From Ocean sound to coastal ecosystem monitoring

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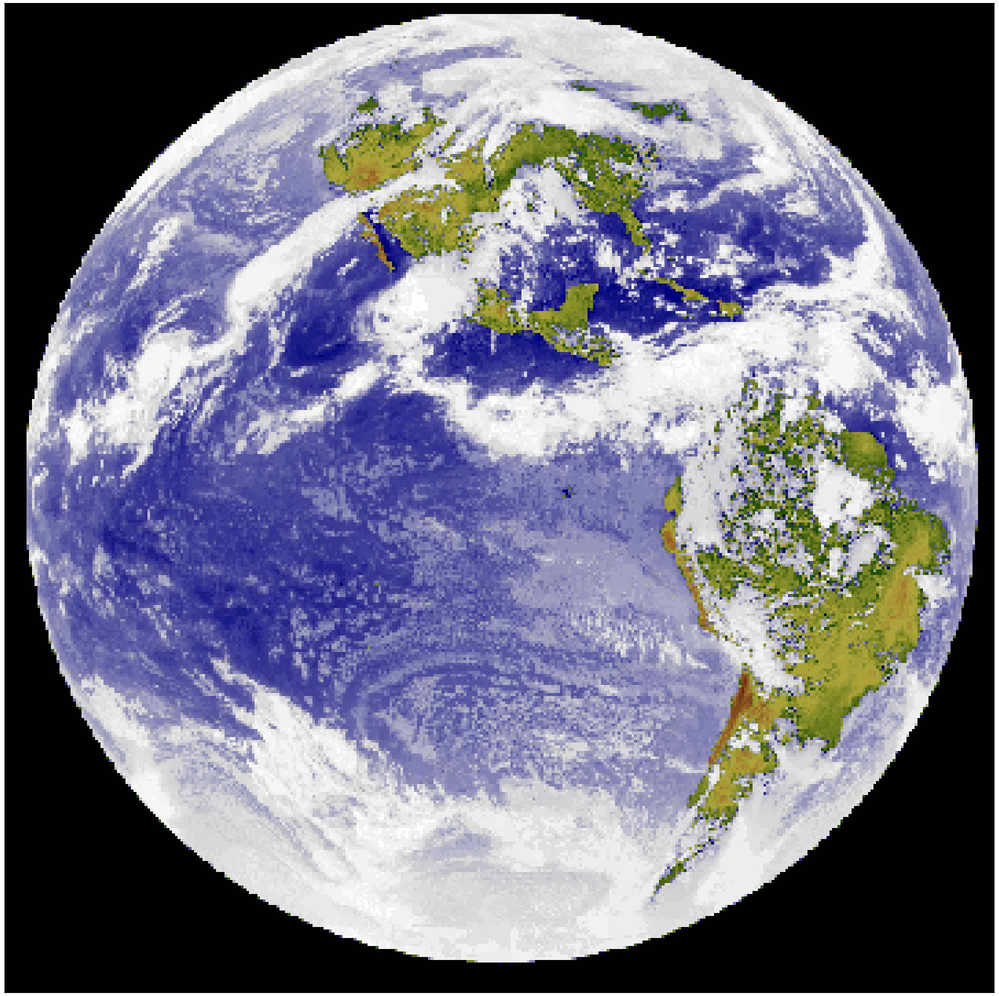
« Time-series analysis in Marine science and applications for industry »
Conference in Logonna-Daoulas, France, 17-22 sept. 2012

Ocean observation a priority of the 21st century



Largely unknown

Global annual value of services provided by the Ocean : 20 900 billions $

Costanza et al. 1997

Coastal areas

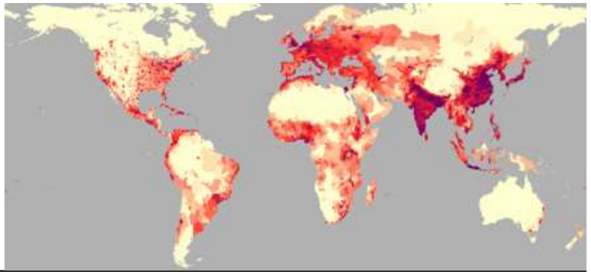
60 % (12 500 M$/year) of the annual value of ocean services ***(Costanza et al., 1997)***

Coastal areas

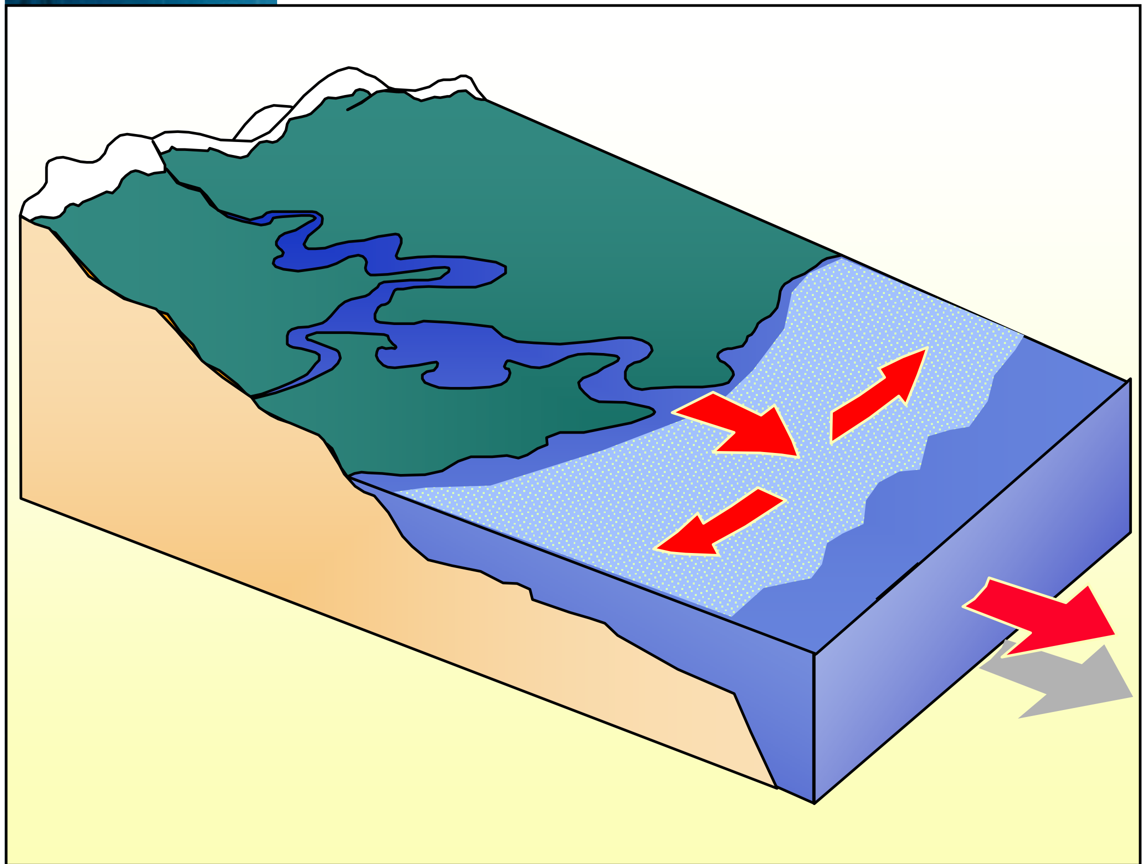
- **8 % of the hydrosphere …. but responsible for**
- **1/3 of the total production of organic carbon** *(Wollast, 1991)*
- **1/2 of the Ocean's productivity** *(Berger et al., 1989)*

Coastal areas

44% of the world's population lives within 150 km from the coast



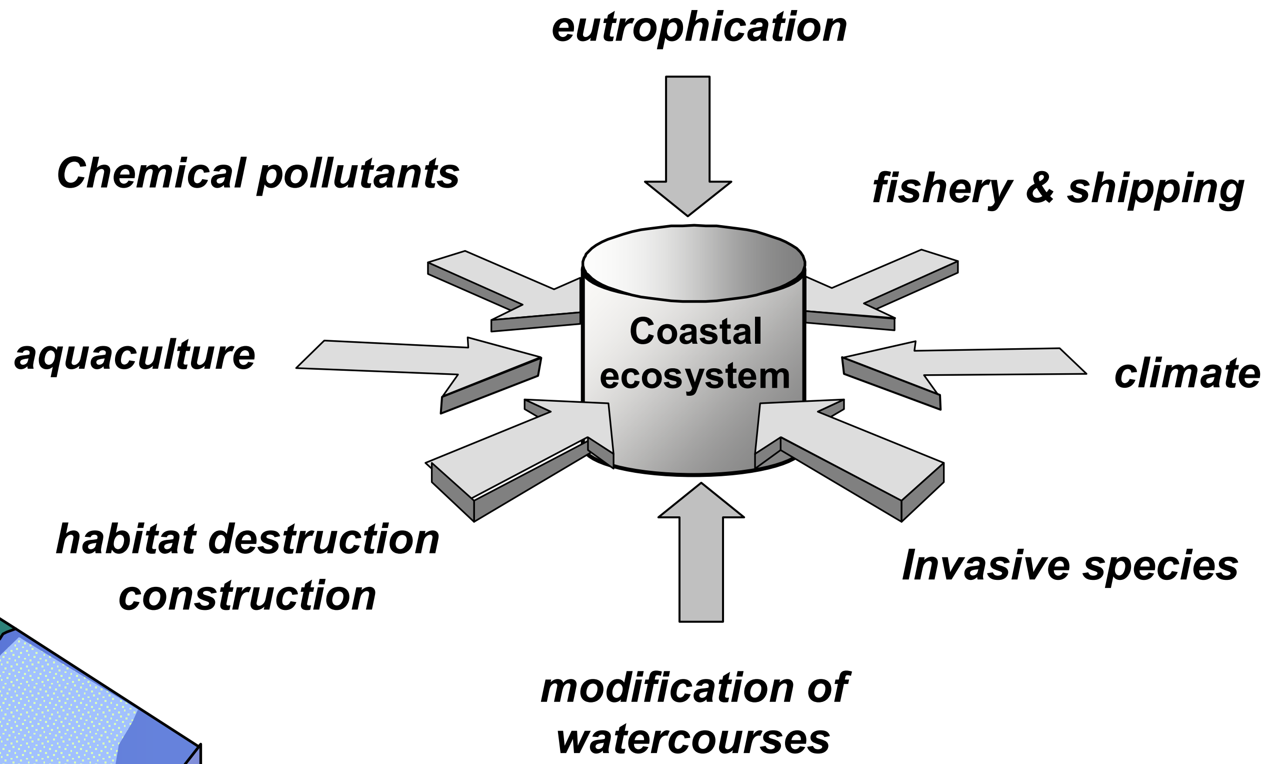
Coastal areas

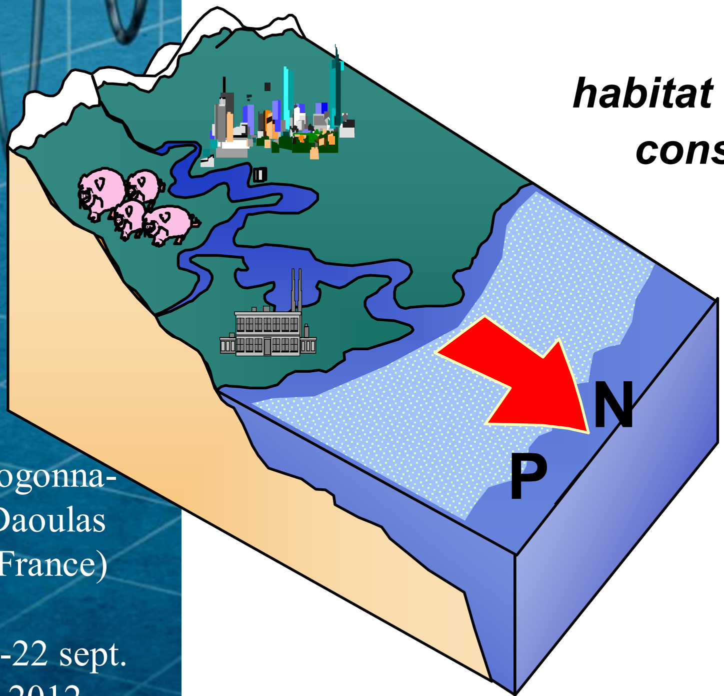


The coastal zone is

- at the interface between terrestrial and marine dynamics
- inevitable transition zone between the continent and the open ocean
- extremely rich in terms of biotic productivity and biodiversity
- highly dynamic (hydrodynamic, sediments, biogeochemistry, ecological communities, mosaic…)

Coastal areas





Coastal ecosystem monitoring!

Climatic and anthropogenic factors including their fluctuations in addition to the natural dynamics of coastal ecosystems

Study and understanding of coastal ecosystem functioning/ dynamics and prediction of environmental changes need and benefit from monitoring methods integrating the different components (biotic, abiotic, anthropogenic) over the long term.

Why passive acoustic time series?

METHOD

- Dynamic! long-term & continuous monitoring at high resolution
- non invasive
- real-time possible
- independent of substrates, environments, weather, day-night …
- cost-effective

ENVIRONMENTAL MONITORING

- Integrative! biotic, abiotic and anthropogenic factors
- from invertebrates to mammals
- from the individual to the ecosystem

Soundscape Ecology

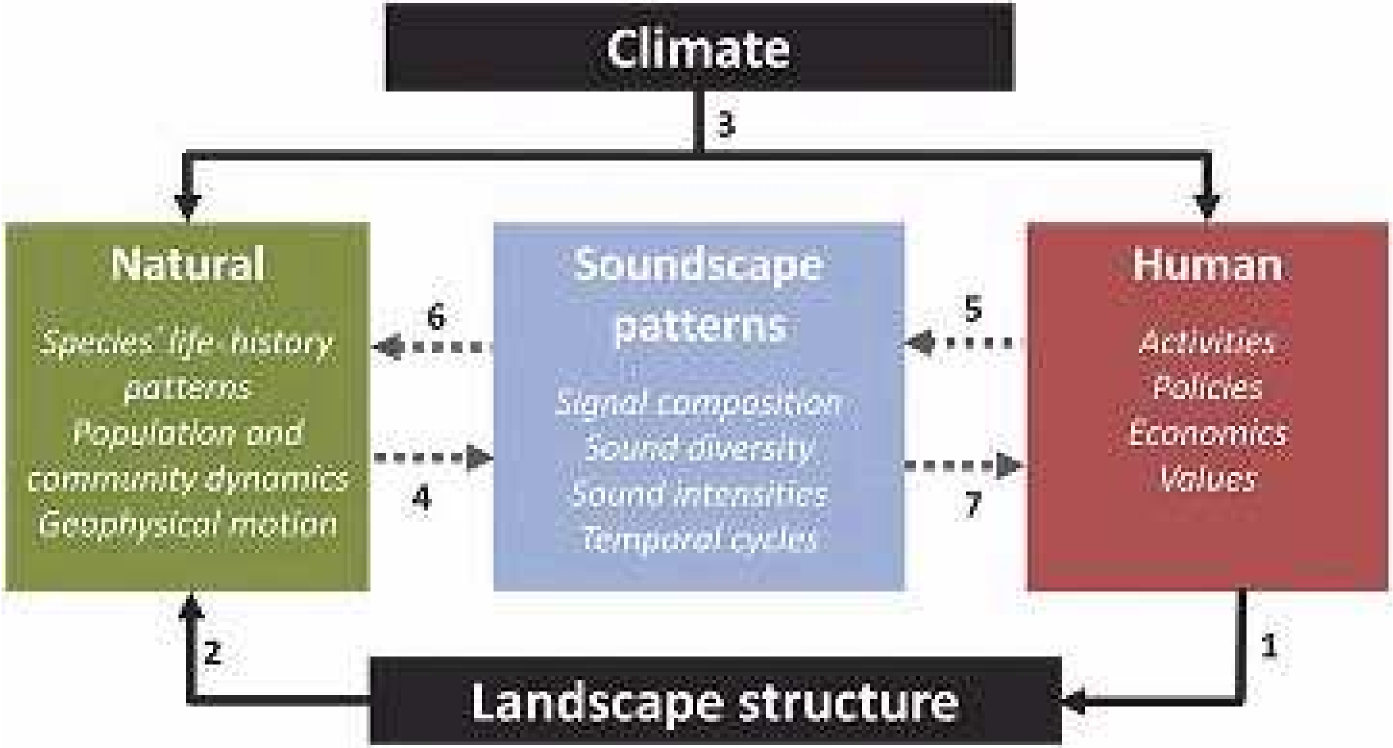
The science of sound in the landscape

"Soundscape ecology can be described as all sounds, those of biophony, geophony, and anthrophony, emanating from a given landscape to create unique acoustical patterns across a variety of spatial and temporal scales".

