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Simultaneous occurrence of tropical cyclones on either side of the equator in the Indian Ocean area

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ABSTRACT. Malurkar (1950) postulated the formation of depressions or cyclones on both sides of equator within a narrow ($\leq 40°$) longitudinal belt. Pisharoty and Kulkarni (1956) conducted some case studies and came to the conclusion that they do form as postulated by Malurkar and there is mutual interaction with one another so much so that when one system intensifies the other weakens. Kuettner (1967) opined that the existence and alignment of hills in Sumatra are responsible for simultaneous occurrences of storms and depressions on both sides of equator. To verify the above conclusions the present study was undertaken. It covers an 11 year period from 1964 to 1974. During the period as many as 14 storms/depressions formed on both sides of equator. Of course, there were some years when such systems did not develop. They form in transition months with a bias towards the post monsoon season. Kuettner's conclusions are generally supported. Pisharoty and Kulkarni's conclusions could not be supported by the present study. Malurkar's conclusion that two tropical storms cannot both continue to move westwards and co-exist on either side of the equator when the longitudinal separation is small ($\leq 10°$) is also supported.

1. Introduction

The existence of two ITCZ on the equator, particularly in the Indian Ocean, had been observed by many workers. Raman (1965) stated that the mean stream analysis of charts for 700 mb level during January and July (1960 to 1964) brought out clearly the existence of independent systems of cyclonic vortices in the two hemispheres separated by a band of westerlies and that the circulation in each hemisphere is determined largely by the trough system in that hemisphere. Saha (1970) arrived at the conclusion that a double ITCZ arises as a special feature of tropical atmospheric circulation when mass sources and mass sinks are placed alternately along the equator. Ramage (1974) indicated that over the Indian and Pacific Oceans, near equatorial troughs coincide with surface temperature maxima and are the birth place of almost all hurricanes. Kuettner (1967) opined that a double vortex system develops south and north of the equator over the Indian Ocean during deep easterly equatorial flow over the Indian Ocean. The vortex pairs become quickly active weather centres, some of them transforming into tropical storms. Malurkar (1948, 1950 and 1958) stated that further westward movement for both of two westward moving tropical cyclonic storms situated on either side of the equator in a small longitudinal sector is restricted that (*a*) either or both cyclonic storms may fill up or (*b*) either or both cyclonic storms might recurve without explicitly mentioning that one might recurve and the other fill-up. Pisharoty and Kulkarni (1956), examined storms in the Bay of Bengal and Arabian Sea in relation to the nearly contemporary storms in the South Indian Ocean west of Long. 100°E, for a period of nearly 20 years, in the light of the ideas presented by Malurkar, and remarked that storms of the northern hemisphere weaken, with some exceptions, when there are developing storms to the south of the equator within a longitudinal belt of about 40 degree. Daily depiction of Tiros nephanalyses during the IIOE period (1963-64) brought to light the occurrence of distinct zones of cumulonimbus activity in association with the troughs in the northern and southern hemispheres. With the help of the Indian Ocean pictures received daily from the satellites, the systems on either side of the equator in the Indian Ocean area that existed simultaneously have been tracked during the eleven year period 1964-74. There were 14 cases of twin systems during this period. An interesting case of three systems occurring simultaneously, two in the northern hemisphere and one in the southern hemisphere was noticed in October 1971.

2. Data

The A.P.T. ground station at Bombay has been receiving daily satellite pictures since 1964.

