

Variability of surface meteorological parameters over the Arabian Sea

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The trends and periodicities of surface meteorological parameters (sea surface temperature, air temperature, cloudiness, wind speed and sea level pressure) over the western, central, eastern and southern Arabian sea regions are studied for the period 1948 to 1972. From the trend analysis, it is observed that in general, most of the surface meteorological parameters show a very gradual increase except sea surface winds, which show marked increase. The spectra and coherence of these parameters are presented for the annual and semiannual periods. Analysis shows that in addition to the dominant annual, semiannual and seasonal (four month) periodicities some parameters exhibit some energy at 2, 3 and 4 year cycles. An analysis of the relationship between different parameters shows that the sea surface temperature and air temperature are positively and significantly correlated over the study area. A similar relationship is found between wind speed and cloudiness amount. Wind speed and cloudiness are negatively and significantly correlated with the mean sea level pressure over all the study areas.

Among the major oceans of the world, the Indian Ocean as a whole and the Arabian sea in particular differ significantly from other regions because of monsoonal circulation which is an unique feature.

Several studies¹⁻⁶ have shown that the quasi-biennial oscillation and the southern oscillation are the only recognised cycles which exhibit a periodicity of more than one year. Parthasarathy and Mooley⁷ on examining the summer monsoon rainfall series over India have found a significant periodicity around 2.7 y. Subsequent studies by Joseph and Pillai⁸ have observed a significant 3 y cycle in the sea surface temperature (SST) over the north Indian Ocean during 1961 to 1973. They have also mentioned that a 3 y oscillation in SST covers a large area of north Indian Ocean, where power spectrum analysis of SST monthly anomalies show significant peaks at confidence level 95% for this oscillation.

In the present study, an attempt has been made to examine the existence of similar periodicities in the surface meteorological parameters like SST, air temperature (AT), wind speed (WS), cloudiness (CLD) and mean sea level pressure (SLP) over the Arabian Sea, using the data for the period 1948-1972. The spectra and coherence of these parameters are also discussed along with the annual cycles.

Materials and Methods

The data needed for the present study were

extracted from the unpublished Bunker data set (obtained from D. Halpern, Jet Propulsion Laboratory, Pasadena, USA) for the Indian Ocean which was compiled from the ship weather observations for the period 1948 to 1972. Quality of the observations was thoroughly checked following Joseph⁴; (i) SST values in the ranges 15°C to 35°C were accepted and no check was made of the method of SST observation whether engine intake or bucket method; (ii) air temperature values in the range 15°C to 39°C were accepted; (iii) surface pressure values in the range 981 to 1030 mb were accepted; and (iv) wind speeds from 0 to 50 m.sec⁻¹ were accepted.

The parameters extracted for the present study include the SST, AT, WS, CLD and SLP at monthly intervals, for the period 1948 to 1972 for the Marsden squares 67, 66, 65 and 29 which represented the western, central, eastern and southern Arabian Sea respectively (Fig.1). The time series of different parameters were subjected to spectral and cross spectral analyses, low pass and band pass filters, and linear regression analysis. For auto-spectra and cross-spectra, the first 288 points of the time series comprising of 300 monthly observations were taken and divided into 3 ensembles to yield six degrees of freedom for the analysis.

Low pass and Band pass filters were applied in the frequency domain following Walters and Heston⁹. For this purpose the entire series of 300 points were

subjected to direct FFT (fast fourier transform). Fourier transforms corresponding to different frequencies, from zero to Nyquist frequency (= 1/2 cycles per month), were multiplied by the desired low pass/band pass filter response function. Inverse FFT was then performed to obtain filtered time series.

For band pass filter, filter response function was specified as unity between the 50-25 months; and zero for periods > 50 months and < 25 months. For low pass filter, the filter response function was specified as unity for periods > 25 months, zero for periods < 20 months, and linearly decreasing (in frequency domain) from unity to zero for periods from 25 to 20 months. Low pass filtering was done by another method also - running mean over 12 months. Linear trends were obtained by standard linear regression analysis.

