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CLIMATOLOGY OF CYCLONIC DISTURBANCES IN THE ARABIAN SEA

1. Annual average of cyclonic disturbances in the Bay of Bengal is about 12 and for the Arabian Sea, it is about 2.6. Several authors have carried out detailed study of storms in the Bay of Bengal *viz.* Mandal (1991), Sen and Pillai (1993) and Ganesan *et al.* (1994 a&b). But such a detailed study on cyclonic disturbances is not available for the Arabian Sea. However, a few authors studied some aspects of cyclonic storms in the Arabian Sea. Mooley and Mohile (1984) after studying the cyclonic storms in the Arabian Sea for the period 1870-1980 remarked that there is an increasing trend in the frequency of cyclonic storms in the Arabian Sea. They also concluded that the storms striking different coasts around the Arabian Sea follow the Poisson probability distribution. A detailed study of cyclonic disturbances in the Arabian Sea for the period 1891-1997 (107 years) was undertaken and the results are presented in this communication. The study has also been extended to cover other Arabian Sea countries such as Pakistan, Oman, Yemen and Africa.

TABLE 1

Formation of cyclonic disturbances (number) in the Arabian Sea in different sub periods

Period	1891-1925	1926-80	1981-97
Total	46	141	24
Pre-monsoon	10	27	1
Monsoon	11	49	10
Post-monsoon	25	64	13
Cyclonic storm	15	32	4
Severe cyclonic storm	29	36	7

2. Material and method

The data for the period 1891-1990 has been collected from the India Met. Department publication (1979, 1996) "Tracks of storms and depressions in the Bay of Bengal and the Arabian Sea" and the data for the period 1991-97 extracted from the RSMC reports of India Met. Dept. From the data, the frequency of formation of disturbances

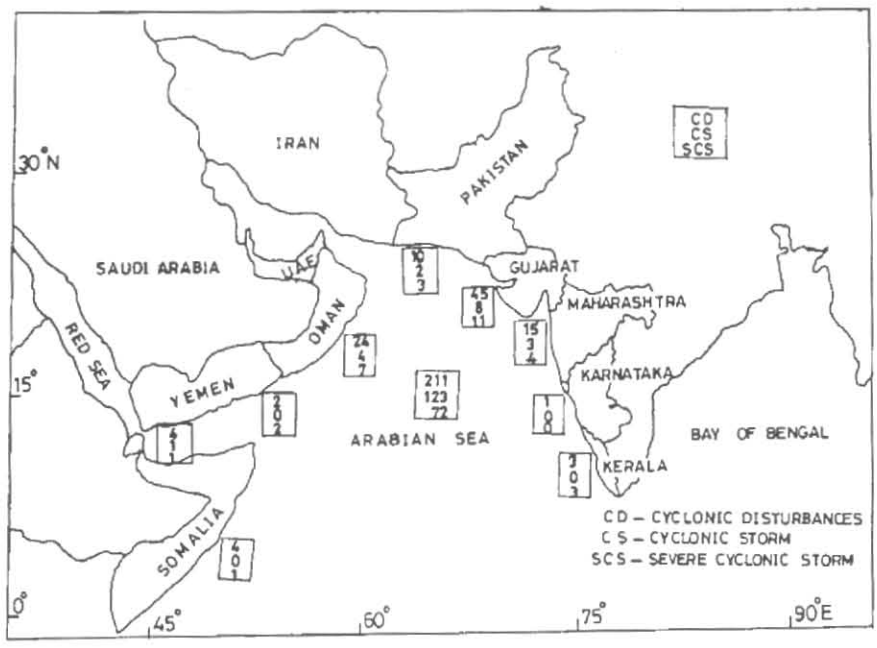

Fig. 1. Number of disturbances formed in the Arabian Sea and those crossed different coastal belts around Arabian Sea

