PORT OF ANCHORAGE
MARINE TERMINAL DEVELOPMENT PROJECT

2008 Underwater Noise Survey During Construction Pile Driving

Prepared for

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Executive Summary

During the period from September 19 through October 9, 2008 an underwater noise survey was conducted at the Port of Anchorage (Port) in order to capture representative noise measurements during in-water construction pile driving and other Port operations. The fourteen-day survey collected over fourteen hours of acoustic data from a drifting vessel using calibrated hydro-acoustic equipment similar to that used in previous noise studies [5][6][16].

Data collection focused on four areas: vibratory pile driving; impact pile driving; pile placement (stabbing) and other noises (noise index). The processing of the acoustic data produced ranges to the 190, 180, and 160 dB re 1 micro Pascal (μPa) root mean square (RMS) isopleths from impact pile driving activities and the range to the 120 dB isopleths for vibratory pile driving. Background noise levels and noise levels from other port activities have also been analyzed and are reported.

A summary of the noise measurements for the vibratory driving for sheet pile, Wye-pile, and temporary round pile (round pile) are shown in **Table A-1**.

Table A-1: Summary of Vibratory Pile Driving Noise Measurements

Parameters	Sheet Pile Face Wall	Wye-Pile	Round Pile	Sheet Pile Tail Wall
SPL avg [dB]	141	134	131	120
SPL max [dB]	157	139	144	122
SPL min [dB]	120	122	120	119
Source Range, avg [m]	757	126	35	84
Source Range, max [m]	1208	152	67	108
Source Range, min [m]	32	88	16	47

In the following table (**Table A-2**) are the estimates for the worst-case sound levels that are determined from a combination of the sound pressure level (SPL) and range. The estimated worst case (shown below in yellow) is a source level of 198 dB that was recorded during a high tide. This source level (SL) would require over 8.2 km to attenuate to 120 dB. For comparison, the average SL for vibratory sheet pile driving of face wall was 187 dB, resulting in a range from the source to the 120 dB isopleth of 2.3 km. The SPL and SL for Wye-Pile and Round Pile had ranges far less than both the worst case and average conditions for the sheet pile.

Table A-2: Summary of Vibratory Pile Driving 120 dB Isopleth Estimates

Parameters	Sheet Pile Face Wall	Wye-Pile	Round Pile	Sheet Pile Tail Wall
SL avg [dB]	187	176	161	158
(Average) [m]	2312	636	109	84
SL max [dB]	198	182	175	161
(Worst Case) [m]	8219	1319	559	111

A summary of the noise measurements during impact driving for sheet pile (shallow and deep measurements), Wye-pile, hairpin, and soft start are found in **Table B-1**. Two methods of measuring noise levels were used: root mean square (RMS) averaging to produce an SPL; and instantaneous peak pressure (IPP). The National Marine Fisheries Service (NMFS) required RMS averaging to be applied over 90% of the total energy in the pulse. Performing pulse detection and then determining the energy between 5% and 95% of the total energy in the pulse envelope implemented this measurement. IPP measurements locate the sample with the largest value over the entire pulse. This second approach is commonly used for noise measurements and provides immediate comparison with prior results.

Table B-1: Summary of Impact Pile Driving Noise Measurements

Parameters	Face Wall		Tail Wall			
	Sheet Pile Shallow	Sheet Pile Deep	Sheet Pile	Wye-Pile	Hairpin	Soft Start
Total Count of Impacts	1,444	1,669	1,332	77	234	9
SPL (NMFS 5%-95%) avg [dB]	143	150	138	141	127	160
SPL (NMFS 5%-95%) max [dB]	157	159	145	151	141	163
SPL (NMFS 5%-95%) min [dB]	123	127	123	132	102	156
IPP (Instantaneous Peak) avg [dB]	166	171	158	161	151	185
IPP (Instantaneous Peak) max [dB]	182	183	168	173	167	188
IPP (Instantaneous Peak) min [dB]	145	145	145	152	121	179
Source Range, avg [m]	202	238	128	299	262	42
Source Range, max [m]	703	521	322	364	559	62
Source Range, min [m]	28	34	32	155	51	25

A worst case SL of 200 dB results was measured during sheet pile impact driving on the deep hydrophone (shown in yellow in **Table B-2**). The estimated range to the 160 dB isopleths (range to source) is 97 m using the SPL value derived from the RMS computation. Using the IPP method, the estimated range to the 160 dB isopleth is 1520 m. However, the NMFS method is required for isopleth creation, per their guidance during the development of the Noise Survey Plan (**Appendix A**). Isopleths construction from the impact data indicated that the sound propagation was projected and not spherical. This is significant when considering the appropriate shutdown ranges during pile driving should marine mammals, particularly Cook Inlet beluga whales (*Delphinapterus leucas*), approach the construction area.

Table B-2: Summary of Impact Pile Driving 160 dB Isopleth Estimates

Parameters	Face Wall		Tail Wall			
	Sheet Pile Shallow	Sheet Pile Deep	Sheet Pile	Wye-Pile	Hairpin	Sheet Pile Shallow
SL (NMFS 5%-95%) [dB]	195	200	188	195	169	194
Est. 160 dB Distance	57	97	24	54	16	51
SL (Instantaneous Peak) [dB]	182	174	168	173	151	183
Est. 160 dB Distance	1096	1520	292	910	36	880

Background noise measurements were taken periodically throughout the data collection period. Background noise levels were found to range from 120 dB to 150 dB and were strongly correlated with wind, and to a lesser extent tide. The background noise at its lowest level (120 dB) is the same as the required shutdown level for vibratory pile driving, making the 120 dB isopleth requirement impossible to attain.

Additional noise sources were identified and measured, including bucket dredging, hand hammering on piling, and a survey vessel operating in the area.

The report also includes a summary of noise attenuation measures and their applicability to the Port of Anchorage Marine Terminal Redevelopment Project.

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Acronyms and Abbreviations

AC	alternating current
ANT	Alaska Native Technologies, LLC
SciFish	Scientific Fishery Systems, Inc.
μPa	micro Pascal
dB RMS	root-mean-square sound pressure level
dB peak	instantaneous peak sound pressure level
dB	decibel
dBA	A-weighted decibel
DC	direct current
ft	feet
FR	Federal Register
GPS	global positioning system
Hz	Hertz
ICRC	Integrated Concepts and Research Corporation
LZeq	a variable (RMS for 1 minute) of sound level meter
LZpeak	a variable (instantaneous peak value) of sound level meter
m	meter
MLLW	mean lower low water
MMPA	Marine Mammal Protection Act
MMSZ	marine mammal safety zone
MTR	Marine Terminal Redevelopment
ms	millisecond
NMEA	National Marine Electronics Association
NMFS	National Marine Fisheries Service
Pa	Pascal
Plan	Noise study plan
POA	Port of Anchorage
RMS	root mean square
SEL	sound exposure level
SL	source level
SLM	sound level meter
SPL	sound pressure level
TL	transmission loss
URS	URS Corporation
USACE	U.S. Army Corps of Engineers
VAC	volts alternating current
VHF	Very High Frequency

1. Introduction

The Port of Anchorage (Port) serves 85 percent of Alaska's population and transports 90 percent of the consumer goods to Alaska. It is the major gateway for Alaska's water-borne commerce and a vital element of the regional economy, generating more than $750 million each year. To keep pace with the future trends in the shipping industry, the Port is undergoing construction to accommodate larger ships, develop larger barge berths, and improve and expand cruise ship facilities. As part of the Marine Terminal Redevelopment Project (MTR), construction is planned for the next several years. To prevent and minimize adverse impacts to marine mammals, underwater noise surveys and marine mammal monitoring are required during in-water Port construction activities, including pile driving, dredging, vessel traffic and dockside activities.

Representatives of the Port of Anchorage (POA) have received an Incidental Harassment Authorization (IHA) permit from the National Marine Fisheries Service (NMFS) dated July 15, 2008 for the construction season (up to July 14, 2009) for small take authorizations under the Marine Mammal Protection Act (MMPA). This permit allows for incidental taking under Level B harassment of the Cook Inlet beluga whale, (*Delphinapterus leucas*), harbor porpoises (*Phocoena phocoena*), killer whales (*Orcinus orca*), and harbor seals (*Phoca vitulina*), incidental to the MTR construction. The POA must comply with the terms of the IHA as well as the mitigation measures stipulated in the US Army Corps of Engineers (USACE) permit number POA-2003-502-N (August 10, 2007). Specific permit conditions will be discussed in Section 1.1.

Integrated Concepts and Research Corporation (ICRC) procured the services of Alaska Native Technologies, LLC (ANT) and Scientific Fishery Systems, Inc. (SciFish) to conduct the survey under a NMFS-approved Underwater Noise Survey Plan (Plan) and included as **Appendix A**. This Plan was written in accordance with the NMFS and USACE permits and details procedures for conducting the noise survey during pile driving activities, and coordination with on-shore marine mammal observers, construction crews, and other Port operations personnel.

1.1 Permit Requirements

Conditions specified in the NMFS IHA 2008 and the USACE 404/10 permits were embedded in the Underwater Noise Survey Plan and adhered to during the data collection effort are summarized as follows:

- Conduct an underwater noise survey to include in-water pile driving, pile stabbing, construction, dockside activities, vessel traffic, and dredging. The survey will confirm or identify harassment isopleths for all types of piles used, including open-cell sheet piles and 36-inch steel piles, and the "stabbing" process. The survey proposal shall be approved by NMFS prior to the start of seasonal in-water pile driving.
- The underwater noise survey shall verify the 190, 180, and 160 dB re 1 microPascal (µPa) root mean square (RMS) isopleths from pile driving activities, and determine the 120 dB isopleths for vibratory pile driving.
- The results of the survey will develop a *Sound Index* to accurately represent noise levels from pile driving and other Port operations, including dockside activities, vessel traffic, dredging, and docking. The evaluation shall characterize current baseline operations noise levels at the Port of Anchorage in order to develop an engineering report that

identifies structural and operational noise reduction measures, if necessary, to minimize the baseline operational noise levels at the expanded Port to the maximum extent practicable.

1.2 Underwater Sound Descriptors

Sound is a physical phenomenon consisting of minute vibrations that travel through a medium, such as air or water. Sound is generally characterized by several variables, including frequency and intensity. Frequency describes the sound's pitch and is measured in Hertz (Hz), while intensity describes the sound's loudness and is measured in decibels (dB). Decibels are measured using a logarithmic scale.

The method commonly used to quantify airborne sounds consists of evaluating all frequencies of a sound according to a weighting system that reflects that human hearing is less sensitive at low frequencies and extremely high frequencies than at the mid-range frequencies. This is called A-weighting, and the decibel level measured is called the A-weighted sound level (dBA). A filtering method to reflect hearing of marine mammals such as whales has not been developed for regulatory purposes. Therefore, sound levels underwater are not weighted and measure the entire frequency range of interest. In the case of marine construction work, the frequency range of interest is 10 to 10,000 Hz.

There are several descriptors are used for underwater sounds. Two common descriptors are the instantaneous peak sound pressure level (dB peak) and the Root Mean Square (dB RMS) pressure level during the pulse or over a defined averaging period. The peak pressure is the instantaneous maximum or minimum overpressure observed during each pulse or sound event and is presented in Pascals (Pa) or decibels (dB) referenced to a pressure of 1 micro Pascal (µPa).

The RMS level is the square root of the energy divided by a defined time period. The duration of a single pulse will be defined as the averaging period for impact pile driving. The RMS or sound pressure level (SPL) average period is not sensitive to continuous sounds from vibratory pile installation, so a period of about 1/8 of a second will be appropriate for evaluating impacts to marine mammals. Other researchers have used longer periods for vibratory driving, but offered no justification. The "impulse" setting of a sound level meter uses 35-millisecond (ms) time averaging. This provides a good approximation of the RMS averaged over the duration of a pulse, since most pile driving impact pulses last about 40 to 60 ms. However, we have opted to utilize a more precise method of measuring the energy in each pulse by identifying the leading and trailing edges of the pulse and then sampling between the locations that represented 5% and 95% of the total pulse energy. This method of processing was recommended by NMFS, as it is believed to provide RMS levels for a wide variation of pulse durations to ensure the appropriate levels are used to assess impacts to marine mammals.

Transmission loss (TL) under water is the decrease in acoustic intensity as an acoustic pressure wave propagates out from a source. Transmission loss parameters vary with frequency, temperature, sea conditions, source and receiver depth, water chemistry, and bottom composition and topography. For this survey, TL will be calculated based on results of underwater sound measurements for several hydrophone positions both close and distant from the pile installation activity.

1.3 Project Objectives

To prevent and minimize adverse impacts to marine mammals, underwater noise surveys and marine mammal monitoring are required during MTR Project activities, including pile driving, pile stabbing, construction, dockside activities, vessel traffic, and dredging. The noise survey was designed to be conducted over a period of approximately fourteen days in order to appropriately capture representative in-water noise measurements of pile driving and existing Port operations. The survey began in late-September 2008 and continued until mid-October 2008. All work was done in coordination with the MTR Project construction subcontractor, Quality Asphalt Paving (QAP), and their schedule for in-water pile driving.

2. Methodology

2.1 Acoustic Data Collection Overview

To create the required sound-index and the associated acoustic isopleths, passive acoustic measurements were taken during a variety of activities, including pile driving, vessel traffic in the channel, and bucket dredging. Furthermore, sampling was done for each type of piling and pile installation technique used by the construction crew during the data collection period.

Sampling was done at multiple locations to produce the required 190, 180, 160, and 120 dB isopleths. Most of the acoustic data collection was performed from a drifting vessel, utilizing the tides and currents to move through the sample area and to reduce the effect of flow noise. Since data collection was performed from a drifting vessel, all acoustic data recordings were time-stamped based on the computer clock. Simultaneously, using the National Marine Electronics Association (NMEA) output of differential global positioning system (GPS), the location of the boat was recorded every second. Each second of acoustic data recording was later "stamped" with corresponding geographic coordinates.

All noise sources were catalogued during collection. A custom data logging application was created to automatically time-stamp textual information used for ground truth using the PC clock. A laser rangefinder was used to measure distance to acoustic noise sources in the sample area.

Two types of acoustical recordings were made:

- the "raw" signal was recorded with Avisoft UltraSoundGate Recorder at 50 kHz sampling frequency and 16 bit resolution (see **Appendix B**); and
- common acoustic parameters such as LZeq, LZpeak, were measured and logged every second using Larson-Davis Model 831 sound level meter (SLM) (see **Appendix C**).

SLM calibration was performed at least once per day prior to data collection. "Raw" data was processed using custom-developed signal processing MatLab scripts. The peak pressure and sound pressure level (RMS) were calculated and compared to the corresponding parameters recorded with SLM.

Acoustical recordings were performed with two different hydrophone deployment methods to ensure that the full dynamic range of the data was being adequately sampled. During the first part of the survey, data was collected with the hydrophone deployed one meter below the water surface. The second part of the survey was performed with the hydrophone deployed approximately one meter above the bottom of the ocean floor.

2.2 Sampling Area

During the survey, pile driving operations were taking place at the northern end of the Port of Anchorage expansion project (**Figure 1**). The sample area for each type of pile driving method was determined based on the estimated Source Level (SL). The sound pressure level (SPL) measured at the receiver is affected by the transmission loss (TL) and attenuation from absorption loss (NA). Assuming spherical sound spreading, these values are related using the following equation:

$$SPL = SL - TL$$
$$TL = S \log R - NA$$

TL is determined by the combination of spreading loss (*S log R*) and absorption (*NA*). Absorption is relatively very small compared with spreading loss and negligible in many situations. Only spreading loss is considered throughout the analysis in this report. However, the spreading loss also varies depending on the sound propagation characteristics. One way of measuring precise spreading loss parameter, *S*, is to deploy two identical hydrophones in a known distance along the straight ray of sound propagation path and to measure the received energy levels from the identical acoustic source at the same time. However, such a measurement also bears uncertainty due to the varying environmental conditions such as water depth, tide level, wind speed, and bathymetry. Therefore, we used a nominal spreading loss parameter, $S = 20$, for the representing estimation of 120dB distances and 160dB distances, and compared them with several possible variations when $S = 16$, 18, 22, and 24. For example, assuming an SL of the vibratory hammer is equal to 185 dB, the distance to 120 dB isopleths could be approximately estimated at 1800 meters.

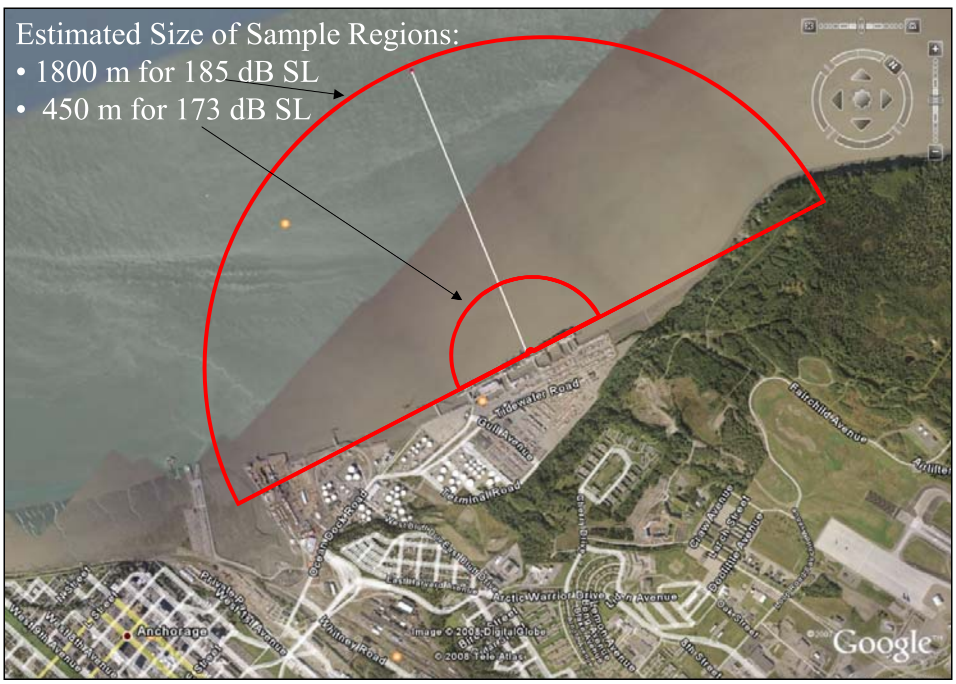


Figure 1. Aerial Map of Port of Anchorage and the Estimated Sample Regions

The starting location of each drift was estimated based on the tide direction, wind speed and the available SPL measurements for pile driving operations. Due to safety requirements during pile driving operations acoustic measurements were collected at distances greater than 50 meters. The exact locations of each set of acoustic measurements for each sound type are provided later in the document.

2.3 Environment

The underwater noise survey sampling area is located in Knik Arm which is well known for a high tidal range. The high tides, strong currents and wind create unfavorable acoustic environment with background noise levels higher than 120 dB re 1 µPa. During the survey background noise levels were periodically measured at different tide levels. While we were expecting to observe lowest background noise during slack tide, the lowest background noise level of approximately 125 dB re 1 µPa was found during the ebb-tide with an average wind speed of 1.9 m/sec. As expected, during time periods with higher wind speed the background noise increased and often exceeded levels of 130 / 140 dB re 1 µPa. These values are comparable to the values obtained during measurements recorded in Knik Arm in August 2004 (Blackwell, 2005). Because background noise levels were always in excess of 120 dB, the range to 120 dB isopleths for the vibratory pile driving operation was estimated based on the calculated source levels. **Figure 2** shows the variation of background noise level and wind speed recorded on October 8, 2008 during survey.

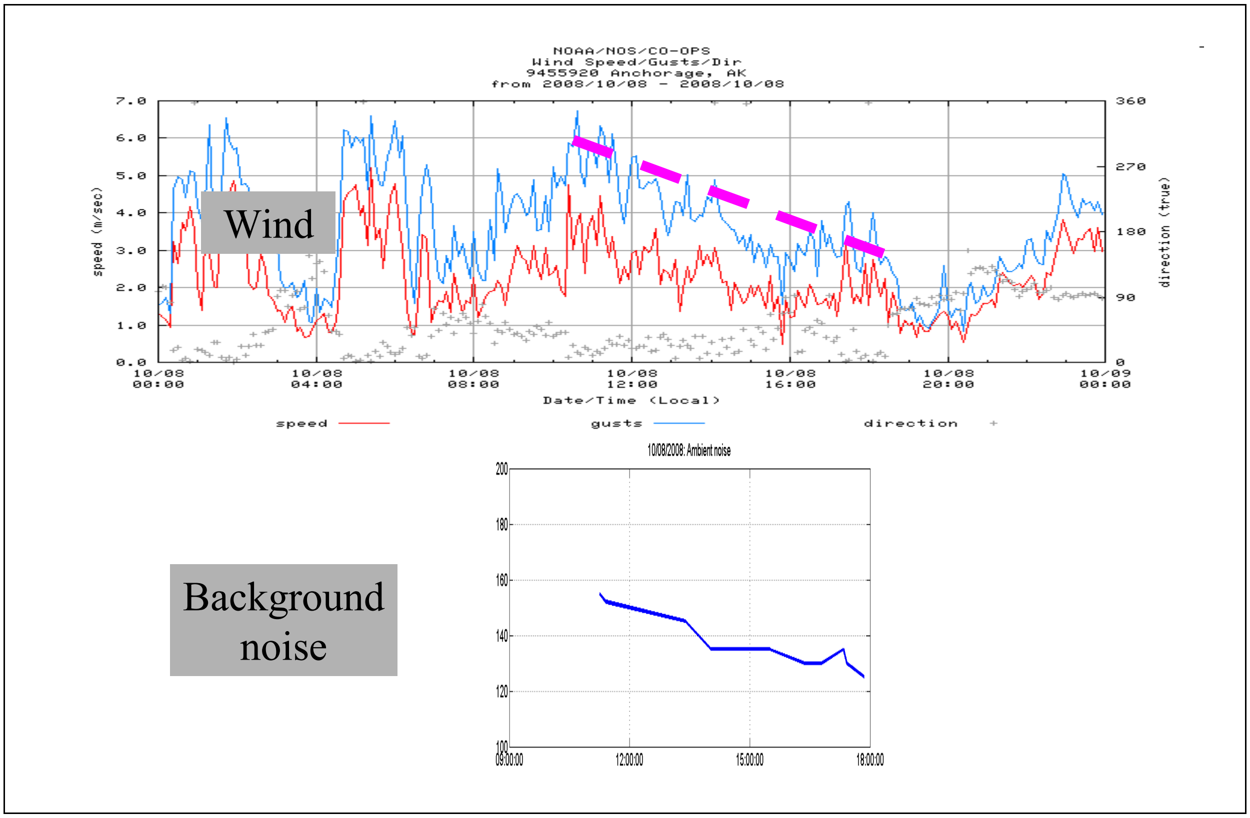


Figure 2. Variation of Background Noise Level and Wind Speed (October 8, 2008)

2.4 Equipment

2.4.1 Boat

Acoustic survey data collection was performed from survey vessel M/V Jella Sea (TerraSond, Inc.). The vessel was equipped with a differential GPS with NMEA port and a depth sounder.

The vessel also provided 110 VAC power through DC to AC invertors. The acoustic equipment was located in an enclosed cabin so that data collection was not be hampered by the weather. The communication between the survey vessel and the pile driving crew on shore was performed via cell phones.

2.4.2 Acoustic Recording

The passive hydro-acoustic monitoring equipment that was selected for this survey is similar to the acoustic equipment used during previous beluga whale noise studies (Blackwell & Greene, 2002; NMFS, 2007; URS, 2007). The following summarizes the acoustic recording equipment, with detailed specifications for key components found in the Appendices:

- Calibrated hydrophone capable of recording from 1 Hz to 25 kHz (Reson TC4013, **Appendix D**)
- Signal amplifier, providing up to 94 dB additional signal strength (Stanford Research Model SR560)
- Data collection system that provides the capability of recording raw data at 50 kHz sampling rate and 16 bit resolution (Avisoft UltraSoundGate 416, **Appendix B**)
- Environmental noise sound level meter that provides real time calculation of various sound level parameters (Larson Davis Model 831, **Appendix C**)
- Pistonphone calibrator with the adaptor for Reson TC4013 hydrophone (PCB Piezoelectronics pistonphone model 394A40
- Nautical charting software to provide immediate reference to the sensor during data collection and to assist with sensor positioning and localization of additional noise sources such as vessel traffic in the sample region
- Toshiba Satellite laptop computer model M105 for data storage and analysis
- MatLab data analysis software for quick-look analysis on the water to confirm system operation and provide immediate noise levels

2.4.3 Laser Range Finder

Bushnell Yardage Pro Trophy Laser Rangefinder was used to determine the range from the data collection vessel to surface-borne acoustic sources. This rangefinder provides distance accuracy up to 800 m.

2.4.4 Water Temperature

Temperature data was collected at least twice per day using an Applied Microsystems Multi-Parameter Water Quality Monitoring Instrument Model EMP 2000 deployed at various depths. The internal clock was synchronized with the GPS at the beginning of each day to mitigate clock drift. Data was time-stamped during collection.

2.4.5 Pile driving hammers

Pile driving was performed with two different types of hammers. The J&M Model 115 hydraulic free-fall hammer was used during impact pile driving operation (see **Appendix E**). This hammer was operated at 75% energy (3 ft stoke). The APE Model 200 variable frequency vibratory pile driver/extractor was used during the vibratory pile driving operation (see **Appendix F**).

2.5 Signal Analysis

All vibratory pile driving signals were analyzed by *RMS* (*root mean square*) computation for continuous time frame of 1/8 sec (0.125 sec) where the signal *RMS* is defined as:

$$x_{rms} = \sqrt{\frac{\sum_{n=1}^{N} x_n^2}{N}}$$

N = number of digital samples for 1/8 sec

All impact pile driving signals were analyzed by the impact detector that takes the time interval between the arrival of 5% and 95% of the total estimated sound energy in the pulse.

Figure 3 shows an example of impact signal in the upper plot and the normalized cumulative sound energy in the lower plot. The pulse duration that is defined by the time interval for the sound energy between 5% and 95% is denoted in red lines. The *RMS* value of the pulse duration was calculated and then converted to sound pressure level (SPL).

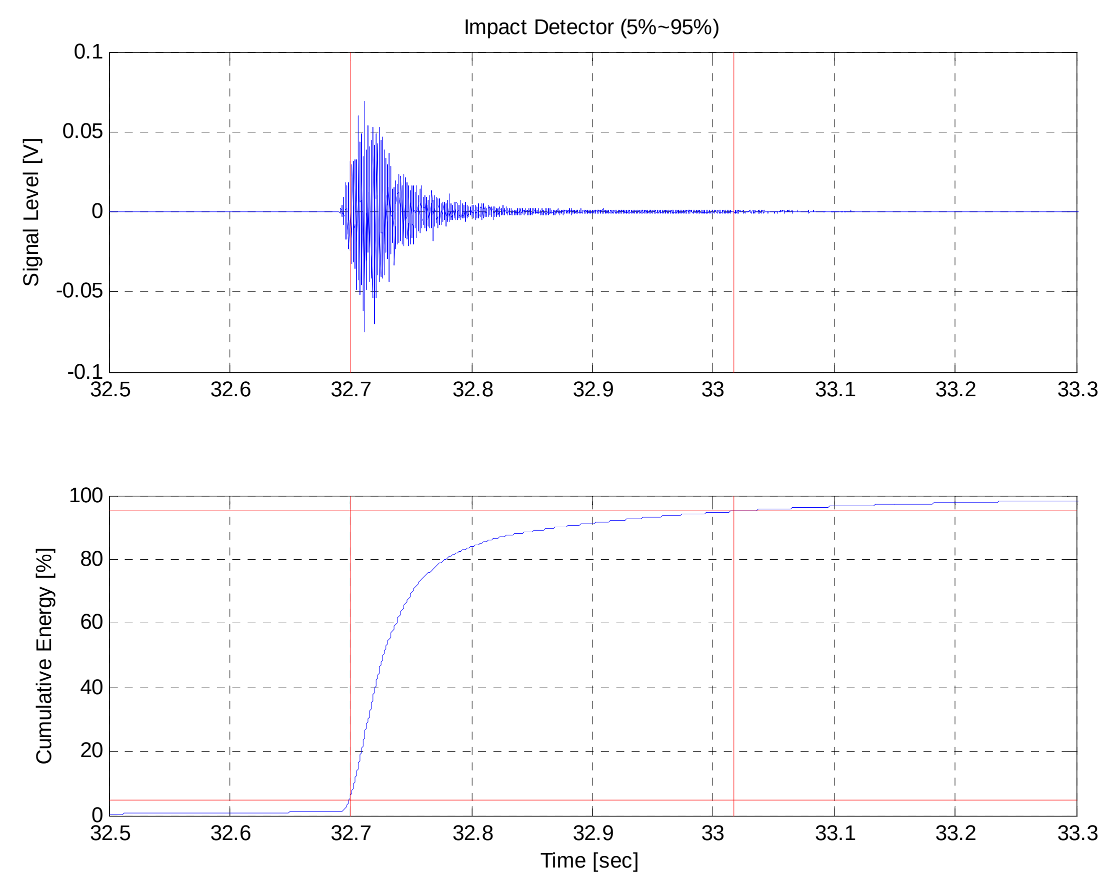


Figure 3. An Example of Impact Detection and Pulse Duration

SPL was computed by averaging values during the pulse duration in *RMS* processing. These values greatly depend on the pulse duration. The low level ringing immediately after each impact causes the elongated pulse duration and eventually results in a relatively lower energy level.

Another way of presenting the sound energy is to use peak pressure that is defined as the instantaneous maximum of the absolute value of sound pressure. Since the peak pressure is not based on averaging process during the pulse duration, it represents the highest possible value.

The worst-case analysis for 120 dB distance or 160 dB distance was conducted using both *RMS*-based SPL and the instantaneous peak pressure.

Spectral analysis of the acoustic signal was based on 1/3 octave spectrum of the received energy. The greatest interest of spectral response lies in the frequency range from 20 to 20,000 Hz. Although it is possible to analyze a source on a frequency by frequency basis, this is impractical and time-consuming. For this reason, a scale of octave bands and 1/3 octave bands was used. Each band covers a specific range of frequencies and excludes all others. The word "octave" is borrowed from musical nomenclature where it refers to a span of eight notes. Therefore, the spectral bins of interest include 8.0, 10.0, 12.5, 16.0, 20.0, 25.0, 31.5, 40.0, 50.0, 63.0, 80.0, 100, 125, 160, 200, 250, 315, 400, 500, 630, 800, 1000, 1250, 1600, 2000, 2500, 3150, 4000, 5000, 6300, 8000, 10000, 12500, 16000, and 20000 Hz.

3. Results

3.1 Vibratory Pile Driving

Multiple sessions of vibratory pile driving were recorded. Each noise analysis of the sheet pile driving, temporary round pipe pile driving, and Wye-pile driving is discussed respectively.

3.1.1 Sheet Pile Driving – Face Wall

The vibratory driving data collection for the sheet pile along the face wall was collected on September 29, 2008 and the summary of the analysis is shown in **Table 1**. The distance to the 120 dB isopleths under worst case conditions was estimated to be 8.2 km assuming spherical spreading loss characteristics[1]. However, the average source level (SL) for sheet pile was 187.28 dB, resulting in a range from the source to the 120 dB isopleths of 2,312.06 m.

Table 1. Summary of Data Analysis (Vibratory, Sheet Pile)

Data Field	Values
Sampling Date & Time	09/29/2008, 08:08:57~10:58:14
Average Source Level [dB]	187.28
Max/Min Source Level [dB]	198.30 / 171.61
Average Sound Pressure Level [dB]	140.76
Max/Min Sound Pressure Level [dB]	156.98 / 119.98
Average Range to Source [m]	757.07
Max/Min Range to Source [m]	1207.66 / 31.62
Estimated 120 dB Distance (Worst Case) [m]	8218.98
Estimated 120 dB Distance (Average) [m]	2,312.06
Tide [ft]	18.93 ~ 30.42

3.1.1.1 Data Collection and Sampling Area

During the data collection, nine separate sessions were recorded with the distance between 32.6 m and 1.2 km under the tide level between 18.9~30.4 ft. **Table 2** shows all nine sessions in detail.

[1] Estimation assumes the spreading loss parameter to be 20 log R. Consideration of different parameters is discussed in the following sections.

Table 2. Data Collection Log (Vibratory, Sheet Pile)

SLM Data			Avisoft Data					Comments
File name	Start time	Stop time	File name	Start time	Stop time	Start offset	End offset	
831_DATA_099.xls	8:02:25	8:10:21	T0000037.wav	8:08:45	8:10:17	00:10	01:00	
831_DATA_100.xls	8:12:00	8:25:25	T0000041.wav	8:20:19	8:24:18	03:36	04:00	Range approx 330 m
			T0000042.wav	8:24:18	8:25:21	00:00	00:52	134 dB on SLM
831_DATA_101.xls	8:25:49	8:30:23	T0000043.wav	8:25:52	8:29:52	02:40	03:39	
831_DATA_102.xls	8:40:01	8:47:44	T0000046.wav	8:43:59	8:47:42	00:43	03:19	845 m away; Very long pile driving
831_DATA_103.xls	8:57:41	9:03:15	T0000047.wav	8:57:46	9:01:45	02:55	04:00	Range approx 1.2 km, signal is getting buried in the ambient noise after 10 sec
			T0000048.wav	9:01:45	9:03:13	00:00	00:50	
831_DATA_104.xls	9:11:37	9:12:39	T0000049.wav	9:11:35	9:12:37	00:00	00:52	30-40 m away, 147 dB on SLM
831_DATA_105.xls	9:19:11	9:21:31	T0000050.wav	9:19:09	9:21:36	00:51	01:26	120 m range, 140 dB on SLM
831_DATA_106.xls	9:27:19	9:32:05	T0000051.wav	9:27:24	9:31:24	02:46	04:00	Survey vessel visible on Avisoft data
			T0000052.wav	9:31:24	9:32:02	00:00	00:20	Range 411 m
831_DATA_111.xls	10:58:02	10:58:40	T0000062.wav	10:57:53	10:58:45	00:00	00:21	

The locations of sampling area and vibratory sheet pile driving site were logged with GPS and were synchronized with acoustic data collection. **Figure 4** shows the relative positions of the pile driving and sampling locations. The yellow push pin icon refers to the location of pile driving site (N 61°15'4.941", W 149°52'56.875") and the light green tracks indicate the data collection locations.

Figure 4. Aerial Map of Sample Location and Pile Driving Site (Vibratory, Sheet Pile)

3.1.1.2 Data Processing and Analysis

The sound pressure levels of all measured vibratory sheet pile driving ranged from 119.98 to 156.98 dB re 1μPa during nine recording sessions. Assuming nominal transmission loss characteristics, their equivalent source levels are estimated to be 171.61 ~ 198.30 dB re 1μPa. The SPL's, SL's, the distance from the pile driving site, and tide levels of all measurement are illustrated in the order they were collected in **Figures 5** and **6**. ("Measurement Index" in the x-axis represents a unitless time index in the order of measurement).

As expected, the tide level significantly affects the propagation of the sound energy (the higher the tide, the more efficient transmission of the sound energy). As illustrated in **Figure 6**, tide levels during the first eight recording sessions were very high (26.1~30.4 ft), but the last session was as low as 18.9 ft, causing the weak reception of sound energy at the recording locations.

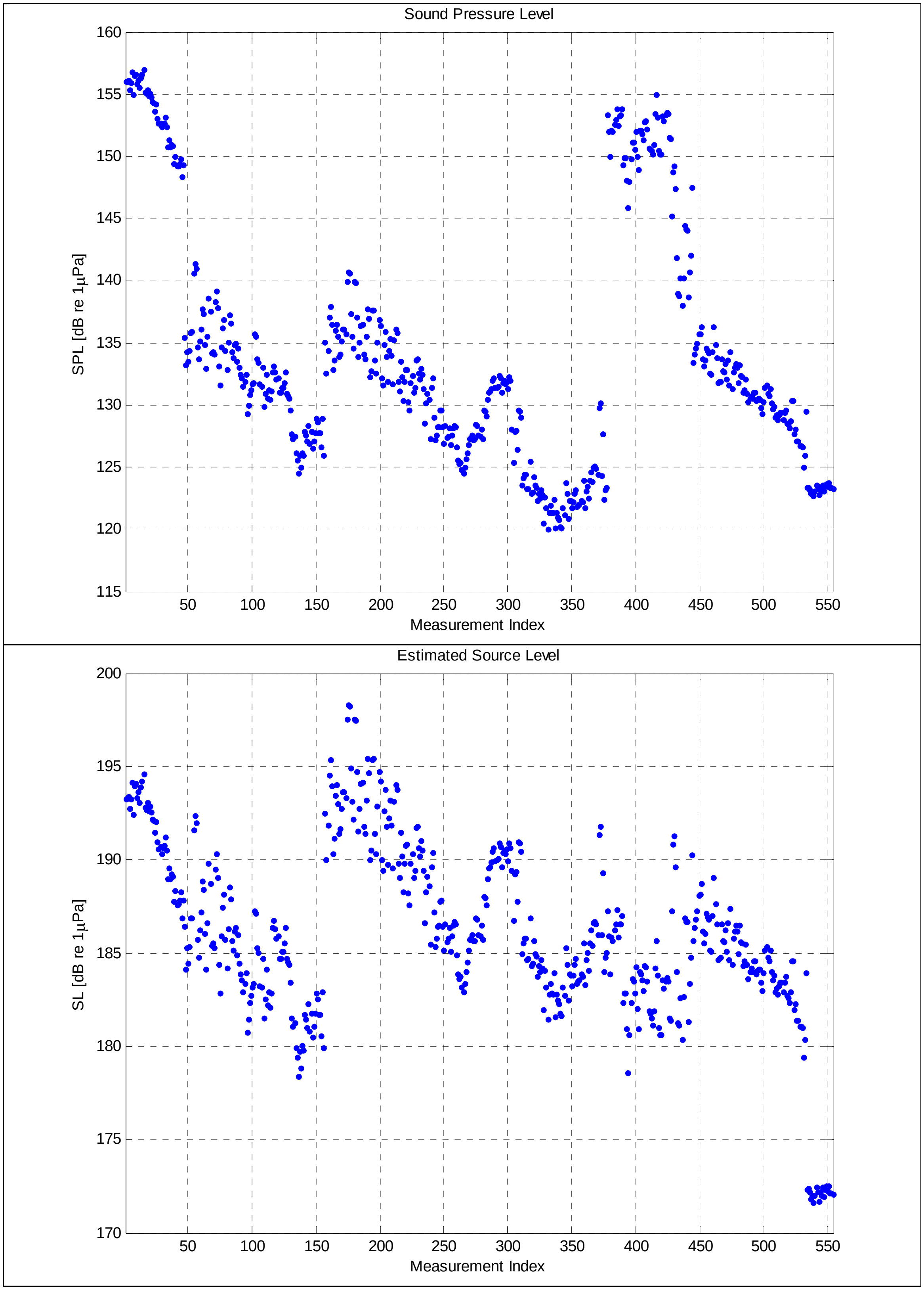
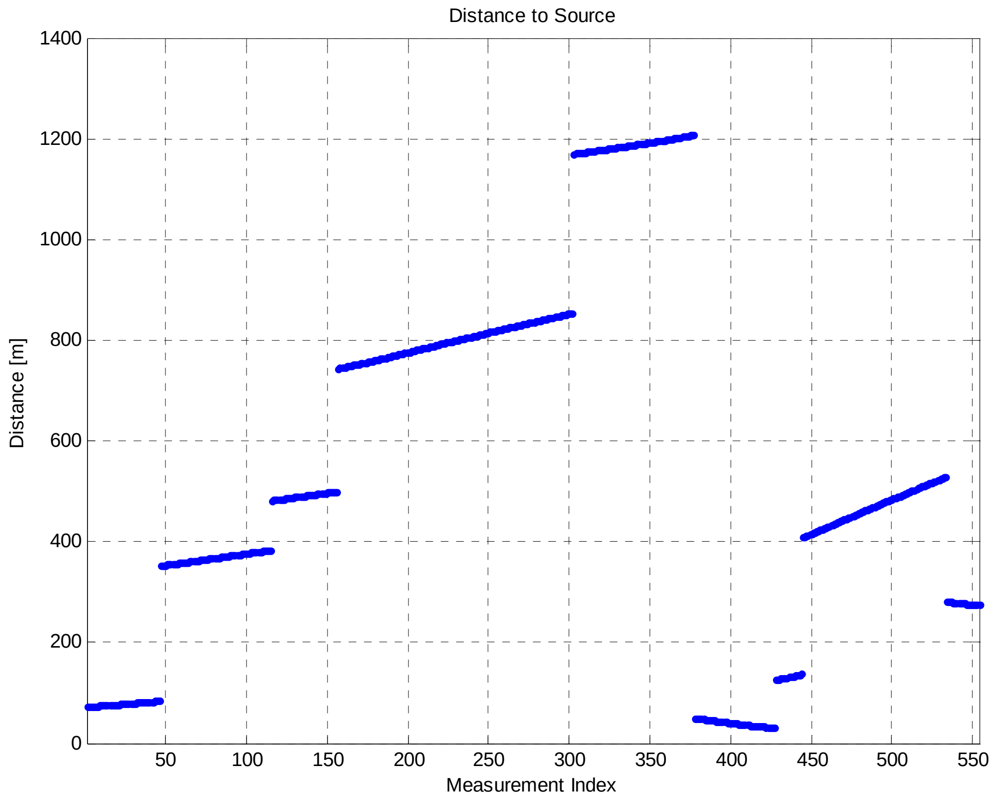


Figure 5. Sound Pressure Level and Estimated Source Level (Vibratory, Sheet Pile)



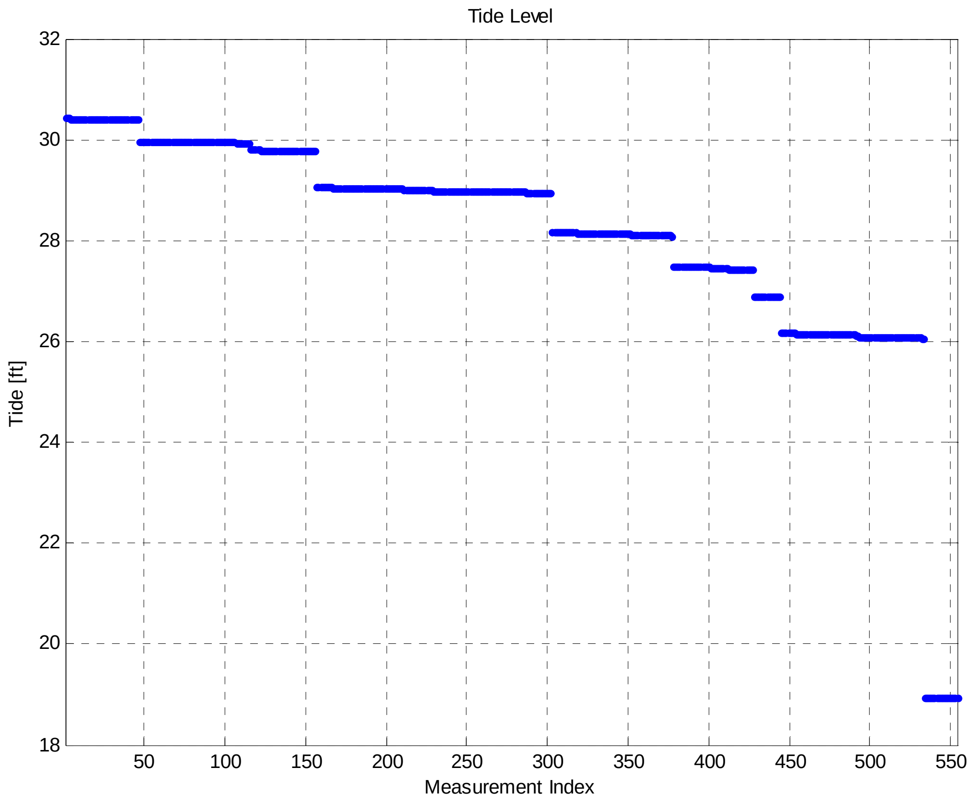


Figure 6. Distance to Source and Tide Level (Vibratory, Sheet Pile)

One-third octave spectrum was averaged over all measured vibratory sheet pile driving. These means and their standard deviation are shown in **Figure 7**. The average spectral energy slowly increases until it peaks at 4 kHz, and sharply declines afterward. The trend of spectral energy distribution is consistent throughout the measurements. Due to the various peak energy levels from all the measurements, the spectral energy around the peak frequency between 1 kHz and 20 kHz exhibits the greatest variation. However, the overall deviation stays relatively low.

3.1.1.3 Worst Case Analysis

When all SPL's are converted to SL's and assuming spherical spreading for transmission loss for the distance from the pile driving site, the incident with the maximum value of SL is taken for the worst case analysis. This sample is considered as the loudest incident among the all measurement in nine recording sessions.

The details of the worst case analysis (**Table 3**), were developed at 8:45:08 am Alaska local time on 9/29/2008. The SPL value of 140.71 dB re 1µPa was measured at the distance of 757.07 m, and its estimated SL is calculated to be 198.30 dB re 1µPa. The tide level was reported at 29.04 ft according to NOAA's estimated tide data[2]. Using this maximum SL value, the distance to the 120 dB isopleth under worst case conditions was estimated to be 8,218.98 m from the pile driving site.

Table 3. Summary of Worst Case Analysis (Vibratory, Sheet Pile)

Data Field	Values
Data File Name	T0000046.WAV
Date & Time	09/29/2008, 08:45:08
Time Offset in File [sec]	69
Range to Source [m]	757.07
Sound Pressure Level [dB re 1µPa]	140.71
Estimated Source Level [dB re 1µPa]	198.30
Estimated 120 dB Distance [m]	8218.98
Tide [ft]	29.04

Actual vibratory pile driving started at the 43rd second and continued until the 199th second in the recorded file (T0000046.wav). The estimated maximum SL value occurred at the 69th second. The raw time series of this worst case signal is depicted in **Figure 8**.

[2] Available at NOAA web site: http://co-ops.nos.noaa.gov/geo.shtml?location=Anchorage%2C+AK

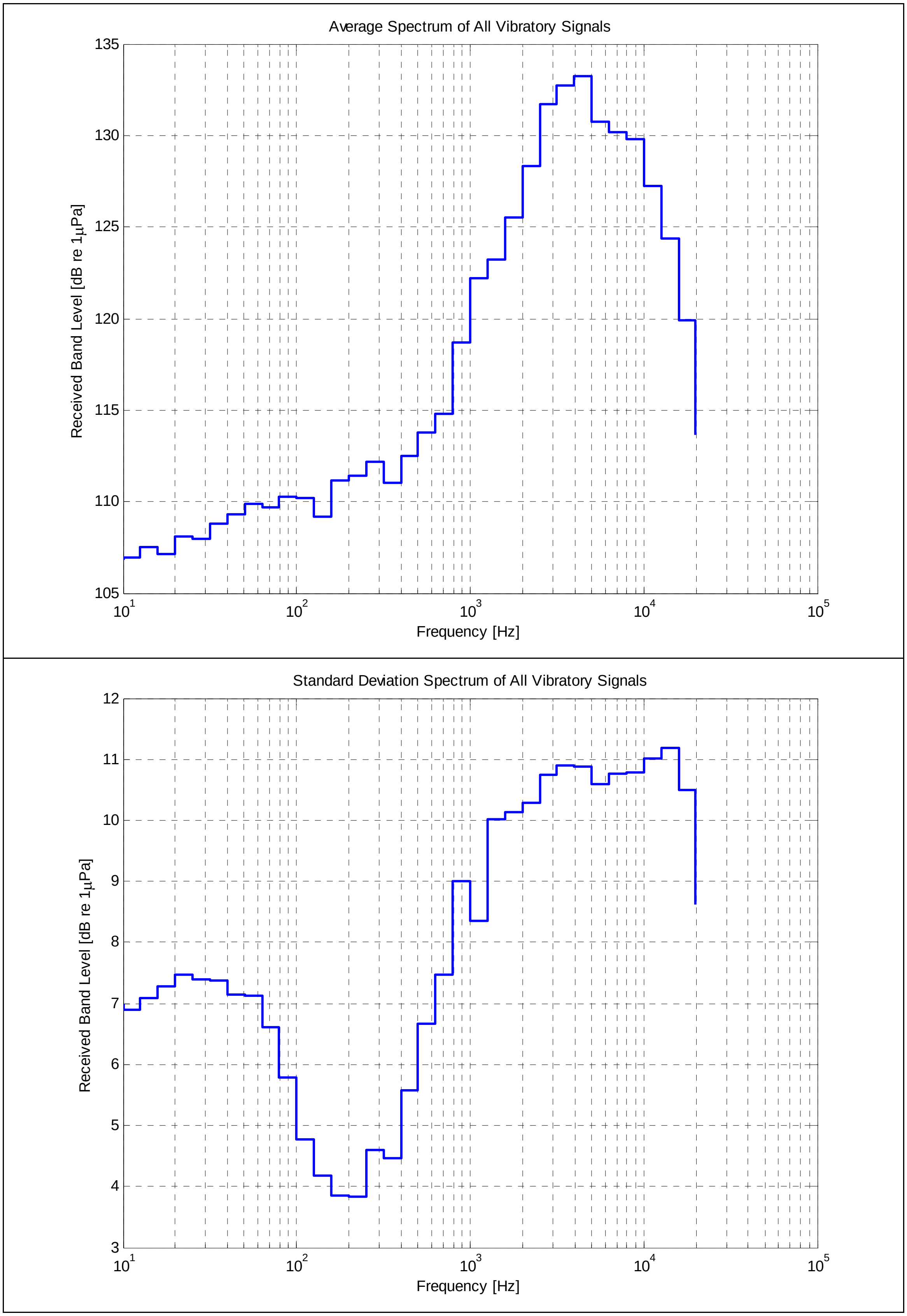
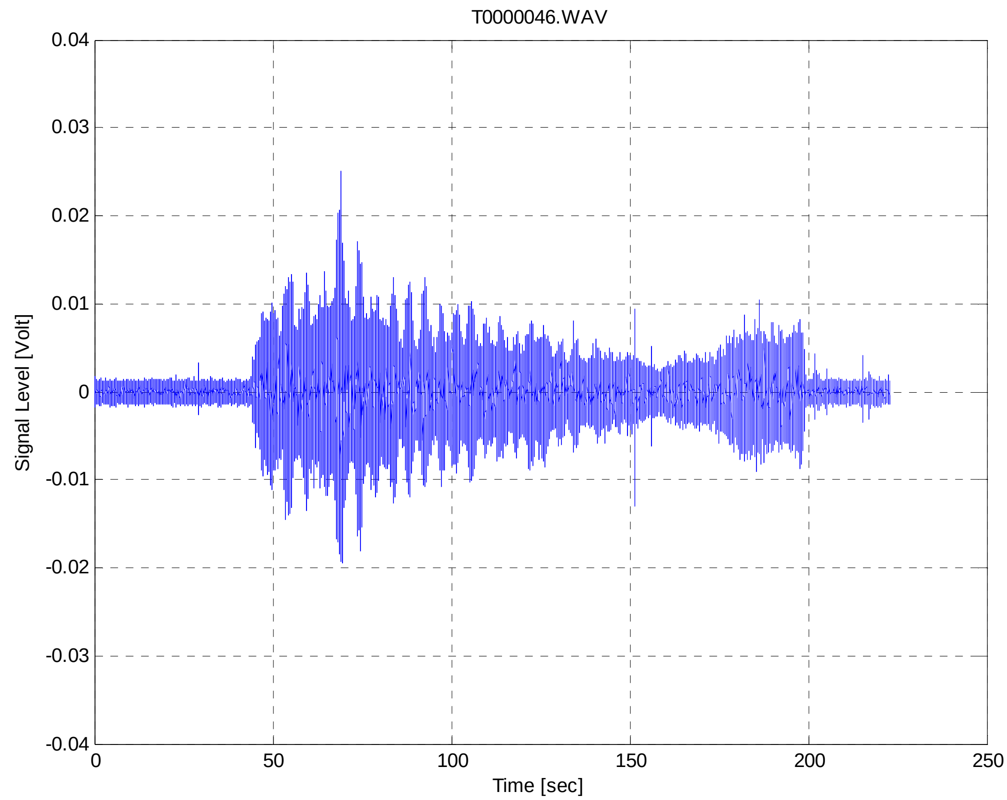


Figure 7. Average Spectrum and Standard Deviation (Vibratory, Sheet Pile)



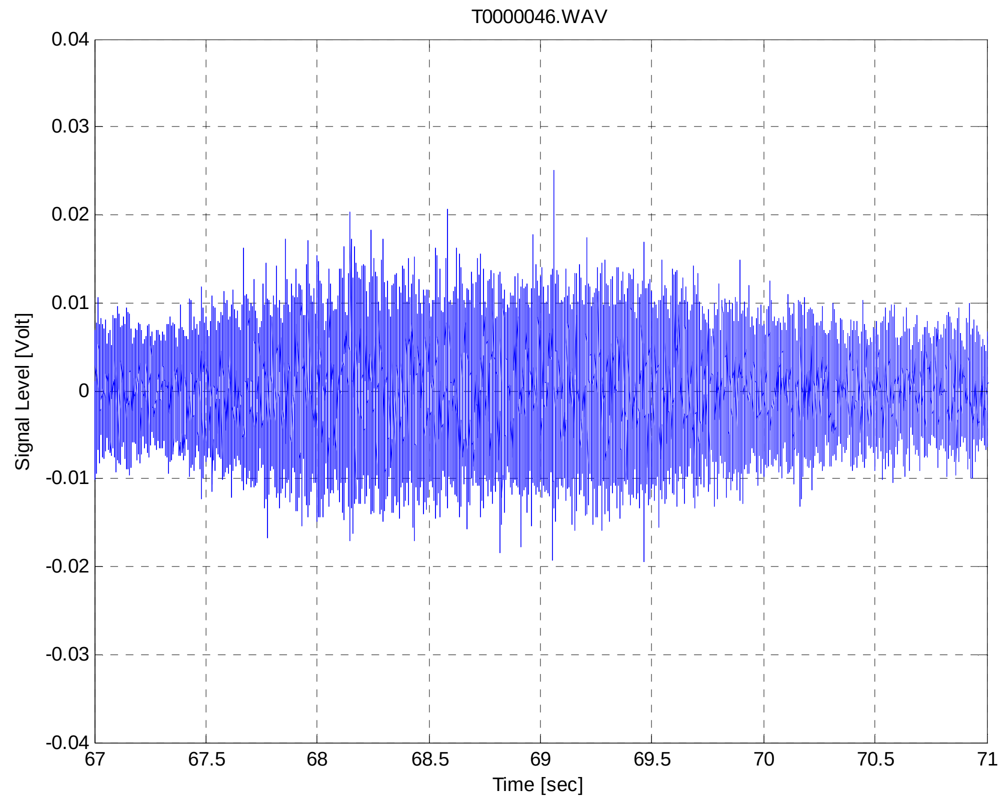


Figure 8. Raw Time Series of Pile Driving (Vibratory, Sheet Pile)

One-third octave spectrum of this particular worst case is shown in **Figure 9**. Most of the spectral energy is concentrated between the 2 kHz and 10 kHz bands, which follows the trend of the rest of the measurement in all nine recording sessions.

