Environmental Monitoring and Risk Perspective – Global Scene Setting

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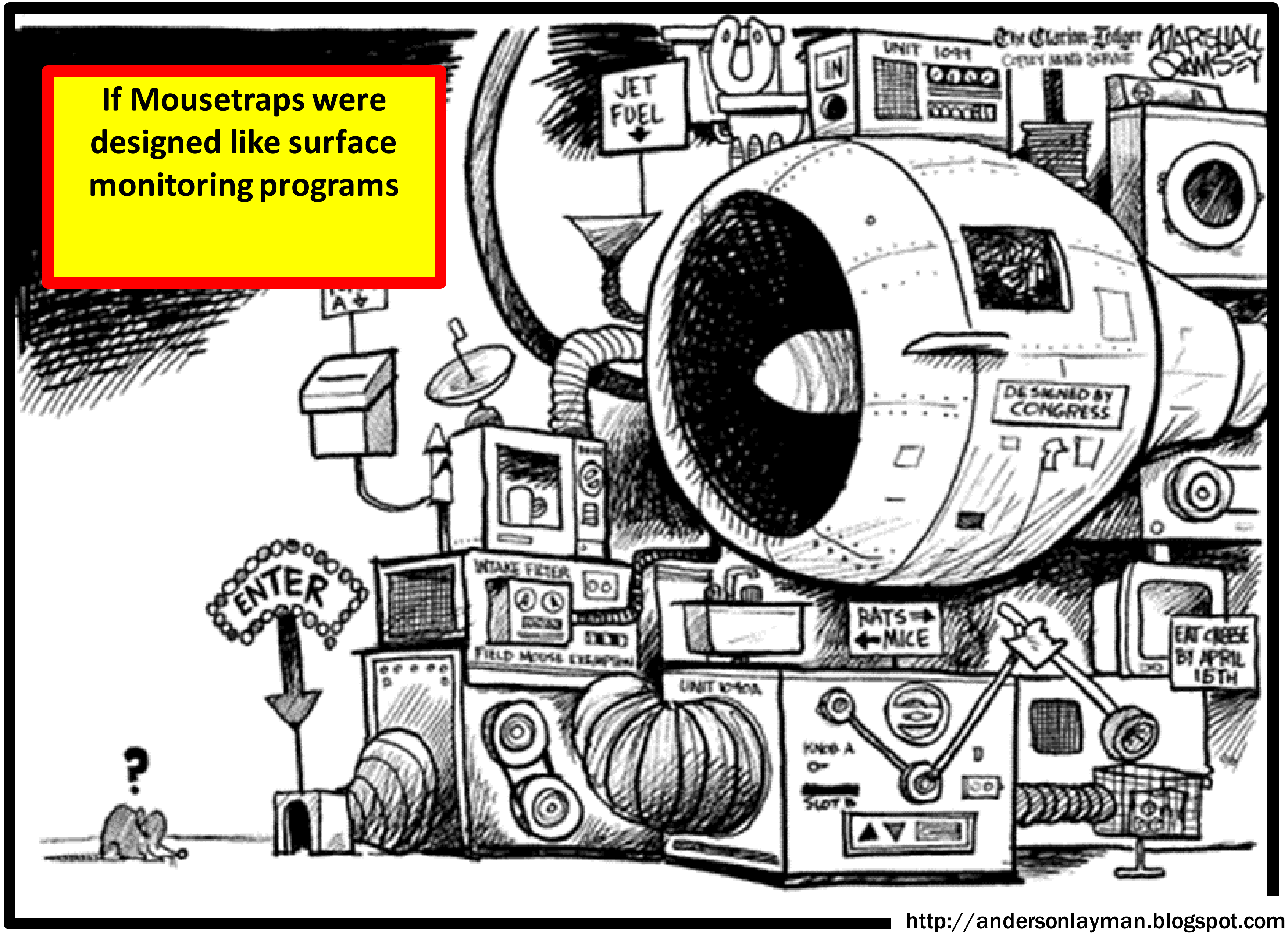
GCCC GULF COAST CARBON CENTER

U.S. DEPARTMENT OF ENERGY
Fossil Energy and Carbon Management

BUREAU OF ECONOMIC GEOLOGY

If Mousetraps were designed like surface monitoring programs



http://andersonlayman.blogspot.com

Environmental Monitoring Overarching Issues

- How much environmental monitoring do we need?
- How big of a leak is important to find?
- Risk of false alarms
- Are we sending mixed messages about leakage?
- Viability of using environmental baseline in a changing world
- Can we meet the regulations?

CO_2 Storage Regulations

Regulatory Body / Monitoring Objectives:	IPCC GHG Guidelines	London Convention and Protocol	OSPAR	EU		US EPA		UNFCCC Clean Development Mechanism
				CCS Directive	ETS Directive	UIC Class VI well regulation	GHG reporting Subpart RR	
Overall Objectives	GHG accounting	Protection of the marine environment	Protection of the environment	Protection of the environment	GHG accounting	Protection of the environment (underground sources of drinking water)	GHG accounting	GHG accounting and protection of the environment

Dixon and Romanak, 2015, International Journal of Greenhouse Gas Control

ISO TC-265 – standards on Capture Performance, Pipeline Transport, Geological Storage, Storage in EOR, Vocabulary

Slight differences but the general workflow is similar among regulations

Global Storage Regulations

- All geologic sites are different
- Regulations are non-prescriptive. Only monitoring “elements” are required
  - Storage performance in the reservoir
  - Initial site characterization (baselines) and environmental (risk) assessment
  - Near-surface anomaly detection
  - Anomaly attribution ← Focus on this
  - Environmental Assessment
  - Leakage accounting
- Project developer and regulator agree on specific approach for each site.
- Expertise/knowledge is required

Success! Attribution in Updates to the Guidance Documents for the EU CCS Directive

Draft Zero for revised Guidance Document 2:

Characterisation of the Storage Complex, CO2 Stream Composition, Monitoring and Corrective Measures

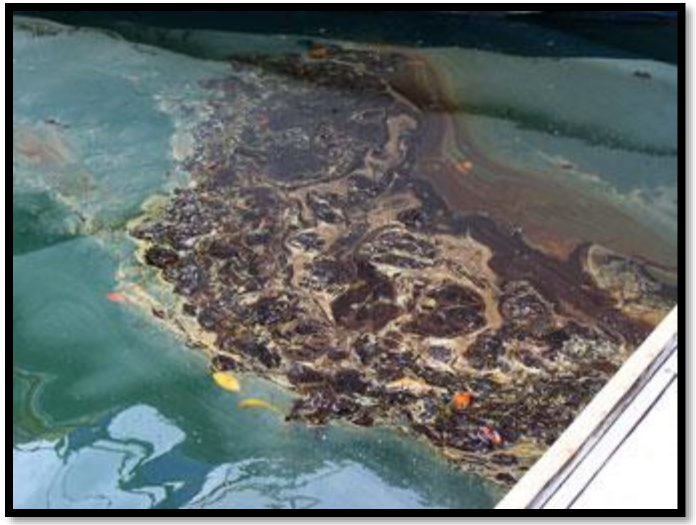
Box 4: Attribution monitoring

Attribution monitoring aims to differentiate naturally occurring CO_2 from CO_2 that has originated from storage operations. Natural processes, such as decay of organic matter, dolomitisation, volcanic activity/ migration of magmatic CO_2 through dikes and sills, and wildfires, can generate CO_2. This is a key consideration in baseline monitoring, so that natural CO_2 can be distinguished from leaked CO_2. Geochemical monitoring methods can sometimes be used to attribute CO_2 to its source.

