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Sakhalin Energy Investment Company LTD.

ACOUSTIC MODEL VALIDATION

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Rev	Location of Change	Brief Description of Change
02	Throughout report	Additional validation examples added

JASCO Research Ltd

Sakhalin Energy

Acoustic Model Validation

Version 1.3
February 18, 2005

VERSION	DATE	DESCRIPTION	AUTHOR
1.0	November 24, 2004	First Version	David Hannay, JASCO
1.1	November 27, 2004	Added PA-B to Points 7 and 8 tracks	David Hannay
1.2	January 28, 2005	Added Comparisons of CDPE with RAMS and KrakenC. Included model fits to transmission loss data at Piltun. Included model comparison with noise measurements of dredging at Lunskoye.	David Hannay
1.3	February 18, 2005	Added model comparison with further measurements of operations at Lunskoye including 1/3-octave frequency band comparisons of model against data.	Roberto Racca, David Hannay, JASCO

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1. TERMS OF REFERENCE

This report describes the Parabolic Equation (PE) acoustic model used in Sakhalin Energy's 2004 noise programs and presents the validation work that was performed to choose geoacoustic parameters so that model predictions agreed with transmission loss measurements made in the Piltun environment offshore Sakhalin Island. The acoustic propagation model is based on a 2-D (range and depth) split-step PE algorithm (Collins,1993) which treats compressional wave propagation in both the water and seabed. Collins' model has been extended for this work to include shear wave losses in reflections from the seabed using a complex density approach. The model results have been fit with transmission loss data collected at Piltun in 2004 over several propagation tracks leading from locations on proposed pipeline routes and ending at test locations within and near the whale feeding area.

The model engine has been incorporated in an automated software package that predicts cumulative spatial distributions of underwater noise produced by multiple sources operating simultaneously. An integrated source level database contains the 1/3-octave source levels for a large number of vessels and platforms. This overall package, including the source level database and computational model engine, has been validated through a comparison of model predictions against measurements taken in 2004 in the vicinity of pipelaying and dredging operations at Lunskoye. The validations of the underlying model and of the integrated model software package establish confidence in the results of predictive modelling at Piltun.

2. PARABOLIC EQUATION MODEL

A parabolic equation (PE) modelling approach was implemented to predict acoustic transmission losses in the shallow Sakhalin environment. As discussed in the introduction, a specialized PE code was developed based on Collins' widely accepted PE code RAM (acronym for Range-dependent Acoustic Model). The reason that RAM was not used directly is that it does not account for shear wave losses at the seabed. Collins has also developed a modified PE code named RAMS, that treats shear waves in a robust sense, but that model is excessively slow because it uses hepta-diagonal matrices instead of the standard tri-diagonal operator matrices in RAM. We instead implemented a shear wave approach that maintains the standard tri-diagonal matrix inversion scheme and uses a complex density method (Zhang and Tindle, 1995). This approach is more than 5 times faster than the reference hepta-diagonal matrix approach and has been shown to produce results that are nearly identical to the reference approach for uniform low shear speed shallow water environments with silt and sand bottoms. This method applies a complex multiplicative factor to the seabed density. The factor is dependent on the shear wave speed and the shear wave attenuation coefficient parameters. The resulting model, referred to as Complex Density Parabolic Equation (CDPE), has been tested extensively by direct comparisons of its transmission loss predictions with those produced by RAM and RAMS. When shear speed is set to zero in CDPE its transmission loss predictions are identical to those from RAM for all frequencies (See Figure 1a). For frequencies below 400 Hz the match between CDPE and RAMS is near perfect, even for shear speeds as high as 600 m/s. Less than 0.5 dB difference between RAMS and CDPE model results was observed at any range along a 10 km track in a shallow upslope environment starting at 30m depth and ending at 10m depth (See Figure 1c). At frequencies above 400 Hz the match in TL amplitude remains good but slight phase errors cause small range mismatches in the locations of nulls. These phase errors do not introduce significant problems for amplitude estimates because the model results are summed over many frequency bands thereby averaging out the influence of individual nulls.

Figure 1C: No shear – CDPE exactly matches RAM.

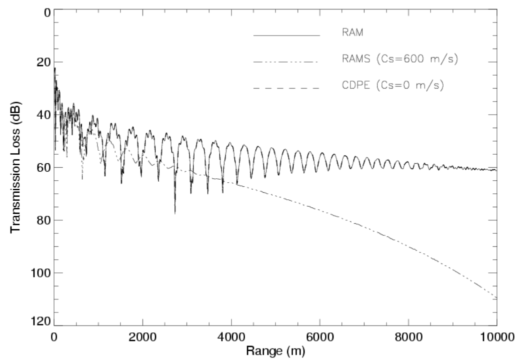


Figure 1B: CDPE with intermediate shear speed of 400 m/s. This shows how TL increases with increasing bottom shear speed.

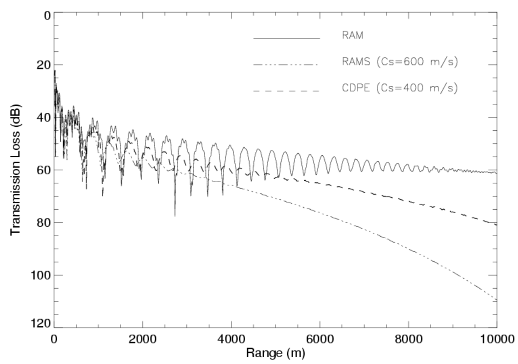


Figure 1A: Cs=600 m/s. Near exact match of CDPE with RAMS

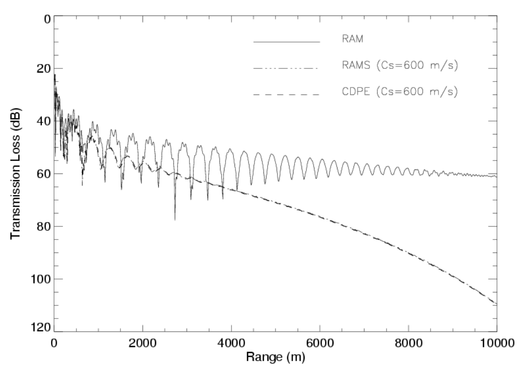


Figure 1: Comparison of Transmission Loss cases for Complex Density PE (CDPE), RAM and RAMS at 250 Hz in shallow wedge environment. Source and receiver are both at 5m depth and receiver is at 10 km range. Bottom depth decreases linearly from 30 m at 0 km (source position), to 16.7 m at 10 km range. Water sound speed is uniform at 1500 m/s and bottom compressional speed is uniform at 1700 m/s and 1.5 g/cm^3 density. In Figures 1a and 1c the CDPE results essentially overlay the respective RAMS and RAM results.

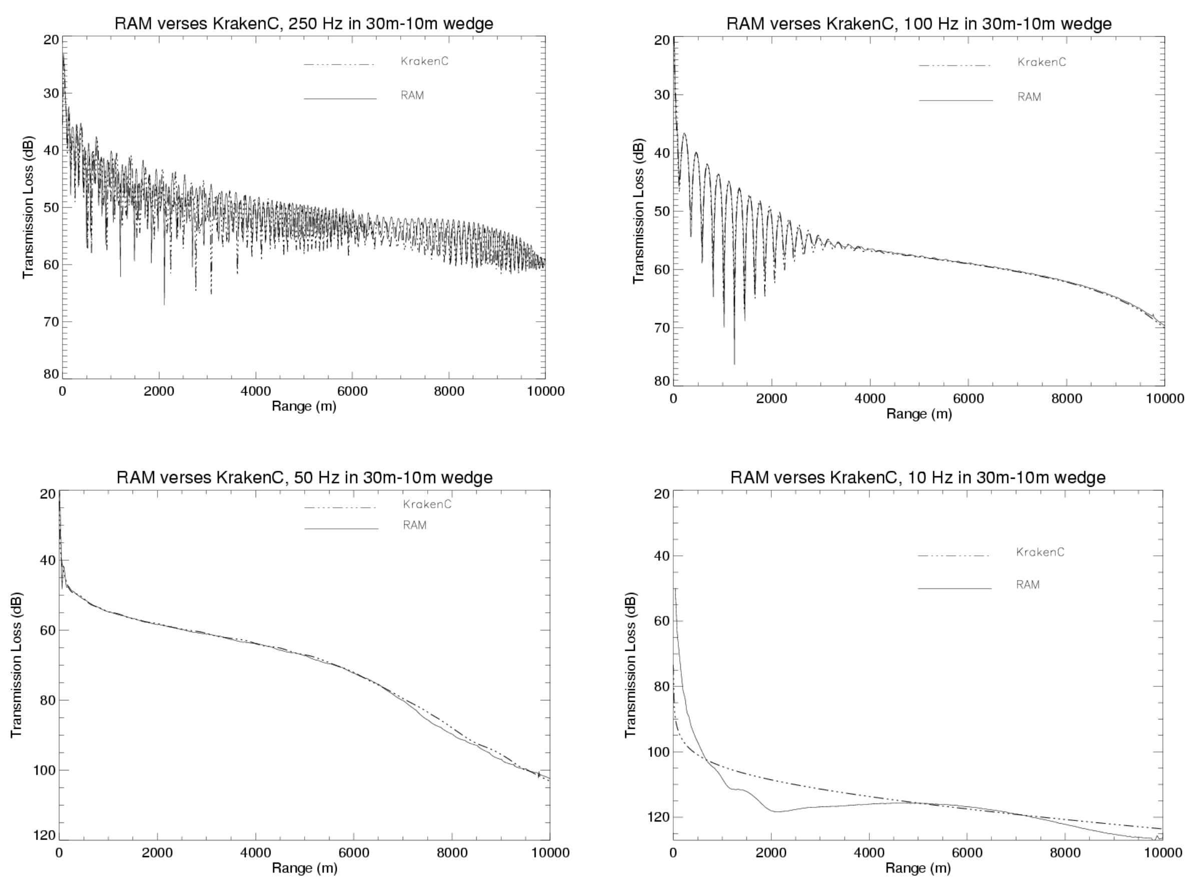
There has been concern about the use of PE instead of a normal mode approach for the very shallow (<40m) Sakhalin offshore environment. Modern PE's such as RAM are fully capable of accurately predicting transmission loss in these shallow water environments. In some very shallow cases the coupled mode and adiabatic mode approaches are even more difficult to apply because no fully-propagating modes remain and the mode search for highly leaky modes is generally time-consuming and prone to missing some of those modes. This is especially true when shear wave losses are included in the problem. Furthermore, the coupled mode and adiabatic mode approaches are not suitable for this work because the rapidly changing water depth requires very large numbers of mode computations – all modes need to be recomputed for each depth regime and this would have precluded obtaining results in a reasonable amount of time. We note that measured depth profiles were input directly to the PE code, in range steps typically of 100 m over tracks extending as far as 15 km.

In order to demonstrate the applicability of PE for these problems we have carried out model comparisons of RAM against KrakenC, a highly accepted range-dependent coupled mode program, for an environment having depth variation representative of the important propagation paths at Piltun. This test environment is similar to that discussed for the CDPE, RAM and RAMS comparisons earlier in this section, except water depth decreases slightly more rapidly - reaching 10 m at 10 km range. Furthermore shear waves in the bottom were neglected because KrakenC had some trouble finding modes for the low frequency cases considered when shear speed was set to reasonable values. The test environment is described in Table 1:

Table 1: Noramal Mode and Parabolic Equation Model comparison test environment.

