Update on Leakage detection

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Detecting anomalies

Signals of potential CO₂ leakage

- Increase in CO₂ concentration or partial pressure of CO₂ (pCO₂) in seawater near the sea bottom
- CO₂ bubbles in the water column
Detecting anomalously high pCO$_2$

Suspected signs of CO$_2$ leakage
✓ Anomalously high pCO$_2$
✓ Rapid increase in pCO$_2$

But these are also seen in the natural variability

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pCO$_2$ variation observed near the sea surface in a semi-enclosed bay by Fujii et al. (2011)
Two threshold methods

• Seasonal threshold
  ➢ a seasonally fixed value of pCO₂

• Covariance threshold
  ➢ the upper limit of a prediction interval of a linear regression of pCO₂ on DO (DO: Dissolved Oxygen)

Which is the better of the two?
Case study: Osaka Bay
semi-enclosed bay in Japan

**Eastern** bay: prone to be stratified throughout the year

**Western** bay: prone to be vertically mixed

**Observation stations**
✓ temperature, salinity, DO, pH etc.
✓ 4 times a year

**pCO₂ and DO near the bottom**

**Eastern**: often low DO and high pCO₂ during summer

**Western**: relatively high DO and low pCO₂ throughout the year

**Low DO and High pCO₂ near the bottom**
Thresholds in Osaka Bay

![Graphs showing thresholds in Osaka Bay](image)

- **Western bay**
  - Covariance threshold
  - Seasonal threshold

- **Eastern bay**
  - Covariance threshold
  - Seasonal threshold

**covariance threshold**
- The upper limit of 99% prediction interval of the straight line regression

**seasonal threshold**
- Average + 2.57 σ (σ: standard deviation)

**low DO and High pCO₂**

vertical mixing

low salinity water

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What is a good threshold?

• A threshold that rarely overlooks CO₂ leakage is good.

  ↓

false-negatives

• A threshold that often misjudges natural phenomena as leakage is bad.

  ↓

false-positives

We should compare false-negatives of the two thresholds under the same level of the occurrence of false-positives
False-positives
To misjudge natural phenomena as leakage

Eastern bay

![Graph showing relationship between pCO₂ (μatm) and DO (%)]
### False-positives

**Eastern bay: stratified area**

<table>
<thead>
<tr>
<th>Threshold</th>
<th>Feb</th>
<th>May</th>
<th>Aug</th>
<th>Nov</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>seasonal</td>
<td>0 (0%)</td>
<td>3 (2.59%)</td>
<td>1 (0.86%)</td>
<td>1 (0.85%)</td>
<td>5 (1.08%)</td>
</tr>
<tr>
<td>covariance</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>6 (5.17%)</td>
<td>2 (1.71%)</td>
<td>8 (1.72%)</td>
</tr>
</tbody>
</table>

**Western bay: vertically mixed area**

<table>
<thead>
<tr>
<th>Threshold</th>
<th>Feb</th>
<th>May</th>
<th>Aug</th>
<th>Nov</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>seasonal</td>
<td>0 (0%)</td>
<td>1 (1.59%)</td>
<td>2 (3.17%)</td>
<td>1 (1.59%)</td>
<td>4 (1.59%)</td>
</tr>
<tr>
<td>covariance</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>3 (4.76%)</td>
<td>3 (1.19%)</td>
</tr>
</tbody>
</table>

- The difference of false-positives between the two thresholds is small.
- Regarding the level of false-positives as the same, we compared the false-negatives.
False-negatives

Assumption: CO$_2$ leakage makes pCO$_2$ increase by $\Delta$pCO$_2$ but DO remains unchanged

Data are translated upward parallel to the vertical axis due to leakage

\[
\Delta pCO_2: \text{detected, } \times: \text{false-negatives}
\]
False-negatives

Western bay

Eastern bay

Western bay

Eastern bay

Feb

May

Aug

Nov

false-negative(%)

0 250 500 750 1000

ΔpCO₂ [μatm]

0 250 500 750 1000

ΔpCO₂ [μatm]

Feb

May

Aug

Nov

pCO₂ variation range between 2002-2010

[μatm]

0 500 1000 2000

350μatm

350μatm

: Seasonal threshold

: covariance threshold
Summary

Observing pCO$_2$ in the sea around the storage sites is an option in marine monitoring to detect CO$_2$ leakage

- **Seasonal threshold**: good detectability in many cases but useless in some cases
- **Covariance threshold**: not necessarily the better but reasonable detectability in any case

Which threshold to use depends on the season and area; it is conjectured that
- in areas and seasons with a large variation in pCO$_2$
  - the **covariance threshold** is better,
- in areas and seasons with a small variation in pCO$_2$
  - the **seasonal threshold** is better.
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The presentation is based on our paper: