# Field Validation of MVA Technology for Offshore CCS: Novel Ultra-High-Resolution 3D Marine Seismic Technology (P-Cable)

Project Number DE-FE0028193

Tip Meckel, Ramon Trevino, & Katherine Romanak

TEXAS Geosciences
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Gulf Coast Carbon Center

U.S. Department of Energy
National Energy Technology Laboratory
**Carbon Capture Front End Engineering Design Studies and CarbonSafe**
**2020 Integrated Review Webinar**
August-17-19 2020

# Program Overview

Funding: $3,123,320 DOE: $2,498,654 Cost Share: $624,666

Project Performance Dates
**October 1, 2016 – September 30, 2021 (originally Sept. 30, 2019)**

**Goal:** Validate technologies to enhance MVA

**Objectives:**

1) Acquire UHR3D seismic dataset and validate MVA technology at operational CCS field demonstration project - FOAK
2) Validate novel positioning techniques
3) Environmental Monitoring

# Project Participants

U.S. DEPARTMENT OF ENERGY

NETL

**Thank you to our Japanese colleagues!**

METI
Ministry of Economy, Trade and Industry

Japan CCS Co., Ltd.

JGI, Inc.

MARINE ECOLOGY RESEARCH INSTITUTE

RITE Research Institute of Innovative Technology for the Earth

TEXAS Geosciences
Bureau of Economic Geology
Jackson School of Geosciences
The University of Texas at Austin



Gulf Coast Carbon Center

# Project Overview

- **Ministry of Economy, Trade and Industry (METI)**
- **Japan CCS Co., Ltd. (JCCS)**
- **2012-2020**
- **Demonstrate and verify integrated CCS system**
  - **$CO_2$ gas separation, compression, transport, geologic storage**
- **100,000 tonnes/year rate, 3 year injection**
  - **$CO_2$ is captured from offgas generated at a hydrogen production unit in refinery**
  - **~70,000 tons by HR3D survey date in August 2017**
- **Moebetsu Formation saline aquifer @ 1100 m**
- **2 INJ; 3 OBS; Conventional 3D seismic, Seismology, Marine Geochemistry**
- **2 reports to METI; "Geological evaluation report of Tomakomai Area", and "Basic Plan of CCS demonstration project at Tomakomai Area"; Other resources in GHGT Proceedings.**

# Technical Approach/Project Scope

**Task 2.0: Ultra-High Resolution 3D Marine Seismic Imaging**

- **Subtask 2.1.1:** $CO_2$ Sensitivity Study
- **Subtask 2.1.2:** Vessel Subcontracting Preparation
- **Subtask 2.2:** P-Cable acquisition survey
- **Subtask 2.3:** P-Cable data processing
- **Subtask 2.3.1:** 4D Repeatability Study
- **Subtask 2.4:** P-Cable data interpretation

**Task 3.0:** Shallow Sediment Core Sampling and Geochemistry

- **Subtask 3.1:** Shallow sediment core sampling
- **Subtask 3.2:** Core geochemistry
- **Subtask 3.3:** Interpretation and integration

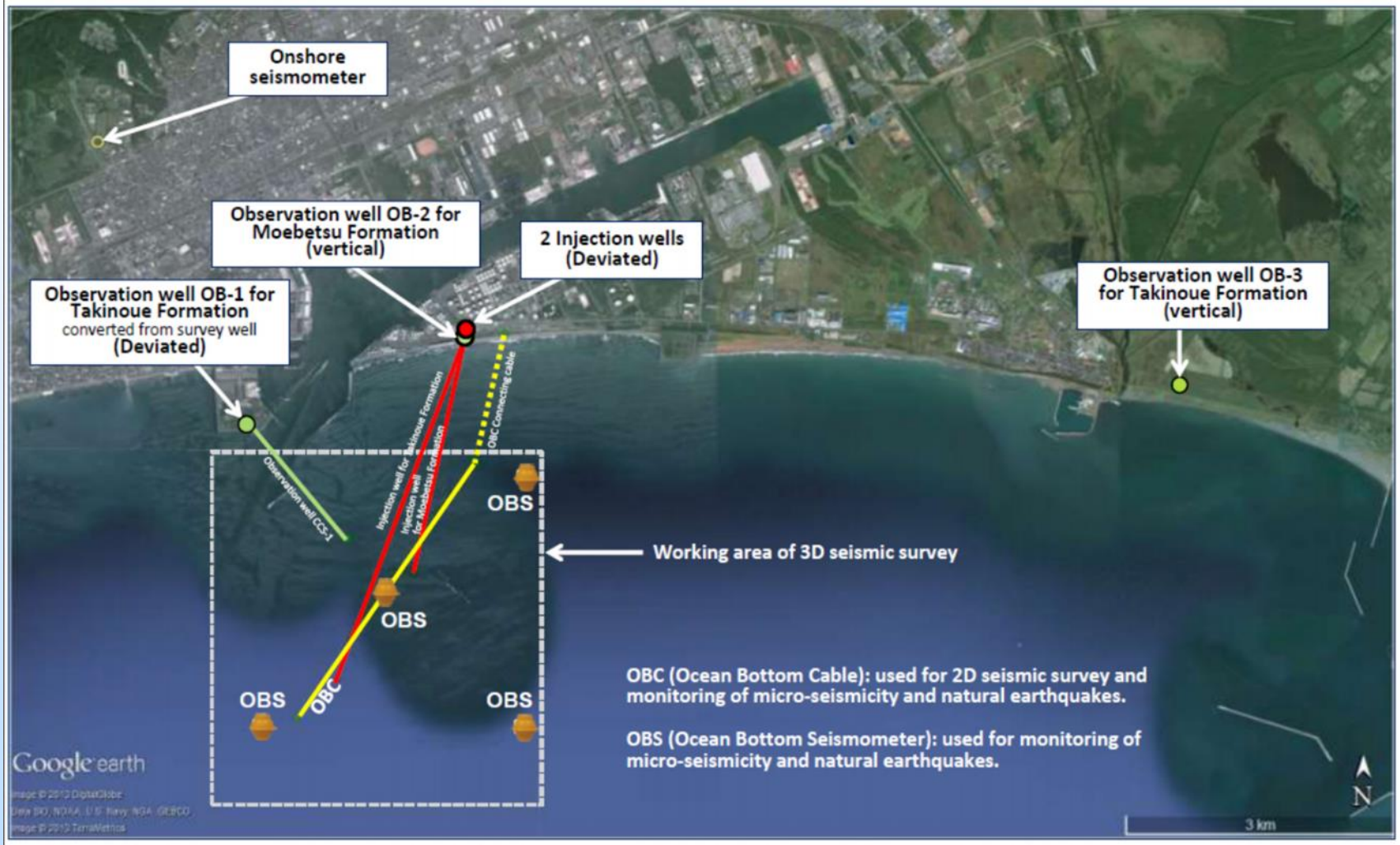
# Project Milestones

| Milestone Description | Planned Completion | Verification Method |
|---|---|---|
| **M1: Tomakomai project data available for CO2 Sensitivity Study.** | 11/30/2016 | **Topical Report of data to be incorporated into $CO_2$ Sensitivity Study.** |
| **M2: Seismic vessel identified (Survey #1)** | 06/30/2017 | **Letter Report: List of potential vessel(s) (Survey #1).** |
| **M3: UHR3D successfully acquired.** | 08/31/2017 | **Letter Report: Plots of single channel field records (Survey #1).** |
| **M4: UHR3D successfully processed.** | 03/23/2018 | **Letter Report: Images from preliminary processed seismic data volume (Survey #1).** |
| **M5: Seismic vessel subcontracted (Survey #2)** | 11/30/2019 | **Letter Report: Signed page of contract (Survey #2).** |
| **M6: UHR3D #2 successfully acquired.** | 02/28/2020 | **Letter Report: Plots of single channel field records (Survey #2).** |
| **M7: Core sampling successful.** | 10/31/2018 | **Letter Report: Map of shallow sediment core sample locations.** |
| **M8: UHR3D #2 successfully processed** | 02/28/2020 | **Letter Report: Images from preliminary processed seismic data (Survey #2).** |
| **M9: Core sediment analyses successful.** | 03/18/2019 | **Letter Report: Tables of geochemistry and isotopic analytical results.** |
| **M10: Successful demonstration of Time-lapse (4D) seismic imaging.** | 07/31/2020 | **Topical Report comparing UHR3D surveys #1 and #2 for detecting $CO_2$ migration.** |

