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Multiple variability of summer sea surface temperature (SST) and evaporation over the Indian Seas

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सार — 1961 से 1991 तक की इक्कीस वर्षों की अवधि के दौरान, उत्तरी हिन्द महासागर से लिए गए समुद्री मौसम वैज्ञानिक आँकड़ों का उपयोग करते हुए अरब सागर और बंगाल की खाड़ी के विभिन्न क्षेत्रों के समुद्र सतह के तापमान तथा वाष्पीकरण का पता लगाया गया है । समुद्र सतह तापमान और वाष्पीकरण के परिवर्तनशील पंचदिवसीय औसत से मई के महीने में अरब सागर में समुद्र सतह तापमान एवं वाष्पीकरण दोनों तथा बंगाल की खाड़ी में वाष्पीकरण प्राचलों से इनकी बढ़ी हुई प्रवृत्तियों का पता चलता है । परिवर्तन की इन प्रवृत्तियों के विश्लेषण से यह पता चला है कि ये परिवर्तन वास्तविक और महत्वपूर्ण हैं । अनुक्रम विश्लेषण से भारतीय समुद्रों के समुद्र सतह तापमान के 2 से 3 वर्ष के महत्वपूर्ण चक्र और वाष्पीकरण के 2 से 5 वर्ष के चक्र का पता चलता है । इसके अलावा, बंगाल की खाड़ी के समुद्र सतह तापमान और अरब सागर में वाष्पीकरण के 15 वर्ष के एक महत्वपूर्ण चक्र का भी पता चला है । अरब सागर तथा बंगाल की खाड़ी के समुद्र सतह तापमान और वाष्पीकरण की विसंगतियों के संबंध में समानुपाती लांबिक फलन के विश्लेषण से यह ज्ञात होता है कि समानुपाती लांबिक प्रथम के समय इनकी प्रवृत्तियाँ बढ़ी हुई थीं ।

ABSTRACT. Utilising thirty one years' marine meteorological data from 1961-91 recorded over the north Indian Ocean the sea surface temperature (SST) and evaporation have been obtained for different regions of the Arabian Sea and the Bay of Bengal. The moving pentad averages of SST and evaporation reveal increasing tendencies of both the parameters over the Arabian Sea and that of evaporation over the Bay of Bengal during May. The changes are real and significant as revealed by the trend analysis. The spectral analysis shows that SST has a 2-3 year significant cycle and evaporation rate has a 2-5 year cycle over the Indian Seas. In addition, a significant 15-year cycle is present in the SST over the Bay of Bengal and evaporation rate over the Arabian Sea. Empirical orthogonal function analysis performed on the anomalies of SST and evaporation rate over the Arabian Sea and the Bay of Bengal reveals that the time coefficient of first EOF has an increasing tendency.

Key words — SST, Evaporation, Moving pentad average, Bucket temperature, Injection temperature, Aerodynamic method, Drag coefficient, El-Nino southern oscillation (ENSO), Spectral analysis, Empirical Orthogonal Function Analysis (EOFA), Correlation coefficient (CC)

1. Introduction

Adequate estimates of global temperature change can not be made without estimating the tendency of temperature over the oceans which cover about 72% of the earth's surface. Air temperature variations over the oceans are primarily determined by the SST changes. The first attempt to estimate SST changes over the ocean areas was made by Paltridge and Woodruff (1981). They reported that the long-term temperature changes over the oceans differ significantly from those over the land.

Barnett (1984) has investigated the long-term trends in SST and air temperature over the oceans. He concludes, "The SST appears to have increased relative to air temperature over the oceans by approximately 0.2°C between the early part of the century and recent times." Hoflich (1973) found a similar result (0.4°C) for the tropical Atlantic.

The changes in SST may lead to changes in evaporation rate over the oceans which may have vital impact on the atmosphere and global water budget.

The influence of Indian seas on the weather and climate of Indian subcontinent which is dominated by monsoons and tropical cyclones can not be overemphasized. Normally the Indian seas are warmest during May; Hastenrath and Lamb (1979). The tendencies of SST and evaporation over the Indian seas in May during recent decades are definitely a subject of considerable interest and importance. The main problem addressed in the present study is the estimation of

