ACCESS
Arctic Climate Change
Economy and Society

SEVENTH FRAMEWORK
PROGRAMME

Project no. 265863

ACCESS

Arctic Climate Change, Economy and Society

Instrument: Collaborative Project

Thematic Priority: Ocean.2010-1 “Quantification of climate change impacts on economic sectors in the Arctic”

D4.57 – Safety zones and noise exposure criteria for marine mammals exposed to anthropogenic noise

Due date of deliverable: **31/03/2014**
Actual submission date: **14/10/2014**

Start date of project: **March 1st, 2011** Duration: **48 months**

Organisation name of lead contractor for this deliverable: **SIO**

Project co-funded by the European Commission within the Seventh Framework Programme (2007-2013)		
Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Contents

Introduction………………………………………………………………………………………. 3

1 Safety zones and noise exposure criteria for marine mammals currently used worldwide…5

1.1 History of Safety zones for marine mammals ……………………………………………5

1.2 NOAA's Interim Sound Threshold Guidance…………………………………......................7.

1.3 Changing of metrics for Noise exposure criteria: Initial scientific recommendation …...8

1.4 Example of using noise thresholds at Seismic Survey in Arctic region of Russia…… 9

1.5 Latest progress in Marine mammal Noise exposure criteria……………………………..10

1.6 Summary for currently used Noise Exposure Criteria…………………………………….12

2 Investigation of tendency in changing size of the Safety Zones around sources of industrial noise in Arctic area depending on potential warming of ocean……………………..13

2.1 Estimation changing the size of the Safety Zones at conducting Seismic Survey in the Arctic Seas……………………………………………………………………………….14

2.1.1 Results of modelling for 1991……………………………………………………………16

2.1.2 Results of modelling for 2010 and forecast on the future……………………………..18

2.1.3 Preliminary Conclusions about decreasing of size of the Safety Zones at Seismic survey ……………………………………………………………………………...19

2.2 Estimation changing the size of the Safety Zones at conducting deep-water Pile Driving in the Arctic Seas……………………………………………………………20

2.2.1 Results of modelling for Pile Driving…………………………………………………..21

2.2.2 Preliminary Conclusions about changing of size of the Safety Zones at Deep-water Pile driving in Arctic Seas…………………………………………………….22.

2.3 Assessment of seasonal changes of the Safety Zones size during hydrocarbon construction in the Arctic Seas ……………………………………………………………22

2.3.1 Estimation of the Safety Zones for Construction of the Production Units…………...23

2.3.2 Noise footprints for the Safety Zone at construction Production Units in cold (May) and warm (September) season…………………………………..26

2.3.3 Estimation of the Safety Zones for Pipeline Construction……………………………28

2.3.4 Conclusion about seasonal decreasing of size of the Safety Zones during hydrocarbon construction………………………………………………………..31

2.4 Conclusions about decreasing sizes of the Safety Zones in Arctic due to possible warming in the ocean………………………………………………….31

Literature……………………………………………………………………………………32

Introduction

Underwater noise caused by industrial activities (seismic surveys, offshore construction work, hydrocarbon production and transport facilities, etc.) has a significant adverse effect on the organisms that the marine environment hosts. Many marine animals have evolved to use sound as their primary means for communication, foraging, navigating, and generally perceiving features in the environment around them. Sound from human activities represents unwanted noise to these species. This noise can disrupt their natural activities, induce stress responses, degrade their environment and, in the more extreme cases, lead to permanent hearing damage, or even death Wright, A.J. (2014). Exposure to noise of high level or to prolonged noise can damage marine animals hearing abilities, cause negative behavioral reaction or mask their communications. Some argue that the impacts of noise are negligible in contrast to the expected consequences of climate change and other threats such as bycatch of marine mammals in fishing gear. However, the aggregated impacts of noise on marine mammals also combine with the effects of climate change and other human pressures. The total chronic impacts of combined human activity (known as cumulative impacts) on marine species can be decreased through reductions in the contributions of each component (Wright, 2014). The fact that underwater noise is an issue of concern for marine life has now reached widespread recognition in scientific, managerial and political circles.

For these reasons, companies of the marine sector are legally obliged to assess the acoustic impact from planned industrial activity prior to beginning their work. This includes Environmental Impact Assessments (EIAs), such as the reviewed EIA Directive (2014/52/EU), and preparation of relevant monitoring and mitigation measures. The reviewed EIA Directive (2014/52/EU) improves the level of environmental protection. Furthermore, federal regulations require oil and gas operators to acquire incidental harassment authorizations for activities that may disturb marine mammals.

The EU Marine Strategy Framework Directive of the European Union (MSFD, 2008/56/EC) was published in 2008 and became law in EU member States in 2010. The aim of the MSFD was to protect, conserve, and where possible, restore the marine environment in order to maintain biodiversity and provide diverse and dynamic oceans and seas that were clean, healthy and productive. The Directive required Member States to achieve Good Environmental Status (GES) in their marine environment by 2020 at the latest. The Marine Strategy Framework Directive explicitly requires consideration of underwater noise in determination of Good Environmental Status (GES). Thus member states must monitor and ultimately limit the amount of anthropogenic noise in European waters (Van der Graaf et al., 2012). Therefore, the effective management of anthropogenic noise in the marine environment is regarded as a high priority for action at the national and regional level and, to this end, ocean noise mapping is highly requested for Descriptor 11 of GES under the EU MSFD (2008/56/EC). Note that legislation of Russian Federation and of some Member States prohibits anthropogenic impact on species listed in the corresponding Red Books. Thus marine noise pollution has become a primary concern to the public, policy-makers, legislators and ocean noise producers.

As hydrocarbon exploration and extraction continue to expand in the oceans, particularly at higher latitudes, there is a growing need for operational standards to minimize impacts, especially when the activities occur in environmentally sensitive areas. This is particularly true for invasive sensing technologies that use loud sounds to image geophysical properties but incidentally expose large ocean areas to potentially damaging or disturbing noise. Sufficient scientific data exist to conclude that seismic airguns used in geophysical exploration have a low probability of directly harming most marine life, except at close range where physical injury is a real danger. While the use of airguns does not appear to disturb animals in some circumstances, in other conditions it can result in moderate to extreme behavioral responses and/or acoustic masking over large areas (Southall et al., 2007; Clark et al., 2009); indeed, recent studies have reported the transmission of sound energy from seismic surveys over vast ranges of nearly 4,000 km (Nieukirk et al., 2012). Most documented responses to seismic exploration or other intermittent human activities involving loud sounds include apparently temporary changes in behavior, but scientific understanding of the prevalence and implications of these effects is limited.

One of the best mitigation measure to protect marine mammals and fish from high levels of manmade noise is establishing Safety Zones (Exclusion Zone (EZ)) around sources of industrial noise. The Exclusion Zone is usually defined as the radius around industrial source of noise within which real-time mitigation measures are implemented if animals are detected (Weir & Dolman, 2007). The size of EZ should depends on type of protected species (pinnipeds or cetaceans, and their functional hearing groups), permitted thresholds of noise levels (noise exposure criteria), type of noise (impulsive or non- impulsive, continuous) and conditions for sound propagation in marine environment (seasonal variability and possible warming of upper water layers at climate change).

First chapter of this report includes review of history and state of the art for Safety Zones based on Noise Exposure Criteria that currently used worldwide and also provide an illustration by example where we took part. In second chapter - we present results of our acoustic modeling showing a tendency in changing size of Safety Zones for different type of manmade noise - impulse noise (seismic survey, pile driving) or continuous noise (construction, pipeline, ships) due to predicted warming of Arctic's water with changing of climate.

1 Safety Zones and Noise Exposure Criteria for marine mammals currently used worldwide

1.1 History of Safety zones for marine mammals

The U.S. took the lead in setting thresholds for levels of sound beyond which marine mammals should not be exposed in 1995. This has come to represent the level at which ‘injury,’ as defined by the US MMPA, occurs as a consequence of noise exposure. Additional, lower criteria were also introduced to define the onset of ‘behavioral harassment,’ also in accordance with the US MMPA. These levels have been changed only once in nearly two decades, when levels for the threshold for ‘injury’ for all cetaceans were reduced to the lower sound levels at which ‘injury’ was already defined for baleen whales and sperm whales. This is largely due to the support for the existing criteria that was provided a few years after their introduction in the findings of an ‘expert’ panel, which involved numerous representatives from the oil and gas industry (High Energy Seismic Study, HESS, 1999). These criteria (and the ‘injury’ threshold in particular) have since been re-used in many other countries around the world, despite advancing scientific understanding.

In 1998, the UK’s Joint Nature Conservation Committee (JNCC, 1998) was the first regulatory body to issue statutory marine mammal mitigation measures for use during industrial seismic surveys in their national waters. Since then Safety or Exclusion Zone (EZ) and various mitigation measures and monitoring protocols have been adopted, or are being considered, for marine seismic surveys around the world. While there are no internationally accepted standards, a number of jurisdictions (e.g., UK, Australia, U.S., New Zealand) have developed their own guidelines with varying degrees of regulatory oversight (Weir & Dolman, 2007), all of which do tend to share some common elements. Regulatory requirements for both monitoring and mitigation of seismic activity vary from one country or jurisdiction to another, despite the common objective of seeking to limit the potential adverse impacts of this invasive sensing technology.

The UK, the Gulf of Mexico, and Canada designate a 500 m EZ for all mitigation measures. Australia has the largest designated EZ at 3000 m. In Brazil, the 500 m EZ is used for airgun shut-down, but a more precautionary 1000 m EZ is used for delays to soft start. In New Zealand, a 200 m EZ is used to delay soft start for most marine mammals, but for stated species of concern a 1500 m EZ is used for delays and a 1000 m EZ for shut-downs. In Sakhalin a 250 m EZ has been designated for pinnipeds, while a standard 1000 m EZ is used for cetaceans. However where feeding groups of western gray whales Eschrichtius robustus are observed, an EZ of 4-5 km was implemented in Russia at Exxon’s Seismic Surveys in 2001 on Sakhalin, Russia.

Defining an EZ is a fundamental component of the real-time mitigation measures used during naval activities. However, the basis for defining exclusion zones remains unclear in most cases. The guidance currently in use by navies to mitigate potential impacts from sonar on marine mammals throughout the world varies in parameters such as the exclusion zone radius, the marine mammal species included in mitigation, and delay/shut-down procedures. Relatively few aspects of current mitigation have a firm scientific basis and proven efficacy in the field, and there remains a total lack of effective mitigation during night and adverse weather. Exclusion zones currently in use by navies vary considerably and can be larger for naval sonar than for seismic surveying, where a 500 m exclusion zone is standard. The Canadian Navy designates 1 nm (1.85 km) for baleen whales and 1 km for other marine mammals. The Italian Navy designates 1500 m for all marine mammals. NURC guidance is more complex, designating 2000 m for beaked whales and endangered species, once normal operations have commenced. It designates 2000 m for mysticetes, odontocetes and pinnipeds for impulsive sources (Dolman et al., 2009). Given the particular sensitivity of beaked whales to mid-frequency active sonar, all navies have a responsibility to conduct their activities in a way that limits potential impacts on those species.

Note the most of aforesaid EZ are based on arbitrarily defined, easy to handle radii, rather than being based on distances at which levels of noise inducing a particular unwanted impact are likely to occur.

Historically, the U.S. National Marine Fisheries Service (NMFS, NOAA Fisheries) used a 180 dB re 1μPa (RMS received SPL over an interval enclosing 90% of the pulse energy, hereafter SPL) received level threshold for predicting injury to mysticete cetaceans from exposure to impulse noise (National Oceanic and Atmospheric Administration (NOAA, 1998). Subsequently, the High Energy Seismic Survey (HESS) Team (1999) concluded that exposure to impulse noise with pulse-averaged received levels exceeding 180 dB SPL would likely result in significant behavioral, physiological, and/or hearing impacts. The NMFS continued to use the 180 dB SPL criterion for predicting injury, as well as a behavioral effect level of 160 dB SPL (NOAA,2013 b) based primarily on observations of mysticete responses to airgun operations (e.g., Malme et al., 1983a, 1983b; Richardson et al. 1986).

Relatively simple, straightforward metrics for predicting zones of potential effect — EZ are needed for field application, and thresholds based on received sound levels provide these. Criteria for predicting effects should be specified for the primary species of concern or animal groups present in a given operational area, and they may require consideration of impulse noise sources (e.g., airguns, pile driving) as well as more continuous noise sources (e.g., drilling, construction, vessel noise).

