Prediction of Indian Monsoon Rainfall: Further Exploration

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ABSTRACT

This study expands recent research into the predictability of Indian monsoon rainfall anomalies. In addition to the April latitude position of the 500 mb ridge over India, and Darwin pressure tendency, the May surface resultant wind speed in a strategic area of the jet axis over the western equatorial Indian Ocean (0–10°S, 45°–50°E) is used as predictor. Regression models developed on 20-yr portions of the 1939–83 record are employed to predict the summer monsoon rainfall anomalies of the 25 yr 1959–83. Correlation, root-mean-square error, bias, and absolute error are presented as measures of forecast performance on the "independent" dataset. It is found that the model constraint optimal for predictive purposes is to be ascertained empirically. "Updating" is not necessarily superior to the use of a fixed regression base period. Relationships between preseason indicators and monsoon rainfall were strongest in the early and late portions of the 1939–83 record, and weakest in the 1950s and 1960s. Antecedent departures in the large-scale circulation setting allowed prediction of more than 60% of the interannual variance of Indian monsoon rainfall for the period 1959–83, and nearly 80% for 1969–83.

1. Introduction

As a foremost objective of the World Climate Research Programme (World Meteorological Organization, 1980, p. 42), climate prediction has received increased attention in recent years (reviews in Hastenrath, 1985, p. 330–352; 1986, 1987a,b). Forecasting the rainfall anomalies of the Indian summer southwest monsoon, in particular, has been the subject of various papers (Banerjee et al., 1978; Thapliyal, 1982; Kung and Sharif, 1982; Wu, 1985; Hastenrath, 1987b; Shukla and Mooley, 1987). Collectively these studies indicate that a substantial portion of the interannual variance of monsoon rainfall over India can be predicted from antecedent departures in the large-scale circulation setting and that the predictors pertaining to the "atmosphere–ocean–land anomaly complex" (Hastenrath, 1987b) can be grouped into three families of preseason indicators of (i) upper-air flow over India, (ii) heat low development over southern Asia and establishment of meridional pressure gradient and cross-equatorial flow over the Indian Ocean, and (iii) the Southern Oscillation (SO). The present paper examines the effect of model constraint on forecast performance, studies secular variations of predictability, offers an appraisal in context with other recent work, and explores the merits of "fixed" versus "updated" regression base periods.

2. Summary of recent work

A comprehensive account of climate prediction for India from the last century to the 1980s has been given elsewhere (Hastenrath, 1985, p. 330–352; 1986). Only the recent results most relevant for the present purposes are summarized here. A breakthrough was the Banerjee et al. (1978) discovery of the April latitude position of the 500 mb ridge along 75°E as a predictor for Indian monsoon rainfall anomalies. This element L is pivotal in the climate prediction exercises of Hastenrath (1987b) and Shukla and Mooley (1987).

Hastenrath (1987b) used, in addition to L, an index of the SO (pressure difference Tahiti minus Darwin) for April, the tendency SOT of this index (difference of SO index value April minus February) for March, and Bombay April temperature BT. Regression models developed on a portion of the 1939–81 record were used to predict the summer monsoon rainfall anomalies of the years 1966–81. It was found that a regression base period of about 20 yr is optimal for prediction into the independent portion of the record, that "updating" offers no advantage over fixed regression base periods, and that about half of the interannual rainfall variance can be predicted from antecedent departures in the large-scale circulation.

Shukla and Mooley (1987) used, in addition to L, only the January to April pressure tendency at Darwin (Ref. Fig. 1). They developed regression models successively with base periods of 30 yr to calculate the monsoon rainfall anomalies for the 32 yr 1939–54 and 1969–84. As a measure of monsoon rainfall they used an all-India June–September rainfall series published

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by Mooley and Parthasarathy (1984) and considered more reliable than previously used compilations. They obtained correlation coefficients of about +0.8 between observed and "regressed" rainfall in their 17 regression models, and a similarly high correlation between observed precipitation and rainfall "calculated" for the 32 yr of "independent" record.

3. Observations and methods

The extensive diagnostic background for Indian rainfall prediction was summarized in a previous paper (Hastenrath, 1987b) and is not repeated here. Drawing on the experience from the two aforementioned very recent studies (Hastenrath, 1987b; Shukla and Mooley, 1987) only a few time series are used here, as illustrated in Figs. 1 and 2. As with most monsoon predictors used previously (review in Hastenrath, 1987b), it is noteworthy that two of these stem from a limited time interval in the transition from the boreal winter to the summer monsoon regimes.

