate ENSO-blocks.

In Fig. 3 the ENSO years are represented by the last one or two positions for each ENSO-block. Double ENSO-years are: 1877–78, 1880–81, 1899–1900, 1904–05, 1913–14, 1918–19, 1925–26, 1940–41, 1944–45, 1957–58, 1968–69, 1982–83, 1986–87, 1991–92–93. As previously mentioned, a progressive increase is recorded in the warmest month temperature for both ENSO and non-ENSO years with the former being approximately 0.45° warmer than the latter with no significant difference in the rate of increase between the two as estimated by the slopes of the regression lines relating temperature to time. The slopes of the regression lines relating the warmest month means on an annual basis in relation to time differ significantly for both ENSO and non-ENSO years to those of similar lines describing the mean temperature of the coldest months ($p < 0.001$) with the former being steeper than the latter (Fig. 1). When examined in detail, the Jakarta/Semarang data indicate that as warming has proceeded, the behavior of

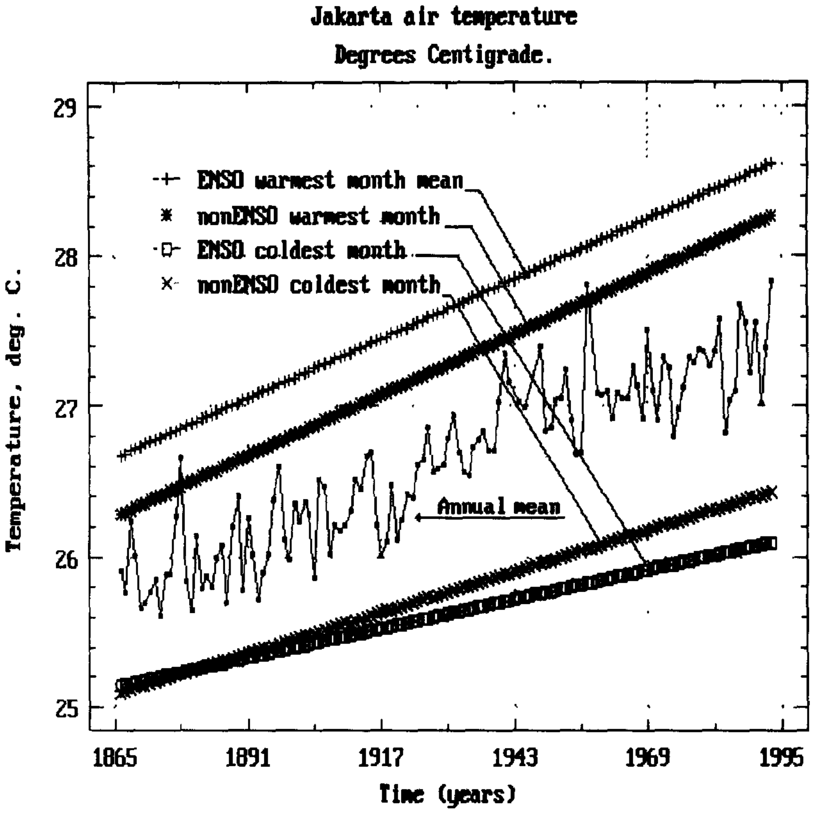


Fig. 1. Jakarta air temperature (°C).

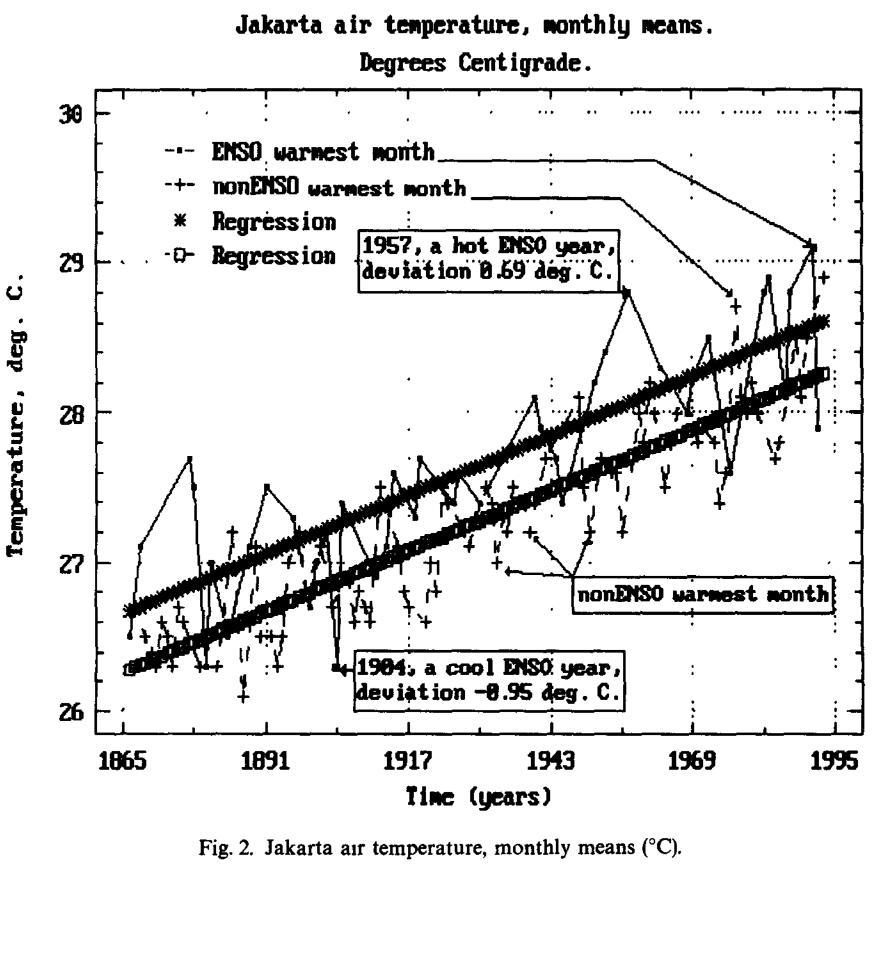


Fig. 2. Jakarta air temperature, monthly means (°C).

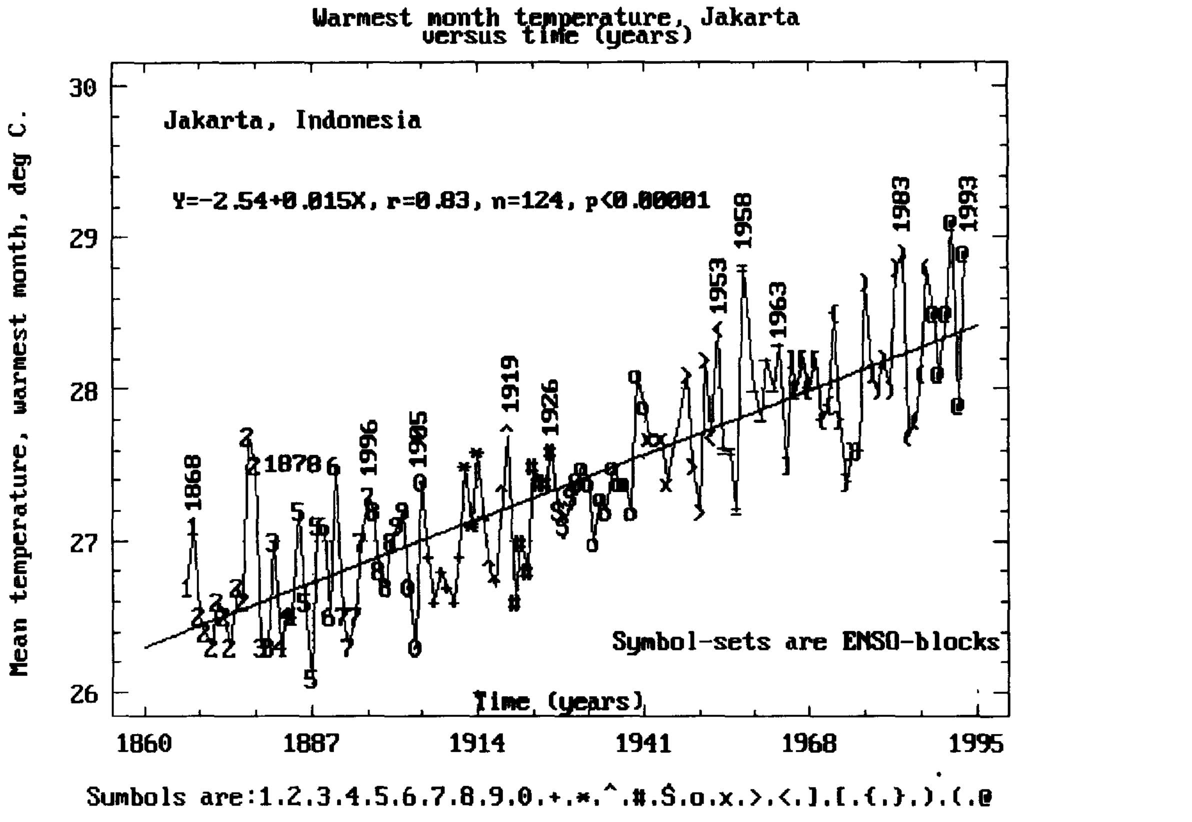


Fig. 3. Warmest month temperature, Jakarta versus time (yr).

both the ENSO and non-ENSO years has apparently changed in a systematic manner over 127 yr in a way that involves an increase in annual fluctuations in mean monthly air temperature with the non-ENSO years now showing a marginally smaller range than the ENSO group. The coldest month temperatures for ENSO years are now slightly lower than for non-ENSO years and the difference was not apparent at the beginning of the record. Overall, the warmest month temperature for all years has increased at a rate of 1.5°C per 100 yr.

The air-temperature records from (port area) Manila (120° 59 min east, 14° 35 min north, elevation 15 m, population 7.9 million, 1992) and from Davao (125° 39 min east, 07° 07 min north, elevation 18 m, population 843,000, 1990), in the Philippines show the same upward trend as for the Jakarta/Semarang set with annual mean warming of 2.2°C and 1.7°C, respectively, per 100 yr. In addition, the annual deviations from the overall secular trend are relatively strongly correlated among all three ($r > 0.4$, $p \leqslant 0.0001$) showing that at least southeast Asia tends to behave as a sympathetic unit as far as temperature variations as well as increases are concerned. The towns of Baguio, 16° 25 min north, 120° 36 min east, elevation 1500 m and Maktan Airport, Cebu 10° 18 min north, 123° 58 min east, elevation 13 m also show upward temperature trends from 1920 and 1950, respectively, with the warmest months growing at 3.5°C and 3.0°C per 100 years. The warmest month deviations for ENSO years are positively correlated for Jakarta and Baguio ($r = 0.69, n = 16$, $p = 0.0026$) and for all years ($r = 0.31$, $n = 61$, $p = 0.012$). It may also be noted that neither Davao nor Manila show a significant difference between the temperatures of the warmest months for ENSO and non-ENSO years and there is likewise no difference in the slopes of regression lines describing changes in the warmest and coldest months with time.

