Echo-location of whales using seismic records

Juan Doblas Prieto, UFRJ/NADC

Abstract

A pioneer methodology, oriented to whale detection in the vicinity of operating seismic vessels is proposed and discussed.

The methodology is based on analytic resolution of the problem given by the presence of a diffracting body receiving and reflecting a wave front coming from a punctual source.

Firstly, a set of synthetic data was computed, using a two-dimensional finite-differences algorithm. We have modeled the seismic experiment using a velocity model extracted from a line offshore of the Southern Espirito Santo basin (Brazil). During the acquisition of this line the encounter of a 12 meters long humpback whale was reported. We have assumed for modeling purposes that the whale was laterally located 1000 meters off the seismic source, and 300 meters below the streamers.

The analytical resolution of the diffracting body problem was applied iteratively to every sample of the synthetic seismic section, in order to focus any potential reflected energy. The result shows a punctual anomaly which corresponds to the energy refracting whale. The coordinates (x,t) of this point can be used to determine the absolute position and depth of the whale.

Introduction

The impact of seismic vessels activity on marine mammals' behavior is a growing global concern. An important number of scientific articles (Gordon, 1998; McCauley, 2000; Hildebrand, 2004; Taylor, 2004) reports prejudicial effects of seismic noise on whales.

Despite this vision not being shared by all the scientific community, the environmental authorities seem to be adopting today the principle of precaution, while trying to determine the real amplitude of these effects. This is translated, in most of the cases, by the reduction of the seismic acquisition activities on areas with a high potential of whale encounters.

There is, in fact, an urgent need for rigorous scientific work on whales behavior, which is still on an early stage of development due to the habitat and diving habits of the big cetaceans. In other words, a practical method to monitor underwater whale behavior is necessary.

Consequently, a number of authors (Gillespie, 1998; Tiemann, 2002; Jarvis, 2002; Clark, 2002; Thode, 2004) are actively working on passive methods of whale detection using their vocalizations. Generally, those methods are based on cross-correlation of one or more vocalizations received almost simultaneously at several hearing stations located on the sea-bottom. Those cross-correlation can be processed to determine the exact position of the 'singing' mammal.

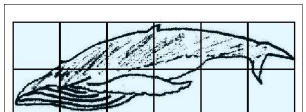
The problem with passive detection method is that two elements are necessary: a) a set of fixed hydrophones and b) a whale vocalizing in the vicinity of the receiver antenna.

A new methodology is proposed, which will use the seismic record itself to detect the presence of whales near the seismic vessel. The objective is to locate and study the movement of a whale on the vicinity of the seismic vessel by analyzing the evolution of the signal received from the reflection of the seismic energy on the animal during its displacement relative to the vessel. This method is not dependent on vocalizations or specific recording devices other than the arrays of hydrophones dragged by the vessel.

If the impact of the signal coming from the whale is strong enough (above the noise level), it will be possible to study and to map the whale movements, determining its hypothetical change of behavior. This would be useful also to monitor the presence of cetaceans near the air guns, allowing the party chief to determine with accuracy when to stop firing in order to avoid any environmental impact.

Method

We have based our study on a documented encounter of an humpback whale with a seismic vessel on the Brazilian offshore of Espirito Santo basin.



Picture 1: Humpback whale as modelled on the dataset: 6x2 elements grid.

The seismic source was positioned at x=2350 meters and z=8 meters. The receivers were located at 10 meters depth, along the x axis. The source was parameterized to produce a Ricker-type pulse, with a central frequency of 80 Hz.
A velocity model 2 kilometers deep x 2.4 kilometers long was created, with a 2 x 2 meters resolution, using the geologic model and velocities interpreted in the area.
A rectangle of 6x2 grid elements, representing the whale

(cf. Picture 1), was inserted on the model at x=1000 and z=300 meters (for an image of the model, see Picture 2).
The P-wave transmission velocity through the whale body (1700 m/s) was inferred from the work of Aroyan et al. (2000).
A 2D finite differences seismic modelling was performed with this velocity model, using the SU (Seismic Unix) open software package of the CWP (Centre for Wave Phenomena) of the Colorado School of Mines. Some screenshots of the simulation are shown on Picture 3.

