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On some sea surface characteristics in relation to storm development over Arabian Sea

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1. Introduction

Palmén (1948) has stated that cyclonic storms develop over oceanic areas where sea surface temperatures are greater than 28°C. Although it is of considerable interest to the synoptic meteorologist to give attention to the prevalent sea surface thermal patterns prior to the development of storms, in actual storm-warning work in the Indian seas sufficient attention has not been given to this aspect. The only observation of the relationship between sea temperature and cyclogenesis which is available in this regard is that due to Koteswaram and Gasper (1956) who have made some studies of storm in the Bay of Bengal. They have reported that in the majority of cases depressions developed over the areas where the sea was warmer than the air above it. No effort appears to have yet been made to investigate along this line in regard to the storms which form over the Arabian Sea.

Cyclonic storms develop in the Arabian Sea usually during the months May, June, October and November. During these periods, however, storms are relatively rare in the month of May (Ray Choudhuri, Subramanyan and Chellappa 1959). In May 1959, a severe cyclonic storm had formed in the southeast Arabian Sea, the earlier one on record being of May 1941. This storm was characterised by some special features both in relation to the preceeding isothermal structure of the sea surface as well as the distant storm surges along the west coast of the Peninsula. The results of an analysis of this storm are presented in this paper.

2. Brief history of the storm

On 16 May 1959, the intertropical convergence zone lay stretched between Lat. 5° and 7°N in the south Arabian Sea. It progressively moved northwards and lay on the 19th along 8°N.

Condition became markedly unsettled in the Laccadives area on 18 May where a depression formed by the next morning. Moving westnorthwestwards it rapidly intensified into a cyclonic storm by the evening of 20 May. Concentrating still further and moving in the same course, it became a severe cyclonic storm by midday of 21 May. Continuing in a westnorthwesterly to westerly direction the severe cyclonic storm moved close to the Arabian coast by the morning of 24 May. It subsequently weakened and filled up without crossing the coast. The track of this storm is shown in Fig. 1.

During the life history of this storm a large number of valuable ships' observations at different synoptic hours has been available for study. The most valuable of all the ships data studied were those of S. S. *Socotra* which moved from west to east in the inner storm area almost across the core. The wind, wave and sea and air temperatures recorded by the ship are shown in Fig. 2. The lowest pressure observed on the barogram of the ship at its closest position to the storm centre was 968 mb.

