A comparison of Environmental Impact Statement methodologies for assessing sound propagation, density determination and impacts on protected marine mammals: BOEMRE & the U.S. Navy

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ABSTRACT

Sound in the world oceans is an increasingly important conservation issue as human impact throughout the oceans continues to grow without signs of abatement. Deep-water background noise is reported to be doubling every decade. In the U.S. two major sources of underwater sound are the seismic industry (regulated by the Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE)) and Naval sonar. Both of these agencies are required to follow national environmental protocols, such as the National Environmental Policy Act, (NEPA) in regard to their impacts on the environment. These two sound sources produced (or regulated) by two different agencies generate similar impacts to the marine environment, in particular protected marine mammals that rely on sound for survival.

The assessment techniques used, and the transparency of the agencies involved is highly in question for actions that produce similar impacts. This master's project analyzes the assessment techniques of BOEMRE and the U.S. Navy concerning underwater sound, exposing the inadequacies and successes of each agency. The analysis was conducted by reading and comparing the techniques used in Environmental Assessments (EA) and Environmental Impact Statements (EIS) produced by both agencies from 2004 to the present. A series of recommendations for both agencies was produced to address the need for more streamlined and transparent analyses that will aid in more accurate and dynamic impact determinations for such projects as the upcoming BOEMRE Programmatic EIS in the Atlantic Planning Region.

I have also developed a GIS-based tool that aids in spatial analysis of propagating sound within the marine environment to improve analysis of potential impacts. This tool allows acoustic propagation models run in the computational program MATLAB® to be imported and integrated in the GIS program ArcGIS ® through the Python scripting language. The integration of this propagation data into GIS allows for better visualizations of sound propagation in 360° around the source and from an aerial perspective. It also allows for further geospatial analysis with other geospatial data such as habitat suitability and species distribution, which can allow for more adaptive species impact determinations and adaptive management for both sonar and seismic survey situations.

ACRONYMS

AFAST: Atlantic Fleet Active Sonar Training
AIM: Acoustic Integration Model
ARBO: Arctic Region Biological Opinion
BO: Biological Opinion
BOEMRE: Bureau of Ocean Energy Management, Regulation and Enforcement
BWASP: Bowhead Whale Aerial Survey Project
c: Sound speed
CEQ: Center on Environmental Quality
CREEM: Center for Research into Ecological and Environmental Modeling
dB: decibel
DEIS: Draft Environmental Impact Statement
DoD: Department of Defense
DSM: Density Surface Models
EA: Environmental Assessment
EEZ: Exclusive Economic Zone
EIS: Environmental Impact Statement
EL: Energy Flux Density Level
ESA: Endangered Species Act
ESME: Effects of Sound on the Marine Environment
FEIS: Final Environmental Impact Statement
FONSI: Finding Of No Significant Impact
FPEA: Final Programmatic Environmental Assessment
FPEIS: Programmatic Environmental Impact Statement
GIS: Geographic Information Systems
GoM: Gulf of Mexico
HFA: High Frequency Active Sonar
HFBL: High Frequency Bottom Loss
HRC: Hawaii Range Complex
Hz: Hertz
IDW: Inverse distance Weighted
IHA: Incidental Harassment Authorization
LFA: Low Frequency Active Sonar
LOA: Letter of Authorization
MFA: Mid Frequency Active Sonar
MMPA: Marine Mammal Protection Act
MMS: Minerals Management Service
NEPA: National Environmental Policy Act
NGDC: National Geophysical Data Center
NMFS: National Marine Fisheries Service
NMML: National Marine Mammal Laboratory
NOAA: National Oceanic and Atmospheric Administration
NODC: National Oceanographic Data Center
NODE: Navy OPAREA Density Estimates

NWFSC: Northwest Fisheries Science Center
ONR: Office of Naval Research
OPAREA: Operation Area
P: pressure
P_0: reference pressure
PE: Parabolic Equation
PEA: Programmatic Environmental Assessment
PEIS: Programmatic Environmental Impact Statement
PTS: Permanent Threshold Shift
RAM: Range-dependent Acoustic Model
S: Salinity
SERDP: Strategic Environmental Research and Development Program
SL: Sound level
SOCAL: Southern California Range Complex
SPL: sound pressure level
SVP: sound velocity profile
SWFSC: Southwest Fisheries Science Center
T: Temperature
TL: Transmission Loss
TTS: Temporary Threshold Shift
USFWS: U.S. Fish & Wildlife Service
WAZ: Wide Azimuth Survey
WHOI: Woods Hole Oceanographic Institution
z: depth
ZOI: Zones of Influence

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Analysis of BOEMRE & Navy NEPA documents– Species Density, Acoustic propagation, and Impact Assessment

1. INTRODUCTION

Sound in the world oceans is an increasingly important conservation issue as human impact throughout the oceans continues to grow without signs of abatement. Deep-water background noise is reported to be increasing 3-5dB re 1μPa rms per decade (Jasney *et al.* 2005; McDonald *et al.* 2006). This is essentially a doubling of noise every 10 years. Within the marine environment there are two forms of sound being produced; natural and human generated (anthropogenic) (Richardson *et al.* 1995). Natural sources consist of ice, rain, wind, waves, natural seismic activity such as earthquakes, and noise made by animals. (Richardson *et al.* 1995) Anthropogenic sound sources consist of commercial shipping traffic, recreational boating, scientific and Navy sonar, explosives, underwater construction, and multiple aspects of the oil and gas industry (drilling, support vessels and seismic exploration). (Richardson *et al.* 1995; Jasney *et al.* 2005) With all these sources of noise in the water column it goes without saying that the ocean is a noisy place. Considering that the natural sources of sound have been present for much longer than the newly introduced anthropogenic sources, it is these latter sound inputs that are causing the 3-5dB re 1μPa rms increase and are of the greatest concern in today's environmental climate (Figure 1).

When looking at the anthropogenic sources in U.S. waters, there are some that are of greater concern when it comes to the impacts that sound has on marine animals (in particular protected marine mammals). These are seismic exploration used in the oil & gas industry and

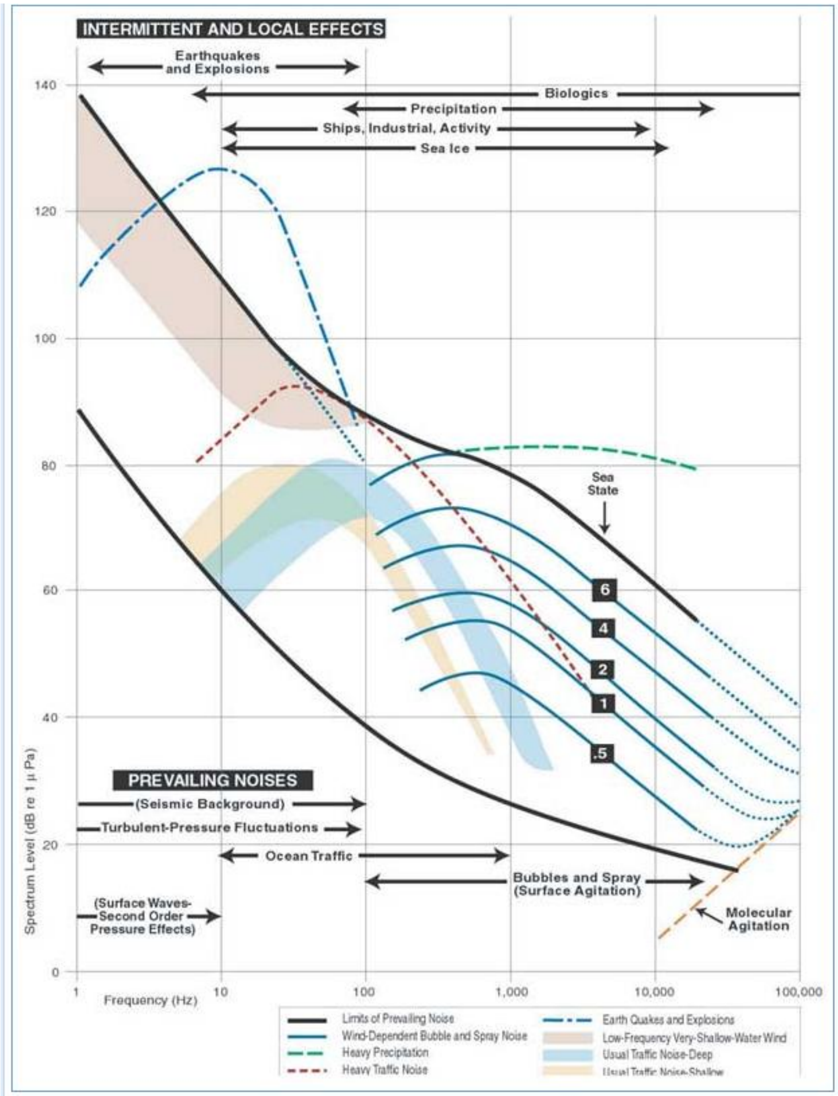


Figure 1. Wenz curves displaying the spectral levels of ambient noise in the marine system. This compasses noise created by natural sources and manmade sources. This set of curves from the National research Council 2003 as adapted from Wenz 1962.

sonar used by the U.S. Navy. Both of these sources of sound are important in today's world, however their use is continuously increasing and this level activity of raises questions about what the immediate and cumulative impacts on marine animals may be. While there are other anthropogenic sources that are also increasing in usage and adding to background noise, such as commercial shipping; seismic exploration and sonar are more focused sources with pre-determined study areas, and are operated within U.S. waters, making them somewhat more tractable from a management standpoint.

Seismic exploration and Navy sonar are both activities permitted or carried out by major U.S. agencies. The seismic industry is controlled by the Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE), and Navy sonar is controlled by the Department of

Defense (DoD). According to U.S. national environmental policy both of these agencies are responsible for understanding and addressing the potential environmental impacts of their particular federal activities. Under National Environmental Policy Act (NEPA), the Marine Mammal Protection Act (MMPA) and the Endangered Species Act (ESA) these "action agencies" must comply with specific standards. However, there appears to be a serious disjoint between the two agencies that are producing similar acoustic impacts to protected marine mammals, how they are addressing those issues in their NEPA documents and the accountability those agencies are then held to by NMFS (the major regulatory agency) and the public.

It is the goal of this paper to address the issue of inconsistency within the NEPA documents of these federal agencies, bring to light the fact that one agency (U.S. Navy) appears to be going above and beyond the requirements, while the other (BOEMRE) lags in its assessments and willingness to research and incorporate more accurate and effective assessment techniques within its impact analyses. By addressing these issues, the goal of this paper is to encourage further scrutiny of these agencies and their actions concerning anthropogenic sound.

2. BACKGROUND

2.1 Properties of Sound

As stated in Richardson *et al.* (1995) "sound is what we hear." For a more technical definition, sound is a mechanical wave moving through an elastic medium caused by a vibrating object (Richardson *et al.* 1995; Au & Hastings 2008). The wave generated by an oscillating or vibrating object is measured in a wavelength (λ), and the number of times a wavelength passes a given point determines the frequency (f) of the sound source. Sound frequency is measured in hertz (Hz) which is a measure of cycles (or oscillations) per second. A source with a high frequency has a short wavelength and a source with a low frequency has a longer wavelength. The speed of sound (*c*), frequency, and wavelength are related in the following equation:

$$c = f\lambda$$

There are multiple different ways (or units) to measure sound. Two of these measurements are sound pressure, and acoustic intensity. Sound pressure, which is measured in micropascals (μPa), is a more common measurement as instruments can detect it, however intensity is important because "it is a fundamental measure of propagating sound" (Richardson *et al.* 1995). The strength of a sound is measured in decibels (dB). The dB is based on a logarithmic scale and is the ratio of a sound pressure (P) and its reference pressure (P_0). The sound pressure level (SPL) for a given P is:

$$\text{SPL (dB)} = 20 \log (P/P_0)$$

When measuring the pressure of sound in a given medium it is important to indicate the reference pressure because these differ depending on the medium the sound is traveling through (i.e. air vs. water). For underwater sound the accepted reference pressure is dB re 1 μPa (Richardson *et al*. 1995). Also important to the measure of sound pressure is the acoustic intensity or Energy Flux Density Level (EL) (NRC 2003). This metric is often used by the U.S. Navy and integrates sound energy over a period of time (HRC 2008):

$$\text{EL} = \text{SPL} + 10\log_{10}(\text{duration})$$

To understand the problem of underwater noise, it is first important to understand these basic properties of sound and how these play a role in the situation. Concerning underwater sound an important factor is the physical interactions of water and sound. Sound travels about 4.5 times faster in water than it does in air with sound speed (*c*) ranging from 1450 to 1540ms^{-1}

(Brekhovskikh and Lysanov 1991). This makes water an ideal medium to use sound for many different applications.

While sound propagates through the water column very effectively in comparison to light, there are also many factors that influence how a given sound source will propagate in a given location. These consist of forms of transmission loss (spreading and absorption) and physical properties of the water column such as temperature, salinity, pressure, and water depth (Richardson *et al*. 1995; Au & Hastings 2008). Some areas and conditions are more conducive to sound transmission than others. The speed of sound in the ocean depends on three local environmental variables, temperature (T), salinity (S) and pressure (P) (which is a function of depth (z)). As stated in Brekhovskikh and Lysanov (1991), the general equation for determining *c* in sea water based on the environmental variables is:

$$c = 1449.2 + 4.6T - 0.05T^2 + 0.00029T^3 + (1.34 - 0.010T)(S-35) + 0.016z$$

Also important to the transmission of sound is the frequency and pressure at which the sound is produced. Acoustic sources produce sound that can be divided into three frequency categories, low, moderate and high (Hildebrand 2009). Low frequency sounds transmit between 10-500Hz, moderate frequency sources transmit 500Hz-25kHz and high frequency sources transmit above 25kHz (Hildebrand 2009). Sources that operate at a low frequency produce sounds that will transmit much further due to longer wavelengths when compared with a higher frequency source at the same source level (SL) which have shorter wavelengths, and the increased attenuation of short wavelengths (Au and Hastings 2008).

For the issue of underwater ocean sound, it is important to consider the environmental and physical conditions which will have an effect on how the sound produced will move throughout the water column, and how species of concern will interact with that sound.

2.2 Species of Concern

The use of sound underwater is important to many groups of marine animals from small invertebrates, such as snapping shrimp, to vertebrates such as fish and marine mammals. For the purposes of this paper, the species of concern are marine mammals. These animals not only rely very heavily on sound in their daily lives, but they are also of the most concern in interactions with anthropogenic sound (Nowacek *et al*. 2007; Myrberg 1990) and are all protected species under U.S. law.

Marine mammals use sound for many aspects of daily survival. Due to rapid attenuation of light in the first ~200m of the water column and the great depths where many marine mammals spend large portions of time, sound then becomes their most efficient sense. In marine mammals, sound is used for communication (of social and survival importance), foraging and navigation. It is also thought that marine mammals use sound to gather information about their surrounding environment. This information is likely to come from natural sources around them such as sounds produced by other animals (whether they be inter- or intra-specific species), or naturally occurring phenomenon like wind activity at the surface or naturally occurring seismic activity such as earthquakes (Richardson *et al.* 1995). Due to their reliance on sound underwater, there are a number of concerns about how anthropogenic sound may be impacting the way marine mammals are able to receive the sounds around them, and how that may be impacting their behavior, and essentially their survival.

Marine mammals are grouped within three orders, and each has their own interactions with anthropogenic sound. The first order, Cetacea, is broken down into two groups, odontocetes (toothed whales) and mysticetes (baleen whales), both of which spend all their time in the water (Evans and Raga, 2001). The second order, Carnivora includes the sub order Pinnipedia ("true" and “fur” seals) who spend time in air and water (Evans and Raga 2001). The third order, Sirenia, includes manatees and dugongs, which spend all their time in coastal waters (Evans and Raga 2001).

Of these three, order Cetacea is of the greatest concern involving interactions with anthropogenic sound sources such as seismic air guns and sonar. Odontocetes and mysticetes can be found in both coastal and offshore waters, both being areas of common use for seismic air guns and sonar. Both groups produce and receive sound in different frequency ranges. Odontocetes operate at higher frequencies, generally communicating in the 1-20kHz range and echolocating up to 150kHz (Richardson *et al.* 1995; Evans and Raga 2001). Mysticetes operate at much lower/moderate frequencies between 12Hz and 8kHz (Richardson *et al.* 1995).

Many of the research and mitigation interests concerning marine mammals and seismic and/or sonar sources are focused around the mysticete group. Concern comes with the overlap of the operation frequencies of both sources, and the dominant frequencies of mysticetes (Nowacek *et al.* 2007). However, greater concern is rising for the impacts from higher frequencies that can be detected in the water column as remnants of lower frequencies of broadband sound sources (Goold & Fish 1998). When oceanographic conditions create a local surface duct, these high frequencies remain trapped in the duct and could pose problems for odontocetes that were originally thought to be of less concern for seismic air guns and sonar (DeRuiter *et al.* 2006). Within the odontocete group, deep diving families such as Ziphidae (beaked whales) are a species of concern regarding Navy sonar (Croll *et al.* 2001; Cox *et al*. 2006), and Physteridae is of concern regarding seismic activity, most notably in the Gulf of Mexico (GoM) (Miller *et al.* 2009; Madsen *et al.* 2006). These deep diving cetaceans may be negatively impacted behaviorally or physiologically while at depth (Miller *et al*. 2009; Cox *et al*. 2006). If disturbed during their deep dive feeding loss of fitness may occur, and the long term impacts from this potential effect are unknown.

2.3 Sources of Concern

2.3. (a) Seismic Exploration

Seismic exploration is an important aspect of the oil and gas industry and serves the purpose of discovering new fossil fuel deposits for future drilling by profiling the sea bed with sound. This is done by producing compressed bubbles in the water column from a set of submerged high pressure “air guns” that produce a high-pressure sound underwater when they collapse, or cavitate. This sound then travels down to the sea floor and bounces back to be recorded on the surface. The sound that is produced can range from 245–260dB re 1μPa rms SPL (Richardson *et al.* 1995) when a full seismic array is fired. This is a very loud blast of sound that is emitted into the ocean every 10-15 seconds at a very low frequency. The energy, or frequency range, for seismic air guns is generally below 250Hz with peak energy in the 10-200Hz range (DeRuiter *et al.* 2006, Richardson *et al.* 1995).

An offshore seismic survey can consist of anywhere from one to four vessels, all carrying six to twelve airgun sub-arrays (Figure 2). The survey travels along a pre-determined line within the leased survey plot. The duration of a survey can last anywhere from one month to two years. During this time the guns are continually firing at full power for the length of each survey line, depending on weather conditions. A minimal source gun (the mitigation gun) usually is operating at 160dB re 1 μPa during turns between survey lines, ostensibly to keep animals from approaching the vessel between lines.

There are important components of the array structure that make this anthropogenic source unique. Due to the goal of seismic activity (finding oil and gas deposits under the sea floor) the sound source is directed vertically in the water column. While a majority of the energy is directed vertically, propagation in the horizontal direction still occurs at depths below the surface, often extending to much greater ranges than expected or theorized by the industry. Madsen *et al.* (2006) reported that sperm whales in the GoM received SPL of 150-160dB re 1μPa (peak to peak) (broad band frequency 3-218Hz) at 400-500m depth and 12km away from the seismic source, indicating that strength of the sound pulses can be equally as strong near the source as it is at great distances. Nieukirk *et al.* (2004) reported pulses from seismic airgun activities that were recorded on passive acoustic arrays along the Mid-Atlantic ridge; the pulses were determined to have originated from sources over 3000km away.

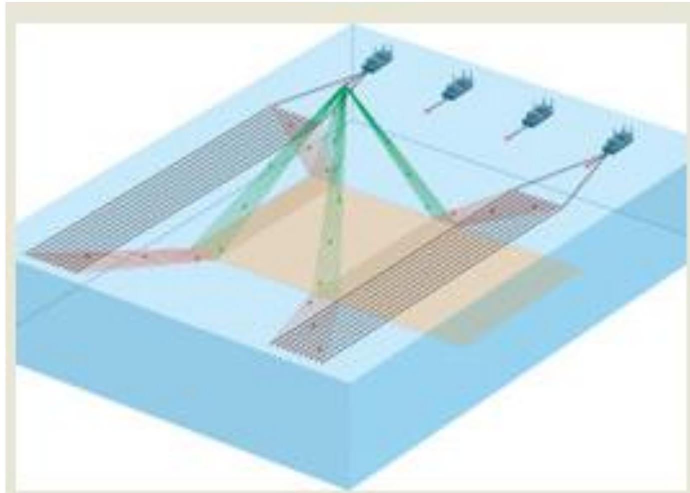


Figure 2: A common Wide Azimuth (WAZ) seismic survey. All 4 vessels serve as source vessels firing air-guns with the two outer vessels also serving as recording vessels. Source: E&P Mag 2011

The seismic exploration industry is very active throughout U.S. waters. With the height of their activity in the GoM, surveys also occur in the Arctic and sparsely off the coast of California (BOEMRE 2011). According to the former Minerals Management Service (now Bureau of Ocean Energy Management, Regulation and Enforcement - BOEMRE) (MMS-2004-054), there are over 370,400km of seismic survey lines shot in the GoM every year. That number has likely increased since that report was written as production and exploration in more remote areas is predicted to increase over time. The increasing frequency and intensity of these surveys drives the growing concern to understand and mitigate the potential impacts on protected marine animals in areas where seismic is already present, such as the GoM, and areas where it has yet to be active such as the Western Mid-Atlantic Ocean.

2.3. (b) Navy Sonar

Sonar has been an integral tool of the Navy's military defense since the technology's invention during World War I (US Navy 2010). The US Navy is responsible for setting up and carrying out sonar training exercises for the purposes of military readiness. For this reason, underwater training sites are set up within U.S. waters (0-200nm offshore). It is these training sites that are of concern for the well being of protected marine mammals that may be disturbed by the training exercises.

There are two forms of sonar that draw concern for marine mammals, each has different characteristics, but both are impactful. These are, Low Frequency Active Sonar (LFA) and Mid Frequency Active Sonar (MFA). Both of these are indicated as "active" sonar, meaning a source produces a tonal sound either at frequencies of <1000Hz (LFA) or 1-10kHz (MFA) with source levels of 200+dB re 1μPa rms (Richardson *et al.* 1995). The sound is sent out from the source, reflects off a target and travels back to a receiver. Training exercises can last for varying amounts of time, and can often include multiple sources. Some of those sources can include: ship based sonar, submarine based sonar, and aircraft deployed sonobuoys (which can be explosive or not) and/or dipping sonar from helicopters (AFAST 2008). The duration and specific source activities and characteristics vary for each training exercise, and are often analyzed individually concerning protected species impacts (AFAST 2008; HRC 2008; SOCAL 2008). High frequency active (HFA) sonar (>10kHz) does not appear as much of a threat to protected marine mammals as these tend to attenuate quickly in seawater, however, there is a lack of current research available to verify that. The majority of research associated with marine mammals and military sonar is focused around LFA and MFA. These sources have been associated with behavioral and physiological impacts on marine species such as baleen and beaked whales (Nowacek, *et al.* 2007).

U.S. Navy sonar training is present throughout many coastal and offshore waters of the United States. The areas of operation are often chosen based on oceanographic conditions that coincide with the required training for that facility. There are currently training ranges that exist in the Western Atlantic Ocean (AFAST, Cherry Point, Jacksonville, Undersea Warfare Training Range, Virginia, and Panama City), Gulf of Mexico, Hawaii, and Southern California (SOCAL) with Environmental Impact Statements currently underway in other locations (NAVFAV 2011).

2.4 Potential Acoustic Impacts

When considering the potential impacts of anthropogenic noise to marine mammals, it is important to understand their basic reliance on sound in the marine environment. Due to the physical characteristics of water, sound is the most efficient physical sense for marine mammals to use when undergoing everyday survival activities such as communication (inter- and intra-specific), navigation, and foraging. According to Nowacek *et al.* (2007) anthropogenic noise has the ability to initiate responses from marine mammals that can consist of behavioral, acoustic or physiological natures. Within these groups of responses, there are a number of individual reactions that are of particular concern regarding marine mammals and their interactions with anthropogenic noises. Impacts that are considered behavioral can include: a flight response, change in response to predators, changes in diving patterns, foraging, breathing, avoidance from important habitat or migration areas, and disruption of social relationships (Tyack 2009; Nowacek *et al* 2007; SOCAL 2008). Acoustic responses consist of masking, change in call rates, and change in call frequency. Physiological responses / impacts can consist of Temporary or Permanent Threshold Shift (TTS & PTS respectively), stress, and direct and indirect tissue effects (Nowacek *et al.* 2007, SOCAL 2008; Southall *et al.* 2007, Wright *et al.* 2007).

Within U.S. marine policy the main areas of concern for marine mammals are the physiological impacts that can be caused by anthropogenic sounds, however, there is growing concern for behavioral and acoustic responses. With increased research efforts, scientists hope to understand what long term impacts in habitat avoidance, changes in diving patterns, or changes in call rates may mean for individual marine mammal stock populations and the larger populations as a whole.

Acoustic thresholds have been accepted by the National Marine Fisheries Service (NMFS) to determine if a sound source is negatively impacting a marine mammal. While there are no official thresholds, the criteria used by NMFS have been recognized and accepted by the seismic industry and the federal government since at least 2004. The two agencies analyzed here operate at different metrics, therefore allowing for different threshold criteria (Figures 3 & 4).

SEISMIC EXPLORTION			
Harassment Level	**Characteristic**	**Received Level**	**Affected Family**
Level A	PTS Onset	190dB re 1μPa	Pinnipeds
		180dB re 1μPa	Cetaceans
Level B	Behavioral / Impulse Noise	160dB re 1μPa	Cetaceans & Pinniped
	Behavioral - Non-Impulse Noise	120dB re 1μPa	Cetaceans & Pinniped

Figure 3. NMFS accepted acoustic threshold criteria for Level A & Level B Harassment for non-military activities (i.e. the seismic industry). Southall *et al*. 2007.

THE U.S. NAVY			
Sound Source	**Harassment Level**	**Characteristic**	**Received Level (Cetacean)**
Low Frequency Active (LFA) Sonar	N/A	All effects	180dB re 1μPa
Mid Frequency Active (MFA) Sonar	Level A	PTS (Injury)	215dB re 1μPa^2-s
	Level B	Behavioral	Risk Function Used
		TTS (Non-Injury)	195dB re 1μPa2-s
Explosives	Level A	Mortality (onset severe lung injury)	30psi/ms (+impulse)
		Injury: (1) Slight Lung Injury	13psi/ms (+impulse)
		Injury: (2) 50% animals ruptured eardrum	205dB re 1μPa (Full Spectrum)
	Level B	TTS (Dual Criterion)	23psi/ma (peak pressure of explosives >2000lbs)
			182dB re 1μPa (peak 1/3 octave band)

Figure 4. NMFS accepted acoustic threshold criteria for Level A & Level B Harassment for military activities. Southall *et al*. 2007; SURTASS 2007, AFAST 2008, HRC 2008

The thresholds are mainly based on physiological effects associated with PTS and TTS, with the particular threshold criteria being based largely around the audiograms known for a few species. Audiograms indicating the frequency range and pressure at which individual species can best hear sounds produced have been used to indicate where these animals are most sensitive to overlapping anthropogenic sounds. Currently audiograms only exist for a handful of pinnipeds and odontocetes as many of these species can be studied in captivity or in the wild (Figure 5). There are no known audiograms for baleen whales, however their auditory thresholds are based on the frequencies and pressure of the sounds they produce, and observations of how baleen whales react to certain frequency sounds. Indirect data allows researchers to assume that baleen whales are sensitive to frequencies below 1kHz (Richardson *et al.* 1995; Ketten 1992).

Both seismic and sonar activity have been studied for the potential impacts they may cause to marine mammals. In order to understand these impacts, and the basis for the current U.S. policies concerning impact thresholds for these acoustic sources, relevant studies and their results are discussed below.

2.4. (a) Seismic Impacts

There have been a limited number of studies conducted to help understand the impacts that oil & gas seismic exploration have on marine mammals (particularly cetaceans). Many cetacean species, such as baleen whales, also produce, and most effectively receive, acoustic signals at lower frequency levels (Richardson *et al.* 1995). This makes the acoustic interaction between baleen whales and a seismic operation a concern for the welfare of the species. It has been reported that migrating bowhead whales in the Arctic region avoided areas where seismic activity was in operation, orienting away from the sound up to 7.5km from a source firing at 248dB re 1μPa rms

(Richardson *et al.* 1986). Di Iorio and Clark (2010) also report that blue whales may be exhibiting a “compensatory behavior” related to local seismic activity by increasing the consistency of their calls when seismic exploration was occurring. Ljungblad *et al.* (1988) reported a number of behavioral responses associated with four geophysical (seismic) survey vessels field experiments in the Alaskan Beaufort Sea. These consisted of shorter surfacing and diving, less blows while at the surface and changes of surface behaviors. They also reported total avoidance of the area at 2.9km from a source operating at 165dB re 1 μPa. More recently McCauley *et al.* (2000) also reported that humpback whales in Western Australia were exhibiting avoidance of seismic air gun arrays at received levels lower than many previous studies (on average 140db re 1 μ Pa rms). Localized avoidance of seismic surveys was also observed by baleen whales in a compilation of JNCC marine mammal observer reports between 1998 and 2000 (Stone 2006).

