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# VARIABILITY OF WIND STRESS AND WIND STRESS CURL OVER THE NORTH INDIAN OCEAN DURING PRE-MONSOON AND MONSOON SEASONS OF 1987 AND 1988

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## ABSTRACT

The computations of wind stress and wind stress curl over the north Indian Ocean have been made for pre-monsoon and monsoon seasons of the years 1987 and 1988 utilising all real-time and non real-time ship observations. During 1987 there was a major monsoon failure (June-September rainfall departure : - 19%) whereas 1988 was an extremely good monsoon year (departure : + 19%).

In general, higher negative values of stress curl over the central and adjoining southern Arabian Sea and higher positive values over the Bay of Bengal are found during the period May-September of 1988 compared to the values during 1987. The magnitudes of wind stress are found to be higher over the southern Bay of Bengal during May, 1988 as compared to those of May, 1987 whereas over the northern Bay of Bengal higher values prevailed during May, 1987.

*Key-words* : Wind stress curl, summer monsoon, vorticity, anticyclonic gyre.

## INTRODUCTION

The meteorological conditions over the north Indian Ocean exhibit large variations from year to year. Similarly there are larger interannual variations in the southwest monsoon rainfall over India. The aim of the present study was to look into the variability of wind stress and wind stress curl over north Indian Ocean during pre-monsoon and monsoon seasons of contrasting monsoon years 1987 and 1988.

There have been some studies on the distribution of surface wind stress curl. Stommel (1965) has presented annual distribution of surface wind stress curl which covers the world ocean betwen $50^0$S - $50^0$N. Hantel (1970) has prepared monthly charts of surface wind stress curl over the Indian Ocean. Lakshman Rao and Naidu (1983) have obtained the distribution of wind stress curl over the Arabian Sea during January and July 1983. Gopalakrishna, Sadhuram and Ramesh Babu (1988 a, b) have discussed the variability of wind stress and wind stress curl during contrasting summer monsoon season of 1977 and 1979. Dube, Luther and O'Brien, (1990) have discussed interannual variability of wind stress curl over the Arabian Sea.

## MATERIAL AND METHODS

All ship observations (received on day-to-day as well as climatological basis) recorded over the Indian Seas during premonsoon and monsoon seasons of the years 1987 and 1988 have been utilised in the present study. Monthly averages of the relevant parameters were arranged in $5^o \times 5^o$ quadrangular grids. Zonal and meridional components of the wind stress were calculated using the following formulae (Hellerman and Rosenstein, 1983).

$$\tau_x = \rho_a C_D U (U^2+V^2)^{1/2}$$

$$\tau_y = \rho_a C_D V (U^2+V^2)^{1/2}$$

where $\rho_a$ is the air density (= 1.8 kg $m^{-3}$; Hellerman, 1967), U and V are zonal and meridional components of the wind ($m\ s^{-1}$) and $C_D$ is the drag coefficient given by (Bunker, 1976).

$$C_D = 0.934 \times 10^{-3} + 0.788 \times 10^{-4} (U^2+V^2)^{1/2} + 0.868 \times 10^{-4} \Delta T - 0.616 \times 10^{-6} (U^2+V^2)^{1/2} - 0.120 \times 10^{-5} (\Delta T)^2 - 0.124 \times 10^{-5} (U^2+V^2)^{1/2} \Delta T$$

where $\Delta T$ is the difference between air temperature at standard height (10 m) and SST.

The vertical component of the curl of the vector $\tau = (\tau_x, \tau_y)$ is given by :

$$Curl_z\, \tau = \frac{l}{R \cos \varphi\, \Delta\varphi} \left\{ \frac{\partial \tau_y}{\partial \lambda} - \frac{\partial}{\partial \varphi} (\tau_x \cos \varphi) \right\}$$

where R denotes the radius of the earth $\phi$ and $\lambda$ are geographical latitude and longitude, respectively. In order to approximate the curl values for the middle $5^o$ square the following discretization formula has been used :

$$Curl_z\, \tau = \frac{l}{R \cos \varphi\, \Delta \varphi} \left\{ \tau_{y4} - \tau_{y2} - \tau_{x1} \cos (\varphi + 5^o) + \tau_{x3} \cos (\varphi - 5^o) \right\}$$

The discretization grid is depicted in Fig. 1.