Pijanowski et al. 2011

Southworth 1969, Schafer 1997, Truax 1999, Krause 1987

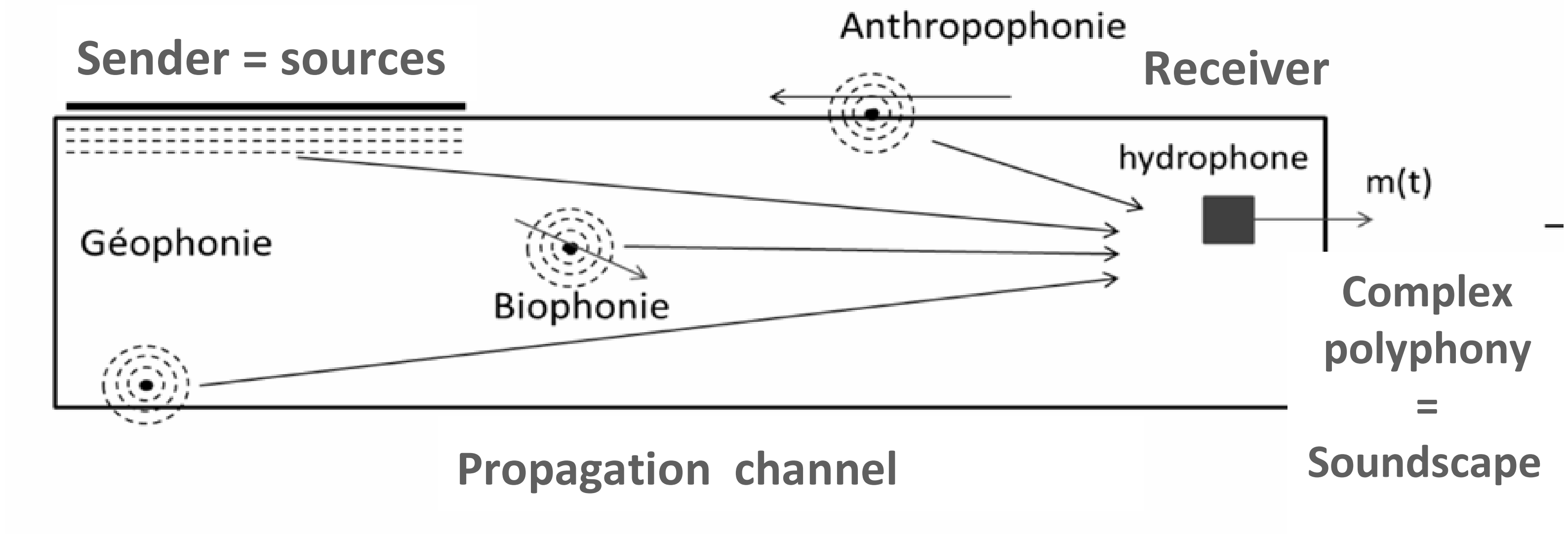
Soundscape Ecology



terrestrial & human-centred

Pijanowski et al. 2011

Soundscape Ecology & the aquatic environment



Received sound characteristics depend on:

- Type of source (continuous, punctual, origin) and behaviour
- Intensity (amplitude) of a signal
- Signal features (frequency content)
- Distance & propagation channel

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Aquatic environment = Soundscape

3 soundscape components

Broadband, impulsive & faint -> narrowband, low, mid, hign frequency, FM & loud

Biophony

Range: 1m -> 10s of m -> 100ds m 1000ds m

Gaussian, variable intensities-> broadband, impulsive & loud

Géophony

Range: > 100, 1000ds m

Gaussian -> impulsive, wideband & always loud

Anthropophony

Range: > 100, 1000ds m

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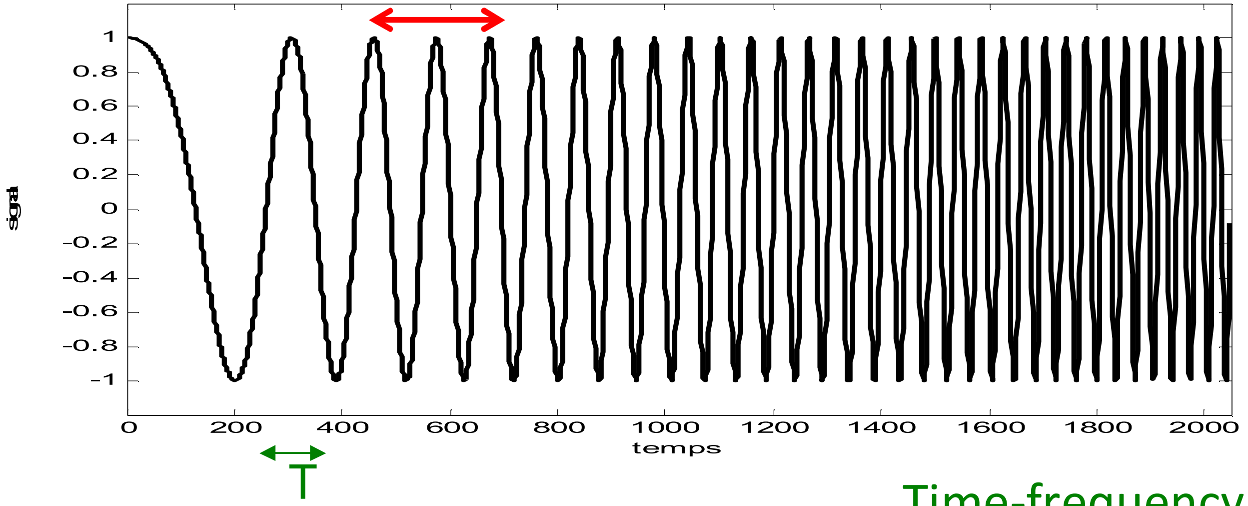
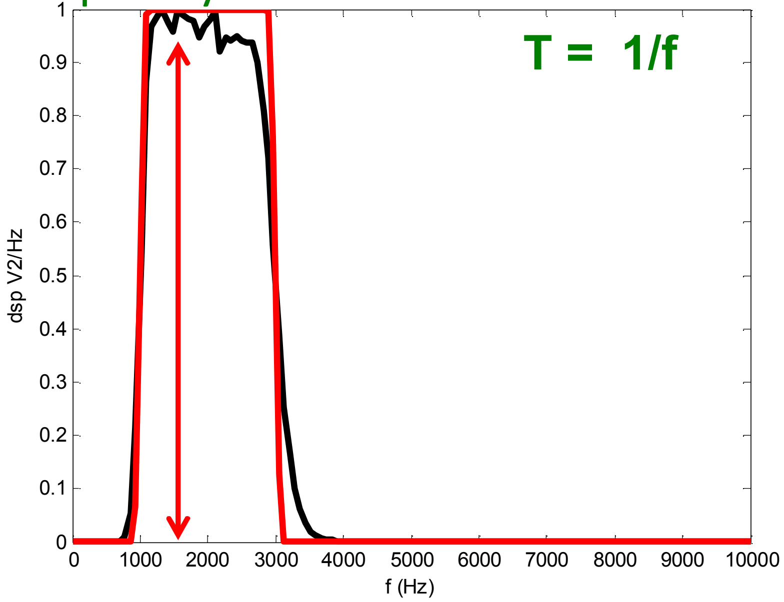
Sound

Sound level in dB (ref 1µPa (@1m)

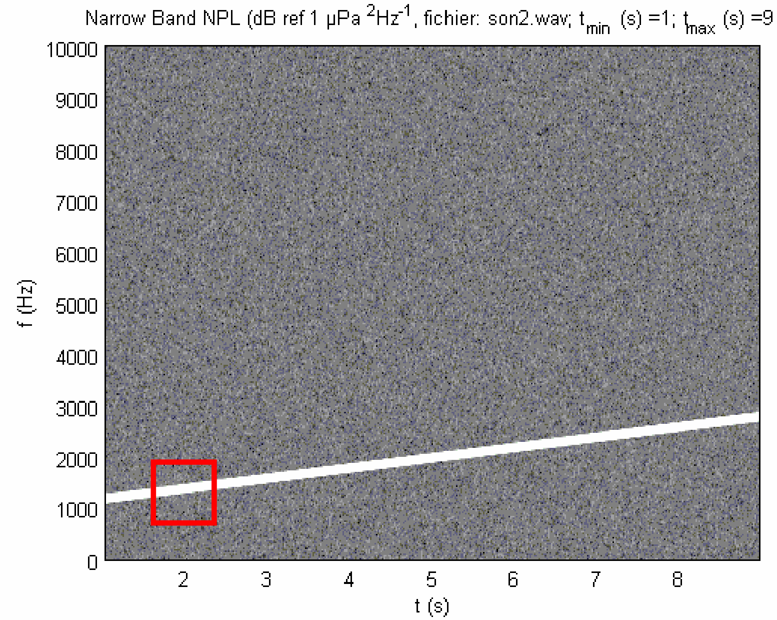
Time domain



Frequency domain



Time-frequency



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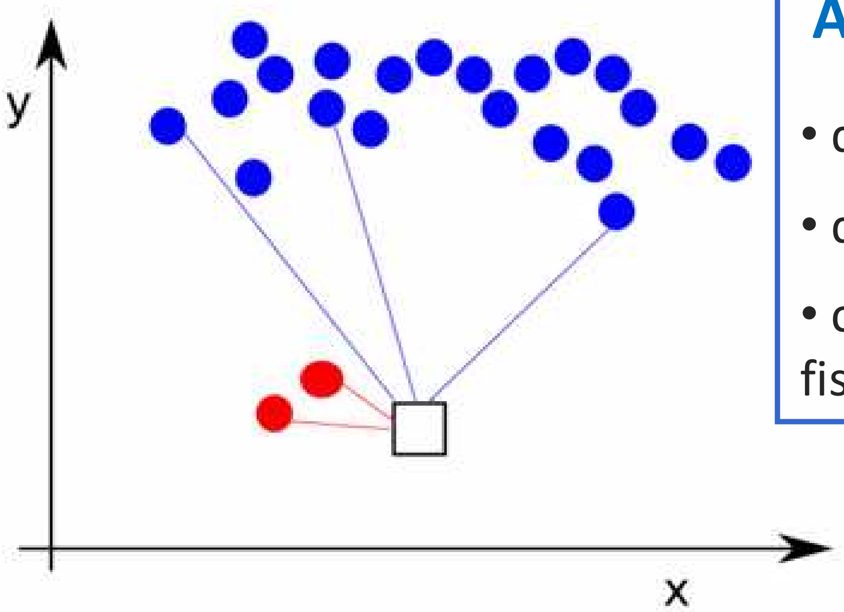
Close vs. distant sources



Ambient noise

- diffuse, random noise, Gaussian
- distant sources
- choruses (sum of boat noises, fish & whale choruses, ...)

Individually distinctive sources

- close sources
- identifiable sounds
- ‘object’-specific sound features

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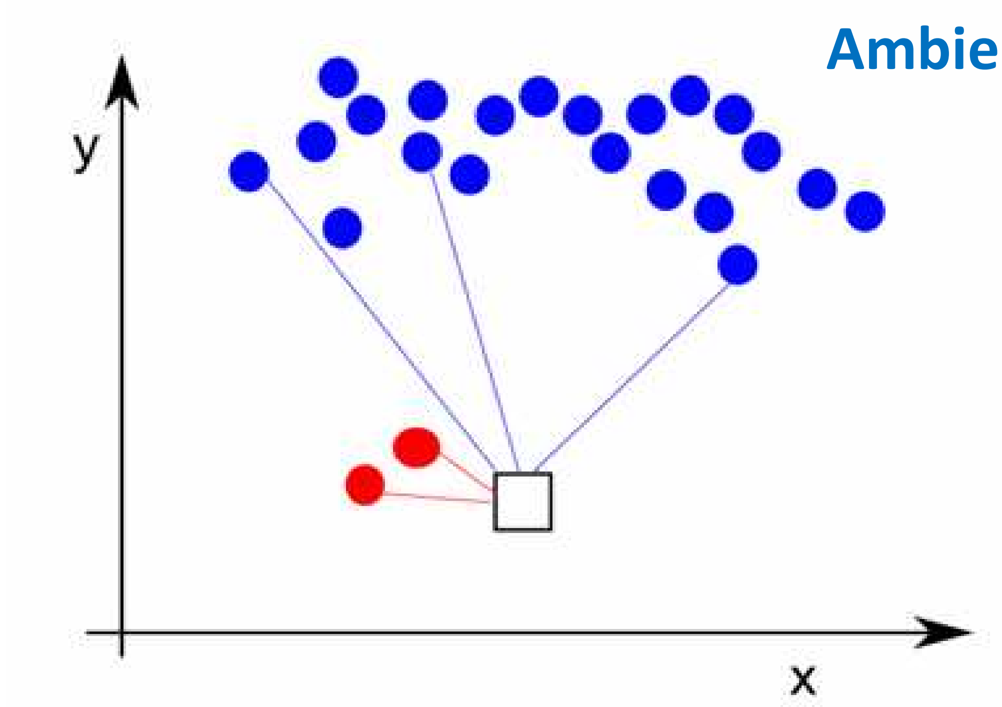
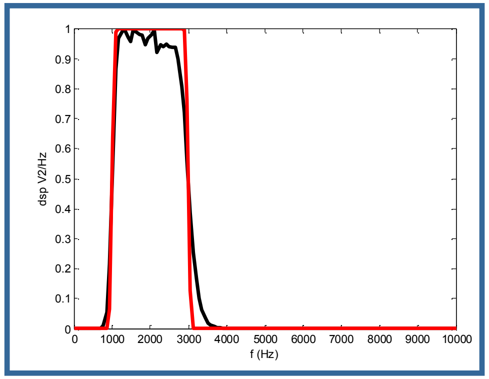
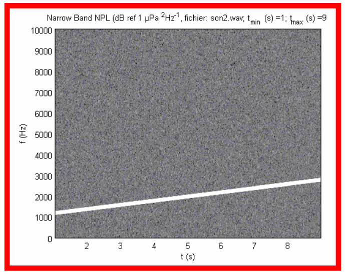
Close vs. distant sources

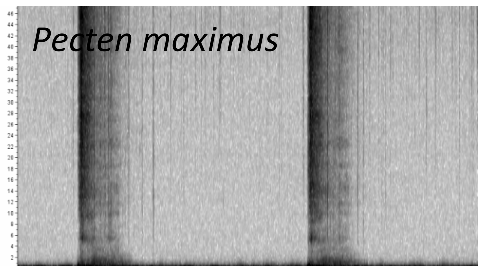


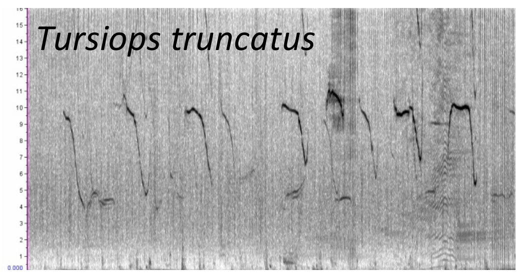
Ambient noise

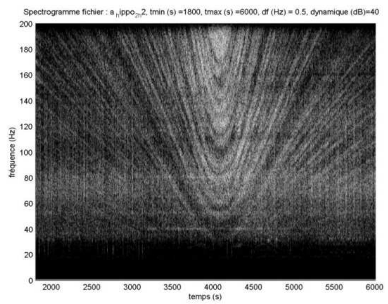


Individually distinctive sources









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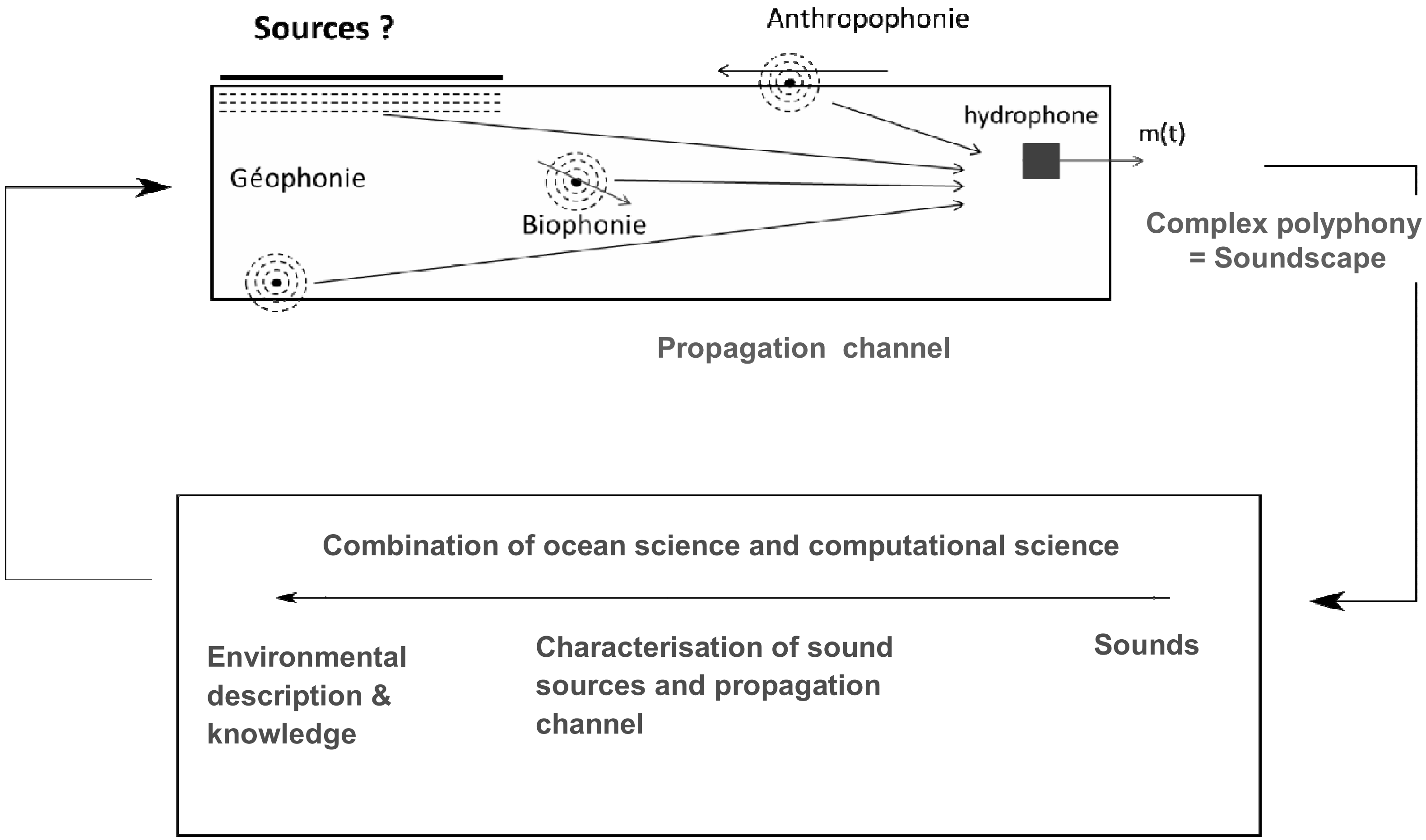

Passive acoustic monitoring of the marine environment

Passive acoustics = indirect, non-selective measure => PROCESSING!

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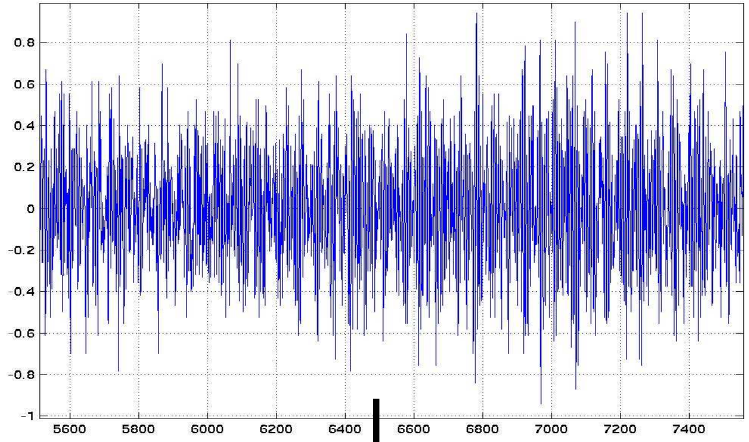
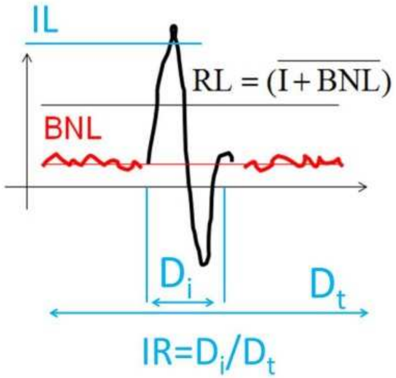
Acoustic descriptors



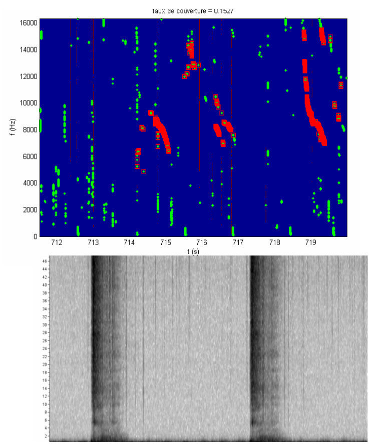
Processing algorithms

Acoustic descriptors!

