

Stepping- and Mile-stones of Monitoring at Tomakomai

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Monitoring Techniques at Tomakomai

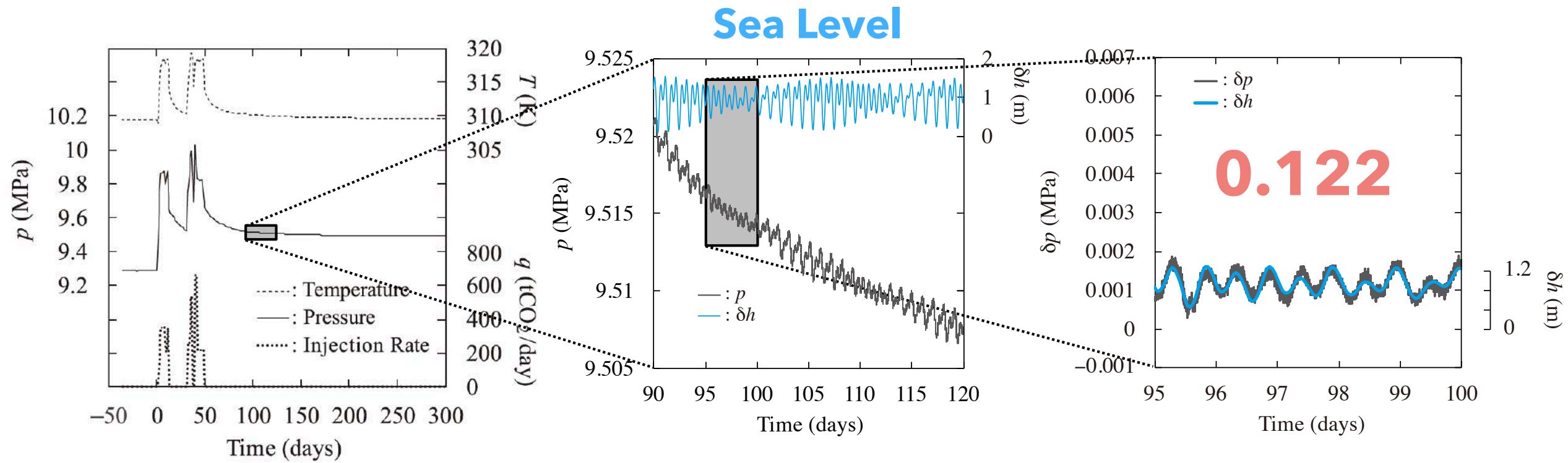
current → **long-term**

Monitoring Purpose	Injection Controls	Containment Assurance	Conformance Assurance	Environmental Impacts
Downhole Pres./Temp.	A	O	A	
2D/3D Seismic		A	A	
OBC/OBS	O			A
Surrounding Seismometry	O			A
Water Column Chemistry				A

