Advancing underwater soundscape in lagoon environments

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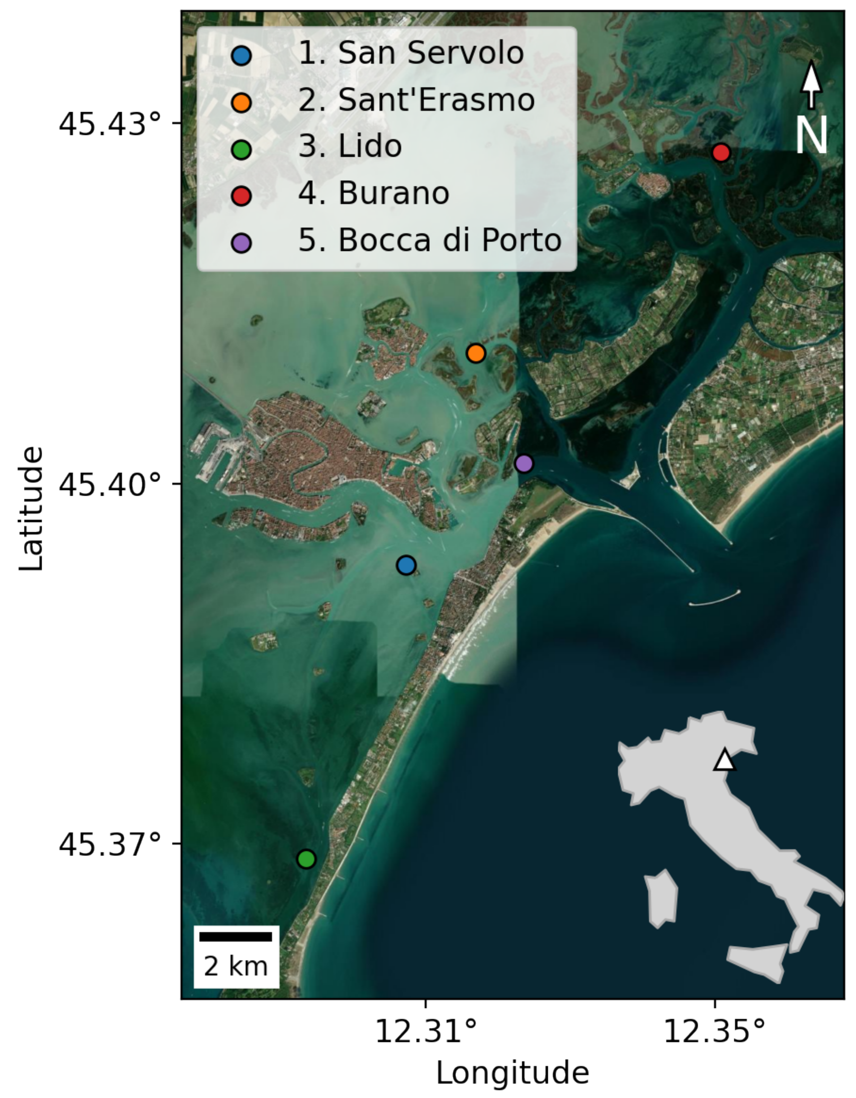
SEA SOUNDS

