Bioacoustics & AI
From Arctic
to Mediterranean Sea

https://cian.lis-lab.fr/europam

Main objectives

EUROPAM aims to increase knowledge of anthropogenic impacts on marine megafauna through large-scale passive acoustic monitoring that allows for comparison of sites and sources of disturbance, as well as the population segments of sperm whales, for example. The cornerstones for achieving the objectives will be :

- A comparative continuous passive acoustic monitoring in the Mediterranean Sea, in the Azores Atlantic Ocean, and offshore Norway, for an equivalent of 23 000 km2;
- A comparison of marine soundscapes from the European Arctic to the Mediterranean Sea, and from relatively quiet marine protected areas to areas under strong human activity pressure;
- An innovative Artificial Intelligence developed to describe and model marine soundscapes and their natural patterns (daily and seasonal) that allows us to build and feed a marine soundscape repository in the cloud;
- A strict protocol that will allow the calibration of measurements and provide comparable data across a large range of temporal and spatial scales;
- An important output is the management of EUROPAM is mitigation of whale-ship collision risks.

9:00 – Introduction : aims of EUROPAM, recent missions in Medsea and Arctic and coming models (H. Glotin, PI, CIAN)

SESSION 1: Arctic Observations and Models

9:30 – Long term acoustic monitoring of 3 superpredators in Arctic versus anthropophony (Justine Girardet, CIAN LIS and Univ Pavia It)

9:55 – Decoding echolocation: Good practices for studying the sonar of marine animals (Nicolas Deloustal, CIAN LIS)

10:20 – 10:30 Coffee Break

10:30 - Arctic Acoustic and Med. Sea Scene's complexity, stakes, and outlooks (H. Glotin, CIAN)

10:55 - Tracking Codas (P. Giraudet, CIAN LIS)

11:35 – Lunch Break 11:50-12-40 (Beal cafeteria)

SESSION 2: Material and Demo : Intelligent Acoustics (Sebastian Marzetti, Valentin Gies, Valentin Barchasz, H.G.)

12:50 – 14:20 – Building compact arrays & embedded AI : Demo of the CRYSTAL BLACK BALL (Bât X SEATECH) with Coffee

SESSION 3: Mediterranean and mid Atlantic observations and models

14:35 – What can tell an array on megafauna vs anthropic pressure ? The stereo Bombyx1 (Justine Girardet, CIAN LIS and Univ Pavia. It)

14:55 – Propagation model for range estimation, perspective on megafauna localisation with in situ experiments in WW6 (Lilou Dantin, CIAN LIS & PNPC)

15:20 – SEGAMAS and transformers for UBF and HF fauna survey (Sébastien Paris, CIAN)

15:50 – Megafauna survey & ship collision risk mitigation: perspectives with the real-time BOMBYX sonobuoy in the Azores (Cláudia Inês Botelho de Oliveira, IMAR)

SESSION 4: General discussion

16:15 – Megafauna-traffic collision risk and deployment of BOMBYX3 (all partners, H. Glotin and PNPC)

16:45 – Next steps, collaborations and discussions / **17:30** – Closure

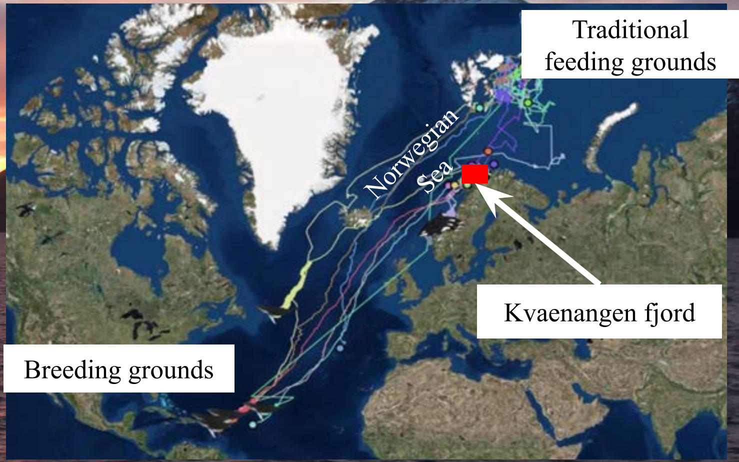
Welcome to Arctic & The Old Symphony

CIAN LIS IM2NP UTLN and PolarPod, ValhallaB, L181

Arctic diel and circadian acoustic pattern of orcas, fin, and humpback whales revealed by two months of continuous recordings

Justine Girardet[1,2,5,6], Hervé Glotin[1,2,3,4,6], Marion Poupard[1], Stéphane Chavin[1,2,6], Julie Guiderdoni[1,3],Véronique Sarano[1,4]

1 Centre International d'Intelligence Artificielle en Acoustique Naturelle
2 Laboratoire d'Informatique et des Systèmes, University of Toulon
3 ValhallaB
4 Longitude181
5 University of Pavia, Italy
6 Chaire IA AID DGA ADSIL ANR-20-CHIA-0014



Migratory map of humpback whales
WhaleTrack/UiT the arctic University of Norway

HERRING : IMPORTANT RESSOURCES

- Aggregate in fjord in winter
- Attract many predators
- Orcas, specialized herring hunters

- Recent northward shift of wintering grounds
- New feeding grounds for humpback and fin whales
- First observation in 2010 since a century

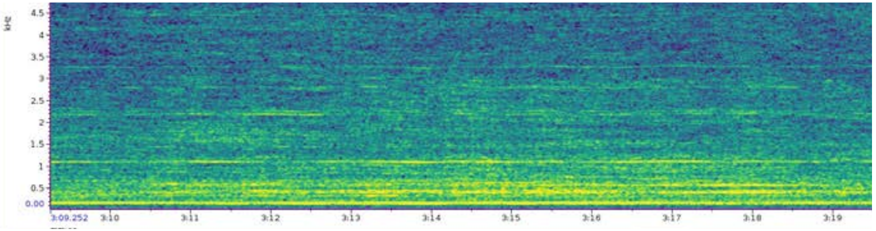
ANTHROPOGENIC ACTIVITIES

- High fishing activity : 400 000 t per year
- Whale watching activities
- Acoustic pollution in low-frequency (10-200 Hz)

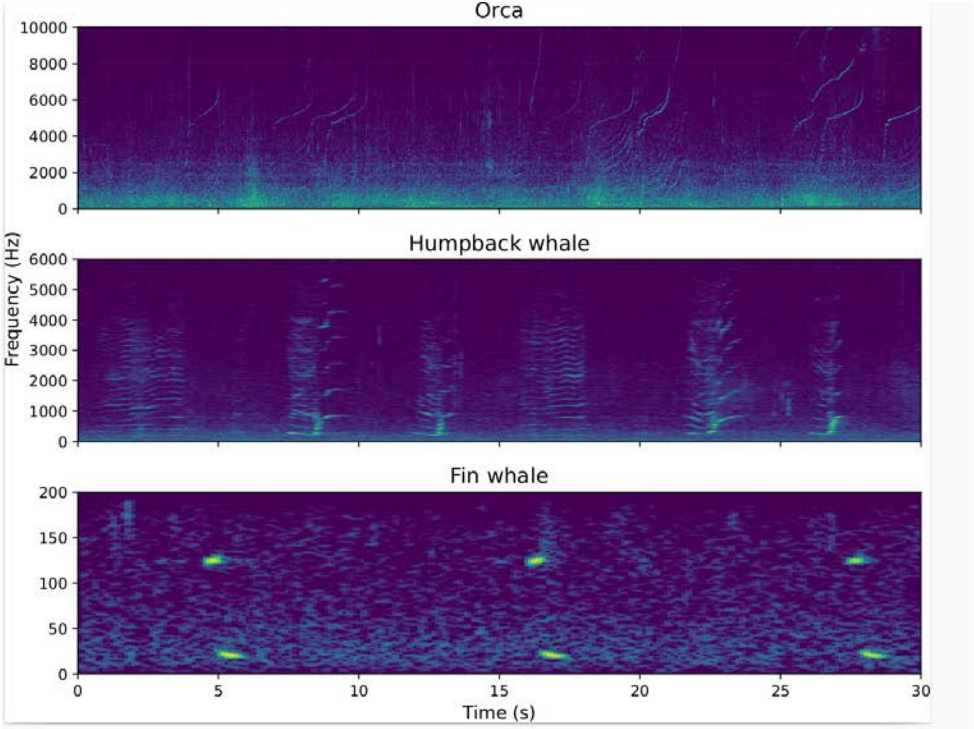
Killer whales feeding near fishing net, winter 2023

Humpback and killer whales feeding near fishing net, winter 2024

Spectrogram of boat noise, 2023-01-15 13:01



ACOUSTIC COMMUNICATION



- Interference with cetaceans behavior

  → What kind of interactions ?

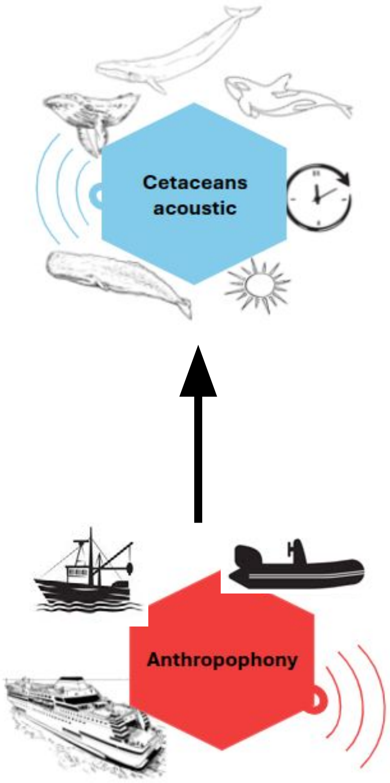
  → Competition ? Depredation ?

OBJECTIVES

Define the daily and seasonal pattern of cetaceans acoustic behavior

Distinguish geophony and anthropophony

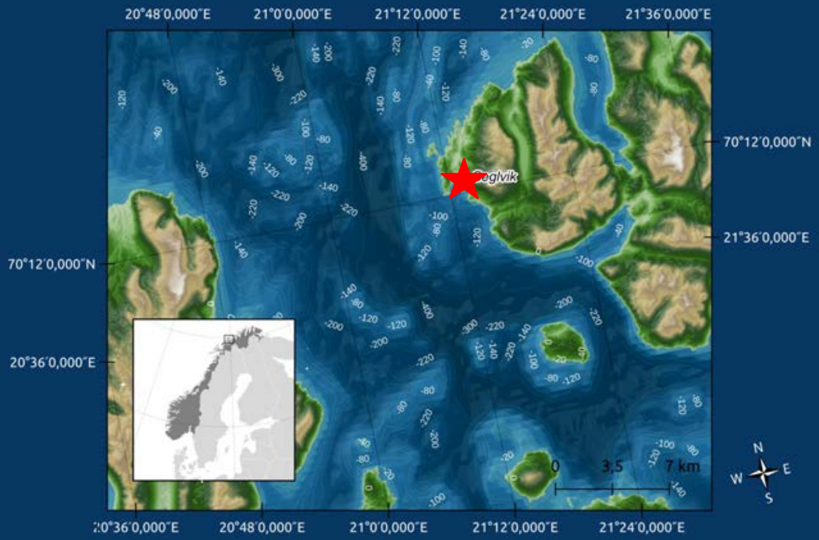
How anthropophony influence the pre-defined patterns ?



DATA ACQUISITION

- November 2022 - January 2023
- Continuous recording
- Fixed stereo antenna
- 1500 hours of recordings

The stereo antenna
(H. Glotin, deployed with M. Poupard nov. 2022)



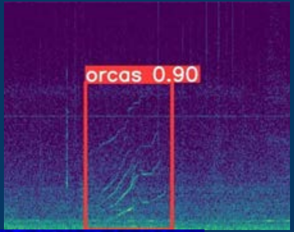
Bathymetric map of the Kvaenangen fjord and location of the antenna (Red star). © S. Chavin

DATA PROCESSING

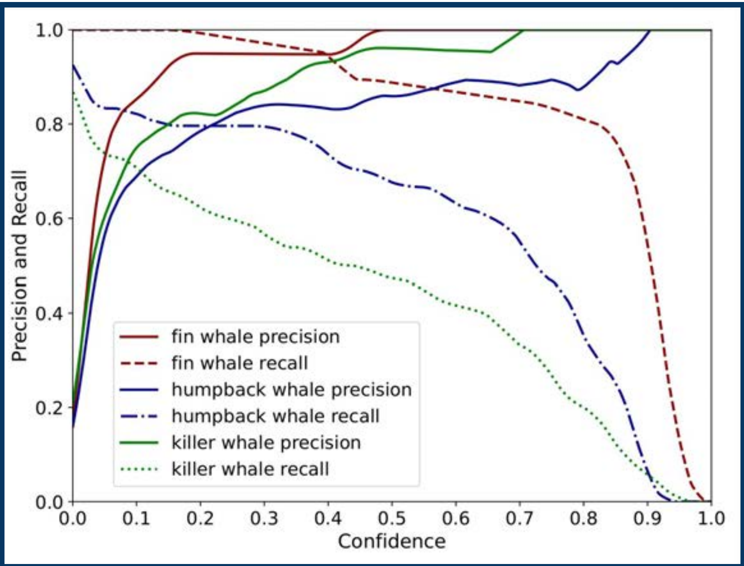
YOLO

- Neural network
- Based on object detection in images
- One model per species
- Tested in different ambient noise conditions

Prediction examples made by YOLO for humpback and killer whale with the detection confidence.



Species	Fin	Humpback	Orcas
Map50 (%)	99	82	74



Precision and recall versus confidence curves for the validation set of YOLO models trained for each species.
Precision : True Positives among all detections
Recall : False negatives
Girardet et al. 2025

DATA ANALYSING

METRICS

Performed for different time unit (daily, hourly (each hour of each day), circadian, and diel (light dependent)).

- Presence rate (PR) = proxy of presence of vocalizing animals

$$= \frac{\textit{number of recordings with detections}}{\textit{total number of recordings}}$$

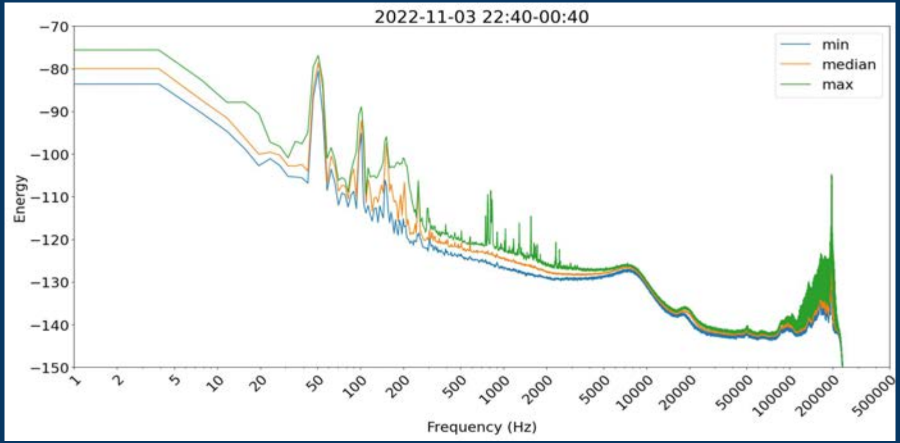
- Detection rate (DR) = proxy of the intensity of acoustic activity

$$= \frac{\textit{number of vocalizations}}{\textit{total recording time (in min)}}$$

AMBIENT NOISE

AMBIENT NOISE

- Power spectral density (PSD) estimation
- PSD converted in decibel
- Normalized by hydrophones parameters



Example of DSP in the fjord in November 2022

DATA SPLITTING

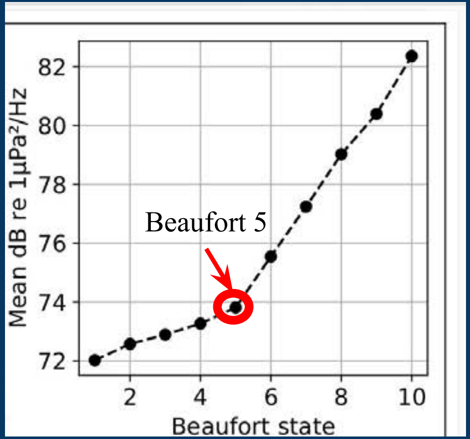
SEA STATE - GEOPHONY

Meteorologisk institutt

- Wind speed retrieved from Meteorological institute
- Wind speed converted into Beaufort scale
- Influence of Beaufort on ambient noise
- Threshold selection

Force	Wind Speed (knots)	Description
0	0–1	Calm
1	1–3	Light air
2	4–6	Light breeze
3	7–10	Gentle breeze
4	11–16	Moderate
5	17–21	Fresh breeze
6	22–27	Strong breeze
7	28–33	Moderate gale
8	34–40	Fresh gale
9	41–47	Strong gale
10	48–55	Whole gale
11	56–63	Storm
12	64+	Hurricane

Beaufort scale



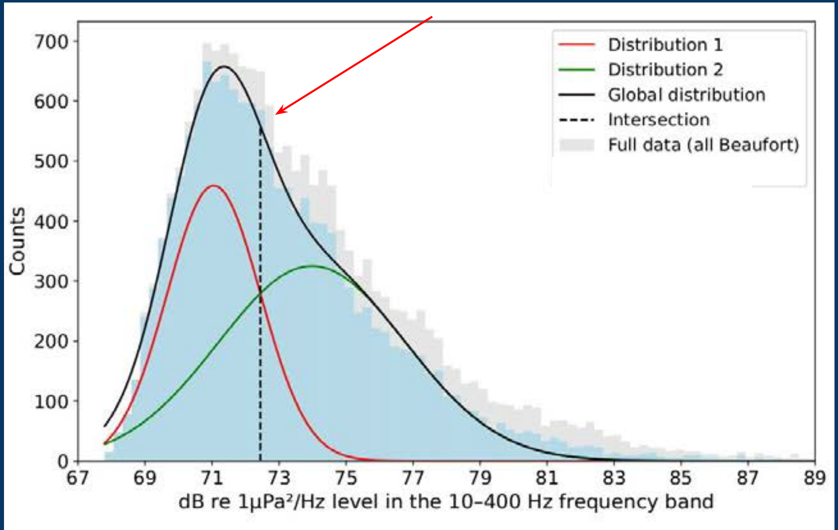
Mean dB re 1µPa²/Hz level for each Beaufort level.

DATA SPLITTING

AMBIENT NOISE - ANTHROPOPHONY

- 10-400 Hz frequency band for anthropophony
- Gaussian fit
- Threshold selection for predominant anthropophony

Selected threshold
72.44 dB re 1µPa²/Hz



Distribution of dB re 1µPa²/Hz levels in the 10-400 Hz.
Girardet et al. 2025

MODEL PERFORMANCES

Species	Fin	Humpback	Orcas
Map50 (%)	99	82	74

- Decrease in performances in higher sea state

Performances for each models in different sea states.

	Fin	Humpback	Orca
All B	82	73	70
B < 3	84	77	73
B = 3-5	79	75	80
B = 6-8	85	76	60
B > 8	86	64	64

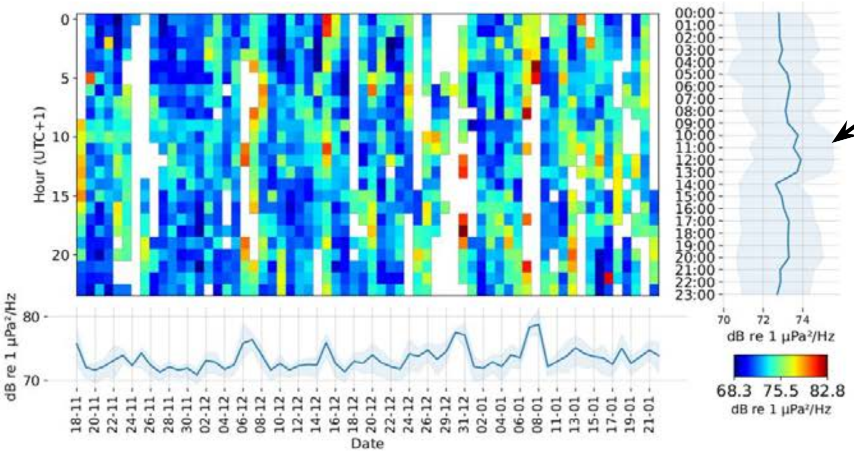
- Similar performances for different anthropophony-like level

Performances for each models in different ambient noise in 10:400 Hz frequency band

	Fin	Humpback	Orca
All A level	95	75	80
A < 72.4	92	79	71
A = 72.5-77.9	96	74	80
A = 78-81.9	98	78	80
A > 82	95	76	90

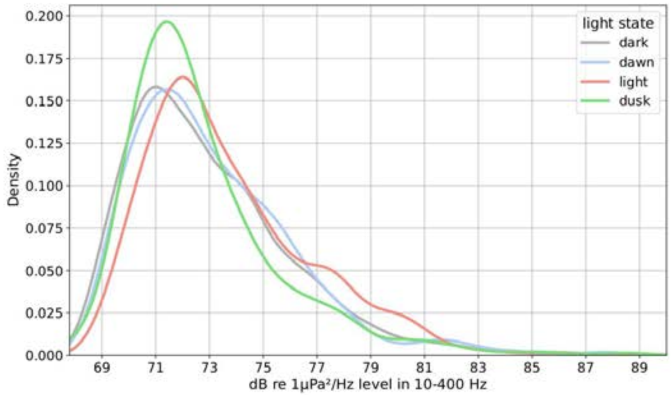
ANTHROPOPHONY-LIKE

- No clear circadian pattern



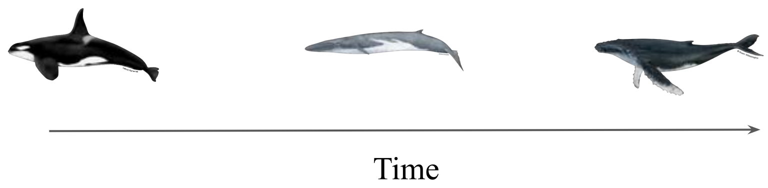
Calendar heatmap showing mean anthropophony levels (anthropophony subset) per hour (y-axis) for each day from 18 Nov. 2022 to 23 Jan. 2023 (x-axis). White cells represent hours without recordings. Evolution of ambient noise levels: daily (bottom) and circadian (right) median values (solid lines) with interquartile ranges (shaded areas between the 25th and 75th percentiles). Girardet et al. 2025

- Anthropohony higher during light



Smoothed distributions (KDE) showing noise levels during dark (n = 10544, grey), dawn (n = 1096, blue), light (n =3398, red) and dusk (n = 1066, green) periods. Girardet et al. 2025

ACOUSTIC BEHAVIOR



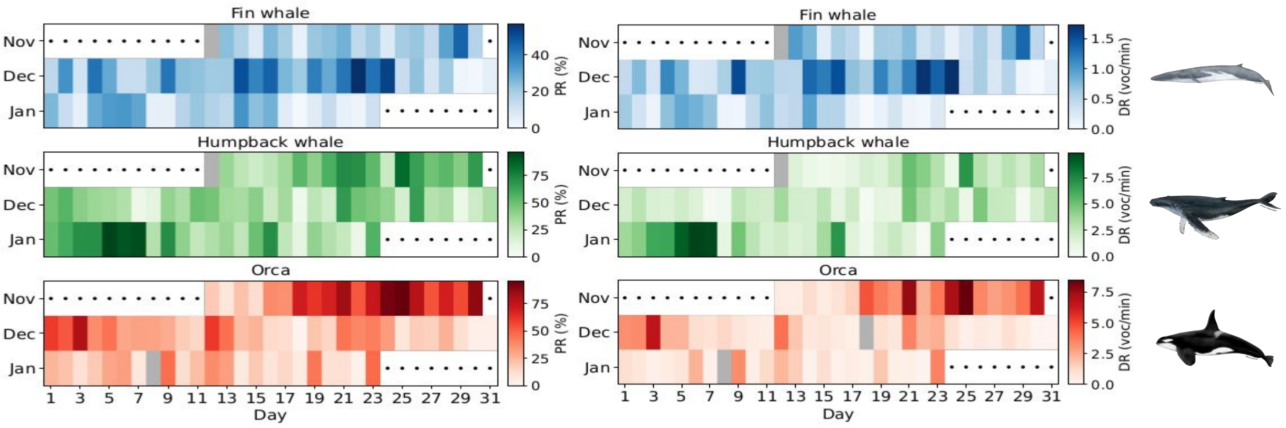
◊ Distinct period of maximum presence and activity

Continuous acoustic presence

Maximum presence and activity: end of november

*Acoustic **presence** rate*

*Acoustic **detection** rate*



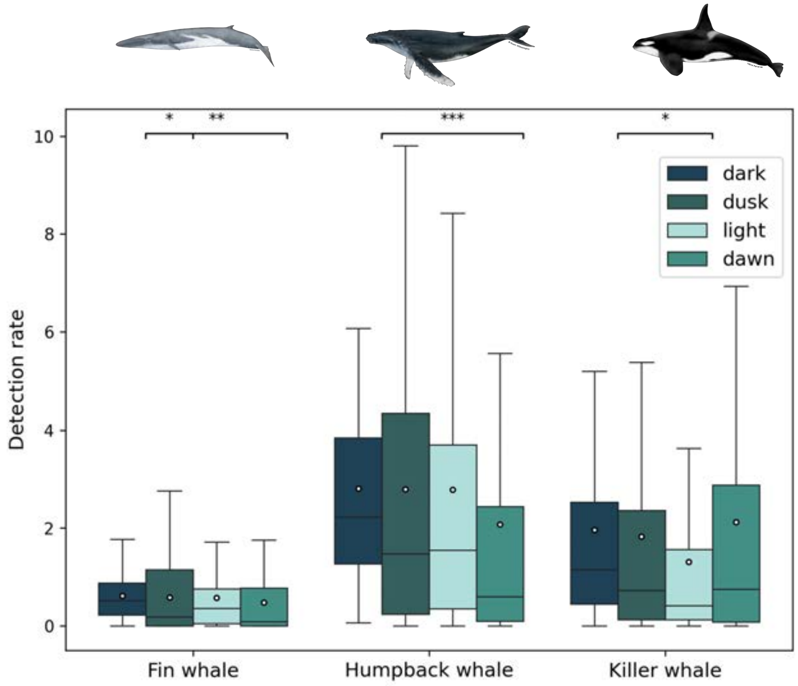
Calendar of daily PR and DR for the three species. Girardet et al.2025

DIEL PATTERNS

- Fin whales significantly more active during dark than dusk and dawn

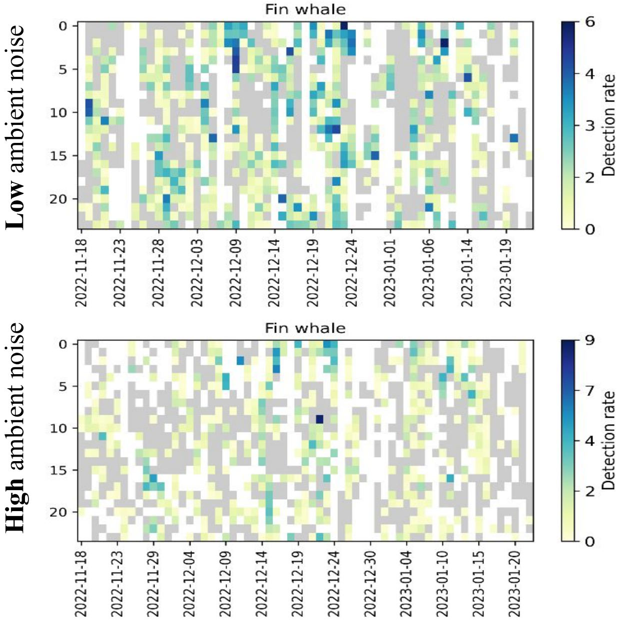
- Humpback whales lower activity during dawn

- Killer whales significantly more active during dark than light.



*Detection rate according to light conditions and differences between them for the three species. Significance levels are illustrated with stars (*p < 0.05; **p < 0.01; ***p < 0.001). Girardet et al. 2025*

ANTHROPOPHONY INFLUENCES

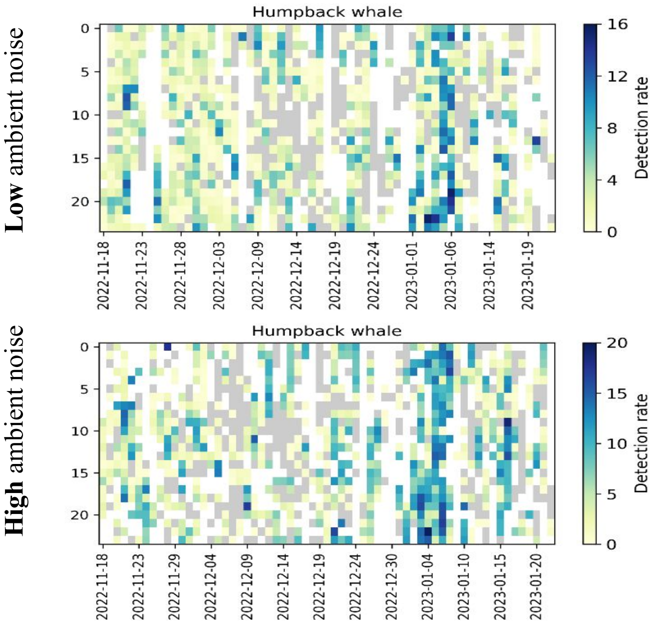


Calendar of DR for each hour of each day of the recording period. Grey cells represent hours without detection, white cells represent hours with no data. Girardet et al. 2025

- Hourly : PR and DR significantly lower in noisy conditions
- Daily : negative correlation between noise and PR or DR

- Limitations in detection performances ?
- **Avoidance ?**
- **Cease vocal activity ?**

ANTHROPOPHONY INFLUENCES



Calendar of DR for each hour of each day of the recording period. Grey cells represent hours without detection, white cells represent hours with no data. Girardet et al. 2025

◇ Hourly : Higher DR in noisy condition, unchanged PR

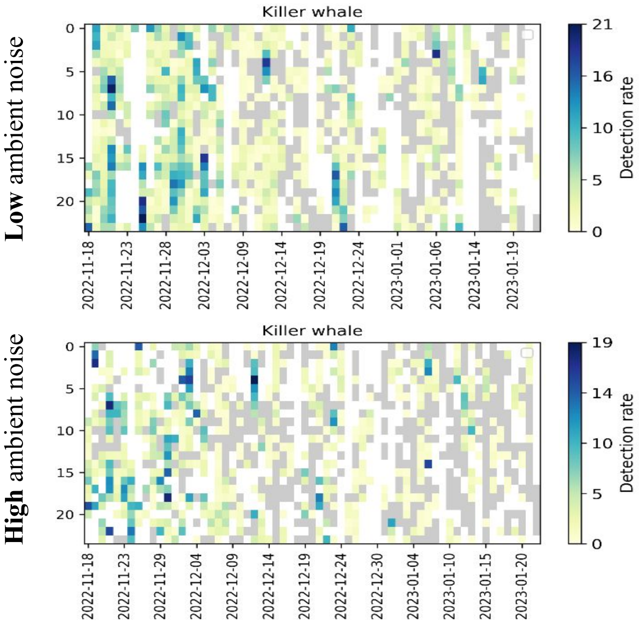
◇ Daily : negative correlation between noise and DR but not PR

◇ Complex response, time scale dependant

◇ **More individuals ? Lombard effect on short term ?**

◇ **Avoidance on long term ? Cease vocal activity ?**

ANTHROPOPHONY INFLUENCES



Calendar of DR for each hour of each day of the recording period. Grey cells represent hours without detection, white cells represent hours with no data. Girardet et al. 2025

- Hourly : DR slightly lower, PR significantly reduced in noisy conditions
- Daily : negative correlation between noise and PR or DR
- Avoidance ?
- **Decreased vocal activity ?**

GEOPHONY INFLUENCES

*Daily and hourly spearman correlation coefficient (ρ) between species PR and geophony noise level with significance levels shown as stars (*p < 0.05; **p < 0.01; ***p < 0.001). n.s. for non significant.*

Species	daily	hourly
Fin	$\rho = -0.41^{***}$	$\rho = -0.21^{***}$
Humpback	$\rho = -0.34^{***}$	n.s.
Orca	$\rho = -0.4^{***}$	$\rho = -0.25^{***}$

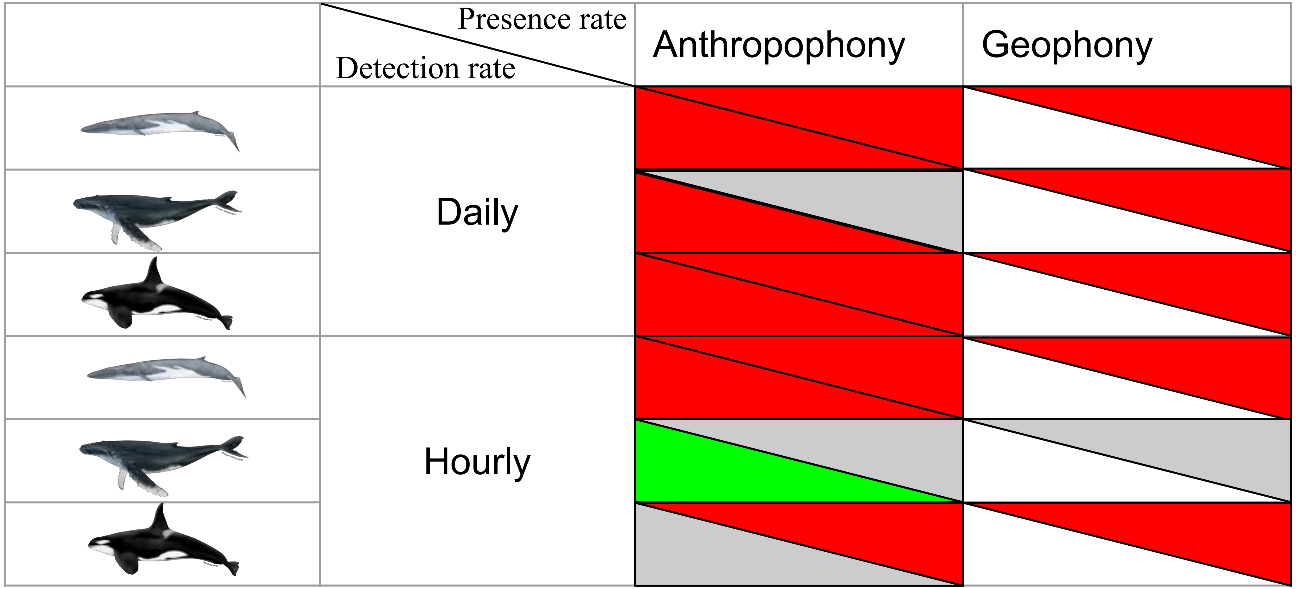
- Presence rate only
- Greater influence on daily basis
- PR of three species negatively influence by geophony

SUM UP

Cetaceans change their acoustic behavior according to ambient noise sources.

<u>Next step:</u>

Distinguish thank to AIS data the impact of fisheries and whale watching.



Significant positive correlation in green, significant negative correlation in red, insignificant correlation in gray, and non tested in white.