## RESULTS AND DISCUSSION

*Wind Stress Curl*

The distributions of wind stress curl for pre-monsoon and monsoon seasons of 1987 and 1988 are shown in Figs. 2(a) and (b) respectively.

There is no significant difference in the distribution of stress curl over the Arabian Sea during March-April period of 1987 from that of 1988. In the month of May, higher negative values of stress curl were observed over the central and adjoining southern Arabian Sea during 1988 as compared to those of 1987. The most striking difference, however, was observed during the month of June. In June 1988

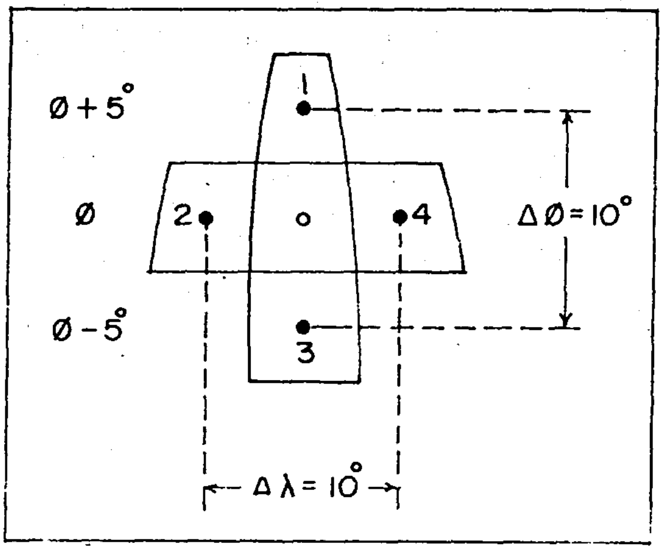


Fig. 1. Discretization grid for the finite-difference curl operator.

the maximum computed value of stress curl over the central and adjoining southern Arabian Sea was $-5.6 \times 10^{-8}$ dynes $cm^{-3}$ whereas the corresponding value for June, 1987 was about $-0.5 \times 10^{-8}$ dynes $cm^{-3}$. Thus in 1988 the anticyclonic wind-stress gyre over the Arabian Sea appeared in May and by June it was at its peak intensity. In 1987 the gyre appeared from June only and was very weak as compared to 1988. It attained its peak intensity in July and was absent in September, 1987. Thus in 1988 the gyre appeared and attained its maximum intensity about a month earlier than that during 1987. During the month of July, the maximum value of stress curl was $-4 \times 10^{-8}$ dynes $cm^{-3}$ in 1987 whereas during the same month of 1988 the maximum value was $-3 \times 10^{-8}$ dynes $cm^{-3}$. In August, however, during both the years maximum value was $-2 \times 10^{-8}$ dynes $cm^{-3}$. By September 1987, positive values of curl were observed at the location of anticyclone gyre. In 1988 the gyre persisted there upto September.

The distribution of stress curl over the Bay of Bengal reveals a different kind of feature from May onwards compared to that over the Arabian Sea. In May 1987, a large portion of the central and southern Bay of Bengal was dominated by negative stress curl whereas in May 1988 the stress curl was predominantly positive over these areas. During June of both years the distribution was more or less same. During the months July-September a large portion of Bay of Bengal was covered by netgative stress curl in 1987 whereas during the same months of 1988 the curl values were positive over a large part of the Bay of Bengal (north and the western parts of the central and southern Bay of Bengal).

