

Estimation of Air-Sea CO₂ Flux in the Coastal Waters of Visakhapatnam

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Abstract

Observations were conducted in a time series mode off Visakhapatnam in Bay of Bengal, for a period of 10 days from 8-19th February 2013 to examine the short-term atmospheric events on chemical processes in the upper 100m water column. Water column temperature, salinity at 2 hours interval from surface to 100m were collected using CTD whereas water samples were collected for nutrients (phosphate and silicate), dissolved inorganic carbon (DIC), pH, total alkalinity (TA) at 4 hours interval in the upper 25m water column. Atmospheric properties such as air temperature, humidity, and wind speed were measured in one minute interval. The winds were normally northeast direction with speed ranged between 0.1 and 8 m/s from 8-13th February and decreased to 0.1-4 m/s between 14 and 19th February 2013. The atmospheric pCO₂ ranged from 380 to 420 μatm whereas surface water pCO₂ ranges from ~370 to 470 μatm during study period. The low pCO₂ levels were associated with low saline water indicating the rich nutrient coastal waters were under saturated with reference to atmosphere. The CO₂ flux estimations for this region showed a significant source to the atmospheric CO₂. This study provides information on changes in the physical and chemical processes in relation to the CO₂ flux at the air-water interface in the coastal Bay of Bengal.

Index Terms: pCO₂, pH, TA, CO₂ Flux

I. INTRODUCTION

The Bay of Bengal is a unique semi enclosed tropical basin, forced locally by the semi-annually reversing monsoon winds and remotely by zonal winds in the equatorial Indian Ocean (EIO)(McCreary, 199). In addition, the Bay of Bengal also receives large quantity of freshwater by excess precipitation and river runoff over evaporation (Varkey et al., 1996). Studies have been conducted (Rao et al., 1994) in order to understand the nutrients and inorganic carbon system in the Bay of Bengal during pre-monsoon periods during both the south west and north east monsoon periods and noticed that surface waters are completely devoid of nutrients due to strong vertical stratification, whereas surface pCO₂ levels were mostly less than atmospheric values. Thus, low pCO₂ levels in the North West coastal region of Bay of Bengal were influenced by both physical and biological processes. Coastal Bay of Bengal shows lower pCO₂ levels in the north western region and higher pCO₂ levels in the south western region than to the atmospheric levels (Sarma et al., 2012). Previous study reports (George et al., 1994; Kumar et al., 1996) suggest that the coastal Bay of Bengal acts as a net source for CO₂ to the atmosphere throughout the year except for a brief north east monsoon period and acts as a source or sink depending on coastal surface circulation led majorly by riverine influx. In order to examine this, the time-series observations were conducted at a single station off Visakhapatnam, east coast of India, to understand how physical and atmospheric forcing influence the biogeochemical processes of the water column in the coastal Bay of Bengal. The main objective of this study is to understand the variation in sea-to-air fluxes of CO₂ in the coastal Bay of Bengal.

II. MATERIALS AND METHODS

SAMPLING AND MEASUREMENTS

The atmospheric data collection and water sampling was carried out at a single station off Visakhapatnam (17° 48.78'N and 83° 58.67'E) where water column depth was ~100 m (Fig-1). The sampling was conducted for 10 days from 8th to 19th February 2013. Due to low depression, sampling was terminated on 11th and 12th February 2013. The atmospheric parameters such as air temperature, air pressure, solar radiation, humidity, wind speed, direction and gust were measured using AWS (Watch Dog, 2000 series) instrument which was mounted on the top of the boat. The atmospheric CO₂ was measured using Li-COR 840A. The partial pressure of carbon dioxide (pCO₂) in air that is in equilibrium with a sample of sea water is measured (Weiss, 1974). The partial pressure of CO₂ is a temperature-dependent property of the sea water sample; thus it is important to record the temperature at

equilibrium. Water samples were collected using 10L Niskin bottles at standard depths from surface to 100 m at 0600hrs every day and up to 25 m at 4 hours interval with varying depths of (0,5,10,15,25m). Subsamples were drawn for pH/total alkalinity(TA), dissolved inorganic carbon and nutrients. Nutrients were analyzed following the standard methods (Grasshoff et al., 1983; Millero et al., 2006). The pH and TA were measured by potentiometer (Metrohm, Switzerland) using Gran titration method following Standard Operating Procedures (SOP) suggested by DOE (1998). Dissolved inorganic carbon (DIC) was measured using a Coulometer (UIC Inc., USA) attached to the in-house built automated sub-sampling system at NIO-RC. The water column pCO_2 was computed using measured salinity, temperature, nutrients (phosphate and silicate), and pH, DIC using dissociation using CO_2 sys program (Lewis and Wallace, 1998).