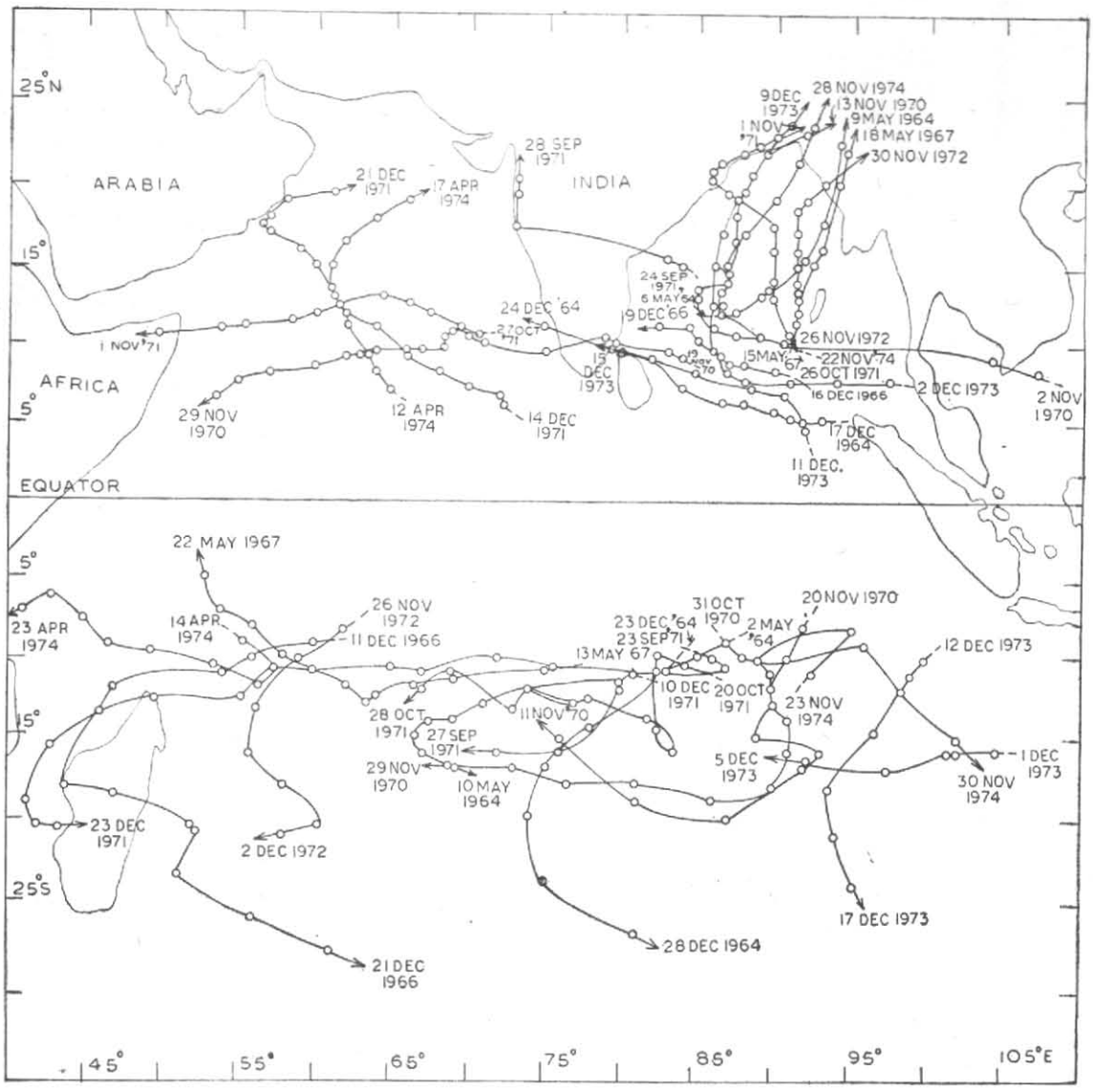

Fig. 1. Tracks of disturbances on both sides of equator (1964-1974)

The station is also issuing daily bulletins depicting the observed cloud features and the centres of tropical systems found in the satellite pictures. A daily bulletin *Satellite Tropical Disturbances Summary* is issued from U.S.A. giving the centres of disturbances observed in the oceanic areas. The India Meteorological Department publishes Tracks of Storms and Depressions in the Bay of Bengal and the Arabian Sea every year. An account of such storms are published under 'Weather' in the *Indian Journal of Meteorology & Geophysics*. The publications 'Meteorological Summary — Tropical Cyclones in the Northern Australian Regions 1963-64 to 1971-72' by the Bureau of Meteorology, Australia, were consulted for the tracks and accounts of the storms that occurred in the south Indian Ocean during this period. Mauritius Meteorological Services publish accounts of the disturbances south of the equator to the west of Long. 100°E in their Annual Reports. All the tracks were constructed with the help of the data available in the above material.

3. Discussion

During the eleven year period 1964-74 there were 14 cases of depressions or cyclonic storms in the Arabian Sea and Bay of Bengal along with the co-existence or the development of a storm in the south Indian Ocean. Out of the 14 cases

studied, storms in both of hemispheres weakened or intensified simultaneously on 6 occasions. The northern storm intensified while the southern one weakened on 5 occasions, the northern system remained same while the southern system intensified on two occasions. In a solitary case the northern hemisphere storm weakened while the southern hemisphere system intensified. Details of all the systems are given in Table 1 and the tracks of the storms are given in Fig. 1. All the fourteen cases are discussed below :

3.1. *Case No. 1 (2-10 May 1964)*

The cyclonic storm *Norma-Karen* in the south Indian Ocean formed near 10°S, 85°E and moved west. On the 3 May 1964, it changed course to westsouthwest, then west whilst slowing down and merging into residual depression *Jessie*. It then moved very slowly west without further intensification, then southwest before recurving completely to southeast and filling up. In the north Indian Ocean, a low pressure area moving from the south Andaman Sea into the northwest Bay of Bengal recurved northeastwards and intensified into a depression by the morning of 6 May 1964. It further intensified into a cyclonic storm of small extent by the next morning and continuing its northeastward movement crossed the Arakan coast during the night of 8th-9th, later it weakened rapidly.

3.2. *Case No. 2 (17-28 December 1964)*

Cyclonic storm *Edna* formed on the 23 December 1964 in a vast area of low pressure midway between Diego Garcia and Cocos Island moving southwesterly at a moderate speed but slowing down the next day. Photographs from Tiros indicated the position of the centre at Lat. 14°S, Long. 78°E and confirmed the presence of a well defined vortex. On the 25th, the course changed to southsouthwest and then to south. This storm then continued to move southeasterly at a slightly greater speed but was already filling up on the 27th. In association with a low pressure wave moving from the east a depression formed in extreme southeast Bay of Bengal and adjoining south Andaman area on the morning of 17 December 1964 with centre near Lat. 5·0°N, Long. 93·0°E. Moving slightly westwards, it intensified into a severe cyclonic storm by the morning of 20th with centre near Lat. 5·0°N, Long. 91·0°E. Moving westnorthwestwards, it lay centred near Lat. 7°N, Long. 84°E on the morning of 22nd. Thereafter it moved rapidly northwestwards and was centred near Lat. 9°N, Long. 82°E on the evening of 22nd. It then took a westnorthwesterly course and moving across the Palk strait crossed the Madras coast near Tondi on the afternoon of 23rd. It weakened into a cyclonic storm by the evening of 23rd and merging into the southeast Arabian Sea off Kerala coast as a depression on 24th moved away westwards as a low pressure area.

3.3. *Case No. 3 (11-21 December 1966)*

A circulation with a low pressure centred at 11°S, 61°E remained a feature of the surface chart for almost a week in early December 1966. On the 4th, the system had a diameter of over 800 miles, but the wind strength was as low as 10-15 kt. Intensification of the southern anticyclone in the following day was accompanied by a slight increase of wind and a reduction of the area covered by the perturbation. On the 7th, the outermost closed isobar was only about 6 degrees of latitude in diameter. Upto the 11th, the disturbance remained in this quiescent state, but on that date, it intensified to some extent and started moving westwards passing the longitude of Agalega in the night of the 11th to 12th. At this stage it was named *Colette*. At 1117 GMT, the 13th ESSA photographs were reported to be showing a vortex centred at 12°S, 51°E with an overcast area of 6° in diameter. The system went round the north coast of Madagascar and moved southwards in the Mojambique channel, entering Madagascar near 17°S on a southeasterly course. After crossing that island, *Colette* emerged over the ocean on the 17th and moved slowly in a general southerly direction as indicated in the track chart for about 4 days but there was no great intensification. It is only on the 20th, that wind of 40 kt were reported for the first time, near Lat. 25°S and this moderate intensity maintained on the 21st, but after that date no observations were received. A low pressure area from the east moved into the south Andaman Sea on the 13 December 1966. It intensified into a depression by the morning of 16th with centre near Lat. 8·0°N, Long. 90·0°E. Moving in a westnorthwest direction it further intensified into a deep depression by 18th morning with centre near Lat 9·5°N, Long. 86·0°E. It took a westerly course from 19th morning and weakened into a low pressure area by 20th of the Madras coast. Moving across the extreme south Peninsula, it passed off the Maldive area by 22nd.

