Initial Quantification of Low Frequency Masking Potential of a Seismic Survey

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ABSTRACT

A distant seismic survey was recorded on 3 autonomous long term acoustic recorders deployed between Tasmania and the Antarctic continent. These instruments were located approximately 450, 1500, and 2800km from the survey site. Recordings were analyzed for the presence of airgun signals with sound files from a five day period separated into 'seismic' vs. 'non-seismic' files for acoustic analysis. Sound levels across a 20-50Hz bandwidth were calculated for 1s samples and compared between the seismic and non-seismic datasets to assess the percentage of time that sound levels increased due to the presence of airgun signals. During seismic operations, a distinct shift in the distribution of sound pressure levels in the 1s samples occurred suggesting even during 'quiet' periods between shots, sound levels remained slightly elevated. Here we present results quantifying the received levels of seismic airgun shots, and the percentages of time that sound levels are elevated at varying distances from a seismic survey.

KEYWORDS: SEISMIC SURVEY, SOUND PROPAGATION, LOW FREQUENCY MASKING

INTRODUCTION

Cetaceans have evolved to rely on underwater sound as a primary means of communication and assessing their environment. They must integrate information and resources over large spatial and temporal scales (Lockyer, 1984, Boyd et al., 1999). Mates may be widely dispersed, and potentially tens or hundreds of miles away. Food resources can be patchy and separated by great distances. As light is attenuated rapidly in water, vision is not an effective means of communication in water at distances of more than a few meters. Sound, however, is a highly efficient means of sending information over long distances underwater (Tyack, 1998).

The efficiency with which sound travels through water highlights the fact that anthropogenic noise sources can potentially have impacts over vast areas of the ocean. Long term increases in background noise in the ocean is widely attributed to distant low frequency shipping noise (McDonald, et al., 2006; Hildebrand, J.A.). The sounds from seismic surveys in particular have been shown to travel coherently across ocean basins (Nieukirk et al., 2004). Relatively recently, there has been a greater focus on the potential for anthropogenic noise to mask the communication of marine mammals, in particular the low frequency specializing baleen whales (Clark et al., 2009; Clark & Ellison, 2004)

While there has been somewhat less focus on the masking potential from seismic surveys due to their intermittent sound production compared to the continuous sound emanating from shipping, it is an area that needs to be examined. Here, we present an initial quantification of the masking potential of a distant seismic survey that occurred off the coast of Australia. From March 25th to May 30th, 2006, the Aragorn 3D Seismic Survey was conducting operations utilizing 2 x 3090 cubic inch airgun arrays in the western edge of the Bass Strait off the north-west coast of King Island (Aragorn 3D Survey Acquisition report, 2006). During this time period, we had 3 long term acoustic loggers deployed between just southwest of Tasmania, down to the Antarctic continent, ranging from approximately 450-2800kms from the survey site. Four noise loggers set along the south-eastern Australian coast maeasured the seismic signals from 1-200 km range, although this data is not presented here. Airgun shots were recorded on all southern ocean loggers during the times of operation of the seismic survey (which we presume is the source of the recorded sounds). The preliminary results from the analysis of these recordings is presented here.

METHODS

Acoustic loggers were developed at Curtin University (see http://www.curtin.edu.au/ products) in conjunction with the Australian Antarctic Division. These loggers sampled sound from HTI 90-U hydrophones (High Tech. Inc., Gulfport, Mississippi) at 4000Hz, giving an effective acoustic recording bandwidth of up to 2000Hz. Due to the increased data recorded at the higher sampling rate and limitations in hard drive space, a sampling schedule was set up to record 13 minutes of sound every hour for the full deployment of over a year at each site.

Three loggers were deployed roughly along a line of longitude in the waters between Tasmania and the Antarctic continent (Figure 1). The central logger (logger 2) was deployed on an in-place oceanographic mooring (CSIRO's SAZ mooring at 53.74° S, 141.77° E) along the mooring cable at a depth of approximately 1500m. The logger began sampling on December 18, 2005 and sampled until recovery on October 5, 2006.

