Detection and classification of marine mammal vocalizations

Context and objectives

- Datasets from underwater listenings in the Hellenic Trench.
- The vocalizations of cetaceans consist mainly of clicks and whistles.

1. Detect and classify sounds as coming from sperm whales or striped dolphins using the PAMGuard software.
2. Compare the efficiency of this method to a classification algorithm using neural networks.

About the Pylos Dataset (2008)

Location :

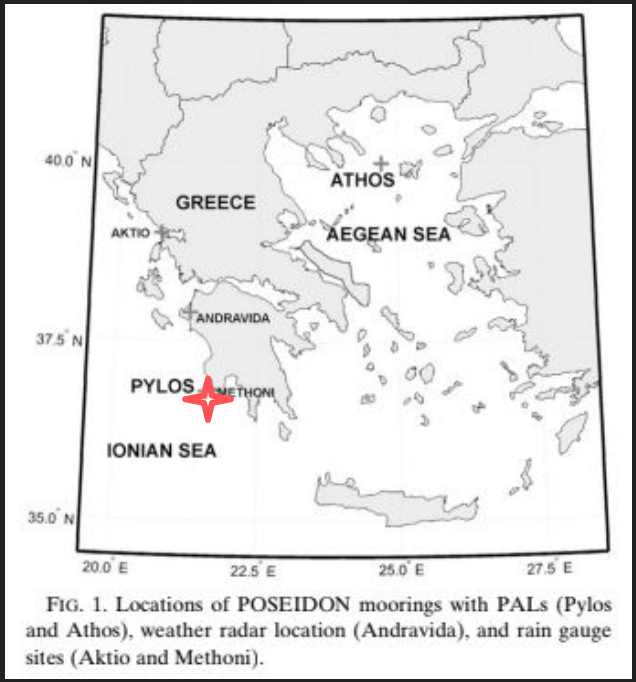


FIG. 1. Locations of POSEIDON moorings with PALs (Pylos and Athos), weather radar location (Andravida), and rain gauge sites (Aktio and Methoni).

- 3160 files between 4/6 seconds
- 476 labeled files as Striped Dolphin or Sperm Whale

Characteristics of the hydrophone :

	Passive Aquatic Listener (PAL) - OLD VERSION
RECORDER (Integrated System)	
Frequency band	Broadband: 100 Hz to 40 kHz
Dynamic range	± 5 Vpp
Channel gain	Two channel gains: 20 dB, 40 dB
Integrated system sensitivity	-155 dB re: 1 V/µPa typical (-145 to -185 available)
Integrated system self noise	Less than 30 dB re 1 μPa^2/Hz from 5-40 kHz
Native storage	2GB SD card
Recording mode	Autonomous
Operation mode	Autonomous
High pass / low pass filters	100 Hz / 40 kHz

Documentation and state of the art

- Classification strategies
- PAMGuard instructions
- Acoustic characteristics of sperm whales and striped dolphins

	Sperm Whale (Clicks)	Striped Dolphin (Clicks)
Frequency Range	100 – 32 000 Hz	300 – 100 000 Hz
Peak Frequency	5 000 – 25 000 Hz	40 000 Hz
Mean Frequency	15 000 Hz	-
Inter Clicks Interval (ICI)	0,25 – 1,4 s	-
Rate	0,2 – 4 Clicks/s	900 Clicks/s

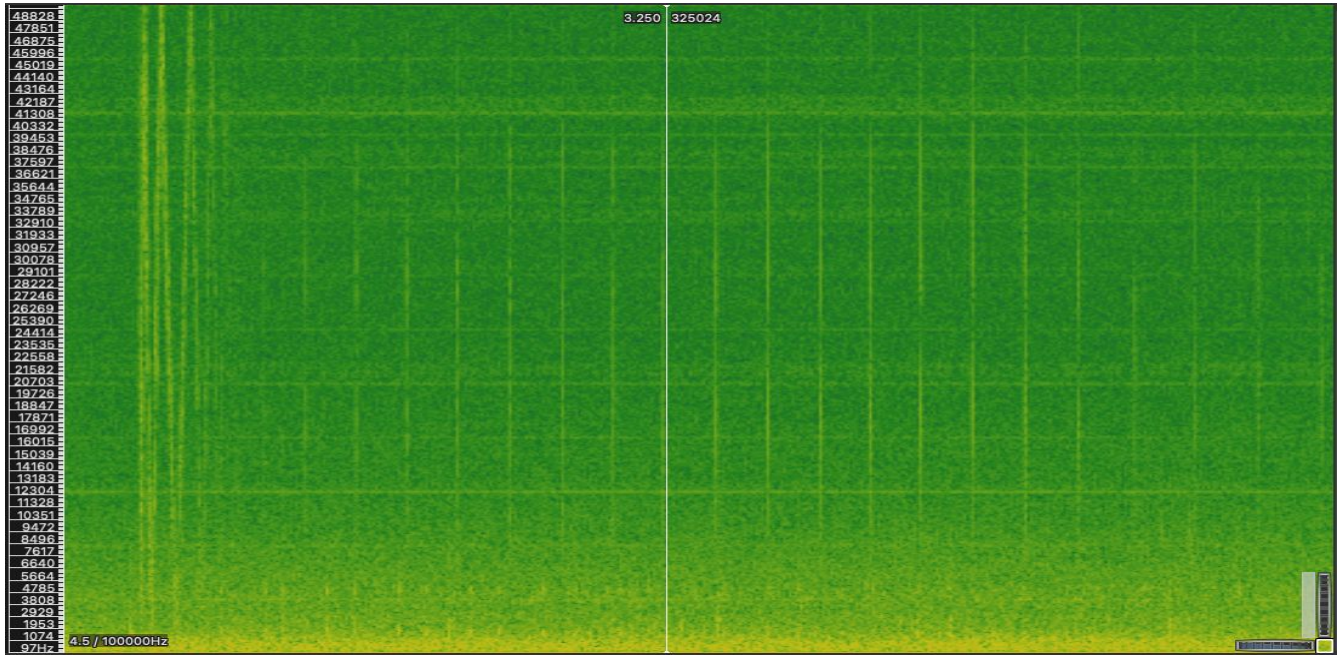
What is PAMGuard ?