The lack of internationally accepted standards regarding response thresholds, mitigation measures, etc., lead to the fact that national or regional standards, where they exist, tend to be inconsistent (Weir & Dolman, 2007). Whereas the guidelines provided by the Joint Nature Conservation Committee (JNCC) (2010) do not specify levels of protection by species, the HESS Team (1999) recognizes marine mammals at three priority levels based on (1) known or inferred sensitivity to low-frequency sounds (e.g., from airguns) and (2) protection status of the species or population. First-priority species are blue (Balaenoptera musculus), humpback, fin (B. physalus), and gray whales; second-priority species are sperm whales (Physeter macrocephalus), elephant seals (Mirounga spp.), and the other mysticetes; and third-priority species are the rest of the odontocetes and pinnipeds. The HESS Team applies this priority classification only to determine monitoring requirements and not mitigation measures (e.g., shutdown criteria). Furthermore, whereas the JNCC (2010) guidelines recommend a fixed exclusion zone of 500 m, the NMFS (NOAA) uses underwater “do not exceed” sound-level criteria for exposure of marine mammals to underwater impulses from seismic airguns. These criteria are currently set at 190 dB SPL for pinnipeds and 180 dB SPL for cetaceans. None of the guidelines distinguish protective measures based on species or population status (e.g., vulnerable, threatened, endangered, and critically endangered).

1.2 NOAA’s Interim Sound Threshold Guidance

To define EZ NOAA is developing comprehensive guidance on sound characteristics likely to cause injury and behavioral disruption in the context of the US Marine Mammal Protection Act (US MMPA, 1972), Endangered Species Act (ESA, 1973) and other statutes but still is used the Interim Sound Thresholds (NMFS 2005, NOAA, 2013 b). Until formal guidance is available, NOAA Fisheries uses conservative thresholds of received sound pressure levels from broad band sounds that may cause behavioral disturbance and injury. These conservative thresholds are applied in MMPA permits and Endangered Species Act Section 7 consultations for marine mammals to evaluate the potential for sound effects. The criterion levels specified below are specific to the levels of harassment permitted under the US MMPA.

NOAA Fisheries current in-water acoustic threshold (excluding tactical sonar and explosives):

Criterion	*Criterion Definition*	*Threshold*
Level A	PTS (injury) conservatively based on TTS	190 dB_{rms} for pinnipeds 180 dB_{rms} for cetaceans
Level B	Behavioral disruption for impulsive noise (e.g., impact pile driving)	160 dB_{rms}
Level B	Behavioral disruption for non-pulse noise (e.g., vibratory pile driving, drilling)	120* dB_{rms}

All decibels referenced to 1 micro Pascal (re: 1uPa). Note all thresholds are based off root mean square (rms) levels.
*The 120 dB threshold may be slightly adjusted if background noise levels are at or above this level.

NOAA Fisheries current in-air acoustic thresholds:

Criterion	*Criterion Definition*	*Threshold*
Level A	PTS (injury) conservatively based on TTS	None established
Level B	Behavioral disruption for harbor seals	90 dB_{rms}
Level B	Behavioral distruption for non-harbor seal pinnipeds	100 dB_{rms}

All decibels referenced to 20 micro Pascals (re: 20uPa). Note all thresholds are based off root mean square (rms) levels.

1.3 Changing of metrics for Noise exposure criteria: Initial scientific recommendations

Southall et al. (2007) reviewed and applied available scientific literature in proposing Marine mammal noise exposure criteria as “Initial scientific recommendations”. Their dual-metric criteria were derived largely from more recent scientific findings, which were quite different from the simplistic NMFS (1998) and HESS Team (1999) criteria. Specifically, Southall et al. (2007) proposed peak SPL (dBpeak re 1μPa, hereafter SPLpeak) and sound exposure level (dB re 1μPa2-s, hereafter SEL) for injury thresholds, as well as frequency-weighting functions to account for the differential hearing capabilities of marine mammals across different frequency bands. It contains detailed analysis of scientific knowledge on the subject available by that moment. However, the guidelines provided in this work could be considered not sufficient for setting reliable noise exposure criteria. Work is in progress to revisit these criteria.

Southall et al. (2007) criteria are based on studies of known or predicted marine mammal auditory thresholds and the SPLpeak and SEL metrics are generally considered more appropriate for evaluating PTS (injury) from impulsive sounds. NOAA’s injury criteria (in RMS) are considered highly conservative, interim thresholds until NOAA’s National Marine Fisheries Service (NMFS) “Guidelines for Assessing Impacts of Anthropogenic Sound on Marine Mammals” are developed (NOAA 2013a).

Although Southall et al.’s (2007) criteria are considered more comprehensive than NOAA criteria and may be more relevant for assessing injury, these thresholds have not been adopted formally by government departments either in Canada or the US.

1.4 Example of using noise thresholds at Seismic Survey in the Arctic region of Russia

Latest seismic survey in sensitive Arctic region (off Sakhalin Island, Ohotsk sea, Russia) close feeding area of endangered Redbook's Gray Whale population took place in 2010 (SEIC, 2010). In that case was applied a unique approach based to some extent on the Southall et al. (2007) recommendations and our own study (Vedenev and Nowacek, 2009) . This project used the best available scientific data for conditions of exposure approximating as closely as possible those of the planned survey, and it integrated additional precautions in view of the critically endangered status of the local whale population. Pertinent details regarding the derivation of these impact criteria are summarized here (for additional details see Nowacek, Vedenev et al 2012, Nowacek, Vedenev et al. 2013). The industrial development off Sakhalin exposes a variety of marine mammals, including gray whales, to both "continuous" or non-impulsive noise and impulses such as those from seismic airguns and pile driving. Consequently, exposure criteria for both types of noise were generated, with impacts considered for both auditory injury and significant behavioral disturbance, particularly the potential for indirect nutritional consequences from the whales' avoidance of prime feeding areas. The focus here is on impulsive noise as airguns are the dominant noise source in seismic surveys. The Southall et al. (2007) impulse noise criterion for the onset of physical injury (198 dB SEL, which was based on temporary hearing loss in odontocetes extrapolated to higher levels for estimating injury and then extrapolated to mysticetes) was considered. However, given the limited underlying data and subsequent extrapolation methods, as well as the critically endangered status of western gray whales, the typically more conservative or risk-averse (in most conditions) historical 180 dB SPL criterion was used as a proxy for injury. This kind of deviation from the recommended criterion given the specific conditions of the exposure situation here was clearly anticipated by Southall et al. (2007), particularly in specific conditions where data are lacking and endangered species are involved. Regarding behavioral responses to impulse noise, the Malme et al. (1984) measurements for eastern gray whales exposed to such noise represented the basis for predicting avoidance behavior. These data indicate estimated 10, 50, and 90% probabilities of gray whale avoidance reactions at 164, 170, and 180 dB SPL, respectively. Given the desire to use an approach that considered both magnitude and duration of exposure (i.e., using SEL), and considering the general recommendations of Southall et al. (2007), we reviewed additional Malme et al. (1986, 1988) reports containing the raw field data on gray whale responses to determine if SEL values could be derived. However, details regarding the range of exposures of many individuals or other pertinent details were lacking, and it was impossible to estimate exposures in terms of SEL. Given this limitation, we assumed a behavioral disturbance threshold of 163 dB SPL for impulse noise, corresponding to approximately a 10% probability that whales would cease feeding according to the results in Malme et al. (1984). Based on both acoustic modeling and actual measurements of airgun pulses in the Sakhalin area this SPL value was determined to correspond to 156 dB SEL, the level ultimately used as the impact criterion for significant behavioral response in contingency planning and the design of mitigation measures for the 2010 survey. The broader message and conclusion is that in planning a seismic survey, a thorough search for pertinent data is necessary so all available data can be incorporated into protective measures.

1.5 Latest progress in Marine mammal Noise exposure criteria

At the end of 2013 the National Oceanic and Atmospheric Administration for assessing the effects of anthropogenic sound on marine mammal species have released a draft “Acoustic Threshold Levels for Onset of Permanent and Temporary Threshold Shifts” of updated acoustic criteria for Level A Harassment, or “injury” (NOAA, 2013a).

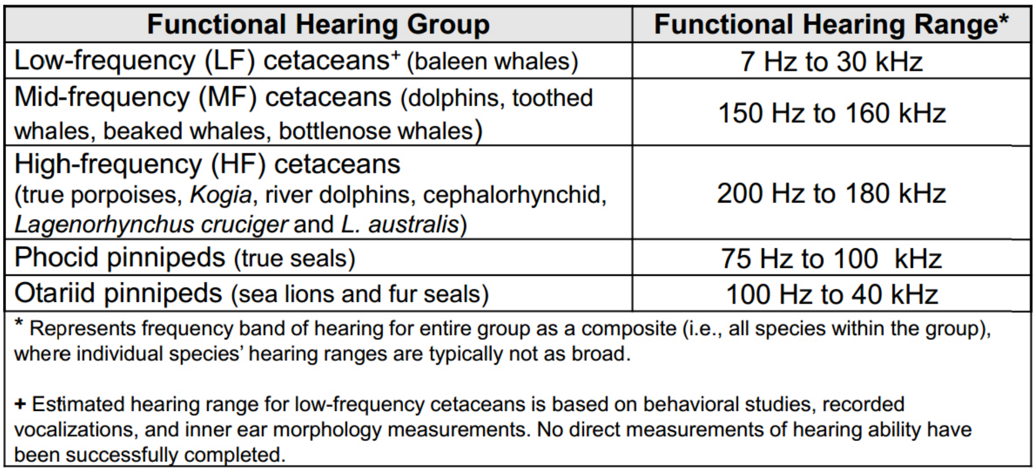
The Guidance provides updated received levels, or acoustic threshold levels, based on the best available science, above which individual marine mammals are predicted to experience changes in their hearing sensitivity (either temporary or permanent) for all underwater anthropogenic sound sources. Details of update:

Sources divided into 2 groups:
- Impulsive: explosives, seismic, impact pile driving
- Non-impulsive: drilling, sonar, vibratory pile driving

Dual metric threshold levels was incorporated:
- Peak pressure
- Cumulative sound exposure level (SELcum)

Accumulation period needed to use Cumulative sound exposure level metric. Proposed Accumulation period - 24 h for exposure models capable of simulating relative movement of receiver and/or source; - 1 h for exposure models not capable of simulating relative movement of receiver and/or source

Marine mammals divided into functional hearing groups:
- Low-, mid-, and high-frequency cetaceans
- Phocid and otariid pinnipeds



Functional Hearing Group	**Functional Hearing Range***
Low-frequency (LF) cetaceans[+] (baleen whales)	7 Hz to 30 kHz
Mid-frequency (MF) cetaceans (dolphins, toothed whales, beaked whales, bottlenose whales)	150 Hz to 160 kHz
High-frequency (HF) cetaceans (true porpoises, *Kogia*, river dolphins, cephalorhynchid, *Lagenorhynchus cruciger* and *L. australis*)	200 Hz to 180 kHz
Phocid pinnipeds (true seals)	75 Hz to 100 kHz
Otariid pinnipeds (sea lions and fur seals)	100 Hz to 40 kHz

* Represents frequency band of hearing for entire group as a composite (i.e., all species within the group), where individual species’ hearing ranges are typically not as broad.

+ Estimated hearing range for low-frequency cetaceans is based on behavioral studies, recorded vocalizations, and inner ear morphology measurements. No direct measurements of hearing ability have been successfully completed.

Auditory weighting functions was incorporated (Fig.1). NOAA proposed weighting function modified from recently proposed function (Finneran & Jenkins 2012):

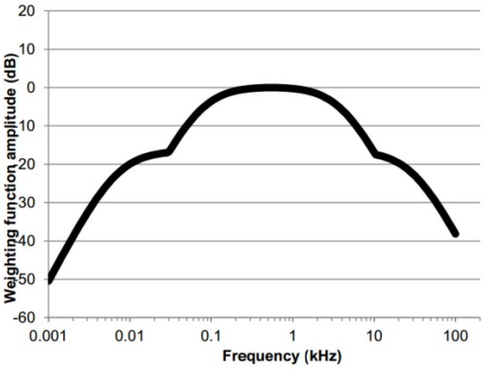


Fig. 1. Weighting function proposed NOAA.

Specifically, the Guidance provides acoustic threshold levels for onset of permanent threshold shift (PTS) and temporary threshold shifts (TTS) for all sound sources. It is intended to be used by NOAA analysts/managers and other relevant user groups/stakeholders, including other federal agencies to better predict a marine mammal's response to sound exposure in a manner that has the potential to trigger certain requirements under one or more of NOAA's statutes (e.g., MMPA, ESA, and National Marine Sanctuaries Act).

To develop these acoustic threshold levels, NOAA has compiled, interpreted, and synthesized best available information currently available on the effects of anthropogenic sound on marine mammals, as well as developed a method for updating these levels through a systematic, transparent process. These thresholds replace those currently in use by NOAA. The document outlines NOAA's updated acoustic threshold levels and describes in detail how the thresholds were developed and how they will be updated in the future.

