551·515·21(267)

On the southerly movement of the Arabian Sea Storm, November 1964

V. VITTAL SARMA

Regional Meteorological Office, Bombay

(*Receivec 18 May 1966*)

ABSTRACT. In November 1964, there was a storm in the Arabian Sea which had an unusual southerly movement during an appreciable period of its life-history. A detailed examination of this disturbance in the Arabian Sea with a view to determine accurately the track of the storm and possible cause for its southerly movement has been undertaken and the results presented in this note. On account of the paucity of data in the central Arabian Sea region where the storm moved south, it is not possible to look for any directive field in the upper troposphere. Hence the distribution of sea surface temperature from all available ships' data have been studied. The charts of anomalies of sea surface temperature show the existence of warmer waters in more southern latitudes when the storm moved south. The distrubance weakened on moving into colder water. Computations of total flux of energy from sea to air have been made to establish evidence of the source of energy of the storm in more southern latitudes during the period in question.

1. Introduction

During the post monsoon season, storms and depressions which form in the Arabian Sea and the Bay of Bengal generally move westwards or northwestwards. Some of them recurve north or northeastwards on reaching higher latitudes. A very small number of these disturbances, however, show a southerly component in the direction of movement mostly in the final stages before they weaken and fill up. Fig. 1 shows the track of the five disturbances in the Arabian Sea which had some southerly course of movement during the months October, November and December extracted from the atlas on storm tracks for the period 1891—1960 (India met. Dep. 1964). Only five to six per cent of the storms and depressions in the Indian seas show this type of unusual behaviour. The extremely low frequency of storms moving towards the equator in the northern hemisphere is probably related to the Coriolis force decreasing nearer the equator.

Whatever the southward movement may be due to, it would be of interest to study these disturbances in order to find out the special aspects of the storm associated with the unusual features of their movement. In November 1964, there were two storms, one in the Arabian Sea (3rd to 12th) and the other in the Bay of Bengal (16th to 29th) with a marked southerly component in their movement for nearly two days. The results of detailed examination of the Arabian Sea storm have been presented in this note.

The major portion of the track of the storm under study lay over the south Arabian Sea in a region far away from the mainland of India in the east and Arabia and Somalia in the west. Except during the initial stages of the storm when the Laccadive Islands and the Kerala coast were affected, data from land stations did not show any effect of the storm and were not useful for the study. Data from TIROS observations and aircraft inflight reports from the region were available for a few days of storm and were not adequate. Only observations from ships traversing in this area constituted the main source of data for this study. It was considered useful to see whether a detailed analysis of the observations provided by the ships in respect of sea surface temperatures and energy distribution give any clue to the behaviour of the storm.

2. Earlier work

A number of studies on the influence of sea surface characteristics on the genesis, intensification and movement of tropical storms have been made both in India and abroad. Mukherjee *et al.* (1961) have shown that cyclogenesis occurred in the Arabian Sea on the warmest part of the sea with the sea surface temperatures greater than 28°C. This is in accordance with similar conclusions arrived at by Palmen (1946), Dunn (1950) and others for tropical storms. Fischer (1957) has made detailed examination with day-to-day composite charts of a large number of hurricanes in the north Atlantic Ocean, Carribean Sea and Gulf of Mexico and concludes that there is an intimate relationship between the sea surface temperature field and the life history of hurricanes near the tropics. The storms formed in areas where the sea surface temperatures were at least 83°F (28·3°C) and possibly higher. There was a marked tendency for the track to be over the warmest water and the storm to dissipate when driven over colder waters. Jordan (1964) has studied the influence of tropical cyclones on the sea surface temperature field and shown that there is cooling from the front to the rear side of the storm and along the storm track. Deep

TABLE 1

Number of ships' observations (for each 2-degree square) from the area during 3 to 12 November 1964