- PAMGuard is an open-source software that allows acoustic analysis of audio files (.wav).

- Various modules :
  - signal processing
  - detection of patterns
  - classification as one or more marine mammal species

PAMGuard - Clicks Detection Module

- Detection of clicks emitted by a sperm whale, striped dolphin or any other marine mammal whose sound frequency range falls within the detection field.



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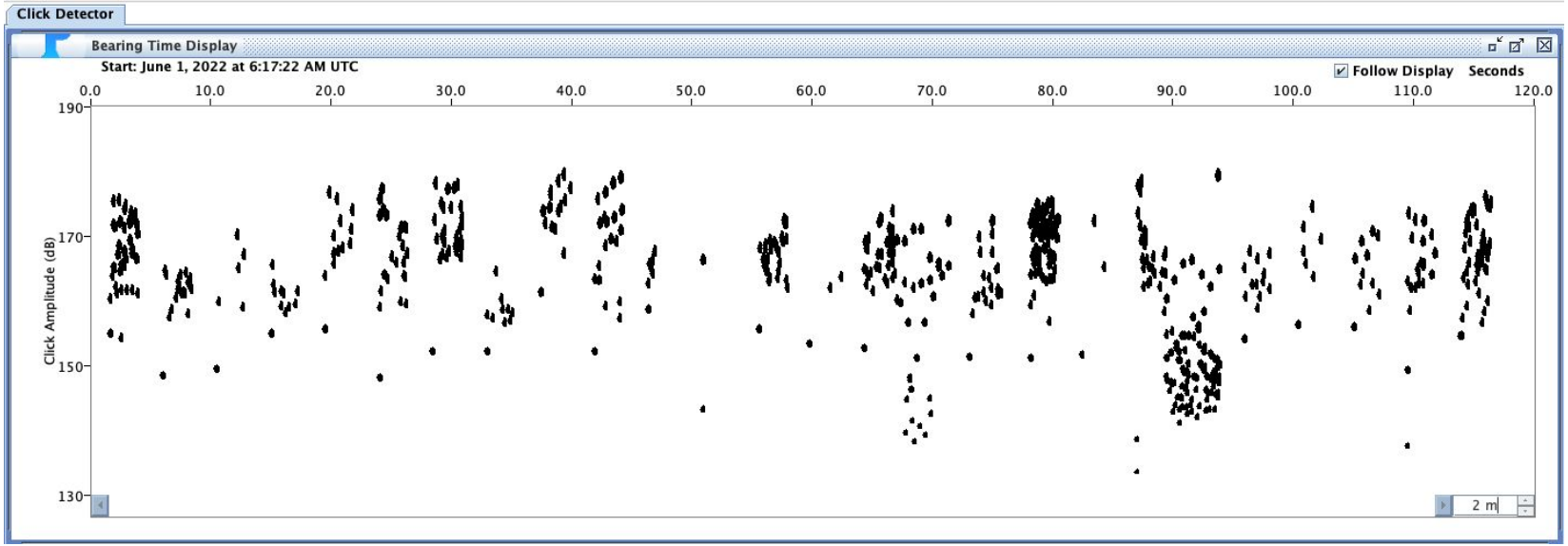
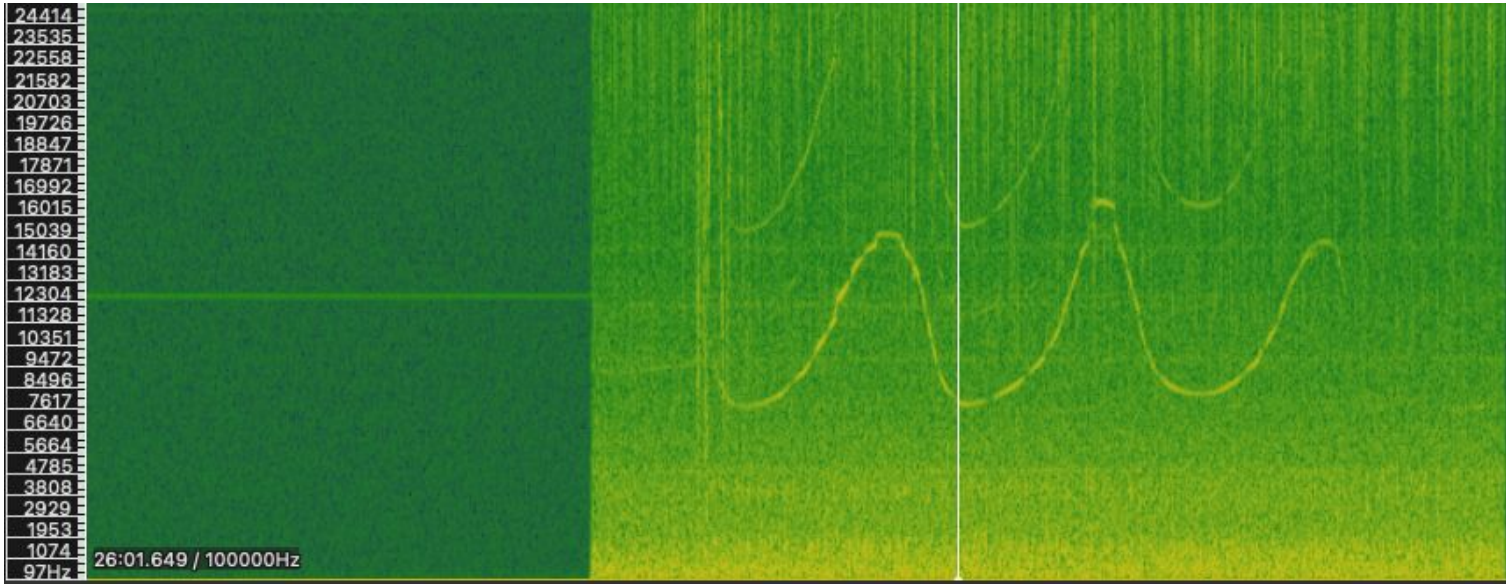


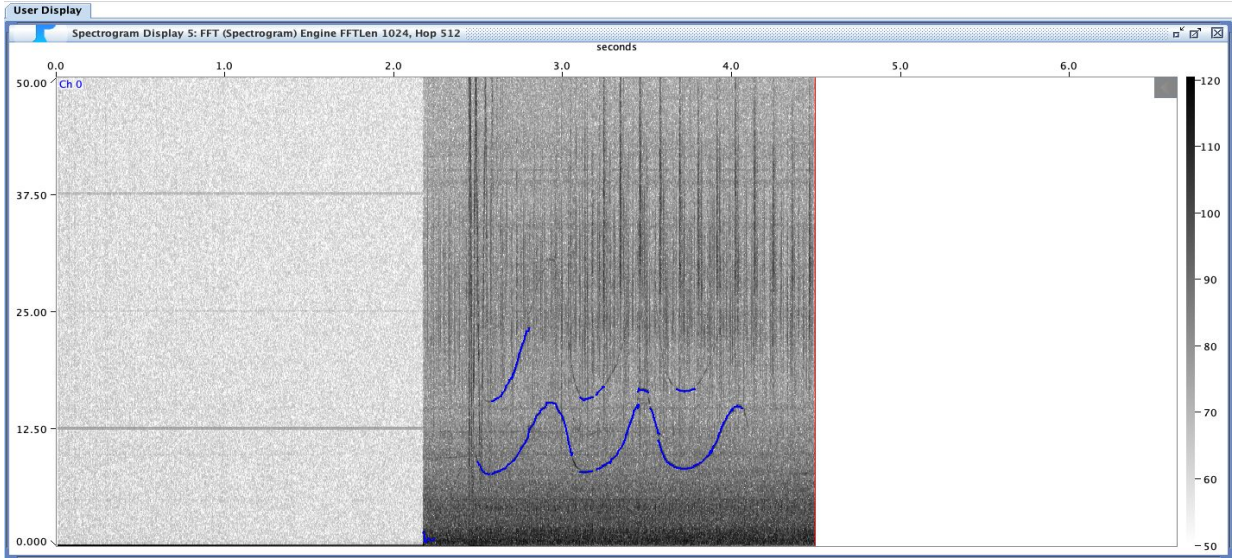
PAMGuard - Whistles Detection Module

- Detection of whistles embedded in the ambient noise of the sea as well as other parasite noises.



PAMGuard - Whistles Detection Module

- Detection of whistles embedded in the ambient noise of the sea as well as other parasite noises.
- This module refers only to Striped Dolphins since sperm whales do not whistle.



PAMGuard - Clicks Classification Module

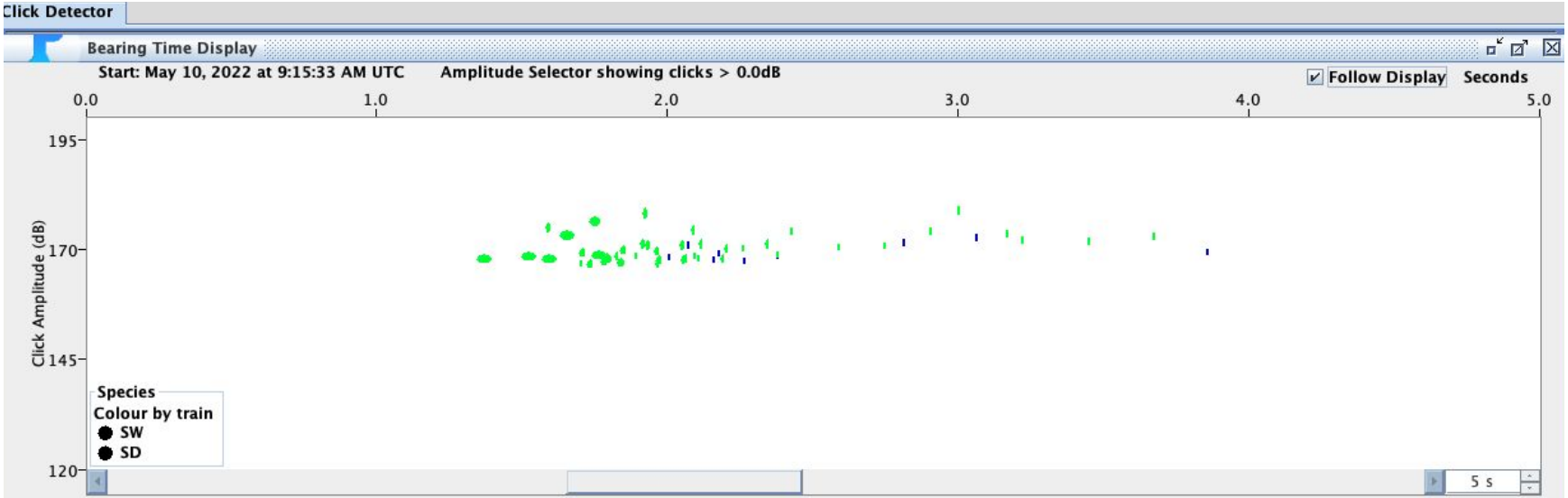
- Submodule of the click detection module.
- Allows labels to be defined according to set parameters.
- Gives a binary response during classification :
    - If the click is within the classification range of the label, the response is the ID of the label.
    - If the click is outside the classification field, the response is 0.