Also found in the Stone study, was a striking lateral spatial avoidance of small odontocetes while seismic air guns were firing. There has been some debate as to whether seismic surveys pose a problem to odontocetes as their hearing sensitivities tend to be at higher frequencies (~10-150 kHz) (Richardson *et al.* 1995). Studies have shown, however, that the broadband nature of the seismic sources and the physical characteristics of the water column can both contribute to higher frequencies being emitted that are of concern for some odontocetes. Goold and Fish (1998) reported that seismic power was recorded within the entire measured range of 200Hz – 22kHz up to 2km from the source. DeRuiter *et al.* (2006) also reported the recording of energy above 500Hz within a surface duct recorded in the Gulf of Mexico. These recordings of higher frequencies associated with seismic pulses indicates the potential for odontocetes to experience interference within their call and reception range, potentially causing problems similar to those associated with baleen whales.

In the Gulf of Mexico, (as well as other locations) the sperm whale (*Physeter macrocephalus*) is a species of concern regarding seismic surveys. Due to their lower frequency calls and their deep diving patterns, it is thought that seismic pulses could inhibit the species ability to forage well at depth, which could in turn lead to decreased survivability over time. Miller *et al.* (2009) reported subtle effects to sperm whale foraging behavior on seven whales at distances from seismic sources greater than current regulations require. This study noted that the subtle effects seen here would require a more in-depth study in order to really understand the impact this may have on the species. However, the findings indicate that "…even small reductions in foraging rate from behavioral disruption or disturbed prey could lead to lower calving rates and thereby hinder recovery of depleted populations."

The problem with many of these studies, however, is that while the acute behavioral or physiological impacts may be apparent, the long term impacts are still greatly unknown. More research will be required to understand these long term impacts, however, given the data that exits, it is important to act in precautionary terms.

2.4. (b) Sonar Impacts

As with research pertaining to seismic survey impacts, there is also limited research dedicated to the impacts that military sonar has on protected marine mammals. The majority of research has been conducted pertaining to the impacts of LFA sonar on baleen whales as these species are of the most concern (as with seismic). However, more recently concern has been raised about the impacts MFA may have on deep diving species such as beaked whales.

Studies looking at the effects of LFA have showed that baleen whales exhibited compensatory vocalizations when in the presence of low frequency anthropogenic sounds. While there is not much evidence that indicates the animals will remove themselves from an area of sonar activity, it appears that those whales that are present will change their call rates and call frequencies to compensate for the increased noise locally. Miller *et al.* (2000) reported that during a study related to the US Navy SURTASS training, humpback whale calls increased in length by 2% during LFA activity. Implications that this may have long term impacts to the species are of concern for managers, and studies indicate that more research is required to understand this further. Croll *et al.* (2001) reported in their study of low-frequency noise effects to foraging *Balaenoptera* (genus of Balenopteridea family of baleen whales that have rorquals) that while their immediate results did not show changes in behavior associated with low frequency noise and short term, small scale effects were not evident, it is important from a precautionary standpoint to gather more knowledge on potential long term, larger scale effects of more continuous low frequency noise.

More recently, MFA is becoming a topic of interest for scientists and mangers as this source contains more energy, there are more in operation and may have more acute and long term effects to more species. Recently there has been concern over the potential association of MFA training and mass standings of marine mammals, in particular beaked whales. According to Cox *et al.* (2006) there were four "atypical" standings (some mass standings) between 1996 and 2002 that coincided with the military sonar training in close proximity to the strand events. It is hypothesized that the sonar events may be associated with hemorrhaging in areas such as the brain, acoustic fats in the jaw and around the ears (Cox *et al.* 2006). No direct link can be made between then sonar events and the standings, however, the similarities in the stranding necropsy results do point toward them as a highly possible cause. It is also not certain what about the acoustic sources may be causing the animals to strand. Researchers hypothesize that the normal deep diving patterns of beaked whales may lead to increased nitrogen accumulation which may cause them to be more vulnerable to diving related diseases, which are triggered by loud acoustic sources within the water column (Cox *et al.* 2006).

Further studies have been conducted on determining TTS in bottlenose dolphins triggered by mid-frequency sources. Finneran *et al.* (2005) reported TTS onset at EL's ≥195 dB re 1μ Pa^2s for frequencies of 3-4.5 kHz. These results are similar to other TTS studies, such as Schlundt *et al.* (2000), and indicate the importance of understanding the effects that TTS could have in the long term for species that are continuously within the range of mid-frequency sources such as MFA military sonar.

2.5 Marine Policy and Law

Within this problem there are several legal mandates that determine how federal agencies must act in regards to federal actions and how those actions may impact protected marine species. The pieces of legislation that play important roles in this problem are the National Environmental Policy Act (NEPA), the Marine Mammal Protection Act (MMPA) and the Endangered Species Act (ESA).

2.5. (a) National Environmental Policy Act

NEPA can be considered a process law and is the mandate that requires any federal agency wishing to carry out a major "federal action" that could have an impact on the "human environment" to undergo an analysis of the potential impacts of that action. Under NEPA, the Council on Environmental Quality (CEQ) was given the responsibility to "ensure that Federal agencies meet their obligation under the Act" (CEQ 2007). In 1978 CEQ developed a set of minimum requirements that must be followed for any agency going through the NEPA process (43 FR 55990, Nov. 28, 1978). Under these requirements specific language guides the "action agencies" in how to implement the NEPA process. The Environmental Protection Agency (EPA) has then been charged with the responsibility to review all EIS's prepared by federal agencies and provide a "Notice of Availability" in the Federal Registrar (EPA 2011).

There are many important components within NEPA, however those that are most pertinent to this situation are the development and content of the analysis documents themselves. These documents range from broad assessments to more intricate and thorough analyses. The most broad is the Environmental Assessment (EA). The EA could conclude that the action is not expected to have any significant impact on the environment, which would result in a Finding of No Significant Impact (FONSI). The more analytical assessment is the Environmental Impact Statement (EIS). If the EA finds that significant impact will occur, or if the action is initially assumed to have significant impact, the EIS is developed.

Within the EIS (under Section 102 (C)) the action agency is responsible for:

> (i) the environmental impact of the proposed action,
> (ii) any adverse environmental effects which cannot be avoided should the proposal be implemented,
> (iii) alternatives to the proposed action,
> (iv) the relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity, and
> (v) any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented.

As part of this, a Draft EIS is first developed, after which the public is free to comment on any aspect of the document (for at least 45 days after the Notice of Availability), followed by a Final EIS that must include and consider the public comments made about the Draft. This is one of the most important parts of this act, and is a way to involve the public in federal activities that could have impacts on the environment they live in or are concerned about.

Because this is a process or procedural law, it only requires the action agencies to indicate potential impacts they could have on the environment and if necessary how they will address those impacts. It does not have the ability to stop an action from occurring. However, in the spirit of the law, it is important that the action agency goes about the impact analysis in a way that is thorough and provides all the correct information to the public so that they are aware of the action, and they can have some say on how it is to proceed.

Other important sections of this Act are stated directly in the Act's purpose:

> The information must be of <u>high quality</u>. Accurate scientific analysis, expert agency comments, and public scrutiny are essential to implementing NEPA. Most important, NEPA documents must <u>concentrate on the issues that are truly significant to the action in question, rather than amassing needless detail</u>." (CEQ Regulations Section 1500.1)

It further states within the CEQ regulations that in order to achieve the purposes of the act as addressed in Section 1502.1 the "Environmental impact statements shall be analytical rather than encyclopedic" (CEQ Regulations Section 1500.2) Also of importance to this issue is how the agencies address the issue of "<u>incomplete and unavailable information</u>" (CEQ Regulations Section 1502.22). Depending on how the agency addresses these key sections plays an integral part in the accuracy and content of the analyses. When analyzing how the two action agencies go about the entire NEPA process, focusing on particular issues allows you to see how the agencies differ, potentially why this may be, and how it can be addressed.

2.5. (b) Marine Mammal Protection Act

This act was developed in 1972 as a species preference act, reflecting the importance of protecting marine mammals for the American public. Under this act, authority and responsibility were given to National Marine Fisheries Service (NMFS) concerning cetaceans and pinnipeds, and the US Fish & Wildlife Service (USFWS) concerning polar bears and manatees. The important section of this mandate for acoustic issues is the designation of "take":

> "*Take* means to harass, hunt, capture, collect, or kill, or attempt to harass, hunt, capture, collect, or kill any marine mammal… or the doing of any other negligent or

> intentional act which results in disturbing or molesting a marine mammal…(50 C.F.R. Part 216.3)".

The key word from this definition is "harass", with harassment broken down into two levels (Levels A & B) for the industry and the military. For non-military actions, Level A indicates the intent to harass an animal with the potential to cause injury. Level B indicates the intent to harass an animal through disturbance in the wild, but does cause injury (50 C.F.R. Part 216.3). Level A and B relative to military readiness are similar to the industry versions, however with the added phrase: "…any act that injures or has the significant potential to injure… " (Level A) and "…any act that disturbs or is likely to disturb…" (Level B) (16 U.S.C. 1362 Sec.3 (B-D). Under these ideas of harassment for both military and non-military, NMFS uses (although it is not yet official) a set of acoustic criteria to be used in determining takes of marine mammals by sound (Figures 3 & 4). NMFS then must be consulted concerning permits to take specific species, and the application of mitigation protocols required to reduce impacts.

2.5. (c) Endangered Species Act

This act was developed in 1973 and can be considered a cultural preference act. The ESA aims at protecting species (and their habitats) that are of concern to become extinct with the understanding that humans should not be the cause of species degradation. For this situation, the most important area of the act is Section 7, Interagency Consultation. In this section, for any agency proposing an action that may interfere or impact an endangered species, the action agency must consult the regulatory agency that controls the management of that species.

Under the ESA NMFS and USFWS are given the authority and responsibility to manage those species under their jurisdiction (the species split is the same as in the MMPA). Because both action agencies have the potential to cause negative impacts on endangered marine species they must consult with NMFS and/or USFWS for a Biological Opinion (BO) on the activity. This is simply a legislative action to attempt to encourage interagency cooperation, however the BO has no power to stop an action should NMFS or USFWS find an activity will be harmful to an endangered species.

3. METHODS

NEPA Document Analysis

For this section of the project the analysis consisted of individual NEPA documents developed by both the U.S. Navy and BOEMRE. All documents in this analysis have been written in the last six years (2004-2010) to ensure that the data and methodologies reflect the most recent information and processes. EIS's or Environmental Assessments (EA)(depending on what was deemed necessary by the agency) were analyzed for each agency. These documents consist of:

U.S. Navy

1) Atlantic Fleet Active Sonar Training (AFAST) EIS – 2008
2) Southern California Range Complex (SOCAL) EIS – 2008
3) Hawaii Range Complex (HRC) EIS- 2008

BOEMRE

1) Geological and Geophysical Exploration for Mineral Resources on the Gulf of Mexico Outer Continental Shelf: Final Programmatic Environmental Assessment – 2004 (MMS 2004-054)
2) Arctic Ocean Outer Continental Shelf Seismic Surveys: Final Programmatic Environmental Assessment – 2006 (MMS 2006-038)
3) Seismic Surveys in the Beaufort and Chukchi Seas, Alaska: Draft EIS – 2007 (MMS 2007-001)
4) Chukchi Sea Planning Area, Oil & Gas Lease Sale 193 and Seismic Surveys Activities in the Chukchi Sea: Final EIS – 2007 (MMS 2007-26)

Along with the EIS's and EA's, the corresponding NMFS documents were also analyzed to determine to what extent the agency agrees with the impact analyses within the statements. These extra documents consisted of the corresponding Biological Opinions (BO), NMFS Final Rule, Letters of Authorization (LOA) (for the Navy) or Incidental Harassment Authorizations (IHA) (for BOEMRE).

The basis of the analysis consisted of looking at the methods used by each agency in determining impacts of sound. The three areas of concern are:

(a) Species Density (calculations & methods) within the project area
(b) Acoustic Propagation Techniques
(c) Overall Species Impact Determination

Also as part of the analysis, the effort towards developing new technology, use of "best available science" and/or collecting recent and up to data for more accurate impact determination and to address the issue of "incomplete and unavailable information". Transparency of information and methodologies was also assessed. Transparency was based on the ability to find necessary documents that should be available to the public, and the ability of the reader to determine the analytical procedures that were performed to address impacts.

4. RESULTS and DISCUSSION

While reviewing the various NEPA documents from both the U.S. Navy and BOEMRE there were several distinct differences in the EA/EIS methodologies carried out by each agency. Because both agencies are affecting the marine environment and its protected species in similar manners one might expect that impact analysis of acoustic sources would be similar, however this does not appear to be the case. Both agencies have different procedures for addressing the NEPA requirements, and while the requirements are all met, it is instructive to see how both agencies go about the process. It is these methods that ultimately end in products that indicate overall impact determinations on protected marine mammals and initiate mitigation protocols to address the problems as deemed appropriate. However, the question of whether those determinations are as accurate as possible and backed by robust analysis is the overarching point of concern.

4.1. U.S. Navy

1) Hawaii Range Complex (HRC) EIS- 2008
2) Atlantic Fleet Active Sonar Training (AFAST) EIS – 2008
3) Southern California Range Complex (SOCAL) EIS – 2008

4.1. (a) Species Density (calculations & methods)

In analyzing the three EIS's for the Navy, each addressed the issue of species density. Within each of the NEPA documents there are distinct methods used for determining the species density within the areas of concern. These methods vary depending on the specific location of the planned activity (i.e. Atlantic locations vs. Pacific locations), however there are similarities in the general approach of the agency to find and analyze the necessary information and develop an up to date investigation.

The first of the Navy NEPA documents analyzed, HRC, was finalized in May 2008. Within the document the species densities are listed in Appendix J of the HRC FEIS/OEIS. This section indicates the importance of understanding the local species density in order to determine an accurate as possible exposure estimate for each species. This EIS made a point to state that because animal densities tend to be given in animals per square kilometer (i.e. units in area), in order to have an accurate exposure calculation, the animal densities need to be "constructed" for three-dimensions (allowing for units of volume) by using depth distributions known for each species.

For the HRC EIS the species density information was extracted from Barlow (2006). The density estimates in this report originated from vessel survey data that were collected around the Hawaiian Island Archipelago in 2002 (August – November). The surveys for this report were set up in the strata: Inner EEZ (Main Islands out to 75nm), and Outer EEZ (75nm out to 200nm). The region covered consisted of the entire Hawaiian Island chain (Main and North West islands) in both summer and fall periods. The Barlow (2006) paper is stated as the best available science for this region, and the data is within eight years of the report, showing that it is the most recent data available as well. The use of data no older than eight years has been accepted as an appropriate timeframe, and first addressed by Wade and Angliss (1997) at the 1996 "Guidelines for Assessing Marine Mammal Stocks" workshop.

Also important to the density calculations was the depth distribution of the species. Within the list of species of concern for the HRC only 10 of the 22 total marine mammals have published depth distribution data. For the remaining 12 species the depth distribution was extrapolated based on information from species of similar body size, prey preferences and dive patterns. While this may not be the most accurate determination, it allowed the Navy to have an estimated idea of the species depth distribution in order to develop exposure estimates based on as much information as possible.

The next Navy EIS analyzed, AFAST, was finalized in December 2008. Within this document, the methods of determining species density were through modeling and / or derived from species abundance reported in the most recent NOAA stock assessments (AFAST 2008). The AFAST region was broken down into three sections, each containing multiple, smaller Operation Areas (OPAREA): Northeast, Southeast and GOMEX. By separating the AFAST into smaller regions, more localized density estimates could be made. These OPAREAs were the basis for three Navy OPAREA Density Estimates (NODEs) that were developed in 2006 & 2007. The 2006 preliminary report was prepared by NOAA (Palka 2006) and the 2007 reports were prepared by a third party contractor (DON 2007a; b). The basis of these reports was to use various forms of data in order to determine the most recent species density with the areas of Naval Operation along the Atlantic Coast.

In the 2006 report, species abundance within the U.S. North Atlantic was determined using shipboard survey data and aerial survey data. Data from this report was then used in the 2007 NE NODE by the Navy's third party contractor to aid in development of local species density estimates. Two estimation methods were used in the 2007 NE NODE; Density Surface Models (DSM) based on line-transect data from Palka (2006) and extrapolation of density from abundance and survey area data. The DSM's used species abundance and secondary environmental characteristics to help develop two-dimensional surface models that depict the species density throughout the region. Also within the 2007 NE NODE report the region was broken down into 11 strata and for all four seasons.

The 2007 SE NODE derived the cetacean density from abundance information reported in Mullin and Fulling (2003) or 2007 NOAA stock assessments (NODE 2007b). For regions where species data were lacking, DSMs were used as a prediction tool (NODE 2007b). Density estimates were reported for all four seasons allowing for changes in seasonal distribution.

According to the AFAST FEIS for the entire Atlantic Region, both NODE reports were used, and the density estimates were compared with 2007 NOAA stock assessments (Waring *et al.* 2007). All spatial models were reviewed by the NMFS technical staff to assure accuracy and credibility by the main protected species permitting agency. In addition to NOAA technical staff, the spatial models were also reviewed by St. Andrews Center for Research into Ecological and

Environmental Modelling (CREEM).

While the AFAST FEIS utilizes and actively seeks out up to date data and adaptive estimates of species density, there are several species where abundance and density information could not be found. In these cases the Navy chose to list those animals in the EIS, however it did not indicate how exposure would be determined for those species with no density data available.

The third Navy EIS, SOCAL, was also finalized in December of 2008. As with the previous two EIS's, SOCAL also used its own methods to determine species density within the areas of concern. Within the Southern California region NMFS has regularly surveyed the area by ship and air. The most recent survey data (collected in 2005) were published by Barlow and Forney (2007), and Forney (2007), and were used as the basis for the density calculations for the SOCAL FEIS. Within the reports the densities are separated by cold and warm water seasons, and the survey areas overlapped with the seven sonar locations within the SOCAL range. For this reason there was no need to further refine the density estimates to fit within the sonar locations.

As was seen in the previous two FEIS's, the importance of species depth distribution was also stated here. Similar methods were used to determine the depth distribution of species for which data existed and for those where they did not. Both the density data and depth distribution data were then combined to determine the three-dimensional density distribution of the species of concern with the SOCAL region.

In reviewing the various techniques used by the U.S. Navy to determine species density within their areas of concern, it is noteworthy to see the varying methods used along with the underlying ideas of obtaining the most recent information and finding outside sources to provide that data. Along with using the most recent NOAA stock assessments, the U.S. Navy makes an effort to interact and collaborate with outside parties to develop new tools to gain more accurate and current information. This can be seen in the use of the NODE reports in the Atlantic, but also further in effort developed after these EIS's were finalized. The Department of Defense (DoD) (which the U.S. Navy lies within) has developed a program called the Strategic Environmental Research and Development Program (SERDP). Within this program, the DoD works with third party sources to develop technological tools to aid in better environmental analysis for potential projects carried out by the DoD (SERDP 2011).

In recent years SERDP has teamed with Duke University and NMFS Southwest Fisheries Science Center (SWFSC) and Southeast Fisheries Science Center (SEFSC) to help develop the Marine Animal Model Mapper (OBIS-SEAMAP 2011, Barlow *et al.* 2009). Duke, SWFSC and SEFSC have all contributed data to the Mapper to show habitat suitability of species and density surface models. The data from these models are available to the public should they request it. The development of these programs and funding toward this technology shows a concerted effort to obtain new / updated information from outside sources and use that data for later environmental assessments.

4.1. (b) Acoustic Propagation Techniques

Concerning acoustic impacts as determined by the U.S. Navy it is important first to point out that the Navy operates on the indices of Energy Flux Density Level (EL) and Sound Pressure Level (SPL). According to the Navy NEPA documents, EL is the best measure of acoustic impact because it not only takes into consideration the pressure of the sound, but also the duration of exposure to that sound for an animal (HRC 2008; AFAST 2008; SOCAL 2008). This is an important factor to consider given animals may not leave an area where acoustic interference is present due to social or ecological factors, which over time could lead to TTS or

PTS for that animal and cause long term damage.

The measure of sound in SPL versus EL is different. SPL is measured in dB re 1µPa, whereas EL is "proportional to the time integral of the pressure squared" and is measured in dB re 1µPa^2-s (Richardson *et al*. 1995). Pulsed acoustic sources measured in EL, therefore, are not comparable to those measured in SPL, as energy levels in EL tend to be less than peak pressure levels in SPL (Richardson *et al.* 1995). It is therefore important to understand if the sound source and its impacts are being measured in SPL or EL, and that a conversion must be made for comparison. One must recognize how these different metrics may impact the acoustic models produced and how those levels apply to the threshold criteria developed by NMFS.

When dealing with sonar sources the sound is produced in pings, therefore the Navy has indicated that it is interested in determining impacts based on the EL for each individual ping. If a given animal is then subject to multiple pings during an exercise, the EL for each ping is summed to give the total EL for that animal. The total EL for an animal then depends on the SPL, the duration of the ping and the number of pings received (HRC 2008).

Within the three EIS's analyzed, the methods for determining acoustic propagation to later determine acoustic impacts were similar and transparent. The sonar of concern for all three EIS's was Mid Frequency Active (MFA) and High Frequency Active (HFA). Because HFA attenuates quickly, the majority of analysis within the EIS's was based on MFA. The transmission loss for Level B harassment (in all three EIS's) for both MFA and HFA was modeled using the CASS/GRAB propagation loss model. This was developed for use by the Navy and is now considered a "Navy Standard model" for sources within 150-100kHz (Keenan 2000; AFAST 2008). The GRAB portion of the model is a Gaussian Ray Bundle that looks at the transmission path of the sound rays from the source to the receiver (i.e. sonar source to a marine mammal). GRAB runs are done multiple times in order to account for movement of the mammal throughout the water column and at different depth ranges. The model essentially provides detailed information on multi-path propagation of the source as a function of range and bearing. The AFAST (2008) indicates that this is useful due to the changes in bottom depth and sediment type allowing for those changes to play a part in the model as they impact how the propagation of the source will change within an area.

The transmission loss for Level A harassment was calculated using spherical spreading in the AFAST EIS. According to this document, using the calculation for basic spherical spreading was sufficient due to the small radii needed to reach the Level A threshold in those environmental characteristics. The HRC and SOCAL EIS's do not indicate this method, and appear to use the CASS/GRAB model for transmission loss for Level A and Level B harassment.

Also standard within the three Navy EIS's was the development of the physical oceanographic environment. Each EIS addressed two seasons (summer and winter) and multiple "environmental provinces" ranging from 20 in the HRC to 36 in the AFAST. The provinces took into account wind speed, bathymetric provinces, sound velocity profile (SVP) provinces and High Frequency Bottom Loss (HFBL) provinces found distinct to each of the three range locations. The characteristics for each province were then used in the GRAB model to account for changes in the physical environment impacting the transmission loss from the sonar sources.

The use of this methodology and its appearance in all three EIS's indicates a potential effort towards developing a standard protocol. This process then allows for more transparency in the procedure and the outcomes. However, one aspect of this process that was lacking in all three of the EIS's was documentation of the source verification (i.e., precisely the source output and transmission pattern) within the three main ranges, and further within the defined environmental provinces within those ranges; source verification is an extremely important aspect of the acoustic propagation modeling. While the models are well developed there can be tendencies for the models to over or under calculate the propagation fields (Tolstoy *et al*. 2004), and this information would be important for the acoustic mitigation process developed for each source and region after overall acoustic impacts are determined.

While field verification for the sound sources may occur before the sonar activities begin, there is no indication of this in the documents. An additional component indicating real time verification of sources or data indicating the effectiveness of the models (e.g., field measurements down range from the source) would be important for the mitigation process, and could potentially aid in developing more accurate models for impact determination.

After analyzing the acoustic propagation component of the Navy EIS's it is evident that there is a clear path towards understanding how propagation loss will vary in the different environments and how important the environmental characteristics are to the system in both the physical oceanography and the bottom components (bathymetry and bottom sediment composition). An understanding of how the sonar source propagates in the different environmental provinces is then an important component to understanding the overall acoustic impacts of the sonar activity in each range and province.

4.1. (c) Overall Species Impact / Acoustic Exposure Determination

Concerning the overall acoustic impacts to species groups, the three Navy EIS's have laid out a multi-step process for determining how Level A and Level B harassment and the number of animals exposed will be calculated. The overall exposure of animals is based on the NMFS threshold criteria for Navy sonar as not exceeding threshold levels at an individual animals location and relies on accurate density and transmission loss data to determine an effective exposure estimate.

The exposure calculation process contains five basic steps that are outlined in all three EIS’s. These steps include:

1) Determining environmental provinces.
2) Calculating Transmission Loss based on source and environmental provinces.
3) Determining Exposure Volumes of accumulated energy from the source. Total received energy (EL) is determined for each point within a grid (this is a combination of the source energy level and transmission loss at each grid).
4) Applying 2 dimensional marine mammal densities to 3 dimensional space based on depth characteristics.
5) Number of exposures calculated by multiplying impact volume and the 3-D animal density.

One of the important aspects discussed in the overall acoustic exposure is the idea of working in three dimensions and addressing the fact that marine mammals can be anywhere in the water column during sonar activities. By recognizing this issue, the agency then works to determine impacts through a volume analysis, estimating how the volume of water surrounding the source will propagate the sound, and how that will impact species within that volume. The exposure analysis process also allows the agency to determine Zones of Influence (ZOI’s) for each hour of sonar activity, and based on the NMFS threshold criteria.

Within the overall impact analysis the Navy has worked with NMFS to develop new ways to address the impact and harassment issue. One such method is through the Conceptual Biological Framework (Figure 5). The framework is based around determining physiological and behavioral acoustic impacts, and was developed to “assist in ordering and evaluating the potential responses of marine mammals to sound” (AFAST 2008). This framework is very similar to one used by NMFS to determine the effects of Navy sonar regarding threatened and endangered species (Figure 6). The NMFS framework is used as part of the consultation process

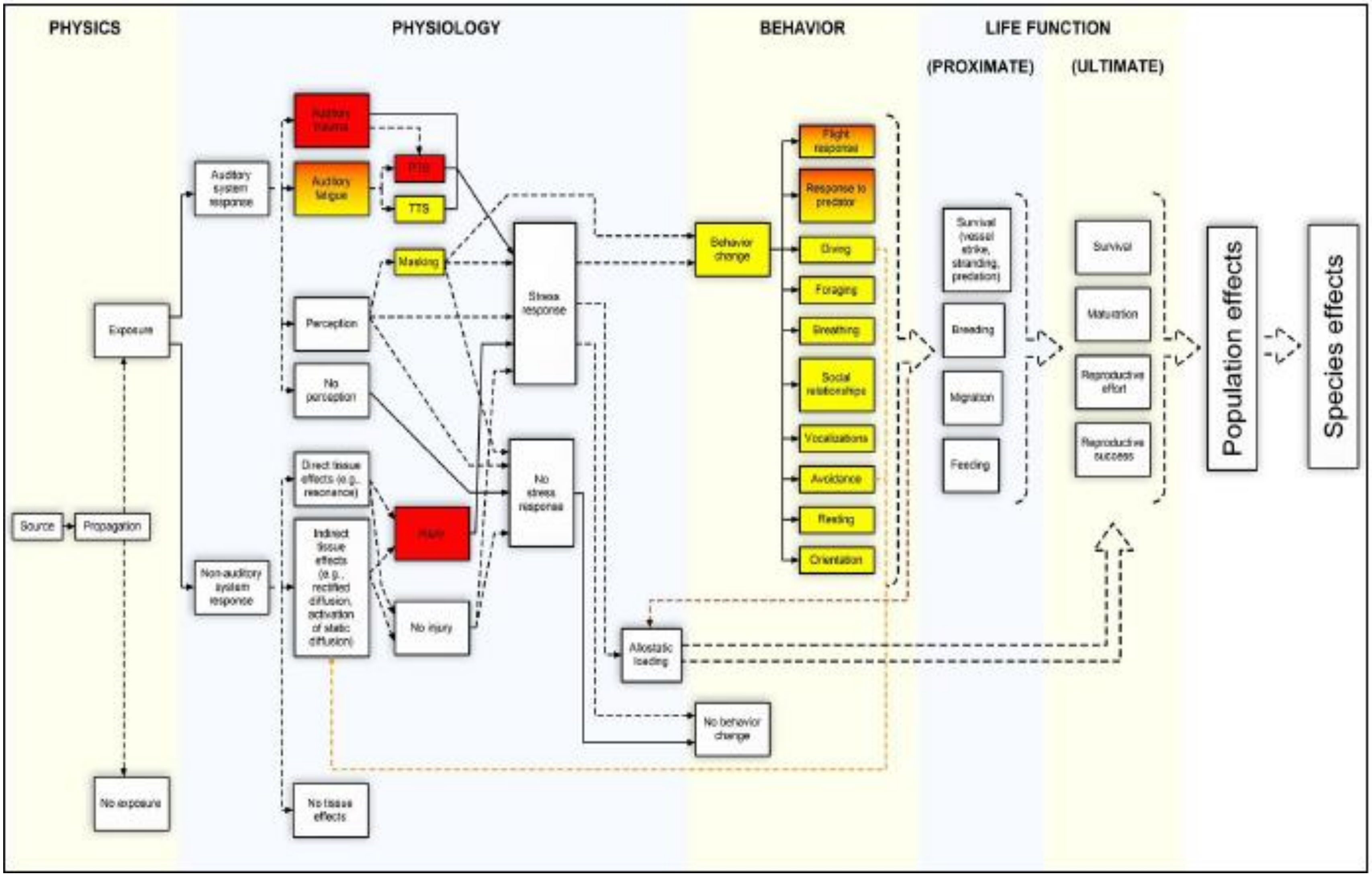


Figure 5. The Conceptual Biological Framework used by the U.S. Navy. Its purpose is to "assist in ordering and evaluating the potential response of marine mammals to sound." AFAST 2008.