3.4. *Case No. 4 (13-22 May 1967)*

Cyclonic storm *Kathy* was formed 300 miles southeast of Diego Garcia on the 13th May 1967. On the 14th, it was centred at 11·5°S, 69°E and

TABLE 1

Positions of disturbances in both hemispheres

Date	Time (GMT)	Position (°N)	Position (°E)	Intensity
		(1) May 1964		
6	03	12·0	86·5	Dep
	12	12·0	87·5	Dep
7	03	13·0	89·0	CS
	12	13·5	89·5	CS
8	03	15·5	92·0	CS
	12	17·5	93·0	CS
9	03	22·5	94·0	Dep
		(2) December 1964		
17	03	5·0	93·0	Dep
18	03	5·0	93·0	Dep
19	03	5·0	92·0	Dep
20	03	5·0	91·0	SCS
	12	5·5	90·0	SCS
21	03	6·0	88·0	SCS
	12	6·0	86·5	SCS
22	03	7·0	84·0	SCS
	12	9·0	82·0	SCS
23	03	9·5	80·0	SCS
	12	10·5	78·0	CS
24	03	11·0	75·0	Dep
		(3) December 1966		
16	03	8·0	90·0	Dep
	12	8·5	88·0	Dep
17	03	8·5	87·0	Dep
	12	9·0	86·5	Dep
18	03	9·5	86·0	Dep
	12	10·0	85·0	Dep
19	03	11·0	84·5	Dep
	12	11·0	82·5	Dep
		(4) May 1967		
15	03	11·5	91·5	Dep
	12	12·0	91·5	Dep
16	03	13·0	91·5	CS
	12	13·5	91·5	SCS
17	03	15·0	92·5	SCS
	12	16·0	93·0	SCS
18	03	20·0	94·0	SCS
	12	22·0	94·5	Dep

Date	Time (GMT)	Position (°S)	Position (°E)	Intensity
		Karen		
2		10·0	85·0	
3		11·0	81·0	CS
4		12·0	74·0	CS
5		13·0	71·0	CS
6		14·0	69·0	CS
7		14·0	67·5	CS
8		15·0	66·5	CS
9		16·0	67·0	CS
10		17·0	69·0	CS
		Edna		
23		11·0	83·0	CS
24		14·5	78·0	CS
25		17·0	75·0	CS
26		20·0	74·0	CS
27		24·0	75·0	CS
28		27·0	81·0	CS
		Colette		
11		9·0	60·0	
12		10·0	56·0	CS
13		11·0	54·0	CS
14		12·0	47·0	CS
15		18·0	44·0	CS
16		18·5	47·0	CS
17		20·5	52·0	CS
18		21·0	52·5	CS
19		23·5	51·0	CS
20		26·0	56·0	SCS
21		18·0	61·0	SCS
		Kathy		
13		11·0	75·0	
14		11·5	69·0	CS
15		12·0	66·5	CS
16		12·5	64·0	Dep
17		13·0	63·5	Dep
18		12·0	62·0	Dep
19		10·0	58·0	Dep
20		8·0	56·0	Dep
21		7·0	54·0	Dep
22		5·0	53·0	Dep

TABLE 1 (*contd.*)

Date	Time (GMT)	Position (°N)	Position (°E)	Intensity	Position (°N)	Position (°E)	Intensity	Date	Time (GMT)	Position (°S)	Position (°E)	Intensity
					(5) November 1970					**Andrea**		
2	0811	8·0	107·0	C+				31 (Oct)		9·0	87·0	B
3	0901	9·0	104·0	C				1		10·0	88·0	C
5	0859	10·0	90·5	B				2		10·0	89·0	C+
8	0300	12·5	86·5	Dep				3		11·0	90·0	C+
9	0300	13·5	86·5	CS				4		13·0	90·0	X1
10	0300	14·5	87·0	CS				5		15·0	89·0	X1
11	0300	16·5	87·5	SCS				6		16·0	93·0	X2
	1200	18·0	87·5	SCS				7		17·0	92·0	X1
12	0300	19·5	88·0	SCS				8		18·0	90·0	C
	1200	22·0	89·5	SCS				9		20·0	87·0	C
13	0300	23·0	92·0	CS				10		19·0	81·0	C
								11		15·0	76·0	C
					(6) November 1970					**Carmen**		
19	0300	9·0	84·0	Dep				20	0000	8·0	92·0	B
	1200	9·5	83·0	Dep					1200	10·0	91·0	B
20	0300	10·0	79·5	Dep				21	0000	12·0	90·0	B
	1200	10·5	79·0	Dep				22	0000	14·0	91·0	X1
21	—	9·5	75·0	C—				23	0000	16·0	91·0	X1
22	0300	10·0	71·0	Dep				24	0000	18·0	90·0	C
23	0300	10·5	70·0	Dep				25	0000	19·0	86·0	C
	1200	11·0	69·0	Dep				26	0000	18·0	81·0	C
24	0300	10·5	68·5	Dep				27	1024	18·0	76·5	C
	1200	9·5	68·5	Dep				28	1121	17·0	73·0	..
25	0300	9·5	67·0	Dep				29	1022	17·0	69·0	..
	1200	9·5	66·0	Dep								
26	0300	9·5	64·0	DD								
	1200	9·0	63·0	DD								
27	0300	9·0	62·0	DD								
	1200	8·5	60·0	DD								
28	0300	8·0	57·0	CS								
	1200	7·5	55·0	CS								
29	..	6·5	53·5	C								
					(7) September 1971							
24	0300	15·0	84·0	Dep				23	0434	10·0	86·0	DA
	1200	15·5	83·0	Dep				24	0815	10·5	87·0	B
25	0300	16·5	80·5	Dep				25	0421	11·5	80·0	B
26	0401	17·5	73·0	C+					0913	12·0	80·0	B
27	0552	19·5	73·0	B				26	1008	16·0	76·0	C
28	0448	20·5	73·0	B				27	—	16·0	72·0	
					(8) October 1971							
26	1200				10·5	91·0	Dep	20	0436	10·5	84·5	B
27	0300	10·5	70·5	Dep	13·0	90·0	Dep	21	0332	10·0	82·5	C+
	1200	11·0	69·5	Dep	14·0	90·0	CS	22	0423	11·0	82·5	B
28	0300	12·0	67·5	Dep	16·0	90·0	SCS	23	0943	14·5	82·5	X3
	1200	12·5	66·0	Dep	17·5	90·0	SCS	24	0846	16·0	83·5	X3
29	0300	13·0	64·5	Dep	19·0	87·5	SCS	25	0944	14·0	82·0	C—
	1200	12·5	61·5	CS	19·5	87·0	SCS	26	0358	12·5	78·0	C—
30	0300	12·0	60·0	CS	20·5	86·0	SCS		1038	13·0	77·0	C—
	1200	11·5	58·5	CS	21·0	86·0	Dep	27	0444	12·0	74·0	C—
31	0300	11·0	55·5	SCS	21·5	86·5	LPA		0917	13·5	73·0	C—
	1200	11·0	54·0	SCS	22·0	88·0		28	0541	11·0	69·0	Vortex
1 (Nov)	0300	10·5	50·0	CS	22·5	89·0			1050	12·0	67·0	Weak
	1200	..	..	Dep	23·0	90·0						centre
					(9) December 1971					**Agnes**		
14	0300	6·0	72·5	Dep				10		11·0	81·0	
	1200	6·5	72·0	Dep				11		10·5	75·5	
15	0300	7·0	70·0	Dep				12		10·0	72·0	
	1200	8·0	68·0	Dep				13	0939	11·0	67·0	X2