First Strategy

Binary Classification : (Here : Classification a Sperm Whale file)

First Strategy

Binary Classification : (Here : Classification of a Striped Dolphin file)



Pros and cons

Pros :

- Very simple classification
- Clear visual trend
- Preliminary results on PAMGuard look positive

Cons :

- This model may not be very robust in case of a new data set
- Possible that noise (low frequency) is taken into account to classify sperm whales
- Never used in the scientific literature

Second Strategy : Multi-label Classification

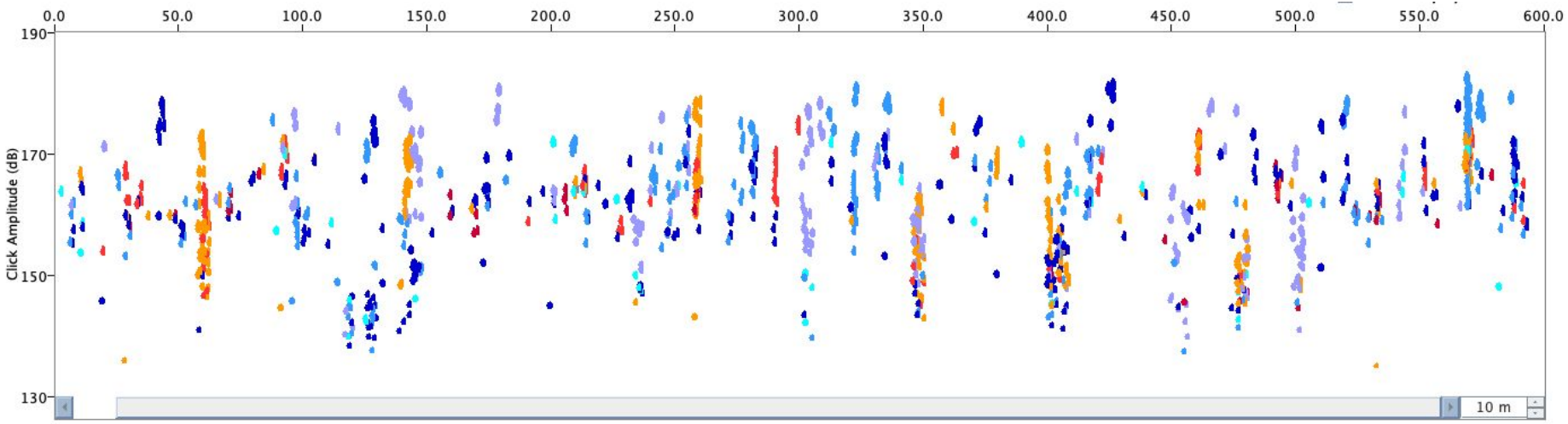
- Increasing the accuracy of click classification
- Based on a larger number of parameters to give a result
- Avoid frequencies where clicks that may belong to both species are present in the same proportions.

Second Strategy : Multi-label Classification

Sperm Whale (shades of blue)	Label 1	Peak frequency 3500-4000Hz
	Label 2	Peak frequency 5000-7000Hz
	Label 3	Peak frequency 10000-15000Hz
	Label 4	Peak frequency 1000-3000Hz and Energy Bands 5000-7000Hz and 10000-15000Hz
Striped Dolphin (shades of red/orange)	Label 5	Peak frequency 19000-25000Hz
	Label 6	Peak frequency 27000-36000Hz
	Label 7	Peak frequency 1000-3000Hz and Energy Band 19000-25000Hz

