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Cruise *ANTITHESIS 2013*
R/V *L'Atalante*

Potential acoustic impact on marine mammals of the *AntiTheSis* scientific cruise

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Table

1. Introduction

Chapter written by Boris Marcaillou, Chief Mission Antithesis

The *AntiTheSis* experiment has strong societal implications in two environmental aspects of primary importance for populations and public authorities in the Lesser Antilles Islands: **seismic hazard** and **biodiversity**.

1.1. Societal settings

These Islands are the unique French territory to undergo **great subduction earthquakes hazard**. These events produce destructive quakes and tsunamis that release 90% of the seismic energy stored on earth. At an international level, after the catastrophic events in Sumatra (2004) and Japan (2011), the hazard related to great subduction earthquakes is a scientific topic of primary importance. In Guadeloupe and the Lesser Antilles Islands, numerous recent earthquakes, frequent aftershocks sequences of the “Les Saintes” earthquake (2004), the consequences of the Montserrat eruption, the increasing fumaroles activity at La Soufrière… remind us every day our vulnerability to the telluric hazard. The Lesser Antilles subduction zone has frequently been the site of big subduction earthquakes and particularly in 1843 with a Mw>8 event. The specialists consider that this kind of events will certainly occur again in the future (Feuillet et al., 2011; Gutscher et al., 2013). Paradoxically, most of the big subduction earthquakes in the Lesser Antilles were nucleated along the less investigated margin segment, the segment from Guadeloupe to Virgin Islands, which will be the study area for the *AntiTheSis* experiment.

The Marine biodiversity is nowadays known as a great richness of the Lesser Antilles natural heritage. Marine Mammals biodiversity is deeply related to the widespread high-sea domain, where observations are sparse and uneasy. Among the 31 species of Marine Mammals reported in the Caribbean only 20 were observed in the Lesser Antilles because of the limited number of observation opportunities on the high sea. Identifying Marine Mammals species, estimating population density and deciphering their migratory behavior is fundamental to preserve this biodiversity and the sustainable development of our region. These scientific objectives are also fundamental for the Guadeloupe National Park and the Protected Marine Area National Agency who actively campaigned to impose “AGOA” as a protected area in the name of the Carthagène international convention (1983). AGOA is particularly dedicated to Marine Mammals observation and protection.

1.2. Antithesis societal impact

Seismology thematic axis

(Partners : Volcanologic and Seismologic Observatory of Martinique, University of Nice-Sophia-Antipolis, BRGM, Institut de Physique du Globe de Paris, PRSN, KNMI).

The *AntiTheSis* experiment primarily aims at investigating the structure of the Lesser Antilles fore-arc and subduction zone in order to image the structural heterogeneities (ridge, seamount, faults) that could possibly trigger earthquake nucleation, allow or stop the co-seismic rupture propagation and favor tsunamis. Offshore of Guadeloupe – Martinique margin segment, the subduction zone produced a big subduction earthquake in 1843 (Mw>8) that released at least a part of the seismic energy stored along the subdcution interface. Contrastingly, the margin segment located to the North (Guadeloupe – Virgin Island), study area for the *AntiTheSis* experiment, has not experienced big subduction earthquake as far as we know. Frequent intermediate magnitude subduction earthquakes testify that this margin segment is not a seismic. Thus, seismic energy related to plates convergence and stored along the subduction

interface has not been released for a long time, generating the highest slip deficit and the highest seismic hazard in the Lesser Antilles. We will investigate the causes for possible future great subduction earthquakes following a 2 steps approach.
We will first image and identify the structural heterogeneities able to trigger or stop the co-seismic rupture. A powerful seismic source is necessary to observe the deepest crustal zones where greatest quakes in the world usually originate. Similar images were recorded offshore off Martinique and Guadeloupe and provide excellent results (Evain et al., n.d.; Kopp et al., 2011). During the *AntiTheSis* experiment we will acquire deep active seismic data using a seismic source consistent with our goals.
Moreover, numerous faults in the fore-arc domain are possibly seismogenic and may create shallow quakes, with destructive impact because of their possible proximity to densely populated coastal areas, as for the Les Saintes earthquake (2004). In order to identify these seismically active faults, we will deploy a 150x150 nm web of Ocean Bottom Seismometers (OBS) during 6 month from November 2013 to May 2014. These devices will record the seismic events complementarily with onland seismometers web operated by our French (observatories in Guadeloupe and Martinique) Porto-Rican (PRSN) and Danish (KNMI) partners. This temporary oceanic web will detect earthquakes with smaller magnitude and improve their location estimate compared to onland devices because of their proximity to the seismic source area. We thus aim at identifying faults that undergo this micro-seismicity and thus may generate big earthquakes in the future. These seismically active faults between Guadeloupe and Virgin Islands are nowadays totally unknown mainly because marine Geophysical data has never been acquired in this area. The experiment results will thus be striking for the understanding and the evaluation of the seismic hazard in this region.

