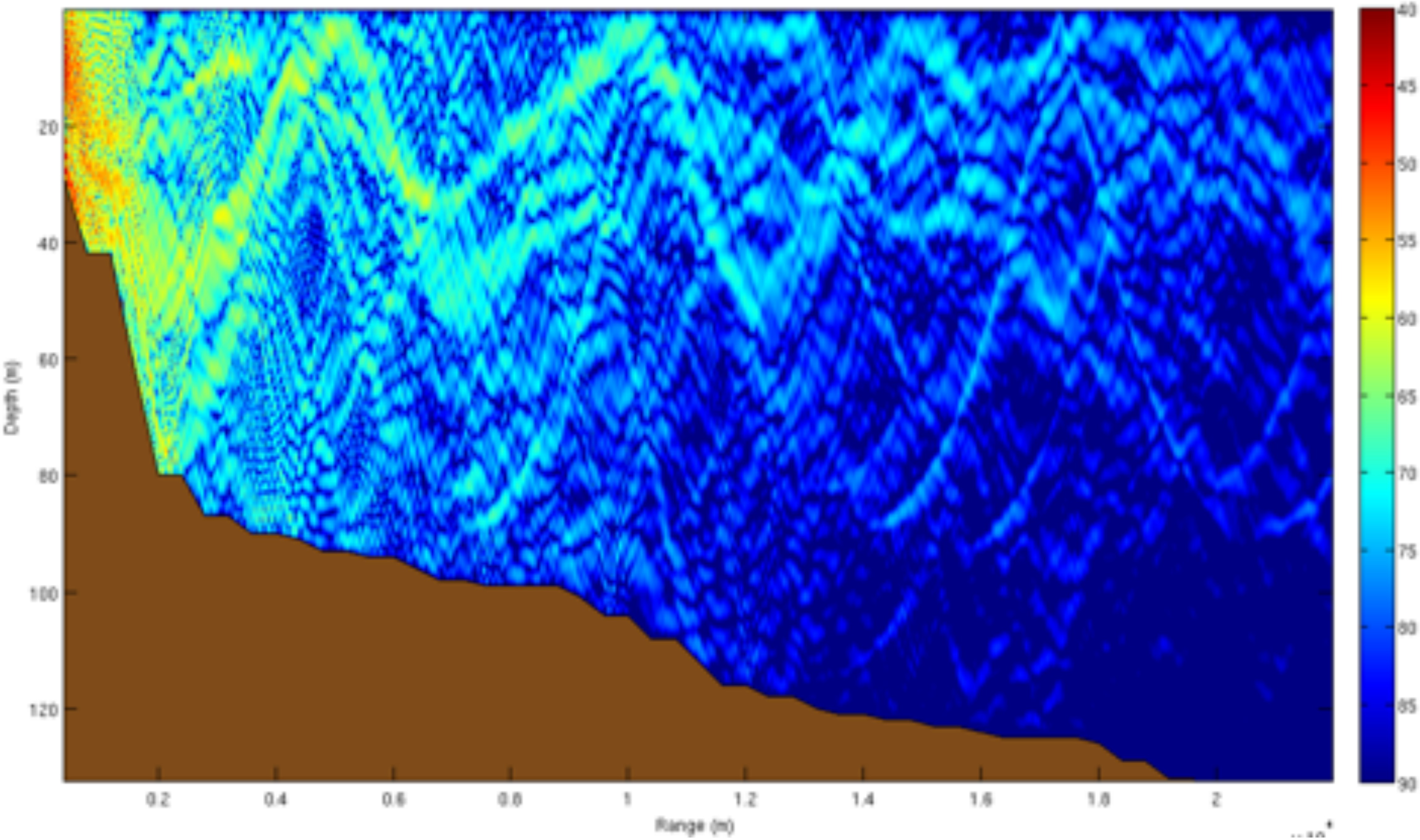
How can we quickly find an underwater acoustic source with a single mobile hydrophone?