# Tomakomai Port, Hokkaido Japan

## Layout of Monitoring Facilities



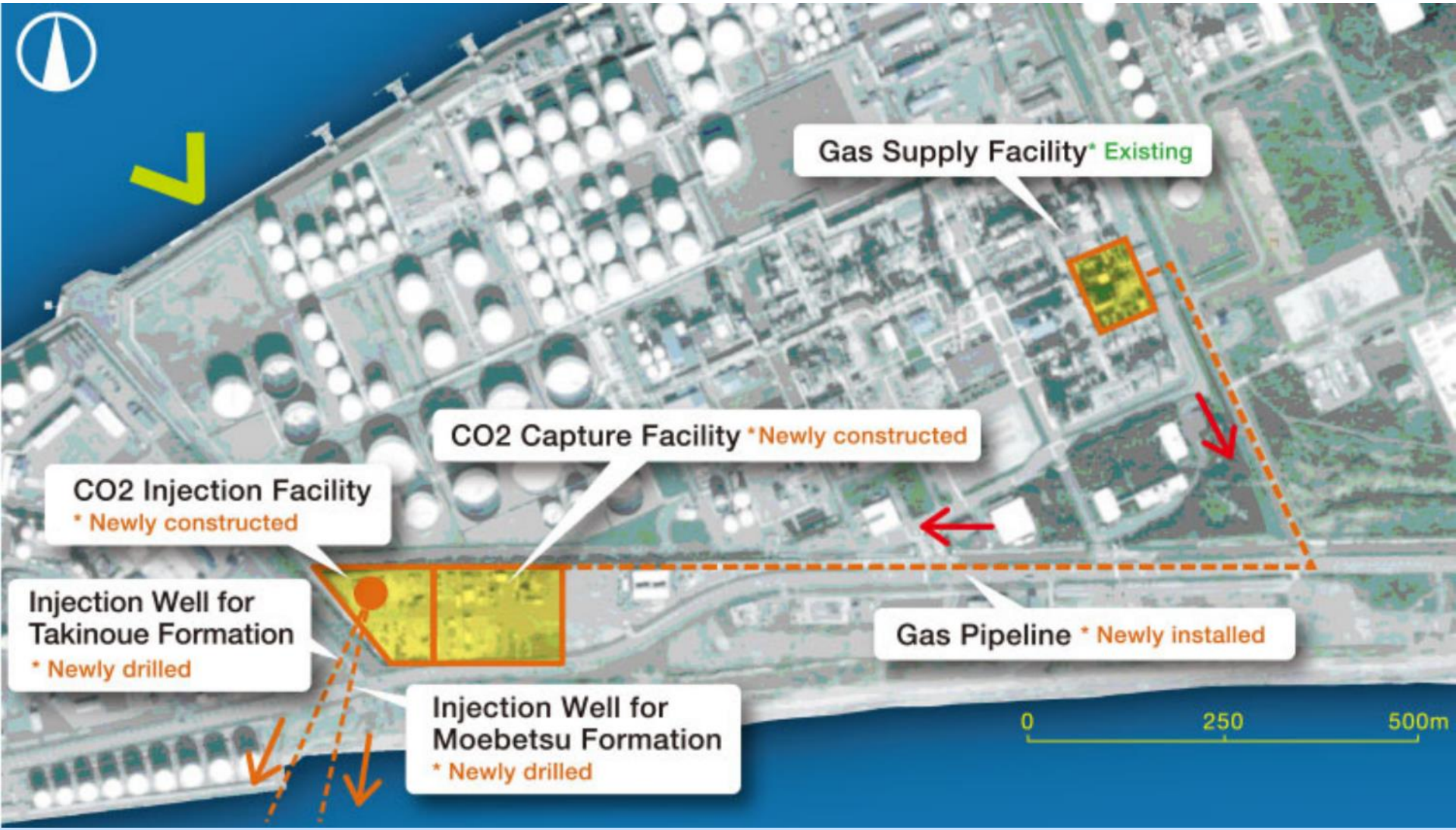






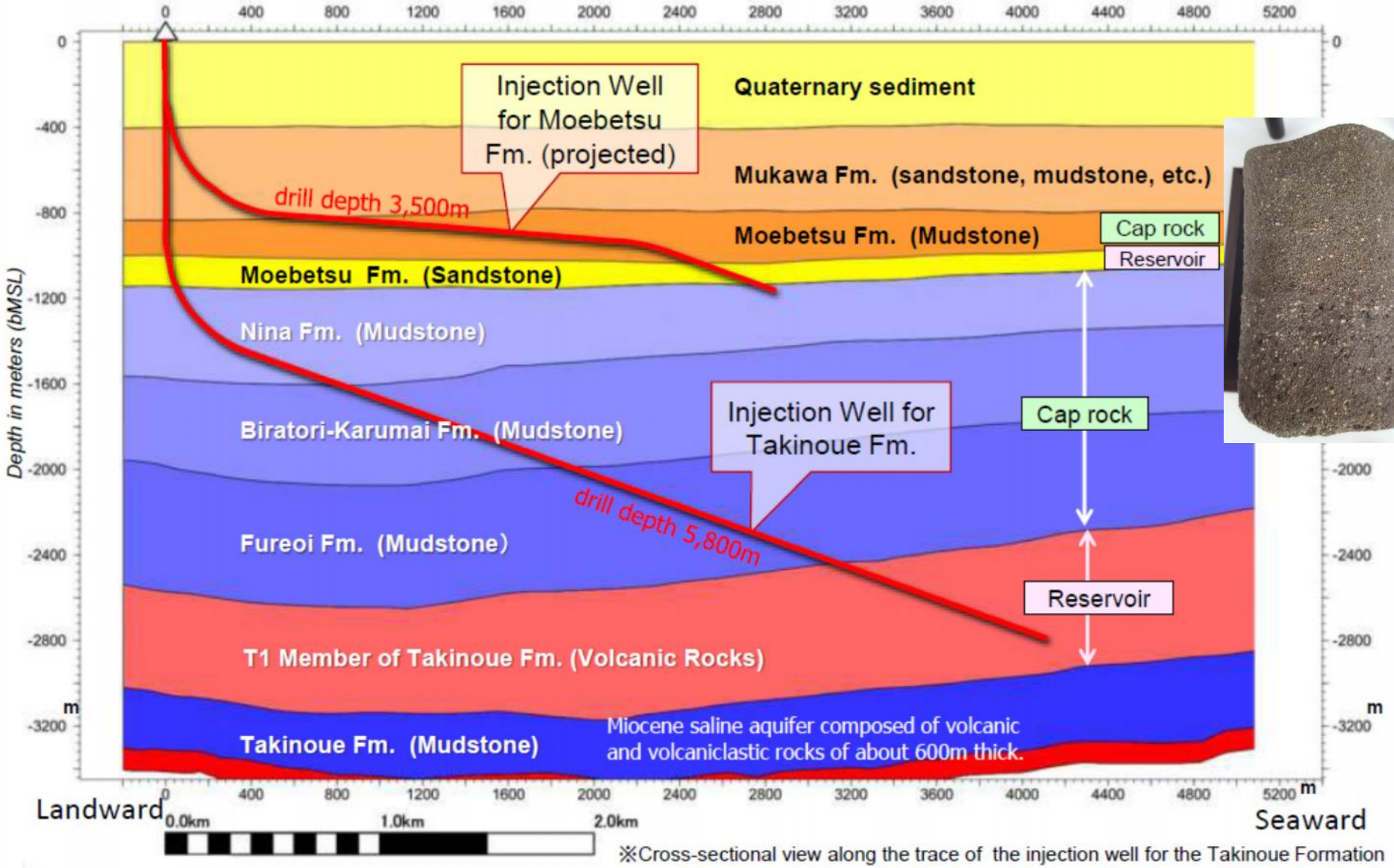



JCCS


Gas Supply Facility* Existing
CO2 Capture Facility *Newly constructed
CO2 Injection Facility
* Newly constructed
Injection Well for
Takinoue Formation
* Newly drilled
Injection Well for
Moebetsu Formation
* Newly drilled
Gas Pipeline * Newly installed
0
250
500m

# Schematic Geological Section






※Cross-sectional view along the trace of the injection well for the Takinoue Formation



