The use of passive acoustics for monitoring CCS facilities

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Outline

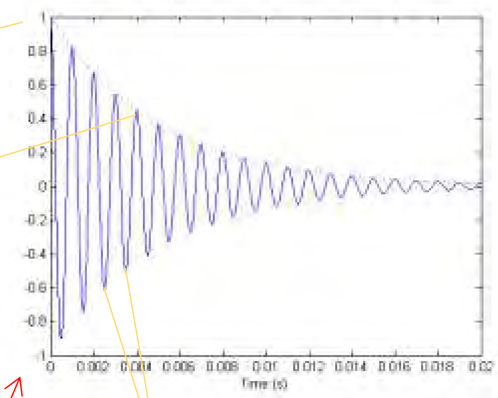
- Motivation
- Detection of a leak
- Quantification
- Tank-based experiment
- Results from QICs

Motivation

- Gas leaks generate bubbles in water
- As a bubble forms it oscillates and efficiently radiates sound.
- The sound emitted is at a frequency which depends on the bubble's size (radius)
  - Small bubbles radiate high frequencies
  - Large bubbles radiate low frequencies
- Questions:
  - Can one detect leaks using passive acoustics?
  - Can one use passive acoustics to quantify leaks?

Model of bubble emission

- If a bubble is formed at t=0, its radius will vary with time, $R(t)$, according to the following:



Initial bubble displacement

Damping coefficient, depends on several factors.

Equilibrium radius

Frequency of oscillation, which directly relates to the bubble size

$$R(t) = R_0 - R_\varepsilon e^{-\alpha t} \cos(2\pi f_0 t)$$

Key assumption

- The initial radius R_ε is a key parameter
  - It controls how loud the sound from each bubble is.
- This parameter is believed to scale with the bubble equilibrium radius, i.e.

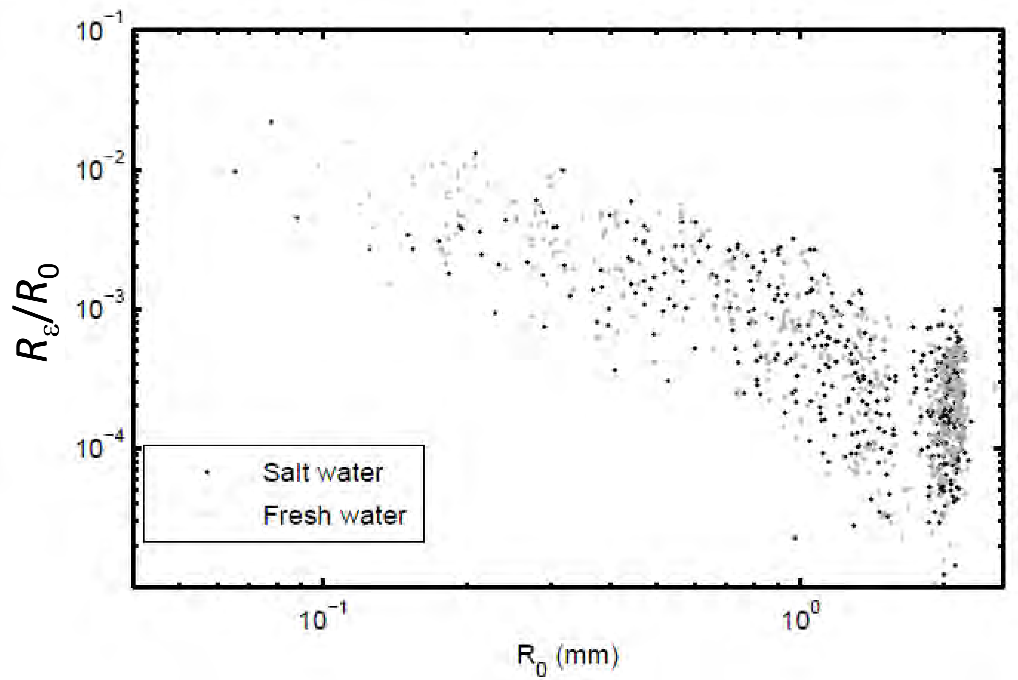
$$R_\varepsilon = R_{\varepsilon 0} R_0$$

Scale factor

- This scale factor is evaluated through experimental results.

Computing $R_{\varepsilon 0}$

- Experimental data obtained by [1].