Parameter	Description	Lower Value	Upper Value
Source Depth	Constant	5 m	
Receiver Depth	Constant	10 m	
Water depth	Decreasing with range	30m at source position	10 m at 10 km range
Water sound speed	Positive gradient	1500 m/s at surface	1550 m/s at 30 m depth
Water density	Uniform	1.03 g/cm^3	
Bottom sound speed	Positive gradient	1700 m/s at seafloor	1800 m/s at 500m below sf
Bottom density	Uniform	1.5 g/cm^3	
Bottom compr. Atten.	Uniform	0.15 dB/wavelength	
Depth of Halfspace	Constant	500 m below seafloor	
Half space sound speed	Uniform	1850 m/s	
Half space density	Uniform	1.5 g/cm^3	
Half space compr. Atten.	Uniform	0.15 dB/wavelength	

The comparisons utilized RAM as the representative Parabolic Equation model, however CDPE produces identical results for all of these test cases when shear speed is set to zero. The results of the comparisons are plotted in Figures 2 for frequencies 10 Hz, 50 Hz, 100 Hz and 250 Hz.



Figures 2: Comparison of Transmission Loss predictions by RAM and KrakenC. (a) 250 Hz, (b) 100 Hz, (c) 50 Hz and (d) 10 Hz in shallow wedge environment described in Table 1.

We note the comparisons of transmission loss results between RAM and KrakenC are remarkably good considering that the two approaches differ significantly in a mathematical sense. The mode computations in KrakenC were performed with 1 m water depth steps, which corresponds with 500 m range steps in the uniformly sloping test environment. We specified the mode phase speed search range for KrakenC between 0 m/s and 1790 m/s. At 10 Hz we used grid spacings in RAM of 1 m in depth and 40 m in range. For 50 Hz, 100 Hz and 250 Hz we used grid spacings of 0.5 m in depth and 10 m in range. The greatest difference between model transmission loss predictions occurs at 10 Hz, where KrakenC found only a single mode and RAM appears to have excited a second. This effect was investigated by varying RAM's grid spacing for depth steps through 0.5 to 2.0 meters, and for range steps through 20 m to 50 m; negligible differences in the predicted TL were observed. A check was also performed to ensure that energy was not reflecting from the lower grid boundary by extending the grid boundary from 2000 m to 3000 m, and increasing attenuation in the absorptive layer, between 600 m and 300 m, from 0.15 dB/wavelength at 600 m to 10 dB/wavelength at 3000 m. Again essentially no difference in the predicted TL was observed. We therefore think that the second mode is real.

The slight differences in null positions apparent in the 250 Hz results are attributed to the different grids used for the two programs. These are not as important and do not appear in the comparison results at the lower frequencies because relative phase changes are smaller for longer wavelengths. The results of the above comparative investigation confirm that use of the PE model is as suitable as the KrakenC Normal Mode model for predicting transmission losses in the shallow Sakhalin environment.

3. TRANSMISSION LOSS MEASUREMENTS

Pacific Oceanological Institute (POI) carried out a dedicated acoustic measurement program offshore Piltun Bay in summer 2004. This program was designed specifically to collect transmission loss (TL) data for validating the propagation model. The TL measurements were obtained using sounds broadcast by transducers (see Figure 3 and Figure 4) operated at 8 m depth through a set of discrete frequencies between 20 Hz and 10 kHz from locations on the proposed pipeline routes. The source locations for all tracks are given in Table 1. Source levels of the transducer were measured continuously using a calibrated hydrophone placed near the transducer. Range scaling of the level on this reference hydrophone was applied to refer the level to 1 m from the source. Digital recordings of the broadcast pressure signals were made at locations inside the whale feeding areas with calibrated autonomous recording buoys. The acoustic recordings were later analysed to obtain received levels, and transmission loss was computed directly by subtracting the received level from the source level.

Figure 3: Low frequency sound source for frequencies up to 300 Hz.

Figure 4: High frequency sound source for frequencies 300 Hz to 10 kHz.

Table 2: Transmission Loss Source Positions

TL Profile	Source Locations	Latitude	Longitude
Piltun: PTL1	PTL1-A	52° 56' 00" N	143° 29' 53.8" E
Piltun: PTL2	PTL2-A	52° 54' 58.9" N	143° 37' 25.9" E
Piltun: PTL2	PTL2-B	52° 54' 49.9" N	143° 35' 13.8" E
Piltun: PTL2	PTL2-C	52° 54' 30.6" N	143° 30' 36.6" E
Piltun: PTL3	PTL3- B	52° 54' 05.1" N	143° 35' 29.6" E
Piltun: PTL3	PTL3- C	52° 52' 32" N	143° 32' 00.8" E
Piltun: PTL4	PTL4-A	52° 51' 02" N	143° 38' 36" E
Piltun: PTL4	PTL4-B	52° 50' 47.5" N	143° 36' 40.2" E
Piltun: PTL4	PTL4- C	52° 50' 30.8" N	143° 34' 27.5" E
Piltun: PTL5	PTL5-A	52° 47' 00" N	143° 38' 59" E
Piltun: PTL5	PTL5-B	52° 47' 13.4" N	143° 37' 37.3" E
Piltun: PTL5	PTL5- C	52° 47' 44.3" N	143° 34' 29" E
Piltun: PTL6	PTL6-A	52° 43' 08" N	143° 39' 18" E
Piltun: PTL6	PTL6-B	52° 43' 21" N	143° 36' 25" E
Piltun: PTL6	PTL6-C	52° 43' 25" N	143° 33' 01" E
Piltun: PTL7	PTL7-A	52° 38' 25" N	143° 39' 18" E
Piltun: PTL7	PTL7-C	52° 42' 55.5" N	143° 28' 00.9" E
Piltun: PTL8	PTL8-A	52° 34' 42.4" N	143° 39' 01.7" E
Piltun: PTL8	PTL8-B	52° 37' 14.7" N	143° 35' 21.2" E
Piltun: PTL8	PTL8-C	52° 42' 53.3" N	143° 27' 08.9" E
Piltun: PTL9	PTL9-A	52° 33' 18.7" N	143° 34' 46.7" E
Piltun: PTL9	PTL9-B	52° 35' 59.4" N	143° 30' 27.3" E
Piltun: PTL10	PTL10-A	52° 32' 07.7" N	143° 28' 14.2" E
Piltun: PTL10	PTL10-B	52° 36' 05.4" N	143° 25' 39.4" E
Piltun: PTL11	PTL11-A*	52° 30' 04.4" N	143° 22' 39" E
Piltun: PTL11	PTL11-B*	52° 32' 02.1" N	143° 22' 38.5" E
Piltun: PTL11	PTL11-C*	52° 36' 09.5" N	143° 22' 36.5" E
Chayvo: PTL12	PTL12-A	52° 28' 13" N	143° 19' 12" E
Chayvo: PTL13	PTL13-A	52° 26' 41" N	143° 21' 06" E

Detailed bathymetric and water sound speed profile measurements were made during the 2004 transmission loss program at Piltun. Sound speed profile measurements were made at several positions along the respective transmission loss paths (between source and sonobuoy locations) always within a few hours of the time of signal broadcast. The bathymetric profile measurements were made using an accurate (±1m) echosounder by sailing between each source and receiver location.

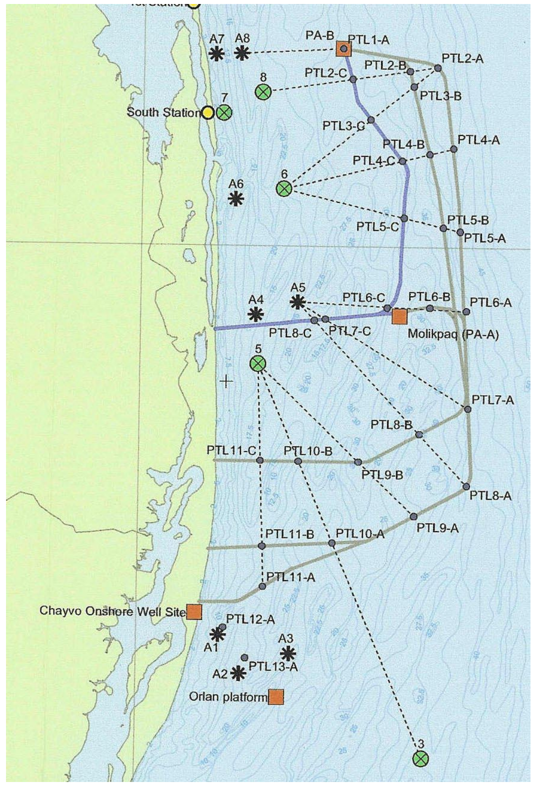


Figure 5: Approximate locations of sources and receivers for 2004 Piltun Transmission Loss experiments.

4. GEOACOUSTIC PARAMETERS FOR MODEL FITS

The acoustic propagation model requires as inputs a set of geoacoustic parameters representing the acoustic properties of the water – seabed environment in which the sound propagates. The rate at which sound level decreases with distance from the source is closely related to the input parameters. The approach taken for performing model fits to transmission loss data has involved using measurements of parameters that could be measured directly and using values typical of the geological environment for other parameters. Two of the most important parameters: bottom compressional speed and shear speed, could not be estimated with sufficient accuracy to ensure valid model outputs. These parameters were chosen based on fitting model predictions with dedicated transmission loss measurements. The fitting method is discussed in following sections.

Water sound speed profiles used for model runs were defined based on the sound speed measurements made during the Piltun measurement program. An example of the sound speed measurements, for track PTL2A, is given in Figure 1. The measurements made along each track were averaged to generate a non-range dependent profile for the respective tracks. The bathymetric measurements were input directly to the model for the respective runs. Figure 2 shows the bathymetry measurement for PTL2A. Range 0 is at the PTL2A source position. The receiver location was at 14.6 km for that track.

No specific measurements of bottom density, compressional wave speed and compressional attenuation, shear wave speed or shear wave attenuation were obtained during the 2004 Piltun program. Consequently a base set of values for these parameters was chosen based on published information on geoacoustic properties of the seabed given in Hamilton (1981 and 1976). Compressional wave attenuation coefficient and sediment density and density gradient are based on values for sandy-silt on the continental terrace for terrigenous sediments. The shear wave attenuation coefficient is based on the average of values for diluvial sand and clay (19.8 dB/λ) and for diluvial sand (7.4 dB/λ). The base values for all parameters are given in Table 3.

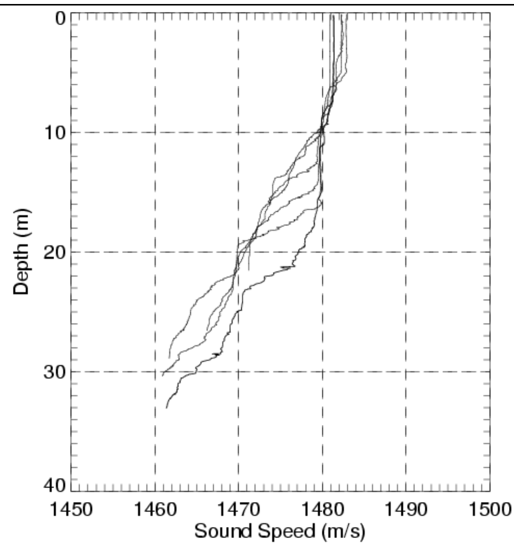


Figure 6: Water sound speed profile at five locations on track PTL2A

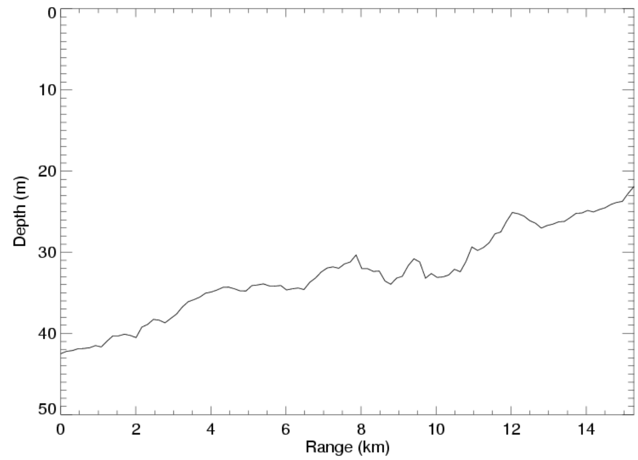


Figure 7: Bathymetry for track PTL2A

Table 3: Base values for model parameters

Parameter	Base Value
Compressional Speed	-
Compressional gradient	1 s^{-1}
Density	1772 kg/m^3 (at seafloor)
Density gradient	1.1 kg/m^4
Comp. Attenuation	0.14 dB/λ
Shear Speed	-
Shear attenuation	13.6 dB/λ

5. MODEL FITS TO MEASUREMENTS

Model runs were performed along all but two of the measurement tracks, using as inputs the measured sound speed profiles and bathymetric profiles and base values from Table 3. The bottom compressional and shear wave speeds were not measured directly, and these parameters have significant influence on the model outputs. The approach to set those parameters involved fitting modelled transmission loss to the measurements discussed previously. An important aspect of the fits is that we use the minimum modelled transmission loss of the last three range points near the receiver range. This approach has also been used for the forward modelling using this model. It is done to avoid excessively high TL estimates that sometimes occur when the receiver is located very close to an interference null.

