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## Evaporation over the Arabian Sea During Two Contrasting Monsoons

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With 10 Figures

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### Summary

Monthly mean surface fields of different meteorological parameters and evaporation are studied for the 1979 (poor monsoon) and 1983 (good monsoon) monsoon seasons over the Arabian Sea, in order to understand the role of evaporation on the Indian monsoon rainfall. It is noticed that in general, the sea surface temperatures are higher in 1983 throughout the monsoon season than in 1979 in the Arabian Sea excepting western region. The mean rates of evaporation on a seasonal scale are found to be equal in both years ( $3.66 \times 10^{10}$  and  $3.59 \times 10^{10}$  tons/day in 1979 and 1983, respectively). No coherence is observed between the evaporation and the west coast rainfall within a season. It is also noted that the pressure distribution over the Arabian Sea is even important to advect the moisture towards the west coast of India, through winds.

### 1. Introduction

The summer monsoon is one of the most outstanding features of the Indian subcontinent. Even though the broad scale features of the monsoon circulation are repetitive from year to year, the total monsoon problem, comprising the year to year fluctuations and vagaries in the onset of the monsoon as well as space time variations in the monsoon activity and rainfall, is very complex and demands intensive study and research (Ananthakrishnan et al., 1979). The different phases of monsoon like Onset, Advance, Withdrawal and Break in monsoon conditions also exhibit large interannual variations.

Numerous investigators (Saha, 1974; Shukla,

1975; Washington et al., 1977; Shukla and Misra, 1977; Rao et al., 1981; Druyan, 1983 a; Druyan et al., 1983 b; Cadet and Diehl, 1984; Ramesh Babu et al., 1985; Joseph and Pillai, 1986; Ramesh Kumar et al., 1986; Sadhuram and Ramesh Kumar, 1988; Rao and Goswami, 1988) have studied the role of Arabian Sea (AS) with the Indian summer monsoon. Shukla (1975) simulated the influence of a sea surface temperature (SST) on the AS with a global primitive equation numerical model. His main conclusions were that the effect of the cold SST anomaly would reduce evaporation over the AS, increase the sea level pressure downwind of the anomaly and reduce precipitation over India. Washington et al. (1977) used the same cold SST anomaly, but used different internal parameterizations and concluded that the SST anomalies have only local effects and they do not have much influence on the monsoon rainfall over India. Druyan (1983 a) using a seven layer, coarse mesh primitive equation climate model, and making SST sensitive to the atmospheric forcing (Druyan et al., 1983 b) found that the increase in precipitation over India can be attributed to the release of moisture obtained upwind by the SST anomaly. In an earlier study (Ramesh Kumar et al., 1986) we have looked into SST variability over the Indian Ocean and its relation with Indian summer monsoon from a predictive point of view utilizing satellite derived SST data. Our results

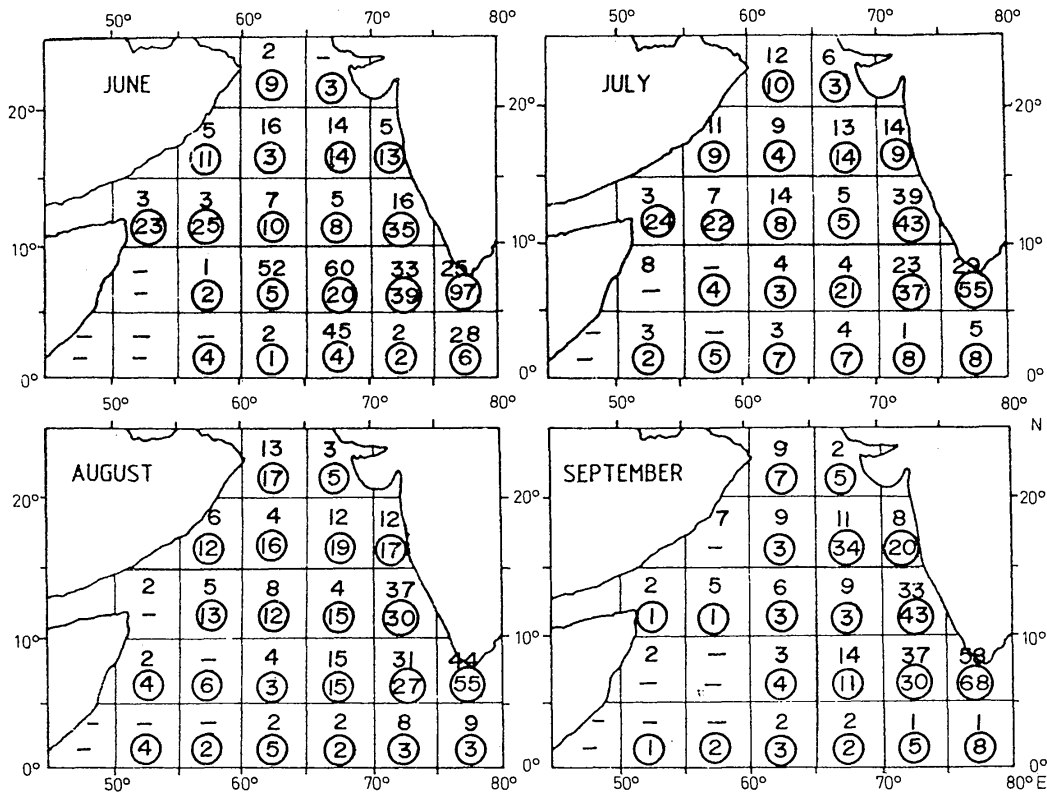


Fig. 1. Density of observations used in the present study

showed that the zonal anomaly of SST off Somalia Coast and Central Indian Ocean were negatively and positively (both significantly) correlated with the monsoon rainfall over the western and central parts of India. Rao and Goswami (1988), based on 80 years data set (1900–1979) have shown that the premonsoon SST anomalies in the southern and western AS have predictive value for forecasting monsoon rainfall. Most of these studies presumed that the higher SSTs lead to higher rates of evaporation which in turn can contribute to a good monsoon rainfall. Joseph and Pillai (1986) indicated that the difference in the rates of evaporation between a weak and an active monsoon period is marginal on a seasonal scale. No such detailed study is available within a season to understand the possible role of evaporation in Indian summer monsoon rainfall. Keeping this in view, we have made an attempt to examine the variability in the surface fields which influence the evaporation over the Arabian Sea during two contrasting monsoon seasons.