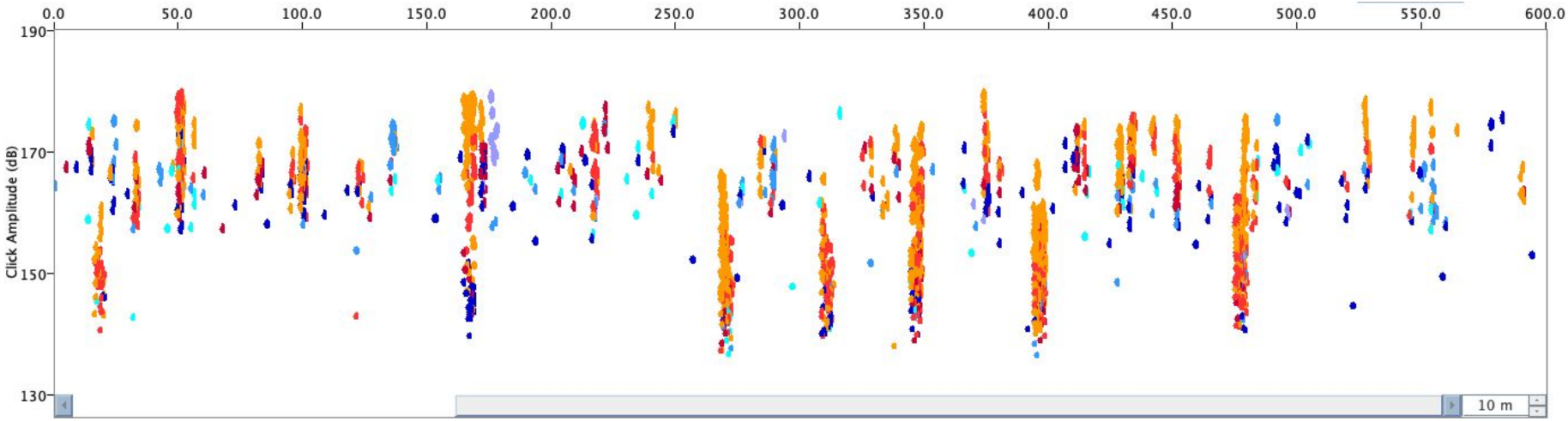
Second Strategy

Multi-label Classification : (Here : Classification for every Sperm Whale files)



Second Strategy

Multi-label Classification : (Here : Classification for every Striped Dolphins files)



First MATLAB Algorithm

- Retrieving the data files created from PAMGuard for final analysis and classification on MATLAB.
- Development of a tree based algorithm that will perform a ratio for each file between clicks in favour of the classification of striped dolphins or sperm whales.

Preliminary Results

Score Stripped Dolphin files

SD_countSW = 39

SD_countSD = 308

SD_TIE = 0

SD_NO_DETECTION = 0

SD_NO_IDENTIFICATION = 1

Score Sperm Whale files

SW_countSW = 70

SW_countSD = 114

SW_TIE = 0

SW_NO_DETECTION = 0

SW_NO_IDENTIFICATION = 0

Score Overall

Total_countSW = 109

Total_countSD = 422

Total_TIE = 0

Total_NO_DETECTION = 0

Total_NO_IDENTIFICATION = 1

Stats

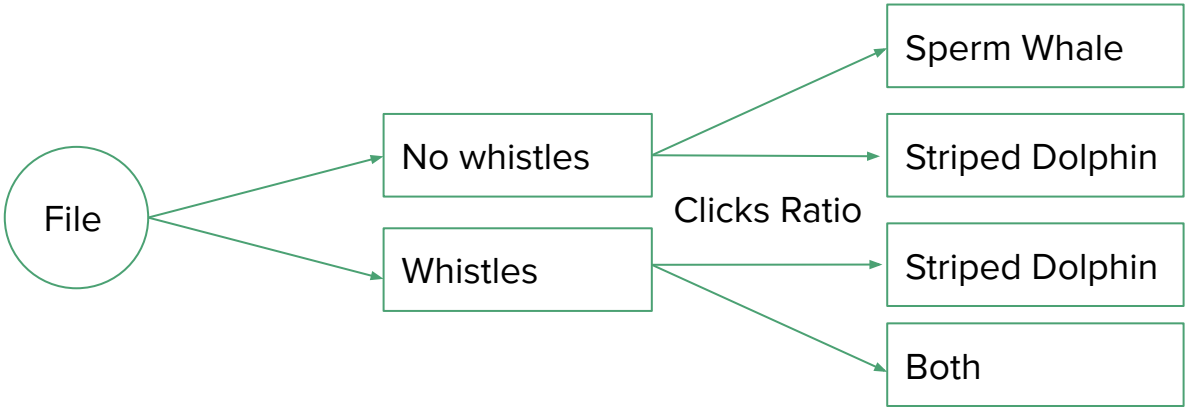
Classification

True_Positive = 71.1864

False_Positive = 28.8136

Improvement of the algorithm

- Adding the whistle detection module to the data.
- Definition of strong labels that are present almost exclusively in one or the other species to reinforce the result.

