The Prodigal Bubble - Celebrating the Return of the Bubble to a Recirculating Suspended Sediment Tower

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Abstract

The measurement and processing of high frequency acoustic backscatter profiles at multiple frequencies is an established technique for measuring suspended sediment load and equivalent mean particle size through the water column. The technique relies on the fact that the intensity of sound scattered by suspended particles is related not only to the particle size, but also the incident acoustic frequency. It is exploited by compact instruments that are deployed on seabed frames, vessels, and in laboratory flumes. However, one of the most significant influences on measurement accuracy comes from the presence of bubbles in the water column. Often found in suspended sediment study areas such as shallow wave-affected waters or highly turbulent flows, they can be of comparable acoustic cross-section to the suspended sediment particles and may dominate backscatter. Acoustic backscatter instrument calibrations and experimental measurements are typically carried out in a recirculating suspended sediment tower where, through careful design, a near homogeneous suspension can be established. Great attention is paid to the choice of fittings and recirculating pumps to ensure that no air is introduced into the flowing liquid, and lengthy periods of degassing are necessary to ensure no bubbles remain before measurements are taken. To tackle the problem of sediment backscatter signal contamination, a new research project is investigating how to detect and quantify bubbles present in sediment suspensions, with the aim of decomposing the backscatter signal into its sediment and bubble components. The first step in evaluating new acoustic techniques is to welcome back the bubble to the sediment tower from its long exile so it can become the focus of observations. The paper describes the recirculating suspended sediment tower and the newly introduced bubble generation and observation apparatus, which is being used to generate and observe controlled bubble populations. Bubble detection and measurement techniques are described, and initial results using a commercial acoustic backscatter profiler are presented.

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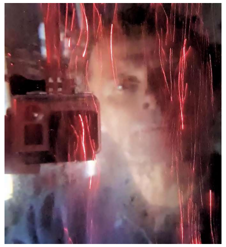


PRESENTED AT:

MOTIVATION

Measurement and analysis of acoustic backscatter intensity from particle suspensions is an established technique to characterize suspended material. Multiple incident frequencies can provide sufficient information to estimate profiles of mean particle size and mass concentration (Thorne and Hanes, 2002), but bubbles frustrate accurate inversion.

We want to improve the measurement capabilities of a commercial multi-frequency acoustic backscatter profiler, the AQUAscat®. One of the most significant impacts on acoustic backscatter inversion comes from the presence of bubbles. Often found in typical suspended sediment environments such as under wave-affected conditions, bubbles can be of a comparable acoustic cross-section to the suspended sediment particles and may dominate backscatter, leading to substantial interpretation errors (Vergne et al., 2020). Methods to detect, quantify, and mitigate for the bubble content of a suspension are essential to increase the practicality of the technique for a wide range of applications.

Such improvements will benefit applications in science and industry, including observation of fundamental oceanographic processes, monitoring of coastal and civil engineering operations, and analysis of industrial processes.

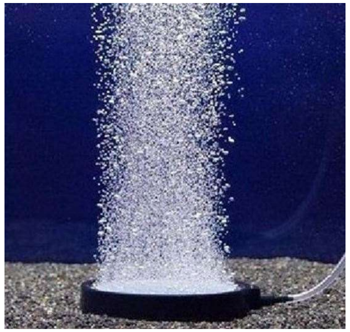
The acoustic backscatter community has spent years trying to remove bubbles from their test tanks. Now it's time to welcome the bubble back to our sediment tower to find out more about it.

