

Report on the
"Bay of Bengal and Monsoon Experiment (BOBMEX)
NIO Component" under the Indian Climate Research Program
(ICRP)

(DST Project File No: ES/48/ICRP/001/99)

Submitted to

Department of Science & Technology, New Delhi

Principal Investigator: **L.V. Gangadhara Rao (till 30.4.2001)**
V. Ramesh Babu (from 1.5.2001)

Co-Investigators : **V.S.N. Murty**
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March, 2003

Title of the Project : **Bay of Bengal and Monsoon Experiment (BOBMEX)**
– **NIO Component** under the Indian Climate Research Program (ICRP)

Principal Investigator : L. V. Gangadhara Rao (till 30.04.2001)
V. Ramesh Babu (from 01.05.2001)

Co-Investigators : V.S. N. Murty
M. Dileep Kumar

Implementing Institution : National Institute of Institution of Oceanography,
Goa

Date of Commencement : 1 July, 1999

Planned Date of Completion : 31 March, 2002

Actual date of Completion : 31 March, 2002

Objectives as stated in the project proposal : See Annexure-1

Deviations made from original, if any, while implementing the project : ---

Experimental work giving full details of experimental set up, methods adopted, data collected supported by necessary tables, charts, diagrams and photographs : See Annexure-2

Detailed analysis of Results indicating Contributions made towards increasing the state of knowledge in the subject : See Annexure-3

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Conclusions summarizing achievements indicating scope for future work : See Annexure-4

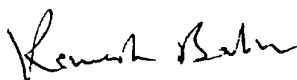
S & T benefits accrued : See Annexure-5

Financial Position : See Annexure -6

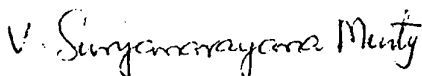
Procurement / usage of Equipment : See Annexure-7

Name and signature

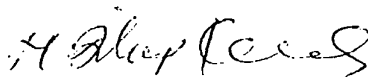
(a) V. Ramesh Babu
(Principal Investigator)



(b) V. S. N. MURTY
(Co-Investigator)



(c) M. Dilipkumar
(Co-Investigator)



Annexure - 1

OBJECTIVES OF THE BOBMEX PROJECT –Oceanography Component;

The objectives of the BOBMEX –Oceanography Component programme are to understand

- **Variability of upper ocean currents in relation to changing wind and thermohaline forcings**
- **Upper ocean thermodynamic processes on intra-seasonal scale**
- **Air-sea coupling**
- **Relationship between marine sulphur emissions and aerosols in atmospheric boundary layer**

The National Institute of Oceanography (NIO), Goa and Indian Institute of Sciences (IISc), Bangalore are the lead organisations for the oceanographic and atmospheric components of the BOBMEX Project. This report is concerned only with the ocean component of the BOBMEX project handled by NIO.

1.0 ACKNOWLEDGEMENTS

The investigators thank Dr. E. Desa, Director, NIO for his encouragement to take up the BOBMEX Project. They are indebted to the Department of Science & Technology (DST) for providing the financial support to the BOBMEX project under the Indian Climate Research Program (ICRP) and to the Department of Ocean Development (DOD), Govt. of India, for providing necessary ship-time of *ORV Sagar Kanya* to carry out necessary observations. The co-operation given by the participants from various organizations during BOBMEX cruise is greatly appreciated. Thanks are also due to the project trainees who assisted in the data processing, analysis and preparation of data CD-ROMs.

Annexure -2

Experimental work giving full details of experimental set up, methods adopted, data collected supported by necessary tables, charts, diagrams and photographs.

Under this Project, BOBMEX cruise was conducted in two phases (cruises SK 147 A & SK 147 B) onboard *ORV Sagar Kanya* for collecting the field data as required for both atmospheric and oceanic components of the programme.

BOBMEX Cruise:

First Phase (SK 147 A):

BOBMEX experimental work regarding ocean component was mainly aimed at collection of time-series oceanographic data at a stationary location in the northern Bay of Bengal in order to study the intra-seasonal variability of the upper oceanic thermo-dynamical processes apart from spatial coverage of a few sections. The first phase of the BOBMEX cruise with Dr VSN Murty (Co-PI) as Chief Scientist was conducted onboard *ORV Sagar Kanya* (Cruise No. SK147 A) in the central and northern Bay of Bengal from 16 July to 8 August, 1999 with participants from NIO, CAOS (IISc), NIOT, IMD, NCMRWF (Delhi), SAC (Ahmedabad), ISAC (Bangalore) and IIT (Delhi). The first phase of the cruise was started from Chennai and ended at Paradip. Fig.1 shows the track of this cruise. Prior to the commencement of actual time-series data collection at TS2 (17.5 °N, 89°E), various measurements were made concurrently onboard *ORV Sagar Kanya* and *INS Sagar Dhvani* at TS1 near NIOT / DS3 data buoy location (13° N, 87° E) for a period of 12 hours (18 July 1999) for inter-comparison. NIOT team members deployed Met-Ocean data buoys successfully at DS3 and DS4 locations and thereafter *ORV Sagarkanya* reached time-series location TS2 to start observational programme after disembarking NIOT team at Paradip. The oceanic measurements in upper 1000m mainly consisted of obtaining vertical profiles of temperature and salinity by CTD (Conductivity-Temperature-Depth) probe, currents by LADCP (Lowered Acoustic Doppler Profiler) & Vessel Mounted Acoustic Doppler Current Profiler (VM-ADCP). Vertical profiles of temperature in upper 760 m during the time of intensive observational periods (IOPs) were also obtained in between CTD casts. Further, seawater samples from various depths were collected for the analysis of dissolved oxygen, nutrients, Dimethyl Sulphide (DMS), and Dimethyl-

sulphoniopropionate (DMSP). DMS was studied as this parameter contributes to formation of aerosols affecting atmospheric radiative transfers and thus global climate change. Data on sea surface temperature and surface salinity were obtained continuously using Thermo-salinograph along ship's track. Surface meteorological parameters (wind speed & direction, air temperature, humidity, atmospheric pressure, global radiation) were automatically collected using ship-borne Automatic Weather Station (AWS).

Second Phase (SK 147B):

The second phase of BOBMEX cruise with V. Ramesh Babu (PI) as Chief Scientist was conducted during 11-31 August 1999. The cruise participants were from NIO, IISc, SAC, IMD, IITM, Cochin University & NCMRWF. It was started from Paradip and ended at Chennai after further carrying out time-series measurements at TS2 location (13-23 August 1999) together with coverage of three sections viz., a) Paradip to TS2 b) DS4 to DS3 c) DS3 to Chennai. Fig. 2 shows the cruise track of ORV Sagar Kanya (SK 147B). The upper oceanic and surface meteorological observations were done as in the first part of the BOBMEX cruise. The frequency of ocean observations was also increased during IOPs. Inter-comparison was again made in the vicinity of DOD / NIOT buoy DS4 for about 12 hours period on 27 August 1999 together with corresponding observations simultaneously taken on board INS Sagar Dhwani.

Detailed cruise reports of above mentioned two phases of BOBMEX cruise and an inter-comparison report on the observations were submitted to DST. BOBMEX data CD-ROMs were distributed to various participating organizations after processing and quality-checking.

Data and Methods

CTD (Conductivity-Temperature-Depth) probe (make: Sea Bird Electronics Inc., USA, Model: SBE plus 9/11) was operated at time-series location as well as at all the hydrographic stations along various sections (Fig.1) to obtain the temperature and salinity profiles. CTD rosette was used to collect water samples from different depths for salinity and chemical analysis. Onboard AUTOSAL (Guildline, USA), calibrated with standard seawater, was used to obtain the salinity. The CTD data were processed using SEASOFT (version 4.0) software and the CTD salinity values were corrected with the help of

regression equations developed after comparing the CTD salinity values with the AUTOSAL (accuracy: ± 0.001 psu) salinity values.

Bucket thermometer was used to measure the sea surface temperature (SST). Surface meteorological parameters of air temperature, relative humidity, wind speed and direction, atmospheric pressure and global solar radiation were recorded at 10 minute interval through Automatic Weather Station (AWS) onboard the ship. The wind data was obtained from two similar sets of sensors located at 22.6 m height above the sea surface on the port and starboard sides of the vessel. The true wind speed and direction referred to True North were estimated using ship's heading and speed at each time interval for both the sets of sensors. The correct wind data set was carefully chosen for the analysis. The atmospheric pressure recorded by AWS was compared with the simultaneously recorded aneroid barometric pressure data and corrected. Data processing details are provided along with the data in the BOBMEX data CD-ROM supplied to various organisations.

SST and surface meteorological data sets were used for estimating the heat fluxes across the air-sea interface. Empirical formulae were considered to compute the incoming solar radiation (Q_I), Effective back (Longwave) radiation (Q_B), latent heat flux (Q_E) and sensible heat flux (Q_H) following the methodology of Stevenson (1982). The computational scheme for obtaining the coefficients of bulk formulae for Q_B , Q_H and Q_E , and the procedure for computing each of the heat flux parameter were adopted from Sarma *et al* (1997). Directly observed Q_I values were also consulted for estimating surface net heat flux (Q_N) which was a residual flux obtained from following heat balance equation

$$Q_N = Q_I - Q_B - Q_H - Q_E \quad (1)$$

The heat content (H) in different layers of the water column was estimated from the temperature profiles at the time-series locations employing the method adopted by Murty *et al.* (1996) for MONTBLEX data by using the equation

$$H = \rho C_p \int_0^z T dz \quad (2)$$

where ρ is the water density, C_p is the specific heat at constant pressure and T is the temperature, z is the depth and dz is the depth interval chosen

Ocean currents in the upper 150 m were recorded continuously along the cruise track using the VM-ADCP. Details of VM-ADCP data processing were given in Murty et al (2000). During the processing of LADCP data, it was suspected that LADCP recorded noise that was too difficult to be removed. On reporting this to the supplier of LADCP i.e., M/s Sontek Inc, USA, they had asked us to send the system for checking. Now the system is expected back after undergoing various checks including replacement of components.

In addition to physical oceanographic data, water samples collected at different depths were analysed for chemical parameters such as dissolved oxygen, Dimethyl sulphide (DMS), Dimethyl sulpho-niopropionate (DMSP) and nutrients (nitrate, nitrite, phosphate and silicate). Measurements on DMS and DMSP in aerosols were also carried out. DMS was studied as it contributes to the formation of aerosols affecting the atmospheric radiation transfers and thereby the global climate.

