Measured sound levels in ice covered shallow water caused by seismic shooting on top of and below floating ice, reviewed for possible impacts on true seals

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Abstract

Seismic surveying of the Arctic is important for several reasons, but also introduces some challenges. One is the concern that seismic may affect the hearing of marine mammals living there, including true seals. We performed two seismic experiments on floating ice on Svalbard in the Norwegian Arctic in early March 2016 and late May 2017, just before and right after the ringed seal breeding period. We used a single airgun below ice and detonating cord on ice, measured sound levels in the water column, compared these with hearing capabilities of true seals found from previous studies, and observed the animal's reactions to exposure to seismic waves in the field. We found that these actual seismic experiments have little potential to cause physical hearing damage, but temporary behaviour change may occur. We also observed a difference in measured sound levels, frequency content, and animal reactions, depending on the type of source used.

Keywords:

Seismic, Arctic, Ice, Seal, Sound level, Impact, TTS, PTS, Behaviour change

Introduction

Seismic surveying of the Arctic will most likely receive increased interest in the years to come, both for hydrocarbon exploration due to an increasing world energy demand, and for possible monitoring of potential thawing of today's permanently frozen tundra (Harris et al. 2009, Trupp et al. 2009). Svalbard in the Norwegian Arctic is an uplifted part of the Barents Sea, and thus serves as a natural laboratory for geoscientists to study prospective hydrocarbon plays in this part of the Arctic (Faleide et al. 1984). To better correlate geological strata exposed on Svalbard to those explored for in the Barents Sea, land seismic profiling has been conducted at several locations to track seismic signatures of possible reservoir units. Seismic data have been acquired both on frozen tundra and on glaciers, see Johannessen et al. (2011) and Johansen et al. (2003, 2011). To further improve such correlations, seismic surveying has been performed along transects starting at frozen tundra, and proceeding onto floating ice to a successively increasing water depth.

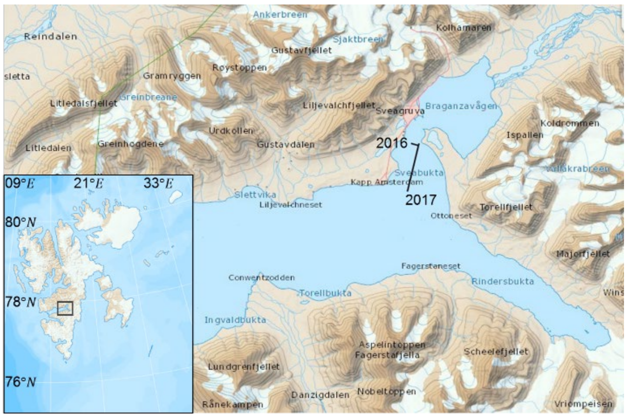

Figure 1

Seismic surveying in shallow open water in the Arctic is from an operational point of view extremely difficult, due to both strongly varying weather conditions, and highly dynamic sea floor conditions caused by strong sedimentation and re-working from glacial activity (Trupp et al. 2009). Operations on fast ice makes the logistics simpler (e.g. permits the use of motorized vehicles for fieldwork), and allows better flexibility for defining optimal geographical lines for geological investigation (Del Molino et al. 2008, Johansen et al. 2011).

Norwegian authorities have imposed severe restrictions on activities within the territory of Svalbard in order to preserve the Arctic nature there. Scientific activities are prohibited if they may cause any imprint on the soil surface (Svalbard Environmental Protection Act 2001). Plans for fieldwork that may have impact on the fauna must undergo a careful review by Svalbard jurisdiction authorities before eventually approved. Land seismic experiments are therefore most convenient to perform during wintertime, since a frozen and snow covered surface shelters the soil during field activities (Trupp et al. 2009). However, seismic surveying implies repeated generation of acoustic waves, and consequently, there are concerns about whether seismic activity on ice covered sea can affect local wildlife, such as Phocid pinnipeds (commonly called true seals, including ringed, bearded, and harbour seals) (e.g. Malakoff 2002, Harris et al. 2001, Hermannsen et al. 2015). Ringed seals are common in the Norwegian Arctic, and spend time both in water and on sea ice. They give birth in April and May in snow caves on ice, making them more vulnerable to possible adverse effects of seismic signals (Krafft et al. 2006). To evaluate possible impacts on surrounding fauna, the strategy is to measure the strength and frequency signature of these pressure waves as a function of distance from the source, and compare data with possible locations and hearing frequency ranges of the surrounding species.

Previous observational studies in Van Mijenfjorden concluded that land seismic activity only had minor effects on the behaviour of animals staying close to the study area (Prestrud and Øritsland 1987). In other locations, seals have not reacted to construction noise at haul-out sites (Edrén et al. 2010), and they are generally known to habituate fast, even to relatively loud sound levels (Fjälling et al. 2006). However, a study by Götz and Janik (2011) found that repeated startle responses, induced by intense noise with a fast rise time, can cause animals to vacate an area otherwise associated with food. Seismic experiments conducted on ice may therefore affect marine mammals residing close to the survey area.

To study such possible impacts, we performed seismic experiments during the winter of 2016 and late spring of 2017 in the inner part of Van Mijenfjorden (Figure 1-2), just before and right after the ringed seal breeding period, when they are protected from human interference. For shooting, we used two types of seismic sources: explosives on top of the ice, and a single airgun below the ice. In 2016, we recorded the seismic wavefield on hydrophones at various depths, from close beneath the ice to just above the sea bottom. We varied the shooting configuration, length of detonating cord (i.e. amount of explosive), airgun pressure, and depth of airgun throughout the survey. We then measured various sound levels, and subsequently evaluated these for possible physiological effects on the hearing in seals. In 2017, seismic shooting was performed when a significant colony of ringed seals was residing relatively close to the survey site. The seismic wavefield was measured below the ice at 5 m depth. Before, during, and after shooting, the behaviour of the seals was observed, to try to identify specific reactions related to the seismic activity. To our knowledge, this the first attempt at producing such data in this type of environment.

Figure 2

Marine mammals and sound

How sound is perceived by marine mammals depends on the pressure, frequency content, and time structure (e.g. impulsive or non-impulsive) of the signal. Animal reactions may also vary with season, initial behavioural state (e.g. foraging, migrating, or nursing), age, and sex. When discussing hearing impact, pressure is often converted to sound pressure level (SPL) or sound exposure level (SEL).

SPL is a measure of how loud one single sound is heard as, and takes no account of the duration or number of sounds. It is by Southall et al. (2007) given as

$$SPL=20log\frac{p_e}{p_0}$$

in unit [dB re 1 µPa] underwater, computed from the 0-to-peak pressure p_e, and reference pressure p_0 (1 µPa underwater). SEL is a cumulative measure of how loud N number of sounds of duration T within a given accumulation period are heard as, and is given by Southall et al. (2007) as

$$SEL = 10\log\frac{\sum_{n=1}^{N}\int_0^T p_n^2(t)dt}{p_0^2}$$

in unit [dB re 1 μPa^{2}s] underwater, computed from the pressure p_n (for shot n, usually rms pressure), and reference pressure p_0. When the offset varies, the nearest shots will contribute most to the computed SEL. Due to the impulsive nature of an airgun shot, the SEL of a single shot will be much lower than the SPL (typically 20-30 dB). Also, using different pressure measurements to compute the sound levels contribute to differing SEL and SPL (e.g. ~3 dB difference between rms and 0-p pressure) (Gausland 2000).

Since marine mammals can only hear a limited range of frequencies, and hearing sensitivity varies with each frequency, the frequency spectrum of the sound should be weighted to assess realistic hearing impacts. If a seal cannot hear a sound, it can probably not be harmed by it either (Southall et al. 2007). True seals are by NMFS (2016) assumed to be able to hear in the frequency range 50 Hz to 86 kHz, with corresponding sensitivities as indicated in Figure 3. Thus, this so-called M-weighting should be applied to estimate the sound levels that a seal will most likely hear.

