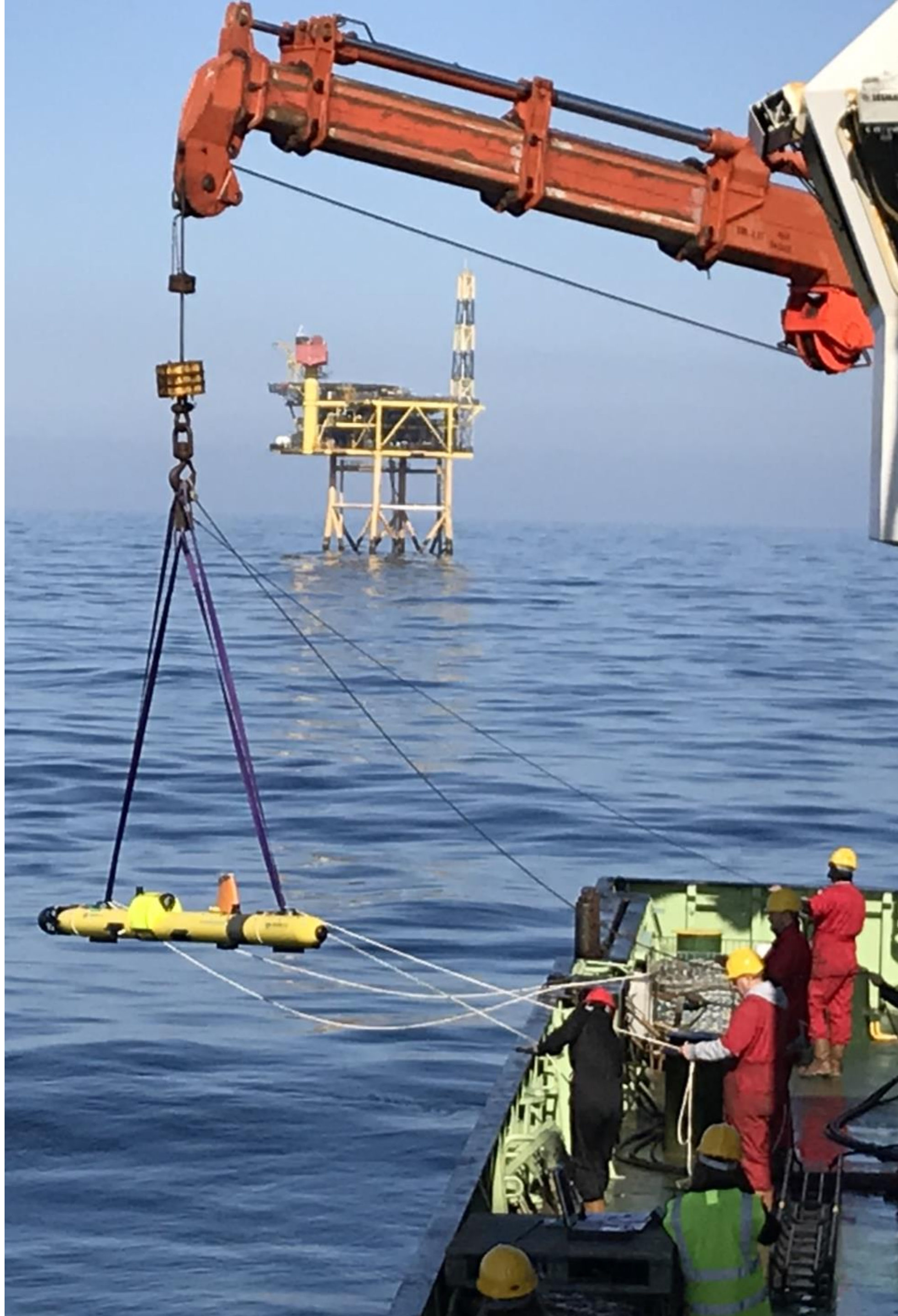
National Oceanography Centre

5th International Workshop on Offshore Geologic CO_2 Storage, 20th May 2022

STEMM-CCS: A summary of outcomes and legacy

Dr Christopher Pearce



STEMM-CCS: Strategies for Environmental Monitoring of Marine Carbon Capture and Storage

EU Horizon 2020 programme: *Enabling decarbonisation of the fossil fuel-based power sector and energy intensive industry through CCS*

Total Budget €15.9M

March 2016 to February 2020

www.stemm-ccs.eu

Special Issue on Monitoring, Measurement and Verification for Offshore CCS: Outcomes of the STEMM-CCS project

International Journal of Greenhouse Gas Control

February 2022

Context

Estimated that offshore sites represent ~66% of the potential CO_2 storage capacity in Europe

Robust strategies for leakage detection and management needed to comply with international marine legislation; EU CCS Directive (2009) monitoring requirements include:

- Comparison between actual and modelled behavior of CO_2 and formation water in the storage site
- Detecting significant irregularities
- Detecting leakage of CO_2
- Detecting significant adverse effects for the surrounding environment
- Assessing effectiveness of any corrective measures taken (in event of leakage)
- Updating the assessment of the safety and integrity of the storage complex short and long timescales

Precursor projects (ECO_2, QICS, ETI) advanced our ability to detect CO_2 at the seafloor, but many of those techniques were yet to be tested under realistic leakage conditions and enhanced models were needed to predict the pathways and impacts of CO_2 migration through the reservoir overburden