Cetology thematic axis

(Partners : University Paris-Sud, University of Toulon and the Var, University of La Rochelle, AAMP)

Marine Mammals Observers (MMOs) have embarked for a decade onto Marine Geophysical cruises that provide rare opportunities of long period of observations in the high sea. Recent publications indicate that new mammal species were reported during these cruises (Weir et al., 2011). Moreover the question of the impact of acoustic experiment onto Marine Mammals population remains unraveled because of contradictory results in previous studies. The *AntiTheSis* campaign will thus offer to MMOs 47 days of observation in the high sea between Guadeloupe and Virgin Island around and within AGOA. Acoustic monitoring of the water columns with hydrophons will complete thus visual observation. One third of the campaign will consist in transit at 10 knots, one third in immobile station and the last third in seismic recording with the acoustic source. Off course we will carefully follow a precise procedure during the period of the seismic source activity in order to preserve Marine Mammals from the acoustic impact. Moreover the period of seismic source inactivity will allow MMOs to compare their observations with those of period of activity and improve our knowledge of the anthropic impact of acoustic experiment at sea onto Marine Mammals presence and behavior. At the end of the cruise, the acoustic data recorded by the hydrophones will be transferred to our Cetologist and Acoustician partners for further studies of water column noises. These data will also be available for everyone who would wish to see them, after the moratorium period.
Moreover, the Ocean Bottom Seismometers also include Hydrophones that will record the noises of the water column during the deployment period, from November 2013 and May 2014 that corresponds to the period of whales migration from feeding zones to the north toward breeding zones to the south. Numerical methods developed by our acoustician partners allow to spot, number and follow mammal populations based on hydrophones webs (Gaspà Rebull et al., 2006). Thus, the 2D OBS web will act as an antenna dedicated to whales detection, quantification in order to decipher their migratory behavior.

2. Work area

The marine scientific cruise *AntiTheSis* will be conducted by the *N/O L'Atalante* from 24 November 2013 to 9 January 2014 off Lesser Antilles. Figure 1 represents the work area. Operations will be limited to a first area between N 15 °- 17° and W 58 ° - 58.8° A second area is located between N 17° - 20° and W 59.5° - 65°. The cruise includes the use of seismic sources (air guns) of the Ifremer "multi channels seismic" systems. The use of the seismic sources involves a preliminary analysis of sound risks (see Appendix A.1) in relation to marine mammals potentially present in the area (see Table1) and the definition of mitigation measures (see Appendix A.2). The purpose of this paper is to prepare this scientific mission regarding of potential environmental implications.

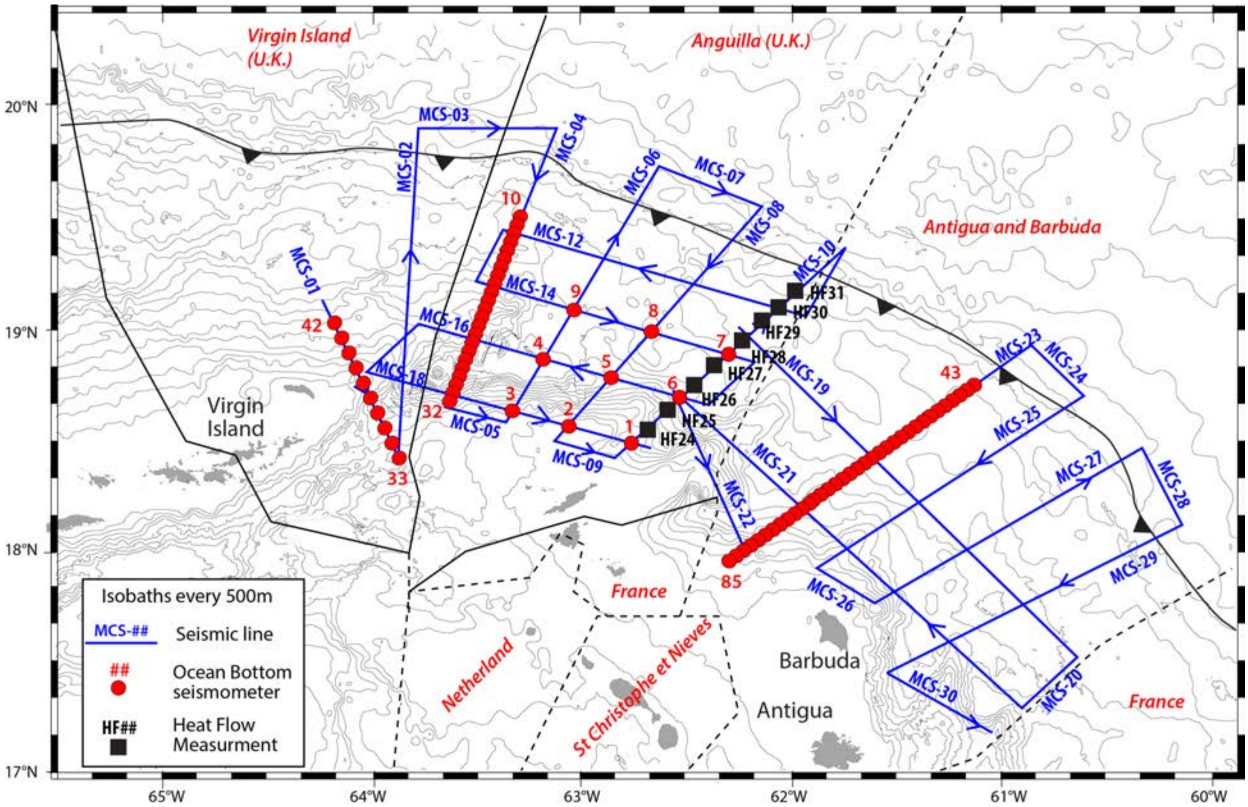

Fig 1 : Location of the reflection seismic lines (blue lines), heat flow stations (solid squares), wide-angle seismic lines with short-term autonomy OBS (red circles)

3. Marine animals in the area under consideration

Around thirty marine mammal species are currently observed inside the Caribbean sea waters. This area represents a feeding ground for some species and a reproductive ground for others at different times of the year. The peak in sighting is in February. According to the International Union of Conservation of Nature (IUCN) some species are considered as vulnerable. Table 1 lists marine mammals species that could be sighted during survey.