Summary of proposed TTS and PTS onset dual acoustic threshold levels (Received Level)

	PTS Onset		TTS Onset	
Hearing Group	Impulsive	Non-impulsive	Impulsive	Non-impulsive
Low-Frequency (LF) Cetaceans	230 dBpeak & 187 dB SELcum	230 dBpeak & 198 dB SELcum	224 dBpeak & 172 dB SELcum	224 dBpeak & 178 dB SELcum
Mid-Frequency (MF) Cetaceans	230 dBpeak & 187 dB SELcum	230 dBpeak & 198dB SELcum	224 dBpeak & 172 dB SELcum	224 dBpeak & 178 dB SELcum
High-Frequency (HF) Cetaceans	201 dBpeak & 161 dB SELcum	201 dBpeak & 180 dB SELcum	195 dBpeak & 146 dB SELcum	195 dBpeak & 160 dB SELcum

Phocid Pinnipeds (Underwater)	235 dBpeak & 192 dB SELcum	235 dBpeak & 197 dB SELcum	229 dBpeak & 177 dB SELcum	229 dBpeak & 183 dB SELcum
Otariid Pinnipeds (Underwater)	235 dBpeak & 215 dB SELcum	235 dBpeak & 220 dB SELcum	229 dBpeak & 200 dB SELcum	229 dBpeak & 206 dB SELcum

Need to note, Guidance for behavioral response of marine mammals to sound not included in this document. NOAA is continuing our examination of the effects of noise on marine mammal behavior and will focus our work over the next year on developing guidance regarding the effects of anthropogenic sound on marine mammal behavior. Behavioral response is a complex question and they determined they still need time to research and address it appropriately. Due to the complexity and variability of marine mammal behavioral responses, NOAA will continue the work.

NOAA's previous acoustic threshold levels (NMFS 2005, NOAA, 2013 b) are expressed as root-mean-square (dBrms), which uses a different metric from peak sound pressure levels (dBpeak) and SELcum that are being recommended for our TTS and PTS onset acoustic threshold levels. Thus, we recommend caution when comparing past acoustic threshold levels to the acoustic threshold levels presented in this document as because they are based on different metrics, they are not directly comparable. For example, a 180 dBrms level is not equal to a 180 dBpeak level. Furthermore, the SELcum metric incorporates time and is an energy level with a different reference value (re: 1μPa2- s), thus it is not directly comparable to other metrics that describe sound pressure levels (re: 1 μPa).

1.6 Summary for currently used Noise Exposure Criteria

As was noted the size of Safety Zones for marine mammals depends mainly on used Noise exposure criteria. Since clear criteria for Level A - Harassment or "injury are still waiting to be established and still need time to research on behavioral responses (Level B - Behavioral disruption) (NOAA, 2013a), still remain for wide using the recommendations for the noise threshold proposed by High Energy Seismic Study (HESS, 1999). The NMFS (NMFS 2005, NOAA, 2013 b) has continued to use the 180-dB Received Level (RL) criterion for predicting injury from acoustic exposure for cetaceans and 190-dB RL for pinnipeds as well as a behavioral impact level of 160-dB RL; based primarily on observations of mysticete cetaceans reacting to air gun pulses (e.g., Malme et al. 1984), a 120-dB RL criterion has been applied by the NMFS in some conditions for some nonimpulsive "continuous" industrial noises.

2 Investigation of tendency in changing size of the Safety Zones around sources of industrial noise in Arctic area depending on potential warming of ocean

According to existing mitigation and monitoring practices currently used for industrial underwater noise two monitoring Safety Zones should be established to protect whales from physical injury or undue disturbance (see Summary in Chapter 1). To protect marine mammals against potential physical injuries at high level of impulsive noise e.g. seismic or pile driving pulse (for cetaceans it is 180 dB rms re 1 µPa, for pinnipeds 190 dB rms re 1 µPa) the radius of "Injury Safety Zone" should be calculated. To protect marine mammals against undue disturbance and displacing marine mammals from feeding areas the radius of "Disturbance Safety Zone" within which the received pulse levels exceed 160 dB rms should be calculated.

If industrial noise is non-impulsive (e.g., vibratory pile driving, drilling, shipping) to prevent behavioral disruption from continuous noise radius Disturbance Safety Zone with level more 120 dB rms re 1 µPa should be estimated. So to investigate the tendency in changing size of the Safety Zones around sources of industrial noise depending on potential warming of ocean we did an acoustic modeling for transmission loss of industrial noise levels by varying environmental parameters of water layers. Sizes of Safety Zone were defined as distance to source of noise where noise level have been decreased to values 180 dB, 160 dB and 120 dB rms re 1 µPa. A numerical modeling approach (i.e., sound propagation model) used to define safety zones must be capable of reproducing all the salient acoustic propagation properties of the region, which can sometimes be complex and even counterintuitive, with down-range levels being higher than those closer to the source (Madsen et al., 2006). Computational methods, such as Parabolic Equation algorithms, are capable of modeling fully range-dependent propagation environments (properties change with distance from the source) in shallow and deep water, and are among the most favored for seismic survey noise footprint estimation (Aviloff, 1992; Porter, 1993; Jensen et al., 2011,). The environmental parameters selected, including the water sound speed profile and the geo-acoustic properties of the bottom, were as close as possible to the prevailing local properties.

For better understanding of variations the size of Safety Zones at changing Arctic conditions due to warming, we calculated functional dependence of the noise transmission loss on distance for different type of manmade noise – impulsive noise from seismic survey and pile driving and non-impulsive, "continuous", industrial noises from platforms and pipeline construction.

We used an accurate acoustic model with input data of environmental parameters of water layers in Barents Sea at different seasons and years (May and September1991, May and September 2010) and a forecast for environment warming in the upper layers of sea water for next decades (up to +5° C). On Fig. 2 profile of sound speed for May 2010 is shown by green curve, blue curve - for September 2010 and red curve is a forecast for September in future (warming uniformly ~+4.7 C in the layer 0-30 m depth and ~ +1 C from 50 m to the bottom).

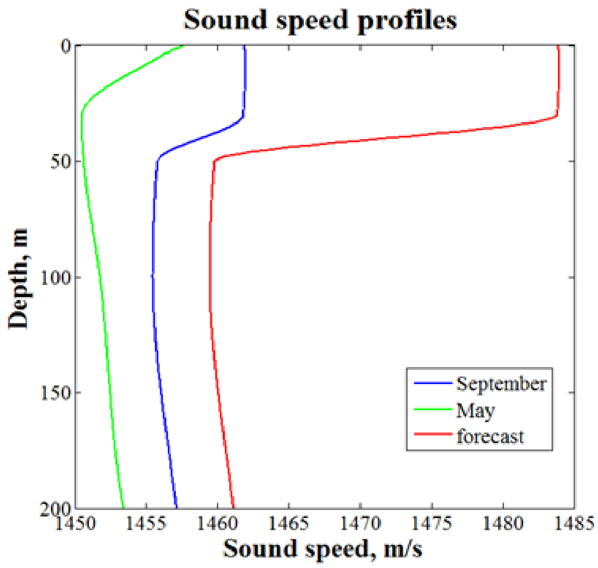


Fig. 2 Typical for 2010 profiles of sound speed in Barents Sea and a forecast for possible changing of profile for next decades,

Accurate modeling made by SIO's methodology (Vedenev et al., 2012) includes 4 steps:

- description of the sources (far-field source signature, source array composition),
- description of the input site-specific environmental data (water and bottom sound speed profiles with the bottom relief and sound attenuation in bottom sediments),
- computation of the impulse response and transfer function for input environmental data by using a Pseudo Differential Parabolic Equation acoustic model (PDPE code) and
- definition of the size of monitoring Safety Zones by distance on pulse Transmission Loss graph where pulse levels decrease to levels 180 dBrms and 160 dB rms re 1 µPa.

2.1 Estimation changing the size of the Safety Zones at conducting Seismic Survey in the Arctic Seas

In this case for estimation changing size of the Safety Zones we investigated propagation of impulsive noise from Seismic Survey in Arctic.

Airgun noise model

For numeric modeling we took parameters of a typical airgun array used at Seismic Survey in Arctic Seas of Russia - Model 2620-5-2000-bolt with includes 20 airguns and clusters working simultaneously with total volume 2600 cub inch. The far-field signature of a seismic pulse and its spectrum are shown on Fig.3. The modeling doesn't involve consideration of directionality of the seismic source which is small in low frequency band.

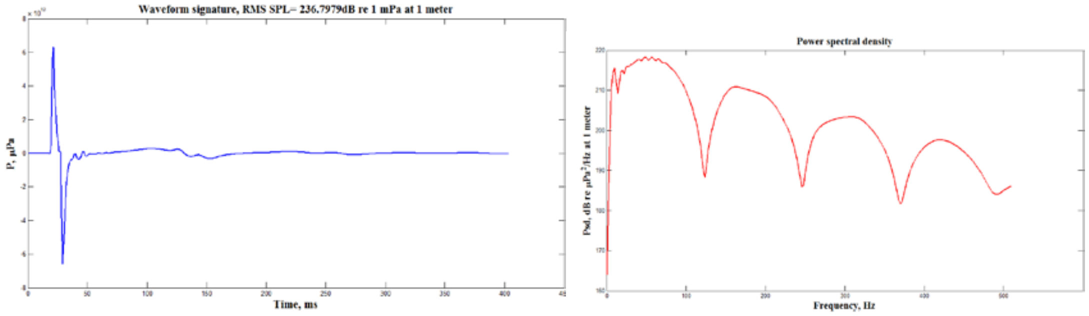


Fig.3 The waveform signature of the real Seismic source (Model 2620-5-2000-bolt) and its spectrum used in modeling.

Seismic Source location and study area

The Seismic Source was located in the Barents Sea (75°30'N 35°30'E) to the west from the Novaya Zemlya Island. The map is shown below on Fig.4.

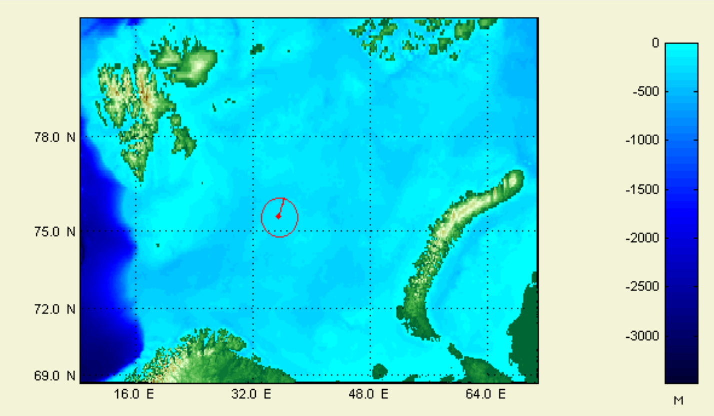


Fig. 4. Map of the study region in the Barents Sea. The red circle denotes the area of modeling, the line inside the circle shows the track, for which TL curves were calculated.

The sound pressure levels were computed for 72 azimuthally oriented tracks (5 degrees between directions of two neighboring tracks). Each track is approximately 70 km long.

Geoacoustic parameters in the study region

Five distributions of sound speed in water were used as input data for sound propagation modeling. Those distributions correspond to May and September 1991, May and September 2010 and distribution of sound speed profile at warming water on 5^{o} C relatively to September 2010 (forecast). The historical data on salinity and temperature of water in the region were obtained from the Arctic Ocean Physics Reanalysis database and used to calculate sound speed profiles. The data on the sea floor acoustic properties were obtained from the ETOPO2 database.

