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# Characteristics of an Arabian Sea cyclone*

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ABSTRACT. The Monsoon Experiment (MONEX) was conducted in the summer of 1979. During the field phase of the experiment, observations were collected by research aircraft over the Arbian Sea. The paper presents wind data associated with a tropical cyclone over the Arabian Sea between 16 and 19 June 1979.

Gray (1978) designed a parameter ($P$) to measure likelihood of cyclone development which is given by

$$P=f\,(\zeta_r+5)\times(1/S_z+3)\times E\times(\partial\theta_e/\partial p+5)\times(\overline{\mathrm{RH}}-40)/30$$

where $\zeta_r$ is the relative vorticity, $f$ is the coriolis parameter, $S_z$ stands for the vertical wind shear between 900 and 200 mb, $E$ is the ocean energy measured in terms of the excess of sea surface temperature over 26°C, $\theta_e$ is the equivalent potential temperature and $\overline{\mathrm{RH}}$ is the mean relative humidity between 500 and 700 mb.

Gray observed approximate value of $P$ equal to $73\times10^{-8}$ cal °K sec$^{-1}$ cm$^{-8}$ for intensifying cyclones over the Pacific Ocean. From the meteorological data collected by research aircraft on 17 and 18 June 1979 over the Arabian Sea, we computed values of $P$ equal to 91 and $76\times10^{-8}$ cal °K sec$^{-1}$ cm$^{-8}$. These are comparable with Gray's estimate for Pacific cyclones.

The paper discusses the flux of absolute angular momentum and other meteorological features of the Arabian Sea cyclone.

## 1. Introduction

An international experiment, named MONEX-79, provided upper air data for a cyclonic storm over the Arabian Sea during the onset stage of the summer monsoon of June 1979 (15-19 June 1979).

The storm initially lay as a low pressure area over the east central Arabian Sea on 15 June. It then intensified into a depression on the 16th. Moving in northnorthwesterly direction upto the 17th evening, and later in westnorthwesterly direction, it intensified into a cyclonic storm by the mid-day of 18 June. Subsequently, it moved westnorthwestwards as a tropical cyclone till its landfall on the coast of Arabia on the morning of 20 June. The track of the storm is shown in Fig. 1. The maximum wind speed associated with the cyclone was estimated to be 45 kt on 18 June.

In this paper, quantitative estimates of meteorological features associated with the cyclone, are presented.

## 2. MONEX data

The dropsonde data which were collected by three US aircraft on 17 and 18 June were utilized for this study. In addition we also used the observations of coastal stations and islands. The wind data that were available for 950 and 200 mb on 17 June are shown in Figs. 2(a) and 2(b).

The following meteorological parameters are important, when we consider the intensification and development of a cyclonic storm :

(*i*) radial ($V_r$) and tangential ($V_\theta$) components of the wind;

(*ii*) relative vorticity;

(*iii*) divergence;

(*iv*) flux of absolute angular momentum and

(*v*) vertical wind shear and equivalent potential temperature profiles.

We computed the above parameters with the help of MONEX wind data. The areal divergence is :

$$D=\nabla\cdot\mathbf{V}=\int_0^{2\pi} V_r\,R\,d\theta\div\text{Area}=2\,\overline{V}_r/R \quad (2\cdot1)$$

where $V_r$ is the radial component of the wind and $R$ is the radial distance from the storm centre.

Similarly, the areal vorticity is :

$$\zeta_r=2\overline{V}_\theta\,/\,R \quad (2\cdot2)$$

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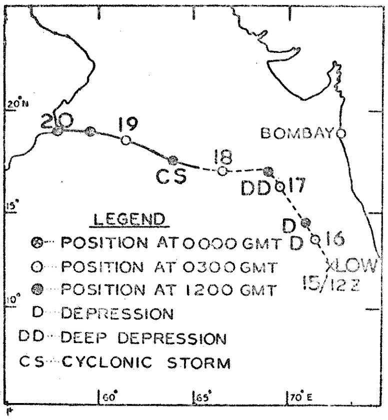