- 75^{th} and 25^{th} percentiles of the data are used

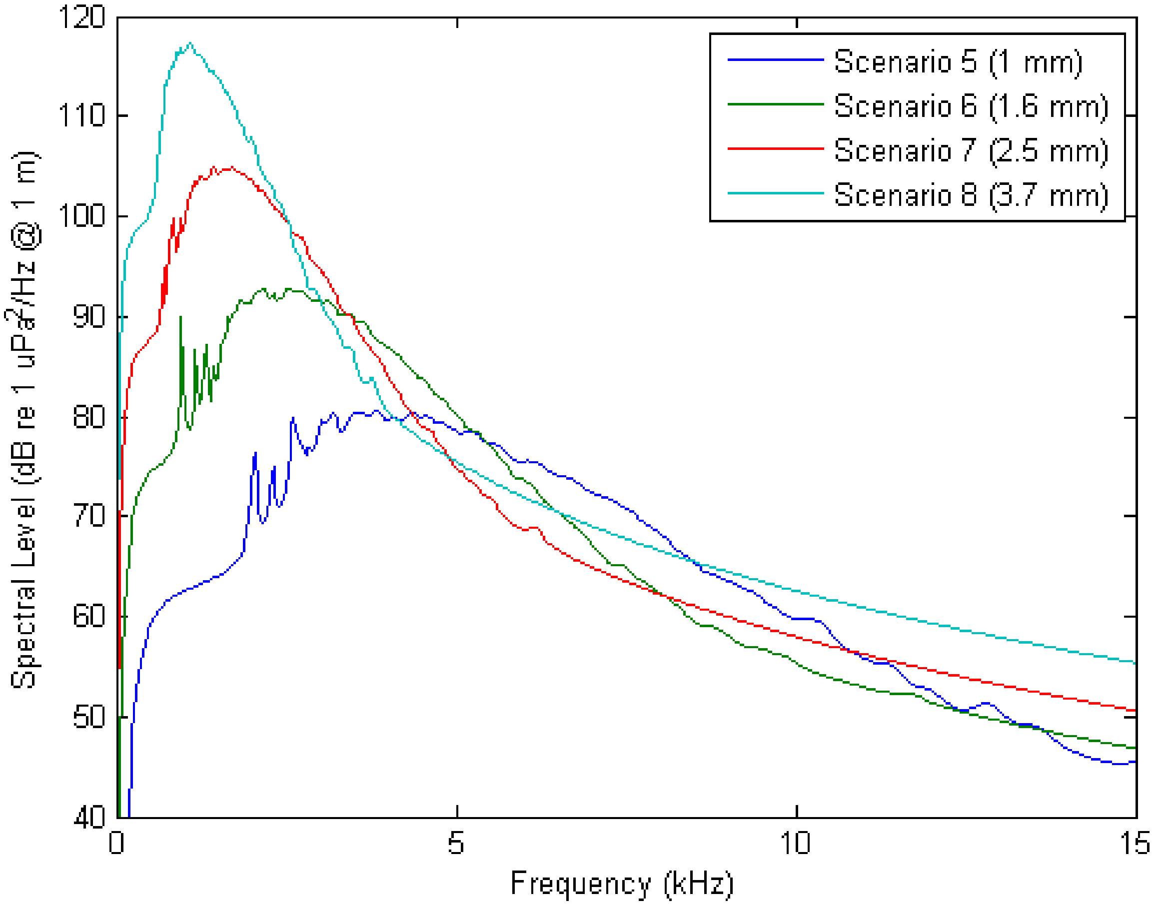
- [1] Deane, G. B., and Stokes, M. D. (**2008**). "The acoustic excitation of air bubbles fragmenting in sheared flow," J. Acoust. Soc. Am., **124**, 3450–3463. doi:10.1121/1.3003076

Detection

- How far away can one detect a leak?
- This depends on many factors:
  - Size of the leak.
    - Large leaks, more bubbles, more noise, easier to detect.
  - Bubble sizes generated by the leak.
  - The sensing system being used.
    - A directional system, e.g. an array, allows detection at greater ranges.
    - Listening for greater periods increases detection ranges
  - Ambient noise level.
    - If the background noise is louder then it is harder to detect a leak.

