Relationships Between Sea Surface Temperature and Wind Speed Over the Central Arabian Sea, and Monsoon Rainfall Over India

J. SHUKLA AND B. M. MISRA

Massachusetts Institute of Technology, Cambridge 02139

(Manuscript received 29 December 1976, in revised form 12 May 1977)

ABSTRACT

Sixty years (1901–60) of mean monthly sea surface temperature (SST) and surface wind speed observations over the central Arabian Sea have been correlated with the observed mean monthly rainfall over India during the peak monsoon months of July and August. It is found that correlation coefficients between SST during July and rainfall over central and western India during August are positive and significant. Correlation coefficients between surface wind speed during July and rainfall during July are also found to be positive, but correlation coefficients between surface wind speed during July and rainfall during August are either negative or insignificant. Spatial homogeneity and statistical significance of correlation coefficients lends support to the hypothesis of a possible relationship between SST over central Arabian Sea and rainfall over central and western India.

Although we do not know the time scales of interaction between the Arabian Sea and the Indian monsoon, the observations suggest that SST during July may be a useful parameter to estimate monsoon rainfall during August.

1. Introduction

Air-sea interaction over the Arabian Sea is considered to be one of the important factors in explaining the fluctuations in the intensity of the monsoon circulation and the associated rate of precipitation over India (Saha, 1974; Pisharoty, 1965; Saha and Bavadekar, 1973). Since a substantial fraction of the moisture, precipitating as monsoon rainfall, comes from the Arabian Sea, it is reasonable to expect that the sea surface temperature (SST) and wind anomalies over the Arabian Sea would have pronounced effects on the monsoon rainfall over India. Ellis (1952) showed that the floods of 1920 and the droughts of 1933 over a large portion of India were well correlated with the anomalies in the sea surface temperature over the Arabian Sea. In a numerical experiment with a GFDL model, Shukla (1975) has shown that a colder temperature anomaly over the Arabian Sea may drastically reduce the rainfall over India and surroundings.

Due to the lack of a long time series of SST and wind data over the Arabian Sea, the ideas mentioned above could not be verified from the observed data. Recently, Fieux and Stommel (1976) examined 60 years of mean monthly SST and wind data along the most frequent ship tracks over the Indian Ocean. This, to our knowledge, is the longest available record of SST and wind data over the Arabian Sea.

The purpose of this paper is to use these data to examine the relationships among SST and wind speed over the central Arabian Sea and the monsoon rainfall over India. The basic approach in this study is the straightforward calculation of correlation coefficients between SST and rainfall, wind speed and rainfall, and SST and wind speed.

Since data are available only as monthly means we cannot examine lag correlations for less than a month. This precludes the possibility of detecting the effects for which the time scale is less than a month. Since the monsoon-onset months of May and June and the monsoon-withdrawal month of September exhibit rapid changes during the month itself, it may not be justified to consider monthly averages for these months. We have, therefore, presented the results for the months of July and August only. During these two months the monsoon activity is at its peak and the behavior of the large-scale monsoon is also quasi-steady.

2. Data

The basic data set used in this study consists of 1) mean monthly values of SST and surface wind speed for the years 1901–60[1] over the central Arabian Sea; and 2) mean monthly rainfall over 29 subdivisions of India shown in Fig. 1 for the years 1901–60.

Assuming that the values of SST for one year are independent of the other year, the gaps in the time series were simply ignored. Similarly, the rainfall and

[1] The data for the SST and wind speed are not available for the years 1917–18 and 1940–45.