Lat.	Longitude (°E)									
	50-52°	52-54°	54-56°	56-58°	58-60°	60-62°	62-64°	64-66°	66-68°	68-70°
20°—18°N		Land		11	20	1	1	5	3	4
18°—16°N		5	12	16	—	4	2	3	8	10
16°—14°N	13	12	5	5	5	2	1	3	1	6
14°—12°N	8	2	4	7	—	—	—	—	1	1
12°—10°N	13	24	27	18	15	18	8	9	11	2
10°—08°N	8	4	12	6	11	15	27	28	33	25
08°—06°N	5	4	2	4	4	3	1	1	—	—
06°—04°N	5	1	—	—	3	7	5	—	—	—
04°—02°N	7	—	—	—	3	4	4	7	3	—
02°—00°N	1	—	—	—	2	3	3	4	7	7

typhoons are in general associated with positive temperature anomalies. Studies on the exchange of energy between the sea and atmosphere in relation to the hurricane behaviour by Fischer have revealed that storm tends to remain near or move along regions where the replenishment of the supply of energy is greatest.

Any evidence of relationship between the sea surface characteristics and behaviour of cyclones is particularly useful in the case of disturbances moving in the south or central Arabian Sea area where one has to depend on ships' observations only as the coastal observatories are stituated too far to be significantly affected by the storm.

3. Data used

Attempt has been made to collect together all the available data from the original logs maintained by the national and foreign ships. In a few cases where the logs could not be readily obtained, data transmitted by the ships by W/T have been resorted to. All possible care has been taken to eliminate errors due to mutilation of data in transmission by comparing with observations reported earlier or later as the case may be and comparing with data from ships in the neighbourhood. A small percentage of ships' observations which could not be reconciled in the above manner had to be discarded. Table 1 shows the distribution of total number of ship's observations for every two-degree square grid during the period 3 to 12 November 1964 available for the analysis from the area between latitudes 0°N and 20°N and longitude 50°E and 70°E. It may be pointed out that nearly 53 per cent of the total number of observations were between Lat. 8°N and 12°N along which belt, the storm had moved during this period.

4. Storm track and the associated synoptic situation

Fig. 2 shows the track of the disturbance in the Arabian Sea from 3 to 12 November 1964. Composite charts of all ships' observations for a period of 18 hours were prepared and the centre of the cyclonic circulation was determined as accurately as possible keeping in mind the pressure distribution and weather report by ships.

A low pressure wave from the east moved into the southeast Arabian Sea off Kerala coast on 1 November 1964. It became well marked and lay over Laccadives-Maldives area on the next day with associated upper air circulation extending upto 6 km. By the evening of 3 November, it intensified into a depression with centre near Lat. 11·5°N and Long. 69°E. The cyclonic circulation extended upto 9 km. During the next 24 hours, the depression had moved westwards and concentrated into a cyclonic storm. It moved westnorthwest during next three days and was centred at 00 GMT on 8th near Lat. 12·5°N and Long. 59·5°E. Subsequently it moved southwards for the next 48 hours along Long. 59·5°E to about 300 km. Ships' observations adequately show an increase of the cloud belt and precipitation area to more southern latitudes on these two days. Debriefing report of aircraft on flight from Aden to Gan Island at flight level 21,600 ft on 9 November records an increase of clouds between Long. 57°E and 62°E with embedded *Cu* and *Cb* clouds tops reaching 25/30,000 ft. In the course of the southward movement, the system weakened into a depression and was centred near Lat. 9·5° N and Long. 59·5°E on 10th morning. Subsequently it moved west and further weakened. On the 13th, there was no evidence of any cyclonic circulation and the sea level winds were all weak.