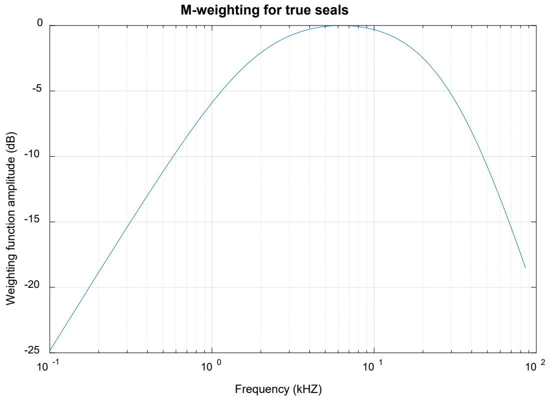

Figure 3

Seismic sources are generally designed to mainly produce energy for frequencies below 100 Hz (Mougenot 2006, Hermannsen et al. 2015), which seals seemingly have low sensitivity for. Consequently, M-weighting often suppresses the impact of sound significantly. However, frequencies up to several kHz have been recorded during seismic surveys (e.g. Landrø et al. 2011), and in these cases M-weighting contributes less.

Exposing marine mammals to high sound levels within their hearing range can lead to change in behaviour, mask other sounds, or give temporary or permanent hearing threshold shifts (TTS or PTS, respectively) due to physical damage at a cellular level in the ear (Richardson et al. 1995, Gordon et al. 2003). TTS is reversed after a short time and is thus not considered an injury, while PTS is a long-term injury that can have serious consequences for the animal (NMFS 2016).

A technical guidance by NMFS (2016) sets limits for TTS onset based on various experiments on humans and other mammals. For impulsive sounds, TTS limits are set to SPL=212 dB re 1 µPa (0-p, unweighted) and SEL=170 dB dB re 1 µPa2s (24 hour accumulation, M-weighted). For PTS, no direct measurements are available, and the limits are determined by assuming PTS onset at 40 dB TTS, as suggested by e.g. Southall et al. (2007). For impulsive sounds, PTS limits are set to SPL=218 dB re 1 µPa (0-p, unweighted) and SEL=185 dB re 1 µPa2s (24 hour accumulation, M-weighted) (NMFS 2016).

Data acquisition

We conducted a 2D seismic acquisition on relatively wet and soft ice in the shallow part of inner Van Mijenfjorden on Spitsbergen, Svalbard, in early March 2016 (Figure 1). We used airguns and detonating cords as seismic sources, and geophones, hydrophones, and ocean bottom seismometers (OBS) as seismic receivers. The spread was along a straight line, 450 m long, and Figure 4 illustrates the hydrophone receiver geometry of this survey.

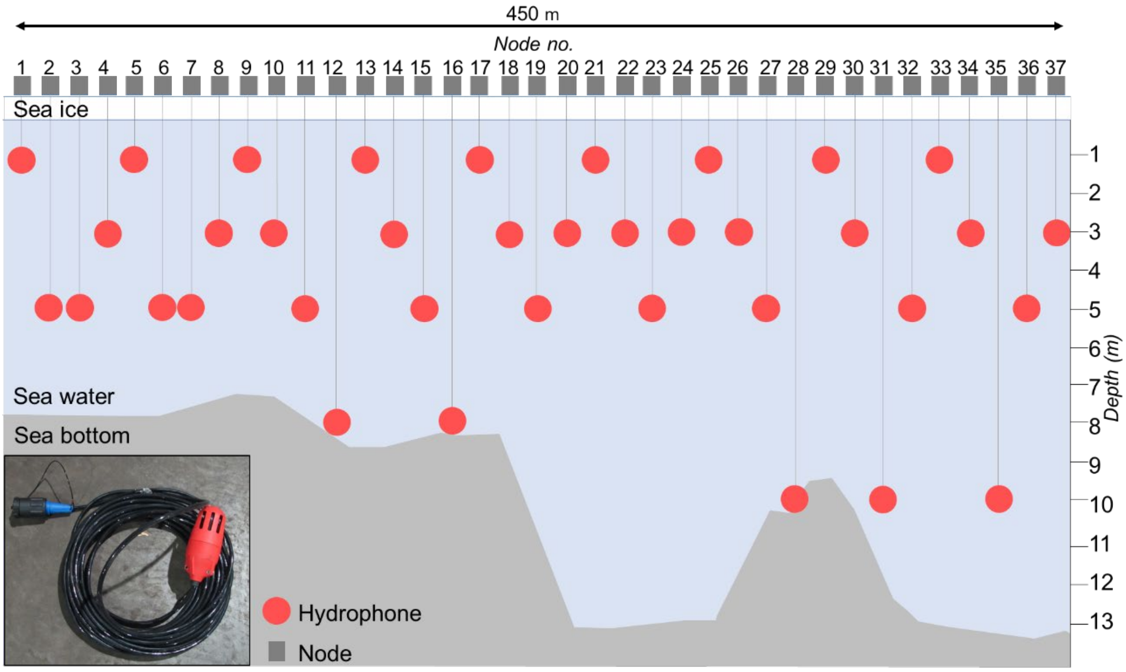

Figure 4

This was just before the breeding season, and very few seals were in the surrounding area. 37 hydrophones with frequency range 0-500 Hz, as well as one calibrated broadband hydrophone with frequency range 0-96 kHz, recorded the seismic wavefield within the water. The sensitivities of the 37 hydrophones were controlled by comparing them to the calibrated hydrophone.

To study behavioural effects, we conducted a similar experiment in the same fjord (see Figure 1) just after the breeding season the subsequent year, i.e. in late May 2017. Similar to in 2016, the seismic sources were detonating cords and a single airgun, but with a different number of shots and size of sources, see Table 1. All the hydrophones were at 5 m depth, deployed at 50 m intervals along a 3000 m long line.

Figures 7a-b and 9a display the computed sound levels for the 2016 data, while Figures 7c-d and 9b show the same data after applying the weighting function in Figure 3. The circles identify the locations of the hydrophones, while the colour defines the sound level for a single shot or multiple shots (for SPL computed from 0-p pressure, or SEL computed from rms pressure, respectively). The energy densities for both source types are shown in Figure 6. Table 1 reveals that source energy levels from 2016 and 2017 are comparable for airgun experiments, while the energy levels for detonating cord shots are generally higher in 2017. To demonstrate this, Figure 8 shows unweighted SPL at hydrophones and OBS for one detonating cord shot and one airgun shot from the 2017 experiment. The water was slightly deeper in 2017, which may have had an impact on the received sound levels due to wave interference effects.

Predicted effects of explosives versus airguns

A seismic source should generate repeatable pulses with a broad frequency spectrum, and be safe to use (Kearey et al. 2002). Airgun arrays are preferred in marine seismic surveying today (Landrø and Amundsen 2010), while detonating cords are often preferred in land seismic surveys when vibrators are less applicable. Fast ice makes it possible to use either detonating cords on top of the ice, or airguns lowered through holes in the ice (Del Molino et al. 2008, Johansen et al. 2011).

Explosives produce a sharper pressure build-up than airguns, and are thus generally considered more harmful to fauna and environment. Therefore, the use of explosives underwater is prohibited (Gordon et al. 2009). The rise time of the source pulse can be moderated by gradually increasing the intensity of the sound ("ramping up"), hopefully scaring animals away before they are physically harmed, but this is easier carried out with airguns than explosives (Gausland 2000). However, when used in detonating cords on top of sea ice, a lot of the energy from explosives leaks to the air and ice, producing a strong air wave that is mainly recorded on the shallowest hydrophones, see Figure 5. Thus, the pressure values in the water from detonating cord on top of the sea ice become less than from an airgun, and diving animals are most likely not strongly affected by seismic waves from detonating cords. Nevertheless, the air wave may affect seals on the ice, while this noise is absent when using an airgun (Press and Ewing 1951). Both types of sources have high repeatability, but the effective source signature of a detonating cord is more influenced by scattering from nearby heterogeneities.