ETI MMV Project

Approach

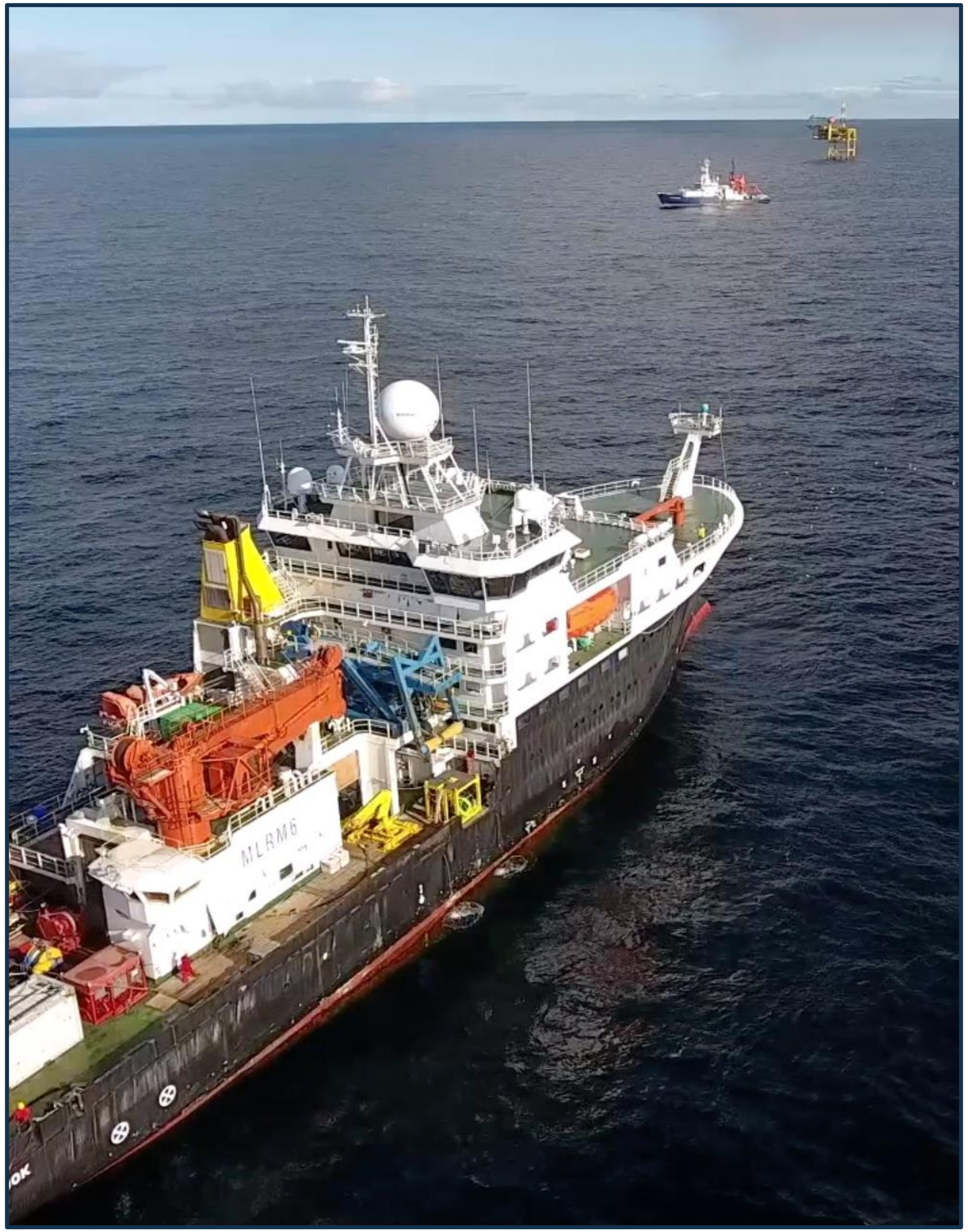
The first controlled sub-seafloor release of CO_2 to be carried out under real life conditions

Establish accurate environmental baseline techniques

Better understanding of fluid flow pathways in the sub-seafloor and their implications for reservoir integrity

Develop methodologies for detecting, tracing and quantifying CO_2 leakage in the marine environment

Assess technologies that can enable cost-effective Measurement, Monitoring and Verification (MMV) of marine CCS operations



RRS James Cook and RV Poseidon at the Goldeneye Platform, May 2019

MMV technologies/techniques tested

Active acoustics
- Single beam echosounders
- Multibeam echosounders
- Sub-bottom profilers