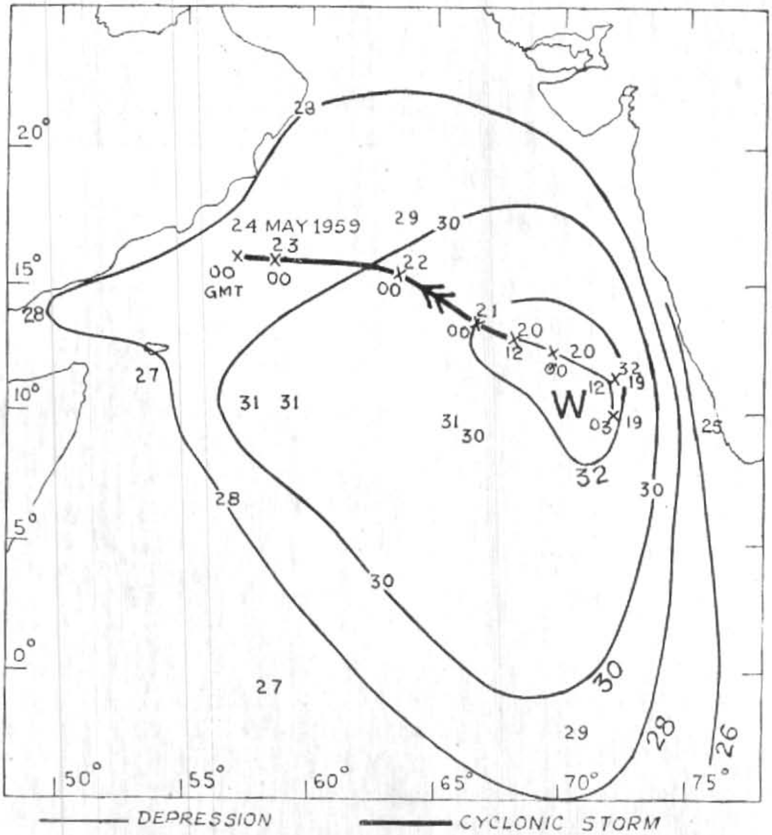


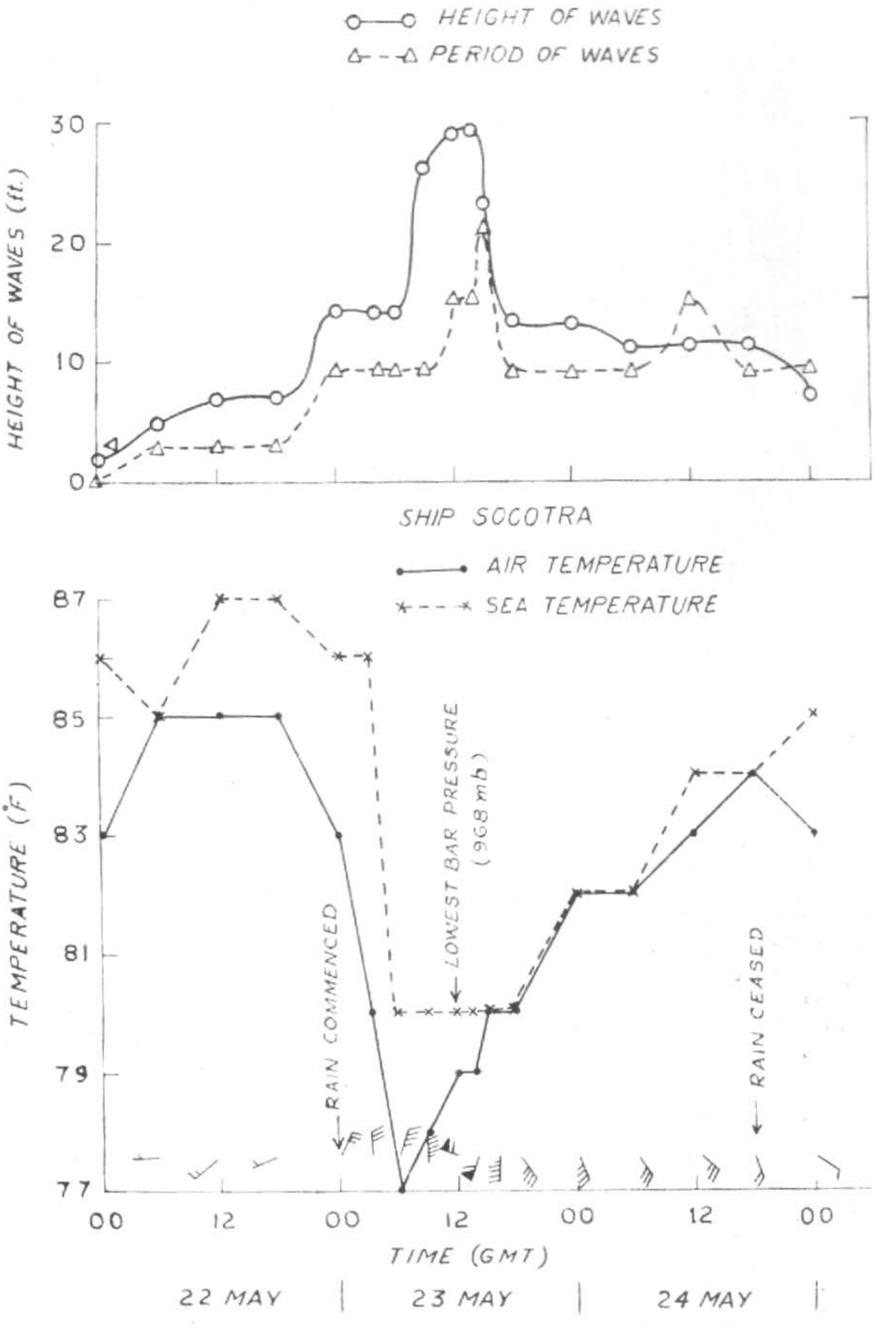
Fig. 1. Track of depression/cyclonic storm of 19–24 May 1959