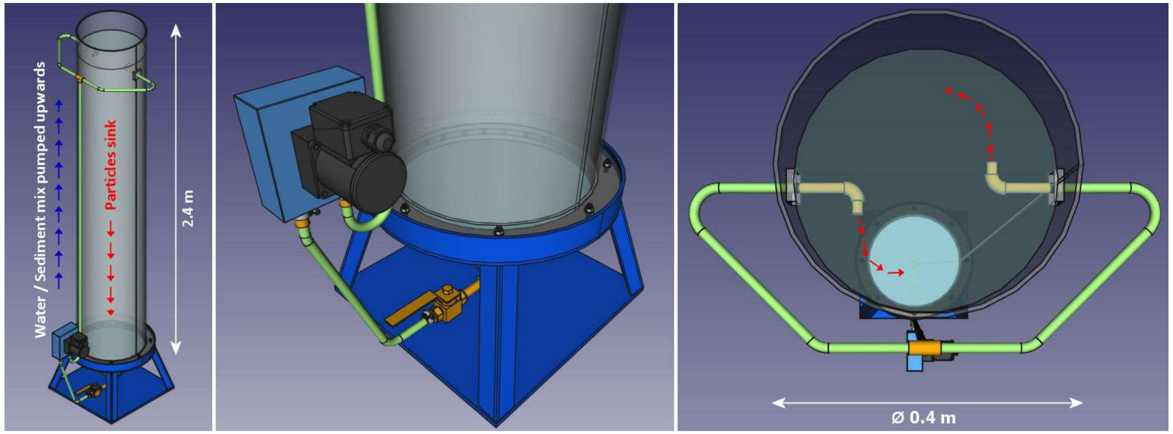
BUBBLE DETECTION AND QUANTIFICATION

We are using acoustics to study the following phenomena, with the aim of detecting and quantifying bubbles in a suspension:

- Bubble Rising Velocity
- Speed of Sound in Bubbly Liquid

Initial experiments were in a recirculating sediment tower at Aquatec Group, UK. It is 2.4 m deep and 0.4 m diameter. Our first bubbles were introduced by pumping air through an aquarium bubble stone.





Aquatec's Suspended Sediment Tower

Bubble Rising Velocity

Gas bubbles in water are buoyant, which distinguishes them from many other suspended particles. The terminal rising velocity of bubbles of different sizes is described by Grace et al. (1978). Measurement of negative velocity can signify the presence of rising bubbles, whose size can be inferred from the velocity magnitude in steady conditions.

Recent work with the AQUA*scat* instrument has demonstrated that particle velocity information can be obtained by measuring the phase velocity of successive complex acoustic backscatter returns from slowly settling sediments (Smerdon 2020). We aimed to adapt this technique to measure the much more rapid rising velocity of bubbles from the bubble stone arrangement.

Speed of Sound in Bubbly Liquids

Wood (1930) showed that the speed of sound in a bubbly liquid varies according to the void fraction, i.e. bubble content of the liquid. For a 50% void fraction, the speed of sound at about 23 ms^{-1} is significantly less than in water (approximately 1481 ms^{-1}) or air (333 ms^{-1}). By measuring the acoustic travel time in static water over a known distance, with knowledge of the speed of sound in comparable non-bubbly water, it should be possible to compute the bubble fraction.

We aim to use the AQUA*scat* instrument to measure the arrival time of successive echoes from the bubble stone surface in the presence and absence of bubbles.

WHY WELCOME BACK THE BUBBLE?

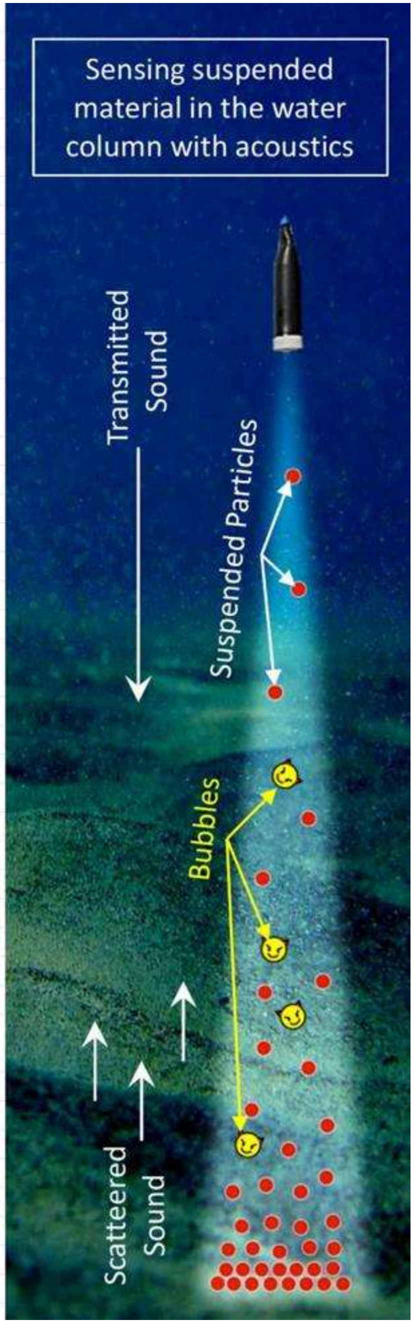
When using high frequency acoustics to monitor suspended sediment, it has been stated that:

"Bubbles are the Enemy"

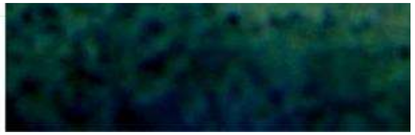
because they can be indistinguishable from sediment particles.

Following Corleone (1974) we have chosen to *keep our enemy close* by inviting them back to our suspended sediment tower.

We assess *Rising Velocity* and *Sound Speed*, with the aim of quantifying & mitigating for their effects



mitigating for their effects



RESULTS, DISCUSSION, AND MACGYVER...

Our initial detection techniques gave mixed results:

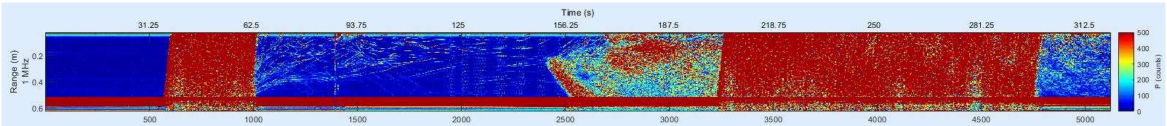
Property	Detected	Quantified
Bubble Rising Velocity	Yes	Only with PIV
Speed of Sound in Bubbly Liquids	Maybe	No

In addition, our Prodigal Bubble did not behave well.

[VIDEO] https://www.youtube.com/embed/1a-1CBpLMNc?rel=0&fs=1&modestbranding=1&rel=0&showinfo=0

The change in acoustic impedance at the air/water interface causes considerable attenuation of sound, especially at the 1 MHz to 2 MHz frequencies that we have been using. The accumulation of bubbles on the transducer faces results in significant reduction in measured backscatter, which has hindered interpretation of results.

To illustrate the use of the various techniques, we have selected one run in the sediment tower. The run, as shown in the 1 MHz backscatter plot below, has 6 phases. The plot shows backscatter intensity, with time and profile number on the x-axis and range from transducer on the y-axis.



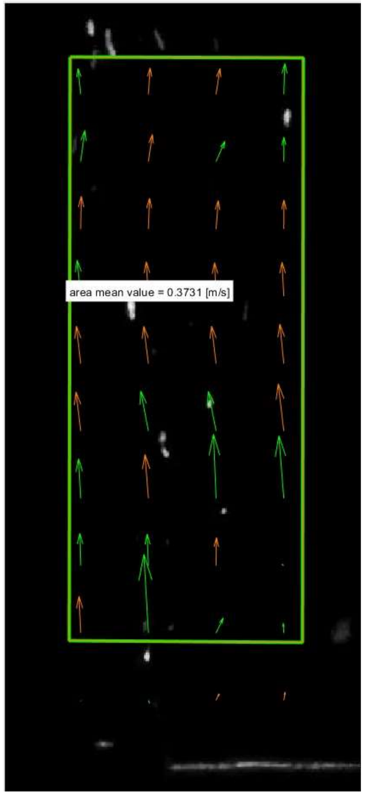
1. Still water
2. Bubble pump starts at profile 562
3. Bubble pump stops at profile 1000 followed by cleaning of transducer
4. Sediment pump starts to recirculate at profile 2400
5. Bubble pump restarts at profile 3220, sediment circulating
6. Bubble pump stops at profile 4750, sediment recirculating

Speed of Sound in Bubbly Liquids

The first point to note is that the echo from the bubble stone at approximately 0.5 m range (based on 1500 ms^{-1} sound speed in water) does not move as might be expected when the bubbles are introduced, although its intensity reduces. From a coarse analysis of still images of the PIV light sheet, we estimate the void fraction to be between 0.1% and 1%, which should give rise to a reduction in sound velocity from approximately 1500 ms^{-1} to between 360 ms^{-1} and 120 ms^{-1}. Such a dramatic change in sound speed would see the echo moving beyond the limit of the instrument's timing range. We believe the residual, non-moving echo position is due to part of the acoustic beam not passing through, and therefore not slowed by, the bubble plume.