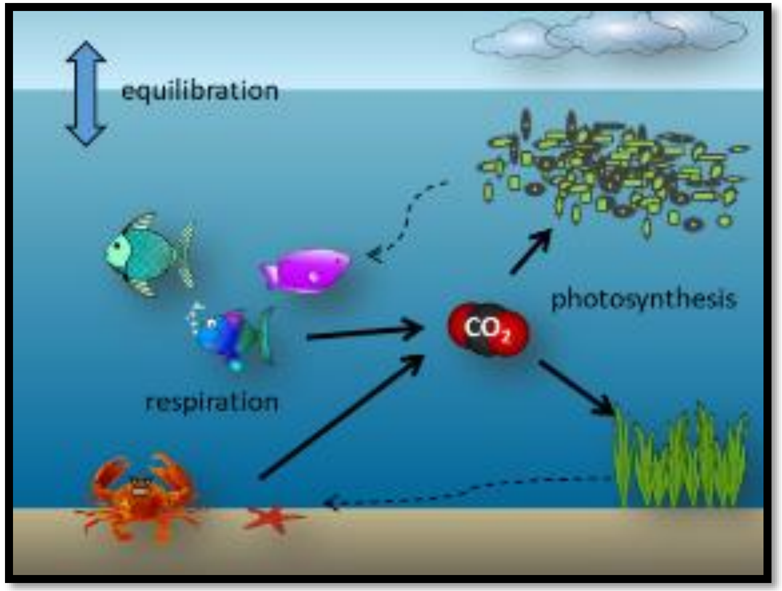
- Environmental monitoring for leakage out of the storage complex towards, at or near the surface, on land or offshore:
  - Detection of suspected leakage anomaly;
  - Attribution of leakage anomaly;
  - Quantification of leakage;
  - Accounting and quantification of emissions from the storage complex for surrender of emissions trading allowances for any leaked emissions under EU ETS Directive 2003/87/EC (see Section 4.2); Not all emissions are relevant to the EU ETS Directive.
  - Safety and Environmental impacts.

Monitoring Challenge

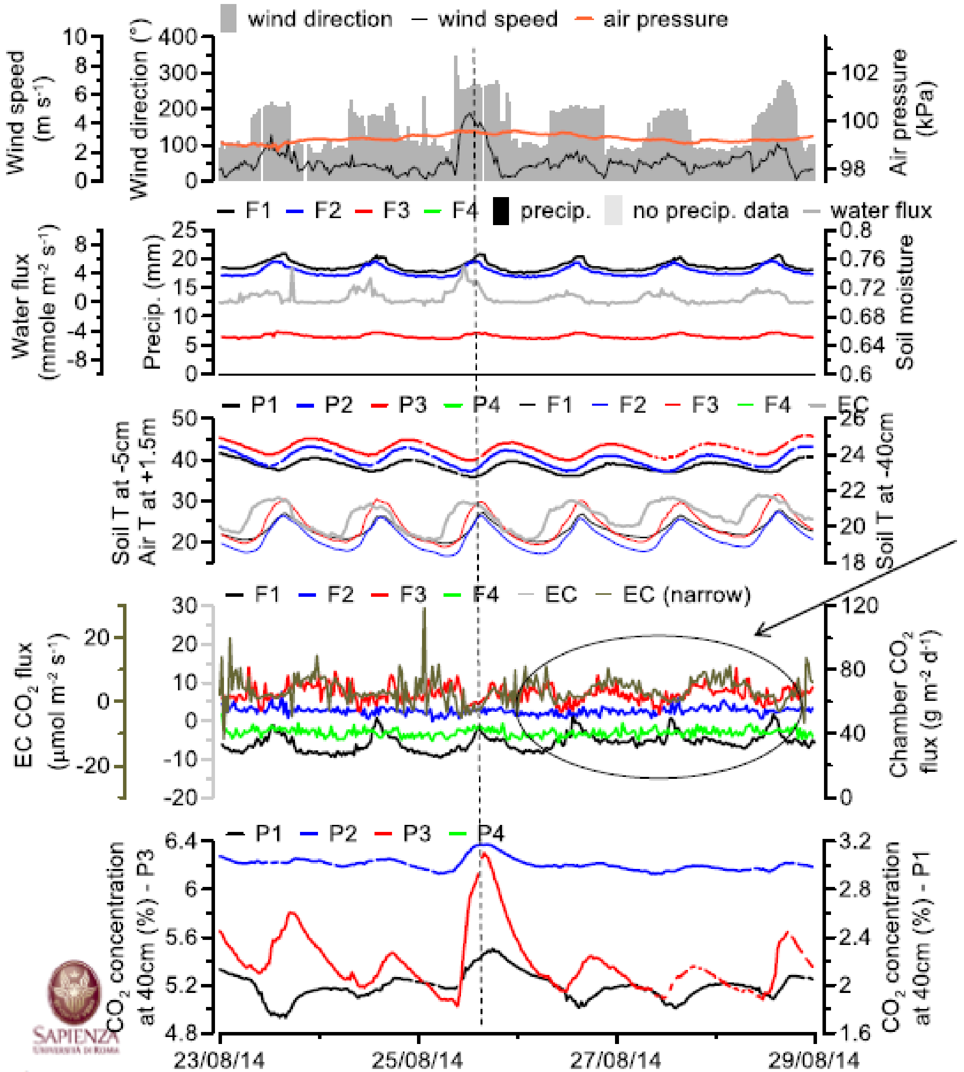
Common pollutants are foreign to the environment and easily attributed



