Individual blue whale recognition. Wigner-Ville time-frequency analysis and preparation for a Kaggle contest

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SCIENCE AND TECHNOLOGY 2013 CONFERENCE

CTBTO PREPARATORY COMMISSION

(T2-P36)

Abstract

.Among one of the most fascinating sea creatures, the blue whale holds a special place. The largest ever living animal, it has been recognized that they can be tracked remotely at large distances at sea using fixed and moored hydrophones. The frequency range (16-100Hz) of their acoustic calls falls within the range of the IMS hydroacoustic stations and it is thus theoretically possible to track them in oceans where the IMS hydrophone stations provide a complete coverage and if the signal they emit is strong enough to be seen at a minimum of two groups of hydrophones. This may be the case in the Indian ocean where two stations are complete enough at the moment to provide detections and an azimuth provided signal from the same individual can be detected at these two sets of hydrophones. We propose to establish a data set that will be rich enough to contain several blue whale individuals and setup a contest on the Kaggle site. The goal is to determine the best method to be used to distinguish among different individuals using distinctive features of their calls, taking into account transmission loss of acoustic power

Project outline

We propose to place on the Kaggle site the problem of feasibility of recognizing an individual blue whale from its acoustic signature. The problem is a challenging one because of several factors:

1- It may be difficult to place an identifier tag on specific acoustic signals. In other words, the problem may have to be tackled as a supervised problem . The clustering into different classes may have to be solved a well as the best classification method once clustering has been identified.

2- Propagation in the oceanic SOFAR channel is complex and acoustic signal does not propagate as a simple plane wave. Different frequencies may follow different paths for instance, and propagate at different velocities.

3- Signals from a single individual may evolve over time, although it is likely that this will happen slowly. There is evidence that animal size influences the frequencies emitted by that animal. This can be inferred for instance from the study by McDonald et al. (2009) that shows evidence of blue whale signal frequencies drifting lower with time over the past several decades. This may be due to an increase in the average size of animals as their population is recovering from whaling.

The following data will be placed on the site:

1- Document explaining the challenge.
2- Snippets of signals detected at all three hydrophones of a station triplet.

Work accomplished

A vDEC (Vaidya et al., 2009) proposal has been written and awaits award. Work has started on the project even in the absence of recent data from the IMS hydro-acoustic stations. Data from the rdss.info site has been acquired (several days for January 2003), and blue whale signal from the Indian Ocean identified on the northern triplet of the Diego Garcia H08 station. The signal corresponds well with the type 9 blue whale signal as identified in McDonald et al. (2006). It consists of an initial sweep at frequencies between 30Hz and 45Hz lasting 20-25 seconds followed by a very monochromatic signal at 20Hz, of about the same duration. The initial hour of the first day in January has been particularly well studied. Nineteen distinct signals can be clearly identified on the filtered signal and spectrogram.

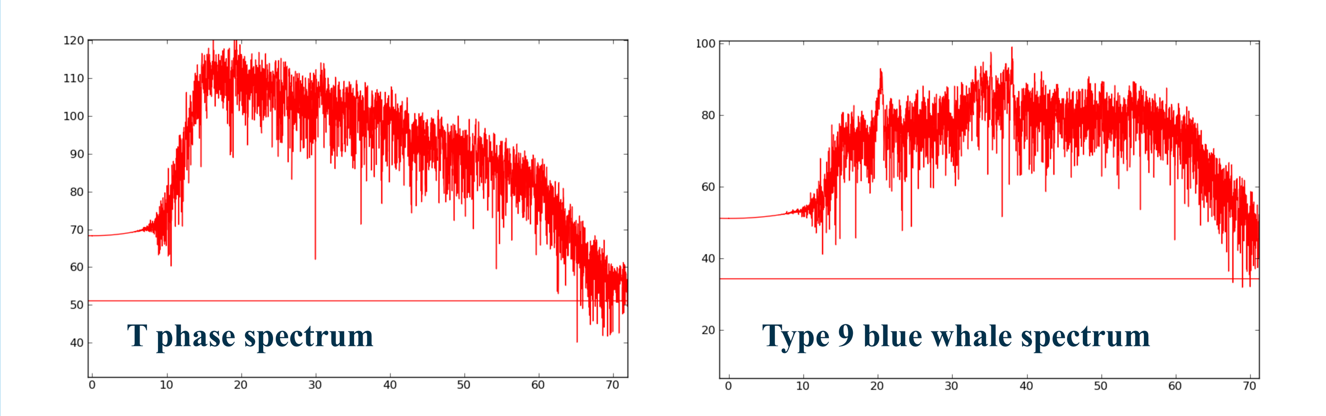
The few days of data were acquired and processed through the following sequence:

