Oceanographic Condition of the Bay of Bengal during November-December 2007

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Abstract

Three sub areas of the Bay of Bengal: northern, eastern and western parts were studied for oceanographic condition. Vertical profiles of temperature, salinity were retrieved from CTD cast while dissolved oxygen and pH were measured from water sample collected at the standard depth. Two core-cold eddies were observed in the north of the Bay. Huge fresh water discharge from main rivers in the Bay plays an important role to shallowness of mixed layer depth of 14-49 m depth and resulting low saline and high temperature water in the north and the east of the Bay. Dissolved oxygen in the east was higher than in the north. The oxygen minimum zone (<0.5 m/l) was also observed at depth greater than 200 m in the north of the Bay. Surface water shallower than 400 m was occupied by three water masses: the Bay of Bengal water (salinity 32-34 psu), the Andaman Sea water (salinity 31-33 psu) and the Indian Central water (temperature 10-15°C, salinity more than 35 psu). The Indian Central water occupied all deepest layer of all survey areas.

Key Words: Bay of Bengal, oceanographic condition

Introduction

The study on oceanographic condition of the Bay of Bengal was conducted with the aim to support the Ecosystem-Based Fishery Management in the Bay of Bengal which is a collaborative survey project of the BIMSTEC (Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation) member countries; Bangladesh, India, Myanmar, Sri Lanka, Nepal and Thailand. The survey was initiated by Thailand, leading country for fishery sector, to observe and collect scientific data concerning to fishery and oceanographic aspects in the Bay of Bengal.

The Bay of Bengal situates in the eastern part of the north Indian Ocean. It is land locked in the North, there is the Andaman and Nicobar Island that separate the Andaman Sea to the East from the Indian Ocean. The shape of the Bay is resemble to a triangle which bordered by member countries of BIMSTEC. There are many large river including the

Ganges, Brahmaputra, Irrawaddy, Godavari, Mahanadi, Krishna and Kaveri emptying freshwater into the Bay.

The Bay of Bengal is influenced by a semi-annually reversing monsoonal wind system. During winter monsoon (November-February), the winds are weak (~5 m/s) and from the Northeast. These trade winds bring cool and dry continental air to the Bay of Bengal. In contrast, during the summer monsoon the strong (~10 m/s) southwest winds bring humid maritime air into the Bay of Bengal. The unique feature of the Bay of Bengal is the large seasonal freshwater pulse, which makes the waters of the upper layers less saline and highly stratified (Narvekar and Prasanna Kumar, 2006).

Materials and Methods

Oceanographic condition of the Bay of Bengal was studied as a part of Ecosystem-Based Fishery Management in the Bay of Bengal. The surveys were planed to collect data from three areas: area A (latitude 16°N-19°N, longitude 88°E-91°E) in the north of the Bay of Bengal, area B (latitude 09°N-14°N, longitude 82°E-85°E) in the western part of the Bay of Bengal and area C (latitude 10°N-12°N, longitude 95°E-97°E) in the Andaman sea (Fig. 1). Due to the influence of cyclone SIDR during the survey period, station 33 to 41 were canceled because of safety reason (Fig. 2). Total survey period was 58 days, which was from 25 October to 21 December 2007.

Data were collected using Falmouth Integrated CTD instrument attached with twelve 2.5 liter Niskin bottles onboard M.V.SEAFDEC. Temperature and salinity were recorded continuously from the surface to the depth of 400 m, which is the maximum length of M.V.SEAFDEC CTD system. The recorded data were then averaged to every one meter depth.

During up cast of CTD operation, water samples were taken at standard depths from surface to 400 m depth. Water samples were then immediately taken for dissolved oxygen determination and pH measurement. Dissolved oxygen was determined by Whinkle titration procedure while pH was measure using Fisher Accumet 1002 pH meter. Please note that dissolved oxygen and pH data were analyzed only in area A and C, because of few data were available. Data were analyzed using Ocean Data View software (Schlitzer, 2005).

The mixed layer depth (MLD), the depth at which the sigma-t value exceeds surface value by 0.2 is defined following Narvekar and Kumar, 2006.

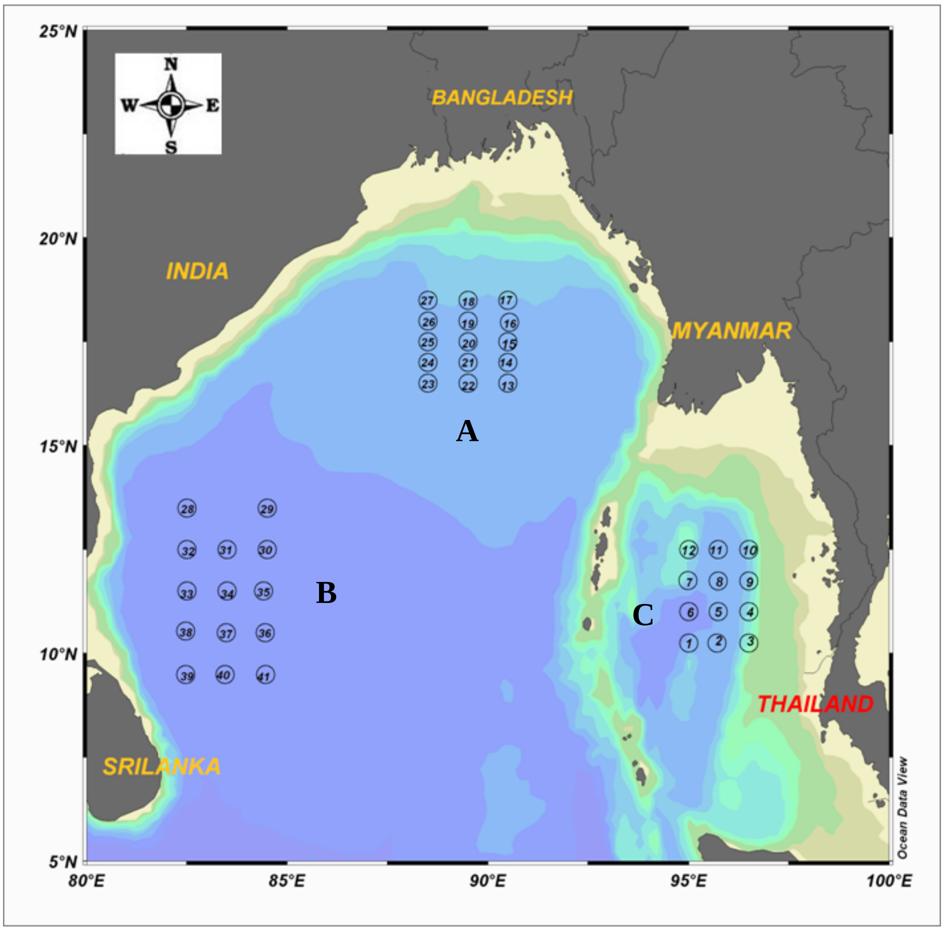

Figure 1 Map showing the survey stations.