Results and Discussion

Most of the parameters in the southern Arabian Sea (MSQ 29) exhibit annual, semiannual and seasonal (four month) periodicities (figure not presented). In addition to the above periodicities most of the parameters in the eastern Arabian Sea (MSQ 65) possess some energy in the 2 to 2.5 y band. In the case of the central Arabian Sea (MSQ 65), some energy was observed in the 2 to 4 y band for all the parameters. In the western Arabian Sea (MSQ 67) only cloudiness and sea level pressure exhibited periodicity in the 2.5 y cycle.

The spectral energy of the surface meteorological parameters at the annual and semiannual periods for the different areas are presented in Table 1 which shows that in most of the cases, the energy is a maximum in the annual cycle, except on a few occasions when the semiannual energy is more.

Figure 2 depicts the spectral energy of SST, AT, WS, SLP and CLD for the different areas. The figure shows that there is significant energy in the 2-4 y band for all the parameters in the case of central Arabian

Sea (MSQ 66). In the case of western Arabian Sea (MSQ 67) only CLD and SLP exhibited energy in the 2.5 y cycle. In the case of eastern Arabian Sea (MSQ 65) most of the parameters exhibited some energy in the 2-2.5 y band.

Since most of the energy is present in the annual cycle, we have computed the annual cycle of different parameters along with their standard deviations for different regions. The analysis shows that (figures not presented) that the annual range of SST is maximum (of the order of 4°C) in the western Arabian Sea and minimum in the eastern and southern Arabian Sea regions (about 2°C). The annual range of AT also shows similar variations with maximum values in the western Arabian Sea (4.7°C) as compared to the eastern or southern Arabian Sea (2°C). The annual range of SLP is maximum in the western Arabian Sea (12.4 mb) and minimum in the southern Arabian Sea (2.4 mb). The standard deviations of SST and AT are < 0.5°C for all the study areas in all months.

Table 2 gives the coherence and phase difference between different parameters for the study areas. In

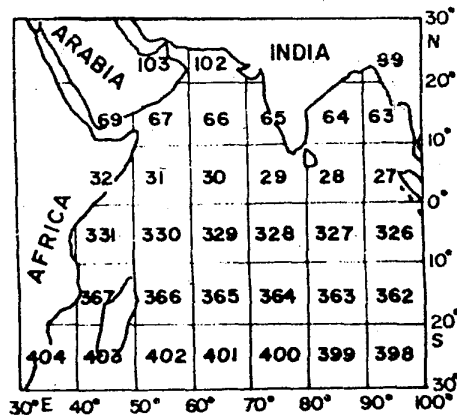


Fig. 1—Study areas

Table 1—Spectral energy* of surface meteorological parameters at annual (12 months), and semiannual (6 months) periods
Areas/Period (months)

Parameter	MSQ-29		MSQ-65		MSQ-66		MSQ-67	
	12	6	12	6	12	6	12	6
SST	20.5	14.1	13.3	23.4	29.2	39.2	28.6	86.0
AT	15.1	8.7	9.0	19.8	52.8	36.5	52.5	62.8
WS	34.6	21.9	111.9	45.0	231.9	196.8	251.2	198.7
CL	37.5	6.2	194.6	8.9	96.7	31.0	10.8	9.4
SLF	44.2	8.1	239.0	7.9	590.2	23.5	1144.9	27.9

* All the above surface meteorological parameters exhibited peaks in energy at 12 and 6 month periods

