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# *Study of the influence of surface energy budget of north Indian Ocean on the behaviour of Indian summer monsoon*

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ABSTRACT. The probable influence of the fluctuations in the energy budget of north Indian Oceanic surface on the general behaviour of Indian summer monsoon during July is investigated in the present study. Normals of the energy budget components as, monthly heat gain by the ocean, solar radiation absorbed by the ocean and the net infrared radiational exchange at the surface, following Budyko's method, latent heat flux and sensible heat flux, following bulk aerodynamic method during July are evaluated using the available marine climatological data over north Indian Ocean. Deviations of energy budget components from their respective normals during break monsoon period are showing significant differences, which are discussed in terms of the behaviour of the summer monsoon. Charts of energy budget components are presented and the associated features are discussed.

## 1. Introduction

In the classical literature, the large-scale flow patterns associated with the south Asian summer monsoon were described to result principally from the interaction of the annual cycle of solar radiation and the differential effective heat capacities of land and ocean water. It is generally believed that although the onset and the existence of the Asiatic summer monsoon is primarily due to land-sea contrast, the fluctuations and the variability of the monsoon activity may depend, at least partially, on the air-sea interaction which takes place during the travel of the monsoon current over the Indian Ocean, Arabian Sea and Bay of Bengal. It has been postulated in earlier studies (*viz.*, Saha 1970, 74; Ellis 1952) that the sea surface temperature (SST) over the Arabian Sea may have important influences on the monsoon flow and associated rainfall. Based upon the results of numerical experiments from the GFDL general circulation model, Shukla (1975) suggested that an SST anomaly of a few degrees centrigrade over the western part of the Arabian Sea could have a significant effect upon the general intensity of precipitation in the neighbourhood of the Indian sub-continent. His results suggest that the SST anomaly significantly affects not only sea level pressure but also the rate of evaporation over the Arabian Sea and accordingly the rate of precipitation over the Indian sub-continent. Observational data collected during International Indian Ocean Expedition suggest the existence of stable atmosphere west of 68°E and unstable atmosphere to the east of the same longitude over Arabian Sea. It is felt that the energy exchanged between the sea and the atmosphere would be largely responsible for the existence of the observed two regimes in the monsoon circulation. A feature of the Arabian Sea is the generally high SST (>24°C). This is due to the high radiation balance north of 10°N, and an excess of evaporation over precipitation, especially in the northwest Arabian Sea. The fluxes of heat and moisture across the air-sea interface and the dynamics and thermodynamics of the oceanic mixed layer are, quite probably, important inputs in any attempt to understand regional monsoon phenomenon.

In the present investigation the authors examined the differences in the energy budget components of north Indian Ocean between normal July conditions

TABLE 1

**Exchange coefficient (× 1000) air-sea temperature (°C).**

| Wind speed (cm/sec) | ⩾5·0 | 4·9 to 1·0 | 0·9 to 0·2 | 0·1 to —0·2 | —0·3 to —1·0 | —1·1 to —5·0 | <—5·0 |
|---|---|---|---|---|---|---|---|
| 1 to 300 | 0·07 | 0·30 | 0·72 | 1·32 | 1·65 | 2·05 | 2·52 |
| 301 to 600 | 0·22 | 0·67 | 1·12 | 1·34 | 1·45 | 1·68 | 2·01 |
| 601 to 900 | 0·69 | 1·17 | 1·36 | 1·44 | 1·46 | 1·58 | 1·79 |
| 901 to 1200 | 1·06 | 1·36 | 1·48 | 1·53 | 1·58 | 1·65 | 1·79 |
| 1201 to 1500 | 1·39 | 1·58 | 1·61 | 1·64 | 1·68 | 1·74 | 1·84 |
| 1501 to 2000 | 1·59 | 1·68 | 1·75 | 1·80 | 1·82 | 1·86 | 1·94 |
| 2001 to 2500 | 1·74 | 1·79 | 1·83 | 1·86 | 1·88 | 1·86 | 1·93 |
| 2501 to 3000 | 1·81 | 1·84 | 1·85 | 1·86 | 1·87 | 1·88 | 1·90 |
| >3000 | 1·86 | 1·86 | 1·86 | 1·86 | 1·86 | 1·86 | 1·86 |

and break monsoon period to assess the influence of oceanic surface on the behaviour of monsoon system.