TABLE 1 (*contd*)

Date	Time (GMT)	Position (°N)	Position (°E)	Intensity	Date	Time (GMT)	Position (°S)	Position (°E)	Intensity
16	03	9·0	66·0	CS	14	0532	10·5	65·0	X2
	12	11·0	64·0	CS	15	1136	11·0	60·0	X2
17	03	12·0	62·0	SCS	16	0506	10·5	57·5	X2
	12	13·0	61·0	SCS		1040	12·5	55·5	X3
18	03	15·0	60·0	SCS	17	1138	12·5	50·0	X3
	12	16·0	59·0	SCS	18	1233	13·5	46·0	X2
19	03	17·0	57·0	CS	19	1136	15·5	43·0	X3·5
	12	17·5	56·5	Dep	20	1130	19·0	41·5	C+
20	03	18·0	57·0	Dep	21	1237	20·5	42·0	C+
	12	19·0	58·9	Dep	22	1237	20·5	42·0	C+
21	03	19·5	61·0	Dep	23	1140	20·5	43·5	C
					(10) November 1972			Ariane	
26	03	13·5	91·5	Dep	26		8·0	62·0	
	12	14·0	91·5	Dep	27		10·0	59·0	Dep
27	03	15·0	91·5	Dep	28		13·0	56·5	CS
	12	16·0	91·5	Dep	29		16·0	56·0	CS
28	03	16·0	91·5	Dep	30		18·0	58·0	SCS
	12	17·0	91·5	Dep	1 (Dec)		20·5	60·5	SCS
29	03	18·5	91·5	Dep	2 (Dec)		21·0	58·0	CS
	12	19·0	92·0	Dep					
30	..	20·0	93·0	Dep					
					(11) December 1973				
2	..	7·5	97·5	DA					
3	..	7·5	94·0	DA	1	0058	15·8	104·7	T 3·0
4	..	7·5	91·0	B	2	0153	15·8	102·0	T 2·5
5	03	7·5	88·0	Dep	3	0054	15·5	102·0	T 2·0
	12	8·0	87·0	Dep	4	0148	17·0	97·5	T 2·0
6	03	9·0	86·5	CS	5	0246	16·5	92·2	T 1·5
	12	9·5	86·0	CS					
7	03	11·0	86·0	SCS					
	12	12·5	86·0	SCS					
8	03	15·0	86·0	SCS					
	12	17·0	86·5	SCS					
9	03	20·5	88·5	SCS					
	12	23·5	91·0	Dep					
					(12) December 1973				
11	1454	4·5	92·0	DA	12	0122	10·0	100·0	T 1·5
12	0337	6·8	90·9	T2·0	13	0218	11·0	99·0	T 2·0
13	1200	7·0	88·5	Dep	14	0127	14·9	96·7	T 3·5
14	0300	8·0	85·0	Dep	15	0222	18·0	93·9	T 4·0
	1200	9·0	82·0	Dep	16	0124	21·0	94·2	T 3·0
15	0300	9·5	80·0	Dep	17	0218	24·0	95·5	T 2·0
	1200	9·5	79·5	Dep					
					(13) April 1974				
12	03	7·0	65·0	Dep					
13	03	8·0	64·0	Dep	14		9·0	55·5	DA
	12	10·0	63·5	CS	15		10·5	57·7	T 1·5
14	12	11·0	62·0	CS	16	1718	11·9	56·3	T 2·0
15	03	13·0	61·0	CS	17	0400	10·3	53·5	T 2·5
	12	15·5	61·0	CS	18	0514	9·8	51·0	T 2·5
16	03	16·5	62·0	CS	19	0429	9·6	49·4	T 3·0
	12	18·0	64·0	Dep	20	0539	9·0	46·8	T 2·0
17	03	19·0	66·0	Dep	21		7·5	45·0	T 2·5
					22	1834	6·0	43·0	T 2·5
					23	0517	7·0	41·0	T 2·0
					(14) November 1974				
22		10·0	90·0	T 2·0					
23		10·5	89·0	Dep	23		11·3	92·5	T 1·5
24	03	10·5	87·5	CS	25		8·0	95·0	T 2·0
	12	11·0	86·0	CS	26		10·0	89·0	—
25	03	13·0	85·0	CS	27	1458	9·0	96·0	T 1·5
	12	13·5	85·0	SCS	29	0210	12·0	98·5	T 1·5
26	03	14·0	87·0	SCS	30		15·0	102·0	T 3·5
	12	15·0	87·0	SCS					
27	03	17·0	88·0	SCS					
	12	19·0	90·0	SCS					
28	03	21·5	91·5	SCS					
	12	23·5	92·5						

