

On interaction between tropical cyclones over Indian seas and neighbourhood

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(Received 7 February 1978)

ABSTRACT. During November 1977 two severe cyclonic storms, one over Arabian Sea, another over Bay of Bengal came close to each other and started interacting. As a result Bay storm moved northnorthwestwards and Arabian Sea storm moved eastsoutheastwards. Based on the theory of motion of binary tropical cyclones as enunciated by Haurwitz, the angles of rotation of the binary axis have been computed and found to have excellent agreement with the observed results. Towards the end another cyclone formed over Indian Ocean south of equator. The possibility of interaction of two cyclones on both sides of equator has also been indicated.

1. Introduction

The tracks of the tropical disturbances over the Bay of Bengal and Arabian Sea as prepared by India Meteorological Department for the period 1896 to 1976 show 27 occasions of simultaneous appearance of two cyclonic systems one each in Bay and Arabian Sea. However the famous "Fujiwhara Effect" was prominently observed during November 1977 over Indian seas. Fujiwhara (1921, 1923) studied the interaction between two vortices. He showed that when two vortices in atmosphere come close to each other, they rotate in an anticlockwise direction in northern hemisphere around a common centre. During this interaction they can either repel or attract each other. The position of the common centre depends on the relative mass and intensity of the vortices. This phenomenon has been seen frequently in the Pacific and less in the Atlantic Oceans (Riehl 1954).

It is the aim of this paper to discuss the relative motion of the two cyclones which appeared during November 1977 in Bay of Bengal and Arabian Sea. In addition to these storms one more storm also appeared in Indian Ocean. The tracks of the above three cyclones as prepared taking into consideration the available conventional data, satellite cloud pictures received at Bombay and satellite tropical disturbance summary received from Washington are shown in Fig. 1. A brief history of the three cyclones is given below:

A well marked low pressure area west of Car Nicobar Islands moved northwest, concentrated into a deep depression on 9 November 1977. This system intensified into a severe cyclonic storm, (hereinafter referred to as 'A') by 10th night, crossed Tamil Nadu coast near Nagapattinam during the night of 11th. It moved westward and emerged into the Arabian Sea near Calicut on 13th morning and further moved in westnorthwest direction and was located on 15th near Lat. 13°N , Long. 66°E . It remained practically stationary for about 12 hours

and later moved slowly southwards and from 16th night it moved eastsoutheastwards and was located near Lat. 9.5°N , Long. 70.5°E by the morning of 19th. Later this system moved northeastwards, crossed Karnataka coast south of Karwar by 22nd morning.

On 13th a low pressure area formed north of Sumatra. This moved westwards and rapidly intensified into a cyclonic storm by 14th morning. On 15th morning it lay near Long. 88°E . It further intensified into a severe cyclonic storm (hereinafter referred to as 'B') on 16th morning with its centre near Lat. 7.5°N , Long. 85.5°E . From this day this system took a turn and moved northwestwards. On 17th, 'B' further intensified into severe cyclonic storm with a core of hurricane winds and moved northwestwards and later northnorthwestwards, crossed Andhra coast south of Masulipatnam by 19th night.

On 19th a depression formed over the Indian Ocean with its centre near Lat. 5.9°S , Long. 82.5°E , this system moved southwestwards upto 20th and intensified into a cyclonic storm. It further intensified into a severe cyclonic storm with a core of hurricane winds (hereinafter referred to as S) by 21st morning and lay near Lat. 11.0°S , Long. 80.5°E . This system moved due south from 21st night onwards and weakened later as seen from satellite tropical disturbance summary.

It is interesting to note from Fig. 1 that on 15th A remained practically stationary while B moved westnorthwestwards. On 16th, B took a turn towards northwest while A moved towards south. From 17th to 19th B moved generally northnorthwestwards and A towards eastsoutheast. It appears that both A and B started interacting with each other from 16th morning and showed Fujiwhara effect giving an anticlockwise rotation around each other till the night of 19th when B crossed coast and weakened. By this time S developed into a storm and

