INTERANNUAL VARIATIONS OF WINTER OCEANIC $p$CO$_2$ AND AIR-SEA CO$_2$ FLUX IN THE WESTERN NORTH PACIFIC

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ABSTRACT

We report the interannual variations of winter CO$_2$ partial pressure in surface waters ($p$CO$_2^{\text{sea}}$) and overlying air ($p$CO$_2^{\text{air}}$) and air-sea CO$_2$ flux in the extensive area (3-34°N) from subtropical to equatorial along 137°E during the period of 1983-2003. The $p$CO$_2^{\text{sea}}$ varied largely in the equatorial region of 3-6°N, depending on the variations of the oceanographic conditions related to the El Niño-Southern Oscillation (ENSO) events. The $p$CO$_2^{\text{sea}}$ variations in the subtropical gyre north of 23°N were small due to highly counteracting effects between anti-correlated sea surface temperature (SST) and dissolved inorganic carbon (DIC) anomalies through the entrainment process, irrespective of large variations of SST. By contrast, it was found that there occurred a low negative correlation between SST and DIC in the region restricted around 15-18°N in the North Equatorial Current, which resulted in a large amplitude of variations of $p$CO$_2^{\text{sea}}$ and hence CO$_2$ influx. The interannual variations of CO$_2$ flux depended predominantly on those of the difference between $p$CO$_2^{\text{sea}}$ and $p$CO$_2^{\text{air}}$ ($\Delta p$CO$_2$) south of 18°N but on those of wind speed in the northern region.

INTRODUCTION

The oceans are understood to be a major sink for increasing atmospheric CO$_2$ resulted from industrial CO$_2$ emissions. Although a number of observational and modeling studies have aimed for evaluating the long-term changes and variability on variable scales in the oceanic sink, its temporal variability is poorly established. The interannual variability of the upper ocean carbon cycle and its controlling factors have been investigated on the basis of the time-series data of the carbonate system at a fixed station in the eastern subtropical North Pacific [Gruber et al., 2002] and the North Atlantic [Brix et al., 2004]. In the western North Pacific, we have previously described the latitudinal and seasonal variations and increasing long-term trend of $p$CO$_2^{\text{sea}}$ from the subtropical to equatorial region along 137°E [Inoue et al., 1995; Ishii et al., 2001; Midorikawa et al., 2005]. In the present study, we report the characteristics of the interannual variations of winter $p$CO$_2^{\text{sea}}$ and air-sea CO$_2$ flux in the western North Pacific for two decades and discuss their controlling factors.

OBSERVATIONS AND METHODS

The observations of $p$CO$_2^{\text{sea}}$, $p$CO$_2^{\text{air}}$, and related hydrographic parameters, such as SST and sea surface salinity, were conducted aboard the R/V Ryofu Maru of the Japan Meteorological Agency from 3°N to 34°N along 137°E in the western North Pacific during nearly the same periods from late January to early February every winter, and details of the methods have been described in Inoue et al. [1995]. The air-sea CO$_2$ flux was estimated from the combination of the observed $\Delta$pCO$_2$ and the empirical equation for the gas transfer coefficient for the long term proposed by Wanninkhof [1992]. The wind speed data were taken from the re-analysis by National Center for Environmental Prediction.

RESULTS AND DISCUSSION

The time series of $p$CO$_2^{\text{sea}}$ revealed significant increasing trend (1.3 ± 0.2 to 2.1 ± 0.2 µatm yr$^{-1}$, $r^2$ = 0.67-0.91) for two decades over the whole area. The detrended $p$CO$_2^{\text{sea}}$ showed significant interannual variations that were different in different regions: the standard deviation of yearly anomalies (blue circles in Fig. 1) from the average of detrended $p$CO$_2^{\text{sea}}$ for 1983-2003 was large (7.2-7.3 µatm) in 3-6°N and 15-18°N, and was small (3.2-4.2 µatm) in 23-32°N.
The amplitude of interannual variations of $pCO_2^{sea}$ was closely related to the extent of compensation between SST and DIC anomalies, contributing to $pCO_2^{sea}$ anomalies often in the opposite direction, in the respective latitudes. The $pCO_2^{sea}$ variations in the northern subtropical region (25-32°N) was depressed by the counteraction between highly anti-correlated SST and DIC variations through the entrainment process resulted from the strong winter northwest monsoon. On the other hand, the variations were relatively large in the equatorial (3-6°N) and northern NEC regions (15-18°N), because the effects of SST and DIC variations were not counteracted each other and, consequently, contributed significantly to $pCO_2^{sea}$ anomalies due to the variations of the oceanographic conditions related to the ENSO events in 3-6°N and probably due to the influence of different source water transported laterally in 15-18°N.

Comparison of time series of air-sea CO$_2$ flux anomaly with those of $\Delta pCO_2$ or wind speed showed distinctly different controlling factors for the interannual variations of CO$_2$ flux in different latitudes. The CO$_2$ flux was dominated by the magnitude of $\Delta pCO_2$ ($r^2 = 0.75-0.91$) south of 18°N, whereas the influx in 23-32°N was dependent on wind speed ($r^2 = 0.60-0.85$) rather than small variations of $\Delta pCO_2$ ($r^2 < 0.43$).

REFERENCES

Fig. 1. Time series of contributions of SST, salinity and DIC concentration to anomaly of detrended $pCO_2^{sea}$ (blue circles). Anomalies of respective properties were converted to $pCO_2^{sea}$ values.