Dep = Depression, SCS = Severe Cyclonic Storm, DA = Disturbed Area, T 1·5 etc=Dvorak's Code,
CS= Cyclonic Storm, DD = Deep Depression, LPA = Low Pressure Area
C, C+, X1, X2, X3, etc.—Tropical distrubance Classification

was of atleast moderate intensity as evidenced by ship's report in the vicinity. It was of small diameter, but the gradient was fairly tight in the south. Movement was in a nearly easterly direction at about 12 kt upto 15th. There was considerable slowing down after that date when the system started weakening and drifting erratically in the area north of St. Brandon. The centre passed between Agalega and Seychelles on a northwesterly course in the morning of the 21st. The storm filled up in the northwestern neighbourhood of Seychelles. Under the influence of a trough of low pressure a depression formed by the morning of 15th with centre near 11·5°N, Long. 91·5°E. Moving northwards it intensified into a cyclonic storm by the next morning centred near Lat. 13·0°N, Long. 91·5°E. Later it moved northeast/northnortheastwards and further intensified into a severe cyclonic storm by 17th morning centred near Lat. 15·0°N, Long. 92·5°E. Crossing the Arakan Coast between Sandoway and Akyab on the early morning of 18th, it rapidly weakened and moved away northnortheastwards as a low pressure area.

3·5. *Case No. 5 (31 October to 13 November 1970)*

(*a*) *Development* — The A.P.T. Station identified a system as '*C plus*' at Lat. 8°N and Long. 107·0°E in the satellite picture received at 0811 GMT on 2 November 1970. It was located at Lat. 9·0°N, Long. 104·0°E at 0901 GMT on 3rd classified as 'C' and on 5th at 9·0°N, 90·5°E at 0859 GMT with intensity 'B'. Probably the system weakened while crossing Thailand at about Lat. 10°N. On 8th, it was declared as a depression with its centre near 12·5°N, 86·5°E approximately 650 km west of Port Blair. Moving very slowly northwards, it intensified into a cyclonic storm on the morning of 9th near 13·5°N, 86·5°E. It was practically stationary near 14·5°N, 87·0°E from the 9th evening to the 10th evening. Later, moving northnortheastwards it intensified into a severe cyclonic storm which was centred on the morning of 11th near 16·5°N, 87·5°E. It crossed Bangla Desh coast during the early part of the night on the 12th. It was centred about 100 km southsoutheast of Agartala on the morning of 13th as a cyclonic storm. Thereafter it weakened rapidly into a low pressure area over south Assam by the same evening. The storm caused fairly widespread rain during its passage, unprecedented havoc on the coastal districts of Bangla Desh and sinking of a merchant ship in the Bay of Bengal. The system in the southern hemisphere was named as *Andrea* by the Australian Bureau of Meteorology. This storm remained over tropical waters throughout its life. It commenced as a weak tropical low in an area to the westnorthwest of Cocos Island and moved southward, then eastward. It then curved to the southwest and northwest, finally filling in tropical waters over the central Indian Ocean. It was a severe storm for about 2 or 3 days of its life time and hurricane force winds probably would have been experienced close to the storm centre. Very few reports of the storm are available. On the morning of 31 October, a weak tropical low with a central pressure of 1006 mb was located about 1000 km westnorthwest of Cocos Island. During the next few days this system drifted southeastwards and then south and slowly deepened. However, on the morning of 4 November, the system began to deepen and accelerate towards the southsouthwest. On the morning of 5 November the centre recurved and moved eastward. By the morning of 6th, *Andrea* had reached maturity with a central pressure of 970 mb located about 500 km southwest of Cocos Island. It then turned to the southwest and remained a severe storm through most of 7 November. During 8 and 9 November it continued on a southwesterly track and weakened. The central pressure on the morning of 9 November was 1000 mb. Late on the 9th, *Andrea* was a weak tropical low. It recurved to the westnorthwest and finally filled over tropical waters on 11 November.

(*b*) *Rainfall* — The only land station affected by cyclone *Andrea* was Cocos Island. The rainfall recorded for 24 hours ending at 0900 local time on 4, 5, 6 November was 9·4, 42·9 and 13·2 mm respectively. A ship 190 km west of the centre at 1200 GMT of 5 November reported showers. The Bay of Bengal storm caused widespread rain in the Bay Islands from 8th to 11th with scattered very heavy falls on the 8th and 9th. There was also fairly widespread rain in Gangetic West Bengal on the 12th and 13th and in south Assam on 13th and 14th. The principal amounts of heavy rainfall were : on 8th, 21 cm at Hut Bay, 13 cm at Port Blair and 8 cm at Long Island and Nancowry; on the 9th, 22 cm at Maya Bunder, 12 cm at Long Island and 10 cm at Port Blair.