 Deep
 Shallow

A	Appropriate
O	Occasional

Tidal Signals in Pressure Transients



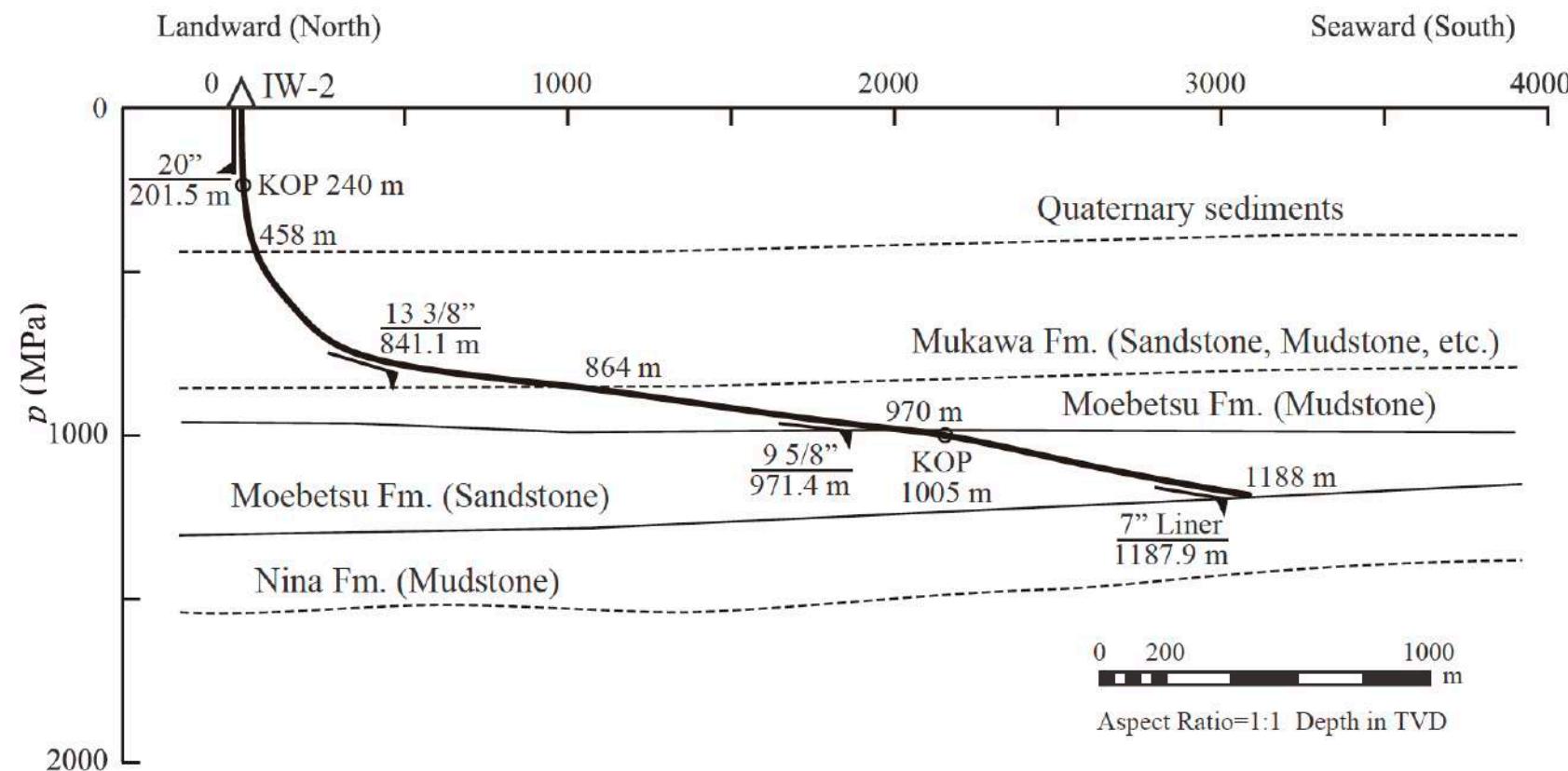
Resolution: 0.00005% FS

0.00001 MPa (0.00145 psi)

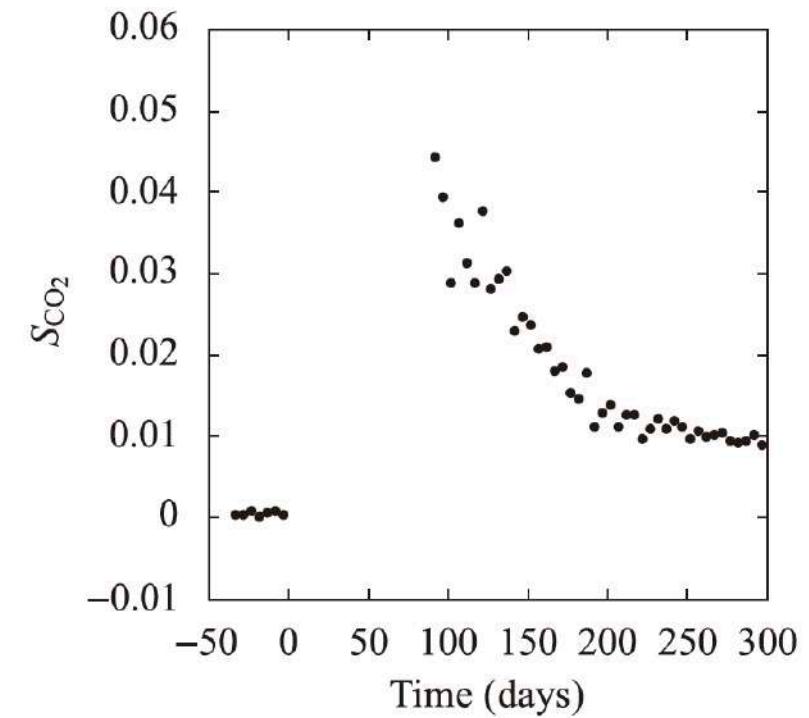
$$R = \frac{1}{\rho_w g} \frac{\delta p}{\delta h}$$

