Decadal-scale increases of anthropogenic CO_2 in Antarctic Bottom Water of the Indian sector of the Southern Ocean

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The Southern Ocean is regarded as one of the most important sinks for global carbon budget, because it is estimated that approx. 40% of ocean uptake of anthropogenic CO_2 (hereafter abbreviated as antCO_2) occurs in the Southern Ocean. In the ocean, it is known that Sub-Antarctic Mode Water and Antarctic Intermediate Water, both of which are Southern Ocean-origin, play a large role in absorbing antCO_2 and transporting it northward. However, for role of Antarctic Bottom Water (AABW) in accumulating and absorbing antCO_2, it is still an open question. In the 1980’s, it was said that that accumulation and uptake of antCO_2 in AABW is small (Chen, 1982; Poisson and Chen, 1988), because existence of sea ices effectively blocks air-sea exchange of CO_2, and because signals of antCO_2 are diluted by mixing with water (e.g., Circumpolar Deep Water) of no or little contamination of antCO_2. Recent studies reveal that AABW is also contaminated significantly by antCO_2, although it is not so high (Ríos et al., 2012; Pardo et al., 2014). Furthermore, influences of ocean climate changes such as warming, desalination, acidification, etc. on ocean uptake of antCO_2 remain unclear.

To elucidate how large AABW, defined as neutral density of $g^n >= 28.27$ kg m^{-3}, takes up antCO_2, we examined decadal-scale increases of antCO_2 (ΔantCO_2) along a zonal section at nominal 62˚S ranging from 30˚E to 160˚E in the Indian sector of the Southern Ocean. For the purpose, we used high-quality data for CO_2-system and related properties collected about 17 years apart in 1994/1995 and 2012/2013. These data were obtained under international observation programs such as World Ocean Circulation Experiment and Global Ship-based Hydrographic Investigations Program. Form depth - longitude section of ΔantCO_2, it was found that there was a clear contrast of distributions of ΔantCO_2 in AABW between the eastern and western sides of the Kerguelen Plateau. That is, higher increases of > 5 mmol kg^{-1} were found in the eastern side, while lower increases or even decreases were found in the western side. In the eastern side, in contrast to previous studies, increases of antCO_2 were largest (> 9.0 mmol kg^{-1}) in the bottom water, i.e., AABW. The higher increases were especially conspicuous east of 110˚E. Significant increases of anthCO_2 in bottom and deep waters were detected through the section, although they became gradually reduced in magnitude and depth range westward from 110˚E. Vertical distributions of ΔantCO_2 showed significant positive correlations with decadal-scale changes in CFC-12 and with distributions of SF_6, both of which can be used as a proxy of ocean circulation and ventilation, meaning that the distributions were mainly controlled by physical processes. Comparison of ΔantCO_2 between calculation methods with and without total alkalinity presented differences of ΔantCO_2 west of 50˚E (the latter was smaller than the former). This may be related to decreases in production of particulate inorganic carbons in the Southern Ocean (Freeman and Lovenduski, 2015). The highest storage rate of antCO_2 was estimated to be 1.1 ±0.6 mol m^{-2} a^{-1} at longitudes 130˚–160˚E, which is a value integrated from surface to bottom layers of statistically-significant ΔantCO_2. With this condition of integration, we believe that the value is conservative. West of the Kerguelen Plateau, the storage rate was 0.2 ±0.1 mol m^{-2} a^{-1} at most. The contrast is due probably to differences of formation regions of AABW; west of 80˚E (Kerguelen Plateau), the AABW consists mostly of Weddell Sea-origin water, while east of it, the AABW consists of both the Adélie coast- and Ross Sea-origin waters.

The above results highlight that processes for uptake and accumulation of antCO_2 by the bottom water work well in the Indian sector of the Southern Ocean, at least, in the eastern part of it.

Keywords: Anthropogenic CO2, Antarctic Bottom Water (AABW), Southern Ocean