The possible values for the fit parameters included three compressional speeds: Cp=1500 m/s, 1750 m/s and 2000 m/s, and three shear speeds Cs = 100 m/s, 200 m/s and 300 m/s. We note that Cs=100 m/s gives results nearly identical to a zero-shear speed case for the Piltun environments considered. The general influence of these parameters on transmission loss in the Piltun environment can be summarized as follows: Higher compressional speeds allow lower frequency modes to propagate into shallower water. Varying bottom compressional speed influenced the magnitude of transmission loss through all frequencies, but more significantly at lower frequencies. Higher shear speeds cause greater reflection loss at all frequencies. Shear speed variations also influenced low-frequency transmission loss more than high frequency transmission loss, but the difference of this influence on low and high frequencies is less than that of compressional speed. The two parameters together can therefore adjust both the magnitude and variation with frequency of the transmission loss characteristics of the environments considered. We point out also that the compressional wave speed gradient was fixed at 1 s^{-1}. The actual sound speed at all depths in the seafloor therefore varied as the seafloor compressional speed changed.

The fit against data was performed by minimizing the mean difference between modelled transmission loss and data in the 50 Hz to 500 Hz frequency band. We considered also minimizing mean square difference, but occasional data outliers caused those fits to be less representative of the more self-consistent data points. The fit statistics, discussed later, include mean difference and mean absolute difference.

The modelled frequencies included all 1/3-octave band center frequencies between 10 Hz and 2 kHz. Example 2-D model results at 40 Hz, 100 Hz, 400 Hz and 1000 Hz are shown in Figure 8.

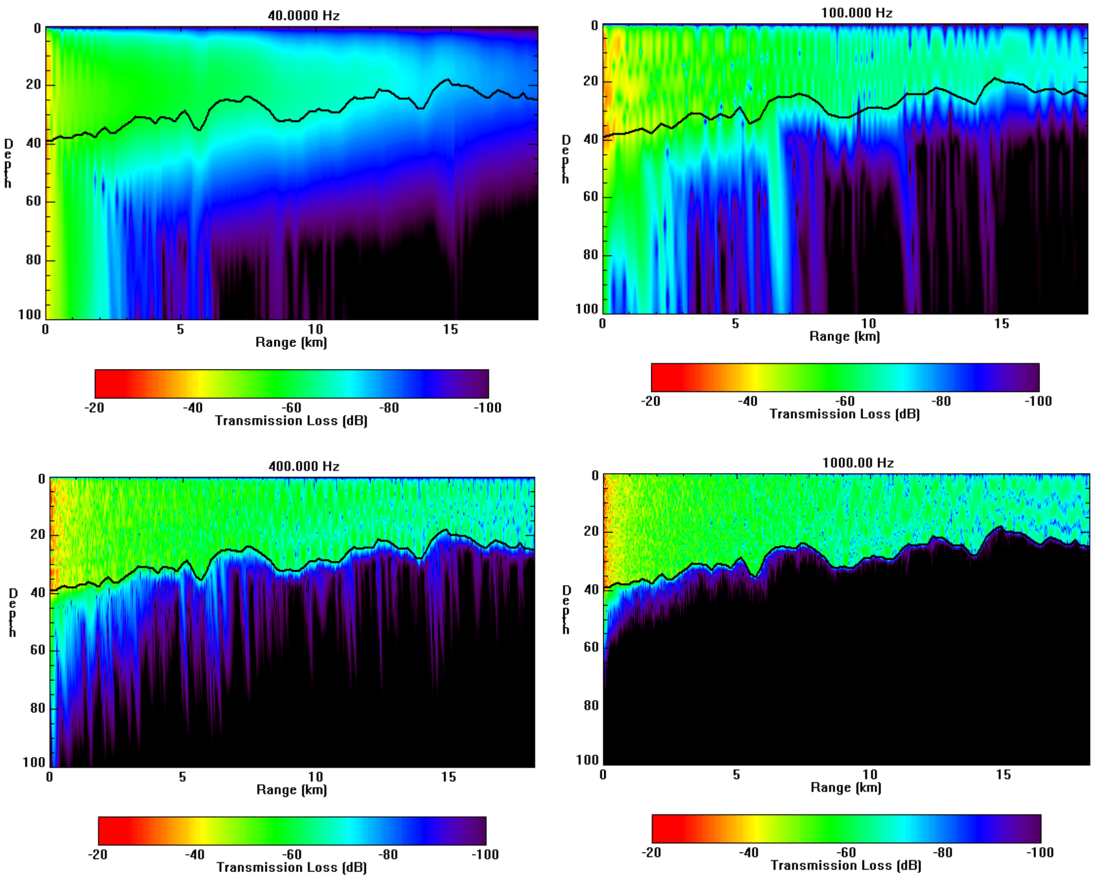


Figure 8: 2-D Transmission loss at 40 Hz, 100 Hz, 400 Hz and 1 kHz on PTL7A. Modal structure in the water column is disrupted by rough bottom. Modal cut-offs are clearly visible at 100 Hz as the sound energy is incident on small hills at pre-critical angle, and transmits into the bottom.

The model TL values at the seafloor at the range corresponding to the sonobuoy locations were plotted against measured values in order to allow model-to-data comparisons and fits. Plots of PTL data in the 10 Hz to 2 kHz frequency range (symbols), overlaid with model predictions (lines) are given in Figure 9 through Figure 28. Note the captions of those figures indicate the best-fit parameter values for bottom compressional and shear speeds, and the model results plotted are based on those values.

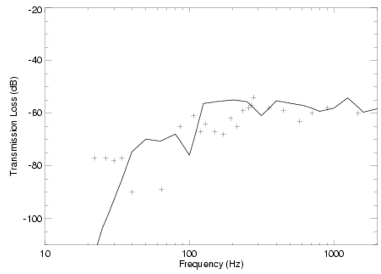


Figure 9: PA-B to A7
Cp=2000, Cs=100

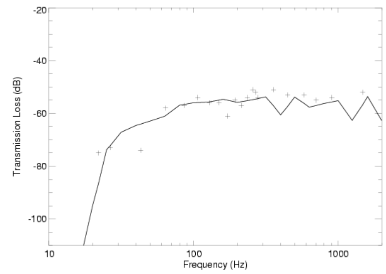


Figure 10: PA-B to A8
Cp=2000, Cs=100

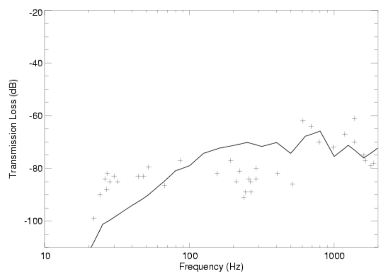


Figure 11: PTL2A
Cp=2000, Cs=200

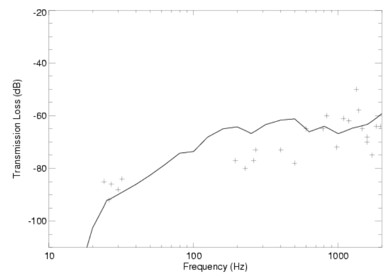


Figure 12: PTL2B
Cp=2000, Cs=200

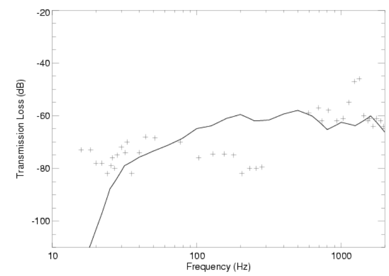


Figure 13: PTL2C
Cp=1750, Cs=200

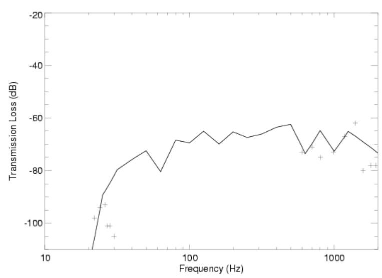


Figure 14: PTL4A
Cp=2000, Cs=100

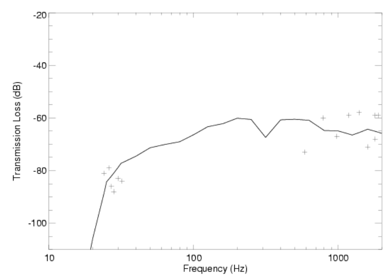


Figure 15: PTL4B
Cp=2000, Cs=100

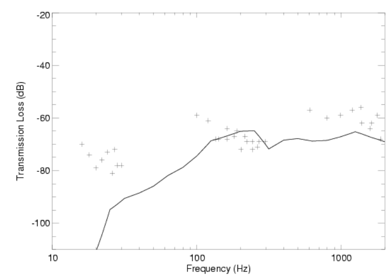


Figure 16: PTL4C
Cp=2000, Cs=200

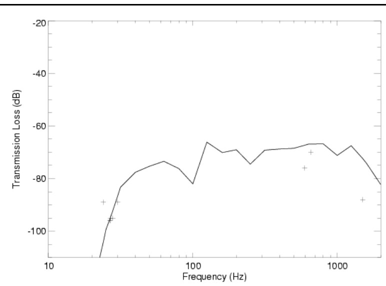


Figure 17: PTL5A
Cp=2000, Cs=100

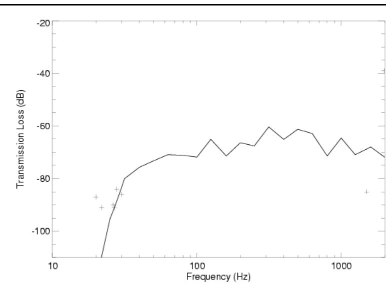


Figure 18: PTL5B
Cp=2000, Cs=100

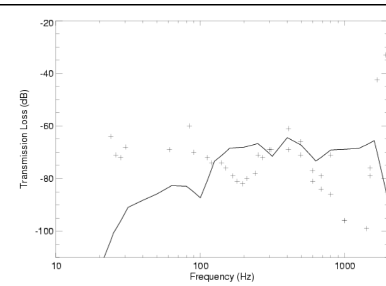
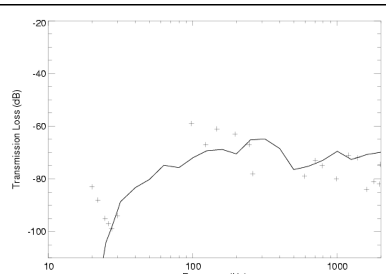
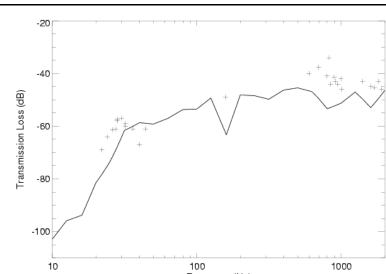