The resulting synthetic session is shown on Picture 4. A subtle hyperbola corresponding to the diffraction on the whale is effectively visible on x=1000. It was isolated by subtraction with the section modeled using a model with no diffracting points.

The next step was to conceptualize a situation involving an emitting seismic source and a whale, in order to determine the position of the diffracting body. Figure 6 illustrates the situation described.

The results of the seismic experience through such a model will involve, in addition to the standard reflections on geologic acoustic impedance contrasts, a hyperbola whose apex will be located at the x position of the whale. The time delay will be a function of the sound velocity through water, the position of the whale and the position of the source (figure 6).

A set of equations was then deducted to determine the shape and location of the expected diffraction. In fact, what we were looking for was an explicit expression of the diffraction hyperbola delay, t, as a function of the offset and delay of the hyperbola apex. The result is the next equation:

$$t(x_i)=\frac{1}{v_a}\sqrt{(x_i-x_p)^2+\left(\frac{v_a t_q}{2}+\frac{x_p^2}{2 v_a t_q}\right)^2}+\sqrt{x^2{}_p+\left(\frac{v_a t_q}{2}+\frac{x_p^2}{2 v_a t_q}\right)^2} \qquad [1]$$

where

- $t(x_i)$ equals the delay of the diffraction arrival at a given receiver
- v_a equals the mean sound velocity on water
- x_i equals the offset of a given receiver
- x_p equals the offset of the diffraction apex
- t_q equals the delay of the diffraction apex

This equation will allow us to perform the last step of our methodology: The focusing of all the possible hyperbolae on the seismic section.

On a double-nested process programmed on c language, all the samples on the synthetic seismic section computed before will be considered as being the apex of a diffracting hyperbola described by the equation [1] .

For every sample, the hyperbola is calculated, and the seismic amplitudes along the hyperbola are added up.

What we expect is a 'focused' seismic section showing a strong anomaly on the hyperbola apex against a 'white' background. The existing anomalies will be clearly visible, and, applying our analytical model, the position of the whale will be determined.

On the 2D case, the equation giving the depth of the whale as a function of the hyperbola apex offset and delay, and the sound velocity on water is:

$$z_p=\frac{v_a t_q}{2}+\frac{x_p^2}{2 v_a t_q}$$

Results

The proposed methodology was applied to the synthetic data shown on picture 4. The results are shown on pictures 7 to 10.

A strong anomaly, located at the expected position, appears clearly on the focused section (pictures 9 and 10).

Applying the last equation, we can accurately enough locate the diffracting whale in offset and depth.

Conclusions

The proposed methodology worked successfully on 2D synthetic data, locating a diffraction point below a single seismic streamer by focalizing the diffracting hyperbola received by the hydrophones.

We can easily imagine the applications of this methodology on biology (determination on cetacean behavior under seismic stimulus) and in seismic operations (real-time locating of whales on the vicinity on the vessel).

Further Work

- The equations showed here are valid for a 2D case. The 3D equations should not be too problematic if every streamer's data is considered individually. The difference between the focused points can be used to determine the whale exact position.
- The method should be tested against real acquisition conditions. Noise and non-straight acquisition geometries will distort the results. Filtering and resampling data could then solve the problem.
- A run of the focusing algorithm took about 30 minutes on a Linux 64-bit machine. That' s too long if we want a real time monitoring of whale presence around the vessel. Algorithm optimization and use of clustered PC's can aid solving this specific problem.

