Assessing the environmental impact of seismic surveys in two very different scenarios: South Africa and Brazil

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Summary

To obtain a permit for any seismic survey it is often necessary to demonstrate the potential impact of seismic sources on any marine mammals present in the survey area. This is called environmental modeling, and is done by estimating the sound levels emitted from the source as well as the corresponding received levels; the latter being what any marine animal present in the area would hear. I consider two different survey areas and the challenges associated with them. A different approach was used for each of them in order to assess the impact on marine fauna in the respective survey areas.

Introduction

The first step in assessing the potential impact of a seismic survey on marine mammals is to model the notional sources for the seismic source in question. The signal emitted by air gun sources is produced by the sudden release of high pressure air into the water. The physical model typically used to describe the pressure signature of an air gun is based on the theory of an oscillating spherical bubble (Ziolkowski, 1998). This physical model precisely describes the seismic energy output for frequencies below 1 kHz. Seismic imaging typically only employs frequencies below 250 Hz, however, air guns produce much higher frequencies than this; albeit with a much weaker signal than at lower frequencies.

With continued research into the hearing capabilities of marine mammals, there is a focus on higher frequencies in environmental impact assessments, which means that modeling needs to be extended to cover higher frequencies as well. One approach to do so is to calibrate the existing source modeling for the higher frequencies with field measurements. This calibration assumes that the higher frequency energy is concentrated at the time when air is released from the gun chamber (Figure 1).

Next, the notional sources need to be propagated from the source to the "receiver", i.e. the marine mammal. Two different approaches for doing so are: simple analytical propagation which assumes a homogenous medium; or advanced parabolic propagation that takes into account seabed properties, water depth and velocity variation in the water column. Generally, the simple analytical propagation only considers direct waves and ghost reflections. Using geometrical spreading it is possible to also take into account other propagation paths (Goertz et al., 2013), which allows us to produce valid results for distances larger than five times the water depth (Urick, 1983). This propagation model is best suited to surveys in shallower waters or for situations with marine mammals in close proximity to the source.

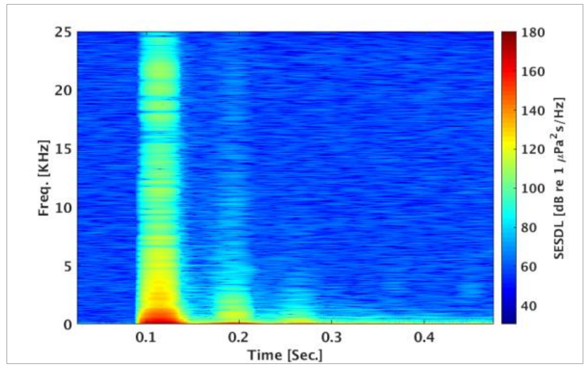

Figure 1: A spectrogram of a nearfield measurement of a single air gun with a volume of 100 in^3. Most of the energy above 1 kHz is concentrated around the main peak of the signature.

The advanced parabolic propagation method can be used to accommodate the sea bed properties, the water depth and the sound speed profile; meaning it is suited for even the deepest water depth and for modeling over large spatial distances.

A number of environmental metrics can be calculated on the received signals after propagation through the water column. The two most commonly used are the Peak Sound Pressure Level (SPLpk) and the Sound Exposure Level (SEL). Mathematically they can be described as follows:

$$SPL_{pk} = 20log_{10}\left(\frac{\max\{|p(t)|\}}{p_{ref}}\right), p_{ref} = 1\ \mu Pa$$

$$SEL = 10log_{10}\left(\frac{\int_t^{t+T} P(t)^2 dt}{SEL_{ref}}\right), SEL_{ref} = 1\ \mu Pa^2.s$$

Where $p(t)$ denotes the pressure signal as a function of time, and T is the time window length used for computing the sound level. SPLpk is thus related to the maximum absolute value of the amplitude of a signal, while SEL is proportional to the total energy of a signal. SEL is however, the most widely accepted metric to assess the potential environmental impact of seismic sources as it is best suited to take into account the cumulative effect of seismic acquisition (Southall *et al.*, 2007).

