CACOUNA ENERGY LNG TERMINAL: ASSESSMENT OF UNDERWATER NOISE IMPACTS

By

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1 Introduction

During the period of September 15 to 23, 2005, JASCO Research conducted a field program to measure underwater ambient noise levels and acoustic transmission loss at selected locations in the St. Lawrence River in the region surrounding Cacouna Energy's proposed LNG Terminal. An acoustic modeling study was then performed to predict underwater noise levels from selected activities that will occur during the construction and operation of the planned LNG port at Gros Cacouna, Quebec. The results of the acoustic field program and acoustic modeling are presented in this report and are used to assess potential noise impacts on marine mammals from the planned LNG Terminal's construction and operation.

2 Acoustic Field Program

2.1 Ambient Noise

2.1.1 Data Collection

In order to determine ambient noise levels in the St. Lawrence River, recordings of underwater ambient noise were performed at seven stations using a bottom-mounted autonomous recorder system. Baseline background noise levels were measured at five locations near the proposed LNG Terminal location at Gros Cacouna and at two locations near Île Rouge. Plans to sample an eighth station at Cap-du-Bon-Désir were cancelled as a result of time and weather constraints. Each deployment was assigned a number for ease of reference. A total of seven deployments are shown in Figure 2 and summarized in Table 1, with their locations, times, and dates.

The autonomous acoustic recorder system, shown schematically in Figure 1, employed a single Reson TC4032 calibrated hydrophone, with nominal sensitivity –170 dB re V/µPa± 1 dB and flat frequency response between 15 Hz and 100 kHz connected to a Marantz PMD660 digital audio recorder. Between 8 and 12 hours of acoustic data were recorded at each site at 44.1 kHz sampling rate with 16-bits resolution. The acoustic recorder was moored to the seabed with concrete weights. Following each deployment, an acoustic release system triggered from the surface detached the weights from the recorder, allowing the system to return to the surface for retrieval. The autonomous recorder was deployed and retrieved from a zodiac operated by PESCA Environnement of Maria, Québec. The zodiac was launched from Cacouna for the deployments on the south shore and from Bergeronnes for the two deployments near Île Rouge.

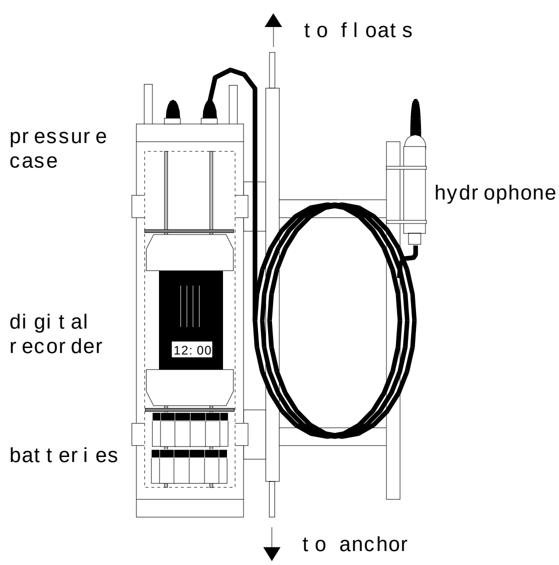

Figure 1: Diagram of autonomous acoustic recorder system used for ambient noise measurements.

Following retrieval of the autonomous recorder, acoustic waveform data were downloaded onto a PC for subsequent analysis. The recorded signals were processed to determine hourly equivalent sound pressure level (hourly Leq) and mean $^{1}/_{3}$-octave band levels. Processed ambient noise data are presented in following sections of this report.

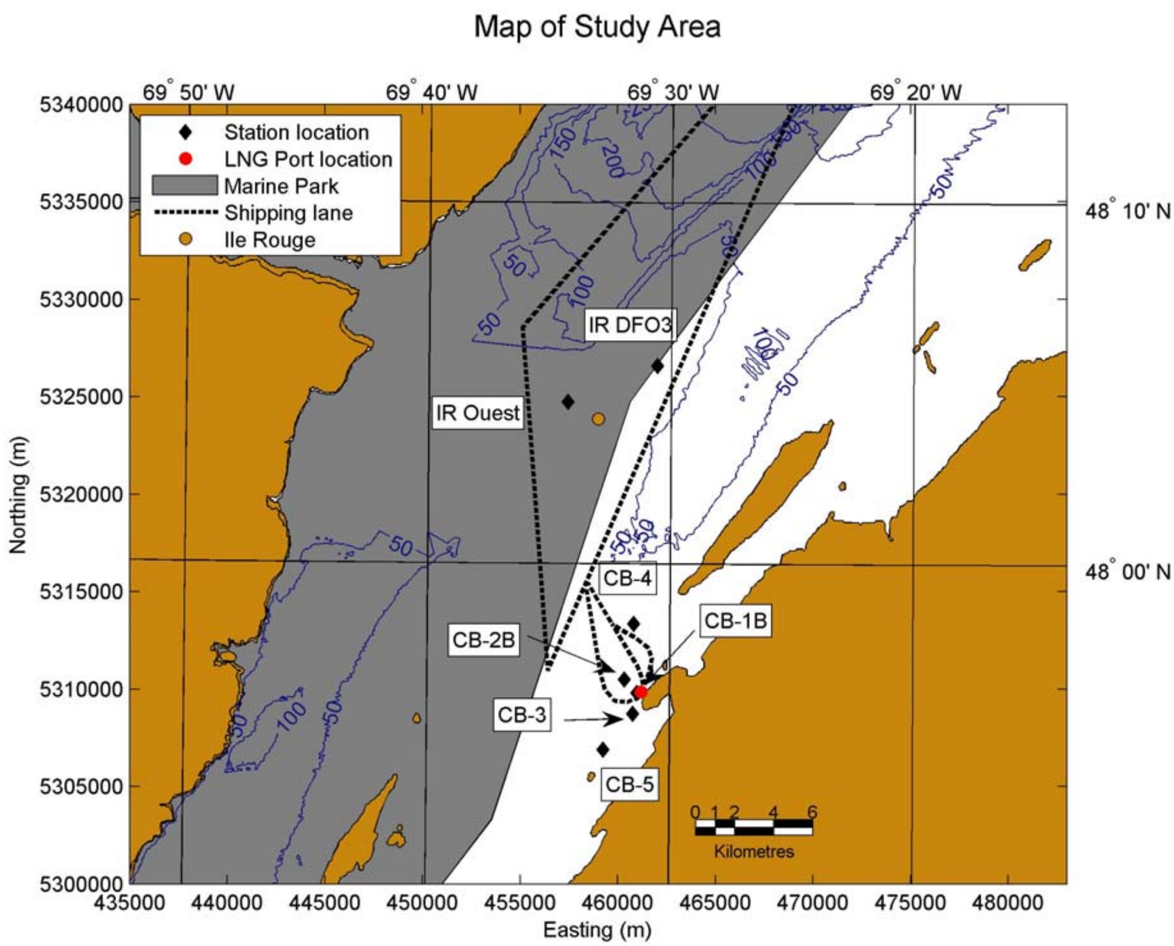

Figure 2: Map of the region near the port of Gros-Cacouna, Quebec, showing the future LNG Terminal location and deployment locations of the autonomous acoustic recorder

Table 1: Details of deployment location of autonomous acoustic recorder system

Deployment number	Zone	Deployment location	Recorder start date and time	Recorder stop date and time	Total Recording Time	Latitude	Longitude	Water depth (m)
1	Cacouna	CB-1B (200 m offshore from LNG terminal)	15-Sep-05 08:28:56	15-Sep-05 16:39:02	8:10:06	47º 56.425’	69º 31.335’	20
2	Cacouna	CB-2B (1km offshore from station CB-1B)	16-Sep-05 07:12:02	16-Sep-05 16:15:02	9:03:00	47º 56.796’	69º 31.87’	28
3	Cacouna	CB-5 (Rocher Percé)	16-Sep-05 19:08:57	17-Sep-05 07:12:57	11:56:00	47º 54.840’	69º 32.722’	8
4	Cacouna	CB-4 (Île Verte)	17-Sep-05 11:41:02	18-Sep-05 00:03:02	12:22:00	47º 58.327’	69º 31.488’	21
5	Cacouna	CB-3 (Harbour entrance)	19-Sep-05 08:50:26	19-Sep-05 17:36:26	8:46:00	47º 55.844’	69º 31.503’	14
6	Île Rouge	IR-DFO-3 (Île Rouge East)	21-Sep-05 16:32:00	22-Sep-05 04:30:00	09:58:00	48º 05.483’	69º 30.569’	27
7	Île Rouge	IR-W (Île Rouge West)	22-Sep-05 10:53:01	23-Sep-05 22:42:58	11:49:57	48º 04.464’	69º 34.262’	19

2.1.2 Data Processing

Wind speed data were obtained from the Environment Canada web site (http://www.climate.weatheroffice.ec.gc.ca/climateData/canada_e.html) for the Île Rouge weather station. Tidal height data were obtained from the Canadian Hydrographic Service web site (http://www.lau.chs-shc.dfo-mpo.gc.ca/english/Canada.shtml) for the Cacouna tide gauge station. Sea state and weather conditions were also noted during the field program.

To produce $^{1}/_{3}$-octave band levels for the ambient noise recordings, the power spectrum for each minute (60 s) of recorded data was calculated using a Fast Fourier Transform. The resulting power spectra were integrated through the frequency range of each of the $^{1}/_{3}$-octave bands between 10 Hz and 20 kHz. Figures A-1 to A-7 in Appendix A contain plots of the wind speed, water level, and broadband ambient noise levels as a function of time for each deployment, as well as colour images of the corresponding $^{1}/_{3}$-octave band level spectrograms. Times during which transmission loss measurements were being made have been deleted from the images. Appendix B presents $^{1}/_{3}$-octave band levels for each deployment, calculated at the time of maximum and minimum water level, as well as mid-way between the two.

The spectrograms also include notation regarding the probable origins of the sounds, with symbols as shown in Table 2 . Each of these noise sources are discussed further in section 2.1.3.

Table 2: Noise source symbols (adapted from Richardson, 1995)

Symbol	Noise source	Typical broadband underwater source level (dB re 1 μPa at 1 m)	Typical frequency range
S	ship	170-185	5 Hz – 1 kHz
E	electronic noise	n/a	1 Hz – 20 kHz
H	hovercraft	130-140	50 Hz – 2000 Hz
D	mooring dragging along bottom	n/a	1 Hz – 20 kHz
B	boat with outboard motor	155-175	100 Hz – 10 kHz

2.1.3 Temporal Variability

Noise levels recorded at the seven deployment locations vary substantially with time as is evident in Appendix A, Figures A-1 to A-7. Section 2.1.4 details how ambient noise levels were selected and processed for each location. The variability in underwater noise, evident in the spectrograms in Appendix A can be caused by a number of factors, including biologics, distant shipping traffic, nearby vessel passage, sea state, wind, rainfall, and current fluctuations associated with the tidal cycle. The acoustic characteristics of each of these source types are discussed below.

2.1.3.1 Instrument Self-Noise

Perhaps the most noticeable component of temporal variability in these particular deployments is the noise caused by water flow past the hydrophone (much like the wind rushing past a microphone). Vibrations of the mooring hardware and an isolated section of electronic noise are also apparent in the recordings.

Flow noise is evident in the recordings as an increase in noise below 50 Hz. It is seen in some of the deployments during the times of tidal change, which is expected since water current velocity is typically highest during tide change. In general, higher current velocities are expected to produce increased flow noise on the hydrophone. Not all deployments suffered from an increase in low-frequency noise during the time of tide change. This is to be expected, since flow noise will depend on local current conditions, which differ for each deployment location.

The mooring itself produces intermittent noise due to flexing of the connections between anchors, acoustic release and the float system. It also appears that the anchor may have dragged along the sea bed in periods of high current and this introduced quite significant broadband noise. Noise due to mooring movement can be seen in the spectrogram as a broadband signals lasting up to two minutes. An example of this type of noise is the signal labelled as D in Deployment 2.

A brief period of electronic noise was observed during deployment 1. This is the only occurrence of static-like sound, and it is marked with an E in the spectrogram shown in Figure A- 1.

2.1.3.2 Biological Noise

Cetaceans present in the autumn, in the St. Lawrence River, that contribute to the biological noise field include, belugas, minke whales, fin whales, harbour porpoises, blue whales and seals. There may also be rare occurrences of humpbacks, sperm whales, Atlantic white-sided dolphins, white-beaked dolphins, long-finned pilot whales, northern bottlenosed whales and killer whales. On September 22, 2005 the Whale News Network (http://www.whales-online.net/eng/FSC.html) reported sightings of belugas, minkes and fin whales in the St. Lawrence between Riviere-du-Loup and Les Escoumins.

The beluga whales are the most abundant and are year-round residents in the St. Lawrence River in the vicinity of the proposed terminal. St. Lawrence beluga vocalisations have been recorded with a mean frequency of 3.6 kHz (Lesage *et al*. 1999). Richardson *et al*. (1995) report beluga whistle dominant frequencies in the range of 2 to 5.9 kHz and other types of vocalisations between 1-8 kHz. Beluga echolocation can be 40-60 kHz or 100-120 kHz (Richardson *et al*. 1995).

Whistles, likely from Belugas, were seen and heard in the ambient noise data in the 2 to 3 kHz range as shown in Figure 3. There may also have been seal and other whale sounds in the data as fin and blue whales were known to be in the area. Seal species in the area include harbour, harp, grey, and hooded seals. In general, the biological sounds were intermittent and often very faint, and likely did not contribute significantly to the overall noise levels.

Invertebrates such as shrimp and crabs can make broad frequency noises, often by rubbing of body parts or production of cavitation bubbles. Some fish can make sounds that are mainly of low frequency (<3 kHz). Little is known about either invertebrate or fish sound production or hearing. These sounds are not expected to contribute substantially to the ambient noise levels in the St. Lawrence.

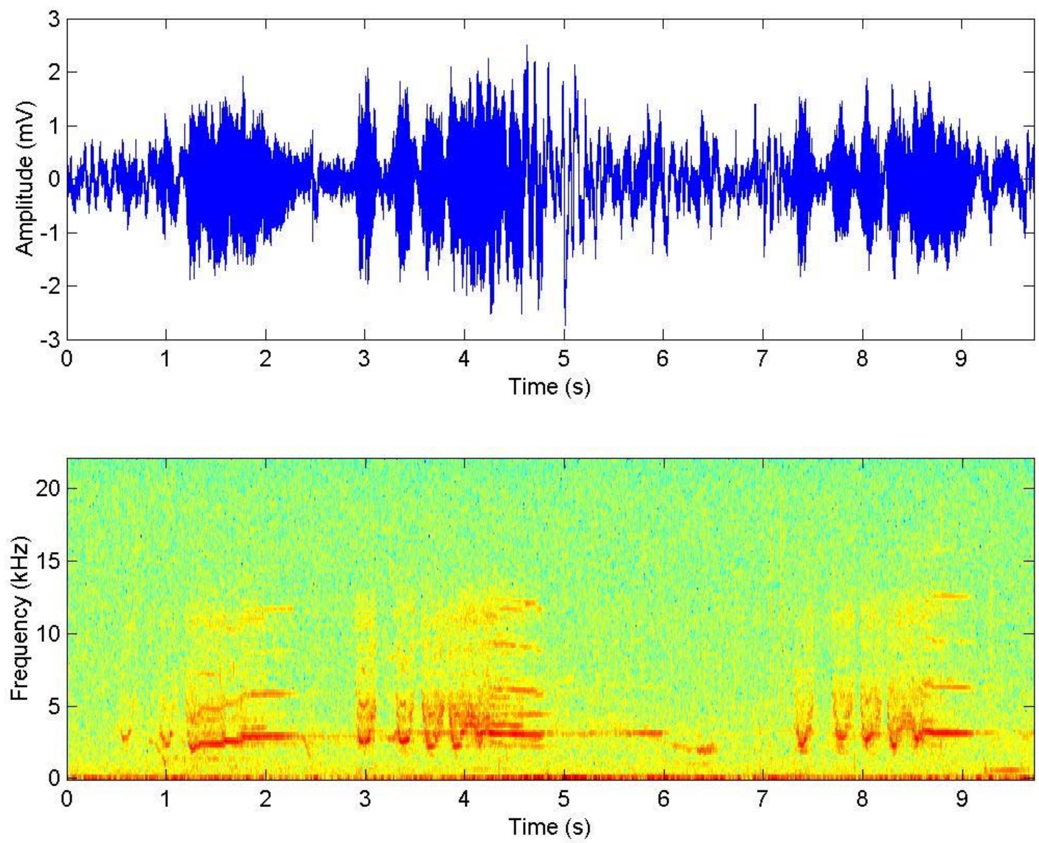

Figure 3: Time and frequency domain representations of whistles

2.1.3.3 Shipping Traffic and Anthropogenic Noise

Vessel noise is divided into two categories: "ship noise", which is observed when a vessel passes near the instrument, and "traffic noise", which is the cumulative noise due to distant ships (Wenz, 1962). Ship noise is intermittent and characterized by narrow-band components at frequencies below 1 kHz, coupled with cavitation noise caused by propellers, which can extend up to several kHz frequencies. Traffic noise depends on the concentration of ships and the transmission properties of the ocean in the region. In an area with low transmission losses, ships at great distances will contribute to the observed ambient noise, while in areas with large transmission losses, only ships in the vicinity of the measurement will contribute to the ambient noise.

Ship noise is clearly evident in the ambient noise spectrograms, appearing as short-duration (30 minutes or less) increases in acoustic energy between 100 Hz and 1 kHz, as shown in Figure 4. Occasionally, more distant ships are suspected to contribute to the higher noise levels observed below 50 Hz. Ships are marked on the spectrograms with the letter S. Ship noise measurements do not show significant energy below approximately 100 Hz. This characteristic is attributed to low frequency mode stripping due to propagation in relatively shallow waters.

Other possible sources of anthropogenic noise include aircraft, hovercraft, and industrial activities. A hovercraft observed passing near the deployed recording system during Deployment 1, is evident in the recordings as marked by the H on the spectrogram in Figure A-1.

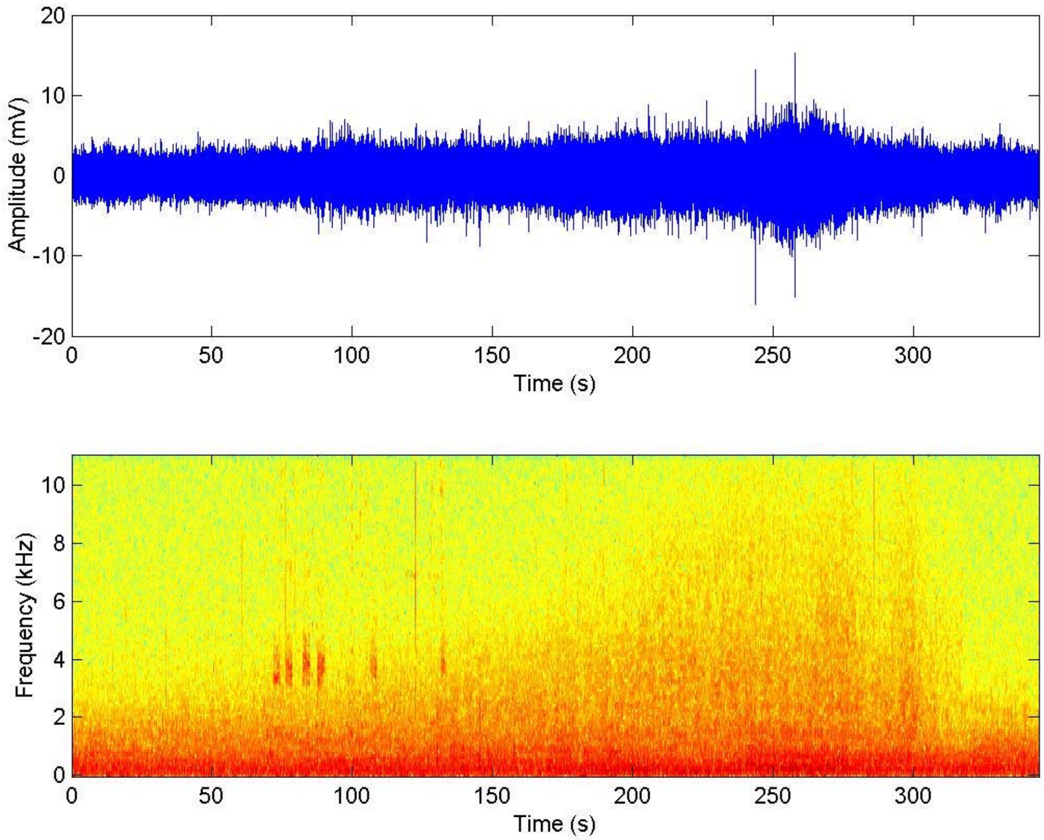

Figure 4: Time and frequency domain representations of a ship transit

2.1.3.4 Wind- and Wave-Generated Noise

The effect of wind and sea state is to uniformly raise the noise levels in the frequency range between 100 Hz and 10 kHz (Wenz, 1962). The increase in noise is due to the increase in surface agitation, which does not necessarily correlate directly with wind speed, but depends on other variables such as wind duration, fetch, and direction relative to local swell, currents, and topography. Surface waves may also generate pressure fluctuations which can affect a transducer or hydrophone; however, these fluctuations peak at a much lower frequency (0.1 Hz) than was investigated during this study (Wenz, 1962).