Moreover, one part of the study area is located in the Agoa sanctuary, where monitoring and protection regulations of marine mammals are stricter. However, the regulations applicable in Agoa do not specify allowable sound exposure levels, or even make specific mention of acoustic pollution.

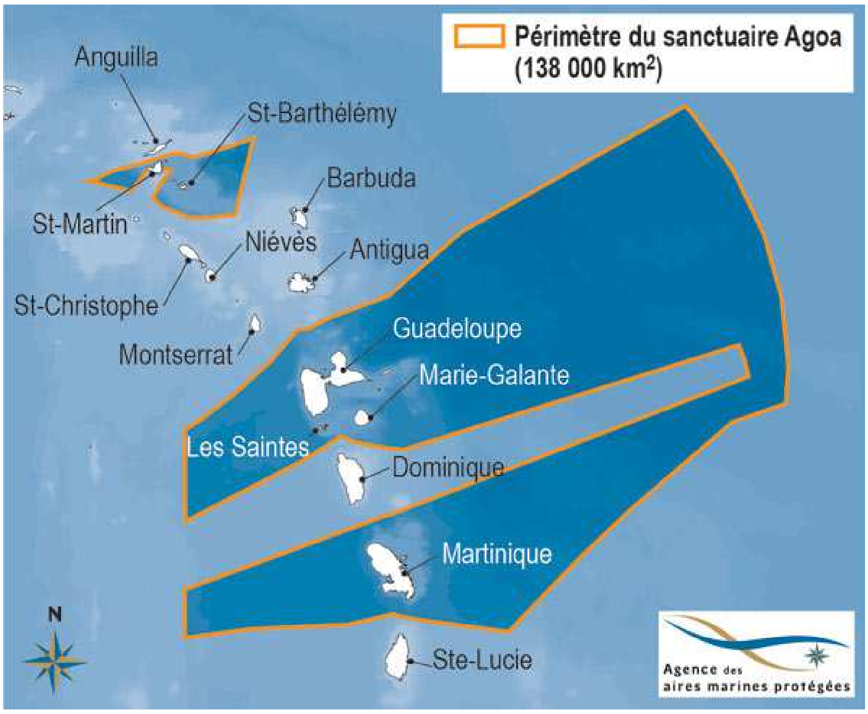

Fig 2 : Agoa Sanctuary boundaries

Nom Scientifique	Nom Commun	Statut UINC
Balaenoptera acutorostrata	Dwarf minke whale	LC
Balaenoptera borealis	Sei whale	EN
Balaenoptera brydei	Brydes whale	DD
Balaenoptera musculus	Blue whale	EN
Balaenoptera Physalus	Fin whale	EN
Megaptera novaeangliae	Humpack whale	VU
Delphinus delphis	Common dolphin	LC
Delphinus capensis	Common dolphin longsnout Saddleback	DD
Eubalaena glacialis	North atlantic right whale	EN
Feresa attenuata	Pygm killer whale	DD
Globicephala macrorhynchus	Short-finned pilot whale	DD
Grampus griseus	Risso's dolphin	LC
Kogia breviceps	Pigmy sperm whale	DD
Kogia simus	Dwarf sperm whale	DD
Lagenodelphis hosei	Frasers dolphin	LC
Mesoplodon densirostris	Blainvilles beaked whale	DD
Mesoplodon europaeus	Gervais beaked whale	DD
Mesoplodon mirus	Trues beaked whale	DD
Orcinus orca	Killer whale	DD
Peponocephala electra	Melon-headed whale	LC
Physeter macrocephalus	Sperm whale	VU
Pseudorca crassidens	False killer whale	DD
Stenella attenuata	Pantropical spotted dolphin	LC
Stenella clymene	Clymene dolphin	DD
Stenella coeruleoalba	Striped dolphin	LC
Stenella frontalis	Atlantic spotted dolphin	DD
Stenella longirostris	Spinner dolphin	DD
Steno bredanensis	Rough-toothed whale	LC
Tursiops truncatus	Bottlenose dolphin	LC
Ziphius cavirostris	Cuvier's beaked whale	LC

Table 1: List of species of marine mammals potentially present during *AntiTheSis* survey. The classification of the International Union for Conservation of Nature (IUNC) is the only internationally recognized methodology for measuring the state of conservation of the species on the planet (DD: Data Deficient, LC : Least concern, VU: Vulnerable, EN : Endangered, Ex: Extinct)

4. Characteristics of Acoustic Sources

The *AntiTheSis* cruise will feature two sources corresponding to different seismic configurations. The emission characteristics of the two configurations are known very accurately, thereby setting the necessary estimates of the magnitudes and danger distances.

4.1. Reflection Seismics

The reflection seismic source used by the *AntiTheSis* cruise consists in 13 airguns GUN and BOLT, representing a total volume of 4343 inch^3. The characteristics of this source are:

- Frequency range 5-50 Hz
- Max peak level of 54 bar @ 1 m
- Shot rate of 30 s.

The simulation of the waveforms in the time domain, performed by Genavir with the *Sisource* software is given in Figure 3.

