Interaction Between the West Arabian Sea and the Indian Monsoon

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ABSTRACT

Examination of the July 1964 sea surface temperatures in the west Arabian Sea shows that during the weak monsoon over India the sea surface experienced a significant drop in temperature over a larger area compared to a period of strong monsoon. Associated with weak and strong monsoons over India are large-scale pressure changes which occur almost over the entire monsoon region and these changes are not considered to be directly related to the sea surface temperature. The pressure change over India appears to have a controlling influence on the strength of the cross-equatorial flow in the west Arabian Sea.

1. Introduction

According to a numerical experiment by Shukla (1975) cold sea surface temperature (SST) over the west Arabian Sea leads to a drastic reduction of monsoon rainfall over India and the adjoining region because the cold sea decreases the evaporation rate and increases the surface pressure leading to a reduction in the cross-equatorial flow and moisture flux downstream. Recently, Krishnamurti *et al.* (1976) conducted a numerical experiment and found that the cross-equatorial flow in the west Arabian Sea intensifies to the Somali jet as a result of the strengthening of the monsoon over India. This may imply that to explain the transition from a strong monsoon to a weak monsoon (reduced rainfall) over India, one has to look for factors other than the strength of the cross-equatorial flow in the west Arabian Sea.

Here we propose to discuss the results of a rather short observational study, but one based on the best set of observations recorded so far in the region.

2. Surface pressure and rainfall

In the middle of July 1964 during the International Indian Ocean Expedition there was a drastic reduction of rainfall in the central parts of India. Using isobaric charts extending from 25°E to 110°E and 0° to 30°N values of sea level pressure at 1200 GMT for the period 1 July 1964–15 August 1964 (46 days) were transcribed at 2.5° longitude intervals along latitudes 0°, 5°, 10°, 15°, 20°, 25° and 30°N. For each of these points the daily anomaly (departure) from its 46-day mean was determined. For the corresponding period the departures of daily rainfall for all the meterological subdivisions were computed from the daily subdivisional rainfall normals based on data ranging from 50 to 60 years. The daily rainfall is for a 24 h period ending at 0300 GMT of date. The regions of particular relevance to our study are indicated in Fig. 1.

Fig. 2 shows that on 11 July the pressure anomaly was negative over an extensive area east of about 40°E, excluding eastern India and Burma and also south Peninsular India and the adjoining Indian ocean where the anomaly was positive. Over most of eastern Africa the anomaly was positive. In the west Arabian Sea the positive anomaly was restricted to south of about 5°N. The monsoon was strong with above normal rainfall over a large area in India where the pressure anomaly was generally negative (Fig. 3). On the next

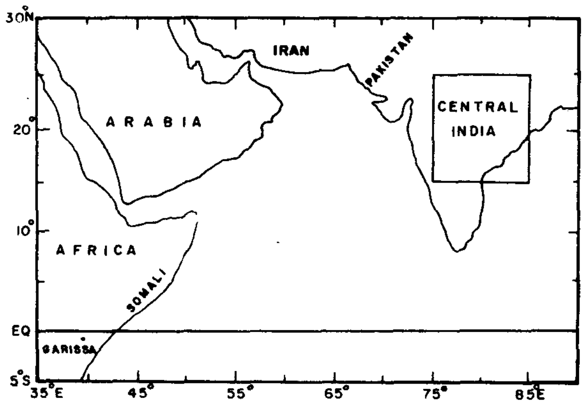

FIG. 1. Location map.

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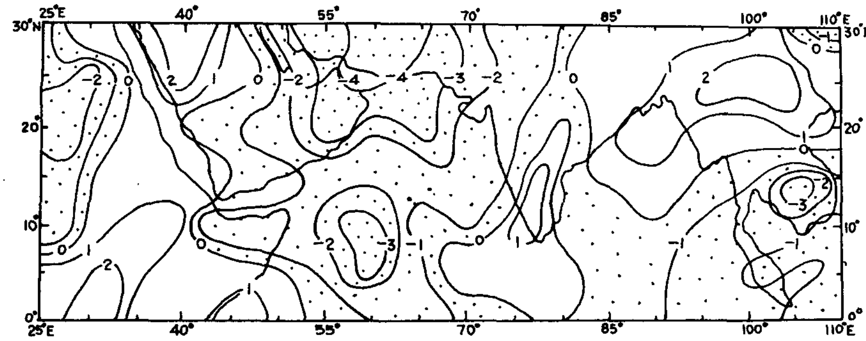

FIG. 2. Sea level pressure anomaly (mb) on 11 July 1964 at 1200 GMT.