Acknowledgements

This work would not have been possible without the financial support of AID DGA Chair ANR-20-CHIA-0014, MITI CNRS, TPM CG83 APRI, the project Biodiversa Europam and ANR for grants ULPCochlea ANR-21-CE04-0020 for AI Bioacoustics.

This research was cofunded by Biodiversa+, the European Biodiversity Partnership under the 2021-2022 BiodivProtect joint call for research proposals, co-funded by the European Commission (GA N°101052342) and the Regional Government of the Azores, through the Regional Fund for Science and Technology (FRCT), under the project EUROPAM -European Spatial-Temporal Large Scale Sea Noise Management & Passive Acoustic Monitoring of Marine Megafauna (ref. 488).

Decoding echolocation: Good practices for studying the sonar of marine animals

***Nicolas Deloustal**[*1,2,4]*, *Hervé Glotin[1,2,4]*, *Cláudia Inês Botelho de Oliveira[1,3]*, *Adeline Paiement[1,2,4]*, *Sébastien Paris[1,2,4]*

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3 IMAR
4 Chaire IA AID DGA ADSIL ANR-20-CHIA-0014

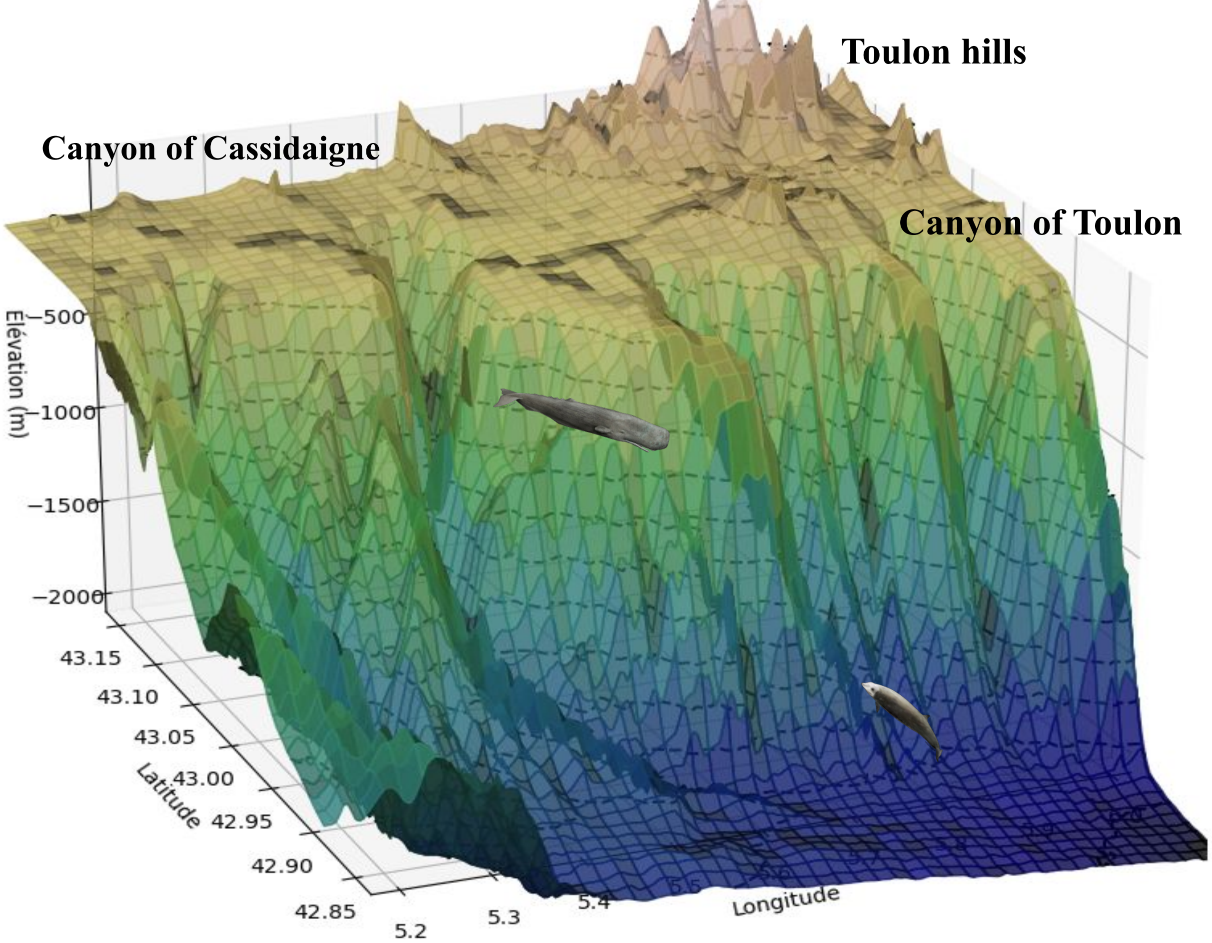
Problem

A dark environment

Navigating without vision

Biosonar

→ Echolocation



Griffin, DR. (1944). Echolocation by blind men, bats and radar. *Science*.
Au, W. (1993). The Sonar of Dolphins Springer, New York, pp. 32, 41–46, 66–70, 148–152.

Echolocation

◿ Detection / Localization

<u>Range measurement :</u>

1 - Sound emission
2 - Echo
3 - Echo analysis

air ≈ 344 m/s
water ≈ 1500 m/s

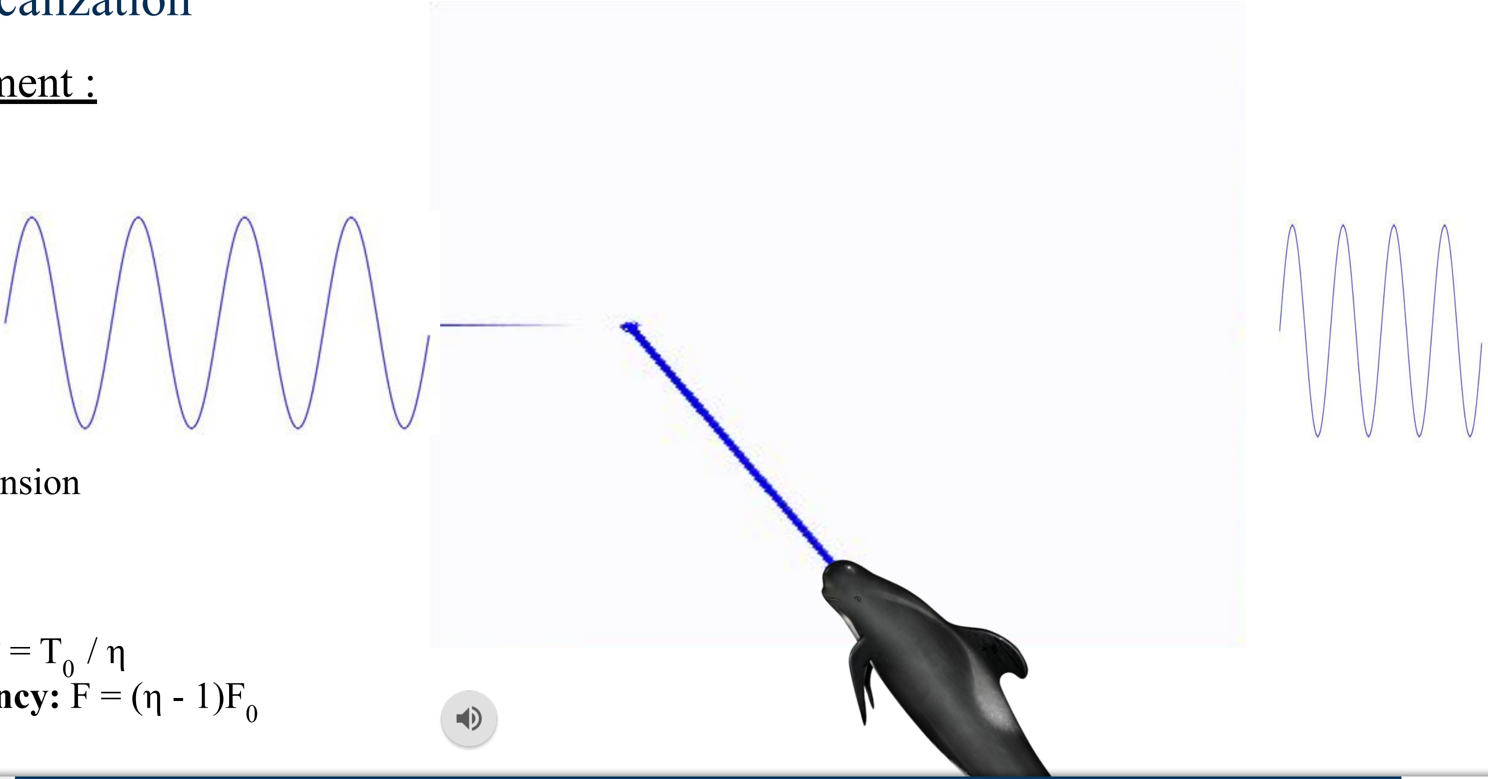
$$\text{Range}_{(\text{sonar/target})} = \frac{t(\text{Sonar} \rightarrow \text{Target} \rightarrow \text{Sonar})}{2} \times \text{speed of sound}$$

Echolocation

Detection / Localization

Speed measurement :

Doppler effect



Distance variation

↓

Compression or expansion

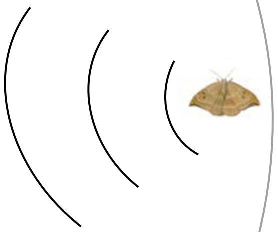
↓

Changes **duration**: $T = T_0 / \eta$
and therefore **frequency:** $F = (\eta - 1)F_0$

Flandrin, P. (2014). Of Bats and Men. In *BIOSTEC* (pp. IS-7).

Echolocation and behavior

Foraging



-10 dB

0 dB

Detection :

- Perceiving movement / velocity

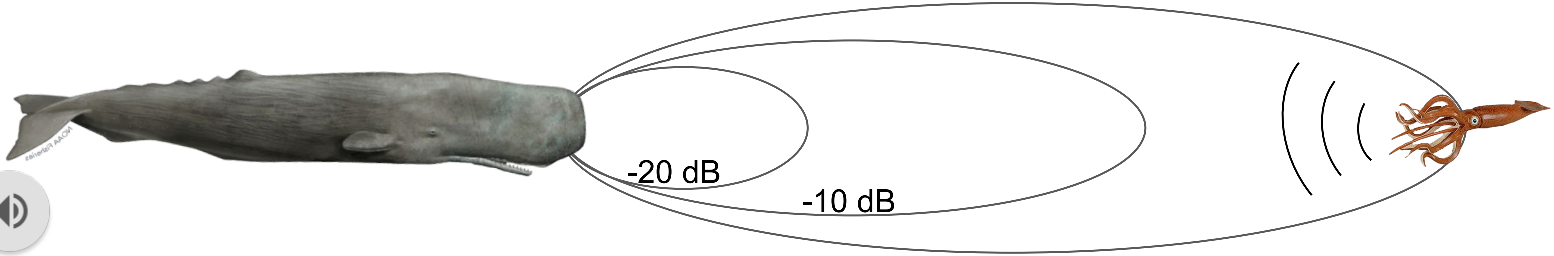
- Finding obstacles and speed in a stationary space

Low frequency, high energy

Very good propagation — Low spatial resolution

Echolocation and behavior

Foraging



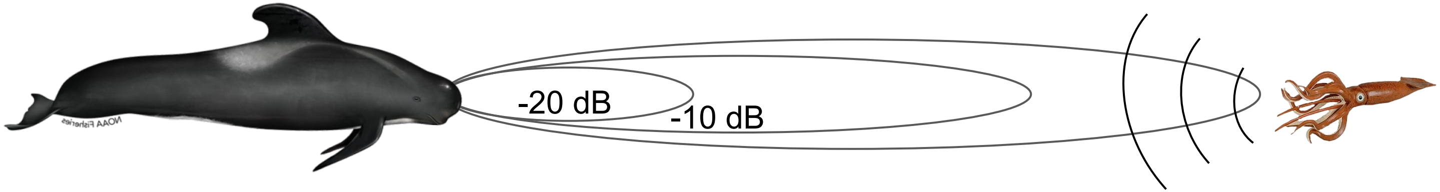
Localization :

- Determine the position of a target (regardless of speed)

Greater frequency bandwidth	
Good spatial resolution, resistant to Doppler effect	Requires close target distance

Echolocation and behavior

Foraging



Characterization :

- Identify the nature of a target (size / shape / texture)

High frequency	
Excellent spatial resolution	Requires close distance to target

Echolocation and behavior

Foraging

Buzz :

- Estimate the most precise **distance** possible

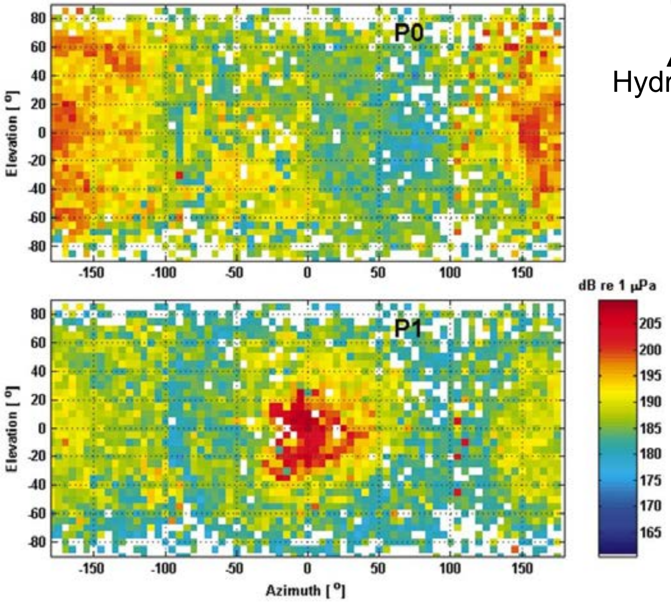
Low energy, short pulse

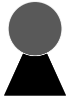
Near real-time target estimation

Short range

Data acquisition - Directivity effect

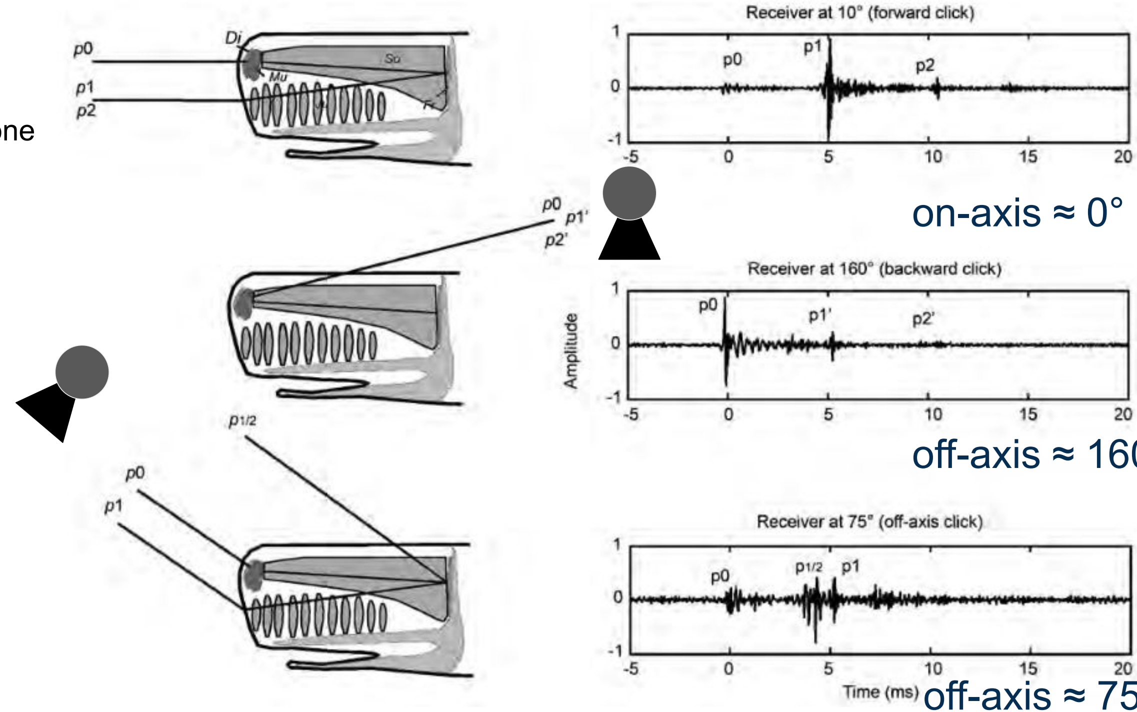
Hydrophone position





Hydrophone

Sperm whale example



on-axis ≈ 0°

off-axis ≈ 160°

off-axis ≈ 75°

p1 = localization

p0 = orientation cues

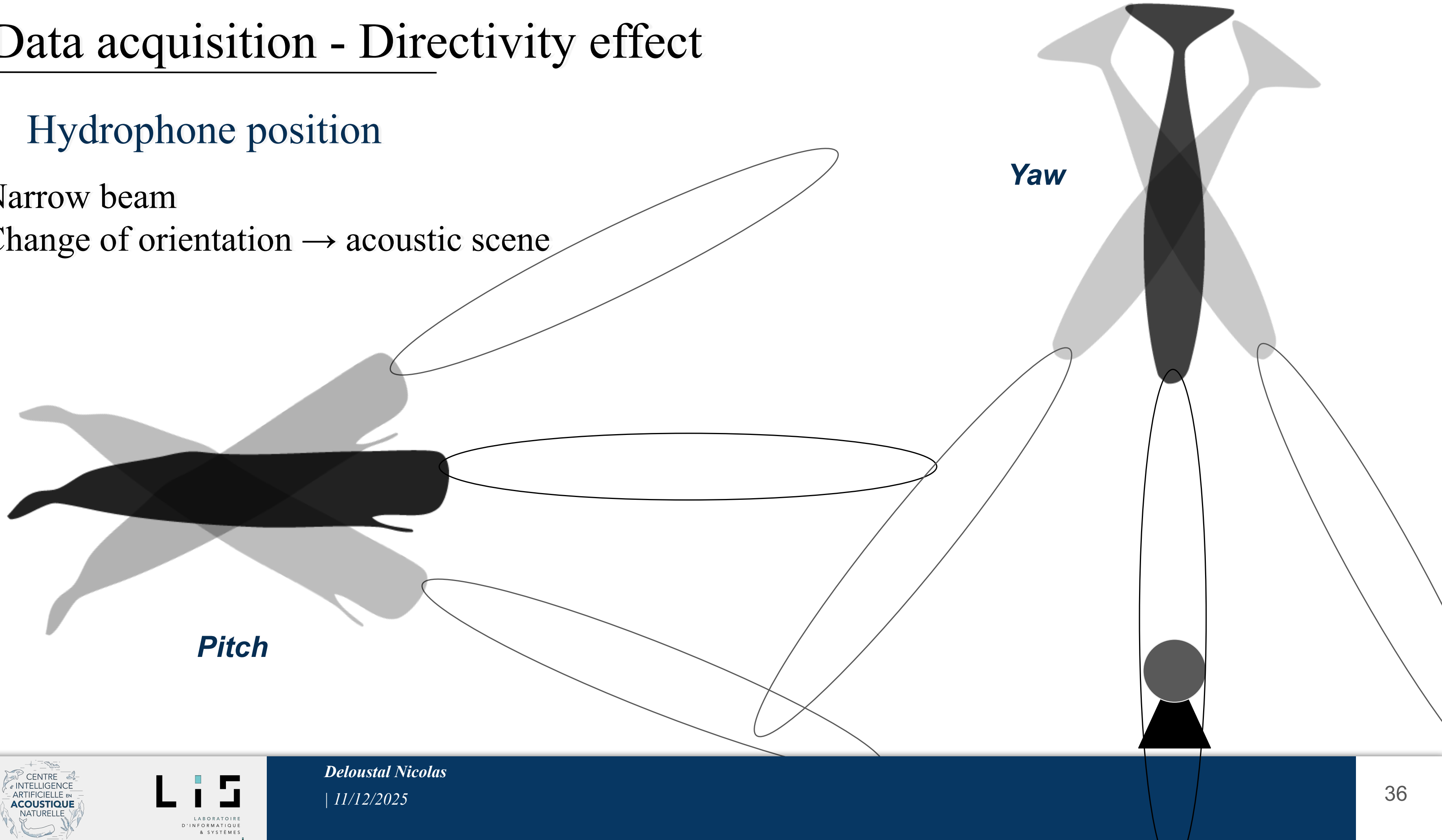
→ Must be on-axis

Zimmer, W. M., Tyack, P. L., Johnson, M. P., & Madsen, P. T. (2005). Three-dimensional beam pattern of regular sperm whale clicks confirms bent-horn hypothesis. The Journal of the Acoustical Society of America, 117(3 Pt 1), 1473–1485.
Teloni, V., Zimmer, W. M., WAahlberg, M., & Madsen, P. (2007). 127 consistent acoustic size estimation of sperm whales using clicks recorded from unknown aspects. *J. Cetacean Res. Manage*, *9*(2), 127-136.

Data acquisition - Directivity effect

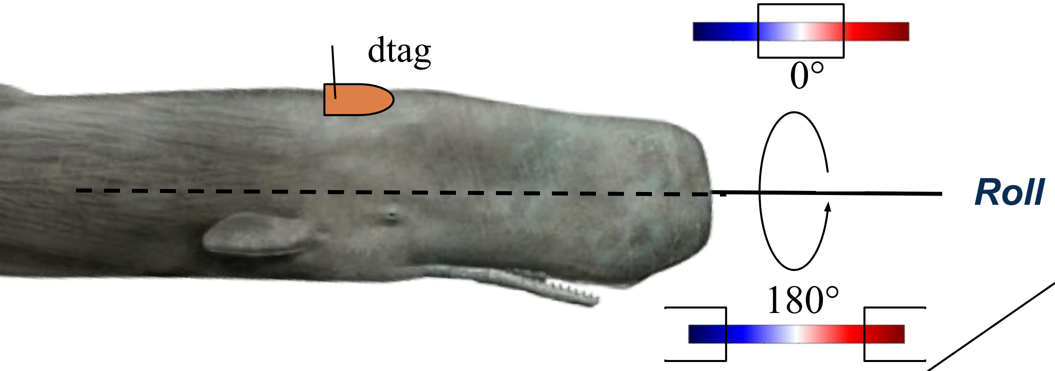
Hydrophone position

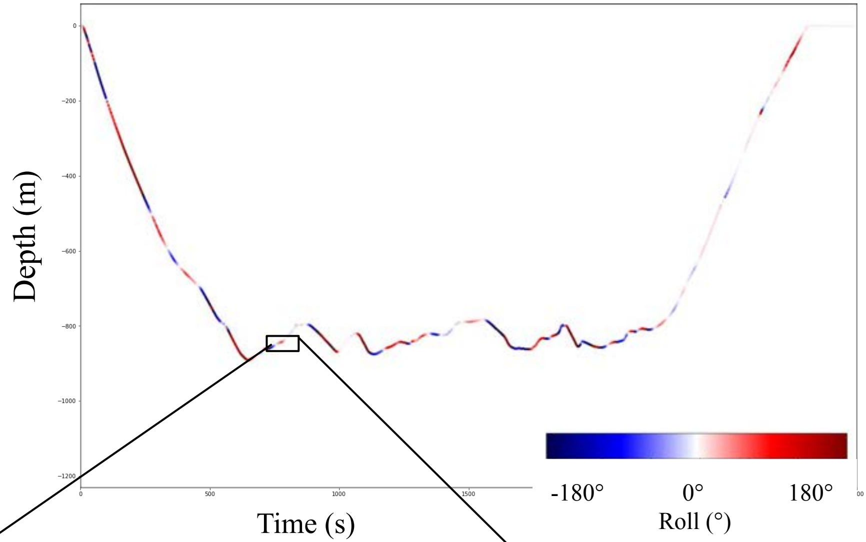
Narrow beam
Change of orientation → acoustic scene

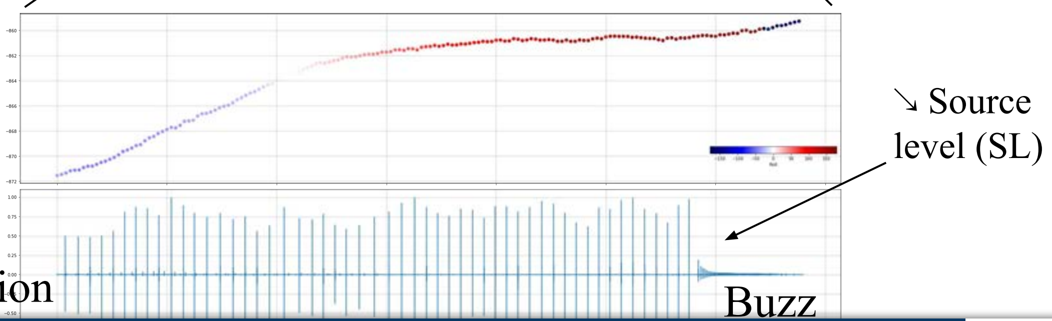


Data acquisition - Directivity effect

Hydrophone position







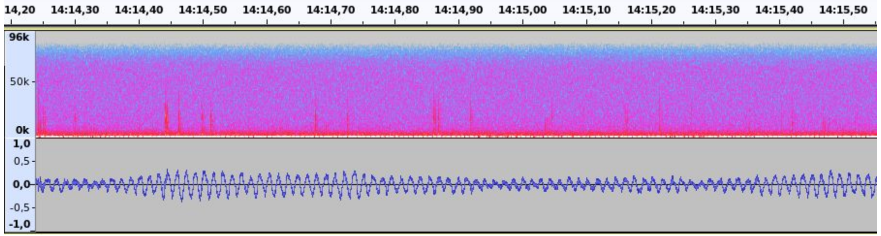
Oliveira, C., Wahlberg, M., Silva, M. A., Johnson, M., Antunes, R., Wisniewska, D. M., Fais, A., Gonçalves, J., & Madsen, P. T. (2016). Sperm whale codas may encode individuality as well as clan identity. The Journal of the Acoustical Society of America, 139(5), 2860.

Data acquisition

Noise

Anthropophony

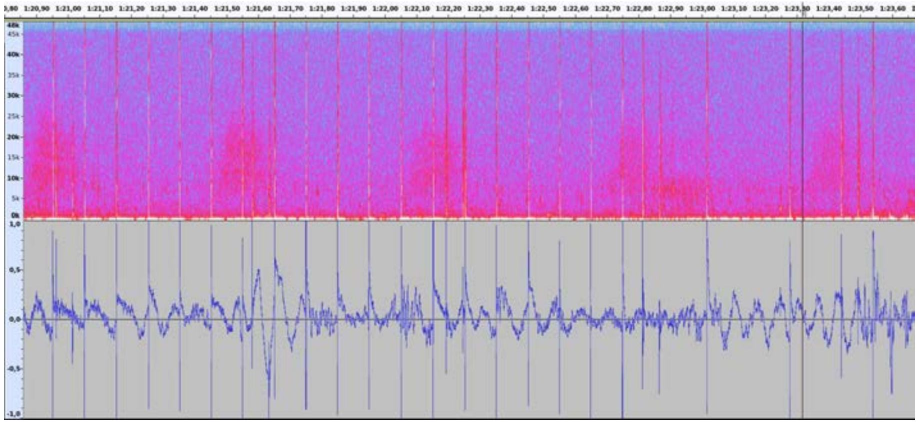
- Boat



Time (s)

Solution: Filtering

- Echosounder



Time (s)

Biophony

- Snapping shrimp

Zimmer, W. M., Tyack, P. L., Johnson, M. P., & Madsen, P. T. (2005). Three-dimensional beam pattern of regular sperm whale clicks confirms bent-horn hypothesis. The Journal of the Acoustical Society of America, 117(3 Pt 1), 1473–1485.
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Data acquisition - Acoustic masking

Propagation

TL: transmission loss

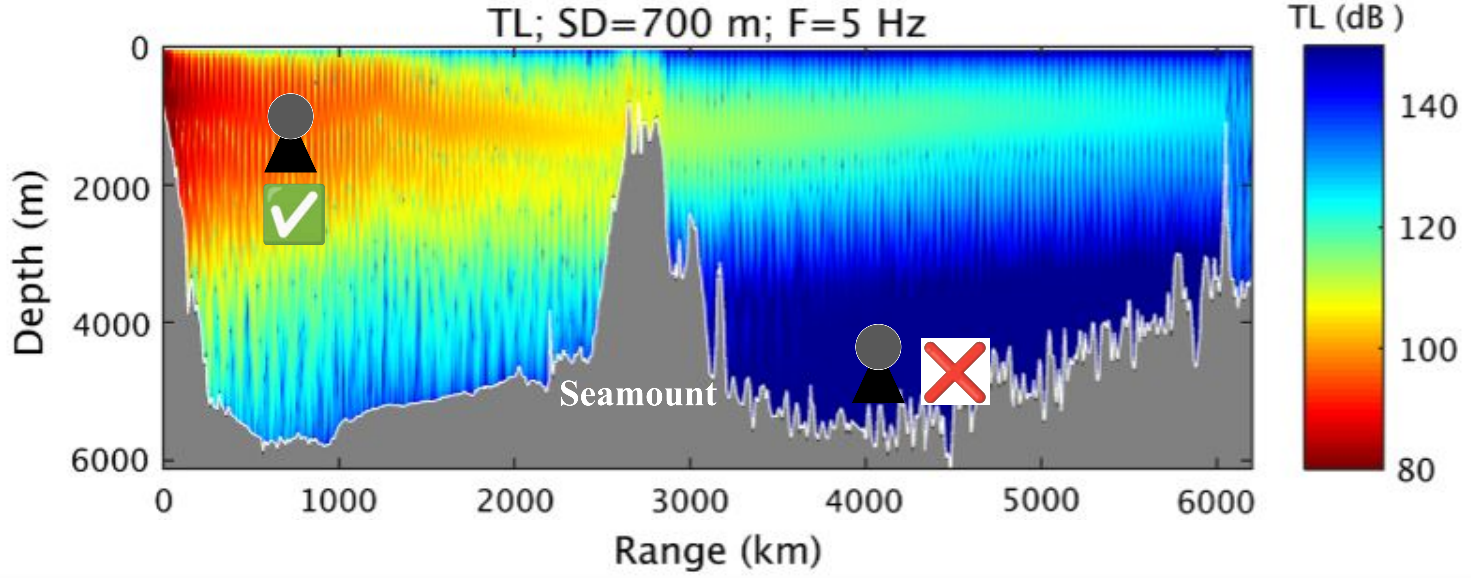
→ affects **spectral** & **temporal** properties,

Factors:

Mixing layers

Acoustic masking

Distance



Functional Convergence in Bat and Toothed Whale Biosonars (2013) P. T. Madsen and A. Surlykke Physiology, 28:5, 276-283
Nielsen, Peter et al., (2021). CTBTO's Data and Analysis Pertaining to the Search for the Missing Argentine Submarine ARA San Juan. Pure and Applied Geophysics.

Signal processing : Quantify information

Ambiguity function

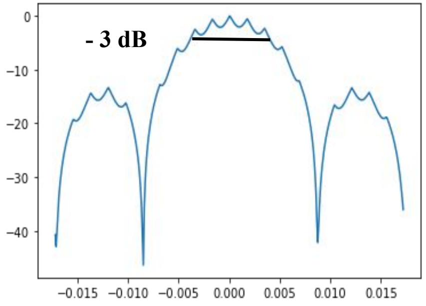
$$\chi(\tau,\eta) = \sqrt{\eta}\int_{-\infty}^{+\infty} s(t)s^{*}(\eta(t-\tau))dt$$

s(t) : biosonar,
s*(η(t-τ)) : echo reflected by targets,
τ : delay,
η : Doppler scaling factor

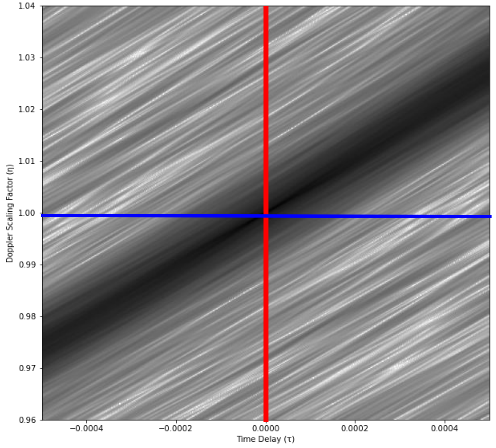
→ Sonar performance measurements

$$RR \propto \frac{c}{2B}$$

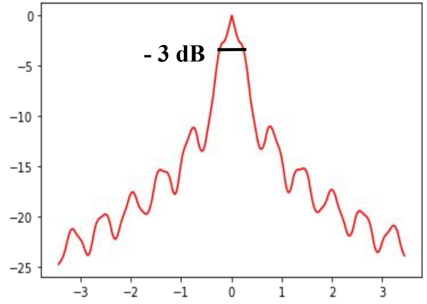
Range Resolution (RR)



surface $|\chi(\tau,\eta)|^2$



Velocity Resolution (VR)



$$VR \propto \frac{c}{2 \cdot f_c \cdot T}$$

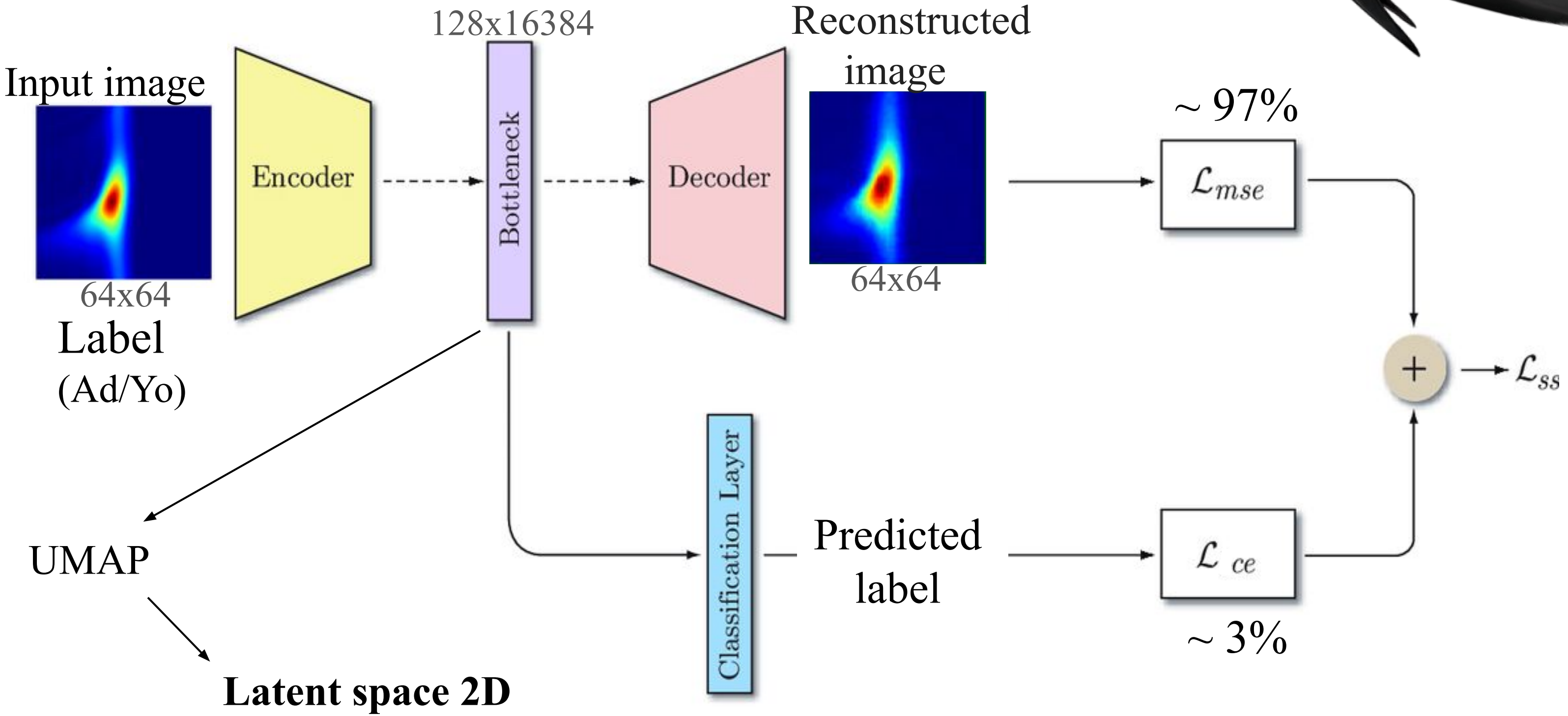
→ Performance = Intentions = Behavior

B: bandwidth
fc: center frequency
T: effective duration
c: speed of sound

Kelly, E. J., and Wishner, R. P. (1965). "Matched-filter theory for high-velocity, accelerating targets," IEEE Transactions on Military Electronics 9, 56–69

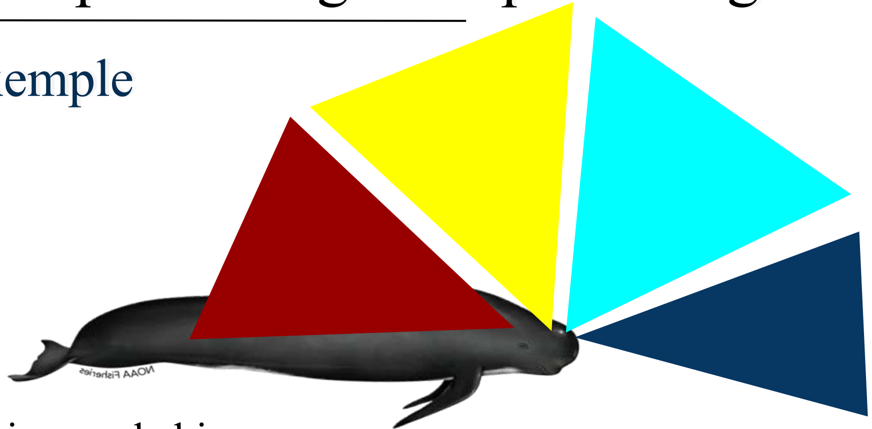
Signal processing : Deep learning

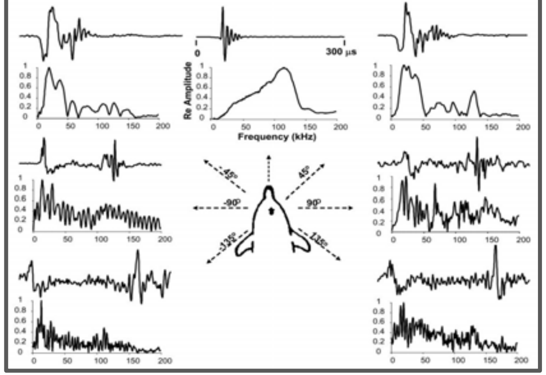
Supervised AE + Classifier



Signal processing : Deep learning

Exemple



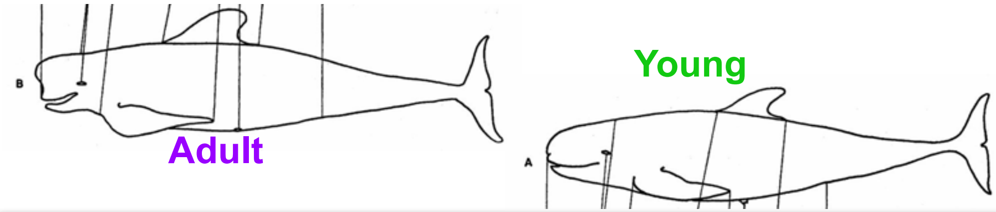


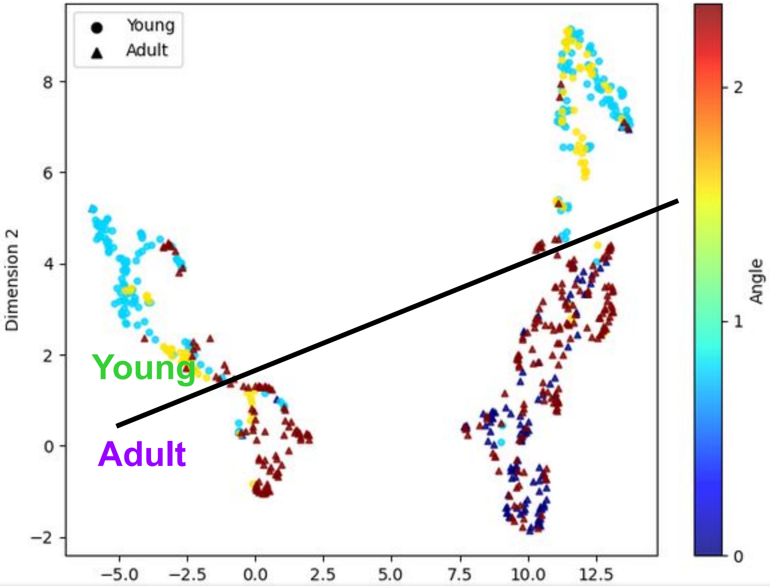
Biosonar click at different angles (horizontal plane)

<u>- Emission angle bias :</u>

Side = Young **Front and Back = Adult**

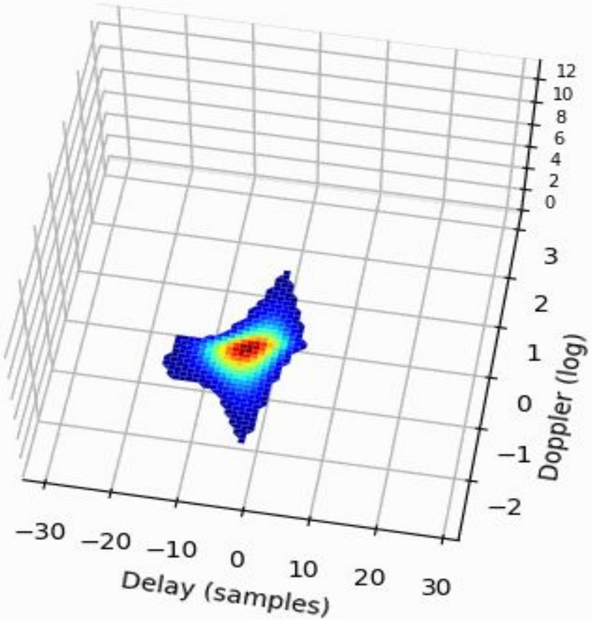
<u>- Visual differentiation between young and adults :</u>



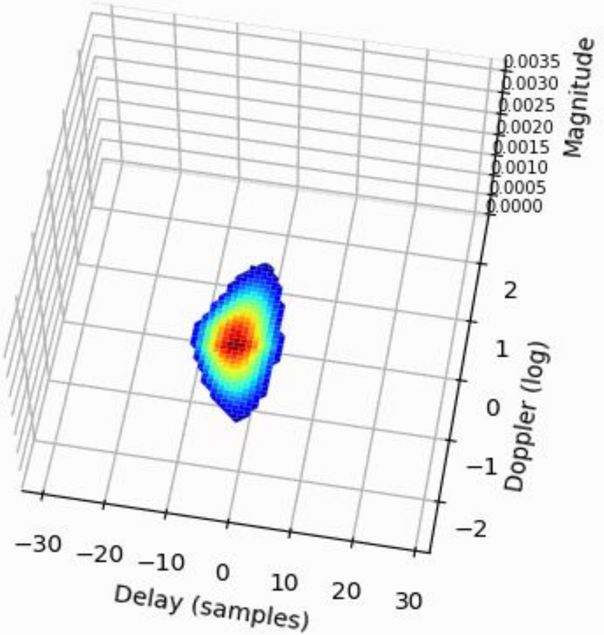


Au WW, et al,. The biosonar field around an Atlantic bottlenose dolphin (Tursiops truncatus). J Acoust Soc Am. 2012 Jan;131(1):569-76

Dynamic patterns : Different Behaviour / biosonar tactic ?



Adult



Young

Thank you for listening

Arctic Acoustic and Med. Sea : Scene's complexity, stakes, and outlooks

Hervé Glotin[1,2,3,4], Véronique Sarano[1,3], Pascale Giraudet [1,2,4], François Sarano[1,3]

et toutes les équipes des missions Fjord3D ADAPREDAT et WhaleWay et SP - 2021-2025

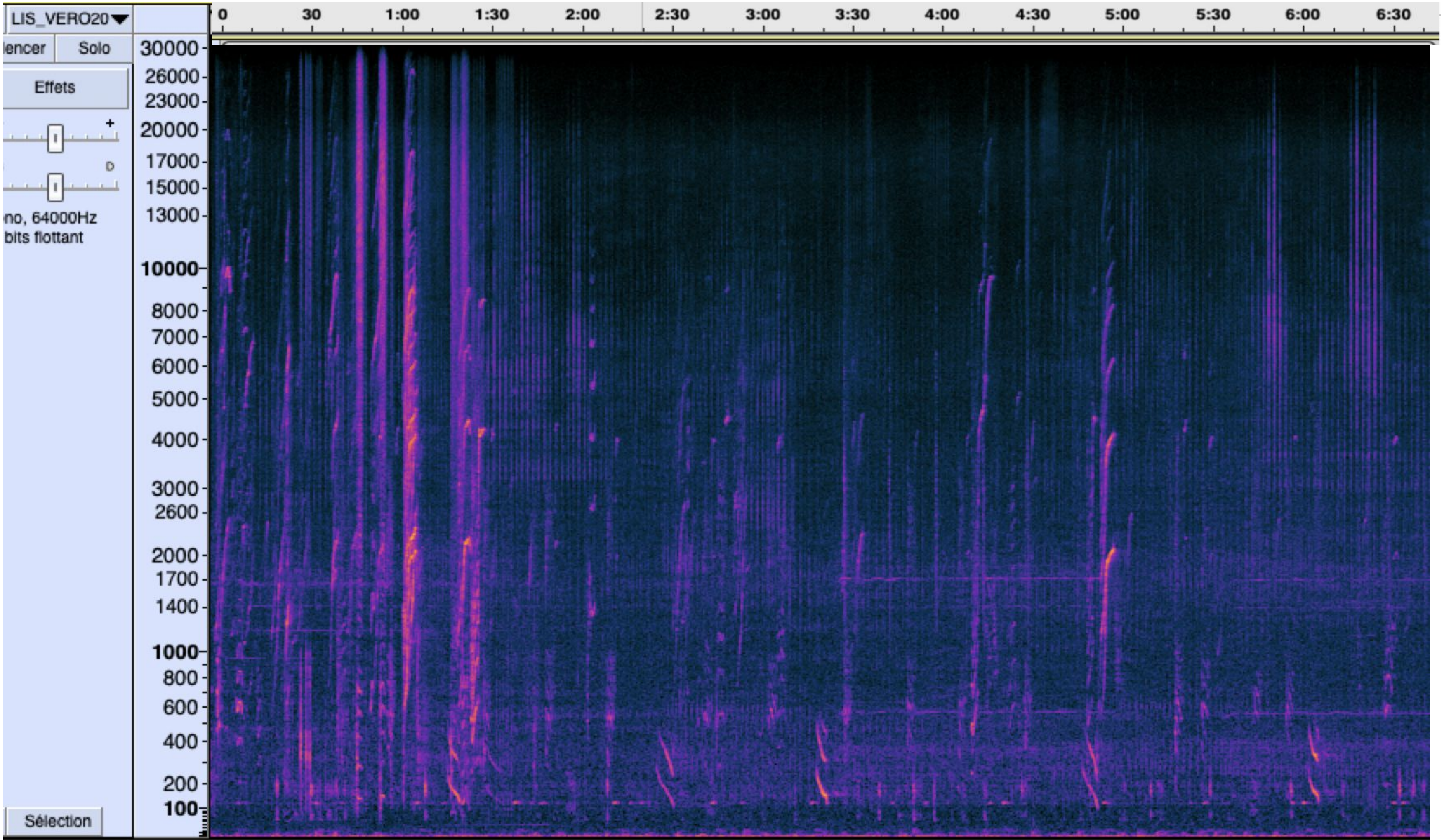
1 Centre International d'Intelligence Artificielle en Acoustique Naturelle, CIAN UTLN

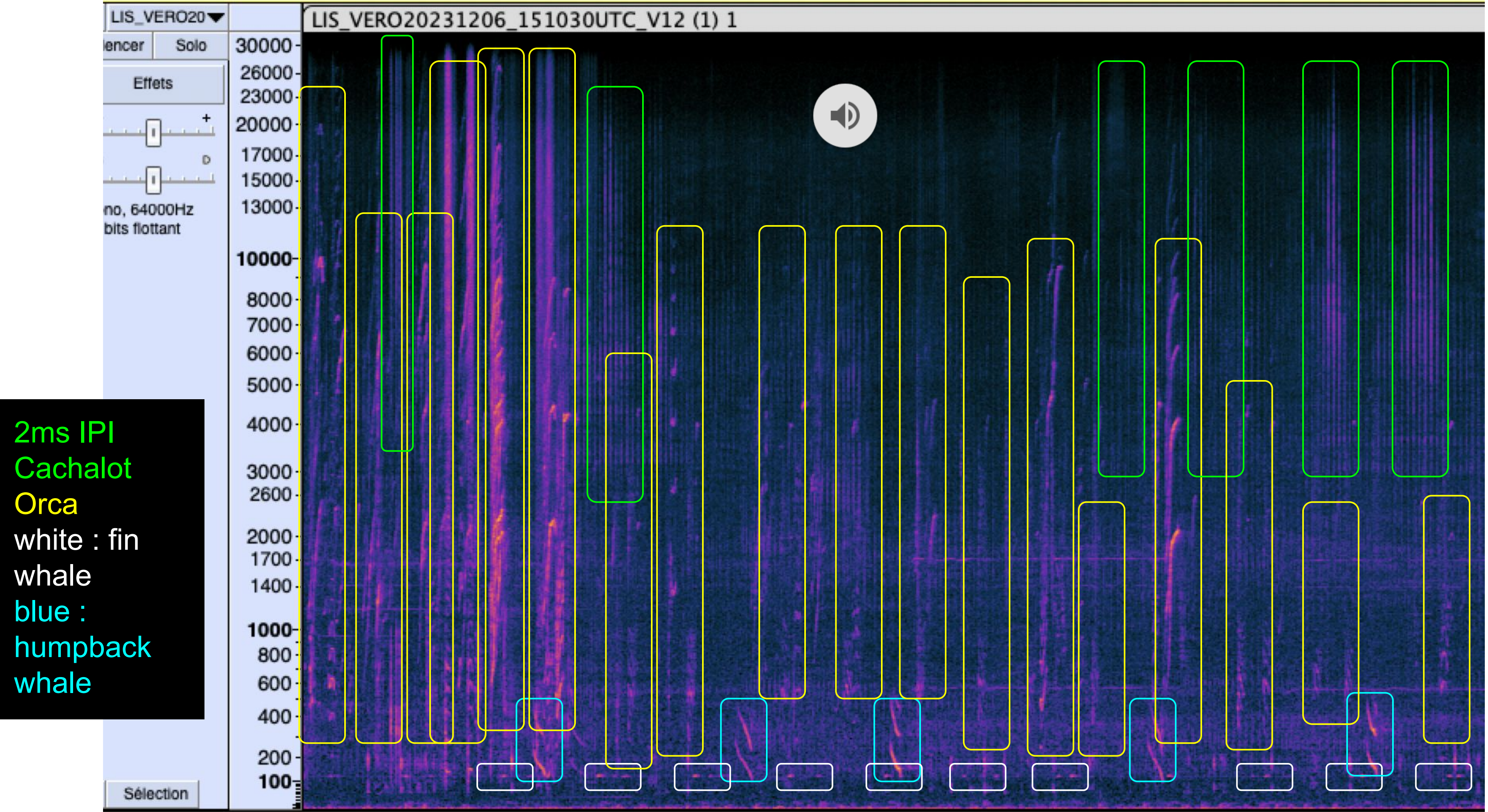
2 Laboratoire d'Informatique et des Systèmes, University of Toulon

3 Longitude 181

4 Chaire IA AID DGA ADSIL ANR-20-CHIA-0014

Scene complexe du fjord durant nos missions




LIS_VERO20
encer
Solo
Effets
no, 64000Hz
bits flottant
Sélection
LIS_VERO20231206_151030UTC_V12 (1) 1
30000
26000
23000
20000
17000
15000
13000
10000
8000
7000
6000
5000
4000
3000
2600
2000
1700
1400
1000
800
600
400
200
100
2ms IPI
Cachalot
Orca
white : fin whale
blue : humpback whale

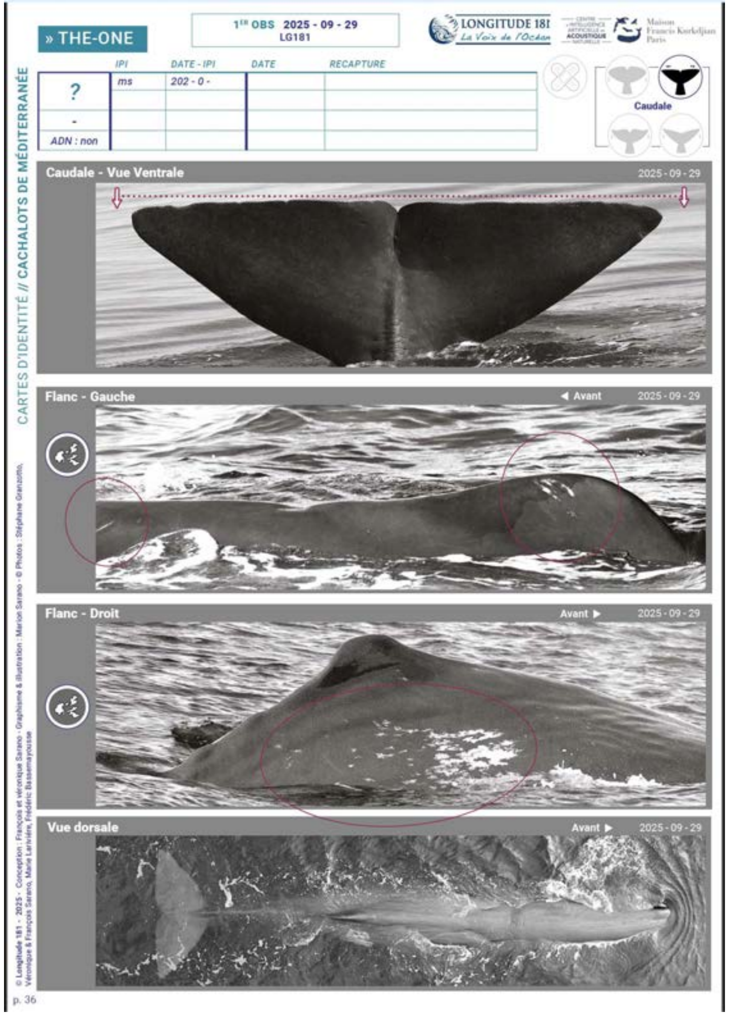

WHALE WAY 6
2025-09-30

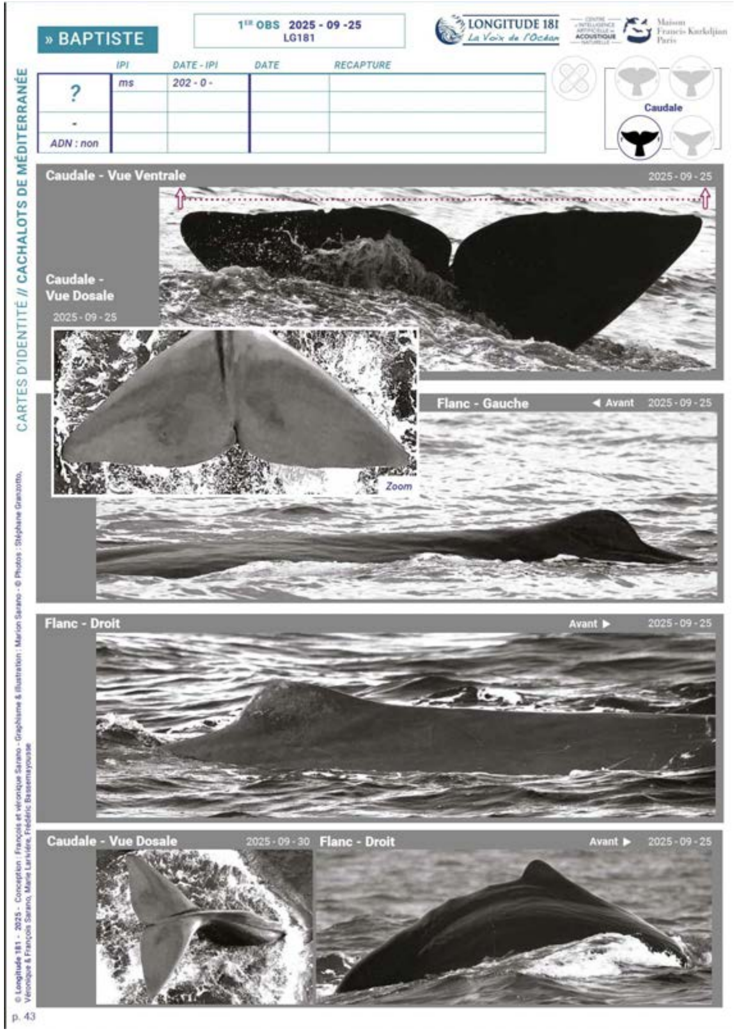
Protocole WhaleWay : (a) Acoustique (antenne MANTA RT,Baguera, hydro profond),
(b) Observations Visuelles, (c) Photo 1 M pixel, (d) Drone

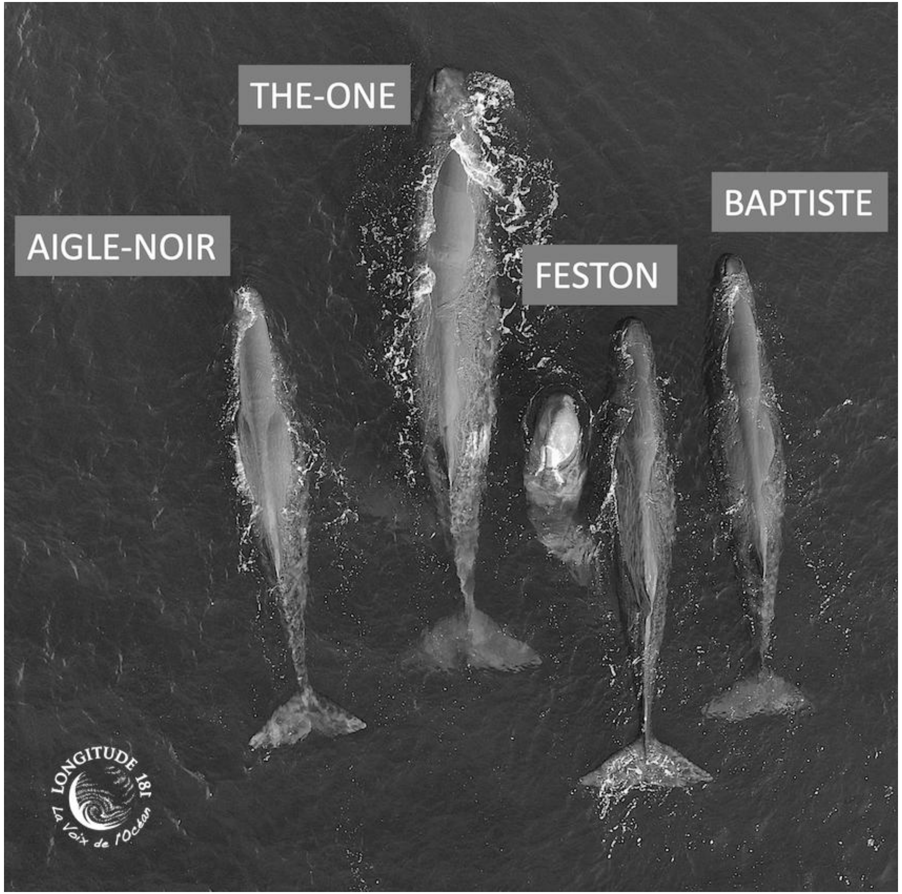
Etude réalisée sous permis de la DREAL, approches suivant la réglementation

Fiche d’identité de L181 : F. et V Sarano

Environ 100 individus en Med. Sea

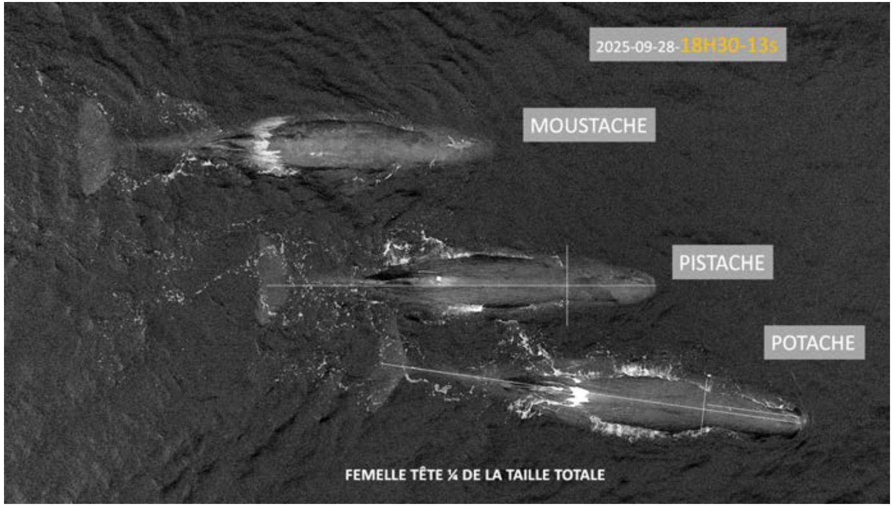


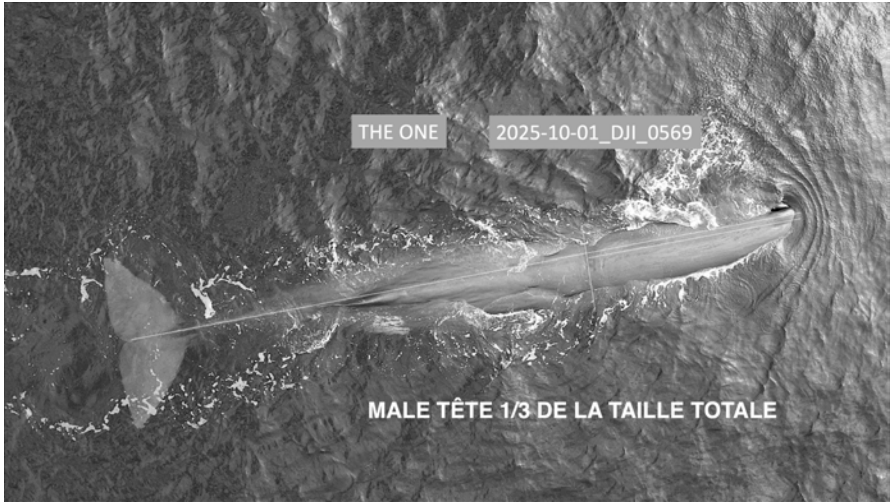




LONGITUDE 181
La Voix de l'Océan

Suivi des âges / Taille : Drones et Intervalle interpulse





1er octobre 2025 : Rencontre d’un groupe de chasseurs Cassidaigne


FESTON
AIGLE-NOIR
THE-ONE
BAPTISTE
SALADIN
2025-09-30-15h23-SONDE-SIMULTANÉE

2025-09-30-14H34-SONDE-SIMULTANÉE

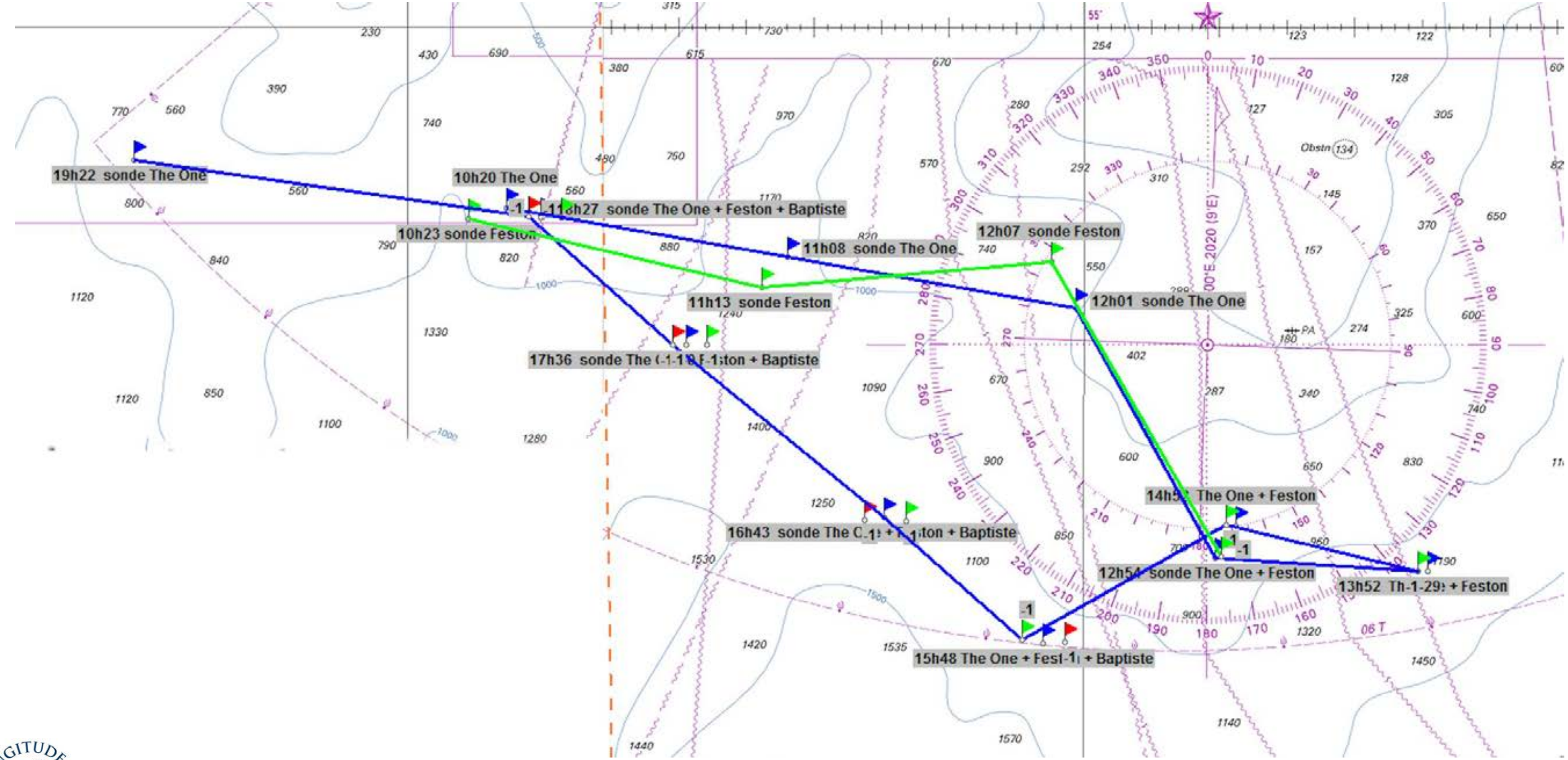
AIGLE-NOIR

PAT’LOVE

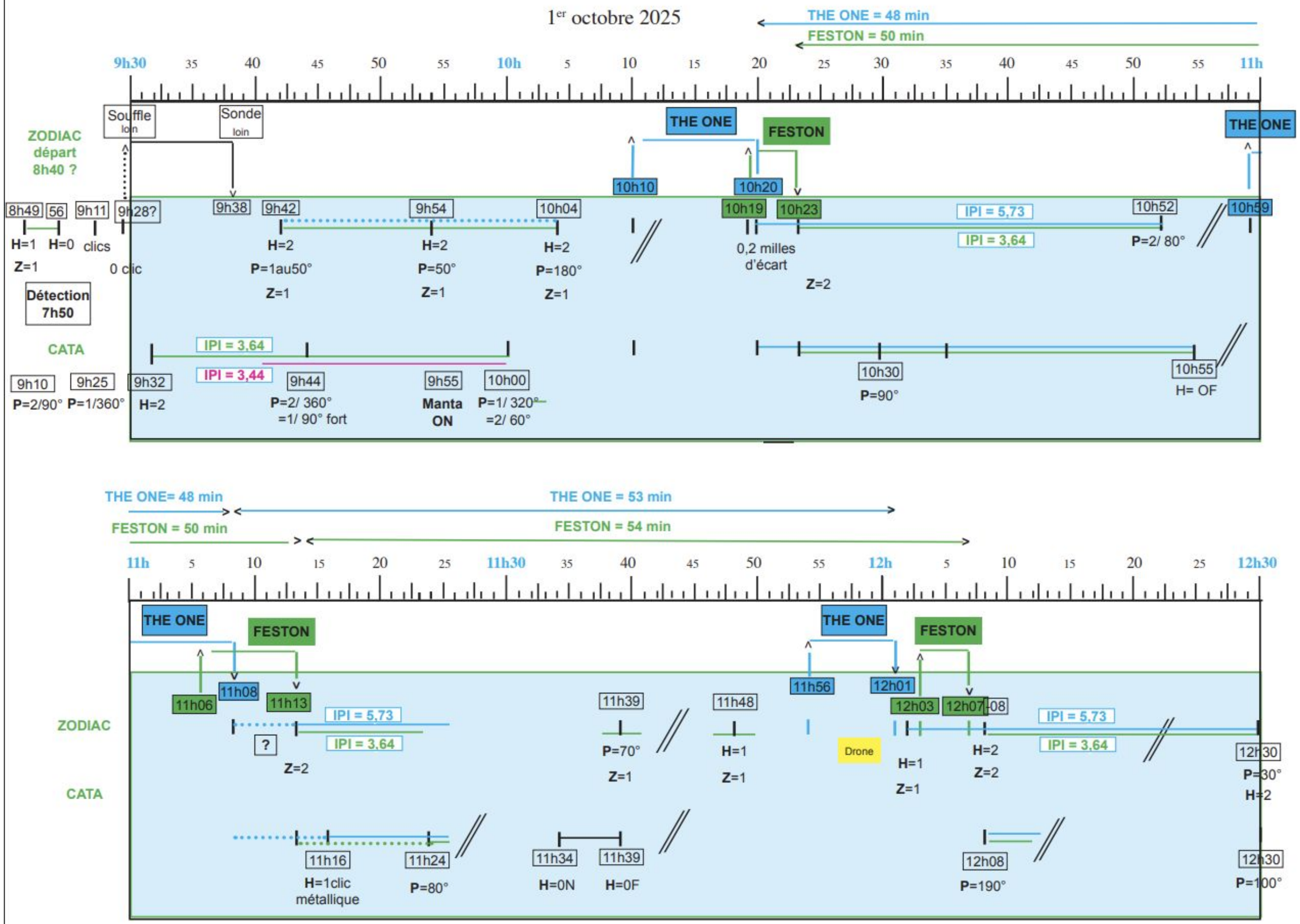

2025-09-30-16h07-SONDE-SIMULTANÉE
AIGLE-NOIR
BAPTISTE
LONGITUDE 181
La Voix de l'Océan

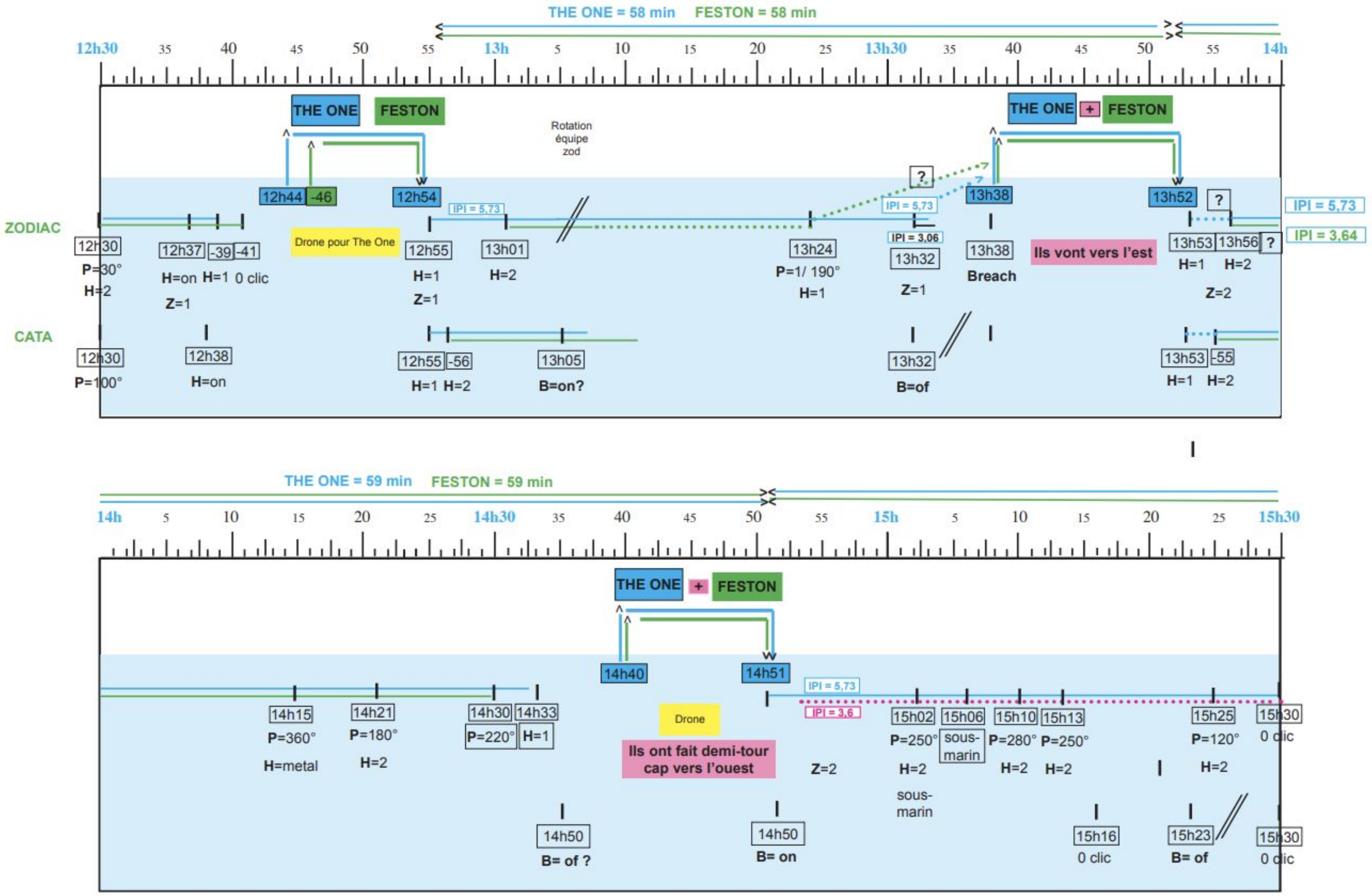

2025-09-30-18H22-SONDE-SIMULTANÉE
AIGLE-NOIR
SALADIN
LONGITUDE 181
La Voix de l'Océan

LONGITUDE 181
La Voix de l'Océan

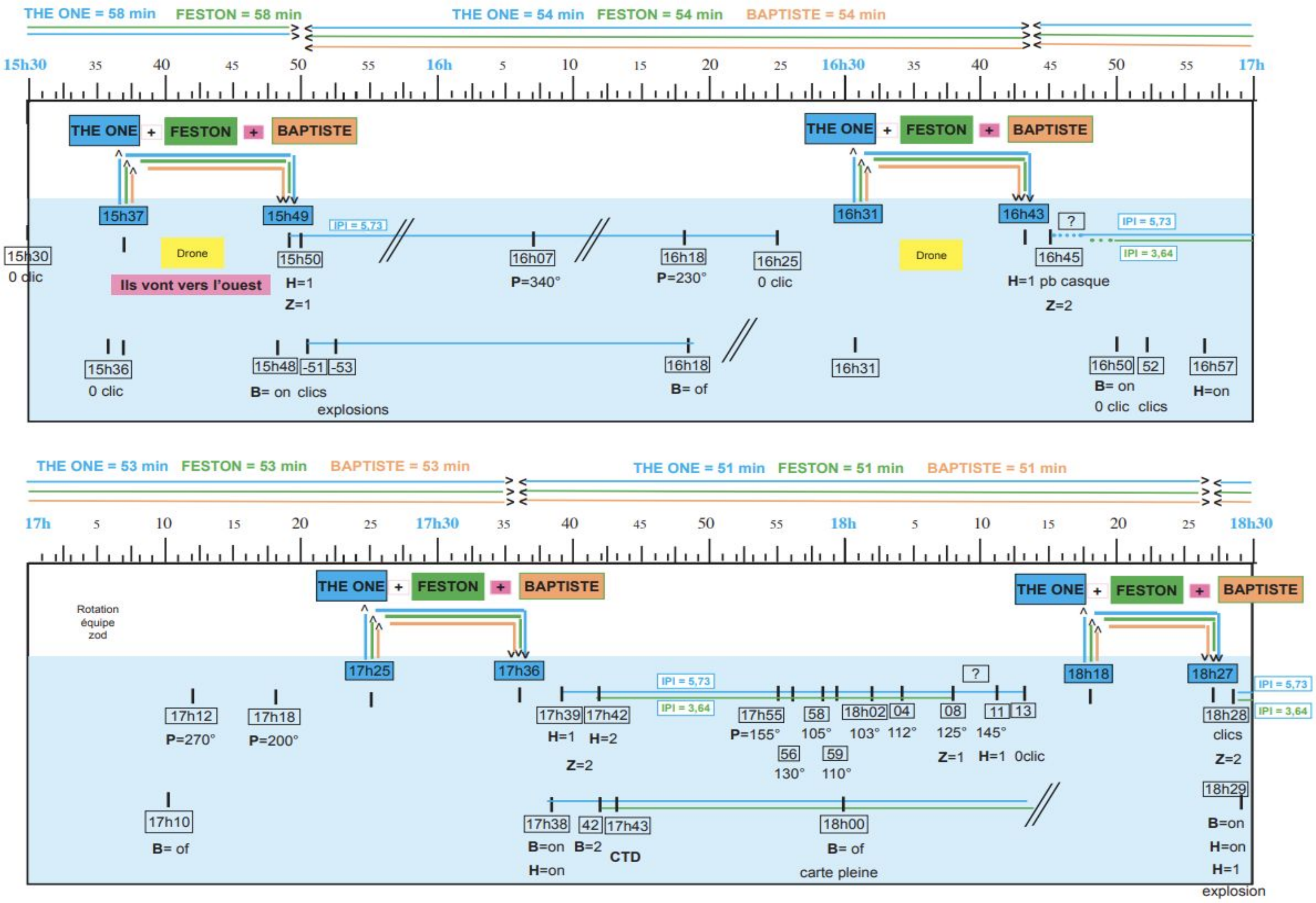

19h22 sonde The One
10h20 The One
11h27 sonde The One + Feston + Baptiste
10h23 sonde Feston
11h08 sonde The One
12h07 sonde Feston
11h13 sonde Feston
12h01 sonde The One
17h36 sonde The One + Feston + Baptiste
14h5? The One + Feston
16h43 sonde The One + Feston + Baptiste
12h54 sonde The One + Feston
13h52 The One + Feston
15h48 The One + Feston + Baptiste
Obstn 134

V. Sarano


1er octobre 2025
THE ONE = 48 min
FESTON = 50 min
9h30
10h
11h
ZODIAC départ 8h40 ?
Souffle loin
Sonde loin
THE ONE
FESTON
10h10
10h20
10h19
10h23
10h52
10h59
8h49
56
9h11
9h28?
9h38
9h42
9h54
10h04
H=1
H=0
clics
Z=1
0 clic
H=2
P=1au50°
P=50°
P=180°
Z=1
0,2 milles d'écart
Z=2
IPI = 5,73
IPI = 3,64
P=2/ 80°
Détection 7h50
CATA
IPI = 3,64
IPI = 3,44
9h10
9h25
9h32
9h44
9h55
10h00
10h30
10h55
P=2/90°
P=1/360°
H=2
P=2/ 360° =1/ 90° fort
Manta ON
P=1/ 320° =2/ 60°
P=90°
H= OF
THE ONE= 48 min
THE ONE = 53 min
FESTON = 50 min
FESTON = 54 min
11h
11h30
12h
12h30
THE ONE
FESTON
11h06
11h08
11h13
11h39
11h48
11h56
12h01
12h03
12h07
08
ZODIAC
IPI = 5,73
IPI = 3,64
?
Z=2
P=70°
Z=1
H=1
Z=1
Drone
H=1
Z=1
H=2
Z=2
12h30
P=30°
H=2
CATA
11h16
11h24
11h34
11h39
12h08
12h30
H=1clic métallique
P=80°
H=0N
H=0F
P=190°
P=100°

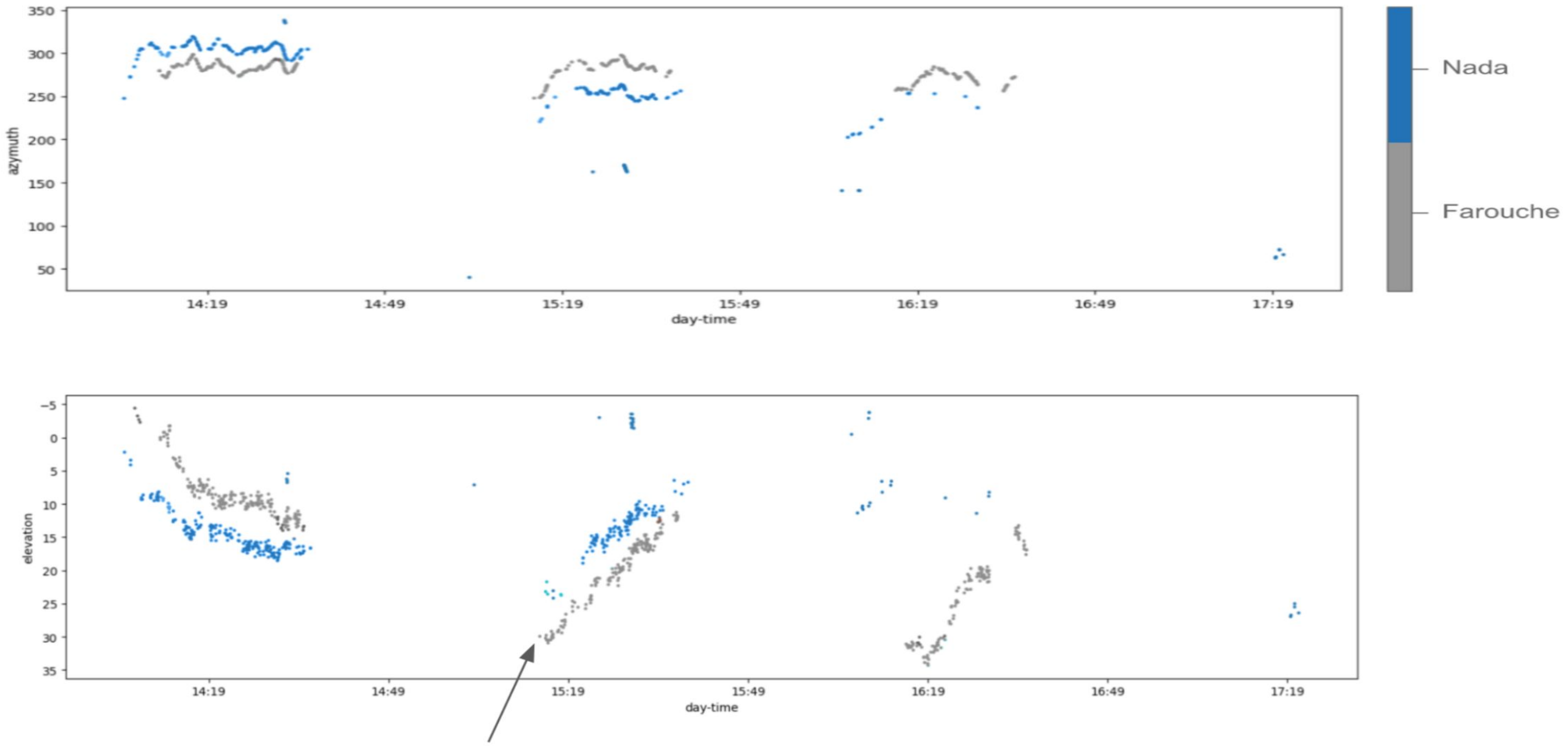

THE ONE = 58 min FESTON = 58 min
12h30 35 40 45 50 55 13h 5 10 15 20 25 13h30 35 40 45 50 55 14h
THE ONE
FESTON
Rotation équipe zod
THE ONE + FESTON
12h44 -46
12h54
IPI = 5,73
?
13h38
13h52
IPI = 5,73
IPI = 3,64
ZODIAC
Drone pour The One
12h30 P=30° H=2
12h37 -39 -41
H=on H=1 0 clic
Z=1
12h55 H=1 Z=1
13h01 H=2
13h24 P=1/ 190° H=1
IPI = 3,06
13h32 Z=1
13h38 Breach
Ils vont vers l'est
13h53 13h56 ?
H=1 H=2
Z=2
CATA
12h30 P=100°
12h38 H=on
12h55 -56 H=1 H=2
13h05 B=on?
13h32 B=of
13h53 -55 H=1 H=2
THE ONE = 59 min FESTON = 59 min
14h 5 10 15 20 25 14h30 35 40 45 50 55 15h 5 10 15 20 25 15h30
THE ONE + FESTON
14h40
14h51
IPI = 5,73
IPI = 3,6
14h15 P=360° H=metal
14h21 P=180° H=2
14h30 14h33
P=220° H=1
Drone
Ils ont fait demi-tour cap vers l'ouest
Z=2
15h02 P=250° H=2 sous-marin
15h06 sous-marin
15h10 P=280° H=2
15h13 P=250° H=2
15h25 P=120° H=2
15h30 0 clic
14h50 B= of ?
14h50 B= on
15h16 0 clic
15h23 B= of
15h30 0 clic

V. Sarano


THE ONE = 58 min FESTON = 58 min
THE ONE = 54 min FESTON = 54 min BAPTISTE = 54 min
15h30 35 40 45 50 55 16h 5 10 15 20 25 16h30 35 40 45 50 55 17h
THE ONE + FESTON + BAPTISTE
15h37
15h49
IPI = 5,73
15h30
0 clic
Drone
Ils vont vers l'ouest
15h50
H=1
Z=1
16h07
P=340°
16h18
P=230°
16h25
0 clic
15h36
0 clic
15h48 -51 -53
B= on clics
explosions
16h18
B= of
THE ONE + FESTON + BAPTISTE
16h31
16h43
?
IPI = 5,73
IPI = 3,64
Drone
16h45
H=1 pb casque
Z=2
16h31
16h50 52
B= on
0 clic clics
16h57
H=on
THE ONE = 53 min FESTON = 53 min BAPTISTE = 53 min
THE ONE = 51 min FESTON = 51 min BAPTISTE = 51 min
17h 5 10 15 20 25 17h30 35 40 45 50 55 18h 5 10 15 20 25 18h30
Rotation équipe zod
THE ONE + FESTON + BAPTISTE
17h25
17h36
17h12
P=270°
17h18
P=200°
17h39 17h42
H=1 H=2
Z=2
IPI = 5,73
IPI = 3,64
17h55
P=155°
58
105°
56
130°
59
110°
18h02 04
103° 112°
08
125°
Z=1
11 13
145°
H=1 0clic
?
17h10
B= of
17h38 42 17h43
B=on B=2
H=on
CTD
18h00
B= of
carte pleine
THE ONE + FESTON + BAPTISTE
18h18
18h27
IPI = 5,73
IPI = 3,64
18h28
clics
Z=2
18h29
B=on
H=on
H=1
explosion

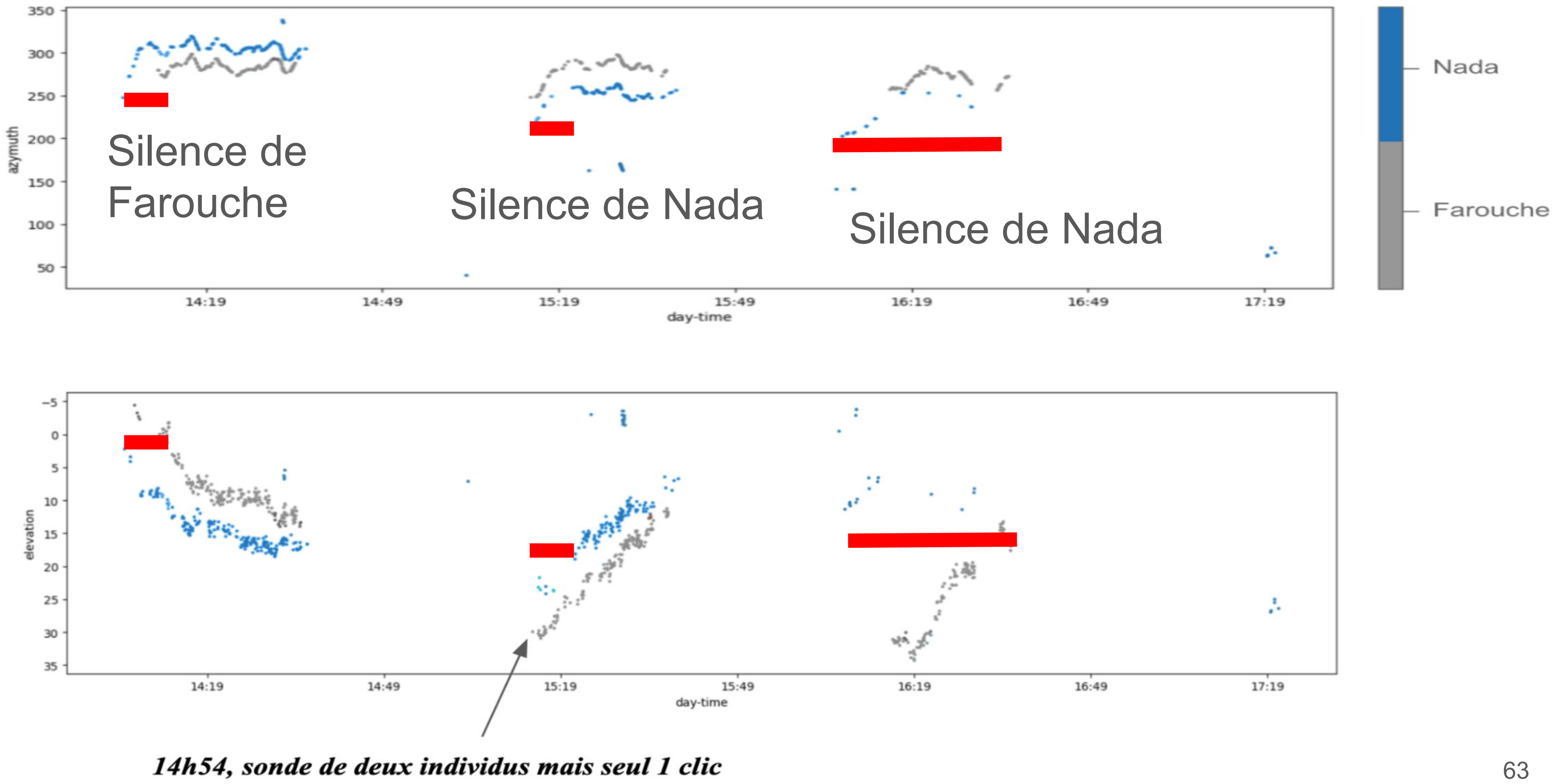
V. Sarano

Estimation Azimuth et Elevation sur 3h30, 2 individus



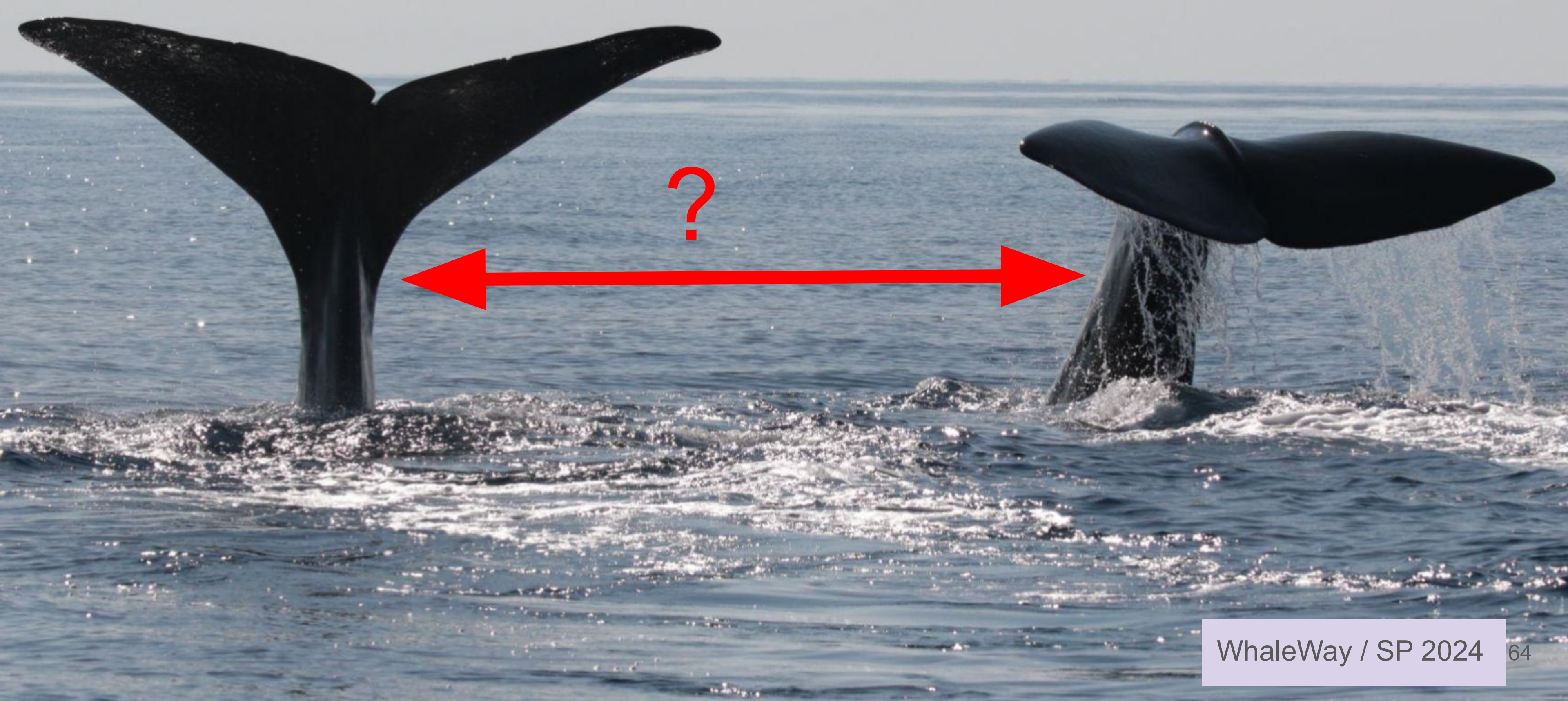
14h54, sonde de deux individus mais seul 1 clic

Estimation Azimuth et Elevation sur 3h30, 2 individus



Interdépendance des super-prédateurs… Chasses en Meute

dans l’obscurité totale à des Km de distance… comment ?



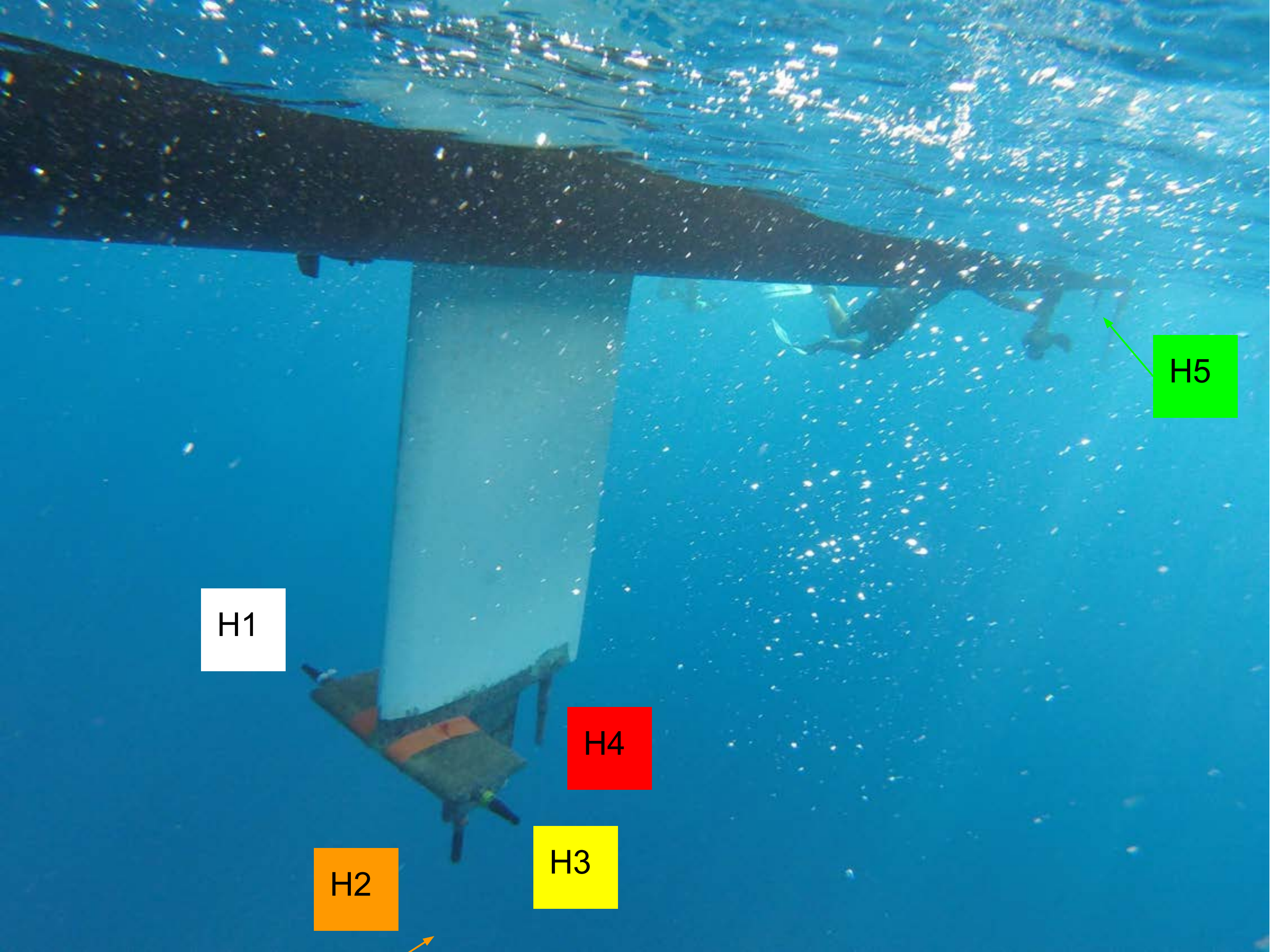
Drone Surface Acoustique Sphyrna

ALV Sphyrna (SeaProven)

Polynesian Design, 20 m, Stable

Hydrodynamic, Low acoustic print

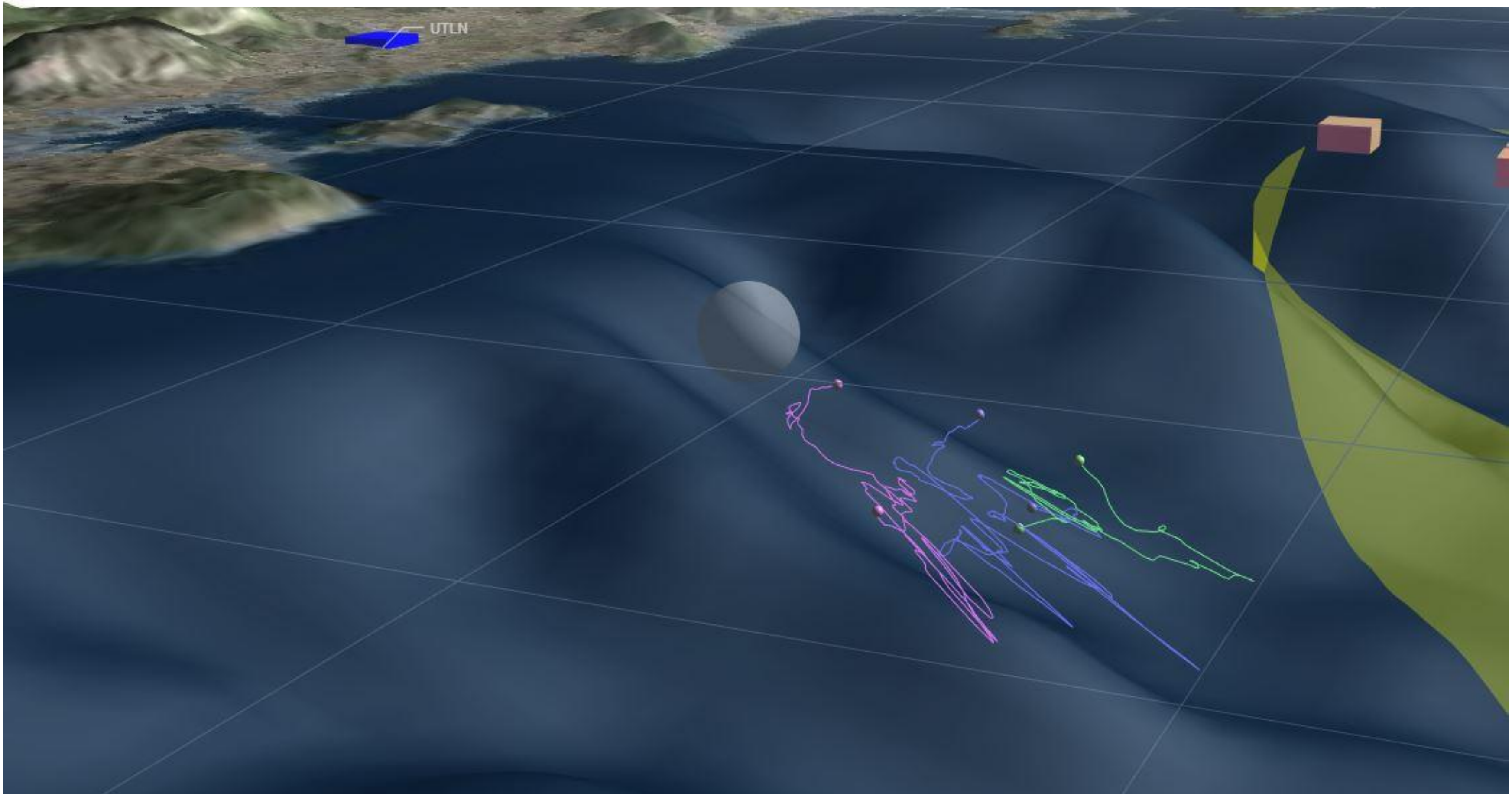
1 t. useful charge.



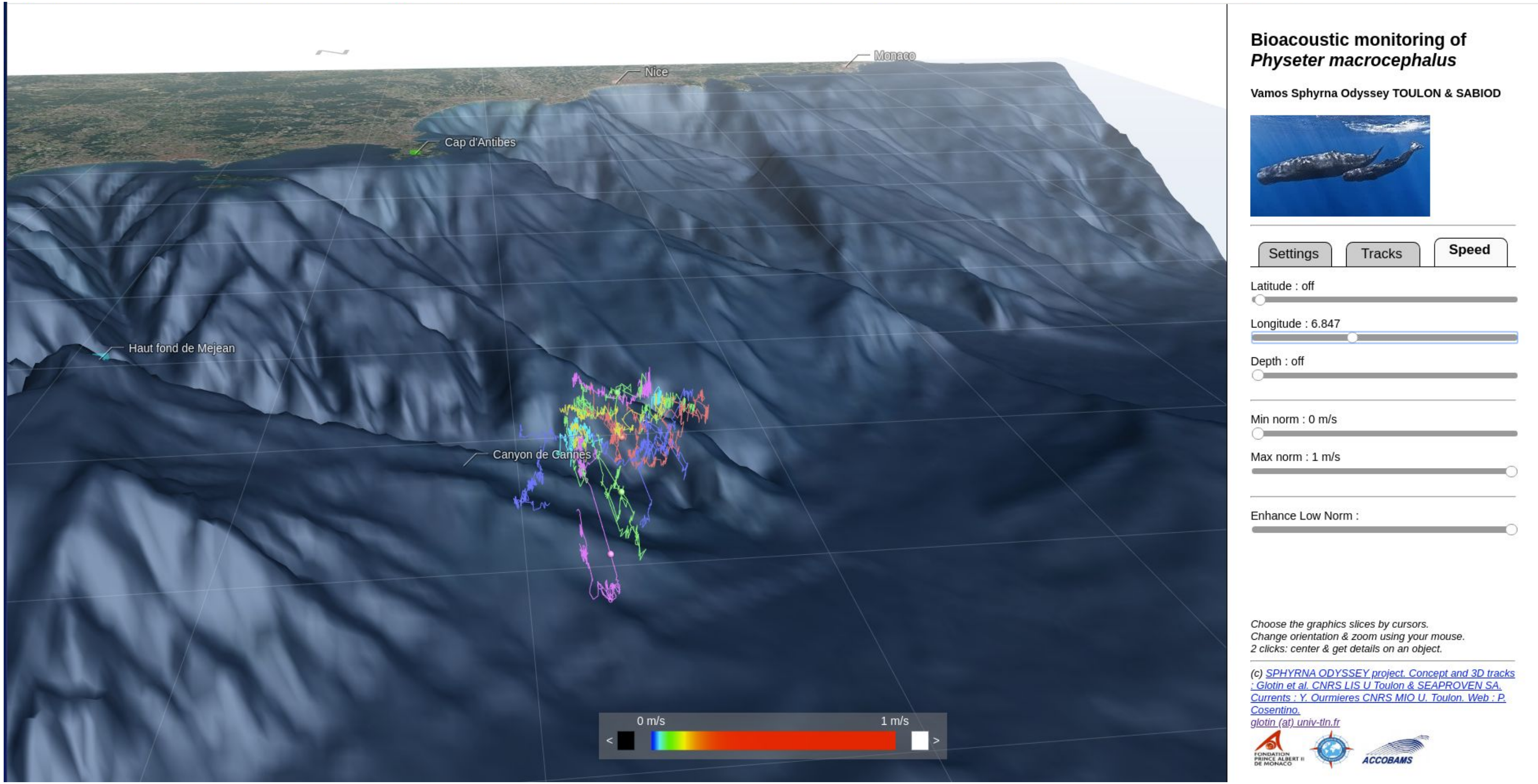
The 5 hydros fixed under the keel of the ASV.