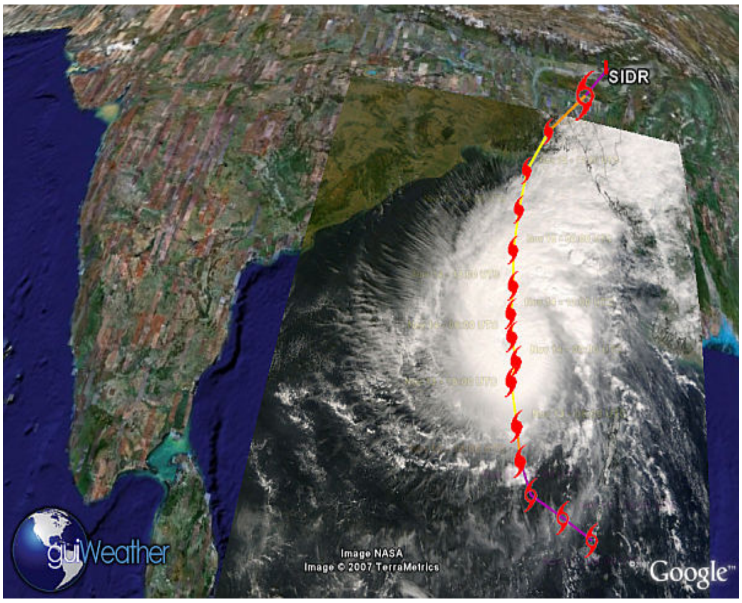

Figure 2 Tropical Cyclone SIDR which formed on November 11, 2007 and dissipated on November 16, 2007 (source: http://www.gearthblog.com/blog/archives/2007/11/tropical_cyclone_sidr.html).

Results

Area A

Sea surface temperature (SST) and sea surface salinity (SSS) of area A were between 27.8 to 29.7 °C and 31.5-33.6 psu, respectively. The higher SST was observed in the eastern part of area A which coincides with the area of low salinity.

There were two cold core eddied with high salinity observed at the surface layer of area A. One of which was located in the Southwest (along of longitude 88° 30′E) where the 27.5 °C isotherm shoaled from 60 m at latitude 17° 30′N to 20 m at latitude 16° 30′N (Fig. 4). The other cold core was observed in the North where 27.5 °C isotherm shoaled from 50 meters at latitude 18°N to 30 m at latitude 18° 30′N in the section plots along of longitude 89° 30′E (Fig. 5).

The average MLD, of area A was 31.3 m depth. The shallowest MLD (19 m) was observed in the areas that occupied by cold-core and high saline water.

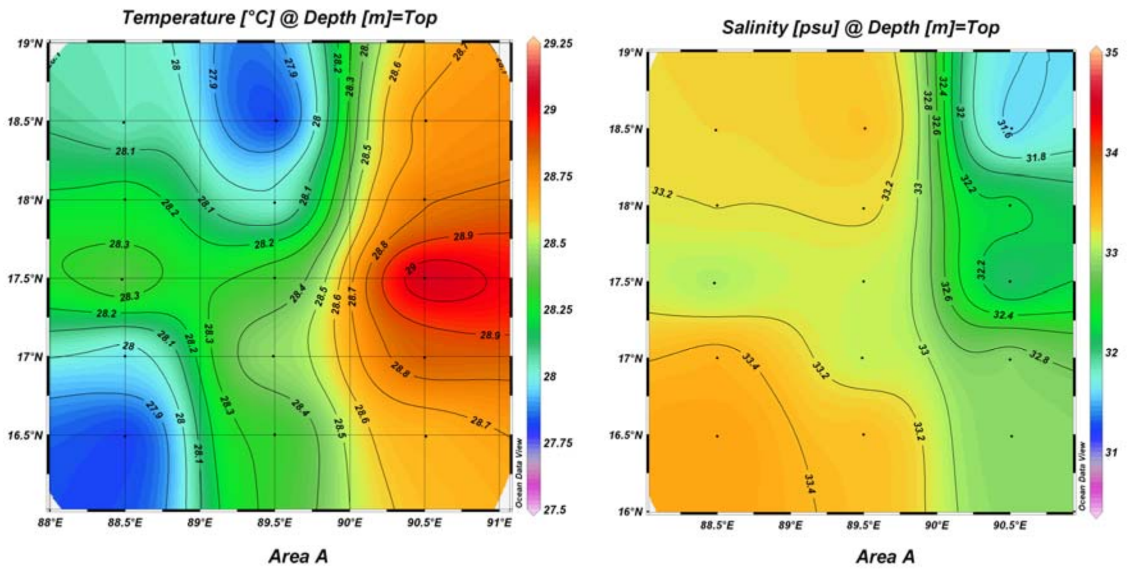

Figure 3 Horizontal plots of temperature (°C) and salinity (psu) at surface layer of area A. (Dots indicate data location)

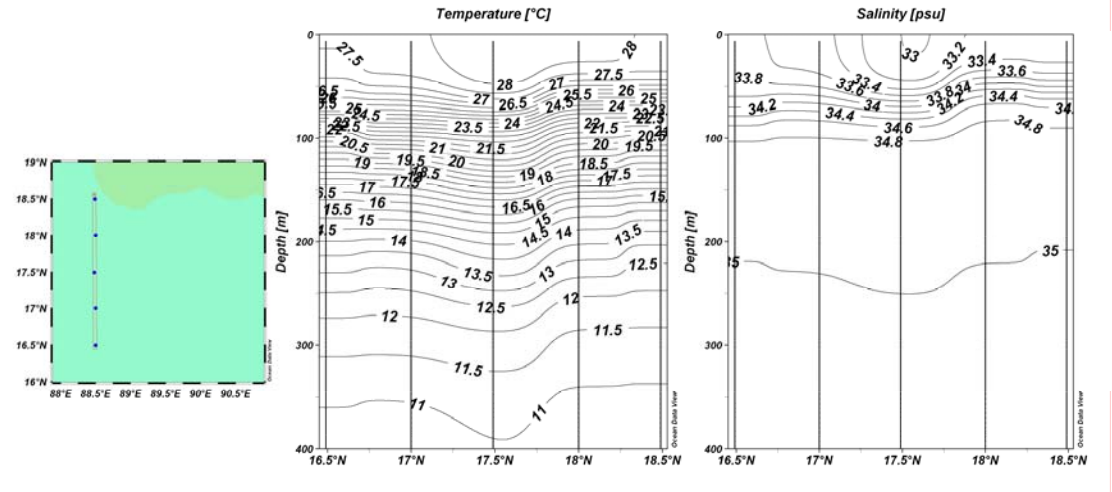

Figure 4 Section plots of temperature (°C) and salinity (psu) of survey stations along longitude 88° 30′E of area A (stations 23-27).

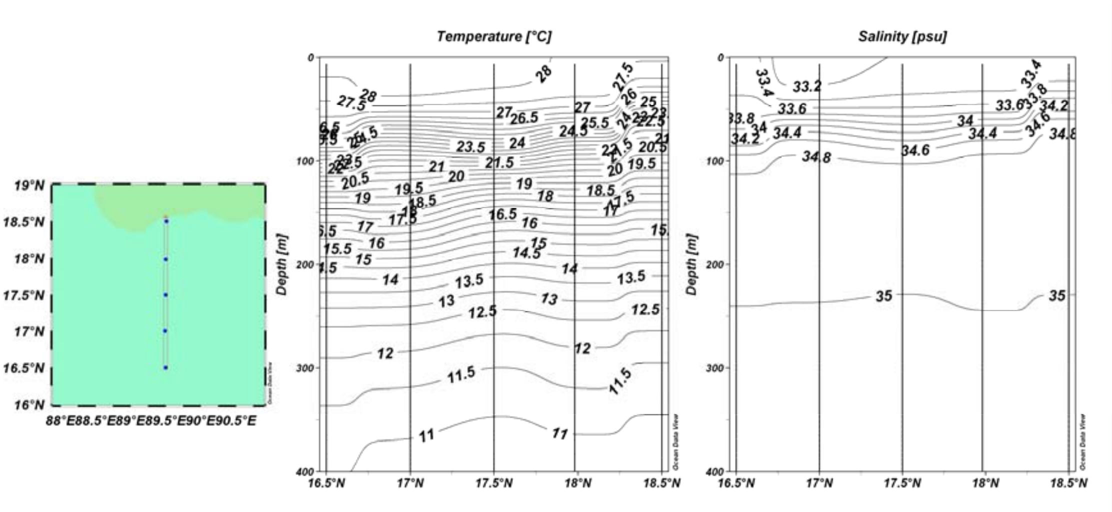

Figure 5 Section plots of temperature (°C) and salinity (psu) of survey stations along longitude 89° 30′E of area A (station 18-22).

