ภาคผนวก

Thai Society of Higher Education Institutes on Environment

The 1st EnvironmentAsia International Conference on "Environmental Supporting in Food and Energy Security: Crisis and Opportunity"
22-25 March 2011, Bangkok, Thailand

Variations of Dissolved Carbon Dioxide in the Inner Gulf of Thailand

Pranitda Peng-ngeiw* and Thanomsak Boonphakdee
Graduate School of Environmental Science, Faculty of Science, Burapha University, Chonburi, 20131, Thailand.
E-mail: jeab_croc@hotmail.com

Abstract

The variations of dissolved carbon dioxide (CO_2) in the Inner Gulf of Thailand were investigated during the dry season (March 2010) and the wet season (September 2010). The partial pressure of CO_2 (pCO_2) was calculated using data on salinity, temperature, pH and total alkalinity. pCO_2 varied from 164.6±42.7 (mean±S.D.) μatm in the dry season to 100.0±35.1 μatm in the wet season. The calculated air-sea CO_2 fluxes were -0.42±0.03 mmol CO_2 m^{-2} day^{-1} in the dry season and -0.04±0.01 mmol CO_2 m^{-2} day^{-1} in the wet season. Our data suggest that the Inner Gulf of Thailand serves as a sink for atmospheric CO_2. Seasonal variations of the pCO_2 in the Inner Gulf of Thailand were influenced by salinity.

Keywords: Inner Gulf of Thailand; Dissolved carbon dioxide (CO_2); partial pressure of CO_2 (pCO_2); air-sea CO_2 fluxes

1. Introduction

It is well known that the ocean is the biggest reservoir of carbon dioxide (CO_2) in the global CO_2 dynamics (Kattner and Pohl, 2007; Taguchi and Fujiwara, 2010). Seventy percent of the earth surface is ocean. Rising atmospheric CO_2 concentrations from fossil fuel emissions will lead to an increase in oceanic CO_2 via thermodynamic equilibration (Meneil and Matear, 2006). The global net exchange of CO_2 between the ocean and the atmosphere was estimated to be an ocean uptake of 2.2±0.5 billion tonnes of carbon per year (Denman *et al.,* 2007), which was approximately 2% of the gross flux. Increasing CO_2 concentrations in the surface ocean via anthropogenic CO_2 uptake results consequences for oceanic pH, when CO_2 dissolves in water forming a weak acid (H_2CO_3). This may for instance reduce calcification by shell-forming organisms, thus disrupting the biological carbon pump (Sabine *et al.,* 2004; Fabry *et al.,* 2008; Turley *et al.,* 2009).

The study of global carbon budgets in coastal ocean are has not been much attention less, in spite of the fact that related flows of carbon and nutrients are disproportionately high in comparison with its surface area (Borges *et al.,* 2005; Cai *et al.,* 2006; Chen and Borges, 2009), a contribution by far larger than its surface area fraction (7%) of the total ocean.Coastal shelf receives massive inputs of nutrients and carbon from rivers that stimulate the production and remineralization of organic matter (Gypens *et al.,* 2004).

The main objective of this paper is to describe the pCO_2 spatial distribution in surface waters of the Inner Gulf of Thailand, to estimate the air-sea fluxes of CO_2, and to discuss the main factors impacting them. The results of this survey elucidate the sinks and sources of CO_2 in the Inner Gulf of Thailand.

2. Materials and methods

In this study partial pressure of CO_2 (pCO_2) related properties were calculated from measured total alkalinity (TA) and pH using CO2sys software provided by CDIAC (Carbon Dioxide Information Analysis Center, http://cdiac.ornl.gov/) (Lewis and Wallace, 1998). TA was measured on board with the acid titration method (Strickland and Parsons, 1977). pH was measured with a glass electrode which was calibrated every time before use using pH standard solutions at pH= 4.01, 7.01 and 10.01 at 25 °C.

Net CO_2 flux (F) was estimated using the equation $F = k \times K_H \times \Delta pCO_2$, where k is the gas transfer velocity of CO_2, K_H is the solubility of CO_2 in seawater (Weiss, 1974), and ΔpCO_2 the mean sea- air pCO_2 difference; air pCO_2 was 360 µatm (Zhai *et al.,* 2005). A positive flux value represents a net CO_2 exchange from sea to the atmosphere and a negative flux value refers to the net CO_2 exchange from atmosphere to the sea.