The other two loggers were deployed as part of autonomous mooring packages that sat on the seafloor. Logger 1 was deployed on a seamount to the south-west of Tasmania (44° 00.138' S, 144° 39.914' E) in 1866m of water. It began sampling on March 11, 2006 and sampled over 10 months until its recovery on January 18, 2007. Logger 3 was deployed on January 21, 2006 off the edge of the Antarctic continental shelf near Dumont D'Urville (65°33.2' S, 140°32.6' E) in a water depth of approximately 1100m. It sampled a full year until recovery on January 25, 2007.

Visual inspection of the acoustic data revealed seismic airgun pulses recorded on all three acoustic loggers between at least late April and mid July, potentially from a variety of sources. For the purposes of this paper, we have examined the 5 day period from April 26 through April 31st, when seismic airgun pulses were recorded on a large percentage of the sound files. These dates, and a subsequent bout of recorded seismic exploration in May perfectly coincide with the operation of the Aragorn 3D Survey. (Aragorn 3D Survey Acquisition report, 2006). Assuming therefore, this survey was the source of the airgun sounds, the loggers were located approximately 450, 1500, and 2800kms moving south from the survey area.

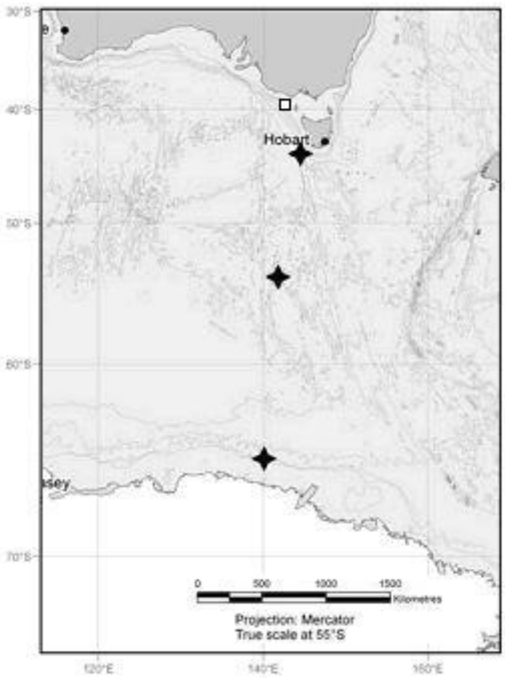

Figure 1: Locations of acoustic loggers (black stars) and presumed location of the seismic survey recorded (white box near King Island to the north-west corner of Tasmania). Logger 1 is the northern-most instrument, logger 2 is the central instrument, and logger 3 is the southern-most on the continental shelf-break of Antarctica.

Data analysis was conducted using custom written code in Matlab 7.1 (www.mathworks.com). Sound files were downsampled from a 4kHz sampling rate to 500Hz. The calibrated power spectral density was then calculated over the 5 day dataset (512 sample FFT sizes, 0% overlap, hanning window) leading to spectral density values (bin size of 0.98Hz) for each second (sample duration of 1.024s) of the recordings. Sound pressure level (SPL) for each second of the recording was integrated over the 20-50Hz bandwidth for comparison between recording sites, and times with and without seismic surveys present. Visual inspection of spectrograms for each sound file was conducted to separate files into those with and without airgun signals present and to remove samples with any other overlying noise sources.

RESULTS

Of the 120 sound files (a 13 minute file every hour for 5 days), logger 1 had 44 with airgun pulses present, and 76 without (Figure 2). Logger 2 had 47 with airgun pulses, and 73 without. Logger 3 had 46 with airgun pulses, and 74 without. The slight differences in numbers between the loggers can be accounted for by the fact that while the loggers were all recording approximately simultaneously, the sounds would take varying lengths of time to reach each logger (roughly 12 minutes delay from 1 to 2, and 26 minutes delay from 1 to 3, based on an approximate sound speed of 1500m/s). Varying background noise conditions at each logger and propagation conditions could also contribute to the small differences.