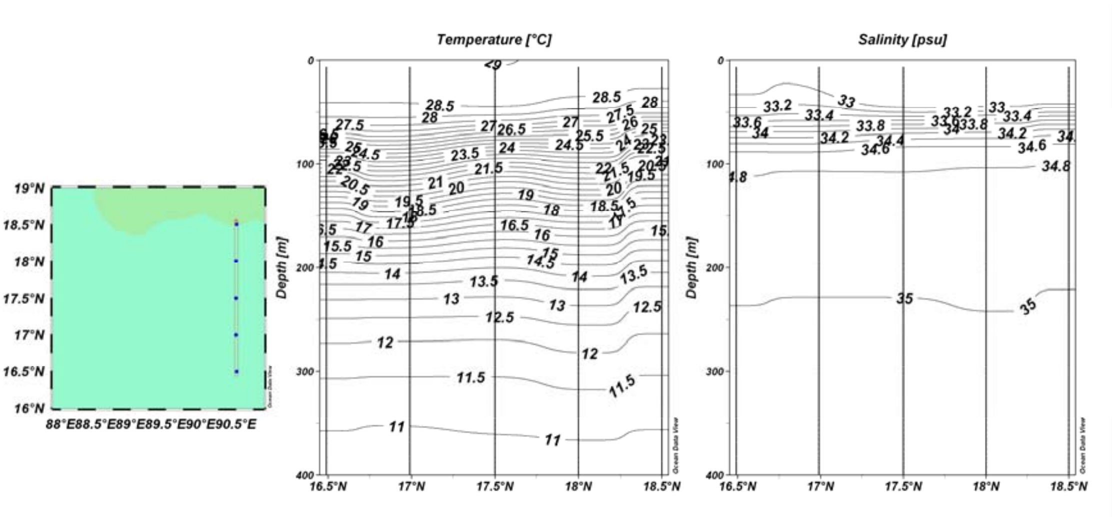

Figure 6 Section plots of temperature (°C) and salinity (psu) of survey station along longitude 90° 30′E of area A (station 13-17).

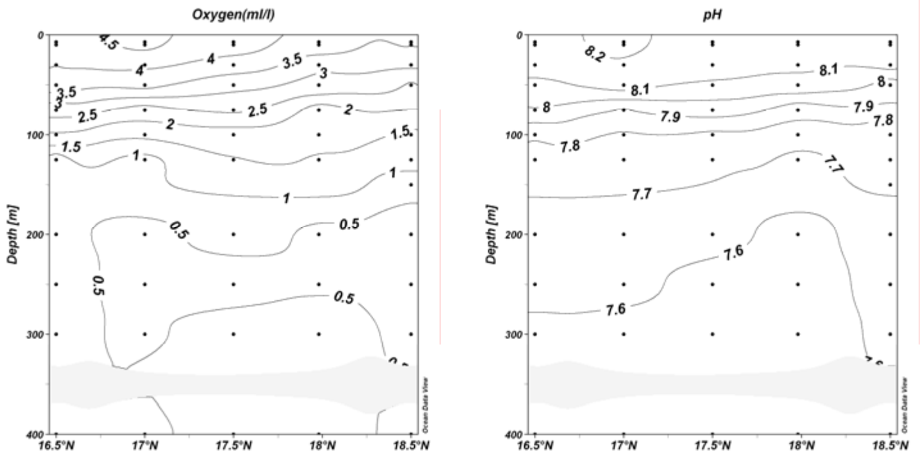

Figure 7 Section plots of oxygen (ml/l) and pH of survey stations along longitude 89° 30′E of area A (station 18-22).
(Dots indicate data location)

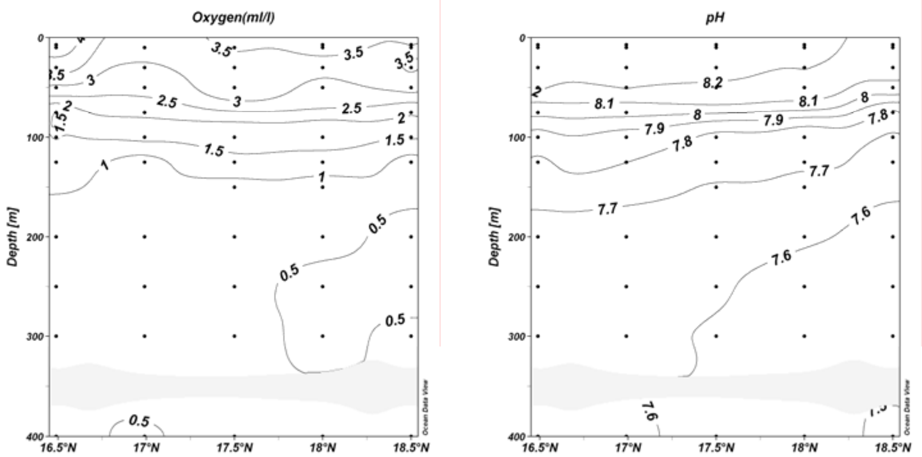

Figure 8 Section plots of oxygen (ml/l) and pH of survey stations along longitude 90° 30′E of area A (station 13-17).
(Dots indicate data location)

Dissolved oxygen concentration of surface water of area A was between 3.94-5.02 ml/l. The changing of dissolved oxygen and pH by depth was observed in surface layer shallower than 150 m, ranges from about 4 to 5 ml/l and 8.2-8.3 to 1 ml/l and 7.7, respectively. Dissolved oxygen and pH were homogeneously below 150 m depth. The tongue like of water mass, whose dissolved oxygen is less than 0.5 ml/l and pH less than 7.6 was observed at depth below 200 m in the north of area A (Fig. 7 and 8).

Area B

SST and SSS patterns of area B are quite homogeneous. The SST ranges between 28.3-28.7°C while SSS ranges between 33.3-34 psu (Fig. 9).

Section plots in Fig.10 show that high salinity gradient occurred only at the upper 100 m depth. There was a strange pattern of salinity at the station 31 where 34.8 psu isohaline was observed at 150 m depth while the other stations were at about 80 m depth.

