DETECTION, LOCALIZATION AND QUANTIFICATION OF THE EMISSIONS OF GAS FROM THE SEABED IN FIELDWORK AND EXPERIMENTAL STUDIES USING ACTIVE SONAR SYSTEMS

M. Tomczyk University of Bremen, Marum, Bremen, Germany (mtomczyk@marum.de)
G.Bohrmann University of Bremen, Marum, Bremen, Germany
B.J.P. Bergès Institute of Sound and Vibration Research, University of Southampton, UK
P.R. White Institute of Sound and Vibration Research, University of Southampton, UK
T. G. Leighton Institute of Sound and Vibration Research, University of Southampton, UK
I.C. Wright National Oceanography Center, Southampton, United Kingdom

1 INTRODUCTION

The global reserve of methane in the form of hydrate has been estimated to be more than twice the worldwide amount of carbon to be found in all known conventional fossil fuels on Earth [1,2]. The formation of gaseous methane from such hydrate, as with all underwater methane gas seepage, may play an important role in a significant increase of atmospheric methane (CH_4). The ability to generate 'greenhouse' warming per molecule of methane gas is at least 20 times that of each CO_2 molecule [2,3], and any assessment of marine gas reserves should also factor in the potential contribution from hydrate dissociation, which will be promoted through warming associated with climate change [2,4]. There is a need for a method by which gas bubbles emanating from the seabed can be accurately quantified. Hydroacoustic methods are candidates to be the most sensitive and reliable way to remotely determine bubble fluxes over a large area. This paper presents preliminary results from two cruises undertaken in 2011 to collect active sonar data from natural gas seeps.

2 METHOD

During two cruises in 2011 a combination of several techniques was evaluated against the task of detecting, localizing, and quantifying gas emissions from natural cold seeps. Figure 1 shows the location of the seeps examined during the Arctic cruise to the western Svalbard shelf and slope. The cruises included a detailed hydroacoustic survey of investigated areas and data analysis with the use of specialized software (e.g. Fledermaus, Arc Map). Acoustic data were collected using different echosounders: two multibeam systems EM122 and EM710, a multifrequency echosounder EK60, and a parametric narrow-beam Parasound echosounder. Detailed location maps of gas seeps, and 3D visualization models showing the registered flares were obtained. These data are given in section 3.

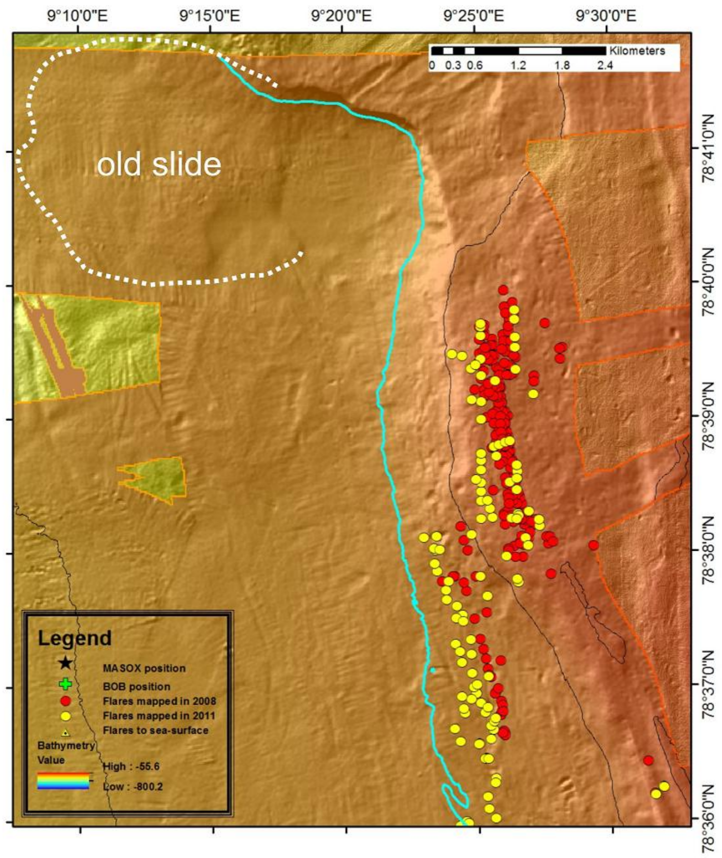


Figure 1: Distribution of some plumes along the western Svalbard shelf and slope. Flares have been mapped using EK 60 Simrad 38 kHz (Kongsberg). Two data-sets from different years allows to investigation the spatial and temporal variability of gas emission in the region. The magenta line indicates the gas hydrate stability zone (GHSZ). Most of the observed flares occur above the GHSZ.