ESTIMATION OF AIR-SEA CO_2 FLUX

The air-sea flux of CO_2 for the study region was estimated using measured atmospheric and water pCO_2 with measured winds using the following empirical relation (Anirban et al., 2012).

$$F = k \beta [pCO_{2w} - pCO_{2a}]$$

Where, k and β respectively are the gas transfer velocity and solubility of CO_2 in sea water.

The gas transfer velocity was calculated using the following relation (Wanninkhof, 1992)

$$k = 0.17 U_{10} (660/Sc)^{2/3} \text{ for } U_{10} < 3.6 \text{ m/s and}$$

$$k = 2.85 U_{10} - 9.65 (660/Sc)^{0.5} \text{ for } 3.6 < U_{10} \leq 13 \text{ m/s}$$

Where U_{10} is the wind speed in m/s, Sc is the Schmidt number, the viscosity of sea water divided by the molecular diffusion co-efficient of CO_2 in water and it can be calculated from the data of sea surface temperature (SST) (Wanninkhof, 1992).

$$Sc = A - Bt + Ct^2 + Dt^3$$

Where $A=1992.1$, $B=121.6$, $C=3.54$, $D=0.04227$ and 't' is the temperature of water. The Ostwald solubility co-efficient, β is a temperature and salinity dependent variable of the seawater sample and was calculated using the following relation.

$$\ln \beta = A1 + A2(100/T) + A3 \ln(T/100) + S[B1 + B2(T/100) + B3(T/100)^2]$$

Where T is the temperature in Kelvin and S is the salinity of the water sample. Positive flux values indicate sea is a source for atmospheric CO_2 and vice versa for sink.

III. RESULTS AND DISCUSSION

The present study was aimed at to understand the influence of physical and chemical processes on CO₂ flux variability in the upper layer of the ocean column at Visakhapatnam coast in the Bay of Bengal.

3.1 VARIATIONS IN WIND MEASUREMENTS

The diurnal variability of the wind speed is mainly due to the variations in the atmospheric conditions and during the study period the winds were mostly north east direction. Initially low pressure conditions were noticed that triggered high winds of 9.2 m/s (Fig-2) during the first three days (9-10th) and wind speeds were decreased to 4 m/s during the next three days with a slight increase of 8.3 m/s in the last two days of the experiment. The air temperature displayed typical day and night variability associated with solar radiation and ranged between 21.6^oC and 31.2^oC (Fig-3). The amplitude of variability in air temperature is relatively low between 9th and 11th February 2013 associated with high wind speeds and has been sharply increased during weak wind period. Such differences were caused due to the variations in heat fluxes at the air-water interface.

3.2 VARIATIONS IN SEAWATER AND ATMOSPHERIC pCO₂

The diurnal variability of surface water and atmospheric pCO₂ is clearly observed from the Fig-4. In the coastal regions because of nutrient rich waters pCO₂ variability will be low. In the present study location the low sea water pCO₂ values were observed i.e. 370-475 µatm and are consistent with the low saline waters as shown in Fig-5 observed from 14th to 19th February. As the water samples were collected up to 25m of depth from surface (depth ranges from 0,5,10,15,25) for every 4 hours during all the cruise days and at every day early 6 hrs the samples were collected up to a depth of 100m from surface (depth ranges from 0,5,10,15,25,50,75,100). The time series analysis of water column pCO₂ measured for all the days at the sampling station is shown in Fig-6. Fig-6a shows pCO₂ measured at early 6 hours for all the days up to 100m water column, shows very high values in the deep waters. From 50m water column the pCO₂ values increased from 450 – 1300 µatm at a depth of 100m. Fig-6b shows pCO₂ measured every 4 hours for all the days within the 25 m water column shows the variability of pCO₂ from 360 – 400 µatm during 15th to 18th February 2013.