BOBMEX Workshop

A workshop on "BOBMEX-Initial Results" was organised at NIO, Goa during 15-16 February, 2001 by the BOBMEX project team. Project PI and Co-PIs together with other collaborators and project trainees attended the workshop. Following papers were presented at the workshop by the project team.

- 1) BOBMEX Ocean Component – An Overview
- 2) Intra-seasonal variation of Sea Surface Salinity in the Bay of Bengal during southwest monsoons of 1998 and 1999.
- 3) Temporal variability of the upper ocean thermal structure in the northern Bay of Bengal during BOBMEX-99.
- 4) Intra-seasonal variation of sea surface height anomaly in the Bay of Bengal during April-September, 1999.

- 5) Surface heat budget and upper ocean thermal characteristics observed during BOBMEX-99.
- 6) Higher Dimethyl Sulphide Emission in the Bay of Bengal driven by atmospheric Convection.

BOBMEX data on CD-ROM

A CD- ROM containing BOBMEX (Ocean component) data was prepared and sent to the participating organizations viz. (1) CAOS/ IISc, Bangalore, (2) IITM, Pune, (3) IIT, Delhi (4) IMD, New Delhi (5) SAC, Ahemedabad (6) NCMRWF, New Delhi and also to DST, New Delhi which is the funding department. This CD-ROM contained the physical oceanographic data from CTD, Thermo-salinograph and surface meteorological data from AWS. Also, another CD-ROM containing processed VM-ADCP data collected during the BOBMEX cruise was prepared and submitted. Each CD-ROM was also provided with README files describing the processing methods, data formats and file names for easy understanding and recovery of the data.

Annexure-3

Detailed analysis of Results indicating contributions made towards increasing the state of knowledge in the subject.

Hydrographic data collected on board ORV Sagar Kanya in the central and northern Bay of Bengal during BOBMEX programme (July-August 1999) were analysed to describe intra-seasonal variability in the thermohaline structures and currents in relation to changing wind forcing and freshwater dynamics. The analysis of BOBMEX data involved in the preparation of hydrographic sections off Paradip and Chennai Coasts; along 88.5°E and time-series sections at TS2 (17.5°N, 89°E) for various ocean parameters (Temperature, Salinity, Density, %Light transmission and Chlorophyll) in the upper 1000 m. It was aimed to study the following:

- a) Sub-seasonal evolution of surface heat fluxes & heat content (0-100 m) and the upper oceanic thermo-haline structures (0-1000m) & upper layer advection using the time-series surface meteorological data, upper ocean temperature & salinity profiles and also ADCP data.
- b) Statistical relationships between Effective Oceanic Layer (EOL - defined as the geopotential thickness of the near-surface stratified layer from the sea surface to the depth of maximum stability); Outgoing Longwave Radiation (OLR) and Sea Surface Salinity (SSS).
- c) Intra-seasonal variability in the sea surface height anomaly (SSHA) and comparison with TOPEX/POSEIDON altimeter data over the Bay of Bengal for the BOBMEX period (July-August, 1999).
- d) Variability of the nutrients, chlorophyll, Dimethyl sulphide (DMS) and Dimethylsulphoniopropionate (DMSP) in the upper layers of the northern Bay of Bengal during the BOBMEX period in response to the prevailing weather conditions which were

characterised by intense and suppressed atmospheric convective regimes during parts I and II of the BOBMEX cruise respectively.

A national workshop on "BOBMEX-Initial Results" (sponsored by DST) at NIO, Goa during 15-16 February, 2001 was organized by the project team. Necessary logistics were provided to the participants from various organisations for facilitating presentations of invited talks and scientific papers (about 40) under various technical sessions of the workshop viz., (1) Atmospheric dynamics, (2) Air-sea Interaction and (3) Ocean Processes, followed by discussions. An 'Abstracts Volume' was brought out at the time of workshop. A 'Summary Document' based on the results of the papers was prepared and submitted to DST.

The intra-seasonal evolution of upper oceanic thermohaline structures during BOBMEX period (July-August 1999) was different in the northern Bay of Bengal than in the southern Bay. Though sea surface temperature (SST) responded to the spells of atmospheric convection (cloudiness) in both regions, sea surface salinity (SSS) over the season as a whole increased (decreased) in the northern (southern) Bay of Bengal. These results delineating north-south differences in the intra-seasonal variability in thermohaline structures were published in the *Bulletin of American Meteorological Society* (Bhat et al 2001).

BOBMEX results showed a spectacular event of arrival of fresh water plume in the northern Bay of Bengal at TS2 time-series location during the period 29 July- 2 August 199991 (Julian days 210-214) (Fig.4) though the depth of thermocline remained around 35 m (Fig.3). This made sea surface salinity (SSS) to fall by about 4 psu. A fall in density in the upper layers was resulted in as a result of this low salinity plume and the depth of pycnocline was shallow reaching to 20 m compared to its deeper value of 35 m (Fig.5). A barrier layer was formed restricting the penetration of mixing processes and heat to deeper layers. The arrival of this plume was attributed to offshore drift (Ekman flow) from the western part of the location. Fig.6 shows the presence of surface currents dominant with eastward zonal and northward meridional velocity components as obtained from ADCP data analysis. The evolution of the barrier layer on account of low salinity plume is

studied in detail and the results were published in *Journal of Geophysical Research* (Vinayachandran, Murty and Ramesh Babu 2002).

Another well-marked (10-m thick; 40- km wide) offshore low-salinity plume (Fig.8) was seen consistently encountering at about 120 km from Paradip coast during two phases of BOBMEX (SK 147A & 147B cruises of ORV Sagar Kanya). Further, the analysis of data collected along a coastal hydrographic section off Paradip coast repeated thrice during the BOBMEX had indicated the presence of coastal sinking as inferred from down-sloping of both isotherms and isohalines towards coast (Figs. 7 and 8). We also collaborated with scientists of NRSA, Hyderabad in mapping out the sea surface suspended sediment distributions of the Bay of Bengal which revealed spreading of fresh waters from main diluted northern-half of the east Indian coastal areas in the form of filaments towards offshore regions. Thermohaline structures along a hydrographic section along 10° N off Chennai coast indicated the presence of coastal upwelling regime (Figs. 9a and 10a). The seasonal dilution of northern Bay of Bengal due to discharge of warm and fresh waters was clearly evident from the analysis of hydrographic data collected along 88.5°E section running from the head Bay to the south up to DS3 (Figs 10a and 10b).

The influence of barrier layer due to offshore advection of low salinity waters from the coast on the atmospheric convection was demonstrated. The association between low regime of sea surface salinity (SSS) and outgoing long-wave radiation (OLR) was shown based on 'Effective Oceanic Layer (EOL) representing the thin upper ocean stratified layer. Estimated mean monthly SSS distributions during July & August 1999 showed prevalence of low values in the northern Bay of Bengal that were in general agreement with BOBMEX observations. The relatively higher heat content within EOL would help in the deep convection and affect OLR. The precipitation associated within the deep convection (lower OLR) alters the difference in evaporation and precipitation (E-P) - a very important mechanism for determining SSS. Refinement in SSS estimation was further suggested by considering advection and mixing processes. These results of study on statistical relationships between OLR and SASS were published in *Geophysical Research Letters* (Murty et al, 2002)

The seasonal evolution of differences in temperature (TS10) and specific humidity (QS10) between sea surface and 10-m height along with surface wind stress are shown in Fig. 11. The surface wind stress was in generally high during first phase and low in the second phase reflecting the effect of weather disturbances during the former period. The low regimes in both wind force and QS10 during second phase caused a fall in evaporative heat flux (Q_E) as well as in the total heat loss from the sea surface (combination of evaporative heat flux, sensible heat flux and effective back radiation) as seen in Fig.12. On an average, the net heat flux (Q_N) across the sea surface was directed to the atmosphere from the sea surface during first phase whereas it was reversed in second phase (Fig.13). The positive value of second phase average Q_N could be attributed to the incidence of larger incoming radiation in association with lesser cloudy conditions. Heat content in the different layers of upper water column incremented by 10m depth (Fig .14) indicated that the top 30 m water column had lost gradually on sub-seasonal time-scale though Q_N was changed from negative to positive with time. However, in the water column between 30 and 100 m depths, a generally increase in the heat content was witnessed showing the effect of general deepening of thermocline during the season. These changes were very clear in the time-evolution of heat contents in each 10 m-thick slab of the water column (Fig.15) suggesting the influence of advection in the heat budget of the near surface layers of the northern Bay of Bengal where atmospheric convection was relatively large compared to that over its southern Bay during summer monsoon season.

Observations made for DMS (Dimethylsulphide) and DMSP (Dimethyl sulfoniopropionate) in aerosols revealed higher concentrations during Phase I cruise (SK147A) compared to Phase II (SK147B) due to scavenging effects during the heavy rainfall of phase I of BOBMEX. The atmospheric dynamics appeared to influence the oceanic DMS production through the regulation of incident ultraviolet radiation (UV). During phase I, the surface DMS varied high compared to that in phase II (Fig.16). In particular, chlorophyll and DMS levels varied coherently with changes in sea surface temperature and UV when cloud bands passed over TS2 location (Fig.17). Strong winds in first phase resulted in higher sea-to-air fluxes of DMS together with higher DMS concentration in aerosols. These results were discussed in a recent published work (Dileep Kumar et al, 2002).

References

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Annexure-4

Conclusions:

i) The intra-seasonal evolution of upper oceanic thermo-haline structure during BOBMEX period (July-August 1999) was different in the northern Bay of Bengal than in the southern Bay. Though sea surface temperature (SST) responded to the spells of atmospheric convection (cloudiness) in both regions, sea surface salinity (SSS) over the season as a whole increased (decreased) in the northern (southern) Bay of Bengal.

ii) The BOBMEX results showed a spectacular event of arrival of freshwater plume at TS2 time-series location. This made SSS to fall by about 4 psu and the thickness of mixed layer to become thinner from 30 m to 10m and thus the formation of barrier layer restricting the penetration of mixing processes deeper. The offshore advection of fresh water plume was attributed to Ekman flow.