It is difficult to identify any particular feature in the data as wind- or wave-generated noise. The frequency range of ship noise directly overlaps with the expected range of wind noise, and the passage of ships often coincide with periods of higher (greater than 20 km/h) winds. Extended period of higher winds would be necessary to generate breaking waves which would result in the higher noise levels. The wind on September 16 and 17 was sustained around 20 km/h. These dates corresponded to the second half of Deployment 3 and all of Deployment 4. However, no consistent increase in noise between 100 Hz and 10 kHz was observed. With the exception noted above, sea states during the measurement program ranged between 0 and 3 corresponding to wind speeds of 0 to 10 knots.

2.1.3.5 Tide Cycle Flow Noise

There is no evidence in the literature that ambient noise levels depend on the tidal cycle. Previous work suggests that the source of observed increases in noise with tidal current velocity is, in fact, flow noise at the receiver (Willis and Dietz, 1961). Turbulence increases with velocity shear near a boundary such as the sea floor, and turbulent pressure fluctuations can directly affect measurements made by a hydrophone (Wenz, 1962). Therefore, turbulence caused by a combination of tidal current velocities and boundary effects can contribute to observed flow noise.

The results obtained from the deployments suggest that there is no consistent increase in ambient noise during any part of the tidal cycle. Occasionally, an increase in noise at frequencies below 50 Hz is seen during the time between high and low tides, but this increase is not observed in all the deployments. In particular, an increase in noise below 50 Hz is observed during the entire tidal cycle for Deployment 6, while there is very little noise below 50 Hz during most of Deployments 1 and 7. The other Deployments (2, 3, 4, and 5) show some signs of an increase in low-frequency noise in mid-tidal cycle; however, at least part of this noise is due to instrument motion, and the remainder is likely to be caused by flow noise at the hydrophone and turbulent pressure fluctuations.

2.1.4 Spatial Variability

Mean and standard deviation in the one-minute broadband ambient noise levels for each deployment (Table 1) were calculated by averaging the one-minute broadband noise levels over the quietest hour of each deployment, that is, when no ships or other obvious sources of noise were observed in the spectrograms. The calculated ambient noise levels are listed in Table 3 and shown on the map in Figure 5.

The ambient noise levels at the locations closest to the harbour (Deployments 1, 2, 3, and 5) range from 89-102 dB, while ambient noise levels at the locations farther from the harbour (Deployments 4, 6, and 7) are slightly higher, ranging from 101-109 dB.

Table 3: Average sound pressure levels and standard deviations (dB re 1 μPa) at each deployment location calculated over the entire deployment, and over the quietest hour of each deployment

Deployment number	SPL during quietest hour	
	Average (dB re 1 μPa)	Standard deviation (dB re 1 μPa)
1	89.6	1.8
2	96.5	4.2
3	93.7	4.3
4	101.6	2.2
5	101.5	4.5
6	108.7	5.8
7	104.0	3.5

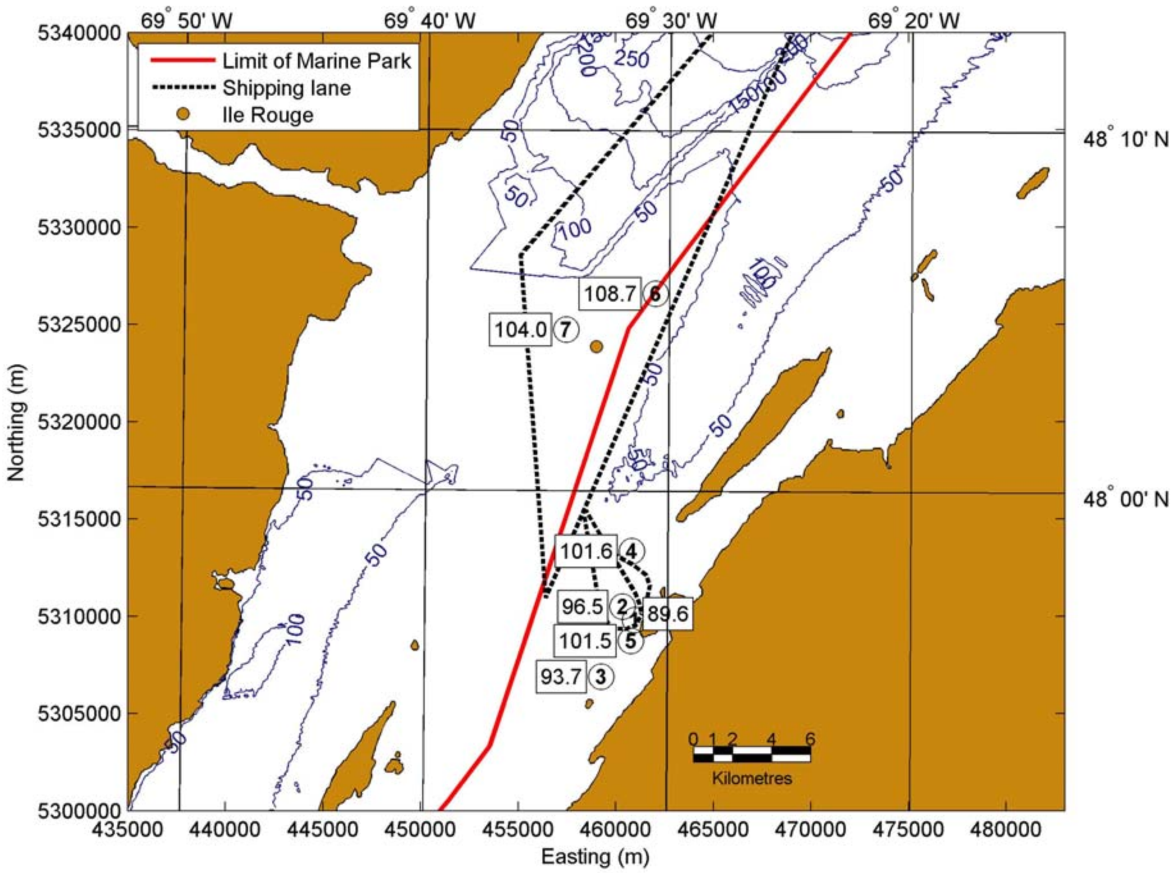

Figure 5: Mean broadband noise levels (dB re 1 µPa) during quietest hour for each pop-up deployment location

2.2 Transmission Loss

Transmission loss measurements were made during a number of deployments. The measurements made during Deployment 5 on September 19th comprised the most comprehensive data set providing transmission loss versus range on a line between Gros Cacouna and Île Verte. The results from Deployment 5 were compared to modeled transmission loss on a line between Gros Cacouna and Île Verte with the source positioned at the locations corresponding to the actual transmission locations as described below.

2.2.1 Data Collection

The pop-up recorder was deployed at 08:40:25 on September 19, 2005 at 47° 55' 50.640" N, 69° 31' 30.180" W. A series of five-second narrowband tones with frequencies at the centre of $^{1}/_{3}$-octave bands ranging from 200 Hz – 2 kHz was transmitted into the water using a Lubell Labs LL-9162 underwater acoustic transducer, and the received sound pressure level at the pop-up was recorded. The source transducer was positioned at 5 m depth and the tones were transmitted from six different locations over the course of the day, as detailed in Table 4.

Table 4: Locations of tone transmissions for transmission loss measurements

Tone transmission	Transmission start time	Latitude (degrees N)	Longitude (degrees W)	Range to pop-up (m)
1	10:24:20	47° 56' 17.280"	69° 31' 23.520"	834
2	16:18:00	47° 56' 07.860"	69° 31' 30.270"	532
3	16:32:53	47° 56' 23.910"	69° 31' 24.180"	1035
4	16:45:35	47° 56' 42.900"	69° 31' 16.080"	1640
5	16:59:04	47° 57' 09.060"	69° 31' 11.640"	2452
6	17:20:40	47° 57' 34.110"	69° 31' 01.770"	3248

CTD casts were made throughout the course of the field program at various locations, including the location of each tone transmission on September 19, as summarized in Table 5. The analysis of the CTD data is described below in section 3.4.2.

Table 5: Dates, tidal states, and locations of CTD casts made throughout the field program. Tidal state is indicated by U for water levels rising, L for low tide, and H for high tide

Cast	Date	Time	Tidal State	Station	Lat (N)	Lon (W)
1	17-Sep-2005	11:34:45	U	CB-4	47° 58' 09.960"	69° 31' 31.020"
2	17-Sep-2005	11:45:25	U	CB-3	47° 57' 07.380"	69° 31' 48.600"
3	17-Sep-2005	11:52:28	U	CB-1B	47° 56' 24.240"	69° 31' 23.220"
4	17-Sep-2005	12:01:37	U	CB-5	47° 54' 47.100"	69° 32' 47.160"
5	17-Sep-2005	12:13:15	U	west of CB-5	47° 55' 22.620"	69° 35' 27.600"
6	19-Sep-2005	08:45:01	L	CB-3	47° 55' 56.820"	69° 31' 27.960"
7	19-Sep-2005	09:13:24	L	west of CB-5	47° 55' 30.720"	69° 35' 10.800"
8	19-Sep-2005	10:29:35	L	CB-1B	47° 56' 17.640"	69° 31' 24.360"
9	19-Sep-2005	16:22:09	H	CB-3	47° 56' 07.380"	69° 31' 30.720"
10	19-Sep-2005	16:48:53	H	CB-1B	47° 56' 41.520"	69° 31' 20.160"
11	19-Sep-2005	17:02:53	H	CB-3	47° 56' 05.760"	69° 31' 14.580"
12	19-Sep-2005	17:14:35	H	CB-4	47° 57' 30.480"	69° 31' 04.020"
13	21-Sep-2005	16:21:44	H	IR DFO3	48° 05' 19.980"	69° 30' 32.340"
14	21-Sep-2005	16:45:18	H	IR Ouest	48° 04' 04.200"	69° 34' 30.840"

2.2.2 Data Processing

The sound transmissions consisted of 5-second tones at each frequency listed in, with source levels as shown in

Table 6. Acoustic source levels, referenced to 1m from the source, at each centre frequency are also presented in this table. The entire frequency cycle was repeated 5 times at each location. Root-mean-square (rms) received sound pressure level was calculated for each 5-second tone, and these levels were averaged over all five repetitions from a given location, resulting in the received sound pressure level as a function of frequency which was used for comparison with model results. The results of the transmission loss measurements and the comparison between measured and modelled transmission loss are addressed in section 3.5.

Table 6: Centre frequencies and source levels for tones used in transmission loss measurements.

Frequency (Hz)	Source level (dB re 1 μPa at 1 m)
200	131.4
251	136.3
316	141.5
398	146.2
501	151.8
631	157.4
794	163.4
1000	167.0
1259	163.8
1584	158.9
1995	158.4

2.3 Source Level Data - Peter R. Cresswell

On September 15, 2005, the opportunity arose to measure the source level of a large gravel carrier, the Peter R. Cresswell, as it was moored in Cacouna harbour. The source level measurements are representative of those expected from large ships while alongside.

The Peter R. Cresswell (shown in Figure 6) is 219.21 m in length, 23.16 m in breadth, and 11.88 m in depth, with a draft of 8.68 m, a gross tonnage of 19,853 t, a self-propelled power of 9,464 brake horsepower, and a maximum speed of 15 knots. The distance to midships during the source level measurements was 134 m.

Figure 6: Peter R. Cresswell alongside at the Cacouna Port

A Reson TC4043 hydrophone was deployed at 3.9 m depth, and its output was routed through an Ithaco amplifier to a Marantz PMD690 hard disk recorder. The total duration of the recording was approximately 35 minutes, but only the first 7 minutes were analyzed to determine the source level, since the distance to the ship was accurately measured, and there were no other vessels or activities to create additional noise. The source level spectrum was calculated by taking the Fast Fourier Transform (FFT) of the recorded data in 1-s increments, and then averaging the spectrum over the entire 7-minute recording. These spectral levels were used to calculate the $^{1}/_{3}$-octave band levels that are shown in Figure 7.

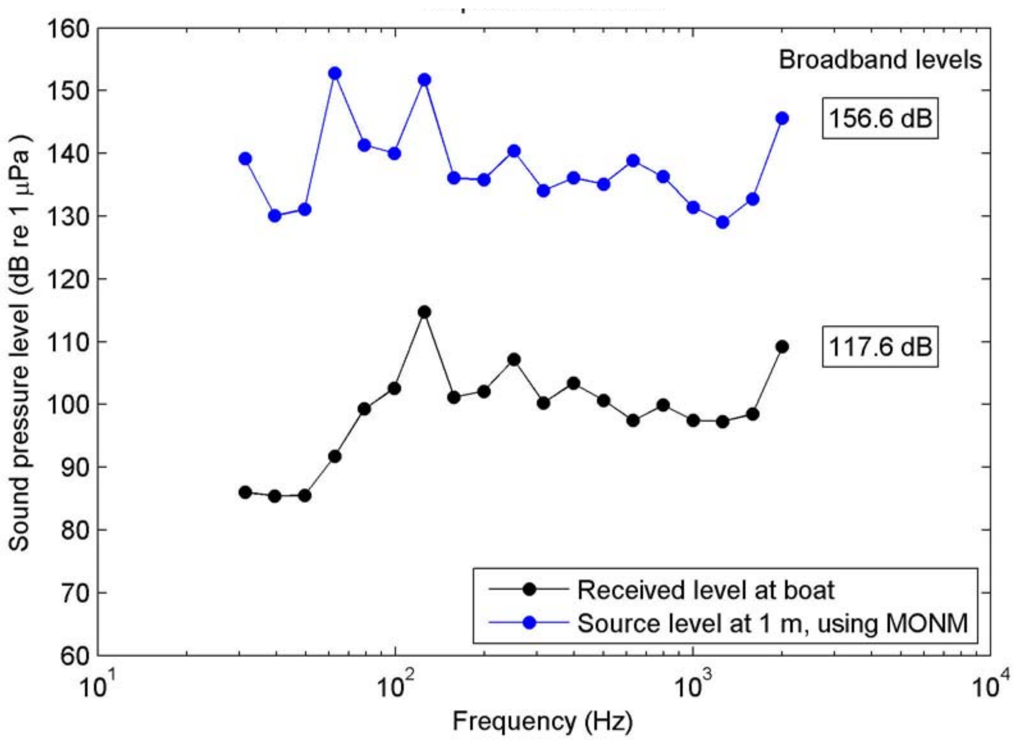

Figure 7: Received sound pressure levels (dB re 1 µPa) and calculated $^{1}/_{3}$-octave band source levels (dB re 1 µPa at 1 m) for the Peter R. Cresswell.

Source levels are referenced to the sound pressure levels measured at 1 m distance from the source, so it was necessary to correct the received level measurements to account for the distance between the source and the measurement location. Propagation in shallow water can be complicated, because the sound may reflect multiple times from the surface and the bottom as it propagates from the source to the receiver. Further, the propagation loss is expected to be frequency dependent. The MONM, incorporating an adapted parabolic equation model was used to compute the back propagation correction.

Data for this harbour (Transport Canada, 2005) indicates a minimum depth at the berths of 10.1 m. Taking this minimum depth into account, and recalling that the draft of the Peter R. Cresswell is 8.68 m, it is thus reasonable to assume 10.1 m for the depth of the water in and near the location where the Peter R. Cresswell was moored. The MONM model was run over a region of uniform depth of 10.1 m with environmental parameters as described in section 3.4, and a source-to-receiver separation of 134 m.

The measured $^{1}/_{3}$-octave band levels, along with the calculated source levels based on the MONM corrections are plotted in Figure 7 as a function of frequency. The broadband levels of 117.6 dB (raw), and 156.6 dB (source level at 1 m) are also shown on the plot.

3 Acoustic Modeling

Acoustic modelling was performed to map underwater noise fields expected to result from the construction and operational activities associated with the proposed Cacouna Energy LNG Terminal. Four scenarios were modeled using the Marine Operations Noise Model:

- the transit of a LNG Carrier accompanied by an escort tug,
- the docking of an LNG carrier assisted by 4 tugs,
- vibro-hammering including support vessels, and
- impact-hammering including support vessels.

Results from the modeling are presented in sections 3.6 and 3.7.

3.1 Basic Acoustic Concepts Related to Modeling

Sound waves are longitudinal pressure waves, that is, the displacement of the medium as the wave passes along the direction of propagation of the wave. The amplitude of an acoustic wave is measured in units of microPascals (μPa) and is often referred to as the sound pressure level (SPL). The relationship among frequency *f*, wavelength λ, and sound speed *c* in a medium is given by

$$c = f\lambda \tag{1}$$

The intensity of a wave is the power passing perpendicularly through a unit area. The energy or acoustic intensity transmitted by sound waves is rarely measured directly but is often discussed. It is important because it is a fundamental measure of propagating sound. It is defined as the acoustical power per unit area in the direction of propagation; the units are watts/m^2. The intensity, power, and energy of an acoustic wave are proportional to the average of the pressure squared (mean square pressure). Acoustics researchers often refer to intensities or powers, but they derive these from pressures squared. For an acoustic wave with root-mean-square (rms) pressure P_{rms}, travelling in a medium of density ρ_A with speed of sound *c*, the time-averaged intensity *I* is given by

$$I = \frac{P_{rms}^2}{\rho_A c} \tag{2}$$

The intensity of sound can range over many orders of magnitude, so a logarithmic scale has been developed in order to facilitate discussion of sound intensities. The intensity of a sound wave, in decibels, is given by

$$I_{dB} = 10\log\frac{I}{I_{ref}} \tag{3}$$

where I_{ref} is a reference intensity. From Equation (2), intensity is proportional to the square of the pressure, so that the intensity can also be written as

$$
\begin{aligned}
I_{dB} &= 10\log\frac{P^2}{P_{ref}^2} \\
&= 20\log\frac{P}{P_{ref}}
\end{aligned}
\tag{4}
$$

The choice of reference pressure P_{ref} has been the source of much confusion in acoustics. The current standard reference pressure for underwater acoustics is $P_{ref} = 1\ \mu$Pa. For clarity, the reference pressure used when quoting an intensity in decibels should *always* be specified along with the measurement. For example, one would write a sound pressure level as "160 dB re 1μPa", indicating 1 μPa as the reference pressure. It should be noted that the reference pressure for underwater sound level measurements differs from that used for in-air sound level measurements. The in-air reference pressure is 20 μPa, resulting in a difference of 20 log 20 = 26 dB between in-air and underwater acoustic intensities.

Quantifying sound propagation can be simplified by considering three components: the source level (SL), the received level (RL), and the transmission loss (TL). The source level is characteristic of the sound pressure level near the source, before the signal suffers any losses due to propagation. Source levels given in decibels must state the reference distance used in the measurement, since the sound pressure level is a function of distance from the source. The reference distance used for acoustic source levels is 1 m. Statements of source levels must refer to both the reference distance and the reference pressure, for example, "180 dB re 1μPa at 1 m".

The received level is the sound pressure level observed at any location. If the received level is stated in decibels, it must always include the reference pressure, for example, "160 dB re 1 μPa". The transmission loss is the ratio of the received level to the source level. When measuring source levels and received levels in decibels, the transmission loss is also measured in decibels and is the difference between source level and received level:

$$
TL_{dB} = SL_{dB} - RL_{dB} \tag{5}
$$

Note that the transmission loss is measured in dimensionless decibels, since it quantifies the ratio of the source pressure to the received pressure. Transmission loss is a complicated function of local bathymetry, sound-speed profile, range, source frequency, absorption, and scattering (Medwin and Clay, 1998). However, if it is possible to measure both the source and received sound pressure levels, Equation (5) may be used to calculate the transmission loss.