Mandar Chitre
Li Kexin

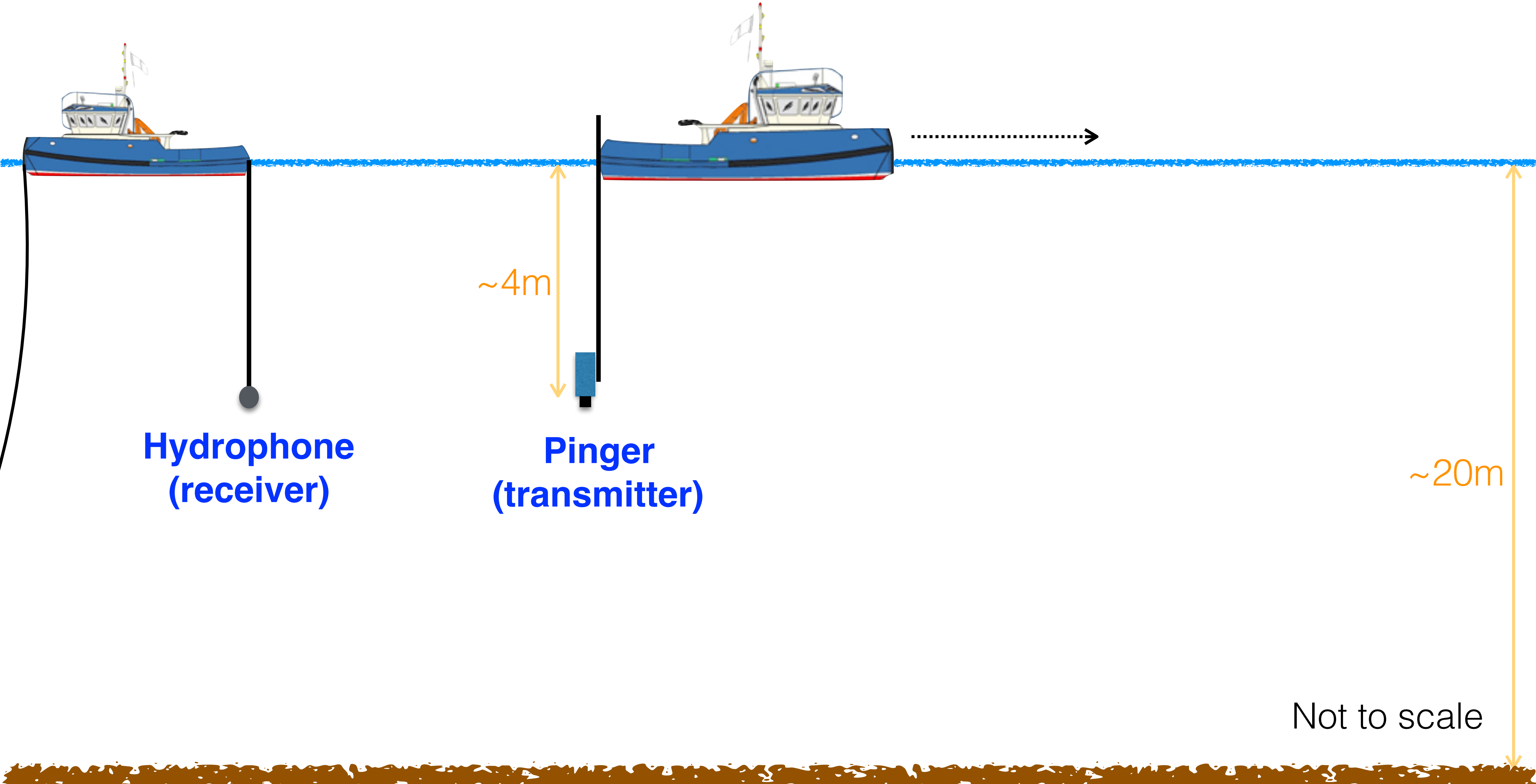
Back in
February 2004…

SWAT 2004 Experiment

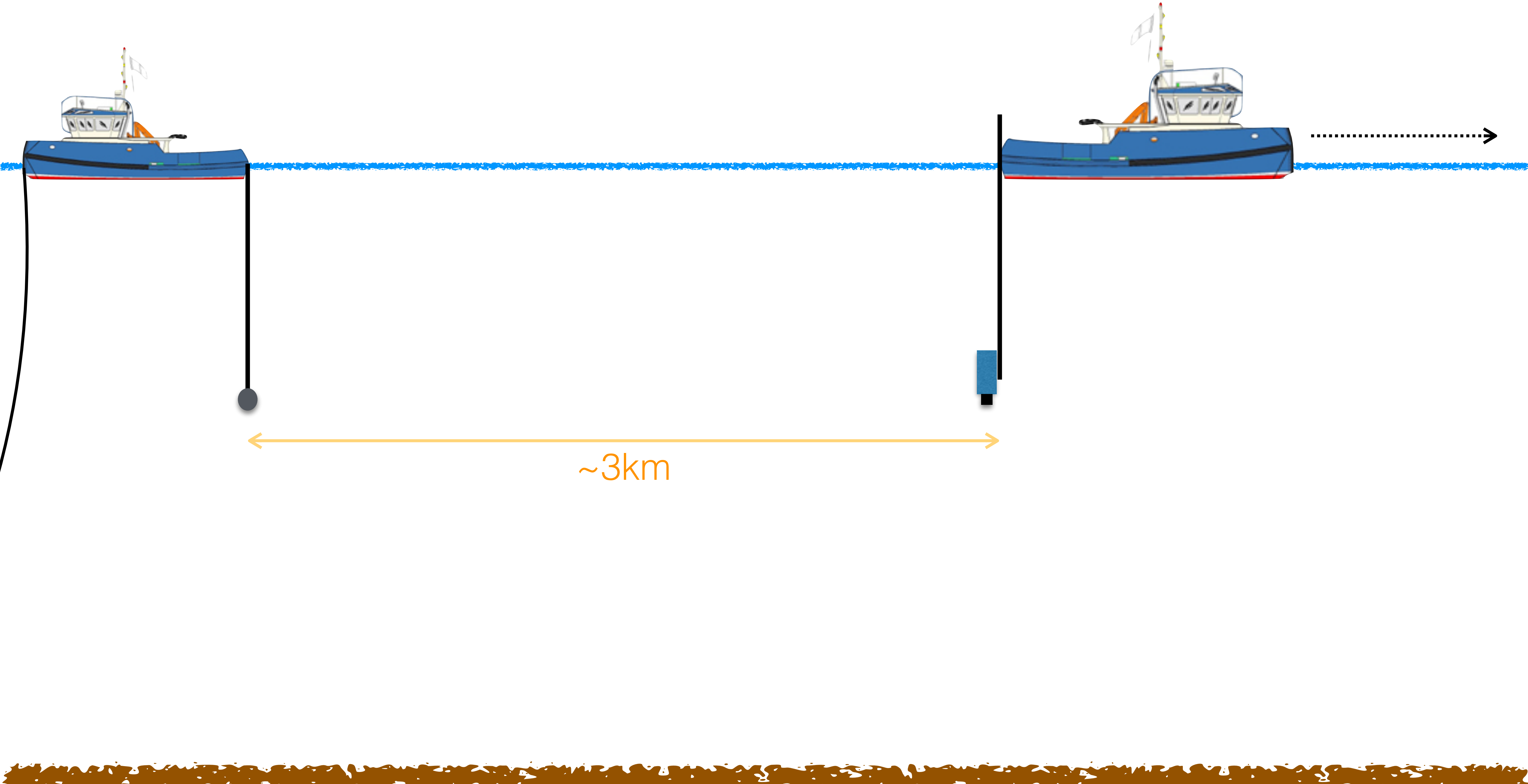
Shallow Water Acoustic Transmission



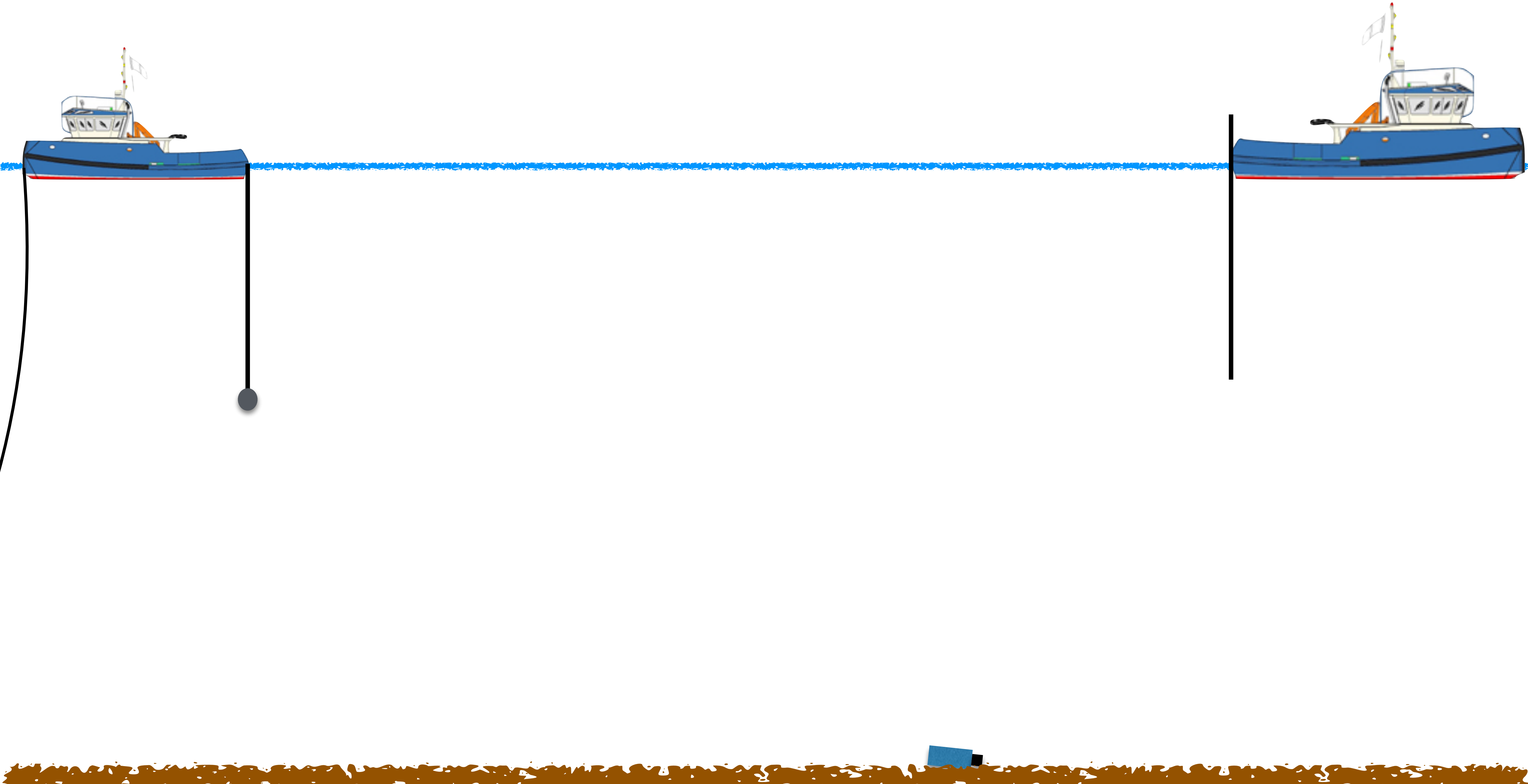
SWAT 2004 Experiment



SWAT 2004 Experiment



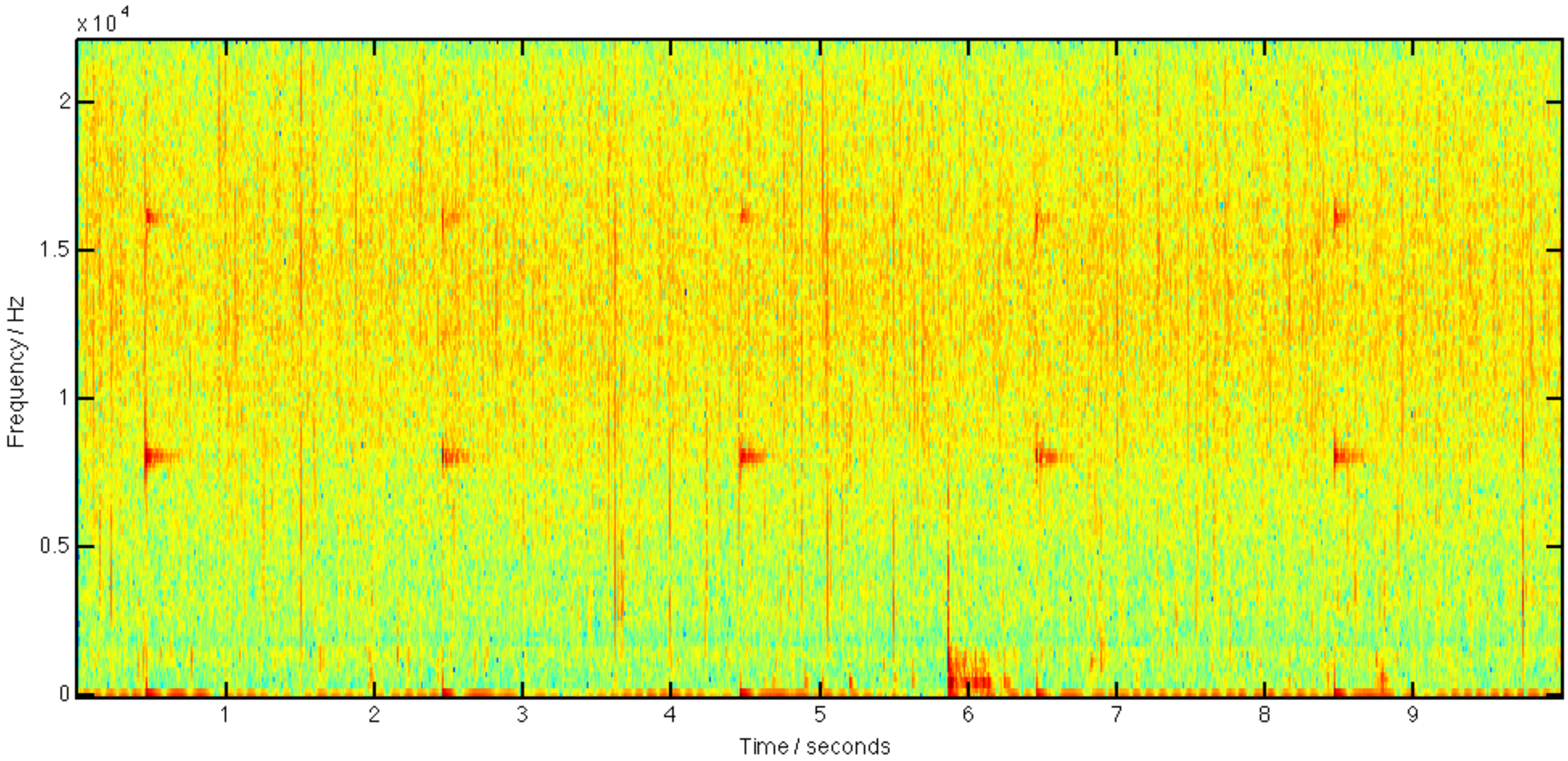
SWAT 2004 Experiment



OnlinE Electronics
Acoustic pinger

Frequency: 8 kHz
Source level: 184 dB re μPa @ 1m
Pulse rate: 5 ms ping, every 2 seconds
Battery life: 3 months

Spectrogram

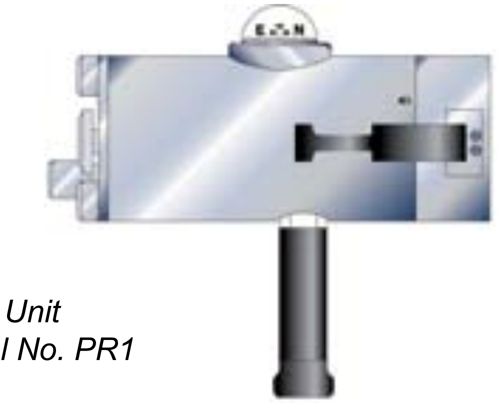


2

OnlinE acoustic pinger receiver system

Diver Operated Pinger Receiver Model No. PR 1

Frequency Range	3 - 97kHz Bandwidth 2kHz, sensitivity 80dB
Hydrophone directivity	Typically 30° between 3dB limits
Battery type	10.8V rechargeable NiCad battery pack
Battery life	30 hours between charges
Charger	110 VAC, 220 V AC adaptor supplied
Operating depth	200m (660ft)
Housing Material	PVC
Housing dimensions	
Length	305mm (12”)
Diameter	114mm (4.5”)
Weight	air: 3/18kg (7 lbs), water: 0.11kg (4oz)



Diver Unit
Model No. PR1

OnlinE Pinger Receiver
Model No. 2001

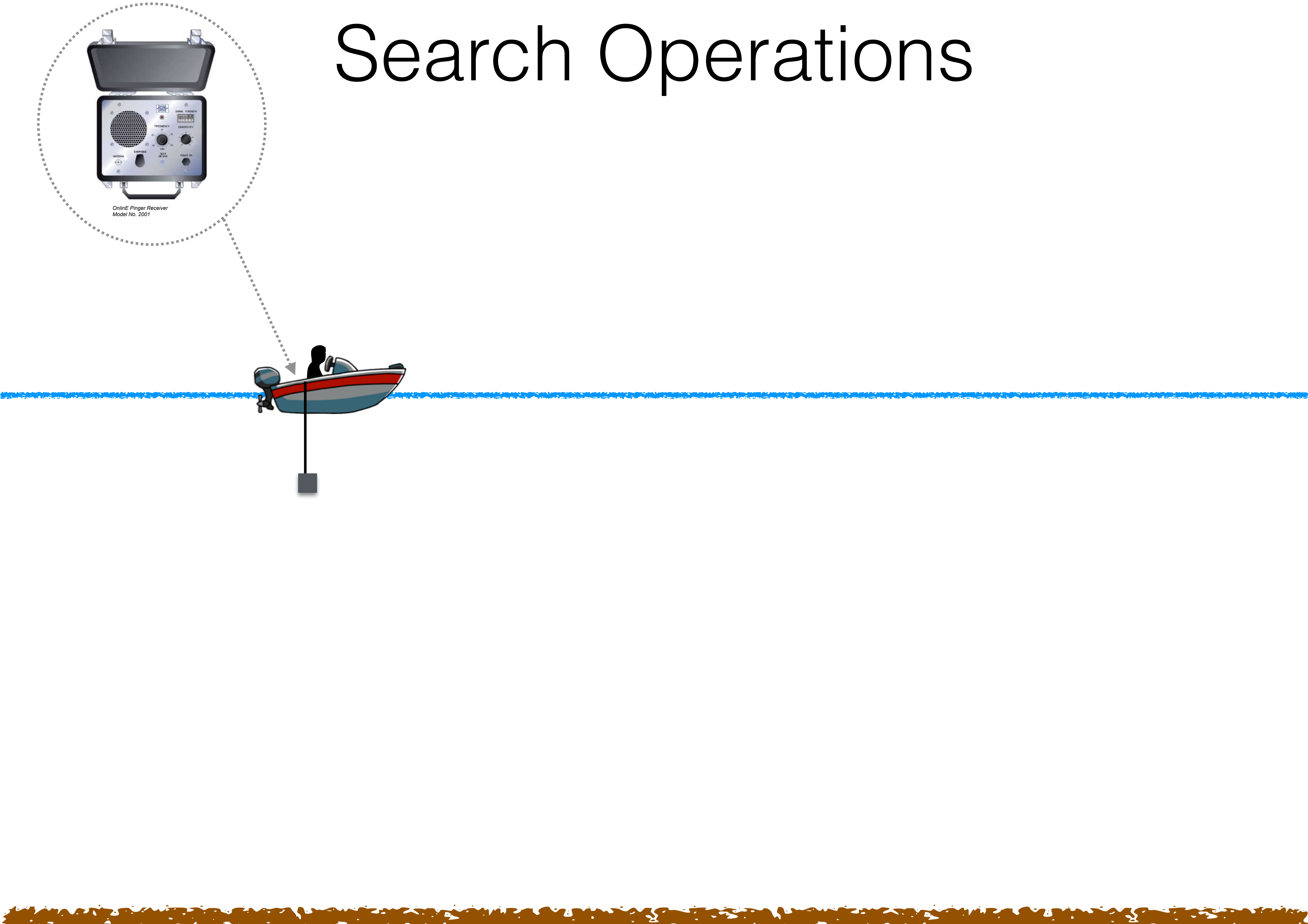
OnlinE Pinger Receiver Model No. 2001

- Excellent sensitivity
- Easy to Operate
- Speaker emits both signal and background noise allowing greater operator selectivity
- Built in system test. Displays battery voltage on a signal strength meter and turns on internal pinging signal source for receiver checkout and calibration
- Water tight floating plastic cabinet
- Splash proof front panel
- Rugged
- 50m hydrophone cable assembly
- 100% electrical screening

