APPENDIX N. Report on Analysis for Marine Mammals Before, During and After the Feb 2011 Submarine Commanders Course Training Exercise.

Prepared 08 Sept 2011 by Stephen W. Martin, SPAWAR Systems Center Pacific, Code 71510 and Thomas Kok, San Diego State University Foundation

This report provides information relative to marine mammals at the Pacific Missile Range Facility (PMRF) before, during and after the Feb 2011 Submarine Commanders Course exercise (SCC) between 11 and 22 Feb 2011. This is the first instance of having acoustic data available during an SCC which allows expanded analysis (such as estimating exposure levels on animals) compared to the report done for the Feb 2010 SCC exercise (Martin 2010).

Results for the average minke boing rate per hr and beaked whale dive rates show animal presence before, during and after the exercise. The variability in the average minke boing rate is high and shows depressed values during parts of the exercise. It is unclear if the depressed values are part of normal variation or a result of the exercise activity. Periods of rapid boings are evident in the data which are suspected as being due to two or more calling whales being in close proximity to one another (Thompson and Friedl 1982). Beaked whale presence, as evidenced by detection of beaked whale foraging clicks, is quantified in terms of dives per hour with presence before, during and after the exercise with no clear implication related to mid frequency active sonar activity (MFA).

Sound pressure levels (SPL's) that marine mammals were exposed to from a US Navy destroyer (DDG) equipped with the AN/SQS-53C sonar transmitting nominal 3kHz MFA pulses are estimated using sonar equations and a ray trace propagation model in post-processing of recorded passive acoustic data for a focus period between 05:58 and 07:39 HST on 17 Feb 2011. Exposure levels are estimated for three separate DDG 3k MFA transmissions at 06:17, 07:35 and 07:38 for a minke whale, a humpback whale and a group of unidentified whales respectively. Results show the highest estimated exposure level of 164 dB SPL re micro Pascal (µPa) was for the group of 3 to 5 unidentified whales that were sighted at 07:39 by observers on the DDG (sighting #9) which were at a distance of 3.4km from the DDG at 07:38. A minke whale was acoustically automatically detected, classified and localized from early morning 17 Feb through 10am, manual validation determined that a total of 15 boing calls were produced between 5:58 and 07:36 and position estimates refined using corrected times of arrival. The minke was exposed to an estimated SPL of 139 to 145dB re µPa at 06:17 at a distance of 16.3km which would be the strongest on this animal as the distance with the DDG opened for the remainder of the event. The minke whale did not seem to significantly change its swim behavior or vocal pattern. A single, manually derived, acoustic localization for a humpback whale at 07:36 was 21 km from the DDG and exposed to a SPL of between 136 to 141 dB re µPa. The range of SPL's is related to the type of propagation path (direct, ducted or bottom bounce) and model used for the estimate.

Analysis of sound pressure levels animals were exposed to for additional focus periods in this exercise are planned using a standard US Navy propagation model (PCIMAT). This exercise provides many opportunities for estimating exposure levels on animals with potential for observing behavioral changes. Analysis of visual sighting # 14 is underway as it was specifically commented on in the cruise report (Farak et al. 2011) due to the animals close proximity to the DDG and multiple sightings at close range.

Introduction

This is the first instance of having acoustic data available for marine mammal monitoring during a US Navy exercise at PMRF, specifically during the 14 – 19 Feb 2011 SCC. This report focuses on sonar exposure to marine mammals between 06:17 and 07:38 on 17 Feb 2011 which covers the period of active 3kHz (nominal) MFA transmissions during the event termed "miniwar III". This event involved three surface ships transmitting MFA signals and one submarine. This effort focuses on the 3kHz MFA (3k MFA) transmissions from the US Navy destroyer (DDG) equipped with the AN/SQS-53C sonar system. The other two surface ships were employing higher frequency mid frequency sonar signals which are not addressed in this report.

The focus time was selected for multiple reasons: 1) to limit the analysis to a manageable effort for understanding what types of information in relationship to exposure levels are available; 2) a sighting was made during the period of MFA activity; 3) acoustic analysis indicates high confidence locations for a minke whale (Balaenoptera acutorostrata) on range during MFA activity; and 4) acoustic analysis also indicates humpback whale (Megaptera novaeangliae) presence on the range during MFA activity.

There was also a visual sighting of an individual humpback whale from trained marine mammal observers aboard an aircraft nearby at 08:10:58. Exposures were not estimated for this sighting due to animal location uncertainty over 30 min from the last 3k MFA transmission.

This effort utilizes sonar analysis employing both a ray trace model and sonar equations to estimate the sound pressure level expected at the animal locations. The use of PMRF bottom hydrophones in validating the exposure level estimations is also described.

Analysis of automated minke and beaked whale signals is performed in a manner similar to that reported for the before and after portions of the Feb 2010 SCC exercise (Martin 2010). The analysis shows presence of these species before, during and after the Feb 2011 exercise. Manual analysis for other species is also provided.

Methods

The method utilized to estimate the sound pressure level animals are exposed to require animal and surface ship locations very close in time to MFA transmissions. Ship positions are obtained from standard PMRF exercise products. Animal locations are determined by sightings and processing of recorded passive acoustic data. Two models are utilized to estimate the sound pressure levels at animal locations; sonar equations and a ray trace program. The acoustic data was also utilized to confirm precise 3k MFA transmission times and to compare with model outputs. The ray trace program (Ray Trace ver. 1.1.1 dated 08-04-2005) was developed by Roy Deveanport, with modifications by F. Ludecke, at the Naval Undersea Warfare Center (NUWC). This ray trace program has only been validated for horizontal ranges up to 10km and does not include bottom reflection losses. Standard US Navy models, such as PCIMAT, are planned to be used in future analysis. A sound velocity profile (SVP) for measured data from 27 April 2009 to 750m depth combined with historical data to the seafloor was utilized. This SVP does show a viable surface duct path. Future efforts should obtain in-situ SVP data.

Parameters and assumptions employed in this analysis, and their nomenclature, are: a 3kHz nominal frequency (f=3); a source level (SL) of 235dB re μPa; absorption coefficient at 3kHz (α) of 0.2 dB per km (Ilyina 2009); a sonar source depth (d) of 5m; animal depths of 10m (ad) ; a surface duct of 50m (H); a sea state (S) of level 2; sonar projections towards animals are at the surface ship sonars maximum response axis (MRA) except as otherwise noted. The environment is deep water environment with viable surface duct and bottom reflection propagation paths. For short range direct path propagation assumes spherical spreading including the absorption coefficient contribution. The surface duct path cannot be validated with PMRF bottom phone data in this analysis; however the validity of the bottom multipath is confirmed with data from the PMRF range hydrophones.

The surface duct (or mixed layer duct) propagation path sonar equation includes transmission loss from spherical spreading, cylindrical spreading, and attenuation coefficients for both normal propagation and duct leakage. The equation appears in Urick's 1983 book, Principles of Underwater sound and is provided as equation 1 where Le is the estimated sound pressure level of the exposure:

Equation 1: Le =SL-(10*log10(ro) + 10*log10(r) + 0.001*r (α + αL)) in (dB)

where: SL is the source level; ro is the transition range (m) from spherical to cylindrical propagation and for this case is estimated as 2568 m (from H/0.3048*sqrt((R/.3048) / (8*(H/.3048-d/03048))) where R is the radius of curvature of the surface duct rays (~ 88,235 m); r = range from source to animal (m); α is the attenuation coefficient (0.2dB/km for 3kHz) and αL is the surface duct leakage coefficient in dB/km and is estimated (Urick 1983) as 2/0.9144*S*sqrt(f*0.3048/H) where f is in kHz. Substituting these parameters and values into equation 1 results in:

Equation 2: Le =200.9 - 10*log10(r) - 0.001*r*(0.2+0.5916))

The surface duct transmission loss is seen to have major contributions from the surface duct leakage component (αL) and the transition range from spherical to cylindrical spreading (ro).

Data for the surface ship (DDG) marine mammal observers sighting at 07:39 is derived from Farak et al. 2011 (the cruise report). The sighting was geo-referenced using the sighting data with ship position at the time of the sighting and a ship heading derived from PMRF standard exercise products. The sighting was of unidentified whales, in a group of from 3 to 5, with report of "at least 3 bushy angled blows likely due to humpback or sperm whales".

The bottom bounce path sonar equation model assumes spherical spreading, constant sound speed profile, a nominal 7dB bottom reflection loss (BRL) for grazing angles from 25 degrees to 70 degrees, a flat bottom depth of 4550m and that d (source depth in m) is << wd (water depth in meters) and that ad (animal depth in m) is also << wd. Equation 3 provides the estimated exposure sound pressure level for the bottom propagation path. Notice their is no correction for the relative heading from the DDG to the animal being significantly off the AN/SQS-53C maximum response azimuth and elevation angles. This is a source of significant error for certain geometries, but is not quantitatively addressed for security reasons in this report.

$$\text{Equation 3: } Le = SL - 20*\log10(sr) - sr*0.001*\alpha - BRL$$

Where BRL is the bottom reflection loss (7dB for grazing angles from 25 to 70 degrees) and sr is a first order estimate of the path slant range between the DDG and animal and is given by simple geometry as sr ~ 2*sqrt(wd2 + r2/4).

Results

Acoustic data collection

Thirty one hydrophones of passive acoustic data was collected continuously (with one 8.5 hr exception) for approximately 257 hrs between Friday 11 Feb 2011 @ 08:20 HST and Tuesday 22 Feb@ 10:32 HST. Figure 1 shows a plot of the approximate location of the range hydrophones recorded for this effort. The northern eighteen BSURE (Barking Sands Underwater Range Expansion) hydrophones analyzed in 2010 were replaced with 41 wider bandwidth (~50Hz to 45kHz) hydrophones early in calendar year 2011 (of which 18 were recorded in lieu of the previous 18 hydrophones). Acoustic data was recorded onto four 3.5" SATA hard drives as files of approximately 10 minutes duration with file name convention shown in table 1. The torpedo exercises (three events) were scheduled to start at 00:00 on Monday 14 Feb 2011 and complete Wed 16 Feb 2011 @ 02:00, while the miniwar exercises were scheduled to begin Wed 16 Feb 2011 @ 05:00 and complete Sat 19 Feb 2011 @ 03:00.

Table 1 – Acoustic data recordings dates, times, filenames, exercise events and number of hours of multiple channel (31 phones) data.

HST date/ start time	HST date / end time	File names	events	# hrs
Fri 11 Feb 2011 08:21	Mon 14 Feb 2011 01:54	11Feb11_182158_001 to 394	Pre exercise & start of torpex I	65.6
Mon 14 Feb 2011 10:02	Wed 16 Feb 2011 13:55	14Feb11_200233_001 to 312	Torpex I,II,III & Miniwar I	52
Wed 16 Feb 2011 13:57	Sat 19 Feb 2011 03:41	16Feb11_235737_001 to 370	Miniwar I - VI	61.6
Sat 19 Feb 2011 03:41	Tues 22 Feb 2011 10:32	19Feb11_134154_001 to 475	Post exercise	79

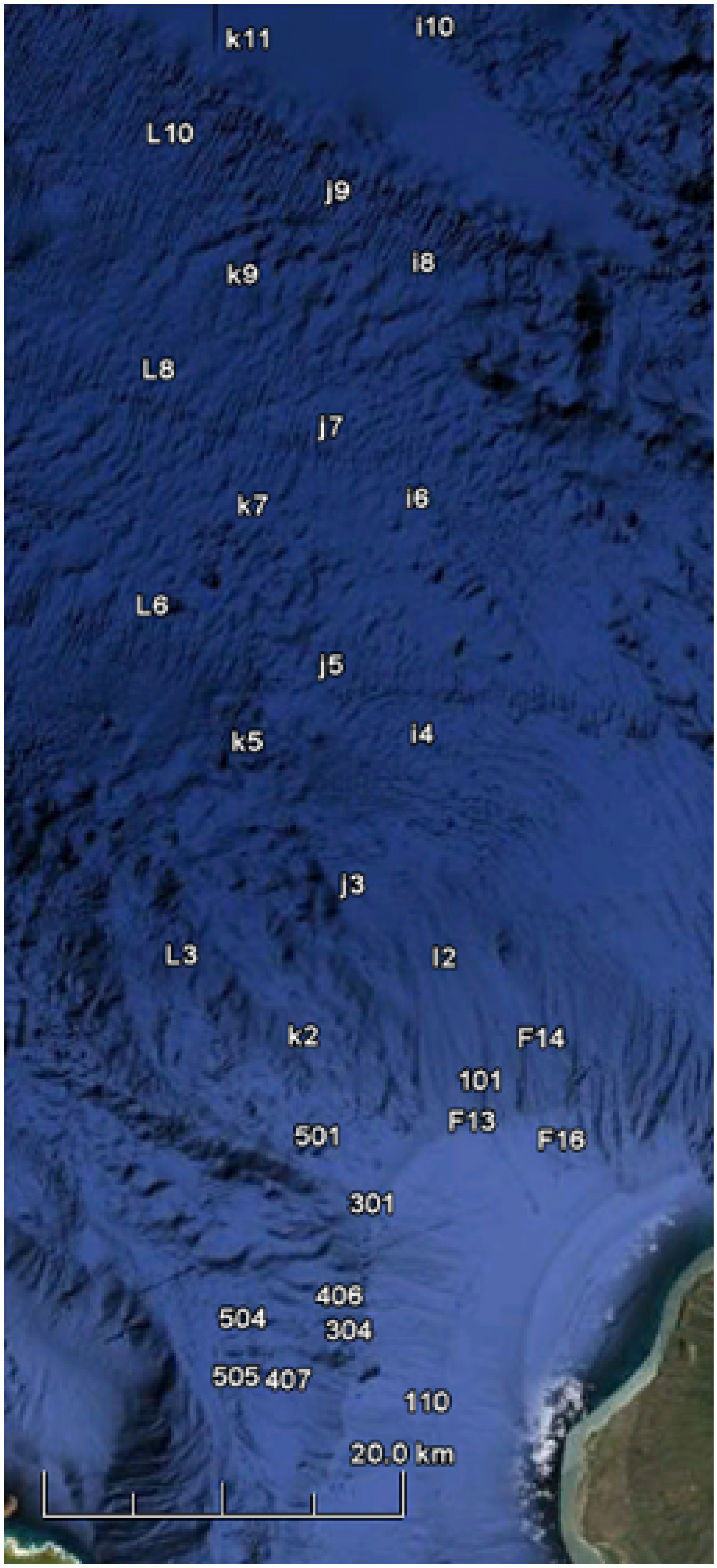

Figure 1 – Thirty-one hydrophones recorded and utilized in the analysis. Kauai lower right.

The newly installed hydrophones (with I, J, K, and L first characters in their nomenclature in figure 1) provide a higher frequency response compared to the old hydrophones (45kHz vs. previous 19kHz) which enables detection of higher frequency calls / echolocation clicks (such as those of beaked whales) for the BSURE replacement phones. Significantly, the replacement BSURE phones also provide a much lower frequency response (advertised 50Hz vice 100Hz) which is enabling detection of 20Hz to 40Hz sounds from large baleen whales (blue, fin, sei, etc.). This opens up additional capabilities for detection of marine mammals, while retaining similar area coverage of the previous hydrophones.

Marine mammal localization and exposure estimates

This exercise has multiple species (minke, beaked, pilot, sperm and humpback) on, or near, the range and vocal during the Feb 2011 exercise. This allows potential repeated localization of the marine mammals by passive acoustic processing methods vice single sighting updates by trained marine mammal observers. Currently only automated techniques are available for localizing minke whale species (Martin et al. 2011) using their "boing" calls (Rankin and Barlow 2005). The automatic localizations show a minke whale on north BSURE from around 02:00 on the 17th through about 10:00. The automatic localizations are believed to be from a single minke whale as the acoustic peak frequency in the 1350Hz to 1440Hz detection band (Mellinger et al. 2011) is nominally 1400Hz (+/- 3Hz) over the entire period and the intervals between these boings corresponds to nominal inter-boing-interval rate of around 6 minutes (Thompson and Friedl 1982). A minke whale visually sighted on the range on 27 April 2009 (Martin 2011) was determined to have a mean inter-boing-interval of 377 sec (sd 112s) with a peak frequency in the detection band of 1384Hz (sd 1.78Hz). The automatic localizations for the 17th were refined for fifteen boings between 05:58 and 07:37 by manually validating the calls, obtaining more accurate start times and utilizing the same two dimensional time difference of arrival hyperbolic localization routine used in the automatic localization. Table 2 provides the times of minke boings utilized in this analysis, which recorded data file the call is detected in, the inter-boing-interval and latitude and longitude of the call source location. Notice that there are three areas where the intervals are significantly larger than the rest marked with asterisks in table 2. This could be due to the animal not making calls between these times, calls being masked by MFA signals, or the animal significantly reducing the level of calls during these periods.

Figure 2 shows a course scale view of the area of the PMRF BSURE range during this analysis period the morning of 17 Feb 2011. The range hydrophones are labeled as three digits with leading alpha characters (i.e. I10, J09, K11, L10), the DDG ship position shown as plus signs with labels and arrows to indicate the times, in a similar manner the fifteen minke whale positions from table 2 are shown as open squares. Two additional symbols show the location of the DDG sighting of a group of between 3 and 5 unidentified whales (open circle at 07:39), and the single manually derived humpback whale position shown as an open diamond at 07:36. Localization accuracy is estimated to be approximately +/- 200m for the minke whale – hydrophone geometry shown using hydrophones J09, I10, K11 and L10 to localize the minke whale.

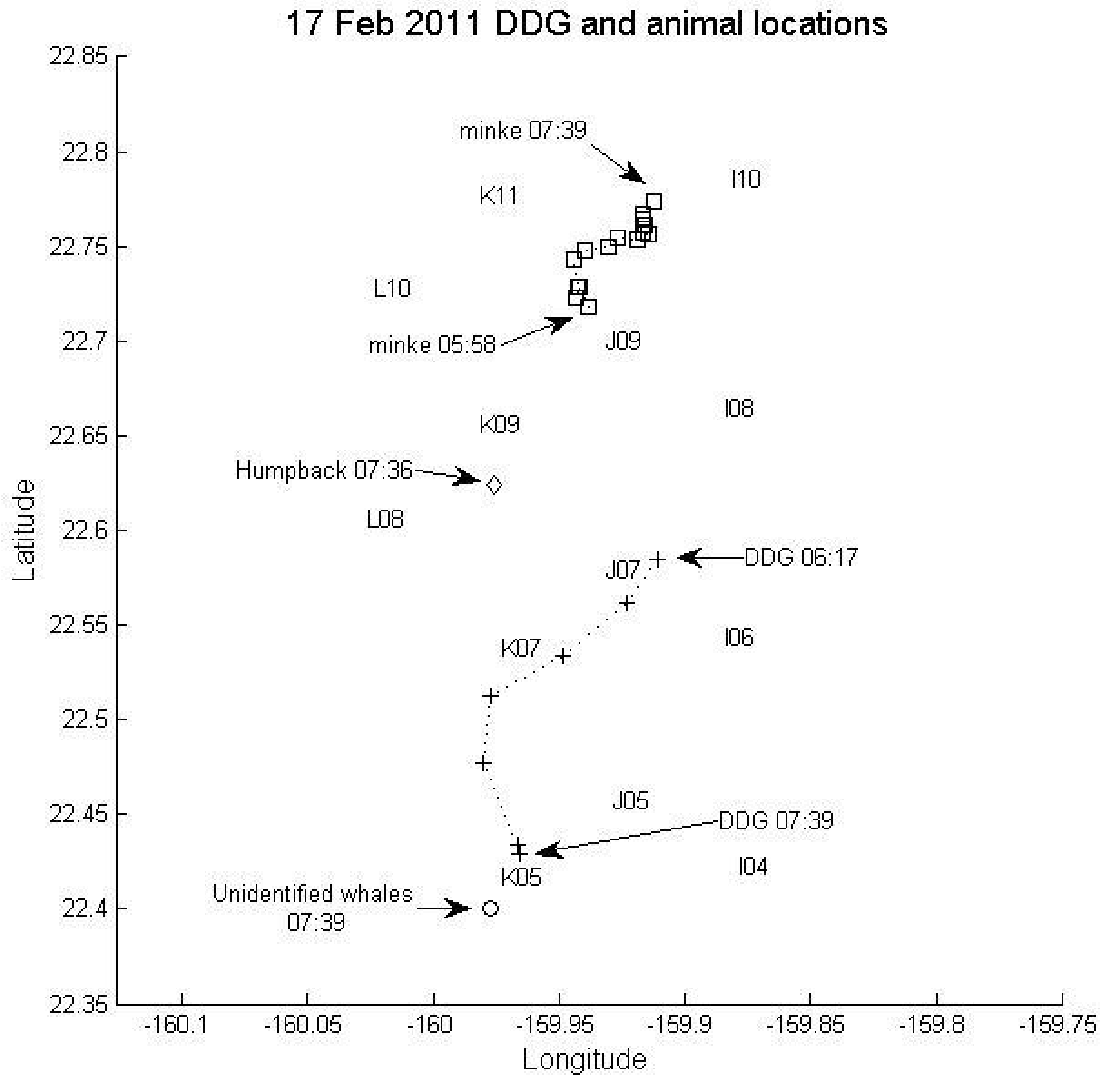

Figure 2 – Plan view of positions of DDG (plus symbols) and whales (minke square symbols, humpback single diamond, unidentified group of whales open circle) between 05:58 HST and 07:39 on 17 Feb 2011. Closest distance from DDG during MFA transmits for unidentified whales are 3.4km at 07:38, followed by 16.3km at 06:17 for minke whales followed by 21km at 07:36 for humpback whale. Note that for the humpback case the whale is nearly astern of the DDG.

Figure 3 shows an expanded view of the minke whale position updates with additional time labels. The animal in general is advancing northward; even before the first MFA of this exercise (of course there were MFA signals a few hours prior in the miniwar II event). The first 3k MFA occurred at 06:17:18 (times reference to closest bottom phone reception time) which is 95s after the animals fourth boing in table 2. Over twelve minutes elapses before detecting the animals' fifth boing. One might expect an additional boing call in between the forth and fifth calls however if one were present it was either very low level compared to other boings from this animal, or it was masked by the MFA signals which saturate the hydrophones for brief periods. The distance the minke traveled between the boings at 06:15:43 and 06:27:50 is estimated as 1.61km in the 717 seconds (2.25m/s or 8.1km/hr). This speed is 66% of that seen between the first and second boings at 05:58:58 and 06:04:38 where the minke is estimated to travel 1.16km in 340 seconds (3.4m/s or 12.2km/h). These speeds are slightly less than reported for the individual sighted by Rankin and Barlow 2005 (5.6km/h) and reasonable relative to reported normal swim speeds of 4.8 to 25km/h. The observed swim rates are also well below maximum burst speeds of up to 34km/h. The animal continued what one would consider normal boing call intervals during the entire 80 minutes of 3k MFA activity and did not exhibit high swim speeds. The animal is observed to be advancing towards the north while the exercise ships were generally advancing south. The animals advance direction is away from the MFA ship, however it was also trending north before the first 3k MFA transmission. Throughout the 05:58 to 07:39 analysis time the animal is within an area defined by four hydrophones (i10, j9, k11 and L10) which generally results in good localization accuracy. It is interesting to note that the higher frequency components of the individual boings are better received at some hydrophones vs. others presumably due to the directional nature of the higher frequency components (which go to over 11kHz) of the boing. If one speculates that the highest frequencies and highest amplitudes are emitted from the front of the animal this gives an indication of where the animals head is pointed at the time of the boing. This illustrates the potential of information possible about marine mammals using acoustic data.

Table 2 – Minke whale boing detection times on phone J9, inter call intervals and locations for exposure analysis of 17 Feb 2011 05:58 to 07:37.

Boing time hh:mm:ss (HST)	Data file sequence # 16Feb11_235737_	Inter Boing Interval (sec)	Lat (dd.ddd)	Lat / long (dd.ddd)
05:58:58	97	Na	22.7184	-159.9387
06:04:38	97	340	22.7283	-159.9423
06:10:29	98	351	22.7233	-159.9432
06:15:43	98	314	22.7283	-159.9430
06:27:50	100	727 *	22.7428	-159.9442
06:33:28	100	378	22.748	-159.9398
06:44:17	101	649*	22.7499	-159.9305
06:49:55	102	338	22.7543	-159.9266
07:00:49	103	654*	22.7532	-159.9191
07:06:43	103	354	22.7568	-159.9149
07:12:26	104	343	22.7574	-159.9168
07:18:25	105	359	22.7608	-159.9163
07:23:39	105	314	22.764	-159.9168
07:30:37	106	418	22.7673	-159.9168
07:37:02	106	385	22.7739	-159.9126

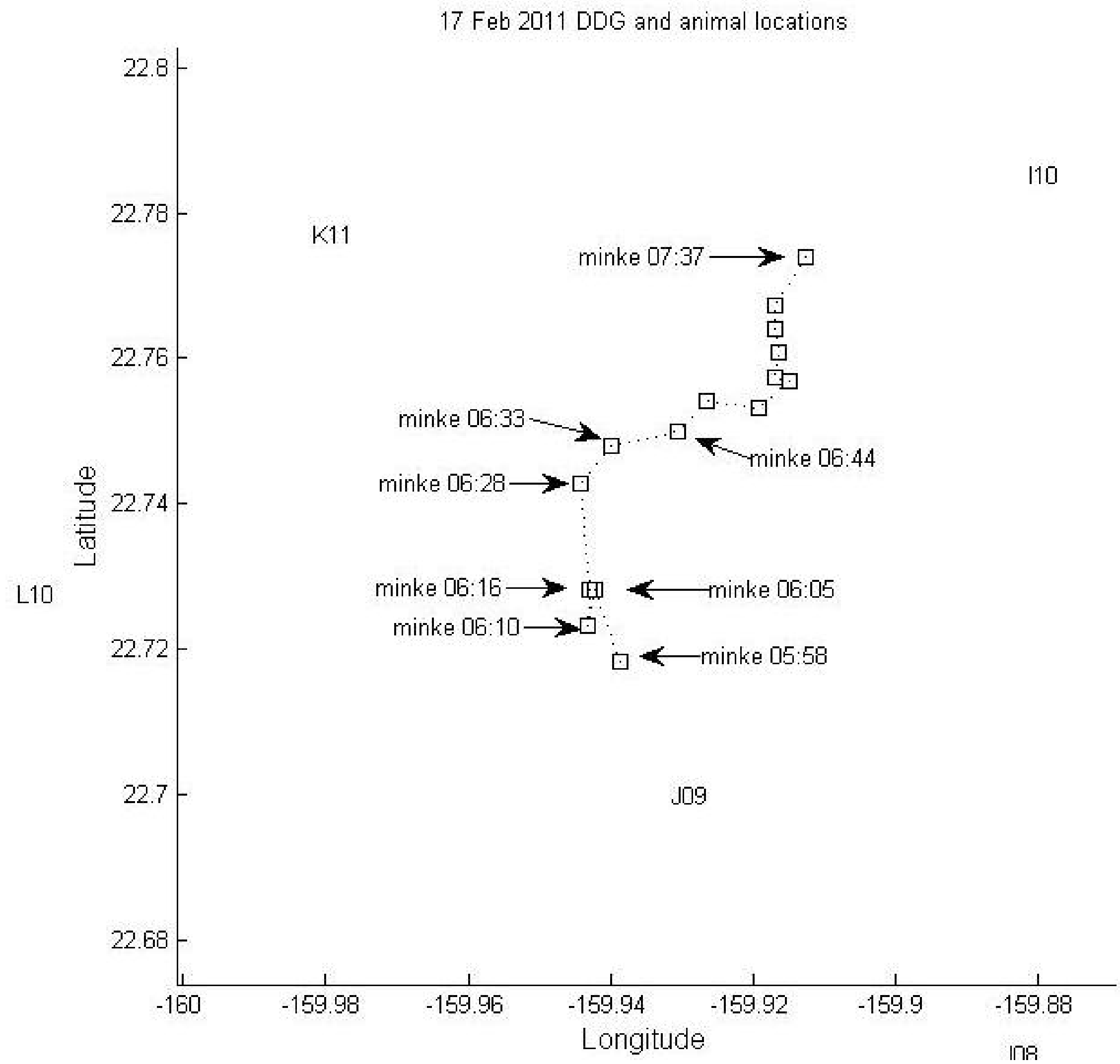

Figure 3 – Close up of minke whale position updates (square symbols) from 05:58 through 07:37 for fifteen boings in table 2. Three bottom hydrophone approximate locations indicated by the J09, K11 and I10 labels. Arrows show approximate times of minke boings so direction of travel is observable. Dotted line connects successive position updates for linking positions rather than implying the animal traveled the dotted path. Initial 3k MFA transmission occurred just after the 06:16 position update and the last transmission from this event occurred at 07:38.

The positional data in table 3 summarizes the ship-whale locations and orientations for the three 3k MFA transmissions analyzed for exposure levels. There were many 3k MFA transmissions from the DDG and additional higher frequency MFA transmissions from the other two surface ships in this event (miniwar III). For simplicity in this analysis the bottom depth is considered flat and fixed at 4550m, 3kHz is the frequency for the analysis, a sea state of 2 will be utilized. Higher sea states increase the mixed layer (surface) duct leakage coefficient, which in turn reduces the exposure level.

Table 3 – Positional data for localized marine mammals and surface ship transmitting nominal 3kHz MFA signals between 06:15 and 07:39 on 17 Feb 2011 during SCC miniwar III event. Times shown for the DDG location correspond to 3k MFA transmission times as received by the closest bottom hydrophone. Estimated DDG heading based upon successive updates of positions vice heading sensor data. Range and true bearing to animal from DDG, along with relative bearing to the whale from the DDG ship also shown.

Time (HST) hh:mm:ss	DDG posit at transmit time or whale posit	Latitude (dd.dddd)	Longitude (ddd.dddd)	est. DDG heading (deg true)	Range (m) & brg DDG to animal	Relative brg DDG to animal
06:15:43	minke acoustic posit	22.7283	-159.9430	na		
06:17:18	DDG posit at transmit time	22.5844	-159.9111	255	16,300 @ 349 true	94
07:36:45	Humpback acoustic posit	22.624	-159.9762	na		
07:35:51	DDG posit at transmit time	22.43443	-159.96617	180	21,000 @ 347 true	167
07:38:07	DDG posit at transmit time	22.4289	-159.9661	180	3,390 @ 201 true	21
07:39:09	Unidentified whale visual posit (group of 3- 5)	22.4002	-159.9775	180	3350 @ 20 rel	20

Plugging values into equation 2 and the ray trace program, one arrives at exposure levels for the three 'encounters' shown in table 3. Each of the two estimation methods, equations and ray trace model, provide output in most cases. Table 4 summarizes the estimated sound pressure levels the animal is exposed (Le) to from two propagation paths (surface duct / direct and bottom bounce).

Table 4 – Estimated exposure of marine mammals (sound pressure level) for marine mammals the morning of 17 Feb 2011 as determined by sonar equation and ray trace models for both a surface duct, or direct path, and one bottom bounce of sound from seafloor to animal.

L_e (dB re micro Pascal)				Horizontal Range	Species and time of MFA (HST)
Includes 7dB of bottom reflection loss			no bottom reflection loss	In meters and rel brg to ship at 3k MFA transmission time	Ba=minke Mn=humpback unid=unidentified whale
Sonar equation model		Ray Trace model			
surface duct	Bottom bounce	surface duct	Bottom bounce		
145.6 dB	138.7 dB	No path	148.4 dB	16300 m @ 94	Ba 06:17:18
141.4 dB	136.4 dB	No path	146.7 dB	21000 m @ 167	Mn 07:35:51
162.4 dB	146.2 dB	164.1 dB @ 2.2s dp	154.7 dB @ 6.44 s	3390 m @ 21	Unid 07:38:07

Model validation efforts

Validating the estimated exposure level is attempted utilizing measured bottom hydrophone data. This process is hampered due to the saturation of the bottom hydrophone data at approximately 120dB re uPa based upon nominal hydrophone response of the BSURE replacement hydrophones considering system gains through the system and for the data recorder utilized. Figure 4 shows the ray trace from the DDG location to bottom phone (phone j9 at 15km horizontal distance) case showing the direct path and bottom-surface multipath propagation for a bottom depth of 4550m. This phone was selected for being in the same azimuthal direction as the minke whale at 06:15 on 17 Feb for the estimated exposure analysis. The direct path arrives at the bottom phone with a modeled level of 149.4dB re uPa (saturated) with the bottom-surface multipath arriving with a level of 146 dB re uPa at 3.04s after the direct path arrival. The ray trace model is not allowing for bottom or surface reflection losses. Actual measured data shows the show the direct path signal at the J9 bottom phone badly saturated, and the bottom-surface multipath right at the saturation level of 120dB re uPa arriving 3.5 seconds after the direct path. The actual data shows a slightly longer delay between the two arrivals and a 26dB weaker signal than the ray trace model predicts. This difference could potentially be explained by a combination of: 1) a 7dB bottom reflection loss; 2) a 4dB surface reflection loss; and 3) a 15dB loss due to the launch angle being significantly off the transmitters' elevation maximum response angle (MRA). The use of actual measured data to validate models (both equation and ray trace models) is strongly encouraged to ensure the models are predicting values one sees in the real world. This exercise shows the magnitude of errors possible when using models that do not properly represent actual conditions.

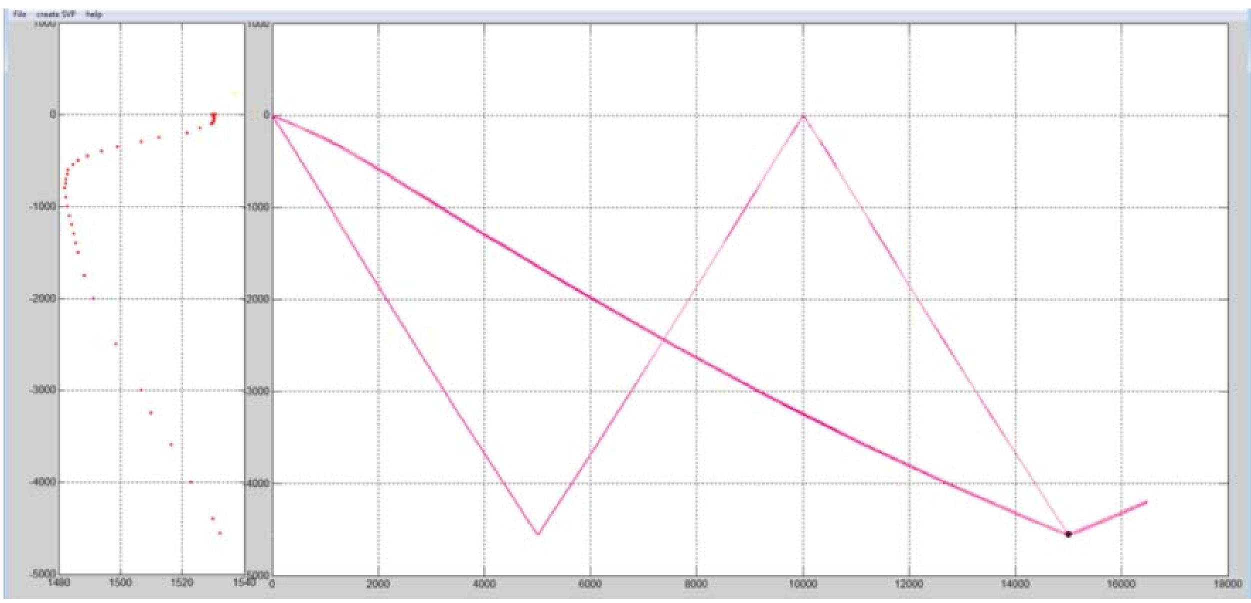

Figure 4 – Ray trace showing direct and bottom-surface multipath of sonar signal from DDG to phone J09 (15km horizontal distance) . Direct path receive level is 149dB for -11 degree vertical launch angle, close to same bearing angle of the minke whale position at 06:15 on 17 Feb. The bottom-surface path, -39 degree launch angle, arrives 3.02s after the direct path and at a level of 146dB.

Minke average boing rate

Figure 5 provides the average boing rate per hr over the 16 most offshore BSURE replacement phones for comparison to results of the Feb 2010 minke whale boing rate analysis. The peak boing rate of over 300 boings per hour occurred around 23:53 on 20 February. This seems to be due to multiple animals on the range and from the rapid boing rate increase previously reported when two animals are in close proximity to one another (Thompson and Friedl 1982). This phenomenon warrants further investigation utilizing the automated tools availble for the minke boing call. The depressed boing rate during the first three miniwar events observed may have contribution from MFA masking the detection of boings, however the boing rate increases during the last half of the minwar events. The lower rate observed for miniwars I through III should also be viewed in light of the pre-event rate and fact that the boing rate was in decline during torpex III. The high degree of variability is observed as it was in the before and after Feb 2010 SCC analysis.

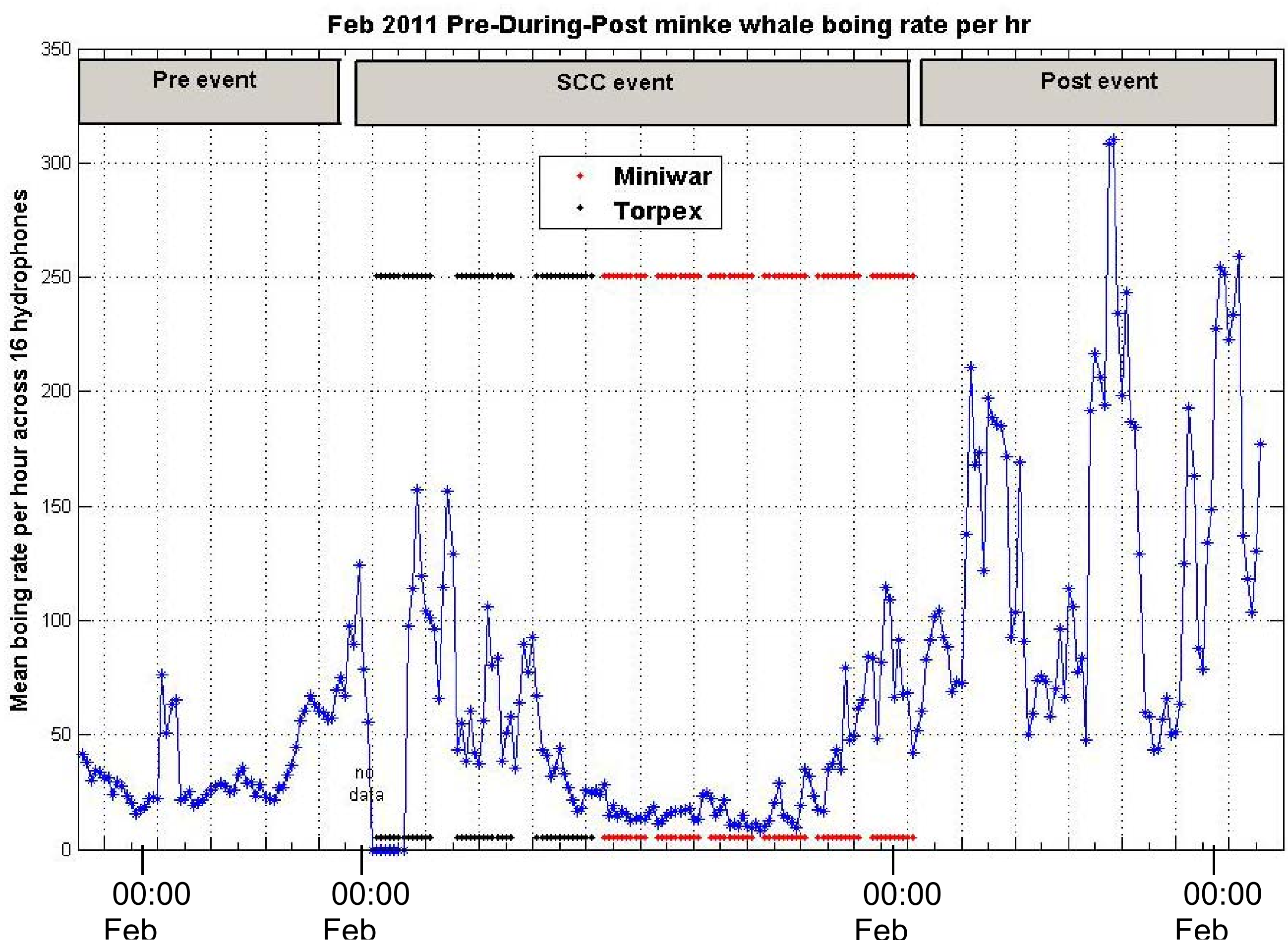

Figure 5 – Average minke boing rate per hour over 16 northern BSURE replacement phones.

The average boing rate, and its standard deviation, for the before, during and after exercise is shown in figure 6. The SCC itself is broken down into two components, the torpex phase (three submarine on submarine events) and the miniwar phase (six surface ships on submarine events).

The pre-SCC mean rate is seen to be 39.3 boings per hour (sd 22.4) over 16 phones, 65.6 boings per hour (sd 37.5) for the torpedo exercise portion of the exercise, 29.8 boings per hour (sd 26.1) for the miniwar portions of the exercise and 129 boings per hour (sd 70.5) after the exercise. While statistical significance tests does show differences in these boing rates, one must be cautioned in attributing these differences to being due soley to the exercise as the normal variations are not fully understood and the low boing rate could be due to fewer calling animals in the area and coincidental with the Navy activity.

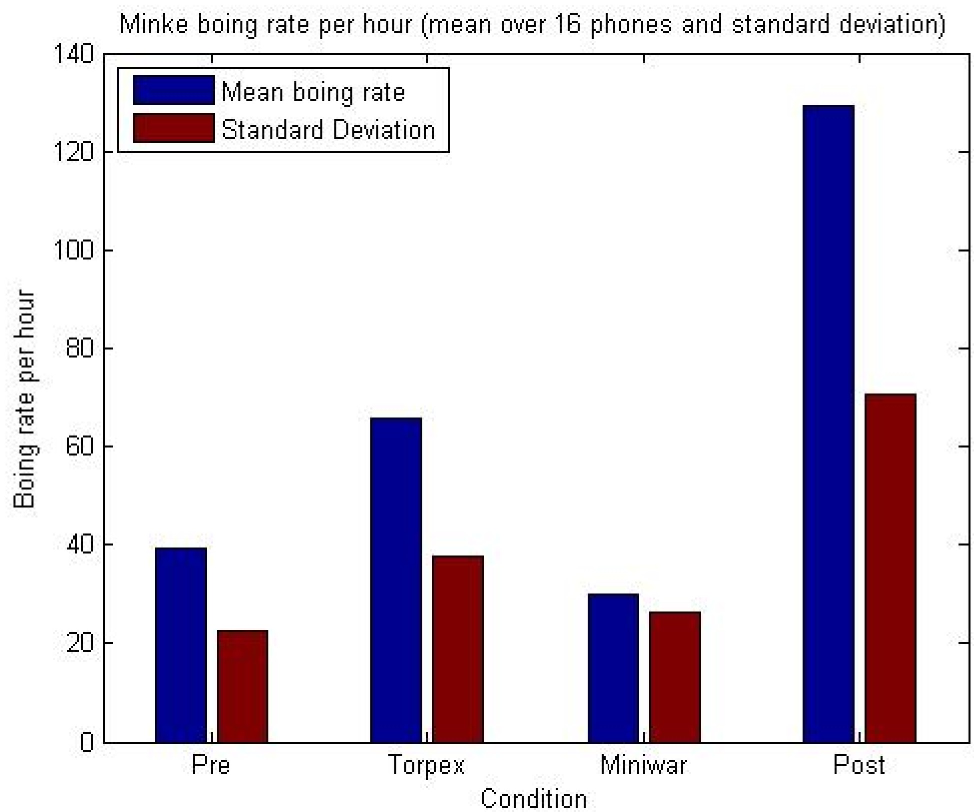

Figure 6 – Average minke boing rate, and its standard deviation, over 16 hydrophones. The SCC exercise is broken down into two components, torpex and miniwar.

Beaked whale detection, validation and dive vocal periods

The beaked whale automatic detection process performed on data from the Feb 2010 SCC (Martin informal report Aug 2010) for 13 hyrdrophones was duplicated on Feb 2011 SCC data for 16 hydrophones. With the higher frequency response of the new BSURE replacement hydrophones, the beaked whale analysis for this exercise represents more than a fourfold increase in available data (twice the temporal data and 30 vice 13 hydrophones). Therefore, effort was initially directed at streamlining the beaked whale validation process to be fully within matlab and allow for visual review of time series, spectrogram and wigner-ville transforms of the signals, along with aural replay at lower sample rates to time shift the data down into the human audio range.

The beaked whale validation process operates on one hydrophone at a time. An operator first reviews available overview type information for each hydrophone, such as long term spectral averages and automated screener and beaked whale click detections, to select a hydrophone and time frame for validation analysis. The validation process then displays a histogram of the inter-detection-intervals for the automatic detections of beaked whale clicks along with the screener detection histograms (all acoustic detections above threshold) as shown in figure 7 for hydrophone 406 in one ten-minute data file. These intervals are one classification clue for beaked whale clicks and the relationship of the intervals provides insight relative to beaked whale presence in the 10 minute data file. In cases where the screener detections are prolific and small values (eg. under 0.1s) one would suspect a high probability of false beaked whale detections. Conversely, when the screener inter-detection-interval is similar to that shown in Figure 7 lower trace, one has higher confidence that there is actually a beaked whale present vice some other odontocete species such as short-finned pilot whales or dolphins. The peak around 0.3 seconds shown in figure 7 keeps this as a viable candidate for actual beaked whale click validation, notice however, that in this case for hydrophone 406 only a small percentage of screener detections are declared beaked whale clicks. This is a result of the very conservative manual validation classification of beaked whale clicks in order to ensure we are correctly identifying areas of beaked whale echolocation foraging click activity.

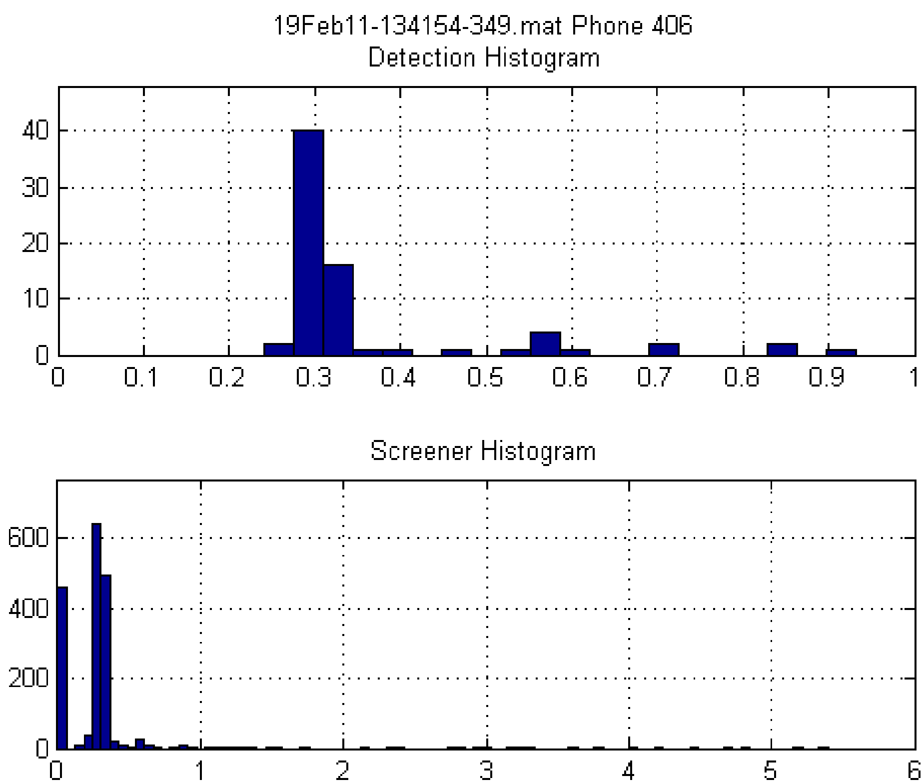

Figure 7 – Inter-detection-interval for ten minutes (one file) of one hydrophone's automatic beaked whale echolocation click detector. The lower plot shows inter-detection-intervals for all acoustic detections over threshold, while the upper plot shows only those detected clicks which meet the criteria to be declared beaked whale echolocation clicks. The groupings around 0.3 seconds are a feature of valid beaked whale clicks.

The next step in the validation process is to go through each automatic detection on the selected hydrophone and make a decision if the signal is indeed a beaked whale foraging echolocation click. This is accomplished by viewing the time series (both click level and for 1 second of data), filtered spectrogram utilized in the FM click decision, a full bandwidth spectrogram and wigner-ville transform of the suspected click. Figure 8 provides a screen shot of the tool being used to validate a beaked whale click from the post SCC period on hydrophone 406. A button is available for listening to the click at a slowed rate for aural analysis.