PATTERNS IN TEMPERATURE DEVIATION

If the secular changes shown by the mean temperature of the warmest months in both ENSO and non-ENSO years are considered separately for the Jakarta/Semarang data, the deviation from the trend shown by the maximum of the mean monthly ENSO temperature values plotted against the deviation of the maximum mean monthly temperature in the following non-ENSO year shows a consistent pattern, $r = -0.64$, $n = 25$, $p = 0.0004$. In brief, if the ENSO year deviation is high and positive the following non-ENSO year deviation will be high and negative. A negative ENSO year warm deviation means a following positive non-ENSO year deviation and so

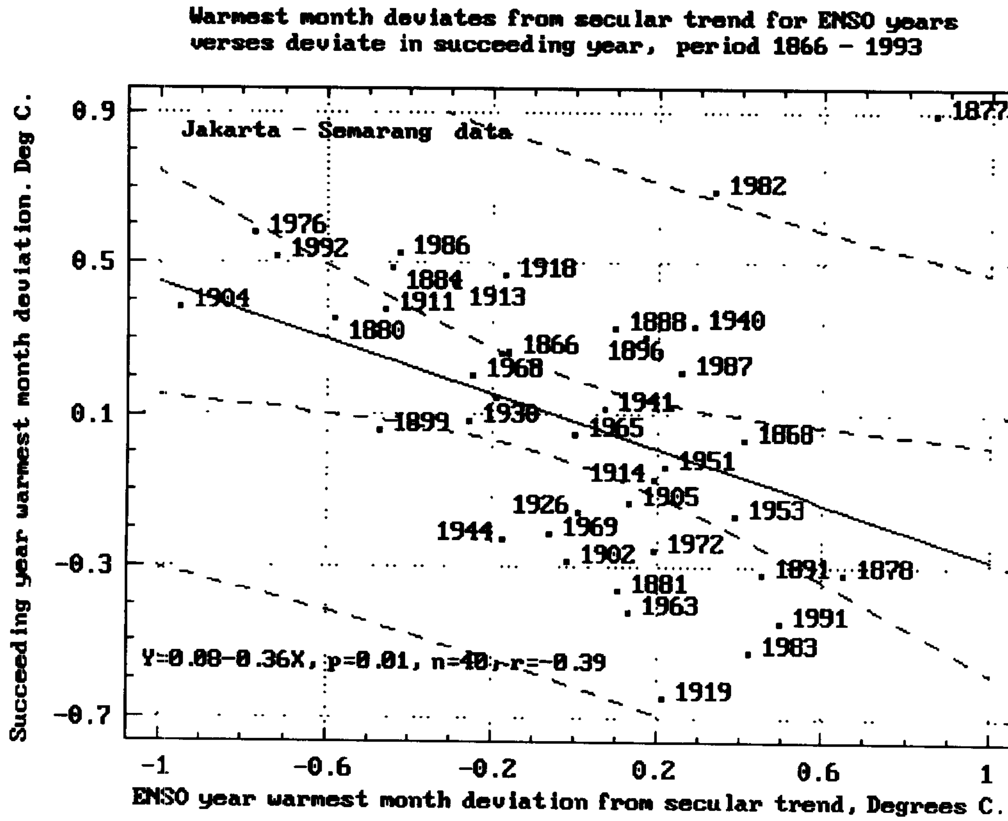


Fig. 4. Warmest month deviates from secular trend for ENSO years versus deviate in succeeding year, period 1866–1993.

forth. This pattern also holds throughout both years of a double ENSO cycle as well as for the next non-ENSO year (Fig. 4).

The data indicate that ENSO years as experienced by the Island of Java are either much warmer than non-ENSO years or only slightly, if at all, warmer than normal (non-ENSO) years (Fig. 2). Hot-dry years initiating ENSO warm events which are also "double-year" activities are almost always followed by cooler wet years and *vice versa.* As indicated previously, this pattern also extends to include the year immediately following the terminal year of an ENSO warm event set. The initial year of an ENSO warm event set may be either hot with a long dry season or relatively cool (nearer to the temperature of a non-ENSO year) and having a short dry season. In recent years, since 1950, of the 9 ENSO warm events, the initial year tends to have been hot and dry for 6 (1951, 1957, 1963, 1972, 1982, 1991) and neutral or cool and wet for 3 (1968, 1976, 1986).

When the blocks of non-ENSO years in themselves are considered, the deviations from the secular trend for warmest month mean temperatures in successive years are positively correlated with that of the next immediate year deviation so that continual warming appears to take place from the termination of one ENSO to the initiation of the next ($r = 0.304$, $p = 0.027$, $n = 52$, $y = -0.065 + 0.2637x$, where y is the following non-ENSO deviation of the warmest month and x is the preceding non-ENSO year warmest month deviation). The relationship is strongest for the year after an ENSO and the succeeding year ($r = 0.485$, $p = 0.035$, $n = 18$).

If the deviations around the secular trend shown by the warmest month average temperatures are summed for the inter-ENSO intervals (the separate non-ENSO years) the resultant "heat-loading" index is positively correlated with the following (initial) ENSO warmest month deviation from the overall ENSO warmest month secular trend ($r = 0.432$, $p = 0.027$, $n = 25$, (one point, 1951, is uncertain since it is missing from the original data and estimated by use of the "southern oscillation index" or SOI) $y = -0.0346 + 0.347x$ where y is the next ENSO year warmest month deviation and x is the sum of the successive yearly warmest month deviations since the last ENSO). This provides an immediate predictive mechanism for the likely strength of an ENSO should one occur in the next year to break a non-ENSO sequence. The length of the build-up and the build-up achieved seems not to be related. The relationship does not in itself predict the occurrence of the "next" ENSO, merely its likely "strength" should one occur.

The relationship involved with the "heat-loading" index is also preserved throughout the whole of an ENSO-block starting with the year following the last identified ENSO year and running through to include the subsequent one or two ENSO years which terminate the sequence. Where the annual deviations of the warmest months recorded from an overall secular trend for both ENSO and non-ENSO years are used to construct the accumulated heat-loading index, the relationship between the successive accumulated deviations and that of the following year is positive, $r = 0.851$, $p < 0.00001$, $n = 89$, $y = 0.0299 + 1.0737x$, where y = the subsequent year heat-loading index accumulation and x the preceding year heat-loading index accumulation. The slope in excess of 1.0 shows that negative trending accumulations tend to remain negative or become more so and the positive accumulating trends tend to become self-reinforcing. The cross-over point for positive reinforcement is a deviation of $\geqslant -0.0278$°C. A positive-starting warm series build-up is almost always followed by a very warm ENSO (1876, 1890, 1912, 1962, 1967, 1971, 1981, 1991). Note that the 1876 series started with a slight positive deviation from the secular trend, then became slightly negative before delivering two very hot ENSO years. In addition, negative-starting and negative-tending series (such as those terminated by the years 1883, 1895, 1910, 1917, 1924, 1929, 1939, 1943—has a critical missing observation, negative by estimation from the SOI, 1950—two initial years are missing from this unit plus the last (1951) which are all negative by estimation from the SOI, 1975, 1985) never result in very warm subsequent ENSOs. The "neutral-trending" multi-year series (having more than 1 inter-ENSO year) not mentioned above (1887, 1898, 1956) do not end in very warm ENSOs and show no apparent trend. The initial years of the block terminating in 1876 with the "hot" 1877–1878 ENSO can be considered as "neutral trending".

As a rule the developing individual year-blocks trace out differing histories and show less variation around the overall trend than the data indicate as a whole. This means that the temperature of the warmest month of succeeding years within an ENSO block (including the actual ENSO year deviations), can be predicted to an extent if the "heat-loading" index build-up is known. However, the identification of a succeeding year (ENSO or non-ENSO) cannot be assumed. If a subsequent ENSO year is postulated then a reasonably accurate estimate of its likely impact can be deduced. The cumulative ENSO-block traces around the secular trend, for the warmest month temperatures depicted in Fig. 3, are illustrated in Fig. 5.

For Indonesia and presumably for much of south-east Asia the ENSO events are variable in expression. As a generality, they are part of successions which

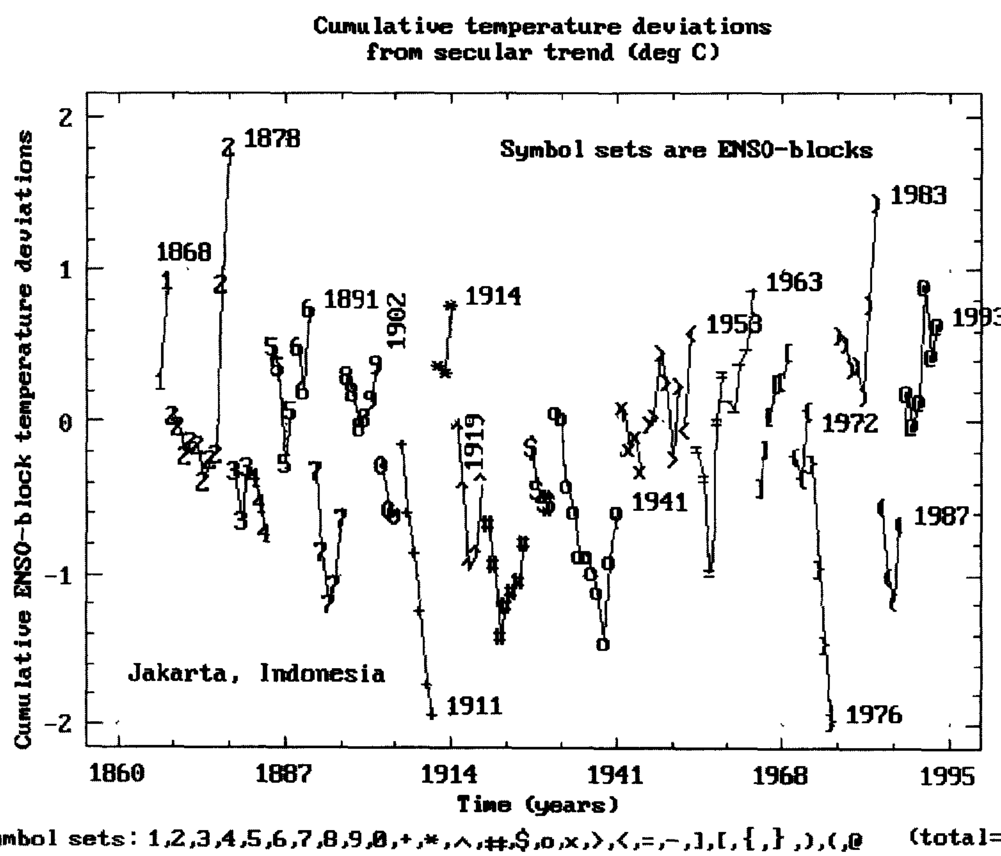


Fig. 5. Cumulative temperature deviations from secular trend (°C).

commence as soon as a warm event is over. The succession involved tracks progressively warmer on a cumulative basis or progressively cooler than the secular warming trend. Cool sequences tend to end with relatively cool initial-year ENSOs with no drought in central Java. Warming sequences end with very hot ENSOs and severe drought. This has been the case since the temperature record was initiated in 1866. There were more warm trending sequences in the beginning (1866–1900 or so), more cold in the middle (1901–1945), and now more warm again (1946–1992).

A further indication of the direct relationship between ENSO and air temperature in west and central Java is shown by the relationship between the deviate from the secular temperature trend for the warmest months of ENSO years which is inversely related to the mean height of the sea-level in the Sunda Straits measured at the Panjang tide gauge over the period 1977–1989, ($r = -0.58$, $n = 14$, $p = 0.022$). This relationship probably arises as the result of the tendency for the ENSO event to be associated with movement of water from the western Pacific across to the east.

