Estimating bottom properties with a Vector Sensor Array during MakaiEx 2005

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Abstract *- Nowadays, vector sensors which measure both acoustic pressure and particle velocity begin to be available in underwater acoustic systems, normally configured as vector sensor arrays (VSA). The spatial filtering capabilities of a VSA can be used, with advantage over traditional pressure only hydrophone arrays, for estimating acoustic field directionality as well as arrival times and spectral content, which could open up the possibility for its use in bottom properties' estimation. An additional motivation for this work is to test the possibility of using high frequency probe signals (say above 2 kHz) for reducing size and cost of actual sub bottom profilers and current geoacoustic inversion methods. This work studies the bottom related structure of the VSA acquired signals, regarding the emitted signal waveform, frequency band and source-receiver geometry in order to estimate bottom properties, specially bottom reflection coefficient characteristics. Such a system was used during the Makai 2005 experiment, off Kauai I., Hawai (USA) to receive precoded signals in a broad frequency band from 8 up to 14 kHz. The agreement between the observed and the modelled acoustic data is discussed and preliminary results on the bottom reflection estimation are presented.*

Keywords *- Vector Sensor, high frequency inversion, geoacoustic properties, reflection loss.*

I. INTRODUCTION

The spatial filtering capabilities of a vector sensor array (VSA), which measures both acoustic pressure and the three components of particle velocity, provide a clear advantage in source localization [1] and opens up the possibility for its usage in other type of applications such as in geoacoustic inversion. Additionally, the use of a VSA at high frequency allows the array length to be substantially shortened, easy to operate and may be possible to use in compact systems and moving platforms (AUV).

The main objective of this work is to test the possibility of using a VSA for estimating bottom properties, specially bottom reflection coefficient characteristics, using a method present in [2].

During the Makai Experiment, that took place off the coast of Kauai I., Hawaii, in September 2005, signals emitted by an acoustic source, were collected with a 4 element vertical VSA. Source bearing could be determined using the horizontal discrimination capability of the VSA and the corresponding beam extracted for vertical resolution analysis. An estimate of the bottom reflection loss versus grazing angle for the signal bandwidth is obtained by dividing the up and downward energy reaching the array. Data and modelled comparison gives sufficient agreement for inferring the sediment and sub bottom acoustic properties in the area of the experiment that shows a plausible match with historical data.

II – REFLECTION COEFFICIENT ESTIMATION

The method presented in [2], consists in dividing downward by upward array beam response.

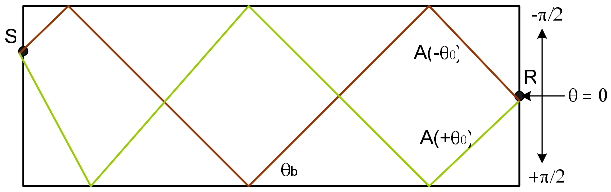


Fig.1. The ray approach geometry of a plane wave emitted by the source (S) and received by the receiver (R) at steer elevation angle θ_0 .

Let us consider an emitted signal $S(\phi,\theta)$, in a range independent environment, function of an elevation angle θ and azimuth ϕ, Fig.1. The array beam pattern $B(\phi,\theta)$, to an azimuthal direction, ϕ, for each steer angle θ_0 is given by the array response $A(\theta_0)$. The ratio between the upward and downward beam response is an approximation to the bottom reflection coefficient (Rb):

$$\frac{A(-\theta_0)}{A(+\theta_0)} = R_b(\theta_b(\theta_0)), \qquad (1)$$

where the angle measured by beamforming at the receiver, θ_0, is corrected to the angle at the seabed, θ_b, according to the sound-speed profile by Snell's law:

$$\theta_b = a\cos((c_b / c_r)\cos(\theta_0)), \qquad (2)$$

where c_b is the sound speed at the bottom and c_r the sound speed at the receiver, according to [2].

The bottom reflection loss (1) deduced from experimental data is compared to the modelled reflection loss using the Bounce module [3] for candidate sets of bottom parameters using a trial and error approach. The best agreement gives an estimate of the bottom layering structure together with its most characteristic parameters.

III – EXPERIMENTAL SETUP

The data analysed here were acquired by a 4 element vertical VSA, with 10cm spacing and deployed at 40m depth, on 25 of September, 2005. The signals were emitted by an acoustic source (model 916C3 from Lubell Labs) towed from a RHIB and deployed at 10m depth.

