Predictability of Java Monsoon Rainfall Anomalies: A Case Study

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(Manuscript received 22 May 1986, in final form 13 August 1986)

ABSTRACT

A substantial portion of the interannual variability of rainfall at Jakarta, Java, can be predicted from antecedent pressure anomalies at Darwin, northern Australia; the pressure persistence, the concurrent correlation of pressure and rainfall, and the predictability of rainfall from antecedent pressure are all largest during the "east" monsoon (June–November). Because of the relatively simple large-scale circulation setting, warranting a single predictor (Darwin pressure), this region is chosen for a series of experiments aimed at exploring the seasonality and secular variations of predictability, optimal length of dependent record, and updating of the regression base period used for predictions on the independent data set.

The major features of pressure–rainfall relationships are common through much of the 1911–83 record, namely sign and general magnitude of correlations and the closer relationships during the east, as compared to the west monsoon. Considerable differences are, however, apparent between decades. These may stem from both sampling deficiencies (noise) and real long-term changes of the pressure–rainfall couplings due to secular alterations in the large-scale circulation setting. The competition between these two factors is relevant concerning the optimal length of the dependent record used for predictions into the independent data set, as well as the updating of the regression base period.

1. Introduction

Climate prediction is a central objective of the World Climate Research Program (World Meteorological Organization, 1980, p. 42), as well as the U.S. National Climate Program (National Climate Program Office, NOAA, 1980). It has been suggested (Charney and Shukla, 1981) that this task should be more feasible for the lower latitudes, because climatic variability in the tropics was, in large part, due to slowly varying anomalies at the lower boundary of the atmosphere. Work in the 1980s has indeed demonstrated that for *certain* tropical regions, nearly half of the interannual rainfall variability can be predicted from antecedent departures in the large-scale circulation (Nicholls, 1981, 1983; Hastenrath et al., 1984; Hastenrath, 1985, 1986).

For Java, such a performance has been accomplished using a single predictor (Nicholls, 1981, 1983). Because of the relatively simple setting, this region was chosen for a series of experiments in empirically based climate prediction, specifically aimed at exploring the following topics: seasonal changes in predictive potential, secular variation of predictability, optimal length of dependent record and updating of this input base. The latter two issues have also been considered by Kung and Sharif (1982) and Nicholls (1984a) for two other low-latitude regions. The present paper is a further case study on the predictability of tropical climate anomalies from empirical methods.

2. General circulation background

The annual cycle of circulation and climate in the greater Indonesian region is extensively documented by Braak (1921–29), Sukanto (1969) and Hastenrath and Lamb (1979). Figure 1 is a sketch of the surface pressure and flow patterns in January and July (around the extremes of the year), and Fig. 2 depicts the annual march of rainfall at Jakarta, Java, and pressure at Darwin, northern Australia.

At the height of the northern winter (December–January; Fig. 1a), the quasi-permanent low pressure center in the Indonesia–North Australian region is best developed, and Darwin in northern Australia experiences its annual minimum of pressure (Fig. 2). Surface airflow over Java and the surrounding seas is approximately from the west (Fig. 1a, and Fig. 2), and lower tropospheric convergence is most pronounced (Hastenrath and Lamb, 1979, vol. 1, charts 30–41). Java is most exposed to the large-scale airflow at this time of the year. On the whole, this is the core of the rainy season of the northern winter west monsoon (Fig. 2), although Indonesia receives precipitation all year round and possesses a puzzling variety of rainfall regimes (Braak, 1921–29, part 1; Sukanto, 1969).

At the opposite extreme of the year, around June–July, the lowest pressure is no longer found in the North Australian region but over southern Asia, while Darwin in northern Australia reaches its annual maximum of

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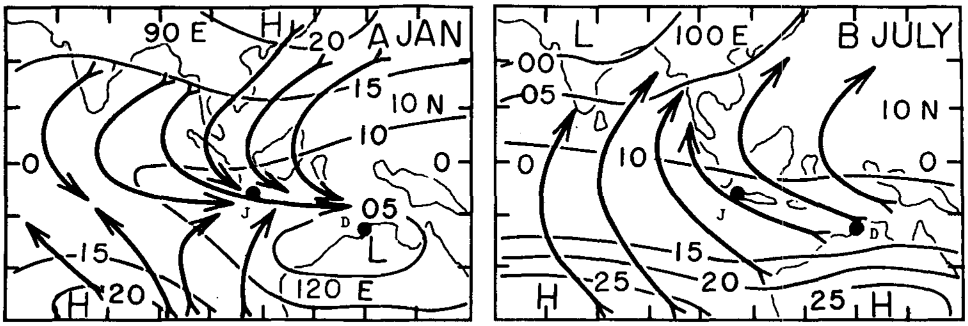