## 2. Monsoon Activity

The years 1979 and 1983 were chosen for the present study because of their contrasting monsoon activities. 1979 was a poor monsoon year with most of the meteorological subdivision over the country experiencing deficient rainfall. The onset was delayed by about 2 weeks. This season also had a largest break of about three weeks duration. In contrast, the year 1983 was an exceptionally good monsoon year with most of the meteorological subdivisions experiencing normal to excess rainfall. Another interesting feature is that there were no break monsoon conditions during 1983. In this year the onset was also delayed by about two weeks. In spite of the delay in onset and fewer depressions, the rainfall was well distributed over the entire country.

## 3. Data and Methodology

The data used for the present study were obtained from the Indian Daily Weather Reports published

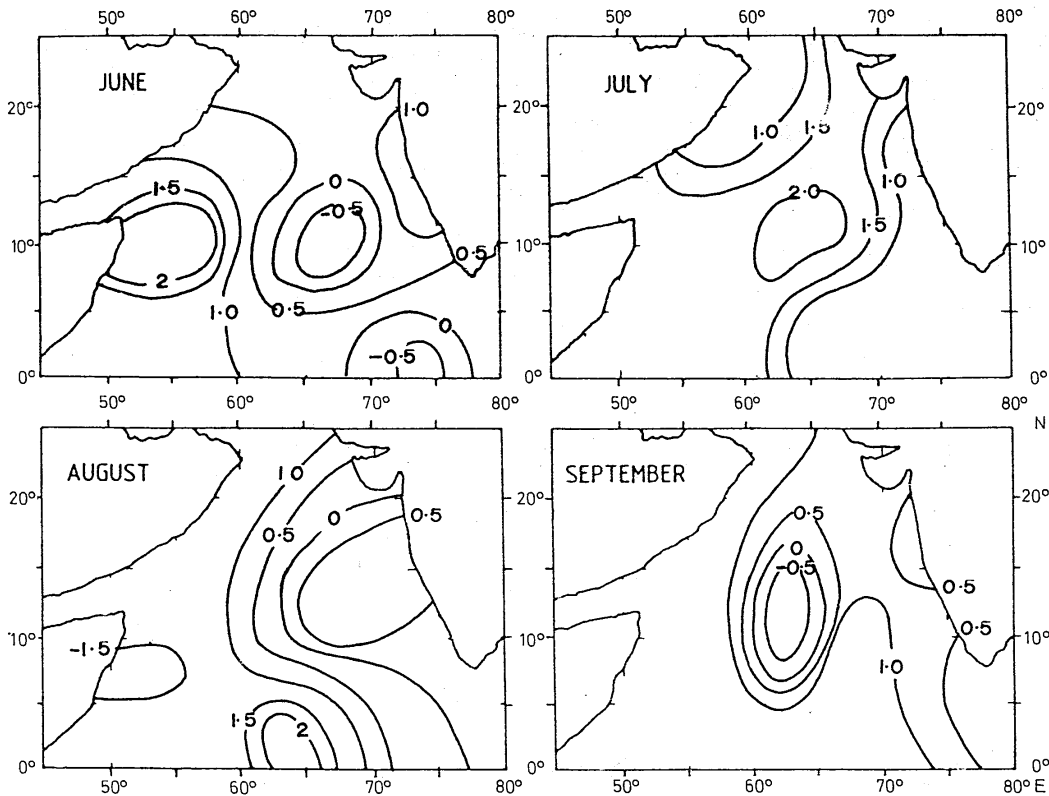


Fig. 2. Differences (1983–1979) in the mean distribution of sea surface temperature ( $^{\circ}\text{C}$ ) over the Arabian Sea during the monsoon season

by the India Meteorological Department. The present study utilises the data on sea surface temperature (SST), air temperature (AT), dew point temperature (DPT), total cloud amount (CL) and sea level pressure. The above parameters have been grouped into various  $5^{\circ} \times 5^{\circ}$  grid and the data density for the years 1979 (open) and 1983 (circled values) are shown in Fig. 1. In general, the data are well distributed over the entire Arabian Sea excepting the western and southern regions.

The rates of evaporation for the months June to September have been computed using the bulk aerodynamic formulae,

$$E = \rho C_e (e_s - e_a) U$$

where  $\rho$  – density of air ( $1.2 \text{ Kg m}^{-3}$ );  $e_s$  and  $e_a$  are the saturation vapour pressure at sea surface and vapour pressure at the deck level (obtained from the dewpoint temperature), respectively, and  $U$  the wind speed (m/sec) at the anemometer level. The exchange coefficient ( $C_e$ ) is taken to be  $1.4 \times 10^{-3}$  for wind speeds  $< 13 \text{ m/sec}$  and  $1.6 \times 10^{-3}$  for wind speeds  $> 16 \text{ m/sec}$  as suggested by Rao et al.

(1981) and was found consistent with those of Meyer and Rao (1985).

