Mahasagar-Bulletin of the National Institute of
Oceanography, **18**(2), 1985, 203–210.

EXCHANGE OF FLUXES ACROSS THE AIR-SEA INTERFACE DURING THE ONSET PHASE OF THE SOUTHWEST MONSOON

D. PANAKALA RAO AND M.V. RAO

National Institute of Oceanography, Dona Paula, Goa - 403 004.

ABSTRACT

The fluxes of momentum, sensible and latent heat over the southwest coast of India for the period of 27th May–10th June, 1984 based on the surface meteorological data have been presented on the time scale. The latent heat transfer has been discussed in relation to the onset phase of the southwest monsoon which has been triggered by the low pressure system extending from Saurashtra Coast to Lakshdweep Sea. The development of the surface layer has also been discussed in the light of the wind induced nearsurface circulation and wave action.

Key-words : Sensible heat, Latent heat, fluxes, monsoon, Arabian Sea.

INTRODUCTION

Studies relating to the evaporation rates over the Arabian Sea with the rainfall along the westcoast of India have drawn considerable attention in the recent years. Bhumralkar (1978) has shown that there is considerable increase in the moisture content downstream of the monsoon air mass over the eastern Arabian Sea before it strikes the west coast of India. Rao, Schaub and Puctz (1981) have also mentioned that after balancing the precipitation over the sea during the summer monsoon season, a good part of the evaporated water (> 60%) from the Arabian Sea will be transported over to the Indian Sub-continent. Colon (1964) suggested that energy exchange between the Arabian Sea and the monsoon air mass has considerable influence on the monsoon flow and the weather patterns over India.

The present study deals with the daily and diurnal variations of the momentum, sensible and latent heat fluxes during the onset phase of the southwest monsoon in 1984, off southwest coast of India in relation to the existing weather conditions. In addition to illustrating the sensible and latent heat fluxes, diurnal as well as daily variations of the atmospheric variables which contribute to those fluxes are also presented.

MATERIALS AND METHODS

Hourly surface meteorological observations such as air temperature (A_T), wet bulb temperature (W_T), wind speed and direction, atmospheric pressure and sea surface temperature (using bucket thermometer) have been collected during the 139th Oceanographic cruise of RV *Gaveshani* from 27th May to 10th June, 1984 in the southeastern Arabian Sea (off southwest coast of India). The station locations are shown in Fig. 1. Wind speed measure-

