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HEAT BUDGET STUDIES OF THE NORTH ARABIAN SEA DURING SUMMER AND WINTER SEASONS, 1992

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ABSTRACT: In this study heat budget components and momentum flux for August and January 1992 over the north Arabian Sea are computed. The marine meteorological data measured on board during the cruises of PAK-US joint project (NASEER) are used for the computation. Significant differences were found in the heat budget components as well as in the momentum flux during different monsoon periods over the north Arabian Sea. The latent heat flux was always positive and attributed to the large vapour pressure gradient. The computed moisture and latent heat fluxes in January were higher than August. The highest value of latent heat flux 309 W/m^2 at station 8 was evaluated. These higher latent heat fluxes were due to the large vapour pressure gradient, air-sea temperature difference, the wind speed, and the prevailing wind direction (from north and northeast). Negative values of sensible heat fluxes in both seasons indicate that the heat transfer was from the atmosphere to the ocean. The negative values of net heat gain indicate that the sea surface field became an energy sink or the sea surface supplied more energy to the atmosphere than it received from it. Large variation in the momentum flux mainly attributed to the variation in the wind speed. Aerial averages of heat and momentum fluxes were also computed.

KEY WORDS: Heat budget - component - momentum flux - north Arabian Sea.

INTRODUCTION

The considerable attention has been paid to the problems related to the interaction of sea and air, since behind any weather disturbance the possible physical process is the thermodynamic system. The thermodynamic system converts other forms of energy into kinetic energy and the dissipation of kinetic energy by viscous stress is balanced by a continuous supply of energy by a flux from the sea to the atmosphere. Any flux of energy from the sea to the air consists largely of the turbulent transfer of heat in the form of sensible and latent heat flux.

Knowledge of heat transfer from ocean to atmosphere is very important for heat balance studies as well as the moisture and energy budget of the atmosphere especially as it relates to planetary scale circulation such as monsoon.

The southwest monsoon is associated with the annual cycle of solar radiation and the differential heating between land and sea. Sea-surface temperature (SST) anomaly over the Arabian Sea could have a significant effect upon the rainfall over the subcontinent (Ellis 1952, Saha 1970).

The precipitation content in the southwest monsoon period over India is also associated with the SST anomaly over the western Arabian Sea (Shukla, 1975). Few attempts have been made for the estimation of fluxes over the Arabian Sea. However, these studies were made during calm condition. Rao *et al.* (1977) evaluated fluxes during normal and break-monsoon period using climatological atlas data. Ramanadham *et al.* (1981) computed heat budget components at selected areas of northern Indian Ocean during different epochs of the summer monsoon of 1977. First time, in a large area, real observed data have been used by Ali Khan *et al.* (1993).

for the estimation of sensible and latent heat fluxes and the Bowen ratio over the north Arabian Sea. In the present study besides sensible and latent heat fluxes, other heat budget components at different stations in the northern Arabian Sea during northeast and southwest monsoon periods (1st and 2nd cruises of PAK-US joint project NASEER) were also investigated. By using the heat budget components the net heat gain at the sea surface and the momentum flux were estimated.

MATERIALS AND METHODS

The marine meteorological data collected on board the ship during the oceanographic cruises of PAK-US joint project were used to evaluate latent and sensible heat exchanges and the net heat gain by the oceanic surface. The surface meteorological parameters, wet and dry bulb temperature, relative humidity, dew point temperature, atmospheric pressure and wind speed and direction were taken on board the ship. The cruise track and the area under study are given in figure 1.