FIG. 1. Surface pressure (in 1000+ mb) and flow patterns over the greater Indonesian region during (a) January, and (b) July. Heavy dots denote locations of rainfall station Jakarta (J), Java (Fig. 2), and pressure station Darwin (D), North Australia (Fig. 2). (sources: Hastenrath and Lamb (1979), charts 30 and 36; Godbole and Shukla (1981), Figs. 2 and 4.)

pressure (Fig. 2). The lower tropospheric flow over Java and most of the equatorial zone is from south of east (Fig. 1b, and Fig. 2). This is the driest time of the year in Jakarta and much of Java (Fig. 2).

The general circulation mechanisms of Java rainfall anomalies are the subject of a recent paper (Hackert and Hastenrath, 1986). The interannual rainfall variability can be understood, in part, as resulting from modulations of the average annual cycle of circulation, in that abundant/deficient rainfall years are characterized by an anomalously strong/weak west monsoon. In November–April, anomalously low pressure, abundant convergence, cloudiness and rainfall, as well as anomalous northwesterlies consistent with the enhanced southward pressure gradient, are associated with a negative sea surface temperature anomaly in the Indonesian waters. In contrast, in May–October, anomalously low pressure, abundant cloudiness and departure northwesterlies accompany anomalously warm Indonesian surface waters. Anomalously low pressure and warm surface waters in May–October are followed by low pressure and low sea temperature in November–April, which in turn are succeeded by high May–October pressure. Note that in November–April, anomalous northwesterlies combine with the basic flow to yield increased wind speed, whereas in May–October they would oppose the basic flow resulting in weaker winds. Enhanced/reduced wind speed, through enhanced/reduced stirring, may lead to cooler/warmer surface waters which, through hydrostatics, favor high/low surface atmospheric pressure. It is hypothesized that these mechanisms may contribute to the observed seasonal reversal of the correlations between surface pressure and sea surface temperature, and the stronger pressure persistence from the northern summer to winter.

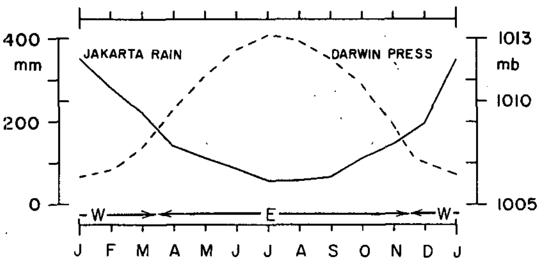

FIG. 2. Annual march of monthly rainfall totals (in mm) at Jakarta, Java, solid line; and of surface pressure (in mb) at Darwin, North Australia, broken line. Period 1911–83. (See Fig. 1 for station locations.) Horizontal arrows and letters W and E indicate the periods of west and east monsoon.

3. Review of Indonesia climate prediction

The interannual variability of rainfall on the densely populated islands of Indonesia attracted the attention of Dutch meteorologists very early on, and led to sustained efforts to predict monsoon rainfall anomalies (Hastenrath, 1985, 1986).

Still most important are the early studies of Braak (1919), who first recognized the essential relationships between long-term pressure, wind and rainfall variations in the Indonesian region. He already noted that pressure variations are remarkably coherent throughout the area, but possessed largest amplitude over northern Australia. As a direct consequence, during high pressure episodes in the Indonesian area the "west" monsoon is weaker and the "east" monsoon (Figs. 1 and 2) is stronger; low pressure episodes are characterized by the inverse wind departures. Braak (1919) also notes that high pressure is associated with deficient rainfall during the east monsoon, although the inverse rainfall departures occur in parts of Java during the west monsoon. Braak (1919) further finds a tendency for cloudiness to vary inversely to pressure, but for the extrema of sea surface temperature to lead the opposite extrema of pressure. The suggestion that the enhanced winds of low pressure episodes, through deeper ocean mixing, may lead to a cooling of the sea surface is also due to Braak (1919). Braak (1919) considers that forecasting for the east monsoon rainfall holds the better prospect, and that pressure should be taken as sole predictor.