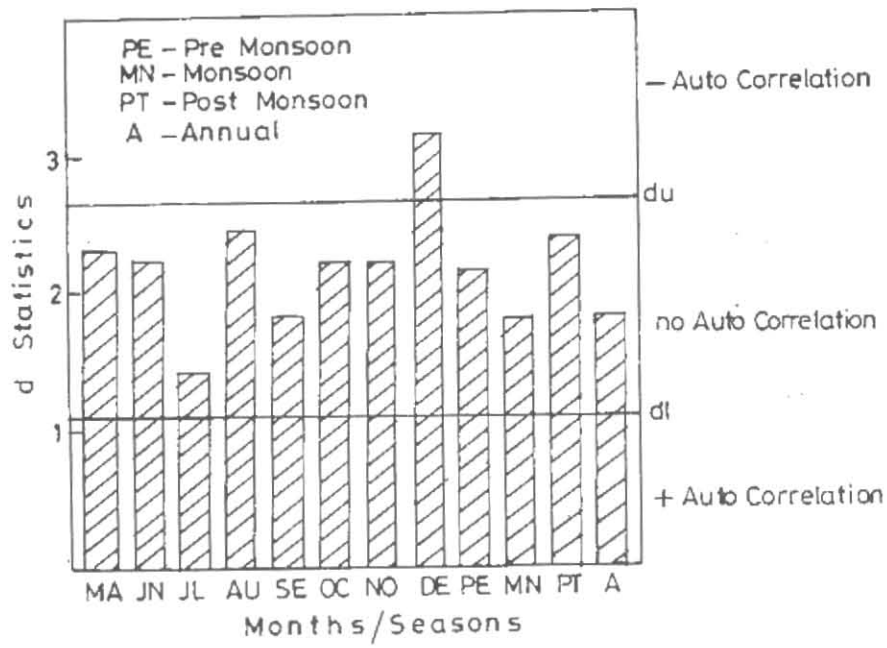

Fig. 2. Month-wise and season-wise Durbin and Watson d-statistics to determine existence of auto correlation /serial correlation in respect of cyclonic disturbances

TABLE 2

Number of cyclonic disturbances crossing different coasts around Arabian Sea

Month	KE	KA	MA	GU	PK	OM	YE	AF	RS	Total
Jan				1						1
				1						1
Apr				2	1					3
				0						0
				1						1
May	2		2	2	1	9	2			18
	0		0	0	1	1	0			2
	2		1	1		4	2			10
Jun			2	13	5	3				23
			1	1	1	1				4
				3	3	1				7
Jul				4		2				6
				0						0
				1						1
Aug				1		1				2
Sep			1	4	2	4				11
				1						1
				1						1
Oct			2	12	1	3		1	3	22
			0	4		1			1	6
			1	2		2				5
Nov	1	1	7	6				2	1	18
			2	1				0	0	3
	1		2	2				1	1	7
Dec			1			2		1		4
						1				1

The top number represents cyclonic disturbances, middle one cyclonic storms and lower one severe cyclonic storms
KE- Kerala, KA-Karnataka, MA-Maharashtra, GU- Gujarat, PK- Pakistan, OM- Oman , YE- Yemen, AF- African coast, RS- Red sea

and their crossing different coasts were computed. Further trend analysis and return period were examined.

3. Results and discussion

3.1. *Cyclonic disturbances*

The coastal belts around the Arabian Sea and details of cyclonic disturbances formed and those crossed different coasts are shown in Fig. 1. During the period under study, 211 cyclonic disturbances (cyclonic disturbances here refer to depressions and all classes of tropical storms) formed in the Arabian Sea of which 123 reached the intensity of cyclonic storm, 72 among them intensified further into severe cyclonic storm. It is seen that the maximum number of disturbances formed during the post-monsoon season (October-December) accounting for 48% of the total. Monsoon months (June-September) account for 33% and the pre-monsoon season (March - May) 18%. In winter season (January-February) only one disturbance formed in the Arabian Sea in the month of January 1935 during the study period. In the pre-monsoon season most of the disturbances formed in the month of May and March is free from any disturbance. In the monsoon season, $1/5^{th}$ of the annual disturbances formed in June and its number is close to those of October and November. August is the month in which least number of disturbances formed in the monsoon season.