(Sato and Horne: IJGGC 76, 2018) 3

CO₂ Saturation for Conformance Assurance



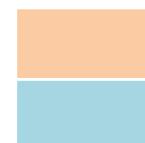
$$R = f(S_{CO_2}, c_w, c_{CO_2}, c_{pp})$$

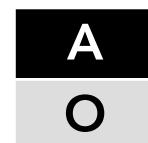


**Saturation Evaluation
without Well Intervention**

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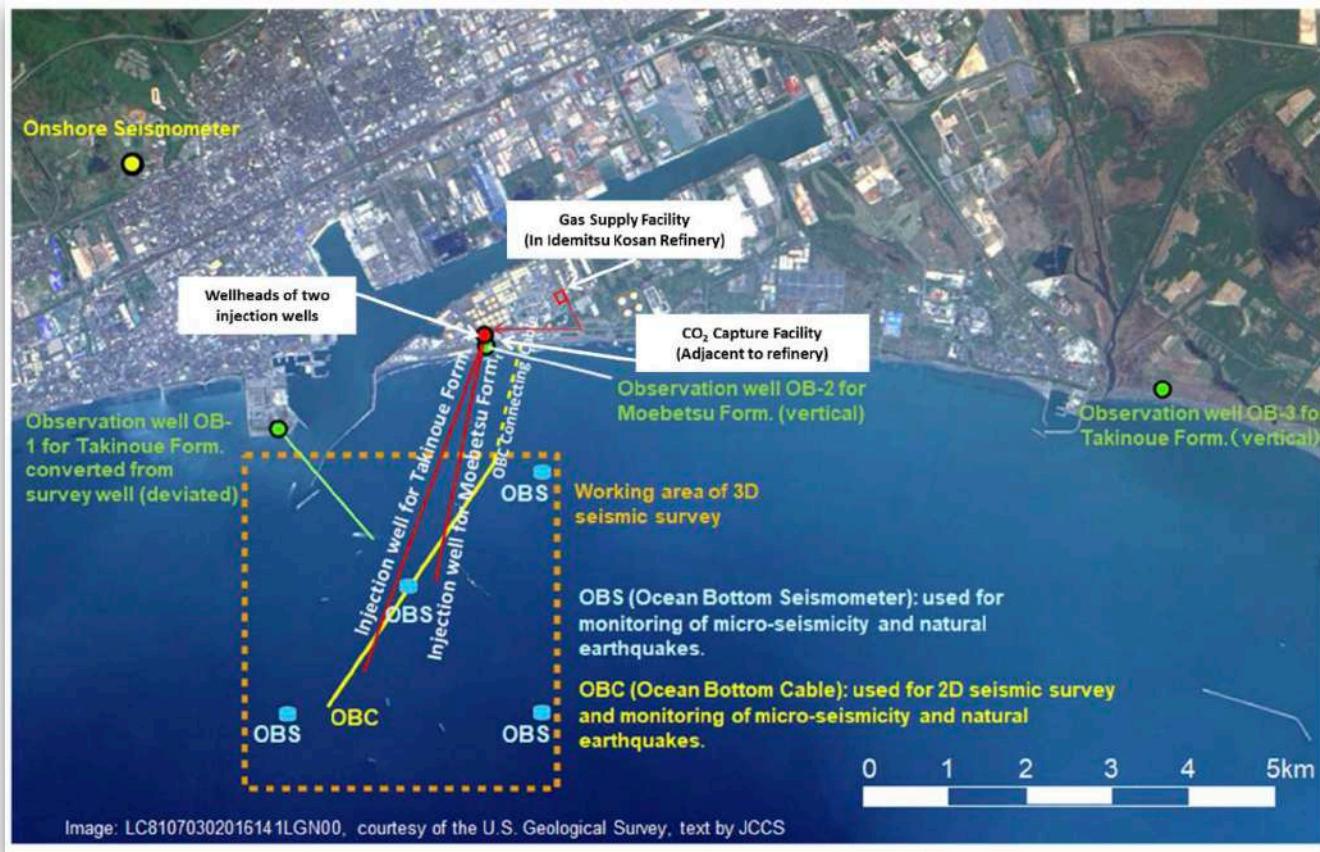