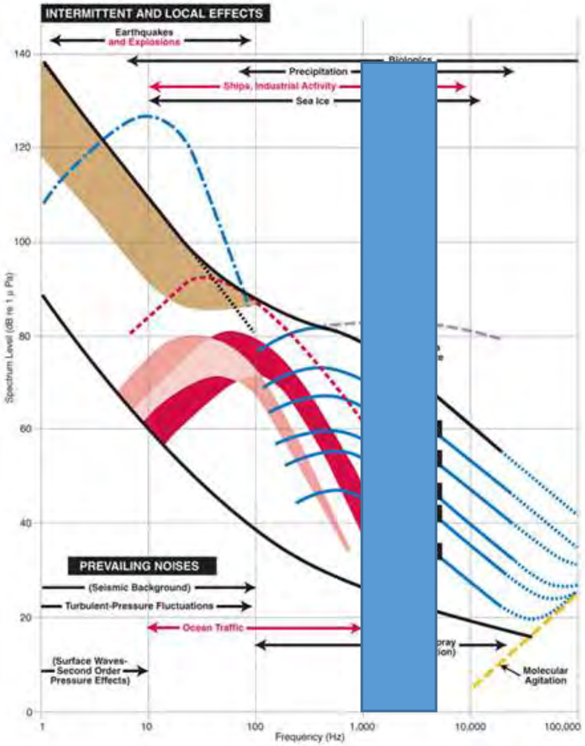
Sound from leaks

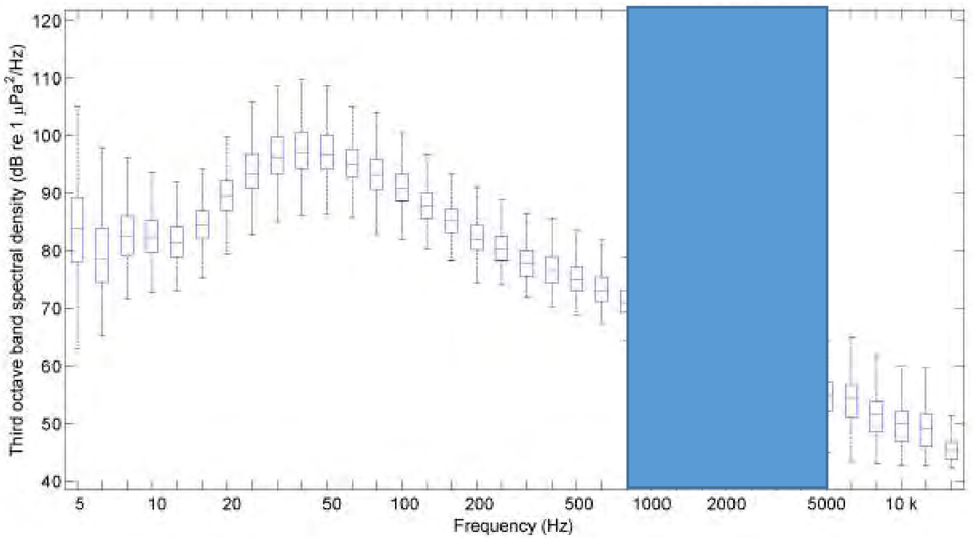
- Predicted power spectra @ 1 m from 4 leaks of CO_2 of 1, 10, 100, 1000 L/min all at 20 m depth, 20° C.



Ambient noise

- Ambient noise in deep water is well characterised.
- In shallow water there is much more variability (both spatially and temporally).





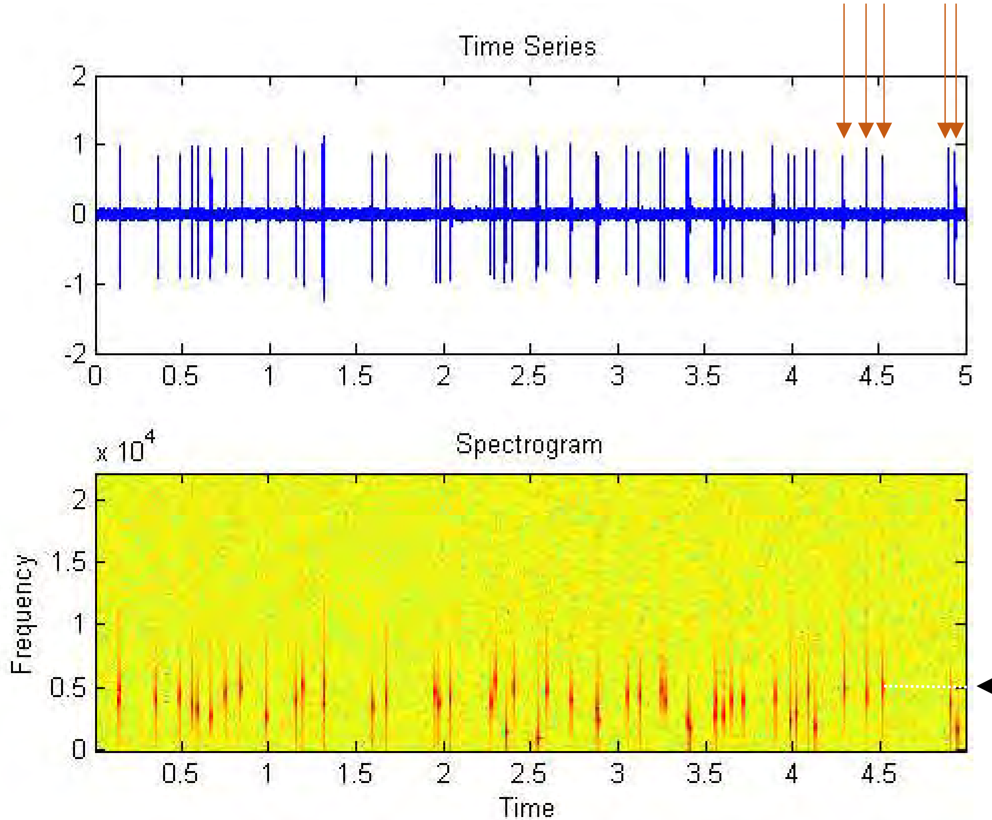
So how far away can you detect a leak?