Figure 19: PTL5C
Cp=2000, Cs=200





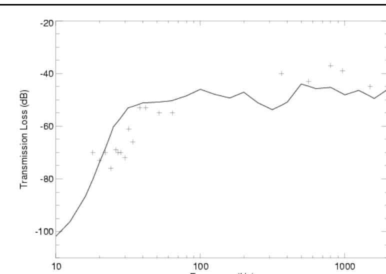
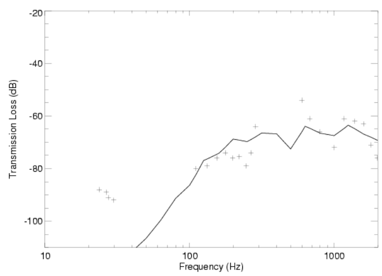
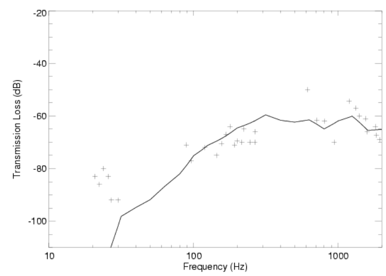


Figure 20: PTL7A
Cp=2000, Cs=100

Figure 21: PTL7C
Cp=2000, Cs=100

Figure 22: PTL8C
Cp=2000, Cs=200





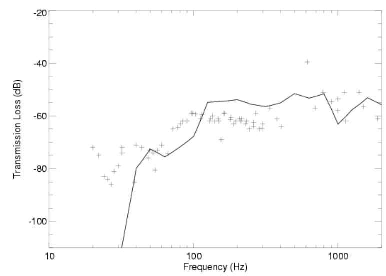
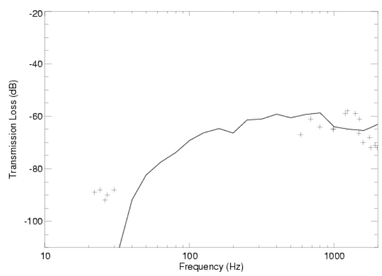
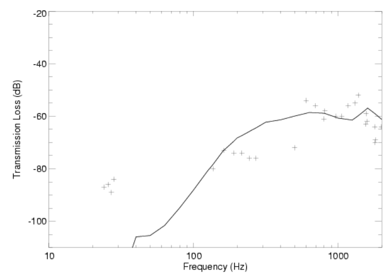


Figure 23: PTL9A
Cp=2000, Cs=200

Figure 24: PTL9B
Cp=2000, Cs=200

Figure 25: PTL10B
Cp=2000, Cs=100





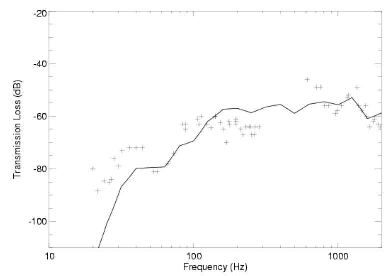


Figure 26: PTL11A
Cp=2000, Cs=100

Figure 27: PTL11B
Cp=2000, Cs=200

Figure 28: PTL11C
Cp=2000, Cs=200

6. MODEL FIT RESULTS

The model fits were performed by finding the bottom compressional speed (at seafloor) and bottom shear speed that minimized mean difference between data and model predictions in the 50 Hz to 500 Hz band. The fit statistics computed included the means and standard deviations of the difference, in decibels between model and measured transmission loss. These statistics were computed separately for the 10-2000 Hz, 10-50 Hz, 50-500 Hz and 500-2000 Hz bands. The values for the best model fit are given in Appendix 2 for all data sets. In general the mean error in the 50 to 500 Hz band is negative, meaning that the model underestimated measured transmission loss. Of the data sets with more than 5 points in the 50-500 Hz band, the average modelled transmission loss exceeded the average measured transmission loss in only for data set PTL7A. For this set of 6 points the average modelled loss was 2.9 dB greater than the average measured loss. The largest average error of 13.5 dB occurred for data set PTL7C, for which there is only a single data point in the 50 Hz to 500 Hz band.

7. INTEGRATED MODEL VALIDATION

The parabolic equation transmission loss model described in previous sections was integrated with a source level database and GIS interface to provide a tool for rapid estimation of received levels from multiple vessels. The integrated model automatically reads bathymetric and geoacoustic data from GIS-formatted files. Modelled transmission losses in 1/3-octave bands between 10 Hz and 2 kHz are applied to the corresponding source levels to compute 1/3-octave received levels. These are summed to compute broadband received levels. The integrated model tessellates the selected modelling area with a large number of radial tracks. Received levels on these tracks are automatically gridded and displayed as sound level isopleths on maps. Broadband sound levels at selected locations can automatically be extracted.

The best test of the integrated model is performed by comparing model results with real operational scenarios. This is the approach taken by Sakhalin Energy to validate the model. Measurements of dredging and pipelaying operations were performed during the real dredging and pipelaying operations carried out at Lunskoye in summer 2004. Those operations are nearly identical to operations that would be performed for pipeline construction in Piltun. Furthermore the bathymetric environment is also similar between the two locations, so the acoustic measurement results obtained at Lunskoye are expected to be closely representative of the same scenarios performed at Piltun.

This section describes a brief test of the integrated model that compares model predictions with noise measurements made during two operations performed at Lunskoye. The operations consisted of scenario 1: a Trailing Suction Hopper Dredging (TSHD) on a section from 6.1 km to 7.3 km offshore, and scenario 2: pipelaying and dredging at less than 1.4 km from shore.

7.1. SCENARIO 1: TSHD DREDGING AT 7 KM

In scenario 1 the TSHD dredge was working on an East-West section of the Lunskoye pipeline route between 6.1 km and 7.2 km from shore. Rough weather had caused all other operations to stop so the measurements made at this time were representative only of the TSHD vessel. Underwater noise measurements were made on five anchored sonobuoys placed along a tracks leading away from the pipeline route (see Figure 29).

Integrated model runs were performed that are representative of dredge vessel locations at both ends of this dredged section. The geoacoustic parameter information used here was set to the base case values from Table 3, with constant water sound speed of 1480 m/s. The bottom compressional and shear wave speed parameters were Cp=2000 m/s and Cs=100 m/s. The broadband model results are shown in Figure 29 and Figure 30 as sound level isopleths (contours) from 100 to 150 dB re µPa. The broadband levels at the receiver sonobuoy locations are also shown in Figure 31.

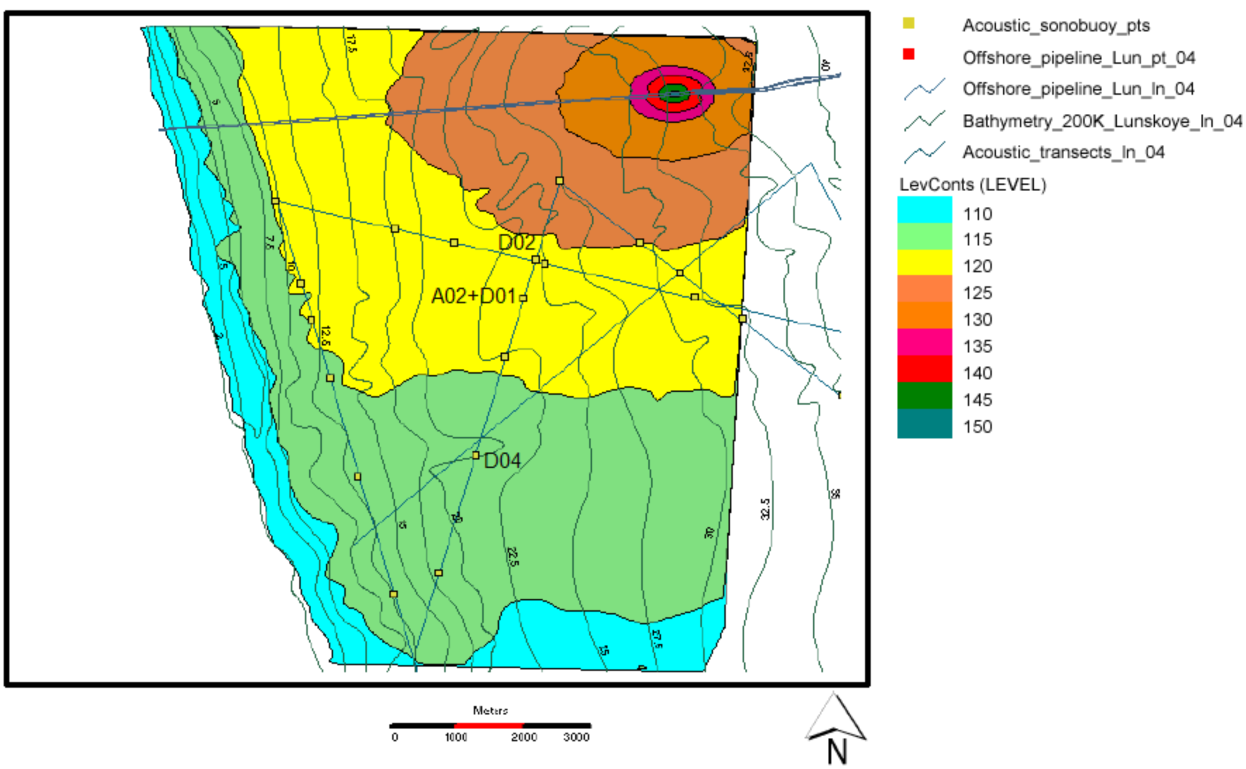


Figure 29: Broadband (10 Hz-2 kHz) integrated noise model predictions of sound levels from a TSHD dredge operating at Lunskoye at the east end (7.2 km from shore) of its working section. D02, A02 and D01, and D05 are sonobuoy positions.

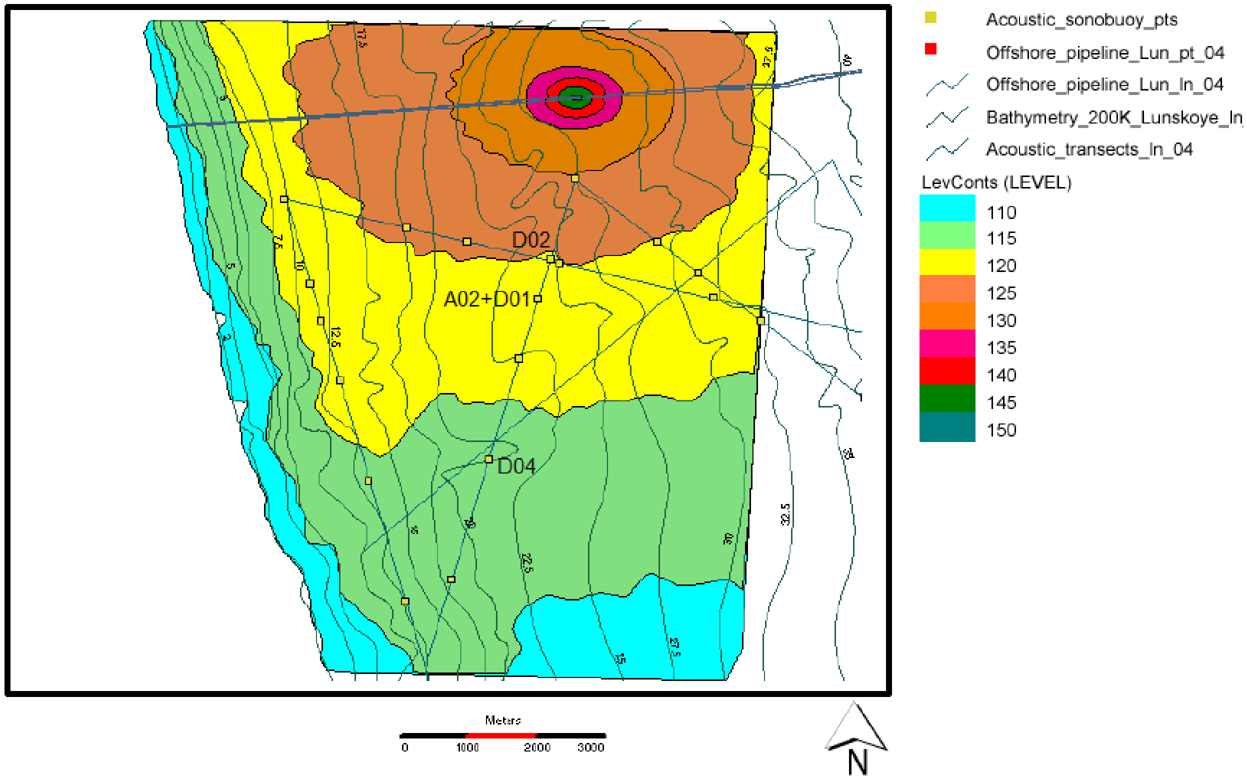


Figure 30: Broadband (10 Hz-2 kHz) integrated noise model predictions of sound levels produced by TSHD dredge operating at Lunskoye at the west end (6.1 km from shore) of its working section.