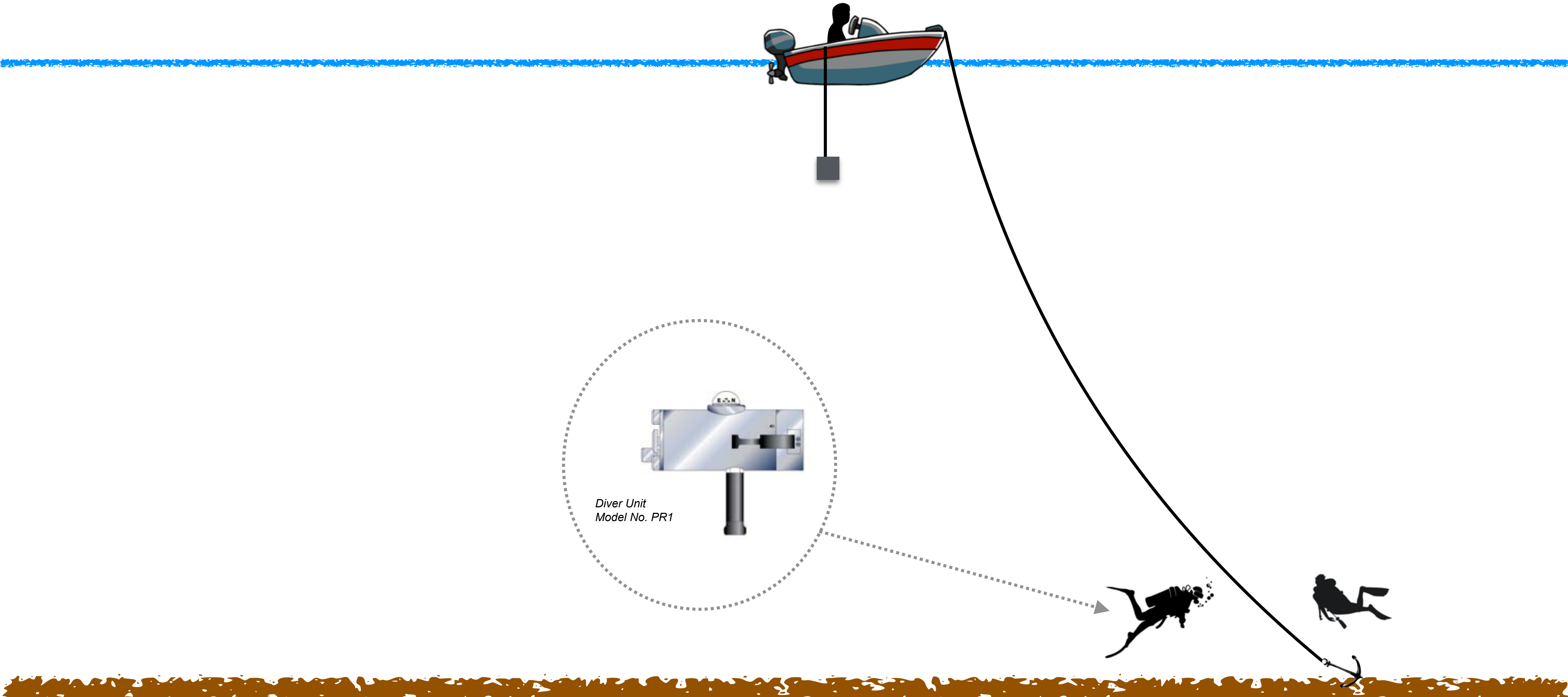
Specifications

Operating frequency	8kHz to 50kHz
Sensitivity	0.5μ VRMS
Intermediate frequency	60kHz
Battery life	150 hours continuous
Power Source	12V DC (8 ‘D’ size Alkaline cells)
Dimensions	
Height	241mm (9.5”)
Width	267mm (10.5”)
Depth	178mm (7”)
Weight	4.5kgs (10lbs)
Cabinet material	Polypropylene
Included with the receiver	50m hydrophone cable assembly, Headset Manual and Batteries

Search Operations



Search Operations

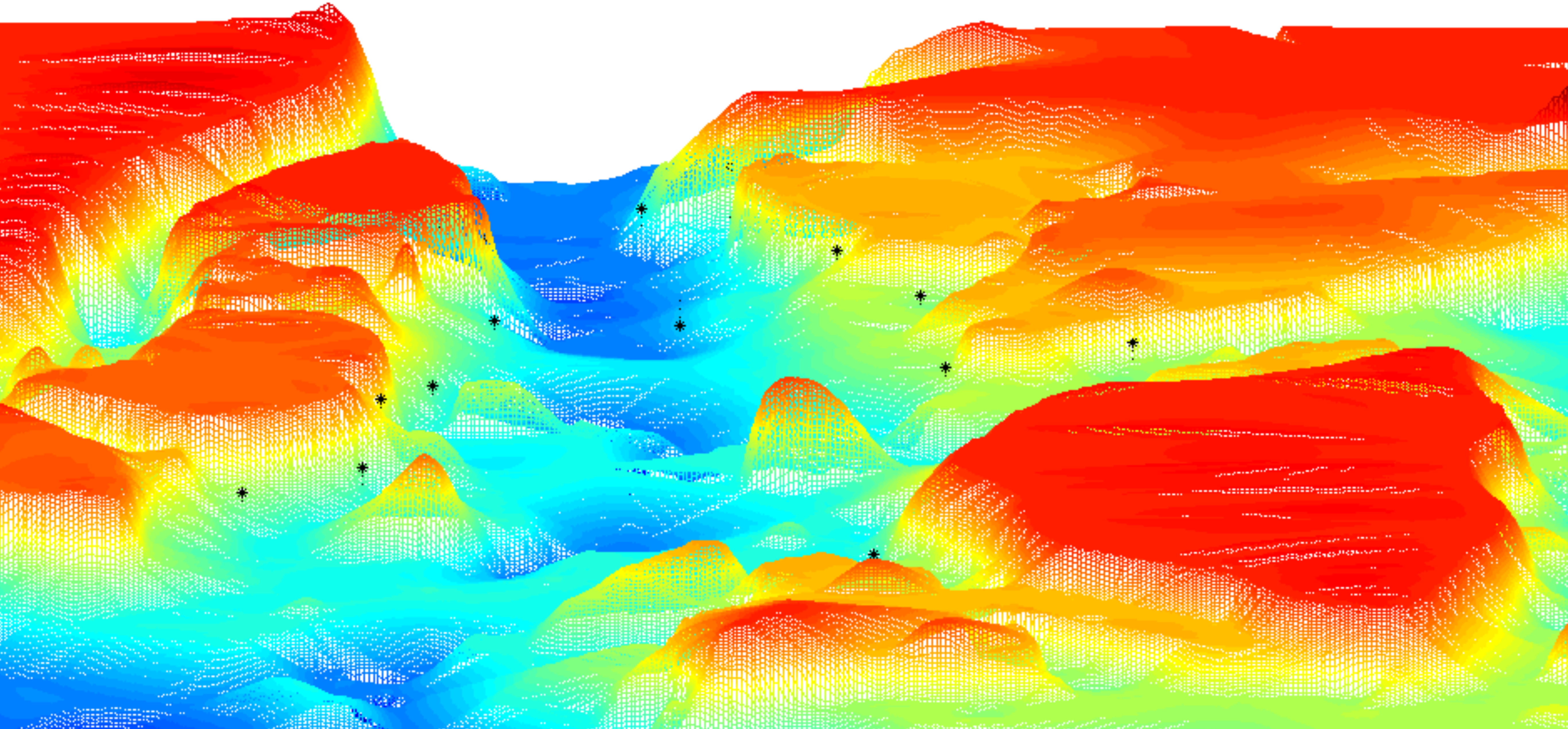


A week later…

No success!

Challenges

- Complex acoustic propagation environment



Challenges

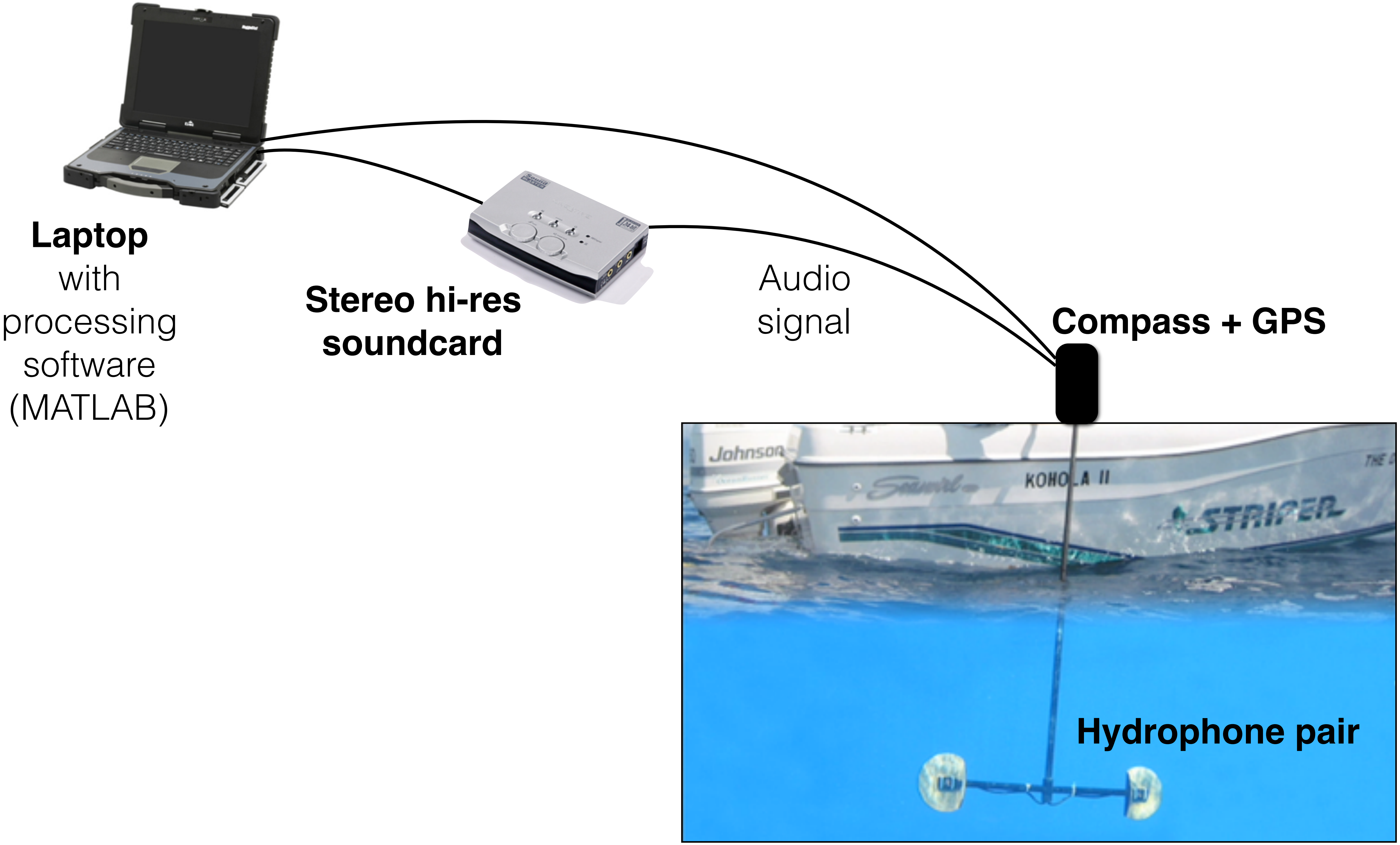
- Complex acoustic propagation environment
- Strong currents:
  - Pinger location may change
  - Difficult boat operations
  - Limited dive window
- Soft sediment (possible burial)
- Poor underwater visibility for search operations

AquaHead

Pack, Potter, Herman, Hoffmann-Kuhnt, Deakos, “Determining Source Levels Sound Fields and Body Sizes of Singing Humpback Whales (Megaptera novaeangliae) in the Hawaiian Winter Ground”, 2003.

