

## The variation of surface heat fluxes during Arabian Sea monsoon experiment

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**सार** – अरब सागर मानसून प्रयोग (आरमेक्स) के चरण I और II के कुल 120 दिनों के दौरान महासागर अनुसंधान पोत सागरकन्या पर विकिरणित फ्लक्सों के प्रत्यक्ष माप लिए गए। सतह उष्मा फ्लक्सों की परिवर्तनशीलता के बारे में इस शोध पत्र में अध्ययन किया गया है और उन्हें इसमें प्रस्तुत किया गया है। मानसून के सक्रिय चरण के दौरान नेट उष्मा फ्लक्स के ऋणात्मक मान सर्वाधिक है। भारी वर्षा के कारण 3 अगस्त 2002 और 8 जून 2003 को आगामिक लघुतरंग विकिरण न्यूनतम रहा। अपतटीय द्रोणी प्रयोग (ओ. एस. टी. ई.) आरमेक्स I – 2002 की अपेक्षा उष्ण जलकुंड प्रयोग (डब्ल्यू. पी. ई.) आरमेक्स II – 2003 के दौरान समुद्र सतह तापमान  $2^{\circ}$  से अधिक रहा। इसी तरह जून के माह में हुए अपतटीय द्रोणी प्रयोग की अपेक्षा उष्णजलकुंड प्रयोग के दौरान समुद्र सतह तापमान  $2.4^{\circ}$  से अधिक रहा। अपतटीय द्रोणी प्रयोग के दौरान समुद्र सतह तापमान के पवनगति के साथ ऋणात्मक सहसंबंध ( $-0.75$ ) तथा अन्तर्निहित उष्मा फ्लक्स के साथ सकारात्मक सहसंबंध (0.52 और 0.48) का पता चलता है। जबकि उष्णजलकुंड प्रयोग के दौरान समुद्र सतह तापमान का पवन गति के साथ सकारात्मक सहसंबंध (0.74) तथा अन्तर्निहित उष्मा फ्लक्स ( $-0.42$ ) और नेट उष्मा फ्लक्स ( $-0.48$ ) के साथ ऋणात्मक सहसंबंध होता है। उष्णजलकुंड प्रयोग के दौरान उर्ध्वाधर नेट उष्मा फ्लक्स की अपेक्षा अभिवहन प्रबल होता है। अपतटीय द्रोणी प्रयोग के साथ उष्ण जलकुंड प्रयोग के समय मार्च, अप्रैल और मई के महीने में औसत नेट उष्मा फ्लक्स सकारात्मक होती है और जून, जुलाई और अगस्त में ऋणात्मक होती है।

**ABSTRACT.** Direct measurement of radiative fluxes on board ORV Sagar Kanya were made during Arabian Sea Monsoon Experiment (ARMEX) phases I & II for a total of 120 days. The variation of surface heat fluxes has been studied in this article. Negative values of net heat flux are predominant during the active phase of monsoon. The incoming short wave radiation is minimum on 3 August 2002 and on 8 June 2003 in association with heavy rainfall. The SST is  $2^{\circ}$  C higher during Warm Pool Experiment (WPE) (ARMEX-II 2003) than Offshore Trough Experiment (OSTE)-ARMEX-2002. Also, the mean SST is  $2.4^{\circ}$  C higher during WPE than OSTE in June. During OSTE, SST is showing negative correlation ( $-0.75$ ) with wind speed and positive correlation (0.52 and 0.48) with latent heat and net heat fluxes respectively. Where as during WPE, the SST is having a positive correlation (0.74) with wind speed and a negative correlation with latent heat flux ( $-0.42$ ) and net heat flux ( $-0.48$ ). During WPE, advection is strong than the vertical net heat flux. The mean net heat flux is positive during March, April and May and is negative during June, July and August during the OSTE as well as WPE.

**Key words** – ARMEX, OSTE, WPE, Short wave radiation, Long wave radiation, Sensible heat flux, Latent heat flux, Net heat flux, Monsoon and SST.

### 1. Introduction

The Arabian Sea Monsoon Experiment (ARMEX) was carried out in two phases during the period 15 June to 16 August 2002 (Phase I) and 15 March to 10 April and 15 May to 18 June 2003 (Phase II). Phase I is an Off Shore Trough Experiment (OSTE) 2002 with two cruises of Sagar Kanya SK-178 and SK-179 and phase II is a Warm Pool Experiment (WPE) 2003 with two cruises SK-190 and SK-193. The study area is the southeastern Arabian Sea during the summer monsoon season (June to August 2002) in Phase I. An important system with organized convection over the Arabian Sea is the Off

Shore Trough (OST). Further the study area is the eastern Arabian Sea during the summer monsoon season (March to June 2003) in phase II.