5. Sea surface temperature and anomalies

The sea surface temperature values from all the ships reporting within a two-degree grid during 24 hours were grouped together and the means worked out for each of this group. These values were plotted on charts at the centre of the respective two-degree square grid. The storm track was within a small three-degree belt around Lat. 10°N and the area considered was, therefore, limited to latitudes 0°N to 20°N between longitude 50°E and 70°E in the Arabian Sea. On these charts isotherms were drawn and sea surface temperatures for every two-degree square grid were picked up. Their deviations from monthly mean values for the corresponding points, read from the *Indian Ocean Atlas* (Deutche Hydrographic Inst. 1960), were obtained and a second set of charts of anomalies of sea temperature was plotted.

The charts of anomalies of sea surface temperature show clearly the day-to-day changes of sea temperature and its relation to the movement of the storm. For this purpose, the observed track of the storm on the next day is also indicated on the chart. A few interesting charts for 3, 4, 6, 7 and 11 November are shown in Figs. 3 to 7.

The following significant features on the daily charts of anomalies of sea surface temperature are noteworthy—

(*a*) The storm track generally lies in a region of positive anomalies of the order of +0·7°C. (Figs. 3, 4 and 5).

(*b*) The track is oriented towards region of maximum positive anomalies. On the 7th, the isopleths of positive ancmaly indicate a well-marked maxima to south of the sotrm near latitude 8°N with the highest value of +1·5°C. (Fig. 6). Coinciding with this shift of the maxima to the south, the storm also moves in a southerly direction during the next 24 hours. Almost similar conditions prevail on 8 November and the system continues southward movement on 9th also.

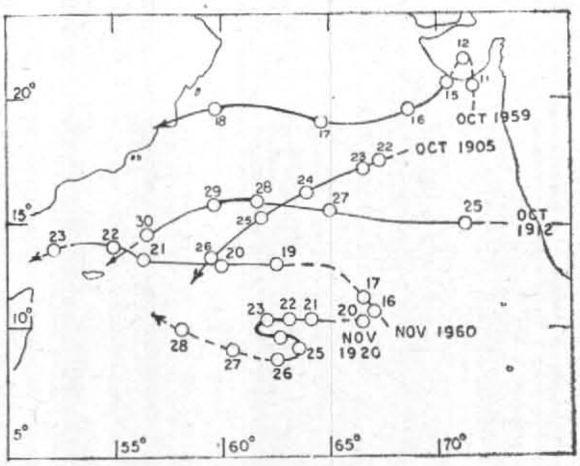

Fig. 1. Tracks of storms and depressions in the Arabian Sea with southerly component in the direction of motions October-December 1891-1960

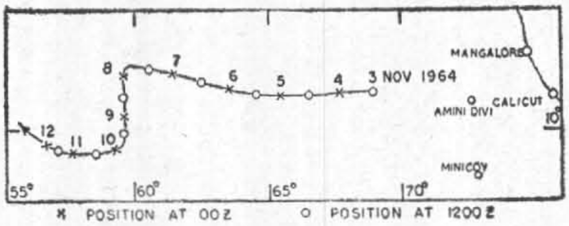

Fig. 2. Tracks of the Arabian Sea storm 3—12 November 1964

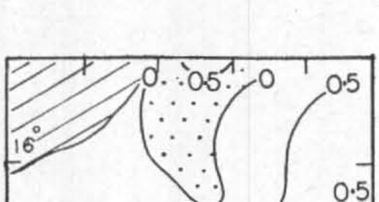

Fig. 3 Anomalies of sea surface temperature (°C)