Since the rate of evaporation mainly depends upon wind speed and SST, the errors in the measurement of these parameters as well as the paucity of data create a problem to estimate evaporation rates accurately on a monthly time scale. For example, Rao and Goswami (1988) reported that intraseasonal synoptic systems affect SST in the Arabian Sea significantly. It may be mentioned here that no detailed information is available so far on the errors in estimating monthly mean heat fluxes over the north Indian Ocean. Recently, the authors have noticed that the estimates of latent heat flux obtained from the data collected on board of a research ship are 30–40% higher than those obtained from IDWR data (Sadhuram et al., 1988).

## 4. Results and Discussion

### 4.1 Sea Surface Temperature

Figure 2 gives the differences in the SST of 1983 to 1979 for the months June to September. The

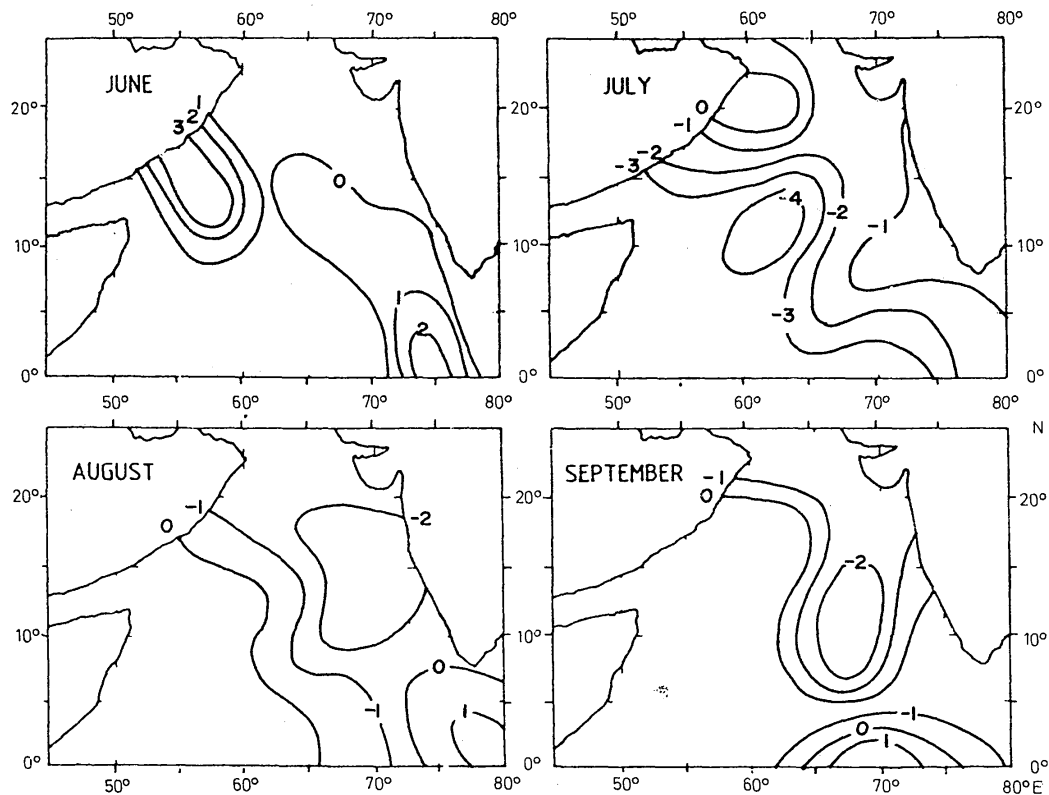


Fig. 3. Same as Fig. 2, but for sea level pressure (mb)

differences hereafter are referred to as anomalies. Figure 2 shows that the SST's were in general warmer over the western Arabian Sea during 1983 than in 1979 by about  $2^{\circ}\text{C}$  in the month of June. The central Arabian Sea exhibits a small positive anomaly. This positive anomaly over the western Arabian Sea shifts to the central and eastern Arabian Sea in July. By August, the SST's are lower in 1983 than in 1979 over the western Arabian Sea area which can be attributed to stronger upwelling in 1983 than in 1979. By September the central Arabian Sea exhibits a small negative anomaly. In general, one can expect higher SSTs in the western Arabian Sea during a poor monsoon season like 1979 because of the weaker upwelling along the Somalia coast associated with the weaker winds compared with the SST in 1983. This was already reported by Ramesh Kumar et al. (1986) from the satellite derived SST data.

#### 4.2 Sea Level Pressure

Figure 3 shows the sea level pressure difference between 1983 and 1979. Large positive anomalies were observed over the northwestern and south-

eastern Arabian Sea during the month of June. In the month of July, large negative anomalies were observed in the central Arabian Sea. By August, these anomalies weakened. They were strengthened and shifted towards eastern Arabian Sea by September.

#### 4.3 Air Temperature

Isopleths of difference in air temperature between 1983 and 1979 are presented in Fig. 4. Positive anomalies were present throughout the season from June to September. Maximum anomalies occurred in the northwest and southeast regions of the Arabian Sea during the month of August.