Time series observations of salinity, DIC, TA and pH for the study period were related with the pCO₂. From Fig-6 it is observed that in the upper water column up to 25 m of depth the pCO₂ values are very low ranging from 370-400µatm during mid 14th to 18th February which were associated with sudden drop in the wind speed (>4m/s) (Fig-2) and the advection of low saline coastal waters (Fig-6) leading to high stratification.

From Fig-7 it is clearly observed that $p\text{CO}_2$ has positive relationship with TA and DIC, whereas an inverse relationship was observed with pH with high values (8.15 -8.24). Thus low $p\text{CO}_2$ levels in the coastal waters were influenced by both physical and biological processes. The atmospheric $p\text{CO}_2$ which were estimated using the wind speed and the air temperature at standard pressure measured onboard the ship with an AWS and varies from 370 - 402 μatm . The $p\text{CO}_2$ values increased 380-402 μatm during mid 17th to 18 February which was associated with increase in the wind speed ($> 6\text{m/s}$) (Fig-4).

The calculated air-sea fluxes of CO_2 suggested that the study region is significant source for atmospheric CO_2 ranging from -2.089 to 7.149 $\mu\text{mol C m}^{-2} 4\text{hr}^{-1}$. Every four hour measurements during the study period were averaged per each day (Fig-8) and the maximum positive flux was 4.56 $\mu\text{mol C m}^{-2} \text{d}^{-1}$ with a negative influx of -0.8 $\mu\text{mol C m}^{-2} \text{d}^{-1}$ as both the fluxes were recorded when high winds were noticed(Fig-4). The daily averaged flux of 0.51 $\mu\text{mol C m}^{-2} \text{d}^{-1}$ were recorded indicating the ocean acts as a source to the atmospheric CO_2 which were also coinciding with the recent results (Sarma et al., 2013), the Coastal Bay of Bengal acts as a source to the atmosphere with a mean flux from the entire coast amounts to 0.2 $\mu\text{mol C m}^{-2} \text{d}^{-1}$ and as a net source of CO_2 to atmosphere during pre-SWM⁵ (0.66 $\mu\text{mol C m}^{-2} \text{d}^{-1}$).

IV. CONCLUSIONS

The analysis of the co-located physical, chemical and biological time series data collected along the Visakhapatnam coast reveals out the diurnal cycle of the physical process and the associated changes in the coastal waters of Bay of Bengal influencing the air-sea interactions. The heavy winds during the first three days caused the vertical mixing in the upper water column to 10s of meters. As well the carbon dynamics at the location was also studied and mainly the sources and sinks of the carbon were mainly influenced by the local or remote forcing. The surface water $p\text{CO}_2$ shows low values associated with the low saline waters and sudden drop in the wind speed and the advection of low saline coastal waters leading to high stratification in the upper water column. This study indicates that the changes in the atmospheric conditions brought significant modifications in the water column with reference to physical structure and also biogeochemical composition. However, more number of in-situ observations are required for the strong justification of the study area that acts as a source.