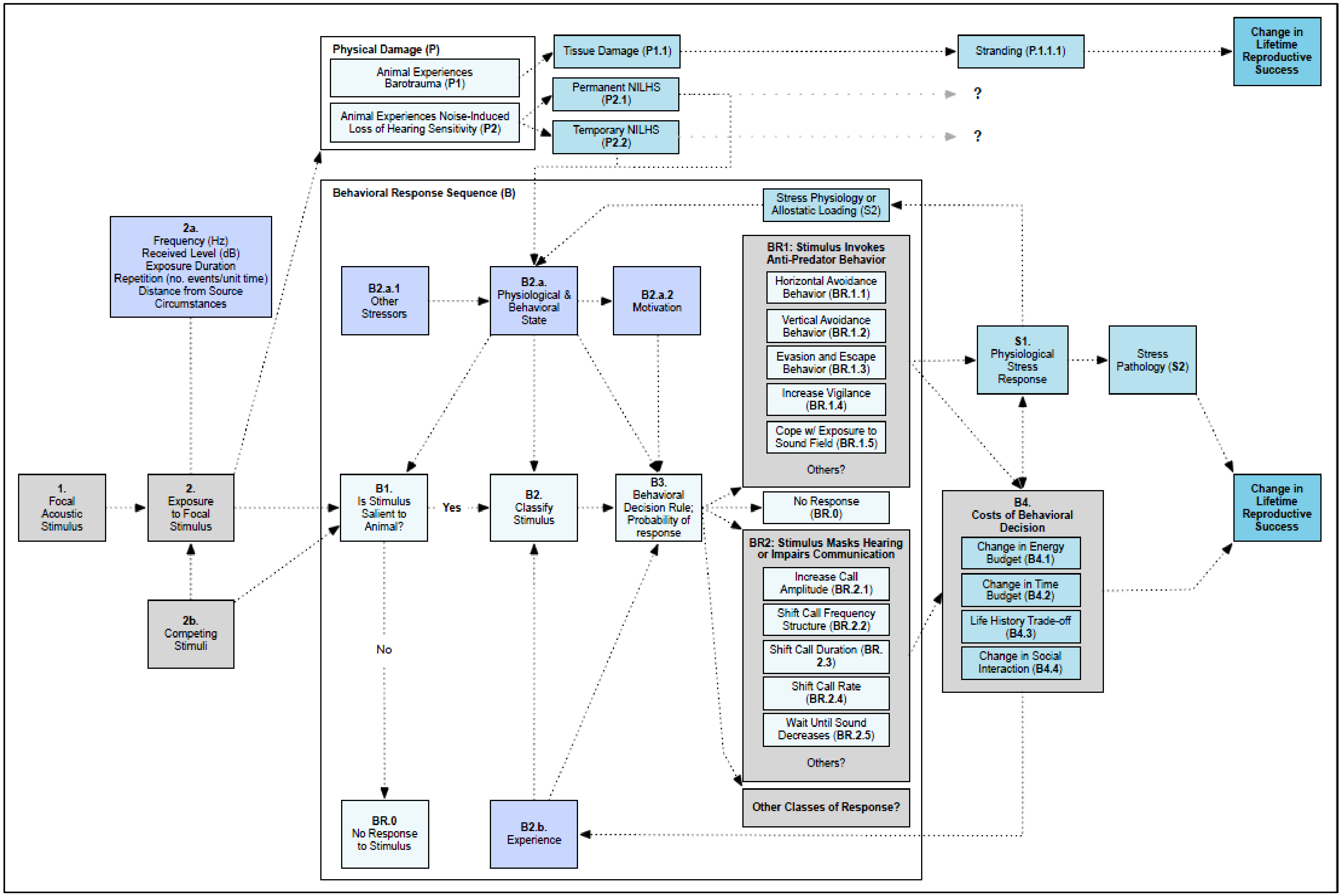


Figure 6. The Conceptual model used by the NMFS to address "the potential responses of endangered and threatened species upon being exposed to active sonar…" Johnson 2010 Per Comm.

initialized by the Navy to comply with Section 7(a)(2) of the ESA.

Also apparent within the Navy EIS's was the collaborative effort with NMFS to develop new techniques for exposure calculations that deal with sound exposure on a more realistic level. As the current NMFS threshold criteria stands, the cutoffs are based on a step function. For example for cetaceans, 215 dB re µ1Pa^2-s is Level A physiological harassment (PTS), but 214 dB re µ1Pa^2-s is not (Figure 7). This assumes that as soon as the EL reaches 215 dB re µ1Pa^2-s PTS will set in, however this does not take into consideration differences in species, age or sex of the animal exposed, or other influential factors. It is very likely that for some animals 214 dB re µ1Pa^2-s may be the limit where PTS will occur, or for others it may be higher than the Level A threshold. Despite this, the step function remains the basis for the regulatory structure at this time.

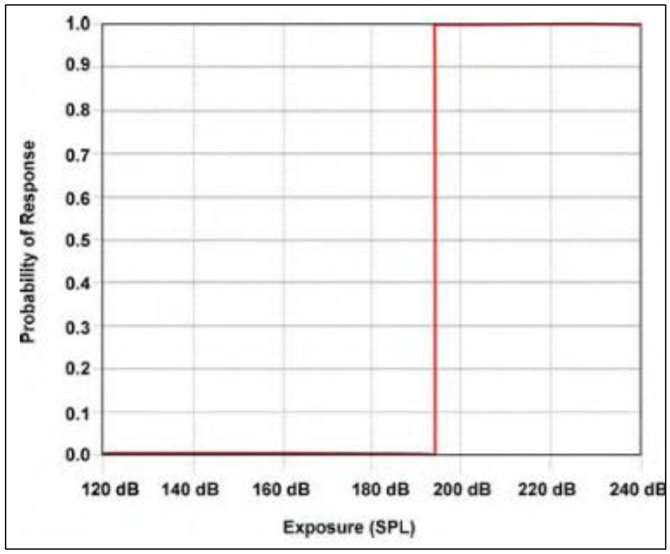


Figure 7. "Typical" step function used by U.S. Navy. AFAST 2008

Recently, however, the Navy and NMFS have collaborated to work on developing a Risk Function that can be used to determine Level B behavioral harassment. This is a more adaptive method that takes into consideration the fact that species' reactions to sound will differ, and that reactions to a sound source do not happen in a step process. The idea behind the risk function is that as the exposure of sound level is received by the animal the potential of a response increases on a curve in a "dose-response function" (Figure 8). The acoustic measure used for the risk

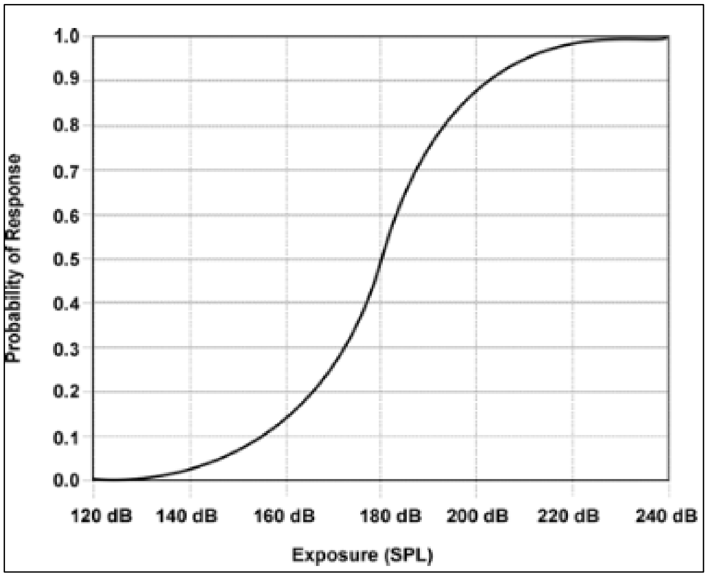


Figure 8. "Typical" risk continuum function used by U.S. Navy. AFAST 2008

function remains in SPL (dB re µ1Pa) while the measure for Level A PTS and Level B TTS remains in EL (dB re µ1Pa^2-s). The agency does not indicate the reasoning behind this method of using SPL instead of EL as the rest of their exposure calculations do. According to all three EIS's the mathematical function for the risk function developed by the NMFS and the Navy is derived from a solution found in a paper by Feller (1968). The function now used was first described in the SURTASS LFA Sonar FEIS (DON 2001). A description of the function and its assumptions can be found in the HRC, AFAST and SOCAL EIS's.

Further addressing overall impacts within the Navy EIS's, the general layout of the documents displayed a very analytical approach. Furthermore, according to NEPA CEQ Regulations Sec. 1502.2, "environmental impact statements shall by analytical rather than encyclopedic." While the NEPA documents were quite long, the strong analytical approach was evident throughout the thorough description of the acoustic analyses, density data and exposure/impact estimates. The layout of each EIS was not identical; however the methods were transparent and could be compared, and the information given was displayed so that the reader could understand the process that was developed for each analysis.

Beyond the collaborative effort with NMFS to develop the risk function, the Navy has also worked to develop acoustic impact models that work to integrate all sectors involved with acoustics and marine mammals. These two models are the Acoustic Integration Model (AIM) and the Effects of Sound on the Marine Environment Model (ESME). Both of these models work to integrate movements of marine mammals, acoustic propagation of a source and the local environmental characteristics that all play a part in the potential exposure of a marine mammal to sound (Frankel *et al*. 2002; Shyu & Hillson 2006). Their integrative aspects allow the user to gain a better, more complete picture of the impacts of sound to the local marine mammal populations taking into consideration their behaviors. Each model has it positive and negative aspects, however both are still in the process of development and refinement and neither was mentioned in any of the three EIS's. They do however, have the potential to aid in the development of future environmental impact studies, and allow for more adaptive impact analysis.

4.1. (d) Overall EIS Analysis

While reading through the Navy NEPA documents transparency of analysis appeared to be a key component of the process. All associated NEPA documents including Records of Decision, NMFS Final Rules and Biological Opinions, as well as Letters of authorization (LOA) were housed within the same website, available to the public and easily accessible (NAVFAC 2011). This structure allowed for ease in collecting documents for the analysis, and developing a solid framework to work from.

The formats of the three EISs did not have the same layout, however the content was similar with respect the individual range locations. Important components of the EIS's were the appendices which described a large portion of the analytical work carried out for each of the three analysis criteria for this paper. The technical component of the appendices allows a reviewer to follow the step by step process carried out, where the data came from, and types of inputs that were used for certain models, etc. By being informed in this way a reviewer can then determine if the protocol used was sufficient for the analyses at hand or whether more are needed.

As part of the overall NEPA process, the other required documents were reviewed as well. For the Navy the LOA's are the document required to request acoustic takes from NMFS. The LOA is valid for one year, and must indicate the forms of proposed takes. The LOA's produced by the Navy in conjunction with each of the EIS's /training ranges mirrored the EIS's in their analytical lay out and information.

Also relevant to the process are the biological opinions (BO) developed by NMFS in response to each EIS. The BO's are prepared as part of Section 7(a)(2) of the ESA and fulfill the responsibility of the consulting agency (NMFS) in addressing the potential impacts to endangered species. Within the BO's, NMFS discusses the use of conceptual biological model(s) and the risk function(s), both of which were used and discussed in the EIS's and which showed the effort for collaborative work between the two agencies to develop more accurate methods of impact assessment.

Overall, addressing the issues of this paper, and looking at the methods used by the U.S. Navy to determine species density, acoustic propagation and overall acoustic impacts to marine mammals, the EIS's developed by the Navy showed attention to analytical approaches of analysis, transparency, and a cooperative effort to develop and incorporate new technologies as they become available.

4.2. Bureau of Ocean Energy Management, Regulation and Enforcement

1) Geological and Geophysical Exploration for Mineral Resources on the Gulf of Mexico Outer Continental Shelf: Final Programmatic Environmental Assessment – 2004 (MMS 2004-054)
2) Arctic Ocean Outer Continental Shelf Seismic Surveys: Final Programmatic Environmental Assessment – 2006 (MMS 2006-038)
3) Seismic Surveys in the Beaufort and Chukchi Seas, Alaska: Draft EIS – 2007 (MMS 2007-001)
4) Chukchi Sea Planning Area, Oil & Gas Lease Sale 193 and Seismic Surveys Activities in the Chukchi Sea: Final EIS – 2007 (MMS 2007-26)

4.2. (a) Species Density (calculations & methods)

In analyzing the four EA's and EIS's produced by the MMS (referred to as BOEMRE for the remainder of this document) between 2004 and 2007 the use of density information was lacking. As species density is one of the key factors necessary to determine acoustic impact it is important that an EIS or EA attempt to find the most current and local species density information.

Three of the BOEMRE EA/EIS's consider the Arctic, specifically the Beaufort and Chukchi Seas. Within these areas there is apparently a lack of species density data, as indicated by the NEPA documents. All three of the Arctic documents do, however, report the abundance for the species of concern within the two seas. The oldest of the three, MMS 2006-038, reports abundance numbers from numerous different sources, with the most recent of those from the NMFS 2005 Alaska Stock Assessment Report. The problem with using abundance numbers within the EIS is that abundance cannot give you density for a specific survey area, or even within the Beaufort of Chukchi Seas independent of the rest of the Alaska. Without some kind of density information within the EIS's it is difficult to make a determination about significance of impact to the species of concern. MMS 2007-01 and MMS 2007-026 report abundance in the same way, with no indication within the EIS's of species density.

While the agency makes a point to state that the NEPA documents prepared for these three activities are programmatic in nature (MMS 2006-038 & MMS 2007-01), it is difficult to believe their determination that the proposed activities will have insignificant impacts based on the general information that is given. They also indicate that it will be important to look at the individual surveys in a case by case situation. This practice is done by way of the individual oil and gas or seismic companies preparing their own Incidental Harassment Authorization (IHA) in compliance with the MMPA. It appears then that BOEMRE is shifting the responsibility of mitigation onto the individual companies with minimal requirements.

Looking further at the IHA's, prepared during the time frame of these three Arctic EA/EIS's, seven of the eleven documents contained information about density within their survey areas. Within those IHA's that did contain density information, the sources varied from Stirling *et al*. (1982) to more recent LGL *et al.* (2008). The most commonly cited studies for density numbers were from Moore *et al*. (2000 & 2003).

Only two of the IHA's used data from the Bowhead Whale Aerial Survey Project (BWASP). This program has been running regular surveys in the Beaufort and Chukchi Seas since 1979 (BOEMRE 2011). BWASP is funded by BOEMRE and now operates in conjunction with NMFS and the National Marine Mammal Laboratory (NMML). The information from these reports would be the most recent abundance and density information concerning the Bowhead whale, the species of most concern within both areas. It is interesting to see that only two of the more recent IHA's actually use this information for their analysis. Furthermore, considering the surveys have been in operation since 1979, it was also interesting to find that none of the three BOEMRE prepared ES/EIS's used information from the BWASP survey for abundance or density numbers. However, MMS 2006-038 does use data from BWASP when discussing "*Areas* *and Situations Where Potential Impacts are Likely to be Greater than Typical* (Section III.F.3.f(10)).” Within this section it was also stated that due to the small area of coverage the numbers reported are likely to be smaller than the actual number of whales present throughout the area. Acknowledgement of this project shows that the data are useable for the analysis, however, lack of the BWASP data in the rest of the EA is suspect, leading one to wonder why the agency did not use the most current, and localized data (i.e., data related to each sea individually or study site) available for the Bowhead whale.

Within the 2004 Gulf of Mexico PEA (MMS 2004-054) the density information is reported mostly as written communication from K. Mullin (2003). According to Appendix L of the PEA, Mullin broke the density calculations into two strata; 20-200m and ≥ 200m. The two strata were further broken into each of the three GoM planning areas; Eastern, Central and Western. The densities for cetaceans found in the GoM were then reported for these strata. Within this section the agency also indicated the importance of understanding detection bias for the species and how this can play a role in the accuracy of the density calculations made by Mullin (2003).

While it is important the density calculations used in this PEA were broken into smaller strata than the entire GoM, it is also imperative to consider a smaller scale, such as focusing on the more frequently used areas of the Gulf. Certain areas in the Gulf are often targeted more for seismic exploration, and later drilling, than others. These areas would be of most concern when attempting to understand the impacts to local marine mammals and how they can be mitigated effectively. By having more accurate data on species distribution throughout the GoM and what the densities may be at a smaller scale, then better take and acoustic impact estimates can be calculated. This would require BOEMRE to participate in or potentially fund operations to collect more accurate density information based on the oil and gas industries use of the GoM. This would allow for the collection of missing data, which is the exact excuse often used by agencies to avoid collecting more accurate information during the NEPA process. Information gaps can impact the effectiveness and accuracy of an environmental analysis which could cause a domino effect of environmental problems in the future.

4.2. (b) Acoustic Propagation Techniques

Acoustic propagation analysis as determined by BOEMRE and the seismic industry varies greatly between the Arctic and the GoM. There has been a progression within the Arctic region towards more dynamic and smaller scale analysis of acoustic propagation, however in the GoM there has been no sign of improvement or movement towards collecting more accurate acoustic propagation information when it concerns protected species.

Within the Arctic region, the EA/EIS's analyzed were very similar in their approach to addressing acoustic propagation of seismic sources. All three described the importance of understanding the local physical characteristics of the marine environment, and how they would impact an analysis, but, they show no indication of how these characteristics should be incorporated. The 2006 PEA (MMS 2006-038) indicates the use of a study conducted by Tolstoy *et al*. (2004) that looked at the acoustic propagation of sounds from air guns of various sizes in the Gulf of Mexico through modeling and field verification. While this study may be useful for general assumptions on the spreading of sound from seismic sources, it does not take into account any local characteristics that may play a very important role not only in the acoustic take calculations, but also in establishing safety radii around the source. This study is also cited in MMS 2007-01 and MMS 2007-026 as a reason why modeling may not produce the most accurate acoustic propagation results. MMS 2007-01 does indicate, however, that the use of field verifications as part of the mitigation process will then be important because of the changes in local environmental and physical characteristics. This EIS also reports that NMFS requires the practice of individual survey field verification in conjunction with modeling during the time that data is still being collected which will aid in more accurate acoustic models. The practice of field verification, however, is only used to determine safety radii, and does not yet play a role in acoustic take / harassment calculations and estimates.

Within the EA/EIS's developed for the Arctic region in 2006 and 2007 there was little to no mention of acoustic modeling of any kind that would aid in the development of impact estimates on local species. All three of the EA/EIS's were very encyclopedic in nature and did not contain much actual analytical analysis. In doing further research, the more analytical approach was in the individual IHA's that were developed independently by the seismic or oil and gas company desiring a permit for a particular seismic exploration. As was similar with the density information found within these IHA's, there was a progression of modeling and acoustic propagation analysis from the earliest IHA available for analysis in 2006 and to the most recent in 2009. Varying amounts of information on methodologies were available regarding how the acoustic propagation was determined in some IHA's. The variety of methods consisted of: the use of TL determined by a 1997 calculation from the Liberty Project (for a 2008 IHA), a modified cylindrical spreading calculation: $TL = 15\log[R]$, models produced by individual contractors such as JASCO, or previous field verification studies that may have not been from the same survey location, but were from the same sea. The variety of methods used is attributed to the fact that the individual companies that will be responsible for the seismic activity are requesting the takes. However, this variation in techniques and sparse information about them leads to inconsistent information and a lack of transparency in the process.

There is no real protocol for how take calculations should be developed, and for this reason there is no way of assessing the effectiveness of the individual techniques used. It is these inconsistencies that need to be addressed by BOEMRE and NMFS in order to develop a protocol that will allow for the most accurate analysis of species impacts associated with seismic sources, and allow them to understand how sound is propagating in the Arctic region as a whole and how it varies throughout the region so that accurate models and assessments can be created.

Looking next at the 2004 FPEA for the Gulf of Mexico, acoustic propagation modeling was absent from the entire NEPA document. Within the document the agency makes a point to state that acoustic propagation from a seismic source is different than from other sources because the majority of the energy is focused in the vertical direction. Because of this, they determine that the best way to address acoustic propagation is not through cylindrical spreading, or through spherical spreading of the source, but through a modified version of cylindrical spreading that uses the calculation: TL = 15log[R]. It is with this calculation, and the impact threshold cutoff for cetaceans used by NMFS in 2004 (Level A = 180dB re 1 µPa rms, Level B = 160dB re 1 µPa rms) that BOEMRE determined impact zones of 300m for Level A and 3000m for Level B. The problem with this transmission loss calculation is that it is entirely too broad and does not take into consideration any of the dynamic changes in the GoM such as changes in water temperature, the sound speed profile, bottom sediment characteristics (in shallow areas), or bathymetry. The calculation also does not consider the size of the seismic source, which will have considerable impacts on how the sound propagates.

This overly general calculation was then used in the one IHA that was produced to cover all three GoM planning areas for five years (2004-2009). Considering the potential for significant changes in acoustic propagation for an area that large, it seems insufficient to use such general calculations to determine acoustic impacts on protected species within the entire U.S. region of the Gulf of Mexico. This calculation also does not leave room for change in how seismic surveys may be run, the gun configuration used for each survey, etc. While the seismic surveys conducted in 2004 and earlier may have only consisted of one vessel operating within a survey plot at a time, the method of seismic operation in the GoM has changed, and more recently the use of Wide Azimuth (WAZ) is common. A WAZ survey consists of three to four vessels running parallel to each other within a survey plot with their air guns operating simultaneously or in a pre-determined pattern that allows for very little time between shots (WesternGeco 2011). It would be important then to determine the ensonified area of a large operation such as a WAZ survey, and how that could greatly change the acoustic impact calculations for that individual survey and the cumulative surveys annually, or within the five year IHA. The 2004 PEA does mention multi-ship surveys, however makes no effort to offer an analysis, or indication of future research that may be required to determine how the acoustic propagation of such a survey would actually impact GoM protected species.

Overall, for acoustic propagation techniques as presented by BOEMRE there is a lack of analytical reporting within the EA/EIS's themselves, and within the individual industry developed IHAs there is a lack of consistency that can lead to overall inaccurate impact determination and analysis. There needs to be a greater level of transparency concerning acoustic propagation and the resulting impacts within the agency and the industry, as the acoustic propagation and transmission loss of the source is an integral part of potential environmental impacts from the seismic industry.

4.2. (c) Overall Species Impact / Acoustic Exposure Determination

As with the other components of BOEMRE NEPA documents and environmental impact analysis, there is a lack of transparency in how acoustic exposures are determined and if they are done on local or general levels. There is no set method used by the agency or by the industry in how acoustic exposure and overall acoustic impacts are determined. The indication of impact or harassment is based on the NMFS threshold criteria, which structures as a step function process where 159dB re 1µPa rms is not Level B harassment, but 160dB re 1µPa rms is. This method does not take into consideration any differences in species reactions to noise based on age, sex or cumulative exposure to anthropogenic sound. There is no indication within the NEPA documents that BOEMRE has made an attempt to collaborate with NMFS to work on better metrics for acoustic threshold criteria or the potential impacts they represent.

In reviewing the various NEPA documents, the method used to determine takes, and therefore acoustic exposure were based on the calculations:

Take = [mammal abundance / 100] * area ensonified * proportion detected

Annual Take = Take * (survey effort per year)

These calculations were first used in the 2004 GoM PEA (MMS 2004-054), and were also indicated as the calculation for take in Arctic Region IHA's. For these calculations the "area ensonified" is determined by the number of linear miles within the survey to be shot, and two times the radial distance of the transmission loss fields. The "proportion detected" takes into consideration the diving characteristics of the animal which would affect the ability of visual monitors to observe them.

While the variables used here are important for determining overall acoustic exposure, these calculations do not take into consideration exposures in a three dimensional context.

Considering that sound propagates in three dimensions and the marine mammals are not always at the surface or always at depth, it is important to develop a technique to address this issue and produce more accurate and dynamic exposure estimates. Development of these techniques would seem to be an ideal situation for increased collaboration with NMFS, or even with the Navy as they have already developed a dynamic method of determining acoustic exposures to animals in a three dimensional environment.

It also may be appropriate to consider adapting the Conceptual Biological Framework or the risk function used by NMFS and the Navy when addressing behavioral harassment to marine mammals. There are new and developing techniques that show an effort to gain more accurate information and which can lead to more dynamic management of acoustic impacts. It would show and effort by BOEMRE and the industry if they participated in similar activities that addressed the seismic industries unique circumstances more directly, while adding to the accumulation of knowledge on the subject.

Throughout the four BOEMRE NEPA documents analyzed there were often very general statements about overall acoustic impacts, including statements of the lack of information for different aspects of the agencies analyses. There was no indication of an effort to address ways to improve the lack of information or how the agency could attend to more specific issues such as how impacts may change during different times of the year or different locations within larger areas of concern (i.e. survey plot vs. Gulf of Mexico planning area).

The Arctic region IHA's did address these issues on the smaller survey by survey scale, which allowed for more dynamic take and harassment assessments. However, the GoM PEA was very general and extrapolated impacts out by five years for the entire U.S. GoM. This is not an accurate way to address acoustic impacts and does not leave room for change in the industry such as an increased number of surveys, increased number of boats per survey or a change in the number or magnitude of various survey types throughout the Gulf between 2004 and 2009. The five year multi survey IHA also does not take into account how those estimated takes over the five years would be allocated among the surveys nor how those allocations would be monitored. It also does not take into consideration the idea that any animals within the GoM could be impacted by multiple surveys during that time and how cumulative impacts would play a role in the overall acoustic impacts to protected species within the region. Overall the BOEMRE impact analysis is weak and needs more effort towards addressing new techniques in order to develop more accurate and effective acoustic exposure and impact analyses.

4.2. (d) Overall EIS Analysis

While reading the NEPA documents associated with the BOEMRE EA/EIS's several trends appeared. The first important point to address is that two of the documents (MMS 2004-054 & MMS 2006-038) are EA's, which are more general documents than EIS's. Both EA's are also programmatic, which also means they will be even more general in nature. Due to this, it is not surprising that the analysis done within these EA's was more encyclopedic than analytical. With regard to the two EIS's developed in the Arctic, given the increase in the number of survey permits received for the area in 2007, it is shocking that the MMS 2007-001 Draft EIS bears a striking resemblance to the 2006 PEA. Many of the sections even contain the same wording, or reference directly information that was provided in the 2006 FPEA. Considering such an EIS should, according to the CEQ NEPA requirements, be more analytical than encyclopedic, this lack of an attempt to develop a more in depth analysis of potential impacts to marine mammals by seismic sources was surprising.

This was also the case with MMS 2007-026, the EIS developed specifically for the Chukchi Sea and Oil & Gas Lease Sale 193. As this is a more localized area, it would be expected that the analysis would reflect this and address more local factors. However, this again was not the case. Information and direct wording was pulled from the 2006 FPEA and no further analyses were conducted.

Of the four NEPA documents the 2004 FPEA for the GoM did have some analytical components, however because of the programmatic nature and the fact that it was an EA not an EIS, the analysis was limited and greatly generalized. It is also important to note that the FPEA (and its subsequent IHA) was the only analysis of acoustic impacts or takes from seismic activity from 2004-2009. The large scale of this analysis makes the projections made for takes during that time frame suspect. It would have been more dynamic and more applicable if, following the FPEA, IHAs had been developed for each of the three planning areas, and for each year within the 2004-2009 timeframe. By making one IHA for five years, the numbers calculated and extrapolated can be considered suspect, and do not allow room for change within the GoM whether the seismic effort is increasing or decreasing during that time.

The documents also demonstrate a lack of collaboration with NMFS, or any effort toward developing more accurate of efficient methods of analysis. NMFS did act as the cooperating agency concerning Section 7(a)(2) of the ESA and did produce BOs associated with the MMS 2004-054 and with the Arctic documents. Within the Arctic Region the 2006 Arctic Region Biological Opinion (ARBO) was produced by NMFS to address potential impacts to endangered species associated with seismic activity in the Beaufort and Chukchi Seas. What was interesting about this BO and the subsequent one in 2008 was that much of the information reported in the BO was taken directly from the 2006 FPEA and Biological Evaluation produced by BOEMRE.

This leads one to question what the impact of NMFS producing the BO was, if they did not offer extra critique to the agency that is producing the document in order to carry out their desired activity.