#### 4.4 Wind Speed

Figure 5 depicts the difference in wind speed between 1983 and 1979. In the month of June, winds are found to be stronger in 1979 than in 1983 while in July the same trend is seen only over the central Arabian Sea. This picture undergoes drastic change in July and small positive anomalies are

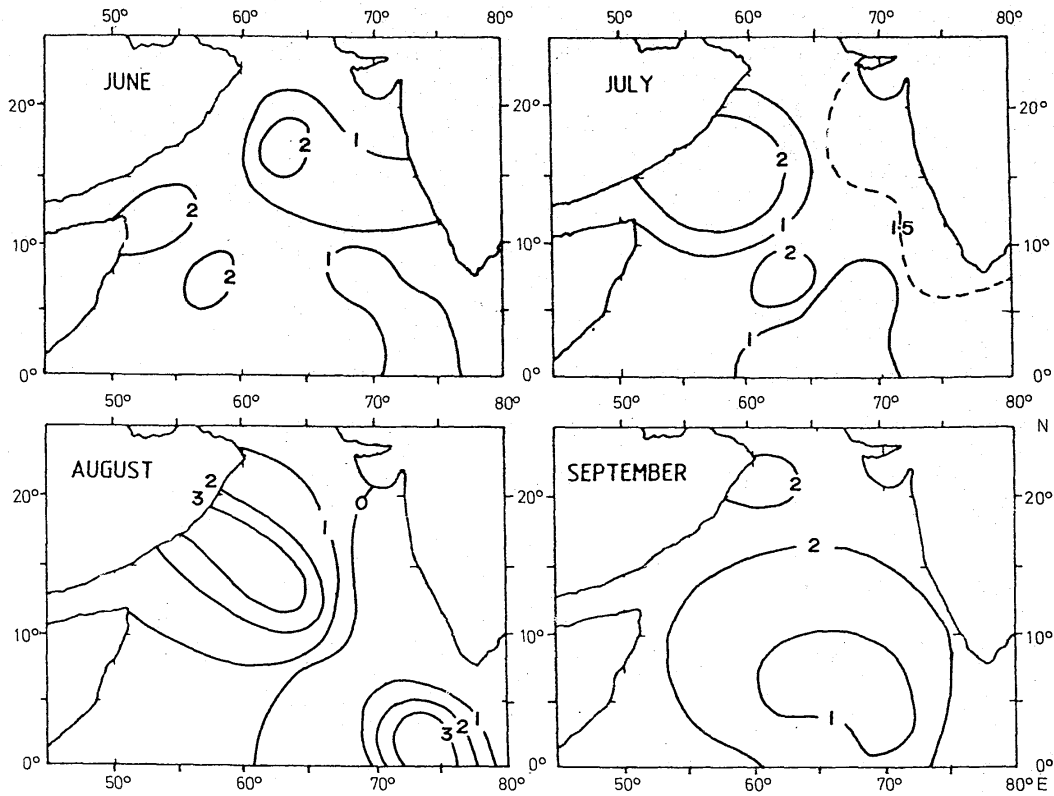


Fig. 4. Same as Fig. 2, but for air temperature ( $^{\circ}\text{C}$ )

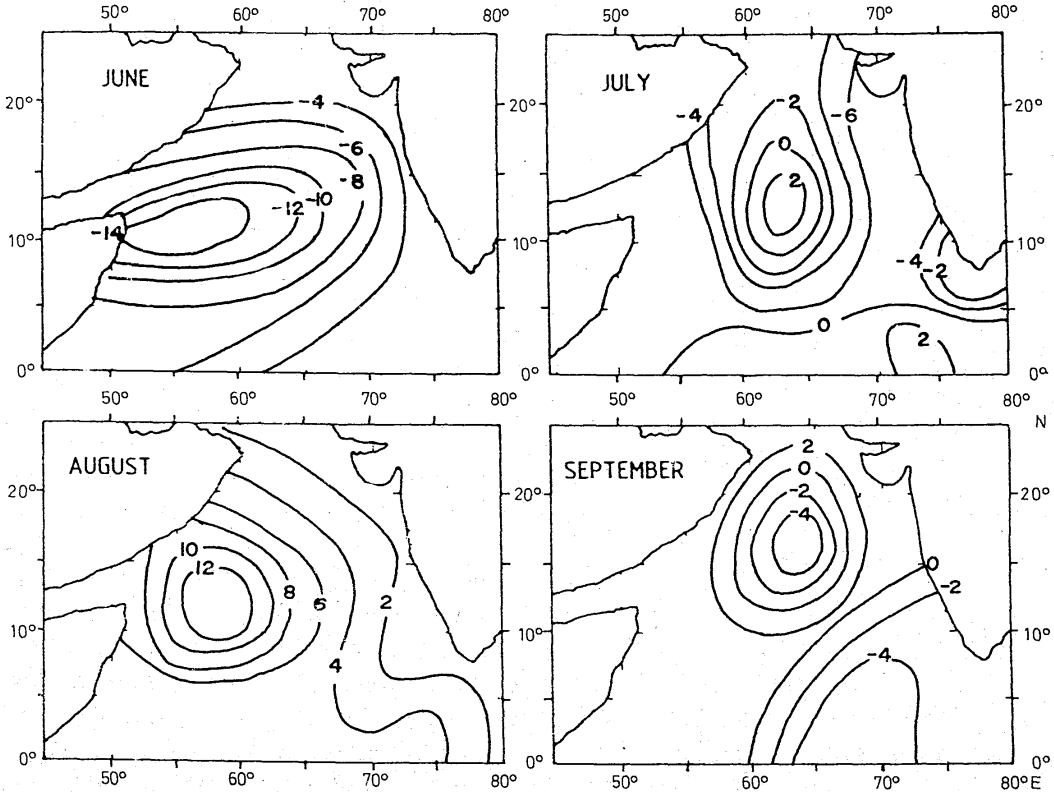


Fig. 5. Same as Fig. 2, but for wind speed (m/sec)