Manual system

Automated Localization System



Laptop
with
processing
software
(MATLAB)

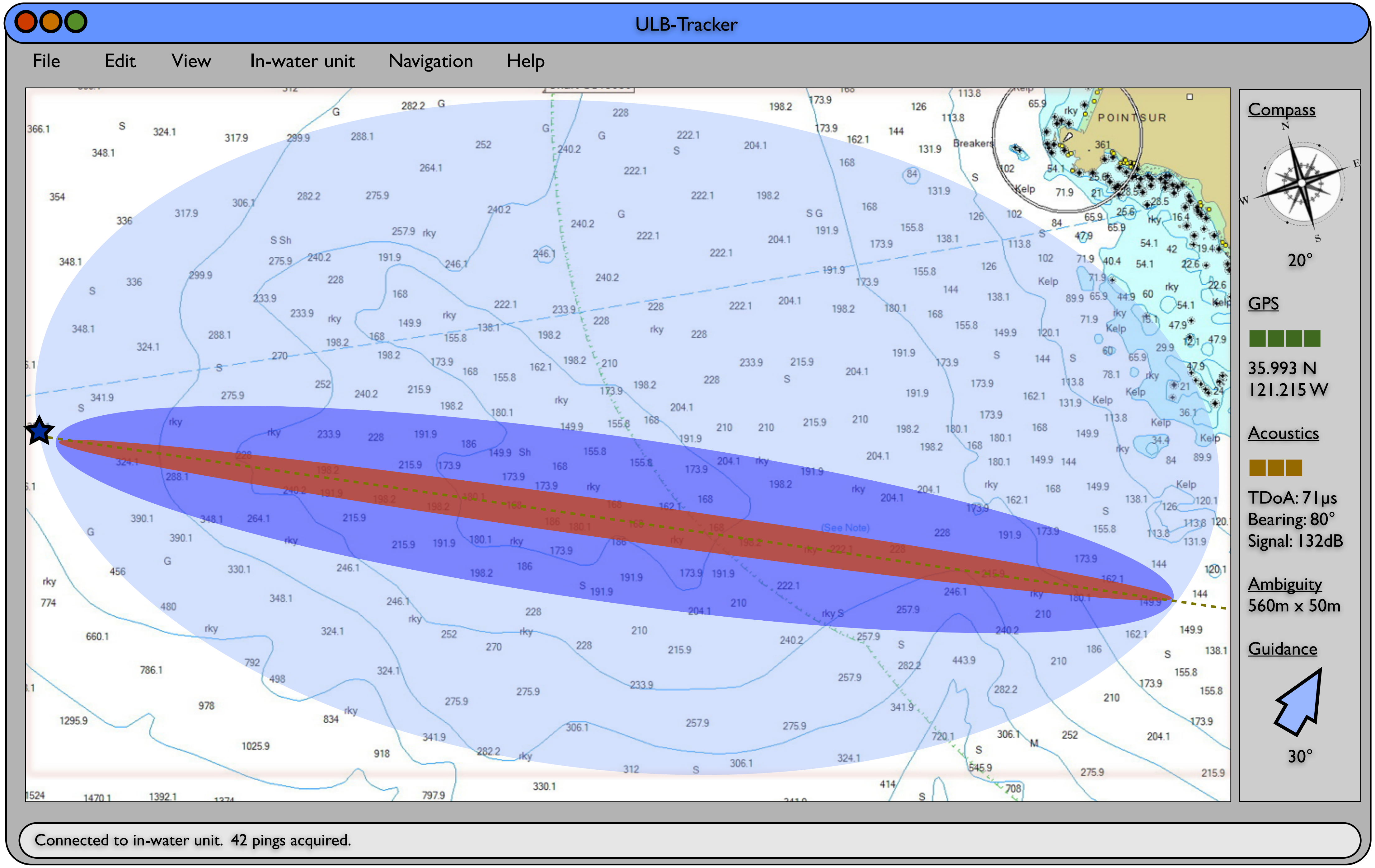
Stereo hi-res soundcard

Audio
signal

Compass + GPS

Hydrophone pair

Automated Localization System



Compass

20°

GPS

🟩🟩🟩🟩

35.993 N
121.215 W

Acoustics

🟫🟫🟫

TDoA: 71μs
Bearing: 80°
Signal: 132dB

Ambiguity
560m x 50m

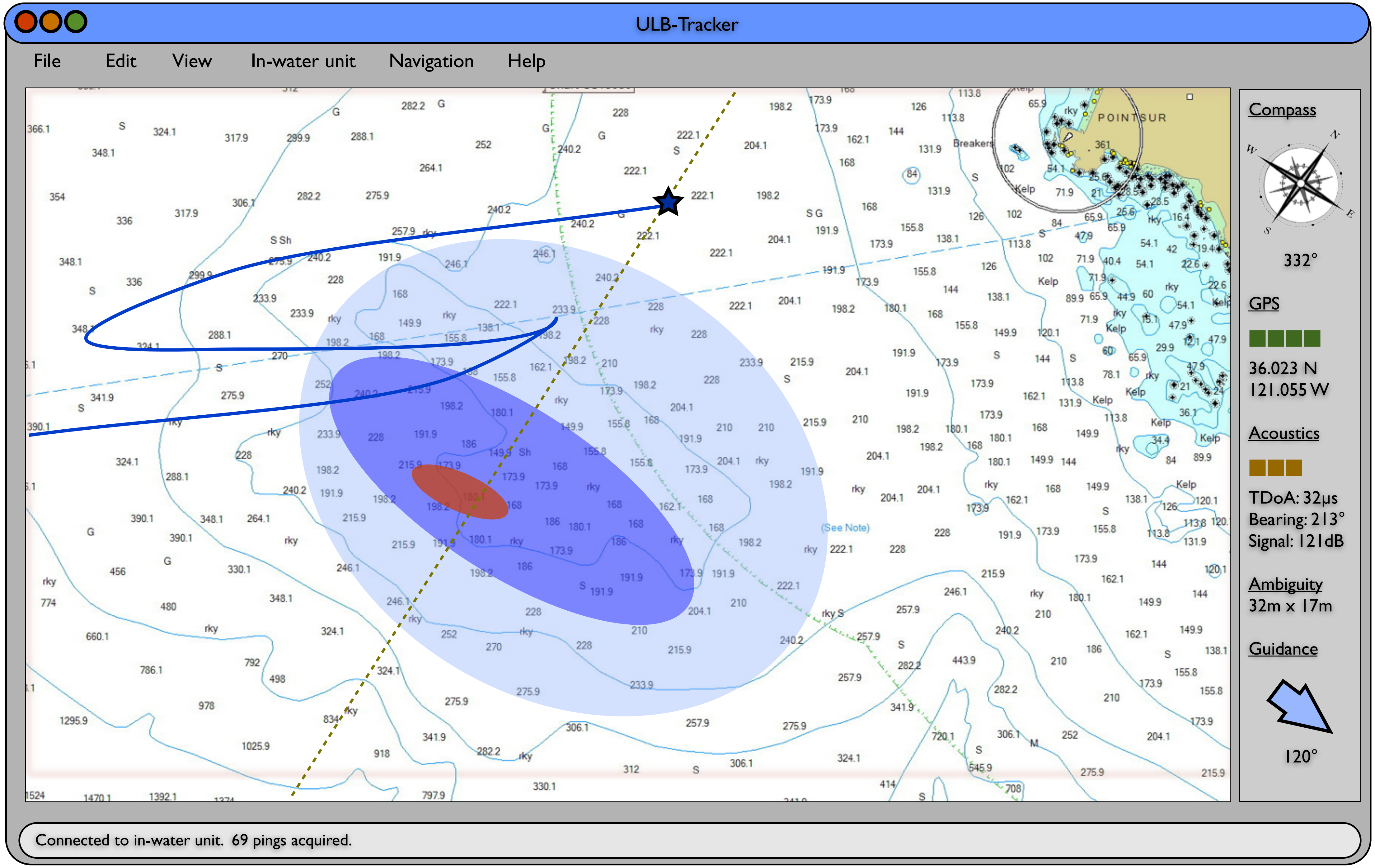
Guidance

30°

Connected to in-water unit. 42 pings acquired.

Concept Illustration

Automated Localization System



Compass
332°

GPS
36.023 N
121.055 W

Acoustics
TDoA: 32μs
Bearing: 213°
Signal: 121dB

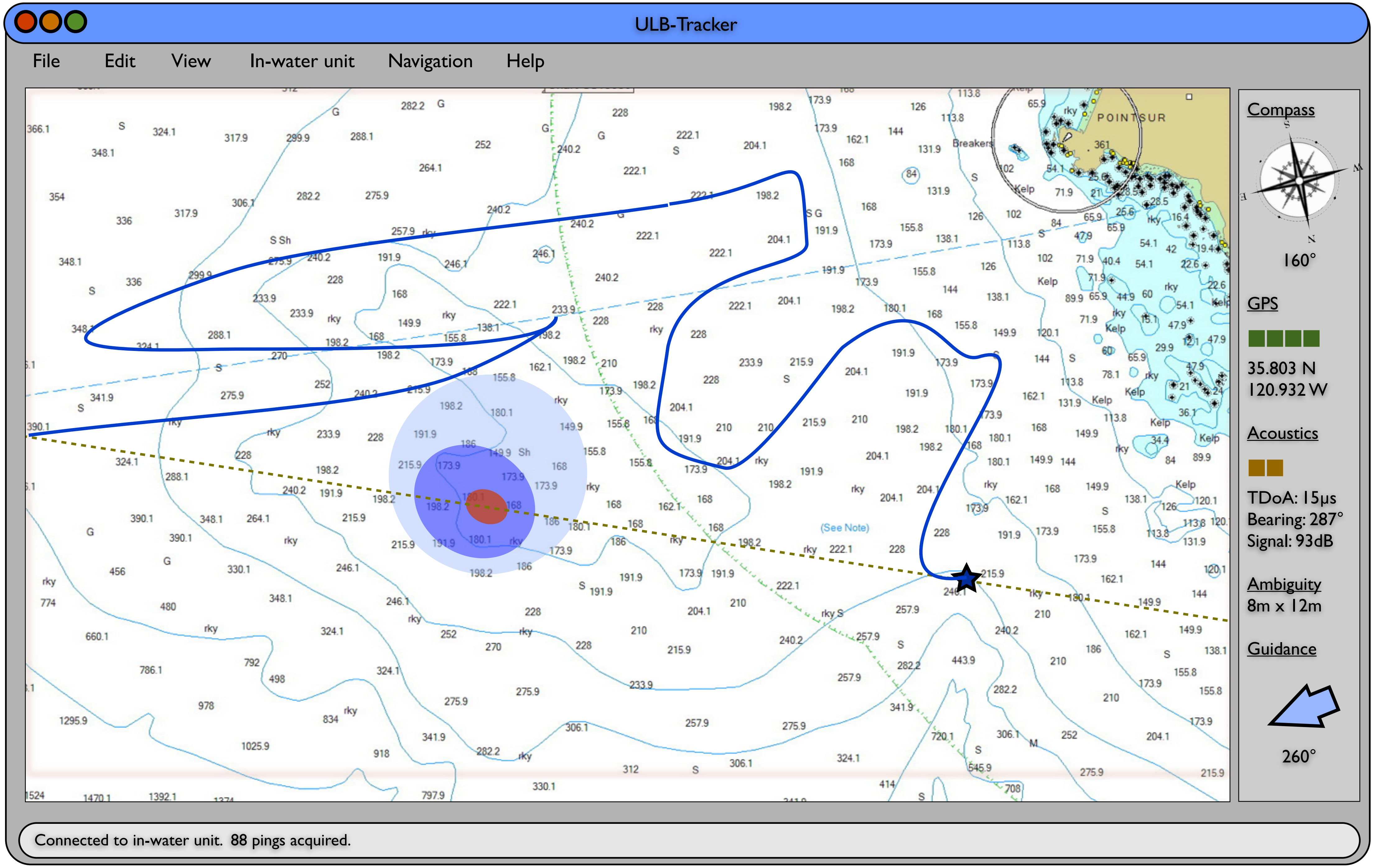
Ambiguity
32m x 17m

Guidance
120°

Connected to in-water unit. 69 pings acquired.

