VARIATIONS AND DISTRIBUTIONS OF pCO_2 IN SURAFCE SEAWATER IN THE WESTERN NORTH PACIFIC DURING 1990 TO 2004

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ABSTRACT

Measurements of the partial pressure of CO_2 in surface seawater (pCO_2^w) have been made frequently and extensively in the western North Pacific (3-35°N, 132-142°E) since 1990. Based on the time series analysis of pCO_2^w data, we obtained a "climatological view" of seasonal variation in pCO_2^w in the western North Pacific. We have examined the relationship between pCO_2^w and sea surface temperature (SST). The pCO_2^w–SST relationship varies spatially and temporally. The pCO_2^w showed an average growth rate of 1.6 µatm yr^{-1} (nearly equal to that of the air, pCO_2^a) with large variability (±8.9µatm yr^{-1}). In 1998, larger growth rates of pCO_2^w occurred in the subtropical gyre and the western equatorial Pacific, which was probably associated with the 1997/98 El Niño phenomena. To know processes affecting long-term variations in pCO_2^w, we have examined seasonal variation in growth rate of pCO_2^w. The linear growth rate of pCO_2^w during the winter season ranged from 1.3±0.2 to 2.1±0.2µatm yr^{-1} with an average of 1.7±0.2µatm yr^{-1}. During spring/summer seasons, the average growth rate of pCO_2^w was larger than 2µatm yr^{-1} north of 27°N, and within the range from 0 to 1µatm yr^{-1} in the North Equatorial Current. These increases were mostly caused by the oceanic uptake of anthropogenic CO_2, and to some extent, other processes controlling the pCO_2^w change: thermodynamic effect, lateral transport and vertical mixing, and biological activity.

INTRODUCTION

It is very important to examine temporal and spatial variations in air-sea CO_2 flux in order to know the current oceanic CO_2 uptake. The air-sea CO_2 flux is usually determined by the products of the gas transfer velocity, the solubility of CO_2 and the difference in the partial pressure of CO_2 between surface seawater and the overlying air. Since 1980s, we have reported the seasonal variation and the long-term trend of pCO_2^w in the western North Pacific Subtropical Gyre (NPSG) and the western equatorial Pacific [*Inoue et al.*, 1995; *Midorikawa et al.*, 2005]. The western NPSG acts as a sink for atmospheric CO_2 and the western equatorial Pacific as a weak source. In the western NPSG, seasonal variations in pCO_2^w are mainly controlled by variations in sea surface temperature (SST) and the biological activities. From winter to summer, decreases of surface total inorganic carbon (TCO_2) were reported in the NPSG. We reported that factors controlling carbonate system in the subtropics (between Hawaii and Japan) are seasonally variable. At the moment, however, to what extent these factors varied spatially and seasonally is poorly understood in the wide area of the western North Pacific. Based on the pCO_2^w data in the western North Pacific measured in January/February since early 1980s, we reported the long-term trend of pCO_2^w that has been increasing at a rate nearly equal to that of the air. In this work, we examine the seasonal, interannual and the long-term trend of pCO_2^w in the western North Pacific based on pCO_2^w.and pCO_2^a data taken after January 1990.

METHODS

From December 1990 to March 2004, measurements of pCO_2^w and pCO_2^a were made at least once a few months in the western North Pacific, which allow us to evaluate seasonal and long-term variation in pCO_2^w and pCO_2^a. The ships used were the R/V Kaiyo and R/V Mirai (Japan Agency for Marine-Earth Science and Technology), the M/S Hokuto-maru and M/S Taisei-maru (National Institute for Sea Training, Independent Administrative