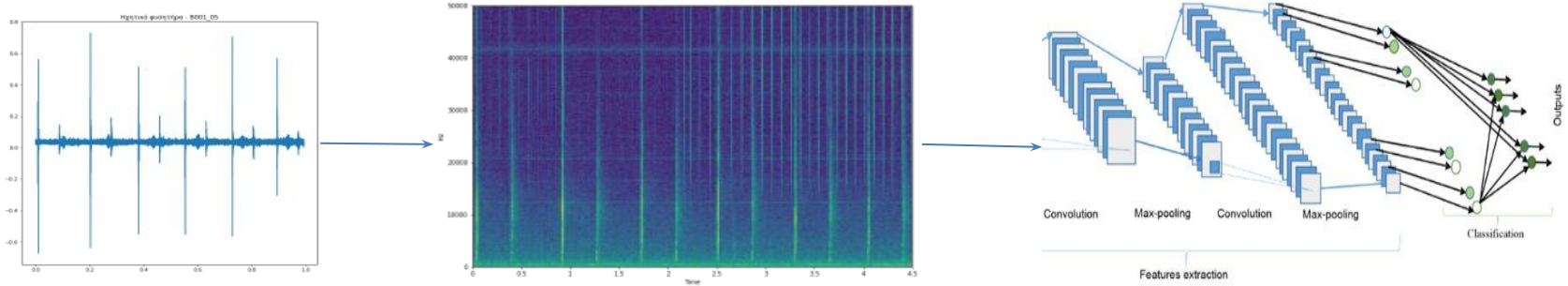


New Pylos Results

OK Striped Dolphins (True Positive)	259		OK Sperm Whales (True Positive)	89
NO Striped Dolphins (False Positive)	70		NO Sperm Whales (False Positive)	59
SD True Positive rate(%)	78,01		SW True Positive rate(%)	61,38
Overall True Positive Rate	72,96			

Deep Learning Techniques for the detection and classification of sperm whale and striped dolphin bioacoustic patterns

- We construct a dataset comprising spectrograms applying the windowed Fourier transform (STFT) to a manually labeled dataset consisting of distinct audio files.
- We generate a training and validation dataset consisting of spectrograms.
- We use a pre-trained residual network (ResNet-101), typically used for image classification and object detection.



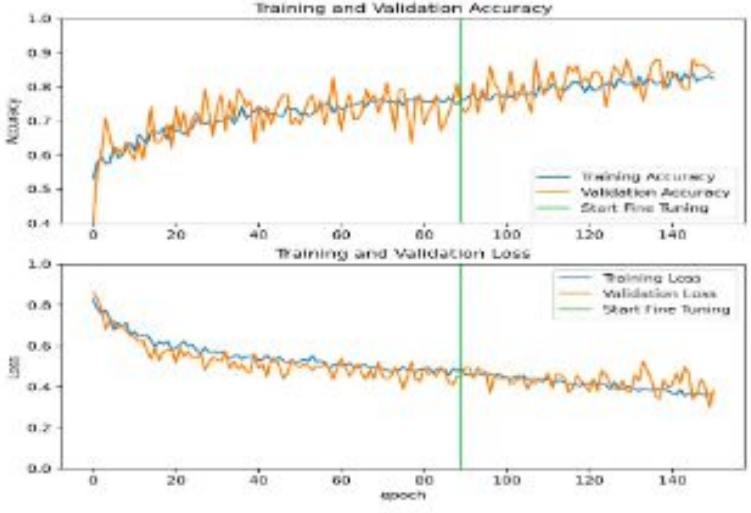
- We append a classifier at the end of the model and classify spectrograms into two categories: Sperm Whales and Striped Dolphins.

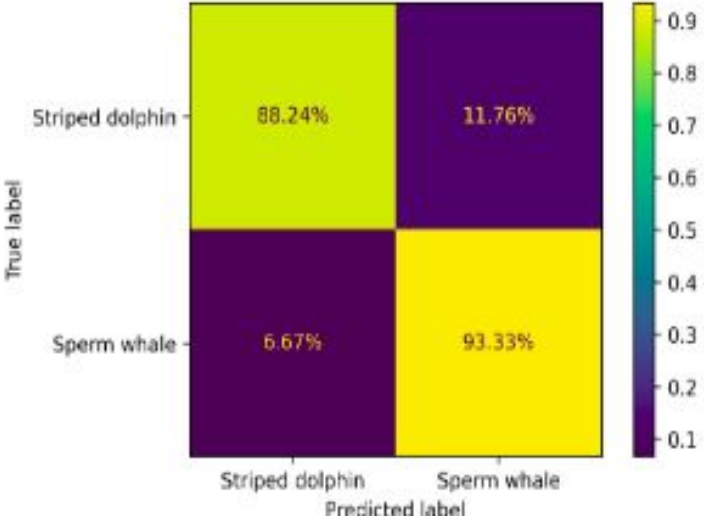
Preliminary Results

- A labeled dataset of Pylos has been used including 242 Sperm Whale vocalizations and 365 Striped-Dolphins vocalizations.

- The deep ResNet-101 transfer deep learning model achieves training and validation classification accuracy of 84% and 88% respectively.

- We investigate the network's generalization ability using 60 unseen spectrograms and observe that the trained model achieves accuracy of 91%.





