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Energy transfer from the Arabian Sea, the Bay of Bengal and the north Indian Ocean

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सार — सन् साठ और सत्तर के बीच जलयानों से एकत्रित आंकड़ों की आई. बी. एम. 360 प्रणाली पर संसाधित एवं विश्लेषित किया गया है । फिर हिन्द महासागर, अरब सागर और बंगाल की खाड़ी से वायुमंडल में वाष्पन, संवेदी और गुप्त ऊष्मा का परिवहन, बौवन अनुपात के मानों एवं कुल उष्मा ऊर्जा के स्थानांतरण के मानों का मूल्यांकन करने की दशा में एक नया प्रयास किया गया है ।

ABSTRACT. Ships' data collected during the sixties have been processed and analysed by IBM-360 system. A fresh attempt has been made towards the evaluation of evaporation, sensible and latent heat transport, Bowen ratio values and the transfer of total heat energy to atmosphere from the Indian Ocean, the Arabian Sea and the Bay of Bengal.

1. Introduction

In the past, sufficient work has been done on estimating the thermodynamic variables like evaporation, sensible and latent heat transfer, Bowen ratio and the total energy transfer to atmosphere. Previous workers Venkateswaran (1956) and Privett (1959) used climatological data. Pisharoty (1965) while examining the water vapour flux across the boundaries of the Arabian Sea during southwest monsoon, concluded that a large amount of water vapour carried over by the monsoon current is due to evaporation over the Arabian Sea. Garstang (1967) studied various thermodynamic parameters over the western Atlantic based on the data collected during a fortysix-day cruise of an oceanographic research vessel. The present study is to find a distant correlation, if any, among various parameters during pre-monsoon season and the subsequent behaviour of monsoon that follows.

2. Data

The data used for the present study consist of ships data during the period 1961 through 1966. The author proposes to present detailed study based on data for last two decades in near future. The main parameters used for the study are sea surface temperature, air temperature, dew point temperature, atmospheric pressure and wind speed. Monthly means for all these parameters have been used for every 5-degree latitude/longitude square covering an area extending from 15 deg. S to 25 deg. N latitude and 40 deg. E to 105 deg. E longitude. This data has undergone extensive zonal, horizontal and climatological quality control checks.

3. Formula used for computations

The following form of equation as suggested by Jacob (1951) and Sverdrup (1951) has been used for evaporation :

$$E = K(e_W - e_a)\,V \qquad (1)$$

where $K = \rho_m\, C_D$

and e_W and e_a are the vapour pressures at the sea surface and in air (6 metres above sea surface) respectively. V is wind speed and K is the evaporation coefficient. K being a highly variable quantity depending on the height (6 metres in this case) wind speed and roughness of the sea. ρ_m is density of moist air (1.2×10^{-3}) and C_D is a constant similar to drag coefficient. The value of K puts a serious limitation on the use of Eqn. (1) which is why the results obtained by different workers may vary.

For south Indian Ocean Venkateswaran (1956) and Privett (1959) used 2.0×10^{-6} and 1.4×10^{-6} respectively as values of K. Privett (1959) used the above average value of K for his work even though he evaluated values of K for different ocean areas. Suryanarayana and Sikka (1973) used 1.62×10^{-6} as the value of K. This value is almost the mean of those used by Venkateswaran and Privett. Garstang (1967) calculated values of C_D for different wind regimes for tropical western Atlantic. Pisharoty (1965) used 2.0×10^{-6} as the value of K for the formulation :

$$E = K(q_s - q_a)\,V \qquad (2)$$

where q_s and q_a are specific humidities over water surface and in air respectively. Other variables are