Fig. 1. Cyclonic storm, 16-19 June 1979

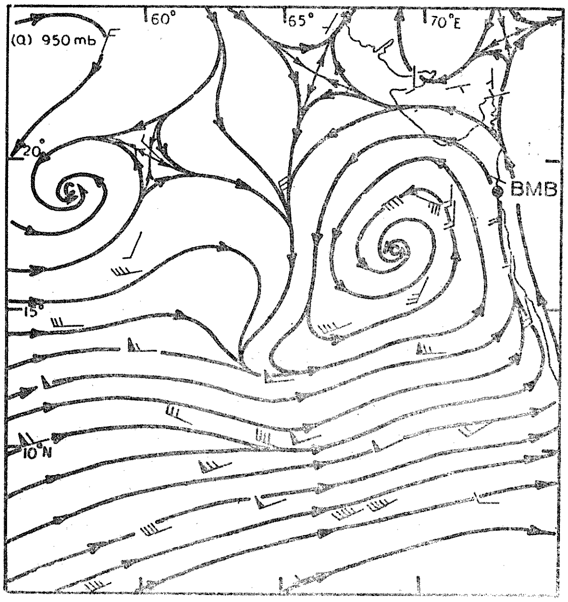



Fig. 2 (a). 950 mb, 17 June 1979

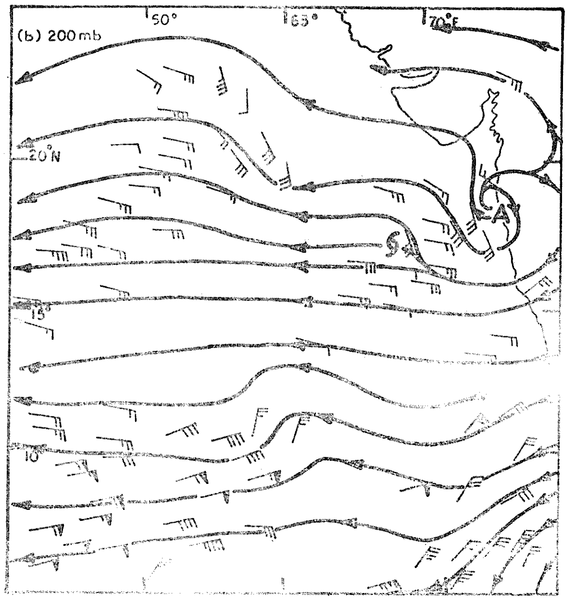



Fig. 2 (b). 200 mb, 17 June 1979

where, $V\theta$ is the tangential component of the wind.

A 'genesis parameter' for tropical cyclones was developed by Gray (1978).

This is :

$$P=f(\zeta_r+5) \times (1/S_z+3) \times E \times \left(\frac{\partial \theta_e}{\partial p}+5\right) \times \left(\frac{\overline{RH}—40}{30}\right) \qquad (2{\cdot}3)$$

where, $\zeta_r$ stands for relative vorticity and $f$ is the coriolis parameter. $S_z$ is the vertical wind shear of the zonal wind between 850 and 200 mb, $E$ is a measure of the ocean energy. The ocean energy is the ocean thermal energy above 26°C or to a depth of 60 m whichever is observed earlier. We have:

$$E = \int_{-60\text{ m}}^{0} \rho\, C\, (26T—)\, dz \qquad (2{\cdot}4)$$

where, $\rho$ is the density of sea water, $C$ is its specific heat and $T$ is the sea surface temperature (deg. C). $E$ is measured in units of $10^3$ cal/cm². $\theta_e$ is the equivalent potential temperature and $\overline{RH}$ is the mean relative humidity between 500 and 700 mb. The humidity factor $(\overline{RH}—40)/30$ is taken as zero when $\overline{RH}$ is less than 40 per cent and one when $\overline{RH}$ is greater than 69 per cent.

In the following sections of the paper, we will discuss the different components of the genesis parameter.