1- Short term average to long term average ratio (STA/LTA) with a window of 1s for the short term and 10s for the long term. A detection is declared at each hydrophone when an SNR of 2 is reached. Groups are identified where detections are made at the three hydrophones of a triplet within a time window. The groups are interpreted as the same wave train being detected at the three hydrophones.

2- An initial estimate of which direction the signal is coming from is made based on the absolute time of the three picks. This crude method leads to surprisingly consistent results, but is subject to instability due to the presence of noise.

3- We have developed automatic detections of the whale signals using a simple spectral ratio method. This works well on the one hour of data tested so far, but will need to be further tested on more signal types.

4- We have attempted to refine the initial estimate of the direction of the incoming signal by using the envelopes of cross-correlations of the individual detections. This method relies on relative travel time picks rather than absolute picks.



The two figures to the left show the spectra for two automatically picked detections. The time window chosen is 50 seconds (10 seconds before and 40 seconds after the picks). Note the distinctive blue whale spectrum on the figure to the right. In particular the peaks at 20 Hz and between 30 and 40 Hz. The data is pre-filtered in a band-pass between 15 and 60 Hz and the spectral ratios between the 50-80 Hz and the 50-80 Hz bands computed. Whale signals have a

Blue whales background

Blue whales are the largest animal that, in the current state of our knowledge, ever existed. Their gigantism is a fairly recent evolutionary feature since the last 31 Ma. (Evans *et al*., 2012)

Blue whale populations are recovering from commercial whaling that was practiced until a 1982 moratorium. A few facts about blue whales:

- *Baleanoptera musculus* is thought to be the largest animal that ever existed. This partly explains the very low frequency of their calls, falling within the CTBTO IMS hydrophones frequency range (16-100 Hz)
- Characteristic songs in each of ten distinct populations worldwide. Category 9 (McDonald *et al., 2006)* recorded at Diego Garcia IMS hydrophones and studied in this preliminary work
- Over 360,000 were caught during the commercial whaling period There are now a few thousand individuals worldwide. International Whaling Commission estimates 2300 in the Southern Ocean at end of last century. Currently 2000 in Northeastern Pacific (J. Hildebrand, Scripps Institution of Oceanography, personal communication)
- It has been observed that the observed dominant frequency of the calls has decreased with time over the past decades. One possible explanation is that after recovery, the average animal size is larger and larger (McDonald *et al*., 2009)

Time-frequency analysis background

To analyze the signal of cetaceans, it is appropriate to explore the available tools in time-frequency analysis. The goal of the project being recognition of individual animals, it may be of value to maximize the resolution of signals in the time-frequency space. This may lead to better characterization of these signals and better ability to separate individuals.

Standard Spectrogram of function $s(t)$:

$$S_w(t,f) = \left| \int_{-\infty}^{\infty} s(\tau) w(\tau - t) e^{-j2\pi f \tau} \, d\tau \right|^2$$

Wigner-Ville Distribution (WVD) of the analytic signal

$$z(t) = s(t) + jH(s(t))$$

where H denotes the Hilbert transform.

$$W_z(t,f) = \left| \int_{-\infty}^{\infty} z\left(t + \frac{\tau}{2}\right) z^*\left(t - \frac{\tau}{2}\right) e^{-j2\pi f \tau} \, d\tau \right|^2$$

