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QICS project: Offshore Environmental Impact Assessment and Monitoring.

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QICS

Quantifying and Monitoring Potential Ecosystem Impacts of Geological Carbon Storage

Two primary research objectives

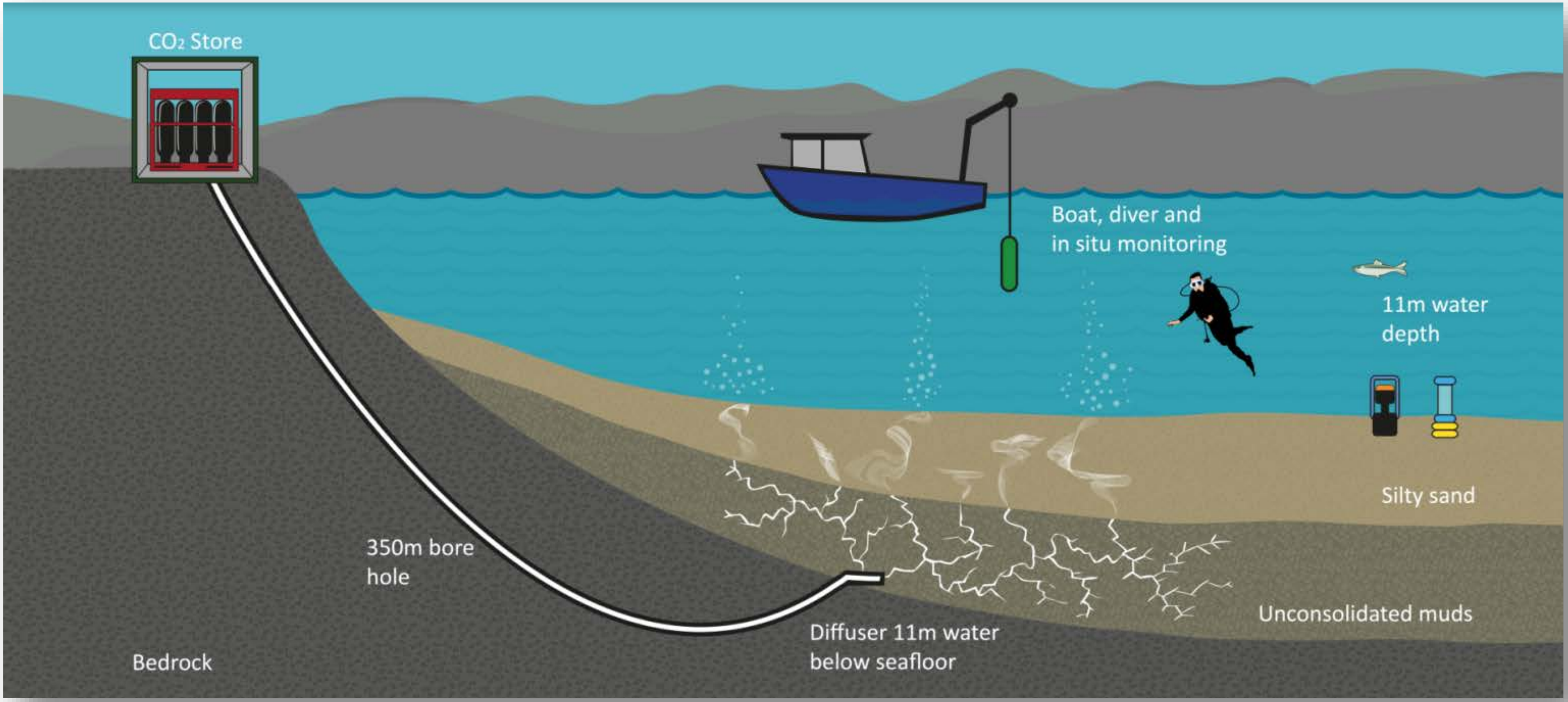
1. If there was a release of CO_2, is the potential environmental impact significant?

    compared with other marine uses and climate change

2. What are the best (economic yet rigorous) methods of monitoring for a leak / assuring no leakage?

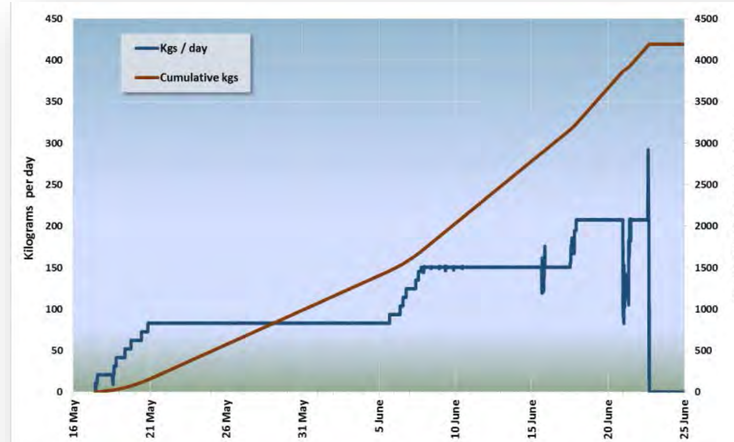
    deep seismic monitoring is expensive and can only "see" relatively large CO_2 volumes. Monitoring at the surface enables detection of and assurance against all leakage

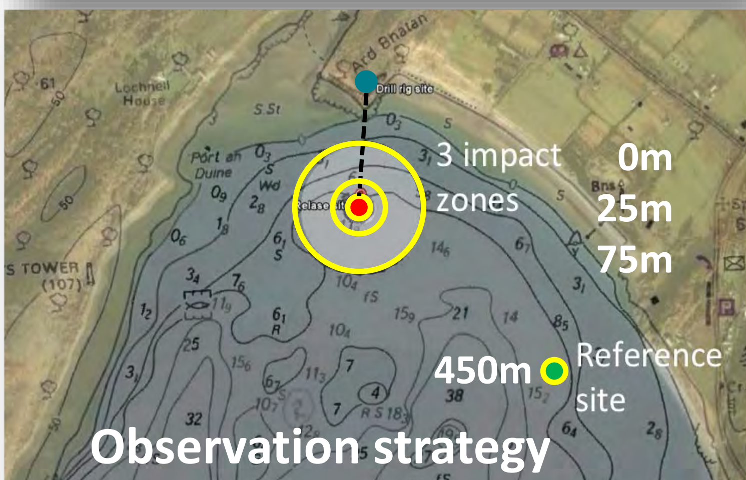
QICS: A Controlled release experiment.



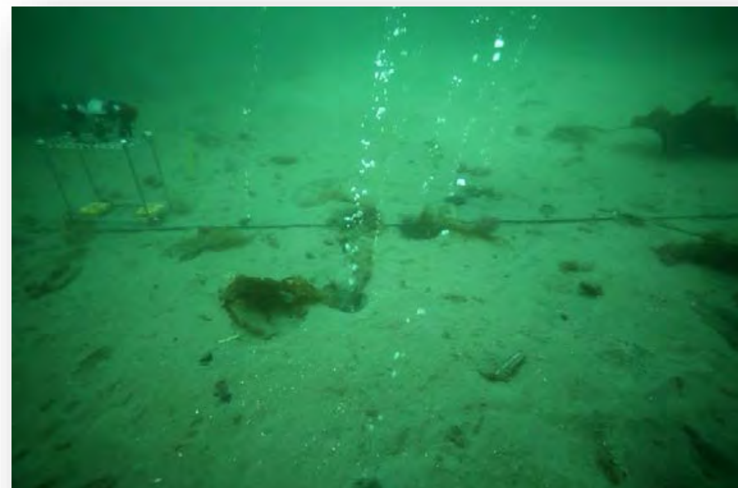
Blackford, JC; Stahl, H; Bull, JM; et al. 2014. *Nature Climate Change* 4, 1011-1016. DOI: 10.1038/NCLIMATE2381
Taylor P., et al., 2015. *International Journal of Greenhouse Gas Control*. Doi:10.1016/j.ijggc.2014.09.007