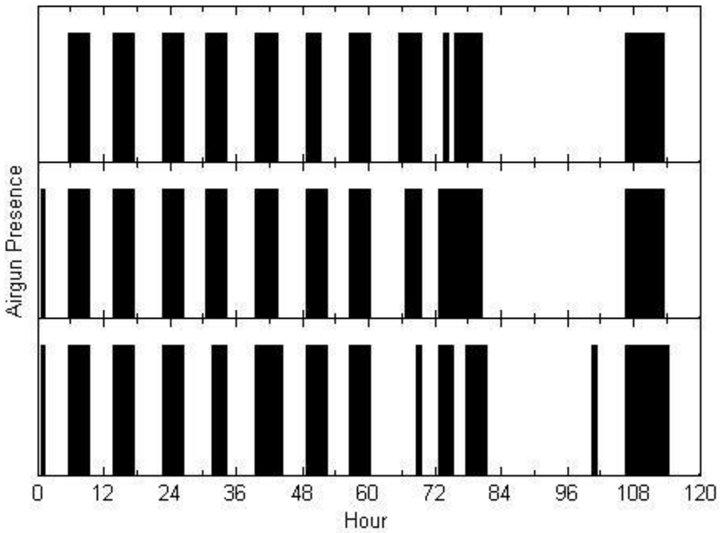

Figure 2: Airgun shot presence on the 3 loggers over the 5 days from April 26-31, 2006. Logger 1-top; Logger 2-middle; Logger 3-bottom

An overall average of SPL for every 1s sample in files with or without airguns appears in Table 1. General background noise levels can be approximated from the data files without seismic survey sounds present. This shows increasing background levels as one moves further south, with the logger on the Antarctic shelf break also having the most variability in levels from second to second. During periods with airgun shots, average SPL was increased by 4.2dB at the closest logger, 3.5dB at the central logger, and 3.0dB at the logger furthest south.

Table 1	Mean SPL (dB re 1uPa) over 20-50Hz without airguns	Mean SPL (dB re 1uPa) over 20-50Hz with airguns
Logger 1	92.0 ± 2.2	96.2 ± 3.9
Logger 2	94.5 ± 2.4	98.0 ± 3.0
Logger 3	96.1 ± 3.6	99.1 ± 2.8

While this generally illustrates increased mean sound levels, by averaging the SPLs from seconds between shots (lower level), with seconds where shots are received (higher level), this does not effectively account for the intermittent nature of shots from a seismic survey as illustrated in Figure 3.