As a measure of the southwest monsoon precipitation, the all-India rainfall series published by Mooley and Parthasarathy (1984) and employed by Shukla and Mooley (1987) is also used here. A time series plot of the index NIR (normalized departures) is presented in Fig. 2a. In this exploratory investigation into predictability, a precipitation index for the country as a whole and the entire rainy season seems most appropriate, although regional and temporal breakdowns and studies of varying onset dates may be of interest at a later stage.

The April latitude position of the 500 mb ridge along 75°E (L) is plotted in Fig. 2b (Ref., also, Fig. 1). The 1939–81 series available from Thapliyal (1982) was updated to 1985 as described in Hastenrath (1987b). This element describing the preseason upper-air flow over India is recognized as a particularly powerful predictor of southwest monsoon rainfall (Banerjee et al., 1978; Thapliyal, 1982; Hastenrath, 1987b; Shukla and Mooley, 1987).

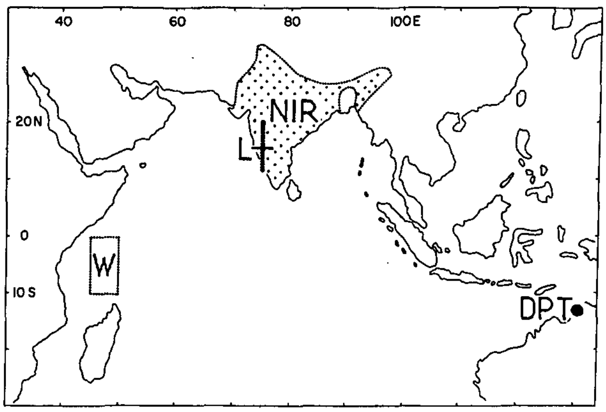

FIG. 1. Orientation map showing spatial context of predictors. Dot raster indicates domain of all-India rainfall index NIR; L is April latitude position of 500 mb ridge along 75°E; DPT, pressure tendency April minus February at Darwin, Northern Australia; and W, May mean surface resultant wind speed in domain 0°–10°S, 45°–50°E.

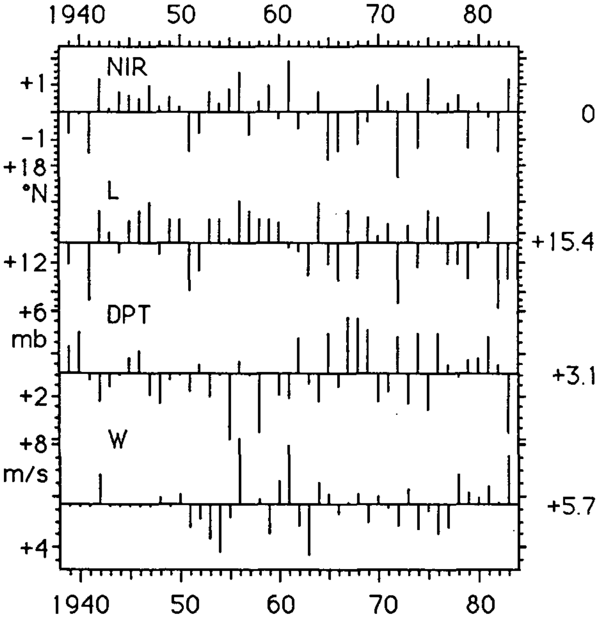

FIG. 2. Time series plots of (a) all-India index of summer monsoon rainfall NIR [unity corresponds to 83 mm per year, and 1939–83 mean = 858 mm per year (Mooley and Parthasarathy, 1984)]; (b) latitude position (tenths of °N) of 500 mb ridge along 75°E in April, L; mean is 15.5°N (Thapliyal, 1982; Hastenrath, 1987b); (c) pressure tendency (April minus January) at Darwin, DPT; mean is 3.1 mb; (d) May mean surface resultant wind speed (domain 0°–10°S and 45°–50°E) is W; mean, 5.7 m s^{-1}.

The pressure tendency (April minus January) at Darwin (Ref. Fig. 1), DPT, is shown in Fig. 2c. This element reflects the SO, but was found to be more strongly correlated with Indian rainfall than other SO indices. Various other SO-related precursors are reviewed in Rasmusson and Carpenter (1983).