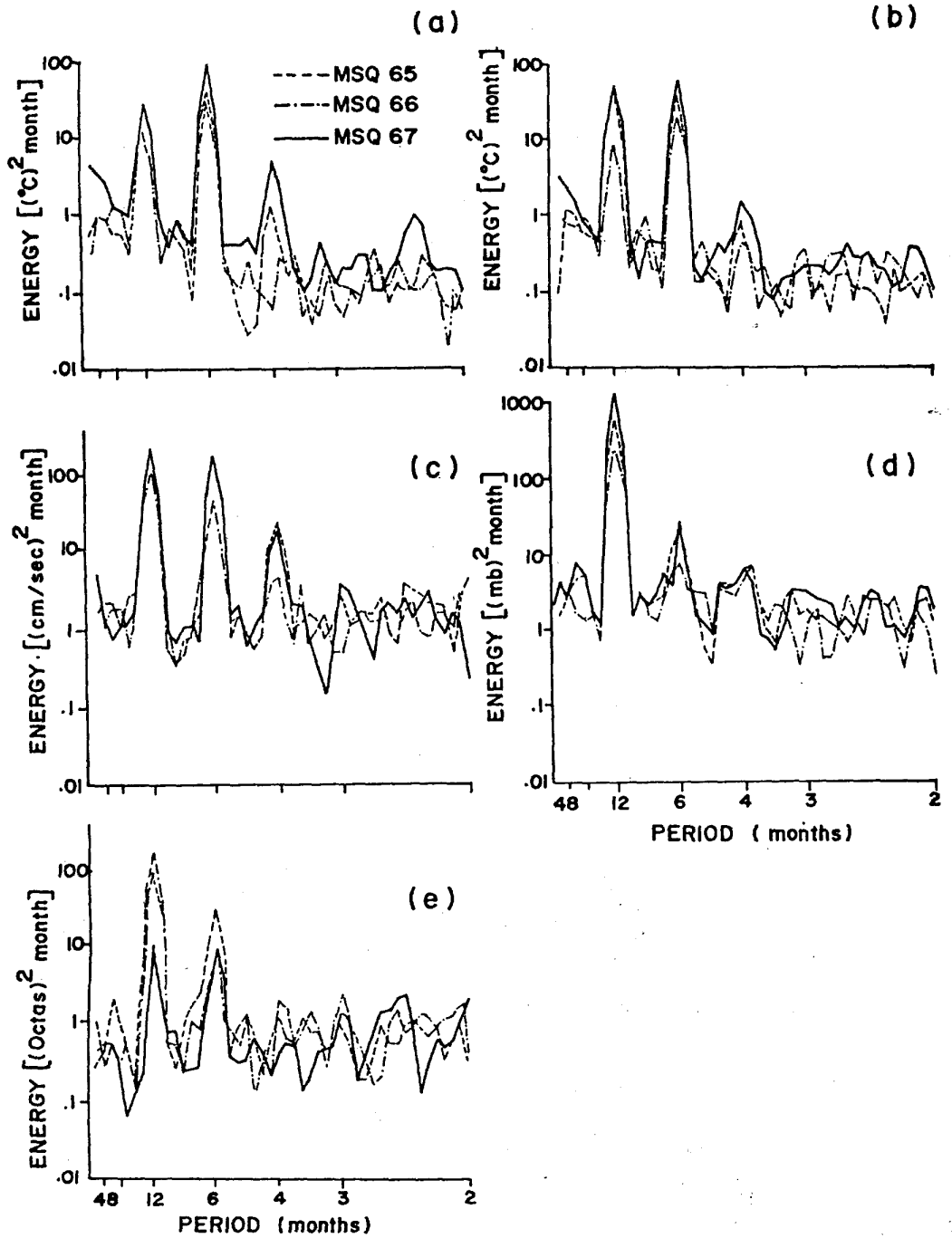


Fig. 2—Spectral energy of (a) sea surface temperature, (b) air temperature, (c) wind speed, (d) sea level pressure, (e) cloudiness

general, most of the meteorological parameters are significantly coherent (at 0.05 significant level) over all the study areas. Coherence is not significant between SST, AT and CLD with the SLP at 6 month period in the case of eastern Arabian Sea; whereas in the case of the western Arabian Sea there is no significant coherence between AT/CLD and WS/CLD at the 12 month period.

Table 3 gives the coherence of the same parameter with different Marsden squares at 12 months and 6 months periodicities. The study shows that there is a

statistically significant coherence in most of the parameters between different areas.

