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The value of C_e for the Arabian Sea during summer monsoon

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Abstract. We estimate, from the moisture budget the bulk aerodynamic coefficient for latent heat flux (C_e) during the monsoon season over the central Arabian Sea. The average value of C_e under active monsoon conditions was found to be 2.25×10^{-3} which is nearly 60% higher than those previously used.

Keywords. Bulk aerodynamic coefficient (C_e); monsoon; moisture budget.

1. Introduction

There is considerable uncertainty about the source of moisture for monsoonal rainfall over the Indian sub-continent (Pisharoty 1965; Saha and Bavdekar 1973; Ghosh *et al* 1978; Cadet and Reverdin 1981; Howland and Sikdar 1983; Murakami *et al* 1984; Sadhuram and Ramesh Kumar 1988). Sadhuram and Ramesh Kumar (1988) pointed out that one cause of this uncertainty is the uncertainty about the bulk transfer coefficient for latent heat flux (C_e). There is no universally accepted scheme to evaluate C_e (Blanc 1985). In this paper we have computed C_e under active monsoon conditions using the equation for conservation of water vapour in a vertical column.

2. Data and method

During MONSOON-1977, four Russian research vessels remained stationary at four locations (12·5°N, 68·0°E; 12·5°N, 64·0°E; 14·5°N, 66·0°E; 10·5°N, 66·0°) in the central Arabian Sea (figure 1) during 7th – 20th June (phase I) and 29th June – 16th July 1977 (phase II). In this study we have used the following data from the four locations during both phases: surface meteorology recorded every hour; upper air observations (dry bulb temperature, dew point, wind speed and direction) made at 00, 06, 12 and 18 GMT. A brief summary of surface heat budget of this region has been given by Rao *et al* (1985).

Moisture budget has been computed for the box whose plan view is given in figure 1. The top of the box was taken to be the 100 mb surface rather than 450 mb which was chosen in an earlier study by Pisharoty (1965). We were prompted to make this choice

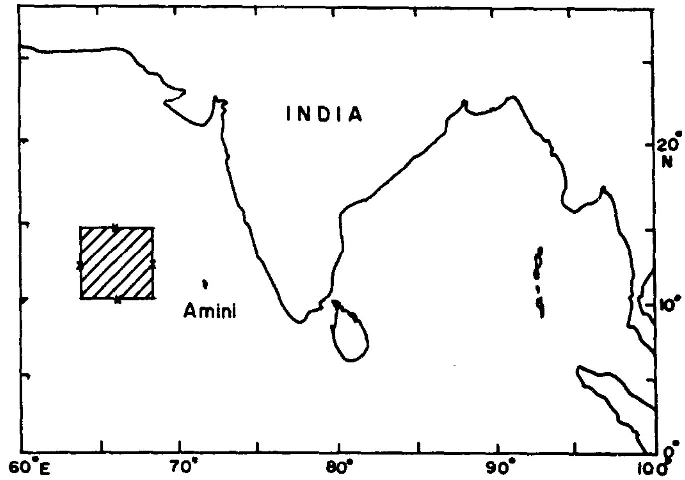

Figure 1. Shaded area represents the study region. Amini island rainfall data have been used in the analysis.

because under active monsoon conditions, moisture parcels rise to great altitudes, and cannot neglect the flux above 500 mb. To obtain accurate estimates of moisture budget, the 100 mb level is considered appropriate (Howland and Sikdar 1983; Murakami *et al* 1984; Sadhuram *et al* 1987).

Net flux of divergence (NFD) was computed from,

$$\mathrm{NFD} = \mathrm{FE} + \mathrm{FW} + \mathrm{FN} + \mathrm{FS}, \tag{1}$$

where FE, FW, FN and FS represent total moisture flux across eastern, western, northern and southern boundaries respectively. Details on the computation across each wall have been described in Sadhuram *et al* (1987) and Sadhuram and Ramesh Kumar (1988). Budget computations have been carried out for each ascent and finally averaged for phase I and phase II (Suryachandra Rao 1993).