Concept Illustration

Automated Localization System



Compass

160°

GPS

🟩🟩🟩🟩

35.803 N
120.932 W

Acoustics

🟫🟫

TDoA: 15μs
Bearing: 287°
Signal: 93dB

Ambiguity

8m x 12m

Guidance

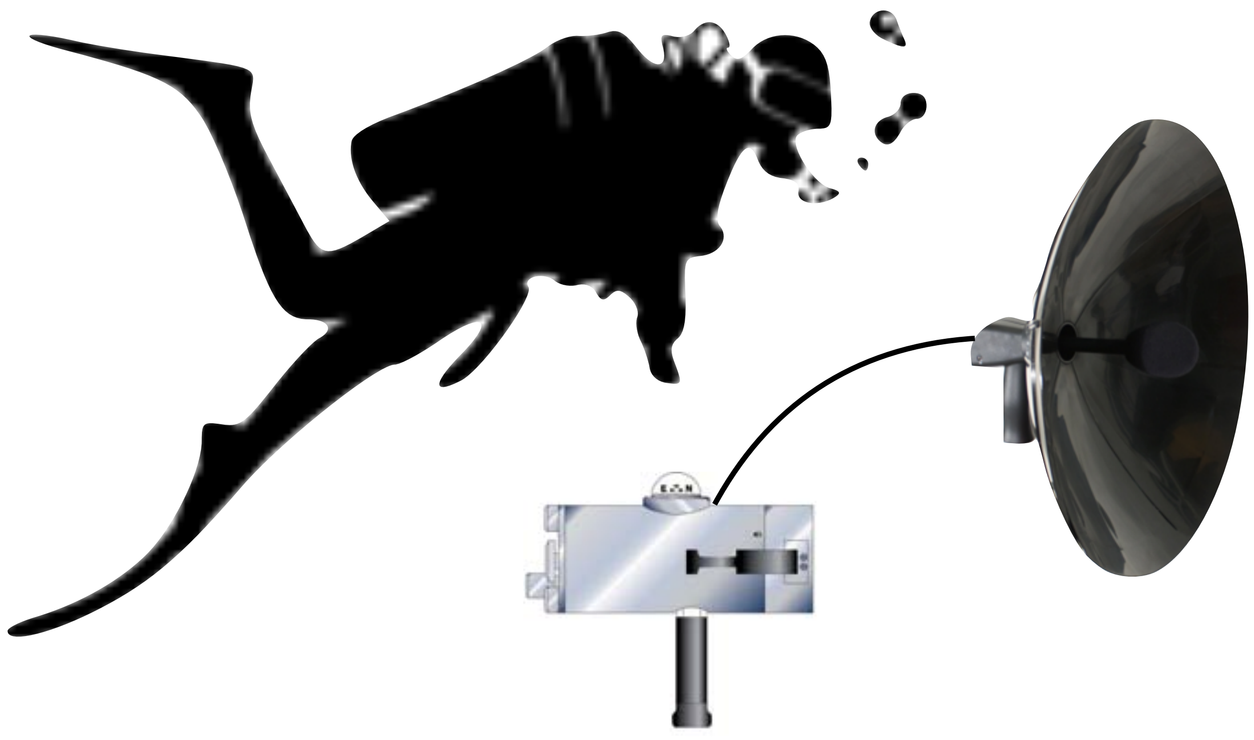
260°

Connected to in-water unit. 88 pings acquired.