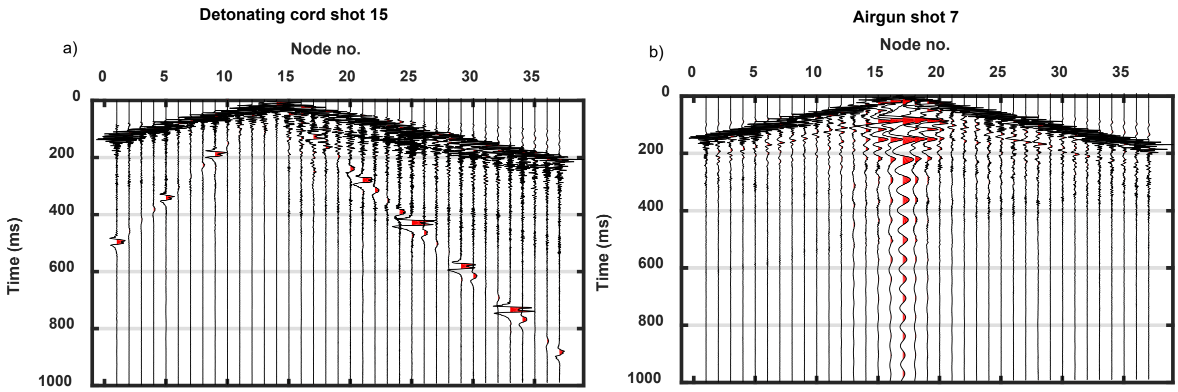

Figure 5

Physiological impacts

In the 2016 data, the airgun in general gives louder noise underwater than the detonating cord, see Figure 6. The figure also shows that for the airgun, the energy is concentrated at the lowest frequencies (<50 Hz), while for the detonating cord, the energy is more evenly distributed within the spectrum.

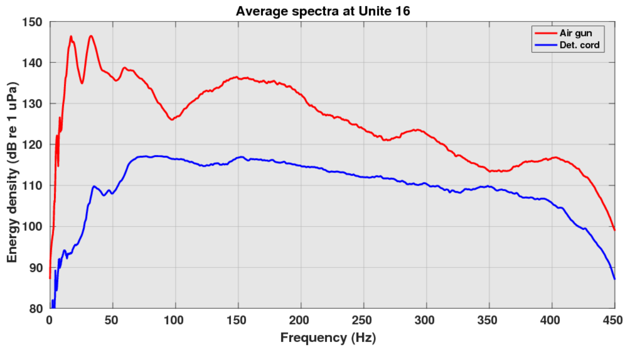

Figure 6

The frequency spectra measured using the broadband hydrophone manifests a decrease in energy with increasing frequency for both source types. The main peak in the frequency spectrum is never above 500 Hz when using airguns, and never above 700 Hz when using detonating cords. The sound levels measured at the 1 kHz sampling frequency hydrophones seem to be adequate for evaluating the maximum sound levels for airgun shots, while they would underestimate the SPLs by up to 10 dB for explosives at short distances (<50m). Because the strongest pressure occurs at low frequencies, Figure 3 indicates that the sound levels should be weighted down minimum 11.1 and 8.5 dB (M-weighting corrections for 500 and 700 Hz) for airgun and explosive shots, respectively.

Figures 7a and b show the SPLs from one single explosive shot, and one single airgun shot, respectively. According to NMFS (2016), frequency weighting is not appropriate for SPL, but Figure 7c and d nevertheless show computed M-weighted SPL corresponding to the shots in Figure 7a and b to demonstrate the large effect of frequency weighting.

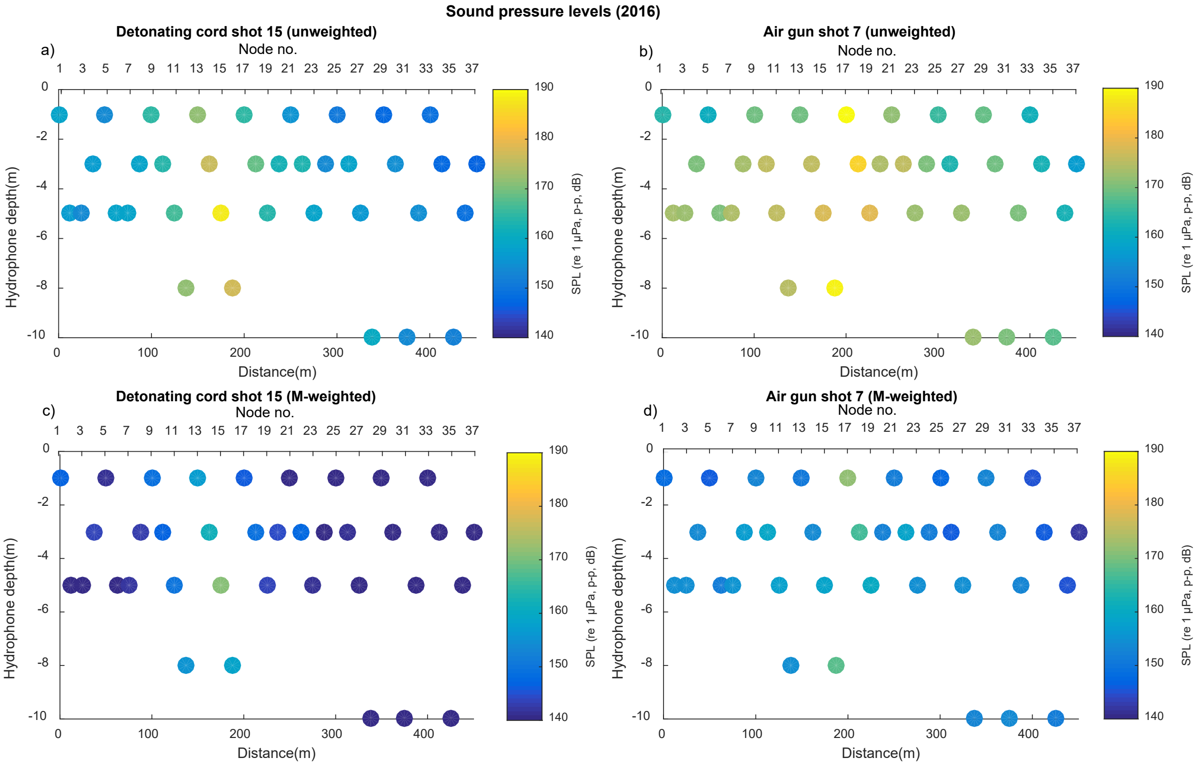

Figure 7

As expected, the highest SPLs are close to the source, but with a relatively rapid decrease in SPL with increasing distance from the source. The decrease is, however, not constant between receivers, most likely due to a complicated wave interference pattern caused by near surface wave phenomena.

NMFS (2016) give the limit for PTS as SPL=218 dB re 1 μPa, assuming unweighted sound pressure. The maximum measured unweighted explosive SPL is 190.8 dB re 1 μPa, and the maximum measured unweighted airgun SPL is 192.2 dB re 1 μPa. The latter value corresponds to the clipping level of the recording equipment, but this value only occurred at offsets less than 12.5 m. The limit for TTS given by NMFS (2016) is SPL=212 dB re 1 μPa, which is well above the measured SPLs, leading to a conclusion that no source type in our experiment causes TTS or PTS at offsets above 12.5 m.

Figure 8 shows that in the 2017 experiment, explosive SPLs are generally lower than airgun SPLs, and since the airgun source levels in the two experiments are comparable, the same conclusion is likely valid for that experiment as well. This was, however, not investigated further in this study.