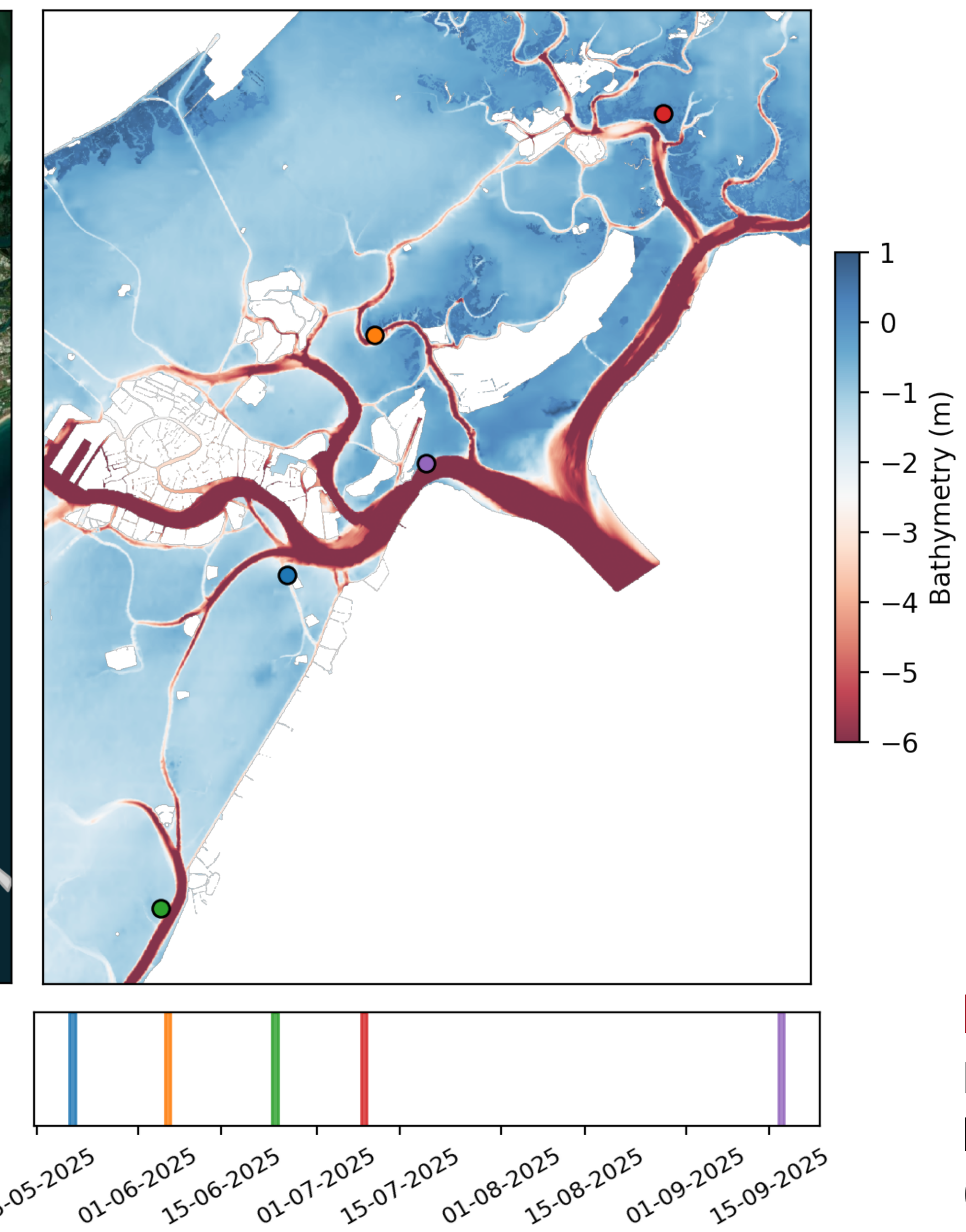
EGU26 GENERAL ASSEMBLY

Introduction

Coastal environments are increasingly exposed to multiple human pressures, among which underwater noise represents a growing but still unevenly quantified component (Frisk, 2012; Boaga and Boschi, 2022). **Shallow transitional systems** such as lagoons are particularly challenging to investigate acoustically, due to spatially heterogeneous shallow bathymetry, soft muddy substrates, strong tidal forcing, and intense maritime activity linked to navigation, port infrastructure, and tourism.

High-quality **underwater acoustic observations** are commonly based on hydrophones and dedicated recording platforms, whose costs and operational constraints often restrict spatial coverage and monitoring duration. The recent availability of **low-cost underwater acoustic recorders** offers new perspectives for dense and flexible observational networks, but their lack of calibration and sensor-to-sensor variability limit their applicability for quantitative soundscape analyses.