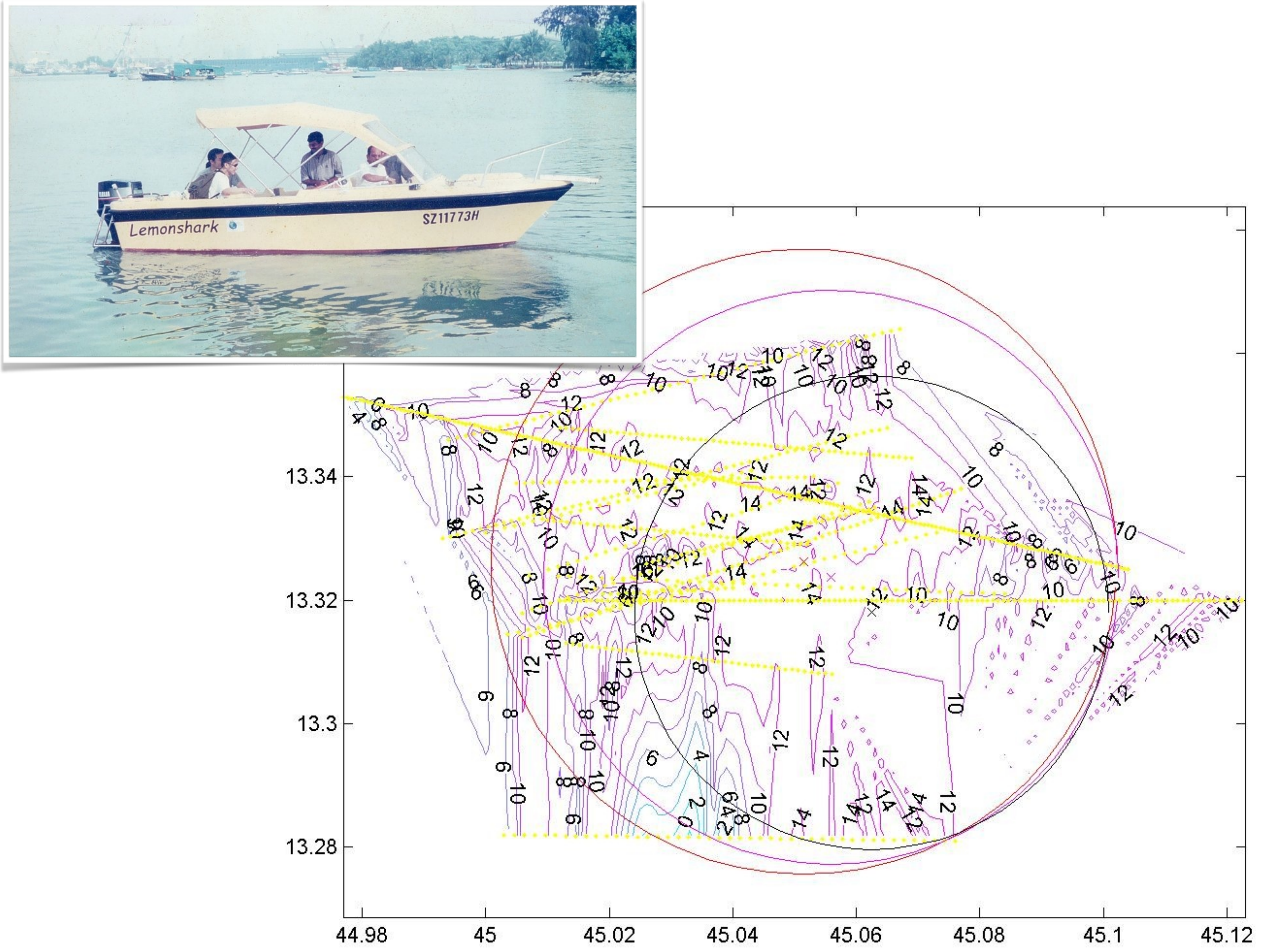
Concept Illustration

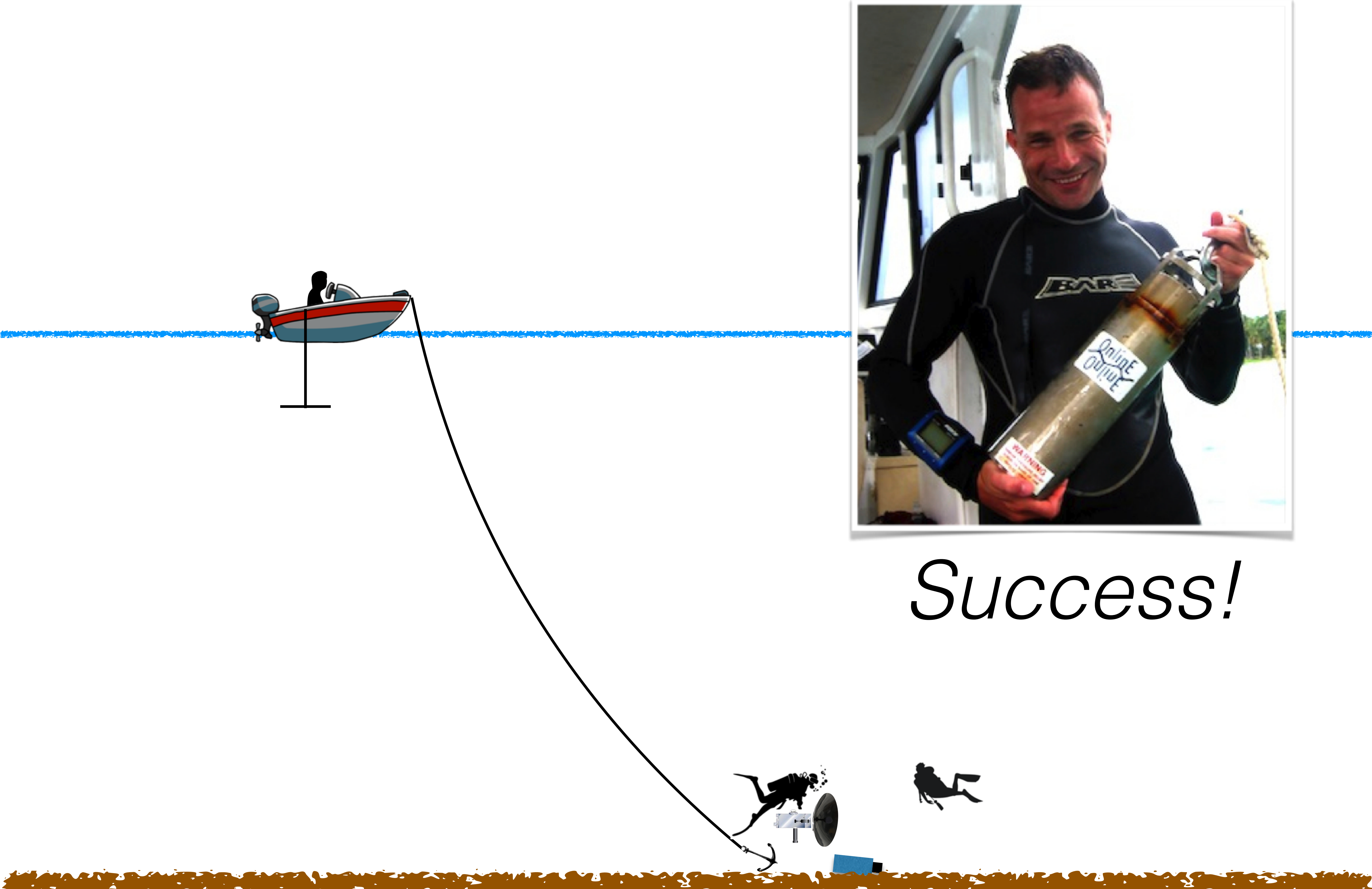
Diver-held Directional Dish

for enhanced underwater direction-finding



Another week later…

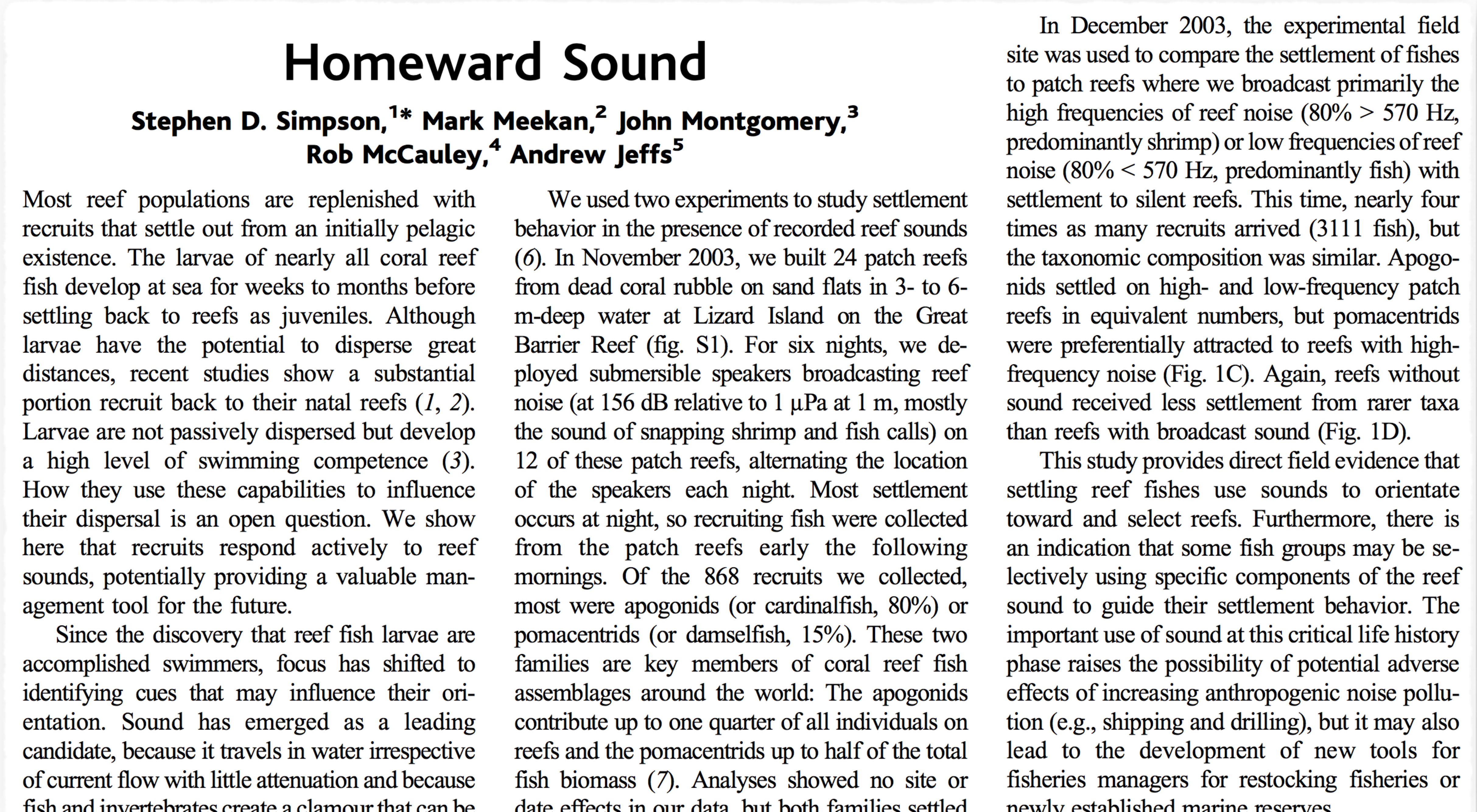

Lemonshark
SZ11773H
13.34
13.32
13.3
13.28
44.98
45
45.02
45.04
45.06
45.08
45.1
45.12



Success!

2 years later…

S. D. Simpson, M. Meekan, J. Montgomery, R. McCauley, and A. Jeffs. Homeward sound. *Science*, 308(5719):221, 2005.



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

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 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.

- The larvae of most 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, a substantial portion recruit back to their natal reefs
- Larvae are not passively dispersed but develop a high level of swimming competence
- Recruits respond actively to reef sounds

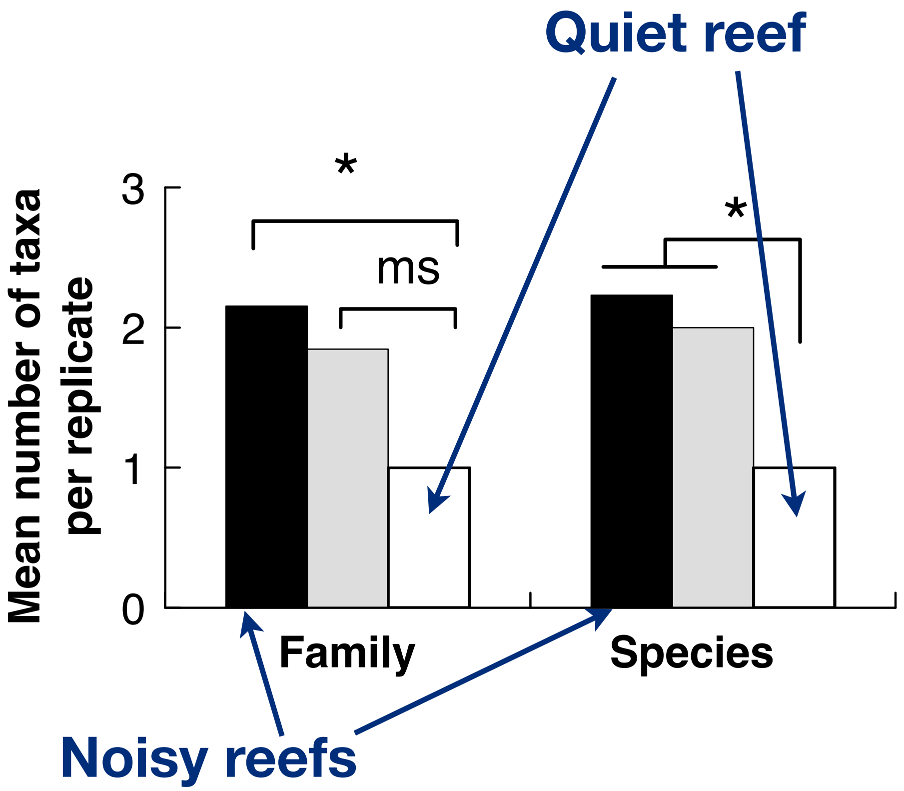
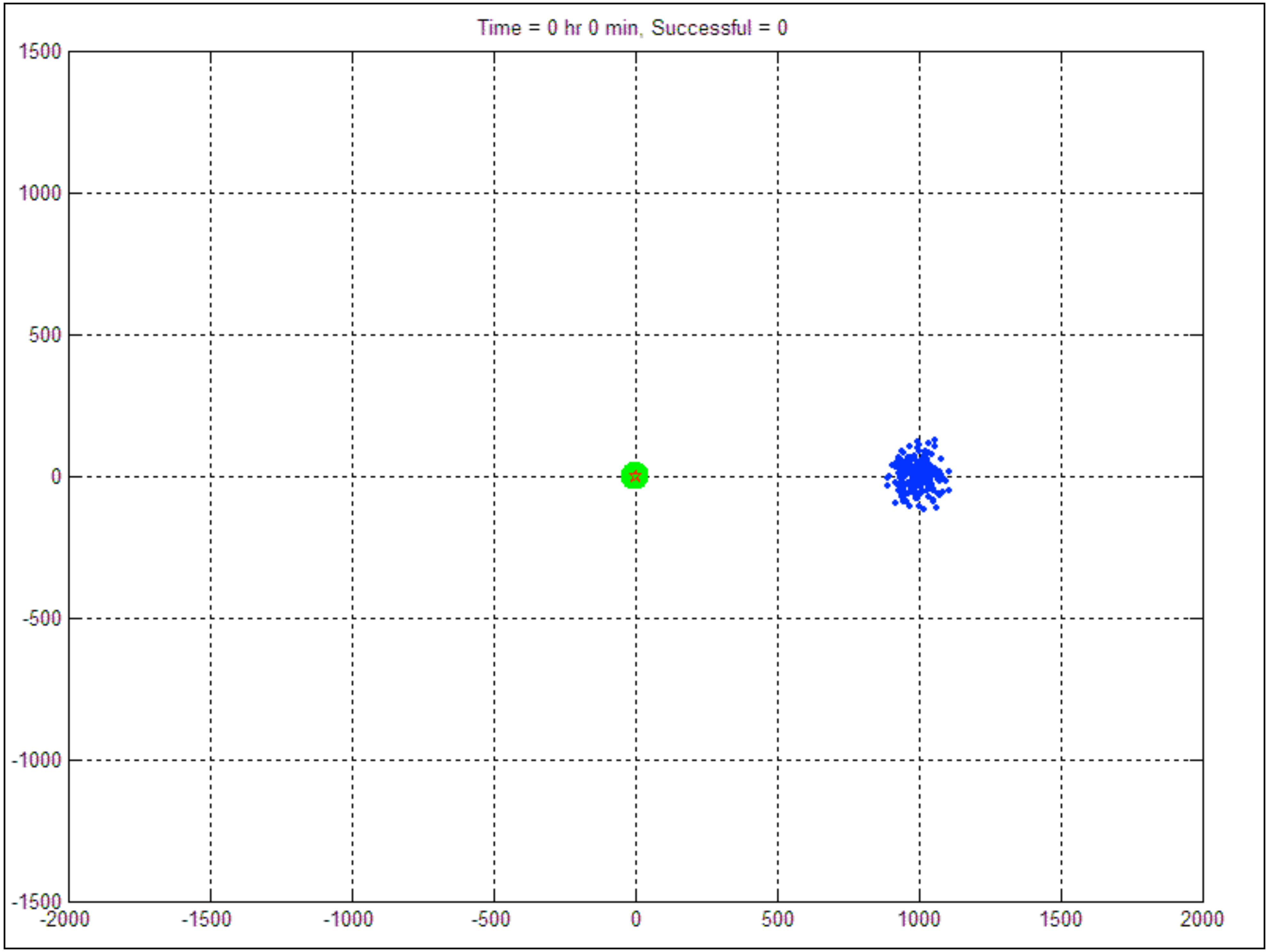
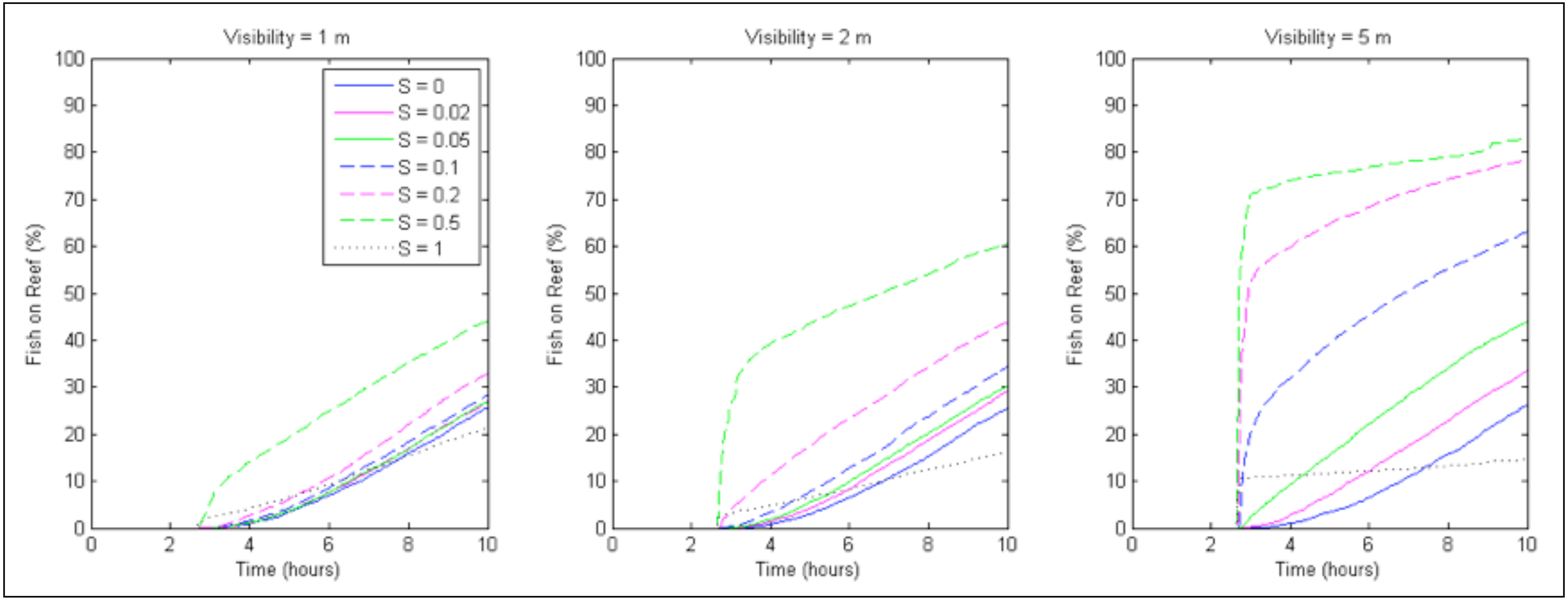