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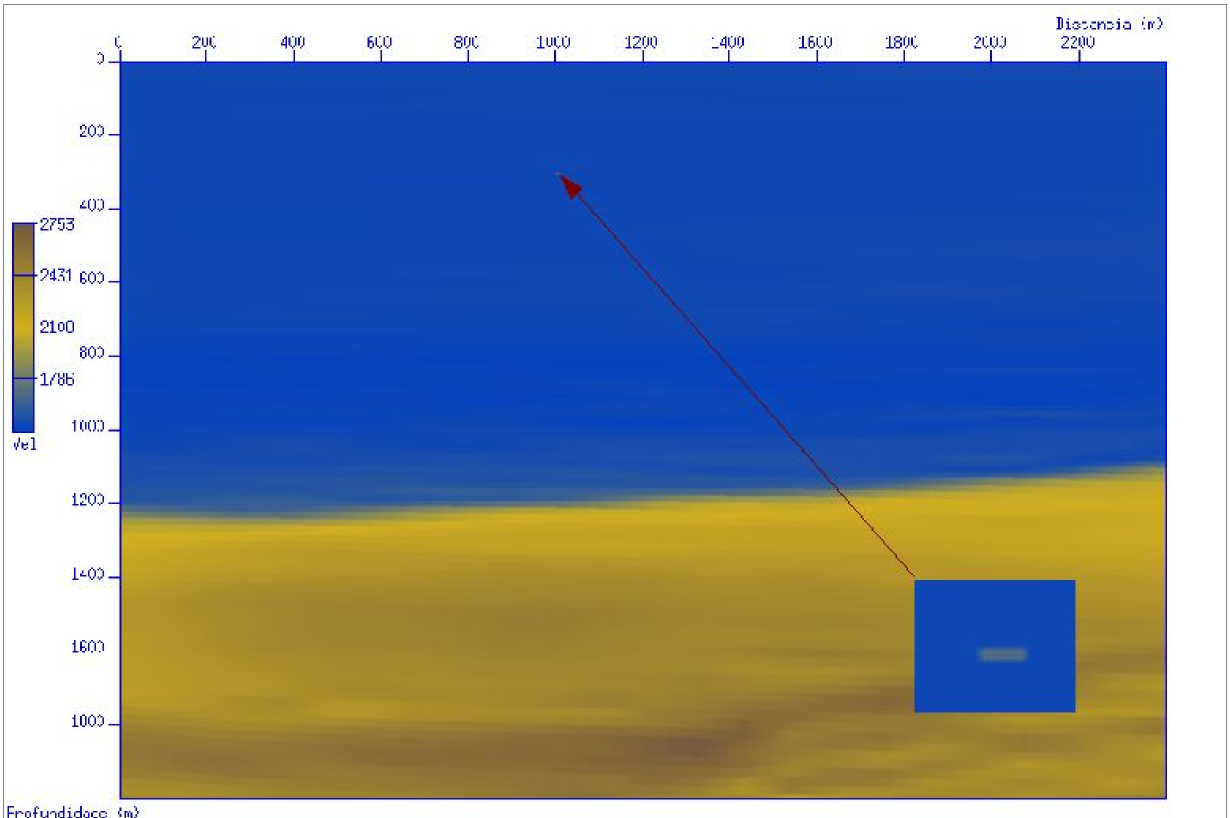
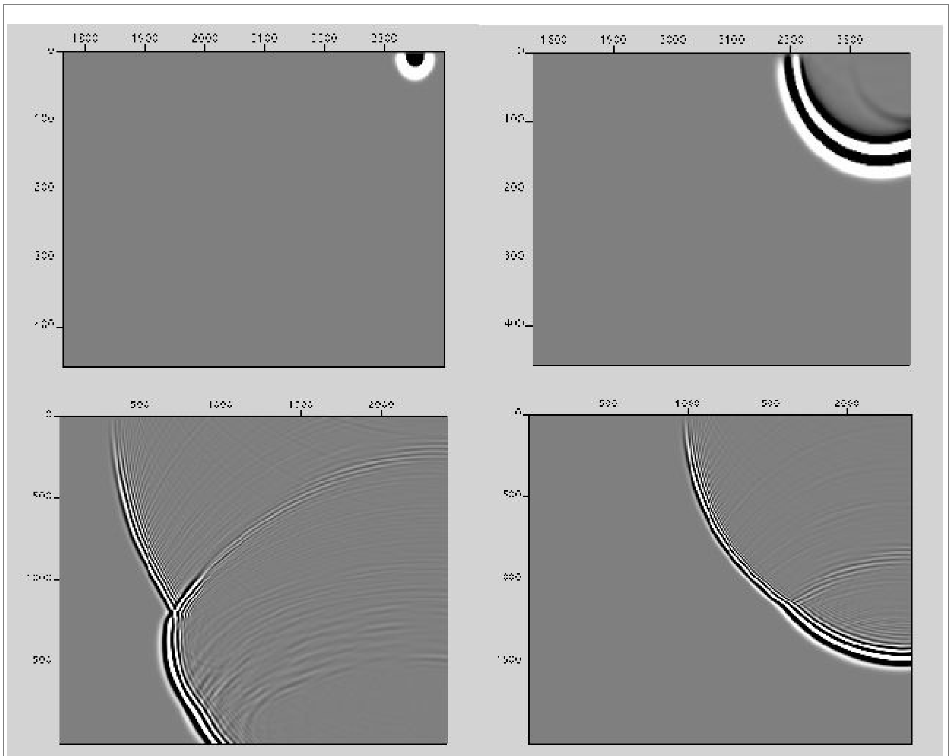
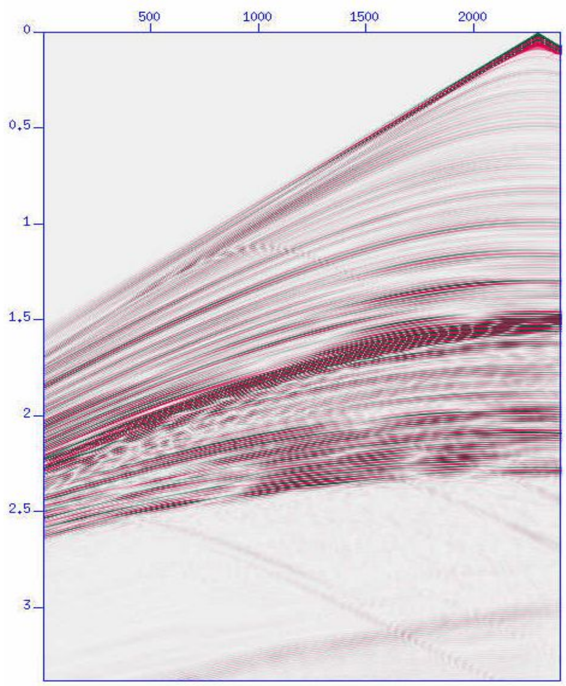