Clear dolphin clicks, TDOA measures, recorded on 5 channels, Chan 1, 4, 5 = gain x 4, Chan 2, 3 = gain 1/2

August 2018, 1 Physeter, 3 tracks, 50 minutes each, down to -1000 m



January 2020, South of Antibes

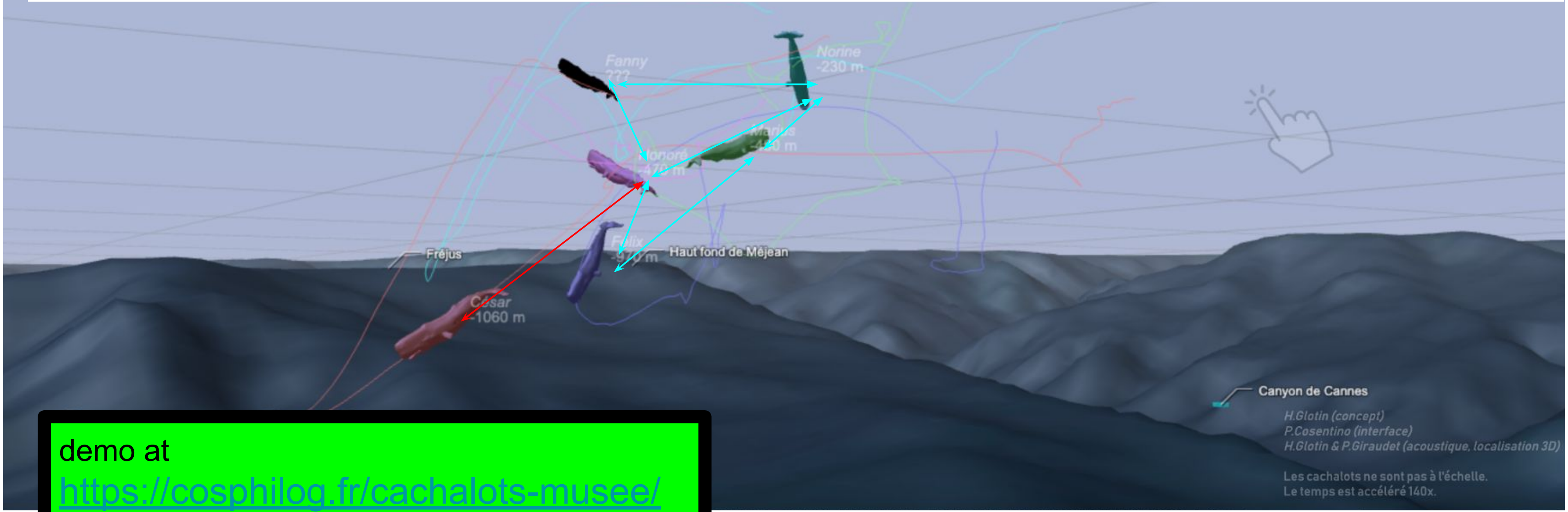


https://sabiod.lis-lab.fr/pub/SPHYRNA/3D/current_norm/

Les plus âgés sondent plus profondément,
les jeunes restent vers - 400 m
Constat : comportement individuel ? Contraintes physiologiques individuels ?

Causalité forte entre trace de Cesars et toutes les autres Alternance Conscience partagée

Statistique des distances entre les couples …



demo at
https://cosphilog.fr/cachalots-musee/

Distances inter-individus : contact acoustique ou non durant leur chasse perception et conscience collaborative (sonar multidynamique)

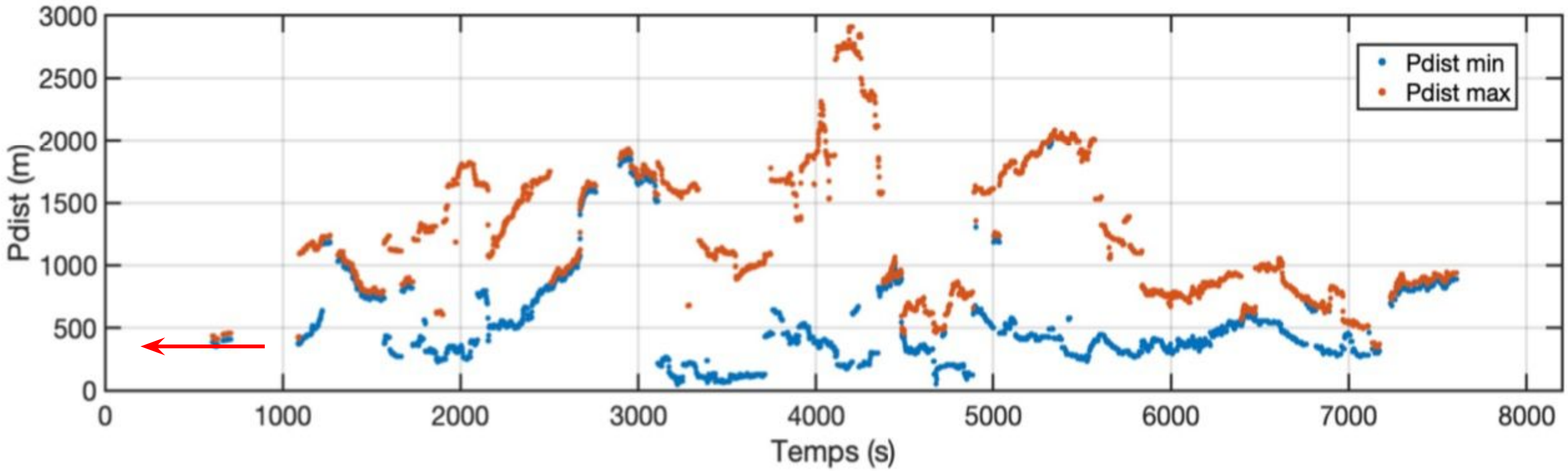


Figure: The minimal and maximal distances of the individuals in the group of 6 hunters during 2 hours of foraging the 14th january 2020 south of Antibes, France, from their 3D tracks computed from passive acoustics (Glotin et al 2020).

The biosonar emission @ 180 dB allows a way and return of the sonar of at least **500m** as shown by the sonar equation :
Echo Energy = SourceLevel − 40 log(Range) − 2α(f)Range + 20 log(0.5) dB, target of 50cm diameter, alpha=1.3dB/m, f=12 kHz.

=> new criteria for the regulation of anthropophony that could cover the communication / collaborative foraging interindividual communication, and thus would contract the hunt and reduce the number of captured preys

Linking Sperm Whale Azimuth to Maritime Traffic Using a Stereophonic Acoustic Array

Justine Girardet[1,2,4,5], Hervé Glotin[1,2,5], Véronique Sarano[1,3]

1 Centre International d'Intelligence Artificielle en Acoustique Naturelle
2 Laboratoire d'Informatique et des Systèmes, University of Toulon
3 Longitude 181
4 University of Pavia, Italy
5 Chaire IA AID DGA ADSIL ANR-20-CHIA-0014

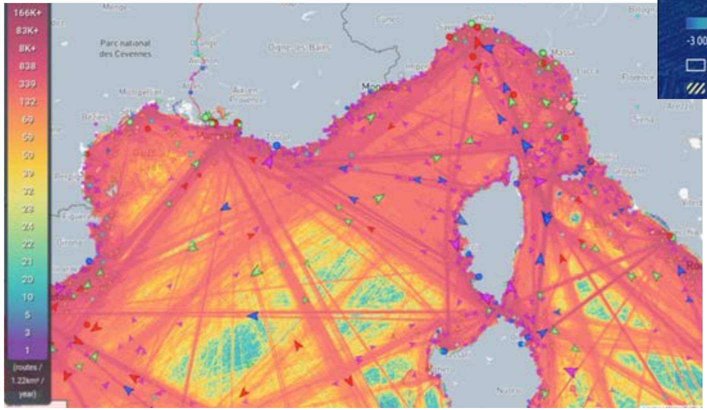
State of the Art

Shipping activity

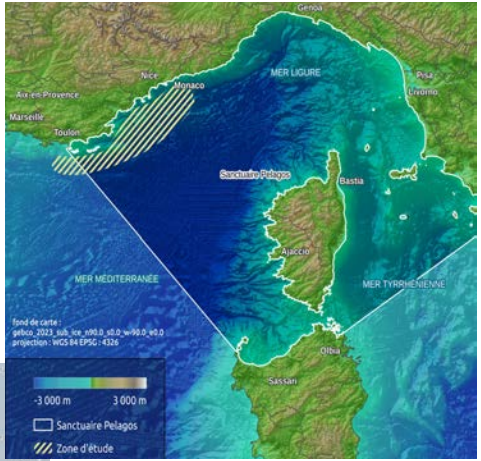
- Around 80% of global trade carried by sea

- Marine traffic is expected to increase by **4% per year**

- **15%** of global shipping activity concentrated in Mediterranean Sea



Map of marine traffic density in Mediterranean Sea in 2022
© MarineTraffic



Map of Pelagos sanctuary
© Chavin

State of the Art

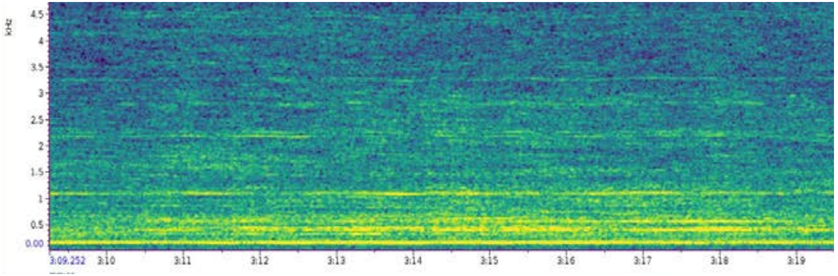
Noise pollution

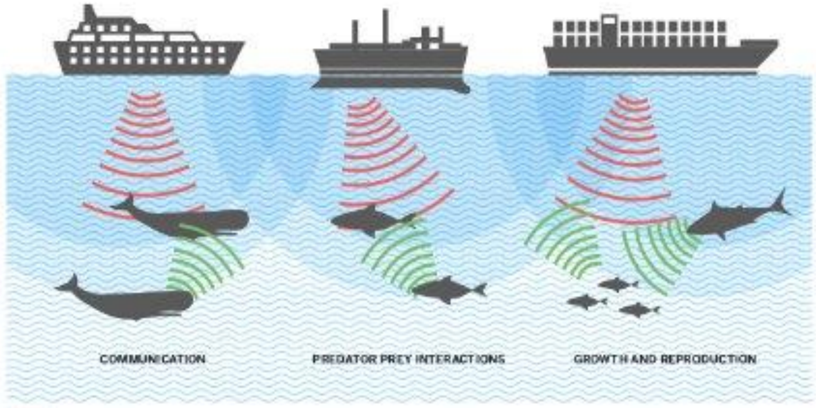
◇ Most ubiquitous and pervasive source of anthropogenic noise in the oceans

◇ Steady rise in ambient noise in low frequency (<500 Hz) (up to 3 dB/decade)

◇ Anthropophony → change behaviour, impair hearing capacity, communication and ability to detect threats or preys

Spectrogram of boat noise, Norway, 2023-15-01 13:01



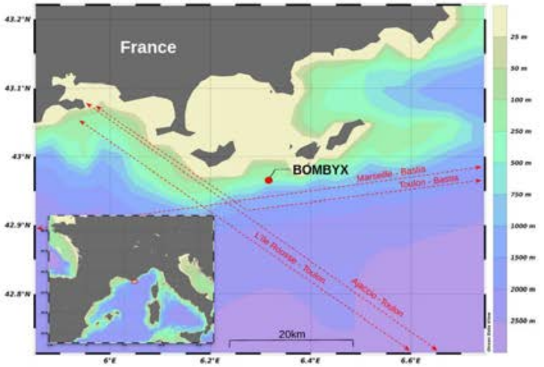


State of the Art

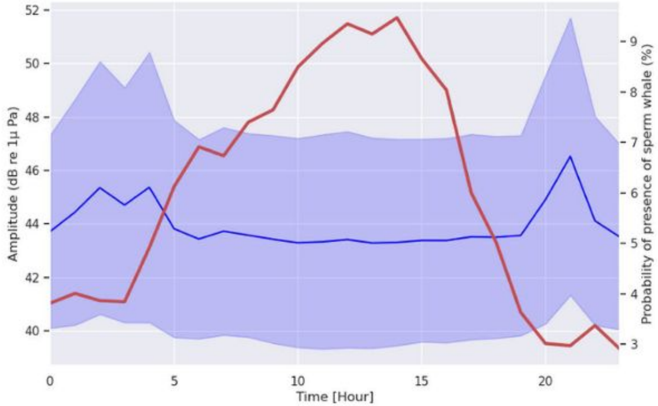
What has been done

- Bombyx 1 - Acoustic recordings
- Two peaks of ambient noise
- Acoustic activity of sperm whale when ambient noise is lower

→ **Lack of AIS data**



Bathymetric map of the region showing the geographic location of the BOMBYX buoy and the ferry's trajectories (red lines). Poupard et al. 2022



Superposition of diel pattern of amplitudes for the octave 12,800 Hz and probability of presence of sperm whales. Poupard et al. 2022

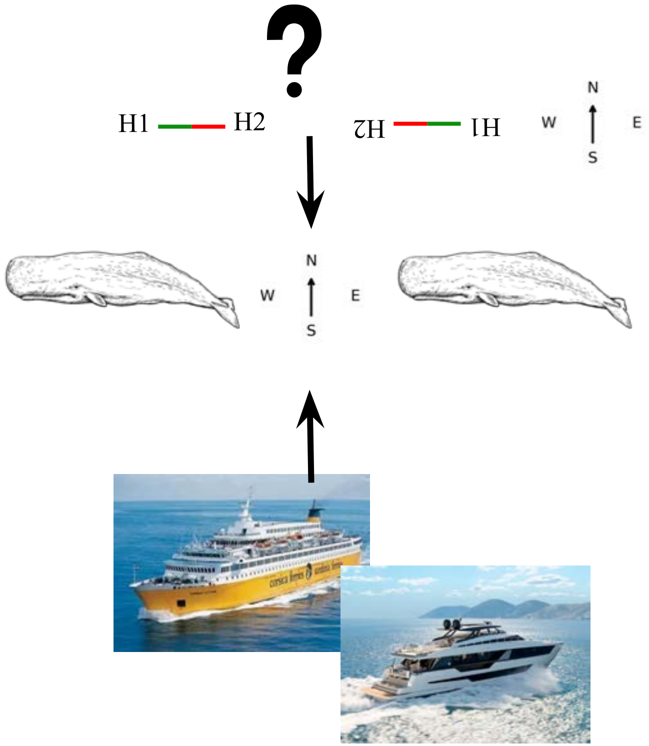
◢ Objectives

Following the purchase of AIS data, an in-depth analysis of BOMBYX 1 data is currently underway.

1. Use AIS data to calibrate bombyx orientation

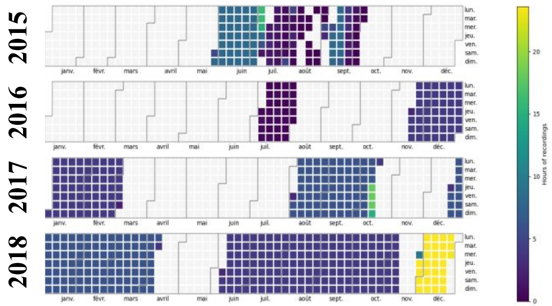
2. Identify sperm sperm whales azimuth

3. Assess the influence of boat on sperm whale behaviour



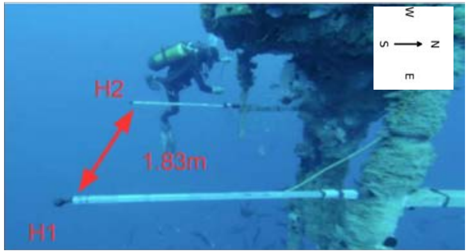
Materials

Calendar recording of Bombyx 1

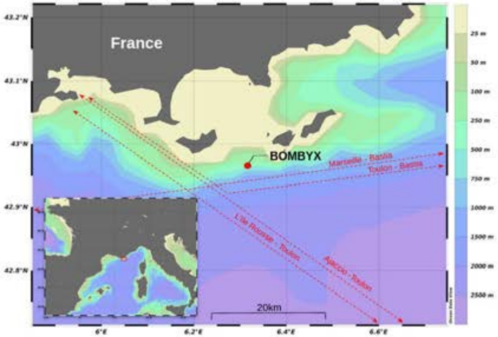


Bombyx-1

- May 2015 to December 2018
- Off Port Cros, close to the drop off
- Stereophony
- Hydrophones supposed to point south



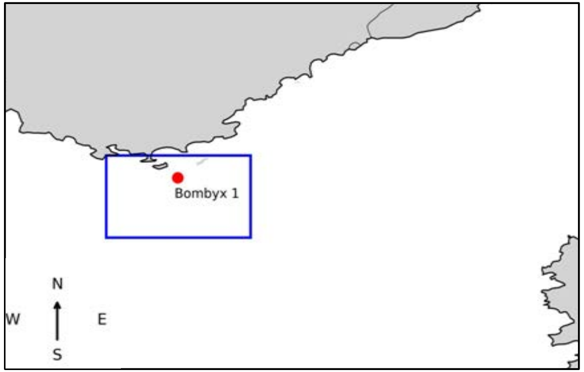
Underwater picture of Bombyx 1



Bathymetric map of the region around Bombyx1. Poupard et al. 2022

AIS data

- Every day of acoustic recording
- 30 on 40 miles

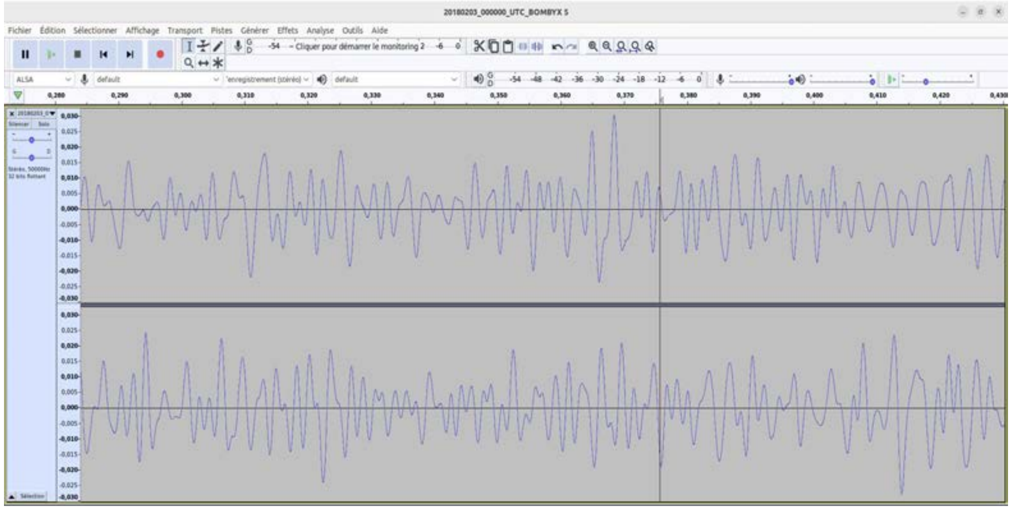


Map showing the requested area for AIS data around Bombyx 1

◢ Calibrate orientation

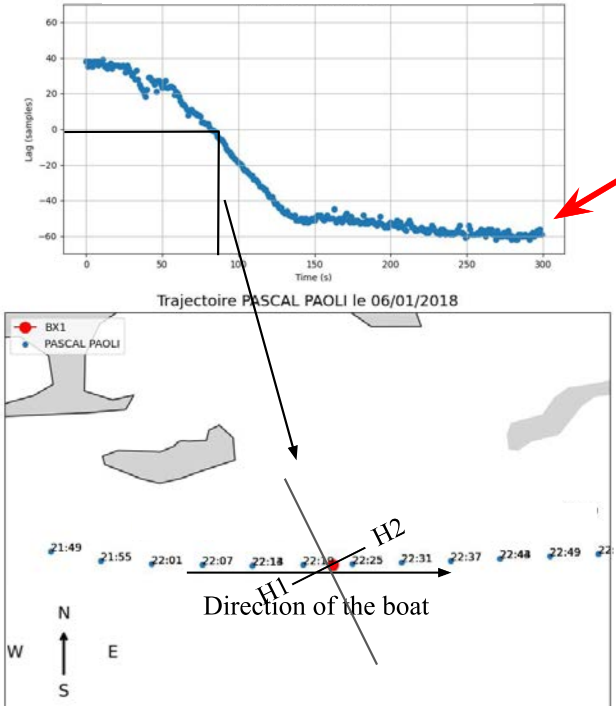
<u>For each day :</u>

- ◊ Select a recording with a ferry nearby and no other boat → this ferry = major noise source
- ◊ Correlation between signals on 1 second frame
- ◊ Positive lag: hydrophone 1 first



Calibrate orientation

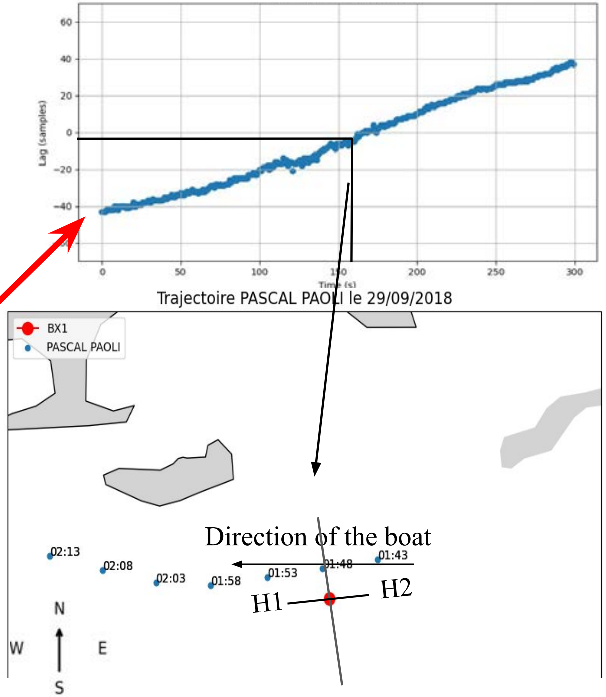
2018-01-06 10:20 p.m.



Examples:

- Positive lag: hydrophone 1 first
- Boat coming west, positive lag = H1 west
- Boat coming east, negative lag = H1 west
- Buoy orientation stable: H1 west with small variations

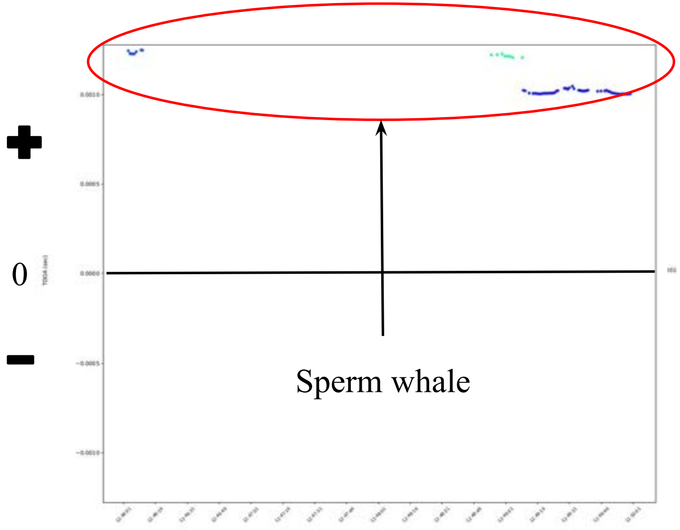
2018-09-29 1:45 a.m.



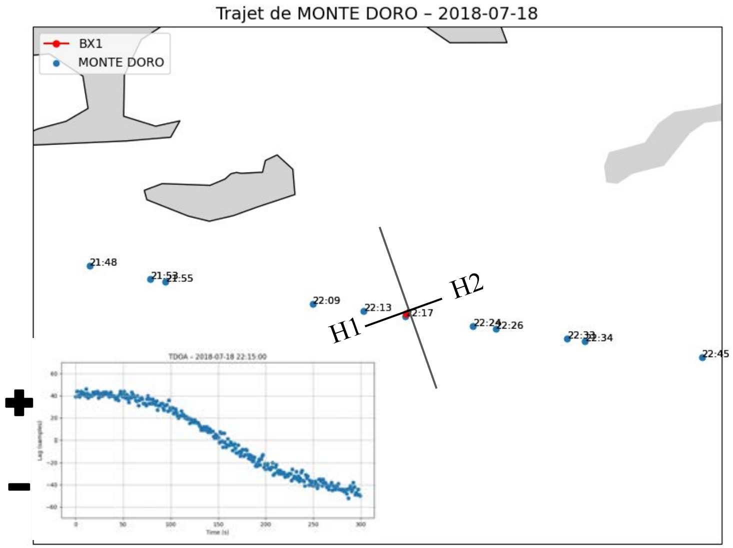
◢ Sperm whale azimuth

2018 07 18 12:45:00

1. Automatic detection of clicks and TDOA track



2. From the known orientation of the buoy

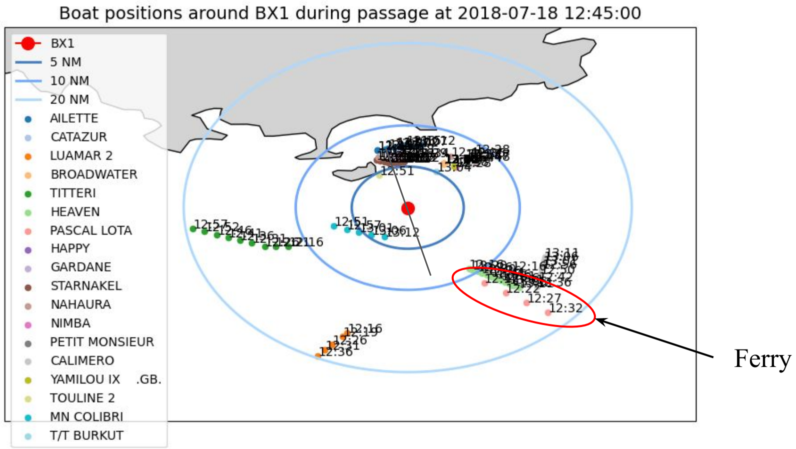


3. Determine sperm whale azimuth: here, at **west**

Marine traffic and sperm whales

2018 07 18 12:45:00

4. Count number of boats at the east and west

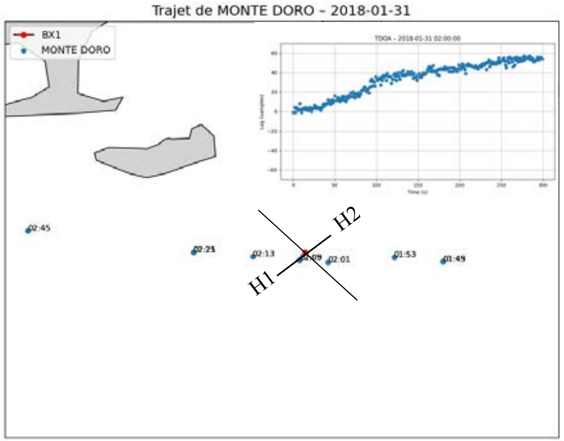


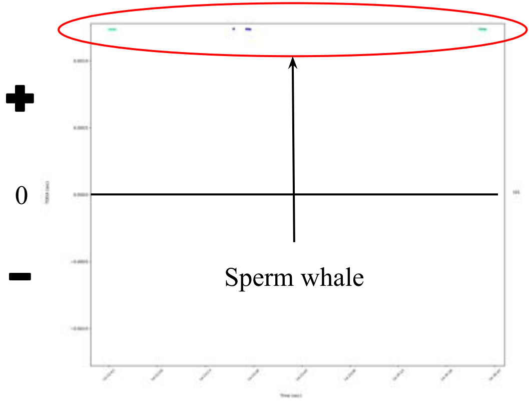
- Only south of the buoy is considered
- Number of boat 30 min before detections

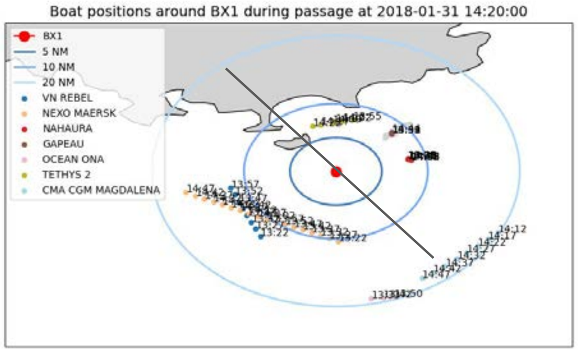
	Nb of boats	Nb of ferry
West	3	0
East	3	1

◢ Marine traffic and sperm whales

- Repeat this methodology







H1 west

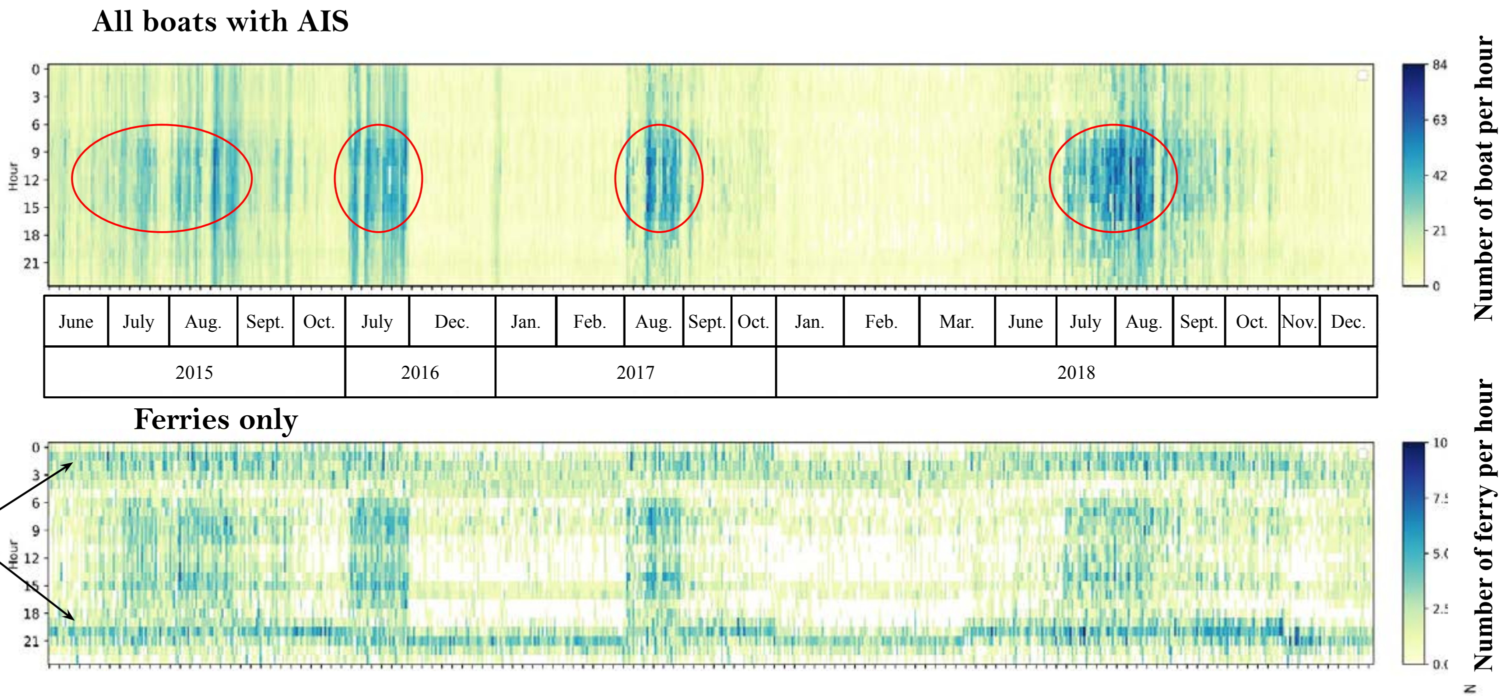
Sperm whale west

	Nb of boats	Nb of ferry
West	3	0
East	2	0

◢ Insights on marine traffic

Intense pressure in summer

Recurrent ferry lines
More ferries in summer



Calendar of hourly number of boat in a 10 miles radius around Bombyx 1. Top: all boats, bottom: ferries only. White cells indicate no boats for the category considered.