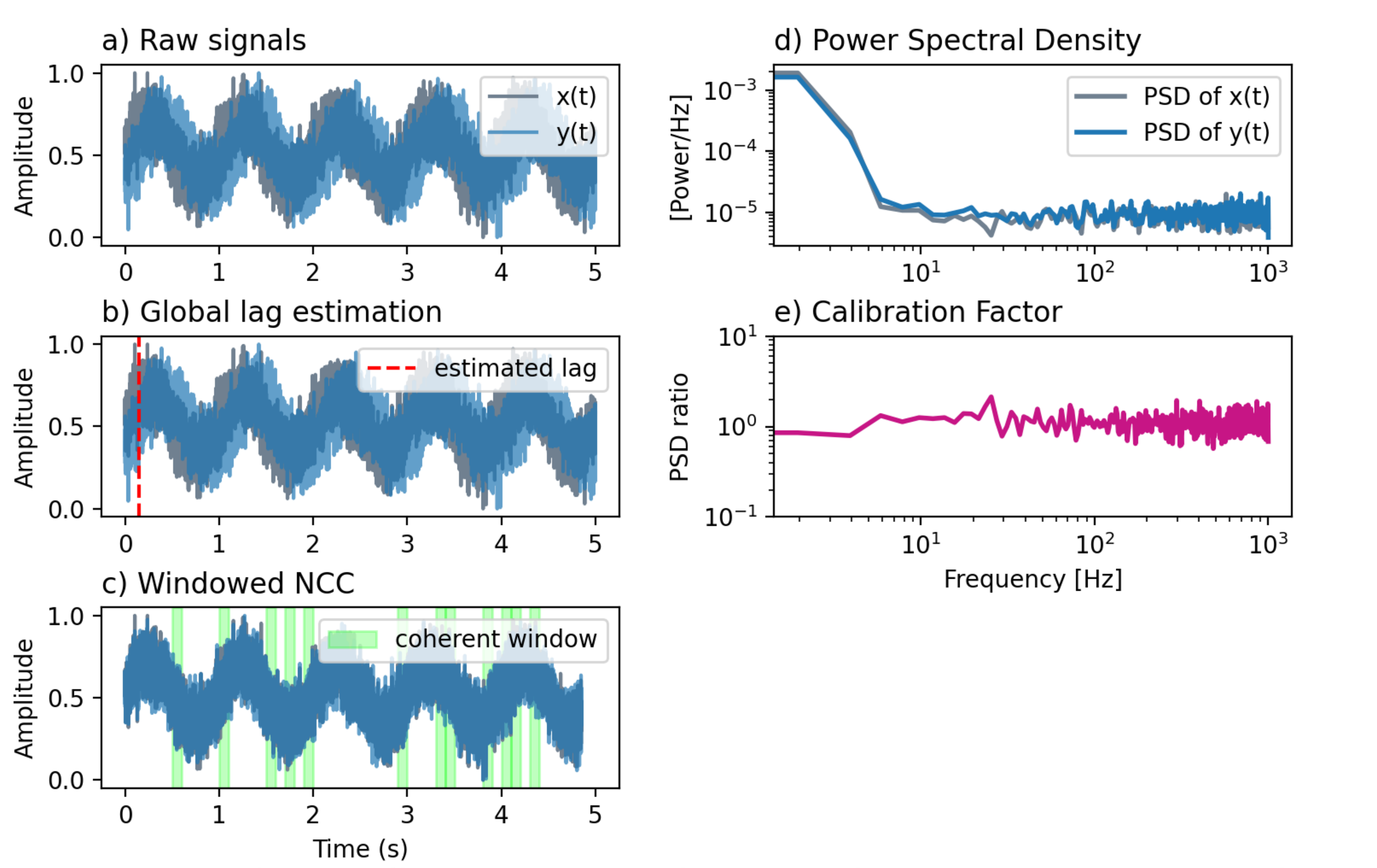
Objectives

- Assess whether **low-cost recorders** can be used for **quantitative analysis** in shallow lagoon systems
- Apply a **practical calibration approach** to express data in SPL (dB re μPa) for intra-sensor comparability
- Evaluate spatio-temporal variability of the **Venice Lagoon soundscape**