V. ACKNOWLEDGEMENT

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VI. REFERENCES

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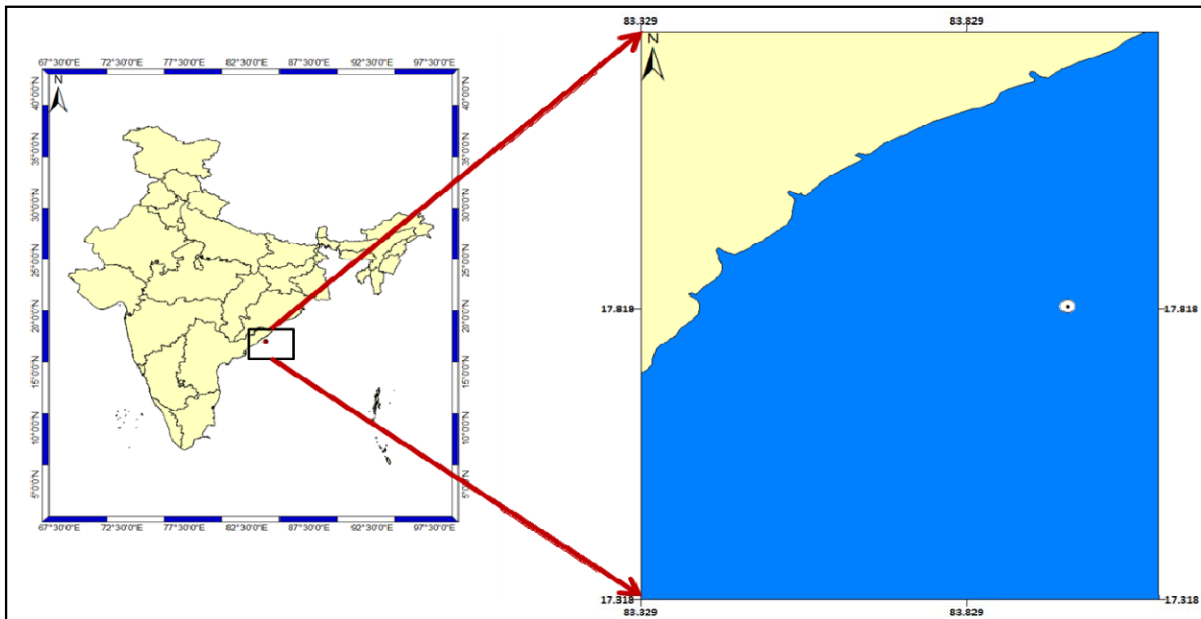


Figure 1: Map showing the geographical distribution of time series location along Visakhapatnam coast.

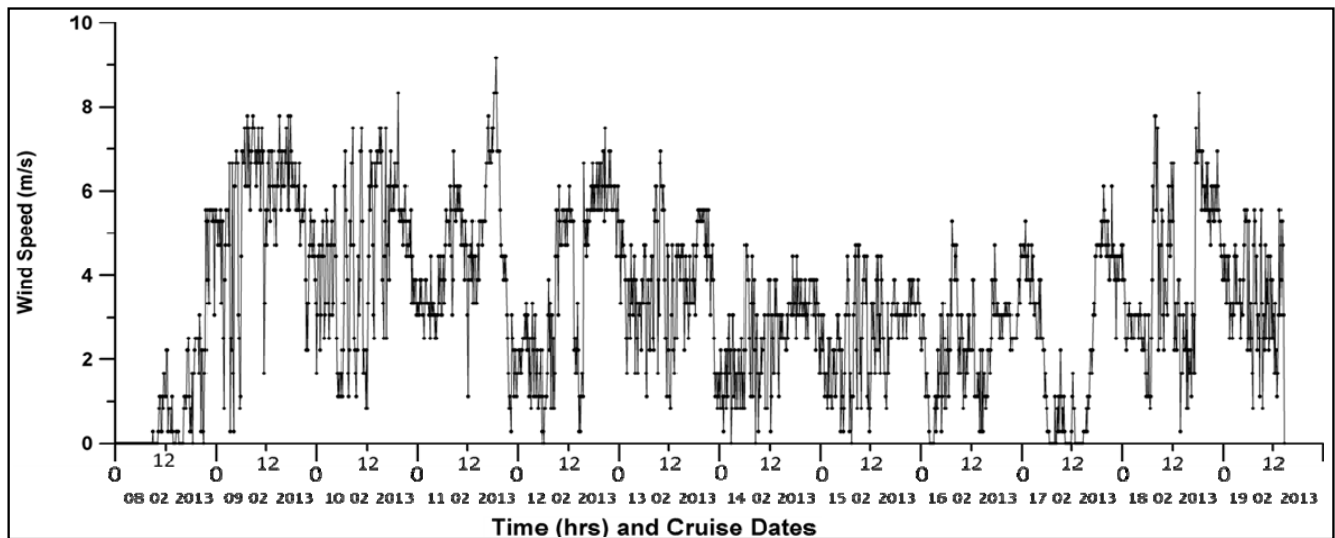


Figure 2: Time Series observation of Wind Speed data collected over the study location