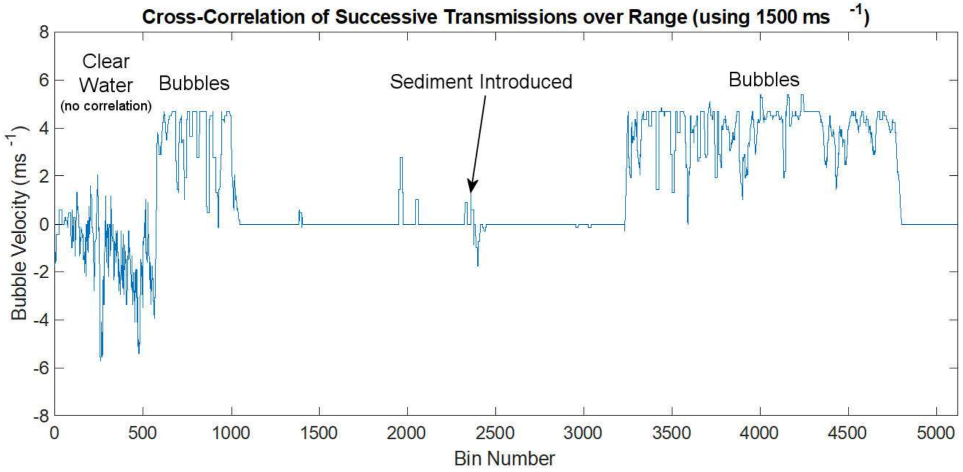
Bubble Rising Velocity

Bubble velocity was measured using the PIV system described in another paper (/default.aspx?s=46-99-16-18-26-AC-D1-31-10-D4-84-64-5C-2F-A3-1F&guestview=true) at this conference. As the image to the right shows, typical rising velocity was of the order of 0.4 ms^{-1}.



Acoustic measurement of bubble rising velocity is not strongly affected by variations in backscatter amplitude, provided there is sufficient signal level to measure the backscatter phase. We attempted to use the phase velocity method described by Smerdon (2020), modified to use two pulses in rapid succession, which should have coped with this velocity. However, results were erratic and appeared to show that the velocity was out of range due to phase measurement ambiguity.

We then performed a cross-correlation of the successive profile pairs over range from the transducer, to track the patterns of bubbles from one frame to the next. The resolution of this approach was very limited, but provided an explanation for the measurement ambiguity.