### 2. Experiment setup & data analysis

Observational strategy for OSTE - 2002 was along  $70^{\circ}$  E to  $72^{\circ}$  E and  $15^{\circ}$  N to  $17^{\circ}$  N and WPE - 2003 for geographic region bounded by  $5^{\circ}$  N and  $12^{\circ}$  N and  $67^{\circ}$  E and  $75^{\circ}$  E, were documented in the Arabian Sea Monsoon Experiment Science Plan (DST, 2001). The radiation field part of the experimental arrangement onboard ORV Sagar Kanya consisted of the Albedometer and net Pyrgeometer

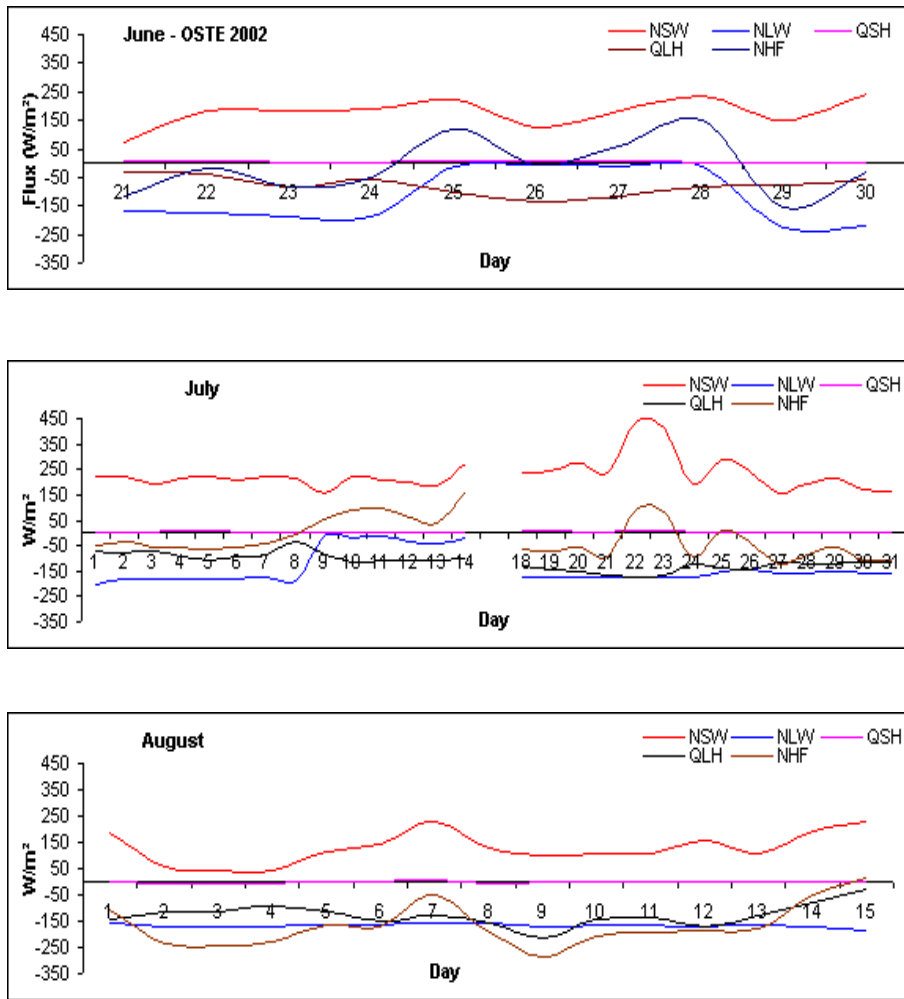


Fig. 1(a). Daily variations of surface fluxes during OSTE

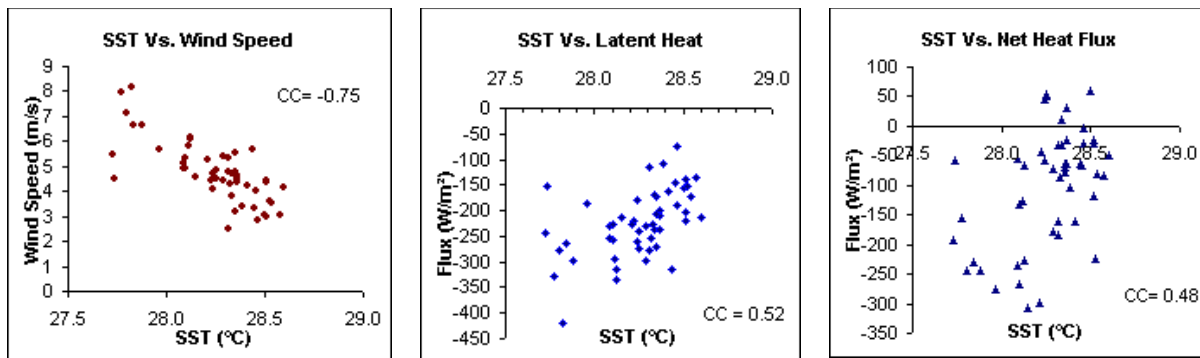


Fig. 1(b). Variation of SST with wind speed, latent heat flux and net heat flux during OSTE

fixed on a boom extending 5m horizontally in front of the bow at the forecastle deck is about 10.5 m above sea level. The two sensors of the Albedometer and Pyrgeometer

share a common body and mounted on a steel rod and instrument details are given in Table 1. The boom is deployed during the time series observations.

TABLE 1

## Radiation Instruments operated during ARMEX Programme

Parameter	Plat form	Instrument	Location	Make	Accuracy	Averaging time	Sampling interval
Short wave radiation (incoming and outgoing)	SK	Albedometer	Boom	Kipp and Zonen, Netherlands	~10W/m <sup>2</sup>	5 min	Continuous
Long wave radiation (incoming and outgoing)	SK	Net Pyrgeometer	Boom	Kipp and Zonen	± 10%	5 min	Continuous

TABLE 2

## Daily variations of surface heat fluxes and meteorological parameters during OSTE – 2002

	SK Cruise No. 178			SK Cruise No. 179		
	Range		Mean	Range		Mean
SWIN	76	315	219	89	481	296
SWOUT	5	20	14	4	27	15
NSW	72	296	206	85	458	281
LWIN	262	457	343	260	279	273
LWOUT	-457	-262	-343	-279	-260	-273
NLW	-226	-5	-117	-186	-143	-166
EA	28	32	30	27	32	28
QSH	-20	0.4	-8	-15	18	-4
QLH	-256	-63	-164	-418	-55	-256
H	-224	60	-67	-467	54	-143
WS	2	5	4	3	8	5
C	4	8	6	4	8	6

## 2.1. Computational procedure

The vertical net surface heat flux entering the ocean surface can be written as