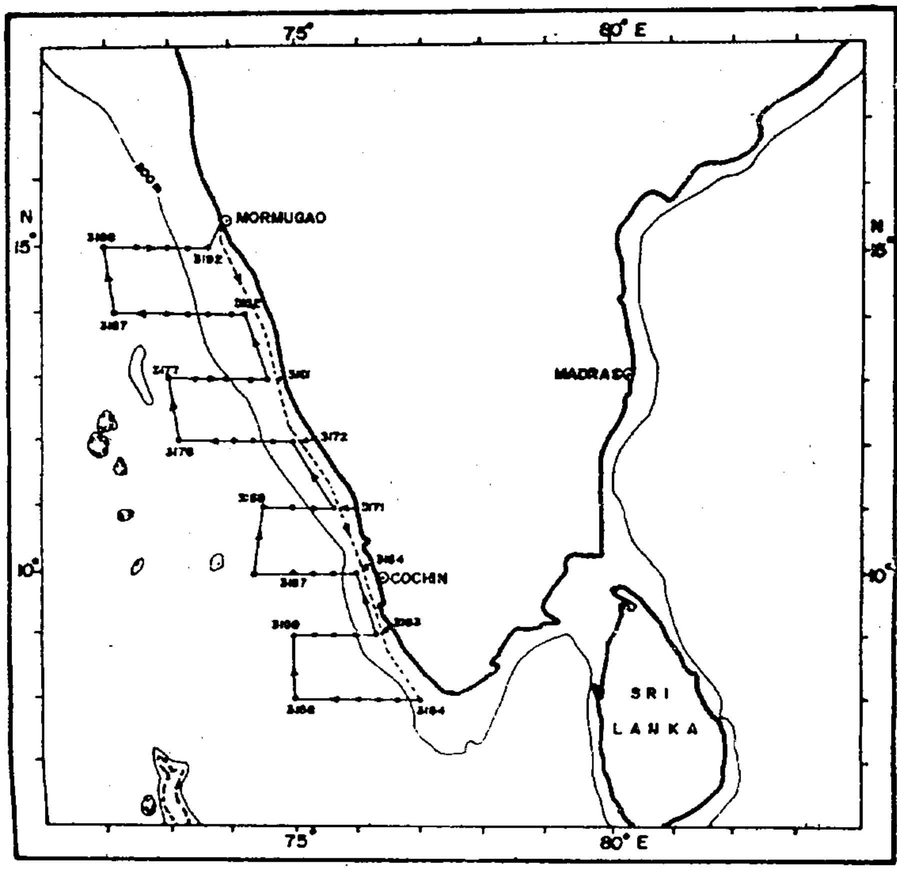

Fig. 1. Map showing station locations.

ments with the moving ship were corrected by applying the equation to obtain the true wind:

$$BD^2 = AB^2 + AD^2 - 2\,AB * AD\,\cos \angle BAD \qquad (1)$$

Where BD is the true wind speed,

AB is the apparent wind speed,

AD is the ship speed and

$\angle BAD$ is given by the difference between the apparent wind direction and the ships' course.

Surface atmospheric parameters collected at deck level have been corrected to the 10 m above the sea level following the equation given by Stevenson (1982).

The momentum flux (τ), sensible heat flux (Qs) and latent heat flux (Qe) at the air sea interface are computed using the bulk aerodynamic formulae:

$$\tau = \rho\, Cd\, U_{10}^2 \qquad (2)$$

$$Qs = \rho\, Cp\, Ch\, (Ts - T_{10})\, U_{10} \qquad (3)$$

$$Qe = \rho\, Ce\, L\, (Qs - Q_{10})\, U_{10} \qquad (4)$$

Where ϱ is the average density of the air ($1.2\text{–}10^{-3}$ g.cm^{-3} Cp is the specific heat of the air at constant pressure (0.24 Cal.g^{-1}. deg^{-1})

L is the latent heat of evaporation of the water (585 Cal.g^{-1})

The variables U^{10}, T^{10} and q^{10} are the wind speed (m.Sec^{-1}), air temperature (°C) and specific humidity at 10 m above sea level respectively. The variables T_s and q_s are the sea surface temperature and saturation specific humidity of air with water temperature (T_s) and sea level pressure (P_s) respectively.

The quantities Cd, Ch and Ce are the transfer coefficients for momentum, sensible and latent heat of evaporation respectively. These transfer coefficients are estimated using the method suggested by Stevenson (1982) for wind speeds more than 4.0 m. sec^{-1}. For wind speeds less than 4.0 m.sec^{-1} the values given by Kondo (1975) were taken. The momentum, sensible heat and latent heat fluxes were computed using equations (2), (3) and (4) respectively for each observation. These values are then averaged for the daily and diurnal mean values. For the present study, the entire southeastern Arabian Sea is considered as one location.

The daily and diurnal variations of wind speed, air, wet bulb and water temperatures and air minus sea surface temperatures are illustrated in Figs. 2 and 4 respectively. The momentum, sensible and latent heat fluxes and evaporation are shown in Figs. 3 and 5 for daily and diurnal time scales respectively.

RESULTS AND DISCUSSION

It is seen from Fig. 2 that there was sudden increase in wind speeds from 28 to 29 May from about 3.6 to 11.6 m sec^{-1} and by 30th May it decreased to 6.5 m sec^{-1}. Again the wind speed increased from 1st to 2 June from about 6.5 to 11.5 m sec^{-1}. It can also be seen that the sea surface temperature fell by about 1.5°C from 27 to 29 May while approaching the southern parts of the Arabian Sea. Air minus sea surface temperatures are negative during the entire period of observations except during 27 to 28 May when there was not any sign of onset of southwest monsoon. The daily variations of fluxes (Fig. 3) indicate that there is difference in the values of momentum (1.7 dyn. cm^{-1}). sensible heat (47.0 w.m^{-1}) and latent heat (155 w.m^{-2}) from their respective mean values. On an average, the sensible heat flux is only about 20% of the latent heat flux. The maximum evaporation of about 1.53 cm per day occurred on 2nd June, coinciding with the high and consistent winds with speeds 11.5 m sec^{-1}. The sea surface temperature was fairly uniform throughout the period of the cruise as seen from Fig. 4 with an average value of 29.3°C. The winds were more gustry reaching maximum value of 11.5 m sec^{-1} on 29th May and 2nd June, 1984. Thereafter, the wind speeds fell. The maximum wind speed after 2nd June was 9.3 m sec^{-1} recorded on 8th June, 1984. By this time the ship moved