**3. Vorticity and divergence**

The vorticity and divergence patterns evaluated with the help of 2.1 and 2.2 for 17 and 18 June,

TABLE 1

**Dynamical parameters for the Arabian Sea cyclonic storm 17 June 1979 (12 GMT)**

| Radius $R$ (°) | $V_r$ Radial wind (ms$^{-1}$) | $V_\theta$ Tangential wind (ms$^{-1}$) | $V_r$ $R$ Mass transport (ms$^{-1}$ deg.) | $(V_\theta R+f R^2/2) \times V_r$ Flux of absolute angular momentum $\times(10^{12}$ cm$^3$ s$^{-2})$ | Areal Div. $\times(10^{-5}$ s$^{-1})$ | Vorticity $\times(10^{-5}$ s$^{-1})$ | $\zeta_{950}-\zeta_{200}$ $\times(10^{-5}$ s$^{-1})$ |
|---|---|---|---|---|---|---|---|
| | | | | **950 mb** | | | |
| 2 | −2.3 | 15.8 | −4.6 | −10.4 | −2.0 | 14.0 | 13.3 |
| 3 | −1.9 | 15.4 | −5.7 | −14.0 | −1.0 | 9.2 | 8.6 |
| 4 | −1.6 | 11.9 | −6.4 | −14.9 | −0.3 | 5.3 | 5.5 |
| 5 | −1.5 | 9.6 | −7.5 | −17.6 | −0.6 | 3.4 | 3.5 |
| | | | | **200 mb** | | | |
| 2 | −0.1 | 0.8 | 0.2 | −1.0 | −0.8 | 0.7 | |
| 3 | 0.1 | −1.0 | 0.3 | 1.3 | 0.4 | −0.6 | |
| 4 | 1.3 | −0.4 | 5.2 | 5.3 | 0.6 | −0.2 | |
| 5 | 1.3 | −0.3 | 5.2 | 8.3 | 0.5 | −0.1 | |

TABLE 2

**Dynamical parameters for the Arabian Sea cyclonic storm**

**18 June 1979 (12 GMT)**

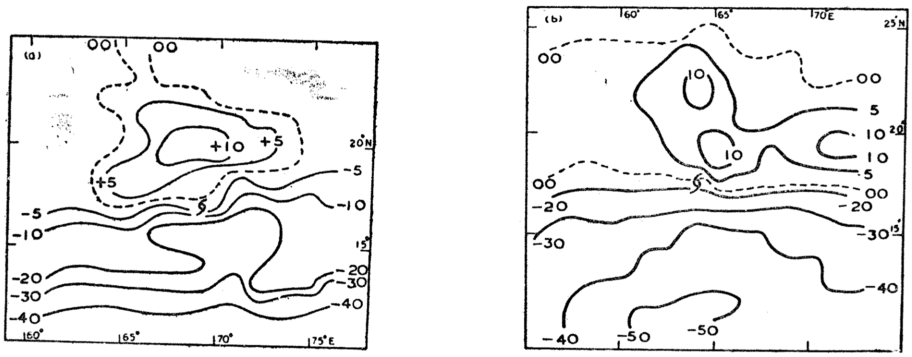
| Radius $R$ (°) | $V_r$ Radial wind (m s$^{-1}$) | $V_\theta$ Tangential wind (m s$^{-1}$ | $V_r \times R$ Mass transport $\times$(m s$^{-1}$ deg.) | $(V_\theta R+f R^2/2)\times V_r$ Flux of absolute angular momentum $\times(10^{12}$ cm$^3$ s$^{-2})$ | Areal div. $\times(10^{-5}$ s$^{-1})$ | Vorticity $\times(10^{-5}$ s$^{-1})$ | $\zeta_{950}-\zeta_{200}$ $\times(10^{-5}$ s$^{-1})$ |
|---|---|---|---|---|---|---|---|
| | | | | **950 mb** | | | |
| 2 | −3.5 | 14.9 | −7.0 | −15.1 | −3.1 | 13.0 | 14.8 |
| 3 | −3.9 | 14.8 | −11.7 | −28.1 | −2.3 | 9.0 | 11.0 |
| 4 | −3.8 | 13.0 | −15.2 | −37.8 | −1.7 | 6.0 | 7.9 |
| 5 | −3.9 | 10.5 | −19.5 | −48.2 | −1.3 | 4.0 | 5.6 |
| | | | | **200 mb** | | | |
| 2 | −0.1 | −2.0 | −0.2 | −0.1 | −0.1 | −1.8 | |
| 3 | 0.5 | −3.4 | 1.5 | 0.6 | 0.3 | −2.0 | |
| 4 | 0.5 | −4.3 | 1.5 | 1.1 | 0.2 | −1.9 | |
| 5 | 0.4 | −4.5 | 1.2 | 1.6 | 0.2 | −1.6 | |