Another well marked (10-m thick; 40- km wide) low-salinity plume was consistently encountered around 120 km from Paradip coast during both ORV Sagar Kanya 147 A & B cruises of BOBMEX. On the whole during the season, upwelling and sinking processes were encountered off Chennai and Paradip coasts respectively.

iii) A new technique for retrieval of SSS from the outgoing long-wave radiation (OLR) was demonstrated based on 'Effective Oceanic Layer' (EOL) representing the thin upper ocean stratified layer. Estimated mean monthly SSS distributions during July & August 1999 showed prevalence of low values in the northern Bay of Bengal that were in general agreement with BOBMEX observations. The relatively higher heat content within EOL would help in increasing atmospheric convection and affect OLR. The precipitation associated within the deep convection (lower OLR) would further alter the difference in evaporation and precipitation (E-P) - a very important

mechanism for determining SSS. Refinement in SSS estimation was further suggested by considering advection and mixing processes.

- iv) Observations made for DMS (dimethylsulphide) and DMSP (dimethyl sulfoniopropionate) in aerosols revealed higher concentrations in phase I compared to phase II due to scavenging effects during the heavy rainfall of phase I of BOBMEX.

Annexure-5

S & T benefits accrued:

I. List of research publications:

Sl No	Authors	Title of the paper	Name of the journal	Vol.	Page No.	Year
1	G S Bhat et al	BOBMEX – The Bay of Bengal Monsoon Experiment	Bulletin of American Meteorological Society	82	2217- 2243	2001
2	V S N Murty, B Subrahmanyam, M S S Sarma, V Tilvi and V Ramesh Babu	Estimation of sea surface salinity in the Bay of Bengal using Outgoing Longwave Radiation	Geophysical Research Letters	29	22-1 to 4	2002
3	M Dileep Kumar et al	Export fluxes of Dimethyl sulphonio- propionate and its break down gases at air-sea interface	Geophysical Research Letters	29	8-1 to 4	2002
4	P N Vinayachandran, V S N Murty and V Ramesh Babu	Observations of barrier layer formation in the Bay of Bengal during summer monsoon	Journal of Geophysical Reserach	107 (C4) 8018	19-1	2002

II. Manpower trained on the project

(a) Research Scientists or Research Associates	NIL
(b) No of Ph Ds Produced	NIL
(c) Other Personnel trained	Three Project Trainees

III. Patents taken, if any

NIL

Annexure-6

Financial Position

No	Financial position	Funds sanctioned (Rs. In Lakhs)	Actual Expenditure (Rs. In Lakhs)	Percentage of total cost (%)
I	Salaries	3.600	3.612	7.3
II	Travel	6.000	4.450	9.0
III	Contingency	3.000	1.159	2.4
IV	Others costs	13.900	17.478	35.4
V	Equipment	18.500	18.201	36.8
VI	Overheads	4.500	4.500	9.1

Annexure-7

Procurement / usage of Equipment:

SI No	Name of Equipment(Make / Model	Cost Rs. (Lakhs) Approx	Date of Installation/ Field testing	Utilisation rate (%)	Remarks regarding maintenance /Breakdown
1	XBT System (Launcher, PC adoptable card) & XBT consumable probes	Sippican Inc; USA	13.00	During BOBMEX cruise	100	No breakdown
2	Portable CTD system	Seabird Inc., USA, Seacat	6.00	Meant to equip the second BOBMEX ship		Extensively being used in NIO in-house programmes
3	Absorption / Attenuation Meter	Wetlabs Inc, USA	11.00	-do-		-do-

Plans for utilising the equipment facilities in future:

All the above equipment will be used in future ICRP field experiments like ARMEX etc.

Name and Signature with Date

a. *Ramesh Babu*

(V. RAMESH BABU)

b. *V. Srinivasan Murthy*

(V.S.N. MURTY)

c. *M. Dilip Kumar*

(M. DILIPKUMAR)

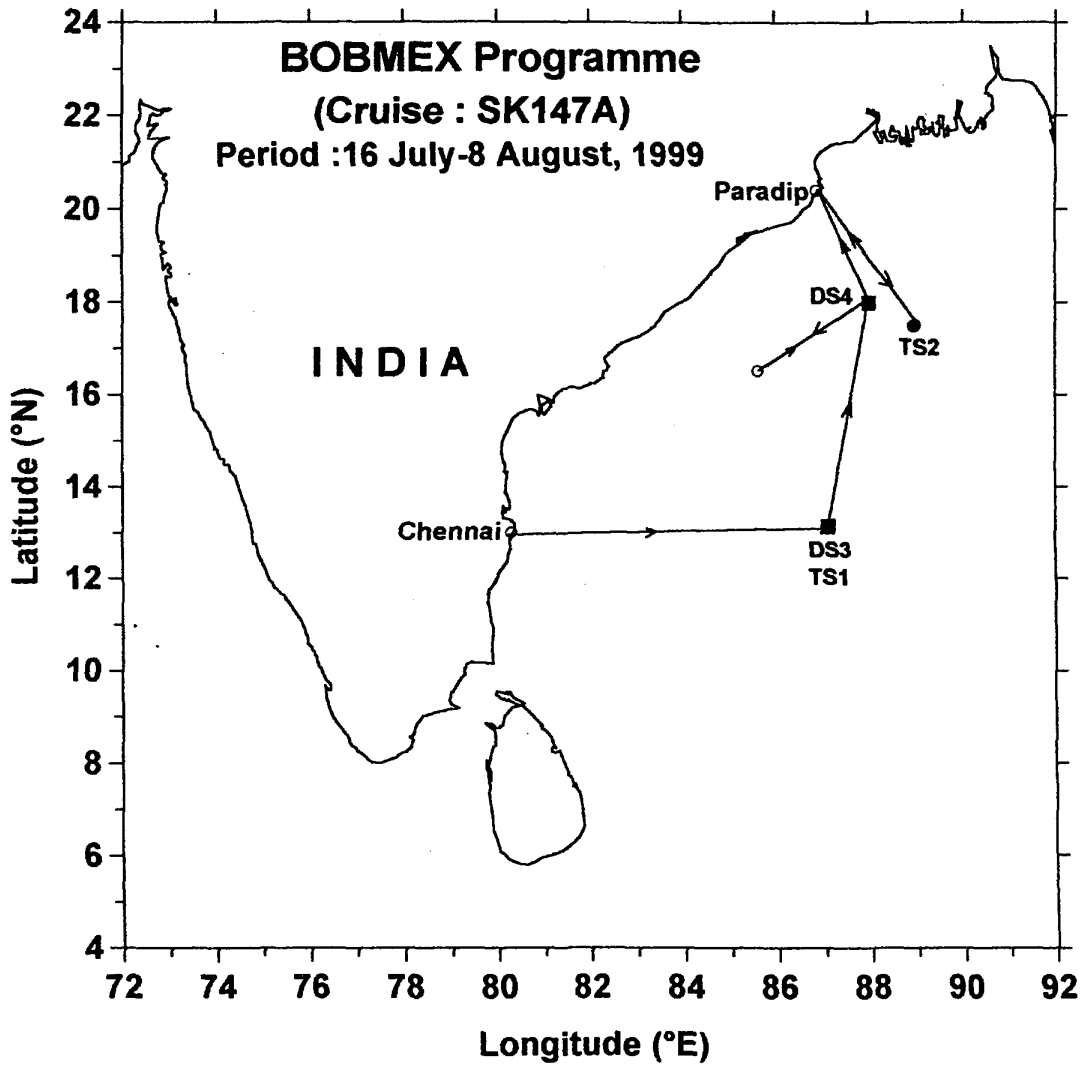


Fig. 1 : ORV Sagar Kanya cruise (SK147A) track.