(*c*) *Damages* — Press reports indicated that the Bay of Bengal cyclone caused unprecedented havoc on the off-shore islands and in the coastal district of Bangla Desh. The damage was mostly on account of storm surges, resulting in the death of a few lakhs of people with damage to crops and property. The heavy rain which it caused in the Bay Islands on the 8th and 9th resulted in floods and damage to property. There was also considerable damage to houses and crops in the Mizo hills district of south Assam. Some damage to

TABLE 2

Data from satellite photographs — Storm of 31 October to 13 November 1970

Satellite	Northern hemisphere (Bay of Bengal)				Southern hemisphere (*Andrea*)				Dia. of overcast Lat.
	Date/ Time (GMT)	Centre (°N)	Centre (°E)	Stage & category	Date/Time (GMT)	Centre (°S)	Centre (°E)	Stage & category	
ESSA 8					31 0259	9·0	87·0	B	
ESSA 8					01 0359	10·0	88·0	C	
ITOS 1					01 0902	11·0	89·0	C+	
ITOS 1					01 2142	11·0	90·0	C+	
ESSA 8					02 0250	11·0	90·0	C+	
ITOS 1	02 0811	8·0	117·0	C+	02 0956	11·0	90·0	C+	
ITOS 1					02 2044	11·0	90·0	C+	
ESSA 8	03 0329	8·0	104·0	C	03 0346	12·0	89·0	C+	
ITOS 1	03 0856	9·0	104·0	C	03 0856	11·0	89·0	X 1	3
ESSA 8					04 0243	12·0	90·0	X 1	4
ITOS 1					04 0952	13·0	90·0	X 1	5
ESSA 8					05 0335	15·0	89·0	X 1	6
ITOS 1	05 0853	10·0	90·5	B	05 0853	15·0	90·0	X 1	8
ITOS 1					05 0138	15·0	92·0	X 2	8
ESSA 8					06 0231	16·0	93·0	X 2	7
ITOS 1					06 0950	17·0	92·0	X 3	3
ESSA 8					07 0322	17·0	92.0	X 1	4
ITOS 1	07 0351	10·0	90·0	B	07 0851	17·0	91·0	X 1	4
ITOS 1	08 0948	11·0	87·0	B	08 0948				
ESSA 8	09 0440	15·0	87·0	X 2	09 0309	20·0	86·0	C	
ITOS 1	09 0853	16·0	87·0	X 3					
ESSA 8	10 0337	15·0	87·0	X 3	10 0400	19·0	80·0	C	
ITOS 1	10 0945	14·5	87·5	X 3	10 0945	18·0	79·0	C	
ESSA 8	11 0428	16·5	87·5	X 3					
ITOS 1	11 0859	17·0	87·5	X 2·5	11 1041	19·0	71·0	C-	
ESSA 8	12 0330	19·5	88·5	X 4					
ITOS 1	12 0956	21·0	89·5	X 2·5					
ESSA 8	13 0416	23·0	92·0	C					
ITOS 1	13 0848	22·0	92·5	C C					

B, C, C+, X1, X2, X3, etc — Tropical disturbance classification

houses and crops was also reported from the southern parts of 24 Parganas. Paradeep port in Orissa was reported to have suffered damage. No damage was reported from the storm *Andrea* in the southern hemisphere.

(d) *Seas* — The ship M. V. *Mahajagamitra* with cargo and 50 persons on board was reported to have been lost in the Bay of Bengal cyclone. In the South Indian Ocean, rough seas and a moderate to heavy swell were reported by ships within 530 km of the centerduring the period 2 to 6 November. The highest sea reported was 20 ft on 4 November by a ship 400 and 515 km southeast of the centre at 1200 and 1800 GMT respectively. The heaviest swell reported was 26 ft from the southsoutheast at 1200 GMT on 5 November, by a ship 160 km west of the centre.

(e) *Satellite analysis* — Cloud satellite pictures from ESSA-8 and ITOS-1 were available daily. Data from selected satellite pictures are given in Table 2.

3.6. *Case No. 6 (19 to 29 November 1970)*

(*a*) *Development* – Washington Bulletin indicated stage 'B' at Lat. 9°N, Long. 89°E in the ITOS picture received at 0851 GMT on 17 November 1970. No identification of this system was contained in their Bulletin of 18th. India Meteorological Department declared in the morning bulletin of 19th that a low pressure area moving westwards from south Andaman Sea, concentrated into a depression near 9°N, 84°E. The depression became deep on that evening and moving westnorthwest, crossed the Tamil Nadu coast near Vedaranniyam on the forenoon of 20th. Thereafter it weakened into a low over Tamil Nadu by night, merged near the Laccadive Islands on the 21st and concentrated again into a depression in the morning of 22nd near 10°N, 71°E. Moving westwards it became deep on the morning of 26th when it was centred near 9·5°N, 64·0°E. Subsequently moving westsouthwestwards, it intensified into a cyclonic storm on the morning of 28th near 8°N, 57°E and thereafter rapidly weakened into a low pressure off the Somalia Coast by the next day. The southern hemisphere system was named as *'Carmen'* by Australian Bureau of Meteorology. This developed from a closed low of 1002 mb about 600 km northwest of Cocos Island on the morning of 20 November. The system was imbedded in a convergence zone extending across the Indian Ocean in the vicinity of 10°S. The centre moved steadily southsouthwest during 20 November with a little deepening. During 21 and 22 November it curved to the southsoutheast and intensified. The storm reached maturity during 23 November with a central pressure of 990 mb and curved to the southwest. On 24 November, the cyclone began to decay and move in a westerly direction. During the next few days it drifted across the central Indian Ocean as a weak tropical low of about 1006 mb. ITOS-1 satellite pictures at Bombay showing both these systems on 26, 27 and 28 November are given in Figs. 2, 3 and 4.

(*b*) *Rainfall* — The northern storm caused fairly widespread rain in Tamil Nadu from the 19th to 21st with scattered heavy to very heavy falls in coastal Tamil Nadu. Low lying areas in coastal belt from Pondicherry to Atiramapattinam were reported to have inundated. Rameswaram and Pamban experienced squally weather. The principal amounts of heavy rainfall were : on the 19th, 13 cm at Cuddalore; on the 20th, 21 cm at Nagapattinam, Pondicherry and Vedaranniyam and 13 cm at Atiramapattinam; on the 21st, 19 cm at Madras Airport and 15 cm at Madras City. Cuddalore recorded an exceptionally heavy rainfall of 31 cm on 20th. The system caused fairly widespread rain over Arabian Sea Islands from the 22nd to 24th. Cyclone *Carmen* remained over the sea during her life time and no rainfall reports from close to the centre are available. However, on 21 and 22 November the centre passed about 450 km to the west of Cocos Island and the rainfall total for the 2 days was 84.1 mm.

(*c*) *Damage* — While no damage was reported about the storm *Carmen*, damage to houses and crops was reported in Tanjavur district from the northern hemisphere system. Heavy rain in Madras on the 21st paralysed the life in the city, flooding low lying areas and rendering many people homeless.