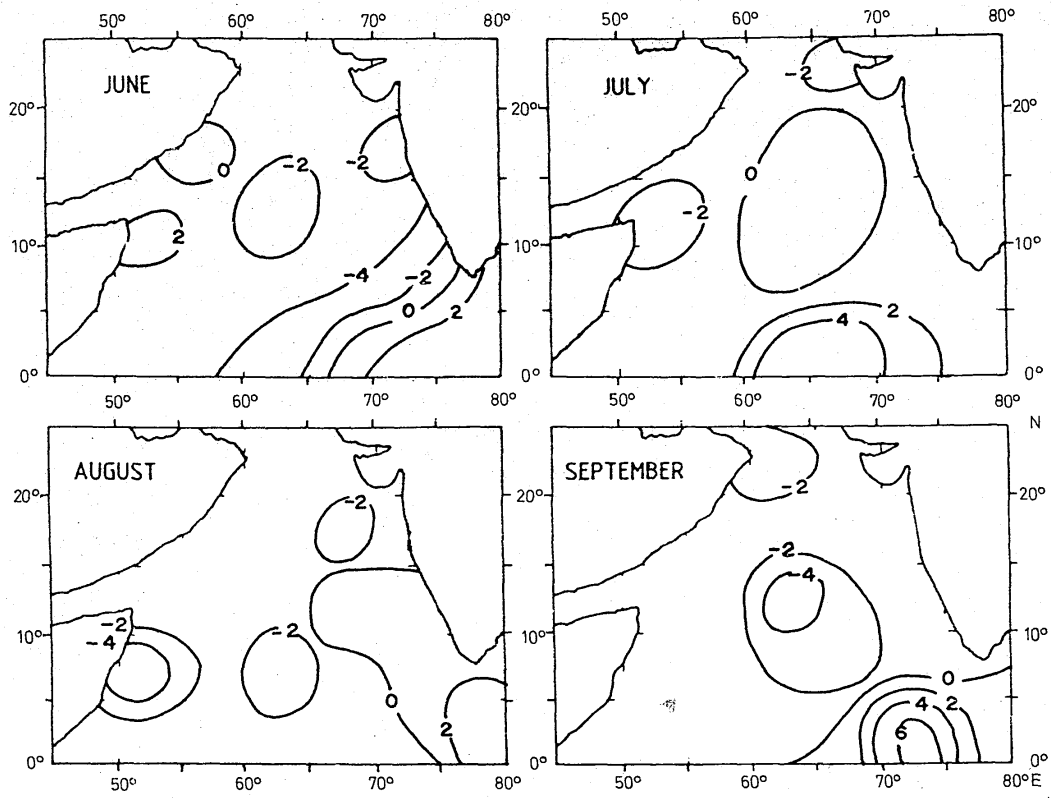


Fig. 6. Same as Fig. 2, but for vapour pressure gradients (mb)

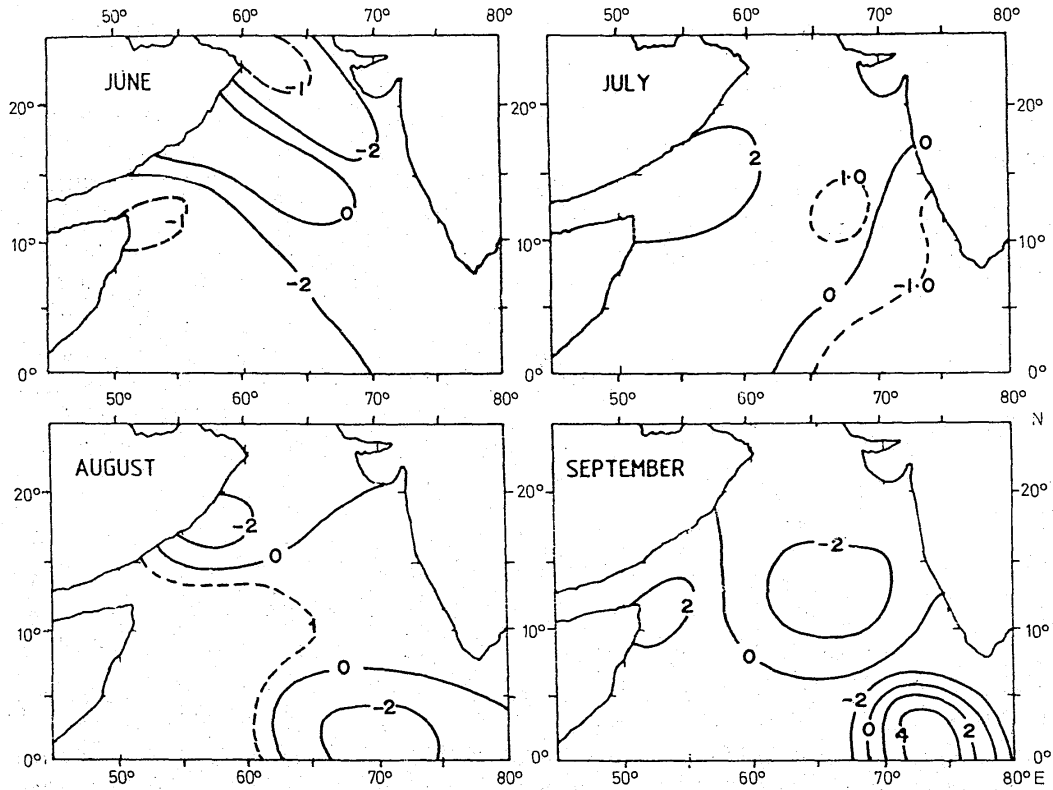


Fig. 7. Same as Fig. 2, but for total cloud amount (Octas)