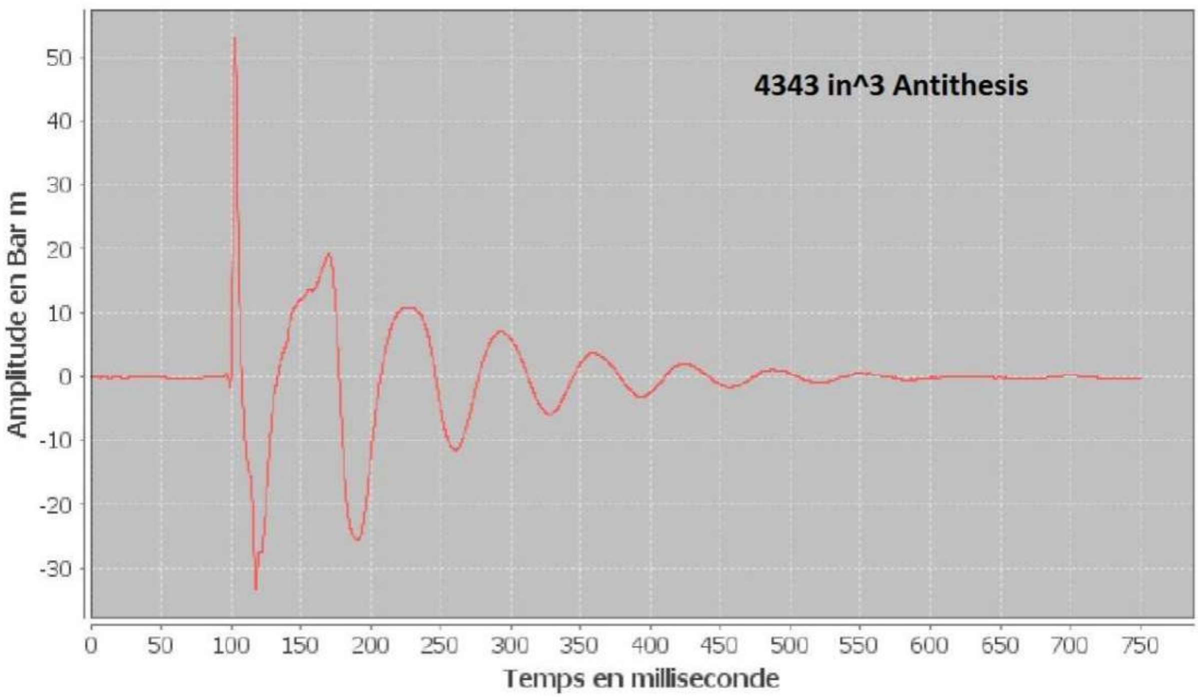

Fig 3 : Characteristics of seismic emission during *AntiTheSis* survey, pressure *p* is given in bar @ 1 m and time *t* in msec.

The maximum pressure level (in absolute value) measured from Figure 2 $p(t)$ is ≈ 54 bar @ 1 m. With 1 bar = 10^{11} µPa, this corresponds to a peak-level source (*SL*):

$$SL(R_0) = 20 \log(54\times10^{11}) \approx 254.7 \text{ dB re } 1\ \mu\text{Pa @ } R_0 = 1 \text{ m}$$

The sound exposure levels (*SEL*) is given by the integration of intensity over time:

$$SEL = 10\log \int p^2(t)dt \text{ in dB re } 1\ \mu\text{Pa}^2\times\text{s}$$

In this case, from the plot of $p(t)$ (see Figure 3), the integrated intensity (at R_0 = 1 m) is approximately 5.03×10^{23} µPa².s.
hence:

$$SEL(R_0) = 10\log(5.03\times10^{23}) \approx 237 \text{ dB re 1 µPa}^2\times\text{s @ } R_0 = 1\text{ m.}$$

4.2. Refraction Seismics

The reflection seismic source used by the *AntiTheSis* cruise consists in 18 airguns GUN and BOLT, representing a total volume of 7070 inch^3. The characteristics of this source are:

- Frequency range 5-100 Hz
- Max peak level of 87.2 bar @ 1 m
- Shot rate of 60 s.

The simulation of the waveforms in the time domain, performed by Genavir with the *Sisource* software is given in Figure 4.

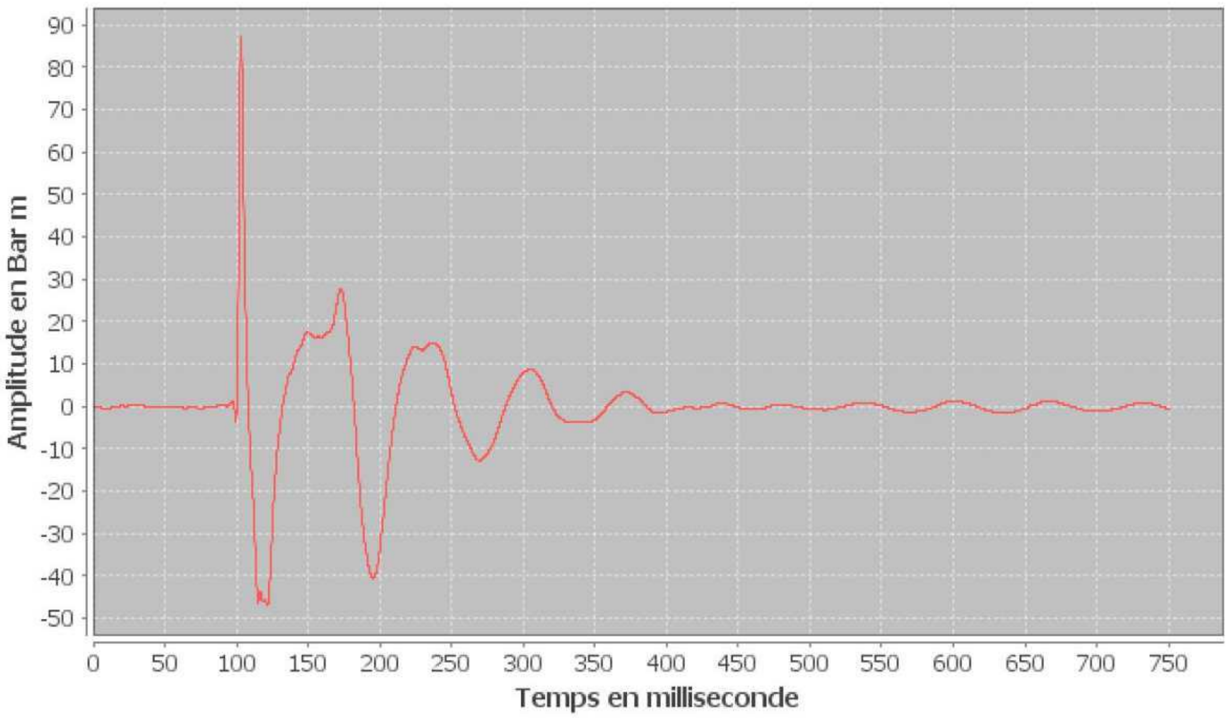

Fig 4 : Characteristics of seismic emission during *AntiTheSis* survey, pressure *p* is given in bar @ 1 m and time *t* in msec.