We took samples of water from 22 stations (Fig. 1) in the Inner Gulf of Thailand: 13 of these stations were nearshore (indicated by dark circles), and 9 stations were offshore indicated by crosses. The samples were obtained twice, first during the dry season (March 2010) and then during the wet season (September 2010). For this purpose we used a Van Dorn water sampler at the sea surface; for simultaneous measurements of temperature, salinity and pH. Temperature and salinity were measured by multi- parameter probes (YSI Sonde v6600) with proper calibrations prior to use.

The study sites were located in the Inner Gulf of Thailand which is a semi-enclosed tropical sea located in the South China Sea (Pacific Ocean). The gulf covers roughly 10,000 km^2 with an average depth at 15 m. Four major rivers, the Chao Phraya, Mae Klong, Tha Chin, and Bang Pakong discharge freshwater into the Inner Gulf of Thailand along this stretch of coastline (about 270 km).

ส่อสภ TSHE
Thai Society of Higher Education Institutes on Environment

The 1st EnvironmentAsia International Conference on "Environmental Supporting in Food and Energy Security: Crisis and Opportunity"
22-25 March 2011, Bangkok, Thailand

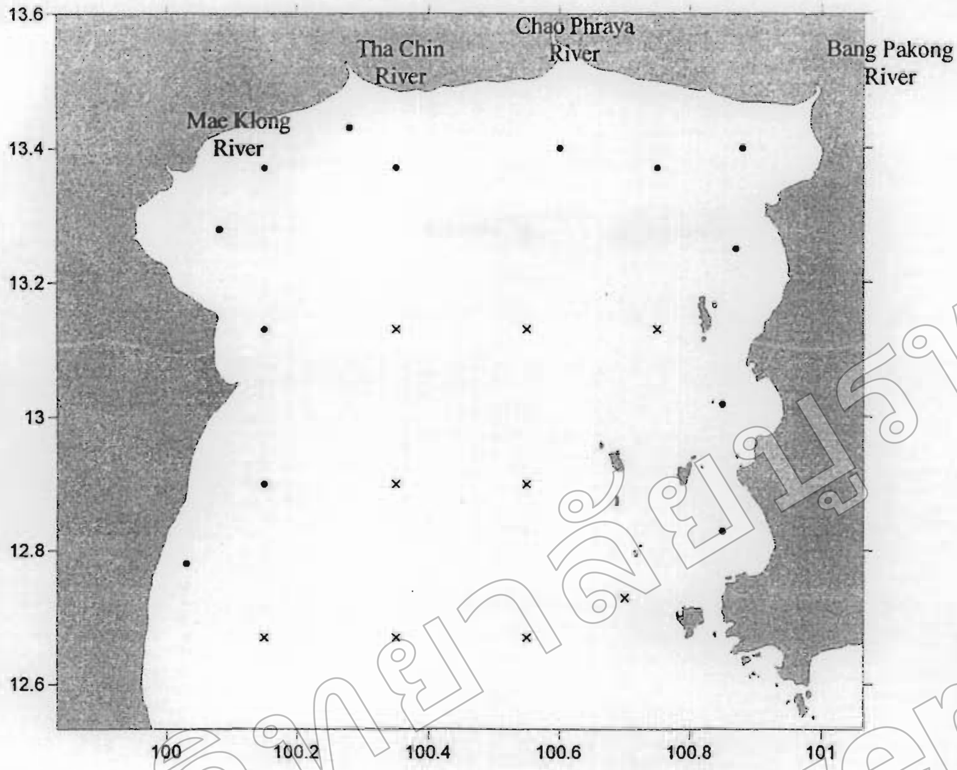

Figure 1. Location of sampling stations in the Inner Gulf of Thailand. Dark circles and crosses indicate near and offshore stations, respectively.

