Virtual Oceans: Simulating Complex Soundscapes

Generating Realistic Acoustic Data for Robust Sonar Benchmarking and Validation

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Introduction

We simulate complex underwater soundscapes that replicate real-world variability. These are used to benchmark detection and tracking algorithms and to support sensor deployment planning.

- Generate noise from multiple ocean sources
- Inject signals for detection & tracking tests
- Quantify algorithm robustness and sensor performance

Noise Sources

The ocean soundscape is a composite of sources, each dominating different parts of the frequency spectrum.

Biological
Marine life sounds (e.g., shrimp, whales, dolphins).

Anthropogenic
Human activities (e.g., commercial shipping, sonar, construction).

Geophysical
Natural physical processes (e.g., wind-driven waves, rain, earthquakes).

Dominant Sources by Frequency

<10 Hz
Wave interactions, ship propellers

10-500 Hz
Surf & storms, commercial shipping, baleen whales

0.5-25 kHz
Breaking waves, mid-freq. sonar, snapping shrimp

>25 kHz
Thermal noise, high-freq. sonar, dolphin echolocation

Case Study: Snapping Shrimp

Bursty
Snaps occur in non-independent clusters.

Heavy-Tailed
Extreme events are more likely than in a Gaussian model.

Impulsive
Frequent, high-amplitude clicks.

1. Snap Timing (When?)

A **Non-Homogeneous Poisson Process (NHPP)** with intensity function λ(t) models snap timing, modulated by temperature and diurnal/tidal cycles.

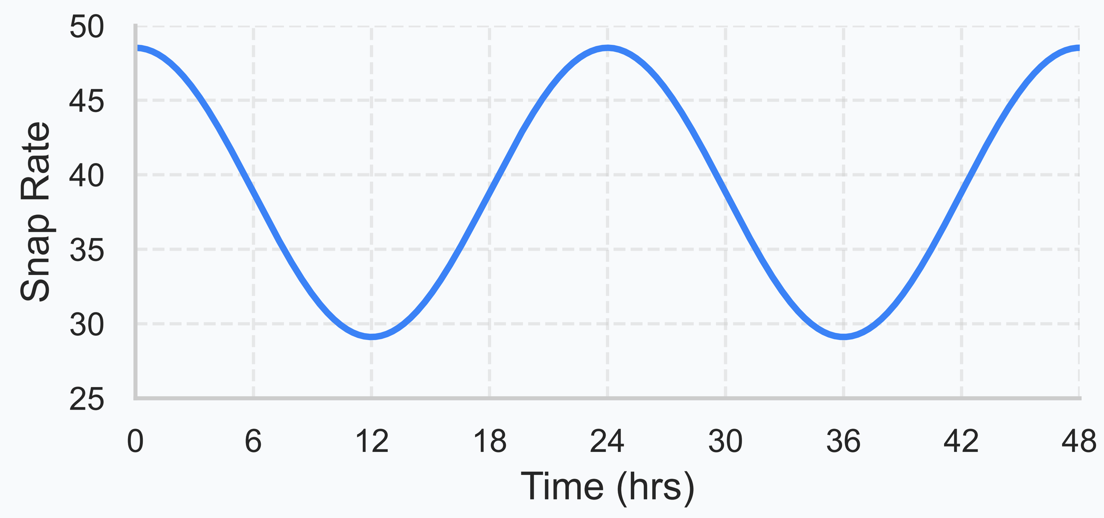

Figure 1. The diurnal cycle shows that snap rates are highest at night.

2. Snap Waveform (What?)

Each ~2ms snap is built using a **Modelled Waveform**, representing the acoustic signature of a collapsing cavitation bubble. This captures the sharp, broadband nature of the sound.

