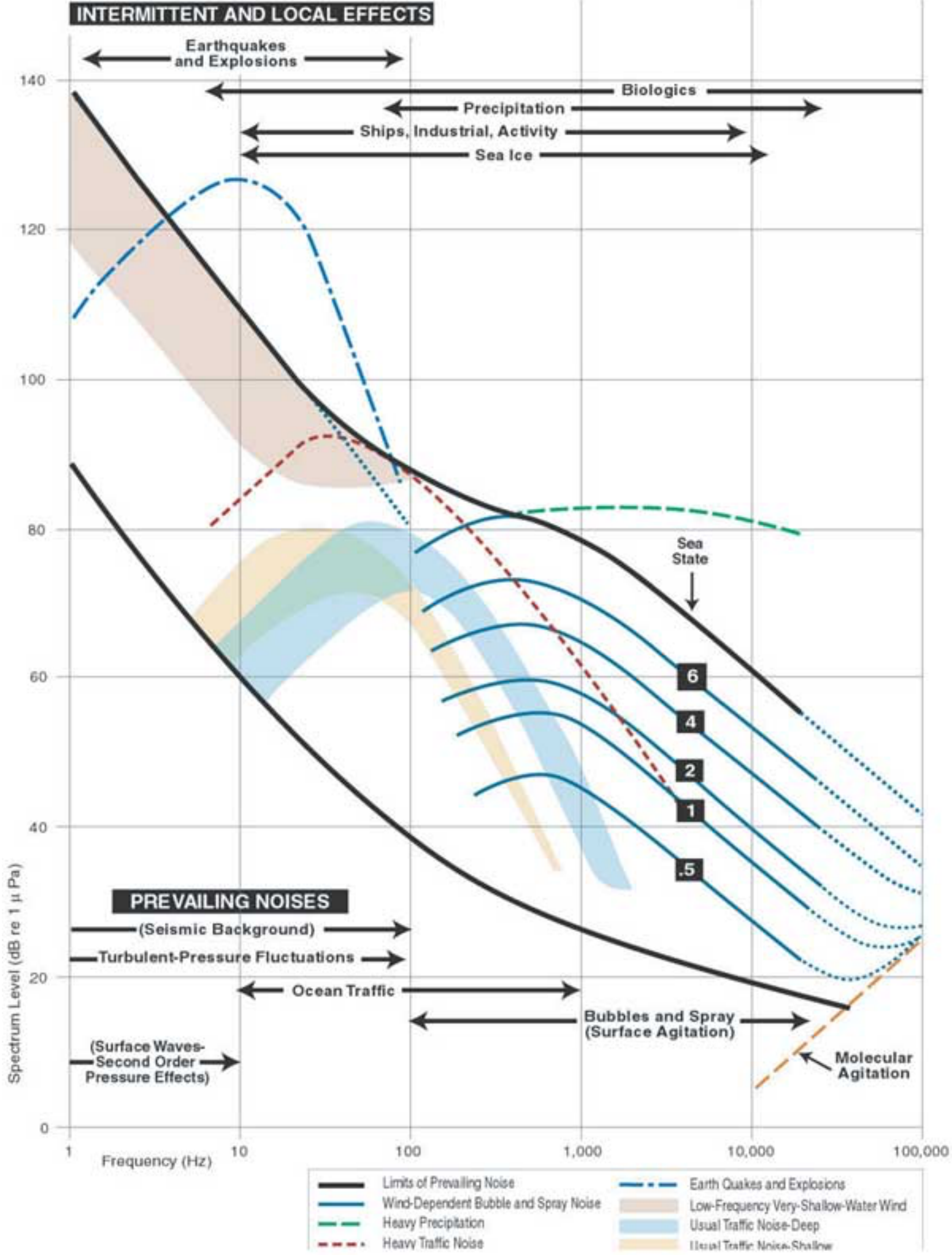
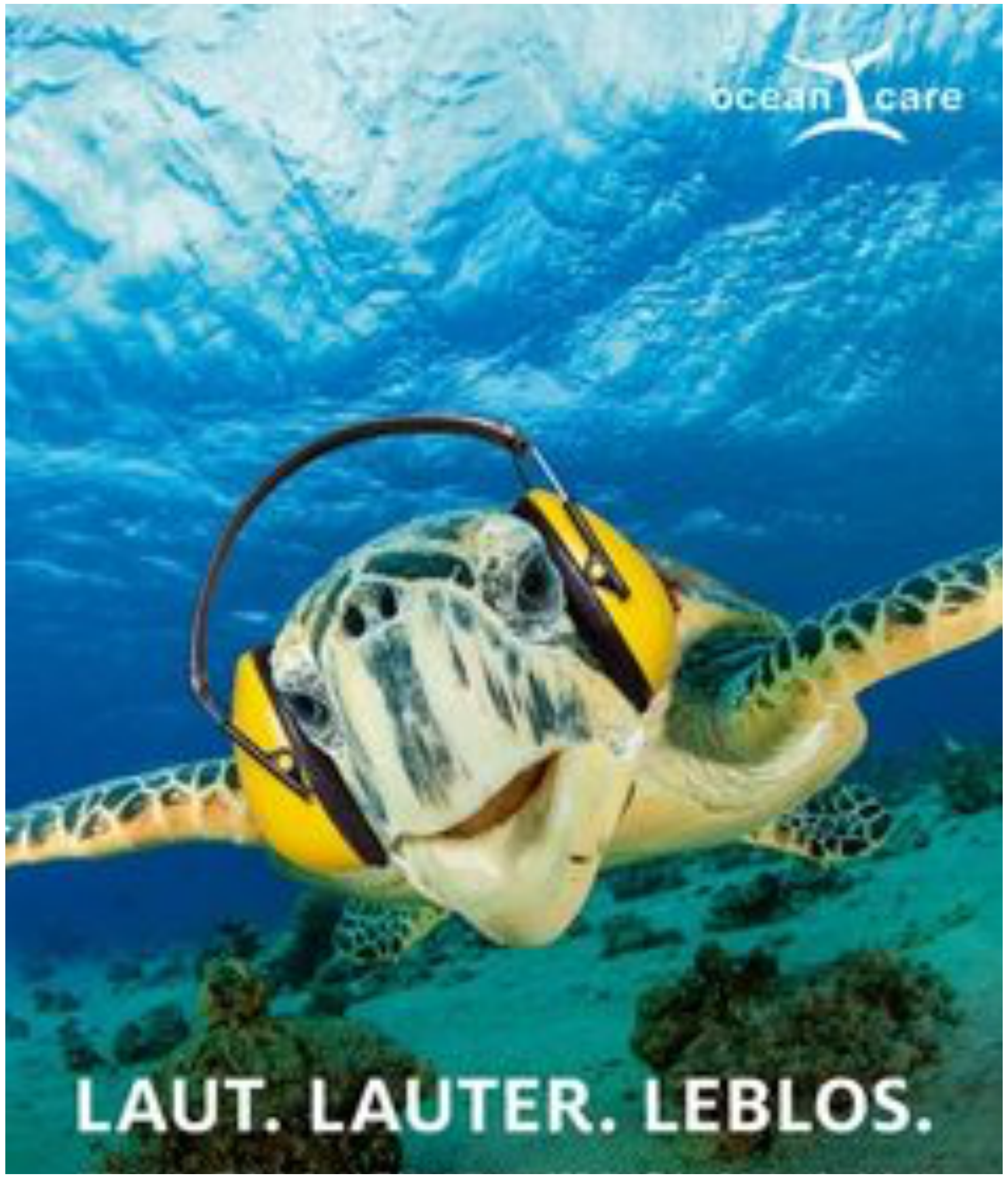
Sensing with noise

Mandar Chitre

Source: Wenz (1962)


INTERMITTENT AND LOCAL EFFECTS
Earthquakes and Explosions
Biologics
Precipitation
Ships, Industrial, Activity
Sea Ice
Sea State
6
4
2
1
.5
PREVAILING NOISES
(Seismic Background)
Turbulent-Pressure Fluctuations
Ocean Traffic
Bubbles and Spray (Surface Agitation)
(Surface Waves-Second Order Pressure Effects)
Molecular Agitation
Spectrum Level (dB re 1 μ Pa)
0
20
40
60
80
100
120
140
Frequency (Hz)
1
10
100
1,000
10,000
100,000
Limits of Prevailing Noise
Wind-Dependent Bubble and Spray Noise
Heavy Precipitation
Heavy Traffic Noise
Earth Quakes and Explosions
Low-Frequency Very-Shallow-Water Wind
Usual Traffic Noise-Deep

Images courtesy of Ocean Care



Homeward Sound

Stephen D. Simpson,[1*] Mark Meekan,[2] John Montgomery,[3] Rob McCauley,[4] Andrew Jeffs[5]

Most reef populations are replenished with recruits that settle out from an initially pelagic existence. The larvae of nearly all coral reef fish develop at sea for weeks to months before settling back to reefs as juveniles. Although larvae have the potential to disperse great distances, recent studies show a substantial portion recruit back to their natal reefs (*1*, *2*). Larvae are not passively dispersed but develop a high level of swimming competence (*3*). How they use these capabilities to influence their dispersal is an open question. We show here that recruits respond actively to reef sounds, potentially providing a valuable management tool for the future.

Since the discovery that reef fish larvae are accomplished swimmers, focus has shifted to identifying cues that may influence their orientation. Sound has emerged as a leading candidate, because it travels in water irrespective of current flow with little attenuation and because fish and invertebrates create a clamour that can be heard for many kilometers around (*4*). We have previously shown the attraction of settlement-stage reef fishes from many families to reef noise, using light traps and prerecorded sound (*5*). Here we provide direct evidence that sound enhances settlement of fish onto patch reefs.

We used two experiments to study settlement behavior in the presence of recorded reef sounds (*6*). In November 2003, we built 24 patch reefs from dead coral rubble on sand flats in 3- to 6-m-deep water at Lizard Island on the Great Barrier Reef (fig. S1). For six nights, we deployed submersible speakers broadcasting reef noise (at 156 dB relative to 1 μPa at 1 m, mostly the sound of snapping shrimp and fish calls) on 12 of these patch reefs, alternating the location of the speakers each night. Most settlement occurs at night, so recruiting fish were collected from the patch reefs early the following mornings. Of the 868 recruits we collected, most were apogonids (or cardinalfish, 80%) or pomacentrids (or damselfish, 15%). These two families are key members of coral reef fish assemblages around the world: The apogonids contribute up to one quarter of all individuals on reefs and the pomacentrids up to half of the total fish biomass (*7*). Analyses showed no site or date effects in our data, but both families settled in greater numbers on noisy patch reefs than on silent reefs (Fig. 1A). A preference for noisy patch reefs was also seen in less common fishes, with marginally more taxa (excluding apogonids and pomacentrids) on patch reefs with broadcast noise than on reefs without (Fig. 1B).