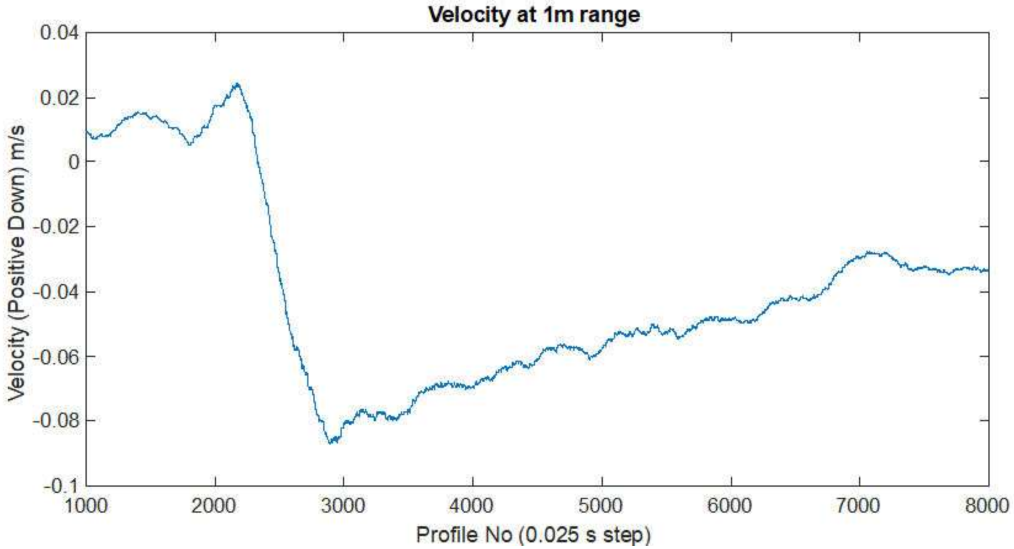


During the periods of bubble injection, the cross-correlation suggests that the bubble velocity is approximately 5 ms^{-1}, compared to around 0.4 ms^{-1} as measured by PIV. This suggests a significant sound speed shift (due to the Wood effect) and may therefore explain why the phase velocity measurement approach did not work.

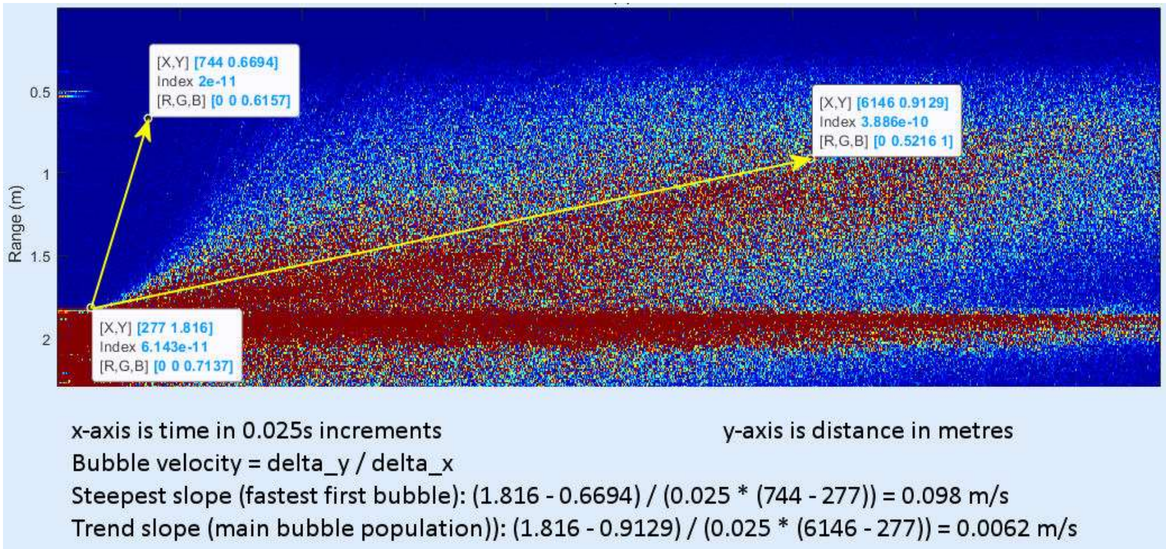
Breaking News

Since this poster was first published, it became apparent that the bubble stone was producing bubbles in greater volume than would normally be encountered in the natural environment. Combining the methods of Blanckaert and Lemmin (2015), and the ethos of MacGyver (see MacGyver sessions at this conference), we constructed a bubble generator from two stainless steel kitchen cooling racks and a laboratory power supply, which generate hydrogen bubbles by electrolysis.