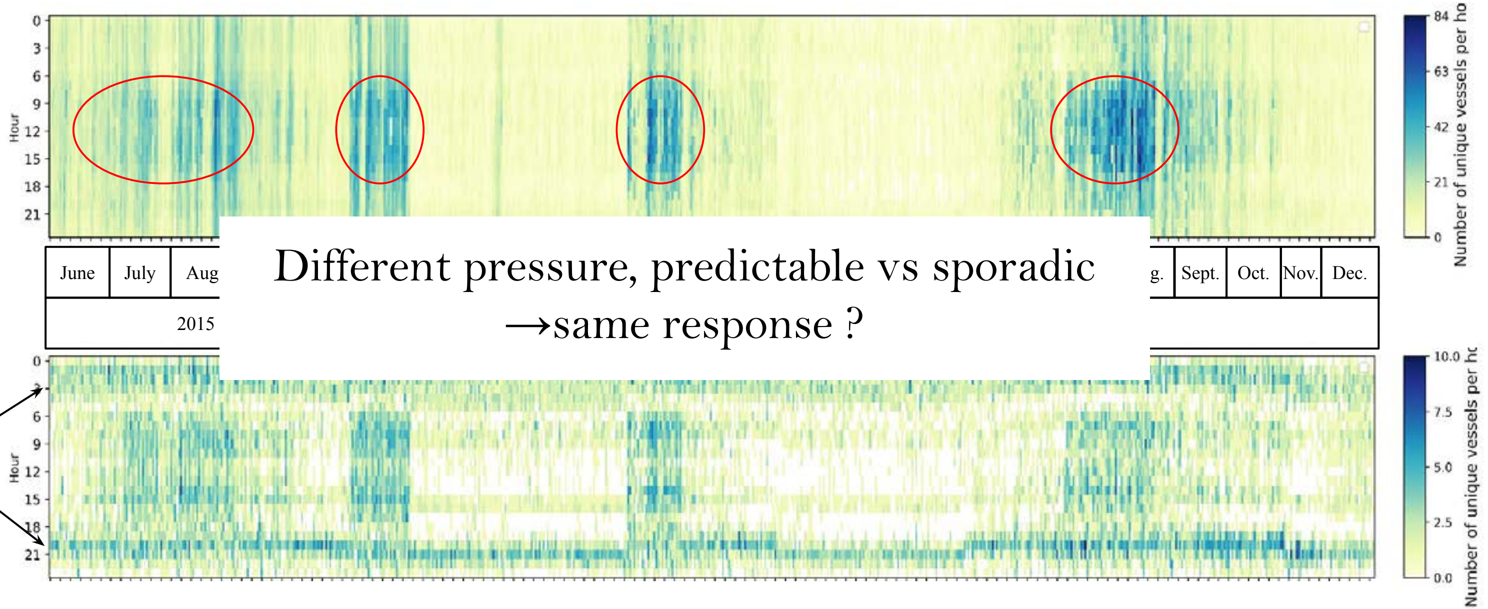
◢ Insights on marine traffic

All boats with AIS

Intense pressure in summer

Ferries only

Recurrent ferry lines
More ferries in summer



Different pressure, predictable vs sporadic
→same response ?

Calendar of hourly number of boat in a 10 miles radius around Bombyx 1. Top: all boats, bottom: ferries only. White cells indicate no boats for the category considered.

◢ Next steps

- Apply the described methodology to all recordings
- Account for small orientation variation of the buoy
- Determine the Inter Pulse Interval → proxy of the size and sex
- Analyse the Inter Click Interval and compare the variation with marine traffic

© Justine Girardet

Thank you for listening !

UNIVERSITÉ DE TOULON

cnrs

CENTRE INTELLIGENCE ARTIFICIELLE EN ACOUSTIQUE NATURELLE

LIS LABORATOIRE D'INFORMATIQUE & SYSTÈMES

UNIVERSITÀ DI PAVIA

europam

biodiversa+ European Biodiversity Partnership

Propagation model for range estimation, perspective on megafauna localisation with in situ experiments :

Whale Way 6 & SeGaMas

Lilou Dantin[1,2,3,5]*, Hervé Glotin*[1,2,5]*, Stéphane Jespers*[1]*, François Sarano*[1,4]*, Pascale Giraudet*[1,2,5]*,*
Véronique Sarano[1,4]*, Adeline Paiement*[1,2,5]*, Sébastien Paris*[1,2,5]

[1] *Centre International d'Intelligence Artificielle en Acoustique Naturelle, https://cian.univ-tln.fr*
[2] *Laboratoire d'Informatique et des Systèmes, CNRS, Université de Toulon*
[3] *Parc National de Port-Cros*
[4] *Longitude 181*
[5] *Chaire IA AID ANR-20-CHIA-0014, ULPCochlea ANR-21-CE04-0020, Europam Biodiversa 2021-488*

WhaleWay6, a Longitude 181 mission

Lilou Dantin[1,2,3], *Hervé Glotin*[1,2,5,6], *Véronique Sarano*[4,1], *Pascale Giraudet*[1,2,5,6], *Denis Ody*[4], *François Sarano*[4,1]

[1] *Centre International d'Intelligence Artificielle en Acoustique Naturelle*
[2] *Laboratoire d'Informatique et des Systèmes, CNRS, Université de Toulon*
[3] *Parc National de Port-Cros*
[4] *Longitude 181*
[5] *Europam Biodiversa 2021-488*
[6] *Chaire IA AID DGA ADSIL ANR-20-CHIA-0014*

WhaleWay6, a 6th mission for *"La voix des cachalots"*

Studying the Mediterranean sperm whale population to better protect them

In two weeks :

- ★ 19 sperm whales never encountered before
- ★ 1 large male *"The-one"*
- ★ Groups of 7 and 8 individuals socializing and hunting

Aerial photo of a group of 4 sperm whales, taken by drone on September 30 (© Ody D).

WhaleWay6, data collected

Photos-identification

Photo-identification of the caudal fin
of the named sperm whale *"Aigle-noir"* (© Sarano F).

- ✓ 16 complete ID cards
- ✓ 3 partial ID cards
- ✓ 6 recaptures during the mission

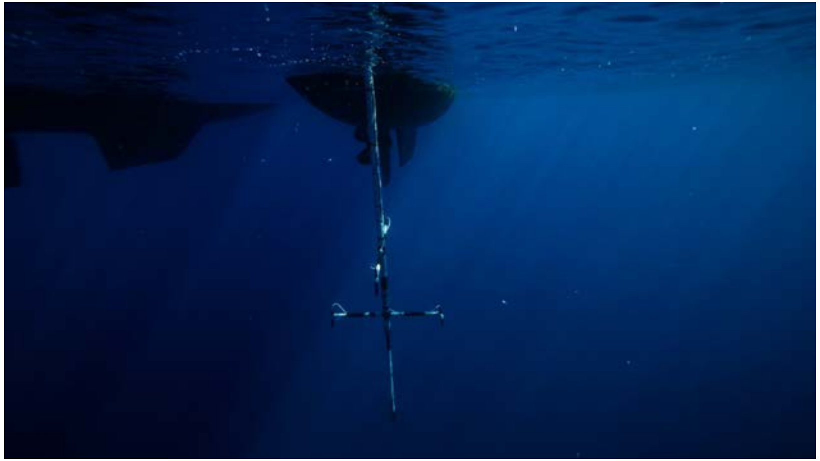
Aerial photos taken by drone

Aerial photo of a group of seven sperm whales,
taken by drone on September 28 (© Ody D).

- ✓ Assist with identification
- ✓ Observe affinities
- ✓ Calculation of individual size

WhaleWay6, data collected

Acoustic recordings



"*Bagheera*" acoustic sensor
with 5 hydrophones (© Chavin S).

- ✓ Recordings after each dive
- ✓ Recordings of codas, including one of a large male

CTD measures

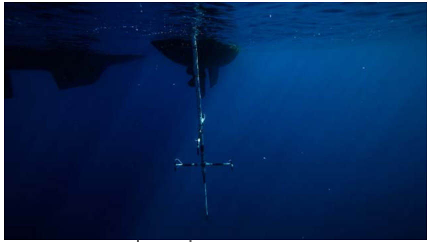
Instrument de mesure CTD *CastAway*,
prêté par Arnaud La Ridant MIO

- ✓ Measures every day
- ✓ Measures after each promising recordings

WhaleWay6, expected analysis

Photos-identification

Acoustic recordings



Aerial photos taken by drone

Associating IPI with individuals

Associate IPI and size of each individual
Establish a function specific
to the Mediterranean IPI/size

Estimating the residence of sperm whales in areas at risk of collision with ships

AIS

CTD measures

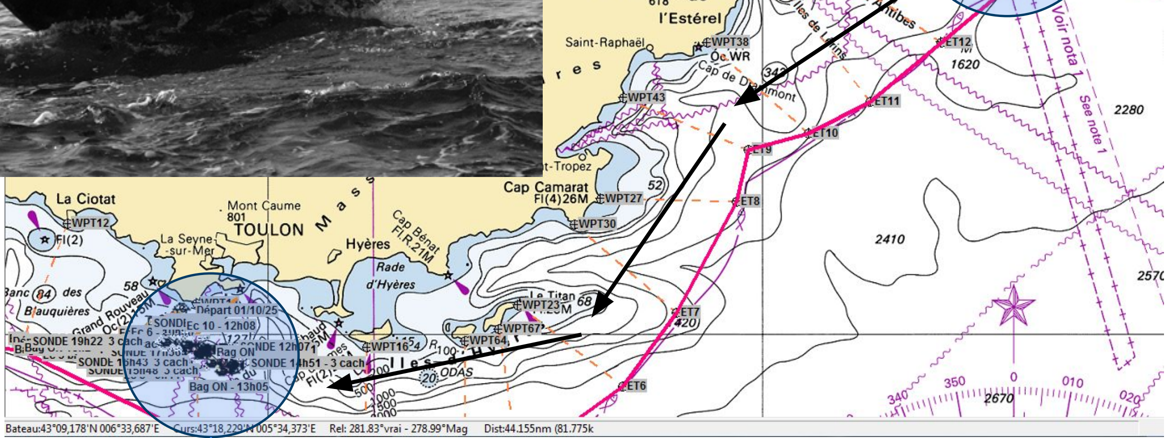
Analyzing acoustic scenes with echo

WhaleWay6, the retaking of “*Baptiste*” and his movement

From September 25 to October 1, 2025:

- \+ 100 NM traveled in 6 days
- \- 12 NM from the coast

“Baptiste” observed on September 25, 2025, Villefranche



Baptiste's observation

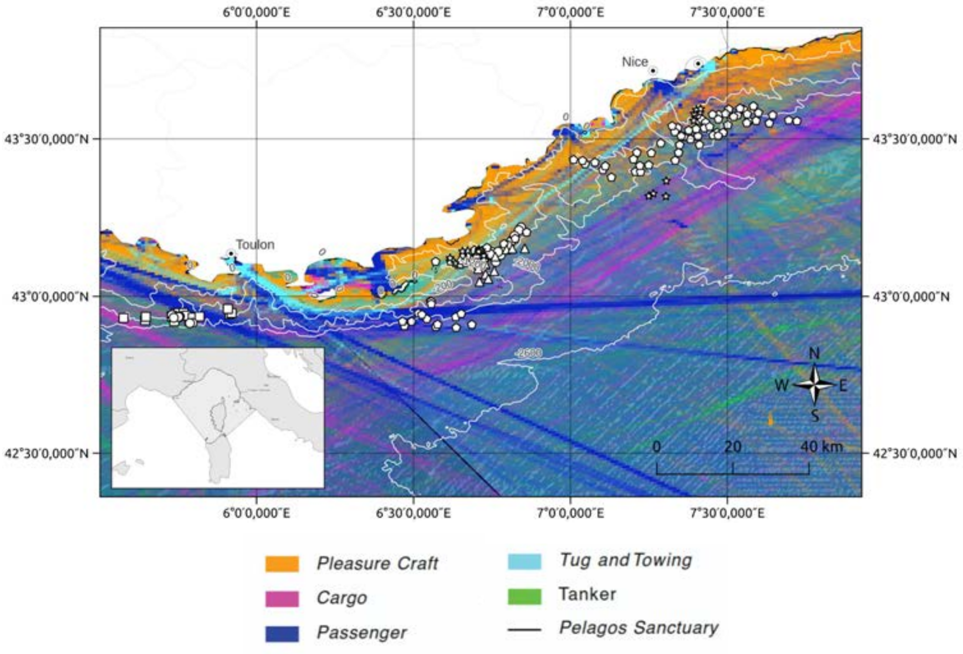
12 NM limit

Potential path of Baptiste in territorial waters

“Baptiste” observed on October 1, 2025, in Toulon

(Left) New sperm whale identified, named “*Baptiste*”
(Right) Observations of “*Baptiste*” during *WhaleWay6*, covering an average of 16 NM per day over 6 days. (© Sarano F. et V.)

◢ **WhaleWay6**, refine collision risk



Positions of sperm whales observed during Longitude 181 missions in 2023 and 2024 with vessel density in September 2022 (© Chavin S.)

(Top) Dive of the sperm whale named "*Saladin*" on a marine rail.
(Bottom) New sperm whale named "*Rescapé*"
injured by a propeller before its dorsal fin (© Sarano F.)

SeGaMas

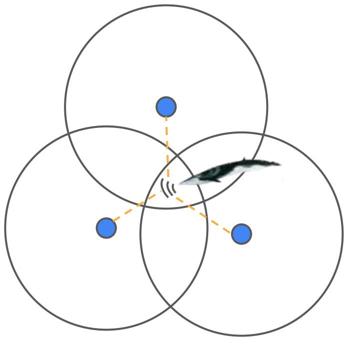
Serious Game for Marine Mammal Survey

Lilou Dantin[1,2,3], *Hervé Glotin*[1,2,4], *Stéphane Jespers*[1], *Adeline Paiement*[1,2,4], *Sébastien Paris*[1,2,4]

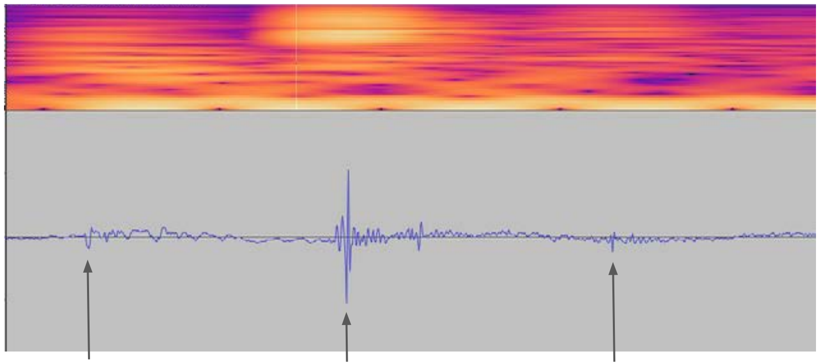
[1] *Centre International d'Intelligence Artificielle en Acoustique Naturelle*
[2] *Laboratoire d'Informatique et des Systèmes, CNRS, Université de Toulon*
[3] *Parc National de Port-Cros*
[4] *Chaire IA ADSIL DGA AID ANR-20-CHIA-0014*

TDoA to locate cetaceans

Time-Difference-of-Arrival



Spectrogram and waveform of a sperm whale click



- ➔ **Ultra-synchronized** hydrophones
- ➔ **Simple** environment

  (**no echo**, causing false positioning)
- ➔ **Simple** sounds (only one speaker at a time) and good quality
- ➔ Network fairly **distant**

2 hydrophones : azimut

3 hydrophones : elevation

4 hydrophones : distance (?)

SeGaMas, complete the traditional method with AI

Sound recordings

Trajectory of the cetacean(s)

Apprentissage end-to-end

Transformers

"Self-attentive model"

Distant temporal relationships

Taking into account the entire click sequence to determine the trajectory

What I need:

Trajectory

Undisturbed

Sound emitted

Close

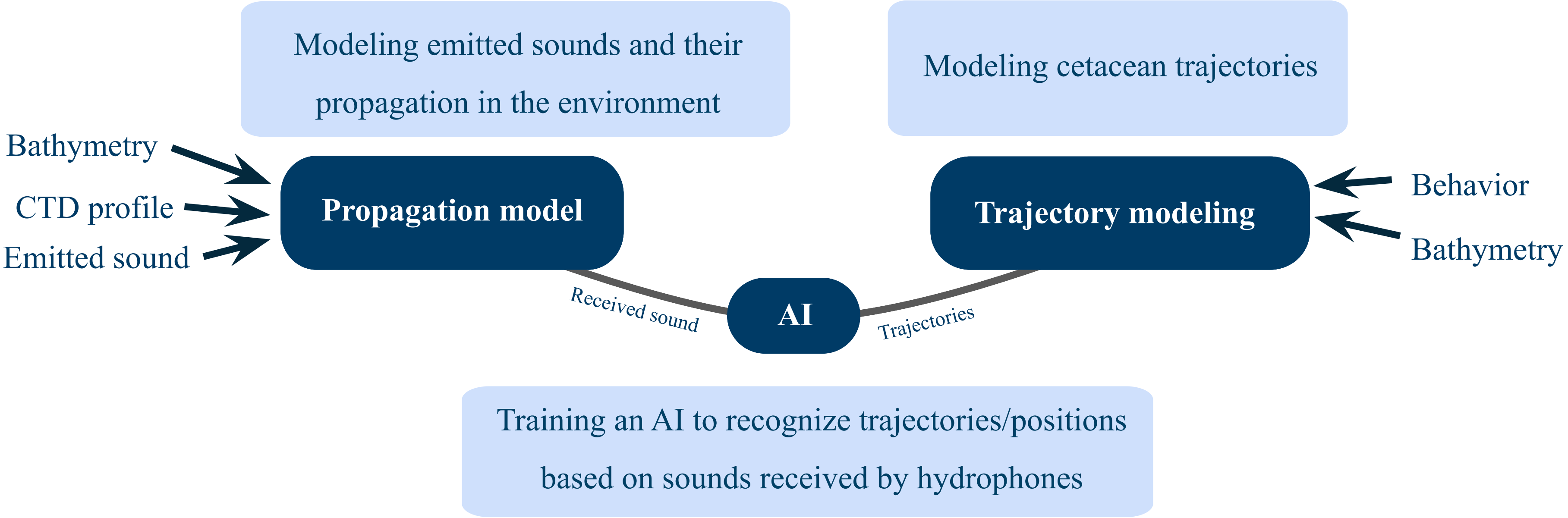
From the front

Sound received

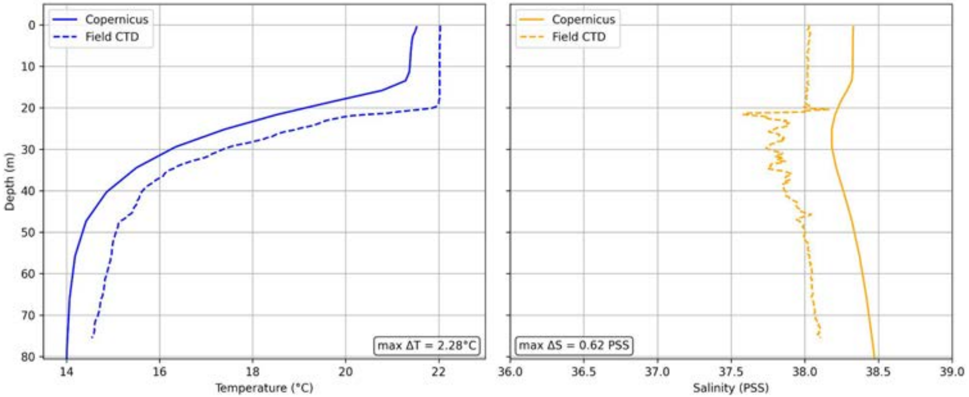
by the hydrophone

Modeling the data

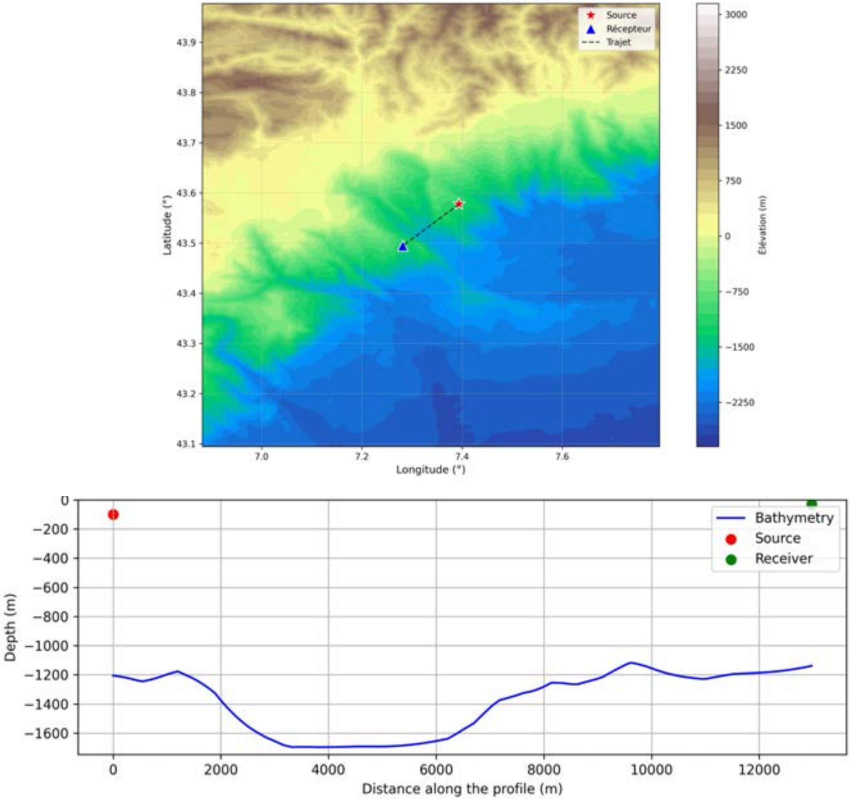
SeGaMas : Serious Game for Marine mammals Survey



BELLHOP, the propagation model



Comparison of temperature and salinity recorded
on September 29, 2025, at 8:24 a.m. at 42.96° N 6.57° E during mission *WW6*
and extracted from the *Copernicus* daily average at 43°N 7°E



GEBCO bathymetry extracted off the coast of Antibes,
for a cross-section between a source and a receiver
(a) Plan view (b) Vertical cross-section

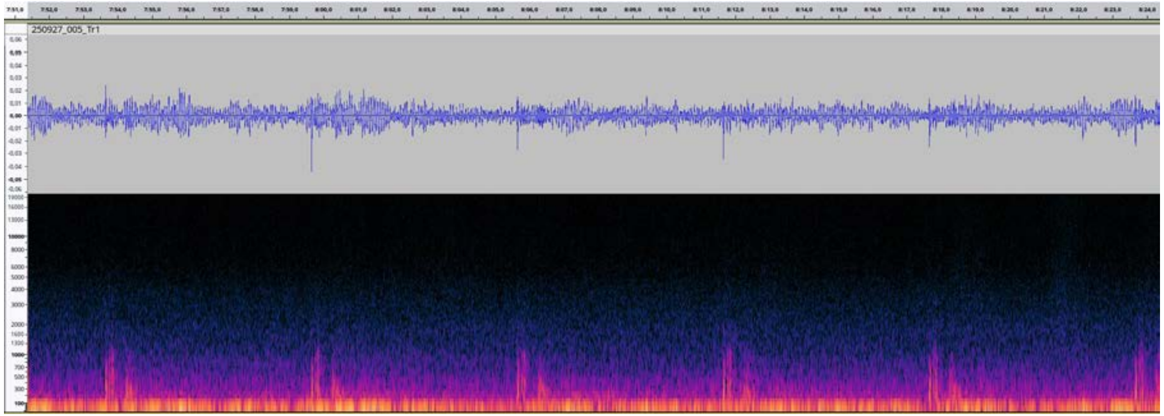
BELLHOP, validation of the model with *Téthys II*

Seismic prospecting of *Tethys II*

Recording from *White Pearl* on *Whale Way 6*

Air gun pulse every 6 seconds

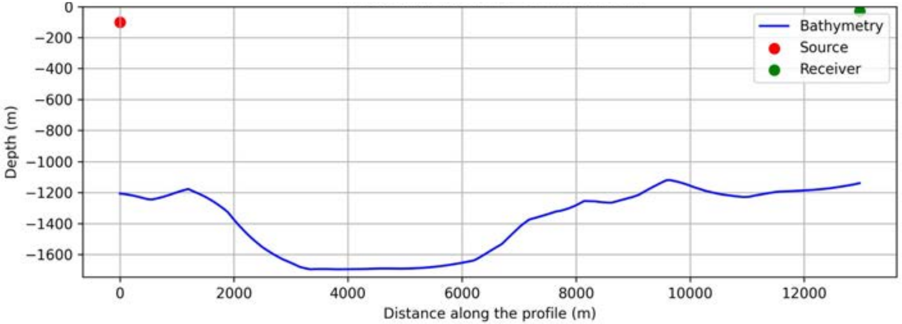
Téthys II (© *Ifremer)*



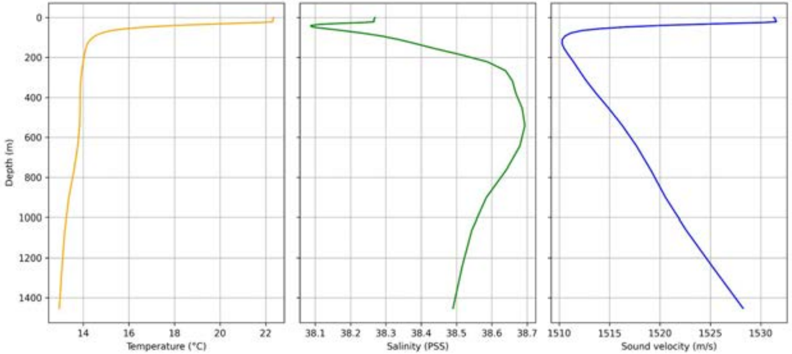
Acoustic recording of sound emissions from *Téthys II*

BELLHOP, validation of the model with *Téthys II*

Position of *Téthys II* and *White Pearl* on September 27, 2025, at 1:57 p.m.



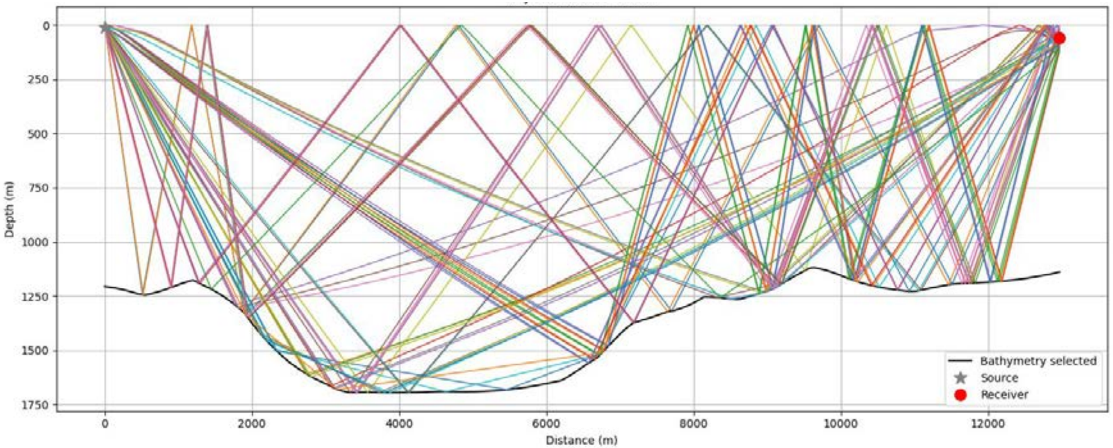
Bathymetric profile between *Téthys II* and *White Pearl*



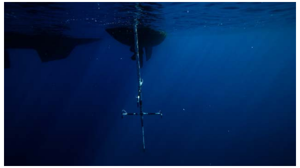
CTD profile between *TéthysII* and *White Pearl* : 43,53° N, 7,33° E

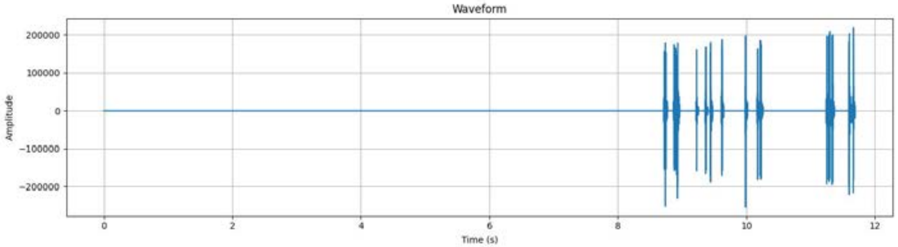
BELLHOP, validation of the model with *Téthys II*

Téthys II (© *Ifremer)*



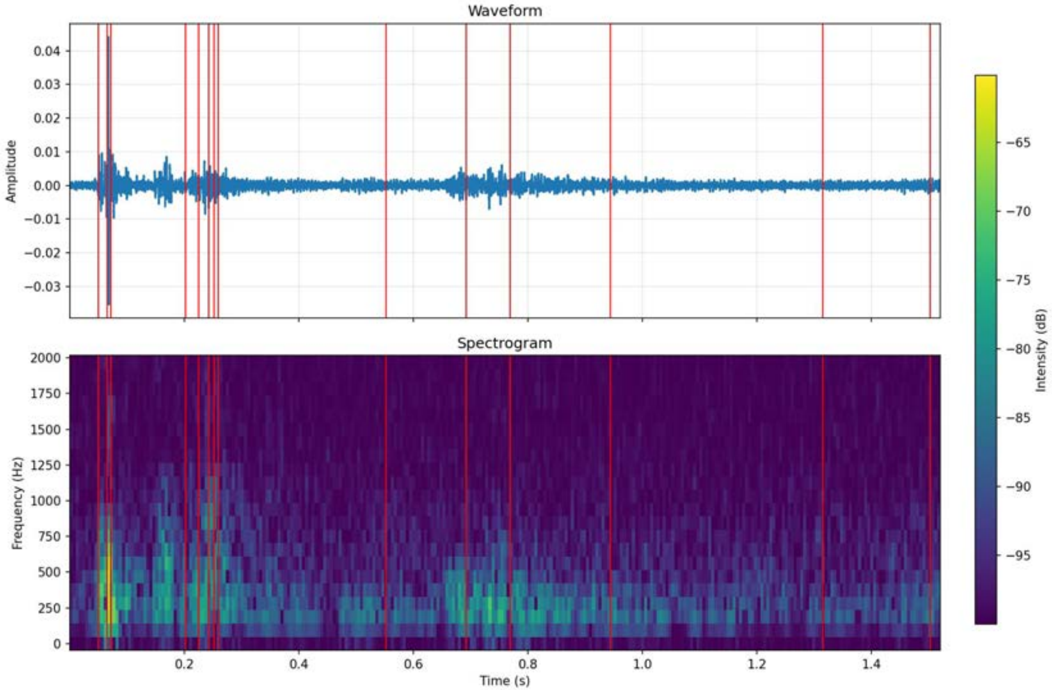
Ray tracing from *Téthys II* and received by *White Pearl*





Waveform of the signal reconstruction

BELLHOP, validation of the model with *Téthys II*



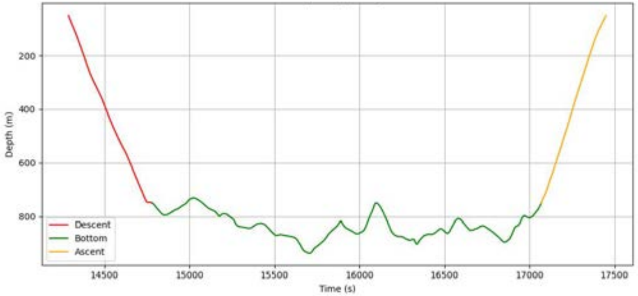
Overlay of the *in situ* acoustic recording from the acoustic survey of *Téthys II*
and the arrival times simulated by *Bellhop*

◢ **Trajectoires**, modeling the dive of sperm whales

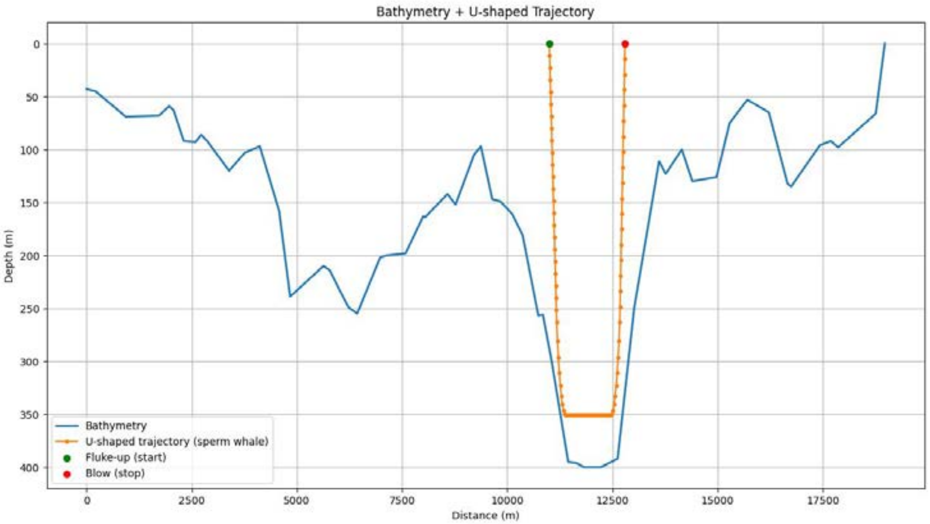
Weakly parametric 2D U-shaped trajectory

Statistics on the seven sperm whales of the Azores, tracked by DTAG by Claudia Oliveira

- 75 U-shaped dive profiles
- averages of descent and ascent rates



Dive profile #5 of the sperm whale *“211bprh”*

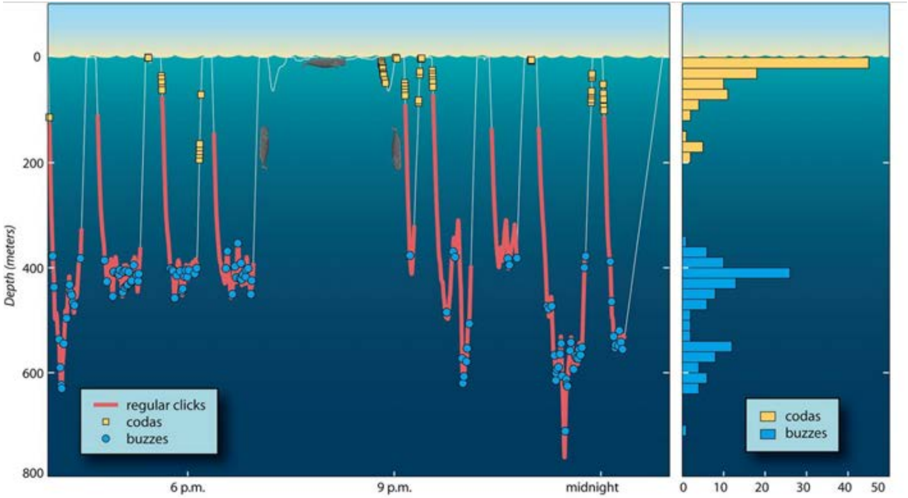


Example of the simulated trajectory of a sperm whale in a 2D cross-section of the Norwegian fjord Seglvik

Dataset, simulate click emissions along trajectories

Creating a dataset:

- Simulation of trajectories in the Mediterranean
- Emission of clicks and buzzes along trajectories
- Acoustic reconstruction
- Training a self-attentive learning model



Jack Cook, WHOI Graphic Services
data from Stephanie Watwood, WHOI

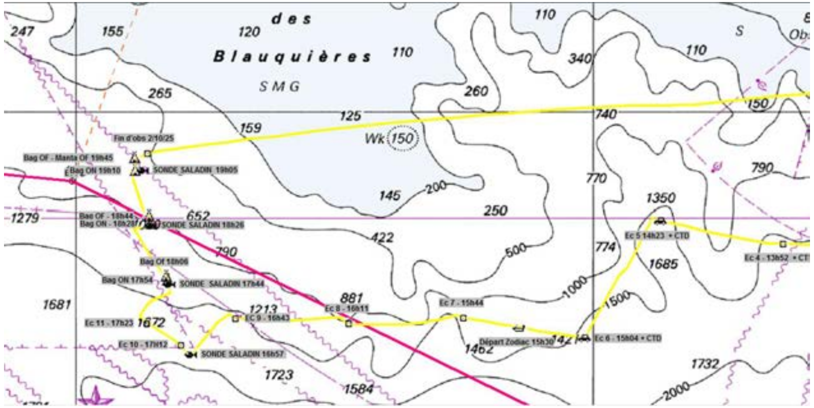
SeGaMas, concrete exemple with *Whale Way 6* data

"Saladin"

single individual

tracked over several diving cycles

photo-identification + IPI + size



Observation of "*Paladin*" during *Whale Way 6*
on October 2, 2025 (© Sarano F. et V.)