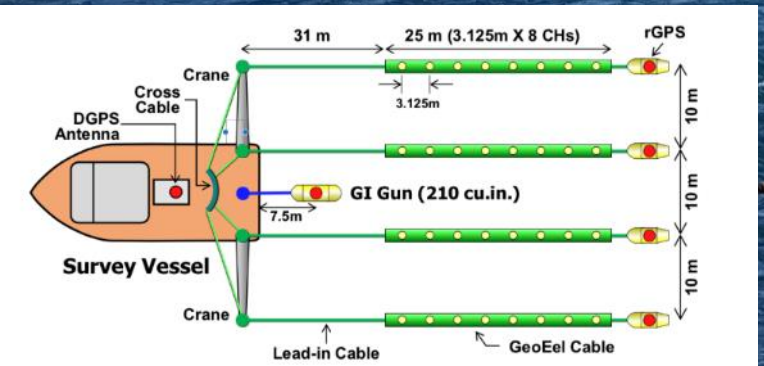


JCCS

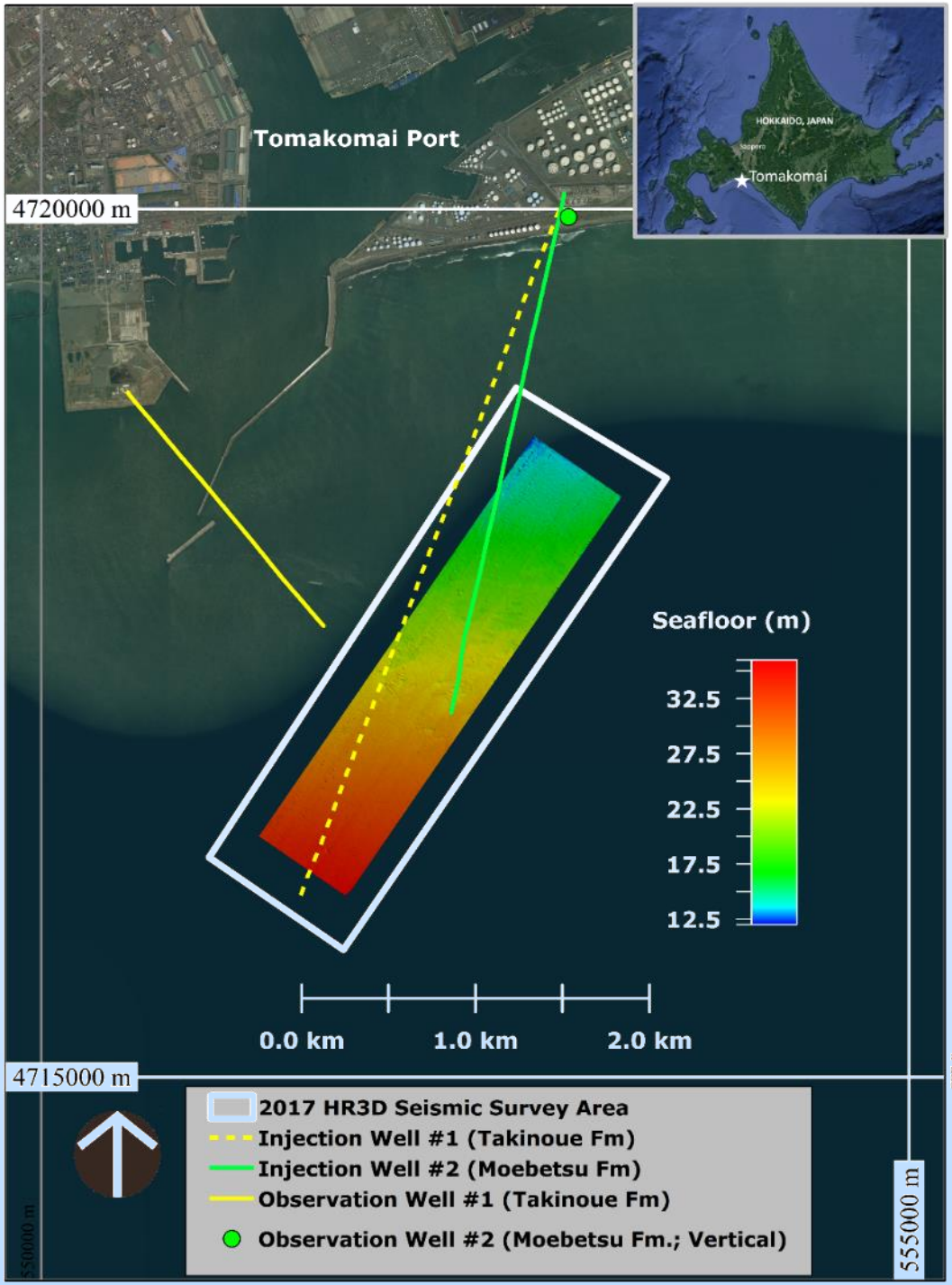
HR3D acquisition August 2017

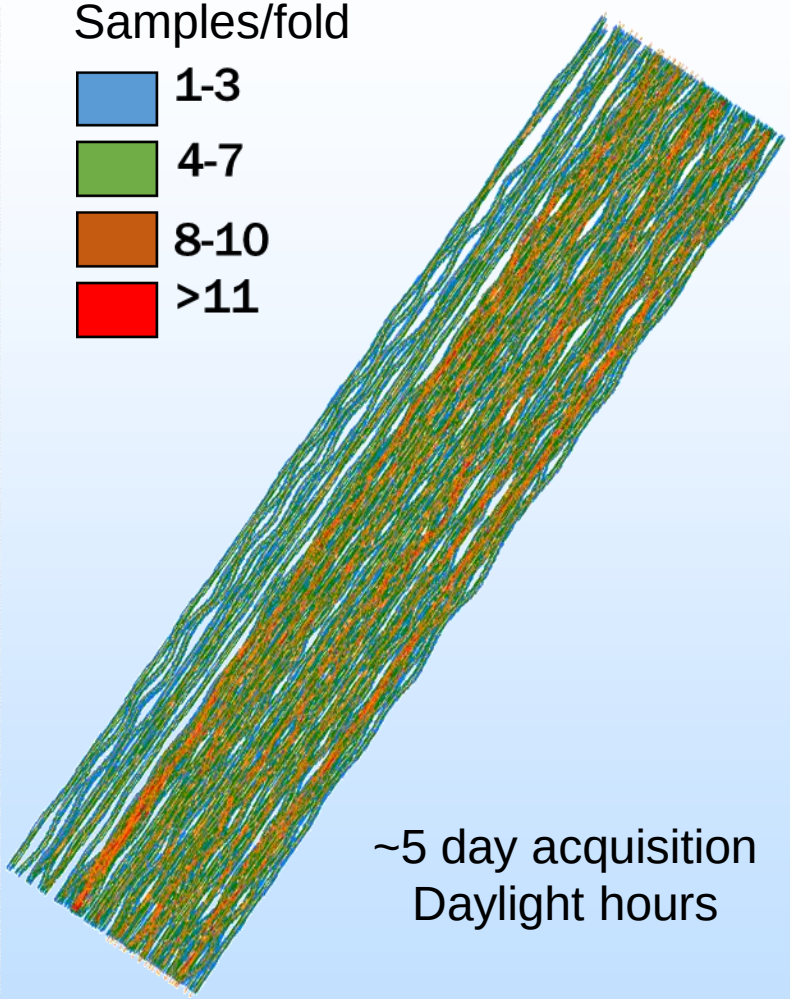
$CO_2$ Injection

Gas Separation



# CDP Binning




~5 day acquisition
Daylight hours

# HR3D data processing workflow

FENG

RadExPro seismic software

Statics correction → Precondi-tioning → NMO → Linear noise suppression → Post-stack T-variant processing → Interpo-lation → Migration → Geometry setup + SEGY output

MADAGASCAR

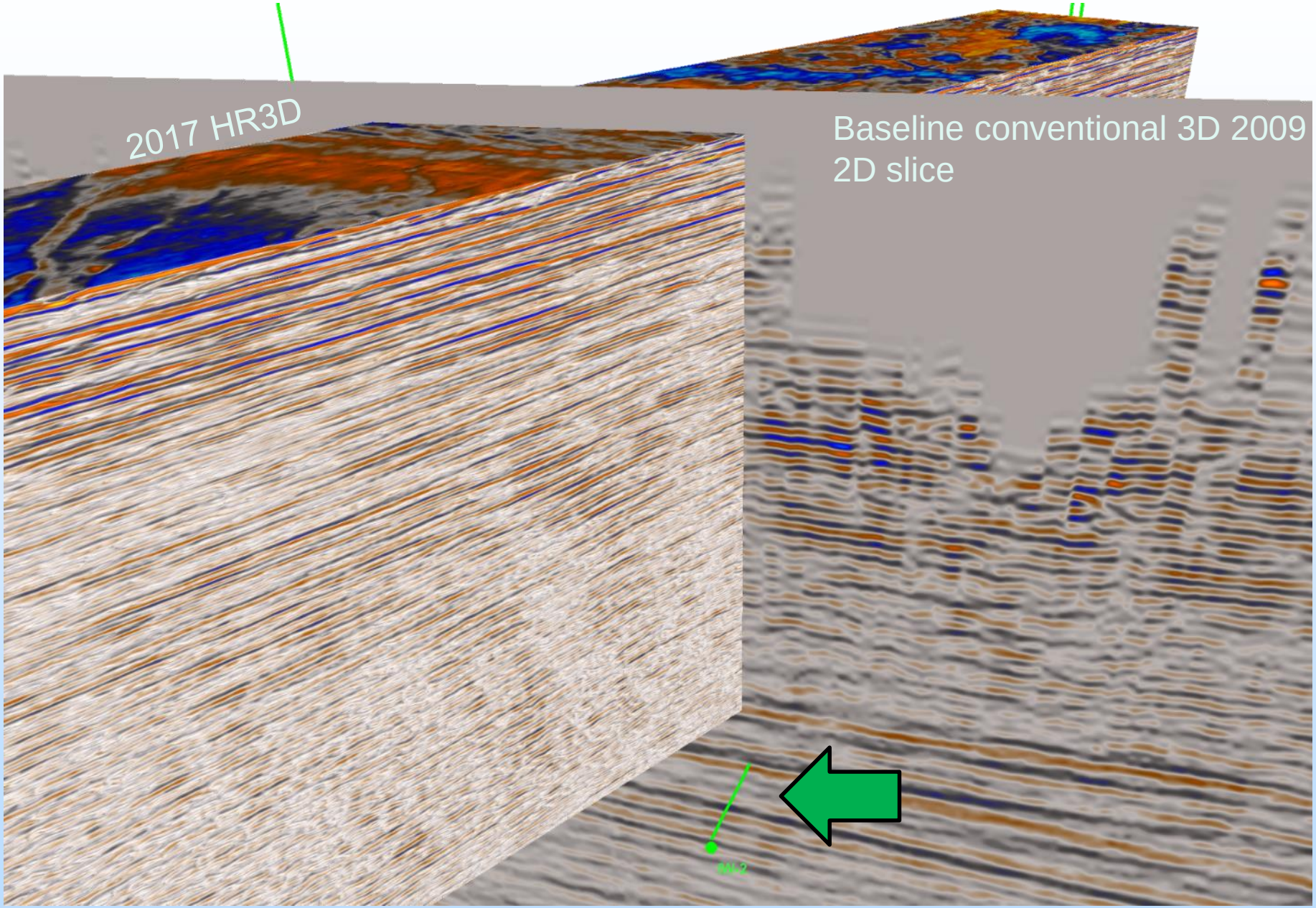
Footprint removal → Stack

Paradigm

OpendTect Pro

Dip-steered analysis

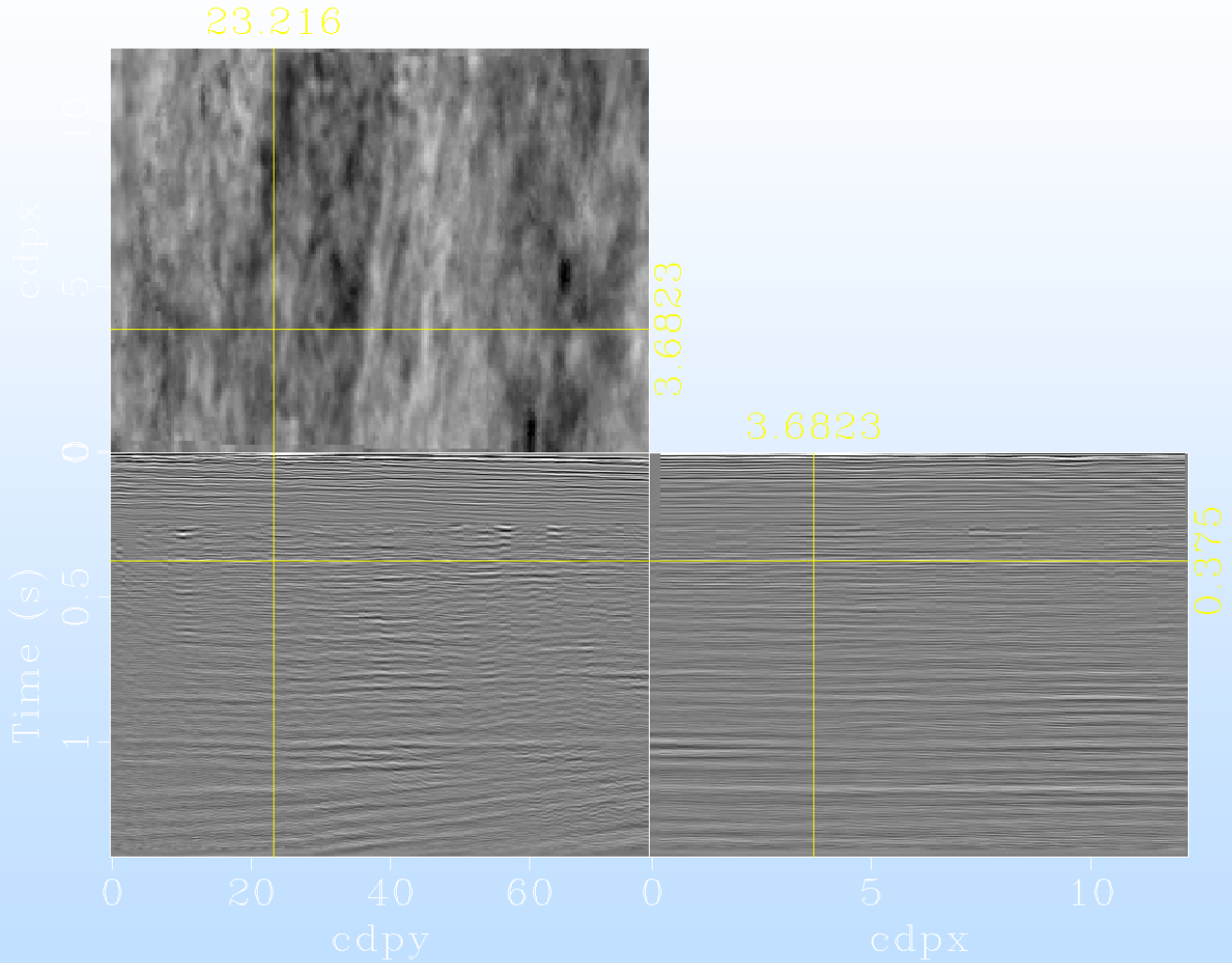
# HR3D vs Conventional 3D



# Recent significant accomplishments: Merged 3D dataset

- HR3D seismic data and convention seafloor cable dataset were successfully merged into a single dataset
  - Single data product for interpreting reservoir and overburden
  - Provided to JCCS project host