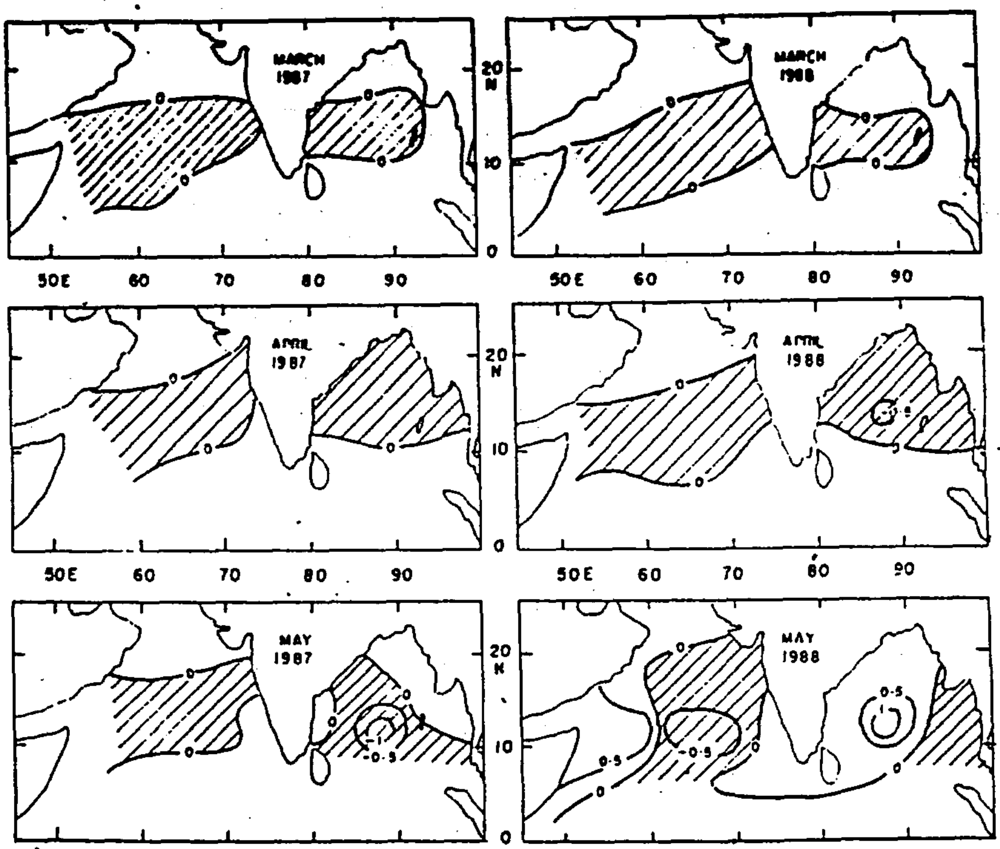


Fig. 2a. Surface wind stress curl during pre-monsoon. Units, $10^{-7}$ kg $m^{-2}$ $sec^{-2}$ = $10^{-8}$ dynes $cm^{-3}$. Negative areas are hatched.

Above results bring out the following :

(i) Stronger negative wind stress curl over the central and adjoining southern Arabian Sea and stronger positive stress curl over the central and adjoining southern Bay of Bengal during the month of May appear to precede a good monsoon. Thus the distribution of stress curl during May over the Arabian Sea and Bay of Bengal can provide predictive indications of ensuing monsoon performance over India.

(ii) During the monsoon months (June-September) occurrence of stronger negative stress curl over larger areas of the Arabian Sea and stronger positive stress curl over larger areas of the Bay of Bengal appears to be a feature of a good monsoon.

*Wind Stress*

The wind stress fields for pre-monsoon and monsoon seasons of 1987 and 1988 are depicted in Fig. 3. As expected the magnitudes of wind stress are generally very