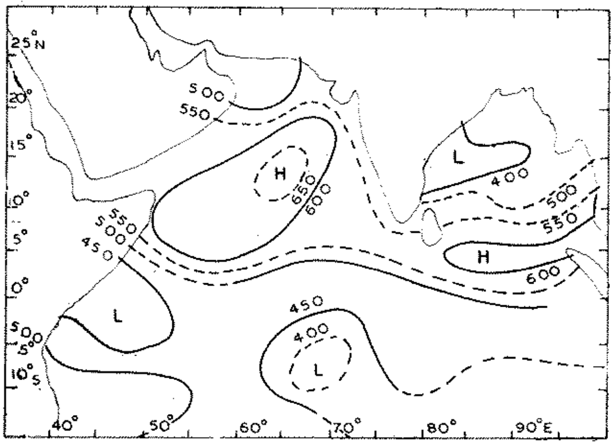

Fig. 1. Mean latent heat (Q_e) flux during February (cal/cm²/day)

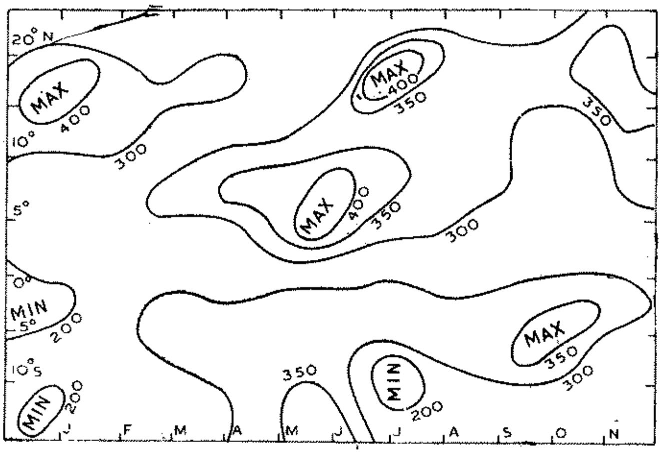

Fig. 2. Meridional distribution of E values (cal/cm²/day) along 65°-75° E during the year (mean value for 1961-66)