 Deep
 Shallow


 A Appropriate
 O Occasional

Baseline
Defensive

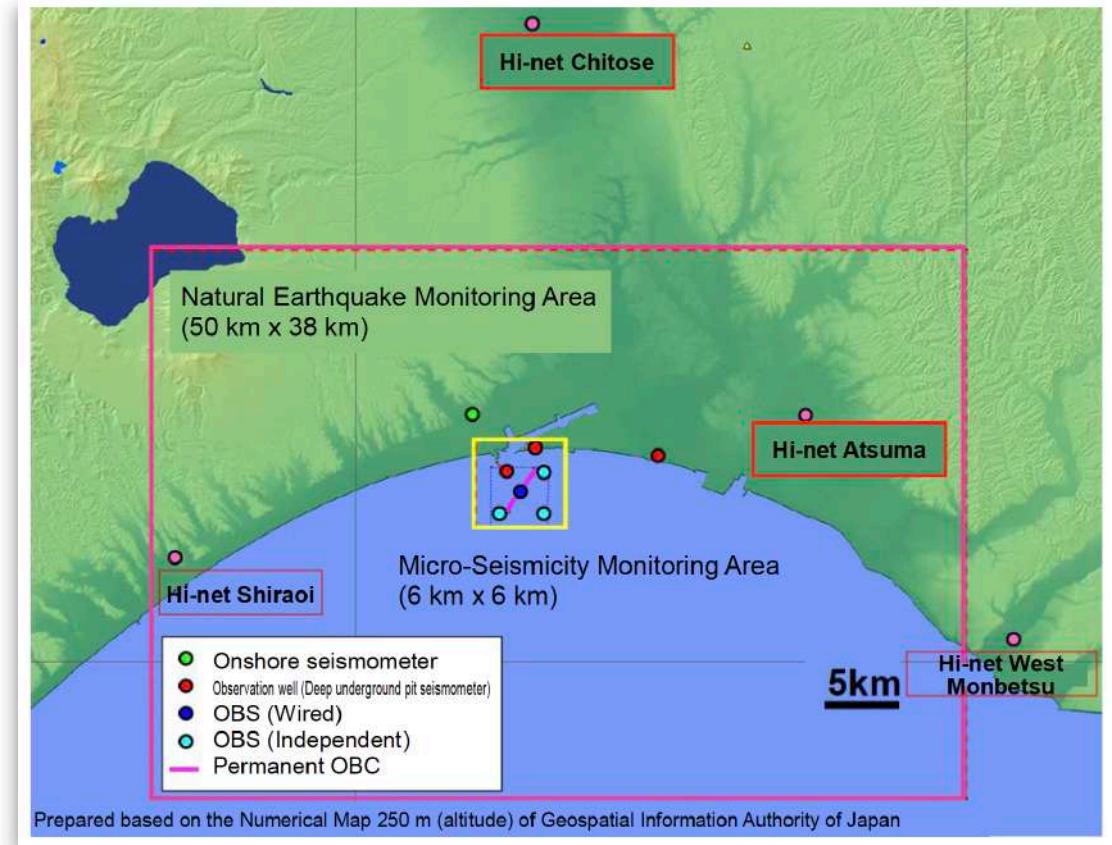
Comprehensive Monitoring of Seismic Activity

OBC (3.6 km)