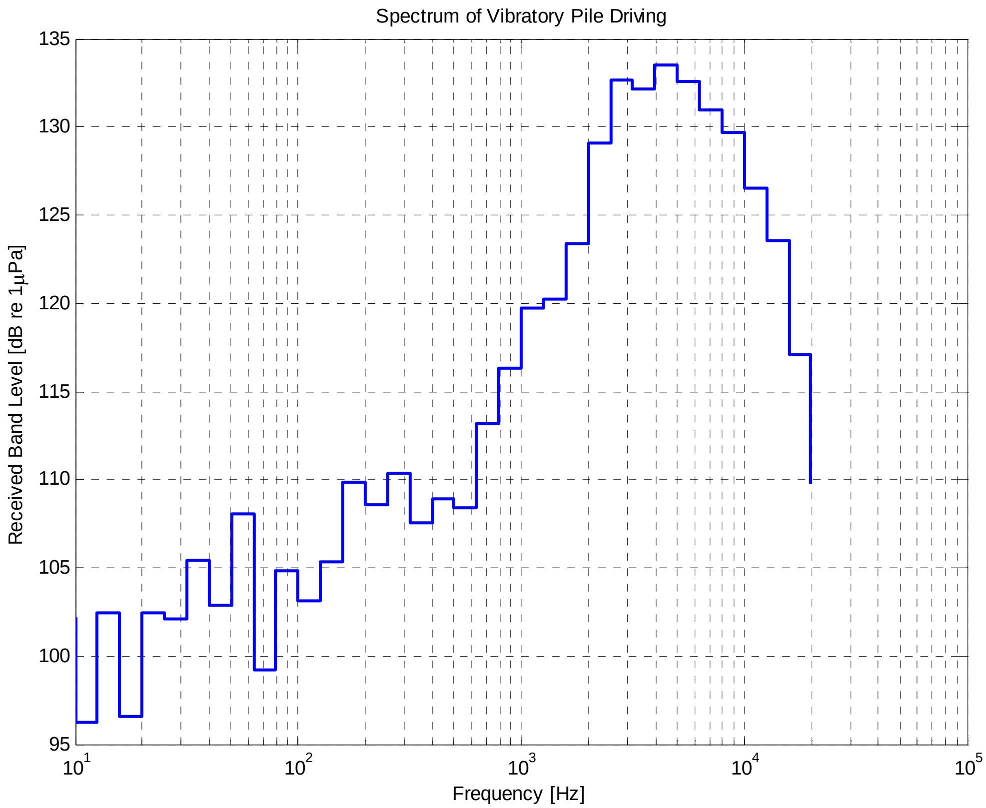


Figure 9. One-Third Octave Spectrum for Pile Driving (Vibratory, Sheet Pile)

A nominal transmission loss of 20 log R was used to calculate SL values, although the actual transmission loss is a function of many complicated environmental variables. Thus, different possibilities for transmission loss, such as 16 log R, 18 log R, 22 log R, and 24 log R, are considered to estimate the SL value at the pile driving location and eventually to compute the 120 dB distance.

Figure 10 shows five possible situations of SPL values for vibratory sheet pile driving (face wall) with the varying ranges up to 10 km based on the worst case measurement: the red curve indicates the SPL using the transmission loss with 16 log R; the magenta curve indicates the SPL using the transmission loss with 18 log R; the blue curve indicates the SPL using the transmission loss with 20 log R; the cyan curve indicates the SPL using the transmission loss with 22 log R; and the green curve indicates the SPL using the transmission loss with 24 log R.

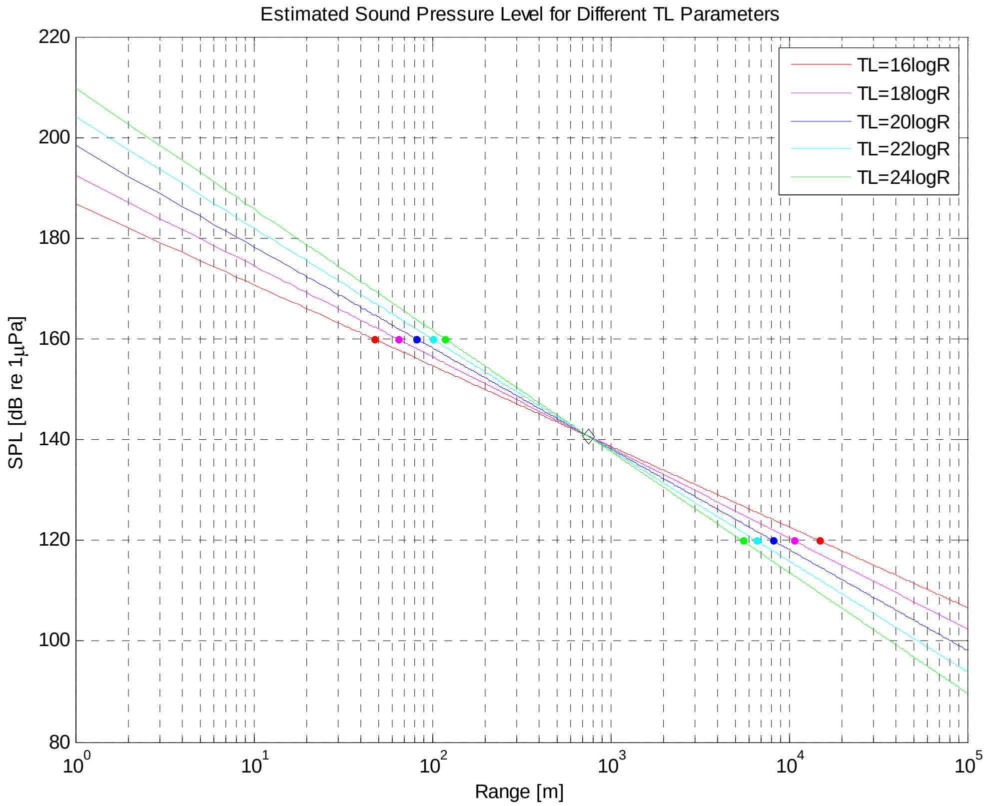


Figure 10. Consideration of Different Transmission Loss Configuration, Vibratory Sheet Pile Driving

The estimated SL's and the corresponding 120 dB distance for these different transmission loss configurations are listed in **Table 4**. In this worst case situation, the nominal transmission loss configuration (20 log R) provides the estimated distance to 120 dB to be 8,218.98 m, but it can possibly range between 5,523.37 m and 14,918.98 m.

Table 4. Estimated Source Level and 120 dB Distances of Worst Case Incidence (Vibratory, Sheet Pile)

Transmission Loss	Estimated SL [dB re 1μPa]	Estimated 120 dB Distance [m]
16 log R	186.78	14918.98
18 log R	192.54	10712.58
20 log R	198.30	8218.98
22 log R	204.05	6617.06
24 log R	209.81	5523.37

3.1.2 Wye-Pile Driving

The Wye-pile driving sessions were collected on September 26, 2008 and the summary of the analysis is shown in **Table 5**. The distance to the 120 dB isopleths under worst case conditions was estimated to be 1.32 km assuming spherical spreading loss characteristics[3]. However, the average source level (SL) for Wye-pile was 176.07 dB, resulting in a range from source to the 120 dB isopleths of 636.06 m.

Table 5. Summary of Data Analysis (Vibratory, Wye-Pile)

Data Field	Values
Sampling Date & Time	09/26/2008, 16:48:50~16:53:27
Average Source Level [dB]	176.07
Max/Min Source Level [dB]	182.40 / 160.82
Average Sound Pressure Level [dB]	133.69
Max/Min Sound Pressure Level [dB]	138.92 / 121.91
Average Range to Source [m]	126.46
Max/Min Range to Source [m]	151.98 / 88.26
Estimated 120 dB Distance (Worst Case) [m]	1318.83
Estimated 120 dB Distance (Average) [m]	636.06

3.1.2.1 Data Collection and Sampling Area

During the data collection, two separate sessions were recorded with the distance between 88.25 m and 151.98 m under the tide level between 26.61 and 26.99 ft. **Table 6** shows both sessions in detail.

Table 6. Data Collection Log (Vibratory, Wye-Pile)

SLM Data			Avisoft Data				
File name	Start time	Stop time	File name	Start time	Stop time	Start offset	End offset
831_DATA_086.xls	16:48:49	16:54:22	T0000017.wav	16:48:49	16:52:49	00:01	01:01
			T0000018.wav	16:52:49	16:54:23	00:29	00:40

The sampling locations and Wye-pile driving site were logged from GPS and were synchronized with acoustic data collection. **Figure 11** shows the relative positions of the pile driving and sampling locations. The yellow push pin icon refers to the location of pile driving site (N 61°15'4.941", W 149°52'56.875") and the light green tracks indicate the data collection locations.

[3] Estimation assumes the spreading loss parameter to be 20 log R. Consideration of different parameters is discussed in the following sections.

Figure 11. Aerial Map of Sample Location and Pile Driving Site (Vibratory, Wye-Pile)

3.1.2.2 Data Processing and Analysis

The sound pressure levels measured during all Wye-pile vibratory driving ranged from 121.91 to 138.92 dB re 1μPa during the two recording sessions. Assuming spherical spreading during transmission loss, the equivalent source levels are estimated between 160.82 and 182.40 dB re 1μPa. The SPL's, SL's, the distance from the pile driving site, and tide levels for all measurements are illustrated in the order they were collected in **Figure 12** and **Figure 13**.

As noted in the previous section, the tide level significantly affects the propagation of the sound energy (the higher tide, the more efficient transmission of the sound energy). As shown in **Figure 13**, tide levels during both recording sessions were relatively high (26.61~26.99 ft).

One-third octave spectrum averaged over all measured Wye-pile driving is shown in **Figure 14**. The spectral energy slowly increases, peaks at 4 kHz, and declines afterward. The trend of spectral energy distribution is consistent throughout the measurement. **Figure 14** also shows the standard deviation spectrum. The low frequency bands have relatively high variation, but the overall deviation stays low.

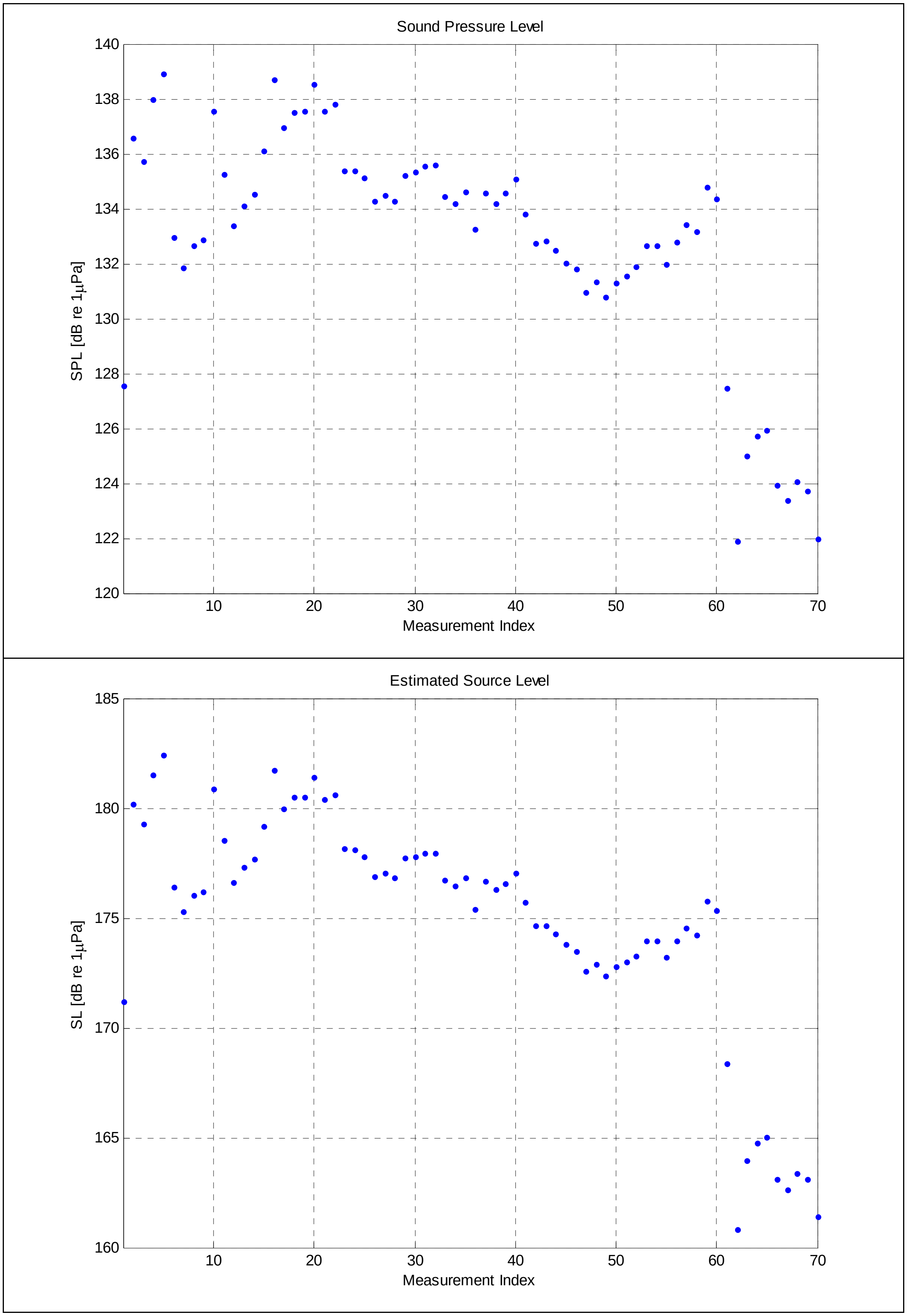


Figure 12. Sound Pressure Level and Estimated Source Level (Vibratory, Wye-Pile)

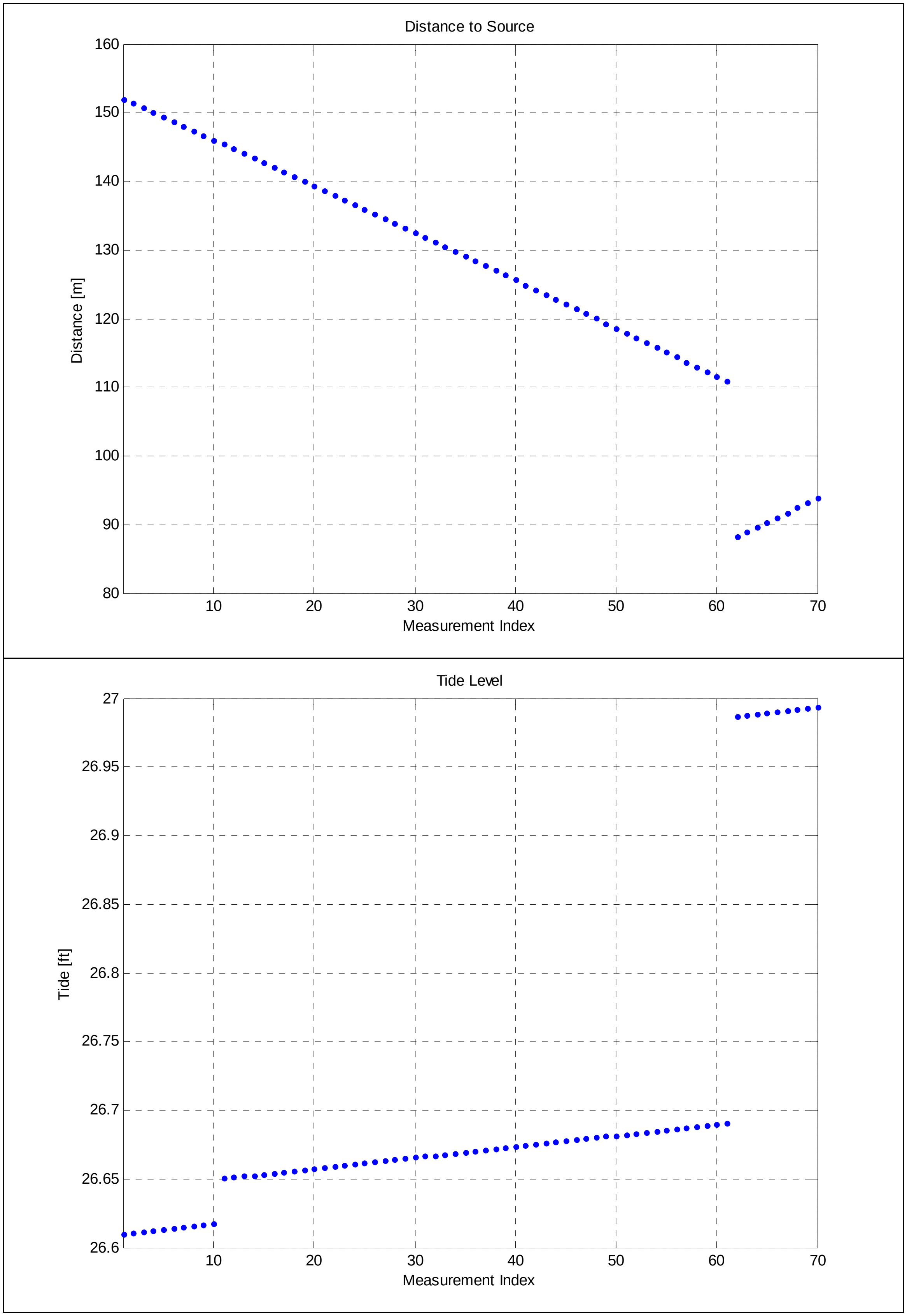


Figure 13. Distance to Source and Tide Level (Vibratory, Wye-Pile)

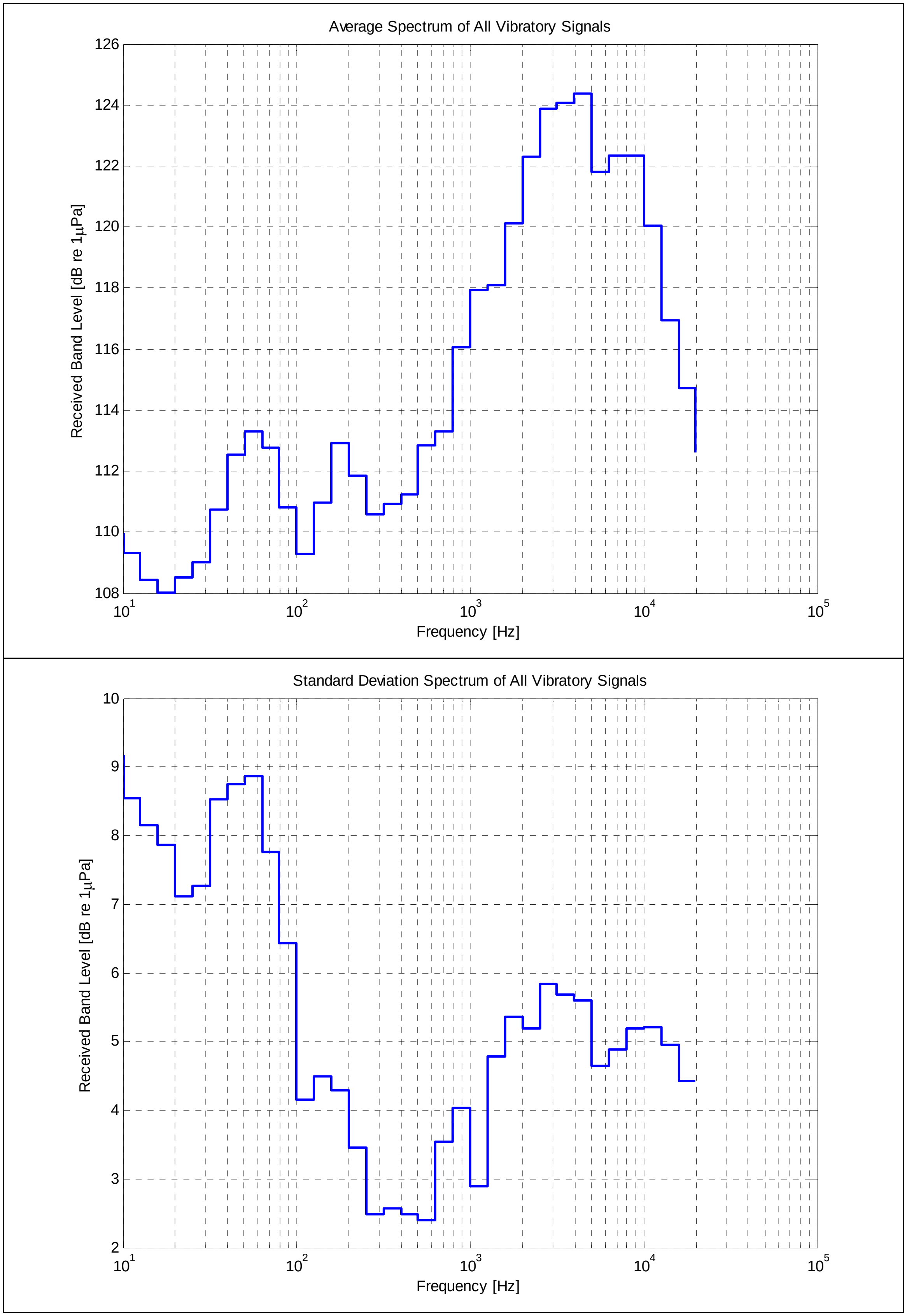


Figure 14. Average Spectrum and Standard Deviation (Vibratory, Wye-Pile)

3.1.2.3 Worst Case Analysis

When all SPL's are converted to SL's and assuming spherical spreading for transmission loss from the pile driving site, the incident with the maximum value of SL is taken for worst case analysis. This sample is considered as the loudest incident among the measurements in both recording sessions.

Table 7 shows the worst case vibratory noise event that occurred during Wye-Pile driving at 4:48:54 pm Alaska local time on 9/26/2008. The SPL value of 138.92 dB re 1µPa was measured at the distance of 149.37 m, and its estimated SL is calculated to be 182.40 dB re 1µPa. The tide level was reported at 26.61 ft. Using this maximum SL value, the distance to the 120 dB isopleth under worst case conditions was estimated to be 1,318.83 m from the pile driving site.

Table 7. Summary of Worst Case Analysis (Vibratory, Wye-Pile)

Data Field	Values
Data File Name	T0000017.WAV
Date & Time	09/26/2008, 16:48:54
Time Offset in File [sec]	5
Range to Source [m]	149.37
Sound Pressure Level [dB]	138.92
Estimated Source Level [dB]	182.40
Estimated 120 dB Distance [m]	1318.83
Tide [ft]	26.61

Actual vibratory pile driving started from the 1st second and continued until the 61st second in the recorded file (T0000017.wav). The estimated maximum SL value occurred at the 5th second. The raw time series of this worst case signal is depicted in **Figure 15**.

One-third octave spectrum of this particular case is shown in **Figure 16**. The majority of the spectral energy is concentrated between the 2 kHz and 10 kHz bands, which follows the trend of the rest of the measurement in both recording sessions.

A nominal transmission loss configuration of 20 log R was used to calculate SL values, although the actual transmission loss is a function of many complicated environmental variables. Thus, different possibilities of transmission loss, such as 16 log R, 18 log R, 22 log R, and 24 log R, are considered to estimate the SL value at the pile driving location and eventually to compute 120 dB distance.

Figure 17 shows five possible situations of SPL values for the vibratory wye pile driving with varying ranges up to 10 km based on the worst case measurement: the red curve indicates the SPL using the transmission loss with 16 log R; the magenta curve indicates the SPL using the transmission loss with 18 log R; the blue curve indicates the SPL using the transmission loss with 20 log R; the cyan curve indicates the SPL using the transmission loss with 22 log R; and the green curve indicates the SPL using the transmission loss with 24 log R.

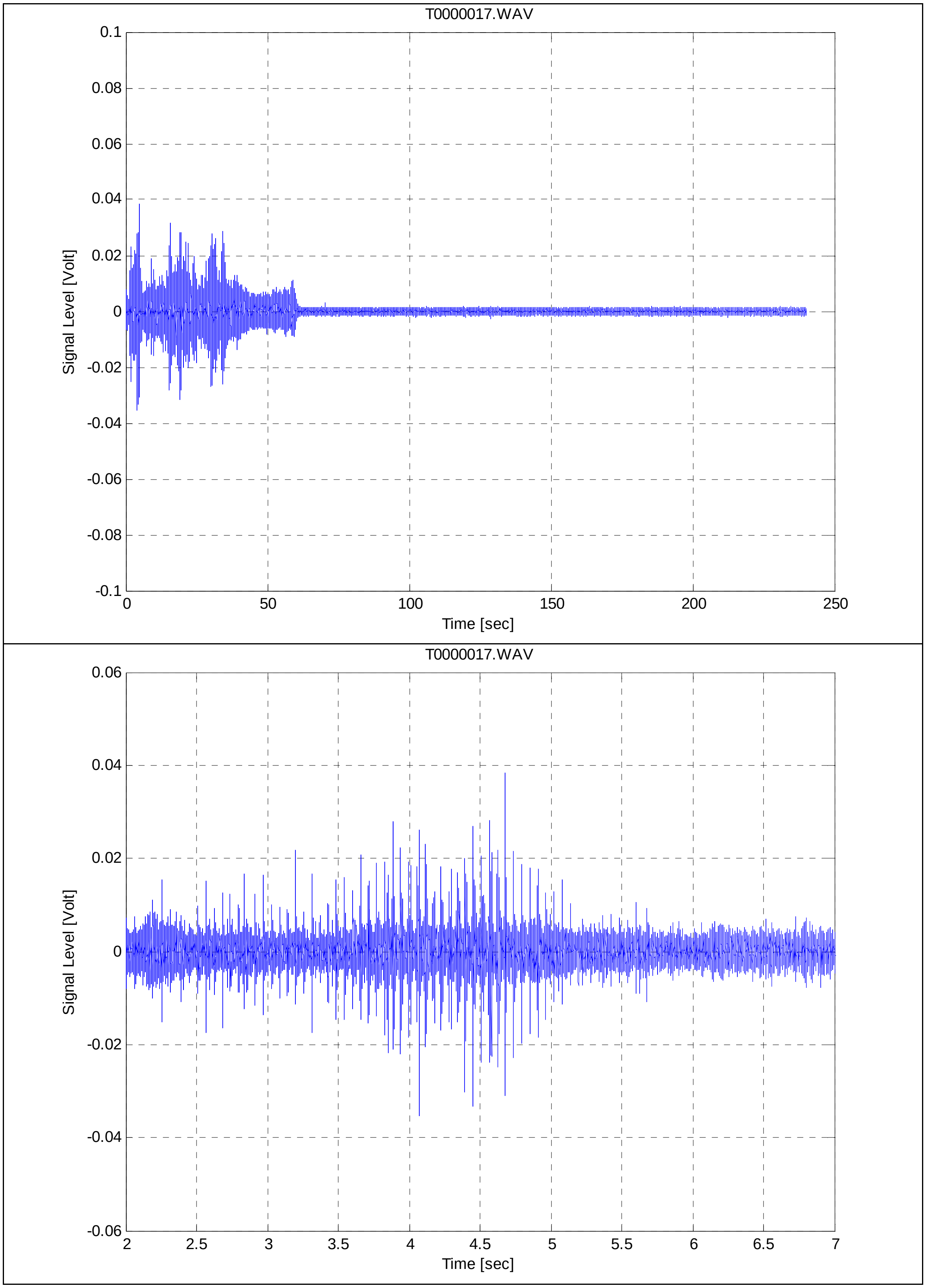


Figure 15. Raw Time Series of Pile Driving (Vibratory, Wye-Pile)

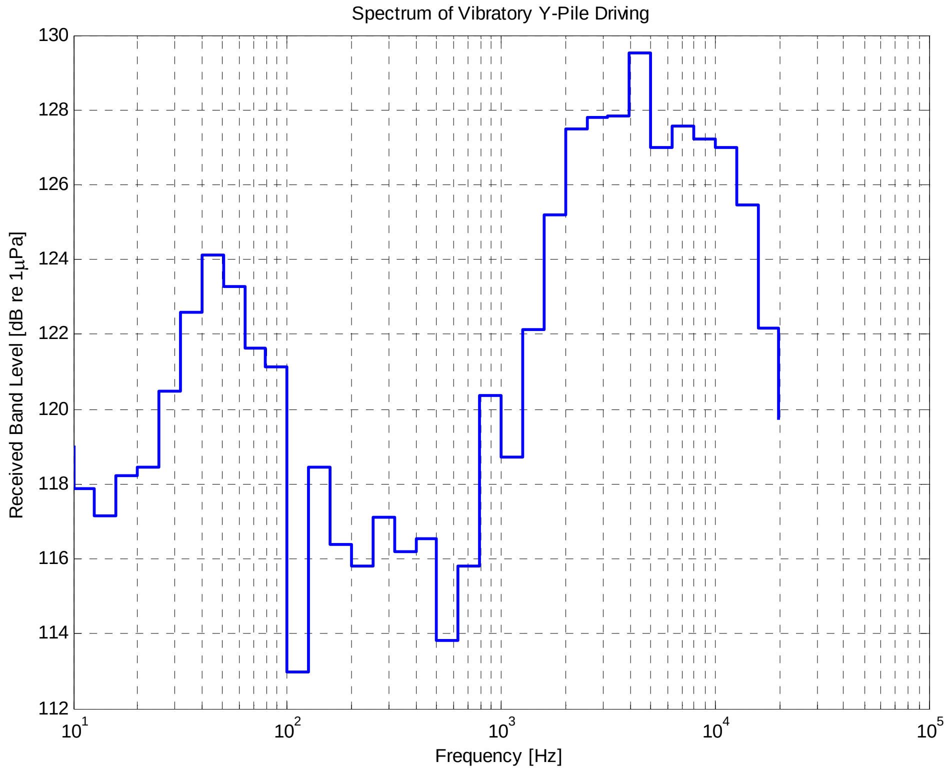


Figure 16. One-Third Octave Spectrum for Pile Driving (Vibratory, Wye-Pile)

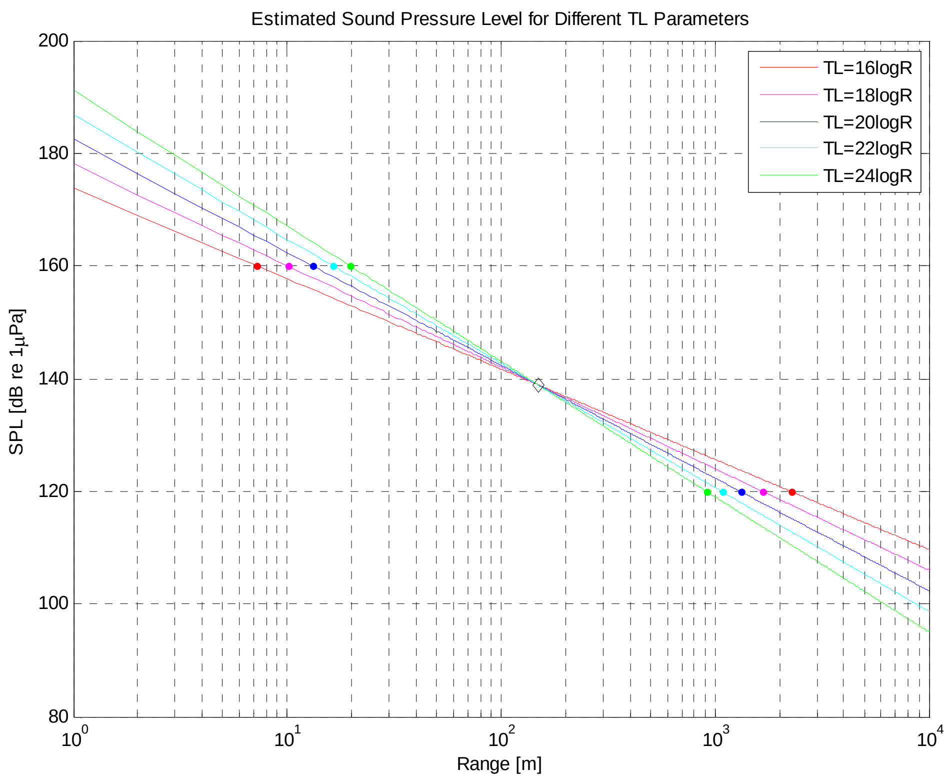


Figure 17. Consideration of Different Transmission Loss Configuration (Vibratory, Wye-Pile)

The estimated SL's and the corresponding 120 dB distance for these different transmission loss configurations are listed in **Table 8**. In this worst case situation, the nominal transmission loss configuration (20 log R) provides the estimated distance to 120 dB to be 1,318.83 m, but can possibly range between 917.35 m and 2,273.40 m.

Table 8. Estimated Source Level and 120 dB Distances of Worst Case Incidence (Vibratory, Wye-Pile)

Transmission Loss	Estimated SL [dB re 1μPa]	Estimated 120 dB Distance [m]
16 log R	173.71	2273.39
18 log R	178.06	1679.94
20 log R	182.40	1318.83
22 log R	186.75	1081.92
24 log R	191.10	917.35

3.1.3 Round Pile Driving

The temporary round pipe pile driving sessions were collected on September 25, 2008 and the summary of the analysis is shown in **Table 9**. The distance to the 120 dB isopleth under worst case conditions was estimated to be 559.23 m assuming spherical spreading loss characteristics[4]. However, the average source level (SL) for round pile was 60.77 dB, resulting in a range from source to the 120 dB isopleth of 109.27 m.

Table 9. Summary of Data Analysis (Vibratory, Round Pile)

Data Field	Values
Sampling Date & Time	09/25/2008, 18:04:39~18:17:03
rms Window Size [sec]	1/8 (0.125)
Average Source Level [dB]	160.77
Max/Min Source Level [dB]	174.95 / 150.73
Average Sound Pressure Level [dB]	131.49
Max/Min Sound Pressure Level [dB]	144.03 / 120.06
Average Range to Source [m]	35.40
Max/Min Range to Source [m]	67.02 / 16.00
Estimated 120 dB Distance (Worst Case) [m]	559.23
Estimated 120 dB Distance (Average) [m]	109.27

3.1.3.1 Data Collection and Sampling Area

During the data collection, two separate sessions were recorded at distances ranging from 16 m to 67 m and tide levels between 27.45~ 27.81 ft. **Table 10** shows both sessions in detail.

[4] Estimation assumes the spreading loss parameter to be 20 log R. Consideration of different parameters is discussed in the following sections.

Table 10. Data Collection Log (Vibratory, Round Pile)

SLM Data			Avisoft Data				
File name	Start time	Stop time	File name	Start time	Stop time	Start offset	End offset
831_DATA_066.xls	18:06:00	18:09:16	T0000053.wav	18:04:39	18:08:39	01:00	04:00
			T0000054.wav	18:08:39	18:09:16	00:00	00:34
831_DATA_068.xls	18:14:00	18:17:03	T0000056.wav	18:13:59	18:17:03	00:33	01:10
				18:13:59	18:17:03	02:00	02:48

The sampling locations and steel pipe pile driving site were logged from GPS and were synchronized with acoustic data collection. **Figure 18** shows the relative positions of the round pile driving and sampling locations. The yellow push pin icon refers to the location of pile driving site (N61°15'4.941", W149°52'56.875") and the light green tracks indicate the data collection locations.

Figure 18. Aerial Map of Sample Location and Pile Driving Site (Vibratory, Round Pile)

3.1.3.2 Data Processing and Analysis

The sound pressure levels of all measured steel pipe pile driving ranged from 120.06 to 144.03 dB re 1μPa during both recording sessions. Assuming spherical spreading transmission loss characteristics, their equivalent source levels are estimated to be 150.73~174.95 dB re 1μPa as shown in **Figure 19 and Figure 20**.

One-third octave spectrum averaged over all measured vibratory round pile driving is shown in **Figure 20**. The spectral energy is concentrated between 200 Hz and 10 kHz with a slight null around 2 kHz bin. The trend of spectral energy distribution is consistent throughout the measurement. **Figure 20** also shows the standard deviation spectrum. The low frequency bands have relatively high variation, but the overall deviation stays low.

3.1.3.3 Worst Case Analysis

When all SPL's are converted to SL's and assuming spherical spreading for transmission loss from the pile driving site, the incident with the maximum value of SL is taken for the worst case analysis. This sample is considered as the loudest incident among the measurements in both recording sessions.

Table 11. Summary of Worst Case Analysis (Vibratory, Round Pile)

Data Field	Values
Data File Name	T0000053.WAV
Date & Time	09/25/2008, 18:05:42
Time Offset in File [sec]	63
Range to Source [m]	35.15
Sound Pressure Level [dB]	144.03
Estimated Source Level [dB]	174.95
[5]Estimated 120 dB Distance [m]	559.23
Tide [ft]	27.82

The actual vibratory pile driving started from the 60th second and continued until the 70th second in the recorded file (T0000053.wav). The estimated maximum SL value occurred at the 63rd second. The raw time series of this worst case signal is depicted in **Figure 19**.

As **Table 11** details, the worst case vibratory noise event that occurred during the driving of steel pipe pile was at 6:05:42 pm Alaska local time on 9/25/2008. The SPL value of 144.03 dB re 1μPa was measured at the distance of 35.15 m, and its estimated SL is calculated to be 174.95 dB re 1μPa. The tide level was reported at 27.82 ft. Using this maximum SL value, the distance to the 120 dB isopleths under worst case conditions was estimated to be 559.23 m from the pile driving site.

The estimated maximum SL value occurred at the 63rd second. The raw time series of this worst case signal is depicted in **Figure 21**.

One-third octave spectrum of this particular case is shown in **Figure 22**. Most of the spectral energy is concentrated between the 1 kHz and 20 kHz bands.

[5] Estimation assumes the spreading loss parameter to be 20 log R. Consideration of different parameters is discussed in the following sections.

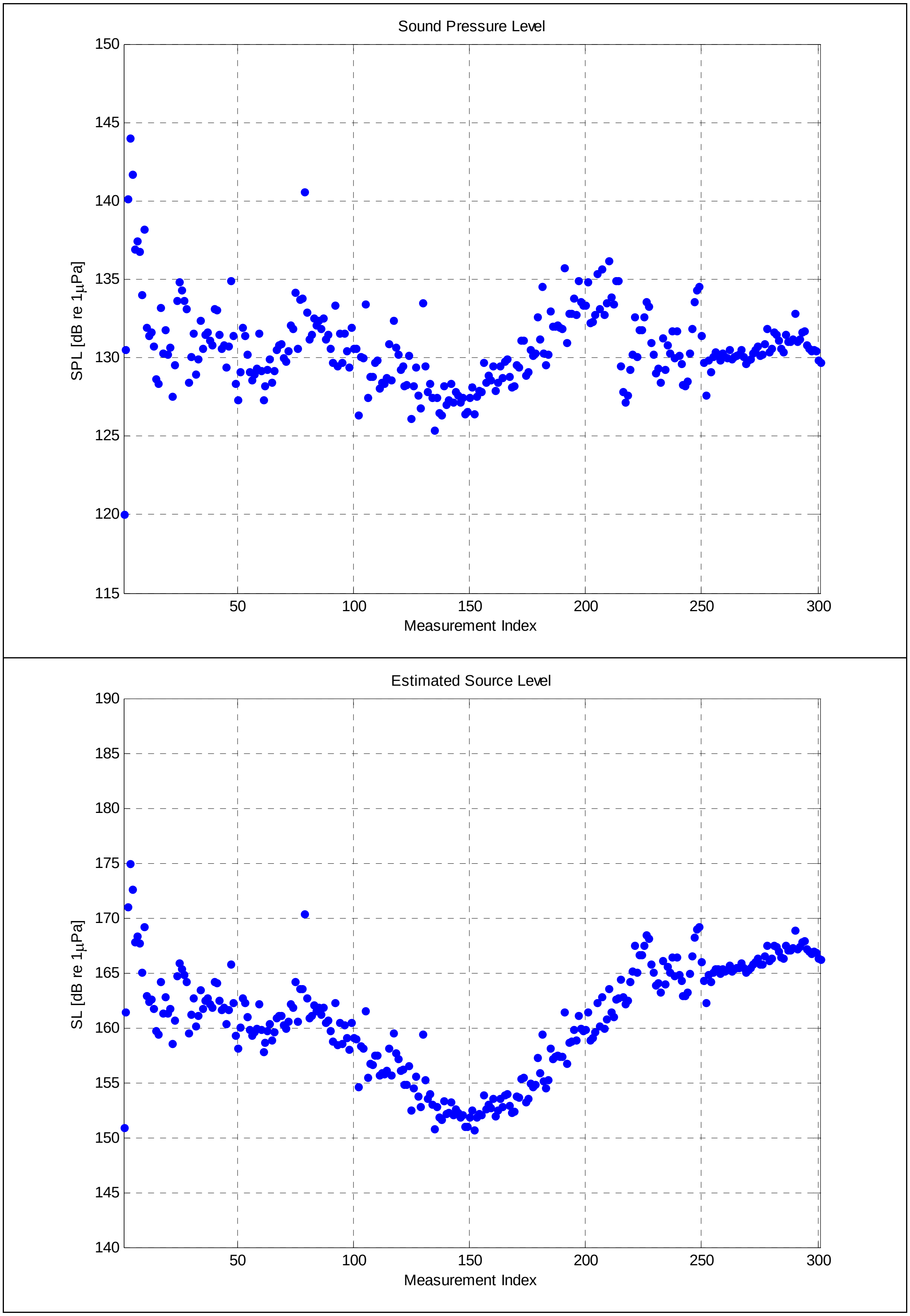


Figure 19. Sound Pressure Level and Estimated Source Level (Vibratory, Round-Pile)

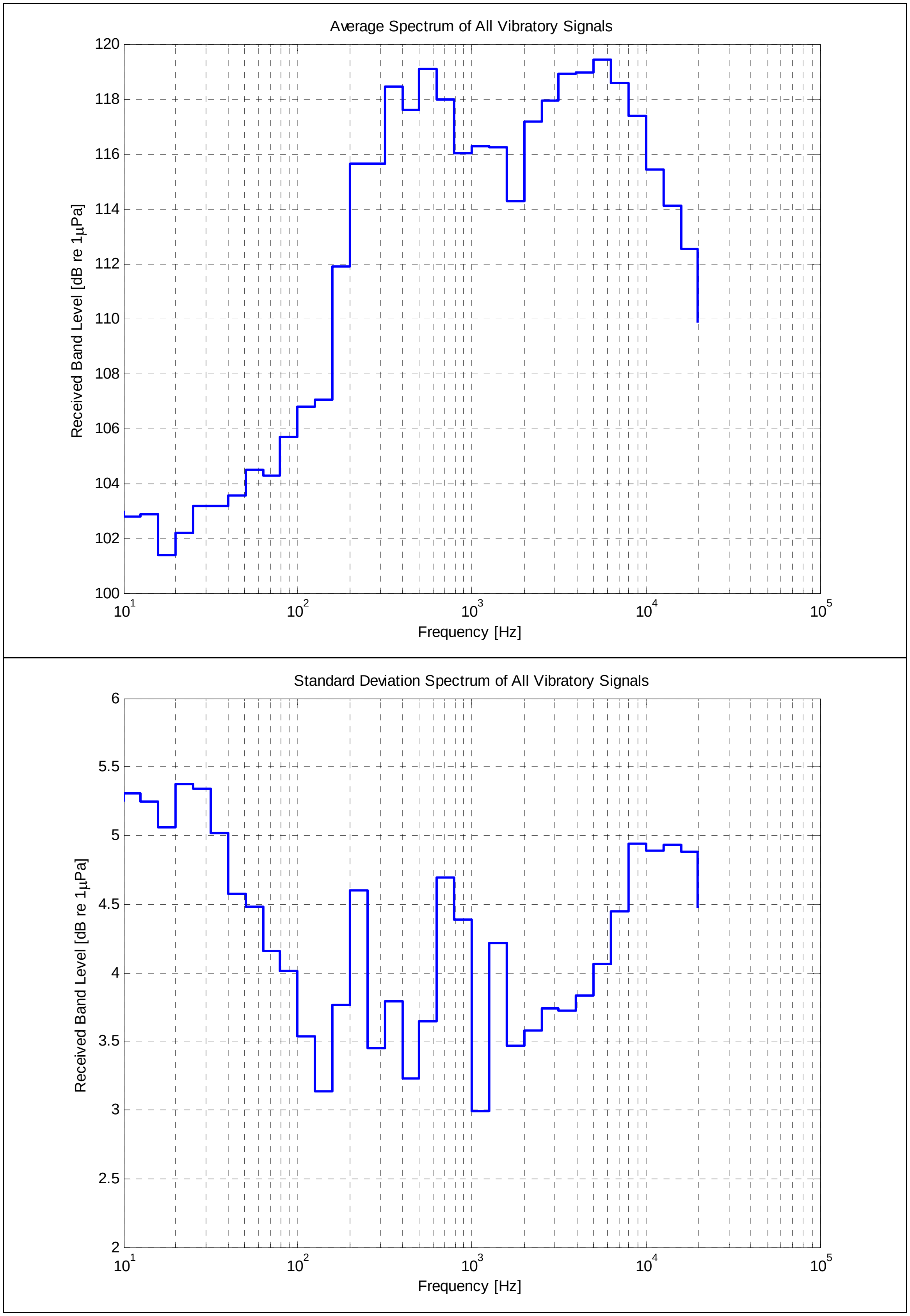


Figure 20. Average Spectrum and Standard Deviation (Vibratory, Round-Pile)

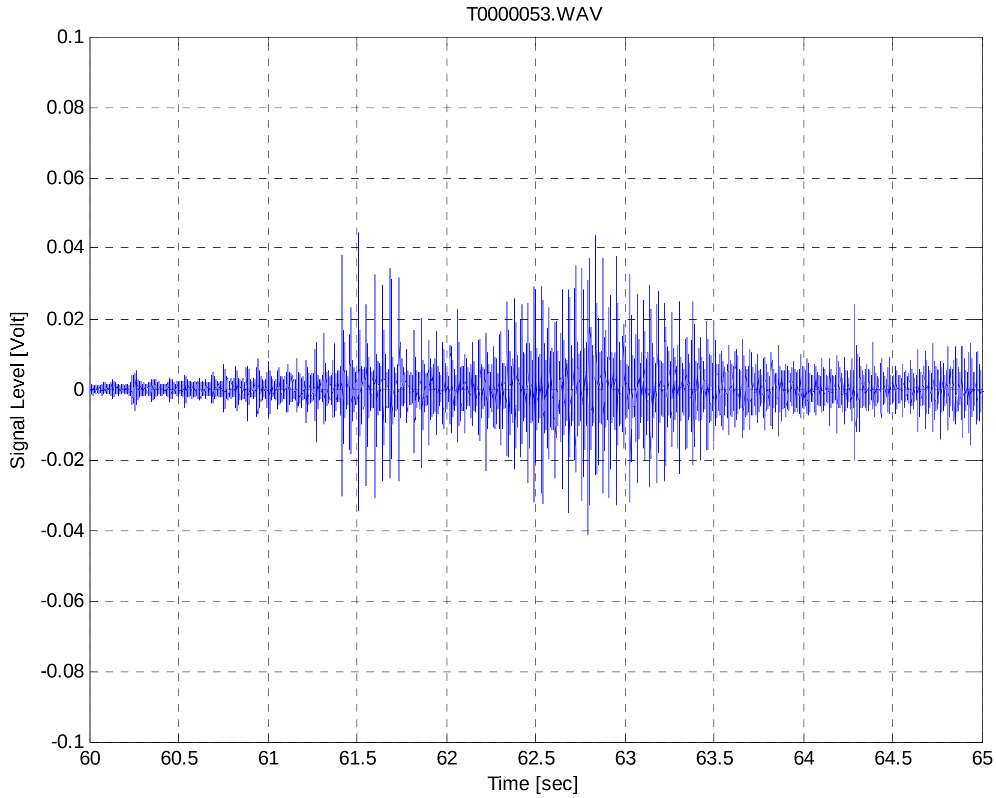


Figure 21. Raw Time Series of Pile Driving (Vibratory, Round Pile)

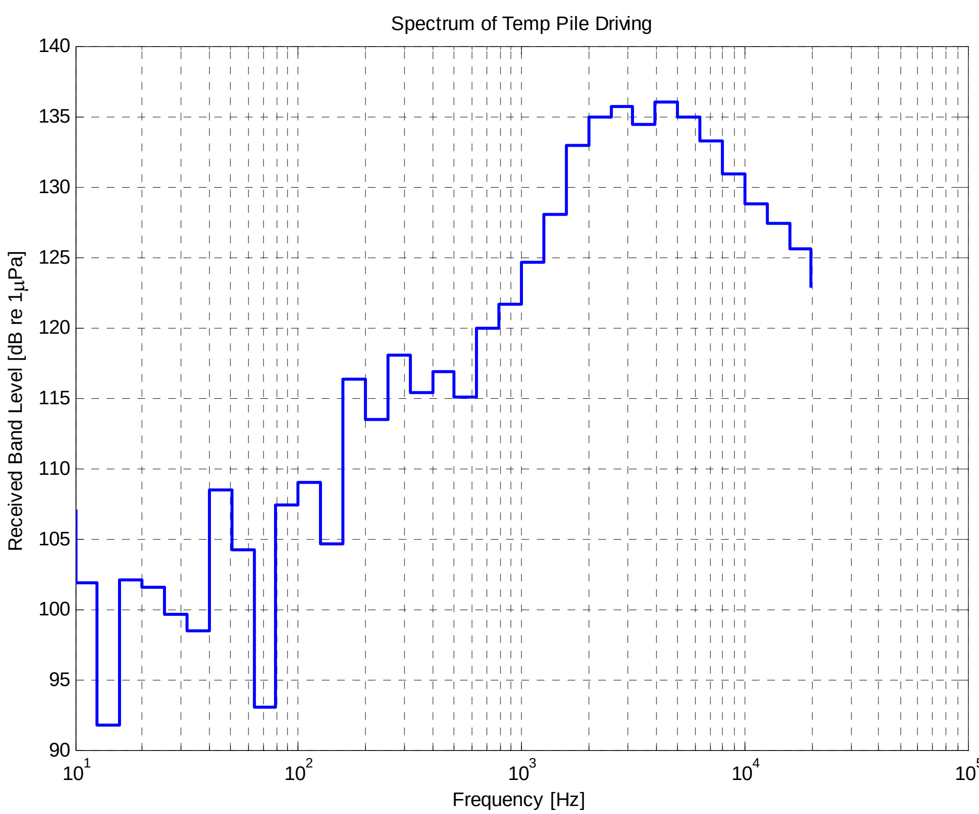


Figure 22. One-Third Octave Spectrum for Pile Driving (Vibratory, Round Pile)

A nominal transmission loss configuration of 20 log R is used to calculate SL values, although the actual transmission loss is a function of many complicated environmental variables. Thus, different possibilities of transmission loss, such as 16 log R, 18 log R, 22 log R, and 24 log R, are considered to estimate the SL value at the pile driving location and eventually to compute 120 dB distance.

Figure 23 shows five possible situations of SPL values for the vibratory round pile driving with varying ranges up to 10 km based on the worst case measurement: the red curve indicates the SPL using the transmission loss with 16 log R; the magenta curve indicates the SPL using the transmission loss with 18 log R; the blue curve indicates the SPL using the transmission loss with 20 log R; the cyan curve indicates the SPL using the transmission loss with 22 log R; and the green curve indicates the SPL using the transmission loss with 24 log R.

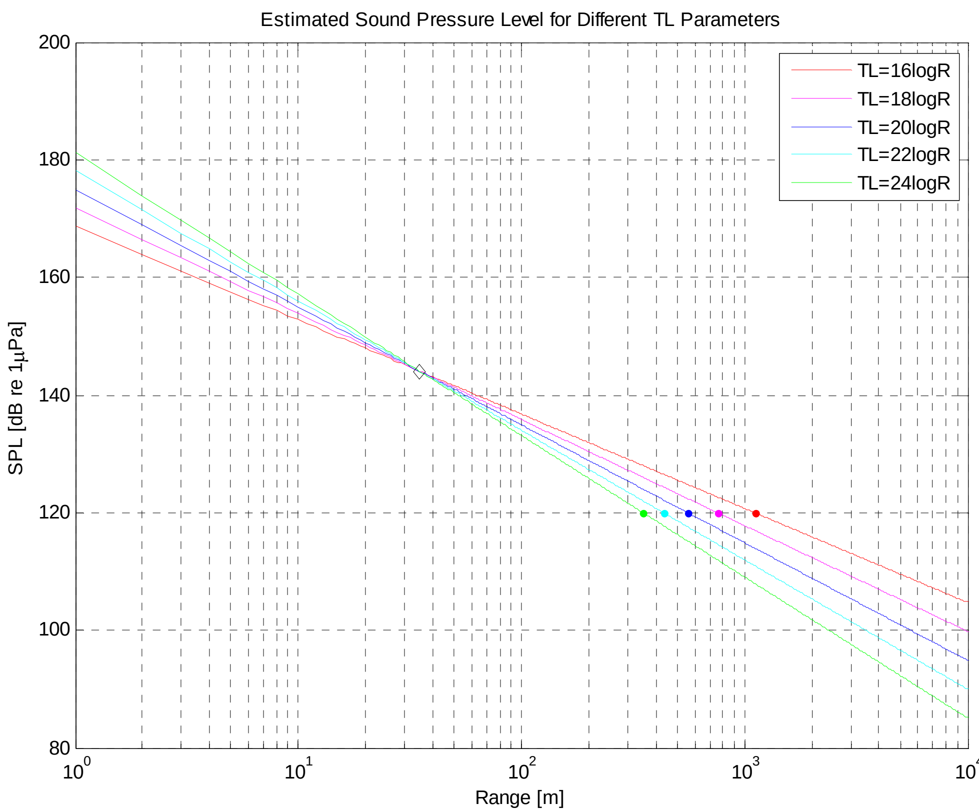


Figure 23. Consideration of Different Transmission Loss Configuration (Vibratory, Round Pile)

The estimated SL's and the corresponding 120 dB distance for these different transmission loss configurations are listed in **Table 12**. In this worst case situation, the nominal transmission loss configuration (20 log R) indicates the estimated distance to 120 dB to be 559.23 m, but it can possibly range between 352.62 m and 1,116.93 m.

Table 12. Estimated Source Level and 120 dB Distances of Worst Case Incidence (Vibratory, Round Pile)

Spreading Loss	Estimated SL [dB re 1 μPa]	Estimated 120 dB Distance [m]
16 log R	168.77	1116.93
18 log R	171.86	760.53
20 log R	174.95	559.23
22 log R	178.04	434.86
24 log R	181.14	352.62

3.1.4 Sheet Pile Driving - Tail Wall

The sheet pile driving sessions were collected on September 25, 2008 and the summary of the analysis is shown in **Table 13**. The distance to the 120 dB isopleths under worst case conditions was estimated to be 111.26 m assuming spherical spreading loss characteristics[6].However, the average source level (SL) for sheet pile for the tail wall was 158.46 dB, resulting in a range from source to the 120 dB isopleths of 83.75 m.

Table 13. Summary of Data Analysis (Vibratory, Sheet Pile – Tail Wall)

Data Field	Values
Sampling Date & Time	09/25/2008, 18:31:09~18:36:09
Average Source Level [dB]	158.46
Max/Min Source Level [dB]	160.93 / 154.60
Average Sound Pressure Level [dB]	120.24
Max/Min Sound Pressure Level [dB]	122.44 / 118.88
Average Range to Source [m]	83.74
Max/Min Range to Source [m]	107.62 / 46.56
Estimated 120dB Distance (Worst Case) [m]	111.26
Estimated 120dB Distance (Average) [m]	83.75
Tide [ft]	26.64 ~ 26.87

3.1.4.1 Data Collection and Sampling Area

During the data collection, two separate sessions were recorded at distances between 46.6 m and 107.6 m and tide levels between 26.6~26.9 ft. **Table 14** shows both sessions in detail.

Table 14. Data Collection Log (Vibratory, Sheet Pile – Tail Wall)

SLM Data			Avisoft Data					Comments
File name	Start time	Stop time	File name	Start time	Stop time	Start offset	End offset	
831_DATA_072.xls	18:30:31	18:32:39	T0000060.wav	18:30:29	18:32:38	00:40	02:09	AC at the beginning of the file. Can barely hear on the speakers. Tail wall is out of the water
831_DATA_073.xls	18:35:34	18:36:29	T0000061.wav	18:35:33	18:36:28	00:00	00:36	Moved closer. Can barely hear on the speakers. Tail wall is out of the water

[6] Estimation assumes the spreading loss parameter to be 20 log R. Consideration of different parameters is discussed in the following sections.

The sampling locations and steel pipe pile driving site were logged from GPS and were synchronized with acoustic data collection. **Figure 24** shows the relative positions of the vibratory sheet pile driving (tail wall) and sampling locations. The yellow push pin icon refers to the location of pile driving site (N61°15'4.941", W149°52'56.875") and the light green tracks indicate the data collection locations.

Figure 24. Aerial Map of Sample Location and Pile Driving Site (Vibratory, Sheet Pile – Tail Wall)

3.1.4.2 Data Processing and Analysis

The sound pressure levels of all measured sheet pile driving along the tail wall ranged from 118.88 to 122.44 dB re 1µPa during two recording sessions. Assuming spherical spreading transmission loss characteristics, their equivalent source levels are estimated to be 154.60 to 160.93 dB re 1µPa. The SPL's, SL's, and the distance from the pile driving site of all measurements are illustrated in the order they were collected in **Figures 25, 26, and 27,** respectively.

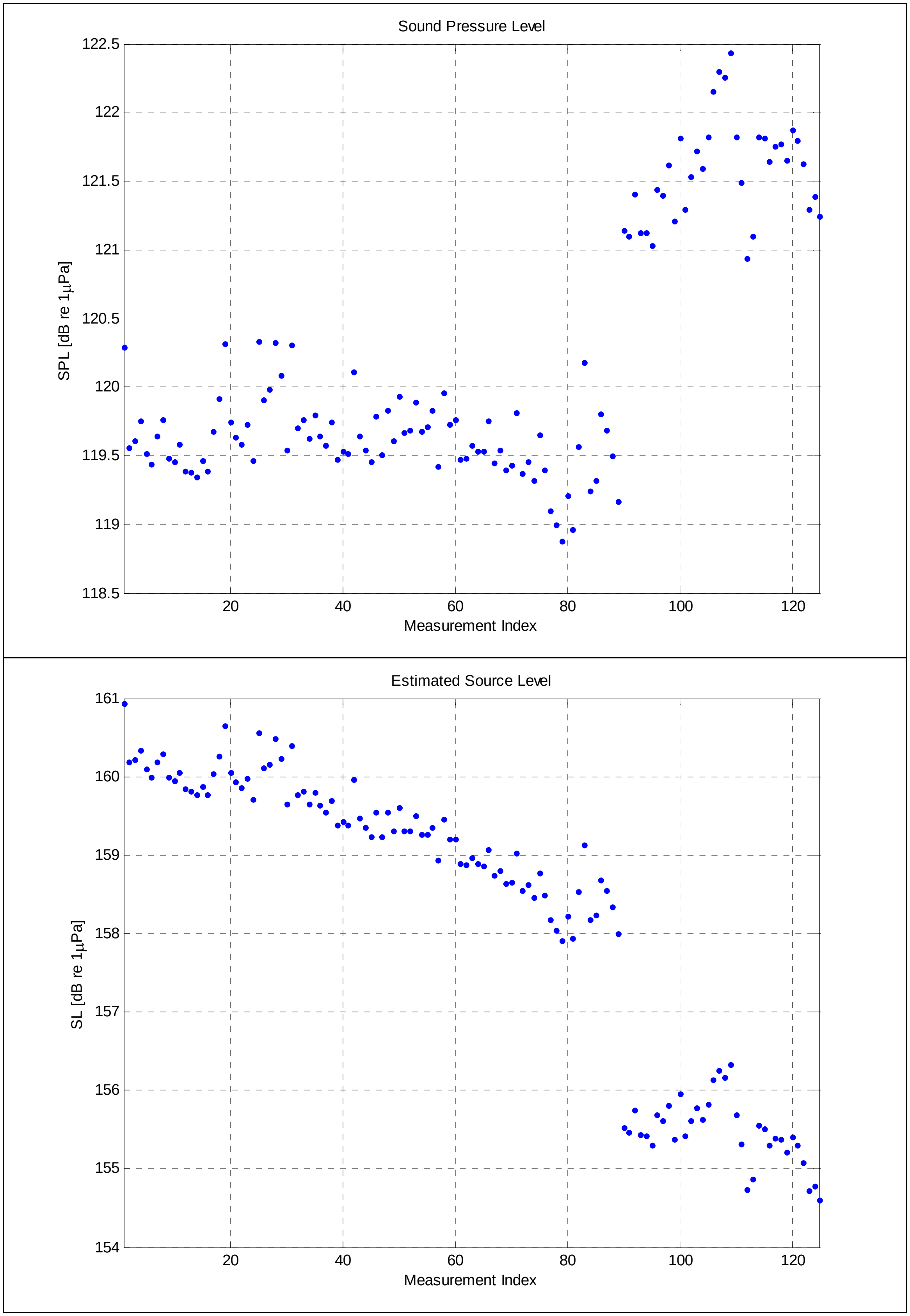


Figure 25. Sound Pressure Level and Estimated Source Level (Vibratory, Sheet Pile – Tail Wall)

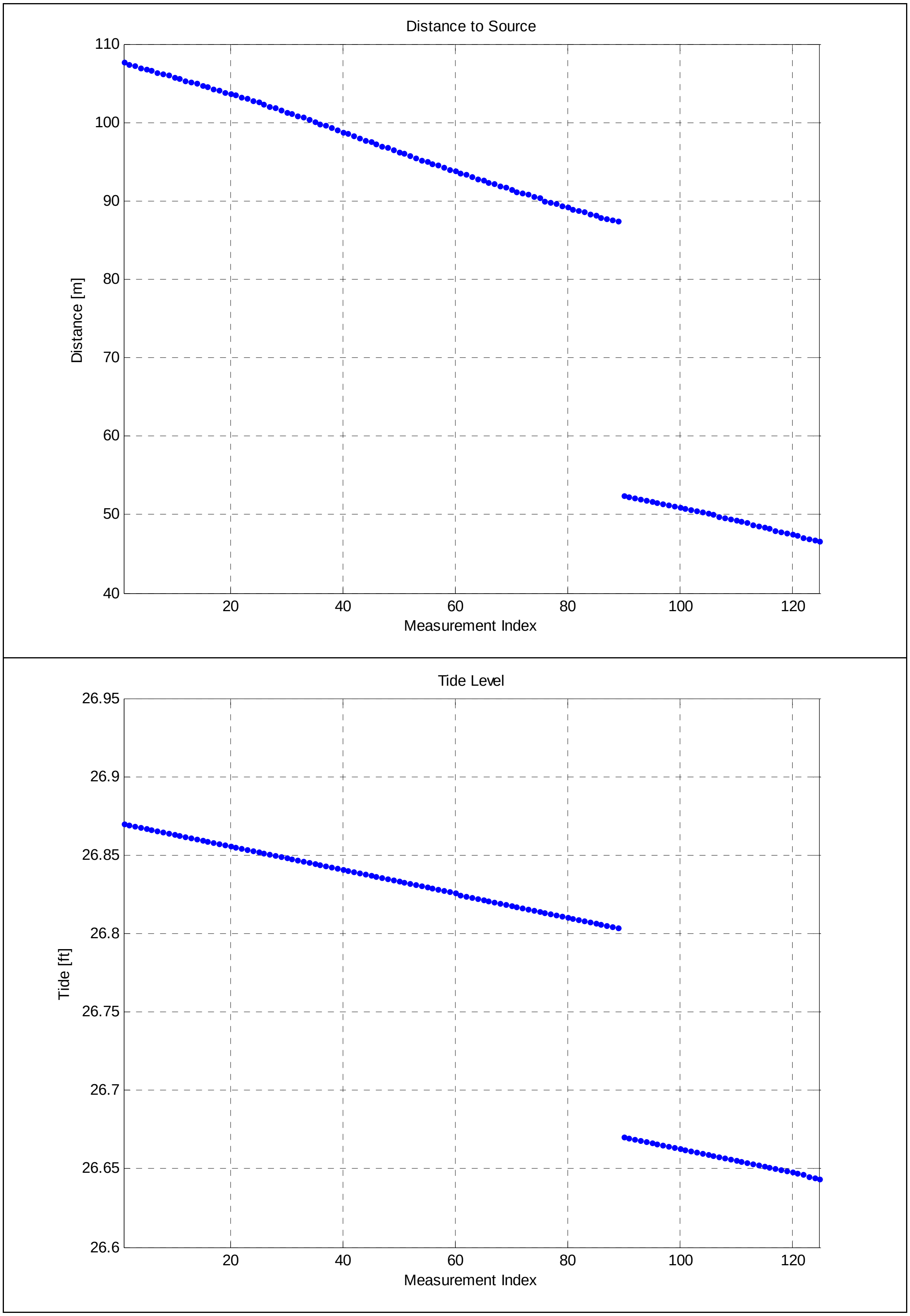


Figure 26. Distance to Source and Tide Level (Vibratory, Sheet Pile – Tail Wall)

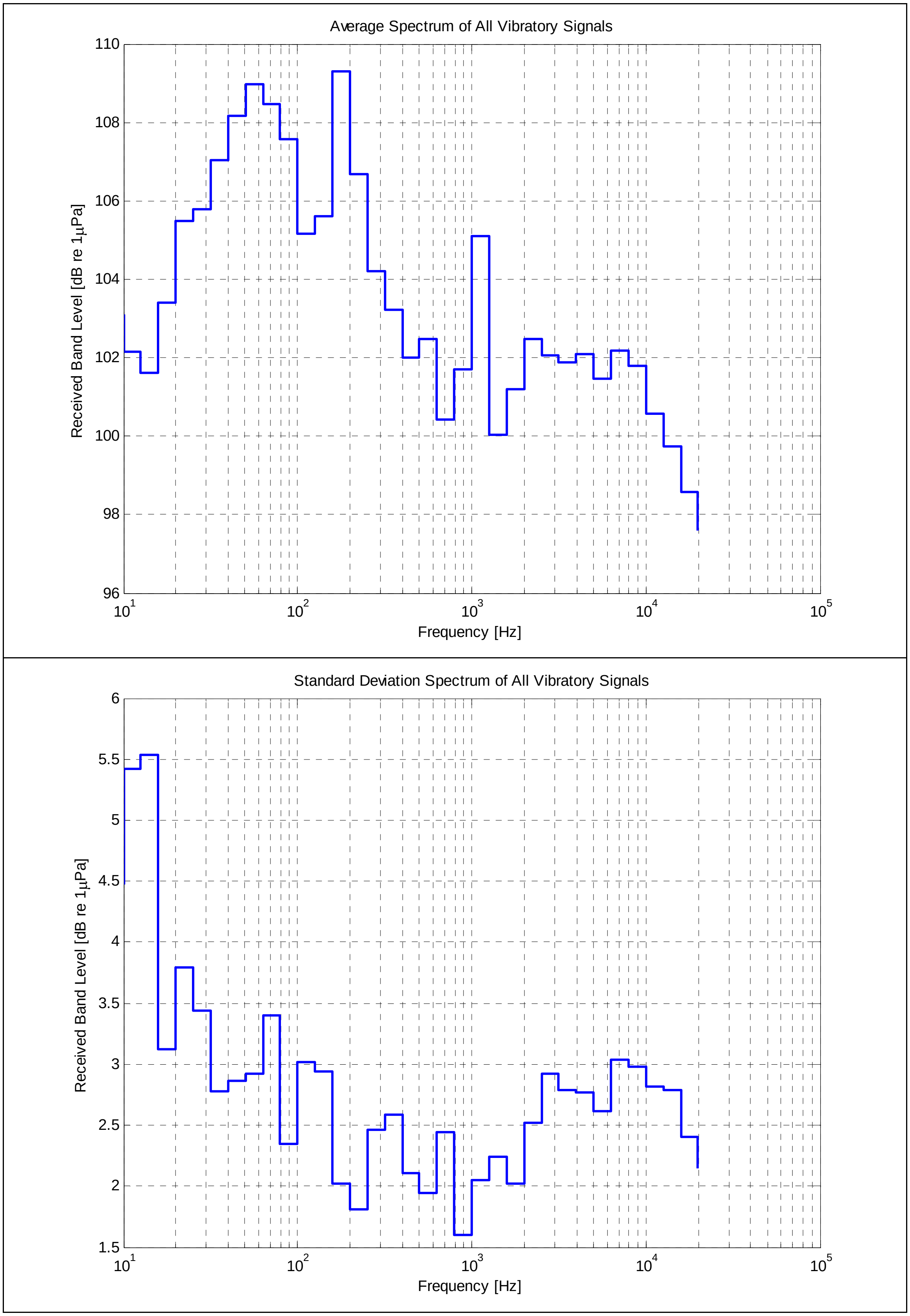


Figure 27. Average Spectrum and Standard Deviation (Vibratory, Sheet Pile – Tail Wall)

As noted earlier, the tide level significantly affects the propagation of the sound energy (the higher the tide, the more efficient transmission of the sound energy). As shown in **Figure 26**, tide levels during both recording sessions were relatively high (26.64 ~ 26.87 ft).

One-third octave spectrum averaged over all measured vibratory sheet pile driving of the tail wall and its standard deviation plot is shown in **Figure 27**. The low spectral energy is dominant between 20 Hz and 400 Hz with peak frequency at 150 Hz. Standard deviation of the spectral distribution is relatively low but had most variation around 10~20 Hz band.

Worst Case Analysis

When all SPL's are converted to SL's and assuming spherical spreading for transmission loss from the pile driving site, the incident with the maximum value of SL is taken for the worst case analysis. This sample is considered as the loudest incident among the all measurement in both recording sessions.

Table 15 shows the details of the worst case analysis, which occurred at 6:31:09 pm Alaska local time on September 25, 2008. The SPL value of 120.29 dB re 1μPa was measured at the distance of 107.62 m, and its estimated SL is calculated to be 160.93 dB re 1μPa. The tide level was reported at 26.9 ft according to NOAA's estimated tide data. Using this maximum SL value, the distance to the 120 dB isopleths under worst case conditions was estimated to be 111.26 m from the pile driving site.

Table 15. Summary of Worst Case Analysis (Vibratory, Sheet Pile – Tail Wall)

Data Field	Values
Data File Name	T0000060.WAV
Date & Time	09/25/2008, 18:31:09
Time Offset in File [sec]	40
Range to Source [m]	107.62
Sound Pressure Level [dB re 1μPa]	120.29
Estimated Source Level [dB re 1μPa]	160.93
Estimated 120dB Distance [m]	111.26
Tide [ft]	26.87

Moderately low signal levels of vibratory noise were monitored during the recording sessions. **Figure 28** depicts raw time series data for both occasions.

One-third octave spectrum of this particular worst case is shown in **Figure 29**. This particular case does not deviate from the average spectrum shown above.

A nominal transmission loss configuration of 20 log R is used to calculate SL values, although the actual transmission loss is a function of many complicated environmental variables. Thus, different possibilities of transmission loss, such as 16 log R, 18 log R, 22 log R, and 24 log R, are considered to estimate the SL value at the pile driving location and eventually to compute 120 dB distance.

Figure 30 shows five possible situations of SPL values for the vibratory round pile driving with varying ranges up to 10 km based on the worst case measurement: the red curve indicates the SPL using the transmission loss with 16 log R; the magenta curve indicates the SPL using the transmission loss with 18 log R; the blue curve indicates the SPL using the transmission loss with 20 log R; the cyan curve indicates the SPL using the transmission loss with 22 log R; and the green curve indicates the SPL using the transmission loss with 24 log R.

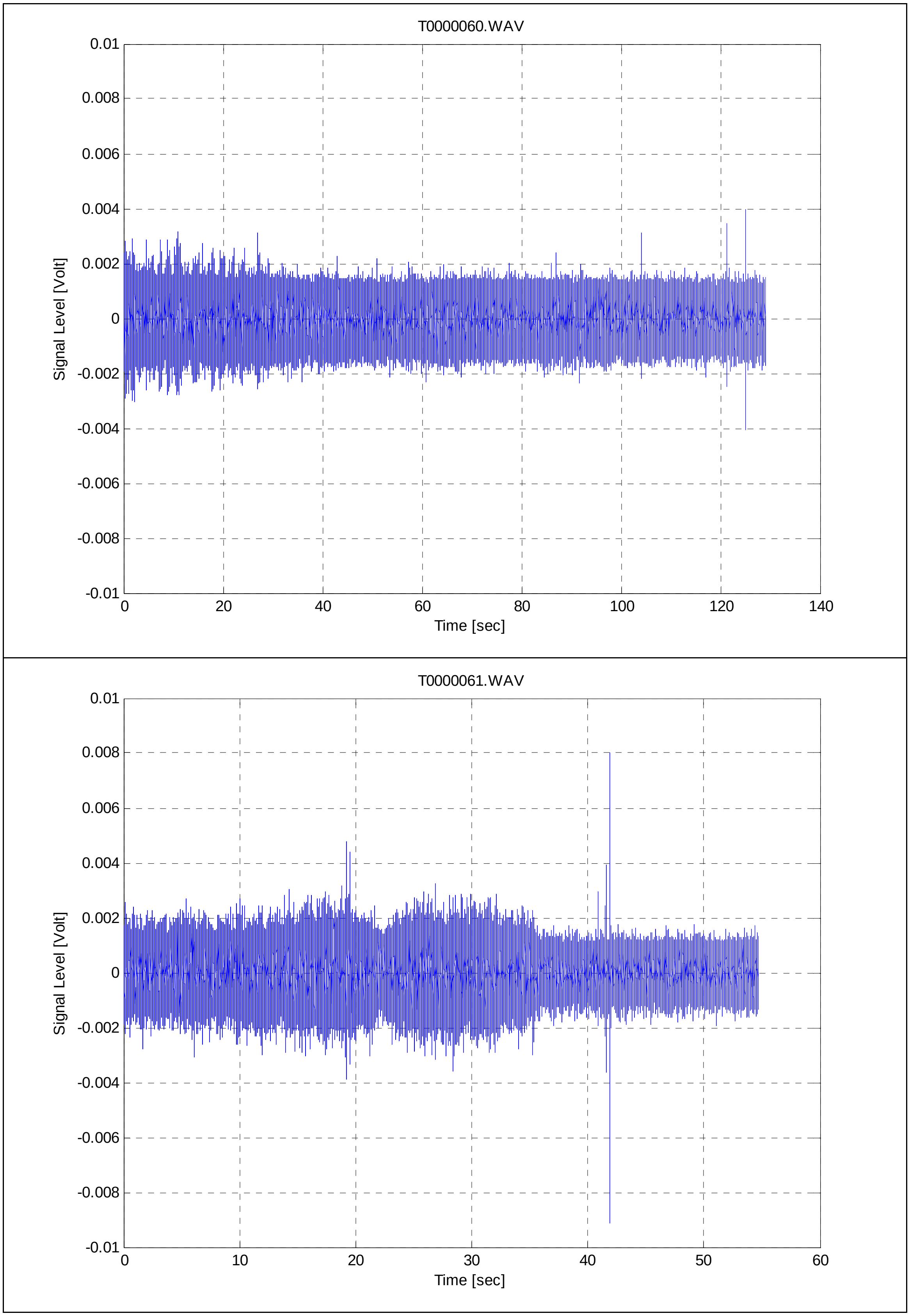


Figure 28. Raw Time Series of Pile Driving (Vibratory, Sheet Pile – Tail Wall)

Figure 29. One-Third Octave Spectrum for Pile Driving (Vibratory, Wye-Pile)

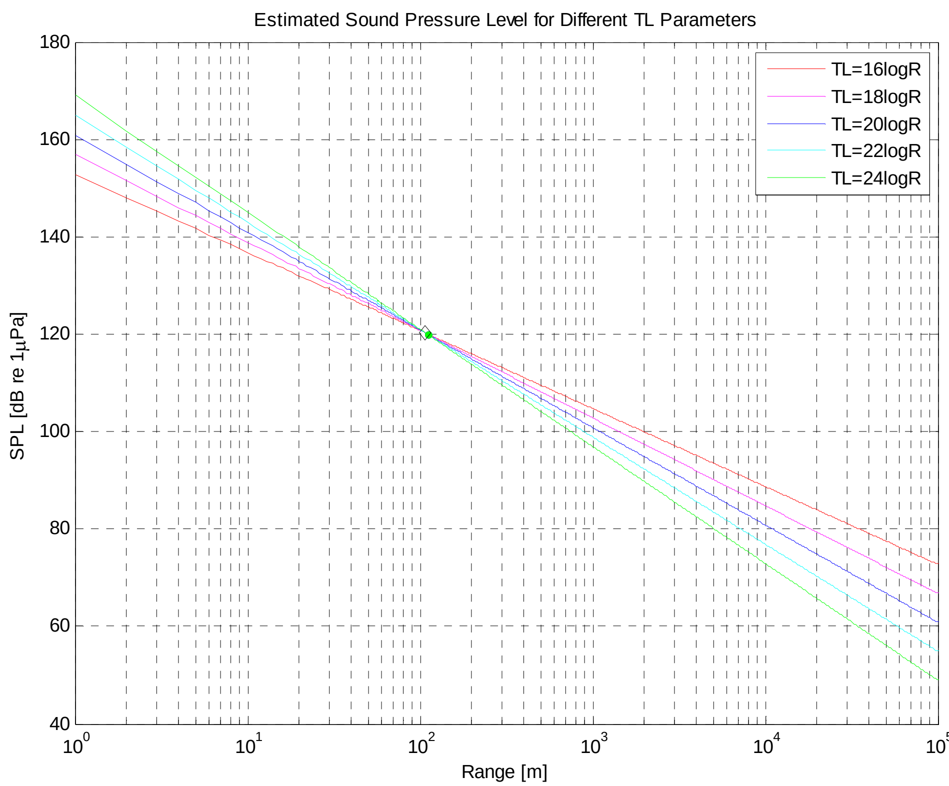


Figure 30. Consideration of Different Transmission Loss Configuration (Vibratory, Sheet Pile – Tail Wall)

The estimated SL's and the corresponding 120 dB distance for different transmission loss configurations are listed in **Table 16**. In this worst case situation, the nominal transmission loss configuration (20 log R) provides the estimated distance to 120 dB at 111.26 m, but can possibly range between 110.65 m and 112.19 m.

Table 16. Estimated Source Level and 120 dB Distances of Worst Case Incidence (Vibratory, Sheet Pile – Tail Wall)

Transmission Loss	Estimated SL [dB re 1uPa]	Estimated 120dB Distance [m]
16logR	152.80	112.19
18logR	156.86	111.67
20logR	160.93	111.26
22logR	164.99	110.92
24logR	169.05	110.64

3.2 Impact Pile Driving

Multiple sessions of impact pile driving were recorded. The analysis of the acoustic characteristics of sheet pile driving, Wye-pile driving, soft-start, and hairpin are discussed in the following sections.

3.2.1 Sheet Pile Driving – Shallow Hydrophone – Face Wall

A number of impact pile driving sessions at the face wall were recorded with the deployment of the hydrophone approximately 1 m below the water surface on September 25, 2008 and the summary of the analysis is shown in **Table 17**. The distance to the 160 dB isopleths under worst case conditions was estimated to be 56.85 m based on SPL value using an RMS computation, but it can be as far as 1,096.47 m when it is derived from instantaneous peak pressure.

Table 17. Summary of Data Analysis (Impact, Sheet Pile, Shallow Hydrophone)

Data Field	Values
Sampling Date & Time	09/25/2008, 14:21:43.40~17:25:53.09
Total Count of Impacts	1,444
Average Source Level [dB]	186.25
Max/Min Source Level [dB]	195.10 / 171.37
Average Sound Pressure Level [dB]	143.25
Max/Min Sound Pressure Level [dB]	157.22 / 123.42
Average Instantaneous Peak Pressure [dB]	165.81
Max/Min Instantaneous Peak Pressure [dB]	182.35 / 144.80
Average Range to Source [m]	202.14
Max/Min Range to Source [m]	703.02 / 27.86
Estimated 160 dB Distance (Worst Case) [m] Based on SPL (RMS)	56.85
Estimated 160 dB Distance (Worst Case) [m] Based on Instantaneous Peak Pressure	1,096.47

3.2.1.1 Data Collection and Sampling Area

During the data collection, 10 separate sessions were recorded with the distance between 27.86 and 703.02 m and tide levels between 15.6 and 28.4 ft. **Table 18** shows all sessions in detail.

The sampling locations during impact pile driving site were logged from GPS and were synchronized with acoustic data collection. **Figure 31** shows the relative positions of the impact pile driving of the face wall and the sampling locations. The yellow push pin icon refers to the location of pile driving site (N 61°15'4.941", W 149°52'56.875") and the light green tracks indicate the data collection locations.

Table 18. Data Collection Log (Impact, Sheet Pile, Shallow Hydrophone)

SLM Data			Avisoft Data					Comments
File name	Start time	Stop time	File name	Start time	Stop time	Start offset	End offset	
831_DATA_041.xls	14:21:52	14:25:15	T0000015.wav	14:21:42	14:25:17	00:00	03:15	SLM shows 162 dB peak, 242 m away, drifting almost parallel to the shore
831_DATA_042.xls	14:29:18	14:34:40	T0000016.wav	14:29:20	14:33:20	00:00	02:30	Drifting away 562 m - 1km away from the source
831_DATA_043.xls	14:40:03	14:50:50	T0000018.wav	14:40:01	14:44:01	00:16	04:00	Floating parallel to the wall, 180 dB at 100 m range
			T0000019.wav	14:44:01	14:48:01	00:00	04:00	
			T0000020.wav	14:48:01	14:50:51	00:00	02:32	
831_DATA_044.xls	14:54:36	14:56:49	T0000021.wav	14:54:16	14:57:03	00:00	02:27	
831_DATA_045.xls	14:58:45	15:00:40	T0000022.wav	14:58:13	15:00:28	00:00	02:06	Running SLM from AC because of batteries
831_DATA_046.xls	15:01:00	15:02:22	T0000023.wav	15:00:54	15:01:55	00:00	00:49	At some point we are 65 m from the wall
831_DATA_047.xls	15:03:52	15:07:09	T0000024.wav	15:03:54	15:07:11	00:06	03:16	At some point we passed 46 m from the wall
831_DATA_054.xls	16:02:07	16:06:11	T0000033.wav	16:02:06	16:06:06	00:21	04:00	Got as close as 40 m from the wall
			T0000034.wav	16:06:06	16:06:10	00:00	00:04	Some AC at the beginning of the file, Ch 2 saturated at the beginning
831_DATA_055.xls	16:08:22	16:10:45	T0000035.wav	16:08:24	16:10:51	00:00	02:11	Avisoft Ch 1 gain picked up 1 div to 18 dB
831_DATA_059.xls	17:07:07	17:08:38	T0000039.wav	17:07:10	17:08:37	00:00	01:17	107 m from the wall
831_DATA_060.xls	17:14:13	17:14:57	T0000040.wav	17:14:12	17:14:55	00:04	00:10	215 m from the wall
831_DATA_061.xls	17:15:31	17:16:10	T0000041.wav	17:15:30	17:16:03	00:03	00:24	193 m from the wall
831_DATA_062.xls	17:17:41	17:26:01	T0000042.wav	17:17:40	17:21:40	00:06	04:00	176 m to 197 m
			T0000043.wav	17:21:40	17:25:40	00:00	04:00	313 m away
			T0000044.wav	17:25:40	17:26:05	00:00	00:16	

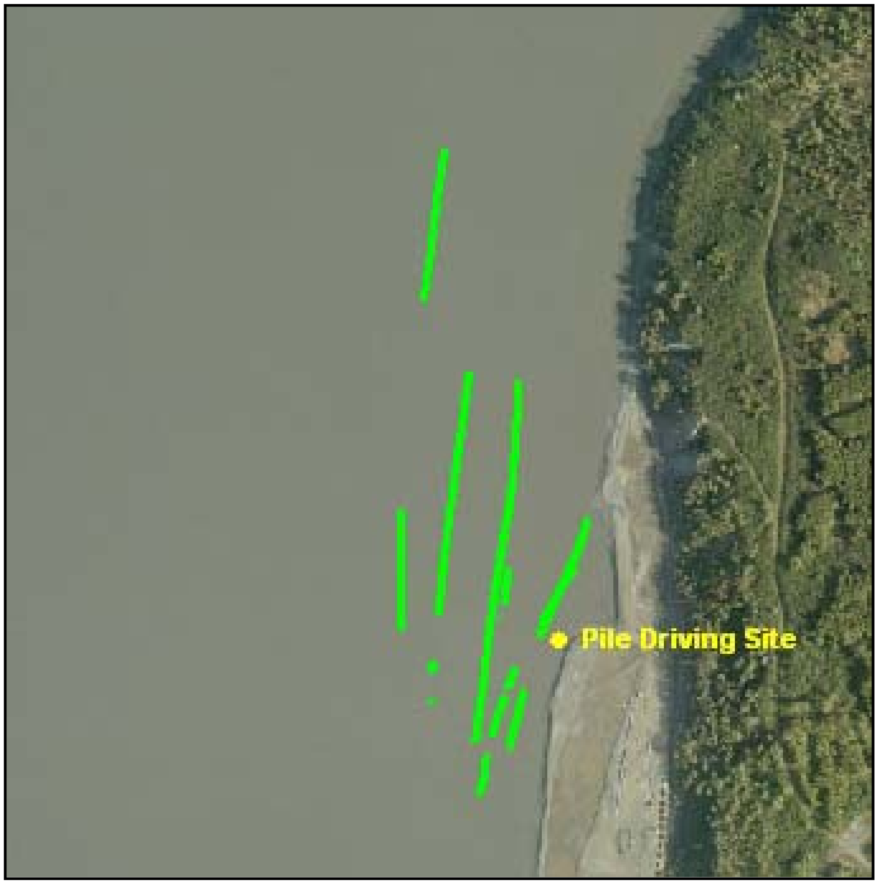


Figure 31. Aerial Map of Sample Location and Pile Driving Site (Impact, Sheet Pile, Shallow Hydrophone)

3.2.1.2 Data Processing and Analysis

The sound pressure levels for the impact pile driving ranged from 123.42 to 157.22 dB re 1μPa during the recording session. Their equivalent instantaneous peak pressures ranged from 144.80 to 182.35 dB re 1μPa.

The 1,444 individual impacts recorded in 18 raw time series of the recorded data are shown in **Figure 32** following processing for sound pressure levels with RMS computation and the instantaneous peak pressures. The range to the 160 dB isopleths was derived for both instances.

As stated previously, the tide level significantly affects the propagation of the sound energy (the higher tide, the more efficient transmission of the sound energy). As illustrated in **Figure 33**, tide levels during first 2/3 of the recording sessions were relatively low (<21 ft) and the remaining 1/3 were fairly high (>25 ft).

The one-third octave spectrum averaged over all measured impact pile driving is shown in **Figure 34**. The distribution of spectral energy is biased toward higher frequency band. The peak band is observed from 8 kHz to 10 kHz.

Figure 34 also shows the standard deviation of one-third octave spectral values. The low frequency bands have relatively high variation as well as the transition area of the distribution around three kHz band, but overall the deviation is low.

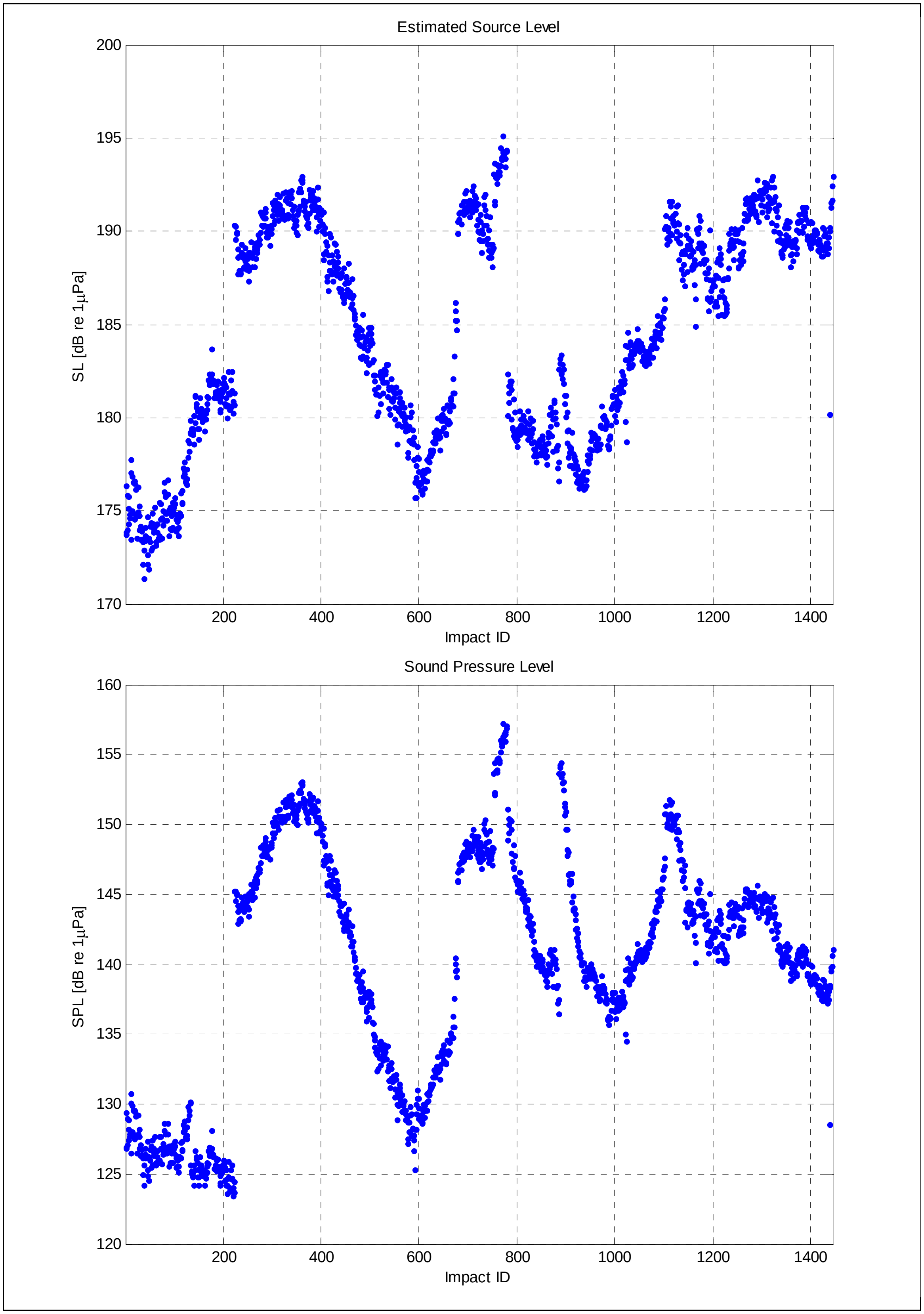


Figure 32. Sound Pressure Level and Estimated Source Level (Impact, Sheet Pile, Shallow Hydrophone)

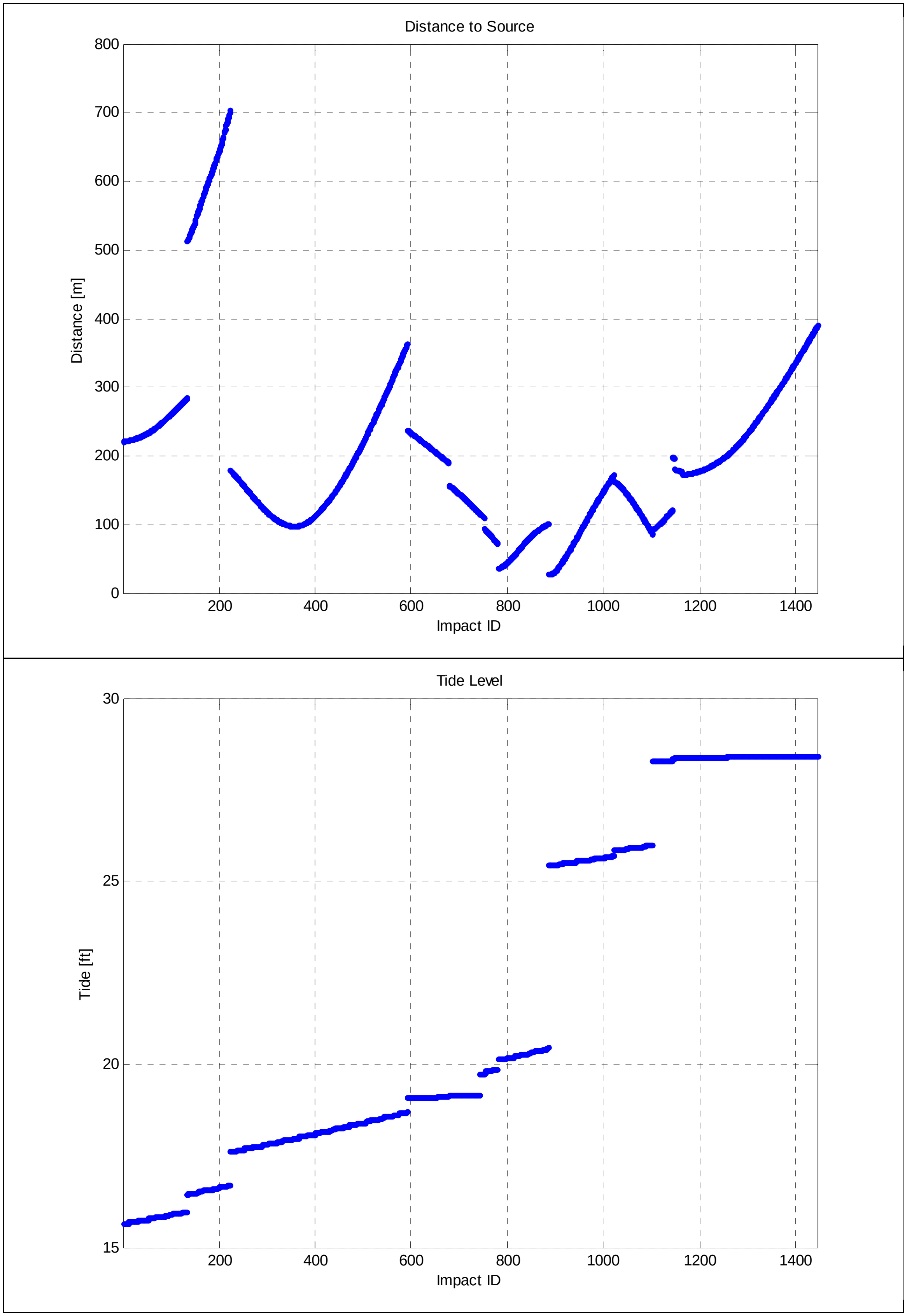


Figure 33. Distance to Source and Tide Level (Impact, Sheet Pile, Shallow Hydrophone)

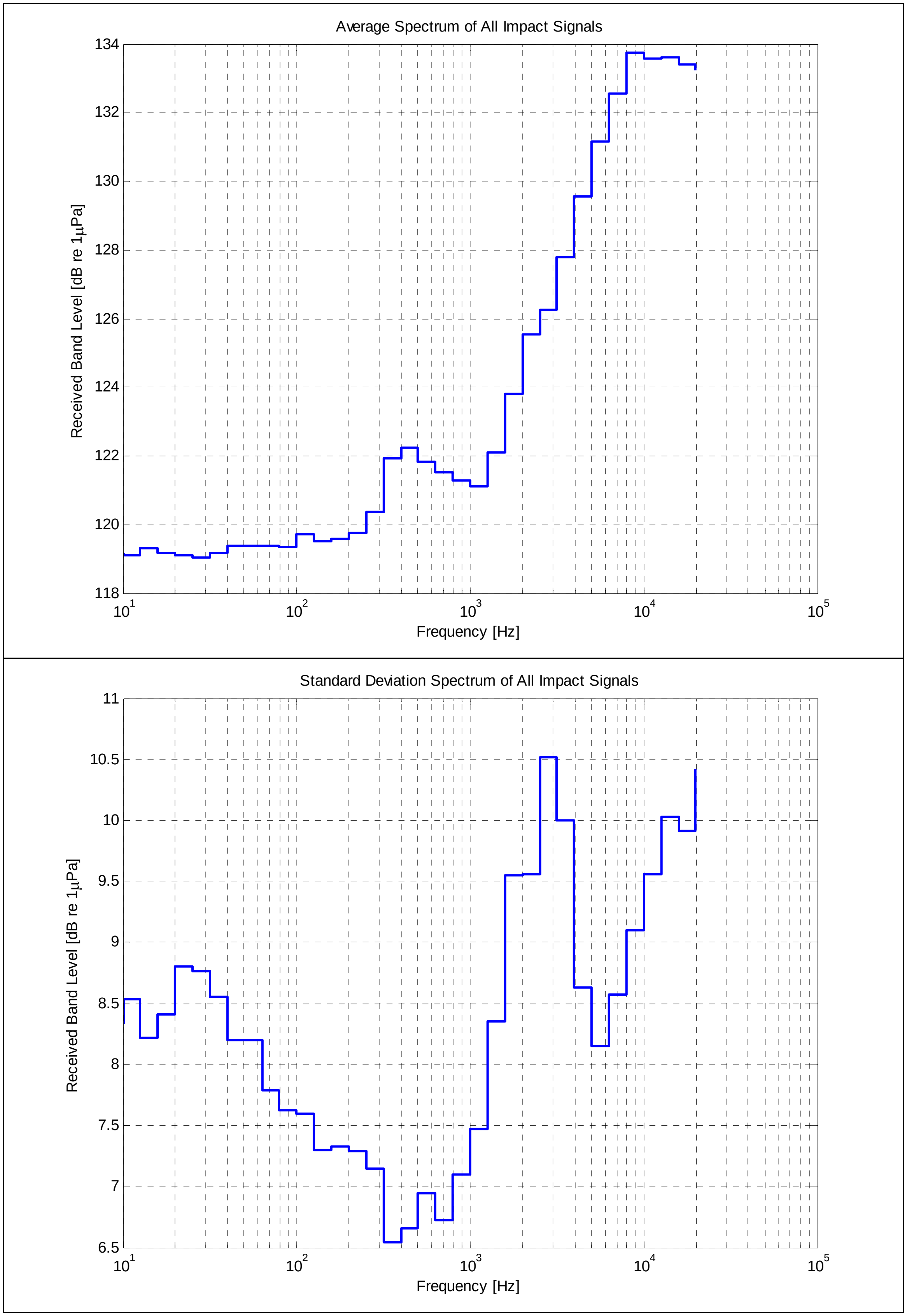


Figure 34. Average Spectrum and Standard Deviation (Impact, Sheet Pile, Shallow Hydrophone)

3.2.1.3 Worst Case Analysis

In computing the sound energy of the impact, a typical calculation is based on the RMS value for the entire pulse duration of the impact. As such, the result of this SPL computation is greatly dependent on the pulse duration that is averaged relative to RMS. The longer the pulse duration, the lower the SPL's. However, a more conservative method to determine the worst case computation is to utilize the instantaneous peak pressure without an averaging process.

When all SPL's are converted to SL's considering the transmission loss for the distance from the pile driving site, the pile driving impact with the maximum value of SL is taken for the worst case analysis. This sample is considered the loudest incident among the all measured impacts in terms of the RMS-based SPL values. This impact occurred at 15:01:28.92 on September 25, 2008 and the range to 160 dB is estimated to be 56.85 m from the pile driving site (**Table 19**).

The other perspective of the worst case incident based on the instantaneous peak pressure (IPP) was measured in another instance at 15:01:17.16 on September 25, 2008 and the range to 160 dB is estimated to be 1,096.47 m from the pile driving site.

Table 19. Summary of Worst Case Analysis (Impact, Sheet Pile, Shallow Hydrophone)

Data Field	Values
Data File Name for Peak Pressure	T0000023.WAV
Range to Source [m]	83.6914023
Date & Time of Peak Pressure	09/25/2008, 15:01:17.16
Time Offset in File [sec]	23.16
Instantaneous Peak Pressure [dB]	182.35
Estimated 160 dB Distance (Worst Case) [m] Based on Instantaneous Peak Pressure	1096.47
Data File Name for Max SPL	T0000023.WAV
Date & Time of Max SPL	09/25/2008, 15:01:28.92
Time Offset in File [sec]	34.92
Range to Source [m]	78.27
Sound Pressure Level [dB]	157.22
Pulse Duration [sec]	0.28
Estimated Source Level [dB]	195.10
Estimated 160 dB Distance (Worst Case) [m] Based on SPL (RMS)	56.85

The maximum impact pile driving in terms of SPL values occurred at the 35th second in the recorded file (T0000023.wav), but the instantaneous peak pressure was observed at the 23rd second in the same data file. A close up view of the raw time series of this worst case signal is depicted in **Figure 35**.

One-third octave spectrum of this particular case is shown in **Figure 36**. The spectrum of this testing period shows a bimodal distribution, one in lower frequency around 20 Hz~ 200 Hz and the other in higher frequency over 6 kHz.

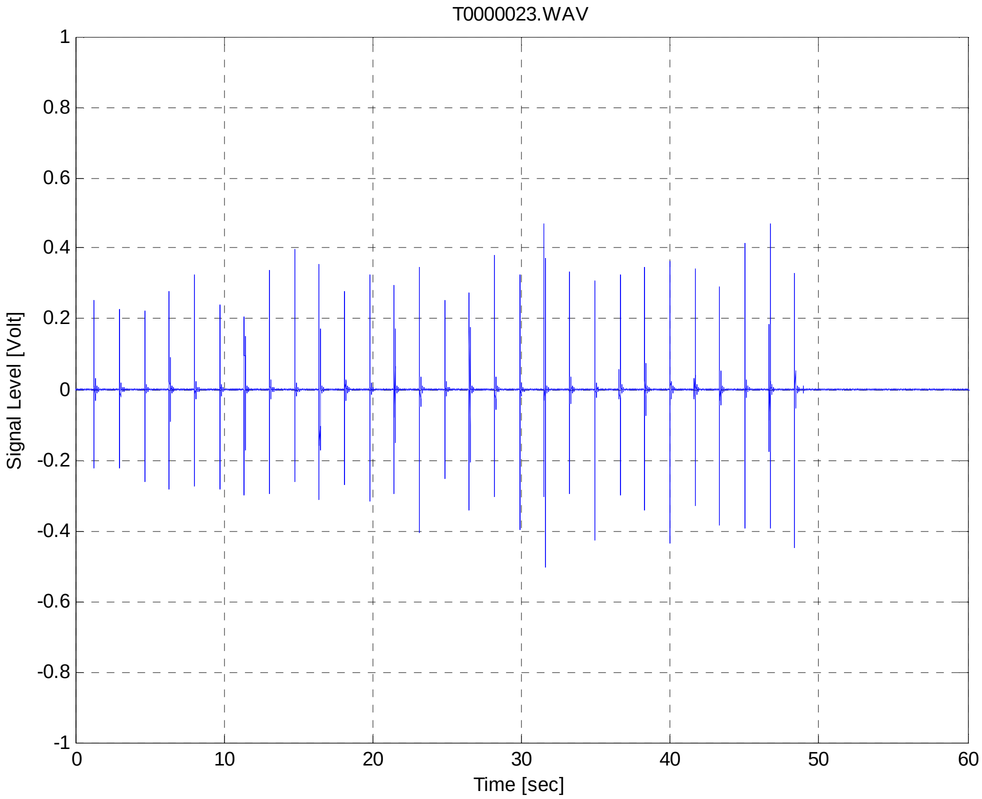


Figure 35. Raw Time Series of Pile Driving (Impact, Sheet Pile, Shallow Hydrophone)

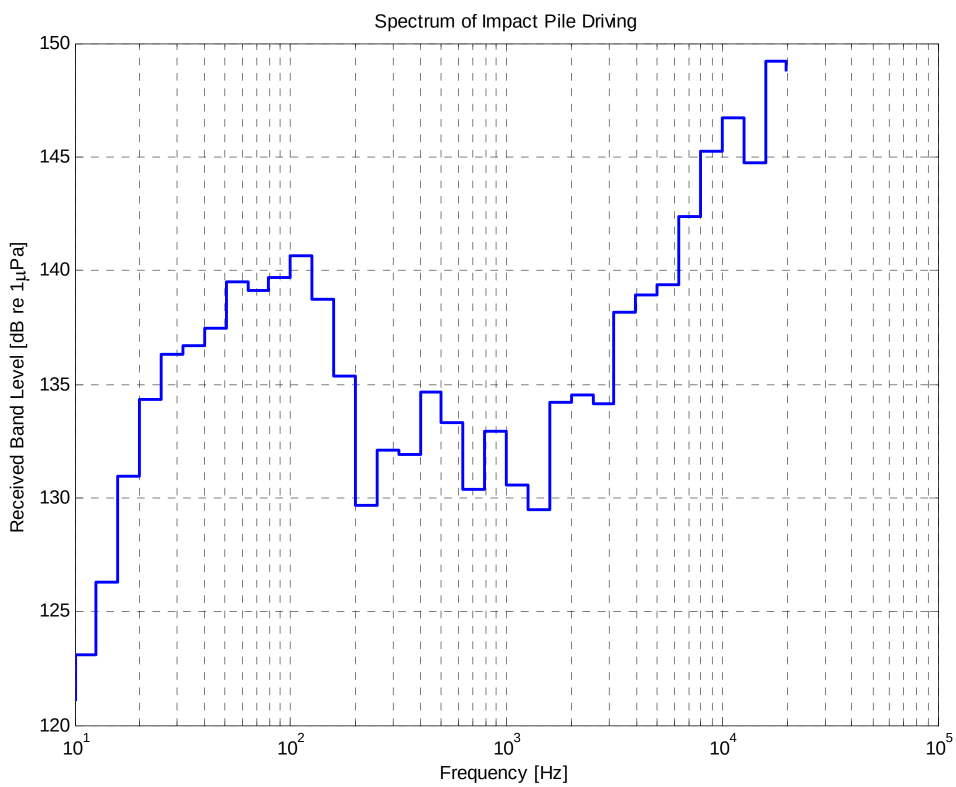


Figure 36. One-Third Octave Spectrum for Pile Driving (Impact, Sheet Pile, Shallow Hydrophone)

A nominal transmission loss configuration of 20 log R was used to calculate SL values, although the actual transmission loss is a function of many complicated environmental variables. Thus, different possibilities of transmission loss, such as 16 log R, 18 log R, 22 log R, and 24 log R, are considered to estimate the SL value at the pile driving location and eventually to compute the range to 160 dB.

Figure 37 shows the estimated instantaneous peak pressures on the left and sound pressure levels on the right for the impact sheet pile driving (shallow hydrophone) with a range up to 10 km. Each plot shows five possible situations of SPL values for the varying ranges up to 10 km based on the worst case measurement: the red curve indicates the SPL using the transmission loss with 16 log R; the magenta curve indicates the SPL using the transmission loss with 18 log R; the blue curve indicates the SPL using the transmission loss with 20 log R; the cyan curve indicates the SPL using the transmission loss with 22 log R; and the green curve indicates the SPL using the transmission loss with 24 log R.

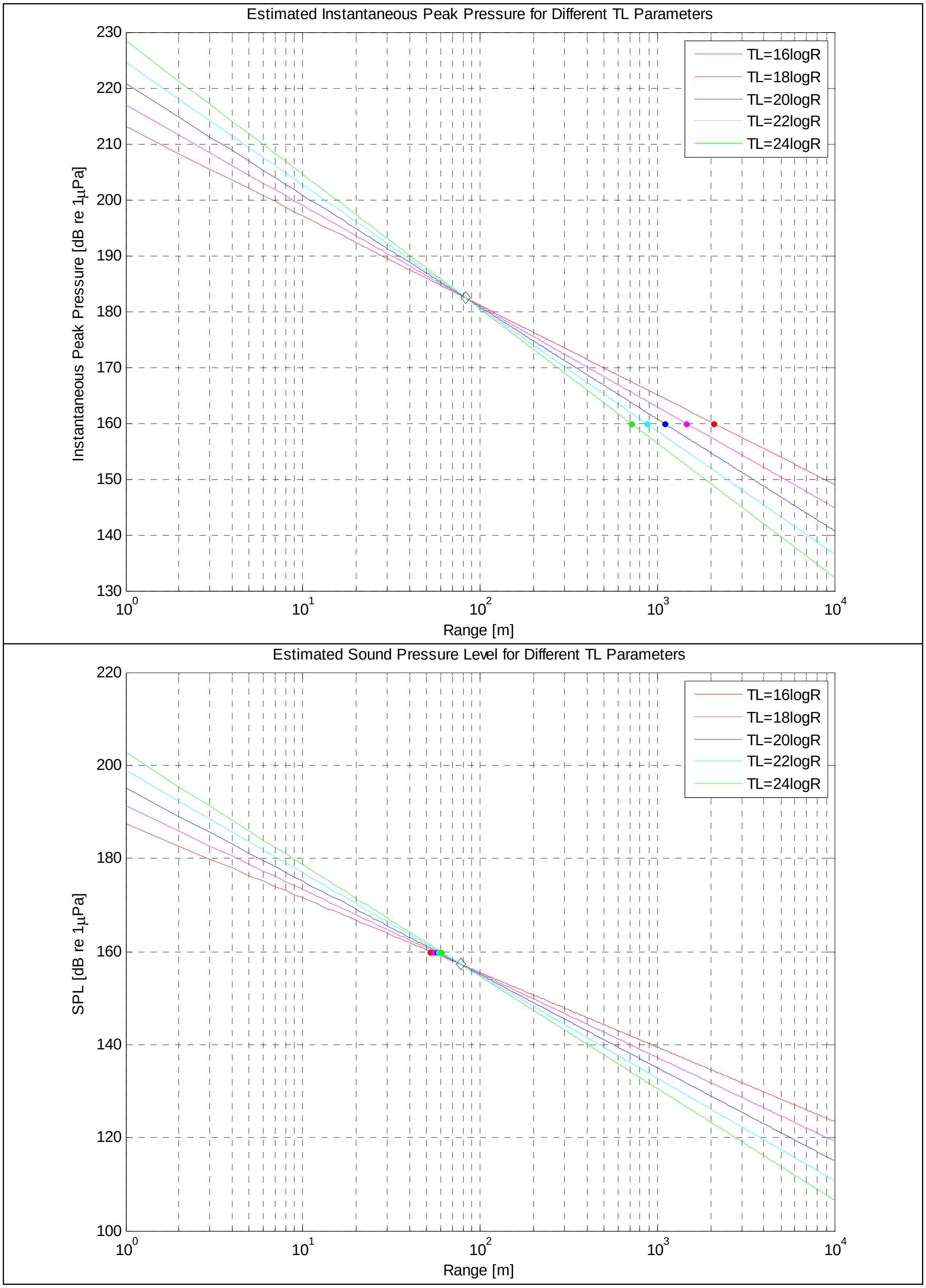


Figure 37. Consideration of Different Transmission Loss Configuration (Impact, Sheet Pile, Shallow Hydrophone)

Estimated 160 dB peak pressure distances and 160 dB SPL distances for these five different transmission loss configurations are listed in the **Table 20**.

Table 20. Estimated 160 dB Distances of Instantaneous Peak Pressures and Sound Pressure Levels (Impact, Sheet Pile)

Transmission Loss	Est. 160 dB Distance [m] Based on Inst. Peak Pressure	Est. 160 dB Distance [m] Based on SPL (RMS)
16 log R	2086.05	52.48
18 log R	1459.29	54.87
20 log R	1096.47	56.85
22 log R	867.80	58.53
24 log R	714.13	59.96

3.2.1.4 Isopleths

The isopleths were generated using one of the paths where the vessel drifted fairly parallel to the shore line (**Figure 38**). Three raw data files that consist of the recording in this path are T0000018.wav, T0000019.wav, and T0000020.wav.