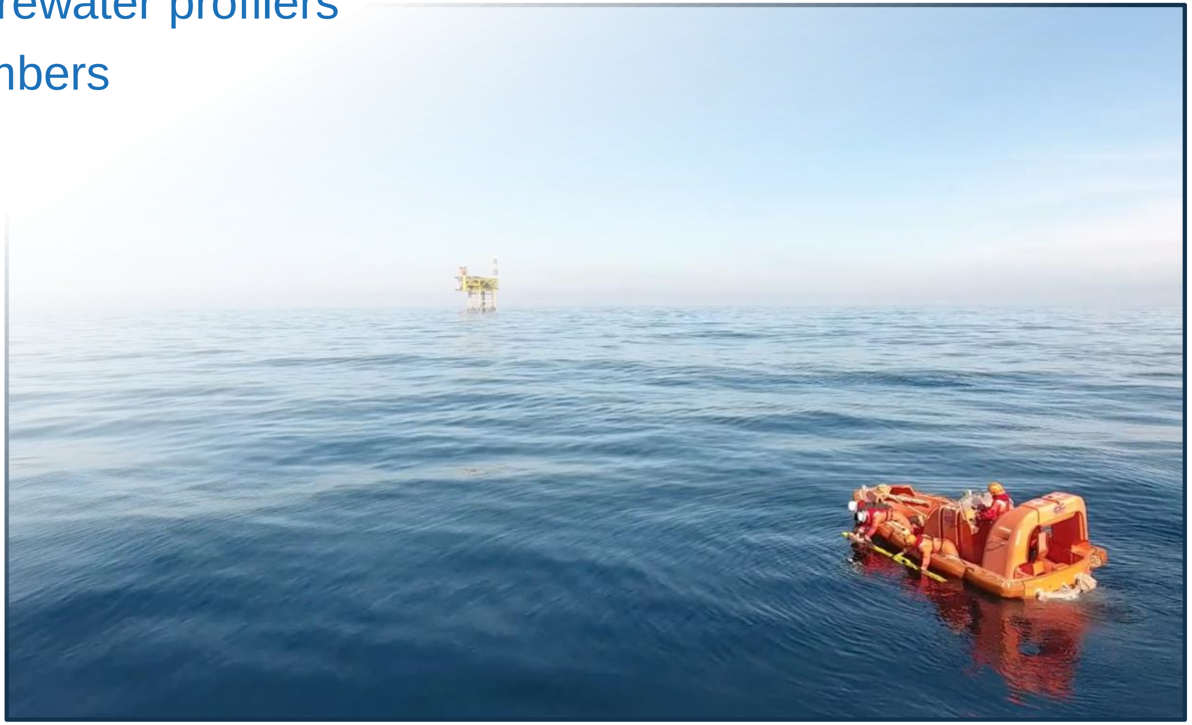
Passive acoustics
- Hydrophones

Optical
- Seafloor imaging
- Water column imaging

Biological
- Community structure mapping

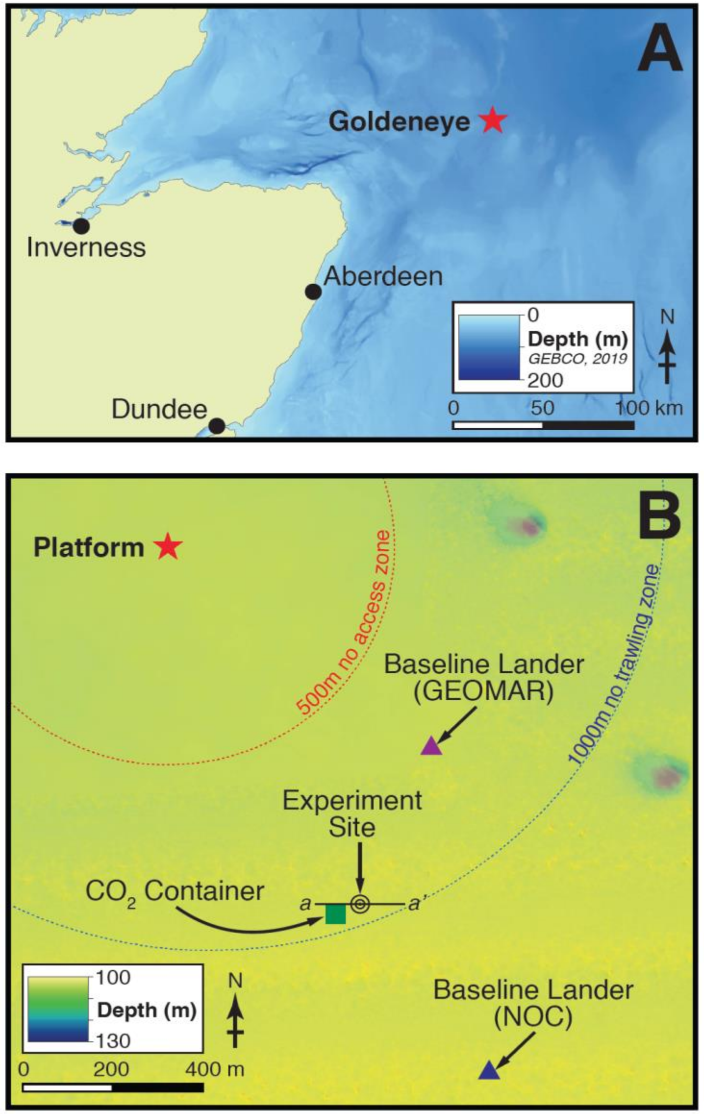
Geochemical
- pH/TA/DIC
- Salinity/Temperature/Pressure (CTD)
- O_2 and metal concentrations
- Sediment/porewater profilers
- Benthic chambers
- Gas tracers

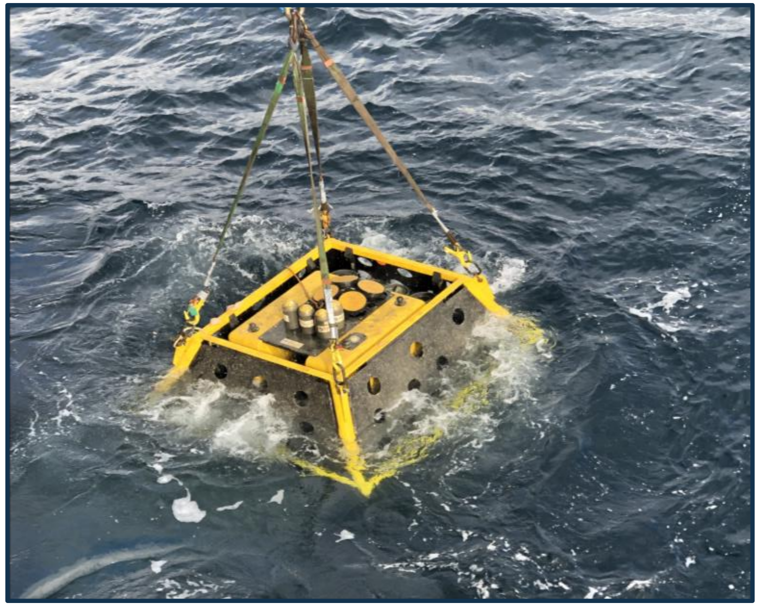
Computational
- C-Seep
- ROC Models
- MEIA