The pioneering studies of Braak (1919) were followed by several decades of forecasting endeavors (Berlage, 1927, 1934; de Boer, 1947; de Boer and Euwe, 1949a,b; Schmidt-ten Hoopen and Schmidt, 1951; Schmidt and van der Vecht, 1952; Reesinck, 1952), which, however, failed to live up to the great prospects held out by Braak's (1919) early work.

It was Nicholls (1981, 1983) who, 60 years later, followed up Braak's (1919) ideas, namely to use Darwin pressure in the first half of the calendar year to predict Java rainfall during the second semester. Nicholls (1983) constructed a linear single-parameter regression model of Jakarta September–November rainfall versus Darwin August pressure during 1951–69. He then used this relationship to predict the Jakarta September–November rainfall during each of the years 1970–80. For this independent data set he succeeded in predicting 44% of the interannual rainfall variance. On similar grounds, Nicholls et al. (1982) and Nicholls (1984b) proposed prediction schemes for the onset of the wet season in northern Australia. However, the present study is limited to the predictability of Java monsoon rainfall anomalies.

4. Observations

The data basis for the present experiments is limited to two time series. Individual monthly rainfall totals for Jakarta on the island of Java (Fig. 1) for the period 1911–83 were obtained through the courtesy of Dr. Ahmed Bey and the Indonesia Meteorological and Geophysical Agency. Individual monthly means of surface pressure at Darwin in northern Australia (during 1911–83, Fig. 1) were obtained from the Australian Bureau of Meteorology.

5. Seasonal changes in predictive potential

Although rainfall in Java peaks around January (Fig. 2), it occurs all year, and climate prediction for both the "west" and "east" monsoons is of interest. Since the large-scale circulation setting changes in the course of the year, with the surface wind field in fact reversing from the height of the northern winter to summer (Figs. 1 and 2), the potential for long-range forecasting may also vary over the year. Note that in the present paper, objectives are limited to exploring the possibility of predicting Jakarta rainfall from the antecedent pressure at Darwin. Information pertinent to the annual march of pressure and rainfall correlations is summarized in Fig. 3. While this presents values for the entire period 1911–83, essentially the same results were obtained for the separate portions of the record, 1911–60 and 1961–83.

Figure 3 illustrates that an inverse correlation between pressure and rainfall (*P/R*) prevails during most of the year, with largest values from July to November or during the east monsoon. Pressure persistence (*P-P*) is considerable throughout the year, but by far largest from June to November, that is, in the east monsoon. The possible causes of this seasonal variation of pressure persistence were first considered by Braak (1919), and were discussed in section 2: the wind departures associated with anomalously low/high pressure would enhance/oppose the basic wind field and thus increase/reduce the wind speed during the west monsoon, but have the opposite effect during the east monsoon; in both seasons, increased/reduced wind speed would entail stronger/weaker stirring of the upper ocean, thus leading to anomalously cold/warm surface waters; whatever the mechanisms, however, pressure and sea surface temperature are indeed correlated positively during the west monsoon, but negatively during the east monsoon, which through hydrostatic effects would allow for a stronger pressure persistence in the latter season, as illustrated in Fig. 3. The plots of concurrent correlation between pressure and rainfall (*P/R*) and of pressure persistence (*P-P*) are directly relevant to the correlation between rainfall and antecedent pressure conditions (*P-R*) also illustrated in Fig. 3. Consistent with the *P/R* and *P-P* plots, by far the largest values of *P-R* are found for June to November, that is the east monsoon.

Figure 3 suggests that the predictability of rainfall anomalies, at least as based solely on pressure, is best for the east monsoon and much less for the west monsoon. Comparison with Fig. 2 indicates that the prospects for climate prediction on the basis of pressure alone are more remote for the season of most abundant rainfall (the west monsoon), but much better for the

