

# Acoustics in water: synergies with marine biology

LAB - LIDO:

Mike van der Schaar, Ludwig Houégnigan, Alba Solsona, Steffen de Vreese, Antonio M. Sánchez, Michel André

ANTARES - AMADEUS:

Robert Lahmann, Kay Graf, ANTARES Collaboration

# Overview

- Introduction LAB
- LIDO deployment at ANTARES
- Sperm whale presence
- MSFD 11.2 Noise Measurements

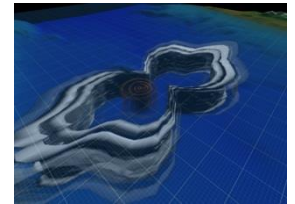
# LAB Introduction



## Environmental Monitoring



## Noise Assessment and Modelling



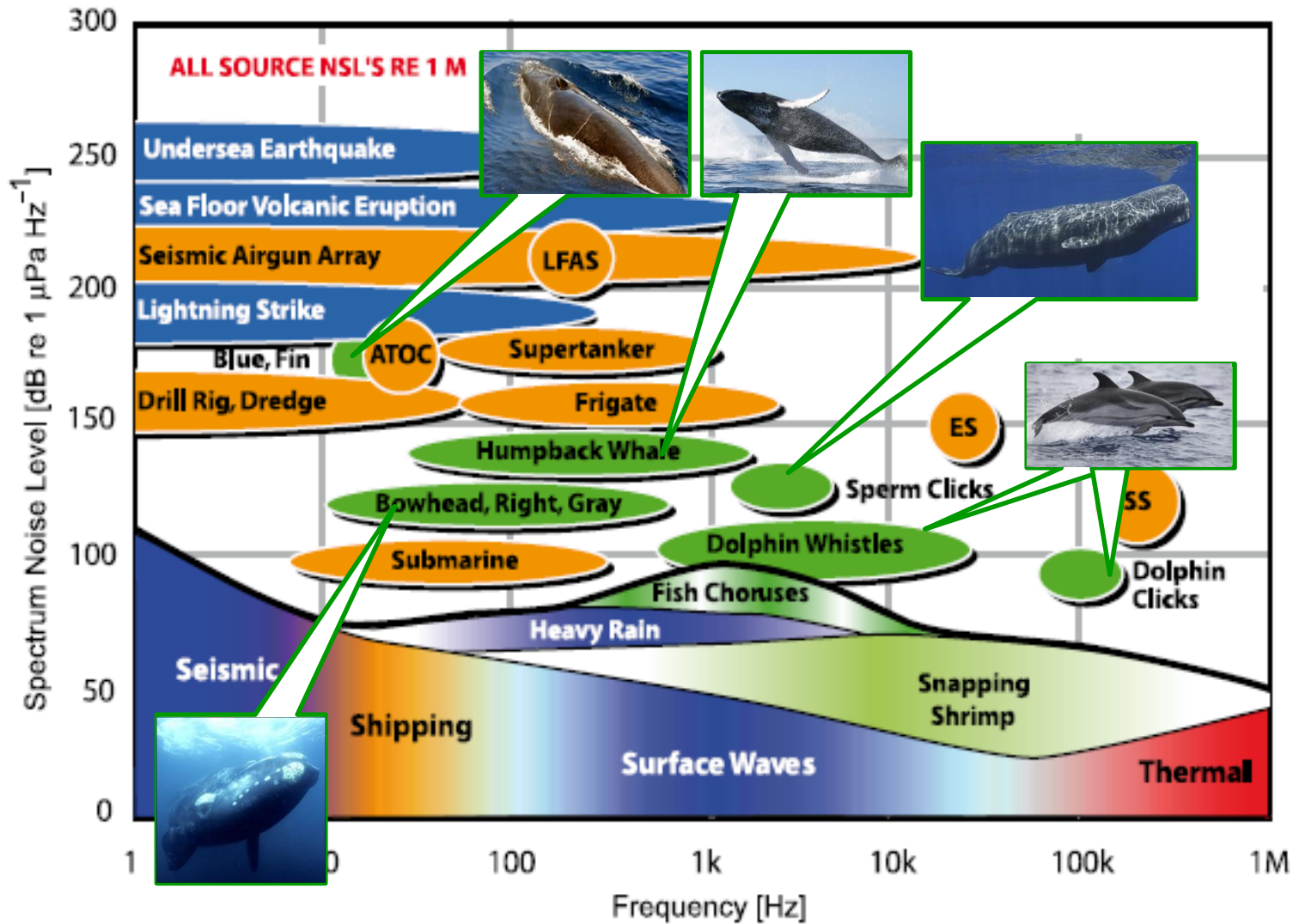