are shown in Tables 1 and 2. Values corresponding to different radial distance from the centre of the storm are indicated. The interesting feature of the cyclone was the existence of positive vorticity even upto 200 mb but, as we proceed outwards from the storm centre, this was replaced by anticyclonic vorticity at 200 mb, which reflects the outflow from the cyclone. A similar feature was observed for the divergence field.

It was suggested by Gray (1978) that the difference in relative vorticity between 900 and 200 mb averaged over a 4 degree radius around the storm centre could be an important measure for distinguishing between developing and non-developing cyclones. For intensifying cyclones over the Pacific region, a difference of $4.7\times10^{-5}$ sec$^{-1}$ was indicated. In the present case, our computed values were 5.5 and $7.9\times10^{-5}$ sec$^{-1}$ on 17 and 18 June respectively. This, we feel, indicated the intensification of the cyclone between 17 and 18 June.

### 4. Vertical wind shear

The vertical wind shear between 200 and 850 mb around the storm centre on 17 and 18




Figs. 3 (a & b). Vertical wind shear (ms—1/650 mb) 200-850 mb on (a) 17 & (b) 18 June 1979

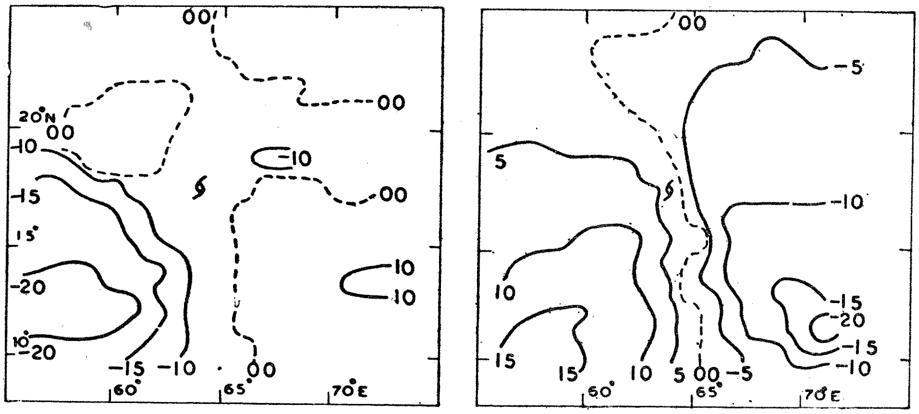



Fig. 4. Radial wind field (mps) at (a) 950 and (b) 200 mb at 12 GMT of 18 June 1979

June is shown in Figs. 3(a) and 3(b). We observed the following important features :

(*i*) little or no vertical shear near the centre of the cyclone,

(*ii*) regions of positive shear to the north, and large negative shear to the south of the storm centre and

(*iii*) a large horizontal gradient of the vertical wind shear.

These features suggest considerable horizontal temperature gradients within the cyclone field. The large negative shear towards south of the storm centre could be accounted for by the presence of a low level westerly jet and a high level easterly jet over this region.

**5. Ocean energy and moist stability**

The ocean energy (Gray 1978) for this cyclone was $15\times10^3$ cal/sec$^2$. This was greater than the values quoted by Gray for the Atlantic Ocean. But, it was almost of the same magnitude as for the cyclonic storms over the Pacific Ocean. The warmer sea surface temperatures in this sector of the Arabian Sea led to higher values of *E*.

