Acoustical analyses of submarine explosions in northern Chile on long term continuous recordings

Franck Malige(1,5,6,7) **Julie Patris**(1,5,6,7)
Susannah Buchan(2,3,4,5,7) **Hervé Glotin**(1,5,6,7)

(1) Université de Toulon, Aix Marseille Université, CNRS, LIS, DYNI team, Marseille, France
(2) COPAS Sur-Austral, University of Concepción, Chile (3) Centro de Estudios Avanzados en Zonas ridas, Chile
(4) Woods Hole Oceanographic Institution, USA (5) BRILAM, STIC AmSud (6) EADM GDRS CNRS MADICS, France (7) SABIOD.org

franck.malige@etu.univ-amu.fr & herve.glotin@univ-tln.fr

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Introduction

The aim of this research was to investigate the type of explosions (aerial, ground or submarine, their charge and location) that have been heard in january and february 2017 near the Chañaral de Aceituno marine reserve zone (Chile, Atacama region).

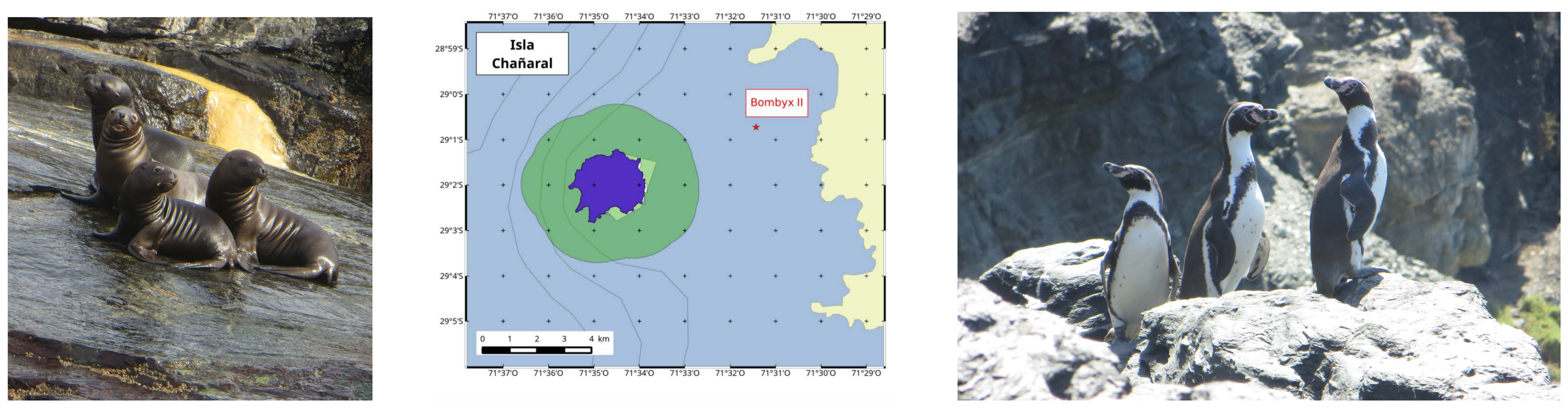

Figure 1: Left : *South american sea lions pups (Otaria flavescens).* Center : *Map of the experiment , the Chañaral marine reserve is one mile around the island, part of the pingüinos de Humboldt national reserve. The red point is the position of bombyx II buoy.* Right : *Pingüinos de Humboldt (Spheniscus humboldti).* Pictures : F.Malige

We set up a moored hydrophone (Bombyx II device) that recorded continuously during three sessions of 2 weeks at 48kHz sampling rate. During the analysis of the data (900h of recordings), we discovered 30 explosions with a sound frequently saturating the sensor (level of saturation 165 dB ref 1μPa). These explosions happened only in the early morning during 11 days out of 40. An example in .wav can be downloaded at http://sabiod.org/workspace/BombyxUTLN_ChanaralChili/

Analisis

In underwater explosions, an "oscillating gaz bubble" appears : the explosion creates a gaz sphere that expands and milliseconds after contracts until it collapses and bounces. Several cycles of expansion-contraction occur that give a very characteristic acoustic pattern. The figure 2 presents the acoustic waveform of one of the explosions recorded. It is consistent with the waveform of a submarine explosion as presented in Mitchell et al. 1976 [7].

