SEASONAL VARIATION IN SURFACE CARBONATE SYSTEM AND ITS CONTROLLING PROCESSES IN THE WESTERN NORTH PACIFIC SUBTROPICAL GYRE

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ABSTRACT

In order to clarify the role of biological activity in determining seasonal variations in carbonate system in the western North Pacific, we have estimated the net community production (NCP) at 10˚N, 20˚N, and 30˚N along 137˚E based on measurements of dissolved inorganic carbon (DIC), $^{13}C/^{12}C$ of DIC, and auxiliary hydrographic parameters. Sample seawaters in the surface/subsurface layers were taken during five cruises conducted between July 2003 and July 2004. From November 2003 to February 2004, the calculated NCP was -21.2±13.1 mmol m^{-2} d^{-1} at 30ºN and -1.7±15.2 mmol m^{-2} d^{-1} at 10ºN, where the negative value represents that the respiration exceeds the biological production. From February 2004 to May 2004, the NCP was calculated to be 25.8±19.2 mmol m^{-2} d^{-1} at 30˚N and 10.7±3.9 mmol m^{-2} d^{-1} at 10˚N. The present results showed a fairly good agreement with those estimated earlier (13-54 mmol m^{-2} d^{-1} in 24-30˚N in winter-spring, Ishii et al., 2001). The NCP was large as compared with the other processes controlling surface carbonate system, although the concentrations of macronutrients remained the lower levels during the annual cycle.

INTRODUCTION

While the ocean is known as one of the major sinks for atmospheric CO_2, the magnitude of the oceanic CO_2 uptake is unclear. It is necessary to clarify how and to what extent the carbonate system in the ocean affects the atmospheric CO_2 concentration via the changes in air-sea CO_2 flux. The air-sea CO_2 flux is conventionally estimated by the products of the gas transfer velocity, solubility of CO_2, and the difference in partial pressure of CO_2 in surface seawater (pCO_2sw) and that in overlying air (pCO_2air). The pCO_2sw is changed by the following factors: biological activities, the ocean dynamics (lateral transport, vertical mixing) and thermodynamic effects derived from changes in surface sea temperature and salinity. In the western North Pacific Subtropical Gyre (NPSG), the pCO_2sw variations were mostly caused by the change in DIC as well as the effect of thermodynamics. But the contribution of biological activities and the ocean dynamics to the DIC change is still unclear. In this work, we estimate the net community production (NCP) in the western North Pacific during each season based on repeated measurements of DIC, $^{13}C/^{12}C$ of DIC, and auxiliary hydrographic parameters in the surface/subsurface layers.

SAMPLING AND METHODS

Seawater samples for measurements of $\delta^{13}C$ were collected at 10˚N, 20˚N, and 30˚N along 137˚E (except 30˚N, 137˚E in June 2003) during five cruises conducted in July 2003, November 2003, February 2004, May 2004, and July 2004. The ships used were the R/V Ryofu-maru and the R/V Keifu-maru belonging to the Japan Meteorological Agency. Seawater samples for measurements of $\delta^{13}C$ (100ml glass bottle) were poisoned with 100 μl of saturated mercuric chloride solution, and stored in the dark and cool place. At the laboratory on land, the sample was transferred to preparation line to collect and purify the CO_2. The $\delta^{13}C$ was measured by a mass spectrometer (Finnigan MAT delta-S). The precision of the $\delta^{13}C$ measurement of DIC is estimated to be ±0.02 ‰ based on measurements of replicate samples (n=9).