It is often necessary in underwater acoustics to know the distribution of frequency content in an acoustic signal. Octave or third-octave frequency bands are commonly used to characterize the frequency spectrum of a signal. An octave represents an increase or decrease by factor of two in frequency, while adjacent third-octave band centres are in the ratio $2^{1/3}$. Typical third-octave band centres are at 50, 63, 80, 100, 125, 160, 200, 250, 315, 400, and 500 Hz. The sound power (in dB re 1 μPa) in a given octave or third-octave band is calculated by first determining the power density spectrum – the distribution of acoustic power as a function of frequency – and then summing these levels for the frequencies within the band of interest. For octave bands, the frequency band for a centre frequency f_0 ranges from $f_0(2^{-1/2})$ to $f_0(2^{1/2})$; for third-octave bands, the frequency band for a centre frequency f_0 ranges from $f_0(2^{-1/6})$ to $f_0(2^{1/6})$. If the sound pressure level is summed over all frequencies present in a signal, the resulting power is called the broadband sound pressure level.

3.2 Methodology

Underwater noise maps were generated using JASCO's Marine Operations Noise Model (MONM). MONM incorporates a state-of-the-art range-dependent split-step parabolic equation acoustic model with shear wave computation capability. The algorithm has been benchmarked against test data sets provided in the open scientific literature and is compliant with recognized underwater acoustic modelling standards. This model has been used in past contracted work for precise estimation of noise produced by sub-sea construction noise, marine facilities operation and seismic exploration in locations that include the Gully oceanic region off Nova Scotia, the Beaufort Sea, Queen Charlotte Basin in British Columbia and Sakhalin Island in Eastern Russia.

3.2.1 Marine Operations Noise Model (MONM)

The core algorithm in MONM computes frequency-dependent sound transmission loss parameters along fans of radial tracks originating from each point in a specified set of source positions. Transmission loss indicates the degree to which sound levels decrease with range from the source locations. The modelling is performed in individual $^1/_3$-octave spectral bands covering frequencies from 10Hz to 2 kHz, which encompasses the overlap between the auditory frequency range of marine mammals and the spectral region in which sound propagates significantly beyond the immediate vicinity of the source.

The MONM software makes use of geo-referenced databases to automatically retrieve the bathymetry and acoustic environment parameters along each propagation traverse, and incorporates a proprietary tessellation algorithm that increases the angular density of modelling segments at greater ranges from a source to provide more computationally efficient coverage of the area of interest. The grid of transmission loss values produced by the model for each source location are used to attenuate the spectral acoustic output levels of the corresponding noise source to generate absolute received sound levels at each grid point; these are then summed across frequencies to provide broadband received levels. A further step of Cartesian re-sampling and summing of the received noise levels from all the sources in a modelling scenario yields the aggregate noise level for the entire operation on a regular grid from which contours can be drawn on a GIS map. The model can either generate contours at evenly spaced levels or draw boundaries representing biologically significant threshold levels.

The MONM has been extensively validated against field measurements in the course of complex undersea construction operations. Figure 8 provides an example of the accuracy of the model in predicting the aggregate noise levels over an area from four vessels performing a dredging and pipe-laying operation. The spectral source levels of the individual vessels, which had been measured independently and in different locations, were used as input to the MONM along with locally measured water column and bottom acoustic parameters. The actual received levels from a line of sonobuoys are in agreement with the model results to within about 2 dB.

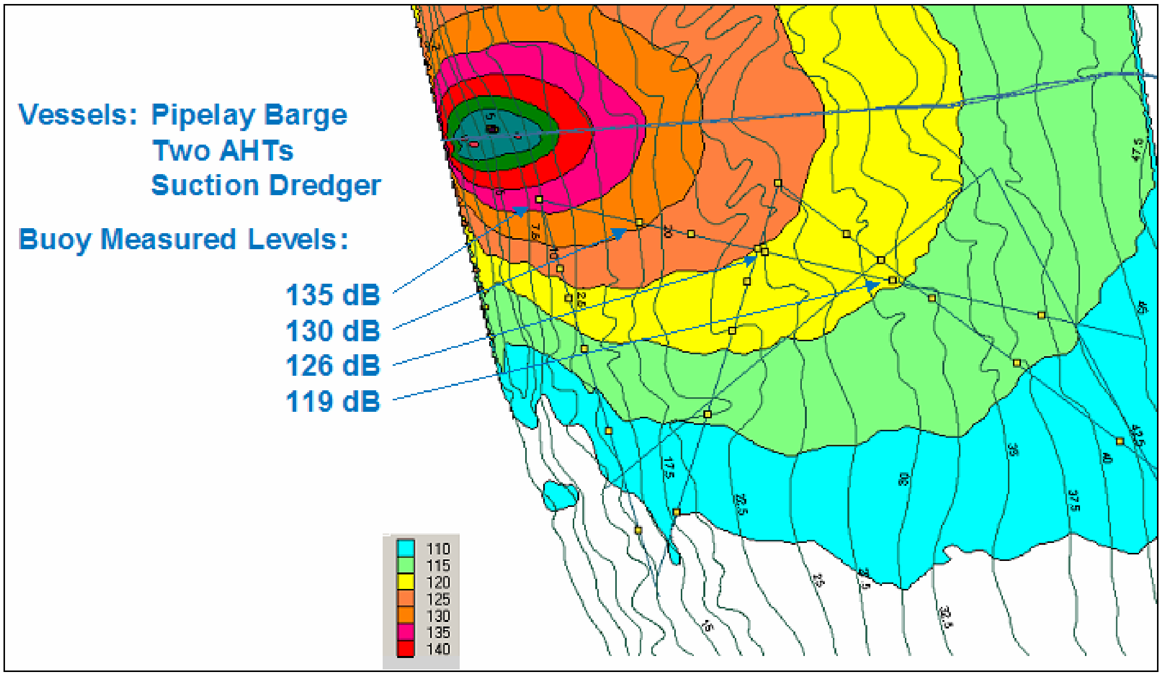

Figure 8: Example of predicted vs measured sound levels

3.3 Types of Noise Associated with Cacouna Energy LNG Terminal and the Relevant Acoustic Impact Criterion

Underwater sounds produced during the construction and operation of the Cacouna Energy LNG Terminal can be classified into two broad categories. Sounds of short duration that are produced intermittently or at regular intervals, such as sounds from pile driving, are classified as "pulsed." Sounds produced for extended periods, such as sounds from generators, are classified as "continuous." Sounds from moving sources, such as ships, can be continuous, but for an animal at a given location, these sounds are "transient" (i.e., increasing in level as the ship approaches and then diminishing as it moves away). Studies indicate that marine animals respond somewhat differently to the two categories of noise. Masking effects are expected to be less severe when sounds are pulsed or transient than when they are continuous.

The measurements of sounds for the purposes of potential impacts to marine organisms are currently reported as root mean square (rms) pressures. The size of the averaging window greatly affects the measured rms level by 2-12 dB (Madsen 2005). It has been suggested that peak-peak and energy flux density measures are more relevant for transient (pulsive) sounds since high peak pressures could impact animals, and energy flux density measures the energy flow per unit area received by the animal (Madsen 2005). Madsen (2005) showed that several sounds with the same peak-peak values can have very different rms levels and energy flux densities. Impact criteria for potential damage or disturbance to marine mammals are currently not known for peak-peak or energy flux density measures of sounds. Impact criteria of rms sound pressure levels have been estimated by the National Marine Fisheries Service (NMFS) in the United States. Therefore, in the absence of an accepted Canadian criterion, the NMFS rms sound pressure level impact criterion will be used for assessment of modeling results at the Cacouna Energy LNG Terminal for both pulsive and continuous sounds.

3.3.1 Continuous sounds

Continuous sounds occur for extended periods. Fixed-location continuous sounds are associated with underwater pumps, the use of generators and drilling operations. The use of a vibro-hammer for the construction of the cell assembly at the Cacouna Energy LNG Terminal will produce sounds that are of a continuous nature, although they will be intermittent and of short duration. The filling of cells with crushed rock and the addition of scour protection around the cells may also produce fixed-location continuous sound for a period of time. The main source of fixed-location continuous noise for the cell construction is expected to be from driving the spud piles and cell sheets into the river bottom using the vibro-hammer.

Transient continuous sounds are produced by moving sources such as ships. These sounds normally increase in level as they approach a location and then diminish as they move away. The transit of an LNG carrier would be considered a source of transient continuous noise.

Whales may be disturbed by continuous noises above a criterion level of 120 dB re 1 μPa (rms) according to current NMFS standards. Baleen whales have been shown to respond to drillship noises at or above 120 dB (Richardson et al. 1990). The same criterion levels are currently used for pinnipeds. Based on the literature reviewed in Richardson et al. (1995), it is apparent that most small and medium-sized toothed whales exposed to prolonged or repeated underwater sounds are unlikely to be displaced unless the overall received level is at least 140 dB re 1 μPa. The 120 dB re 1 μPa (rms) criterion has been adopted in the present analysis.

3.3.2 Pulsed sounds

Pulsive sounds are of short duration and occur intermittently or at regular intervals. Pile driving using an impact hammer and and seismic airgun blasts are examples of underwater noise that are characterized as pulsed sound. They produce brief noise pulses whose peak levels are much higher than those of most continuous or intermittent noises. The noise generated by the proposed Cacouna Energy LNG Terminal project will mostly be continuous sources. However, project may require the use of an impact hammer, as a contigrncy, to drive the sheets that surround the cells, the last few meters into clay. The use of the impact hammer will be available as a contingent measure only in the unlikely event that it is required for the final setting of the piles.

For pulsed sounds, a broadband received sound pressure level of 180 dB re 1 μPa (rms) or greater is to be used as an indication of potential concern about temporary and/or permanent hearing impairment (Level A Harassment) to cetaceans (Madsen 2005; NMFS 2003). Level A Harassment is defined as “any act of pursuit, torment, or annoyance which has the potential to injure a marine mammal or marine mammal stock in the wild” (NRC 2003). The criterion to reduce the potential for Level A Harassment to pinnipeds from pulsive sounds is exposure to received levels of 190 dB re 1 μPa (rms) or greater.

A broadband received sound pressure level of 160 dB re 1 μPa (rms) or greater is currently the best estimate available to indicate potential concern to cause disruption of behavioural patterns (Level B Harassment) to marine mammals. Level B Harassment is defined as “any act of pursuit, torment, or annoyance which has the potential to disturb a marine mammal or marine mammal stock in the wild by causing disruption of behavioural patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering but which does not have the potential to injure a marine mammal or marine mammal stock in the wild” (NRC 2003).

3.3.3 Intermittent Noise

Intermittent noise is noise that is discontinuous or widely variable in level, but not impulsive. The 120 dB re 1 μPa (rms) criterion selected for continuous noise will be used to evaluate impacts of intermittent underwater noise. However, it is felt that the potential for impacts on marine mammals is further reduced because of the discontinuous nature of the noise.

3.3.4 Frequency range

Beluga whale hearing range extends from approximately 40 Hz up to 150 kHz with the highest sensitivity between 5 to 100 kHz (Richardson et al. 1995). In addition, it should be noted that the impact criteria do not specify frequency bands but instead set a limit on acceptable *broadband* noise levels. It is therefore reasonable to consider the frequency range of the noise which might be generated by the Cacouna Energy LNG Terminal construction and operations in the context of the range of beluga whale hearing. No measured audiograms exist for any of the other whale species expected to be present in the St. Lawrence. Fin whales are expected to be able to hear sounds over the range 14 Hz to 1 kHz, although the bulk of their communication appears to take place around 20 Hz; no information on their hearing thresholds is available (Richardson, 1995).

The major sources of vessel noise are from propellers and propulsion or other machinery, which can produce significant noise at low frequencies but little noise at frequencies greater than 5 kHz, where wind and wave-generated noise dominates the spectrum of oceanic noise (Wenz, 1962). In addition, higher-frequency noise is strongly attenuated in seawater: for example, at 10 kHz, the absorption loss is 1.3 dB/km, and at 100 kHz, the absorption loss is 20 dB/km (Wenz, 1962). Shipping noise is dominant below 300 Hz and does not extend much beyond 1000 Hz (Wenz 1962).

Larger vessels produce lower frequency noises due to slower propellers, and medium to large vessels produce tones that are the loudest below 50 Hz (Richardson et al. 1995). Propeller cavitation and flow noise can extend to 100 kHz, but peak at 50-150 Hz (Ross 1976); again, the highest-frequency components would be strongly attenuated. Other machinery onboard can produce sounds up to a few kilohertz; however, these are not the dominant sources of noise on vessels. Smaller outboard engines can produce noise to many kHz, however this type of noise is not of concern for this project. Generally, construction noise is only a significant component of the noise spectrum at frequencies below 1 kHz. Occasionally, machinery can produce tones for which harmonics extend as high as 6 kHz (Richardson, 1995).

The MONM model is effective at characterizing transmission losses for frequencies in the range of 100 Hz to 2 kHz; at higher frequencies, a different type of model (for example, a ray tracing model) would be needed to accurately represent transmission loss. Since the primary sources of concern for the Cacouna Energy LNG Terminal are ship noise, construction noise, and other anthropogenic noises, which dominate the spectrum below 1-2 kHz but do not produce significant higher-frequency components, the MONM model allows for sufficient characterization of the possible effects of the Cacouna Energy LNG Terminal construction and operations on the marine mammal populations present in the area based on the impact criteria discussed above. In addition, it is important to recall that the ambient noise for frequencies above 1 kHz stems largely from waves, wind, and heavy precipitation, and not from human activity.

In summary, although beluga whale hearing extends to frequencies as high as 100 kHz, the construction and operation of the Cacouna Energy LNG Terminal is only expected to generate significant noise at frequencies generally less than 1 kHz. Therefore, the MONM model will allow the accurate calculation of broadband sound pressure levels required for evaluation of the impact criteria.

3.4 Geoacoustic and Oceanographic Environment

Ocean environment data for the area is required to model sound propagation. Necessary parameters include geoacoustic profiles of the seabed over the region of study, seasonal sound velocity profiles, and bathymetry. The geoacoustic properties used in the modelling are summarized in Table 7 and explained in the following sections.

Table 7: Summary of environmental properties used in the propagation modelling

Geoacoustic Properties		
	Layer 1 (silty sand)	**Layer 2 (limestone bedrock)**
Sound speed:	1646 m/s	3000 m/s
Spound speed gradient:	1.3 m/s /m	0 m/s /m
Denstiy:	1.8 g/cm^3	2.4 g/cm^3
Attenutation:	1.56 dB/λ	0.10 dB/λ
	Shear Waves	
Velocity:	350 m/s	
Attenuation:	4.6 dB/λ	
Speed of sound in water	***Depth (m)***	***c (m/s)***
Summer:	1.8	1475.0
	13.5	1460.8
	35.8	1461.1
	38.4	1455.0
Fall:	1.6	1467.6
	13.3	1464.9
	16.0	1462.9
	25.0	1462.9

3.4.1 Geoacoustic properties

The river bed sediments in the immediate vicinity of the port of Gros-Cacouna are a mixture of clay, silt, sand, and gravel. The proportions of the grain sizes can vary, but average values were 13% clays, 38% silts, 48% sands, and 2% gravels (Golder Associates, 2005). This mixture corresponds most closely to "silty sand" (Hamilton, 1980), which is 57.6% sand, 28.9% silt, and 13.5% clay; therefore, the density, porosity, and sound velocity for silty sand as found in Hamilton (1980) were used as model inputs for the sea bed. Core samples indicate that at least the first 50 m consists of mixed sediments (Sandwell Engineering a, 2005). Therefore, the model was set up assuming a 50-m layer of silty sand sediment, overlying bedrock, with values taken from Hamilton (1980) for silty sand and Jensen (2000) for the bedrock.

3.4.2 Sound Velocity

Sound velocity was calculated (Mackenzie 1981) from Conductivity, Temperature and Depth (CTD) casts taken in the area during the time of transmission loss experiments. During the course of the field program, 14 CTD casts were taken at various positions near the proposed port location. The sound speed profiles calculated from the CTD datasets were examined and several were excluded for reasons including data anamolies, location not determined to be representative of the larger modelling region, or shallow water depth near sample site. The result was four sound speed profiles shown in Figure 9 (a), which were averaged to generate the profile shown in Figure 9(b). A representative sound speed profile, based on the average sound speed profile, was used as the input to MONM to model the transmission loss for scenarios expected to occur during the fall.

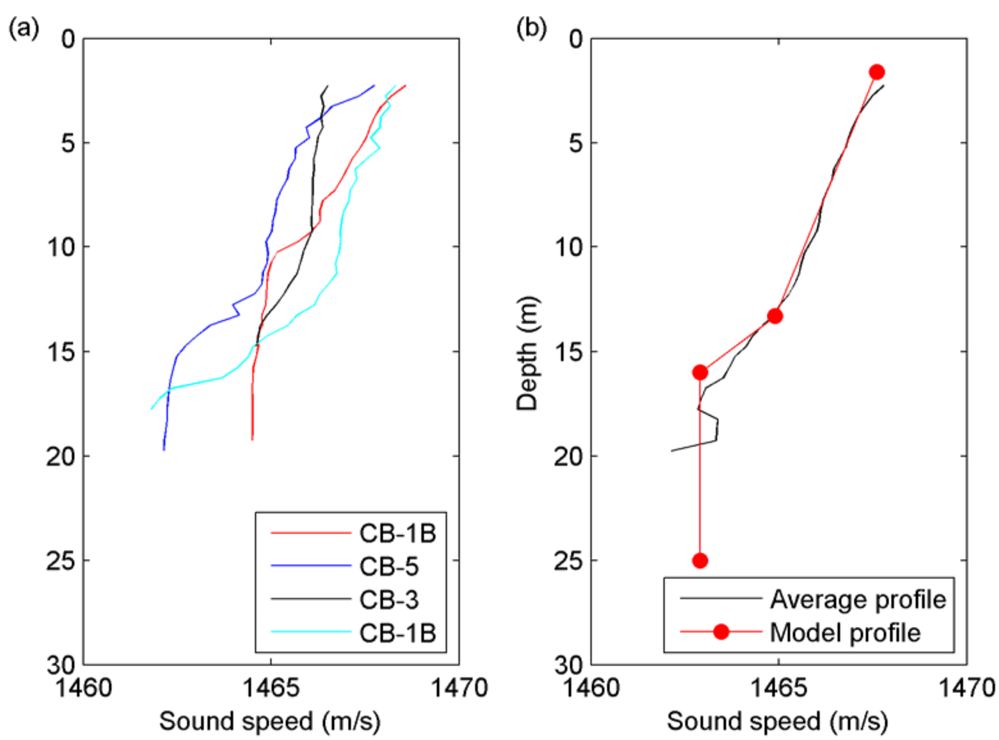

**Figure 9: (a) Sound speed versus depth from four CTD casts,
(b) Average of the sound speed profiles in (a), and approximate profile used as model input.**

Construction is expected to take place in the late spring, summer, and early fall. Summer was selected as the representative season for the construction scenario modelling. A sound speed profile for the summer months was required as input to the model. Quality controlled CTD profiles are available from the Marine Environmental Data Service (MEDS) at Fisheries and Oceans Canada. However, there was only a single profile available for the region, at 47° 59' 53.880" N, 69° 33' 49.721" W, taken on July 19, 2005. The sound speed profile calculated from this single MEDS dataset is shown in Figure 10, along with the points chosen to represent the shape of the summer sound speed profile in the model.