(Top) Photo-identification of "*Paladin*" (© Sarano F. et V.)
(Bottom) Aerial photos taken by drone (© Ody D).

Thank you for your attention!

& thanks to our co-funders:

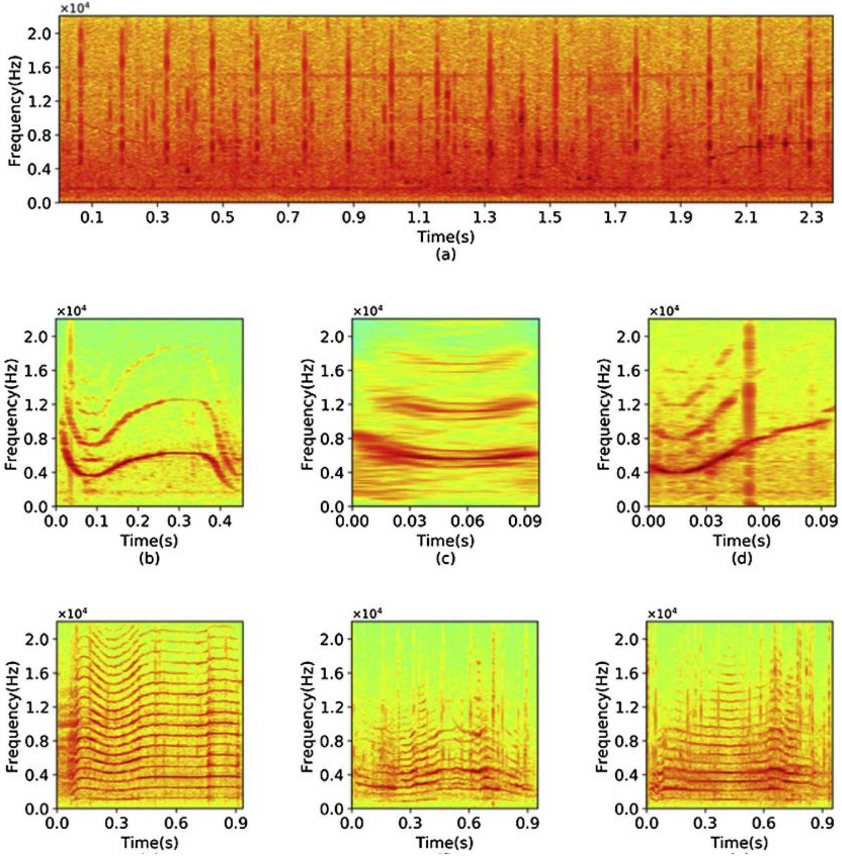
Chaire Int. Artificielle ADSIL AID DGA ANR-20-CHIA-0014,
Région Sud,
Fondation Prince Albert II,
ULPCochlea ANR-21-CE04-0020,
Europam Biodiversa 2021-488,
Longitude181,
UTLN, LIS, CIAN LIS.

From classification to cetaceans tracking by Passive Acoustic and AI Frameworks

Sébastien Paris[1,2,4] *Hervé Glotin*[1,2,4], *Lilou Dantin*[1,2,3,4], *Pascale Giraudet*[1,2,4], *Adeline Paiement*[1,2,4], *Stéphane Jespers*[1]

[1] *Centre International d'Intelligence Artificielle en Acoustique Naturelle*
[2] *Laboratoire d'Informatique et des Systèmes, CNRS, Université de Toulon*
[3] *Parc National de Port-Cros*
[4] *Chaire IA ADSIL AID DGA ANR-20-CHIA-0014*

What type of acoustic signals are emitted by marine mammals ?



Spectrogrammes (Représentations temps-fréquences)

Clics → Echolocation

Whistles

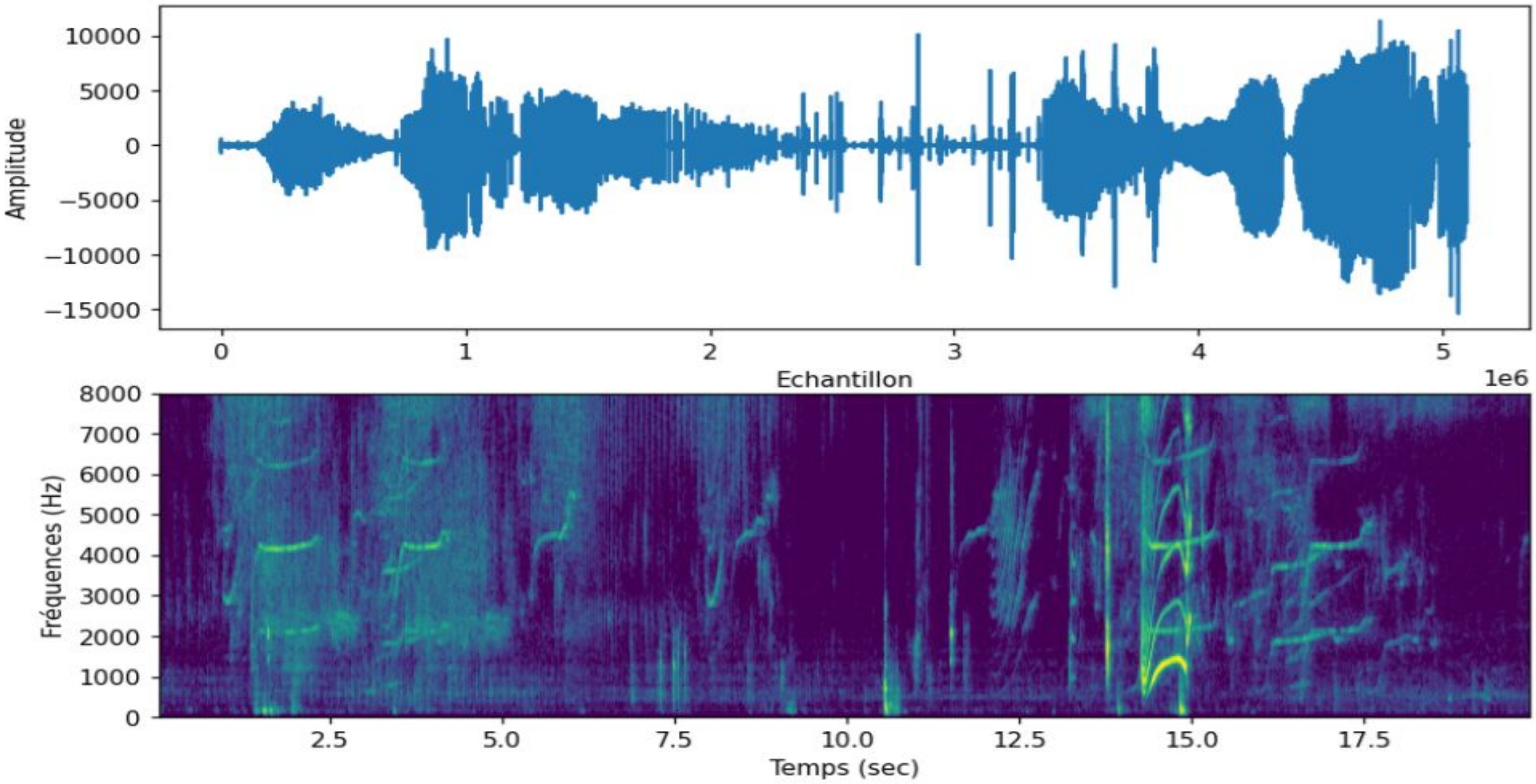
→ Socialization & Communication

Pulsed "calls"

Everything together:
Huge Cocktail party !!!

Jiang, J., et al,. (2019). Study of the relationship between pilot whale (Globicephala melas) behaviour and the ambiguity function of its sounds. *Applied Acoustics*, *146*, 31-37.

Everything together: huge Cocktail party !!!



Main motivations from our bioacoustic works (from 2000...)

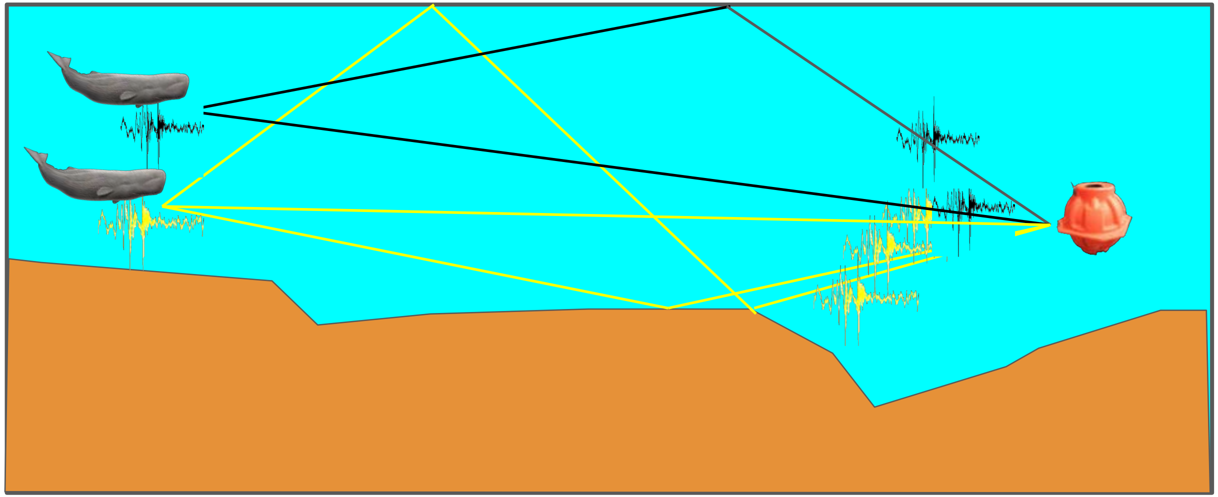
Given some collected underwater acoustic data **in a passive way** (mostly unsupervised), we are working (since decades) on these 5 different tasks:

1 - Detection : Is there at least one animal surrounding the sonobuoy ?
2 - Classification: What species have been detected ?
3 - Sequence modeling : What mammals are trying to say ? (communication understanding)
4 - Tracking : Where mammals are ?
5 - Optimal control/Reinforcement Learning: Where to deploy our sonobuoy ? (to maximize the last four tasks performances)

→ **Automatic tool to output biopopulation indicators**

A common denominator for all these tasks: we went from signal processing/statistical modeling to some (full) machine learning (ML)/artificial intelligence (AI) solutions....

Underwater acoustic channel



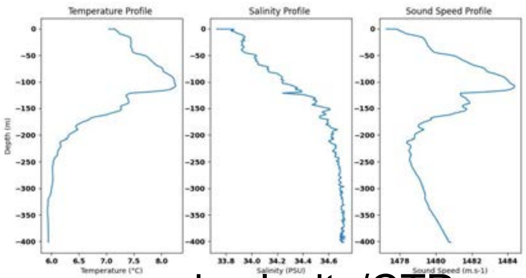
$$r_i(t) = (g(s(t) * h_i(t) + n(t)) * a_i(t) + b(t)$$

$s(t)$: source signal (calls, clicks, ...)
$h_i(t)$: propagation/scattering equivalent transfer function
$g(t)$: transmission loss
$n(t)$: ambient sea noise
$a_i(t)$: hydrophone transfer function
$b(t)$: receiver noise
$r_i(t)$: observed signal on hydrophone i

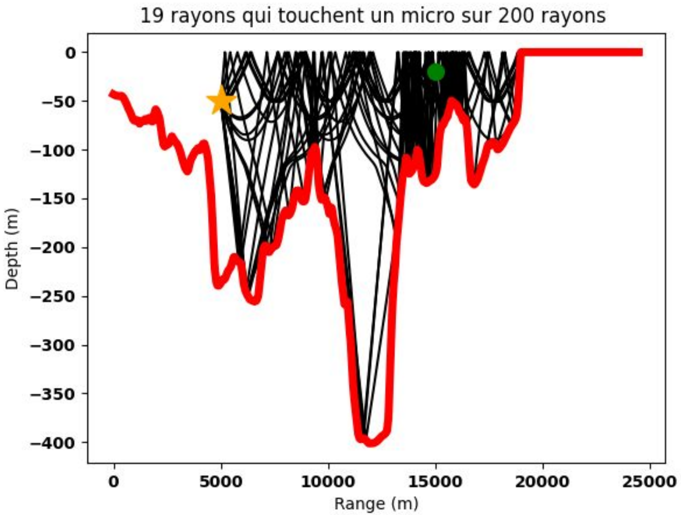
⇒ Very complex and noisy signal

Just to give an idea of the channel complexity

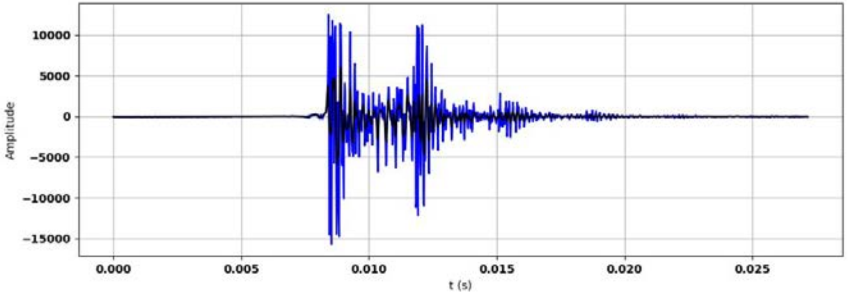
The sound propagation involves many physical aspects : *reflexion, refraction, diffraction, back-scattering, etc…* and depends a lot of parameters: *frequency, bathymetry, pressure, temperature, soil regularity, etc….*



sound velocity/CTD



ray-tracing engine

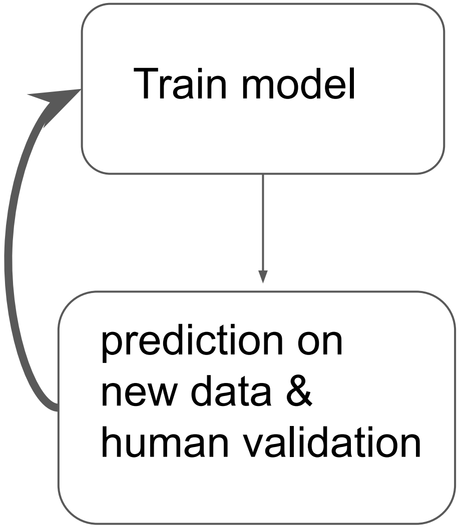


emitted *s(t)* (blue) and transmitted (black) acoustic signals *h(t)*s(t)*

Using AI in bioacoustic : what was (and still is) the more challenging ?

GET LABELS/GROUND TRUTH !!!!! (especially for task 4 in PAM framework)

- We started with just hundreds of examples in total: highly unbalanced and with a lot of label noise



- Starting with mostly unsupervised techniques
- took years to have acceptable results

From signal processing to statistical learning (< 2013)

- At least for **tasks 1-2**, from 2006-2007 => more datasets available (with partial labeling),
- we started to work on (mostly) unsupervised ML technics to produce **latent representations**

$$\mathbf{z} = f_\theta(l(\mathbf{r};\beta))$$

where *l* can be typically a TF representation (*STFT, MELcep, scalogram*, etc..) with fixed β hyper-parameter and θ is the trained non-supervised representation. Among them:

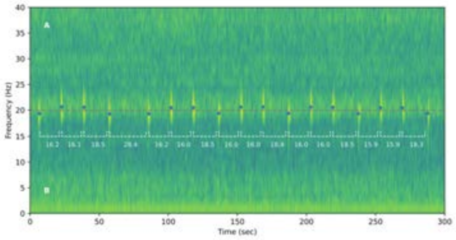
- *clustering/Bag Of ..*
- *GMM*
- *sparse coding+dictionary learning*
- *Fisher vectors*
- *etc…*
- Can be considered of a first trained hybrid learned representation
- Improved a lot performances for tasks 1-2

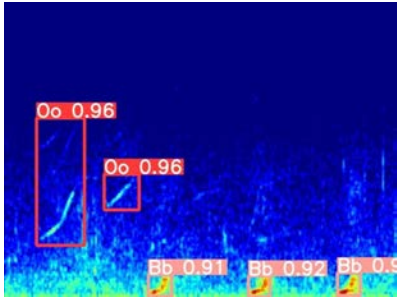
From 2013 for tasks 1-2

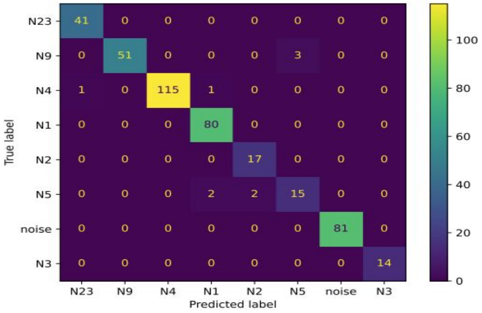
The IA’s tsunami began. Better **latent representations** are obtained with modern *NN* architectures (*CNN, RNN, Unet, Transfomer, etc…*). Key points were:

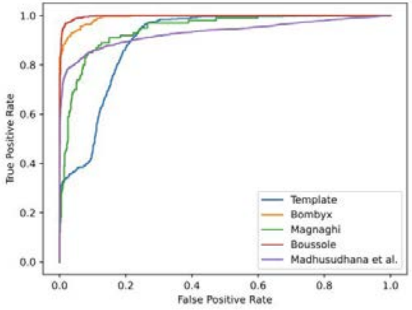
- Huge effort in labeling (partially) databases
- Better optimization gradient based solutions (*Adam, autodiff, etc...*),
- Transfer learning, self-supervised learning, active learning technics
- Regularization by data augmentation (noise, transform, *etc..*), dedicated layers

Whales detection/classification[1,2] with low-power CNN based architectures



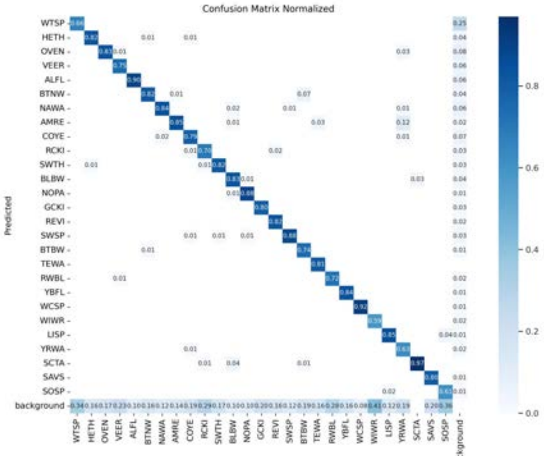




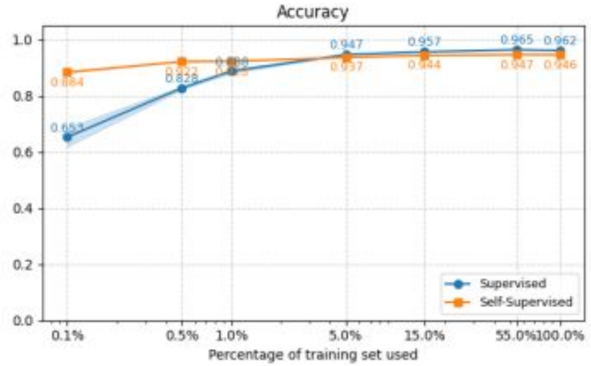


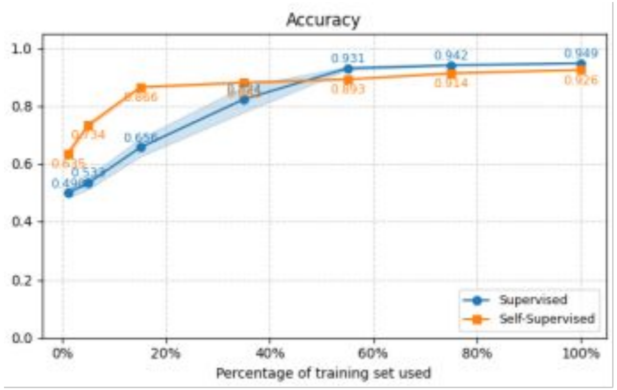
[1] Paul Best, *Automated Detection and Classification of Cetacean Acoustic Signals*, PhD Thesis, 2022
[2] Paul Best and al, *Temporal evolution of the Mediterranean fin whale song,* Scientific Report, 2022

- Birds classification[3] (TFR + preprocessing + YoLo V12)



- Fin whale detection[4] (SSL vs Supervised Transformer model)





[3] Stéphane Chavin, PhD Thesis, 2023-...
[4] Adam Chareyre and al, *Self-Supervised vs Supervised Representation Learning for Fin Whale Vocalization Detection,* Neurips, 2025

For tasks 1-2, job is (almost) done !

Take home message:

- Performances for tasks 1-2 are **now quiet good** (> 85% Acc for most datasets)
- More and more sequences are **automatically extracted**, **analysed and labelled** (> [10K-300K] detections per inference session)
- **In practice,** for tasks 1-2, fine-tuned YOLO Vx.. reaches ~SOTA even in cocktail party
- **In most of the case,** no really need cumbersome ultra advanced IA arsenal (low-energy embedded system incompatible)

Why AI also for tasks 4-5 ?

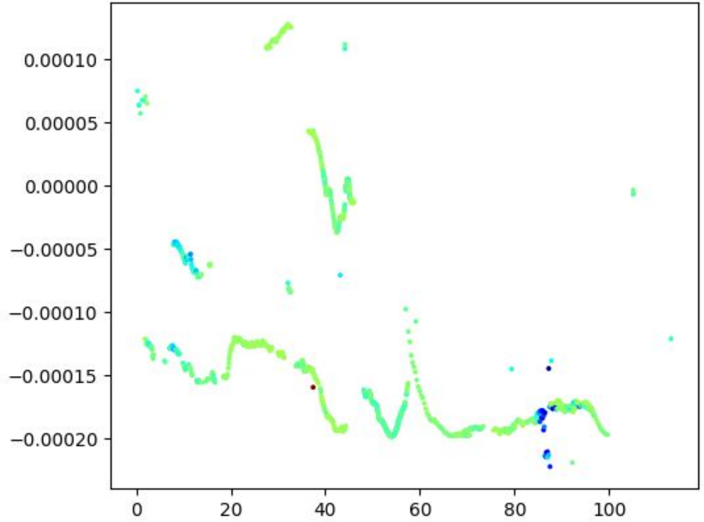
For **task 4**, with sonobuoy/hardware developpements we increased the :

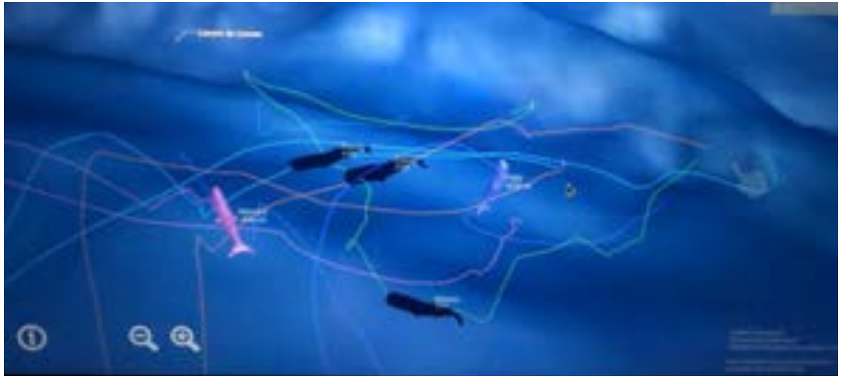
- number of hydrophones (up to 5)
- frequency sampling (up to 512 kHz)
- sensitivity/SNR

more robust/accurate TDOA estimators BUT CRLB shows **poor range estimators** from TDOA/TOA measurements.

1- direct localization approach : from TDOA's → $\hat{\mathbf{x}}_k = f^{-1}(\hat{\tau}_k)$

- hyperboloids intersection
- Weighted LLS



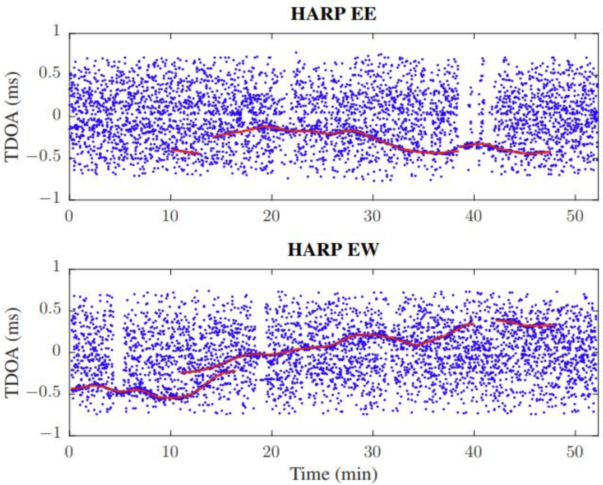


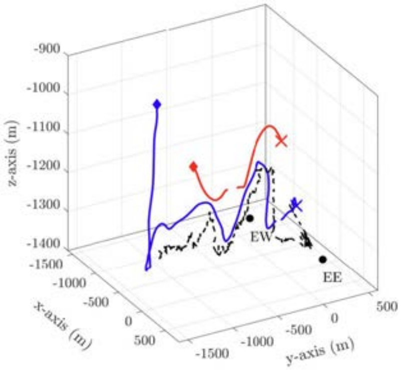
- need to remove clutter/ghosts TDOAs and
- isolate individual track.
- Can be done offline by unsupervised learning (advanced clustering GNN). Not yet fully automatic

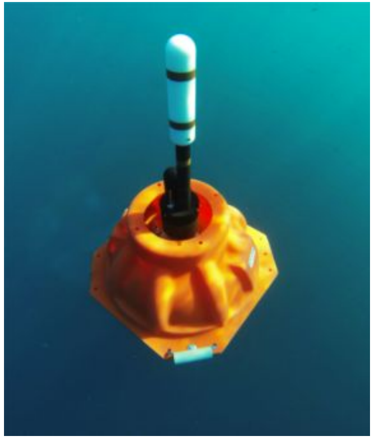
Sequential nonlinear filtering for MultiTarget Tracking

2- sequential tracking approach : given a sequence of *TDOA* *(or doppler,angle,range, etc)*.

from localization $\widehat{\mathbf{x}}_k^l = f^{-1}(\widehat{\tau}_k^l)$ → $\widehat{p}(\mathbf{x}_k^l | \widehat{\tau}_1, \ldots, \widehat{\tau}_k)$ to tracking





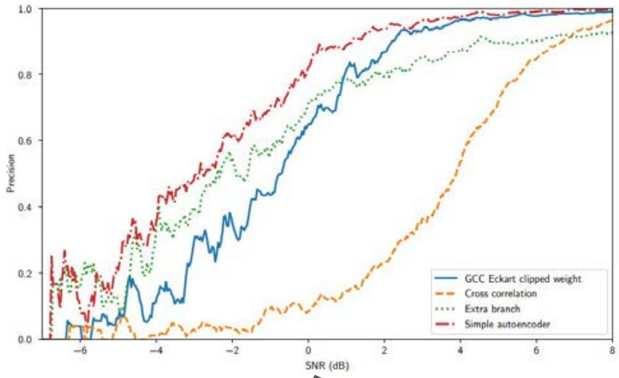


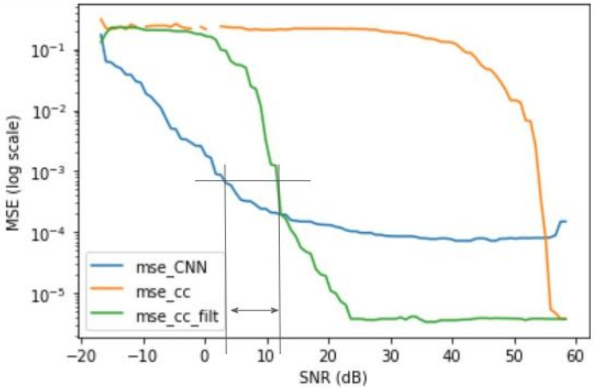
Main difficulty in MTT is the (combinatorial) **assignment problem between measures and targets** => *(P)MHT, JPDAF, Bayesian filter[5], ect..*

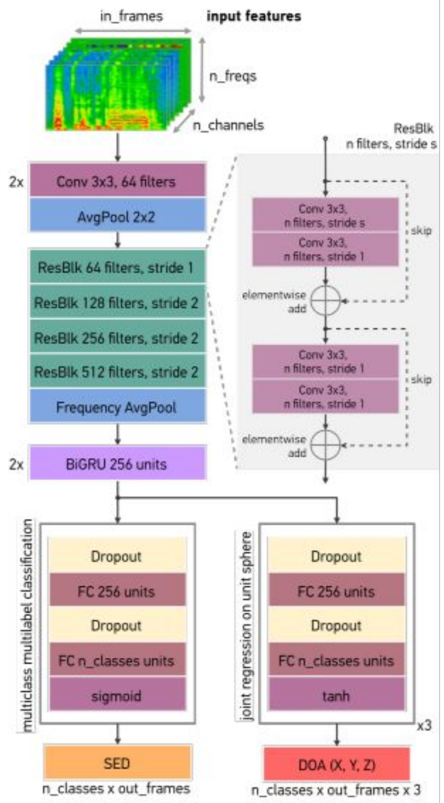
[5] J Jang, Bayesian Detection and Tracking of Odontocetes in 3-D from Their Echolocation Clicks, arXiv preprint arXiv:2210.12318

Coupling AI and MultiTarget Tracking

One way to overcome combinatory : train model robust *TDOA/DOA/range/angle* estimators[6] (even direct positioning) from sound events **with builtin source separation**[7]







Independent parallel filtering

$$\widehat{p}(\mathbf{x}_k^l|\widehat{\tau}_1^l,\ldots,\widehat{\tau}_k^l)$$

$$\widehat{p}(\mathbf{x}_k^l|\widehat{\mathbf{DOA}}_1^l,\ldots,\widehat{\mathbf{DOA}}_k^l) \quad \widehat{\mathbf{DOA}}_k^l = f_{\hat{\theta}}(\mathbf{r}_\mathbf{k})$$

[6] Maxence Ferrari, *Study of a Biosonar Based on the Modeling …..*, PhD Thesis, 2020
[7] T. Nguyen, *Spatial Cue-Augmented Log-Spectrogram Features for Polyphonic Sound Event Localization and Detection, IEEE Trans ASLP*

New framework : Multi-Target Tracking with Transformer

3 - With Transformer like we can train **directly** (acoustic) sequences to (trajectories) sequences

$$\mathbf{Z} = (\mathbf{z}_1, \ldots, \mathbf{z}_n), \mathbf{z}_i \in \mathbb{R}^p$$

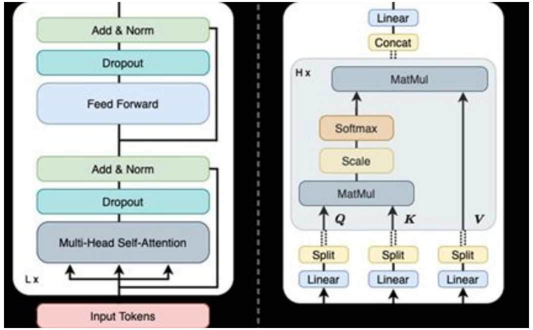
(eg. embedding from signals per hydrophone)

Transformer $\mathbf{X} = g_{\hat{\theta}}(\mathbf{Z})$

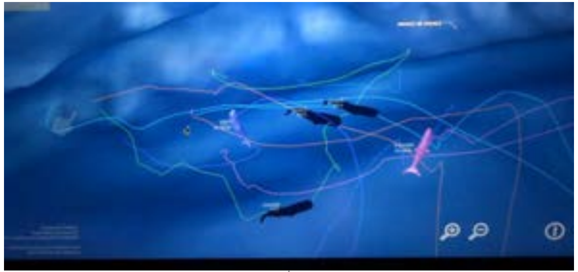
$$\mathbf{X} = (\mathbf{x}_1, \ldots, \mathbf{x}_n), \mathbf{x}_i \in \mathbb{R}^v$$

(eg. animal's position)

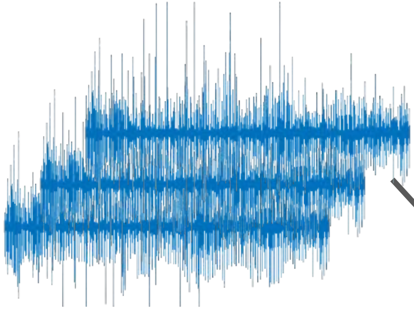
Attention layer $\mathbf{x}_i = \mathbf{W}_O \left(\sum_{j=1}^{n} \alpha_{i,j} \mathbf{W}_V \mathbf{z}_j \right)$ $\alpha_{i,j} = \dfrac{\exp\left(\frac{(\mathbf{W}_Q \mathbf{z}_i)(\mathbf{W}_K \mathbf{z}_j)}{\sqrt{d_k}}\right)}{\sum_{k=0}^{n} \exp\left(\frac{(\mathbf{W}_Q \mathbf{z}_i)(\mathbf{W}_K \mathbf{z}_k)}{\sqrt{d_k}}\right)}$



Passive Acoustic Tracking with Transformer

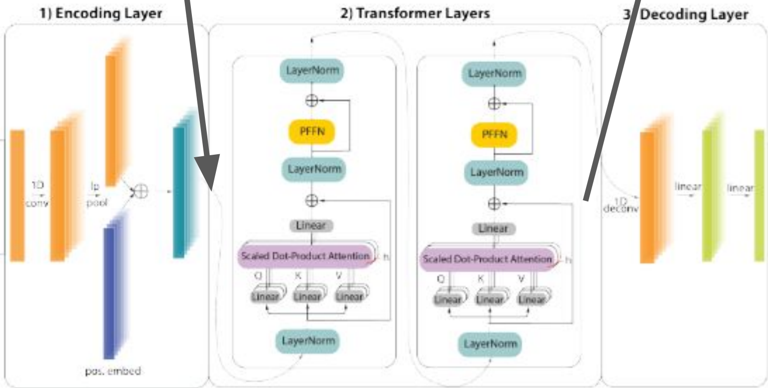


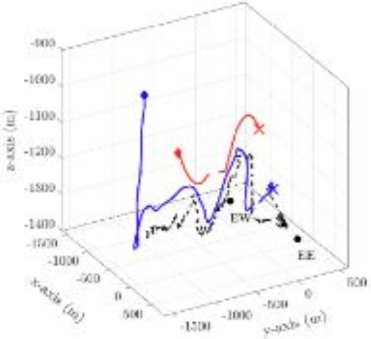
$$\{\mathbf{x}_1, \ldots, \mathbf{x}_K\} = g_{\hat{\theta}}(\{\mathbf{z}_1, \ldots, \mathbf{z}_K\})$$

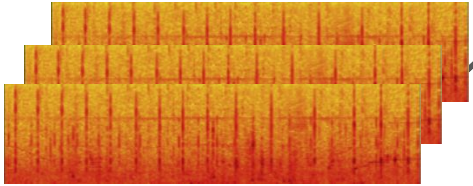


$$\{\mathbf{z}_1, \ldots, \mathbf{z}_K\} \quad \{\mathbf{x}_1, \ldots, \mathbf{x}_K\}$$

$$\mathcal{L}(\hat{\mathbf{r}}_k, \mathbf{r}_k)$$



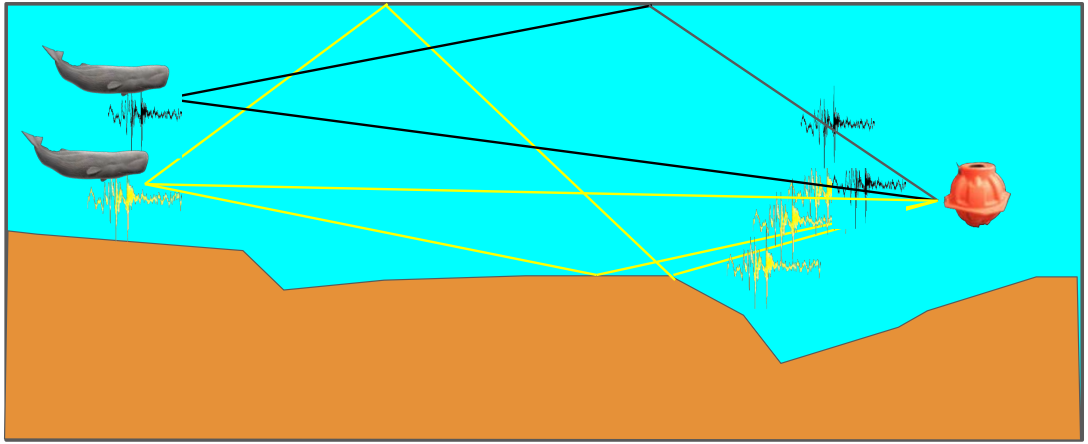


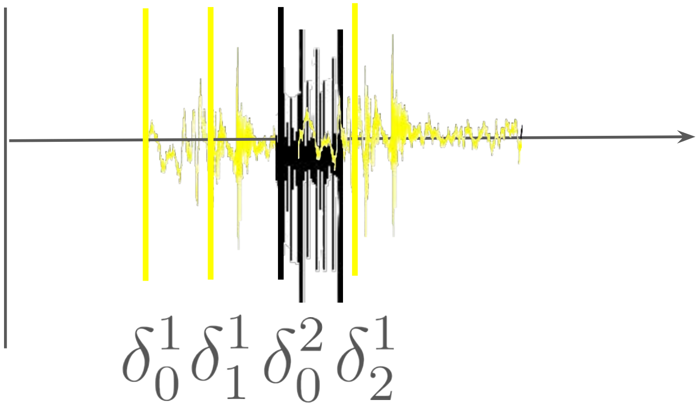


ViT

What the representation must learn via Transformer ?

