
UNDERWATER NOISE MEASUREMENT

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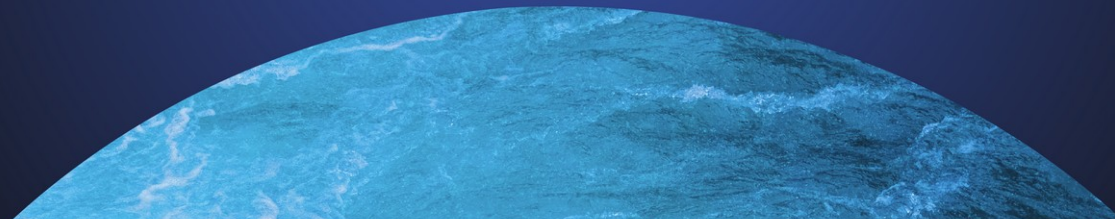




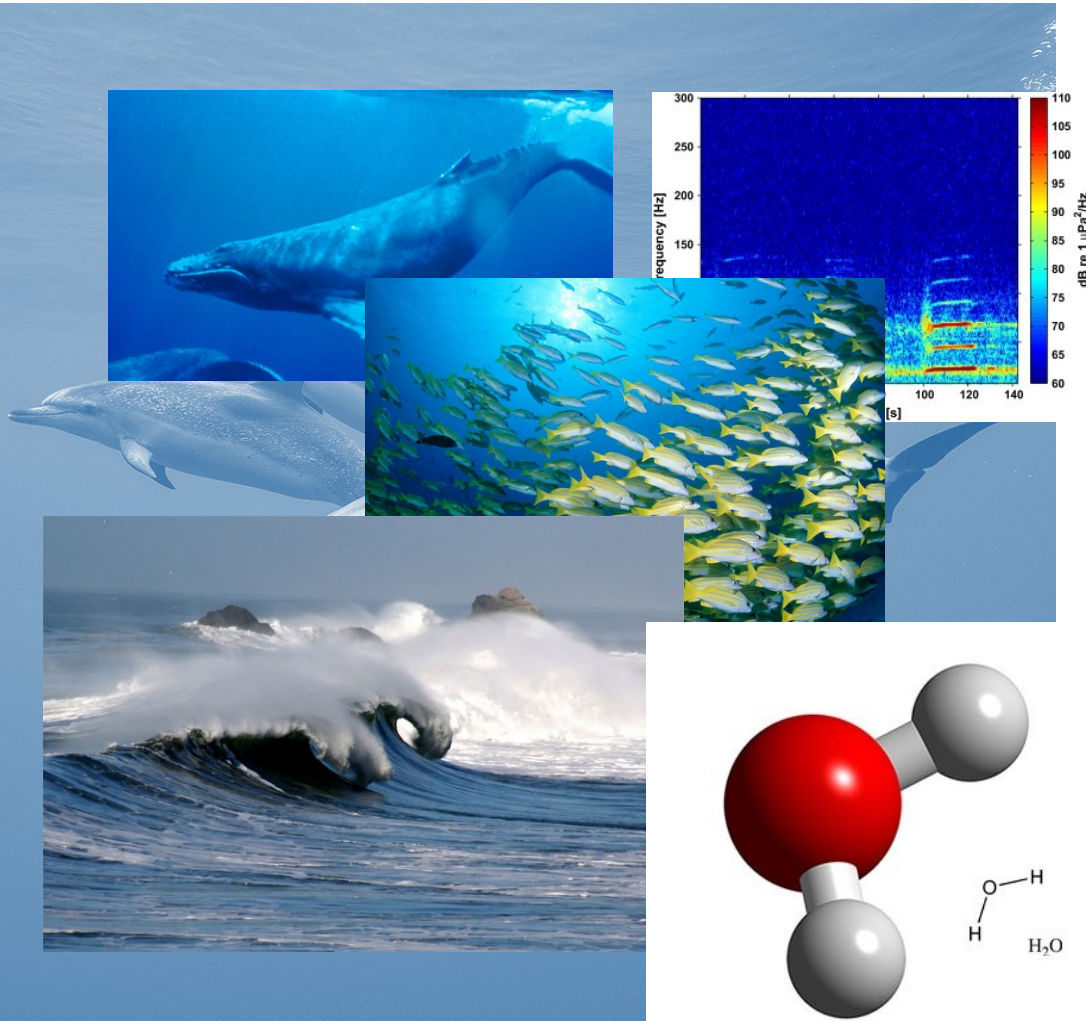
TABLE OF CONTENTS

01

INTRODUCTION

Ocean Sound and
Underwater Noise

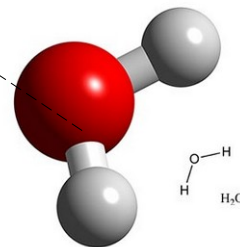
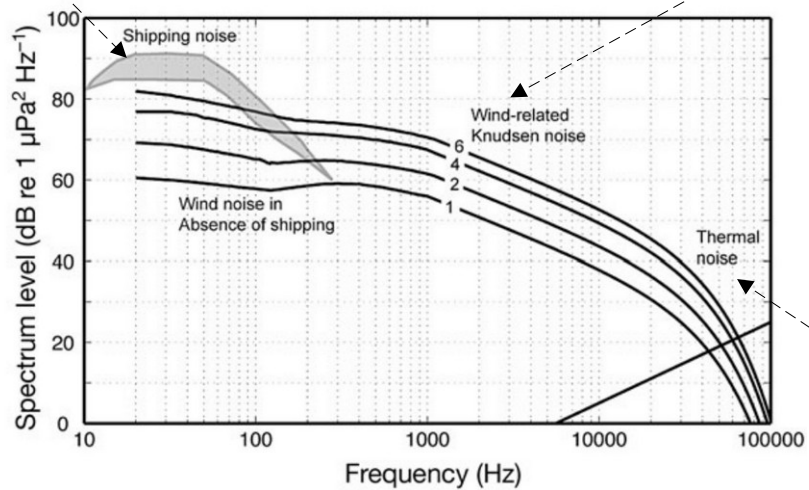
OCEAN SOUND