Institution), and the Ryofu-maru and Keifu-maru (Japan Meteorological Agency). We also use pCO_2^w data taken in the western North Pacific during cruises of the North Pacific Carbon Cycle Study (NOPACCS, http://www.kanso.co.jp). The data of pCO_2^w have been smoothed in time using the following methods. First, the pCO_2^w data were fitted to Eq. (1),

$$f(t) = \sum_{i=0}^{2} A_i t^i + \sum_{j=1}^{2} \left[B_j \cos(2\pi jt) + C_j \sin(2\pi jt) \right] \tag{1}$$

where *t* denotes the time in years since January 1, 1990. The coefficients A_i, B_j, and C_j are constants determined by the least squares method. We then calculated the residuals of the data from values obtained by Eq. (1), and smoothed it by a low-pass filter with a full width at half maximum of about 3 months. The residuals smoothed with the low pass filter were added to *f(t)* to show variations on time scale longer than a few months. In order to analyze the long-term trend, a low-pass filter with a full width at half maximum of about 2 years was applied to the data.

RESULTS AND DISCUSSION

Figure 1 shows the relationship between de-trended seasonal variation in pCO_2^w and SST (WOA01) at 20°N and 30°N along 137°E. From December to March, the pCO_2^w at 30°N remained fairly constant and low. Over the same period, the pCO_2^w at 20°N varied fairly largely, suggesting that factors controlling seasonal variation pCO_2^w differ from that of 30°N. At 30°N, the pCO_2^w began to increase in March and reached a maximum in August. The pCO_2^w decreased by 15µatm between August and September. From September to December, the pCO_2^w level was considerably low as compared with that during spring to summer. At 20°N, the pCO_2^w occurred maximum in July, while at 30°N in August, and the rapid decrease in pCO_2^w occurred between September and October. The pCO_2^w showed an average growth rate of 1.6 µatm yr^{-1} (nearly equal to that of the air, pCO_2^a) with large variability (±8.9µatm yr^{-1}). In 1998, larger growth rates of pCO_2^w occurred in the subtropical gyre and the western equatorial Pacific, which was probably associated with the 1997/98 El Niño phenomena. To know processes affecting long-term variations in pCO_2^w, we have examined seasonal variations in growth rate of pCO_2^w. The linear long-term trend of pCO_2^w for each season varied spatially. In winter season, the growth rate of pCO_2^w (1.7±0.2µatm yr^{-1}) was nearly equal to that of pCO_2^a, while that in spring/summer ranged from 0 to 2µatm yr^{-1}. The growth rate of pCO_2^w tended to be high south of Kuroshio (>2µatm yr^{-1} north of 27°N) and low in the North Equatorial Current (0-1µatm yr^{-1}). The long-term trend of pCO_2^w can be mostly caused by the uptake of anthropogenic CO_2, and to some extent by changes in thermodynamic effect (SST rise), lateral transport and vertical mixing, and biological activity.

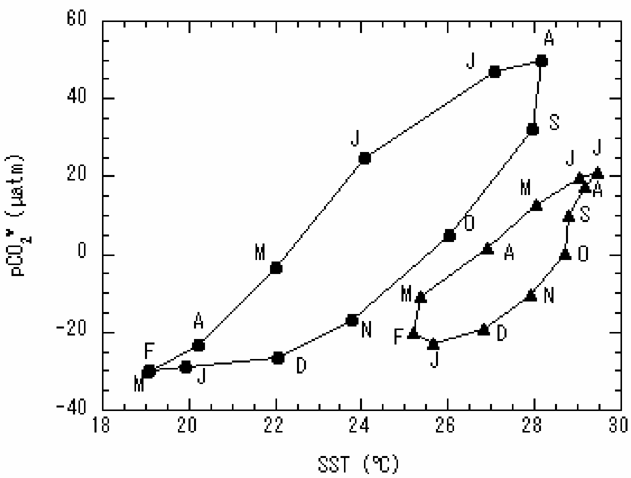

Figure 1. Relationship between de-trended seasonal variation in pCO_2^w and SST at 20°N, 137°E (solid triangle) and 30°N, 137°E (solid circle).

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