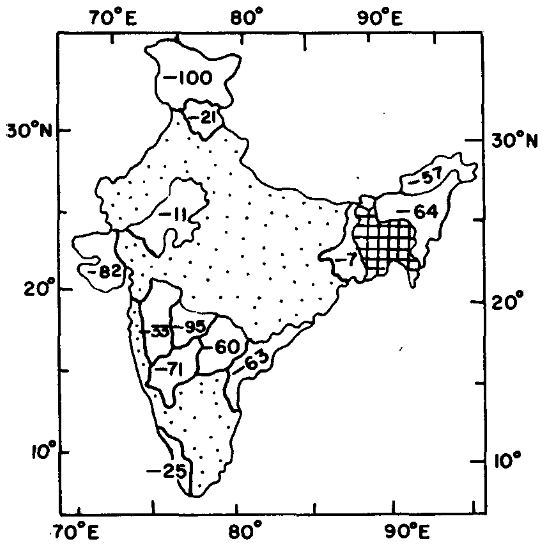

FIG. 3. Percentage departure of rainfall for the 24 h period ending at 0300 GMT 12 July 1964. Positive areas are stippled and negative areas refer to the meteorological subdivisions.

day the positive anomaly increased considerably over Africa. South of 5°N in the west Arabian Sea the positive area of the previous day changed to a negative one. At the same time north of 5°N, where the anomaly was negative, a positive area appeared (Fig. 4). The positive anomaly over eastern India intensified and extended westward covering practically the whole country. This day marked the onset of drought over central India and the adjoining area (Fig. 5).

On 13 July the positive anomaly over India further intensified to 3–5 mb and extended westward over a major portion of the Arabian sea (Fig. 6). The high pressure area over Africa weakened markedly. South of 5°N in the west Arabian Sea the negative anomaly of the previous day became positive. North of 5°N the positive anomaly changed to negative. These erratic variations of pressure in the west Arabian Sea ceased by 17 July (Fig. 7) when the entire Arabian Sea came within the zone of positive anomaly which had been steadily expanding westward from India after 11 July. The drought persisted over a wide area in India (Fig. 8).

Fig. 9 shows that by 21 July the positive anomaly zone extended further westward to Arabia and eastern Africa. The west Arabian Sea continued to be within this zone with a positive anomaly of about 2 mb. The drought continued to be intense (Fig. 10). On 22 July a negative anomaly appeared in the northernmost and southernmost parts of India. On 23 July the negative anomaly intensified over these two areas and extended to the central parts of India and also to the oceanic areas of the country (Fig. 11). A significant decrease

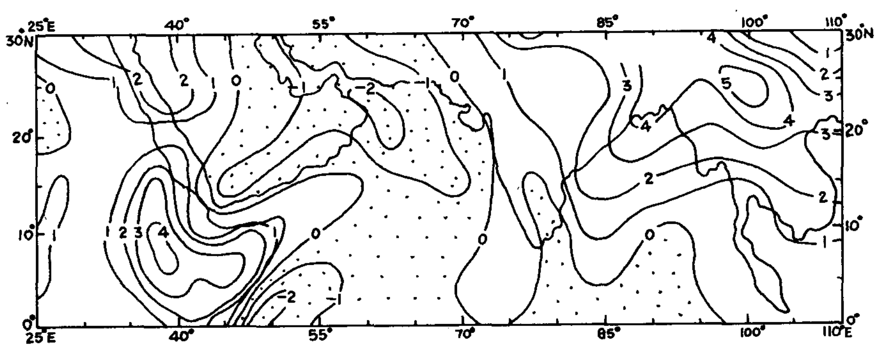

FIG. 4. As in Fig. 2 except at 1200 GMT 12 July 1964.

of pressure of 2–3 mb occurred over the region between 25 and 110°E. Over India, where the anomaly was negative, the monsoon revived and the drought ceased (Fig. 12).

