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MOISTURE SOURCE FOR SUMMER MONSOON RAINFALL OVER INDIA

Y.Sadhuram and D.P.Rao

National Institute of Oceanography, Regional centre,
176, Lawsons Bay Colony, Visakhapatnam -530017

ABSTRACT

Southwest monsoon plays a vital role in India's economy as the major income comes from agriculture. (More than 70% of the annual rainfall is received during southwest monsoon (June-september). Floods and droughts greatly influence the economy of our country and most of the droughts are associated with ENSO (El-Nino - Southern Oscillation).)

What could be the moisture source for this copious amount of rainfall over the Indian sub-continent? (There is a divergent opinion on this aspect among the scientists.) This has been studied in detail and noticed that the average evaporation and precipitation rates over the Arabian sea during SW monsoon season are 2.78 and 2.21 ($\times 10^{10}$ tons/day) respectively. This suggests that the possible contribution from evaporation towards the moisture transport across the west coast of India is not significant irrespective of the monsoon activity. It is also noticed that the mean rate of evaporation is almost equal (3.66 and 3.59×10^{10} tons/day) under active and weak monsoons. But, the rate of evaporation is almost double under an active phase compared with a weak phase, over central Arabian sea. The role of Findlater's Jet in the transport of moisture towards west coast is also discussed.

From the above studies, it could be inferred that the moisture flux from southern hemisphere and the synoptic conditions over the Arabian sea are found to be important for monsoon rainfall over India during SW monsoon season.

INTRODUCTION

The southwest monsoon which gives 70-80 % of the annual rainfall of the Indian sub-continent during four months period (June-September) is one of the most spectacular features of Indian monsoon meteorology. Since, India's major economy depends on agriculture, the quantum of rainfall during SW monsoon season plays a vital role in India's economy. Droughts and floods greatly affect the economy of our country and most of the droughts are associated with ENSO. Meteorologists have been attempting to forecast monsoon rainfall by using different techniques over the last 100 years. Krishnakumar et.al (1995) have summarised the forecasting techniques. Recently, Sadhuram & Wells (1996) and Sadhuram (1997) showed that sea surface temperature during October month of the previous year in the eastern equatorial Indian ocean ($0-5^{\circ}$ N; $80-85^{\circ}$ E, southeast of Srilanka) is useful to predict monsoon rainfall about 7 months in advance.

The main mechanism behind the voluminous rainfall could be the availability and advection of moisture by the prevailing winds. Pisharoty (1965) studied the moisture budget over the Arabian sea by using IIOE data. He concluded that the evaporation from the Arabian sea was the major contributor for Indian summer monsoon-rains. Later, Saha and Bavadekar (1973) proved that 70% of the contribution is

from moisture flux from southern hemisphere which contradicts the above results. Many scientists investigated this aspect and supported either the former or the latter hypothesis (Ghosh et.al 1978; Cadet & Reverdin, 1981; Rao et.al, 1981; Murakami et.al. 1984; Sadhuram and Ramesh kumar , 1988) .

In the present study, this problem has been dealt from a different angle and a plausible explanation for the controversy has been given.

DATA AND METHODOLOGY

(i) Moisture budget:

Moisture budget over the Arabian sea could be expressed as

$$E - P = FE + FW + FS + FN$$

where E and P denote the total amount of evaporation and precipitation over the Arabian sea respectively. FE , FW,FS and FN represents the total moisture flux across eastern, western, southern and northern boundaries (Fig.1: ABCD- 1964; PQR- 1975; OBMN -1979). The rate of evaporation (E) is computed from the bulk aerodynamic method.

$$E = \rho C_e (e_s - e_a) U$$

where ρ is the density of air (1.2 kg/m³), e_s and e_a represent saturated vapour pressure at sea surface temperature and vapour pressure at dew point temperature respectively, U is the wind speed at anemometer level. C_e is the bulk transfer coefficient for latent heat flux.

(ii) Total evaporation over the Arabian sea under weak and active monsoon seasons

Mean monthly marine surface meteorological data for 1979 and 1983 from Indian Daily Weather Reports have been used to compute evaporation during the four months, June-September.

(iii) Mean fields of latent heat flux under active and weak phases of summer monsoon, 1986

Marine surface meteorological data collected onboard ORV Sagarkanya during the period, 4th July- 7 th Sept. 1986. had been used. The data had been averaged for 4x4 degree grids under active and weak phases of summer monsoon . 1986. Distribution of wind speed, surface pressure and latent heat flux under active and weak phases had been presented for Arabian sea.

More details on computations of (i) to (iii) are presented earlier (Sadhuram and Ramesh Kumar, 1988; Ramesh Kumar and Sadhuram, 1989; Vinaychandran et al, 1989).