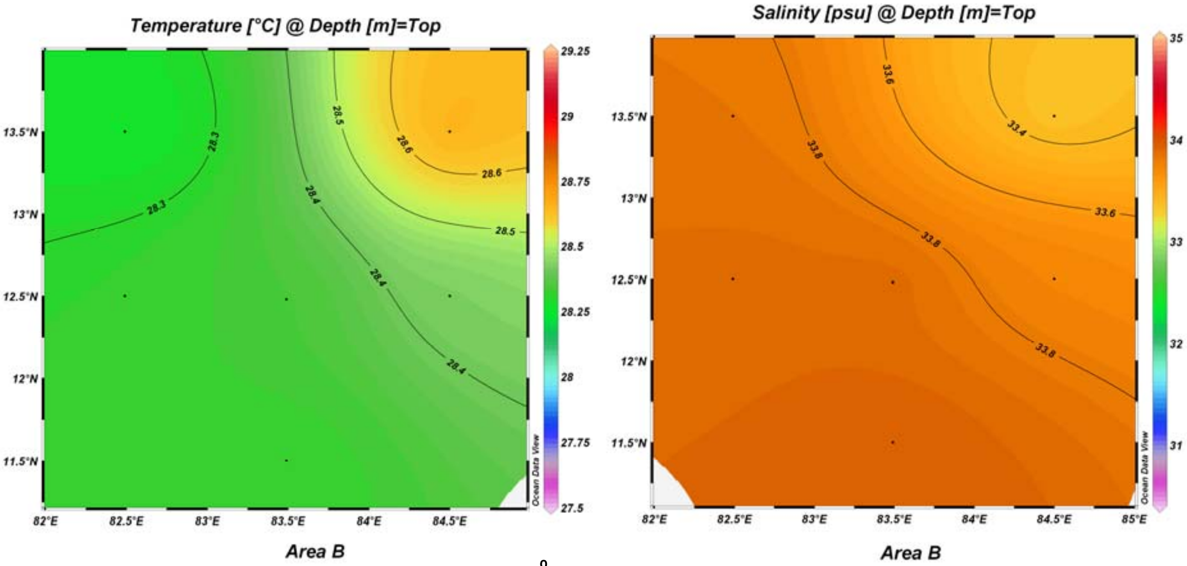

Figure 9 Horizontal plots of temperature (°C) and salinity (psu) at surface of area B. (Dots indicate data location)

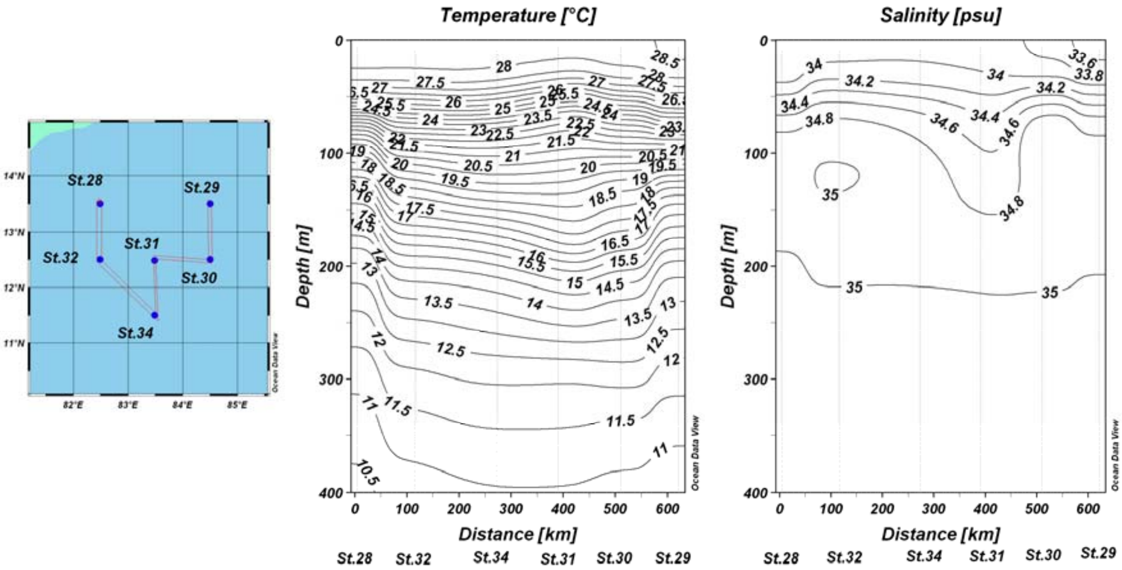

Figure 10 Section plots of temperature (°C) and salinity (psu) of all stations in area B. (Dots indicate data location)

The average mix layer depth of area B was 37.8 m depth. The shallowest MLD was observed in the east side of area B.

Due to the bad weather condition during the survey period of area B, water samples from just a few stations could be collected to determine dissolved oxygen and pH. Therefore, the analyses of these two parameters were not possible.

Area C

The surface salinity of area C, ranges 30.78-32.9 psu, was lower than the others. Lower saline water was observed at the north and the east of the area, indicating the influence of outflow from the rivers from the northern part of the area.

SST of area C ranges from 27.99-28.93°C. The highest SST was observed in the southwest of the area (Fig. 11).

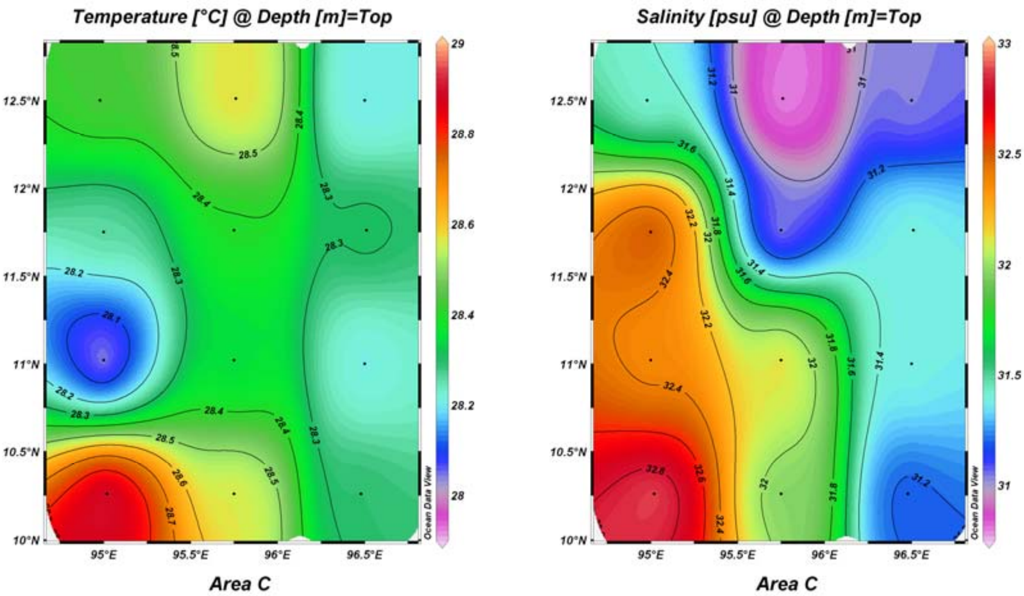

Figure 11 Horizontal plots of temperature (°C) and salinity (psu) at surface of area C. (Dots indicate data location)

Section plots of temperature and salinity along longitude 95°E, 95° 45′E and 96° 30′E show that strong gradient of temperature and salinity occurred from the surface to about 150 m depth, which was deeper than in the area A and B (Figs. 12, 13 and 14). Only in the most northern stations, higher temperature and lower salinity were observed at the same depth (Fig.12). Salinity and temperature of this station were more similar to those of the stations in the eastern part of the area.

MLD was about 19 to 34 m depth. Average MLD of area C was 24 m, which was the shallowest among three survey areas.

