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SHOM
300 ans d'hydrographie

Bayesian method for acoustic data processing in uncertain environment

- Sérénade 2022 -

H. Pihan-Le Bars and B. G. Kinda

Context

European Marine Framework Strategy Directive (MFSD)

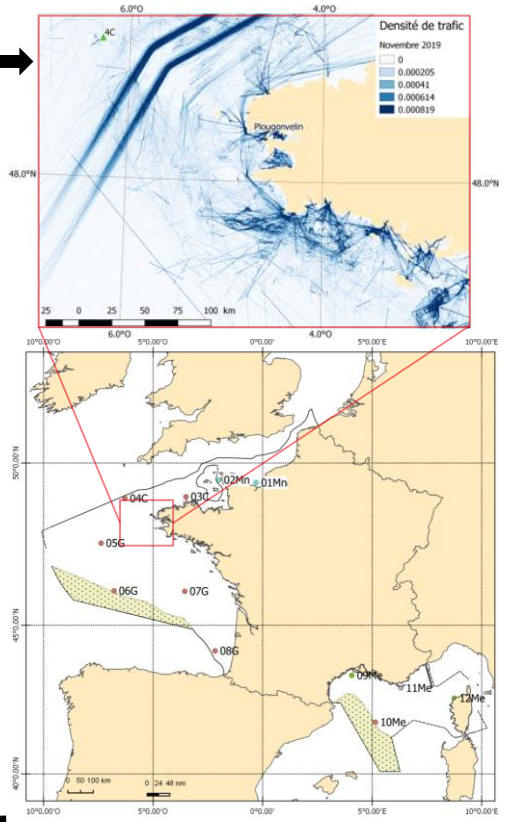
Goal : Evaluation of anthropic pressure on marine ecosystems through ambient noise study

- Estimation of noise level generated by human activities on :
  - Continous component (traffic)
  - Impulsive component (offshore activities)
- Transient signals extraction/classification

MAMBO network : acoustic monitoring and opportunity noise measurements

- 12 stations spread in the French Exclusive Economic Zone (EEZ)
- Expected amount of data ~ 50 To / year
- Homogeneous sensor network

Traffic density map close to 04C station



MAMBO network's anchorages map

Context

Requirement for continuous noise estimation

EMSF – ambient noise descriptor : production of reference time series of noise measurements to assess the robustness of traffic noise models. → Noise estimation

Targets properties for noise estimation

- Continuous estimation under signal presence uncertainty
- Deal with complex and non stationary environments & noise
- Include (far) traffic noise
- Fully automatic
- Error between <1-3dB

Chosen approach: **Recursive** methods with estimation of **signal presence probability** (SPP) (*) with production of time-frequency map of noise and SPP

↓

Joint signal detection!

(*) I. Cohen, “Noise spectrum estimation in adverse environments: improved minima controlled recursive averaging,” IEEE Transactions on Speech and Audio Processing, vol. 11, no. 5, pp. 466–475, Sep. 2003

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Recursive estimate from speech processing field – From I. Cohen, 2003 (*)

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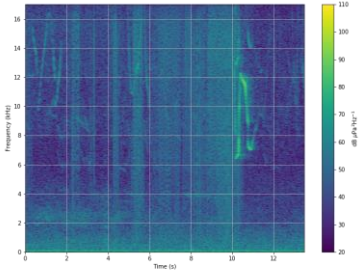

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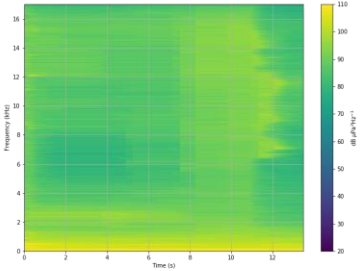


Prior noise estimate

Minimum statistics
3 stationarity modes
based on user decision

Initialization

Periodogram smoothing

SNR ratios

Exponential and χ^2 distributions

SNR thresholds

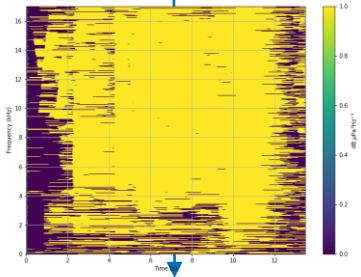
Signal absence probability q(k,l)

$\lambda(k,l-1)$ $G(k,l-1)$
$\xi(k,l-1)$ $\gamma(k,l-1)$

k – frequency line
l – time step

Spectral gain – G(k,l)

Signal presence probability – p(k,l)



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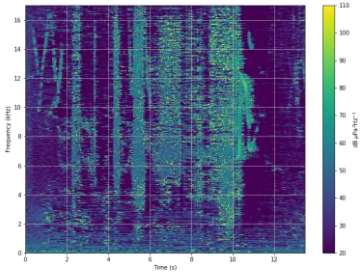
SNR ratios update
ξ(k,l), γ(k,l)



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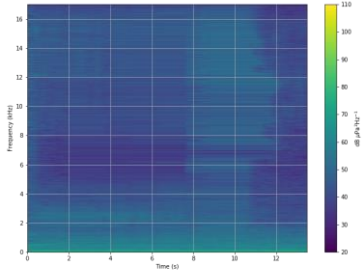