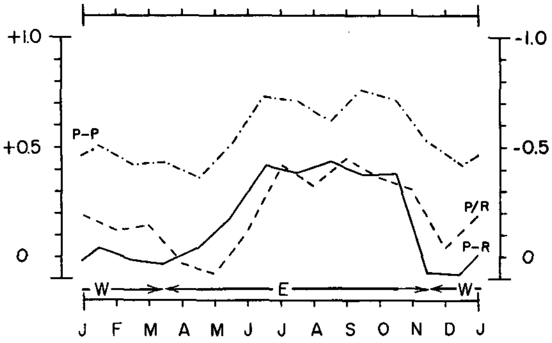

FIG. 3. Annual march of correlation coefficients between Darwin pressure (*P*) and Jakarta rainfall (*R*). (See Fig. 1 for station locations.) Correlations between pressure in successive months, *P-P*, dash-dotted line, left-hand scale; concurrent correlations between pressure and rainfall, *P/R*, broken line, right-hand scale; correlations between pressure and rainfall in the following calendar month, *P-R*, solid line, right-hand scale (note that for *P/R* and *P-R* the scale is inverted as compared to *P-P*). Period 1911–83. Correlations beyond approximately 0.25 and 0.31 in absolute value correspond to the 5 and 1% significance levels, respectively. Quenouille's (1952, p. 168) method was used to account for the reduction of effective numbers of degrees of freedom due to persistence. As in Fig. 2, horizontal arrows and letters W and E indicate the periods of west and east monsoon, respectively.

drier time of the year, namely the east monsoon. It appears that climate prediction would be more practical for seasonal intervals than for single calendar months, and that combination of several months would also serve to enhance data stability.

From such considerations, various seasonal combinations were chosen for experiments, as shown in Table 1. The first block contains various groupings for the west monsoon rains, together with pressure for combinations of immediately preceding calendar months. There is a considerable practical interest in the prediction of the west monsoon rains, since these account for the bulk of the annual precipitation total. The various correlation coefficients have the plausible negative sign and are diagnostically interesting, but on the whole they are small and hold out only a modest prospect for prognostic application. Likewise, the correlations between rainfall in the second semester and pressure in the preceding first semester of the calendar year are small, albeit of the plausible negative sign. The remaining combinations in the last block of Table 1 all deal with the relationships between the east monsoon rains and antecedent pressure. This group contains the strongest correlations. From an inspection of Table 1, the most interesting combinations are selected for the experiments in sections 7 and 8. The breakdown into the intervals 1911–60, 61–83 and 11–83 in Table 1 gives an indication of the variations of correlations between the different portions of the record, but also separates the subset to be used later on as "dependent" data set (1911–60) from the interval reserved as "independent" data set (1961–83).

6. Secular variation of predictability

The results reviewed in sections 2 and 3 point to the remarkable coupling between Java rainfall and the antecedent pressure conditions, although the evidence presented in section 5 also shows that this relationship varies in the course of the year. With a view towards prognostic applications, it must further be anticipated that the pressure–rainfall relationships may not be invariant throughout the century. This issue is explored in Table 2, which lists the pressure–rainfall correlations for the seven successive decadal intervals of the 1911–80 record.

TABLE 1. Correlation coefficients (in hundredths) between Darwin pressure (*P*) and following Jakarta rainfall (*R*). One and two asterisks indicate significance at the 5% and 1% significance levels, respectively; Quenouille's (1952, p. 168) method was used to account for the reduction of the effective number of degrees of freedom due to persistence. An "X" at the left-hand margin of the table indicates the combinations considered in sections 7 and 8.

	P		*R*	1911–60	61–83	11–83
			West monsoon rains			
	May–Oct	→	Nov–Apr	−33**	−23	−27*
	Sept–Oct	→	Nov–Feb	−26	−43	−31*
	Sept–Oct	→	Nov–Mar	−28	−44	−32*
	Oct–Nov	→	Dec–Mar	−16	−52*	−29*
			East monsoon rains			
	Jan–June	→	July–Dec	−10	−10	−10
	May–June	→	July–Nov	−50**	−51*	−50**
X	June	→	July–Nov	−46**	−66**	−52**
X	June–July	→	Aug–Nov	−50**	−57*	−52**
	June–Aug	→	Sept–Nov	−46**	−55*	−48**
X	Aug	→	Sept–Nov	−49**	−55*	−50**

The major features of pressure–rainfall relationships discussed in sections 2, 3 and 5 are common throughout much of the century, namely sign and general magnitude of correlations (Table 2), and the closer relationship during the east as compared to the west monsoon (not documented here). In detail, however, Table 2 bears out considerable variations between decades. For the east monsoon rains, the pressure–rainfall correlations were best in the decades 1921–30 and 1961–70. For the west monsoon rains, the correlations (not shown here) were largest during the decades 1911–20 and 1961–70, and smallest in the decades 1921–30, 1931–40 and 1971–80.