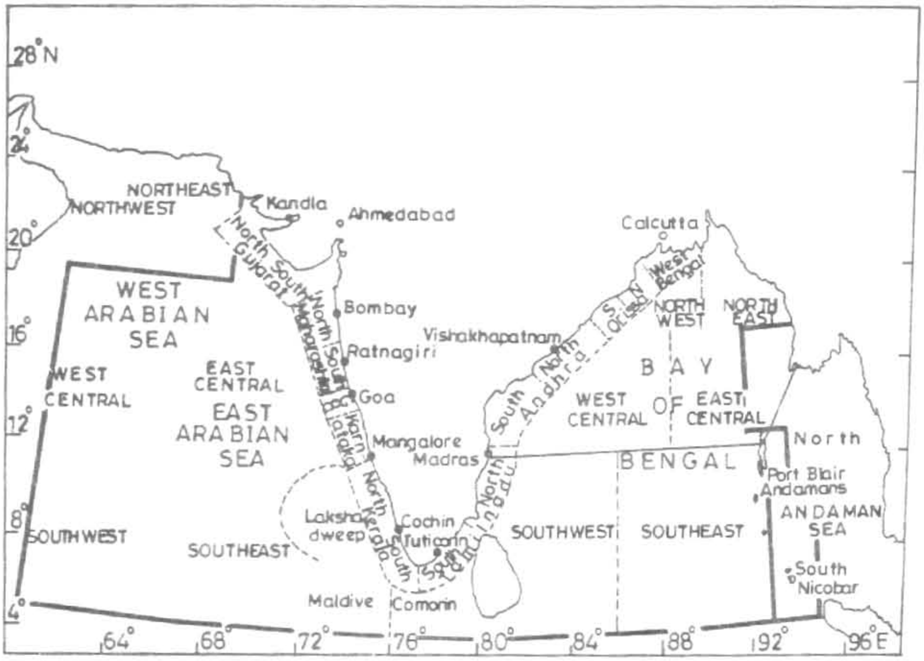

Fig.1. Different areas over the Arabian Sea and Bay of Bengal

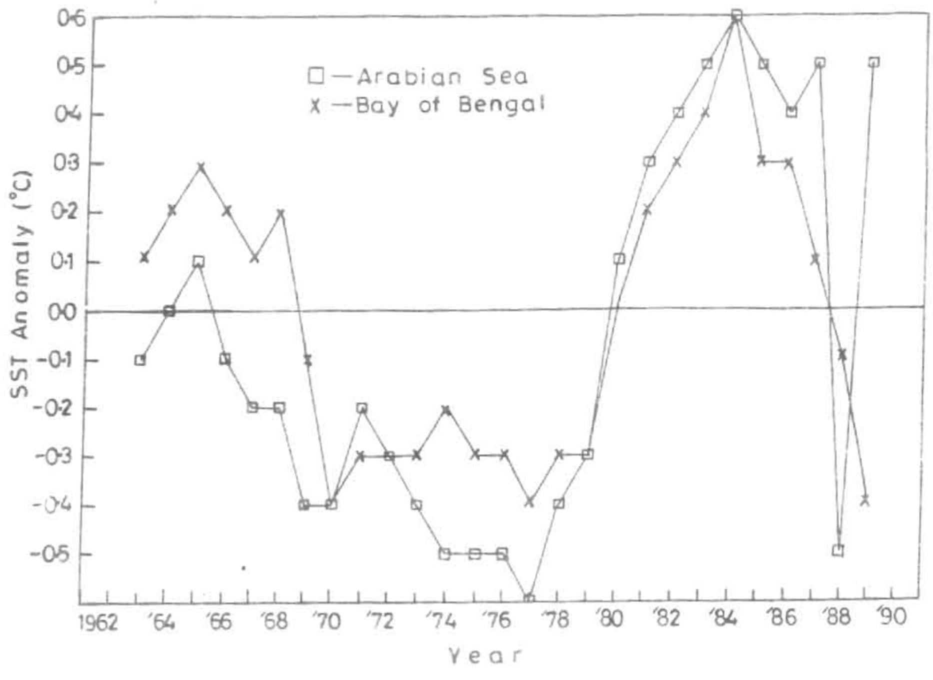

Fig.2. Anomalies of moving pentad averages of SST over Arabian Sea and Bay of Bengal during May

trends of SST and evaporation over the Indian seas in the month of May during last three decades.

It may be remarked that although the variabilities of SST and other marine parameters over the Atlantic and Pacific Oceans have been extensively studied, not much has been done as far as Indian seas are concerned. Recently Tanimoto *et al.* (1991) investigated the variability of SST over the north Pacific Ocean during 37 years period from 1950 to 1986. They have reported different characteristic scales in SST variations.