CO_2 is a natural ecosystem component. Source attribution is complex



Dynamic Complexity



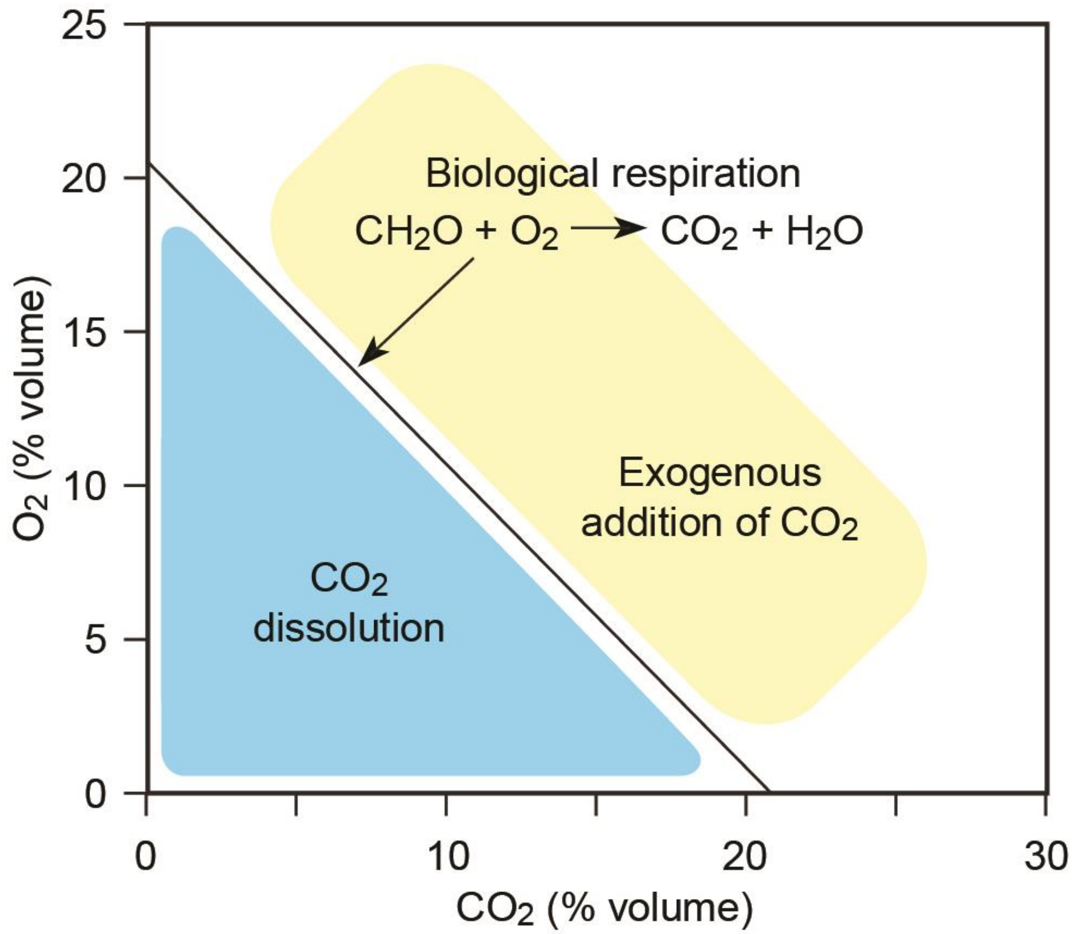
Dave Jones, British Geological Survey

Attribution is Complex

- Environmental "Baseline" concentrations are increasing due to climate change – baseline approaches will lead to false positives for leakage (e.g. Tomakomai)
- Introduced tracers
  - Expensive
  - Not necessarily conservative
  - Works in the reservoir but no proof it works to surface
- Natural tracers
  - Overlap in carbon isotopes
  - Carbon 14
  - Noble gases complex and difficult to measure
  - Multiple sources from hub storage
  - Reactivity to surface

Process-Based Soil Gas Ratios

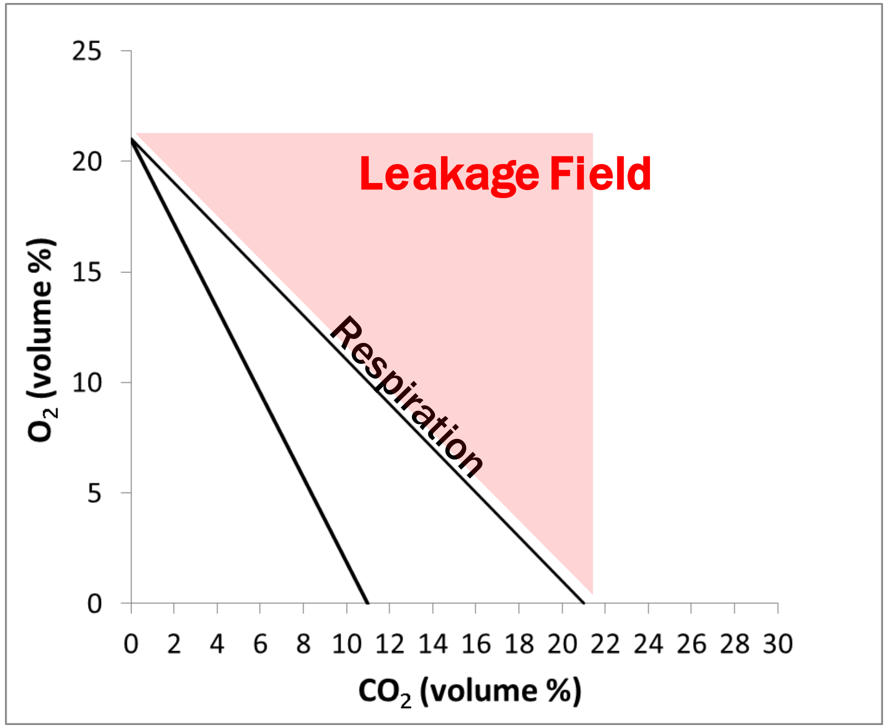
- Based on respiration-the main source of CO2
- Uses simple gas relationships to identify **processes.**
- No need for years of background.
- Method can be applied in any environment regardless of variability



Romanak et al., 2012, Geophysical Research Letters, 39 (15).
Romanak et al., 2014, International Journal of Greenhouse Gas Control, 30, 42-57
Dixon and Romanak, 2015, *International Journal of Greenhouse Gas Control*, *41*, 29-40