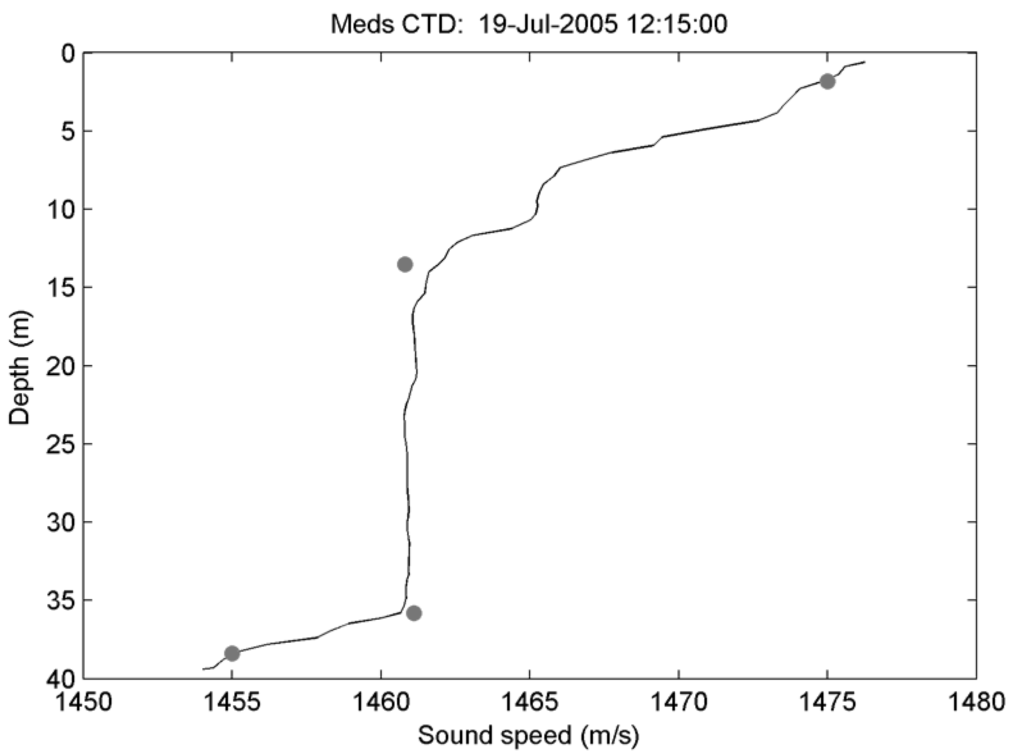

Figure 10: Sound speed vs. depth calculated from the MEDS CTD data. The gray dots are the data points used to characterize sound speed in the MONM during the summer

3.4.3 Bathymetry

Two bathymetric datasets were obtained from Nautical Data, Inc., which were combined to cover the region between approximately 47° 44' 11" N and 48° 14' 35" N and 69° 13' 51" W and 69° 58' 28" W. The datasets, originally with a horizontal resolution of between 60-90 m, were linearly interpolated on a regular grid with 50 m resolution for input to the MONM. Bathmetry contours are plotted in blue in 50 m contours on the underwater noise maps.

3.5 Comparison with Transmission Loss Measurements

A comparison of measured and modelled transmission loss was used to validate the choice of geophysical parameters used in the model. Sound speed profiles were directly measured during the transmission loss measurements. However, the geoacoustic properties had been inferred from publicly-available data for the region.

The MONM model was configured with a receiver at the location of the pop-up recorder, and sources at the locations of the tone transmissions. The frequency dependent transmitted source level shown in Figure 11 was measured by JASCO Research using a hydrophone mounted near the transmitter. Figure C - 1 through Figure C - 6 show the modelled and measured transmission loss in third-octave bands for each transmission location.

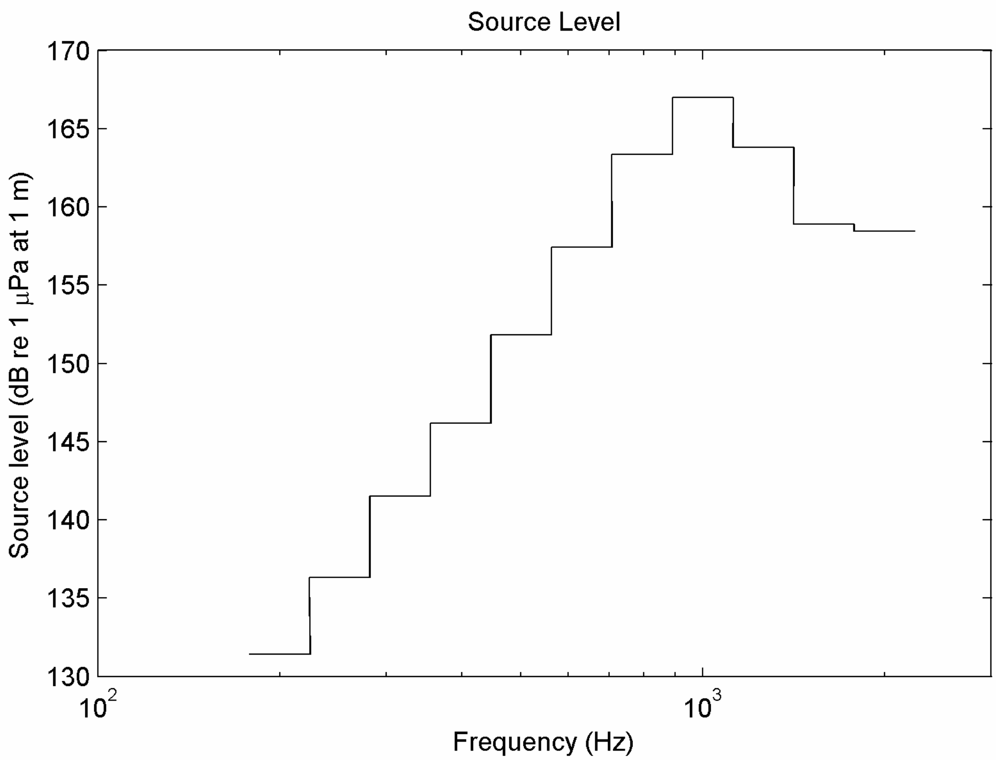

Figure 11: Source level as a function of frequency for the transducer used in TL experiments

Agreement between third-octave measured and modelled transmission loss is generally good, with typical differences between 2-5 dB, and few outliers. Measured and modelled broadband received levels are plotted in Figure C - 7 as a function of range. The measured and modelled broadband received level results are in excellent agreement, with a maximum difference of 3.5 dB, and a mean difference of 0.9 dB, suggesting that the model can accurately predict received sound pressure levels in this region when configured using the geoacoustic parameters specified in Section 3.4.1.

3.6 Model Results – Marine Transportation Scenarios

Two marine transportation scenarios were modeled: an LNG carrier transiting between Ile Rouge and the port, and an LNG carrier during a docking operation at the port. The sound pressure levels were modelled over the region 47° 44' 11" N and 48° 14' 35" N and 69° 13' 51" W and 69° 58' 28" W.

3.6.1 LNG Transit Scenario

The LNG transit scenario was modelled using sound speed data for the late summer/early fall, although transits will occur year round. The carrier was modelled in transit approximately halfway between Ile Rouge and the mainland (48° 02' 02.145" W, 69° 30' 35.000" N), corresponding to the planned shipping route for the LNG carrier. The planned operational procedures call for a tug escort, which was included as an additional noise source in the modeled scenario.

Measurements of underwater noise generated by LNG carriers are not available. However, some work has been done to characterize underwater noise from large tankers. Source levels used in the modeling are calculated based on empirical formulas.

Large commercial vessels and supertankers have powerful engines and large, slow-turning propellers. These vessels produce high sound levels, mainly at low frequencies. At these frequencies the noise is dominated by propeller cavitation noise combined with dominant tones arising from the propeller blade rate. An empirical expression (Junger, 1987) for the source spectrum level (1 Hz bandwidth) in the frequency range between 100 Hz and 10 kHz is

$$\mathrm{SL} = 163 + 10\log_{10}\frac{BD^4N^3}{f^2}\,\mathrm{dB\ re\ 1\ \mu Pa} \qquad (6)$$

where B = number of blades, D = propeller diameter in metres, N = propeller revolutions/s, and f = frequency in Hz. For ducted propellers, the constant is some 7 dB larger.

The LNG carrier $^1/_3$-octave band source levels were calculated using Equation (6). The tug's $^1/_3$-octave band spectrum levels are from measurements made by Jasco Research on the tug Katun. The $^1/_3$-octave band source levels for the two vessels are tabulated in Table 8.

Table 8: Broadband source levels, source depths and $^{1}/_{3}$-octave band source levels used in the LNG Transit Scenario

	LNG carrier Half speed – 45 rpm (calculated)	Katun (tug) (measured)
	Broadband source level (dB re 1 μPa at 1m)	
	174.6	184.4
	Source depth (m)	
	8.0	3.2
Centre frequency (Hz)	**Source level (dB re 1μPa at 1m)**	
10	163.6	126.4
12.5	163.6	122.4
16	163.6	121.2
20	163.6	127.0
25	163.6	163.7
31.5	163.6	146.8
40	163.6	125.1
50	163.6	138.0
63	163.6	109.7
80	163.6	130.2
100	163.6	121.7
125	161.7	110.5
160	159.5	119.4
200	157.6	131.0
250	155.7	135.7
315	153.7	137.8
400	151.6	140.3
500	149.6	150.4
630	147.6	150.4
800	145.6	142.9
1000	143.6	139.2
1250	141.7	144.4
1600	139.5	138.2
2000	137.6	139.4

Figure D - 1 is a contour plot of the received sound pressure level in the region near the Cacouna Energy LNG Terminal for the LNG carrier transit scenario. The area inside each contour level (including regions experiencing sound pressure level greater than or equal to the specified level) and mean distance to each contour are given in Table 9.

Ship noise is classified as continuous sound, so the 120-dB contour is the relevant impact criterion. The sound level drops below 120 dB for ranges greater than 1.8 km from the ship, and the area in which the sound levels exceed 120 dB is 10 km^2.

Table 9: LNG transit scenario results summary.

Contour level (dB)	Area inside (km^2)	Average range (m)
110	46	3900
120	**10**	**1800**
130	2	700

3.6.2 LNG Docking Scenario

The LNG docking scenario was modelled in the fall, using the measured fall sound speed profile. The LNG carrier was modelled at the location (47° 56' 27.332" W, 69° 31' 10.367" N), accompanied by four tugs (one at each corner of the docking area). In the ice season, there would be 4 tugs, one doing ice management and the other three providing docking assistance. In the non-ice season (spring, summer and fall), three tugs providing docking assistance would likely be required with one standing by for emergency only. Calculated source levels used in the LNG transit scenario were used as LNG carrier source levels, and Katun source levels were used as the tug source levels as tabulated in Table 8.

Figure D - 2 is a contour plot of the received sound pressure level in the region near the Cacouna Energy LNG Terminal for the LNG carrier docking scenario. The area inside each contour level (including regions experiencing sound pressure level greater than or equal to the specified level) and mean distance to each contour are given in Table 10.

Ship noise is classified as continuous sound, so the 120-dB contour is the relevant impact criterion. The sound level drops below 120 dB for ranges greater than 0.7 km from the ship, and the area in which the sound levels exceed 120 dB is 2 km^2.

Table 10: LNG docking scenario results summary

Contour level (dB)	Area inside (km^2)	Average range (m)
110	5	1300
120	**2**	**700**

3.7 Model Results – Construction Scenarios

Two marine construction scenarios were modeled: vibro-hammering and impact hammering of piles. Both scenarios were modelled during the summer season. In addition to the hammering, two barges and one tug were included in both scenarios.

Vibro-hammering $^1/_3$-octave band source levels were calculated from measurements made by Subacoustech, Ltd. on operations in the Arun River, England (Nedwell and Edwards, 2002). The soil conditions at Gros-Cacouna are very soft and therefore the source levels used may be louder and therefore overly conservative estimates of those which may occur during actual construction. Impact-hammering $^1/_3$-octave band source levels were taken from measurements made on the Scotian Shelf by Greeneridge Sciences, Inc (Greene, 1999). The barge source levels are from measurements made by JASCO on the Semac 1, a lay barge. The tug source levels used were from the Katun. All of the source levels used in modeling the scenarios are summarized in Table 11. The sources were all placed at the port location (47° 56' 30.883" N, 69° 31' 05.920" W).

Table 11: Broadband source levels, source depths 1/3-octave band source levels used in the Construction Scenarios

	Katun (tug)	Semac (lay barge)	Vibro-hammer	Impact hammer (contigency)
	Broadband source level (dB re 1 μPa at 1m)			
	184.4	179.3	164.3	216.0
	Source depth (m)			
	3.2	9.6	5.0	5.0
Centre frequency (Hz)	Source level (dB re 1 μPa at 1m)			
10	126.4	159.7	126.4	--
12.5	122.4	151.8	122.4	202.0
16	121.2	157.8	121.2	192.0
20	127.0	158.1	127.0	187.0
25	163.7	161.5	163.7	184.0
31.5	146.8	163.2	146.8	186.0
40	125.1	166.0	125.1	188.0
50	138.0	165.8	138.0	184.0
63	109.7	164.6	109.7	188.0
80	130.2	166.3	130.2	198.0
100	121.7	163.4	121.7	200.0
125	110.5	163.0	110.5	204.0
160	119.4	163.4	119.4	208.0
200	131.0	163.6	131.0	209.5
250	135.7	176.9	135.7	209.0
315	137.8	162.2	137.8	204.0
400	140.3	160.8	140.3	204.5
500	150.4	161.3	150.4	205.0
630	150.4	160.5	150.4	198.0
800	142.9	159.5	142.9	195.0
1000	139.2	155.8	139.2	194.0
1250	144.4	150.5	144.4	195.0
1600	138.2	147.8	138.2	194.0
2000	139.4	145.6	139.4	192.0

3.7.1 Vibro-Hammering Scenario

Figure D - 3 is a contour plot of the received sound pressure level in the region near the Cacouna Energy LNG Terminal for the vibro-hammer scenario. The area inside each contour level (including regions experiencing sound pressure level greater than or equal to the specified level) and mean distance to each contour are given in Table 12.

The vibro-hammer noise is classified as continuous sound, so the 120-dB contour is the relevant impact criterion. The sound level drops below 120 dB for ranges greater than 1.6 km from the hammer, and the area in which the sound levels exceed 120 dB is 7 km^2.

Table 12 Vibro-hammering scenario results summary.

Contour level (dB)	Area inside (km^2)	Average range (m)
110	29	3400
120	**7**	**1600**
130	2	700

3.7.2 Impact Hammering Scenario

Figure D - 4 is a contour plot of the received sound pressure level in the region near the Cacouna Energy LNG Terminal for the impact hammering scenario. The area inside each contour level (including regions experiencing sound pressure level greater than or equal to the specified level) and mean distance to each contour are given in Table 13.

The impact hammering noise is classified as pulsive sound, so the 160 and 180-dB contours show the levels corresponding to the relevant impact criterion for marine mammals. The sound level drops below 180 dB for ranges greater than 130 m from the source and the area in which the sound levels exceed 180 dB is .05 km^2.

Table 13 Impact hammering scenario results summary

Contour level (dB)	Area inside (km^2)	Average range (m)
110	324	13500
120	225	10800
130	116	7800
140	40	4000
150	14	2300
160	**2.9**	**1100**
170	0.55	430
180	**0.050**	**130**
190	**0.006**	**46**

4 Summary

An underwater acoustic measurement program and site specific sound propagation modeling were conducted to estimate potential acoustic impacts on marine mammals from the construction and subsequent operation of Cacouna Energy's proposed LNG Terminal.

Mean broadband ambient noise levels were determined from the measured data during low noise periods, that is, times during which flow noise was at a minimum and there were no identifiable sources of man made noise such as nearby shipping. Mean broadband ambient noise levels ranged between:

- 89.6 and 101.6 dB re 1µPa in the region surrounding Gros Cacouna and
- 104.0 and 108.7 dB re 1µPa near Île Rouge.

Acoustic modeling using site specific data and validated by measurements of transmission loss was performed to estimate the potential underwater noise impacts from four scenarios:

- LNG Transit
- LNG Docking
- Vibro-hammering, and
- Impact hammering.

The average ranges to the 120 dB criterion used to asses impacts from vibro-hammering, LNG transit and LNG docking scenarios were 1600 m, 1800 m and 700 m respectively. The 190, 180 and 160 dB criteria were applied to evaluate potential impacts from impact hammering of piles, an activity considered as a contingency requirement only. The average ranges to the three criteria were 46 m, 130 m and 1100 m respectively.