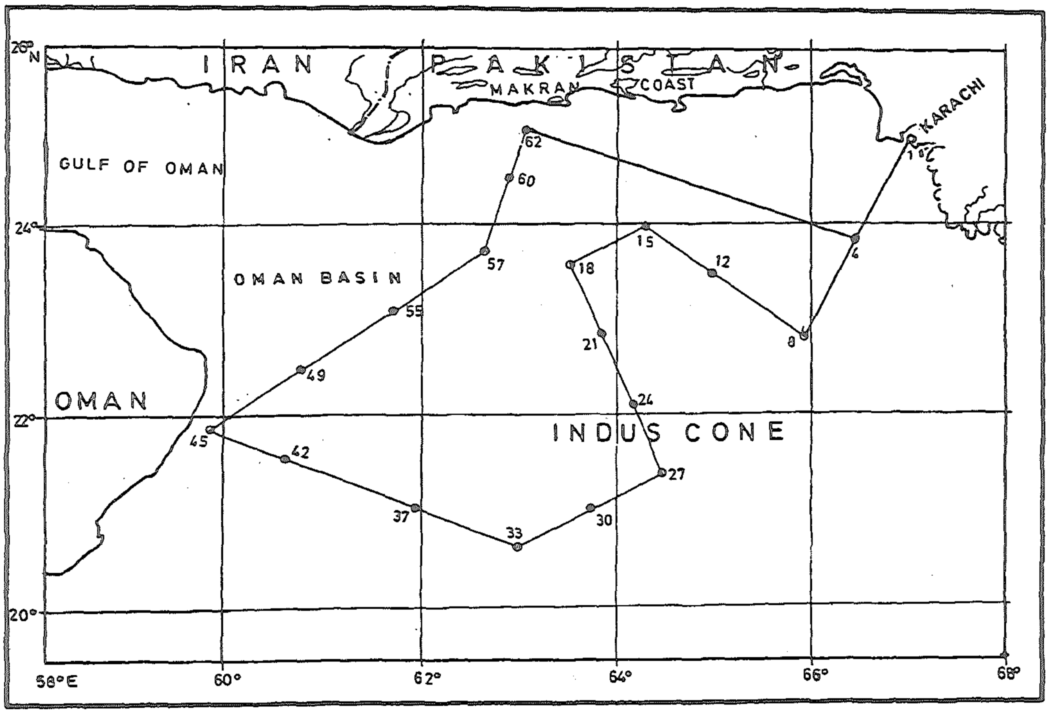

Figure 1. Location map, showing cruise track and the area understudy.

COMPUTATIONAL PROCEDURE

The energy removed from the sea by evaporation or returned by condensation are used to calculate fluxes over the sea surface. The bulk aerodynamical formulae are used to calculate the sensible and latent heat fluxes, (Q_h) and (Q_e) respectively. The other heat budget components are estimated by using empirical formulae developed by Laevastu and Hubert (1970).

The empirical equations used to calculate the various fluxes are as follows:

$$Q_h = \rho_a\ C_p C_h (T_w - T_a) V$$
$$Q_e = \rho_a\ L C_e (q_w - q_a) V$$

The balance equation is

$$Q = Q_i - (Q_b + Q_a + Q_e + Q_h)$$

if

$$Q_n = Q_i - (Q_b + Q_a)$$

then

$$Q = Q_n - (Q_e + Q_h)$$

Where

$$Q_i = 0.0068\ A_s T_d\ (1.0 - 0.0006\ C^3)$$
$$Q_a = 0.0726\ Q_i - (0.01\ Q_i)^2$$
$$Q_b = 143.7 - 0.90\ T_w - 0.46\ R_h\ (1 - 0.0765\ C)$$

and

$$\tau = \rho_a\ C_d V^2$$

Where Q_i is the net downward flux of solar radiation, Q_b is the effective upward flux of long-wave radiation, Q_a is the reflected solar radiation, Q_n is the net radiation, Q is the heat gain at the sea surface, T_d is the sunshine duration (minutes), A_s is the altitude of the sun at noon time (degrees), C is the cloud amount (tenths), R_h is the relative humidity (%), ρ_a is the air density, C_p is the specific heat of air at constant pressure, L is the latent heat of evaporation, V is the wind speed, T_w and T_a are the sea surface and air temperature respectively, C_h and C_e are the sensible and latent heat exchange coefficients respectively, C_d is the drag coefficient, τ is the momentum flux, q_a is the specific humidity in the air and q_w is the specific humidity at sea surface temperature. The water vapour pressure (e_a) and saturation vapour pressure at sea surface (e_w) are used to calculate the specific humidities, q_a and q_w respectively.