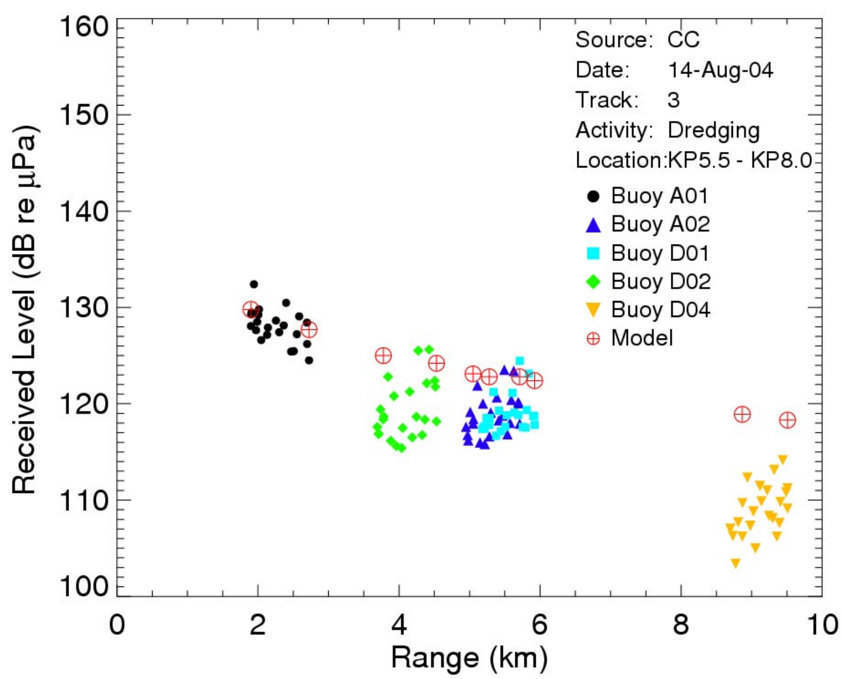


Figure 31: Broadband (10 Hz – 2 kHz) noise level measurements and Integrated noise model predictions at sonobuoy locations during TSHD dredging nominally 7 km offshore Lunskoye. Corresponding 1/3-octave levels are given in Appendix 1.

The noise measurements of dredge activities shown in Figure 31 were obtained over a two-hour period during which the dredge made passes back and forth between the ends of its dredging section. The range spread of data points for each of the fixed buoys is due to movement of the dredge vessel over its operating section as it moved relatively closer and farther away from the buoys. The model results are in pairs representing the two model runs performed for the vessel at the ends of the section. A comparison of the corresponding 1/3-octave levels for this scenario is given in Appendix 1.

Some of the variability of measurements may be ascribed to the change in position of the source, but as the pairs of modelled points show, the change in vessel position could only account for at most 5 dB out of the 10 dB or so variability, which moreover seems to be fairly uncorrelated to range except for at closest buoy A01. This temporal variability could be attributed to source level changes of the dredge, to additive noise from sources other than the dredge, and to measurement system noise. The latter could include flow noise around the hydrophones. The agreement between the model and the sampled measurements, taking scatter into consideration, is quite good at buoys A02, D01 and D02 at nominal ranges 5.5 km, 4 km and 5.5 km respectively. The model overestimated by between about 5 dB the highest readings from buoy D04 at 9-9.5 km from the dredge vessel. The reason for over-estimation can be partly attributed to the conservative approach taken for modelling transmission loss; geoacoustic parameters used for model predictions are based on fits to transmission loss data at Piltun in which the final model estimates typically underestimated the mean measured values in the 50 Hz to 500 Hz band by a few decibels. The spread of measured values, however, appears to fall significantly below what would be consistent with a normal attenuation curve passing through the measurements at shorter ranges. It may be speculated that some small-scale feature of the bathymetry not resolved in the survey data available might have blocked the noise reception at this specific location.

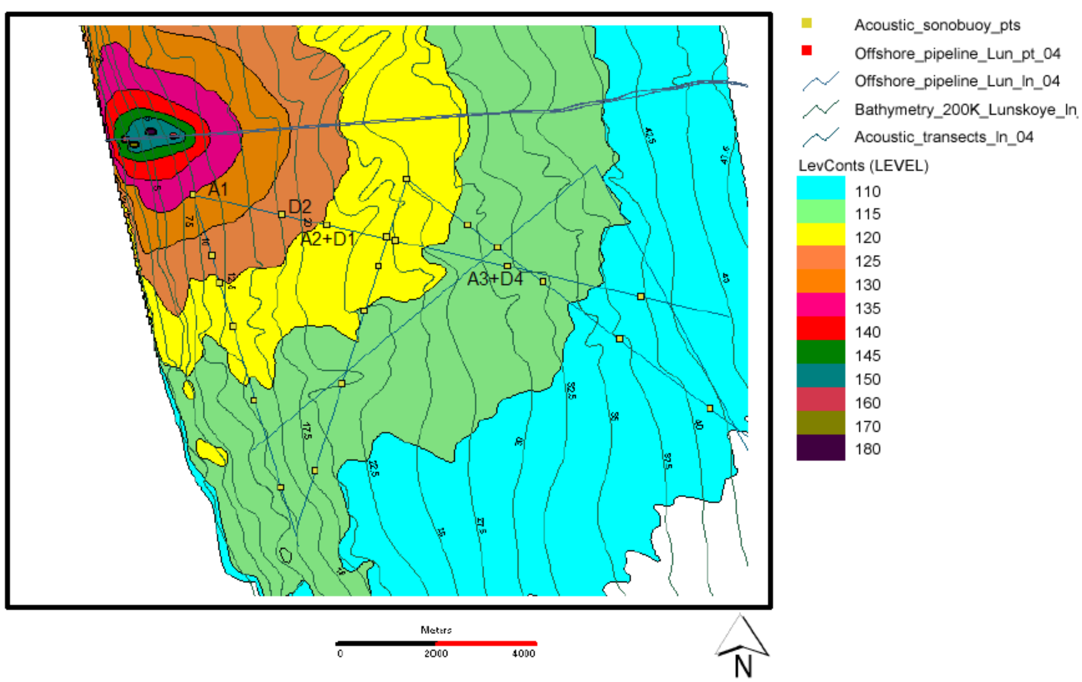


Figure 32: Modelled Received Levels from a snapshot of actual 2004 Lunskoye near-shore operations. A pipelaying barge was operating 400 m from shore supported by two anchor handling tugs. A TSHD dredge was operating at 1.4 km offshore. Real-time monitoring buoy

7.2. SCENARIO 2: MULTI-VESSEL PIPELAYING NEARSHORE

The most complete validation of the integrated model is achieved by comparing the predicted and measured sound levels along a line of sonobuoys arising from several vessels operating at the same time. In the scenario 2 case that follows, a dredging and pipe-laying spread consisting of a Pipe-laying Barge (PB), two Anchor

Handling Tugs (AHTs) and a Trailing Suction Hopper Dredge (TSHD) all operating within 1.5 km from the shoreline along the Lunskoye route. In this spread the distance between the vessels is such that only through individual modelling of the sound propagation from each source and subsequent summing can the aggregate acoustic footprint be accurately predicted at a range of a few kilometres. The instantaneous positions of the individual vessels were known from logging of marine Automatic Identification System (AIS) information as received by the monitoring ship, or from vessel logs.

An integrated model run was performed that is representative of the vessel locations as indicated above. The geoacoustic parameters were set as in the previous examples. The source levels used in the modelling were recorded for the actual vessels conducting similar activities, but at different times and locations. The broadband model results are shown in Figure 32 as sound level isopleths (contours) from 100 to 180 dB re μPa. The corresponding 1/3-octave measured and modelled levels, from which these broadband levels were computed, are presented in plots in Appendix 1. The locations of the individual vessels can be pinpointed by the small higher-level contours concentrated at each source; from nearest to farthest from shore are the PB, the two AHTs and the TSHD. In this case, because of the complex interplay of multiple noise sources all in relative motion, it is not possible to produce a level versus range scatter plot as in the previous example. We have therefore presented in Table 4 the instantaneous broadband levels levels (or more precisely their averaged values over a five minute interval as per the signal analysis methodology used in the field) measured at the various sonobuoys and the corresponding predicted values from the integrated model based on the vessel position at the nominal sample time. In this case measurements were available from two analogue buoys (A1, A2 and A3) and three digital buoys (D1, D2 and D4), two of each deployed pairwise at approximately the same location and overall spanning ranges from about 2 km to over 8 km from the centre of the spread. Considering that, as discussed earlier, there would be an intrinsic variability in the sound field at any given time as the vessels individually altered their regime, the agreement between measurement and model is extremely good. It should be noted that sonobuoys A3 and D4, which being located within 150 m of each other should have given identical readings, exhibit a constant offset throughout the recording of approximately 5 decibels. We cannot determine which of these sonobuoys has greater accuracy, but in general the digital sonobuoys were found to be less prone to baseline shifts due to external interference.

Table 4: Comparison of measured and modelled broadband levels at several hydrophone locations generated by pipelaying and dredging activities from a spread of four vessels at Lunskoye. Sonobuoys A2 and D1, and A3 and D4 have the same modelled levels because they are essentially pairwise co-located.

BuoyID	Measured Level (dB re μPa)	Modelled Level (dB re μPa)
A1	134.9	135.0
D2	129.9	127.8
A2	125.6	124.6
D1	126.5	124.6
A3	114.1	117.4
D4	118.9	117.4

8. SUMMARY

Modelled transmission loss results between 10 Hz and 2 kHz were compared to measurement data for 20 source-receiver configurations along 12 primary tracks representing noise transmission paths between source points on Sakhalin Energy’s proposed pipeline routes and receiver locations in the Western Gray Whale feeding area off Piltun Bay. At frequencies above 50 Hz the model reproduced well both the transmission loss magnitude and the measured variation of transmission loss with frequency. The model in some cases overestimated transmission loss at frequencies less than 40 Hz. These low frequencies, however, are less important in terms of noise impact than the 50 to 500 Hz band because transmission loss below 40 Hz is significantly greater than at higher frequencies due to the fact that low frequency modes are not supported well in the shallow water environment. In the IUCN Panel Report (Reeve 2005) it is suggested that low frequency sound propagating as interface waves between bottom layers of high impedance contrast could be a reason for mismatch between model and data at low frequencies. The basic compressional gradient and

constant shear speed bottom model used for the present work does not include detailed descriptions of sub-bottom layers and consequently would not reproduce such interface wave propagation. However, as discussed previously, even the measured rate of transmission loss is so high at these low frequencies that the resulting noise fields at distances beyond a few hundred meters are dominated by higher-frequency noise energy. Measurements of noise from dredging and pipelaying activities at Lunskoye in 2004, at ranges between 2 and 9 km, confirmed that the acoustic transmission loss at frequencies under 50 Hz is large relative to that at higher frequencies, and that the naval and industrial equipment used offshore generate most noise at frequencies below 500 Hz.