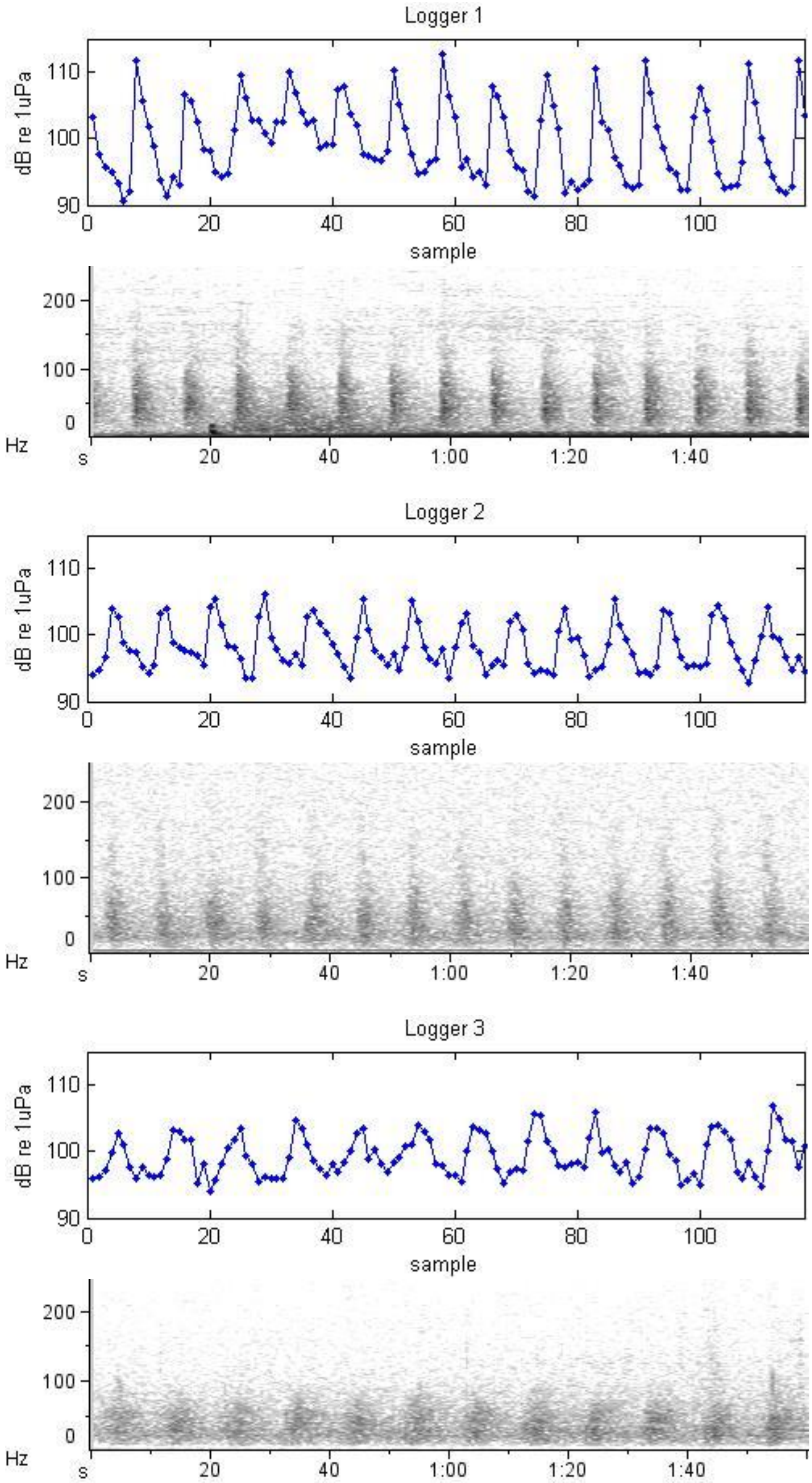

Figure 3: Spectrograms of 2 minutes of recorded airgun shots. Above each spectrogram, the SPL (20-50Hz) for each 1s sample is plotted. Note that due to the time delay in sound arrival, these are not the identical airgun shots, but are what was recorded on each logger over the same time period on April 26, 0500UTC. Hence, the shots recorded on the southern-most logger 3, therefore would actually have been produced prior to those recorded at logger 2, which would similarly have been produced prior to those recorded at logger 1.

Figure 3 shows a 2 minute section of the intermittent received airgun shots at the loggers. The spectrograms show, as expected, the received sounds have less high frequency energy and become longer in duration as distance increases further to the south from loggers 1 to 3. Above each spectrogram, the basic SPL data for 1s samples is plotted with the airgun signals clearly rising above background noise to levels much greater than appears in Table 1.

For each of the 3 loggers, the distribution of all 1s sample SPLs is plotted in Figure 4 for both seismic, and non-seismic periods. On logger 1, closest to the seismic survey, 88% of samples from files with airgun shots present were above the mean of samples from files without airgun shots present (92.0 ± 2.2dB re 1uPa). Sixty-one percent were above the non-seismic mean plus 1 standard deviation (sd), 41% were above the mean plus 2sd, and 28% were above the mean plus 3 sd.