The selection of drag and exchange coefficients are important in the computation of fluxes. Several authors proposed similar exchange coefficients based on the wind speeds and air-water temperature differences (Masagutov, 1981; Bunker, 1976). In the present study the exchange coefficients used, are related to the wind speed and C_h is the function of C_e(C_h= 0.94 C_e) as suggested by Rao *et al.*, (1981) and found consistent with those of Meyer and Rao (1985). Similarly the drag coefficient 1.52×10^{-3} is used here, as suggested by Ramesh-Kumar *et al.* (1989).

RESULTS AND DISCUSSION

The variation of the observed and computed meteorological parameters on board vessel in the Northern Arabian Sea for the period of 7 to 25 August, 1992 and 5 to 25 January, 1992 are shown in figures 2 and 3 respectively. Similarly variations of energy fluxes during the above mentioned periods are shown in figures 4 and 5 respectively. Computation of momentum fluxes are presented in figures 6 and 7 respectively. Table I shows the aerial averages of fluxes for both the seasons.

Table I. Aerial averages of heat and momentum fluxes for southwest and northeast monsoon period.

Monsoon season	Q_h (Watt)	Q_e (Watt)	Q (Watt)	Momentum Flux (Newton)
Southwest	2.5×10^{11}	1.6×10^{13}	3.5×10^{13}	1.0×10^{13}
Northeast	1.3×10^{12}	2.3×10^{13}	-8.7×10^{12}	5.6×10^{12}