TABLE 1

Time-series of sea surface temperature (°C) over the Indian seas during May

S. No.	Year	S W Arabian Sea	S E Arabian Sea	W C Arabian Sea	E C Arabian Sea	N W Arabian Sea	N E Arabian Sea	S W Bay of Bengal	S E Bay of Bengal	W C Bay of Bengal	E C Bay of Bengal	North Bay of Bengal	Arabian Sea (Mean)	Bay of Bengal (Mean)
01	1961	29.2	29.5	29.5	29.9	28.6	28.4	30.0	29.2	30.5	29.2	30.2	29.2	29.8
02	1962	29.4	29.8	29.5	29.5	-	-	29.4	29.7	30.1	30.1	30.5	29.5	30.0
03	1963	28.9	29.9	29.6	30.1	28.7	28.7	30.0	30.1	29.7	-	-	29.3	29.9
04	1964	-	29.9	29.5	29.8	-	-	30.2	29.3	30.3	-	29.5	29.7	29.8
05	1965	30.4	30.1	29.1	29.7	28.9	-	30.3	30.2	28.5	-	-	29.6	29.7
06	1966	30.1	31.1	29.3	29.7	-	-	29.6	30.6	-	-	-	30.0	30.1
07	1967	-	-	-	-	-	-	-	-	30.6	-	-	-	30.6
08	1968	29.7	29.6	28.7	29.1	27.9	27.3	29.3	29.5	29.6	29.6	29.2	28.7	29.4
09	1969	29.9	30.1	30.0	29.4	28.6	28.6	30.1	30.4	30.5	29.4	29.8	29.4	30.0
10	1970	29.6	29.7	29.8	29.7	28.9	29.2	29.3	29.2	-	29.9	29.6	29.5	29.5
11	1971	-	-	-	-	-	-	28.5	28.5	-	28.6	29.3	-	28.7
12	1972	29.9	29.7	29.3	29.4	28.5	28.7	29.5	29.2	30.0	27.5	29.3	29.3	29.1
13	1973	29.8	30.1	29.4	29.7	28.7	28.9	29.6	29.4	30.0	29.6	29.9	29.4	29.7
14	1974	29.3	29.6	28.9	29.5	28.6	28.9	30.0	30.3	29.5	31.5	29.3	29.1	30.1
15	1975	29.0	29.1	28.9	29.1	28.7	28.4	29.4	29.1	29.3	28.9	29.5	28.9	29.2
16	1976	29.6	29.6	29.3	29.3	28.3	28.0	29.0	29.2	29.8	29.5	29.1	29.0	29.3
17	1977	29.3	29.8	29.8	29.8	28.6	28.2	29.1	29.5	29.5	28.6	27.9	29.2	28.9
18	1978	29.3	29.6	29.2	29.5	28.8	28.5	29.5	29.5	29.5	29.3	29.8	29.1	29.5
19	1979	29.9	29.7	29.4	29.3	28.5	27.5	29.2	29.1	29.5	30.0	29.7	29.0	29.5
20	1980	30.3	30.7	30.0	30.4	29.0	29.7	29.7	30.1	29.8	31.4	27.3	30.0	29.7
21	1981	29.7	30.3	29.8	29.6	28.2	28.9	28.9	29.0	29.7	28.7	29.6	29.4	29.2
22	1982	-	32.0	32.0	28.5	-	-	30.4	30.4	30.8	-	-	30.8	30.5
23	1983	-	29.9	30.5	30.3	30.6	-	29.9	28.9	32.1	31.4	30.2	30.3	30.5
24	1984	-	30.0	30.5	29.8	27.6	30.0	30.1	29.7	29.8	30.0	30.4	29.6	30.0
25	1985	-	-	30.6	30.2	30.0	-	30.7	30.1	31.0	30.3	-	30.3	30.5
26	1986	30.1	29.5	29.9	29.7	-	-	29.2	29.2	29.9	31.3	-	29.8	29.9
27	1987	30.5	31.0	29.9	30.1	-	-	30.1	29.3	28.7	28.7	-	30.4	29.2
28	1988	28.9	30.4	29.8	30.3	-	-	30.9	29.6	31.1	30.0	-	29.9	30.5
29	1989	30.0	29.9	30.3	29.5	-	-	28.7	29.8	29.2	28.8	-	29.9	29.1
30	1990	31.5	30.3	31.1	30.1	-	-	29.6	30.5	28.3	28.3	-	30.7	29.2
31	1991	30.0	29.8	29.4	30.1	-	-	29.3	29.8	27.1	-	-	29.8	28.7
Linear Trend per decade		+0.24 ##	+0.14	+0.38 #	+0.11	+0.24	+0.34 ##	0.0	+0.01	-0.22	+0.04	-0.26	+0.30 #	-0.08
CC		+0.39	+0.25	+0.51	+0.24	+0.25	+0.31	0.0	+0.02	-0.21	+0.04	-0.22	+0.52	-0.14

Significant at 99% level, ## Significant at 90% level.