These secular variations of predictability are also interesting in relation to Nicholls' (1983) experiment of predicting the September–November rainfall at Jakarta during 1970–80 from the antecedent August pressure at Darwin, in which exercise he explained 44% of the observed interannual rainfall variability. Thus it is noteworthy (Table 2) that the pressure–rainfall relation was rather strong during the 1971–80 decade, whereas the forecast performance would have been much inferior for 1961–70 (explained variance 4%). On the other hand, for the 1951–60 decade, the antecedent Darwin pressure explains as much as 69% of the interannual rainfall variability at Jakarta.

Note that in the case of a relation between two variables *R* and *P* only, a regression model constructed from a dependent data set will always explain all of the *R* variance accounted for by *P* in the independent data set (Panofsky and Brier, 1968). Thus, the square of the correlation coefficients in Table 2 represents also the total percentage variance explained by a linear pressure–rainfall regression fit in a predictive mode.

It is proposed here that the secular variation of pressure–rainfall correlations in Table 2 results from two components: (i) deficiencies in sampling related to observational noise and the limited time intervals; and (ii) real long-term changes of the pressure–rainfall couplings due to secular alterations in the large-scale circulation setting.

7. Optimal length of dependent record

The issue addressed in this section is the most appropriate length of dependent record for the development of the regression model to be used in a predictive mode on an independent data set. In other words, what length of dependent base period will lead to the best

TABLE 2. Correlation coefficients (in hundredths) between Darwin pressure (*P*) and following Jakarata rainfall (*R*), for various decadal intervals during 1911–80. One and two asterisks indicate significance at the 5% and 1% significance levels, respectively; Quenouille's (1952, p. 168) method was used to account for the reduction of the effective number of degrees of freedom due to persistence.

			Decadal interval						
P		*R*	1911–20	1921–30	1931–40	1941–50	1951–60	1961–70	1971–80
June	→	July–Nov	−53	+17	−67*	−52	−69*	−55	−67*
June–July	→	Aug–Nov	−73*	−3	−46	−43	−79**	−41	−58
Aug	→	Sept–Nov	−51	−55	−26	−49	−83**	−21	−69*

forecast performance in the independent data set? This problem has been investigated empirically before by Kung and Sharif (1982) for India summer monsoon rainfall and by Nicholls (1984a) for Australian spring rainfall.

Two conflicting considerations come to mind. From a strictly statistical point of view it may appear that the longer the dependent record used, the better the sampling, and the better the relationships between *P* and *R* can be described. From that consideration alone, a long dependent record would favor the forecast performance on the independent data set. By contrast, from a meteorological perspective it is realized that long-term changes in the large-scale circulation setting will entail variations in the relationship between *P* and *R*. Accordingly, a long dependent record (say 1911–60) may contain much "outdated" information on the large-scale circulation setting, as compared to a shorter base period confined to a more recent time span (say 1951–60). These "statistical" and "meteorological" considerations compete against each other, and the choice of the optimal length of the regression base period does not seem to be possible on general theoretical grounds: conceivably, the "noise" may have differing secular variations in various regions and epochs; and likewise the large-scale circulation setting and hence the relations between predictor(s) and predictand may vary differently, depending on region and time. Accordingly, the issue of optimal length of dependent record is to be explored on empirical grounds.

In this section, the record up to 1960 is used as a dependent data set, and observations from 1961 onward as an independent data set. Experiments are limited to the three seasonal combinations for the east monsoon rains identified in Tables 1 and 2, for which the strongest pressure–rainfall relationships were found.

The experiments presented in the preceding sections 5 and 6 are confined to dependent data sets and are diagnostic in nature. For prediction proper, a regression model of the form

$$R = a + b \times P \tag{1}$$

is to be constructed in the first place from a dependent data set. Here *R* is Jakarta rainfall, *P* Darwin pressure, and *a* and *b* are coefficients to be determined by the regression analysis. Equation (1) is then to be applied in a predictive mode on an independent data set, which was not used in the development of the regression model. The forecast values of *R* are then to be compared with the observed *R*. The square of the correlation coefficient between the forecast and the observed *R* represents the fraction of observed rainfall variance in the independent data set explained by the forecast method and is thus a measure of forecast performance. However, as noted in section 6, in the case of only two variables (*P* and *R*) any regression model of the form of Eq. (1) in a predictive mode will explain all of the *R* variance accounted for by *P* in the independent data set.