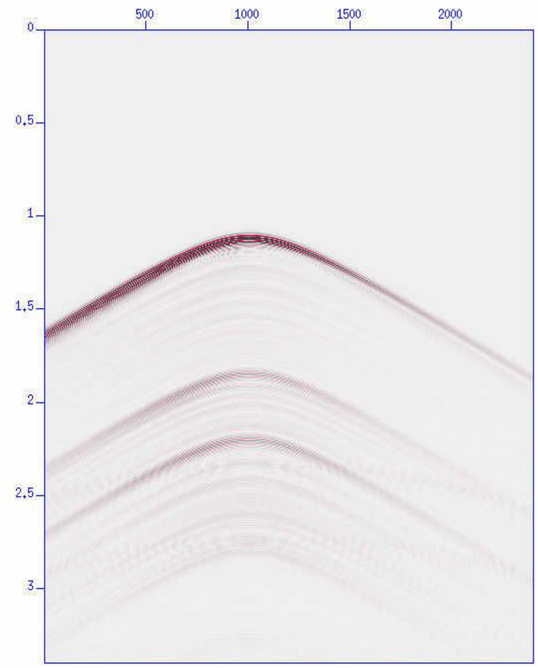
Picture 2: Velocity model entered on the 2d-finite differences algorithm. In the detail window, the whale as a 6x2 rectangle. Horizontal and vertical coordinates are in meters.



