

DIURNAL VARIABILITY OF SURFACE FLUXES AT AN OCEANIC STATION IN THE BAY OF BENGAL

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ABSTRACT

Diurnal variability of the surface fluxes and ocean heat content was studied using the time-series data on marine surface meteorological parameters and upper ocean temperature collected at an oceanic station in the Bay of Bengal during 1st to 8th November, 1985. During this period the mean heat storage in the upper 125 m water column is found to be 300 W.m^{-2} . The net surface heat fluxes indicate a mean loss of 37 W.m^{-2} across the sea surface. Estimation of the heat flux divergence as residual from the complete heat budget equation for ocean indicates that a mean heat flux divergence of 263 W.m^{-2} is required in order to achieve a complete heat balance for the period of study.

INTRODUCTION

The turbulent exchange of heat in the form of sensible heat, latent heat and momentum fluxes between the ocean and atmosphere is the principal mechanism that maintains the global heat budget. The seasonal variability of the heat budget parameters in the Bay of Bengal have been studied earlier by Rao (1972), and Hastenrath and Lamb (1979) utilizing the climatological data on the surface meteorological parameters. Studies on the diurnal variability of the heat budget components in the eastern Bay of Bengal, which is prone to cyclonic storms during Fall, particularly during November, are sparse. We present here the results of our study on the diurnal variability of the surface fluxes and upper ocean heat storage.

DATA AND METHODS

Surface meteorological measurements viz., wind speed, atmospheric pressure, dry bulb and wet bulb temperatures of the atmosphere, sea surface temperature and cloud amount were taken at hourly intervals onboard RV *Sagar Kanya* in the Bay of Bengal while the ship remained stationary at a location (11.5°N and 91°E) from 1st to 8th November 1985 (Fig. 1). During the same period water temperature was also measured every hour using a MICOM bathythermograph. The above data have been used to study the diurnal variability of the sensible heat, latent heat and momentum fluxes.

The net surface heat flux, Q consists of incoming short wave solar radiation Q_s , outgoing long wave radiation Q_b , latent heat flux Q_e and sensible heat flux Q_h , thus

$$Q = Q_s (1-\alpha) - Q_b - Q_e - Q_h \quad (1)$$

where, α is the sea surface albedo, taken as 0.06. The short wave solar radiation, Q_s , is given by

$$Q_s = Q_{s0} (1 - 0.62 N + 0.0019 \alpha_s) \quad (2)$$

where Q_{s0} is the solar radiation under clear sky conditions, which is a function of latitude and time of the year. This has been determined from the formula given by Seckel and Beaudry (1973). The term in the parenthesis is cloud correction factor due to Reed (1977). N is the day time averaged cloud amount in tenths and α_s is the noon time altitude of the sun in degrees.

Each component of the heat fluxes is estimated using the bulk aerodynamic formulae;

$$Q_b = [\epsilon \sigma T_s^4 (0.39 - 0.05 e_{a1/2}) + 4 \epsilon T_s (T_s - T_a) T_{s3}^{(1-0.7 N)}] \quad (3)$$

where ϵ is the emissivity of the sea surface, σ is the Stefan-Boltzman constant, e_a is water vapour pressure at 10 m height. T_s is the sea surface temperature and T_a is air temperature at 10 m height above sea surface. There are several different