NATURAL SOURCES

- Marine mammals
- Fish swarms
- Wind and waves
- Earthquakes
- Thermal sound

OCEAN SOUND

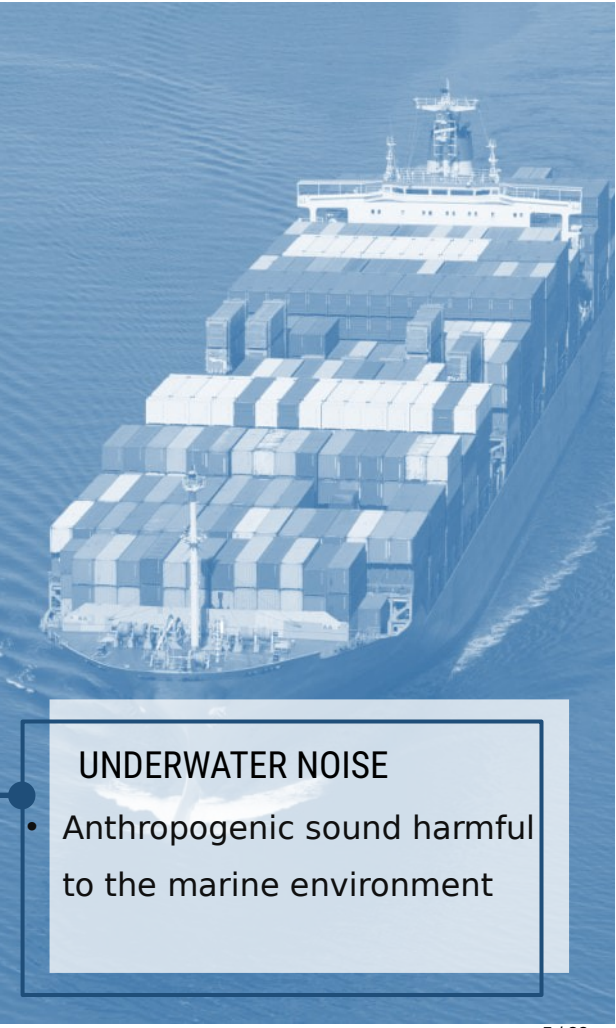


A photograph of several white offshore wind turbines in a blue ocean under a clear sky. The text 'OCEAN SOUND' is written vertically in white on the left side of the image.

OCEAN SOUND

ANTHROPOGENIC SOURCES

- Shipping
- Seismic exploration
- Sonar
- Offshore energy
- ...

A photograph of a large container ship sailing on the ocean, viewed from an elevated angle. The ship is heavily loaded with colorful shipping containers.

UNDERWATER NOISE

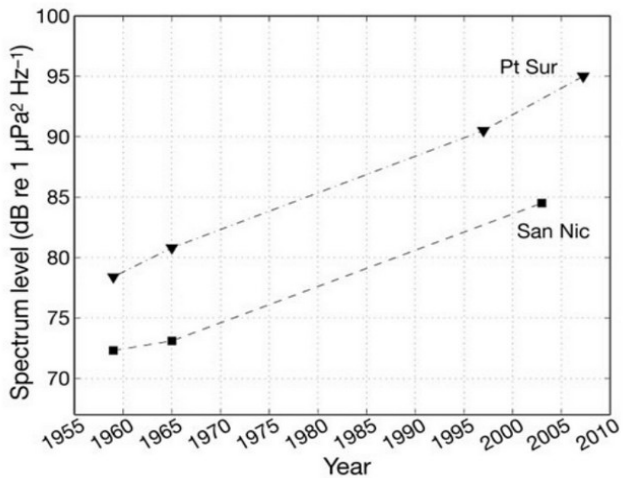
- Anthropogenic sound harmful to the marine environment

