

Diagnostic study of a Bay of Bengal monsoon depression, July 1979*

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(Received 12 September 1986)

सार — अवदाब क्षेत्र से ऊपरी हवाएं, विशेष रूप से निर्माण की अवस्था में, जब इस अवस्था में उनकी विस्तृत संरचना का अध्ययन करना हो तो मुख्य रूप से बाधक होती हैं।

1979 में मानसून प्रयोग से 7 जुलाई 1979 को उत्तरी बंगाल की खाड़ी में उत्पन्न अवदाब क्षेत्र के पर्याप्त आंकड़े प्राप्त किए हैं। इन प्रेक्षणों के आधार पर अवदाब से सम्बद्ध तापीय संरचना, भ्रमिलता के वितरण, अपसरण, रेडियल तथा स्पर्श रेखीय पवन ऊर्जाघर वायु अपसरण के बहिर्वाह एवं अंतर्वाह तथा ऊर्जाघर वेगों से कुछ लक्षणों का परिलक्षण किया गया है तथा उनके परिणामों को इस शोधपत्र में प्रस्तुत किया गया है।

तूफान के विकास के लिए, ग्रे (1978) द्वारा प्रतिपादित "उत्पत्ति प्राचल" (जेनेसिस पैरामीटर) को कोरियालिस प्राचल, भ्रमिलता प्राचल, ऊर्जाघर वायु अपसरण प्राचल, महासागर ऊर्जा प्राचल, स्थिरता प्राचल और आपक्षिक आर्द्रता प्राचलों के गुणन पर आधारित मानकर, इनकी गणना की गई है। प्रस्तुत मामले में, उपरोक्त उत्पत्ति प्राचल की गणना, $(46 \times 10^{-8} \text{ कैलोरी}^{\circ} \text{ केल्विन/से}^{\circ}/\text{सेमी}^3)$ है जो कि अटलांटिक सागर में उत्पन्न अविकसित अवदाब $(26 \times 10^{-8} \text{ कैलोरी}^{\circ} \text{ केल्विन/से}^{\circ}/\text{सेमी}^3)$ से औसत से अधिक तथा विकासमान अवदाब $(55 \times 10^{-8} \text{ कैलोरी}^{\circ} \text{ केल्विन/से}^{\circ}/\text{सेमी}^3)$ से कम है।

ABSTRACT. Upper winds from the depression field especially in the formation stage are the major constraints, for studying their detailed structure at this stage.

Monsoon Experiment (MONEX) in 1979 has provided adequate upper air data from a depression field which formed in the north Bay of Bengal on 7 July 1979. Based on these observations, certain features like thermal structure, distribution of vorticities, divergence, radial and tangential wind, vertical wind shear inflow and outflow and vertical velocities associated with the depression have been computed and the results presented in this paper.

"Genesis Parameter" designed by Gray (1978) for the development of the storm based on the product of coriolis parameter, vorticity parameter, vertical wind shear parameter, ocean energy parameter, stability parameter and relative humidity parameter have been computed. In the present case, the above genesis parameter is computed to be $46 \times 10^{-8} \text{ cal}^{\circ} \text{ K sec}^{-1} \text{ cm}^{-3}$ which is more than the average non-developing depression $(26 \times 10^{-8} \text{ cal}^{\circ} \text{ K sec}^{-1} \text{ cm}^{-3})$ and less than the developing depression $(55 \times 10^{-8} \text{ cal}^{\circ} \text{ K sec}^{-1} \text{ cm}^{-3})$ in the Atlantic.

