Assessment of communication masking in Antarctic marine mammals by airgun sound

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Submitted by Germany

1. Introduction

Underwater noise is, besides hazardous substances and nutrients, one of the sources of marine pollution which is not yet sufficiently investigated. It is also one of the key pollutants created by human activities in the Southern Ocean. According to Erbe et al. 2019, "one of the key pollutants created by human activities in the Antarctic is noise, which is primarily caused by ship traffic (from tourism, fisheries, and research), but also by geophysical research (e.g., seismic surveys) and by research station support activities (including construction)." Broadband impulsive sounds of high intensities are considered especially detrimental for the marine environment. Marine airguns used for scientific seismic surveys produce this kind of sound pulses that generates most of its energy in the low frequency range.

Concern about potential impacts of anthropogenic sound in the Southern Ocean was first raised at the ATCM in 2000 and has been discussed most recently at ATCM XLII (SCAR WP 68 & BP 03, published as a SCAR Bulletin in 2021). The need for alternative sound sources (e.g. ATCM XXXIV IP 29 Potential of Technical Measures to Reduce the Acoustical Effects of Airguns) and also for seismic mitigation guidelines (e.g. ATCM XXX IP 80 Taking Action on Marine Noise in the Southern Ocean) has been voiced. These concerns are mirrored in two of the 80 most pressing questions identified by SCARs Antarctic and Southern Ocean Science Horizon Scan undertaken in 2014 (Kennicutt et al. 2015): “*How will organism and ecosystems respond to a changing soundscape?*” and “*What will be the impacts of large-scale, direct human modification of the Antarctic environment?*”.

Marine mammals highly depend on their sense of hearing. The ability to acoustically perceive their environment is vital. Anthropogenic underwater noise may interfere with communication signals and prey, predator or natural sounds that are of importance to the animal and therefore, ‘mask’ their ability to perceive these biologically important sounds. Airguns mostly produce low frequency sounds that correspond to the frequency range e.g. Antarctic baleen whales predominantly use for communication. Airguns have been considered for potentially deleterious effects in close distances up to a few kilometres. Masking, however, was only partly considered and only a few studies have considered masking effects of airguns as a potentially adverse effect on marine mammals in long distances.

Signals change their temporal structure (level, frequency content and duration) as they radiate from the sound source. Airgun sounds can travel vast distances in water. During this sound propagation process, sound waves are reflected multiple times on the water surface and diffracted in sound channels. Due to these processes the frequency content of the received sound level in large distances changes and the received signal is stretched and may cover the whole time between airgun shots. Hence, the impulsive sound source airgun can develop continuous properties and lead to a general increase in background noise and furthermore to masking effects over large distances.

The German Environment Agency (UBA) issued a 2-phased project to evaluate the potential masking effects of scientific airgun use in Antarctica to provide a sound scientific basis for permitting geophysical surveys. Work has been carried out as an international cooperation with institutes from Australia, Denmark, Germany, Netherlands and USA.

1. Project Overview

The frequency range of seismic airgun signals overlaps with many marine mammal vocalizations, especially the songs and calls of baleen whales. Airguns may therefore mask the perception of acoustic environmental cues as well as marine mammal communication signals even at large distances from the airgun location. This project assesses the communication masking potential of airgun noise in the Southern Ocean using a modelling approach. The first step includes propagation modelling of the airgun signals over vast areas up to 2,000 km. To assess the impact of the received airgun signals on the animal vocalisation, a masking model was developed as the second evaluation step.