While the two above elements have been used in the recent studies of Indian climate prediction (Hastenrath, 1987b; Shukla and Mooley, 1987), a further predictor is introduced in Fig. 2d and Fig. 1. This pertains to the family (ii) of preseason symptoms for continental heat low development, meridional pressure gradient, and cross-equatorial surface flow referred to in the Introduction. As documented by long-term mean charts (Hastenrath and Lamb, 1979, Part 1, charts 14–25; Sadler et al., 1987, p. 4–26), the boreal summer monsoon flow from the Southern into the Northern Hemisphere develops from April onward, with a jetlike concentration of wind over the western Indian Ocean. The 1911–72 dataset of surface ship observations described in our atlas (Hastenrath and Lamb, 1979, part 1) has been updated to 1983 and was used in various of our earlier investigations and the present study. Sadler et al.'s (1987) atlas is based on the COADS compilation, which has more recently become available. Recognizing that the lower-tropospheric jet over the western Indian Ocean constitutes the "backbone" of the boreal summer southwest monsoon, we extracted from our ship dataset the monthly mean surface resultant wind speed of April, May, and June, for domains strategically located near the climatic mean speed maxima in the Southern and Northern hemispheres (Hastenrath and Lamb, 1979, part 1, charts 18–20; Sadler et al., 1987, p. 10–14), namely the 5° square areas contained between 5°–15°S and 35°–55°E, and between 5°–10°N and 50°–55°E. Correlations were found to be largest for May in two 5° square blocks making up the domain 0°–10°S and 45°–50°E (ref. Fig. 1), broadly coincident with the long-term mean jet axis (Hastenrath and Lamb, 1979, part 1, chart 18). Therefore, a time series W of May surface resultant wind speed was computed for this domain over the period 1939–83, as plotted in Fig. 2d. Observations are missing for at least one of the two aforementioned 5° square blocks in May of 1939, 1940, 1941, 1943, 1944, 1945, 1946, 1947, and 1949. These were substituted by the May 1939–58 mean of the domain 0°–10°S and 45°–50°E.

Correlations of the surface wind field with the subsequent summer monsoon rainfall are high in May but much less in both April and June as already shown in Wu and Hastenrath (1986). The low correlations for April appear readily understandable with reference to the annual cycle evolution of the surface flow (Hastenrath and Lamb, 1979, part 1, charts 17, 18), in that it is not until May before the cross-equatorial airstream becomes fully organized and extends continuously from the southeast trades of the southern Indian Ocean to the southwest monsoon flow over the Arabian Sea. The overall further intensification of the cross-equatorial surface flow over the western Indian Ocean from May to June is accompanied by a dropoff of wind-rainfall correlations, and the causes for this may be more complex. By way of comparison it should likewise be noted that the upper-air ridge over India in April—rather than later—is a good precursor of monsoon rainfall anomalies.

The time series plotted in Fig. 2b and d show some similarity with the interannual variations of NIR (Fig. 2a), but also among themselves. These time series serve as input to a stepwise multiple regression scheme (Statware, 1986). The general regression equations are

$$\mathrm{NIR} = b_0 + b_1X_1 + b_2X_2 + \cdots b_nX_n \qquad (1)$$

where NIR is the predictand, the b_i the coefficients of the regression model, the X_i the regressors (variables plotted in Fig. 2b–d), and n the number of regressors employed in the regression model. A significance level α is specified where the retained regression coefficients are accepted as different from zero.

As discussed in Hastenrath (1987b), a regression model is constructed on a "dependent" dataset, and the formula in the form of Eq. (1) thus obtained is then used in a predictive mode on an "independent" dataset. That is, the coefficients b_i are determined from a subset of the record, and these coefficients along with the observed values of X_i (elements plotted in Fig. 2b–d) are then entered in Eq. (1) to calculate the values of NIR for a portion of the record not used in determining the coefficients b_i. In an operational setting, the early portion of the record must be used to develop predictions of later years. In accordance with this practical reality, prediction experiments are performed here for the latter portion of the total 1939–83 period, based on an antecedent part of the record. In particular, the time span 1939–58 will be used to determine the regression coefficients, while the years 1959–83 are to be predicted. However, as considerable analyses have previously been conducted on nearly all of the time series plotted in Fig. 2, the 1959–83 portion of the record is not claimed to be a blind sample. With this qualification, the 1939–58 portion of the record will be referred to in this paper, in brief, as a "dependent" dataset, and the portion of the record reserved for prediction as "independent" dataset.