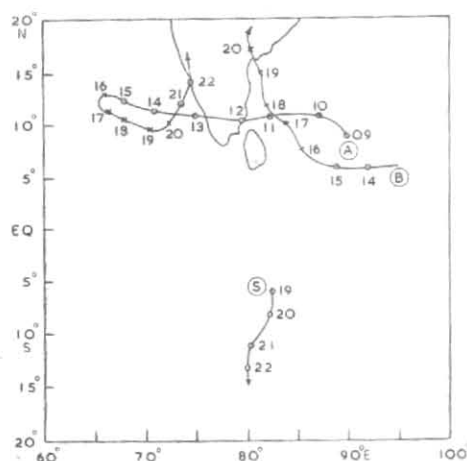


Fig. 1. Tracks of cyclones in the Indian Ocean during November 1977

exerted influence on A. As a result of mutual interaction between these two A moved in a north-easterly direction while S moved south.

2. Theory

Original treatment of interaction between vortices by Fujiwhara is complicated. We have proceeded to compute the rotation of binary vortices in the northern hemisphere by a simple method given by Haurwitz (1951).

Let us take two vortices as shown in Fig. 2 and start with the following assumptions:

- (1) Vortices are close to each other so that they can interact.
- (2) Velocity field of each individual vortex is only a function of the distance from the centre of this vortex.
- (3) Velocity of centre of each vortex due to the velocity field of this vortex is zero.
- (4) Instantaneous velocity of the centre of one vortex is entirely due to the velocity of the second vortex.
- (5) Velocities are perpendicular to the axis joining the centre of the vortex.
- (6) Velocity field of each vortex resembles a Rankine vortex.

The Rankine vortex consists of an inner core in solid rotation, with velocity distribution $v = \omega r$, where r is the distance from the vortex centre and ω the angular velocity of the rotation, and of an outer region for $r > R$ where,

$$v = \omega \frac{R^2}{r} \quad (1)$$

R is defined as the spread radius which separates an inner core in solid rotation from an outer, irrotational flow field. In fact Rankine vortex cannot

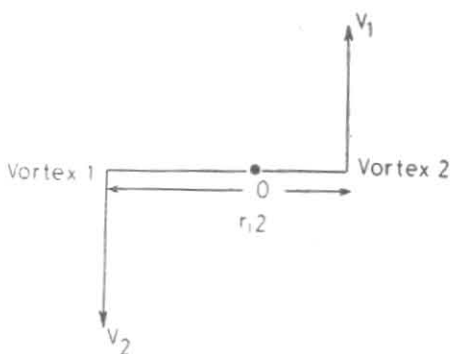


Fig. 2. Schematic of rotation of vortices (After Haurwitz)

O = centre of mass, V_1 and V_2 are instantaneous velocities of centre of vortices 2 and 1 respectively, r_{12} = Distance between the centres of vortices 1 and 2.

normally be used in dynamical reasoning because the total kinetic energy of a Rankine vortex is infinite. In tropical cyclones it has often been found that the velocity distribution resembles a Rankine vortex. As the inner core of a tropical cyclone is small, it can be assumed that each vortex is in the outer part of the other vortex so that,

$$V_i = \frac{\omega_i R_i^2}{r_{12}^2}, \quad i = 1, 2 \quad (2)$$

where V_i is the instantaneous velocity of the centre of any vortex and r_{12} is the distance between the centre of two vortices.

Let us choose

$$\bar{M}_i = \omega_i R_i^2 \quad (3)$$

where \bar{M}_i may be referred to as the "mass" of the vortex, though dimensionally it is relative angular momentum per unit mass of air about vertical axis. The angular velocity of rotation of the binary axis is given by

$$\alpha = (\bar{M}_1 + \bar{M}_2) / r_{12}^2 \text{ rad./sec} \quad (4)$$

or

$$\alpha = \left(\frac{\bar{M}_1 + \bar{M}_2}{r_{12}^2} \right) \times 49.5 \times 10^5 \text{ }^\circ/\text{day} \quad (5)$$

In order to find out α vortex masses M_1 and M_2 must be known. The mass of the vortex can be found out from the wind field since in the outer region of each vortex according to Eqns. (1) and (2),

$$V_i = \frac{\bar{M}_i}{r} \quad (6)$$

Haurwitz (1951) used gradient wind relation for calculating the mass of the vortex and obtained good results.