(*d*) *Seas* — A ship reported on 25th at 0800 GMT showers and wind speed of 32 m.p.s. (62·2 kt) at the position 10·03°N, 65·48°E, while the Arabian Sea storm was centred at 9·0°N, 66·5°E. No sea reports were available in the south Indian Ocean but rough seas and a moderate to heavy swell would probably have been experienced within 100 miles of the centre of the cyclone *Carmen*.

(*e*) *Satellite analysis* — Cloud photographs received from ESSA 8 and ITOS 1 satellites depicted the various stages and location of the centre, during most of the lifetime of these two systems. The estimated position of the centre based on a selection of satellite pictures is shown in Table 3. An estimate of the various stages is given together with the diameter of the overcast wherever available.

3.7. *Case No. 7 (23 to 28 September 1971)* — Both systems intensified into depressions only. The northern hemisphere system travelled westerly for 2 days and curved northwards for the next 2 days confining itself to the latitudes 15°N to 20°N. The southern hemisphere system moved, within the latitudes 10°S to 16°S, first southeastwards, then westwards for the first two days, turning southwest next day and again moving westwards before dissipating.

3.8. *Case No. 8 (20 October to 1 November 1971)* — There were two storms in the northern hemisphere one each in the Arabian Sea and Bay of Bengal and one system in the southern hemisphere. All systems intensified into cyclonic storms. The system in the Bay of Bengal moved generally northwards, while the system in the Arabian Sea moved eastwards. The southern hemisphere system initially moved south for two days, made a loop and then travelled generally westwards later for the next 3 days before dissipating.