To appraise the forecast potential, four measures are used here: the correlation coefficient (CORR) between the forecast *R*′ and the observed *R*, the root-mean-square error (RMSE), the bias (BIAS) and the absolute error (ABSE). The forecast period spans the 23 years 1961–83, and the aforementioned statistics are computed as follows (Nicholls, 1984a):

$$\mathrm{RMSE} = [\sum_{61}^{83} (R' - R)^2/23]^{0.5}$$

$$\mathrm{BIAS} = \sum_{61}^{83} (R' - R)/23$$

$$\mathrm{ABSE} = \sum_{61}^{83} |R' - R|/23$$

where the summation extends over the 23 forecast years 1961–83. These measures are used to estimate the optimal length of the dependent record and the merits of updating the base period (sections 7 and 8).

Refer to Table 3, part A (FIXED). In each of the three forecast combinations, CORR is independent of the length of the regression base period. RMSE tends to decrease with increasing length of the regression base period, but reaches the smallest value around 40 yr rather than at the longest period of 50 yr. BIAS changes from small negative numbers at 10 yr to small positive values at larger regression base periods. ABSE varies little, but also tends to be smallest around 40 yr rather than at the longest period used of 50 yr.

The results summarized in Table 3 can be interpreted in the sense that the optimal length of the dependent

TABLE 3. Appraisal of Jakarta rainfall (*R*) from Darwin pressure (*P*) during 1961–83. Correlation coefficient (CORR) in hundredths; root-mean-square error (RMSE); bias (BIAS); absolute error (ABSE) all in centimeters. Regression models [Eq. (1)] used for forecasting the 23 yr were constructed from base periods of varying length, as indicated in labels at top of the table. a. In the Fixed experiments all regression base periods end in 1960 (i.e., the 10-yr regression model is constructed from the years 1951–60, . . . the 50-yr regression model from the years 1911–60). b. In the Updated experiments all regression base periods end with the year preceding the predicted year (example: in the case of the 30-yr regression base period, the dependent years 1930–60 are used to predict 1961, . . . the dependent years 1936–65 to predict 1966, etc.) One and two asterisks indicate significance at the 5 and 1% significance levels, respectively; Quenouille's (1952, p. 168) method was used to account for the reduction of the effective number of degrees of freedom due to persistence.

			Length of regression base period (yr)				
P		*R*	Statistic	10	20	30	40	50
				a. Fixed				
June	→	July–Nov	CORR	−66**	−66**	−66**	−66**	−66**
			RMSE	13	14	13	13	14
			BIAS	−1	+6	+3	+2	+3
			ABSE	11	11	10	10	10
June–July	→	Aug–Nov	CORR	−57*	−57*	−57*	−57*	−57*
			RMSE	13	15	14	13	13
			BIAS	−4	+5	+2	+1	+1
			ABSE	13	11	11	11	11
Aug	→	Sept–Nov	CORR	−55*	−55*	−55*	−55*	−55*
			RMSE	14	12	12	12	12
			BIAS	−5	+4	+2	+2	+4
			ABSE	12	11	9	9	10
				b. Updated				
June	→	July–Nov	CORR	+59*	+55*	+59*	+66*	+66*
			RMSE	15	15	14	13	13
			BIAS	−3	+1	+1	+1	+1
			ABSE	12	12	11	11	10
June–July	→	Aug–Nov	CORR	+46	+42	+49	+54*	+54*
			RMSE	13	15	14	13	13
			BIAS	−3	−2	+0	+1	+1
			ABSE	13	12	11	11	11
Aug	→	Sept–Nov	CORR	+49	+44	+48	+50	+49
			RMSE	12	13	13	12	12
			BIAS	−4	−2	−1	+1	+1
			ABSE	10	10	10	10	10

record is of the order of several decades, but rather shorter than half a century. By comparison, it is noteworthy that optimum periods of less than 20 yr were found by Kung and Sharif (1982) for India and by Nicholls (1984a) for Australia rainfall.

8. Updating of base period

In the discussion of the optimal length of the base period used for the development of the regression models (section 7), it was realized that, because of possible long-term changes in the large-scale circulation setting, the most recent information of the dependent record may be most useful for predictions into the independent time interval. From these considerations, the updating of the regression model base period appears an attractive option. This possibility is explored in the present section.