RESULTS AND DISCUSSION

Table.1 shows the mean rates of evaporation (E) and precipitation (P) over the Arabian sea for different years . The overall seasonal means of E & P are 2.78 and 2.21 (X10¹⁰tons/day) respectively. These values suggest the possibility of a minor contribution towards the rainfall over the Indian sub-continent. In other words, most of the evaporation is contributing towards the local rainfall over the sea itself. To identify the role of moisture flux from southern hemisphere , the fluxes across different boundary walls for the same years had been shown in Table.2. It is seen from the Table.2 that the fluxes are quite high across southern and western walls compared with the other boundaries. It is interesting to see that the ratio between FS and FE is more than 70% (Table.3) irrespective of the monsoon activity. The ratio between E and FE is 57% which is almost 3 times higher than the value (20%) obtained from Table 1. The higher value (57%) is due to the fact that the contribution of evaporation towards rainfall over the sea is ignored.

Table.1: Mean values of evaporation (E) and precipitation (P) over the Arabian sea
(Unit: 10^{10} tons/day)

Month		1964	1973	1979	mean
June	E	3.5	2.55	3.18	3.08
	P	2.5	2.19	3.16	2.62
July	E	3.2	2.98	3.02	3.07
	P	2.7	1.60	2.98	2.43
August	E	2.5	3.10	2.12	2.57
	P	2.1	---	1.67	1.88
September	E	2.4	----	1.86	2.13
	P	1.7	----	2.09	1.89
Mean	E	2.90	2.88	2.55	2.78
	P	2.25	1.89	2.48	2.21

Table.2: Moisture flux across different boundary walls (-ve inward: +ve outward)
(Unit: 10^{10} tons/day)

	1964				1975				1979			
	J	J	A	S	J	J	A	S	J	Ju	A	S
FW	0.11	0.50	-0.67	0.15	0.80	1.40	0.60	0.90	-0.31	-1.19	-0.66	0.45
FN	-1.21	-1.53	-1.46	-1.27	--	--	---	--	-0.35	-0.23	-0.49	-.67
FE	4.99	5.87	5.75	4.95	9.2	7.40	8.70	7.20	3.91	4.45	4.31	1.45
FS	-3.38	-4.36	-3.89	-3.01	-6.9	-5.8	-5.8	-5.3	-3.23	-2.99	-2.71	-1.46
E	3.50	3.20	2.50	2.40	3.90	3.6	3.4	3.3	3.18	3.02	2.12	1.86
P	2.50	2.70	2.10	1.70	0.80	0.60	-0.1	0.50	3.16	2.98	1.67	2.09

Fig.2 shows the differences in the rate of evaporation (1983 minus 1979) during SW monsoon seasons. It is obvious from Fig 2 that the rate of the evaporation over the central Arabian sea was higher in the month of June 1979 compared with 1983. The reverse is seen in the southern Arabian sea. The differences are small in the month of July and September. Positive values are dominant during August. From the total evaporation rates on seasonal scale (Table 4), it could be inferred that the mean seasonal evaporation was almost stable (3.66 and 3.59×10^{10} tons/day) during 1979 and 1983 monsoon seasons). To examine this within a particular season, spatial distributions of surface pressure, wind speed (Figs. 3a-d), vapour pressure gradient and latent heat flux (4a-d) under an active and weak phase of 1986 summer monsoon have been presented for Arabian sea. It is interesting to see that the latent heat flux is almost double over central Arabian sea under an active phase when compared with a weak phase. This maximum shifted to SE Arabian sea (Figs 4c & d) under a weak phase. By examining the surface pressure and wind speed fields (Fig 3) it could be inferred that there was a ridge in the pressure field over central Arabian sea under a weak phase which blocks the moisture transport towards west coast of India. Wind field indicates the possibility of a change in the position of Findlater's Jet from its normal position (Fig. 3c & d). Normally, the Findlater's Jet travels SW-NE direction over the central Arabian sea region. But, during 1986 summer monsoon season, it was present along 15° N. This Jet plays an important role in transporting moisture from southern hemisphere. The above reasons could be attributed for the drastic deficit in rainfall along west coast of India during 1986 SW monsoon.

From the overall results, it could be inferred that the moisture transport from southern hemisphere is the major contributor for the monsoon rainfall over the Indian sub-continent. The synoptic features over the Arabian sea under active and weak cycles of monsoon are also important to advect the moisture towards west coast.