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PCRA

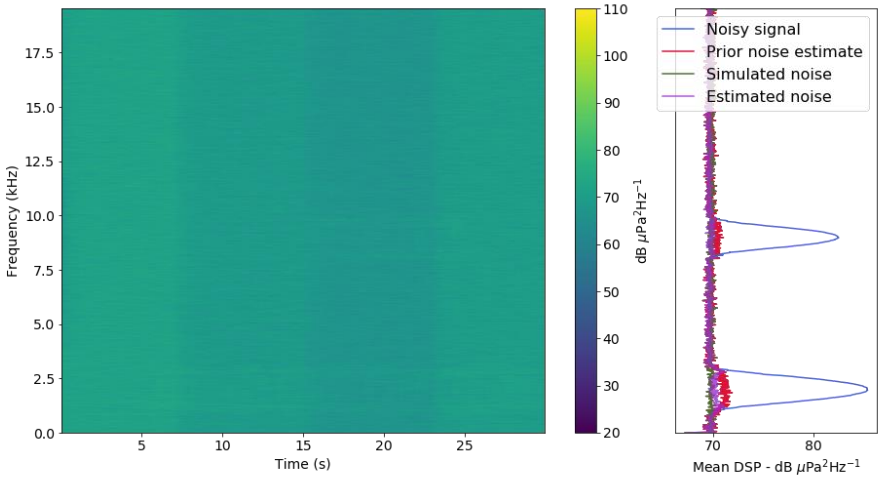
Bayesian SPP and recursive noise estimation from Cohen 2003

A weighted average of past noise estimate and current spectrum coefficients, controlled by a SPP :

$$N(k,l) = \hat{\alpha}_n(k,l)\, N(k,l-1) + (1-\hat{\alpha}_n(k,l))\, Y(k,l)$$

With

- Smoothing coefficient – $\hat{\alpha}_n(k,l) = \alpha_n + (1-\alpha_n)\, p(k,l)$
- Signal presence probability (SPP) – $p(k,l)$
- Noise estimate $N(k,l)$ for frequency bin k and time step l
- Spectrum coefficient $Y(k,l)$



Noise estimate and mean PSD for a simulated sample with two gaussian pulse trains and a background noise composed of 4 white noise samples with different levels.

Conditional SPP estimation : from Bayes rules, conditional probability density for observed signal and SNRs

$$p(k,l) = P(H_1(k,l)||Y(k,l)|^2) = [1 + \frac{q(k,l)}{1-q(k,l)}(1+\xi(k,l)) \times e^{\frac{\xi(k,l)\gamma(k,l)}{1+\xi(k,l)}}]^{-1}$$

A priori signal absence probability

Clean signal to noise ratio

Noisy signal to noise ratio

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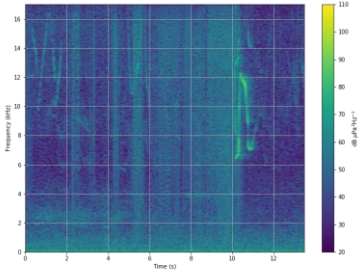

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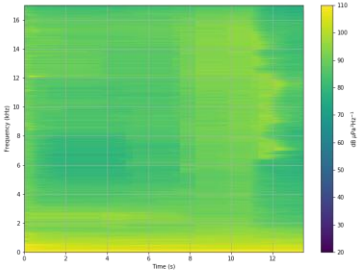

Exponential and χ^2 distributions

Periodogram smoothing

Signal absence probability q(k,l)

SNR thresholds

SNR ratios

Initialization

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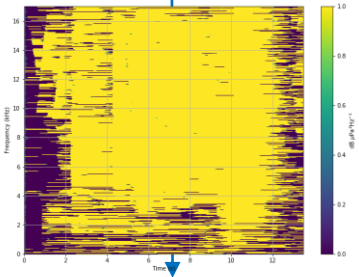

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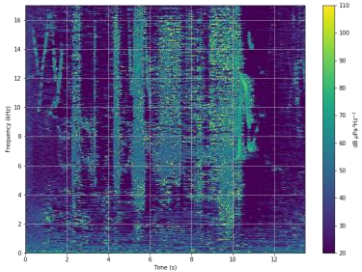

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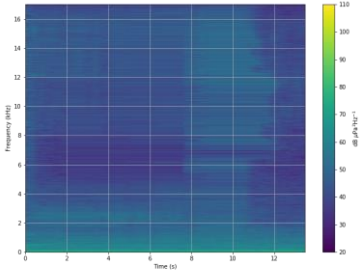

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Performance assessment

Simulations – Results of Monte-Carlo simulation

Segmental logarithmic error (SLE) : Mean value of log-ratio of estimated noise $\hat{N}$ and true noise N :

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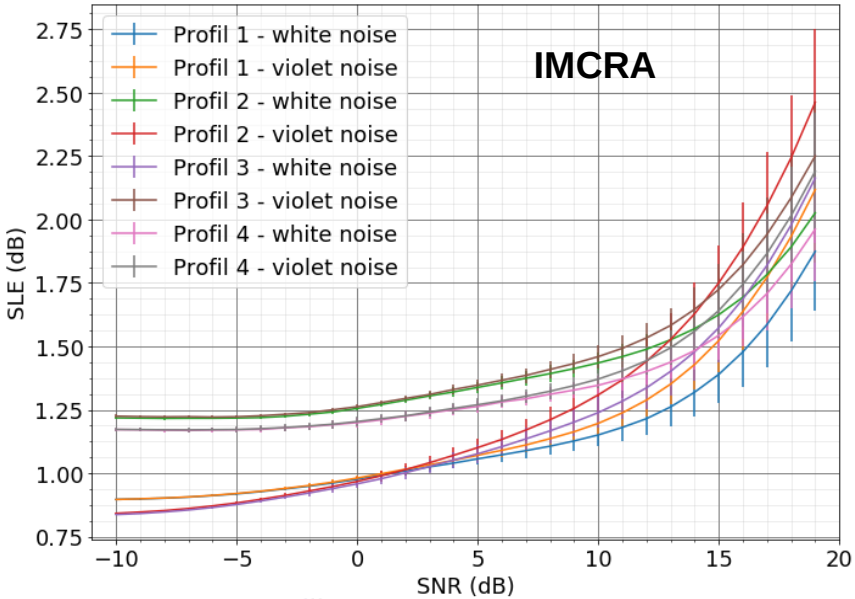
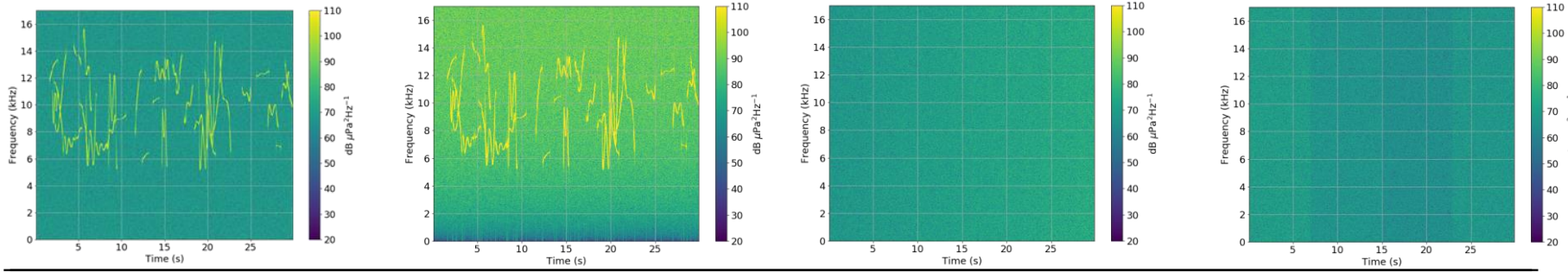