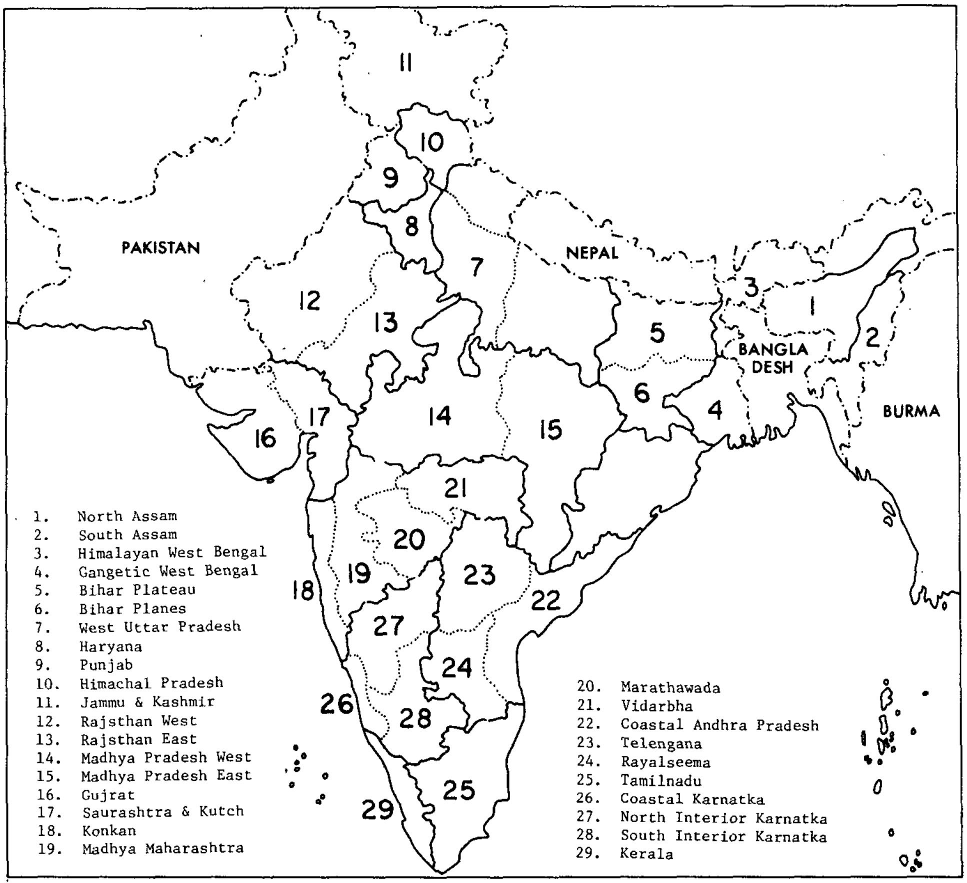

Fig. 1. Names and locations of Indian subdivisions.

the wind speed data for the corresponding years were also ignored. The final time series therefore consisted of 52 data points. The area over which the SST and the wind speed are averaged is shown (hatched) in Fig. 2. This area lies between 60 and 70°E and its latitudinal width is about 2°, centered along 10°N. Since this area has one of the most frequent ship routes, the frequency of observations was maximum and therefore reliable monthly means could be estimated by averaging the available observations. From the National Oceanographic Data Center tapes, the values of SST and wind speed were extracted by Fieux and Stommel (1976) for individual 1° squares and then averaged to get a mean value for the region under consideration. Fieux and Stommel (1976) have also examined the space-time structure of the SST anomalies obtained by calculating the departure from the time mean. They have concluded that the anomalies are physically real because they are spatially continuous and temporally persistent.

The mean monthly values of rainfall over India were provided by the India Meteorological Department. Since the rainfall over India is not spatially homogeneous, we have separately examined the rainfall of 29 subdivisions of India (Fig. 1). The rainfall data for eastern Uttar Pradesh and Orissa were not available.

3. Results

Table 1 gives the values of correlation coefficients between SST and wind speed over the central Arabian Sea during the same month and also for a lag of one month. The results show that the SST for the two consecutive months are strongly correlated with each other and the wind speeds are not. This also reflects in the results presented in Fig. 2 where the values of correlation coefficients between the wind speed of one month and the rainfall of the following month for a subdivision are generally small and insignificant.

Correlations between SST and surface winds are always negative which suggests that high wind speeds are related with low SST over the Arabian Sea. Stronger winds may cause increased evaporation, increased upwelling and increased spreading of coastal cold waters, resulting in colder SST over the Arabian Sea.

For a sample size of 50, correlation coefficients of 0.23, 0.273 and 0.354 are significant at the 90, 95 and 99% level of confidence. All the subdivisions in