The match between model and data in the 50 to 500 Hz range was very good for most tracks in the Piltun transmission loss experiments. Mean differences between modelled transmission loss and data ranged from –12.3 dB to +1.04 dB for all the tracks having more than 10 data points. If the measurements on the single track 2 were omitted the overall results would have been much closer: -4.2 dB to +1.04 dB. The fact that the model generally tends to underestimate transmission loss by a few decibels leads to overestimation of received levels in propagation modelling. The model therefore is expected to produce conservative estimates of the received sound levels used in predicting noise impacts.

The integrated source level and transmission loss model was validated in a comparative study against noise measurements made during dredging operations performed at Lunskoye in 2004. The operations monitored were comparable to those proposed for pipeline construction at Piltun, and the geoacoustic environment at Lunskoye is very similar to that at Piltun. In a sample case involving a single dredge operating at various locations, the model results fell within the distribution of measured levels at distances from 2 km to 6 km from the operation, generally overestimating the mean. At a monitoring point 9 km from the operation the model overestimated by about 5 dB the largest observations in the spread of measured levels. In a second validation scenario involving multiple vessels in a near-shore pipelaying and dredging operation the model results were highly consistent with the measurements made at 5 sonobuoys deployed between 2 km and 8 km from the operational area, with agreement of broadband levels within 3.3 dB. The model also reproduced accurately the spectral distribution of energy, especially in the frequency range from 50 Hz to 500 Hz where most of the received noise energy is concentrated.

9. REFERENCES

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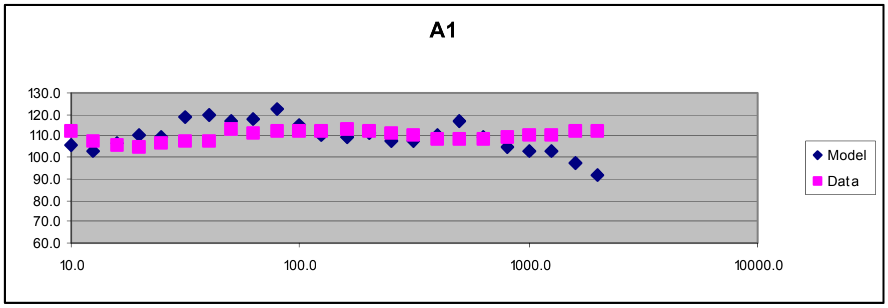
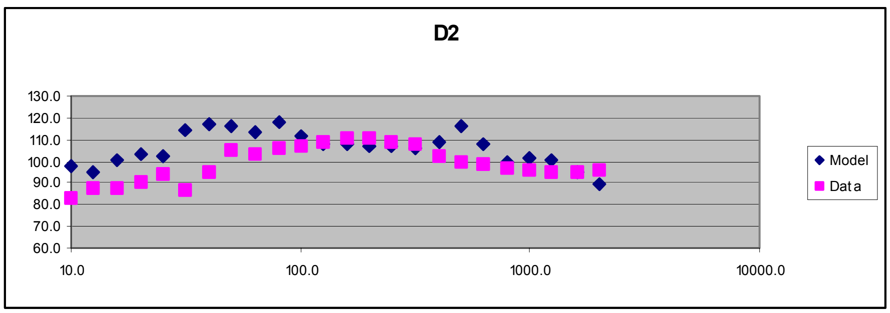
Reeve R. (Ed.) (2005), Report of the Independent Scientific Review Panel on the Impacts of Sakhalin II Phase 2 on Western North Pacific Gray Whales and Related Biodiversity, IUCN Report, February 2005.

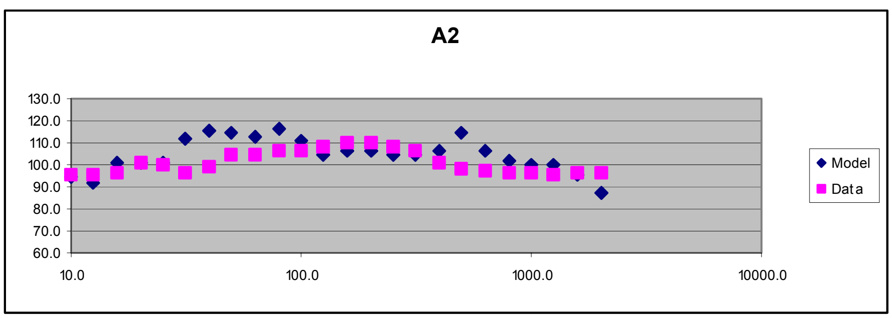
10. APPENDIX 1: 1/3-OCTAVE MEASURED AND MODELLED NOISE LEVELS FROM DREDGING AND PIPELAYING AT LUNSKOYE IN 2004.

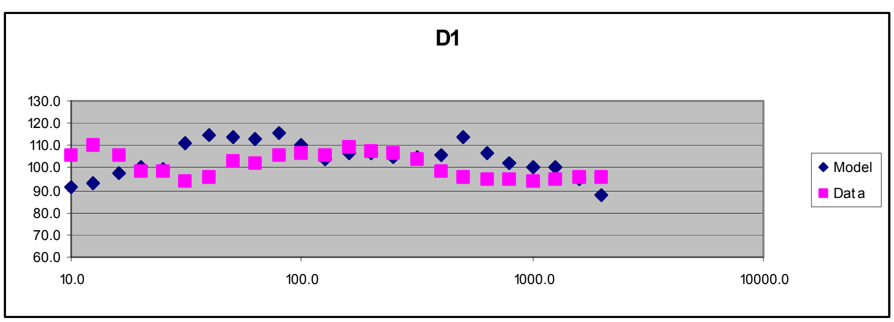
10.1. TSHD DREDGING 7.0 KM FROM SHORE.

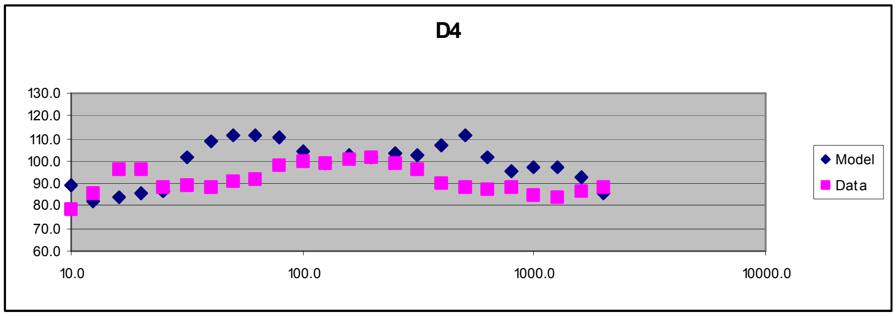
The following plots show 1/3-octave integrated model predictions and corresponding measurements of absolute noise produced from TSHD dredging operations at 7 km from shore at Lunskoye in 2004. X-axis is frequency in Hz, and y-axis is 1/3-octave RMS noise level in decibels relative to 1 µPa.





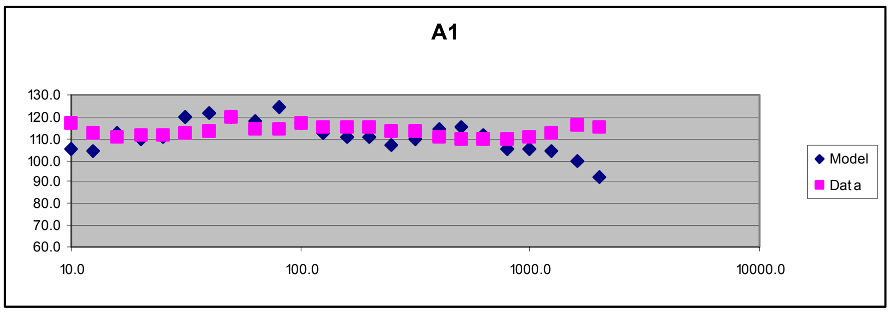


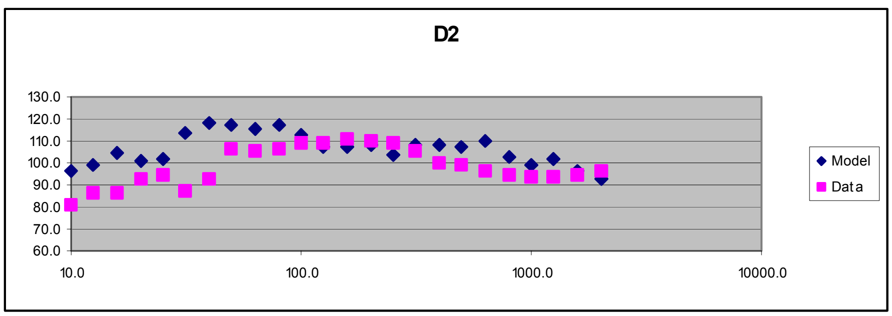


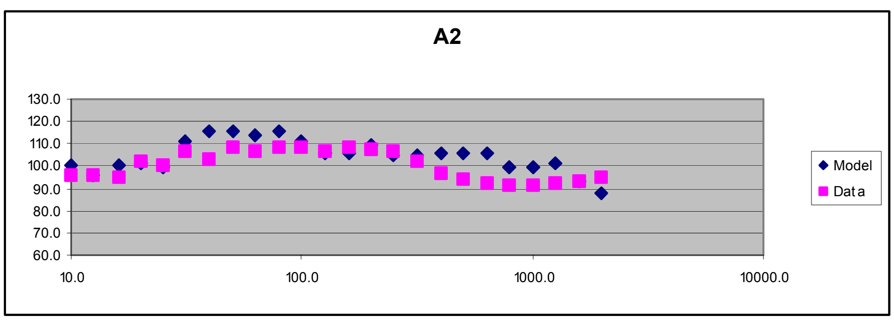


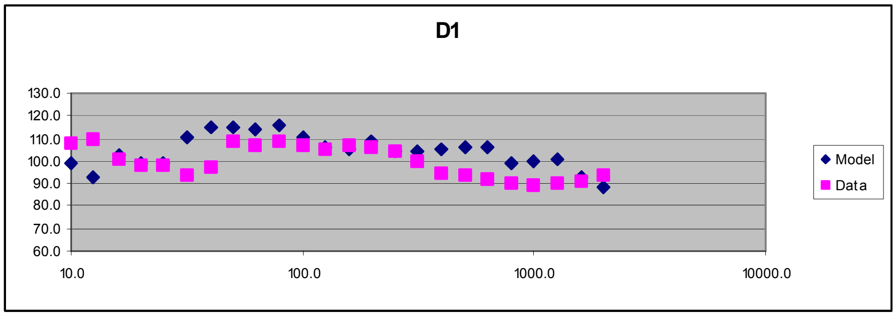
10.2. TSHD DREDGING 6.2 KM FROM SHORE.

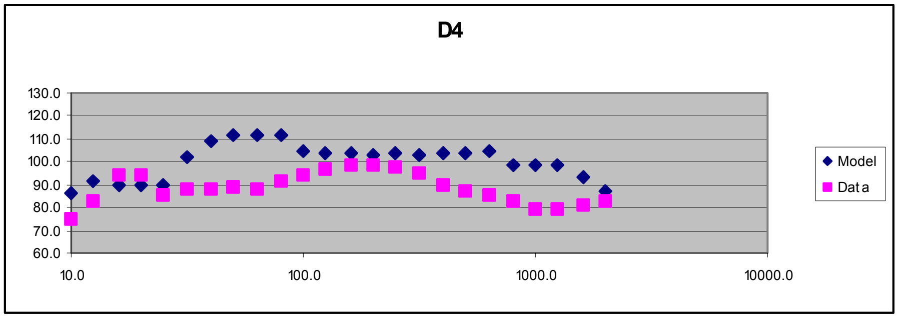
The following plots show 1/3-octave integrated model predictions and corresponding measurements of absolute noise produced from TSHD dredging operations at 6.2 km from shore at Lunskoye in 2004. X-axis is frequency in Hz, and y-axis is 1/3-octave RMS noise level in decibels relative to 1 µPa.





