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Air-sea CO_2 flux pattern along the southern Bay of Bengal waters

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ABSTRACT

Physico-chemical observations made from January 2013 to March 2015 in coastal waters of the southwest Bay of Bengal show pronounced seasonal variation in physico-chemical parameters including total alkalinity (TA: 1927.390–4088.642 μmol kg^{-1}), chlorophyll (0.13–19.41 μg l^{-1}) and also calculated dissolved inorganic carbon (DIC: 1574.219–3790.954 μmol kg^{-1}), partial pressure of carbon dioxide (pCO_2: 155.520–1488.607 μatm) and air-sea CO_2 flux (FCO_2: −4.808 to 11.255 mmol Cm^{-2} d^{-1}). Most of the physical parameters are at their maximum during summer due to the increased solar radiation at cloud free conditions, less or no riverine inputs, and lack of vertical mixing of water column which leads to the lowest nutrients concentration, dissolved oxygen (DO), biological production, pCO_2 and negative flux of CO_2 to the atmosphere. Chlorophyll and DO concentrations enhanced due to increased nutrients during premonsoon and monsoon season due to the vertical mixing of water column driven by the strong winds and external inputs at respective seasons. The constant positive loading of nutrients, TA, DIC, chlorophyll, pCO_2 and FCO_2 against atmospheric temperature (AT), lux, sea surface temperature (SST), pH and salinity observed in principal component analysis (PCA) suggested that physical and biological parameters play vital role in the seasonal distribution of pCO_2 along the southwest Bay of Bengal. The annual variability of CO_2 flux clearly depicted that the southwest Bay of Bengal switch from sink (2013) to source status in the recent years (2014 and 2015) and it act as significant source of CO_2 to the atmosphere with a mean flux of 0.204 ± 1.449 mmol Cm^{-2} d^{-1}.

1. Introduction

The global climate change is intimately connected to the carbon cycle with carbon dioxide as one of the major greenhouse gases. Since carbon dioxide is a climatalogically significant constituent of atmosphere which constitutes about 0.4% of the air. Industrial revolution and human activities such as fossil fuel combustion, forest burning etc. resulted in increase of atmospheric CO_2 levels in the past five decades as compared to the pre-industrial CO_2 concentrations. The atmospheric concentration of CO_2 is being regulated by continuous exchange of oceanic CO_2 at the surface of the oceans through air-sea

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interaction and enters the ocean waters by simple diffusion. In that way, significant portion of the anthropogenically released carbon dioxide is taken up by the oceans, thus acting as largest reservoir of carbon in the biosphere. Approximatetly, the oceans stores about 93% of the earth carbon dioxide ~40 Tt CO_2 (Feely et al., 2001; Nellemann et al., 2009). In addition, oceans cycle about 90 Gt of CO_2 Y^{-1} and remove over 30% of the carbon released to the atmosphere (González et al., 2008).

Most of the carbon in the oceans is present as inorganic carbon and the carbon uptake can be estimated with more reliability than the terrestrial biosphere. Uptake of CO_2 depends on inorganic carbon chemistry and largely influenced by hydrography, circulation of water masses, mixed layer dynamics, wind stresses and biological processes in the ocean (Broecker and Peng, 1982). The increase in CO_2 concentration alters the chemical equilibrium and lowers the pH of the seawater. Over a period of time, the capacity of the ocean to sequester the additional quantities of atmospheric CO_2 reduces due to the altered ocean's carbonate system (Prentice et al., 2001; Bindoff et al., 2007; Solomon et al., 2007).

Ocean's uptake of CO_2 through transfer process is a function of CO_2 solubility in seawater across the air-sea interface which is temperature (SST) dependent and it is high in high latitude cold waters rather than in the low latitude warm waters due to the reduced solubility of CO_2 (Lekshmi, 2013) at high SST. Besides SST, increased rate of photosynthetic activity leads to increased uptake of CO_2 by the seawater (Chester, 2000) usually in the bloom conditions. Most of the carbon absorbed at the surface of the ocean tends to transported to the deep waters and stored over millions of years at the ocean basin (Feely et al., 2001).