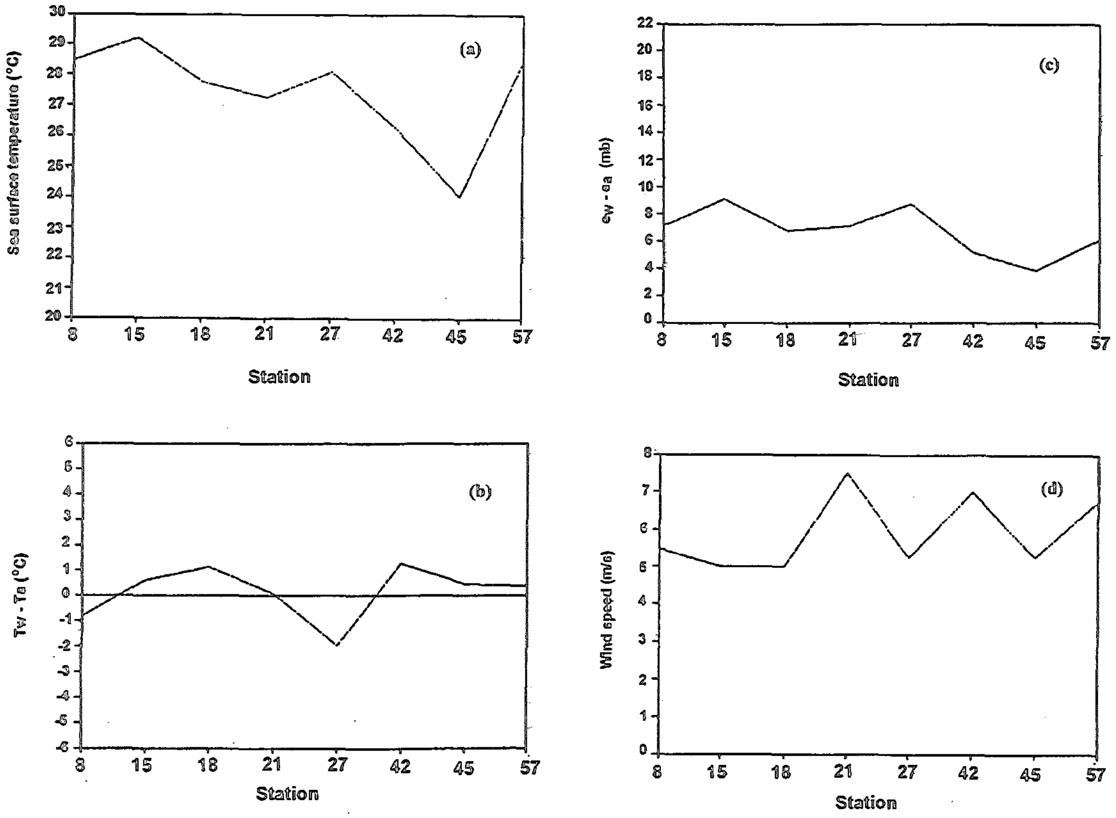

Figure 2. Variation of (a) sea surface temperature (b) sea-air temperature difference (c) sea-air vapour pressure difference and (d) wind speed from 7 to 25 August, 1992.

In this study it is assumed that during southwest monsoon cruise, 7-25 August, 1992, the average cloud amount was 50% and in the northeast monsoon period, 5-24 January 1992, there was a clear sky.

The maximum latent and sensible heat fluxes at some observing stations were observed. The large values of Q_e and Q_h can be mainly attributed to the large vapour pressure gradient, air sea temperature difference and as well as the wind speed. The larger value of latent heat flux 137 W/m^2 at station 21, on August 12, is due to the low pressure area over the central Pakistan, eastern Sindh and Oman.

