Estimated acoustic exposures on marine mammals sighted during a US Naval training event in February 2011

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Stephen W. Martin and Roanne A. Manzano-Roth
SPAWAR Systems Center Pacific
San Diego, CA 92152

Summary

Sound pressure levels that sighted marine mammals were exposed to from AN/SQS-53C sonar transmissions are estimated during the Feb 2011 Submarine Commanders Course training event (SCC) at the Pacific Missile Range Facility (PMRF), Kauai, Hawaii. Experienced marine mammal observers aboard both a US Navy surface ship and an aerial survey plane provided sightings during the training event. The acoustic exposure is estimated as the sound pressure levels (SPL) in dB rms re 1 micro Pascal (1 μPa). This analysis considers MFA only from the AN/SQS-53C sonar system, at an assumed 235 dB re 1 μPa source level. The US Navy standard PCIMAT (personal computer interactive multi-sensor analysis training) acoustic propagation model is utilized to estimate the exposure levels on animals at a distance based upon the visual sighting and a presumed depth. All visual sightings were evaluated for presence of MFA transmissions within a time window criteria (+/- 2 minute maximum utilized) in order to bound the animal location uncertainty at the time of exposure.

Estimated SPLs are provided for a total of sixteen sightings/re-sightings: seven shipboard sightings; three shipboard re-sightings: and six aerial sightings. The estimated SPLs vary from 136dB re 1 μPa to a maximum of 196.9dB re 1 μPa. This maximum value is for a worst case assumption for the animal being closer to the MFA ship at the time of MFA transmission, which was 33 s prior to the sighting. The estimated minimum SPL for this sighting is 183.6dB re 1 μPa, which assumes the animal had been as far as possible from the ship when the MFA was transmitted. This highlights the need to consider the details of each sighting event, especially for short ranges with higher SPLs involved.

One can potentially obtain animal movement information by combining analysis from re-sightings or focal follows, of which one shipboard instance existed relative to MFA activity during this training event. Data from this re-sighting instance indicates a group of humpback whales was moving at high speed towards the oncoming MFA transmitting ship for a period of over 4 minutes. This may fit with the humpback behavior of “competition for females by a surface active group with multiple males present” (Darling 2001) and suggesting that the animals were not paying attention to the MFA.

Introduction

Since the 15-16 March 2000 stranding of marine mammals in the Bahamas in conjunction with US Naval ship active sonar activity (Evans et.al. 2000) there has been an emphasis to better understand how active sonar affects marine mammals to mitigate the risk of future strandings. A great deal of research has been, and continues to be, directed in this area, including large behavioral response studies in the Bahamas, Mediterranean and Southern California (see Southall et.al. 2007-2011).

The sound pressure levels (SPLs) in dB re 1 micro Pascal rms (dB re 1 μPa) that sighted marine mammals are exposed to from MFA activity during US Naval training events may be estimated by obtaining appropriate data from the training events. The data include the ship's latitude and longitude position updates, the marine mammal observer's detailed sighting logs, and information of when the MFA transmissions occurred. One then needs to determine if there was MFA activity close in time to the sighting, and if so obtain the transmitting ships' locations at both the time of the sighting and the time of the nearest MFA transmission in time.

The Feb 2011 Submarine Commanders Course (Feb 2011 SCC) training event was conducted between 14 and 18 February 2011 at the Pacific Missile Range Facility (PMRF) located off Kauai, Hawaii. This is the first time that data provided post-training event included acoustic data recorded during the training event. Previously acoustic data only before and after training events were provided. Trained marine mammal observers were aboard both a US Navy destroyer (DDG) equipped with the AN/SQS-53C mid frequency active (MFA) sonar and an aerial survey plane. DDGs were assumed to be transmitting omni-directional (in both azimuth and elevation angles) MFA signals with an assumed source level of 235 dB re 1 μPa at a nominal frequency of 3.3 kHz during the training event (Evans et al. 2000). Additional surface ships were involved with the training event transmitting higher frequency (approx. 6 to 9 kHz) sonar signals; however the focus of this report is on the AN/SQS-53C sonar signals from DDGs, termed MFA herein.

A previous report (Martin and Kok 2011) on this training event provided test case studies for estimated sound pressure levels (SPL) that both sighted, and acoustically tracked, marine mammals were exposed to during a two hour period the morning of 17Feb 2011. This report expands upon the previous report by improved analysis methodology and analyzing all of the visual sightings with MFA activity made by the trained marine mammal observers during the training event.

Methods

Recorded acoustic data and range products:

The PMRF standard training event products (Range User Handbook 2007) include detailed ship latitudes and longitudes updates relative to a precise Greenwich Mean Time (GMT) reference for all events which comprise the training event. The ship heading is inferred based upon the once per second position updates. GMT information is also synchronously recorded along with 31 range hydrophones' acoustic data continuously throughout the training event. Recording GMT with the acoustic data allows post training event acoustic data analysis synchronization with ship positions to determine when MFA transmissions occurred and from which ship.

Figure 1 illustrates the approximate locations for the 31 hydrophones recorded during this training event. All but seven of the hydrophones' data (504, 406, 407, 102, F13, F14 and F16) have frequency responses from 100Hz, or lower, to approximately 45kHz and provide reception of MFA transmissions and vocalizations of multiple species of marine mammals. The seven hydrophones noted are high-pass filtered at approximately 10kHz and are utilized for higher frequency analysis (e.g. echolocation clicks and whistles). Recorded acoustic data is sampled synchronously at 96 kHz and represented as 16 bits per sample. Additional PMRF hydrophones are available, however the data recording system utilized was limited to 32 channels.

The recorded acoustic data is utilized to determine when MFA transmissions occurred, as this level of detail is not present in the standard PMRF data products for the training event. For all sighting times, the recorded acoustic data is reviewed with a custom multiple channel broadband playback tool which provides a visual display of the GMT time and broadband energy for all 31 phones with aural and spectrogram monitoring for a single user selected hydrophone. This tool was utilized to determine if there were any MFA activity within a specified time of sightings, and if so, the time of reception on the nearest hydrophone (t_r). An automated detector (Mellinger et al. 2011) has since been tuned to automatically detect MFA activity which reduces the manual effort involved in this step.

The maximum time allowed between a MFA transmission and the sighting is limited in order to constrain the location uncertainty of the sighted animal due to potential animal movement over this time period. A two minute criterion is utilized in this analysis, reducing this time further may result in fewer cases of estimated exposures. While increasing this time can add additional sightings for analysis, the errors associated with the animal location grow accordingly and are reflected in the minimum and maximum estimated SPLs.

Higher frequency active sonar signals were also involved in the training event by other surface ship participants and readily evident in the acoustic data; however these signals were not considered in this analysis. If there is no MFA activity within the specified time window, the sighting is dismissed from the exposure analysis. Similarly if the sighting information is insufficient to locate the animal to earth coordinates it is dismissed from the exposure analysis. And finally, if ship positional data is not available for the period of the sighting, the sighting is also dismissed from further analysis.

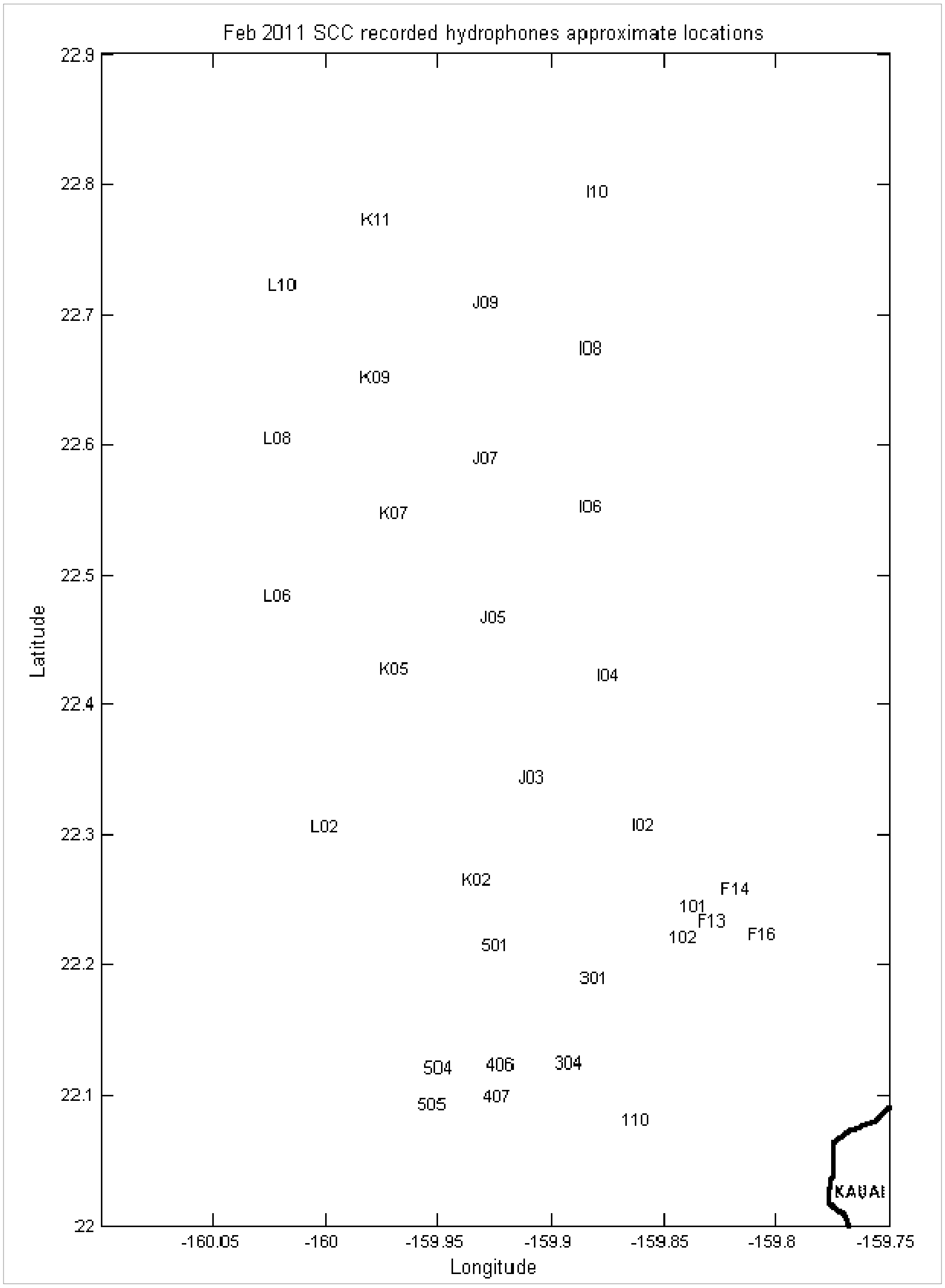

Figure 1 – Approximate location and labels for the 31 hydrophones recorded during the Feb 2011 SCC training event. Note that the horizontal and vertical scales are different for clarity of relative phone positions. The approximate location of the western shore of Kauai is shown at lower right of the figure.

Sightings Summaries: Shipboard and Aerial

Marine mammals were sighted by observers from both an aerial survey plane and the primary MFA transmitting ship during the training event. The observers are trained in identification of marine mammals and species identification is logged when possible.

The aerial survey report (Mobley 2011) includes: the species (when known) and number in the group; comments; potential behavioral states; and the latitude and longitude of the aircraft at the date and time of the sighting. When aerial survey comments provide additional information relative to the position of the sighted marine mammals it is utilized in this analysis, otherwise the aircraft position at the time of the sighting is utilized.

The shipboard survey report (Farak et al. 2011) includes: the calculated distance to, and relative bearing of, the sighted animal(s); species and number in the group; the location, heading and speed of the ship; comments; and the date and time of the sighting. The ship heading as derived from PMRF training event data is believed to be more accurate than the ship heading in the sighting report given its continuous rapid updates and considering the time delays involved for the marine mammal observers to obtain and record ship heading information. A detailed shipboard sighting spreadsheet also provides re-sightings (Farak 2011) when available as the shipboard survey report only contains the initial sightings. Re-sightings provide additional updates for the same animal(s). Sighting and re-sighting information should be sufficient to locate the sighted animals to earth coordinates (e.g. latitude and longitude) and exist within the maximum specific time window criteria (+/- 2 minutes) to be included in the estimated SPL analysis.

Measurement errors are involved in the sighting processes; however calibration data is not available for either the shipboard or aerial sightings. The errors involved with the sightings are not addressed in this report. These error sources include: accuracy of reported times; the azimuth and elevation angles from the observer to the animal; and errors in sighting platform location and heading. For shipboard observations reported here azimuth was estimated using a bearing board relative to the platform heading while elevation angles were estimated via binocular reticules.

Hypothetical geometry illustration:

Due to the complexity of the temporal and spatial relationship of the MFA transmitting ship, visual observers, and the sighted animals, a hypothetical sighting example is provided. Figure 2 is a plan view map for a hypothetical shipboard sighting at time t_s where the observers were on-board the ship transmitting MFA (as typically occurred in this training event). Five ship positions are shown as plus symbols for 20 min prior to the sighting and 10 min after the sighting indicate the ship moving at a heading of ~ 30 degrees true. The sighting information places the sighted animal at a distance of 3.6km at ~ 70 degrees true at the time of the sighting. Ignoring the errors involved in the sighting process, this places the sighted animal at the center of the circle shown in figure 2. In this example, the MFA transmission occurs 2 minutes prior to the sighting, putting the ship at a distance of 4km from the position of the animal sighted 2 minutes later. We assume a maximum burst speed for an unidentified whale of 25 knots, which results in potential movement in a 2 min period of ~ 1.5km. The heading of the sighted animal is unknown for a single isolated sighting, therefore the animal could have moved anywhere within a circle of 1.5km from the sighted position at the time of the MFA transmission. For this hypothetical example, the animal could be somewhere between 2.5km and 5.5km from the ship when the MFA transmission occurred.

Estimated SPLs decrease logarithmically with increasing distances between the ship (source) and the animal (receiver). This example illustrates the need to consider ship (known) and animal (unknown) movements between the sighting time and the MFA transmission time. For rare instances where the MFA transmission occurs at the same exact time of the sighting, the animal movement uncertainty is zero, however the errors associated with locating the sighted animal to earth coordinates still remain. To illustrate potentially large errors involved, if the original sighting in this example (figure 2) was at a distance of 500m from the ship, the animal uncertainty in the 2 minute period could place the animal anywhere from at the ship bow to ~ 3km from the ship at the time of the MFA transmission. This would result in the animal being exposed to a maximum level of the full source level to a minimum over 60dB lower.

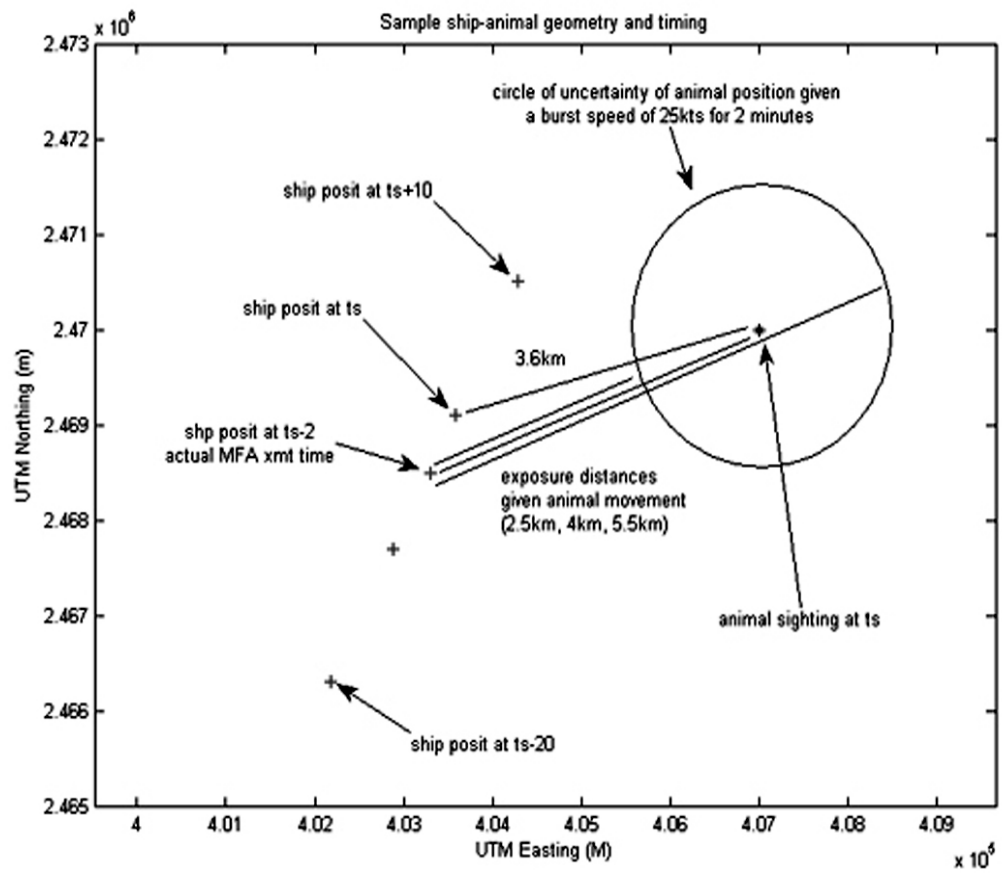

Figure 2 – Hypothetical geometry (not to scale) of MFA transmitting ship over a 30 min period (20 min prior to and 10 min after a sighting). An animal is sighted from the surface ship at time t_s at a distance of 3.6km on a bearing of ~ 70 degrees true. The ship transmitted an MFA pulse at t_s minus 2 min putting the ship at a distance of 4 km from the sighted animal location due to ship movement. Potential animal movement at 25knots over the 2 min could place the animal anywhere within the circle shown (radius ~ 1.5km) for a minimum range of 2.5km and maximum range of 5.5km at the time of MFA transmission.