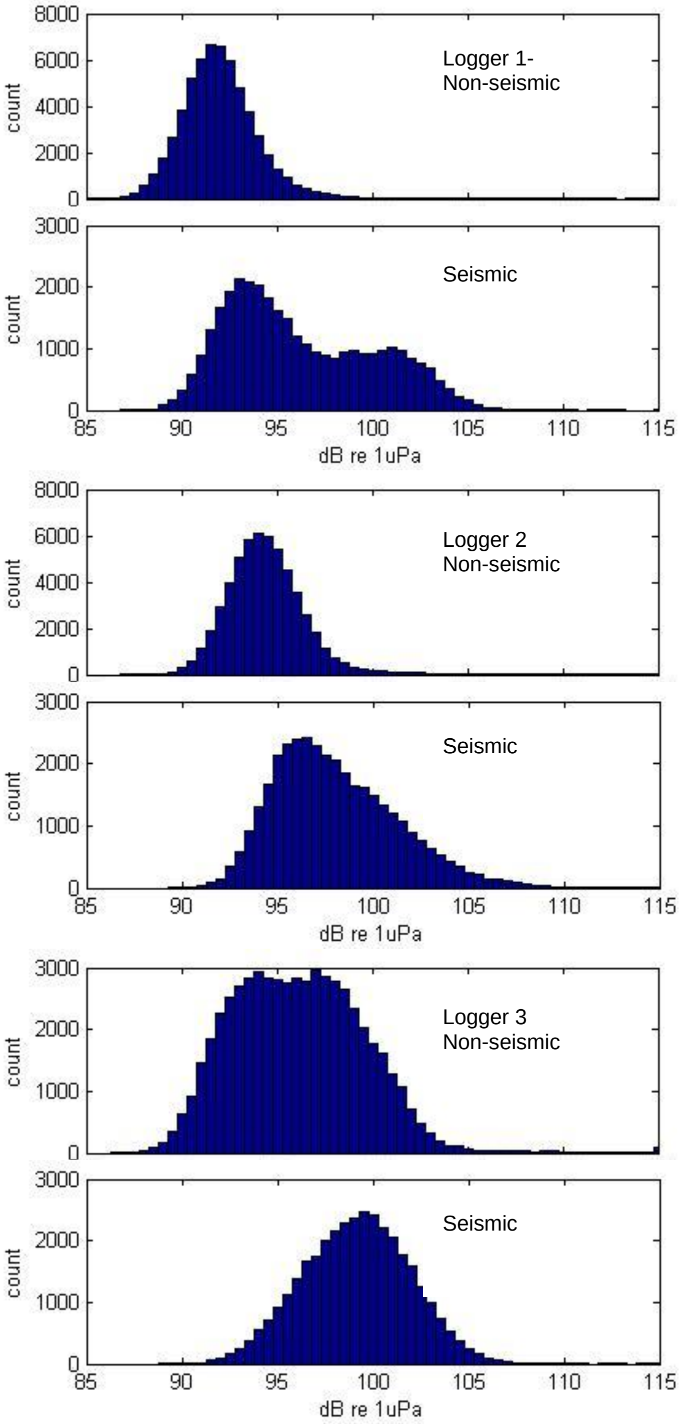

Figure 4: Distribution of SPLs (20-50Hz) from all 1s samples during recordings with or without airgun shots.

On the central logger 2, 88% of 1s sample SPLs from files with airgun shots were above the non-seismic mean (94.5 ± 2.4dB re 1uPa). Fifty-nine percent were above the non-seismic mean plus 1 sd, 32% were above the mean plus 2 sd, and 14% were above 3sd. Finally on the southern-most logger 3, 85% were above the non-seismic mean (96.1 ± 3.6dB re 1uPa), 43% were above the mean plus 1 sd, 7% were above 2 sd, and only 0.5% were above the mean plus 3sd.

In each case illustrated in Figure 4, the effect of seismic presence on the distribution of the 1s sample SPLs is clear. Interestingly, even the lower portions of the 'seismic' distributions appear to be shifted to the right. One would expect, if the impact of airgun shots on background levels were truly discrete and limited to short durations of even a few seconds, that sound levels would return to 'non-seismic' levels in between shots. The lower end of the distribution would appear similar in seismic and non-seismic periods, with just a greater spread in the upper end of the distribution accounting for the times when the shots were occurring. This does not appear to be the case, suggesting that even during the times between airgun shots (in this instance shot interval was ~8s), SPL did not return to prior or subsequent background levels from the non-seismic periods.

Assuming, therefore, that the mean SPL from samples recorded in files without seismic activity present is representative of the 'true' background sound level, the degree to which a distant seismic survey raises sound levels can be quantified relative to this level. These percentage increases in background noise during seismic periods can be compared with natural variability in sound levels. The two are overlaid in Figure 5.