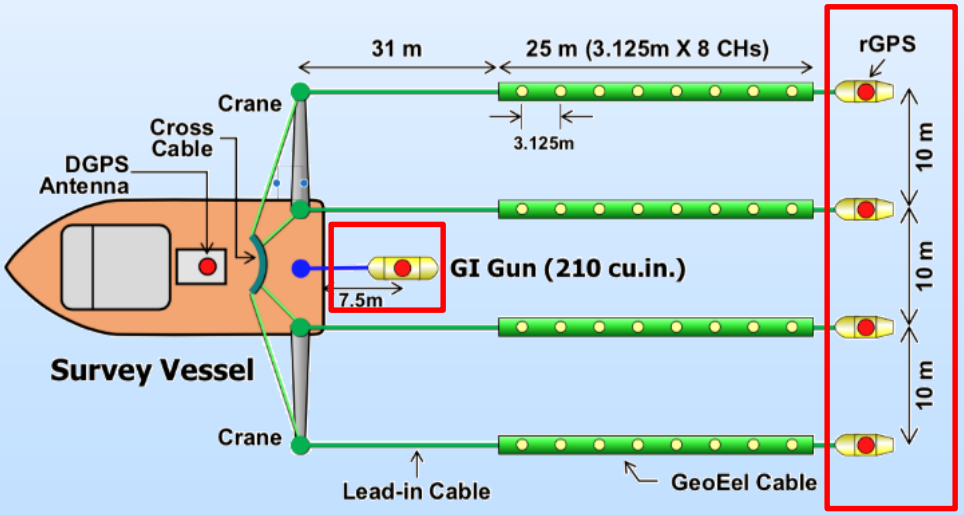
# Merging HR3D and Conventional




Method: Matching and **merging** high-resolution and legacy **seismic** images. S **Greer**, S **Fomel**. **Geophysics** 83 (2), V115-V122, 2018.

# Recent significant accomplishments: Positioning

- Original intent to use short-baseline acoustics for source-receiver positioning was unsuccessful.
  - Alternative construction of GPS units successful



# Task 3- Environmental Monitoring Objectives

- Provide insight into subsurface field conditions informed by high resolution 3D seismic survey.
- <u>D8- Summary Report</u>: Interpretation of core sediment geochemistry Katherine Romanak

Marine Pollution Bulletin 159 (2020) 111520

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

What natural and social scientists need from each other for effective marine environmental assessment: Insights from collaborative research on the Tomakomai CCS Demonstration Project

Leslie Mabon[a,*], Jun Kita[b], Hiromitsu Onchi[b], Midori Kawabe[c], Toshiya Katano[c], Hiroshi Kohno[c], Yi-Chen Huang[d]


- Augment existing monitoring activities with additional analyses/techniques
- Learn marine monitoring techniques

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# Synergy Opportunities

- International Offshore CCS Workshop
  - Bergen February 2020 – Meckel Presentation
  - Contact with Univ. Tromso – Stefan Buenz
- Other projects:
  - Synergy with GoMCARB, STEMM-CCS (UK), and Northern Lights Project.

# Accomplishments to Date

- Pre-survey Sensitivity Study complete
- Marine geochemistry methods and data analysis complete
- Successful HR3D seismic dataset acquired
- Developed advanced processing techniques
- No NRMS anomalies detected in overburden
  - Demonstration of containment
- Repeatability study complete
- Second survey being planned

International Journal of Greenhouse Gas Control 88 (2019) 124–133

Contents lists available at ScienceDirect

International Journal of Greenhouse Gas Control

journal homepage: www.elsevier.com/locate/ijggc

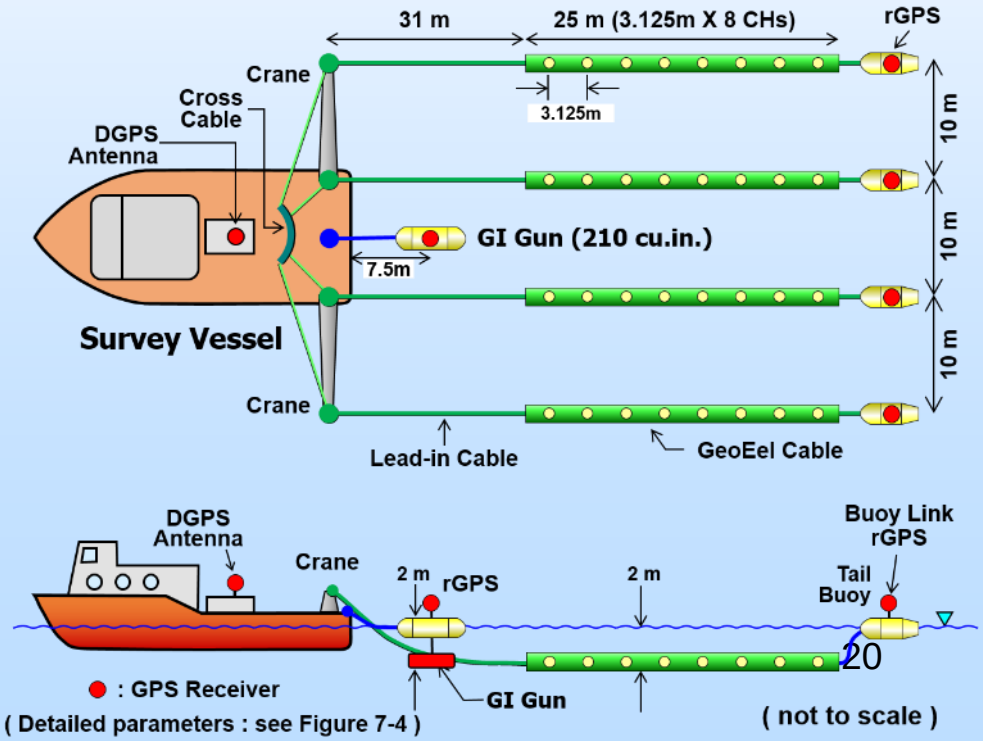
# High-resolution 3D marine seismic acquisition in the overburden at the Tomakomai $CO_2$ storage project, offshore Hokkaido, Japan

T.A. Meckel*, Y.E. Feng, R.H. Treviño, D. Sava

*Gulf Coast Carbon Center, Bureau of Economic Geology, Jackson School of Geosciences, The University of Texas at Austin, Austin, TX, USA*

SSRN's Top Ten download list for the Earth Science Research Network: Seismology topic.

The SSRN is a research repository and an international journal. The ranking demonstrates the study's value to the broader scientific community. View the full article here.



# Report of Tomakomai CCS Demonstration Project at 300 thousand tonnes cumulative injection ("Summary Report")

## - Overview -

**May 2020**

**Ministry of Economy, Trade and Industry (METI)**

**New Energy and Industrial Technology Development Organization (NEDO)**

**Japan CCS Co., Ltd. (JCCS)**

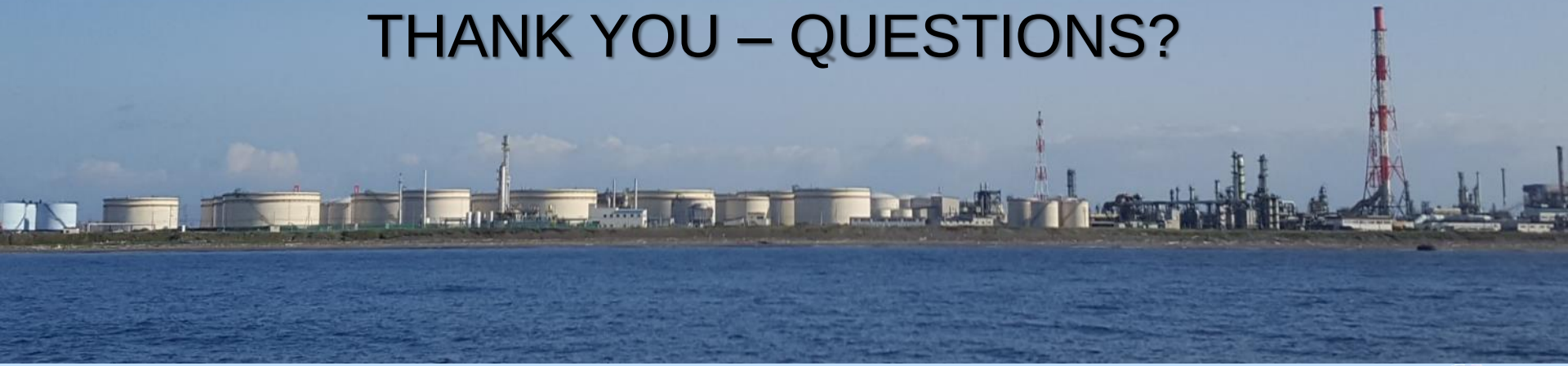
# Lessons Learned

- International deployment demonstrated
  - Overseas shipping transport, contracts, costs, production rates
  - Vessel modifications
  - International communications
- Real-time modifications of survey acquisition
  - Data coverage, density
- Processing techniques – hybrid commercial + other
- Local fisheries consultation and negotiation very important; National group, strong locally.

# SUMMARY

1. **Successful demonstration of HR3D as CCS characterization and monitoring tool in overburden.**
2. A successful first high-resolution 3D survey was collected Aug. 2017.
   - Imaging depth ~600 ms = source energy; very noisy port environment.
   - Lack of any apparent faults or fluid/gas anomalies in overburden.
3. Repeatability Study – results look promising for 4D in shallow interval.
   - A second survey cannot be hosted at Tomakomai
     - Fisheries negotiations critical.
4. Second HR3D survey location under negotiation.