2.1.1 Results of modelling for 1991

Sound velocity profiles in water column and in bottom used at modeling of the sound propagation shown on Fig.5

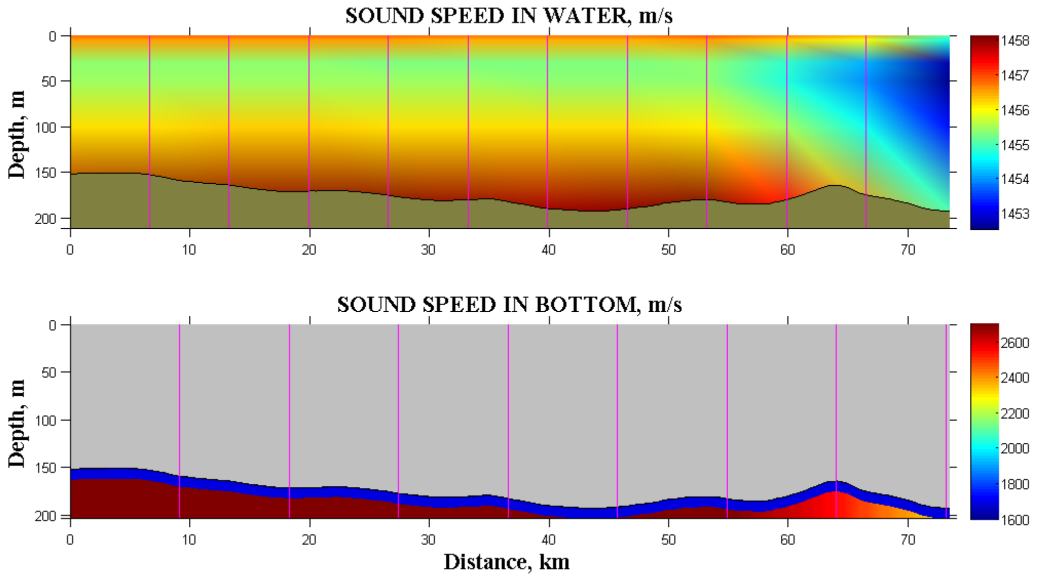


Fig. 5. Example of 2-D distributions of sound speed in water (upper plot) and bottom (lower plot) in May 1991 along a track shown on Fig.4

Examples of modeling for Transmission Loss (TL) of Sound Pressure Level (SPL) of seismic pulse on distance at using 1991 environmental conditions data are shown below. Two-dimensional color plots of SPL rms for the same track in May, 1991 and September, 1991 are shown on Fig.6. These plots seem to be almost similar despite there is some difference in the data. To make it easier to see that difference, sound pressure level curves along the track for fixed depth are shown on Fig. 7 with zoom into the domain around 180 dB level.

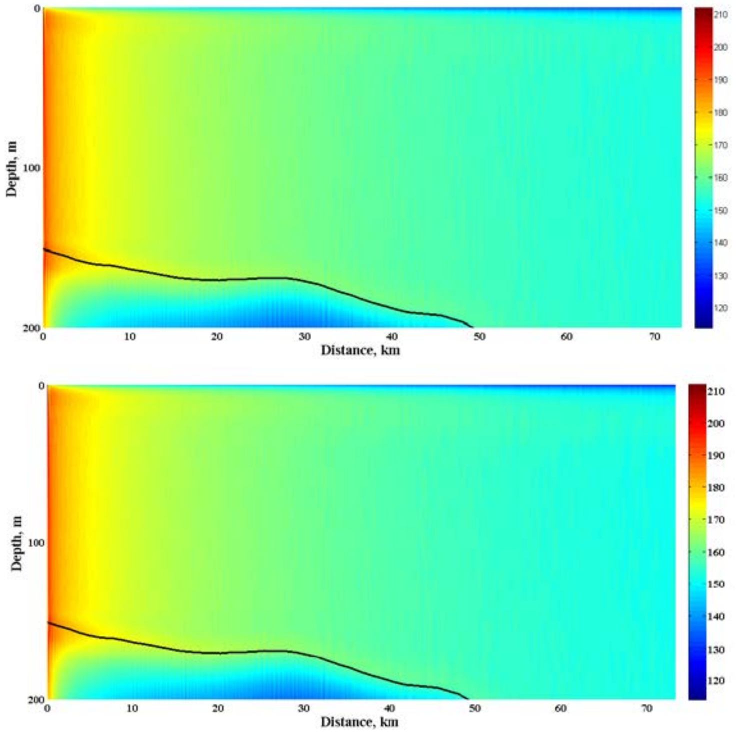


Fig. 6 SPL color plots for one track in May, 1991 (up) and September, 1991 (down).

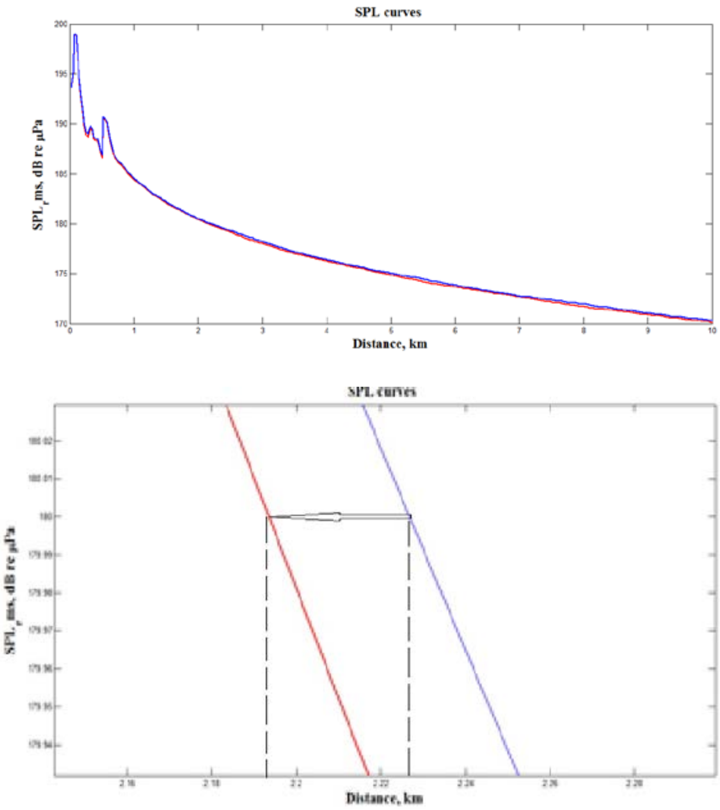


Fig. 7 SPL curves for fixed depth (September 1991 red, May 1991 blue) and a zoom into 180 dB domain (below) illustrating some shift of SPL 180 dB in direction to source

2.1.2 Results of modelling for 2010 and forecast on the future

Examples of two-dimensional distributions of sound speed in water and in bottom along a track (Fig. 4) for 2010 are shown on Fig.8.

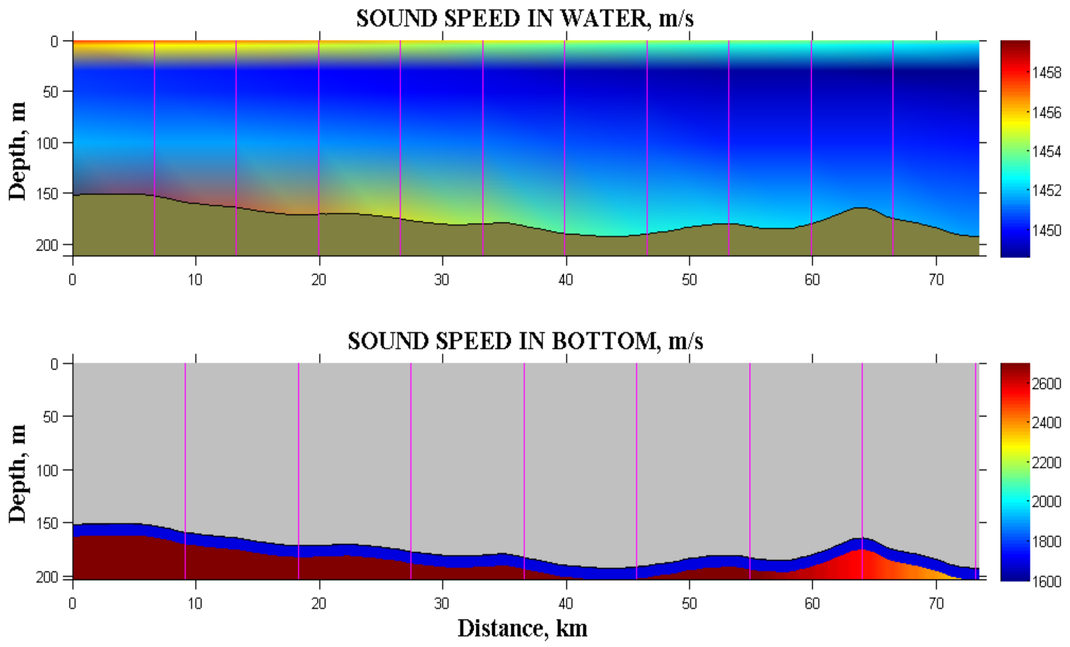


Fig. 8 2-D distributions of sound speed in water (upper plot) and bottom (lower plot) in May 2010 along the track shown on Fig.4.

Seismic source was approximated as Point source. Modeling TL for the year 2010 was based on typical for 2010 profiles of sound speed in Barents Sea and forecast of possible changing for next decade shown on Fig.2. Results modeling TL for the year 2010 (green - May 2010, blue - Sep.2010, red – forecast for Sep. in future) are shown below on Fig.9. Decreasing of sound pressure level on TL curves along the track for fixed depth 100 m are shown on Fig.9 with a zoom (below) into the domain around 180 dB levels.

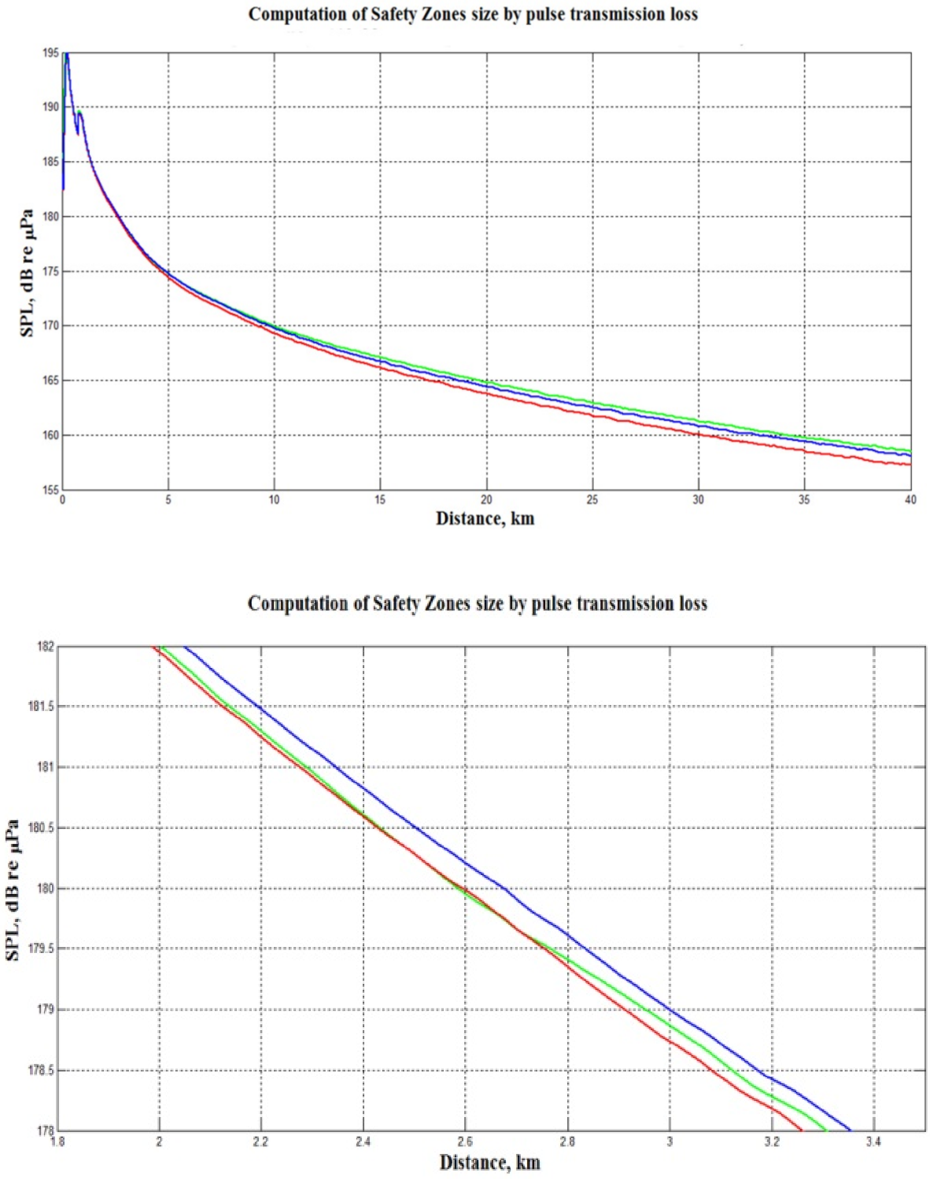


Fig. 9. Transmission Loss curves for fixed depth (September 2010 blue, May 2010 green, forecast for September in future - red) and below a zoom into 180 dB domain.