As in the previous paper (Hastenrath, 1987b) four measures are used to appraise the forecast potential: the correlation coefficient between the forecast NIR′ and the observed NIR, the root-mean-square error RMSE, the bias BIAS, and the absolute error ABSE. The forecast period spans the 25 yr 1959–83, and the aforementioned statistics are computed as follows (Nicholls, 1984; Hastenrath, 1987b):

$$\mathrm{RMSE} = [\sum_{59}^{83} (\mathrm{NIR}' - \mathrm{NIR})^2/25]^{0.5}$$

$$\mathrm{BIAS} = \sum_{59}^{83} (\mathrm{NIR}' - \mathrm{NIR})/25$$

$$\mathrm{ABSE} = \sum_{59}^{83} |\mathrm{NIR}' - \mathrm{NIR}|/25$$

where the summation extends over the 25 forecast yr 1959–83.

Regarding the significance testing of correlation coefficients, it should be noted that geophysical time series are not, as a rule, serially independent. Therefore, Quenouille's (1952, p. 168) method was used to account for the reduction of the effective number of degrees of freedom due to persistence. This is based on the lag autocorrelations of the time series.

4. Model constraint

The construction of the regression model, Eq. (1), can be constrained by specifying a significance level α at which the regression coefficients retained can be accepted as different from zero. A larger value of α may allow more regressors to enter and may result in a larger multiple correlation coefficient (MCC) for the regression model. This is, however, not necessarily advantageous for application of the model in a predictive mode on an independent dataset. In fact, a more strongly constrained regression model (small α) may lead to a larger explained variance in the prediction period, presumably because a small α serves to keep out noise although it may also exclude some information. Therefore, the level α should be judiciously chosen with the aim of enhanced prediction performance. In general, a very small α may unduly eliminate important information, while a very large α may admit excessive noise, but no universally valid optimal α should be expected.

In earlier climate prediction work (Hastenrath et al., 1984; Hastenrath, 1987b), we successfully used $\alpha = 5$ percent. In the present study, regressors include W, in addition to the previously employed L and DPT. Experiments showed that L is accepted at better than $\alpha = 5\%$ for regression base periods of both 30 (1939–68) and 20 (1939–58) yr; DPT at better than 5% for 30 yr, but only at 24% for 20 yr; and W at 25% for 30 yr and at 28% for 20 yr. In confirmation of earlier work (Kung and Sharif, 1982; Hastenrath, 1987b), it also became apparent that a 30-yr regression base period offered no advantage over a 20-yr model for prediction purposes. Accordingly, this paper presents results with $\alpha = 30\%$ and primarily a regression base period of 20 years.

5. Fixed base period

Earlier work on Indian climate prediction (Kung and Sharif, 1982; Hastenrath, 1987b; Shukla and Mooley, 1987) yielded as optimal length of the dependent regression base period about 20 yr. Additional experiments directed to this issue were conducted here, using the fixed regression base periods 1939–58, 1939–63, and 1939–68, to predict the remaining years of "independent" record to 1983. These experiments corroborated the earlier findings and are not detailed here.

In this section the fixed 20-yr period 1939–58 is primarily used to construct the regression models and the 1959–83 portion of the record is reserved for prediction experiments. Table 1a compares the (L, DPT) and (L, DPT, W) models. The MCCs of the regression models differ little, while for the prediction into the "independent" portion of the record the (L, DPT, W) performs better than the (L, DPT) model, in that the explained variance is increased from 55% to 61%, and RMSE, BIAS, and ABSE are all decreased; the increase of explained variance is significant at the 9% level (Burr, 1974, p. 384–385).

It is remarkable, however, that for the (L, DPT) model, both the multiple correlation coefficient of the regression model MCC and the correlation coefficient CORR between predicted and observed rainfall are

TABLE 1. Synopsis of regression models and prediction experiments for a) fixed and b) updated regression base periods. Code is as follows: L, April latitude position of 500 mb ridge; DPT, Darwin pressure tendency (April minus January); W, May mean surface resultant wind speed in domain 0°–10°S and 45°–50°E; MCC, multiple correlation coefficient (in hundredths) of regression model; CORR, correlation coefficient (in hundredths) between predicted (NIR′) and observed (NIR) India monsoon rainfall index; RMSE, root-mean-square error; BIAS, bias; and ABSE, absolute error (all in NIR × 100, so that 100 units correspond to 83 mm per year). Two asterisks indicate significance at the one percent level. Quenouille's (1952, p. 168) method was used to account for the reduction of the effective number of degrees of freedom due to persistency.