Answer: the underlying source separation problem (animals, echoes, etc..)

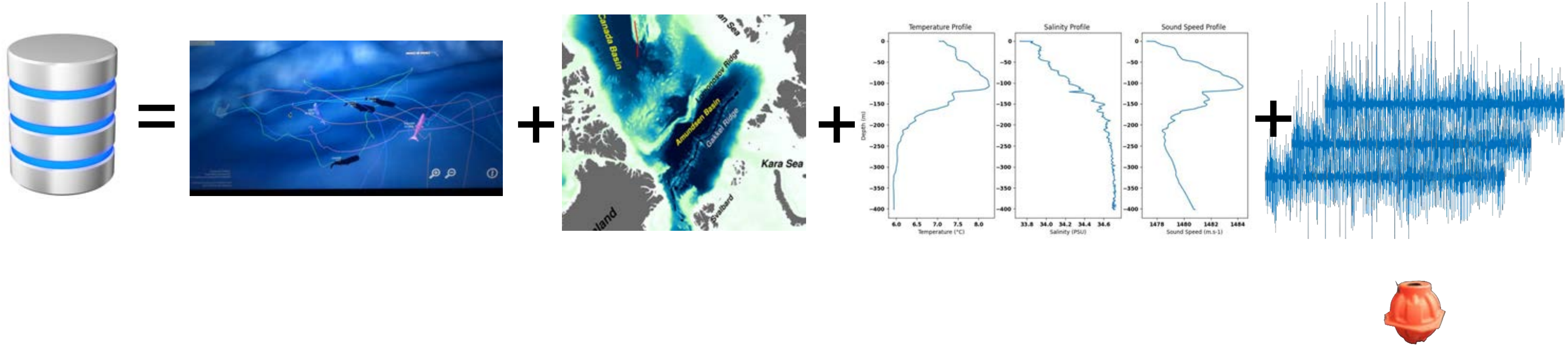




We need a dataset dedicated to PAT !!!!

- Whatever tracking with 1/2/3 approach**, we need ground truth data** with **acoustic data** (A) and animal's **trajectories** (T) to train models.

- Few datasets are available with all these informations together.

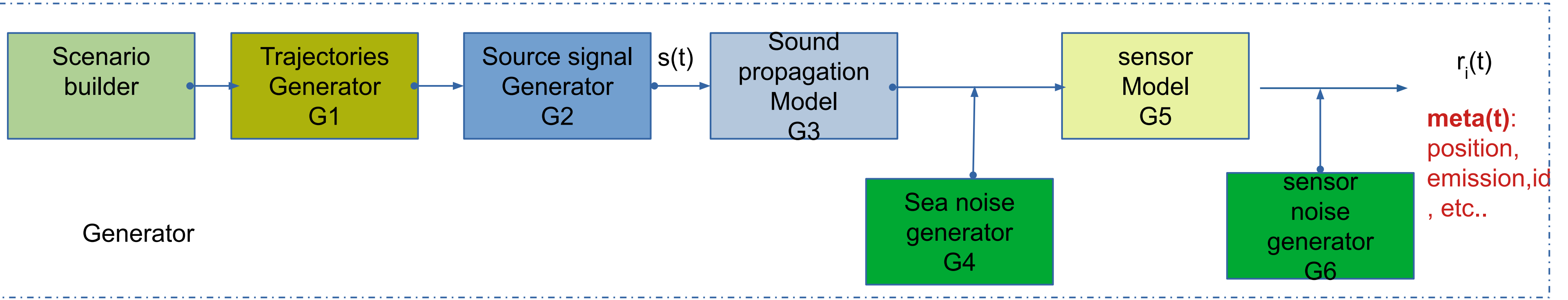


- **We need a digital twin/serious game of marine mammals** to generate realistic data

SeGaMas - Generator -

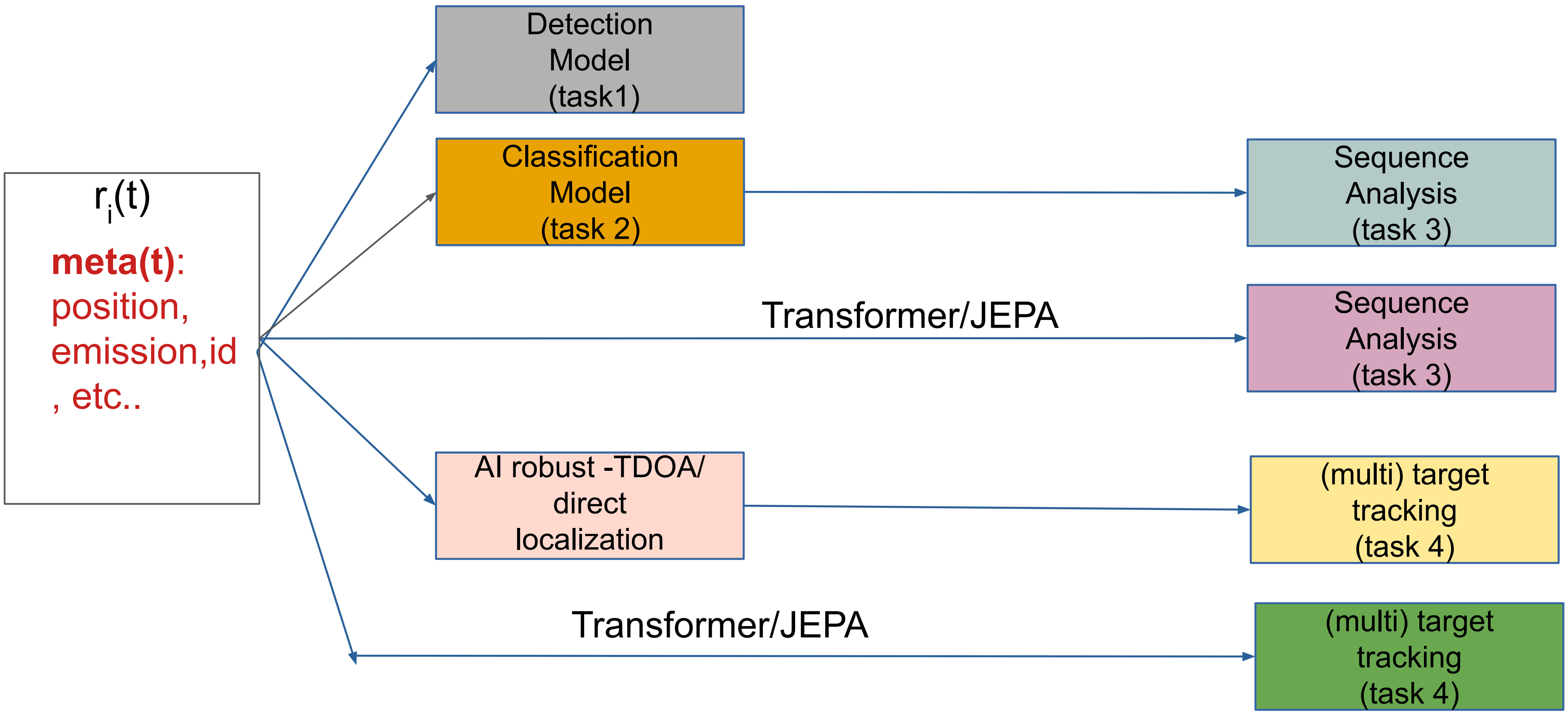
We started to build a complete **serious game** (L. Dantin 2025-) divided in two parts **: generator & trainers**. The generator has to:

- generate realistic mammals trajectories (cinematic, behavior, ROI, weather, food, multiple animals, etc...)
- generate realistic source emissions
- model sound propagation and sea noise characteristics
- model sonobuoy geometry and sensor characteristics



With SeGaMas generator, the goal is not only to generate realistic acoustic signals but **also all important associated meta-data/labels** for tasks 2-3-4-5

SeGaMas - Training models



SeGaMas - Generator + Trainers

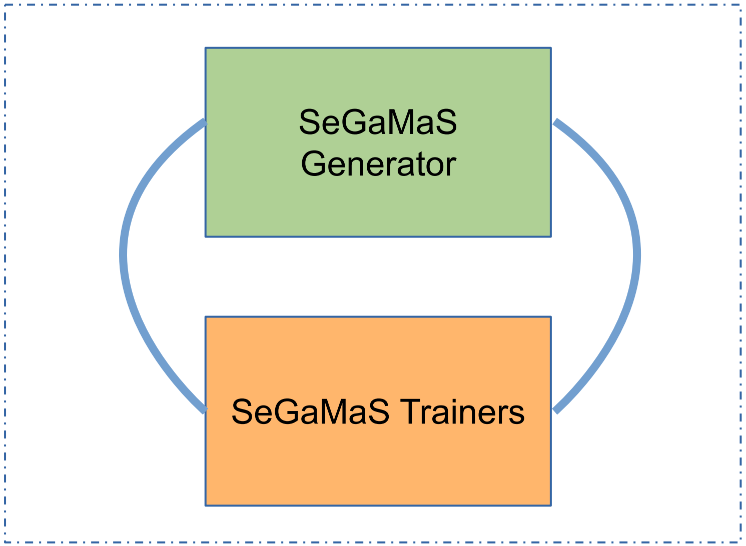
For **task 5** , thanks to all generated trajectories and associated sound events & meta labels, we can imagine find the best sensor's location minimizing such loss

$$L(\boldsymbol{U}) = \min_{\boldsymbol{U}} \{ E_{\boldsymbol{T}} [\sum_{k} det(cov(\boldsymbol{x}_k | \boldsymbol{Z}_{1:k}(\boldsymbol{U})))] \}$$

Sensor's location

Trajectories from G1

MTT (task 4) or PCRB



L(**U**) can be optimized by stochastic optimization technics or via RL (agent = sonobuoy)
Would be interesting to compare both way to solve the corresponding problem

Thanks for your attention !!
Questions ?

Putting all together for

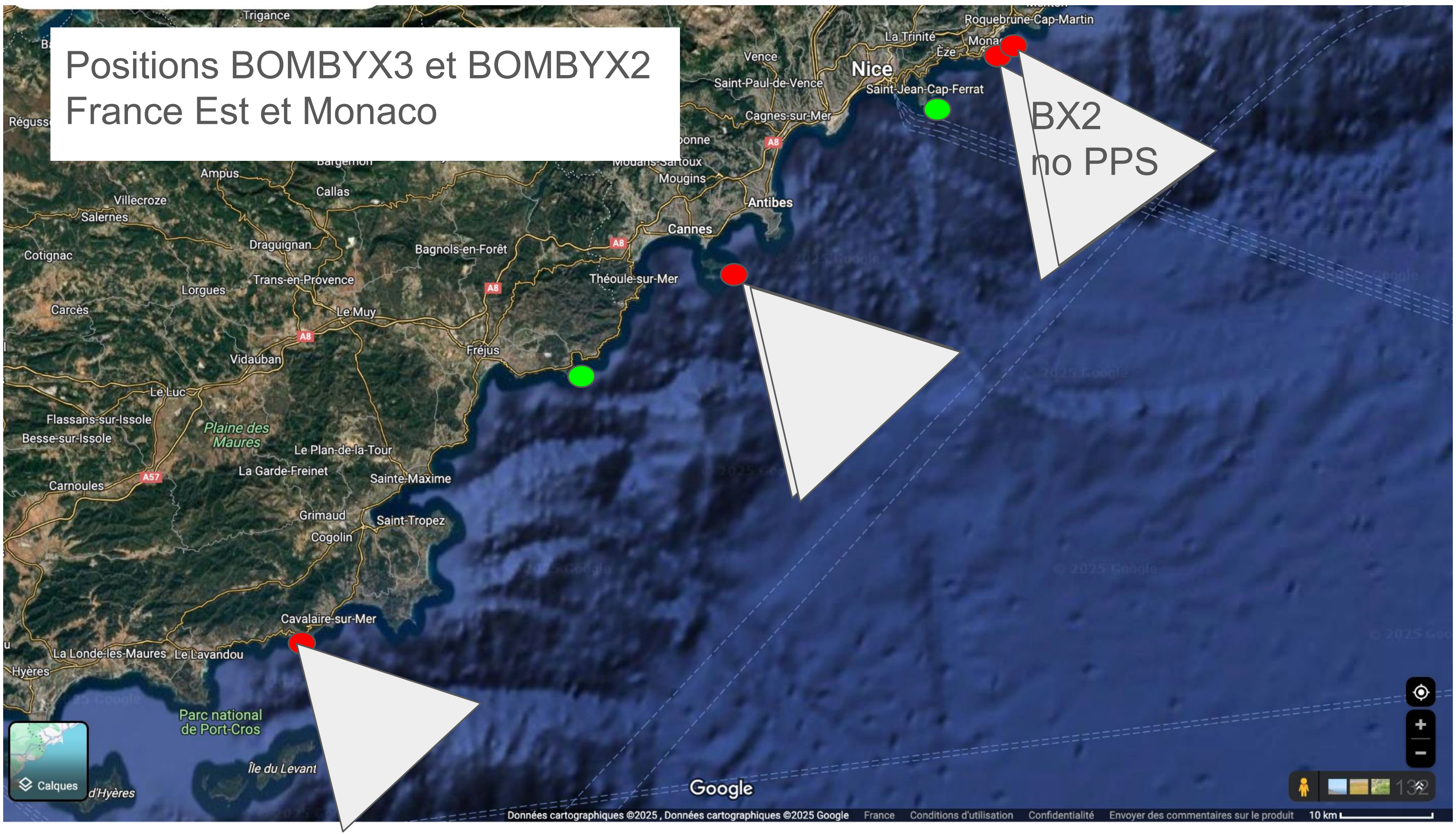
megafauna survey & ship collision risk mitigation

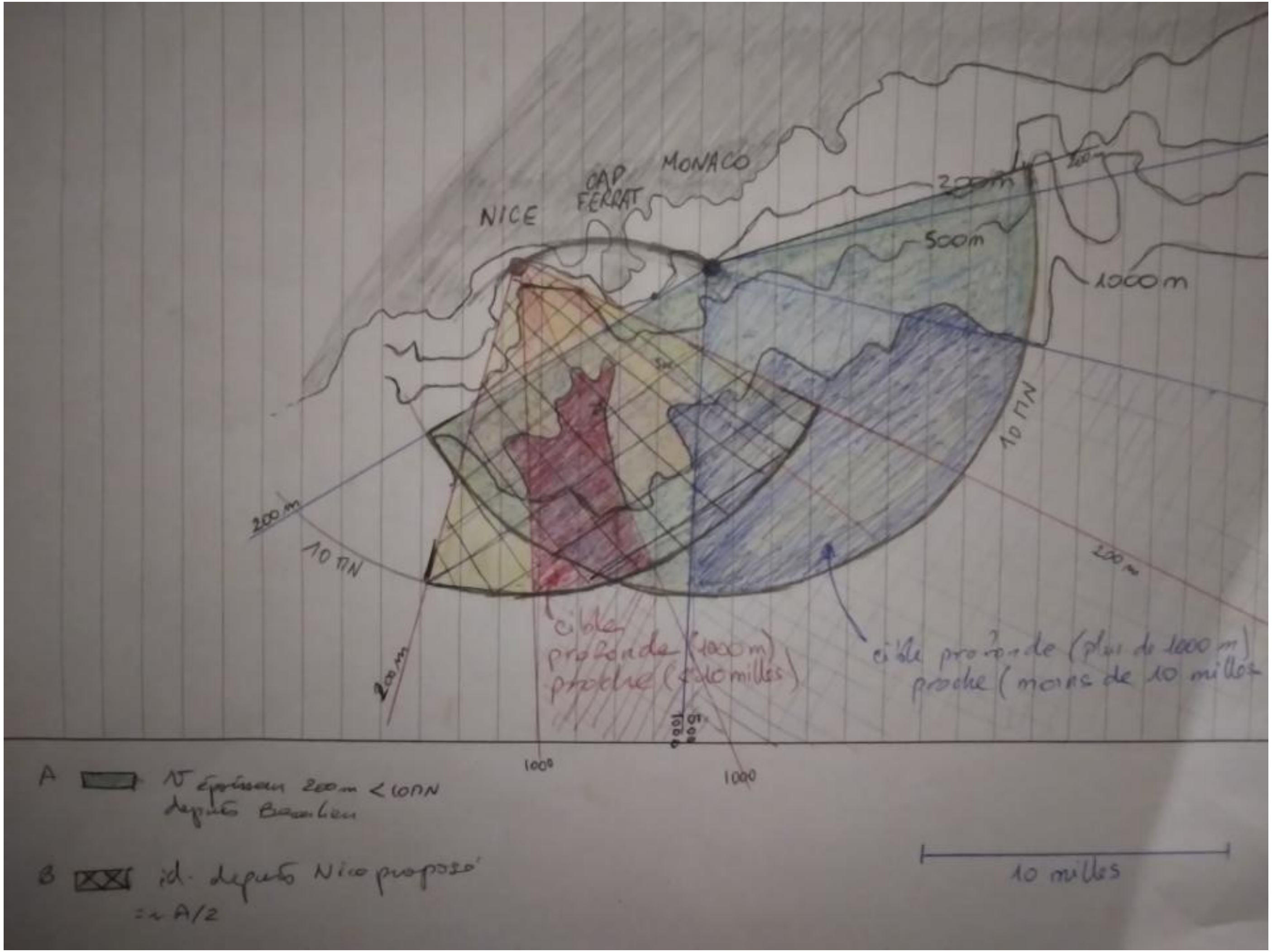
All[1]

[1] *Centre International d'Intelligence Artificielle en Acoustique Naturelle*


Monaco
Nice
Cagnes-sur-Mer
A8

Positions BOMBYX3 et BOMBYX2 France Est et Monaco




MONACO
CAP FERRAT
NICE
200 m
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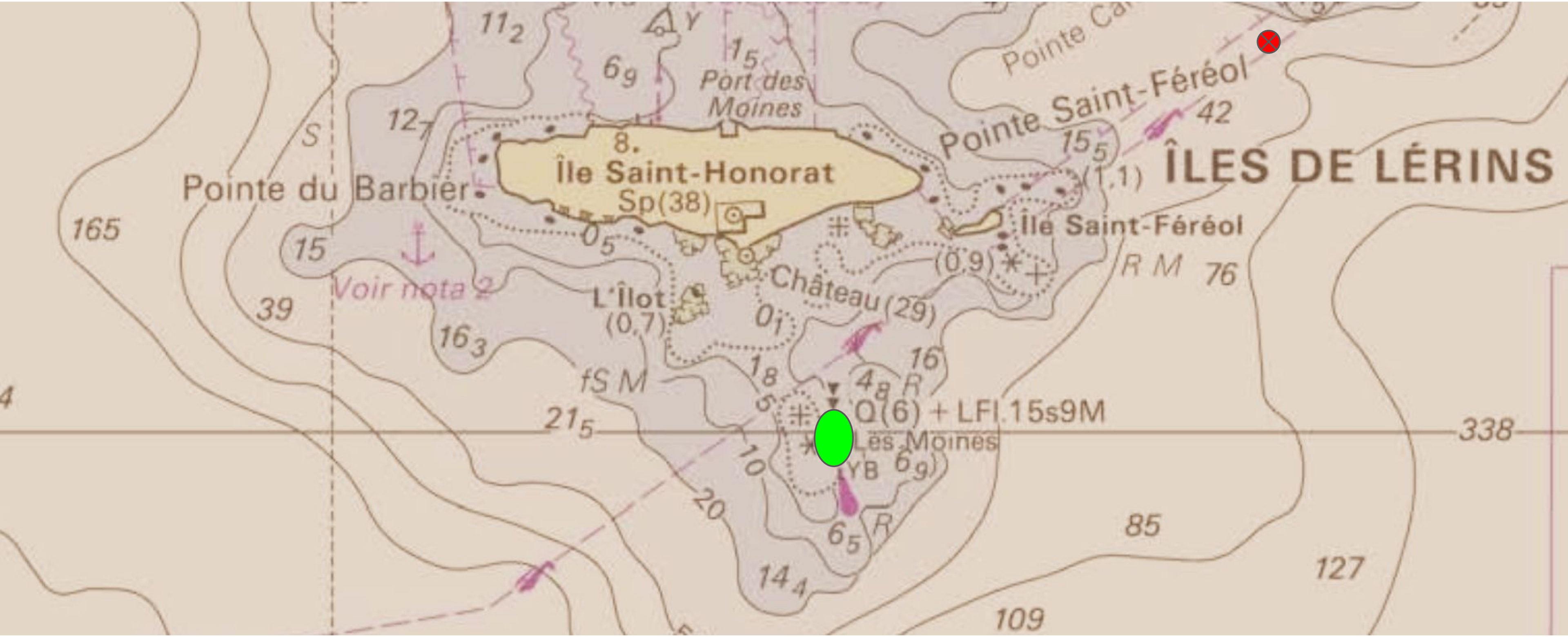
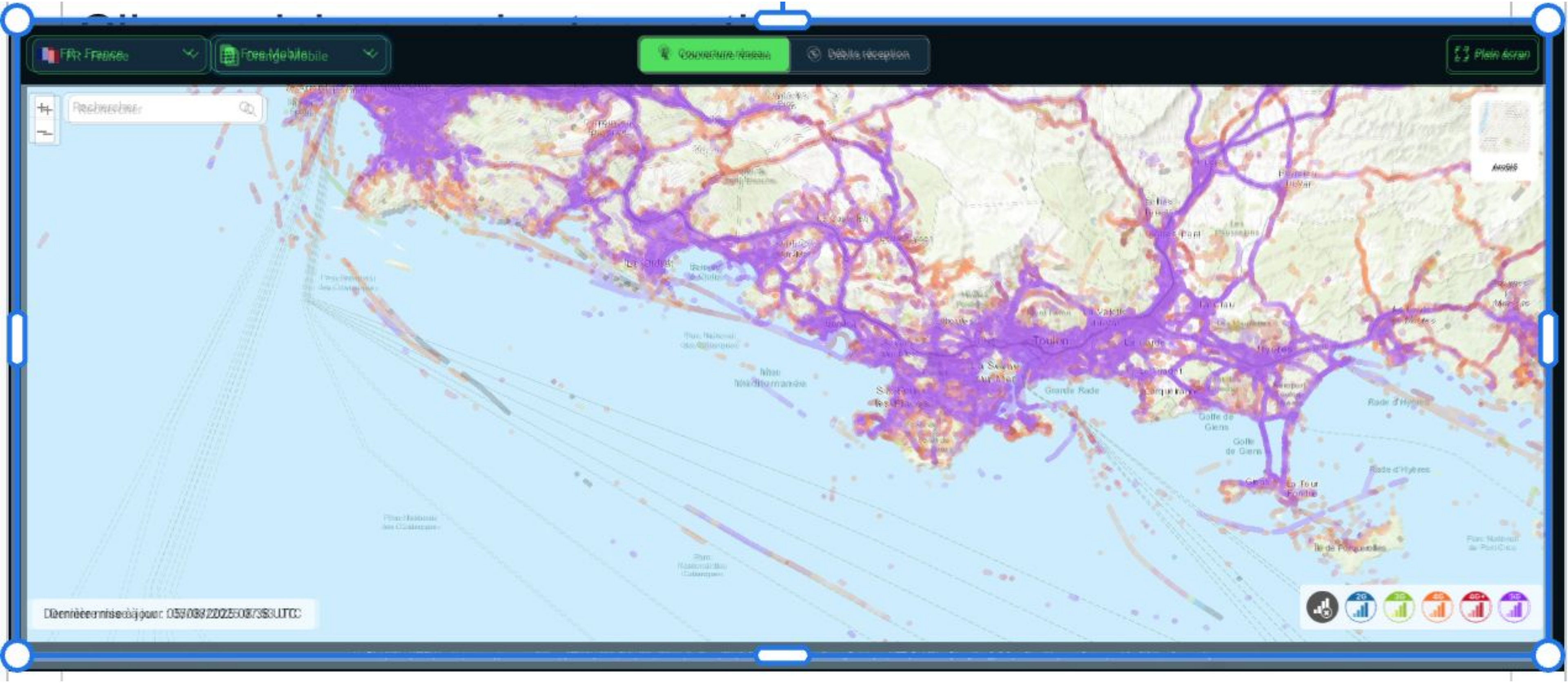
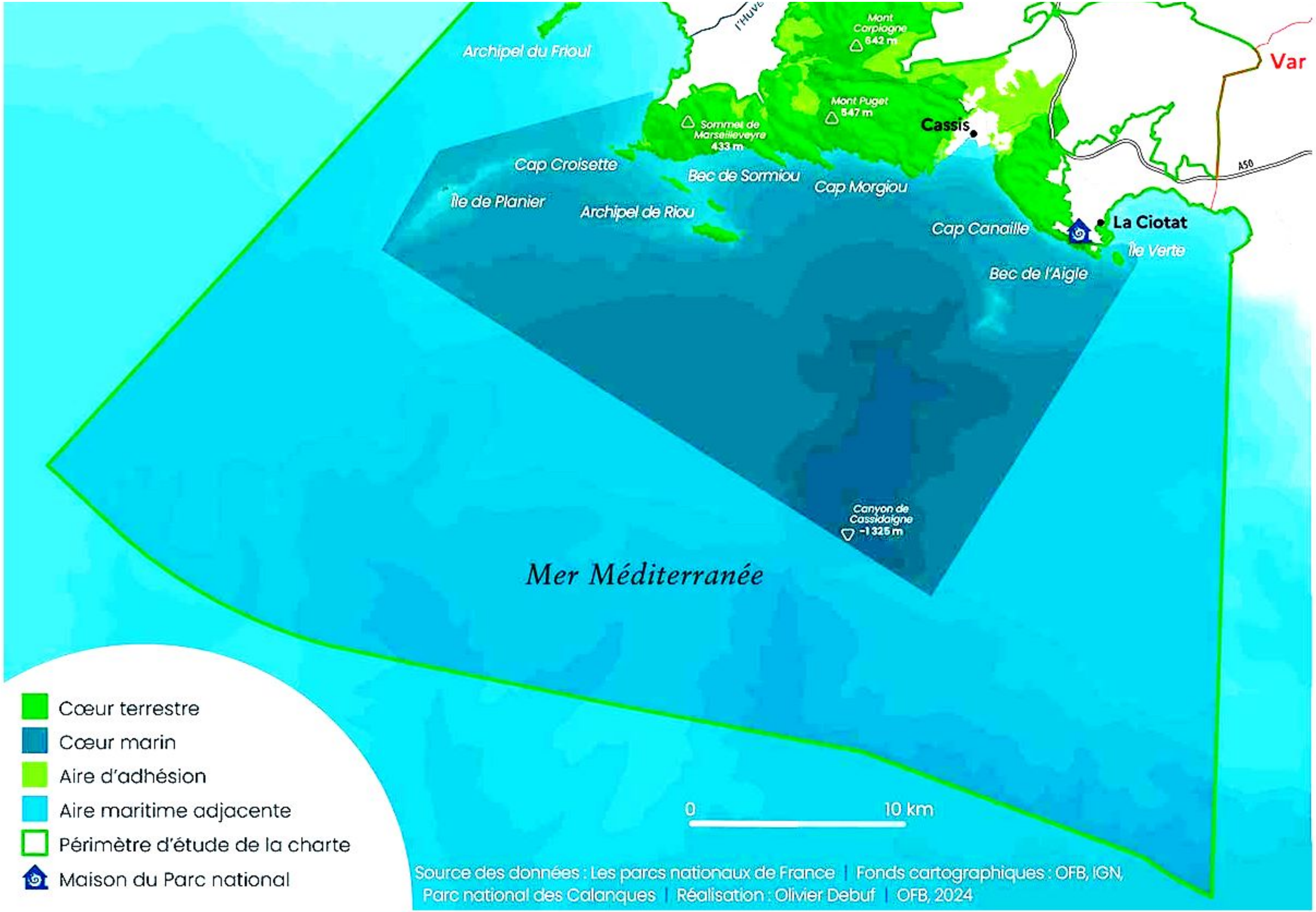
FRANCE : Bombyx3 Antibes / LERINS (en demande)



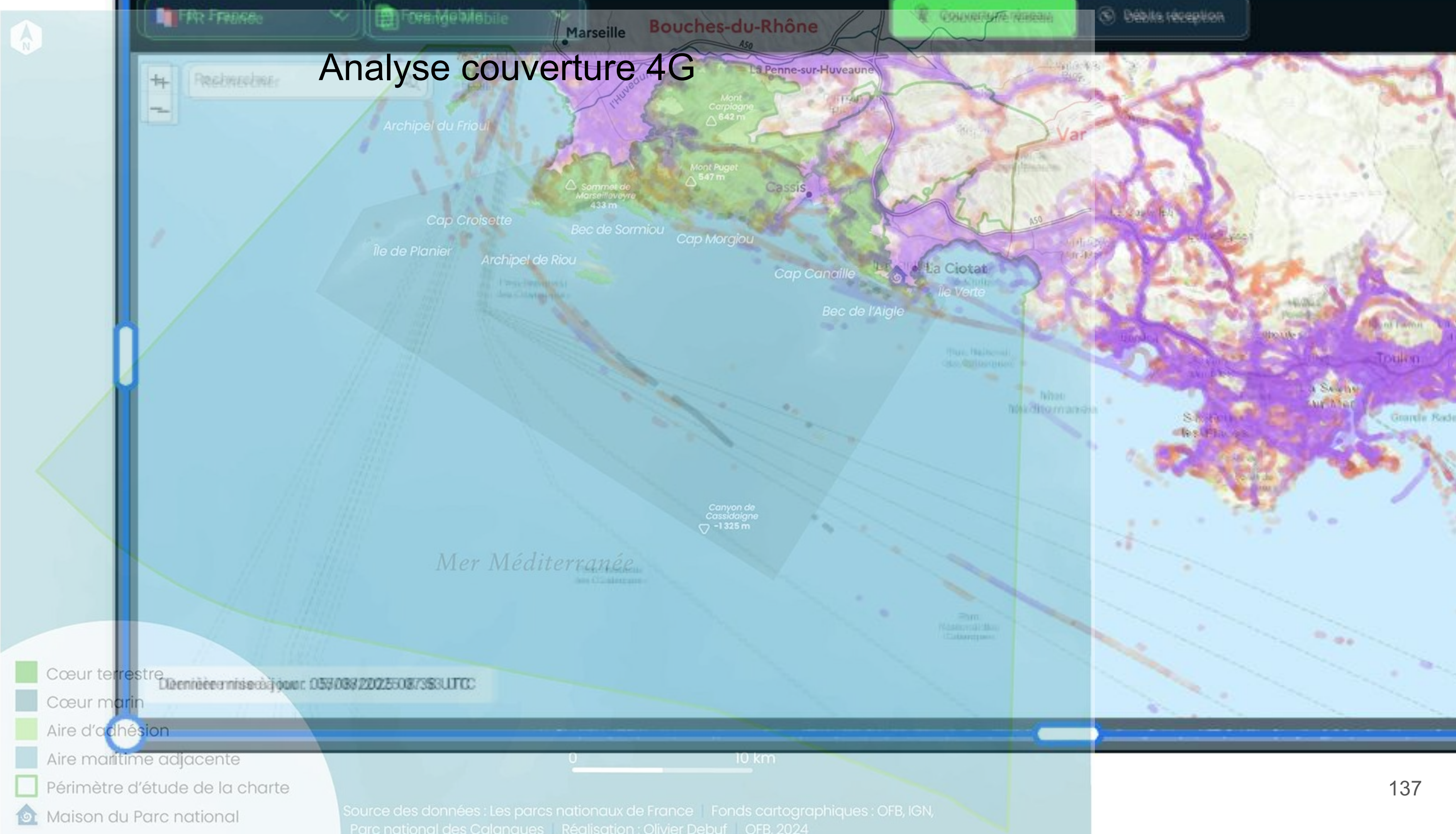
Analyse couverture 4G



FRANCE : Bombyx3 PNC (en demande)



Analyse couverture 4G



Analyse couverture 4G