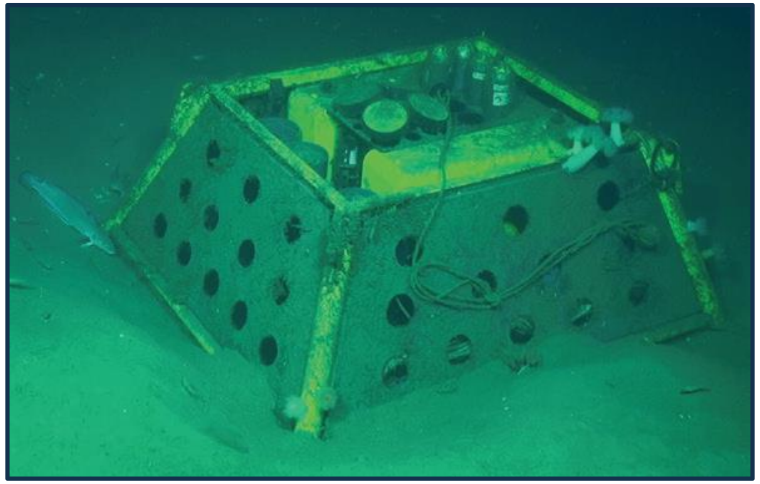


Launching AUV at the Goldeneye Platform, May 2019

Baseline monitoring and site characterisation

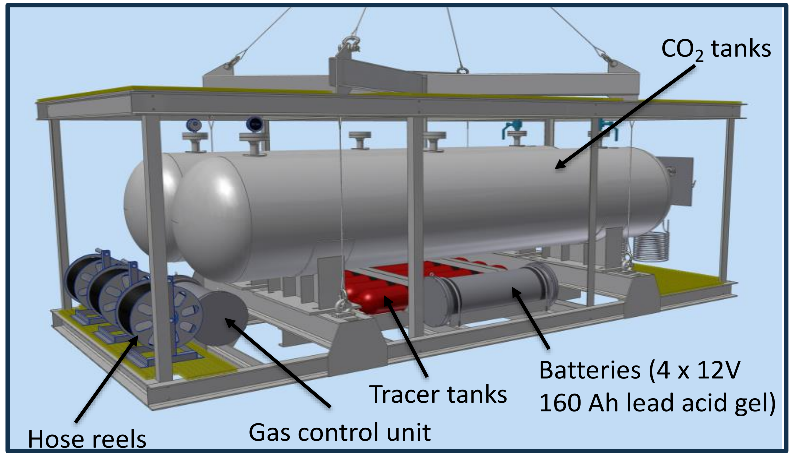


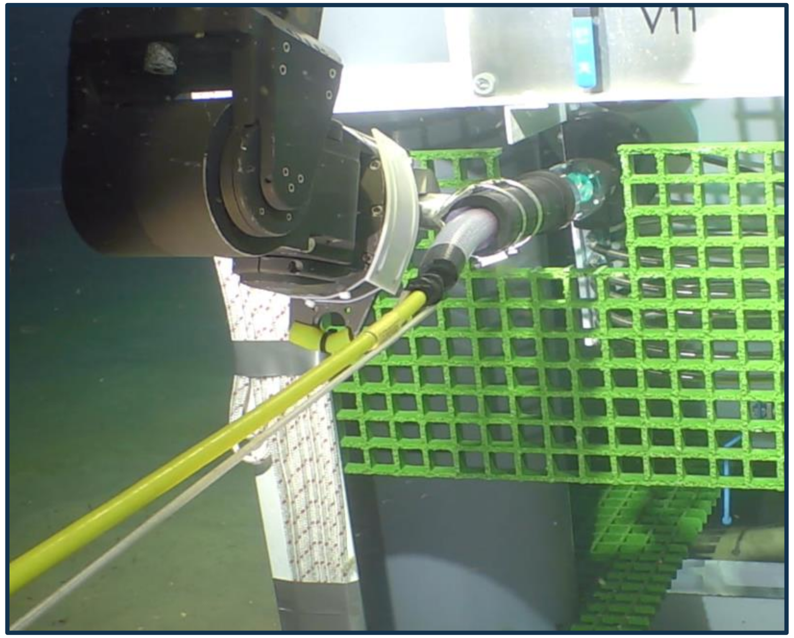


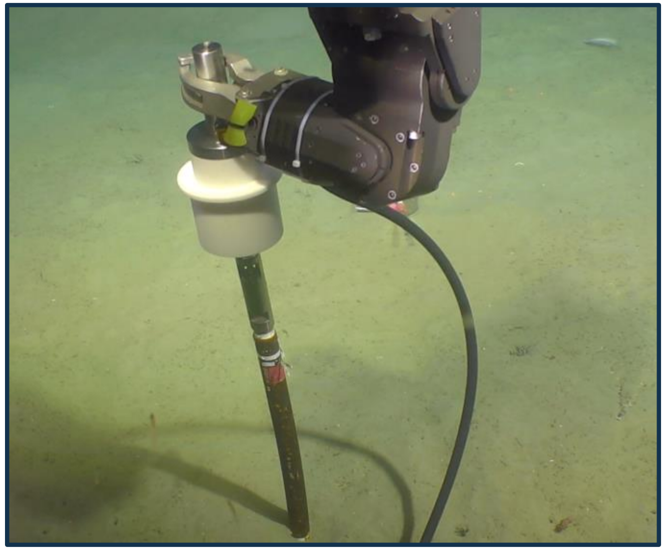


Connelly et al. (In Review) Renewable and Sustainable Energy Reviews

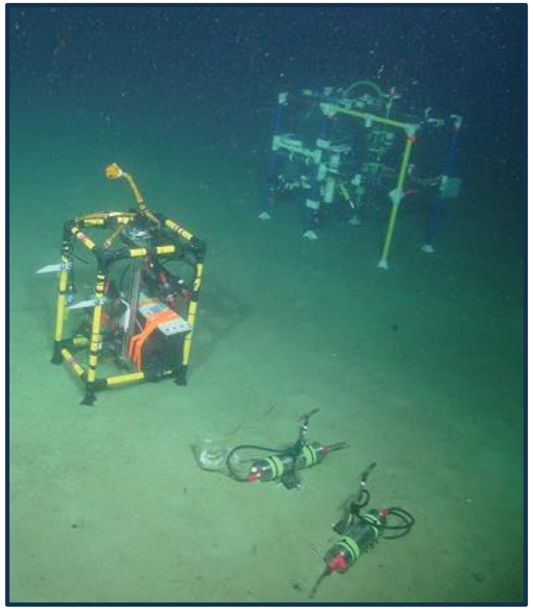
Engineering solutions for controlled CO_2 release