TABLE 1

Date (Nov 77)	Bay of Bengal					
	Position at 06 GMT (°)	r (km)	r' (km)	P (mb)	P' (mb)	$M_1 \times 10^{10}$ (cm ² /sec)
16	7.5 N, 85.5 E	160	220	1000	1004	6.272
17	10.0 N, 84.0 E	100	160	998	1000	2.373
18	12.0 N, 82.0 E	130	200	1000	1004	4.471
19	15.0 N, 81.5 E	100	170	1000	1004	2.960
20	17.5 N, 80.5 E	—	—	—	—	—

TABLE 1 (contd)

Date (Nov 77)	Arabian Sea						r_{12} (km)	Angle (α) between 06 GMT and next day 06 GMT positions	
	Position at 06 GMT (°)	r (km)	r' (km)	P (mb)	P' (mb)	$M_2 \times 10^{10}$ (cm ² /sec)		Computed	Observed
								(°/day)	(°/day)
16	13.0 N, 66.0 E	150	270	1006	1008	2.985	2200	9.46	11.5
17	11.5 N, 66.5 E	200	320	1004	1006	4.304	1930	8.87	9.5
18	10.5 N, 68.0 E	220	320	1004	1006	5.177	1500	21.2	22
19	9.5 N, 70.5 E	160	240	1004	1006	3.368	1320	17.97	18
20	9.8 N, 72.5 E	—	—	—	—	—	—	—	—

r_{12} = Distance between cyclones

The gradient wind relation is given as follows :

$$\left(\frac{V^2}{r}\right) + fV = \frac{1}{\rho} \left(\frac{\partial P}{\partial r}\right) \quad (7)$$

where, $f=2\omega \sin \phi$, the Coriolis parameter, P is the pressure and ρ is the density of air.

If we substitute Eqn. (6) in Eqn. (7) and integrate from r to r' with pressure P to P' , we get,

$$\begin{aligned} \frac{1}{2} M_i^2 \left(\frac{1}{r^2} - \frac{1}{r'^2} \right) + f M_i \ln \frac{r'}{r} \\ = \frac{P' - P}{\rho} \end{aligned} \quad (8)$$

Therefore, the vortex mass can be found by measuring the distance of two isobars from the centre and solving the quadratic Eqn. (8) for M_i .

We have used Eqn. (8) for calculating the masses of 'A' and 'B'. These values of masses were put in Eqn. (5) to get the angle of rotation of the axis.

3. Data

Satellite cloud pictures as received at Bombay and satellite tropical disturbance summary received from Washington and daily weather charts prepared at Regional Meteorological Centre, Bombay have been used in this study. It was observed during the life period of these cyclones that more conventional data were generally available over Arabian Sea and Bay of Bengal at 0600 GMT. Satellite pictures during day time were close to 0600 GMT. Hence positions of the cyclones at 0600 GMT have been taken for calculations. These are shown in Fig. 1 by cross marks.

