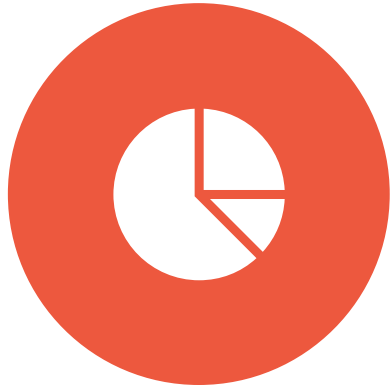




Underwater noise pollution in relation to modern warfare techniques

DR. TIBERIU PAZARA
MBNAR, CONSTANTA

CONTENT



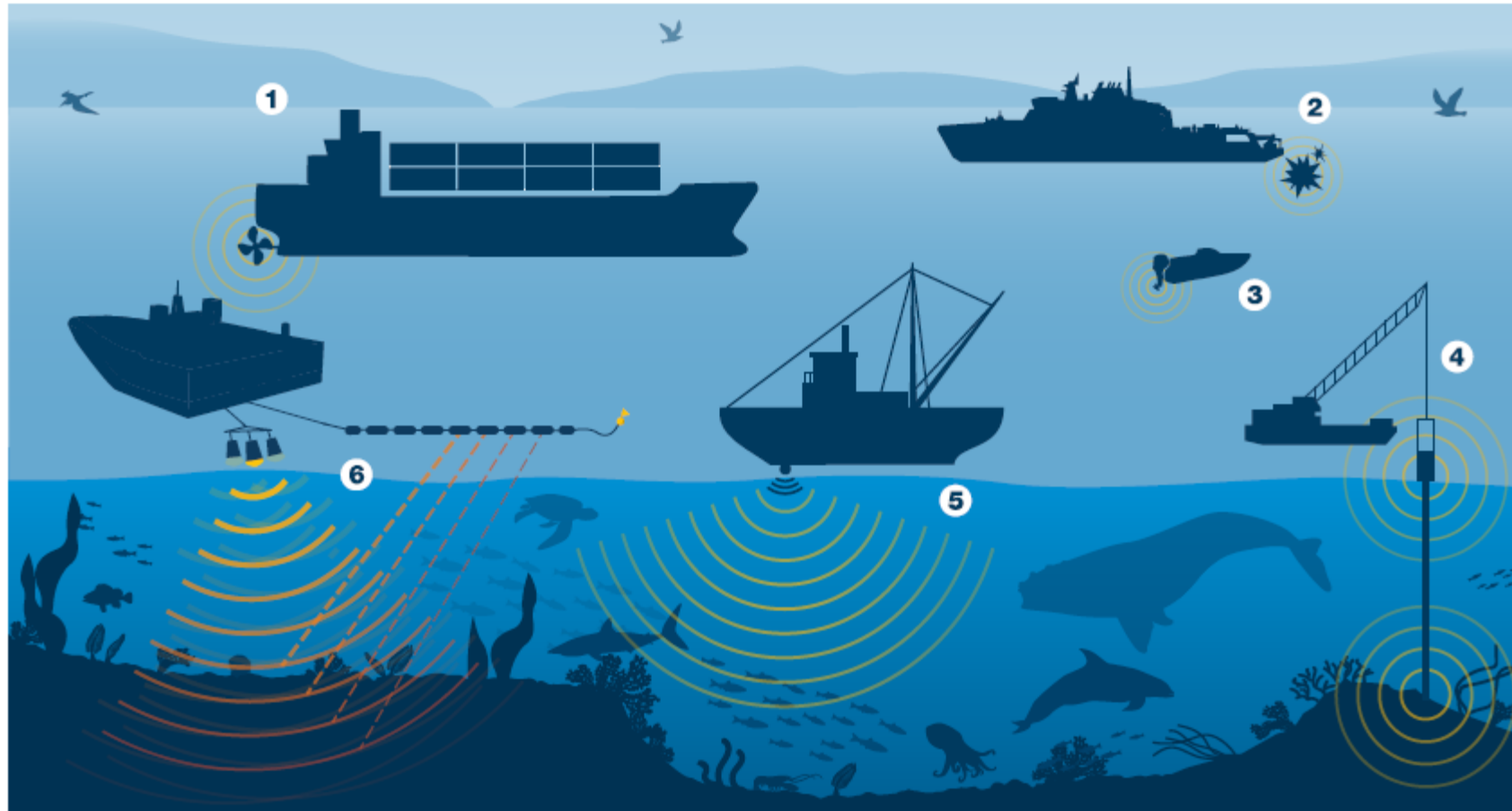
UNDERWATER NOISE AND
MILITARY ACTIVITIES



MARINE DRONES AND
MODERN CONFLICTS



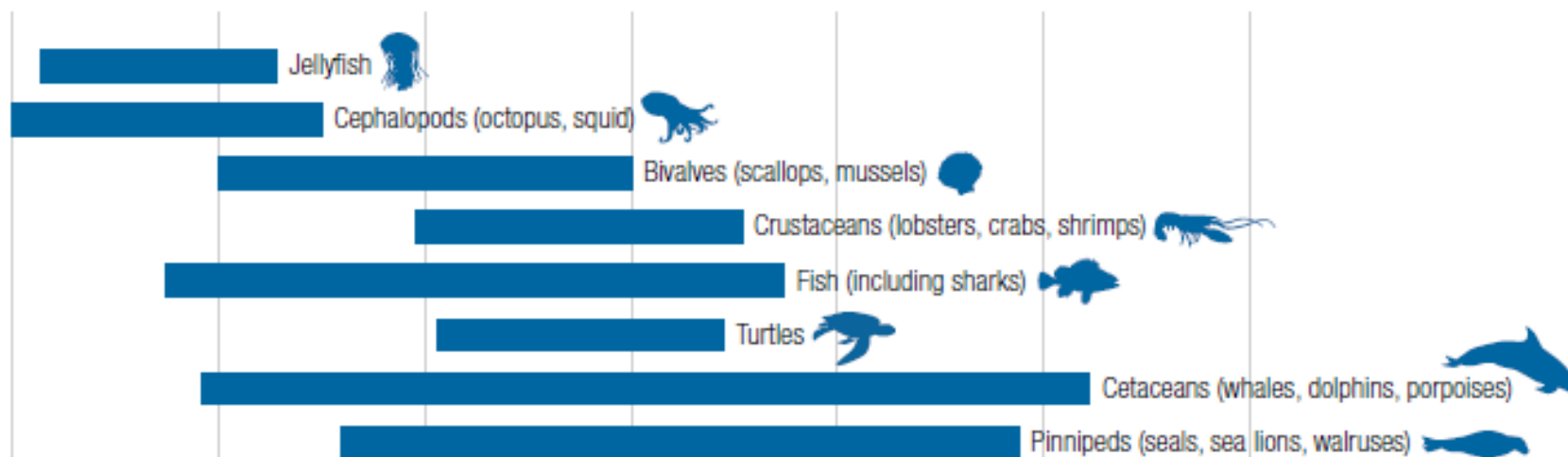
DISCUSSIONS



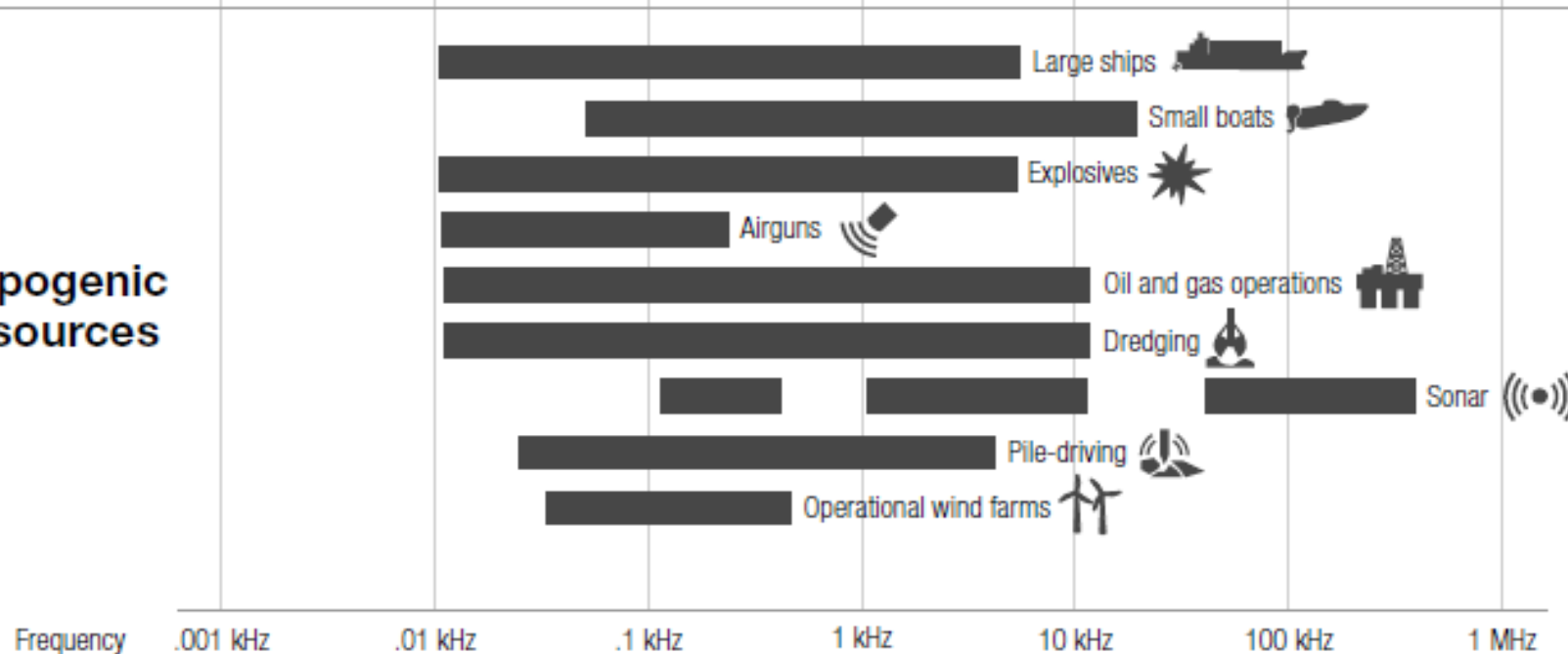
ANTHROPOGENIC SOURCES OF **OCEAN NOISE**

① Large vessels ② Military activities ③ Small vessels ④ Industrial activities and construction ⑤ Echosounders and sonars ⑥ Seismic surveying

Animal hearing ranges



Anthropogenic noise sources



Frequencies of animal hearing ranges and anthropogenic noise sources (adapted from Duarte et al. (2021)¹⁷ and Vergara et al. (2021)⁴⁵).