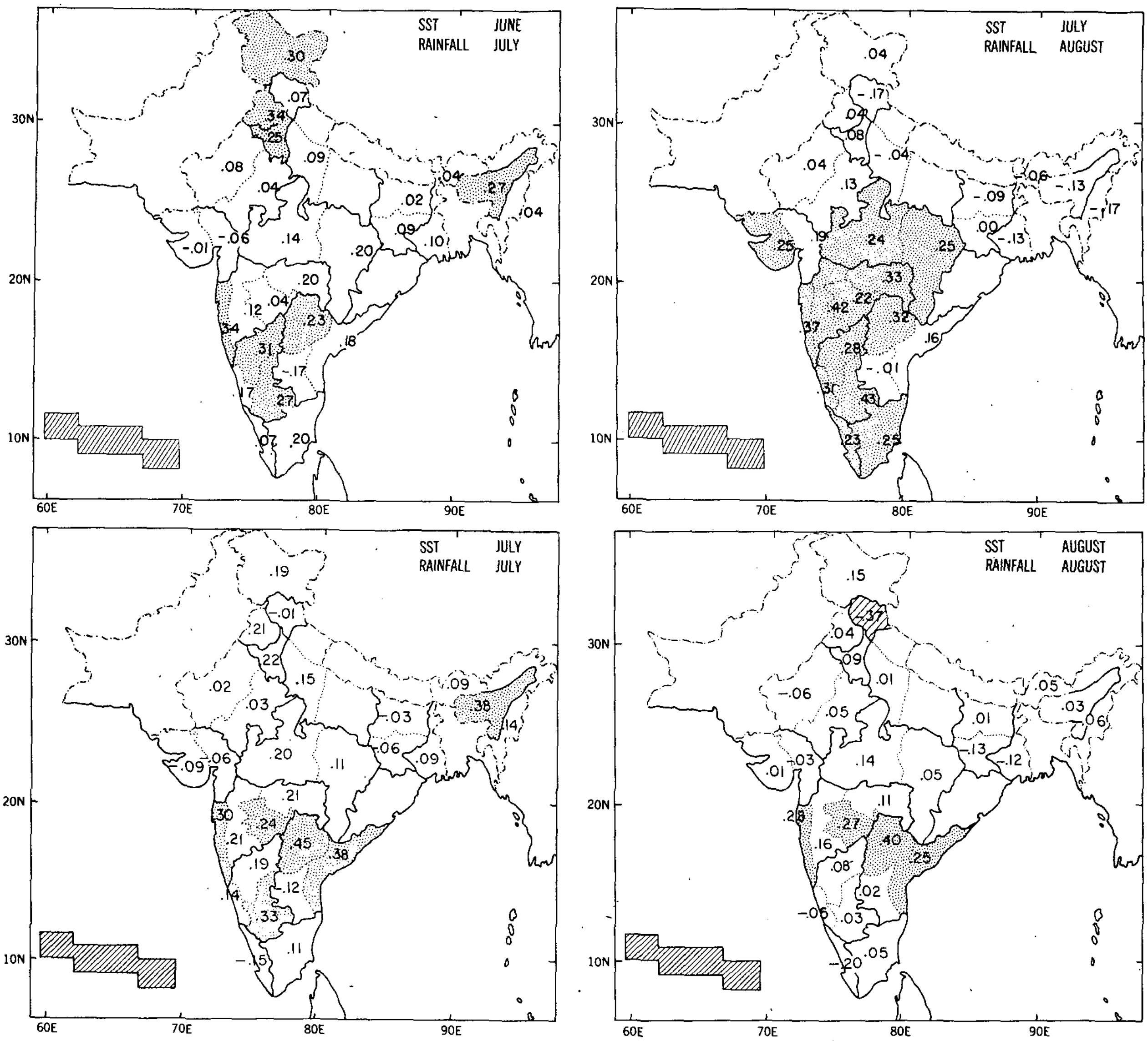

FIG. 2. Correlation coefficients between SST (averaged over the hatched area in the Arabian Sea) and rainfall over Indian subdivisions.

Figs. 2 and 3, for which correlation coefficients ⩾0.23 have been shaded in order to show the continuity of significant correlations.

Table 1 also shows that the correlation coefficients between SST and rainfall are generally positive and significant, whereas those between wind speed and rainfall are positive during the same month but negative for one month lag. These results tend to suggest that the stronger winds during June or July cool the surface, and that colder SST persists for

TABLE 1. Correlation coefficients between surface winds and SST over the Arabian Sea and mean rainfall over India.