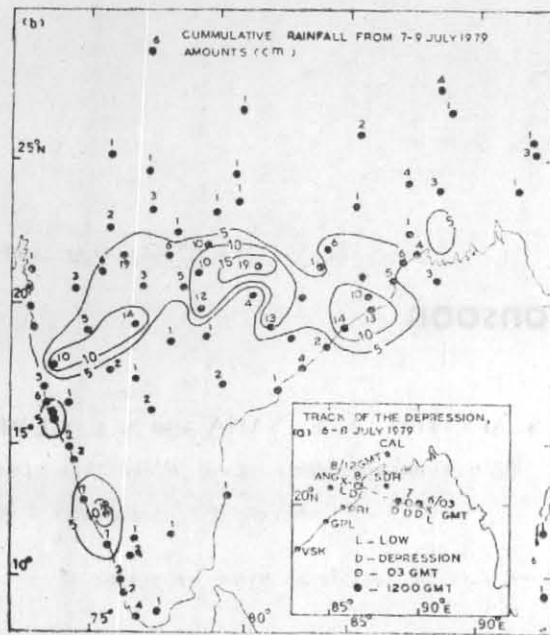
1. Introduction

Detailed study of the monsoon depression was one of the scientific objectives of the Summer Monex Experiment (MONEX), 1979. During the second phase of this experiment in July 1979, a depression formed in the Bay of Bengal on 7 July 1979 when it was centred around 19.5 N and 89.5 E about 300 km southeast of Calcutta. Moving westward it crossed Orissa coast in the early morning of 8th and weakened into a low over central parts of Madhya Pradesh on 9th morning. Track of the depression is shown in Fig. 1 (a). In this study, quantitative estimates of some of the meteorological features associated with this depression are presented.

2. Data source and formulae used in computations

The drop-sonde data collected by the U.S. aircraft on 6 and 7 July are utilised for the computations of the various parameters like vorticity, vergence field, vertical wind shear etc which are considered important for the development of such systems. In addition, the observations from the coastal and inland stations are utilised. Satellite wind data alongwith the data from the inland stations are utilised for these computations at 200 mb. The winds utilised for the computations for 7th at various levels alongwith the temperature values are shown in Fig. 2 (Observations over the limited oceanic area around the depression field are only shown).

*Paper was presented in the "National Symposium on Early Results of Monsoon Experiment" Delhi, March 1981.



Figs. 1 (a & b)

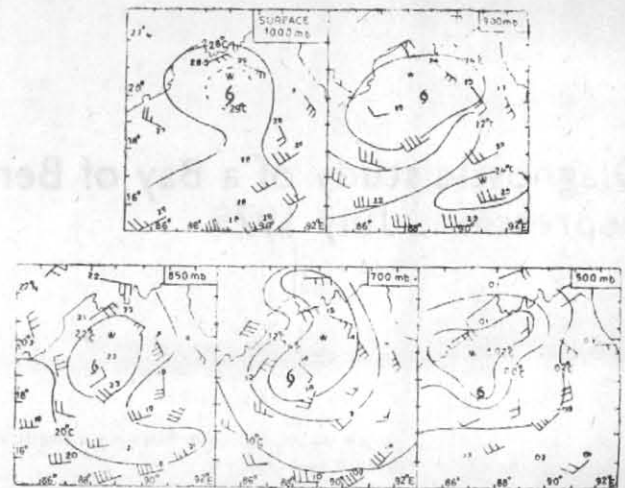


Fig. 2. Temperature and wind distribution around the depression field, 7 July 1979

Nita and Masuda (1981) studied certain aspects of this depression. Some of the computed parameters and the methodology used for computation here are, however, different. Mandal *et al.* (1981) have computed some meteorological parameters important for the development of a cyclone. Same methods of computations are used for the computations of vorticity, divergence, mass flow, flux of absolute angular momentum and genesis parameter. For the benefit of the readers, however, the formulae used for computations are repeated below :

$$D = \nabla \cdot \vec{V} = \int_0^{2\pi} V_r R d\theta \div \text{Area} = 2 V_r / R \quad (1)$$

where V_r is the radial component of the wind and ' R ' is the radial distance from the storm centre. Other terms have usual meaning.

$$\text{Similarly, } \zeta_r = 2 V_\theta / R \quad (2)$$

where V_θ is tangential wind component.