Position of storm at 1200 GMT is marked X with track during next day

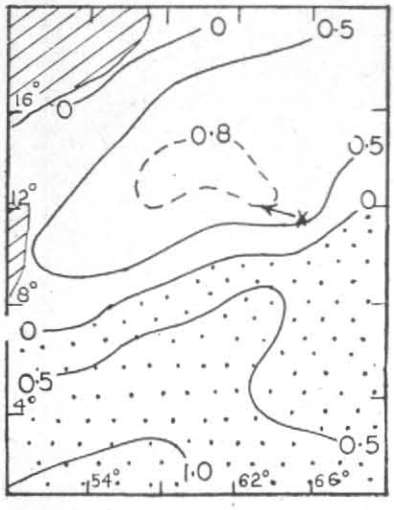

Fig. 4

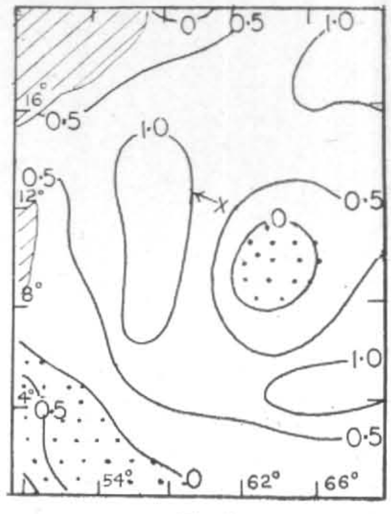

Fig. 5

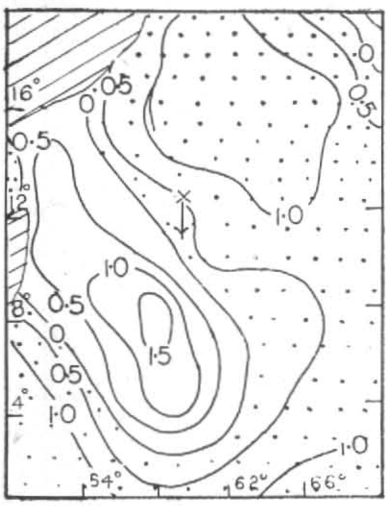

Fig. 6

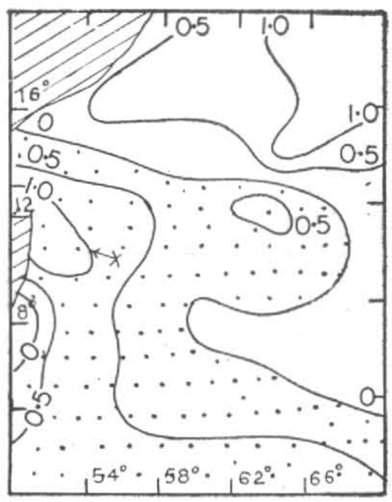

Fig. 7

Figs. 4—7. Anomalies of sea surface tempeature (°C)
Position of storm at 12 GMT of the day is marked X with track during next day

(*c*) Comparitively lower temperatures prevail in the rear of the storm on all the days.

(*d*) On 9 November and the subsequent days, there is a significant decrease in the anomalies of sea surface temperature. Large areas of high positive anomalies of the order 1·5 to 1·8°C are replaced by regions of negative anomalies more than 1°C. For instance, on 11 November a well-marked region of negative anomalies with the lowest value of −1·4°C exists to the west of the depression centre (Fig. 7). The depression has moved into colder waters and is probably responsible for its weakening during next 24 hours. Similar conditions of large negative anomalies prevail on 12th and 13th.

Summing up, it will be seen that the storm has shown a marked tendency to move over warmer waters on all the days and finally to dissipate when moving over colder water.

6. Distribution of energy flux

The physical process involved in this behaviour of the storm is too well known to need any detailed explanation. The storm derives its energy by a flux from the sea to the atmosphere in the vicinity of the storm which in turn depends on the temperature of the sea surface. It is, therefore, possible to substantiate the above relationship by a study of the distribution of energy flux over the area concerned during the life history of the storm. Computation of flux of energy from sea to the air has been made adopting the method followed by