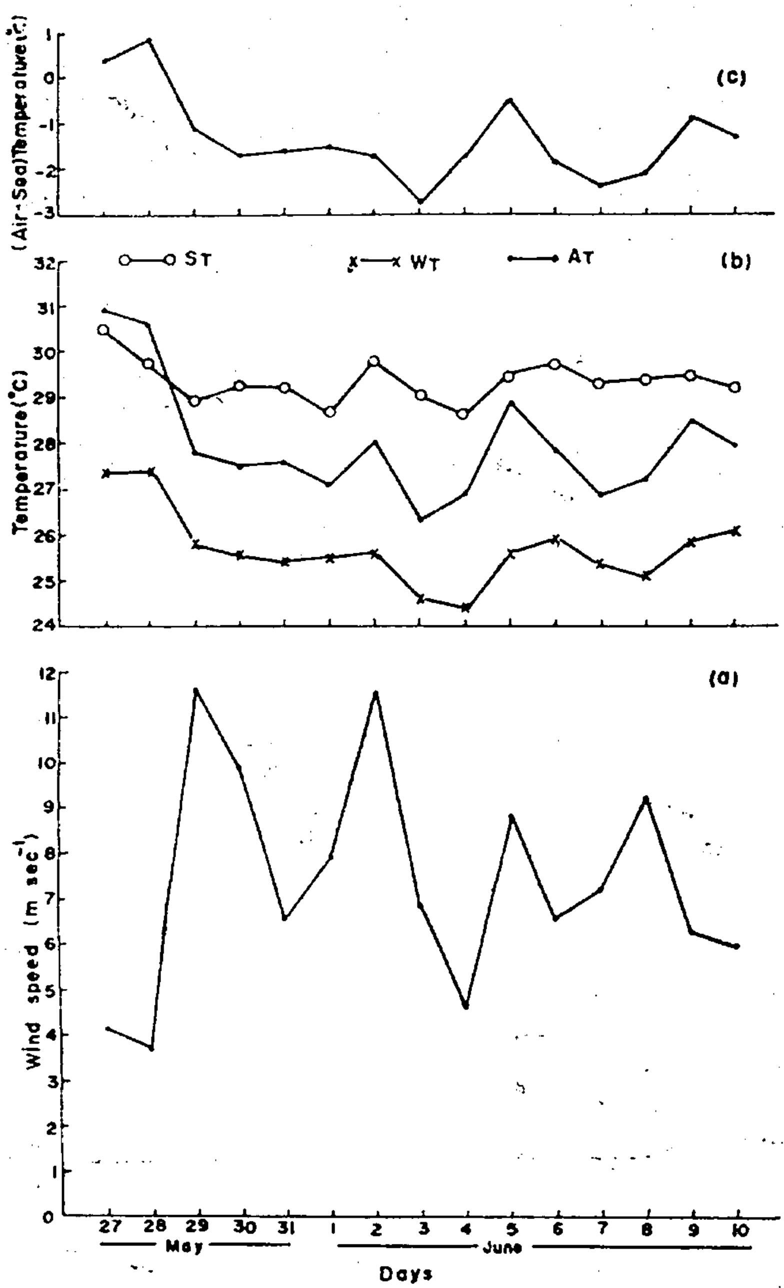

Fig. 2. Daily variation of (a) Wind speed (b) Air, wetbulb and water temperature (c) Air-Sea temperature.

northwards to about 15° N. The mean evaporation was observed to be maximum during the early hours while minimum during the local noon (Fig. 5).