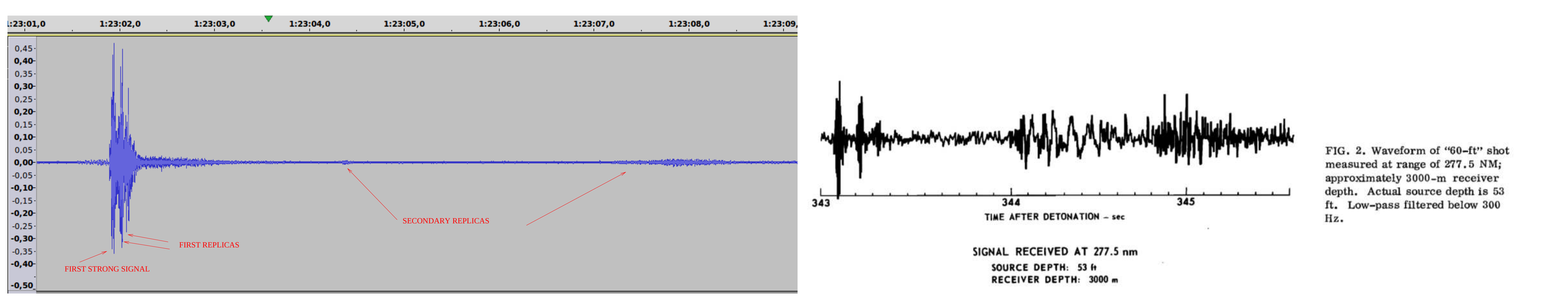

Figure 2: *Explosion recorded in Chañaral in wave form (Left) and underwater explosion in waveform from Mitchel et al. 1976 [7]*

The bubble pulse periods

The "bubble pulse periods" are the duration between the signal and its first replica (T_1), the duration between the first replica and the second (T_2), and so on (see Cole 1948 [3] for details).

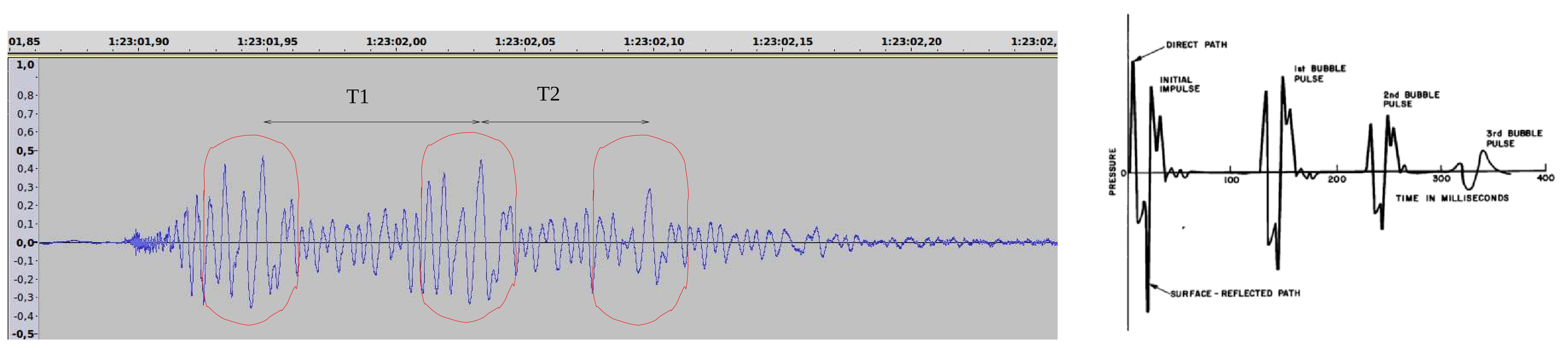

Figure 3: Left : *Explosions recorded in Chañaral in waveform and bubble pulse periods T_i* Right : *Waveform of a submarine explosion from Hanna et al. 1974 [6]*

We measured T_1 and T_2 by autocorrelation of the signal, using OCTAVE. It was possible to measure T_1 for all explosions but one and we measured T_2 for only 12 explosions because of the poor signal to noise ratio. For these measures, the ratio T_2/T_1 is almost constant and very compatible with the values presented in Chapman 1985 [2] which reinforce the assumption of being in presence of underwater explosions. We checked also that, due to the bathymetry of the zone and the times T_i, the replicas are not bounces on the floor, sea shore or surface.

Estimation of depth and charge by means of the bubble pulse periods

The bubble pulse periods T_i depend strongly on the charge and the depth of the explosion (Prior et al. 2010 [8]) :

$$T_i \simeq K \times \frac{w^{1/3}}{(10,1+z_i)^{5/6}}(1-\frac{R_i}{5z_i})$$

where T_i is in seconds, $K = 2.11$, z_i is the depth in meters of and w is the charge of the explosion, in kg of TNT equivalent and R_i, in meter, is the radius of the bubble number i.

Hour	T_1 (ms)	T_2 (ms)	T_2/T_1	Depth z_1 (m)	Charge w (kg. of TNT eq.)
1h17	87,58	67,64	0,772	19.2	0.39
1h22	79,19	59,96	0,757	23.4	0.35
1h23	84,85	65,65	0,774	17.8	0.27
1h27	88,45	68,27	0,772	19.6	0.36
1h50	80,98	61,27	0,757	24.6	0.41
1h52	89,46	69,35	0,775	18.7	0.35

In Prior et al. 2010 [8] a method is given to compute the values of w and z_1 using the values of T_1 and T_2. This method requires a very good precision on T_1 and T_2. When the explosions were saturated (6 explosions out of 12), the autocorrelation of the signal didn't give sufficiently precise results for T_1 and T_2. For the remaining 6 explosions, all happening during the 17th of january, the results are in the table presented.