These observations show that an organized high-pressure area developed over India in association with the onset of drought there. As the drought intensified, the positive pressure anomaly increased and progressively extended westward. By the time the drought reached its maximum intensity over India, the positive pressure anomaly pervaded the entire Arabian Sea and eastern Africa.

3. Sea surface temperature and surface pressure

From an examination of the July and August 1964 sea-surface temperature data it was found that the number of SST observations increase with distance from the African coast but their quality deteriorates seriously. Therefore, we have preferred to consider the temperature in the area west of 55°E. Since the daily observations were meager we made a composite chart and worked out the SST anomaly (departure from climatological normal) for the weak monsoon period over India from 12–22 July 1964 (Fig. 13). A similar chart was also prepared for the strong monsoon period 23–29 July 1964 (Fig. 14). The major difference in the SST during the weak and strong monsoons, as revealed by Figs. 13 and 14, is that during the weak monsoon the

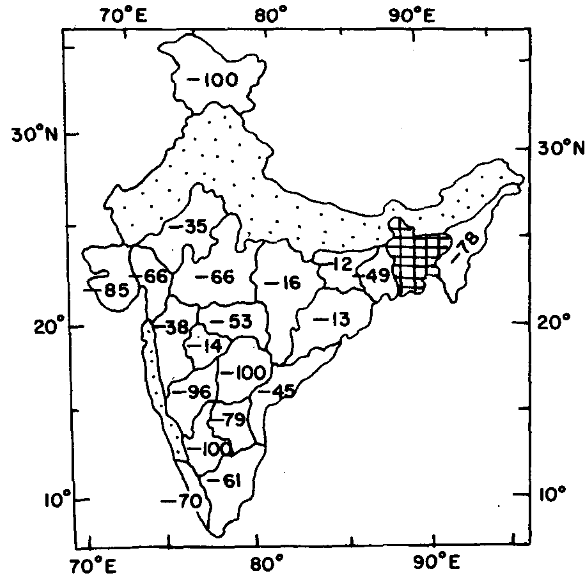

FIG. 5. As in Fig. 3 except for 0300 GMT 13 July 1964.

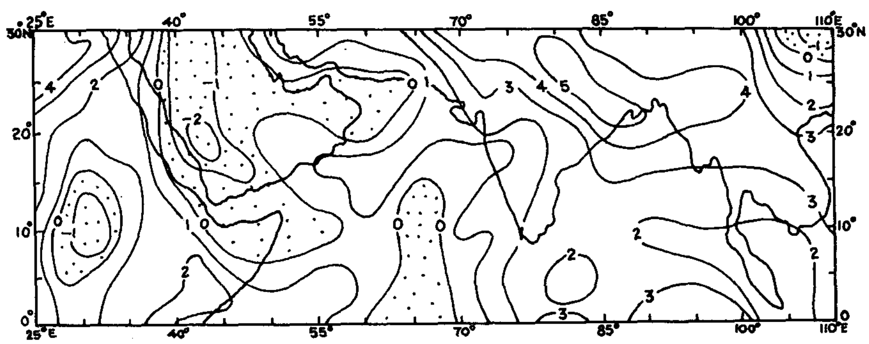

FIG. 6. As in Fig. 2 except at 1200 GMT 13 July 1964.

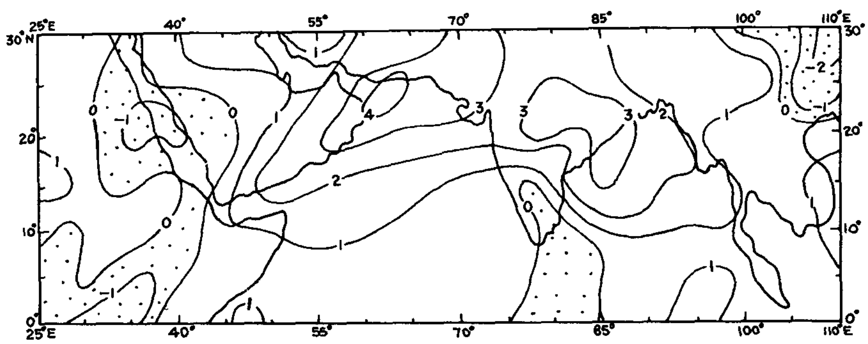

FIG. 7. As in Fig. 2 except at 1200 GMT 17 July 1964.

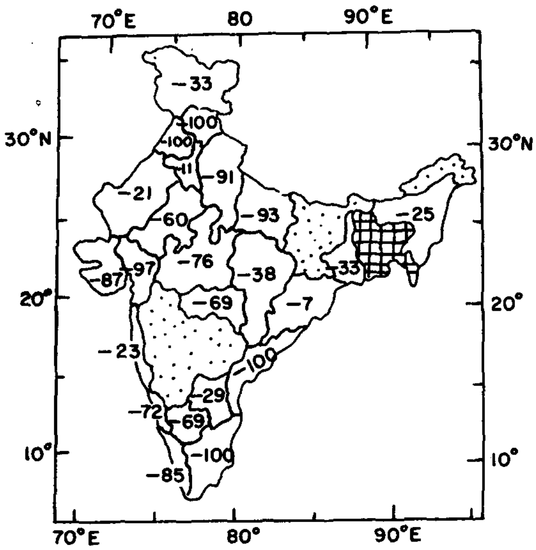

FIG. 8. As in Fig. 3 except for 0300 GMT 18 July 1964.

TABLE 1. Correlation coefficients between Garissa wind speed and central India pressure.

Sample size	Correlation coefficient	Central India pressure advanced or lagged (days)	Level of significance 5%	1%
26	−0.40	advanced 5	0.3893	0.4969
27	−0.53	advanced 4	0.3809	0.4869
28	−0.62	advanced 3	0.3746	0.4793
29	−0.64	advanced 2	0.3683	0.4717
30	−0.62	advanced 1	0.3620	0.4641
31	−0.54	not lagged 0	0.3557	0.4565
30	−0.50	lagged 1	0.3620	0.4641
29	−0.38	lagged 2	0.3683	0.4717
28	−0.27	lagged 3	0.3746	0.4793
27	−0.19	lagged 4	0.3809	0.4869
26	−0.14	lagged 5	0.3893	0.4969

surface of the sea was colder by 2–3°C over an appreciably larger area.

In the absence of a satisfactory series of daily SST observations it has not been possible to determine whether this remarkable decrease of SST is a phenomenon occurring simultaneously with the Indian drought or developing a couple of days prior to the drought. However, we have noticed that from the beginning of the drought there was no organized increase of pressure in the west Arabian Sea as would be expected for a cold sea. The pressure in the west Arabian Sea remained unchanged until a high pressure belt progressively approached the sea from the Indian region where the drought by then had nearly reached its maximum intensity. Drought as well as monsoon revival were associated with a significant pressure change over practically the entire monsoon region. Such large-scale pressure changes probably vitiate the influence of sea-surface temperature on surface pressure.

4. Cross-equatorial flow and monsoon

During the Indian monsoon the southeast trades cross the equator between 40°E and 100°E. The trades attain their maximum speed on crossing the equator between about 40°E and 55°E. North of the equator in the monsoon system they become westerlies. Strengthening of the westerlies over India, it may be pointed out, is generally associated with an increase of rainfall and therefore the term *strong monsoon* denotes either wind or rainfall or both. Here we propose to examine the relation between the strength of the cross-equatorial flow and the strength of the Indian monsoon.