Noise impacts on marine life



Physical injury

Intense noise exposure may cause physical injury, including temporary or permanent hearing impairment, and potentially even death. While all animals have different hearing ranges, animals exposed to intense sound have been shown to be unable to detect signals in their entire hearing range for a period of time following exposure. Although the magnitude of this impairment normally decreases over time, noise exposure can sometimes result in permanent hearing damage. This permanent inability to detect signals at particular frequencies could impair vital life functions to the point where the animal's survival is jeopardized.

Physiological impacts

Noise may have various physiological impacts, including increased stress, changed metabolic rates, weakened immune system responses, and reduced reproductive rates. Extended exposures and repeated increases in stress could have long-term health impacts on marine animals.

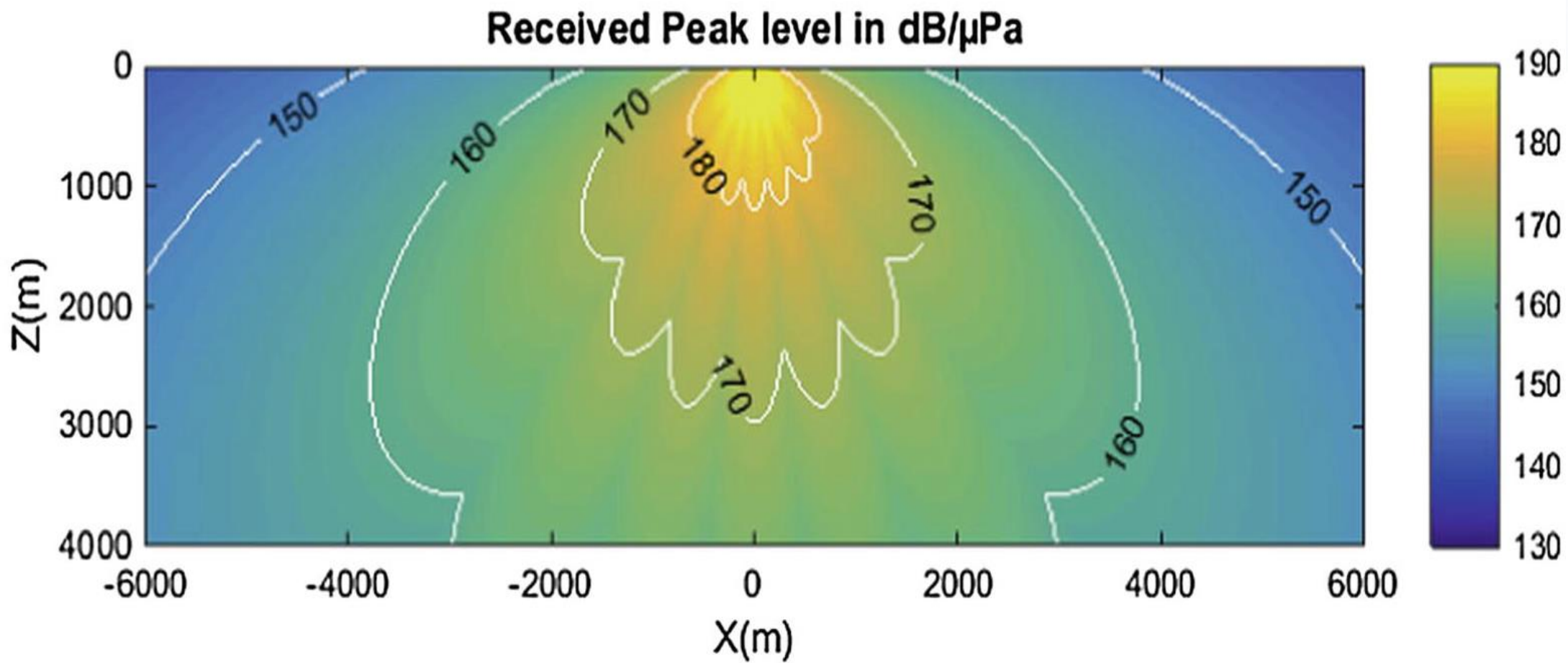
Behavioral changes

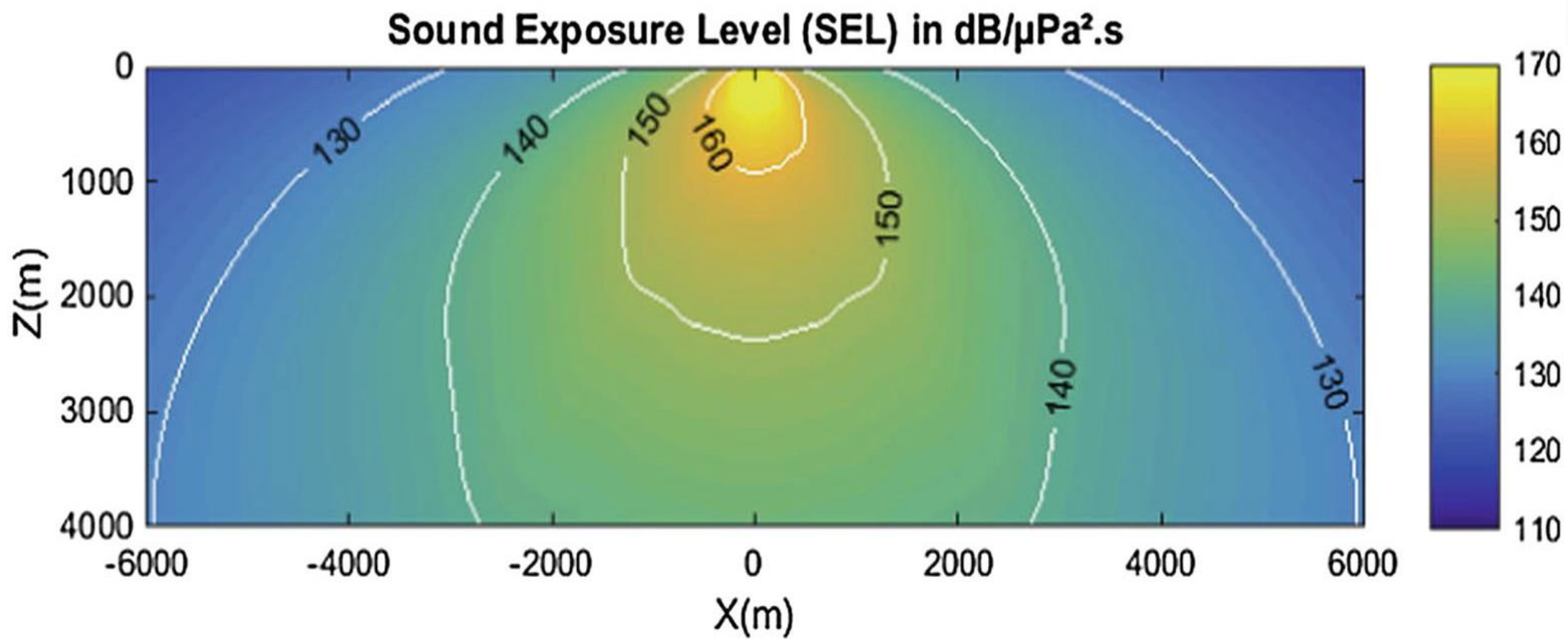
Noise exposure may cause behavioral changes and interruptions of normal activities, including changes in acoustic communication (or vocalizations), withdrawal from feeding or social interactions, changes in movement or diving behavior, and temporary or permanent habitat abandonment. Over the long term, any permanent behavioral change could impact an animal's ability to find food and reproduce. In severe cases, noise can also cause acute and severe reactions, such as panic, flight, stampeding, or stranding which can result in the animal's injury or death.