Figure 38. Aerial Map of Sample Location and Pile Driving Site (Impact, Sheet Pile, Shallow Hydrophone)

The individual values of SPL or instantaneous peak pressure are widely varying in the raw data recording; the running average operation with adjacent values was used to smooth the values to result in a more acceptable presentation of isopleths. Two different window sizes of five and nine samples were employed.

For the worst case scenario, the isopleths based on the instantaneous peak pressures were computed and shown in **Figure 39** and **Figure 40**. The isopleths in **Figure 39** was generated with a window size of five and that in **Figure 40** with a window size of nine, respectively.

The isopleths based on SPL values that are conventionally presented as RMS sound energy were computed and shown in **Figure 41** and **Figure 42**. The isopleths in **Figure 41** was generated with a window size of five and that in **Figure 42** with a window size of nine, respectively.

One noticeable discovery from the isopleths was that the propagation of the impact sound energy is not uniform (cylindrical/spherical) but directional. For example, 160 dB isopleths are not uniformly observed in all cases. The presentation of the worst case noise study should take into consideration the irregularity of the spreading pattern.

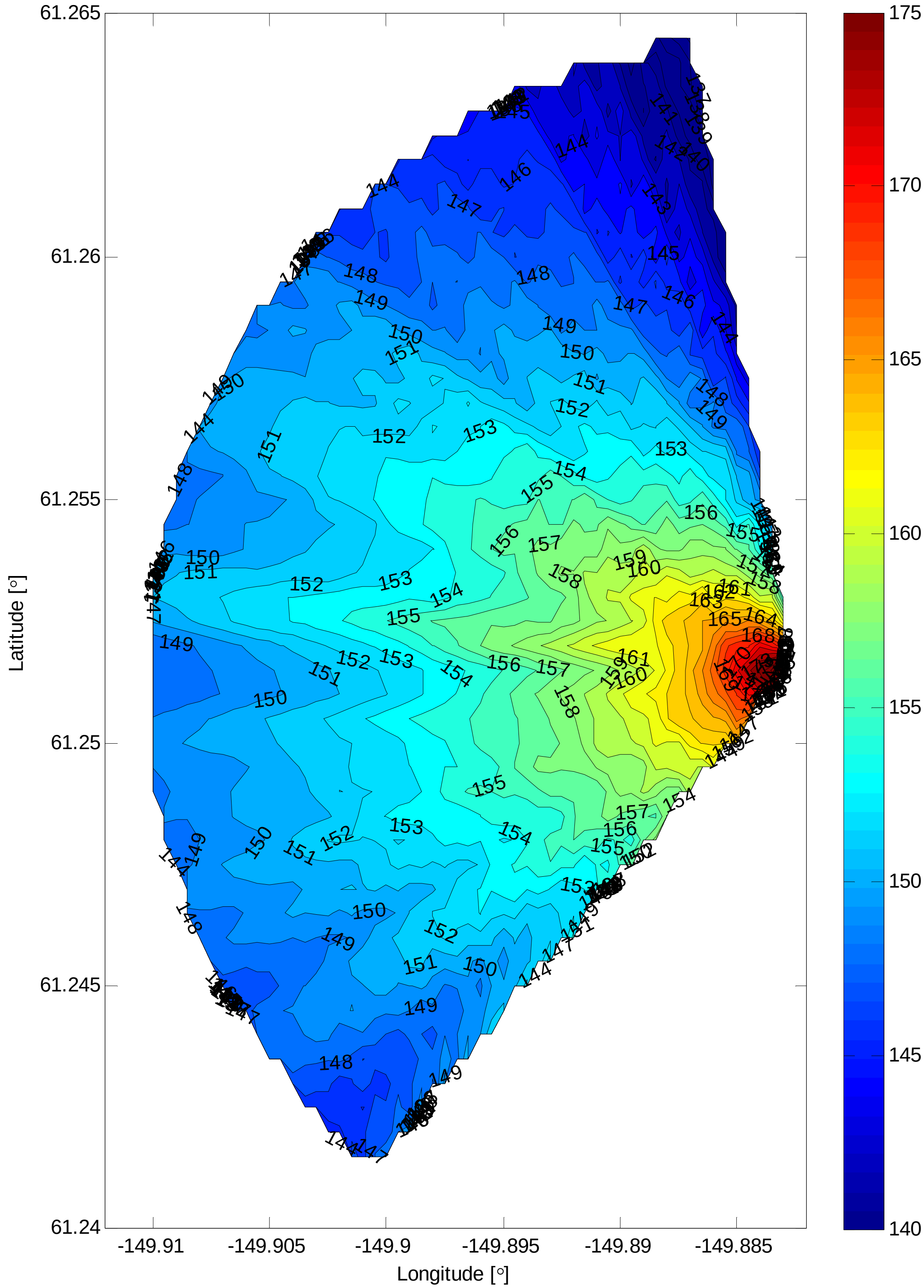


Figure 39. Isopleths from Instantaneous Peak Pressure with Smoothing Window Size of 5 (Impact, Sheet Pile, Shallow Hydrophone)

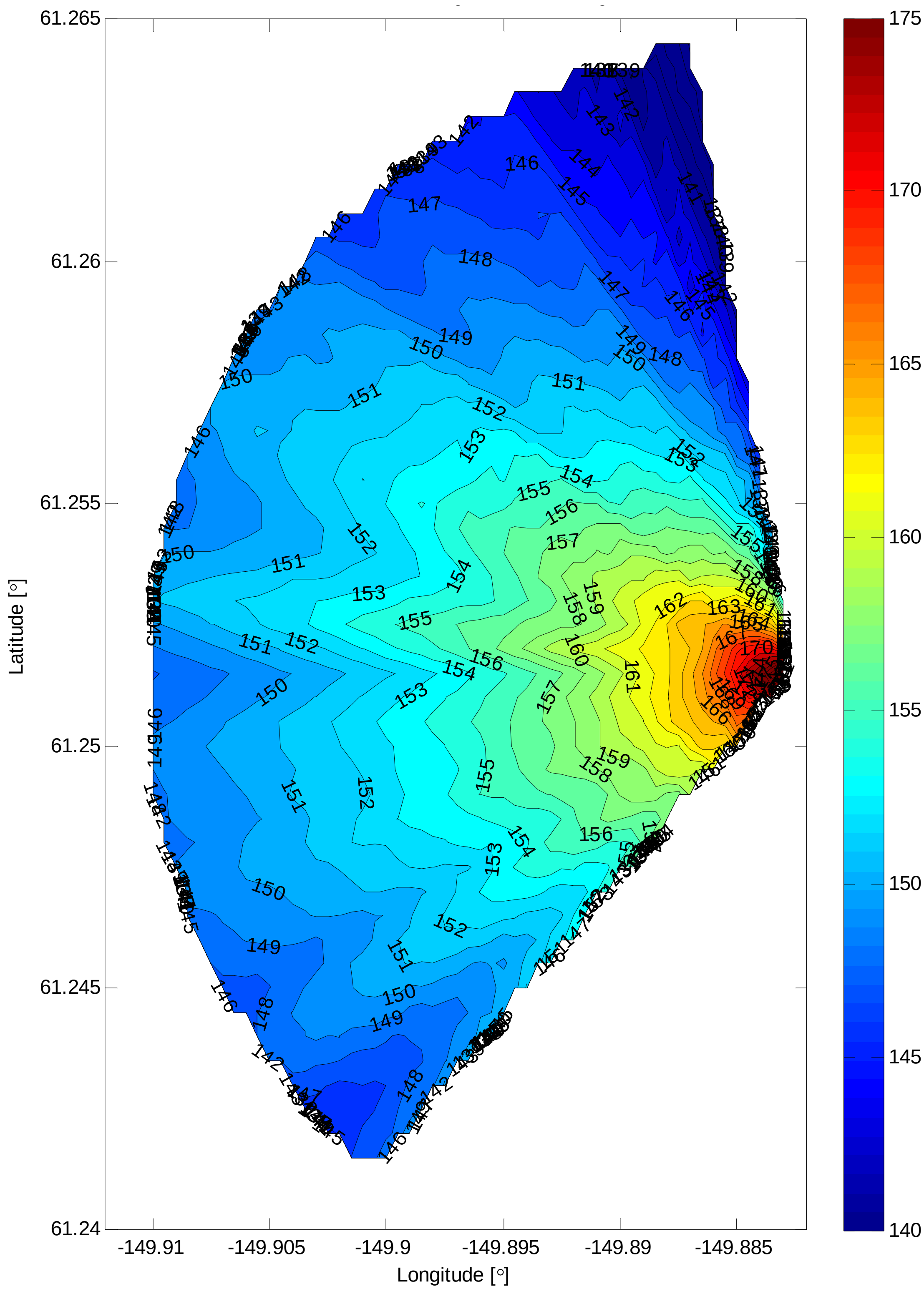


Figure 40. Isopleths from Instantaneous Peak Pressure with Smoothing Window Size of 9 (Impact, Sheet Pile, Shallow Hydrophone)

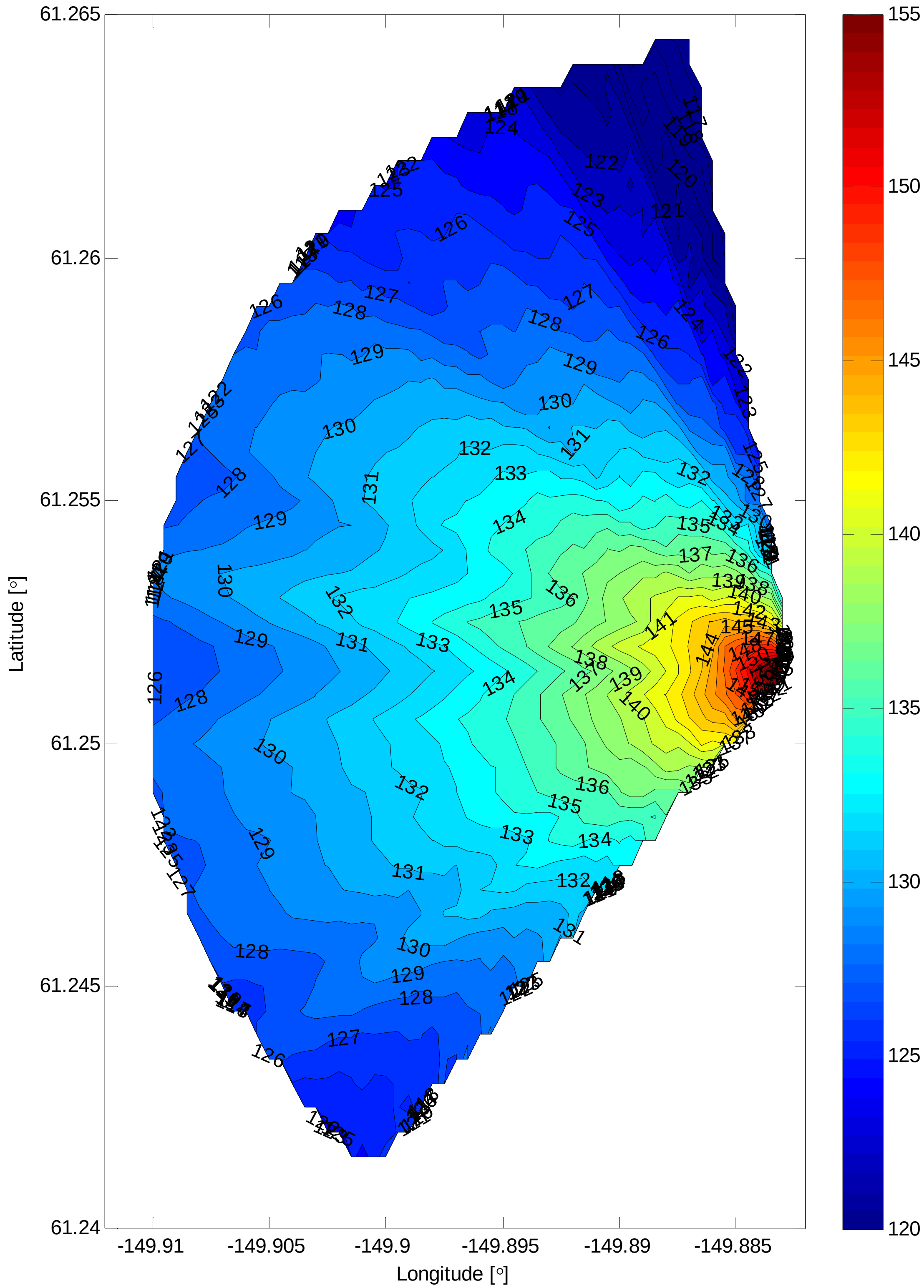


Figure 41. Isopleths from Sound Pressure Level with Smoothing Window Size of 5 (Impact, Sheet Pile, Shallow Hydrophone)

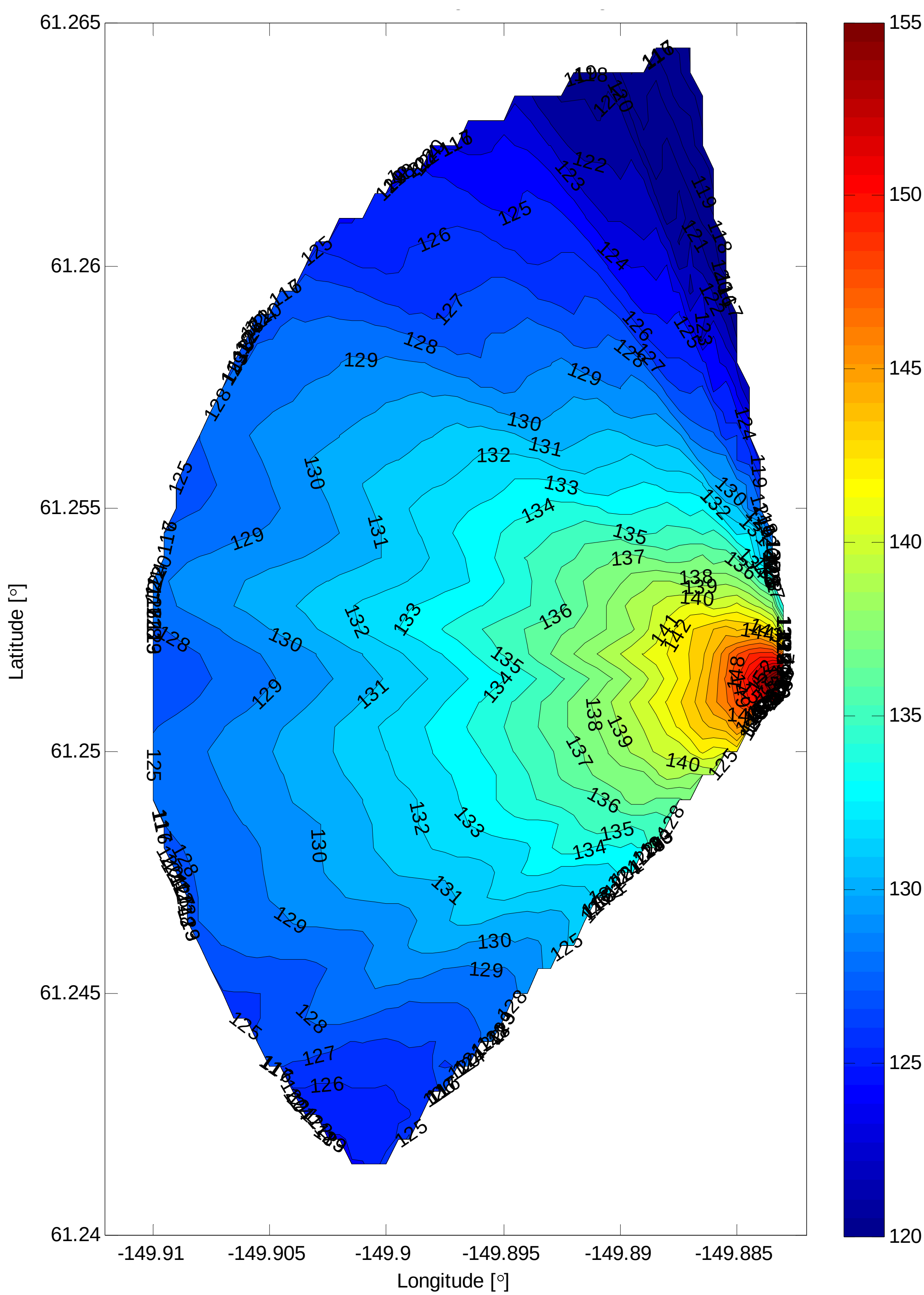


Figure 42. Isopleths from Sound Pressure Level with Smoothing Window Size of 9 (Impact, Sheet Pile, Shallow Hydrophone)

3.2.2 Sheet Pile Driving – Deep Hydrophone – Face Wall

A number of impact pile driving sessions at the face wall were recorded with the deployment of the hydrophone approximately 1 m above the sea floor bottom on September 30, 2008. The summary of the analysis is shown in **Table 21**. The distance to the 160 dB isopleth under worst case conditions was estimated to be 96.97 m based on SPL value using an RMS computation, but it can be as far as 1,519.57 m when it is derived from instantaneous peak pressure.

Table 21. Summary of Data Analysis (Impact, Sheet Pile, Deep Hydrophone)

Data Field	Values
Sampling Date & Time	09/30/2008, 08:36:47.71~10:11:11.85
Total Count of Impact Driving	1669
Average Source Level [dB]	194.50
Max/Min Source Level [dB]	200.47 / 174.13
Average Sound Pressure Level [dB]	149.68
Max/Min Sound Pressure Level [dB]	159.30 / 127.39
Average Instantaneous Peak Pressure [dB]	170.57
Max/Min Instantaneous Peak Pressure [dB]	182.86 / 145.10
Average Range to Source [m]	238.34
Max/Min Range to Source [m]	520.88 / 34.16
Estimated 160 dB Distance (Worst Case) [m] Based on SPL (RMS)	96.96
Estimated 160 dB Distance (Worst Case) [m] Based on Instantaneous Peak Pressure	1519.57

Table 22. Data Collection Log (Impact, Sheet Pile, Deep Hydrophone)

SLM Data			Avisoft Data					Comments
File name	Start time	Stop time	File name	Start time	Stop time	Start offset	End offset	
831_DATA_115.xls	8:35:19	8:39:28	T0000066.wav	8:36:15	8:39:33	00:32	03:08	Soft start, Range approx 77 m, very high tide
831_DATA_116.xls	8:40:48	8:48:19	T0000067.wav	8:40:46	8:44:46	00:39	04:00	Good data set SPL vs range, floating north
			T0000068.wav	8:44:46	8:48:17	00:00	01:38	Started approx 127 m away, finished way pass 300 m, hitting bottom at the end
				8:44:46	8:48:17	02:00	03:21	
831_DATA_117.xls	8:49:14	8:51:03	T0000069.wav	8:49:12	8:51:06	01:09	01:33	Range 340 m at start, much lower signal
831_DATA_118.xls	8:51:43	8:57:43	T0000070.wav	8:51:45	8:55:45	01:12	04:00	Range 435 and still moving north
			T0000071.wav	8:55:45	8:57:42	00:00	01:48	SPL is 154 dB
831_DATA_119.xls	9:03:02	9:04:13	T0000072.wav	9:03:01	9:04:11	00:00	01:01	Range 442 m,152 dB SPL
831_DATA_120.xls	9:07:39	9:12:58	T0000073.wav	9:07:38	9:11:38	00:02	04:00	Range 167 m, LZI 163 dB, drifting west
			T0000074.wav	9:11:38	9:12:57	00:00	01:08	213 m range, 162 dB LZI
831_DATA_122.xls	9:14:34	9:21:35	T0000076.wav	9:14:21	9:18:21	00:00	04:00	Approx 160 dB LZI 278 m range
			T0000077.wav	9:18:21	9:21:34	00:00	03:05	Range 393 m, below 160 dB LZI, stopped recording when depth was 7 ft

831_DATA_123.xls	9:26:45	9:34:06	T0000078.wav	9:26:48	9:30:48	02:11	04:00	Hitting the bottom at the beginning of the file
			T0000079.wav	9:30:48	9:34:05	00:00	03:01	159 m - 166 dB LZI, 136 m - 167 dB, 170 m - 162 dB, 213 m - 160 dB
831_DATA_124.xls	9:36:46	10:05:51	T0000081.wav	10:00:01	10:04:01	00:26	04:00	Range 82 m - 163 dB
			T0000082.wav	10:04:01	10:05:50	00:00	01:50	Range 102 m - 160 dB
831_DATA_125.xls	10:09:55	10:11:22	T0000083.wav	10:09:58	10:11:27	00:00	01:15	Range 180 m

3.2.2.1 Data Collection and Sampling Area

During the data collection, 10 separate sessions were recorded with the distance between 34.16 and 520.88 m at tide levels between 25.73 and 30.45 ft. **Table 22** shows all sessions in detail.

The sample locations during impact pile driving were logged with a GPS that was synchronized with acoustic data collection. **Figure 43** shows the relative positions of the impact sheet pile driving and sample locations. The yellow push pin icon refers to the location of the pile driving site (N61°15'4.941", W149°52'56.875") and the light green tracks indicate the data collection locations.

Figure 43. Aerial Map of Sample Location and Pile Driving Site (Impact, Sheet Pile, Deep Hydrophone)

3.2.2.2 Data Processing and Analysis

The sound pressure levels for impact pile driving ranged from 127.38 to 159.30 dB re 1μPa during the recording session. Their equivalent instantaneous peak pressures ranged from 145.10 to 182.86 dB re 1μPa.

The 1,669 individual impacts recorded in 16 raw time series are shown in **Figure 44** following processing for sound pressure levels with RMS computation and the instantaneous peak pressures. The range to the 160 dB isopleths was derived for both instances.

The tide level significantly affects the propagation of the sound energy (the higher tide, the more efficient transmission of the sound energy). As shown in **Figure 45**, tide levels during the first eight recording sessions were very high (30.45~28.25ft) and the last two sessions were relatively low, but not too low to notably impede the propagation of the sound energy.

One-third octave spectrum was averaged over all measured impact pile driving and are shown in **Figure 46**. Most of the spectral energy is concentrated between the 400 Hz and 20 kHz spectral bands, and the peak band is observed at 8 kHz~10 kHz.

Figure 46 also shows the standard deviation spectrum. The low frequency bands have relatively high variation, but the overall deviation stays low.

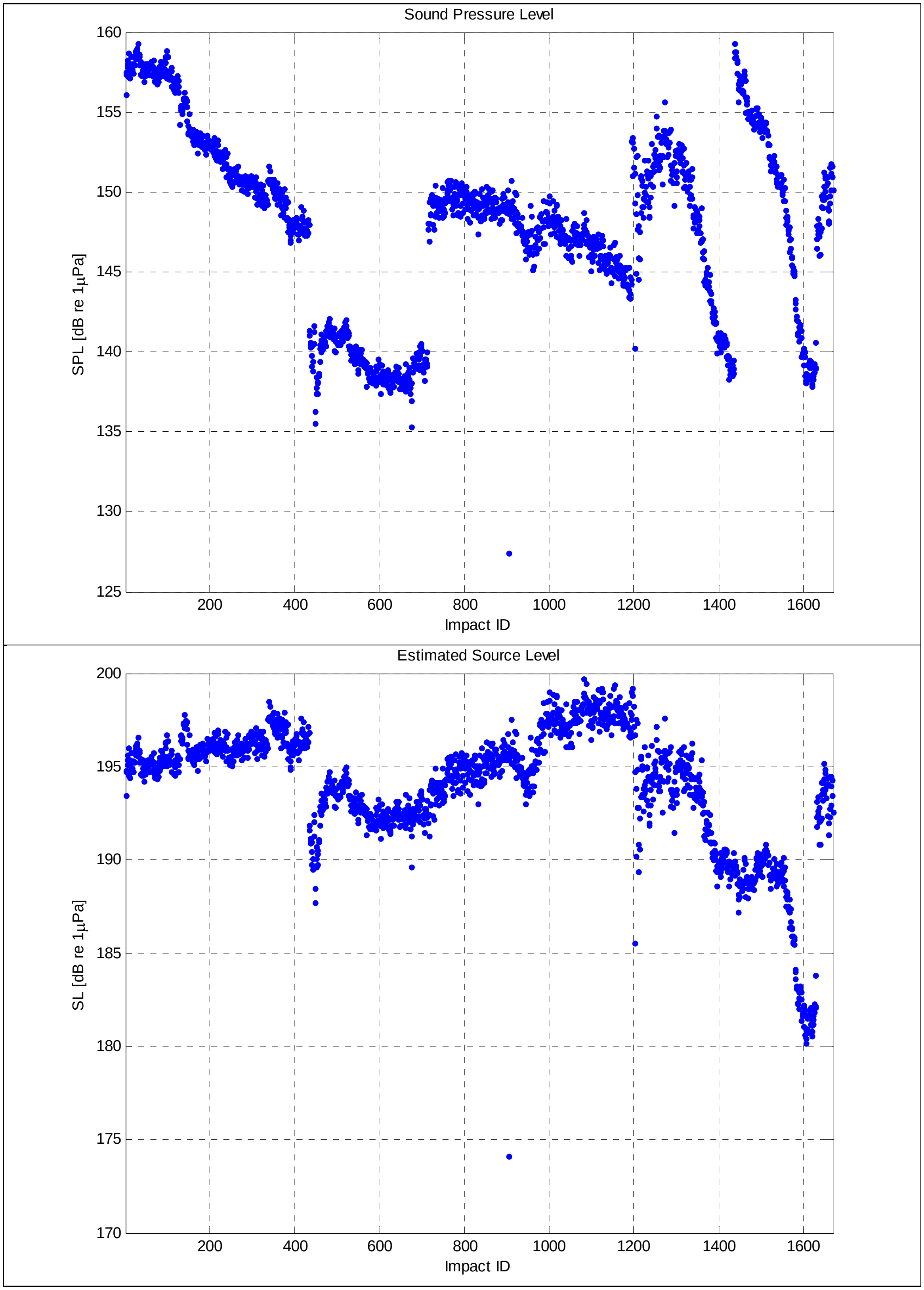


Figure 44. Sound Pressure Level and Estimated Source Level (Impact, Sheet Pile, Deep Hydrophone)

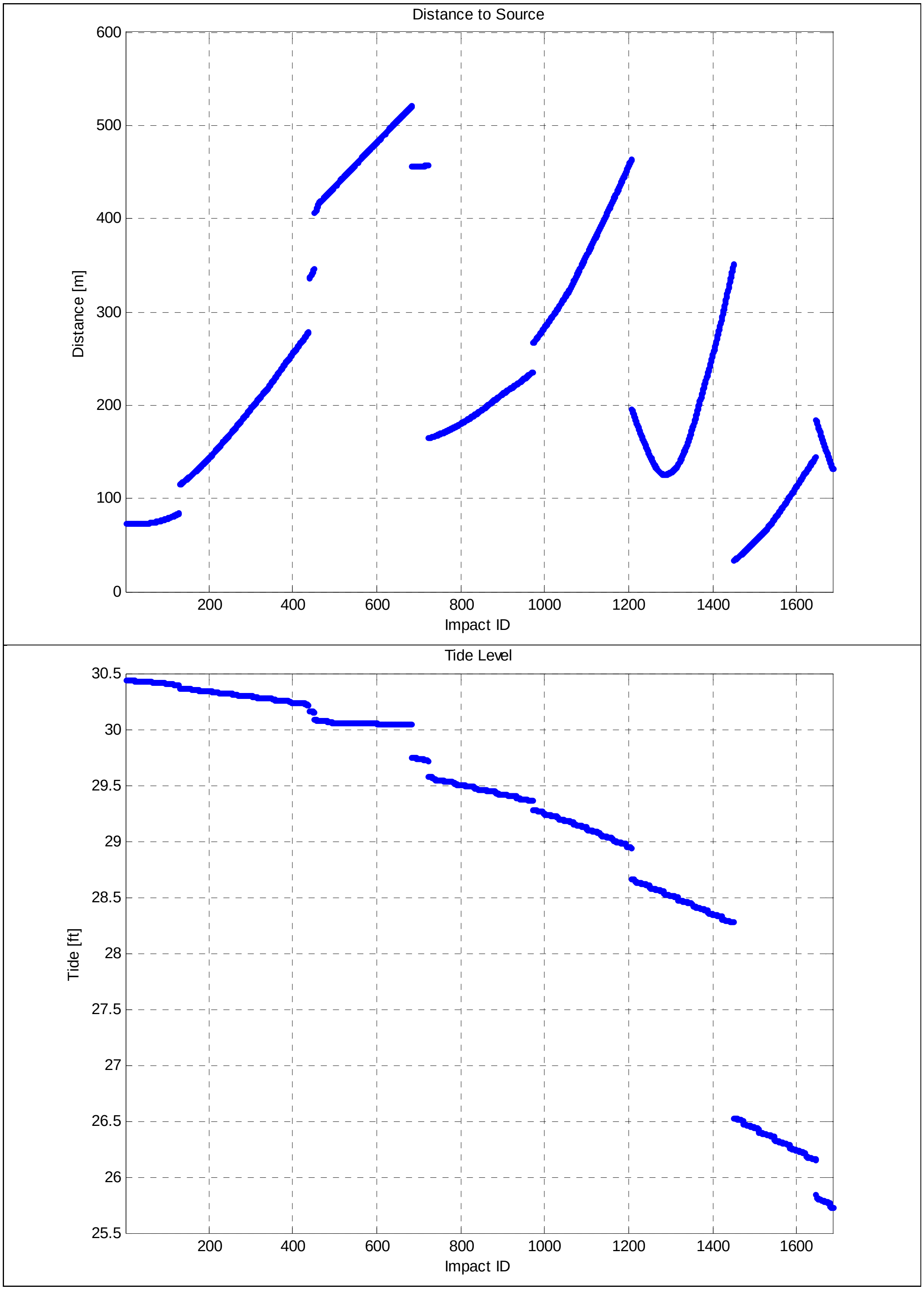


Figure 45. Distance to Source and Tide Level (Impact, Sheet Pile, Deep Hydrophone)

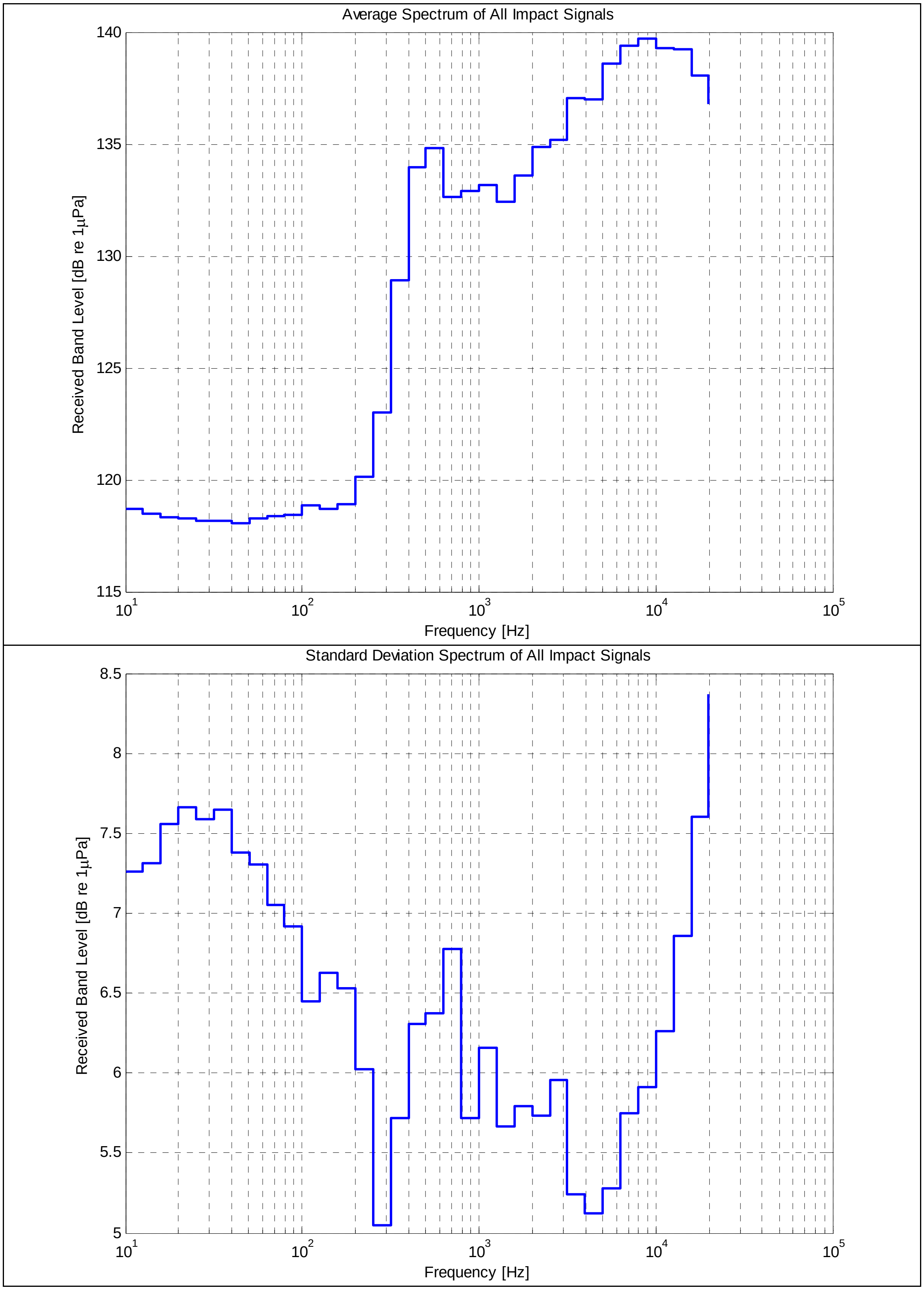


Figure 46. Average Spectrum and Standard Deviation (Impact, Sheet Pile, Deep Hydrophone)

3.2.2.3 Worst Case Analysis

In computing the sound energy of the impact, a typical calculation is based on RMS value for the pulse duration of the impact. The result of this SPL computation is greatly dependent on the pulse duration that is averaged relative to RMS. Longer pulse durations result in lower SPL's. A more conservative method of determining the worst case utilizes the instantaneous peak pressure without an averaging process.

When all SPL's are converted to SL's, assuming a spherical spreading transmission loss for the distance from the pile driving site, the incident with the maximum value of SL is used for the worst case analysis. This sample marks the loudest incident among the all measured impacts in terms of RMS-based SPL values (**Table 23**). This event occurred at 09:17:47.66 on September 30, 2008 and the range to the 160 dB SPL is estimated to be 96.97 m from the pile driving site.

The other perspective of the worst case incident based on the instantaneous peak pressure was measured in another instance at 09:15:49.54 on September 20, 2008; its range to the 160 dB peak pressure is estimated to be 1519.57 m from the pile driving site.

Table 23. Summary of Worst Case Analysis (Impact, Sheet Pile, Deep Hydrophone)

Data Field	Values
Data File Name for Peak Pressure	T0000076.WAV
Range to Source [m]	301.06
Date & Time of Peak Pressure	09/30/2008, 09:15:49.54
Time Offset in File [sec]	88.54
Instantaneous Peak Pressure [dB]	174.06
Estimated 160 dB Distance (Worst Case) [m] Based on Instantaneous Peak Pressure	1519.57
Data File Name for Max SPL	T0000076.wav
Date & Time of Max SPL	09/30/2008, 09:17:47.66
Time Offset in File [sec]	206.66
Range to Source [m]	355.66
Sound Pressure Level [dB]	148.71
Pulse Duration [sec]	0.32
Estimated Source Level [dB]	199.73
Estimated 160 dB Distance (Worst Case) [m] Based on SPL (RMS)	96.97

The maximum impact pile driving in term of SPL values occurred at the 206th second in the recorded file (T0000076.wav), but that of the instantaneous peak pressure was observed at the 301st second in the same data file. The close up view of the raw time series of this worst case signal is depicted in **Figure 47**.

One-third octave spectrum of this particular case is shown in **Figure 48**. Most of the spectral energy is concentrated between the 400 Hz and 20 kHz bands, which follows the trend of the rest of the measurements in all 10 recording sessions.

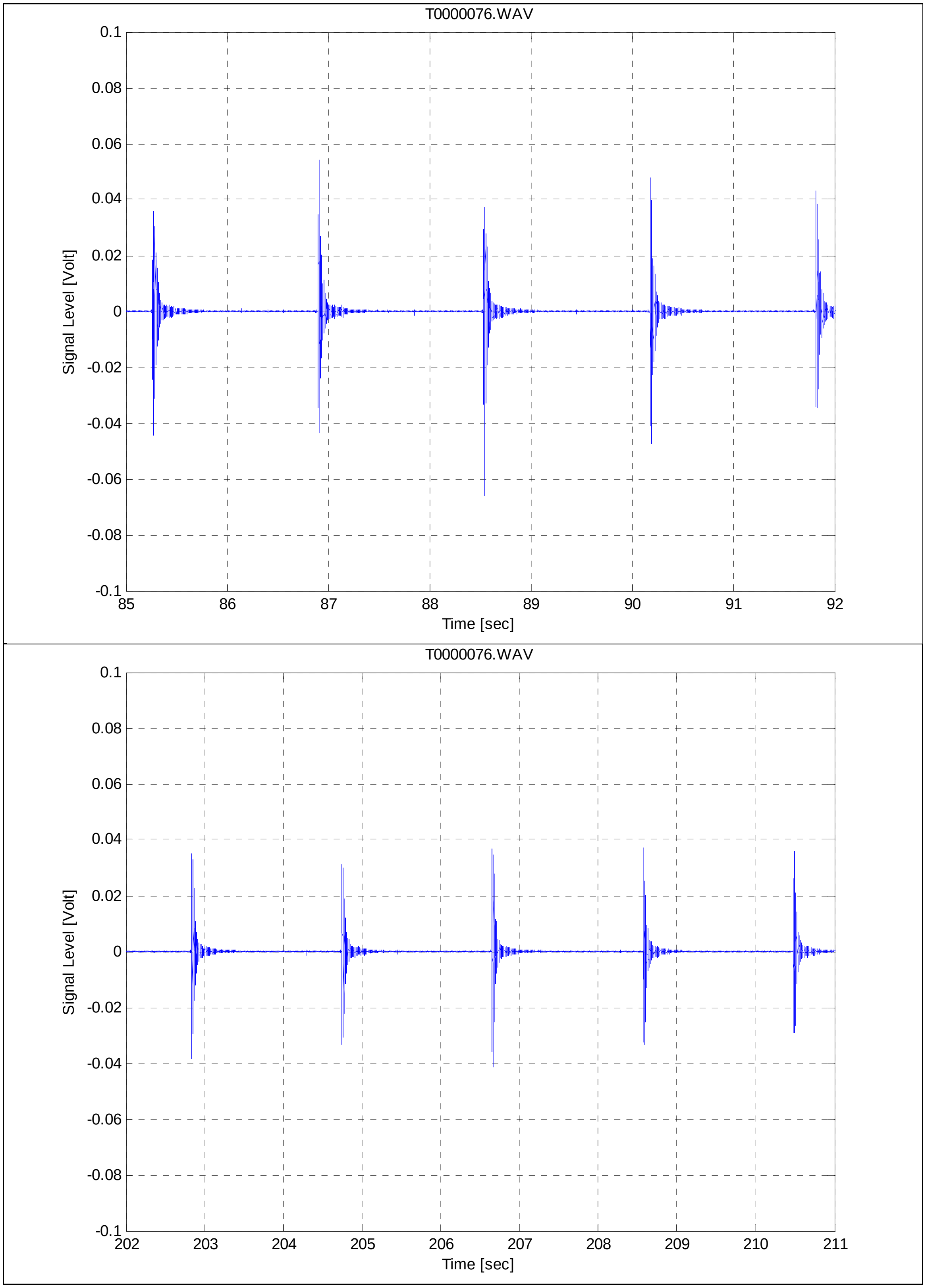


Figure 47. Raw Time Series of Pile Driving (Impact, Sheet Pile, Deep Hydrophone)

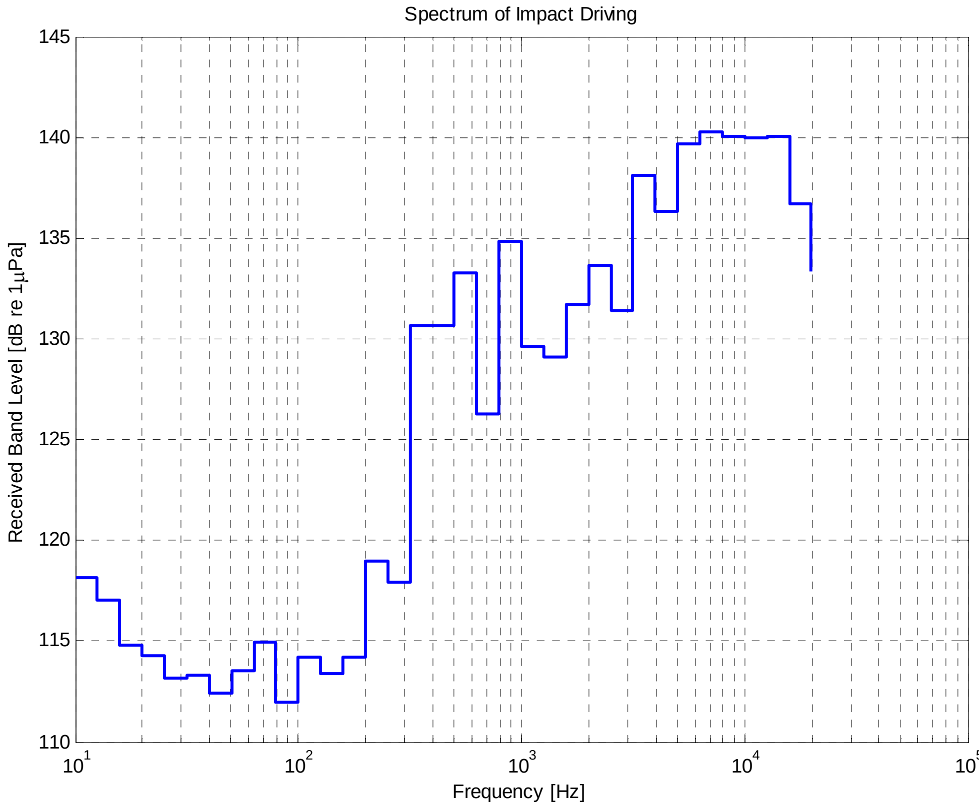


Figure 48. One-Third Octave Spectrum for Pile Driving (Impact, Sheet Pile, Deep Hydrophone)

A nominal transmission loss configuration of 20 log R is used to calculate SL values, although the actual transmission loss is a function of many complicated environmental variables. Thus, different possibilities of transmission loss, such as 16 log R, 18 log R, 22 log R, and 24 log R, are considered to estimate the SL value at the pile driving location and eventually to compute the range to 160 dB.

Figure 49 shows the estimated instantaneous peak pressures in the left column and sound pressure levels in the right column for the impact sheet pile driving with range up to 10 km. Each plot shows five possible situations of SPL values for the varying ranges up to 10 km based on the worst case measurement: the red curve indicates the SPL using the transmission loss with 16 log R, the magenta curve indicates the SPL using the transmission loss with 18 log R; the blue curve indicates the SPL using the transmission loss with 20 log R; the cyan curve indicates the SPL using the transmission loss with 22 log R; and the green curve indicates the SPL using the transmission loss with 24 log R.

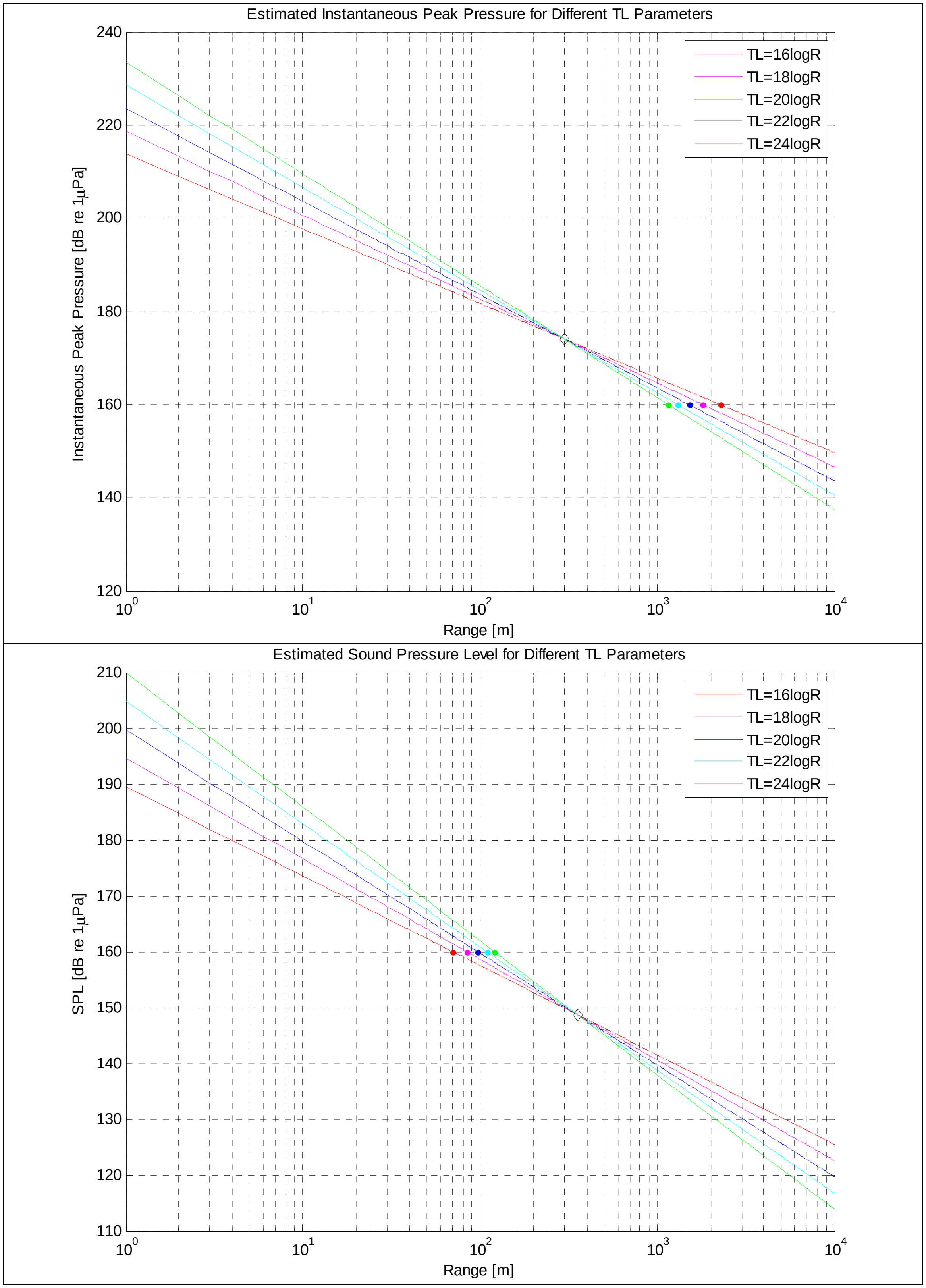


Figure 49. Consideration of Different Transmission Loss Configuration (Impact, Sheet Pile, Deep Hydrophone)

The estimated range to the 160 dB peak pressure and 160 dB SPL for these five different transmission loss configurations are listed in **Table 24**.

Table 24. Estimated 160 dB Distances of Instantaneous Peak Pressures and Sound Pressure Levels (Impact, Sheet Pile, Deep Hydrophone)

Transmission Loss	Est. 160 dB Distance [m] Based on Inst. Peak Pressure	Est. 160 dB Distance [m] Based on SPL (RMS)
16 log R	2277.65	70.07
18 log R	1819.03	83.93
20 log R	1519.57	96.97
22 log R	1311.61	109.13
24 log R	1160.23	120.42

3.2.2.4 Isopleths

Using one of the paths that went parallel to the shore line (**Figure 50**), the isopleths for deep impact were generated. Two raw data files comprise the recording in this path: T0000078.wav and T0000079.wav.

Figure 50. Aerial Map of Sample Location and Pile Driving Site (Impact, Sheet Pile, Deep Hydrophone)

The individual values of SPL and instantaneous peak pressure are widely varying in the raw data recording. Therefore, the running average operation with adjacent values helped smooth out the values to result in more acceptable presentation of isopleths. Two different window sizes of five and nine samples were tried for this reason.

For the worst case scenario, the isopleths based on the instantaneous peak pressures were computed and shown in **Figure 51** and **Figure 52**. The isopleths in **Figure 51** were generated with a window size of five and that in **Figure 52** with a window size of nine, respectively.

The isopleths based on SPL values that are conventionally presented as RMS sound energy were computed and shown in **Figure 53** and **Figure 54**. The isopleths in **Figure 53** were generated with a window size of five and that in **Figure 54** with a window size of nine, respectively.

One noticeable discovery from the isopleths was that the propagation of the impact sound energy is not uniform (cylindrical/spherical) but directional. For example, 160 dB isopleths are not uniformly observed in all cases. The presentation of the worst case noise study should take into consideration the irregularity of the spreading pattern.

