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Baseline

Scales and drivers of seasonal pCO_2 dynamics and net ecosystem exchange along the coastal waters of southeastern Arabian Sea

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ABSTRACT

The impact of seasonal coastal upwelling on the dynamics of dissolved inorganic carbon (DIC) and sea-air fluxes of CO_2 along the coastal waters of Kochi was investigated during 2015, as a part of Ecosystem Modelling Project. The surface water pCO_2 varied from 396 to 630 µatm during the study period. Significant inter-seasonal variations were found in the distribution of physico-chemical variables and surface pCO_2. An increase of 102.1 µatm of pCO_2 was noticed over a two-decade period with a rate of 5.3 µatm y^{-1}. There was an agreement between the fluxes of CO_2 and net ecosystem production (NEP) with respect to the trophic status while NEP was higher than CO_2 fluxes by a factor of 3.9. The annual net ecosystem exchange (NEE) was estimated to be 15.02 mmol C m^{-2} d^{-1} indicating that the coastal waters of Kochi are highly heterotrophic in nature.

The continental seas are the dynamic interface between the terrestrial, ocean and atmosphere components of the Earth's biogeochemical system and play a vital role in the current global climate. Although the continental seas represent only 7% of the total ocean surface area, they play a major role in the global marine primary production and storage of carbon (Walsh, 1991; Liu et al., 2000; Muller-Karger et al., 2005; Doney et al., 2009). Despite their small area, these environments account for ~30% of the total sea-air exchange of CO_2 to the global carbon budget (Chen and Borges, 2009). It is unclear to what extent these environments act as sinks or sources of CO_2 with respect to the atmosphere. The sea-air flux of CO_2 is a result of a wide variety of processes such as production or degradation or export of organic matter, shift in carbonate system, upwelling and the thermodynamic effects related to both water temperature variations and water mass mixing (Borges and Frankignoulle, 2003). Several studies have reported that coastal seas are autotrophic as the production of organic matter is higher than its total remineralization; thus, such a system exports and/or stores organic matter and is therefore potentially a sink for atmospheric CO_2 (Gattuso et al., 1998; Wollast, 1998). The production in these seas may be fueled by the enormous amounts of nutrients from estuarine/riverine discharge, upwelling and organic matter remineralization. Due to the high metabolic activity in these regions an intense sea-air exchange of CO_2 can be expected (Thomas et al., 2004; Chen and Borges, 2009). Most of the continental seas are partially/active upwelling regions. Coastal upwelling zones are known to be biogeochemically active sites and are supersaturated with CO_2 with respect to the atmosphere due to the input of CO_2 rich deep waters (Feely et al., 2004; Evans et al., 2011). However, the nutrient rich water due to upwelling fuels the primary production and lowers the pCO_2 (Walsh et al., 1988). As these two processes affect the variation of CO_2 across the sea-air interface, it is difficult to understand whether these regions are sink or source of atmospheric CO_2.

Arabian Sea is a unique ecosystem that experiences variations in trophic status in response to seasonal atmospheric driving forces such as semi-annual reversal of surface circulation between southwest and northeast monsoon (Wyrtki, 1973; Brock et al., 1992; Shetye et al., 1994). During monsoon the wind energy disturbs the development of the mixed layer resulting in the nutrient rich euphotic environment, thus alters the trophic status of the basin (Dickson et al., 2001). Arabian Sea experiences two monsoonal events occurring during the Southwest Monsoon and the Northeast Monsoon. Among the two seasons the southwest monsoon is stronger with higher wind speeds and deeper mixed layer depths (McCreary and Kundu, 1989; Brock et al., 1991; Brock et al., 1992) resulting in the accumulation of organic matter fueled by new production (Bauer et al., 1991).

Several studies have shown the Arabian Sea as a perennial source of CO_2 to the atmosphere (George et al., 1994; Goyet et al., 1998; Sarma et al., 1998; Sarma, 2003). Sarma et al., (2000) found that during the southwest monsoon the southwest coast of India was enriched with high pCO_2 and some of the northern parts acted as a sink for

