6. Summary and conclusions

We developed an empirical method to estimate monthly pCO_2s and sea-air CO_2 flux over the Pacific since 1985 using the LDEO database V1.0 (Takahashi et al., 2008) of global pCO_2s observations. First, we determined the long-term trend of pCO_2s. Second, we analyzed regional and seasonal variations of pCO_2s. We divided the Pacific Ocean into 14 regions and derived multiple regression equations for estimating monthly pCO_2s for each region incorporating data for SST, SSS and Chl-*a*. Previously it had been difficult to reproduce pCO_2s in the subpolar regions where there are spring blooms and high net biological consumption of inorganic carbon, but the bias in the estimates was significantly reduced by including Chl-*a* data in the analysis. Mean bias of estimated pCO_2s in each region ranged from –10 to +10 μatm.

The estimated mean annual CO_2 flux in the Pacific Ocean is −0.70 ± 0.14 PgC yr^{-1} (negative value indicates uptake by the ocean) for the period from 1985 to 2009. The CO_2 flux varies seasonally and inter-annually. While there is CO_2 emission throughout the year in the equatorial region, there is strong CO_2 uptake along the mid-latitudes in winter. We found that CO_2 flux in the equatorial region varies largely with ENSO. In particular, the CO_2 emission decreased by 0.2 PgC yr^{-1} during the 1997/1998 El Nino event. The region included in this study is about 46% of the global ocean. To further understand the global carbon cycle, it will be necessary to investigate whether the empirical method developed in this study can be applied to the Atlantic and Indian oceans to expand the region of CO_2 flux estimation.

There is a significant uncertainty remaining in the CO_2 flux estimates. The different gas transfer coefficient equations used in this study resulted in differences of 15% to 20% in estimated fluxes. The CO_2 emission in the equatorial region, when evaluated using the wind-speed product from the JRA25/JCDAS reanalysis, is about 0.12 PgC yr^{-1} (20%) higher than that estimated using CDAS1. The CO_2 flux estimates in the other regions are consistent between reanalysis data sets.

To reduce the uncertainty in CO_2 flux estimates, it will be necessary to continue investigations into better wind-speed analysis and gas transfer coefficients. There are plans to update the global pCO_2s database annually with the accumulated pCO_2s observation data. Therefore, there should be a continuous review of the equations and the regional divisions used for pCO_2s estimation to reduce uncertainties where the data are sparse. It is important to use observations to monitor inter-annual variations and long-term trends of pCO_2s.

Furthermore, it is important to compare CO_2 flux as estimated using other approaches such as atmospheric CO_2 inversion, forward ocean carbon cycle modeling, and ocean carbon inversion. Discrepancies in the estimates from these methods must be reduced to better understand the carbon cycle and to improve projections of global warming.