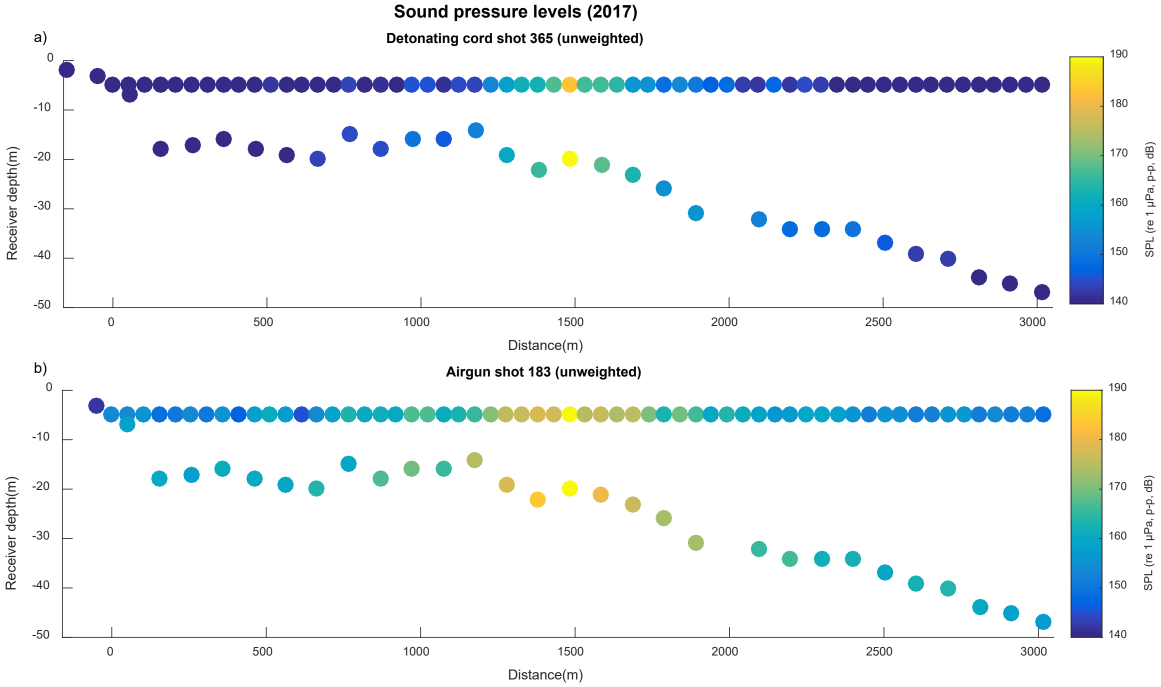

Figure 8

Figure 9a shows the SELs including all 2016 airgun shots, and Figure 9b shows the corresponding M-weighted SELs. We only computed SEL for airgun shots, as the source position was different for each detonating cord shot.

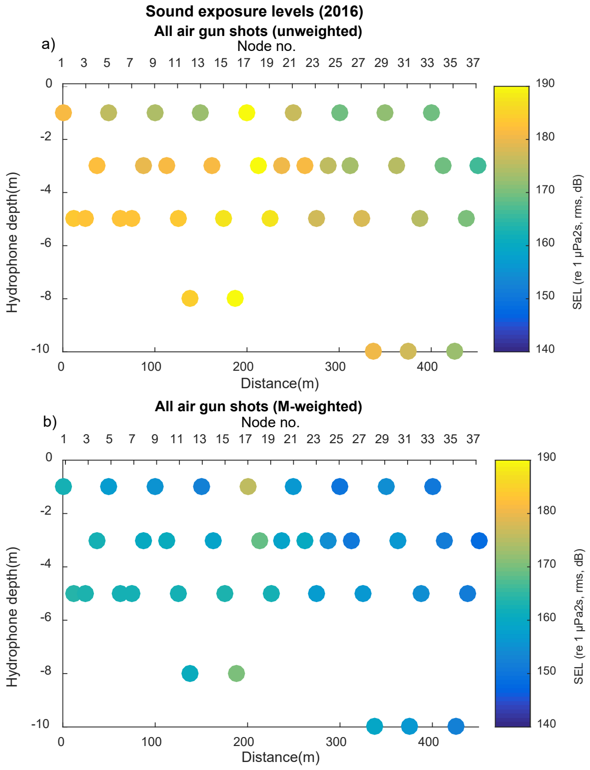

Figure 9

Just like for SPLs, we find the highest SELs close to the source positions, and there is a rapid decrease in SEL away from the source. M-weighting on average decreases the SEL by 20.9 dB. NMFS (2016) give the limit for PTS as SEL=185 dB re 1 μPas^2, assuming that the sound pressure is appropriately weighted, and that the accumulation period is 24 hours. Thus, the M-weighted measured SELs should be compared with this limit, and it should be kept in mind that the accumulation period was longer than 24 hours. The maximum measured M-weighted airgun SEL is 175.2 dB re 1 μPas^2, which is well below this limit, so no PTS was caused by our airgun experiments. As the limit for TTS given by NMFS (2016) is SEL=170 dB re 1 μPas^2, this means that if an animal stays constantly very close to the source (<12.5 m offset) for a prolonged time (i.e. does not get scared off), TTS might be possible. Nevertheless, our results imply that our experiments caused no serious physiological injuries.

Behaviour impacts

During the spring 2017 seismic survey, two observers were scanning the survey area for ringed seals two days prior to the start of the sound tests, following the entire exposure period, and three days after the tests ended. To account for other factors that could influence seal distribution and behaviour, we monitored the number of seals continuously during the period with up to four visual scans per tidal level, with an optimal duration of 30 minutes per tide.

The number of ringed seals visible during the study period varied between 20 and 143 animals. The seals tended to vacate the area during exposure to explosive shots, but with no significant effect caused by the airgun shots. There was a small, but insignificant difference in the detection numbers between the two observers.

There was a small variation in the number of seals during the days with noise from detonating cords, seemingly related to wind direction. For the air wave caused by explosions, direction and speed of the wind seemed to influence how the animals responded. However, there was no indication that the seals permanently fled their resting area when exposed to these waves.

Seismic waves travelling in the water and subsurface did not have any effect on the visible population of seals in the survey area, but the impact of the experiments on the seals can of course not be thoroughly concluded from our observations. The seals were mainly on top of the ice, and were therefore less exposed to these waves, but may on occasion leave the vicinity of their breathing holes for foraging. If they are swimming under the ice when exposure occurs, their activity can be disrupted.

Usefulness

Our study considers effects of relatively small surveys compared to commercial surveys used in hydrocarbon exploration, and the results are not necessarily transferable to impacts of larger surveys. The study provides an idea of how SPL decreases with increasing distance from the source, by comparing SPLs from the same shot, but measured at different receivers. Sound is often assumed to spread out spherically or cylindrically from a source, following a relationship on the form $P(r)=P(s)-A\log(r)$, where $P(r)$ is the SPL at the receiver, $P(s)$ is the SPL 1 m from the source, and A is a constant (Richardson et al. 1995). By using linear regression on our data, we find that a formula on this form is not adequate here ($A\neq$constant). Thus, we cannot easily extend our results to predict sound levels at other locations than at the hydrophones, based on the measured SPLs alone.

The results have some weaknesses and uncertainties. The limited dynamic range of the hydrophones means that the SPLs measured closest to the source should not be trusted, due to a cut-off of the peak amplitudes. We therefore excluded the sound pressures from shots within 10 m distance of the receiver when computing SELs. Although the hydrophones were calibrated, some variation in sensitivity of the various hydrophones may have led to errors in estimated SPLs and SELs. Additionally, polar bears were on several occasions actively hunting for seals during the experiment in 2017. This, together with snowmobile traffic on the ice in the haul-out region (both caused by ongoing experiments and local tourism), has most certainly had an effect on the behaviour of ringed seals in the survey area.

Summary

We have analysed possible impacts of seismic shooting on true seals, based on experiments performed on Svalbard in 2016 and 2017. Our main result is that a seismic survey of this size is most likely not physically injurious, but temporary behaviour change may occur. The population of seals did not seem to alter during the experiments, but the use of detonating cord caused some reaction. Some seals temporarily fled during those shots, most likely due to surface noise, which decreases rapidly with depth in the water. No indication of permanent disruption to the population of seals was observed. The detonating cord generated a pulse with higher frequencies, while the airgun gave more low frequency energy. However, the airgun provided a more high-energetic pulse. We found the highest sound levels for both types of sources at frequencies that seals cannot hear well (<700 Hz).

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Captions:

Figure 1: The seismic experiments were performed in the inner part of Van Mijenfjorden on Svalbard. The locations of the experiments are plotted. Map from Norwegian Polar Institute.