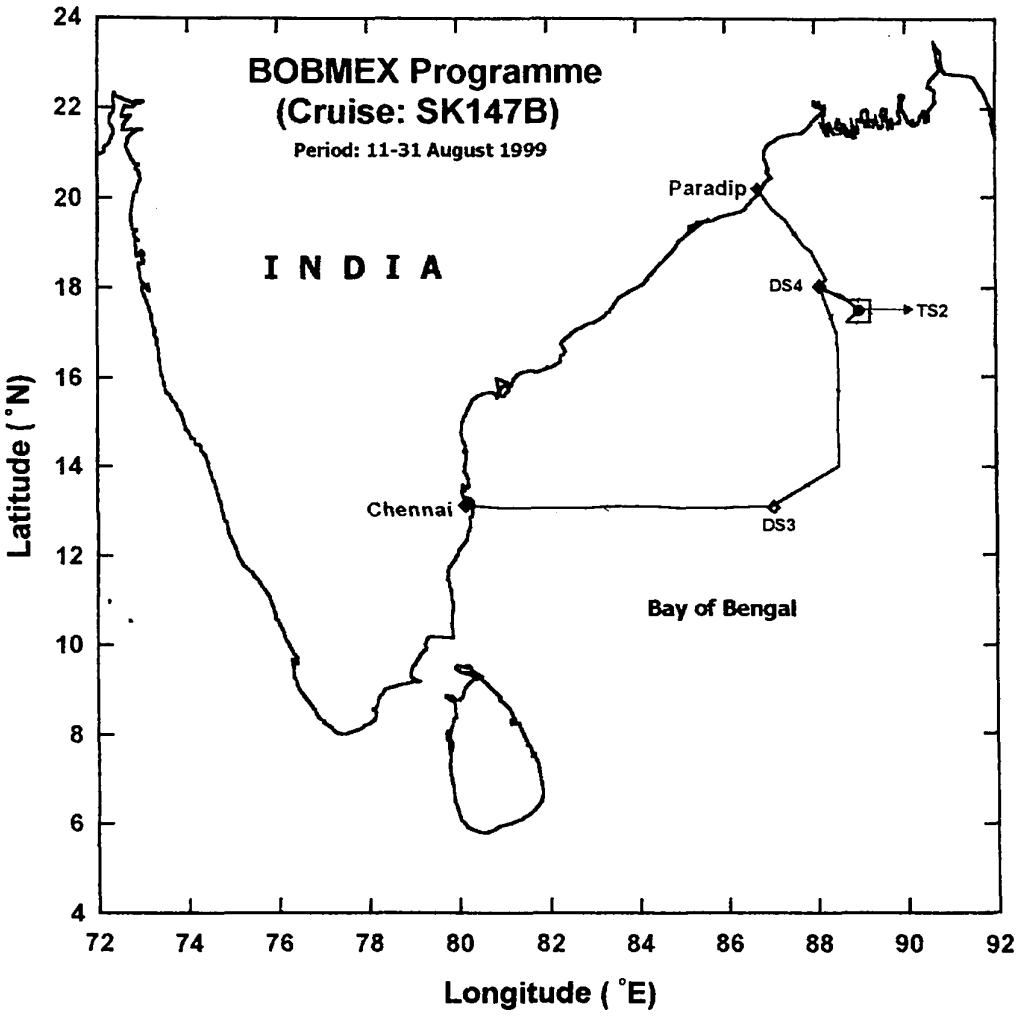


Fig. 2 ORV Sagar Kanya Cruise (SK147B) track

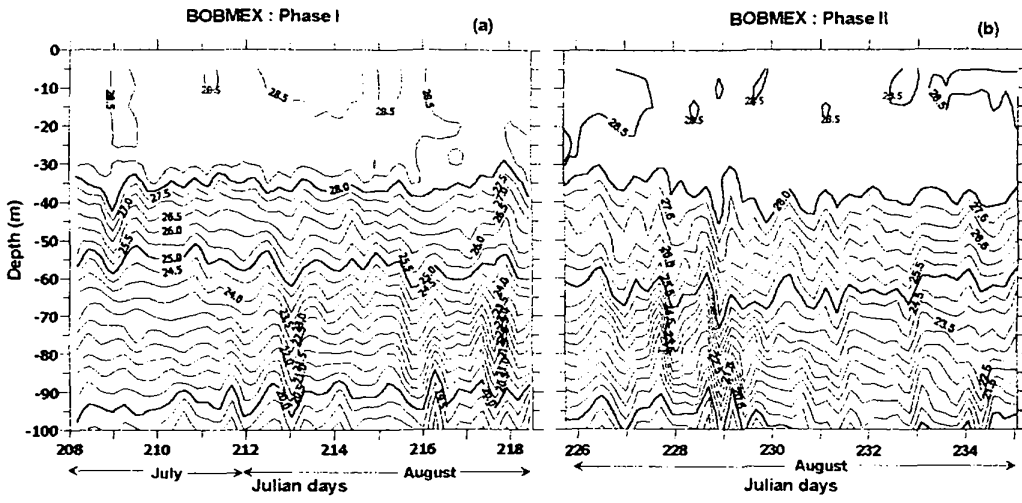


Fig. 3 Temporal variability of thermal structure at TS2 location (17.5°N, 89°E) in the northern Bay of Bengal during (a) Phase I and (b) Phase II of BOBMEX-99

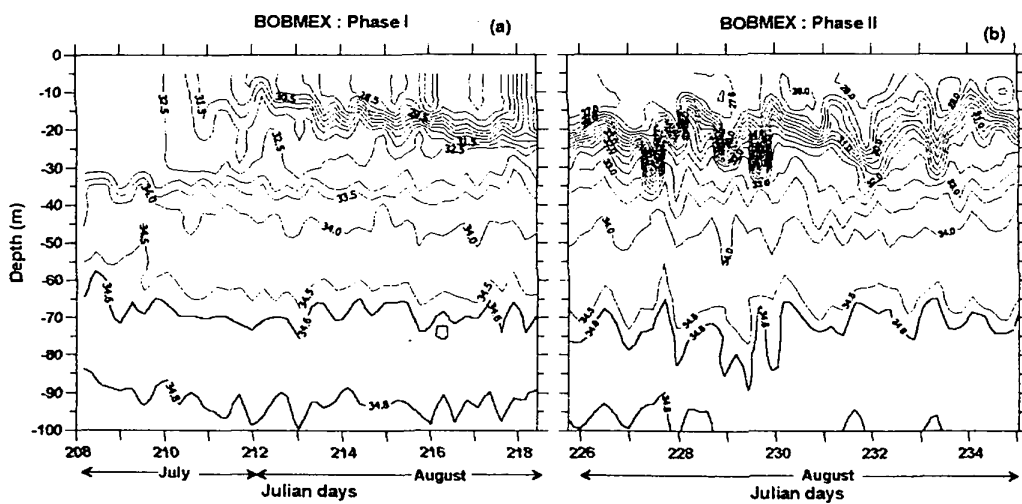


Fig. 4 Temporal variability of salinity structure at TS2 location (17.5°N, 89°E) in the northern Bay of Bengal during (a) Phase I and (b) Phase II of BOBMEX-99

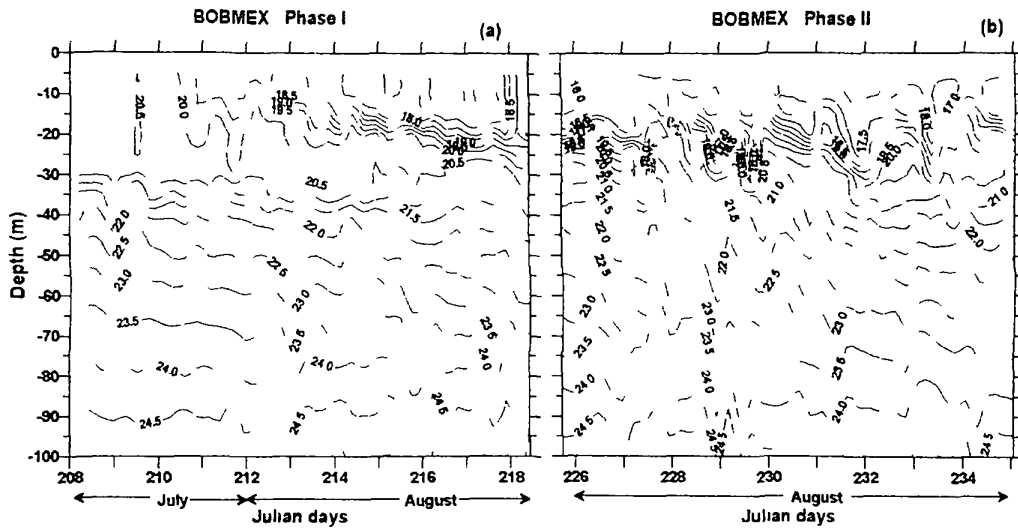


Fig 5 Temporal variability of density structure at TS2 location (17°5'N, 89°E) in the northern Bay of Bengal during (a) Phase I and (b) Phase II of BOBMEX-99

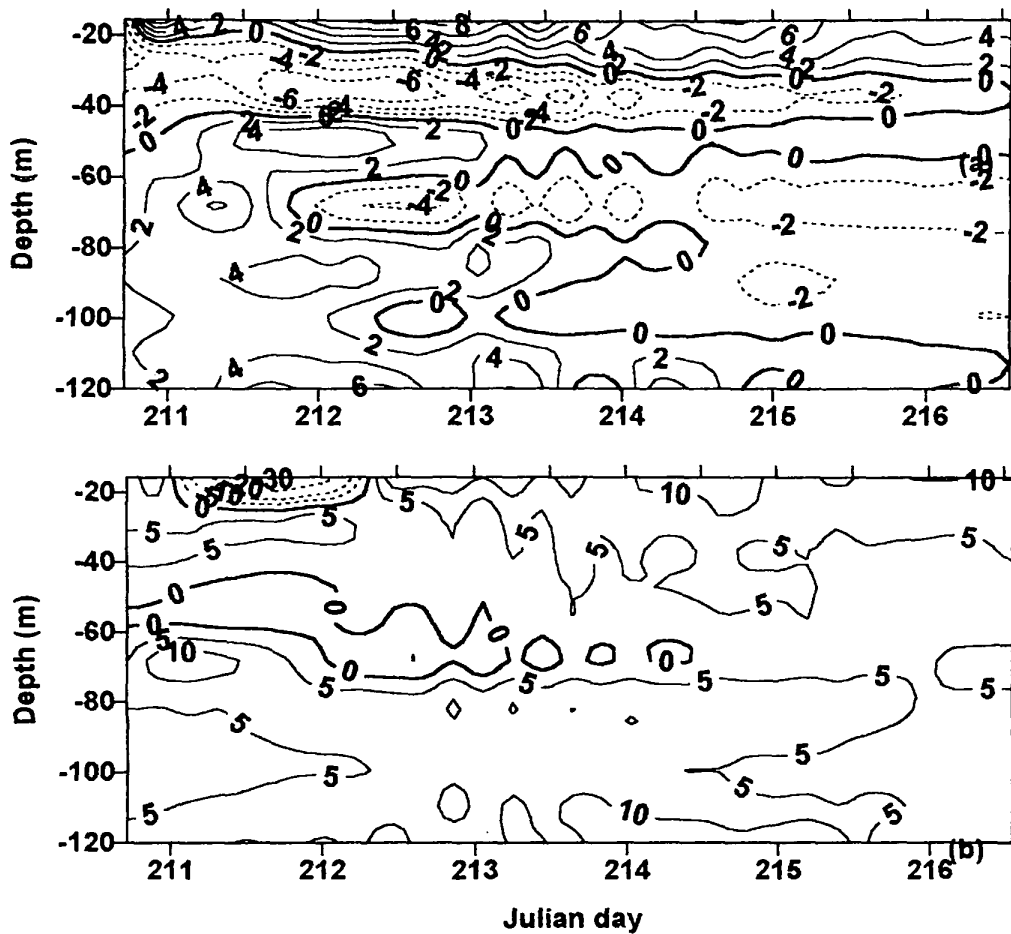


Fig. 6 VM-ADCP measured current structure (a) zonal velocity (cm/s) and (b) meridional velocity (cm/s) averaged at 6 hourly interval at TS2 location in the northern Bay of Bengal during BOBMEX-99