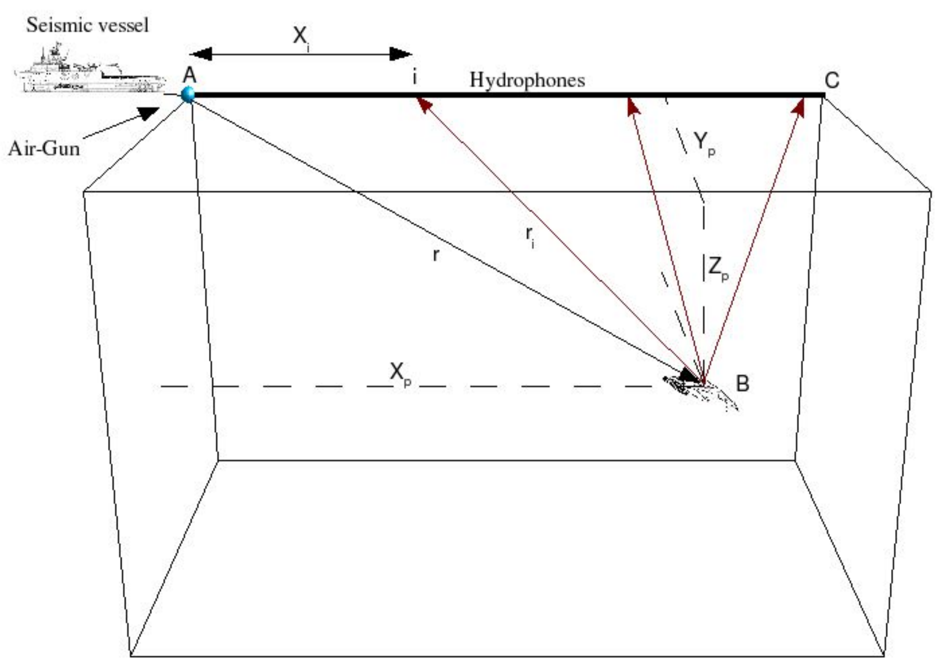
Picture 3: Simulation of seismic acquisition using a finite differences algorithm. The input velocity model is the one shown above. The times showed are, clockwise: 0.01, 0.123, 0.138 and 0,942 seconds. Note that the scale can change depending on the image. The model size is 2.4x 1.2 kilometers.



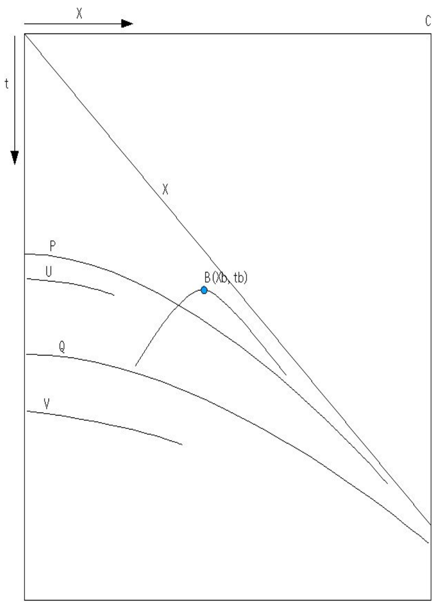
Picture 4: Results of the finite differences modeling. The obtained seismic section shows a subtle hyperbolic refraction. It can be isolated by subtracting the synthetic section by another one computed with a model with no diffraction point on it. The result is shown on picture 5.



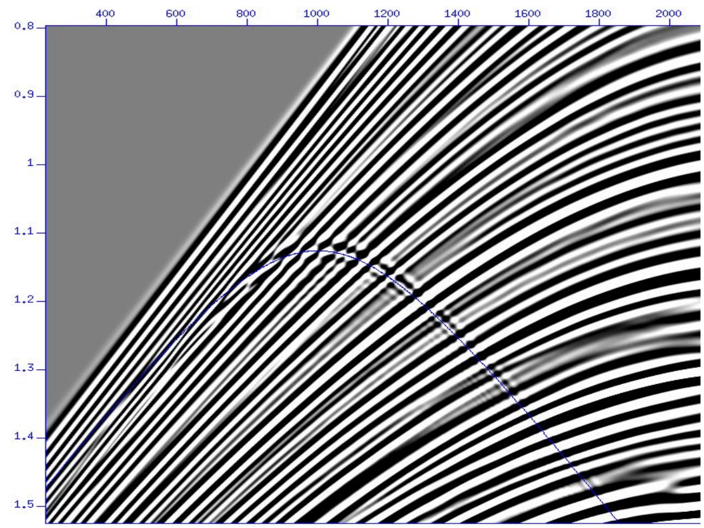
Picture 5: Isolated diffraction hyperbola obtained by subtracting the synthetic section from a section computed from a model without diffracting points.