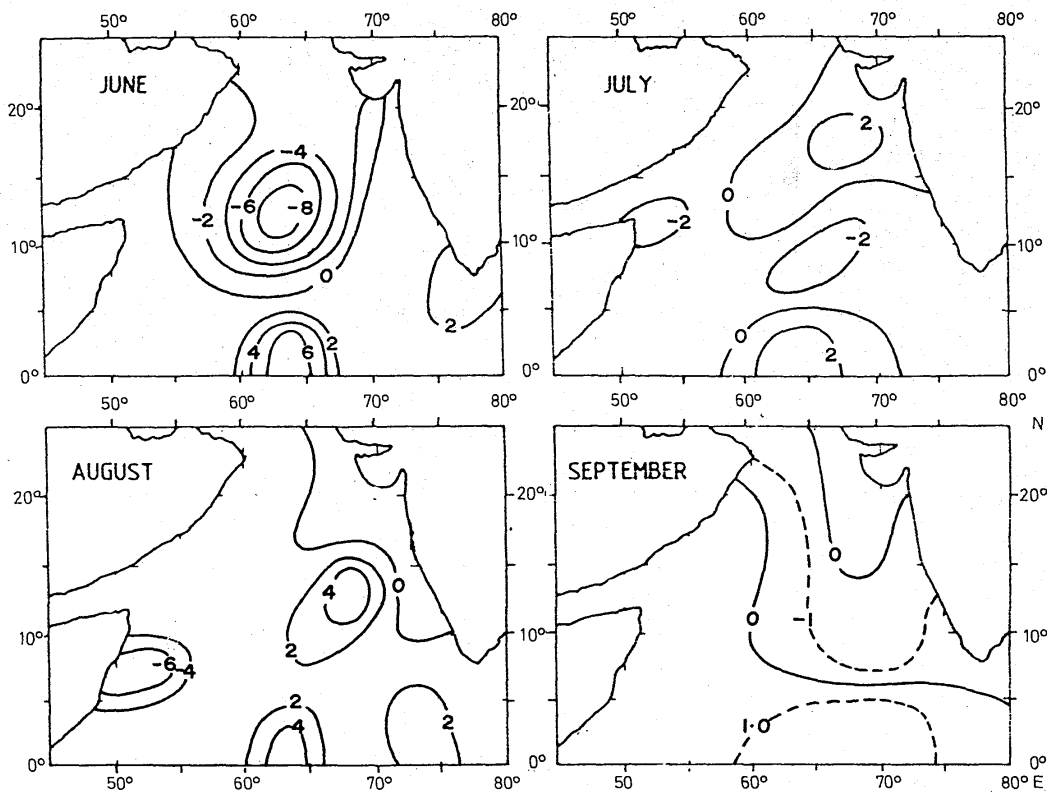


Fig. 8. Same as Fig. 2, but for evaporation ( $\text{Kg/m}^2/\text{day}$ )

observed in the central Arabian Sea with negative anomalies in the western and eastern regions. In the month of August, the anomalies strengthen and large positive anomalies are observed in the western Arabian Sea with positive anomalies throughout the study area. In the month of September, the pattern again undergoes change with negative anomalies in the central and southeastern Arabian Sea.

#### 4.5 Vapour Pressure Gradient

Figure 6 shows the vapour pressure gradient (VPG) difference between 1983 and 1979. The VPG's are negative in the central and eastern Arabian Sea in the month of June. In the month of July, they become positive in the southeastern region with negative anomalies in the north eastern and western regions. The negative anomalies in the western region strengthen by August and shift towards the central Arabian Sea. The positive anomalies in the southeastern Arabian Sea also strengthen.

#### 4.6 Cloudiness

The difference in cloudiness amount between 1983 and 1979 is given Fig. 7. The total cloud amount over the northern and southwestern regions during 1979 was greater than in 1983, for the month of June. In July the cloudiness was more in 1983 compared to 1979, except over the southeastern region. In the month of August the negative anomalies are observed in the northwestern and southeastern regions. In September, the cloudiness was more over the western and eastern regions in 1983, while in the central Arabian Sea the cloudiness was more during 1979.

#### 4.7 Evaporation

Figure 8 gives the spatial differences in evaporation rates for different months between 1983 and 1979. From the figure it is obvious that the evaporation rates were quite high over the central AS in 1979 compared to 1983, in the month of June. Large positive anomalies are observed over the southern AS. In July the whole pattern changes