4.2 tonnes injected over 37 days





~ abandoned well bore scenario

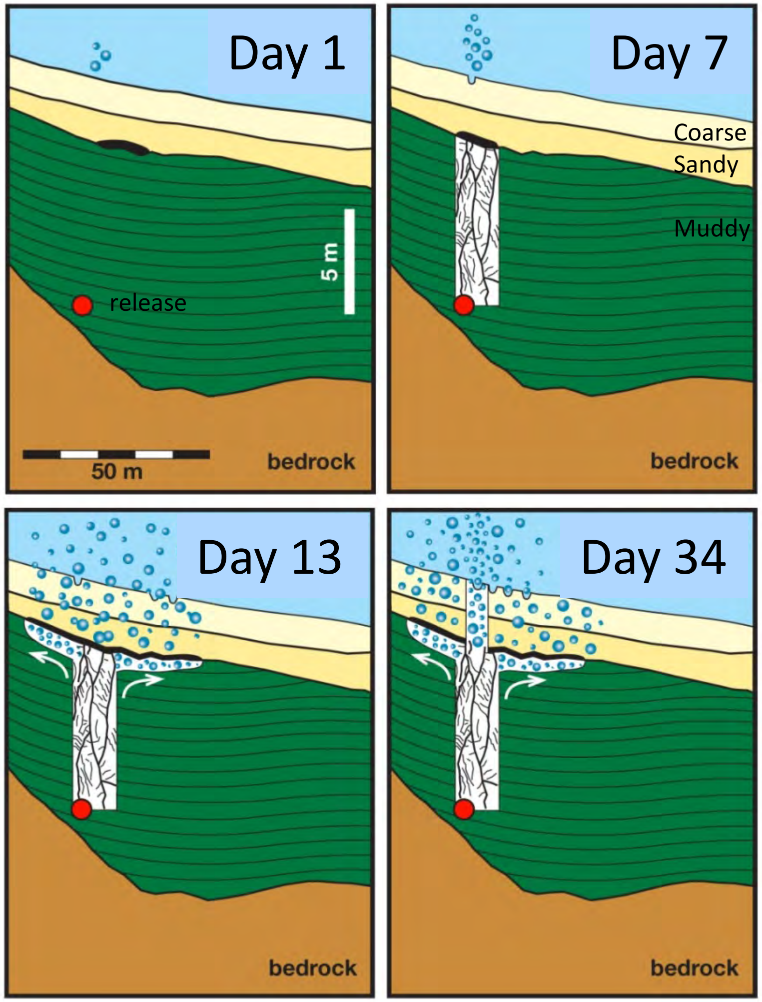


May | Pre-release | Injection | Recovery | September

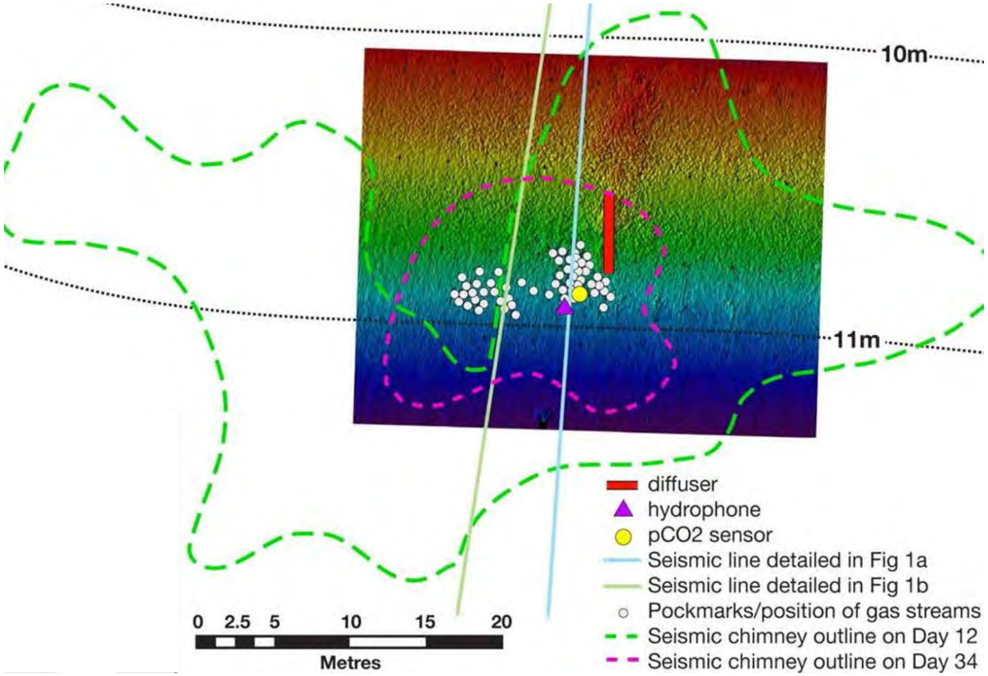
Day -7 | Day 0 | Day 14 | D35 | Day 41 | Day 57 | Day 126

Taylor P., Stahl H., Vardy M.E., Bull J.M., Akhurst M., Hauton C., James R.H., Lichtschlag A., Long D., Aleynik D., Toberman M., Naylor M., Connelly D., Smith D., Sayer M.D.J., Widdicombe S., Wright I.C., Blackford J., 2015. International Journal of Greenhouse Gas Control. Doi:10.1016/j.ijggc.2014.09.007

Gas flow in sediments



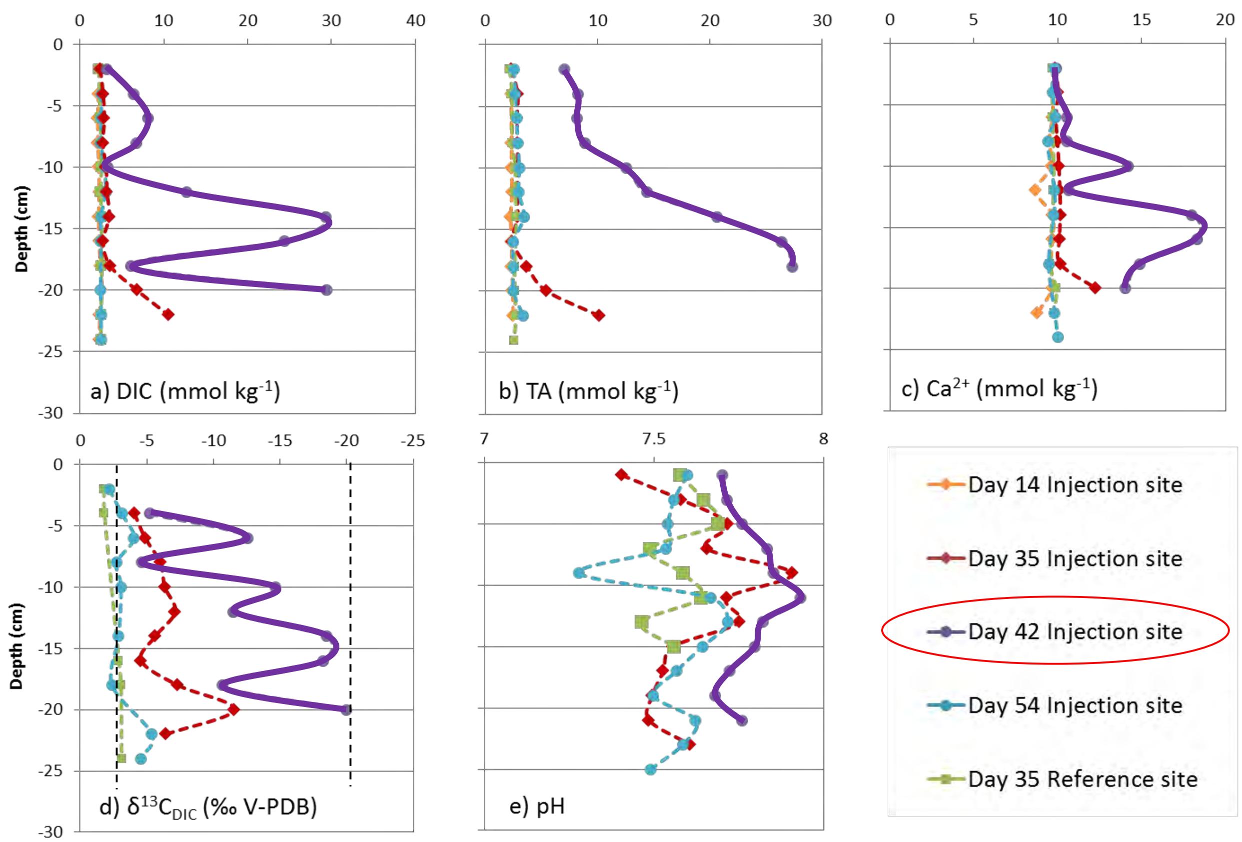
Day 1: Gas propagation via pre-existent pathways.
Day 7: Clear chimney in muddy sediments, only.
Day 13: Area of reflectivity increased.
Day 34: Narrower chimney from diffuser to surface. Vigorous venting into water column