A laboratory investigation using a multi-frequency active sonar (Imaginex 881A) and a self-constructed bubble-making system was carried out, in order to establish a method for quantification of the gas emission. Figure 2 and 3 show the laboratory experiment. The bubble injection system has a full-control on flow rate and is capable of producing a range of bubble sizes. Ideally the bubble sizes and void fractions produced in the tank would resemble those encountered at sea. Whilst there is extensive knowledge of the bubble size distributions produced at sea by breaking waves [5-9], there are far less data on the bubble size distribution produced by cold seeps [2,10,11]. For this study therefore an injection system was used, which tends to produce bubbles on the larger end of the spectrum seen in wave-breaking conditions [5-9], but is not dissimilar to the sparse data available for seeps [2,10,11]. It is however important to note that, since those data were obtained by photographic and video imaging, there will be some lower limit of bubble size such that smaller bubbles will be difficult to detect by photography (although the addition of stroboscopic lighting has the potential to extend the detectable range of bubble sizes significantly [2,12]).

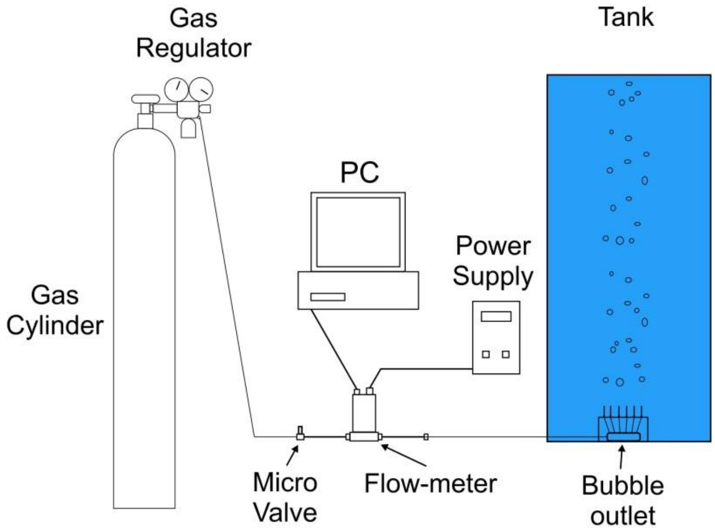


Figure 2: An experimental setup of the gas bubble making-system.

