ACKNOWLEDGEMENT
This work is part of an R&D project "Research and Development of Safety Technology for Geological CO₂ Storage", commissioned to the Geological Carbon Dioxide Storage Technology Research Association by the Ministry of Economy, Trade and Industry (METI) of Japan.
• Detection of CO$_2$ bubbles with side-scan sonar (SSS)
• Detection of high pCO$_2$ (partial pressure of CO$_2$) in seawater
  – due to leakage of CO$_2$ or natural variability?
Bubble detection with SSS

Side-scan sonar (SSS) detects the seafloor or objects in the water column by transmitting acoustic pulses and receiving the reflections.

https://woodshole.er.usgs.gov/operations/sfmapping/sonar.htm
Bubble detection with SSS

Bubble release experiment

• What is the minimum leakage rate which is detectable with SSS?

• What differences are there in SSS images depending on the distance between SSS and bubbles?
Initial diameter of bubbles: about 1 cm

SSS mounted on a rubber raft hull
raft speed: 2 knot≈3.7 km/h

SSS: EdgeTech4200MP
Frequency: 600kHz

Experimental design

SEATEC II
a measurement barge

Initial diameter of bubbles: about 1 cm
# Bubble detection with SSS

**Release rate**

<table>
<thead>
<tr>
<th>Air bubbles</th>
<th>CO₂ bubbles</th>
</tr>
</thead>
<tbody>
<tr>
<td>- 750 ml/min</td>
<td>- 250 ml/min</td>
</tr>
<tr>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>- 250 ml/min</td>
<td>- 1500 ml/min</td>
</tr>
<tr>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>- 100 ml/min</td>
<td>- 500 ml/min</td>
</tr>
<tr>
<td>○</td>
<td>×</td>
</tr>
</tbody>
</table>

Detecting CO₂ bubbles is more difficult than air.
Bubble detection with SSS

SSS image: **air** bubbles
release rate: 250ml/min

Distance from SSS: 35 25 0 35 [m]

- Water column

- Waterline of SEATEC II

- Bubbles

- Nearly 20m

- Sea surface

- Seafloor

- Rough identification of the leakage point

The right end of the bubble signal represents the position of bubbles at the depth of SSS.

About 32m
Bubble detection with SSS

SSS image: **air** bubbles
release rate: 250ml/min

Note: Bubbles do not always rise straight in the water column.
Bubble detection with SSS

SSS image: \textbf{CO}_2\textbf{ bubbles}

release rate: \textbf{1500ml/min}=\textbf{6tonnes/yr}

Signal of \textbf{CO}_2\textbf{ is weak.}

\textbf{CO}_2\textbf{ bubbles (1500ml/min)} \quad \text{air bubbles (250ml/min)}
High pCO$_2$ detection

What is the problem?

Anomalously high value of pCO$_2$
• due to CO$_2$ leakage
• due to natural variability

A constant value of pCO$_2$ is unsuitable for the threshold where natural variability of pCO$_2$ is large.

A threshold using not only pCO$_2$ but also dissolved oxygen (DO)
High pCO$_2$ detection

Example: Eastern part of Osaka Bay in Japan

O$_2$ and pH: observed near the bottom 4 times a year from 2002 to 2010

pCO$_2$: calculated using CO2SYS from pH and alkalinity estimated from salinity.
High pCO$_2$ detection

Natural variability in the Eastern part of Osaka Bay is very large

- Average ± σ
- W: western part
- E: eastern part

Range of pCO$_2$ between 2002 and 2010 in Osaka Bay

- About 1400μatm
- About 1600μatm
High pCO$_2$ detection

Using relationship between pCO$_2$ and O$_2$

◆ Biological process
  
  photosynthesis
  
  $122H_2O + 16HNO_3 + H_3PO_4 + 106CO_2 \rightleftharpoons 138O_2 + (CH_2O)_{106}(NH_3)_{16}(H_3PO_4)$
  
  respiration, degradation
High pCO₂ detection

Eastern part of Osaka Bay


regression line (R²=0.86)

99% prediction interval

false-negatives are prone to occur in O₂-rich water

assessed as anomalous

a threshold of constant pCO₂ (mean+3σ)

false-positives are prone to occur in O₂-poor water

assessed as normal

(Dissolved Oxygen)
High pCO$_2$ detection

Eastern part of Osaka Bay

Regression line ($R^2=0.86$)

99% prediction interval


Assessed as anomalous (Dissolved oxygen)
Summary

Two methods for detecting leakage in the sea

- **Detection of CO$_2$ bubbles** with side-scan sonar
  - SSS can detect CO$_2$ bubbles released at 1500 ml/min
  - SSS images provide us a clue to identifying the leakage point

- **Detection of anomalously High pCO$_2$** using the relationship between pCO$_2$ and DO (dissolved O$_2$)
  - false-positive/negative problem are improved
Challenges to be tackled

**CO$_2$ bubble detection with SSS**

To clarify

- dependency on the speed of the observation boat
  - the faster, the better for the monitoring
- dependency on the initial size of bubbles
  - Smaller bubbles are easier to dissolve in seawater

**High pCO$_2$ detection using the pCO$_2$-DO relation**

To clarify

- how many data is necessary to make a reliable threshold?