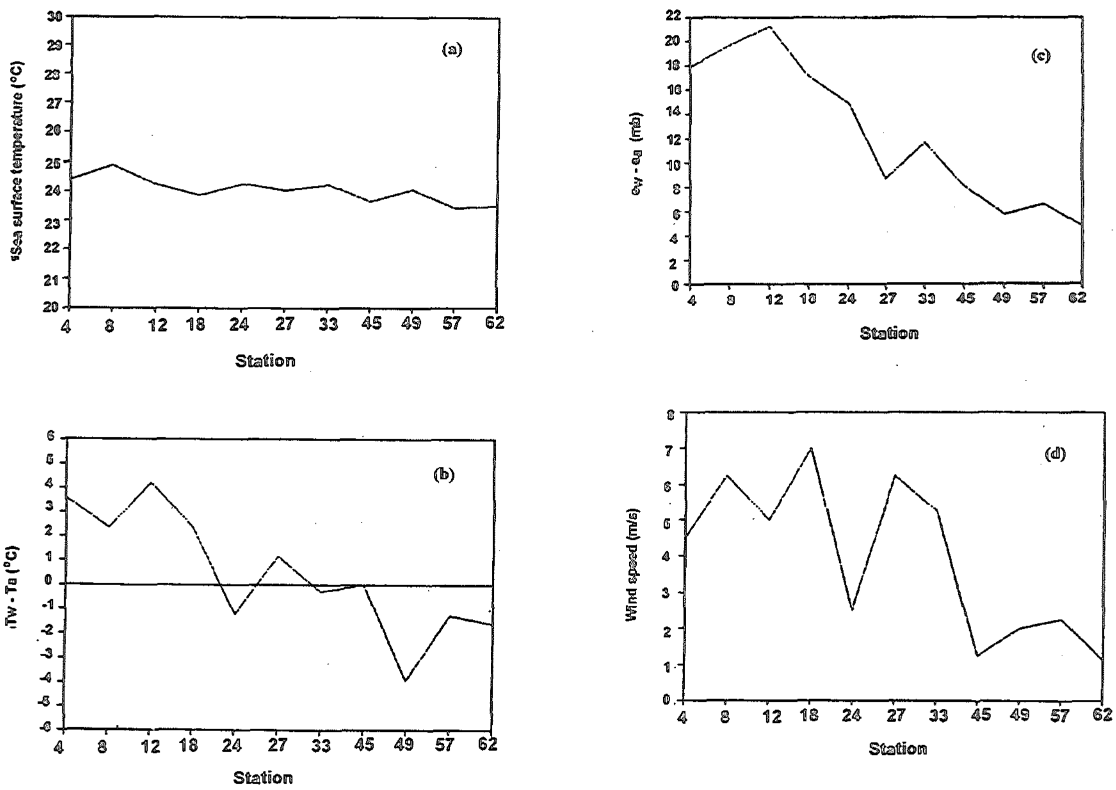

Figure 3. Variation of (a) sea surface temperature (b) sea-air temperature difference (c) sea-air vapour pressure difference and (d) wind speed from 5 to 24 January. 1992.

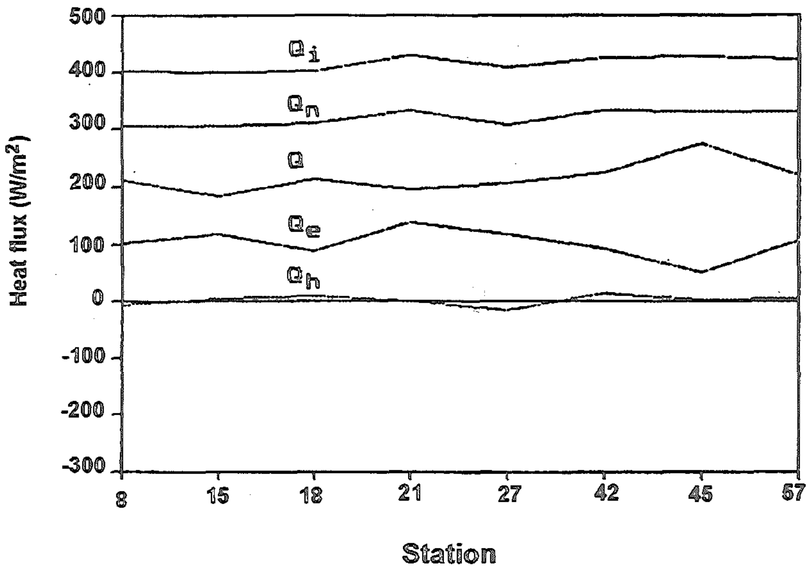

Figure 4. Variation of fluxes: sensible heat Qh , latent heat Qe, solar radiation Qi, net radiation Qn and the net heat at the air-sea interface from 7 to 25 August, 1992.