3. Results and Discussion

3.1. Spatial and temporal variations of surface pCO_2 in the Inner Gulf of Thailand

Sea surface pCO_2 varied from 105.3 to 270.3 μatm in the dry season and 49.2 to 166.9 μatm in the wet season, while surface salinity varied from 25.2 to 33.9 in the dry season and mostly within a wide range of 7.7 to 32.2 in the wet season. Surface pCO_2 and salinity were higher during the dry season than in the wet season, suggesting that water mass exchanges and/or freshwater influx play important role in determining factor on the seasonal variations of surface pCO_2. Surface pCO_2 was undersaturated ($pCO_2 < 360$ μatm; atmospheric pCO_2 level of about 360 μatm (Zhai *et al.*, 2005)) during both seasons, suggesting that the Inner Gulf of Thailand serves as a sink for atmospheric CO_2. Most previous studies reported that oceans act as sinks for atmospheric CO_2, for examples, European coastal waters (Borges *et al.*, 2006), Southern Ocean (Le Quere *et al.*, 2007), and Aegean Sea (Krasakopoulou *et al.*, 2009). On the other hand, Zhai and Dai (2009) found that surface pCO_2 in the outer Changjiang Estuary an average of 375 μatm (oversaturated) in autumn, indicating this area acted as a source of atmospheric CO_2.

We observed variations in the surface temperature from 27.0 to 31.4 °C and 27.5 to 32.7 °C during the dry season and the wet season, respectively. The high temperatures during the wet season than in the dry season contrasting low values of pCO_2 in the wet season suggest that rising surface temperatures will decrease the solubility of CO_2 in sea water (Hardman-

Mountford *et al.*, 2009). Consequently, the oceans will draw down CO_2 from the atmosphere less efficiently. While the surface pH varied from 7.9 to 8.2 in the dry season and 8.1 to 8.5 in the wet season, comparison of pH and pCO_2 shows a negative correlation (r^2= -0.91), indicating an increase in the solubility of CO_2 in surface water leads to a decrease in pH, which results in ocean acidification. Such a comparison between pH and pCO_2 shows a significant relationship in the eastern Bering Abyssal Plain with lower pCO_2 values and higher pH values (Liqi *et al.*, 2004).

The variations of surface pCO_2 in the nearshore were thus generally higher than offshore during the both seasons (Fig. 2), indicating an influence by carbon input from land. This influence was reflected by a very dynamic distribution pattern observed in nearshore regions, similar to that observed in other continental shelves (Frankignoulle and Borges, 2001; Zhai *et al.*, 2005). Determinative processes that controlled *p*CO2 in these nearshore regions were complex and might be related to diverse hydrodynamic processes (Zhai *et al.*, 2005) such as upwelling, river discharge and tides.

3.2. Air- sea CO_2 flux

The air-sea flux calculations provided an overview of the CO_2 air-sea exchange in the gulf (Fig. 1). The results of fluxes varied from -0.42±0.03 mmol CO_2 m^{-2} day^{-1} in the dry season to -0.04±0.01 mmol CO_2 m^{-2} day^{-1} in the wet season. Comparing with the other regions, South China Sea the CO_2 flux offset caused by this diurnal variation is ±0.48-0.77 mmol CO_2 m^{-2} day^{-1} (Dai *et al.*, 2009), and the outer Changjiang Estuary was thus generally as a sink of atmospheric CO_2 with an air- sea CO_2 flux of -10.4±2.3 mmol CO_2 m^{-2} day^{-1} in winter, -8.8±5.8 mmol CO_2 m^{-2} day^{-1} in spring, and -4.9±4.0 mmol CO_2 m^{-2} day^{-1} in summer with an only exception of autumn served as a source of atmospheric CO_2 with an air-sea CO_2 flux of 2.9±2.5 mmol CO_2 m^{-2} day^{-1} (Zhai and Dai, 2009). It should be noted that the air- sea CO_2 fluxes in the continental margin remain debatable, but that a current estimate is on the order of -1.9 mmol CO_2 m^{-2} day^{-1} (Cai *et al.*, 2006). It must be pointed out that the continental shelf is a system characterized by highly variable distributions in space.

The net flux of CO_2 in the Inner Gulf of Thailand was estimated as an ocean uptake of 37x 10^3 tons of carbon per year (-0.084 mol CO_2 m^{-2} y^{-1}), this value is less than other regions such as the air-sea flux in coastal waters of the southern bight of the north sea was -0.17 mol CO_2 m^{-2} y^{-1} (Gypens *et al.*, 2004), and European coastal waters was
-1.9 mol CO_2 m^{-2} y^{-1} (Borges *et al.*, 2006). We therefore conclude that the Inner Gulf of Thailand is mostly undersaturated with respect to CO_2 transport from the atmosphere throughout the both seasons. In the future, the Inner Gulf of Thailand may reduce some of its efficiency of CO_2 uptake. Recent studies suggest that the efficiency of CO_2 uptake by the oceans may be decreasing in some oceanic regions, but not in others. For example, atmospheric CO_2 levels suggest that the Southern Ocean CO_2 sink (south of 45°S) did not increase from 1981 to 2004, despite increasing atmospheric CO_2 levels (Le Quere *et al.*, 2007).