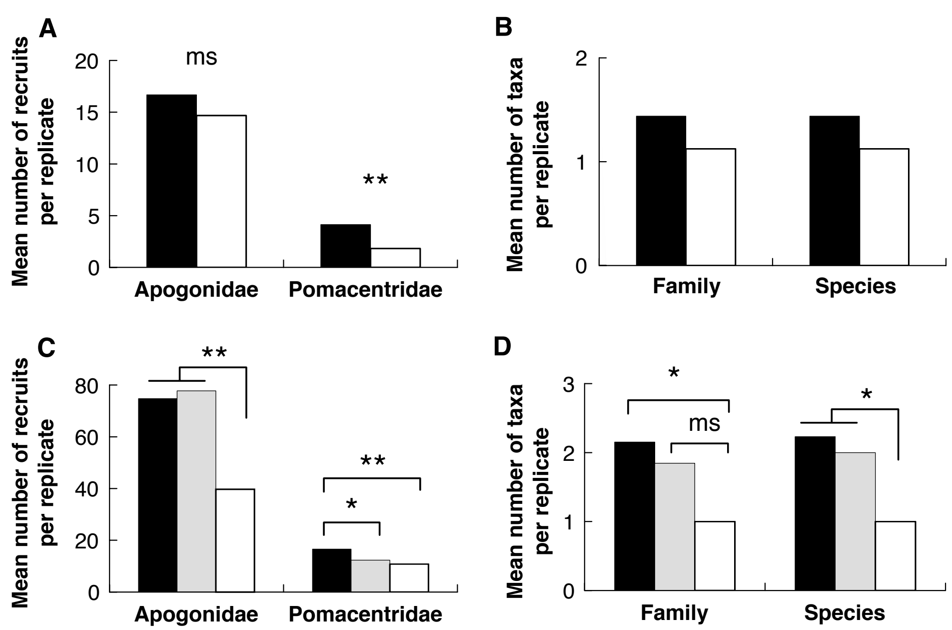


Fig. 1. Comparison of catches from patch reefs with different sound treatments (tables S1 to S3). (**A** and **B**) Reefs broadcasting reef noise (black) or silent reefs (white). (**C** and **D**) Reefs with high-frequency (black) or low-frequency (gray) reef noise or silent reefs (white). Statistical results are for (A) Chi-squared analyses, (B) Wilcoxon's matched pairs test, (C) pairwise Chi-squared analyses with Bonferroni corrections, and (D) pairwise Wilcoxon's matched pairs test with Bonferroni corrections (ms, $P < 0.1$; *, $P < 0.05$; **, $P < 0.01$). All apogonids and pomacentrids were excluded from the analyses in (B) and (D).

In December 2003, the experimental field site was used to compare the settlement of fishes to patch reefs where we broadcast primarily the high frequencies of reef noise (80% > 570 Hz, predominantly shrimp) or low frequencies of reef noise (80% < 570 Hz, predominantly fish) with settlement to silent reefs. This time, nearly four times as many recruits arrived (3111 fish), but the taxonomic composition was similar. Apogonids settled on high- and low-frequency patch reefs in equivalent numbers, but pomacentrids were preferentially attracted to reefs with high-frequency noise (Fig. 1C). Again, reefs without sound received less settlement from rarer taxa than reefs with broadcast sound (Fig. 1D).

This study provides direct field evidence that settling reef fishes use sounds to orientate toward and select reefs. Furthermore, there is an indication that some fish groups may be selectively using specific components of the reef sound to guide their settlement behavior. The important use of sound at this critical life history phase raises the possibility of potential adverse effects of increasing anthropogenic noise pollution (e.g., shipping and drilling), but it may also lead to the development of new tools for fisheries managers for restocking fisheries or newly established marine reserves.

References and Notes

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6. Materials and methods are available as supporting material on *Science* Online.
7. J. L. Ackerman, D. R. Bellwood, *Mar. Ecol. Prog. Ser.* **206**, 227 (2000).

8. We thank the staff at Lizard Island Research Station for logistic support. Supported by the British Ecological Society and the Fisheries Society of the British Isles (S.S.), the Marsden Fund of New Zealand, and the Australian Institute of Marine Science.

Supporting Online Material
www.sciencemag.org/cgi/content/full/308/5719/221/DC1
Materials and Methods
Fig. S1
Tables S1 to S3

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A passive fathometer technique for imaging seabed layering using ambient noise

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A passive acoustics method is presented that uses the ocean ambient noise field to determine water depth and seabed sub-bottom layering. Correlating the noise field measured by two sensors one can recover a function that closely resembles the two-point Green's function representing the impulse response between the two sensors. Here, a technique is described that is based on noise correlations and produces what is effectively a passive fathometer that can also be used to identify sub-bottom layers. In principle, just one or two hydrophones are needed—given enough averaging time. However, b

Bayesian geoacoustic inversion using wind-driven ambient noise

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This paper applies Bayesian inversion to bottom-loss data derived from wind-driven ambient noise measurements from a vertical line array to quantify the information content constraining seabed geoacoustic parameters. The inversion utilizes a previously proposed ray-based representation of the ambient noise field as a forward model for fast computations of bottom loss data for a layered

Compressive geoacoustic inversion using ambient noise

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Surface generated ambient noise can be used to infer sediment properties. Here, a passive geoacoustic inversion method that uses noise recorded by a drifting vertical array is adopted. The array is steered using beamforming to compute the noise arriving at the array from various directions. This information is used in two different ways: Coherently (cross-correlation of upward/downward propagating noise using a minimum variance distortionless response fathometer), and incoherently (bottom loss vs frequency and angle using a conventional beamformer) to obtain the bottom properties. Compressive sensing is used to invert for the number of sediment layer interfaces and their depths using coherent passive fathometry. Then the incoherent bottom loss estimate is used to refine the sediment thickness, sound speed, density, and attenuation values. Compressive sensing fathometry enables automatic determination of the number of interfaces. It also tightens the sediment thickness priors for the incoherent bottom loss inversion which reduces the search space. The method is demonstrated on drifting array data collected during the Boundary 2003 experiment. © 2014 Acoustical Society of America
[http://dx.doi.org/10.1121/1.4864792]

PACS number(s): 43.60.Pt, 43.30.Pc, 43.60.Fg [SED] Pages: 1245–1255

I. INTRODUCTION

Geoacoustic inversion estimates ocean environment parameters such as the water column sound speed profile (SSP) and seafloor parameters such as the sediment layer thicknesses, SSPs, density, and attenuation values. This paper introduces a passive geoacoustic inversion algorithm for use with drifting vertical line array (VLA) data. The sea-surface generated ambient noise observed by the VLA is used to invert for the sediment parameters. This inversion algorithm has two important features.

First, passive fathometry[1] and bottom loss measurements[2] are used together. Passive fathometry is a coherent technique that depends on the cross-correlation of upward and downward pointing beams and the bottom loss method is an incoherent technique that depends on the ratio of noise levels coming from different matched pairs of vertical arrival angles. Inversion methods that use either one of these have different properties and performance characteristics. Thus, using both of them together is an attractive combination. Here, the fathometer is used to estimate the water depth, the number of layers, and sediment thicknesses. This is followed by an inversion that uses incoherent bottom loss measurements, estimating the sound speed, attenuation, and density profiles in addition to refining the previously obtained sediment thicknesses.

Second, compressive sensing (CS) is incorporated in the fathometer inversion. Here we take advantage of the sparse nature of sediment formations where there are a finite number of layer interfaces that create strong reflections. CS provides a theoretical framework that enables expressing the problem as a convex optimization problem which then can be solved efficiently.[3,4]

In recent years, CS has been used in diverse fields.[5–8] In addition to some early applications,[9] recent underwater acoustic work includes sensor network representations,[10] compressive channel sensing for underwater communication,[11,12] beamforming,[13] and matched-field processing.[14] Sparsely distributed reflector depths can be recovered using CS as long as a spatially sparse representation that can represent the fathometer output using linear functions exists.[15,16] CS achieves this by minimizing not only the error between the observation and the forward model but also the number of reflections.

Ocean acoustic passive fathometry is a coherent method that computes the cross-correlation between the upward and downward propagating noise.[1,17,18] A geoacoustic inversion algorithm based on passive fathometry then can be used to infer the sediment properties. This approach to fathometry is a passive method since it only uses the surface-generated noise field. It requires the decomposition of the ambient noise wave field into its upward and downward propagating components. A common way of achieving this is using beamforming to steer the VLA. Adaptive fathometry based on the minimum variance distortionless response (MVDR)[18–20] and the white noise constrained (WNC) beamformers[19] has been shown to outperform fathometry that uses conventional beamforming. This is due to the fact that the adaptive beamformers are able to suppress much better noise coming from unwanted angles. A multiple model particle filter is used in Ref. 21 to track the range-dependent sediment thicknesses in an environment where the number of interfaces changes. Here MVDR fathometry is used together with CS to estimate the water depth and sediment thicknesses.

Bottom loss estimation is another passive inversion method that uses ocean ambient noise.[2] This method is based on the ratio of the bottom-reflected upward propagating noise power to the downward propagating surface-generated noise power.[22,23] Since the method is based on the ratio of noise powers, it is an incoherent method. The sensitivity of this method to parameters such as array tilt, water absorption, and non-surface generated noise sources is studied in

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High-Frequency Geoacoustic Inversion of Ambient Noise Data Using Short Arrays

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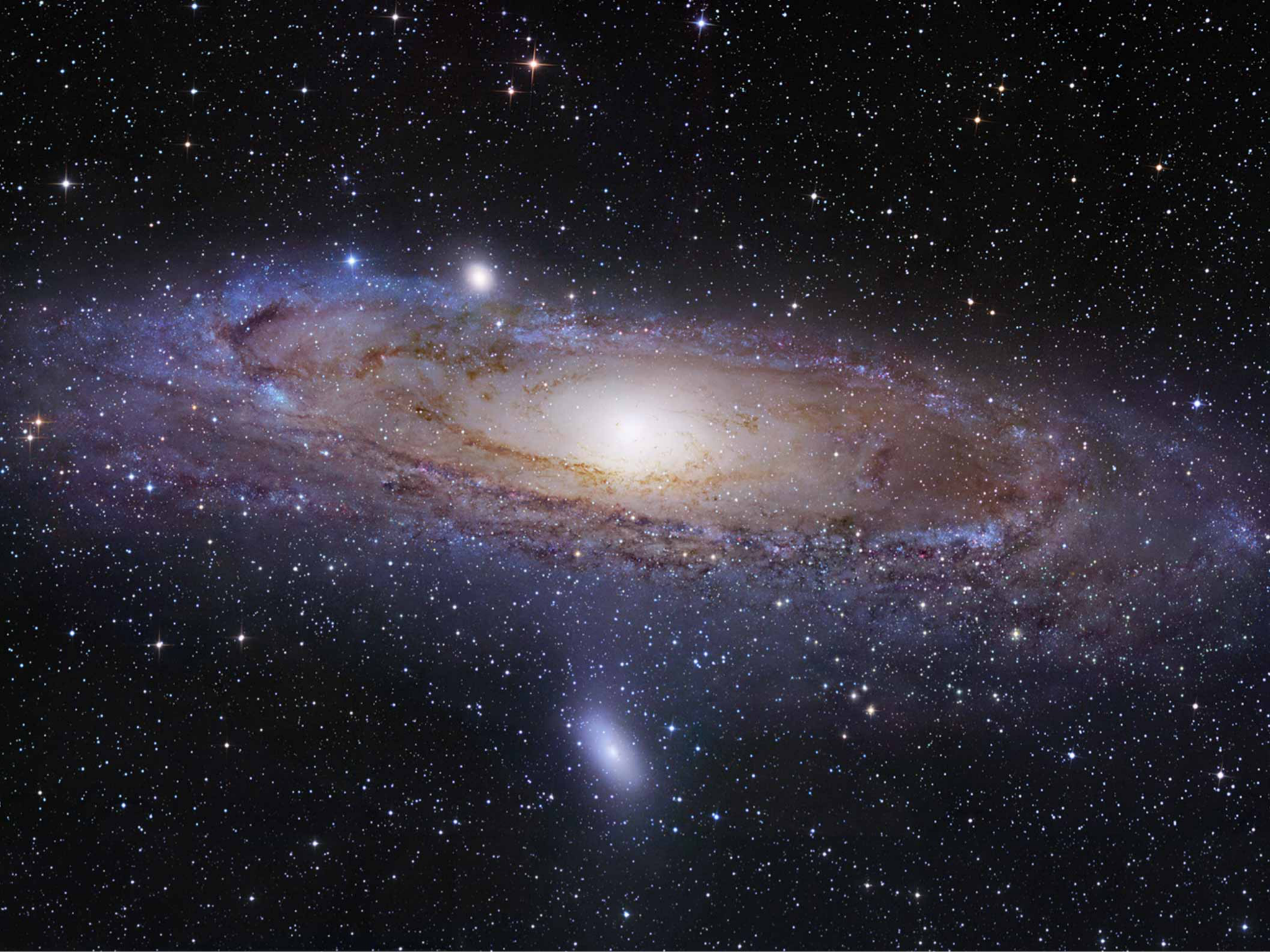
Abstract. Ocean ambient noise is generated in many ways such as from winds, rain and shipping. A technique has recently been developed (Harrison and Simons, J. Acoust. Soc. Am, Vol. 112 no. 4, 2002) that uses the vertical directionality of ambient noise to determine seabed properties. It was shown that taking a ratio of upward looking beams to downward produces an estimate of the reflection loss. This technique was applied to data in the 200–1500 Hz band using a 16-m vertical array. Extending this to higher frequencies allows the array length to be substantially shortened and greatly reduces interference from shipping. If array lengths can be reduced to about 1 m then it may be possible to hull-mount or tow such an array from a surface ship or submerged vehicle (e.g. an autonomous underwater vehicle). Although this seems attractive the noise is primarily generated by wind which in turn causes a rough sea-surface and bubbles and these factors combined with increased volume attenuation may degrade this type of reflection loss estimate at high frequencies. In this paper, we examine measured noise data from the October 2003 ElbaEx experiment using a 5.5 m array in the 1–4 kHz frequency band. Results indicate the noise field is predictable with modeling and the ratio of upward looking to downward looking beams produces an approximation to the reflection loss which can be inverted for seabed properties. For short arrays (a 1 m aperture is considered here), the beamforming is not ideal over a broad-band of frequencies. The beams are broadened and this leads to an up/down ratio that does not produce a good estimate of reflection loss. This can be especially problematic at low grazing angles which is the part of the reflection loss curve that is often most important to estimate correctly. Techniques will be presented for mitigating the impact of beamwidth and grating lobes on estimating the seabed properties.

INTRODUCTION

Using measurements of ocean ambient noise to produce an estimate of seabed properties is attractive for several reasons. 1) Since ambient noise results from wind and rain interacting with the sea-surface the sound sources exist everywhere. 2) This sheet source provides an angular spread of plane-waves that have interacted with the bottom and therefore contain information about seabed properties. 3) Passive measurements not requiring a sound projector greatly simplify the design of an experiment or survey technique. 4) With concerns over the impact of sound on marine mammals, an environmentally friendly geoacoustic inversion method that does not require a human-made sound source is highly attractive.

Although the dependency of ambient noise on seabed properties has been widely reported, only recently has a method been developed that uses vertical directionality of



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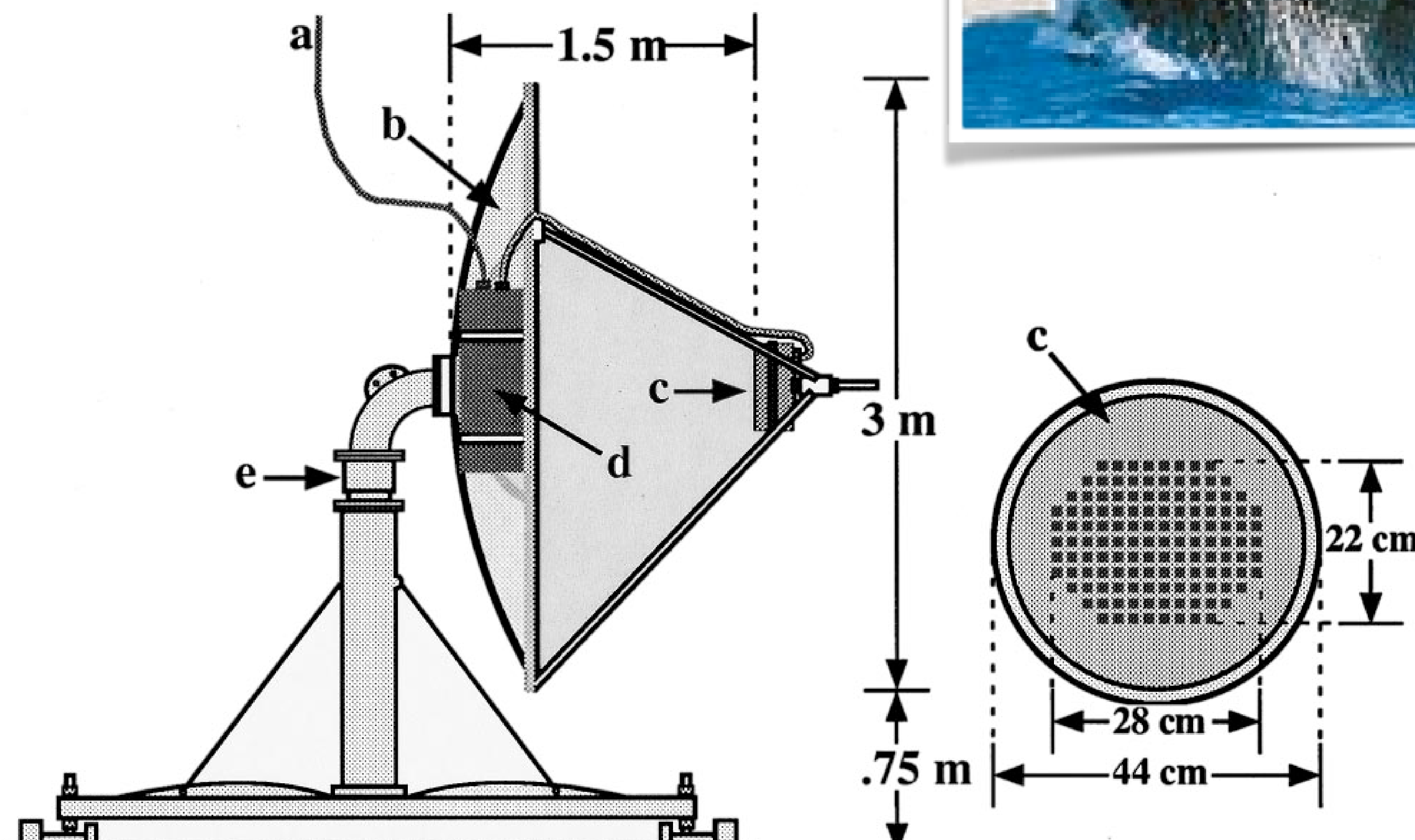

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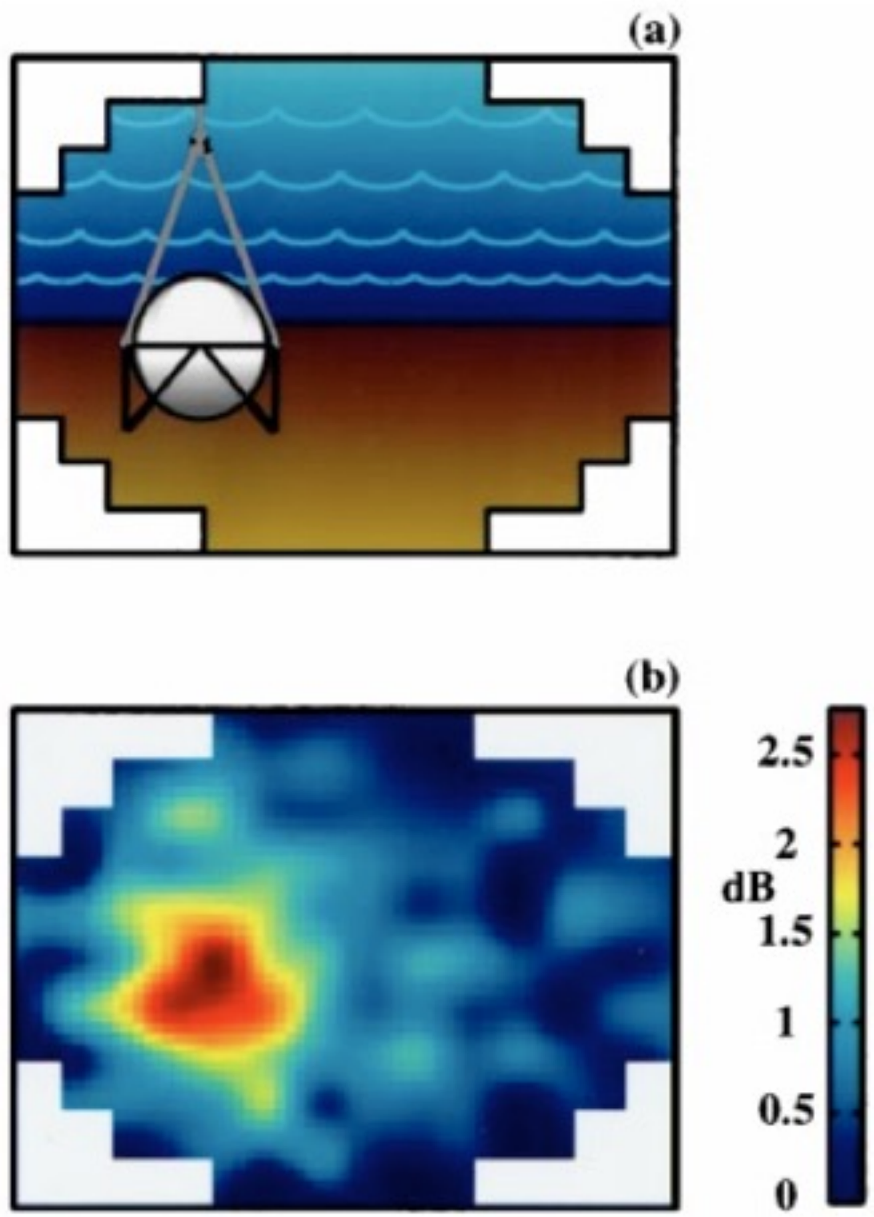