Figure reproduced from:

S. D. Simpson, M. Meekan, J. Montgomery, R. McCauley, and A. Jeffs. Homeward sound. *Science*, 308(5719):221, 2005.

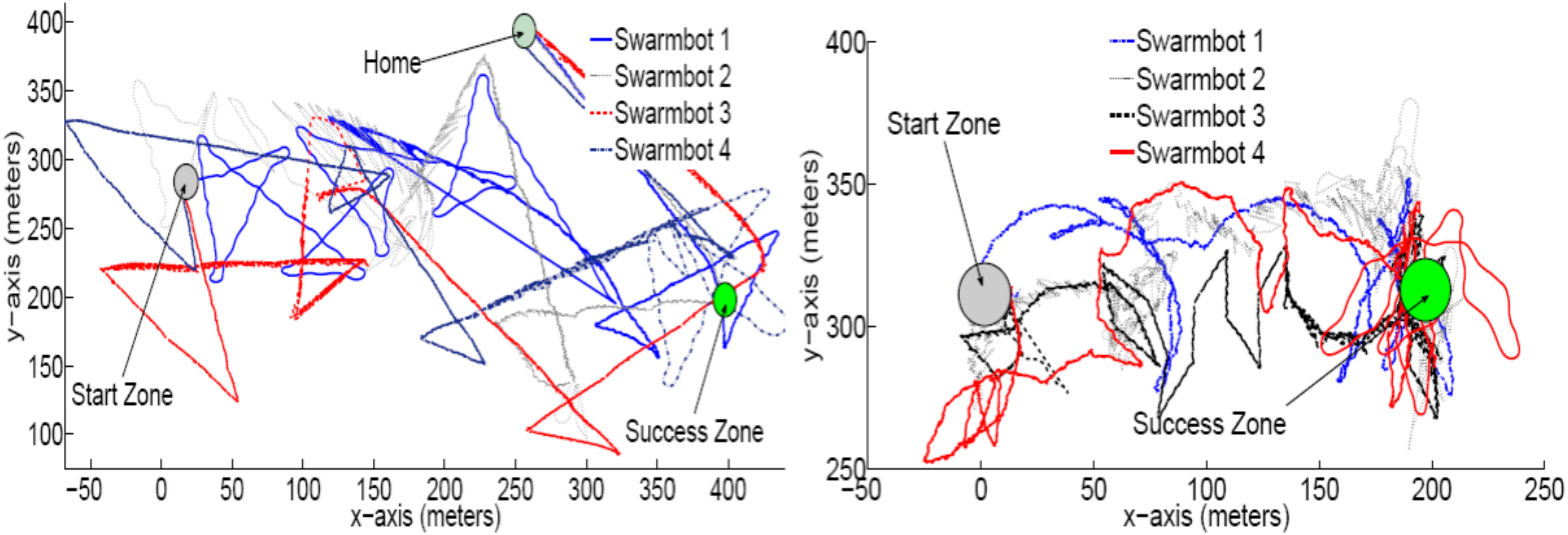
J. R. Potter and M. A. Chitre. Do fish fry use emergent behaviour in schools to find coral reefs by sound? In *AGU Ocean Sciences Meeting*, Honolulu, Hawaii, February 2006.





Visibility = 1 m
Visibility = 2 m
Visibility = 5 m
Fish on Reef (%)
Time (hours)
0
10
20
30
40
50
60
70
80
90
100
0
2
4
6
8
10
S = 0
S = 0.02
S = 0.05
S = 0.1
S = 0.2
S = 0.5
S = 1

SwarmBots



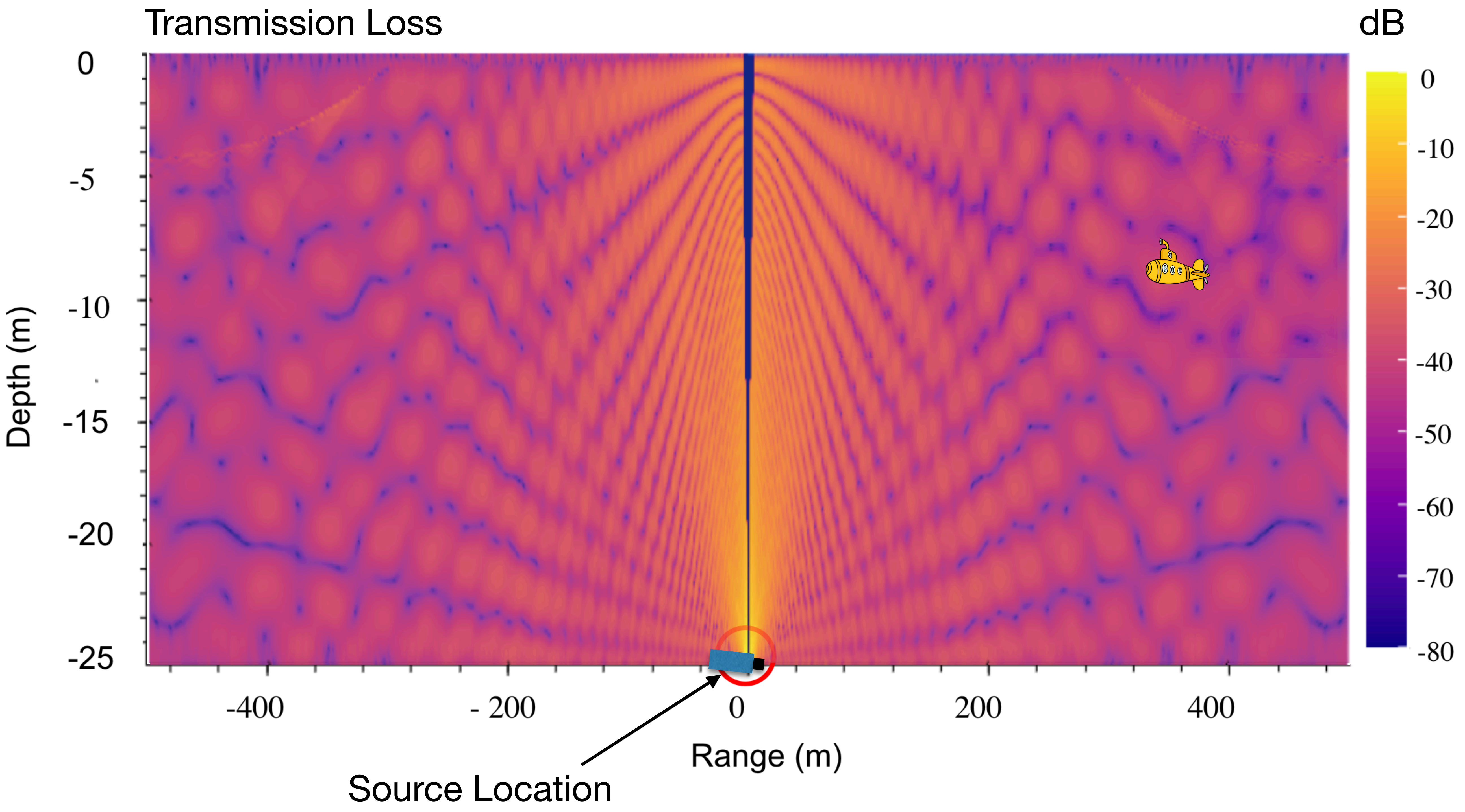
M. Chitre and M. Shaukat, “Bio-inspired algorithms for distributed control of small teams of low-cost aquatic robots,” in International Conference on Robotics and Automation (ICRA) 2015 Workshop on Persistent Autonomy for Aquatic Robotics: the Role of Control and Learning in Single and Multi-Robot Systems, (Seattle, USA), May 2015.

Today…

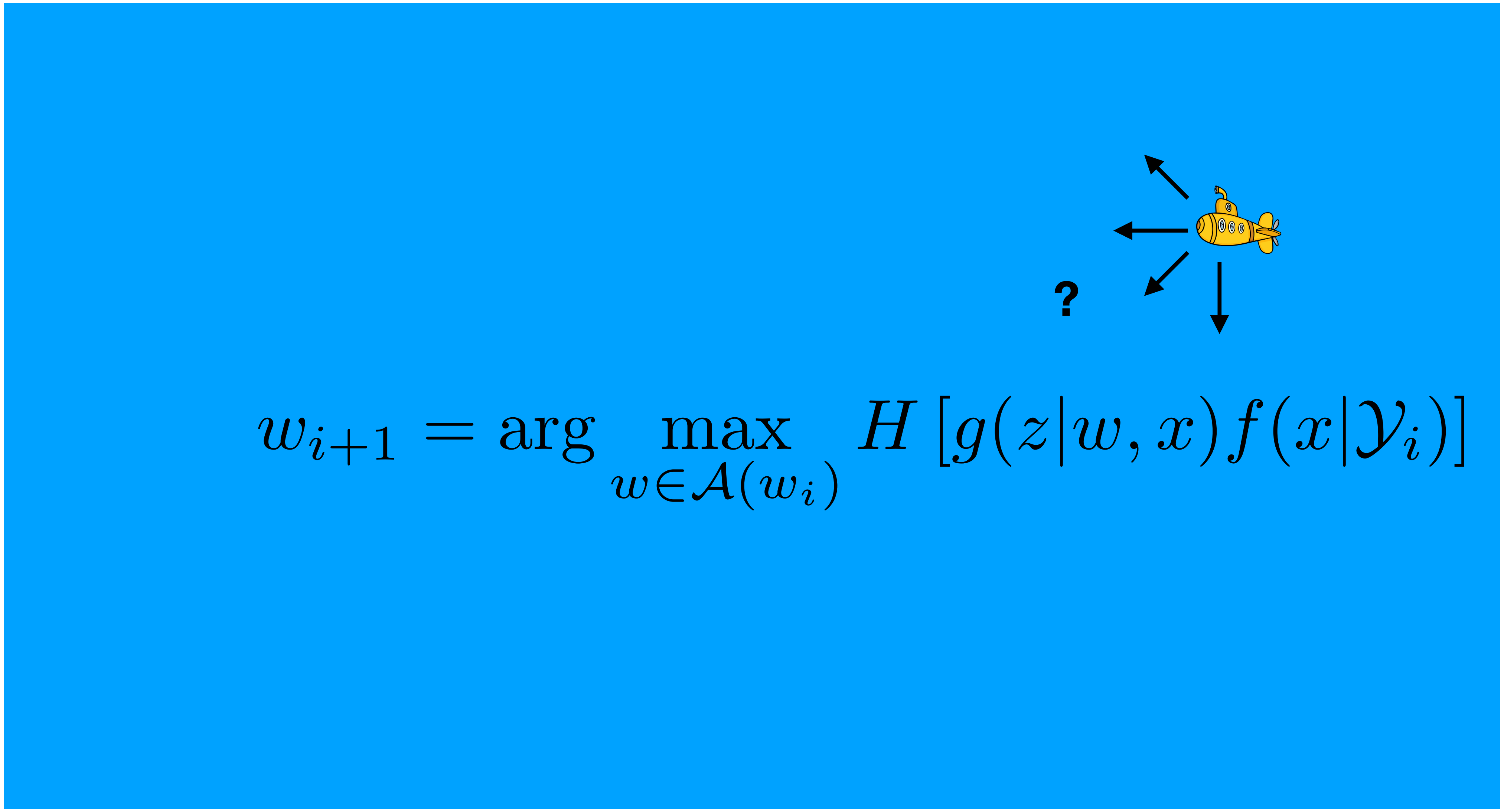
Problem Statement

- Underwater sound source localization
- Sound intensity measurements using single hydrophone on an AUV
- Known environment
- Adaptive path planning to find source quickly