Estimating Sound Pressure Levels for sighted marine mammals:

It is worth repeating that estimation of sound pressure levels that marine mammals were exposed to from MFA sonar transmissions during a training event requires the following: the locations of the MFA ship at the time of the transmissions; the locations of sighted animals when the MFA ensonifies them; and acoustic propagation model to estimate sound pressure levels that exist at the distances and presumed depths of the sighted marine mammals.

The surface ships positions are available from PMRF data products as latitude and longitude at specific GMT times. Latitudes and longitudes are converted to Universal Transverse Mercator (UTM) northing and easting using the NAD 83 (North American Datum) and WGS 84 (World Geodetic System) datum. Ship heading is assumed based upon position updates. The UTM northing and easting coordinates then allow geometric determination of the locations of sighted marine mammals using detailed sighting reports.

Recorded acoustic data is reviewed for MFA activity within the maximum allowed time window criteria relative to the sighting times. The approximate time of the MFA transmission (t_{mfa}) is then estimated using equation # 1 which utilizes the time of reception (t_r) of the MFA pulse on the hydrophone nearest to the transmitting ship and back-propagates the sound to the ship position at t_r. This estimate is approximate, but given the sound travels about 100 times faster than the ship and that a recorded bottom phone should be well within 15km of the ship, the estimate should be within a second of the actual transmission time.

Equation # 1: $t_{mfa} = t_r - 1/c * ((nh_d - s_d)^2 + (s_n - nh_n)^2 + (s_e - nh_e)^2)^{0.5}$

Where: t_r = time of MFA reception on nearest bottom hydrophone
c = average speed of sound considering depth in the area (1500 m/s utilized)
s_d = the depth of the source (11m utilized)
s_n and s_e are the northing and easting UTM location of the source at t_r
nh_d = the depth of the nearest hydrophone (m)
nh_n and nh_e are the northing and easting UTM locations of the nearest hydrophone

The location of the sighted animal at the time it is ensonified by the MFA transmission can be approximated as the location of the animal at the time of transmission. This approximation is within 1% of the correct distance (the ratio of the speed of the animal to the speed of sound). This distance correction results in SPL differences under 0.1dB which can be considered negligible.

For this analysis the maximum time window criteria between the sighting and the MFA transmission time was selected as +/- 2 minutes to constrain the animal location uncertainty. Potential animal movement is calculated over this time difference ($|t_{mfa} - t_s|$). Utilizing a maximum burst speed for an undetermined whale species of 25 knots (46.3 km/h or 12.87 m/s), the +/- 2 minute window results in a maximum potential animal movement of +/- 1.544 km. This speed roughly corresponds to some of the fastest whale species (e.g. sei, orca). Humpback whales are often the subject of sightings at PMRF, utilizing a humpback whale maximum burst speed of 12.5 knots (6.435 m/s) a +/- 2min time windows results in animal location uncertainty of +/- 772 m. The animal location uncertainty is most significant for shorter range sightings, where the animal movement can cause large variations in estimated SPLs. Longer range sightings are less impacted by the animal location uncertainty. For example the estimated SPL variations for an unknown whale species sighted at 15km with a 2 minute latency (+/-1.5km) results in a variation in the estimated SPL of under 2dB.

The estimated distance to the sighted animal are corrected for both ship movement and the minimum and maximum distance the animal could potentially travel in the time interval between the sighting and MFA transmission. This results in having both a maximum and minimum distance to the animal due to its potential movement over the time interval between sighting and MFA transmission.

In the hypothetical example in figure 2 with a two minute elapsed time between transmission and sighting, the maximum range from the animal to the MFA ship (5.5km) is over twice the minimum range (2.5km) which results in approximately 7dB less SPL. If the initial sighting in figure 2 was at 1000m vice 3.6km, the differences in SPLs due to animal movement could be over 60dB! These distances (ship at time of MFA to animal uncertain locations) are utilized with acoustic modeling to estimate the SPLs that the animals are exposed to.

Acoustic modeling:

Once the geometry, locations and timing are determined, the sound pressure levels are estimated for the animal locations, and presumed depth, using acoustic propagation modeling. This report utilizes the PCIMAT tool as the primary model and the sonar equation as a secondary model. PCIMAT incorporates the Comprehensive Acoustic System Simulation propagation model (CASS) and the Oceanographic and Atmospheric Master Library (OAML) databases which have detailed bathymetry for the area. Passive propagation modeling is utilized to estimate the SPLs given the following parameters: ship (source) location; date and time; source transmit level; source depth; source frequency; receiver (animals) location; receiver depth; wind speed; bottom type; and sound velocity profile. Assumptions utilized throughout this analysis are: a nominal omni-directional MFA pulse with a 3.3 kHz frequency at an rms source level of 235 dB re 1 μPa; a sonar source depth of 11m; a whale (receiver) depth of 11 m; 10 knot winds; a sand/mud bottom type; and historic sound velocity profiles from the date of the sighting. The PCIMAT outputs are the transmission loss from the MFA ship to the whale, or group of whales. The sonar equation is also utilized to estimate the SPLs (in dB re 1 μPa) as a sanity check on model outputs. The sonar equation utilized (equation #2) includes spherical and cylindrical spreading and absorption of sound by the seawater. The sonar equation does not include bathymetry or variable sound speeds and is not expected to be as accurate as PCIMAT. None the less, when the PCIMAT model output is significantly different (i.e. > +/- 10dB) from the sonar equation one should understand the reasons why. Differences can be attributed from ducted propagation, SVP characteristics, multipath propagation and detailed bathymetry.

Equation # 2: $SPL = SL – TL = SL - (10*\log10(r_o) + 10*\log10(r) + alpha*(r/1000))$

Where: SL = source level (dB re 1 μPa at 1 m)
TL = transmission loss (dB)
alpha = absorption coefficient in dB per km (0.15 dB/km utilized for 3.3kHz)
r = range (m) between the source and receiver
r_o = range (m) between source and receiver limited to the transition distance from spherical to cylindrical spreading (2560m utilized).