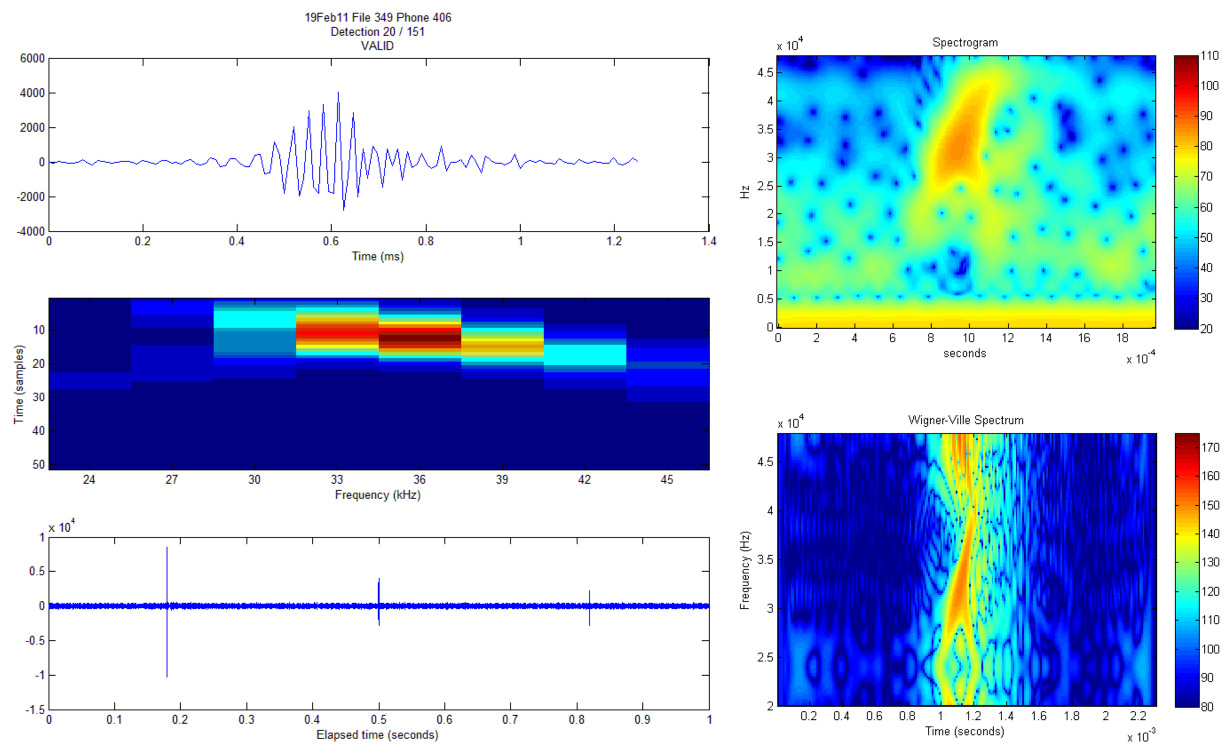

Figure 8 – Screen shot of beaked whale validation process in matlab. Left upper shows time series for 1.2msec of data, left middle shows the frequency (horizontal) vs samples showing the FM sweep, lower left shows one second of data showing click under investigation at 0.5s and additional clicks before and after. Right panels show: upper – short time FFT of unfiltered data and lower – wigner ville transform of click.

After validation of suspect areas of beaked whale foraging click activity for multiple hydrophones and time frames, one can put together a summary of the validation results. Table 5 provides results of the validation analysis for beaked whale foraging clicks for the pre-SCC period, SCC torpex period, SCC miniwar period, and post SCC period. One sees similar numbers of dive vocal periods per hour for the pre-SCC and SCC-minwar periods and slightly lower numbers for the SCC-torpex and post-SCC periods. Difficult to make any sense out of that relative to MFA sonar activity (SCC-miniwar) as the dive vocal periods per hour are similar to the pre-SCC period and higher than both the post-SCC and SCC-torpex periods. The number of hydrophones in this analysis does NOT guarantee detecting beaked whale dives due to limited spatial sampling, thus one simply uses this analysis to indicate that there was beaked whale activity over the range area throughout the time period. This does not fit with what has been seen at AUTEC in terms of beaked whales leaving the area during MFA activity and returning afterwards. However, the PMRF area is large compared to AUTEC (Moretti et al. 2010) and it is possible beaked whales could continue activity distant from MFA activity, or alternatively that the beaked whales have become acclimated to the MFA activity.

Table 5 – Summary of validated beaked whale foraging clicks grouped into dive vocal periods for the pre-SCC, SCC-torpex, SCC-miniwar and post-SCC.

	Pre-SCC 11-13 Feb, 2011	SCC-torpex 14-16Feb, 2011	SCC-miniwar 16-18 Feb, 2011	Post-SCC 19-22 Feb, 2011
Time (hours)	61.67	52	61.67	79.17
Dive Vocal Periods	44	31	49	46
Dive Vocal Periods/hr	0.713	0.596	0.795	0.581
BW Clicks in dives	1831	2062	3269	2245
BW Clicks per hour	29.69	39.65	53.01	28.36
BW Clicks per dive	41.61	66.52	66.71	48.80

When some marine mammal species move through the range (possible melon headed whale, pilot whales, other blackfish) in large extended groups, one hydrophones 10 minute file can contain thousands of false positive beaked whale click detections (suspect due primarily to pilot whale clicks). By evaluating the overall screener acoustic detections (shown in Feb 2010 report) one essentially rejects full validation on these files as even with a streamlined tool as this, it would take excessive time. The dive vocal periods per hour shown in table 5 is felt to be a meaningful metric whereas the number of clicks detected is highly variable depending upon the distance from the diving beaked whale group to the hydrophone.

It is interesting to note that there were validated beaked whale clicks from hydrophones far offshore in water depth near 5km. This was not expected and previously the offshore phones did not respond to beaked whale click frequencies. For the pre-SCC period over 10% of the validated beaked whale dive vocal periods and validated beaked whale clicks came from phones J9, L8, I8 and I10.

Other species

During the analysis any other species acoustically identified, or suspected are noted for further review and analysis. This includes humpback whale vocalizations, as there were humpback whales on the range as verified by experienced marine mammal observers on both the DDG and an aircraft. Some low frequency (~35Hz to 20Hz) pulse sounds (typically occurring in groups of three at a time) have also been noted during the exercise which may be attributable to fin or sei whales. This low frequency analysis is much more feasible with the advent of the BSURE replacement hydrophones which were operational around Jan 2011. Tagged pilot whales (Baird 2011) also were seen to be on the range, albeit in the after exercise time period. Pilot whale echolocation clicks are often confused with beaked whale clicks by the current beaked whale click detector being utilized. Echolocation clicks from unknown odontocetes were also observed. Sperm whale clicks sometimes observed throughout the data.

Some impact type sounds (center frequency < 1kHz) are also observed during exercises. It is unclear if these are man made in origin or could be from whale breaching, or tail/fluke slaps on the surface.

Humpbacks: Humpbacks were on the range during the exercise in Feb 2011 and were sighted by both surface craft (DDG) and an aerial survey conducted by Joe Mobley/HDR within relatively short distances of the DDG (a few km's). Manual analysis has been conducted in attempt to develop a method for automatic localization of humpback whales, which has met with limited initial success.

One effort at localizing humpbacks sounds occurred in time around the 17 Feb 07:39 HST period, which ties in with the analysis reported for minke whales and the unidentified group of whales sighted from the DDG. The low frquency sounds were also observed in this area on phone L08 at 07:42. Effort at localizing one humpback at 07:36:45 (file sequence 106) on phones I08, J07 and K07 allowed a localization as reported in table 3 and shown on figure 2. The signal being utilized was 202-287Hz upsweep of 0.34 s duration followed 3.563 s later by a 135Hz-234Hz upsweep signal. Note that for minke whale localizations we require four good hydrophone arrival times, it is appearing more difficult to associate the same humpback calls on four different hydrophones in efforts to date.

An earlier effort focused on file 359 for the recording started 16 Feb (actual time 01:37 on 19 Feb) for phones i10, j9, i8, k11 humpback whales. A sequence of humpback calls were localized to 22.7399 -159.8812, 22.7407 -159.8794 and 22.7403 -159.8788 which are all close to one another giving confidence in the process as aural analysis confirms the calls are from the same animal. There are also minke boings (potentially at the rapid rate) occurring, humpback upsweeps, and the 'barking' type thump trains here in the first 1 min of data on J9. There exists a need to better associate humpback calls across hydrophones and investigate the "barking" or thump train type signals to see if the sounds are produced by humpbacks or some other species. Due to the repeated calls similarity for humpbacks this process is felt to be to immature at this time and needs more work for reliable localization. This is highly desired as the exposure levels should be significantly higher than the one case for minke whale presented herin, and the spatial location updates may reveal swim speed and direction of travel relative to the DDG. In addition, careful analysis of the vocalizations should be done to determine if they are song units or non-song units, and if non-song units when they have been observed by researchers previously (behavioral states, etc.). Analysis of an encounter on 18 Feb 2011 at 09:47 of the actively transmitting DDG with a group of humpback whales at close range is currently under investigation (sighting # 14).