UNDERWATER NOISE



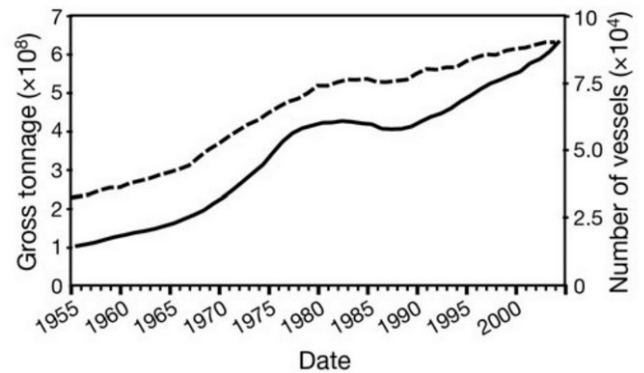
UNDERWATER SOUND

OCEAN SOUND TRENDS

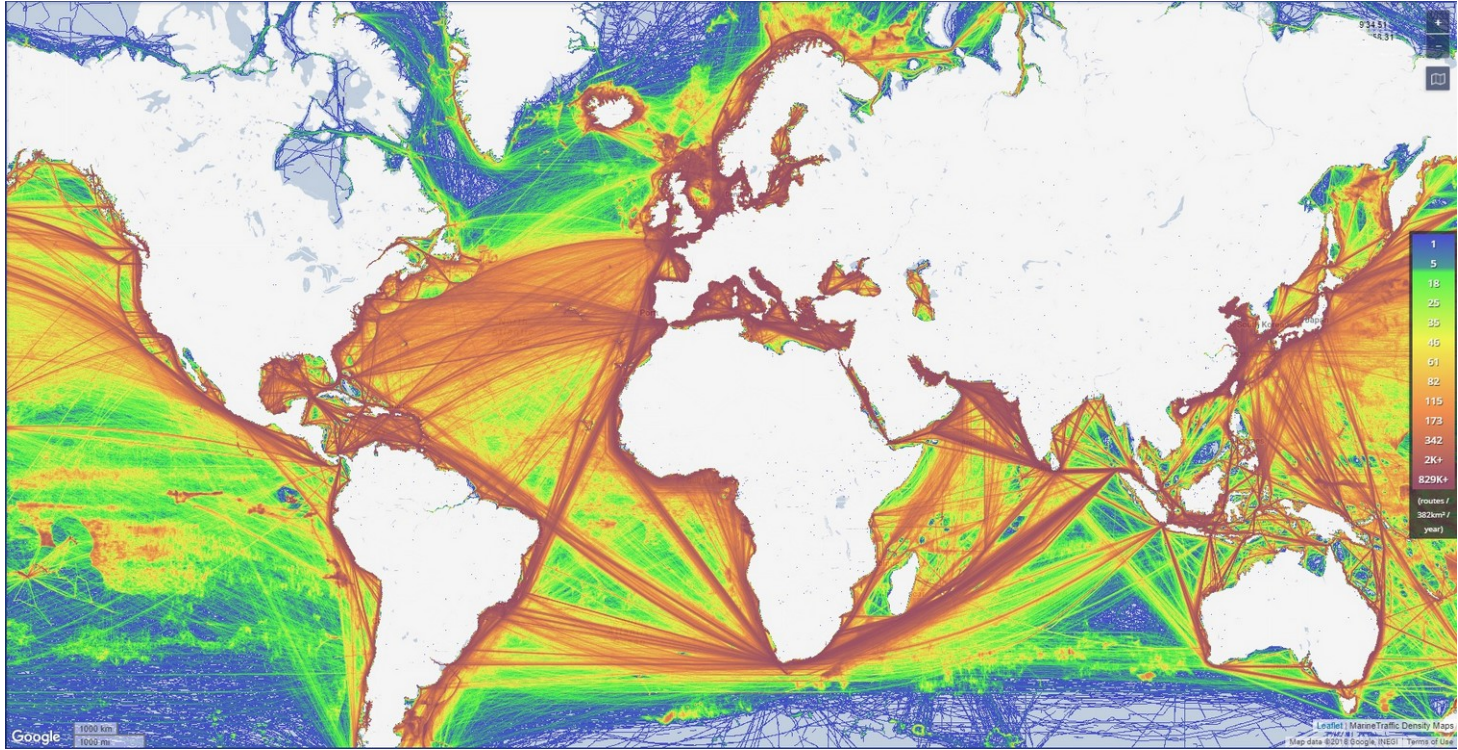


- Increase of about 3 dB/decade (northeastern Pacific at 40 Hz)

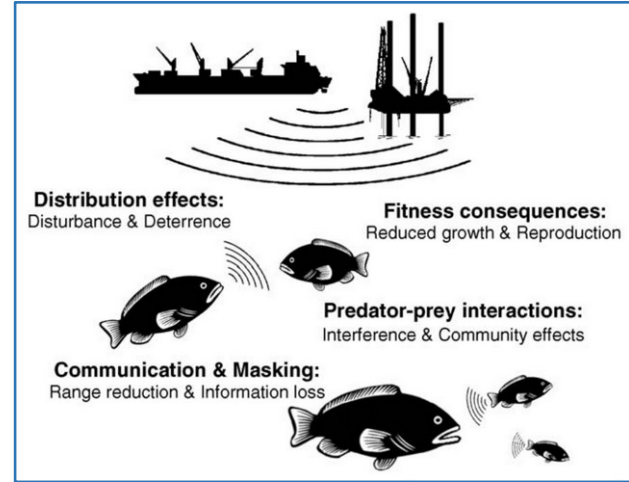
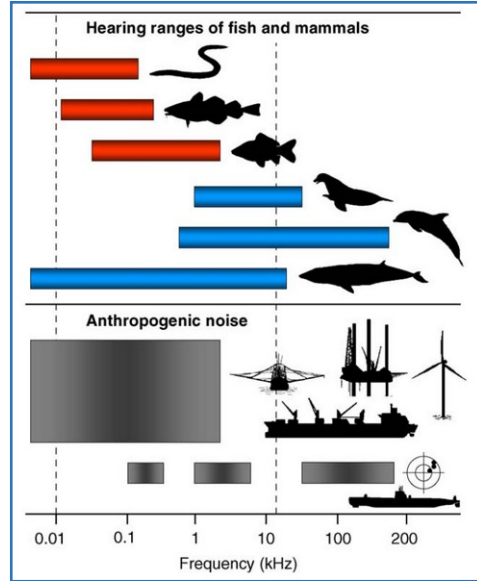
WORLD'S FLEET



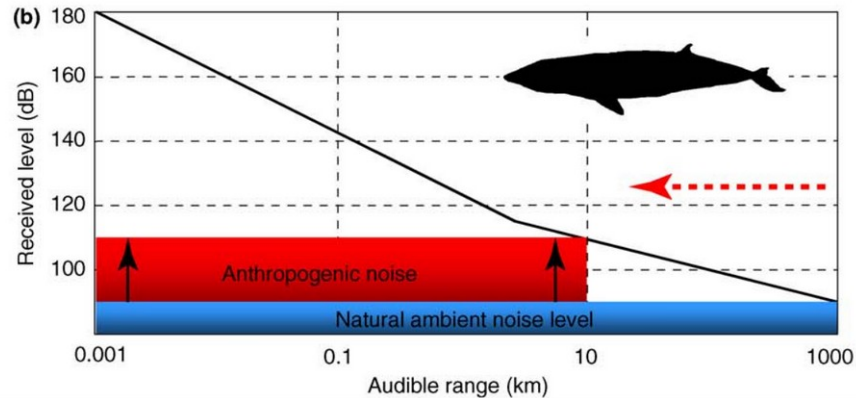
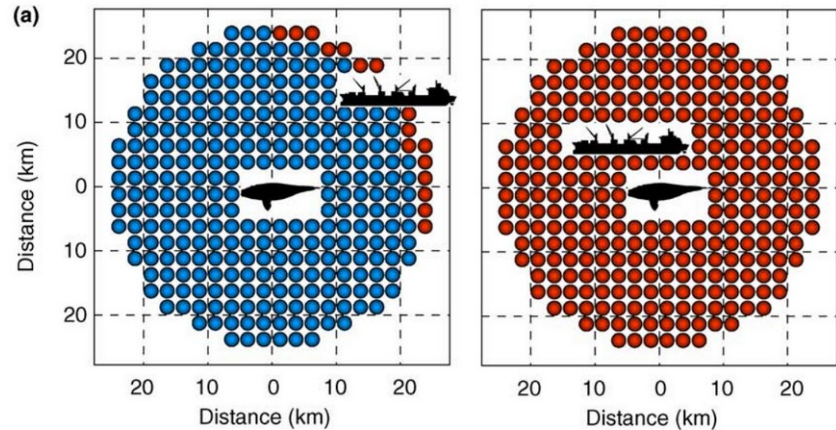
UNDERWATER NOISE



UNDERWATER NOISE



MASKING



MARINE STRATEGY FRAMEWORK DIRECTIVE (MSFD)

- European Union Directive
- Aims to achieve a “*good environmental status*” (GES)
- Defines 11 descriptors
- Including underwater noise