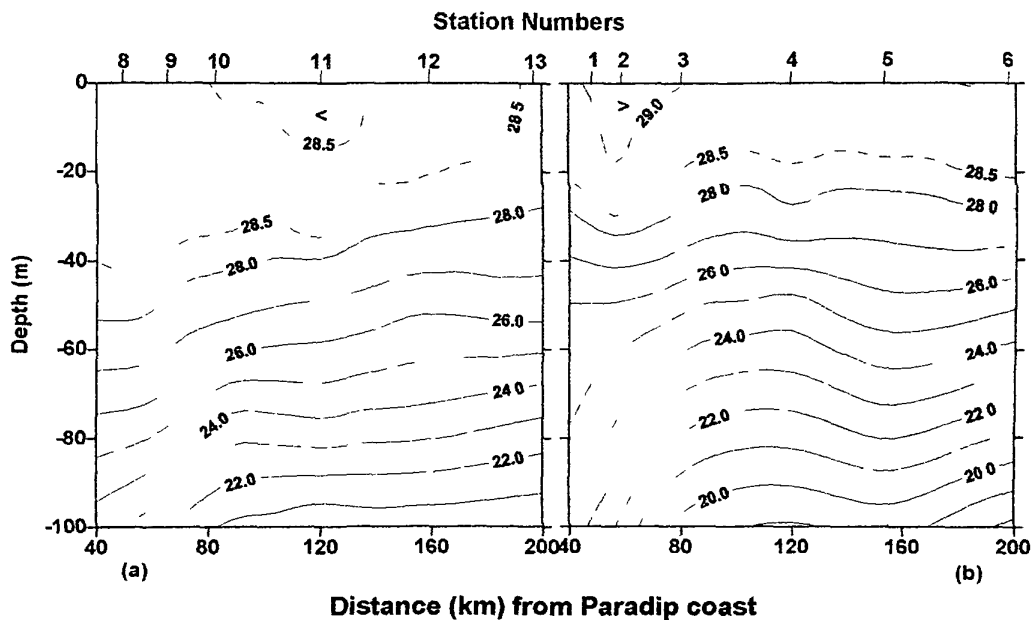


Fig 7 Thermal structure along a section off Paradip coast during (a) Phase I and (b) Phase II of the BOBMEX-99

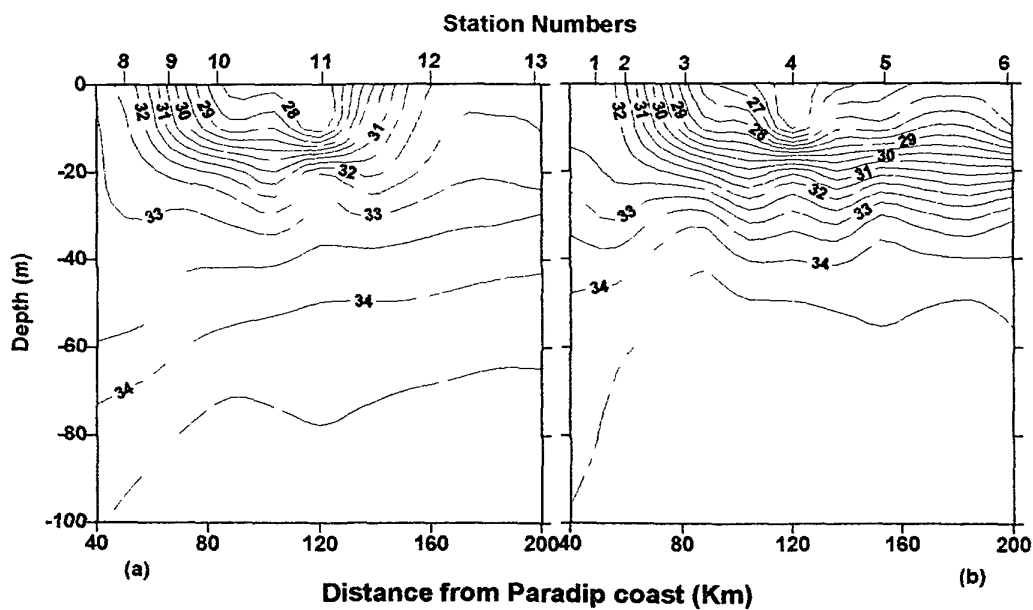


Fig 8 Salinity structure along a section off Paradip coast during (a) Phase I and (b) Phase II of the BOBMEX-99

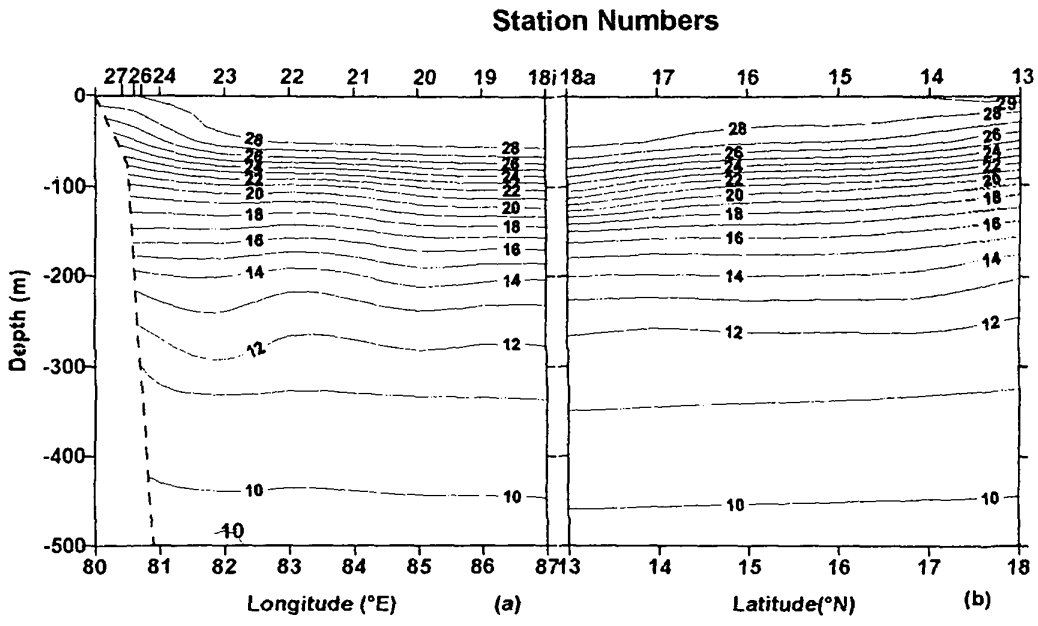


Fig. 9 Thermal structures along (a) 13°N and (b) 88.5°E during phase II of BOBMEX-99

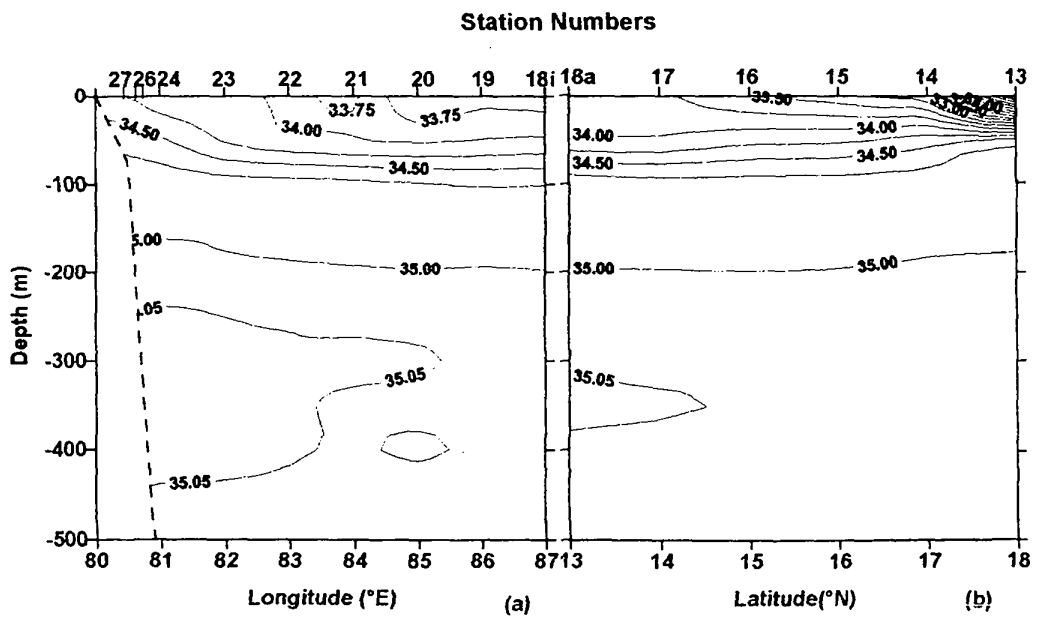


Fig. 10 Salinity structures along (a) 13°N and (b) 88.5°E during phase II of BOBMEX-99

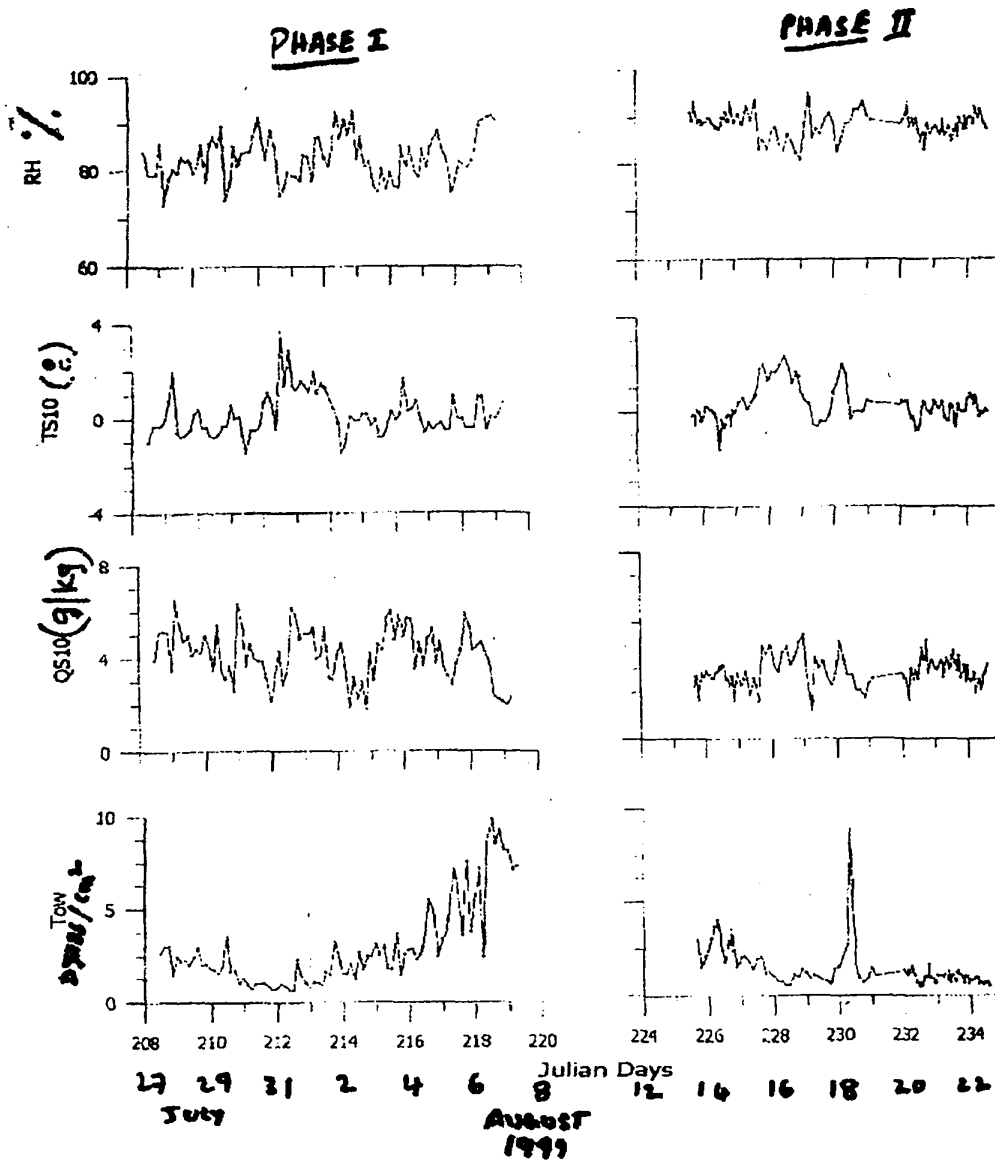


Fig. 11 Variation of RH (Relative Humidity), TS10 (Difference between SST and air temperature at 10 m height above sea surface), QS10 (Difference between saturated specific humidity at SST and specific humidity of air at 10 m height above sea surface) & surface wind stress at TS2 location