4 OBS

Surface S. + 4 Hi-net

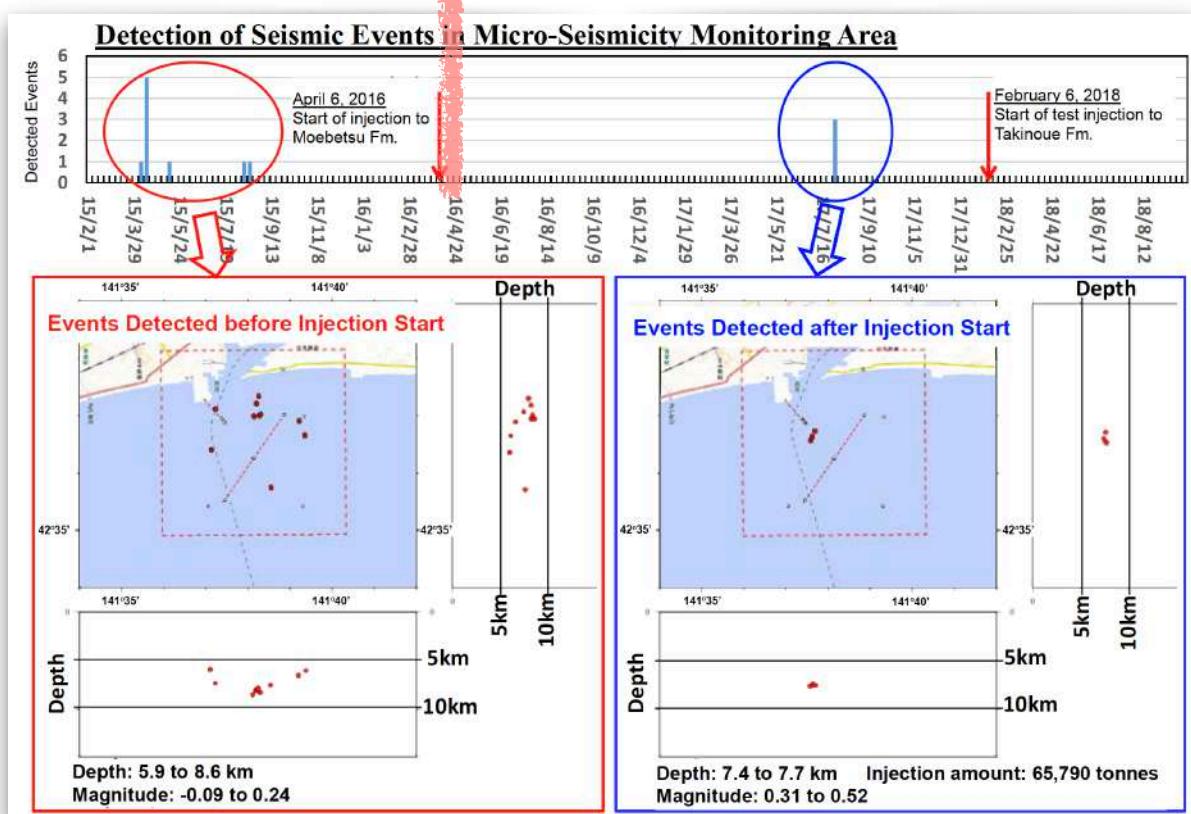


(JCCS: Summary Report on Tomakomai CCS Demonstration Project, 2020)