Garissa (Fig. 1) in Kenya is considered to be an appropriate station to study the cross-equatorial flow since the trades here are remarkably uniform. Since this is a pibal station we are able to obtain a satisfactory series of wind observations in the monsoon season. During the last decade July 1973 was the month when both the 0400 and 1000 GMT wind

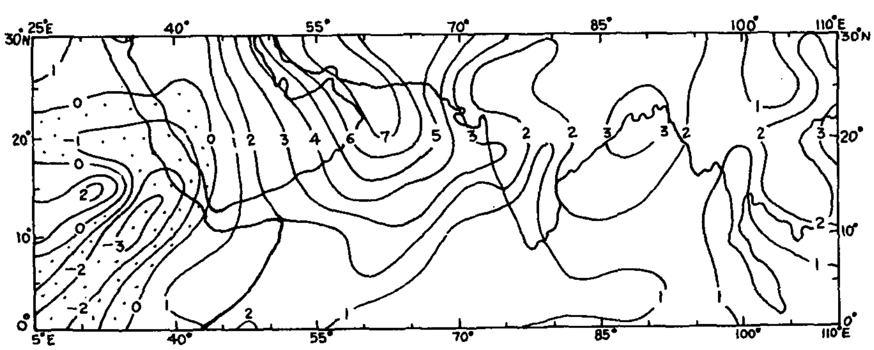

FIG. 9. As in Fig. 2 except at 1200 GMT 21 July 1964.

observations at 0.9, 1.2 and 1.5 km were a maximum. These have been averaged for both hours and correlated with the 1200 GMT average surface pressure over central India. The correlations in Table 1 indicate that a decrease (increase) of central India pressure is followed by an increase (decrease) of Garissa wind within a day or two. The pressure changes in the monsoon system are large-scaled and nearly synoptic and it is probable that most of the monsoon system winds respond to the pressure change in a day or two.

5. Summary and concluding remarks

During the Indian drought of July 1964 the west Arabian Sea was cold over a larger area compared to a wet spell in the same month. Until a high-pressure belt approached from India during the drought, there was no organized high-pressure zone in the west Arabian Sea as would be expected as a result of the low temperature there.

Associated with the strengthening and weakening of the Indian monsoon are pressure changes on a synoptic scale. They are so large that Garissa winds, and presumably most of the monsoon system winds, respond to the Indian pressure change in a day or two. This tempts us to believe that the strength of the Indian monsoon does not depend on the strength of the cross-equatorial flow, which according to Findlater (1969) has a controlling influence on the monsoon.

This has some special significance to the low-level winds over eastern Africa. As the pressure decreases in association with the strengthening of the Indian monsoon, the monsoon westerlies over Africa may strengthen. Strengthening of the westerlies over Africa is favorable, according to Raghavan and Sikka (1977), for the intensification of the seasonal trough of low pressure in the lee of the African barrier leading to an explosive drift of air across the equator. This may explain how the strengthening of the Indian monsoon causes the development of the Somali jet.

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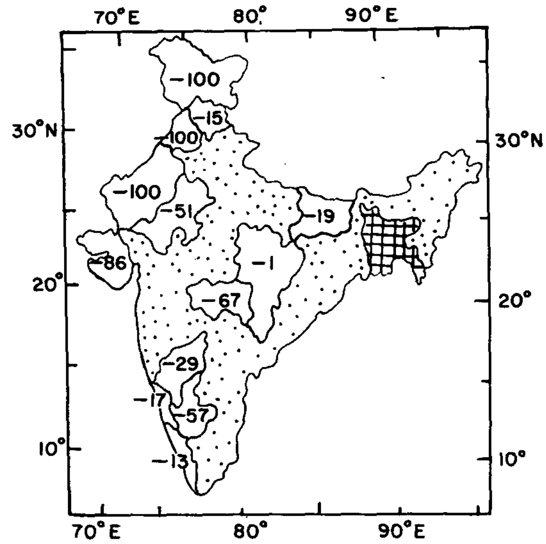

Fig. 12. As in Fig. 3 except for 0300 GMT 24 July 1964.