## Physiological Affects



## Acoustic Sensing



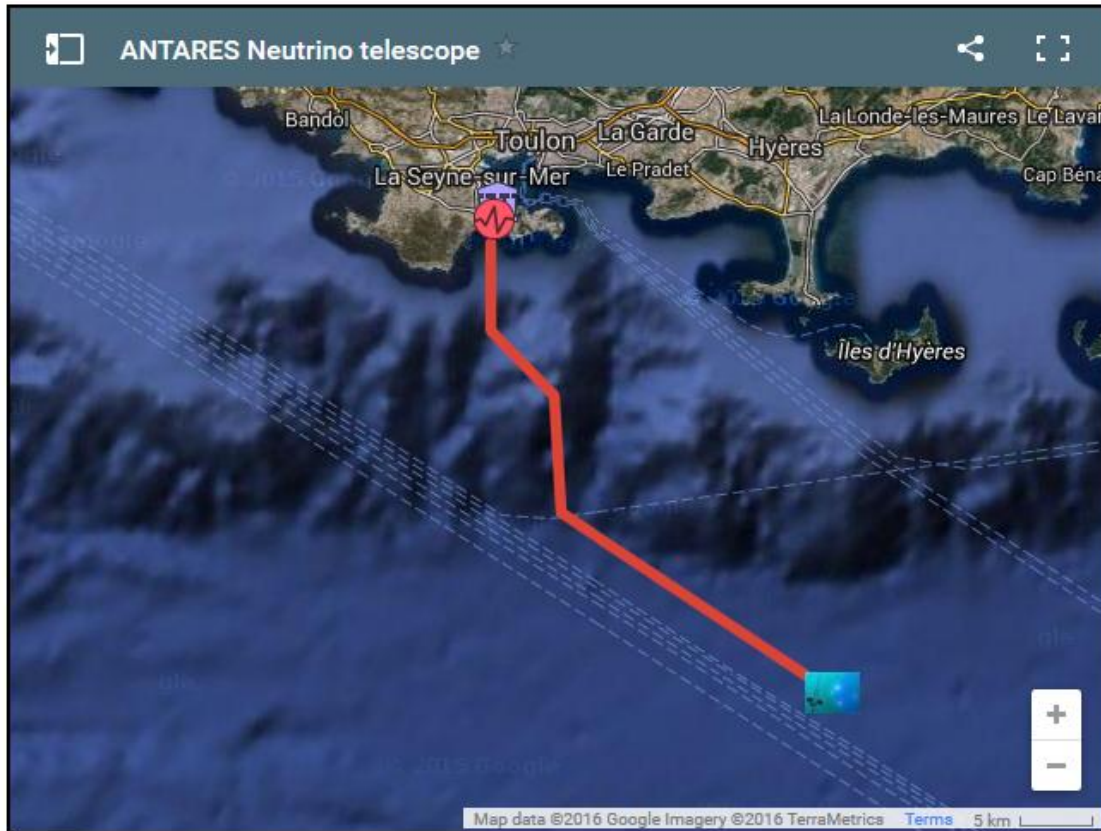
# Underwater Sounds



- natural
- biologic
- man made

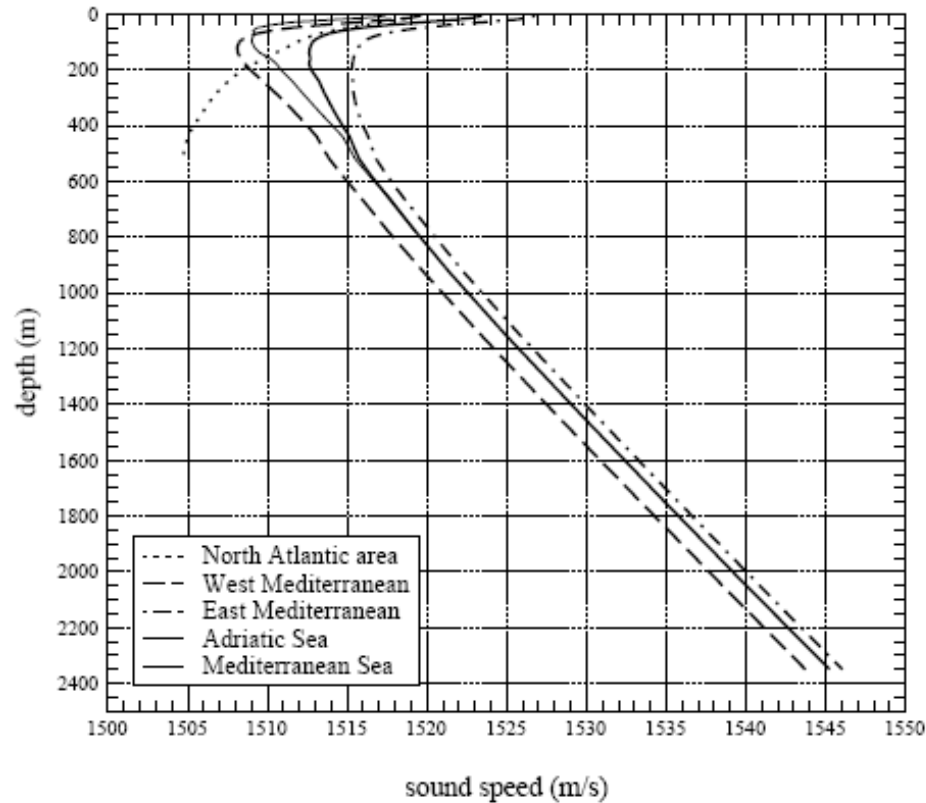
©Seiche Ltd. 2006

# LIDO at ANTARES



ANTARES is composed of 12 lines of about 350m each, covering a surface area of 0.1 km<sup>2</sup>.

# LIDO at ANTARES



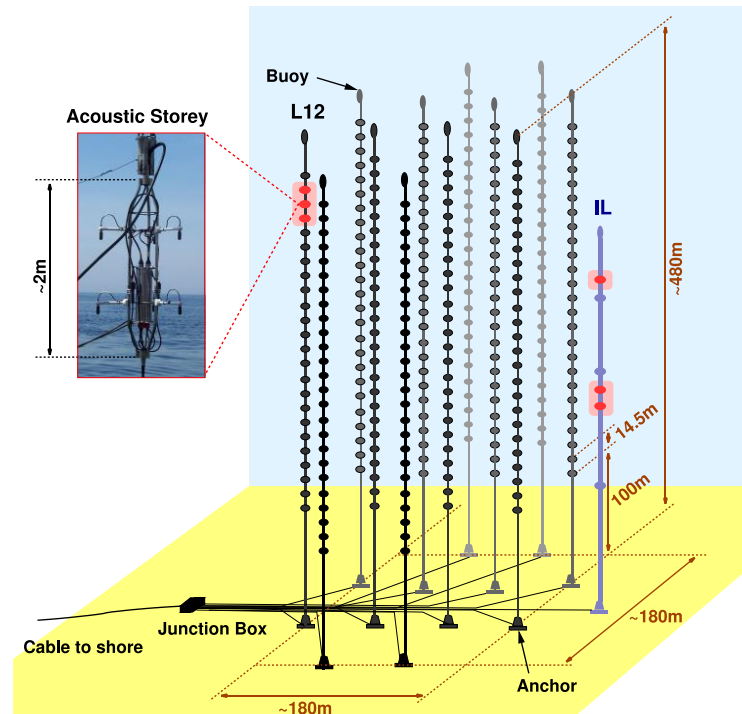
**Sound speed in the Mediterranean Sea: an analysis from a climatological data set**

**S. Salon<sup>1</sup>, A. Crise<sup>1</sup>, P. Picco<sup>2</sup>, E. de Marinis<sup>3</sup>, and O. Gasparini<sup>3</sup>**