3.2. *Cyclonic storms*

If we consider cyclonic storms (CS) alone, 25 of them (49%) formed during post-monsoon season, 18 (35%) in monsoon season and 7 (14%) in pre-monsoon

TABLE 3

Percentage of cyclonic storms and severe cyclonic storms weakening into depressions or low pressure areas

Month	Cyclonic storms			Severe cyclonic storm			
	Crossed as Depression	Weakened Lopar	Total	Crossed as CS	Depression	Weakened Lopar	Total
Apr	0	100	2/2	0	50	25	3/4
May	60	40	5/5	13	7	13	5/15
Jun	13	63	6/8	7	8	33	6/12
Jul	50	0	1/2	0	0	0	0/0
Aug	33	67	3/3	0	0	0	0/0
Sep	40	40	4/5	0	33	33	2/3
Oct	0	67	8/12	0	8	31	5/13
Nov	13	38	4/8	7	17	48	16/23
Dec	0	80	4/5	0	50	50	2/2
Total	20	54	37/50	6	15	33	39/72

Total - Total weakened / Total formed

season. The study has indicated that the maximum number of CS formed in October.

3.3. *Severe cyclonic storms*

The season-wise distribution of cyclonic storms reflects the total system distribution but the case is different for severe cyclonic storms (SCS). 38 SCS (53%) formed during post-monsoon season, 19 (26%) in pre-monsoon season and 15 (21%) in monsoon season. In the monsoon season, in the month of August, no severe cyclonic storm formed in the Arabian Sea.

3.4. *Trend analysis*

From trend analysis performed on the number of disturbances formed in the Arabian Sea during the period 1891 to 1997 it is seen that there is neither decrease nor increase in the number of disturbances in any of the month, *i.e.* the correlations are insignificant. But on the other hand, if we examine the data for the period 1891-1980, an increasing trend is noticed in the formation of disturbances with the correlation coefficient of 0.90 that is in agreement with the conclusion made by Mooley and Mohile (1984) based on their study on cyclonic storms in the Arabian Sea. To substantiate the above argument, our study period has been divided into three sub-periods, namely, 1891-1925, 1926-80 and 1981-97 and the frequency of disturbances in each period is given in Table 1. It is seen that the mean formation in the second sub-period is significantly higher than other two sub-periods at 1% level of significance and it is also observed that during second sub-period, mean annual number of formation is double the mean annual number in other two sub-periods taken together. The *t*-test applied on the mean number of formation in different seasons also shows similar variation. In the case of cyclonic storm also, same type of variation is observed. But in the case of severe cyclonic storm, the mean number of formation of severe cyclonic storms in the first sub-period is significantly higher than the third sub-period and among the first and second sub-periods, the difference is not statistically significant.

The result of serial correlation analysis is shown in Fig. 2. From this study, it is observed that no cyclic character exists in the formation of disturbances in annual, seasonal or in any month. We may hence conclude that the number of disturbances formed in any given year is independent of the disturbances formed in earlier years.

3.5. *Bi-modal characteristics*

The Arabian Sea exhibits a bi-modal distribution in the formation of cyclonic disturbances. Maximum number of formation occurs in the post-monsoon months of October and November and a secondary peak is seen in June. It is interesting to note that correlation between the number of disturbances formed between March to July and August to December is 0.95, *i.e.*, in the Arabian Sea,

the formation is not only bi-modal but also similar to individual months in respect of the above two periods, contrary to the Bay of Bengal.

3.6. *Disturbances crossing the coasts*

Around 49% of the disturbances formed weaken into low pressure area in the sea itself and the remaining crossed various coasts around Arabian Sea. In the pre-monsoon season, 55% of the disturbances formed in the Arabian Sea, crossed the coast, in the monsoon season, 60% of them crossed the coast and in post-monsoon season, only 43% of them crossed the coast. It is observed that the monthly values vary between 31% to 85% with least value in December and highest in September (excluding January).

3.7. *Coast-wise analysis*

Cyclonic disturbances crossing different coasts around Arabian Sea are shown in Table 2. It is seen that the probability of a disturbance to cross Gujarat coast is 67% in April while in June, it is 57% and in October it is 55%. It is seen that the disturbances crossing Gujarat coast is also well correlated with the formation of systems in the Arabian Sea with the correlation coefficient of 0.81 whereas other coastal strips do not have any such relationship.

Over Maharashtra, the probability that a disturbance to cross coast is highest in November (41%). The cyclonic disturbances crossed Maharashtra coast only in the months of May, June and September to December.