- With 1 hydrophone, listening for 1 s, you can detect a leaks of 10 L/min at ranges of 1-5 m
- With an array of hydrophones (say 10), one can increase this to in excess of 10-20 m.
- By listening for greater periods of time one can (in theory) increase this to arbitrarily large distance! Realistically 100 m is not unrealistic.

Quantification: Low Flow Rates

- If the gas is leaking slowly then one can detect the sound of individual bubbles: allowing one to count and size them individually.

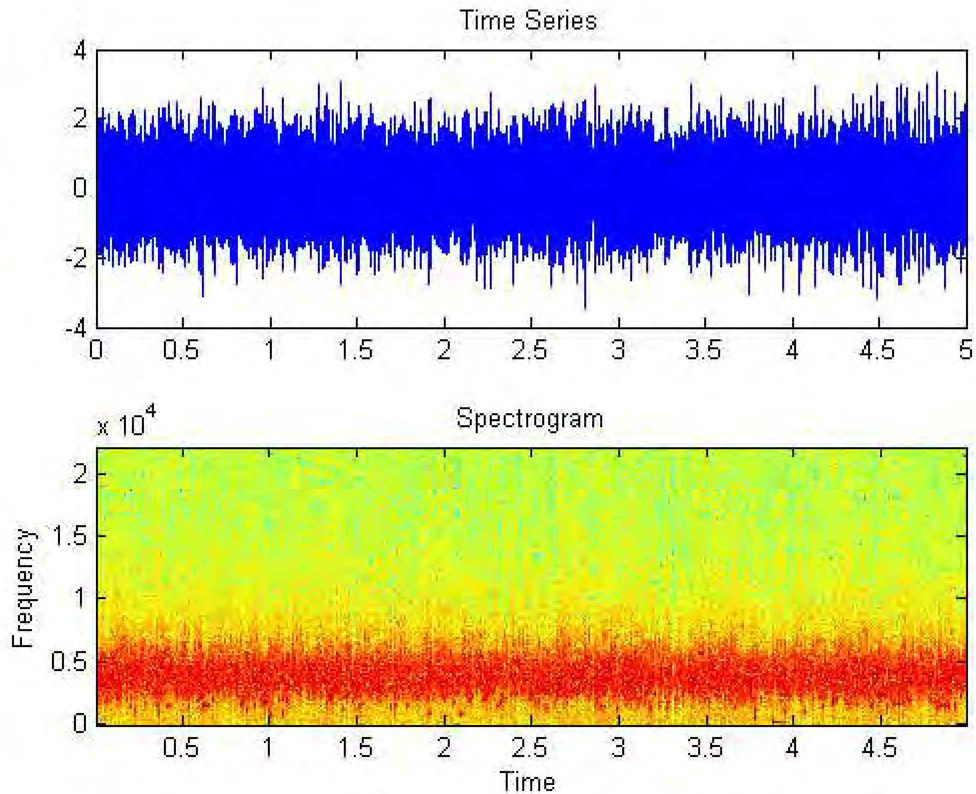