**Annales Geophysicae (2003) 21: 833–846**

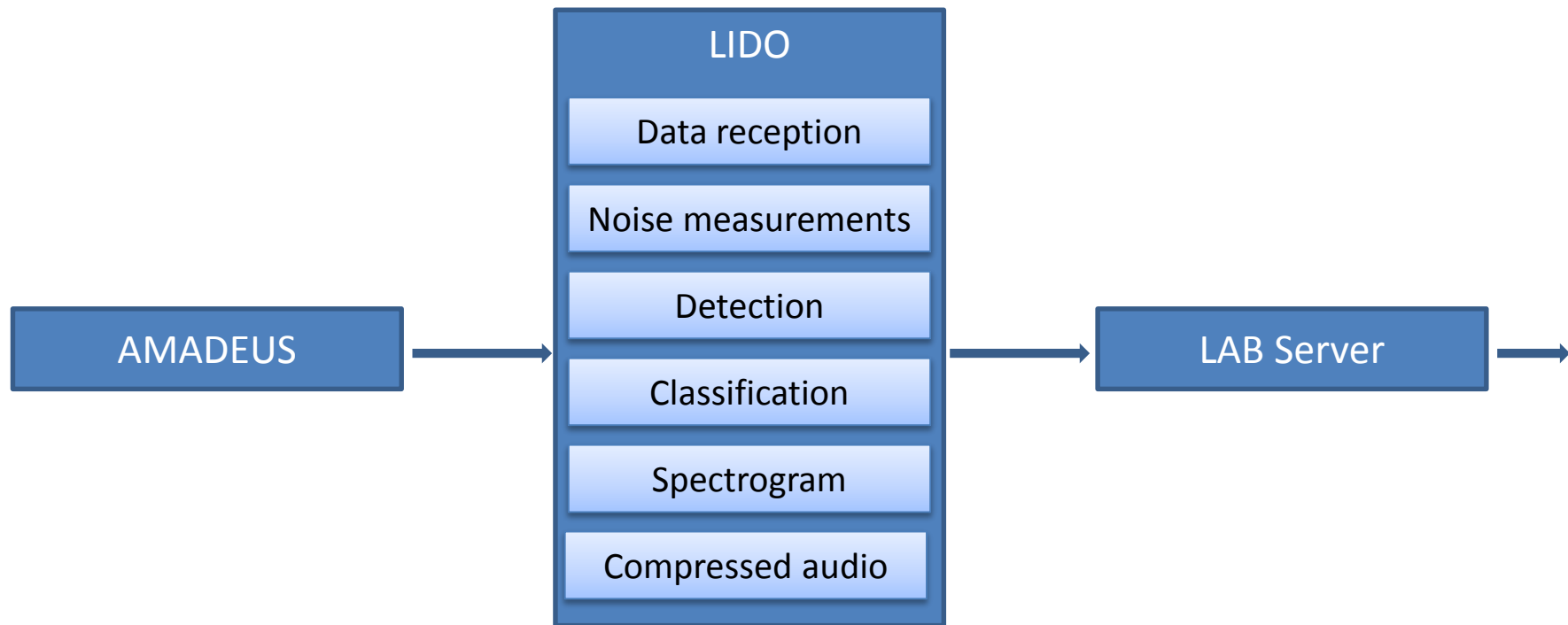


# LIDO at ANTARES



The six AMADEUS acoustic storeys are highlighted in red.

# LIDO at ANTARES

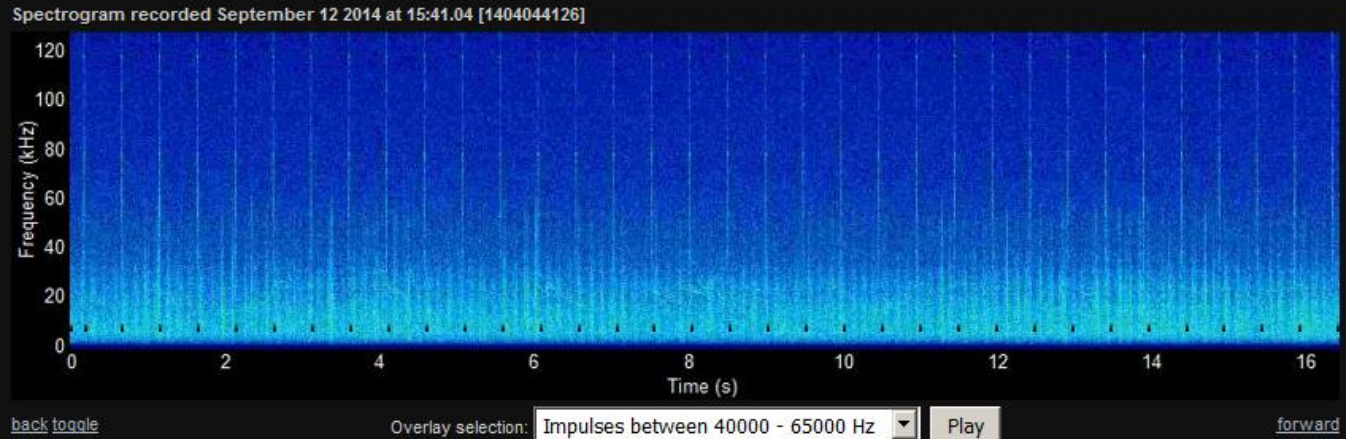




# LIDO at ANTARES

## Impulsive signals:

- Generally broadband
- Well defined in time
- Detected based on a dynamic energy threshold in a filtered time-domain
- Biosonar, shrimps, shipping, airguns

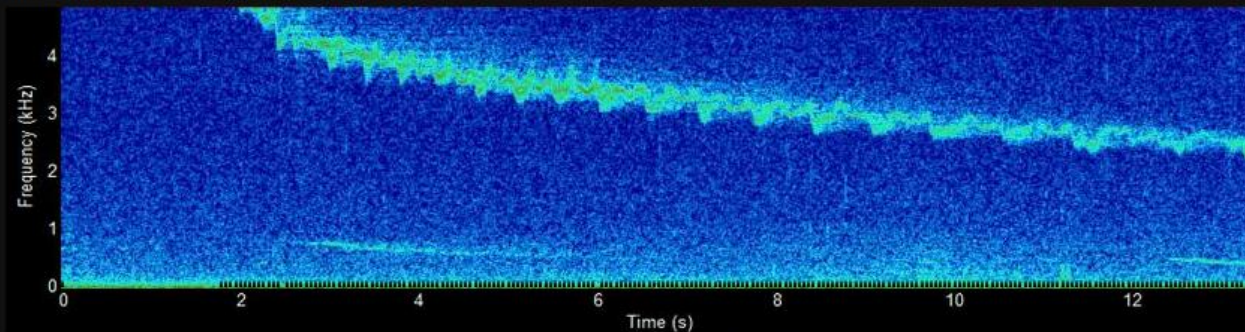


# LIDO at ANTARES

## Short tonal signals:

- Well defined in frequency
- Long duration
- Detected based on contour extraction in time-frequency domain
- Constant tonal signals are removed
- Dolphin whistles, baleen whale calls, fish, chain noise, some shipping