AIR-TEMPERATURE RECORDS FROM INDONESIA

The earliest systematic record of air temperature from Indonesia appears to be that associated with the observatory set up by the Dutch administration in the City of Jakarta (Batavia), dating from 1866 and continuing in an almost unbroken sequence through to the present with the exception of the years 1943, 1947 and 1958. A number of other stations were however, established throughout the archipelago around 1912–1913 and later. Records from these locations were maintained without moving the original recording sites until at least 1938. Many of these stations were reactivated in 1949 and the early 1950s however, only a few of these locations were used continuously. For the most part, the actual recording sites were shifted over relatively short distances ranging from 1 to 25 km or so to coincide with more convenient locations such as new airports, research stations and so forth. Many new locations were added to the overall national monitoring effort although at the same time measurements at a significant number of older sites were discontinued. Between the early 1950s to the present, as many as 5–6 minor adjustments were made to monitoring locations in particular instances.

To initiate an assessment of air-temperature trends in Indonesia, an effort has been made to examine records from a broad array of stations throughout the archipelago. The summary disposition of the information examined is shown in Table 1. With the exception of the temperature records from 1986 to 1938 which were drawn from Boerema (1940), all remaining data for Indonesia were extracted by hand from the information-sets held by Badan Meterologie dan Geafisika (Indonesian Meteorological and Geophysical Organization) and the Indonesian Ministry of Agriculture in non-computerized formats.

In view of the preceding discussion, the available station records were divided into three groups. Group 1 consisting of 14 stations consists only of continuous monthly records generated by the Dutch administration over periods not less than 10 yr between 1866 and 1944 (Boerema, 1940), Table 2. Group 2 consists of all stations which were continued by the new republic either at the original monitoring site or close by. This comprises a set of 16 stations, Table 3. A third set of "modern" observations has also been defined as the last apparently "coherent" array of measurements from active or recently active stations, Table 4. A total of 33 record-sets are involved here.

The three groups are not mutually independent and only group 1 consists exclusively of stations which were never moved throughout the period of record. Station movement may obviously effect the temperature record either by forcing a step-wise upshift or downshift. A record from any of the "moving stations" was judged to be "coherent" if no simple "step" was observed in association with a location change and if the general range of associated variation did not apparently exceed that displayed by the comprehensive Jakarta Pusat data set. This judgment was performed visually rather than statistically.

Group 2 consists of 12/16 locations with measurements obtained at 2 or more sites (small altitude changes were not classified as site-shifts) and group 3 contains 17/33 such locations. Measurements recorded in group 2, long-term, are also reflected in the information exhibited by groups 1 (early) and 2 (late or "modern"). The station at Padang (Sumatra) for instance shows a continuous early record from 1913 to 1938 and again later from 1971 to 1989. The temperature trend in each of the two sectors is positive and significant. The early series showing an increase of 1.3°C per 100 yr and the later also 1.3°C per 100 yr (see Table 1). There is a marked temperature downshift between the two associated with the change in recording site so that the overall trend is negative with a decrease of 0.7°C per 100 yr. No overt adjustment is made to account for this effect when all the stations in group 2 are considered so that the overall trend is considered to be negative but the data set is not classified as "coherent". Group 1 and group 3 subsets (early and late, see above) are each considered separately to be coherent for the Padang station. Full details of the data sets considered are given in Table 1. There are overall 7 station locations from Sumatra, and adjacent islands, 13 from Java, 5 from Kalimantan, 3 from Sulawesi and 8 from east Indonesia to make a total of 36 in all.

Temperatures increased for all 14 stations examined in group 1 for the period 1866–1944. The majority of the data were from the period 1912–1938. The reason for considering these stations was that they were mainly associated with records continuing into post-colonial times. The sole exception being

Table 1. Stations considered from throughout the Indonesian archipelego

Station	Span years	Time frame	Significance	Slope	Sample size	Sites	Coherence	Latitude	Longitude	Ht (m)	Duration
Sumatra											
Sabang	4	76–79	NS	0.0070	162	2	Y	06 09N	095 08E	40	76–77
								05 52N	095 19E	126	78–79
Medan	76	14–89	< 0.0005	0.01	636	5	Y	03 35N	098 41E	25	14–50
								03 34N	098 40E	31	51–63
								03 34N	098 41E	?	71–75
								03 32N	098 39E	?	76–79
								03 34N	098 41E	27	80–89
Medan	25	14–38	< 0.0005	0.02	289	1	Y	03 35N	098 41E	25	14–50
Medan	41	49–89	< 0.0005	0.0149	346	5	Y	03 35N	098 41E	25	49–50
								03 34N	098 40E	31	51–63
								03 34N	098 41E	?	71–75
								03 32N	098 39E	?	76–79
								03 34N	098 41E	27	80–89
Padang	77	13–89	< 0.0005	−0.007	527	2	N	00 53S	100 21E	2	13–38
								00 56S	100 22E	7	71–89
Padang	26	13–38	< 0.0005	0.013	307	1	Y	00 56S	100 22E	7	13–38
Padang	19	71–89	< 0.0005	0.013	219	1	Y	00 53S	100 21E	2	71–89
Bandar Aceh	16	73–88	NS	0.01	125	1	Y	05 31N	095 25E	19	73–88
Jambi	27	53–79	< 0.0005	0.009	387	4	?	01 35S	103 38E	10	53–60
								01 35S	103 36E	10	61–69
								01 38S	103 39E	10/26	71–74
								01 35S	103 38E	10	65–79
Kijang	26	63–88	NS	− 0.003	186	5	Y	00 56N	104 32E	17	80–89
								00 55N	104 32E	18	71–75
								00 32N	104 27E	27	76–77
								05 55N	104 32E	17	78–79
								05 54N	104 22E	2	63–65
Lampung	17	73–89	< 0.0005	0.052	182	3	Y	05 15S	105 11E	96	73–74
								05 15S	105 11E	10	75–76
								05 15S	105 11E	85	77–89
Java											
Jakarta Pusat	127	1866	< 0.0005	0.0134	1468	2	Y	06 11S	106 50E	8	1866–1960
		1992						06 10S	106 49E	8	61–92
Jakarta Pusat	79	1866	< 0.0005	0.0144	935	1	Y	06 11S	106 50E	8	1866–1960
		1944									
Jakarta Pusat	32	61–92	< 0.0005	0.0121	381	1	Y	06 10S	106 49E	8	61–92
Tanjung Priok	40	51–90	< 0.0005	0.0097	324	2	Y	06 05S	106 53E	3	51–60
								06 06S	106 54E	2	71–91
Halim	29	63–91	< 0.0005	0.029	235	2	Y	06 16S	106 53E	26	79
							Y	06 16S	106 54E	31	63–64
							Y	06 16S	106 54E	31	75–77
							Y	06 16S	106 54E	30	74

Serang	21	49–69	NS	0.012	167	1	Y	06 07S	106 08E	40	49–69
Borobudur	19	71–89	< 0.005	0.022	220	1	Y	07 37S	110 01E	270	
Jogjakarta	39	51–89	< 0.01	0.087	331	2	Y	07 47S	110 26E	122	71–89
								07 47S	110 24E	122	51–65
Ngipiksar	19	71–89	< 0.0005	0.093	193	1	Y	07 37S	110 26E	775	71–79
								07 37S	110 26E	766	81–89
Bandung	59	12–70	< 0.0005	0.007	550	5	Y	06 56S	107 36E	730	12–38
								06 16S	105 54E	743	52–53
								06 54S	107 35E	743	52–53
								06 54S	107 36E	743	54–60
								06 54S	107 36E	772	61–65
								06 16S	106 54E	743	61–70
Bandung	27	12–38	< 0.0005	0.02	311	1	Y	06 55S	107 36E	730	12–38
Bandung	19	52–70	NS	– 0.01	239	4	Y	06 16S	105 54E	743	52–53
								06 54S	107 35E	743	54–60
								06 54S	107 36E	772	61–65
								06 16S	106 54E	743	61–70
Surabaya	72	19–90	< 0.005	0.014	606	2	Y	07 16S	112 54E	7	19–38
								07 13S	112 45E	7	52–79
Surabaya	20	19–38	< 0.05	0.014	223	1	Y	07 17S	112 45E	7	19–38
Surabaya	39	52–90	< 0.0005	0.023	380	3	Y	07 16S	112 43E	3	61–65
								07 13S	112 45E	7	72–79
								07 13S	112 46E	?	80
Pasuruan	57	14–70	< 0.0005	0.01	542	1	Y	07 38S	112 55E	5	14–70
Pasuruan	25	14–38	< 0.0005	0.024	297	1	Y	07 38S	112 55E	5	14–70
Pasuruan	22	49–70	< 0.0005	0.028	244	1	Y	07 38S	112 55E	5	14–70
Djember	39	12–50	NS	0.006	332	1	Y	08 09S	113 44E	13	12–50
Djember	27	12–38	< 0.005	0.006	311	1	Y	08 09S	113 44E	13	12–50
Karanganjar	17	17–33	< 0.0005	0.032	203	1	Y	07 34S	109 34E	13	17–33
Semarang (all)	74	19–92	< 0.0005	0.0099	479	6	Y	07 00S	110 25E	10	19–23
								06 59S	110 22E	3	49–50
								06 58S	110 25E	1	71–89
								07 00S	110 04E		76
								06 59S	110 22E	1	51–88
								06 57S	110 25E	1	78–79, 81–89
Semarang	22	71–92	NS	– 0.0056	397	3	Y	06 58S	110 25E	1	71–89
								07 00S	110 04E	?	76
Semarang (all)	22	71–92	< 0.005	– 0.024	200	4	Y	06 59S	110 22E	1	51–88
								06 58S	110 25E	1	71–89
								07 00S	110 04E		76
								06 57S	110 25E	1	78–79, 81–89
Kalimantan											
Tarakan	52	14–65	< 0.0005	0.018	443	3	Y	03 19N	116 36E	12	14–38
								03 19N	117 36E	12	50
								03 20N	117 34E	1	51–65

Table 1. (*Continued*)

