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Observed Air-Sea Interface Conditions and a Monsoon Depression During MONEX-79

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With 2 Figures

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Summary

The air-sea interface properties during the early stages of formation of a depression over East Central Arabian Sea during summer MONEX are examined by analyzing the ship data for air and sea temperatures, sea level pressures, sea state numbers and wind fields. Analysis of the data revealed a pronounced increase in sea-air temperature difference (2–4 °C) and this increase in the value is considered, obviously, to be due to a drop in the air temperature. The variations in the sea-air temperature difference and surface pressure are in opposite phase to each other. Some of the plausible mechanisms for the incipient development and movement of the depression are also discussed.

Zusammenfassung

Während MONEX-79 beobachtete Verhältnisse im Luft-Meer-Grenzbereich und eine Monsun-Depression

Es werden die Verhältnisse im Luft-Meer-Grenzbereich im frühen Entwicklungsstand einer Depression über der östlichen zentralen Arabischen See während der Monsun MONEX-79 durch Analyse der Schiffsbeobachtungsdaten über Luft- und Meerestemperaturen, Luftdruck an der Oberfläche, Seegang und Wind untersucht. Diese Analyse zeigte eine ausgesprochene Zunahme der Temperaturdifferenz zwischen Meer und Luft (2–4 °C) und diese Zunahme erweist sich klar als durch eine Abnahme der Lufttemperatur verursacht. Die Änderungen in der Temperaturdifferenz zwischen Meer und Luft und des Luftdrucks verlaufen in zueinander entgegengesetzter Phase. Einige einleuchtende Mechanismen für die beginnende Entwicklung und die Bewegung der Depression werden auch besprochen.

1. Introduction

It is well known that the tropical cylcones owe their energy to the heat released during the condensation, so that they form only over warm tropical oceans where there is an abundant supply of water vapour. For this reason

it becomes evident that the preferred areas of formation and subsequent paths of the storm are related in some systematic way to certain parameters at the air-sea interface which determine the amount of moisture in the air such as sea and air temperature [2, 12].
During MONEX-79 an opportunity has arisen to examine a case study of a depression which occurred over the East Central Arabian Sea on 16 June 1979 with its mean position 13°N and 71°E. In the present study we have examined the preferred regions of the formation of a depression and its subsequent movement in association with air-sea interface utilizing MONEX data such as sea surface temperature, air temperature, sea level pressure, wind field and sea state number.
The ship's data of the present study pertaining to sea-air temperatures, sea level pressures and sea state numbers were extracted from the reports published by the National Institute of Oceanography, Goa, India, for the period 8 to 18 June 1979 [16]. The area covered by the ship is the limits 11° to 15°N and 67° to 72°E. Also the data for the sea surface temperatures were extracted from the Indian Daily Weather Reports published by the India Meteorological Department.

2. Analysis and Results

Sea surface temperature: A mean chart of sea surface temperature over the area is prepared by averaging the values obtained from 8 to 15 June (8 days) and is shown in Fig. 1. The daily mean values of the sea surface temperature over the region of study is also given in Table 1 for the period 8 to 18 June. A tongue of highly warm water mass (30.8 °C) is located between the latitudes 10 to 13°N and longitudes 67 to 72°E (Fig. 1). This warm water mass is surrounded by a relatively colder water mass (~ 29.5 °C) in the west and south. These water masses are separated by a 30 °C isotherm which is running from the Arabia coast to Kerala coast through the Central Arabian Sea. The sea surface temperature over the region is around 30.5 °C.
Air temperature: Daily mean values of the air temperatures over the region are given in Table 1. The temperatures were oscillating around 29 °C upto 13 June and subsequently started decreasing and reached a minimum of 27 °C on 16 June when the depression formed over the region. The fall of temperature is 2–3 °C.
Surface pressure distribution: Daily mean values of the pressure field over the region were obtained and plotted in Fig. 2. The pressure is more or less uniform and the mean is ~1006 mb upto 12 June and a gradual fall is observed subsequently. A minimum in pressure occurred on 16–17 June (999 mb). The average pressure fall after 12 June is ~ 1 mb per day. The range of pressure for whole period is 10 mb in 11 days. Day to day pressure