- Seismic reflectance can "see" gas above a threshold. Flow mechanisms are complex
- Flow became more focussed as chimneys developed through the sediment

Blackford, JC; Stahl, H; Bull, JM; et al. 2014. *Nature Climate Change* 4, 1011-1016. DOI: 10.1038/NCLIMATE2381
Cevatoglu M., Bull J.M., Vardy M.E., Gernon T.M., Wright I.C., Long D., 2015.. International Journal of Greenhouse Gas Control. Doi:10.1016/j.ijggc.2015.03.005

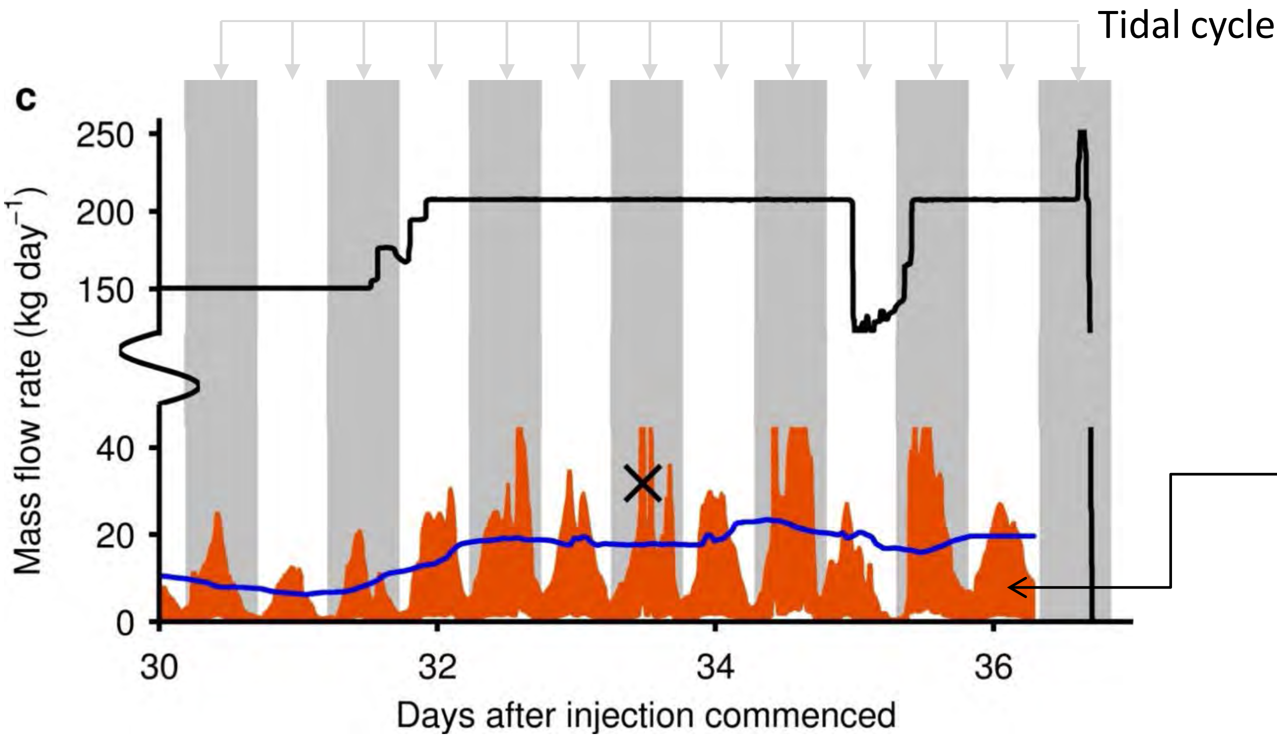
Release experiment: Benthic chemistry



- Strong evidence for buffering
- Change in pH is limited, intermittently reversed, reducing impacts
- Some evidence for mobilisation of heavy metals, but not to the extent of exceeding environmental impact thresholds

Blackford, JC; Stahl, H; Bull, JM; et al. 2014. *Nature Climate Change* 4, 1011-1016. DOI: 10.1038/NCLIMATE2381
Lichtschlag A., James R.H. Stahl H., Connelly D., 2015. *International Journal of Greenhouse Gas Control*. Doi:10.1016/j.ijggc.2014.10.008

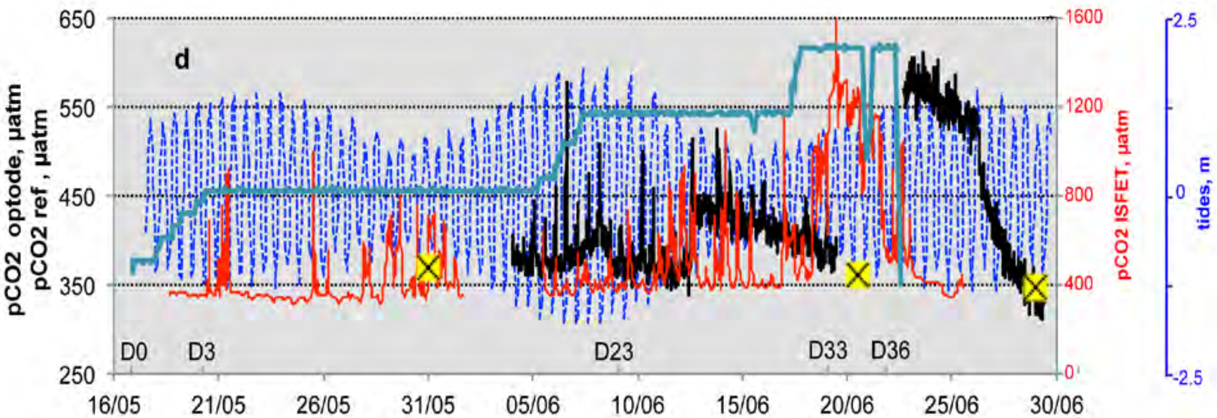
Gas fluxes into the water column

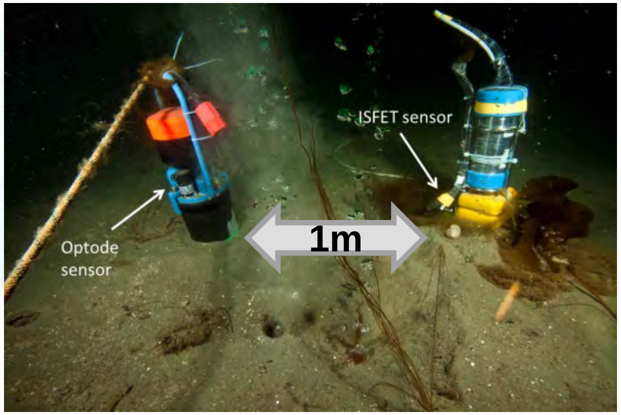


- Gas plumes readily revealed by active acoustics (sonar)
- Gas also detected and quantified by hydrophones
- Gas flow was heavily influenced by the tidal state, almost ceasing at high tide
- Hence bubbles and plumes may not be a constant feature of a release