## 2. Theory

The energy exchange at the ocean surface has been computed by Budyko (1963) from the equation

$$A = Q\,(1 - a) - I_R - L_E - S \qquad (1)$$

where,

$A$ is the monthly heat gain by the ocean;

$Q\,(1 - a)$ is the solar radiation absorbed by the ocean;

$I_R$ is the net infrared radiational exchange at the surface;

$L_E$ is the latent heat flux due to evaporation and

$S$ is the sensible heat exchange with the atmosphere

The bulk aerodynamic exchange equations developed principally by Sverdrup (1937), Jacobs (1942) and Budyko (1963) can be expressed in the following forms

$$E = C_E\,(\bar{q}_s - \bar{q}_a)\,\bar{U}_a \qquad (2)$$

$$S = \rho C_P C_H\,(\bar{T}_s - \bar{T}_a)\,\bar{U}_a \qquad (3)$$

Here $E$ and $S$ are the monthly averages of the transfer of water vapour and sensible heat;

$\rho$ is the density of the air;

$C_E$ and $C_H$ are the coefficients of water vapour and sensible heat respectively:

$\bar{U}_a$ is the monthly average wind speed at 10 metres or ship anemometer level;

$\bar{q}_s$ and $\bar{q}_a$ are the monthly average mixing ratios of the air in contact with the water and at the 10 m or deck level, and

$\bar{T}_s$ and $\bar{T}_a$ are the average temperatures of the sea surface and the air at 10 m or deck level.

As has been noted, Sverdrup, Jacobs and Budyko used a single, constant value of the exchange coefficient which was determined from evaporation measurements or balancing of the energy budget for the oceans. With the accumulation of observations of wind, fluxes and gradients the coefficients indicated their variability with wind speed and stability. As suggested by Bunker (1975) the values of the transfer coefficient for water vapour have been applied to the computations of the sensible heat flux. There is evidence that the heat transfer coefficient may be a few per cent larger than the water vapour coefficient but the determination is less certain. Since the sensible heat exchange over the ocean is small compared to the latent heat and radiational transfers, any error in the total heat budget of the oceans resulting from the assumption of equal coefficients will be very small. Table 1 gives the values of $C_E$ for different wind speeds and stabilities. Values of the latent heat and sensible heat flux have been computed from each point using these values.

The solar and infrared radiation fluxes at the sea surface have been computed by the method following Budyko (1963). Budyko's method utilizes a table of solar radiation received at the surface on a cloudless day, $Q_0$, for each 5° of latitude and each month. The solar radiation received is given by the empirical formula

$$Q = Q_0 (1 - aN - bN^2) \quad (4)$$

where $N$ is the monthly average of the total cloud cover; $a$ and $b$ are coefficients that vary with latitude.

The amount of radiation absorbed by the ocean is given by $Q(1 - \alpha)$, where $\alpha$ is the albedo of the ocean. The albedo also varies with latitude and month. Here the values of $\alpha$ are taken from Payne's (1972) work.

The net infrared radiation, $I_R$, has been computed from the equation used by Budyko,

$$I_R = S\,\sigma\theta_a^4\,(11.7 - 0.23e)(1 - CN) + 4S\,\sigma\,\theta_a^3(\theta_s - \theta_a) \quad (5)$$

where $S$ and $C$ are constants;

$e$ is the vapour pressure of the air and

$\theta_s$ and $\theta_a$ are the potential temperatures of the sea surface and the air.

Once all of the radiational and turbulent flux terms have been estimated the values of $A$, the net energy gain, can be found from Eqn. (1).

## 3. Data sources

In the present investigation the energy budget components are evaluated for normal July and break (15-31 July 1972) monsoon period. For normal July the values of the meteorological parameters are extracted from the following sources.

(*i*) *Surface pressure and dew point temperature* — Selected Level Heights, Temperatures and Dew Points for the Northern Hemisphere (NAVAIR 50-IC-52) published by Direction of Commander, Naval Weather Service Command by H.L. Crutcher and J.M. Meserve, 1970.

(*ii*) *Dry bulb temperature* — The General Circulation of the Tropical Atmosphere and Interactions with Extratropical Latitudes, Vol. I, 1972, by Reginald E. Newell *et al.*

(*iii*) *Cloud amount* — Personal Communication with Dr. J.S. Winston.