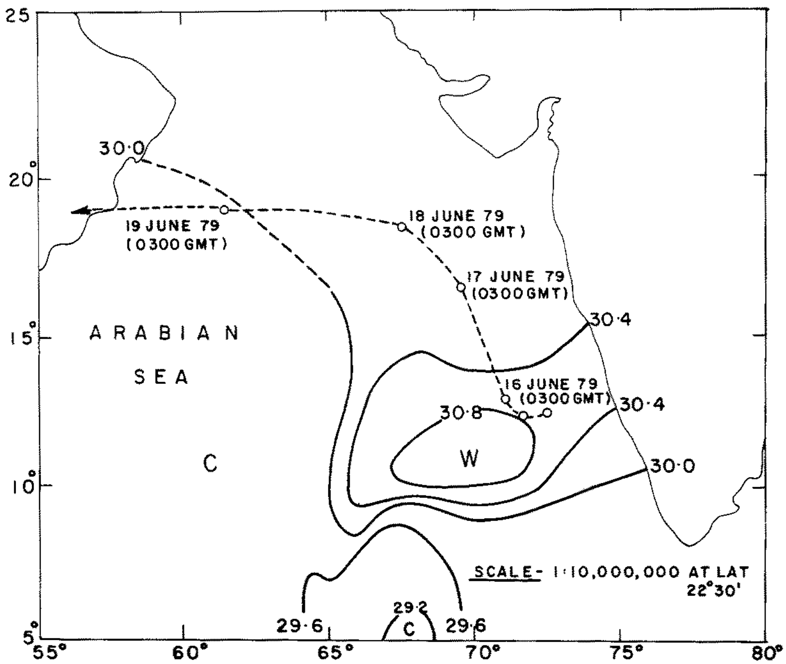

Fig. 1. Sea surface temperature before the monsoon depression, 08–15 June, and the depression path. Temperatures (°C) averaged by 1° quadrangle

changes are very significant over this region. The fall in pressure is reflected also in the increasing wind speeds and sea state number (Fig. 2).

Sea-air temperature difference: To understand the evoluational processes of air-sea interface during the period of observation over the area, we have evaluated the difference in sea surface and air temperatures and then obtained the mean. Fig. 2 shows an increasing trend in the value throughout the period. But major changes are observed to be between 13 and 18 June.

Table 1. *Daily Mean Values of Air and Sea Surface Temperatures Observed During the Period 08 to 18 June*

Date	8	9	10	11	12	13	14	15	16	17	18
Air temperature, °C											
	29.4	29.4	29.3	28.9	29.0	28.7	27.8	27.2	27.1	27.2	27.5
Sea surface temperature, °C											
	30.6	30.5	30.7	30.7	30.7	30.7	30.5	30.4	30.4	30.2	29.6