2.1.3 Preliminary Conclusions about decreasing of size of the Safety Zones at Seismic survey

A preliminary analysis of the model results showed that typically the shift in boundaries of the Injury Safety Zones (level 180 dB) is not significant while the shift of boundaries of the Disturbance Safety Zones (level 160 dB) can be up to several kilometers in the direction of the Seismic Source. A higher temperature in the upper layer of water leads to a decrease in pressure levels at sound propagation due to ray paths bending towards the sea floor enlarging the interaction with the sea-floor and therefore the size of Safety Zones will be decreased.

These results anticipate that the change in the water column temperature in the Arctic region will have consequences in the way sounds propagate, thus demanding that the monitoring and mitigation policies take into account these changes to properly address noise issues and ensure a good environmental status in the region.

2.2 Estimation changing size of the Safety Zones at conducting Deep-water Pile Driving in the Arctic Seas

In this case for estimation changing of size the Safety Zones we investigated propagation impulsive noise from Deep-water Pile driving in Arctic.

Anthropogenic noise emitted during construction of infrastructure for hydrocarbon extraction in the Arctic shelf includes not only continuous sound from various sources but also impulsive sound of diverse origin, such as airgun pulses or sound from impact underwater pile driving. In order to obtain an example of influence of changes in environmental conditions on propagation of this type of sound we modeled transmission loss functions for sound emitted by underwater pile driving.

Input data for acoustical modeling

The source was placed in the same point as the large construction vessel at study of noise propagation from construction activity (73°7.266'N, 43°58.728'E, depth in the point is 338 m) at the depth of 300 meters because Pile driving was as element of the construction process (see below Section 2.3., Fig 13). The environmental data used as input for modeling is the same data set as in the Section 2.3 at investigation of propagation for continuous noise. Most researches show that better results of modeling of the pile driving sound propagation are achieved when the sound source is considered to be a set of points distributed along a vertical line rather than a point source due to oscillations of pressure in the water are excited by vibrations in the whole body of the pile. However, this effect has most influence when the water depth is comparable to the pile’s length, which is the case in most published researches. Deep-water pile driving during hydrocarbon construction in the Arctic presents different conditions as the length of the pile is assumed to be small compared to the water depth. For this reason we used a simple point source model. The equivalent spectrum of the source (Fig. 10) was calculated on the basis of published results of measurements during impact pile driving at an offshore wind farm in the NE Scotland (Bailey, 2010).

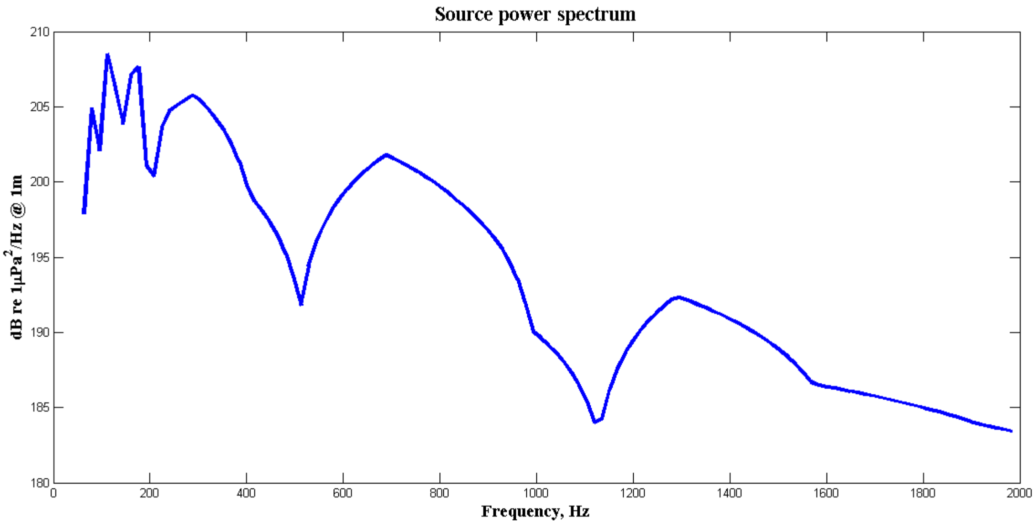


Fig. 10 Point-source spectrum used as input for modeling of pile driving noise propagation.

2.2.1 Results of acoustical modeling for Pile Driving

Examples of modeled received sound pressure levels depending on depth and distance along a track are shown on Fig.11.

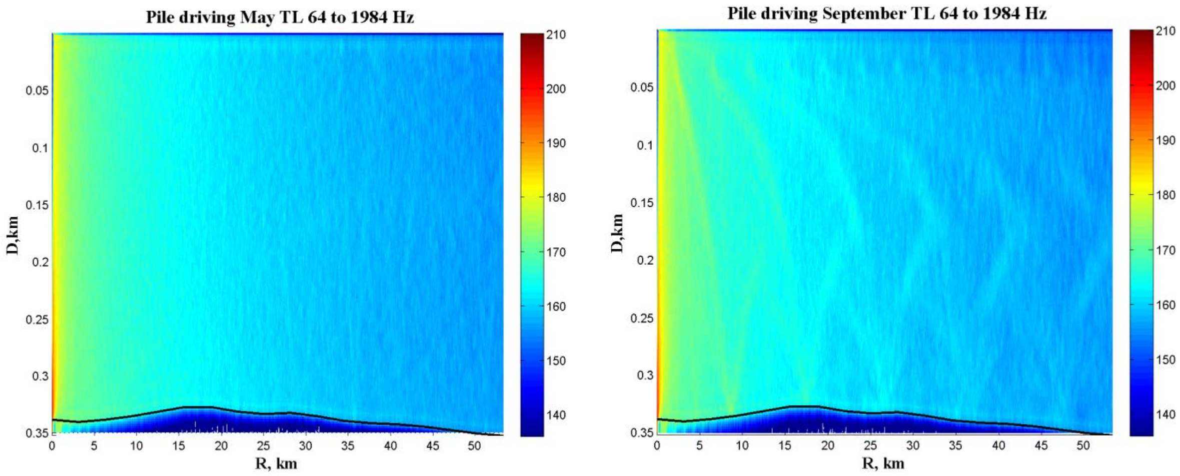


Fig. 11 Received SPL along a track in May (left) and September (right).

Examples of sound pressure levels received at 50 meters depth along a track are shown on Fig.12.

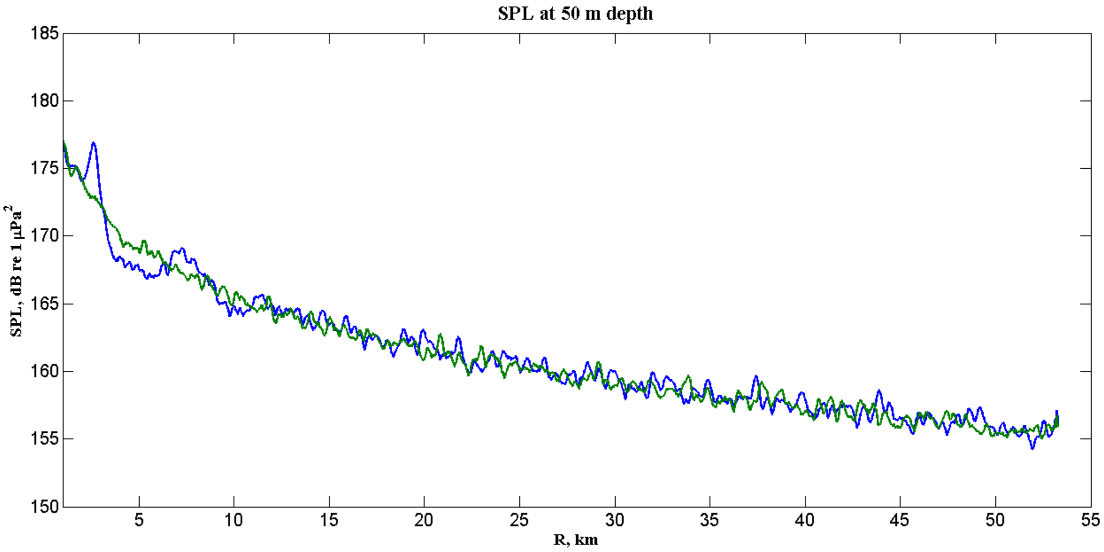


Fig. 12 Modeled SPL along a track at 50m depth in May (green) and September (blue).

As could be seen from Fig.11 and Fig.12, in this case warmer upper layer in general does not lead to better conditions for sound propagation, although inhomogeneities in the distribution of the sound pressure level become more significant and small regions with increased SPL appear.

2.2.2 Preliminary conclusions about changing of size of the Safety Zones at Deep-water Pile driving in Arctic Seas

Acoustical modeling of sound propagation shows that warming in the upper layer of water column leads to significantly higher transmission loss at most depths (which means decrease in the acoustic impact zones) area for continuous noise from shipping. On the other hand, as could be seen from Fig.12, in the case of the sound source located close to the bottom, warming in the upper layer of seawater can lead to emersion of small regions with increased SPL although in general conditions for sound propagation do not improve significantly. So shift of the Safety Zones at Deep-water Pile driving will be small if any.

2.3 Assessment of seasonal changes of the Safety Zones size during hydrocarbon construction in the Arctic seas

Hydrocarbon activities along with the ship traffic are the main sources of manmade noise in the ocean. However, very little information on the noise emitted from E&P industry activities in the Arctic is currently available. We expect increase of the background noise level in the

Russian sector of the Barents Sea in the next decade due to large scale construction planned at the Shtokman project, one of the world's largest natural gas deposits. The location of the Stockman Developments Project is given in Fig. 13. Estimation of the acoustic impact zones for marine mammals during hydrocarbon construction in the Barents Sea was carried out for two typical types of operation which can emit continuous noise. In all cases modeling of sound propagation was performed with use of one-way approximation of the pseudo-differential parabolic equations treating three-dimensional heterogeneities of the environment as a set of two-dimensional approximations, i.e. without taking into account the side refraction (Aviloff , 1992).

2.3.1 Estimation of the Safety Zones for Construction of the Production Units

The stage of construction Production Units (PU) involves three sources of underwater sound - a large construction vessel and two tug vessels to the north and to the south from the construction vessel. Coordinates of the construction vessel’s position are 73°7.266'N, 43°58.728'E. Distance between the construction vessel and each tug vessel is 0.7 nautical miles. Depth at the construction vessel’s location is 338 meters. Modeling of sound propagation for each sound source was carried out for 72 azimuthal tracks (5 degrees between neighboring tracks).

Input data for acoustical modeling

A map of the region is shown on Fig.13. The red circle denotes the area for which modeling of sound propagation was performed; the red dot denotes position of the construction vessel. Fig.14 gives a closer look at bathymetry in the modeling area.

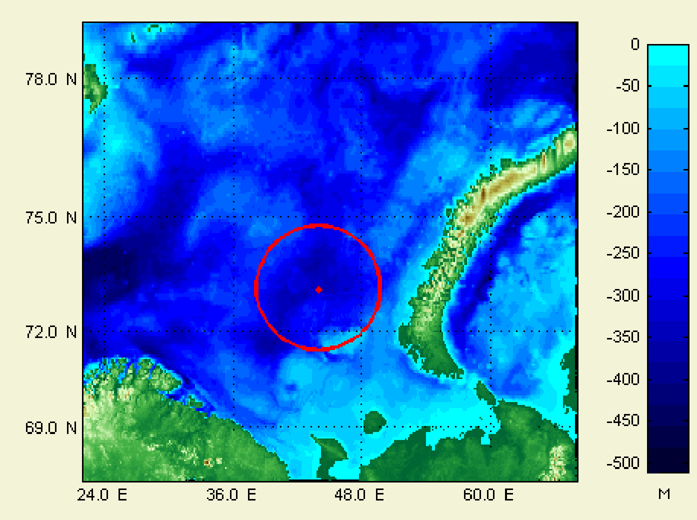


Fig. 13 Map of the region.

