1. Introduction

Currently, the global oceans are considered to be absorbing about 30% of the carbon dioxide (CO_2) released by fossil-fuel combustion (IPCC, 2007). However, where and how the CO_2 is absorbed from the atmosphere into the oceans and how this absorption changes with time are largely unknown. It is important to assess the sea-air CO_2 flux and its detailed spatiotemporal variation over the global oceans with minimal uncertainty to understand the ocean carbon cycle and its controlling processes. This will help to reduce the uncertainty of predicted future atmospheric CO_2 concentrations and to improve projections of global warming.

Data for the CO_2 partial pressure in surface seawater ($p$$CO_2$s) are necessary for calculating the sea-air CO_2 flux. To date, millions of $p$$CO_2$s data have been acquired (Takahashi et al., 2008). However, $p$$CO_2$s is extremely variable in space and time. To document the changes in $p$$CO_2$s and sea-air CO_2 flux at basin to global scales with sufficient temporal resolution, it is necessary to fill in the spatial and temporal gaps in the data.

Takahashi et al. (1993, 2002, 2009b) have estimated the climatological monthly $p$$CO_2$s by using a time-space interpolation of $p$$CO_2$s data. In this method, $p$$CO_2$s data are first corrected to those in a reference year using the rate of increase in atmospheric CO_2 concentration, and then a climatological $p$$CO_2$s distribution is constructed by interpolation based on a lateral two-dimensional advection-diffusion model. However, this method does not account for the influences of year-to-year and decadal variations such as those associated with the El Niño/Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO).

Empirical methods using the relationships between $p$$CO_2$s and other parameters such as sea surface temperature (SST) and salinity (SSS) have been developed to deduce year-to-year variability. For example, Park et al. (2010) estimated global $p$$CO_2$s by using $p$$CO_2$s-SST relationships. The Japan Meteorological Agency (JMA) has provided CO_2 flux information for the subtropical western North Pacific annually since 1999, and for the equatorial Pacific since 2007, by using empirical analysis methods based on SST-$p$$CO_2$s and SSS-$p$$CO_2$s relationships (Murata et al., 1996; Nakadate and Ishii, 2007). However, these simple methods are insufficient for representing the drawdown of $p$$CO_2$s due to biological CO_2 uptake, such as in the subpolar regions, and there are areas for which there are insufficient data to develop an accurate empirical method. Therefore, the area for which JMA provides CO_2 flux estimates has been limited to only about 1/12 of the global ocean. Improvements in the empirical method are required to expand the estimation area to the global ocean.

Recently, remote sensing data for chlorophyll-*a* concentrations (Chl-*a*) from satellites have become available, and these data are also used in empirical methods to represent the $p$$CO_2$s drawdown due to biological CO_2 uptake (Ono et al., 2004; Sarma et al., 2006; Chierici et al., 2009). In addition, the database of global $p$$CO_2$s has been revised (Takahashi et al., 2008). In this study, we develop an empirical method to estimate $p$$CO_2$s in the Pacific by generating equations from multiple regression analysis between $p$$CO_2$s and other parameters, including Chl-*a*. These relationships vary regionally. We divided the Pacific Ocean into smaller regions for the multiple regression analyses so that the $p$$CO_2$s in each region could be expressed by a single relationship between $p$$CO_2$s and other parameters. The estimation biases were no more than ±10 μatm as confirmed by comparison with observational data (Takahashi et al., 2009a). The inclusion of Chl-*a* data significantly reduces the estimation errors in the subpolar areas, which have intense biological activity.

In addition, we calculated the monthly pCO$_2$s and CO$_2$ flux in the Pacific for the past 25 years (1985–2009). We calculated the monthly CO$_2$ flux by using different combinations of gas transfer coefficient equations and three data sets of wind speed at 10 m above sea level (U$_{10}$) to evaluate the uncertainty.

We describe the target region and data sets used in this study in section 2. The method of pCO$_2$s estimation, including the partitioning of the region and the multiple regression analysis, is presented in section 3. In section 4, we discuss the estimation of pCO$_2$s and its error. Finally, in section 5 we provide seasonal maps and time series of the CO$_2$ flux, investigate the effects of the choice of gas transfer coefficient equations and U$_{10}$ data sets on the flux estimates, and compare our mean CO$_2$ flux values with the climatological values presented by Takahashi et al. (2009b).