Military Sonars



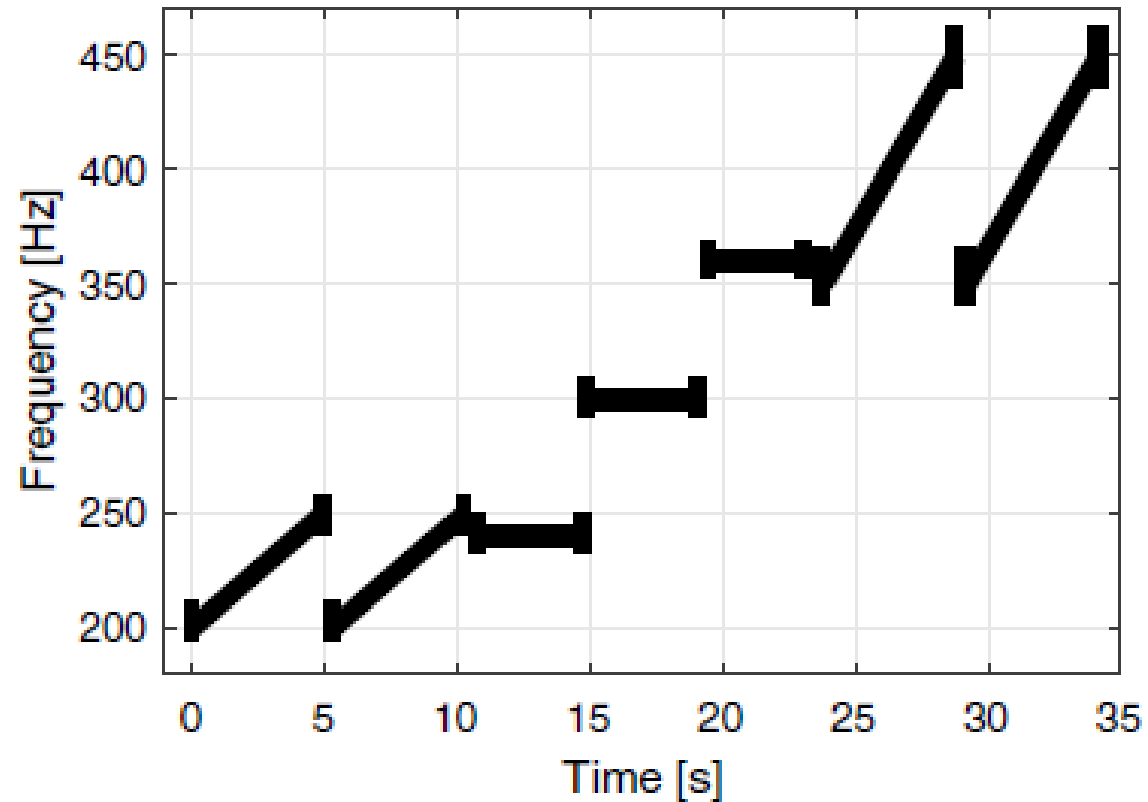
Anti-submarine warfare active sonars are used in defense exercises to detect submarines, underwater vehicles, moored mines, or underwater obstacles (Lurton 2004). They typically operate at frequencies between 100 Hz and 20 kHz, transmitting CW and FM pulses seconds long in duration. They can cover up to 360° of the field of view, and source levels have been reported between 160 and 235 dB re 1 μ Pa m. Military sonars can be classified as low-frequency active sonar (LFAS) or mid-frequency active sonar (MFAS). The long-range LFASs usually operate at frequencies between 200 Hz and 2 kHz. Tactical mid-range MFASs operate at between 2 and 20 kHz. Both LFAS and MFAS can produce a range of pulse types, depending on the operational needs. Narrow-band CW pulses are used to detect movement, while FM signals are used in reverberant environments to improve SNR. Typically, a sequence of CW and/or FM signals is emitted followed by a waiting period to listen to the returning echoes. The number, order, frequency, and beamwidth of pulses may vary with the purpose of the exercise.



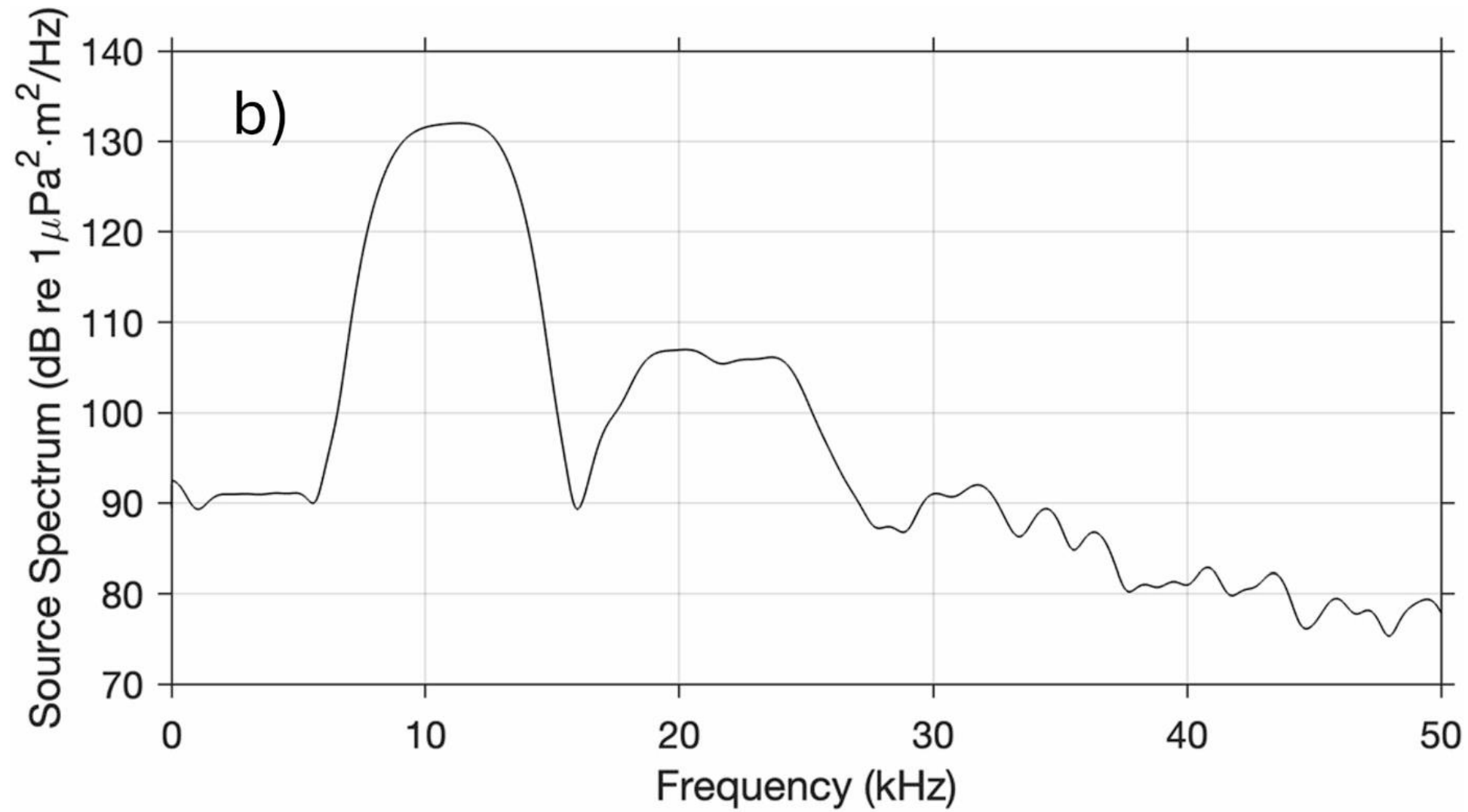




Military sonar type	Frequency	Pulse duration	Inter-pulse interval	Source level (L_p)
Low-frequency active sonar (LFAS)	100–3300 Hz	0.3–12 s	20–60 s	182–235 dB re 1 μ Pa m
Mid-frequency active sonar (MFAS)	3000–8000 Hz	0.5–4 s	20–60 s	160–226 dB re 1 μ Pa m



Sketched spectrogram of an active low-frequency sonar transmission sequence consisting of CW and FM tones, similar to those reported elsewhere for LFAS and MFAS



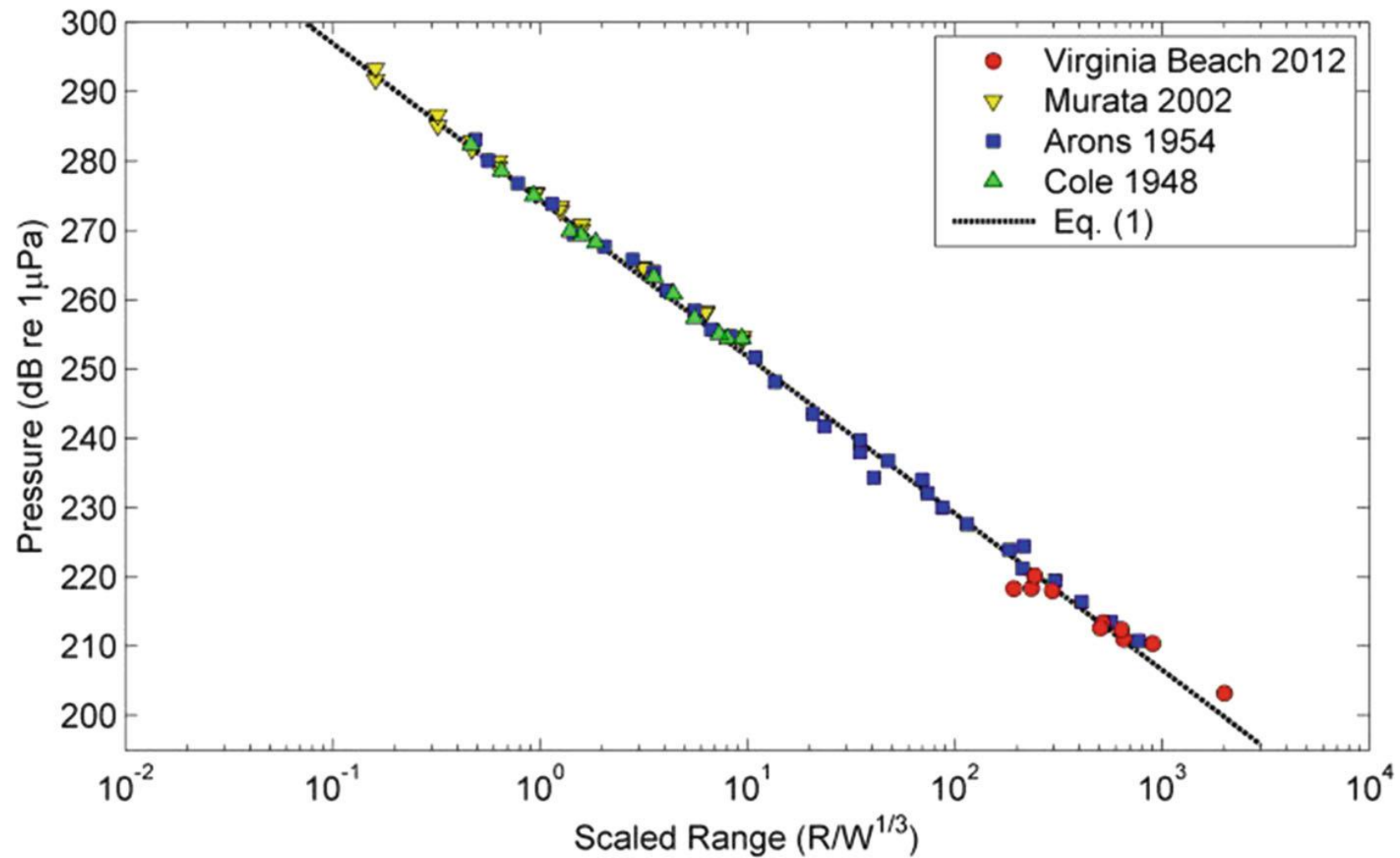
Spectrum of an EdgeTech SB-424 sub-bottom profiler



Explosions

There are many explosive sources of sound in the ocean. Unexploded ordnance (abbreviated UXO or UO) is regularly found. In Europe, these are often weapons from World Wars I and II that simply failed to detonate. In other parts of the world, they are found in military training grounds, such as off the island of Vieques, Puerto Rico. In the United States alone, about 400 sites have been identified with potential UXOs. Efforts are ongoing to clear these areas, typically by open detonation. This then raises obvious questions about the impact on the marine environment.

