

Meridional Variability in Multi-decadal Trends of Dissolved Inorganic Carbon in Surface Seawater along the 165°E Line

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1. Introduction

The ocean plays an important role in mitigating the atmospheric CO₂ increase and global warming by absorbing about a quarter of anthropogenic CO₂ released into the atmosphere. However, CO₂ uptake by the ocean leads to an increase in dissolved inorganic carbon (DIC) concentration and a decrease in pH in seawater commonly referred to as "ocean acidification", and it is expected to have negative effects on marine ecosystems. To project future ocean acidification derived from atmospheric CO₂ increase under different socioeconomic scenarios, we need to accurately understand the current long-term trends of DIC and pH at each region. In this study, we investigated the long-term trends of nDIC in surface seawater on the basis of data obtained from the shipboard measurements from subarctic to equatorial zones along 165°E line for 1996–2019.

2. Data & Methods

We calculated the values of DIC from the partial pressure of CO₂ ($p\text{CO}_2^{\text{sea}}$), total alkalinity (TA), phosphate and silicate in surface seawater by a method of Dickson et al. (2007) using the dissociation constants of carbon acid given by Lurker et al. (2000). We used $p\text{CO}_2^{\text{sea}}$ data which were measured by JMA for 1996–2019 and those stored in the Surface Ocean CO₂ Atlas version 2020. We also used the average values of nTA (salinity-normalized TA) at 5°S–32°N and 33°N–46°N because they showed little variability in space and time, respectively. In the subtropical-to-subarctic transition zone from 33°N to 46°N, we derived an empirical equation for surface nTA using multiple linear regression (MLR) analysis with sea surface salinity (SSS) and satellite sea surface dynamic height as explanatory variables in reference to the method described by Takatani et al. (2014). Additionally, climatological phosphate and silicate concentrations taken from World Ocean Atlas 2018 were used. We also applied MLR analysis to the nDIC (salinity-normalized DIC) calculated as above using observation year, SST and SSS as explanatory variables to estimate the mean growth rates of nDIC during 1996–2019 at each 1° latitude from 5°S–50°N along the 165°E line.

3. Result & Discussion

The growth rates of nDIC along the 165°E line exhibited clear meridional variabilities with higher in the subtropical and tropical zones and lower in the subarctic zone, and ranged from $+0.09 \pm 0.14$ to $+1.64 \pm 0.16 \mu\text{mol kg}^{-1} \text{yr}^{-1}$ (Figure). The rates were particularly lower in the northern zone and were not statistically significant at the 95% confidence level 49°N ($+0.32 \pm 0.19 \mu\text{mol kg}^{-1} \text{yr}^{-1}$, $p=0.10$) and at 50°N ($+0.09 \pm 0.14 \mu\text{mol kg}^{-1} \text{yr}^{-1}$, $p=0.52$). The nDIC trends were consistent with those expected from the increase in atmospheric CO₂ concentrations at nearly all latitudinal zones, but were significantly different at some latitudes.

We attributed the significantly lower rates observed in the central part of western subarctic gyre at around 50°N and southern part of subtropical gyre at around 10°N to nDIC variabilities associated with the variabilities in ocean circulation. However, it was significantly higher at 33°N to the south of Kuroshio Extension (KE). This appears to have been caused by the change in winter vertical mixing related to the decadal variabilities in KE path stability.

Figure caption

Locations of repeat lines along 165°E and 137°E (thick black lines) and meridional distribution of the mean rate of nDIC change between 1996 and 2019 from 5°S to 50°N along the 165°E line (red circles) and from 3°N to 33°N along the 137°E line (blue circles). The shaded range denotes the 95% confidence interval. The values of nDIC trends that are not statistically distinguishable from zero are shown by open circles. The black circle filled with red color at 5°S shows the mean rate during 2002–2019. The thin black line indicates the rate of nDIC change expected from the rate of $p\text{CO}_2^{\text{air}}$ change along the 165°E line calculated from monthly $p\text{CO}_2^{\text{air}}$ data analyzed by JMA from 1985 to 2019 at each latitude. Colors superposed on the map represent sea surface dynamic heights averaged over 1993–2019 acquired from AVISO+.

Keywords: 165°E line, Dissolved inorganic carbon, Growth rate, Multiple linear regression analysis