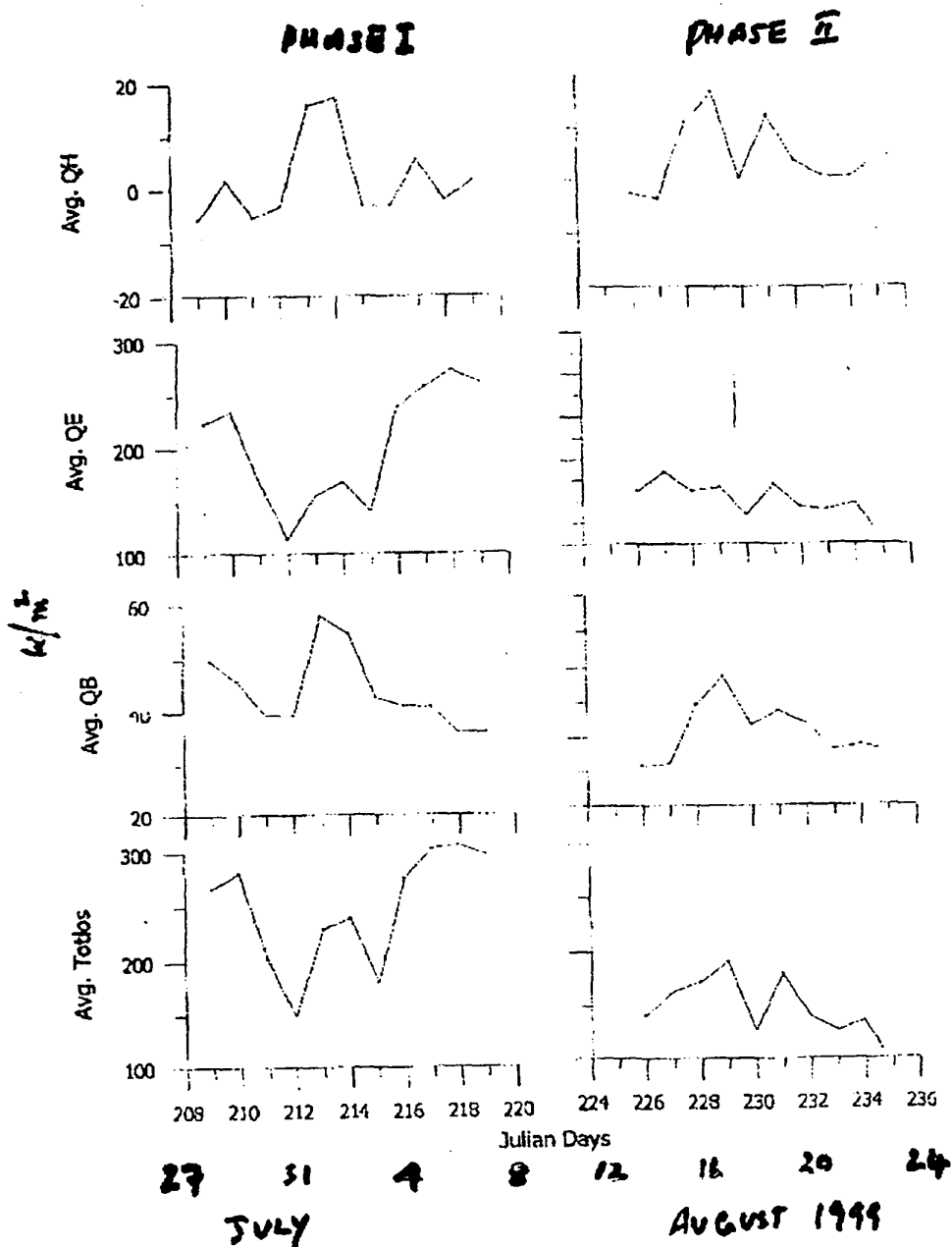


Fig. 12 Variations in the daily averaged heat budget Components - Sensible heat flux (Q_H), Latent heat flux (Q_E), Effective back radiation (Q_B) & Total surface heat loss (Totlos $Q_H + Q_L + Q_B$) at TS2 location.

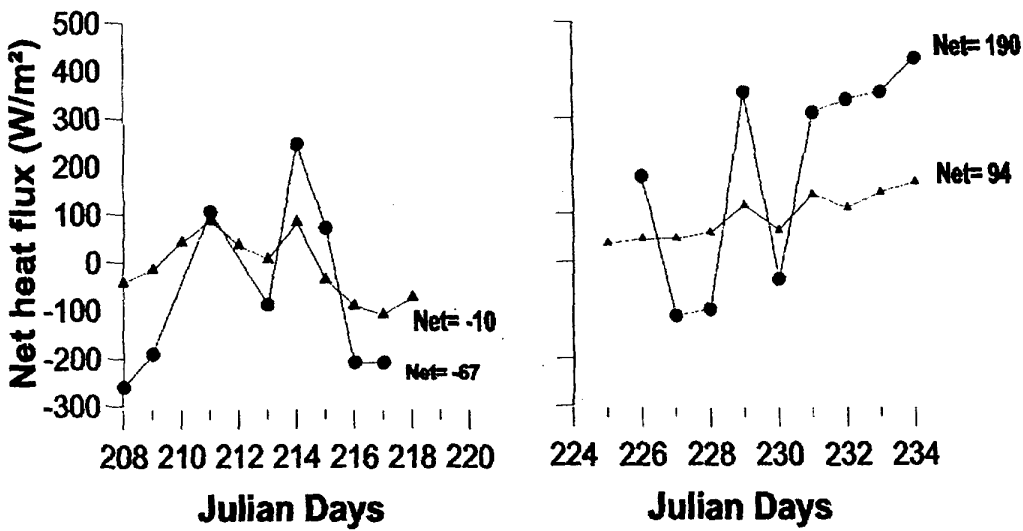


Fig. 13 Daily march of net heat flux (Q_N) based on estimates using empirical equation ($\bullet\text{---}\bullet$) and direct measurements ($\Delta\text{---}\Delta$) of solar radiation (Q) during the Phases I and II of BOBMEX-99 at TS2 location.

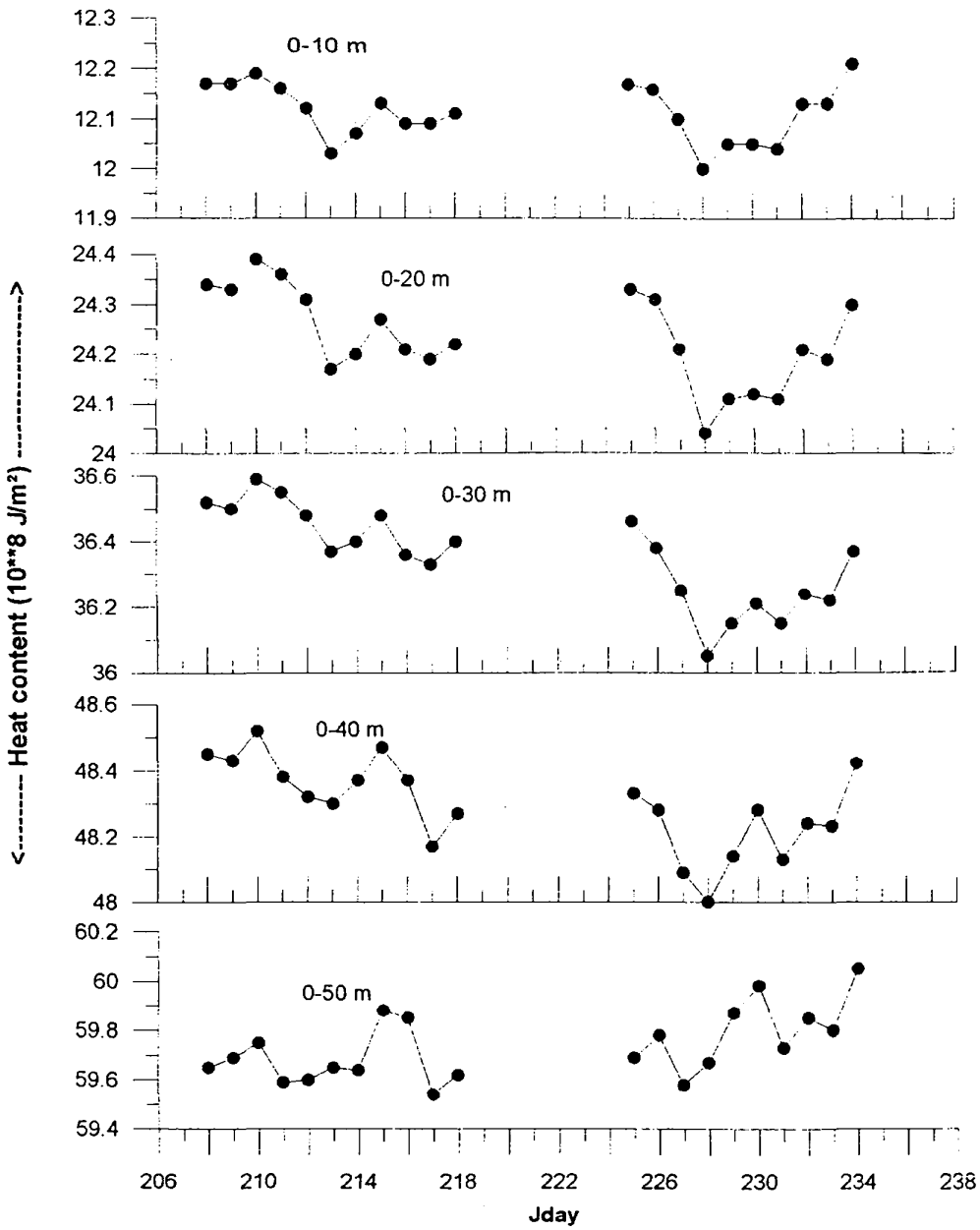


Fig. 14 Variability in daily averaged heat content in different layers of upper water column (incremented by 10m) during Phases I and II of BOEMEX-99 at TS2 location.