Detecting/counting bubbles



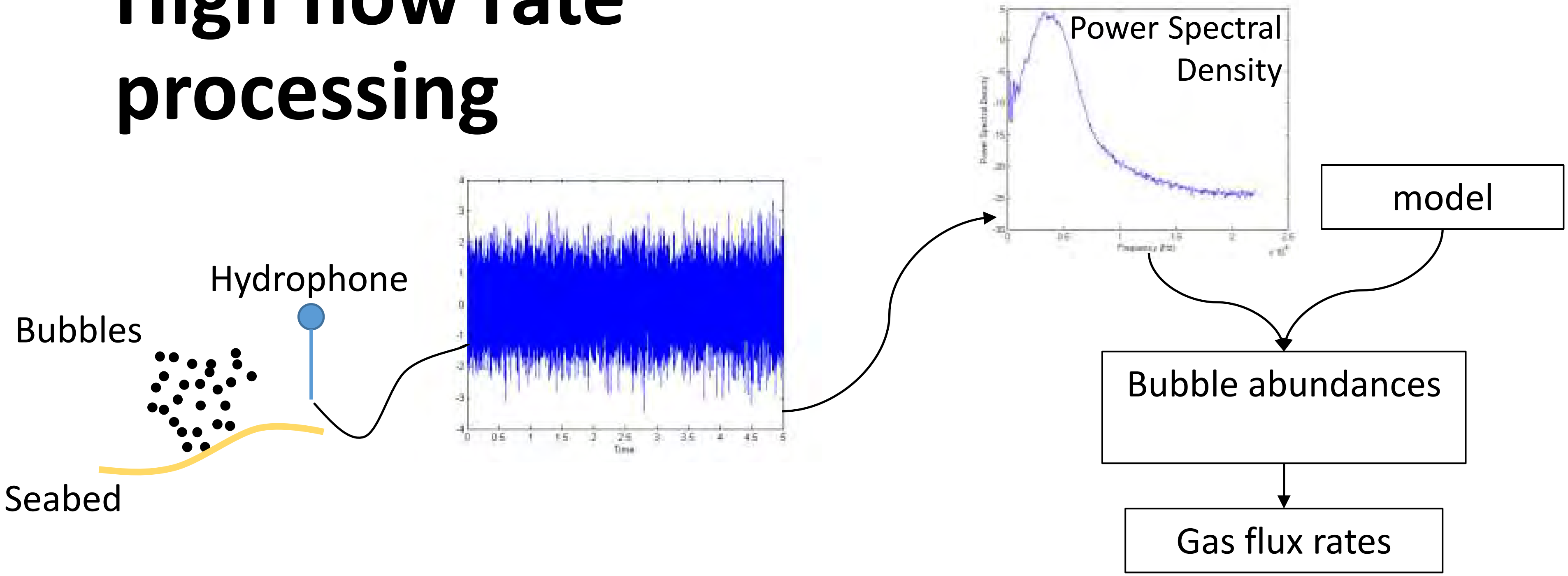
Centre frequency tells one the bubble size (radius, r).
Can compute gas volume as $4\pi r^3/3$.

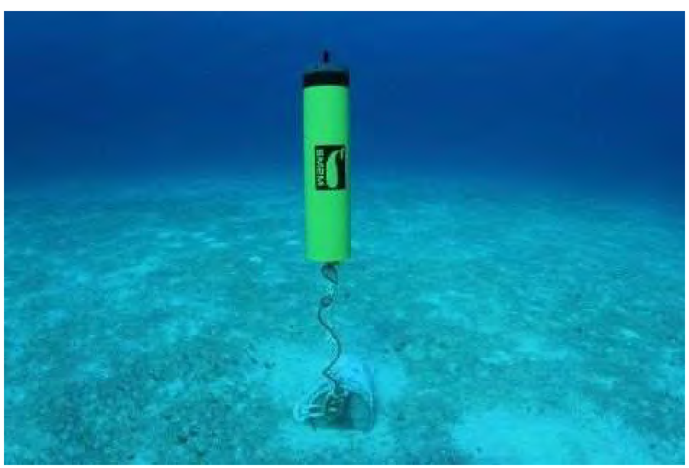
Quantification: High Flow Rates

- When many bubbles are generated, bubble signatures overlap and individual bubbles can’t be counted.



High flow rate processing

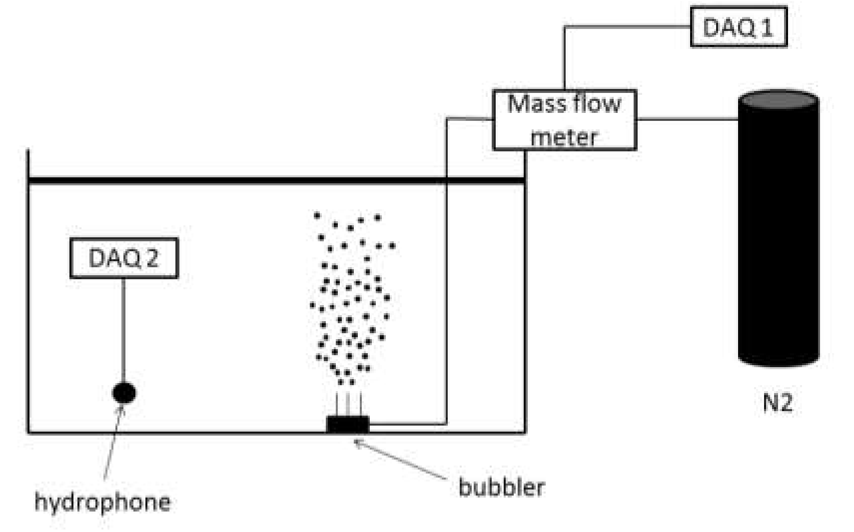


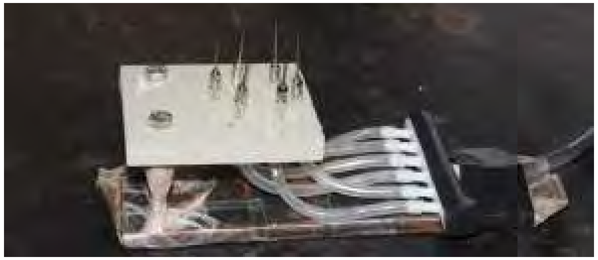


- Easy to implement
- Cost effective
- Long term and real time monitoring
- Low power