Results

A total of 16 sightings/re-sightings satisfied the criteria for MFA transmission within 2 minutes of the sighting and having ship positional data available. Each of these sightings are listed in table 1 chronologically providing the estimated SPLs for each sighting, along with the dates, times (HST), sighting platform (Ship or Aerial) and species sighted (humpback or unknown), MFA latency time ($|t_{mfa}-t_s|$), and minimum and maximum ranges. When the span of min-max ranges and SPLs are less than +/- 5% and +/- 1dB respectively), a single value is shown. As one would expect, the shortest sighting distance on 18 Feb 2011 @ 09:51:34, results in the highest estimated SPLs of 186.3 to 196.9dB re 1 μPa. The MFA transmission occurred 33 seconds before the sighting. If one assumes the animal was moving towards the ship over this time period, the distance would have been 497 m with an estimated SPL of 183.6 dB re 1 μPa. On the other hand, if the animal was moving away from the ship over this time period, the distance would be only 85 m with an estimated SPL of 196.9 dB re 1 μPa. If one assumed no animal movement between the sighting and the MFA transmission, the distance to the animal would have been 291 m with an estimated SPL of 187.8 dB re 1 μPa.

2011 Date	HST Time (hh:mm:ss)	Sighting platform (S or A) and species (humpback or unidentified)	MFA Latency Time (+/-seconds)	Min/Max Ranges (km)	Min/Max SPLs (dB re 1 μPa)
16 Feb	14:05:01	A, humpback	-35	5.7	169
16 Feb	14:06:23	S, humpback	31	6.6	168
16 Feb	14:07:47	S, humpback	20	15.8	159.2
16 Feb	14:12:01	A, humpback	-14	4.9	167.4
16 Feb	14:42:27	S, unidentified	10	6.1	167.5
17 Feb	07:39:09	S, unidentified	-65	2.3 / 3.9	170.2 / 172.1
17 Feb	11:44:58	A, humpback	-18	55.3	143.3
17 Feb	11:45:48	A, humpback	-27	59.7	142.8
17 Feb	11:48:45	A, humpback	7	71.7	136.2
18 Feb	09:47:49	S, humpback	-13	3.6	170.2
18 Feb	09:48:10	S, humpback	18	3.4	170.4
18 Feb	09:49:45	S, humpback	-27	1.85 / 2.2	172.3 / 173
18 Feb	09:51:34	S, humpback	-33	0.085 / 0.497	183.6 / 196.9
18 Feb	10:11:14	S, unidentified	-10	9.1	163.3
18 Feb	10:22:02	A, humpback	-16	1.9/4.1	170.4 / 172.8
18 Feb	14:26:12	S*, unidentified	-6	21.6	156.5

Table 1 – PCIMAT estimated SPLs on sighted animals for the Feb 2011 SCC training event for shipboard (S) and aerial (A) sightings within 2 min of MFA activity. MFA latency time is the elapsed time between the sighting and the MFA transmission. Note: the S* sighting was from the same DDG as the previous sightings but the MFA was transmitted from a different DDG.

Shipboard sightings are limited by the line of sight due to the observer's altitude, while the aerial sightings are seen to have multiple usable sightings at 50+km. In this report the maximum distance from a DDG transmitting MFA and the sighted animal(s) was 71km with an estimated SPL of 136 dB re 1 μPa. For the first 15 entries in table 1, the US Navy DDG with trained marine mammal observers on-board transmitted the MFA signals which were analyzed. The last entry in table 1 on 18 Feb 2011 @ 14:26:12 HST for a shipboard sighting (S* in the table) was for a different DDG that transmitted the MFA. This resulted in a 21.6 km distance from animal(s) sighted to the DDG which transmitted the MFA.

Figure 3 provides a visual representation of the data provided in table 1 for the estimated SPLs with respect to log scaled horizontal range between 80m and 100km. The PCIMAT estimated SPLs are shown as symbols and the solid line represents the sonar equation estimated SPL continuous with range. Red and green colored symbols with the same shape represent a single sighting showing the minimum and maximum ranges and estimated SPLs. Black symbols are shown for singular values of ranges and estimated SPL. The break between spherical and cylindrical spreading is visible in the sonar equation solid line at approximately 2.5km.

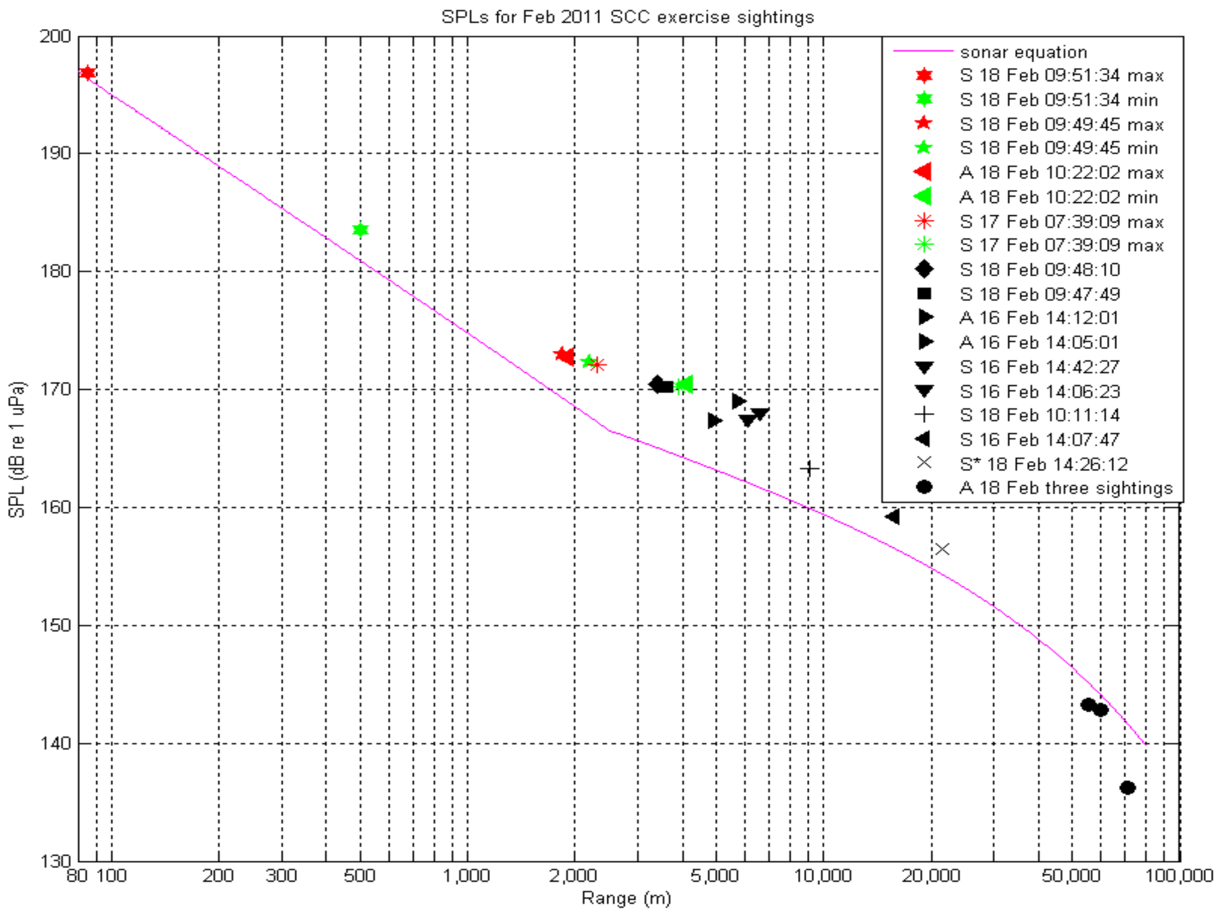

Figure 3 – Estimated SPLs vs. log scaled range for shipboard and aerial sightings. PCIMAT modeled exposure SPLs shown as different symbols while the sonar equation is shown as a continuous line. Green and red symbol colors show min and max estimated SPLs for individual sightings. The 'A' and 'S' in the legend indicate aerial or shipboard sighting.

Discussion

This study provides estimated SPLs that sighted animals were exposed to during a US Navy training event. To estimate the SPLs sufficient information is required for the both the sightings and the MFA ship. The sighting information should include information to locate the sighted animals in earth coordinates as precisely as possible, preferably with calibration data for understanding how accurate the locations are. The MFA ship activity information must be adequate to determine ship positions, ship headings, and MFA transmissions details (e.g. time of occurrence and frequency).

For this Feb 2011 training event, sixteen different exposure levels were estimated for sighted humpback and unidentified whales (single, and in groups). The lowest estimated SPL of 136 dB re 1 μPa should have good signal to noise ratio assuming an ambient noise level at 3.3kHz of 60 dB re 1 $\mu Pa^2/Hz$ (Urick 1975). Baleen whale audiograms are largely unknown; however it would not be unreasonable to assume the humpback whales can hear a 136dB re 1 μPa, 3.3kHz MFA sound. The temporary threshold shift onset sound exposure level (SEL) value of 195dB re 1 μPa^2-s for odontocetes is applied to baleen whale species due to the lack of better information (EIS/OESI 2008). If one assumes one second pulse durations for the MFA transmissions during this training event, the SPLs reported in table 1 and figure 3 would be equal to the SELs.

The highest estimated SPL in this analysis is 196.9 dB re 1 μPa for the maximum possible occurring for a shipboard re-sighting of a group of 4 or 5 humpback whales at 09:51:34 on 18 Feb 2011 assuming the animals were as close as possible to the MFA ship when it transmitted at 09:51:01. The minimum estimated SPL for this re-sighting (183.6dB re 1 μPa) assumes the animal was as far away as possible from the ship when it transmitted the MFA pulse. The minimum and maximum SPLs are calculated for each sighting, and re-sighting, as independent events. However, re-sightings may provide additional location information for the sighted animals which allows one to constrain the simple circles of animal location uncertainty (see the Re-sightings section below). The initial sighting and two re-sightings of these same animals prior to the closest sighting, indicate the animals were heading on a south-southwest course, which would imply they were farther from the ship at transmission time than the maximum SPL analysis assumes. This would result in exposure levels closer to the minimum value of 183.6dB re 1 μPa rather than the 196.9 dB re 1 μPa maximum indicated in table 1 and figure 3. This indicates the need to consider details of when various events occur (e.g. sightings, re-sightings and MFA transmissions) and how much animals can potentially move.

Estimation Errors:

This study illustrates the need to control and accurately measure, or estimate, as many parameters as possible when estimating exposure levels during US Naval training events. Designed behavioral response studies (BRS) are done specifically to control as many of the pertinent parameters involved in estimating sound exposures to marine mammals from MFA and potential behavioral responses. BRS's typically include tags that directly measure animal movements and sound pressure levels. While monitoring of US Naval training events is much less controlled, one can obtain samples of estimated exposure levels relatively inexpensively. Monitoring naval training events can not take the place of behavioral response studies, but results such as this may be able to not only support required monitoring activities but also potentially augment BRS data.

Minimum and maximum estimated exposure levels are provided in table 1 to specifically highlight the issue of presenting a single exposure level in certain situations, primarily for shorter range sightings. Of the 16 sightings with estimated SPLs, four had min-max estimated SPLs that varied by over +/-1dB resulting from short transmitter-receiver distances of under 5km. The other 12 sightings had min-max estimated SPLs variations less than 1 dB re 1 μPa. Factors such as the accuracies of the sighting location and the acoustic propagation model details influence all estimated exposure min-max variations. There is a need to expand this type of analysis to include estimating the other error sources not considered in this study.

The acoustic propagation for long range surface ducted conditions with the source and receiver in the upper 15m of the water column are complex and difficult to model. One can see variations of over 10dB for the same conditions depending upon which propagation model is utilized or by making small changes in assumed parameters from the same model. Additional estimated SPL exposure analyses are underway which also utilize the PCIMAT propagation model. It is desirable for the community to standardize on a single model (or models even if other than PCIMAT) such that similar efforts estimating SPLs are more comparable to one another. Having acoustic sensors deployed near the surface would also help with model validation efforts (recall the range hydrophones are all located near the seafloor).

This study did not address the measurement error for the two sighting methods, however one could make simple assumptions for the azimuth angular errors (e.g. +/- some number of degrees) and the distances reported in terms of +/- some % of total distance. This was not done herein due to unfamiliarity with the sighting methodologies and protocols utilized. If future efforts concentrate on additional analysis of estimated exposure levels from sightings, it is recommended that each sighting protocol include some form of calibration effort, or error estimation, in order to better estimate sound pressure level exposures for the sightings.