2. Data and methodology

Archived ship observations from the north Indian Ocean for the period 1961-91 have been used in this study. SST data comprises of both bucket and injection temperatures. However, it may be remarked that recent SST data have come largely from thermometers located in the ship's water cooling intake line, called injection temperature. The injection temperatures are biased high whereas bucket temperatures are biased low; Roll (1965). The bucket- injection bias is of the order of about 0.3°C; Tabata (1978). The change of observational technique of SST would lead to an increase in SST. Barnett (1984) has established that the magnitude of this error is 0.3-0.7°C since early 1900's. Thus the increase of SST during last three decades due to bucket-injection bias should not exceed 0.2°C. Any increase in SST in excess of 0.2°C would be real.

All ship observations comprising of SST, pressure, air temperature, wind and dew point temperature were arranged by 5° latitude X longitude squares. Means of less than five observations have been rejected. In all about one lakh observations recorded over the Indian seas during May (1961-91) have been considered. The evaporation rates (mm/day) over different areas of Indian seas were computed using aerodynamic formula with drag coefficients that vary with wind speed and stability. The computational details are given by Singh and Joshi (1993). The geographical locations of sea areas have been depicted in Fig.1.

TABLE 2

Time-series of evaporation (mm/day) over the Indian seas during May

S. No.	Year	S W Arabian Sea	S E Arabian Sea	W C Arabian Sea	E C Arabian Sea	N W Arabian Sea	N E Arabian Sea	S W Bay of Bengal	S E Bay of Bengal	W C Bay of Bengal	E C Bay of Bengal	North Bay of Bengal	Arabian Sea (Mean)	Bay of Bengal (Mean)
01	1961	3.9	3.9	2.8	3.4	3.1	3.5	4.9	4.9	3.0	2.8	2.6	3.4	3.6
02	1962	6.0	5.7	3.0	3.2	1.6	-	3.8	3.9	2.9	2.5	2.1	3.9	3.0
03	1963	4.3	3.5	3.9	3.8	3.1	3.5	3.5	4.1	3.3	-	-	3.7	3.6
04	1964	4.2	4.2	3.0	3.9	-	-	4.9	4.2	2.8	-	3.6	3.8	3.9
05	1965	1.5	1.8	1.6	1.8	1.6	1.0	2.9	3.3	4.7	4.6	-	1.5	3.9
06	1966	-	-	-	-	-	-	-	-	-	-	-	-	-
07	1967	-	-	-	-	-	-	-	-	-	-	-	-	-
08	1968	2.0	3.0	3.0	2.4	2.8	2.7	3.3	3.4	3.6	2.8	4.3	2.7	3.5
09	1969	5.0	2.2	3.7	2.7	1.6	1.5	3.6	3.6	3.4	1.9	1.0	2.8	2.7
10	1970	4.2	3.6	3.6	3.2	2.9	2.9	3.3	3.9	2.2	2.8	0.2	3.4	2.5
11	1971	-	-	-	-	-	-	-	-	-	-	-	-	-
12.	1972	2.3	3.3	3.0	2.6	2.6	2.6	5.6	3.8	4.1	-	2.9	2.7	4.1
13	1973	4.0	3.5	3.5	2.8	3.4	3.6	4.7	4.3	4.4	3.1	5.6	3.5	4.4
14	1974	3.8	3.7	4.0	3.7	3.2	2.6	3.5	6.0	3.7	4.1	-	3.5	4.3
15	1975	4.9	4.1	4.0	3.1	3.5	2.3	4.7	4.1	2.1	-	2.6	3.7	2.7
16	1976	3.6	3.6	3.6	3.3	3.7	3.4	4.8	4.6	3.7	4.1	4.0	3.5	4.2
17	1977	3.5	3.8	3.9	2.7	2.9	1.5	5.3	4.2	2.7	2.7	1.4	3.1	3.3
18	1978	6.3	5.1	4.9	3.3	3.1	2.1	4.5	5.0	2.4	4.3	2.2	4.1	3.7
19	1979	3.3	3.5	2.9	3.9	3.5	2.8	6.7	4.6	3.0	6.0	6.7	3.3	5.4
20	1980	4.3	2.8	3.4	2.7	4.3	4.7	4.1	3.8	2.7	3.0	-	3.7	3.4
21	1981	-	3.7	4.3	3.3	3.4	4.2	3.5	3.4	2.5	1.8	3.1	3.8	2.9
22	1982	-	1.8	2.1	0.4	-	-	3.1	3.2	-	-	-	2.1	3.1
23	1983	-	6.4	3.9	4.7	-	-	-	7.0	-	7.3	-	5.0	7.1
24	1984	-	3.9	-	3.3	2.2	6.7	4.9	4.1	6.8	2.8	5.4	4.0	4.8
25	1985	-	-	4.9	3.5	4.3	-	9.2	6.0	9.2	9.7	-	4.2	8.5
26	1986	3.9	2.3	2.5	3.2	-	-	4.0	4.4	3.4	5.7	-	3.0	4.3
27	1987	3.1	3.3	3.1	3.9	-	-	1.7	2.1	-	-	-	3.3	1.9
28	1988	3.5	5.5	5.6	4.5	-	-	6.1	5.0	4.2	4.9	-	4.8	5.1
29	1989	-	5.5	3.7	4.2	-	-	3.9	7.7	4.7	3.0	-	4.5	4.9
30	1990	5.8	5.0	4.7	4.3	-	-	5.2	5.5	5.4	-	-	4.9	5.4
31	1991	3.1	2.3	2.9	2.6	-	-	2.2	3.1	-	-	-	2.7	2.7
Linear trend per decade		+0.03	+0.16	+0.34 ##	+0.21	+0.60 ##	+0.92	+0.18	+0.32	+0.74 ##	+1.00	+0.92	+0.31 ##	+0.49 ##
C C		+0.02	+0.13	+0.35	+0.23	+0.59	+0.46	+0.11	+0.24	+0.42	+0.43	+0.35	+0.35	+0.32