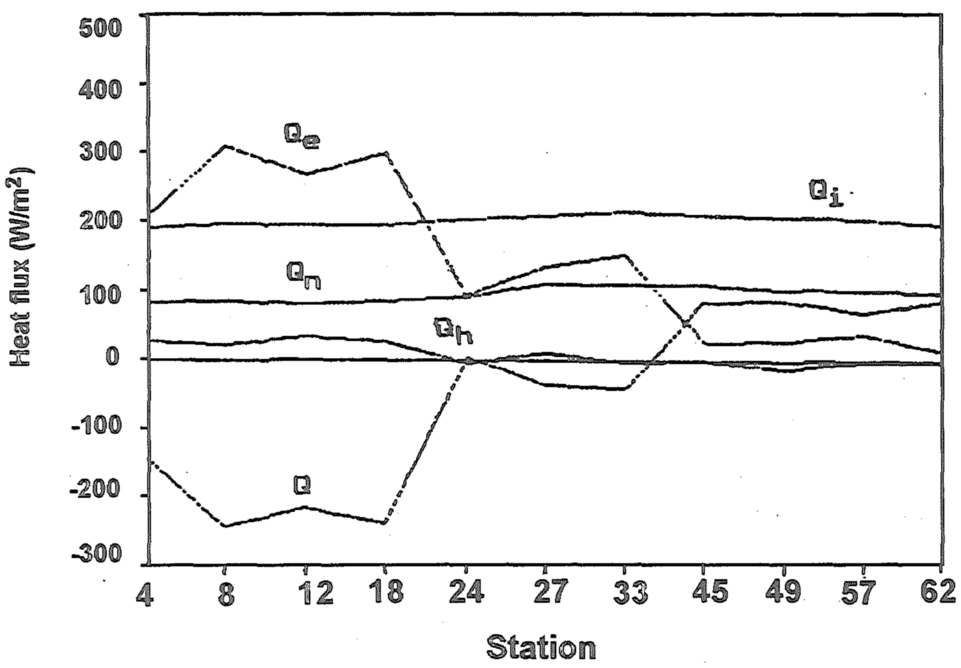

Figure 5. Variation of fluxes: sensible heat Qh, latent heat Qe, solar radiation Qi, net radiation Qn and the net heat at the air-sea interface from 5 to 24 January, 1992.

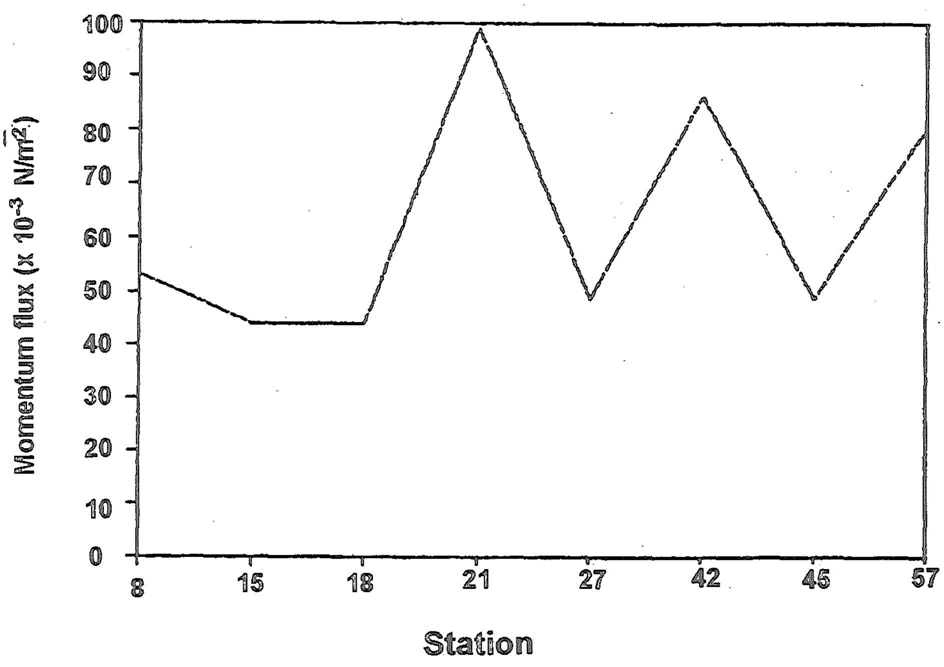

Figure 6. Variation of momentum flux from 7 to 25 August, 1992.