IMCRA :
- Two trends, no clear link with pattern and noise type
- Growing instability with increasing SNR



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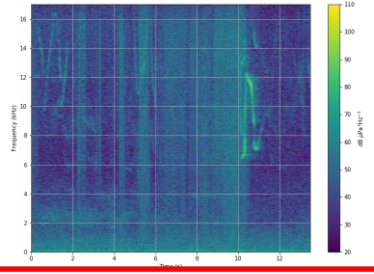

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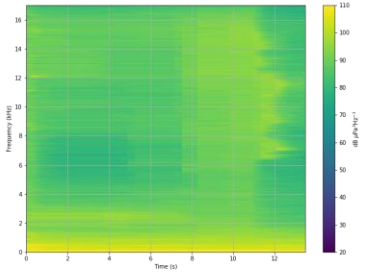

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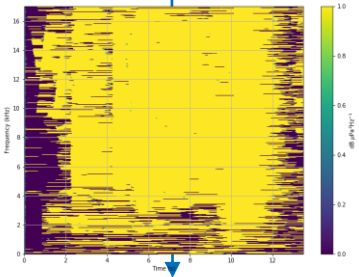

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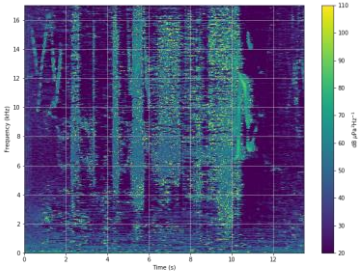

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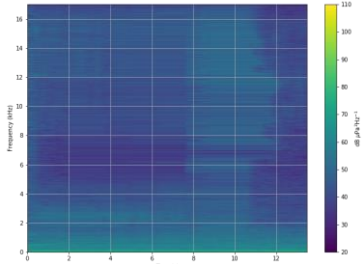

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H. Pihan-Le Bars and B. G. Kinda *under review(**)*

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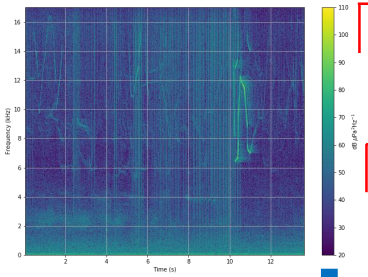

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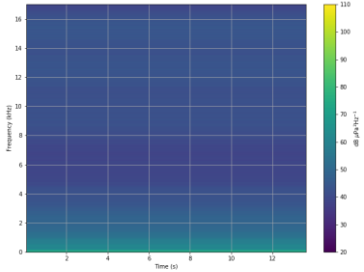

Beta-prime distributions

Ratio of spectrogram coefficient with χ^2 distributions

Spectral subtraction

Clean signal to noise ratio estimated from spectral subtraction of noisy signal and prior noise estimate

Prior noise estimate

Adaptative percentile

Best stationarity window research with automatic tuning

Signal absence probability

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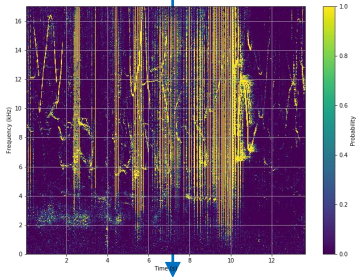

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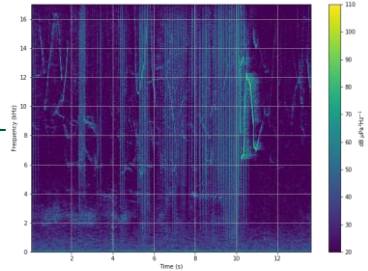

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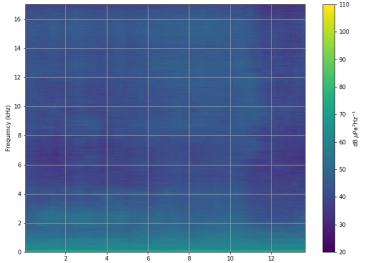

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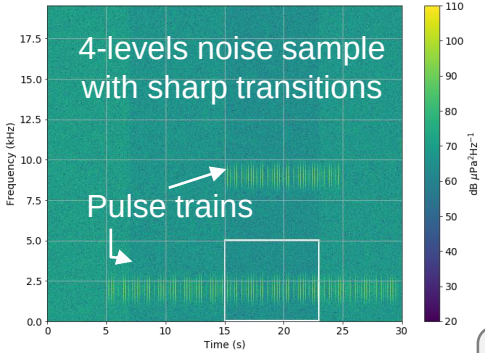
(**) H. Pihan-Le Bars and B. G. Kinda, “Percentile Controlled Recursive Averaging (PCRA) method for noise estimation in underwater acoustics,” under review in JOE.