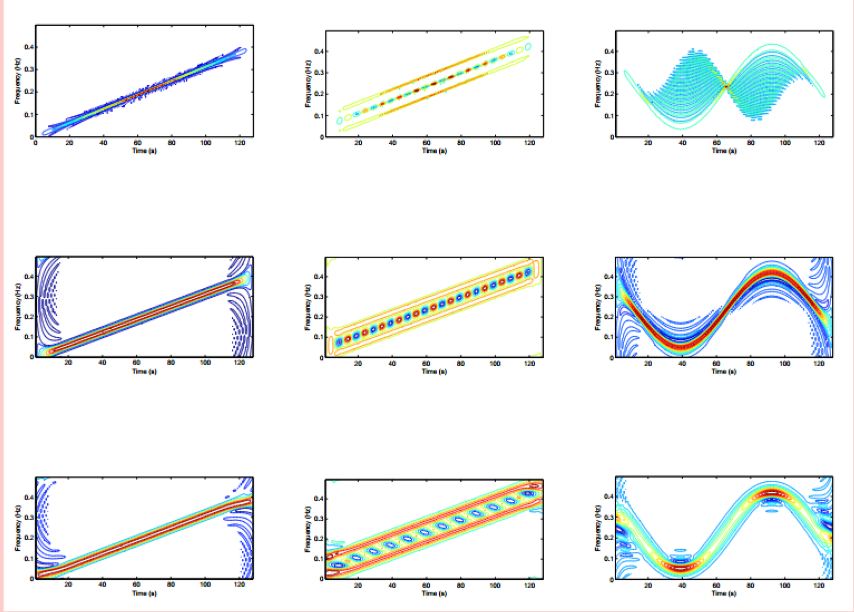
Quadratic class of Time-Frequency Distributions:

$$\rho_z(t,f) = \left| \iiint_{-\infty}^{\infty} g(\tau,\nu) z\left(u + \frac{\tau}{2}\right) z^*\left(u - \frac{\tau}{2}\right) e^{j2\pi\nu(u-t)} e^{-j2\pi f \tau} \, dv\, du\, d\tau \right|^2$$

The Smoothed Pseudo Wigner-Ville Distribution is obtained with a smoothing kernel G(ν) and the heaviside function h(τ):

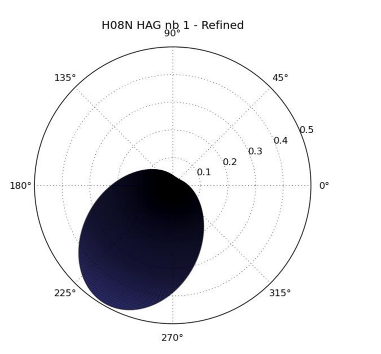
$g(\tau,\nu) = G(\nu)h(\tau)$

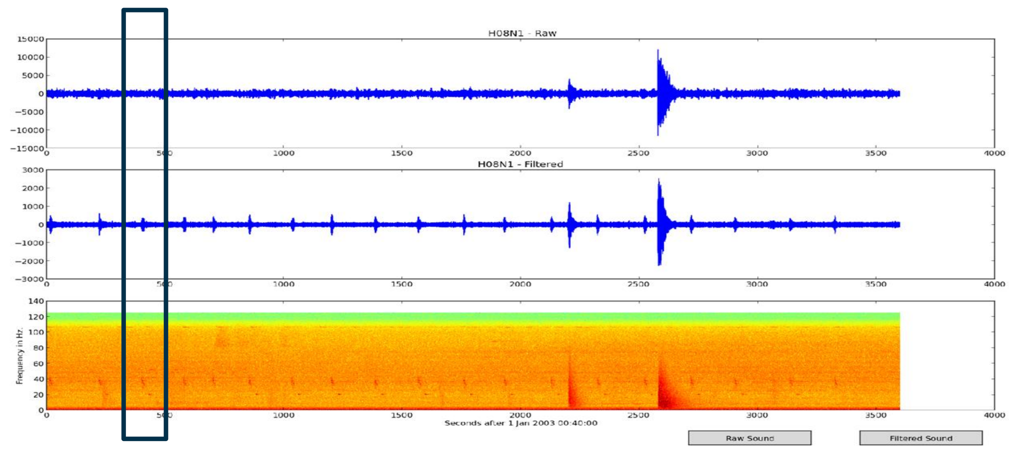
This method has been applied to the three records of the same wave train passing through the triplet of geophones at station H08N1.