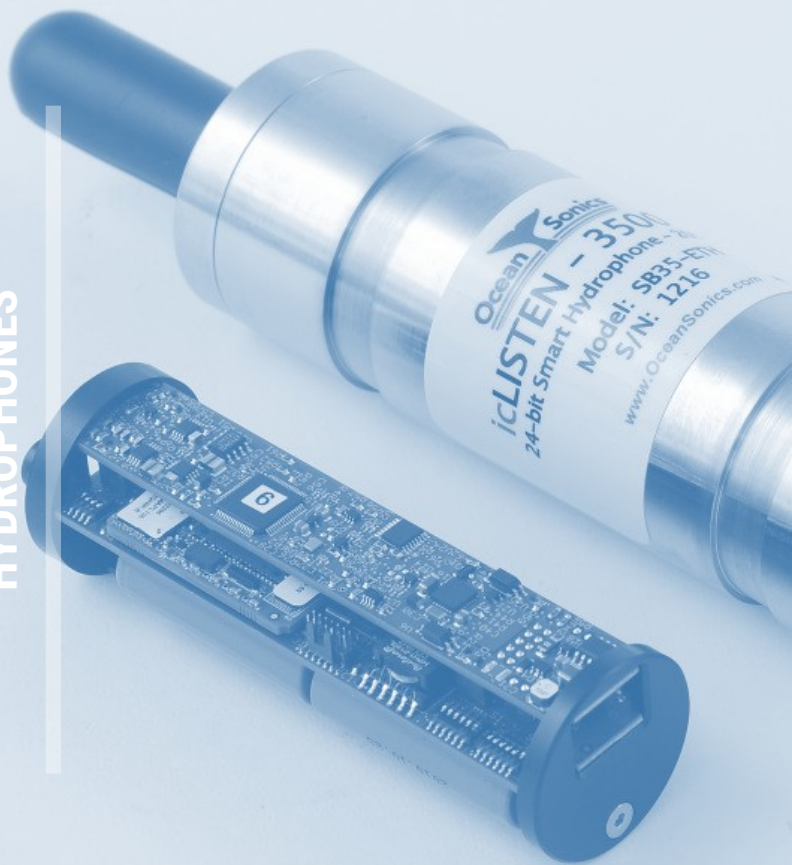


TABLE OF CONTENTS

02

HYDROPHONES AND
OBSERVATION PLATFORMS

HYDROPHONES



HYDROPHONES

- Complex sensor systems
- Measure underwater sound
- Very high data volume
- Highly heterogeneous

Deployment strategies

- Standalone (hydrophone + batteries)
 - Internal recordings
 - No real-time communications
- Integrated into observation platforms
 - ↑ Spatial coverage
 - ↑ Autonomy
 - ↑ Real-time communications

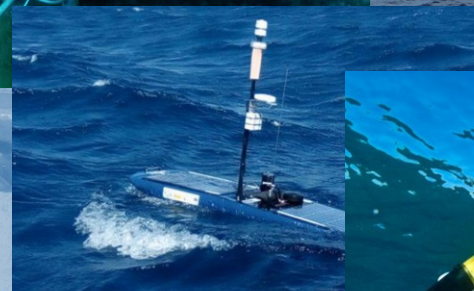
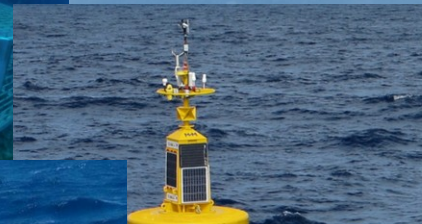
OBSERVATION PLATFORMS

OBSERVATION PLATFORMS

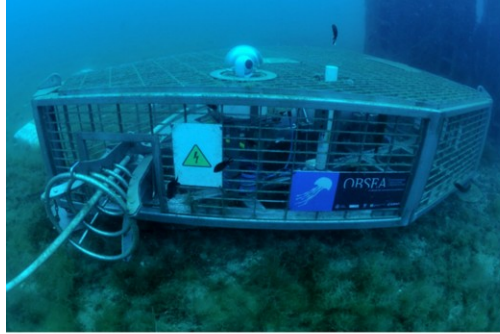
- Stations/vehicles that host sensors
- Fixed or mobile
- Provide power and telemetry
- Highly heterogeneous

USUAL CONSTRAINTS

- Power availability
- Bandwidth (satellite, RF, ...)
- Computational resources



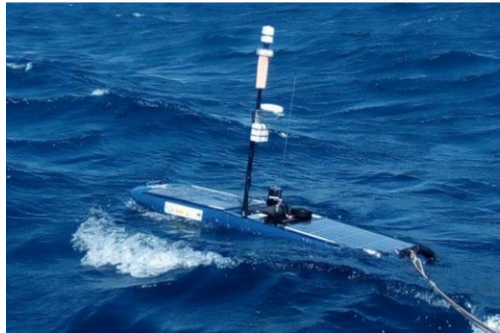
OBSERVATION PLATFORMS



(a) **Cabled Observatories**
Power availability: Very High
Telemetry: Broadband Ethernet



(b) **Moored Buoys**
Power availability: Medium
Telemetry: GSM / satellite



(c) **Autonomous Surface Crafts**
Power availability: low
Telemetry: satellite



(d) **Underwater Gliders**
Power availability: ultra-low
Telemetry: satellite (intermittent)

HYDROPHONE INTEGRATION



HYDROPHONE INTEGRATION

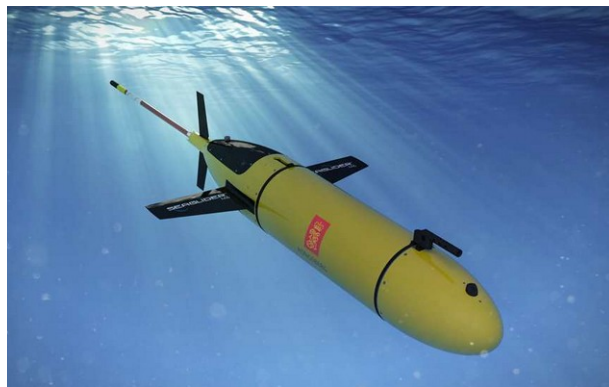
- Acoustic Recordings (WAV)
 - × Up to tens of GB / day
 - × Not RT data via GSM/Satellite
 - × Large on-board storage required

HYDROPHONE INTEGRATION



HYDROPHONE INTEGRATION

- Acoustic Recordings (WAV)
 - × Up to tens of GB / day
 - × Not RT data via GSM/Satellite
 - × Large on-board storage required
- In Situ Processing
 - ✓ Few KB / day → real-time delivery
 - × On-board signal processing
 - × Computational resources



SEAGLIDER

- Battery capacity: 17 MJ¹
- Telemetry: Satellite (Iridium)
- Telemetry cost: 35 J/Kbyte²
- Hydrophone: 16 bit

TX RAW HYDROPHONE DATA

Sampling (kHz)	Volume (GB / day)	Tx energy (MJ)	Battery (% / day)
2	0.35	12.25	72.06
6	1.04	36.4	214.12
24	4.15	145.25	854.41
96	16.59	580.65	3415.59
192	33.18	1161.3	6831.18

TX PROCESSED DATA

T snapshot (s)	Volume (KB / day)	Tx energy (MJ)	Battery (% / day)
1	8640	0.3024	1.78
10	864	0.03024	0.18
20	432	0.01512	0.09
60	144	0.00504	0.03
300	28.8	0.001008	0.01

¹ www.kongsberg.com

² Rudnick, Daniel L., et al. "Underwater gliders for ocean research." *Marine Technology Society Journal* 38.2 (2004): 73-84.