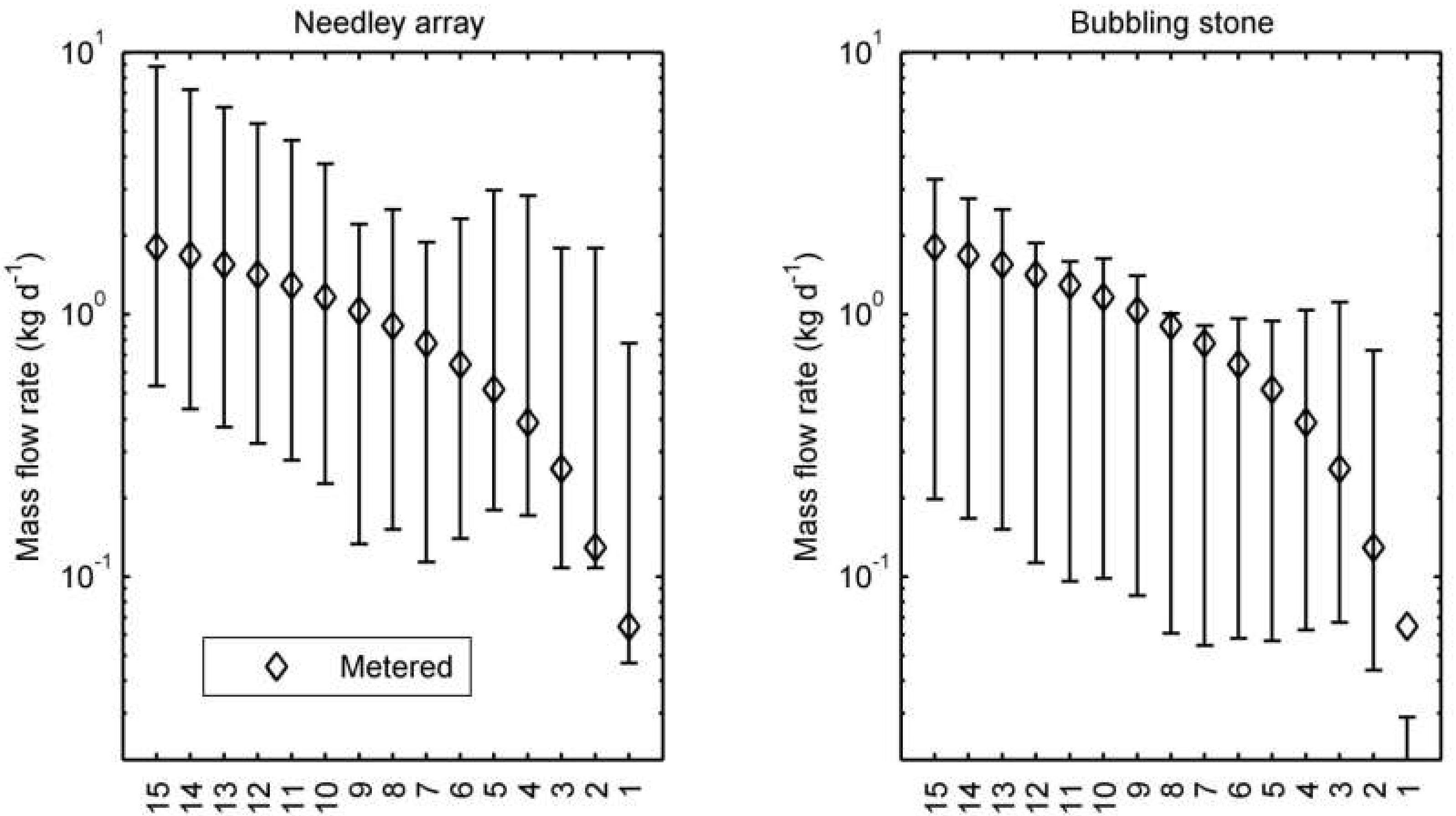
Tank-based Experiment

- Experimental settings:
  - Bubble plumes generated in a water tank (8 m x 8 m x 5 m)
    - A bubbling stone
    - An arrangement of needles
- Measurements in the direct field