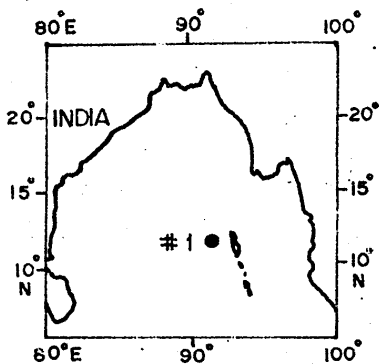


Fig. 1. Station Location

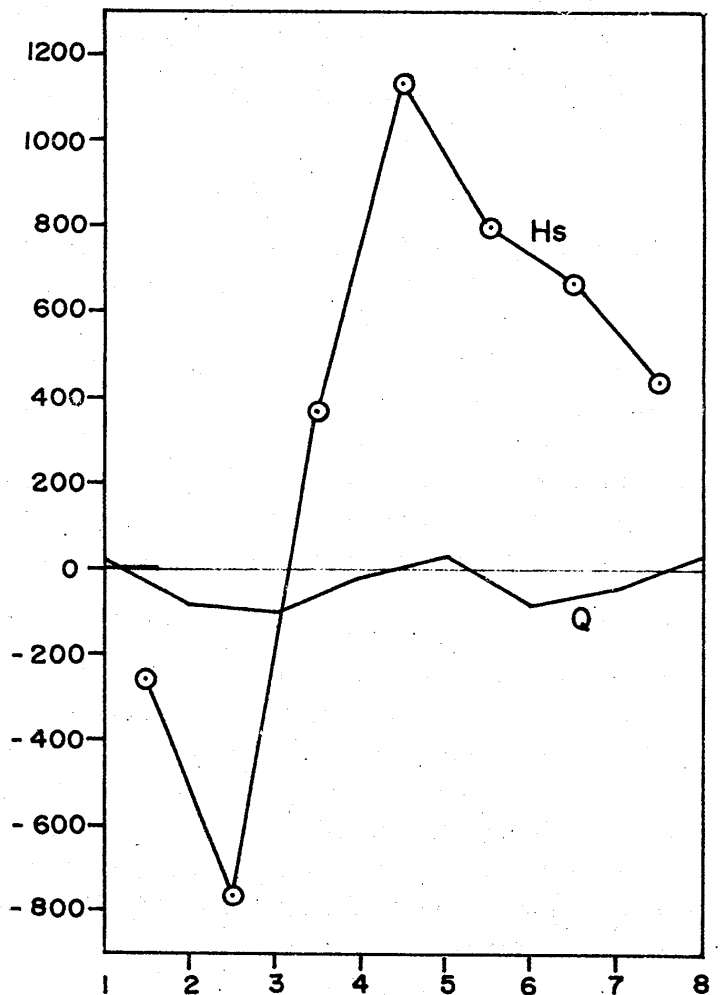


Fig. 2. Daily averages of net surface heat flux (Q) and Ocean heat storage (H_s).

cloud correction factors available in the literature but here we used (1-0.7 N) following Reed (1976).

$$Q_e = \rho_a C_e L_e (q_s - q_a)U_a \quad (4)$$

$$Q_h = \rho_a C_{pa} C_h (T_s - T_a)U_a \quad (5)$$

Where, ρ_a is air density, C_e is turbulence transfer coefficient for evaporation, L_e is latent heat of vaporisation, C_{pa} is heat capacity of dry air, C_h is turbulence transfer coefficient for heat, q_s is specific humidity of saturated air at sea surface temperature and q_a is specific humidity of air at 10 m height.

In the present study, the bulk aerodynamic formulae (eqns 3,4 and 5) are all applied at the standard height of 10 m above the sea surface. This will enable one to compare the results presented in this paper with climatological studies. The instruments for collecting the basic meteorological parameters are placed at a height of 22.6 m above the sea surface onboard RV *Sagar Kanya* (Prabhu Desai and Desa, 1986). Hence the wind speed, temperature and humidity differences were corrected to 10 m height and the turbulence transfer coefficients were corrected for stability and height. The procedure for correcting the above mentioned parameters is outlined in Stevenson (1982).

RESULTS AND DISCUSSION

Sea surface temperature is 29.5°C in the first day of observations and then decreased by nearly 1°C by the 4th day and thereafter it remained more or less steady until the end of the observations. The temperature gradient ($T_s - T_a$) is always positive during this period except for a few hours on 2nd and 4th day and the Richardson Number is negative. This indicates that the atmosphere is unstable throughout this period. The latent heat flux (Q_e) is higher on the 2nd day when the momentum flux and specific humidity gradients are higher. Bowen ratio ($B = Q_h/Q_e$) is generally low and positive (Table 1), which indicates a transfer of heat from the sea to the atmosphere. Q_b is more or less constant. The mean evaporation for the period of study is 0.6 cm.day⁻¹.

Table 1. Daily Averages of Heat Budget Components (Q_s , Q_e , Q_b and Q_h in W.m⁻²)

Date	Q_s	Q_e	Q_h	Q_b	Evap	B
1	206	133	7	60	0.47	0.05
2	220	239	6	58	0.85	0.03
3	157	169	12	68	0.60	0.08
4	230	177	4	56	0.63	0.02
5	238	162	6	60	0.57	0.04
6	150	155	13	66	0.55	0.08
7	182	159	7	60	0.56	0.04
8	210	122	14	68	0.43	0.11
Mean	199	163	9	62	0.58	0.06

During this period, the heat flux terms indicate both gain and loss of heat across the sea surface. The net surface heat flux term Q , presented in Fig. 2, indicates a

loss of heat in the form of sensible heat, latent heat and back radiation. The mean loss for this period is about 37 W.m^{-2} . Heat storage (Hs) in the upper 125 m of the water column is estimated from the following equation;

$$Hs = \partial Hc / \partial t \quad (6)$$

where,

$$Hc = \rho_w c_p \int_0^{125} T \cdot dz \quad (7)$$

In the above equation Hc is the heat content, ρ_w is the sea water density, C_p is specific heat of sea water, T is the mean temperature of the water column and dz is its thickness. The daily averages of heat storage in the upper ocean (Fig. 2) show the variability similar in trend with the variability of surface heat fluxes. Except on the 3rd and 4th day when an increase is observed, there is a continuous fall in heat storage in the upper layer of the ocean during this period. On the other hand, the net surface heat flux term except for a very low and positive value on the 5th day, is negative during this period. This indicates that the atmosphere has been continuously gaining heat from the sea. The upper ocean shows a mean heat storage of about 300 W.m^{-2} for these days.

In summary, it is found that the diurnal variability of the net surface heat flux and the upper ocean heat storage are in phase, in the sense that, the loss of gain in one parameter is manifested in similar trend in the other. Here, we have not attempted for a quantitative balance of the heat in the ocean-atmosphere system because our data set is too small to do so. Nevertheless, we did make an indirect estimation of the heat flux divergence (Q_v) as residual from the complete heat budget equation for the ocean ($Q_s - Q_b - Q_e - Q_h + Q_v + Q_t = 0$). It shows that during this period about 263 W.m^{-2} of heat flux divergence is required in order to achieve a complete balance of heat at this location.

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