Genesis parameter

$$P = f(\zeta_r + 5) \left(\frac{1}{S_z + 3} \right) (E) \left(\frac{\partial \theta_e}{\partial p} + 5 \right) \left(\frac{\overline{RH} - 40}{30} \right) \quad (3)$$

where ζ_r is relative vorticity. S_z is the vertical wind shear of the zonal component of wind between 850 mb and 200 mb.

$$E = \int_{-60n}^0 \rho C (T - 26) dz \quad (4)$$

where ρ is the density of sea water; ' C ' is specific heat; ' T ' is sea surface temperature; \overline{RH} is the mean relative humidity between 500 and 700 mb. ' θ_e ' is Equivalent potential temperature.

$$\text{Mass transport} = V_r R \quad (5)$$

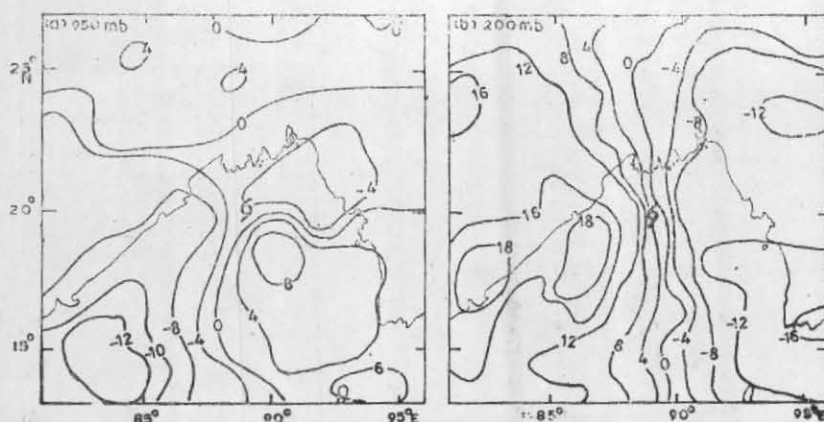
$$\text{Flux of absolute angular momentum} = V_\theta R + \frac{f^2 R^2}{2}$$

The purpose of such computations is to find out the order of magnitude of these parameters at the formative stage of a depression by computing them in as many cases as possible (whenever upper air data from the depression fields are available), so that critical values of these parameters for the developing and non-developing cases may be decided. The computations of these parameters for 6th and 7th have only been made because on 8th it was over the land.

3. Wind and temperature structure and rainfall associated with the system

The system was in its maximum intensity on 8th morning when Bhubaneswar reported wind of 30-40 kt from north to northeasterly direction at 900 m asl. Wind observations taken by the research aircraft from the depression field indicated a tilt in the circulation centre towards south with height by about 3 degree of latitude between surface and 500 mb (Fig. 2).

Dropsonde observations of temperatures around the depression at different levels from surface to 500 mb for 7 July, are shown in Fig. 2. Within the frictional layer not much of temperature change is observed. However, between 850 mb and 500 mb level within the depression field the central areas were warmer than its surroundings.



Figs. 3 (a & b). Radial wind velocity (m/s) (a) 950 mb and (b) 200 mb, 7 July 1979 (+ve values indicate outflow & -ve values indicate inflow)

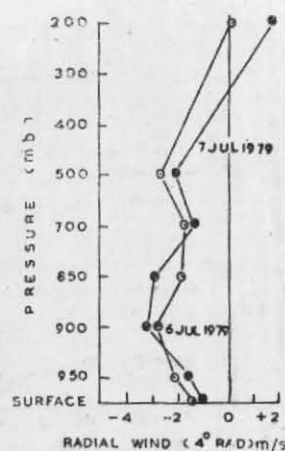


Fig. 4. Radial wind (in 4 deg. rad.) m/sec

In association with this system generally widespread rain occurred in Orissa and east Madhya Pradesh from 7 July to 9 July and in north coastal Andhra Pradesh on 8th and Marathwada, Vidarbha and west Madhya Pradesh on 9th. There had been some heavy falls in Orissa, Vidarbha and Madhya Pradesh during this period. A composite rainfall map for 7 to 9 July with isohetal pattern is shown in Fig. 1(b). Generally, 24 hourly accumulated rainfall in association with a depression is 10-20 cm and isolated falls exceeding 30 cm in 24-hour is also not uncommon (Sikka 1978). The isohetal pattern reveals that rainfall associated with the depression under study is not comparable to that of average rainfall of a depression. This may be due to the short life of the depression.

4. Radial wind

The field of radial velocity is important because the radial velocity times the radius is proportional to the radial mass flow which is consequently related with the minimum pressure. The mass convergence of the water vapour by the radial transport results, in the release of the latent heat which is in turn is related with the conversion of potential energy to kinetic energy (Miller 1964). At higher level, compensating radial mass flow outward occurs in order to achieve mass balance in a steady state. Figs. 3 (a) & (b) show the horizontal distribution of radial wind at 950 mb and 200 mb for 7 July respectively. Fig. 4 shows the vertical distribution of radial wind at 4 degree radius for 6 and 7 July.