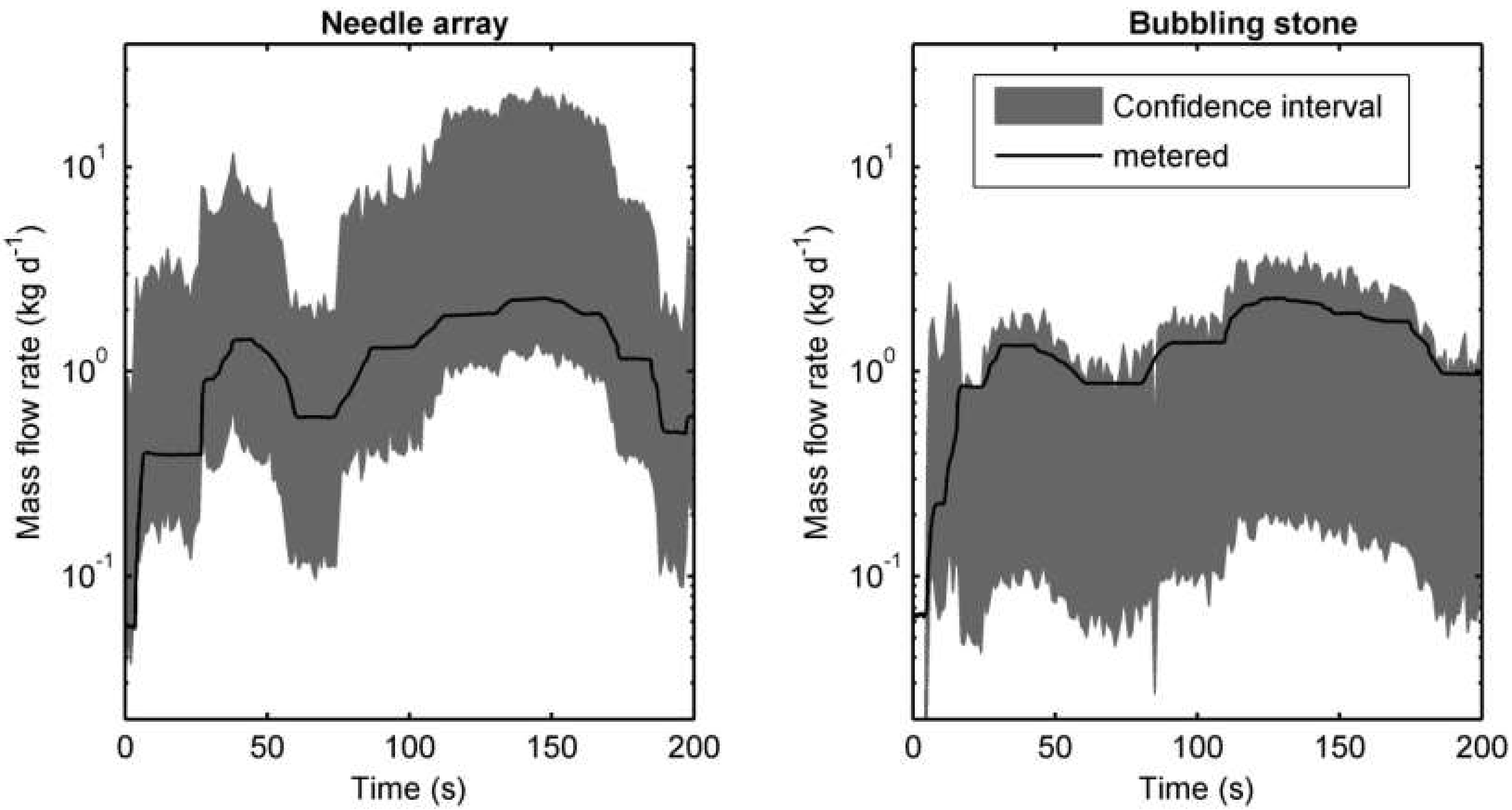




Results for a fixed flux rate



Results for a varying flux rate



QICs experiment

QICS

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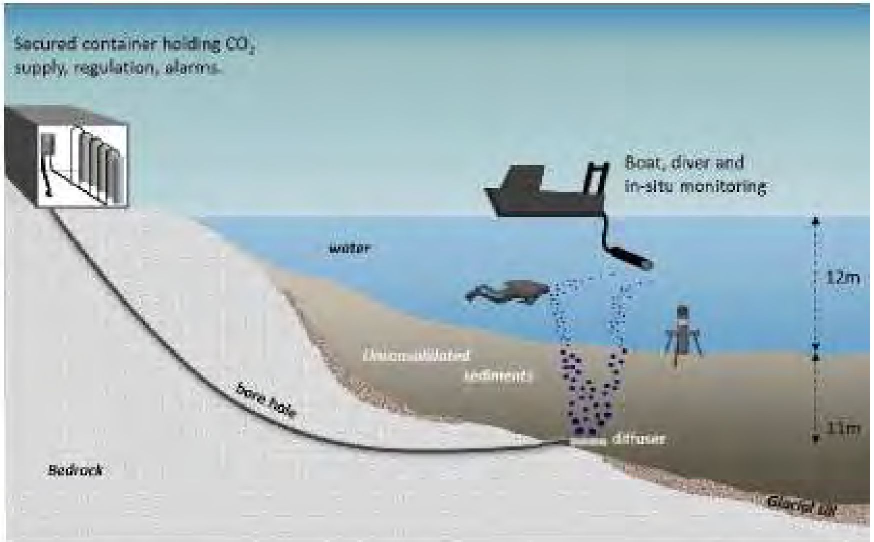
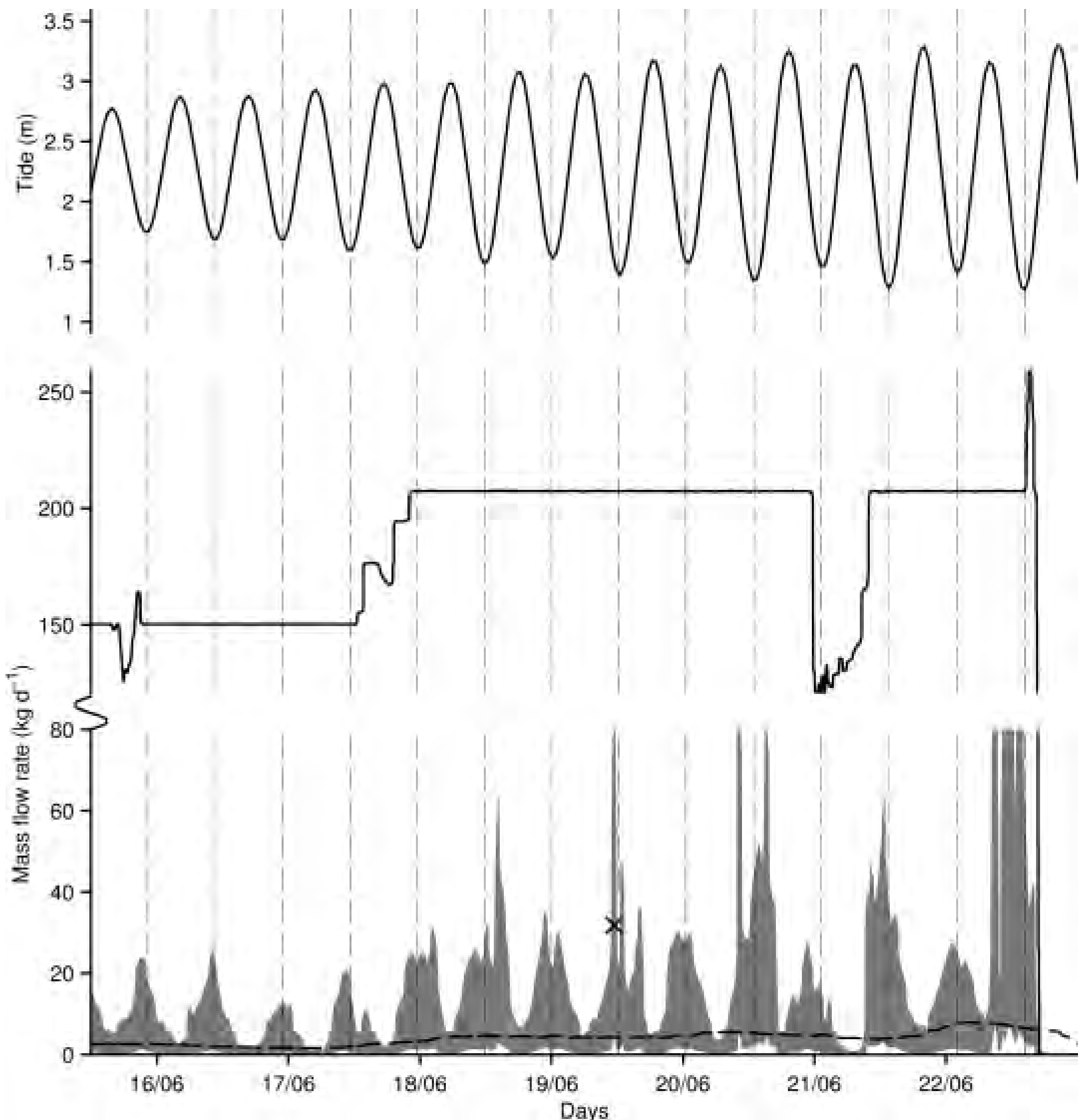


At sea experiment



Conclusion

- Passive acoustics offers a suitable technique for long-term monitoring.
- It can detect leaks at modest ranges, probably significantly less than active acoustic methods.
- It provides a technique which can quantify leaks.

The end