CALCULATIONS

The seasonal variation in DIC in the surface layer was expressed by the term of horizontal advection (ADV), air-sea CO_2 exchange (GAS), vertical mixing (MIX), net community production (NCP) and entrainment (ENT) [*Quay and Stutsman*, 2003]. Thus the DIC budget in the mixed layer can be written as

$$\frac{d(H\mathrm{DIC})}{dt} = \mathrm{ADV} + \mathrm{GAS} + \mathrm{MIX} - \mathrm{NCP} + \mathrm{ENT}\ .$$

The $DI^{13}C$ (^{13}C component of the DIC, $DI^{13}C$ = DIC $^{13}C/^{12}C$) budget can be expressed using the same terms as

$$\frac{d(H\mathrm{DI}^{13}\mathrm{C})}{dt} = \mathrm{ADV}\frac{^{13}\mathrm{C}}{^{12}\mathrm{C}_{adv}} + \mathrm{GAS}\frac{^{13}\mathrm{C}}{^{12}\mathrm{C}_{gas}} + \mathrm{MIX}\frac{^{13}\mathrm{C}}{^{12}\mathrm{C}_{\mathrm{mix}}} - \mathrm{NCP}\frac{^{13}\mathrm{C}}{^{12}\mathrm{C}_{oc}} + \mathrm{ENT}\frac{^{13}\mathrm{C}}{^{12}\mathrm{C}_{ent}}\ .$$

These two equations were solved for NCP and MIX.

RESULTS AND DISCUSSION

The normalized DIC concentration (n-DIC, S=35) in surface water increased from fall to winter along with the $\delta^{13}C$ decrease at all stations. From November 2003 to February 2004, the n-DIC concentration increased by 29 μmol kg^{-1} from 1967 to 1996 μmol kg^{-1} at 30ºN, 137ºE and by 8 μmol kg^{-1} from 1944 to 1952 μmol kg^{-1} at 10ºN, 137ºE. Over the same period, the $\delta^{13}C$ decreased by 0.25 ‰ from 1.06 to 0.81 ‰ at 30ºN and by 0.10 ‰ from 1.26 to 1.16 ‰ at 10ºN. In this period, the calculated NCP was -21.2±13.1 mmol m^{-2} d^{-1} at 30ºN and -1.7±15.2 mmol m^{-2} d^{-1} at 10ºN, respectively. The negative value indicates that the respiration exceeded the biological production. During fall to winter, the dominant factor that affects the DIC change was the entrainment due to the deepening of mixed layer. From February 2004 to May 2004, the n-DIC concentration decreased by 11 μmol kg^{-1} from 1996 to 1985 μmol kg^{-1} at 30ºN, and the $\delta^{13}C$ increased by 0.16 ‰ from 0.81 to 0.97 ‰. At 10ºN the n-DIC concentration increased by 13 μmol kg^{-1} from 1952 to 1965 μmol kg^{-1} during the same period. The $\delta^{13}C$ decreased by 0.02 ‰ from 1.16 to 1.14 ‰. At the moment, it is not clear that the observed seasonal variation is an average feature in surface carbonate system at 10ºN from winter to spring. From February 2004 to May 2004, the NCP was calculated to be 25.8±19.2 mmol m^{-2} d^{-1} at 30˚N, and 10.7±3.9 mmol m^{-2} d^{-1} at 10˚N. Table 1 shows the contribution of each factor to the DIC change at 30ºN during each period. It indicates that the NCP was the major factor of DIC change during February 2004 to May 2004. *Ishii et al.* [2001] reported that the NCP in 24-30˚N in winter-spring was in the range from 13 to 54 mmol m^{-2} d^{-1}. The present work suggests that the DIC change via the biological activity is considerable factors controlling the pCO_2sw except for the changes in surface sea temperature in the western North Pacific Subtropical Gyre.

Table 1. Control factor of DIC change at 137ºE-30ºN during each period.

Term	2003Nov.-2004Feb.	2004Feb.-2004May	2004May-2004July
	DIC (μmol kg^{-1})	DIC (μmol kg^{-1})	DIC (μmol kg^{-1})
Air-sea CO_2 exchange	4.0±2.7	8.8±5.8	6.7±4.4
Entrainment	26.2±4.1	-	-
Horizontal advection	-0.4±1.4	-1.8±2.8	2.0±2.0
Vertical mixing	-14.8±10.3	5.1±18.1	-19.3±15.2
Net community production	13.4±8.3	-22.5±16.8	-11.2±9.3
Net change of DIC	29±3	-11±3	-22±3

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