Station	Span years	Time frame	Significance	Slope	Sample size	Sites	Coherence	Latitude	Longitude	Ht (m)	Duration
Tarakan	25	14–38	< 0.0005	0.031	292	1	Y	03 19N	116 36E	12	14–38
Tarakan	16	50–65	< 0.0005	0.121	149	2	Y	03 19N	117 36E	12	50
								03 20N	117 34E	1	51–65
Balikpapan	76	13–88	< 0.0005	0.012	408	3	Y	01 17S	116 51E	3	13–62
								01 13S	116 13E	3	67–69
								01 16S	116 54E	3	71–88
Balikpapan	50	13–62	< 0.0005	0.018	179	1	Y	01 17S	116 51E	3	13–62
Balikpapan	23	70–92	NS	– .004	206	1	Y	01 16S	116 54E	3	71–88
Pontianak	80	13–92	< 0.0005	– .008	631	4	N	00 01S	109 20E	3	13–61
								00 01S	109 23E	3	71–73
								00 01S	109 20E	3	74
								00 01E	109 23E	3	75–92
Pontianak	26	13–38	< 0.0005	0.047	281	1	Y	00 01S	109 20E	3	13–61
Pontianak	22	71–92	< 0.005	0.015	238	3	Y	00 01S	109 23E	3	71–73
								00 01S	109 20E	3	74
								00 01E	109 23E	3	75–92
Pontianak	10	52–61	< 0.0005	– .087	110	1	Y	00 01S	109 20E	3	52–61
Panerung	12	78–89	< 0.05	– .027	118	1	Y	02 15S	113 55E	1	78–89
Banjarmasin	38	52–92	< 0.0005	– .013	416	3	N	02 27S	114 45E	11	56–79
								03 27S	114 45E	20	80–92
								03 27S	114 50E	12	75–89
Banjarmasin	15	75–89	< 0.005	0.017	318	3	Y	03 27S	114 50E	12	75–89
								03 27S	114 45E	20	80–92
								03 27S	114 45E	11	73–79
Samarinda	15	78–92	< 0.0005	– .106	133	1	Y	00 28S	117 00E	10	78–79
								00 28S	117 00E	5	81–92
Sulawesi											
Mapanget	20	31–50	< 0.0005	0.079	115	1	Y	01 32N	124 55E	86	31–50
Ujung Pandang	68	22–89	NS	0.001	453	3	?	05 08S	119 28E	2	22–32
								05 04S	119 32E	14	22–32
								04 04S	119 33E	14	71–89
Ujung Pandang	11	22–32	< 0.0005	0.096	125	1	Y	05 08S	119 28E	2	22–32
Ujung Pandang	39	51–89	< 0.0005	– 0.011	327	2	N	05 04S	119 32E	14	51–56
								04 04S	119 33E	14	71–89
Ujung Pandang	19	71–89	< 0.0005	0.034	221	1	Y	04 04S	119 33E	14	71–89
Manado	58	12–69	< 0.05	– .0027	412	4	N	01 32N	124 51E	8	12–33
								01 30N	124 55E	86	53
								01 30N	124 59E	3	54–60
								01 30N	124 356	3	61–69
Manado	22	12–33	< 0.025	0 013	245	1	Y	01 30N	124 55E	86	53
Manado	17	53–69	< 0.0005	0.033	166	3	Y	01 32N	124 59E	3	54–60
								01 30N	124 59E	3	54–60
								01 30N	124 56E	3	61–69

East Indonesia											
Ambon	39	12–50	NS	0.009	222	1	Y	03 42S	120 10E	4	12–50
Ambon	27	12–38	< 0.0005	0.034	315	1	Y	03 42S	120 10E	4	12–50
Tual (Kai)	15	76–90	NS	0.02	156	1	Y	05 41S	132 46E	3	73–89
Den Pasar (Bali)	36	53–88	< 0.0005	– .02	340	3	N	08 45S	115 13E	1	56–60
								08 40S	113 13E	1	62–66
								08 45S	115 10E	1	71–88
Den Pasar (Bali)	18	71–88	NS	0.002	195	1	Y	08 45S	115 10E	1	71–88
Besakih (Bali)	16	74–89	NS	0.003	159	1	Y	08 22S	115 28E	900	74–89
Sumbawa Besar	19	71–89	0.0005	0.027	222	3	Y	08 26S	117 25E	3	71–74
								08 12S	117 25E	3	75–79
								08 26S	117 26E	3	80–89
Kaimana	12	77–88	NS	0.025	110	2	Y	03 45S	133 10E	3	77–79
(Irian Jaya)								03 38S	133 43E	3	80–88
Kupung	76	13–88	< 0.01	0.0038	500	2	Y	10 10S	123 34E	45	13–52
Kupung	26	13–38	< 0.0005	0.045	309	1	Y	10 10S	123 34E	45	13–38
Kupung	18	71–88	NS	– 0.0002	174	1	Y	10 10S	123 40E	102	71–88
Dili	13	77–89	NS	– 0.02	149	1	Y	08 34S	124 34E	4	

Jakarta, limited data

(other stations)	Yrs	Span	St Dv	Mean	# Obs	Sites	Coherent	Lat	Long	Ht	Period
Curung	5	64–68	0.699	26.001	53	1	Y	06 15S	106 34E		64–68
Kebayoran Baru	4	54–57	0.525	26.717	39	1	Y	06 14S	106 41E		54–57
Sjah Bandar	7	54–60	0.727	27.454	62	2	Y	06 38S	107 41E		57, 54–60
						Y	Y	06 05S	106 44E	3	54–60
Kuyper	8	534–60	0.564	27.784	53	1	Y	06 02S	106 44E		53–56, 60
Kemayoran	8	63–70	1.948	27.694	38	1	Y	06 08S	106 51E		63, 64, 66, 67, 69, 70
Cenkarang	5	85–89	0.519	26.600	40	1	Y				83, 86, 88, 89
Halim	5	85–89	0.504	26.78	45	1	Y			26	83, 86, 88,0198 9
Jakarta Pusat	5	85–89	0.607	27.45	48	1	Y			8	83, 86, 88,0198 9
Tanjung Priok	5	85–89	0.571	27.74	45	1	Y			2	83, 86, 88,0198 9
Jakarta Pusat only											
	5	64–68	0.592	27.085	60	1	Y				
	4	54–57	0.745	27.025	48	1	Y				
	7	54–57	0.698	27.044	72	1	Y				
	8	53–60	0.675	27.072	84	1	Y				
	8	63–70	0.613	27.140	96	1	Y				
	5	85–89	0.643	27.396	60	1	Y				

Table 2. Stations with continuous records obtained during Dutch administration

Station	Trend	Significant ?	Deg C change/100 yr	Span years	Time frame	Coherent?	Number sites involved
Medan	+ ve	Yes	2 0	20	14–38	Yes	1
Padang	+ ve	Yes	1 3	26	13–38	Yes	1
Jakarta Pusat	+ ve	Yes	1.44	79	1866/1944	Yes	1
Bandung	+ ve	Yes	2.0	27	12–38	Yes	1
Surabaya	+ ve	Yes	1.4	20	19–38	Yes	1
Pasuruan	+ ve	Yes	2 4	25	14–38	Yes	1
Djember	+ ve	Yes	0.6	27	12–38	Yes	1
Karanganjar*	+ ve	Yes	3.2	17	17–33	Yes	1–1933
Tarakan	+ ve	Yes	3.1	25	14–38	Yes	1
Pontianak	+ ve	Yes	4.7	26	13–38	Yes	1
Ujung Pandang	+ ve	Yes	9 6	11	22–32	Yes	1
Manado	+ ve	Yes	1.3	22	12–33	Yes	1
Ambon	+ ve	Yes	3.4	27	12–38	Yes	1
Kupung	+ ve	Yes	4.5	26	13–38	Yes	1

Total number of stations = 14.
Average temperature change/100 yr = + 2.92°C.

Table 3. Stations (16) with records obtained during Dutch administration and extended by the Republic of Indonesia

Station	Trend	Significant	Deg. C change/100 yr	Span years	Time frame	Coherent?	Number sites involved
Medan	+ ve	Yes	1.0	76	14–89	Yes	5
Padang	– ve	Yes	– 0.7	77	13–89	No	2
Jakarta Pusat	+ ve	Yes	1.34	127	1866/1992	Yes	2
Bandung	+ ve	Yes	0.7	59	12–70	Yes	5
Surabaya	+ ve	Yes	1.4	72	19–90	Yes	2
Pasuruan	+ ve	Yes	1.0	57	14–70	Yes	1
Djember	+ ve	No	0.6	39	12–50	Yes	1
Semarang (all)	+ ve	Yes	0.99	74	19–92	Yes	6
Tarakan	+ ve	Yes	1.8	52	14–65	Yes	3
Balikpapan	+ ve	Yes	1.2	76	13–88	Yes	3
Pontianak	– ve	Yes	– 0.8	80	13–92	No	4
Mapanget	+ ve	Yes	7.9	20	31–50	Yes	1
Ujung Pandang	+ ve	No	0.1	68	22–89	?	3
Manado	– ve	Yes	– 0.27	58	12–69	No	4
Ambon	+ ve	No	0.9	39	12–50	Yes	1
Kupang	+ ve	Yes	0.38	76	13–88	Yes	2

Overall estimated temperature change/100 yr = + 1.08°C.
Est. temp change/100 yr, significant trends only = + 1.23°C.

Karangjar in Java. The mean station-wise unweighed temperature increase pro-rated to 100 yr was 2.92°C.

In group 2, the long-term set, when only stations exhibiting a significant trend were considered 10 + ve, 3 – ve), the overall warming trend was 1.23°C per 100 yr. The maximum time-span in the group of 16 stations was 127 yr (Jakarta Pusat). The mean time-span was 66.12 yr. It is worth emphasizing that individual temperature patterns obtained from each station have not been weighted by either the number of observations involved nor by the number of years spanned by the individual station data sets. In spite of this it is somewhat surprising to note that the mean value of 1.23°C is very close to the long-term rate for Jakarta which is 1.34°C per 100 yr. When all records are so considered regardless of whether their indicated trends are statistically significant or not then the overall warming is set at 1.08°C per 100 yr.

Data from the stations assembled into group 3 (modern, 1948–1992) is more varied and covers the widest geographic area. The set includes 16/33 where the recording site was apparently not shifted within the period examined. For the group as a whole 18 stations exhibit a significant positive trend and 3 are significantly negative giving an overall warming rate of 1.64°C per 100 yr. If all stations are assessed without regard to whether or not they exhibited significant trends in themselves, the overall warming is set at 1.35°C per 100 yr. Four stations were judged to exhibit extreme values with changes exceeding 5.0°C per 100 yr. When these are disregarded, the remaining stations with significant trends warm at 1.35°C per

Table 4. Stations with records obtained by the Republic of Indonesia, last coherent set of records

Station	Trend	Significant ?	Deg. C change/100 yr	Span years	Time frame	Coherent?	Number sites involved
Sabang	+ ve	No	0.7	4	76–79	yes	2
Medan	+ ve	Yes	1.49	41	49–89	Yes	5
Padang	+ ve	Yes	1.3	19	71–89	Yes	1
Bandar Aceh	+ ve	No	1.0	16	73–88	Yes	1
Jambi	+ ve	Yes	0.9	32	58–89	Yes	4
Kijang	– ve	No	– 0.3	26	63–88	Yes	5
Lampung	+ ve	Yes	5.2[a]	17	73–89	Yes	3
Jakarta Pusat	+ ve	Yes	1.21	32	61–92	Yes	1
Tanjung Priok	+ ve	Yes	0.97	40	51–90	Yes	2
Halim	+ ve	Yes	2.9	29	63–91	Yes	2
Serang	+ ve	No	1.2	21	49–69	Yes	1
Borobudur	+ ve	Yes	2.2	19	71–89	Yes	1
Jogjakarta	+ ve	Yes	0.87	39	51–89	Yes	2
Ngipiksar	+ ve	Yes	9.3[a]	19	71–89	Yes	1
Bandung	– ve	No	– 1.0	19	52–70	Yes	4
Surabaya	+ ve	Yes	2.3	39	52–90	Yes	3
Pasuruan	+ ve	Yes	2.8	22	49–70	Yes	1
Semarang (all)	– ve	Yes	– 2.4	22	71–92	Yes	4
Tarakan	+ ve	Yes	12.1[a]	16	50–65	Yes	2
Balikpapan	– ve	No	– 0.4	23	70–92	Yes	1
Pontianak	+ ve	Yes	1.5	22	71–92	Yes	3
Panerung	– ve	Yes	– 2.7	12	78–89	Yes	1
Banjarmasin	+ ve	Yes	1.7	15	75–89	Yes	3
Samarinda	– ve	Yes	– 10.6[a]	15	78–92	Yes	1
Ujung Pandang	+ ve	Yes	3.4	19	71–89	Yes	1
Manado	+ ve	Yes	3.3	17	53–69	Yes	3
Tual (Kai)	+ ve	No	2.0	15	76–90	Yes	1
Den Pasar, Bali	+ ve	No	0.2	18	71–89	Yes	1
Besakih, Bali	+ ve	No	0.3	15	74–89	Yes	1
Sumbawa Besar	+ ve	Yes	2.7	19	71–89	Yes	3
Kaimana, Irian	+ ve	No	2.5	12	77–88	Yes	2
Kupung	– ve	No	– 0.002	18	71–88	Yes	1
Dili	– ve	No	– 2.0	13	77–89	Yes	1

[a] Extreme values
Total number of stations = 33.
Overall estimated temperature change/100 yr = + 1.35°C.
Estimated temperature change/100 yr, significant trends only = + 1.64°C.
Disregarding extreme values
Overall estimated temperature change/100 yr = + 0.98°C.
Estimated temperature change/100 yr, significant trends only = + 1.35°C
Stations with records from one site only:
Overall estimated temperature change/100 yr = + 0.75°C.
Estimated temperature change/100 yr, significant trends only = + 0.91°C.
Stations with records from multiple sites:
Overall estimated temperature change/100 yr = + 1.22°C
Estimated temperature change/100 yr, significant trends only = + 1.47°C.