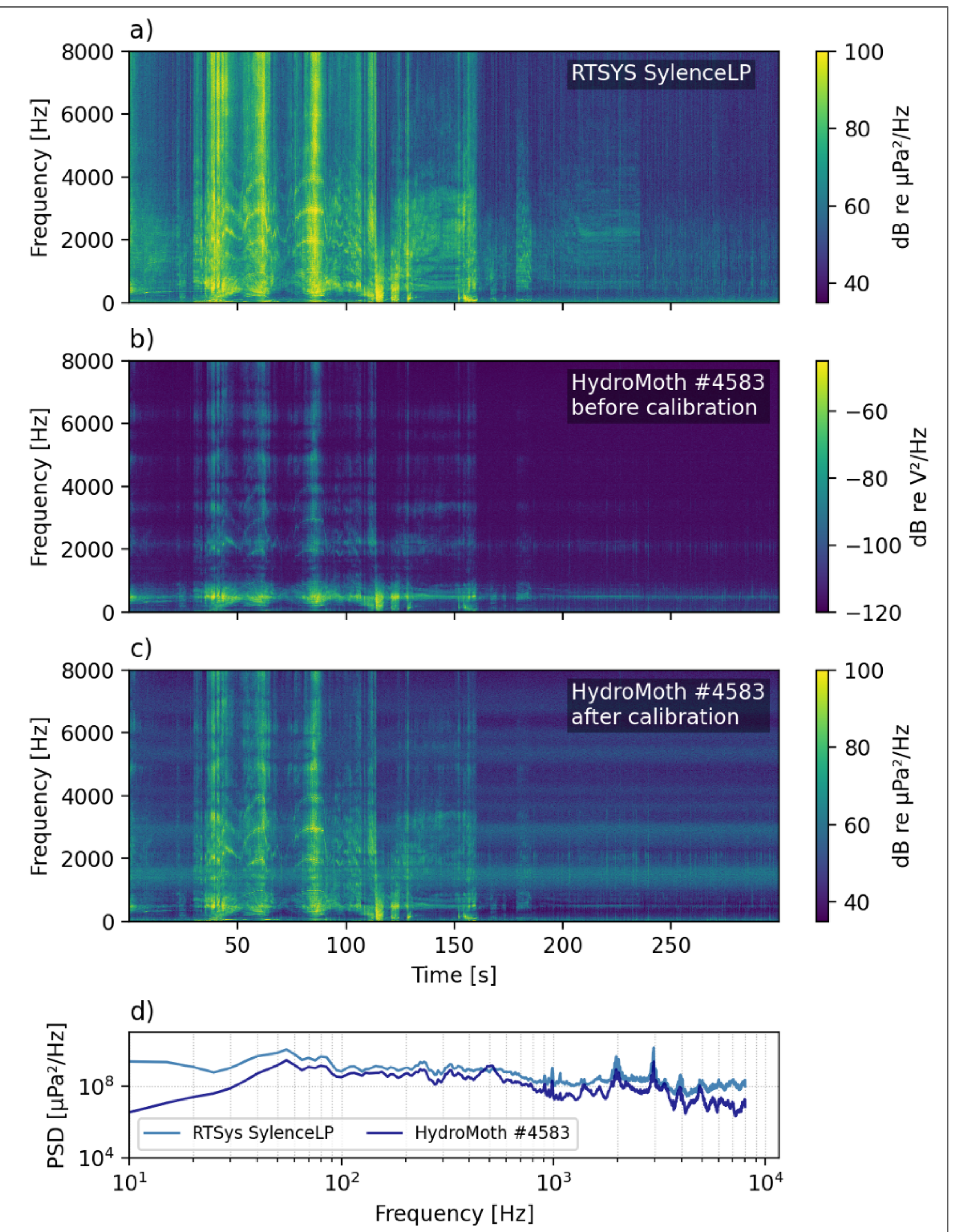
The *calibration* procedure

Simultaneous recordings from three HydroMoth loggers and one SylenceLP hydrophone were acquired in a controlled experiment (co-located sensors, repeated boat passes). Due to the lack of GPS synchronization and differing acquisition settings, an a-posteriori alignment was required. The workflow includes:

a) File pairing (timestamps) and Pre-processing (resampling + mean removal);
b) Global time-offset estimation (cross-correlation) and Signal alignment;
c) Windowed NCC to select coherent segments (NCC ≥ 0.75);
d - e) Frequency-dependent calibration factor (*CF*) computed from *PSD* ratios



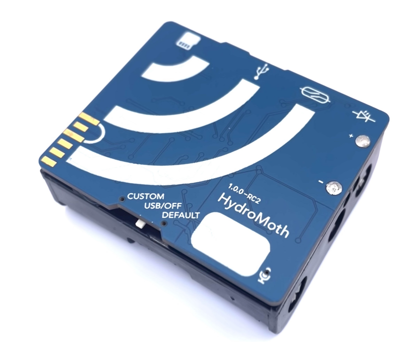
*CF*s were aggregated over all segments to obtain a robust sensor response, then applied to convert HydroMoth spectra from voltage to absolute acoustic pressure.