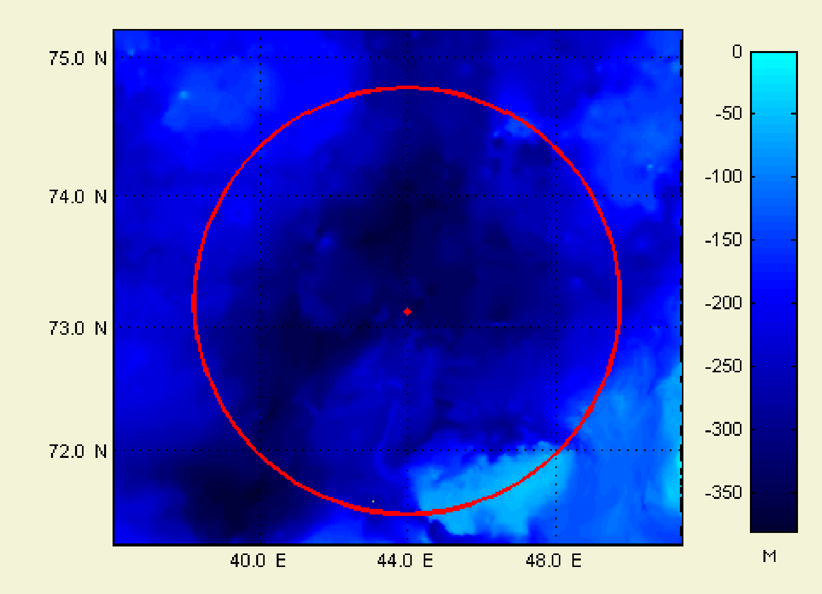
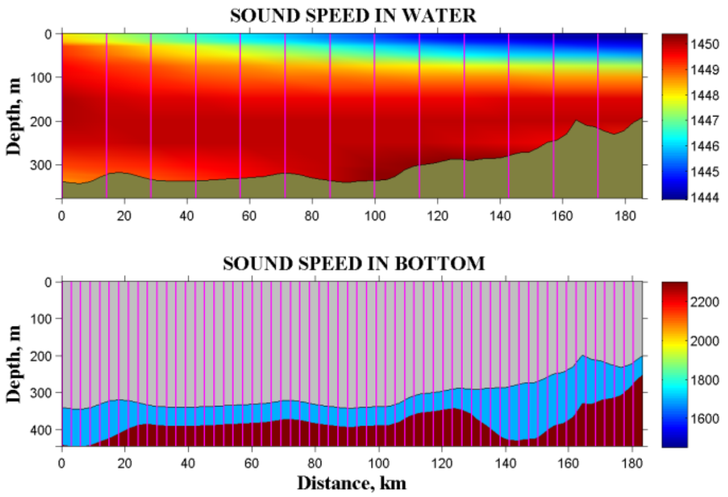


Fig. 14 Bathymetry in the modeling area

Two data sets corresponding to typical environmental conditions in September and May were used as input for modeling. The data sets include three-dimensional fields of temperature, salinity and the pH parameter in water layers, two-dimensional bottom relief (see Fig.14), three-dimensional field of density for unconsolidated sediment layers and rocky seafloors and velocity of compressional waves in the seafloor. The bottom configuration was taken from the Etopo1 database (Amante and Eakins, 2009). Sound speed profiles were calculated using the Chen-Millero formula (Chen and Millero, 1977) from data on temperature and salinity obtained from the Atlas (Monterey and Levitus, 1997). Examples of sound speed distributions along azimuthal tracks are shown on Fig.15.

a)



b)

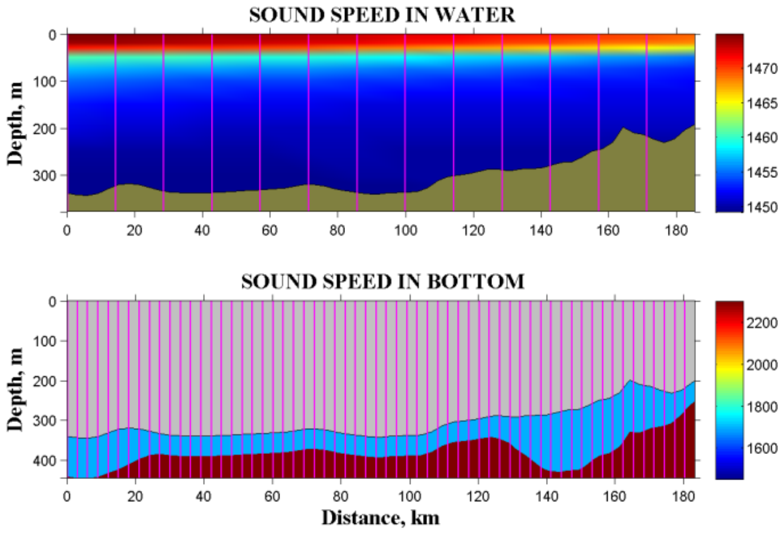


Fig. 15 Distribution of sound speed in water and bottom for a track in May - a) and September- b).

Data on spectral characteristics of equivalent point sources for vessels was taken from Reports related to platform construction off Sakhalin Island during the Sakhalin 2 project. Power spectral density functions for tug vessels were calculated with an algorithm for constructing piecewise integral splines from measured 1/3-octave sound pressure levels of the «Stril Commander» tug vessel at full speed. This vessel was chosen due to very high level of noise, arguably one of the highest among published data, which is in line with the scale and complexity of projects related to hydrocarbon construction in the Arctic.

Fig.16 Ship “Deep Blue” and towboat “Strill Commander”

Due to lack of published data on spectral characteristics of sound emitted by large construction vessels at different operation modes, the same spectrum amplified by the factor of 5 dB was used as an equivalent point-source spectrum for the construction vessel. Power spectral density function of the noise emitted by the tug vessel is shown in Fig.17. Sound propagation modeling was carried out for the band from 32 to 508 Hz with 4 Hz step. Source level of the tug vessel in this band is 192 dB re 1 μPa at 1 meter. Depth of the equivalent point source was set to 6 meters for the large construction vessel and to 4 meters for tug vessels.

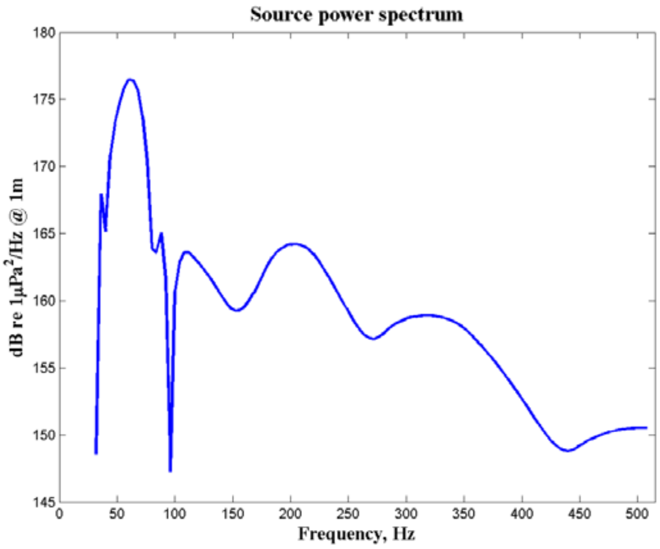


Fig. 17 Equivalent point-source spectrum of the tug vessel used as input for modeling.

2.3. 2 Noise footprints for Safety Zone at construction Production Units in cold (May) and warm (September) season

Examples of noise footprints for estimation of acoustic impact zones for marine mammals are shown on Fig.18. By black circular line show the boundary of Safety Zone at SPL level equal to 120 dB. Power function of received signal at fixed depth from each source was smoothed along azimuthal tracks with a moving average and interpolated to a rectangular grid covering the area. Radius and azimuth of a point in the grid are equal to the great-circle distance from the origin (large construction vessel's position) and the azimuth of that great circle. At every point of the grid interpolated powers of signal from each source were summed as the sound sources are assumed to be incoherent.

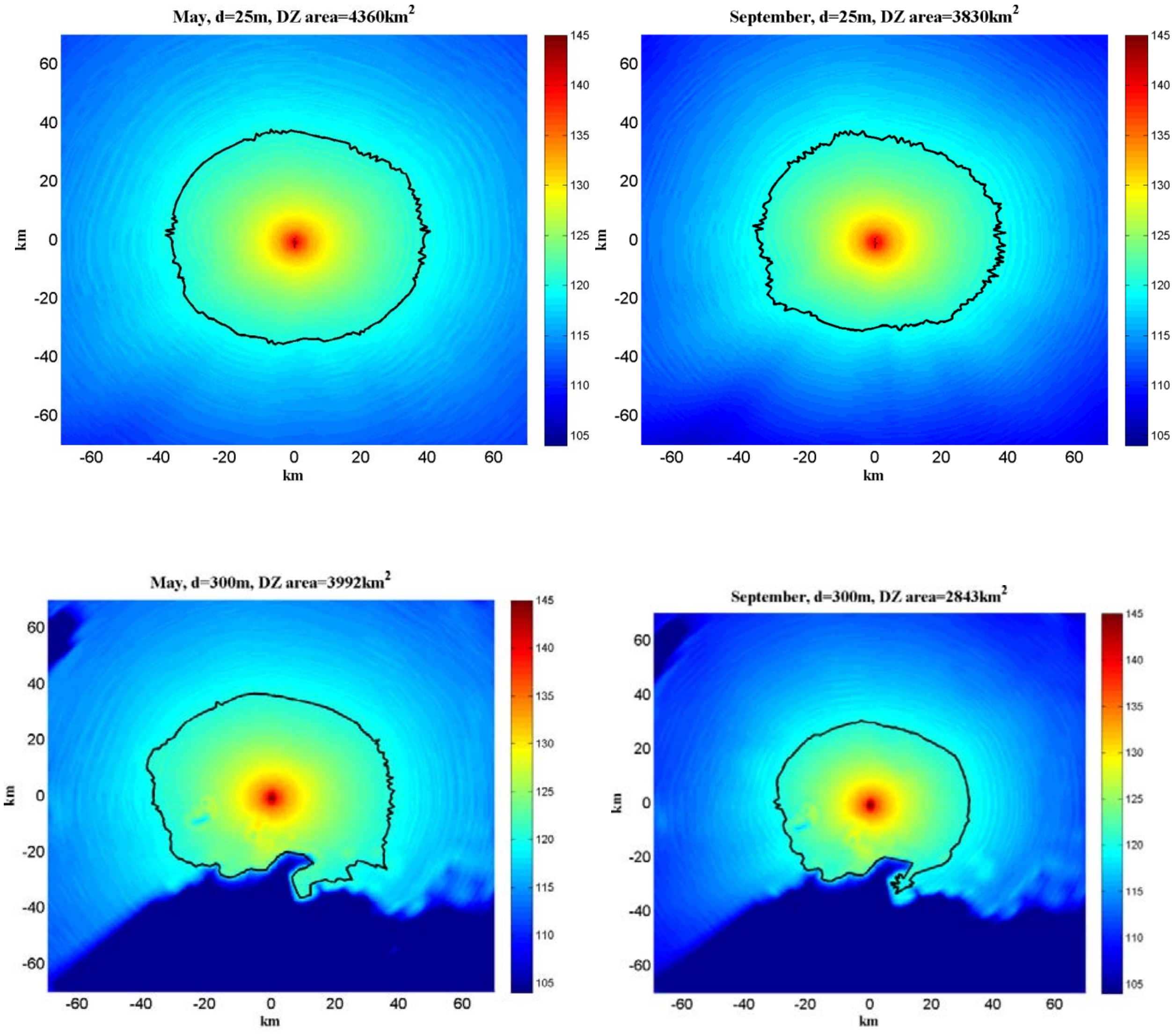


Fig. 18 Examples of noise footprints and boundary of Safety Zone at SPL level equal to 120 dB in May (left) and September (right) at depth 25 m (up) and 300 m (down)

On Fig.18 we can see that square of "behavioral" EZ (with noise levels exceeding 120 dB) decrease from value in May ($S_{120\ \mathrm{dB}}$ = 4360 km^2) to be in September ($S_{120\ \mathrm{dB}}$ = 3830 km^2) on depth 25 m and decrease from May ($S_{120\ \mathrm{dB}}$ = 3392 km^2) to be in September ($S_{120\ \mathrm{dB}}$ = 2843 km^2) on depth 300 m.

Examples of modeled received sound pressure levels depending on depth and distance along a track are shown on Fig.19.

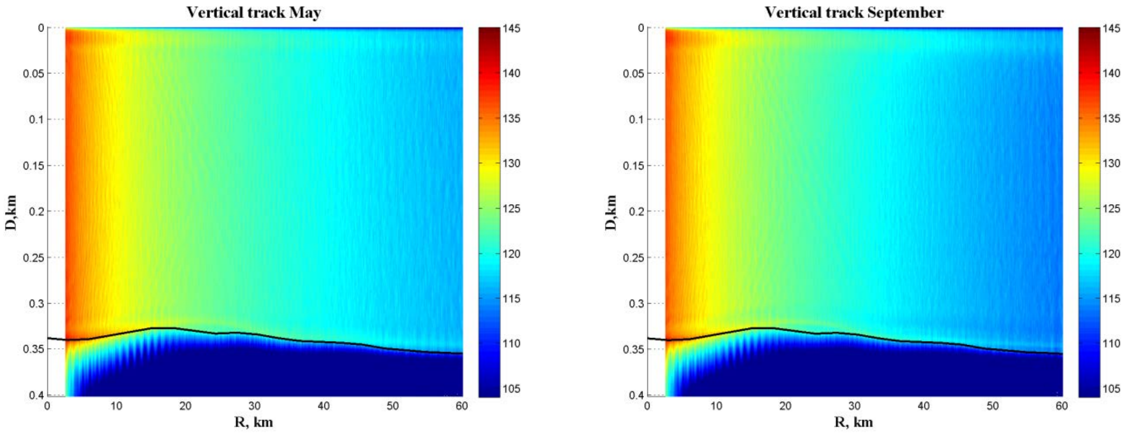


Fig. 19 Received SPL along a track in May (left) and September (right).