Blackford, JC; Stahl, H; Bull, JM; et al. 2014. *Nature Climate Change* 4, 1011-1016. DOI: 10.1038/NCLIMATE2381
Bergès B.J.P., Leighton T.G., White P.R., 2015. International Journal of Greenhouse Gas Control. Doi:10.1016/j.ijggc.2015.02.008

CO_2 flux into the water column





ISFET sensor ~ 3cm from seabed

Optode sensor ~25cm from seabed

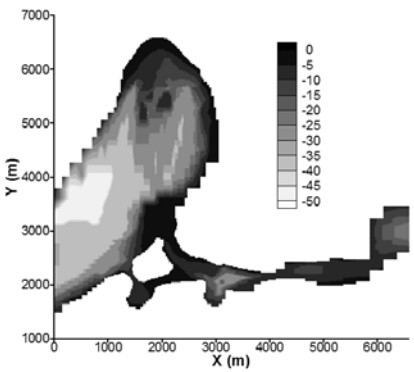
- Carbonate observations very dependent on sensor positioning: huge small scale heterogeneity - implications for monitoring.

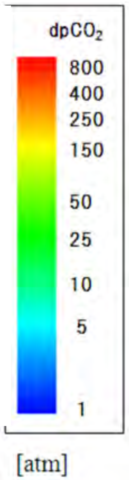
Blackford, JC; Stahl, H; Bull, JM; et al. 2014. *Nature Climate Change* 4, 1011-1016. DOI: 10.1038/NCLIMATE2381
Shitashima et al, 2015. *International Journal of Greenhouse Gas Control*, 38, 135-142
Mori et al, 2015. *International Journal of Greenhouse Gas Control*, 38, 153-161

Where has the CO_2 gone?

Can observed water column pCO_2 be explained by only gas bubble flow? – no

Model recreation of sea floor flux in Ardmucknish Bay





Case	A	B	C
Gas %	8	8	8
Dissolved %	17	42	67
Remaining %	75	50	25

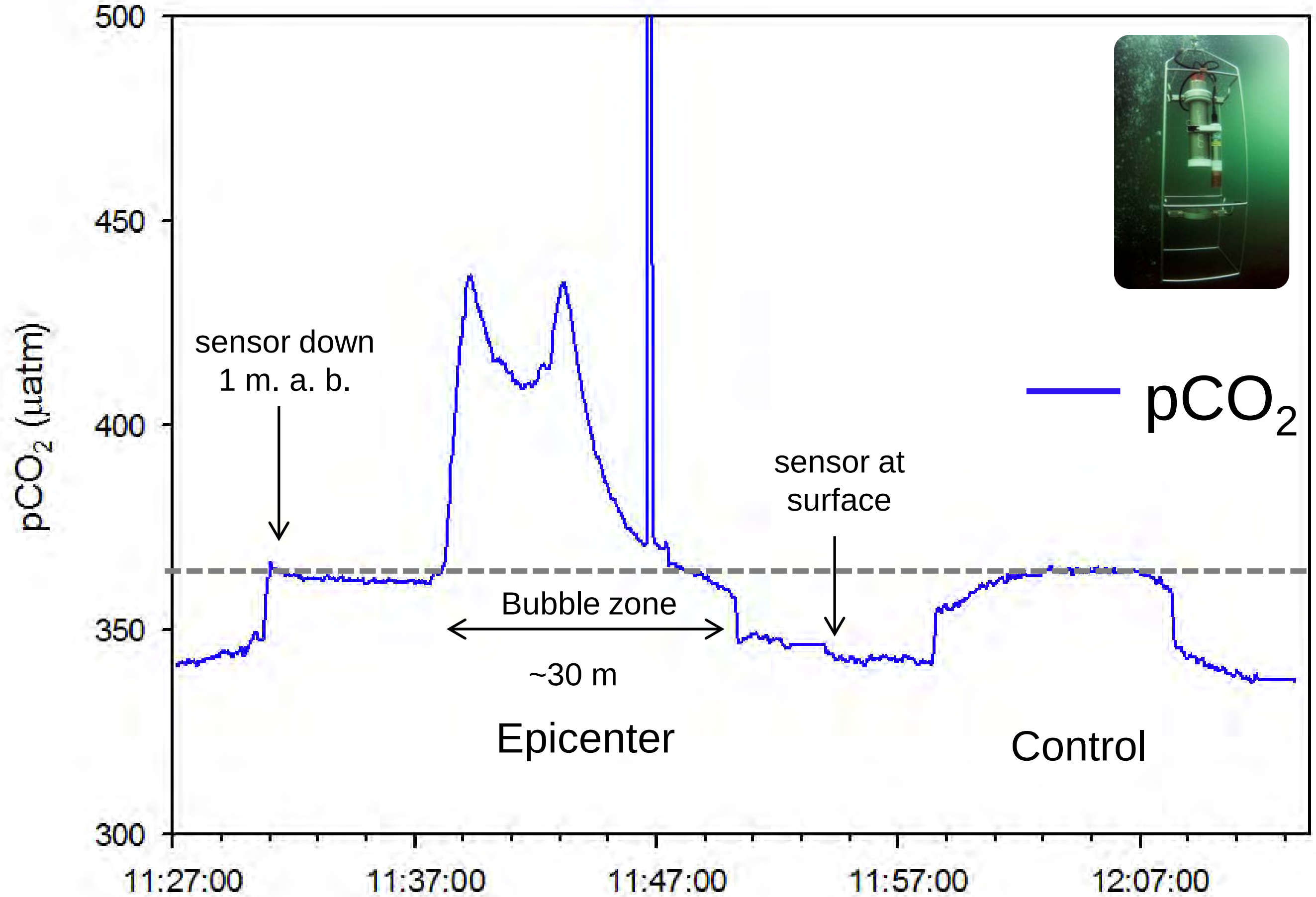
Closest match to observations (B)

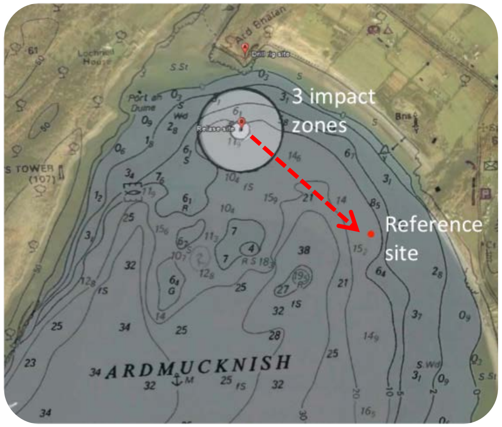
- Concluded: Significant "invisible" dissolved flow had occurred.
- ~15% CO_2 emitted as bubbles, ~35% in the dissolved phase, within the bubble plumes and ~50% retained in the sediments – implications for quantification.