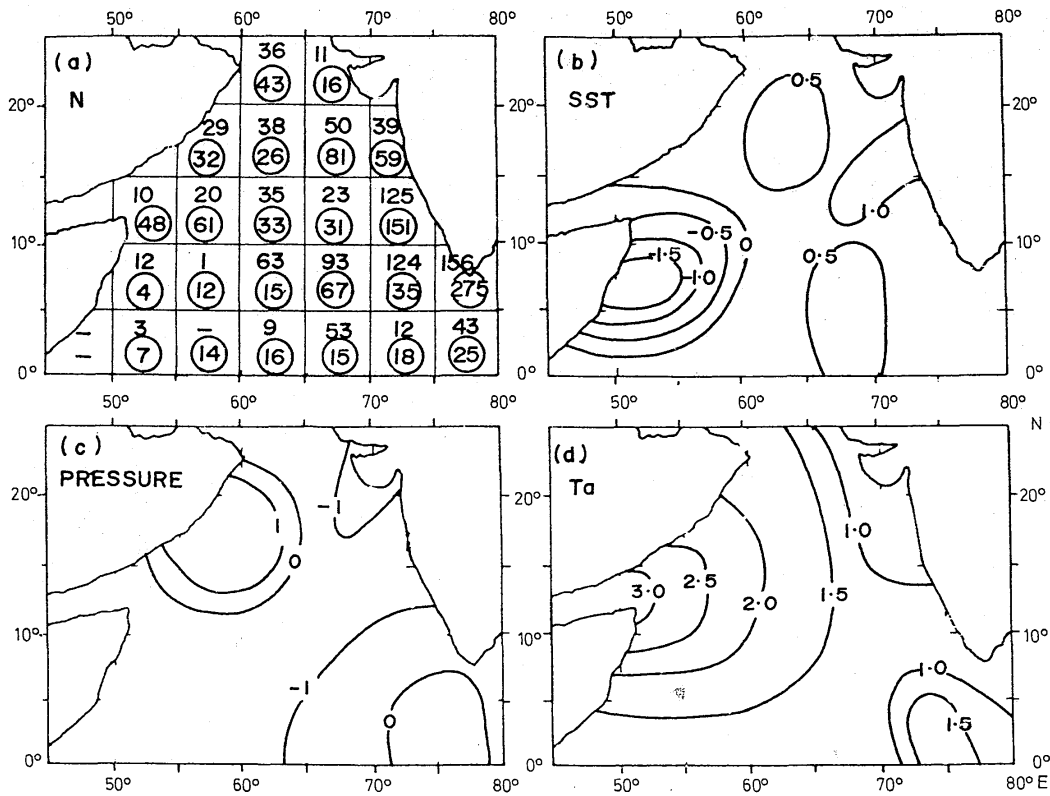


Fig. 9. (a) Total number of observations during the monsoon season for 1979 and 1983 (circled values). Distribution of seasonal mean differences (1983–1979) of (b) Sea surface temperature, (c) Sea level pressure, (d) Air temperature

and small positive anomalies are observed in the central AS and southern areas, whereas small negative anomalies are observed over the western region. By August, both the anomalies strengthen at the central and southern (positive) and western AS (negative). In the month of September, most of the eastern AS has got small negative anomalies.

#### 4.8 Seasonal Mean Differences

Figures 9 and 10 give the seasonal mean (June to September) differences between the years 1983 and 1979. Figure 9 (a) gives the total number of observations for the study period for the years 1979 and 1983 (circled values). Figure 9 (b) gives the seasonal mean SST difference between 1983 and 1979. From the figure it can be noticed that there was a negative anomaly (of the order of  $-1.5^{\circ}\text{C}$ ) over the western Arabian Sea and a positive anomaly over the eastern Arabian Sea. These results support the earlier studies of Joseph and Pillai (1986), Ramesh Kumar et al. (1986), and Ramesh Babu et al. (1985) in that the negative anomalies over the western Arabian sea are resultant of

strong upwelling during 1983 (which was an exceptionally good monsoon than 1979 which was a poor monsoon) and positive SST anomalies over the eastern Arabian Sea are conducive for larger convective activity over this area. Figure 9 (c) gives the mean seasonal sea level pressure difference between 1983 and 1979. From the figure it can be seen that the pressure was more in the north-western Arabian Sea and less in the northeastern and southeastern Arabian Sea. A similar type of pressure distribution for the seasonal means was observed by Joseph and Pillai for the years 1972 and 1973. Figure 9 (d) gives the seasonal mean air temperature differences between 1983 and 1979. Positive anomalies were observed throughout the Arabian Sea with the largest anomalies occurring over the western Arabian Sea (of the order of  $3^{\circ}\text{C}$ ).

Figure 10 (a) gives the seasonal mean wind speed differences between 1983 and 1979. From the figure it can be observed that relatively higher wind speeds were observed in northwestern, central, southern and southeastern regions during 1983 compared to 1979. Figure 10 (b) gives the mean seasonal vapour pressure gradient difference



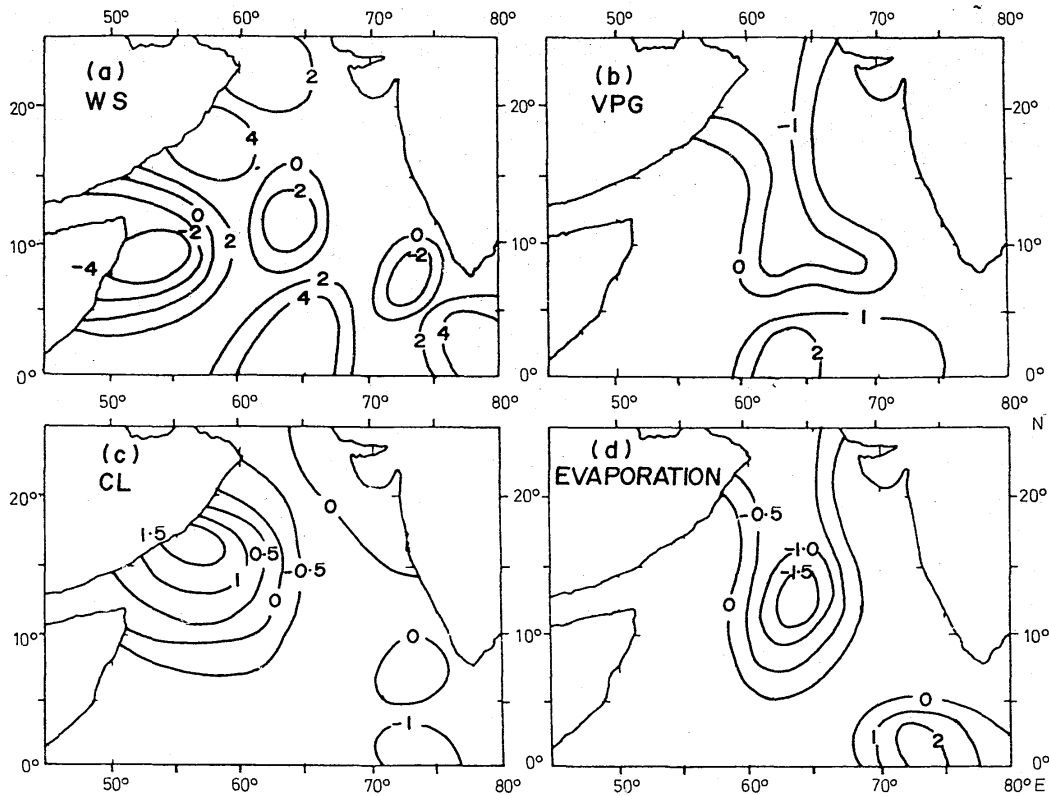


Fig. 10. Distribution of seasonal mean differences (1983–1979) of (a) Wind speed, (b) Vapour pressure gradients, (c) Total cloud amount, (d) Evaporation

