J. mar. biol. Ass. India, 1972, **14** (2): 663-670

MEAN MONTHLY FLUXES OF SENSIBLE AND LATENT HEAT FROM THE SURFACE OF THE INDIAN OCEAN*

K. R. SAHA AND R. SURYANARAYANA

Institute of Tropical Meteorology, Poona-5, India

ABSTRACT

Mean monthly values of vertical fluxes of sensible and latent heat from the surface of the Indian ocean are computed for a five-year period. Extensive areas of strong evaporation and upward and downward sensible heat fluxes are located. Their role in the context of monsoon circulation and formation of cloud and precipitation is discussed.

INTRODUCTION

IN the heat balance of the surface of the Indian Ocean as well as in the hydrologic cycle of the Indian monsoon, fluxes of sensible heat and water vapour from the surface of the Indian ocean play a major role. These fluxes are directly proportional to the gradients of temperature and vapour pressure between the ocean and the atmosphere across the ocean-atmosphere interface and the mean wind speed approximately at shipdeck level. For the determination of the fluxes, therefore, a knowledge of the ocean surface temperature and the properties of the overlying atmosphere such as air temperature, dew-point, and wind speed are required.

Venkateswaran (1956) and Privett (1959) used climatological data to compute evaporation from the surface of the Indian Ocean. Computations of mean monthly sea surface temperatures and air-sea exchange parameters based on actual data for individual years were first carried out under the Meteorology Programme of the International Indian Ocean Expedition (1963-64) (Miller *et al.*, 1963). The distributions of mean monthly sea surface temperature over the Indian Ocean for years 1963 and 1964 have been presented by Miller and Jefferies (1967). Results of computation of evaporation flux for year 1963 have been presented by Suryanarayana and Sikka (1965). Mean monthly fluxes of sensible and latent heat for year 1964 have been discussed by Saha (1970).

The present paper gives the results of further computations of mean monthly sea surface temperature and fluxes of air-sea heat exchanges during summer monsoon months of subsequent years, 1965-67, using ships' weather data collected after the IIOE period. Mean monthly values for July and August during individual years as well as three-year averages of the following parameters are presented: (1) Ocean surface temperature, (2) flux of sensible heat and (3) flux of latent heat. The area covered by the computation extends from 40°E to 100°E and from 20°S to 30°N.

---

* Presented at the 'Symposium on Indian Ocean and Adjacent Seas—Their Origin, Science and Resources' held by the Marine Biological Association of India at Cochin from January 12 to 18, 1971.

COMPUTATIONS

The IBM 1620 computer at the Institute of Tropical Meteorology, Poona, was used for processing of ships' weather reports as well as for computing the fluxes, using method described by Suryanarayana and Miller (1964). In this method, the computer programme checks the validity of all meteorological parameters and sea surface temperatures within preset limits, based on climatology, and average them into 5 degree latitude-longitude blocks. On an average, the number of ships' reports processed per month varied from 5000 to 6000. The fluxes were computed using the following equations (Miller, Sivaramakrishnan and Suryanarayana, 1963) :

$$Q_e = 81.9\,(e_{ss}-e_{sa})\,V, \text{ where } e_{ss} > e_{sa} \qquad (1)$$

$$Q_h = 21.7\,(.26+.39V)\,(T_s-T_a), \text{ where } T_s > T_a \qquad (2)$$

$$Q_h = .83V\,(T_s-T_a), \text{ where } T_s < T_a \qquad (3)$$

where Q_e is the rate of heat exchange between the ocean and the atmosphere due to evaporation, (Unit : Cals/cm²/day)

Q_h is the rate of sensible heat exchange between the ocean and the atmosphere, positive upward. (Unit : Cals/cm²/day).

e_{ss} is the saturation vapour pressure at the temperature of the ocean surface. (Unit : inches of mercury).

e_{sa} is the saturation vapour pressure at the dew-point of the air. (Unit : inches of mercury).

T_s is the ocean surface temperature (°F).

T_a is the air temperature (°F).

and V is the wind speed (knots).

The constants used in equations (2) and (3) were those used by Tabata (1958).