Ambient noise



Individually distinctive signals



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Acoustic time series for marine soundscape ecology

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Acoustic time series for marine soundscape ecology

- access difficult or limited
- high temporal turnover and dynamics of coastal areas (ecological communities, substrates, …)
- limited knowledge of temporal changes in ecological communities (biodiversity, key species,...)
- challenge in distinguishing changes attributed to external factors (anthropogenic activities) from underlying natural variability
- rates of temporal turnover vary amongst ecosystem types and in relation to environmental factors

Upsurge of interest in long-term datasets and need for high-frequency, integrative, non intrusive, easily deployable monitoring systems

Magurran et al. 2010

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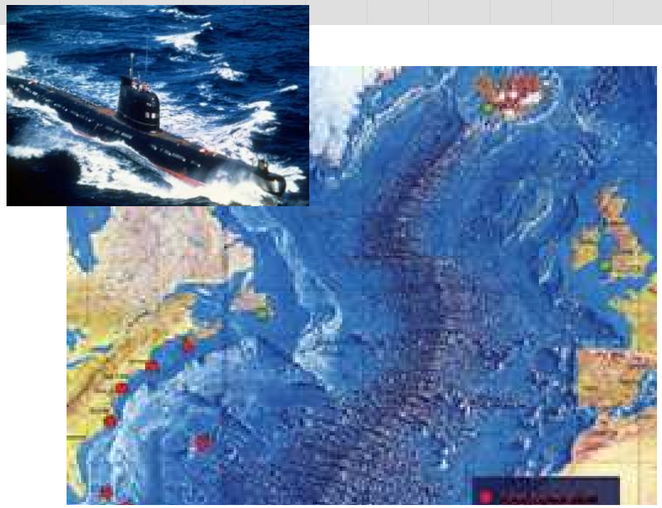
Use of passive acoustic time series in the ocean



To date, no coherent theory regarding the ecological significance of all sounds emanating from a landscape exists.

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Acoustic time series for marine soundscape ecology

BIOPHONY

Chronobiology *(Radford et al. 2008)*

Habitat description

(Cato, 1978, Radford et al. & Kennedy et al. 2010)

Species-specific choruses

(Johnson et al. 1947, Cato & Bell, 1992, Radford et al. 2008)

GEOPHONY

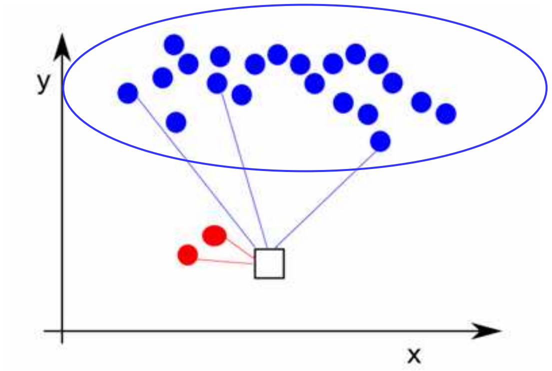
Wind & weather

(Nyusten 1985, Nyusten et al. 2010, Reeder et al. 2011)

ANTHROPOPHONY

Marine Strategy Framework Directive

Impact studies *(e.g., Southall et al. 2007)*



No attempt to extract the 3 components from long-term acoustic datasets to fully describe marine ecological soundscapes via budgets

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Objectives

- How to describe a marine coastal ecological soundscape: which acoustic descriptors (metrics)? Which algorithms ?

- Reconstruct an acoustic landscape using the time series of the descriptors

- Analyse the time series (spatio-temporal patterns): their contribution to the description and understanding of the environment

BIOPHONY – GEOPHONY - ANTHROPOPHONY

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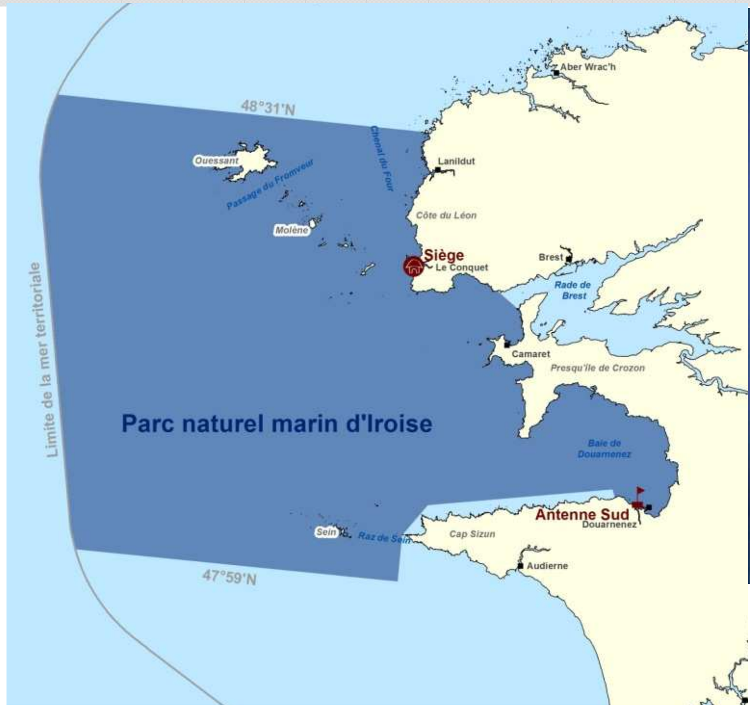
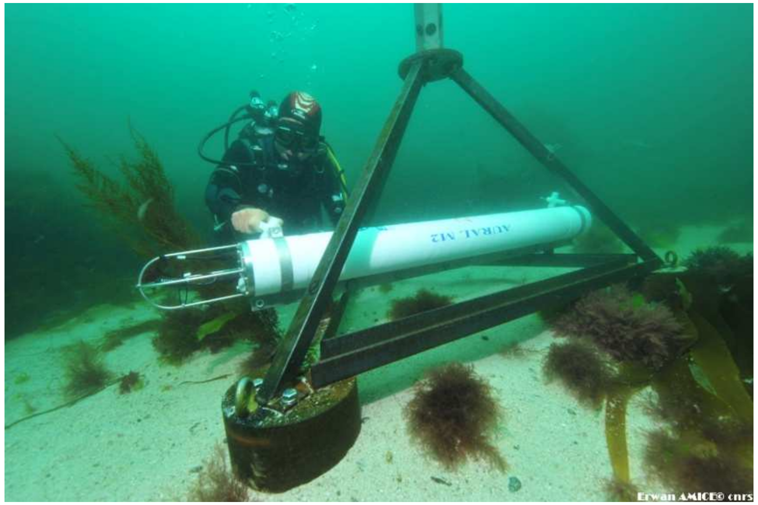
Study site





Recordings: 10/06 – 20/11/2011

Rec: sf=32362Hz , continuous

Weather station & models (Previmer, Y. Stephan (SHOM))

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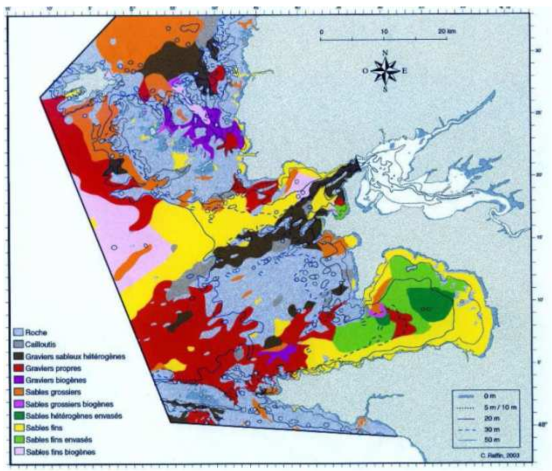
Study site

800 – 1000 animal species
300 - 400 species of algae & plants, *(Raffin 2003)*



Alpheus macrocheles
1000 / ha
(Grall, J. OSU Brest, 2011)

Echinus esculentus
2000 / ha (100mx100m)
(Grall, J. OSU Brest, 2011)

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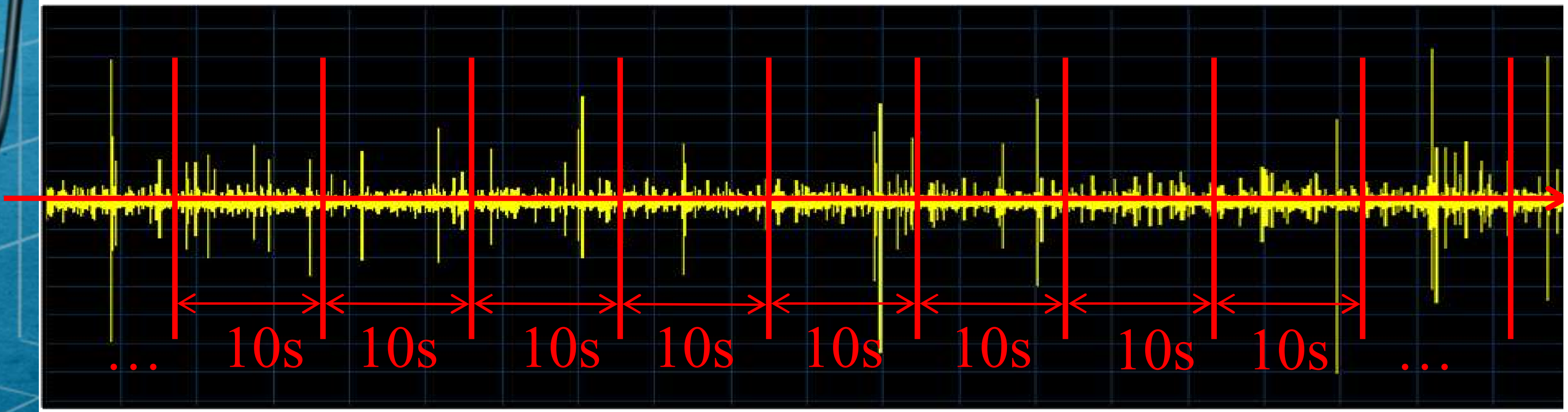
Some numbers

- 1 year = signal processing development & pilot experiments

- 6 months observations (3 terabytes raw data, 3 recorders 3x15 k€ , boat trips ~ 6 k€)



- 2 months of data processing & analysis

=> 35 days PC calculations

=> 1.5 Mio segments

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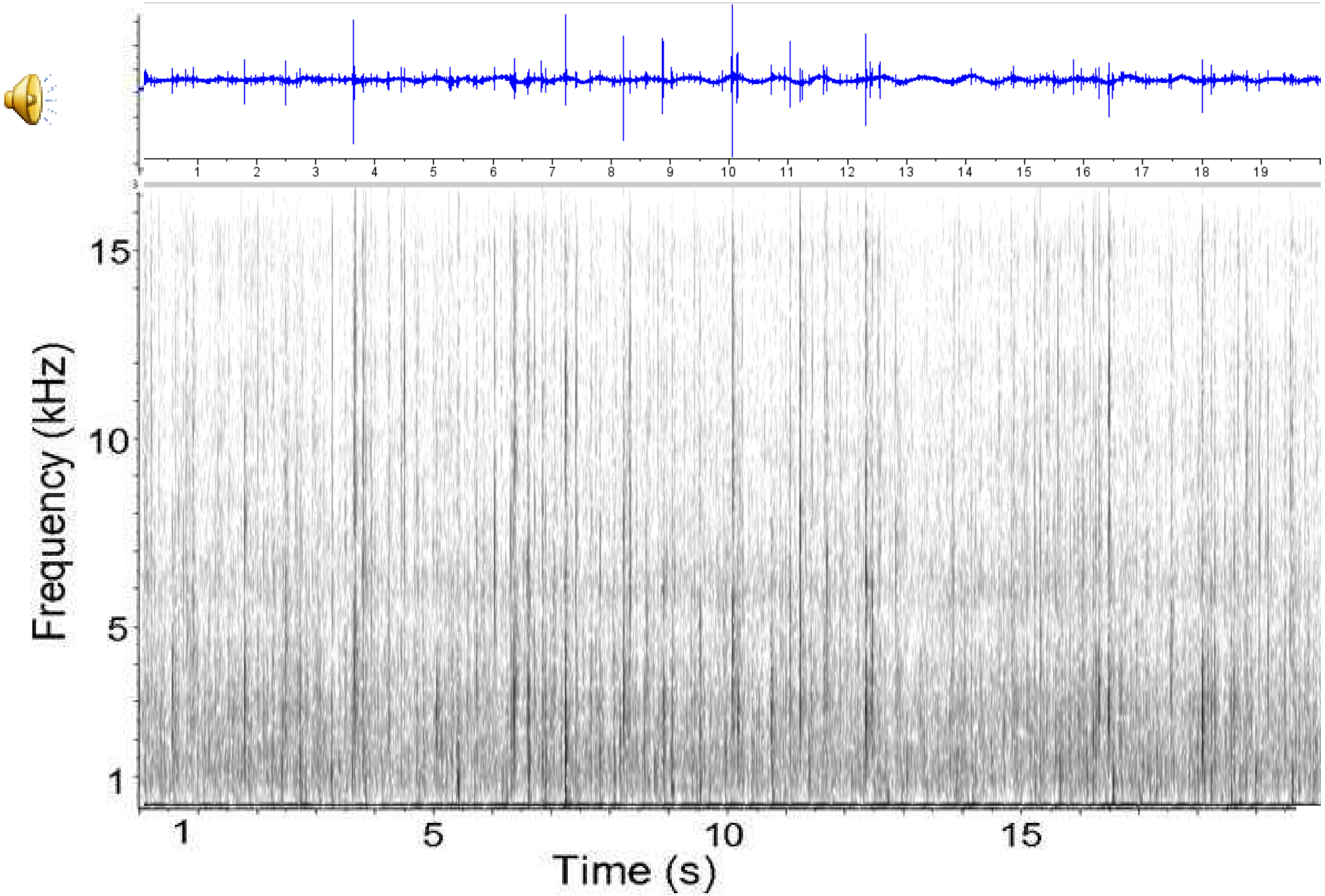
Typical ambient noise segment



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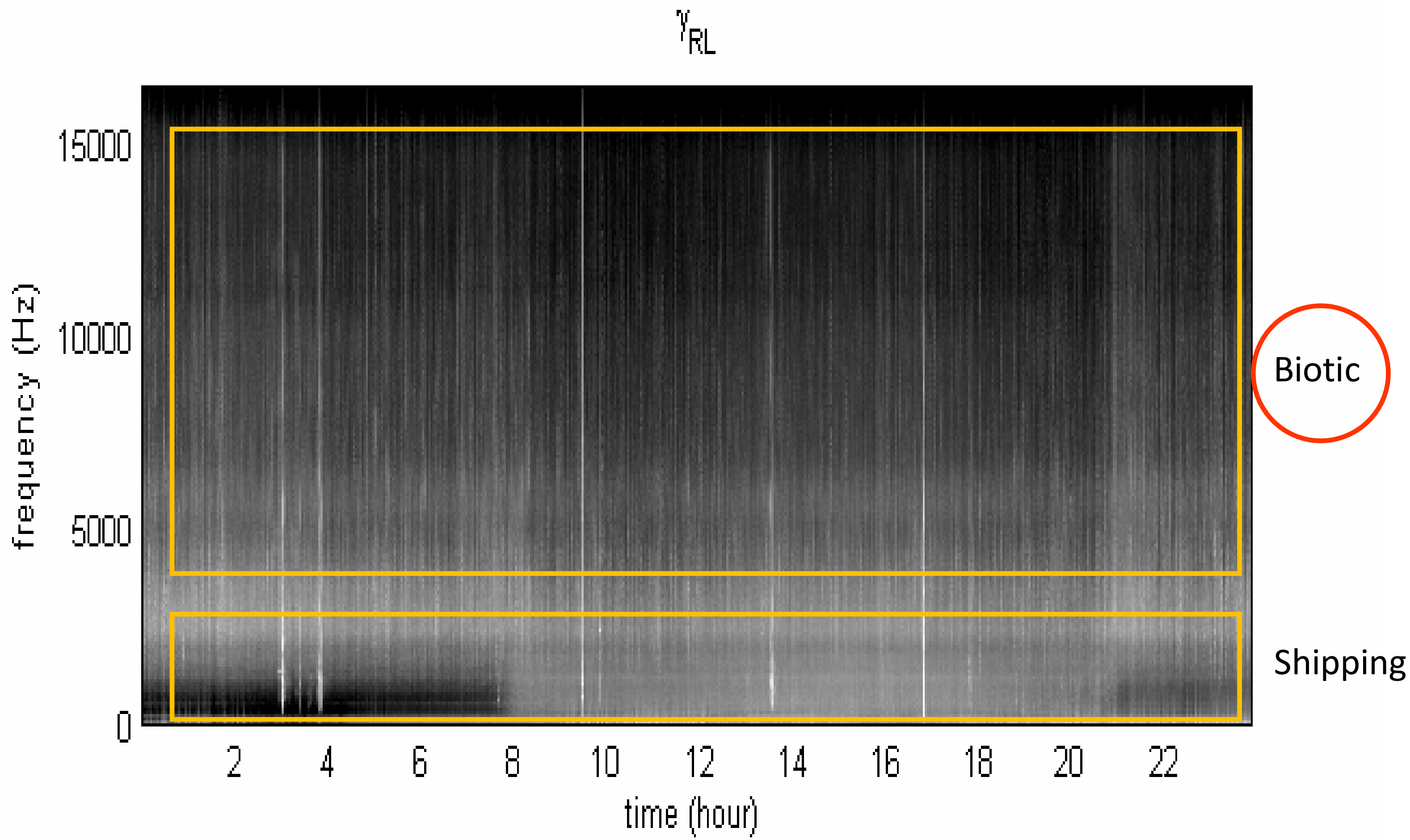
Diagnostics
24h spectrogram