The discrepancy between the sonar equation (equation 2) and the PCIMAT model estimated SPLs shows a positive bias for the PCIMAT values by a few to several dBs as seen in figure 3. A report (Fromm 2009) that estimated acoustic exposure on orca whales in Haro Strait from a US Navy DDG also indicated modeled values which were 1 to 10dB re 1 μPa higher than available recorded data. The reason(s) for the positive bias shown in figure 3 are not fully understood. One possibility is that the surface duct is focusing the sound, resulting in less transmission loss than the sonar equation predicts.

The break between spherical and cylindrical spreading for the two models appears to be in good agreement showing transitions between 2km and 4km. PCIMAT model runs utilized historical SVP's for the dates of the sightings as actual sound velocity profiles (SVPs) were not available from the 2011 Feb SCC. The longer distance SPL estimates involve multiple bottom surface interactions and ducting which are modeled by PCIMAT but not by the sonar equation which may explain the differences between the two models at longer distances. It is noteworthy that the PCIMAT propagation losses have also been observed to vary by 4-5 dB at distances of just a few kilometers when using historical SVPs from different days. This highlights the desire to have actual SVPs from future training events to be analyzed (SVPs have been obtained from PMRF for more recent SCC training events).

Re-sightings:

When re-sighting information is available, the result is repeated updates on the estimated position of an animal, or group of animals. This typically reduces the animal location uncertainty compared to instances of single isolated sightings such as depicted in figure 2 where one must assume the animal could have moved in any direction from its sighted position in the time elapsed between the sighting and the MFA transmission. Re-sightings may occur from both shipboard and aircraft observers and for focal follow situations. No aerial re-sightings were available from this training event coincident with MFA activity; however one shipboard re-sighting did coincide with MFA activity (i.e. 09:47 to 09:56 on 18 Feb 2011). There were a total of eleven re-sightings from both port and starboard observers of the group of humpback whales after the initial sighting in this instance. This sighting with re-sightings instance also accounts for four of the sixteen estimated SPL's in this report. Some re-sightings did not have sufficient information to place the sighted animal in earth coordinates. The last five re-sightings were not included in the exposure analysis as they occurred over 2 minutes after the last MFA transmission at 09:51:01 when the sonar was secured due to proximity of marine mammals. Utilizing the reported animal positions from the detailed sighting spreadsheet (Farak 2011) and PMRF data products, one can plot ship positions (including those when sightings and when MFA transmission occurred) along with the sighted animals' reported positions.

The one instance of re-sightings with respect to MFA activity in this training event occurred for a shipboard sighting for a training event which began at approximately 09:30 on 18 Feb. A total of 13 MFA transmissions occurred with the first MFA at 09:39:27 and the last, prior to securing the sonar due to marine mammal's proximity, at 09:51:01. Figure 4 provides a plot of ship positions (squares) and sighted animal positions (triangles) for this single shipboard sighting with re-sightings between 09:46 and 09:57 on 18 Feb 2011. Shading of the symbols represents the age of the position update (lightest shading most recent position update while darkest are the earliest). The ship was moving on a course of approximately 18 degrees true over the time shown in figure 4.

A detailed analysis can be conducted on the sighting and re-sightings; however the measurement errors of the sightings themselves should be included in such an analysis. The initial sightings and first re-sighting of the group of humpback whales (at 09:47:49 and 09:48:10 respectively) are reported as the same distances and occur 21s apart in time. Given the ship motion, that would indicate that the animals actually were headed on a northern course at this time, however there is also potential error due to sighting of different individuals in the group and how far apart members of the group are. The 2nd re-sighting with animal location information at 09:49:45 was at a distance of 1829m from the ship at a relative bearing reported as the starboard bow. Assuming 5 degrees off the starboard bow this indicates the animals moved a fairly large distance at a heading of approximately 225 degrees true from the prior sighting in only 95 s, indicating a high rate of speed near a humpbacks' maximum reported burst speed. The 3rd re-sighting with animal location information, and the last associated with MFA, occurred at 09:51:34 at a reported distance of 137m 5 degrees off the bow (angles off the bow go from 0 to

180 degrees for the starboard side and 180 to 360 degrees for the port side). The animals would again have had to move on a course of approximately 225 degrees true at near maximum burst speed almost directly towards the approaching surface ship while it was transmitting MFA signals for over 3 minutes. The ship secured its sonar per protocol after the MFA transmitted at 09:51:01 due to the US Navy observers sighting marine mammals within 1000 yards. At approximately 09:52 the ship and animals converged, with the animals diving off the bow of the ship and resurfacing as two groups. Sightings after 09:52 with positional information (with no MFA involved within the +/- 2 minute window) are plotted in figure 4 as up pointing triangle (port and starboard sightings at 09:54:32 and a sighting at 09:55:47), indicating that the animals reversed course and reduced their speed.

The indicated high travel speed potentially fits with humpback surface active group behaviors associated with a competitive group (i.e. multiple males competing for a female: Darling 2001). The shipboard observers did report a calf in this group but gender of the adults was undetermined. Calves are often with their mothers, which gives some support to the hypothesis of a surface competitive group. The whales' behavior for such a group during this time would presumably be dominated by their competition for the female and possibly not paying attention to the approaching surface ship transmitting MFA signals. Alternatively, one could also speculate the animals were attracted toward the ship transmitting MFA. However, when the ship met the group of whales at approximately 09:52, the animals appears to have reacted by splitting into two groups, reversing course and reducing their speed.