3 Monitoring Wells

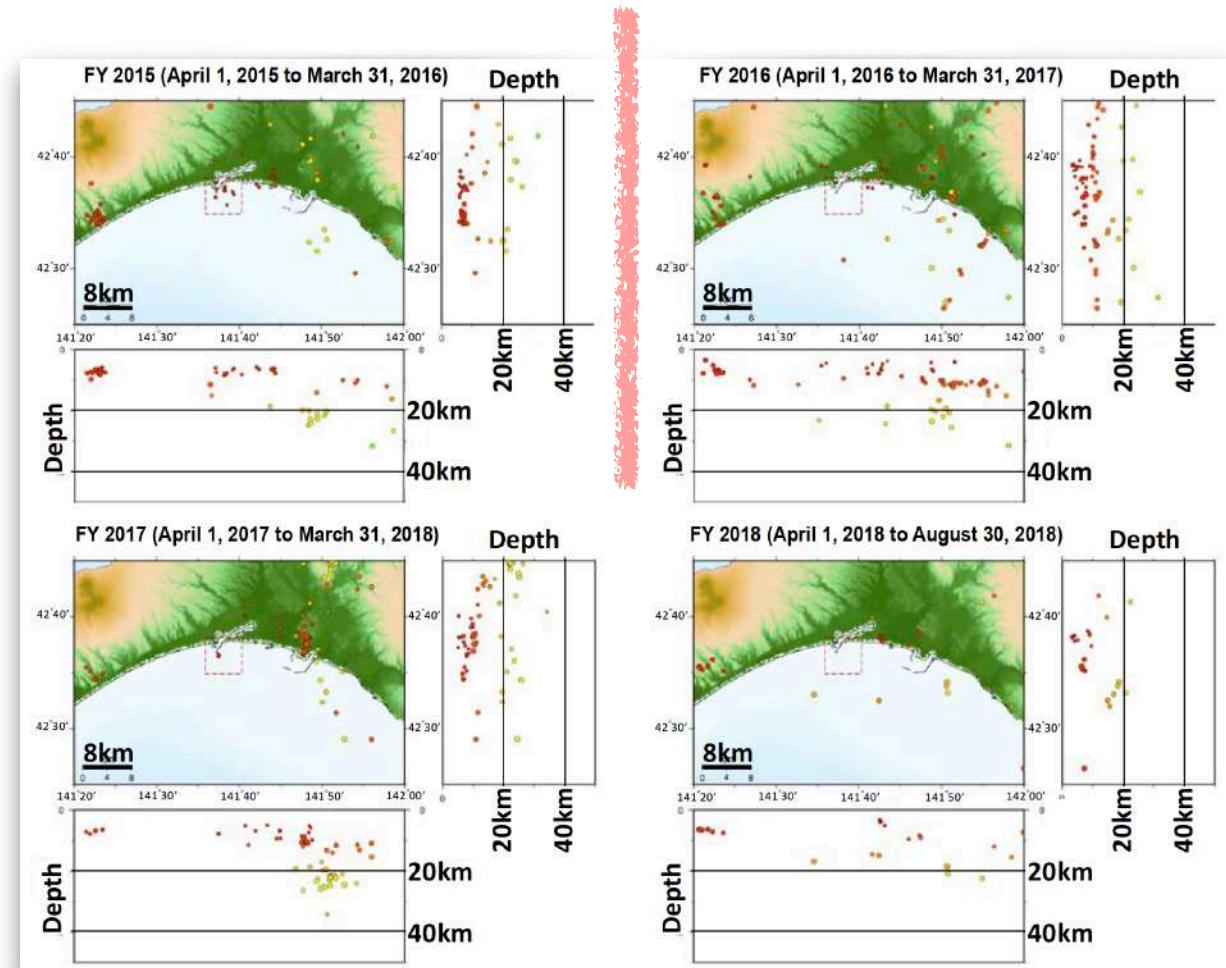
Accumulation of "Defensive" Baselines

9 vs. 3 events



> 6 km

< M 0.52



(JCCS: Summary Report on Tomakomai CCS Demonstration Project, 2020)