Source: *Marine Mammal Acoustics in a Noisy Ocean (2025)*



Peak pressure from a variety of explosives plotted against a range scaled by the size of the charge. Reprinted from Soloway AG, Dahl PH (2014)

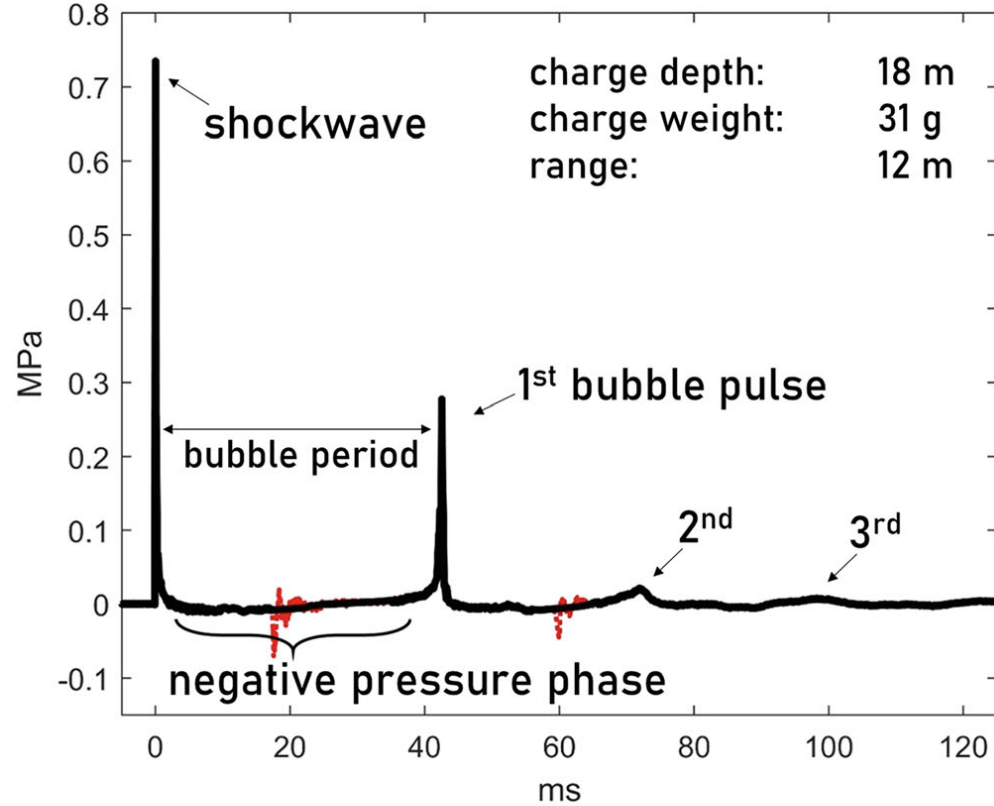
Source: *Marine Mammal Acoustics in a Noisy Ocean* (2025)



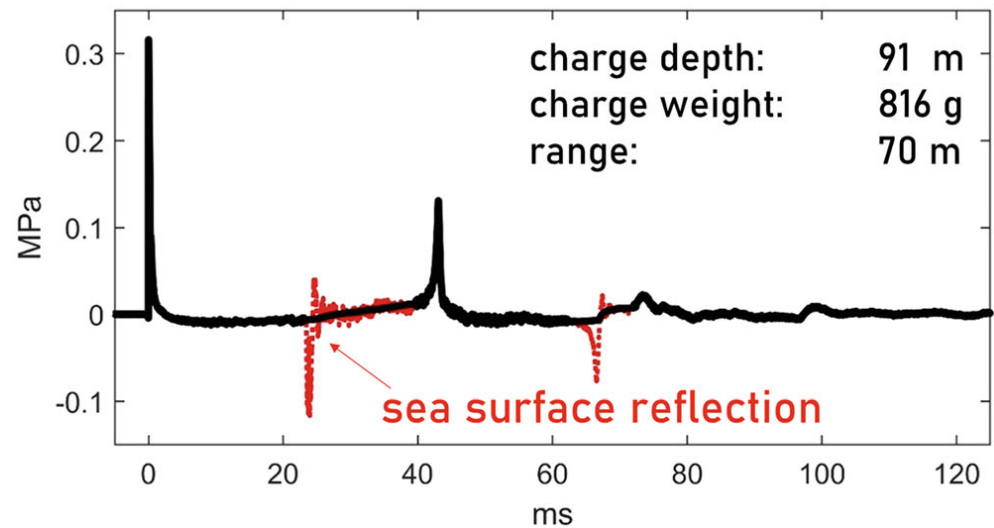
The sound from detonations of unexploded ordnance has been well studied in the European North Sea. Salomons et al. (2021) compared model with measurements from 140 and 325 kg TNT-equivalent detonations in shallow water. Received levels at 1.5, 6, and 12 km range were 195, 178, and 170 dB re 1 μPa^2 s, respectively, for the smaller charge and 212, 198, and 187 dB re 1 μPa (peak pressure), respectively, for the larger charge in these environments. The likelihood of hearing loss in harbor porpoises (*Phocoena phocoena*) was modeled.

The use of explosives in fishing, also known as destructive fishing or fish blasting, is common practice in shallow coral reefs around Southeast Asia. They are usually weak shock blasts produced by a mix of ammonium nitrate fertilizer and kerosine (fuel oil) of ~ 0.5 kg equivalent charge weight (Woodman et al. 2003). The authors showed a received signal with a peak pressure of 0.8 kPa, which corresponded to a compressional SPLpk of 218 dB re 1 μPa at a range of 250 m. This agreed well with the predicted level of 217.6 dB re 1 μPa for this charge weight and range. The signal at 3000 m range was complicated by many seabed and surface reflections. The measured compressional SPLpk of 194.0 dB re 1 μPa was close to the predicted level of 193.2 dB re 1 μPa ; however, the measured rarefactional SPLpk was somewhat larger at 198.6 dB re 1 μPa , which indicated that in this case the signal was long enough to allow some constructive interference between different acoustic paths (Woodman et al. 2003).

Source: *Marine Mammal Acoustics in a Noisy Ocean (2025)*



Pressure signal from a Mk64 (top) and Mk82 (bottom) SUS charge measured by a hydrophone suspended 20 m below the surface. Red lines: reflections from the sea surface.



Source: *Marine Mammal Acoustics in a Noisy Ocean (2025)*



Marine Drones

Unmanned Autonomous Vehicles (AUVs) for the undersea domain have taken many forms in the past decades. AUV capability, and particularly autonomy, of these devices have increased significantly as AUV technology has evolved. AUV underwater devices range from simple data gathering devices to highly sophisticated Unmanned Undersea Vehicles (UUVs).

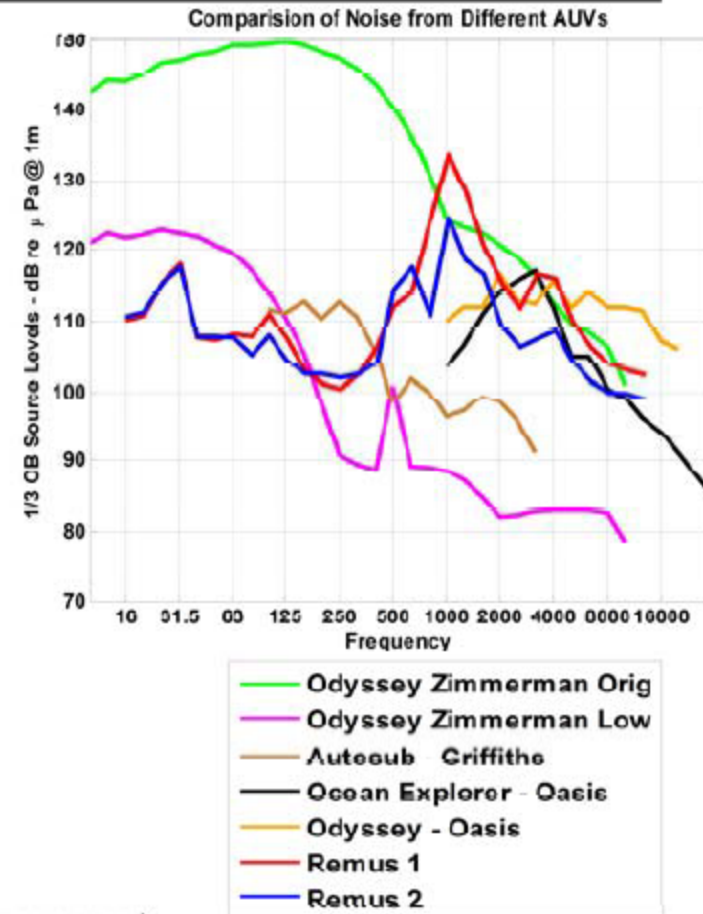
Military AUVs network with unmanned aerial vehicles(drones used for tactical planning and observation) to provide a cross-domain intelligence, surveillance and reconnaissance (ISR) solution for missions. Modern AUVs are powered by rechargeable batteries, fuel cells or solar power and utilize an advanced navigation system due to radio restriction. The Marine Inertial Navigation System (INS) is used to attain the velocity approximation, acceleration and position of the AUV. For propulsion, AUVs utilize electrical thrusters and propellers; however, current underwater gliders (recognized as AUV subsets) manage their depth using variable buoyancy and move forward by converting hydrofoils.