Prior noise estimate with adaptative percentile

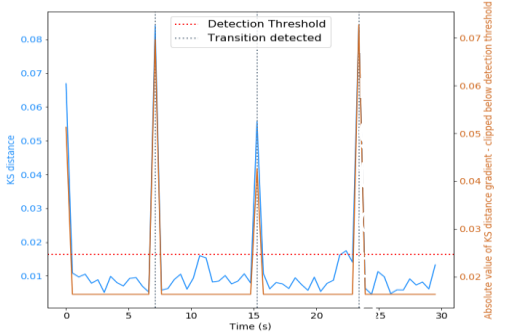
Exemple d'échantillon simulé



Raw data

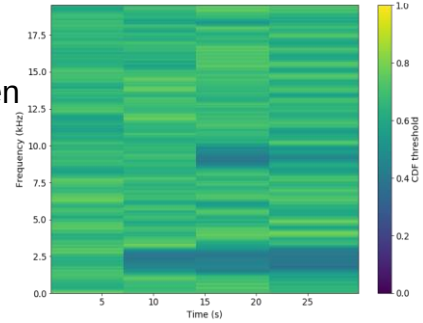
0- Best stationarity window search using KS statistics

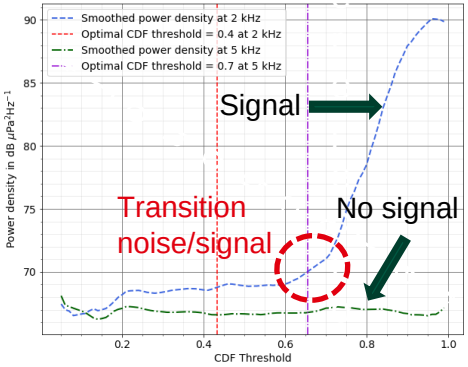
- 2-sample KS test on pairs or time serie sub-samples
- Similarity hypothesis rejection based on significance threshold
- Minimal stationarity horizon estimation



1- Sample segmentation & optimal CDF threshold research ∀ frequency line

- Noise level along the CDF threshold range (1-100%)
- Detection of transition between noise and signal dominance regime





2- Prior noise $\lambda_{N,p}(f)$ from adaptative percentile $q_p(f)$

$$\lambda_{N,p}(f) = -\frac{q_p(f)}{\ln(1-p)} \quad \forall \text{ segments}$$

B. G. Kinda, *et. al.* ,"Under-ice ambient noise in eastern beaufort sea, canadian arctic, and its relation to environmental forcing," J. Acoust. Soc. Am., vol. 134, pp. 1–11, 2013

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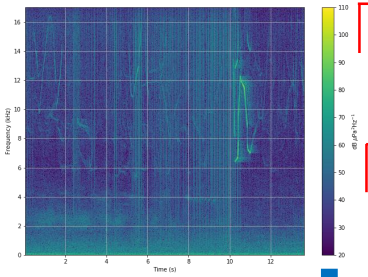

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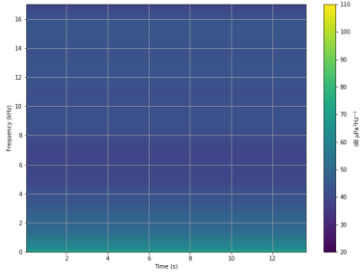

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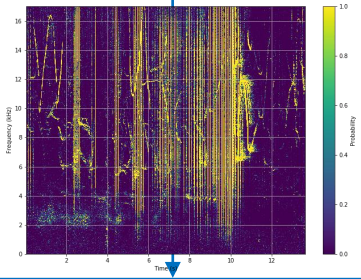

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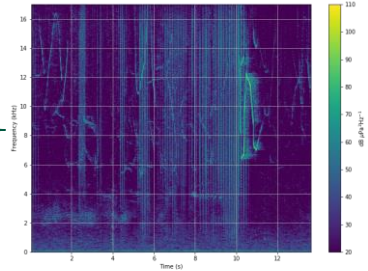

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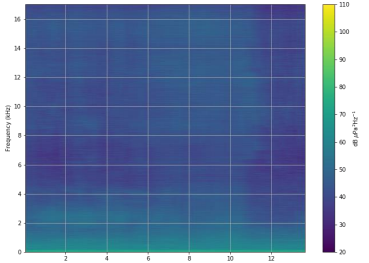

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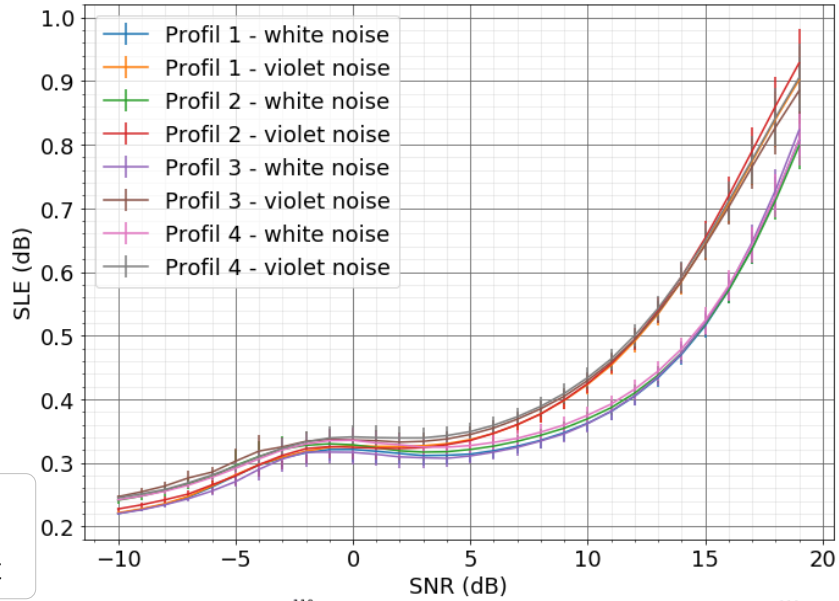
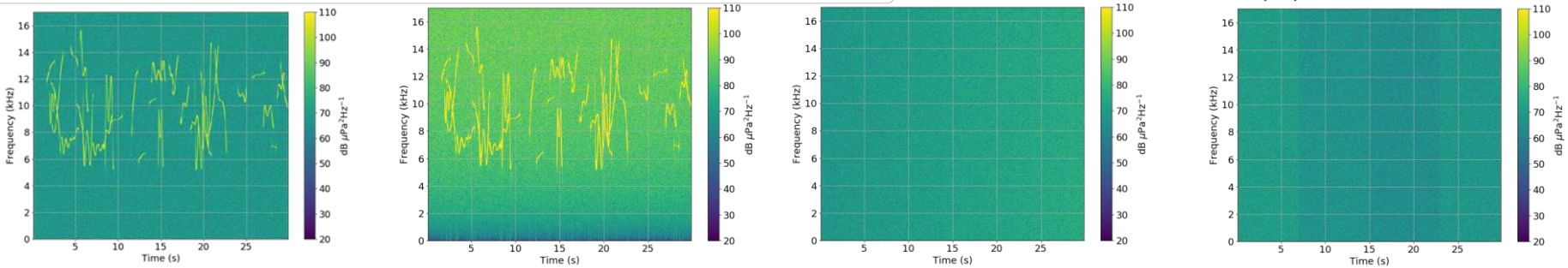