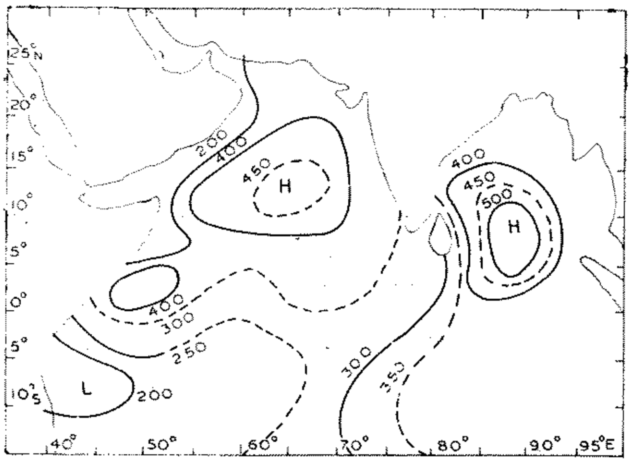

Fig. 3. Evaporation (cal/cm²/day) in May 1961

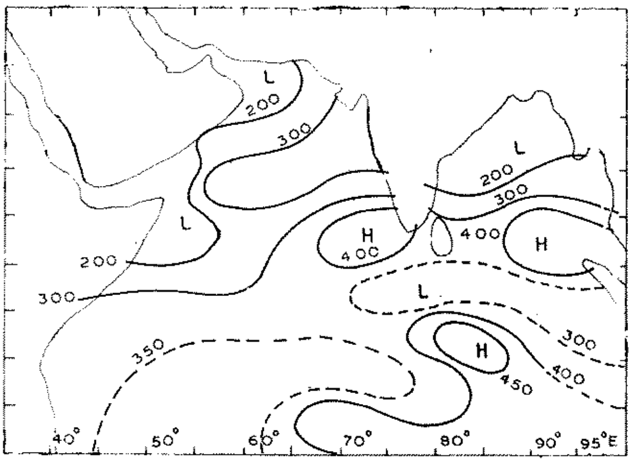

Fig. 4. Evaporation (cal/cm²/day) in May 1966

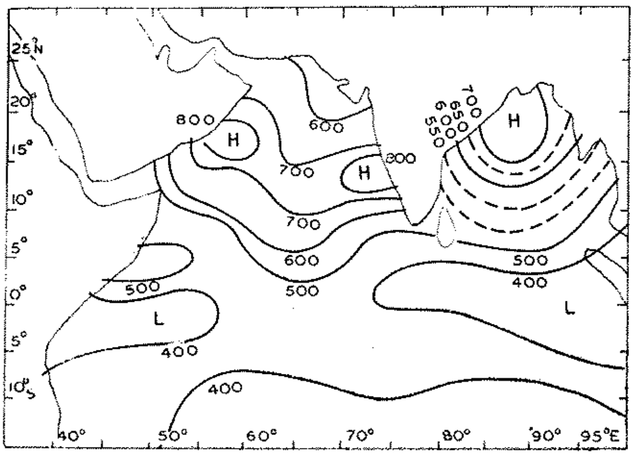

Fig. 5. Latent heat transport in February 1961

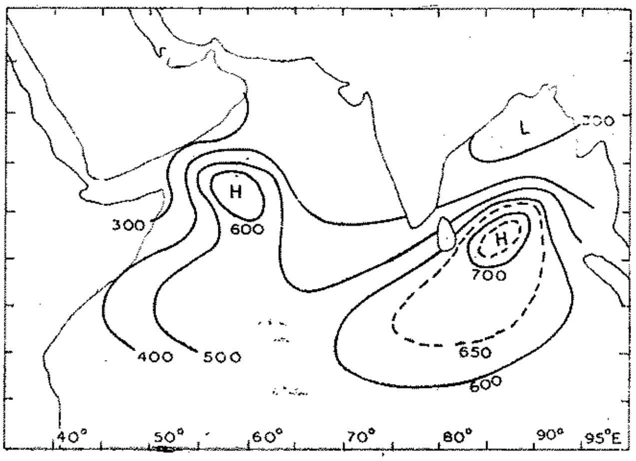

Fig. 6. Latent heat transport in April 1966

TABLE 1

Energy transport under varying wind condition

Month	Wind condition Min.	Wind condition Max.	Q_h Max.	Q_h Min.	Q_e Max.	Q_e Min.	Bowen ratio Max.	Bowen ratio Min.	Total energy exchange Max.	Total energy exchange Min.
Jan	4.5	7.5	10.805	0.6580	724.98	352.79	0.019	0.002	735.80	353.99
Feb	4.0	8.8	7.0602	-0.6270	643.69	323.77	0.014	-0.002	650.69	326.79
Mar	4.0	7.5	6.8896	-18.4475	619.39	242.94	0.013	-0.076	625.01	224.49
Apr	4.0	7.8	8.3991	-1.4195	680.14	335.83	0.014	-0.004	688.54	340.67
May	6.0	12.0	6.4391	-6.5907	823.36	367.42	0.010	-0.015	827.68	361.83
Jun	7.0	12.8	6.8587	-16.2862	750.71	200.49	0.012	-0.068	749.77	190.55
Jul	7.0	14.0	9.3017	-16.2142	786.61	78.32	0.014	-0.186	778.52	59.71
Aug	7.0	13.8	5.7380	-16.8800	792.87	79.22	0.011	-0.199	787.79	63·49
Sep	4.0	11.5	5.5205	-13.5005	748.09	232.45	0.011	-0.058	751.08	218.86
Oct	4.0	9.0	24.1889	-1.4116	783.88	356.86	0.065	-0.004	789.21	358.36
Nov	5.3	7.8	10.7901	1.2499	731.38	401.54	0.017	0.003	742.17	406.45
Dec	4.8	8.8	12.5076	-0.9208	805.52	398.37	0.026	-0.002	810.95	404.79
Annual	5.1	10.1	9.5414	-7.5385	740.88	280.83	0.019	-0.042	744.77	275.83
Annual mean	7.62		1.0		510.85		-0.012		510.30	

Units : Wind : metre sec^{-1}, Q_h : cal cm^{-2} day^{-1}, Q_e : cal cm^{-2} day^{-1}