The equivalent potential temperature profile provides a measure of the potential of the atmosphere for sustaining deep cumulus convection. The potential buoyancy for an intensifying cyclone has been estimated to be between 15 and 20 deg. K. For the present cyclone values were estimated to be between 14 and 16 deg. K on 17 and 18 June. The potential buoyancy is the difference in equivalent potential temperatures at the surface and 500 mb. It measures, in an approximate manner, the possibility of free convection in the cyclone field. This is particularly true of this cyclone, in view of the high relative humidity that prevailed on 17 and 18 June.

**6. Genesis parameter** (*P*)

We computed the value of *P* with the help of (2.3). The values for 17 and 18 June are shown in Table 3. Our computed values were 91 and $76\times10^{-8}$ cal °K sec$^{-1}$ cm$^{-3}$ for 17 and 18 June respectively. The average values for similar disturbances over the Pacific and the Atlantic were 73 and $48\times10^{-8}$ cal °K sec$^{-1}$ cm$^{-3}$ (Mc Bride and Gray 1979). The magnitude of *P* was thus a little higher for this cyclone.

**7. Radial wind and mass transport**

The field of radial velocity is important because it is related to the minimum pressure of the storm and to the conversion of kinetic energy to the potential energy. Fig. 4 represents

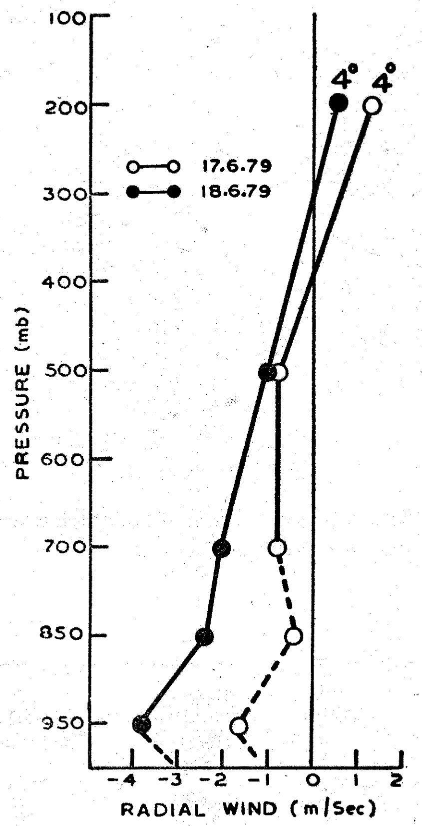



Fig. 5

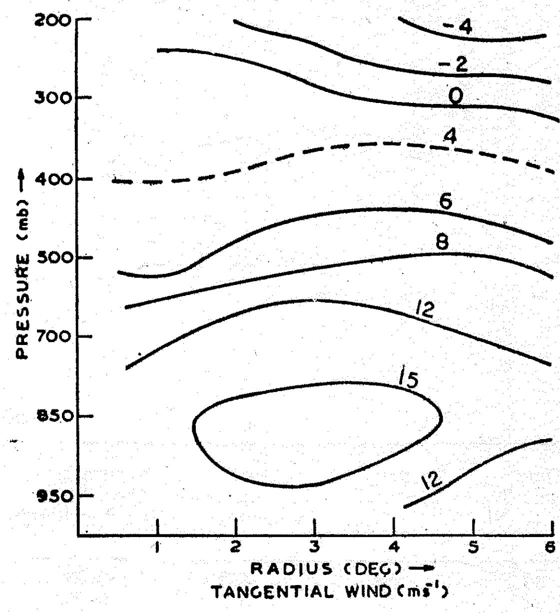



Fig. 6

the field of radial velocity at 950 and 200 mb for 18 June. Fig. 5 shows the plot of the radial winds at 4 deg. radius for 17 and 18 June. The significant features brought out by these figures are: (*i*) presence of very strong inflow in the southwest quadrant, (*ii*) maximum inflow at 950 mb and (*iii*) significant increase of the inflow on 18th in comparison to 17th.

Radial velocity times the radius is proportional to the mass transport. Values of mass transport at 950 and 200 mb are shown in Tables 1 and 2. Significant increase in the mass transport is observed on 18th in comparison to that on 17th.