PCRA

- Negligible effect of stationarity profile
- Weak impact of stationarity window underestimation
- Increased sensitivity for violet noise is due to simulation artefact



Performance assessment

Real data – Error indicators on 10 s sub-samples

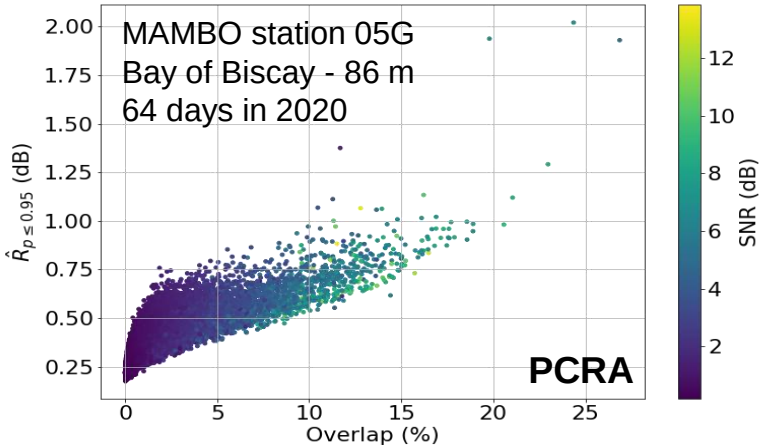
Indicators :

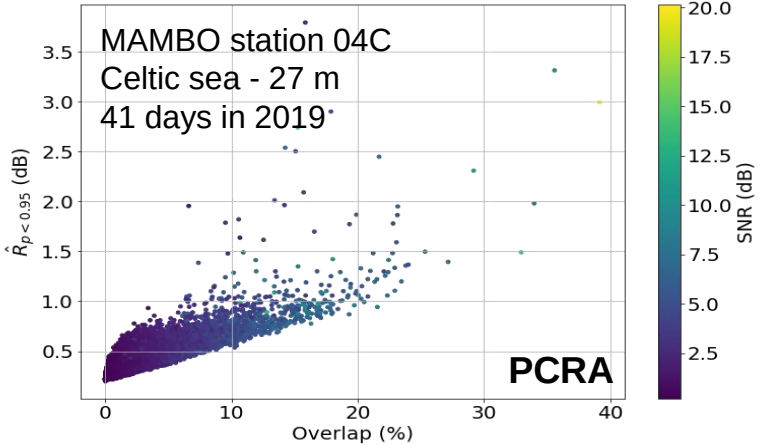
- ❖ SNR (dB) : $R = Y/N$
- ❖ Approximated SLE (dB) : $\tilde{R}_{0,95} = Y_{p<0,95}/N$
- ❖ Signal attenuation (dB): $\Delta R = \left|R - \tilde{R}_{0,95}\right|$

with: Y – Noisy signal spectrogram
N – Estimated noise spectrogram
$Y_{p<0,95}$ – Noisy signal masked if SPP > 0.95

Results :

- Error related to the signal overlap
- Minimal error consistent with those obtained on simulated data
- For an overlap <20%, a large part of the errors are < 1 dB
- The error dispersion for 04C station is likely due to flow noise, negligible for deep-sea station such as 05G