Model	Regression MCC	Prediction CORR	RMSE	BIAS	ABSE
		a. Fixed			
20 yr	1939–58	1959–83			
L, DPT	+79	+74**	76	−8	69
L, DPT, W	+81	+78**	70	−6	58
20 yr	1949–68	1969–83			
L, DPT	+71	+84**	65	−25	49
L, DPT, W	+73	+89**	57	−22	45
30 yr	1939–68	1969–83			
L, DPT	+75	+77**	64	−17	62
L, DPT, W	+77	+86**	57	−14	46
		b. Updated			
20 yr	1939–58 to 1963–82	1959–83			
L, DPT	+48 to +86	+76**	71	−11	56
L, DPT, W	+58 to +86	+70**	78	−13	63
20 yr	1949–68 to 1963–82	1969–83			
L, DPT	+69 to +86	+87**	59	−18	45
L, DPT, W	+71 to +86	+86**	60	−22	51
30 yr	1939–68 to 1953–82	1969–83			
L, DPT	+71 to +82	+83**	60	−17	47
L, DPT, W	+74 to +83	+87**	60	−13	46

distinctly smaller than in Shukla and Mooley's (1987) recent paper. Additional experiments with fixed regression base periods of 20 yr (1949–68) and 30 yr (1939–68), also summarized in Table 1, shed light on the causes of this apparent discrepancy. As Shukla and Mooley (1987) used regression base periods of 30 yr, regression models were here constructed from the first 30 yr of the record to predict the remaining later years 1969–83. Compared to the (L, DPT) the (L, DPT, W) model yields smaller RMSE, BIAS, and ABSE, while the explained variance is increased from 59% to 74%, significant at the 3.2 percent level (Burr, 1974, p. 384–385). Prediction performance of the 30-yr (1939–68) regression models for the years 1969–83, as measured by CORR, RMSE, BIAS, and ABSE, appears better than that of the 20-yr (1939–58) model for the 25 yr 1959–83. As the prediction periods differ for these two sets of experiments, a further comparison is desirable: 20-yr (1949–68) regression models were constructed to predict for the 1969–83 period. In terms of CORR, RMSE, and ABSE, the prediction performance appears superior to both the other 20-yr and 30-yr sets, although the negative BIAS is somewhat larger. Compared to the (L, DPT), the (L, DPT, W) model again yields smaller RMSE, BIAS, and ABSE, and an increase of explained variance from 71% to 79%, significant at the 6% level (Burr, 1974, p. 384–385). These comparisons between various regression base periods and various portions of the record reserved for prediction point to a better intrinsic predictability in the latter part of the 1939–83 record, rather than length of regression base period, as a major factor for the aforementioned apparent discrepancy between Shukla and Mooley's (1987) and the present results.

The prediction experiments from the fixed regression base periods summarized in Table 1a indicate a somewhat better performance of the (L, DPT, W) as compared to the (L, DPT) models. For the last 15 yr of the 1939–83 record, the 20-yr (L, DPT, W) model proved capable to explain as much as 79% of the observed rainfall variance. Most representative are, of course, the predictions for the latter 25 yr of the total record, based on the (L, DPT, W) model developed from the first 20-yr interval. A scatter plot of this experiment is shown in Fig. 3.