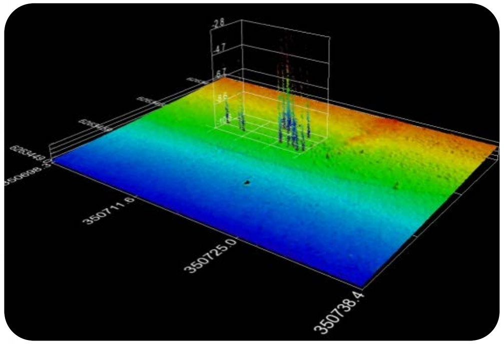
Mori C., Sato T., Kano Y., Oyama H., Aleynik D., Tsumune D., Maeda Y., 2015. International Journal of Greenhouse Gas Control. Doi:10.1016/j.ijggc.2014.11.023

CO_2 in the water column

How far did the CO_2 plume spread?

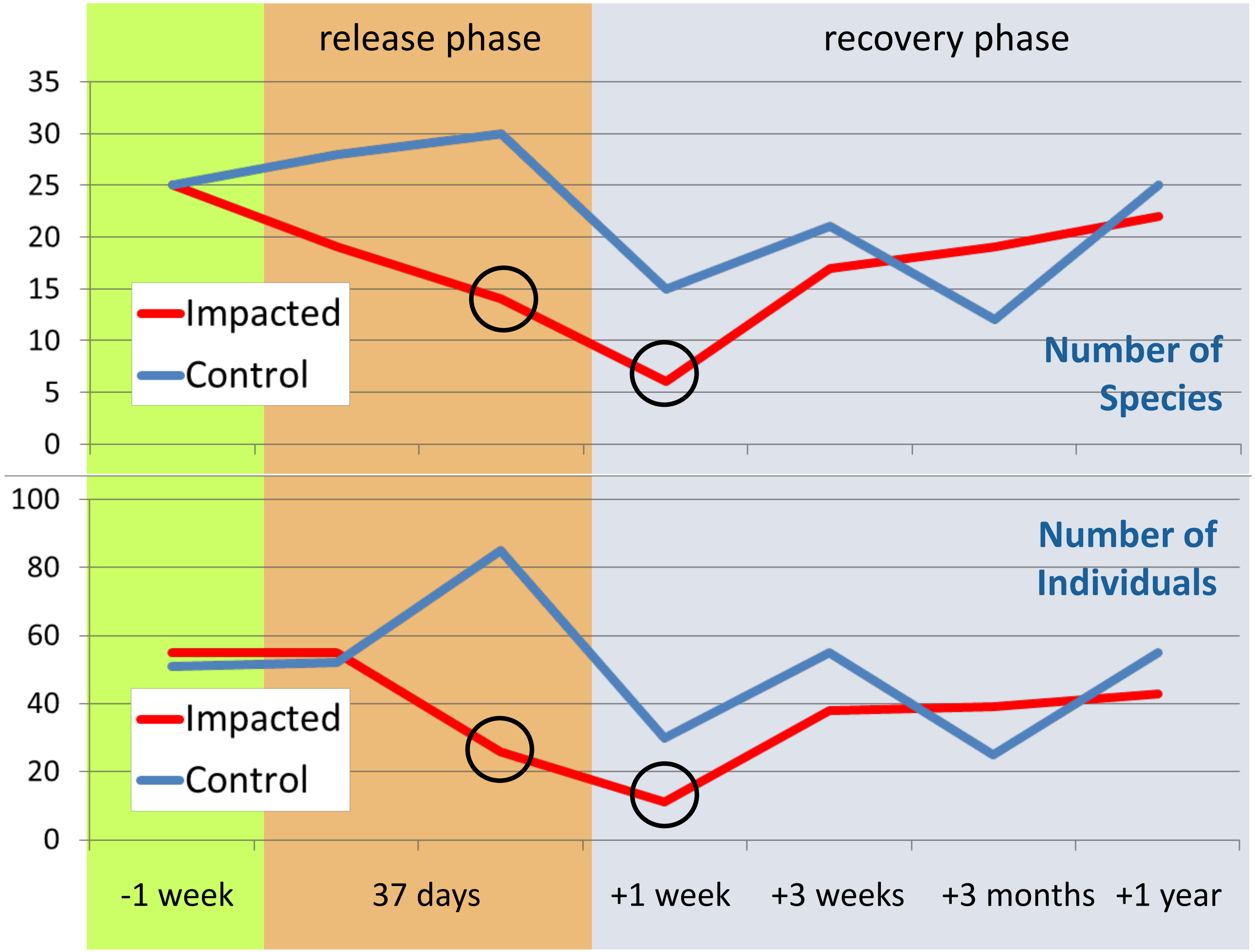






Elevated CO_2 concentrations in bottom water confined to release epicentre

Release experiment: Biological response

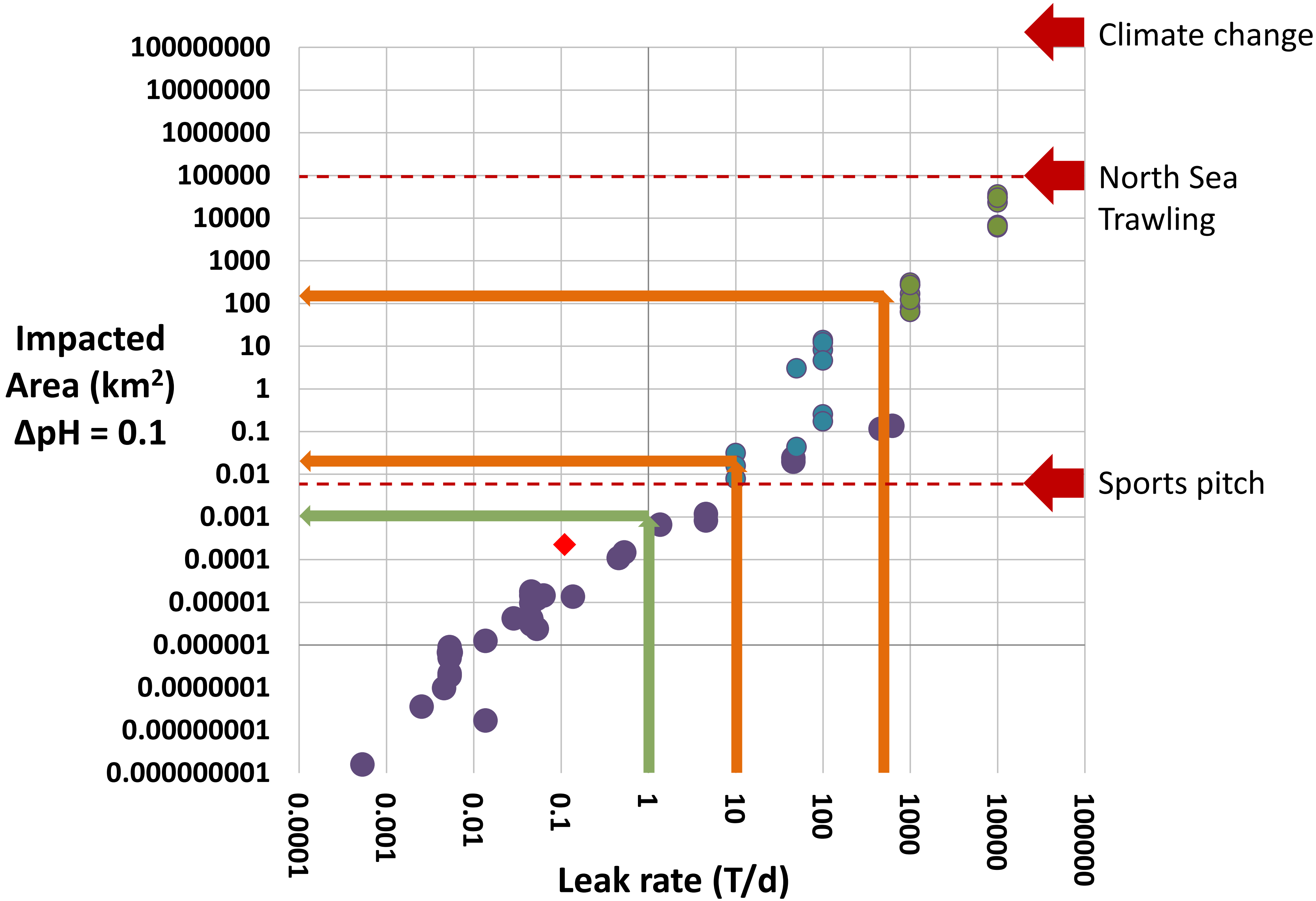


Impacts only at the release site,

recovery within ~3 weeks