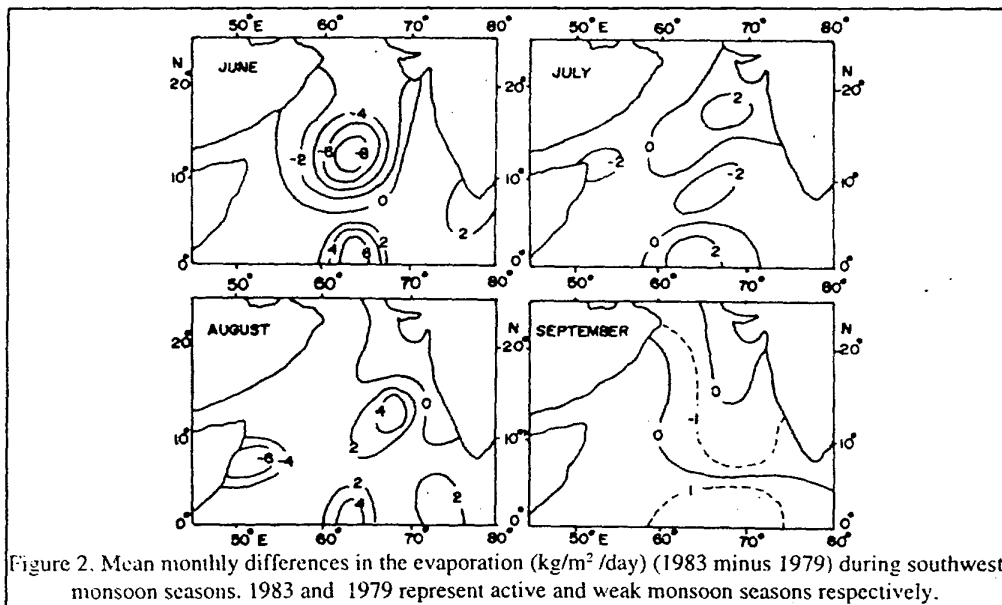
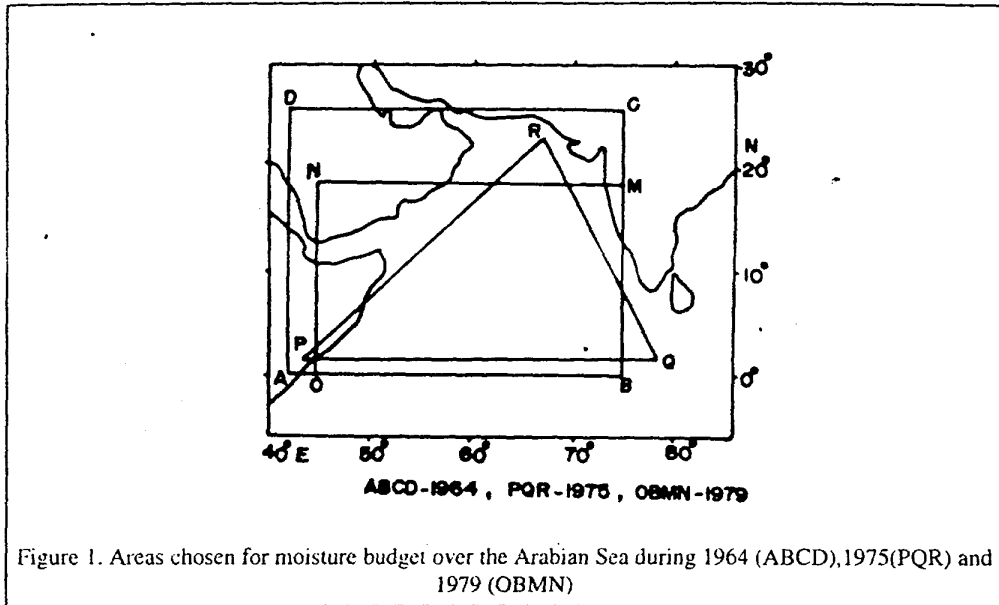
What could be the reasons for the controversy on this aspect? There are many reasons. The main reason could be the lack of systematic dense data set over the Arabian sea and uncertainty in the estimation of evaporation from bulk aerodynamic method. The bulk transfer coefficient C_e which is involved in the formula varied from study to study. A value of the order of 2×10^{-3} under active monsoon conditions had been reported earlier, which is quite higher than the normally used value (1.4×10^{-3}) (Suryachandra Rao et.al. 1995). But, under non monsoon months, the available values of C_e in the literature appear to be valid (Sadhuram, 1991). This appears to be reasonable because the Findlater's Jet enhances the turbulence in the lower boundary layer under active monsoon conditions. It should be mentioned here that C_e values in the other oceanic areas are estimated where the low level Jet was absent. Secondly, the rate of precipitation over the sea which is involved in the moisture budget is not known accurately. At present, it is indirectly derived from the satellite data, but the accuracy is questionable. Accurate measurements on precipitation over the sea, in addition to the Radiosonde data is very much essential, to throw better light on the moisture source for summer monsoon rainfall.

CONCLUSIONS

1. Moisture flux from southern hemisphere appears to be the major contributor for Indian summer monsoon rainfall over the Indian sub-continent.
2. Latent heat flux over the Arabian sea is almost double under an active phase when compared with a weak phase, during 1986 monsoon.