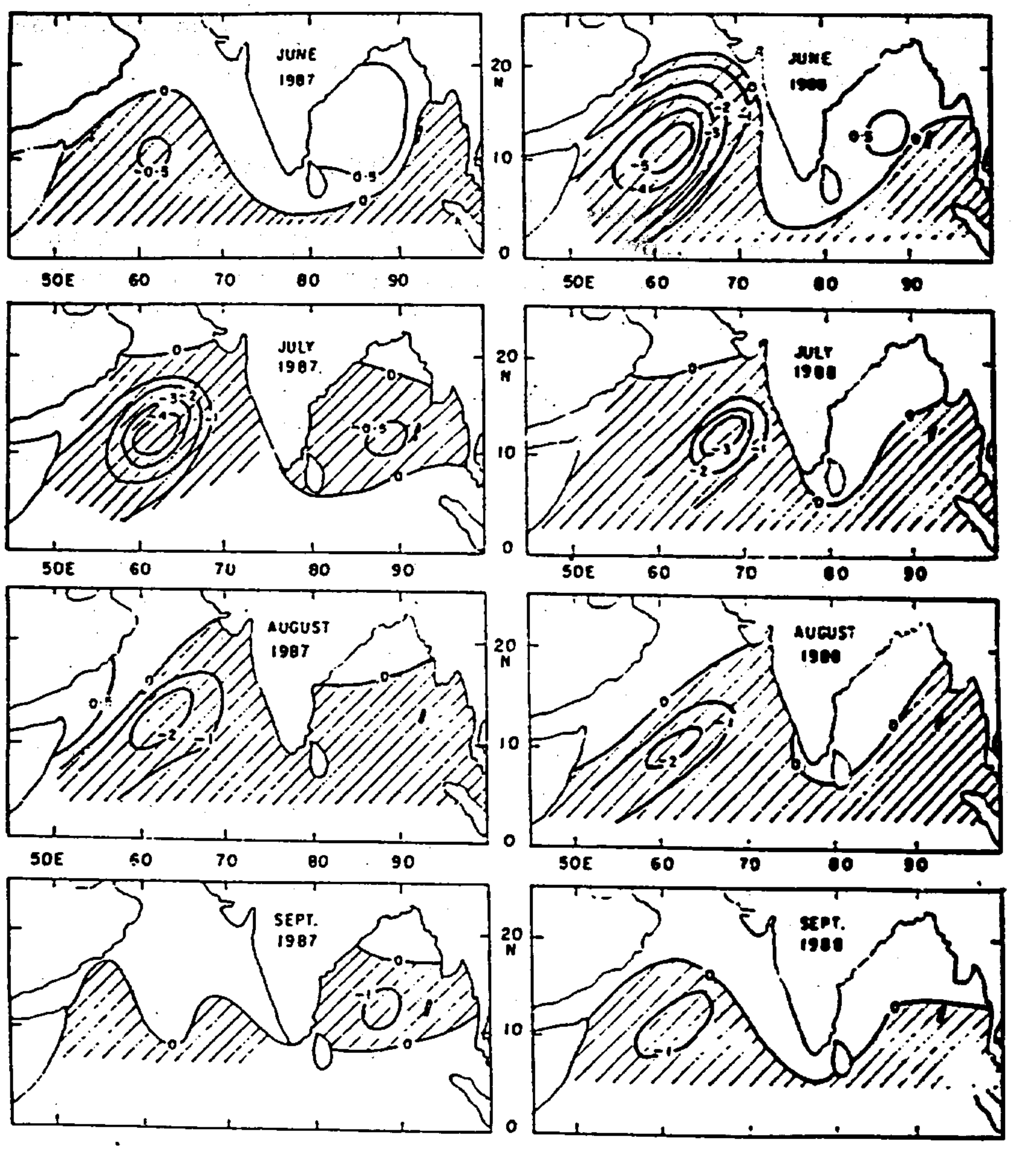


Fig. 2b. Surface wind stress curl during SW monsoon. Units, $10^{-7}$ kg $m^{-2}$ $sec^{-2}$ = $10^{-8}$ dynes $cm^{-3}$. Negative areas are hatched.

small in the months of March and April during both the years. In the month of May, however, the wind stress values were significantly higher over the southern Bay of Bengal and southern and central parts of the Arabian Sea during 1988 as compared to the corresponding values of 1987. Over the northern Bay of Bengal, however, the situation is reverse where higher magnitudes of wind stress are observed during May 1987 as compared to May 1988. Thus it appears that a strong wind stress field over the southern Bay of Bengal and southern Arabian Sea during the month of May is favourable for better ensuing summer monsoon performance over India.

Western sector of the central Arabian Sea was dominated by stronger stresses in June 1988 as compared to corresponding values of 1987. Over central Bay of Bengal, however, the field was weaker in June 1988 as compared to that of June 1987. In July, higher magnitudes were seen over the south-western Arabian Sea during both the years. Over Bay of Bengal the stress field was stronger in July 1987 as compared to that of July 1988.