Significant at 90 % level.

The time-series of SST and evaporation rate for different regions of Arabian Sea and Bay of Bengal have been presented in Tables 1 and 2. The moving pentad averages of SST and evaporation rate and their anomalies have been computed from the time-series of respective parameters.

3. Results and discussion

3.1. *SST variability over the Arabian Sea*

Time-series of SST over different regions of Arabian Sea alongwith trends per decade have been presented in Table 1. It may be pointed out that linear trends of SST over different areas of Arabian Sea range from 0.1°- 0.4°C per decade. Noteworthy feature is that the trends are positive over each segment of Arabian Sea. Some of the trends are not statistically significant but marine parameters like SST and evaporation rate exhibit very small trends. A trend of only + 0.1°C/decade in SST is practically significant and very important although it may or may not be statistically significant.

During 1960's, barring 1965 and 1966, the mean SSTs over SW Arabian Sea were below 30°C mark whereas during 1970's over the same area the SSTs never reached 30°C. The contrast during 1980's is significant showing mean SSTs more than 30°C during all the years except 1981 and 1988. More quantitatively the mean SST in May over the SW Arabian Sea during 1960's was 29.7°C, during 1970's it was 29.5°C and during 1980's it was 30.1°C. The

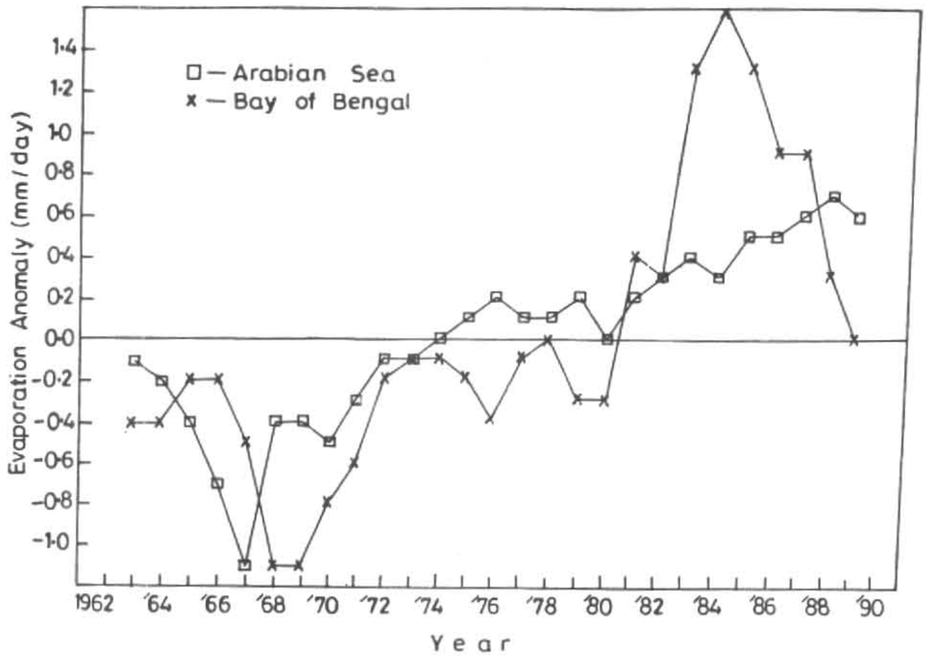

Fig.3. Anomalies of moving pentad averages of evaporation over Arabian Sea and Bay of Bengal during May

mean SST during 1990-91 was 30.3°C. This shows an increasing tendency of SST over the SW Arabian Sea from 1970's to early 1990's. As revealed by the trend analysis the trend during entire period is about 0.7°C.