Figure 2: Deploying the seismic receivers in 2016 (top), and scanning the survey area for seals in 2017 (bottom left). An observed ringed seal (bottom right). Bottom images by Carl Ballantine.

Figure 3: M-weighting according to the plotted function can be applied to measured sound pressures to reflect the sound level a seal will most likely hear.

Figure 4: 2016 hydrophone layout. Hydrophones with 1 kHz sampling frequency (small picture) were placed relative to nodes 12.5 m apart. The water depth was approximately 7-13 m in 2016, and 3-47 m in 2017.

Figure 5: Shot gathers for a) an explosive shot in front of node 15, and b) an airgun shot 3 m below node 17 (160 bar airgun pressure). The air wave is only present when using explosives, and its strength decreases rapidly with increasing hydrophone depth. Traces are scaled individually and with time.

Figure 6: Energy density for average of all airgun (red) and explosive (blue) shots, recorded at the hydrophone 8 m below node 16. Airgun shots were louder than detonating cord shots. The hydrophone only recorded up to ~450 Hz due to an anti-alias filter.

Figure 7: SPLs for the shots in Figure 5, for a) an explosive shot in front of node 15, and b) an airgun shot 3 m below node 17 (160 bar airgun pressure). The SPLs have been M-weighted using the function in Figure 3, and the resulting SPLs are displayed in c) for the shot in a), and in d) for the shot in b). The SPLs closest to the source are clipped.

Figure 8: SPLs at hydrophones in water and OBS from the 2017 experiment for a) an explosive shot, and b) an airgun shot at 2 m depth, both close to the middle of the spread. The SPLs closest to the source are clipped.

Figure 9: a) SELs for all airgun shots, fired 50 m before node 1 and at node 17. b) The same shots with M-weighting applied.

Table 1: Detonating cords and airguns were used during the seismic experiments. The location, depth and size of the source varied during the experiments.

Year	Source type	No. of shots	Shot location	Depth and size
2016	Detonating cord	43	1 shot every 12.5 m	On ice, 5 m length
			1 shot every 50 m from + 50 m to + 250 m outside spread	On ice, 10 m length
			2 shots at + 250 m outside spread	On ice, 12.5 m length
	Airgun Mini GI 15+15 cu.in.	63	23 shots at - 50 m outside spread	3 or 5 m depth, 100 to 160 bar
			38 shots in the middle of spread	1.5 or 3 m depth, 90 to 160 bar
2017	Detonating cord	202	1 shot every 25 m	On ice, 2 x 25 m length
	Airgun Bolt 1900 LL 40 cu.in.	93	3 shots every 100 m	2, 4 and 6 m depth at each location, 120 to 140 bar

Table 1

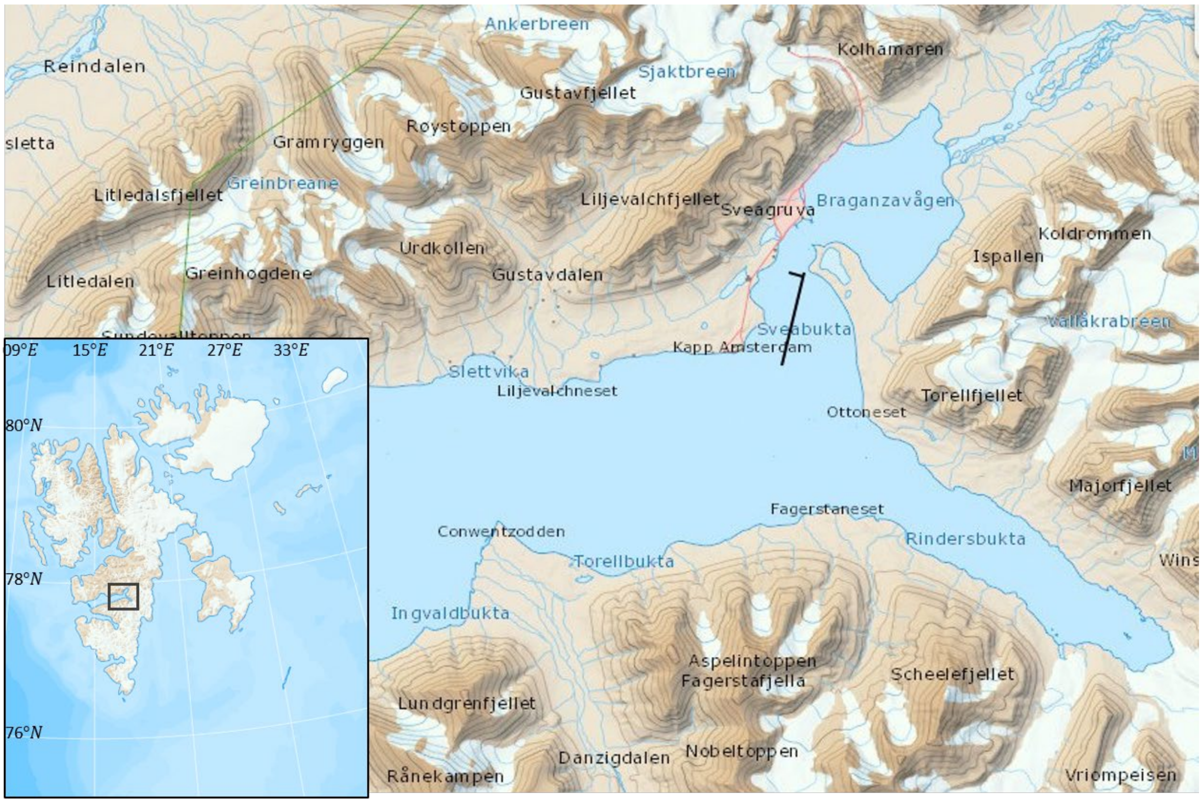

Ankerbreen
Reindalen
Sjaktbreen
Kolhamaren
Gustavfjellet
Gramryggen
Røystoppen
sletta
Litledalsfjellet
Greinbreane
Liljevalchfjellet
Sveagruva
Braganzavågen
Koldrommen
Urdkollen
Ispallen
Gustavdalen
Litledalen
Greinhogdene
Sveabukta
Vallåkrabreen
Kapp Amsterdam
Slettvika
Liljevalchneset
Torellfjellet
Ottoneset
Majorfjellet
Fagerstaneset
Conwentzodden
Rindersbukta
Torellbukta
Wins
Ingvaldbukta
Aspelintoppen
Fagerstafjella
Scheelefjellet
Lundgrenfjellet
Danzigdalen
Nobeltoppen
Rånekampen
Vriompeisen
09°E
15°E
21°E
27°E
33°E
80°N
78°N
76°N