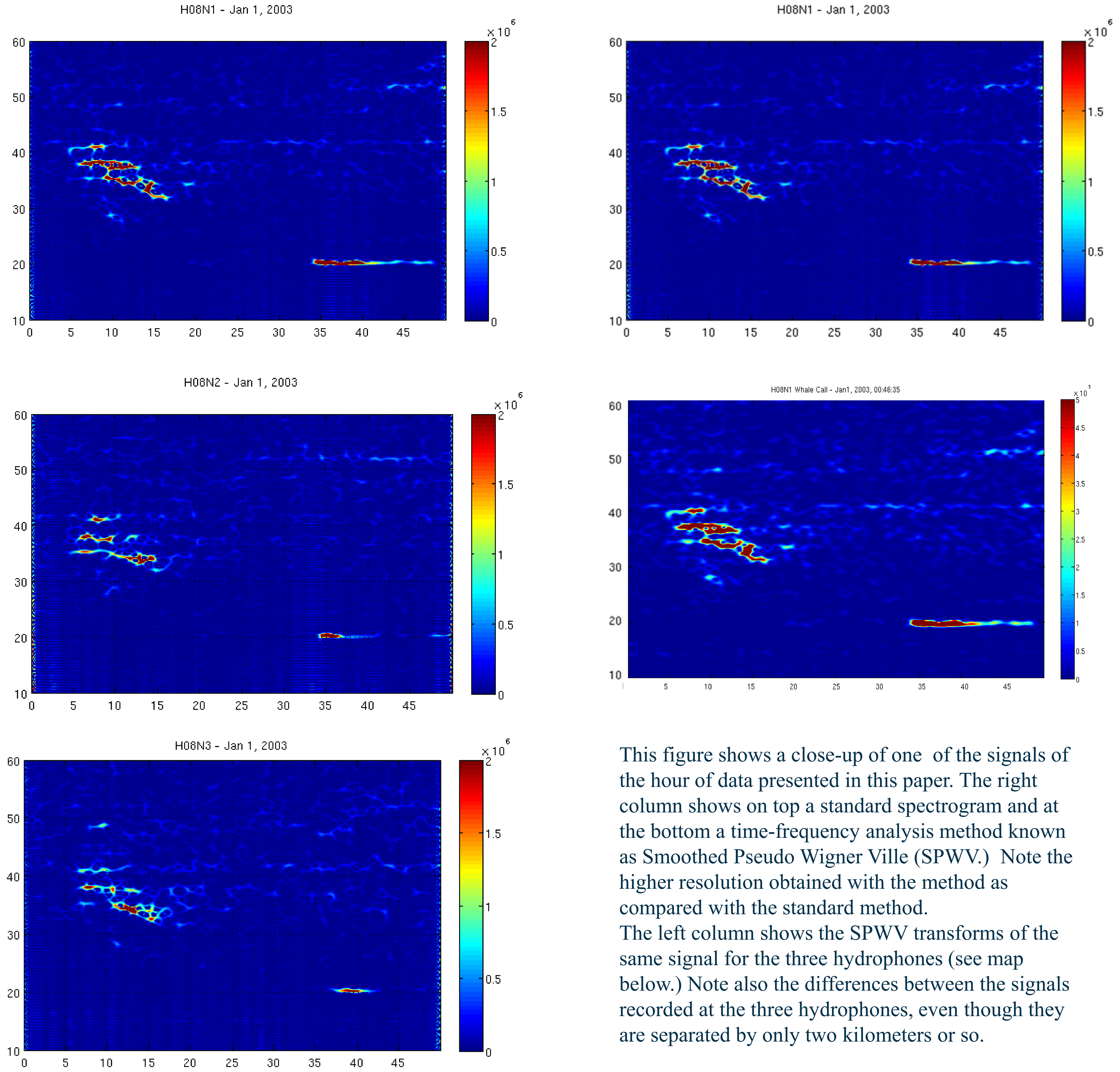
Examples of application of the Wigner-Ville, (top) Pseudo Wigner-Ville (middle) and Smoother Pseudo Wigner-Ville (bottom) on non-stationary signals.