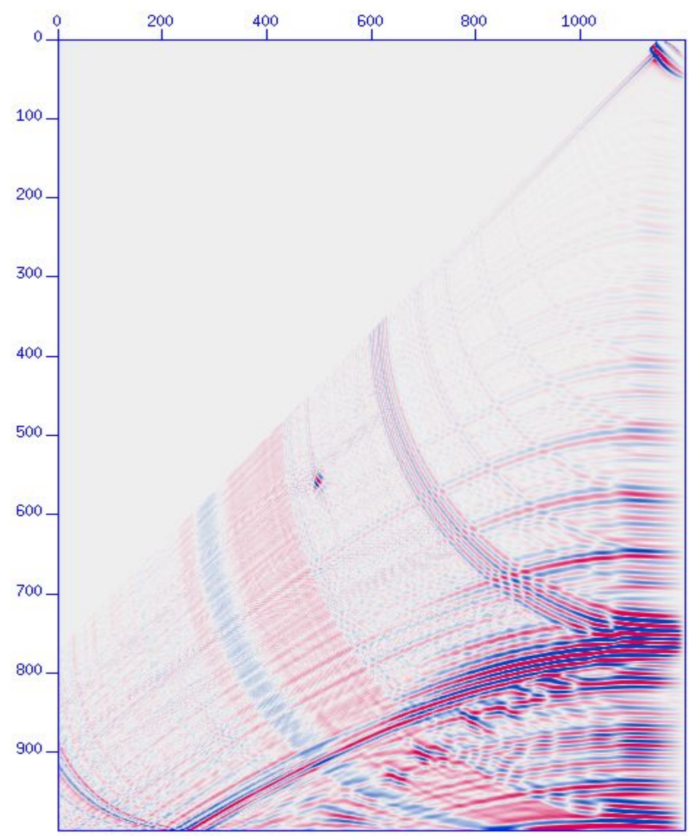
Picture 6: Conceptual sketch of the considered situation for the analytical deduction of the equations of the hyperbolic diffractions observed above. A is the seismic source, B the diffracting body, the line AC is the hydrophone array towed behind the seismic vessel. The wave front coming from A will be diffracted on B and then the diffraction will reach the line of hydrophones AC, having a total travel distance equal to $r+r_i$*. For simplicity purposes* y_p *is zeroed on equations resolved on this paper.*



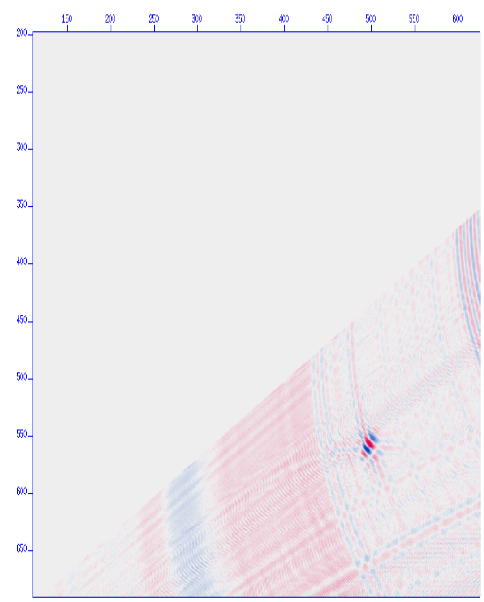
Picture 7: Sketch of the expected record shot. Note the diffraction B.



Picture 8: The hyperbola analytic modeling allows one to compute the diffraction curve for every sample of the seismic section. In the picture is shown the diffraction curve (blue) computed on the hyperbola apex of the synthetic section.



Picture 9: Result of the proposed focusing methodology. An anomalous point is clearly visible on the middle of the image. It corresponds to the concentrated diffraction coming from the modeled whale. Using the coordinates of this point is possible to find the exact position of the diffracting whale. Horizontal scale on traces (multiply by two to obtain meters). Vertical scale on miliseonds.



Picture 10: Detail of the previous picture. The focused point is highly visible.