$$Q_H = Q_{NSW} - (Q_{NLW} + Q_{LH} + Q_{SH}) \quad (1)$$

where  $Q_H$  is the net surface heat flux,  $Q_{NSW}$  is the net shortwave radiation,  $Q_{NLW}$  is the net long wave radiation,  $Q_{LH}$  is the latent heat flux,  $Q_{SH}$  is the sensible heat flux.

The radiative fluxes, net incoming radiation and net long wave radiation are obtained from the observed data during the ARMEX cruise periods. During the cruise period long wave radiation could not be recorded for few days. The net long wave radiation data gaps are filled using Anderson (1952) formula as reviewed by Fung

*et al.*, (1984). The latent heat flux and the sensible heat flux have been estimated using standard surface meteorological data and bulk parameterization formulae (Gopala Reddy and Fechner 1987). Because the advection of heat maintains long-term balance on the climatic scale, its contribution is not considered in this study.

## 3. Results and discussion

In this section, temporal and spatial variation of the surface heat flux during OSTE - 2002 and WPE - 2003 over the Arabian Sea are presented. Large fluctuations in the incoming short wave radiation are observed during convectively active periods of the monsoon (minimum values of 101 W/m<sup>2</sup> and 252 W/m<sup>2</sup> are observed on 8 June 2003 and 3 August 2002 at noon time owing to extensive low clouds) and clear sky during break monsoon periods

TABLE 3

Daily variations of surface heat fluxes and meteorological parameters during WPE – 2003

	SK Cruise No. 190			SK Cruise No. 193		
	Range	Mean		Range	Mean	
SWIN	53	159	126	9	159	105
SWOUT	3	13	7	1	14	5
NSW	50	153	119	8	145	100
LWIN	270	455	363	267	380	353
LWOUT	-455	-270	-363	-380	-267	-353
NLW	-138	-38	-81	-131	-55	-90
EA	29	33	31	31	35	33
QSH	-7	6	-1	-19	9	-3
QLH	-378	-52	-132	-251	-116	-164
H	-307	10	-95	-347	-68	-157
WS	1	9	3	2	5	3
C	0	6	2	1	8	5

(maximum values of 1081 W/m<sup>2</sup> and 1217 W/m<sup>2</sup> are observed on 13 July 2002 and 9 June 2003 respectively at noon time as convection is suppressed).