A revised shipboard sighting report was provided when this report was being prepared. The revision was to make blanket corrections for some observers for a perceived procedural error in the distance calculation. For the sighting / re-sighting period indicated in figure 4, the revised sighting report had corrections for the initial and 1st re-sighting for this sequence at 09:47:49 and 09:48:10 (changed the distances from 3502m to 2170m). This would place the animals very close to the sighting at 09:55:47 at around 09:48 (vice up at the top of figure 4 as currently shown). This would imply the animals were originally headed away from the surface ship at fairly high speed (due to 09:49:45 sighting), however the sighting at 09:51:34 would indicate the animals turned toward the ship and traveled at relatively high speed in that time interval. A final course reversal by the animals is implied by the sightings after 09:52. While it is unclear which data is most correct, the thought of animals on more of a constant heading with a single course reversal is more appealing than that of animals going at high speeds with two course reversals in several minutes time. If the revised report had also corrected the sighting at 09:49:45 to be in the area of the initial and 1st re-sighting, the data would indicate animals at low speeds, possibly milling in the area, which may be more sensible than either of the previous interpretations. This highlights the need for accurate sighting methodology if one is to infer animal behavioral states based upon kinematics.

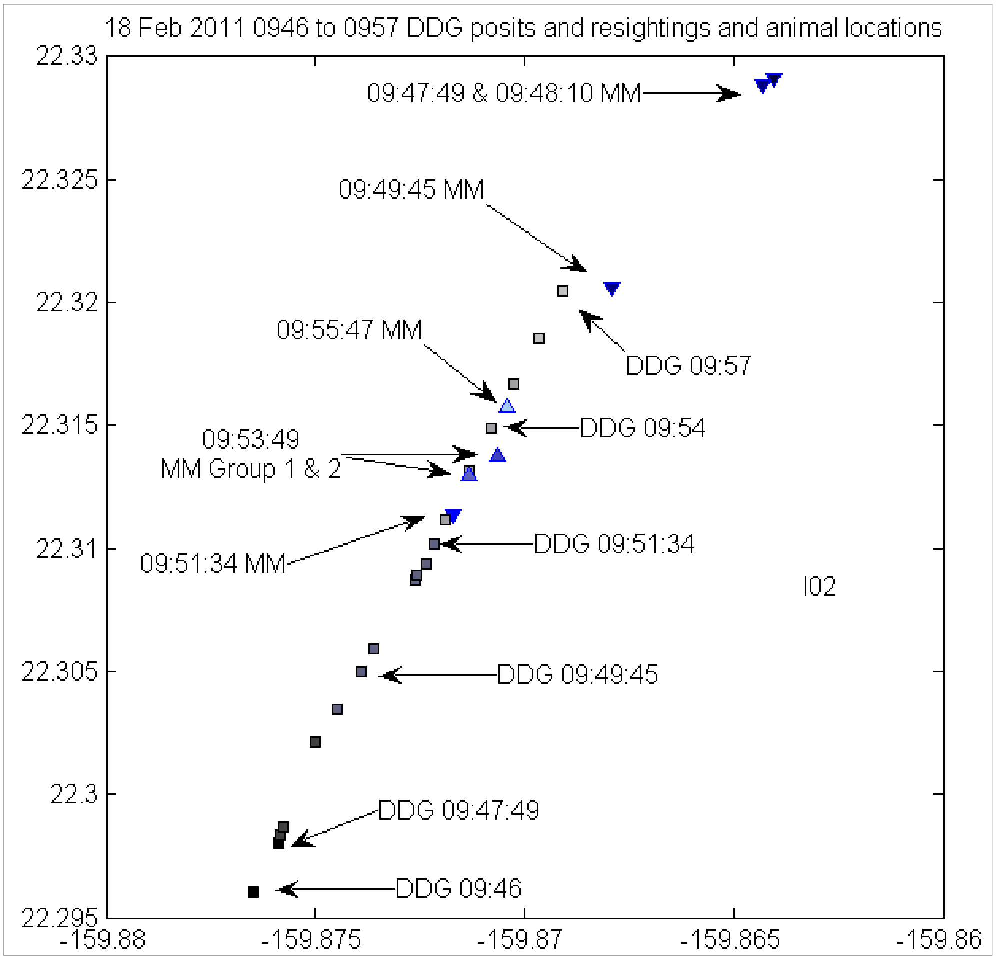

Figure 4 – Plan view (not to scale) of multiple re-sightings 0946 to 0957 on 18 Feb 2011 from shipboard observers, all times HST. Ship positions shown as squares, animal sighting locations as triangles, with shading representing time (darkest indicate oldest time positions, lighter indicate latest time positions). The group of 4 to 5 humpback whales was traveling towards the MFA transmitting ship at a fairly high speed, last MFA at 09:51:01 and at approximately 09:52 the ship and animals meet, with the animals diving off the bow and resurfacing as two groups.

Conclusions

In naval training events involving MFA activity with sightings of marine mammals, one may estimate SPLs that sighted animals received from the MFA activity if suitable data is available. The data required is the MFA ship information (positions, times of MFA transmissions and the MFA signal characteristics) and information to localize sighted animals. This analysis utilized: sighting reports to derive sighted animal locations; PMRF standard data products for ship positions; and acoustic data during the exercise to determine the time of the MFA transmission and which ship transmitted it. This report provides estimated SPLs for sixteen of the marine mammal sightings and re-sightings which occurred for the Feb 2011 SCC training event.

Multiple re-sightings provide additional information which potentially provides insight into the behavioral state of the whales based upon kinematics. In the one re-sighting case coincident with MFA activity reported here it may be reasonable to assume that the group of 4 or 5 sighted humpback whales and calf were potentially multiple males escorting a female with calf, at relatively high speeds, which could indicate competition for a female (although the sighting did not report a female, the presence of the calf may indicate a female was in the group). In this sighting / re-sighting instance, the animals appeared headed nearly directly towards the MFA ship which was closing on the animals. The MFA activity was secured per Navy protocol due to the proximity of the whales sighted by US Navy lookouts, however due to the short distances involved the last MFA transmission could have potentially exposed the whales to levels sufficient to induce TTS. If the shipboard sighting measurement errors are large, the derived speed estimates would be incorrect and not only would the estimated SPLs need to be recalculated, but the concept of a surface group of males in competition for a female may be less likely.

For future efforts involving visual sighting with a goal of estimating SPL exposures, the following recommendations are provided: aerial surveys attempt to obtain positions of sighted animals; both survey platforms utilize some form of measurement calibration protocol in order to have quantified data on the sighting location accuracy; and collect actual sound velocity profiles during the exercise.

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