If we consider Pakistan, disturbances crossed the coast in April, May, June, September and October. The highest number of disturbances crossed Pakistan coast in the month of June. Over Oman, the disturbances crossed the coast in the months of May to December excluding November, the highest being in the month of May. Over Yemen, the disturbances crossed only in the month of May. Over Africa, the disturbances crossed the coast in the post-monsoon months, the highest being in November.

3.7.1. *Cyclonic storms*

On examining the cyclonic storms crossing different coasts, it is seen that around 8.5% of the disturbances that formed in the Arabian Sea crossed the coast as cyclonic storms. Of these cyclonic storms, 44% crossed Gujarat coast and 22% Oman coast. If we consider individual months, October accounts for 50% of the cyclonic storms that crossed Gujarat coast. No cyclonic storm crossed any coast in April and August. In the month of November, the cyclonic storms crossed only Maharashtra and Gujarat coasts. No cyclonic storm crossed Kerala, Karnataka Yemen and Africa coasts.

TABLE 4

The return period in years for a coast being hit by atleast one cyclonic disturbance

Month	MA	GU	PK	OM	YE	AF	RS
Jan		111.1					
Apr		58.2	111.1				
May	58.2	58.2	111.1	17.5	58.2		
Jun	58.2	14.1	26.6	40.6			
Jul		31.8		58.2			
Aug		111.1		111.1			
Sep	111.1	31.8	58.2	31.8			
Oct	58.2	14.8	111.1	40.6		111.1	40.6
Nov	20.7	23.1				58.2	
Dec	111.1			58.2		111.1	

3.7.2. *Severe cyclonic storms*

The study has indicated that about 15% of the disturbances that formed in the Arabian Sea crossed different coasts as severe cyclonic storms. From Table 2, it can be inferred that 34% of the severe cyclonic storms crossed Gujarat coast and 22% Oman coast.

3.8. *Weakening of cyclonic/severe cyclonic storms*

The statistics of the disturbances after reaching cyclonic/severe cyclonic storm intensity weakening in the sea is given in Table 3. It is seen that 74% of the cyclonic storms weakened into depressions in all the months taken together, out of which, 54% further weakened into low pressure area and remaining crossed the coast as depressions. During the months of April, May and August, all the cyclonic storms formed in the Arabian Sea weakened into depressions before crossing the coast and the probabilities of such depressions to cross the coast are nil in April, 60% in May and 33% in August. In the months of July and November, 50% of the disturbances formed in the Arabian Sea weakened into depressions before crossing the coast. Further weakening into low pressure area in the sea itself is higher than the disturbances crossing as depressions in majority of months. In the month of October and December, all the

cyclonic storms weakened as depression over the sea weakened further as low pressure area.

In the case of severe cyclonic storms, only 6% of them weakened into cyclonic storms and crossed the coast with same intensity. About 48% of severe cyclonic storms weakened further as depression before crossing the coast and only 15% of them crossed the coast as depression. The highest probability of weakening of severe cyclonic storm into depression stage is in the month of December (100%).

3.9. *Return period of disturbances crossing the coasts*

With the assumption that the frequency of cyclonic disturbances crossing various coasts obey Poisson probability distribution, the return periods in different months are given in Table 4. It is seen that the lowest return period for Maharashtra coast being hit by atleast one disturbance is in November, for Gujarat, it is June closely followed by October, for Pakistan, it is June and for Oman, it is May.

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References

Ganesan, G.S., Muthuchami, A. and Sukumar, E.R., 1994a, "A climatological study of cyclonic storms crossing east coast of India", *Mausam*, **45**, 1, 7-16.

Ganesan, G.S., Muthuchami, A. and Sukumar, E.R., 1994b, "Formation of tropical cyclones over the Bay of Bengal", *Mausam*, **45**, 3, 235-242.

India Met. Deptt., 1979 & 1996, "Tracks of storms and depressions in the Bay of Bengal and the Arabian Sea".

Mandal, G.S., 1991, " Tropical cyclones and their forecasting and warning systems in the north Indian Ocean", TCP 28, WMO/TD 430.

Mooley, D.A. and Mohile, C.M., 1984, " Cyclonic storms of the Arabian Sea, 1877-1980", *Mausam*, **35**, 2, 127-134.

Sen, P.N. and Pillai P.V., 1993, " Cyclonic storms crossing 1° latitude zones of Indian coasts during the period 1877-1990", IMD, PPSR, 93/1.

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