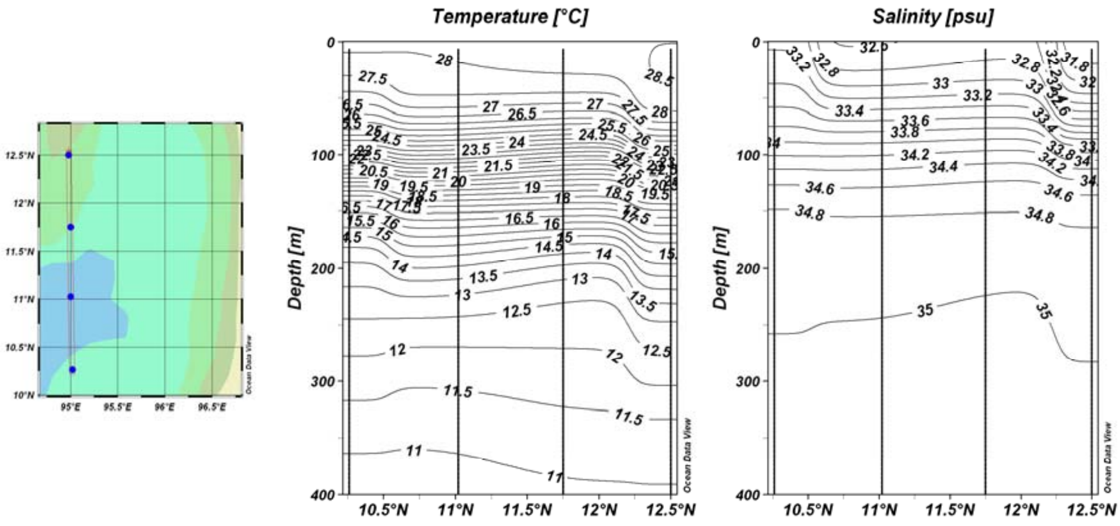

Figure 12 Section plots of temperature (°C) and salinity (psu) of stations along longitude 95°E in area C (station 1, 6, 7 and 12).
(Dots indicate data location)

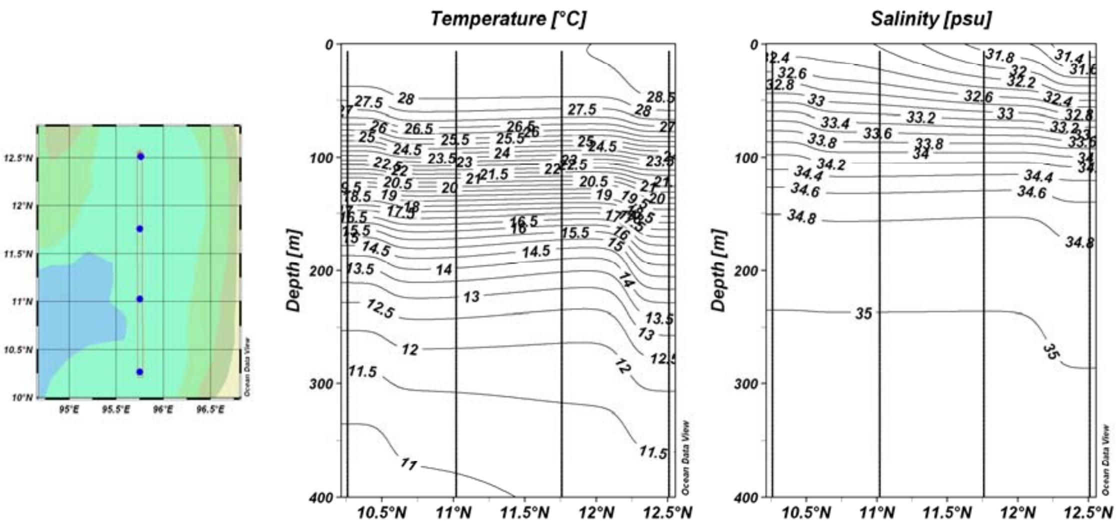

Figure 13 Section plots of temperature (°C) and salinity (psu) of stations along longitude 95° 45′E in area C (station 2, 5, 8 and 11).
(Dots indicate data location)

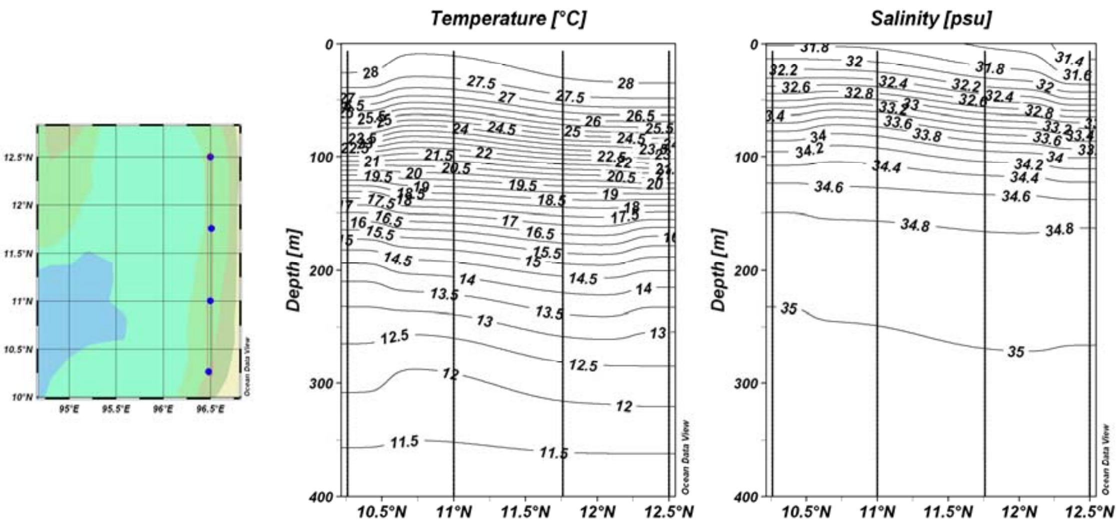

Figure 14 Section plots of temperature ($^{\circ}$C) and salinity (psu) of stations along longitude 96° 30′E in area C (station 3, 4, 9 and 10).
(Dots indicate data location)

Section plots of dissolved oxygen and pH along longitude 95°E, 95° 45′E and 96° 30′E also show strong gradient from the surface to 150 m depth. Below that water are homogeneous. Surface dissolved oxygen ranges from 4.97-5.01 ml/l. At the same depth, dissolved oxygen concentration in area C was higher than area A by 0.5 to 1 ml/l. The lowest dissolved oxygen line (0.5 ml/l), observed in area A, did not occur in area C. The pH also shows similar pattern. Surface pH ranges from 8.21-8.27.

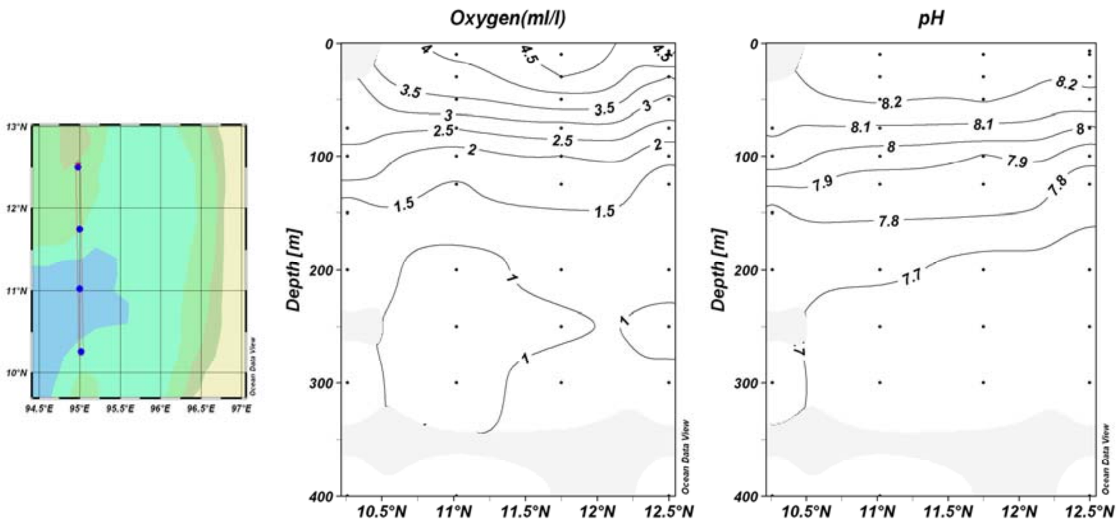

Figure 15 Section plots of dissolved oxygen (ml/l) and pH of stations along longitude 95°E in area C (station 1, 6, 7 and 12).
(Dots indicate data location)