Ratios Providing "User-Friendly" Monitoring

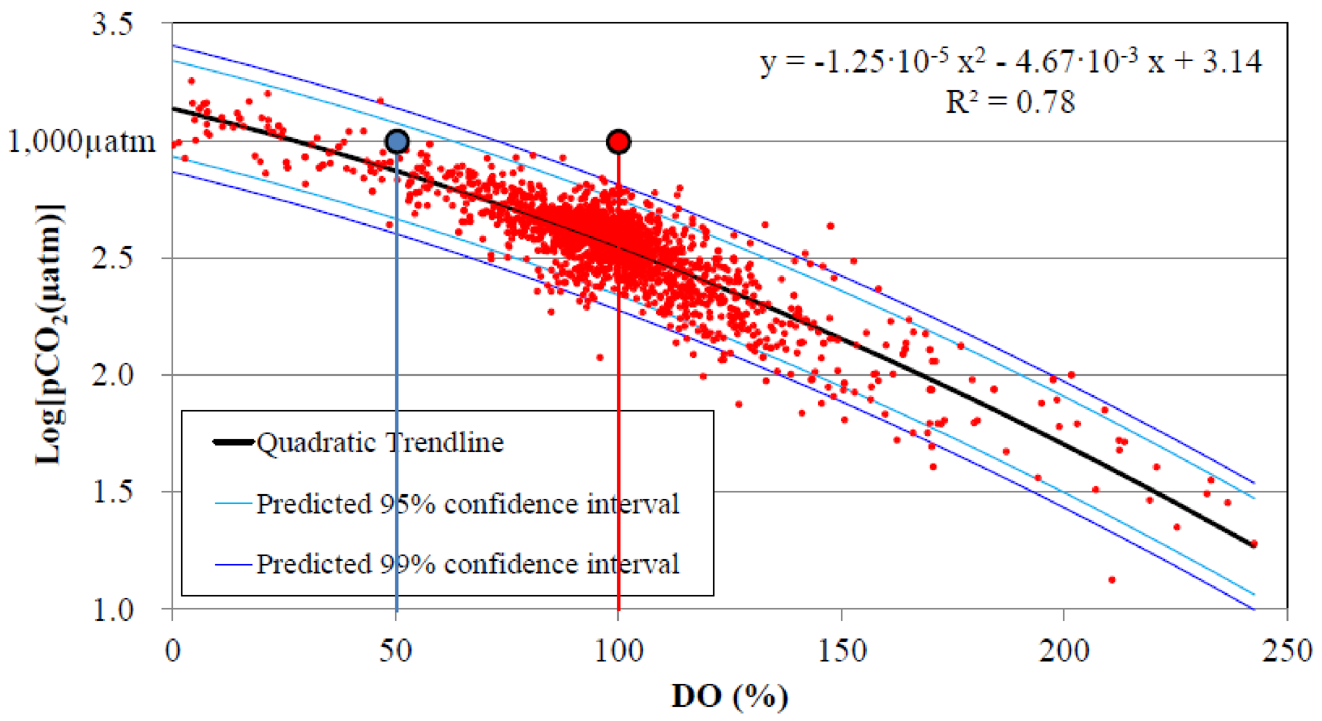
- Respiration line as a universal trigger point
- No need for years of baseline- only need a one-time characterization.
- Easy to explain and engage stakeholders
- Instant data reduction and graphical analysis



Katherine Romanak BEG

Bio-oceanographic Method

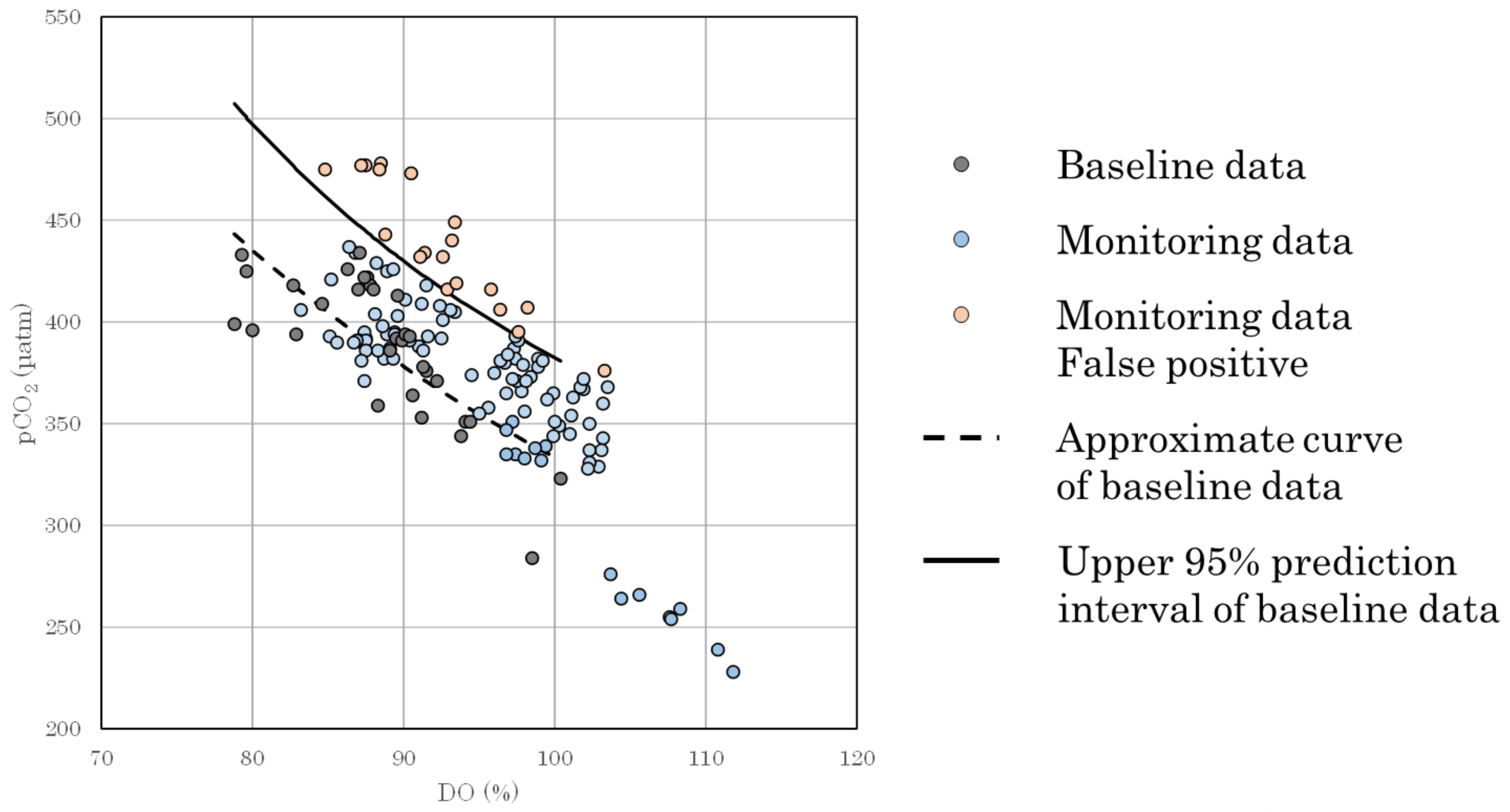
Relationship between DO (%) and Log[pCO_2 (μatm)]
Osaka Bay