(a) Spectrogram of Sylence LP in physical units, (b) spectrogram of HydroMoth pre-calibration and (c) post-calibration. (d) Mean PSDs of Sylence LP (a) and calibrated HydroMoth #4583 (c).

Methods

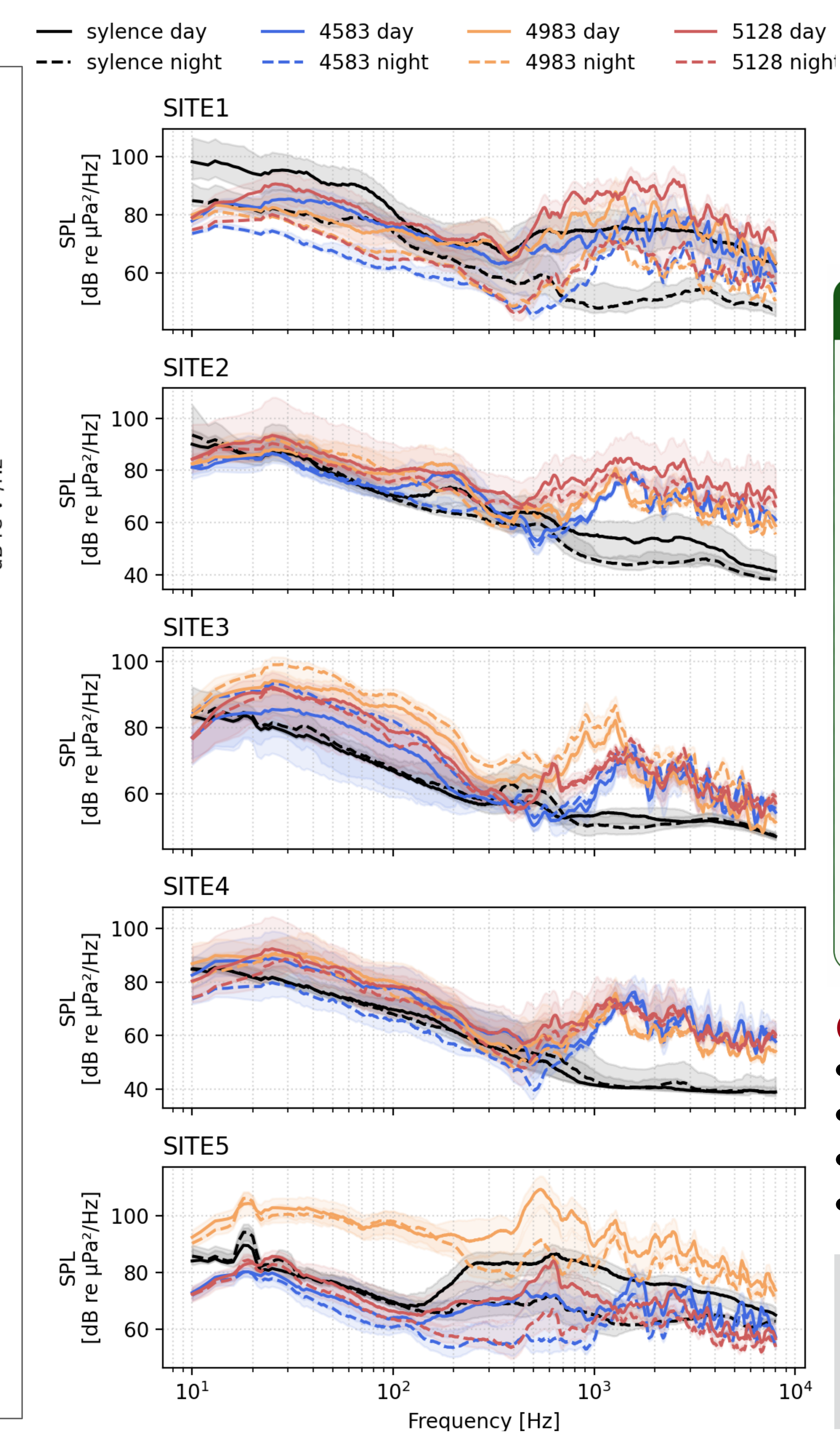
A distributed **array of recorders** was deployed across multiple sites in the Venice Lagoon (IT), covering complete **diel cycles**. HydroMoth responses were characterised and cross-validated through controlled measurements against a reference-calibrated hydrophone, allowing conversion of recorded signals into **physical units** and improving inter-sensor consistency. Acoustic observations were analysed jointly with ancillary **environmental and anthropogenic data**, including tidal conditions, vessel presence, and meteorological parameters.