Superimposed on an overall increasing trend is the interannual variability. During 1965 and 1966 the mean SSTs over the SW Arabian Sea were quite high, *i.e.*, 30.4°C and 30.1°C. It is interesting to note that summer monsoons during these years were deficient yielding only 82% and 87% of the all India normal monsoon rainfall. Similarly, during 1970's the years 1972 and 1979 registered highest SST, *i.e.*, 29.9°C. SW monsoon performance during both these years was extremely poor (77% and 81% respectively of the normal rainfall). During 1980's the highest SST was recorded in 1987 which was again a highly deficient monsoon year; 81% of the normal rainfall. The foregoing discussions clearly bring out a significant interannual variability of SST over the SW Arabian Sea exhibiting good negative correlation with the monsoon rainfall (Singh and Pai, 1996). However, a one-to-one correspondence between mean SST over the SW Arabian Sea and subsequent monsoon rainfall should not be expected. The year 1990 appears to be an exception with SST of 31.5°C but normal monsoon rainfall (107 % of normal).

The SSTs over SE Arabian Sea also exhibit more or less similar pattern with 1970's registering lowest SST followed by 1960's whereas 1980's and early 1990's registered highest SST. The quantitative details are being omitted which could be easily worked out from Table 1. The linear trend during the period 1961-91 is +0.4°C which is less than that observed over SW Arabian Sea.

As we move on to WC Arabian Sea the increasing trend of SST becomes more pronounced with trend value of +0.38°C per decade (Table 1). The pronounced increasing trend is evident from the mean SSTs during 1960's, 1970's, 1980's and early 1990's which are 29.4°C, 29.3°C, 30.3°C and 30.3°C respectively. Table 1 shows that the trend since 1961 over WC Arabian Sea is 1.1°C which was only 0.7°C over the SW Arabian Sea. It may be pointed that the entire magnitude of these changes may not be real which will be discussed later.

The interannual variability of summer SST diminishes over the WC Arabian Sea which is clear from the fact that highest SSTs were not necessarily observed during below normal monsoon years. Thus the correlation between SST over the WC Arabian Sea and the monsoon rainfall over India is practically non-existent. As this aspect has already been discussed by Singh and Pai (1996) the details are omitted.

Over the EC Arabian Sea also increasing trend in SST is observed. However trend is only the 0.11°C/decade which is significantly less than that over the WC Arabian Sea.

The availability of SST data over the north Arabian Sea is not satisfactory. This is a common problem as the north Arabian Sea does not lie in main shipping lanes. Thus no definite conclusions are being drawn here for the north

TABLE 3

Comparison of decadal means with mean of entire period (1961-91) using Cramer's test

S.No.	Decade	Parameter							
		SST				Evaporation			
		Arabian Sea		Bay of Bengal		Arabian Sea		Bay of Bengal	
		1	2	1	2	1	2	1	2
1	1961-70	NS	-0.1	NS	0.2	S*	-0.4	S*	-0.8
2	1971-80	S*	-0.3	S*	-0.3	NS	-0.1	NS	-0.2
3	1981-90	S*	0.6	NS	0.1	S*	0.4	S*	0.7

* Significant at 95% level, NS - Not significant,

1- Level of Significance, 2- Difference between decadal and long term mean.

TABLE 4

Results of power spectrum analysis

S No.	Parameter	Significant periods in years
1	SST over Arabian Sea	20**, 2.5*, 2.2**
2	SST over Bay of Bengal	15*, 3.0**, 1.93**
3	Evaporation over Arabian Sea	15*, 2.2**
4	Evaporation over Bay of Bengal	5*, 2.86**

* Significant at 95% level, **Significant at 90% level.

Arabian Sea. However, the available data shows an increasing SST trend of 0.24°C/decade over the NW Arabian Sea and 0.34°C/decade over the NE Arabian Sea. Before we take up the trend in grand mean SST over the Arabian Sea some salient features of SST trends over different areas of Arabian Sea may be pointed out. Firstly, the most pronounced trend has been observed over the WC Arabian Sea and lowest trend over the EC Arabian Sea. Secondly, in general the western Arabian Sea has witnessed more warming as compared to the eastern Arabian Sea.