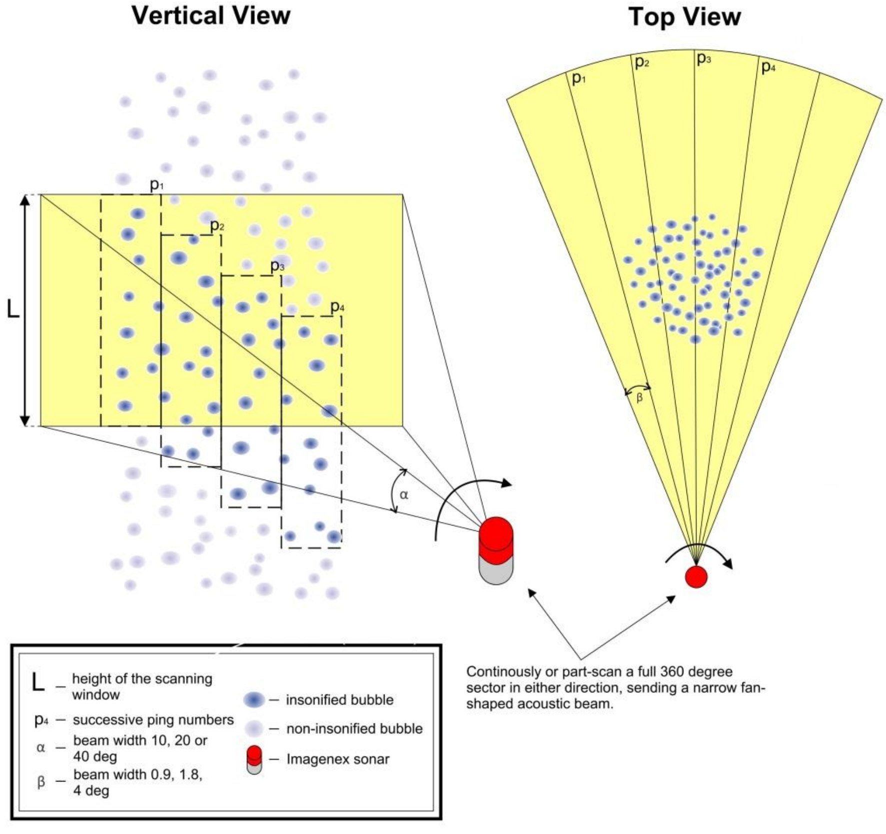


Figure 3: The sketch shows the operation procedure for forward-looking sonar. The Imagenex 881a sonar-head has a rotating system providing the capability to obtain a full 360 degree sector scanning. The sonar measures the scatter intensities from objects by sending a narrow fan-shaped acoustic beam.

The eventual aims of these experiments are also to provide bubble size distribution data from the backscatter of the active sonar. Provided the sonar covers an appropriately wide range of frequencies, this can be done if the absolute intensity of the signal emitted by the sonar is known, and the absolute intensity of the echo from the cloud (if the absolute levels are not known, but the ratio is, then an estimate can still be made) by consideration of the acoustic scattering cross-section of the bubbles in the cloud [13,14]). The first stage of this process is therefore the absolute calibration of the active sonar. These data are given in section 4.

3 RESULTS OF FIELD DATA

The cruise to the Black Sea (R/V Meteor cruise M84/2) conducted an acoustic investigation of gas bubble emission from the seafloor at a deep submarine cold seep site. The Parasound echosounder DS-3/P70 (Atlas Hydrographic) was used for ship-borne flare imaging in the water column (Figure 4). In addition, multibeam EM 122 and EM 710 were used to identify the location of gas emissions (the exact locations of the flares were extracted manually). Furthermore, subbotom profiles allowed the correlation of free gas migration through sediment with high-backscatter features in the water column (Figure 4). The direct measurements of gas bubble emissions conducted from remotely operated vehicle (ROV) were conducted for further comparison with hydroacoustic technique. Post-processing of the data was conducted using the Fledermaus software and Matlab. The location of bubble releasing seeps was identified by picking the position of flare-shaped backscatter signals in echograms, which are caused by bubbles in the water column.

When examining such images as Figure 4, it is important to bear in mind that there is a sound speed/distance ambiguity, in that the range of a scatterer from the active sonar is inferred from time of flight. That inference uses an assumed sound speed (or in the more sophisticated cases, sound speed profile). Bubbles can cause strong perturbations in sound speed, an undetected reduction in sound speed causing an overestimation of the range to the features, and an undetected increase causing an underestimation of the range. It is important therefore that features such as bathymetry and the position of scattering layers in the seabed, be ground truthed separated to avoid bubble-induced sound speed perturbations to be interpreted as ‘dips’ and ‘mounds’ that do not exist in reality. Indeed, if the actual position of the scattering features is independently (i.e. non-acoustically) verified, then such sound speed perturbations can be used to estimate the void fractions of bubbles present [15] provided that the individual bubble behavior is appropriately included in the model (e.g. with inclusion of the effect of sediment if the bubble is within the seabed [16]).

The arctic cruise to the western Svalbard shelf and slope during the summer of 2011 aimed to collect data on the temporal variability of gas emission from the site discovered in 2008 [4]. Westbrook et al. [4] suggested that gas hydrate deposits may destabilize and release gas bubbles from the seafloor due to bottom water warming, as was recently observed west of Svalbard. Good quality data were recorded during calm sea conditions, when the ship was at anchor above the seepages. A new gas bubble emission site was observed in shallower water at a depth of approximately 80 meters. There, gas bubbles are reaching the surface as shown by echo-sounder data. Further investigation is needed in order to estimate the gas emission flux from the seabed to the water column and subsequently from the water column to the atmosphere.