Table 1. Surface pCO_2, salinity, temperature and *pH* in the Inner Gulf of Thailand

Observation time	pCO_2 (µatm)		Salinity		Temperature (°C)		pH	
	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.
March 2010 (dry season)	164.6	42.7	32.0	2.2	30.6	0.9	8.1	0.1
September 2010 (wet season)	100.0	35.1	24.9	8.1	31.3	1.2	8.3	0.1

n=22

Table 2. Surface pCO_2 in the near shore and off shore

Observation time	pCO2(µatm) in the nearshore			pCO2(µatm) in the offshore		
	mean	S.D. (n= 13)	range	mean	S.D. (n= 9)	range
March 2010 (dry season)	185.8	51.3	105.3-270.3	143.4	15.3	127.2-167.7
September 2010 (wet season)	105.7	41.2	49.2- 166.9	91.8	23.4	70.2- 142.4

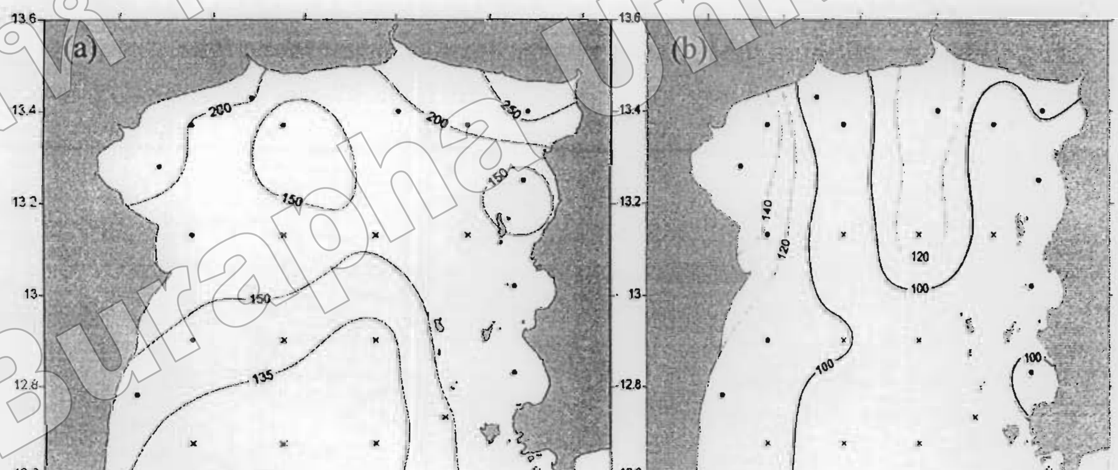

Figure 2. Variations of pCO_2(in µatm) in surface waters of the Inner Gulf of Thailand. (a) pCO_2 variability in March 2010 (dryseason). (b) pCO_2 variability in September 2010 (wet season)

4. Acknowledgment

This research was supported by the Center of Excellence on Environmental Health, Toxicology and Management of Chemicals (ETM). The authors would like to thank Prof. Dr. H. F. Helander for providing constructive comments on improving this manuscript.

5. References

Borges AV, Delille B, Frankignoulle M. Budgeting sinks and sources of CO_2 in the coastal ocean: diversity of ecosystems counts. Geophysical Research Letters 2005; 32: 4pp.

Borges AV, Schiettecatte LS, Abril G, Delille B, Gazeau F. Carbon dioxide in European coastal waters. Estuarine Coastal and Shelf Science 2006; 70: 375-387.

Cai W-J, Dai M, Wang Y. Air-sea exchange of carbon dioxide in ocean margins: a province based synthesis. Geophysical Research Letters 2006; 33: 4pp.

Chen C-TA, Borges AV. Reconciling opposing views on carbon cycling in the coastal ocean: continental shelves as sinks and nearshore ecosystems as sources of atmospheric CO_2. Deep-Sea Research Part 2 2009; 56: 578-590.