During August-September 1988 the stress fields were stronger over western parts of Arabian Sea as compared to the corresponding fields of 1987. Over Bay of Bengal the situation continued to be opposite, *i.e.* stronger stress fields during 1987 as compared to 1988.

The study has thus brought out that the distributions of wind stress and wind stress curl over the Indian Seas during the month of May can give useful indications

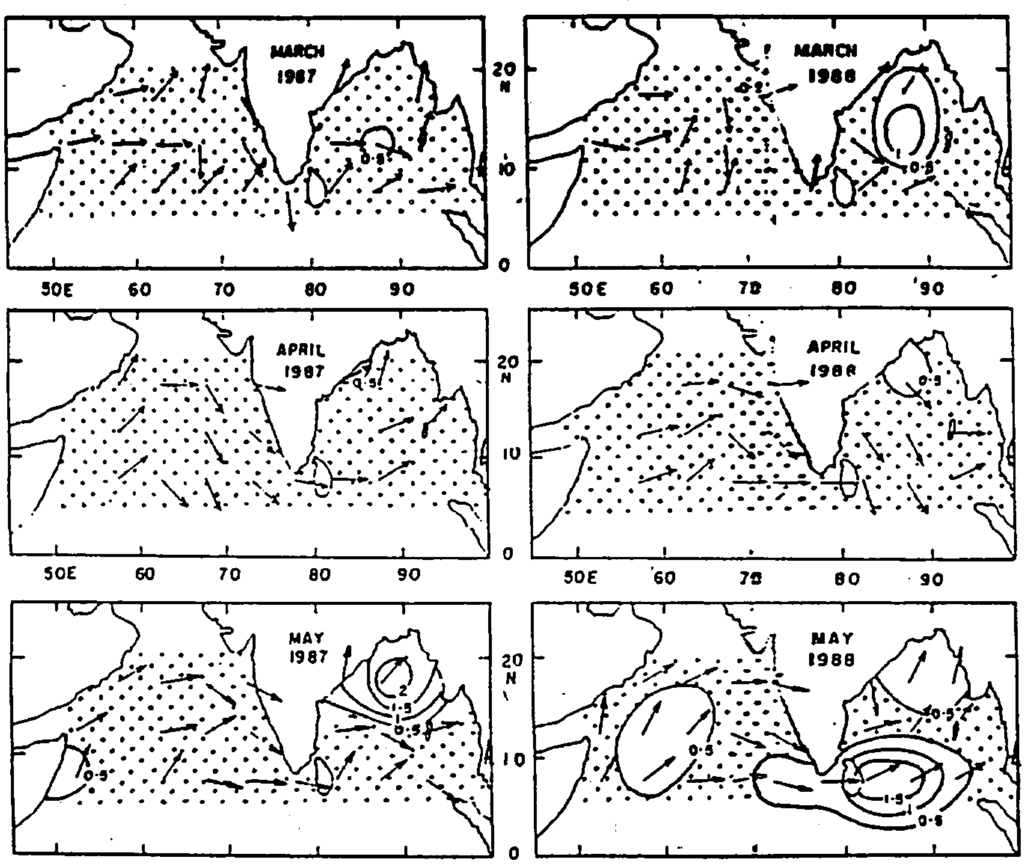


Fig. 3a. Wind stress fields during pre-monsoon. Arrows indicate direction and contours the magnitude (dynes cm$^{-2}$) of the wind stress vectors. Stippling area corresponds to magnitudes <0.5 dynes cm$^{-2}$.