### 3.1. The daily variations of surface heat fluxes over the Arabian Sea

Daily means of net short wave flux, net long wave flux, sensible heat flux, latent heat flux and net heat flux are shown in Fig. 1(a) & Fig. 2(a) for OSTE and WPE respectively.

### 3.2. Offshore trough experiment - 2002

Daily variations of surface heat fluxes and meteorological parameters are given in Table 2. During active monsoon period (2-6 August 2002) the incoming short wave radiation reduced by about 20% due to low cloud amount of 8 oktas. Also heavy rainfall event observed during 2-6 August at OSTE-2002 coincided with a time lag of 4 to 5 days with an intense rainfall event (on 7-10 August 2002) along the west coast of India (Mohanty, U. C. *et al.*, 2002). The SST range is small from 27.7° C to 28.4° C with a mean of 28.1° C. The air temperature range is from 26.9° C to 29.5° C with a mean of 28.4° C, the mean cloud amount during this period is 6 oktas and the wind speed range is from 4.3 m/s to 8.2 m/s.

During OSTE 2002 (SK178 and SK179), the SST range is from 26.2° C to 28.7° C with a mean value of

28° C. During OSTE-2002, the mean SST is below threshold value (28° C) for convective process. Fig. 1(b) shows the correlations between SST and wind speed, latent heat and net heat flux during the time series period of OSTE. SST is having a negative correlation of -0.75 with the wind speed and a positive correlation of 0.52 and 0.48 with latent heat flux and net heat flux (heat leaving the ocean surface is taken as negative) respectively. It is likely that SST oscillations during OSTE are mainly forced by net heat flux changes due to variation of clouds and winds.

### 3.3. Warm pool experiment - 2003

Daily variations of surface heat fluxes and meteorological parameters are given in Table 3. The SST had reduced its maximum (30.7° C) well before the onset of monsoon. The air temperature range is from 28.5° C to 30.7° C with a mean of 29.9° C, the mean cloud amount during this period is 5 oktas and the wind speed range is 2.1 m/s to 4.8 m/s. During WPE the average SST is 30.1° C, which is above the threshold value for convective process (28° C). The SST is having a positive correlation (0.74) with wind speed and a negative correlation with latent heat flux (-0.42) and net heat flux (-0.48) (heat leaving the ocean surface is taken as negative) during time series period, as shown in Fig. 2(b). The SST variation during WPE is not explainable merely by surface net heat flux. This suggests that SST oscillations are forced by net heat as well as advection and episodes of mixed layer deepening processes in the eastern Arabian Sea during