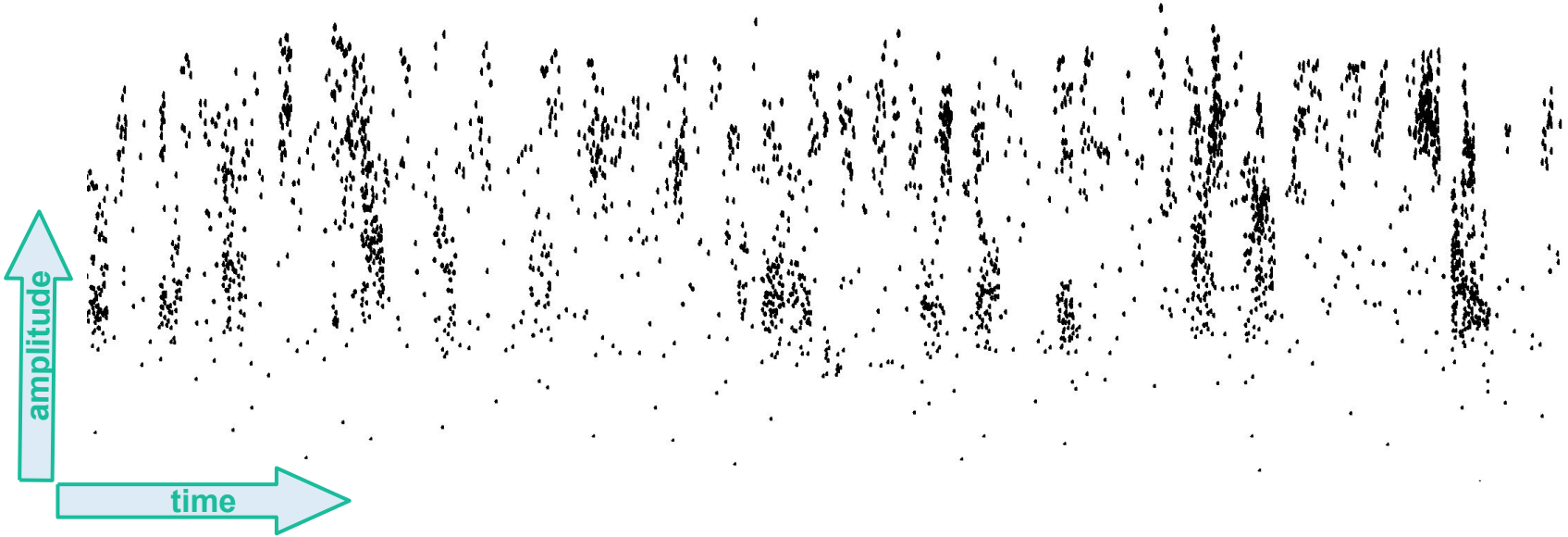
A PAMpal approach for species classification

- Using PAMGuard to detect clicks in cetacean audio recordings.
- Using the PAMpal R package to extract the time-domain and spectral features of the detected clicks.
- Employing statistical and machine learning techniques for species classification on a dataset of striped dolphin and sperm whale recordings.

. Using PAMGuard to detect clicks in cetacean audio recordings.

The batch of striped dolphin and sperm whale acoustic recordings (~ 500 files of ~ 4s duration) is processed by the PAMGuard ClickDetector module.

In a single recording, a number of signal portions are detected as clicks when their amplitude is high compared to the overall signal (SNR calculation and thresholding).

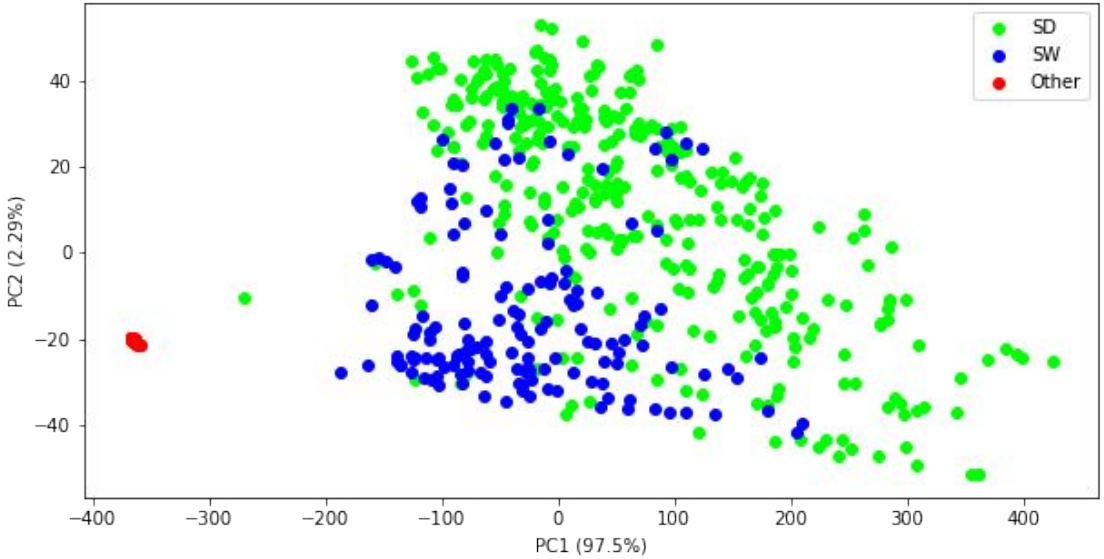


- **Using the PAMpal R package to extract the time-domain and spectral features of the detected clicks.**

The detected clicks are loaded to R and their time-domain (e.g. time duration) and spectral (e.g. peak frequency) features/characteristics are calculated using the PAMpal package.

The click features are aggregated on an event basis, i.e. their mean value is calculated per file/recording.

The species are separable in the reduced feature space of the two first principal components.



- **Employing statistical and machine learning techniques for species classification on a dataset of striped dolphin and sperm whale recordings.**

A number of statistical (Gausian Naive Bayes, Logistic Regression) and machine learning (k-Nearest Neighbors, Support Vector Machine, Random Forest) classifiers are trained for species classification on the PAMpal extracted click features dataset.

All classifiers were trained (and their hyperparameters, when existent, tuned) on 80% of the dataset.

Then, they were evaluated on the remaining dataset (20%).

The best classification was acquired for the Random Forest classifier.