Although the overall opinion of the BOEMRE EA/EIS's is that they are significantly substandard, it is possible to look at these NEPA documents as a sign of progression over time. Starting with MMS 2004-054 in the GoM, this document was very general, covered a large area and attempted to determine impacts for the entire region for five years. There was very basic analysis that did not take into consideration local dynamics of the system or the species that live in it. The IHA developed for this FPEA was equally as broad with the five year extrapolation as well.

The next document, MMS 2006-038 in the Arctic was also a very broad and generalized programmatic look at seismic impacts in the large region. There was a lack of technical analysis and a heavy reliance on the encyclopedic format, often burying information within dense text. The next two documents, MMS 2007-01 & 026, were targeted to be more analytical due to their EIS status, however they too were lacking in analytical content. The real progression during this time was found in the IHA's developed during 2006 and 2010. Within these documents there was a trend from minimal information provided and questionable techniques to more emphasis on modeling, using more recent and accurate density estimates and calculations, and even contracting out to third parties for the analysis. It also appears within the Arctic region that there may be even further progression within the EIS documents as supplemental EISs are being developed for individual surveys rather than an entire region. This should lead to the ability of the preparer to develop more localized analysis that considers not only local species, but local oceanographic effects to understand the local acoustic environment better.

Considering this progression it would then be important, when looking into the future and the current PEIS underway in the Western Atlantic, to address the issues that have been raised about past BOEMRE documents, and apply them to the new EIS in order to develop a comprehensive EIS in an area that has yet to be subjected to heavy oil and gas pressure and assures an accurate analysis of the system and its marine mammals.

Lastly, the lack in transparency when collecting all the BOEMRE NEPA documents is important to bring forward. In order to obtain the EA/EISs, BOs, and IHAs multiple websites needed to searched, and even then, not all the documents could be found. There were several IHAs which existed in the Federal Register, however could not be found on the NMFS IHA website. In order for the public to be able to view the documents a dedicated hunt was required. This lack of transparency can be disheartening, when one of the main aspects of NEPA is to involve and inform the public of federal activities that may have an impact on something of concern to them. Overall, better transparency is needed in the analysis within the documents and in the location of the document themselves.

5. CONCLUSION and RECOMMENDATIONS

Reviewing the various NEPA related documents from both the U.S. Navy and BOEMRE has brought forward several similarities as well as differences between the two agencies. Neither agency is perfect in how they approach the issue of acoustic impacts on protected marine mammals, however it is evident that one agency is contributing more resources and taking a more proactive approach than the other, which is leading to more comprehensive and potentially more effective mitigation and management.

At this time, and based on the NEPA documents reviewed, the U.S. Navy is a more adaptive and engaged agency in relation to acoustic impacts of their sonar activities. The U.S. Navy works closely with NMFS and third party contractors to develop increasingly adaptive methods for acoustic impact determination. Examples of these efforts are the ongoing efforts of the Office of Naval Research (ONR) and the SERDP Seamap Project in conjunction with NMFS and Duke University, and a comprehensive predictive cetacean density modeling project of the Eastern Pacific Ocean that was carried out by NMFS Southwest Fisheries Science Center (Barlow *et al.* 2009). By participating in, funding and using the data from these projects, the Navy is making significant efforts to gain as much knowledge as possible concerning the issue of acoustic impacts in order to operate accordingly, and to assure they are upholding the MMPA and ESA.

Despite the efforts the Navy has put forth in recent years, there has still been a concerted push back from the general public and NGO's towards the Navy's sonar activities and its interactions with marine mammals. The Navy appears to be attacked more publicly in court, with the general public's perceptions largely being that the Navy is injuring and killing cetaceans with no effort to avoid interactions with them. Because of this, the Navy has then been even more diligent in recent years to ensure that they are taking more concerted efforts to avoid that issue and display to the public that they are taking efforts towards mitigation and to understand how their acoustic sources are actually affecting marine mammals.

While the acoustic activities of the Navy do have impacts on marine mammals, it seems as though they acknowledge and address those issues in a more proactive manner. With this being the case, the public's efforts may need to be redirected towards the activities of BOEMRE and the seismic industry. In reading the BOEMRE documents related to NEPA there was a distinct reliance on the earliest FPEA (MMS 2006-038). This document was produced as a programmatic document with the intent to encompass all seismic activity to take place in the Arctic region. While that method is approved and accepted under NEPA requirements, it is an inadequate way of addressing any local environmental variables that may have an impact on sound propagation, species distribution, etc.

Another problem with relying heavily on MMS 2006-038 as a reference document is that is it very encyclopedic in nature, burying facts deep within its contents, and that it does not take current technologies or mitigation activities into account. Current technologies and programs exist that should be considered, such as those made publically available by the Navy, however they are not used. This lack of current practices and overuse of the Programmatic EA is also apparent in the GoM. Within this region, the only real NEPA document that has considered seismic impacts directly in the GoM is the FPEA MMS 2004-054. This document is structured very similar to MMS 2006-038, however, unlike the Arctic's FPEA where individual IHA's are required to be submitted by the seismic or oil and gas company wishing to carry out the seismic activity, only one all-GoM encompassing IHA was submitted back in 2004 with the FPEA. There is no individual component to this IHA, so it is difficult to determine whether that IHA was accurate in its assumptions of GoM seismic activity and how much of an impact the many surveys carried out there would have. No other IHA's have been submitted since then, confirming that more recent data and technologies or mitigation practices have not been used or implemented to aid in adaptive mitigation and management.

In reading through the BOEMRE documents, there was an evident progression in the type and content of documents that were produced over time. The very programmatic and basic nature of the 2004 GoM FPEA did not indicate great effort to obtain any updated or current data that would aid in the assessment. The Arctic 2006 FPEA did show more involvement in the process, however there was still a lack of acknowledgement of the importance in understanding the local environmental characteristics and variables that could have impacts on the individual survey level. In the Arctic, however, BOEMRE does require that the individual oil and gas or seismic company carry out their own IHA where a more individual look at the survey plot can be addressed. Within these IHA's, there still appears to be a lack of effort in collecting and/or using the most up to date data, and a lack in more accurate analysis of the acoustic environment and how that may impact the local protected marine mammals. There was also a progression in the amount of pre-survey modeling that was done, however the accuracy of models greatly relies on the accuracy of the input data, and reliance on previous data from similar but not the same location or time frame can affect the outcomes of models, further affecting how mitigation protocols are set up for that region.

It is encouraging to see this progression occur, however, more attention needs to be paid to understanding the local survey environment. It is not sufficient to rely on past data from previous studies in different locations. There can be small differences in the survey plot that can greatly affect the outcome, and these need to be addressed. Using acoustic transmission loss models that encompass the survey site and consider local environmental variables can be very useful in setting out preliminary mitigation protocols and directing the surveyors to where in the survey plot it is necessary to take field verifications to better understand the potentially varying acoustic environment. This would then allow for more adaptive mitigation protocols that could take into account the varying transmission loss conditions throughout the survey plot.

Being able to address those environmental characteristics and changes within a survey plot in a spatial context is the goal of Section II of this paper. Addressing how those characteristics vary in space and time is an important component of understanding the impacts that a sound source will have on the marine mammal populations and, in turn, important to an impact assessment. The Navy addresses this issue by establishing an environmental profile for their sonar ranges within each EIS. Section II of this paper aims to express the usefulness of addressing these issues on a survey plot in the Arctic by the creation of a tool that allows the data from a transmission loss model to be displayed and analyzed in a geospatial context of the ArcGIS® program.

This progression towards more local importance is displayed in an IHA recently approved by NMFS. Shell Offshore Industries states in their 2010 IHA application their plan to deploy acoustic recorders in the Beaufort Sea. "The purpose of the array will be to further understand, define, and document sound characteristics and propagation resulting from site clearance and shallow hazards surveys that may have the potential to cause deflections of bowhead whales from their migratory pathway (SOI 2010)." While this does not indicate seismic directly, it would be interesting to see, should this program be put into effect, if the data and information collected from the survey would be used for understanding how seismic sources are also impacting bowhead whales within this environment. If this is the case, then it is encouraging that individual oil and gas and seismic companies are working towards obtaining more information for their own analyses, regardless of the fact that BOEMRE (their regulating agency) is not showing any action to make this progression a requirement.

There is some hope, however, that BOEMRE will begin also follow this path of progression. With the recent restructuring of BOEMRE from the MMS there has been an indication that the agency will be working on improving its environmental stewardship. On August 6, 2010 Secretary Salazar announced that BOEMRE would be revisiting how it addresses the NEPA process by undertaking a comprehensive review of the previous MMS NEPA program (BEOMRE 2011). On October 12, 2010 the announcement was made that a Supplemental EIS would be developed for the Chukchi Sea to address issues that were raised in court. One of those issues is the agency's failure to determine if missing information was important and if it would be economically feasible to obtain that missing information (BOEMRE 2011). It is encouraging to see that this issue was raised most recently by the public, and that BOEMRE reacted by requiring a Supplemental EIS to be developed. This indicates that the restructuring may have a positive effect on how the agency address seismic activity in the future and that public action can force the agency to be held accountable for its actions (or lack thereof). BOEMRE developing and requiring more in depth analyses of their activities acoustic impacts, among other issues, may now be more likely.

Lastly, the analysis of NEPA documents from both agencies has showed that there are differences in methodologies in impact analysis, data collection and use, techniques and technologies and overall report format. Despite the fact the two agencies are working with noise producing elements that cause similar impacts to protected marine mammals, there are no commonalities between the two in terms of environmental impact assessments and no evidence of idea sharing. Both agencies could gain to learn from each other in terms of information and protocol sharing. One aspect of information that would be beneficial to both agencies to share is the environmental characteristics of regions of the U.S. EEZ. Sharing this information from both sides would be beneficial in that it would reduce redundancy in data collection and the cost of impact analysis. It is possible that idea sharing could also encourage both agencies to be more comprehensive in their studies if they are interacting with the other and being held accountable for their analyses by the agencies themselves, NMFS as the regulatory agency for marine mammal interactions, and the general public. One opportunity for a collaborative effort that would be beneficial for both agencies is incorporating the Arctic region in the SERDP Seamap project. Within the project there is currently no information on habitat suitability surfaces or species distribution information for marine mammals in the Arctic region. Both agencies could benefit from collaborative efforts in this context. BOEMRE would also gain to learn about the ESME and AIM programs that the Navy has developed to address more adaptive mitigation practices.

It would also be useful to develop a mechanism for more transparency in analysis and document availability for both agencies. The transparency of the Navy's NEPA process was much better than that of BOEMRE. All of the Navy NEPA documents concerning sonar were located in the same place, and within the documents, the processes followed and information used was easily found. The BOEMRE documents were not as easy to discover, and much of the important information for understating their process was either buried in the thick encyclopedic format or non-existent. It would be useful for BOEMRE, in its restructuring, to address this issue, and make these documents, that are required to be public knowledge, to actually be readily available to the public.

The analysis of both the U.S. Navy and BOEMRE has allowed the methodologies of both of these agencies, regarding acoustic sources and marine mammals, to be addressed and exposed in a comparative format. As both of these agencies are producing similar impacts on protected marine mammals, it would be expected that both agencies would have similar protocols in analysis and assessment, but this has proven not to be the case. It is the hope that the issues addressed in this section will aid in more adaptive mitigation by BOEMRE and more collaborative efforts between both agencies so that acoustic impacts to marine mammals can be mitigated effectively overall.

SECTION II:

Transmission Loss Modeling and MATLAB® / ArcGIS® Integration and Interpolation Tool

1. INTRODUCTION

As discussed earlier in Section I, Transmission Loss (TL) is an important component of underwater acoustics. TL can play a very important role in the way the sound is received by the marine animals within specific vicinity, and what the potential for impacts may be. The amount of TL from a source is based on the type of sound source (continuous or impulse), the energy level, frequency and direction of the source, and the physical characteristics of the marine environment where the source is operated. The physical marine environment is a key component of determining accurate TL, and, as was observed in the NEPA documents analysis for this report, was the most commonly omitted component of the TL process.

It was the goal of this section to address this issue and produce a geospatial tool based in a Geographic Information Systems (GIS) format that could be used to display the TL patterns around a point source within a given survey site. The product could then play an important role in overall effective mitigation for protected marine mammals from the sound. Based on what has been determined in the NEPA analysis section of this report, what is greatly lacking in the BOEMRE analyses of potential acoustic impacts and overall take calculations is acknowledgement of changing physical and environmental characteristics of the survey area. While acoustic models have been shown to both under and over estimate the amount of sound transmission and there are often large assumptions made with then, models can be valuable tools in risk determination when other techniques, such as field verification are not feasible in the assessment timeframe. For example, models can allow the user to address localized changes in acoustic transmission which can then provide information that will allow for more accurate take calculations, or adaptive mitigation. Models can also aid in determining the bounds of a problem by allowing the analyst to address the best and worst case scenarios of the problem.

By developing a GIS tool that allows a user to run an acoustic model in a separate computing program such as MATLAB®, then integrating the acoustic model outputs into a geospatial context, better visualization of the transmission loss and more adaptive mitigation will be possible. The hope is then that it would be possible to also integrate other geospatial models such as habitat suitability or density surface models that would allow for further impact analysis on more local scales.

2. BACKGROUND

Within the seismic industry, adaptive mitigation is not often used and accurate representations of their areas of concern, relating to environmental impacts, seems limited and constrained. In order to effectively determine how protected marine mammals will be impacted by a sound source, it is important to determine how that sound source will transmit within a given location, and how the sound transmission may interact spatially with other components. This can be achieved through the use of models that use local information to estimate the desired outcome. For this study, two types of models are being used: acoustic propagation, and geospatial interpolation. Both of these techniques can be used to better understand the dynamic environment that a seismic survey is being carried out in, and aid in effective and adaptive mitigation of the sound source.

2.1 Acoustic Models

There are various mathematical approaches that can be used to determine underwater acoustic propagation and transmission loss. These approaches are applied in models to give an estimate of the acoustic field. The success of the model and the estimate produced greatly depends on the "quality of the… information used…" (NRC 2003) The mathematical approaches include normal mode, wavenumber integration, ray theory and the parabolic equation. These approaches are then implemented in models which then produce data that describe how sound will travel based on the characteristics of the environment and the mathematical approach itself. Each of the theories (and models thereafter) can be beneficial depending on varying factors of the situation being modeled.

Normal mode models can be very useful and efficient for modeling frequencies below 1000Hz, but its strong range-dependency can limit its accuracy. An example of a normal mode model is KRAKEN which allows for a 3-dimensional calculation. Wavenumber integration is also efficient at frequencies below 1000Hz, however this theory is limited to range-independent areas. An example of the use of this theory is the SCOOTER model. Ray theory is found to work most efficiently at frequencies above 1000Hz, and is fairly accurate for all environments (range dependent and independent). An example of the use of this theory is the BELLHOP model which uses beam tracing theory (a derivative of ray theory) to track deep reflections from a source to a receiver.

The last theory is the parabolic equation (PE). PE is useful with frequencies below 1000Hz and in range dependent environments. An example of this theory is the RAM model. The RAM model was developed at the Naval Research Laboratory and its range dependency makes it useful in situations such as shallow water where the sound waves are likely to be interacting with the surface and the bottom (Collins 1993). According to Collins, RAM "is the most efficient PE algorithm that has been developed."

The RAM model has been used in various studies conducted by the Naval Research Laboratory, as well as becoming more common within individual / private research as well. One of the more recent uses if RAM within the Naval context was in the Effects of Sound on the Marine Environment (ESME) program. Within the ESME program, RAM performed well in uneven bathymetric and spatially-varying sound speed profile conditions. Despite the fact that RAM is a Naval program it has been made available to the public and can be applied by any researcher who wishes to use this PE method for ocean acoustic propagation studies.

There have been a number of studies that have used RAM applied not only to sonar and explosives (as the Navy does), but also to oil and gas seismic source operations. Hannay *et al*. (2010) used the RAM model in the propagation of underwater sound from an industry standard seismic air-gun array during the soft-start process in Arctic waters. Tashmukhambetov *et al*. (2008) used a modified version of RAM to quantitatively model the absolute pressure from a three-dimensional seismic array in the Gulf of Mexico. And lastly, DeRuiter *et al*. (2006) used the RAM model to determine transmission loss from a source to receiver in the Gulf of Mexico. The source being an industry standard seismic air-gun array, and the receiver being a DTag attached to a free swimming sperm whale. All three of these studies display the various uses of the RAM model, and how it has been applied to underwater acoustics for elements of the oil and gas industry.

Another aspect that is important to consider within acoustic modeling is the nature of the sound source. Broadband sound sources are common in underwater acoustics; a single frequency rarely dominates within an acoustic signal. Seismic, as well as sonar sources, often operate at a wide range of frequencies, making it important to understand the full range of frequencies being observed in order to understand how the sound will transmit (Harrison and Harrison 1995; Au and Hastings 2008). For broadband systems such as sonar and seismic air-gun arrays, assuming single frequency propagation can be misleading. Frequency and range averages have been used to model and represent the broadband nature of these systems and can avoid the necessity of multiple model runs in order to cover the frequency spread of the system (Harrison and Harrison 1995), but these averages can be difficult to interpret particularly when using a logarithmic unit such as dB.

Along with the nature of the sound source, it is also important to understand the environmental conditions of the area of concern. Environmental characteristics of the area play an integral role in the propagation of sound from the source. Important environmental characteristics consist of the salinity, water temperature, depth (all 3 which integrate to form the SVP), any local currents and the composition of the bottom sediments. Bottom sediment composition is most important where depth is a limiting factor such as in shallow water conditions where interaction with the bottom could greatly affect how the sound propagates. By knowing the environmental characteristics of the area, one is able to determine the sound velocity profile or SVP. The shape of the SVP with depth can be an indication of how the sound will travel with depth and range. In certain conditions, for example, a surface duct can form trapping high frequency sounds from seismic arrays and carrying those frequencies with relatively little transmission loss (DeRuiter *et al*. 2006). Knowledge of a physical condition in the water column, such as this, can aid in better understanding the propagation, and potential implications that may have for mitigation of the source.

2.2 Geospatial models

The second component of this study includes a model developed to allow for geospatial visualization and analysis of acoustic propagation from a point source, such as a seismic air-gun array. Geospatial analysis is a rapidly growing field, especially in the marine system, and can allow for adaptive management techniques where they have not previously been used. The technique is used to relate geographic locations of variables and explore interactions in space. This can be useful when thinking about how, in the present case, protected marine mammals may be impacted by underwater acoustic sources.

Geospatial analysis is associated with powerful spatial software such as Geographic Information Systems (GIS) and analytical methods. "GIS is a system used to describe and characterize the earth and other geographies for the purpose of visualizing and analyzing geographically referenced information (ESRI ArcGIS® 10 Help 2010)." The use of this system can allow for the integration of multiple geospatial analyses and aid in visualizations that can assist in management decisions

Prior to this study, the integration of acoustic propagation and transmission loss data derived from acoustic models calculated in the MATLAB® computing program into a GIS format had not been demonstrated. By integrating this information in ArcGIS®, visualizations of point source sound fields can be effective for mitigation. Within this system, multiple techniques can be used to create the visualizations. For this tool, interpolation of the data points was chosen to display how the sound propagated away from the source at varying depth levels.

Interpolation is a technique that creates a grid surface from the data points provided in order to display a continuous surface for analysis. There are four interpolation techniques present in the ArcGIS® format. These are: Inverse Distance Weighted (IDW), Kriging, Natural

Neighbor and Spline. Depending on the desired end product and the nature of the data points being used, the interpolation technique chosen may vary. For example IDW is useful for scattered data points and is based on the assumption that points closer together are weighted greater than those farther away when forming the interpolated surface, whereas the Spline method can be useful when interpolating between points of equal distance and produced a smooth interpolated surface. The interpolation method chosen can alter the way the final output data is represented, and up to the discretion of the analyst based on what he/she wishes to display or analyze with the interpolated surface.

The interpolation of data points from MATLAB® can then aid in visualization of the sound fields, as well as further geospatial analysis with other models such as habitat suitability and density surface models. The integration of these data streams has not yet been explored and could provide more accurate and dynamic information about the interactions of protected marine mammals and seismic air-gun arrays in areas of concern.

3. METHODS

3.1 Transmission Loss Models & GIS Tool

Propagation models are an important aspect of understanding how an underwater sound source will impact the surrounding environment. While they cannot provide information for the exact propagation of sound, they can give a better idea of how the sound will travel from the source given the local environmental characteristics and the characteristics of the sound source. For current analysis, the RAM model (Shyu & Hillson 2006; Houser 2006) was used to develop transmission loss calculations from a seismic point source in a given location out to ranges of 11km and to depths of 55meters. To display the utility of this model I focused on one study site, which is the location of a current seismic survey activity in the Arctic Ocean that has been approved and permitted by NMFS and BOEMRE for oil and gas exploration and covers 915mi^2 (Figure 1). The importance of this chosen location is that it is an area of growing interest in the oil and gas industry, and it appears that little work on developing new ideas and tools to better understand the acoustic environment associated with individual/dynamic seismic has been done in this Arctic region.

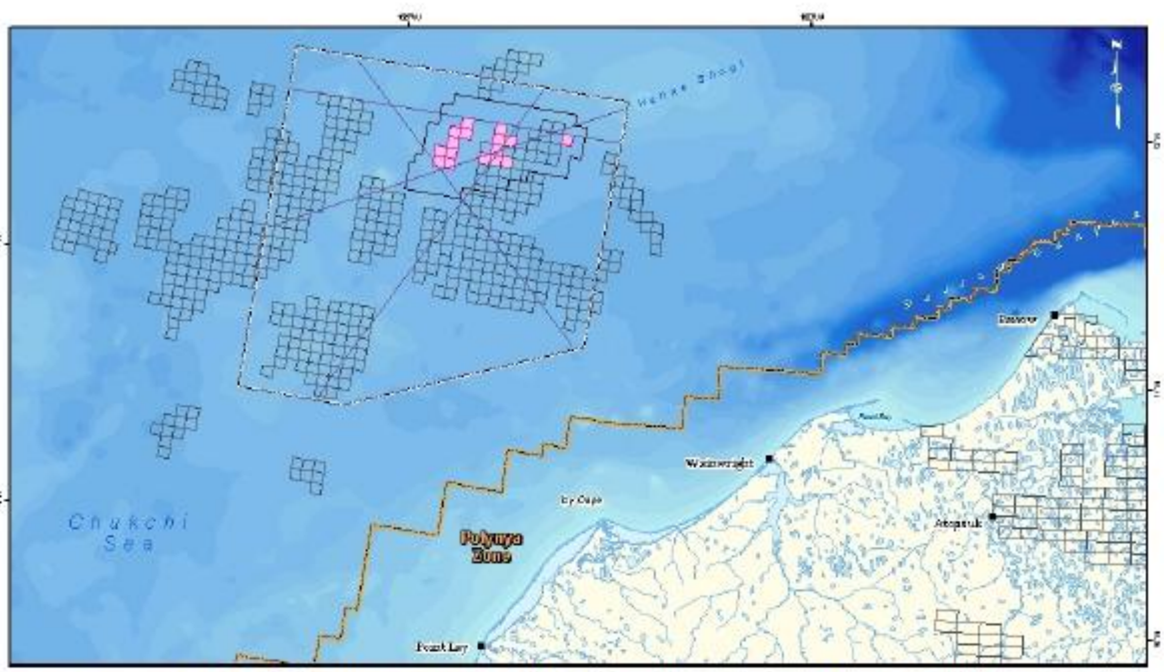


FIGURE 1. Location of the 3D seismic survey area (black outline) and 2D tracklines (purple lines). **The dotted line represents** the permit area and encompasses all 2D tracklines and the 3D survey area. The boundary of the polynya is shown by the orange line. Map prepared for by ASRC Energy Services.

Figure 1. StatOil survey plot from StatOil IHA 2010

The model chosen is useful in range-dependent situations such as a sloping or irregular bottom (Richardson *et al*. 1995). The propagation models are based on the following environmental and physical characteristics:

1) Sound speed profile (developed from local salinity, temperature and depth data)
2) Bottom profile
3) Bottom sediment characteristics

The anthropogenic sound source characteristics for the model were based on actual source information from recent seismic survey activity in the Arctic Ocean (Statoil 2010). The source information consists of:

1) Source level – 3000in^3/array; 245dB re1μPa rms, 0-205Hz (average frequency at 100Hz)
2) Source size – 26 total gun; 2 sources; 3 sub-arrays
3) Source depth – 6m below surface
4) Receiver Depth – 6m

3.1. (a) MATLAB® modeling

The transmission loss modeling was done in conjunction with the Physical Oceanography department at Wood Hole Oceanographic Institution (WHOI). The RAM model was run in MATLAB® (Appendix I, Script 1). Multiple runs were done with varying environmental and physical characteristics throughout the survey area. The goal was to show how sound propagation and transmission loss can change within a single seismic survey area and this must be taken into consideration in the impact analysis and later mitigation measures applied to oil and gas seismic surveys.

The environmental and physical data was obtained from a number of sources:

1) Bathymetry data: NOAA National Geophysical Data Center (NGDC) (NGDC 2011)
2) Salinity & Temperature Data: National Oceanographic Data Center (NODC) operated by NOAA. Data parameters for downloading were:
    a. <u>Coordinates of the test site</u>: 72.125N, 162.375W, 70.375N, 165.0W
    b. <u>Grid</u>: ¼ degree
    c. <u>Figure Type</u>: Climatological Mean
    d. <u>Time Period</u>: August & October (separately received data)
    e. <u>Depth</u>: Surface (will give data for all depth available for those data points)

The sound speed profiles for each location on average and for each data point were calculated using the MATLAB® Acoustic toolbox Seawater Version 3. The function run was sw_svel. The product from this was the sound speed (*c*) and sound velocity profiles (SVP) for each data point. The SVPs can be used to understand the nature of the acoustic environment, and allow the person analyzing the information to get a general idea of how sound should be propagating in this environment.

The sound speed matrices developed for each season were then important components for the input within the RAM transmission loss model. A script was developed to run the RAM model within the MATLAB® program; run_plot_ram.m (Appendix I, Script 1). The script allows the user to alter the input file (arctic.in) as often as possible, plots a transmission loss from the point to receiver figure and the decibel loss figure. It also exports the transmission loss data calculated within the model to a text file that can later be used in a python script that converts MATLAB® data into data that is useful in the ArcGIS® format for spatial analysis.

3.1. (b) ArcGIS® Tool Development

The last step was to develop an ArcGIS® tool that allows the results of the propagation models run in MATLAB® to be integrated with a Geographic Information System (GIS) to allow for further geospatial analysis and better visualization of the various acoustic propagation situations. This was done through the development of a Python script that uses exported matrix data from MATLAB®, converts it to data with spatial information, and displays the information within the Arc interface. The tool is designed to allow for user defined input points (latitude & longitude) of the point source, and interpolation methods of the transmission loss data. The python process was broken into two scripts. The first script: sys_matlab_to_arc.py (Appendix I, Script 2), creates point shapefiles that are used to represent a point in space where the transmission loss was calculated within RAM. Also within the script, the text files exported by the run_plot_ram.m MATLAB script are used to populate the shapefiles created. The final product of this script is a merged shapefile that is populated with the transmission loss data for each point within the shapefile (Appendix II, Figure A1).

The second script: sys_project_and_interpolation.py (Appendix I, Script 3), takes the final merged shapefile from the first script and allows the user to decide which interpolation he/she wishes to use for their particular interests. The final interpolated outputs are both in the UTM projection (which the entire script was run in) and North American Datum 1983. The UTM projection output allows the user to see the results in meters from the source, and the North American Datum allows the user to perform more accurate geospatial analysis is necessary as the outcome in displayed in decimal degrees.

3.1. (c) Practice Analysis Using RAM and ArcGIS® tool

An analysis was run to test the ability of the ArcGIS® tool in displaying TL data from RAM outputs in a geospatial context. Two scenarios were used to test this tool, and its effectiveness in displaying varying acoustic propagation within a test site. Data was collected for the test site for two months (August & October) during which time a seismic survey is likely to be run in the Arctic and the acoustic propagation between these two months is expected to differ. Within in ArcMap 10.0®, four random sample points within the test site were generated using 'Create Random Points' tool (Figure 2). These random points were used for the remainder of the analysis.