Jun Kita, MERI, Japan
Uchimoto et al.,

Tomakomai Project Japan-Learnings

- Thresholds based on 1 year of baseline data
- False positive for leakage



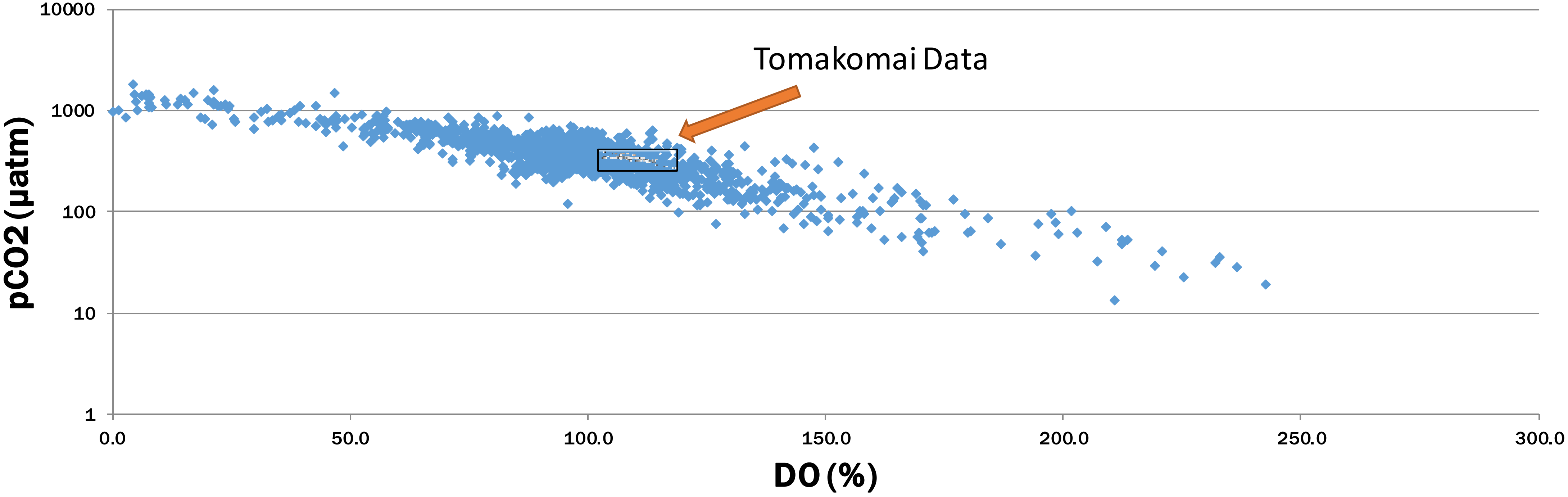
Jun Kita, 2017, 2nd International Workshop on Offshore Geologic CO2 storage

Tomakomai False Positive

- Tomakomai Offshore demonstration project Hokkaido Japan
- Derived leakage thresholds from 1 year of baseline data
- Injection began April 2016 with routine environmental monitoring plan
- May, 2016, operations were halted after 7,163 ton CO_2 was injected
- High CO_2 levels observed in the routine monitoring
- February 2017 operations resumed

Slide courtesy of Jun Kita, MERI

1 year Tomakomai Data Compared to 10 Years of Osaka Bay Data

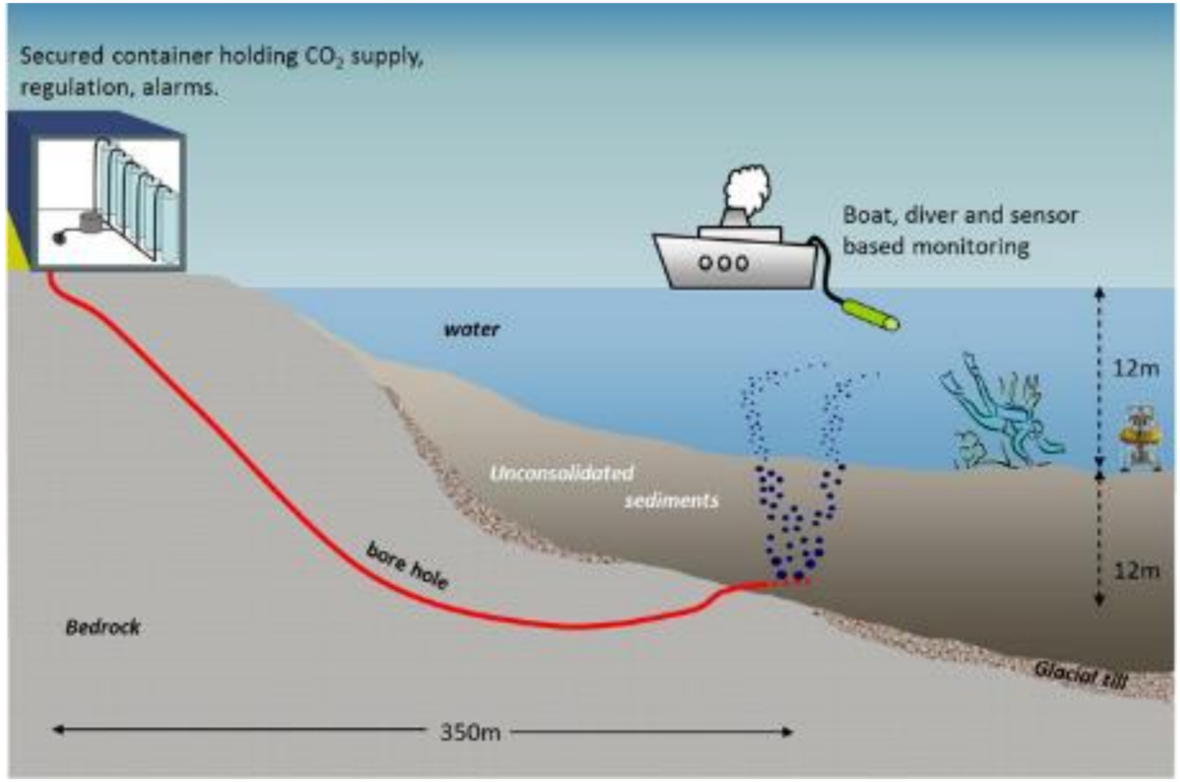


Scientific Advancements on Impacts

- Learnings from terrestrial CCS projects
- UK and EU offshore projects
  - ECO2
  - RISCS
  - QICS - Plymouth Marine Laboratory and
  - STEMM-CCS National Oceanographic Institution Southampton
  - Sonardyne Harbor Trials
- Japan - Tomakomai
- Goldeneye and Northern Lights Project
- ANLEC Studies Gippsland Basin Australia
- International Workshop on Offshore Geological CO_2 Storage
- ACT Projects