Spectrogram recorded April 22 2014 at 17:38.00



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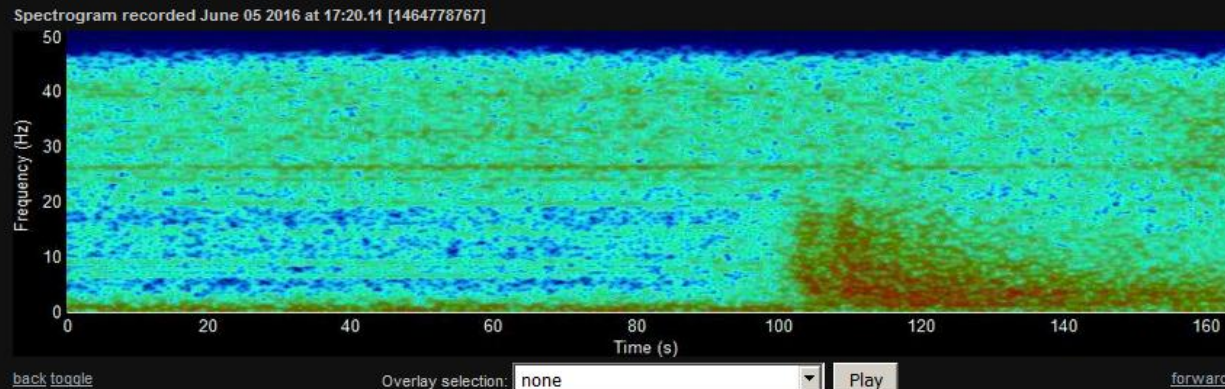
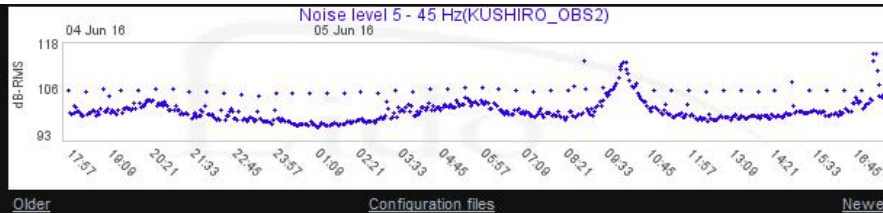
Overlay selection:

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Signals with energy spread broadly over both time and frequency are not specifically detected, but registered with noise measurements (e.g. earthquakes, some fish).



# LIDO at ANTARES

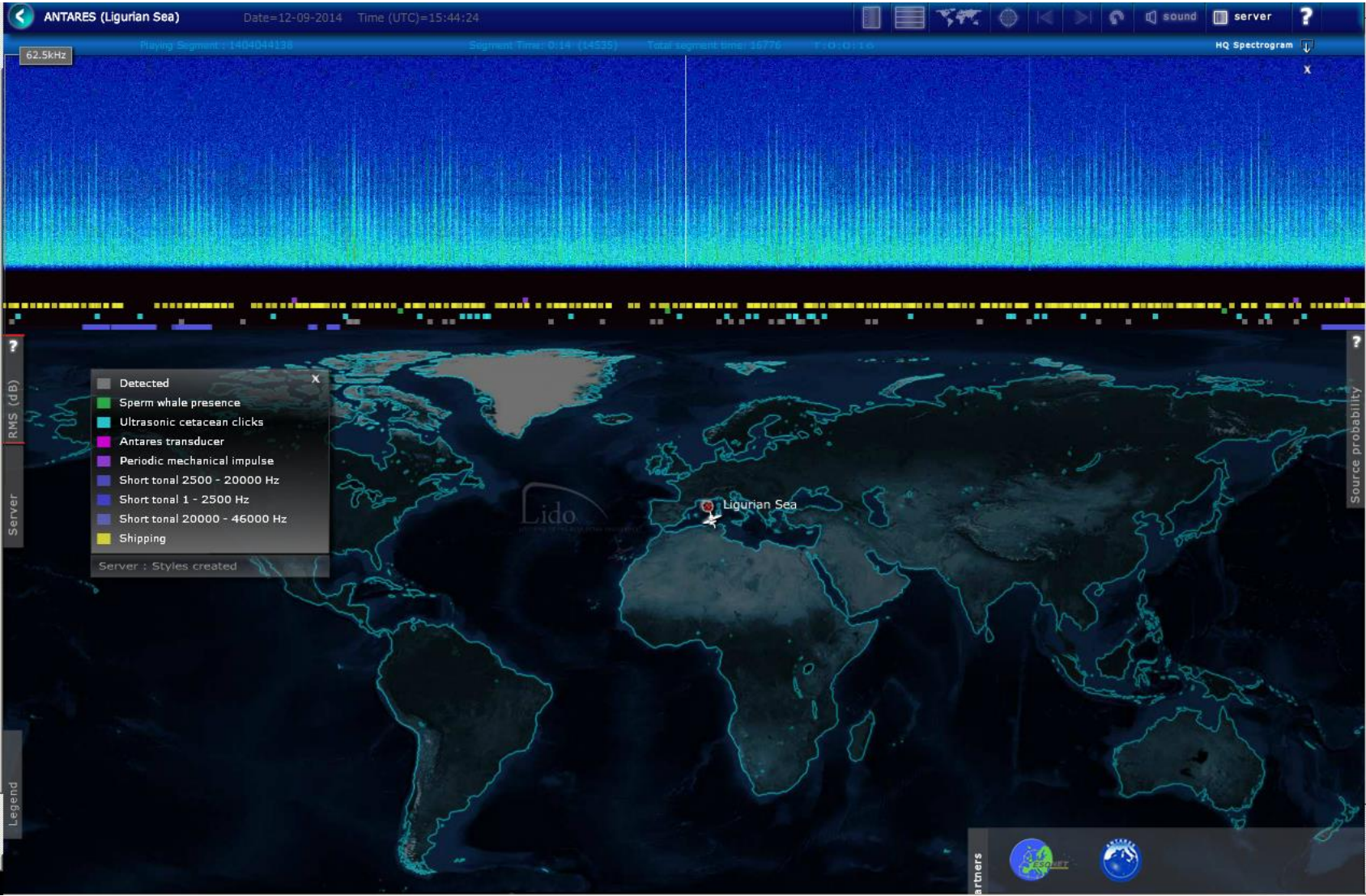
Main interest at ANTARES is presence of cetaceans in relationship with anthropogenic sources, specifically:

- Sperm whale presence
- Dolphin presence
- Beaked whale presence

This kind of analysis requires multiple year recordings.