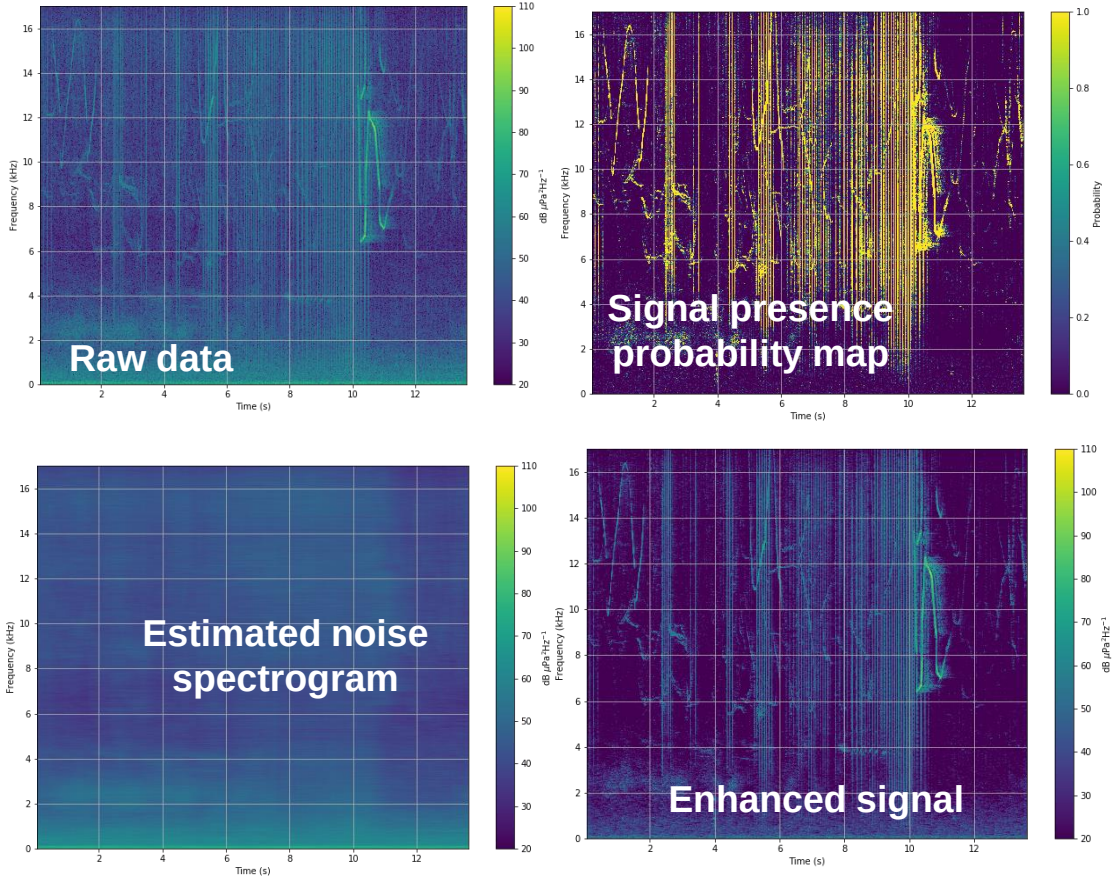




Available products

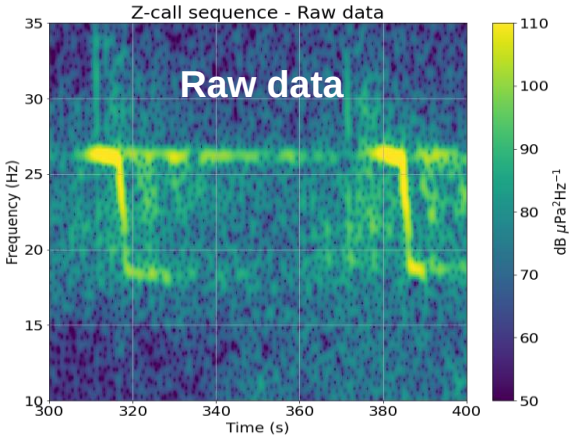
Example of MAMBO sample dolphin (clicks & whistle) + vessel

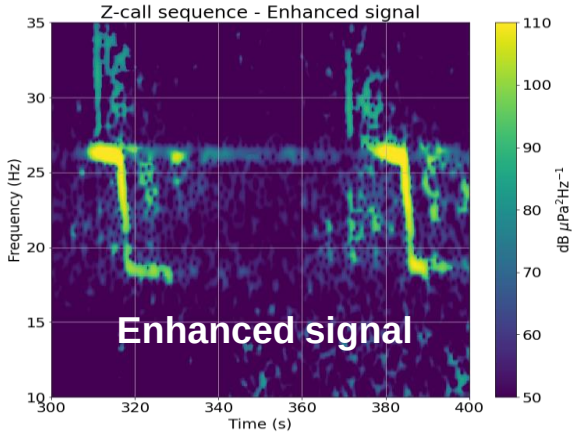
- Noise and detection maps
- Enhanced signal
- Quality indicators