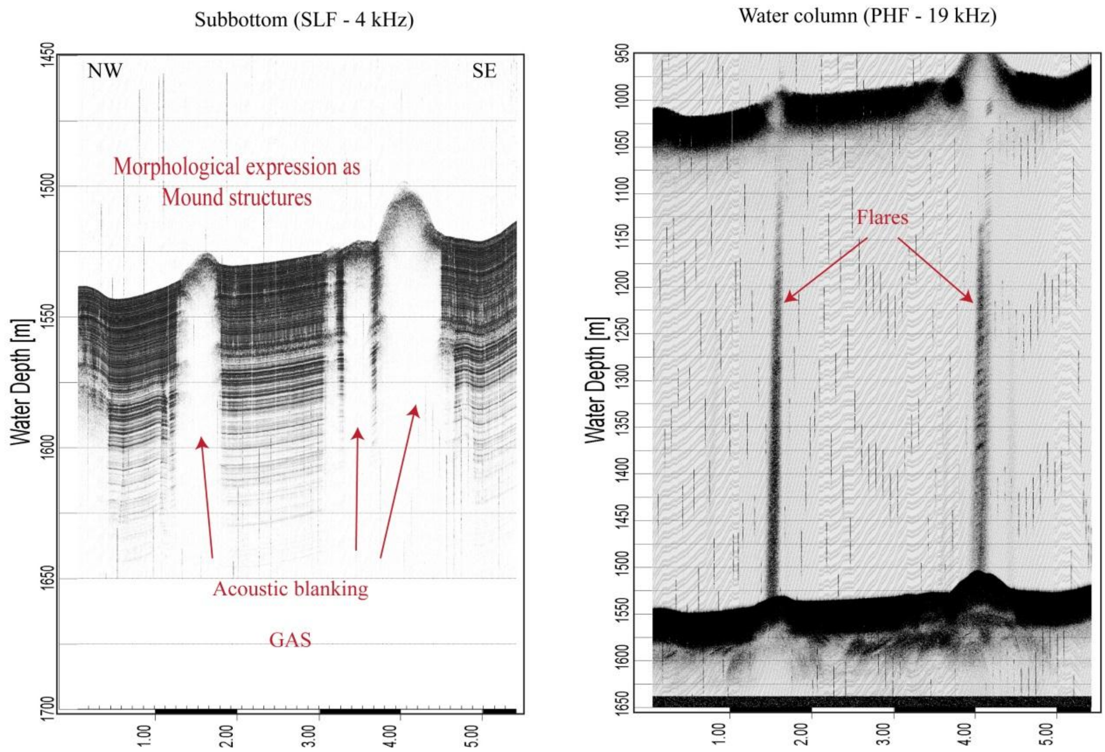


Figure 4: Three distinct zones of columnar blanking have been located beneath gas flares in the water column, which were documented with the Parasound 18 kHz signal (M. Romer, unpublished data, Meteor M84/2 expedition, 2011).

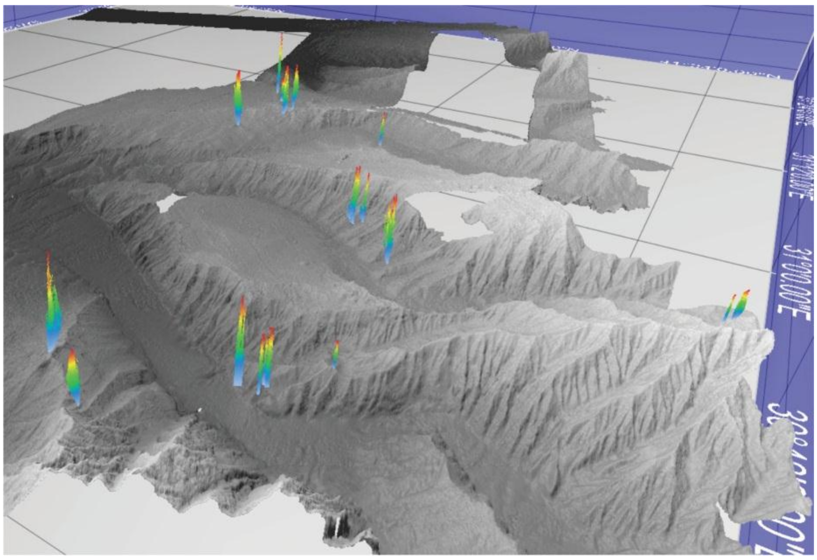
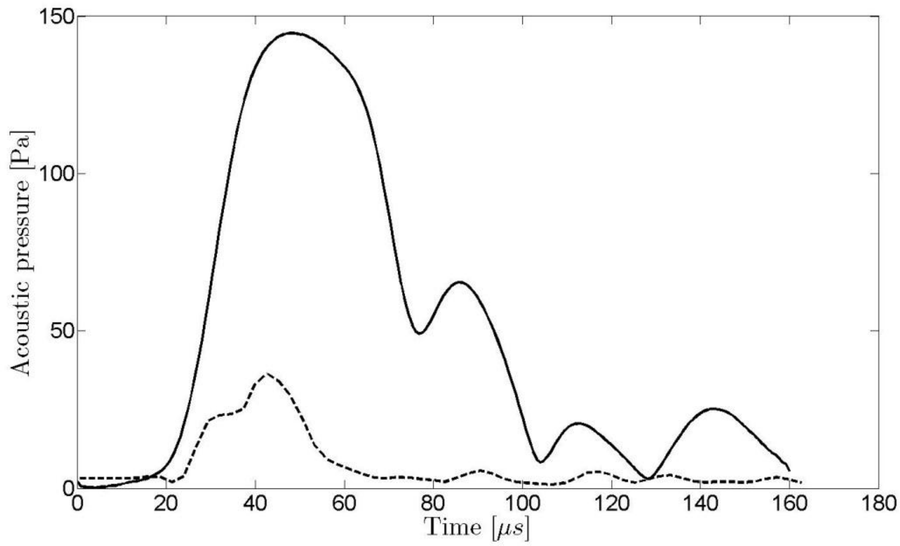