HYDROPHONE INTEGRATION

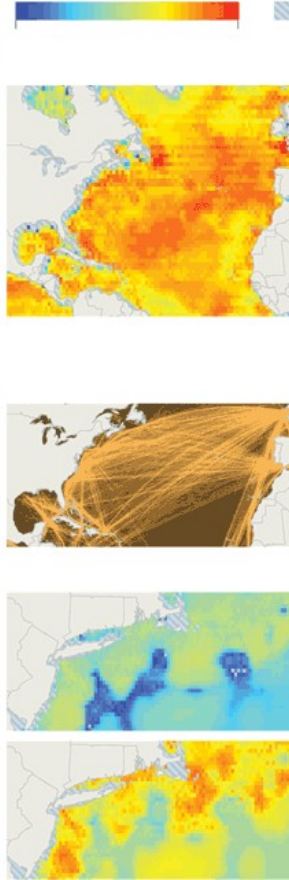
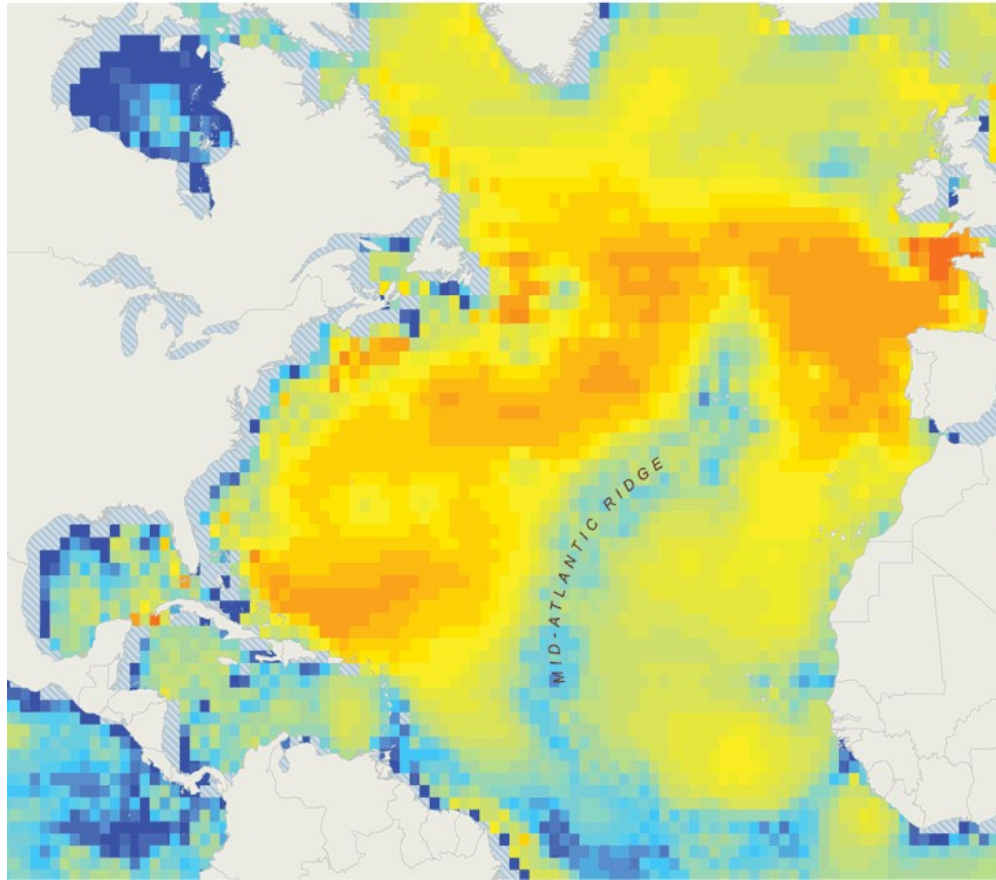




TABLE OF CONTENTS

03

UNDERWATER NOISE
ALGORITHMS

<p>Biological diversity</p> <p>1. </p>	<p>Non-indigenous species</p> <p>2. </p>	<p>Population of commercial fish/shellfish</p> <p>3. </p>	<p>Elements of marine food webs</p> <p>4. </p>
<p>Eutrophication</p> <p>5. </p>	<p>Sea floor integrity</p> <p>6. </p>	<p>Alteration of hydrographical conditions</p> <p>7. </p>	<p>Concentrations of contaminants</p> <p>8. </p>
<p>Good Environmental Status</p>	<p>Contaminants in fish/seafood for human consumption</p> <p>9. </p>	<p>Marine litter</p> <p>10. </p>	<p>Introduction of energy including underwater noise</p> <p>11. </p>

Contribution: Interoperable Architecture

- Based on standards
- Any sensor (including hydrophones)
- Any observation platform

Apply to Passive Acoustics

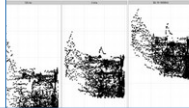
- Demonstrate feasibility
- In situ processing

Use Case: MSFD Descriptor

- 11.1 Impulsive Sounds
- 11.2 Continuous low-frequency sound

European Marine Strategy Framework Directive Good Environmental Status (MSFD-GES)

Report of the Technical Subgroup on Underwater Noise
and other forms of energy



Good Practice Guide No. 133

Underwater Noise Measurement

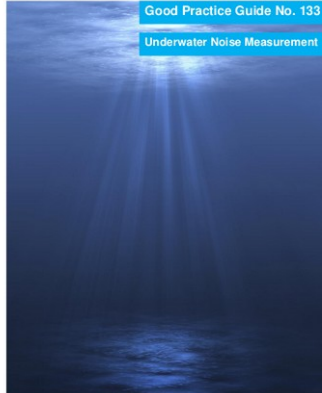
JRC SCIENTIFIC AND POLICY REPORTS

Monitoring Guidance for
Underwater Noise in European Seas

Part II: Monitoring Guidance
Specifications

A guidance document within the
Common Implementation
Strategy for the Marine
Strategy Framework Directive