Refer to Table 3, part B (UPDATED). For each of the five record lengths (i.e., 10, 20, . . . , 50 years) a total of 23 regression models were constructed. Each of these models was then used to predict the rainfall for the year immediately following the last year of the respective regression base period. Table 3 shows that on the whole the "updated" prediction models yield smaller CORR and larger RMSE than those using a fixed regression base period. Also, the "updated" models tend to yield the largest CORR for the long regression base periods. Only for one of the combinations (July–November rainfall predicted from June pressure) do the updated models with regression base periods of 40 years and longer yield CORR as high as the "fixed" model.

Complementing Table 3 are the scatter plots Figs. 4 and 5, showing results of August–November rainfall predictions from antecedent June–July pressure for the 23 years 1961–83. In both plots regression base periods of 40 years are used. However, Fig. 4 shows the results using the "fixed" base period 1921–60, whereas Fig. 5 displays the compilations from "updated" regression

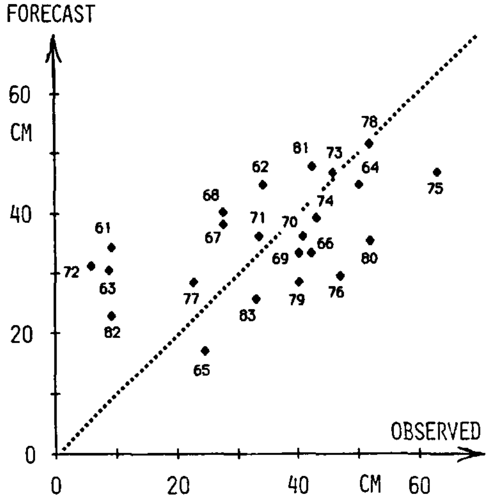

FIG. 4. Scatter diagram of forecast vs observed August–November Jakarta rainfall. Regression base period is 1921–60, forecast period 1961–83, and predictor June–July Darwin pressure. Numbers indicate the years and dotted line 45° angle. Correlation coefficient r = +0.57 is significant at the 5% level. The RMSE = 13, BIAS = +5, ABSE = 11.

models with the regression base period of 40 years always ending with the year immediately preceding the year to be predicted. The correlation coefficient of "forecast" versus "observed" (Table 3) is +0.57 for the model using a "fixed" base period (Fig. 4), but only +0.54 for the "updated" models (Fig. 5).

In order to appraise the merits of "updating," compare Table 3, parts B (UPDATED) and A (FIXED), and Fig. 5 to Fig. 4. Generally, CORR is smaller and RMSE larger for the "updated" than for the "fixed" models. This is further illustrated by comparison of the scatter plots, Fig. 5 versus Fig. 4. Collectively, this evidence indicates that for the prediction of Jakarta rainfall from Darwin pressure, "updating" is inferior to the use of "fixed" regression models. This is contrary to Kung and Sharif's (1982) conjecture for India, and Nicholls' (1984a) findings for Australia rainfall.

9. Conclusions

It has been suggested on theoretical grounds that the interannual variability of climate should be more predictable for the tropics than for the mid-latitudes; of foremost importance for the tropics are the vagaries of rainfall. Indonesia is one of two low-latitude regions for which earlier research has demonstrated that nearly half of the interannual rainfall variability can be explained from antecedent anomalies in the large-scale circulation. Moreover, this forecast performance has been accomplished using a single predictor. Because of the relatively simple large-scale circulation setting, the Java monsoon rainfall was found particularly suited for exploring various topics of more general relevance for empirically based climate prediction in the tropics.

In the Indonesian region, the potential of predicting rainfall from the antecedent pressure anomalies differs markedly between the northern winter "west" and the summer "east" monsoon. Pressure variations are remarkably coherent throughout the region, and low/high pressure anomalies as a rule entail a steepening/slackening of the meridional pressure gradient, which is in turn accompanied by departure westerlies/easterlies. Departure westerlies reinforce the basic flow and result in larger wind speed during the northern winter west monsoon, but oppose the basic flow and cause reduced wind speed during the east monsoon. Stronger/weaker wind stirring is considered conducive to a cold/warm ocean surface. At any rate, anomalously low/high pressure is typically associated with cold/warm surface waters during the west monsoon, but with the inverse sea surface temperature departure during the east monsoon. These sea surface temperature anomalies, through hydrostatic effects, favor pressure persistence during the east, but not the west monsoon. For reasons not entirely obvious, the concurrent correlations between pressure and rainfall are largest during the east monsoon. This circumstance, together with the aforementioned pressure persistence, results in a particularly strong correlation between rainfall and antecedent pressure during the east monsoon. Unfortunately, the predictability of rainfall from antecedent pressure is much less during the west monsoon, which accounts for the bulk of the annual rainfall totals on Java.