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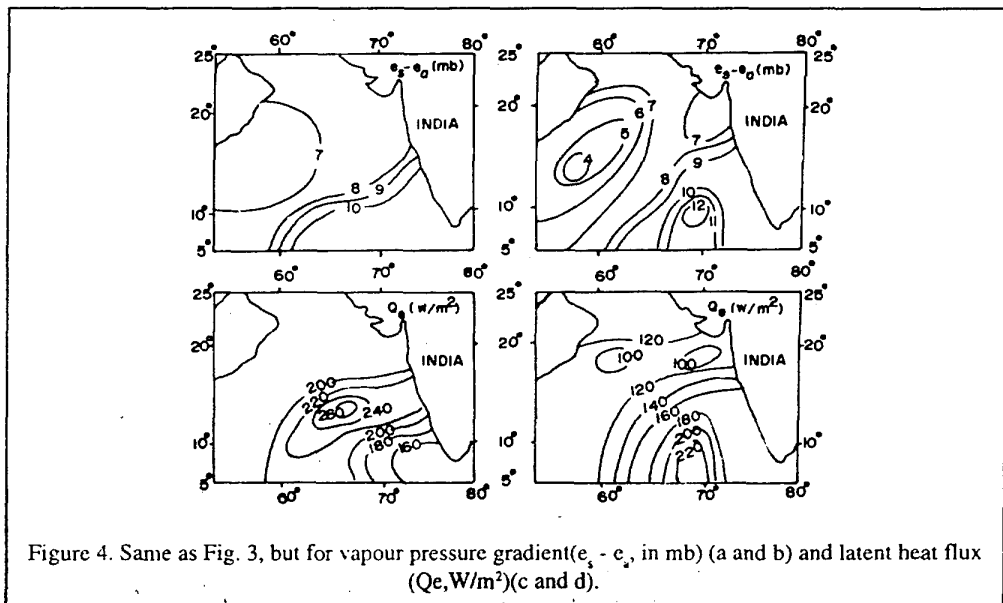
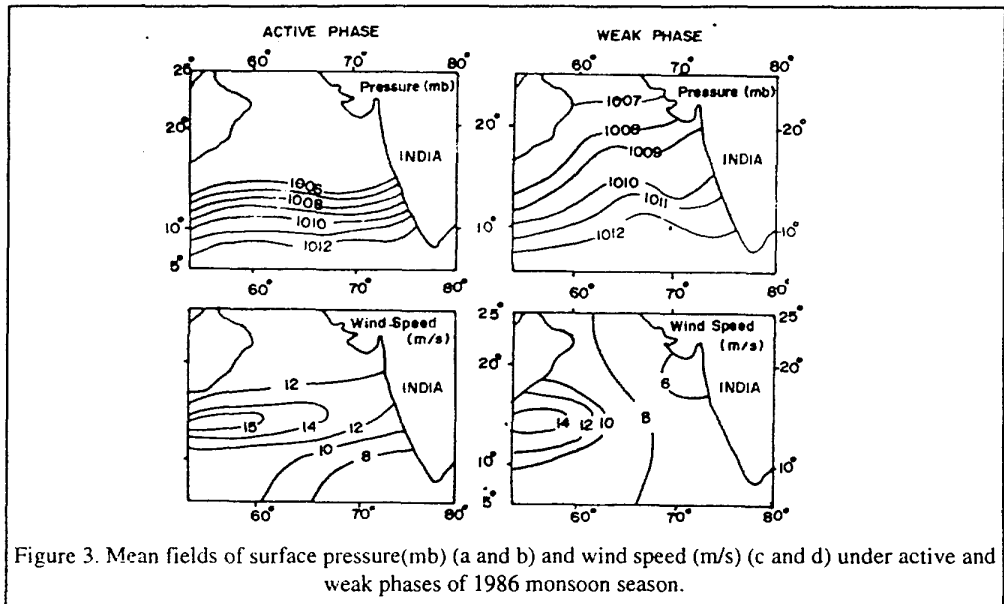


Table 3.: Seasonal means and percentage ratio between FS:FE and E:FE
(FW, FN, FE, FS, E, FS/FE, E/FE) (10¹⁰tons/day)

	1964	1975	1979
FW	0.02	0.93	-0.42
FN	-1.37	---	-0.44
FE	5.39	8.13	3.53
FS	-3.66	-5.95	-2.60
E	2.90	3.55	2.55
FS/FE	68	73	74
E/FE	54	44	72

Table.4: Evaporation rates during strong (1983) and weak (1979) monsoon seasons
(June, July, August, September) (10¹⁰tons/day)

Month/year	1979	1983	difference (1983-1979)
June	4.63	4.43	-0.20
July	4.36	3.55	-0.75
August	2.97	3.68	0.72
September	2.70	2.70	-0.06
Mean	3.67	3.59	-0.07

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