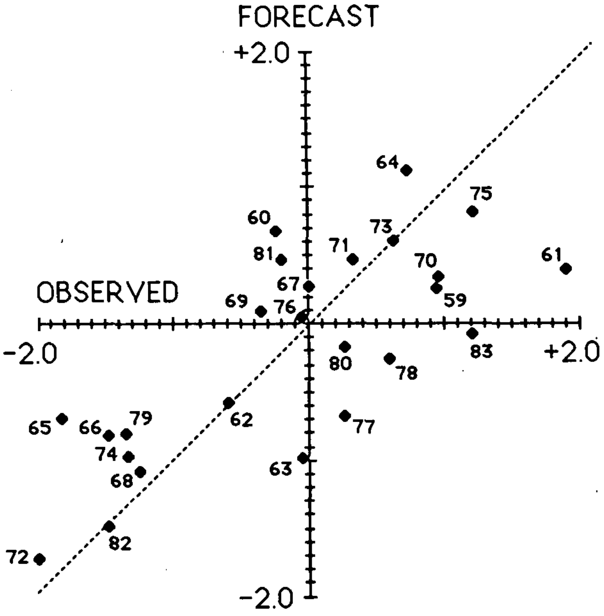

FIG. 3. Scatter diagram of forecast vs observed all-India summer monsoon rainfall index. Regression base period for (L, DPT, W) is 1939–58 and forecast period 1959–83. Numbers indicate the years and dotted line 45° angle. Correlation coefficient $r = +0.78$ is significant at the 1% level. Quenouille's (1952, p. 168) method was used to account for the reduction of the effective number of degrees of freedom due to persistence. The RMSE = 70, BIAS = −6, and ABSE = 58 (all in NIR × 100, so that 100 units correspond to 83 mm yr^{-1}).

6. Updating of base period

As discussed in the earlier paper (Hastenrath, 1987b), it has been conjectured that because of long-term changes in the large-scale circulation setting, the most recent portion of the dependent record may be most valuable for predictions into the independent time interval. This contention has been examined in two earlier papers (Hastenrath, 1987a,b), and is again considered here as follows.

Regression models were constructed with a base period of 20 yr but ending, successively, in 1958, 1959, . . . , 1982, to enable prediction for the 25 yr 1959, . . . , 1983. Results of these "updated" experiments are shown in Table 1b. The (L, DPT, W) model appears, if anything, inferior to the (L, DPT) model. Comparison with the 20-yr (1939–58) fixed models shows for (L, DPT, W) a deterioration in terms of CORR, RMSE, BIAS, and ABSE, and for (L, DPT) no substantial overall improvement.

Updating experiments were also conducted with regression base periods of 20 and 30 yr, to predict the last 15 yr (1969–83). In the two sets, (L, DPT, W) performs similar to or somewhat better than (L, DPT). On the whole, prediction performance for the last 15 yr 1969–83 is better than for the 25-yr period 1959–83, concordant with the experiment using fixed regression base periods.

In synthesis, the experiments summarized in Table 1b, do not support the notion that "updating" should necessarily improve forecast performance over that of "fixed" regression models, as found by Nicholls (1984) for Australia and conjectured by Kung and Sharif (1982) for India. This result is, however, consistent with two other recent studies (Hastenrath, 1987a,b). Most representative are the predictions for the latter 15 yr of the total record, based on the (L, DPT, W) model. A scatter plot of this experiment is shown in Fig. 4 for comparison with Fig. 3.

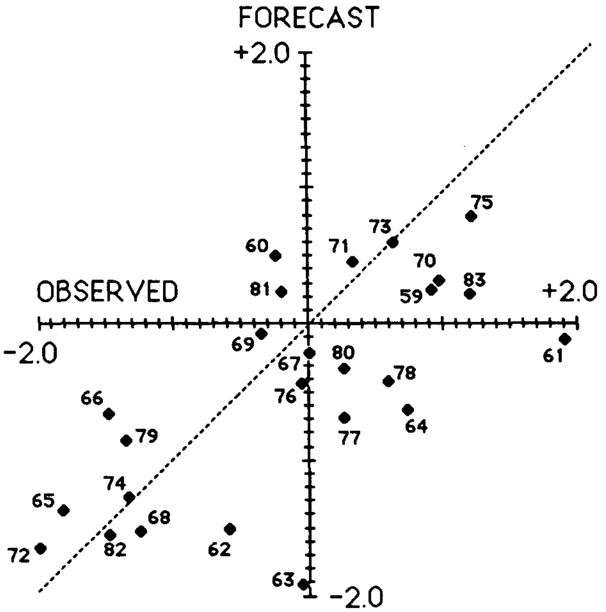

FIG. 4. Scatter diagram of forecast vs observed all-India summer monsoon rainfall index for the years 1959–83. The length of the regression base period is always 20 years, but forecasts are made from models (L, DPT, W) with regression base periods ending 1 year before the predicted year (e.g., the dependent record 1939–58 serves to predict 1959, . . . ; the record 1946–65 to predict 1966, etc.). Numbers indicate the years and dotted line 45 degree angle. Correlation coefficient $r = +0.70$ is significant at the 1% level. Quenouille's (1952, p. 168) method was used to account for the reduction of the effective number of degrees of freedom due to persistence. The RMSE = 78, BIAS = −13, ABSE = 63 (all in NIR × 100, so that 100 units correspond to 83 mm yr^{-1}).