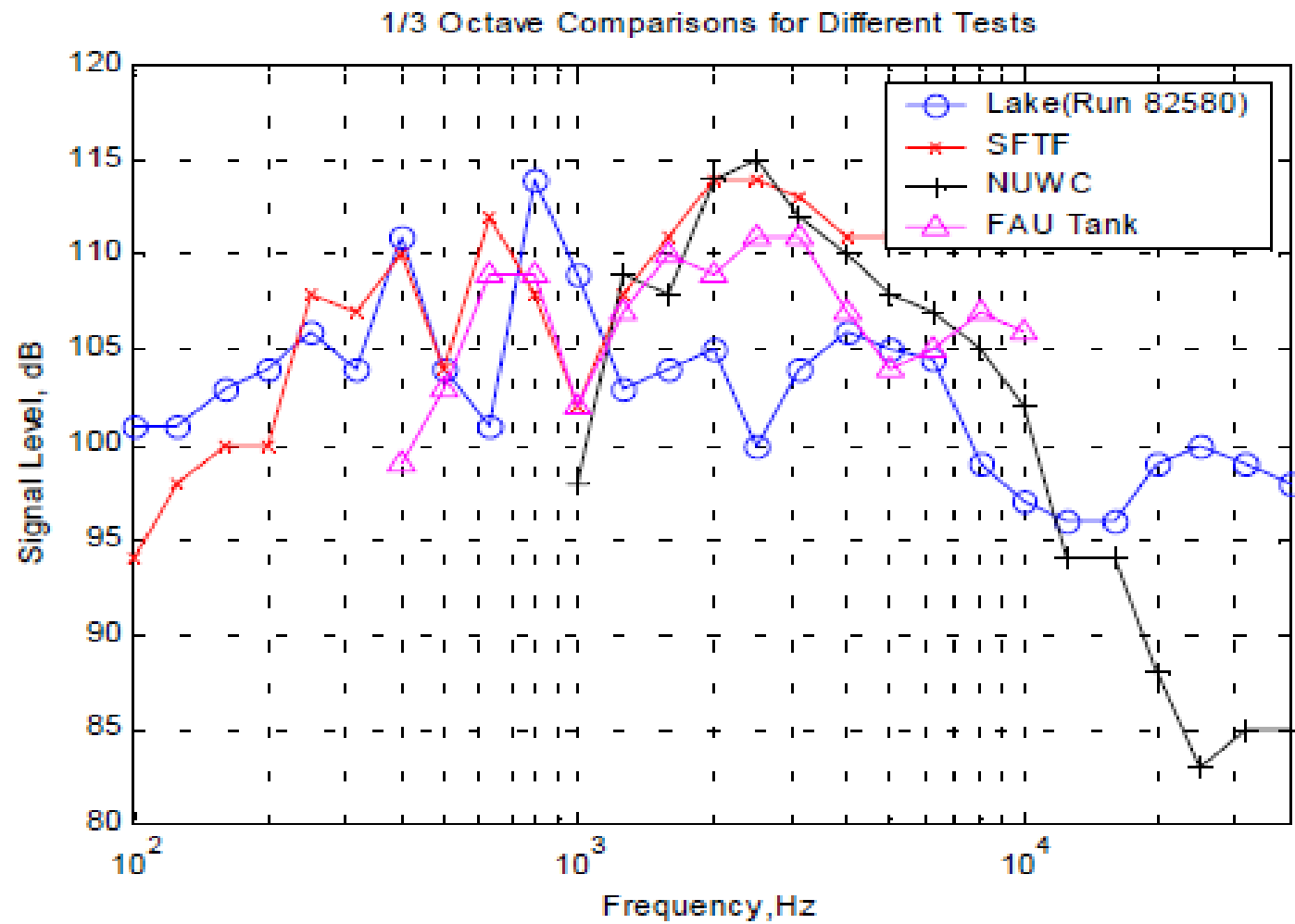
Summary of typical vehicle noise

- 1/3 Octave band source levels compared for several similar sized AUVs at 3-5 knots.
 - Odyssey IIb from Zimmerman et al
 - Quieted Odyssey IIb from Zimmerman et al (significant improvement over base model – may be ambient limited)
 - Autosub from Griffiths et. al.
 - Ocean Explorer from Oasis report
*Odyssey from Oasis report *
 - Measured REMUS hull 1 (5 knots)
 - Measured REMUS hull 2 (5 knots)
- All from published measurements or literature
- Base figure from OASIS report from Lee Frietag - WHOI

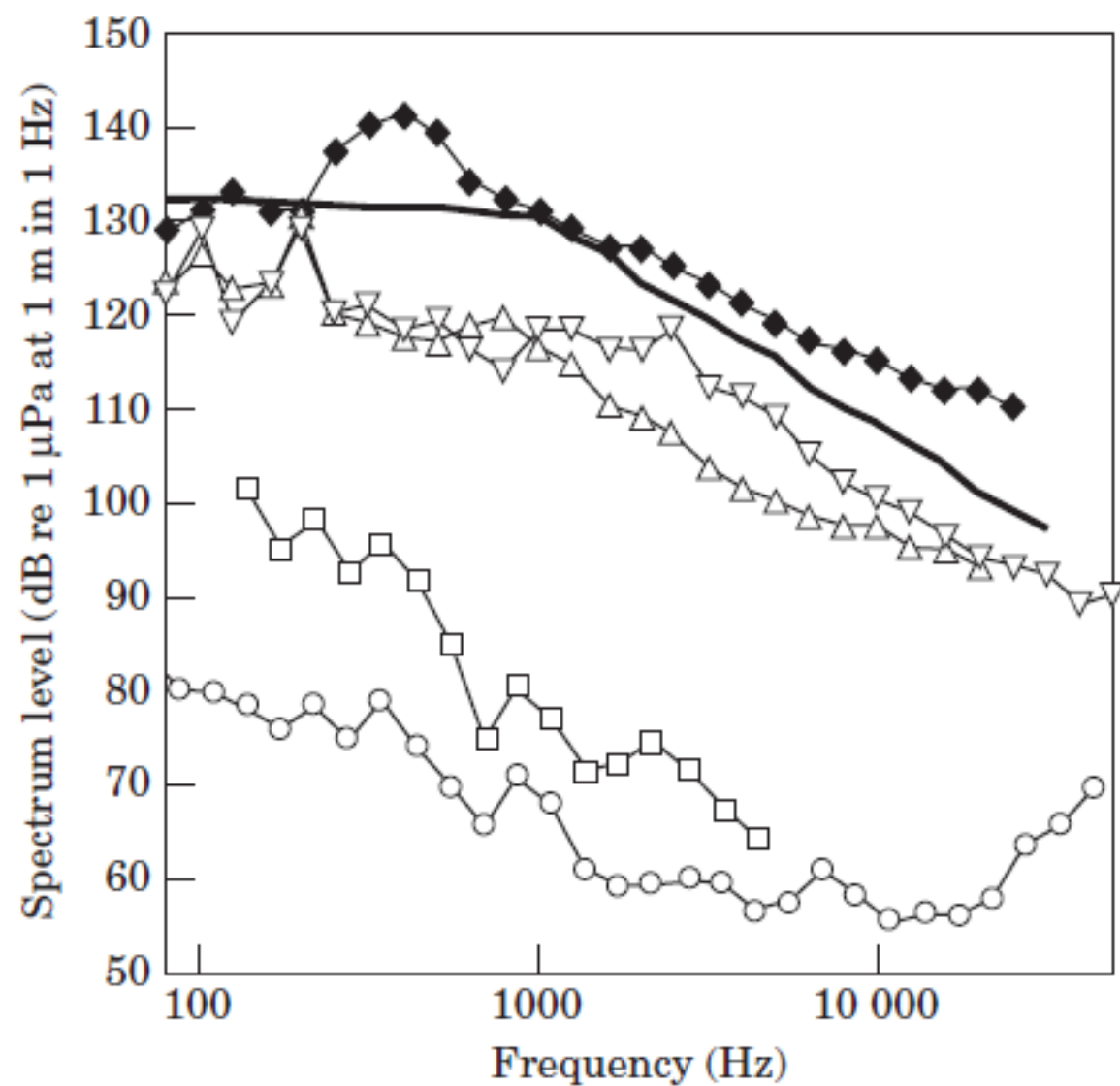
* Vehicles in OASIS report had props removed



Source: *An overview of unmanned underwater vehicle noise in the low to mid frequencies bands*



Comparison of AUV 1/3 octave signal levels for different radiated noise tests
Source: *AUV Self Noise Control and Acoustic Signature Experimental Analysis*



Comparison of the radiated noise spectrum of Auto-sub (□) with the ICES fisheries research ship recommendation (solid black line), the FRV "Scotia" at 4.1 kt (▽) and at 9.9 kt (△), the RRS "James Clark Ross" at 9.8 kt (◆) and, for reference the ambient noise during the Plymouth Autosub radiated noise trials (○). Note that FRV "Scotia" is quieter at 9.9 kt than at 4.1 kt as the vessel has been optimised for underway acoustic surveys at the higher speed.