**8. Tangential wind**

Strong tangential wind, which is a measure of the circulation, is a distinctive feature of a mature tropical cyclone. Fig. 6 shows the vertical cross-section of the tangential component of the wind for 18 June 79. Fig. 7 shows the values of the tangential wind for 16 and 18 June at different radii for lower levels. Positive and negative values indicate cyclonic and anticyclonic flow respectively. Examination of the diagrams bring out the following interesting features: (*i*) The existence of the cyclonic wind maxima between 900 and 850 mb, (*ii*) change of cyclonic into anticyclonic flow at about 250 mb and (*iii*) significant increase of the tangential wind from 16 June to 18 June indicates the increase in the intensity of the system on 18th.

Strength of the tangential wind is an important parameter to distinguish between a developing and non-developing system. The increase of the tangential wind is the dynamic response of the atmosphere to the warming and subsequent increase in the pressure gradients which operate over the cyclone field.

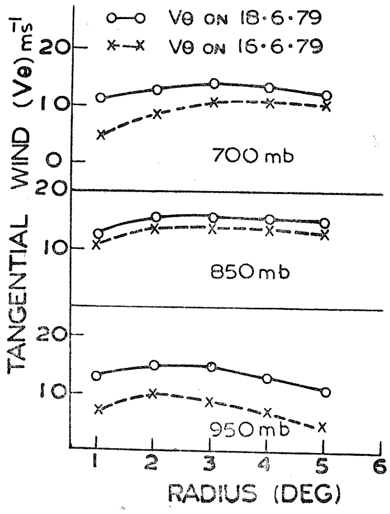



Fig. 7

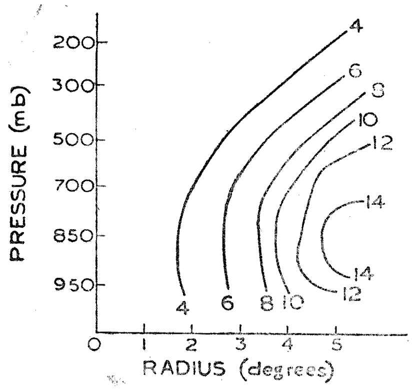



Fig. 8. Schematic cross-section of the absolute angular momentum $10^{10}$ cm²/sec

TABLE 3

Genesis parameter

| Date (June 79) | Vorticity ($\times 10^{-6}$ sec$^{-1}$) | Coriolis parameter ($\times 10^{-5}$ sec$^{-1}$) | Vertical wind shear factor (m$^{-1}$ s 650 mb) | Ocean energy ($10^3$ cal cm$^{-2}$) | Moist stability (° K/450 mb) | Mean Humidity $(\overline{RH})$ (%) | $P$ ($\times 10^{-8}$ cal °K s$^{-1}$ cm$^{-3}$) |
|---|---|---|---|---|---|---|---|
| 17 | 92 | 4.2 | 0.08 | 15 | 14 | >70 | 91 |
| 18 | 90 | 4.2 | 0.06 | 15 | 16 | >70 | 76 |

**9. Flux of absolute angular momentum**

Computed values of the flux of absolute angular momentum for the present case are shown in Tables 1 and 2.

In the lower level, the flux of absolute angular momentum increased with the increase of intensity. Compared to 17th, values are considerably higher on 18th. The results show that generally, the flux of absolute angular momentum has the same sign and tendency as the radical velocity for a given radius. Intensity trends agree well with the trends of the two computed quantities. A schematic vertical cross-section of absolute angular momentum is shown in Fig. 8. The figure reveals a feature similar to a mature cyclone (Anthes 1974)

**10. Conclusion**

Genesis parameter values are worked out in case of a cyclonic storm in the Arabian Sea following Gray's work (1978). Results are comparable with the results of similar disturbances in the Pacific, but the values in the Arabian Sea are greater in magnitude than those of the Atlantic Ocean.

The fields of vorticity, divergence, radial and tangential wind and the horizontal distribution of the vertical wind shear of the zonal winds around the storm centre in case of the present cyclone reveal similarities with such fields observed in case of similar disturbances in the Pacific and the Atlantic.

*Acknowledgement*

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