The diurnal variation of evaporation flux may be explained on the basis of temporal variation of surface wind speed (Fig. 4a) and the vapour pressure difference between air (10 m above sea level) and sea surface. The maximum diurnal value of sea surface temperature was 29.5 °C and occurred between 1500 and 1600 hrs IST with two minima of about 29.0 °C occurring at 0300 and 2300 hrs IST. The mean diurnal variations of sea surface tem-

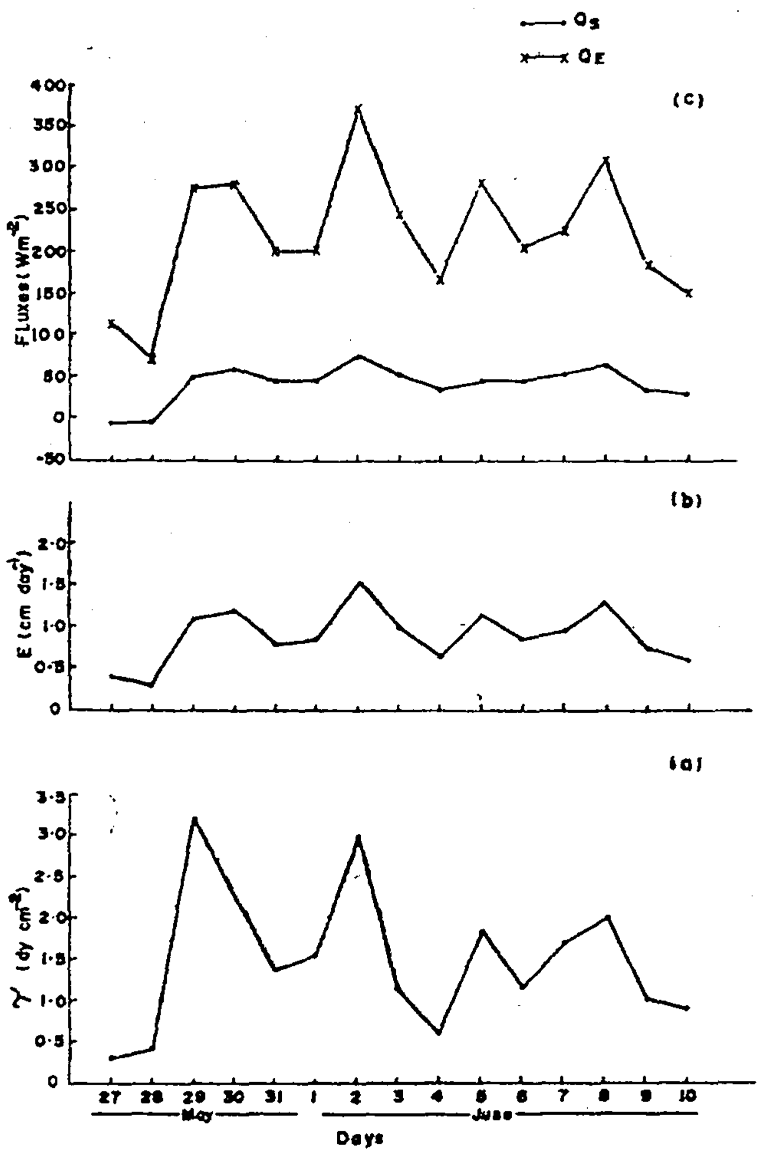

Fig. 3. Daily variations of (a) Momentum flux (b) Evaporation (c) Sensible & latent heat fluxes.

perature difference was about 0.4 °C. The mean diurnal variation of SST in the lower latitudes has been reported to be between 0.3 and 0.4 °C by Meinardus (1923) and Wegemann (1920) with the extremes occurring between 0230 and 0300 hrs and between 1430 and 1500 hrs of local time respectively. The maximum evaporation occurred on 2nd June when the vessel was at position 9 ° 59.2 ′ N, 74 ° 59.7 ′ E. The weather pattern had shown a low level trough extending from south Saurashtra-Maharashtra coasts to Lakshdweep Sea on 2nd June. The trough further concentrated into a depression and became unimportant after 3–4 days. Under the influence of this system, the southwest monsoon has been activated over the southwest coast of India. The low level trough concentrating as depression developed strong wind field over Lakshd-