3. Discussion

3·1. *Thermal structure of sea surface in relation to storm*—As already mentioned Palmén has shown that cyclogenesis is favoured over oceanic areas with sea temperatures greater than 28°C. This condition was amply fulfilled in the case of the present storm as seen from the isotherms of sea surface temperatures (Fig. 1). *In general* the warmest part of the sea on 16 to 19 May was where the depression subsequently formed. The patterns of isotherms subsequent to the formation of depression (charts not shown) do not appear to be related to the intensification and decay of the storm. This is probably on account of the effect of cloudiness and precipitation over the oceanic areas consequent on the formation of depression. However, it is worth mentioning that the isothermal pattern over the sea appeared to show a displacement of hottest area to the northwest ahead of the subsequent movement of the storm centre.

The fact that the sea was warmer than the air above it in the case of this storm was manifested by the synoptic charts themselves during the various stages of the storm. That such was the condition in the inner core of the storm also is seen clearly from the data reported by S. S. *Socotra* during 22 to 24 May when the ship's course lay in the proximity of the storm centre. This is illustrated in Fig. 2.

3·2. *Storm surges on west coast*—A feature of the storm was the damage and destruction by waves caused by the storm along and off the west coast. The storm coincided with a



HEIGHT OF WAVES
PERIOD OF WAVES
HEIGHT OF WAVES (ft.)
PERIOD OF WAVES (sec)
30
20
10
0
15
10
5
SHIP SOCOTRA
AIR TEMPERATURE
SEA TEMPERATURE
TEMPERATURE (°F)
87
85
83
81
79
77
RAIN COMMENCED
LOWEST BAR PRESSURE (968 mb)
RAIN CEASED
00
12
00
12
00
12
00
TIME (GMT)
22 MAY
23 MAY
24 MAY

Fig. 2

TABLE 1

Maximum dimensions of the recurrent waves of the ocean in relation to speed of wind

(After Mackey and Whittingham)

Speed of wind (mph)	Period (sec)	Length (ft)	Height (ft)	Length/ Height (ratio)
30	7·0	250	22	11·5
35	8·0	330	25	13
40	9·5	470	29	16
50	11·5	670	35	19
60	13·5	930	41	22·5
70	15·5	1230	48	26
*80	17·5	1560	55	—

*Extrapolated

period of extremely high tides—the predicated high tide of Bombay on 24 May 1959, for instance, being practically the highest tide of the place for the year. Commencing from the night of 20 May 1959 reports were received of numerous sailing vessels (country craft) running into serious difficulties on account of rough seas along and off north Kanara, Konkan, and Kathiawar coasts and in the Gulf of Cambay. Rough seas were encountered mostly when the tide was high. The sea-wall at Bombay was breached at a number of places. Salt pans around Thana and Bassein creeks and at Bhavnagar were inundated and partly destroyed on 22 May by high seas.

The above were only a few examples of the damage due to the waves during the storm period. It is to be noted that all the damage and destruction occurred at Bombay along coast north of Bombay at a time when the storm was several hundreds of miles away from the places and was moving away from them.

Let us now calculate the maximum swell produced by the storm. It should first be noted that Bombay was always to the right rear side of storm during its severe cyclonic stage. For calculating these the following assumptions were made—(*i*) the strongest wind reported by the ships in the storm field was assumed to be the strongest wind caused by the storm; this is most probably an under-estimation, and (*ii*) the strongest wind caused the maximum dimensions of recurrent waves; this will be an over-estimation.

The relevant ships' observations are given in Table 2, maximum wind speeds reported at different hours being shown in column 7. Maximum dimensions of recurrent waves as given by Mackey and Whittingham (1956) are reproduced in Table 1 in which the last time corresponding to the wind speed of 80 mph is obtained by extrapolation. The maximum periods and heights of waves in the storm field were picked up from this table and are given in columns 10 and 11 of Table 2. It was assumed that on the right rear quadrant waves of these dimensions were produced by the wind. The distance of the centre of the storm from Bombay at the time of observation was read from the synoptic chart. Munk and Arthur (1951) have given a nomogram of wave decay to be used in practical form in forecasting. Wave heights after the decay due to travel of this distance were directly picked up from the nomogram. The time of travel was also picked up from the same nomogram. They are given in columns 12 to 14 of Table 2.