Figure 1

Figure 2

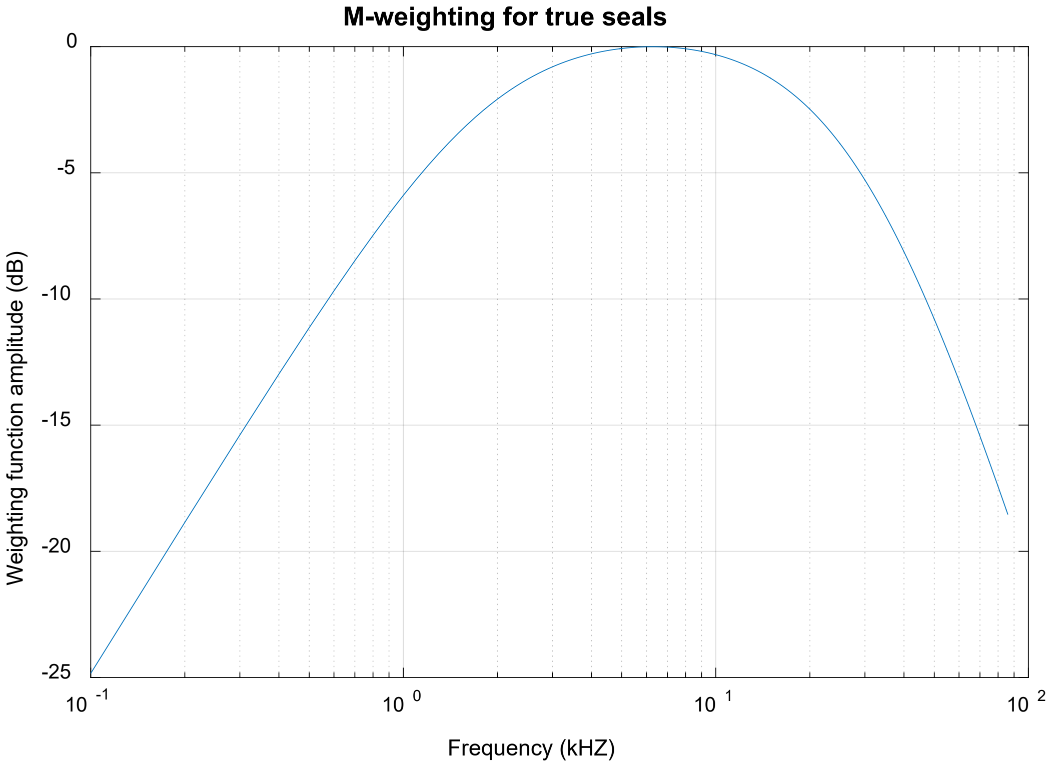

M-weighting for true seals
0
-5
-10
-15
-20
-25
Weighting function amplitude (dB)
10^{-1}
10^{0}
10^{1}
10^{2}
Frequency (kHZ)

Figure 3

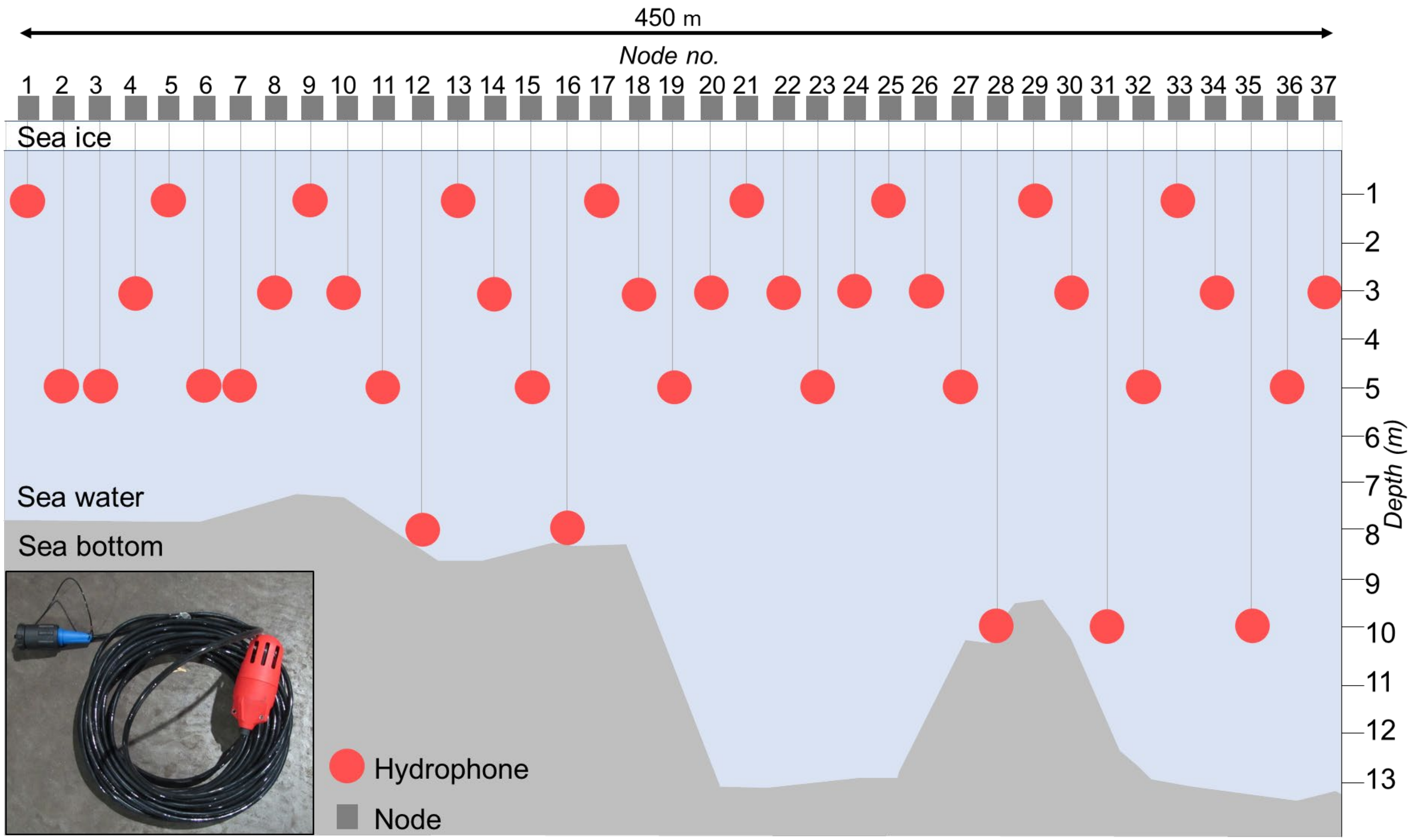
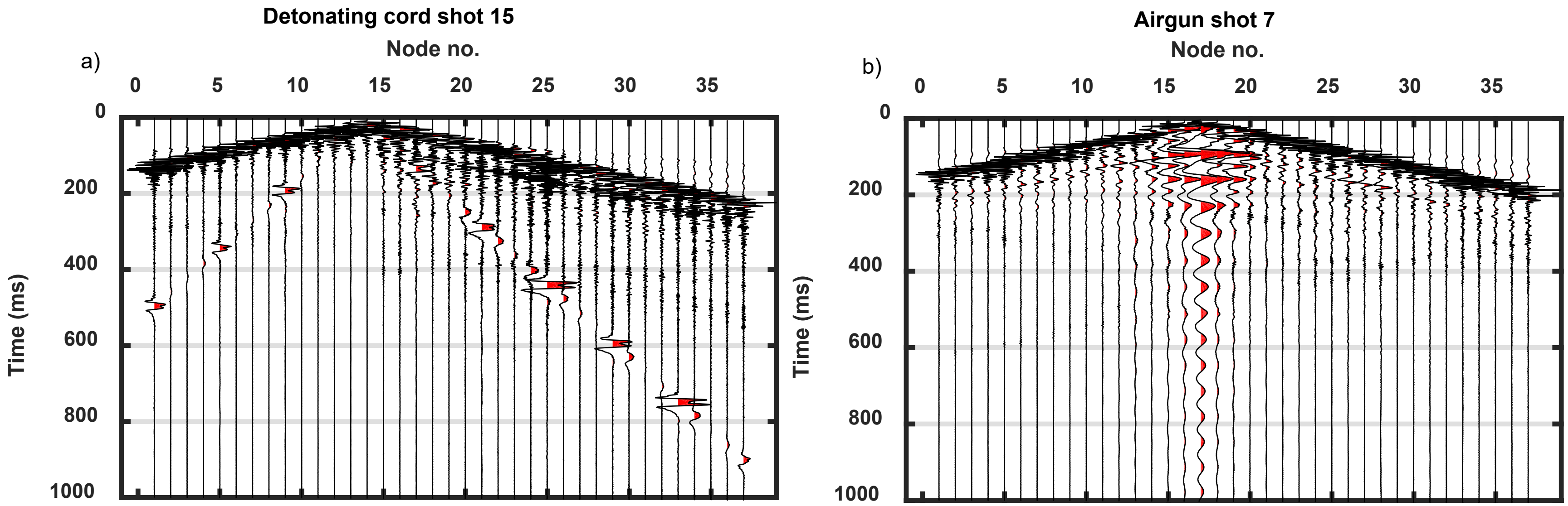