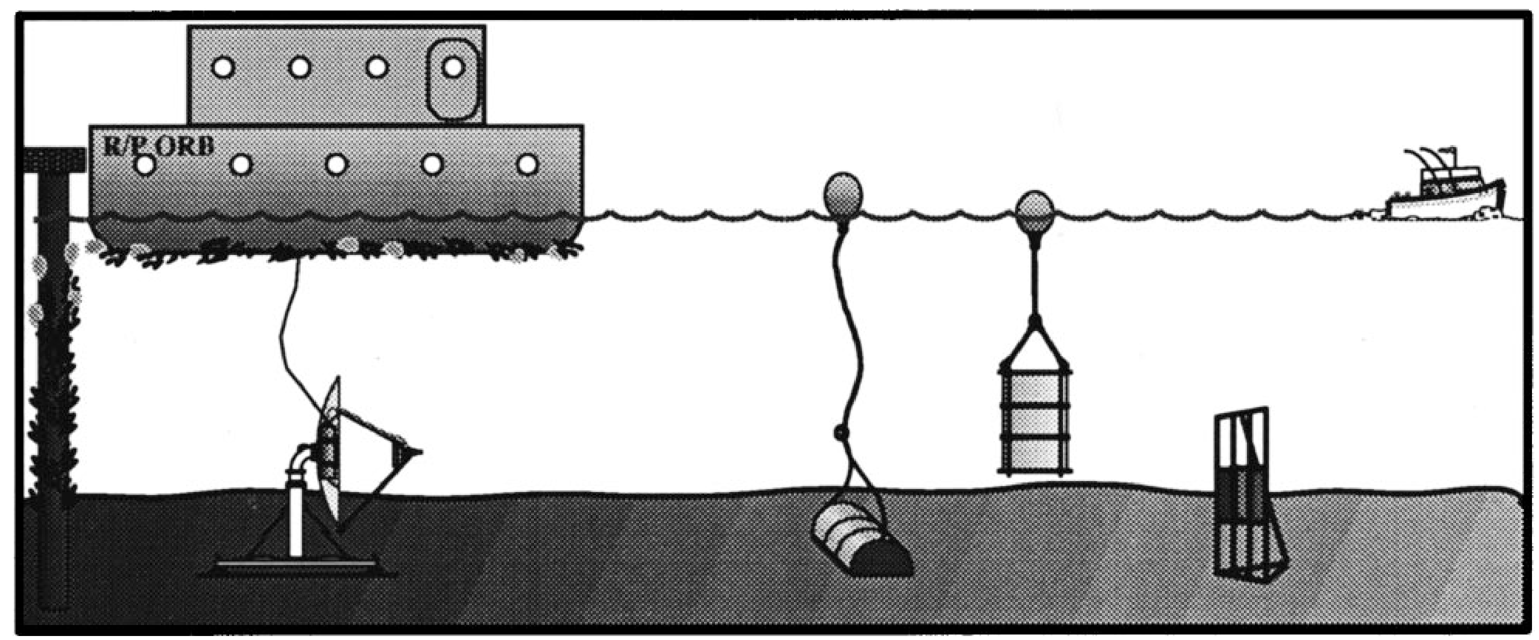

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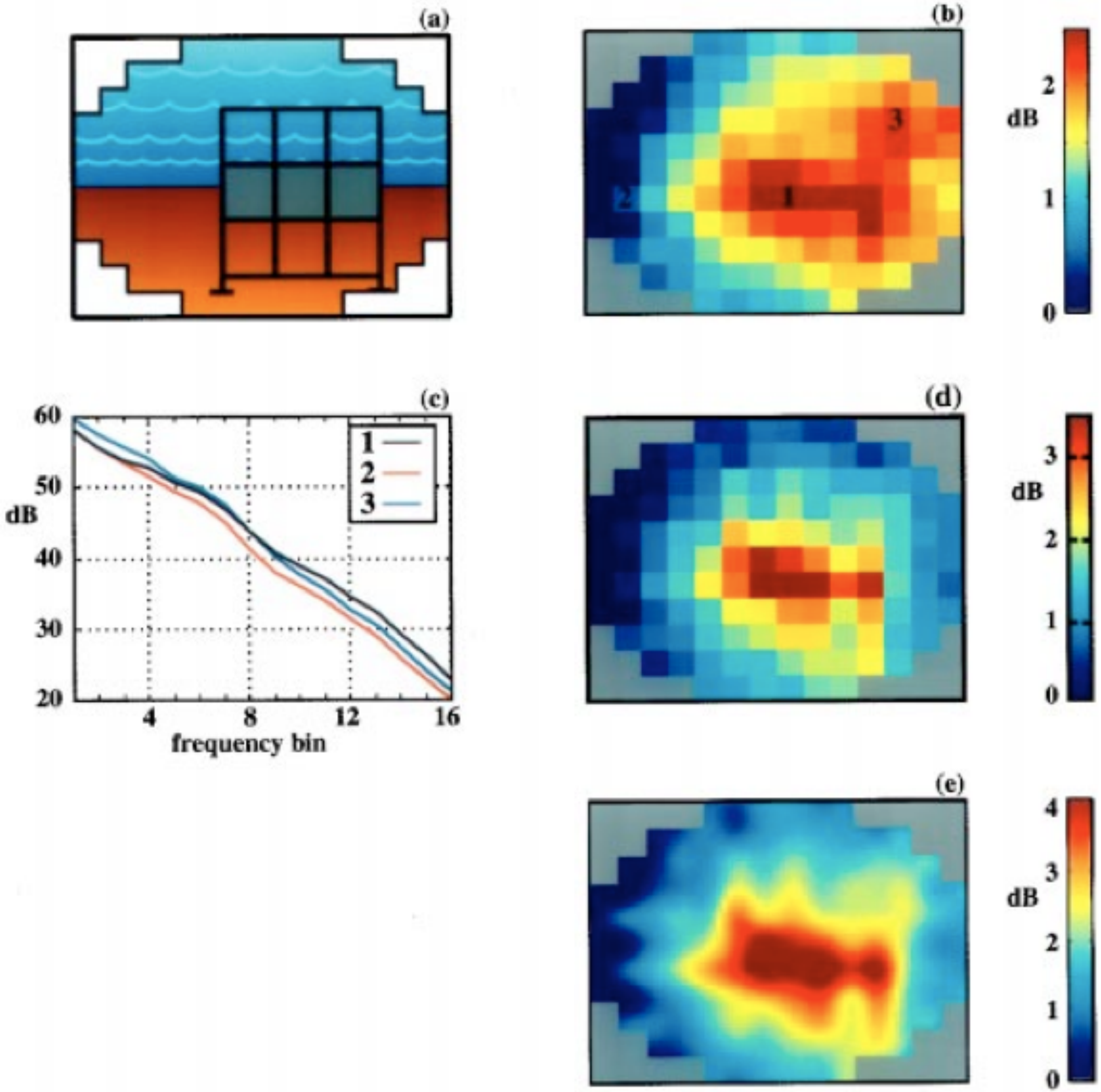
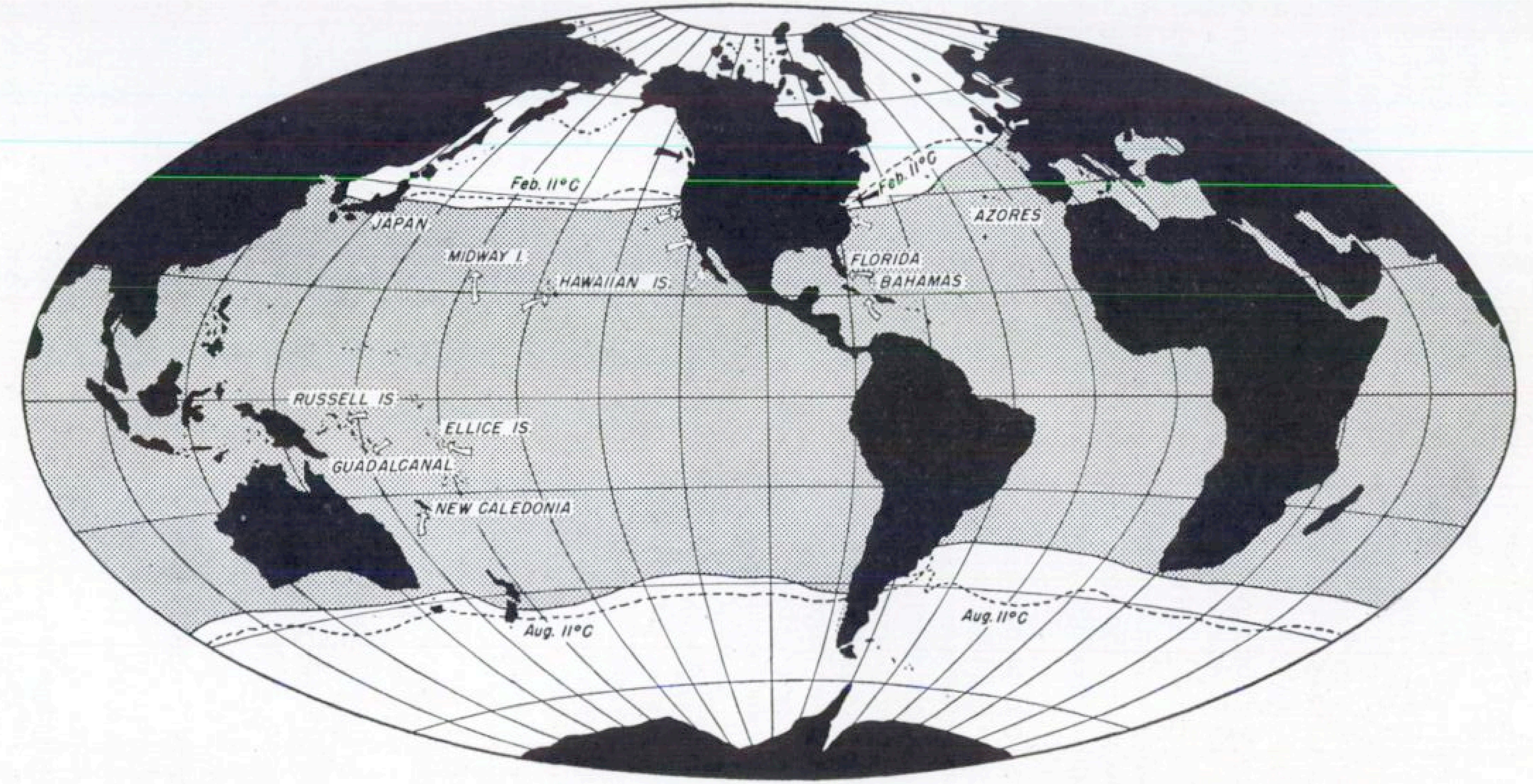