Random Forest without PCA:

	precision	recall	f1-score	support
Other	1.00	1.00	1.00	12
SD	0.93	0.97	0.95	72
SW	0.92	0.81	0.86	27
accuracy			0.94	111
macro avg	0.95	0.93	0.94	111
weighted avg	0.94	0.94	0.94	111

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	precision	recall	f1-score	support
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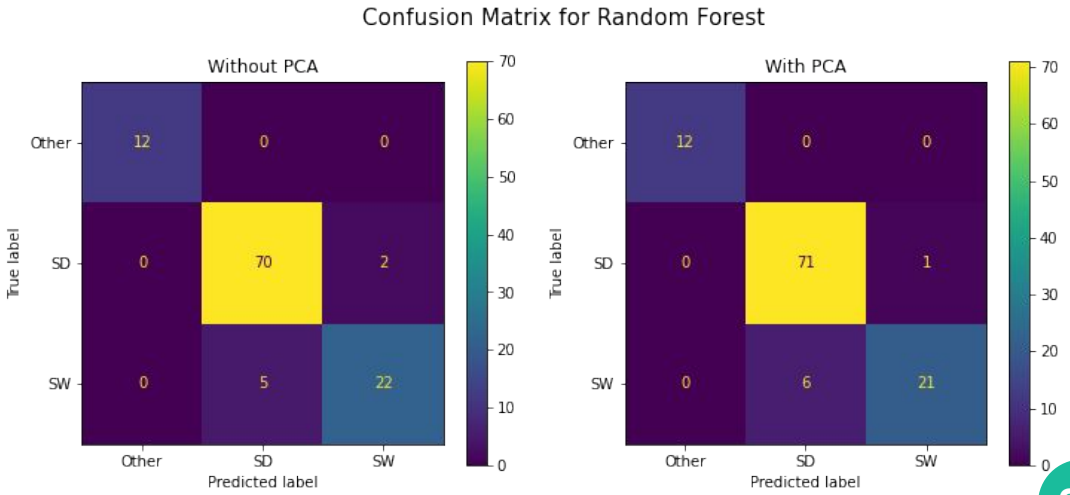

Comparison between these 3 techniques

True Positive

Results	PAMGuard	PAMPAL	Machine Learning
OK	345	471	401
NO	131	5	75
Rate	72,4789916	98,9495798	84,24369748
Agree ? 3/3	314	Agree ? 2/3	429
Rate	65,9663866	Rate	90,12605042

New Dataset (Summer 2020-2021)

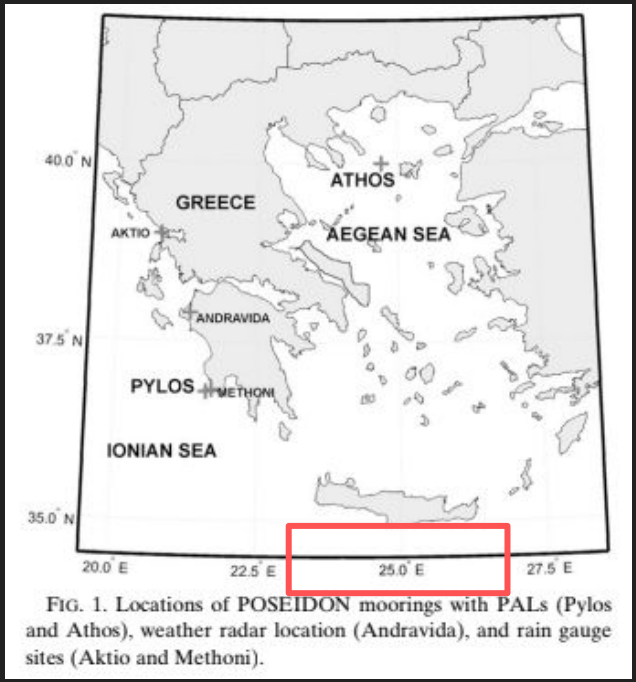

FIG. 1. Locations of POSEIDON moorings with PALs (Pylos and Athos), weather radar location (Andravida), and rain gauge sites (Aktio and Methoni).

- From “SAvE Whales observatory”
- 3 acoustic stations with 1 hydrophone suspended at a depth of 100m.
- Recordings carried out with a sampling frequency of 100 kHz.
- A 30 minute stream separated into 5 second files => 360 audio files.

Classification process

1. Split the stream into 5 second files to have 360 files.
2. Run them in PAMGuard with exactly the same configuration as for Pylos Dataset.
3. Data processing on MATLAB with the same algorithm except that the ratio is slightly lowered because the noise of the audio files is almost zero.
4. Automatic report writing and analysis of results.

Results

- 61.39 % of Classification as Sperm Whales.
- 24.44 % of files with no clicks detected.
- 10.28 % of files with clicks detected but not clear enough to classify them.

```
Global results SWAN files.

Score Striped Dolphins.

0 SD with high confidence
11 SD with medium confidence
1 SD with low confidence
12 files classified as SD.
This represents 3.33 % of the overall SWAN files.

Score Sperm Whales.

0 SW with high confidence
144 SW with medium confidence
77 SW with low confidence
221 files classified as SW.
This represents 61.39 % of the overall SWAN files.

Score others.

2 files classified as both SD & SW.
This represents 0.56 % of the overall SWAN files.
88 files with no clicks detected.
This represents 24.44 % of the overall SWAN files.
37 files with no labels.
This represents 10.28 % of the overall SWAN files.
```

Next Steps

- Verify the accuracy of the results obtained on the New Dataset.

- Try applying the protocol to a new dataset containing a larger number of whistles.