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Appendix A

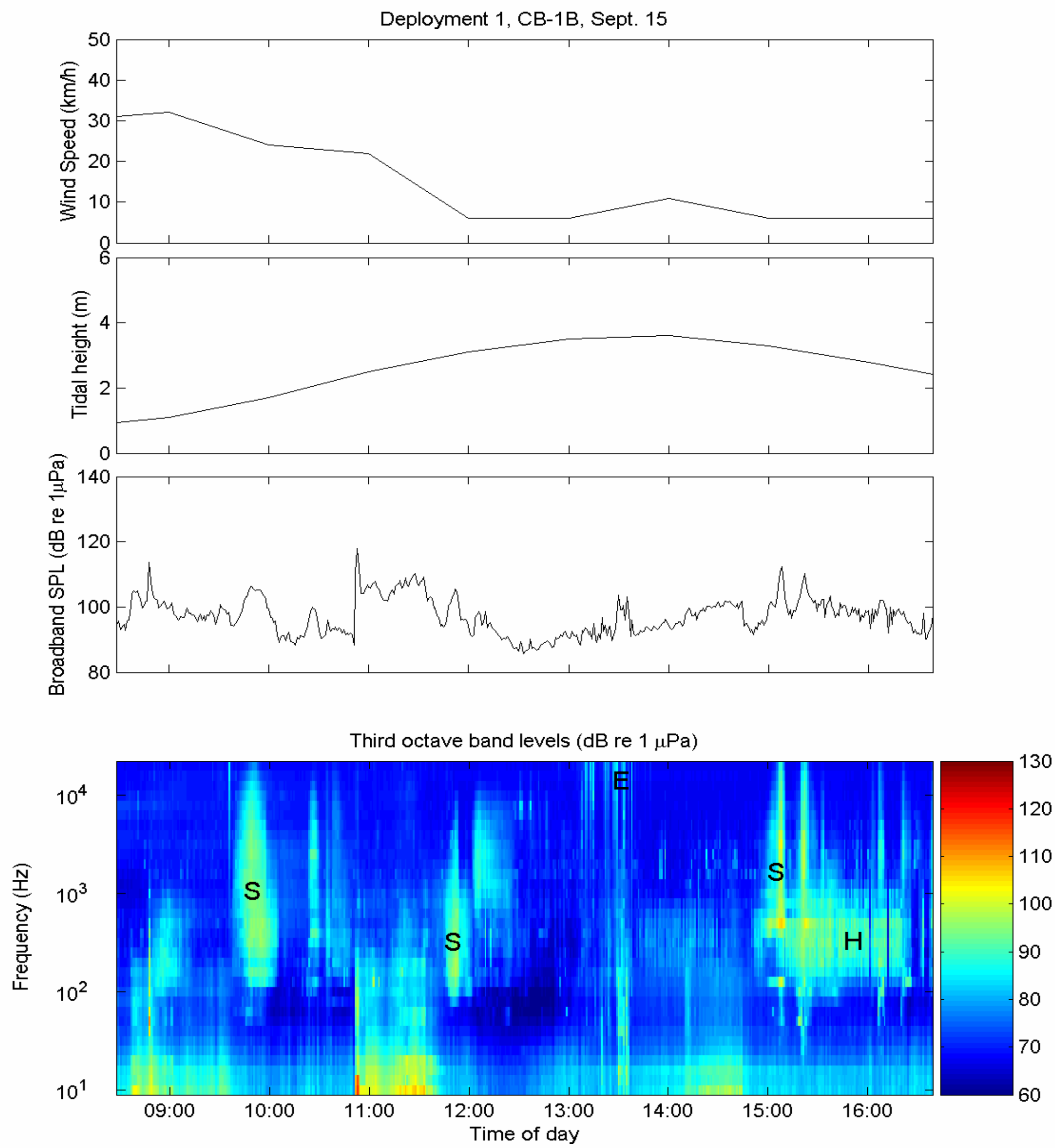

Figure A- 1: Deployment 1, CB-1B, September 15, 2005

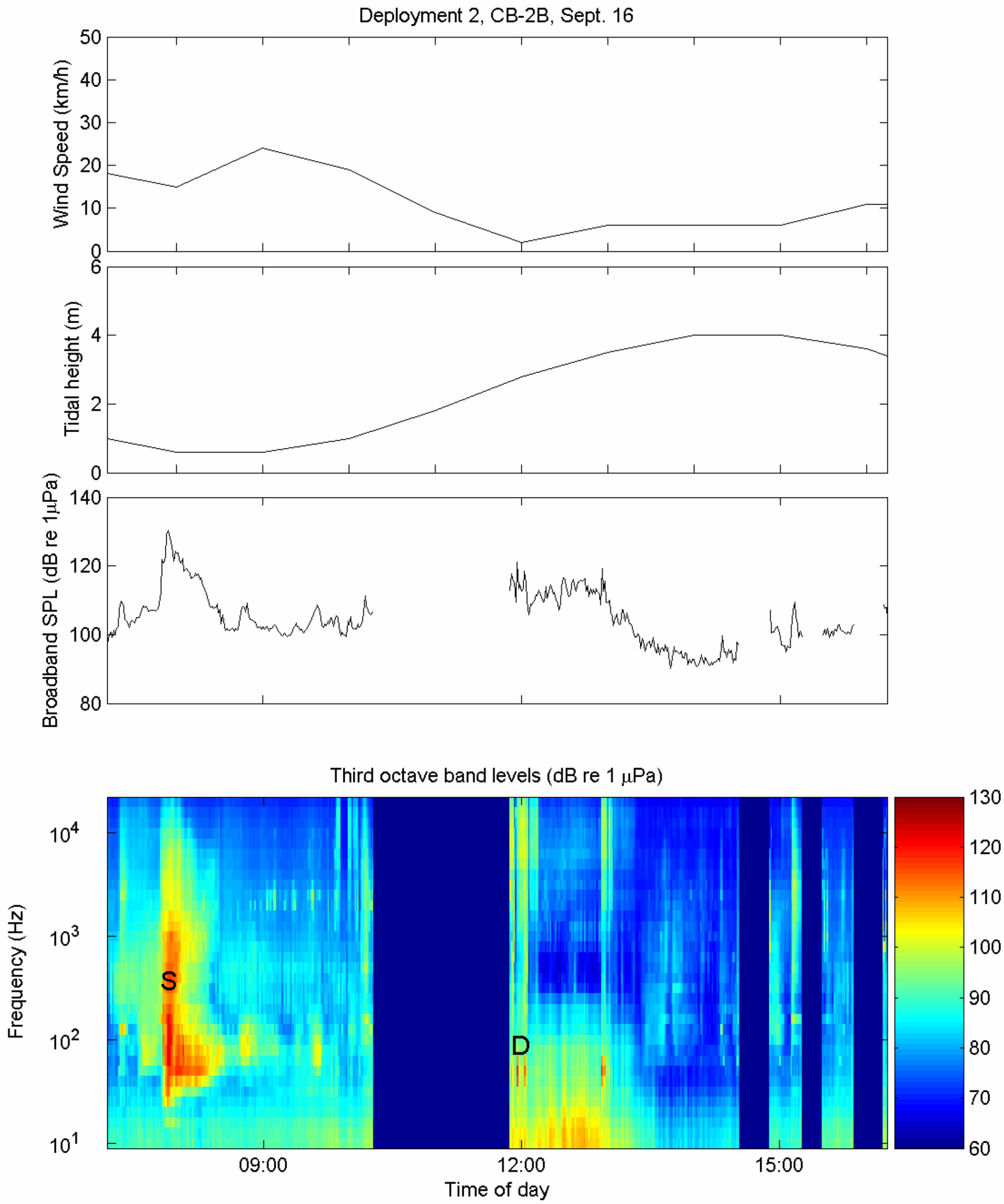

Figure A- 2: Deployment 2, CB-2B, September 16, 2005

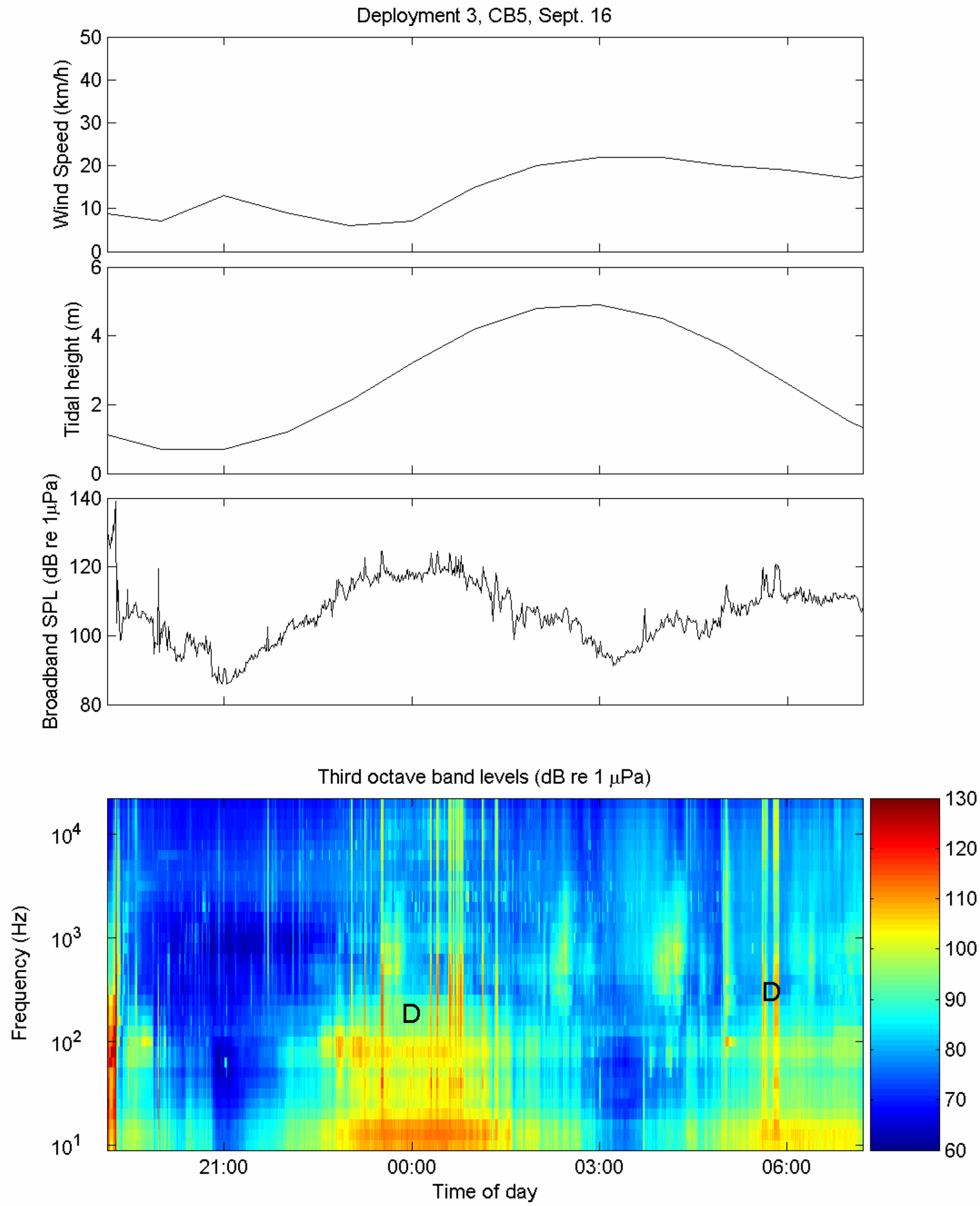

Figure A- 3: Deployment 3, CB5, September 16, 2005

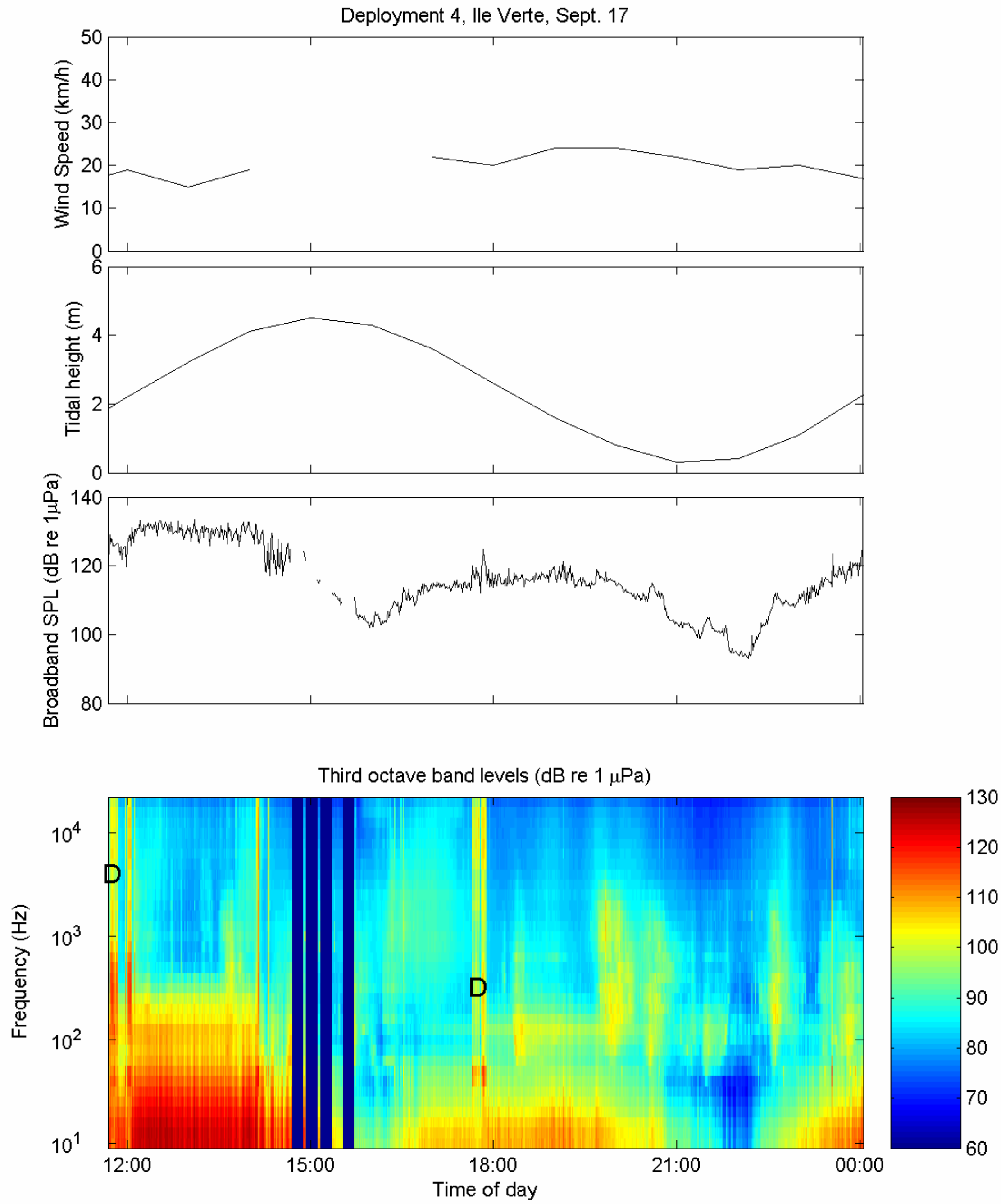

Figure A- 4: Deployment 4, Île Verte, September 17, 2005

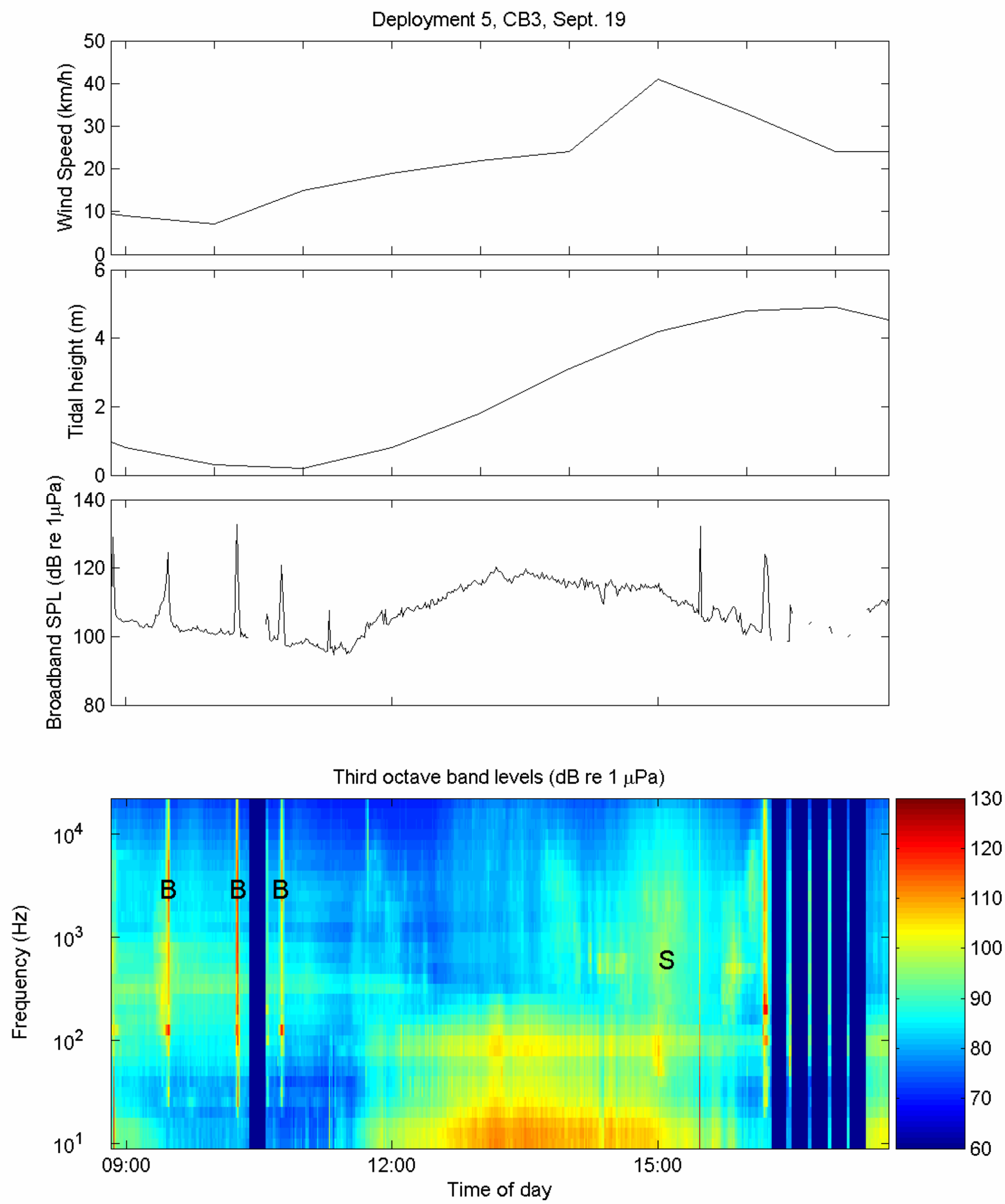

Figure A- 5: Deployment 5, CB3, September 19, 2005

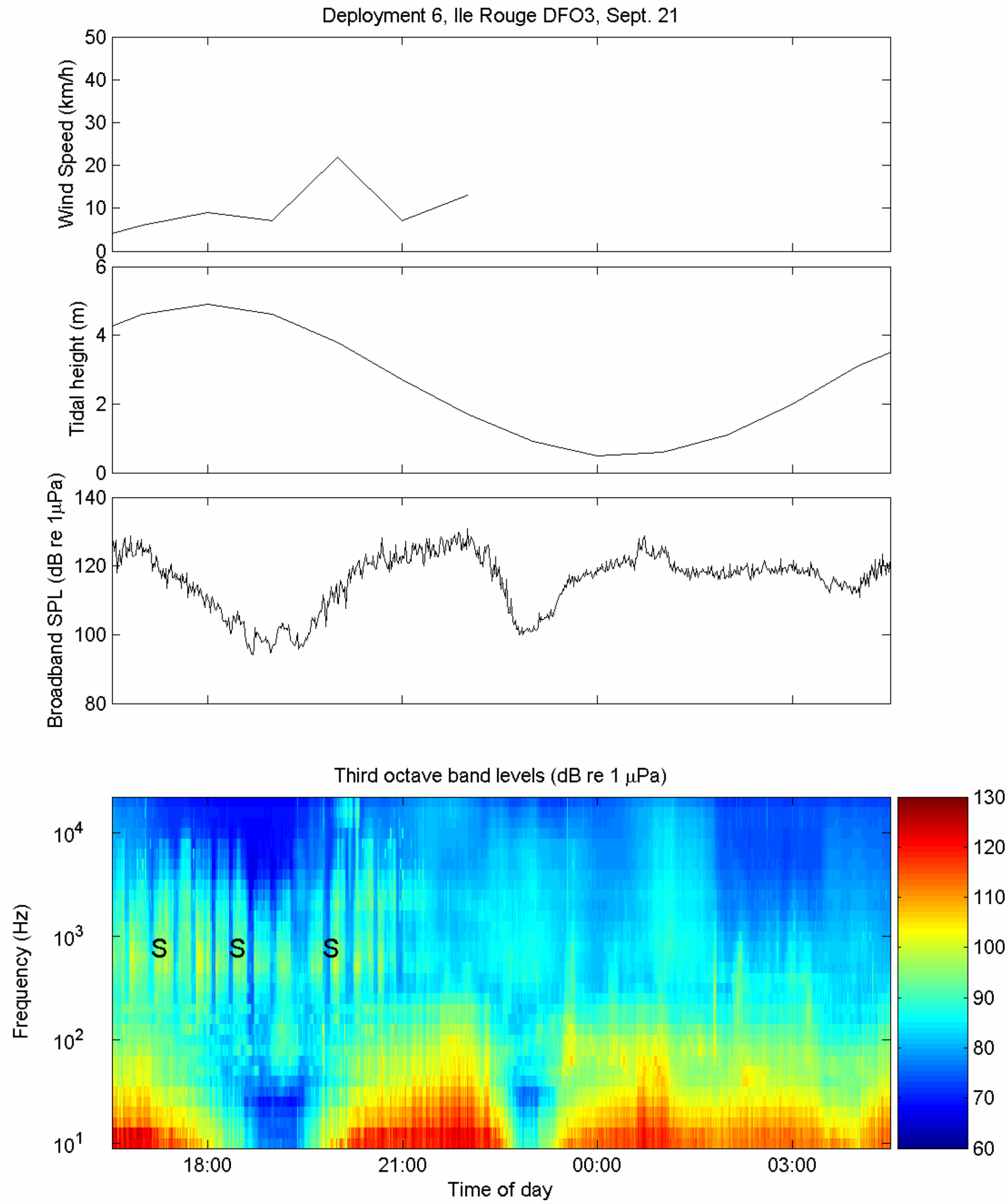

Figure A- 6: Deployment 6, DFO3 - Île Rouge, September 21, 2005

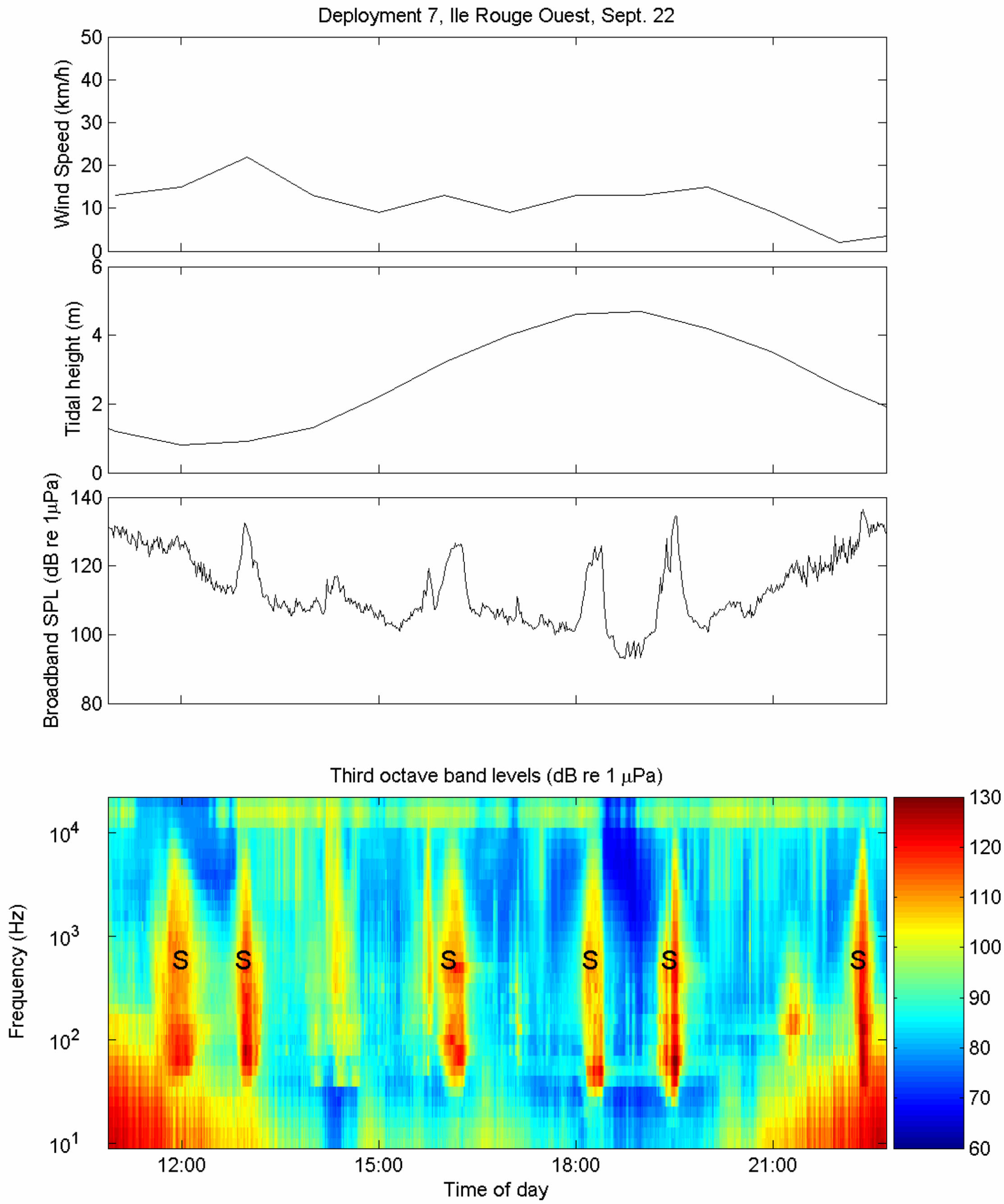

Figure A- 7: Deployment 7, DFO3 - Île Rouge West, September 22, 2005

Appendix B

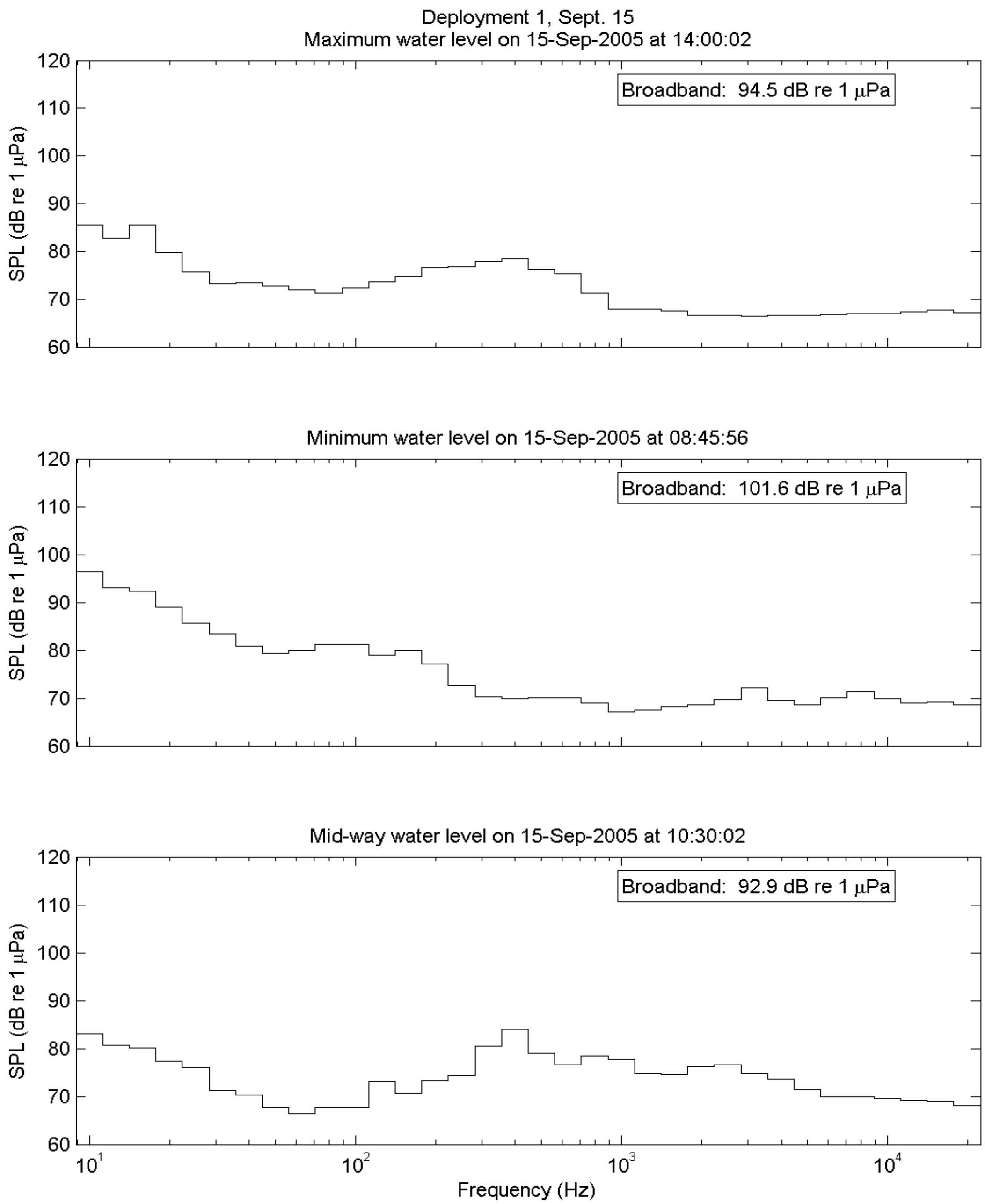