Values of low pass filtered time series of SST, SLP and CLD for some selected regions are presented in Fig. 3, which shows the existence of 2.5 to 3 y cycle in the SST time series of the western, central and eastern Arabian Sea (Fig. 3a). A similar cycle was observed by Parthasarathy and Mooley⁷ for the summer monsoon rainfall series over the Indian subcontinent with a periodicity around 2.7 y. Similar periodicities were also found in the SLP time series of the southern

Table 2—Coherence and phase¹ of surface meteorological parameters for different study areas

Parameters	Period ²	MSQ-29		MSQ-65		MSQ-66		MSQ-67	
		Coh	Phase	Coh	Phase	Coh	Phase	Coh	Phase
SST/AT	12m	0.97	-18.0	0.97	-11.0	0.99	-12.7	0.99	-30.1
	6 m	0.98	12.4	0.98	8.8	0.99	2.6	1.00	1.4
SST/WS	12 m	0.95	-114.9	0.98	-73.8	0.98	-38.6	0.99	-78.1
	6 m	0.98	-132.0	0.99	-135.3	1.00	-127.8	0.99	-136.8
SST/CL	12 m	0.95	-121.8	0.98	-84.2	0.95	-53.0	0.80	-94.8
	6 m	0.93	-65.6	0.81	-112.7	0.97	-130.8	0.94	-129.3
SST/SLP	12 m	0.96	94.4	0.98	113.9	0.98	154.7	1.00	115.6
	6 m	0.93	127.6	0.76*	106.9	0.92	78.9	0.95	32.2
AT/WS	12 m	0.98	-95.7	0.97	-62.4	0.99	-26.2	0.99	-48.3
	6 m	0.98	-145.1	0.97	-145.0	0.98	-130.2	0.99	-138.2
AT/CL	12 m	0.96	-103.1	0.97	-72.1	0.95	-41.0	0.75*	-63.7
	6 m	0.94	-80.1	0.86	-123.5	0.98	-134.0	0.95	-131.1
AT/SLP	12 m	0.96	114.0	0.96	125.7	0.98	167.3	1.00	145.8
	6 m	0.92	113.7	0.68*	94.5	0.95	75.5	0.95	30.9
WS/CL	12 m	0.96	-6.2	0.98	-11.3	0.98	-15.1	0.72*	-17.2
	6 m	0.95	65.6	0.86	24.1	0.95	-2.9	0.95	6.4
WS/SLP	12 m	0.99	-149.6	0.99	-172.9	1.00	-167.0	0.99	-165.9
	6 m	0.95	-100.0	0.82	-120.2	0.91	-153.2	0.97	169.0
CL/SLP	12 m	0.97	-143.3	0.99	-161.6	0.98	-152.3	0.77	-151.2
	6 m	0.92	-167.9	0.73*	-153.7	0.99	-150.5	0.93	161.7

¹ Positive phase indicates that the latter parameter leads

² Period in months

* Indicates that the coherence is less than 0.78 which is not significant at 95% for 6 degrees of freedom

Table 3—Coherence and Phase* (in brackets) between different Marsden squares at 12 months and 6 months periodicities

Parameter	MSQ 67-66		MSQ 67-65		MSQ 67-29	
	12	6	12	6	12	6
SST	0.98	0.99	0.98	0.98	0.97	1.00
	(-36)	(-08)	(06)	(-02)	(39)	(18)
WS	0.99	0.99	0.98	0.99	0.99	0.98
	(03)	(01)	(11)	(00)	(-04)	(22)
SLP	0.99	0.83	0.99	0.68	1.00	0.88
	(02)	(40)	(04)	(71)	(18)	(114)
CL	0.85	0.89	0.73	0.85	0.71	0.96
	(02)	(-09)	(17)	(19)	(13)	(80)
AT	0.99	1.00	0.96	0.96	0.96	0.99
	(-19)	(-07)	(25)	(07)	(50)	(29)

* Positive phase indicates that the parameter at the latter MSQ leads

Table 4—Trend analysis of various surface meteorological parameters (where A = mean and B = slope = units per year)