MEAN MONTHLY OCEAN SURFACE TEMPERATURE (T_s)

The distributions of mean ocean surface temperature for the three individual years, 1965, 1966 and 1967 as well as the three-year average temperature for the months of (a) July and (b) August are shown in Fig. 1. The distributions would appear to show the following essential features :

(*a*) *During July*, the mean monthly ocean temperature over the western Arabian Sea near the coasts of Somalia and Arabia is about 4°C lower than that in eastern Arabian Sea and about 6-8°C lower than that in Persian Gulf and the Red Sea in all the years under study. A flat temperature distribution is observed in equatorial eastern Indian Ocean north of about 5°S, although a steep temperature gradient exists to south of this latitude. The sea surface temperature in the Bay of Bengal is generally slightly higher than that over the eastern Arabian Sea.

(*b*) *The August* features are similar to those observed during July. The western Arabian sea, west of about 60°E, continues to be colder than the eastern Arabian sea as well as the Persian Gulf and the Red Sea. The flat temperature pro-

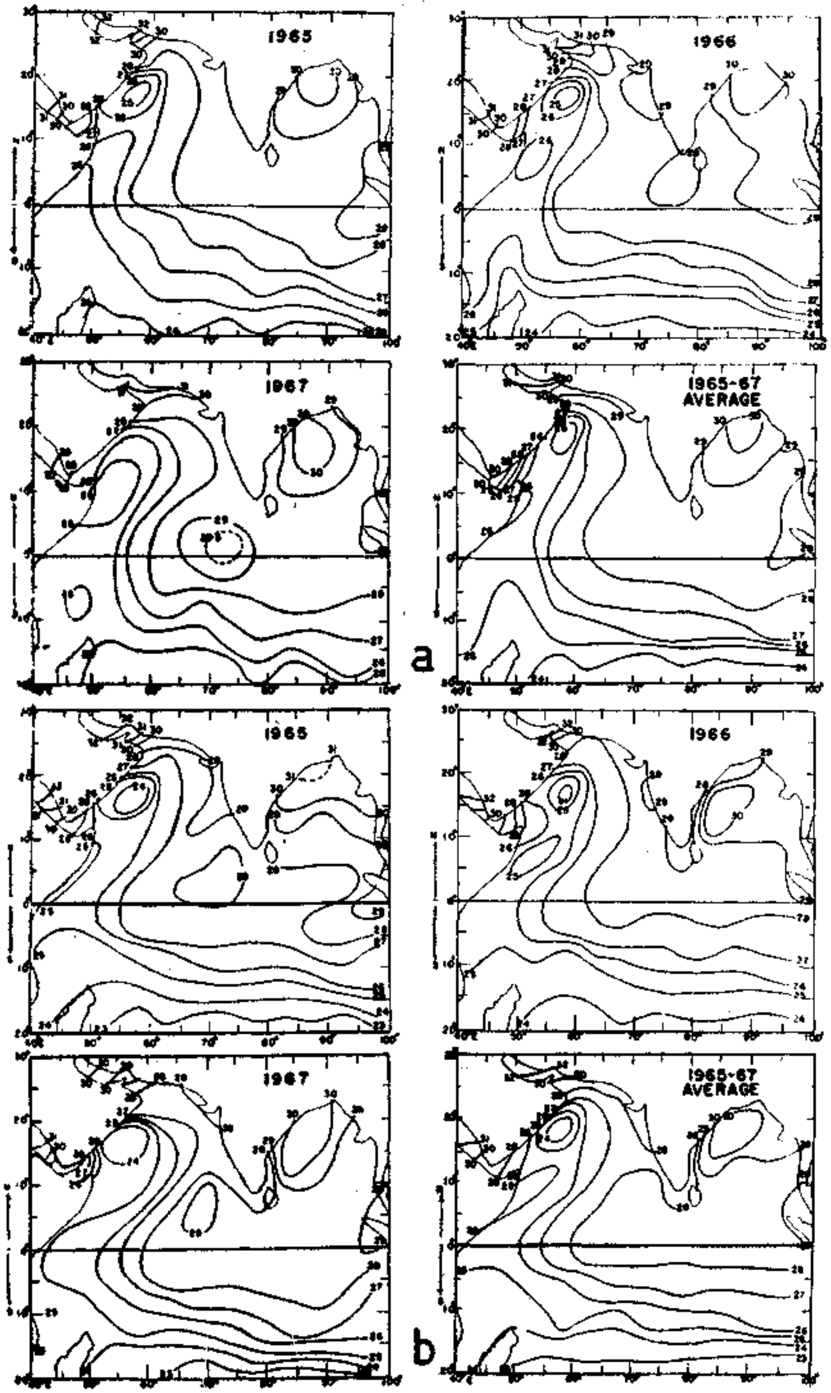

Fig. 1. Distribution of mean monthly sea surface temperature (°C) in Indian Ocean during 1965, 1966, 1967 and the three-year averages during (a) July and (b) August.

file across the equator in eastern Indian ocean continues and the Bay of Bengal continues to be warmer than the Arabian Sea.

There is some indication that ocean surface temperature contrast between the western Indian Ocean and the eastern Indian Ocean during 1967 was somewhat more pronounced than during the earlier two years. This, however, requires further study.

Distribution of mean monthly flux of sensible heat (Q_h)

The distribution of mean monthly exchanges of sensible heat between the ocean and the atmosphere over the Indian Ocean during (a) July and (b) August are shown in Fig. 2. The salient features of the distribution for the individual years as well as the three-year average may be summarised as follows :