The first phase of the project ran from 2012 to 2013 (results in Siebert et al. 2014, Wittekind et al. 2016). It started with vocalisations from 3 species (blue whale, fin whale and Weddell seal) and used a leaky integrator to model for the auditory processes. The ‘leaky integrator’ accumulates the received energy within the frequency band of the focal vocalization in a temporally lossy manner. The accumulated energy levels of vocalization and noise are analysed and compared to evaluate whether a signal can be detected. The second phase (2015 to 2019) developed the project and particularly the masking model further (results in Gavrilov 2018, Wölfing et al. 2021, download at <https://www.umweltbundesamt.de/publikationen/assessment-of-communication-masking-in-antarctic>. The **propagation model** was refined (from spherical spreading to a numerical model) and tested with two datasets of airgun signals recorded in the Southern Ocean. The range of tested vocalisations was expanded to include the multiharmonic killer whale call. The **auditory model** was significantly modified and changed (a. o.) from a band-pass leaky integrator to a more specific spectrogram correlator. The ‘spectrogram correlator’ represents a phase-insensitive receiver. It matches a representation of the incoming sound sample with a spectral representation (a characteristic frequency and intensity pattern) of the search signal and evaluates their similarity over time. This principle functionally corresponds to the comparison of the stimulation pattern of the cochlear output over time with a search pattern of the signal. Finally, the **detection model** was fundamentally changed. While the first phase directly compared accumulated energy levels, the second phase used a fundamentally different approach. Successful detection was assessed using standardized classification theory (receiver operating characteristic curve).

1. Results Overview

The output of the models shows that seismic surveys which are conducted in lower latitudes outside the Antarctic Treaty area (Australia) may even have masking potential in distant areas in higher latitudes within the Antarctic Treaty area. As expected, masking generally decreases (and communication ranges generally increase) with growing distance from the airgun source. However, as the transmitted total (airgun) energy does not decline monotonously over distance to the source, the models indicate local deviations from the general trend.

Results for numerous scenarios (5 different vocalisations, 2 ocean depth, 3 receiver depth, 2 vocalisation depth, 6 ambient noise level and 2 receiver models) were modelled for the project. The models show that transmission loss depends on **ocean depth** and is distinctly higher in the deep ocean scenarios. Consequently, the effect ranges of airguns in deep ocean scenarios are generally higher than in the shallow ocean. Different **receiver depths** produce striking differences between the respective sound propagations due to the influence of surface effects. This causes larger irregularities in propagation close to the source at shallow receiver depths. The effect ranges of airguns for 200 m receiver depth are distinctly higher than for 10 m or 50 m receiver depth for e.g. communication distances of blue whales and fin whales. The level of the propagated sound originating from a depth of 5 m, is more attenuated than the sound originating from a **vocalization depth** of 50 m for the low-frequency transmission loss at long ranges. Thus, an increase in communication ranges is expected for blue and fin whales if these species vocalize at greater depths (50 m versus 5 m sender depth). As expected, the effect range of airguns are generally larger in low **ambient ocean noise** scenarios than in higher ocean noise scenarios. Equally, predicted animal communication ranges rapidly decreases as ambient noise level increases.

The model results indicate that seismic airgun sounds can lead to a significant loss (close to 100 %) in communication range for blue and fin whales up to 2,000 km from the source. However, the intensity of the ambient noise is a relevant parameter. While the model shows that airgun noise reduces communication ranges severely (> 75 % loss) in low (80 dB) ambient noise scenarios, this impact is drastically reduced in higher ambient noise scenarios (90-112 dB). Nevertheless, for medium distances from 50 – 200 km to the airgun, a significant number of scenarios still predict severe (>75%) loss of communication ranges compared to natural communication range

*Table 1: Comparison of masking impact for several scenarios for the blue whale Z-call (vocalisation depth 50 m) for different water depth, receiver depth and distance between airgun and listener. Additionally, 4 different ambient noise conditions are incorporated in the scenarios: quiet ambient noise conditions (80 dB), moderate ambient noise (94 dB), medium ambient noise (102 dB) and high ambient noise (112 dB). In phase I of the project only “quiet” ambient noise conditions (80 dB) where included in the model.*