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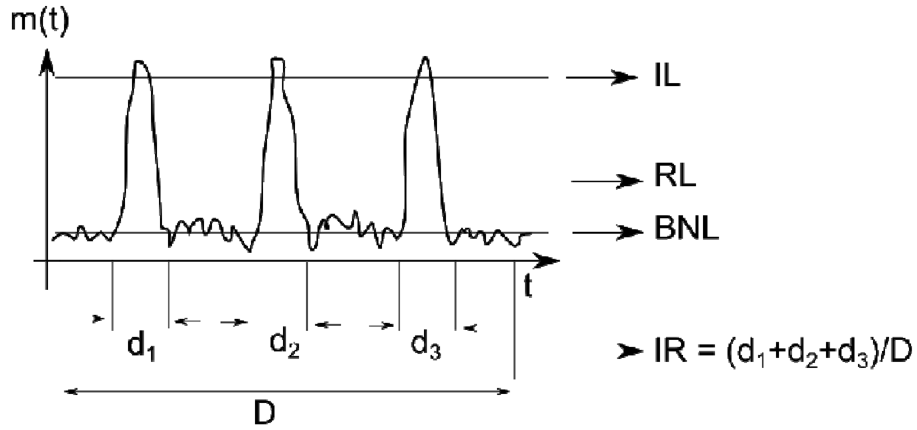
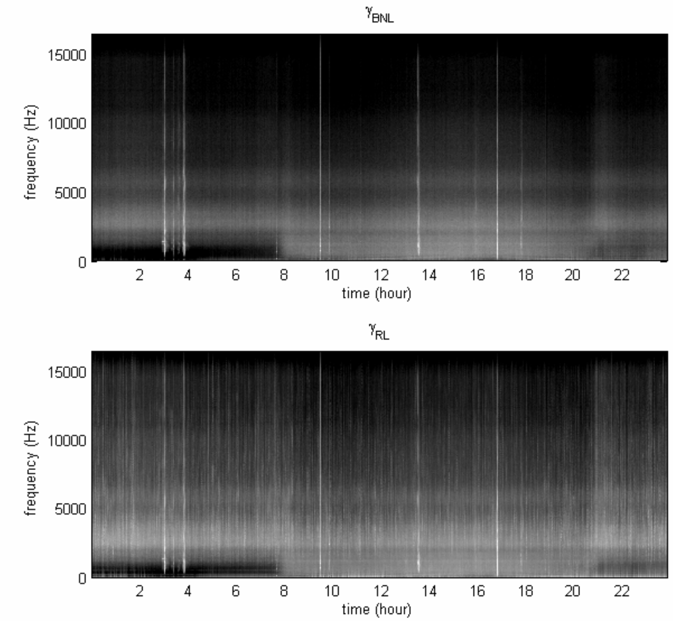
Outputs
acoustic metrics of ambient noise





Quantile	1%	5%	25%	**50%**	75%	95%	99%
Kurtosis							
Kurtosis	353	503	720	910	1141	1617	2011
Level dB ref 1 μPa^2							
RL	93	93.58	95.11	**96.25**	97.2	98.72	99.38
BNL	85.41	86.11	87.50	**88.7**	89.93	91.58	92.54
IL	106.72	107.35	108.51	**109.45**	110.3	111.4	112.28
Impulse Rate (%)							
IR	0.014	0.02	0.03	**0.035**	0.043	0.051	0.054

RL: Dominated by impulsive sounds
BNL: no impulsive sounds

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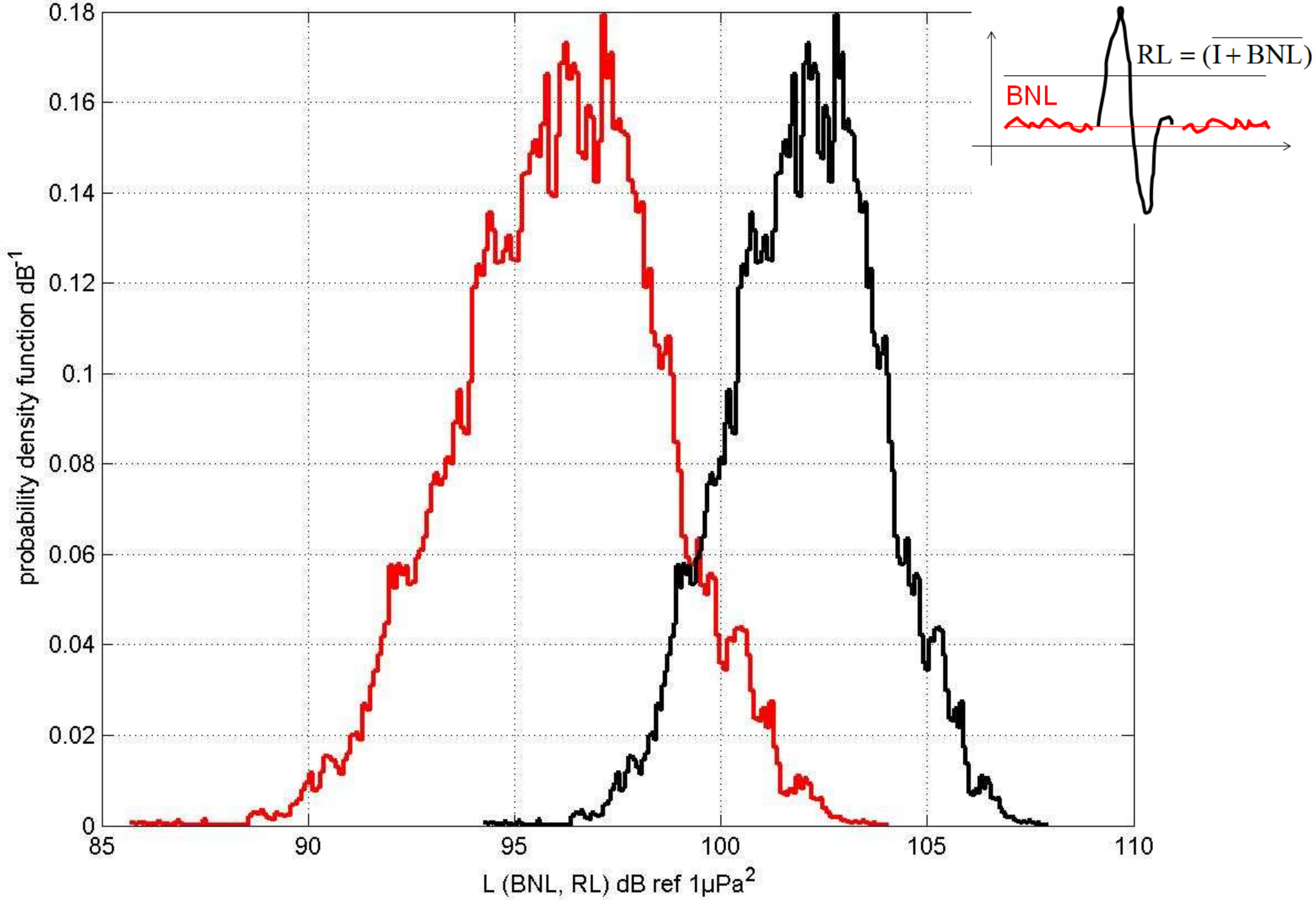
Distribution of RL & BNL
(Biotic band) 6 months



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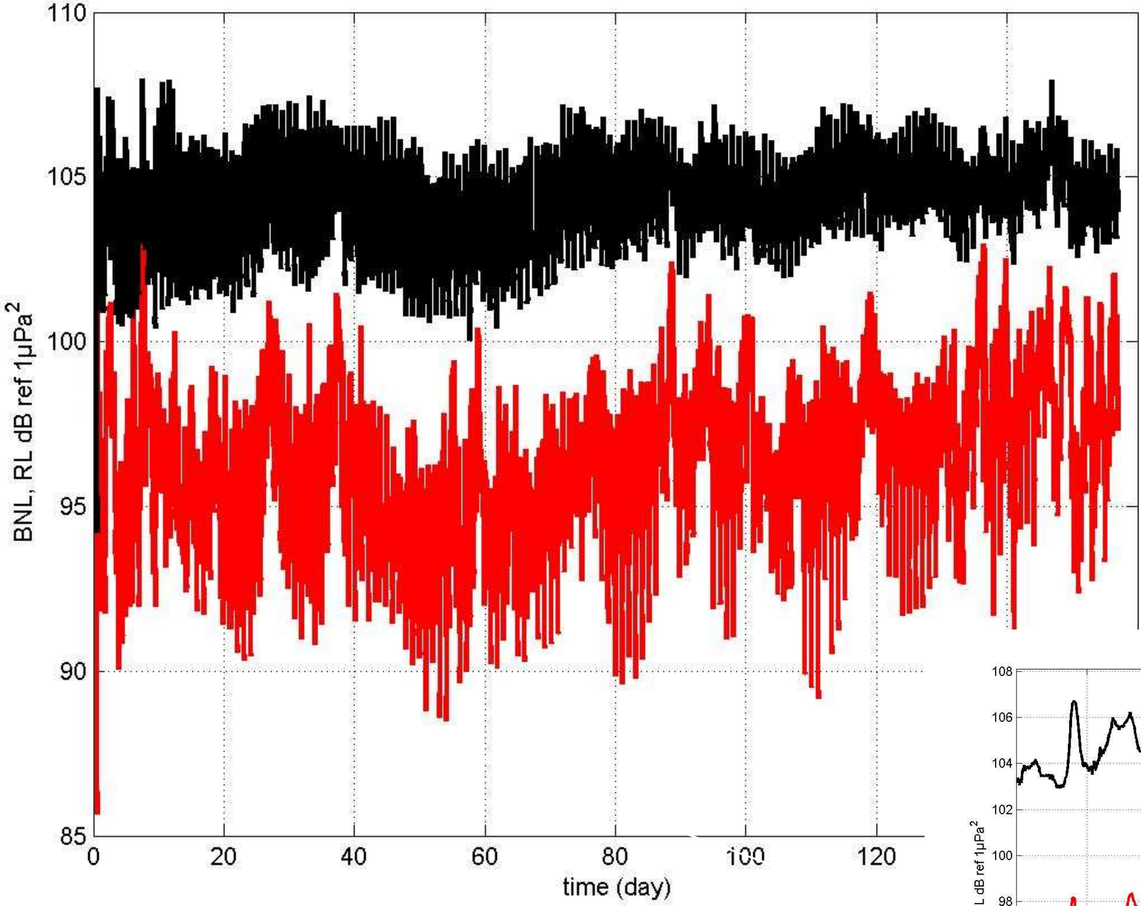
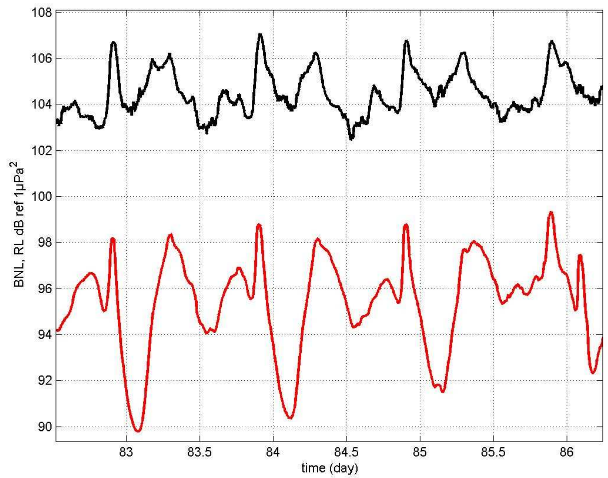
6 months time series of RL & BNL
(Biotic band)





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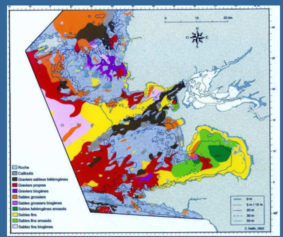
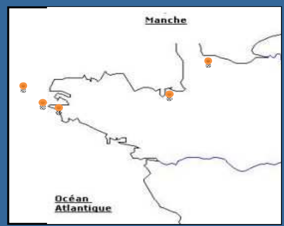
Use of acoustic time series

« Macro » acoustics





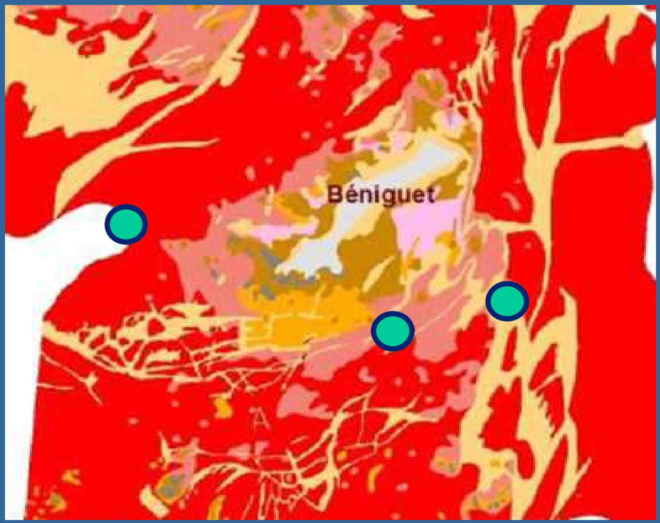
- Ecosystem
- Spatial (& temporal) patterns

« Meso » acoustics

- Communities/ population
- Habitat description
- Temporal patterns

« Macro » acoustics

Spatial acoustic activity – habitats & environments



Comparison of the different sites

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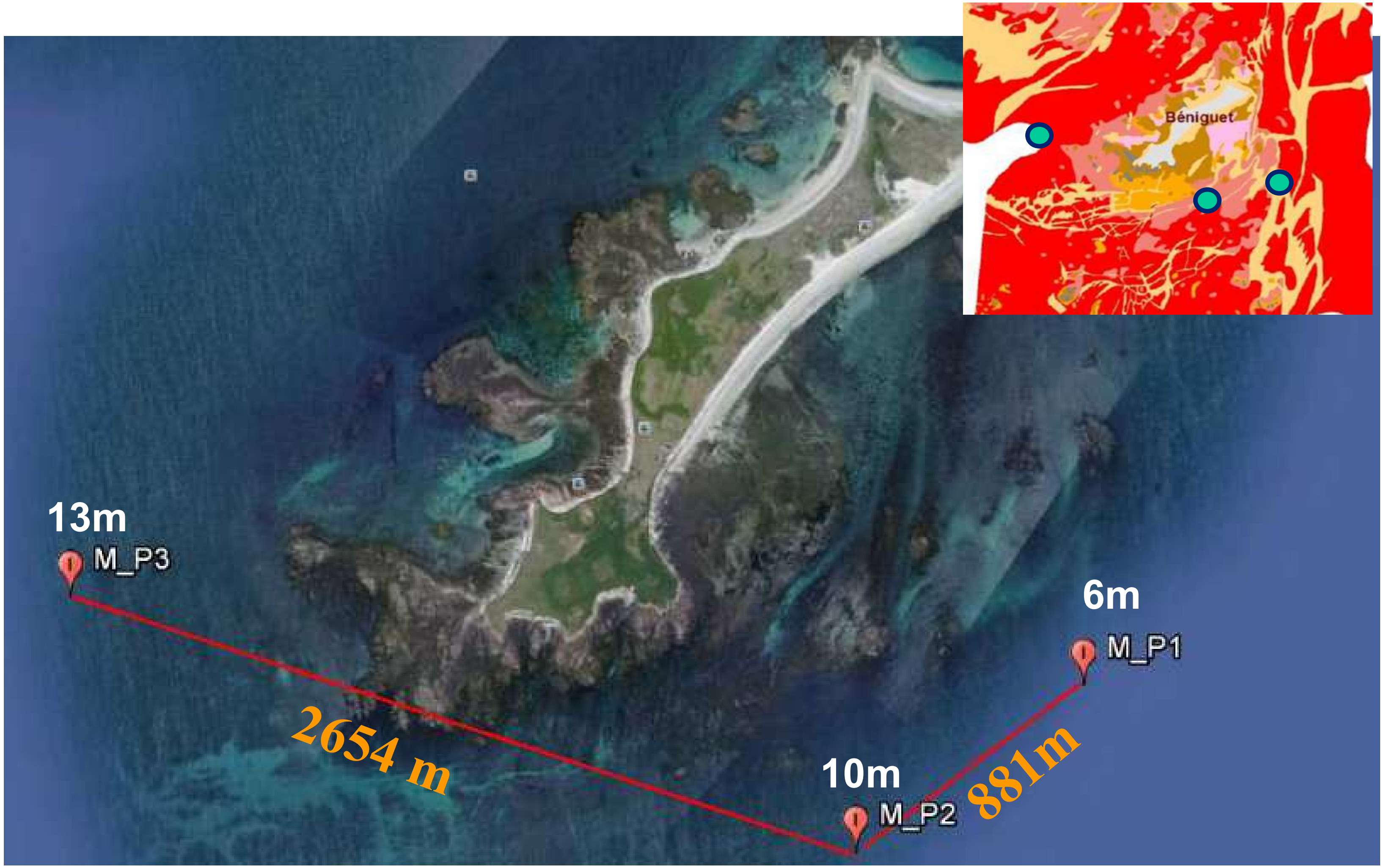

Position 1 48° 20.342', 4° 50.397' E Béniguet
Position 2 48°20.069' , 4°51.701’ S Béniguet
Position 3 48° 20.566', 4° 53.023' W Béniguet