between 1983 and 1979. It is surprising that there is little variation in the vapour gradient fields except over the southern and central Arabian Sea. The mean seasonal cloudiness difference between 1983 and 1979 is depicted in Fig. 10 (c). The total cloudiness was more over the northwestern Arabian Sea during 1983 than 1979. The mean seasonal difference in evaporation between 1983 and 1979 is shown in Fig. 10 (d). From the figure it can be concluded that the evaporation over the central Arabian Sea was stronger during a poor monsoon year (1979) than during a good monsoon year (1983). This could be attributed to the dominance of sea surface cooling over central Arabian Sea.

In order to examine the differences in evaporation rates (integrated over the entire Arabian Sea) between the two contrasting monsoon years, we have computed the values on a monthly scale for the above two monsoon seasons and the results are presented in Table 1. It is evident from the table that the rates of evaporation are higher in 1979 during June and July compared with those

in 1983. Because of the delay in onset of monsoon in both the years, one naturally expects higher SSTs which could influence the vapour pressure gradients. In general, the vapour pressure gradients and wind speeds are stronger in 1979 than in 1983 (see Figs. 5 and 6) which are responsible for the higher rates of evaporation observed in June and July 1979. A sharp fall is noticed from July to August in 1979 while a similar trend is seen from August to September in 1983 which could

Table 1. Rates of Evaporation over the Arabian Sea for Two Contrasting Monsoon Years (1979 and 1983). Unit:  $10^{10}$  tons/day

Month/Year	1979	1983	Difference (1983–1979)
June	4.63	4.43	–0.20
July	4.30	3.55	–0.75
August	2.96	3.68	0.72
September	2.76	2.70	–0.06
Mean	3.66	3.59	–0.07

Table 2. Mean Monthly Rainfall (in cms) Along the West Coast of India During 1979 and 1983 Monsoon Seasons

Month/Year	1979	1983	Difference (1983-1979)
June	83.2	47.0	-36.2
July	61.7	104.2	42.5
August	42.0	99.2	57.2
September	21.5	57.6	36.1
Total	208.4	308.0	99.6

be attributed to the weakening of winds. One would expect a gradual decreasing trend in the evaporation with the progress of monsoon due to sea surface cooling. Contrary to this a slight increase is noticed in 1983 from July to August which could be due to the dominance of winds. In September, the rate of evaporation is almost same for both the years, due to the fact that the influence of stronger vapour pressure gradients in the SE Arabian Sea in 1983 might have been compensated by the stronger winds in 1979 (see Figs. 5 and 6). It is interesting to note that the mean evaporation rates are almost equal in both the years on a seasonal scale. To examine the influence of evaporation on west coast rainfall, we present the mean monthly rainfall along the west coast of India (average rainfall of 7 coastal stations Viz; Bombay, Ratnagiri, Goa, Karwar, Mangalore, Cochin and Trivandrum) in Table 2. It is obvious from the table that the rainfall is excessive in 1983 compared to 1979, excepting the month of June. By comparing Tables 1 and 2, one could infer that there is no coherence between the trends in evaporation and rainfall.

It appears that there is an inverse relationship between pressure anomalies and rainfall departure along west coast of India. In the month of June, the anomalies in pressure are predominantly positive while the departure in rainfall is negative (Fig. 3 and Table 2). In the other months the pressure anomalies are generally negative. From this one can say that the pressure pattern which can influence the circulation over the Arabian Sea influences the transport of moisture towards the west coast of India. Sometimes, moisture flux may enter the western Arabian Sea, but it cannot be advected towards the coast if the pressure distribution is not favourable.

The trends in cloud anomalies are not exactly following the pressure anomalies, except for the month of June (Fig. 7).

From the overall results it is difficult to arrive at the conclusion that the evaporation from the Arabian Sea does not play any role in monsoon rainfall. Detailed information on the evaporation from the southern India Ocean, cross-equatorial flux and the amount of precipitation over the Arabian Sea are very essential to shed light on the above problem. A few details about the relative roles of evaporation and cross equatorial flux were already reported by the authors (Sadhuram and Ramesh Kumar, 1988). A separate study is planned to address the above points in a more detailed way.

## 5. Conclusions

1. SSTs are in general higher over the Arabian Sea during 1983 than in 1979, excepting the western region where SSTs are lower in 1983 than in 1979 due to strong monsoonal cooling along the Somalia coast.
2. The pressure distribution is found to be closely related to the observed rainfall pattern along the west coast of India.
3. On a seasonal scale, the integrated evaporation over the Arabian Sea is almost equal in a good (1983) and a poor (1979) monsoon season. It is also noticed that the evaporation rates over the Arabian Sea do not have any influence on the rainfall along the west coast of India.
4. The study indirectly suggests that the moisture flux from the southern hemisphere plays a dominant role in monsoon rainfall over the west coast of India. The pressure distribution over the Arabian Sea also plays an even important role in the advection of moisture towards the west coast of India.
5. Due to the lack of sufficient number of observations in different grids especially in the western and southern regions, our above conclusions need to be considered with a certain amount of reservation.

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