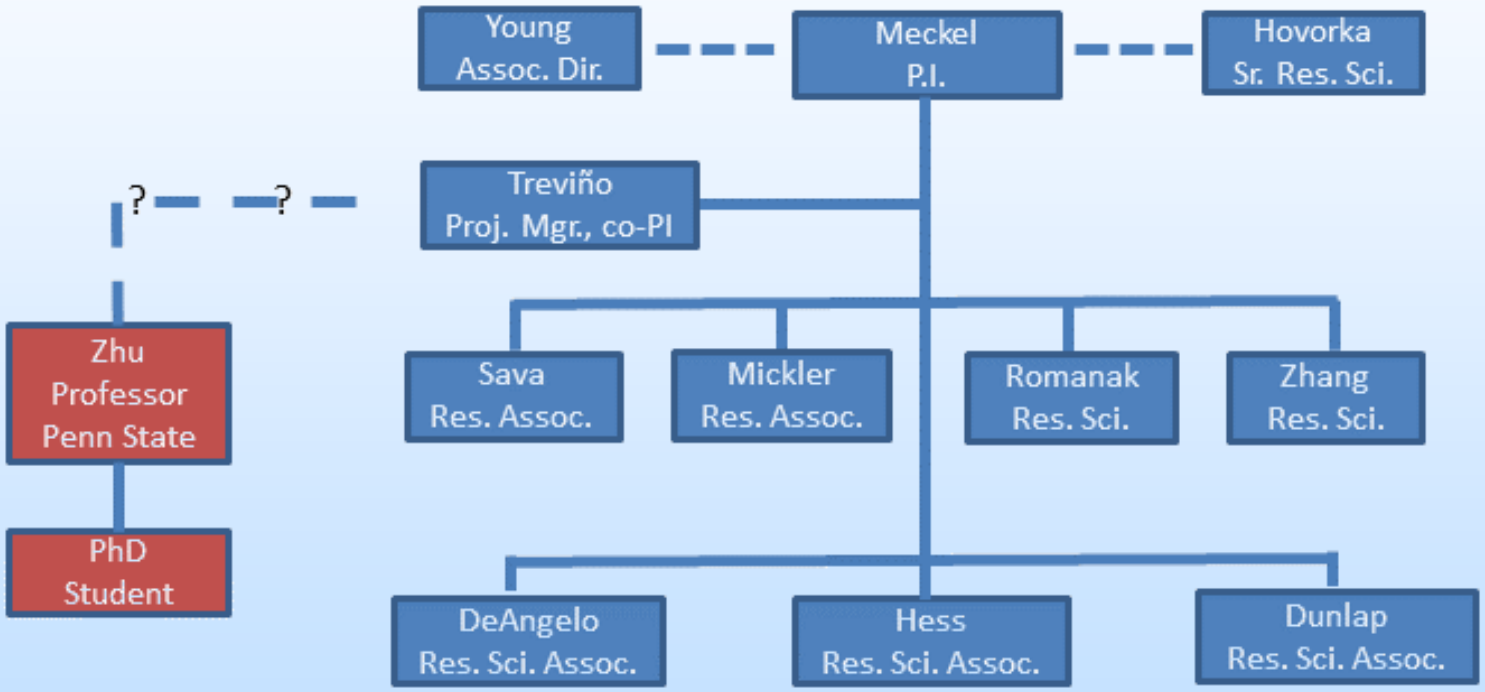
## THANK YOU – QUESTIONS?



# Appendix

– These slides will not be discussed during the presentation, but are mandatory.

# Organization Chart



# Gantt Chart

| | | BUDGET PERIOD 1 | | | BUDGET PERIOD 2 | | | | BUDGET PERIOD 3 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | YEAR 1 | | | | YEAR 2 | | | | YEAR 3 | | | | YEAR 4 | | | |
| Task | Tasks | qtr 1 | qtr2 | qtr3 | qtr4 | qtr 1 | qtr2 | qtr3 | qtr4 | qtr 1 | qtr2 | qtr3 | qtr4 | qtr 1 | qtr2 | qtr3 | qtr4 |
| **Field Validation of MVA Technology for Offshore CCS: Novel Ultra-High-Resolution 3D Marine Seismic Technology (P-Cable)** | | | | | | | | | | | | | | | | | |
| **1) PROJECT MANAGEMENT, PLANNING, and REPORTING** | | | | | | | | | | | | | | | | | |
| 1.1 | PMP, TMP, DMP | D1 D2 D3 | | | | | | | | | | | | | | | |
| 1.2 | Meetings | | | | | | | | | | | | | | | | |
| 1.3 | Reporting | Q | Q | Q | Q | Q | Q | Q | Q | Q | Q | Q | Q | Q | Q | Q | Q F |
| 1,4 | Project Management | | | | | | | | | | | | | | | | |
| **2) UHR3D SEISMIC IMAGING** | | | | | | | | | | | | | | | | | |
| 2.1 | CO2 SENSITIVITY STUDY | | | D4 M1 DP1 | | | | | | | | | | | | | |
| 2.2 | P-Cable ACQUISITION | | | | M2 M3 | | | | | | | | | M5 | M6 | | |
| 2.3 | P-Cable PROCESSING | | | | | D5 | M4 D6 DP2 | | | | | | | | | | M8 D9 |
| 2.4 | P-Cable INTERPRETATION | | | | | | | | | D7 | | | | | | | M10 |
| **3) SHALLOW SEDIMENT CORE SAMPLING AND GEOCHEMISTRY** | | | | | | | | | | | | | | | | | |
| 3.1 | Shallow Sediment Core Sampling | | | | | | | | | M7 | | | | | | | |
| 3.2 | Core Geochemistry | | | | | | | | | | M9 | | | | | | |
| 3.3 | Interpretation & Integration | | | | | | | | | | | D8 | | | | | |

Q = Quarterly Report; A = Annual Report; F = Final Report
M = Milestone; DP = Decision Point; D = Deliverable;

# Benefit to the Program

Program goal being addressed:

- This study supports SubTER pillar 4 (new subsurface signals) and advances the long-term Carbon Storage program goal of developing technologies to ensure 99 percent storage permanence.

Benefits statement:

- The project will conduct research under Area of Interest 1, Field Demonstration of MVA Technologies, by deploying and validating novel ultra-high resolution 3D seismic technology for CCS MVA at an active operational field site. This research will advance the MVA technology development pathway to TRL 7 by validating a fully integrated prototype seismic imaging system including untested dynamic acoustic positioning. The technology will demonstrate significantly improved spatial resolution over a commercially-meaningful area with improved accuracy and economic viability, decreasing the cost and uncertainty in measurements needed to satisfy regulations for tracking the subsurface fate of $CO_2$.

# Bibliography

– List peer reviewed publications generated from the project per the format of the examples below.


- Meckel, T.A., Y. Feng, R.H. Trevino, and D. Sava, 2019, *High-resolution 3D marine seismic acquisition in the overburden at the Tomakomai CO2 storage project, offshore Hokkaido, Japan*, IJGGC, 88:124-133. https://doi.org/10.1016/j.ijggc.2019.05.034

# Extra Slides

# Moebetsu Formation

Temperature=44.8 C
Pore Pressure=10.67 MPa

BRINE
2.49 Bulk modulus (Gpa)
1007 Density (kg/m$^3$)

$CO_2$
0.0038 Bulk modulus (Gpa)
265 Density (kg/m$^3$)

RESIDUAL GAS
0.02 Bulk modulus (Gpa)
137 Density (kg/m$^3$)

**Mineral Composition of Moebetsu**
(average values from cores over the interval 968 - 1079.35 m)

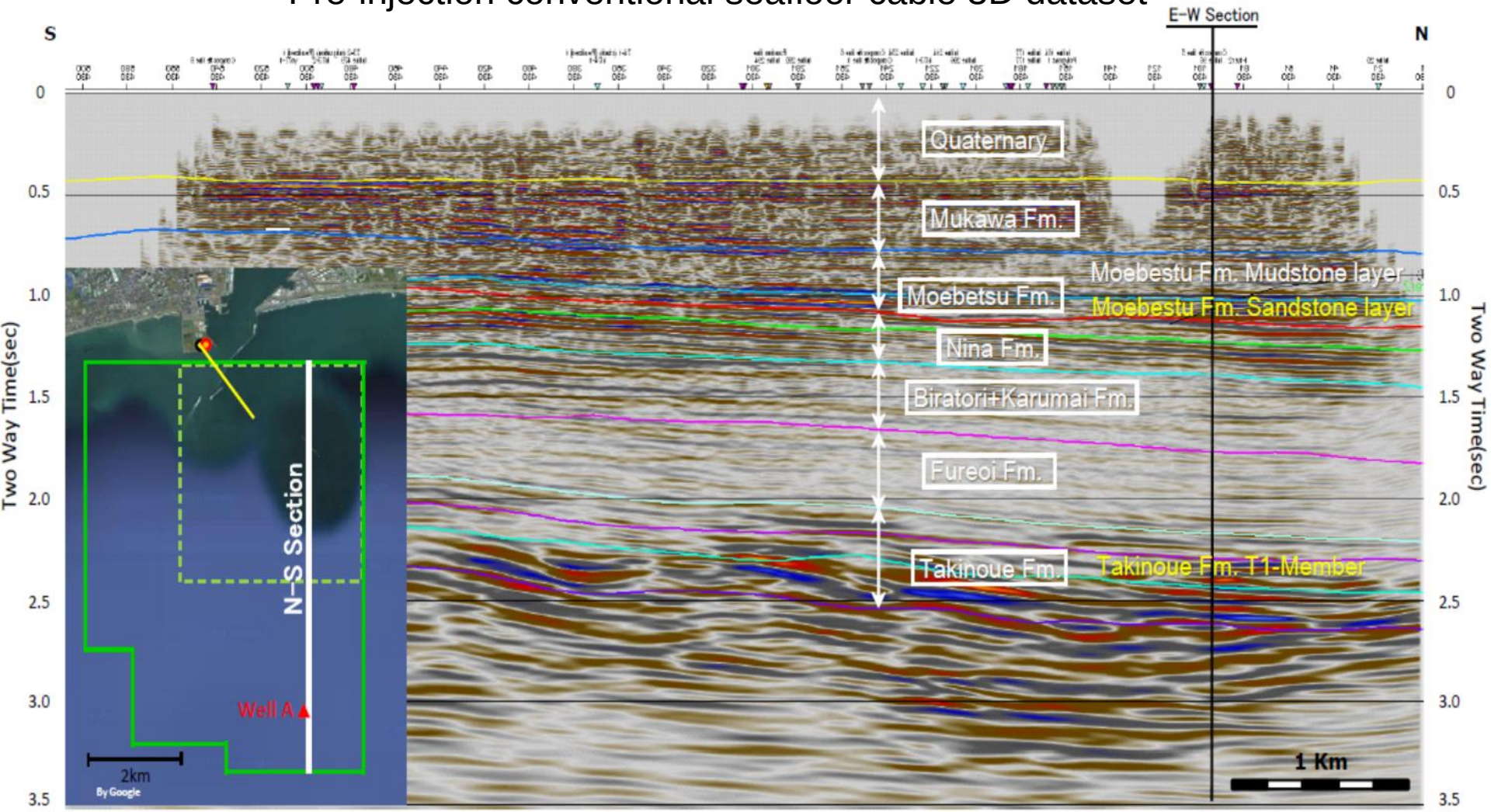
**Plagioclase**: 36% , Bulk modulus = 75.6 GPa
**Clay minerals**: 34.5%, Bulk modulus = 25 GPa
**Quartz**: 23%, Bulk modulus = 37 GPa
**K feldspar** 6.5%, Bulk modulus = 37.5 GPa