MSFD Technical Subgroup on
Underwater Noise
2014



marinescotland

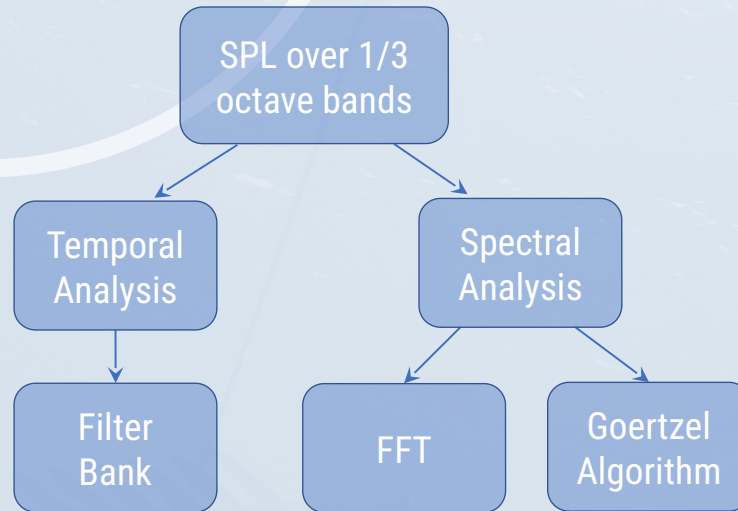


THE CROWN
ESTATE

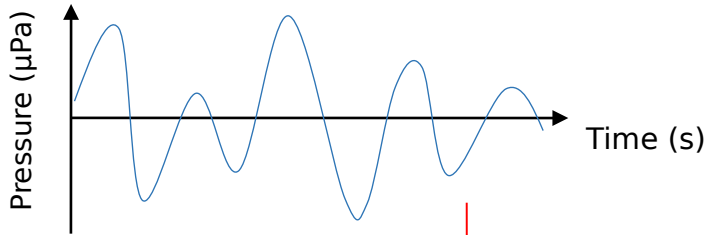
CONTINUOUS LOW-FREQUENCY SOUND

- Different metrics can be used
 - Best practices
 - MSFD Specifications
- Sound Pressure Level (SPL)
- Third-octave frequency bands:
 - 63 Hz, 125 Hz (and 2 kHz)
 - 10 Hz - 20 kHz (optional)
- Time snapshot (10 - 60 secs)

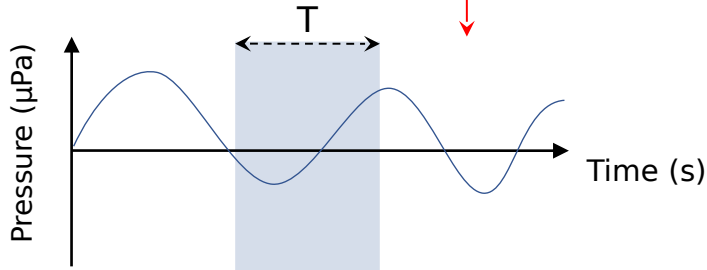
SPL ALGORITHMS



TEMPORAL ANALYSIS

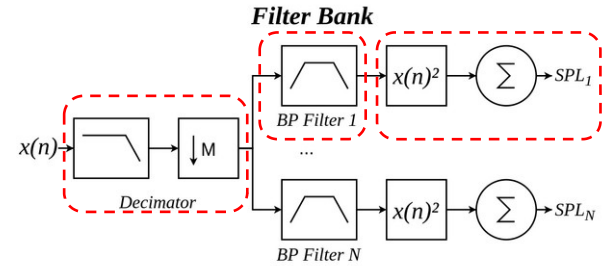


Filter



$$SPL_N = 10 \log_{10} \left(\frac{1}{N} \sum_N \frac{p(n)^2}{p_0^2} \right) [dB \text{ re } \mu Pa]$$

97.54 dB re μPa



FILTER BANK

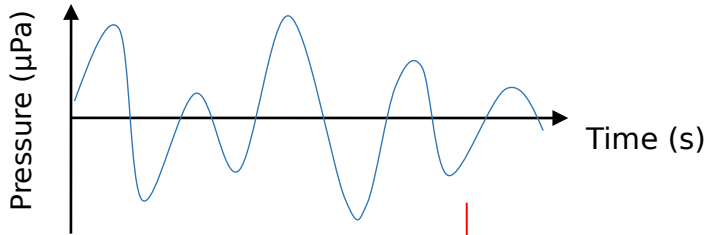
- Decimating (sampling rate $\downarrow \downarrow$)
- Apply band-pass filter
- SPL equation (temporal)
- Once filter per band

Filter Bank

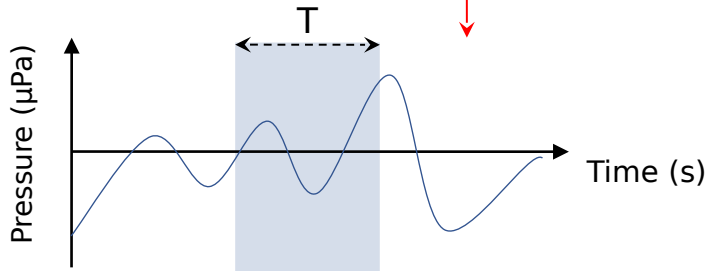
FFT

Goertzel

TEMPORAL ANALYSIS

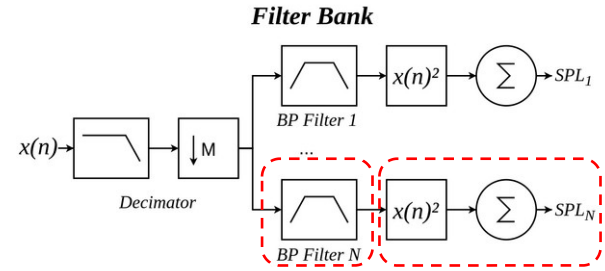


Filter



$$SPL_N = 10 \log_{10} \left(\frac{1}{N} \sum_N \frac{p(n)^2}{p_0^2} \right) [dB \text{ re } \mu Pa]$$

97.54 dB re μPa
 85.32 dB re μPa

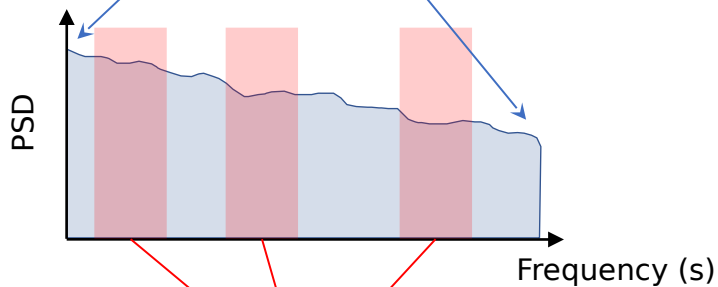
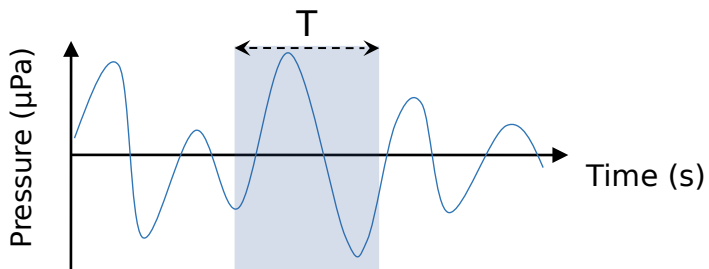