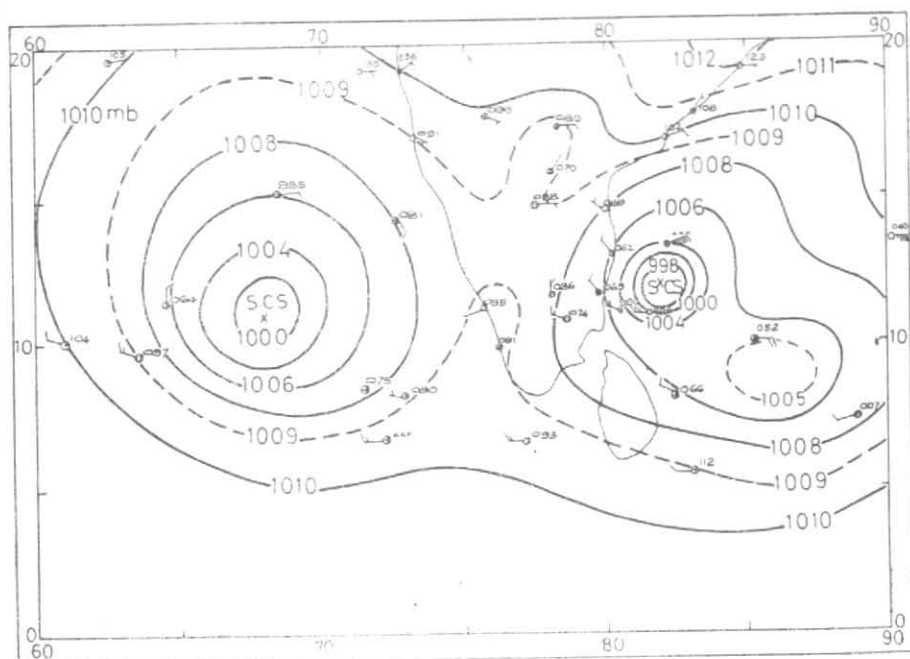


Fig. 3. Surface 0600 GMT chart of 18 November 1977

4. Computation

We solved Eqn. (5) with the help of Eqn. (8) to find out the angles of rotation of the binary axis from 16th to 19th. The values of the parameters contained in these equations along with the calculated angles and observed angles are shown in Table 1. The selection of the two isobars of each system on every day have been made on the availability of conventional observations, where the isobars were confidently drawn. As an example the surface chart of 0600 GMT on 18 November is shown in Fig. 3. Considerable care has been taken in measuring the distances r and r' of the isobars from the centre of the respective systems along the axis of the binary, and on that side of the cyclone which is farther away from the other one, as it will avoid the mutual deformation of the pressure fields acting on each other. It may be seen from Table 1 that the computed and observed angles of rotation are in excellent agreement.

The satellite cloud pictures for the above four days and of 20 and 21 November are shown in Figs. 4-9. From the results given in Table 1 it can be inferred that 'A' and 'B' interacted from 16th to 19th, confirming Fujiwhara effect over Indian seas.

In 27 cases simultaneous appearance of systems over Bay of Bengal and Arabian Sea, the Fujiwhara effect was not seen apparently because the distances between them were comparatively more or they were differing in intensity to the extent that one or both of them could not be assumed to be of Rankine vortex type. In December 1965 and September 1926 and 1966, when two storms came closer,

interactions were probably present but were not so prominent as in the present case.

It can be seen from the treatment given in the theory that interaction is due to the nature of the vortices and does not concern about the positions of vortices either north or south of equator. It is, therefore, theoretically possible that if two storms one to the north and other to the south of equator are present within reasonable distance, they may also start interacting with each other.

Interaction between cyclones across equator has been a subject of study for Indian meteorologists (Malurkar 1950; Pisharoty and Kulkarni 1956 and Mukherjee and Padmanabham 1977). Mukherjee and Padmanabham came to the conclusion that two systems on either side of equator may behave independently so far as their intensity is concerned. All the above meteorologists concluded that these cyclones may continue to move simultaneously westwards. In our present case, we got an exception to the above conclusions.

We can understand why two vortices interacting in northern hemisphere show anticlockwise rotation around a common centre and similarly clockwise rotation in the southern hemisphere. It is difficult to understand the influence of one storm on the movement of the other across the equator. According to the assumption (4) of Sec. (2), it can be seen that storms of both the hemispheres will have the tendency to move towards east due to mutual interaction as shown in Fig. 10. Air coming from southern hemispherical system after crossing equator and entering into northern hemispherical system may carry anticyclonic vorticity along