(*a*) *During July*, a broad area of negative (downward) sensible heat flux appears over the western Arabian Sea adjoining to the coasts of Somalia and Arabia. In the three-year average distribution, the magnitude of the negative sensible heat flux amounts to as low as-30 calories/cm^2/day. Over rest of the Arabian Sea as well as over the Bay of Bengal and the south Indian Ocean, the sensible heat flux is positive. Positive flux as high as 60 cals/cm^2/day is observed over northern parts of the Bay of Bengal,

(*b*) *During August*, the mean features observed are similar to those during July, although there are some variations in points of detail. The mean flux continues to be negative over western Arabian Sea, west of about 60°E. Two broad areas of high positive flux observed during July also appear in the three-year average picture, one over the northern parts of the Bay of Bengal and the other in eastern parts of south Indian Ocean.

Distributions of mean monthly flux of latent heat (Q_e)

The values of mean monthly latent heat flux for July and August for the three years and their average are presented in Fig. 3 (a) and (b). They reveal the following general features :

(*a*) *During July*, evaporation is generally high over the Arabian Sea and the Bay of Bengal and also over the south Indian Ocean south of about 10°S. It is generally small in equatorial Indian Ocean.

(*b*) *During August*, the patterns observed are broadly similar to those during July, although the magnitudes of evaporation over the Arabian Sea and the Bay of Bengal are considerably less during August than during July. The evaporation flux over the south Indian Ocean, however, appears to be higher during August than during July. Very little change is noticeable in equatorial region.

Discussion

It may be seen from Fig. 1 that the mean monthly sea surface temperature is minimum in western Arabian Sea adjoining to coasts of Somalia and Arabia during all the three years under study. In fact, a line passing through the minimum sea surface temperature appears to run somewhat parallel and fairly close to the African