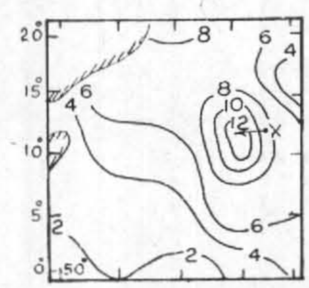

Fig. 8. 3 November 1964

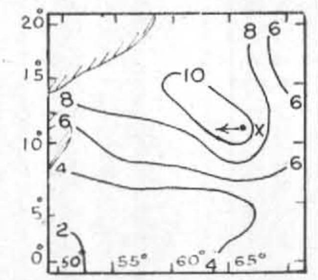

Fig. 9. 4 November 1964

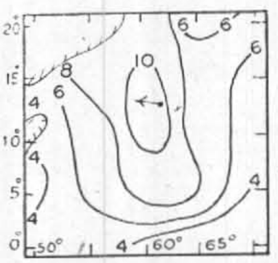

Fig. 10. 6 November 1964

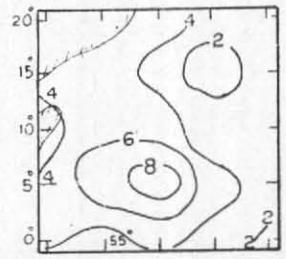

Fig. 11. 7 November 1964

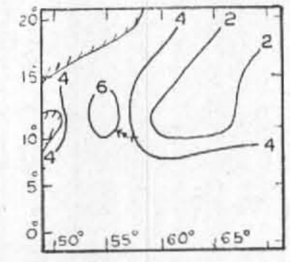

Fig. 12. 11 November 1964

Figs. 8—12. Total eddy flux of energy form sea to air in hundred of ergs cal/sq. cm/day

Position of the storm at 1200 GMT of the day is marked X with track during the next day

Fischer (1957) in his study of behaviour of hurricanes. The equation for total eddy transport of heat (latent and sensible) is represented by

$$Q_a = Q_e + Q_c$$

where, Q_e (the latent heat term)$=145\cdot4\,(e_w-e_a)\times w_a$ and Q_c (the sensible heat term)$=0\cdot01(t_w-t_a)\times Q_e\,/\,(e_w-e_a)$ (using Bowmen's ratio of heat losses by conduction and by evaporation from water surface). Summing up the two terms

$$Q_a = 145\cdot4\ [\,(e_w - e_a) + 0\cdot01\ (t_w - t_a)\,]\ W_a \quad \text{erg cal/cm}^2\text{/day}$$

where, e_w = vapour pressure of saturated air at the temperature of water surface,

e_a = vapour pressure of air at the anemometer level,

t_w = sea surface temperature,

t_a = air temperature, and

W_a = wind speed at anemometer level, expressed in standard units.

The ideal method of computing energy flux using the above equation would be to substitute values of frequent observations of all the elements at any one point and integrate the energy transport at that point for 24 hours period. Owing to scarcity of data only an approximate method can be attempted. For this purpose daily values of air temperature, dew point and wind from all the ships in a two-degree square grid were grouped together and mean values plotted on separate maps as in the case of sea surface temperature charts. Isopleths were drawn and the values of the different elements for every five-degree square grid read out. Energy flux were then worked out for these points. Figs. 8 to 12 show the distribution of the flux in the area on a few days during this period 3 to 12 November 1964. The centre of the storm at 12 GMT of the day and the track of the storm for the following day are also shown on these charts.

An examination of the charts reveal the following aspects—

(*a*) On all the days the energy flux is positive. High values of energy flux are associated with the storm centre and this is obviously due to the presence of strong winds near the centre. The maximum value of energy flux is generally located ahead of the storm exhibiting a marked tendency for the storm to seek tongues of largest energy flux.