Dai M, Lu Z, Zhai W, Chen B, Cao Z, Zhou K, Cai W-J, Chen C-TA. Diurnal variations of surface seawater pCO_2 in contrasting coastal environments. Limnology and Oceanography 2009; 54: 735-745.

Denman KL, Brasseur G, Chidthaisong A, Ciais P, Cox PM, Dickinson RE, Hauglustaine D, Heinze C, Holland E, Jacob D, Lohman U, Ramachandran S, Da Silva Dias PL, Wofsy SC, Zhang X. Couplings between changes in the climate system and biogeochemistry. In: Climate Change 2007: The physical science basis. contribution of working group I to the fourth assessment report of the intergovermental panel on climate change. [Solomon SD, Qin M, Manning Z, Chen M, Marquis KB, Averyt M, Tignor HL, Miller (eds.)] Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA 2007.

Fabry VJ, Seibel BA, Feely RA, Orr JC. Impacts of ocean acidification on marine fauna and ecosystem processes. Marine Science 2008; 65: 414-432.

Frankignoulle M, Borges AV. European continental shelf as a significant sink for atmospheric carbon dioxide. Global Biogeochemal Cycles 2001; 15, 569-576.

Gypens N, Lancelot C, Borges AV. Carbon dynamics and CO_2 air-sea exchanges in the eutrophied coastal waters of the southern bight of the north sea: a modelling study. Biogeosciences 2004; 1: 147-157.

Hardman-Mountford N, Litt E, Mangi S, Dye S, Schuster U, Bakker D, Watson A. Ocean uptake of carbon dioxide (CO_2). MCCIP Briefing Notes 2009; 9pp.

Kattner G, Pohl C. 9th International estuarine biogeochemistry symposium, Estuaries and enclosed sea under changing environmental condition. Marine Chemistry 2007; 107: 277pp.

Krasakopoulou E, Rapsomanikis S, Papadopoulos A, Papathanassiou E. Partial pressure and air-sea flux in the Aegean Sea during february 2006. Continental Shelf Research 2009; 29: 1477-1488.

Le Quere C, Rodenbeck C, Buitenhuis ET, Conway TJ, Lagenfelds R, Gomez A, Labuschange C, Ramonet M, Nakazawa T, Metzl N, Gillentt N, Heimann M. Saturation of the southern ocean CO_2 sink due to recent climate change. Science 2007;316: 1735-1738.

Lewis E, Wallace DWR. Program Developed for CO_2 System Calculations. ORNL/CDIAC-105. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory. U.S. Department of Energy, Oak Ridge, Tennessee 1998.

Liqi C, Zhongyong G, Weiqiang W, Xulin Y. Characteristics of in surface water of the bering abyssal plain and their effects on carbon cycle in the Western Arctic Ocean. Science in China 2004; 47: 1035-1044.

Mcneil BJ, Matear R. Projected climate change impact on oceanic acidification. Carbon Balance and Management 2006; 1: 1-6.

Sabine CL, Feely RA, Gruber N, Key RM, Lee K, Bullister JL, Wanninkhof R, Wong CS, Wallace DWR, Tilbrook B, Millero FJ, Peng T, Kozyr A, Ono T, Rios AF. The oceanic sink for anthropogenic CO_2. Science 2004; 305: 367-371.

Strickland JDH, Parsons TR. A Practical Handbook of Seawater Analysis. Minister of Supply and Services. Canada 1977; 310pp.

Taguchi F, Fujiwara T. Carbon dioxide stored and acidified low oxygen bottom waters in coastal seas, Japan. Estuarine, Coastal and Shelf Science 2010; 86: 429-433.

Turley C, Findlay HS, Mangi S, Ridgwell A, Schimdt DN. CO_2 and ocean acidification. MCCIP Ecosystem Linkages Report Card 2009; 25pp.

Weiss RF. Carbon dioxide in water and seawater: the solubility of a non-ideal gas. Marine Chemistry 1974; 2: 203-215.

Zhai W, Dai M, Cai W, Wang Y, Hong H. The partial pressure of carbon dioxide and air-sea fluxes in the Northern South China Sea in spring, summer and autumn. Marine Chemistry 2005; 96: 87-97.

Zhai W. Dai M. On the Seasonal Variation of Air-Sea CO_2 Fluxes in the outer Changjiang (Yangtze River) Estuary, East China Sea. Marine Chemistry 2009; 117: 2-10.