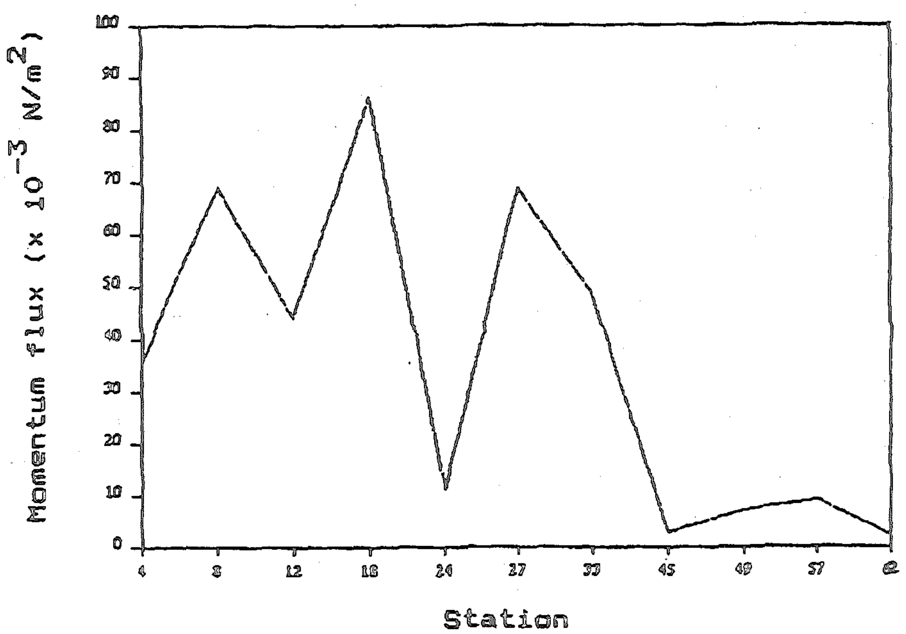

Figure 7. Variation of momentum flux from 5 to 24 January, 1992.

and Oman. However, there was a sudden drop of Q at stations 42 and 45 from 117 W/m^2 to less than 52 W/m^2 in the southwest monsoon period this could be attributed mainly to the drop in the air sea temperature difference and the vapour pressure gradient, even though the winds was quite strong at these stations. During northeast monsoon period the Q_e varied from 309 W/m^2 at station 8 to 13 W/m^2 at station 62. According to the synoptic maps of January 12, 1992, the low pressure area over Iran, which was extended to the Baluchistan and Sindh, might be the main cause of high latent heat flux at station 18 (300 W/m^2).

A comparison of Q_e values for summer and winter showed that the values were higher during winter than summer, which can be due mainly to a larger vapour pressure gradient over this area. The results indicate that the latent heat flux is positive in both seasons. The zone of lower Q_e in the last legs of the cruises were observed. The decreasing pattern of Q_e in the northeast monsoon attributed to the smaller values of vapour pressure gradient.

Similarly there were drop in Q_h values from 14 W/m^2 to -15 W/m^2 in the month of August and 33 W/m^2 to -12 W/m^2 in the northeast monsoon period. The contributing factors of those drops were air-sea temperature difference and the wind speed. The sensible heat flux is not always positive as in the case of latent heat flux. The negative values of sensible heat flux was observed during both the seasons. The negative values of sensible heat fluxes indicate that the heat flux was from the atmosphere to the ocean.

Sensible heat flux (Q_h) was also larger during northeast monsoon period, with the largest values observed at station 12. These large values were due to the combined effects of large air-sea temperature difference (4.2°C) and somehow with the high wind speed (about 7 m/s^{-1}).

The negative values of net heat gain (Q), though varying in the both seasons indicate that the sea surface field became an energy sink or that the sea surface supplied more energy to the atmosphere than it received from it. It is obvious from the graphs that the energy supplied from the sea surface to the atmosphere is in the form of latent heat flux.

Large variation in the momentum flux during both seasons can be seen in figures 6 and 7. This large variations mainly attributed to the variation in wind speed. Comparatively the large values occur during August than in January. The larger values of momentum fluxes in the southwest monsoon are obviously due to the higher wind speed.

According to Ramanadham *et al.* (1981) the average value of latent heat flux over Arabian Sea in the normal monsoon condition is 129 W/m^2. In the present study the average latent heat flux is 101 W/m^2. The reasons for this difference are: 1) in this study the area under consideration is above 20°N, 2) use of different exchange coefficients for the computations of Q_e and Q_h and 3) may be the interannual variation of fluxes (Ramesh-Kumar, 1989). However, the latent heat flux from the Arabian sea is always larger than the other places in the Indian Ocean (Ramanadham *et al.* 1981).

In the present study significant differences are found in the heat budget components and momentum flux during different monsoon periods over the Arabian Sea. This study may lead to a better understanding of monsoon in the southwest Asia in relation to air sea flux processes. Furthermore, the large scale data collection programme over the northern Arabian Sea is required to study the air-sea exchange rates and atmospheric circulation and their influence on the monsoon pattern.

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