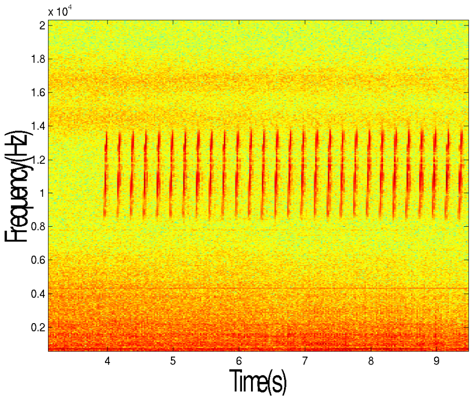


Fig. 2. Spectrogram of the signal acquired by VSA.

The source periodically transmitted a series of known waveforms consisting in linear frequency modulated (LFM) 50 ms duration pulses in the band 8 to 14 kHz (Fig. 2). The signal transmit rate is 200ms and the source – VSA range varies from 2300 to 300m, corresponding to nearly one hour of data. Because of the range dependent bathymetry of the area, only the second last portion of this run was considered in this study. At 500 m source range the water depth was varying from 119 m at the source location to approximately 99 m at the VSA, which was considered to be approximately a range independent bathymetry. The bathymetry map, the localization of the VSA and the RHIB trajectory are shown in Fig. 3.

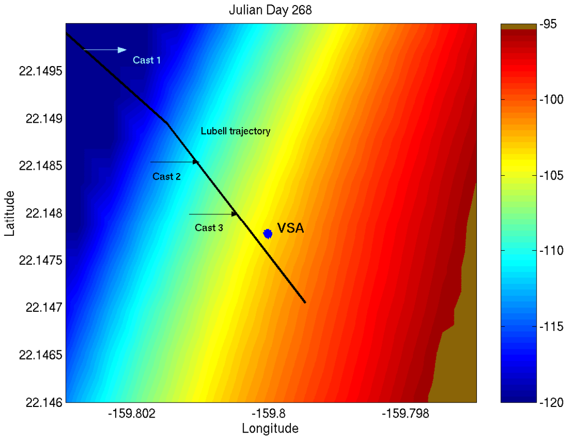


Fig. 3.The bathymetry map and the localization of the equipment on 25 of September, 2005.

As shown in Fig. 3, three instants in time will be discussed: minute 38 (cast 1), minute 44 (cast 2) and minute 48 (cast 3) corresponding to approximately 500m, 400m and 300m source range, respectively.

Ground truth measurements were carried out in the area during previous experiments and showed that the bottom in the flat area is covered with coral sands over a basalt hard bottom with possibly a variable structure to the west. The sound velocity in coral sands should be approximately 1700 m/s and the sediment thickness was unknown but expected to be a fraction of a meter. The baseline environment is shown in Fig. 4.

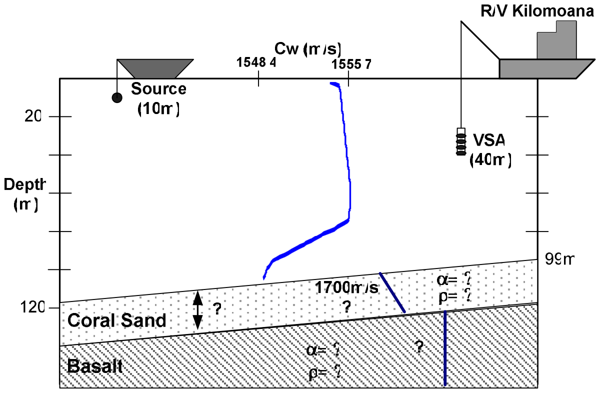


Fig. 4. Experimental drawing diagram of baseline environment with sound speed profile.