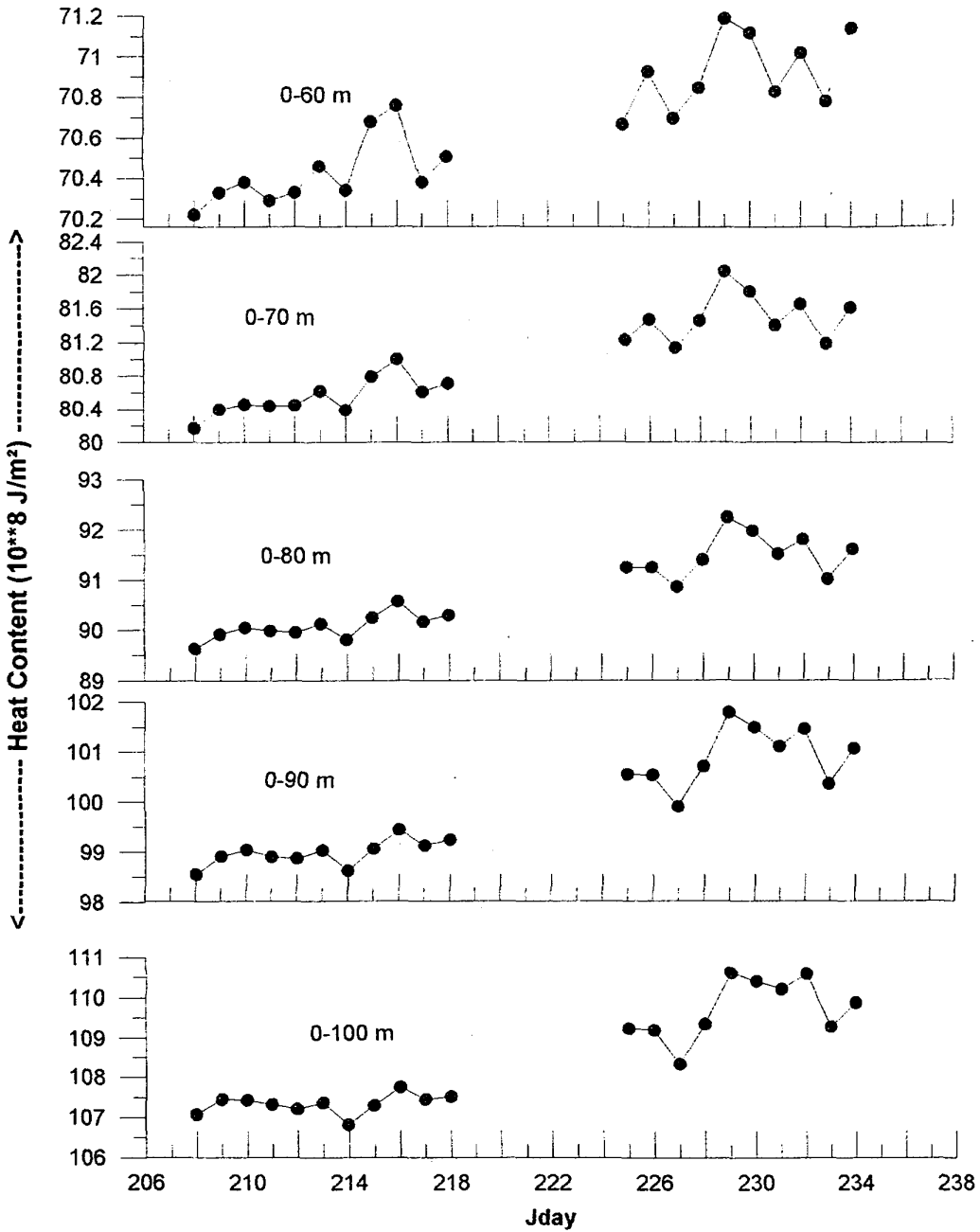


Fig. 14 Contd.

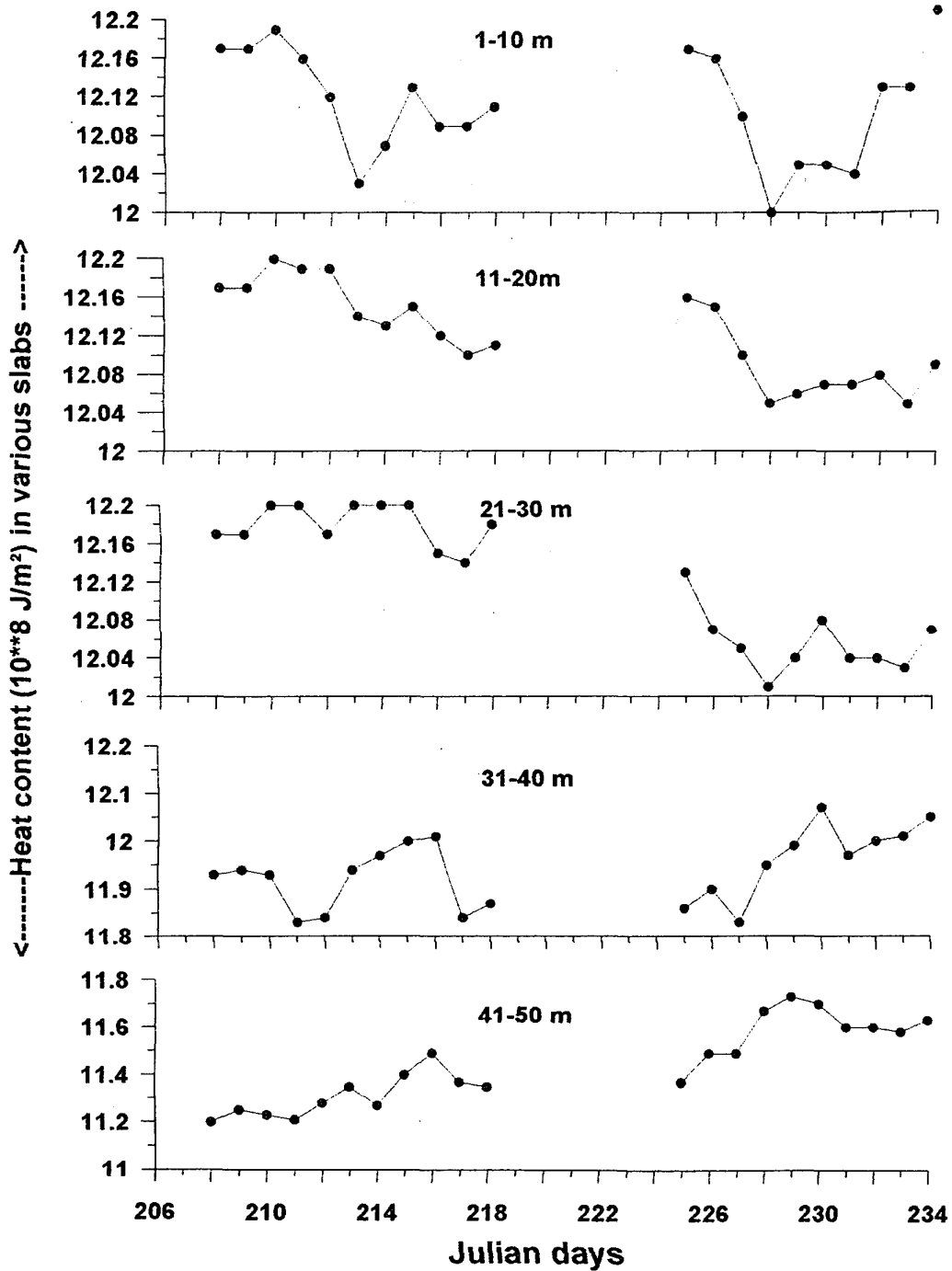


Fig. 15 Variability in the daily averaged heat content in different slabs of 10 m- thick at TS2 location during phases I and II of BOBMEX-99