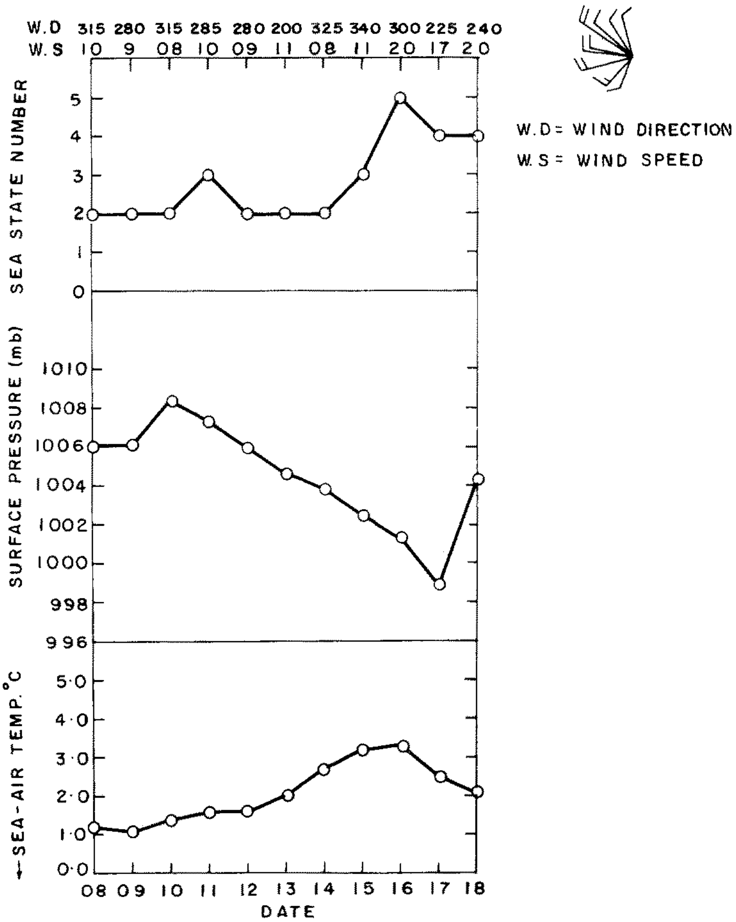

Fig. 2. Daily mean values of sea-air temperature difference (°C), sea-level pressure (mb) and sea state number (08–18 June)

These changes can be attributed to the incipient development of the depression. The greatest difference between the sea surface and air temperatures is found on 16 June. Based on quantitative considerations, the values less than 1.5 °C are observed prior to the formation and more than 3.0 °C during and thereafter. The sea surface temperature remained nearly constant, whereas noticeable changes occurred in air temperature. The change in air temperature is reflected in the anomaly of sea-air interface and is in opposite phase with the surface pressure.

3. Discussion

It is generally believed that during the early part of June the monsoon advances northwards and its arrival is usually ushered in by a storm of moderate intensity. In the Arabian sea most of the storms originate to the east of 67°E and between 12 to 20°N, and generally they move N or NNW and usually turn westwards north of 18°N, though a few recurve to northeast [14]. During the MONEX-79 a depression was formed over East Central Arabian Sea with its mean position at 13°N and 71°E just before the advance of the monsoon over India.

The depression was observed to be formed over a fairly well mixed warm surface water (~ 30.5 °C) where most of the turbulent convective processes are expected to take place. The value (30.5 °C) is as high (3–4 °C) as that of the values observed by many workers in the past. Palmen [7] has shown that the lowest water temperature for which warm core tropical cyclones are likely to form is about 26–27 °C. Sikka [11] has shown that for a depression to survive the sea water temperature must be at least 29 °C. Gray [3, 4] and Wendland [15] have concluded that the sea water temperature must maintain in the range of at least 26–27 °C or more to sustain the tropical disturbance throughout its period of intensification. Recently, Tuleya and Kurihara [13] by numerical experiments, obtained a spectrum of tropical disturbance development stages from a weakening wave to a mature tropical storm with a range of sea surface temperature from 298°K (24.8 °C) to 303°K (29.8 °C) respectively. The pressure field remains constant (1006 mb) during the early stages (8 to 12 June) and afterwards it starts falling gradually over the region and attains a low value on 17 June (999 mb). The pressure-wind and sea state number relations were maintained very closely.

A surface low of intensity ~ 1004 mb is observed to have moved from southeast over the area between 13–15 June, and has intensified into a depression on 16 June. This feature is verified from the daily weather reports of the India Meteorological Department, Pune. From this we can speculate that a surface low is necessary on the warm water masses for the initial formative stage of a depression. This study requires further investigation. However, the following observed features are of interest to identify air-sea interaction in association with the depression.

Sea surface temperatures presented here have not changed during the study whereas the significant change observed is in air-temperature vis-a-vis pressure. In order to evaluate the changes in air-sea interface we have obtained sea-air temperature differences. The analysis of the sea-air temperature differences has clearly brought out that cold air is advecting always towards the cyclogenesis area. Probably these temperature anomalies may provide a place for the turbulent exchange of heat and moisture from the sea surface to the underlying lower atmosphere and these fluxes are greatly utilized for the storm development. Similar features for the storm intensification were described in [2, 9, 10]. Pisharoty [8] mentioned that the atmosphere over the equatorial belt of Indian ocean is in its average state close to the threshold of latent vertical instability (convective) so that even a small positive anomaly of heating and evaporation (resulting from an anomaly of 1 to 2 °C of the sea-air interface) can release a vast amount of atmospheric potential energy. In the present study we have observed that the air temperature were much less than the sea surface temperatures, the difference being 3–4 °C. Agnihotri and Sikka [1] have also observed similar feature.