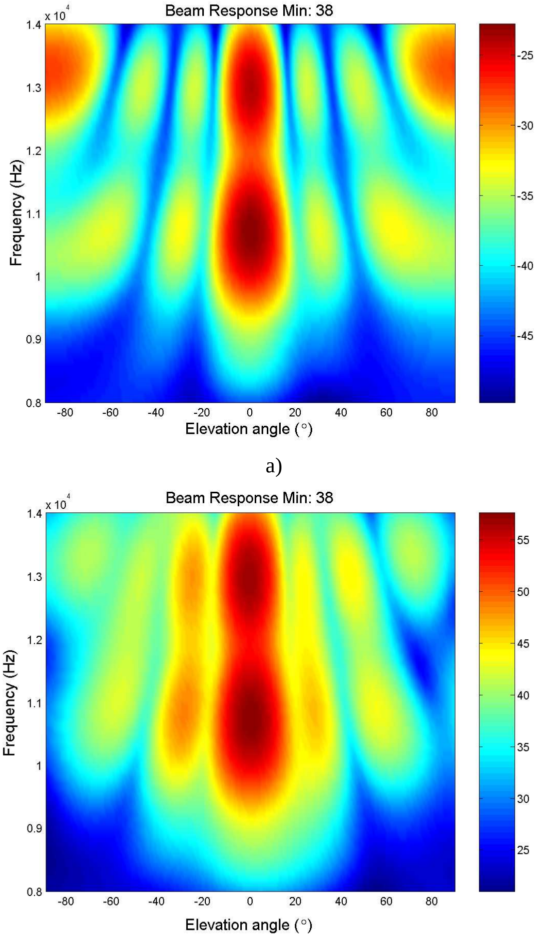
As a first step to find the bearing of the source, conventional vector sensor beamforming was used considering the 4 elements VSA (see [1] for details and properties of VSA beamforming with this data set).

Then the vertical beam response for each frequency was extracted for the source bearing of interest, considering both only the 4 omnidirectional pressure sensors, and the 4 omni + directional elements of the VSA. (Fig. 5 a) and b)).

The beam response in the omni directional case, Fig. 5 a), is nearly symmetric for the negative and positive elevation angles (up and down respectively), conducting to poor information about the bottom attenuation. Comparing with the directional case, Fig. 5 b), the vertical beam response clearly differentiates up and downward energy allowing for retrieving bottom information. This is clearly an unique capability resulting from the processing gain provided by the VSA.

IV – ANALISYS OF RESULTS

Dividing the up and down beam response for the same elevation angle, the frequency versus bottom angle reflection losses curves were calculated, for the three moments of acquisition (Fig. 6).



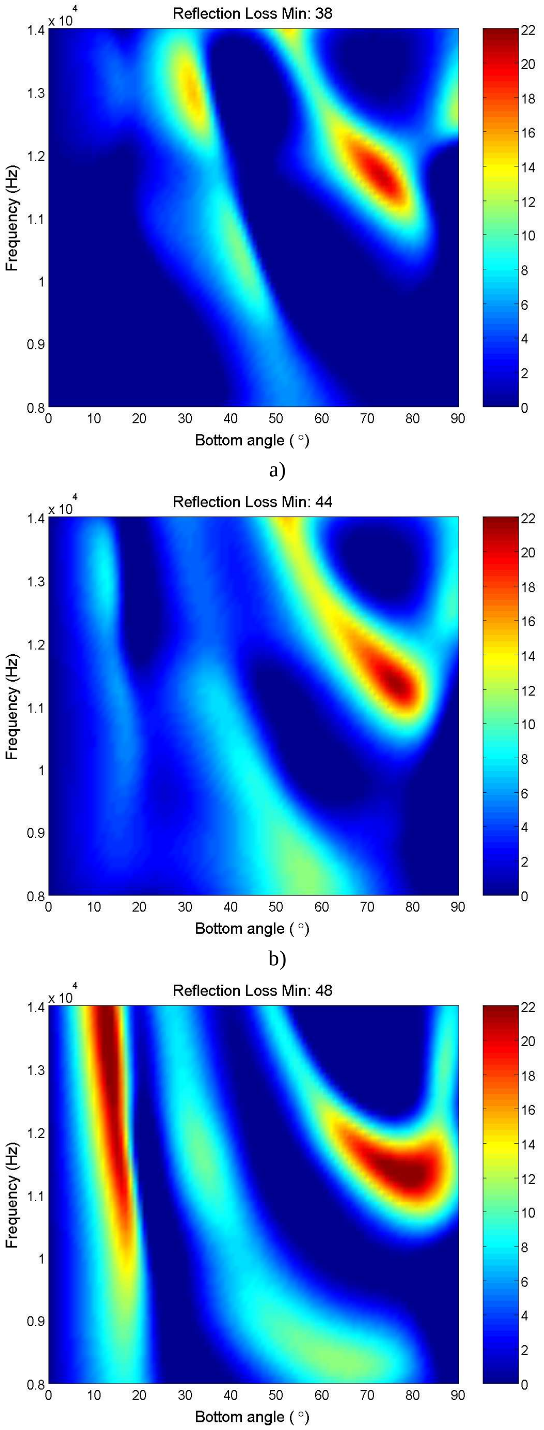
a)

b)

Fig. 5. The beam response at source azimuthal direction obtained by the 4: a) omnidirectional pressure sensors and b) omni + directional elements of the VSA.