(*b*) The variation of the daily maximum value of energy flux is closely related to the intensity of the system. The values decreased appreciably from 1290 erg calories on 3rd to 555 erg cal/cm² /day on 12 November. The highest value for energy flux, *viz.*, 1290 erg calories for the point 10°N and 65°E on the 3rd was followed by the intensification of the depression into a cyclonic storm centred near 11·5°N and 67·5°E at 1200 GMT on 4th (Fig. 9)

TABLE 2

Percentage variation of energy flux with the changes in values of elements of sea surface temperature (SST), air temperature (AT), dew point temperature (DP) and wind for two sets of constant values of the other elements

Element	Change in °C/kt	Percentage variation of flux with constant values of SST : 27°C, AT : 27°C, DP : 22°C, Wind : 15 kt	SST : 28°C, AT : 27°C DP : 23°C, Wind : 15 kt
SST (Sea Surface Temp.)	+0·5	+15	+13
	−0·5	−17	−15
AT (Air Temp.)	+0·5	− 1	− 8
	−0·5	+ 4	+ 2
DP (Dew Point Temp.)	+0·5	− 5	− 6
	−0·5	+ 9	+10
Wind	+02 kt	+12·5	+12·5
	−02 kt	−14	−14

(*c*) The storm moved westnorthwest with the same intensity during the next three days and was associated with large areas of high flux values exceeding 1000 erg calories (Figs. 9 and 10).

(*d*) On 7 November (Fig. 11) the closed area of high energy flux shifted to the south near latitude 5°N. The maximum value is reduced to 802 erg calories as compared to 1050 erg calories on the previous day. Subsequently, the storm moved southwards and weakened into a depression on 8th. Similar features persisted on the 8th also with the depression continuing to move south.

(*e*) On the succeeding three days the flux values decreased over the south and the maximum region was located near Lat. 10°N. The depression moved westwards during the final stages (Fig. 12).

(*f*) These charts show also a general reduction in the values of energy flux over the entire area during the last 3 days. There is no closed region of maximum values on 12 November. This has resulted in the weakening of the depression and its filling up.

7. Limitations of the analysis

There is a remarkable coincidence in the daily variation of energy flux distribution with the intensity and movement of the storm under study despite a number of limitations in the method of analysis followed. First and foremost is the uncertainty involved in the data of ships' observations specially the measurment of sea surface temperature.

This is a serious problem facing any study of oceanic weather systems. Until and unless the basic methods of observations are improved, the handicaps will continue to exist but this should not deter any tentative study and conclusion on the basis of all available data collected. It is, however, hoped that the method of compositing observation for 24 hours from more than one ship travelling in a two-degree square grid might eliminate extreme inaccuracies of data. As stated earlier in the note, considerable part of the storm track was in the shipping lane between Bombay and Aden and consequently the increase of density of observations within the 4-degree latitude belt of the storm track must have reduced appreciably percentage error of the data in the vicinity of the storm.

There is some amount of subjectivity in the analysis and preparation of isothermal charts of sea surface temperature, air temperature and dew point and isotach of surface winds over the area. This is, however, reduced to a minimum by a careful analysis of the charts with strong emphasis on continuity of the various features on each chart. An examination of the equation will show that the significant contribution to the energy flux is due to the two terms $(e_w - e_a)$ and W_a . In

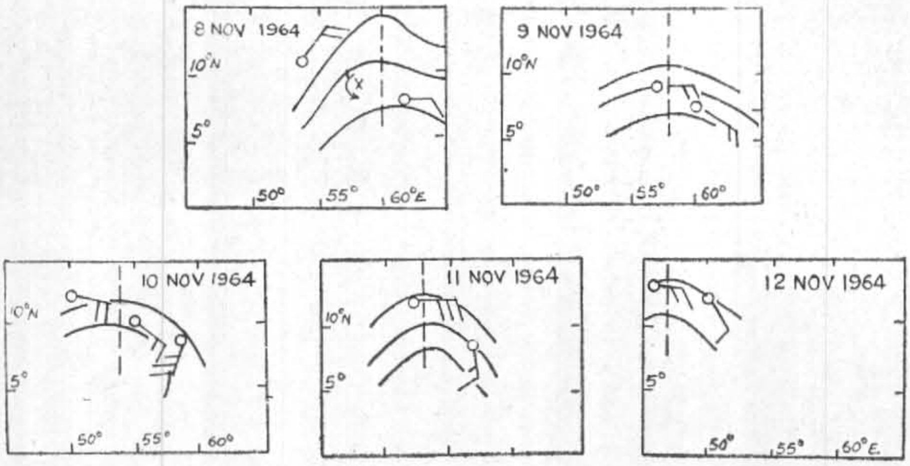

Fig. 13

Upper winds at about 500 mb(FL 21,500 ft) from aircraft in flight reports showing the movement of uppr air trough
Time of observation : about 8-9 GMT