(*iv*) *Wind speed* — Wind speed of the Northern Hemisphere, published by direction of the Chief of Naval Operations (NAVAIR-50-IC-51), 1966.

(*v*) *Sea surface temperature* — Digitized Global Monthly Mean Ocean Surface Temperatures. NCAR Technical Notes 54, 1970 by W.M. Washington and L.G. Thiel, and Monthly Charts of Mean, Minimum and Maximum SST of the Indian Ocean (SP-99) Naval Oceanographic Office, Washington D.C., 1967.

For the break monsoon period the values of the meteorological parameters are collected from the ship observations published in *Indian Daily Weather Reports* by India Meteorological Department. The parameters as cloud amount, wind speed, surface pressure, dry bulb temperature, dew point temperature and sea surface temperature are averaged for 00 and 12 GMT at the grid points separated by 5° latitude and 5° longitude over north Indian Ocean. Then 00 and 12 GMT values are again averaged.

## 4. Discussion

*Net radiation*

The distribution of net radiation during July is presented in Fig. 1(a). A maximum value of 325 cal/cm$^2$/day is observed over west Arabian Sea off Somalia coast with a decreasing trend towards west coast of India. In northern Bay of Bengal a minimum value of 225 cal is found with an increasing trend towards south. These gradients are mainly due to cloud distribution in the atmosphere over the respective regions. These results are in good agreements with Ramage's (1972) results over Arabian Sea. But over Bay of Bengal during July 1964 the values of net radiation of Ramage increased from south to north which is in disagreement with the present findings. It is but natural to expect minimum net radiation at the head of Bay of Bengal where maximum number of depressions originate causing greater cloudiness. During break monsoon period, shown in Fig. 1(b) the locations of the maximum and minimum values are the same as for July but the magnitudes of the values are higher by 25 cal which confirms the decrease in cloudiness. The region off west coast