The time-series of grand mean SST over the Arabian Sea during May is also given in Table 1. Moving pentad averages of SST have been computed for the period 1963-89. The anomalies of such averages have been presented in Fig.3. Table 1 shows that the linear trend of grand mean SST over the Arabian Sea is 0.9°C during the three decade period under consideration which is significant at 99% level. Subtracting the bucket-injection bias of about 0.2°-0.3°C from this trend the real trend would be of the order of 0.6°- 0.7°C which is also significant. This would mean that May SSTs over the Arabian Sea have been registering an increasing trend of about 0.2°C per decade, thus making the Arabian Sea warmer by about half a degree celcius by mid of twenty first century from now.

Comparison of decadal means with the mean of entire period (1961- 91) have been made and the results are presented in Table 3. The means for 1971-80 and 1971-90 are significantly different (at 95% level) from the mean of entire period.

The results of power spectrum analysis performed on the grand mean SSTs and evaporation rates over the Arabian Sea and Bay of Bengal have been presented in Table 4. A 2.5 year cycle (significant at 95% level) and a 20 year cycle (significant at 90% level) have been observed in the SST variations over the Arabian Sea. This shows the existence of a prominent ENSO cycle in SST.

3.2. *SST variability over the Bay of Bengal*

Table 1 shows that mean SST over the SW Bay of Bengal during 1960's was 29.9°C. During 1970's and 1980's the values were 29.3°C and 29.9°C respectively, whereas the mean during 1990 and 1991 was 29.5°C. Table 1 shows that there is no trend of SST over SW Bay unlike that over the SW Arabian Sea. Another significant difference between the SST variabilities over SW Arabian Sea and SW Bay of Bengal is that the interannual variability over SW Bay does not show good monsoon rainfall.

Over SE Bay of Bengal mean SSTs during 1960's, 1970's, 1980's and early 1990's were 29.9°C, 29.3°C, 29.6°C and 30.1°C respectively. There is a little increasing trend of 0.1°C per decade which is not significant.

Marine data coverage over central and northern Bay of Bengal is extremely poor due to their locations being far away from the main shipping lanes and therefore no definite conclusions could be drawn about the SST variability.

Moving pentad averages of grand mean SST over the Bay of Bengal have been depicted in Fig.2. Table 1 shows that there exists no significant trend in SST in May over the Bay of Bengal during last three decades. However, 2-3 and 15 year cycles are present (Table 4).

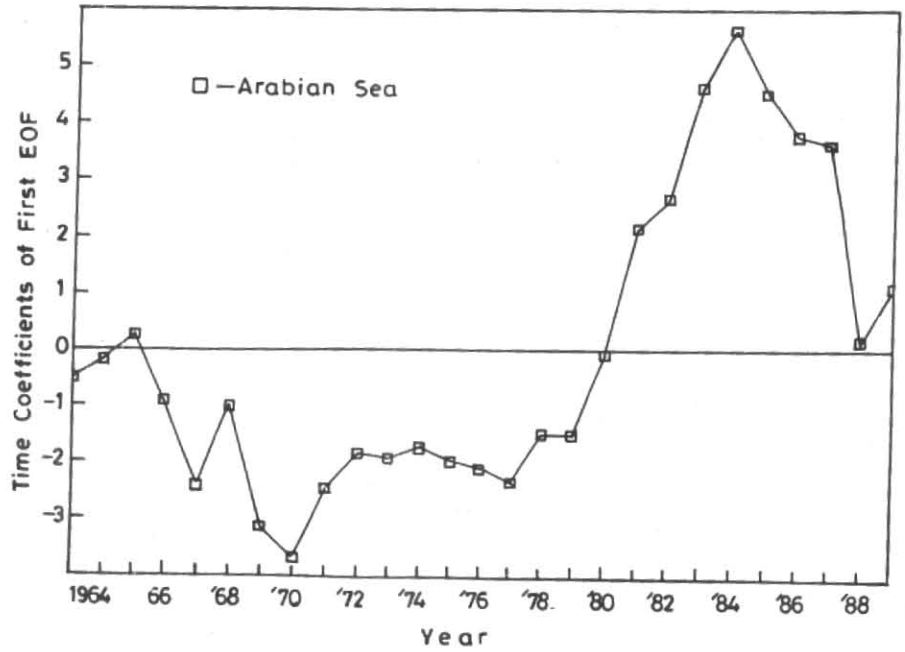

Fig.4. Time coefficients of first EOF

TABLE 5

Results of EOF Analysis

(A) Input correlation matrix

Parameter	1	2	3	4
1	1	-	-	-
2	0.74	1	-	-
3	0.37	0.60	1	-
4	0.64	0.55	0.68	1

1- SST anomaly over Arabian Sea, 2 - SST anomaly over Bay of Bengal,
3- Evaporation anomaly over Arabian Sea, 4- Evaporation anomaly over Bay of Bengal.