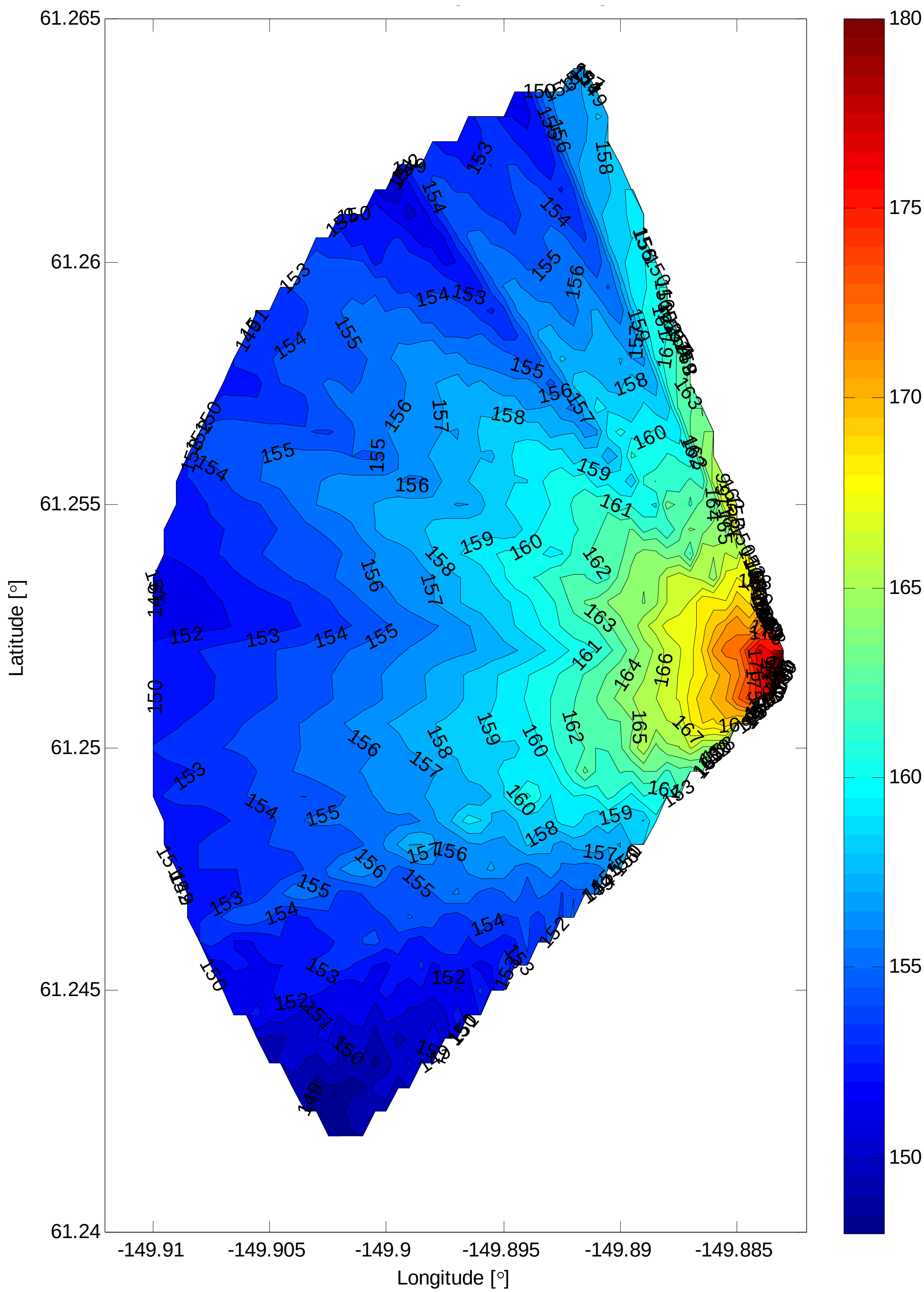


Figure 51. Isopleths from Instantaneous Peak Pressure with Smoothing Window Size of 5 (Impact, Sheet Pile, Deep Hydrophone)

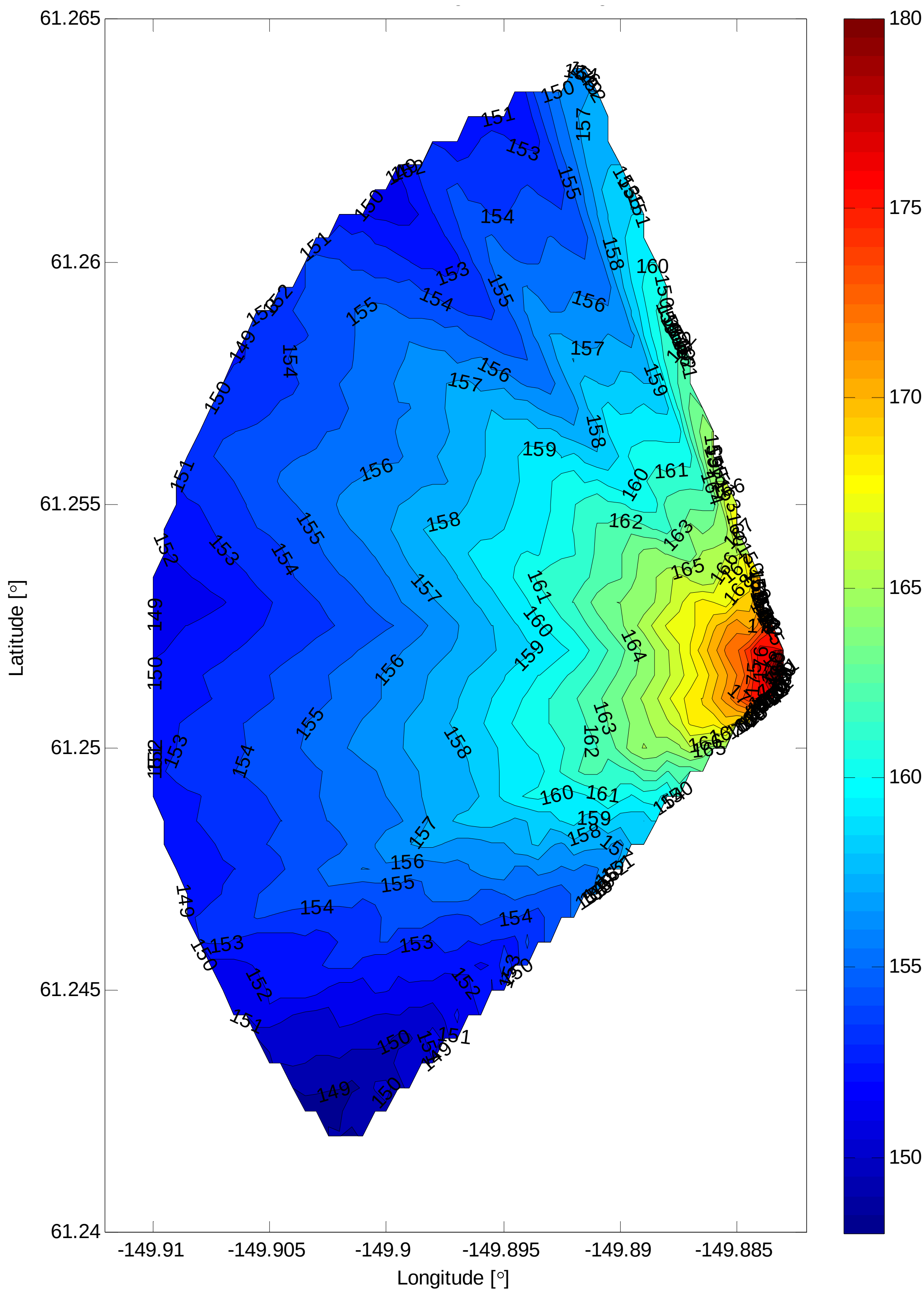


Figure 52. Isopleths from Instantaneous Peak Pressure with Smoothing Window Size of 9 (Impact, Sheet Pile, Deep Hydrophone)

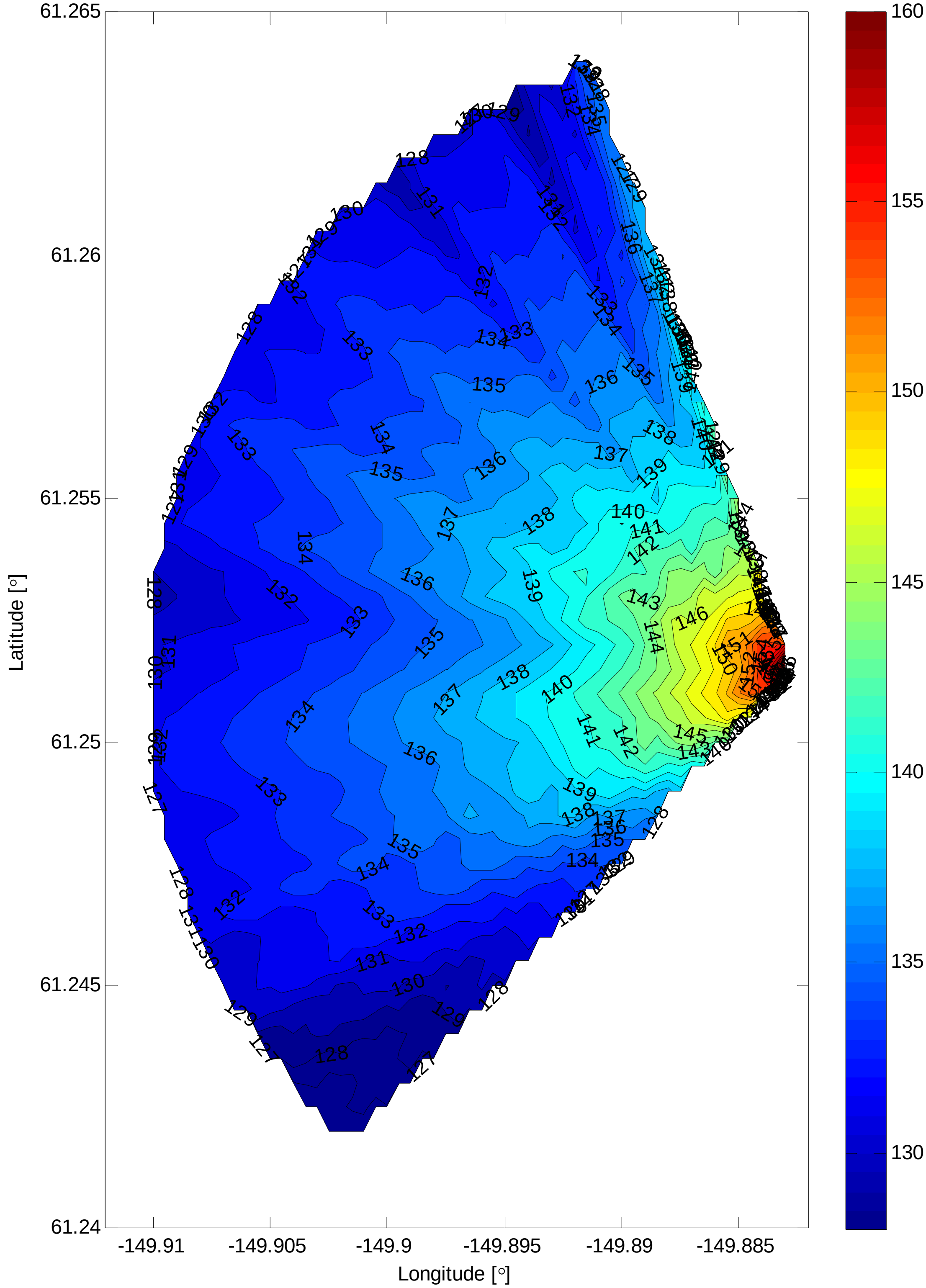


Figure 53. Isopleths from Sound Pressure Level with Smoothing Window Size of 5 (Impact, Sheet Pile, Shallow Hydrophone)

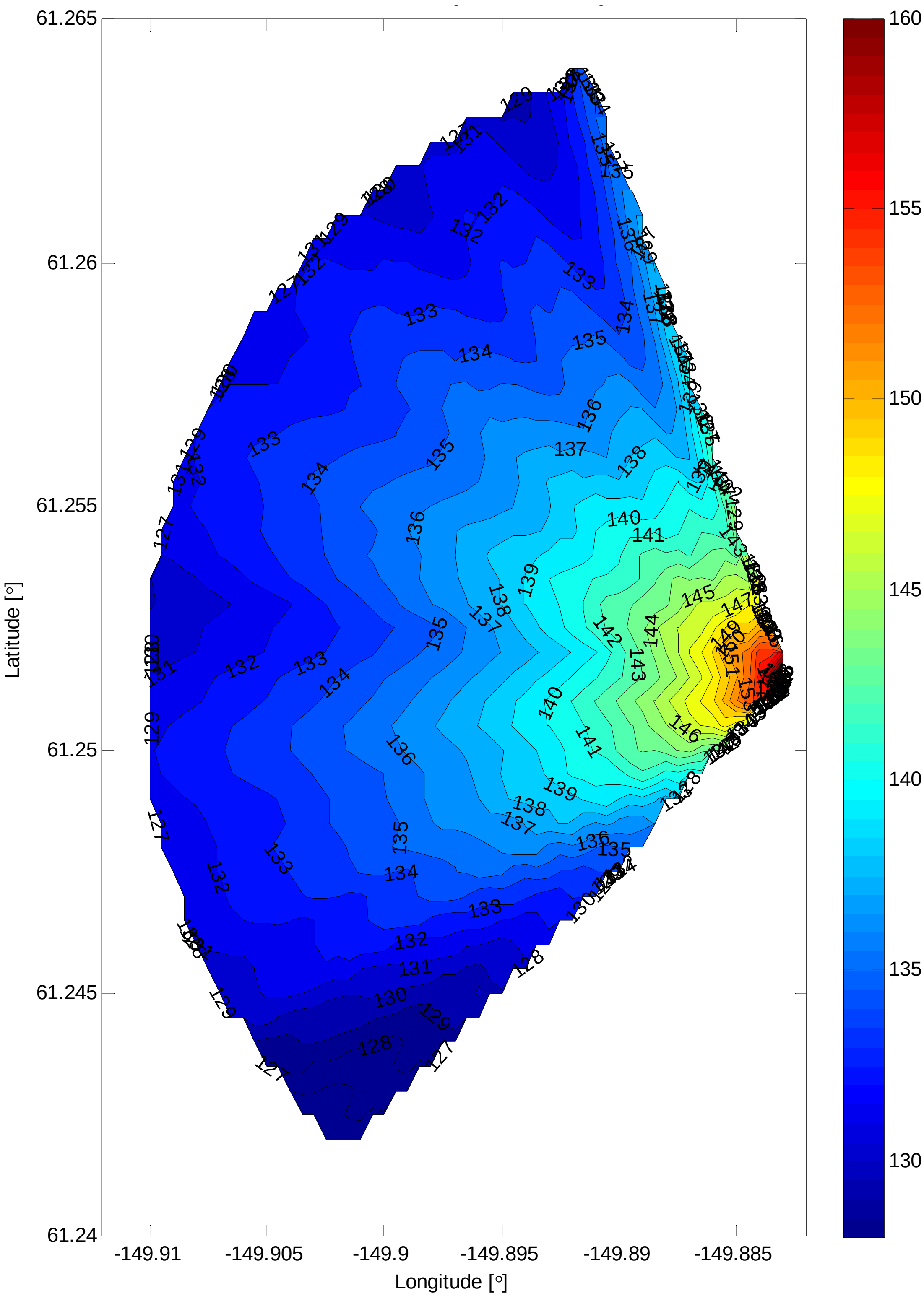


Figure 54. Isopleths from Sound Pressure Level with Smoothing Window Size of 9 (Impact, Sheet Pile, Shallow Hydrophone)

3.2.3 Wye-Pile Driving

The Wye-pile driving sessions were collected on October 1, 2008 and the summary of the analysis is shown in **Table 25**. The distance to the 160 dB isopleth under worst case conditions was estimated to be 54.09 m based on SPL value using an RMS computation, but it can be as far as 700.96 m when it is derived from instantaneous peak pressure.

Table 25. Summary of Data Analysis (Impact, Wye-Pile)

Data Field	Values
Sampling Date & Time	10/01/2008, 10:14:12.40~10:25:14.49
Total Count of Impacts	77
Average Source Level [dB]	189.16
Max/Min Source Level [dB]	194.66 / 178.18
Average Sound Pressure Level [dB]	140.51
Max/Min Sound Pressure Level [dB]	150.84 / 132.33
Average Instantaneous Peak Pressure [dB]	160.66
Max/Min Instantaneous Peak Pressure [dB]	173.10 / 151.75
Average Range to Source [m]	298.56
Max/Min Range to Source [m]	363.89 / 155.04
Estimated 160 dB Distance (Worst Case) [m] Based on SPL (RMS)	54.08
Estimated 160 dB Distance (Worst Case) [m] Based on Instantaneous Peak Pressure	700.96

3.2.3.1 Data Collection and Sampling Area

During the data collection, two separate sessions were recorded with the distance between 155.04 m and 363.89 m at tide levels between 26.98 and 27.67 ft. **Table 26** shows both sessions in detail.

Table 26. Data Collection Log (Impact, Wye-Pile)

SLM Data			Avisoft Data					Comments
File name	Start time	Stop time	File name	Start time	Stop time	Start offset	End offset	
831_DATA_144.xls	10:13:09	10:20:49	T0000124.wav	10:17:11	10:20:48	0:55	03.37	
831_DATA_145.xls	10:24:05	10:25:35	T0000125.wav	10:24:07	10:25:34	0:00	01:10	360 m, LZI approx 156 dB

The sampling locations during impact pile driving were logged with a GPS that was synchronized with acoustic data collection. **Figure 55** shows the relative positions of the wye pile impact driving and the sampling locations. The yellow push pin icon refers to the location of the pile driving site (N 61°15'4.941", W 149°52'56.875") and the three light green tracks indicate the sampling locations.

Figure 55. Aerial Map of Sample Location and Pile Driving Site (Impact, Wye-Pile)

3.2.3.2 Data Processing and Analysis

Sound pressure levels for the Wye-pile driving ranged from 132.33 to 150.84 dB re 1μPa during the recording session. Their equivalent instantaneous peak pressures ranged from 151.75 to 173.10 dB re 1μPa.

The 77 individual impacts recorded in two raw time series of the recorded data are shown in **Figure 56** following processing for sound pressure levels with RMS computation and the instantaneous peak pressures. The range to the 160 dB isopleths was derived for both instances.

The tide level significantly affects the propagation of the sound energy (the higher tide, the more efficient transmission of the sound energy). As illustrated in **Figure 57**, tide levels during the two recording sessions were relatively high (26.98~27.67ft).

One-third octave spectrum averaged over all measured Wye-pile driving is shown in **Figure 58**. The spectral energy slowly increases, peaks at 8 kHz~10 kHz, and declines afterward. The trend of spectral energy distribution is consistent throughout the measurement.

Figure 58 also shows the standard deviation spectrum. The low frequency bands have relatively high variation, but the overall deviation stays low.

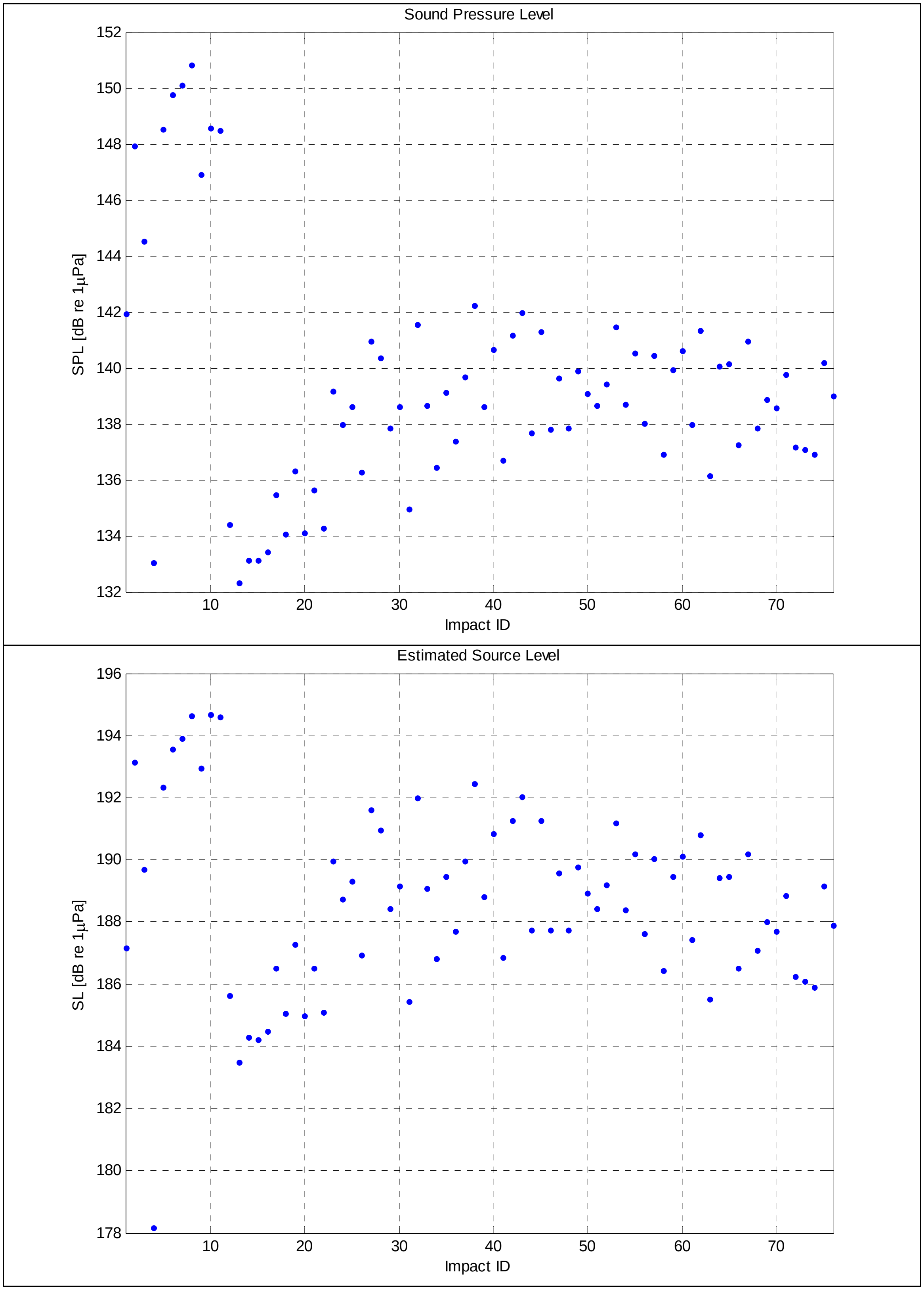


Figure 56. Sound Pressure Level and Estimated Source Level (Impact, Wye-Pile)

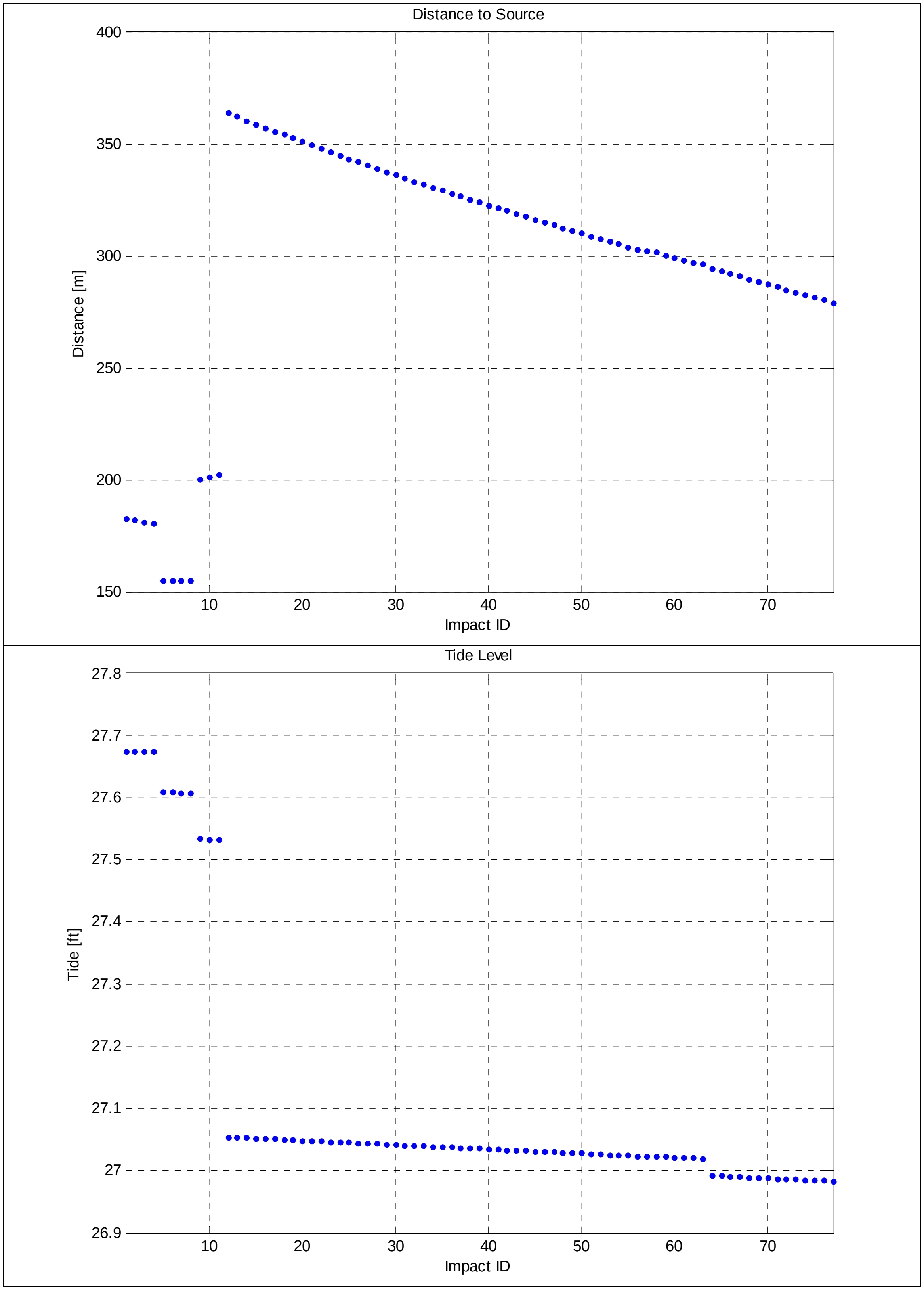


Figure 57. Distance to Source and Tide Level (Impact, Wye-Pile)

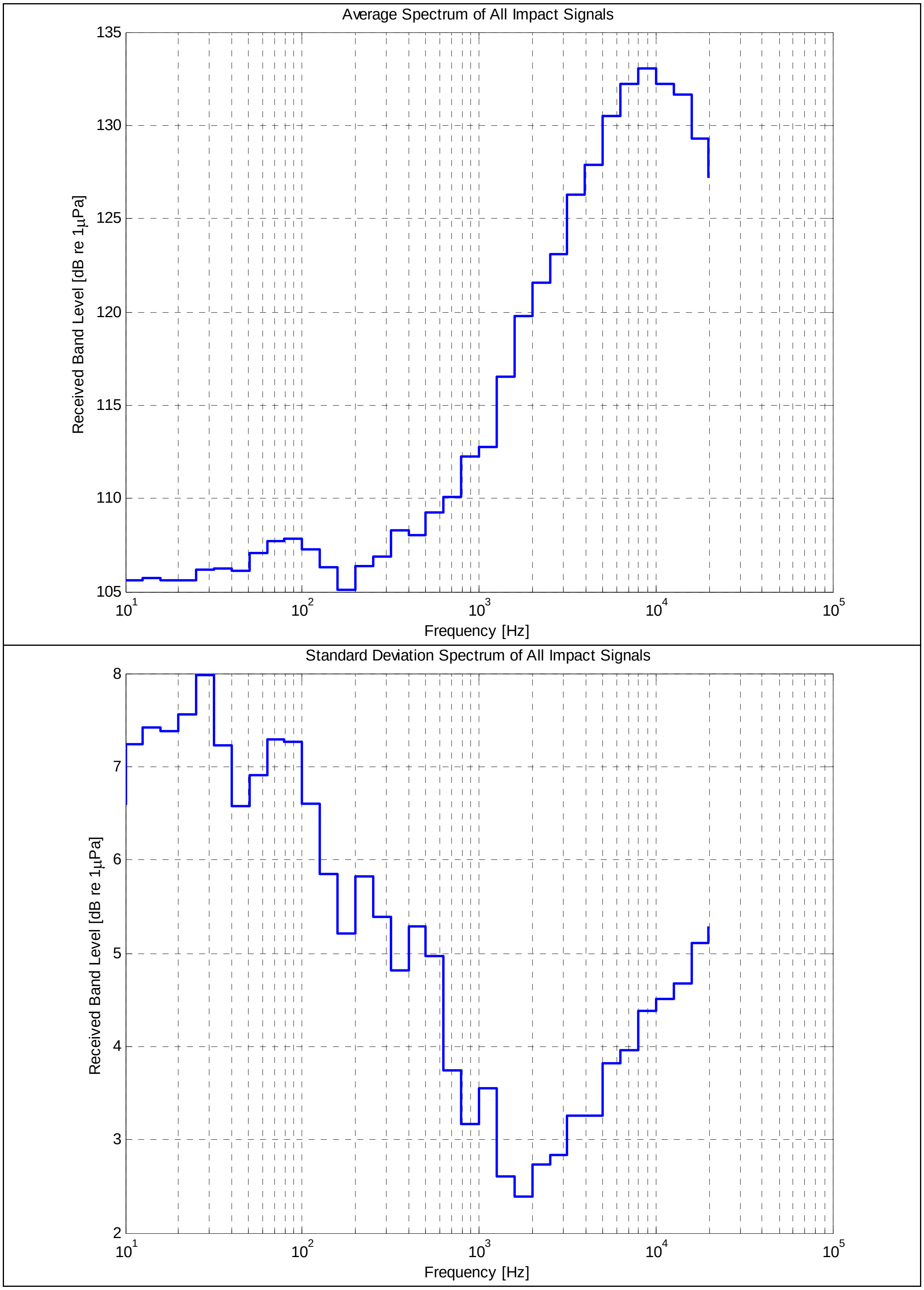


Figure 58. Average Spectrum and Standard Deviation (Impact, Wye-Pile)

3.2.3.3 Worst Case Analysis

In computing the sound energy of the impact, a typical calculation is based on RMS value for the pulse duration of the impact. The result of this SPL computation is greatly dependent on the pulse duration that is averaged relative to RMS. The longer pulse duration, the lower SPL is. However, a more conservative method of the worst case computation can be based on the instantaneous peak pressure without averaging process.

When all SPL's are converted to SL's, considering the transmission loss for the distance from the pile driving site, the incident with the maximum value of SL is taken for the worst case analysis. This sample is considered as the loudest incident among all measured impacts in terms of RMS-based SPL values (**Table 27**). It happened 10:16:47.07 October 1, 2008 during the recording session, and its 160 dB SPL distance is estimated to be 54.0809 m from the pile driving site.

The other perspective of the worst case incident based on the instantaneous peak pressure was measured in another instance at 10:15:24.46 October 1, 2008 and its 160 dB peak pressure distance is estimated to be 700.96 m from the pile driving site.

Table 27. Summary of Worst Case Analysis (Impact, Wye-Pile)

Data Field	Values
Data File Name for Peak Pressure	T0000123.WAV
Range to Source [m]	201.34
Date and Time of Peak Pressure	10/01/2008, 10:15:24.46
Time Offset in File [sec]	132.46
Instantaneous Peak Pressure [dB]	173.10
Estimated 160 dB Distance (Worst Case) [m] Based on Instantaneous Peak Pressure	909.76
Data File Name for Max SPL	T0000123.WAV
Date and Time of Max SPL	10/01/2008, 10:16:47.07
Time Offset in File [sec]	215.07
Range to Source [m]	155.18
Sound Pressure Level [dB]	148.58
Pulse Duration [sec]	0.31
Estimated Source Level [dB]	194.66
Estimated 160 dB Distance (Worst Case) [m] Based on SPL (RMS)	54.08

The maximum impact Wye-pile driving in term of SPL values occurred at the 215th second in the recorded file (T0000123.wav), but that of the instantaneous peak pressure was observed at the 132nd second in the same data file. The close-up view of the raw time series of this worst case signal is depicted in **Figure 59**.

One-third octave spectrum of this particular case is shown in **Figure 60**. Most of the spectral energy is concentrated between the 5 kHz and 20 kHz bands, which follows the trend of the rest of the measurement in both recording sessions.

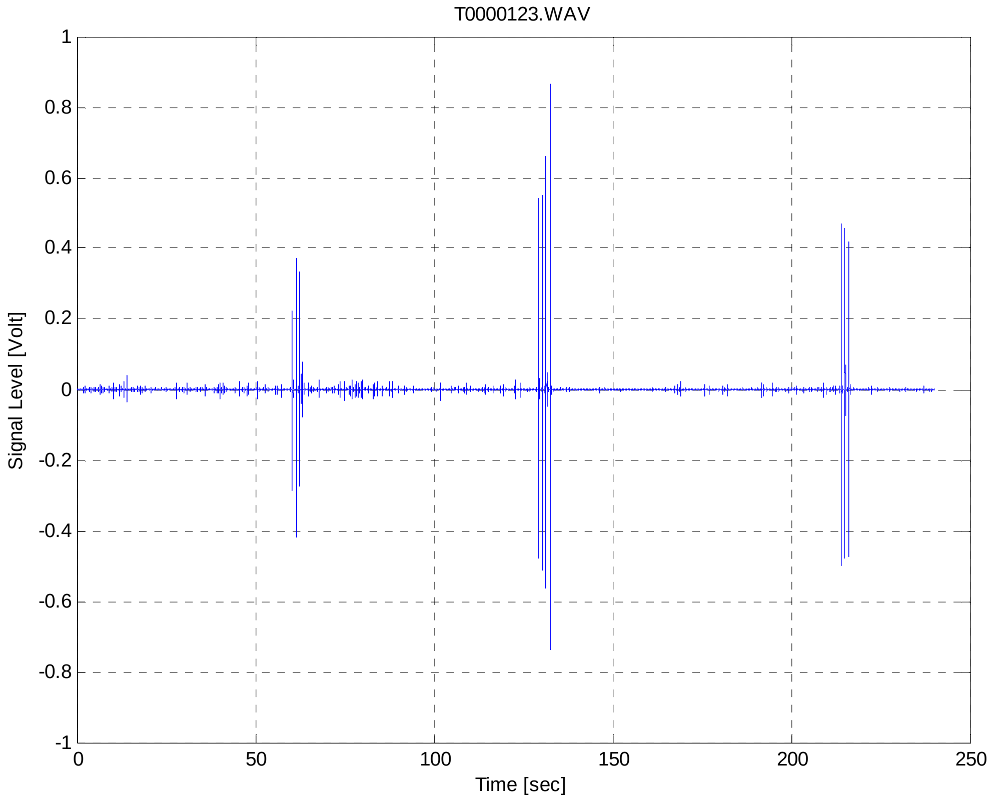


Figure 59. Raw Time Series of Pile Driving (Impact, Wye-Pile)

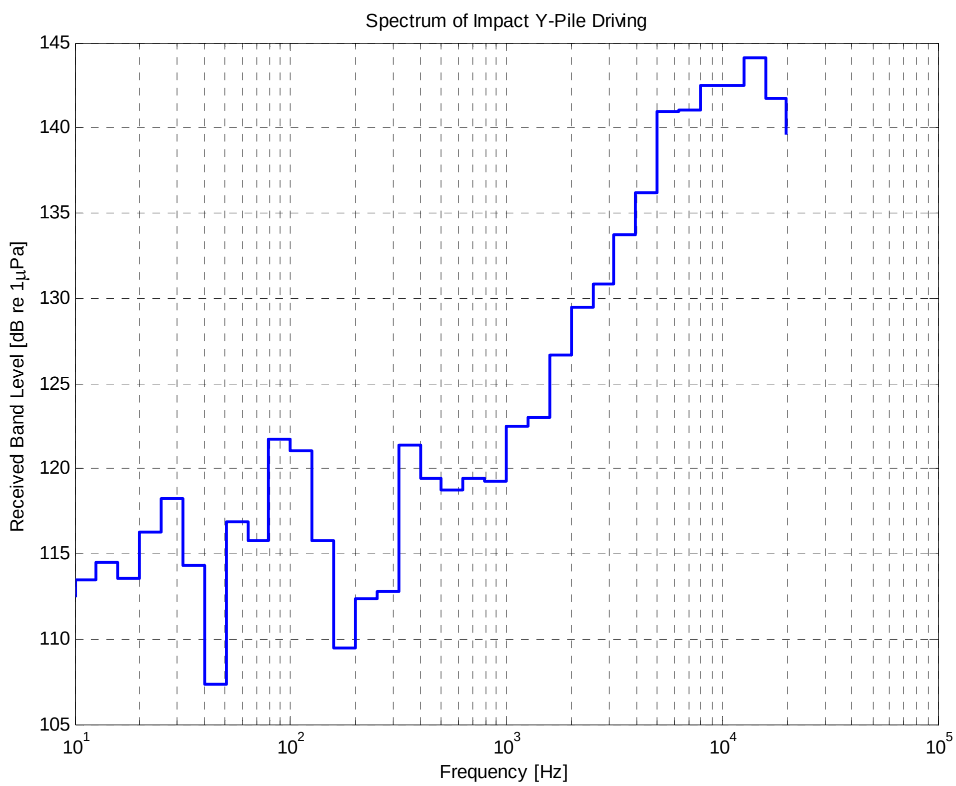


Figure 60. One-Third Octave Spectrum for Pile Driving (Impact, Wye-Pile)

A nominal transmission loss configuration of 20 log R is used to calculate SL values, although the actual transmission loss is a function of many complicated environmental variables. Thus, different possibilities of transmission loss, such as 16 log R, 18 log R, 22 log R, and 24 log R, are considered to estimate the SL value at the pile driving location and eventually to compute the distance to 160 dB.

Figure 61 shows the estimated instantaneous peak pressures in the left column and sound pressure levels in the right column for the impact wye pile driving with range up to 10 km. Each plot shows five possible situations of SPL values for the varying ranges up to 10 km based on the worst case measurement: the red curve indicates the SPL using the transmission loss with 16 log R; the magenta curve indicates the SPL using the transmission loss with 18 log R; the blue curve indicates the SPL using the transmission loss with 20 log R; the cyan curve indicates the SPL using the transmission loss with 22 log R; and the green curve indicates the SPL using the transmission loss with 24 log R.

Their estimated 160 dB peak pressure distances and 160 dB SPL distances for these five different transmission loss configurations are listed in the **Table 28**.

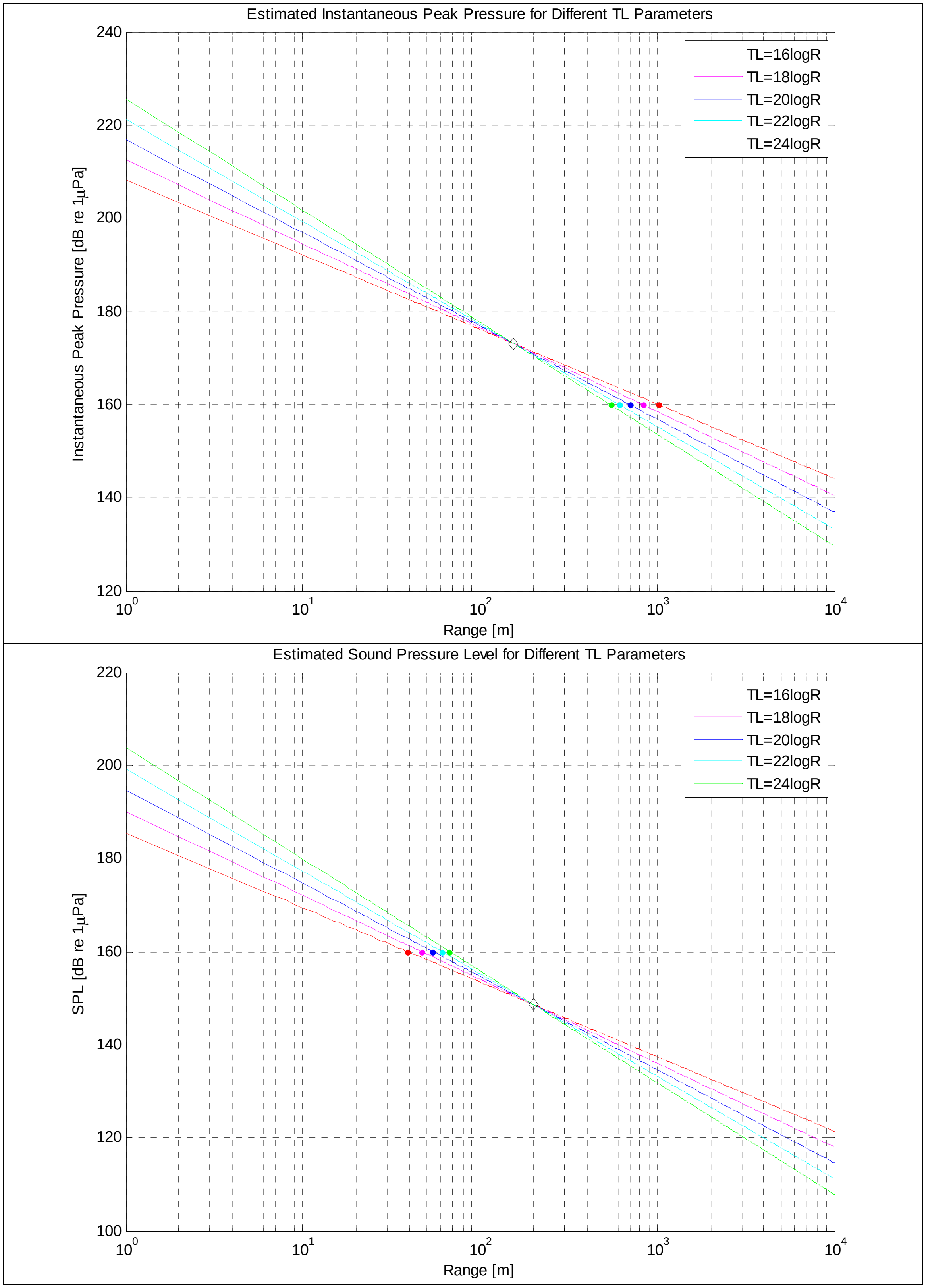


Figure 61. Consideration of Different Transmission Loss Configuration (Impact, Wye-Pile)

Table 28. Estimated 160 dB Distances of Instantaneous Peak Pressures and Sound Pressure Levels (Impact, Wye-Pile)

Transmission Loss	Est. 160 dB Distance [m] Based on Inst. Peak Pressure	Est. 160 dB Distance [m] Based on SPL (RMS)
16 log R	1021.90	38.93
18 log R	828.81	46.73
20 log R	700.96	54.08
22 log R	611.17	60.95
24 log R	545.19	67.33

3.2.4 Sheet Pile Driving – Tail Wall

A number of impact pile driving sessions at tail wall locations were recorded on September 30, 2008 and October 1, 2008 and a summary of the analysis is shown in **Table 29**. The distance to the 160 dB isopleth under worst case conditions was estimated to be 23.81 m based on SPL value using an RMS computation, but it can be as far as 291.85 m when it is derived from instantaneous peak pressure (IPP).

Table 29. Summary of Data Analysis (Vibratory, Sheet Pile – Tail Wall)

Data Field	Values
Sampling Date & Time	09/30/2008 10:17:48.1 ~ 10/01/2008 10:11:11.9
Total Count of Impact Driving	1332
Average Source Level [dB]	179.36
Max/Min Source Level [dB]	187.53 / 155.59
Average Sound Pressure Level [dB]	137.68
Max/Min Sound Pressure Level [dB]	145.43 / 122.81
Average Instantaneous Peak Pressure [dB]	157.90
Max/Min Instantaneous Peak Pressure [dB]	168.19 / 144.85
Average Range to Source [m]	127.78
Max/Min Range to Source [m]	321.71 / 32.01
Estimated 160dB Distance (Worst Case) [m] Based on SPL (rms)	23.81
Estimated 160dB Distance (Worst Case) [m] Based on Instantaneous Peak Pressure	291.85

3.2.4.1 Data Collection and Sampling Area

During the data collection, 10 separate sessions were recorded with the distance between 32.01 m and 321.71 m and tide levels between 18.50 and 26.62 ft. **Table 30** shows all sessions in detail.

Table 30. Data Collection Log (Impact, Sheet Pile – Tail Wall)

SLM Data			Avisoft Data					Comments
File name	Start time	Stop time	File name	Start time	Stop time	Start offset	End offset	
831_DATA_126.xls	10:16:02	10:27:46	T0000084.wav	10:16:01	10:20:01	01:47	04:00	Range 97 m, 154 dB
			T0000085.wav	10:20:01	10:24:01	00:00	04:00	125 m - 153 dB, 128 m - 155 dB (we are more in front of the wall)
			T0000086.wav	10:24:01	10:27:45	00:00	03:43	
831_DATA_127.xls	10:31:55	10:33:47	T0000087.wav	10:32:00	10:33:46	00:00	01:47	148 m, 152 dB
831_DATA_128.xls	10:36:55	10:39:42	T0000088.wav	10:37:00	10:39:40	00:00	02:41	67 m, 156 dB
831_DATA_129.xls	11:23:30	11:23:59	T0000089.wav	11:23:28	11:23:58	00:00	00:26	No signal visible - low or no water
831_DATA_130.xls	11:26:17	11:31:41	T0000090.wav	11:26:16	11:30:16	00:00	04:00	39 m from the wall
			T0000091.wav	11:30:16	11:31:39	00:00	01:23	Data visible on Ch 3 and Ch 4 - low water or no water
831_DATA_131.xls	11:34:18	11:35:45	T0000092.wav	11:34:16	11:35:45	00:00	01:23	Same pile, closer to the wall, 36 m - 143 dB LZI
831_DATA_146.xls	10:25:56	10:31:27	T0000127.wav	10:29:54	10:31:25	00:38	01:31	270 m away, 150 dB
831_DATA_148.xls	11:13:05	11:16:38	T0000129.wav	11:13:04	11:16:37	00:26	03:33	292 m away - 149 dB
831_DATA_149.xls	11:22:32	11:26:36	T0000130.wav	11:22:35	11:26:35	00:00	01:18	57 m - 152 dB, hitting bottom
				11:22:35	11:26:35	01:37	04:00	
831_DATA_150.xls	11:31:31	11:33:51	T0000131.wav	11:31:30	11:33:49	00:00	03:19	Signal barely visible
			T0000132.wav	11:38:00	11:38:51	00:00	00:38	SLM battery "dead" Tail wall is out of the water

The sampling locations during impact pile driving site were logged from GPS and were synchronized with acoustic data collection. **Figure 62** shows the relative positions of the impact sheet pile driving (tail wall) and the sampling locations. The yellow push pin icon refers to the location of the pile driving site (N 61°15'4.941", W 149°52'56.875") and the light green tracks indicate the data collection locations.

Figure 62. Aerial Map of Sample Location and Pile Driving Site (Impact, Sheet Pile – Tail Wall)

3.2.4.2 Data Processing and Analysis

The sound pressure levels for the impact pile driving ranged from 145.43 to 122.81 dB re 1μPa during the recording session. Their equivalent instantaneous peak pressures ranged from 144.85 to 168.19 dB re 1μPa.

The 1332 individual impacts from 14 raw time series of the recorded data shown in **Figure 63** following processing for sound pressure levels with RMS computation and the instantaneous peak pressures. The range to the 160 dB isopleths was derived for both instances.

As stated previously, the tide level significantly affects the propagation of the sound energy (the higher tide, the more efficient transmission of the sound energy). As illustrated in **Figure 64**, tide levels during the 10 recording sessions varied widely.

One-third octave spectrum averaged over all measured impact pile driving is shown in **Figure 65**. Most of spectral energy is concentrated over 2 kHz bands with peak frequency at 7 kHz. The standard deviation plot shows small variation in distribution of spectral energy.

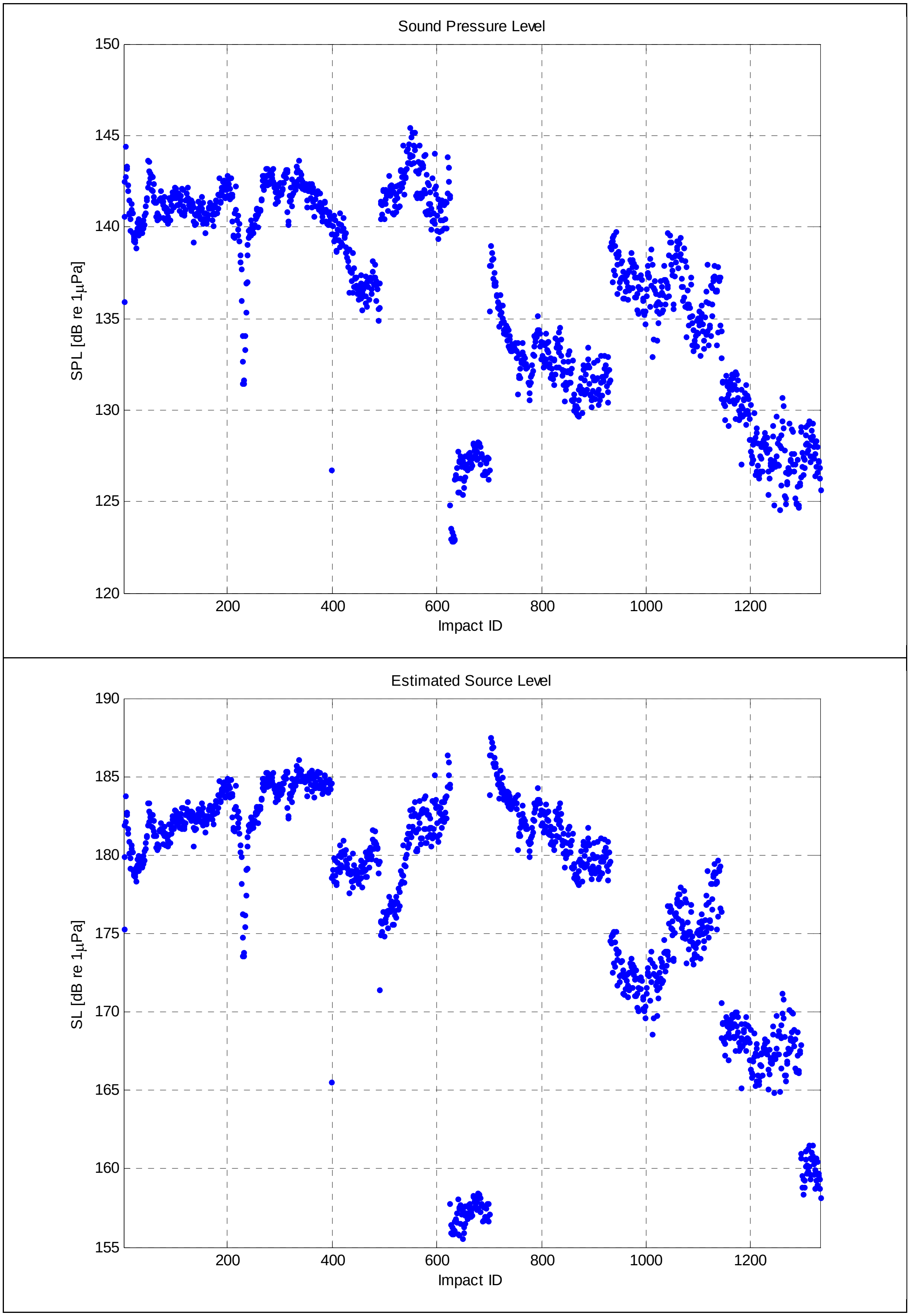


Figure 63. Sound Pressure Level and Estimated Source Level (Impact, Sheet Pile – Tail Wall)

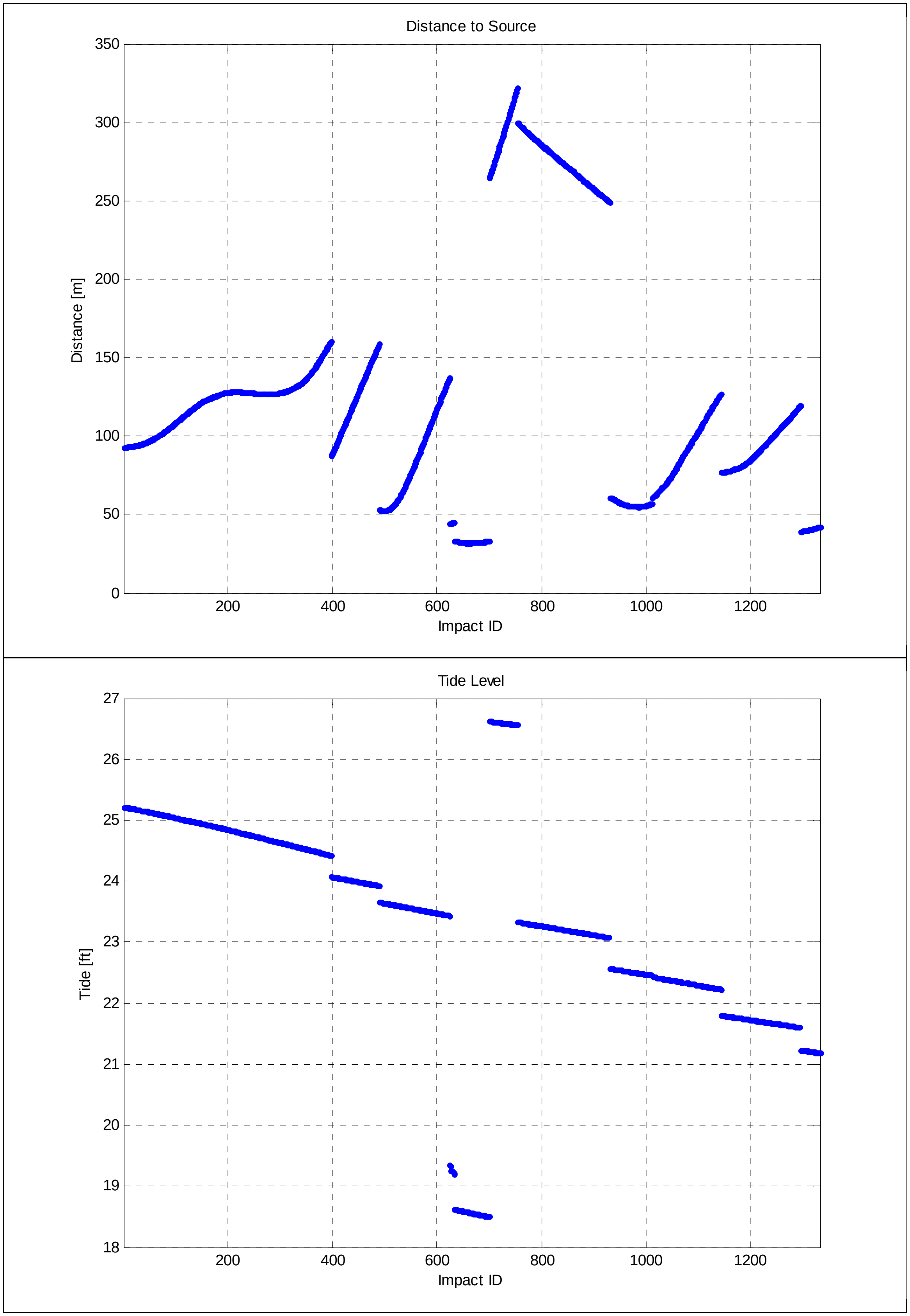


Figure 64. Distance to Source and Tide Level (Impact, Sheet Pile – Tail Wall)

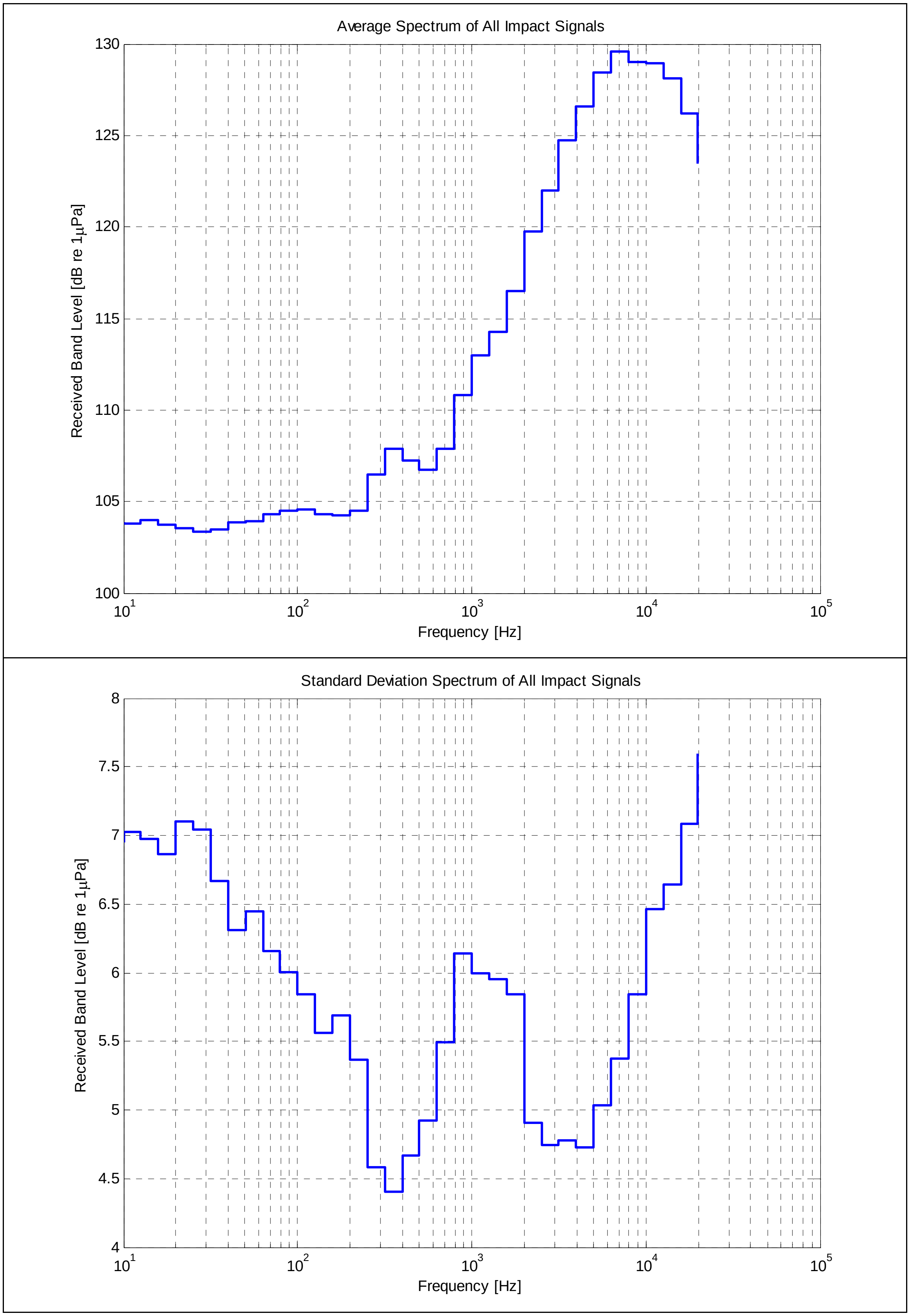


Figure 65. Average Spectrum and Standard Deviation (Impact, Sheet Pile, Shallow Hydrophone)

3.2.4.3 Worst Case Analysis

In computing the sound energy of the impact, a typical calculation is based on the RMS value for the entire pulse duration of the impact. As such, the result of this SPL computation is greatly dependent on the pulse duration that is averaged relative to RMS. The longer the pulse duration, the lower the SPL is. However, a more conservative way to determine the worst case computation is to utilize the instantaneous peak pressure without an averaging process.

When all SPL's are converted to SL's considering the transmission loss for the distance from the pile driving site, the pile driving impact with the maximum value of SL is taken for the worst case analysis. This sample is considered the loudest incident among the all measured impacts in terms of the RMS-based SPL values. This impact occurred at 10:30:35.36 on September 30, 2008 and the range to 160 dB is estimated to be 23.81 m from the pile driving site (**Table 31**).

The other perspective of the worst case incident based on the instantaneous peak pressure was measured in another instance at 10:39:04.36 on October 1, 2008 and the range to 160 dB is estimated to be 291.85 m from the pile driving site.

Table 31. Summary of Worst Case Analysis (Impact, Sheet Pile – Tail Wall)

Data Field	Values
Data File Name for Peak Pressure	T0000088.WAV
Range to Source [m]	113.64
Date & Time of Peak Pressure	09/30/2008, 10:39:04.36
Time Offset in File [sec]	124.36
Instantaneous Peak Pressure [dB]	168.19
Estimated 160dB Distance (Worst Case) [m] Based on Instantaneous Peak Pressure	291.85
Data File Name for Max SPL	T0000127.WAV
Date & Time of Max SPL	10/01/2008, 10:30:35.36
Time Offset in File [sec]	41.36
Range to Source [m]	267.74
Sound Pressure Level [dB]	138.98
Pulse Duration [sec]	0.31
Estimated Source Level [dB]	187.53
Estimated 160dB Distance (Worst Case) [m] Based on SPL (rms)	23.81

The maximum impact pile driving in term of SPL values occurred at the 124th second in the recorded file (T0000088.wav), but that of the instantaneous peak pressure was observed at the 41st second in different data file. The close-up view of the raw time series of this worst case signal is depicted in **Figure 66**.

One-third octave spectrum of this particular case is shown in **Figure 67**. Most of the spectral energy is concentrated over 3 kHz, which follows the trend of the rest of the measurement.