Source: Johnson et al. (1947)

Coastal warm waters



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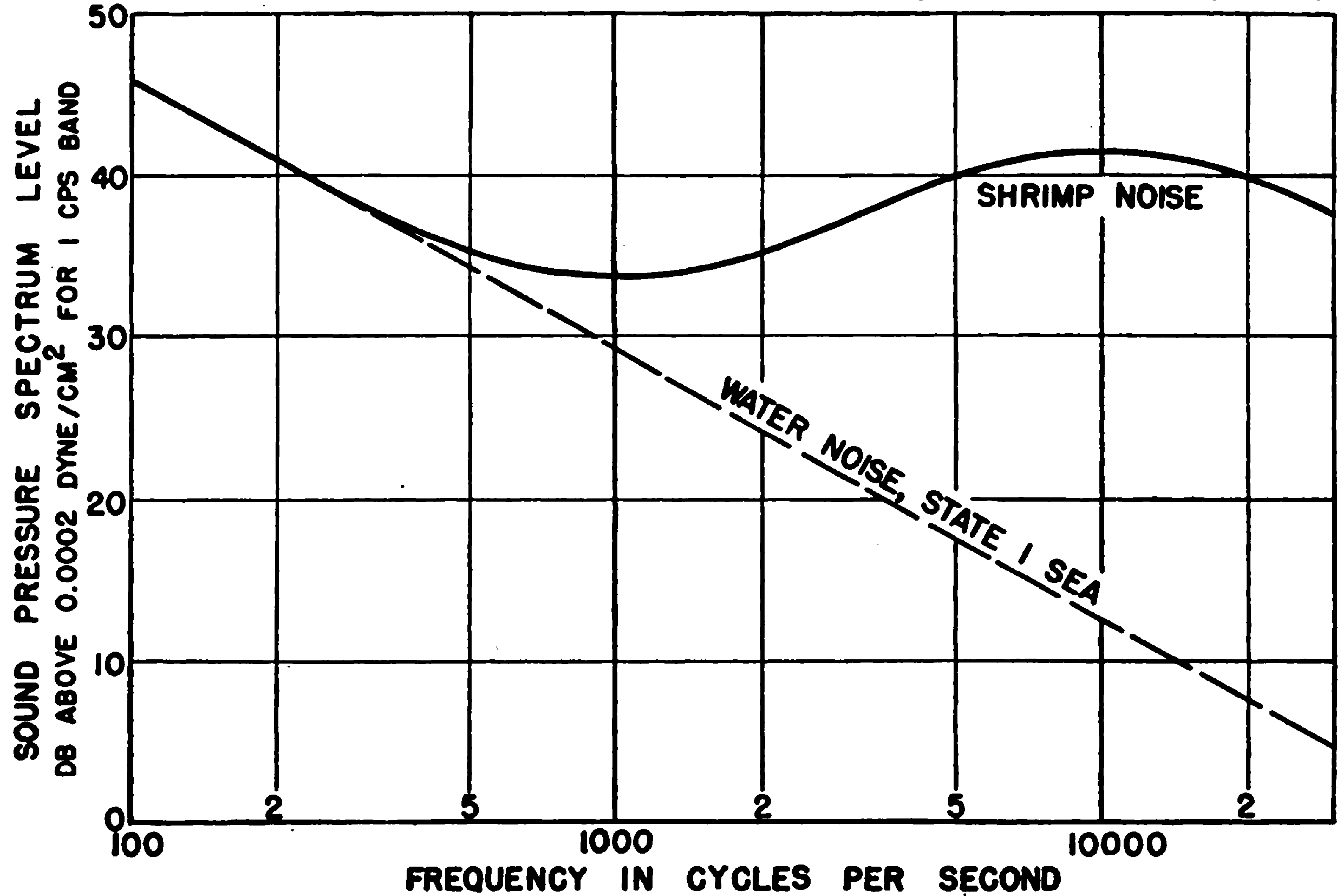
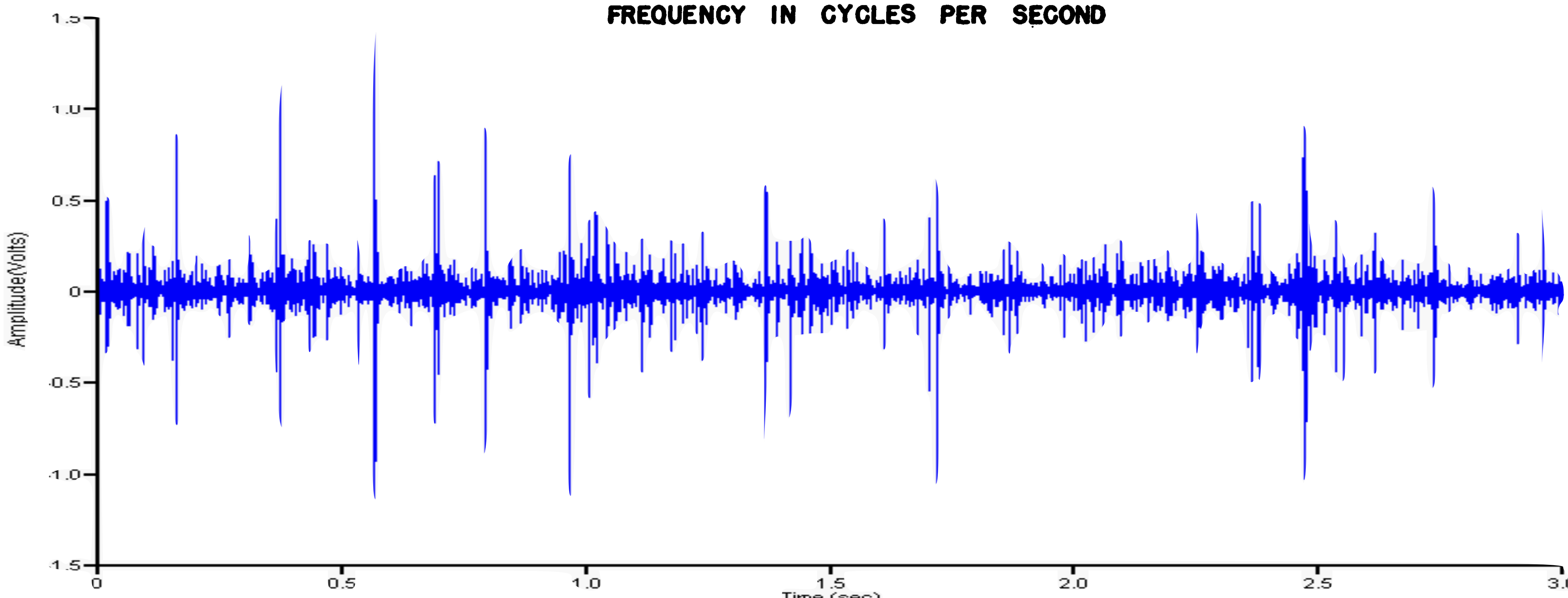
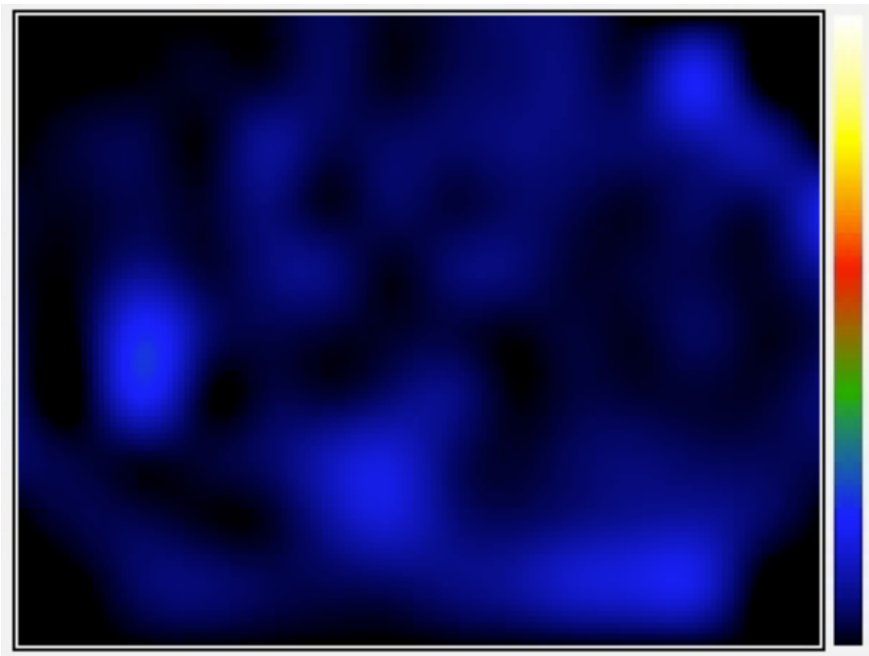
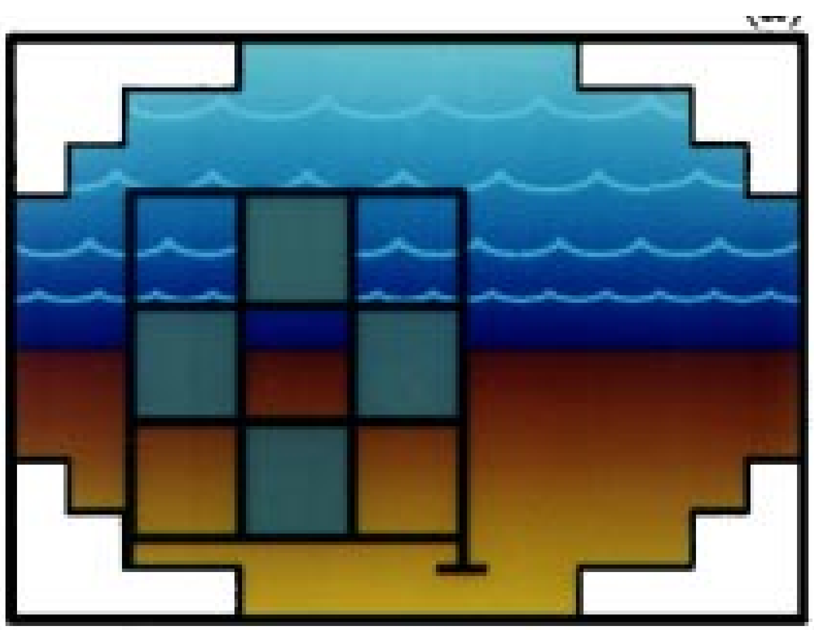
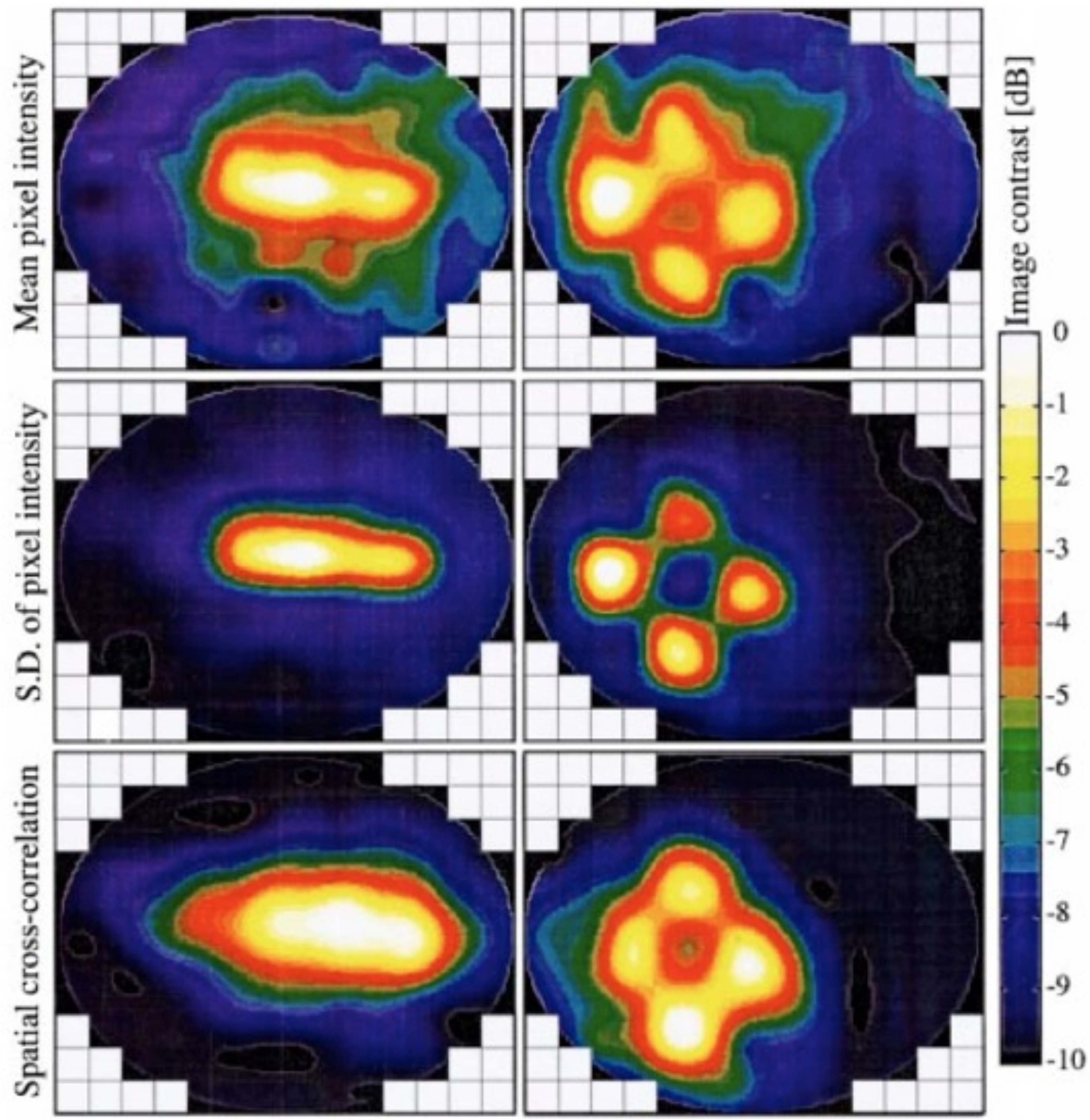