Significant features observed in these diagrams are :

- (i) Maximum inflow is in the southwest quadrant in the lower level changing to outflow at 300 mb.
- (ii) Inflow is maximum around 900 mb and it increases with the increase in intensity.

5. Tangential wind

Fig. 5(a) shows the tangential wind at different radial for 950, 850 and 700 mb for 6 and 7 July and Fig. 5 (b) shows the vertical distribution of tangential wind at different radius for 7 July. Figures reveal that slight

increase in the strength of the tangential wind from 6th to 7th and maximum of the tangential wind is observed at about 850 mb. Compared to the intensity of the system, the strength of the tangential wind at 850 mb on 7th is quite high. The values of the tangential wind at different radii for 950 and 200 mb are given in Table 1, alongwith the other values like radial wind, mass transport, aerial divergence, vorticity etc. From the table it can be seen that in the lower levels, cyclonic winds increase with decreasing radius and at 200 mb level anti-cyclonic winds decrease with increasing radius.

6. Mass transport

Radial velocity times the radius is a measure of the mass transport. The mass transport values in different radii for 7 July, for 950 and 200 mb is shown in Table 1. The values show the decrease in the mass inflow with decreasing radius in the lower level on all the days. The mass inflow in different radii increases from 6th to 7th showing the increase in intensity from 6th to 7th. At 200 mb values show the increase in the mass outflow with increase in radius.

7. Vorticity and divergence

The fields of vorticity and divergence in lower and higher levels are generally linked with the intensity of the system. Gray (1978) has indicated that the algebraic difference between the relative vorticities at lower (950 mb) and at higher (200 mb) level is a good measure of the development of the system. The values of the areal velocity and divergence and the difference of relative vorticities at 950 and 200 mb for 7 July are shown in Table 1. The values of divergence and vorticities at different radii except at 1 degree radii are typical that of an average value of such system (monsoon depression) over the region. At 1 degree radii the computations are rather unreliable because of the error in the interpolation of the wind field when they are not actually observed. Interestingly, the difference between the values of relative vorticities at 950 mb and 200 mb in all the radii were more on 7th in comparison to 6th showing its intensification from 6th to 7th.

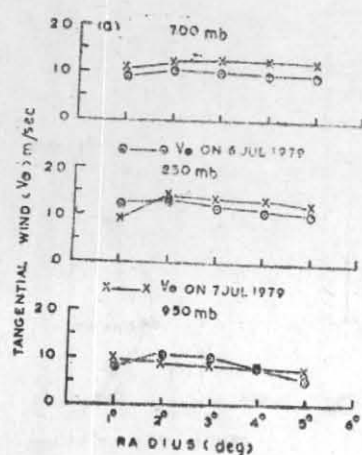


Fig. 5 (a&b)

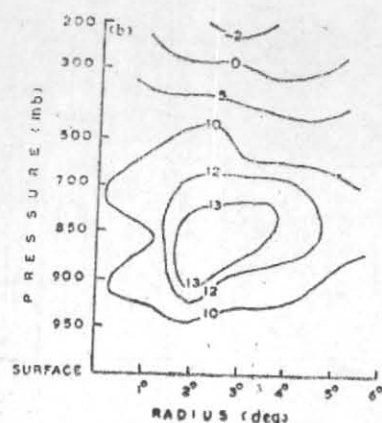
Fig. 6. Vertical velocity, 800 mb, 7 July 1979 (unit: 10^{-3} mb/sec)

TABLE 1
Dynamical parameters for the depression Bay of Bengal, 7 July 1979 (12 GMI)