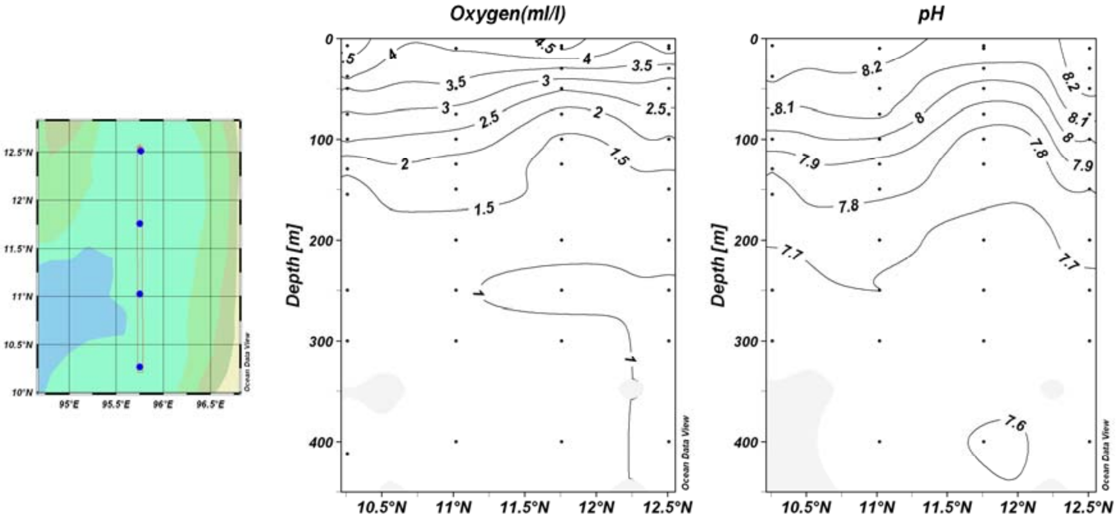

Figure 16 Section plots of dissolved oxygen (ml/l) and pH of stations along longitude 95° 45′E in area C (station 2, 5, 8 and 11).
(Dots indicate data location)

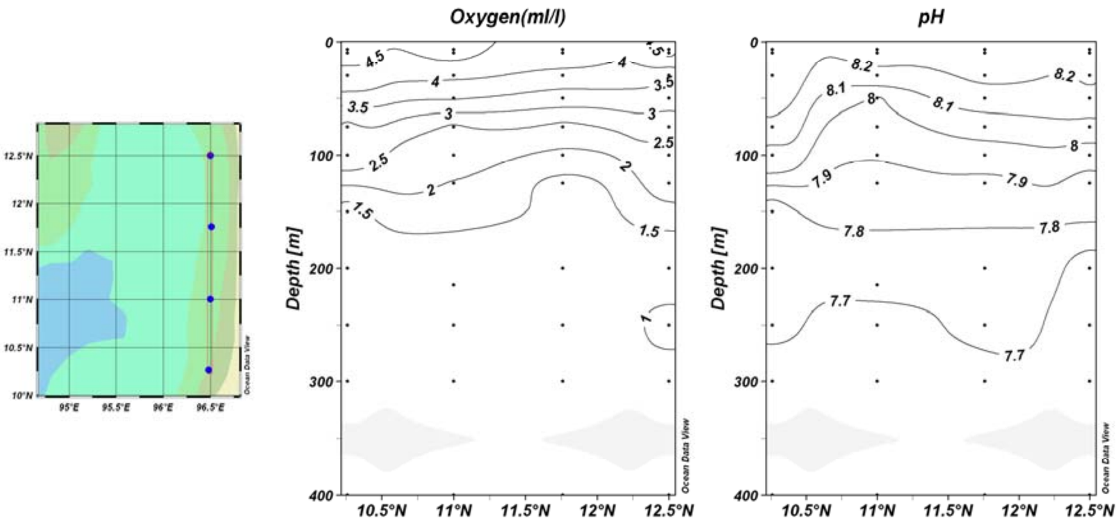

Figure 17 Section plots of dissolved oxygen (ml/l) and pH of stations along longitude 96° 30′E in area C (station 3, 4, 9 and 10).
(Dots indicate data location)

Temperature-Salinity Diagram

Three water masses were observed during the survey (Fig. 18, 19 and 20). Surface layers ranges down to nearly 100 m thick of area A and B were occupied by low salinity water (32-34 psu). This water is known as the "Bay of Bengal water" (BBW). At the surface layer of area C, salinity is lower than that in area A and B by about 1 psu (31-33 psu). Surface water thickness in area C was nearly 150 m. This water mass may be originated in the Andaman Sea from the outflow of large rivers in the area.

The deepest layer in all survey areas, was occupied by low temperature (10-15°C) and high salinity water (more than 35psu), which its property is resemble to the Indian Central Water (ICW) (Rao, 1965 and Tomczak and Godfrey, 2001). It was noted that data of station 31 in area B show a strange characteristic, which could not be explained here.

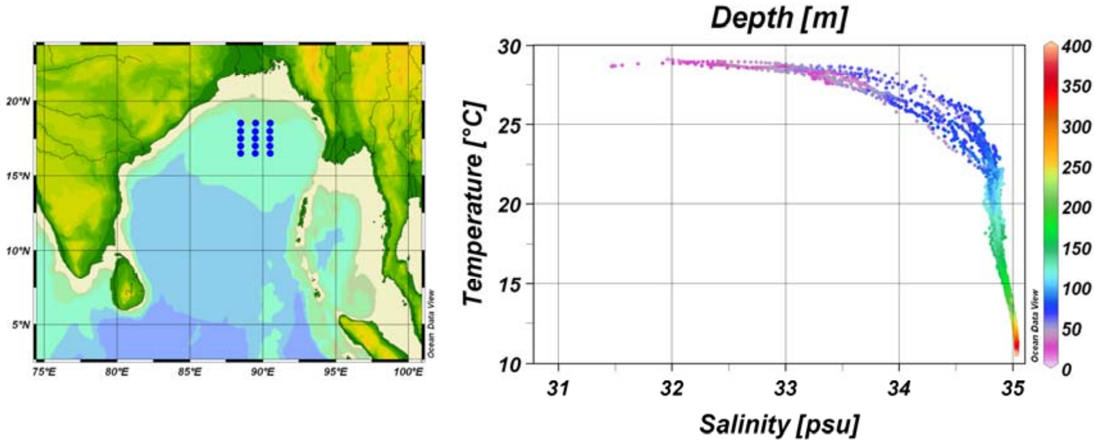

Figure 18 TS diagram of water mass in area A. (colors indicate water depth)