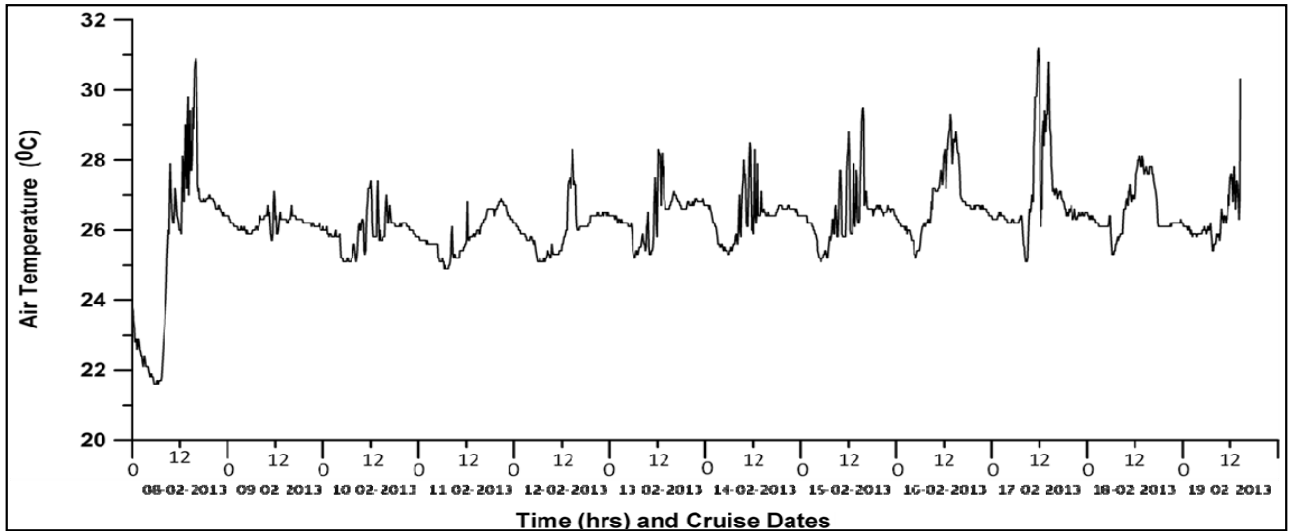


Figure 3: Time Series observation of Air Temperature data collected over the study location.

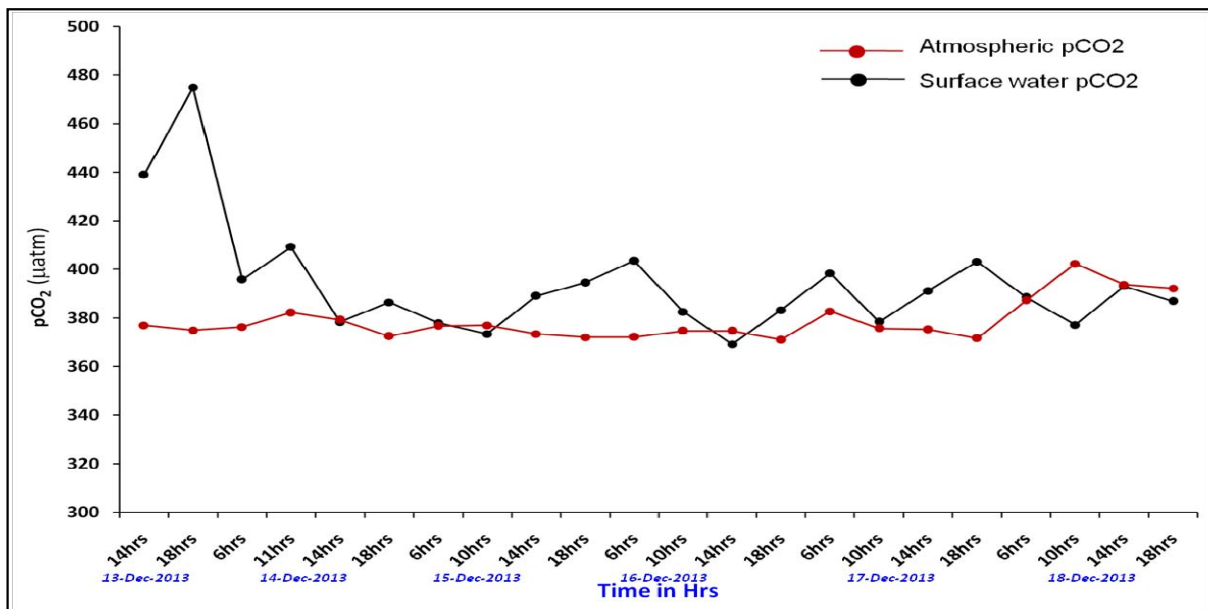


Figure 4: Sea water and atmospheric pCO₂ measured during the study period from 13th to 18 February 2013 for every 4 hrs.