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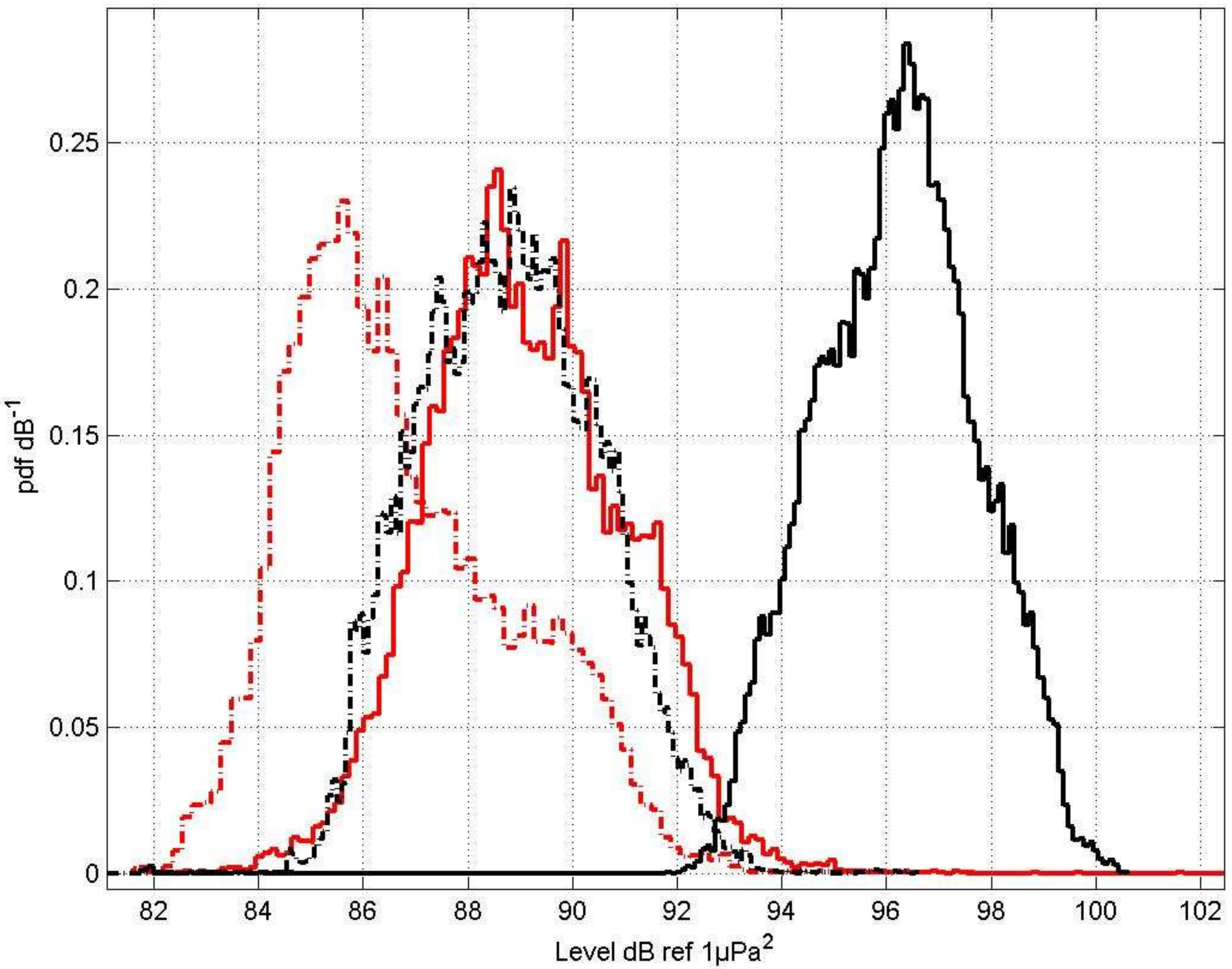
Distribution of RL & BNL for P1 & P2

6 months

Red: P1 , Black: P2 - continuous line: RL, dotted line: BNL



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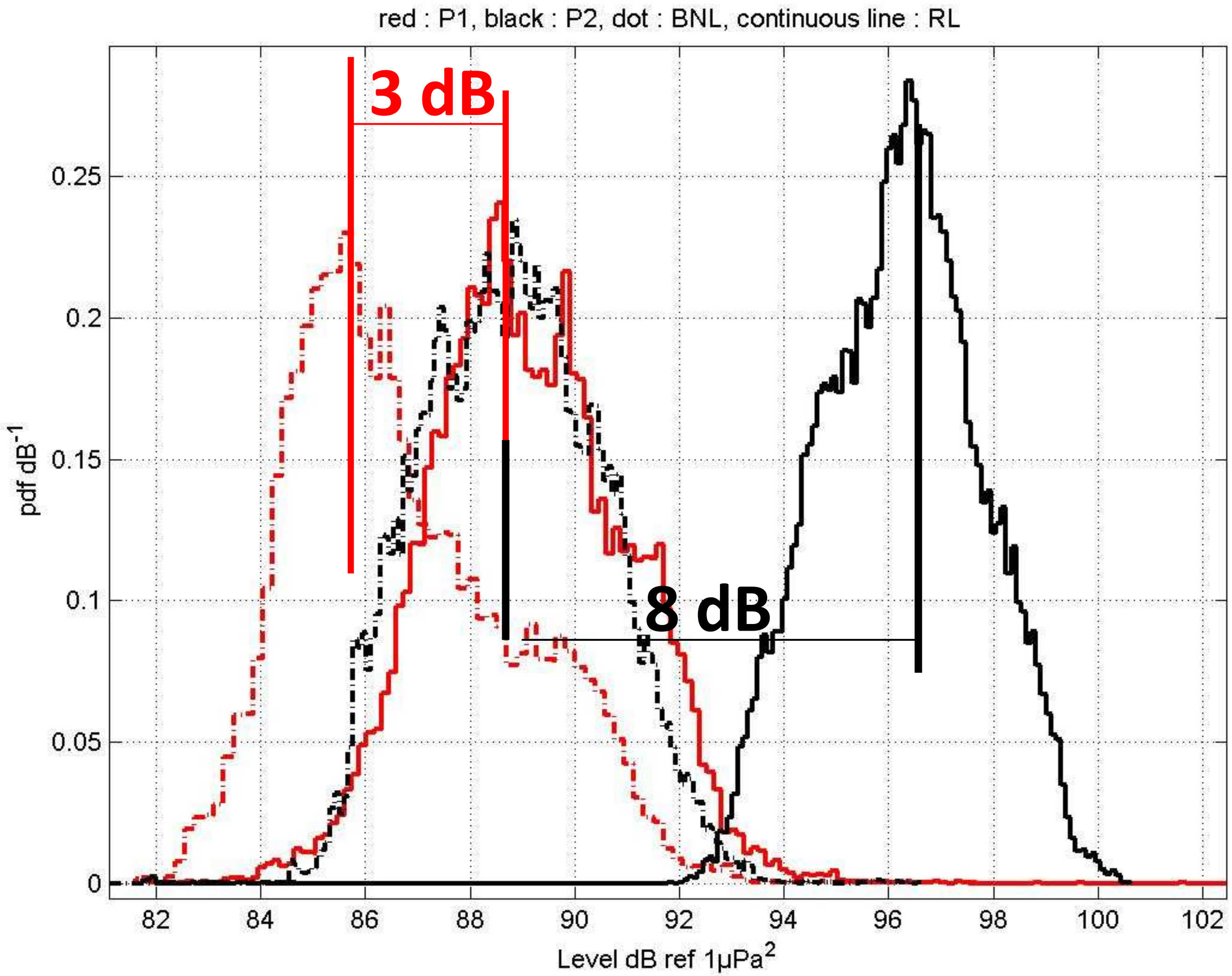

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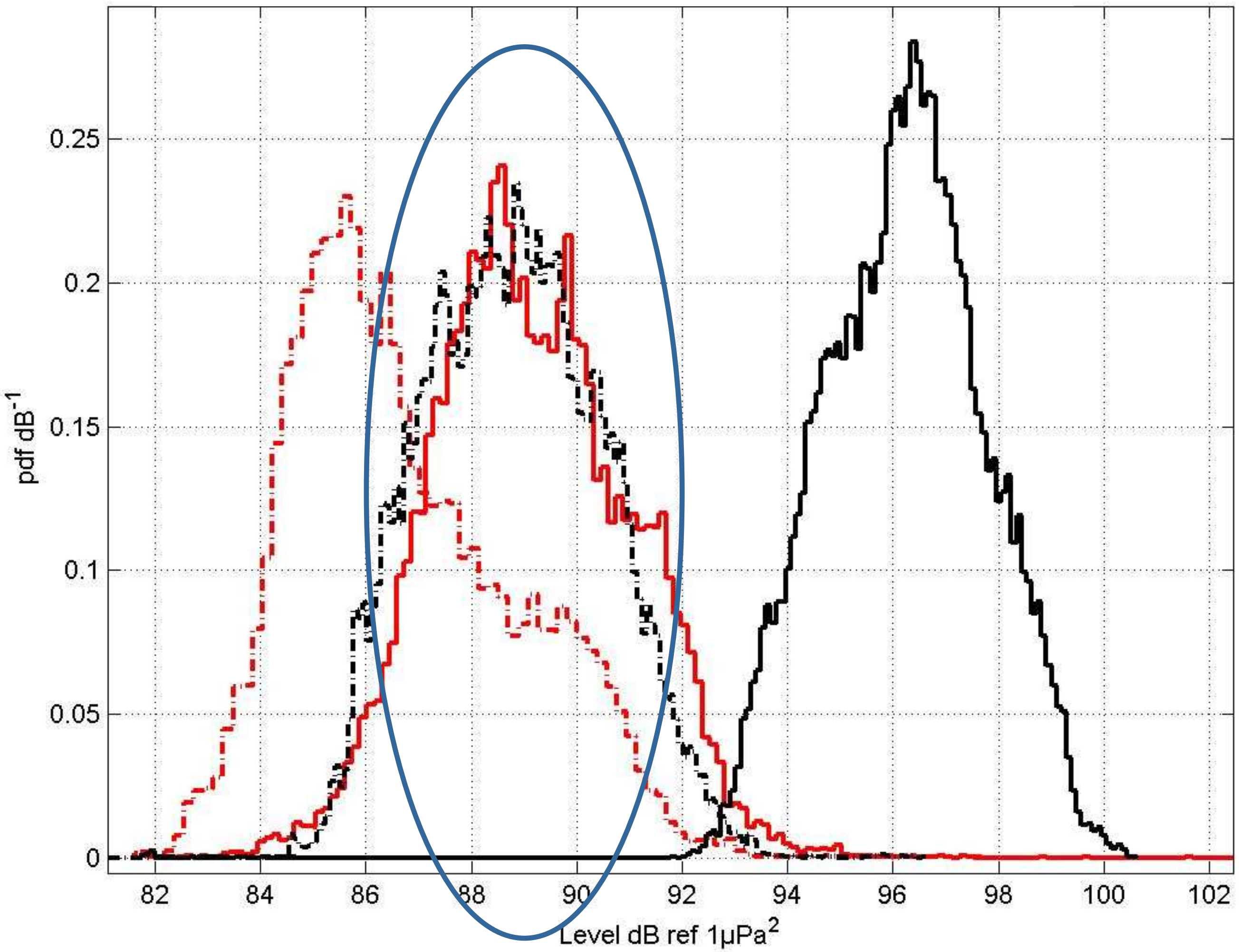
Distribution of RL & BNL for P1 & P2
6 months

RL P1 overlapping with **BNL P2**



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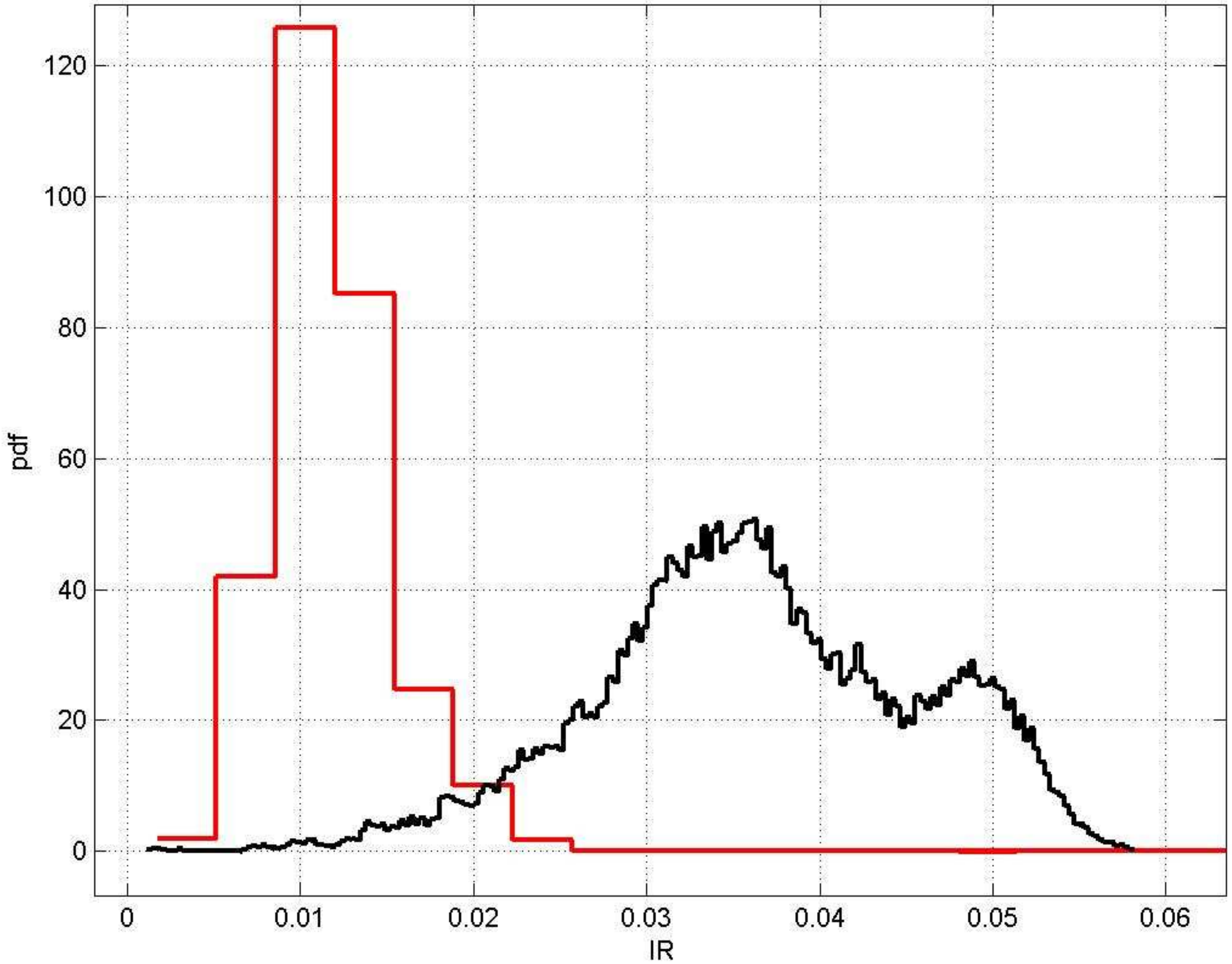
Distribution of impulse rate for P1 & P2

6 months

Red: P1 , Black: P2



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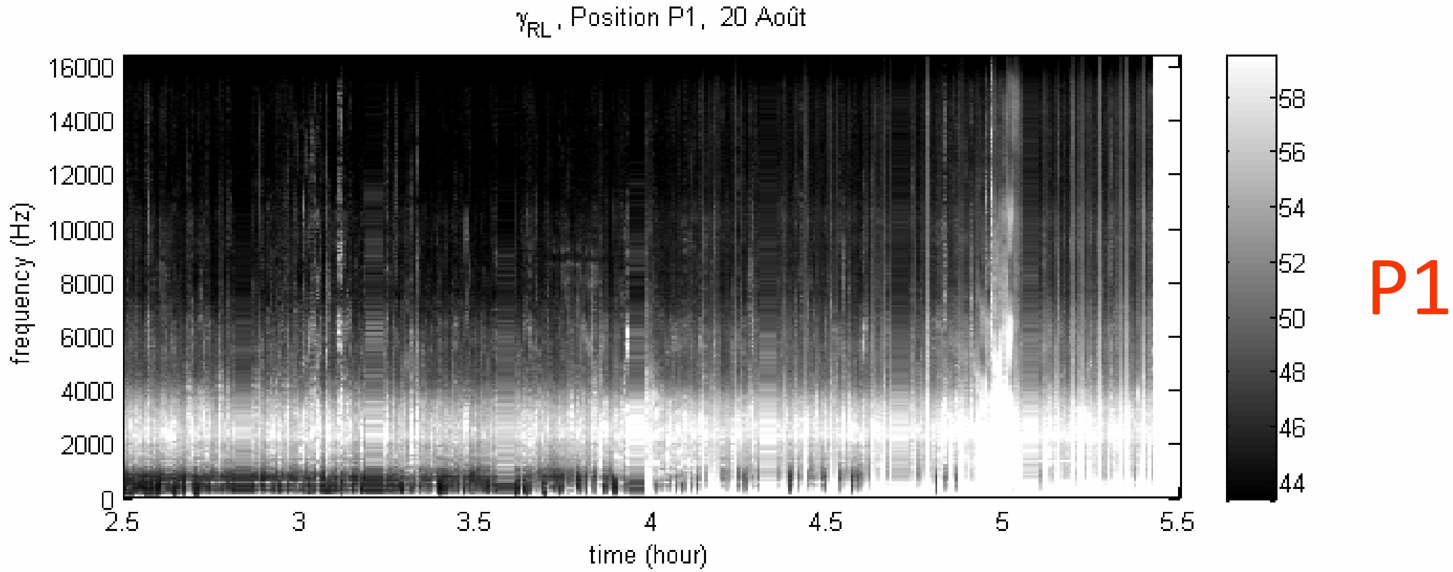
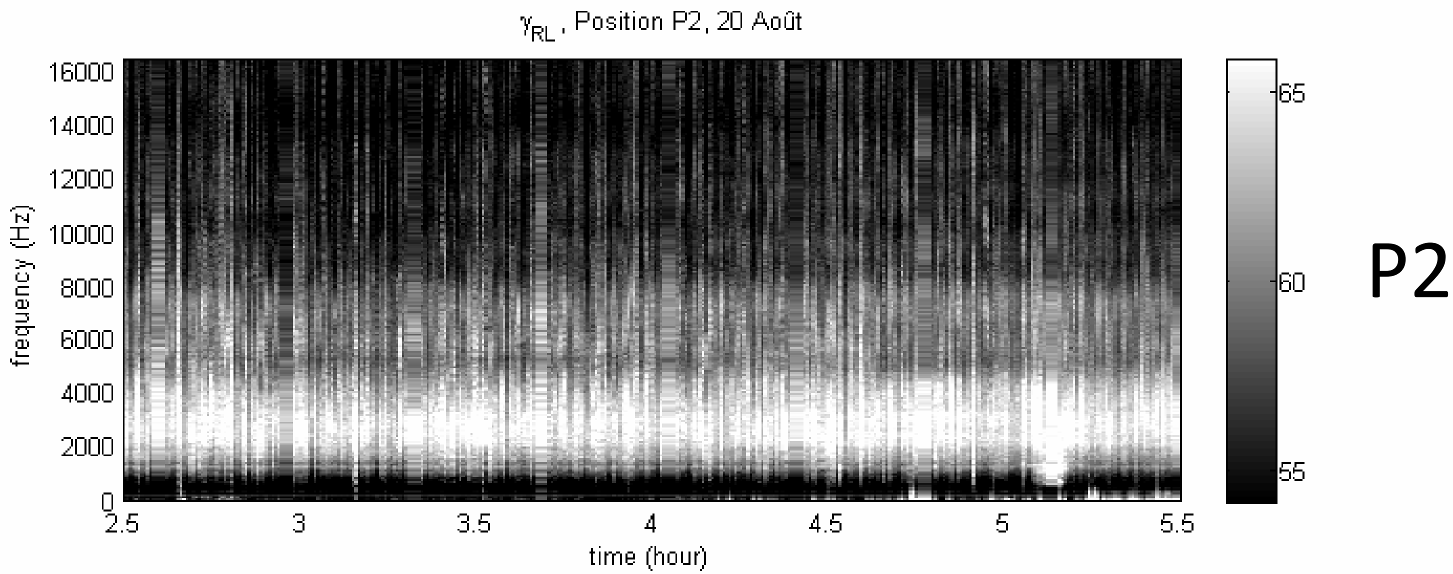
Impulse rate for P1 & P2