Widdicombe et al, 2015. Impact of sub-seabed CO2 leakage on macrobenthic community structure and diversity. *International Journal of Greenhouse Gas Control*.
Doi:10.1016/j.ijggc.2015.01.003

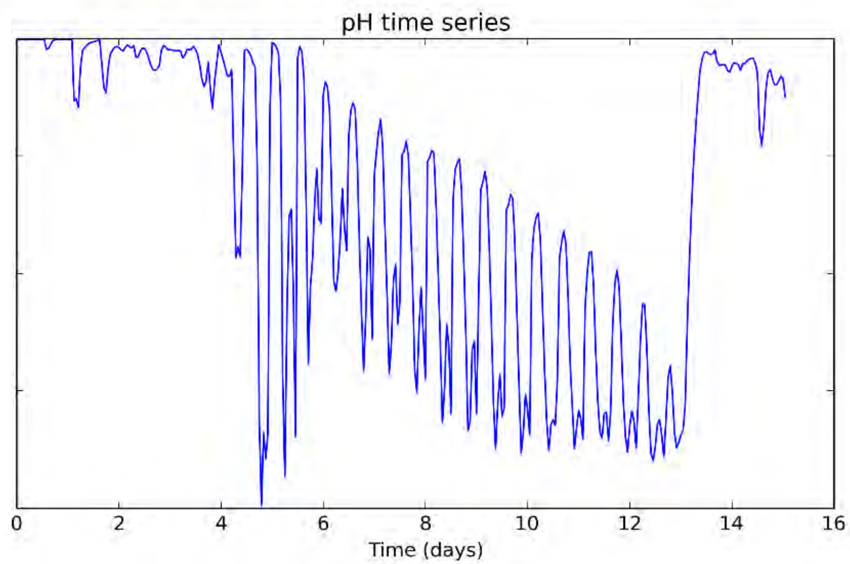
How large an area could be affected? Meta analysis of leak simulations



Monitoring: Leaks are complex

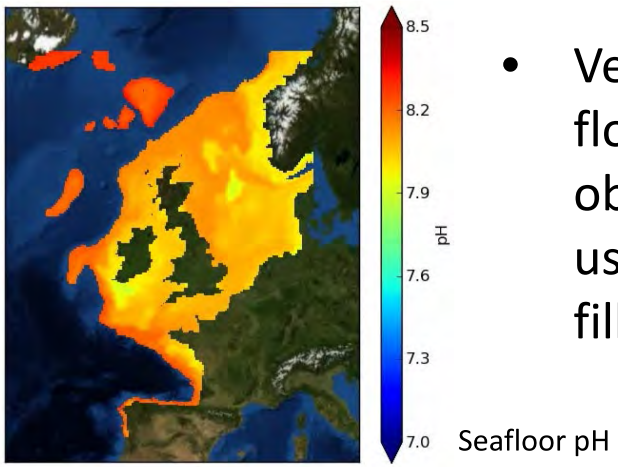
- Tidal mixing means that footprint of a leak will be dynamic
- No two leaks will look the same
- Large variability driven by tidal state, currents, stratification, leak rate, bubble size, phase chemistry.

- Monitoring: moving target
- Exposure: may be cyclic
- Chemical recovery is very rapid