The maximum pressure level (in absolute value) measured from Figure 4 $p(t)$ is ≈ 87.2 bar @ 1m. With 1 bar = 10^{11} µPa, this corresponds to a peak-level source (SL):

$$SL(R_0) = 20\log(87.2\times10^{11}) \approx 258.8 \text{ dB re 1 µPa @ } R_0 = 1\text{ m}$$

The sound exposure levels (SEL) is given by the integration of intensity over time:

$$SEL = 10\log\int p^2(t)dt \text{ in dB re 1 µPa}^2\times\text{s}$$

In this case, from the plot of $p(t)$ (see Figure 3), the integrated intensity (at R_0 = 1 m) is approximately 1.05×10^{23} µPa²×s.

hence:

$$SEL(R_0) = 10\log(1.05\times10^{23}) \approx 240 \text{ dB re 1 µPa}^2\times\text{s @ } R_0 = 1 \text{ m.}$$

4.3. Other sound sources

Kongsberg EM122 multibeam (MBES) and Sub-Bottom Profiler (SBP) are also acoustic sources. However, both devices do not require specific mitigation measure, either for SBS due to the low sound level transmitted or for MBES, the pulse signals transmitted are very short and because of the narrow selectivity of the directivity pattern.

5. Risk thresholds and establishing corresponding distances

The *SEL* and the *RL* values measured at the receiver are here compared to relevant tolerable thresholds. They are not weighted by frequency (the different weighting for toothed whales and baleen whales is proposed in the report Southall et al. 2007) and are therefore, in this sense, maximum "conservative" estimates (ie maximizing the degree of care). We consider the risk of damage thresholds physiological set today for cetaceans (Southall et al, 2007) :

- Threshold level *RL*-peak 230 dB re 1 µPa;
- Threshold level *SEL* exposure 198 dB re µPa^2× s.

The received level limits corresponding to the thresholds defined above are defined using the spherical divergence propagation model $TL(R) = 20 \log R$.

If $TL(R)$ is the transmission loss (in dB), the received level *RL* and the sound exposure level *SEL* at range *R* are given by:

$$RL(R) = SL(R_0) - TL(R)$$

$$SEL(R) = SEL(R_0) + TL(R) + 10 \log N,$$

where *N* is the number of shots received, thus dependent on the total duration of the presence of an animal in the insonified area and the rate of airgun firing (here a shot every 30 or 60 s depending on the used source).
When positioning at threshold value SEL_T of *SEL*, and considering formula described above, we can define the exclusion zone radius (Figure 5) for a given shot number:

$$SEL_T(R) = SEL(R_0) + TL(R) + 10 \log N$$

5.1. Reflection seismics

Considering the maximum level observed, the distance corresponding to the risk level RL_T = 230 dB re 1µPa corresponds to a distance (17 m) from the source less than 20 m. The probability that this level is observed locally by an animal is therefore negligible.

The *SEL* predicted for exposure to one shot is equal to 237 dB re 1µPa²×s at 1 m. Considering the maximum level observed, the distance corresponding to the threshold SEL_T = 198 dB re 1µPa²×s is equal to 90 m. An increase of the *SEL* for an exposure to 20 shots (corresponding to an exposure time of 10 minutes when shooting every 30 s) equal to 10log20 = 13 dB has to be compensated by a decrease of the received level of the same value, which corresponds to a distance of 400 m.

5.2. Refraction seismics

Considering the maximum level observed, the distance corresponding to the level of risk RL_T = 230 dB re 1µPa corresponds to a distance (28 m) from the source less than 20 m. The probability that this level is observed locally by an animal is therefore negligible.

The *SEL* predicted for exposure to one shot is equal to 240 dB re 1µPa²×s at 1 m. Considering the maximum level observed, the distance corresponding to the threshold SEL_T = 198 dB re 1µPa²×s is equal to 130 m. An increase of the *SEL* for exposure of 10 shots (corresponding to an exposure time of 10 minutes when shooting every 60 s) equal to 10log10=10 dB has to be compensated by a decrease of the received level of the same value, which corresponds to a distance of 407 m.