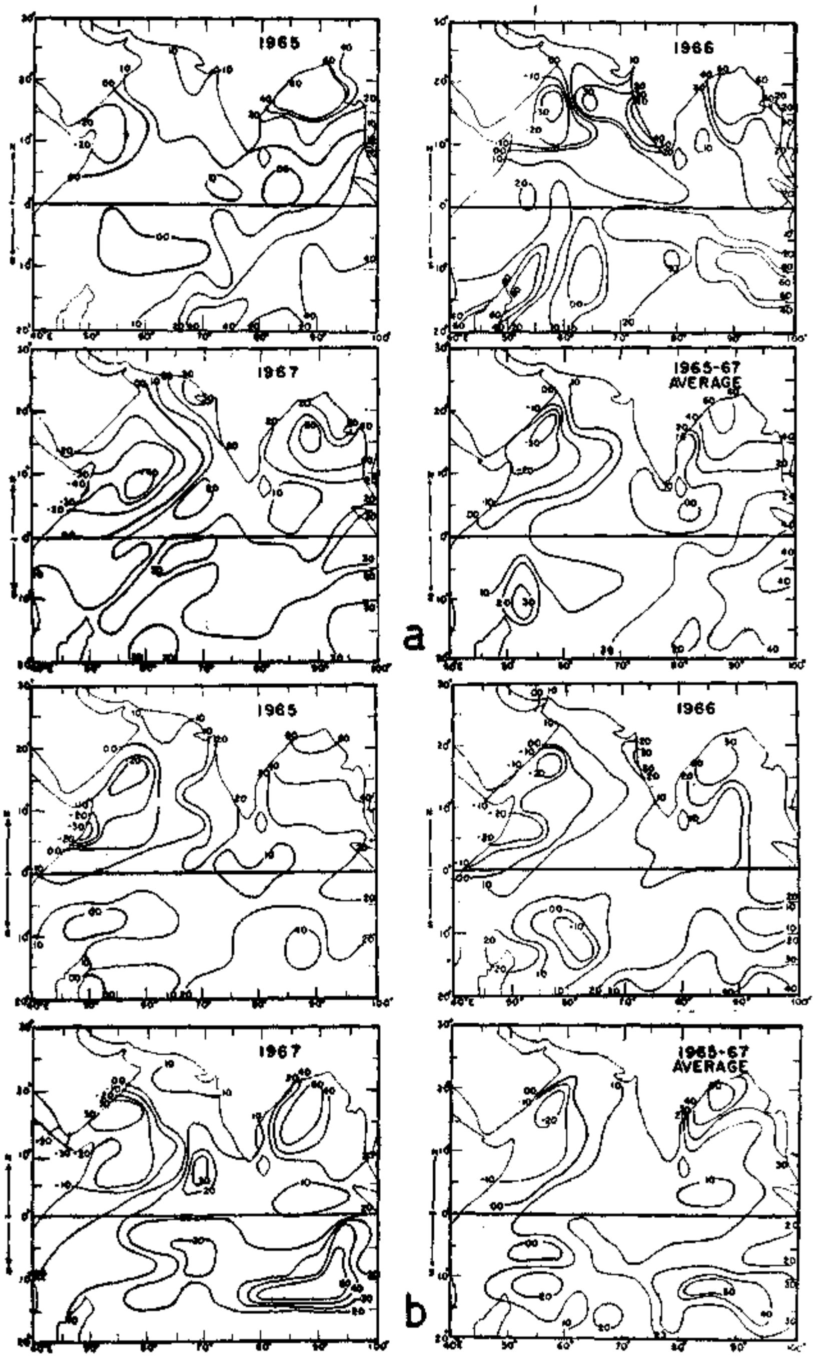

Fig. 2. Distribution of mean monthly flux of sensible heat (cals/cm²/day) in Indian Ocean during 1965, 1966, 1967 and the three-year averages during (a) July and (b) August.