Short-finned pilot whales: Personnel from Cascadia Research Collective (Baird et al. 2011) tagged short finned pilot whales before the exercise of which at least one came back onto the range during the AFTER SCC time period. Specifically the tag #51 animal had good satellite location (location class 3 for location accuracy of under 250m) at 19:05 Z on 21 Feb 2011 and was in close proximity to hydrophones 501 and K02. Automatic beaked whale click detections from these hydrophones at this time show echolocation clicks similar to beaked whales in terms of having some frequency modulation sweep present, but with less duration and lower center frequencies. These echolocation clicks are believed to be from the pilot whales.

Low frequency suspected fin/sei calls: The new BSURE replacement hydrophones are revealing 20Hz pulses and 40Hz to 20Hz downsweeps that are similar to calls reported for fin and sei whales. Figure 9 provides an example of the downsweep signals,for hydrophone J7 as received in file 380 of the recording started on 11Feb11 (23:32 HST 13 Feb 2011) on 22 seconds of data is shown from DC to 180Hz. This data is from the PRE SCC period from phone I6 and has acoustic evidence of humpbacks, some odontocete clicks, and these ~40Hz to 20Hz downsweeps which occur in groups of three. Similar signals from phones J7 and K7 were utilized to localize this call sequence to 22.3943 deg lat and -159.8439 deg long. The group of three pulses could be multipath versions of a single pulse. The low frequency analysis is tentative in the early stages of effort and it is currently unclear if the animal is near or very distant, which in the later case would invalidate the localization position as the code to localize assumes direct path arrival.

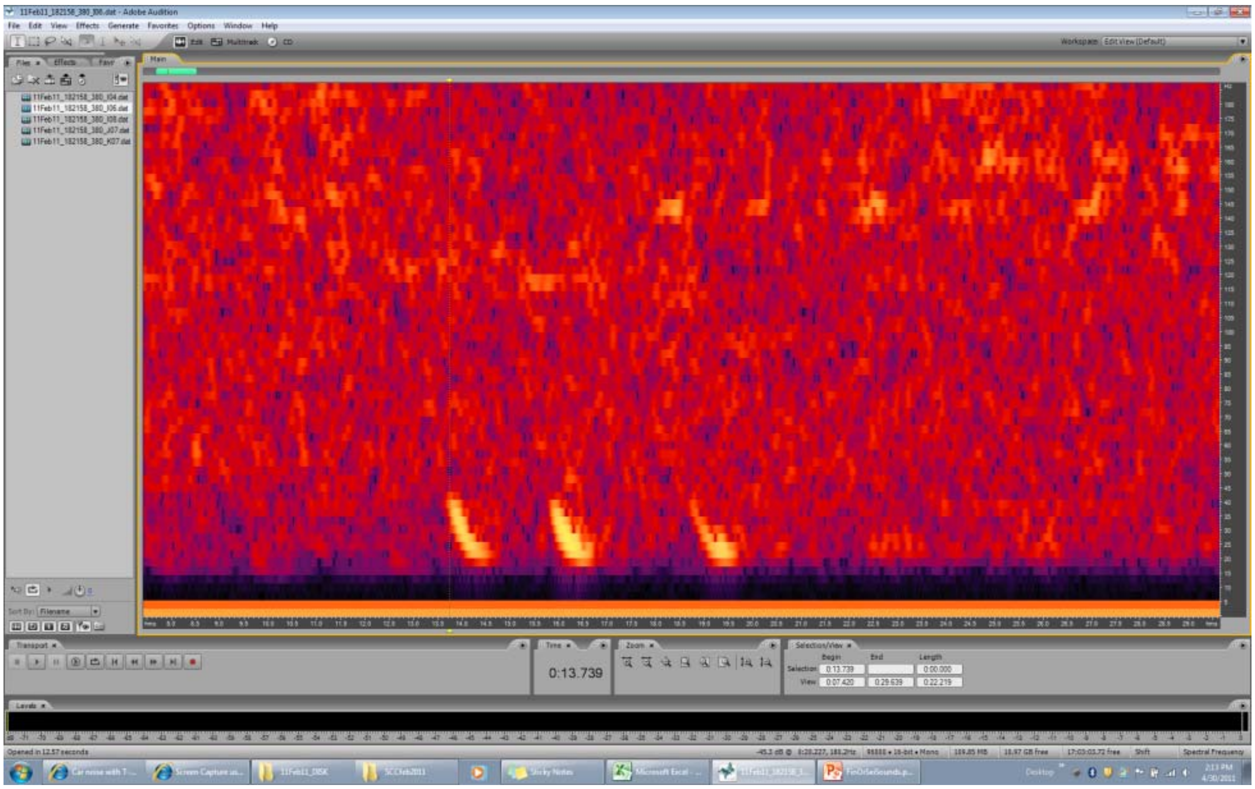

Figure 9 – Example of low frequency downsweeps in the range of 40Hz to 20Hz. This example is of 22 seconds of data from DC to 180Hz for hydrophone J7 on at 23:32 HST on 13 Feb 2011).

Very strong low frequency signals are present in data file 108 for the recording started on 16 Feb (actual time of this data is 17 Feb @ 07:51:12 HST). These have very strong ~35Hz to ~20Hz downsweep signals obvious on phones L8, K9 and L10, approx 0.8s duration every ~ 25 sec, which matches reported descriptions of fin whale pulses (Thompson and Friedl 1982, McDonald and Fox 1999) These signals continue through file 110 and are noted due to the very strong signal strenghts observed which may imply the animal is closer to the phones and potentially on the range. A juvenile fin whale was encountered in the area of 22.2 – 22.3, -159.68 to -159.77 at 1130 to 1230 HST on 16 Feb 2010 by the 57' sailboat Vanessa being utilized by the company Oasis for independent testing over this period during the SCC, the whale followed the sailboat over this period. This sighting was 19 hrs before these strong signals were picked up in an area ~30km to the N-NW of the visual sighting, too distant in time for any speculation as to wheather the sounds were from the sighted individual. 13:58 HST 16 Feb phone i10 has strong LF data, so not the same animal as sighted much farther south.

Discussion

Passive acoustic methods are seen to be a powerful tool when marine mammals are present and vocal on range for analysis of exposure levels of marine mammals during US Navy training exercises. Visual sightings can also be analyzed for exposure levels and use of passive acoustic data allows precise expsoure times and distances determination. The automated processing currently available for minke whale boing calls enables detailed analysis with minimal manually intensive analysis. For the case of minke whales, this analysis shows it is possible to evaluate behavioral response, in terms of swim rate and advance direction, relative to mid frequency active sonar transmissions. For the minke whale analyzed here, there does not appear to be a significant reaction by the minke whale to the MFA transmissions which occurred over 16km away with estimated exposure levels in the range of 139 to 145dB sound pressure level re micro Pascal. Unfortunately, we can not currently perform similar automatic processing for humpback and other large low frequency baleen whale sounds detected by the range hydrophones. Thus, extensive manual analysis is required to determine whale locations, and even this poses issues for humpback whales with repeatable calls and when multiple groups are present. The rapid rate of progress in the area of passive acoustic DCL should reduce the labor required for automated DCL for additional species as time progresses. Acoustic density estimation is also considered a valuable tool for understanding potential consequences of Navy activities on instrumented ranges, such as PMRF, as normal variations (both short term and long term) are better understood.

For this report one must rely on models to estimate the sound pressure level animals are exposed to. For close range cases the various models agree quite well with expected data. It would be very helpful to have shallow hydrophone(s) deployed (e.g. sonobuoys) during the exercise such that model validation efforts can be conducted for shallow depths where typical baleen whales are expected to be encountered. Similary collecting in-situ SVP's would also improve modelling efforts and PMRF has said they can collect SVP for future SSC's. At long ranges the various models do not agree with one another well (have seen 15dB differences in two high fidelity US Navy models for ducted propagation at over 15km). The sonar equation predicts on the order of 15dB more ducted transmission loss due to duct leakage than other models and this is using a sea state of 2. The actual sea state is reported to have been in the 4 to 5 range which would exhaberate this difference by another 10dB. Future modellling will use the PCIMAT standard US Navy model.

The products of this analysis show that it is possible to obtain results similar to those being sought by behavioral response studies (animal locations over time) with much less effort by monitoring ongoing US Navy exercises. The advantage of the US Navy exercise is that actual mid frequency sonar systems are utilized, vice surrogate sonars with less source levels. The disadvantage of the US Navy exercise is lack of controls and need to estimate exposure levels as there is not an acoustic tag on animals. Combining results from these exercises with research behavioral response studies could result in improved understanding.

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