450 m
Node no.
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
Sea ice
Sea water
Sea bottom
Hydrophone
Node
Depth (m)
1
2
3
4
5
6
7
8
9
10
11
12
13

Figure 4



Detonating cord shot 15

Airgun shot 7

Figure 5

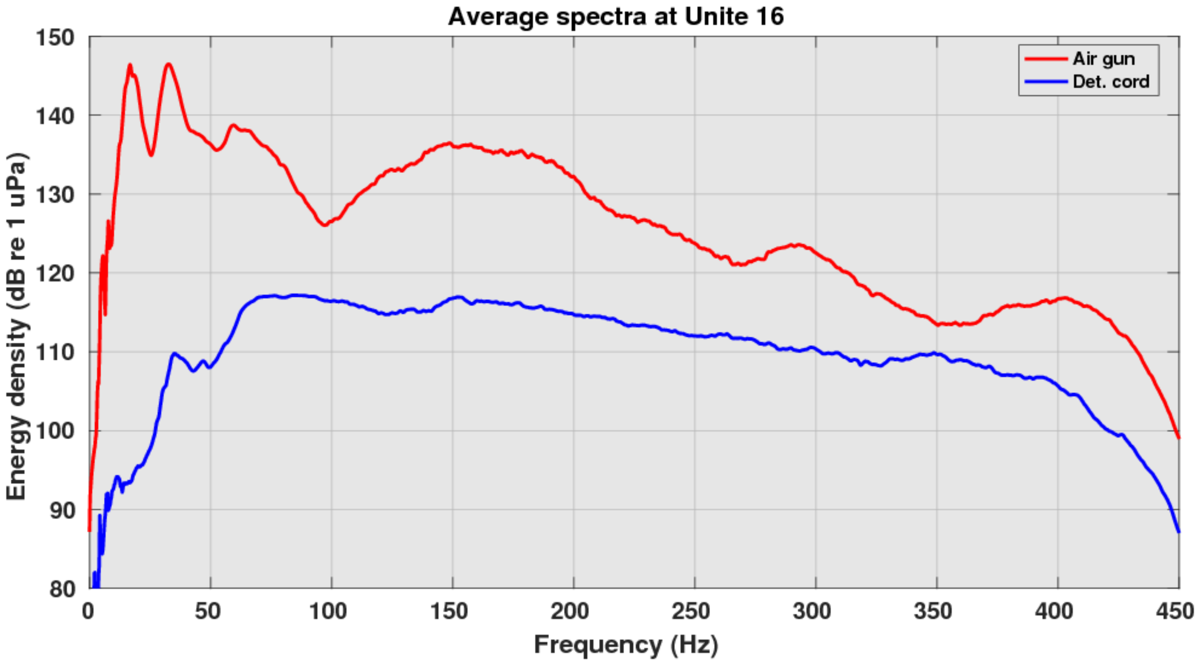

Average spectra at Unite 16
Air gun
Det. cord
Energy density (dB re 1 uPa)
150
140
130
120
110
100
90
80
0
50
100
150
200
250
300
350
400
450
Frequency (Hz)

Figure 6

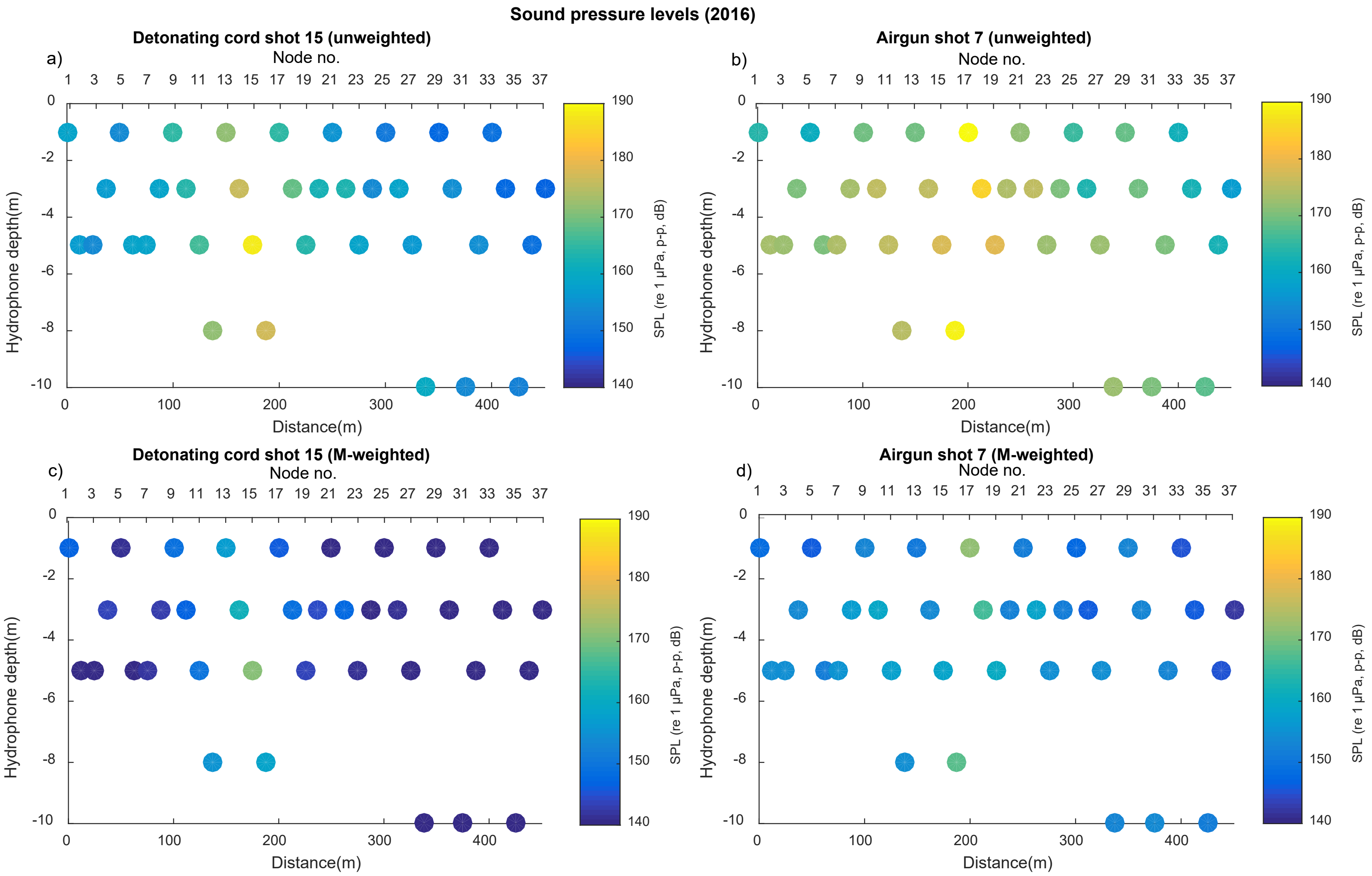

Sound pressure levels (2016)
a)
Detonating cord shot 15 (unweighted)
b)
Airgun shot 7 (unweighted)
c)
Detonating cord shot 15 (M-weighted)
d)
Airgun shot 7 (M-weighted)
Node no.
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37
Hydrophone depth(m)
0
-2
-4
-6
-8
-10
Distance(m)
0
100
200
300
400
SPL (re 1 µPa, p-p, dB)
140
150
160
170
180
190