100 yr. Stations with single recording sites and significant trends (9) warm at 0.91°C per 100 yr and those with multiple recording sites and significant trends (11) warm at 1.22°C per 100 yr. Mixed-site stations thus exhibit marginally higher warming trends than single-site stations.

The pre-cursor to modern Jakarta (Batavia) is credited with a population of 10,000 in 1619, 27,068 in 1673, 35,000 in 1730, 70,000 in 1850 and 115,000 in 1900 (Abeyasekere, 1987). By 1792 it was reported that sugar cropping had necessitated clearance of forest up to the hills and 7 h of travel were required to obtain wood for fuel (Abeyasekere, 1987). Population growth between 1850 to 1992 fits the exponential growth equation: population size = exp(– 64.13 + 0.0402133 yr), $r = 0.968$, $n = 15$, with a predicted population size of 55,600 for 1866, 660,500 for 1928, 687,800 for 1929 and 8,320,600 for 1991 (data from Abeyasekere, 1987 and Indonesian Bureau of Statistics), Table 5.

There are three possible explanations for the observed changes: (1) an effect induced by increasing city size and presumed energy use; (2) a temperature change caused by physiographic alterations including vegetation shifts and modifications; (3) a general effect due to global warming. In the early data, the range of stations involved tends to weigh against the concept of a city effect as determined by urban size and energy

Table 5. Current and previous number of inhabitants of major cities in Indonesia (sources Bureau of statistics data 1961–1992; National Library data 1920, 1930)

Town	Inhabitants						
	1920	1930	1961	1971	1980	1990	1992
Sumatra							
Sabang				17,600	23,821	24,416	24,500
Banda Aceh			40,100	53,700	171,868	184,699	222,900
Medan		76,585	479,100	637,600	1,373,747	1,730,750	1,807,700
Padang		52,054	143,700	196,300	480,607	631,543	669,800
Jambi		22,071	113,100	158,600	230,046	339,944	368,800
Bandar Lampung			133,900	199,000	284,167	636,706	740,000
Java							
Jakarta	253,818	435,184	2,906,500	4,567,000	6,503,449	8,254,035	8,632,500
Bandung	94,800	166,815	972,600	1,201,700	1,461,407	2,058,649	2,159,000
Semarang		217,796	503,200	646,600	673,518	1,250,971	1,297,100
Yogyakarta		136,649	312,700	342,300	398,192	412,392	412,200
Surabaya		341,675	1,007,900	1,556,300	2,017,527	2,483,871	2,592,100
Kalimantan							
Pontianak		45,196	150,200	217,600	304,490	397,343	420,500
Banjarmasin		65,698	214,100	281,700	380,884	481,371	505,300
Balikpapan		29,843	91,700	137,300	279,852	344,405	358,600
Samarinda		11,086	69,700	137,500	264,012	407,339	443,800
Sulawesi							
Ujung Pandang		84,855	384,800	437,800	708,465	944,685	1,007,400
Bitung						105,638	
Manado		27,544	129,900	169,700	217,091	320,990	346,400
Maluku							
Ambon			56,000	79,600	207,702	276,955	293,000
Nusa Tenggara							
Denpasar		16,693			504,300		699,600
Sumbawa Besar		7171			304,134		387,300
Kupang					403,110		554,700
Dili					67,039		138,200

Jakarta: 1619 10,000; 1673 27,068; 1730 35,000; 1850 70,000; 1900 115,000; 1930 435,000; 1948 823,000 1,050,000[a], 1952 1,782,000; 1966 3,600,000; 1965 3,813,000; 1976 5,700,000.
Surabaya: 1815 24,500, 1900 147,000.
Source: Abeyasekere, Susan; "Jakarta, a history". Oxford University Press, Singapore, Oxford, NewYork, 1987 280 pp
[a]The larger figure is an estimate, the smaller is the official census.

use. This does not preclude effects due to initial deforestation or changing microclimate associated with physiographic alterations. Temperature shifts observed in the later data sets might well be associated with increasing city size yet the rates of change in the latter sets either do not differ from those in earlier years or are if anything, somewhat lower. Nor is direct forest clearance likely to provide the answer since the majority of sites are now associated with relatively stable vegetation patterns even if these now differ from the situation which may have prevailed had the locations in question not been subject to "human development". For Jakarta in particular, timber clearance was apparently widespread by 1792. All the mountain sites examined in Java likewise show warming trends (Table 1).

The data from edge-stations around Jakarta do not wholly clarify this issue. The port, Tanjung Priok, adjacent to the Java Sea on the northern edge, tends to exhibit higher temperatures than Jakarta Pusat. Halim airport on the southern edge is slightly (0.67°C) but overall not significantly lower than the center (Jakarta Pusat) but the new airport at Cengkareng, 40 km to the east of the city edge is 0.85°C lower than the city center data for some limited observations (Table 1). If the global trend is taken at approximately 0.5°C per 100 yr and 0.6°C is marked off the currently considered data set as being due to microclimate shifts (including city effects) a difference of $2.1 - 1.1 = 1.0$°C might be considered as unique to the region as a maximum.

Population records were located for 23 of the cities and towns associated with the meteorological stations indicated in Table 4. Available information covered census records from 1961, 1971, 1980, 1990 and 1992 and the data are shown in Table 5 for the cities of Sabang, Banda Aceh, Medan, Padang, Jambi, Bandar Lampung, Jakarta, Bandung, Semarang, Yogyakarta, Surabaya, Pontianak, Banjarmasin, Balikpapan, Samarinda, Ujung Pandang, Bitung, Manado, Ambon, Denpasar, Sumbawa Besar, Kupang and Dili. Of the larger population centers, data were not available for Pasaruan, Tarakan, Tual, and Kaimana only. Other stations such as Kijang, Serang, Borobudur, Ngipiksar, Djember, Karanganjar, Panerung, Mapanget and Besakih (mountain site) were defined as too small to qualify as population centers and can thus be regarded as essentially undisturbed or "rural" in nature.

An attempt was made to determine systematic influences arising from "city or geographical effects" on the expression of the temperature trends shown by the 23 stations indicated above. Comparisons were made between the arithmetic slope of the secular temperature trend and each of the following factors: city population size in 1992; the exponential growth coefficient for a regression line fitted to the available data; the population doubling time on the basis of an exponential growth curve (a variant of the proceeding factor); the yearly arithmetic population increase for the available data (straight-line fit); the height of the station above sea level; station latitude; station longitude. No significant association was detected for any of the listed comparisons.

The air temperature record from Manila and from Davao also both somewhat north of the equator in the Philippines show the same upward trend as for the Jakarta/Semarang set. In addition, the annual deviations from the overall secular trend are relatively strongly correlated among all three ($r > 0.4$, $p \leqslant 0.0001$) showing that at least southeast Asia tends to behave as a sympathetic unit as far as temperature increase is concerned. Major stations considered from southeast Asia are shown in Map 1.

The extent to which the secular trend in temperature increase shown by these southeast Asian tropical cities reflects a general climatic warming trend rather than a secondary effect due primarily to the combined influences of urbanization may be open to question. That they form part of the influence promoting such a trend, summarized by Jones and Briffa (1992) as 0.5°C (over the last 140 yr) is clear. The extent to which these data reflect the overall trend as manifest in the global tropical belt is at question. Widespread regional warming for Indonesia over the past 80–120 yr or so, in excess of the global trend by around 0.5–1.0°C per 100 yr cannot be excluded. From around 1912–1938 a regular warming trend of around 2.9°C per 100 yr was experienced by the indicated stations in lowland Indonesia. The long-term warming (1866–1992) is somewhat lower at 1.23°C per 100 yr. The trend in recent years (1949–1992) appears to be around 1.35–1.64°C per 100 yr. An overall average estimate might be around 2.1°C for the last 100 yr. Map 2 indicates the relative temperature changes for major stations considered in southeast Asia.

EL SALVADOR

Wasser, personal communication (1992), also indicates temperature increases similar to those in southeast Asia are shown by small-town and isolated stations in western El Salvador (between 13° 52′ to 14° 01′ N). The station at Los Andes, 13° 51′ N, 89° 38′ W and approximately 1800 m above mean sea level, on top of the Santa Ana volcano, shows a mean temperature increase of 3.0°C per 100 yr for 1961–1990, from 16.1 to 16.97°C. Map 3 indicates the relative position of stations in El Salvador as opposed to those in southeast Asia. The combined station records of Santa Ana, El Palmar, 13° 59′ N, 89° 39′ E (10 km from city population 208,000, altitude 750 m) plus Ahuachapan, 14° 02′ N, 89° 50′ west (14 km from town population 63,500, altitude around 600 m) show an annual increase in the mean temperature of 4.3°C per 100 yr for 1958–1990, from 22.4 to 23.74°C. The relative temperature changes exhibited by major stations considered in El Salvador as opposed to southeast Asia are shown in Map 4.

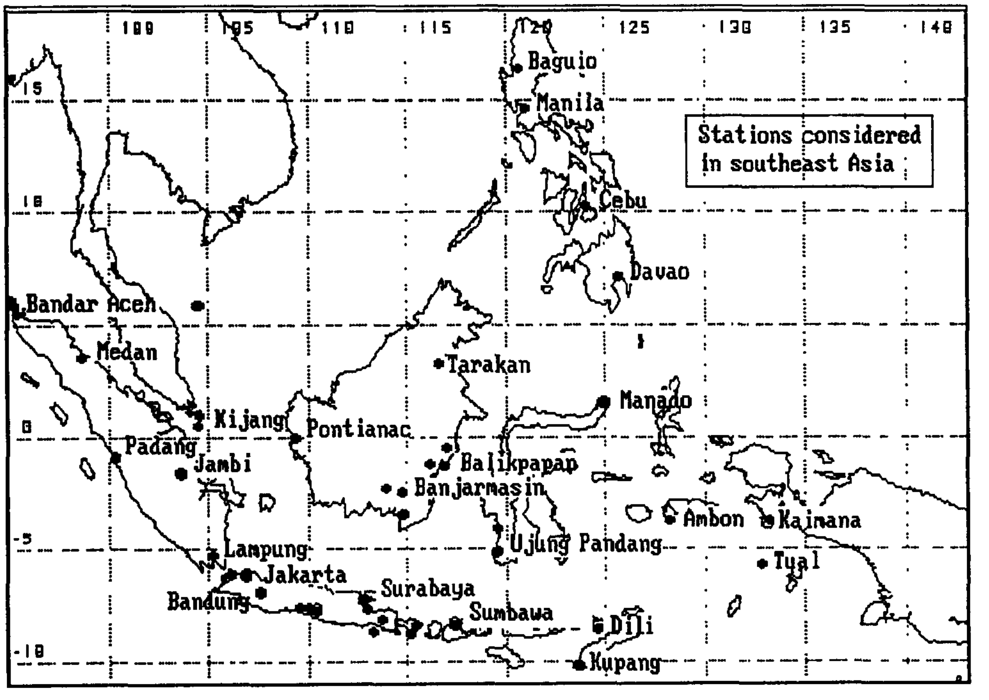
The warmest month temperature deviates (all years) from the secular trend shown by the Los Andes record are positively correlated with those of the Jakarta record in the same form ($r = 0.345$, $n = 28$, $p = 0.07$), with Baguio ($r = 0.569$, $n = 28$, $p = 0.0015$), with Manila ($r = 0.606$, $n = 25$, $p = 0.0013$). For ENSO years only, with Jakarta($r = 0.629$, $n = 10$, $p = 0.051$), with Davao, ($r = 0.72$, $n = 10$, $p = 0.018$), with Manila, ($r = 0.612$, $n = 9$, $p = 0.079$).