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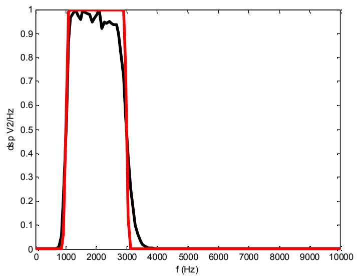
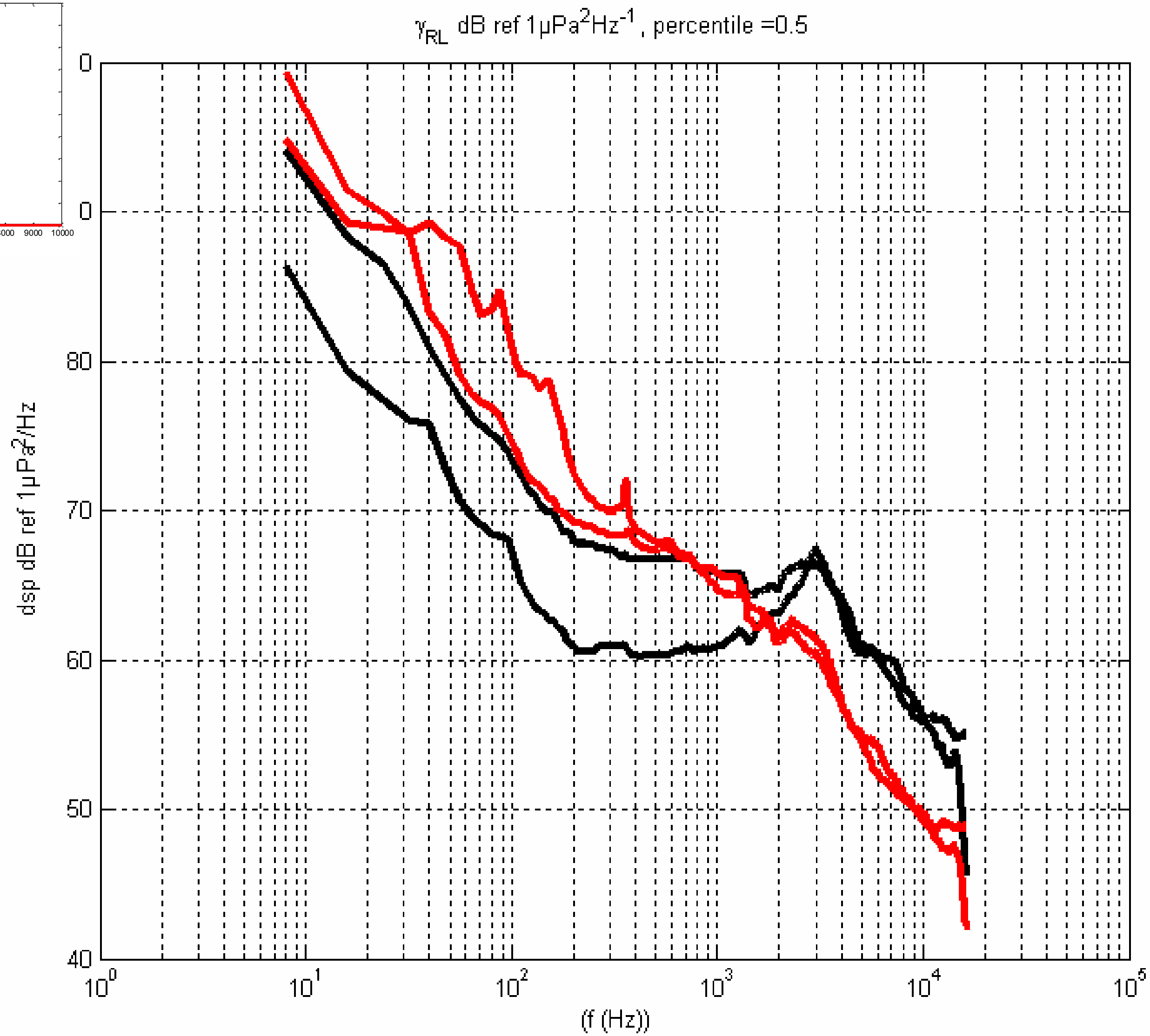
Power spectra (frequency representation)





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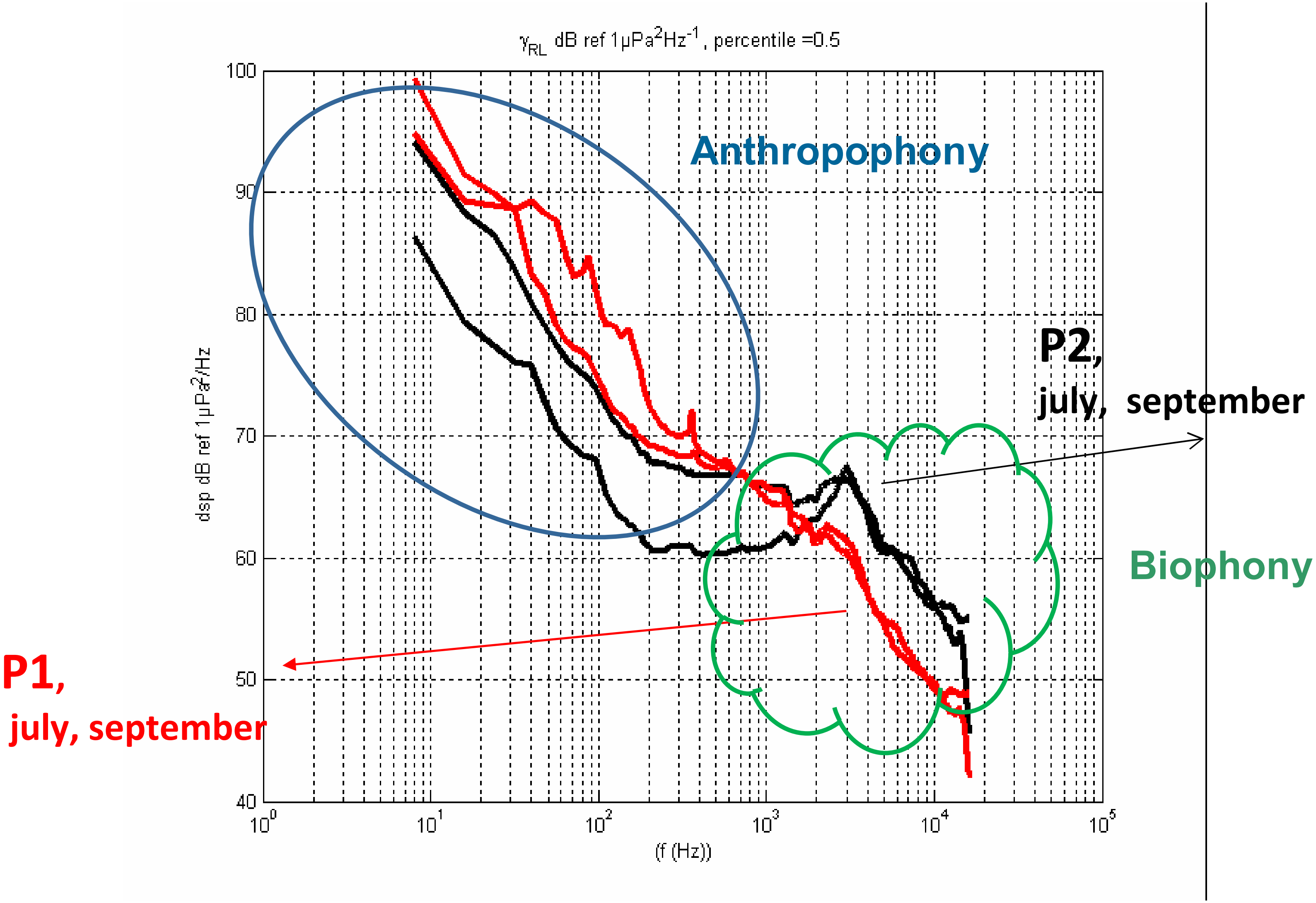
Power spectra (frequency representation)



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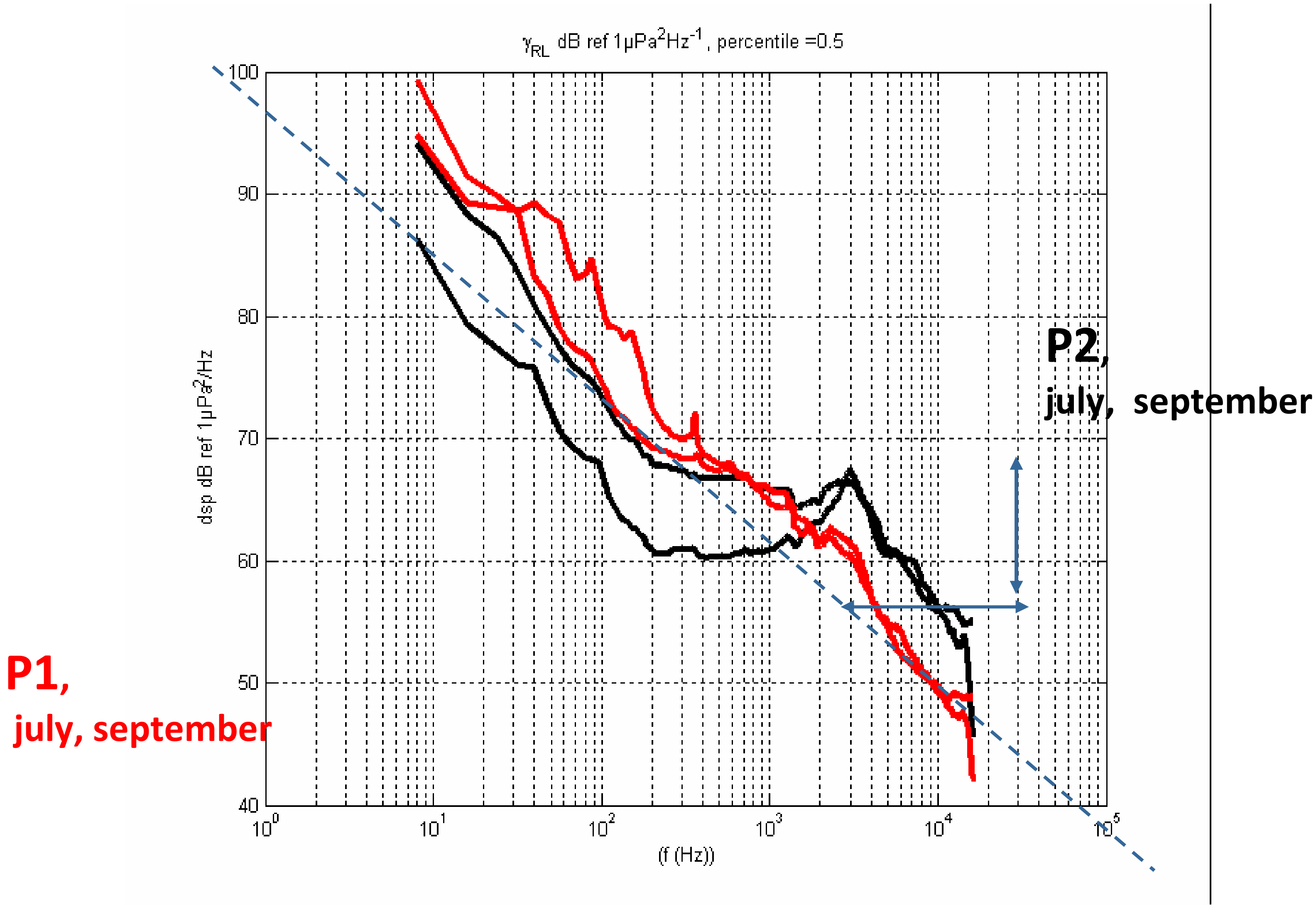

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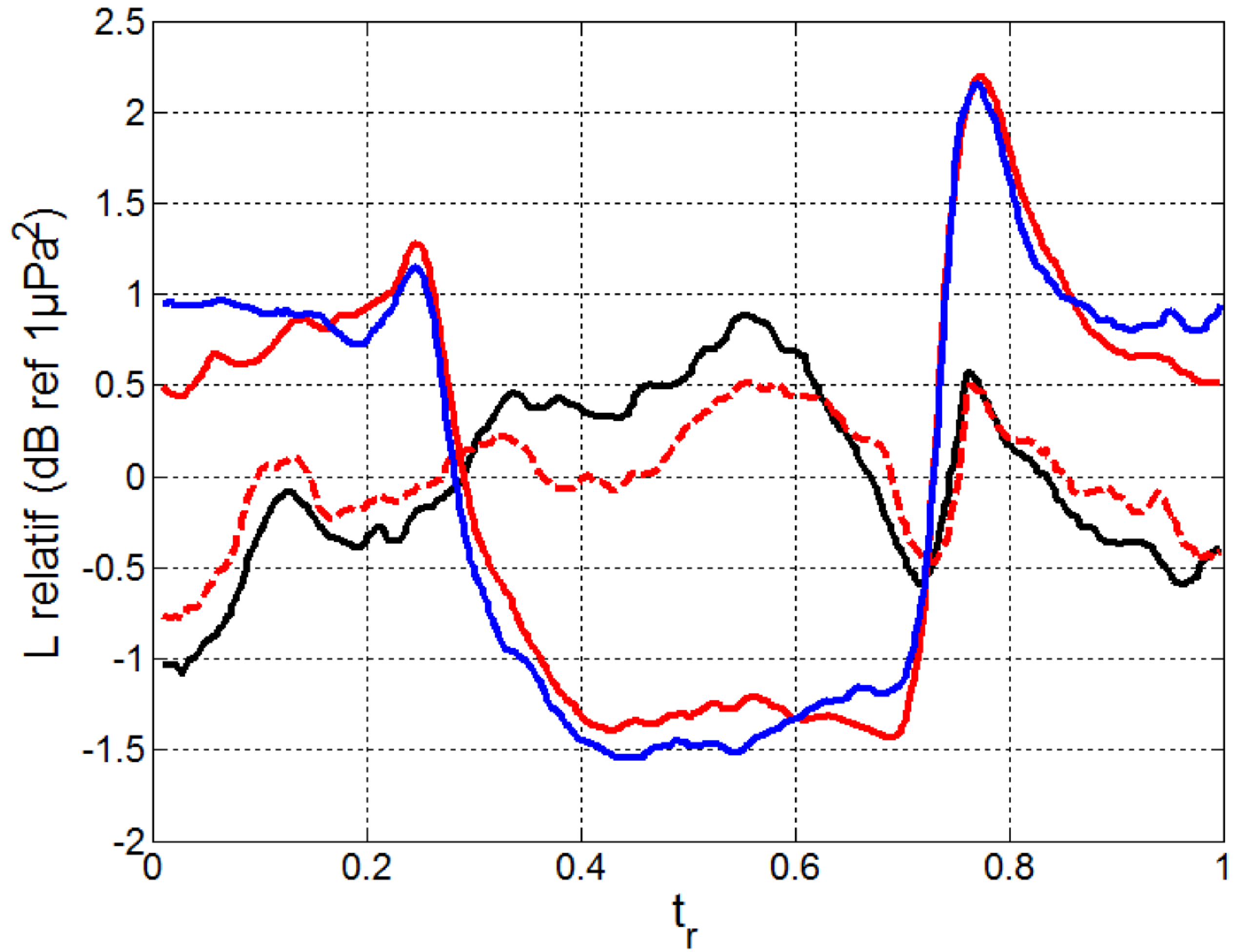
Spatio-temporal variation of relative Received Levels

relRL: Black: P1, Red: P2 , Blue P3 dotted red: **relBNL** P2



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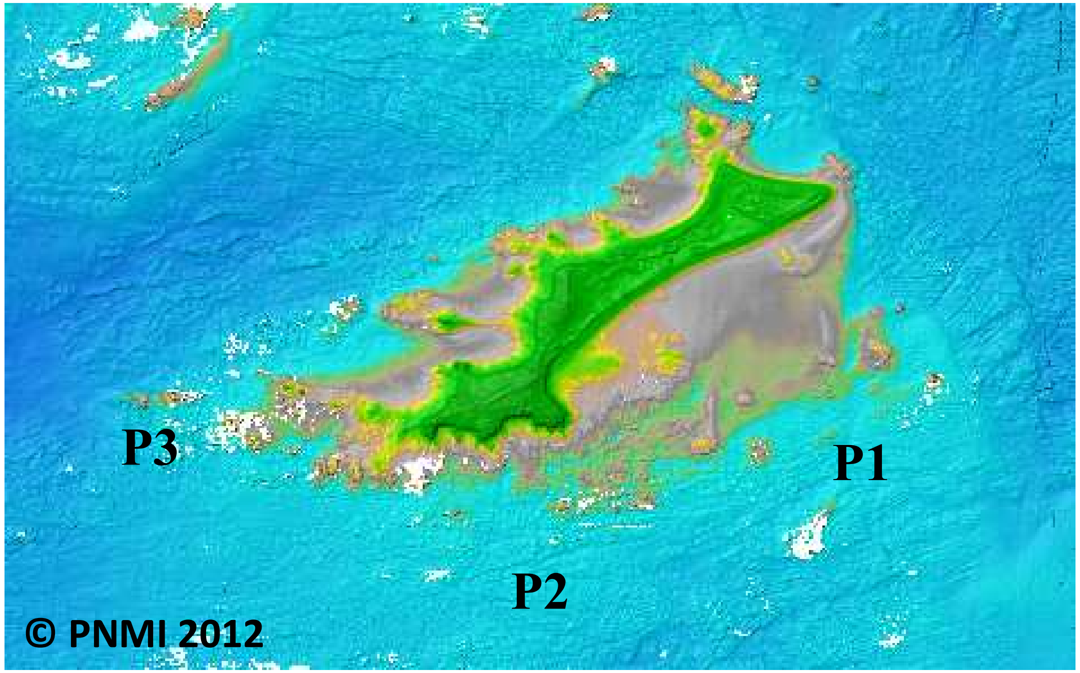
Spatio-temporal variation of relative Received Levels



P2, P3 similar :

- High IR
- Biologically rich
- Strong differences between RL & BNL (shapes & magnitudes)
- Pronounced diel variation

P1 different:

- Few impulsive signals
- RL P1 = BNL P2
- P1 is not a source of biotic sound production but captures distant sound (P2)?