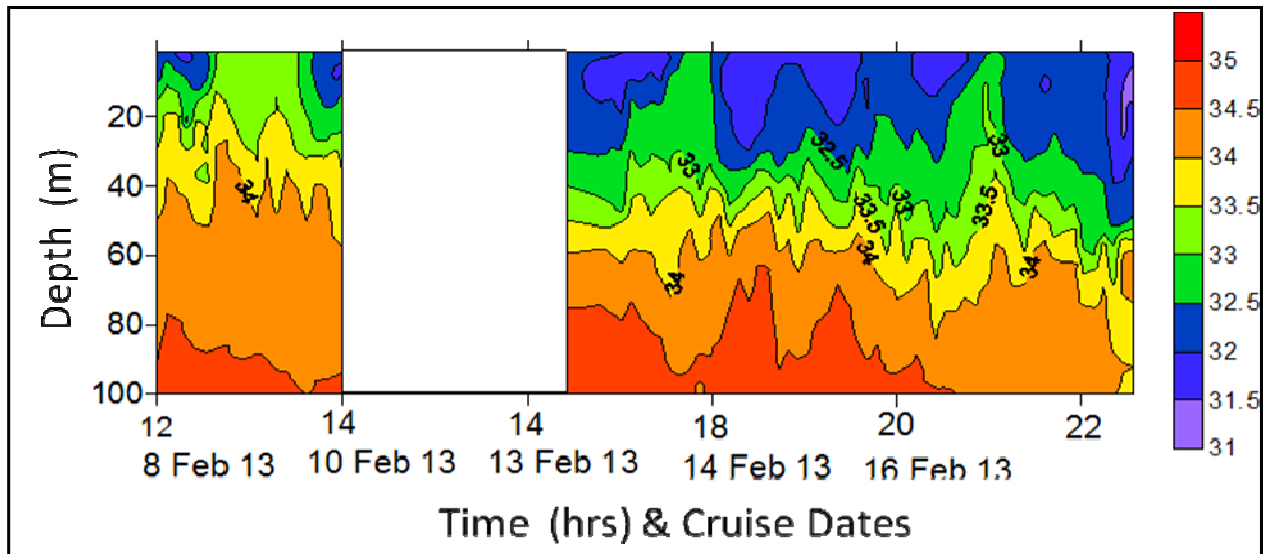


Figure 5: Water column (a) $p\text{CO}_2$ (b) Salinity (c) DIC (d) TA and (e) pH data up to 100m depth collected for every one hour interval during 09th to 18th February 2013.