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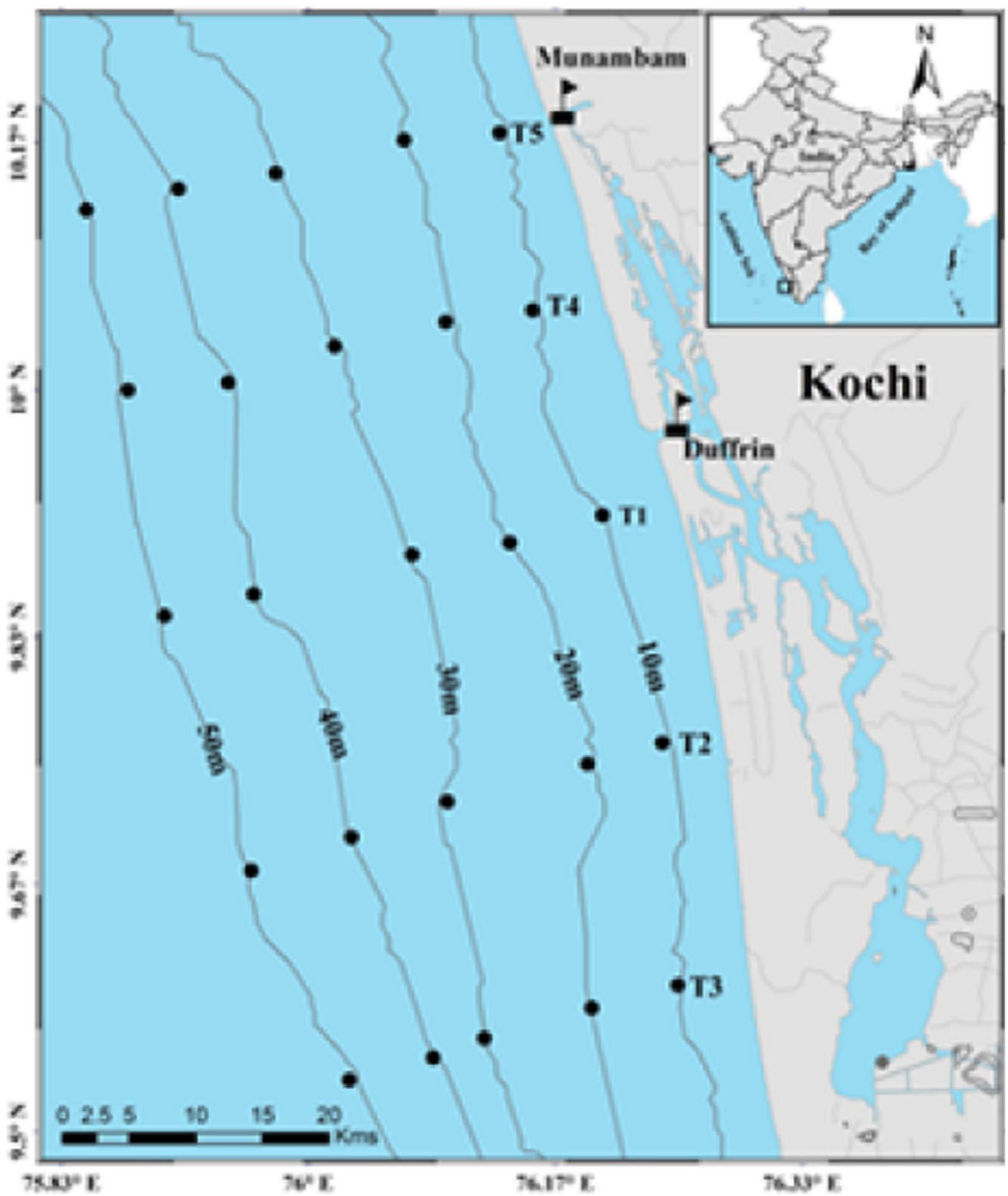

Fig. 1. Map showing the study locations (black dots on depth contours) along the coastal waters of Kochi, India.

atmospheric CO_2. Most of these studies were carried out with coarse resolutions along selected transects on a seasonal basis (Sarma et al., 1998; Millero et al., 1998). In several studies the pCO_2, dissolved inorganic carbon (DIC) and total alkalinity (TA) were derived by using the regression equations based on in situ and remote sensing data for the sea surface temperature, salinity and chlorophyll-a (*Chl-a*) (Goyet et al., 1998; Sabine et al., 1999; Sarma, 2003; Bates et al., 2006) for the entire basin. Observational evidence on the variability of pCO_2 and its sea-air fluxes with space and time along the southwest coast of India, in particular regarding the influence of coastal upwelling, is generally lacking for the past two decades. Due to the paucity of pCO_2 data at closer grid interval, the extrapolation of available sparse data will result in underestimation or overestimation of global carbon fluxes. Hence, the present study aimed to address the spatio-temporal dynamics of DIC and pCO_2 to evaluate quantitative fluxes of sea-air exchange of CO_2 along the coastal waters of southeastern Arabian Sea.

The inorganic carbon dynamics in the coastal waters of Kochi is closely associated with the seasonal changes in the coastal currents, especially the West Indian Coastal Current (WICC) during monsoon and the East Indian Coastal Current (EICC) during post-monsoon. The EICC during post-monsoon carries low-saline waters from the Bay of Bengal and partially stratifies the upper water column (Prasannakumar et al., 2004). In addition, the coastal waters of Kochi receive huge nutrient loads from the Kochi backwaters through the estuarine inlets even in the dry season (Vinita et al., 2015). Further, the coastal waters of Kochi are strongly influenced by the coastal upwelling during monsoon leading to the enrichment of surface inorganic nutrients and carbon and thereby making the shelf waters of Kochi highly productive (Gupta et al., 2016).

Sampling was carried out during four different months representing the four seasons of 2015, i.e., winter monsoon (WM) (January), spring inter-monsoon (SIM) (April), summer monsoon (SM) (August), and fall inter-monsoon (FIM) (November), to understand the spatio-temporal variations in inorganic carbon dynamics and for the estimation of seasonal CO_2 budget in the coastal waters of Kochi. Five transects with 25 locations were selected i.e., up to 50 m depth contour with a stretch of 70 km along the coastal waters of Kochi. (Fig. 1). The entire sampling was performed on board RV Sagar Manjusha and Sagar Purvi.

Water samples were collected using 5 L Niskin sampler at each station from surface (0.5 m) to bottom with fixed depths (0.5, 10, 20,