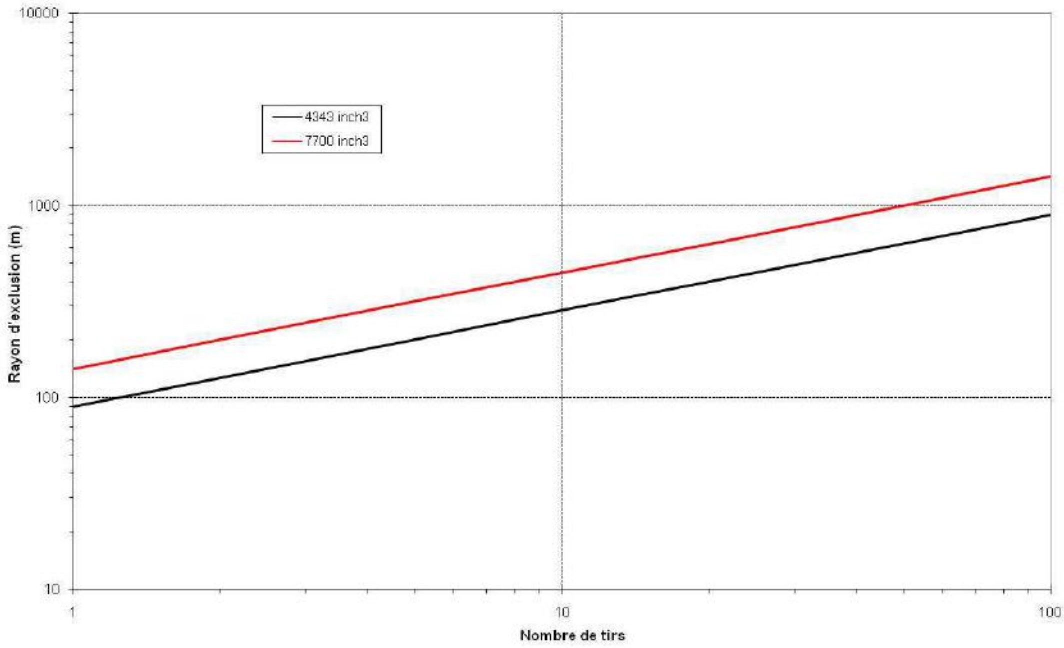

Fig 5 : Evolution of limit distance / number of shots trade-off for both source configurations used during the survey

6. Synthesis and conclusions

The *AntiTheSis* scientific cruise will take place from 24 November 2013 to 9 January 2014 off Lesser Antilles. However, the seismic survey will occur from 24 November to 23 December 2013. Excepting the Agoa sanctuary, the work area is not located on protected areas. Nevertheless, the regulations applicable in Agoa do not specify allowable sound exposure levels, or even make specific mention of acoustic pollution.

According to our calculations, an exclusion zone of 500 m is required to protect marine mammals exposed to such sound sources, greater than the thresholds discussed above and causing injury.
To our knowledge, if the operations are conducted respecting these conditions, seismic signals are not likely to cause a direct physiological effect on marine mammals.

MMO (Marine Mammals Observers) staff will be on board during the *AntiTheSis* scientific cruise. They will monitor presence of marine mammals by visual observations. In this way, they will ensure that operations are halted if any marine mammal is sighted within the exclusion zone.

A Passive Acoustic Monitoring (PAM) system, recently acquired by Ifremer, will complete the visual observations. This device is also a crucial tool regarding the Biodiversity aspect of the scientific program of the *AntitTheSis* cruise.

A ramp-up procedure, in which the power output of the acoustic source is gradually increased from the minimum practicable level to full power, will be applied during the survey.

The responsibility is of course left to the relevant administrative authorities to decide whether the elements detailed above are consistent with any specific regulatory requirements of the coastal state concerned. Ifremer will obviously comply with all documented and quantitatively justified requirements presented by the coastal state.

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8. Appendix A.1. Effects on marine mammals of airguns and other sounds of human origin

This chapter is a brief summary of current knowledge on the effects of seismic acquisition on marine mammals, focusing on information relevant to the implementation of acoustic and seismic systems of Ifremer. More information on the subject is available in the literature (Gordon et al, 2004. Hildebrand, 2005; National Research Council, 2005, Richardson et al, 1995. Tyack, 2008).
Military sonar and air guns are the most powerful sound sources used at sea, with levels that can exceed 240 dB re 1 uPa rms @ 1m for sonar and 260 dB re 1 uPa peak @ 1m for airguns (Richardson et al., 1995).

The active sonar systems can be divided into low-(<1 kHz), medium-(1-10 kHz), and high frequency (> 10 kHz). Seismic sources produce essentially low frequency energy (tens to hundreds of Hz) and can be divided into conventional high intensity systems and very low frequency on the one hand, and high-resolution systems using fewer or less powerful and smaller air guns, and therefore emitting much less intense and higher frequency sounds, on the other hand. Active naval sonars and low- average frequency seem to have the greatest potential for adverse environmental impacts for several reasons:

· The range of frequency of use of these systems (a few kHz) overlaps the hearing sensitivity and noise sensitivity of many animals;
· Signals are long-term (up to several seconds), and emitted in all directions;
· The signals are relatively low frequency, they can propagage along very large distances with little attenuation, and therefore affect large areas;
· Research and observations made during naval maneuvers demonstrate animal reactions to this type of sonar, and especially the correlation between accidental groundings and operations using military sonar.

Conventional air guns used in seismic have comparable intensities (or superior) to those of military sonar, and are therefore likely to have serious negative effects on marine mammals. However, to date, only one accident was associated with the use of air guns: a stranding of two beaked whales Ziphius cavirostris, in the Gulf of California in 2002 (Petersen, 2003) during a seismic shooting campaign. The examination of stranded animals, to determine the cause of death has not been possible at the time of the accident, and the grounding has therefore not been conclusively linked to the deployment of airguns.