Radius (Deg.) R	V_r Radial wind ($m.s^{-1}$)	V_θ Tangential wind ($m.s^{-1}$)	$V_r \times R$ Mass transport ($m.s^{-1} \text{ Deg.}$)	$\left(V_\theta R + f \frac{R^2}{2} \right) \times V_r$ Flux of absolute angular momentum $\times (10^{12} \text{ cm}^2 \text{ s}^{-2})$	Areal div. $\times (10^{-5} \text{ s}^{-1})$	Vorticity $\times (10^{-5} \text{ s}^{-1})$	$\frac{\zeta}{950-200}$ $\times (10^{-5} \text{ s}^{-1})$
950 mb							
1	-0.9	9.0	-0.9	-1.2	-1.6	16.2	16.1
2	-1.2	9.1	-2.4	-3.9	-1.1	8.2	9.4
3	-2.1	9.0	-6.3	-11.9	-1.3	5.4	6.4
4	-1.6	8.2	-6.4	-13.5	-0.7	3.7	4.0
5	-1.4	7.2	-7.0	-16.1	-0.5	2.6	2.8
200 mb							
1	1.6	0.0	1.6	0.5	2.8	0.1	
2	2.2	-1.4	4.4	3.3	2.0	-1.2	
3	2.4	-1.7	7.2	5.2	1.4	-1.0	
4	1.8	-0.8	7.2	8.1	0.8	-0.3	
5	1.4	-0.5	7.0	10.2	0.5	-0.2	

8. Vertical velocity

Calculation of vertical velocity was done by the usual kinematic method as suggested by Chien and Smith (1973) from the manually picked up grid point data at 1 degree interval. Fig. 6 shows the distribution of the vertical velocity at 800 mb for 7 July. Large upward vertical velocities are observed in the southwest and northeast of the depression centre. The distribution of the vertical velocity to a large extent was consistent with the clouding as seen in the satellite pictures.

Downward velocities are observed to the northwest and southeast of the depression centre.

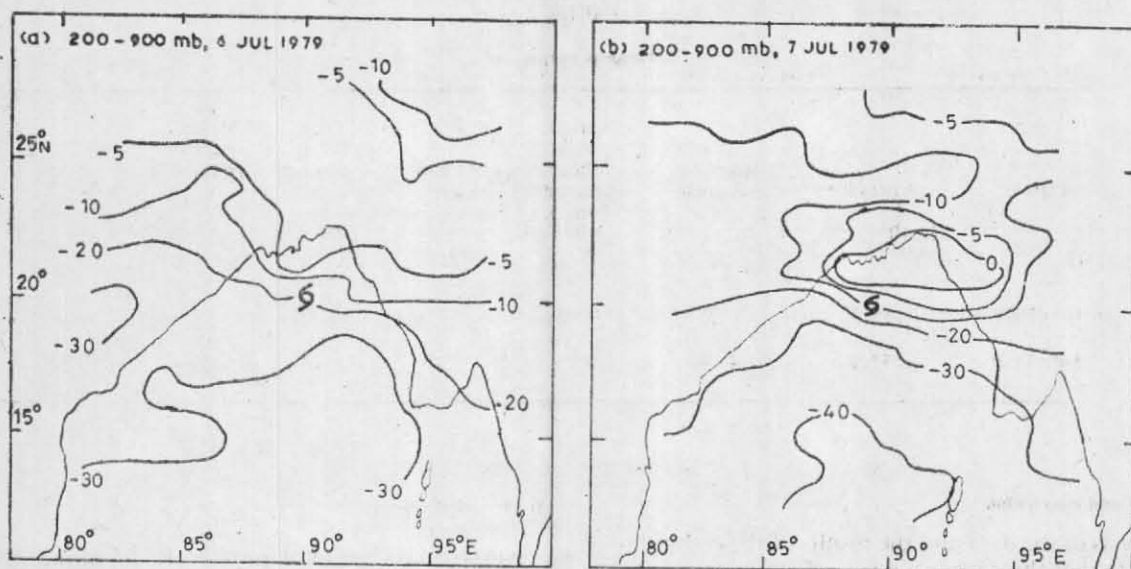
9. Flux of absolute angular momentum

The computations of absolute angular momentum

(Table 1) reveal that in the lower level the flux of absolute angular momentum inwards decrease with decreasing radius whereas in higher level (200 mb) they are increasing outwards with increase in radius. The values are comparable with the values generally seen to be associated with the developing depressions in the Atlantic. Their average values at 950 mb at 4 degree radius is 9.0.