(B) Cumulative proportion of total variance explained by different EOFs

S.No.	EOF	Total Variance Explained
1	First	64.0 %
2	Second	89.9 %
3	Third	96.7 %
4	Fourth	100.0 %

3.3. *Variability of evaporation rate over the Arabian Sea and the Bay of Bengal*

SST is an important physical parameter governing the evaporation rate from the ocean. But there are other important factors like wind speed, dew point temperature and drag coefficient that determine the rate of evaporation. Thus probably the identical variations of SST and evaporation over the oceans can not be always expected. The relationship between the SST and evaporation is further complicated by the fact that keeping all other factors constant, higher SST would lead to higher rate of evaporation. But the converse is not true. Higher evaporation rate lowers the SST.

The evaporation variabilities over the Arabian Sea and the Bay of Bengal have been presented in Fig.3 and the time-series alongwith linear trends are given in Table 2.

Fig.3 clearly brings out the monotonic increasing trend of evaporation rate in May over the Arabian Sea since 1961. Table 2 shows that the linear trend is 0.9 mm/day per decade during last three decades which is significant at 90% level. Keeping in view the instrumental bias in SST leading to an increase in evaporation the real trend may be about 0.6 mm/day per decade which is statistically as well as practically significant. Thus there is an increasing trend in summer evaporation over the Arabian Sea which is about 0.2 mm/day per decade. Needless to mention, this magnitude of real trend in evaporation is sufficient to cause far reaching changes in the weather and climate of India and neighbouring regions.

Interannual variability and the variabilities of other scales in the evaporation rate are less dominant as compared to the linear increasing trend. However, certain observations could possibly be made. The dip in evaporation rate over the Arabian Sea during mid 1960's coincides with the period of generally bad monsoon years, *i.e.*, 1965-68 followed by generally good monsoon years 1961-64.

Similar dips in the evaporation curve are observed during 1979 and 1982-83 as well. Thus a positive correlation between the summer evaporation over the Arabian Sea and Indian monsoon rainfall exists. The correlation coefficient is +0.64 which is significant (Singh and Pai, 1996).

Variability of evaporation rate over the Bay of Bengal is significantly different from that over the Arabian Sea. In addition to the increasing trend the variations on the scale of 3-5 years are present (Table 4).The linear trend is more than that over the Arabian Sea, *i.e.*, 1.5 mm/day per decade (Table 2). Thus the real positive trend of evaporation rate over the Bay of Bengal will be about 0.8-1.0 mm/day per decade.

The most interesting aspect of evaporation variability over the Bay of Bengal is the ENSO scale (3-5 years) variability. The cause-and-effect relationships in the ocean atmosphere system are so complex that it seems difficult to comment on the reasons for the observed multiple time-scale structure of the evaporation rate variations over the Bay of Bengal.

3.4. *Time coefficients of first Empirical Orthogonal Function (EOF)*

The four variables, *viz*, SST and evaporation anomalies over the Arabian Sea and Bay of Bengal were subjected to the Empirical Orthogonal Function Analysis (EOFA) due to their inter dependence (Table 5A). The first EOF explained 64% of the total variance (Table 5B). The time coefficients of first EOF are presented in Fig.3. The increasing trend in these time coefficients clearly reveals that the SST and evaporation rate over the Indian seas have increased since early 1960's.

5. Conclusions

The study has brought out the following results.

(*i*) The sea surface temperature has shown an increasing trend in May over the Arabian Sea during last three decades. The trend is real and significant which is 0.6-0.7°C during the entire period. The SST trend over the Bay of Bengal is not significant. The real evaporation rate trend is +0.6 mm/day over the Arabian Sea and +0.9 mm/day over the Bay of Bengal; both trends being significant.

(*ii*) The SST variations exhibit 2-3 year (ENSO scale) and 15-20 year cycles over the Indian seas.

(*iii*) The evaporation rate over the Indian seas shows an ENSO scale (2-5 years) variability and a 15 year cycle.

(*iv*) The time coefficients of first EOF of all four variables (*i.e.*, SST and evaporation over the Arabian Sea and the Bay of Bengal) show an increasing trend.

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