Traditionally, the entire CO_2 system can be computed from the combination of any two of the four parameters: pH, pCO_2, DIC and TA. Moreover, the speciation of CO_2 in seawater has been mainly determined by pH and considered as a "master variable" in carbonate system. As the total carbonate system of CO_2 includes reactions, CO_2 species and constants. It is not possible to analytically detect the concentrations of carbonic acid, bicarbonate and carbonate which is controlled by dissociation constants that depend on pressure, temperature and salinity (Luger, 2003).

Though Indian Ocean has known as net sink of atmospheric CO_2 (Takahashi, 1989; Louanchi et al., 1996), the North Indian Ocean is found to be richer in CO_2 than the atmosphere (Tans et al., 1990) where the present study area also falls. There are several reports on the northwestern Indian Ocean (Arabian Sea) (Kumar et al., 1996; Sarma et al., 1996,1998), whereas its eastern counterpart Bay of Bengal is given with lesser importance (Kumar et al., 1992; George et al., 1994; Sarma et al., 2011). Kumar et al. (1996) and Takahashi et al. (2009) reported the Bay of Bengal as a perennial sink for atmospheric CO_2 whereas; Sarma et al. (2011) reported it as a net source of CO_2 to the atmosphere throughout the year except the brief northeast monsoon.

The quantum of freshwater discharged in the Bay of Bengal by its perennial and seasonal rivers causing strong thermohaline stratification which greatly inhibits the vertical mixing of water column (Ku and Luo, 1994; Naqvi et al., 1994; Rao et al., 1994). Most of the Indian estuaries act as a significant source of CO_2 to the atmosphere during the entire year and maximum during the high discharge period (Mandovi and Zuari: Sarma et al., 2001; Chilka lake: Gupta et al., 2008; Cochin estuary: Gupta et al., 2009; and Godavari estuary: Sarma et al., 2011). Consequently, freshwater discharge from these estuaries to the coastal margin might have considerable impact on spatial gradients in the fluxes of CO_2 to the atmosphere. The seasonal distribution of pCO_2 and air-sea CO_2 flux is strongly determined by the role of physical, chemical and biological variables in the specified ecosystem. Hence, the present study was made to find the effect of physical, chemical and biological variables on spatial and temporal distribution of surface water pCO_2 and air-sea CO_2 flux of the southwest Bay of Bengal.

2. Materials and methods

Bay of Bengal is a less productive basin when compared to its western counterpart Arabian Sea and experiencing the seasonal reversal in monsoon *i.e.* southwest and northeast monsoons. Northern Bay of Bengal is known for its low saline surface waters due to the immense discharge of river water from perennial rivers. However, the rivers drain along the southwest Bay of Bengal (Fig. 1) is seasonal and they are more active only during northeast monsoon. These less saline water masses form a strong stratification which cannot be erode by the weaker winds available at the surface, confluence the carbon dioxide system. Besides this, presence of several eddies and their role in enhancing the availability of nutrients and biological production in the surface waters of the northeastern Indian Ocean waters have been reported earlier (Prasanna Kumar et al., 2007; Sardessai et al., 2007). Because of these unique properties of the Bay of Bengal waters receive special attention to studying the global carbon cycle.

Monthly coastal samplings were conducted at three sampling stations viz. Chennai, Cuddalore, and Parangipettai along the Tamilnadu coast of the southwest Bay of Bengal from January 2013 to March 2015. The stations were fixed with the help of Global Positioning System (GPS). The entire data was clustered into four seasons namely postmonsoon (January to March), summer (April to June), premonsoon (south west monsoon – July to September) and monsoon classified based on northeast monsoon prevails in the region during October to December.

2.1. Physico-chemical and biological variables

Surface water samples were collected by using Niskin water sampler and drawn in clean polyethylene bottles for further analysis. Surface water temperature (SST) was measured using digital multi-stem thermometer of 0.1 °C accuracy. Salinity was measured using a hand held refractometer (Atago hand refractometer, Japan). Dissolved oxygen was estimated by the Winkler's method using the 905 Titrando (Metrohm) meter (Strickland and Parsons, 1972). Water samples were filtered