Source: *On the radiated noise of the Autosub autonomous underwater vehicle*

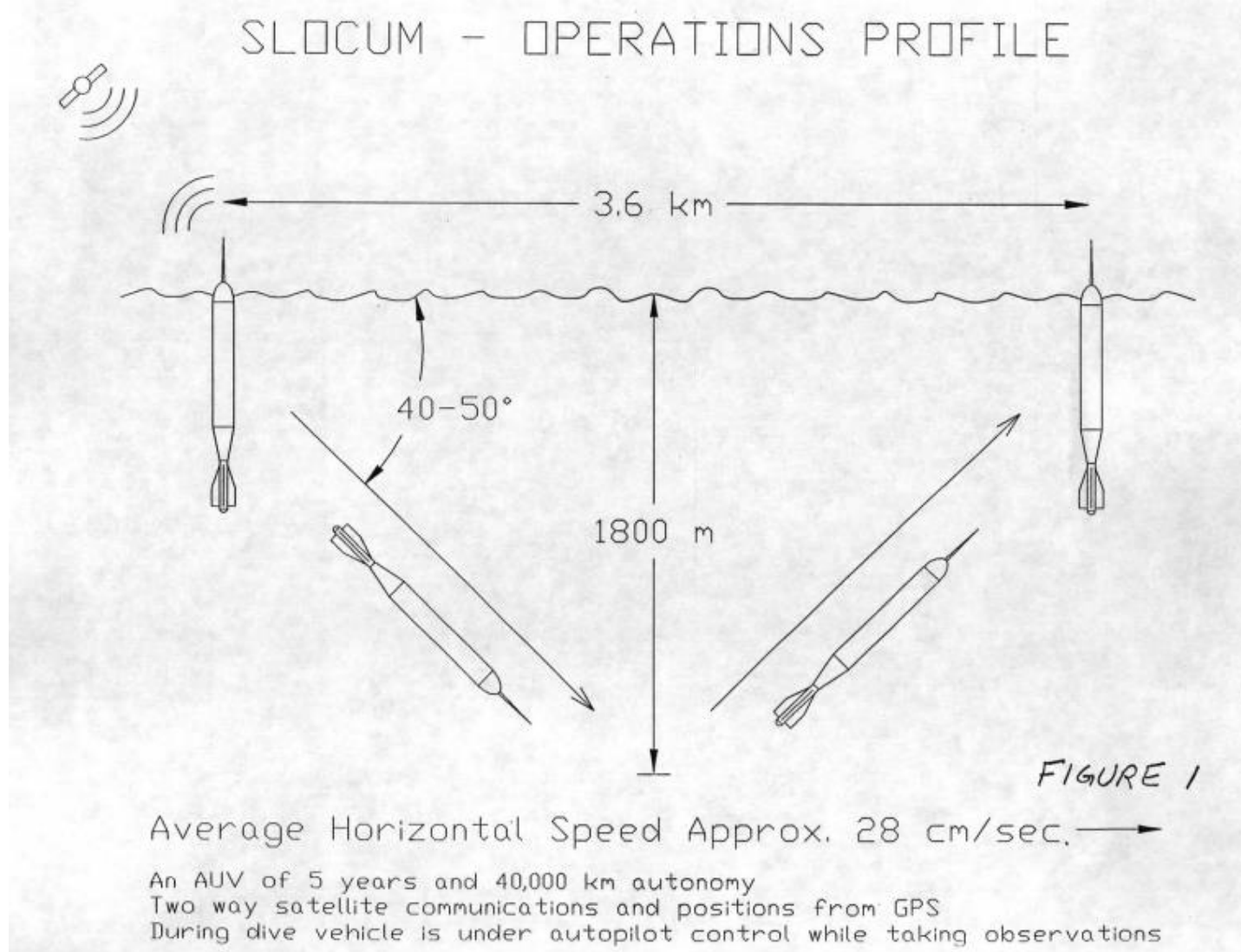


Between the simple data gathering devices and highly sophisticated UUVs, exists a class of vehicle known as underwater gliders.

Underwater gliders function by changing buoyancy to move up and down vertically while fixed wings turn vertical motion into horizontal motion. The trajectory is ‘saw-tooth’ in nature as the glider repetitively descends and ascends the ocean environment. During these saw-tooth evolutions, the vehicle’s sensor and data acquisition systems are constantly taking and recording data. Every 6 hours the glider is programmed to surface so that data may be uploaded via a satellite (Iridium, ARGOS) and additional or modified commands downloaded to the glider to alter its planned location/glide path.

Source: *An Analysis of Undersea Glider Architectures and an Assessment of Undersea Glider Integration into Undersea Applications*

Barker, William P.



SLOCUM Glider Dive Profile, from (P. Simonetti, 1992)



Gliders are inherently quieter than traditional Autonomous Underwater Vehicles (AUVs) due to their method of propulsion. Unlike a typical AUV, gliders do not have propellers; instead they traverse the water column in a sawtooth pattern by adjusting buoyancy and redistributing weight [1]. During a mission, the Seaglider performs a series of dives, descending to a preset depth, up to 1000 m, then returning to the surface where it obtains position and time using Global Positioning System (GPS) and communicates via satellite connection before proceeding to the next dive.

The Seaglider moves through the water by changing buoyancy, pitch, and roll, which are managed by the guidance and control system. The Seaglider begins a dive decreasing buoyancy by bleeding oil from an external bladder into an internal reservoir. To ascend, the Seaglider increases its buoyancy by pumping oil from the internal reservoir into the external bladder. To control the angle at which the vehicle travels through the water, the pitch of the Seaglider is manipulated by shifting a weighted internal battery forward and aft along a track. The Seaglider manipulates roll by rotating the weighted internal battery about the track, causing the center of gravity within the body of the Seaglider to shift, reorientating the fixed fins and pointing the device in the desired direction.

Seaglider vehicle operations and integrated oceanographic sensors produce some sounds, which contribute to the self-noise profile of a Seaglider. Here we characterize vehicle self-noise associated with Seaglider operations and sensors using acoustic data collected by an integrated passive acoustic monitor (PAM).



The greatest capability of underwater gliders is their ability to maintain a persistent and continuous presence in a specified operating area.

Gliders are being used worldwide in various operating areas ranging from deep-ocean to shallow-littorals.

A fleet of gliders could also provide a low-cost network for determining the patrol patterns of threat submarine fleets.

Gliders are classified as man-portable UUV's. This means they could be launched quickly from small platforms such as a RIB or covertly from the DDS of a submarine.

The significant departure in capabilities between gliders and AUVs is in terms of overall mission endurance which drives many design aspects. Underwater gliders have endurances in terms of months to years while AUV endurance is in terms of hours or days. Vehicle endurance is a function of the speed at which the mission is accomplished. Higher speed vehicles typically consume energy at significantly higher rates. Thus, the actual mission speed of completion requirement drives the determination if an underwater glider or alternate AUV would be suitable for a given mission.

So, AUV's (surface drones) are used for carrying explosives that can be deployed fast to the target. While Gliders are prone to stealthier missions when targets are difficult to reach or the environment is unpractical for AUV's (like very shallow waters at the entrance in a port or the mooring area).