The apparent relative insensitivity of odontocètes [1] to air gun noise is not surprising, considering that most of the energy produced by these guns is very low frequency (<500 Hz). This frequency range is lower than the center frequency of the cries of all toothed whales, well below the optimal frequency of hearing for some species for which audiograms have been determined experimentally, it is therefore likely that the toothed whales are not very sensitive to very low frequencies. On the other hand, the frequency ranges emitted by the airguns overlap with the sounds emitted by most mysticètes[2], airguns and emit energy to frequencies up to 1 kHz and beyond, albeit with less intensity. The whales do not generally respond dramatically to the sounds of air guns, although changes in behavior are observed: for example, sperm whales sometimes move away from the guns, or change the characteristics of

[1] toothed cetaceans: whales, dolphins, porpoises, killer whales, beaked whales
[2] Baleen whales or common Cetaceans: whales, right whales, humpback whales ...

their own noise, the bowhead whales, gray whales and humpback whales sometimes slow their swimming speed, turn or move away from the source, or change their breathing rhythms and diving patterns in the presence of airguns (Richardson et al., 1995). One study found a decline in biodiversity in cetaceans during increased seismic activity in Brazilian waters (Parente et al., 2007). Observations of marine mammals collected during the geophysical exploration by industry in British waters (Stone and Tasker, 2006) and off Angola (Weir, 2008) indicated that whales are sighted farther away from the airguns during shooting, and they are less likely to approach cannons during operation.

The effects of airguns on marine fish was also observed, and most studies that describe these effects reported physiological damage to the auditory system (McCauley et al, 2003. Popper et al., 2005; Song et al, 2008.) and lower industrial fishing catch (Engas et al, 1996. Hassel et al, 2004. Skalski et al, 1992.; Slotte et al., 2004), as well as behavioral effects caused by noise levels of 161 dB re 1µPa (peak level, Pearson et al., 1992) or more. Several studies have shown that air guns can damage the hearing of fish or cause temporary hearing loss, although the levels that cause (or not) these effects differ between studies and species, and we can not say whether the injuries are temporary or permanent. (McCauley et al, 2003. Popper et al., 2005; Song et al, 2008.). The behavioral effects caused by air guns include increased swimming speed and alarm reactions or avoidance (Hassel et al, 2004. McCauley et al, 2000.; McCauley et al, 2003. Pearson et al, 1992. Wardle et al, 2001), formation of schools of fish (McCauley et al, 2003.. Pearson et al, 1992), or a change in depth (usually an increase) (Pearson et al, 1992. Slotte et al, 2004.).

The reaction of the turtles to airguns is little studied. Loggerhead turtles avoided to come within 30 meters of a set of three air guns in an experimental channel (O'Hara and Wilcox, 1990). Young loggerhead turtles have also avoided a assembly of two air guns from their first exposure, but this response disappeared after 3 exposures, due to habituation or hearing loss noted by researchers (McCauley et al, 2000. Moein Bartol and Musick, 2003). A green turtle and a loggerhead turtle, in cages, increased their swimming speed after exposure to an air gun (165 dB re 1 uPa rms), and their behavior became increasingly erratic as that the level of exposure increased (175 dB re 1 uPa rms) (McCauley et al., 2000). These studies suggest that the turtles avoid airguns. However, the analysis of data by visual observers collected during industrial geophysical explorations in Angolan and Brazilian waters did not lead to conclusions about this question, because of the limited extent of the data, although they found some evidence of short distance avoidance (Gurjão et al, 2005. Parente et al, 2006. Weir, 2007).

Based on current knowledge, exposure to air guns has no significant effect on invertebrates: the analysis did not detect any effect on the behavior, the health or the fishing of crabs (Christian et al, 2003. Pearson et al, 1994.) or lobsters (Parry and Gason 2006), but a similar study on squid showed probable behavioral effects (McCauley et al., 2000). These results are not particularly surprising, given the limited hearing ability of most invertebrates.

In addition to military sonar and air guns, a wide variety of other sources sound is used in the ocean : sounder and sonar mapping, navigation, fishing ... These systems typically generate noise levels well below the level of the military sonar, and they emit in narrow beams and therefore affect relatively limited areas. Moreover, they generally operate at ultrasonic frequencies (several tens or hundreds of kHz), which are attenuated rapidly in seawater, as compared to the sounds of low and medium frequencies. On the other hand, they are still very likely to be a significant source of noise pollution of the environment ocean: they are much more numerous than the military systems (even the smallest fishing boats and pleasure craft often have a sounder), and many work in frequency ranges used by toothed whales for echolocation and communication. In fact, as summarized below, several studies have examined the response of some cetaceans, seals and fish to active acoustic systems (detailed by Richardson et al. 1995), little information is available for other marine mammals, turtles, or invertebrates.

According to the published results, the reactions of most commonly observed marine mammals to high-frequency acoustic systems (> 10 kHz) are avoidance and changes in noise emissions. In the 50s, high frequency sonar or acoustic transmitters were installed on whaling ships, and the whales (probably sperm whales and baleen whales) responded by surfacing and therefore became relatively easy to find and catch (Richardson et al, 1995.; Tønnessen and Johnsen, 1982). In the scientific literature, there is no mention of grounding, direct injury, or death of marine mammals in relation to civilian operation of sonars, echo- sounders or other acoustic systems assets (excluding, therefore, the military and possibly airguns sonar).

Finally, there is also some evidence that a coherent and sustained noise pollution (not necessarily related to the use of sonar or seismic) can hunt animals out of areas that are important for them, especially the feeding and reproduction sites. For example, gray whales were excluded from one of their main breeding sites in the Baja California Lagoon during a decade of heavy maritime transport operations and dredging activities. Again, the dolphins began to avoid feeding areas, previously occupied by them, when tourist boats have become more and more common in these areas (Tyack, 2008). Such effects are unlikely to result from operations of short duration, such as oceanographic campaigns, particular those of a regional type

9. Appendix A.2. regulations

9.1. A.2.1. International regulations on sound and marine mammals

The negative impact of certain types of noise on marine mammals and other species having either been proven or assumed to be possible, a number of regulatory safeguards have been put in place by countries involved in noisy marine activities.