Figure B - 1: Deployment 1, CB-1B, September 15, 2005

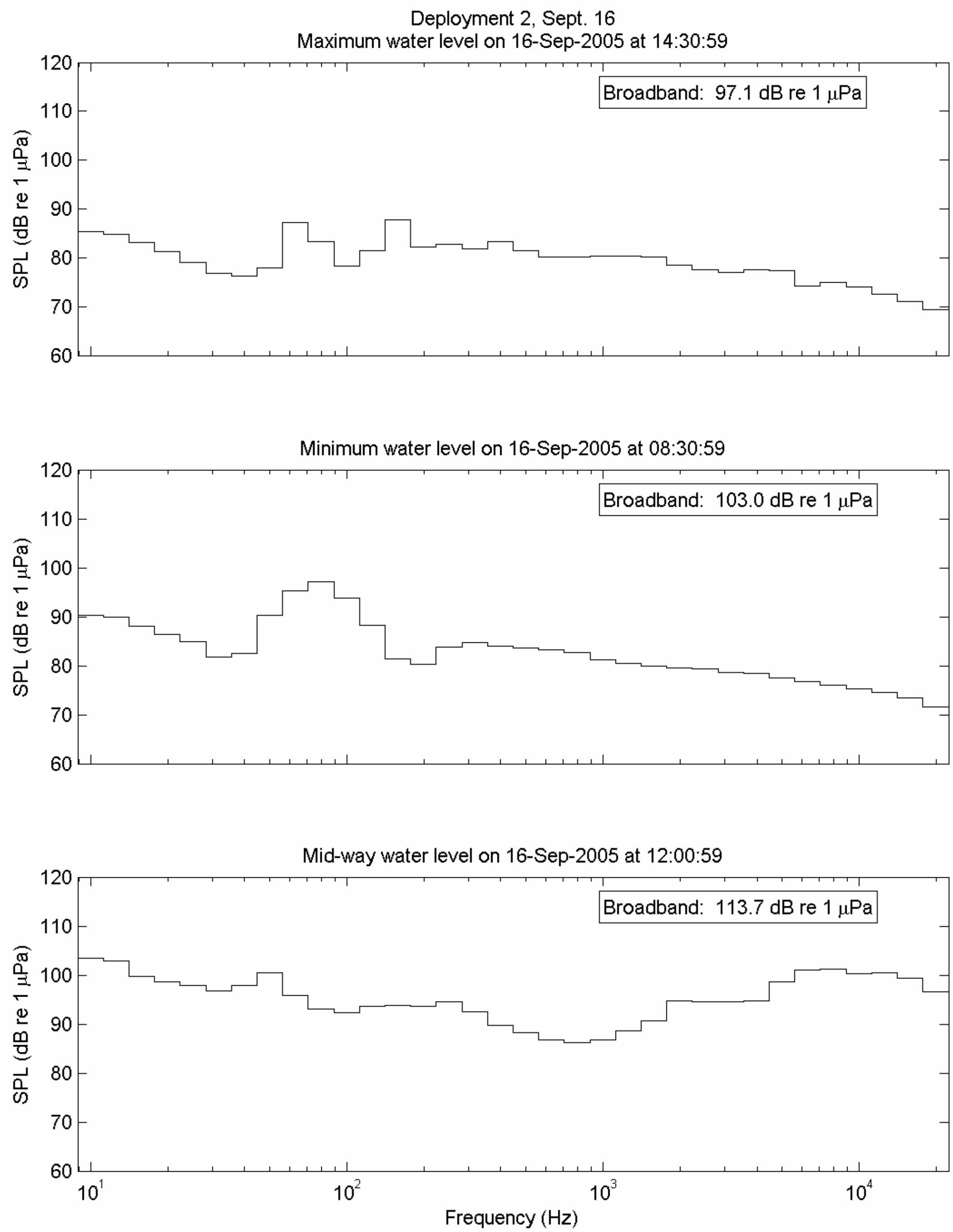

Figure B - 2: Deployment 2, CB-2B, September 16, 2005

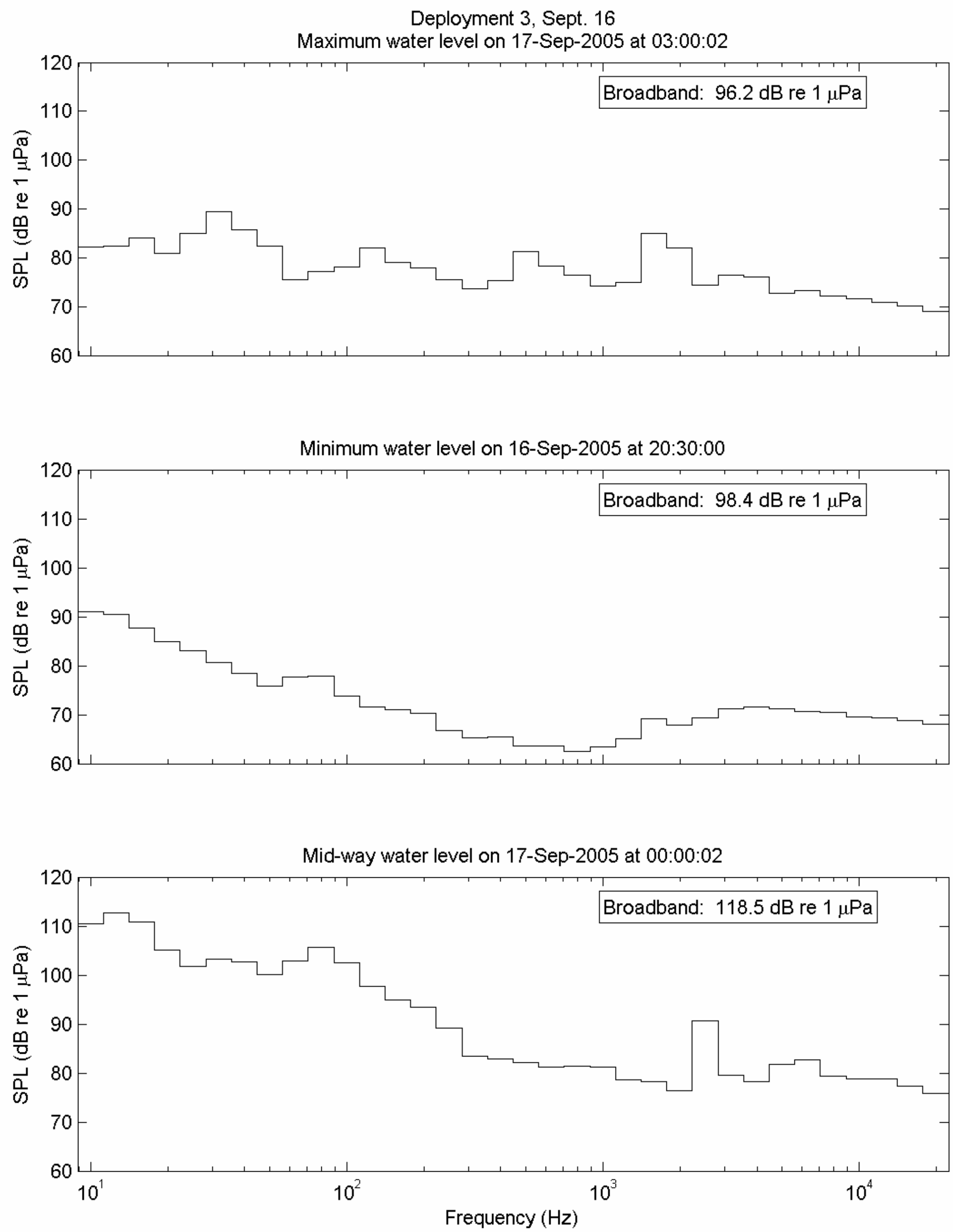

Figure B - 3: Deployment 3, CB5, September 16, 2005

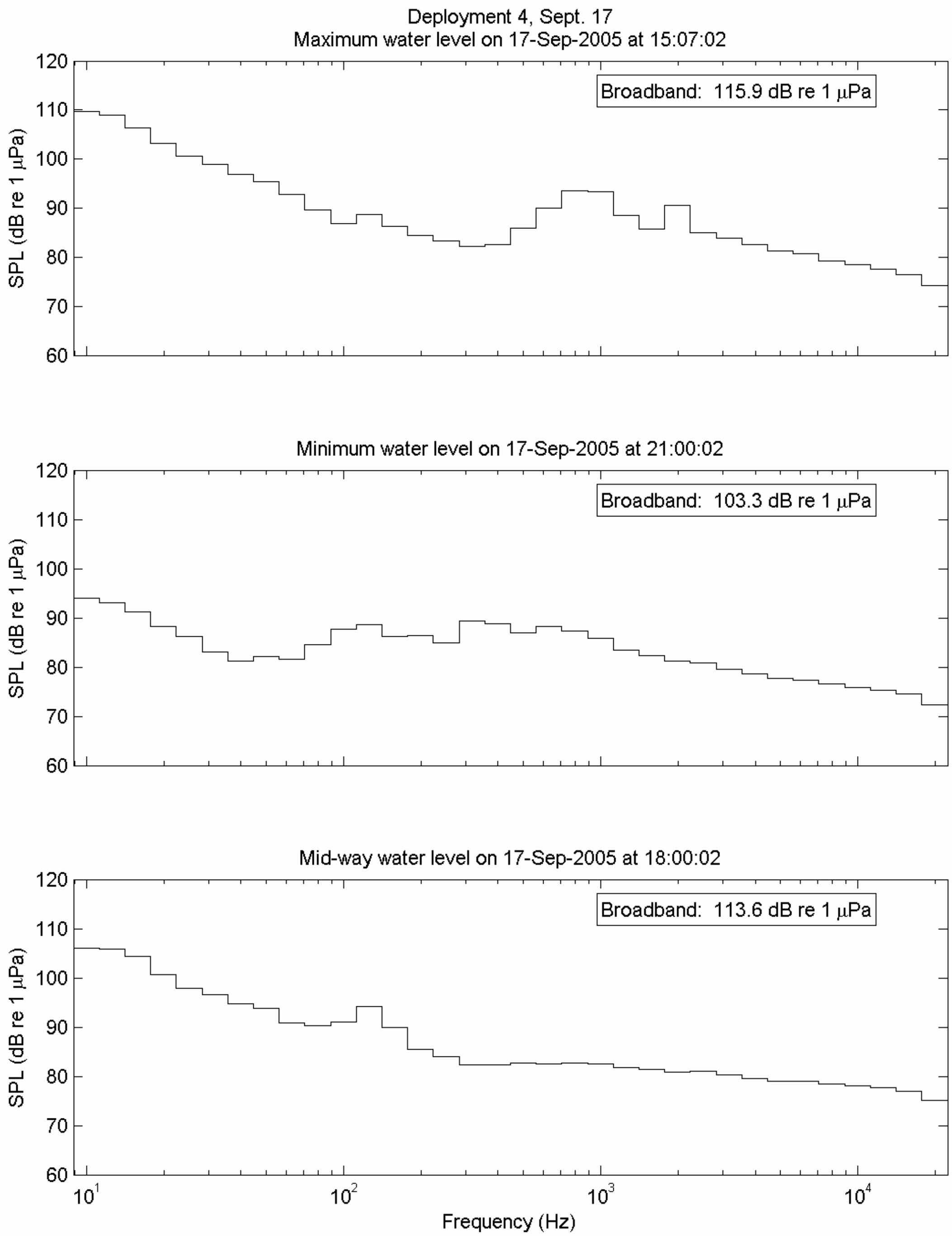

Figure B - 4: Deployment 4, Île Verte, September 17, 2005

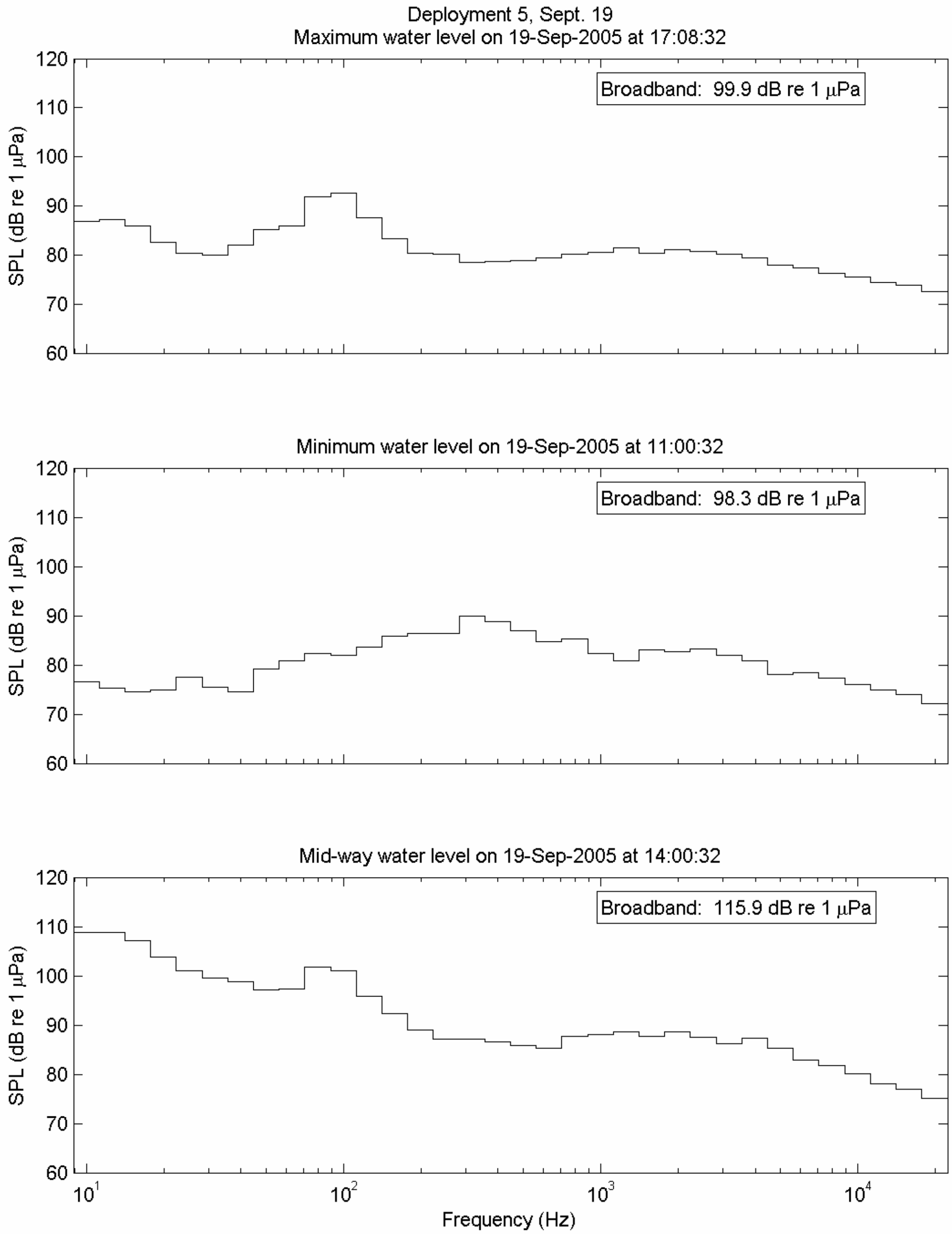

Figure B - 5: Deployment 5, CB3, September 19, 2005

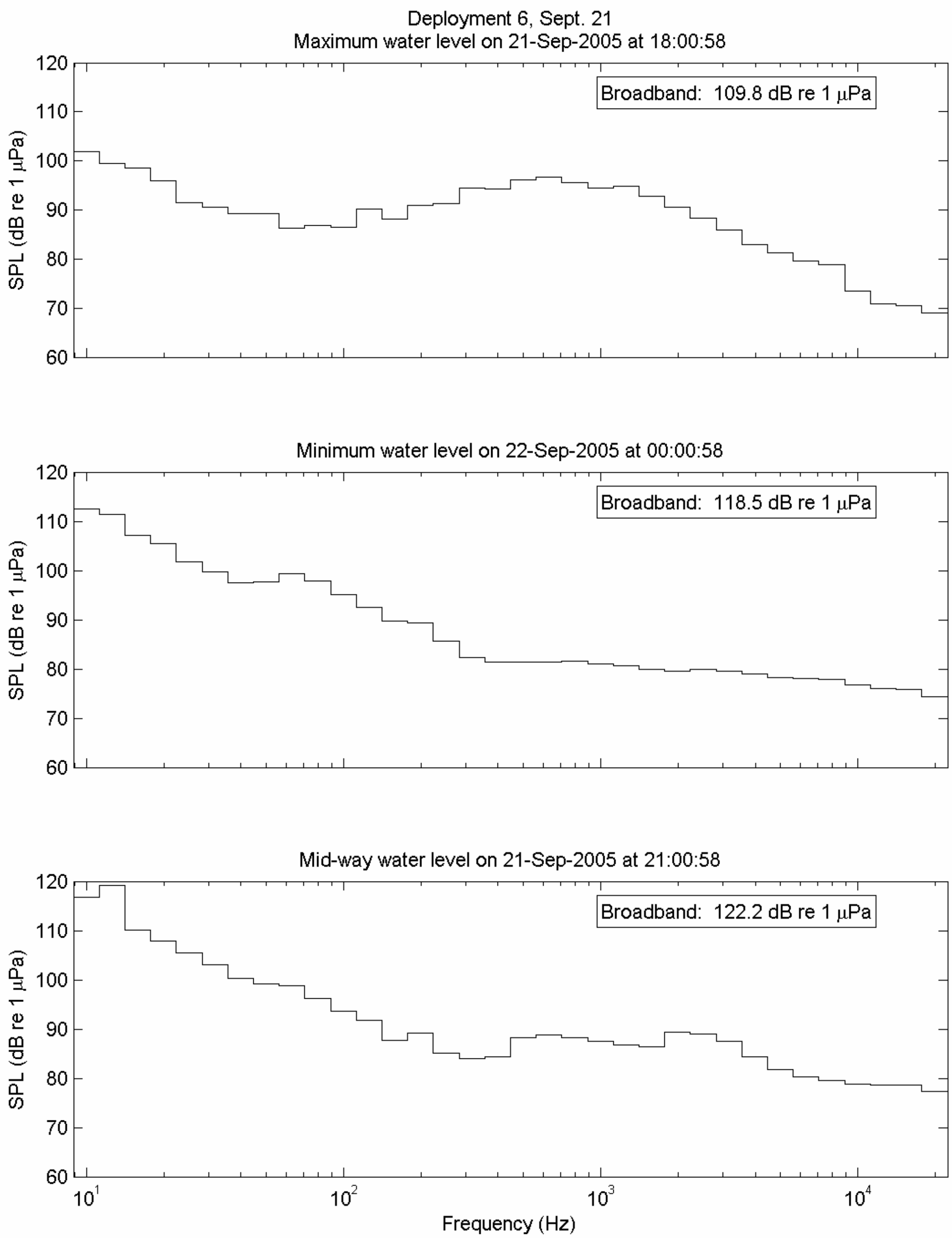

Figure B - 6: Deployment 6, DFO3 - Île Rouge, September 21, 2005

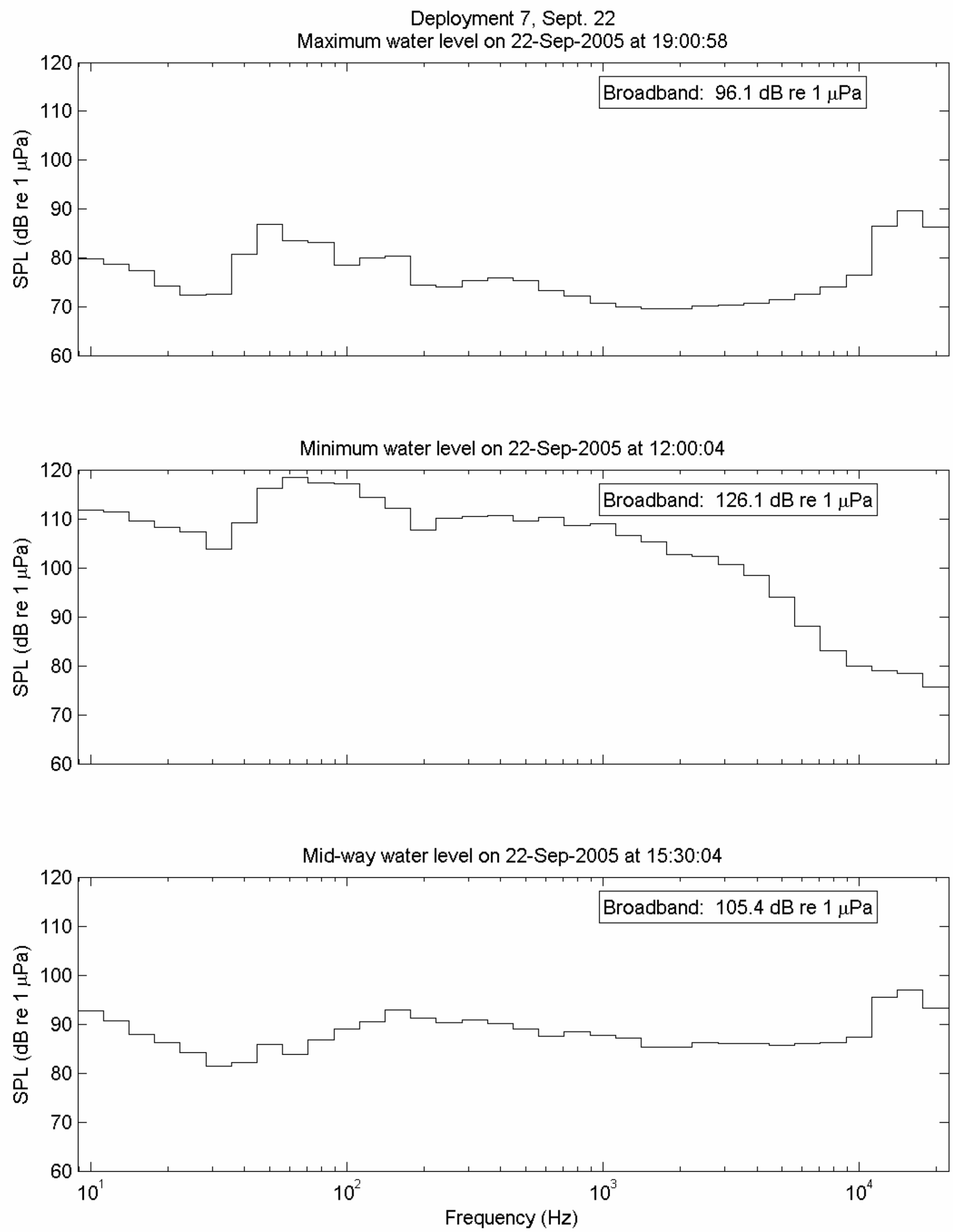

Figure B - 7: Deployment 7, DFO3 - Île Rouge West, September 22, 2005

Appendix C

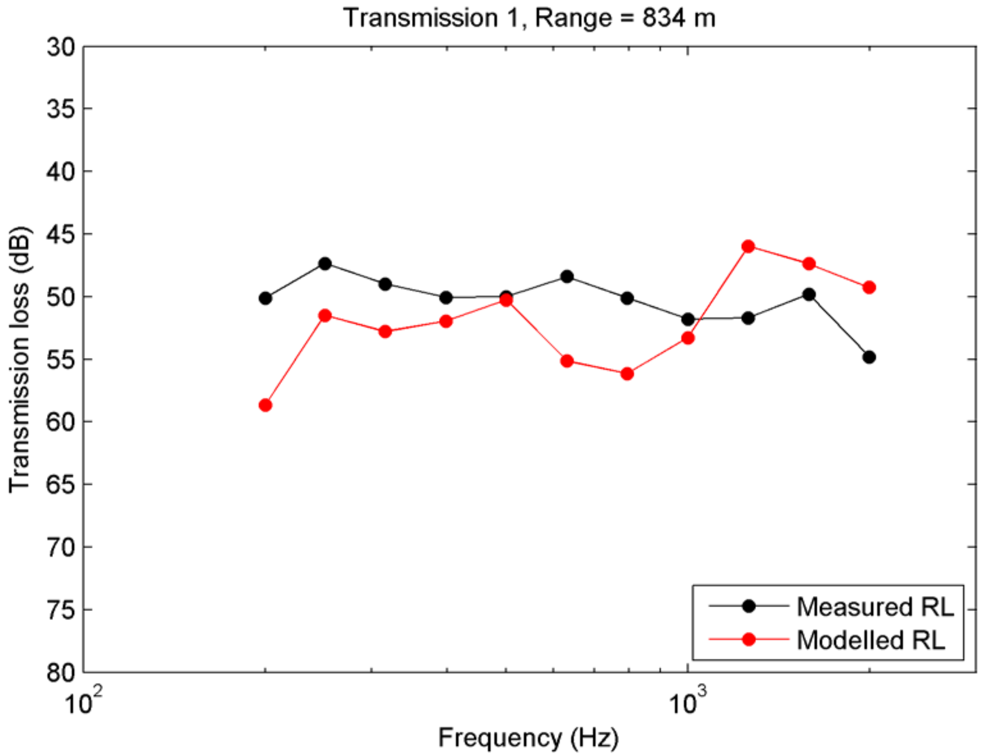

Figure C - 1: Transmission loss (dB) as a function of third-octave band centre frequency for measurements and model results for transmission #1