# LIDO at ANTARES



# LIDO at ANTARES

Statistical Analysis of Acoustic Data

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**Bioacoustics**  
**Listen on Site**  
**Sound Library**  
**Statistical Analysis**  
**Data Export**  
**Making Sense of Sounds**  
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View analysis from (click to set, UTC):  at

Data time span:   Summary statistic:

Data grouping:  none  per hour  per day of week  
 Add trendline

<input type="text" value="Ligurian Sea"/>	<input type="text" value="Impulses between 5000 - 2000"/>	<input type="text" value="Noise level 5000 - 20000 Hz"/>
<input type="text" value="None"/>	<input type="text" value=""/>	<input type="text" value="output"/>
<input type="text" value="None"/>	<input type="text" value=""/>	<input type="text" value="output"/>
<input type="text" value="None"/>	<input type="text" value=""/>	<input type="text" value="output"/>

Noise level 5000 - 20000 Hz(ANTARES)

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Spectrogram recorded October 18 2015 at 20:21.31 [1439314751]

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# LIDO at ANTARES



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LISTENING TO THE DEEP OCEAN ENVIRONMENT

Statistical Analysis of Acoustic Data

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View analysis from (click to set, UTC):  at

Data time span:   Summary statistic:

Data grouping:  none  per hour  per day of week

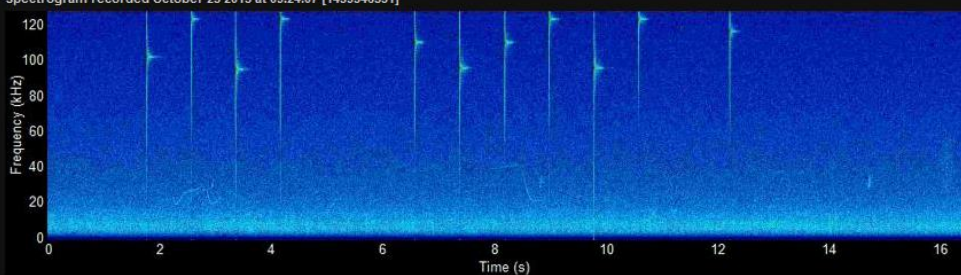
Add trendline

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<input type="text" value="None"/>	<input type="text" value=""/>	<input type="text" value="output"/>
<input type="text" value="None"/>	<input type="text" value=""/>	<input type="text" value="output"/>
<input type="text" value="None"/>	<input type="text" value=""/>	<input type="text" value="output"/>





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Spectrogram recorded October 25 2015 at 09:24.07 [1439346531]







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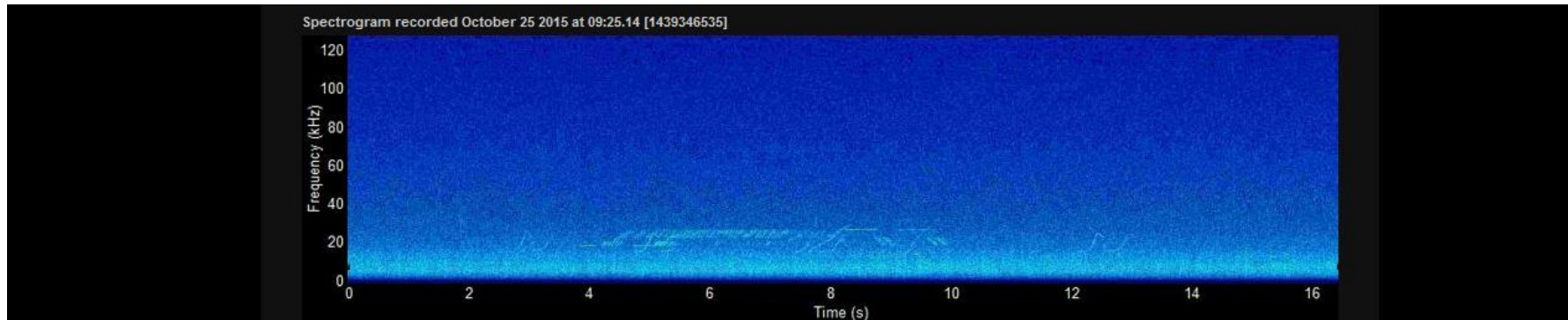
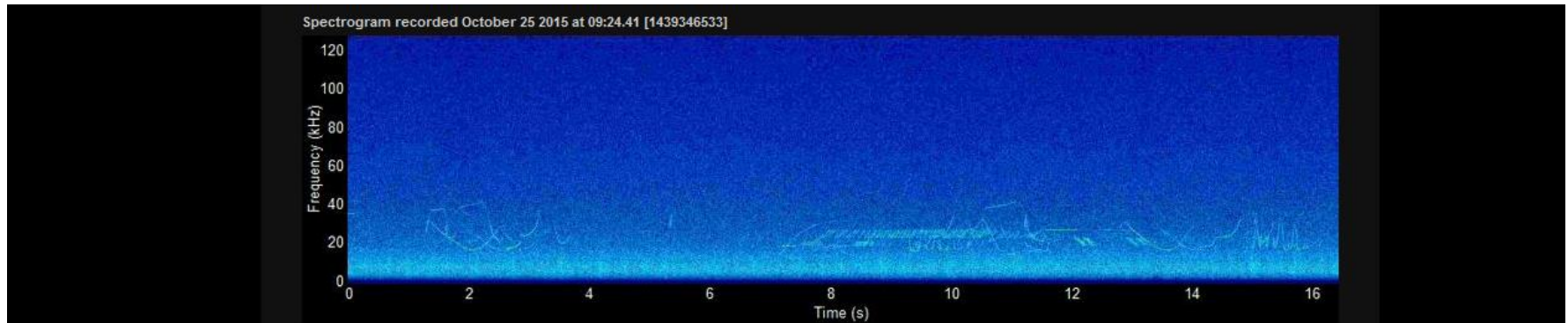
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# LIDO at ANTARES

Unknown short tonal signal:



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Data time span:   Summary statistic:

Data grouping:  none  per hour  per day of week

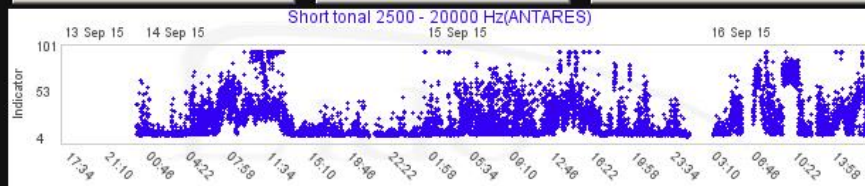
Add trendline

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<input type="text" value="None"/>	<input type="text" value=""/>	<input type="text" value="output"/>
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<input type="text" value="None"/>	<input type="text" value=""/>	<input type="text" value="output"/>

Show data

Show first available data

Show last available data

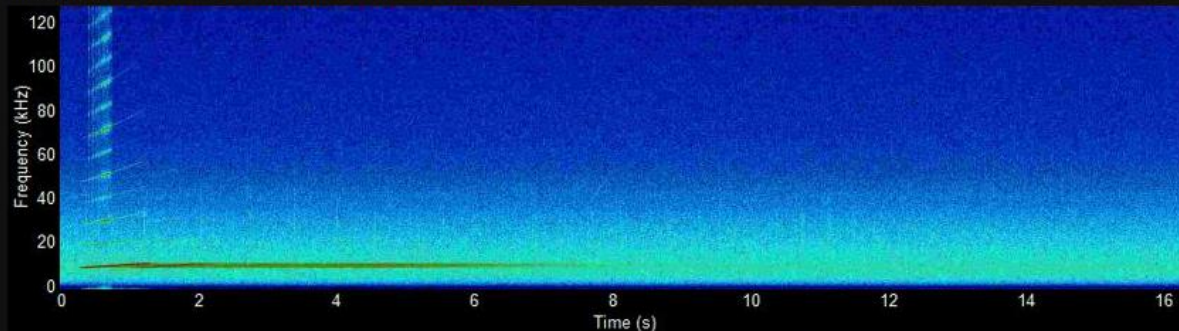


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Spectrogram recorded September 14 2015 at 12:47.42 [1439152338]



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View analysis from (click to set, UTC):  at

Data time span:   Summary statistic:

Data grouping:  none  per hour  per day of week

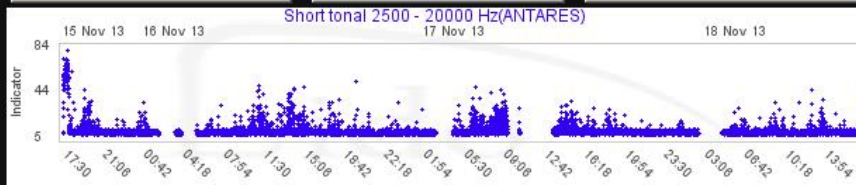
Add trendline

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<input type="text" value="None"/>	<input type="text" value=""/>	<input type="text" value="output"/>
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<input type="text" value="None"/>	<input type="text" value=""/>	<input type="text" value="output"/>

Show data

Show first available data

Show last available data

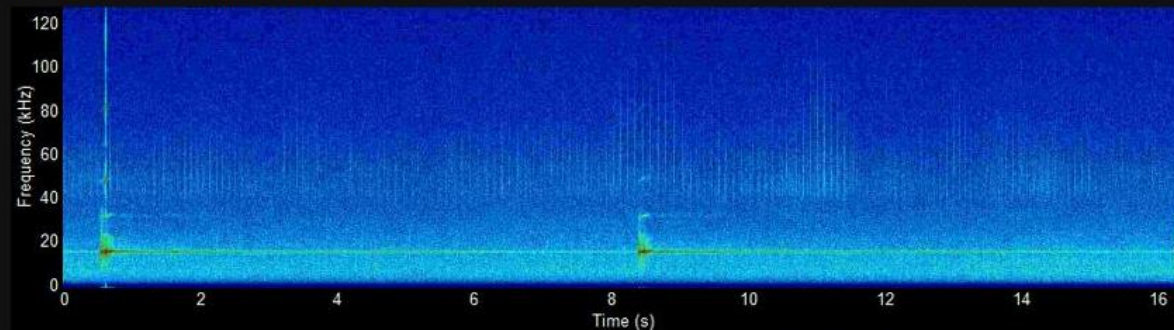


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Spectrogram recorded November 15 2013 at 17:44.37 [1353906579]



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View analysis from (click to set, UTC):  at

Data time span:   Summary statistic:

Data grouping:  none  per hour  per day of week

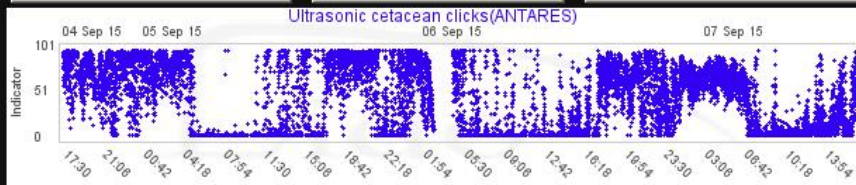
Add trendline

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<input type="text" value="Ligurian Sea"/>	<input type="text" value="No selection"/>	<input type="text" value="-"/>
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<input type="text" value="None"/>	<input type="text" value=""/>	<input type="text" value="output"/>

Show data

Show first available data

Show last available data

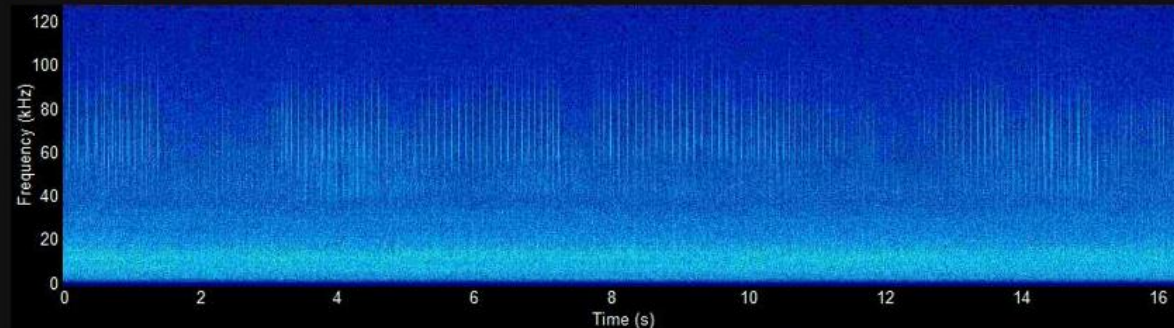


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Spectrogram recorded September 07 2015 at 03:55.39 [1439118322]