CITY EFFECTS

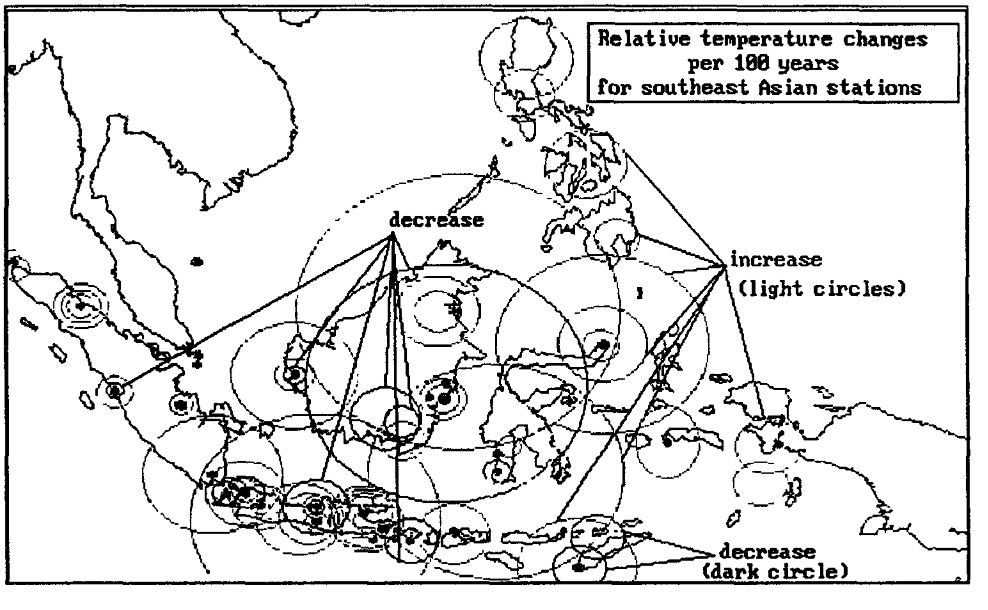
Air temperatures for Jakarta over the period 1866–1945 have been calculated on the basis of observations made at two-hourly intervals and the monthly means used herein are thus based on 24 h records (Boerema, 1940). Subsequent measurements from 1947–1991 have been calculated on the basis of hourly readings over 24 h intervals. The recording site was a park in Menteng Prapatan (Jakarta) until 1980 and was thereafter shifted a short distance to the present location in front of the meteorological office, Badan Meterologi dan Geofisika, Jakarta, Indonesia (Winasso, personal communication).

The major industrial development in infrastructure for Jakarta has been significant only since 1980 or so and was not apparent before 1970 when the city had the aspect of an extended village with few large buildings (greater than 3–4 stories) and no extensive highways. Unlike the bulk of work which has been undertaken to examine heat-island effects outside the equatorial region (Karl *et al.*, 1988; Wang *et al.*, 1990), the analysis herein is concerned with a climate where no artificial heating is required and where moreover the wide-spread use of air conditioners did not come into effect much before the late 1960s and in most places not before the mid-1970s.

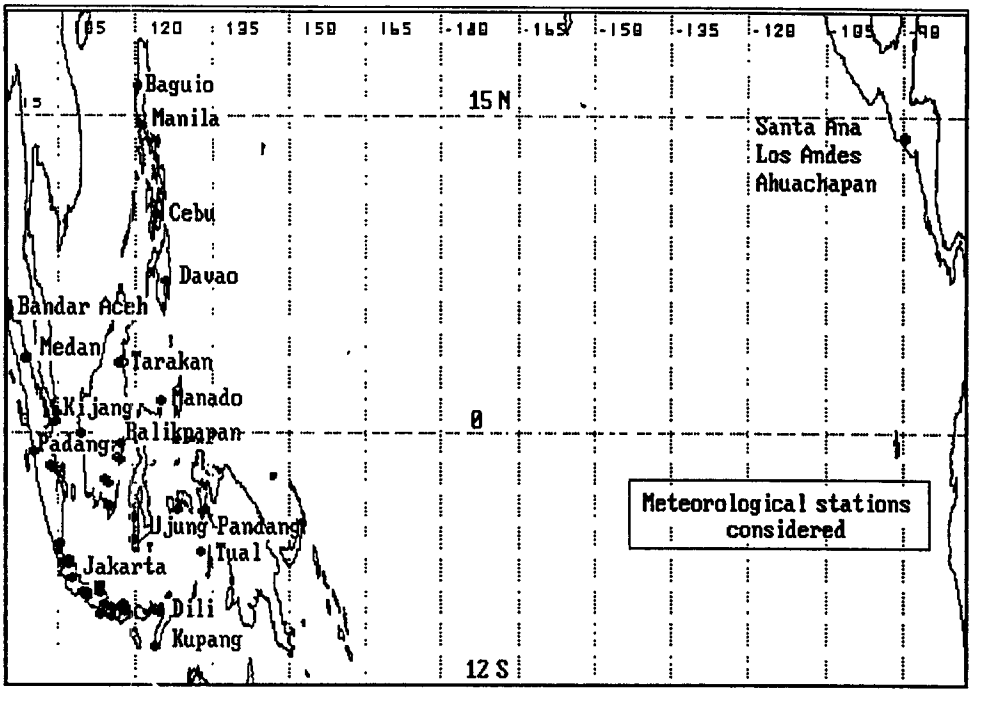
Sham Sani 1986, noted when comparing temperatures between microclimates in shaded urban parks as opposed to those in the open city (no shade), that urban heat-island effects have been capable of raising temperatures "in excess of 2–3°C" in the case of Kuala Lumpur during day-light hours in November 1985. Temperature differences at night were much lower ranging from 0.1°C. The warming trend from



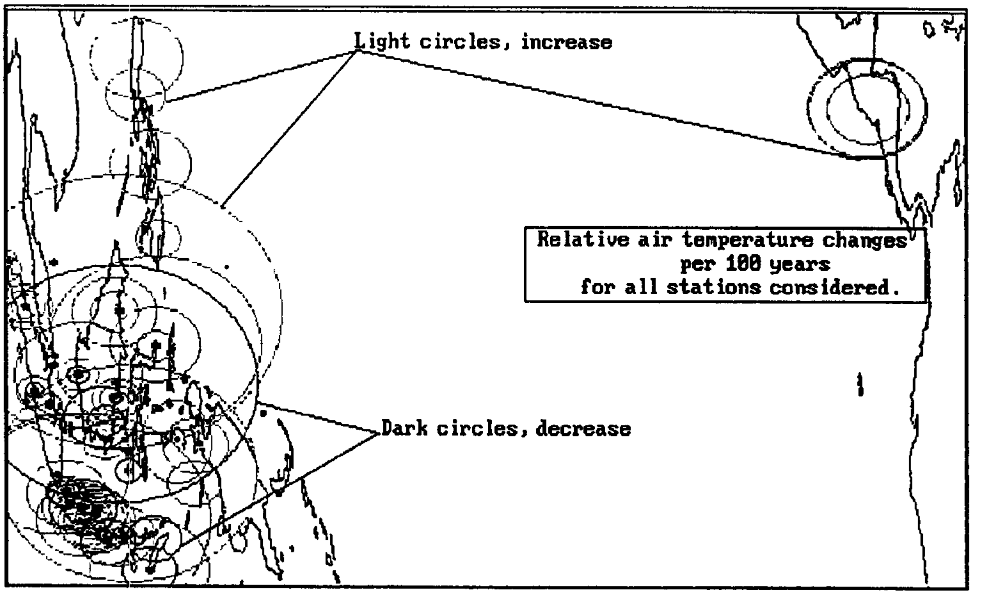
Map 1. Major stations considered in southeast Asia



Map 2. Relative temperature changes for southeast Asian stations.



Map 3. Location of stations in southeast Asia as opposed to those in El Salvador.



Map 4. Relative temperature changes per 100 years for stations considered both in south east Asia and El Salvador.

1866–1928 is slightly higher but similar to that from 1929–1991. There is no significant difference in the regression line slopes relating temperature to time for these two segments of the data set taken independently meaning that the earlier and smaller (simpler) city warmed at the same rate as the later, larger and more complex city

Among those factors to be considered when looking at historical urban/rural temperature shifts in southeast Asia and in addition to the presumed positive effects of increasing population and energy use densities on the promotion of secular temperature change within and adjacent to urban centers, there is also expected to be a shift in rural temperatures due to changing environmental factors. Thus, in undisturbed peat-forests in South Sumatra (Padang Island) the midday maximum surface temperature was measured by Brady (personal communication) as 34.5°C (dry) and 34.0°C (wet) with a nighttime minimum of 22.0°C (wet and dry) during 1989–1990. The average daily temperature fluctuated between 27.0 and 28.0°C with a 12.0°C maximum fluctuation. In forest gaps of greater than 250 m^2, the maximum daytime temperature was 42°C and the nighttime maximum was 22°C with a maximum daily range of 20.0°C. In adjacent cleared agricultural areas the same 60-day record showed a daily maximum of 42°C (dry) and 37°C (wet) with a range of 20.0°C and a nighttime maximum of 22.0°C. Bouman and Drissen (1985) indicate that the surface temperature of exposed peat may reach as high as 70.0°C.

The early segments of the Jakarta and the Manila records, obtained when neither city was industrialized to any great extent, increase at a rate that is not statistically different from the most recent segments. Some support for the notion that urbanization influences in western USSR, eastern China and eastern Australia are not significant temperature determinants is provided by Jones *et al.* (1990). Their study showed that comparisons between grid-derived interpolated data reflecting on the one hand urban stations, and on the other rural temperature measurements, showed no significant difference between the two. Earlier work (Jones *et al.*, 1986) however, showed that similar comparisons between urban and rural stations from the contiguous United States revealed significant differences with urban values tending to be higher by 0.15°C over the period 1901–1984. This situation is taken as presumably reflecting "a typical" urban growth compared with many other parts of the world (Jones *et al.*, 1990) and with the other less-industrialized regions of the world likely to be less affected. Some indication that this might indeed be the case is provided by the analysis of Chinese data by Wang *et al.* (1990) which shows rural and urban temperature differences converged between 1954 and 1966 and then diverged after 1966–1983 The period before 1966 is associated with the "great leap forward" and that after with the "cultural revolution". As late as 1982 shops and businesses were unheated during the winter in Beijing and in Qingdao this was also the case up to 1988.