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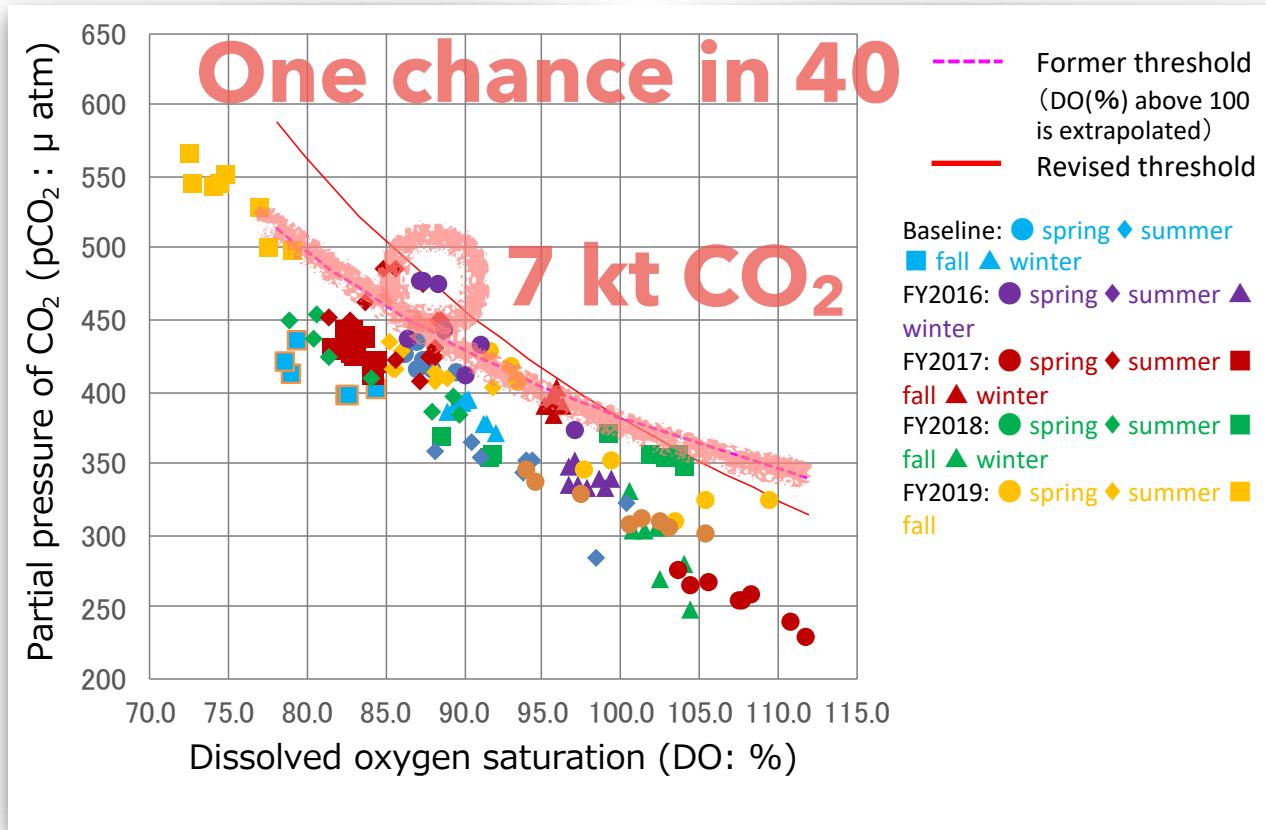
**Baseline
Defensive**



A Appropriate
O Occasional

Shallow Survey for Containment Assurance?

95% Confidence Interval



(JCCS: Summary Report on Tomakomai CCS Demonstration Project, 2020)

**Project Suspension
(6 months)
due to False Positive**

Shallow properties “are all part of open systems that are perturbed by many more things than containment failure.”

M&V Reviewed and Revised: Quest to Peterhead

	Pre-Injection	Injection	Post-Injection
Seabed and Shallow Layers	CO ₂ flux baseline monitoring ROV gas leak (bubble) detection under the platform Seabed surveys (MBES/SSS) Seabed samples GPS on platform	MBES/SSS	MBES/SSS Seabed samples
Geosphere	4D seismic/VSP	4D seismic/VSP	4D seismic/VSP
Monitoring Wells	Cement bond/casing integrity Sigma/Neutron	Annular pressure and DTS+DAS Sigma/Neutron Downhole sampling	
Injection Wells	PDG/Long term gauge Cement bond/casing integrity Sigma/Neutron PDG/Long term gauge	Annular pressure and DTS+DAS Tubing integrity	

Start of injection Mid-injection 1 Year post-injection

Baseline **Defensive**

Red circles highlight 'Seabed samples' in the Seabed and Shallow Layers section of the Pre-Injection, Injection, and Post-Injection phases.

(Dean and Tucker: IJGGC 61, 2017)

**M&V plan reviewed
every 3 years**

"Measurements intended to detect unlikely hazards were dropped or relegated to backup status."

"... shallow monitoring should focus mainly on assuring against environmental impacts."

(Jenkins et al.: IJGGC 40, 2015)

(Jenkins: IJGGC 100, 2020)

Concluding Remarks (1)

- Investigative Data Acquisition
 - ▶ Invariably measured pressure (with high resolution) was successfully used for estimating CO₂ saturation changes through tidal-signal analyses.
 - ▶ Comprehensive monitoring of seismicity provides sufficient evidence to dismiss the causal relationship between the Tomakomai CCS and the 2018 Hokkaido Eastern Iburi earthquake.

Concluding Remarks (2)

- Overuse of Shallow Monitoring
 - ▶ Loose correlation between pCO₂ and DO resulted in false positive and eventually hindered the operation.
 - ▶ A well-defined issue “containment” needs to be distinguished from vague concerns “environmental impact.”

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