The values obtained by the above method are impressive. It may, however, be said that they are over-estimates. We have, therefore, considered the wave data given by these ships and calculated the swell that can be produced by these waves by the method stated above. The wave data are reproduced in columns 8 and 9 of Table 2. The heights of swells produced at Bombay by waves of those dimensions, assuming them to be the maximum ones produced in the storm field were calculated. A scrutiny of the positions of these ships at the times of the reports shows that they were to the left of the storm. On the right rear quadrant where wind has maximum fetch waves of much greater dimensions are expected. Our calculation will, therefore, give us values for swells which may be seriously under-estimated. Even after considering this drawback the calculation was

TABLE 2

Heights of swells and their times of arrival as calculated from ships' reports

(May 1959)

S. No.	Date	Ship	Time	Position		Wind speed	Wave		Max. wave from wind speed		Swell					
											From wind speed			From wave data		
									Period	Ht.	Date	Time of arrival	Ht.	Date	Time of arrival	Ht.
			(GMT)	Lat. °N	Long. °E	(kts)	Period (sec)	Ht. (ft)	(sec)	(ft)		(GMT)	(ft)		(GMT)	(ft)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	21	*Amra*	0800	12·7	64·5	52	6	19	13·0	39	22	0800	28	22	2000	5·5
2	21	,,	1400	11·4	64·6	47	6	25	12·0	37	22	1600	22	23	0200	7·5
3	22	,,	0600	12·8	64·7	52	5	11	13·0	39	23	1000	25	Not calculated		
4	22	*Malika*	1400	14·9	59·5	60	—	—	14·5	45	23	1700	30	—	—	—
5	22	,,	1800	14·8	59·5	68	—	—	16·5	51	23	2100	36	—	—	—
6	23	*Socotra*	1200	15·2	57·3	60	10	29	14·5	45	24	1600	27	25	0600	12
7	24	*City of Portsmouth*	1200	14·1	56·0	50	—	—	12·5	38	26	0400	19	—	—	—

performed and the results are given in columns 15-17 of Table 2. From the data given in Table 2 we infer that swell of maximum height of 36 ft and minimum height of 12 ft might have reached Bombay on the night of 22 May 1959 and persisted upto the 26th. These maximum and minimum height figures are probably on the side of over-estimates, judged from the actual wave observations recorded by the ships.

Incidentally we may compare the swells caused by distant typhoons as observed in Japan. Unoki and Nakano (1955) from a study of ocean waves at Hachijo Island conclude that high waves with heights of 3-4 metres are noticed, though typhoons are as far away as 2000 or 3000 km and are moving away from the Island. Unoki (1955) in a separate study on ocean waves at various coasts of Japan has also come to a similar conclusion.

Mackey and Whittingham found that there may be tidal effect of cyclonic storm when it is at a distance. They conclude from a study of such effects in Australia that level of water rises above the level of predicted tide level when the cyclonic storm is at a distance and winds are either off-shore or parallel to the coast.

In the present case winds (SSE-ly) parallel to the coast blew for several days during the storm period. The stress exerted by the wind was expected to have caused a rise in water level. The autographic tidal charts at Bombay were studied for the period in question but it was found that the levels of high and low water actually recorded did not appreciably differ from the predicted values given in tide tables. Thus the storm did not cause an increase in general tide level at Bombay and possibly on the whole of west coast. The rough seas experienced on the coast and also along some distance from it were, therefore, only due to the swell by the storm.

The broad conclusion that can be drawn from the above facts is that if a storm exists at a distance in the Arabian Sea there is a considerable risk of damage on the right rear side due to swell resulting from the distant storm. If the storm appears during the period of high tide in the west coast, the low areas along the coast may become vulnerable. Extending this idea to the Gulf of Cambay, it can be inferred that the effect of swell will be to cause rougher seas because of its funnel like appearance. All these will happen even when the storm has actually moved away and the risk of the bad weather is over.

5. Acknowledgements

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