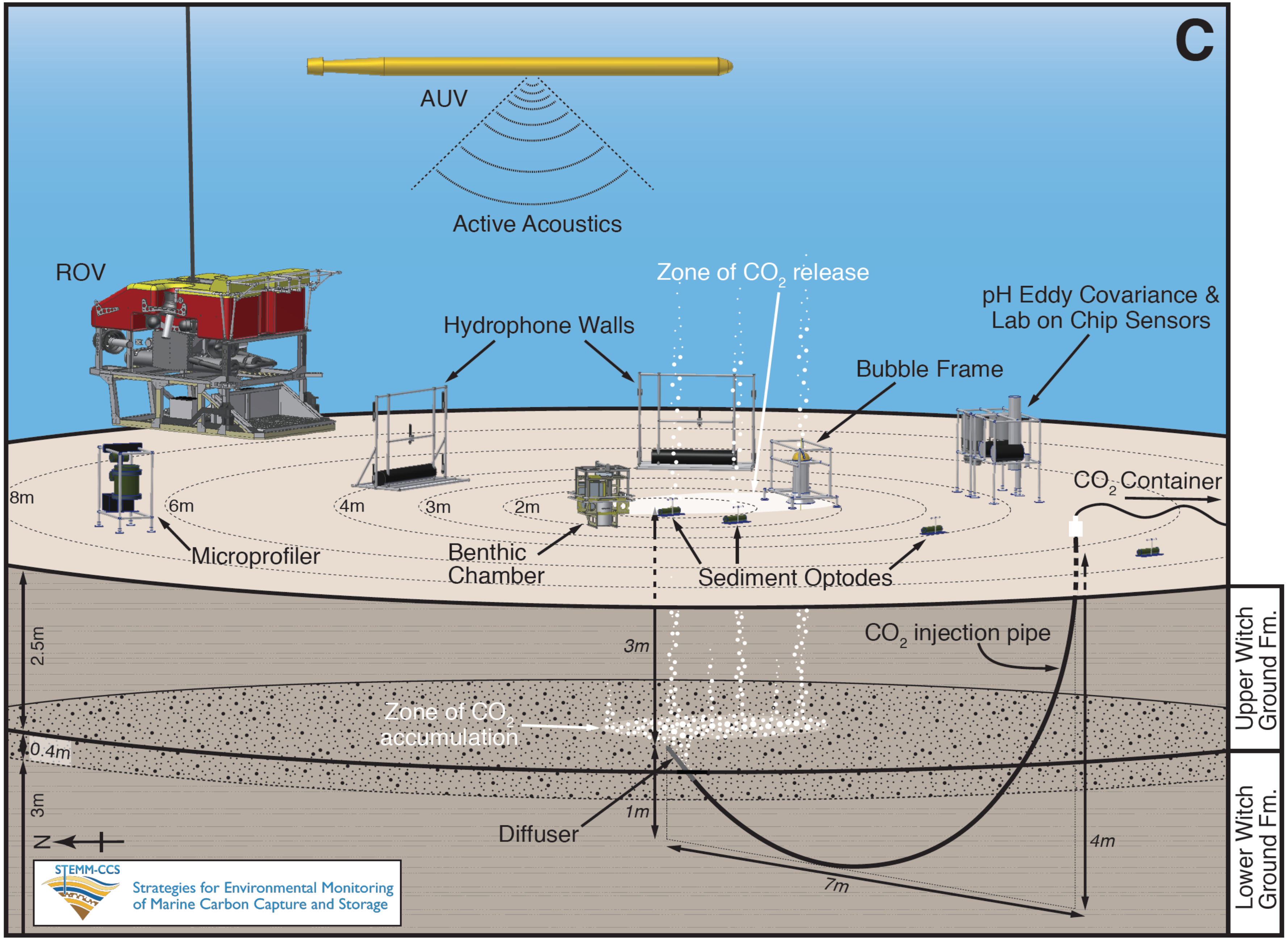






Schematic of site and deployed equipment





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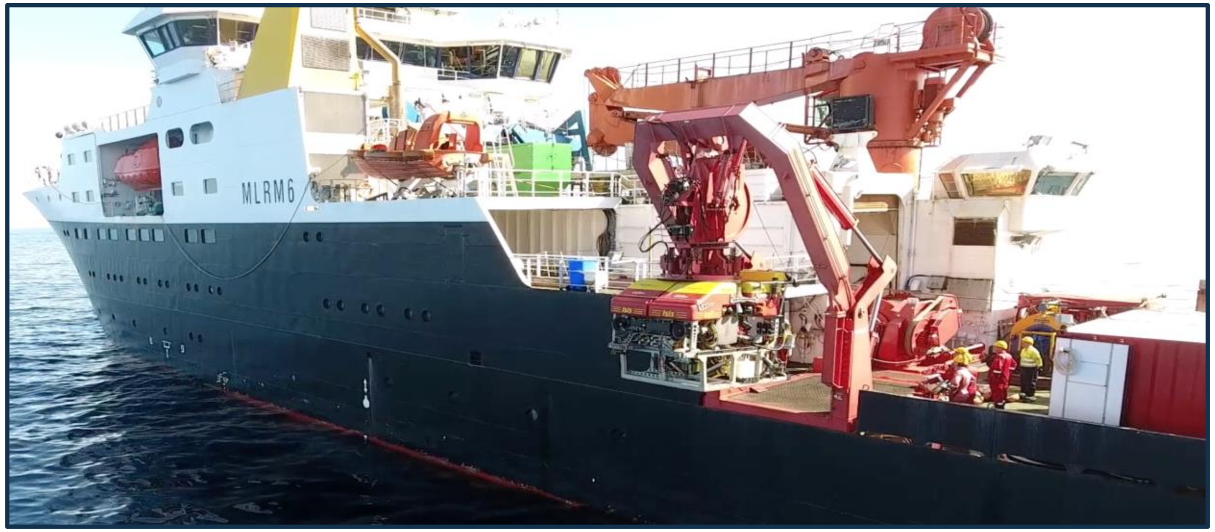
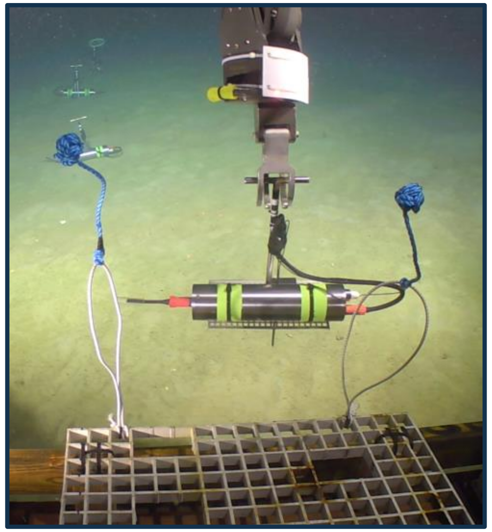
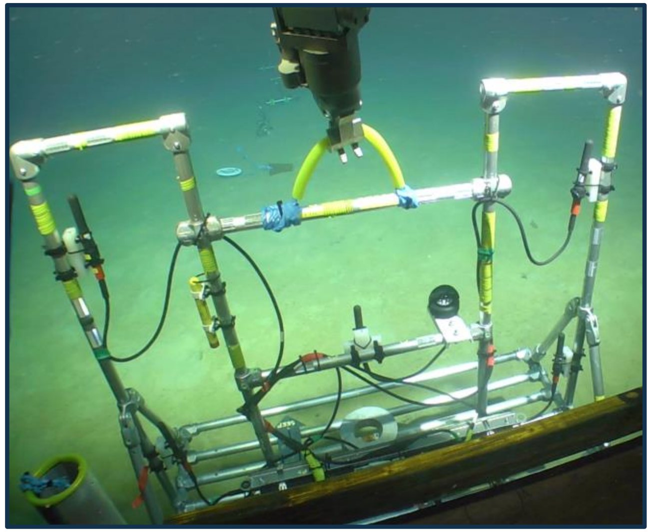
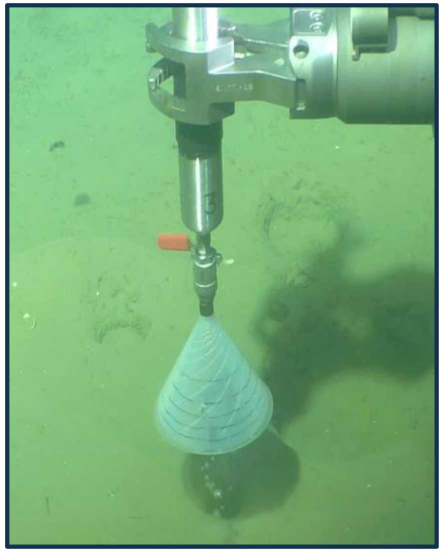
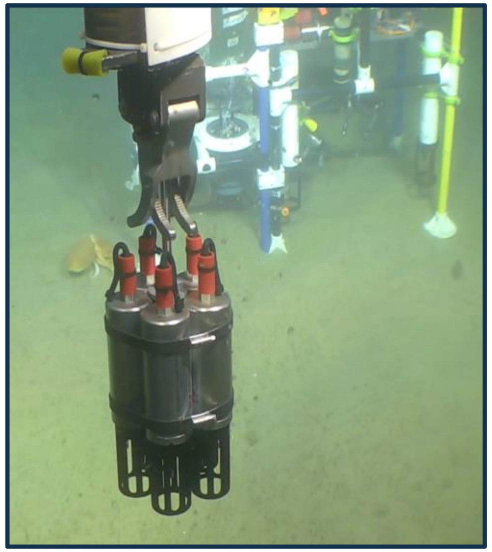
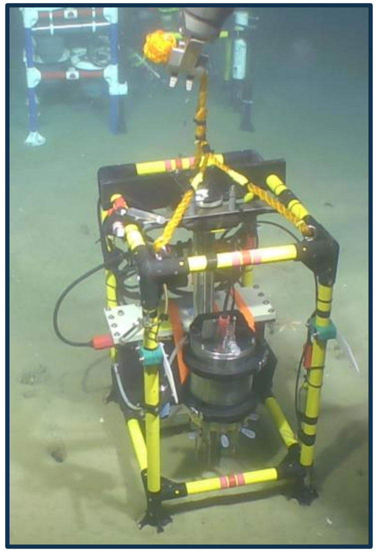
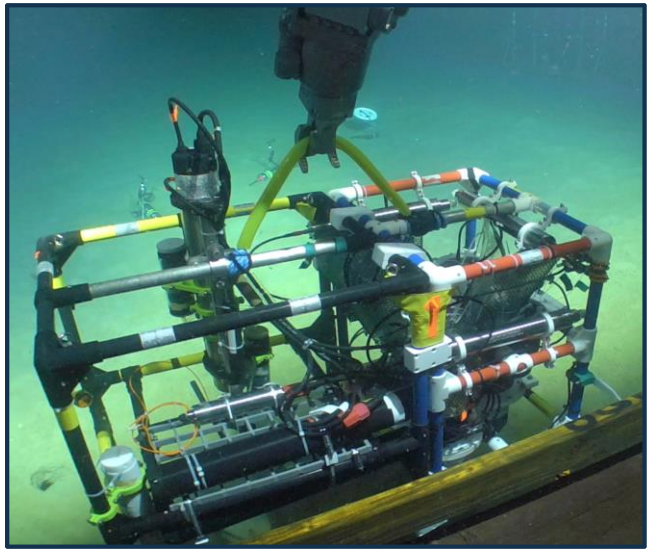
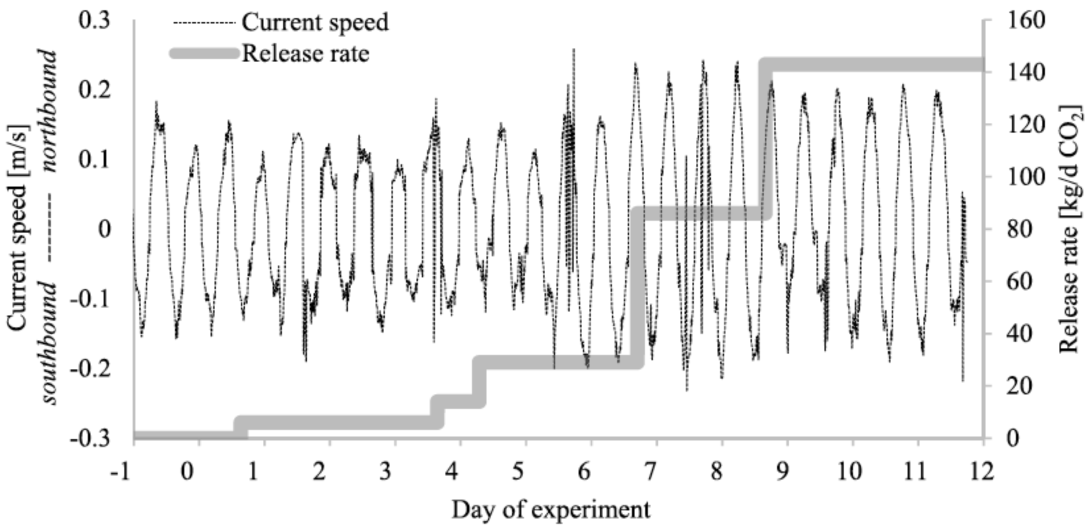
MMV technologies/approaches in-situ