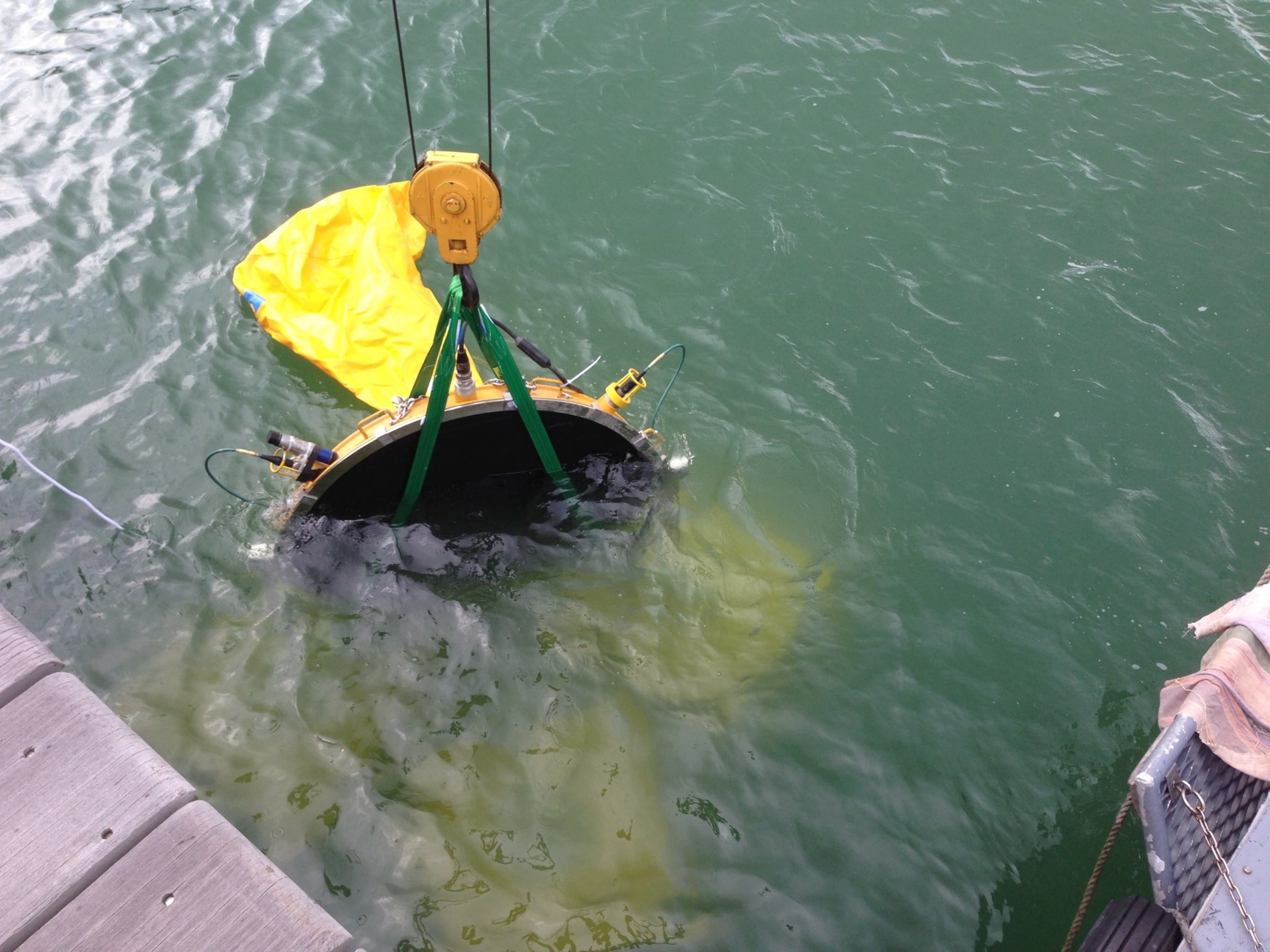


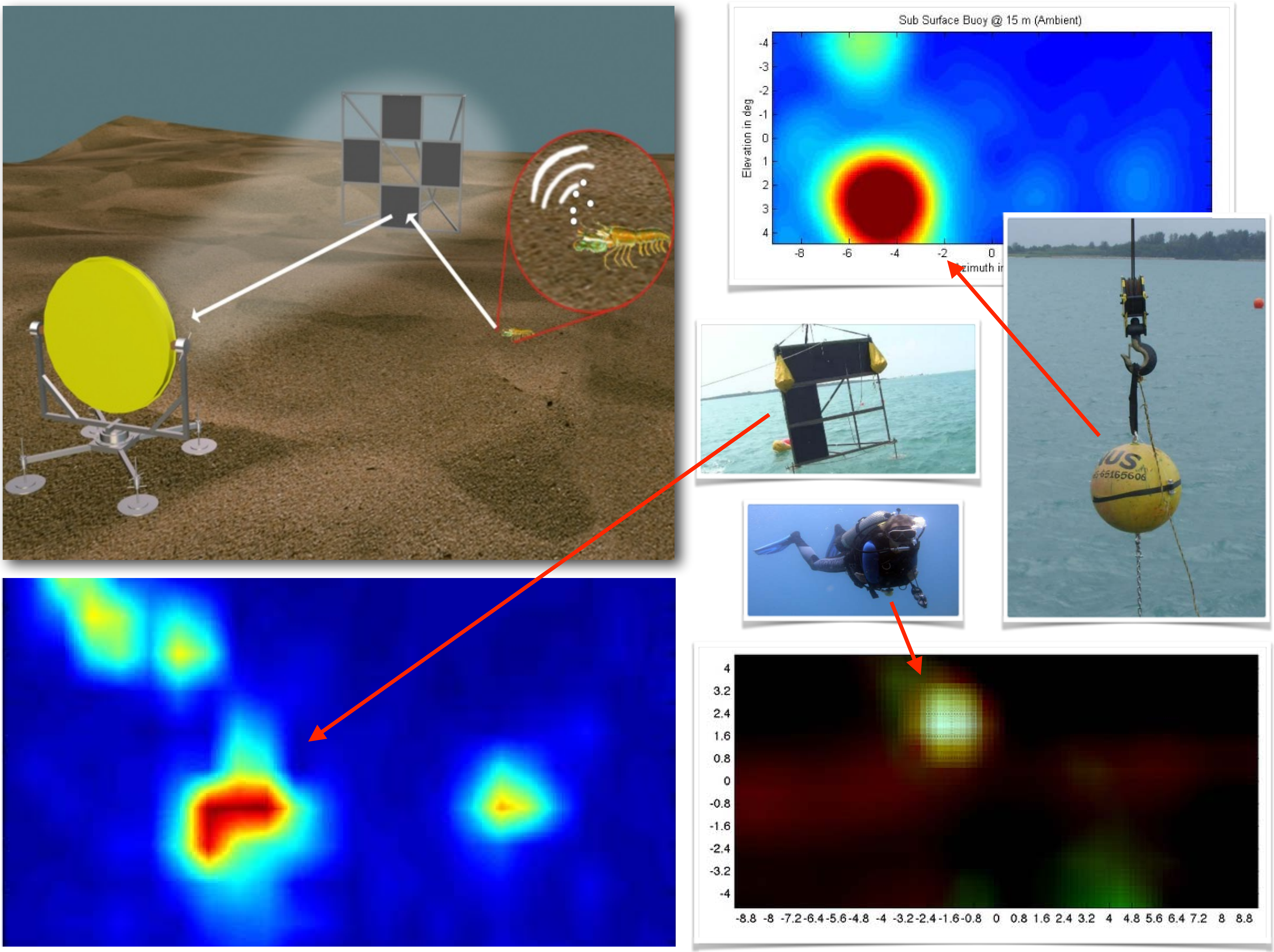


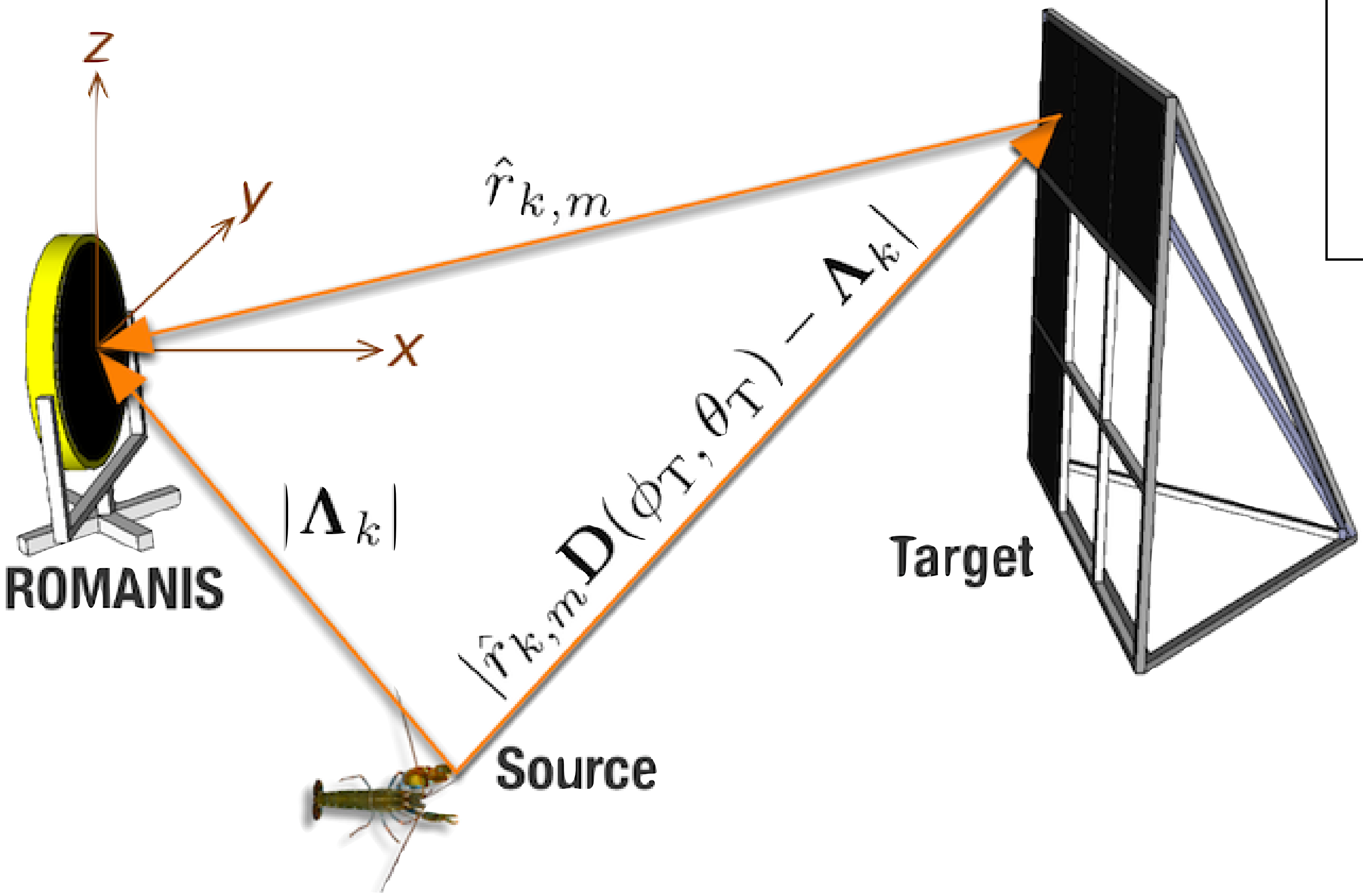


Target at 38m range






Sub Surface Buoy @ 15 m (Ambient)
Elevation in deg
-4 -3 -2 -1 0 1 2 3 4
-8 -6 -4 -2 0
4 3.2 2.4 1.6 0.8 0 -0.8 -1.6 -2.4 -3.2 -4