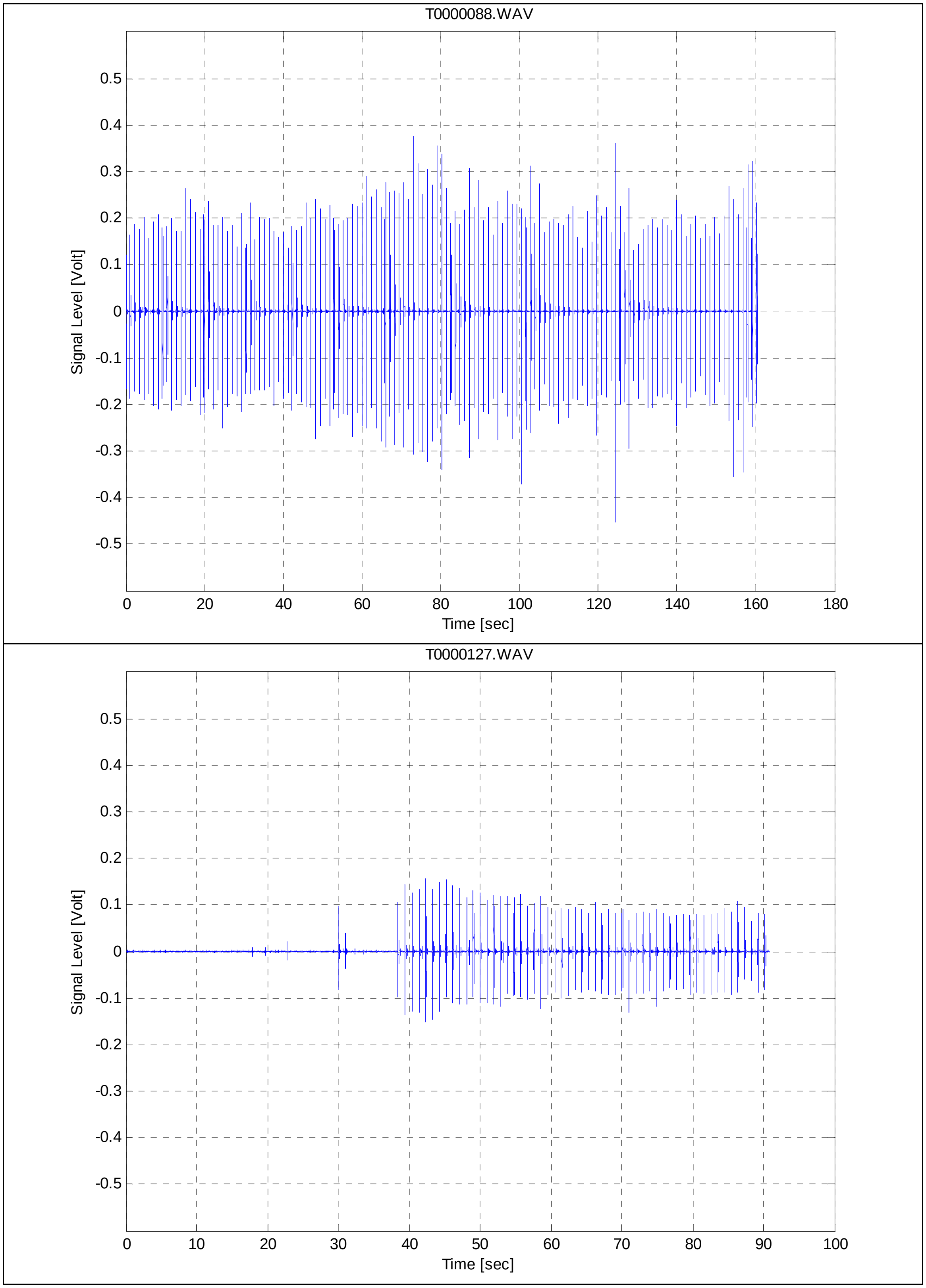


Figure 66. Raw Time Series of Pile Driving (Impact, Sheet Pile – Tail Wall)

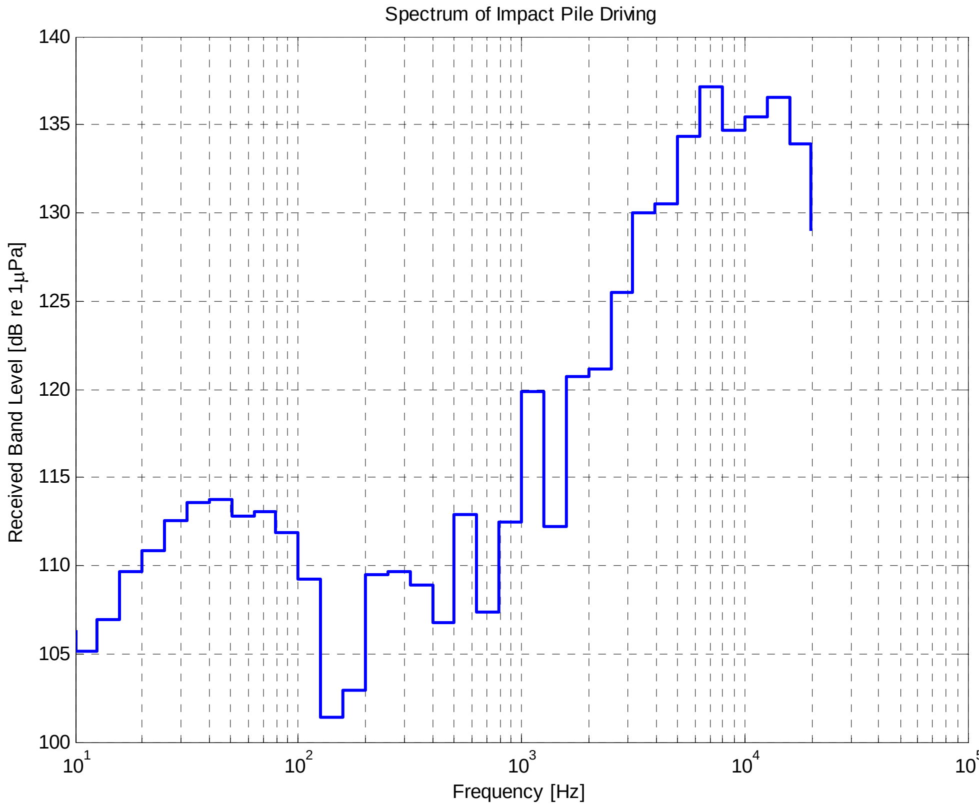


Figure 67. One-Third Octave Spectrum for Pile Driving (Impact, Sheet Pile – Tail Wall)

A nominal transmission loss configuration of 20 log R is used to calculate SL values, although the actual transmission loss is a function of many complicated environmental variables. Thus, different possibilities of transmission loss, such as 16 log R, 18 log R, 22 log R, and 24 log R, are considered to estimate the SL value at the pile driving location and to eventually compute the range to 160 dB.

Figure 68 shows the estimated instantaneous peak pressures on the left and sound pressure levels on the right for the impact pile driving (tail wall) with range up to 10 km. Each plot shows five possible situations of SPL values for the varying ranges up to 10 km based on the worst case measurement: the red curve indicates the SPL using the transmission loss with 16 log R; the magenta curve indicates the SPL using the transmission loss with 18 log R; the blue curve indicates the SPL using the transmission loss with 20 log R; the cyan curve indicates the SPL using the transmission loss with 22 log R; and the green curve indicates the SPL using the transmission loss with 24 log R.

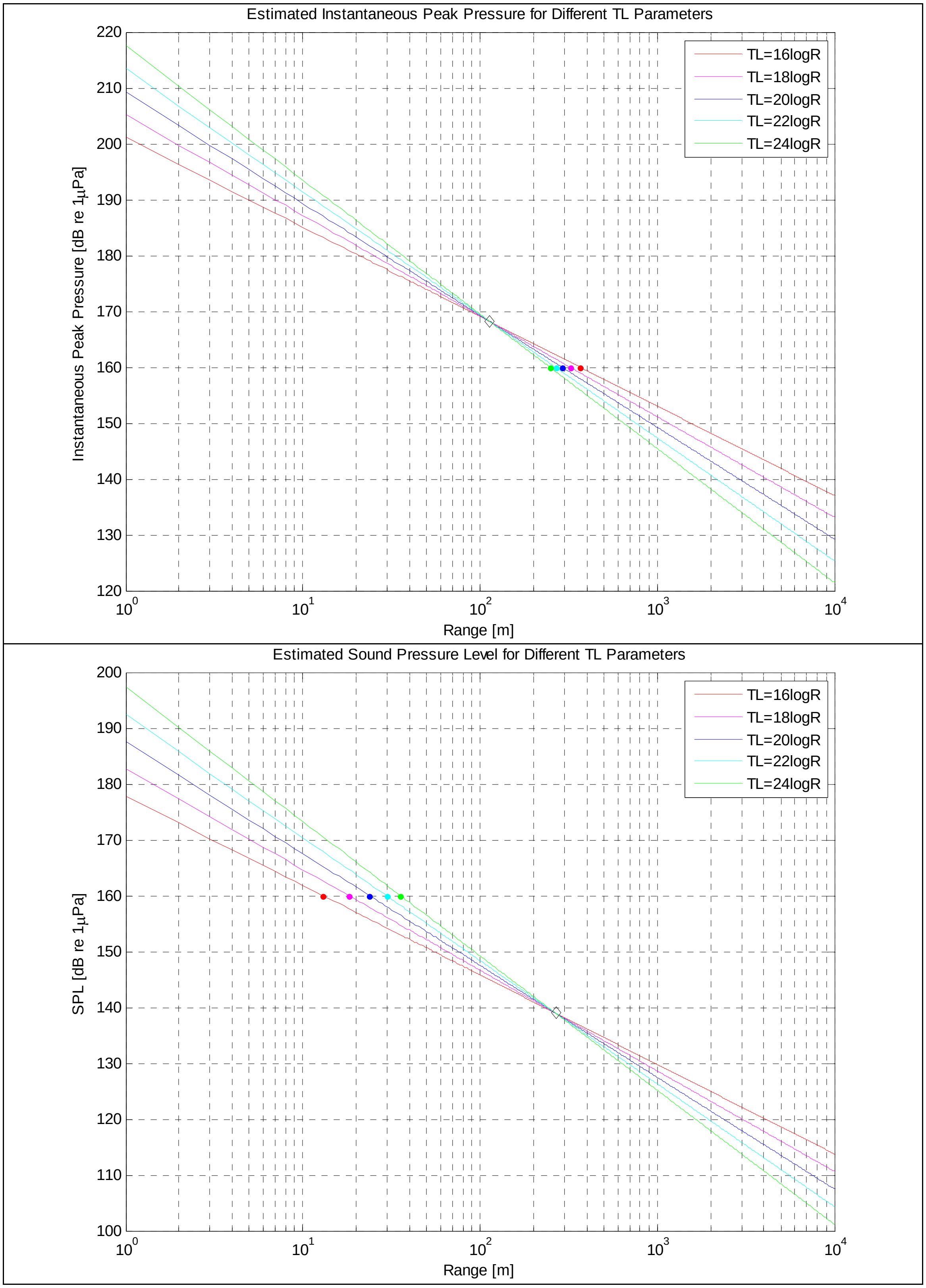


Figure 68. Consideration of Different Transmission Loss Configurations (Impact, Sheet Pile – Tail Wall)

The estimated 160 dB peak pressure distances and 160 dB SPL distances for these five different transmission loss configurations are listed in the **Table 32**.

Table 32. Estimated 160 dB Distances of Instantaneous Peak Pressures and Sound Pressure Levels (Impact, Sheet Pile)

Transmission Loss	Est. 160dB Distance [m] Based on Inst. Peak Pressure	Est. 160dB Distance [m] Based on SPL (rms)
16logR	369.4596	12.9989
18logR	324.0948	18.1964
20logR	291.8478	23.8083
22logR	267.8652	29.6670
24logR	249.3925	35.6355

3.2.5 Hairpin

Hairpin impact pile driving sessions were collected on September 26, 2008 and the summary of the analysis is shown in **Table 33**. The distance to the 160 dB isopleth under worst case conditions was estimated to be 15.65 m based on SPL value using an RMS computation, but it can be as far as 205.74 m when it is derived from instantaneous peak pressure.

Table 33. Summary of Data Analysis (Impact, Hairpin)

Data Field	Values
Sampling Date & Time	09/26/2008, 16:02:25.85~16:31:56.87
Total Count of Hairpin Impacts	234
Average Source Level [dB]	169.11
Max/Min Source Level [dB]	169.11 / 148.10
Average Sound Pressure Level [dB]	126.92
Max/Min Sound Pressure Level [dB]	141.18 / 101.93
Average Instantaneous Peak Pressure [dB]	151.46
Max/Min Instantaneous Peak Pressure [dB]	167.45 / 121.31
Average Range to Source [m]	262.12
Max/Min Range to Source [m]	558.66 / 50.63
Estimated 160 dB Distance (Worst Case) [m] Based on SPL (RMS)	15.65
Estimated 160 dB Distance (Worst Case) [m] Based on Instantaneous Peak Pressure	205.74

3.2.5.1 Data Collection and Sampling Area

During data collection, three separate sessions were recorded at distances between 50.63 and 558.66 m at tide levels between 21.98 and 25.09 ft. **Table 34** shows all three sessions in detail.

Table 34. Data Collection Log (Impact, Hairpin)

SLM Data			Avisoft Data					Comments
File name	Start time	Stop time	File name	Start time	Stop time	Start offset	End offset	
831_DATA_083.xls	15:51:25	16:08:46	T0000010.wav	16:02:24	16:06:24	00:01	00:07	Staged. Drifting starting approx 50 m away from the wall
				16:02:24	16:06:24	00:56	04:00	
			T0000011.wav	16:06:24	16:08:46	00:00	02:20	Ending past 200 m away from the wall
831_DATA_084.xls	16:12:27	16:20:24	T0000012.wav	16:12:25	16:16:25	00:00	04:00	Staged. Started approx 100 m away from the wall
			T0000013.wav	16:16:25	16:20:21	00:00	04:00	Ending past 333 m
831_DATA_085.xls	16:23:55	16:32:45	T0000014.wav	16:23:59	16:27:59	00:05	00:31	Staged. Started drifting approx 490 m away from the wall
				16:23:59	16:27:59	01:00	04:00	Ending about 560 m away
			T0000015.wav	16:27:59	16:31:59	00:00	04:00	Tide is 22 ft, speed approx 4 km/hour

The sampling locations for vibratory driving of sheet pile were logged with a GPS that was synchronized with acoustic data collection. **Figure 69** shows the relative positions of the hairpin impact pile driving and the sample locations. The yellow push pin icon refers to the location of pile driving site (N 61°15'4.941", W 149°52'56.875") and three light green tracks indicate the locations of data collection.

Figure 69. Aerial Map of Sample Location and Pile Driving Site (Impact, Hairpin)

3.2.5.2 Data Processing and Analysis

The sound pressure levels for the hairpin impact pile driving ranged from 101.93 to 141.18 dB re 1μPa during the recording session. Their equivalent instantaneous peak pressures ranged from 121.31 to 167.45 dB re 1μPa.

The 234 individual impacts from six raw time series of the recorded data are shown in **Figure 70** following processing for sound pressure levels with RMS computation and the instantaneous peak pressures. The distance to the 160 dB isopleths was derived for both instances.

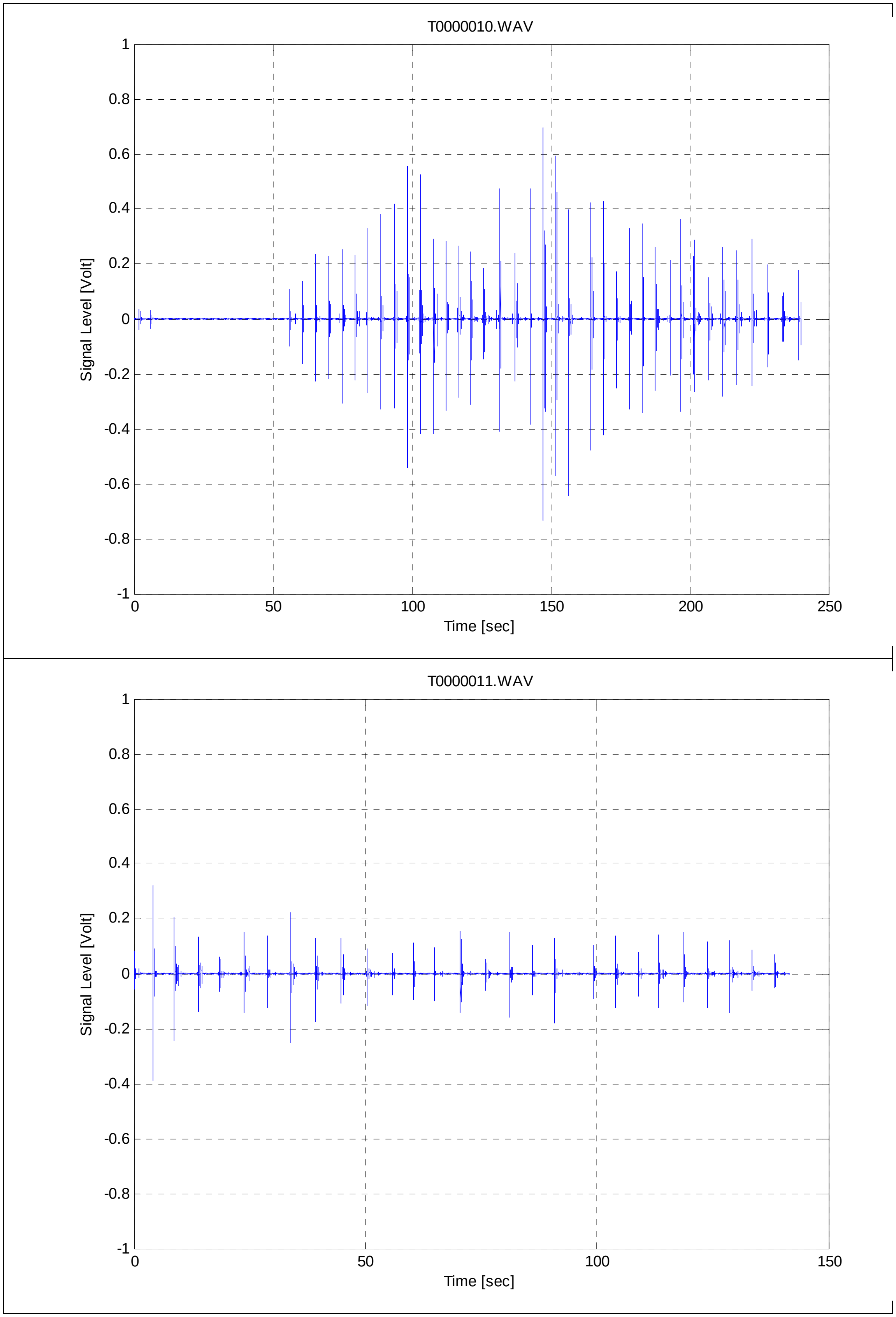
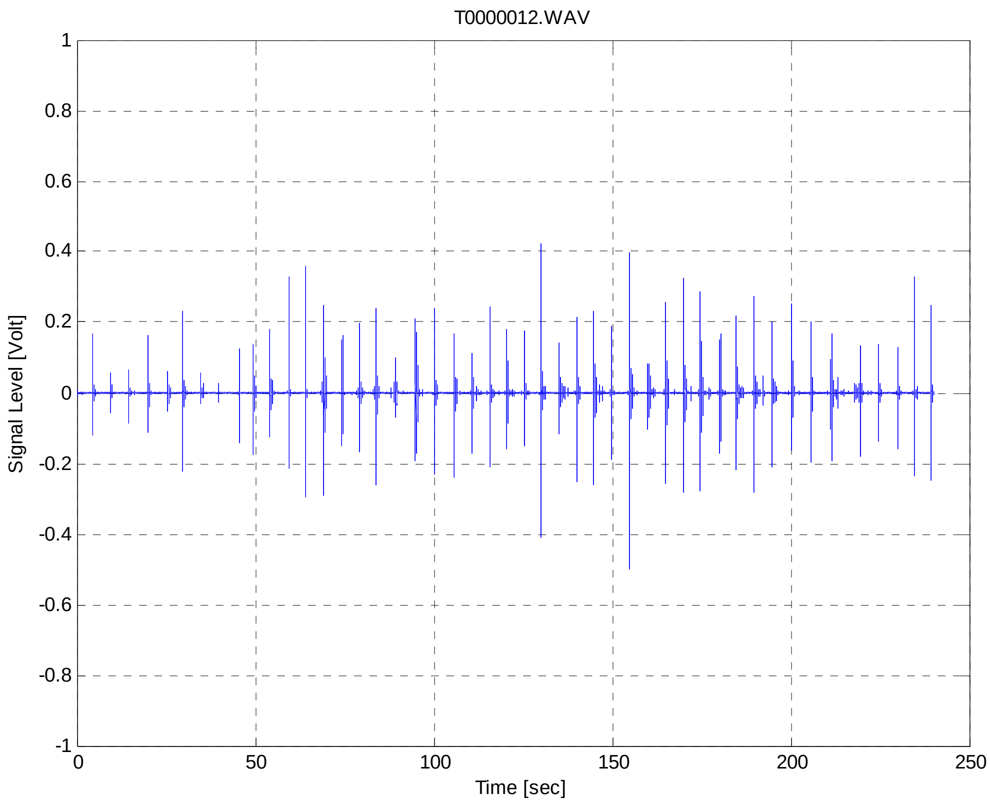


Figure 70 (a). Raw Time Series of Impact Pile Driving (Impact, Hairpin)



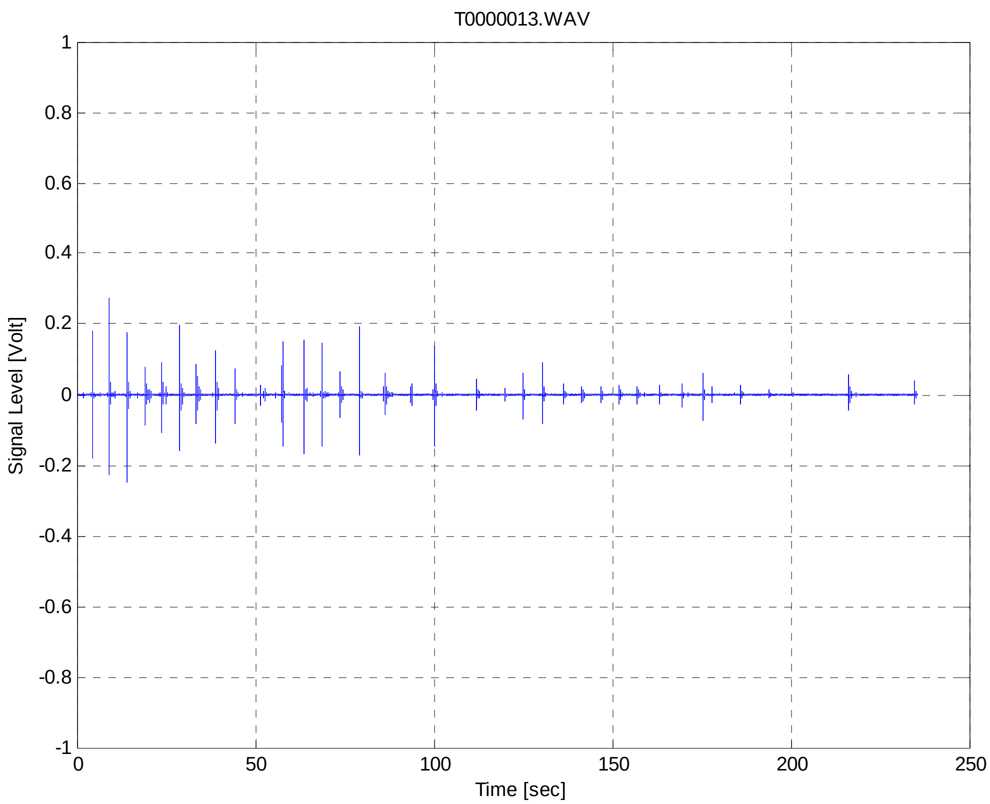
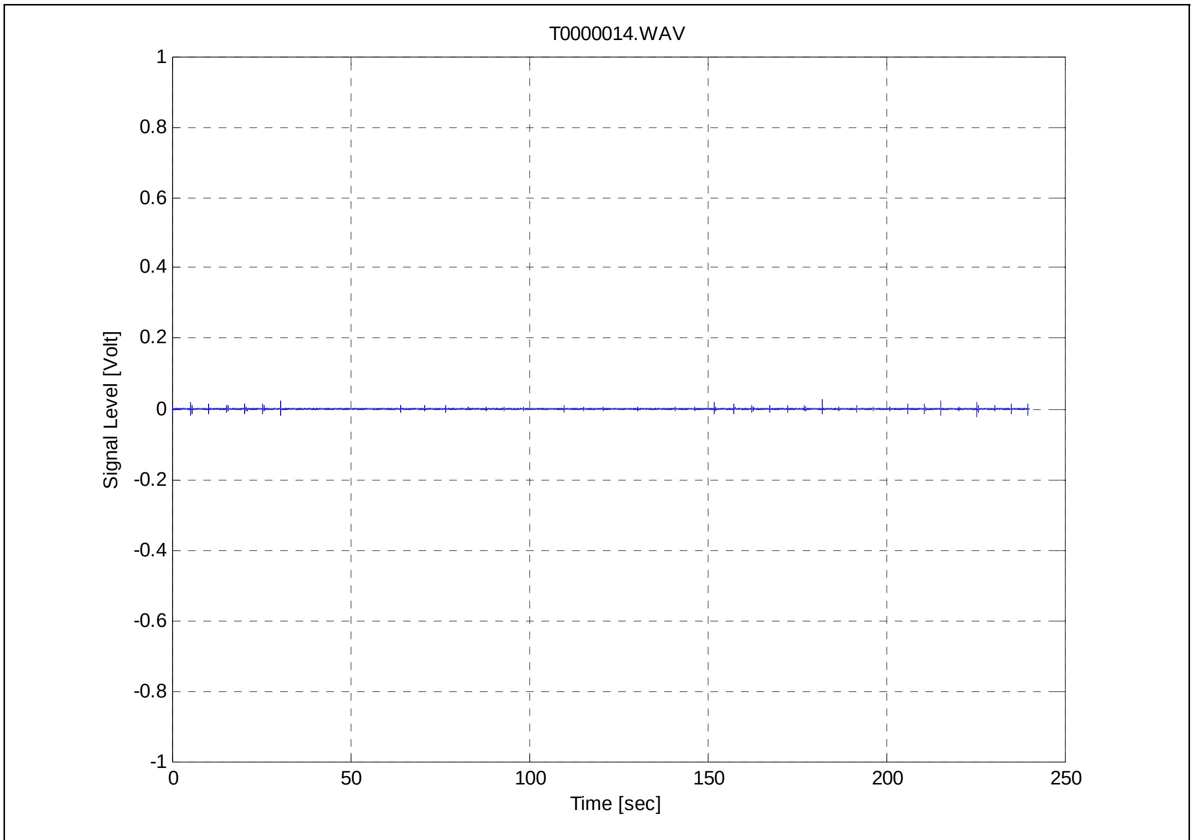


Figure 70 (b). Raw Time Series of Impact Pile Driving (Impact, Hairpin)



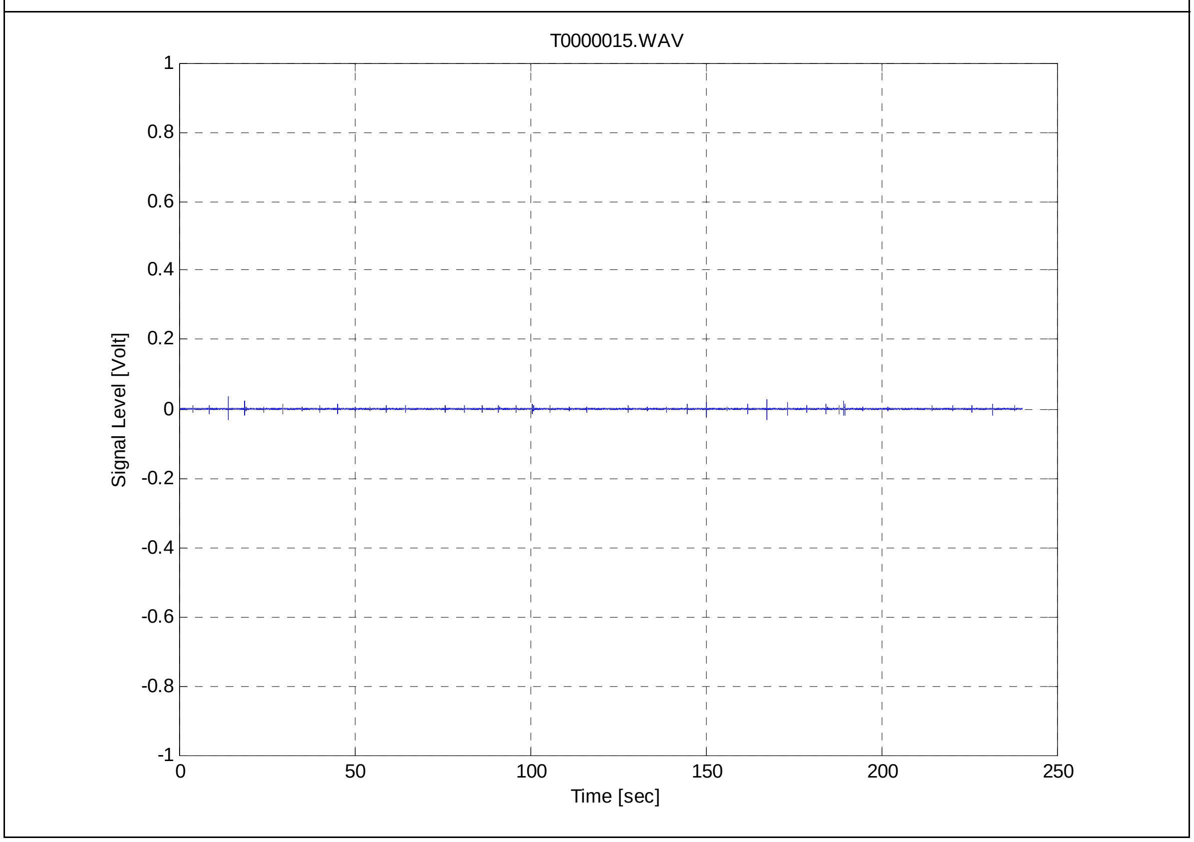


Figure 70 (c). Raw Time Series of Impact Pile Driving (Impact, Hairpin)

3.2.5.3 Worst Case Analysis

In computing the sound energy of the impact, a typical calculation is based on RMS value for the pulse duration of the impact. The result of this SPL computation is greatly dependent on the pulse duration that is averaged relative to RMS. Longer pulse durations produce lower SPL's. A more conservative method of computing the worst case can be based on the instantaneous peak pressure without averaging process.

When all SPL's are converted to SL's, assuming spherical spreading transmission loss for the distance from the pile driving site, the incident with the maximum value of SL is used for the worst case analysis. This sample is considered as the loudest incident among the all measured impacts in terms of RMS-based SPL values. This event occurred at 16:15:00.03 on September 26, 2008 and the range to the 160 dB SPL is estimated to be 15.65 m from the pile driving site. The alternate perspective of the worst case incident based on the instantaneous peak pressure was measured in the same instance and its range to the 160 dB peak pressure is estimated to be 282.24 m from the pile driving site (**Table 35**).

Table 35. Summary of Worst Case Analysis (Impact, Hairpin)

Data Field	Values
Data File Name	T0000012.WAV
Date & Time	09/26/2008, 16:15:00.03
Time Offset in File [sec]	155.03
Range to Source [m]	105.86
Sound Pressure Level [dB]	142.55
Pulse Duration [sec]	0.38
Estimated Source Level [dB]	183.88
Estimated 160 dB Distance (Worst Case) [m] Based on SPL (RMS)	15.65
Instantaneous Peak Pressure [dB]	150.73
Estimated 160 dB Distance (Worst Case) [m] Based on Instantaneous Peak Pressure	282.24
Tide [ft]	23.32

The actual hairpin impact pile driving occurred at the 155th second in the recorded file (T0000012.wav). The close up view of the raw time series for this worst case signal is depicted in **Figure 71**.

One-third octave spectrum of this particular case is shown in **Figure 72**. The peak spectral energy is observed around 10 kHz band in this particular impact.

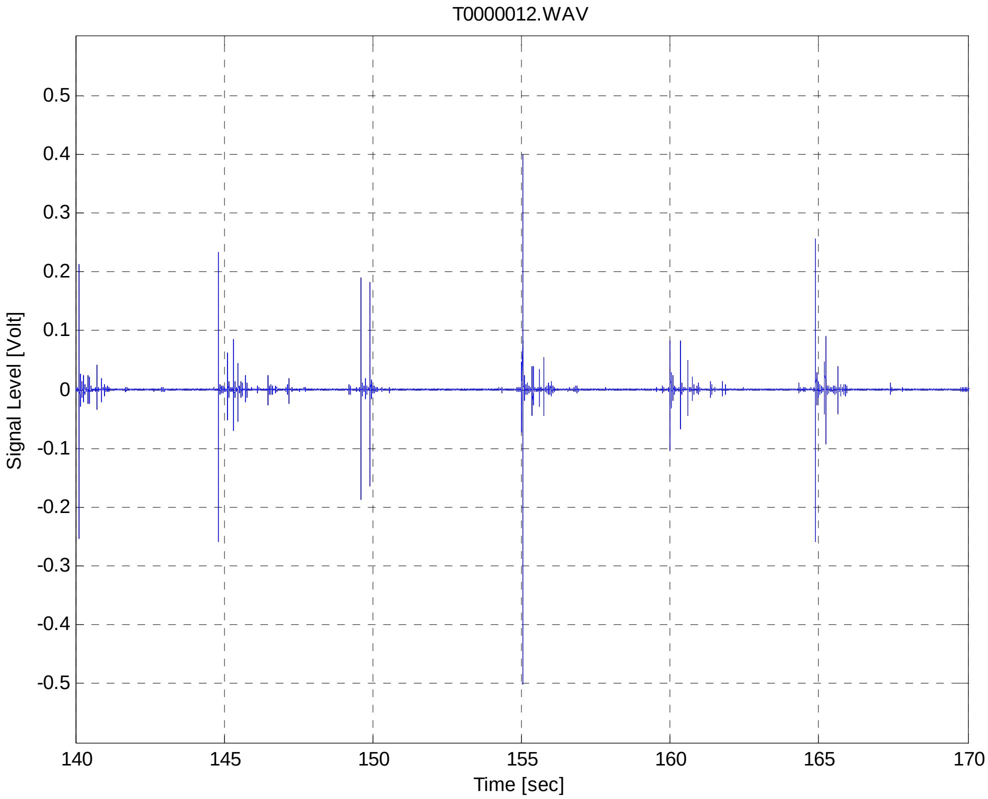


Figure 71. Raw Time Series of Worst Case Impact Pile Driving (Impact, Hairpin)

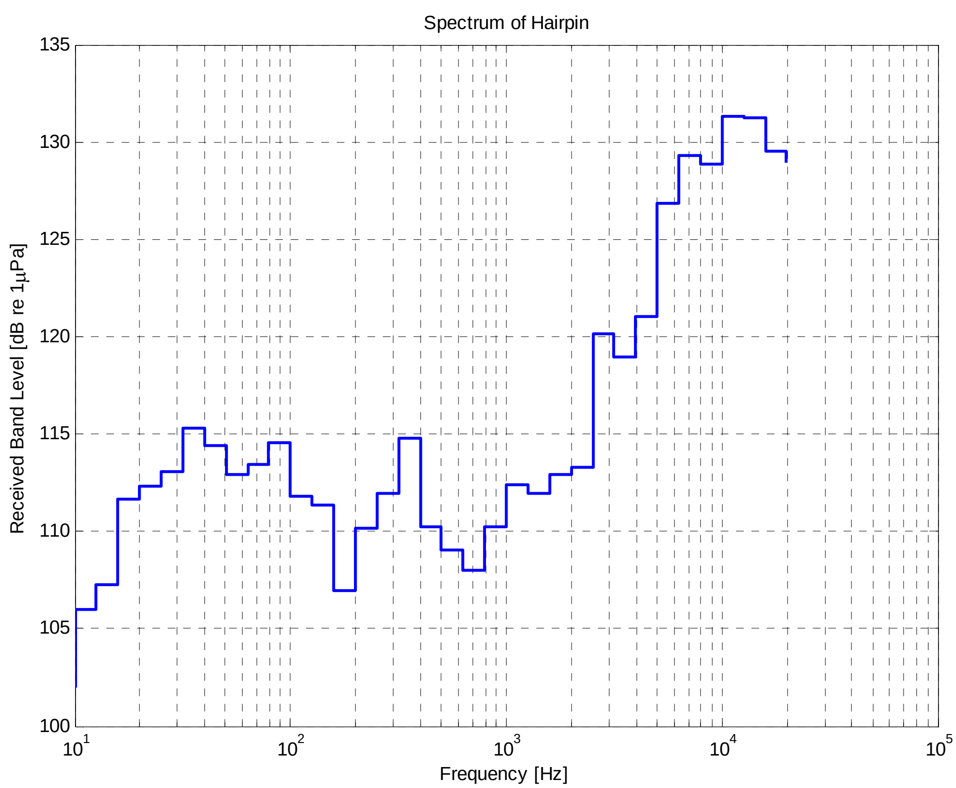


Figure 72. One-Third Octave Spectrum for Pile Driving (Impact, Hairpin)

A nominal spherical spreading transmission loss configuration of 20 log R is used to calculate SL values, although the actual transmission loss is a function of many complicated environmental variables. Thus, different possibilities of transmission loss, such as 16 log R, 18 log R, 22 log R, and 24 log R, are considered to estimate the SL value at the pile driving location and eventually to compute 160 dB distance.

Figure 73 shows the estimated instantaneous peak pressures in the left column and sound pressure levels in the right column for the hairpin impact pile driving with range up to 10 km in all individual impacts in the order they were recorded. Each plot shows five possible situations of SPL values for the varying ranges up to 10 km based on the worst case measurement: the red curve indicates the SPL using the transmission loss with 16 log R; the magenta curve indicates the SPL using the transmission loss with 18 log R; the blue curve indicates the SPL using the transmission loss with 20 log R; the cyan curve indicates the SPL using the transmission loss with 22 log R; and the green curve indicates the SPL using the transmission loss with 24 log R.

The estimated range to the 160 dB peak pressure and 160 dB SPL for these five different transmission loss configurations are listed in **Table 36**.

Table 36. Estimated 160 dB Distances of Instantaneous Peak Pressures and Sound Pressure Levels (Impact, Hairpin)

Transmission Loss	Est. 160 dB Distance [m] Based on Inst. Peak Pressure	Est. 160 dB Distance [m] Based on SPL (RMS)
16 log R	360.66	9.48
18 log R	314.73	12.52
20 log R	282.24	15.65
22 log R	258.17	18.78
24 log R	239.68	21.86

3.2.6. Soft Start

The sheet pile driving sessions were collected on September 30, 2008; the summary of the analysis is shown in **Table 37**. The distance to the 160 dB isopleth under worst case conditions was estimated to be 51.28 m based on SPL value using an RMS computation, but it can be as far as 880.00 m when it is derived from instantaneous peak pressure.

Table 37. Summary of Data Analysis (Impact, Soft Start)

Data Field	Values
Sampling Date & Time	09/30/2008, 9:56:19~9:58:54
Total Count of Impact Driving	9
Average Source Level [dB]	191.80
Max/Min Source Level [dB]	194.20 / 188.23
Average Sound Pressure Level [dB]	159.95
Max/Min Sound Pressure Level [dB]	163.12 / 155.62
Average Instantaneous Peak Pressure [dB]	184.80
Max/Min Instantaneous Peak Pressure [dB]	187.95 / 178.56
Average Range to Source [m]	42.16
Max/Min Range to Source [m]	62.47 / 25.18
Estimated 160 dB Distance (Worst Case) [m] Based on SPL (RMS)	51.28
Estimated 160 dB Distance (Worst Case) [m] Based on Instantaneous Peak Pressure	880.02

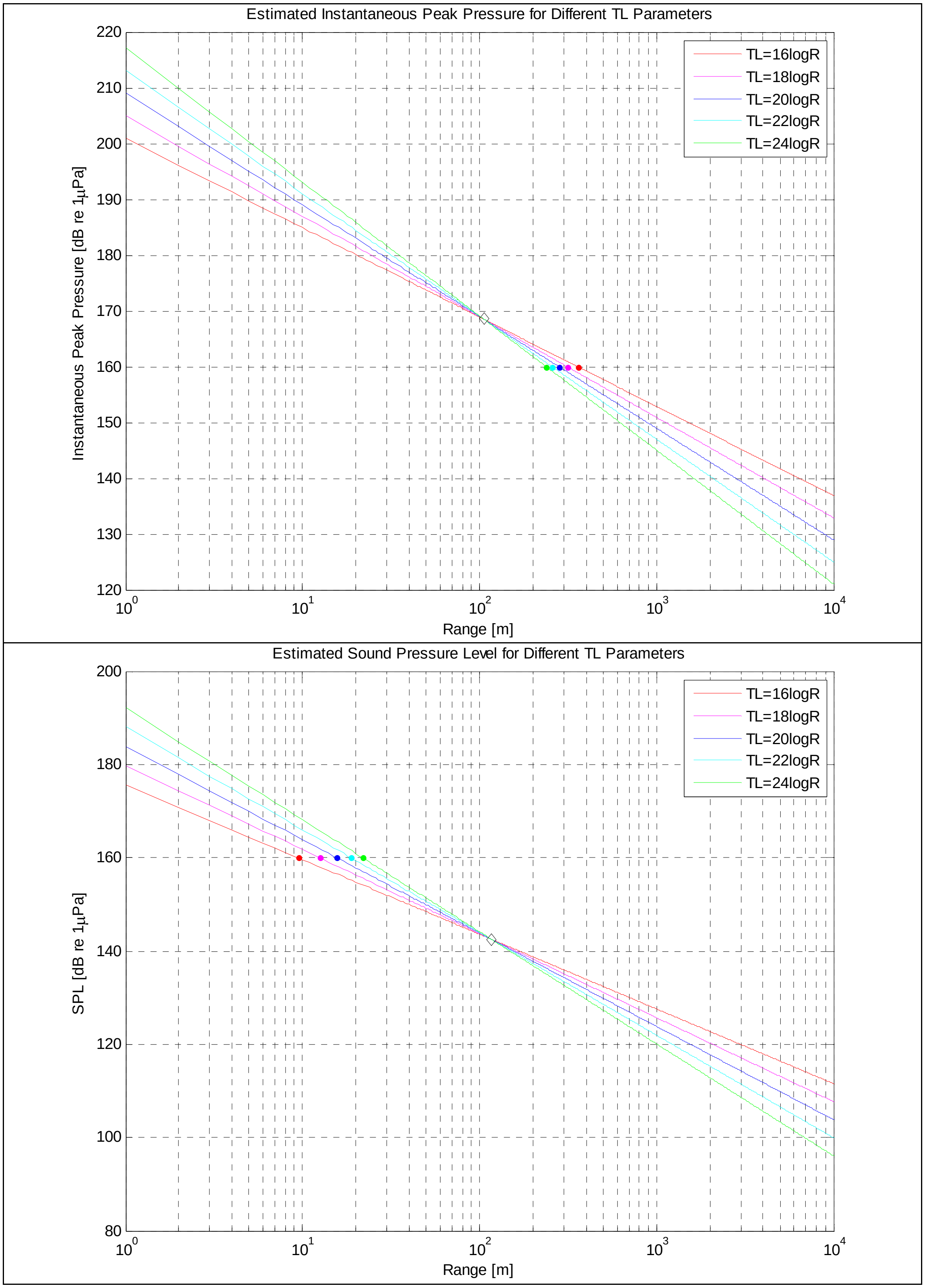


Figure 73. Consideration of Different Transmission Loss Configuration (Impact, Hairpin)

3.2.6.1 Data Collection and Sampling Area

During the data collection, only one session was recorded at a fairly close range (25.18m~62.47m) with relatively high tide level (26.93~26.95 ft). **Table 38** shows the data collection log of the recording session in detail.

Table 38. Data Collection Log (Impact, Soft Start)

SLM Data			Avisoft Data					Comments
File name	Start time	Stop time	File name	Start time	Stop time	Start offset	End offset	
831_DATA_124.xls	9:36:46	10:05:51	T0000080.wav	9:56:01	10:00:01	00:18	00:22	Hydrophone raised to 30' below surface, recorded three soft starts
						01:41	01:45	
						02:48	02:53	

The locations of sampling area and soft-start impact pile driving site were logged from GPS that were synchronized with acoustic data collection. **Figure 74** shows the relative positions of the pile driving soft start and the sample locations. The yellow pushing pin icon refers to the location of pile driving site (N61°15'4.941", W149°52'56.875") and the light green tracks indicate the locations of data collection.

Figure 74. Aerial Map of Sample Location and Pile Driving Site (Impact, Soft Start)

3.2.6.2 Data Processing and Analysis

The sound pressure levels for the soft-start impact pile driving ranged from 155.6217 to 163.1169 dB re 1μPa during the recording session. Their equivalent instantaneous peak pressures ranged from 178.56 to 187.95 dB re 1μPa.

The raw time series of the nine individual impacts are shown in **Figure 75** and were processed to produce sound pressure levels with RMS computation and the instantaneous peak pressures. The range to 160 dB was derived for both instances. **Table 39** shows the outcome of all nine individual impacts for soft-start.

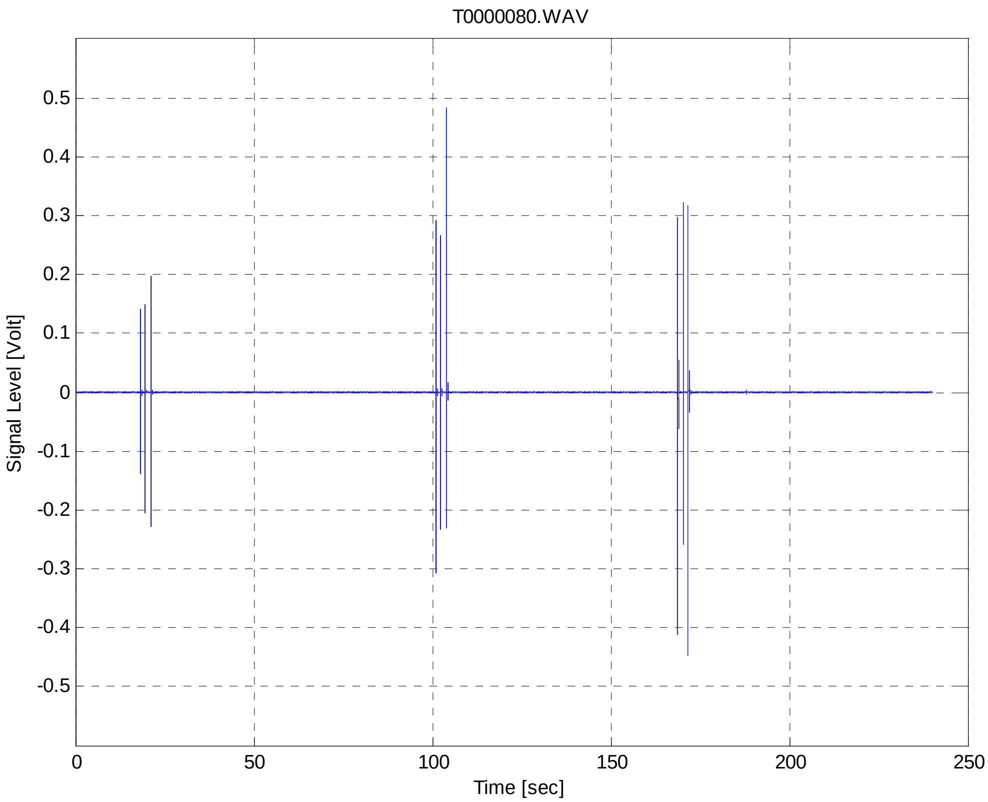
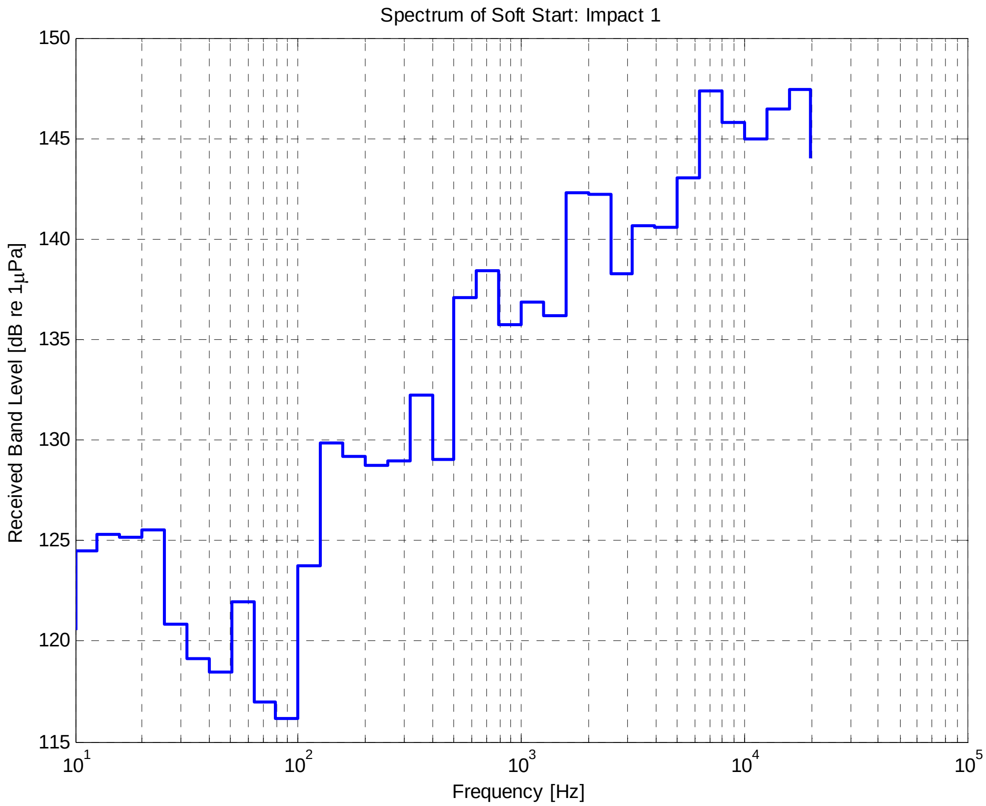


Figure 75. Raw Time Series of Soft Start Impact Pile Driving (Impact, Soft Start)

Table 39. Data Analysis of Soft Start Impact Driving

Impact ID	1	2	3	4	5	6	7	8	9
Date	09/30	09/30	09/30	09/30	09/30	09/30	09/30	09/30	09/30
Time	09:56:19	09:56:1	09:56:22	09:57:42	09:57:43	09:57:45	09:58:50	09:58:51	09:58:53
Offset in File [sec]	18.22	19.58	21.05	101.02	102.42	103.90	168.89	170.29	171.77
Range [m]	62.47	62.10	61.69	39.45	39.05	38.62	25.52	25.35	25.18
SPL [dB]	155.6217	158.2518	157.4582	159.5692	162.3667	159.4614	160.9645	163.1169	160.2065
Pulse Duration [s]	0.2862	0.2204	0.3546	0.3124	0.1994	0.4052	0.2997	0.2194	0.4163
Est. SL [dB]	191.5356	194.1137	193.2621	191.4892	194.1989	191.1980	189.1028	191.1956	188.2289
Est. 160 dB Dist. Based on SPL [m]	37.7408	50.7808	46.0370	37.5403	51.2817	36.3025	28.5236	36.2921	25.7928
Inst. Peak Pressure [dB]	178.5626	180.9179	183.0860	183.4203	185.2363	186.8752	187.9468	184.9618	187.8457
Est. 160 dB Dist. Based on Peak Pressure [m]	529.4527	690.2261	880.0179	584.8150	713.5486	852.2938	637.1660	448.7722	621.4448
Tide [ft]	26.95	26.95	26.95	26.94	26.94	26.94	26.93	26.93	26.93

One-third octave spectra of all nine impacts shown in **Figures 76 (a) through (e)** show the spectral energy distribution during the pulse duration. Although there are some variations among the individual spectra, the trend of the distribution stays relatively consistent.