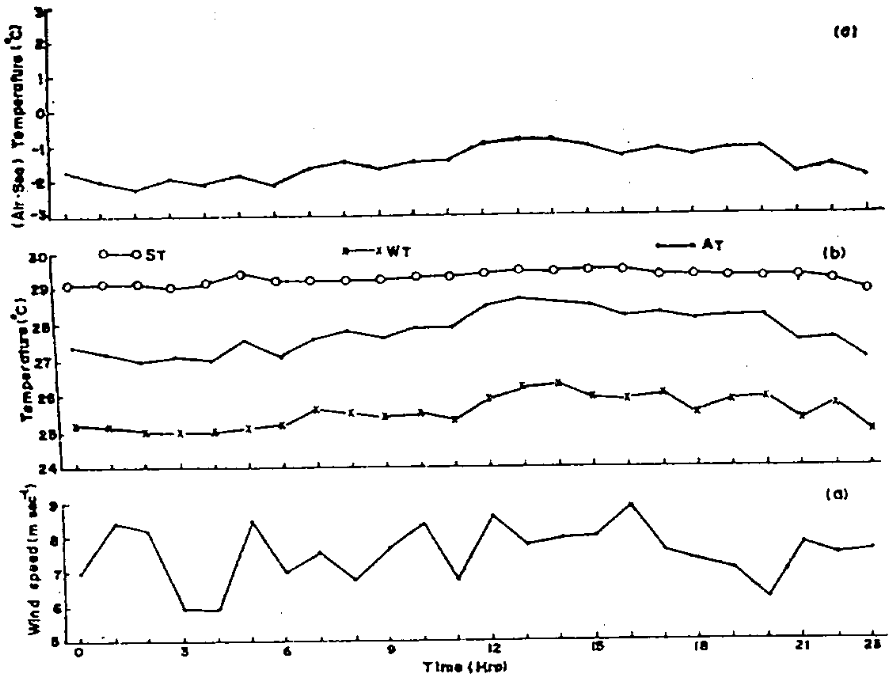

Fig. 4. Diurnal variation of (a) Wind speed (b) Air, wetbulb and water temperatures (c) Air-Sea temperature.

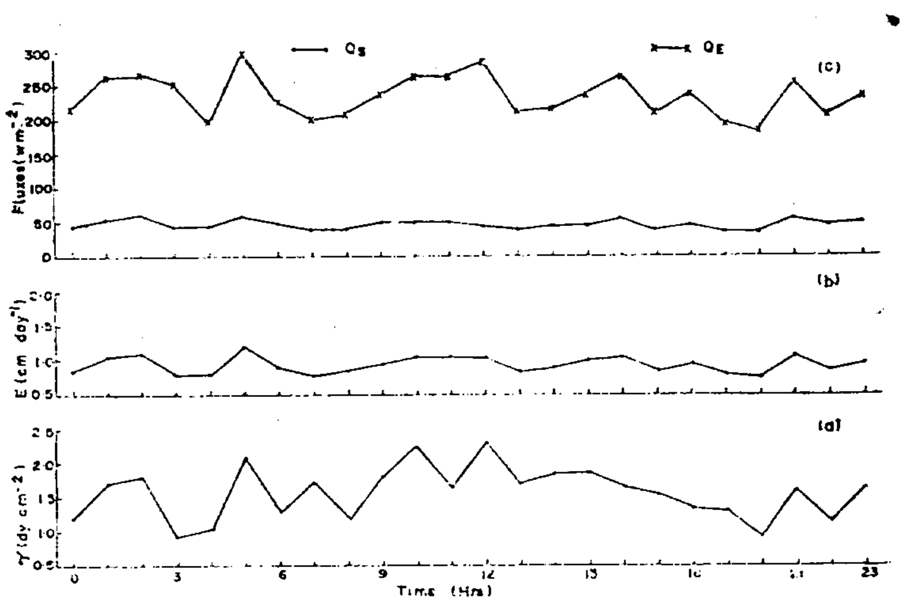

Fig. 5. Diurnal variation of (a) Momentum flux (b) Evaporation (c) Sensible & latent heat fluxes.