Examples of sound pressure levels for continuous noise from construction calculated at particular depth 50 m along a track are shown below.

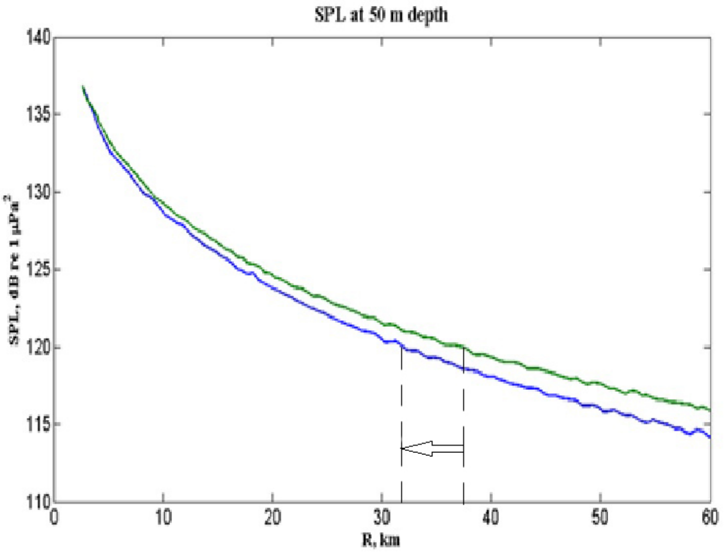


Fig. 20 Received SPL along a track at 50m depth in May (green) and September (blue).

On Fig. 20 we can see shifting boundary of Safety Zone (EZ) on level SPL 120 dB (from May to September) in direction to source about 6 km that means decreasing of EZ in warm season.

2.3.3 Estimation of the Safety Zones for Pipeline Construction

This stage of construction involves two sources of underwater sound – a construction vessel and a tug vessel. Distance between vessels is 33.5 km, azimuth angle of direction from construction vessel to the tug vessel is 260°. Coordinates of the construction vessel's position are 69° 45' N, 36° 39' E. Depth at the construction vessel's location is 136 meters. Modeling of sound propagation for each sound source was carried out for 72 azimuthal tracks (5 degrees between neighboring tracks), as in the case of modeling for PU operation mode.

Input data for acoustical modeling

A map of the region is shown on Fig.21. The red circle denotes the area for which modeling of sound propagation was performed, red dots denote positions of vessels. A closer look at bathymetry in the modeling area is given in Fig.22.

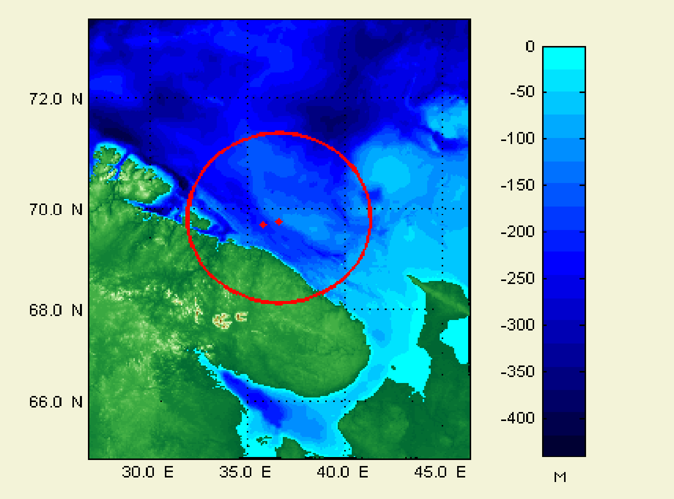


Fig. 21 Map of the region.

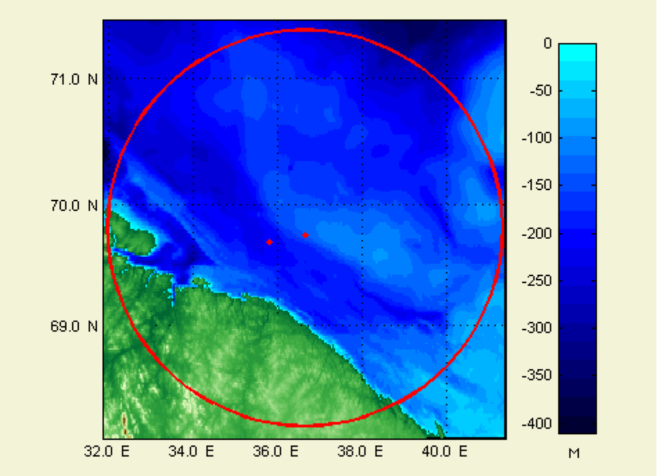


Fig. 22 Bathymetry in the modeling area.

As in case of modeling for PU construction, environmental data sets corresponding to typical conditions in September and May were used as input for modeling. The input data includes the same parameters and were obtained from the same sources as in case of modeling for PU construction . Examples of sound speed distributions along azimuthal tracks are shown on Fig.23.

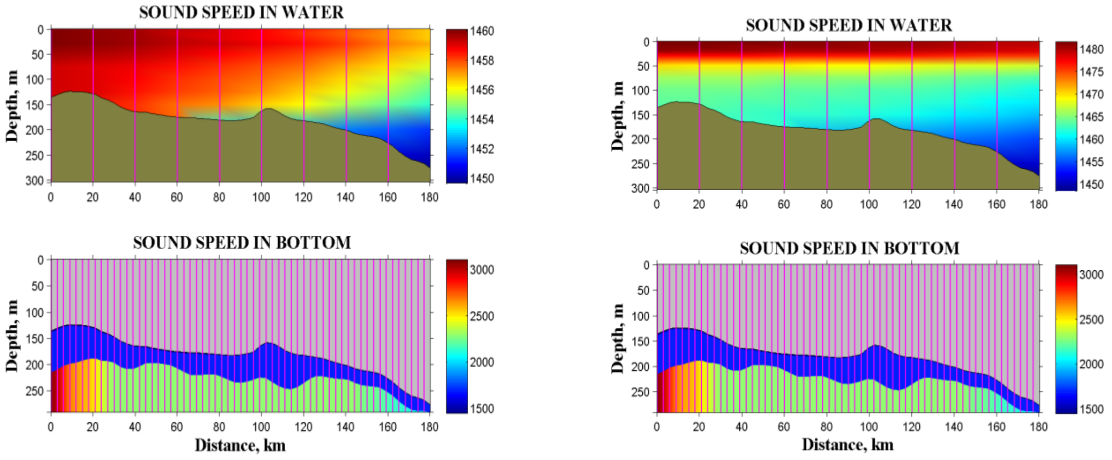
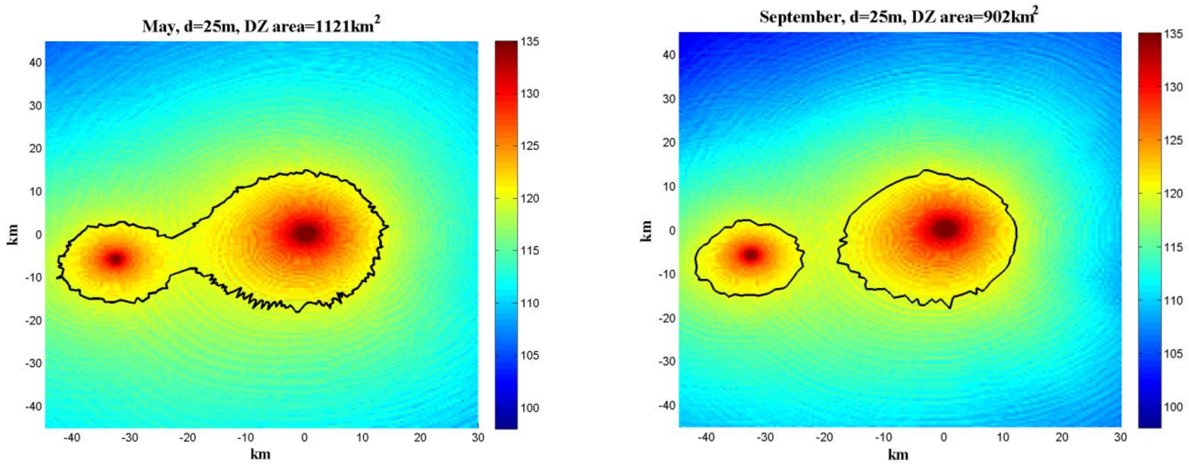


Fig. 23 Distribution of sound speed in water and bottom for a track in May (left) and September (right).

The equivalent point-source spectrum for construction vessel in pipeline construction mode was the same as the tug vessel spectrum in case of PU construction, and the spectrum of tug vessel was reduced by 5 dB.

Results of acoustical modeling for cold (May) and warm (September) season

Examples of noise footprints for estimation of acoustic impact zones for marine mammals are shown on Fig.24. Interpolation and energy summation procedure is the same as in case of modeling for PU construction.



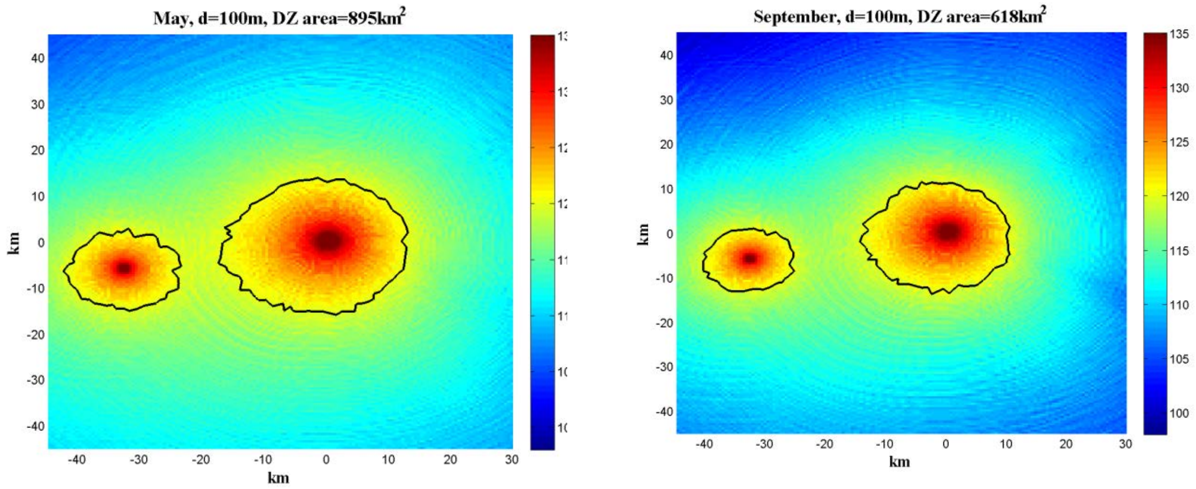


Fig. 24 Examples of noise footprints and boundary of Safety Zone at SPL level equal to 120 dB in May (left) and September (right) at depth 25 m (up)and 100 m (down)

On Fig.24 we can see that square of Disturbance Safety Zone, EZ_{120dB} at Pipeline Construction, the same like at stage of construction Production Units decrease from value in May ($S_{120\ dB}$ = 1121 km^2) to be in September ($S_{120\ dB}$ = 902 km^2) on depth 25 m and decrease from May ($S_{120\ dB}$ = 895 km^2) to be in September ($S_{120\ dB}$ = 618 km^2) on depth 100 m.

2.3.4 Conclusions about seasonal decreasing of size of the Safety Zones during hydrocarbon construction

Calculation made by SIO for continuous noise (shipping noise at Shtokman construction) supports conclusion about decreasing size of the Safety Zones for impulsive noise (at Seismic survey and Pile driving). Results the same - square of acoustic Impact zone (120 dB) from source of continuous noise becomes less from May to September according with increasing temperature during summer season.

2.4 Conclusions about changing of the Safety Zones size depending on warming in ocean

- Defining Safety Zones (EZ) for marine mammal is a fundamental component of the real-time mitigation measures used during industrial activities in Seas. However, the basis for defining exclusion zones remains unclear in most cases. Since clear criteria for “injury” are still waiting to be established and still need time to research on behavioral responses, still remain in wide practice the recommendations for the noise threshold proposed by HESS in 1999. The NMFS and others continue to use the 180-dB (SPL rms) criterion for predicting injury from acoustic exposure for cetaceans and 190-dB RL for pinnipeds as well as a behavioral impact level of 160-dB RL for pulsed noise, and 120-dB SPL rms criterion non impulsive, “continuous” industrial noises.