GLOBAL TEMPERATURE RECORD

The general warming trend shown by the global temperature anomalies over the same period closely parallels the pattern shown by the Jakarta/Semarang data set. Figure 6 shows the course of global warming in relation to the ENSO-blocks for the period 1868–1990. ENSO-block symbols are the same as those used in Figs 3 and 4. The global temperature anomalies (Boden *et al.*, 1992) are strongly correlated with the warmest month temperatures of the Jakarta/Semarang data set ($r = 0.84$, $n = 121$, $p < 0.00001$), for the period of available data, 1958–1990 with Ahuachapan ($r = 0.81$, $n = 20$,- $p < 0.0001$) and with Los Andes ($r = 0.73$, $n = 28$, $p < 0.0001$). When the secular trends are removed the residual deviations shown by the Jakarta/Semarang warmest month data are correlated with the deviations shown by the annual global anomalies ($r = 0.53$, $n = 121$, $p < 0.00001$). This is of some interest since the Jakarta/Semarang warmest month indications are obtained usually by May or June (10/35 ENSO-years) or at least by October (31/35) of any one year. The Jakarta/Semarang warmest month temperatures are also closely related to the warmest month temperature deviations in say Manila, the Philippines which develop by April–May.

The cumulative ENSO-block temperature deviations around the secular trend indicated by the global temperature anomalies are shown in Fig. 7. Note the overall similarity of this diagram with that shown in Fig. 5 (Jakarta/Semarang). The temperature deviation of the warmest month in the Jakarta/Semarang data set can perhaps be used as a harbinger for estimating global warmth for the year as a whole This in turn may suggest that what happens in the equatorial region of the western Pacific in terms of heat build-up and ENSO activity significantly determines a global response. The admittedly restricted data set from El Salvador also suggests a wider equatorial association may exist. The deviations from the global temperature trend are correlated with the warmest month temperature deviates from the secular trend (all years) for the Manila record ($r = 0.23$, $n = 80$, $p = 0.04$), Baguio ($r = 0.38$, $n = 63$, $p = 0.002$), Davao ($r = 0.51$, $n = 44$, $p = 0.0005$), Los Andes ($r = 0.57$, $n = 28$, $p = 0.001$). In the case of ENSO years only: for Jakarta ($r = 0.54$, $n = 40$, $p = 0.003$), Davao, ($r = 0.7$, $n = 14$, $p = 0.005$), Baguio, ($r = 0.83$, $n = 17$, $p < 0.0001$), and for Los Andes, ($r = 0.71$, $n = 10$, $p = 0.02$).

Figure 8 illustrates the relationship between the temperature deviations shown by the warmest months in the Jakarta/Semarang record and the secular deviations exhibited in the record of global temperature anomalies for all years.

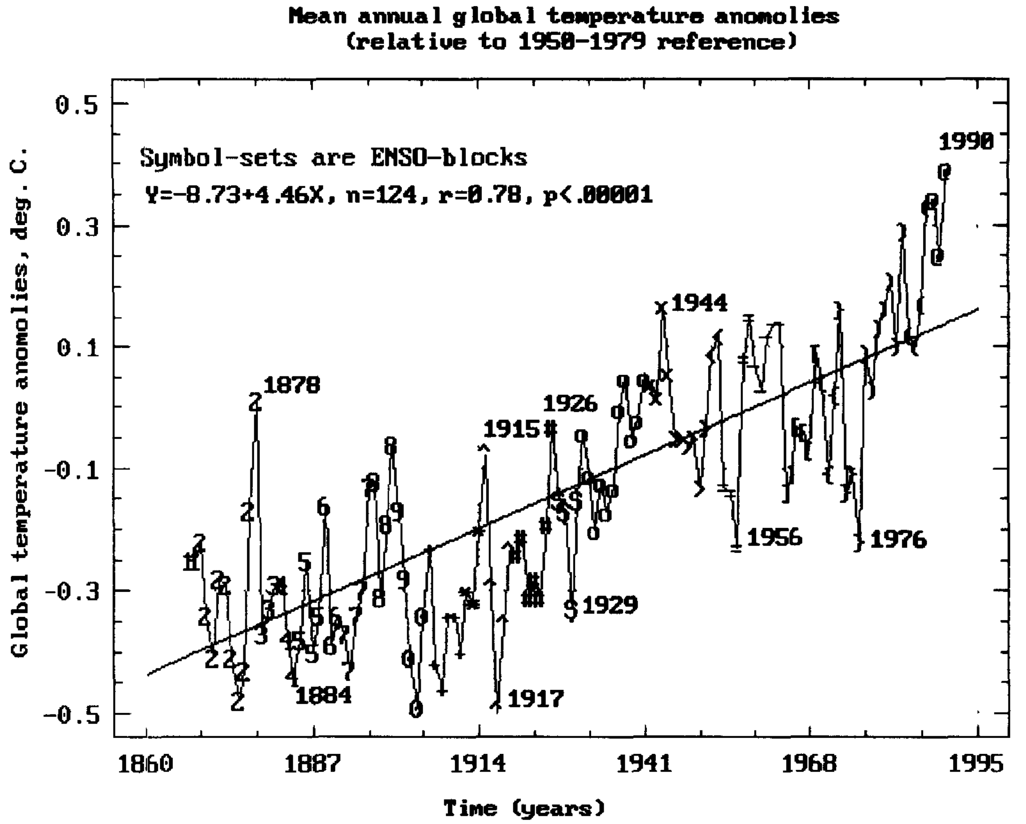


Fig 6. Mean annual global temperature anomalies (relative to 1950–1979 reference).

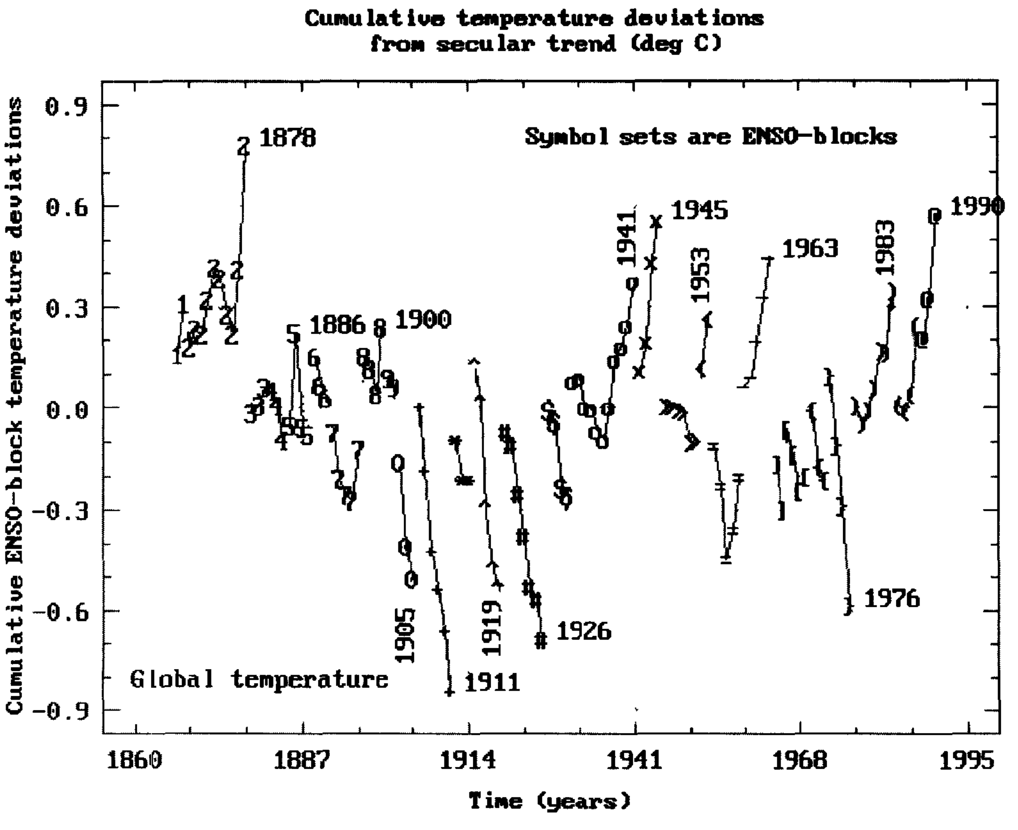


Fig. 7. Cumulative temperature deviations from secular trend (°C).

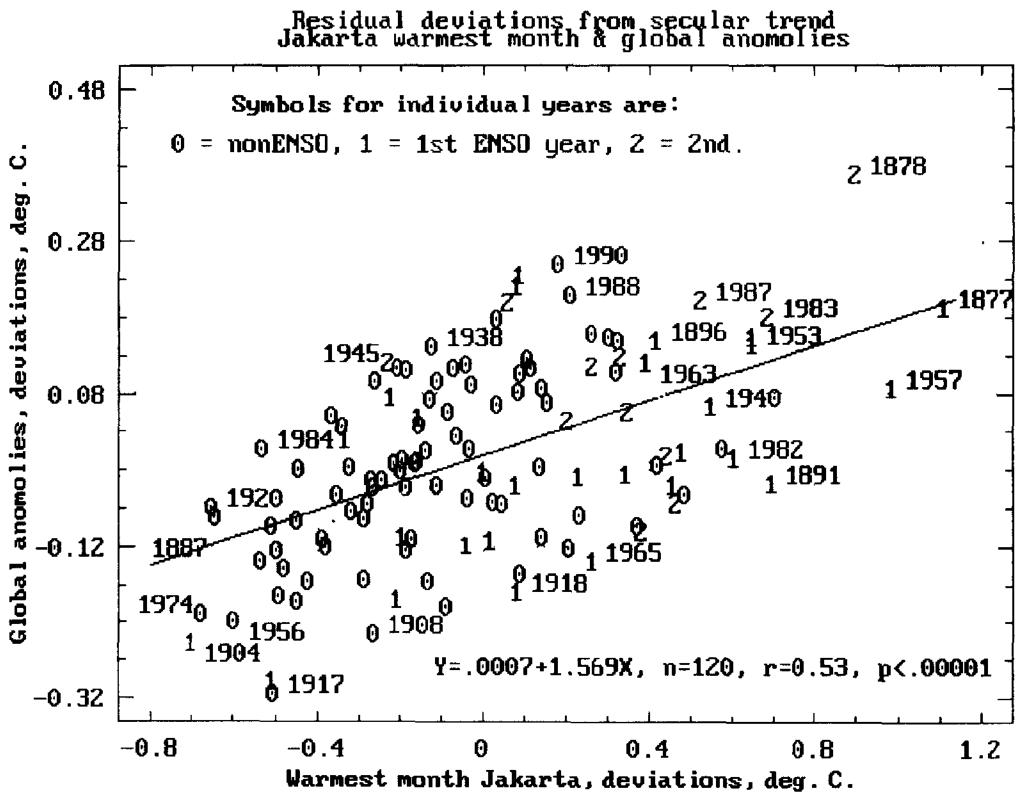


Fig 8. Residual deviations from secular trend Jakarta warmest month & global anomalies.

The relationship is positive ($r = 0.53$, $n = 120$, $p < 0.00001$). Since the Jakarta/Semarang data set represents a very limited area compared with the globe as a whole, this high association rather suggests that events on the equator play a significant role in determining a global response.