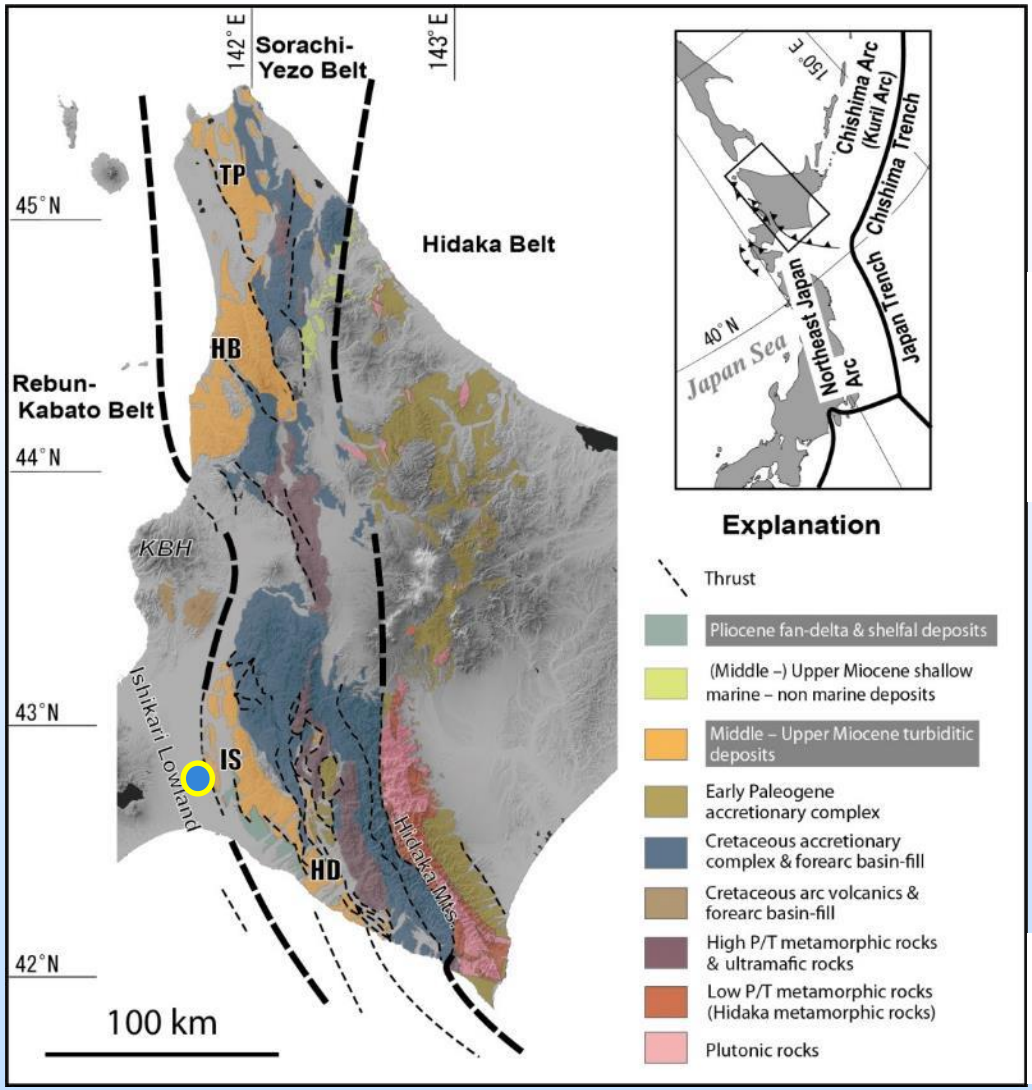
Bulk modulus of the mixture = 40.9 GPa
(Hashin Strikman bounds)

**Ito et al., 2013**, *Reservoir evaluation for the Moebetsu Formation at Tomakomai candidate site for CCS demonstration project in Japan*, Energy Procedia, No. 37, 4937-4945.

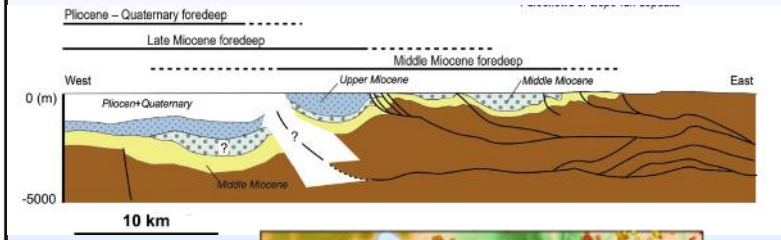
# Geological Structure: North-South Section by 3 D Seismic Survey

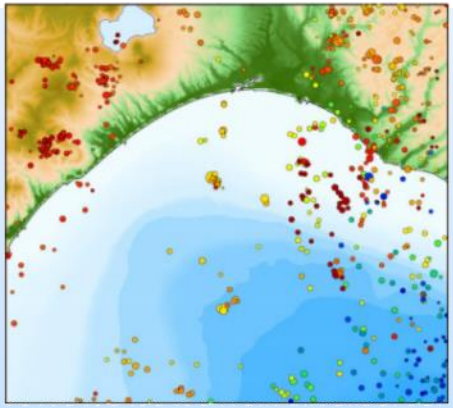
## Pre-injection conventional seafloor cable 3D dataset






Yufutsu oil and gas field
JapEx, 1988
Entirely fracture permeability
Up to 40 MMcfd in 2005

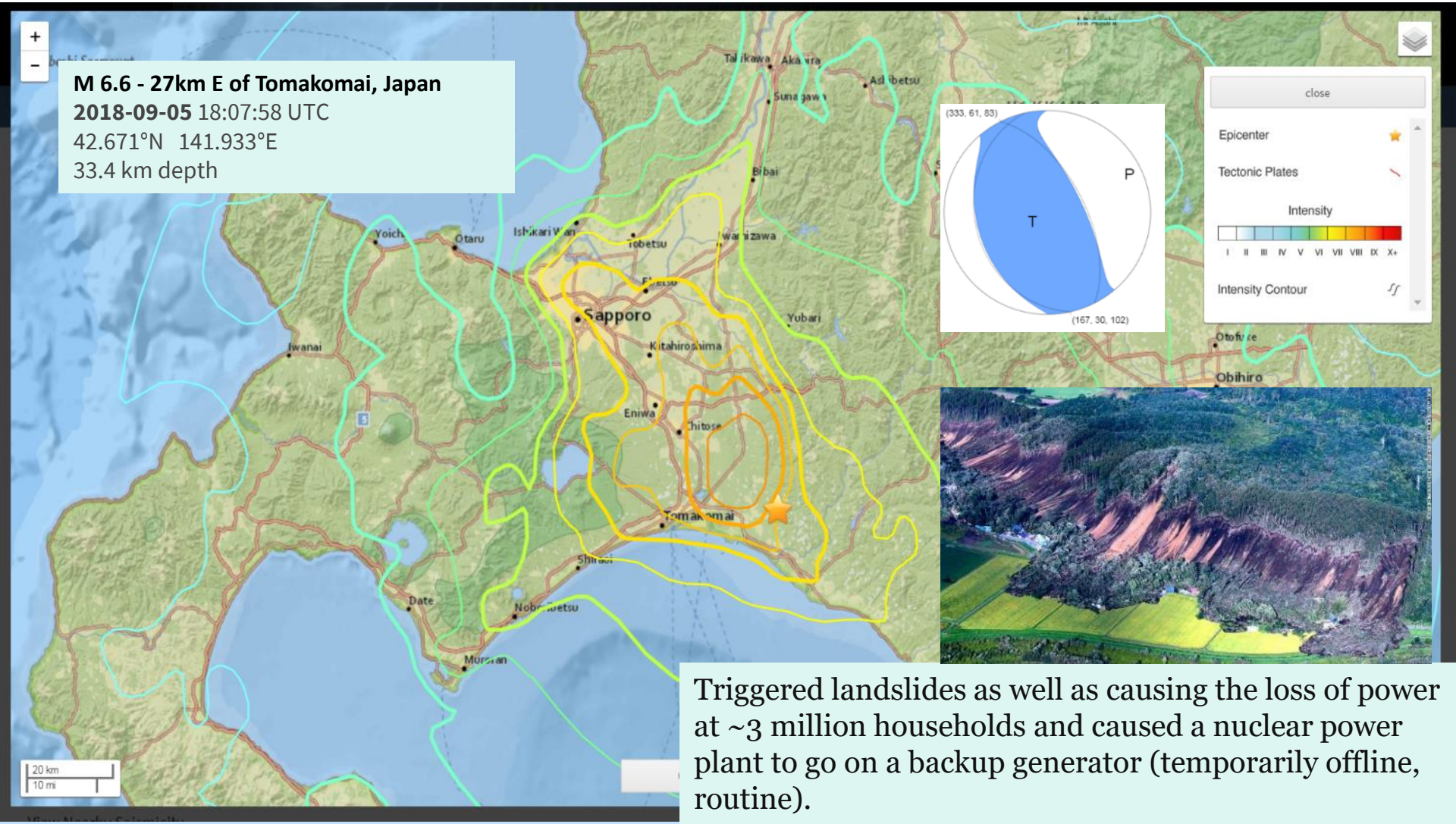


Natural earthquake hypocenter distribution occurred from 2001 to 2010

Fault stability analysis related to $CO_2$ injection at Tomakomai, Hokkaido, Japan