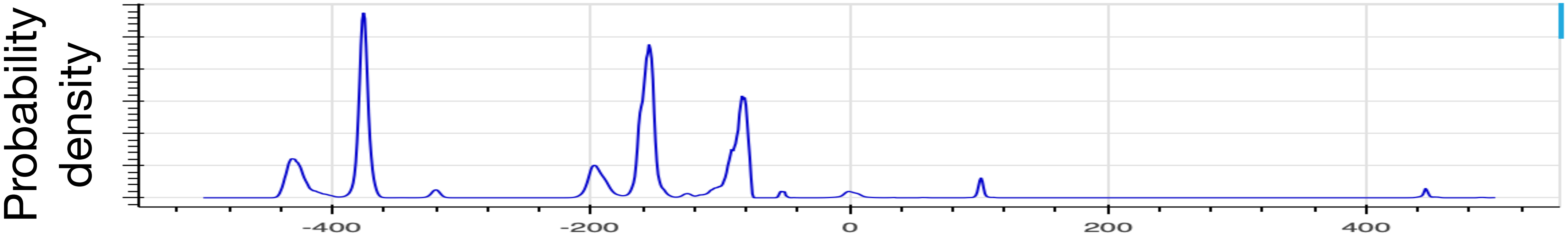
Matched Field Processing



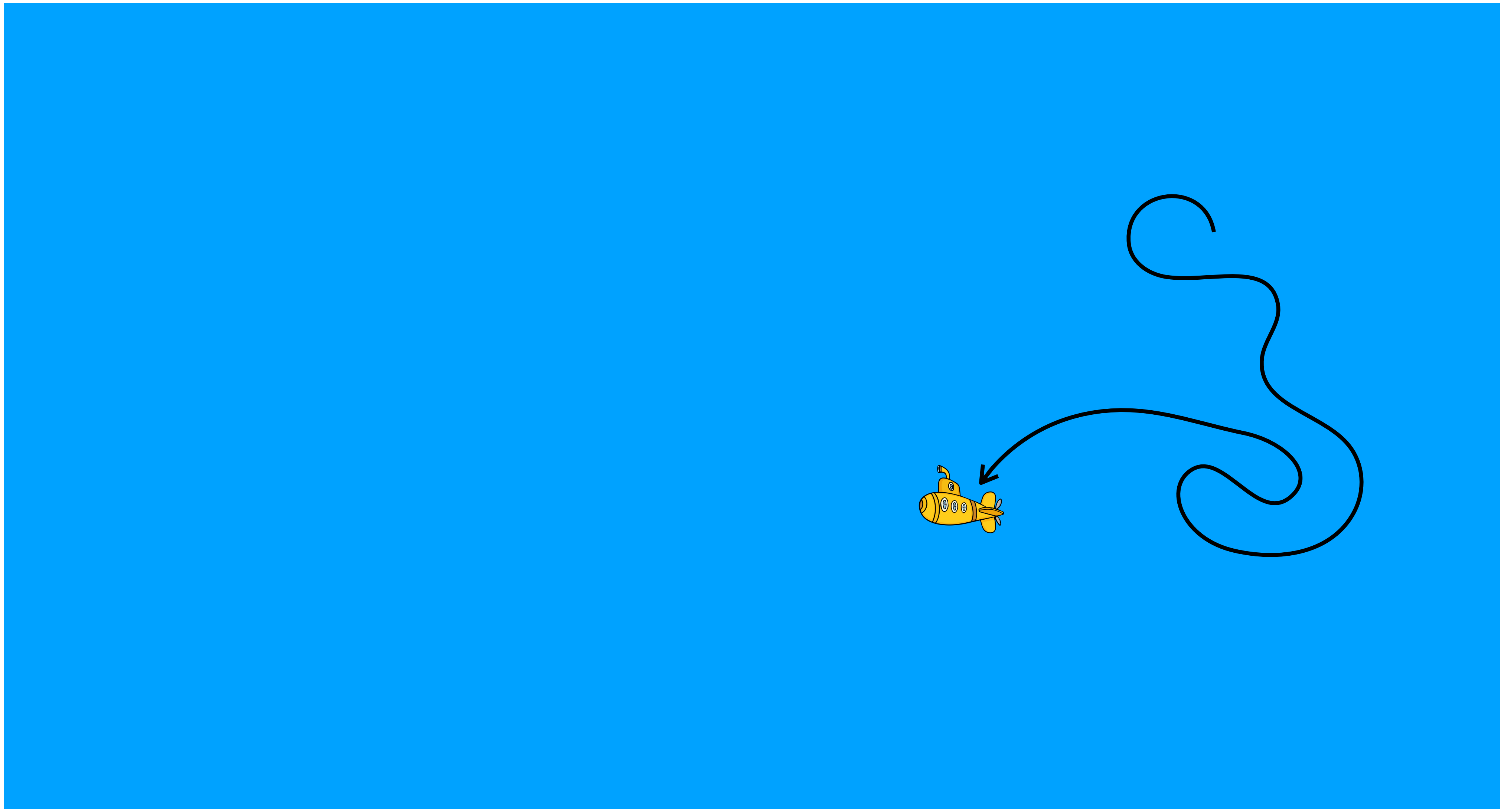
Informative Path Planning

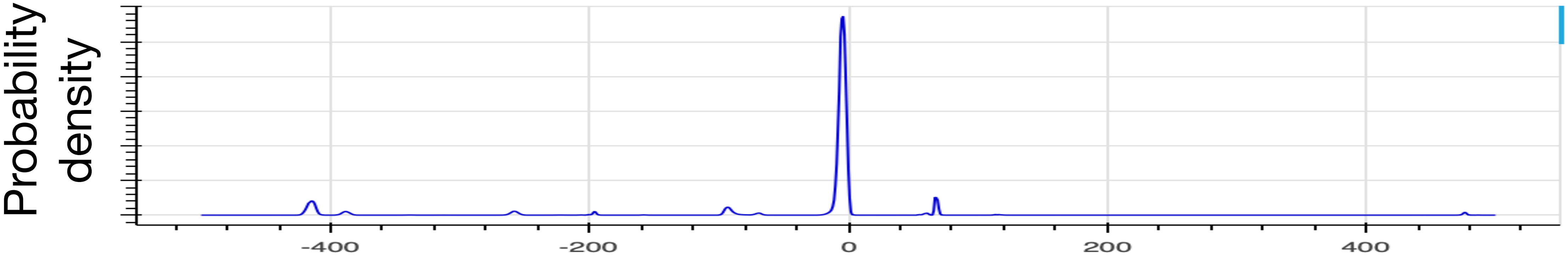


$$w_{i+1} = \arg \max_{w \in \mathcal{A}(w_i)} H\left[g(z|w,x)f(x|\mathcal{Y}_i)\right]$$

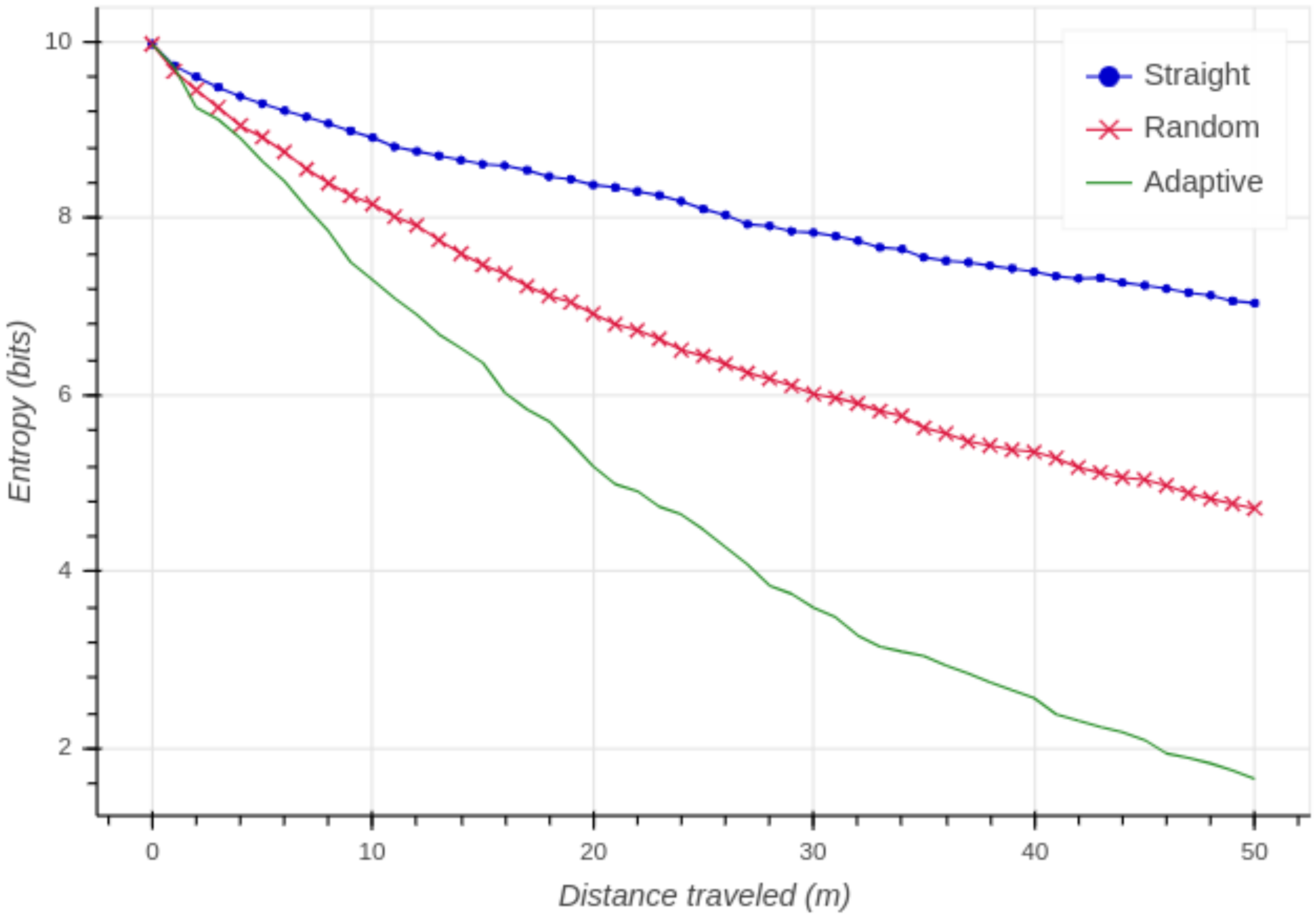


Informative Path Planning





Results



Policy	RMS Error	No. of outliers
Straight	239.0 m	0/100
Random	61.3 m	13/100
Adaptive	1.0 m	9/100

Next steps…

- 3D model
- Sensitivity analysis to environmental knowledge
- Experimental demonstration