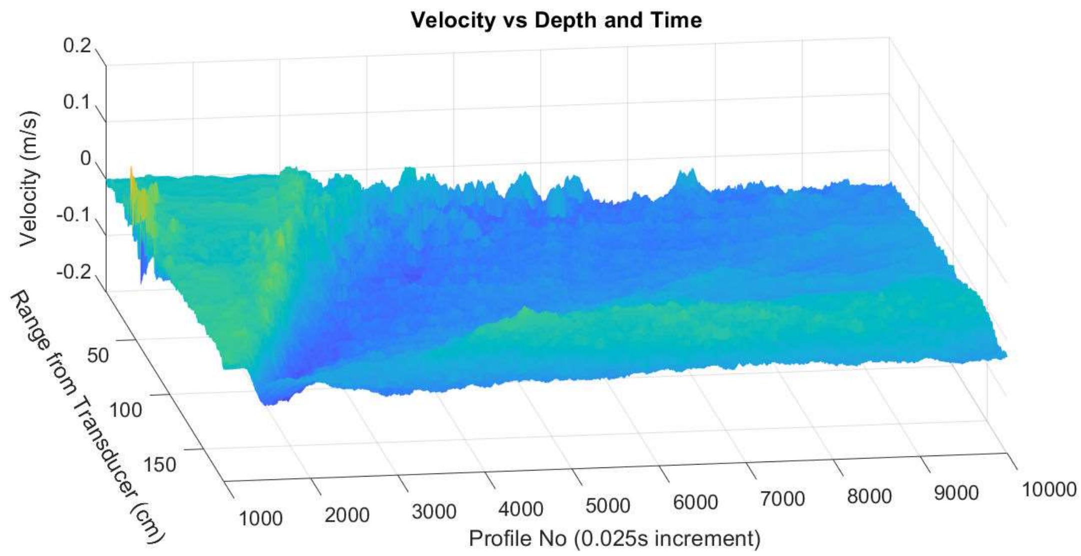
The resulting finer bubble stream allowed acoustic measurements of bubble velocity to be evaluated. In the following figure, the velocity in the 1 cm measurement cell 1 m from the acoustic transducer face is plotted against acoustic profile as a proxy for time. Bubble generation starts at around profile 1280 at a depth of approximately 1.8 m, and the fastest bubbles reach this cell around 20 - 300 profiles later.



Initially, only the largest and fastest bubbles are detected, but gradually the slower bubbles reach this cell, and the average measured velocity begins to fall. The acoustic backscatter plot below shows rising traces of both the fastest and general bubble population.



Finally in the 3D plot below, the evolution of the rising plume, and the reduction in mean rising velocity can be seen, with profile number as a proxy for time on the x-axis, range from the transducer (tank bottom nearest on the y-axis, and velocity on the z-axis.



Velocity vs Depth and Time
Velocity (m/s)
0.2
0.1
0
-0.1
-0.2
Range from Transducer (cm)
50
100
150
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Profile No (0.025s increment)

AMBITIONS AND FURTHER WORK

There is a reason why bubbles have been exiled from acoustic sediment towers: not only do they make the measurement of sediment more difficult. They also make their own measurement more difficult.

We used two primitive bubble generators to evaluate certain characteristics of bubble suspensions with acoustics. The initial bubbles generated were larger and more highly concentrated than normally encountered in typical sediment monitoring applications. The resulting relatively high void fraction dramatically reduces the speed of sound, while the large bubbles also have a rapid rising terminal velocity. Combining these two factors invalidated our phase velocity approach for velocity measurement.

We continued to introduce smaller bubbles in lower concentrations using another home-made bubble generator, that facilitated the measurement of rising velocity. We will continue to further work with a dedicated microbubble generator that will ultimately ensure a more uniform spatial distribution.

In addition to revisiting the rising velocity and speed of sound measurements, we will also be exploring several modes of acoustic resonance and investigating the non-linear acoustic characteristics of bubble populations.

DISCLOSURES

Some of the work described is supported by funding from the European Union's Horizon 2020 research and innovation programme under Grant agreement No 101000825 — NAUTILOS.

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The measurement and processing of high frequency acoustic backscatter profiles at multiple frequencies is an established technique for measuring suspended sediment load and equivalent mean particle size through the water column. The technique relies on the fact that the intensity of sound scattered by suspended particles is related not only to the particle size, but also the incident acoustic frequency. It is exploited by compact instruments that are deployed on seabed frames, vessels, and in laboratory flumes. However, one of the most significant influences on measurement accuracy comes from the presence of bubbles in the water column. Often found in suspended sediment study areas such as shallow wave-affected waters or highly turbulent flows, they can be of comparable acoustic cross-section to the suspended sediment particles and may dominate backscatter.

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