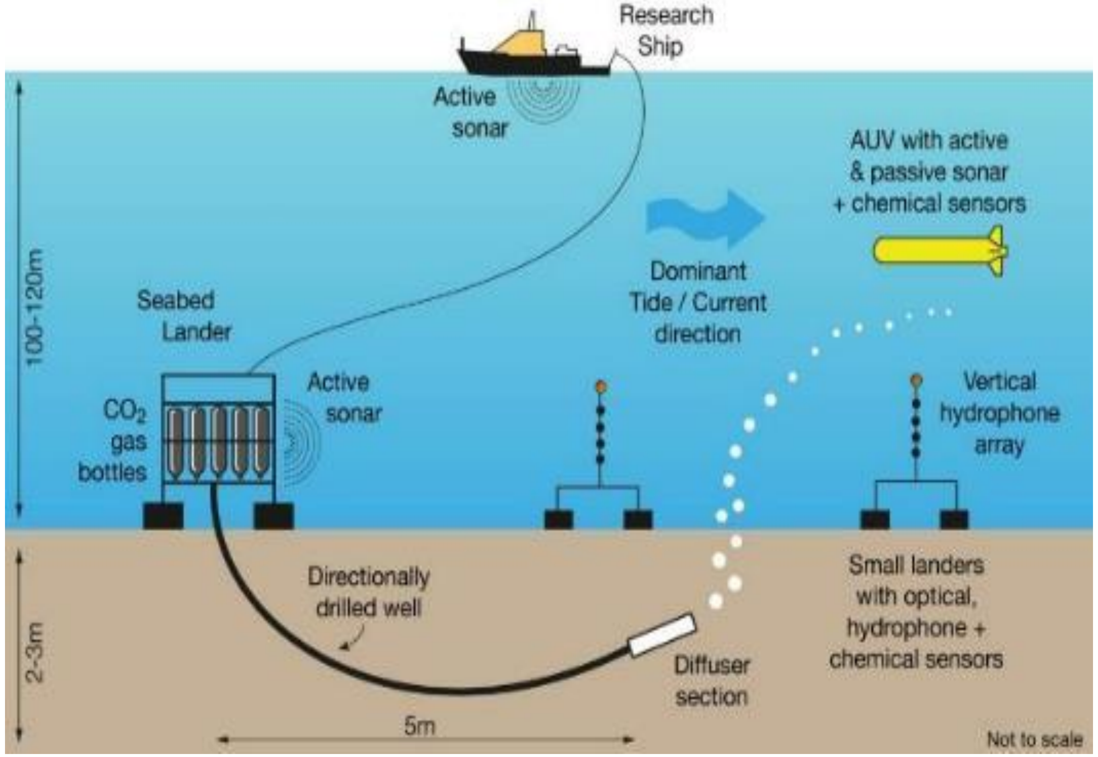
Offshore Controlled Releases

QICS -Scotland



Blackford, et. al., 2014. Nature Climate Change 4, 1011-1016.

STEMM-CCS North Sea



https://www.stemm-ccs.eu/

QICS

Quantifying and Monitoring Potential Ecosystem Impacts of Geological Carbon Storage

Conclusions:

- CO_2 bubbles were seen in the water column within hours of injection
- Gas chimneys and pock marks could be observed in sub-surface/surface sediments by seismic profiling and multibeam sonar
- Up to 35 distinct bubble streams were observed, with flow rates affected by tidal phase.
- ~10% of injected gas escaping as bubbles at low tide
- ~ 85% was retained in the sediments
- Elevated pCO_2 values values where observed in BW at release site – varied with tidal phase and injection rate
- Calcite dissolution had a buffering effect on the dissolved CO_2
- No evidence of elevated 'dissolved' flux of DIC
- Impacts were spatially restricted and recovery to background values occurred within a month after terminating the gas release.

Learnings From International Projects

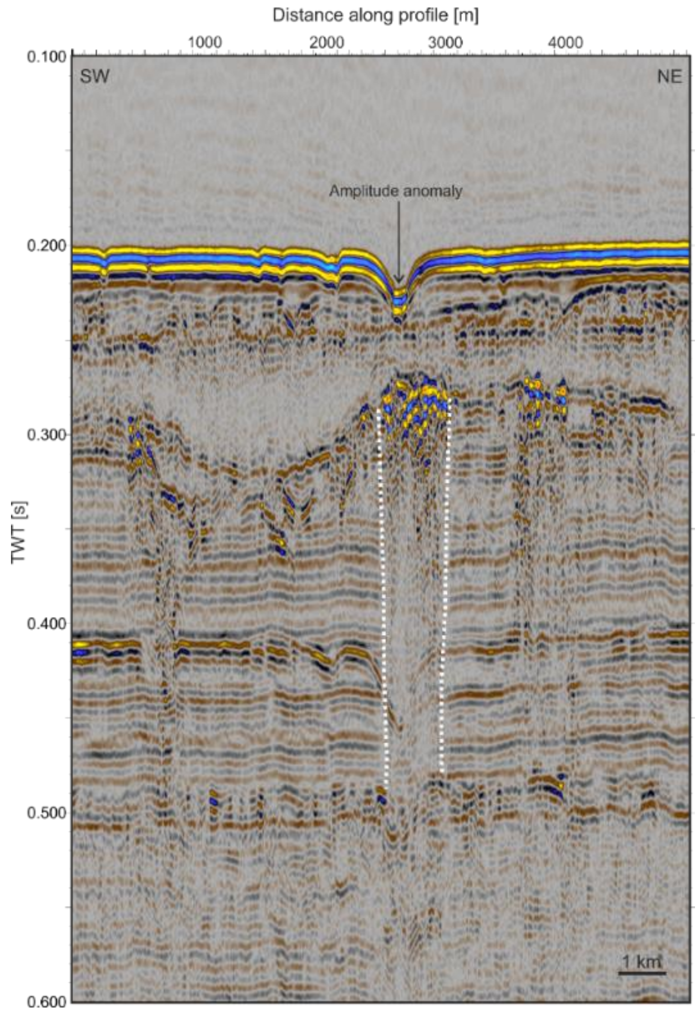
- Leakage is rare – need shallow controlled releases to study it!
- Impacts are spatially limited and transient, ecosystem recovery is generally fast.
- The locations of seabed emissions are difficult to predict, even with a well blowout
- CO_2 bubbles, gas chimneys and pock marks can be physically observed in sea bottom sediments
- CO_2 is readily dispersed in the seawater column by tides and currents


Courtesy of Jun Kita

Overall conclusion: Impacts of CO_2 leakage are relatively mild. The environment already has uptake mechanisms in place.

Identifying Pathways - Offshore

- Chimney features are common in offshore basins.
- Past or present leakage of fluids/gases.
- Can they act as preferential pathways for CO_2 migration?
- Easily mapped and monitored
- Bubbles are the superpower of offshore monitoring



Commercial Projects Following Suit

Goldeneye Site Permit

Seabed surveys

"Multi Beam Echo Sounder and Side Scan Sonar surveys to observe bubble streams that could indicate leakage. There is no need to disrupt the benthos by the use of intrusive sampling methods unless bubbles or changes are observed which would trigger the contingency monitoring plan"

Northern Lights Fit for Purpose

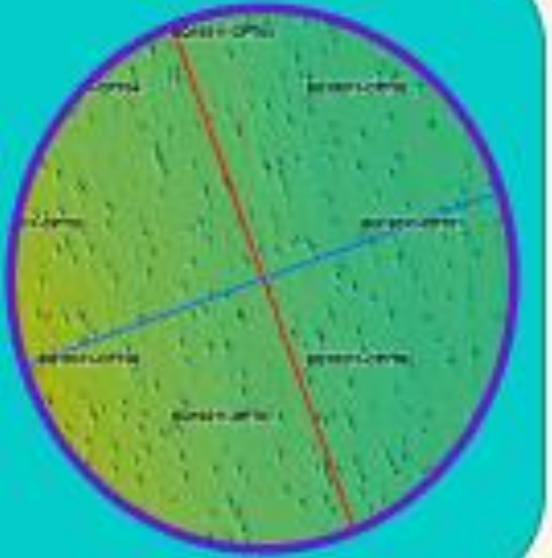
Baseline surveys and data

→ **No planned environmental survey before injection**

- Seabed surveys
- 4D Seismic baseline
- Regular environmental sediment monitoring in the area
- Extensive databases for O&G risk assessment