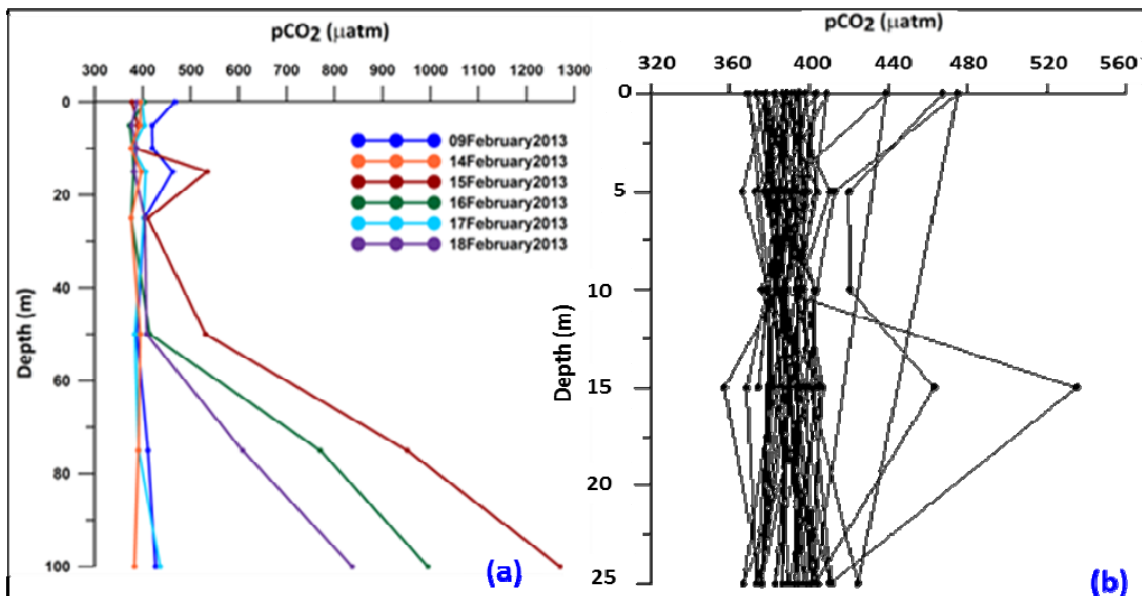


Figure 6: Water column $p\text{CO}_2$ from (a) surface to 100m depth measured at early 6 hrs and (b) surface to 25m for every 4 hour interval during 9th to 18th February 2013.