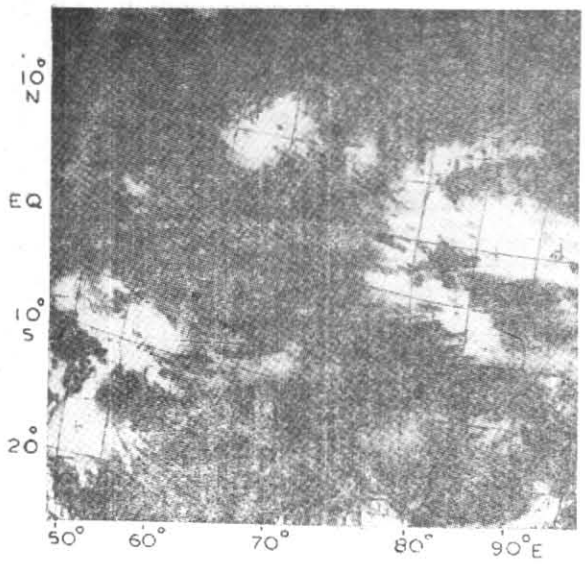

Fig. 2
ITOS-1, 26 November 1970, NH 9·5°N, 62·5°E
SH 19.0°S, 78.0°E

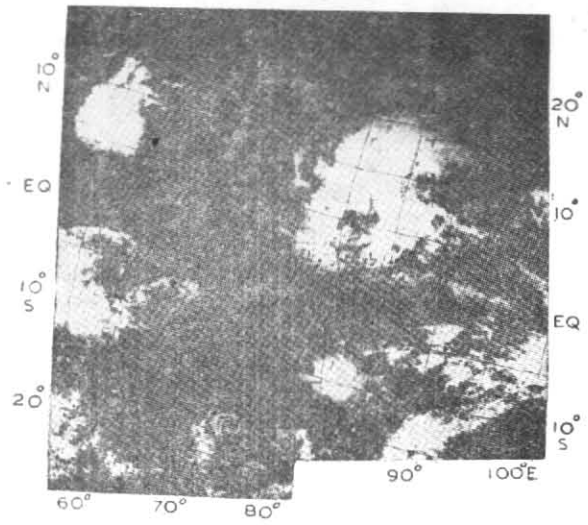

Fig. 4
ITOS-1, 28 November 1970, NH 7·5°N, 55·0°E
SH 17·0°S, 73·0°E

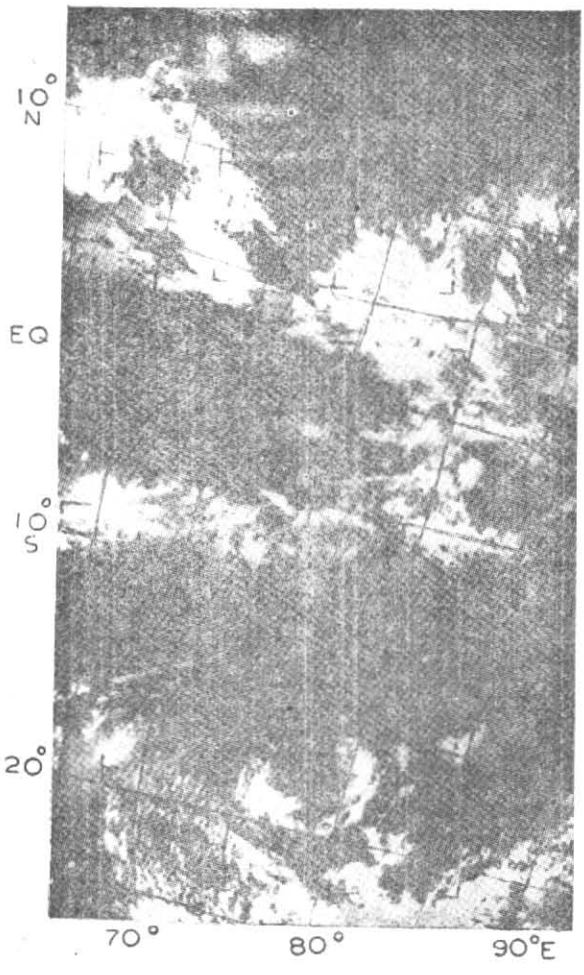

Fig. 3
ITOS-1, 27 November 1970, NH 10.0°N, 60·0°E
SH 18·0°S, 76·5°E

TABLE 3

Data from Satellite photographs — Storms of 17 to 29 November 1970

Satellite		Northern hemisphere (Arabian Sea storm) Date/ Time (GMT)	Centre (°N)	(°E)	Stage & category	Southern hemisphere (*Carmen*) Date/ Time (GMT)	Centre (°S)	(°E)	Stage & category	Dia. of overcast Lat.
ITOS	1	17 0851	9·0	89·0	B					
ESSA	8	19 0344	9·5	82·0	B					
ITOS	1	19 1032	9·0	80·5	X 1					
ESSA	8	20 0429	10·5	79·5	X 1	20 0258	8·0	92·0	B	
ITOS	1					20 0937	8·0	92·0	B	
ESSA	8	21 0520	9·5	75·0	C⁻	21 0349	12·0	90·0	B	
ESSA	8	22 0416	10·0	72.0	C	22 0245	14·5	92·0	X 1	6/8
ITOS	1	22 0931	10·0	70·0	C	22 0931	14·0	91·0	X 1	6
ESSA	8	23 0508	11·5	68·5	C+	23 0337	16·0	91·5	X 1	4/5
ITOS	1	23 1027	11·0	68·5	C+					
ESSA	8	24 0600	10·5	65·5	C	24 0233	17·5	90·0	C	
ITOS	1	24 1124	10·0	65·0	C	24 0932	18·0	87·5	C	
ESSA	8	25 0456	10·0	66·0	C	25 0324	18·5	86·0	C	
ITOS	1	25 1025	10·0	66·0	C	25 1025	19·0	84·5	C	
ESSA	8	26 0547	9.5	63·5	C+					
ITOS	1	26 1123	9·5	62·5	X 1	26 1117	19·0	80·0	C	
ESSA	8	27 0443	10·5	61·0	X 1	27 0312	17·5	77·5	C	
ITOS	1	27 1024	10·0	60·0	X 1	27 1024	18·0	76·5	C	
ESSA	8	28 0534	8·0	56·5	X 1					
ITOS	1	28 1121	7·5	55·0	X 1	28 1121	17·0	73·0	C⁻	
ESSA	8	29 0625	6·5	53·5	C⁻					
ITOS	1					29 1022	17·0	69·0	C⁻	

B, C+, C⁻, X 1, X 2, X 3, etc — Tropical disturbance classification

3.9. *Case No. 9 (10 to 23 December 1971)* — The northern system moved northwest and recurved northeastwards towards the end while the southern system moved westwards for four days, turned south and then recurved eastwards towards the end. Both intensified into severe cyclonic storms.

3.10. *Case No. 10 (26 November to 2 December 1972)* — The ITCZ was well marked near Lat. 7°S between longitudes 50°E and 70°E from mid-November. Satellite photographs indicated a significant cloud cluster near 5·0°S, 65·0°E on the 22 November 1972. By the 25 November organisation of weak spiral bands was noticeable. On the 26 November, a marked vortex was centred near 8°S, 62°E. After a slow westward drift of about 3 degrees, it evolved into a cyclonic storm named *Ariane* on the 28th. It moved southwest at about 10 kt and was about 90 miles north of Mauritius by the 30th when it had intensified into a severe cyclonic storm. Then it started moving southeast until the first December when it was about 150 miles east of Mauritius. Then it recurved and moved west southwest whilst considerably weakening. On the 2nd it was about 60 miles off the south coast of Mauritius; thereafter it disintegrated. A low pressure area moving northnorthwest from Andaman Sea concentrated into a depression on the 26th near 13·5°N, 91·5°E. It became deep on the 27th and recurving northnortheastwards, it weakened into a low close to Arakan coast near Akyab on 29th late evening.

3.11. *Case No. 11 (1 to 9 December 1973)* — Both systems intensified into cyclonic storms and moved westwards initially for four days. While the northern system curved and moved northwards for the next four days, the southern system dissipated on 5 December after four days of moving westwards in parallel with the above system.

3.12. *Case No. 12 (11 to 17 December 1973)*— While the northern system intensified into a depression only, the southern system became a cyclonic storm. The former moved northwestwards while the latter moved generally southwards.

3.13. *Case No. 13 (12 to 23 April 1974)* — Both systems intensified into cyclonic storms and confined to the west of Long. 65° E. The northern system moved northwards for 2 days and curved northeastwards towards the end whereas its southern counterpart moved southeast in the beginning and curved towards west after a day and continued so for another 7 days before dissipating.

3.14. *Case No. 14 (22 to 30 November 1974)* — The southern storm moved northeast, made a loop and travelled southeast later, while the northern storm moved initially northwest and then northeast. The northern system intensified into a severe cyclonic storm while the southern system intensified into a cyclonic storm only.

4. Conclusion

From this study we come to the following conclusions about simultaneous occurrences of storms or depressions on both sides of the equator over the Indian Ocean.

(*i*) These storms generally occur during the transition season with a bias towards September to December.

(*ii*) The frequency of occurrence may be termed as 3 every two years. However, in some years there may not be any simultaneous occurrence of storms.

(*iii*) Kuettner's conclusion that the storms or depressions should occur between the longitudes 100°E and 80°E is generally verified. This has been explained by him as an effect of the existence and alignment of hills in Sumatra. However, simultaneous occurrence of storms on both hemispheres can also occur in a different longitudinal belt further west over Indian Ocean.

(*iv*) Pisharoty and Kulkarni's conclusions : (*a*) that storms of northern hemisphere weaken when there are developing storms to the south of the equator—is not supported by the facts presented here, (*b*) that as a rule southern hemispheric storms apparently exert a greater dissipating influence on the northern hemispheric storms than the northern hemispheric storms on the southern ones —could not be confirmed.

(*v*) No relationship could be found between the tracks of these two systems.

(*vi*) An examination of the data from day to day position and movements do not contradict the restriction of continued westward movement of two cyclonic storms one on either side of the equator in a small longitudinal sector ($\leqslant 10°$). Discontinuance of westward movement would include change in intensity of the cyclonic storm and its recurvature. They seem to support the deduction by Malurkar. Even in the same hemisphere, cyclonic storms are found to exist independently when there is sufficient longitudinal separation and when they have westward movement.

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