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# Sperm Whale Presence

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View analysis from (click to set, UTC):  at

Data time span:   Summary statistic:

Data grouping:  none  per hour  per day of week

Add trendline

<input type="text" value="Ligurian Sea"/>	<input type="text" value="Sperm whale presence"/>	<input type="text" value="output"/>
<input type="text" value="None"/>	<input type="text" value="No selection"/>	<input type="text" value="-"/>
<input type="text" value="None"/>	<input type="text" value=""/>	<input type="text" value="output"/>
<input type="text" value="None"/>	<input type="text" value=""/>	<input type="text" value="output"/>

Sperm whale presence (ANTARES)

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Spectrogram recorded September 06 2015 at 14:29.01 [1439115442]

[back toggle](#) Overlay selection:   [forward](#)

<http://www.listen-to-the-deep.com:4444/acoustics/soundlibrary/listenrt.php?idSeg=1439115442&idLoc=9&idRun=62035&ts=1441549741>



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# Sperm Whale Presence

Sperm whale presence decision process:

- Impulse detection 1000 – 5000 Hz and 5000 – 20000 Hz bands.
- Real-time GMM classifier for sperm whales, shipping and biosonar.
- Offline presence model based on acquired data.

# Sperm Whale Presence

Feature extraction, 10 (normalized) energy features in time and frequency domain, combined with pulse repetition rate:

A measure of location was obtained by

$$m_1 = \sum_{k=1}^n kE_k \quad (1)$$

A measure of dispersion was obtained by

$$m_2 = \sqrt{\sum_{k=1}^n (k - m_1)^2 E_k} \quad (2)$$

A measure of asymmetry was obtained by

$$m_3 = \frac{1}{m_2^3} \sum_{k=1}^n (k - m_1)^3 E_k \quad (3)$$

A measure of concentration around a single value was obtained by

$$m_4 = \frac{1}{m_2^4} \sum_{k=1}^n (k - m_1)^4 E_k \quad (4)$$

A measure of the degree of peakiness was obtained by (5), which is identical to the Shannon entropy normalised for the total number of values  $n$ .

$$p = -\frac{1}{\log(n)} \sum_{k=1}^n E_k \log(E_k) \quad (5)$$



# Sperm Whale Presence

$$p(\mathbf{x}) = \sum_{k=1}^K w_k \mathcal{N}(\mathbf{x} | \mu_k, \Sigma_k),$$

$$0 \leq w_k \leq 1, \quad \sum_{k=1}^K w_k = 1$$

Online classification is performed through a GMM; each class is described with a single model.

- The winner class is the one with highest likelihood.
- Unknown classes (ideally) receive low likelihood.
- A pattern can receive multiple class labels.

# Sperm Whale Presence

Initial online classification results:

Statistic	$\lambda$	AUC	FPR	FNR	NPV	PPV
SWC	3	0.84 (0.78 – 0.90)	0.03 (0.02 – 0.05)	0.42 (0.30 – 0.54)	0.93 (0.92 – 0.95)	0.75 (0.64 – 0.85)
ISN	5	0.93 (0.90 – 0.96)	0.09 (0.06 – 0.13)	0.14 (0.08 – 0.20)	0.93 (0.90 – 0.95)	0.82 (0.77 – 0.87)
UCC	9	0.93 (0.89 – 0.96)	0.14 (0.08 – 0.21)	0.07 (0.04 – 0.10)	0.83 (0.77 – 0.88)	0.94 (0.92 – 0.96)

Training data accuracy: threshold ( $\lambda$ ), Area under the curve (AUC), false positive rates (FPR), false negative rate (FNR), Negative predictive value (NPV) and positive predictive value (PPV) from sperm whales, shipping and dolphins presence. Confidence intervals are at 95 %, with the AUC, FPR and FNR calculations using 2000 stratified bootstrap replicates and the NPV and PPV for the asymptotic limits.

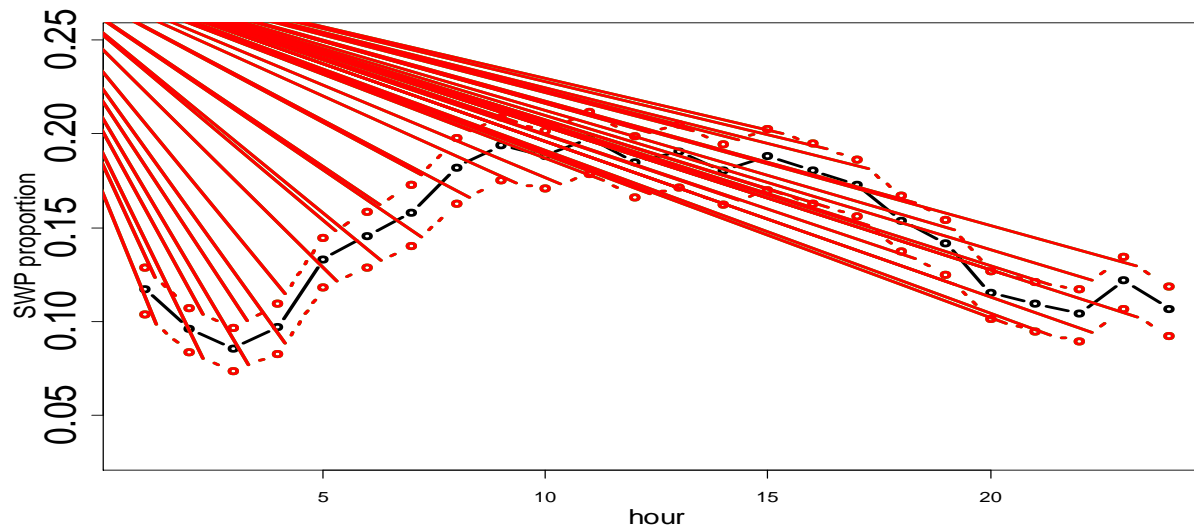
# Sperm Whale Presence

Presence model (GLM) taking into account sequence of segments and presence of multiple classes.