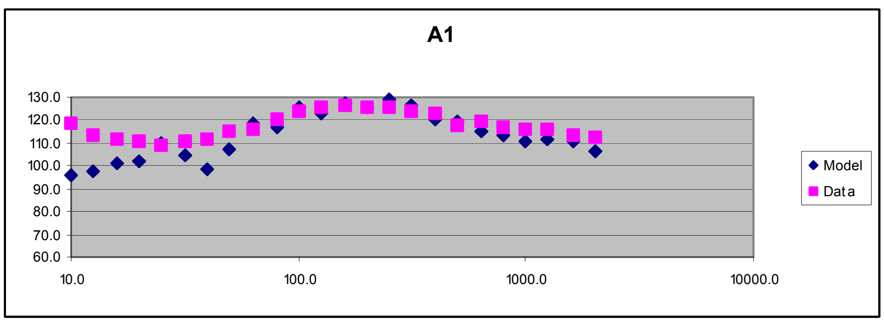


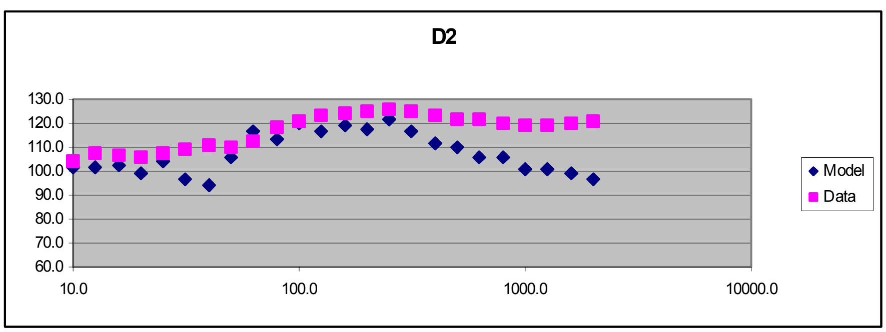


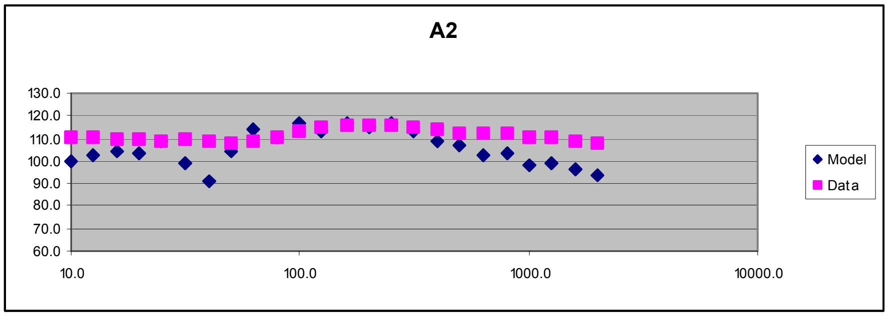


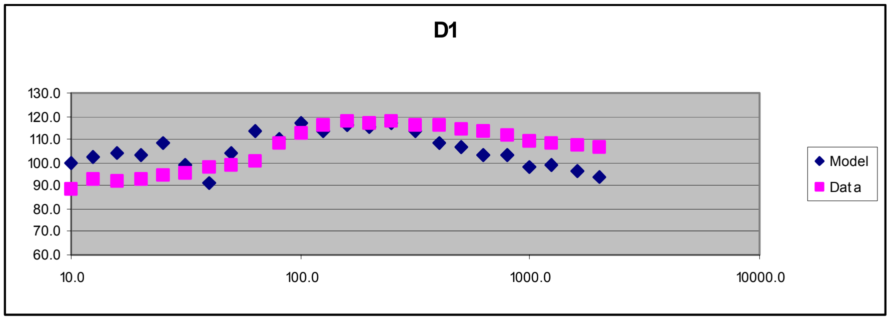
10.3. PIPELAYING AND TSHD DREDGING NEAR-SHORE.

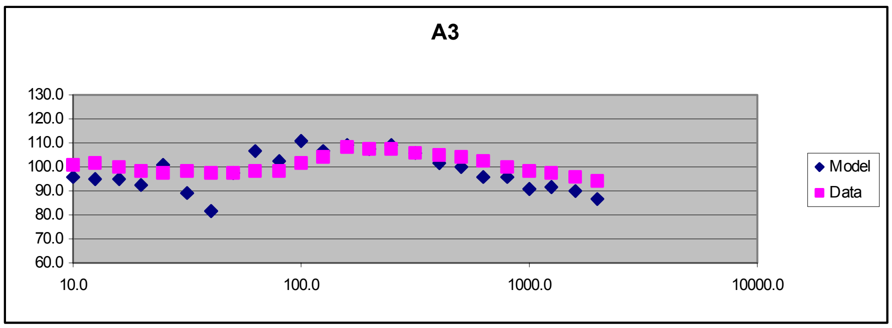
The following plots show 1/3-octave integrated model predictions and corresponding measurements of absolute noise produced from near-shore pipelaying operations and simultaneous shallow dredging at Lunskoye in 2004. The pipelaying operations included a pipelay barge and two anchor-handling tugs. X-axis is frequency in Hz, and y-axis is 1/3-octave RMS noise level in decibels relative to 1 μPa.






A2
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
10.0
100.0
1000.0
10000.0
Model
Data


D1
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
10.0
100.0
1000.0
10000.0
Model
Data


A3
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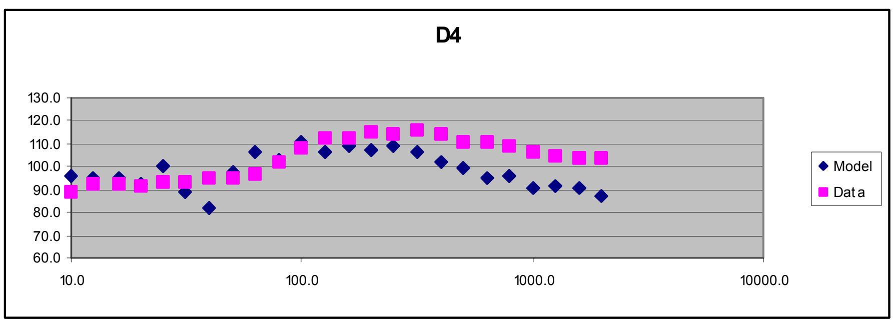
120.0
110.0
100.0
90.0
80.0
70.0
60.0
10.0
100.0
1000.0
10000.0
Model
Data


D4
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
10.0
100.0
1000.0
10000.0
Model
Data

11. APPENDIX 2: MODEL – DATA FIT PARAMETERS

PA-B to A7

cp = 2000.00 cs = 100.000

Broadband:
Number of data points: 24
Mean error = -0.215565 Positive means modelled loss greater than measured
Standard dev = 12.0812
Mean absolute error = 8.80026

Less than 50 Hz
Number of data points: 5
Mean error = 13.5980 Positive means modelled loss greater than measured
Standard dev = 17.2516
Mean absolute error = 19.7386

From 50 Hz to 500 Hz
Number of data points: 15
Mean error = -4.23540 Positive means modelled loss greater than measured
Standard dev = 7.18955
Mean absolute error = 6.76787

From 500 Hz to 2000 Hz
Number of data points: 4
Mean error = -2.40818 Positive means modelled loss greater than measured
Standard dev = 2.44095
Mean absolute error = 2.74885

PA-B to A8

cp = 2000.00 cs = 100.000

Statistics
Broadband:
Number of data points: 21
Mean error = 1.28358 Positive means modelled loss greater than measured
Standard dev = 4.17770
Mean absolute error = 3.18493

Less than 50 Hz
Number of data points: 3
Mean error = 0.243698 Positive means modelled loss greater than measured
Standard dev = 8.76866
Mean absolute error = 7.39776

From 50 Hz to 500 Hz
Number of data points: 14
Mean error = 1.03804 Positive means modelled loss greater than measured
Standard dev = 2.86700
Mean absolute error = 2.35707

From 500 Hz to 2000 Hz
Number of data points: 4
Mean error = 2.92285 Positive means modelled loss greater than measured
Standard dev = 1.21812
Mean absolute error = 2.92285

PTL2A

cp = 2000.00 cs = 200.000

Statistics
Broadband:
Number of data points: 37
Mean error = -0.231017 Positive means modelled loss greater than measured
Standard dev = 11.2688
Mean absolute error = 9.88568

Less than 50 Hz
Number of data points: 10
Mean error = 13.0390 Positive means modelled loss greater than measured
Standard dev = 3.17062
Mean absolute error = 13.0390

From 50 Hz to 500 Hz
Number of data points: 15
Mean error = -9.75325 Positive means modelled loss greater than measured
Standard dev = 8.18968
Mean absolute error = 11.5892

From 500 Hz to 2000 Hz
Number of data points: 12
Mean error = 0.613405 Positive means modelled loss greater than measured
Standard dev = 6.20672
Mean absolute error = 5.12846

PTL2B

cp = 2000.00 cs = 200.000

Statistics
Broadband:
Number of data points: 25
Mean error = -2.29771 Positive means modelled loss greater than measured
Standard dev = 7.87859
Mean absolute error = 6.70106

Less than 50 Hz
Number of data points: 5
Mean error = 4.29408 Positive means modelled loss greater than measured
Standard dev = 3.24669
Mean absolute error = 4.37419

From 50 Hz to 500 Hz
Number of data points: 5
Mean error = -11.2489 Positive means modelled loss greater than measured
Standard dev = 2.38361
Mean absolute error = 11.2489

From 500 Hz to 2000 Hz
Number of data points: 14
Mean error = -0.419826 Positive means modelled loss greater than measured
Standard dev = 6.51036
Mean absolute error = 5.18715

PTL2C

cp = 1750.00 cs = 200.000

Statistics
Broadband:
Number of data points: 41
Mean error = 3.18597 Positive means modelled loss greater than measured
Standard dev = 13.3752
Mean absolute error = 9.86580

Less than 50 Hz
Number of data points: 15
Mean error = 12.7953 Positive means modelled loss greater than measured
Standard dev = 12.6724
Mean absolute error = 13.3989

From 50 Hz to 500 Hz
Number of data points: 10
Mean error = -12.3145 Positive means modelled loss greater than measured
Standard dev = 7.93763
Mean absolute error = 13.2521

From 500 Hz to 2000 Hz
Number of data points: 16
Mean error = 3.86500 Positive means modelled loss greater than measured
Standard dev = 5.59394
Mean absolute error = 4.43711

PTL4A

cp = 2000.00 cs = 100.000

Statistics
Broadband:
Number of data points: 15
Mean error = -5.53138 Positive means modelled loss greater than measured
Standard dev = 7.98994
Mean absolute error = 7.29901

Less than 50 Hz
Number of data points: 6
Mean error = -8.46076 Positive means modelled loss greater than measured
Standard dev = 10.5053
Mean absolute error = 11.2151

From 50 Hz to 500 Hz
*** No measurements in this frequency range ***

From 500 Hz to 2000 Hz
Number of data points: 9
Mean error = -3.57846 Positive means modelled loss greater than measured
Standard dev = 4.82593
Mean absolute error = 4.68827

PTL4B

cp = 2000.00 cs = 100.000

Statistics

Broadband:
Number of data points: 15
Mean error = -0.172349 Positive means modelled loss greater than measured
Standard dev = 6.41888
Mean absolute error = 5.96012

Less than 50 Hz
Number of data points: 6
Mean error = -1.70812 Positive means modelled loss greater than measured
Standard dev = 5.59383
Mean absolute error = 5.63463

From 50 Hz to 500 Hz
*** No measurements in this frequency range ***

From 500 Hz to 2000 Hz
Number of data points: 9
Mean error = 0.851498 Positive means modelled loss greater than measured
Standard dev = 6.72226
Mean absolute error = 6.17712