Y. Kano[a]*, T. Funatsu[a], S. Nakao[a], K. Kusunose[a], T. Ishido[a], X.-L. Lei[a], T. Tosha[a]



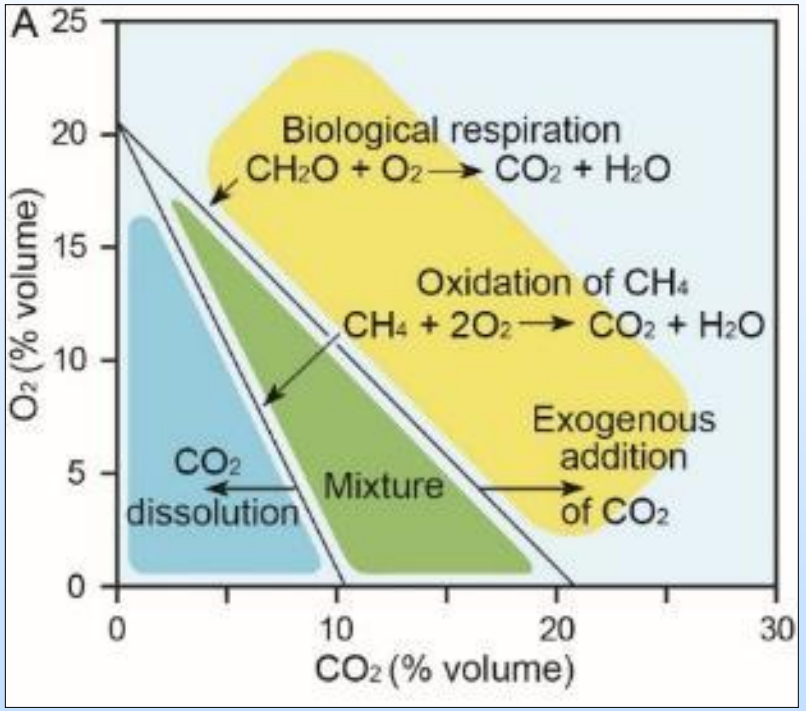

Triggered landslides as well as causing the loss of power at ~3 million households and caused a nuclear power plant to go on a backup generator (temporarily offline, routine).

# Task 3- Additional Monitoring Objectives

- Help address source attribution of current data to aid decisions on $CO_2$ injection
- Advance "bio-oceanographic" source attribution methodology
  - Aims to use geochemical relationships to attribute the source of anomalies rather than concentrations

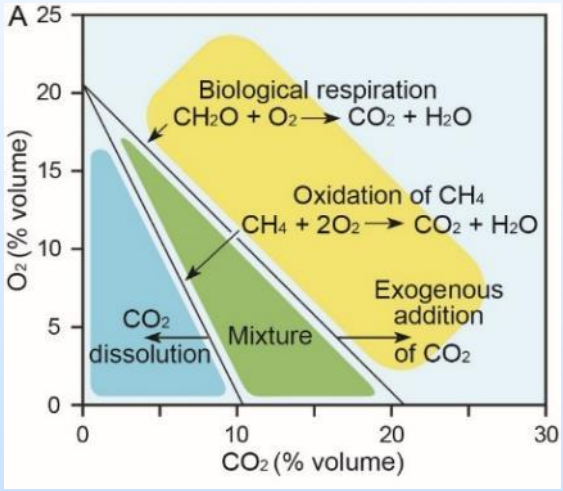
# Process-Based Monitoring

- Uses simple stoichiometric relationships to identify processes for attribution
  - Respiration, methane oxidation, dissolution, leakage
- No need for years of baseline.
- Universal trigger point
- Stakeholder engagement