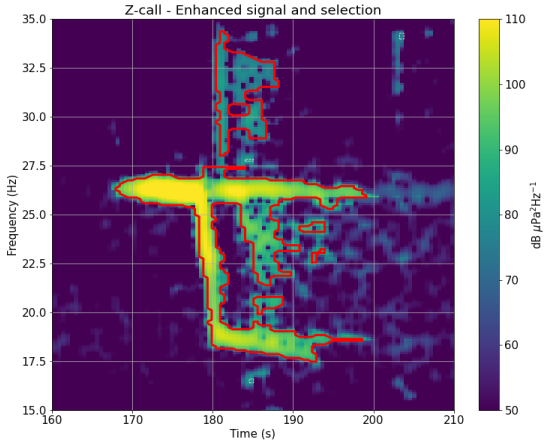


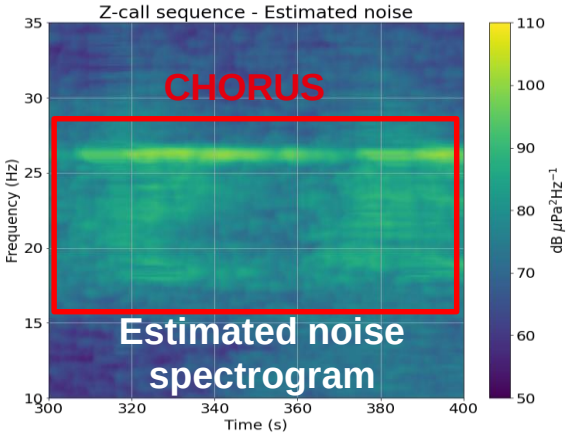
A few examples

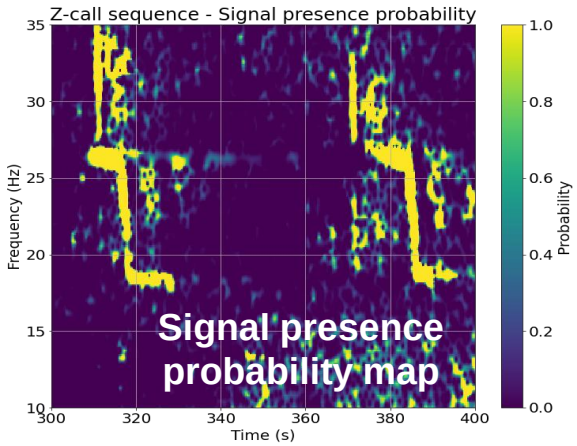
Blue Whale Z-call – Rhum-Rum



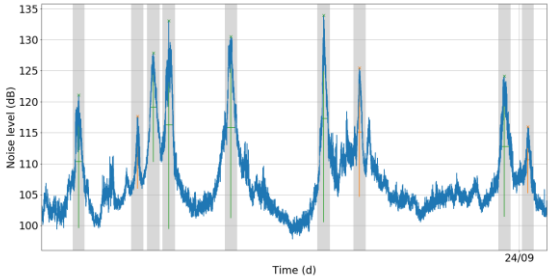




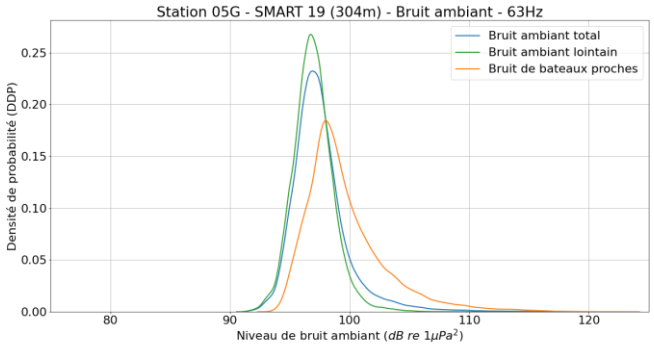


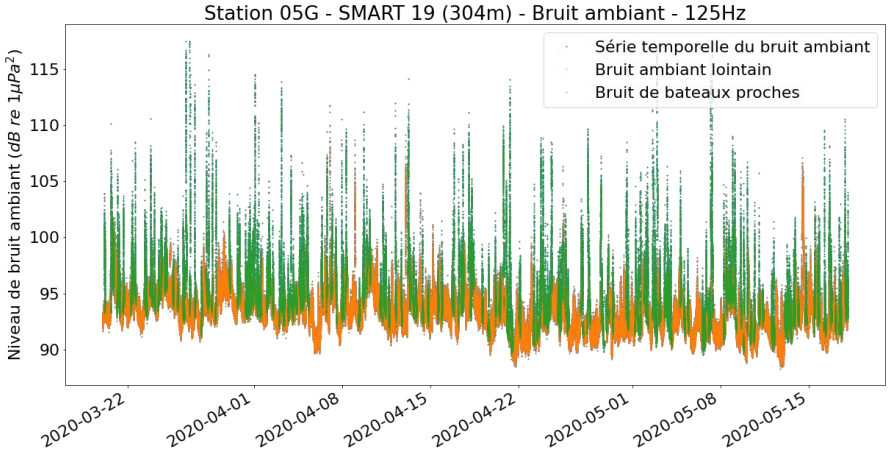


Application to vessel detection in daily time series



Close passages detection and separation



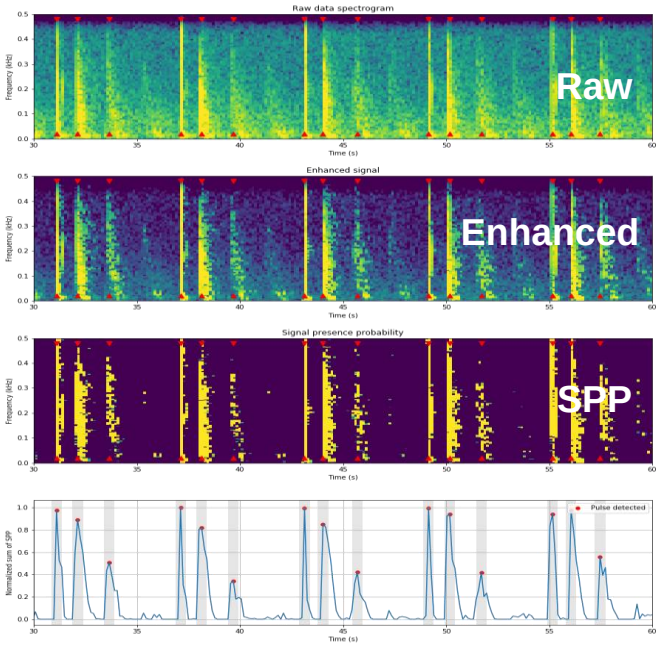


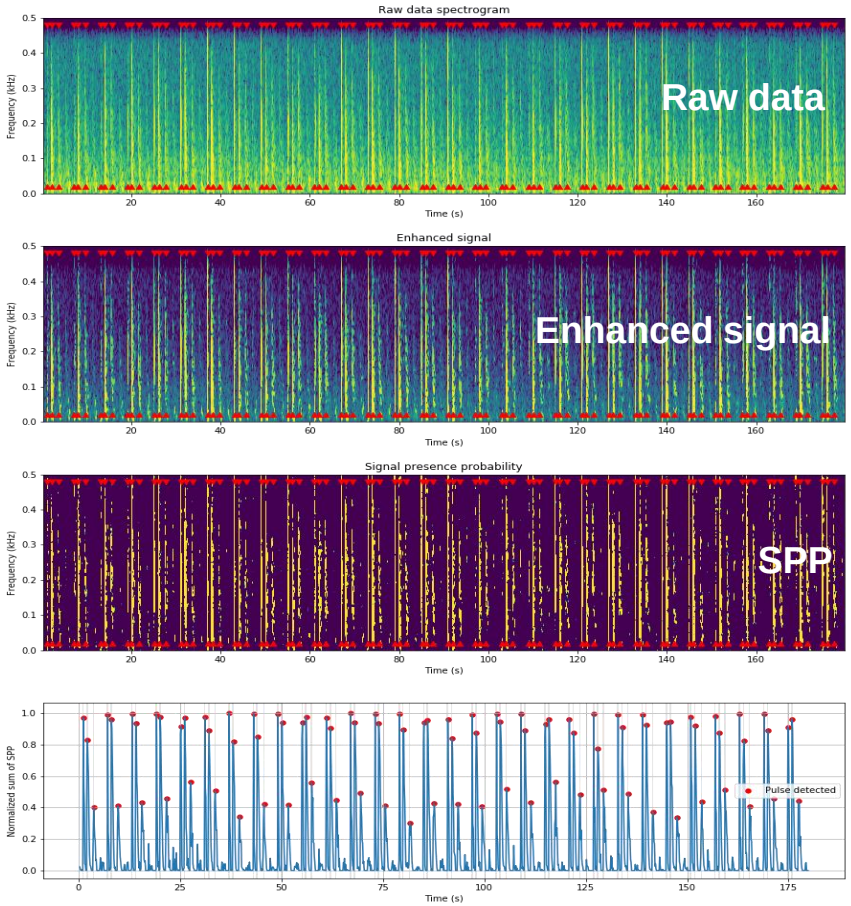
Separation of near and far traffic contributions