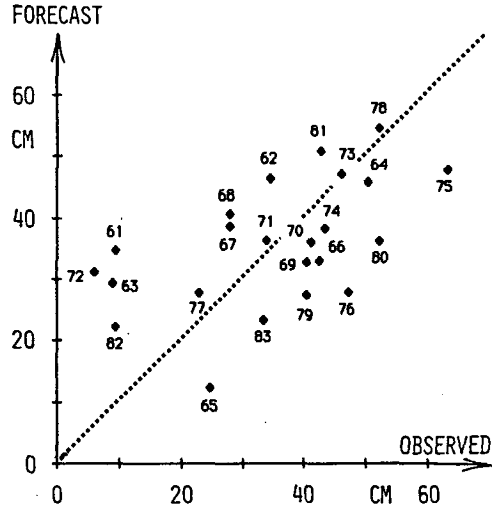

FIG. 5. Scatter diagram of forecast vs observed August–November Jakarta rainfall for the 23 yr 1961–83, using as predictor June–July pressure at Darwin. The length of the regression base period is always 40 yr, but forecasts are made from models with regression base periods ending 1 yr before the predicted year (ex: the dependent record 1921–60 serves to predict 1961, . . . the record 1926–65 to predict 1966, etc.). Numbers indicate the years and dotted line 45° angle. Correlation coefficient r = +0.54 is significant at the 5% level. The RMSE = 13, BIAS = −2, ABSE = 12.

Concerning the secular variation of predictability, it is found that the major features of pressure–rainfall relationships are common through much of the century, such as the sign and general magnitude of correlations and the closer relationships during the east as compared to the west monsoon. In detail, however, considerable differences are apparent between decades. These may result from two different components: i) "noise" or sampling deficiencies related to the limited observation periods; and ii) real long-term changes of the pressure–rainfall couplings concomitant with secular alterations of the large-scale circulation setting. The relative importance of these two factors is likely to vary between regions and epochs, and cannot readily be assessed.

A pragmatically important issue in empirically based climate prediction is the optimal length of the (dependent) regression base period, from which forecasts are to be made into the years of the independent data set. The aforementioned competition between sampling deficiencies ("noise") and real circulation-caused changes in statistical relationships is directly relevant concerning the optimal length of the dependent record. While from a purely statistical standpoint a very long dependent record appears desirable, possible secular changes in the large-scale circulation setting and concomitant real changes in, say, pressure–rainfall relationships may render the information in the most recent portion of the dependent record most relevant for predictions into the time interval of the independent data set. This issue was explored empirically. It was concluded that, for the problem at hand, the optimal length of the dependent record is of the order of several decades, but shorter than half a century. It is noted, however, that conditions may differ for other regions and time periods, as is exemplified by the investigations of Kung and Sharif (1982) for India, and Nicholls (1984a) for Australia.

The possible long-term variations in the large-scale circulation setting are likely to entail changes in the statistical relationships between individual elements. On these grounds it seemed plausible that the most recent portion of the past record may be most relevant for predictions into the independent data set, as conjectured by Kung and Sharif (1982) for India, and as shown by Nicholls (1984a) for Australia. However, such an updating was not found to be advantageous for Java.

This study is not aimed exclusively at the long-range forecasting of Java monsoon rainfall anomalies, but is intended as a contribution to the development of tropical climate prediction in general. In fact, the four major topics addressed, namely seasonal changes in predictive potential, secular variation of predictability, optimal length of dependent record, and updating of base period, need to be explored further in regional studies of climate prediction in the tropics.

Acknowledgments. This study was supported by NSF Grant ATM84-13575. Stephan Jansen did the computer programming. I thank Dr. Ahmed Bey, the Indonesian Meteorological and Geophysical Agency and the Australian Bureau of Meteorology for unpublished data, and Peter Lamb and Neville Nicholls for comments on a draft of this paper.

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