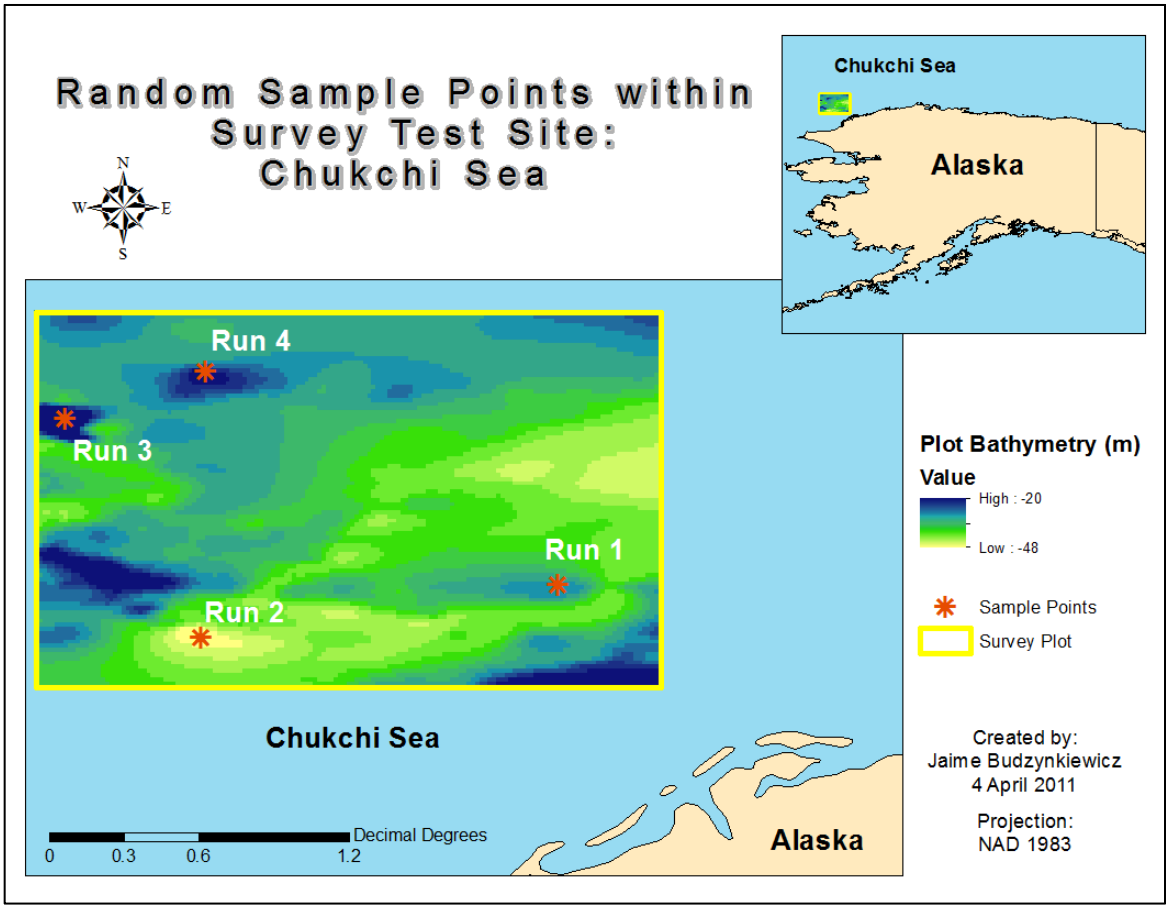
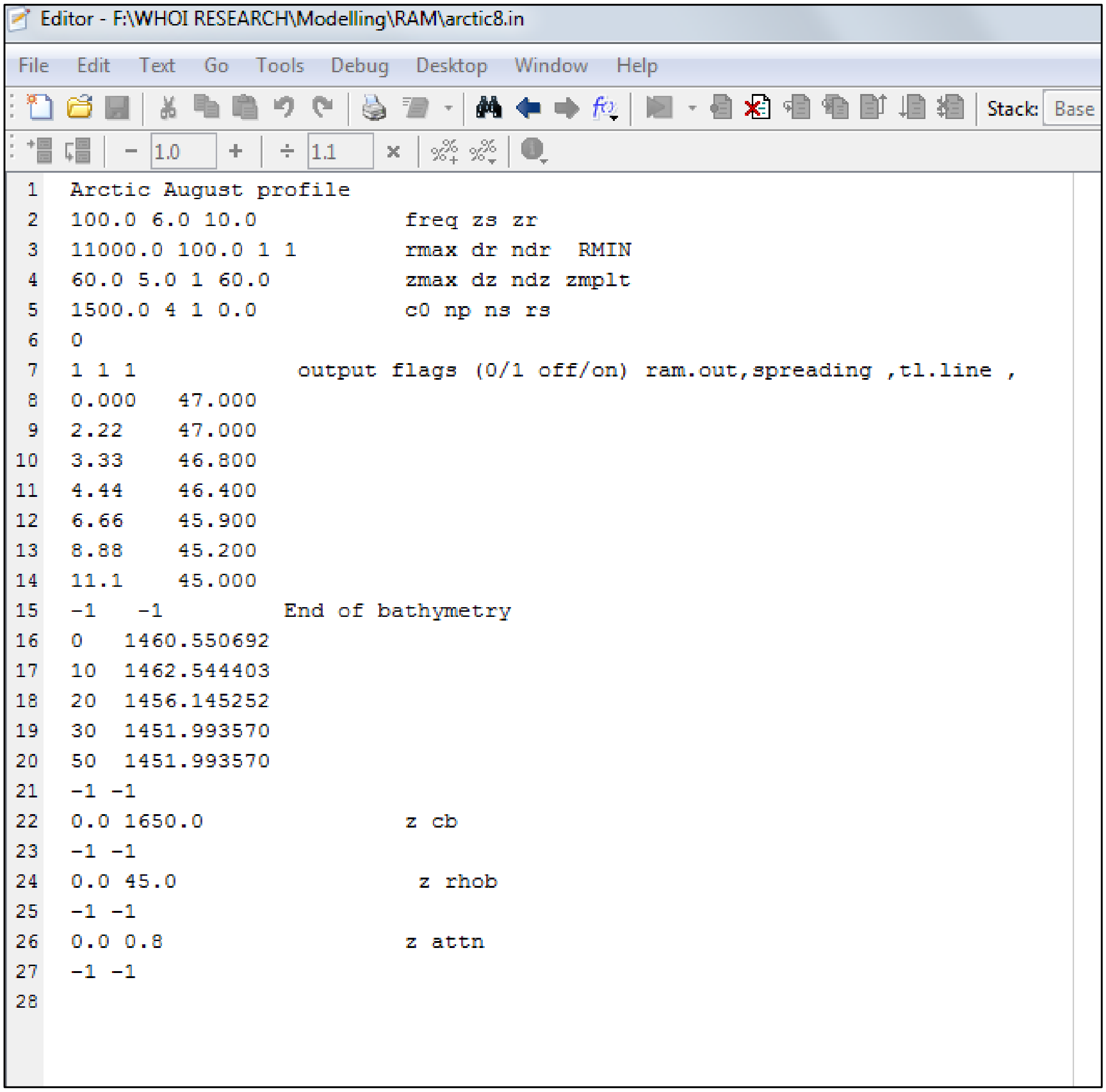


Figure 2. Spatial locations of the random points generated serving as the basis for all the model and

Using MATLAB® a sound speed matrix was determined for the entire test site. This information was then used to extract the sound speed for the four sample points. The frequency chosen was 100Hz, as this is an average of the 0-205Hz frequency range reported by StatOil 2010. The source and receiver depths were both set to 6 meters. The max depth of the area was set at 60 meters with 5 meter intervals set for the output. The reference sound speed was set to 1500ms^{-1} and the Padé number was set at 4. It was determined that a maximum range of 11km would be used with 100 meters intervals (Figure 3).




```
Arctic August profile
100.0 6.0 10.0             freq zs zr
11000.0 100.0 1 1          rmax dr ndr   RMIN
60.0 5.0 1 60.0            zmax dz ndz zmplt
1500.0 4 1 0.0             c0 np ns rs
0
1 1 1              output flags (0/1 off/on) ram.out,spreading ,tl.line ,
0.000    47.000
2.22     47.000
3.33     46.800
4.44     46.400
6.66     45.900
8.88     45.200
11.1     45.000
-1    -1          End of bathymetry
0    1460.550692
10   1462.544403
20   1456.145252
30   1451.993570
50   1451.993570
-1 -1
0.0 1650.0                 z cb
-1 -1
0.0 45.0                    z rhob
-1 -1
0.0 0.8                    z attn
-1 -1
```

Figure 3. Example of a .in file used as the RAM input.

Within the 11km range, the depth around each sample point was determined using a bathymetry raster file obtained from NGDC. A cross section of the range buffer was taken using the 3D Analyst tool bar. This cross section was determined by the user to be the most representative of the entire 11km radius. The cross section was then used to determine how the depth changed with range away from the point source and was used as an input into in the .in file for RAM. The SVPS's were created and sound speed as calculated by using the Acoustic toolbox Seawater Version 3 in MATLAB® was also used (Appendix II, Figure A2-3). For this section, the depth intervals used were 0m (surface), 10m, 20m, 30m and 50m, based on the format the temperature and salinity data obtained from the NODC site. The last set of information in the .in file was the bottom sediment data, which were obtained from the NGDC Deck 41 Superficial Sediment Composition (NGDCb). The sediment composition of the test site was primarily sand, so the geo-acoustic properties of sand taken from Jensen *et al*. (2000) were used in the model.

RAM was run via run_plot_ram.m for each sample point for both August and October scenarios for a total of eight runs. The eight output text files from this process where then used to as inputs for eight separate runs of the two scripts forming the ArcGIS® tool TransmissionLoss.tbx. The final outputs from the ArcGIS® tool were then displayed in a series of maps to allow for visualization of the varying acoustic transmission loss situations throughout the test site.

4. RESULTS and DISCUSSION

The overall goal of this section was to develop a GIS tool that would allow for the integration of acoustic models run in MATLAB® into ArcGIS® for geospatial visualization and analysis. With the development of the tool it was also important to test its ability to achieve this goal by using a current oil and gas seismic survey as a hypothetical analysis situation. It was through the practice analysis that the importance of this tool was displayed, showing the large variations in acoustic propagation throughout the test site that could play important roles in effective mitigation during a seismic survey.

4.1 Practice Analysis, Environmental Conditions and RAM results

As the first component of this study it was important to establish the environmental conditions that were present within the study site. These consisted of the temperature and salinity profiles, which were combined with depth to determine the SVP of the overall study site during both August and October (Appendix II, Figures A2 & A3). These analyses revealed differences in the SVP's between the two months, confirming the fact that there will be changes in acoustic propagation and transmission loss between the two seasons and throughout the study site. These figures also display a layer with negative refraction in August where sound speed is decreasing with depth, and in shallow water conditions (such as those in this study site) the sound propagates through reflections off the bottom (Brekhovskikh and Lysanov 1991). This may then be an important factor in the subsequent RAM runs. It is also important to recognize that while the general trends of the SVP's are similar in each month, the actual SVP's vary greatly throughout the site, which can also have implications on the transmission loss at varying sample points.

The eight RAM runs associated with the four sample points and two separate months showed interesting differences in TL with time and location. The MATLAB® outputs from the RAM model display the changes in decibel loss with range and depth. The differences are displayed well by comparing across place: Run 1 in August (Figure 4) and Run 4 in August (Figure 5); as well time: as Run 2 in August (Figure 5) and Run 2 in October (Figure 6). There is then the potential to use these results and apply them to a spatial context for further analysis. (The full compilation of the MATLAB outputs, dB surface and transmission loss of source to receiver, can be found in Appendix II, Figures A4-19)

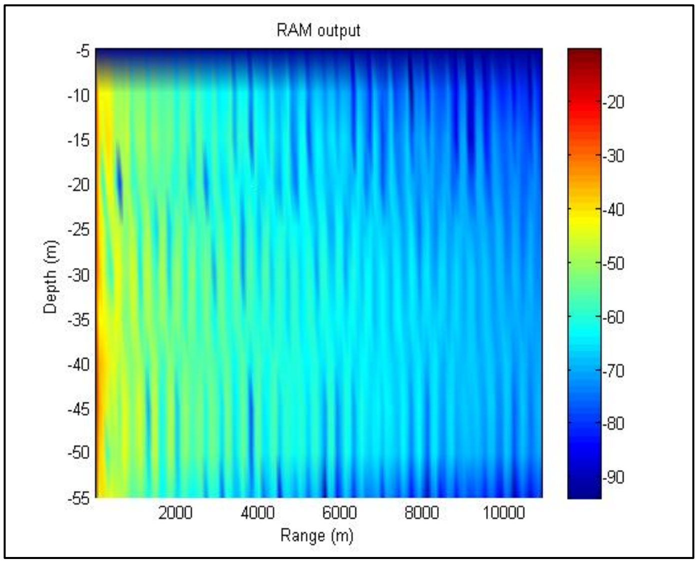


Figure 4. **August Run 1** dB loss for entire water column within a 11km range from the point source. dB re 1μPa

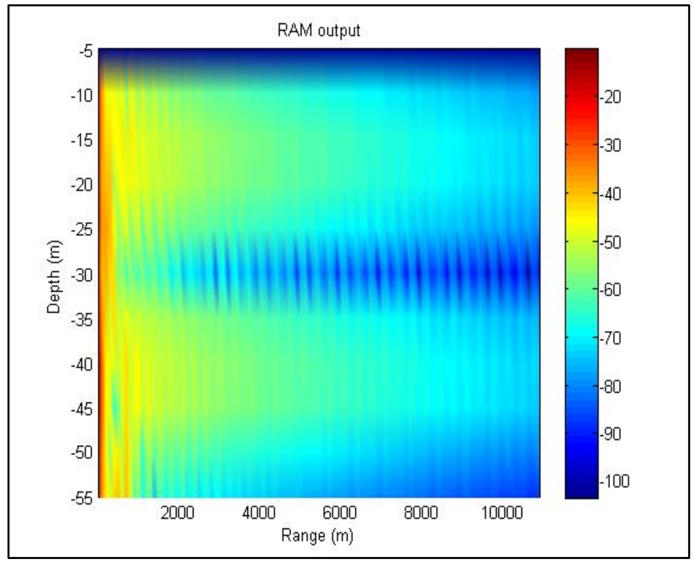


Figure 5. **August Run 4** dB loss for entire water column within a 11km range from the point source. dB re 1μPa

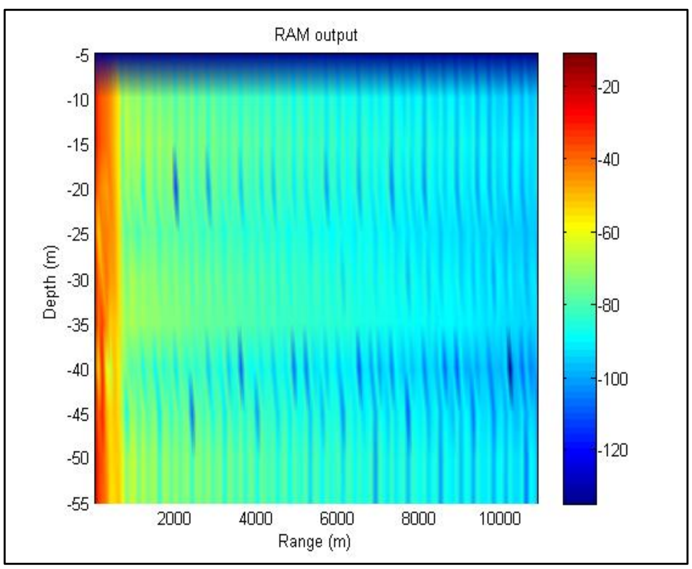


Figure 6. **August Run 2** dB loss for entire water column within a 11km range from the point source. dB re 1μPa

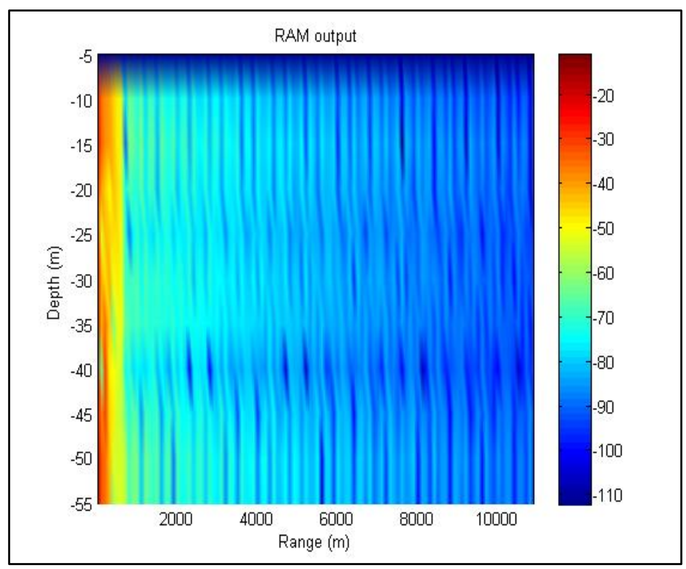


Figure 7. **October Run 2** dB loss for entire water column within a 11km range from the point source. dB re 1μPa

4.2 GIS Tool Results

The integration of the MATLAB® data into the GIS tool then allowed the observer to see the spatial relationships of the sample points and how transmission loss changes with location, depth and time. Looking at Run 1 there are distinct TL differences in the top three layers between August and October (Figures 8 & 9). Within Run 1 in October (Figure 9), there are also distinct differences in the TL surface at 10m and 55m, where as in August (Figure 8) there is little change between the 10m and 55m TL surfaces.

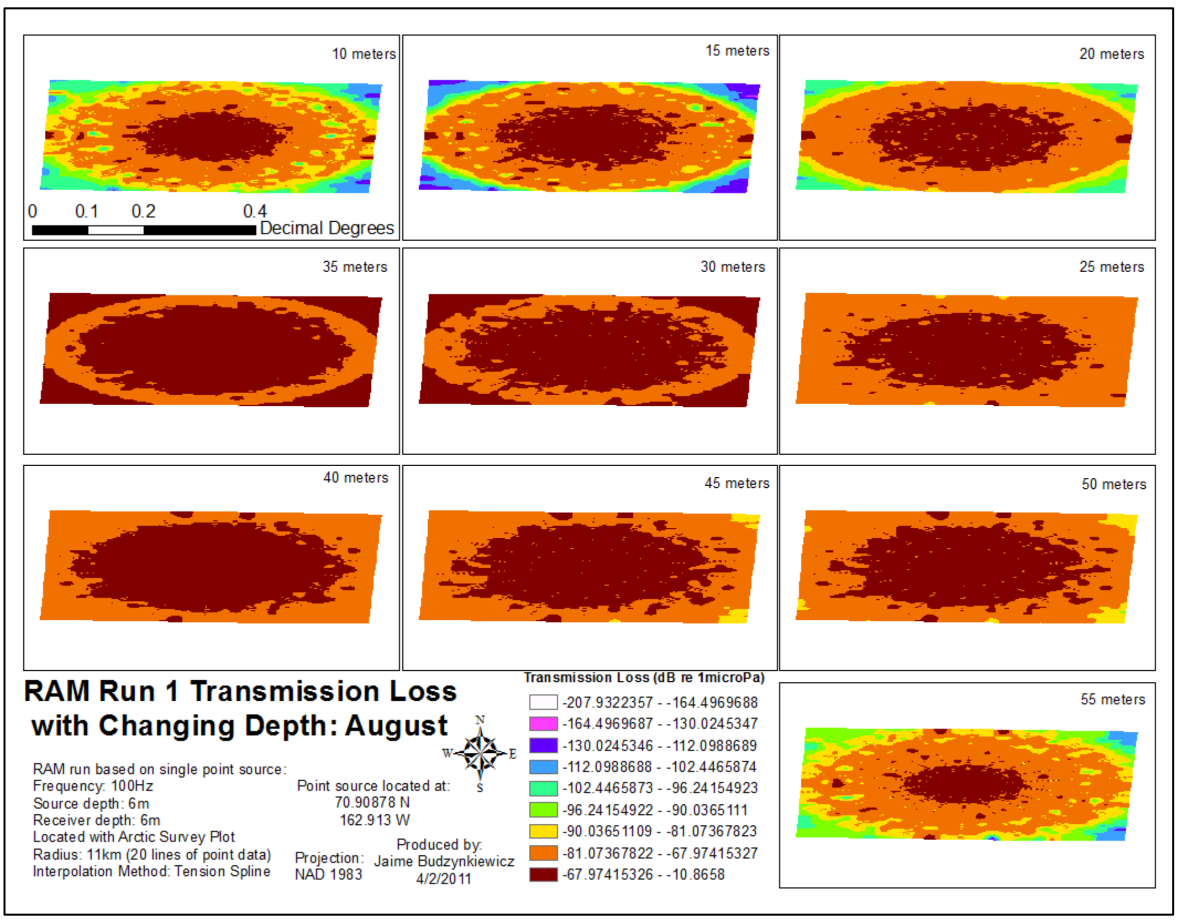


Figure 8. Run 1 August

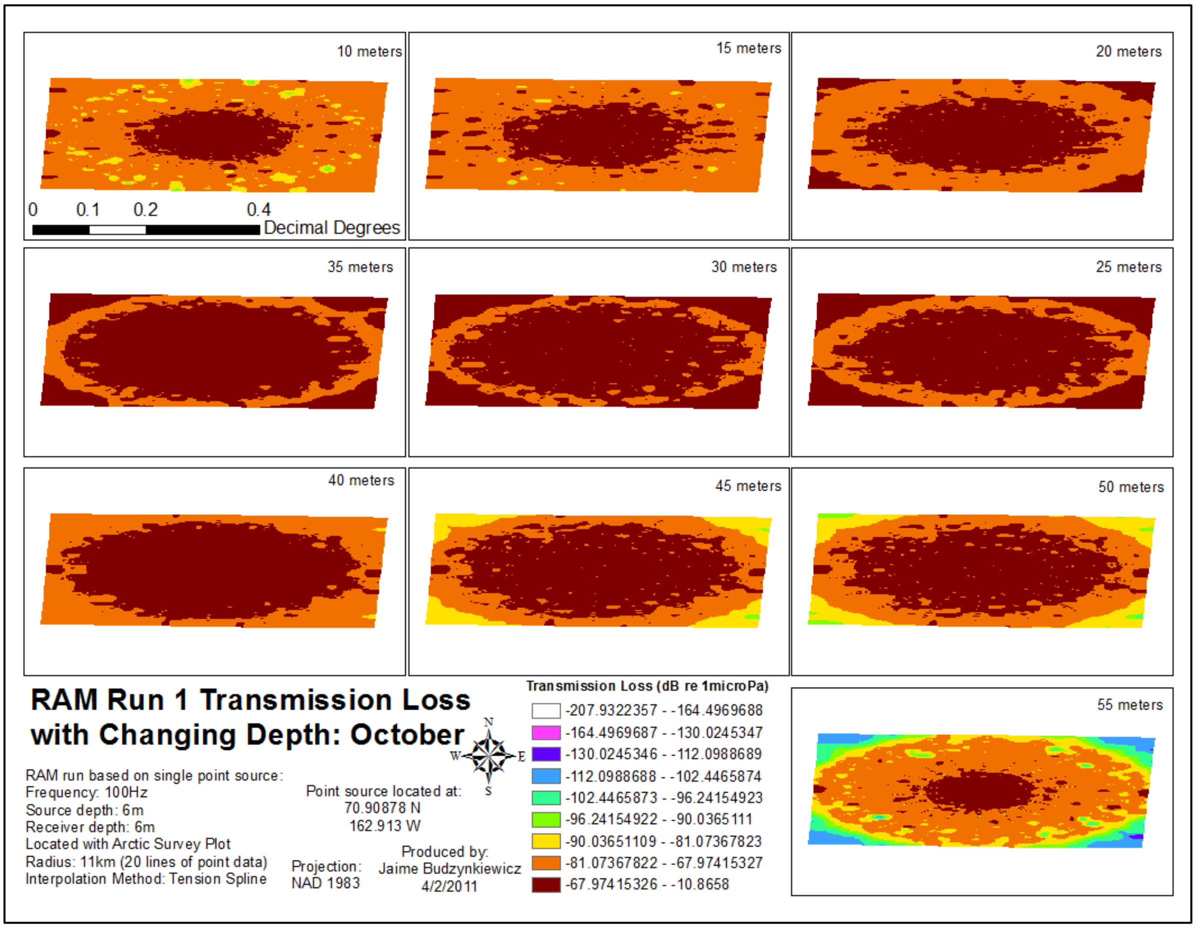


Figure 9. Run 1 October

There are also differences in place within the test site. When looking at just the 10m TL surfaces at the four locations the TL variation is evident (Figure 10). This can be attributed to the differing SVP's and bathymetry of all four locations. The results from all four tests runs (August and October) can be found in Appendix II Figures A20-28. The compilation of all eight maps allows the viewer to observe the changes in a larger context.

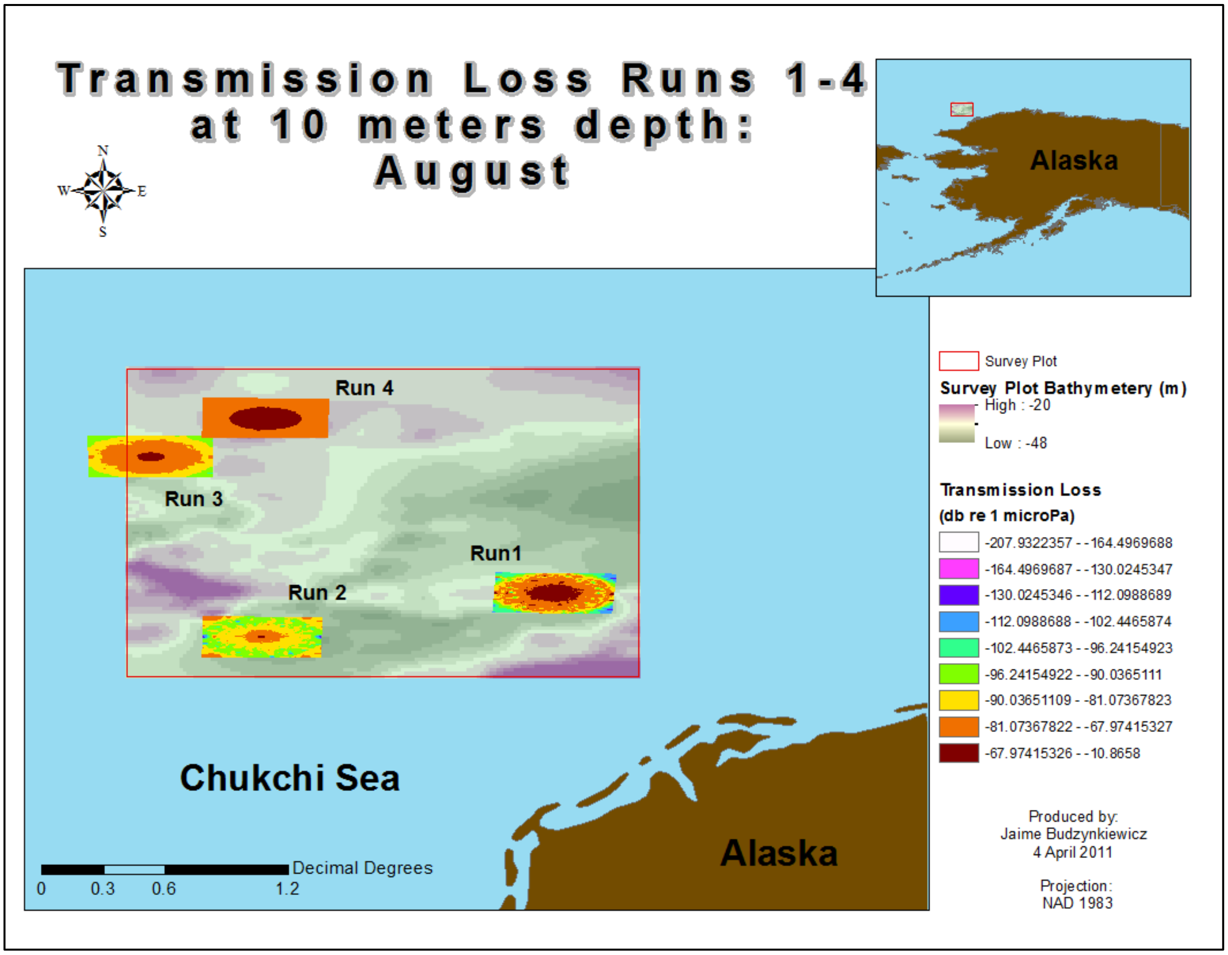


Figure 10. Comparison of four TL runs at 10meters depth. Showing the variability in TL with location.

The GIS tool developed has aided in producing spatial products of TL surfaces that can be used for general visualizations, or for further geospatial analysis in association with other variables (such as habitat suitability surfaces) that can aid in effective management and mitigation decisions. By using the tool to address a potential situation, the value in understanding the environmental characteristics and local variables within a survey plot becomes evident. In Section I of this report, the NEPA analysis showed that BOEMRE and the oil and gas industry have paid little attention to individual variables, and have often neglected a more focused review of the area of concern. By doing this, the acoustic impacts to protected marine mammals can be downplayed and the number of allowable takes due to acoustic interactions can be inflated.

The products of the tool also show that local variability can be present even within a smaller location (915mi^2). Differences within the area can then have implications on how a seismic project will proceed, and what mitigation measures may be required. By recognizing the variability within the area, the hope is that a more adaptive mitigation protocol could be admitted instead of the current stagnant safety radius method that is used or reliance on environmental data from other sections of the Arctic region that are being applied liberally throughout the Arctic ocean. The need to address acoustic propagation and TL on a more local scale becomes evident here.

It is also important to address the limitations of this model and the assumptions that were made. No model is perfect; however, by understanding the assumptions, the data can be used effectively. For the RAM model, there are multiple assumptions that could have influenced the outcomes, the first being the frequency chosen for all eight of the runs. 100Hz was chosen as it was the center frequency of the overall 0-206Hz frequency range for the seismic air-gun array as stated in the StatOil IHA (2010). It is likely that the chosen frequency is not the best representation of the seismic source, however for this project, the goal was to produce transmission loss grids that could be integrated into ArcGIS®, and the accuracy of the seismic array spectrum was of less concern. By maintaining the 100Hz input for all eight of the runs, consistency across all runs was apparent and allowed for later comparison based on other factors such as time of year and location. A more accurate representation would be necessary for alter use of this model for mitigation purposes.