TABLE 2

Values of sensible heat (Q_h), latent heat (Q_e) fluxes, Bowen's ratio and total energy transport (Q_t)

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Mean
(a) Good Monsoon years															
Q_h	Max.	13.785	8.812	6.082	8.777	6.294	5.171	11.262	6.097	7.246	48.108	7.841	11.559	11.753	2.505
	Min.	0.450	-0.941	0.855	-3.047	-6.608	-12.975	-14.742	-22.713	-11.737	1.412	-0.989	-7.051	-6.742	
Q_e	Max.	744.84	784.18	588.17	843.16	853.46	771.61	749.28	840.94	849.04	730.15	594.05	804.71	762.80	526.76
	Min.	323.51	369.95	125.40	392.66	248.51	284.88	83.61	58.16	243.90	331.69	388.79	337.60	290.73	
B_R	Max.	0.023	0.017	0.012	0.016	0.010	0.007	0.018	0.011	0.014	0.113	0.019	0.024	0.024	-0.0125
	Min.	0.001	-0.001	0.002	-0.004	-0.027	-0.038	-0.158	0.314	-0.042	0.002	-0.002	-0.013	-0.049	
Q_t	Max.	757.57	792.99	592.21	850.99	859.63	770.32	754.18	836.74	851.14	737.42	597.87	813.12	767.85	528.01
	Min.	323.96	374.52	430.67	394.38	241.90	276.58	70.40	39.86	243.90	336.68	390.91	341.52	288.77	
(b) Bad Monsoon years															
Q_h	Max.	11.240	7.484	7.632	11.262	6.744	9.034	7.349	5.394	5.172	9.442	10.790	13.381	8.77	-0.471
	Min.	-1.144	-4.230	-35.87	-3.556	-5.489	-19.678	-17.296	-13.227	-15.333	-4.496	1.217	2.541	-9.713	
Q_e	Max.	681.92	679.26	676.71	748.62	796.73	799.31	829.84	744.80	788.59	838.05	951.81	804.71	778.36	498.00
	Min.	324.77	291.91	41.87	48.61	364.65	132.98	68.65	94.39	183.61	318.57	369.29	372.42	217.64	
B_R	Max.	0.025	0.016	0.015	0.015	0.011	0.017	0.011	0.011	0.010	0.018	0.017	0.028	0.016	-0.052
	Min.	-0.003	-0.010	-0.857	-0.007	-0.014	-0.098	-0.219	-0.140	-0.084	-0.014	0.002	0.003	-0.120	
Q_t	Max.	689.12	683.96	682.82	759.88	803.09	802.99	819.68	738.92	740.26	841.27	957.06	807.25	779.19	497.85
	Min.	324.00	291.55	6.002	148.27	363.37	122.17	49.67	81.11	168.28	314.07	375.71	377.76	218.50	

Units of Q_h, Q_e and Q_t : cal cm^{-2} day^{-1}

as in (1) above. In this study a value of 1.64×10^{-6} have been used throughout for K.

For the computation of sensible heat flux (q_h) from sea to atmosphere the following formulation have been used :

$$Q_h = \frac{4.15\,(T_W - T_a)\,V_a}{5.742\left[\ln\left(\dfrac{a+z_0}{z_0}\right)\right]^2 + 0.16\,V_a} \qquad (3)$$

where T_W and T_a are temperatures of water surface and that of air respectively, V_a is the wind speed (in cm/sec) at the height of observation and z_0 is the roughness parameter. The thickness of the laminar boundary layer is assumed constant at 0.16 cm and corresponding to this the value of z_0 is taken as 14. The latent heat flux due to evaporation (Q_e) has been calculated using the formula :

$$Q_e = 585\ E \qquad (4)$$

where E is the evaporation in cal cm^{-2} day^{-1}.

Bowen ratios have been evaluated by two formulae :

$$B_R = Q_h/Q_e \quad (5)$$

and

$$\text{BOWRA} = 0.64 \frac{P}{1000} \frac{(T_W - T_a)}{e_W - e_a} \quad (6)$$

P, being atmospheric pressure.