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« Meso » acoustics

Acoustic activity of a population or communities
& characterisation of the environment

- Chronobiology
- Biodiversity, community ID?
- Abiotic (& anthropogenic) sundscape contributions

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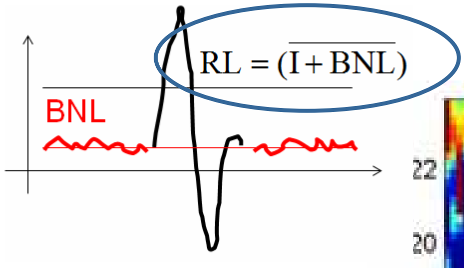
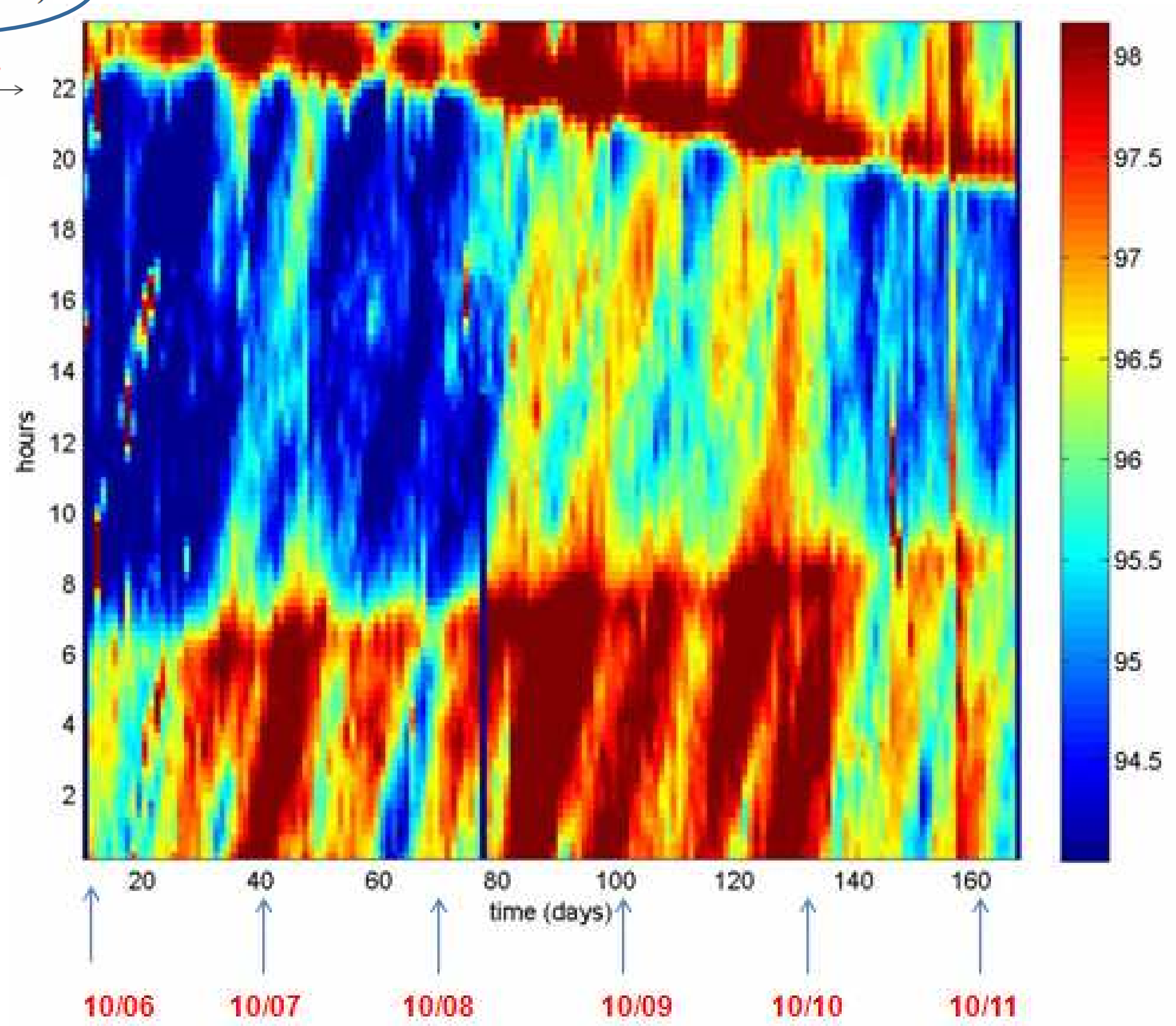
Biophony

Temporal pattern of RL in P2





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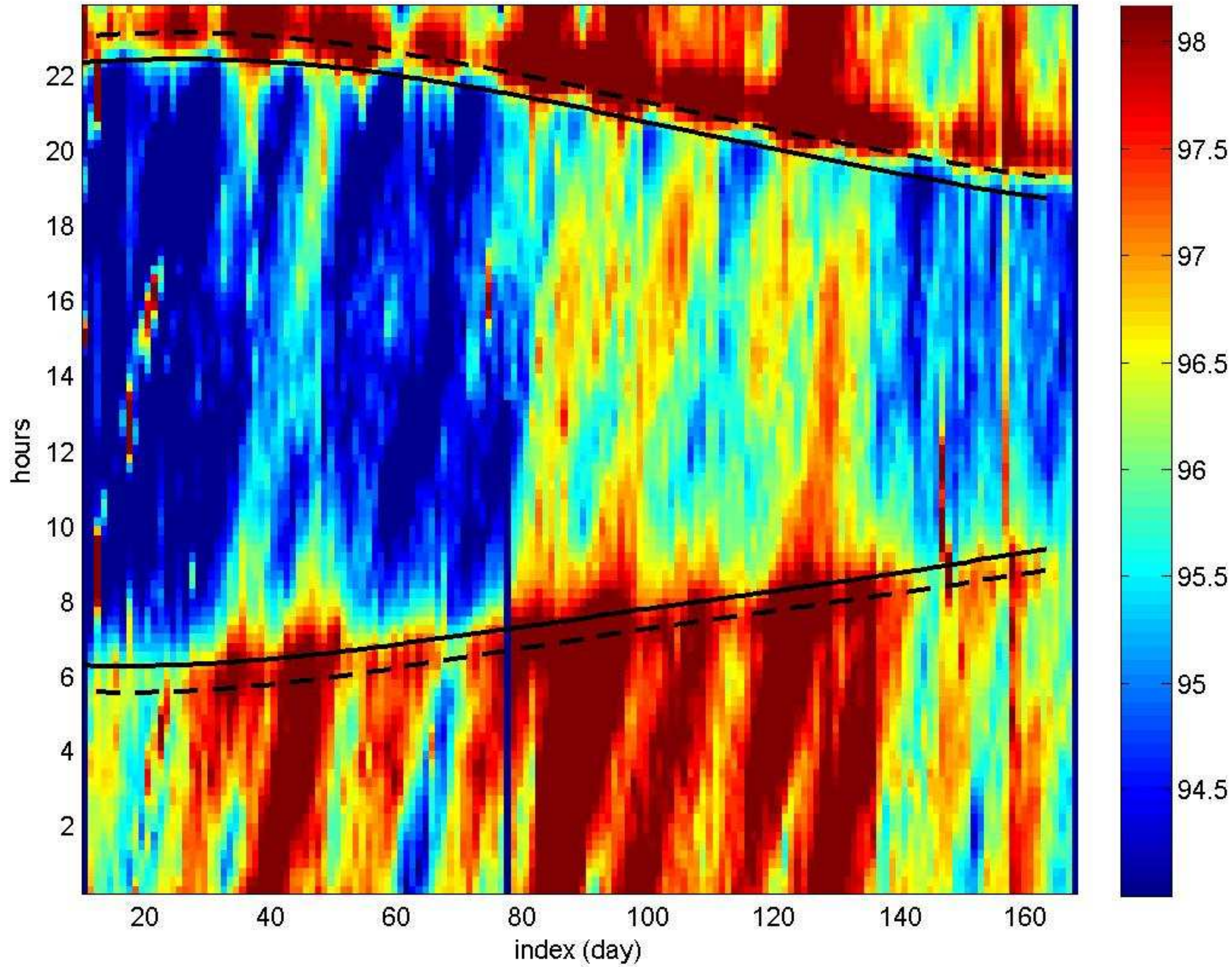
Biophony

Temporal pattern of RL in P2

sunset



sunrise

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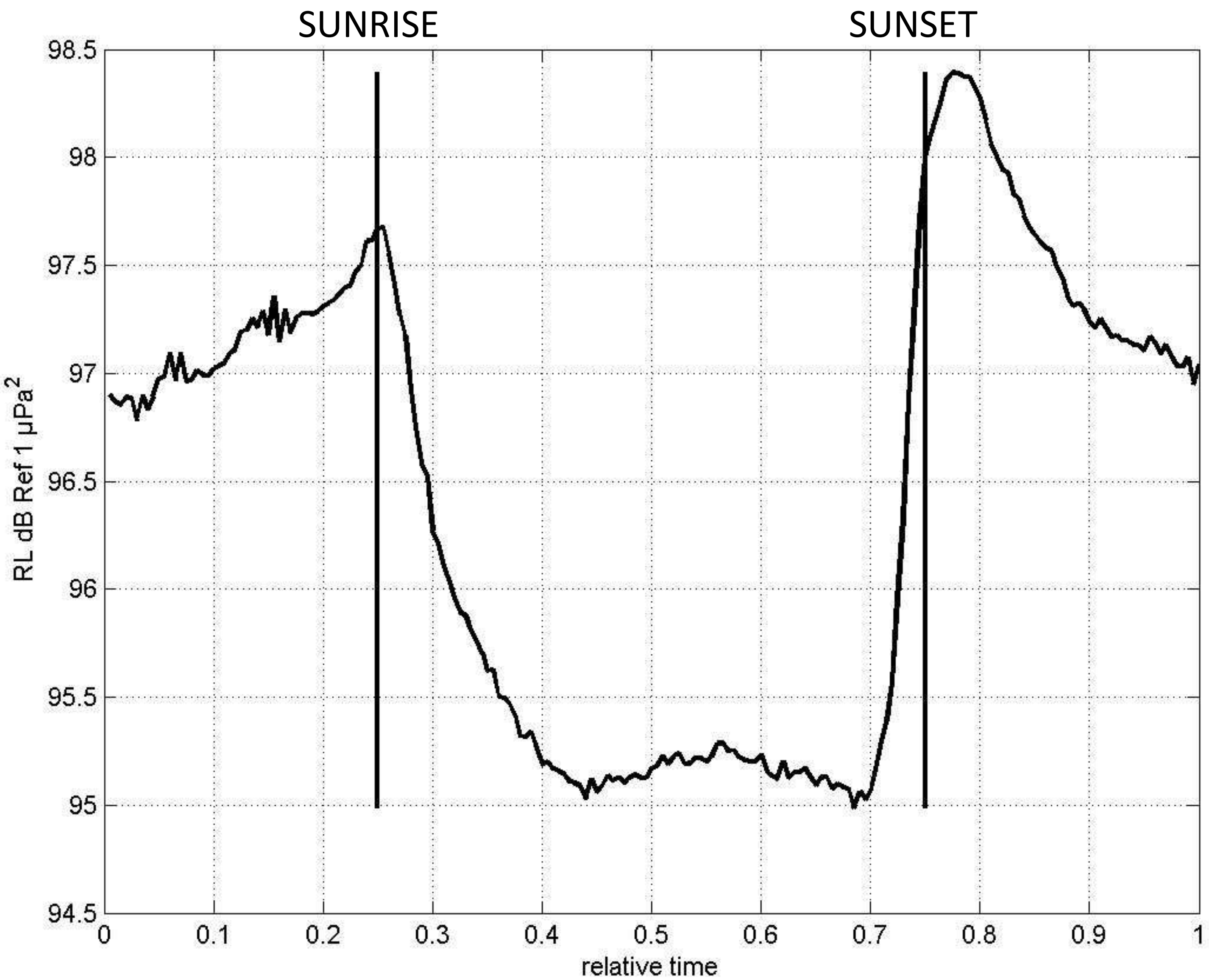
Biophony

24h rhythm of RL in P2



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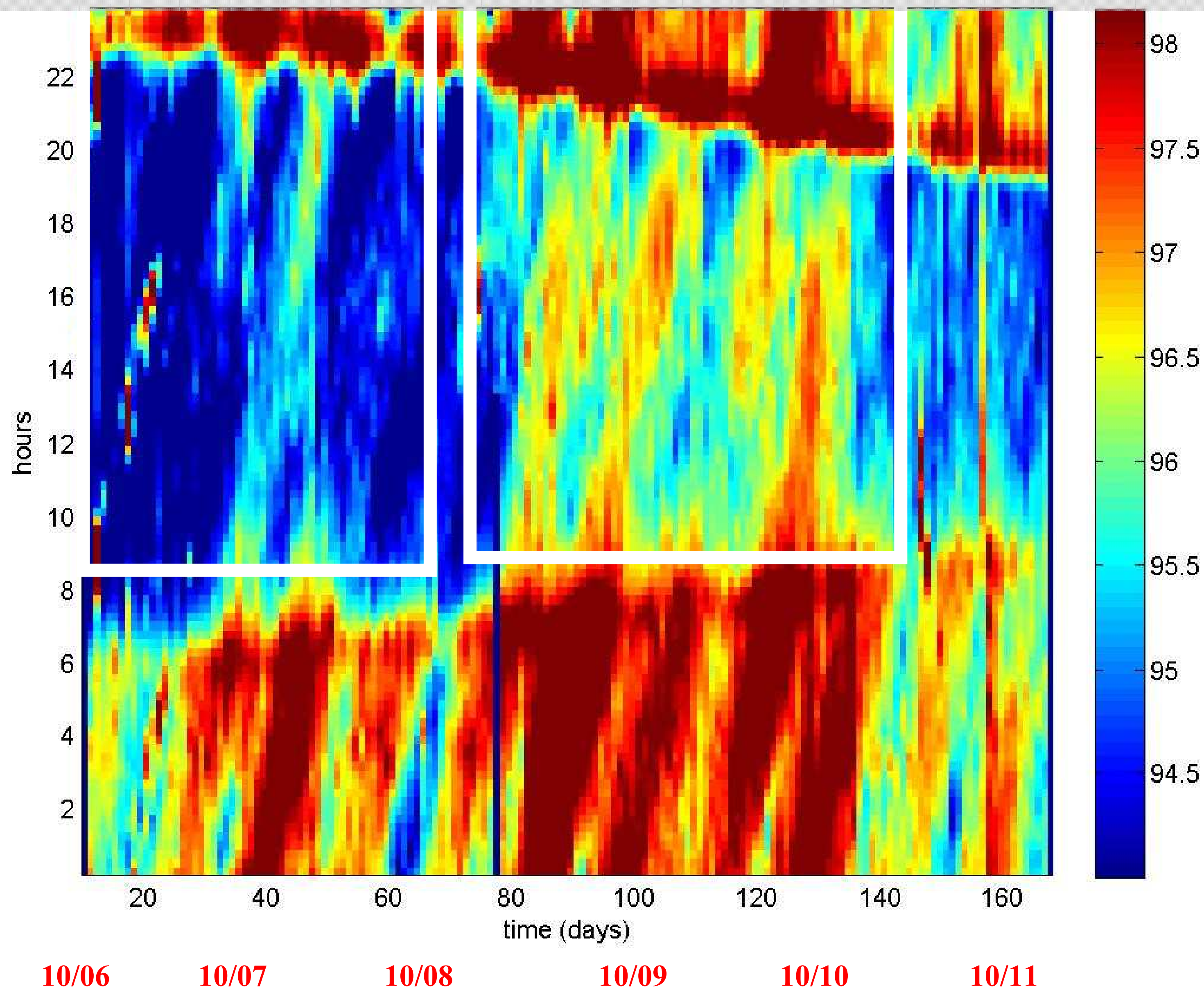
Biophony

Seasonal variation of RL in P2



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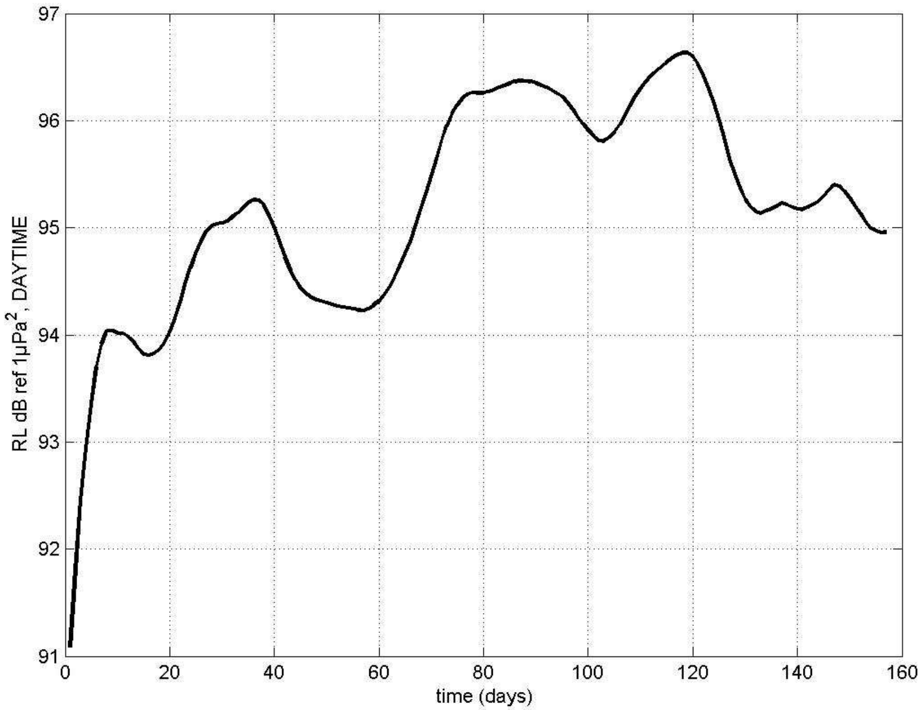
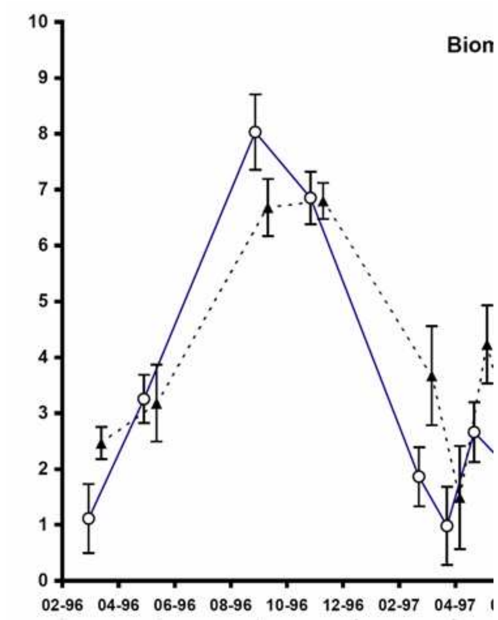
Biophony

Seasonal variation of RL in P2

?