-8.8 -8 -7.2 -6.4 -5.6 -4.8 -4 -3.2 -2.4 -1.6 -0.8 0 0.8 1.6 2.4 3.2 4 4.8 5.6 6.4 7.2 8 8.8



$\hat{r}_{k,m}$
$|\hat{r}_{k,m}\mathbf{D}(\phi_T,\theta_T) - \mathbf{\Lambda}_k|$
$|\mathbf{\Lambda}_k|$
z
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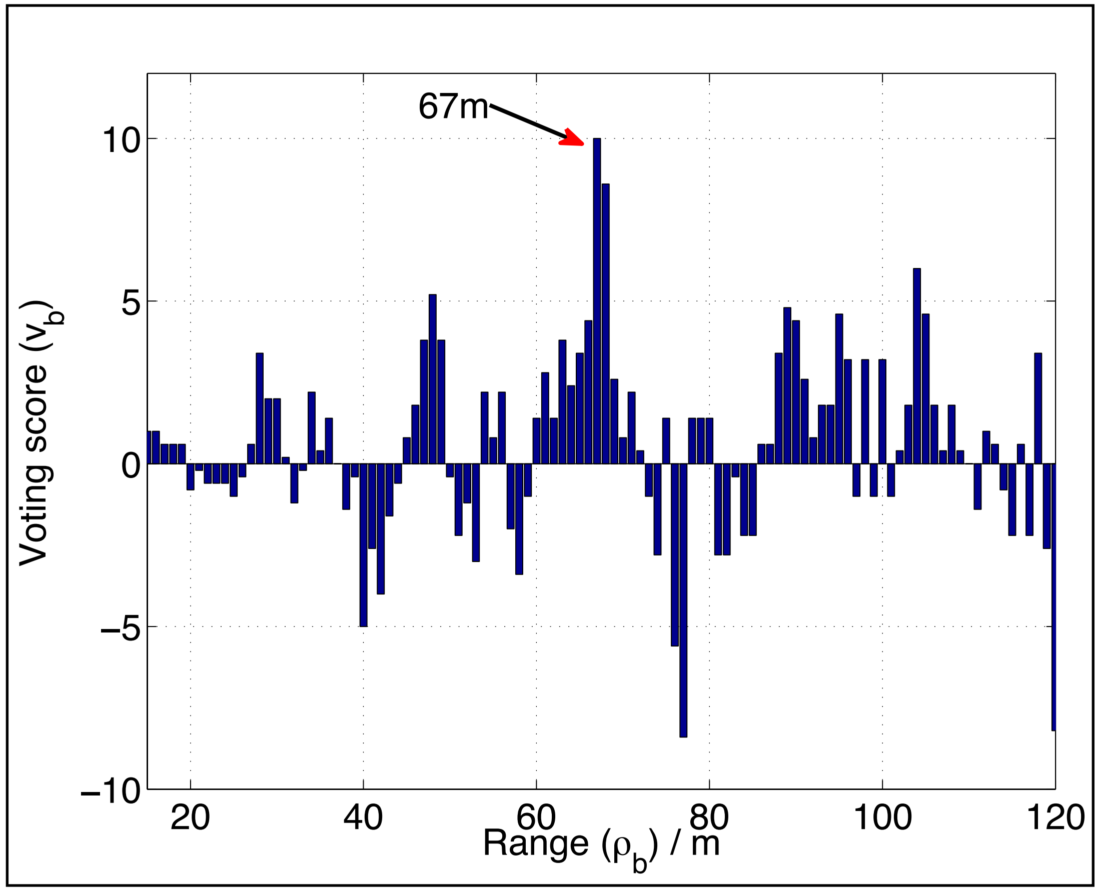
ROMANIS
Target
Source