The second assumption was that the depth profile was uniform within an 11km radius around the point source. In order to obtain bathymetry data and apply it to the RAM model, the most effective method was to develop an average bathymetry cross profile of the radius and apply those bathymetric changes with range to the RAM input. Bathymetry is an important variable for acoustic models of shallow water conditions. Interactions with the bottom can have great impacts on propagation and transmission loss, so it was necessary to have some component addressing the varying depth conditions to ensure that the results were as accurate as possible.

Within the GIS tool there are also several assumptions made and limitations to the tool. The first assumption of the tool is that, due to the nature of the MATLAB® TL data for each point source, the TL data is only related to a single line of data points extending to a range of 11km from the source. Thus it was necessary to create a pinwheel pattern around the point source so that interpolation between those points can be carried out later. This pinwheel affect of one line of data extending from the point source may cause bias to the tools output, however due to the averaged nature of the bathymetry and the SVP's calculated for each point source, the interpolation of the TL surface around the source can be assumed to be fairly accurate.

The second assumption made is that this point source is only a single activity, when in reality, during a seismic survey this source would be firing at intervals of 10-15 seconds along a predetermined shot line. This would then make cumulative sound exposure an important issue with the potential overlap of the TL surfaces. This RAM model and GIS tool do not take into account how the continuous firing would affect the acoustic propagation. This would be a potential next step in the process, and an interesting angle for future work and additions to the tool.

A few other caveats of this process are also important to mention. The RAM model does not take into consideration the configuration of the seismic air-gun array, which could have important implications into how the sound is transmitted into the water column and subsequently propagated. Also, the interpolation technique chosen by the tool operator can change the visualization outcome, and display some, fairly small, differences in the TL surface. Lastly, within the GIS tool, the script was written to project the final TL surface into the North American Datum 1983 projection. This then means that the section of the script setting this projection would need to be altered in order for the tool to be useful in locations where another projection may be more accurate and useful. Making this option more user defined is another task for future work.

Despite these caveats and assumptions, the idea behind the necessity and usefulness of the tool is still valid. Addressing the issue of local changes in environmental and physical conditions which can affect transmission loss, and the value in addressing the data in a spatial context for further analyses remains important in the further development or protected marine mammal acoustic mitigation and management.

5. CONCLUSIONS

As indicated in Section I of this paper, BOEMRE and the oil and gas industry are lacking innovative and adaptive procedures for understanding the acoustic environment within which they are operating and creating environmental impacts. Unlike the U.S. Navy, BOEMRE has not applied effort to understanding the physical environment of its areas of concern, and has greatly lagged behind in a addressing issues on a more local and individual scale. By developing the GIS toolbox (Transmission Loss.tbx), the goal was to demonstrate that accounting for acoustic propagation on a local level was important and that understanding the local environmental conditions can play an important role in the overall acoustic propagation within a zone. The spatial context in which it is addressed then becomes apparent. The ability to display and visualize the TL data in a spatial context also has greater implications for more adaptive mitigation and management through the integration of various other spatial techniques. Within this GIS tool, as well as others, the ultimate goal of addressing acoustic impact issues on a more local scale, and encouraging for adaptive and innovative acoustic impact assessment and mitigation techniques can be achieved.

ACKNOWLEDGEMENTS

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APPENDIX I
Scripts: MATLAB® and Python

Script 1. RAM Script: run_plot_ram.m

Editor - F:\WHOI RESEARCH\Modelling\RAM\run_plot_ram.m

```
% ----------------------------------------
%  run_plot_ram
%
%  run and plot ram in one place
%
% Adapted from Arthur Gaylord(WHOI) by:
%   Jaime Budzynkiewicz
%   4/2/2011
% ----------------------------------------

% First edit input profile
% arctic#.in

% Name of input profile
infile ='arctic10.in';

[success] = copyfile(infile,'ram.in');
if success == 0,
    error('file copy');
end

% Run ram
!ram


% Plot dB surface with depth and range
figure(1); clf
plotram

% Plot TL line with depth and range
figure(2); clf
load tl.line
plot(tl(:,1),-tl(:,2));
title('transmission loss s->r');
grid on;

% Output dB matirx for export to text file, adn later import to
% GIS format
dB = 20*log10(abs(P))

export(dataset(fliplr(rot90(dB,3))),'file','dB10_output_run2.txt')
```

arctic8.in | run_plot_ram.m

script | Ln 38 | Col 14 | OVR

Script 2. Python: sys_matlab_to_arc.py

```python
# sys_matlab_to_arc.py
# Description:
#   First script in series.
#   Takes text files that have been generated from a RAM acoustic
#   propagation model run in MATLAB and imports then into the ArcGIS system. The
#   text information is covnereted into point shapefiles that can
#   be used as the input in the next script (sys_project_and_interpolation.py).
#   This script has been developed to allow for user defined inputs
#   for the starting point source location, and where and how the files
#   will be stored.
#
# Created by:
#   Jaime Budzynkiewicz
#   jbudzynkiewicz@gmail.com
#   April 1, 2011

# Import modules
import sys, os, arcpy, math, numpy
from arcpy.sa import *
from math import cos,sin


# Input point source location.
# If point source location in decimal degrees, must convert to UTM.
# This can be done at http://home.hiwaay.net/~taylorc/toolbox/geography/geoutm.html
uX = sys.argv[1]    # UTM easting (Longitude)
uY = sys.argv[2]   # UTM northing (Latitude)

userX = float(uX)
userY = float(uY)

# Set the workspace. outWS and dataDir can be the same path name.
outWS = sys.argv[3]
arcpy.env.workspace = outWS
dataDir = sys.argv[4]
arcpy.env.overwriteOutput = 1
spatial_ref = os.path.join(dataDir,sys.argv[5])

# Name the output point files. They will be count consecutivly and be stored seperatly.
outputPts = sys.argv[6]

# Intialize the list object
files = []

# Begin the loop to creat the feature class. This loop will repeat 18 times for
# every 20 degree angle within a 360 degree circle. This will create the empty point shapefiles
# that will later be populated with decibal loss data from the Matlab text files.
counter = 1
```

```
for angles in range (0,360,20):
    ptFC = arcpy.CreateFeatureclass_management(outWS, outputPts + str(counter) + ".shp", "POINT", "", "ENABLED", "ENABLED", spatial_ref)
    files.append(ptFC)
    cur = arcpy.InsertCursor(ptFC,spatial_ref)

    #convert degrees to radian
    real = 90 - angles
    print angles
    radians = real * 0.0174532925
    counter = counter + 1


    # Because the Matlab data is displayed in a range of every 100 meters from the point source
    # out to a total range of 11km, the point shapefiles must be calculated in this context.
    for distances in range (1,11000,100):
        print distances

        #calculate changes in x and y to get new points
        ychange = (math.sin(radians)) * distances
        Y1 = userY + ychange
        xchange = (math.cos(radians)) * distances
        X1 = userX + xchange
        print Y1
        print X1

        P1 = arcpy.Point(userX, userY)
        P2 = arcpy.Point(X1, Y1)
        feat = cur.newRow()
        feat.shape = P2
        cur.insertRow(feat)

    del cur

# Adding the fields in the point shapefiles so they can be populated with the correct data
for file in files:
    ptFC = file
    Depthparameter = "Depth"
    for DepthSeries in range(1,11):
        fldName = '%s%s' %(Depthparameter,DepthSeries)
        arcpy.AddField_management(ptFC,fldName,"FLOAT")

# This is the saved MATLAB text file for which ever sound source / situation is being studied here.
MatLabTxt = sys.argv[7]

# Read in the .txt file exported from MATLAB containing the transmission loss data
valFN = os.path.join(dataDir, MatLabTxt)
# Create array from data file
valArr = numpy.genfromtxt(valFN,skiprows=1,delimiter='\t')

```

```
for file in files:
    ptFC = file

    #Create an update cursor and update values
    cur = arcpy.UpdateCursor(ptFC)
    cur.reset()
    for r in range(0,110):
        rec = cur.next()
        for c in range(1,11):
            val = valArr[r,c]
            fldName = 'Depth%s' %c
            rec.setValue(fldName,val)
        cur.updateRow(rec)
    del rec, cur


# Merging all 18 individual point shapefiles into one for later interpolation
# of decinal loss.
oldDB = files
newDB = sys.argv[8]
arcpy.Merge_management(oldDB, newDB, "")
print "Merged dB shapefile complete"
```

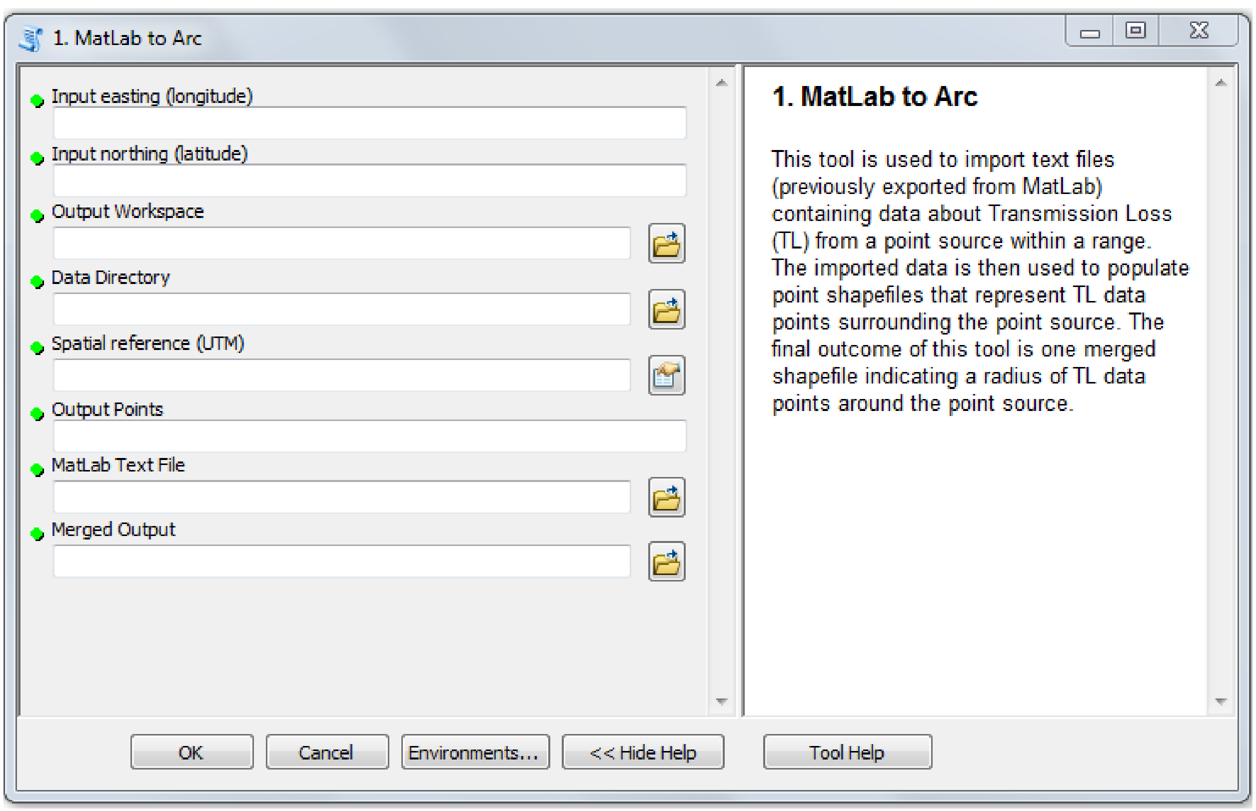


Figure A1. ArcGIS® interface for Script 2

Script 3. Python: sys_project_and_interpolation.py

```python
# sys_project_and_interpolation.py
# Description:
#   Second script in series.
#   Takes the merged shapefile created in the first script of this series
#   (sys_malab_to_arc.py) and allows the user to define the type of
#   interpolation technique he/she should choose based on the desired outcome
#   of the tool. The script creates interpolation in the UTM projection, as well
#   as projecting the interpolation into the NAD 1983 projection for better spatial
#   analysis.  The user can decide which output will work best for them.
#
# Created by:
#   Jaime Budzynkiewicz
#   jbudzynkiewicz@gmail.com
#   April 1, 2011

# Import modules
import sys, os, arcpy, math, numpy
from arcpy.sa import *

# Set the workspace. outWS and dataDir can be the same path name.
outWS = sys.argv[1]
arcpy.env.workspace = outWS
dataDir = sys.argv[2]
arcpy.env.overwriteOutput = 1
spatial_refOLD = os.path.join(dataDir,sys.argv[3])
spatial_refNEW =os.path.join(dataDir,r'C:\Program Files (x86)\ArcGIS\Desktop10.0\Coordinate Systems\Geographic Coordinate Systems\North America\NAD 1983.prj')

# Inputing the dB shapefile from the first script (db_final).
# And setting the user define output file path names
dB_final = sys.argv[4]
interpOutput = sys.argv[5]
interpPrj = sys.argv[6]

# Check out the ArcGIS Spatial Analyst extension license
arcpy.CheckOutExtension("Spatial")

# The user can chose which of the four interpolation methods he/she wishes to choose:
# Spline, Kriging, Natural Neighbor, Inverse Distance Weighted
userInterp = sys.argv[7]

if userInterp == "Spline" :
    counter = 1
    for counter in range(1,11):

        # Execute and save Spline Interpolation
        outputSplineDB = Spline(dB_final, "Depth" + str(counter), 87.208, "TENSION", 0.1, 12)
```

```
        ##outputSplineDB.save(r'F:\WHOI RESEARCH\Modelling\Data\Script_Outputs\Run3\dB8_spline' + str(counter) + '.img')
        outputSplineDB.save(interpOutput + str(counter) + '.img')

        # Project .img Raster from UTM to NAD 1983
        # This will allow the data to be used with other local data in the WGS format for
        # further spatial analysis as the user sees necessary.
        ##arcpy.ProjectRaster_management(r'F:\WHOI RESEARCH\Modelling\Data\Script_Outputs\Run3\dB8_spline' + str(counter) + '.img', r'F:\WHOI RESEARCH\Modelling\Data\Script_Outputs\Run3\db8_prj' + str(counter) + '.img', spatial_refNEW, "", "", "NAD_1983_To_WGS_1984_3", "#", spatial_refOLD)
        arcpy.ProjectRaster_management(interpOutput + str(counter) + '.img', interpPrj + str(counter) + '.img', spatial_refNEW, "", "", "NAD_1983_To_WGS_1984_3", "#", spatial_refOLD)
        counter = counter + 1

    print "Transmission Loss Interpolated and Projected"
    print "DONE!"


elif userInterp == "Kriging":
    counter = 1
    for counter in range(1,11):

        # Execute and save Spline Interpolation
        outputKrigingDB = Kriging(dB_final, "Depth" + str(counter), "Spherical", 87.208, "Variable 12")
        ##outputSplineDB.save(r'F:\WHOI RESEARCH\Modelling\Data\Script_Outputs\Run2\dB8_spline' + str(counter) + '.img')
        outputKrigingDB.save(interpOutput + str(counter) + '.img')

        # Project img Raster from UTM to NAD 1983
        # This will allow the data to be used with other local data in the WGS format for
        # further spatial analysis as the user sees necessary.
        ##arcpy.ProjectRaster_management(r'F:\WHOI RESEARCH\Modelling\Data\Script_Outputs\Run2\dB8_spline' + str(counter) + '.img', r'F:\WHOI RESEARCH\Modelling\Data\Script_Outputs\Run2\db8_prj' + str(counter) + '.img', spatial_refNEW, "", "", "NAD_1983_To_WGS_1984_3", "#", spatial_refOLD)
        arcpy.ProjectRaster_management(interpOutput + str(counter) + '.img', interpPrj + str(counter) + '.img', spatial_refNEW, "", "", "NAD_1983_To_WGS_1984_3", "#", spatial_refOLD)
        counter = counter + 1


elif userInterp == "NaturalNeighbor":
    counter = 1
    for counter in range(1,11):
```

```

        # Execute and save Spline Interpolation
        outputNNDB = NaturalNeighbor(dB_final, "Depth" + str(counter), 87.208)
        ##outputSplineDB.save(r'F:\WHOI RESEARCH\Modelling\Data\Script_Outputs\Run2\dB8_spline' + str(counter) + '.img')
        outputNNDB.save(interpOutput + str(counter) + '.img')

        # Project img Raster from UTM to NAD 1983
        # This will allow the data to be used with other local data in the WGS format for
        # further spatial analysis as the user sees necessary.
        ##arcpy.ProjectRaster_management(r'F:\WHOI RESEARCH\Modelling\Data\Script_Outputs\Run2\dB8_spline' + str(counter) + '.img', r'F:\WHOI RESEARCH\Modelling\Data\Script_Outputs\Run2\db8_prj' + str(counter) + '.img', spatial_refNEW, "", "", "NAD_1983_To_WGS_1984_3", "#", spatial_refOLD)
        arcpy.ProjectRaster_management(interpOutput + str(counter) + '.img', interpPrj + str(counter) + '.img', spatial_refNEW, "", "", "NAD_1983_To_WGS_1984_3", "#", spatial_refOLD)
        counter = counter + 1


elif userInterp == "IDW":
    counter = 1
    for counter in range(1,11):

        # Execute and save Spline Interpolation
        outputIDWDB = Idw(dB_final, "Depth" + str(counter),87.208,"", RadiusVariable("",""))
        ##outputSplineDB.save(r'F:\WHOI RESEARCH\Modelling\Data\Script_Outputs\Run2\dB8_spline' + str(counter) + '.img')
        outputIDWDB.save(interpOutput + str(counter) + '.img')

        # Project img Raster from UTM to NAD 1983
        # This will allow the data to be used with other local data in the WGS format for
        # further spatial analysis as the user sees necessary.
        ##arcpy.ProjectRaster_management(r'F:\WHOI RESEARCH\Modelling\Data\Script_Outputs\Run2\dB8_spline' + str(counter) + '.img', r'F:\WHOI RESEARCH\Modelling\Data\Script_Outputs\Run2\db8_prj' + str(counter) + '.img', spatial_refNEW, "", "", "NAD_1983_To_WGS_1984_3", "#", spatial_refOLD)
        arcpy.ProjectRaster_management(interpOutput + str(counter) + '.img', interpPrj + str(counter) + '.img', spatial_refNEW, "", "", "NAD_1983_To_WGS_1984_3", "#", spatial_refOLD)
        counter = counter + 1


else:
    print "Failed to Interpolate"
```

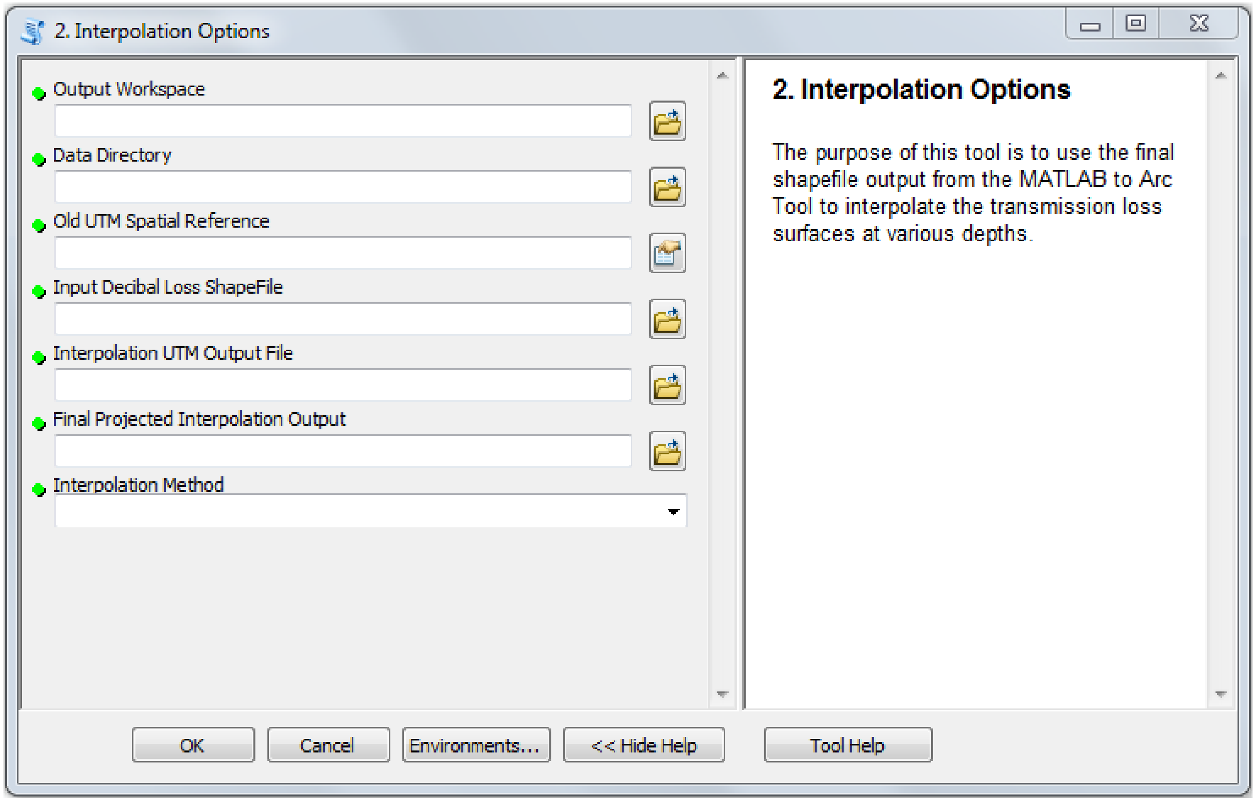


Figure A2. ArcGIS® interface for Script 3

APPENDIX II
MATLAB® Figures and ArcGIS® Maps

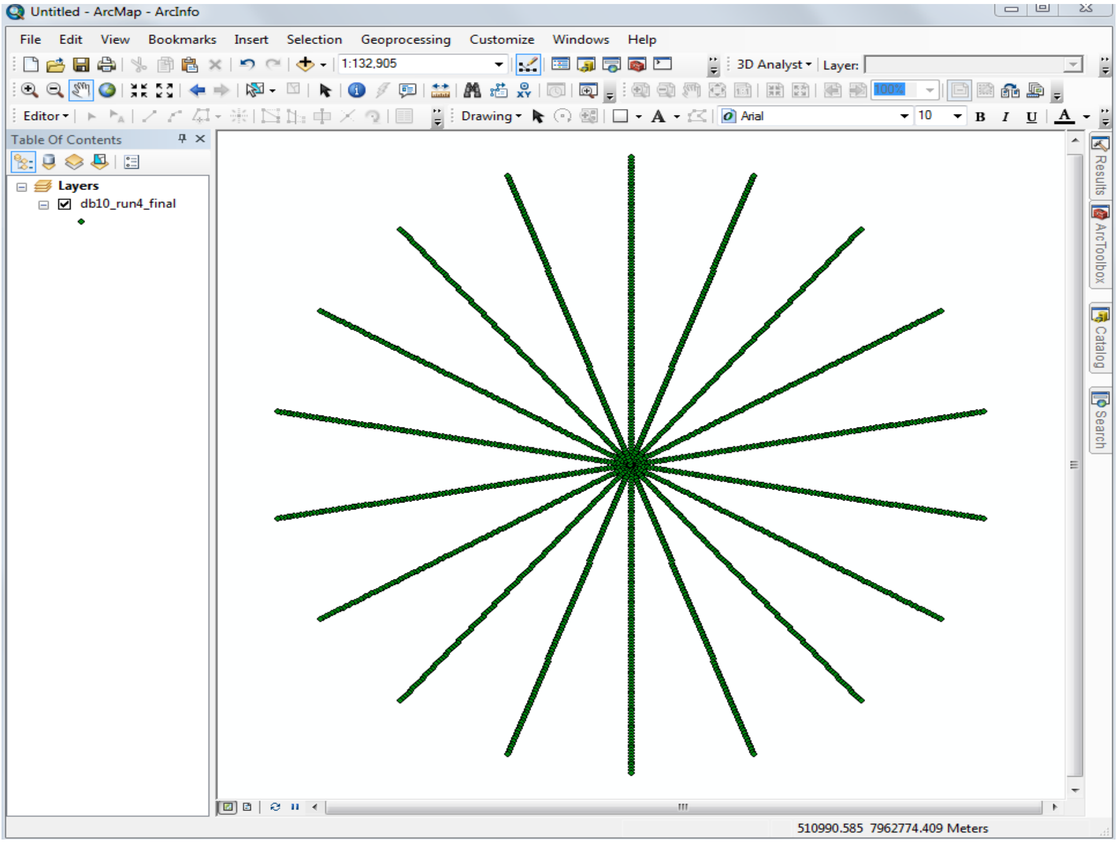


Figure A1. Example of merged points in pinwheel structure. Each line represents the line of data imported as a function of range from the point source. This is an initial output from Appendix II Script 2. Each data point contains dB loss data from the MATLAB® outputs.

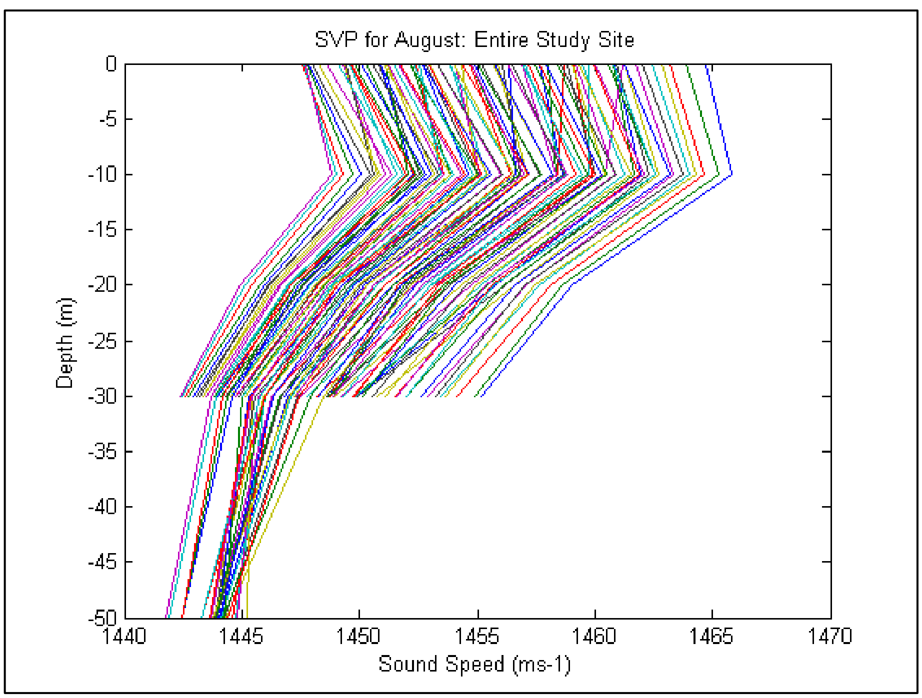


Figure A2. South Velocity Profile for data points with survey test site during August. These were created in MATLAB® from the Acoustic toolbox Seawater Version 3.

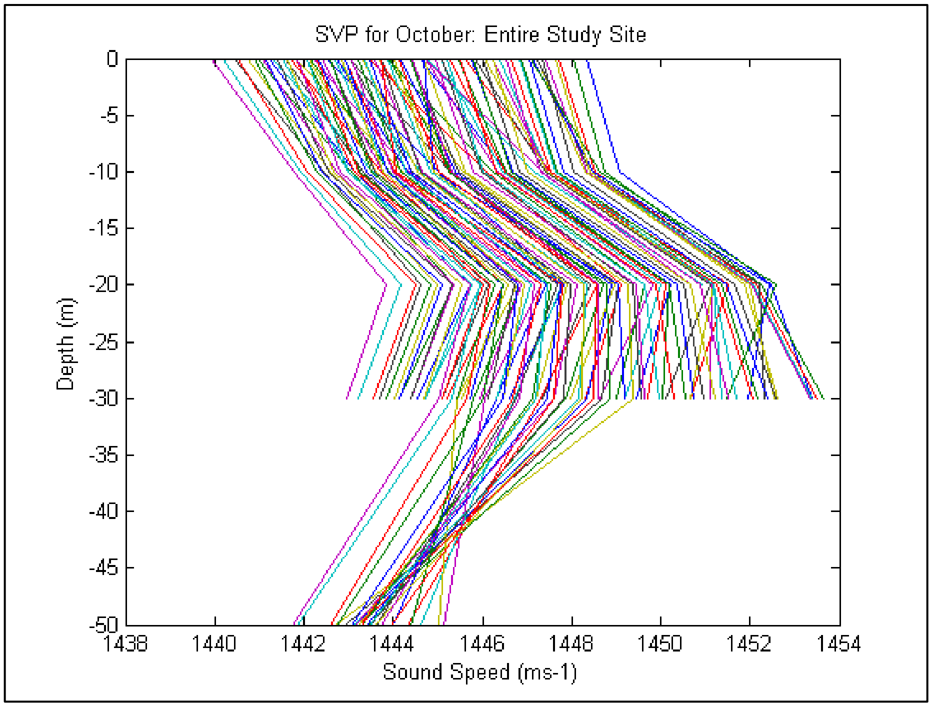


Figure A3. South Velocity Profile for data points with survey test site during October. These were created in MATLAB® from the Acoustic toolbox Seawater Version 3.