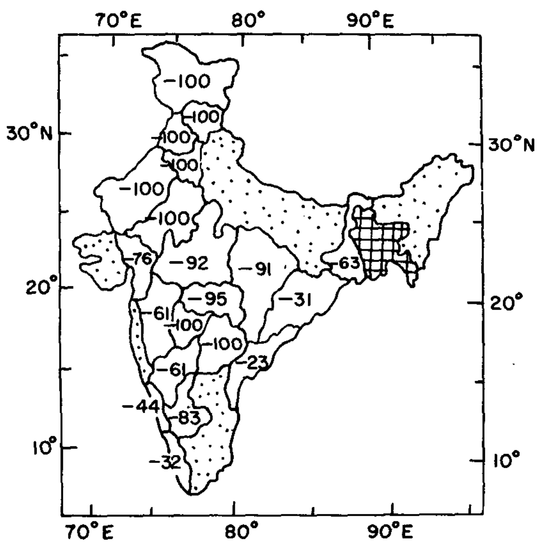

Fig. 10. As in Fig. 3 except for 0300 GMT 23 July 1964.

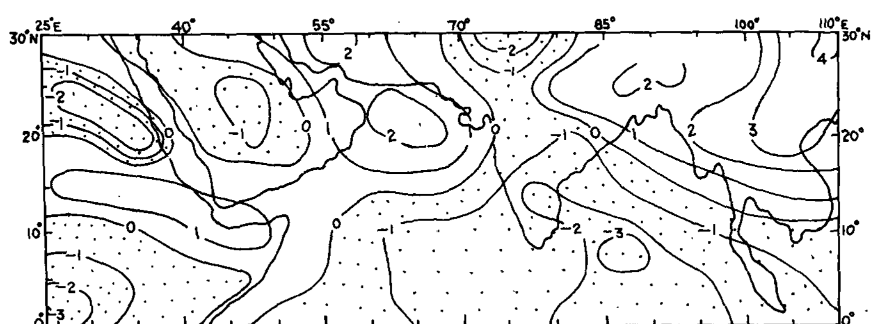

Fig. 11. As in Fig. 2 except at 1200 GMT 23 July 1964.

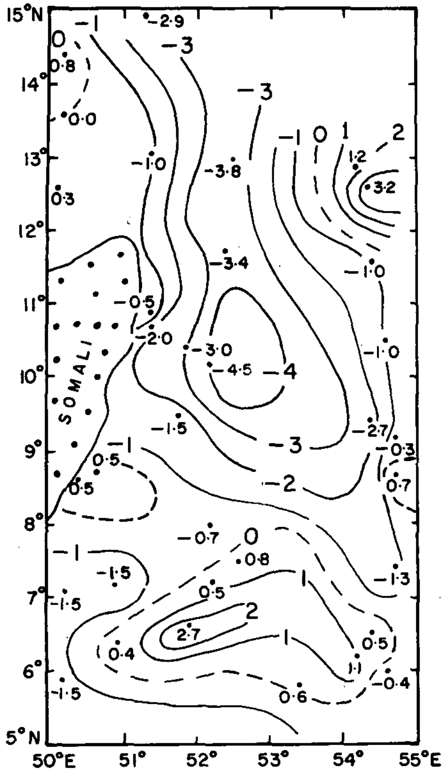

FIG. 13. Sea surface temperature anomaly (°C) for the weak monsoon period 12–22 July 1964.

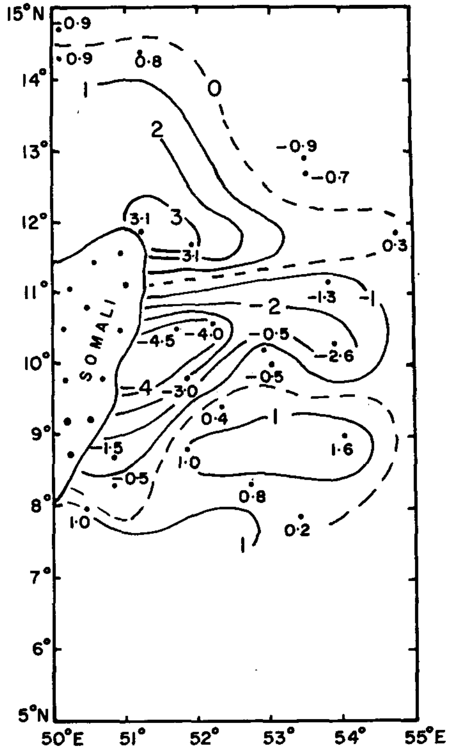

FIG. 14. As in Fig. 13 except for the strong monsoon period 23–29 July 1964.

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