- The size of Safety Zones for marine mammals exposed to anthropogenic noise depends on hearing protected species (functional hearing groups of pinnipeds and cetaceans), used Noise Exposure Criteria (permitted thresholds for SPL rms or SPLpeak and SEL metrics), type of noise (impulsive or non - impulsive, continuous) and conditions for sound propagation in marine environment - seasonal variability and possible warming of upper layers of water due to climate change.
- Analysis of the model results for propagation pulsed noise originated by Seismic Survey in Arctic shown that typically the shift in boundaries of the Injury Safety Zones (level 180 dB) is not significant while the shift of boundaries of the Disturbance Safety Zones (level 160 dB) can be up to several kilometers in the direction of the Seismic Source. A higher temperature in the upper layer of water leads to a decrease in pressure levels at sound propagation due to ray paths bending towards the sea floor enlarging the interaction with the sea-floor and therefore the size of Safety Zones will be decreased.
- Acoustical modeling of sound propagation of the noise originated by Deep-water Pile driving (near bottom at 300 m depth) shown that shift of the Safety Zones will be small if any. In this case warmer upper layer in general does not lead to better conditions for sound propagation.
- Acoustical modeling for sound propagation of the noise originated by hydrocarbon construction on Arctic shelf shows that warming in the upper layer of water column leads to significantly higher transmission loss at most depths which means decrease in size of the acoustic impact zones area (120 dB) for continuous noise at hydrocarbon construction (e.g., platforms, pipeline construction or vibratory pile driving or drilling)
- Investigation of tendency in changing size of the Safety Zones around sources of industrial noise in Arctic area show some beneficial effect for marine mammals in future if Arctic Seas will get warm.

Literature

Aviloff C.V. (1992) An Effective Numerical Solution of Guided Waves Equations, Second French Conference on Acoustics, Journal de Physique IV, Colloque C1, Supplement au Journal de Physique III, no. 4, Avril 1992, vol. 2, pp. C1-1023 – C1-1026.

Amante, C. and B. W. Eakins (2009) ETOPO1 1 Arc-Minute Global Relief Model: Procedures, Data Sources and Analysis. NOAA Technical Memorandum NESDIS NGDC-24, 19 pp, March 2009. http://www.ngdc.noaa.gov/mgg/global/global.htm

Bailey H.*et al.*, (2010) Assessing underwater noise levels during pile-driving at an offshore windfarm and its potential effects on marine mammals, Marine Pollution Bulletin (60) 2010 888-897.

Clark, C. W., Ellison, W. T., Southall, B. L., Hatch, L., Van Parijs, S. M., Frankel, A., & Ponirakis, D. (2009). Acoustic masking in marine ecosystems: Intuitions, analysis, and implication. Marine Ecology Progress Series, 395, 201-222. http://dx.doi.org/10.3354/meps08402

Chen C.-T. and Millero F. J. (1977) ''Speed of sound in seawater at high pressures,'' J. Acoust. Soc. Am. 62, 1129–1135.

Collins M.D. (1993) A split-step Pade solution for parabolic equation method, J. Acoust. Soc. Am., V. 93, pp. 1736-1742, 1993.

DIRECTIVE 2008/56/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive)

DIRECTIVE 2014/52/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 April 2014 amending Directive 2011/92/EU on the assessment of the effects of certain public and private projects on the environment

Dolman S. J., Weir C. R. Jasny M., (2009) Comparative review of marine mammal guidance implemented during naval exercises. Marine Pollution Bulletin 58 (2009) 465–477

Ellison, W. T., Southall, B. L., Clark, C. W., & Frankel, A. S. (2012). A new context-based approach to assess marine mammal behavioral responses to anthropogenic sounds. Conservation Biology, 26(1), 21-28. http://dx.doi.org/10.1111/j.1523-1739.2011.01803.x

Jensen, F. B., Kuperman, W. A., Porter, M. B., & Schmidt, H. (2011). Computational ocean acoustics (2nd ed.). New York: Springer

Joint Nature Conservation Committee JNCC, (1998) Guidelines for Minimizing Acoustic Disturbance to Marine Mammals from Seismic Surveys. Joint Nature Conservation Committee, Peterborough, UK.

Joint Nature Conservation Committee (JNCC). (2010). JNCC guidelines for minimizing the risk of injury and disturbance to marine mammals from seismic surveys. Aberdeen, Scotland: JNCC. 16 pp.

High Energy Seismic Survey (HESS) Team. (Ed.). (1999). High Energy Seismic Survey (HESS) review process and interim operational guidelines for marine surveys offshore southern California. Camarillo: California State Lands Commission and U.S. Minerals Management Service.

McCrodan, A. and Hannay, D. 2013. Modelling of Underwater Noise for Pacific NorthWest LNG Marine Construction and Shipping Scenarios Marine Construction and Shipping Scenarios. JASCO Document 00669, Version 2.14. Technical report by JASCO Applied Sciences.

Malme, C., Würsig, B., Bird, J. E., & Tyack, P. L. (1986). Behavioral responses of gray whales to industrial noise: Feeding observations and predictive modelling. Washington, DC: National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

Malme, C., Würsig, B., Bird, J. E., & Tyack, P. L. (1988). Observations of feeding gray whale responses to controlled industrial noise exposure. In W. M. Sackinger, M. O. Jefferies, J. L. Imm, & S. D. Treacy (Eds.), Port and ocean engineering under Arctic conditions (pp. 55-73). Fairbanks: University of Alaska.

Malme, C. I., Miles, P. R., Clark, C. W., Tyack, P. L., & Bird, J. E. (1983a). Investigations of the potential effects of underwater noise from petroleum industry activities on migrating gray whale behavior. Washington, DC: U.S. Department of the Interior, Minerals Management Service.

Malme, C. I., Miles, P. R., Clark, C. W., Tyack, P. L., & Bird, J. E. (1983b). Investigations of the potential effects of underwater noise from petroleum industry activities on migrating gray whale behavior. Washington, DC: U.S. Department of the Interior, Minerals Management Service. 63 pp.

Malme, C. I., Miles, P. R., Clark, C. W., Tyack, P. L., & Bird, J. E. (1984). Investigations of the potential effects of underwater noise from petroleum industry activities on migrating gray whale behavior. Phase II: January 1984 migration. Washington, DC: U.S. Department of the Interior, Minerals Management Service.

Monterey, G. I., and S. Levitus (1997) Climatological cycle of mixed layer depth in the world ocean. U.S. Gov. Printing Office, NOAA NESDIS, 5pp. NODC_WOA94 data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/data/gridded/data.nodc.woa94.html

[NOAA] National Oceanic and Atmospheric Administration. 2013a. NOAA's Marine Mammal Acoustic Guidelines (webpage). National Oceanic and Atmospheric Administration.http://www.nmfs.noaa.gov/pr/acoustics/guidelines.htm (Accessed July 14, 2013).

[NOAA] National Oceanic and Atmospheric Administration. 2013b. Interim Sound Threshold Guidance (webpage). National Oceanic and Atmospheric Administration.http://www.westcoast.fisheries.noaa.gov/protected_species/marine_mammals/threshold_guidance.html

Nowacek, D. P., Thorne, L. H., Johnston, D. W., & Tyack, P. L. (2007). Responses of cetaceans to anthropogenic noise: An update and review of behavioural and some physiological effects. Mammal Review, 37, 81-115. http://dx.doi.org/10.1111/j.1365-2907.2007.00104.x

Nowacek, D. P., Vedenev, A., Southall, B. L., & Racca, R. (2012). Development and implementation of criteria for exposure of western gray whales to oil and gas industry noise. Advances in Experimental Medicine and Biology, 730, 523-528. http://dx.doi.org/10.1007/978-1-4419-7311-5_119

Nowacek D. P., Broker K., Donovan G., Gailey G., Racca R.,. Reeves R. R, Vedenev A. I.,. Weller D. W, and Southall B. L. (2013),“ Responsible Practices for Minimizing and Monitoring Environmental Impacts of Marine Seismic Surveys with an Emphasis on Marine Mammals”, Aquatic Mammals, 39(4), pp. 356-377

Nieukirk, S. L., Mellinger, D. K., Moore, S. E., Klinck, K., Dziak, R. P., & Goslin, J. (2012). Sounds from airguns and fin whales recorded in the mid-Atlantic Ocean, 1999-2009 (Research Support, Non-U.S. Gov’t Research Support, U.S. Gov’t, Non-P.H.S.). The Journal of the Acoustical Society of America, 131(2), 1102-1112. http://dx.doi.org/10.1121/1.3672648

National Oceanic and Atmospheric Administration (NOAA). (1998). Incidental taking of marine mammals: Acoustic harassment. Federal Register, 63(143), 40103.

NRC, National Research Council, (2003). Effects of Noise on Marine Mammals. In Ocean Noise and Marine Mammals. National Academies Press, Washington DC. pp. 83– 108.

NRC, National Research Council. (2005). Marine mammal populations and ocean noise: Determining when noise causes biologically significant effects. Washington, DC: National Academy of Sciences.

New Zealand Department of Conservation. (2012). 2012 code of conduct for minimising acoustic disturbance to marine mammals from seismic survey operations. Wellington, NZ: Department of Conservation.

European Union Environmental Assessment, http://ec.europa.eu/environment/eia/home.htm;

Richardson, W. J., Würsig, B., & Greene, C. R., Jr. (1986). Reactions of bowhead whales, Balaena mysticetus, to seismic exploration in the Canadian Beaufort Sea. The Journal of the Acoustical Society of America, 79(4), 1117-1128. http://dx.doi.org/10.1121/1.393384

Madsen, P. T., Johnson, M., Miller, P. J. O., Soto, N. A., Lynch, J., & Tyack, P. L. (2006). Quantitative measures of air-gun pulses recorded on sperm whales (Physeter macrocephalus) using acoustic tags during controlled exposure experiments. The Journal of the Acoustical Society of America, 120(4), 2366-2379. http://dx.doi.org/10.1121/1.2229287

Porter, M. B. (1993). Acoustic models and sonar systems. IEEE Journal of Oceanic Engineering, 18(4), 425-437. http://dx.doi.org/10.1109/48.262293

Richardson W. J. et al. (1995). MARINE MAMMALS AND NOISE.

Southall, B. L., Bowles, A. E., Ellison, W. T., Finneran, J. J., Gentry, R. L., Greene, C. R., Jr… Tyack, P. L. (2007). Marine mammal noise exposure criteria: Initial scientific recommendations. Aquatic Mammals, 33(4), 411-521. http://dx.doi.org/10.1578/AM.33.4.2007.411

Sakhalin Energy Investment Company, (SEIC, 2010). Environmental impact MPACT assessment of Sakhalin Energy Investment Company's 3-D seismic programme in the Piltun-Astokh Area, Sakhalin Island, Russia. Yuzhno-Sakhalinsk, Russia.

Vedenev, A. I. Nowacek, D. (2009), Development and application of noise exposure criteria for gray whale monitoring off Sakhalin Island, Russia. Proceeding of the 23 European Cetacean Society Conference, Istanbul, Turkey

Vedenev A. I., Avilov K., Shavykin A., (2012),"Assessment of zones of the acoustic impact on the arctic marine mammals at industrial activity in Barents Sea", Proceeding of the 26th, Edited by: Barry McGovern, Simon Berrow, Enda McKeogh, Ian O'Connor, 26th-28th March, Galway Ireland

Van der Graaf AJ, Ainslie MA, André M, Brensing K, Dalen J, Dekeling RPA, Robinson S, Tasker ML, Thomsen F, Werner S (2012). European Marine Strategy Framework Directive - Good Environmental Status (MSFD GES): Report of the Technical Subgroup on Underwater noise and other forms of energy.

Weir, C. R., & Dolman, S. J. (2007). Comparative review of the regional marine mammal mitigation guidelines implemented during industrial seismic surveys, and guidance towards a worldwide standard. Journal of International Wildlife Law & Policy, 10(1), 1-27. http://dx.doi.org/10.1080/13880290701229838

Wright, A.J. (2014). Reducing Impacts of Human Ocean Noise on Cetaceans: Knowledge Gap Analysis and Recommendations. WWF Global Arctic Programme, Ottawa, Canada

US MMPA (U.S. Marine Mammal Protection Act) of 1972. As amended. As amended 2007 NOAA's National Marine Fisheries Service 1315 East-West Highway Silver Spring, MD 20910