Coefficient	Estimation	Std. Error	Z value	Pr(> z )
Intercept	-3.279	0.293	-11.180	<2e-16
SWC	1.205	0.191	6.296	3e-10
ISN	0.003	0.005	0.600	0.548
SWC * ISN	-0.007	0.003	-2.935	0.003

$$SWP = \frac{1}{1 + \exp(-X\beta)} = \frac{1}{1 + \exp(-(-3.279 + 1.205 SWC - 0.007 SWC * ISN))}$$

# Sperm Whale Presence



Proportion of sperm whale presence predictions considering only the segments with relative SPL lower than 1 (avoiding masking by shipping or other noise).

This pattern is persistent throughout all seasons.

# Noise Measurements

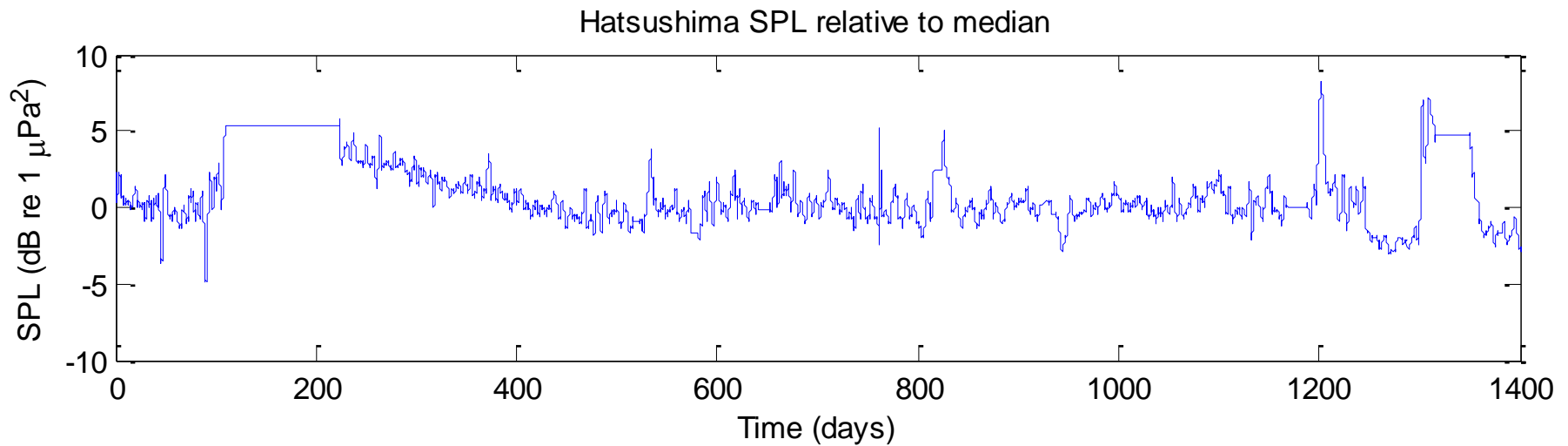
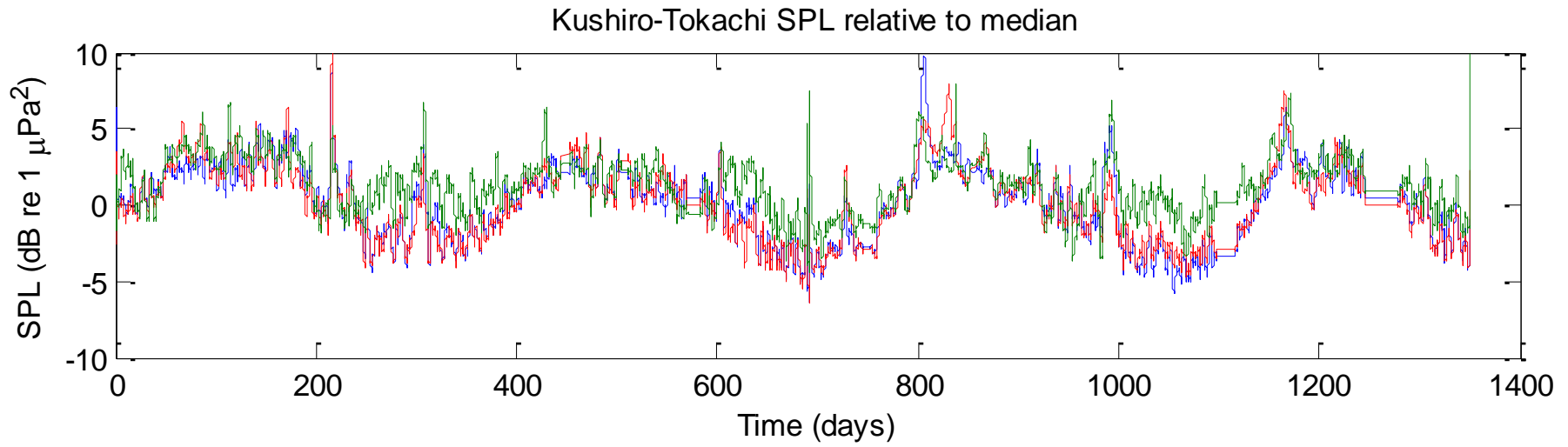
## Good Environmental Status - Marine Strategy Framework Directive 11

1. Count the number of expected impulses based on modelling.
2. Measure noise in third octave bands centred on 63 and 125 Hz  
(shipping noise, pile driving, explosions, etc.)

## When can noise be considered harmful ?

- Audiograms only available for a few marine mammal species
- Hearing most sensitive in vocalization range?
- Fishes, cephalopods, bivalves?

# Noise Measurements – Biological Contribution



# Noise Measurements – Biological Contribution

**Statistical Analysis**

**Data Export**

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Kushiro OBS 2	Impulses between 15 - 25 Hz	output
None		output
None		output
None		output

[Show data](#) [Show last available data](#)

Impulses between 15 - 25 Hz(KUSHIRO\_OBS2)

Indicator

May 2014

7 53

14 May 23 May 01 Jun 10 Jun 18 Jun 28 Jun 07 Jul 18 Jul 25 Jul 03 Aug 12 Aug 21 Aug 30 Aug 08 Sep 17 Sep 28 Sep 05 Oct 14 Oct 23 Oct 01 Nov

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Spectrogram recorded October 18 2014 at 03:07.27 [1412516988]

Frequency (Hz)

Time (s)

back Overlay selection: Impulses between 15 - 25 Hz forward



# Synergies

Bioacoustics (environmental monitoring in general) can greatly benefit from permanent installations.

When feasible, acoustic design should take into account the complete frequency bandwidth for optimal usage.

Installations can be used for regulation (MSFD) e.g. as control station.