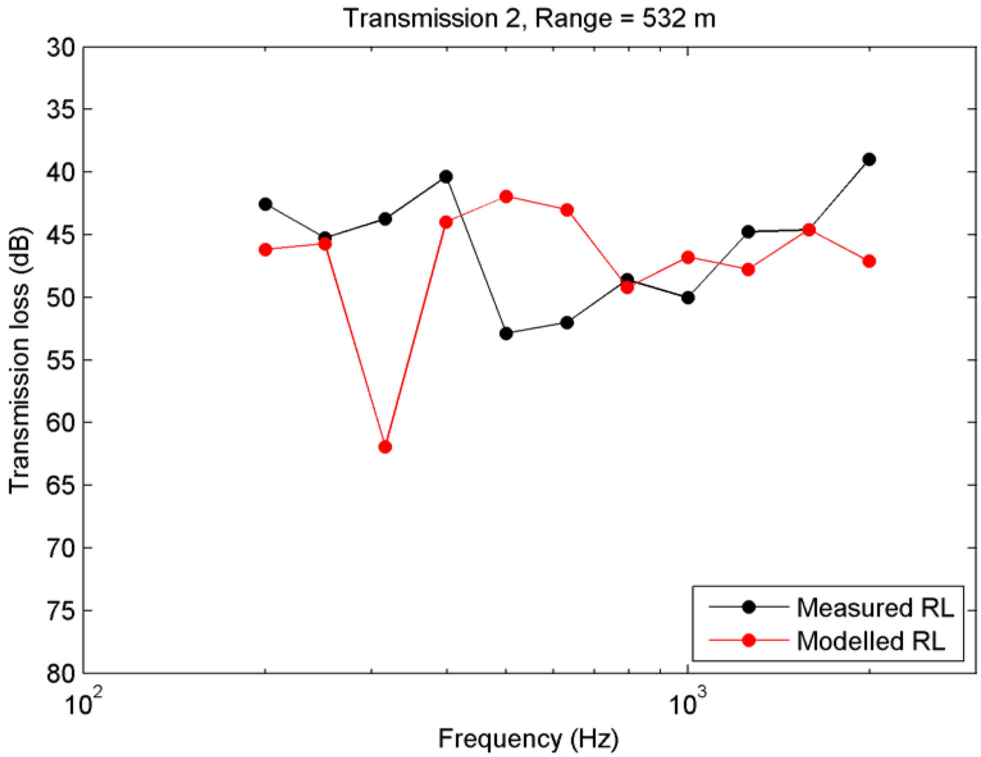

Figure C - 2: Transmission loss (dB) as a function of third-octave band centre frequency for measurements and model results for transmission #2

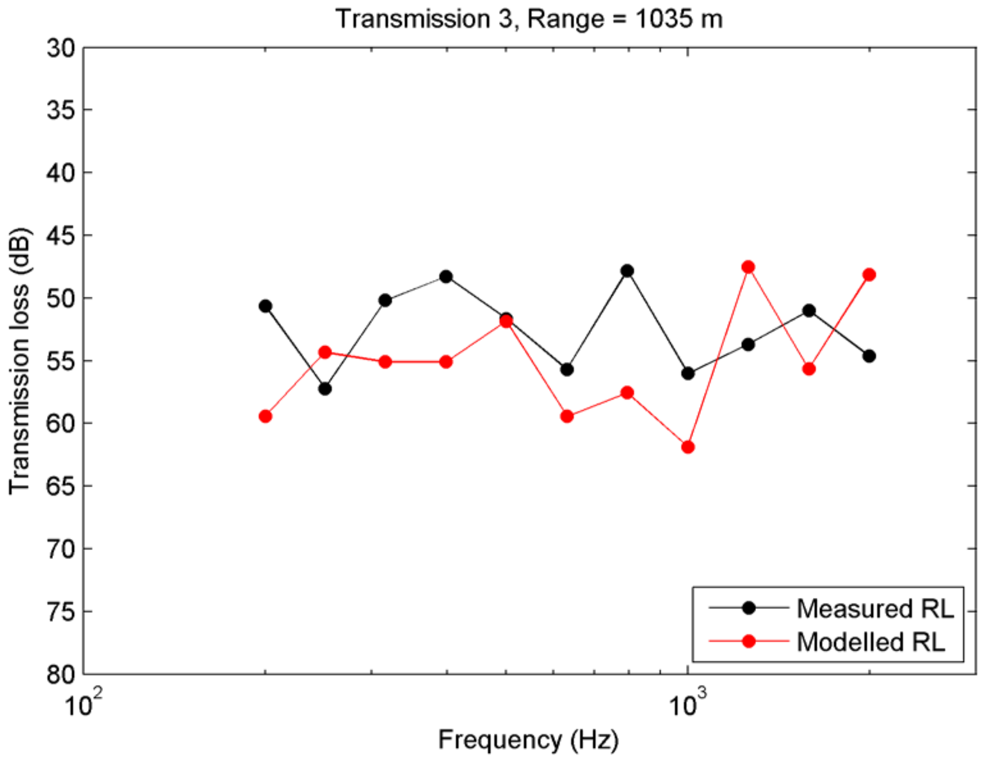

Figure C - 3: Transmission loss (dB) as a function of third-octave band centre frequency for measurements and model results for transmission #3

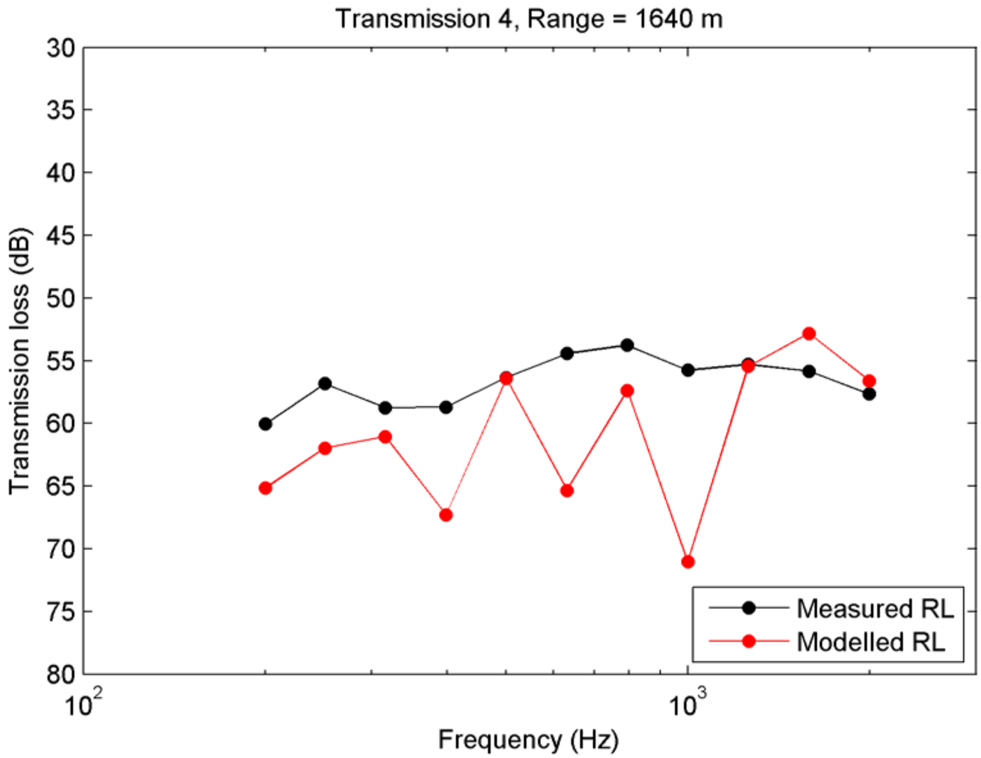

Figure C - 4: Transmission loss (dB) as a function of third-octave band centre frequency for measurements and model results for transmission #4

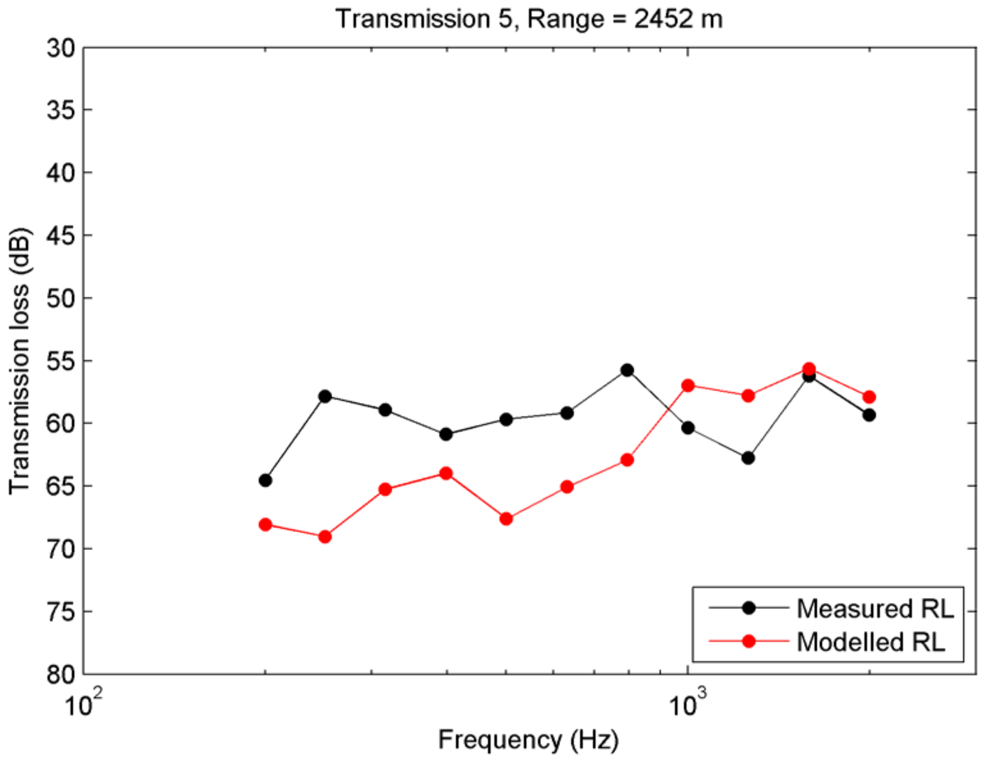

Figure C - 5: Transmission loss (dB) as a function of third-octave band centre frequency for measurements and model results for transmission #5