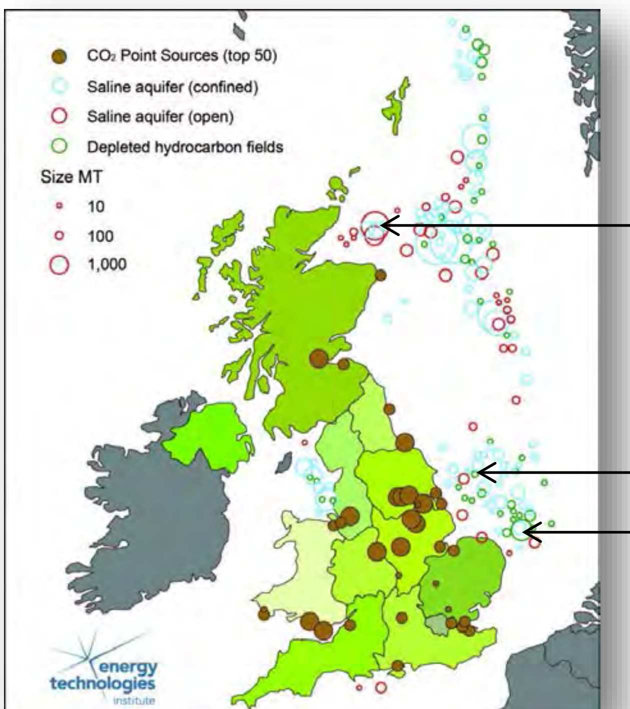


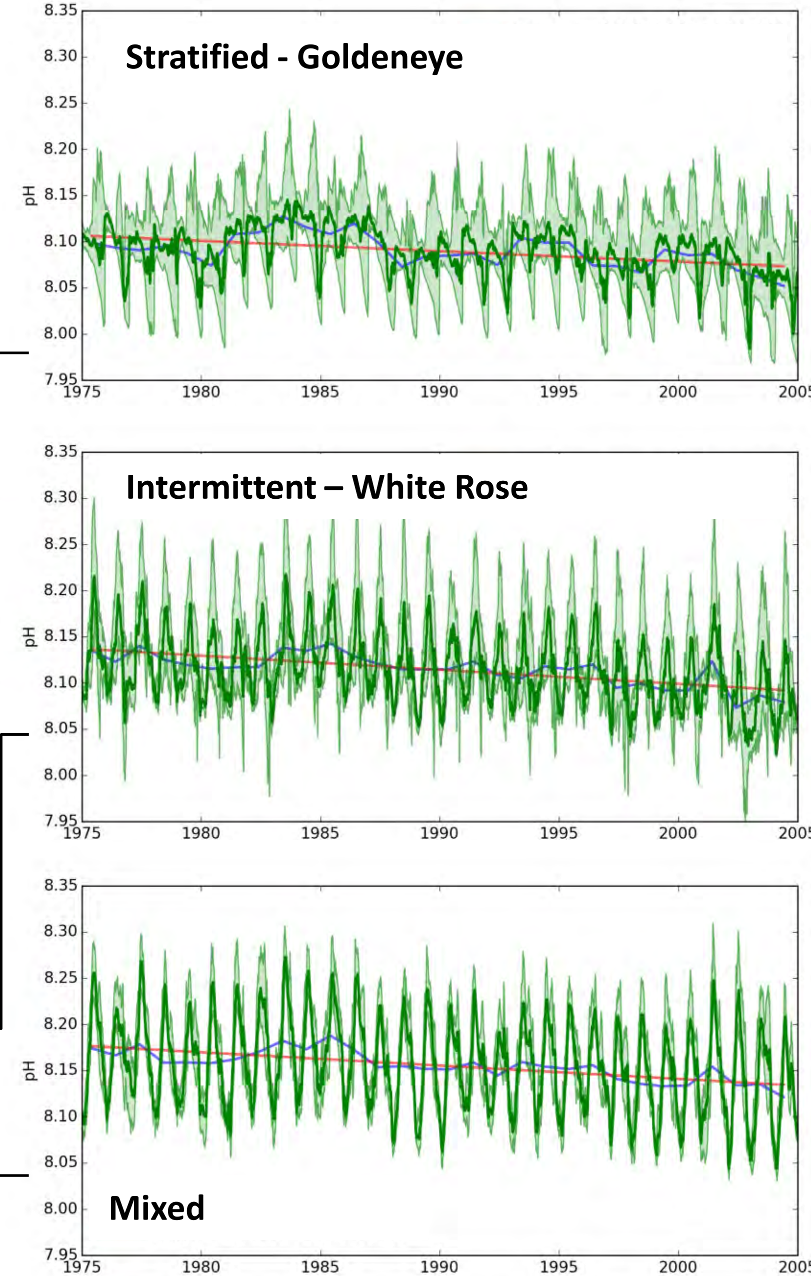
Blackford et al, 2008, *Marine Pollution Bulletin*, 56. 1461 - 1468
Phelps et al, 2015*, International Journal of Greenhouse Gas Control*, 38, 210-220.
Blackford, JC; Torres, R; Artioli, Y; Cazenave, P. 2013 *Energy Procedia*, 37. 3379 - 3386. Doi: 10.1016/j.egypro.2013.06.226

Natural systems are very complex



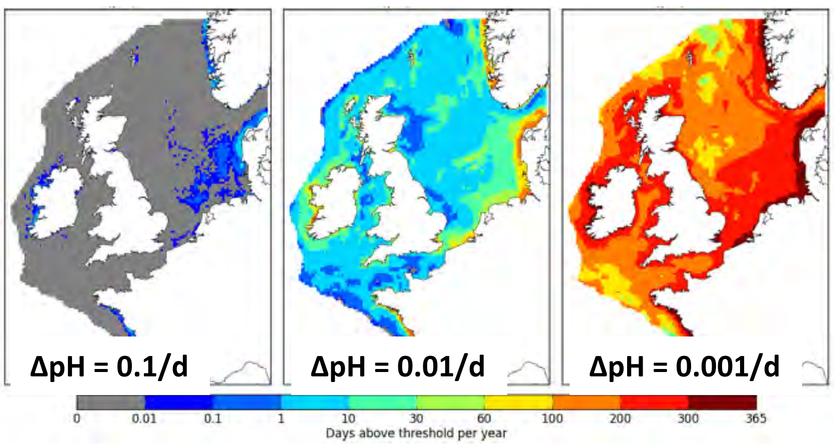
- Very few sea floor pH observations – use models to fill in the gaps



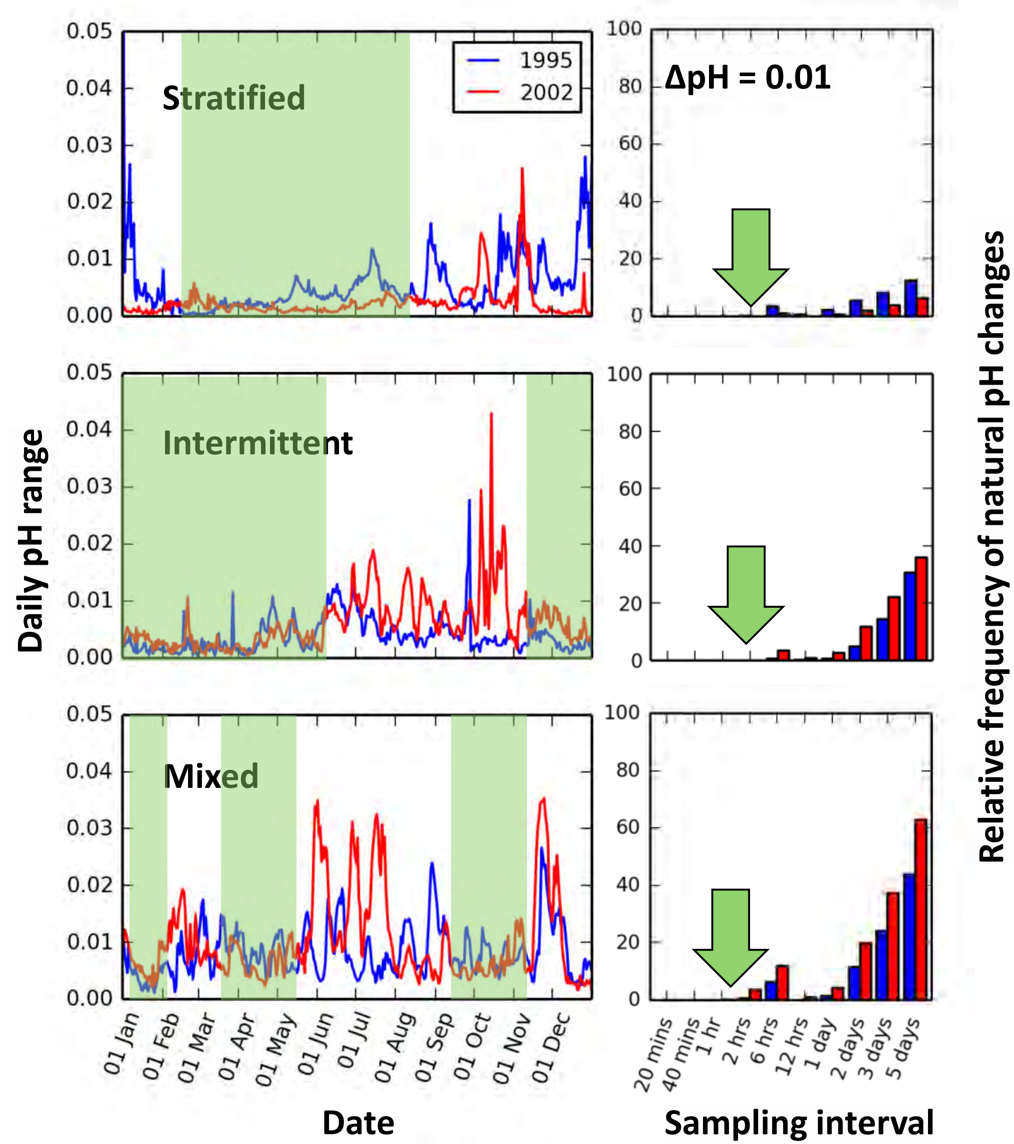


Detection criteria: looking for short term, unusual ΔpH

- Sensors can resolve changes of 0.001 pH units or less



- However short term changes of that order are naturally ubiquitous
- Rapid changes of between 0.1-0.01 pH units are more likely to indicate an anomaly
- Highly dependant on season and site



Operational Monitoring Options

Monitoring strategy, four stages:

1. Detect anomalies / Ensure no leakage
2. Confirmation and attribution
3. Quantification of flux
4. Impact assessment

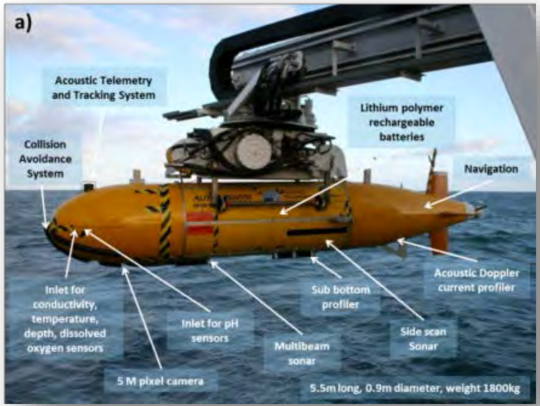
Four methods	Power needs	Range	Sensitivity	Detection	Confirmation	Quantification	Impact assess
Passive acoustics (listening for bubbles)	✓	✓		✓		✓	
Active acoustics (sonar for bubbles / seismic reflectance)	✗	✓		✓			
Chemical (pH, tracers, isotopes, etc)	✓	✓		✓	✓	✓	✓
Biological (abnormal behaviour, mortality)	✗	✗	✗				✓

Summary

- Well managed and operated carbon storage should not leak.
- If a small leak occurred the impact footprint would be minimal, certainly << less than other marine uses.
- Monitoring will be challenging and will require site specific detection strategies coupled with a very good understanding of natural carbonate system variability.
- Monitoring may well require more complex detection algorithms based on co-variance relationships (e.g. DIC – O_2 – N) as well as detection based on sound.

Work continues in the EU within the STEMM-CCS project:

- Characterisation of biogeochemical baseline at Goldeneye
- Controlled deeper ~100m CO_2 release
- Development of sensors, platforms, monitoring strategies

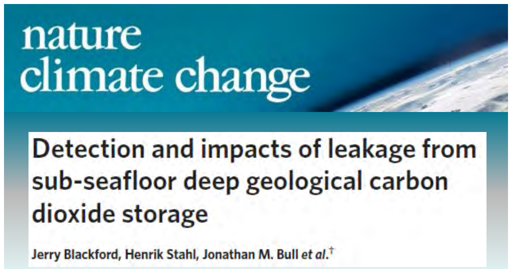


STEMM-CCS

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

Outputs

www.qics.co.uk

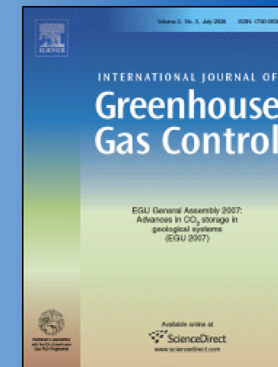


Factsheets
Brochure

Special issue

21 research papers

July 2015



- Blackford et al ***Nature Climate Change*** 4, 1011-1016. DOI:10.1038/NCLIMATE2381
- ***International Journal of Greenhouse Gas Control*, 38**, 2015. Special Issue

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Funders	Research Councils UK; NERC Science of the Environment; The Scottish Government; METI 経済産業省 Ministry of Economy, Trade and Industry
UK Participants	PML Plymouth Marine Laboratory; SAMS; National Oceanography Centre, Natural Environment Research Council; Heriot Watt University; British Geological Survey, Natural Environment Research Council; University of Southampton; The University of Edinburgh
Japanese Participants	RITE Research Institute of Innovative Technology for the Earth; 東京大学 The University of Tokyo; I²CNER Kyushu University; CRIEPI; KANSOテクノス; National Institute of Advanced Industrial Science and Technology AIST; JANUS


Crab defending bubble stream

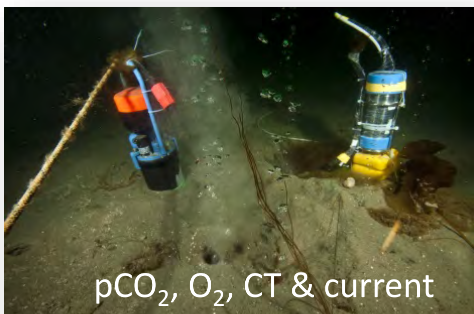
Diving surveys & sampling: >260 individual dives

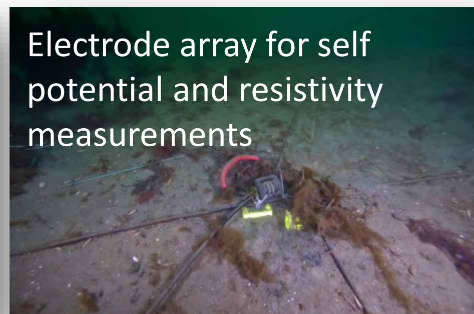

>650 individual cores collected

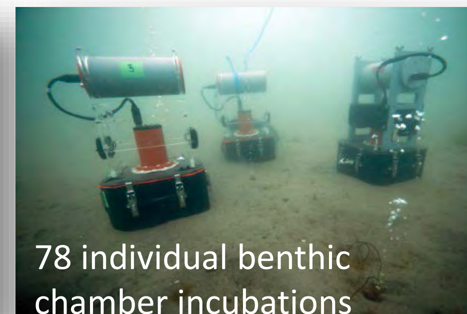

>300 water samples taken


24 mussel cages deployed

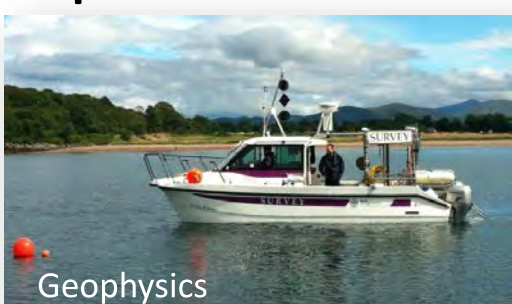
In situ sensors & measurements

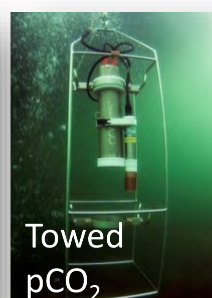

pCO_2, O_2, CT & current

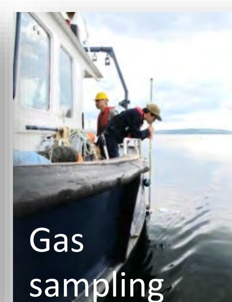

Electrode array for self potential and resistivity measurements


78 individual benthic chamber incubations

Ship-board measurements


Geophysics


Towed pCO_2


Gas sampling


AUV sampling

Shallow seismics (sediment gas)

Sonar (water column gas)

Passive acoustics (listening for bubbles)

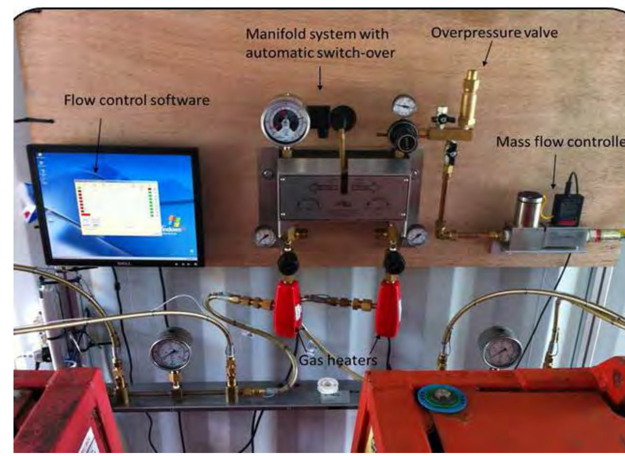
Chemical (pH, carbonate system, isotopes)

Biological sampling


Drilling rig


Terminal diffuser


Double door container with CO2 gas + injection system
Telehandler for changing gas pallets


Manifold system with automatic switch-over
Overpressure valve
Flow control software
Mass flow controller
Gas heaters


Wash pit


allenwatson.com