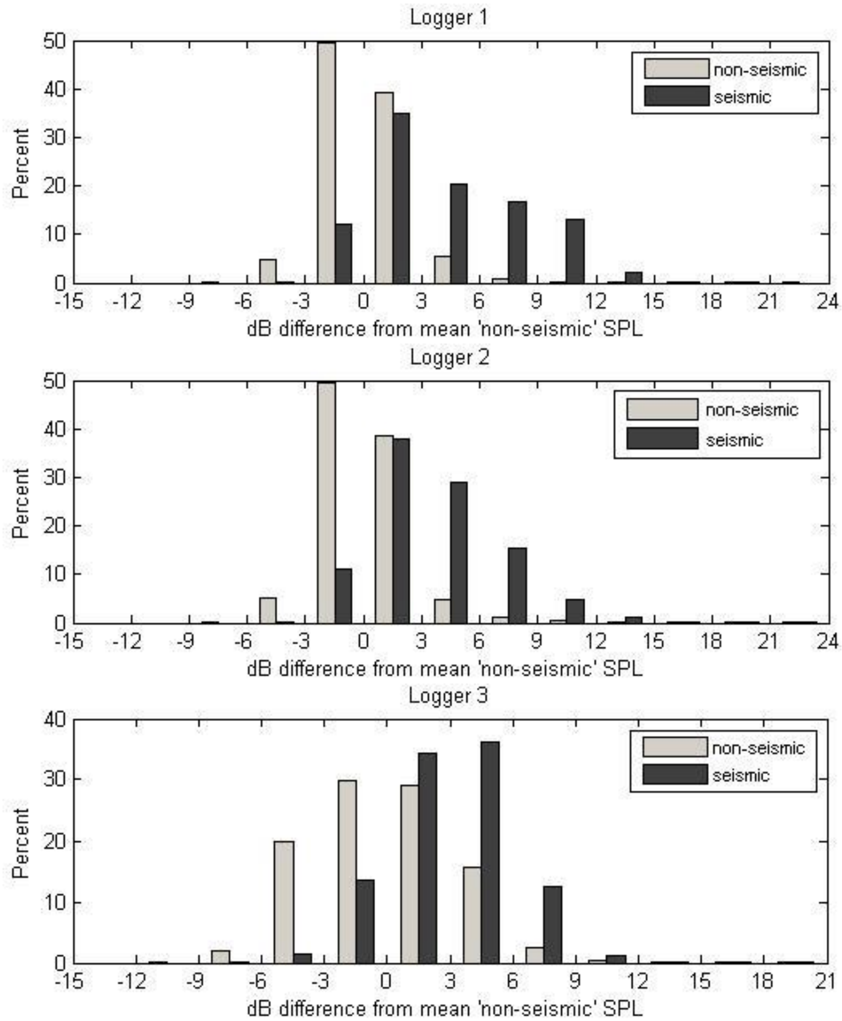

Figure 5—Difference between all 1s sample SPLs and mean SPL of samples from 'non-seismic' data files. Percentages of occurrence in 3 dB bins are shown with samples from non-seismic periods in light gray, and from seismic periods in dark gray.

On logger 1, located approximately 450km from the survey site, noise levels were increased by between 6-15dB for 32% of the time when airgun shots were recorded. During non-seismic periods, sound levels were this elevated less than 1% of the time. Fifty two percent of the time sound levels were elevated by more than 3dB during seismic surveys, compared to just 6 percent of the time during non seismic periods. On the central logger, levels were increased by 6+ dB for 22% of the time during seismic periods, as compared to just 2% during non-seismic periods. Levels were increased by 3+ dB for 51% of the time during seismic periods, compared to 7% during non seismic periods. And finally, on the southern-most logger, levels were elevated by at least 3dB for 50% of the time during seismic, compared to 19% during non-seismic periods.

We have not attempted to calculate how these increases in ambient noise levels would impact on the detection of vocalisations in the 20-50 Hz bandwidth (for example spanning the blue whale vocalisation frequencies) or on what the implications of this would be. Clearly the noise increases would decrease the detection range of biological signals or would make signals more difficult to detect at reasonable ranges from a source.

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