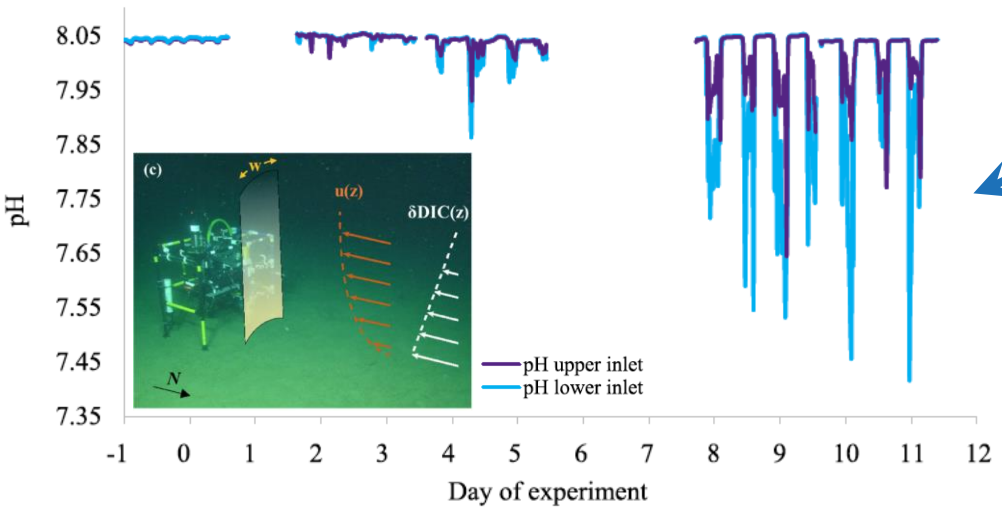





Comparison of pH sensor capabilities

Sensor Type	Precision	Accuracy	Range	Measurement Period	Deployment Duration	Lander	AUV
Lab on Chip	0.003	0.005	7.5-8.5	10 minutes	6 months	Yes	Yes
Microsensors	0.010	0.010	0-12	5 seconds	1-3 days	Yes	
Eddy Covariance	0.002		6.5-9.0	0.2 seconds	3 days	Yes	
Optodes	0.010	0.050	7.0-9.0	10 seconds	2 months	Yes	
SeaFET	0.004	0.050	6.5-9.0	1 second	1 year	Yes	Yes





Schaap et al. (2021) International Journal of Greenhouse Gas Control v110, 103427
Lichtschlag et al. (2021) International Journal of Greenhouse Gas Control v112, 103510