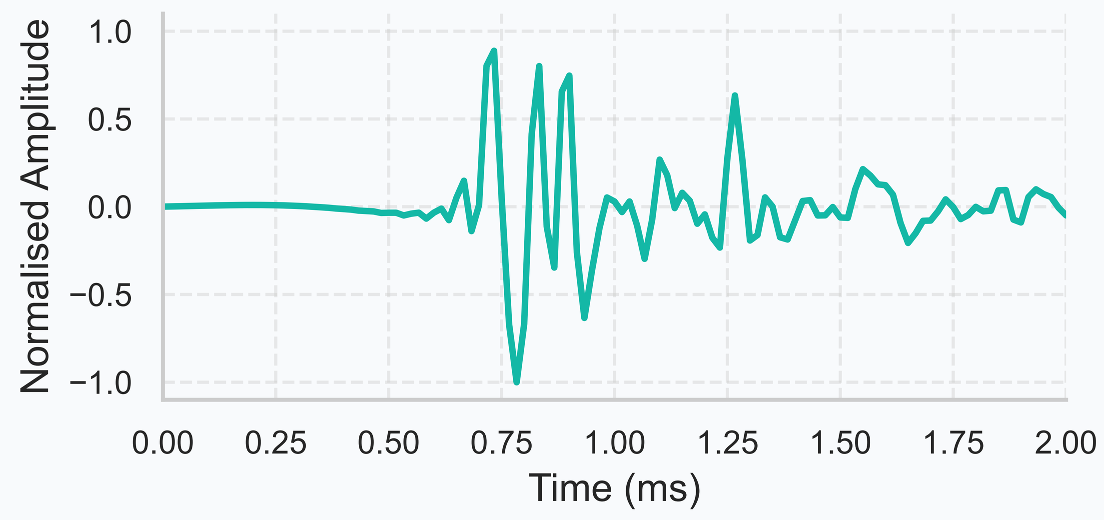

Figure 2. Modelled snap waveform (~2 ms).

3. Snap Amplitude (How Loud?)

Loudness is modelled with a heavy-tailed **Symmetric Alpha-Stable (SαS)** distribution. This correctly predicts the probability of the extremely loud snaps that characterise this type of noise.

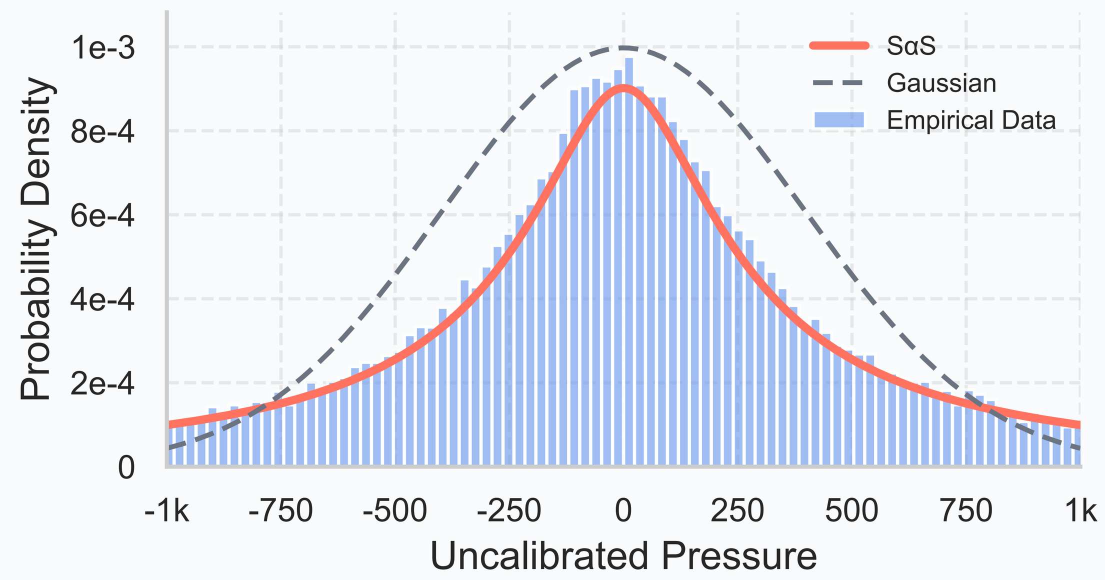

Figure 3. The SαS distribution correctly models the heavy tail of real data, unlike a traditional Gaussian model.

Detection & Tracking

The simulated soundscape enables realistic testing of tracker performance under dynamic acoustic conditions.

Detection
Measure probability of detection and false alarm rate as functions of SNR.

Tracking
Evaluate localisation error, ID switches, track fragmentation and continuity under variable noise and source density.

Operational impacts
Distant shipping reduces SNR and detection range; snapping shrimp produce clustered false positives; wind and wave noise increase background noise.

Key Points

- **Realism:** Models reproduce empirical statistics across noise types.
- **Benchmarking:** Generates labelled acoustic datasets for algorithm validation.
- **Impact:** Informs robust tracker design and optimal sensor placement.

More Info

Scan for audio samples, references & extra materials

https://jjwakefield.github.io/showcase2025poster/infographic.html

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