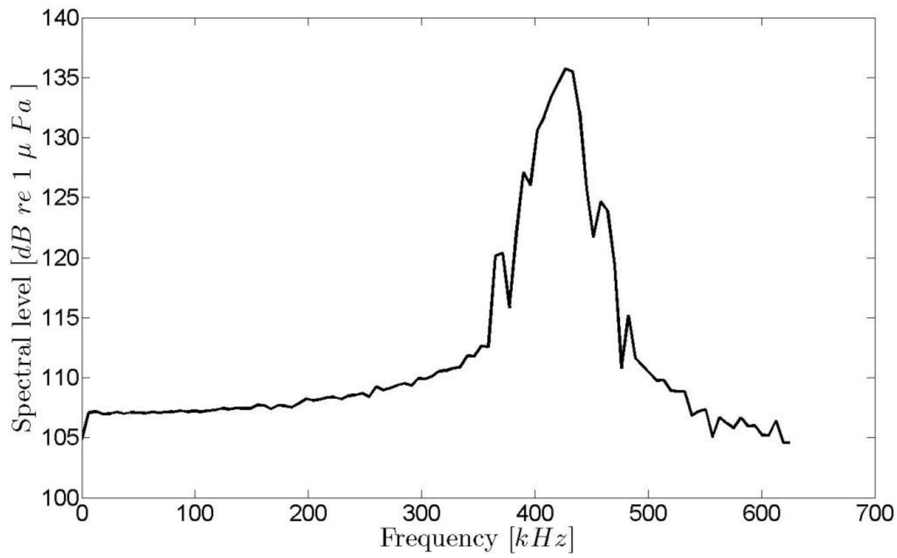
Figure 5: Multibeam data presentation from the Black Sea. Multibeam echosounder allows to detect acoustic backscatter from gas seeps (column-like features so-called flares, color code by flare height) over large swaths of the ocean floor.

4 PRELIMINARY RESULTS FOR CALIBRATION OF SONAR

The Imagenex 881a device is a digital multifrequency imaging SONAR. As exemplified by the schematic presented in figure 3, it is a rotating system that is aimed to scan bubble plumes in order to obtain their echo levels at different frequencies. The emission frequencies range from 280 kHz to 1.1 MHz in 5 kHz steps. The SONAR head contains a processing unit that gives relative echo levels as outputs. In order to obtain absolute backscattering volumes (as is needed to quantify the gas flux), it is paramount to calibrate the digital output of the system at each frequency. To this purpose, measures were undertaken in a test tank with a high frequency calibrated hydrophone (Reson TC4038) and standard targets: tungsten carbine spheres of 38.1 mm and 50 mm diameter. The data are currently being processed and figure 6 exhibits preliminary results of this calibration at 425 kHz. This shows the spectrum of the signal recorded by the hydrophone with a peak at 425 kHz and the comparison of signal envelopes from the scattering of the 38.1mm sphere acquired by the calibrated hydrophone and the Imaginex 81a.



a)



b)

Figure 6: preliminary results for the calibration of the Imaginex 81a system. The top figure a) shows signal envelopes from the scattering of the 38.1mm sphere insonified at 425 kHz. The solid line is the signal captured by the hydrophone in Pa and the dashed line represents the output from the

Imaginex 81a in a relative acoustic pressure unit. The bottom figure b) is the signal spectrum from the hydrophone, exhibiting a peak at 425 kHz.