From Figs. 1 and 2 if we consider the sea surface isotherms and wind field, the wind is always blowing across the isotherms from the cold water side to warm water side (most of the time the winds are oscillating between NNW and SW). This type of transport of air from a cold water side to warm water side also contributes towards enhanced heat and moisture to the atmosphere by buoyancy forces which causes surface convergence in the lower atmosphere. This enhanced transport as defined by Laevastu et al. [6], is known as the "Providing Cycle" which is used for their model experiments. Kraus and Hanson [5] have also mentioned about the foregoing mechanism, as the air moves from a cold to warm surface, convective activity would increase because of both this increased surface heat supply and surface convergence. This mechanism, probably, might have played an important role in the incipient development of the depression over this area in the present case.

The parameters of the air-sea interface such as the air temperature, sea surface temperature and the sea state numbers start modifying from their disturbed states immediately after the passage of the depression from the area. The air temperature and the disturbed sea surface slowly restore to their equilibrium states while the sea surface temperature continues to fall below its original value.

The decrease in sea surface temperature is probably mainly due to the surface cooling by evaporation or mechanical mixing of the upper surface layers or upwelling due to the divergence of the surface waters away from the disturbed region. The rise in air temperature is mainly due to the subsidence in the rear of the depression. Hence the lowering of the sea-air temperature difference is mostly due to the rise in air temperature only.

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References

1. Agnihotri, R. D., Sikka, D. R.: Oceanic Response to Tropical Cyclone: A Case Study with the Data Collected by INS Betwa in the Bay of Bengal. National Symposium on Early Results of Monsoon Experiments, New Delhi, 9–11 March, 1981.
2. Fisher, E. L.: Hurricanes and the Sea Surface Temperature: Part I. National Hurricane Research Project No. 8. U.S. Department of Commerce, Washington, D.C., 1957.
3. Gray, W. M.: Tropical Cyclone Genesis. Paper No. 234. Dept. Atmos. Sci., Colorado State University, 121 pp., 1975.
4. Gray, W. M.: Hurricane: Their Formation, Structure and Likely Role in the Tropical Circulation. Dept. Atmos. Sci., Colorado State University, Fort Collins, CO 80523, 1980.
5. Kraus, E. B., Hauson, H. P.: Air-Sea Interaction as a Propogator of Equitorial Ocean Surface Temperature Anomalies. J. Phys. Oceanogr. *13*, 130–138 (1983).
6. Laevastu, T., et al.: Mesoscale Feedback from the Ocean to the Atmosphere in Coastal and Oceanic Frontal Regions. Environmental Prediction Research Facility (Navy) Montery, California, pp. 7–8, 1974.
7. Palmen, E.: On the Formation and Structure of Tropical Hurricanes. Geophysica (Helsinki) *3*, 26–38 (1948).
8. Pisharoty, P. R.: Sea-Surface Temperature and Monsoon. Monsoon Dynamics (James Hight Hill, R. P. Pearce, eds.), pp. 238–251. London: University Press 1981.
9. Pyke, C. B.: On the Role of Air-Sea Interaction in the Development of Cyclones. Bull. Amer. Met. Soc. *46*, 4–8 (1965).
10. Ramage: The Typhoons of October 1970 in the South China Sea: Intensification, Decay and Ocean Interaction. J. Appl. Met. *13*, 739–751 (1974).
11. Sikka, D. R.: Some Aspects of the Life History, Structure and Movement of Monsoon Depressions. Pageoph. *115*, 1501–1529 (1977).
12. Tisdale, C. F., Clapp, P. F.: Origin and Paths of Hurricanes and Tropical Storms Related to Certain Physical Parameters at the Air-Sea Interface. J. Appl. Met. *2*, 358–367 (1963).
13. Tuleya, R. E., Yoshio Kurihara: A Note on the Sea Surface Temperature Sensitivity of Numerical Model of Tropical Storm Genesis. Mon. Weath. Rev. *110*, 2063–2069 (1982).
14. Weather in the Indian Ocean, Vol. 1, 1943.
15. Wendland, W. M.: Tropical Storm Frequencies Related to Sea Surface Temperatures. J. Appl. Met. *16*, 477–481 (1977).
16. FGGE MONEX-79, Environmental Data, NIO, Goa: 4003004 (India).

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