Initial data analysis and collection

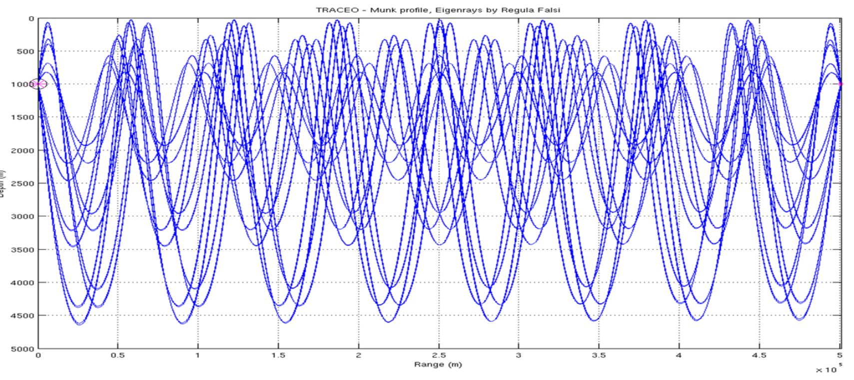


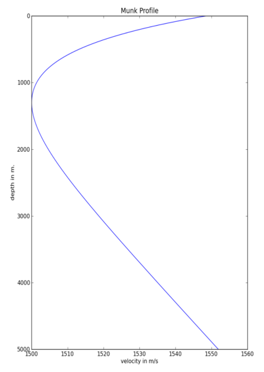


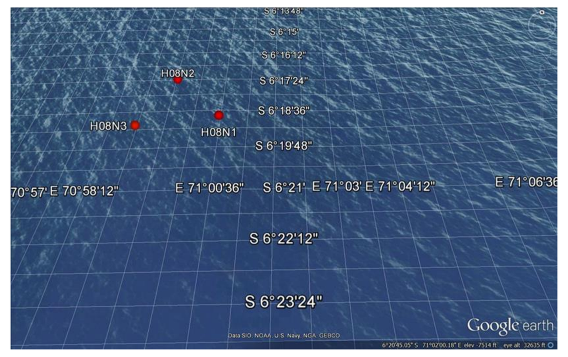
The figure to the right shows one hour of data at hydrophone H08N1, on January 1, 2003, starting at 00:40:00. The top trace is the raw data, the second is the data filtered between 10 and 60 Hz, enhancing the whale calls which are dominant in that frequency band. The spectrogram for the whole hour is shown below and the calls are very clear in this image. There are two distinct frequency ranges for the calls. The dominant one is centered around 40 Hz and the second one is centered around 20 Hz. This second call usually follows-- but not systematically-- the higher frequency one. This is typical of the type 9 blue whale calls (McDonald *et al*., 2006). The large signals during the second half of the hour are likely T phases generated by earthquakes.
The map at the bottom of the panel shows the disposition of the three hydrophones forming the H0N triplet near the Chagos archipelago in the Indian Ocean. The red dots are the location of the hydrophones. The water depth is respectively 2308m for H08N1, 2373m for H08N2, and 2342m for H08N3. The hydrophones are placed at the depth of the SOFAR channel.
The figure to the left shows tan estimate of the incoming direction of the signal as estimated by using the envelope of the cross-correlation of the signals.



This figure shows a close-up of one of the signals of the hour of data presented in this paper. The right column shows on top a standard spectrogram and at the bottom a time-frequency analysis method known as Smoothed Pseudo Wigner Ville (SPWV.) Note the higher resolution obtained with the method as compared with the standard method.
The left column shows the SPWV transforms of the same signal for the three hydrophones (see map below.) Note also the differences between the signals recorded at the three hydrophones, even though they are separated by only two kilometers or so.







Gaussian ray tracing in a standard ocean, using the Munk depth profile for the acoustic velocity. The depth of the source and receiver are at 1000m, which corresponds roughly to the axis of the SOFAR channel. The computation and graphics are made using the Traceo software (Rodriguez, 2011, Santos *et al.,* 2010.). Future work will involve more precise modeling of the waveforms and propagation using the Traceo software..

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