PTL4C

cp = 2000.00 cs = 200.000

Statistics
Broadband:
Number of data points: 35
Mean error = 9.32340 Positive means modelled loss greater than measured
Standard dev = 15.1969
Mean absolute error = 11.2306

Less than 50 Hz
Number of data points: 9
Mean error = 29.0872 Positive means modelled loss greater than measured
Standard dev = 16.4400
Mean absolute error = 29.0872

From 50 Hz to 500 Hz
Number of data points: 16
Mean error = -0.293070 Positive means modelled loss greater than measured
Standard dev = 5.52910
Mean absolute error = 3.87888

From 500 Hz to 2000 Hz
Number of data points: 10
Mean error = 6.92235 Positive means modelled loss greater than measured
Standard dev = 3.29827
Mean absolute error = 6.92235

PTL5A

cp = 2000.00 cs = 100.000

Statistics
Broadband:
Number of data points: 9
Mean error = -2.17263 Positive means modelled loss greater than measured
Standard dev = 7.66195

Mean absolute error = 5.51418

Less than 50 Hz
Number of data points: 6
Mean error = 1.30352 Positive means modelled loss greater than measured
Standard dev = 6.22502
Mean absolute error = 3.70880

From 50 Hz to 500 Hz
*** No measurements in this frequency range ***

From 500 Hz to 2000 Hz
Number of data points: 3
Mean error = -9.12493 Positive means modelled loss greater than measured
Standard dev = 5.11006
Mean absolute error = 9.12493

PTL5B

cp = 2000.00 cs = 100.000

Statistics
Broadband:
Number of data points: 8
Mean error = 8.79210 Positive means modelled loss greater than measured
Standard dev = 16.0706
Mean absolute error = 13.5144

Less than 50 Hz
Number of data points: 6
Mean error = 8.98149 Positive means modelled loss greater than measured
Standard dev = 12.0338
Mean absolute error = 9.86658

From 50 Hz to 500 Hz
*** No measurements in this frequency range ***

From 500 Hz to 2000 Hz
Number of data points: 2
Mean error = 8.22393 Positive means modelled loss greater than measured
Standard dev = 24.4578
Mean absolute error = 24.4578

PTL5C

cp = 2000.00 cs = 200.000

Statistics
Broadband:
Number of data points: 37
Mean error = 0.589738 Positive means modelled loss greater than measured
Standard dev = 18.1611
Mean absolute error = 13.8829

Less than 50 Hz
Number of data points: 4
Mean error = 29.1426 Positive means modelled loss greater than measured
Standard dev = 6.13340

Mean absolute error = 29.1426

From 50 Hz to 500 Hz
Number of data points: 20
Mean error = -0.665632 Positive means modelled loss greater than measured
Standard dev = 9.84688
Mean absolute error = 7.90079

From 500 Hz to 2000 Hz
Number of data points: 13
Mean error = -6.26442 Positive means modelled loss greater than measured
Standard dev = 21.8570
Mean absolute error = 18.3908

PTL7A

cp = 2000.00 cs = 100.000

Statistics
Broadband:
Number of data points: 22
Mean error = 2.69013 Positive means modelled loss greater than measured
Standard dev = 14.4767
Mean absolute error = 9.30170

Less than 50 Hz
Number of data points: 6
Mean error = 16.0166 Positive means modelled loss greater than measured
Standard dev = 19.0737
Mean absolute error = 16.8134

From 50 Hz to 500 Hz
Number of data points: 6
Mean error = 2.86585 Positive means modelled loss greater than measured
Standard dev = 8.37170
Mean absolute error = 7.56002

From 500 Hz to 2000 Hz
Number of data points: 10
Mean error = -5.41117 Positive means modelled loss greater than measured
Standard dev = 5.34064
Mean absolute error = 5.83967

PTL7C

cp = 2000.00 cs = 100.000

Statistics
Broadband:
Number of data points: 28
Mean error = 7.23902 Positive means modelled loss greater than measured
Standard dev = 5.30703
Mean absolute error = 8.04947

Less than 50 Hz
Number of data points: 12
Mean error = 4.92663 Positive means modelled loss greater than measured
Standard dev = 6.02874

Mean absolute error = 6.81769

From 50 Hz to 500 Hz
Number of data points: 1
Mean error = 13.5103 Positive means modelled loss greater than measured
Standard dev = 0.000000
Mean absolute error = 13.5103

From 500 Hz to 2000 Hz
Number of data points: 15
Mean error = 8.67084 Positive means modelled loss greater than measured
Standard dev = 3.81412
Mean absolute error = 8.67084

PTL8C

cp = 2000.00 cs = 200.000

Statistics
Broadband:
Number of data points: 19
Mean error = -2.91733 Positive means modelled loss greater than measured
Standard dev = 8.66661
Mean absolute error = 7.69617

Less than 50 Hz
Number of data points: 12
Mean error = -6.74424 Positive means modelled loss greater than measured
Standard dev = 7.62452
Mean absolute error = 8.57082

From 50 Hz to 500 Hz
Number of data points: 3
Mean error = 1.05126 Positive means modelled loss greater than measured
Standard dev = 7.81008
Mean absolute error = 7.00986

From 500 Hz to 2000 Hz
Number of data points: 4
Mean error = 5.58697 Positive means modelled loss greater than measured
Standard dev = 2.92478
Mean absolute error = 5.58697

PTL9A

cp = 2000.00 cs = 200.000

Statistics
Broadband:
Number of data points: 22
Mean error = 5.25265 Positive means modelled loss greater than measured
Standard dev = 14.0485
Mean absolute error = 9.62610

Less than 50 Hz
Number of data points: 4
Mean error = 32.7065 Positive means modelled loss greater than measured
Standard dev = 6.39314
Mean absolute error = 32.7065

From 50 Hz to 500 Hz
Number of data points: 9
Mean error = -3.06250 Positive means modelled loss greater than measured
Standard dev = 4.09823
Mean absolute error = 4.45215

From 500 Hz to 2000 Hz
Number of data points: 9
Mean error = 1.36609 Positive means modelled loss greater than measured
Standard dev = 5.31453
Mean absolute error = 4.54210

PTL9B

cp = 2000.00 cs = 200.000

Statistics
Broadband:
Number of data points: 32
Mean error = 5.26503 Positive means modelled loss greater than measured
Standard dev = 14.1427
Mean absolute error = 8.97926

Less than 50 Hz
Number of data points: 6
Mean error = 30.5411 Positive means modelled loss greater than measured
Standard dev = 13.3164
Mean absolute error = 30.5411

From 50 Hz to 500 Hz
Number of data points: 14
Mean error = -2.48074 Positive means modelled loss greater than measured
Standard dev = 4.22303
Mean absolute error = 4.04715

From 500 Hz to 2000 Hz
Number of data points: 12
Mean error = 1.66372 Positive means modelled loss greater than measured
Standard dev = 4.63709
Mean absolute error = 3.95247

PTL10B

cp = 2000.00 cs = 100.000

Statistics
Broadband:
Number of data points: 68
Mean error = 3.90937 Positive means modelled loss greater than measured
Standard dev = 15.5897
Mean absolute error = 10.5215

Less than 50 Hz
Number of data points: 14
Mean error = 26.1570 Positive means modelled loss greater than measured
Standard dev = 19.4542
Mean absolute error = 26.7261

From 50 Hz to 500 Hz
Number of data points: 43
Mean error = -3.07248 Positive means modelled loss greater than measured
Standard dev = 6.46252
Mean absolute error = 6.53079

From 500 Hz to 2000 Hz
Number of data points: 11
Mean error = 2.88691 Positive means modelled loss greater than measured
Standard dev = 5.99423
Mean absolute error = 5.49770

PTL11A

cp = 2000.00 cs = 100.000

Statistics
Broadband:
Number of data points: 20
Mean error = 14.9339 Positive means modelled loss greater than measured
Standard dev = 30.8433
Mean absolute error = 19.9632

Less than 50 Hz
Number of data points: 5
Mean error = 65.1887 Positive means modelled loss greater than measured
Standard dev = 18.9048
Mean absolute error = 65.1887

From 50 Hz to 500 Hz
*** No measurements in this frequency range ***

From 500 Hz to 2000 Hz
Number of data points: 15
Mean error = -1.81773 Positive means modelled loss greater than measured
Standard dev = 5.17862
Mean absolute error = 4.88804

PTL11B

cp = 2000.00 cs = 200.000

Statistics
Broadband:
Number of data points: 27
Mean error = 6.99590 Positive means modelled loss greater than measured
Standard dev = 23.8754
Mean absolute error = 13.6288

Less than 50 Hz
Number of data points: 4
Mean error = 62.4912 Positive means modelled loss greater than measured
Standard dev = 6.63851
Mean absolute error = 62.4912

From 50 Hz to 500 Hz

Number of data points: 6
Mean error = -5.76019 Positive means modelled loss greater than measured
Standard dev = 4.19372
Mean absolute error = 5.76019

From 500 Hz to 2000 Hz
Number of data points: 16
Mean error = -0.902830 Positive means modelled loss greater than measured
Standard dev = 5.31657
Mean absolute error = 4.46142

PTL11C

cp = 2000.00 cs = 200.000

Statistics
Broadband:
Number of data points: 62
Mean error = 1.60498 Positive means modelled loss greater than measured
Standard dev = 8.64453
Mean absolute error = 6.31903

Less than 50 Hz
Number of data points: 11
Mean error = 15.7795 Positive means modelled loss greater than measured
Standard dev = 7.76626
Mean absolute error = 15.7795

From 50 Hz to 500 Hz
Number of data points: 31
Mean error = -2.71352 Positive means modelled loss greater than measured
Standard dev = 5.25768
Mean absolute error = 5.09747

From 500 Hz to 2000 Hz
Number of data points: 20
Mean error = 0.502656 Positive means modelled loss greater than measured
Standard dev = 3.87428
Mean absolute error = 3.00917

12. APPENDIX 3: COMPUTATIONAL PARAMETERS FOR PE MODEL

The computational model engine used for the modelling work in this report is Complex Density Parabolic Equation (CDPE). The model is a parabolic equation model based on the well-known code RAM (Range-dependent Acoustic Model) developed by Michael Collins for U.S. Naval Research Laboratory. CDPE has been extensively tested against RAM, and has been found to produce essentially identical results when shear speed in the bottom is turned off (by setting it to zero in CDPE). It has also been tested against RAMS in realistic elastic conditions of non-zero shear speed in the bottom. Finally the PE approach has been compared with the KrakenC coupled mode program, providing nearly identical results in a range-dependent environment. In order to facilitate comparisons with other models we have included below a snippet of the actual FORTRAN90 code showing the frequency-dependent grid parameter definitions. The frequency in double precision is input in variable freq. Output variables dr, dz and nz are respectively the range step, depth step and number of depth points used for modelling at Piltun. To avoid reflections from the bottom of the computational grid, compressional wave attenuation was increased over the bottom nz/8 points of the grid from its true value, at nz/8, to its true value plus 10 dB/λ at nz.

```
select case (ifix(sngl(freq)))
case (:50) ! less than 51.0 Hz
 dr = 100.0
 dz = 1.0
 nz = 2000
case (51:100) ! 51.0 to 100.999 Hz
 dr = 100.0
 dz = 1.0
 nz = 2000
case (101:200) ! 101 to 201 Hz
 dr = 50.0
 dz = 1.0
 nz = 2000
case (201:400) ! 201 to 401 Hz
 dr = 25
 dz = 0.5
 nz = 2400
case (401:800) ! 401 to 801 Hz
 dr = 16
 dz = 0.25
 nz = 3200
case (801:1600) ! 801 to 1601 Hz
 dr = 8.0
 dz = 0.125
 nz = 3200
case (1601:) ! Greater than or equal to 1601.0 Hz.
 dr = 4.0
 dz = 0.06125
 nz = 3200
end select
```