

Variations of partial pressure of CO₂ in surface seawater and air-sea CO₂ flux in the Southern Ocean

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The oceans have played an important role in reducing global warming by taking up about 30% of anthropogenic CO₂ emissions into the atmosphere since the Industrial Revolution. The Southern Ocean has played a significant role in the CO₂ uptake, accounting for about 40% of the anthropogenic CO₂ absorbed by the global oceans. However, observations of atmospheric and oceanic CO₂ in the Southern Ocean are limited due to remoteness from civilization, severe sea conditions and the presence of sea ice. To investigate the variability of surface water CO₂ in the Southern Ocean, we analyzed the CO₂ partial pressure (pCO_{2,sea}) data in the surface sea water obtained by shipboard observations. The shipboard observations were conducted in the Indian Ocean of the Southern Ocean (Fremantle –Syowa Station, and Syowa Station –Sydney) during the eleven cruises of the research vessel (R/V) Shirase during the austral summer (December to March) from 2009 to 2019. The pCO_{2,sea} data were obtained by using an on-board continuous measurement system with a nondispersive infrared (NDIR) gas analyzer and a flow-through system type gas-liquid equilibrator. We investigated long-term pCO_{2,sea} variations at the cruise tracks along the 110°E line from 40°S to 60°S (Area 1) and the spatial variations of pCO_{2,sea} around the Antarctic coastal area (Area 2). In this study, the Area 1 was divided into Sub Antarctic Zone (SAZ), Polar Frontal Zone (PFZ) and Antarctic Zone (AZ) according to the oceanic fronts.

In the Area 1, we compared the latitudinal distribution of the pCO_{2,sea} observed on-board the R/V Shirase (pCO_{2,sea_obs}) with that of the global grid data released by Japan Meteorological Agency (pCO_{2,sea_grid}). In AZ, the pCO_{2,sea_obs} data were systematically larger than the pCO_{2,sea_grid} data by about 20 μatm, which could have a significant impact on the estimate of CO₂ uptake in the Southern Ocean. The observed data (pCO_{2,sea_obs}) showed rapid change at the Sub Antarctic Front while pCO_{2,sea_grid} did not, indicating that the grid data are unable to represent fine structures of the pCO_{2,sea} distributions.

We calculated CO₂ fluxes along the cruise tracks of R/V Shirase by using pCO_{2,sea}, pCO_{2,air}, sea surface temperature (SST), wind speed and sea surface salinity and investigated long-term trends of the CO₂ fluxes in December of each year from 2009–2019. As a result, CO₂ flux (positive flux represents CO₂ uptake from the atmosphere to the ocean) increased at a rate of 0.08 and 0.14 gC/m²/month/yr in SAZ and PFZ. In contrast, there was no trend of CO₂ flux in AZ. The CO₂ flux increase was found to be largely determined by increase of pCO₂ difference between the atmosphere and surface seawater. In SAZ and PFZ, pCO_{2,sea} increased at a rate of 1.1–1.9 μatm/yr, which were smaller than the pCO₂ increase in the atmosphere (pCO_{2,air}) (2.4 μatm/yr). On the other hand, the pCO_{2,air} increase in AZ was about the same rate as the pCO_{2,sea} trend. The component analysis of the pCO_{2,sea} trend showed that the contribution of increased dissolved inorganic carbon (DIC) in the sea water was significant.

In the Area 2, We observed low pCO_{2,sea} (< 300 μatm) in the ocean around Lutzow-Holm Bay, Cape Danley and Totten Glacier. We examined the relationship between pCO_{2,sea} and SST and between pCO_{2,sea} and SSS around Cape Danley and found no correlation between pCO_{2,sea} and SST, but there was a positive correlation between pCO_{2,sea} and SSS, suggesting that a part of pCO_{2,sea} decrease was due to dilution by meltwater from sea ice. However, since the pCO_{2,sea} normalized by salinity shows still low value around 260 μatm. This suggests that the pCO_{2,sea} is reduced by factors other than dilution by meltwater, such as active biological activity at the ice margin region.

Keywords: Southern Ocean, Air-sea CO₂flux, partial pressure of CO₂