5 CONCLUSION

This paper reports on methane seepage hydroacoustic data collected during two cruises in 2011, in the Black sea and in West Spitsbergen continental margin region. Both areas exhibit strong bubble plume activity that were mapped using multibeam and single beam echosounders along with sub bottom profilers. Another part of this study is to quantify those gas releases from active acoustic data using an Imaginex 81a system (multifrequency imaging SONAR). To this purpose, measurements in a test tank were performed in order to calibrate this device. The data are currently being processed and some preliminary results are presented.

ACKNOWLEDGEMENTS

The studentship of Mr. Tomczyk is sponsored by the SENSEnet project within an EU Framework 7 funded Marie Curie Initial Training Network. The studentship of Mr. Berges is sponsored by Statoil Ltd.

REFERENCES

1. Dillon, W. Gas (methane) hydrates: a new frontier. US Geological Survey, Marine and Coastal Geology Program Fact Sheet, OCLC No.: ocm40490917. 1995 Coastal and Marine Geology Program (Geological Survey), US Geological Survey, US Department of the Interior, Woods Hole, MA.
2. Leighton, T.G. and White, P.R. Quantification of undersea gas leaks from carbon capture and storage facilities, from pipelines and from methane seeps, by their acoustic emissions. Proc. R. Soc. A, 2012. **468**: p. 485-510.
3. Khalil, M. A. K. & Rasmussen, R. A. The changing composition of the Earth's atmosphere. In Composition, chemistry, and climate of the atmosphere (ed. H. B. Singh), 1995, p. 50–97. New York, NY: Van Nostrand Reinhold.
4. Westbrook, G. K. et al. Escape of methane gas from the seabed along the West Spitsbergen continental margin. Geo. Res. Lett. 2009. **36**: L15608.
5. Leighton, T.G., D.C. Finfer, P.R. White, G.H. Chua, and J.K. Dix, Clutter suppression and classification using twin inverted pulse sonar (TWIPS). Proc. R. Soc. A, 2010. **466**: p. 3453-3478.
6. Leighton, T. G., Meers, S. D. and White, P. R. Propagation through nonlinear time-dependent bubble clouds and the estimation of bubble populations from measured acoustic characteristics. Proc. R. Soc. Lond. A 2004. **460**: p. 2521–2550.
7. Breitz, N. D. & Medwin, H. Instrumentation for in situ acoustical measurements of bubble spectra under breaking waves. J. Acoust. Soc. Amer. 1989. **86**: p. 739–743.
8. Deane, G. B. & Stokes, M. D. Air entrainment processes and bubble size distributions in the surf zone. J. Phys. Oceanogr. 1999. **29**: p. 1393–1403
9. Farmer, D. M. & Vagle, S. Waveguide propagation of ambient sound in the ocean-surface bubble layer. J. Acoust. Soc. Am. 1989. **86**: p. 1897–1908.
10. Leifer, I. & Culling, D. Formation of seep bubble plumes in the coal oil point seep field. Geo-Mar. Lett. 2010. **30**: p. 339–353.
11. Sauter, E. J., Muyakshin, S. I., Charlou, J.-L., Schlüter, M., Boetius, A., Jerosch, K., Damm, E., Foucher, J.-P. & Klages, M. 2006 Methane discharge from a deep-sea submarine mud volcano into the upper water column by gas hydrate-coated methane bubbles. Earth Planet. Sci. Lett. 2010. **243**: p. 354–365. (doi:10.1016/j.epsl.2006.01.041)
12. Leighton, T. G., Baik, K. and Jiang, J. The use of acoustic inversion to estimate the bubble size distribution in pipelines. Proc. R. Soc. Lond. A 2012. (Published online April 2012) doi:10.1098/rspa.2012.0053

13. Ainslie, M.A. and Leighton, T.G. Review of theory for scattering and extinction cross-sections, damping factors and resonance frequencies of spherical gas bubbles, J. Acoust. Soc. Am., 2011. **130**(5): p. 3184-3208
14. Ainslie, M.A. and Leighton, T.G. Near resonant bubble acoustic cross-section corrections, including examples from oceanography, volcanology, and biomedical ultrasound, J. Acoust. Soc. Am., 2009. **126**(5): p. 2163-2175.
15. Leighton, T.G. and Robb, G.B.N. *Preliminary mapping of void fractions and sound speeds in gassy marine sediments from subbottom profiles.* J. Acoust. Soc. Am 2008. 124(5): p. EL313-EL320.
16. Leighton, T.G., *Theory for acoustic propagation in marine sediment containing gas bubbles which may pulsate in a non-stationary nonlinear manner*, Geophysical Research Letters, 2007. **34**: L17607.