67m
Voting score (v_b)
Range (ρ_b) / m
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5
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−5
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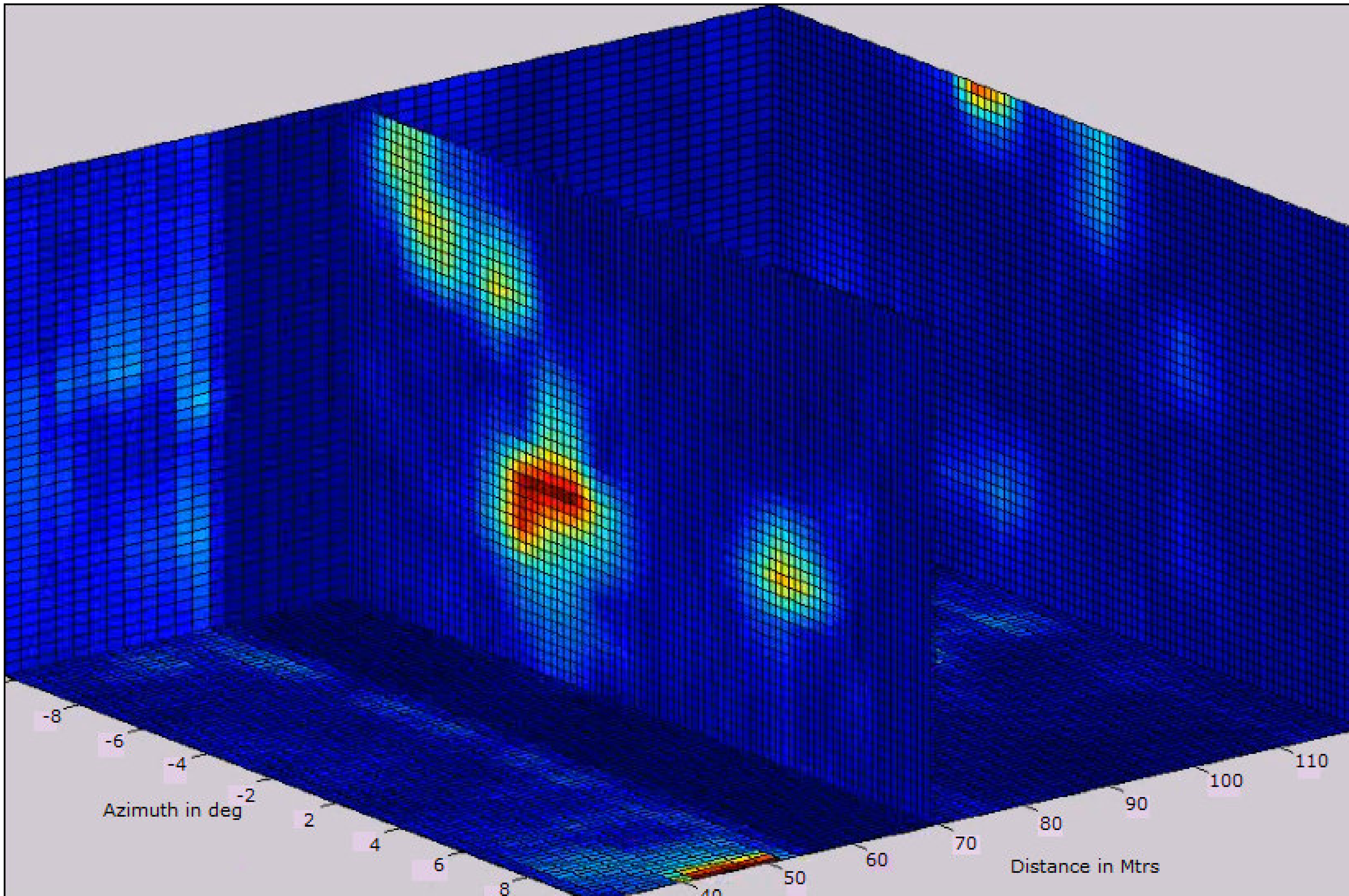

-8
-6
-4
-2
Azimuth in deg
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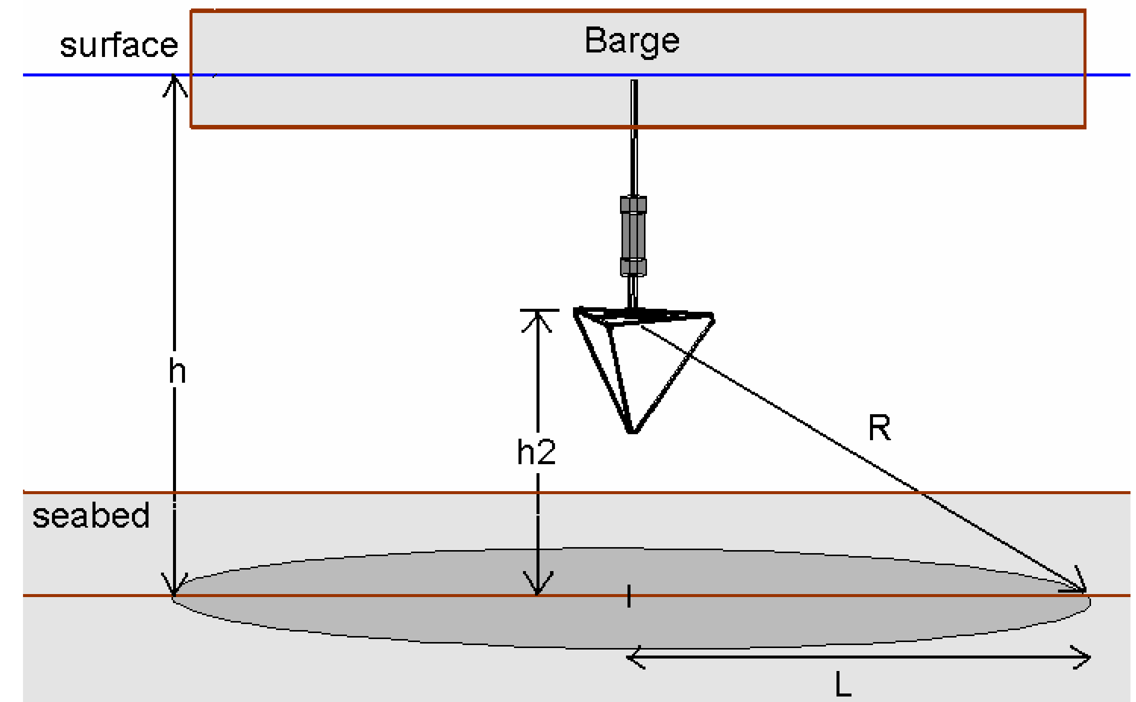
90
100
110
Distance in Mtrs


surface
Barge
h
h2
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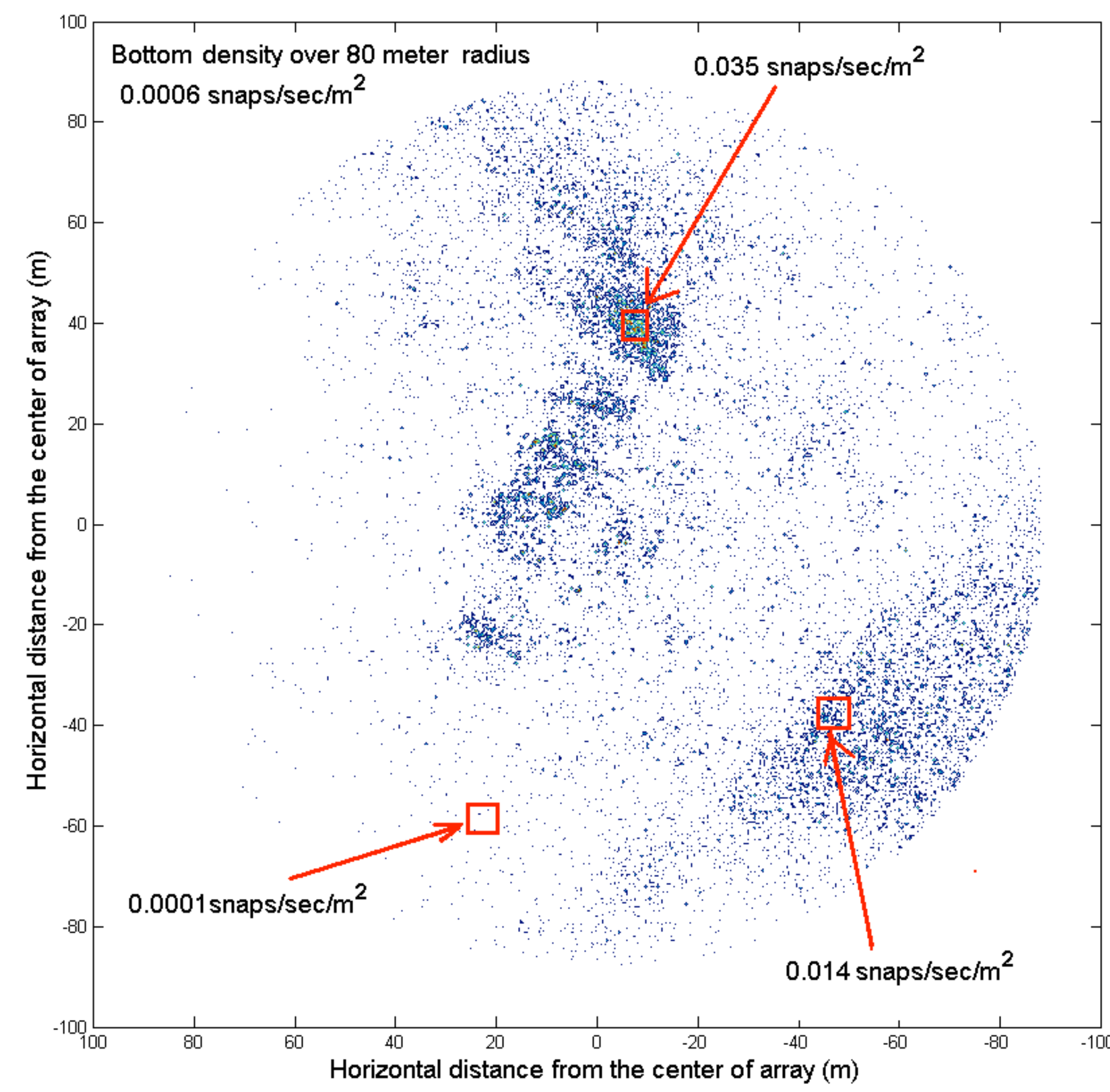
seabed
L


Bottom density over 80 meter radius
0.0006 snaps/sec/m2
0.035 snaps/sec/m2
0.0001snaps/sec/m2
0.014 snaps/sec/m2
Horizontal distance from the center of array (m)
Horizontal distance from the center of array (m)