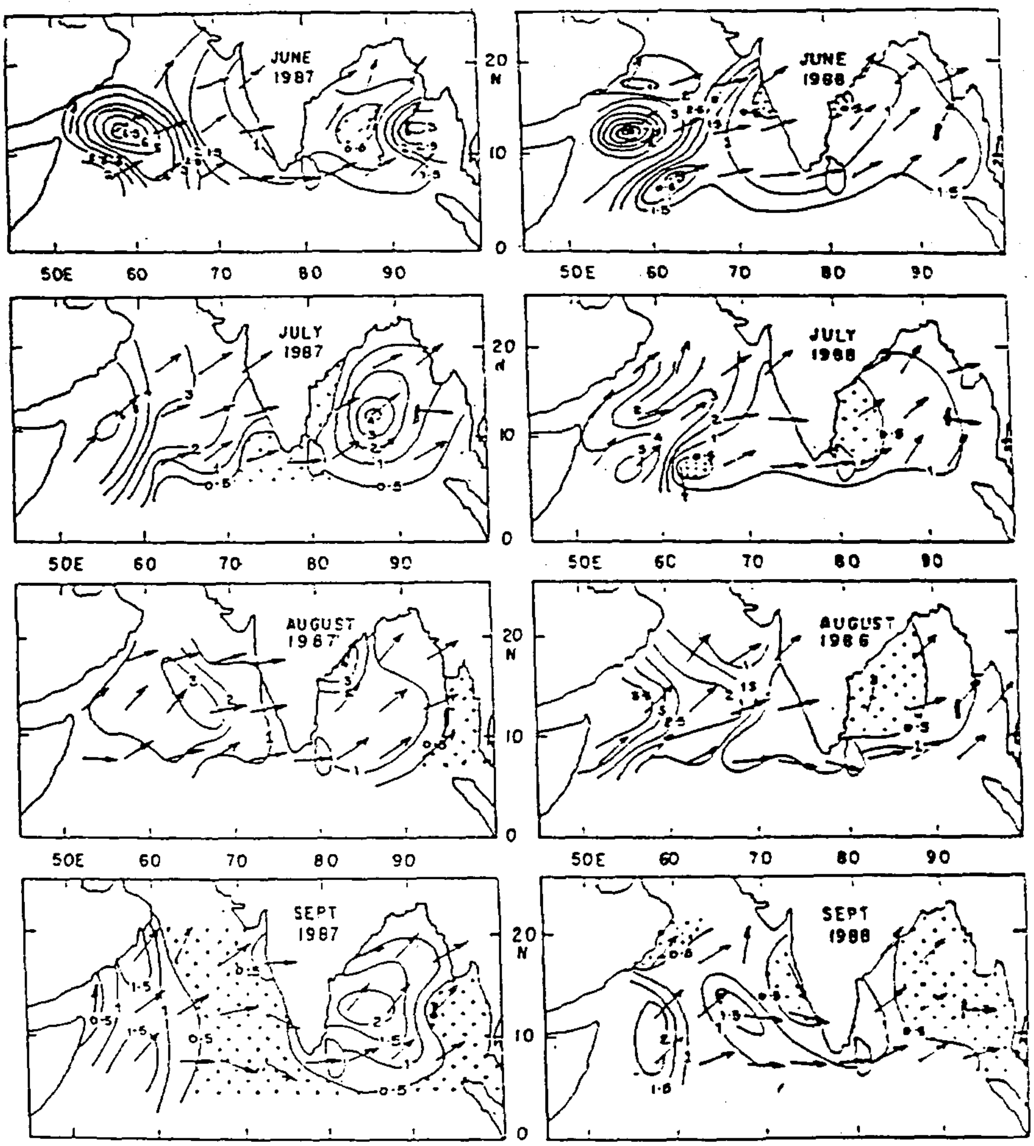


Fig. 3b. Wind stress fields during SW monsoon. Arrows indicate direction and contours the magnitude (dynes $cm^{-2}$) of the wind stress vectors. Stippling area corresponds to magnitudes <0.5 dynes $cm^{-2}$.

of subsequent Indian summer monsoon. The distributions during March-April do not appear to provide any indications. The fields, during the monsoon months (June-September) may be the effect of monsoon and hence may not have much predictive applications. Thus it may be stated that May is the crucial month while looking for local predictors for Indian summer monsoon. However, it is felt that though the consecutive contrasting monsoon years of the type of 1987 and 1988 are not very common, there is a need to consider more number of good and bad monsoon years in order to draw more definite conclusions.

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