Parameter	MSQ-67		MSQ-66		MSQ-65		MSQ-29	
	A	B	A	B	A	B	A	B
AT	26.6	.002	27.2	.001	27.8	.009	27.9	-.001
SST	26.3	.022	27.6	.016	28.3	.027	28.2	.015
CL	2.5	.002	3.3	-.005	3.8	.004	4.4	.016
WS	5.7	.053	6.4	.012	5.1	.026	5.3	0.30
SLP	1010	.017	1010	-.004	1010	.015	1010	.002

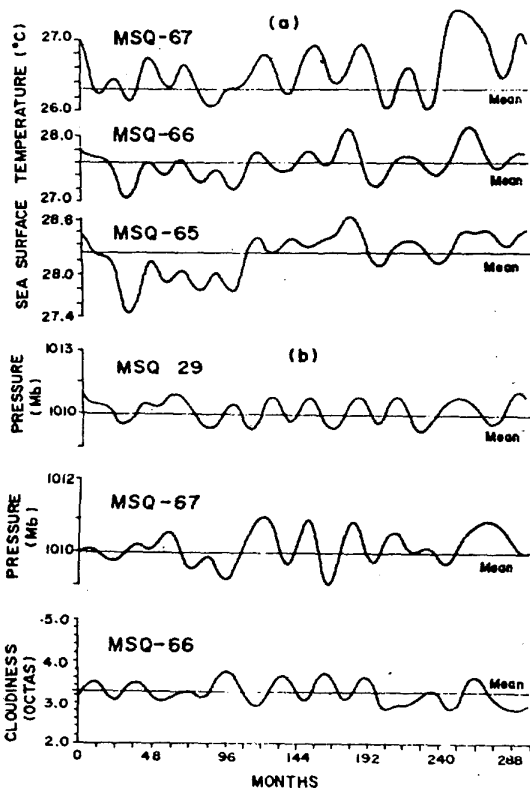


Fig. 3—Low pass filtered time series of (a) sea surface temperature at MSQ-67, MSQ-66 and MSQ-65, (b) sea level pressure at MSQ-29, MSQ-67 and cloudiness at MSQ-66

and western Arabian Sea (Fig.3b). The CLD of the central Arabian Sea also depicts similar periodicity (Fig.3b). Thus it appears that the surface meteorological parameters over the Arabian sea play a major role in the monsoonal circulation and rainfall over the Indian subcontinent.

The trends of different surface meteorological parameters (Table 4) show a very gradual increase with exceptions like CLD and SLP in the case of central Arabian Sea and AT in the case of southern

Table 5—Correlation coefficients between different surface meteorological parameters

Parameters	MSQ-67	MSQ-66	MSQ-65	MSQ-29
SST & AT	0.89*	0.93*	0.85	0.86*
SST & CL	-0.24	0.10	0.02	-0.19
SST & WS	-0.31*	0.04	-0.09	-0.41*
SST & SLP	-0.05	-0.48*	-0.22	-0.13
WS & SLP	-0.73*	-0.75*	-0.81*	-0.51*
WS & CL	0.63*	0.86*	0.78*	0.57*
SLP & CL	-0.73*	-0.75*	-0.67*	-0.35*

* Significant at 0.001 level

Arabian Sea which show a decreasing trend. Further it is seen that the WS exhibits a marked increase compared to other parameters.

Table 5 gives the correlation between various surface meteorological parameters in the Arabian Sea. SST and AT are positively and significantly correlated in all regions. The wind speed and cloudiness amount are also positively correlated in all the regions. WS and CLD are found to be negatively and significantly correlated with the SLP values. It was also found that there was no significant relationship between CLD and WS with the SST over the study areas. The SST and SLP are negatively and significantly correlated only in the central Arabian Sea. Recent study of Ramesh Kumar and Sastry¹⁰ has shown that the premonsoon SST's of the three oceanic regions namely the western Arabian Sea, eastern Arabian Sea and the Somalia coast (MSQ 31) are positively and significantly correlated with the monsoon rainfall (at 95% level). Their study further shows that the southern oscillation index (SOI) is negatively and significantly correlated (at 90% level) with the premonsoon ST over the eastern Arabian Sea. The winter SST over the western Arabian Sea is negatively and significantly correlated with the SOI (at 95% level).

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