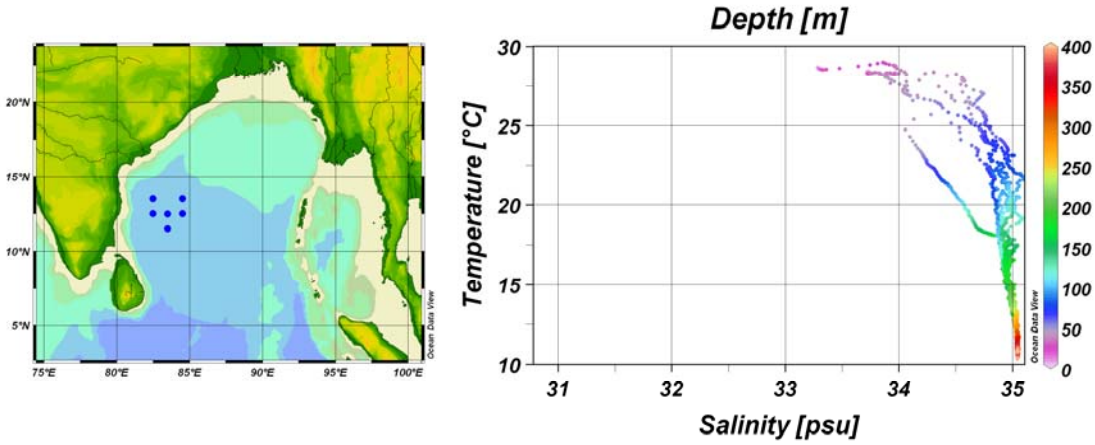

Figure 19 TS diagram of water mass in area B. (colors indicate water depth)

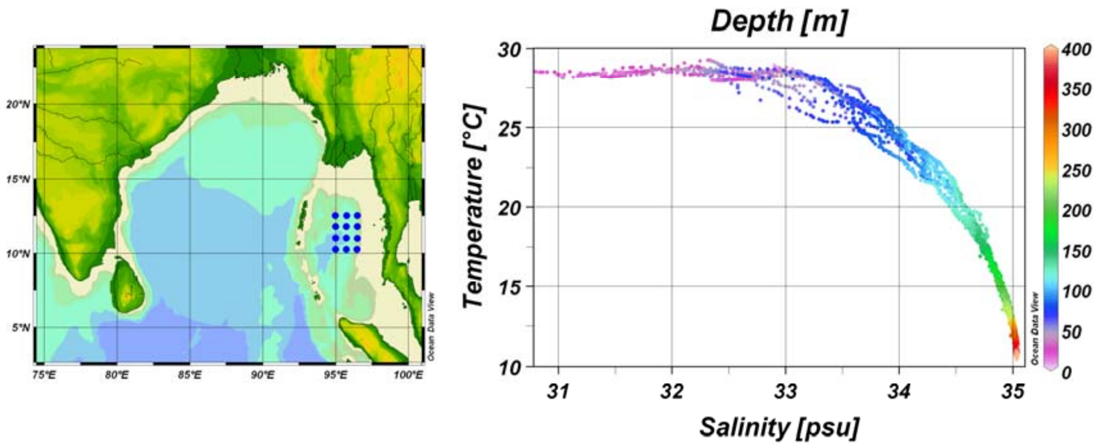

Figure 20 TS diagram of water mass in area C. (colors indicate water depth)

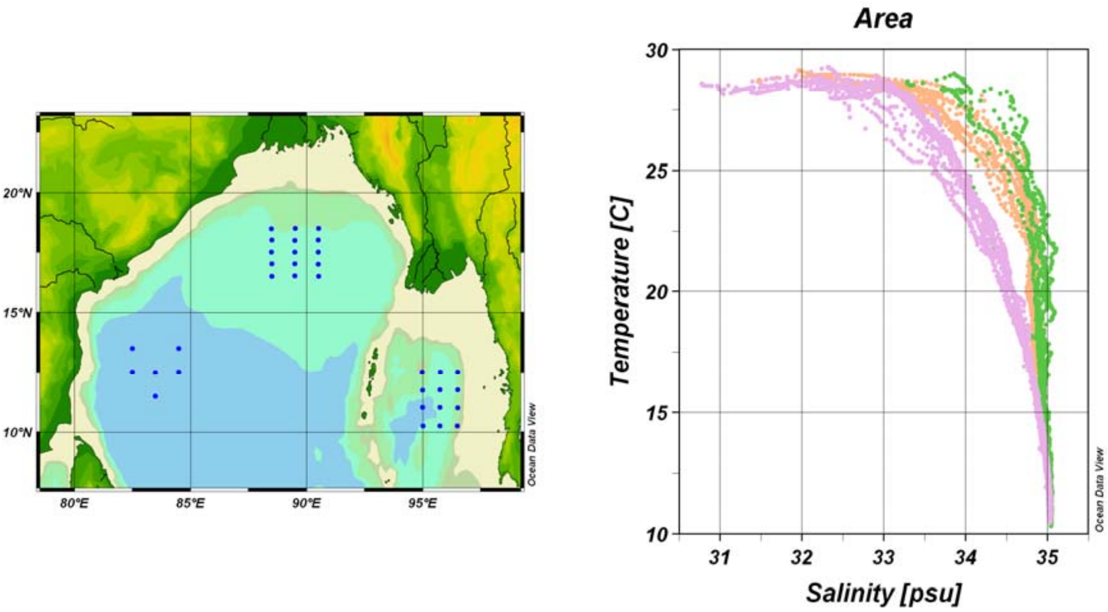

Figure 21 TS diagram of all survey areas.
(colors denote survey area; orange, green and pink represent data from area A, B and C respectively)

Discussions

Salinity of water in the west of the Bay was higher than that in the north and the eastern boundary. Wind direction (Fig. 22) and surface current direction (Fig. 23) explain the observational results that high saline water flows into the Bay from the South, then flows northward and eastward by wind driven current. At the west of the Bay wind direction was northeastward. At the North, wind flowed northward except at the station along longitude $88^{o}30'$E that wind flowed eastward. And at the east of the Bay, wind flowed southeastward and eastward. Due to the influence of cyclone during the survey period, wind directions were not resemble to general wind pattern that during November to December where the Northeast Monsoon prevails in the Bay of Bengal (Tomczak and Godfrey, 2001).

Surface salinity of three areas also shows that water circulation of the Bay was influenced by density driven. At the north and the east of the Bay, large rivers supply huge amount of fresh water that can lead salinity in this area to be lower than at the west by 2-3 psu.

Two cold core eddies were discernible from a low temperature and high salinity water mass in the surface plot and the upheaval of isotherms below the surface in the vertical plot. The occurrence of eddy was reported by Kumar *et al*. (2004). This phenomenon plays as an important mechanism of vertical transfer of nutrients across the halocline to the oligotrophic euphotic zone when the Bay of Bengal is highly stratified.

MLD of area A in this study (31 m) is deeper than in the study of Narvekar and Kumar, (2006) who studied seasonal variability of MLD in the central Bay of Bengal from a long term data set (1900-2004). Their results showed that from the north of latitude 15^{o}N, MLD remained shallow at about 20 m for the most of the year without any appreciable seasonality. The stability of shallow MLD in the north of latitude 15^{o}N was explained by low salinity water, perennially presenting in the northern Bay.

The deeper MLD of this study, compared to that from the average long term data set, may be due to the influence of SIDR cyclone that induces MLD to be deeper than normal situation.

MLD of area B was the deepest (37.8 m) in this study, similar to the results study from long term dataset (Narvekar and Kumar, 2006). The deep MLD is due to moderate to rough sea condition during the survey.

The average shallowest MLD (24 m) was observed in area C. It was coincided with its characteristic that lowest saline area (30.78-32.9 psu). Low surface salinity, influenced from river outflow, may intensify stratification of the water column and decrease vertical mixing in area C.