The above metrics become useful by applying so called M-weights or marine mammal hearing filters. Southall *et al.* (2007) set a standard of M-weights, which are based on research into the hearing capabilities of marine mammals and thus mimic their susceptibility to man-made sounds. Finneran (2016) re-defined these M-weights based on further research into hearing capabilities of marine mammals. These M-weights or marine mammal hearing filters are used to define thresholds for behavioral changes and injury in 5 major hearing groups based on Southall *et al.*'s (2007) and Finneran's (2016) research.

Survey examples

To illustrate the use of the simple analytical propagation model, we will look at a survey that took place offshore South Africa. In the planning phase of the survey concerns were raised about the proximity of the survey area to a penguin colony. It was thus necessary to demonstrate with an environmental impact assessment that neither the penguins nor the marine species that feed off them would be adversely affected by the operation of seismic sources during the acquisition of this survey.

Water depths closest to the penguin colony were around 100 m. Cylindrical modelling was thus chosen for the impact assessment as this type of geometrical spreading works well for water depths shallower than 150 m. SEL was computed 1 m below the source for a 6 km x 6 km grid with the source array at the center of the grid. Unweighted as well as M-weighted results were calculated for a single shot. An example result is shown in Figure 2.

The dashed blue circles in the figure highlight different distances in km from the source array. Figure 3 shows the general trend of SEL values as decreasing with distance, and also illustrates the difference in sound levels for four marine mammal groups.

The computation showed that at 500 m distance from the source both in inline and crossline direction the SEL values for the different marine mammal groups were between 10-29 dB re 1 µPa².s lower than the injury criteria defined by Southall *et. al* (2007).

To measure the cumulative effect of multiple exposures to the seismic source, energies from the multiple pulses are 'linearly' summed together assuming no recovery of hearing between exposures, and the summed energy represents a single exposure "equivalent" value or cumulative SEL. To achieve this a sail line of 18 km with a shot point spacing of 25 m was simulated. That corresponds to approximately 2 hours of seismic acquisition. A 3 km receiver line is placed perpendicular to the sail line in the middle of the 18 km sail line. SEL is calculated at receiver positions along that receiver line as the vessel approaches and moves away from it. Computation was again carried out both for unweighted as well as M-weighted scenarios. An example of a cumulative SEL result is shown in Figure 4.

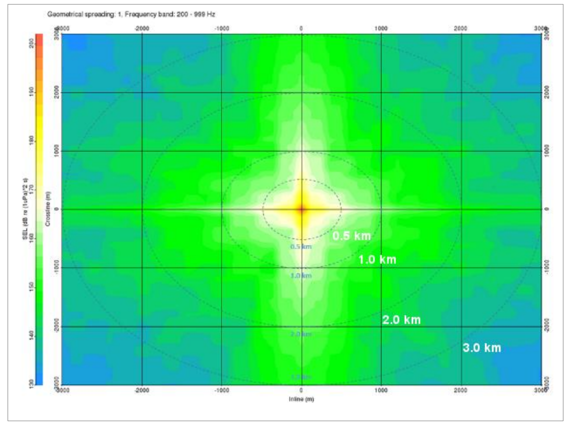

Figure 2: High frequency M-weighted SEL plot for the modelled source signature.

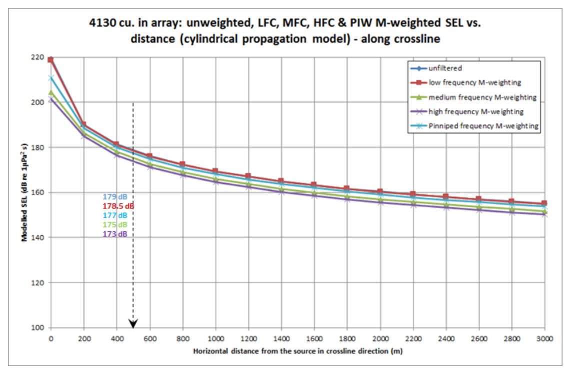

Figure 3: Comparison of unweighted and M-weighted SEL profiles along the cross-line direction.

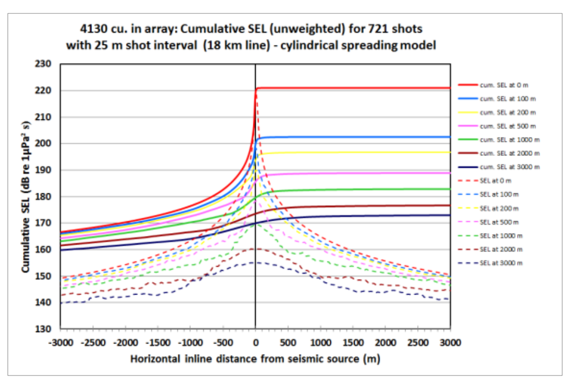

Figure 4: Unweighted cumulative SEL profiles (solid lines) compared to unweighted single pulse SEL profiles (dashed lines).