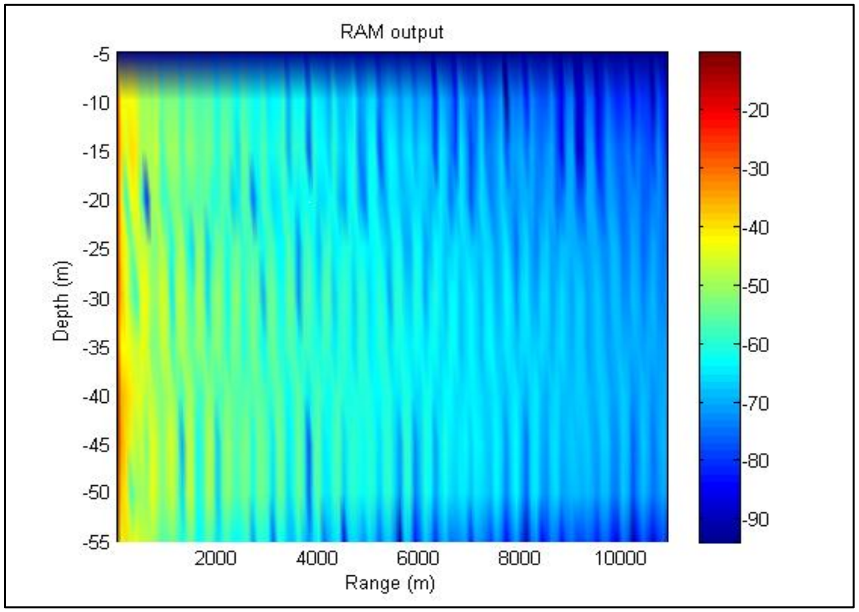


Figure A4. *August Run 1* dB loss for entire water column within a 11km range from the point source. dB re 1µPa. Figure from RAM MATLAB® run.

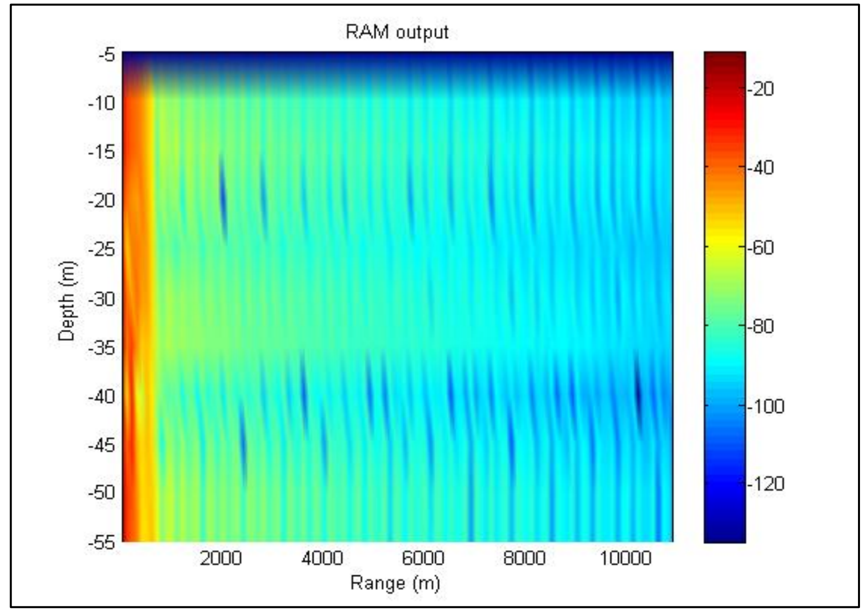


Figure A5. *August Run 2* dB loss for entire water column within a 11km range from the point source. dB re 1µPa. Figure from RAM MATLAB® run.

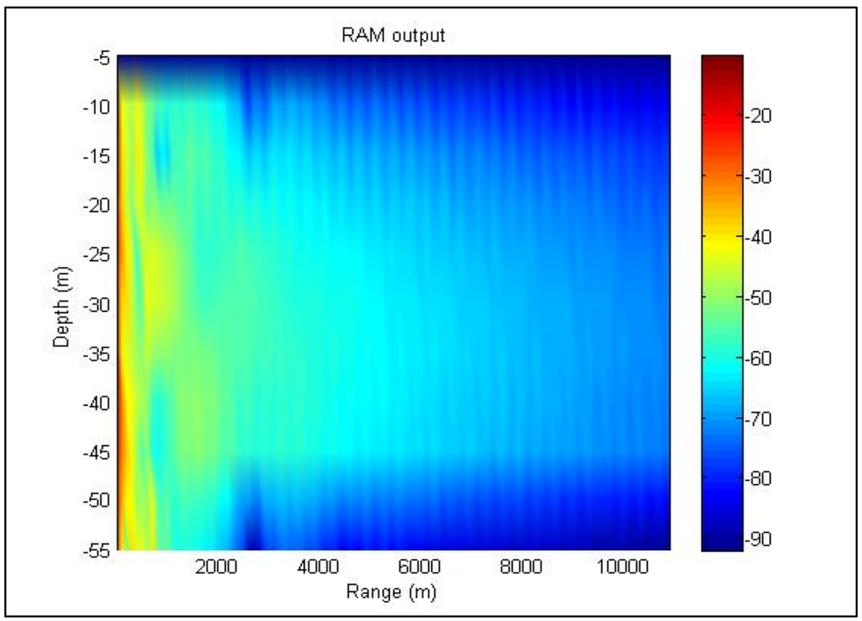
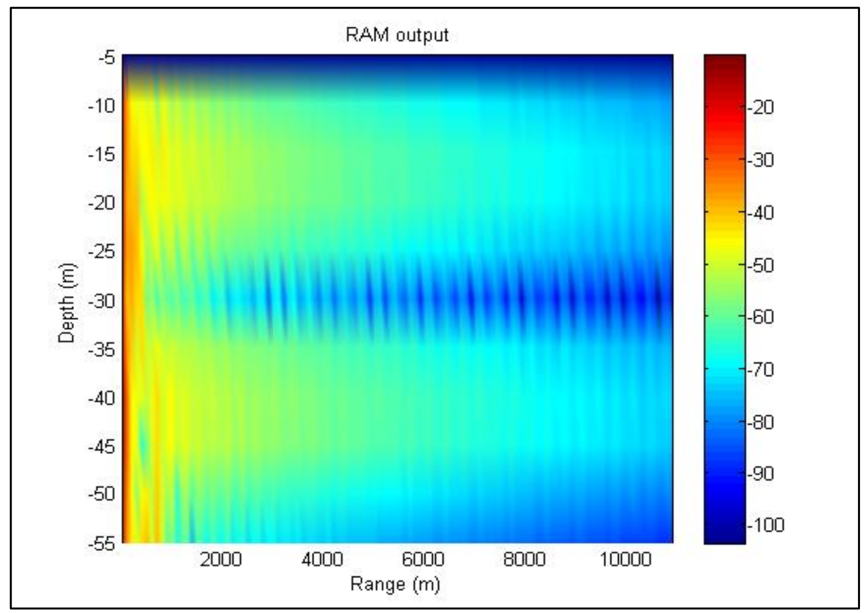


Figure A6. *August Run 3* dB loss for entire water column within a 11km range from the point source. dB re 1µPa. Figure from RAM MATLAB® run.



FigureA7. *August Run 4* dB loss for entire water column within a 11km range from the point source. dB re 1µPa. Figure from RAM MATLAB® run.

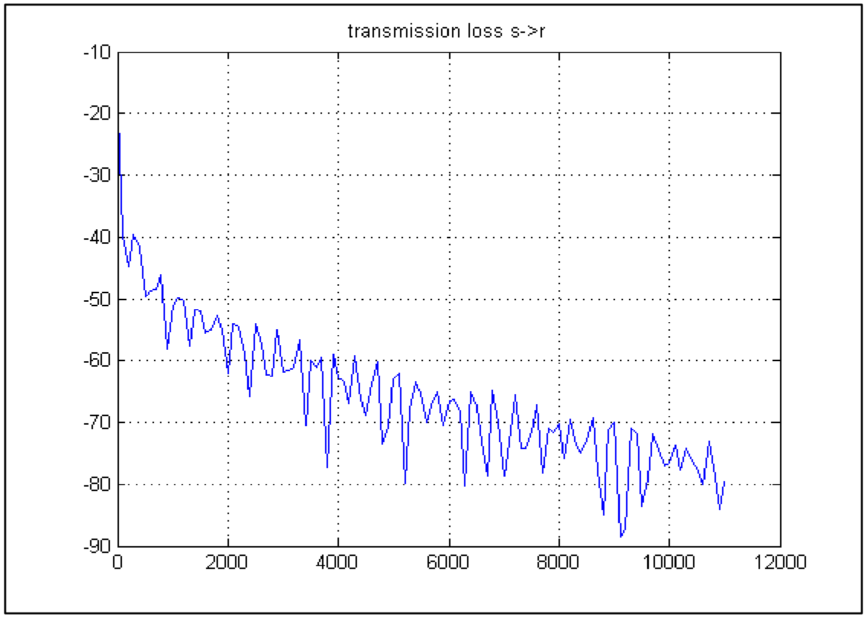


Figure A8. *__August Run 1__* TL from source to receiver. Y-axis represents dB re 1µPa, Y axis represents Range (m). Figure from RAM MATLAB® run.

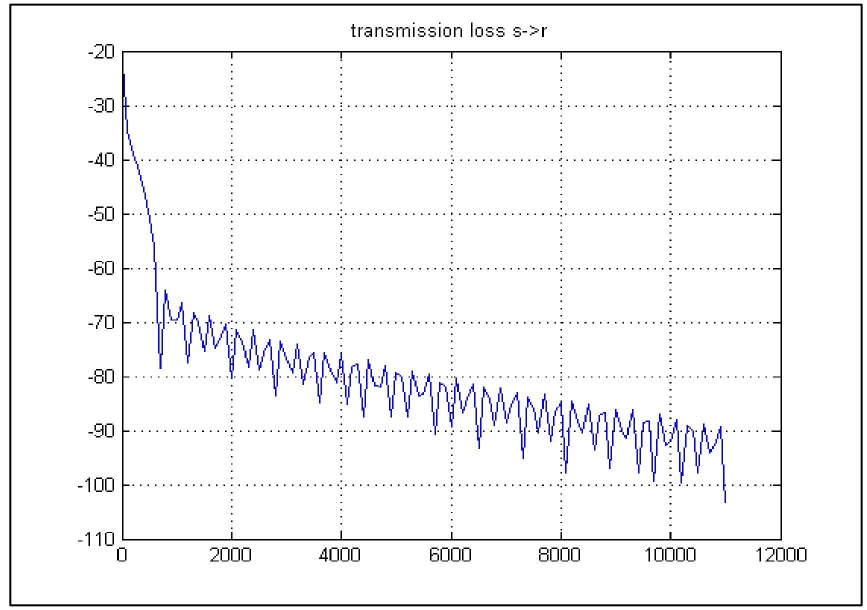


Figure A9. *__August Run 2__* TL from source to receiver. Y-axis represents dB re 1µPa, Y axis represents Range (m). Figure from RAM MATLAB® run.

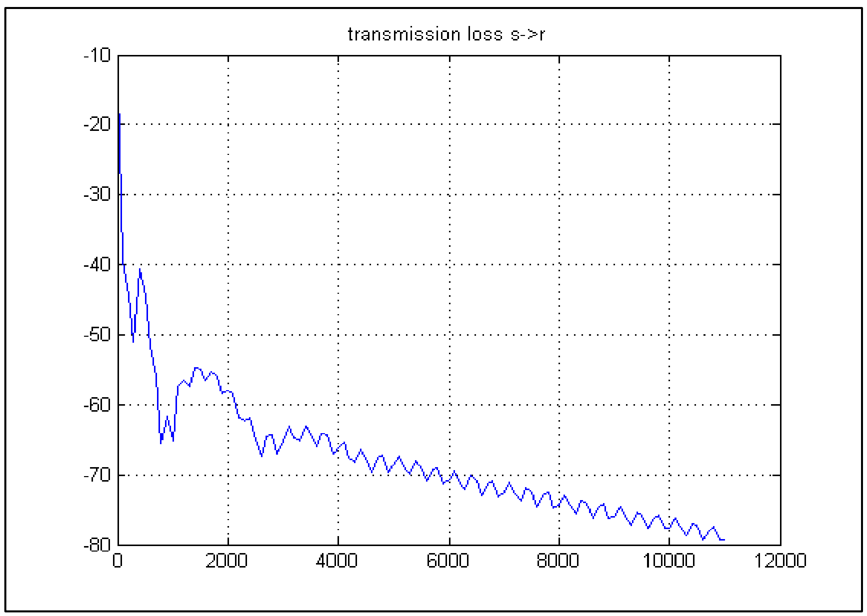


Figure A10. *__August Run 3__* TL from source to receiver. Y-axis represents dB re 1µPa, Y axis represents Range (m). Figure from RAM MATLAB® run.

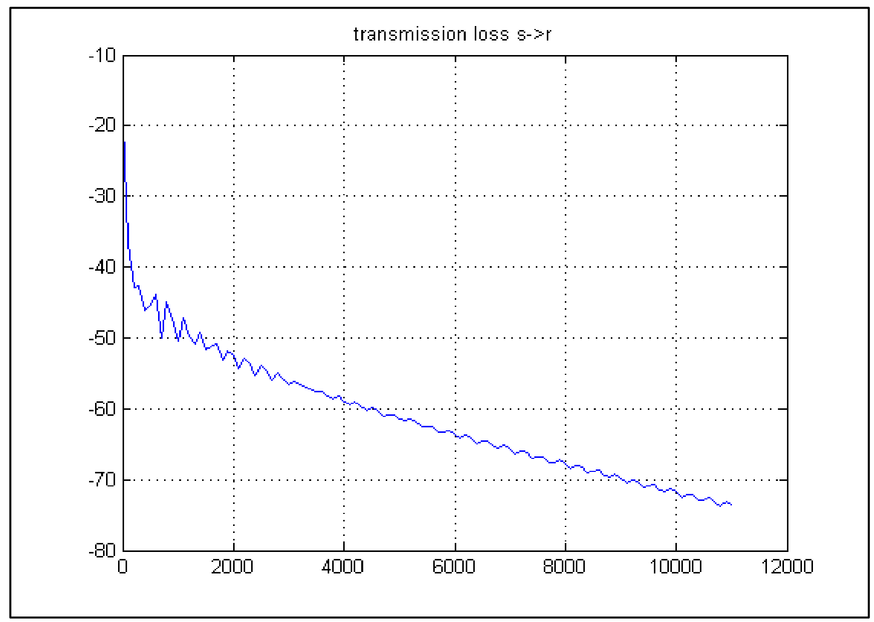


Figure A11. *__August Run 4__* TL from source to receiver. Y-axis represents dB re 1µPa, Y axis represents Range (m). Figure from RAM MATLAB® run.

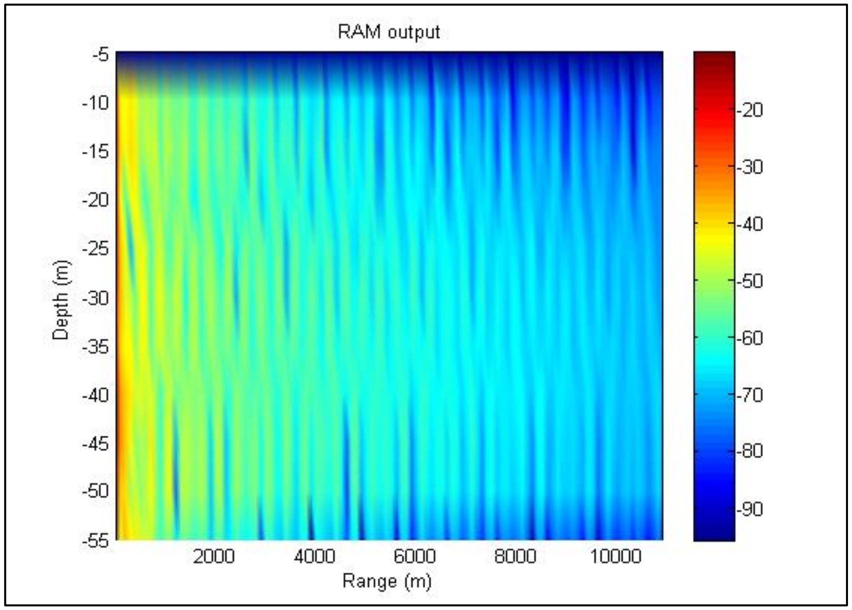


Figure A12. *October Run 1* dB loss for entire water column within a 11km range from the point source. dB re 1μPa. Figure from RAM MATLAB® run.

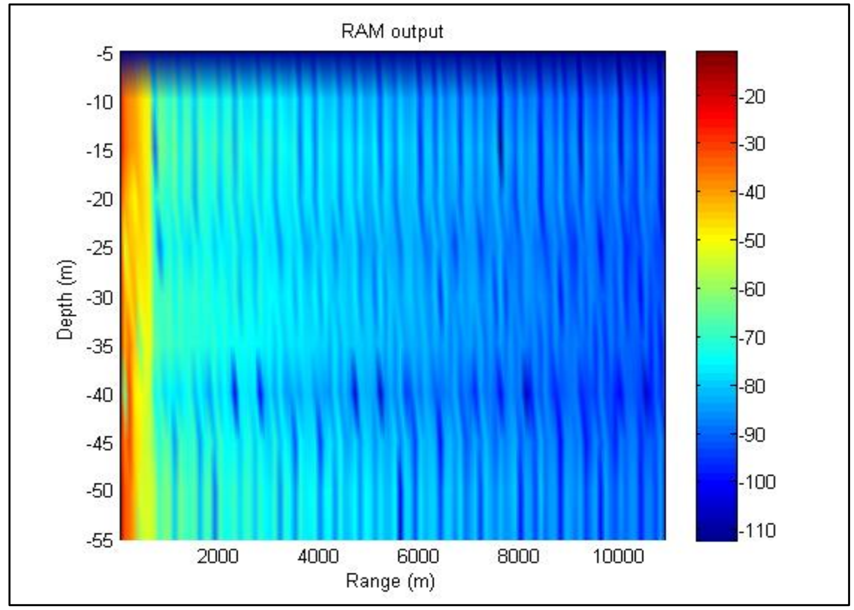


Figure A13 *October Run 2* dB loss for entire water column within a 11km range from the point source. dB re 1μPa. Figure from RAM MATLAB® run.

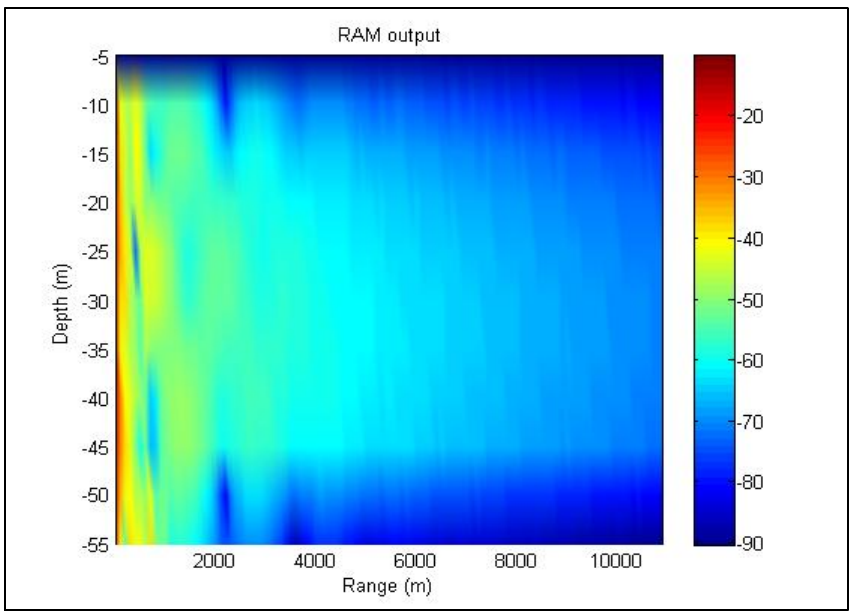


Figure A14. *October Run 3* dB loss for entire water column within a 11km range from the point source. dB re 1μPa. Figure from RAM MATLAB® run.

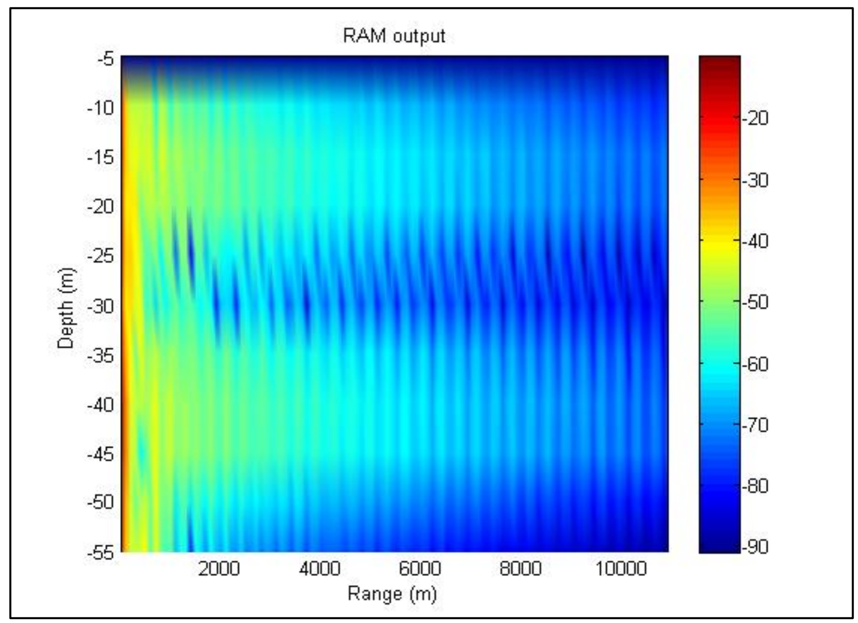


Figure A15. *October Run 4* dB loss for entire water column within a 11km range from the point source. dB re 1μPa. Figure from RAM MATLAB® run.

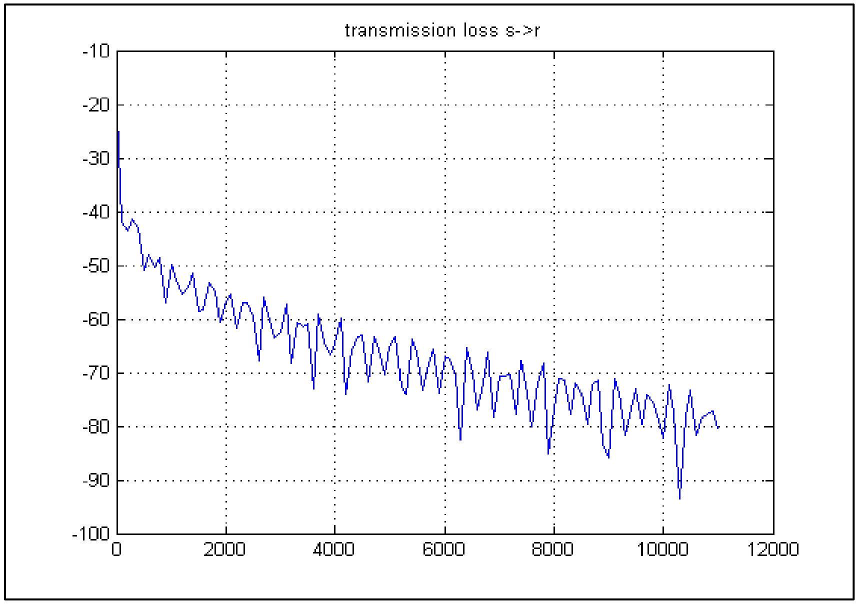


Figure A16. *<u>October Run 1</u>* TL from source to receiver. Y-axis represents dB re 1μPa, Y axis represents Range (m). Figure from RAM MATLAB® run.

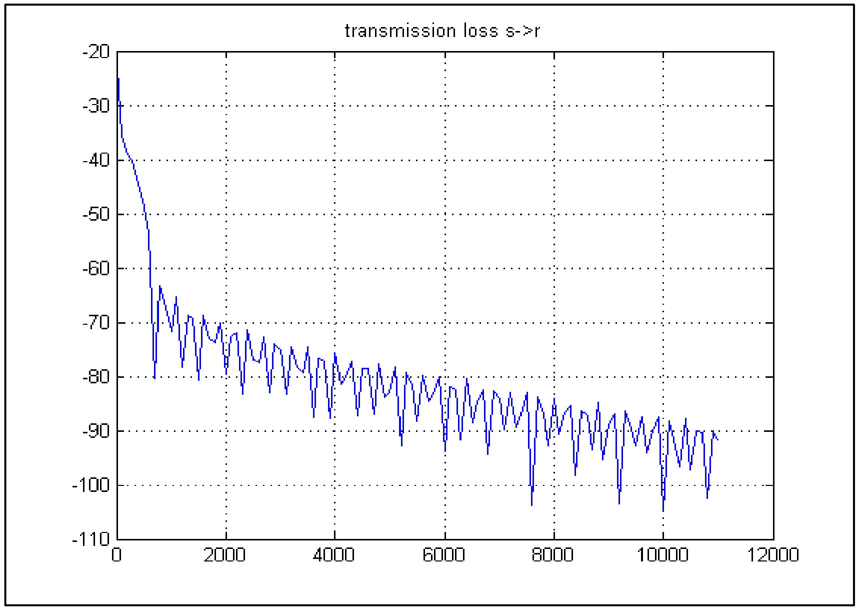


Figure A17. *<u>October Run 2</u>* TL from source to receiver. Y-axis represents dB re 1μPa, Y axis represents Range (m). Figure from RAM MATLAB® run.

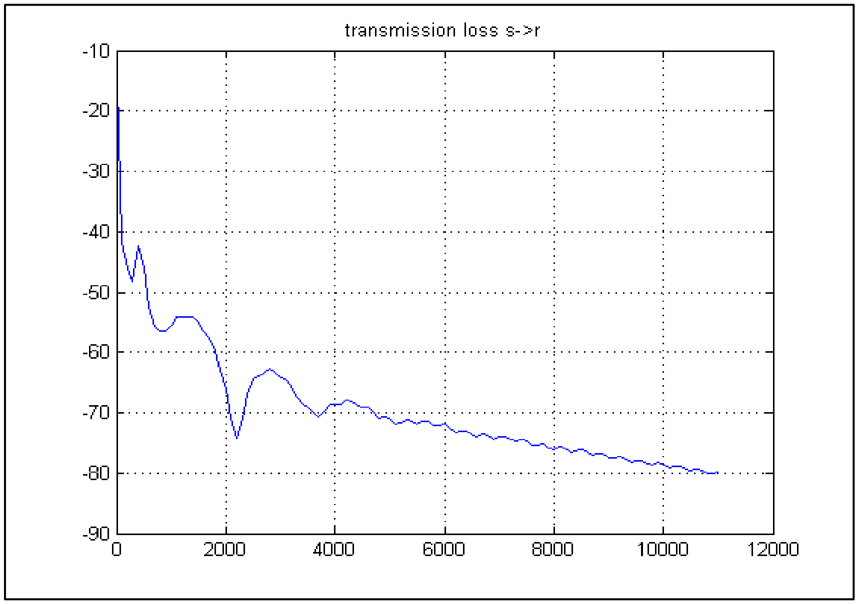


Figure A18. *<u>October Run 3</u>* TL from source to receiver. Y-axis represents dB re 1μPa, Y axis represents Range (m). Figure from RAM MATLAB® run.

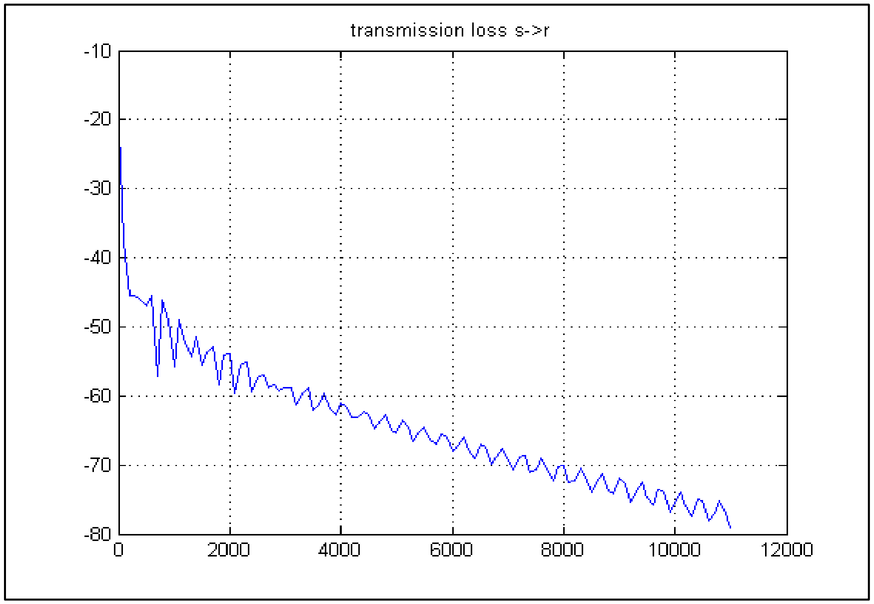


Figure A19. *<u>October Run 4</u>* TL from source to receiver. Y-axis represents dB re 1μPa, Y axis represents Range (m). Figure from RAM MATLAB® run.