HydroMoth		SylenceLP
Open Acoustic Devices	manufacturer	RTsys
~100-200 $	price range	~20.000 – 25.000 $
open source	phylosophy	industrial
built-in MEMS microphone	sensor	external quality hydrophones
8 - 384 kHz	bandwidth	64 – 512 kHz
1 microSD	storage	up to ~2 TB (multiple microSD)
moderate (lower S/N)	signal quality	high (dynamic range >100 dB)
AA batteries	sower supply	high-capacity D-cell batteries
~ -30 m (with case)	max depth	~ -250 m

Results

Meteorological and tidal conditions showed consistent diel patterns (stronger daytime winds, higher tides), precipitations were quite negligible. Acoustic data revealed clear day-night variability (typically +3/10 dB during daytime) and strong spatial heterogeneity, with Site5 as the most dynamic/noisy and Site1 the quietest.



Spectral shapes were consistent across sensors at low frequencies (10-600 Hz), while HydroMoth showed higher levels at above 5 kHz, likely due to instrument noise (Lamont et al., 2022). Overall amplitude RMS levels ranged ~90-150 dB re μPa, with slightly higher daytime values and greater variability across sites than between devices.

STRENGTHS

Consistent acoustic information
HydroMoths capture the same acoustic events as the reference hydrophone (e.g., boat noise) with coherent spectral and temporal features.

Reliable for qualitative analysis
Capable of detecting and characterizing acoustic events and spatial gradients across the lagoon (e.g., SITE5 > SITE1).

Quantitative comparison enabled
Field calibration with a reference instrument allows expressing data in dB re μPa and comparing multiple sensors.

Scalability & spatial coverage
Low cost enables deployment of many units, increasing spatial representativeness and capturing fine-scale variability.

Practical & easy to deploy
Compact, lightweight and easy to install, well-suited for complex and shallow environments like lagoons.

VS.

LIMITATIONS

Limited quantitative accuracy
HydroMoths do not provide fully reliable SPL estimates over long periods, especially at high frequencies (> 1 kHz).

High amplitude variability
Significant differences between sensors, even at the same site and time, persist after calibration.

Hardware limitations
Lower signal-to-noise ratio and non-uniform frequency response; reliable mainly below ~15 kHz.

Directionality & deployment effects
Sensor orientation, tilt and coupling with the seabed strongly affect recordings, especially at high frequencies.

Environmental variability
Differences in wind, tides, precipitation and seasonality influence sound propagation and background noise.

No laboratory calibration
Simplified field calibration limits absolute SPL accuracy and comparability with other studies.

Outlook

- Improve deployment strategies
- Promote standardized calibration procedures
- Support noise regulation in the Venice Lagoon
- Develop ML-based sound source detection

Boaga, J., and L. Boschi, 2022, Impact of Anthropogenic Activities on Underwater Noise Pollution in Venice: Water, Air, & Soil Pollution, **233**, 221.
Frisk, G. V., 2012, Noiseonomics: The relationship between ambient noise levels in the sea and global economic trends: Scientific Reports, **2**, 437.
Lamont, T. A. C., L. Chapuis, B. Williams, S. Dines, T. Gridley, G. Frainer, J. Fearey, P. B. Maulana, M. E. Prasetya, J. Jompa, D. J. Smith, and S. D. Simpson, 2022, HydroMoth: Testing a prototype low-cost acoustic recorder for aquatic environments: Remote Sensing in Ecology and Conservation, **8**, 362–378.