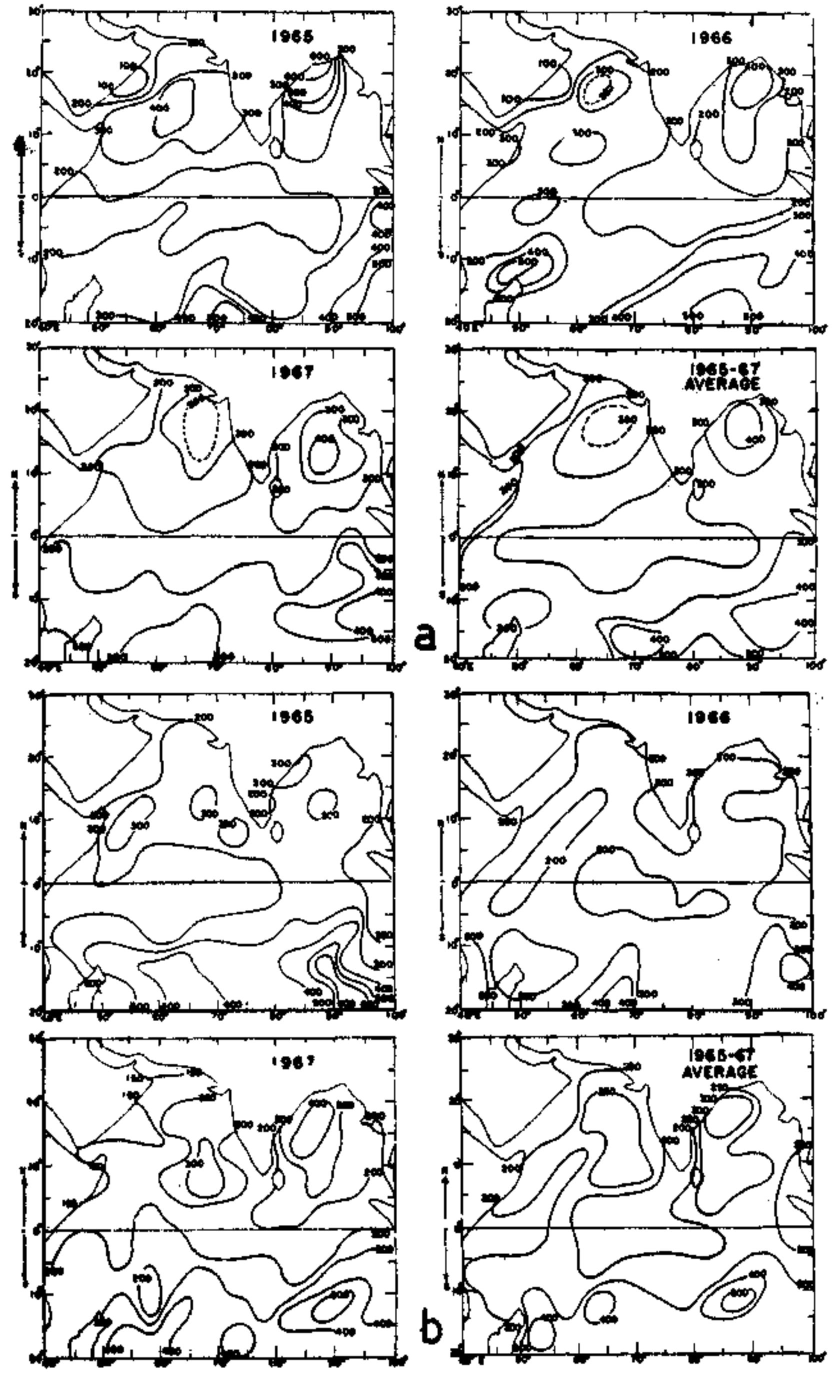

Fig. 3. Distribution of mean monthly flux of latent heat of evaporation (cals/cm²/day) in Indian Ocean during 1965, 1966, 1967 and the three-year averages during (a) July and (b) August.

coast lines and extend from about 15°S to about 20°N. Bunker (1965) sought to explain the presence of strong low-level SW'ly winds near the coast of Somalia during the summer monsoon on the basis of pressure gradient that develops between a wedge of high pressure over the cold coastal waters and a trough of low pressure over the hot hinterland of Somalia. Subsequently, Findlater (1969) has produced observational evidence of the presence of very strong low level air currents extending from near Malagasy to Arabia across coastal belts of East Africa and Somalia. If Bunker's explanation of Somali jet is valid, it would seem that the same could be extended to cross-equatorial aircurrents reported by Findlater. However, the matter requires further examination with adequate oceanic and meteorological data.

Fig. 2 appears to show that although the general distributions of sensible heat flux during the three years studied are similar, some variations in areal extent and magnitude of negative heat flux over Arabian Sea occurred. For example, during 1967 the area under negative sensible heat flux extends southward to almost equator and eastward to longitude about 70°E with the maximum negative value of -45 cals/m^2/day over western Arabian Sea. During 1965 and 1966, the areal extent as well as magnitude of negative heat flux were smaller. It may be mentioned here that the sensible heat flux pattern during 1967 is comparable to that during 1964 in areal extent as well as in magnitude (Saha, 1970) and both happened to be good monsoon years in contrast to 1965 and 1966. This remark, however, requires further examination with more detailed data.