order to get an idea of the possible error in the energy flux values, computations were made of variation in energy flux by varying one of the three temperature values and keeping the other two constant. Two sets of constant temperature values representing the mean conditions of the present series of values and an average wind speed of 15 knots were assumed for these calculations. Table 2 shows the percentage variation in the values of eddy flux by these variations of temperature. It will be seen that possible error is only about 15 per cent for a change of sea surface temperature of $\pm 0 \cdot 5$°C. In the case of air temperature and dew point, the percentage variation is smaller and is only of the order of 10 per cent or less. Variation of wind by 2 knots results in a variation of flux by 13 per cent. Since the isopleths of energy flux have been drawn at intervals of 200 erg cal/cm^2 /day it is likely that there may not be any significant change in the pattern of flux distribution on account of possible errors in the estimate of mean values of the four elements.

The equation and the constants used for calculating eddy flux of energy is based on an empirical approach and needs further modification in the light of more rigorous theoretical treatment. Nevertheless this technique has been adopted elsewhere (Fischer 1957) for a study of behaviour of hurricanes with encouraging results. As a preliminary approach to the problem of unusual behaviour of the storm in the Indian seas, the study is well justified even if the conclusions reached may be only of a tentative nature.

8. Conclusion

Within the limited scope of the present analysis, it can be concluded that this Arabian Sea storm showed a marked tendency to move towards region of positive anomalies of sea surface temperature and of highest energy flux. There is an indication of the southerly shift of the positive anomaly area in sea surface temperture field and also the maximum energy flux during 7 and 8 November 1964, preceding the southerly movement of the storm on 8th and 9th. The southerly track is supported by evidence for the movement of an upper air trough in the easterlies as seen from the meagre data of inflight reports for this period (Fig. 13). The question arises whether the upper troposphere provides the steering force for the low level systems in these latitudes or whether the sea temperature field and energy flux distribution influence the movement of the tropical storms. It is hoped that further studies of the behaviour of the storms both in the Arabian Sea and Bay of Bengal with reference to the distribution of sea surface temperature and total eddy flux of energy at the air-sea interface may provide the answer. Recently during the I.I.O.E. period special weather research aircraft and oceanic research vessels were used to survey the Indian seas during the southwest and northeast monsoon. Similar aircraft flights and sea expeditions during the post monsoon storm season, together with the regular TIROS observations might enable us to track the storms and establish conclusively evidence of relationship in the movement, intensity and decay of the storm with changes of sea surface temperature and eddy transport of heat.

9. Acknowledgement

The author has great pleasure to record his grateful thanks to Dr. T. M. K. Nedungadi, Regional Director, Bombay for his helpful guidance in the course of the study.

REFERENCES

Deutche Hydrographic Inst., Hamburg	1960	*Indian Ocean Atlas.*
Dunn, G. E.	1950	*Atlantic Hurricanes.*
Fischer, E. L.	1957	*National Hurricane Research Project*, 8, Pts. 1, 2.
India met. Dep.	1964	*Tracks of storms and depressions in the Bay of Bengal and the Arabian Sea, 1877-1960.*
Jordan, C. L.	1964	*Proc. Symp. Tropical Meteorology*, p. 614.
Mukherjee, A. K. *et al.*	1961	*Indian J. Met. Geophys.*, **12**, p. 598.
Palmen, E.	1948	*Geophysica*, Helsingfors, 3, p. 26.