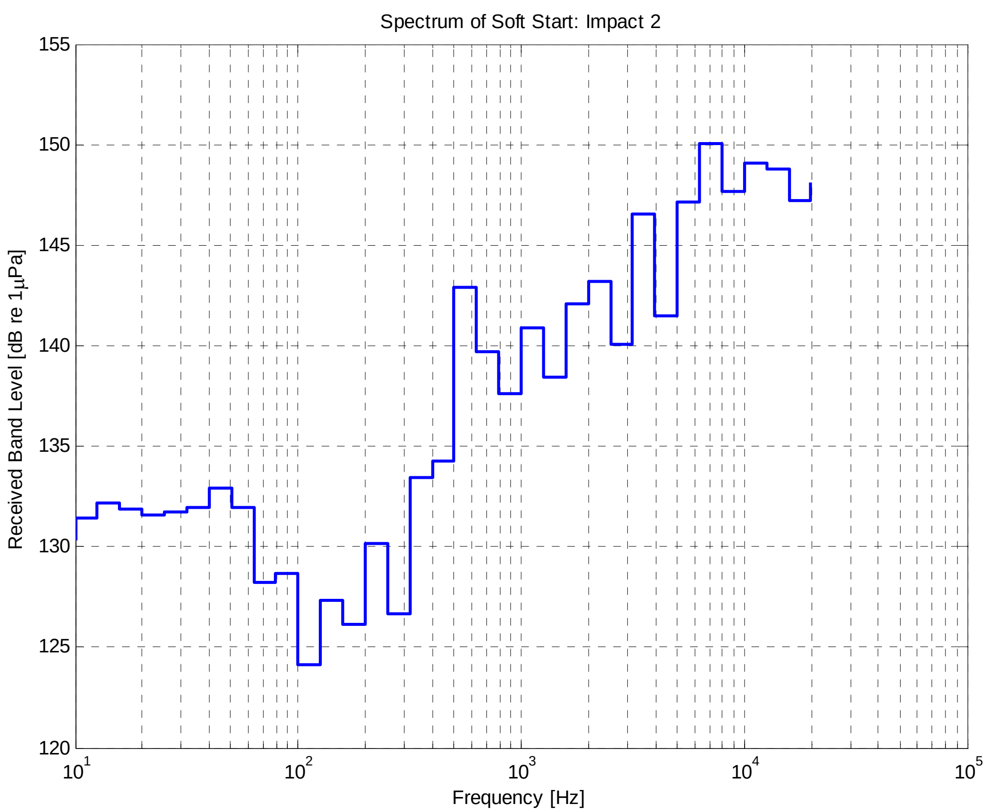
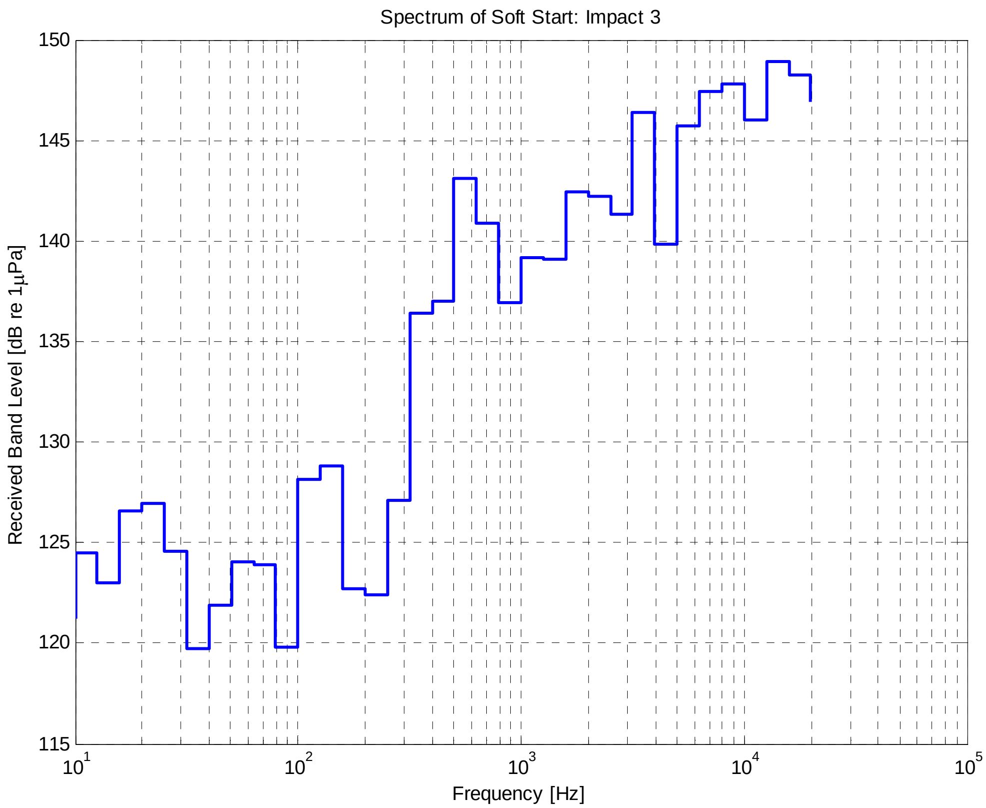


Figure 76 (a). One-Third Octave Spectrum for Pile Driving (Impact, Soft Start)



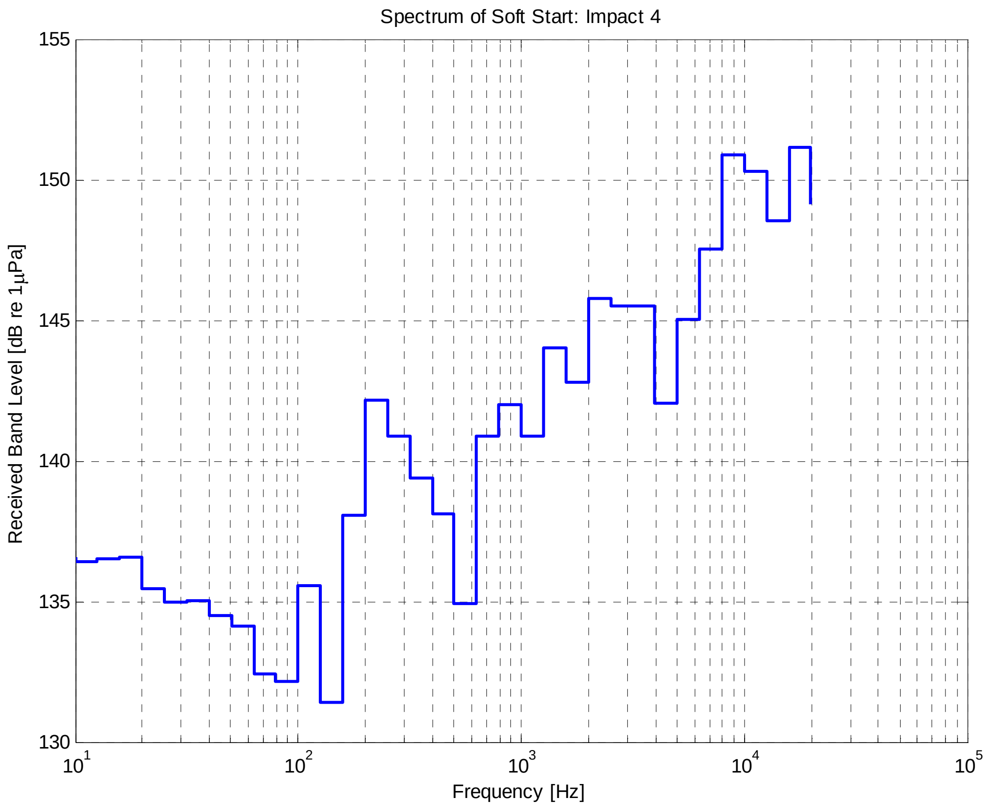


Figure 76 (b). One-Third Octave Spectrum for Pile Driving (Impact, Soft Start)

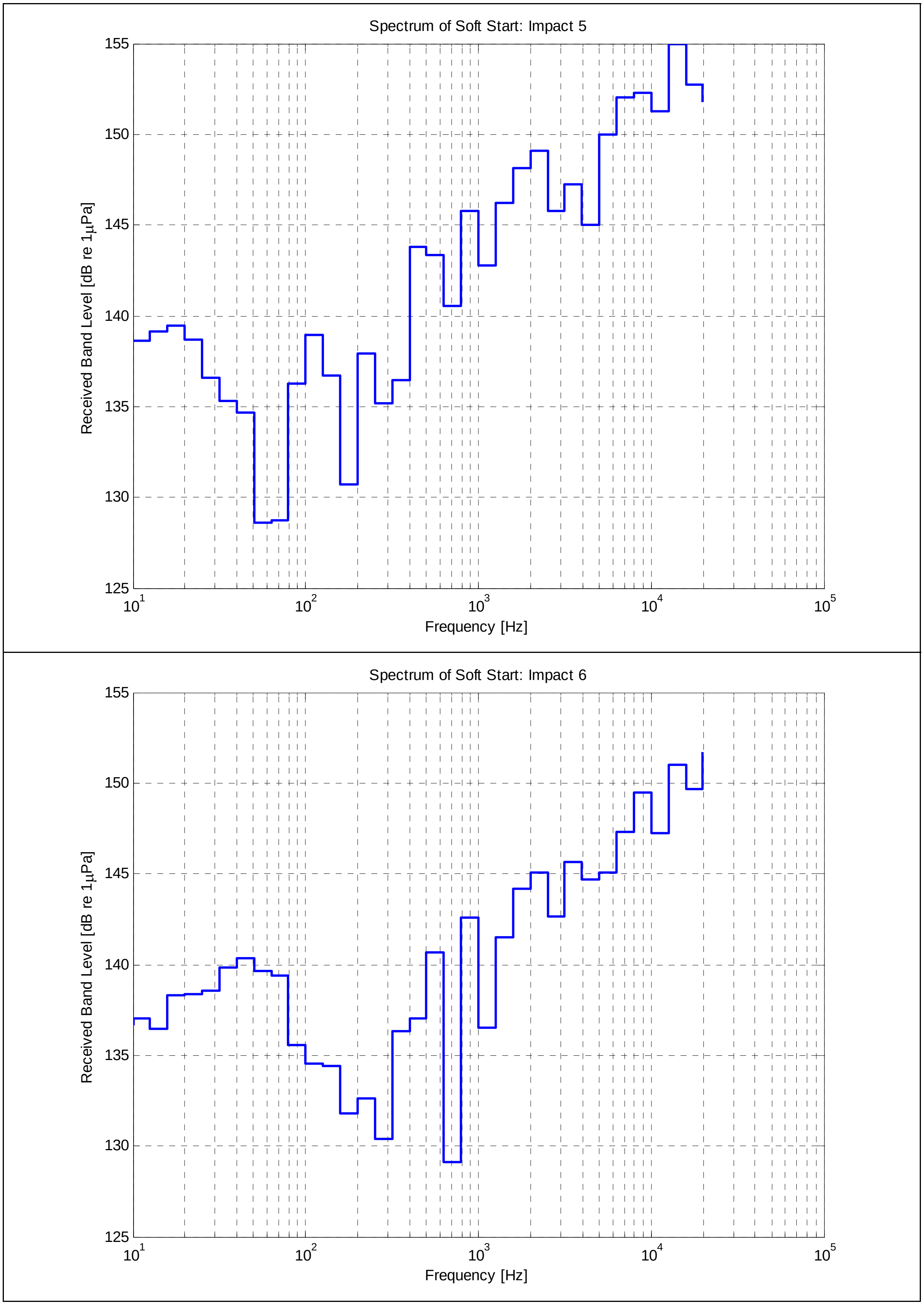
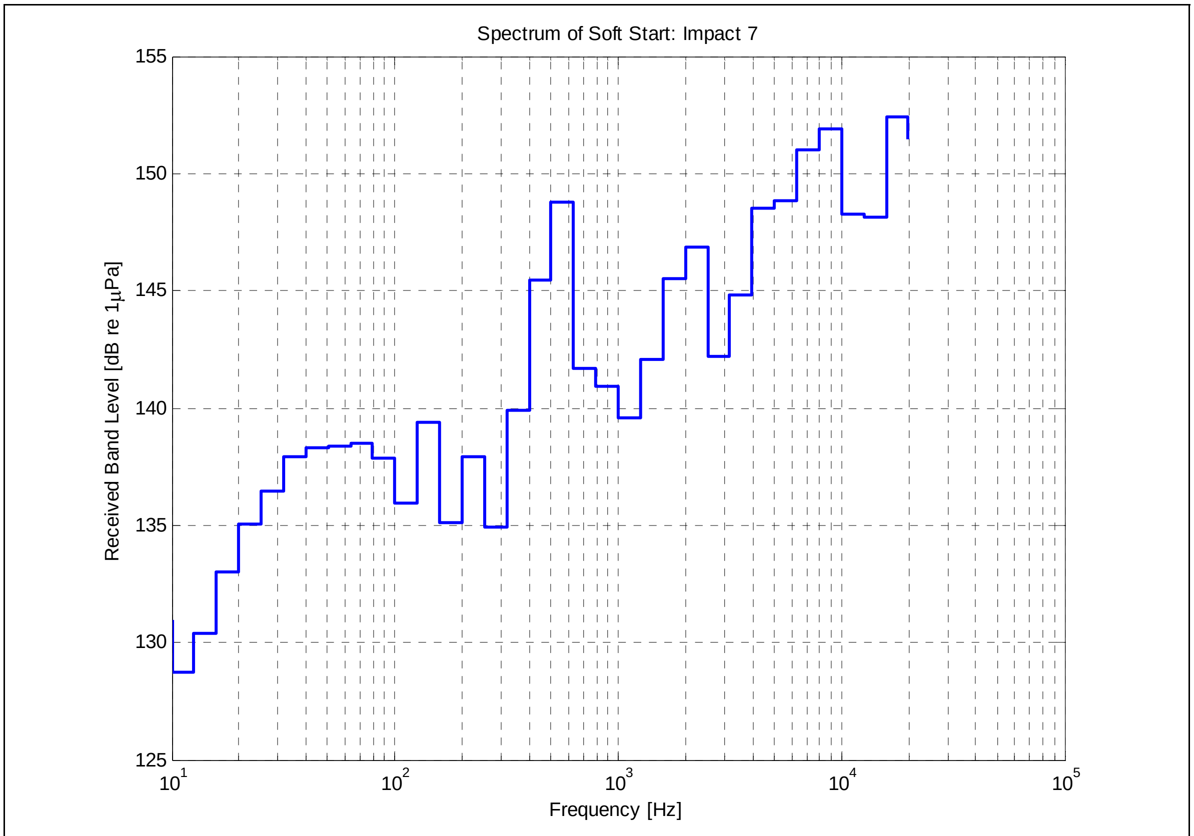


Figure 76 (c). One-Third Octave Spectrum for Pile Driving (Impact, Soft Start)



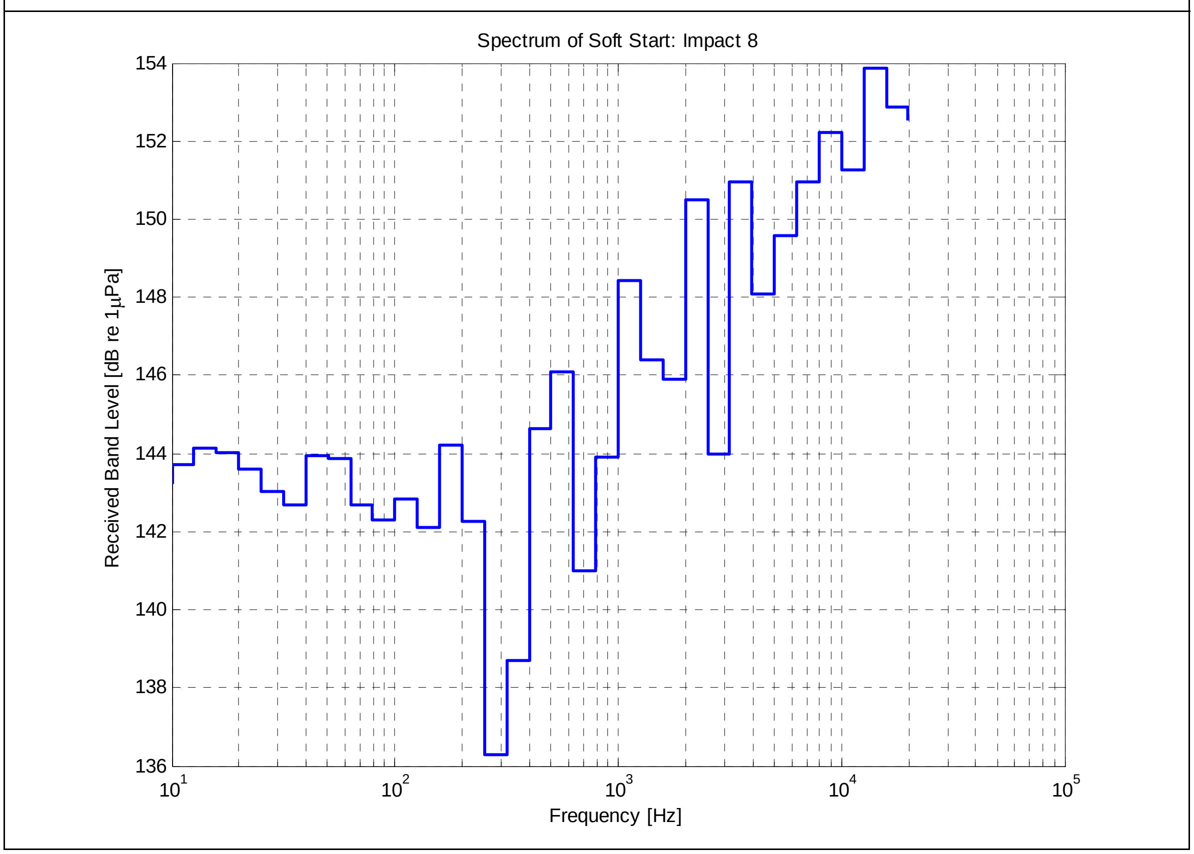


Figure 76 (d). One-Third Octave Spectrum for Pile Driving (Impact, Soft Start)

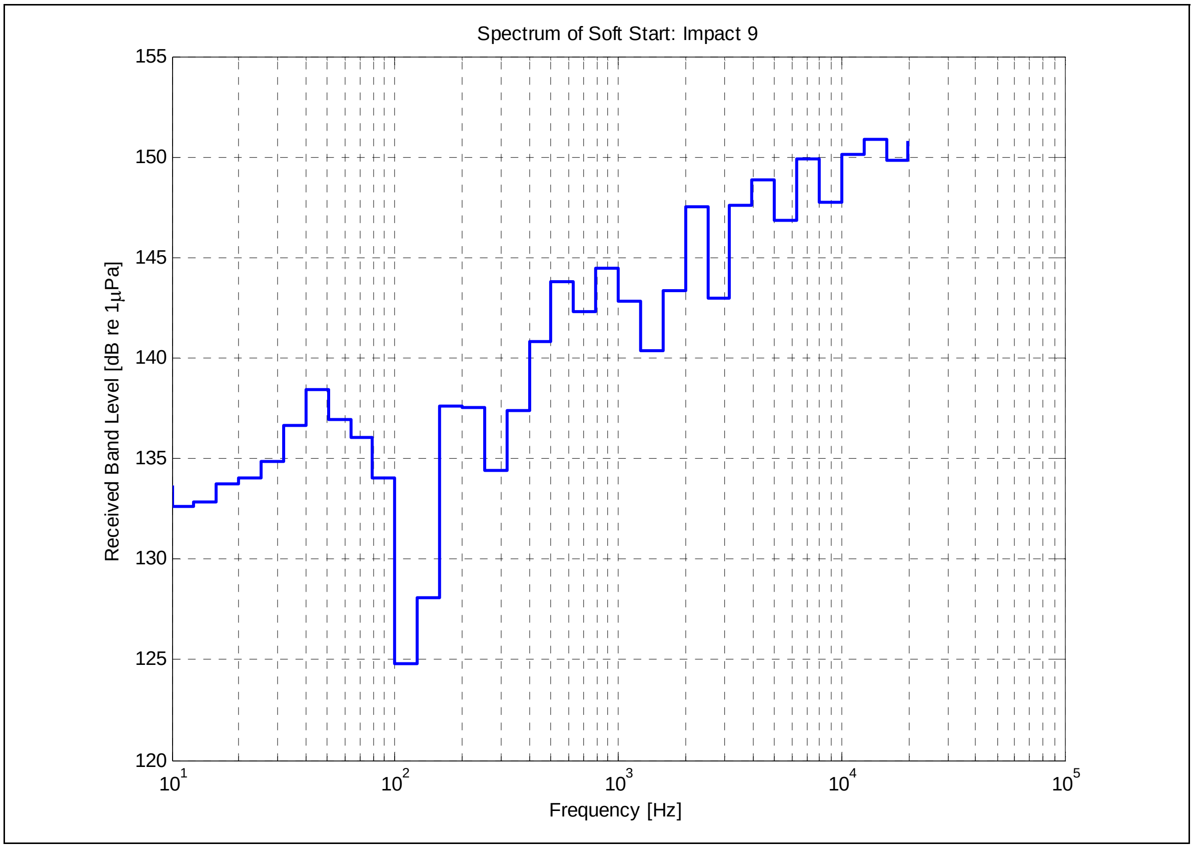


Figure 76 (e). One-Third Octave Spectrum for Pile Driving (Impact, Soft Start)

3.2.6.3 Worst Case Analysis

As mentioned above, computing the sound energy of the impact, a typical calculation is based on RMS value for the pulse duration of the impact. The result of this SPL computation is greatly dependent on the pulse duration that is averaged relative to RMS. Longer pulse durations produce lower SPL's. A more conservative method of computing the worst case can be based on the instantaneous peak pressure without averaging process.

When all SPL's are converted to SL's, assuming spherical spreading transmission loss for the distance from the pile driving site, the incident with the maximum value of SL is used for the worst case analysis. This sample is considered as the loudest incident among the all measured impacts in terms of RMS-based SPL values. This event occurred during the 5th impact in the recording session, and the range to 160 dB SPL is estimated to be 51.28 m from the pile driving site.

The other perspective of the worst case incident based on the instantaneous peak pressure was measured during the 3rd impact in the recording session and the range to 160 dB peak pressure is estimated to be 880 m from the pile driving site.

A nominal transmission loss configuration of 20 log R is used to calculate SL values, although the actual transmission loss is a function of many complicated environmental variables. Thus, different possibilities of transmission loss, such as 16 log R, 18 log R, 22 log R, and 24 log R, are considered to estimate the SL value at the pile driving location and eventually to compute the range to 160 dB.

Figures 77 (a) through (i) show the estimated instantaneous peak pressures in the left column and sound pressure levels in the right column for the soft start with range up to 10 km for all nine individual impacts in the order they were recorded. Each plot shows five possible situations of SPL values for the varying ranges up to 10 km based on the worst case measurement: the red curve indicates the SPL using the transmission loss with 16 log R; the magenta curve indicates the SPL using the transmission loss with 18 log R; the blue curve indicates the SPL using the transmission loss with 20 log R; the cyan curve indicates the SPL using the transmission loss with 22 log R; and the green curve indicates the SPL using the transmission loss with 24 log R.

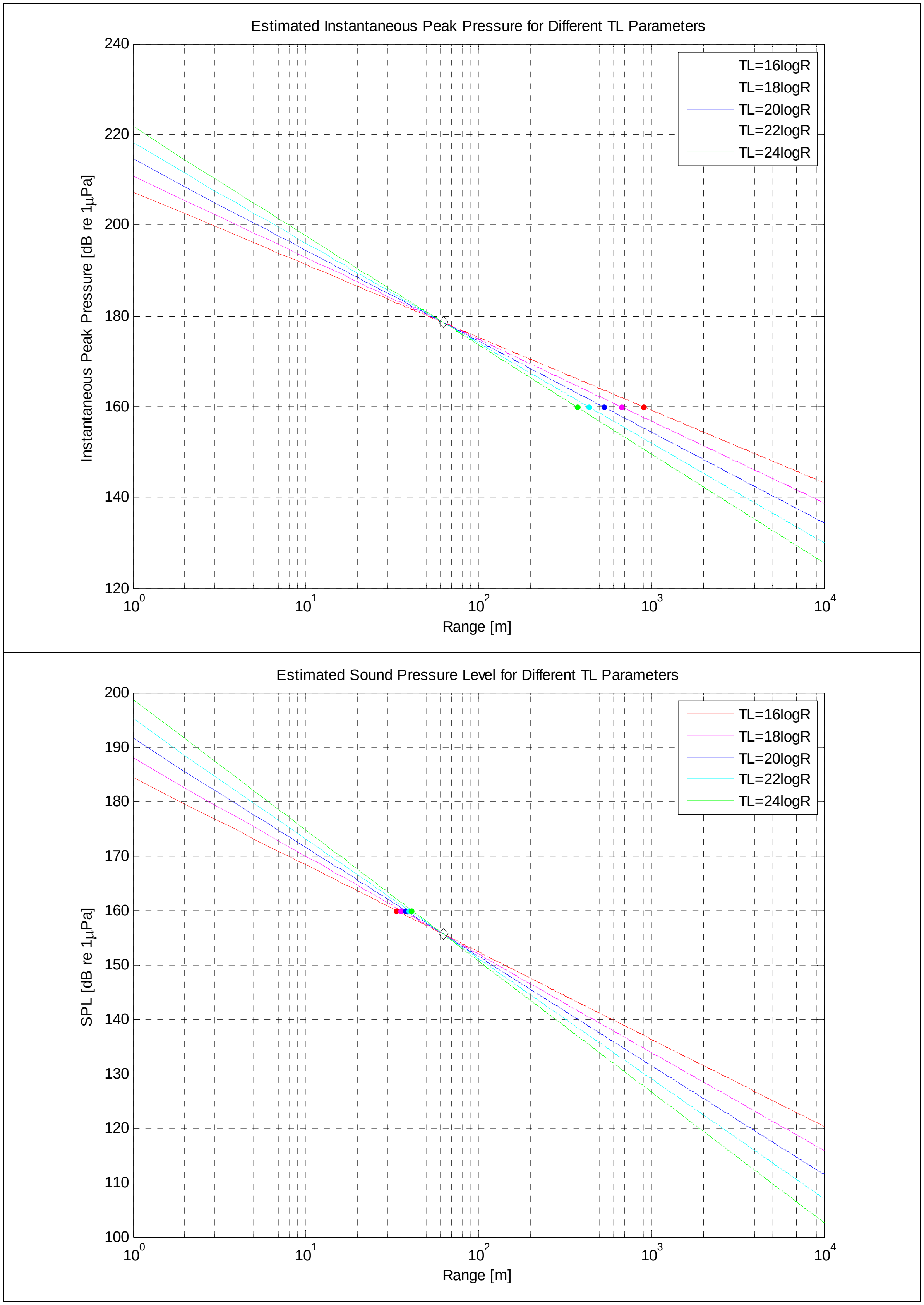


Figure 77 (a). Consideration of Different Transmission Loss Configuration for Impact ID 1

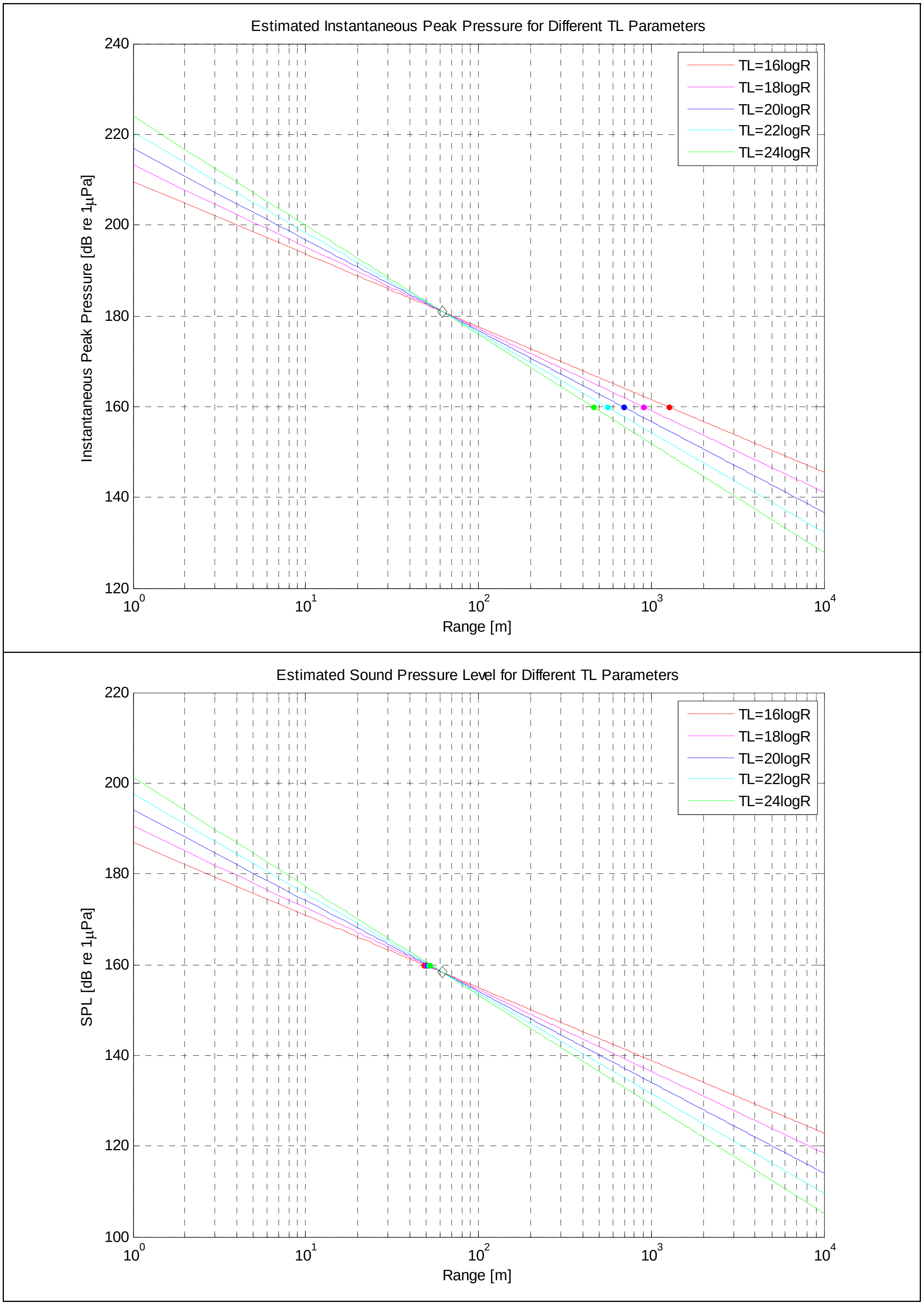


Figure 77 (b). Consideration of Different Transmission Loss Configuration for Impact ID 2

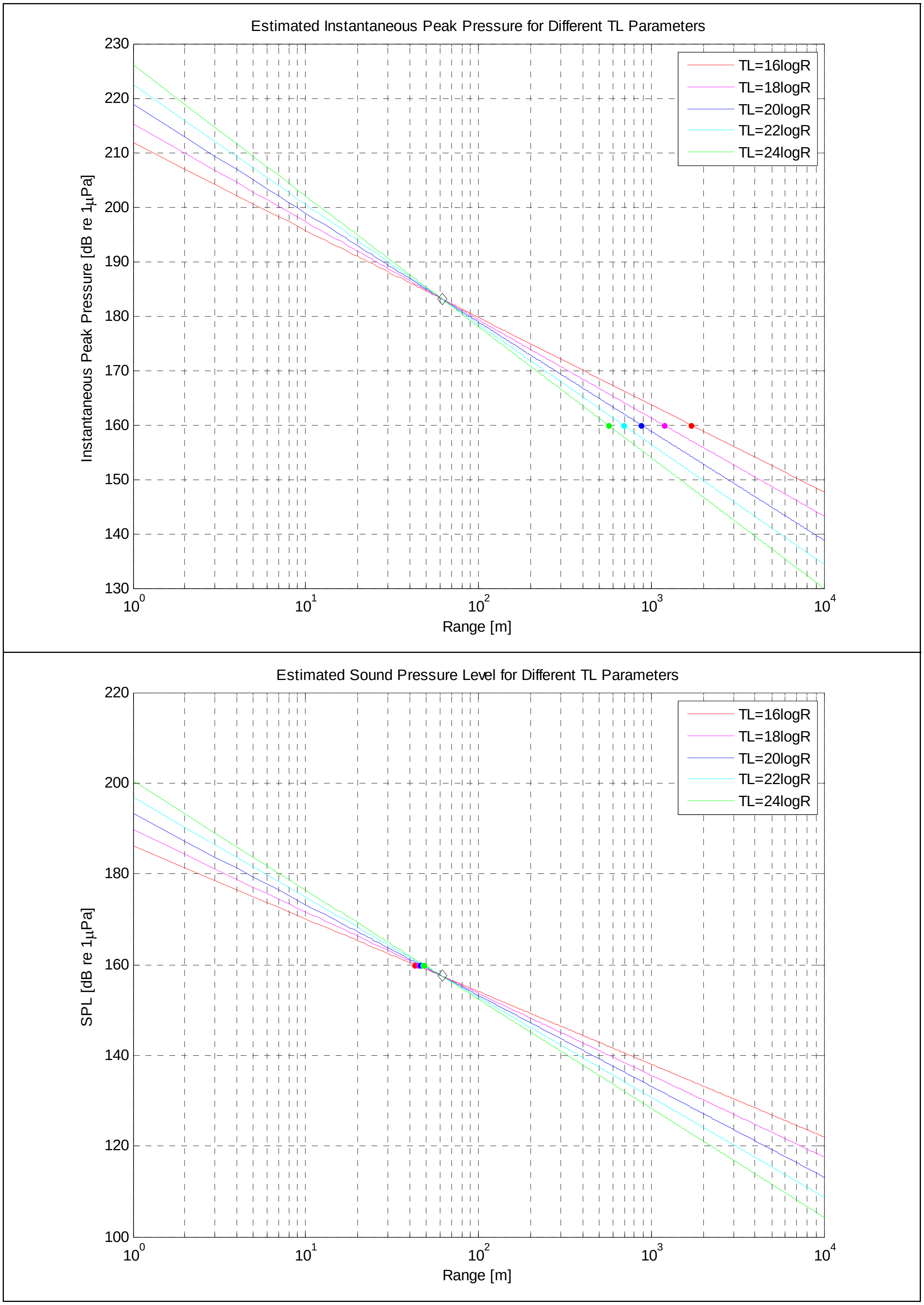


Figure 77 (c). Consideration of Different Transmission Loss Configuration for Impact ID 3

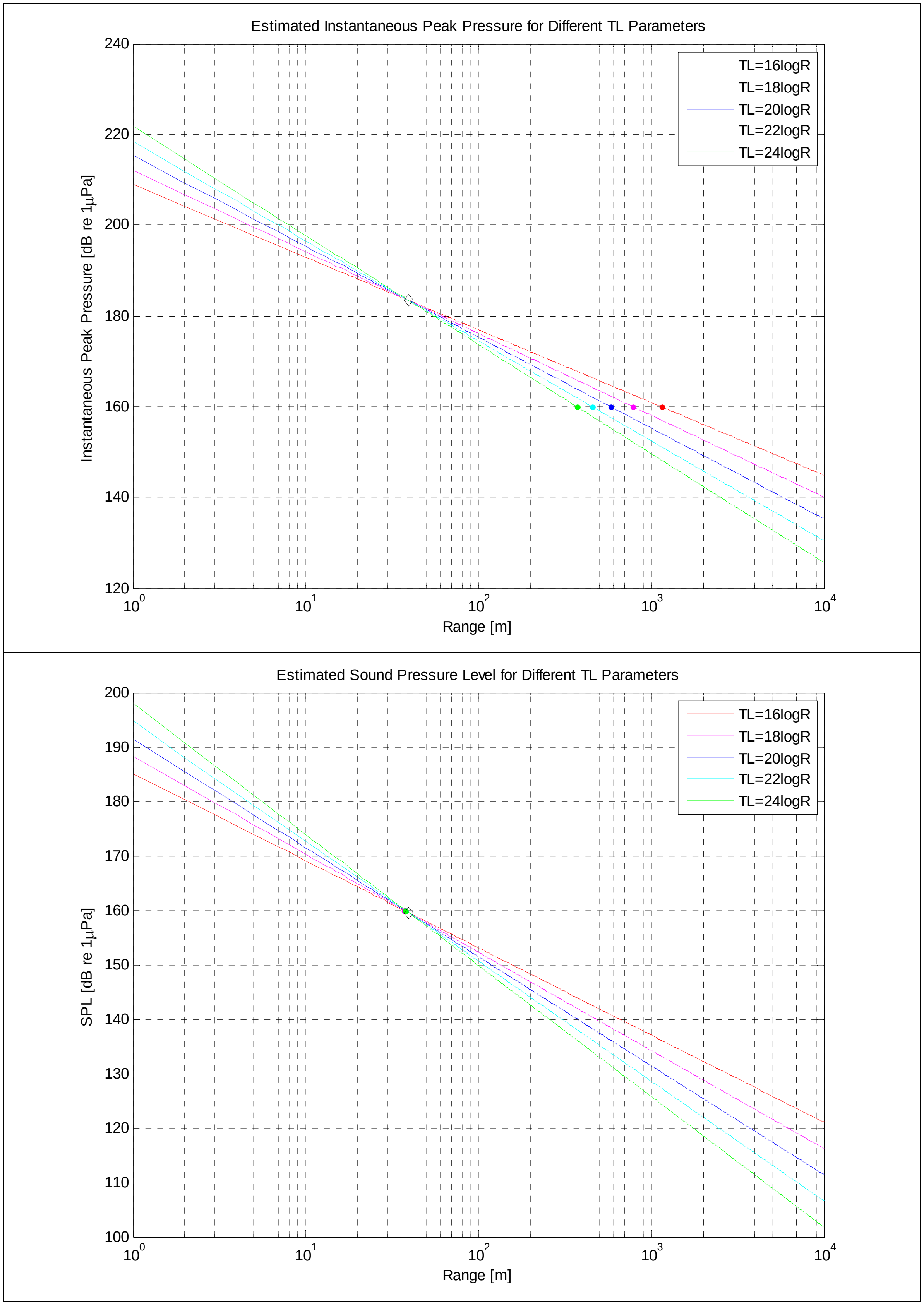


Figure 77 (d). Consideration of Different Transmission Loss Configuration for Impact ID 4

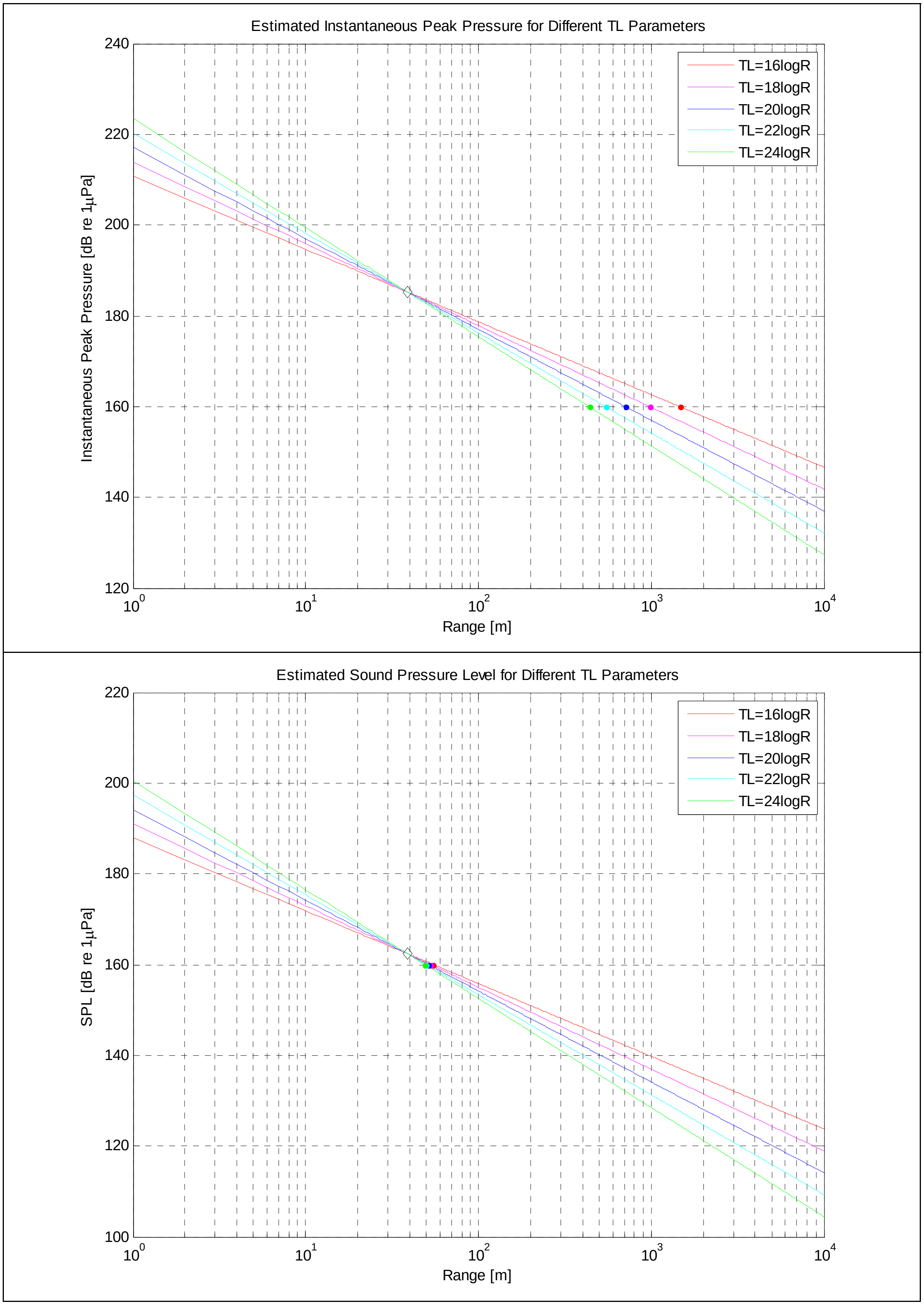


Figure 77 (e). Consideration of Different Transmission Loss Configuration for Impact ID 5

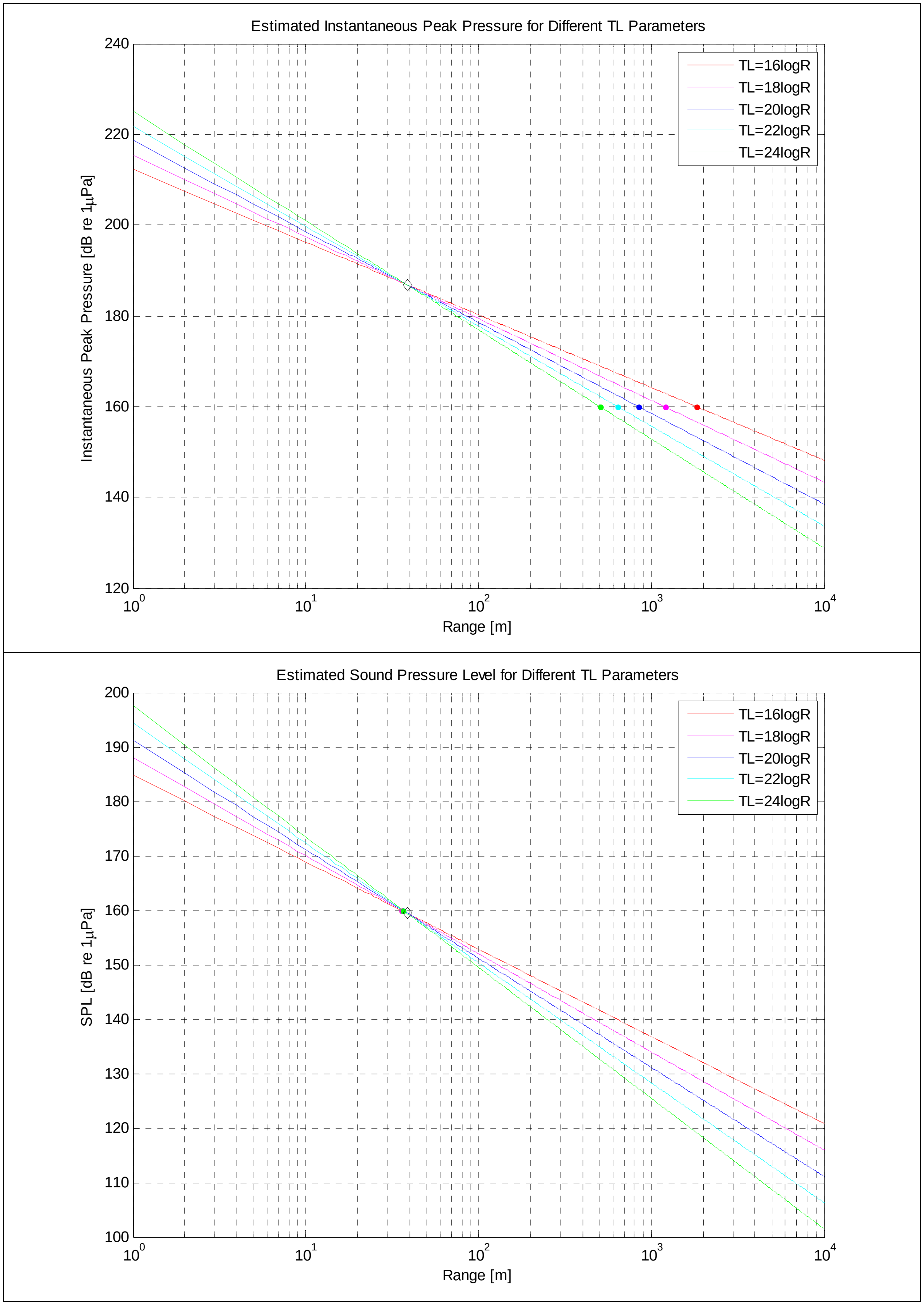
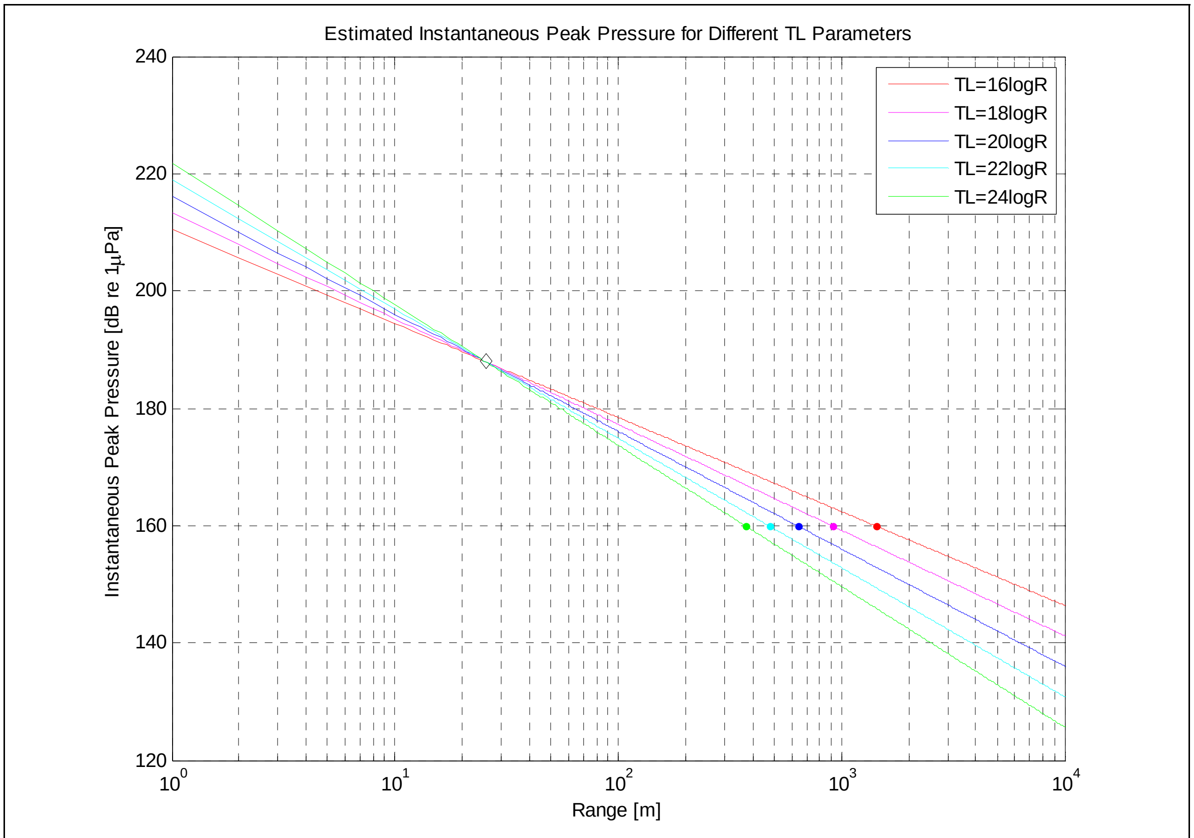


Figure 77 (f). Consideration of Different Transmission Loss Configuration for Impact ID 6



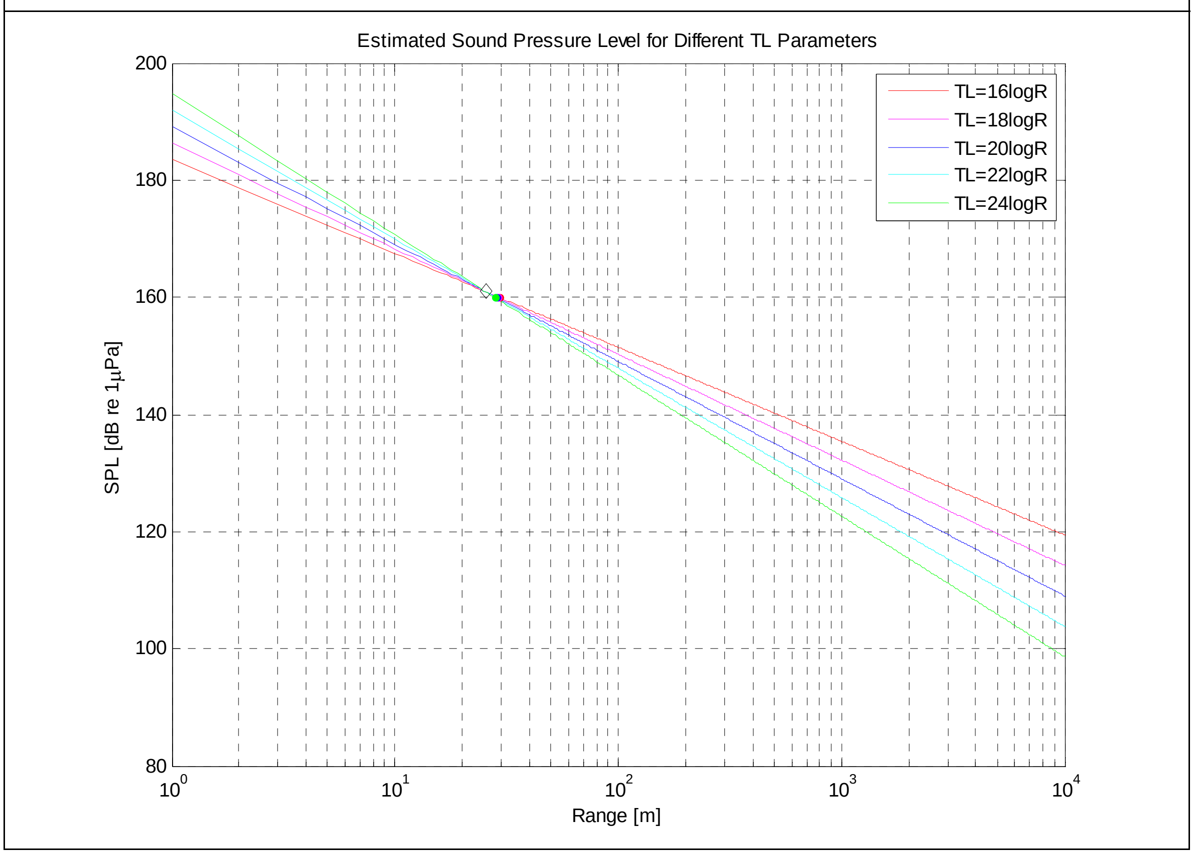


Figure 77 (g). Consideration of Different Transmission Loss Configuration for Impact ID 7

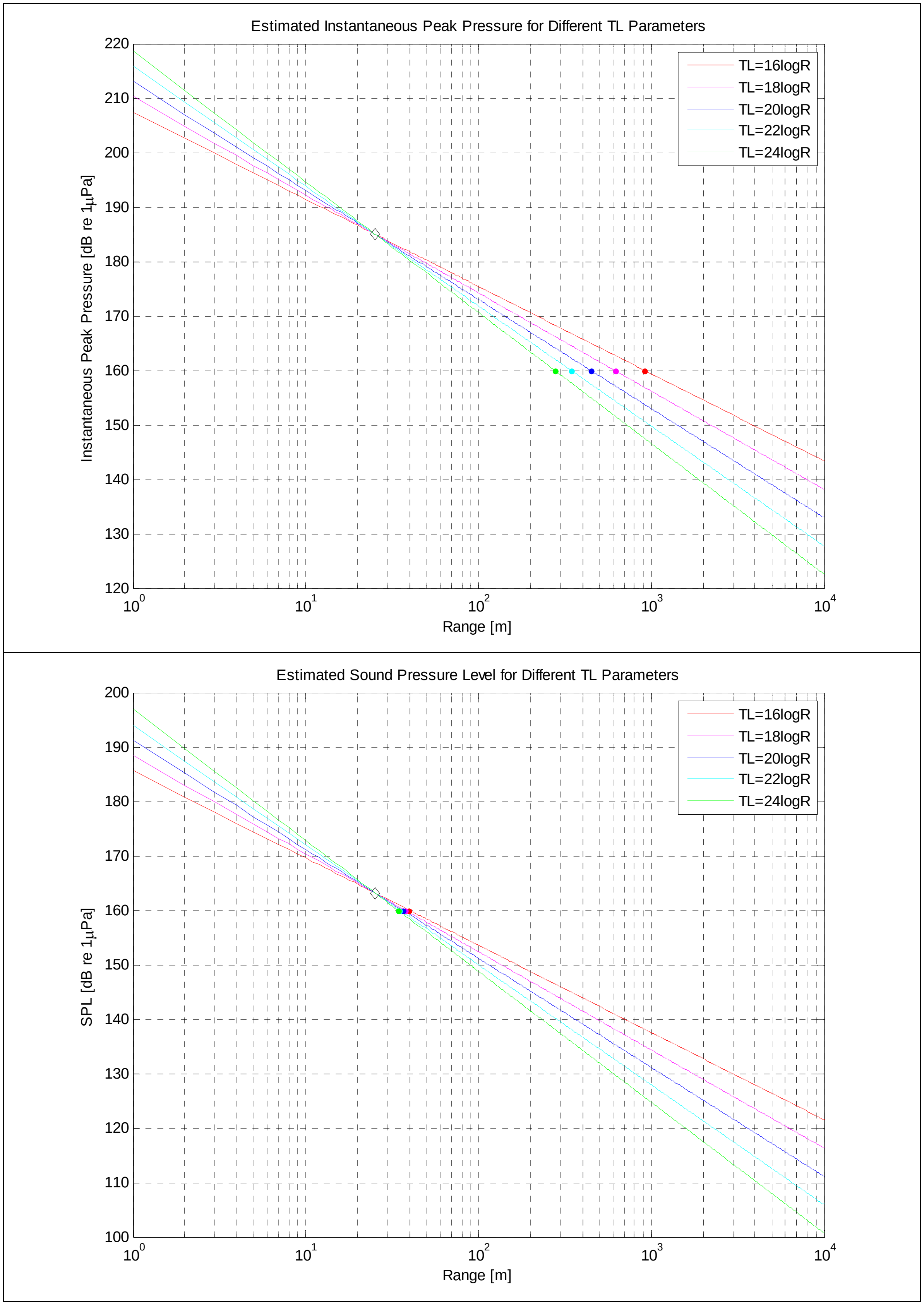


Figure 77 (h). Consideration of Different Transmission Loss Configuration for Impact ID 8

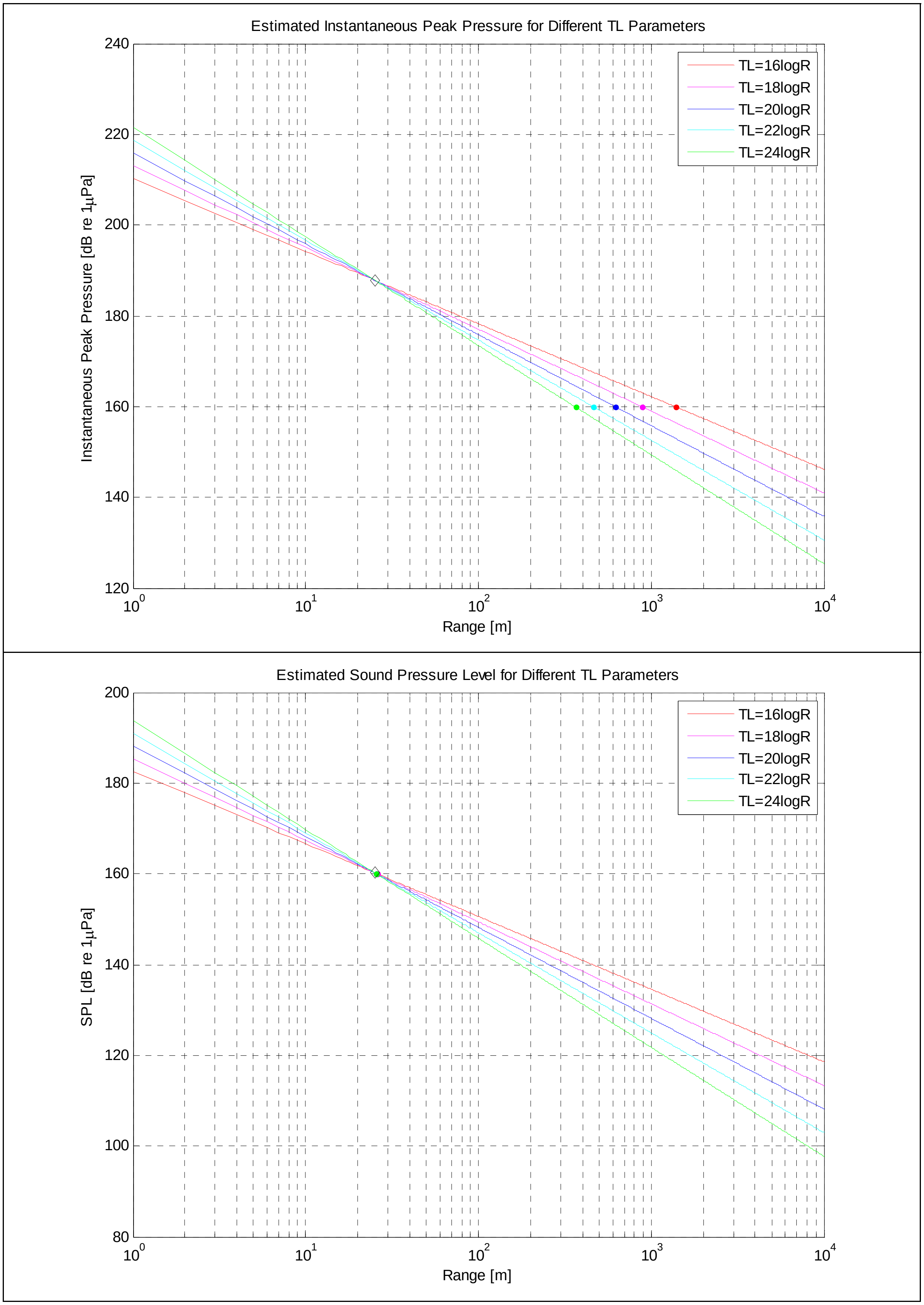


Figure 77 (i). Consideration of Different Transmission Loss Configuration for Impact ID 9

The estimated range to the 160 dB peak pressure and 160 dB SPL for five different transmission loss configurations are listed in **Table 40**.