# Bio-oceanographic source attribution

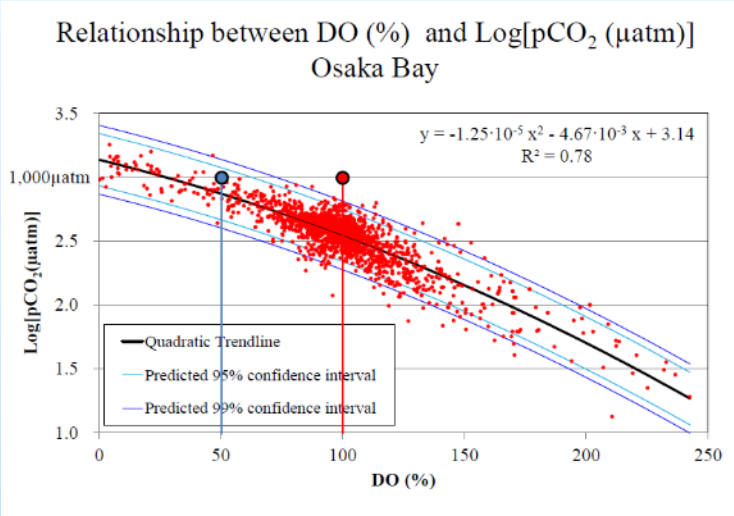
Onshore:
Process-Based Method




Katherine Romanak, BEG, USA
Romanak et al., 2012, 2014
Dixon and Romanak, 2015

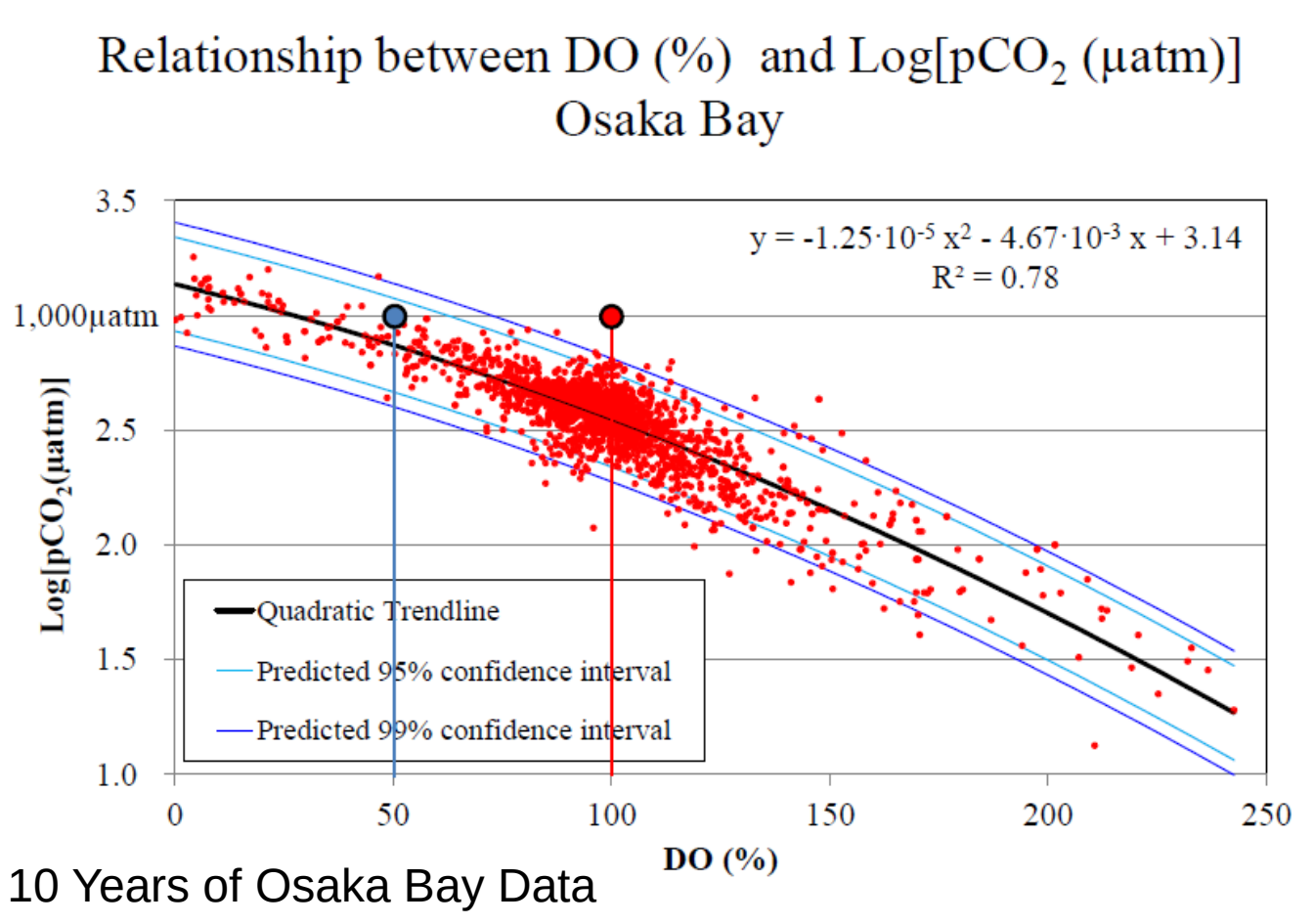
IEAGHG Meetings

Offshore:
Bio-Oceanographic Method




Jun Kita, MERI, Japan

# Bio-oceanographic Method




10 Years of Osaka Bay Data



Jun Kita, MERI, Japan
Uchimoto et al., in review

# Tomakomai Environmental Monitoring

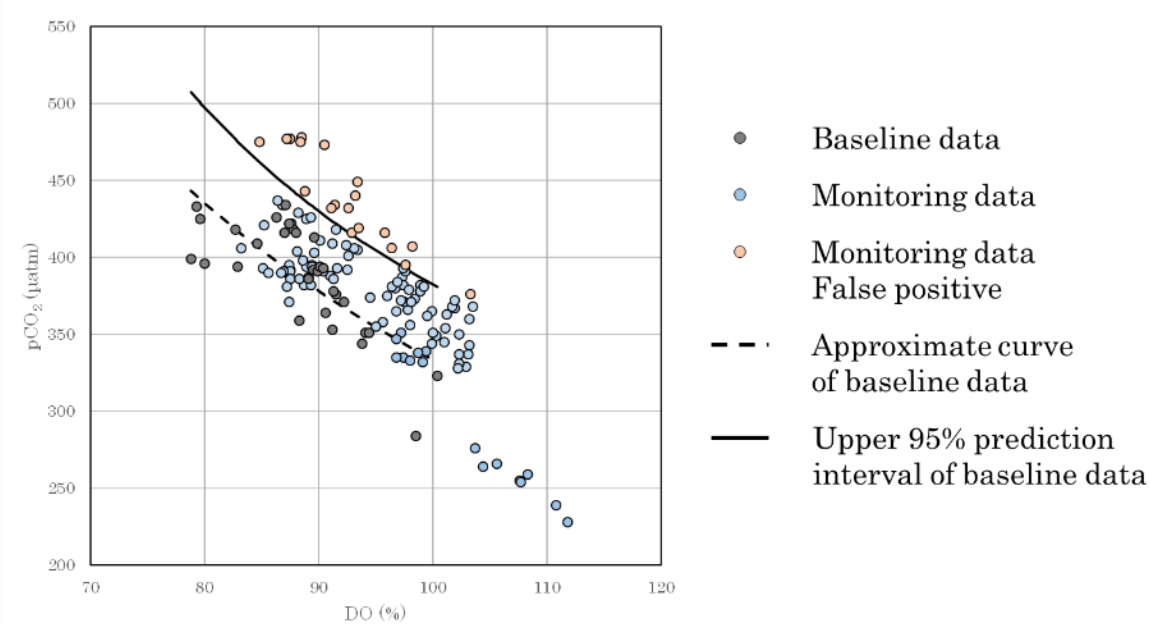
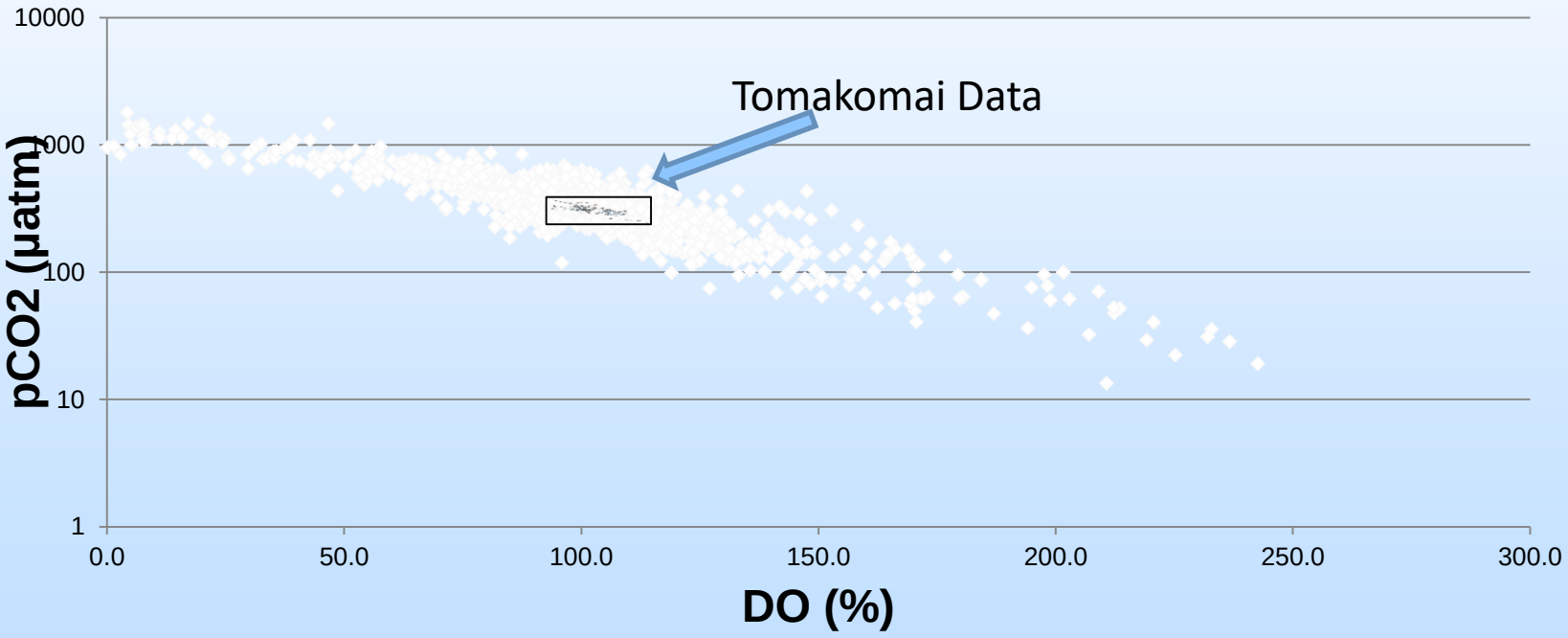



Fig. Relationship between oxygen saturation (DO) and $CO_2$ partial pressure ($pCO_2$) of bottom seawater (2 m above the seafloor).

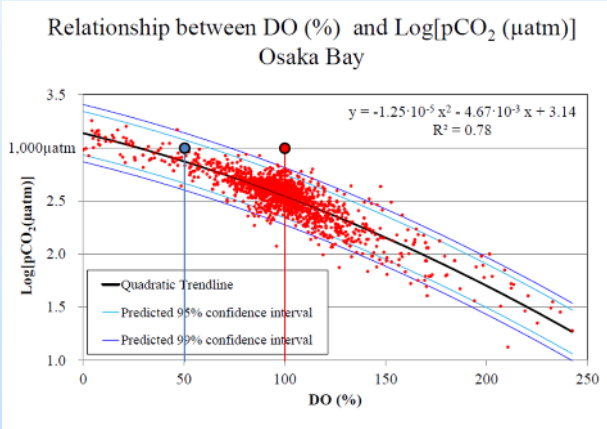
"Regulatory authority urged strongly to use the relationship between concentrations of oxygen and carbon dioxide to detect leakage. Since the baseline data did not fully reflect the natural variation, false positive occurred. Ultimately, the observed value (false positives) were judged to be within the range or natural variation by the expert judge. In other words, no leakage was observed".

# 10 Years of Osaka Bay Data
# 1 year Tomakomai Data



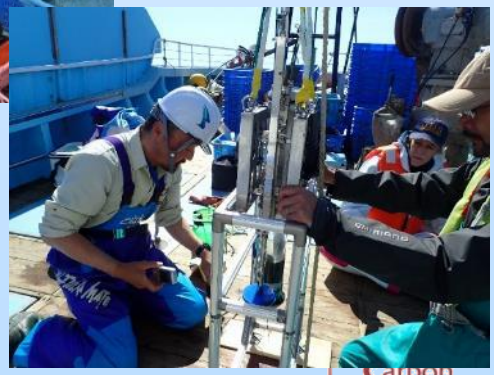
# Plans for Method Advancement

- Current bio-oceanographic method is still baseline-dependent
- Instead we will attempt to:
  - Use stoichiometric relationships
  - Reduce scatter arising from differences in gas solubility
    - Salinity (34-7 psu)
    - Temperature (6-31C)
    - Depth (0-67 m)
- Osaka Bay data
- CO2sys program
- Weiss equation linking concentration to salinity and temperature

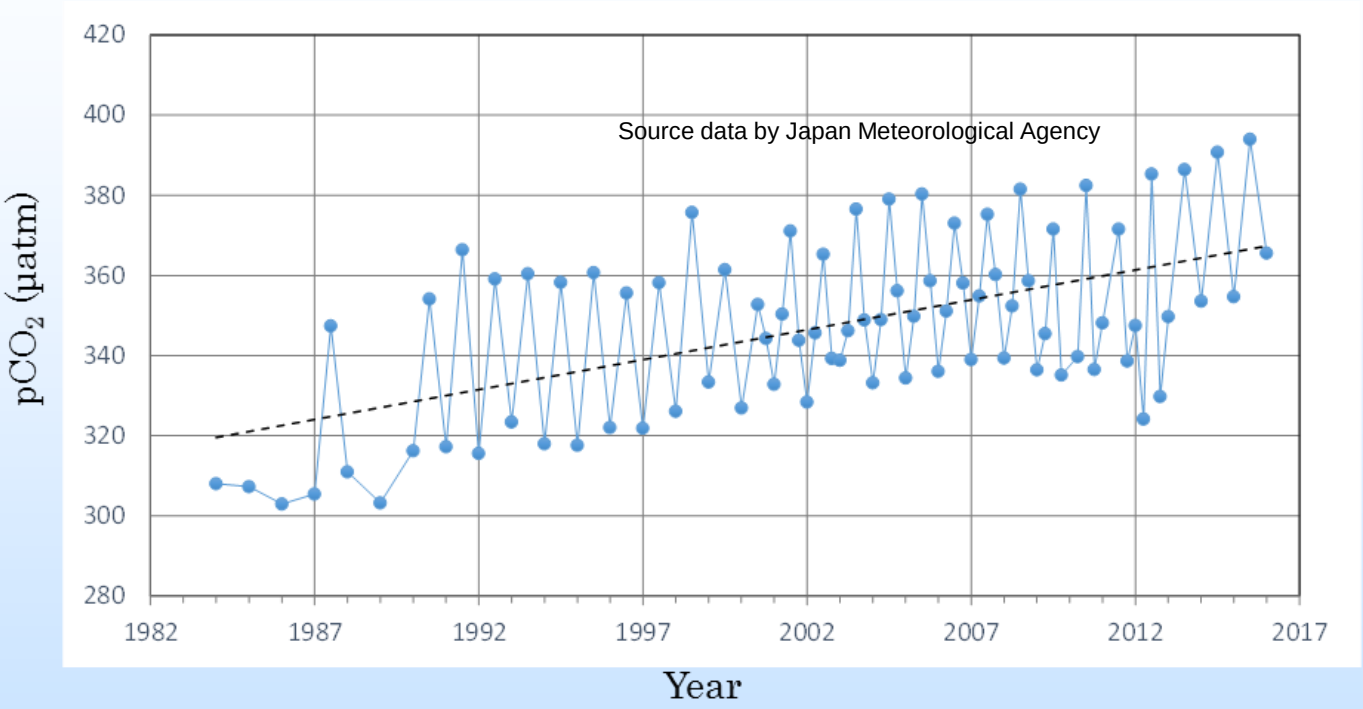


# Sediment and Water Sampling

- Accompany environmental sampling team on a routine monitoring trip
- Add sediment pore water analysis
- Add $^{14}C$ and hydrocarbons to analytical suite
- Collaborate to integrate analyses with current monitoring parameters and methods



# Baselines are Shifting in the Offshore




Time series of surface seawater $CO_2$ level near Japan
(137 degrees East longitude, 3-34 degrees North latitude)

Courtesy of Jun Kita, MERI