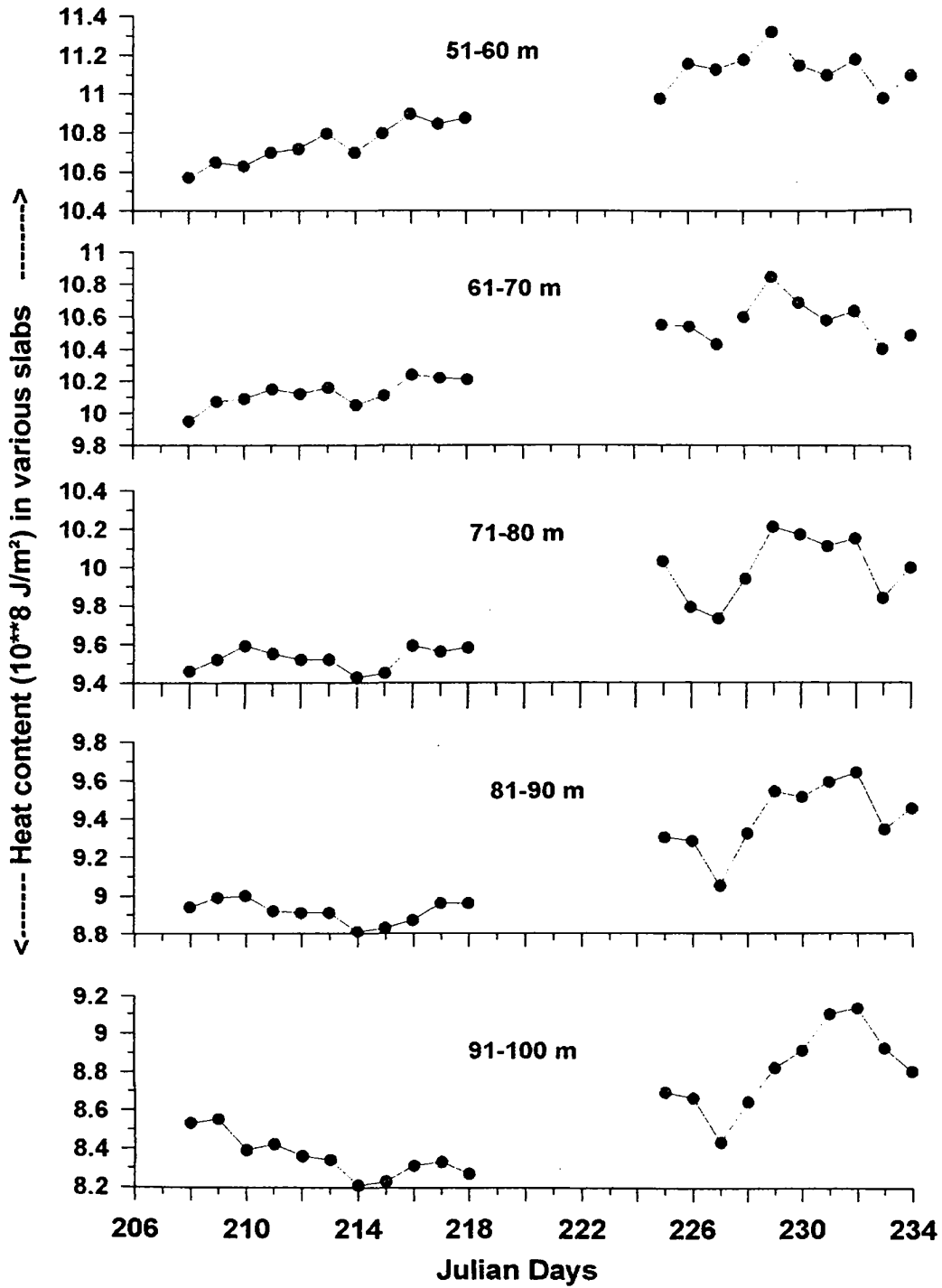


Fig. 15 Contd.

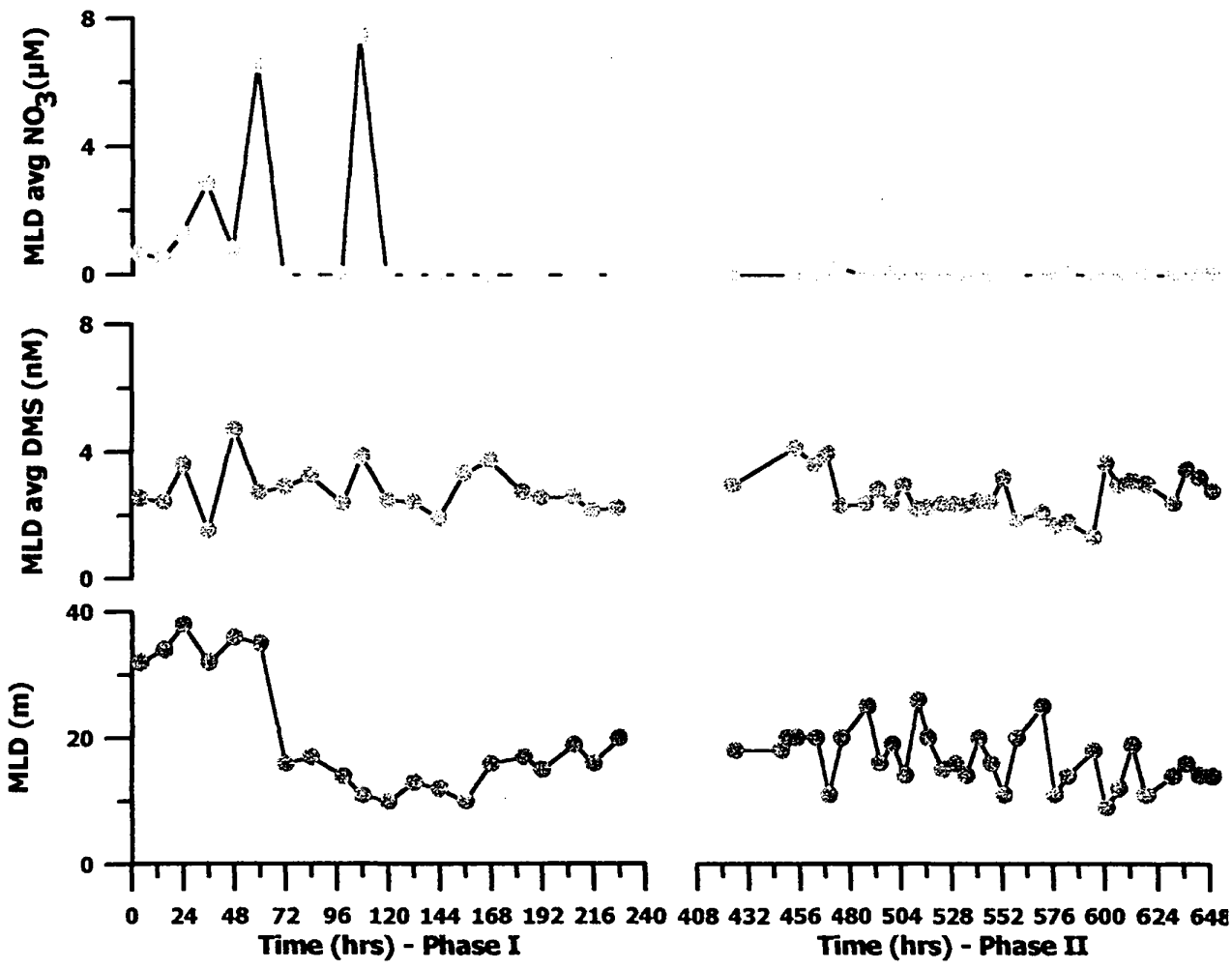


Fig. 16 Variation of the mixed layer depth (MLD), MLD-averaged DMS and Nitrate at TS2 location during phases I and II of BOBMEX-99.

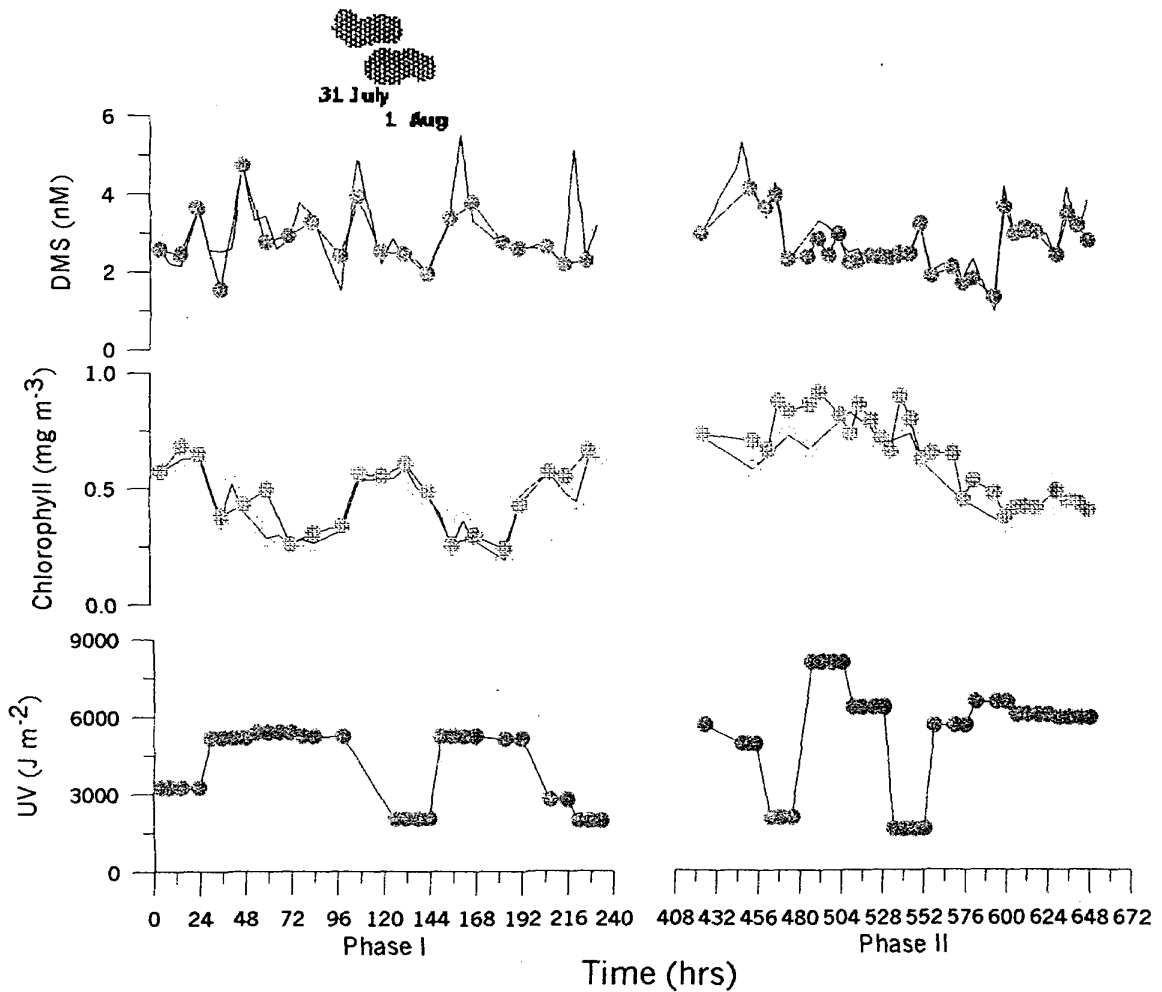


Fig. 17. Variation of DMS, Chlorophyll, and UV radiation at TS2 location in the northern northern Bay of Bengal during Phases I and II of BOEMEX-99. Open symbols indicate surface values and bold symbols indicate MLD-averaged values. Grey patches represent the cloudy conditions on the dates mentioned.