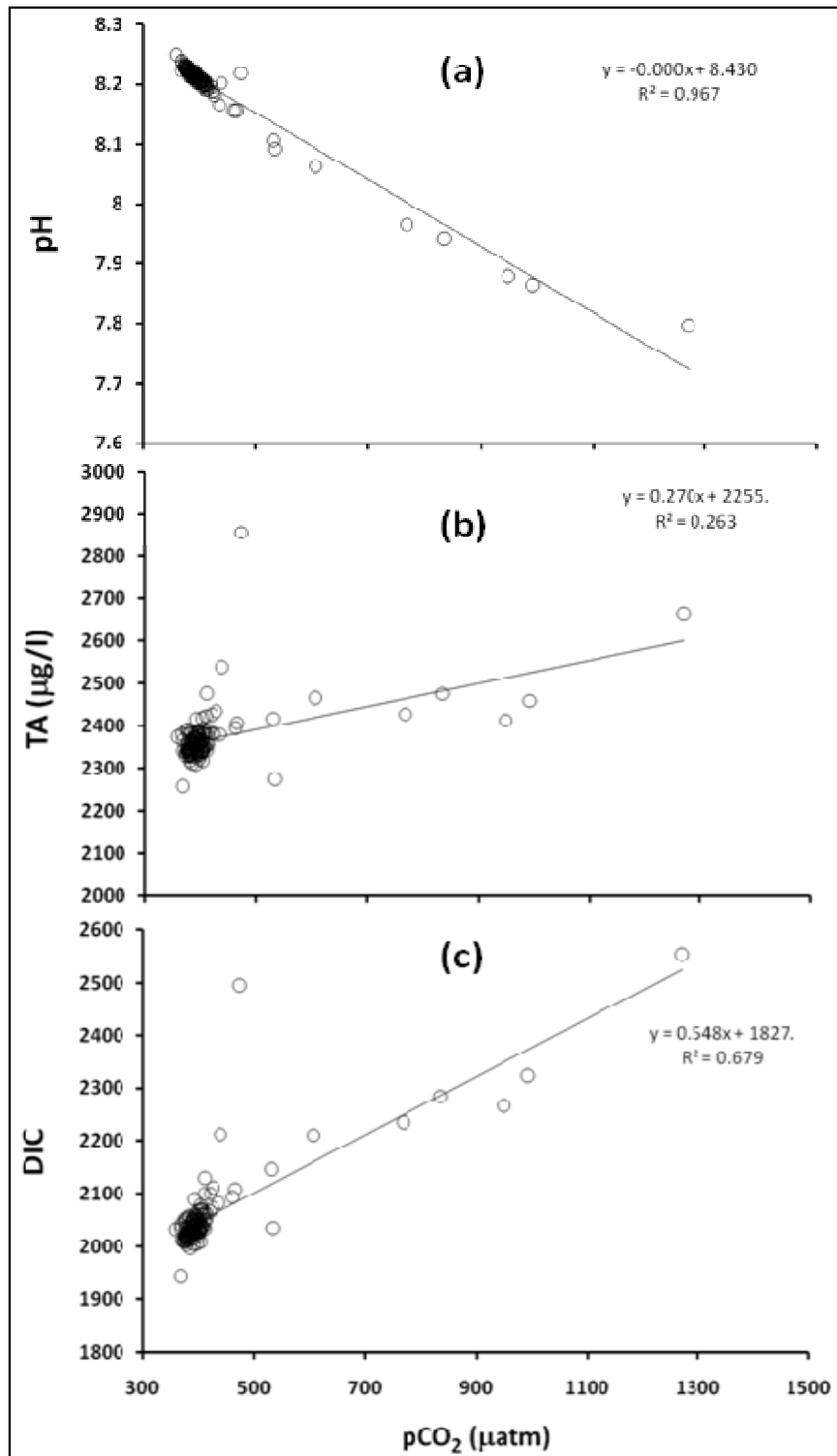


Figure 7: pCO_2 relationship with (a) pH (b) TA and (c) DIC

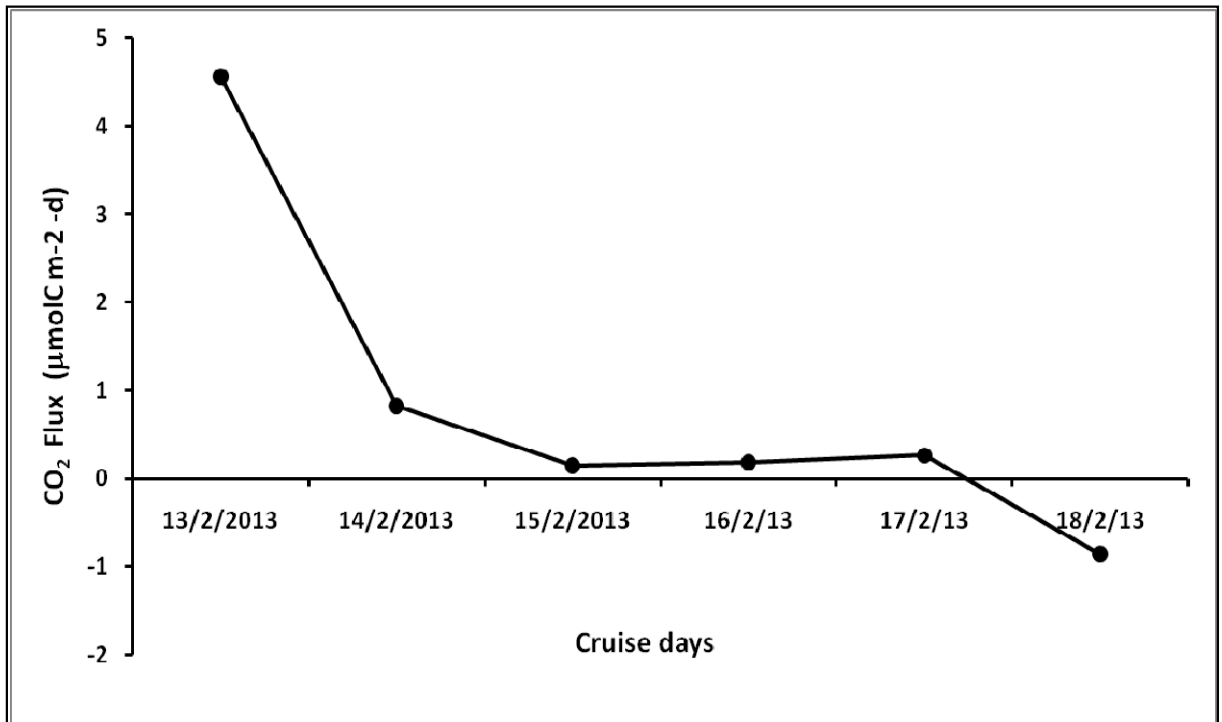


Figure 8: Mean Air-sea CO₂ flux calculated for every 4 hrs and averaged per day from 13th to 18th February, 2013.