Dissolve oxygen in this study was low in the North. The concentration was 0.5 to 1 ml/l lower than in the east of the Bay. It was explained in the study of Naqvi (2006) that the distinguishing feature of the Indian Ocean that Asian land mass restrict its northern expanse to the tropic, not allowing adequate ventilation of the thermocline from the North and, to a small extent, a porous eastern boundary (opening between the Indonesian Islands), which facilitates exchange of water with the Pacific Ocean at the low latitudes. The oxygen minimum zone (OMZ) which dissolved oxygen <0.5 ml/l was observed only occurred in area A at depth greater than 200 m. Due to the limitation of wire length, the depth range of OMZ cannot be specified. However, the OMZ depth of this study is within ranges mentioned in the study of Sardessai *et al*. (2007) that OMZ in the Bay of Bengal occurs at intermediate depth (60-800 m). It was suggested that the circulation of the water mass, under the influence of season, and the geochemical processes play a significant role to regenerative processes and OMZ regulation in the Bay of Bengal.

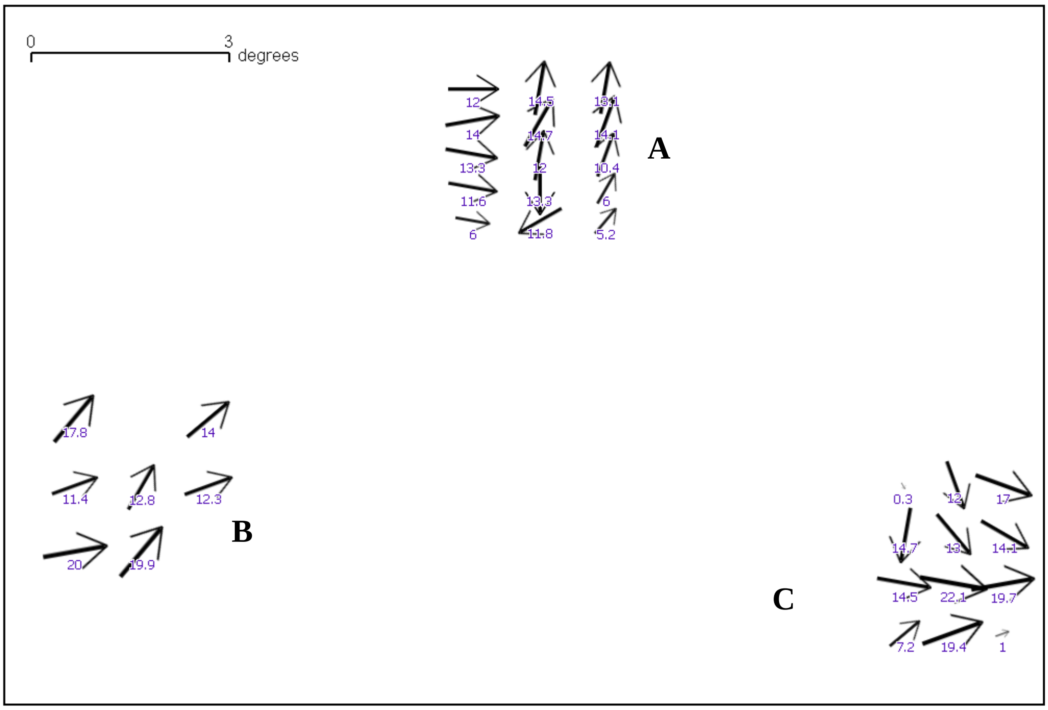

Figure 22 Wind speed and direction recorded from wind indictor during the survey period.

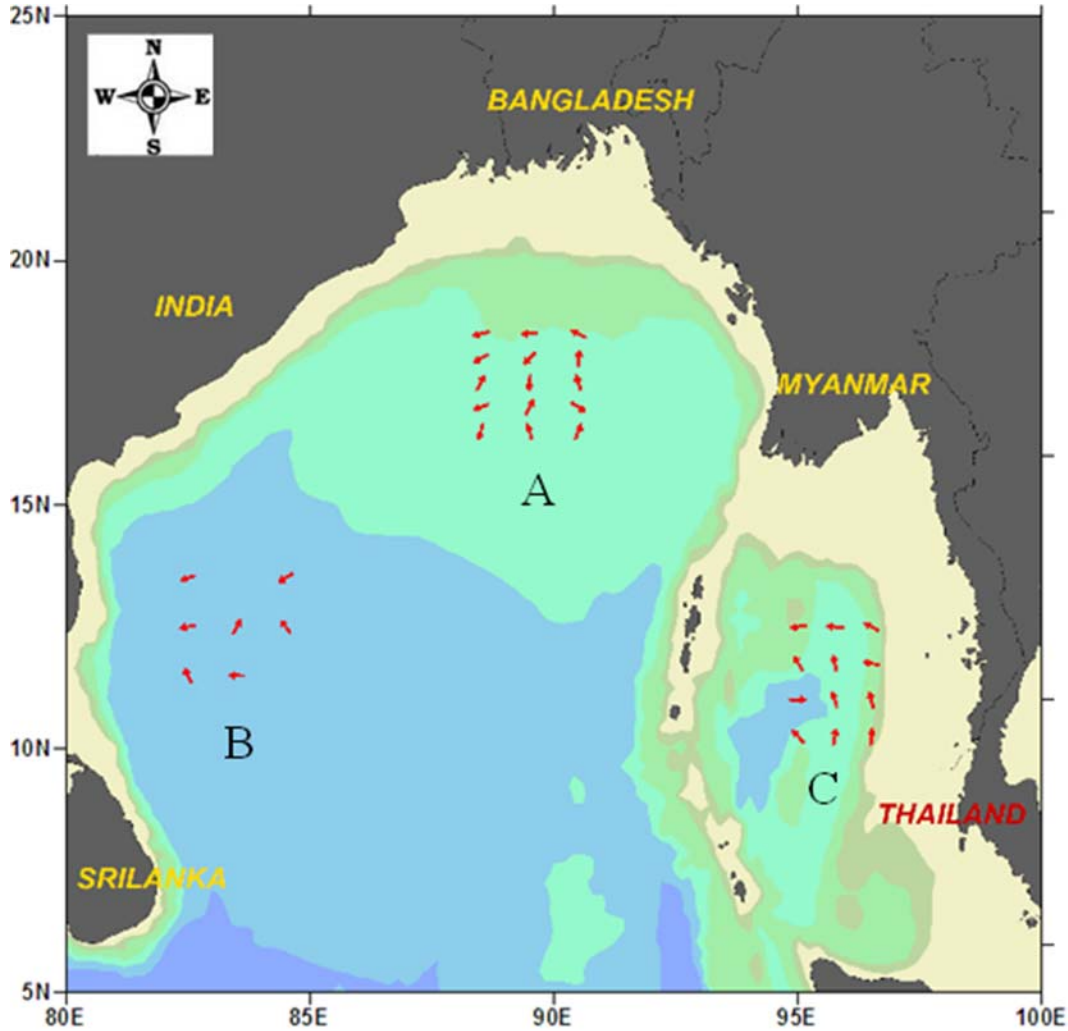

Figure 23 Surface current directions during the survey period.

Conclusions

Two core-cold eddies were observed in the north of the Bay. Huge amount of fresh water supply from main rivers in the Bay plays an important role to mixed layer depth shallowness at the north and the east of the Bay. Dissolved oxygen in the East was higher than in the North. OMZ (<0.5 m/l) was also observed at depth greater than 200 m in the north of the Bay. Surface water beyond 400 m was occupied by three water masses: the Bay of Bengal water (salinity 32-34 psu), the Andaman sea water (salinity 31-33 psu) and the Indian central water (temperature 10-15°C, salinity more than 35 psu). The Indian central water occupied all the deepest layer of all survey areas.

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