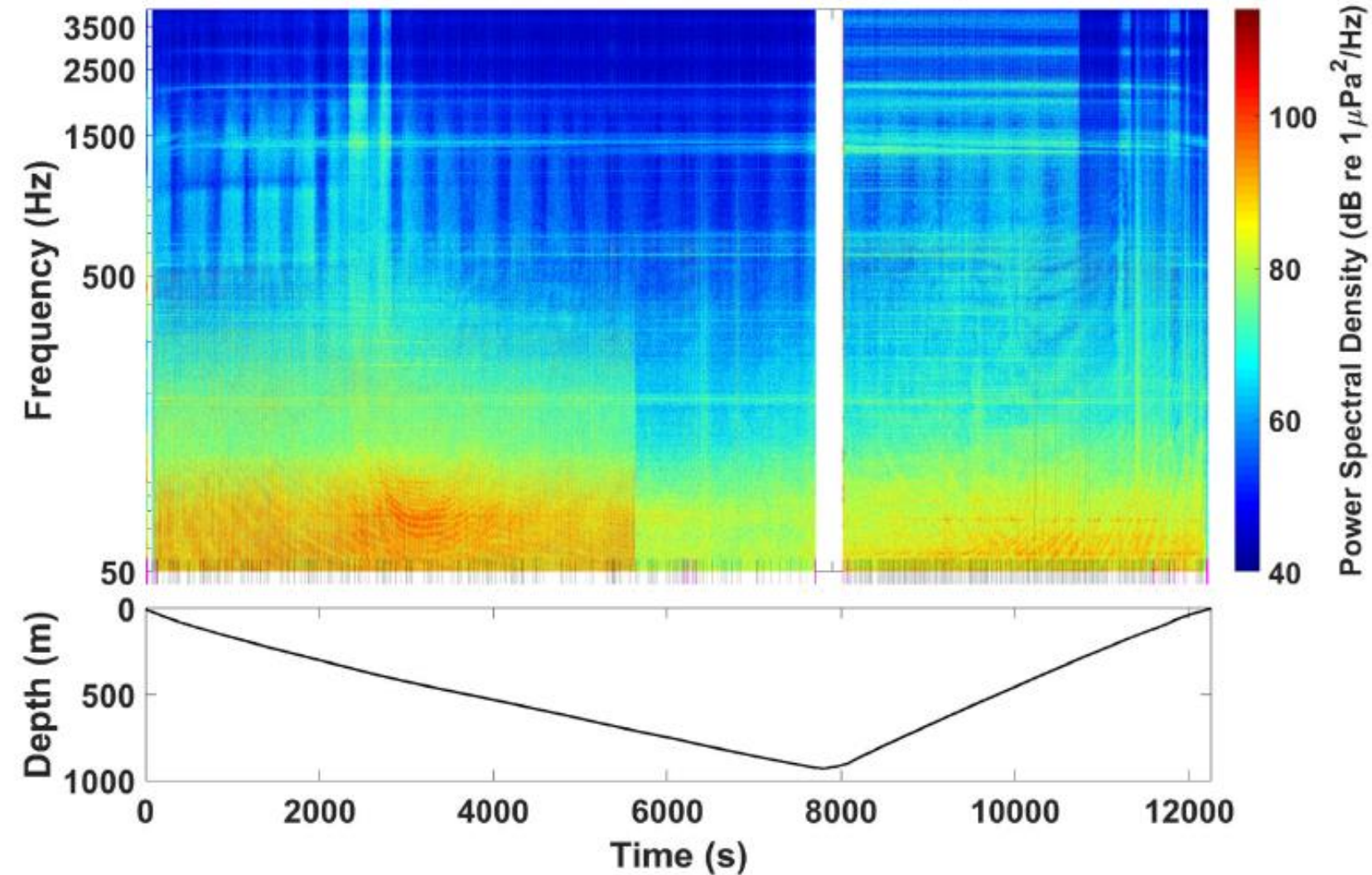


Photograph of an acoustic Sea-Wing underwater glider

Some Specifications of the Acoustic Sea-Wing Underwater Glider

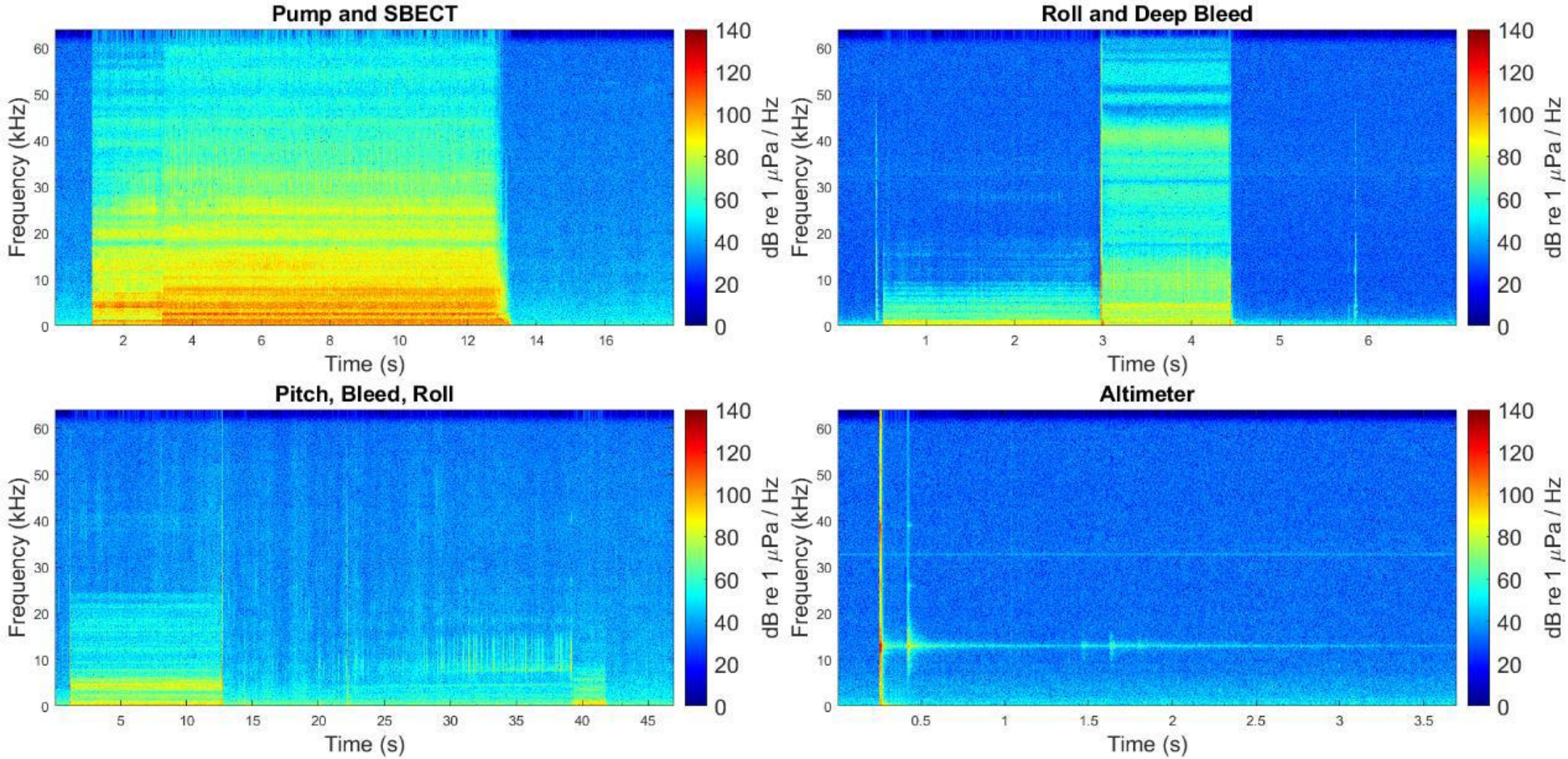
Size (m)	Hull diameter 0.22, vehicle length 2, wing span 1.2
Weight (kg)	65
Inflection Depth (m)	1000
Cruising Speed (m/s)	0.25, maximum 0.5
Range (km)	> 1100
Communications	Iridium, radio frequency and acoustic communication
Navigation	Global positioning system, altimeter and electronic compass
Science Sensor	CTD, hydrophone and acoustic modem

Source: *Self-Noise Spectrum Analysis and Joint Noise Filtering for the Sea-Wing Underwater Glider Based on Experimental Data*
JIE SUN, JIN WANG, YANG SHI, FENG HU, XU WANG, JIANCHENG YU AND AIQUN ZHANG



Data collected during a gliding period with the relative time in the cycle set as the abscissa. Upper panel: spectral density of the received signal. White spaces in the spectrogram represent data deleted when the buoyancy motors were working near the surface and the inflection depth. The black vertical lines at the abscissa represent the rudder regulating moments and the purple lines show the pitch regulating moments. Lower panel: the diving depth of the glider with the relative time in the cycle.

Source: *Self-Noise Spectrum Analysis and Joint Noise Filtering for the Sea-Wing Underwater Glider Based on Experimental Data*
 JIE SUN, JIN WANG, YANG SHI, FENG HU, XU WANG, JIANCHENG YU AND AIQUN ZHANG



Spectrograms showing self-noise due to Seaglider operations

Source: *A Self-noise Analysis Of A Seaglider AUV Using A Passive Acoustic Monitor*

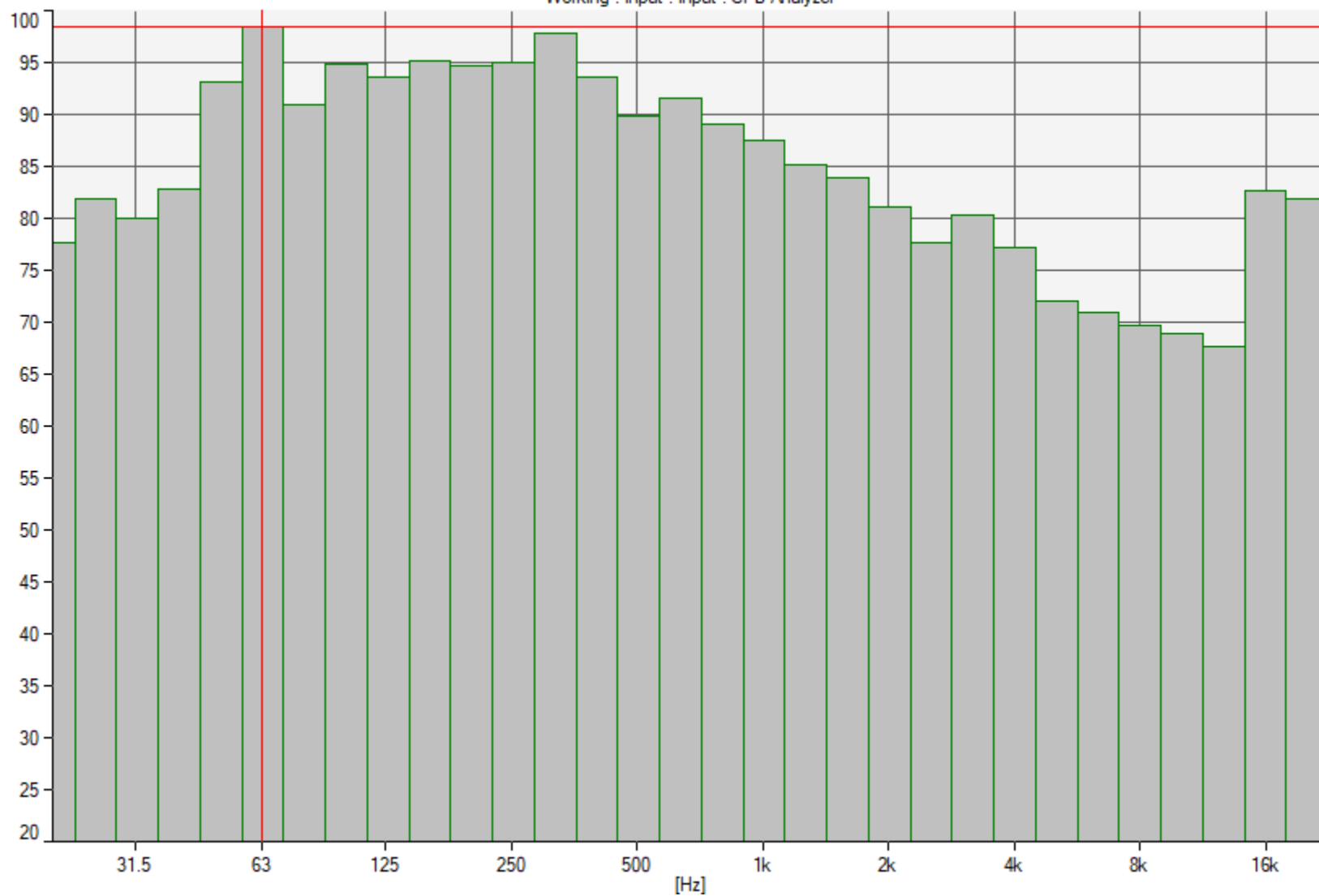


UNDERWATER NOISE MEASUREMENTS IN THE ROMANIAN BLACK SEA AREA



[dB/1.00u Pa]