SIGNIFICANT ENSO EVENTS

Kiladis and Diaz (1986), investigated some of the conditions relating the 1877–1878 ENSO event to that of 1982–1983. The analysis reported herein for the Jakarta and Semarang air-temperature data shows that in absolute terms the mean annual temperatures of the four years concerned were 26.27, 26.66, 27.37 and 27.58°C making the former event cooler. Table 6 however, shows that the relative deviations of the maximum of the mean monthly temperatures of the four years from the overall secular trend was 0.86, 0.64, 0.33 and 0.41°C making the former event relatively more extreme than the latter. However, the difference in temperature between the warmest and coolest months for each of the years was 2.7, 1.8, 3.1 and 2.7 making the scope of the latter event somewhat more "sweeping". This in turn is a consequence of the secular increase which has taken place between the maximum and minimum temperatures in the interval between the two events. The ENSO years having the warmest temperature deviations from the secular trend can be identified from Table 6. The warmest month temperature deviations from the secular for 1991 and 1993 (for the ENSO set 1991–1993) are 0.49 and 0.26°C with respective maximum temperatures of 29.1 and 28.9°C. The deviation of the warmest month temperature from the secular trend in the Jakarta air-temperature record may thus serve as a measure of the intensity of an El Nino event (Quinn *et al.*, 1987), at least on the edge of the western Pacific.

No particular patterns of significance could be detected associated with ENSO cool event years (Kiladis and Diaz, 1989; Brookfield and Allen, 1991), which are regarded here as a subset of non-ENSO years.

DISCUSSION

The data show that a consistent structure underlies ENSO events for the last century and a quarter. However, as a process monitored by mean monthly air-temperature measurements at Jakarta–Semarang, the system is changing in character with time in association with an overall atmospheric temperature increase in a way that involves increased intra-annual temperature fluctuations. In general ENSO years are associated with higher temperatures than non-ENSO years, with a significant negative correlation between

Table 6. Intensity of ENSO events as indicated by the deviation of the recorded mean monthly temperature from the secular trend in the Jakarta/Semarang data set from 1886–1993. Residual deviation from secular trend: monthly mean air temperatures °C Jakarta/Semarang

Row	Year	ENSO-year warmest month deviation	All years warmest month deviation	0 = non-ENSO 1 = ENSO	Row	Year	ENSO-year warmest month deviation	All years warmest month deviation	0 = non-ENSO 1 = ENSO
1	1866	– 0.161640	0.079906	1	56	1921		– 0.262756	0
2	1867		0.264585	0	57	1922		– 0.478078	0
3	1868	0.407269	0.649264	1	58	1923		0.206601	0
4	1869		0.033943	0	59	1924		0.091280	0
5	1870		– 0.081378	0	60	1925	– 0.178820	0.075959	1
6	1871		– 0.196699	0	61	1926	0.005634	0.260638	1
7	1872		0.087980	0	62	1927		– 0.154683	0
8	1873		– 0.027342	0	63	1928		– 0.270004	0
9	1874		– 0.242663	0	64	1929		– 0.085326	0
10	1875		0.142016	0	65	1930	– 0.256548	– 0.000647	1
11	1876		0.026695	0	66	1931		0.084032	0
12	1877	0.867360	1.111370	1	67	1932		– 0.0312289	0
13	1878	0 651815	0.896053	1	68	1933		– 0.446610	0
14	1879		– 0.319268	0	69	1934		– 0.161931	0
15	1880	– 0.579276	– 0.334590	1	70	1935		– 0.277252	0
16	1881	0.105178	0.350089	1	71	1936		0.007426	0
17	1882		– 0.365232	0	72	1937		– 0.107895	0
18	1883		– 0.180553	0	73	1938		– 0.123216	0
19	1884	– 0.441458	– 0.195874	1	74	1939		– 0.338537	0
20	1885		0.488805	0	75	1940	0.287998	0.546142	1
21	1886		– 0.126516	0	76	1941	0.072453	0.330821	1
22	1887		– 0.641838	0	77	1942		0.115500	0
23	1888	0 096360	0.342841	1	78	1943			0
24	1889		0.327520	0	79	1944	– 0.174184	0.084857	1
25	1890		– 0.287801	0	80	1945	– 0.489729	– 0.230464	1
26	1891	0.449724	0.696878	1	81	1946			0
27	1892		– 0.318443	0	82	1947			0
28	1893		– 0.533764	0	83	1948		0.423573	0
29	1894		– 0.349086	0	84	1949		– 0.191748	0
30	1895		0.135593	0	85	1950		– 0.507070	0
31	1896	0.171997	0.420272	1	86	1951	0.216998	0.477609	1
32	1897		0.304951	0	87	1952		– 0.037712	0
33	1898		– 0.110370	0	88	1953	0.385908	0.646967	1
34	1899	– 0.474639	– 0.225691	1	89	1954		– 0.168354	0
35	1900	– 0.190185	0.058987	1	90	1955	– 0.183675	– 0.183675	0
36	1901		0.143666	0	91	1956		– 0.598996	0
37	1902	– 0.021276	0.228345	1	92	1957	0.723726	0.985682	1
38	1903		– 0.286876	0	93	1958	(0.026 est)[a]		1
39	1904	– 0.952366	– 0.702297	1	94	1959		0.155040	0

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Table 6. (*Continued*)

Row	Year	ENSO-year warmest month deviation	All years warmest month deviation	0 = non-ENSO 1 = ENSO	Row	Year	ENSO-year warmest month deviation	All years warmest month deviation	0 = non-ENSO 1 = ENSO
40	1905	0.132088	0.382382	1	95	1960		−0.060281	0
41	1906		−0.132939	0	96	1961		0.324398	0
42	1907		−0.448260	0	97	1962		0.109077	0
43	1908		−0.263582	0	98	1963	0.130453	0.393756	1
44	1909		−0.378903	0	99	1964		−0.421566	0
45	1910		−0.494224	0	100	1965	0.000638	0.263113	1
46	1911	−0.461184	−0.209545	1	101	1966		0.047792	0
47	1912		0.375134	0	102	1967		0.232471	0
48	1913	−0.292275	−0.040187	1	103	1968	−0.247274	0.017150	1
49	1914	0.192179	0.444492	1	104	1969	−0.062819	0.201829	1
50	1915		−0.070830	0	105	1970		−0.213492	0
51	1916		−0.386151	0	106	1971		−0.128814	0
52	1917		−0.501472	0	107	1972	0.190544	0.455865	1
53	1918	−0.170002	0.083207	1	108	1973		−0.259456	0
54	1919	0.214452	0.467886	1	109	1974		−0.674777	0
55	1920		−0.647435	0	110	1975		−0.490098	0
					111	1976	−0.771637	−0.505419	1
					112	1977		0.579260	0
					113	1978		−0.036062	0
					114	1979		−0.151383	0
					115	1980		0.033296	0
					115	1981		−0.182025	0
					117	1982	0.335090	0.602654	1
					118	1983	0.419545	0.687333	1
					119	1984		−0.527988	0
					120	1985		−0.443310	0
					121	1986	−0.427092	−0.158631	1
					122	1987	0.257363	0.526048	1
					123	1988		0.210727	0
					124	1989		−0.204594	0
					125	1990		0.180085	0
					126	1991	0.495181	0.764764	1
					127	1992	−0.720364	−0.450558	1
					128	1993	0.264090	0.517130	1

[a] from SOI.

subsequent years which are thereafter systematically cooler.

The warm month Jakarta/Semarang deviates themselves may be directly related to the size and relative movement of the western Pacific warm pool, particularly in the ENSO warm-event years. The most obvious time periods to seek temperature induced changes in biomass burning of southeast Asia would undoubtedly correspond with ENSO warm-event years and particularly those in which marked positive deviations from the overall secular trend are apparent. In recent years these are: 1991, 1987, 1983, 1982, 1972, 1963, 1958(?), 1957, 1953 and 1951 (Table 6). The heat build-up in southeast Asia and the western Pacific presumably commences *before* the Kelvin wave resurgence from the western to the eastern Pacific which seems to have started in October to mid-December in recent years although in 1993 a Kelvin wave was also detected in August and then in late October (Kousky, 1993). The warmest month of the first ENSO year usually takes place in either September (3 times in the record), October (18) or November (4) and can also show up in May (7) and June (2) as well. In itself, a significant warm deviation above the secular trend in average monthly temperature for any of these months signals an upcoming warmer-than-average ENSO with a hit-ratio of 21:6.

CONCLUSION

Atmospheric temperature build-up possibly associated with the greenhouse effect may be coupled to an increasingly wider temperature swing in west and central Java associated with the warm pool influence but anchored by the ocean-sink. In southeast Asia, longer dry periods coupled with increased temperatures may thus result from an ENSO-driven mechanism which may force increased equatorial aridity as global carbon dioxide concentrations increase resulting in a change from "ever-wet" conditions. Forest fires have become a persistent problem in Kalimantan, Indonesia in the ENSO-associated droughts of recent years. The warm event years seem to provide the driving mechanism. The temperature record shown by the southeast Asian cities studied to data indicate a progressive annual warming for the region of around 0.013°C over the last century. This is almost an order of magnitude greater than the global mean cited above.

ENSO year warm events vary in their effects as estimated by deviation of warmest month mean air temperature from the secular trend exhibited by the Jakarta/Semarang data set and perhaps more widely throughout southeast Asia. The strength of this temperature deviation from the secular trend for ENSO year may provide a quantitative key to understanding the form of the teleconnections passed outwards from the region of southeast Asia and the associated "warm pool" of surface sea water that accumulates against the western margin of the equatorial Pacific.

In general, ENSO years are associated with higher temperatures than non-ENSO years, with a significant negative correlation between subsequent years which are thereafter systematically cooler. This may be because the ENSO event acts as a heat-pump and actively mixes excess heat energy into the ocean-sink to an extent that is in direct proportion to the outstanding positive temperature deviation. A weak ENSO, preceded by a relatively modest temperature build-up in the lead-up non-ENSO years, then results in limited mixing which leads to a relatively warm subsequent year while a strong event leads to extensive mixing and so generally results in a following very much cooler year. The differentiation between non-ENSO/ENSO blocks showing trends of positive "heat-loading" indices as opposed to those showing decreasing trends suggests that heat build-up alone may not be the only critical variable but that perhaps two subcategories of ENSO initiating mechanisms may be involved. Those dominated by heat forcing, and those by water-mass forcing. Both however, generating heat re-distribution into the Pacific Ocean.

On the basis of the evidence assembled herein, the warming-pulse effect of the ENSO warm-events observed recently are probably not quantitatively different from the "great dry event" of 1877–1878 however, the overall global temperature is now around 0.5°C higher and perhaps as much as 1.5–2.0° in the region of the equator. The Jakarta air-temperature data, near the equator, show a clear change in amplitude and degree over the 127 yr record. It is of course relatively easy to dismiss these changes in a superficial way by attributing them to a "city effect". Similar changes overall throughout the Indonesian and Philippines archipelagos together with those from El Salvador are less easily dismissed. The fact is however, that ecological conditions and vegetation cover have probably also been changed markedly in the same interval making it difficult to ascribe such observed effects entirely to secular responses of a global nature. It is certain that if the instrumental record of the 1877–1878 ENSO event did not exist, the events observed in 1982–1983 and 1991–1992–1993 would appear to be quite extra-ordinarily severe in relation to all activity from 1879 forward.

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Meteorological data for Indonesia: courtesy Badan Meterologi dan Geofisika, Jakarta, Indonesia and Indonesian Ministry of Agriculture.

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