10. Vertical wind shear

Vertical wind shear between lower and higher levels (950 mb and 200 mb) is one of the significant factors when we consider the development of a low pressure system.



Figs. 7 (a&b). Vertical wind shear (m/s/700 mb) 200-900 mb: (a) 6 July 1979 & (b) 7 July 1979

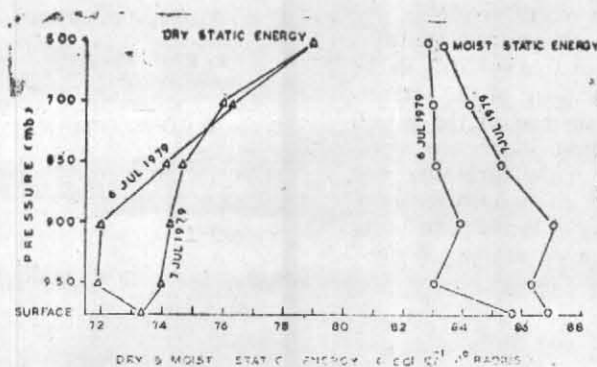


Fig. 8

The distribution of the vertical wind shear around the depression on 6 and 7 July 1979 are shown in Figs. 7(a) and 7(b). The low vertical wind shear (± 10 kt) around the low pressure system is one of the pre-requisite for its development. In the present case, the vertical wind shear on 7th was less than 10 kt and the north-south horizontal gradient of the vertical wind shear was larger on 7th than on 6th which is considered favourable for development.

11. Dry and moist static energy

The values of dry and moist static energy for 6th and 7th have been shown in Fig. 8. The values of the average dry and moist static energy computed over 4 degree radii around the centre of the depression on 7th are approximately 73 cal gr^{-1} and 87 cal gr^{-1} respectively. Though in the lower troposphere there

had been some increase in these values from 6th to 7th, no significant increase in these values is observed between 6th and 7th on the surface.

12. Genesis parameter

Gray (1978) designed a genesis parameter for getting an idea of development potential of a depression based on the product of coriolis parameter, vorticity parameter, vertical wind shear parameter, ocean energy parameter, stability parameter and relative humidity parameter. Mandal *et al.* (1981) calculated genesis parameter of an Arabian Sea cyclone based on such method. Computational methods and formulae used, have been discussed in brief earlier. In the present case, the genesis parameter is computed to be $46 \times 10^{-8} \text{ cal}^\circ\text{K s}^{-1} \text{ cm}^{-3}$ (Table 2) which is higher than that of a non-developing depression and comparable with that of a developing depression in the Atlantic.

TABLE 2
Genesis parameter

Date	Vorticity ($\times 10^{-6} \text{sec}^{-1}$)	Coriolis parameter ($\times 10^{-5} \text{sec}^{-1}$)	Vertical wind shear factor f (m s^{-1} 650 mb)	Ocean energy (10^3 cal cm^{-2})	Moist stability ($0^\circ \text{K}/$ 450 mb)	Mean humidity (RH) (%)	P ($\times 10^{-8}$ $\text{Cal}^\circ \text{K s}^{-1} \text{cm}^{-2}$)
6 July 1979	45.5	4.98	0.05	15	11.9	>70	29.9
7 July 1979	52.9	4.98	0.05	15	16.3	>70	45.8

13. Summary and conclusion

The analysis of the data and the results of the computations indicate that the depression was of warm core type. There was a slight tilt in the centre of the circulation towards south with increasing altitude. The radial wind component suggests no significant change in the values in the formative and developing stages. The distribution of two-dimensional tangential wind shows the maximum at 200 km away from the depression centre with cyclonic circulation in the lower and middle troposphere and anti-cyclonic circulation at 200 mb. Associated vergence and relative vorticity fields are typical of a monsoon depression. Computations also reveals that the difference between relative vorticity in the higher and lower level is a good measure of the intensification potential of a depression instead of the actual vorticity itself. Energy computation shows no significant change in the energy values in the formative and developing stages. Values of the genesis parameter associated with this depression in the Bay of Bengal are larger and are comparable with that of a developing depression in the Atlantic.

Acknowledgement

Authors are grateful to Dr. R. P. Sarker, Director General of Meteorology for going through the manuscript and for his valuable suggestions.

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