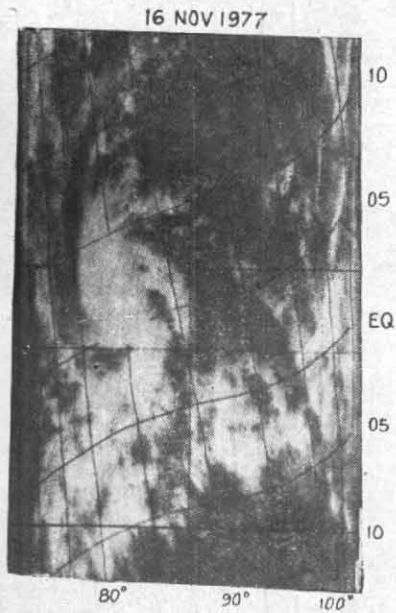


Fig. 4

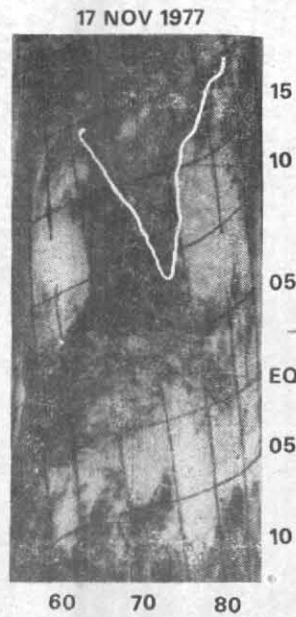


Fig. 5

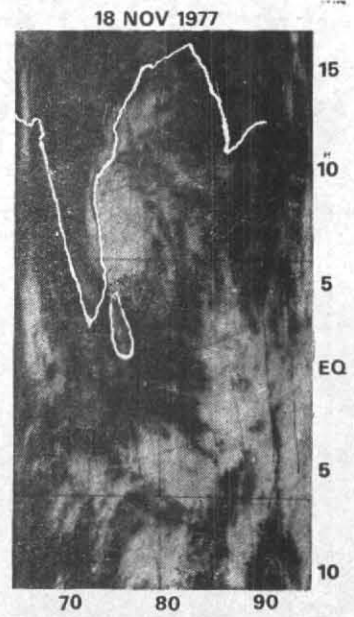


Fig. 6

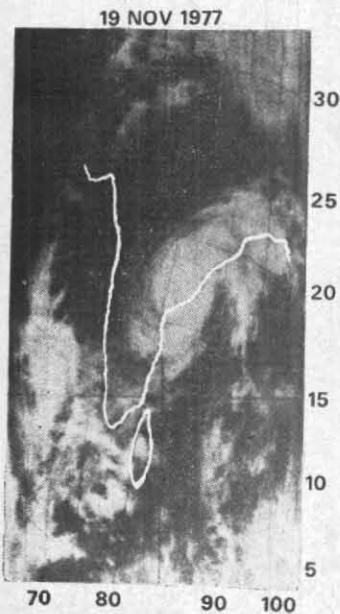


Fig. 7



Fig. 8



Fig. 9

with it. The same is true for air going from northern hemispherical system to southern hemispherical system. This will be quite prominent on the northern end of southern system and southern end of northern system, thus causing imbalance in vorticity with a relative increase in vorticity away from the equator and decrease near equator. Thus the two storms will repel each other. In the present

study the northern hemispherical storm moved northeastwards and southern hemispherical storm moved southwards after 20th. Thus they repelled each other so much so 'A' crossed coast south of Karwar and 'S' moved southwards. It can also be seen from Fig. 9 that clouds of the two systems have participated on 21st in each other circulations.

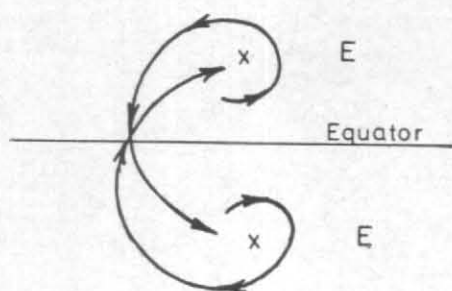


Fig. 10. Schematic diagram of interaction of two systems on both sides of equator.
(E for eastward and × for centre of system)

5. Conclusions

(1) It is obvious from the present study that 'A' and 'B' interacted and showed Fujiwhara effect prominently, *i.e.*, systems attracted each other and rotated in an anticlockwise direction around each other.

(2) As the computed angles of rotation were found to be very close to the observed angles of rotation, it can be concluded that Eqn. (5) can be applied also in Indian seas for forecasting the motion of the two interacting cyclones.

(3) At least in Indian seas the assumption that the cyclonic storm is a Rankine vortex seems to be very near to the actual conditions.

(4) It is very difficult to say under what conditions two systems will interact but it seems that the distance between the cyclones plays a dominant role.

(5) Intervening land between two cyclonic storms does not always play important role in interaction process.

Acknowledgement

Authors are thankful to Dr. B.N. Desai, retired Dy. Director General of Observatories (Forecasting) for useful discussions.

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