Biomass curve

10/06 10/07 10/08 10/09 10/10

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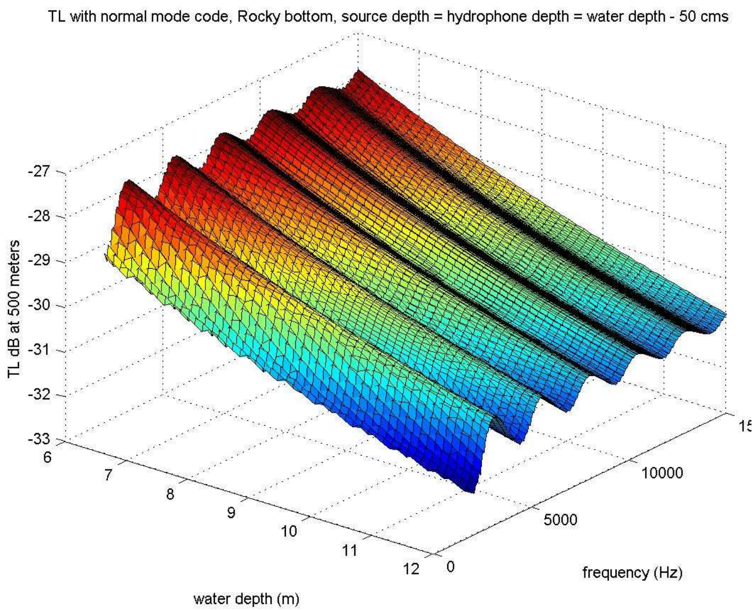
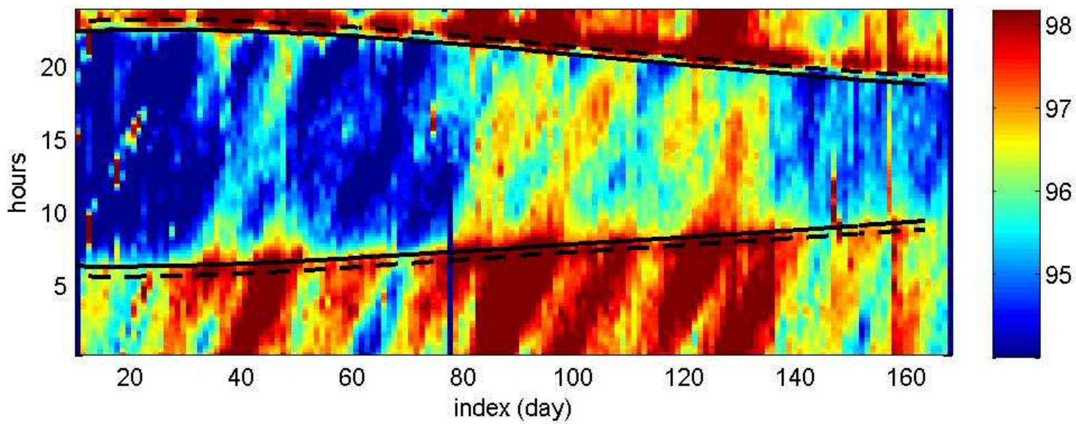
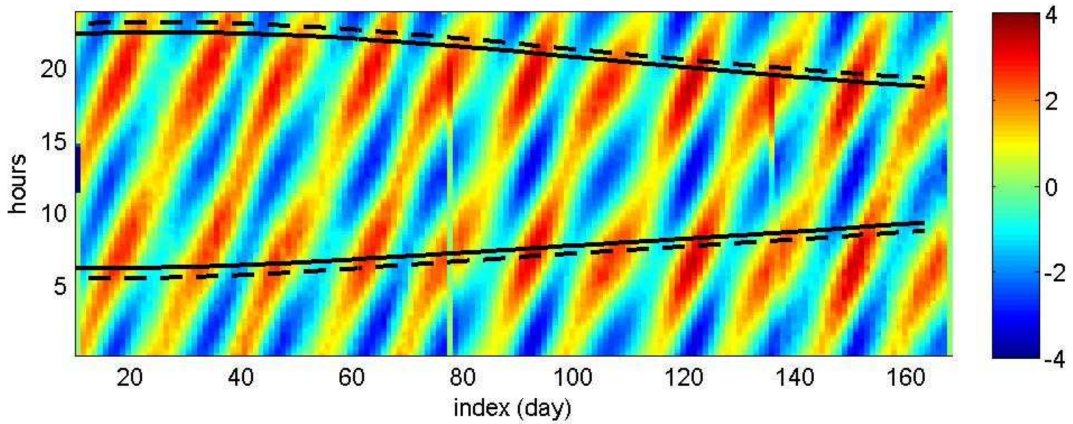
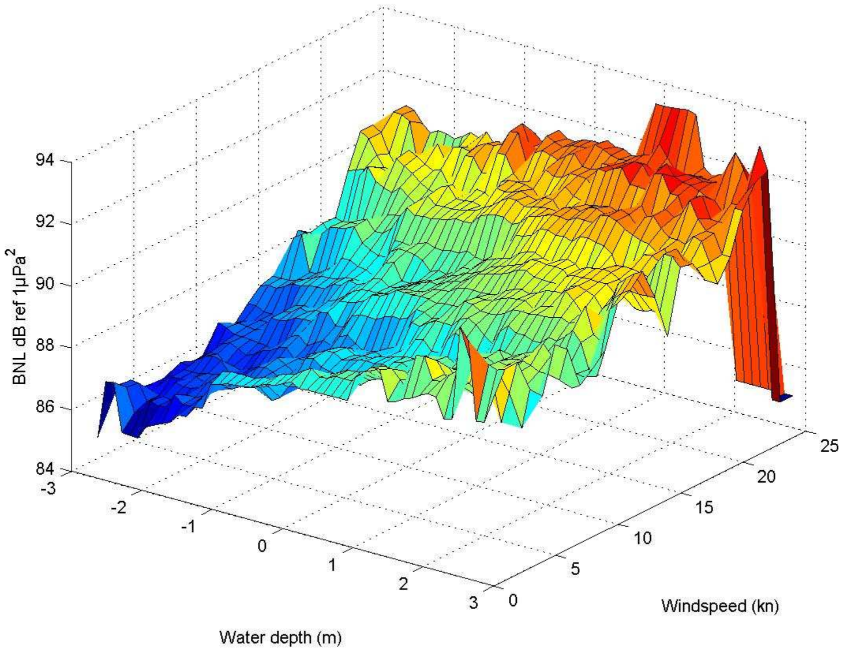
Geophony
influence of water depth on RL & BNL

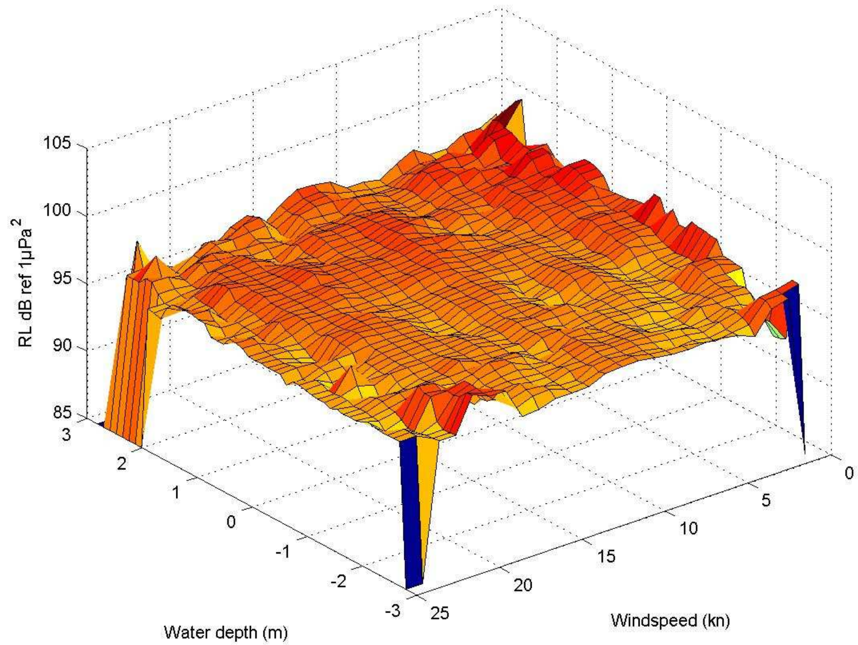






Geophony
influence of water depth & wind





BNL versus Wind speed
Water depth

RL versus Wind speed,
water depth

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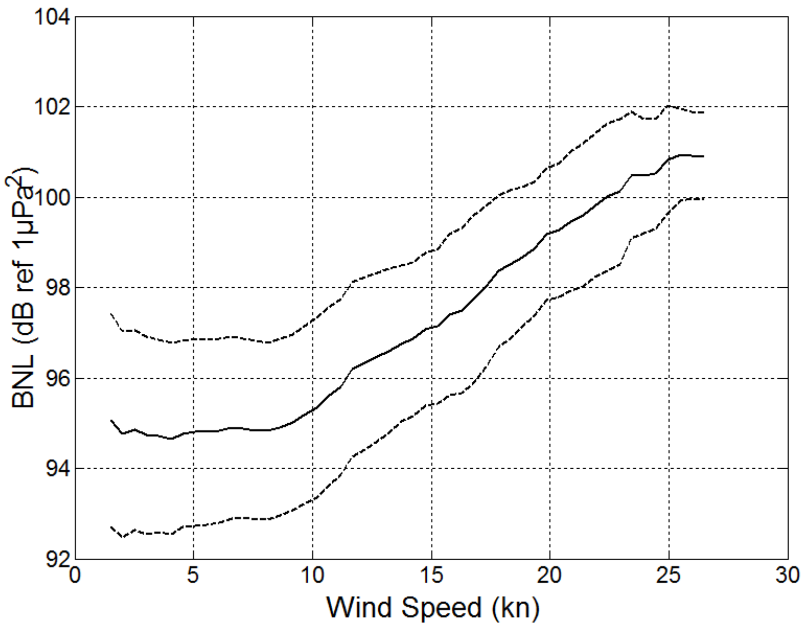
Geophony
influence of wind on BNL and RL

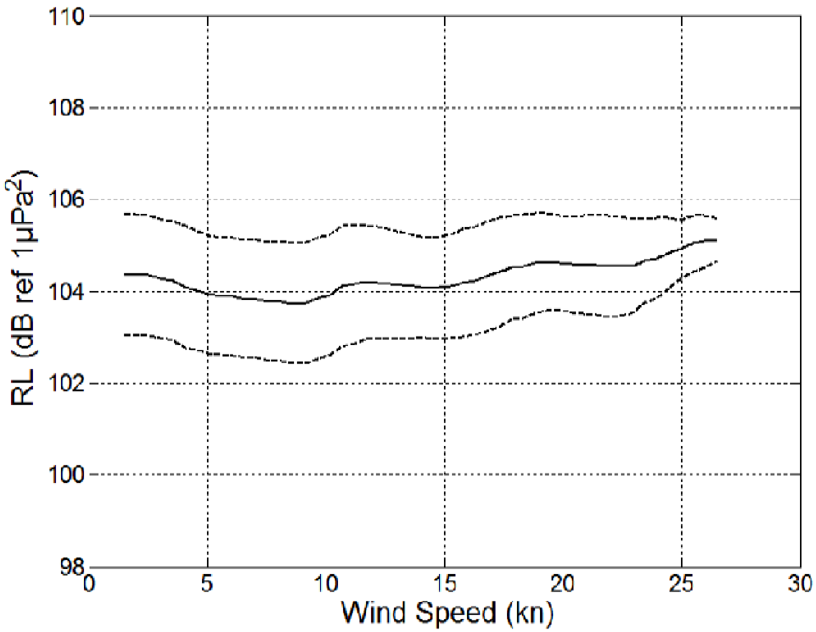
BNL



Wind Speed < 10kn : linear regression coeff = 0.06dB per wind octave, p=0.84).

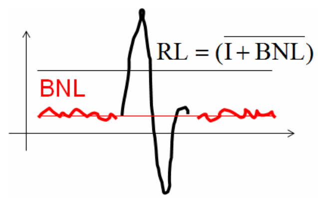
Wind Speed > 10kn : linear regression coeff = 4.2 dB per wind octave, r^2=0.98, p < 0.0001).

RL



Linear regression, r^2 close to 0, p=0.92

WL = 96.9+4.96log2(WS)



Urick, 1984 ; Nystuen& al, 1993 ; Ramji & al, 2008, Reeder et al. 2011

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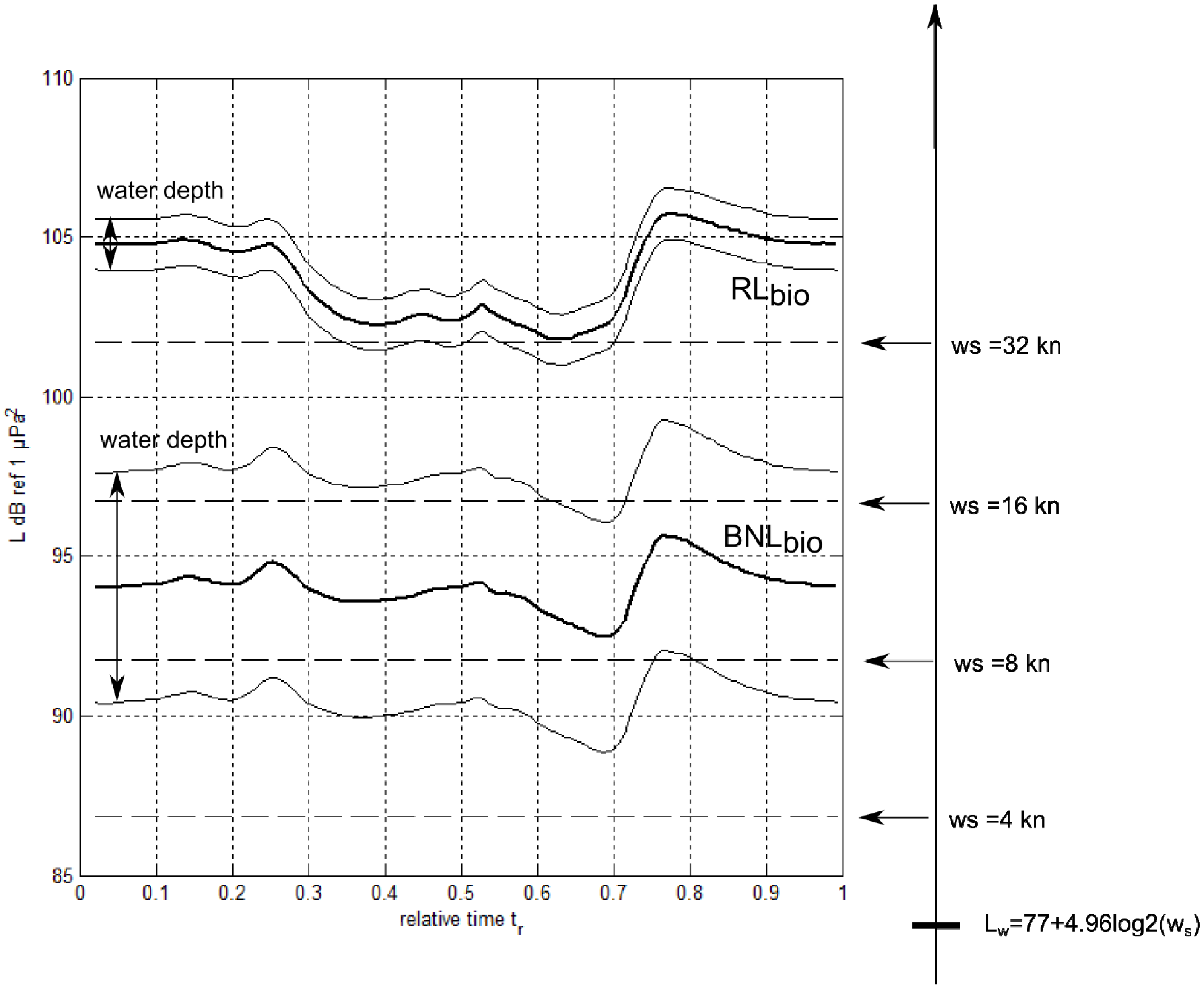
Geophony

influence of wind on BNL and RL



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Soundscape budgets P2

	BNL	RL
L dynamic: (95% confidence interval)	9.68 dB	4.8 dB
Biophony (benthos)	2 dB soit 20% of L	3 dB , **62%** of L
Geophony (wind: 7-24kn)	10 dB soit **100%** of L	2.8 dB , 58% of L
Transmission Loss due to water depth Range: 7-13 m	5.4 dB soit 55% of L	1.5 dB , 31% of L
Phenomena not taken into account	1.9 dB soit 20% 0f L	1 dB , 20% of L

Acoustic Metric = Fonction of (B,G,H)-TL

3 periodic uknown variables (B,H,TL)

=> Towards assimilation models using RL and BNL for ecological soundscape description

$$M:\ BNL = p_1 \times (h - \bar{h}) + 10log_{10}(BNL_{bio}(t_r) + BNL_{ws}) + \varepsilon_{BNL}$$

$$M:\ RL = p_1 \times (h - \bar{h}) + 10log_{10}(RL_{bio}(t_r) + RL_{ws}) + \varepsilon_{RL}$$

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Conclusions

« Macro » acoustics

- Spatio-temporal patterns
- Biological richness (benthos!)

« Meso » acoustics

- Chronobiology
- RL good biotic descriptor
- BNL good abiotic descriptor
- habitat characterisation through soundscape budgets

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Conclusions & Perspectives

•First integrative sound budget description (RL & BNL)

•Consolidation of methods and descriptors & interpretations

• Natural vs. abiotic vs. anthropogenic variability

• Towards the identification of most abundant soniferous benthic communities (role of benthos!)

• Correlations/interactions between soundscape components

• Correlation of acoustic metrics with other physico-chemical & biological parameters

• Integration of acoustic metrics in time-series analyis!

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