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It can be seen that cumulative SEL results are higher than single pulse results and increase with distance from the source. However, like the single pulse results, the cumulative SEL values are below the injury criteria values for the different marine mammal groups at 500 m distance from the source by between 2.4-18.3 dB re 1 µPa².s.

One key factor to ensure safety of marine mammals present in any seismic survey area is soft-start. This is a procedure that happens at the start of a sail line whereby firing of all guns including spare guns present in the source array is done one by one until the full volume of the source array is reached. This process typically takes approximately 20 minutes. SEL computation is again performed over a 6 km x 6 km grid with the source array at the center of the grid. As before unweighted and M-weighted results are being computed. An example of such a SEL result is shown in Figure 5.

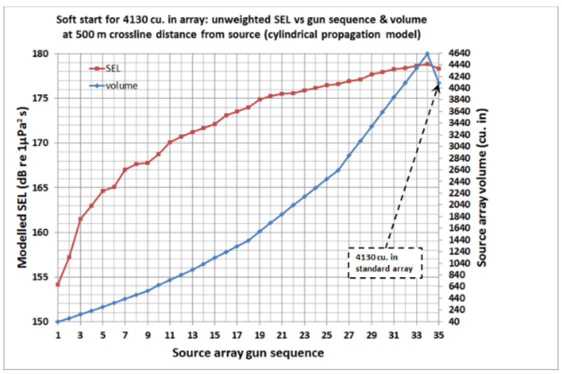

Figure 5: Unweighted SEL profile for the soft-start computed at 500 m cross-line offset.

As can be seen, for a short while during the soft-start procedure when all spare guns are also firing the SEL value is a little bit higher than for the actual source array volume. Source volume is indicated by the blue line in Figure 5, while SEL values are illustrated by the red line. However, at 500 m distance from the source the SEL values are again below the defined injury criteria values for the different marine mammal groups.

A slightly different approach was needed for a survey offshore Brazil. In that region there is a requirement to investigate the cumulative effect of two surveys shot adjacent to each other at the same time. Advanced parabolic propagation was used in order to not only accurately take into account the variation in water depth from very shallow to more than 2000 m in water depth, but also to ensure that all wave propagation forms in the source-receiver plane as well as source array directivity were accounted for. In addition to single shot SEL calculations similar to those shown for the South Africa survey example, the cumulative SEL calculation was key here. An example of a cumulative SEL result for two shots fired 60 km apart from each other is shown in Figure 6. This setup was chosen to mimic the scenario described above of the two adjacent surveys happening at the same time. In this case Finneran's (2016) proposed M-weights were used to determine the likelihood of disturbance or injury of any marine mammals present in the survey area.

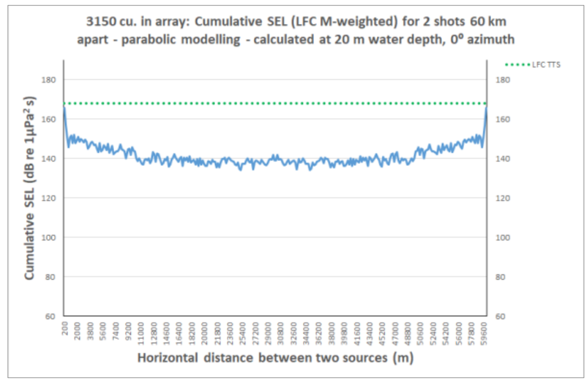

Figure 6. Low-frequency M-weighted cumulative SEL (blue line) with behavioral threshold (light green line).

Conclusions

In both cases, South Africa and Brazil, the environmental impact assessment showed that with the source configuration proposed for acquisition the sound exposure levels remained below the thresholds defined to avoid disturbance or injury of any marine mammals present in, or in the vicinity of the survey area. It is vital to choose a propagation model that will allow for a good representation of the water column as well as the water bottom of the intended survey area. Combined with accurate source signature modeling, it is then possible to calculate expected sound exposure levels.

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