TREND OF THE TOTAL INORGANIC CARBON INCREASE IN THE SUBTROPICAL WESTERN NORTH PACIFIC SINCE EARLY 1990S

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ABSTRACT

High-quality data of total inorganic carbon (TCO_2) and other oceanographic parameters have been acquired repeatedly between 1994 and 2003 along 137ºE (WOCE P9) in the western North Pacific. They indicate the significant increase in TCO_2, apparent oxygen utilization (AOU) and preformed TCO_2 in the water columns between 20ºN and 30ºN, in particular, in the North Pacific Subtropical Mode Water (NPSTMW). The increase in the preformed TCO_2 suggests the 0.9 to 1.1 mol m^{-2} yr^{-1} accumulation of the anthropogenic CO_2 in this region. However, the change in the preformed TCO_2 associated with the change in the formation region and/or advection of NPSTMW is also suggested.

INTRODUCTION

The ocean is considered as a major sink of the anthropogenic CO_2. It is demonstrated by the long-term increase in the CO_2 partial pressure in surface water (pCO_2sw) [*e.g. Inoue and Ishii*, 2005; *Midorikwa et al.*, 2005]. However, observations of the oceanic CO_2 parameters in surface waters and, in particular, in the water columns were limited in time and space. What is lacking is our knowledge on the rate of the anthropogenic CO_2 accumulation and its possible variability associated with the variability in the ocean circulation and biogeochemistry. We will report the trend of TCO_2 increase in the water columns of the deeply ventilated subtropical western North Pacific that includes the NPSTMW and the North Pacific Intermediate Water (NPIW).

OBSERVATIONS

We have repeatedly observed vertical section of TCO_2 together with other oceanographic properties along 137ºE in the western North Pacific (Fig.1) in July-August 1994 (WOCE P9), January-February 1997, July 2000, and October-November 2003 using a coulometric method on board the JMA's *R/V Ryofu Maru* and *R/V Keifu Maru*. For all TCO_2 analyses, certified reference material provided by Dr A. G. Dickson in the University of California, San Diego, has been used for quality control.

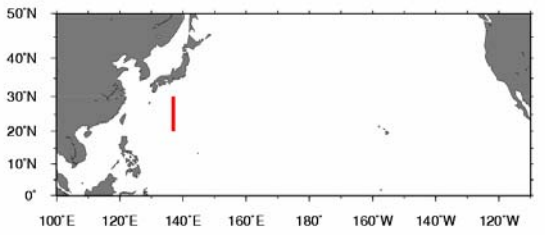

Fig.1 Location of 137ºE in the western North Pacific.

DATA ANALYSES

Data of potential temperature (θ), salinity (S), TCO_2 normalized at S=35 ($NTCO_2$), AOU, and preformed $NTCO_2$ [= (TCO_2-AOU*106/170)*35/S] collected below the seasonal thermocline between 20ºN and 30ºN in the region of the Kuroshio recirculation were taken from the data set of each cruise. In the next, these data in July 1994 were fitted with fourth-order polynomial functions of potential density (σ_θ) for σ_θ<26.5 and for $\sigma_\theta \geq 26.5$, respectively, by least-squares method. The standard deviations of residuals from these functions were 0.152 ºC for θ, 0.029 for S, 4.3 μmol kg^{-1} for $NTCO_2$, 3.6 μmol kg^{-1} for AOU, and 3.0 μmol kg^{-1} for preformed $NTCO_2$. Finally, increases or decreases in θ, S, $NTCO_2$, AOU and preformed $NTCO_2$ with time were determined by comparing the data collected in 1997, in 2000 and in 2003, respectively, with the fitting curves for the data in 1994.