These six firsts explosions seem to happen at little depth (around 20 m) and with small charges (around 0.35 kg), which is very compatible with fish-bombing (see Woodman et al. 2003 [9]).

Analysis of the distance between the hydrophone and the explosions

Positionning the explosion is a hard task, especially in the shallow waters of Chañaral zone where propagation effects are important. We perfomed a qualitative estimation of this distance, very important to estimate if these explosions could have happened in the reserve.

Qualitative analysis of the waveform

The theorical waveform from an underwater explosion is displayed in the figure 4 left.

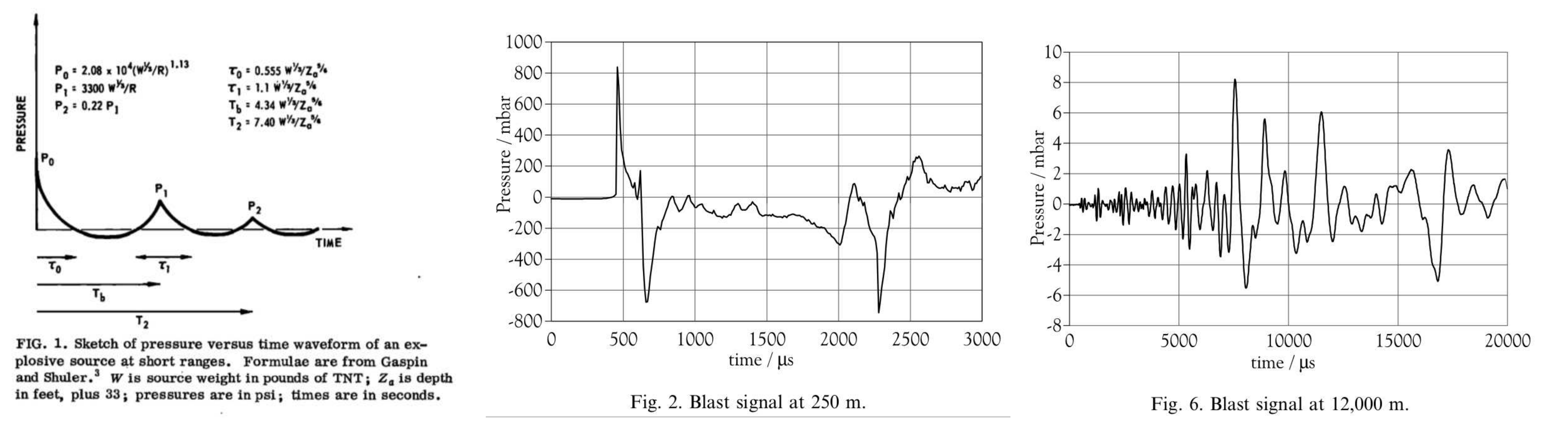

Figure 4: Left : *Theoretical explosion's waveform (In Mitchell 1976 [7])* Center and right : *Waveform of fish bombing at short range (250m) and at long range (12 kms) (Woodman et Al. 2003, [9])*

Nevertheless, the received waveform is generally more complex due to propagation (see figure 4 center and right), especially in shallow waters.

In Woodman et Al. 2003 [9], for a sea-depth of 20-30m and an explosion between 7 and 12m, the transition between short and long range type of waveform is around 2-3km (figure 4). In Chañaral, we have an ocean depth of 66m where bombyx II is placed and explosions in a typical depth of 20m so we can expect to have a similar transition range of few kms between the short range waveform and long range waveform. So the explosions are probably situated at some kilometers of the hydrophone (figures 3, 4).

Analysis of the energy received

To evaluate the range of the explosions, we evaluate roughly the received energy, assuming that we know the charge. Our device is saturated for a 1V tension, which correspond to an acoustic pressure of 165 dB ref $1\mu Pa$. For a fish bombing charge (0.3 kg of TNT equivalent), it corresponds to a distance around 5 km (Woodman et Al. 2003, [9]). This estimation is consistant with the estimation of the previous paragraph : we have a distance around few kilometers between the explosion and the hydrophone.

Results

- Due to their typical waveform, **explosions are submarine**.
- The depth and charge of the explosions could be computed (when the sound did not saturate the sensor) and are **compatible with fish bombing**.
- The distance between explosions and hydrophone are around **few kilometers**. And this range is very compatible with fishing in the reserve.

This method (recorder and analyse) could be distributed in marine reserves, and could be joint to automatic trigger for a real time alert (see Abeille et al. 2012 [1], Gies 2018 [5] and Fourniol 2018 [4]).

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