Suitability analysis

http://stemm-ccs.eu/monitoring-tool/

Approach	Technique and targeted environment	Task: Detection	Task: Attribution	Task: Quantification	Survey platform: Vessel	Survey platform: AUV	Survey platform: ROV	Time	Cost: CAPEX	Cost: OPEX	CO_2 leakage phase	Spatial coverage	TRL
Approaches for leakage detection tested during the STEMM-CCS experiment													
Active acoustics from ship: single beam echosounder (e.g. EK60/80)	Sensors in water column	+			✓			near instantaneous	high	low	bubbles only	high	commercially available
Active acoustics from ship: multibeam echosounders and sonars	Sensors in water column	+			✓			near instantaneous	high	low	bubbles only	high	commercially available
Active acoustics, sub-bottom profiler	Sensors in water column	+			✓	✓		near instantaneous	high	low	bubbles only	high	commercially available
imaging from AUV													
Multipurpose video-CTD, including mounted sensors	Sensors in water column	+	(+)	+	✓			near instantaneous	medium	low	dissolved and bubbles	high	near market
Microprofiler	Sensors in water column and sediment	+			✓		✓	days-weeks	high	medium	dissolved and bubbles	low	commercially available
Passive or active acoustics on seabed lander	Sensors in water column	+		+	✓		✓	days-weeks	high	medium	bubbles only	medium	commercially available

STEMM-CCS

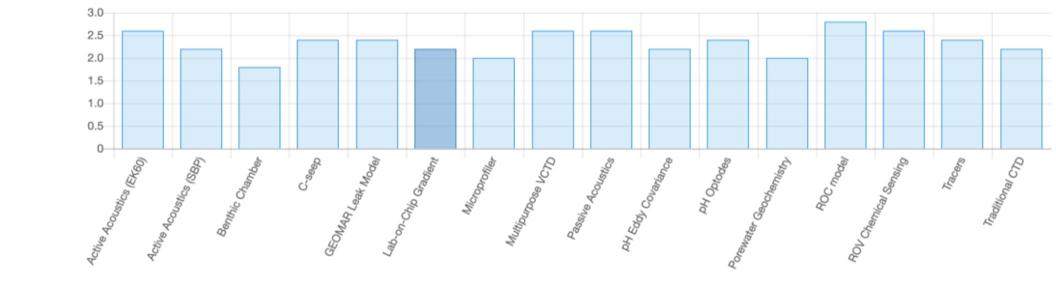
Strategies for Environmental Monitoring of Marine Carbon Capture and Storage

Leakage Detection

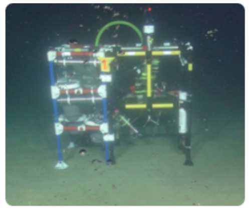
In line with the CCS Directive, any CCS storage complex monitoring strategy needs to assess whether any migration or leakage or CO_2 is occurring within the surrounding area. Such strategies need to accommodate the fact that CO_2 leakage may occur from a single point source or as more diffuse discharge over a larger area, and similarly that the leaking CO_2 may be present in form of CO_2 gas bubbles or dissolved into the interstitial waters of the sediments and overlying water column. Given these complexities, a number of different methods and techniques for detecting CO_2 leakage under varying scenarios were tested through the STEMM-CCS project, with their relative performance and individual merits summarised below.

User Guide

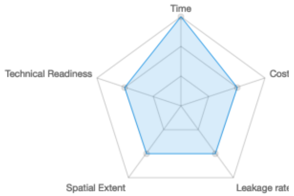
Monitoring Methods — Comparison Mode



Lab-on-Chip Gradient



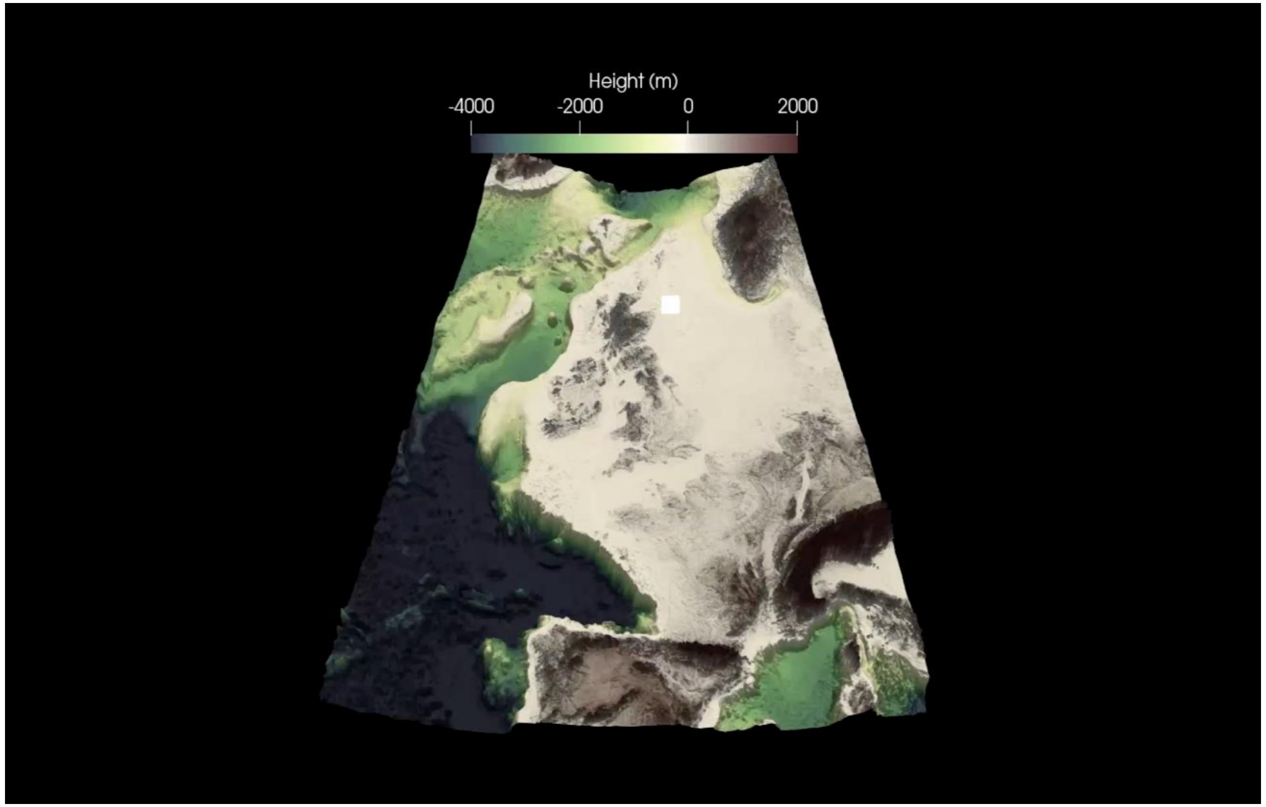
Lab-on-chip sensors perform in-situ chemical analysis of the seawater. A lab-on-chip sensor for dissolved inorganic carbon (DIC), or a combination of pH and total alkalinity sensor, can quantify the excess DIC in the water which is a results of dissolved CO_2 bubbles. By measuring at two heights above the seafloor and combining the data with current measurements, a total mass flow rate of DIC can be established. The instrument must be located downstream of the source. Some training is required to operate the instruments, and interpret the data.