The evaporation flux shown in Fig. 3 shows uniformly higher values over the Bay of Bengal than over the Arabian Sea and these values are somewhat higher than in previous years. This appears somewhat puzzling in view of the presence of stronger winds over the Arabian Sea than over the Bay of Bengal. The matter certainly requires to be examined with more oceanic and meteorological data. It is, however, likely that the higher values of sea surface temperature in the Bay of Bengal (Fig. 1) during the periods studied might have contributed to the computed higher evaporation fluxes over the region.

Finally, it may be noted that computed evaporation flux over the extreme western parts of north Arabian sea adjacent to the coasts of Arabia and Somalia are definitely smaller than that in middle or eastern parts. The region of this low evaporation flux appears to correlate strongly with the regions of upwelling and cold sea surface. Strong gradients of evaporation flux appear to coincide with corresponding gradients of sea surface temperature across about 60°E. This may indicate a possibility that the effect of strong winds may be reduced by that of lower saturation vapour pressure of a cold sea surface.

References

BUNKER, A. F. 1965. Interaction of the summer monsoon air with the Arabian Sea. *Proc. Sym. Met. Results, IIOE, Bombay* (Ed. : P. R. Pisharoty), 3-16.

FINDLATER, J. 1969. A major low-level air current near the Indian Ocean during the northern summer. *Quart. J. R. Met. Soc.*, **95** : 362-380.

MILLER, F. R., and JEFFERIS, C. 1967. Mean monthly sea surface temperatures of the Indian Ocean during the International Indian Ocean Expedition. *Hawaii Institute of Geophysics, Report* No. HIG-67-14.

MILLER, F. R., SIVARAMAKRISHNAN, M. V. and SURYANARAYANA, R. 1963. Preliminary results and future plans of IIOE meteorology programmes—computer plans. *Proc. Seminar, jointly sponsored by NSF (USA), Ind. Met. Dept. and U.S.I.S.*, 30-41.

PRIVETT, D. W. 1959. Monthly charts of evaporation from the N. Indian Ocean (including the Red Sea and Persian Gulf). *Quart. J. R. Met. Soc.*, **85** : 424-428.

SAHA, K. R. 1970. Zonal anomaly of sea surface temperature in equatorial Indian Ocean and its possible effect upon monsoon circulation. *Tellus*, **22** (2).

SURYANARAYANA, R. and MILLER, F. R. 1964. Electronic computer aids research in Indian Ocean expedition. *Bull. Amer. Met. Soc.*, **45**, (10) : 644-647.

——— and SIKKA, D. R. 1965. Evaporation over the Indian Ocean during 1963. *Proc. Sym. Met. Res., IIOE, Bombay*, 68-69, Ed. : P. R. Pisharoty.

TABATA, S. 1958. Heat budget of the water in the vicinity of Triple Island British Columbia. *J. Fish. Res. Bd. Canada*, **15** : 429-451.

VENKATESWARAN, S. V. 1956. On evaporation from the Indian Ocean. *Ind. J. Meteorology and Geophysics*, **7** : 266-283.

DISCUSSION

D. R. SIKKA : Dr. Saha in an earlier paper emphasised the role of the warmer sea surface temperature in the equatorial region on the formation of double equatorial cloud bands. He showed that there were lesser number of occasions of southern equatorial band in July 1967. In this paper the sea surface temperature distribution during July 1967 shows a maximum in the equatorial zone. How do we reconcile this maximum with lesser occasions of southern equatorial cloud band ?

K. R. SAHA : A study of complex ocean-atmosphere interaction based on distribution of ocean surface temperature no doubt helps us in understanding the general distribution of clouds and cloud groups in equatorial Indian Ocean but the actual manner in which cloud evolution takes place i.e. whether it is in the form of organised bands or irregularly distributed cloud clusters is still very imperfectly understood. It is probable that the meridional temperature gradient through its thermal wind effect may decide between the two possibilities. With more clusters formed, there may be fewer bands and vice-versa. In other words, it may be a question of degree of organisation or sharpness of the zone of convergence in the flow field south of the equator, as discussed in the present paper.