Figure 7

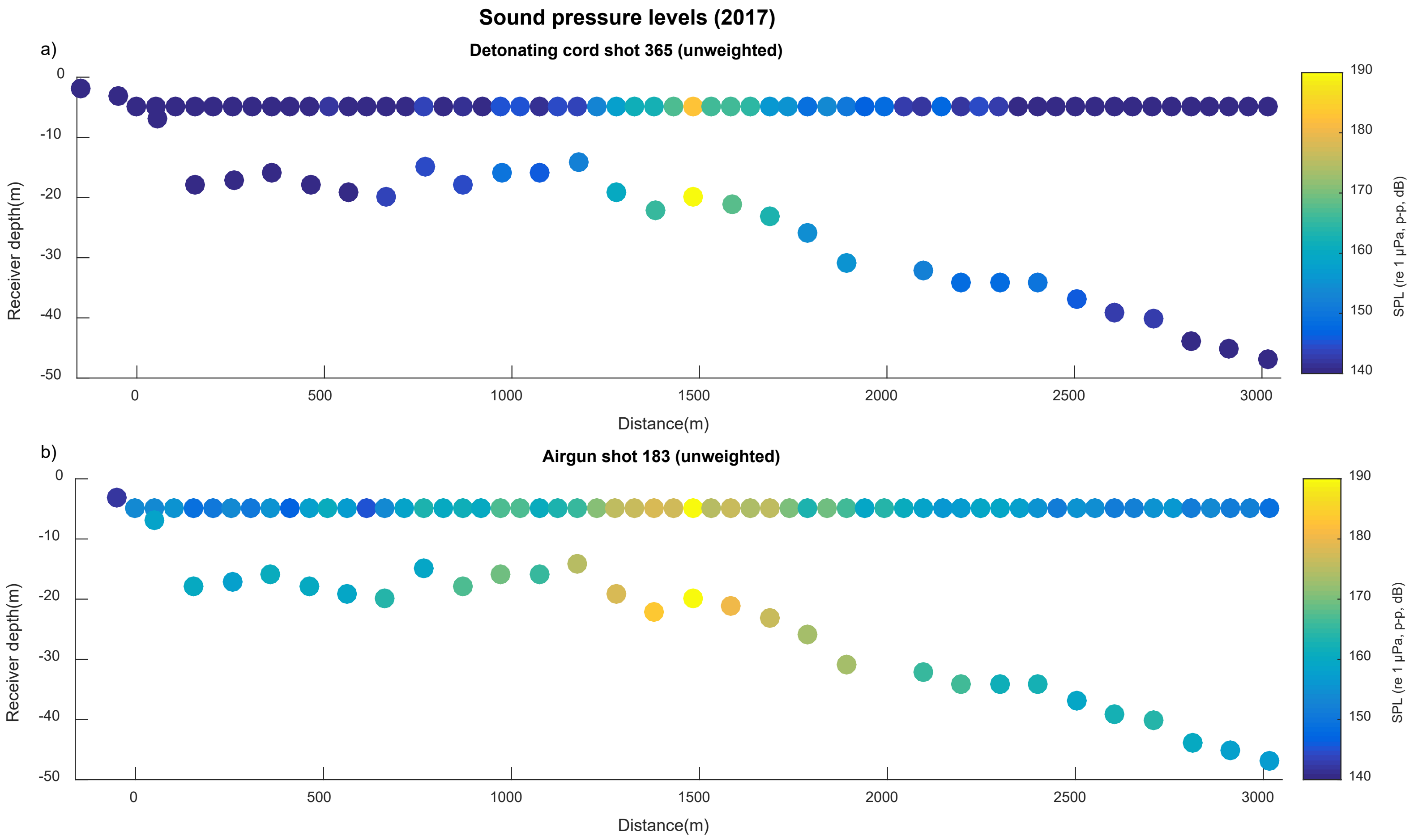

Sound pressure levels (2017)
a)
Detonating cord shot 365 (unweighted)
0
-10
-20
-30
-40
-50
Receiver depth(m)
0
500
1000
1500
2000
2500
3000
Distance(m)
190
180
170
160
150
140
SPL (re 1 µPa, p-p, dB)
b)
Airgun shot 183 (unweighted)
0
-10
-20
-30
-40
-50
Receiver depth(m)
0
500
1000
1500
2000
2500
3000
Distance(m)
190
180
170
160
150
140
SPL (re 1 µPa, p-p, dB)

Figure 8

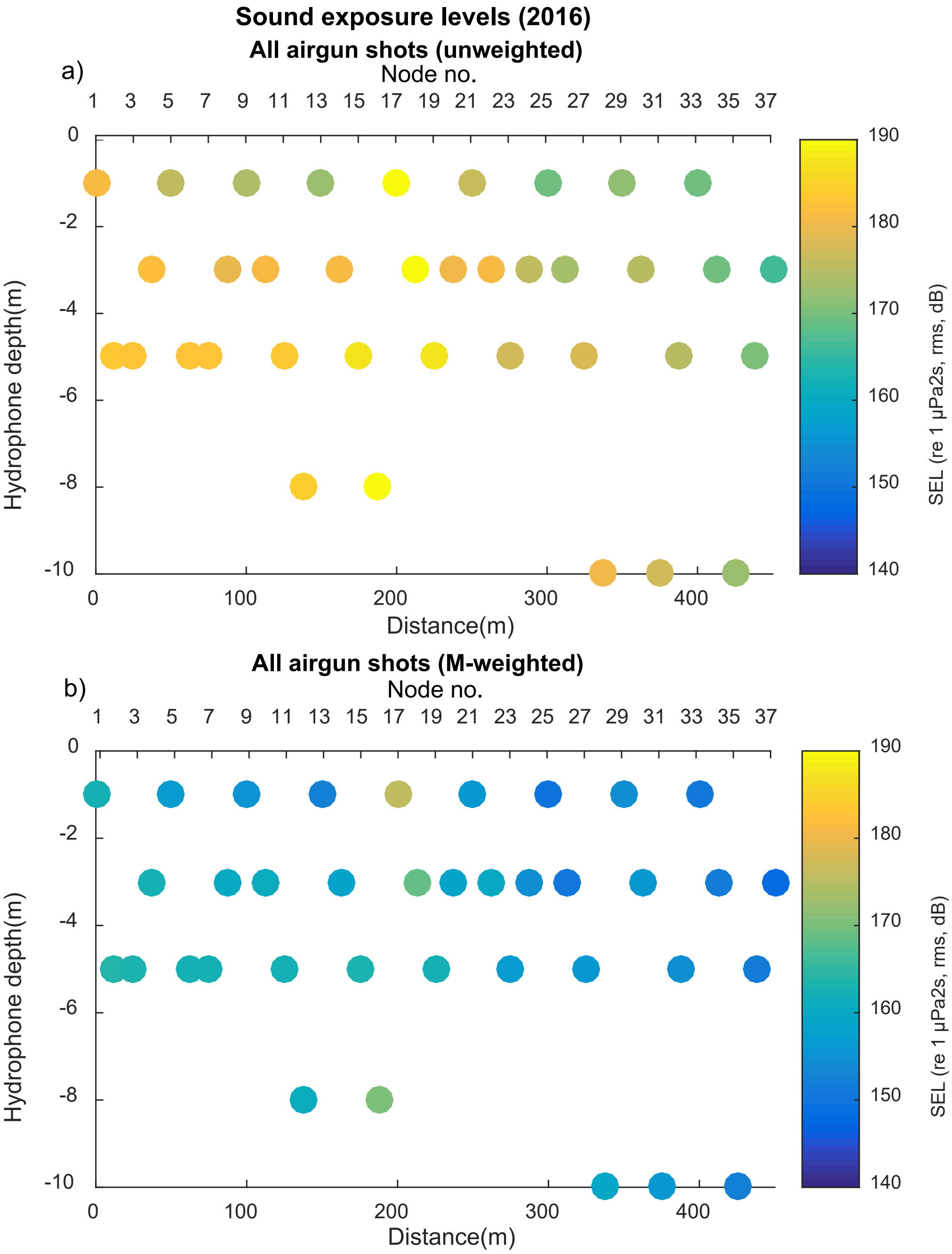

Sound exposure levels (2016)
All airgun shots (unweighted)
a)
Node no.
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37
Hydrophone depth(m)
0
-2
-4
-6
-8
-10
Distance(m)
0 100 200 300 400
SEL (re 1 µPa2s, rms, dB)
190
180
170
160
150
140
All airgun shots (M-weighted)
b)
Node no.
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37
Hydrophone depth(m)
0
-2
-4
-6
-8
-10
Distance(m)
0 100 200 300 400
SEL (re 1 µPa2s, rms, dB)
190
180
170
160
150
140

Figure 9