weep Sea and southwest coast of India. This strong wind field enhanced the momentum exchange and latent heat fluxes resulting in the maximum evopa-ration of about 1.53 cm/day on 2 June, 1984. However, when the depression weakened after 2nd June and crossed the coast off Saurashtra, the wind field has weakened and consequently, the reduction in the momentum and latent heat exchange. These features could be seen from Figs. 2 and 4 respectively. Though the onset of southwest monsoon has been triggered by the formation of this trough, lower winds were noticed onboard the ship after 2 June because the advance of the monsoon front is relatively slower than the advance of the ship to the north. With the crossing of the depression over the Saurashtra coast, the existing conditions over the Lakshdweep Sea could not have been more favourable for the quick advance of the monsoon front and hence the exchange of fluxes have shown a reduction till the vessel reached Mormugao port on 10 June, 1984. The rainfall observed in Goa on 1st June, 1984 was 0.1 mm and reached a higher value of 25 mm on 3rd June and decreased on 4 and 5 June, coinciding with the passage of the system. Thus, it is seen that with the weakening of the wind field, there was reduction both in the latent heat flux and the occurrence of rainfall over the southwest coast of India after 3rd June. This is in confirmation with the findings of Bhumralkar (1978) who suggested that the latent heat flux exchanges over the Arabian Sea play a significant role in the rainfall patterns along the westcoast of India during summer monsoon. A cursory look at the wind field (Fig. 2a) shows a periodicity of 4–5 day cycle.

The wind induced nearsurface circulation generated during this period appears to have persisted for sometime after the system crossed the coast. An examination of the daily mean surface temperatures showed a drop after 28th May and attained a value of 28.6°C on 4th June. Similarly, the thickness of the surface mixed layer as observed from the bathythermographs has shown an increase to 30–40 m after 2nd June over the values of 15–20 m observed before the formation of the low pressure. The lowering of the sea surface temperatures has been the result of cooling due to vertical mixing. The intense wave action also might have contributed towards this process besides the nearsurface circulation. The development of the surface layer and the lowering of the surface temperatures, thus suggest that eventhough the contribution of surface wind forcing towards the exchange of fluxes has decreased, the wind generated wave action and the nearsurface circulation persisted for some more time after the low pressure crossed the coast.

ACKNOWLEDGEMENTS

The authors are thankful to Director, National Institute of Oceeanography and Dr. J.S. Sastry, Dy. Director and Head, Physical Oceanography Division for their encouragement in this work. The authors also express their gratitude to Shri D. Sunder and Shri A.A. Michael for their help in collecting the data onboard the ship. Shri V.S.N. Murty, POD, NIO is duly thanked for making available the computer programme for the computational work. Thanks are also due to the Master, Officers and crew of RV Gaveshani for their cooperation in the cruise.

REFERENCES

Bhumralkar, C.M., 1978. Relation between evaporation over the Arabian Sea and rainfall at the west coast of India during summer monsoon: *Indian Journal of Meteorology. Hydrology and Geophysics,* **29:** 150–161.

Colon, J.A., 1964. On interaction between the southwest monsoon current and the sea surface over the Arabian Sea. *Indian Journal of Meteorology and Geophysics* **15:** 183–200.

Kondo, J., 1975. Air-Sea bulk transfer coefficients in diabatic conditions. *Boundary layer Meteorology,* **9:** 91–112.

Meinardus, W., 1923. Meteorologie Ergebuisse der Deutschen Sudpolar-Expedition 1901–1903 (V. Drygalski, ed.) Vol. III. Meteorologie I, 1.

Rao, G.V., W.R. Schaub Jr. and J. Puctz. 1981. Evaporation and precipitation over the Arabian Sea during several monsoon seasons. *Monthly Weather Review,* **109:** 364–370.

Stevenson, J.W., 1982. Computation of heat and momentum fluxes at the sea surface during the Hawaii to Tahiti shuttle experiment (University of Hawaii, Hawaii) p. 1–17.

Wegemann, G., 1920. Der tagliche Gang der temperatur des meeres etc. *Wiss Meercsuntcr-suchungen* (Kiel) (N.S), **19:** No. 2.