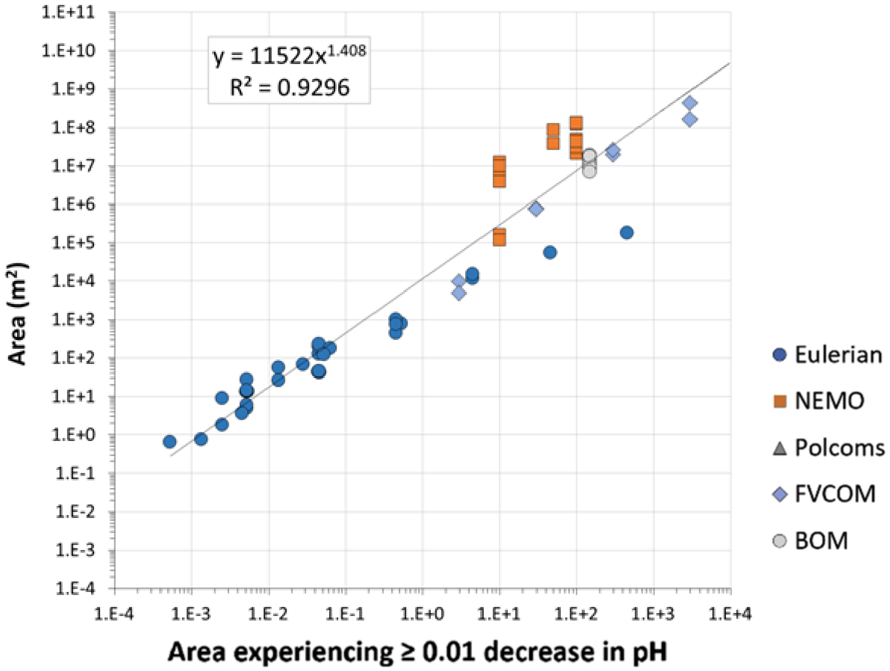


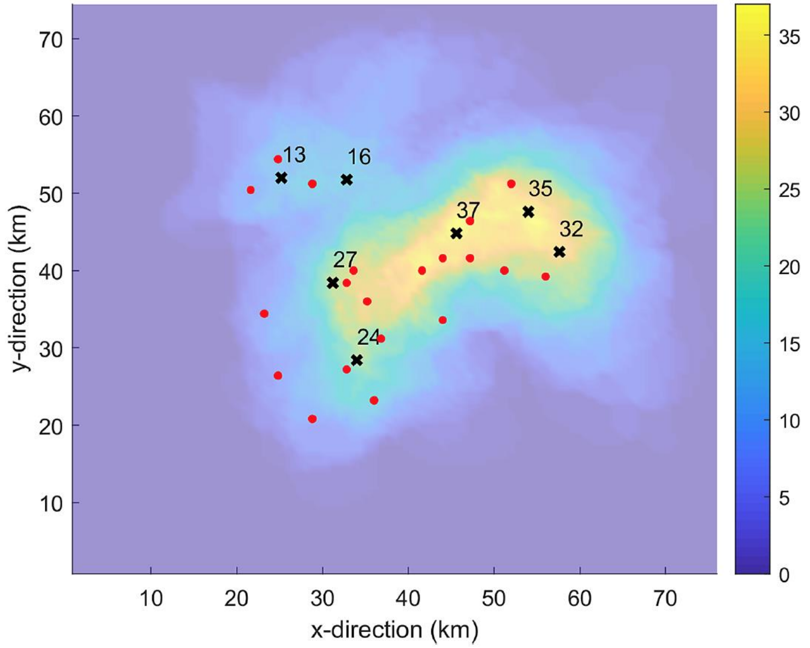
Method Scoring: Lab-on-Chip Gradient			
Time needed to obtain final results (in months)	3+	2	✓ 0-1
Cost of measurement	High	✓ Medium	Low
CO_2 leakage rate and nature of leakage	High (Bubbles)	✓ Low to High (Bubbles)	Low (Bubbles and Dissolved)
Spatial extent (coverage) of measurement	Low	✓ Medium	High
Technical readiness level of the method	In development	✓ Near market	Commercially available

Survey optimization

Model simulations of hypothetical leaks, coupled with machine-learning techniques can identify optimal deployment of both fixed and mobile sensors

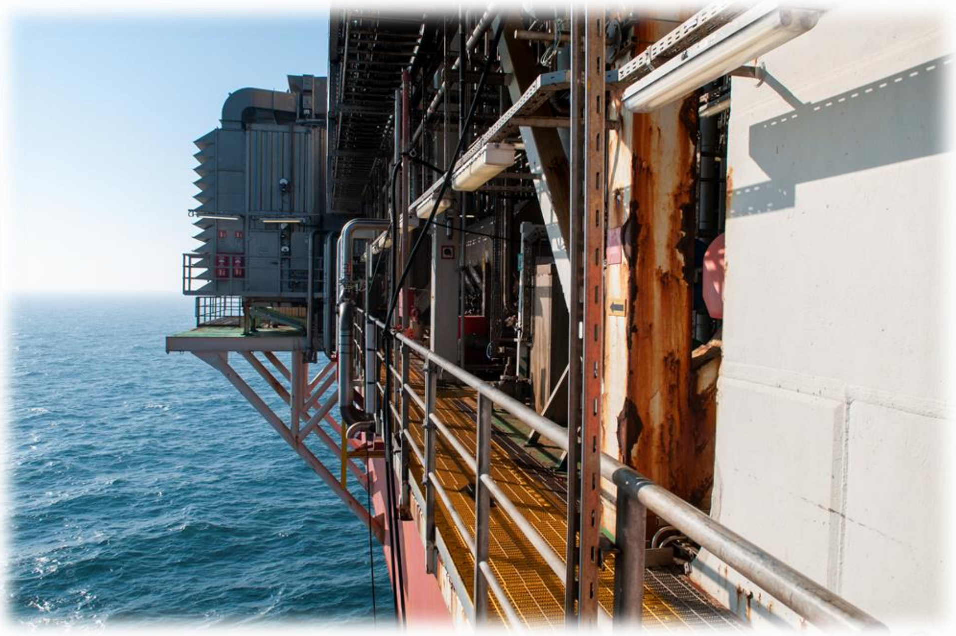






Blackford et al. (2021) International Journal of Greenhouse Gas Control v109, 103388

Implementation of project outcomes



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Supporting the development and application of marine sensors for offshore MMV of the storage complex

Technology assessment for remote seabed environmental monitoring, informing development of the monitoring plan

Northern Endurance Partnership

National Oceanography Centre

STEMM-CCS

Thank you

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