There are also a number of international agreements about noise pollution in the marine environment: for example, France is a member of ACCOBAMS (Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and Contiguous Atlantic Area), which recommended the research and regulation to understand and minimize effects of this pollution[3].

Cetaceans and many other marine mammals are fully protected under the Community legislation in the EU (Habitats and Species Directive of 1992 Council Directive number 92/43/EEC). In European waters, it is forbidden to deliberately capture, injure, kill or disturb marine mammals and all actions which may cause the destruction or deterioration of their sites feeding or resting. These regulations do not specifically mention the noise pollution.

French law also establishes the principle of the protection of marine mammals (Ministerial Decree of 27 July 1995). However, this Decree is not supported by technical constraints and quantitative figures – Also it makes no explicit mention of sound risks. Today, the regulations do not specifically state limitations in the levels of sonar or seismic emissions. The control measures are in practice the responsibility of operators.

On the other hand, in the United Kingdom, the national legislation prohibits the disturbance and injuries caused by man-made sounds, and the JNCC has established for this purpose specific regulations related to industrial seismic surveys in British [4] waters. This regulation does not specify acceptable or prohibited levels of noise exposure. However, the instructions prohibit seismic surveys to start firing air guns for at least 30 minutes when marine mammals were seen within 500 meters from the vessel.

In the United States, legislation on the effects of sound on marine mammals including the Marine Mammal Protection Act, which prohibits harassment of marine mammals. The National Marine Fisheries Service (NMFS), the agency responsible for regulations, oversees a licensing process for all operations that can subject marine mammals to discomfort level A (permanent physiological damage) or Level B (behavioral disturbance), basing its judgment in general on the sound exposure levels. There are also specific regulations requiring protection measures (including video surveillance and sometimes acoustic observers) for all seismic surveys in the Gulf of Mexico. The level of noise exposure normally cited in impact studies in the United States for several year now is set at a level of sound pressure of 180 dB re 1 uPa rms (for whales dolphins and porpoises) or 190 dB re 1 uPa rms (for seals, walruses and sea lions), considered capable of causing nuisance level (permanent damage physiological) and at a level of 160 dB re 1 uPa rms which can cause nuisance level B (behavioral changes). These

[3] MOP Resolution 3.10% 203.10% http://www.accobams.org/file.php/1290/Res 20EN.pdf
[4] JNCC Guidelines 2004 http://www.jncc.gov.uk/pdf/Seismic_survey_guidelines_200404.pdf

standards are currently being reviewed and are likely to change in the near future (Southall et al. 2007) as summarized below for nuisance level A:

· The peak level of noise exposure should not exceed 230 dB re 1 uPa for cetaceans, 218 dB re 1 uPa for pinnipeds in water, and 149 dB re 20 uPa for pinnipeds in air;

· The sound exposure levels weighted frequency must not exceed 198 dB re 1 μPa^2-s for cetaceans exposed to sounds impulsionnels[5], 215 dB re 1 μPa^2-s for cetaceans exposed to non-pulsed sounds, 186 dB re 1 μPa^2-s for pinnipeds underwater exposed to pulsed sounds, 203 dB re 1 μPa^2-s for pinnipeds in water exposed to non-pulsed sounds, 144 dB re $(20\ uPa)^2$-s for pinnipeds in air exposed to pulsed sounds, and 144.5 dB re $(20\ uPa)^2$-s for pinnipeds in air exposed to non-pulse sounds.

· As evidenced by studies of behavioral responses to sounds of low level, Level B limits of risk are likely to be much lower.

Several other countries (Australia, New Zealand ...) designed and implemented regulations very similar to those briefly described above (Compton et al, 2008; Weir and Dolman, 2007).

9.2. A.2.2. Ifremer's Own mitigation measures

Cruises operated by Ifremer in an international context oblige by the regulatory requirements of countries whose national waters are concerned. Furthermore, in order to anticipate these technical constraints, and to respond to the lack of national regulations specifically related to scientific cruises in French waters, Ifremer has established voluntarily from 2006 a number of actions and preventive measures.

· A syntheses study (Lurton and Antoine, 2007) was conducted to assess the level risk presented by the different acoustic instruments owned by Ifremer, and set limits to their use

· Sound radiation models that predict the noise levels perceived in water are available for all seismic and sonar systems used by Ifremer.

· The evolution of scientific work in the field, as well as the evolution of international standards, is followed closely by Ifremer scientists, in order to be able to adapt the measures if so required.

· To summarize the current British and American standards, a value of precautionary radius of the area in which a sound source of high power may affect marine mammals is taken either as the distance at which exposure levels received exceed the standards previously discussed by Southall et al. (2007), as a radius of 500 meters (whichever is greater of the two values).

· During a high power seismic survey, the presence of marine mammals in the exclusion zone is proved by visual monitoring conducted, as appropriate, by the crew, the scientific team or by independent expert observers (MMOs.for *Marine Mammal Observers*); these observers should always be associated to campaigns involving oil industry types of seismic emissions.

[5] In this context, impulsive sounds are defined as sounds for which the acoustic pressure level measured in a time window of 35 msec was at least higher by 3 dB than that measured in a window of 125 msec

· A procedure for gradual ramp (Ramp-up or called Soft-start) is used in the case of seismic emission of high power.

· A prototype system of passive acoustic monitoring (PAM or for Passive Acoustic Monitoring) has been installed on L'Atalante (Ifremer main ship for seismic acquisition), and is currently (October 2010) in the test phase. In the future this system can be used by MMOs, as a system that is intended to supplement visual observations when they become problematic.

In practice, the level of vigilance and action for a given campaign depends on the material used. Each configuration is the subject of a specific study and special instructions.