Decadal changes of dissolved inorganic carbon in the Pacific

Akihiko Murata, Shinya Kouketsu, Toshimasa Doi, Kazuhiko Hayashi and Yuichiro Kumamoto

Ocean Climate Change Research Program, Research Institute for Global Change (RIGC), Japan Agency for Marine-Earth Science and Technology (JAMSTEC)
Course of talking

- **Background**
  History of ocean inventory study

- **Data and method**
  Data used
  How to estimate total, anthro. and natural CO₂ changes

- **Results**
  Decadal changes of total, anthro. and natural CO₂
  Water column inventories

- **Summary and future studies**
History of ocean inventory study

- During the late 1980s to the 1990s, WOCE, JGOFS, and national programs, etc. provided baseline data.
- About 10 years ago, data-based inventories were obtained.
- From 5 years ago, data synthesis activities such as CARINA, PACIFICA, GLODAP, etc. are continuing.
- Detecting decadal-scale changes
Anthro. CO$_2$ in the ocean (mol m$^{-2}$)

Indian Ocean 22 Pg C

Pacific Ocean 44 Pg C

Atlantic Ocean 40 Pg C

Global inventory = 118 ± 19 PgC for the Anthropocene (1800 – 1994)

Sabine et al. (2004)
Data used

<table>
<thead>
<tr>
<th>Line</th>
<th>WOCE</th>
<th>Revisit</th>
</tr>
</thead>
<tbody>
<tr>
<td>P01</td>
<td>1999</td>
<td>2007</td>
</tr>
<tr>
<td>P02</td>
<td>1994</td>
<td>2004</td>
</tr>
<tr>
<td>P06</td>
<td>1993</td>
<td>2003</td>
</tr>
<tr>
<td>P10</td>
<td>1993</td>
<td>2009</td>
</tr>
<tr>
<td>P14</td>
<td>1992/1993</td>
<td>2005</td>
</tr>
<tr>
<td>P16</td>
<td>1991</td>
<td>2007</td>
</tr>
<tr>
<td>P17</td>
<td>1993</td>
<td>2001</td>
</tr>
<tr>
<td>P18</td>
<td>1994</td>
<td>2008</td>
</tr>
<tr>
<td>P21</td>
<td>1994</td>
<td>2009</td>
</tr>
</tbody>
</table>
Data obtained by JAMSTEC

After 2000, over 50% of the WOCE stations in the Pacific Ocean were re-occupied by JAMSTEC.

Available from CDIAC and CCHDO
Calculation method (1)

◆ Total CO₂ changes (Δ Cₜ)

\[ Δ Cₜ = Cₜ(R) - Cₜ(W), \]

where \( Cₜ(R) \) and \( Cₜ(W) \) indicate dissolved inorganic carbon measured in Revisit and WOCE cruises, respectively.

◆ Anthro. CO₂ changes (Δ nCₜ \text{CAL})

\[ Δ nCₜ \text{CAL} = nCₜ \text{CAL}(R) - nCₜ \text{CAL}(W), \]

where \( nCₜ \text{CAL}(R) \) and \( nCₜ \text{CAL}(W) \) are the preformed \( Cₜ (= Cₜ − 0.69 × \text{AOU}) \) for Revisit and WOCE cruises, respectively. “n” implies that the values are normalized to a salinity of 35.
Calculation method (2)

◆ Natural CO₂ changes (Δ nC_{AOU})

\[ \Delta nC_{AOU} = nC_{AOU}(R) - nC_{AOU}(W), \]

where \( C_{AOU}(R) \) and \( C_{AOU}(W) \) are equal to \( 0.69 \times \text{AOU} \) for Revisit and WOCE cruises, respectively. “n” implies that the values are normalized to a salinity of 35.