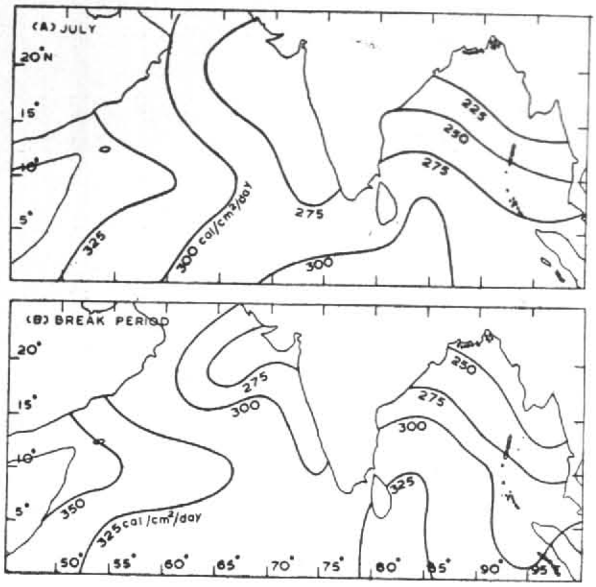


Fig. 1. Net radiation over north Indian Ocean

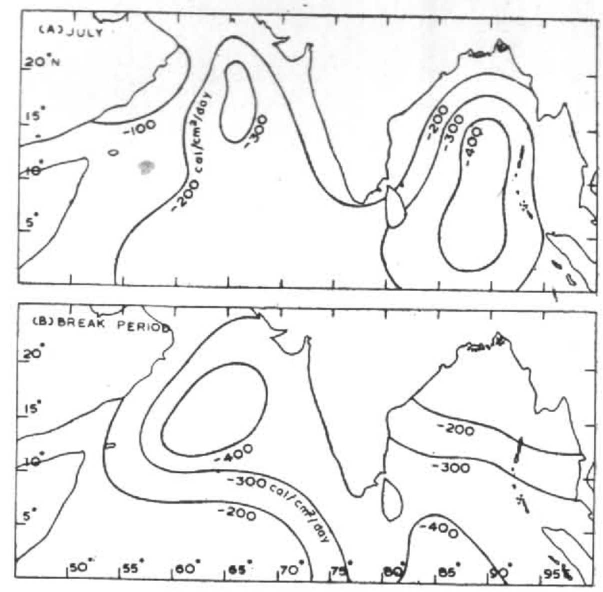


Fig. 2. Energy $(LE+S)$ exchange over north Indian Ocean

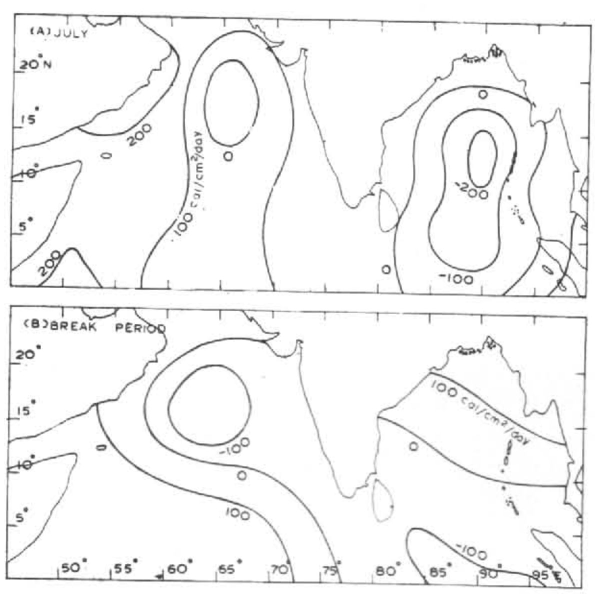


Fig. 3. Net heat gain by north Indian Ocean

of India experiences slightly higher values during break monsoon period may be due to the absence of cloudiness associated with offshore vortices.

*Energy exchange from ocean*

Fig. 2(a & b) shows the distribution of energy exchange between the atmosphere and north Indian Ocean for July and break monsoon period. During July, greater energy exchange is taking place over Bay of Bengal compared to that over Arabian Sea. A maximum value of 400 cal is observed over central Bay of Bengal for a corresponding value of 300 cal over north central Arabian Sea. A minimum value of 100 cal is lost to the atmosphere off Arabian coast. During July 1964, Ramage's (1972) values are higher over Arabian Sea than over Bay of Bengal. But

Saha's (1972) corresponding values of 1965-67 average indicate that Bay of Bengal loses more energy than Arabian Sea. South Bay of Bengal losing more energy than north Bay is in fairly good agreement with a similar finding of Ramanadham *et al.* (1967). During break monsoon period the reverse distribution is observed. A maximum value of 400 cal, is seen over north Arabian Sea with a decreasing trend towards southwest. Over Bay of Bengal the area of maximum heat exchange has shifted towards south to equatorial region. Northern parts of Bay of Bengal experience small losses as low as 200 cal during break period.

*Heat gain by the ocean*

During July the whole Bay of Bengal loses energy to the atmosphere with a maximum value of 200 cal over north central Bay. Only the coastal waters of Bay of Bengal gain a little energy and southeast Bay gains around 100 cal per day. Excepting a small pocket over north central Arabian Sea the rest of Arabian Sea is gaining energy. High values of 200 cal are observed over off Somalia and Arabia coasts. During break monsoon period approximately north of 10°N latitude in Bay of Bengal the ocean surface gains energy while south of it loses energy. North central Arabian Sea loses energy to a tune of 100 cal while southwest Arabian Sea gains a same amount.

## 5. Conclusions

(*i*) During July net radiation is smaller by 25 cal/cm$^2$/day throughout north Indian Ocean, over the corresponding values of break monsoon.

(*ii*) During July higher energy losses occur over north Bay of Bengal compared to north Arabian Sea and *vice versa* during break monsoon period.

(*iii*) During July the net gain of heat is negative over Bay of Bengal for a larger area compared to Arabian Sea. During break monsoon period north Bay of Bengal gains heat while north Arabian Sea loses heat.

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## DISCUSSION

(Paper presented by R. R. Rao)

PETER J. WEBSTER : You note large differences between break and normal monsoon conditions in the Bay of Bengal. Are the differences in heat balance mainly attributable to cloudiness differences?

AUTHOR : Primarily due to differences in energy exchanges and secondarily due to differences in cloudiness.

B.M. MISRA : How cloudiness affects the radiation balance at Somali coast?

AUTHOR : In this case study little differences in cloudiness are observed at 10°N and 55°E.