FILTER BANK

- Decimating (sampling rate $\downarrow \downarrow$)
- Apply band-pass filter
- SPL equation (temporal)
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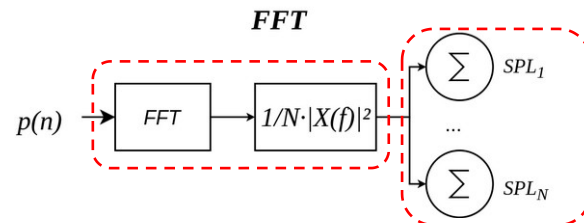
Filter Bank FFT Goertzel

SPECTRAL ANALYSIS



$$SPL_{f,N} = 10 \log_{10} \left(\frac{2}{N} \sum_{f_l}^{f_h} \bar{P}_{xx}(f) \right) [dB \text{ re } \mu Pa]$$

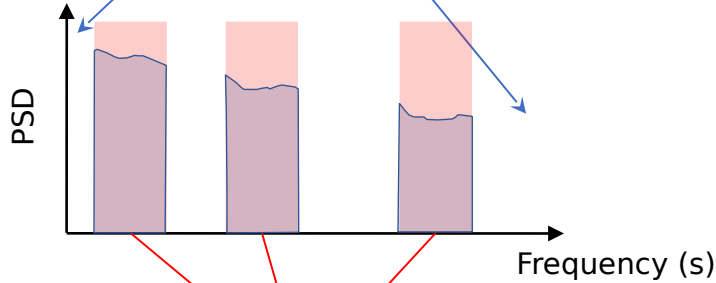
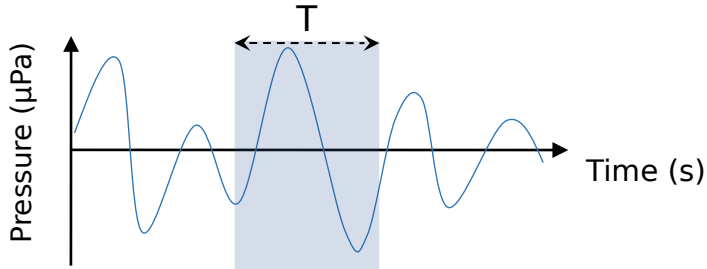
- 97.54 dB re μPa
- 85.32 dB re μPa
- 91.83 dB re μPa



FAST FOURIER TRANSFORM

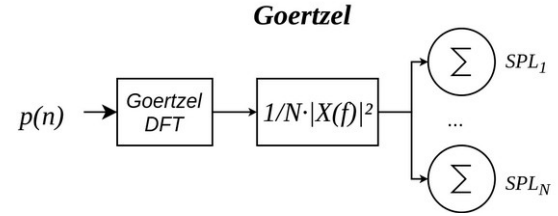
- DFT optimized for $N = 2^M$
- Estimate PSD using FFT
- Select bands of interest
- Integrate frequency bands

SPECTRAL ANALYSIS



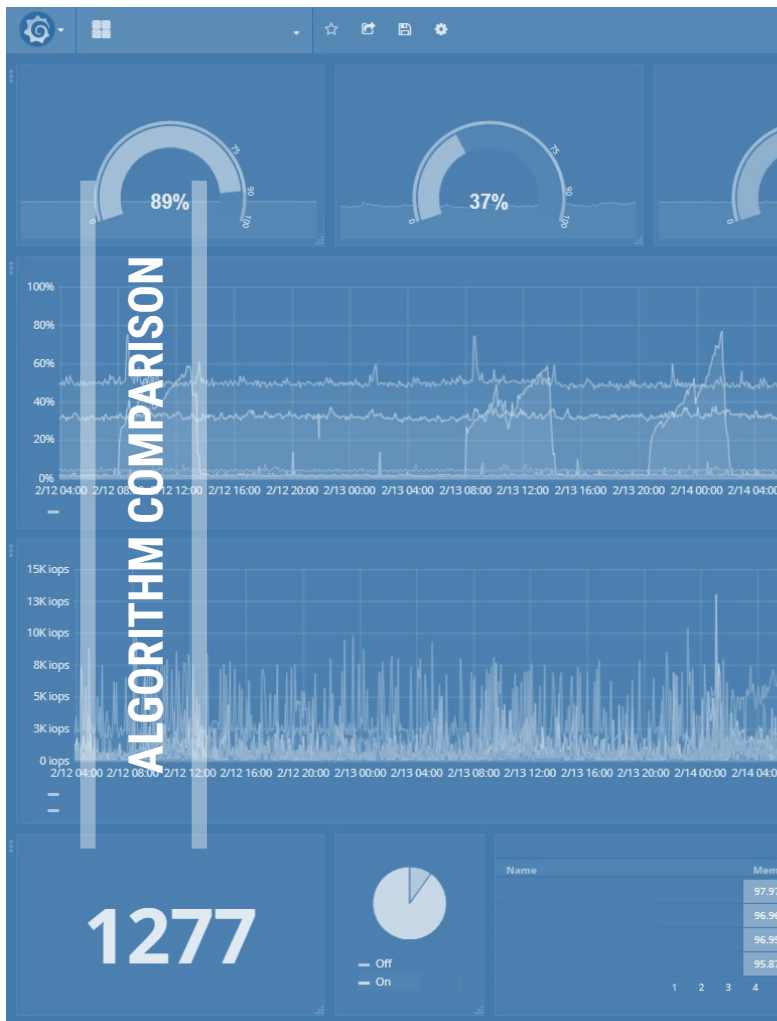
$$SPL_{f,N} = 10 \log_{10} \left(\frac{2}{N} \sum_{f_l}^{f_h} \bar{P}_{xx}(f) \right) [dB \text{ re } \mu Pa]$$

→ 97.54 dB re μPa
→ 85.32 dB re μPa
→ 91.83 dB re μPa



GOERTZEL'S ALGORITHM

- DFT (slower than FFT)
- Individual DFT terms
- Only bands of interest
- SPL in frequency domain



SPL ALGORITHM COMPARISON

Compare algorithm performance to obtain SPL level:

- Filter Bank
- FFT
- Goertzel

Parameters to evaluate:

- Execution time
- RAM memory used

Test conditions:

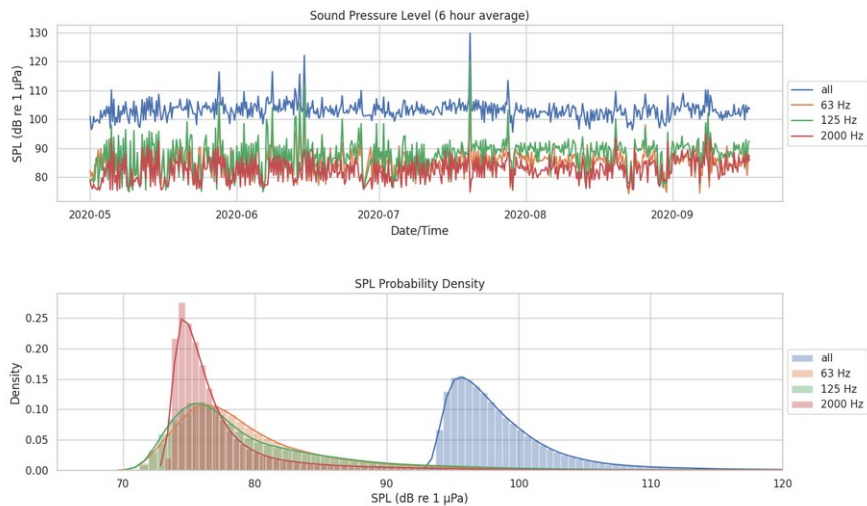
- Increase time snapshot T ($\Delta f = fs/N$)
- Increase third-octave bands



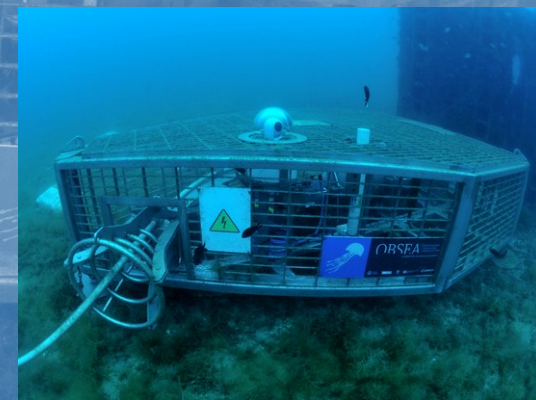
TABLE OF CONTENTS

04
USE CASES

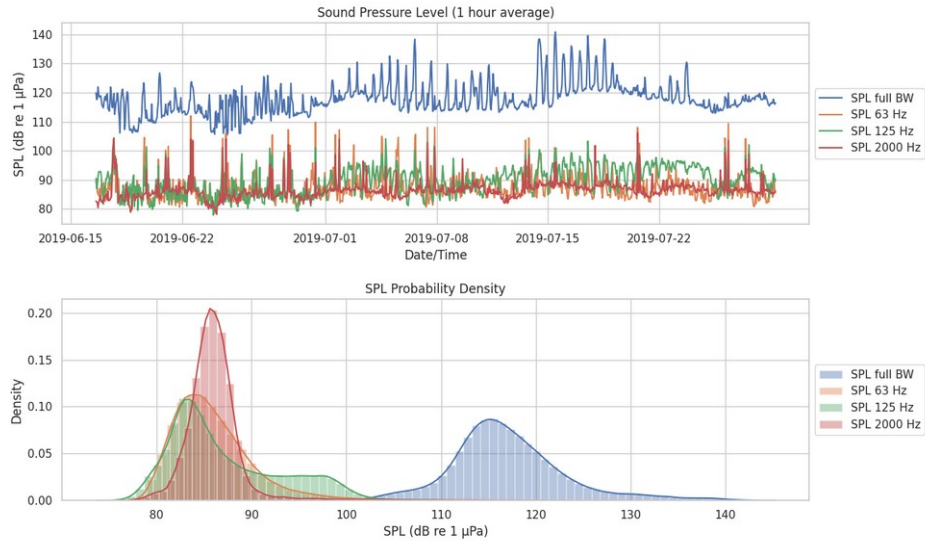
OBSEA



Name	OBSEA
Platform type	Cabled Observatory
Telemetry	Ethernet
Location	Vilanova i la Geltrú
Processing	Real-time / Server
Sensor Interfaces	UDP



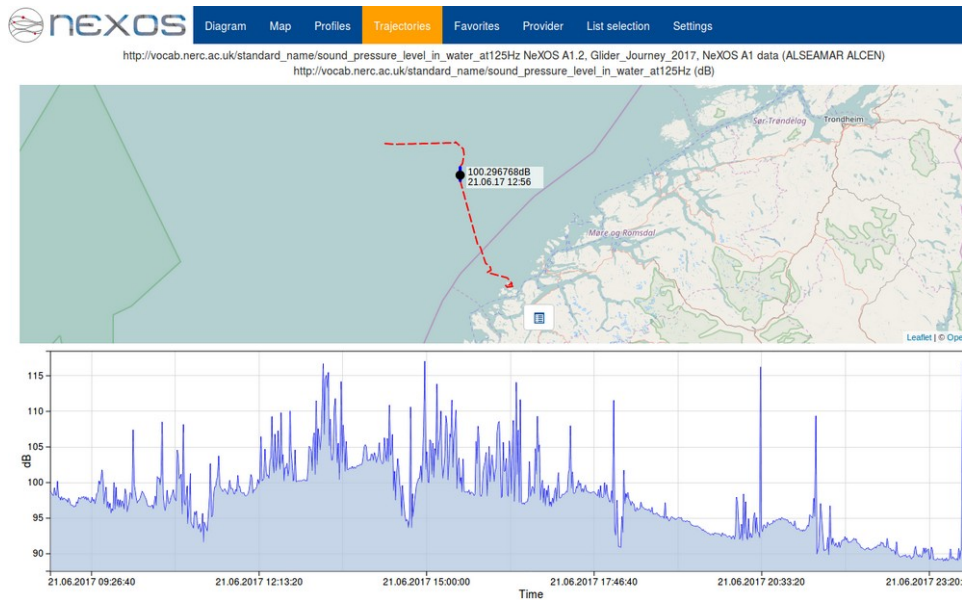
EGIM



Name	EGIM
Platform type	Datalogger / mooring
Telemetry	None
Location	Taliarte (Gran Canaria)
Processing unit	PC (offline)
Sensor Interfaces	UDP, Serial



SEAEXPLORER GLIDER



Name	SeaExplorer
Platform type	Underwater glider
Telemetry	Iridium
Location	Norway
Processing unit	Real-time / uC
Sensor Interfaces	RS232



THANK YOU FOR YOUR ATTENTION



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BARCELONATECH**

Departament d'Enginyeria Electrònica