	SST/SST	Wind speed/ Wind speed	Wind speed/ SST	SST/Rainfall	Wind speed/ Rainfall
June/July	0.54	0.11	−0.11	0.35	−0.20
July/July			−0.26	0.31	0.30
July/August	0.47	0.05	−0.29	0.30	−0.14
August/August			−0.09	−0.01	0.22

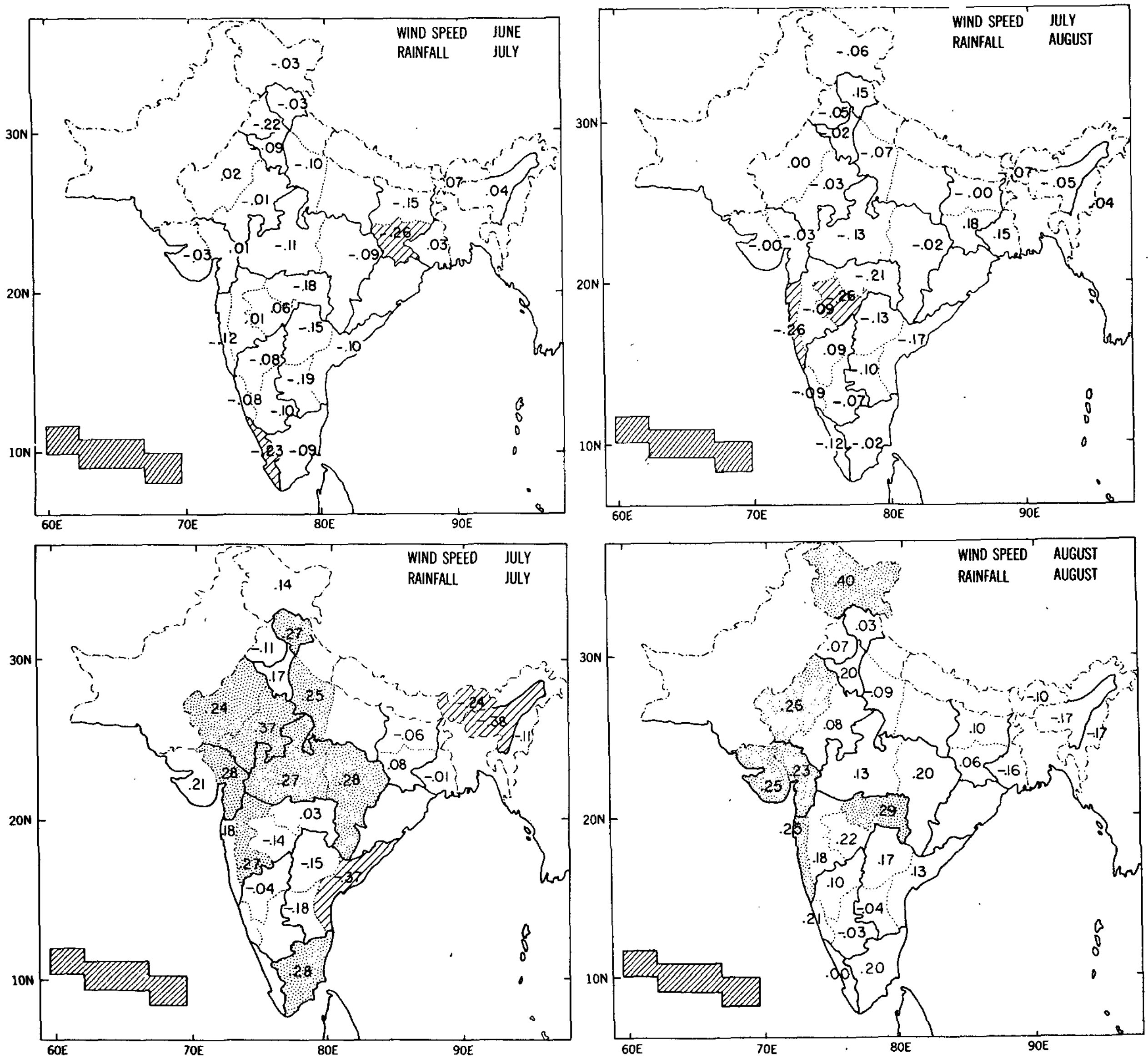

FIG. 3. Correlation coefficients between wind speed (averaged over the hatched area in the Arabian Sea) and rainfall over Indian subdivisions.

more than a month and contributes to reduction in the monsoon rainfall for the next month.

Fig. 2 shows the values of correlation coefficients between rainfall over 29 subdivisions and SST over the Arabian Sea for the same month and also for one-month lag. Fig. 3 shows similar maps for correlations between the rainfall and surface wind speed. From the magnitudes and the distribution of the correlation coefficients, the following conclusions may be drawn:

1) Although there is a large spatial inhomogeneity in the distribution of Indian rainfall, the western and the central parts of India show a positive significant relationship with SST over the central Arabian Sea. This result is not unreasonable because the Western Ghats of India are the first to bear the onslaught of the moisture-laden monsoon current.