As shown in Fig. 6 a), low loss can be observed up to a critical angle (~30º) and two interference lobes, one covering nearly all the frequency band and other for frequencies above 11 kHz for a critical angle of (~60º). These structure suggests that the area can be modelled as a three-layer environment (two boundaries): water, sediment and the half-space.

In Fig. 6 b) and c) the same lobes at critical angles 30º and 60º appear and the same structure can be concluded with however, the interplay of a third interface that becomes visible up to the critical angle (~10º) at high frequencies (clearly seen for minute 48, when the source is closer to the VSA). This third lobe suggests another layer. Some preliminary hypothesis open to debate point to: 1 – in fact the environment is four layer (three boundaries), but in Fig 6 a), because of larger 500m range the top layer could not be resolved, or 2 – the bottom structure is really variable along range and that third layer is only present near the VSA location.



a)

b)

c)

Fig. 6. Bottom reflection loss deduced from the up-to-down ratio of the beams at minute: a) 38, b) 44 and c) 48.

These effects can be modelled using the *BOUNCE reflection coefficient model* [3], for a given set of geoacoustic parameters.: compressional wave speed, c_p, shear wave speed, c_s, compressional wave attenuation, α_p, shear attenuation, α_s and the density, ρ. As shown in Table 1, a few parameters from a first reference were taken, [4], as a starting point and then adjustments by hand was made to estimate a reflection loss picture similar to that obtained with the experimental data.

Sediment	**Sand**	**Basalt**
$\rho\ (g/cm^3)$	1.9	2.7
$c_p\ (m/s)$	1650	5250
$c_s\ (m/s)$	110*(thickness)^0.3	2500
$\alpha_p\ (dB/\lambda)$	0.8	0.1
$\alpha_s\ (dB/\lambda)$	2.5	0.2

Table 1. Reference geoacoustic parameters for the two layer model.

The layer thickness is also an important parameter for agreement of fringe separation, as well the sound speeds on the various layers and in the half-space.

The reflection loss obtained with the model is presented in Fig. 7. The figure presents the same features as those observed in the experimental data. The four layers were simulated and the three lobes do appear, although not exactly at the same critical angles. Whether the proposes bottom structure represents the actual bottom variation in the area is an open question. As a first approximation the baseline environment of Fig. 2, can be completed with the estimated parameters and with another layer (Table 2).

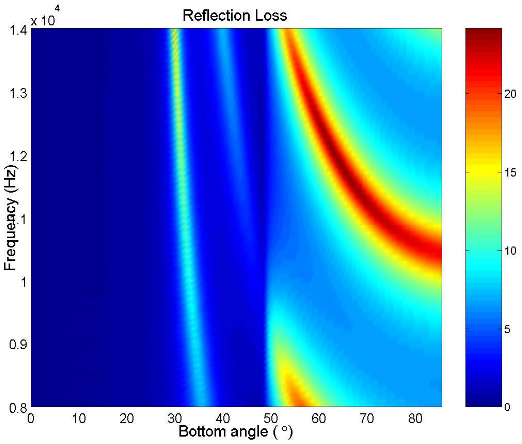


Fig. 7. Reflection loss modelled by the BOUNCE model.

Sediment	**Sand**	**Gravel**	**Basalt**
Thickness (m)	0.2	0.2	---
$\rho\ (g/cm^3)$	1.4	2.0	2.0
$c_p\ (m/s)$	1650 - 1680	1800	2270
$c_s\ (m/s)$	67.9	111.1	750
$\alpha_p\ (dB/\lambda)$	0.3	0.6	0.1
$\alpha_s\ (dB/\lambda)$	2.5	1.5	0.2

Table 2. Estimated bottom parameters for three layer model.

IV – CONCLUSION

In this paper the possibility of using a Vector Sensor Array and active signals in the 8 – 14 kHz band to estimate bottom properties was examined. Determining the bottom reflection coefficient deduced by the ratio of the upward and downward beam response became a simple method for estimating the bottom structure and respective geoacoustic parameters. It is shown that the VSA provides a unique capability for both source bearing estimation and vertical beam response information extraction when compared with the performance of a pressure only array with the same aperture.

The reflection loss curves observed with the experimental data are coherent with source range variation and allowed for establishing a bottom model structure and respective parameters that is compatible with the historical and geological information available for the area.

Thus the proposed technique provides a viable alternative for a compact and easy to deploy system in case no surface wind generated noise is available at the time of the experiment. The results presented also demonstrate that the channel signature has sufficient structure in this normally considered high-frequency band, for bottom estimation.

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