# 南大洋における表層海水中のCO2分圧及び大気海洋間CO2フラックスの変動

# 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 $CO_2$ emissions into the atmosphere since the Industrial Revolution. The Southern Ocean has played a significant role in the $CO_2$ uptake, accounting for about 40% of the anthropogenic $CO_2$ absorbed by the global oceans. However, observations of atmospheric and oceanic $CO_2$ 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 $CO_2$ in the Southern Ocean, we analyzed the $CO_2$ 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 ($pCO_{2,sea\_gird}$). In AZ, the $pCO2_{,sea\_obs}$ 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 $CO_2$ uptake in the Southern Ocean. The observed data ($pCO2_{,sea\_obs}$) 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 $CO_2$ 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 $CO_2$ fluxes in December of each year from 2009–2019. As a result, $CO_2$ flux (positive flux represents $CO_2$ uptake form the atmosphere to the ocean) increased at a rate of 0.08 and 0.14 gC/m$^2$/month/yr in SAZ and PFZ. In contrast, there was no trend of $CO_2$ flux in AZ. The $CO_2$ flux increase was found to be largely determined by increase of $pCO_2$ 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 $pCO_2$ 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.

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