Autospectrum(2700263) - Input1
Working : Input : Input : CPB Analyzer



Cursor Values

Y = 98.3 dB/1.00u Pa

X = 63.00 Hz

Status

25-Oct-25 17:26:40.796

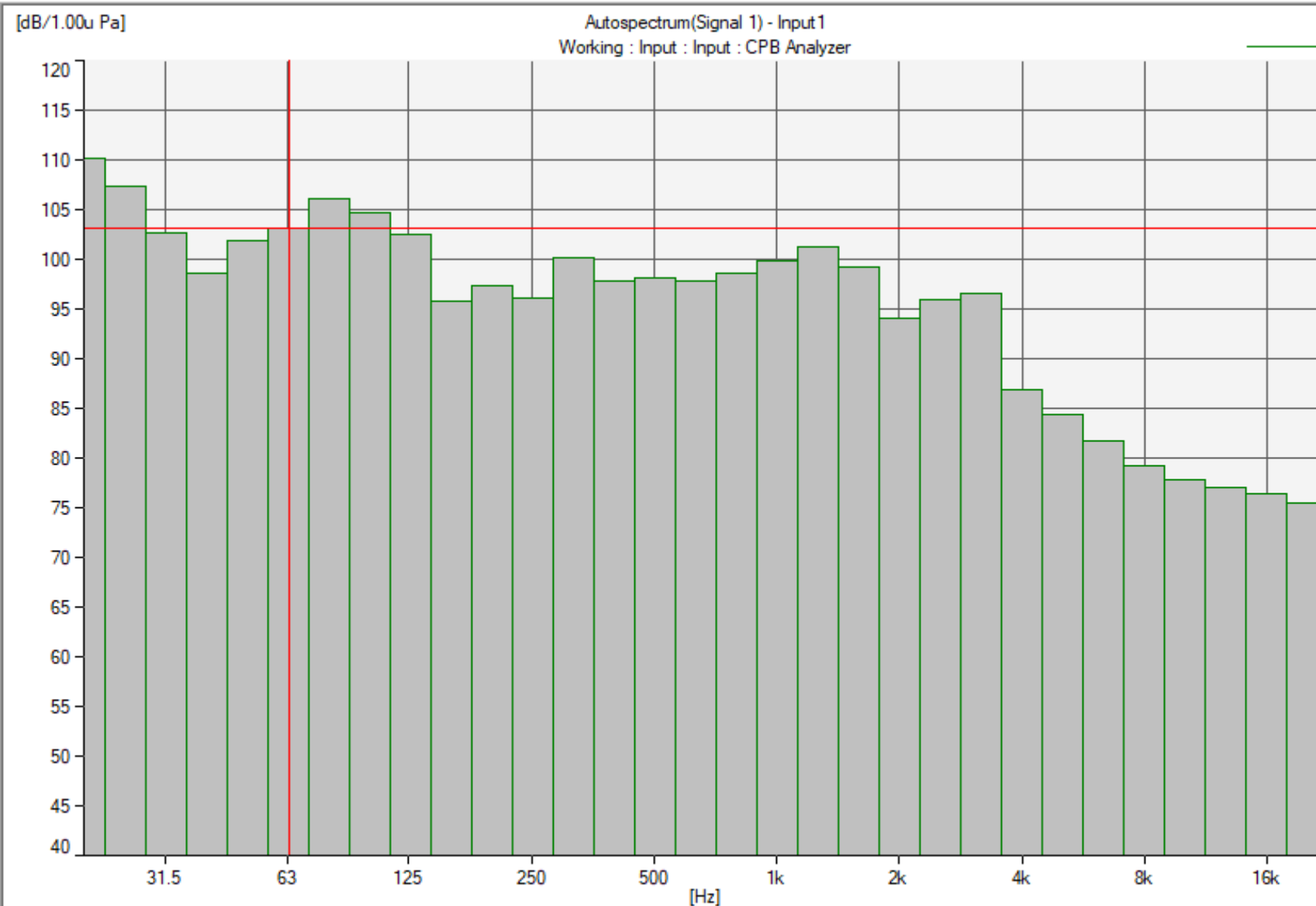
Averaging time: 1 s

Overload: 0.00 %

Total

Sum = 106dB/1.00u Pa





Cursor Values

Y = 103 dB/1.00u Pa

X = 63.00 Hz

Status

24-Sep-25 11:41:42.709

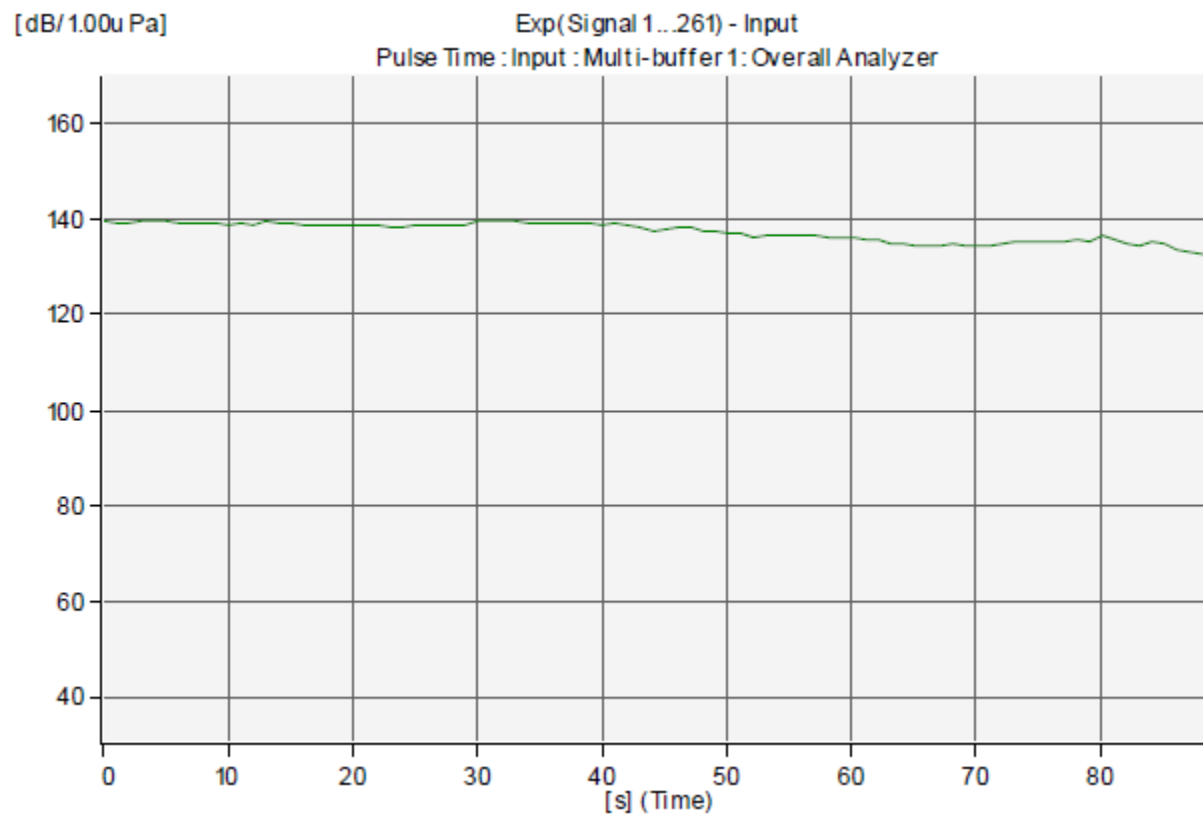
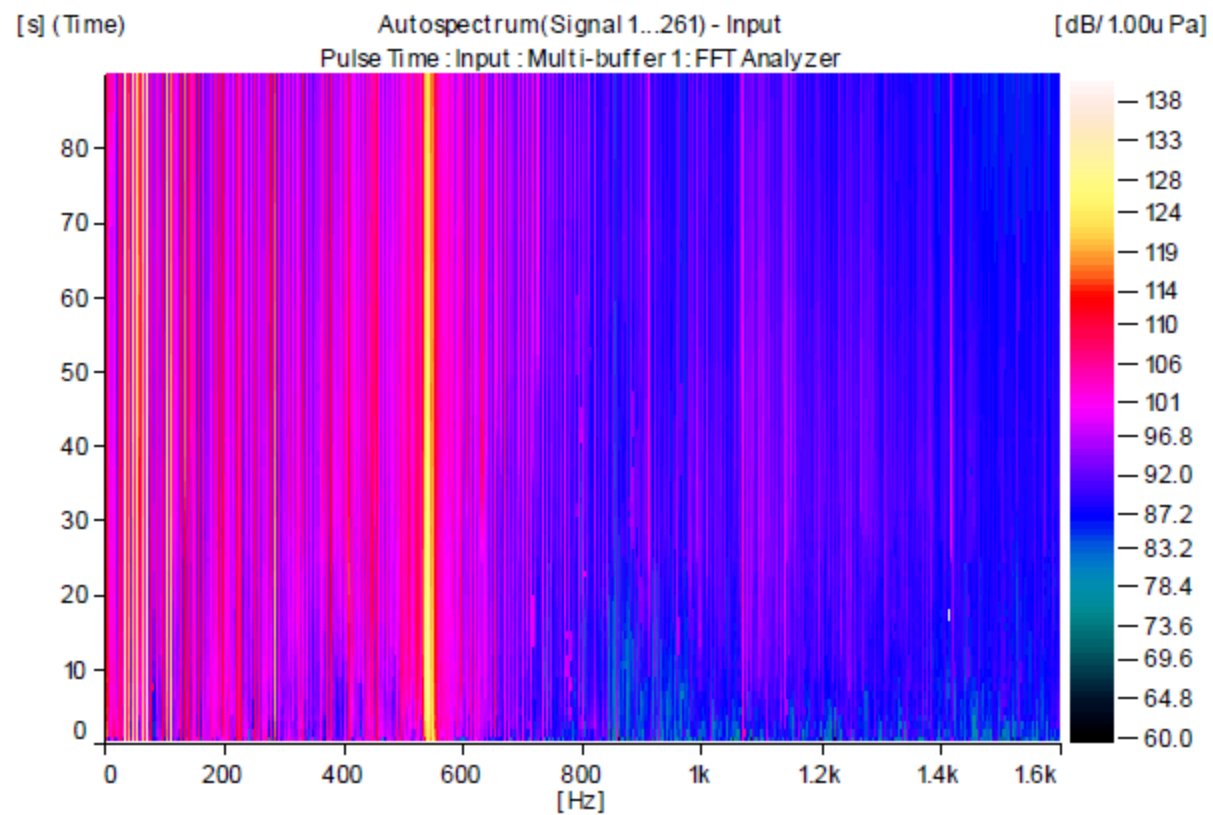
Averaging time: 1 s

Overload: 0.00 %

Total

Sum = 116dB/1.00u Pa





2024.12.17 / Hour 10.11. Ship: Dilek. Route: passing

Discussions



1. What is the underwater noise level produced by marine drones?
2. What are the damages that can produce a marine drone?
3. What is the impact of a marine drone upon environment?
4. How can be detected?
5. How can be stopped?