Total heat fluxes (Q_t) has been calculated by the formula :

$$Q_t = Q_h + Q_e \quad (7)$$

4. Analysis and computation

Thermodynamic parameters like evaporation (using vapour pressures both in mb and inches of mercury) sensible and latent heat fluxes, Bowen ratio values (using both Eqns. 5 and 6 above) and total energy exchange have been calculated for every month at every 5-degree square block for the area under discussion. Computations have also been done jointly for all the years together to obtain a composite mean picture. To visualize the difference between *Good monsoon* and *Bad monsoon* years and *Early onset* and *Late onset* years data have been composited separately and all the computations repeated. Maps for all these computed values have not been presented here for obvious reasons of space. Only those maps that have significant features have been presented.

5. Discussion

Evaporation as computed generally agrees with the studies of earlier workers like Venkateswaran (1956), Privett (1959) and Suryanarayana and Sikka (1973). Similarly mean values of latent heat transport for the month of February (Fig. 1) broadly agrees with those presented by Garstang (1967) for western Atlantic. Bowen ratio values though calculated separately by Eqns. (5) and (6) generally agrees with each other. The maximum and minimum values of Bowen ratio varied from + 0.019 to —0.042. Mean energy transport in the form of sensible and latent heats and Bowen ratio values under varying wind conditions during the year for the six years composite have been presented in Table 1. All the parameters calculated for *Good monsoon* (1961 to 1964) and *Bad monsoon* (1965 to 66) years as well as for *Early onset* (18 May 1961) and *Late onset* (8 June 1966) years. Table 2 shows maximum/minimum of the parameters for the whole area under study. *Early onset* year evaporation chart shows high E values dominated a major portion of south Arabian Sea and Indian Ocean region right from 40 deg. E to 90 deg. E. Even in the month of February high evaporation values dominated Arabian Sea between 5 deg. and 15 deg. N. On the other hand in the late onset year high E values were restricted mainly to the eastern side (Bay of Bengal) and Arabian Sea was dominated by low to moderate values of evaporation. Meridional distribution of E values along 65 deg.-75 deg. E blocks during the year (Fig. 2) show somewhat higher values compared to those obtained by earlier workers even though broad pattern remains same. Jagannathan and Ramasastry (1964) have also got somewhat higher values. This may be due to different period of averaging and to somewhat higher values of wind speed in the present study. This meridional distribution pattern changes very interestingly from year to year. Due to lack of adequate data coverage meridional distribution for other blocks could not be studied with authenticity.

Evaporation calculated by converting vapour pressure into inches of mercury and wind speed in knots show somewhat interesting patterns for early onset year (1961) and late onset year (1966). In Fig. 3 high values of E dominated the vital area of Arabian Sea (10 deg.-15 deg. N and 60 deg.-70 deg. E longitude) and Bay of Bengal (5 deg. -10 deg. N and 85 deg.-90 deg. E longitude). In contrast, same chart for May 1966 shows (Fig. 4) comparatively lesser *High* values dominate more southern latitudes and more eastern longitudes. Similar striking constrast can be noticed between Fig. 5 and Fig. 6 which is the distribution of latent heat fluxes in early and late onset years.

6. Conclusion

One of the objectives of the present study is to find a distant correlation between distribution of various thermodynamic parameters and the behaviour of the monsoon that follows. The study of the charts bring out the following salient features :

(1) During years of good monsoon values of thermodynamic variables are considerably higher than those for bad monsoon.

(2) Total energy exchange from sea to atmosphere shows upwards trends right from the month of March-April in good monsoon years whereas these values start picking up only in June-July in the case of bad monsoon years.

(3) Annual mean values of the variables remain more or less constant, only the pattern of their rate of change varies from year to year.

(4) Areas of prominent high values of evaporation occupy areas bound by latitudes 7.5 deg. N right in the month of May for years of early onset whereas in case of years of late onset high evaporation areas are not so prominent and they occupy much southern latitudes in corresponding months.

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