Northern Lights

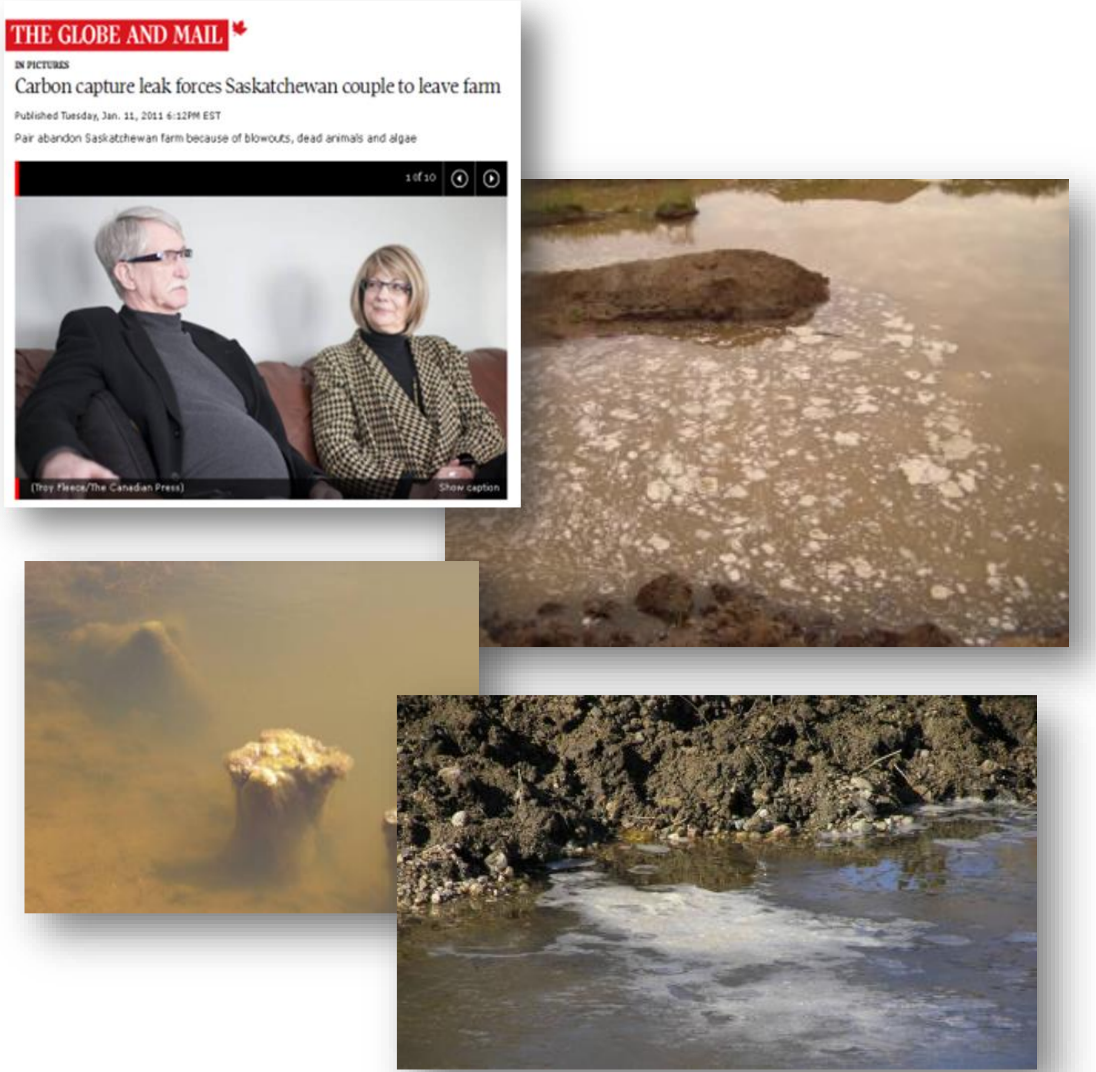
- Flat
- Covered with shallow pockmarks
- Sonar investigations show no gas seepage
- No connection to the deep CO_2 storage



Courtesy of Laurence Pinturier

Need Response Plans - Kerr Example

- IEAGHG Weyburn CO_2 Monitoring and Storage project, Saskatchewan Canada
- Farmers perceived environmental change and blamed on the CO_2 storage project
- Attribution protocols for responding to stakeholder concerns were not in place
- Unexperienced consultant wrongly attributed the anomaly to leakage.



Conclusions- How Should We Monitor?

- General
  - In the offshore we can “see” the leakage - bubbles, pockmarks, shallow seismic
  - We have the technology- (AUVs and side scan sonar)
  - Chemical attribution is a very big challenge –don’t look for small signals
  - Use a variety of parameters
  - Wells will signal if problems arise
- Characterization and risk assessment
  - Map existing pockmarks and shallow seismic features
  - Do homework on attribution parameters beyond CO_2

Conclusions- How Should We Monitor?

- Operational
  - Risk-based and tiered-
    - Impacts are low and risk of false positives is high
    - De-emphasize routine environmental monitoring
    - Only monitor the environment when there is a reason – look to well-based signals or stakeholder questions
    - Have a plan for attribution in your back pocket
    - Need more dependable performance metrics for regulators