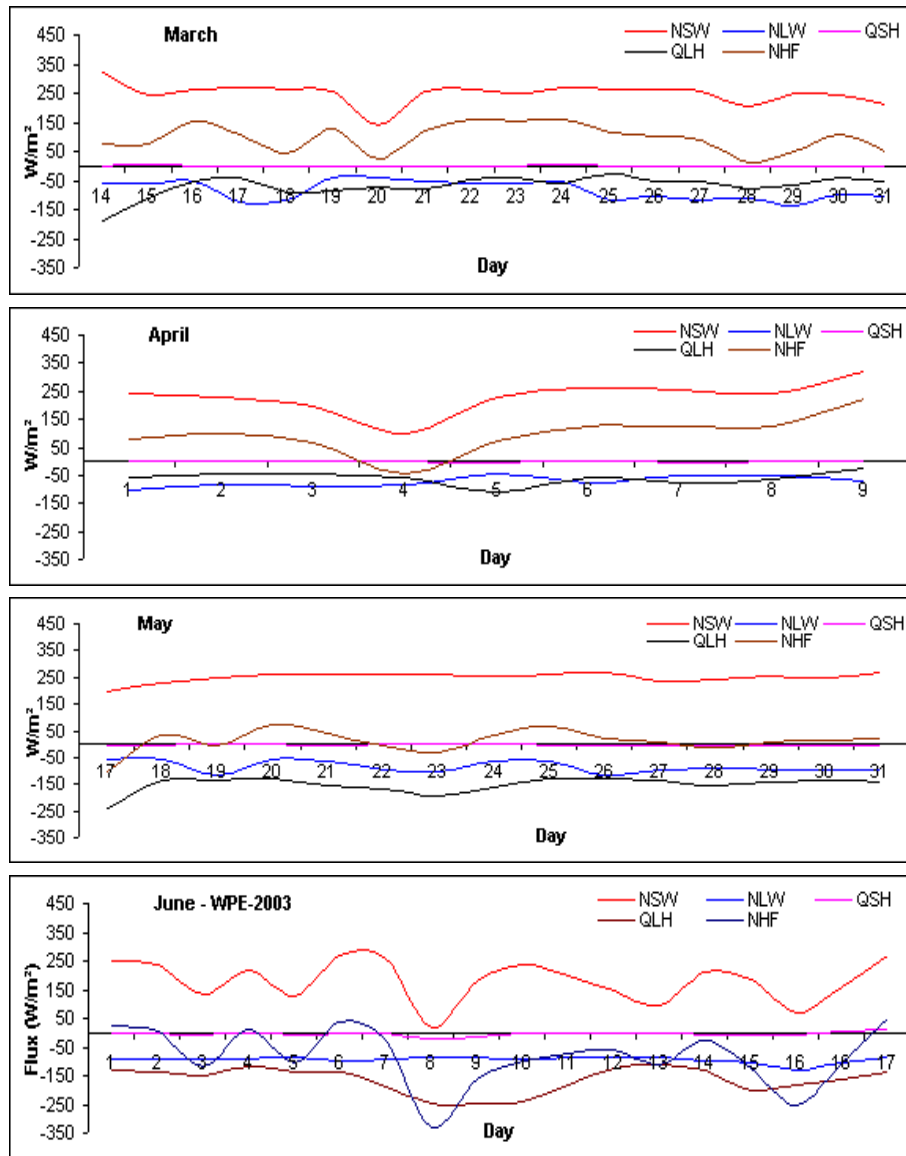


Fig. 2(a). Daily variation of surface fluxes during WPE

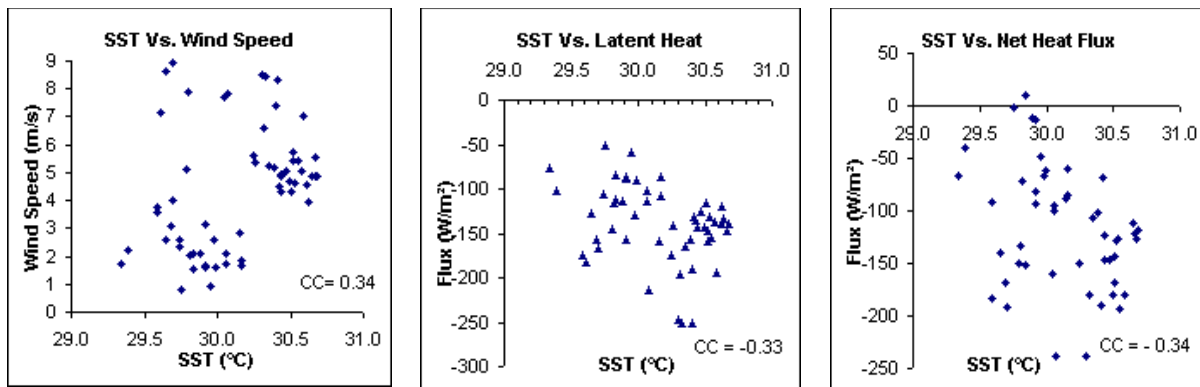


Fig. 2(b). Variation of SST with wind speed, latent heat flux and net heat flux during WPE

WPE. Estimation of advection and the mixed layer deepening is not possible due to non-availability of spatial *in situ* data and surface profiles of temperature and salinity.

#### 4. Conclusions

During OSTE-2002, SST ranges between 26.2° C and 28.7° C with a mean value of 28° C. Heavy rainfall event is observed during 2-6 August, at OSTE-2002. This coincides with the intense rainfall event (7-10 August 2002) along the west coast of India with a time lag of 4 to 5 days. During WPE 2003, SST ranges from 29.3° C to 30.7° C with a mean value of 30.1° C. The SST is 2° C more during WPE than OSTE in Arabian Sea.

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