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Water  depth | Receiver  Depth [m] | Distance  Airgun-Receiver [km] | Loss in acoustic communication distances [%] | | | | | |
| 80 dB noise  = the noise situation modelled in phase I | | | 94 dB noise = moderate ocean noise | 102 dB noise = medium  ocean noise | 112 dB noise = high  ocean noise |
| leaky integrator (phase I) | leaky integrator (phase II) | spectrogram correlator  (phase II) | spectrogram correlator  (phase II) | spectrogram correlator  (phase II) | spectrogram correlator  (phase II) |
| 4000 m | 10 | 500 | ***98 %*** | ***97 %*** | ***94 %*** | ***36 %*** | ***36 %*** | ***0 %*** |
| 10 | 2000 | ***96 %*** | ***84 %*** | ***88 %*** | ***36 %*** | ***0 %*** | ***0 %*** |
| 50 | 500 | ***99%*** | ***97 %*** | ***92 %*** | ***65 %*** | ***80 %*** | ***61 %*** |
| 50 | 2000 | ***99%*** | ***77 %*** | ***88 %*** | ***65 %*** | ***65 %*** | ***61 %*** |
| 200 | 500 | ***99%*** | ***97 %*** | ***88%*** | ***74 %*** | ***75 %*** | ***68 %*** |
| 200 | 2000 | ***98%*** | ***81 %*** | ***65 %*** | ***68 %*** | ***60 %*** | ***0 %*** |
| 500 m | 10 | 500 | ***97 %*** | ***89 %*** | ***79 %*** | ***0 %*** | ***0 %*** | ***0 %*** |
| 10 | 2000 | ***89 %*** | ***67 %*** | ***50 %*** | ***0 %*** | ***0 %*** | ***0 %*** |
| 50 | 500 | ***99 %*** | ***70 %*** | ***87 %*** | ***29 %*** | ***38 %*** | ***0 %*** |
| 50 | 2000 | ***97 %*** | ***91 %*** | ***27 %*** | ***0 %*** | ***13 %*** | ***0 %*** |
| 200 | 500 | ***99 %*** | ***98 %*** | ***53 %*** | ***0 %*** | ***44 %*** | ***0 %*** |
| 200 | 2000 | ***97 %*** | ***77 %*** | ***27 %*** | ***0 %*** | ***0 %*** | ***0 %*** |

For better visualization the output of the models for all scenarios (5 vocalisations, 2 ocean depth, 3 receiver depth, 2 vocalisation depth, 6 ambient noise level and 2 receiver models) have been visualized with an interactive multimedia tool which provides a summary overview, explanations and individual illustrations (<https://tschaffeld.shinyapps.io/UBA_mask>). The tool provides overviews like in figure 1 below.

Overview illustrations showing masking of Antarctic blue whale z-calls by airgun noise. Graphs show the percentage loss in communication distance relative to equivalent scenarios with no airgun present and apply to medium ambient noise levels of 102 dB. The effect ranges of airguns in the shallow ocean scenarios are generally lower than in the deep ocean scenario.

*Figure 1: Overview illustrations showing masking of Antarctic blue whale z-calls by airgun noise. Graphs show the percentage loss in communication distance relative to equivalent scenarios with no airgun present and apply to medium ambient noise levels of 102 dB (calling and listening animal at 50 m depth). The effect ranges of airguns in the shallow ocean scenarios are generally lower than in the deep ocean scenario.*

Marine mammals have evolved to use sound as their primary sensory modality. While there have been several other studies modelling the propagation of airgun signals over large distances (e.g. Kyhn et al. 2019) similar to this study, the masking model is unique and allows for a more detailed evaluation of masking impact. Any interference of acoustic communication can have severe effects on both sender and receiver leading to impacts on fitness, for example if masking impedes signal detection (e.g. Branstetter et al. 2016). Behavioural responses can be highly variable and may not be fully predictable with simple acoustic exposure metrics e.g. like the received sound exposure level. While disturbance responses have been studied in the field, this is much more challenging with masking. Disturbance responses are often associated with sudden changes in behaviour which can be observed in the field. Masking however, may result in an observable anti-masking strategy (cf. Blackwell et al. 2015, Thode et al. 2020) as well as in a nonresponse due to a masked signal. Studying masking based on behavioural observations requires knowledge on how the animal behaves in the presence and absence of biological cues. To validate the modelling results, further experimental studies on masking effects are needed. Nevertheless, the current results are already a valuable resource for the evaluation of acoustic masking effects as they provide us with a better understanding of the relationship between various parameters and their influence on communication ranges of marine mammals in Antarctica.

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