Thank You

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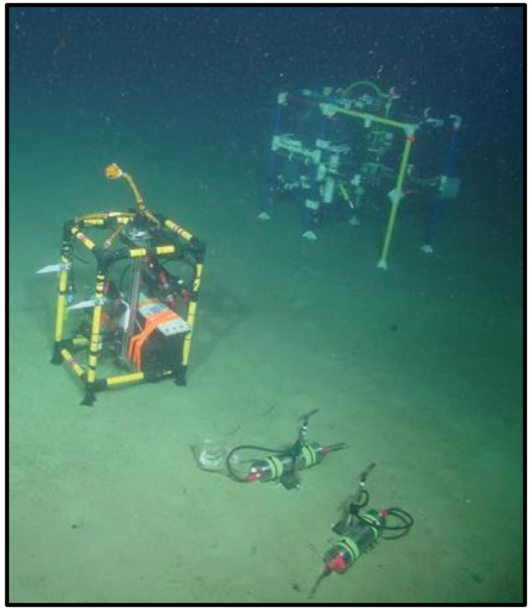
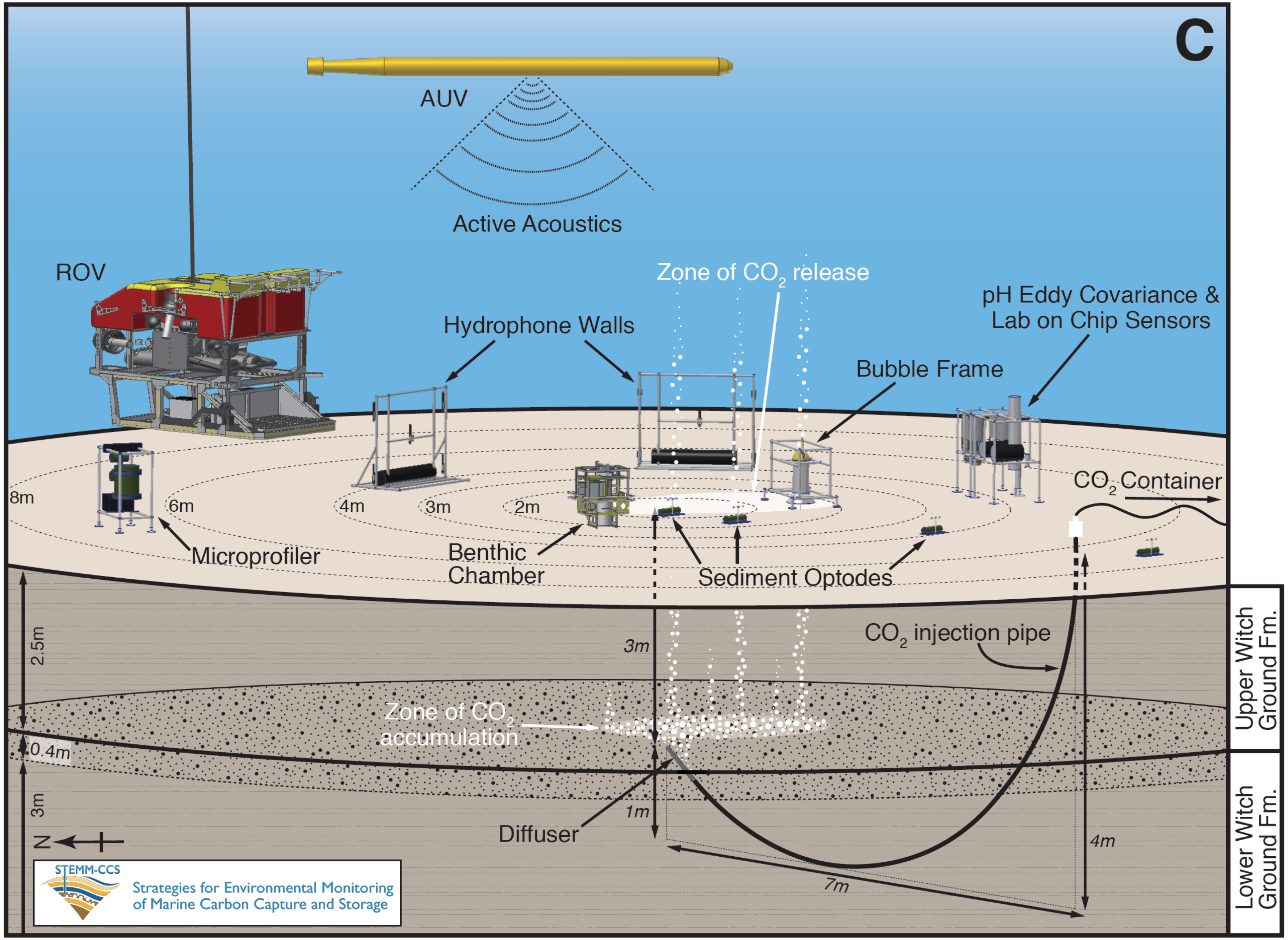
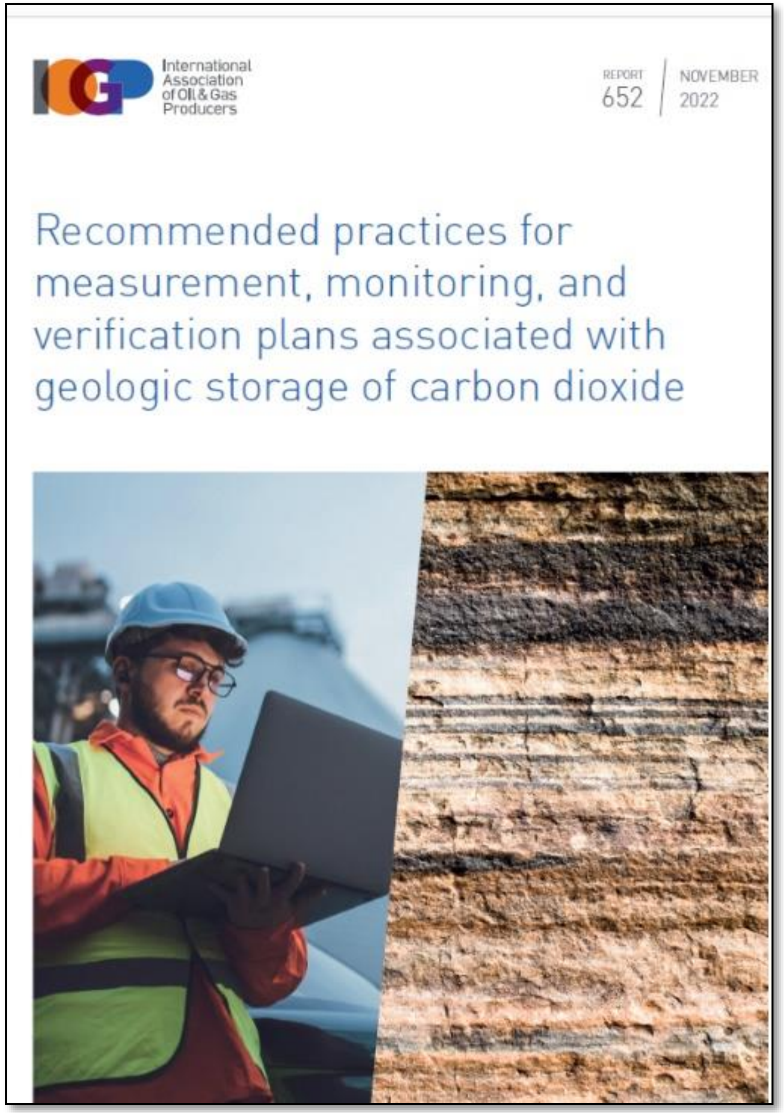
Schematic of site and deployed equipment





Connelly et al. (In Review) Renewable and Sustainable Energy Reviews

Available Monitoring Tools



<== Increasing importance		
Recommended	Optional	Supporting
Consider	Consider	Consider
Perform site-sprecific feasibility	Perform site-sprecific feasibility	Perform site-sprecific feasibility
Deploy	Deploy	Deploy

Increasing commitment ==>

...nes, based on ... Storage of CO2

		M1 Award of Exploration	M2 Award of Storage	M3 Start Injection	M4 Cease Injection/Clo	M5 Transfer Responsibilit	
		Phase 1 Assessment	Phase 2 Characterisation	Phase 3 Development	Phase 4 Operation	Phase 5 Post-Closure/ Pre-Transfer	Phase 6 Post Transfer (as applicable)
Category	**MMV Activities**						
Geochemical Monitoring	Water chemistry monitoring						
	Water pH, conductivity, tubidity monitoring						
	U-tube fluid sampling						
	Isotube fluid sampling???						
	Fluid associated gas analysis						
	Artificial tracers: PFCs						
	Artificial tracers: noble gas isotopes						
	Natural tracers: noble gas isotopes						
	Natural tracers: carbon isotopes						
	Natural tracers: halogen isotopes						

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