The value of C_e is estimated from the following equations,

$$E = P + \mathrm{NFD}, \tag{2}$$

$$C_e = \frac{(P + \mathrm{NFD})}{(Q_s - Q_a)U}, \tag{3}$$

where E is rate of evaporation (cm/day), P is rainfall (cm/day), U is mean wind speed at anemometer height (m/sec), Q_s is saturation specific humidity at sea surface temperature (kg/kg), Q_a is specific humidity at dew point temperature. Q_s and Q_a are computed following formulae suggested by Murray (1967),

$$Q_a = \frac{0{\cdot}62e}{p - 0{\cdot}378e}, \tag{4}$$

where p is the atmospheric pressure and e is the vapour pressure, given by

$$e = T_d^A \times 10^{(B + C/T_d)}, \tag{5}$$

where T_d is the dew point temperature, $A = -4{\cdot}928$, $B = 23{\cdot}55$ and $C = -2937$.

No information on rainfall (P) was available at the study area. Rainfall observed at the nearby island station, viz., Amini (11°10′N; 72°30′E) is used in equation 2.

3. Results and discussion

Table 1a shows the moisture flux across the four walls (FE, FW, FN and FS) and net flux divergence of moisture (NFD). Table 1b shows the computed values of C_e for phase I and II, from the moisture budget. For the sake of comparison, the rate of evaporation obtained from the bulk aerodynamic method (E_b) is also presented. Rate of evaporation (E) from the moisture budget is found to be 1·75 and 1·56 cm/day for phase I and II respectively, which is quite high compared to E_b (1·07 and 0·86 cm/day). The estimates of C_e are $2{\cdot}2 \times 10^{-3}$ and $2{\cdot}3 \times 10^{-3}$ for phases I and II, and higher than the values normally used in the bulk aerodynamic method.

Table 2 compares C_e estimated by us with earlier estimates. Our value of C_e is 60% higher than the values obtained by Kondo (1975), Bunker (1976), Rao *et al* (1981) and Meyer and Rao (1985). It is close to that used in a model by Washington and Williamson (1977). In this model, high C_e values ($2{\cdot}1 \times 10^{-3}$) had been used to compensate low climatological winds. Pisharoty's (1965) value is much higher ($3{\cdot}0 \times 10^{-3}$) compared to the present result. This could be attributed to the fact that he

Table 1(a). Total moisture flux across eastern (FE), western (FW), northern (FN) and southern (FS) boundaries, and Net Flux Divergence (NFD) (Unit: 10^{10} tons/day).

Period	FE	FW	FN	FS	NFD
Phase I	2·72	−2·52	−0·33	−0·13	−0·26
Phase II	2·03	−2·33	0·71	−0·44	0·07

Table 1(b). Computation of C_e from moisture budget.

Period	E	E_b	P	NFD	$10^3 \times C_e$
		——cm/day——			
Phase I	1·75	1·07	3·1	−1·35	2·2
Phase II	1·56	0·86	1·2	0·36	2·3

Table 2. Comparison of C_e with the earlier values.

Scheme	$10^3 \times C_e$ Phase I	Phase II
Present study	2·20	2·30
Kondo (1975)	1·37	1·42
Bunker (1976)	1·70	1·70
Rao *et al* (1981) and Meyer and Rao (1985)	1·40	1·40
Washington and Williamson (1977)	2·10	2·10
Pisharoty (1965)	3·00	3·00

neglected the moisture flux above the 450 mb level. The value of C_e ($2{\cdot}25 \times 10^{-3}$) appears to be fairly representative for the moist monsoon regime of the Arabian Sea (Pisharoty 1994). It may be mentioned here that Sadhuram (1991), estimated C_e for the equatorial region (0–8°N, 60–68°E) for the pre-monsoon of 1988 and got a value of $1{\cdot}7 \times 10^{-3}$. Hence, the present C_e value appears to be reasonable for active monsoon conditions over the central Arabian Sea. By using this C_e value, earlier estimates of evaporation over the Arabian Sea (Ramesh Kumar and Sadhuram 1989) will approximately enhance by 40–50%.

4. Conclusion

The authors suggest that C_e should be of the order of 2×10^{-3}, under active monsoon conditions to compute evaporation accurately over the Arabian Sea.

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