7. Secular variations

Results discussed above with reference to Table 1 indicate a better predictability for the time span 1969–83 than for the 25-yr period 1959–83. Following is a limited investigation into the secular variations of precursor relationships (Ref. Table 2).

Correlations with NIR are high for L in the early and late portions of the 1939–83 record, and much lower in the middle two decades. For DPT, the correlation improves from the earlier to the later decades. For W, correlations are highest during 1961–80. Regarding correlations between predictors, W shares little variance with L throughout the record, and this makes it, in fact, a useful addition to the set of predictors. However W shows a remarkably strong correlation with DPT in the early and late portion of the record, and DPT has a sizable correlation with L during 1971–80. These secular changes of the relationships in the ensemble (NIR, L, DPT, W) are further reflected in the multiple correlation coefficient (MCC) of the (L, DPT) and (L, DPT, W) regression models. Thus, for both sets of models, MCCs are highest in the early and late portions of the record and lowest in the decades 1951–60 and 1961–70.

Comparing the 1959–83 and 1969–83 periods, the individual correlation coefficients of the three predictors with NIR, as well as the MCCs, are higher for the latter interval, consistent with the previous conjecture of better predictability for that time span. Similarly, the apparent higher performance suggested by the values reported in Shukla and Mooley (1987) must be understood in the context of the particularly high correlation of L with NIR in the very early and very late part of the 1939–83 record.

8. Conclusions

This investigation into the predictability of Indian monsoon rainfall anomalies deliberately simulated the practical reality of operational application, in devel-

TABLE 2. Correlation coefficients (in hundredths) between variables plotted in Fig. 2, for various time intervals during 1939–83. Code is as follows: NIR, all-India summer monsoon rainfall index; L, April latitude position of 500 mb ridge; DPT, Darwin pressure tendency (April minus February); W, May mean surface resultant wind speed in domain 0°–10°S, 45°–50°E. Quenouilles's (1952, p. 168) method was used to account for the reduction of the effective number of degrees of freedom due to persistence.

Model	1939–48	1941–50	1951–60	1961–70	1971–80	1974–83	1939–58	1958–83	1939–68	1969–83	1939–83
					(a) Correlations with NIR						
L	+87*	+84*	+68*	+52	+82	+47	+77*	+59*	+70*	+60*	+66**
DPT	−32	−10	−13	−60	−75	−67	−22	−64*	−39*	−71*	−51**
W	+42	+34	+24	+47	+37	+35	+35	+37	+31	+46	+35*
					(b) Correlations between predictors						
L, DPT	−9	+10	+6	−01	−58	+17	−5	−10	−14	−06	−13
L, W	+27	+24	+35	+25	+5	−25	−29	+6	+26	−10	+26
DPT, W	−51	−50	+11	−24	−55	−60	−6	−41*	−01	−64*	−25
					(c) Multiple correlation coefficients with NIR						
L, DPT	+91	+86	+70	+79	+88	+90	+79	+83	+75	+91	+79
L, DPT, W	+91	+87	+70	+82	+89	+90	+81	+83	+77	+91	+81

* Significance at 5% level.
** Significance at 1% level.

oping regression models from the earlier portion of the available record to conduct prediction experiments on the latter 25 years of the 1939–83 period. Of the three predictors used, the April 500 mb ridge latitude (L) highlights the preseason upper air circulation over India; the May surface resultant wind speed—in a strategic location over the western equatorial Indian Ocean (W)—captures the development of the lower-tropospheric cross-equatorial flow; and the Darwin pressure tendency (DPT) represents the Southern Oscillation. Forecast performance on the independent portion of the record, in terms of explained variance, RMSE, BIAS, and ABSE, serves as a sole yardstick in method appraisal. To this end, the optimal model constraint was explored on empirical grounds. A regression base period of about 2 decades was found adequate, in confirmation of earlier work. "Updating" is not necessarily preferable to a fixed regression base period. Predictability varied in the course of the 45-yr interval, being best in the early and late portions of the record. Over a time span of one-quarter century, more than 60% of the interannual rainfall variance could be predicted from antecedent departures in the large-scale circulation and, for the better-behaved last 15 yr of the record, this share was nearly 80%. This overall encouraging state of affairs does not preclude forecast failures for individual years. As all pertinent observations are not yet available, it remains to be seen how well the method would have performed for the most severe, 1987, drought year in India.

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