◆ Water column inventories of anthro. (Δ nC_{T_{CAL}}) and natural (Δ nC_{AOU}) CO₂ changes

20° longitudinal or 10° latitudinal interval.
Shortcomings of method used

◆ Assumptions
  No significant changes in $A_T$
  Constant $\Delta C_{Tdiseq}$
  Constant Redfield ratio
  •
  •
  •

Hold true on a basin scale

For the details, refer to Kouketsu et al. (201?), GBC.
Distributions of $\Delta C_T$, $\Delta nC_T^{\text{CAL}}$ and $\Delta nC_{AOU}$ along 3 sections

Total CO$_2$

Anthro. CO$_2$

Natural CO$_2$
Total CO₂

Anthro. CO₂

Natural CO₂
Specific water column inventories of anthro. CO₂ changes
Specific water column inventories of anthro. CO$_2$ changes for mode and intermediate waters

Mode water

Intermediate water

MW: $\gamma_n = 25.6 – 26.5$ and $25.6 – 26.8$ kg m$^{-3}$ for the North and South Pacific, respectively.

IW: $\gamma_n = 26.6 – 27.6$ and $26.9 – 27.6$ kg m$^{-3}$ for the North and South Pacific, respectively.
Specific water column inventories of natural CO$_2$ changes
Decadal storages of anthropogenic and natural CO$_2$ for latitudinal bands

<table>
<thead>
<tr>
<th>Area</th>
<th>$\Delta nC_T^{\text{CAL}}$ PgC decade$^{-1}$</th>
<th>$\Delta nC_{\text{AOU}}$ PgC decade$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>40°N – 65°N</td>
<td>0.3 ± 0.2</td>
<td>−0.1 ± 0.1</td>
</tr>
<tr>
<td>20°N – 40°N</td>
<td>1.5 ± 0.2</td>
<td>0.5 ± 0.1</td>
</tr>
<tr>
<td>20°S – 20°N</td>
<td>2.7 ± 0.4</td>
<td>0.3 ± 0.3</td>
</tr>
<tr>
<td>50°S – 20°S</td>
<td>3.9 ± 0.3</td>
<td>−0.1 ± 0.3</td>
</tr>
<tr>
<td>50°S – 65°N</td>
<td>8.4 ± 0.5</td>
<td>0.6 ± 0.4</td>
</tr>
</tbody>
</table>

Values show average ± standard error

About 40% of the estimate for the global ocean (2.2 PgC a$^{-1}$; Fletcher et al. 2006)
Summary

✓ In the Pacific, anthropogenic CO₂ both increased (> 20 μ mol kg⁻¹) and decreased (< −20 μ mol kg⁻¹) on a decadal scale.

✓ Decadal-scale storage of anthropogenic CO₂ north of 40°N was close to ± 0 mol m⁻² a⁻¹.

✓ In the subtropical regions of both hemispheres, an increasing trend of > 10 μ mol kg⁻¹ for oceanic uptake of anthropogenic CO₂ was found, reflecting accumulation in mode waters.

✓ Water column inventories calculated throughout the Pacific Ocean revealed relatively high values (> 0.7 mol m⁻² a⁻¹) in the subtropical regions of both hemispheres and low values in the tropical Pacific.
The distribution pattern of water column inventories of anthropogenic CO$_2$ changes is similar to previous estimates for the Anthropocene, implying that the re-distribution processes of anthropogenic CO$_2$ have not changed on a basin scale over the last decade.

The total anthropogenic and natural CO$_2$ storage in the Pacific Ocean was estimated at 8.4 ± 0.5 and 0.6 ± 0.4 PgC decade$^{-1}$, respectively.
Future studies

- Global mapping with CARINA, PACIFICA, etc.
Future studies (cont.)

- Influences of meso-scale eddies

$pCO_2 (\mu \text{atm})$ reconstructed from $T$, $S$, and $DO$ Argo floats with $T$, $S$ and $DO$ sensors

![Map showing $pCO_2$ distribution over different dates and locations.](image)
Future studies (cont.)

- Ocean acidification

Murata and Saito (2012)
Thank you for your attention!