2) Largest positive and significant correlations are found between the SST during July and the monsoon rainfall during August. In general, the correlation coefficients between SST and rainfall during the same month are not as large and homogeneous as that between the SST of one month and the rainfall of the next month.

3) Correlation coefficients between wind speed and rainfall during the same month are generally positive, but the correlation coefficients between the wind speed for one month and the rainfall for the following month are generally negative.

Since the correlation coefficients between SST and wind speed over the Arabian Sea are negative, the aforesaid consistency in the distribution of correlation coefficients provides additional evidence for the physical reality of SST and wind anomalies. Stronger winds over the Arabian Sea, which are positively correlated with a larger rainfall over India, tend to reduce the SST over the Arabian Sea which, in turn, tends to reduce the rainfall over India. We are not able to delineate the exact time scale at which these mechanisms operate because our data are only in the units of monthly means. It seems quite likely, however, that the joint effects of SST and the surface wind provide a negative feedback mechanism to influence the rainfall over India and the adjoining areas. The time scale of this interaction seems to be about a month or less.

It should, however, be pointed out that the magnitude of the correlation coefficients is not very large and they explain only a small fraction of the total variance. This hypothesis, therefore, should be tested on a large independent sample in the future. SST over other parts of the Arabian Sea should also be correlated with rainfall over India. It is not unlikely that the one-month lag between SST and rainfall is, in part, due to the location of the area over which SST is being considered. For example, correlations between SST over an area adjacent to the west coast and rainfall over the west coast may be found to be large and positive even during the same month.

4. Conclusions

The purpose of this paper was to examine the relationships between the SST and the surface wind speed over the central Arabian Sea and the monsoon rainfall over India. We had a unique data set which consisted of 60 years of mean monthly observed SST and wind speed over the Arabian Sea. We computed the correlation coefficients using the observed time series of SST, wind speed and rainfall. Rainfall over the western and the central parts of India was found to be positively correlated with SST over the central Arabian Sea. Correlation coefficients between the SST of one month and the rainfall of the following month were larger than the correlation coefficients between the SST and the rainfall of the same month. This suggests the possibility of using SST as a predictor parameter in connection with the monthly forecasting of the monsoon rainfall. Correlation coefficients between SST and wind speed over the central Arabian Sea were found to be negative. Although the simultaneous correlation coefficients between the wind speed over the Arabian Sea and the rainfall over several subdivisions of India were found to be positive and significant, the lag relationships were very poor.

Finally it may be noted that the results of this observational study have verified *a posteriori* the results of a numerical experiment by Shukla (1975) in which it was suggested that colder SST anomalies over the western Arabian Sea tend to reduce monsoon rainfall over India. The deficiency of the general circulation model used for this numerical experiment, in simulating the monsoon rainfall over Northern India, did not affect the results of the experiment, perhaps because the areas of significant correlation are found to be over western and central parts of India. It is hoped that continuous monitoring of the SST over the Arabian Sea, which may be done by satellite observations, would provide an additional tool to predict fluctuations of monsoon rainfall.

Acknowledgments. We are extremely grateful to Prof. H. Stommel for his encouragement and constructive suggestions during this study. We are thankful to Michele Fieux for providing the SST and wind data and to the India Meteorological Department for providing the rainfall data.

This research was partly supported by National Science Foundation under Contract NSF-DES, 74-19782.

REFERENCES

Ellis, R. S., 1952: A preliminary study of a relation between surface temperature of the north Indian Ocean and precipitation over India. M.S. thesis, Dept. of Meteorology, Florida State University.

Fieux, M., and H. Stommel, 1976: Historical sea-surface temperature in the Arabian Sea. *Ann. Inst. Oceanogr. Paris,* **52**, 5–15.

Pisharoty, P. R., 1965: Evaporation from the Arabian Sea and the Indian Southwest Monsoon. *Proc. Int. Indian Ocean Expedition*, P. R. Pisharoty, Ed., 43–54.

Saha, K. R., 1974: Some aspects of the Arabian Sea summer monsoon. *Tellus*, **26**, 464–476.

——, and S. N. Bavadekar, 1973: Water vapour budget and precipitation over the Arabian Sea during the northern summer. *Quart. J. Roy. Meteor. Soc.*, **99**, 273–278.

Shukla, J., 1975: Effect of Arabian Sea surface temperature anomaly on Indian summer monsoon: A numerical experiment with the GFDL model. *J. Atmos. Sci.*, **32**, 503–511.