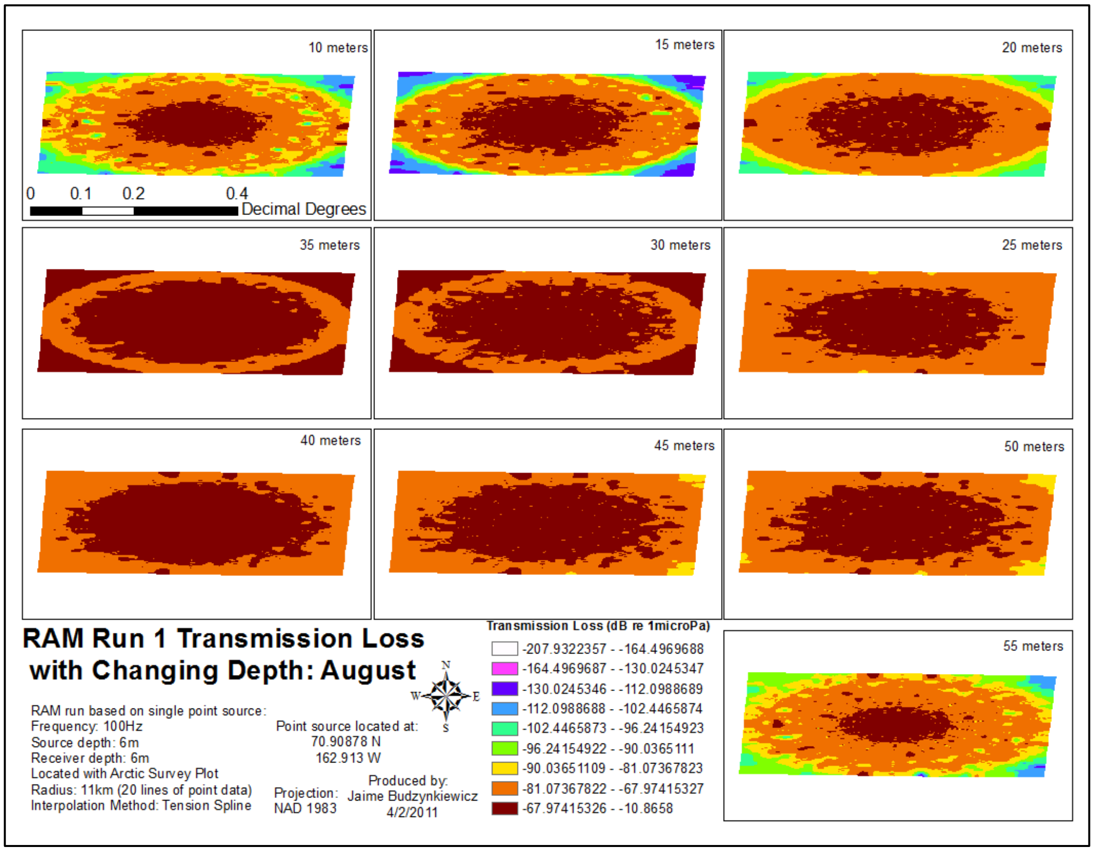


Figure A20. Run 1 August

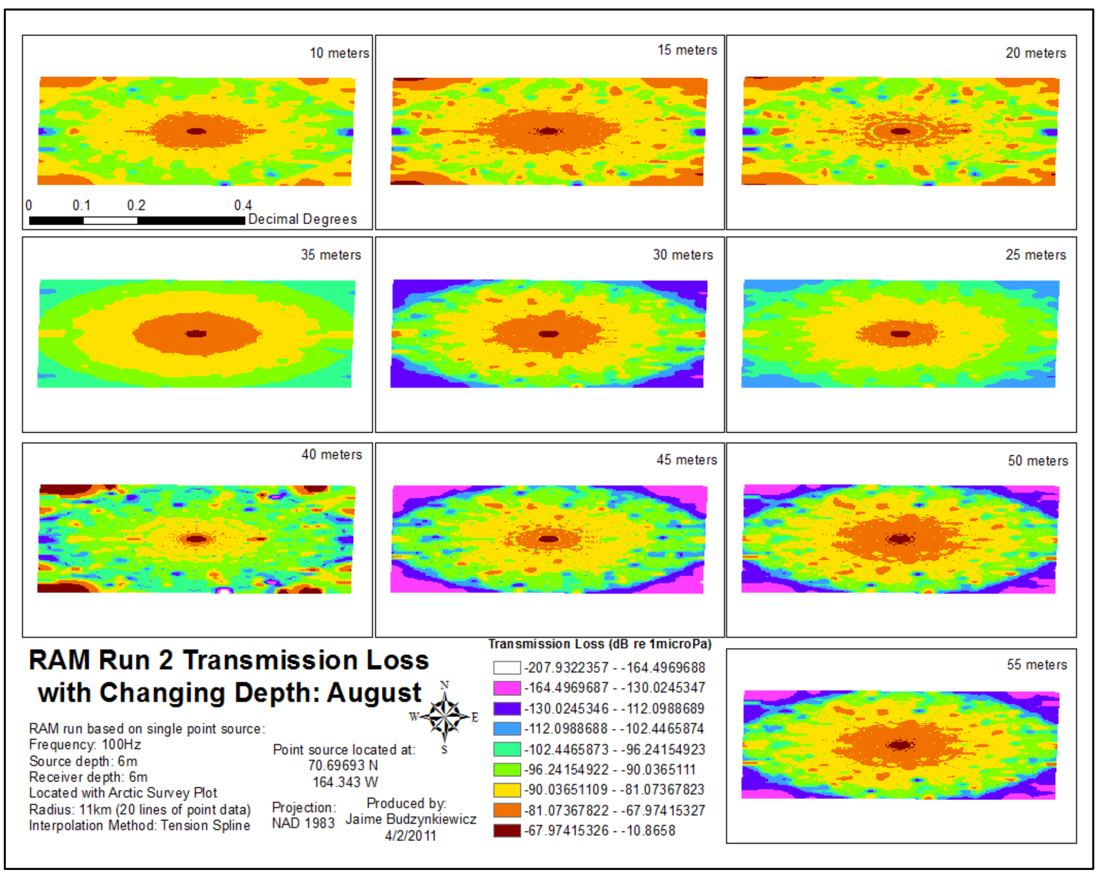


Figure A21. Run 2 August

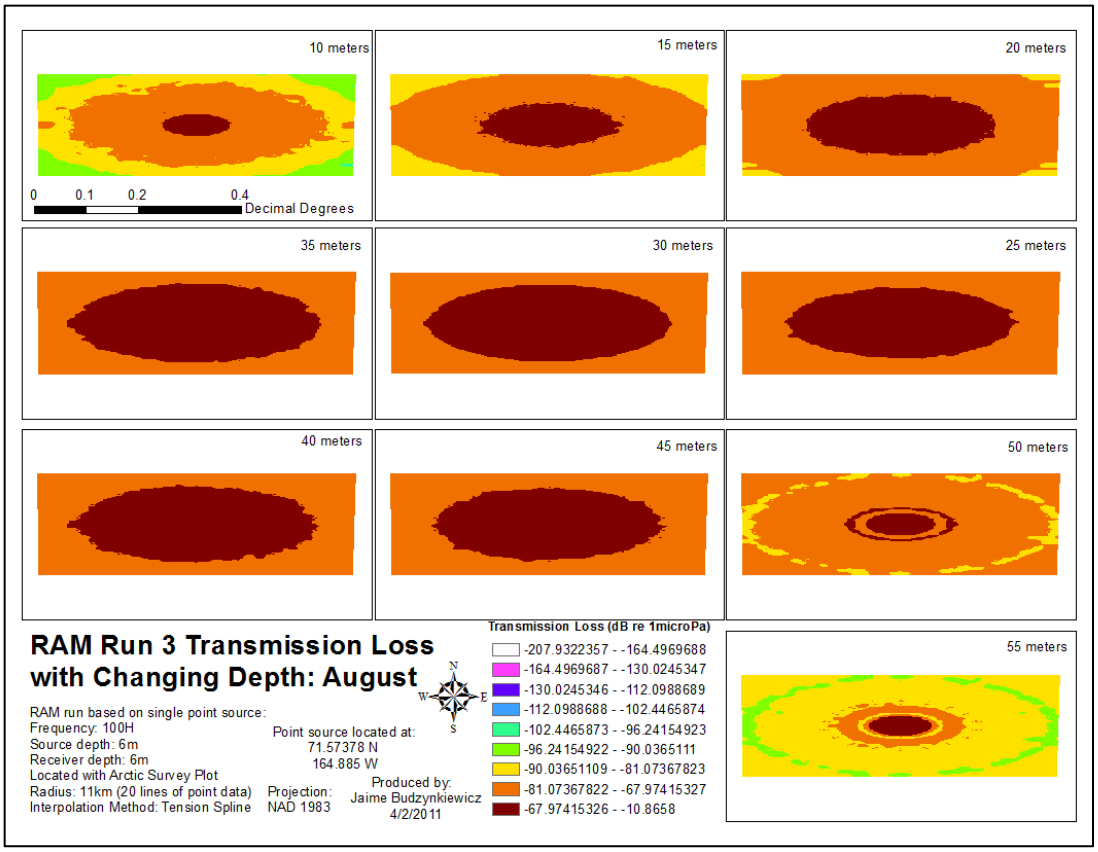


Figure A22. Run 3 August

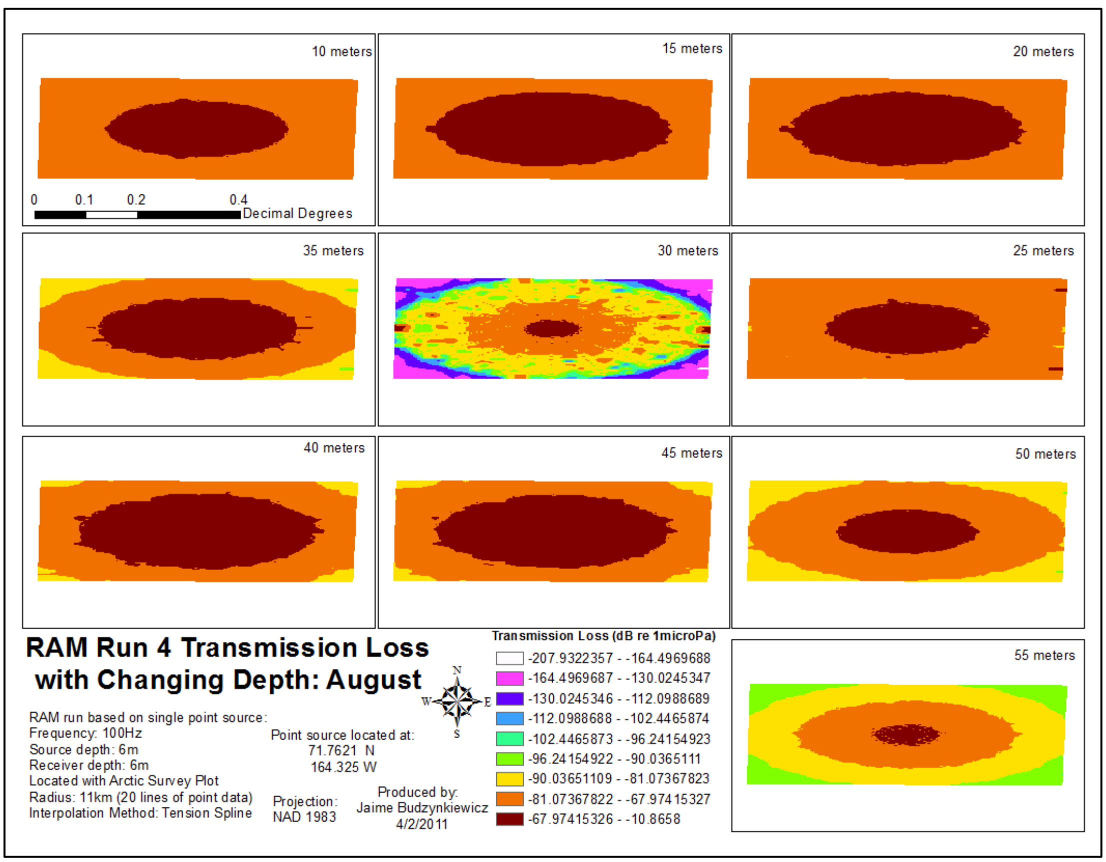


Figure A23. Run 4 August

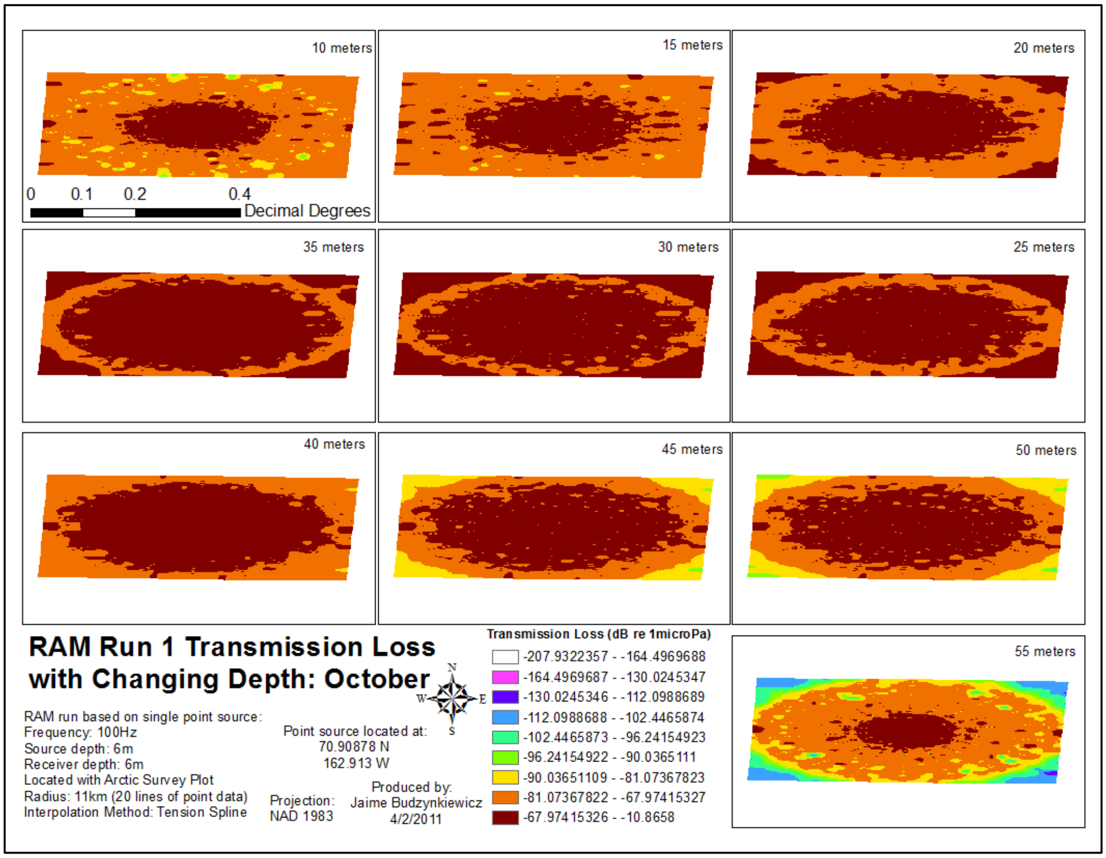


Figure A24. Run 1 October

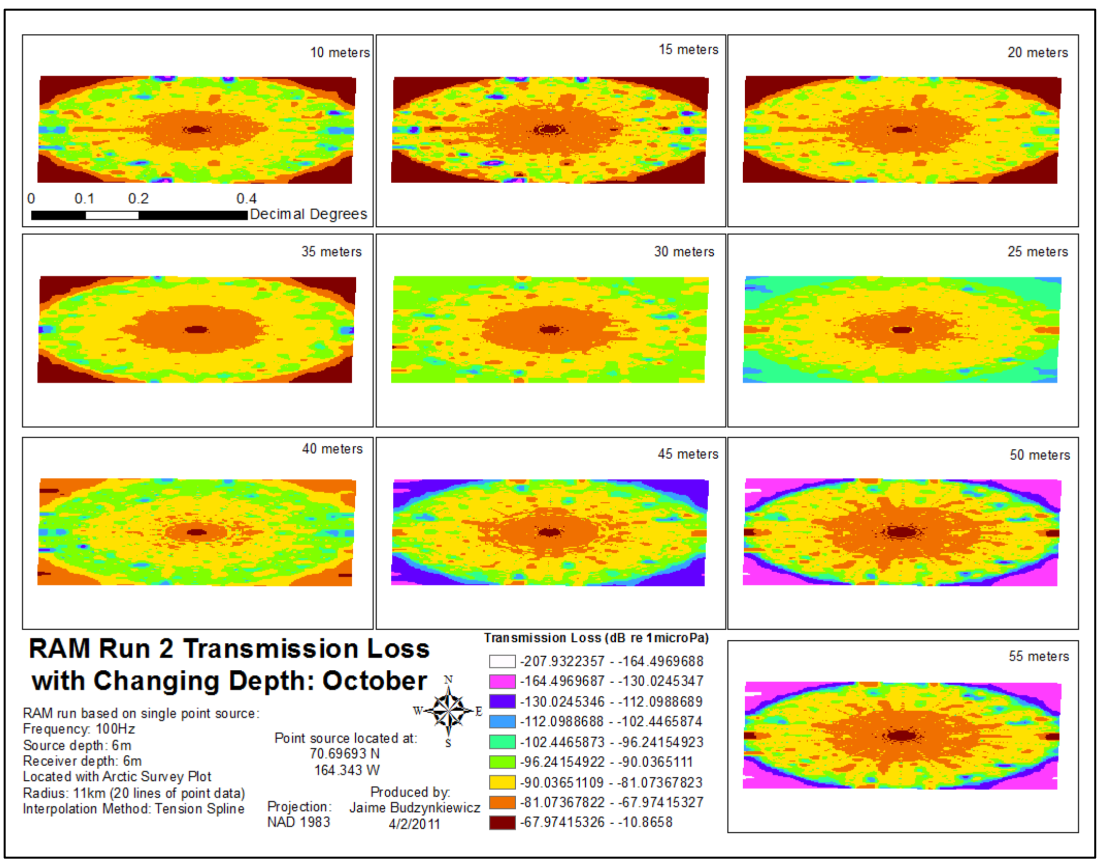


Figure A25. Run 2 October

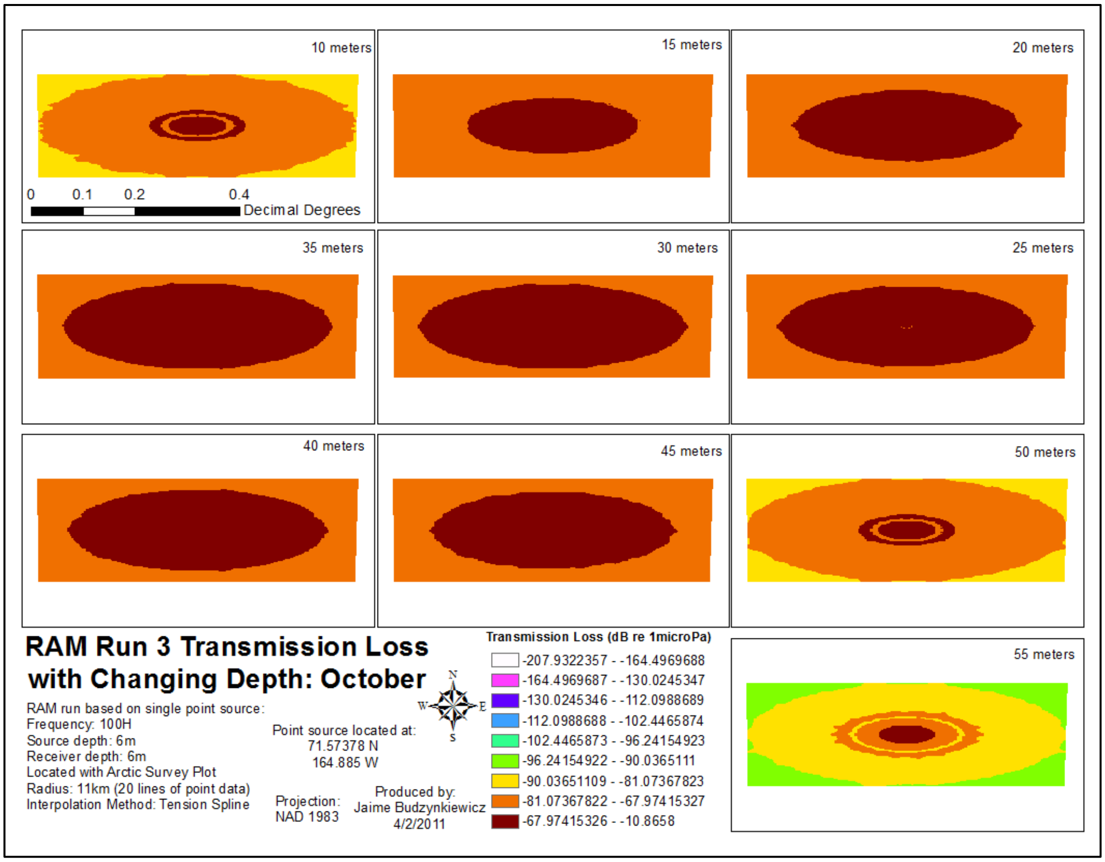


Figure A26. Run 3 October

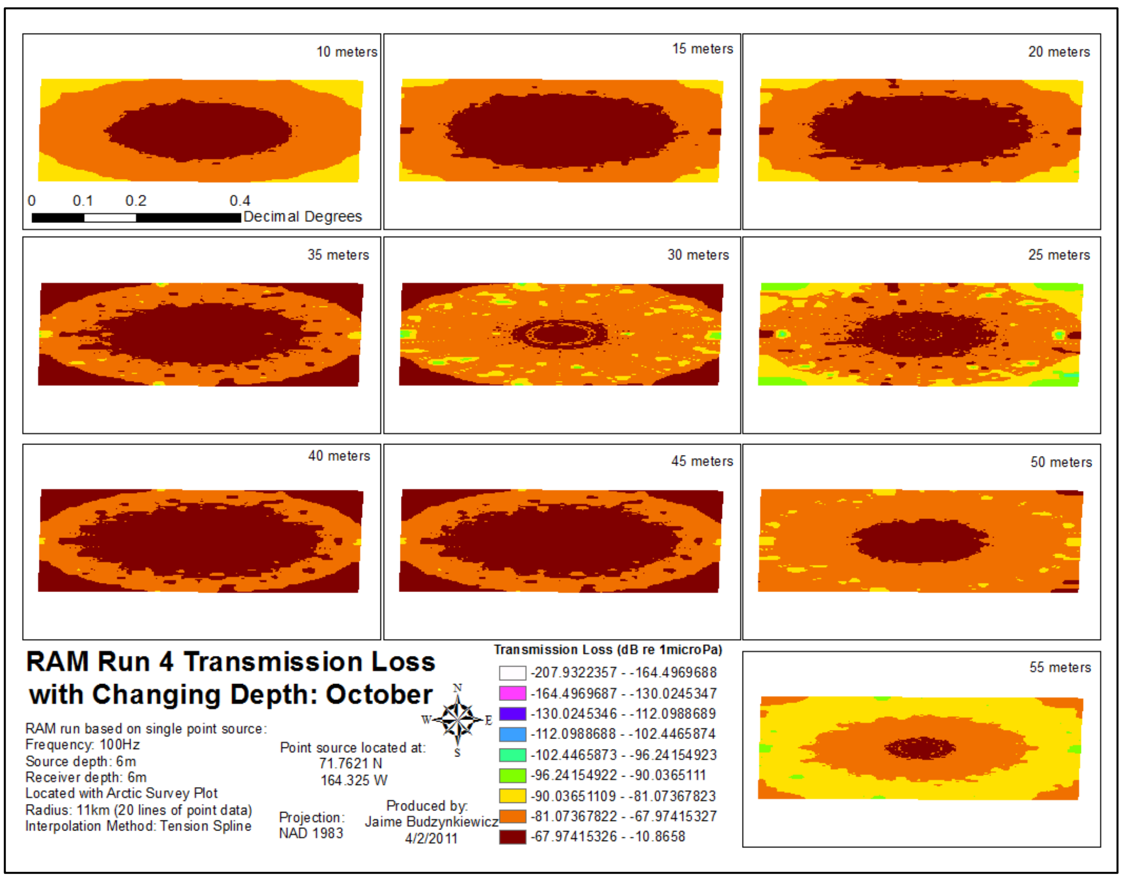


Figure A27. Run 4 October

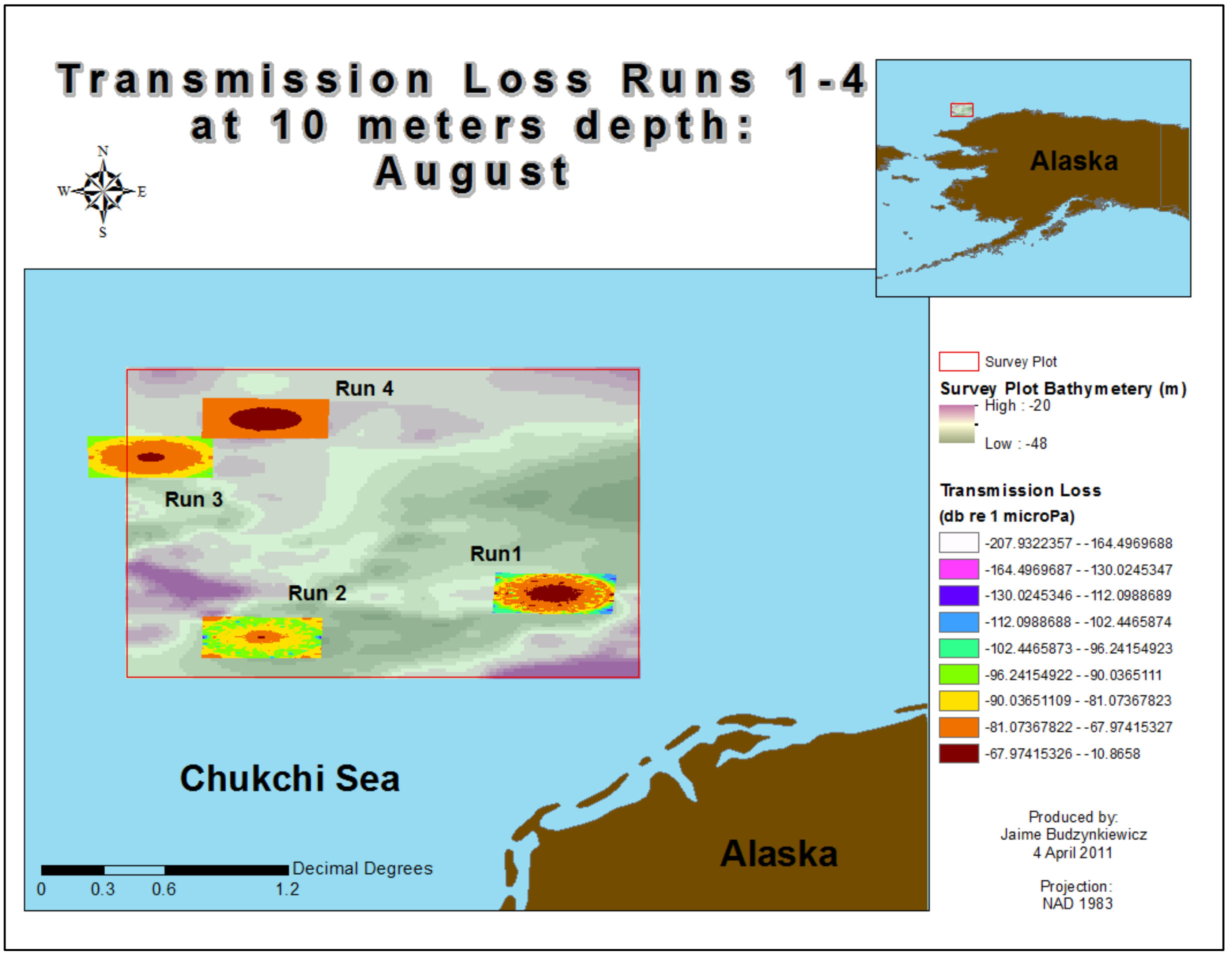


Figure A28. Comparison of four TL runs at 10meters depth. Showing the variability in TL with location.