RESULTS AND DISCUSSION

We have found the significant increases in $NTCO_2$ (+17.3±3.1 μmol kg^{-1}), AOU (+6.8±2.6 μmol kg^{-1}) and preformed $NTCO_2$ (+12.9±1.9 μmol kg^{-1}) above 25.7σ_θ density surface in 2003 as compared with those in 1994 (Fig.2). The increase in AOU suggests the slow down of ventilation and/or the change in the biogeochemistry in the NPSTMW and its adjacent waters, but the increase in $NTCO_2$ can be explained primarily by the increase in preformed $NTCO_2$, *i.e.,* accumulation of the anthropogenic CO_2. Since the buffer factor in this region is *ca* 9.3, the increase in preformed $NTCO_2$ is consistent with the mean increase rate of pCO_2sw along 137ºE (+1.7±0.2 μatm yr^{-1}, *i.e.*, mean TCO_2 increase rate calculated is +1.2±0.1 μmol kg^{-1} yr^{-1}) [*Midorikawa et al.*, 2005]. The increase of $NTCO_2$ as well as preformed $NTCO_2$ from 1994 to 2003 showed a tendency to decrease with depth, and they were +3.8 ±5.0 μmol kg^{-1} and +2.7±1.0 μmol kg^{-1}, respectively, in the NPIW (26.5 ≤ σ_θ ≤ 27.0) (Table 1). Mean water column integrated increase rate of the preformed $NTCO_2$ ranged from +0.9±0.2 mol m^{-2} yr^{-1} to +1.1±0.3 mol m^{-2} yr^{-1}, depending on the depth of ventilation. However, it should be noted that $NTCO_2$ and preformed $NTCO_2$ have not been increasing monotonously with time. In 1997 when θ and S at 25.0 ≤ σ_θ ≤ 25.5 were higher than in 1994, $NTCO_2$ and preformed $NTCO_2$ in those density surfaces were rather lower. In contrast, in 2000 and 2003 when θ and S were lower, $NTCO_2$ and preformed $NTCO_2$ were higher. These results suggest that the changes in $NTCO_2$ and preformed $NTCO_2$ on an isopycnal surface are more or less affected by the variability in the formation region and/or the advection of the NPSTMW.

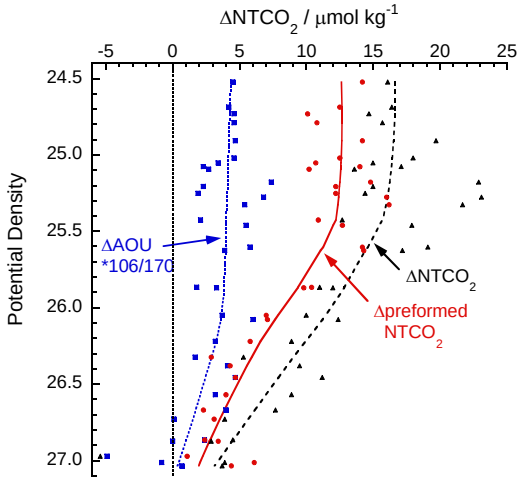

Fig.2. Increase of $NTCO_2$, AOU, and preformed $NTCO_2$ from 1994 to 2003 (137ºE, 20ºN -30ºN).

Table 1. Increase in $NTCO_2$, AOU, and preformed $NTCO_2$ between 20ºN and 30ºN along 137ºE

Range of σ_θ	Period	θ ºC	S	ΔNTCO$_2$ μmol kg^{-1}	ΔAOU μmol kg^{-1}	Δpreformed NTCO$_2$ μmol kg^{-1}
25.0 – 25.5	1997–1994	+0.12±0.03	+0.038±0.009	–4.9±3.1	–0.1 ±4.3	–3.6±1.6
	2000–1994	–0.08±0.09	–0.057±0.031	+17.5±5.7	+8.1 ±4.6	+12.2±3.0
	2003–1994	–0.23±0.03	–0.072±0.010	+17.4±3.7	+6.5 ±3.2	+13.0±2.1
26.5 – 27.0	1997–1994	+0.08±0.12	+0.013±0.021	–2.3±4.3	+5.1±11.0	–5.5±2.9
	2000–1994	+0.18±0.14	+0.029±0.023	+3.4±3.5	+7.3 ±9.1	–1.5±3.9
	2003–1994	+0.11±0.19	+0.018±0.031	+3.8±5.0	+1.3 ±5.2	+2.7±1.0

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