Ongoing internship on vessels detection and environnemental impact on noise level

Pulsed signal tagging

CARAPASS 2019 air gun sequence





(*) http://www.rhum-rum.net/fr/

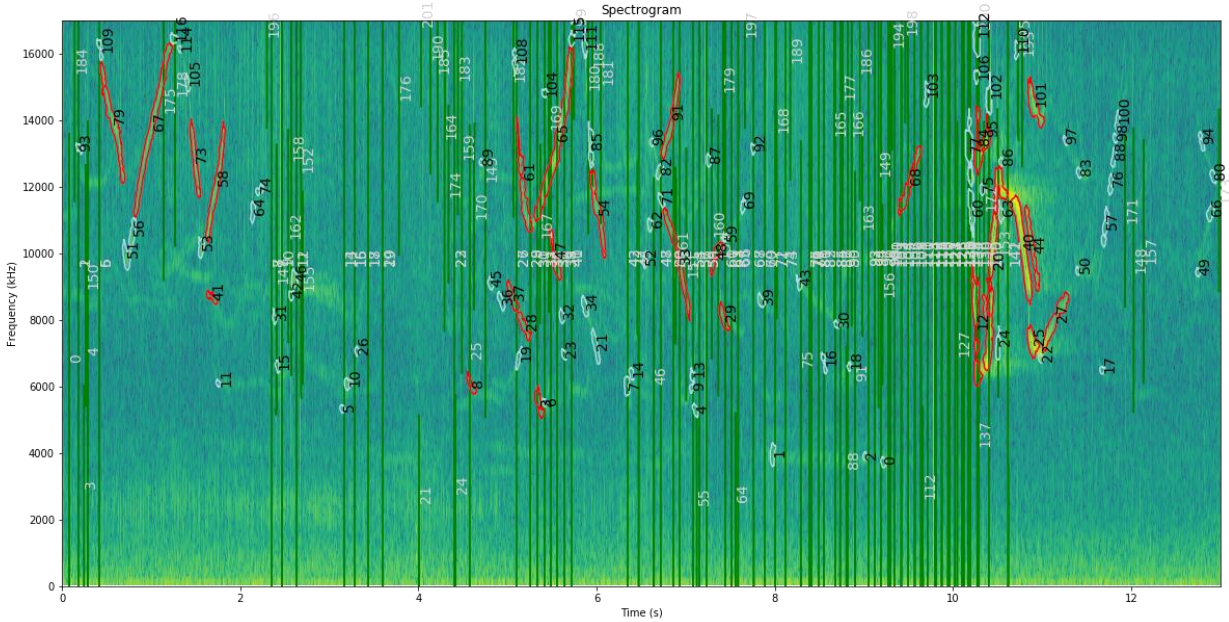
Basic signal features extraction

Clicks and whistle disentanglement

MAMBO sample with dolphin tonal and pulse emission

Basic treatments on SPP image to :

- Transient signal tagging
- Pulsed and Tonal signals disentanglement



(*) http://www.rhum-rum.net/fr/

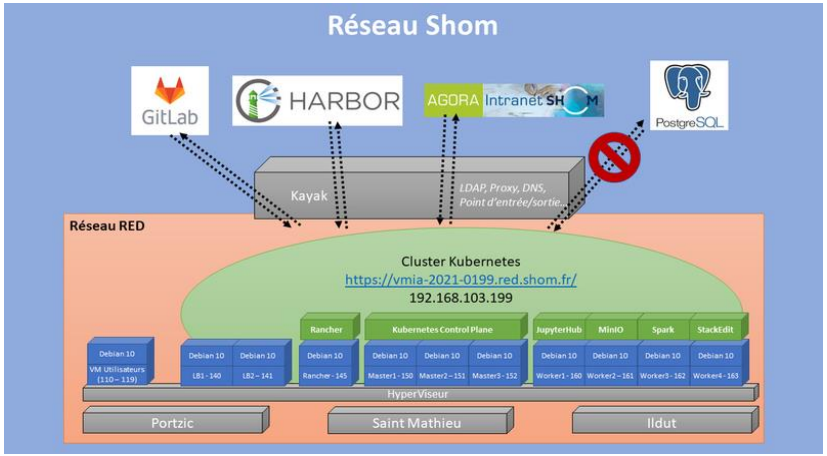
Building of a first dataset for transient signals

- Tag isolated transients and vessels
- Give insights on their TF structure/type (pulsed or tonal)
- Local and segmental statistics

Transient/vessel object creation

Creation of an object oriented database on minio-S3

Labellisation on target segments/events with selection based on signal features to cover a large variety of signals



Réseau Recherche & Développement du SHOM

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(*) http://www.rhum-rum.net/fr/

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Thanks !

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