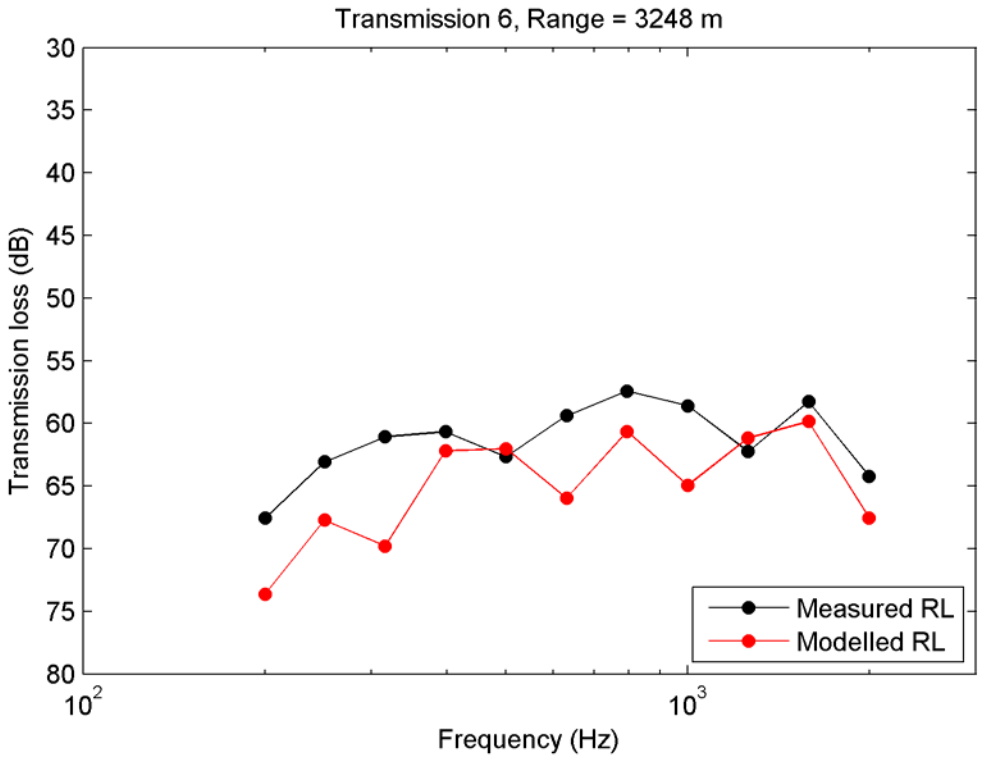

Figure C - 6: Transmission loss (dB) as a function of third-octave band centre frequency for measurements and model results for transmission #6

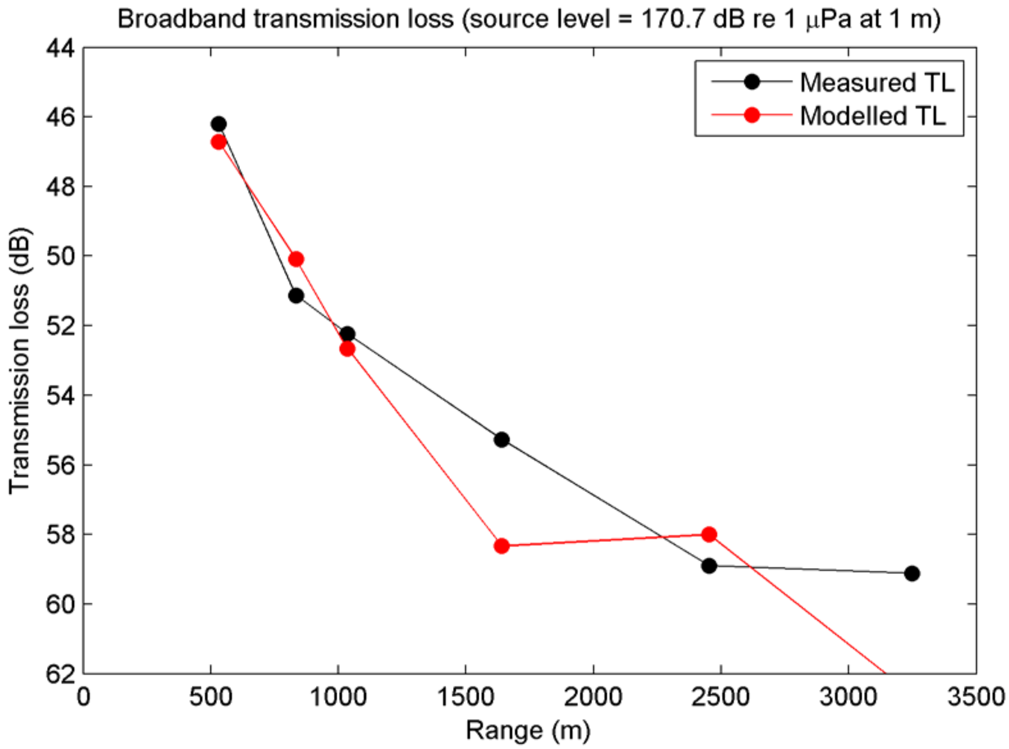

Figure C - 7: Broadband received level for transmission loss measurements and as calculated using the MONM model, as a function of range

Appendix D

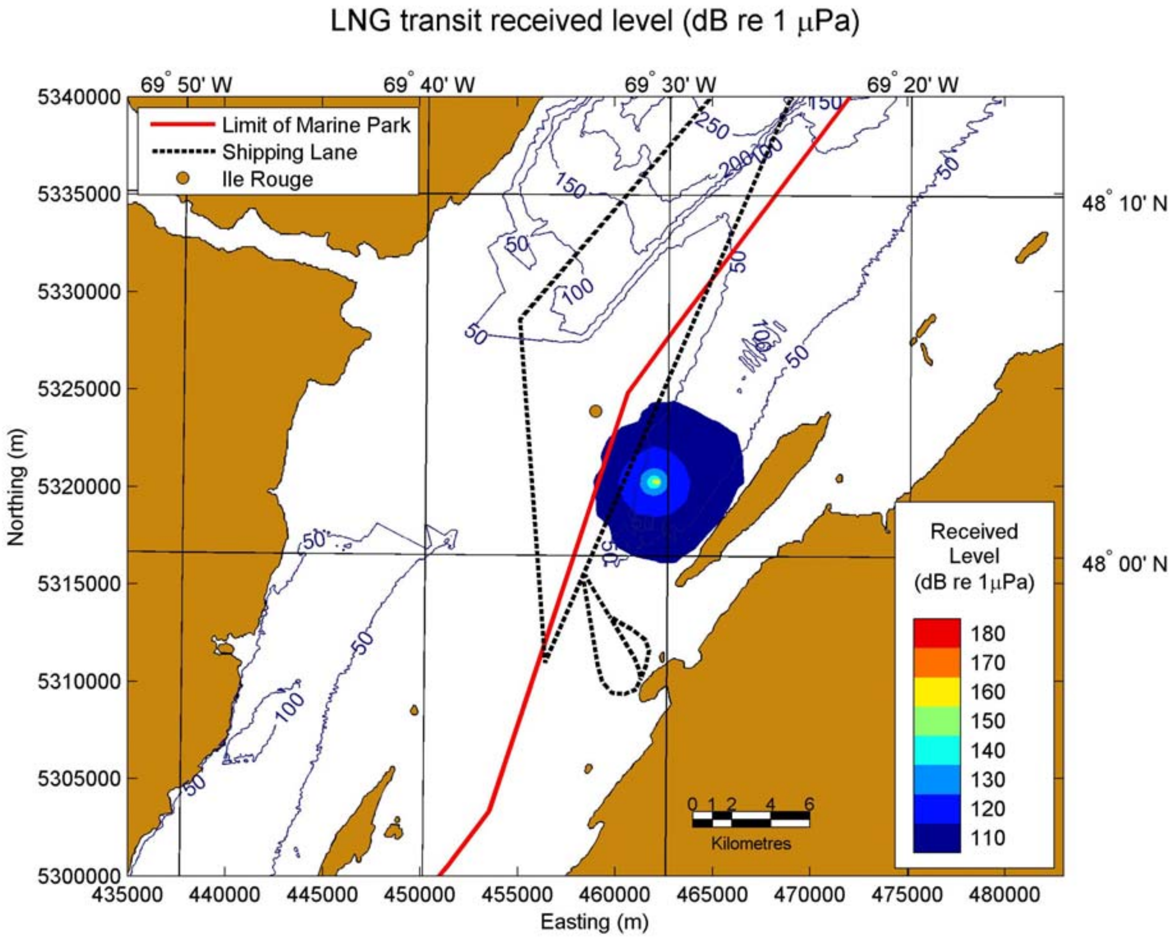

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Figure D - 1: Contour plot of received sound pressure levels in the region surrounding the Cacouna Energy LNG Terminal for the LNG carrier transit scenario

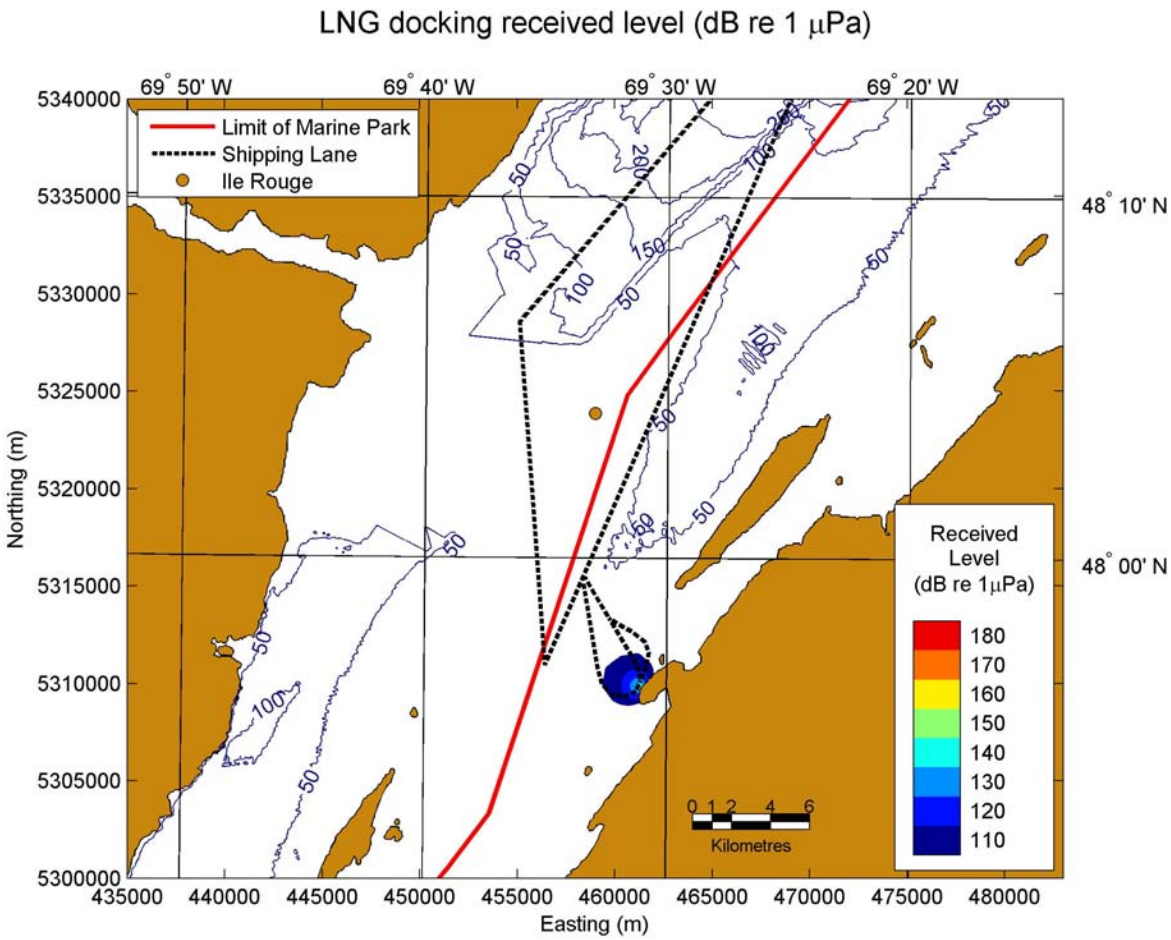

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Figure D - 2: Contour plot of received sound pressure levels in the region surrounding the Cacouna Energy LNG Terminal for the LNG carrier docking scenario

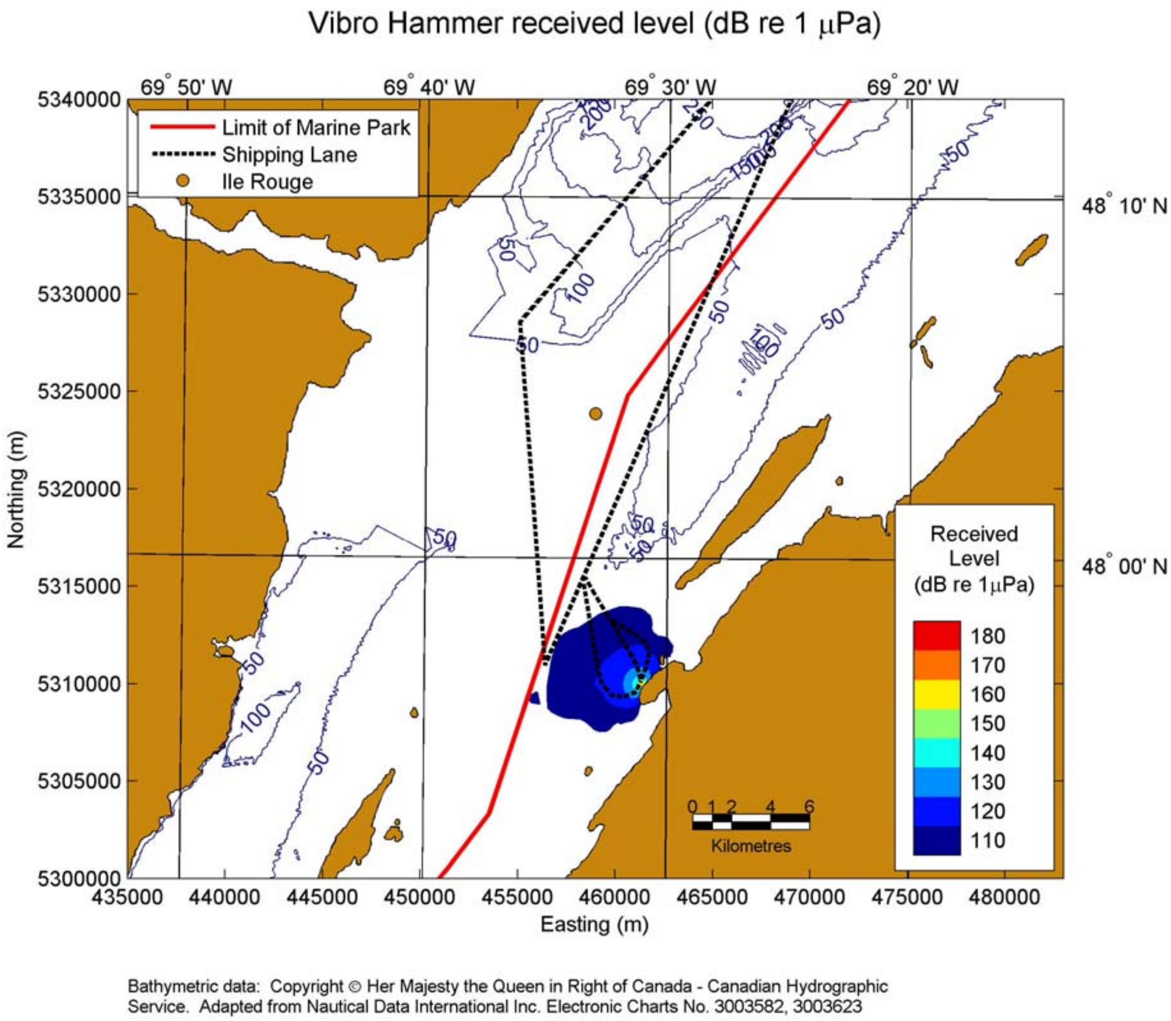

Figure D - 3: Contour plot of received sound pressure levels in the region surrounding the Cacouna Energy LNG Terminal for the vibro-hammering scenario

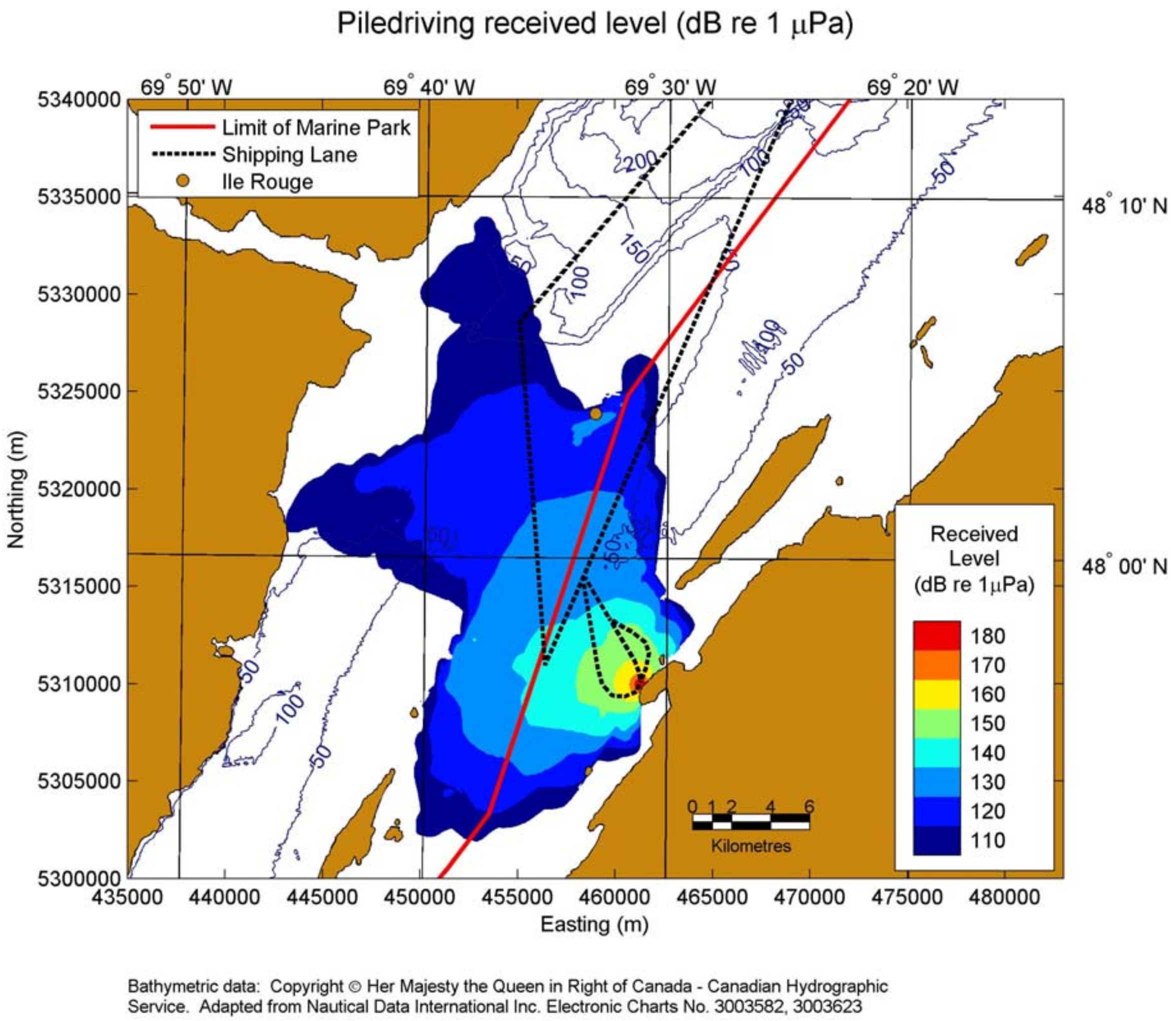

Figure D - 4: Contour plot of received sound pressure levels in the region surrounding the Cacouna Energy LNG Terminal for the impact-hammering scenario