Table 40. Estimated 160 dB Distances for Instantaneous Peak Pressures and Sound Pressure Levels (Impact, Soft Start)

Impact ID	Est. 160 dB Distance [m] Based on Instantaneous Peak Pressure					Est. 160 dB Distance [m] Based on SPL (RMS)				
	16 log R	18 log R	**20 log R**	22 log R	24 log R	16 log R	18 log R	**20 log R**	22 log R	24 log R
1	903.36	671.36	**529.45**	435.97	370.80	33.27	35.69	**37.74**	39.51	41.05
2	1260.28	901.99	**690.23**	554.51	462.04	48.29	49.66	**50.78**	51.72	52.51
3	1710.28	1182.35	**880.02**	691.12	565.08	42.79	44.57	**46.04**	47.28	48.34
4	1147.55	789.10	**584.82**	457.68	373.12	37.08	37.33	**37.54**	37.71	37.85
5	1475.29	985.43	**713.55**	547.92	439.66	54.90	52.86	**51.28**	50.03	49.00
6	1847.26	1201.98	**852.29**	643.32	508.90	35.74	36.05	**36.30**	36.51	36.68
7	1424.26	910.99	**637.17**	475.58	372.70	29.33	28.88	**28.52**	28.24	28.00
8	920.55	617.59	**448.77**	345.59	277.98	39.70	37.77	**36.29**	35.13	34.18
9	1385.08	887.36	**621.44**	464.33	364.21	25.94	25.86	**25.79**	25.74	25.69

3.3 Stabbing

After threading the pile sheet into the wye connector, the pile sheet is lifted by a crane several feet above the sea floor or embankment and dropped. The resulting momentum drives the pile tip into the embankment or floor. This procedure is called stabbing.

3.3.1 Stabbing - Sliding and Dropping

The process of sliding and dropping the pile on the ground as an initial step of pile driving was monitored over a short period of time on September 26, 2008. The summary of the recording is shown in **Table 41**. The overall SPL values are very small compared to other pile active (vibratory or impact) driving.

Table 41. Summary of Data Analysis (Stabbing)

Data Field	Values
Sampling Date & Time	09/26/2008, 08:18:03~08:38:58
rms Window Size [sec]	1/8 (0.125)
Average Source Level [dB]	154.31
Max/Min Source Level [dB]	168.66 / 150.25
Average Sound Pressure Level [dB]	118.07
Max/Min Sound Pressure Level [dB]	132.61 / 113.82
Average Range to Source [m]	65.10
Max/Min Range to Source [m]	66.27 / 63.96
Estimated 120 dB Distance (Worst Case) [m]	2.75

3.3.1.1 Data Collection and Sampling Area

During the data collection, two separate sessions were recorded with the distance around 65 m under the tide level between 18.03 ~ 19.45 ft. **Table 42** shows the two sessions in detail.

Table 42. Data Collection Log (Sliding and Dropping)

SLM Data			Avisoft Data					Comments
File name	Start time	Stop time	File name	Start time	Stop time	Start offset	End offset	
831_DATA_076.xls	8:18:03	8:21:59	T0000003.wav	8:18:03	8:21:58	03:10	03:21	18:36 - sheet is going into water 20:39 - sliding down 20:53 - sheet stopped half way, 21:27 - all the way in the water
831_DATA_079.xls	8:36:54	8:38:59	T0000006.wav	8:36:57	8:38:58	01:17	01:18	38:36 - sheet dropped into water, nicely visible on Ch 4., sheets are almost out of the water

The sampling locations of stabbing sites were logged with a GPS that was synchronized with acoustic data collection. **Figure 78** shows the relative positions of the pile sliding and the sampling locations. The yellow push pin icon refers to the location of pile driving site (N 61°15'4.941", W 149°52'56.875") and the light green dot indicates the location of data collection.

Figure 78. Aerial Map of Sample Location and Pile Driving Site (Stabbing)

3.3.1.2 Data Processing and Analysis

The sound pressure levels for the sliding process ranged from 113.82 to132.61 dB re 1μPa during the recording session. Their equivalent source levels ranged from 150.25 to 168.66 dB re 1μPa. There were two sliding processes observed during the recording sessions and they are individually analyzed in this section.

The first sliding process was monitored at around 8:21:17 am Alaska local time and found around the 194th second in the data file "T0000003.WAV" as shown in the red dotted circle on the left plot in **Figure 79**.

The second sliding process was monitored at 8:38:15 am Alaska local time and found at the 78th second in the data file "T0000006.WAV" as shown in the red dotted circle on the right plot in **Figure 79**.

One-third octave spectra of both incidences are plotted in **Figure 80**. The distribution of the spectral energy in each case is somewhat different. The first sliding process shows more energy in the lower frequencies below 400 Hz whereas the second sliding process shows more energy above 1 kHz.

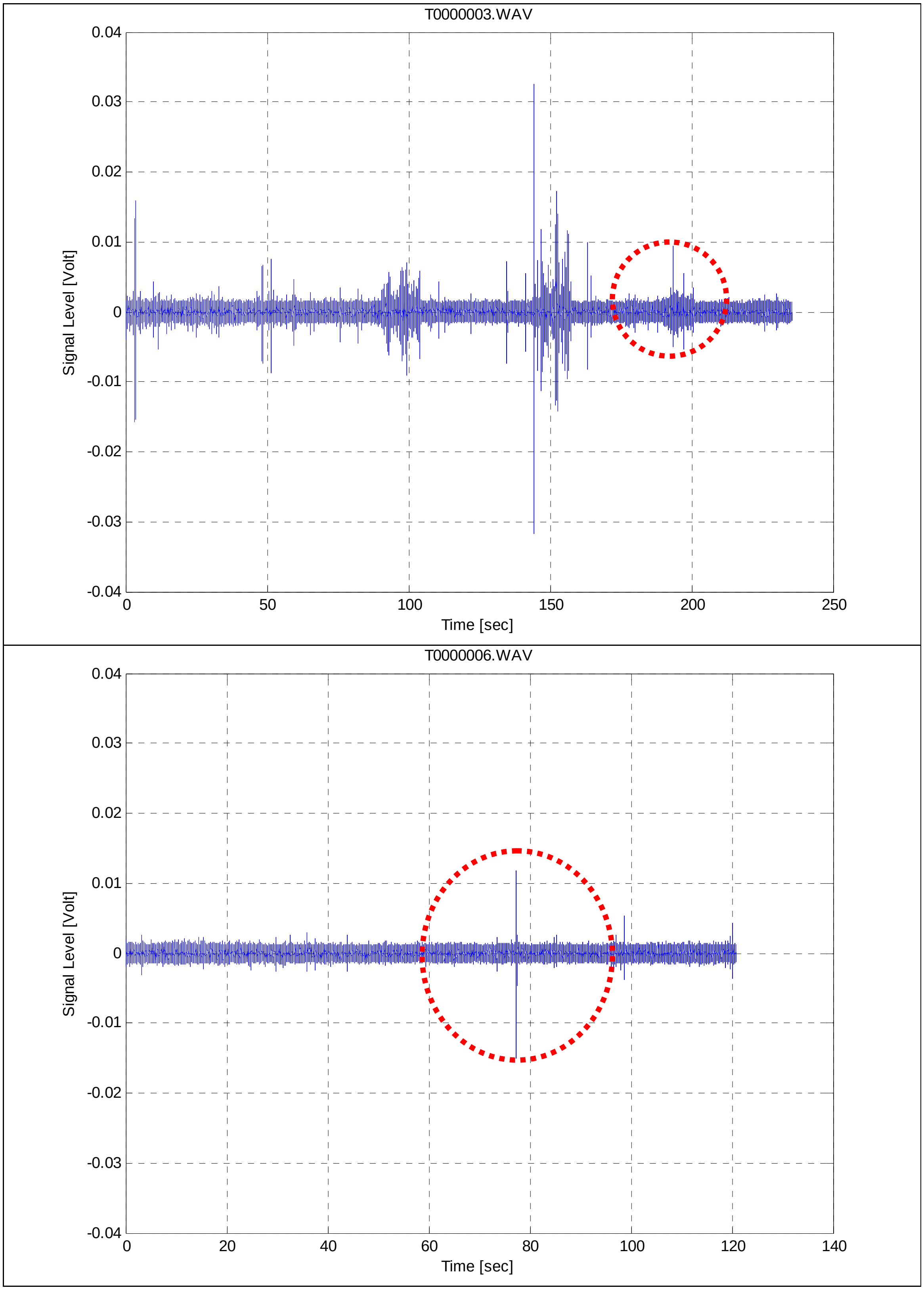


Figure 79. Raw Time Series of Sliding Operation (Stabbing)

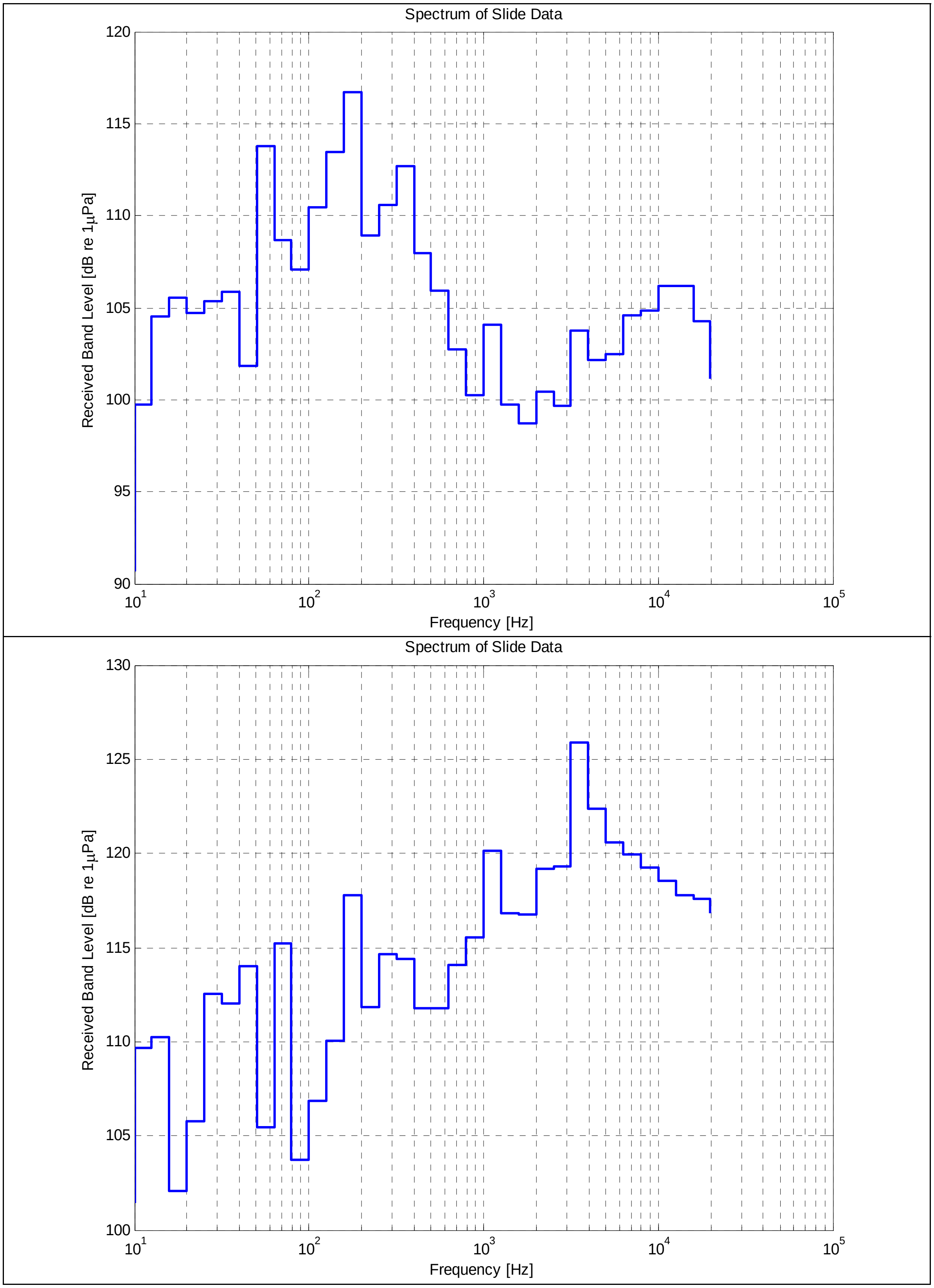


Figure 80. One-Third Octave Spectrum for Pile Driving (Stabbing)

For the first sliding process, the distance to the pile driving site for this monitoring was 64.73 m. The SL of 159.58 dB is estimated from the SPL of 123.36 dB based on spherical spreading transmission loss characteristics at medium tide levels of 19.4 ft. For the second sliding process, the distance to the pile driving site for this monitoring was 63.49 m. The SL of 168.66 dB is estimated from the SPL of 132.61 dB based on spherical spreading transmission loss characteristics at medium tide levels of 18 ft as shown in **Table 43**.

Table 43. Summary of Worst Case Analysis (Stabbing)

Data Field	1st Sliding	2nd Sliding
Data File Name	T0000003.WAV	T0000006.WAV
Date & Time	09/26/2008, 08:21:17	09/26/2008, 08:38:15
Time Offset in File [sec]	194	78
Range to Source [m]	64.73	63.49
Sound Pressure Level [dB]	123.36	132.61
Estimated Source Level [dB]	159.58	168.66
Estimated 120 dB Distance [m]	95.26	271.10
Tide [ft]	19.45	18.03

A nominal transmission loss configuration of 20 log R is used to calculate SL values, although the actual transmission loss is a function of many complicated environmental variables. Thus, different possibilities of transmission loss, such as 16 log R, 18 log R, 22 log R, and 24 log R, are considered to estimate the SL value at the pile driving location and eventually to compute the range to 120 dB.

Figure 81 shows five possible situations of SPL values for the pile sliding with varying ranges up to 1 km based on the worst case measurement in each of two sessions: the red curve indicates the SPL using the transmission loss with 16 log R; the magenta curve indicates the SPL using the transmission loss with 18 log R; the blue curve indicates the SPL using the transmission loss with 20 log R; the cyan curve indicates the SPL using the transmission loss with 22 log R; and the green curve indicates the SPL using the transmission loss with 24 log R.

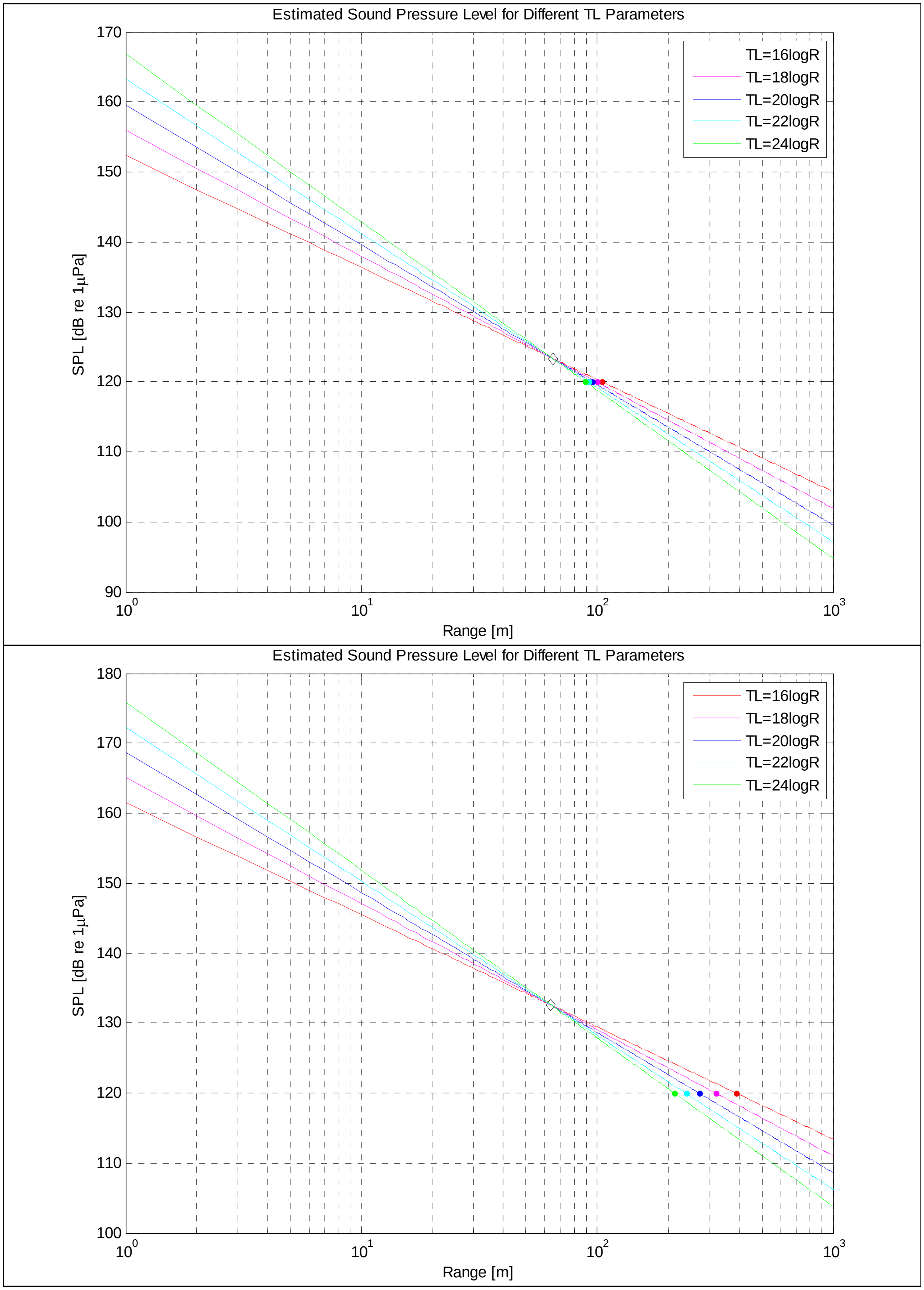


Figure 81. Consideration of Different Transmission Loss Configuration (Stabbing)

The estimated SL's and range to 120 dB for different transmission loss configurations are listed for both sliding processes in the **Table 44**. The worst case is the second sliding process; the nominal transmission configuration (20 log R) provides the estimated range to 120 dB to be 271.10 m, with a range between 212.85 m and 389.71 m.

Table 44. Estimated Source Levels and 120 dB Distances (Stabbing)

Transmission Loss	1st Sliding		2nd Sliding	
	Estimated SL [dB re 1μPa]	Estimated 120 dB Distance [m]	Estimated SL [dB re 1μPa]	Estimated 120 dB Distance [m]
16 log R	152.33	104.92	161.45	389.71
18 log R	155.96	99.44	165.06	318.55
20 log R	159.58	95.26	168.66	271.10
22 log R	163.20	91.97	172.27	237.59
24 log R	166.82	89.32	175.87	212.85

3.4 Noise Index

Several instances of manual hammering at the pile driving site, bucket dredging operations, and survey vessel traffic were recorded during acoustic noise survey. Analysis of these corresponding sound recordings is provided below.

3.4.1 Background Noise

A number of background noise recording sessions were conducted when no other activities were observed around the sampling area. **Table 45** shows 25 individual background noise analyses including file start time, file end time, average noise level, average tide level, average tide level change, average wind speed, and average water temperature. Appendix G shows corresponding plots of 25 individual sessions.

Table 45. Summary of Background Noise Recordings (Background Noise)

Date	Start Time [hh:mm:ss]	End Time [hh:mm:ss]	Avg Noise Level [dB re μPa]	Avg Tide [ft]	Avg Tide Change [ft/sec]	Avg Wind Speed [m/s]	Avg Water Temperature [°C]
10/08/2008	11:15:22	11:16:21	149.38	13.28	0.001144	3.81	7.35
10/08/2008	11:16:22	11:16:43	149.77	13.33	0.001117	3.70	7.35
10/08/2008	11:18:01	11:18:33	149.95	13.45	0.001083	3.42	7.35
10/08/2008	11:24:59	11:25:58	150.43	13.92	0.001083	2.95	7.33
10/08/2008	11:25:59	11:26:12	149.89	13.96	0.000894	3.01	7.33
10/08/2008	13:23:47	13:24:46	142.53	20.43	0.000894	2.53	7.71
10/08/2008	13:24:47	13:24:54	138.78	20.46	0.000797	2.50	7.71
10/08/2008	14:01:50	14:02:42	130.65	22.40	-0.000108	2.75	7.61
10/08/2008	15:30:46	15:31:02	131.79	24.56	-0.000608	2.18	7.79
10/08/2008	16:20:26	16:21:25	125.95	23.49	-0.000608	1.55	7.80
10/08/2008	16:21:26	16:22:25	128.43	23.45	-0.000608	1.52	7.80
10/08/2008	16:22:26	16:22:55	131.16	23.43	-0.000608	1.51	7.80
10/08/2008	16:22:57	16:23:19	130.14	23.41	-0.000800	1.49	7.80
10/08/2008	16:46:47	16:47:34	127.21	22.36	-0.000964	1.56	7.81
10/08/2008	17:15:49	17:16:40	128.56	20.79	-0.000964	1.77	7.79
10/08/2008	17:16:41	17:17:40	126.19	20.74	-0.000964	1.89	7.79
10/08/2008	17:17:41	17:18:40	130.77	20.68	-0.000983	2.03	7.79
10/08/2008	17:18:41	17:19:40	129.43	20.62	-0.000983	2.23	7.79
10/08/2008	17:19:41	17:20:41	129.01	20.56	-0.000983	2.43	7.79
10/08/2008	17:20:42	17:21:27	128.49	20.51	-0.000983	2.62	7.80
10/08/2008	17:23:57	17:24:41	128.50	20.32	-0.001000	3.17	7.80
10/08/2008	17:24:42	17:25:41	128.24	20.27	-0.001000	3.05	7.80
10/08/2008	17:25:42	17:25:52	128.12	20.23	-0.001014	2.98	7.80
10/08/2008	17:50:15	17:51:07	122.66	18.72	-0.001014	2.06	7.80
10/08/2008	17:51:08	17:51:23	120.42	18.69	0.001144	2.16	7.80

The relationship between tide level and noise level during these 25 recording sessions is plotted in **Figure 82**. Also, the relationship between tide level change and the noise level is illustrated. Although the number of samples is not large, the trend of the 25 independent incidences shows that greater tide level changes caused higher noise levels during the recording sessions. Each red marker represents average value in each session.

Another important factor in background noise is the wind speed, especially when high winds generate breaking waves. **Figure 83** shows the relationship between the wind speed and the background noise. There were many instances of high (≈150 dB) background noise when the wind speeds were at or over 3 m/s. The water temperature remained fairly constant during the recording sessions and was not correlated with the background noise that was collected.

Figure 84 plots this relationship in three-dimensions: tide level (or tide level change), wind speed, and background noise level.

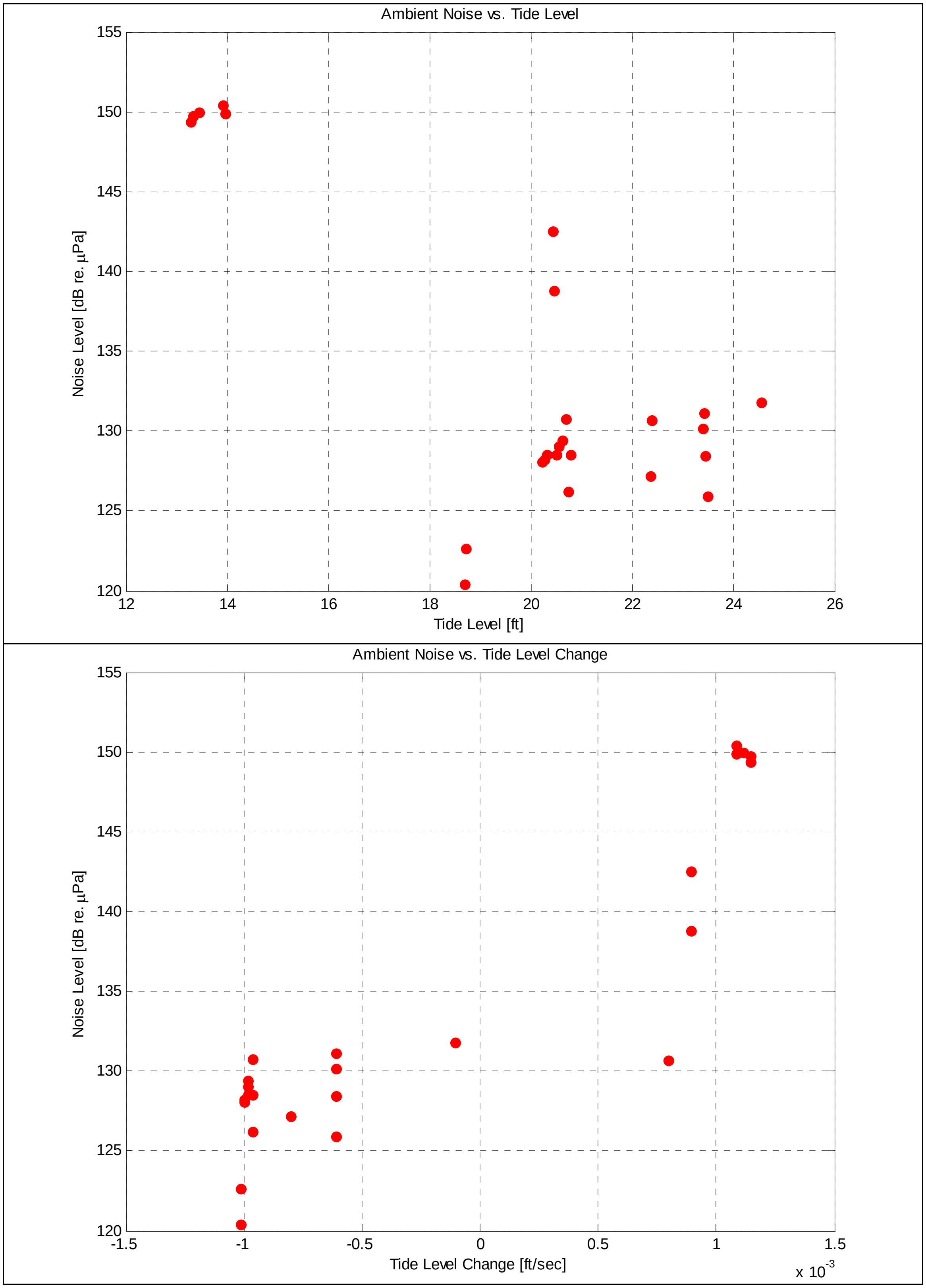


Figure 82. Relationship Between Background Noise Level and Tide / Tide Change

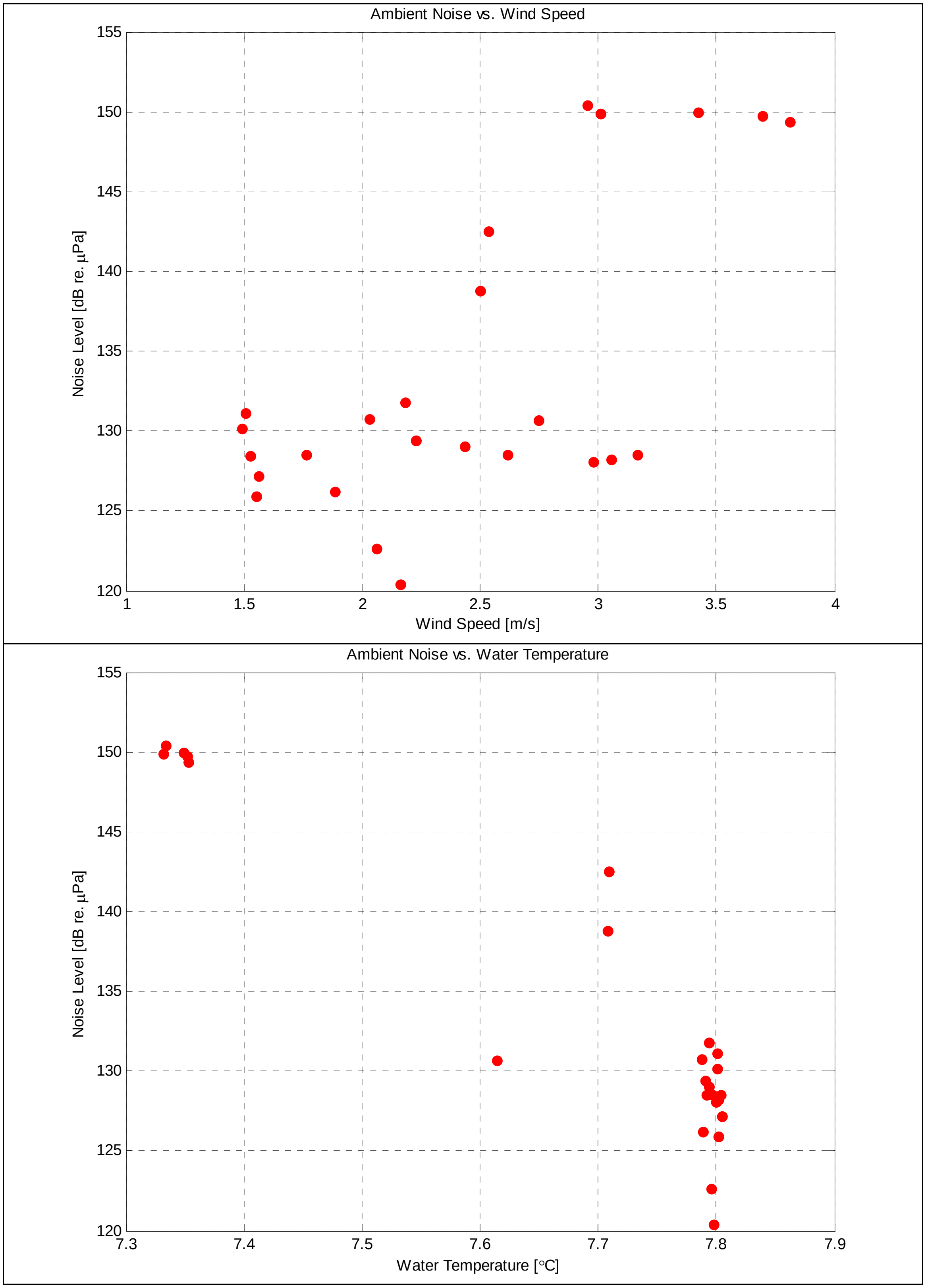


Figure 83. Wind Speed, Water Temperature, and the Relationship with Background Noise Level

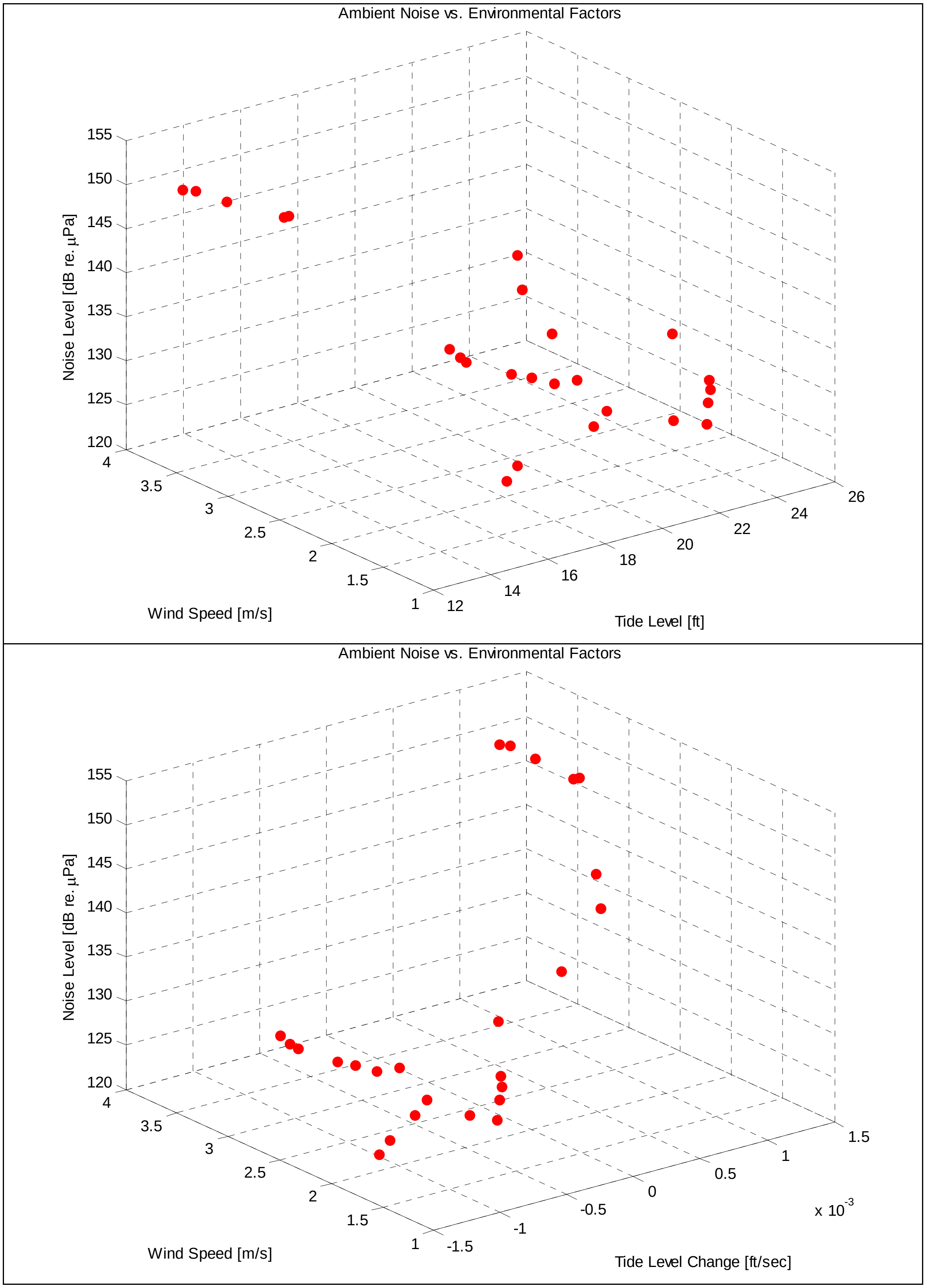


Figure 84. Relationship Between Background Noise Level, Wind Speed, and Tide / Tide Change

3.4.2 Bucket Dredging Operation

The underwater sounds produced by bucket dredging operations were collected on September 24, 2008 and the summary of the analysis is shown in **Table 46**. The distance to the 160 dB isopleth was estimated to be 21 m utilizing spherical spreading loss characteristics[7].

Table 46. Summary of Data Analysis (Bucket Dredging)

Data Field	Values
Sampling Date & Time	09/24/2008, 11:40:36 ~12:07:05
Max Source Level [dB]	186.40
Max Sound Pressure Level [dB]	156.90
Range to Source [m]	30.00
Estimated 160 dB Distance (Worst Case) [m]	21.00
Tide [ft]	7.30 - 9.40

3.4.2.1 Data Collection and Sampling Area

During the data collection, approximately 25 minutes of bucket dredging operation sounds were recorded at the distance of approximately 30 meters with the tide level ranging between 7.3 and 9.4 ft. **Table 47** shows the list of all recorded files in detail.

The sampling locations during bucket dredging operations are presented in **Figure 85**. The yellow push pin icon refers to the bucket dredging operation site (N 61°14'39.59", W 149°53'8.73") and the green push pin icon indicates the location of the data recording site.

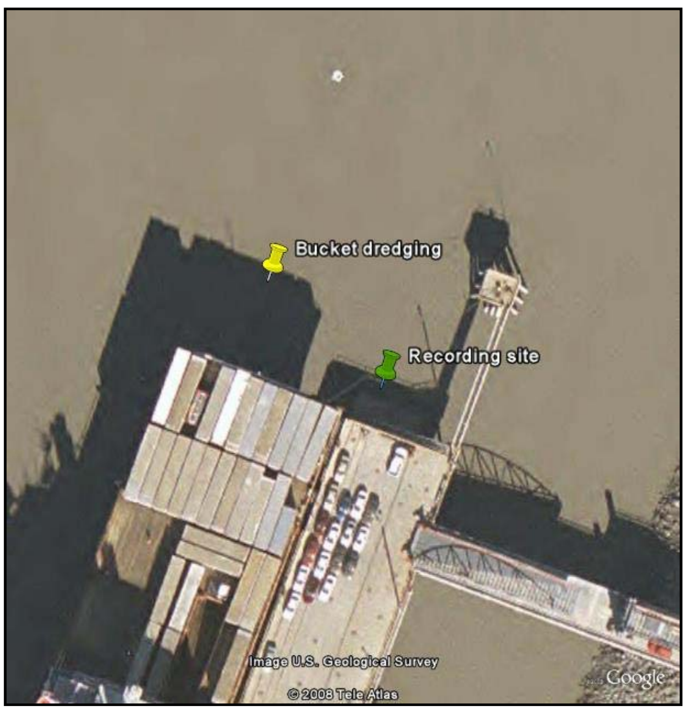


Figure 85. Aerial Map of Sample Location and Bucket Dredging Site

[7] Estimation assumes the spreading loss parameter to be 20 log R. Consideration of different parameters is discussed in the following sections.

Table 47. Data Collection Log (Bucket Dredging)

SLM Data			Avisoft Data			Time boundaries		Comments
File name	Start time	Stop time	File name	Start time	Stop time	Start offset	End offset	
831_DATA_022.xls	11:40:36	12:07:05	T0000015. wav	11:42:10	11:43:10			
			T0000016. wav	11:43:10	11:44:10			
			T0000017. wav	11:44:10	11:45:10			
			T0000018. wav	11:45:10	11:45:29			
			T0000019. wav	11:45:37	11:46:37			Avisoft - max gain, SR preamp - 10x, picking up cell phone signal
			T0000020. wav	11:46:37	11:47:37			
			T0000021. wav	11:47:37	11:48:37			
			T0000022. wav	11:48:37	11:49:37			
			T0000023. wav	11:49:37	11:50:37	00:02.0	00:02.4	Wave file has saturated peaks
				11:49:37	11:50:37	00:20.2	00:20.4	
			T0000024. wav	11:50:37	11:51:37			
			T0000025. wav	11:51:37	11:52:38			
			T0000026. wav	11:52:38	11:53;38			
			T0000027. wav	11:53;38	11:54:38	00:22.3	00:22.4	
			T0000028. wav	11:54:38	11:55:38			
			T0000029. wav	11:55:38	11:56:38			
			T0000030. wav	11:56:38	11:57:38			
			T0000031. wav	11:57:38	11:58:38			
			T0000032. wav	11:58:38	11:59:39	00:56.5	00:57.0	
			T0000033. wav	11:59:39	12:00:39	00:12.5	00:12.6	Wave file has saturated peaks
			T0000034. wav	12:00:39	12:01:39			
			T0000035. wav	12:01:39	12:02:39			
			T0000036. wav	12:02:39	12:03:39			
			T0000037. wav	12:03:39	12:04:39			
			T0000038. wav	12:04:39	12:04:44			
			T0000039. wav	12:04:57	12:05:57	00:18.1	00:18.4	Avisoft - max gain, SR preamp - 20x

				12:04:57	12:05:57	00:23.0	00:23.2	Wave file has saturated peaks
				12:04:57	12:05:57	00:31.4	00:31.5	Wave file has saturated peaks
			T0000040.wav	12:05:57	12:06:57			
			T0000041.wav	12:06:57	12:07:02			

3.4.2.2 Data Processing and Analysis

Each cycle of bucket dredging operations consist of various sound types such as dredge bucket striking the bottom, bucket digging, jaws of bucket closing, etc. Eight recordings with maximum peak levels were selected for analysis. The snapshots of recorded signal are presented in **Figures 86 (a) through (c)**. The peak levels of these measured dredging sounds ranged from 157.2 to 159.9 dB re 1μPa during eight recording sessions.

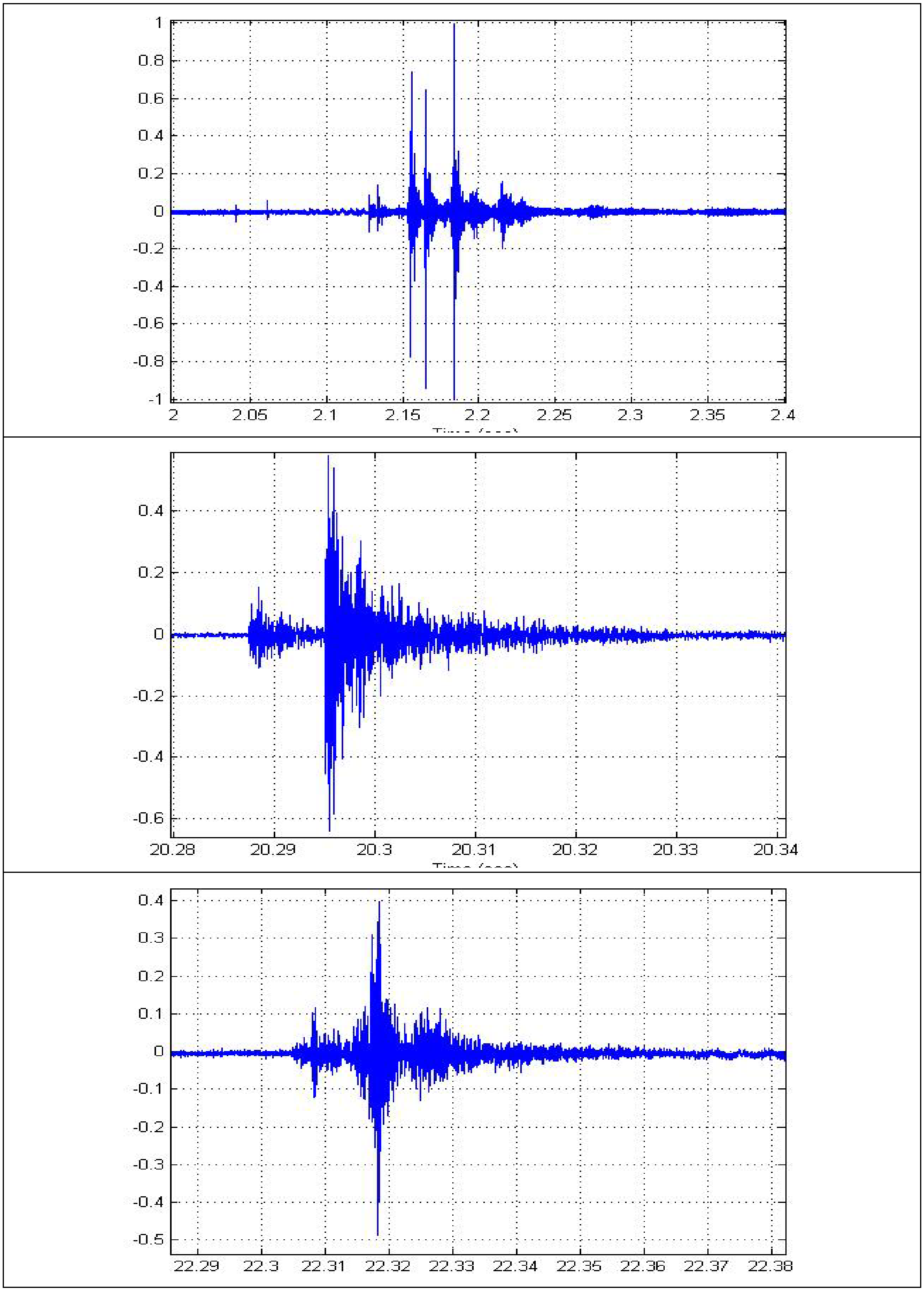


Figure 86(a). Raw Time Series of Dredging Operation

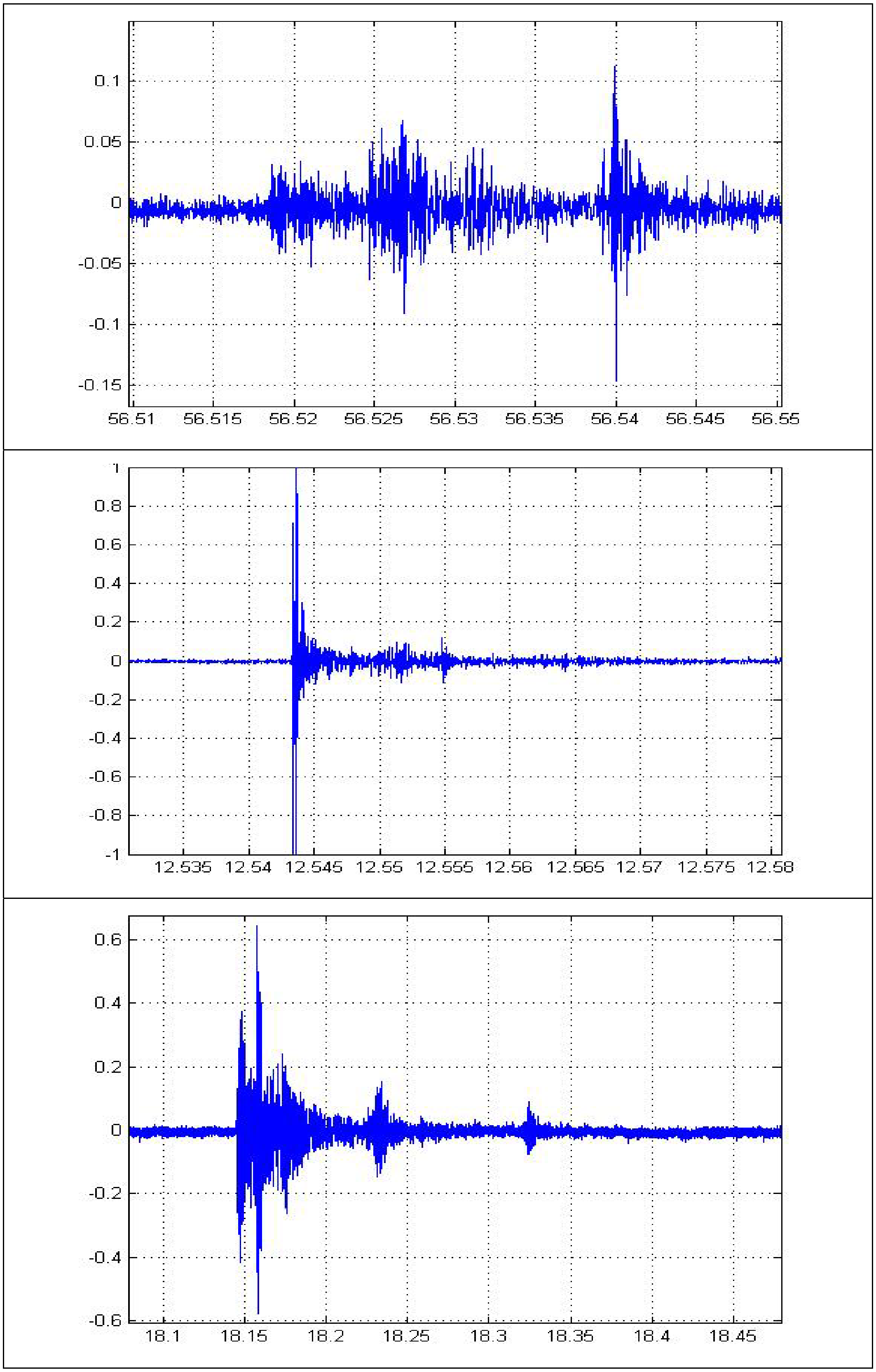


Figure 86(b). Raw Time Series of Dredging Operation

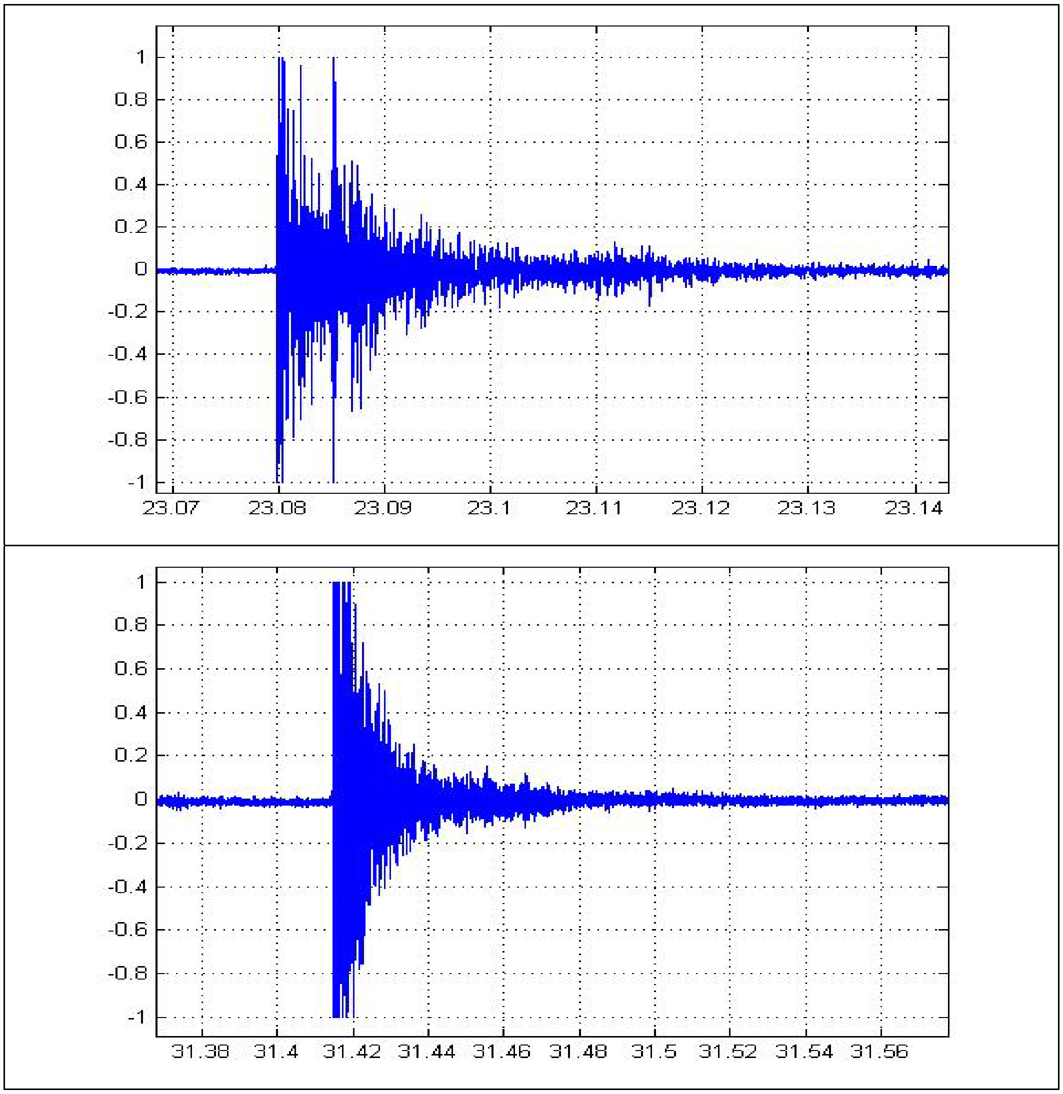


Figure 86(c). Raw Time Series of Dredging Operation

3.4.2.3 Worst Case Analysis

Due to the significant variability of the dredging operation sound recordings, only the incident with the maximum peak value was used for the worst case analysis. This sample is considered as the loudest incident among all measurements in eight processed recordings.

The raw data recorded with Avisoft device was saturated for this particular sound. Corresponding LZpeak value recorded with Larson-Davis 831 SLM was used to calculate equivalent SPL level.

Table 48 shows the details of the worst case analysis at 11:59:51 on September 24, 2008. The peak value of 159.90 dB re 1µPa was measured at the distance of 30 m, equivalent SPL level is calculated to be 156.90 dB re 1µPa. Corresponding SL level is 186.40 dB re 1µPa assuming 20 log R spreading loss. Using this maximum SL value, the distance to 160 dB SPL point is estimated to be 21 m from the dredging site.

Table 48. Summary of Worst Case Analysis (Bucket Dredging)

Data Field	Values
Data File Name	831_DATA_022.XLS / T0000033.WAV
Date & Time	09/24/2008, 11:59:51
Time Offset in File [sec]	6912.5
Range to Source [m]	30.00
Sound Pressure Level [dB re 1µPa]	156.90
Estimated Source Level [dB re 1µPa]	186.40
[8]Estimated 160 dB Distance [m]	21.00

One-third octave spectrum of corresponding SLM LZI max values is shown in **Figure 87**. Most of the spectral energy is concentrated below100 Hz and above 5 kHz.

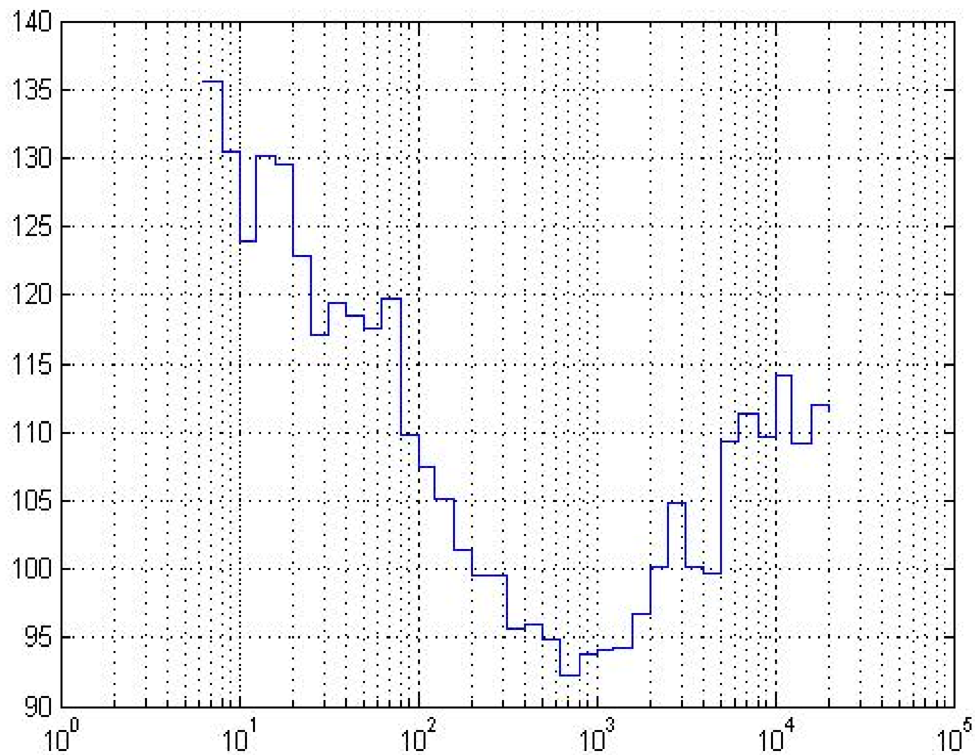


Figure 87. One-Third Octave Spectrum for Bucket Dredging

A nominal transmission loss configuration of 20 log R was used to calculate SL values, although the actual transmission loss is a function of many complicated environmental variables. Thus, different possibilities of transmission loss, such as 16 log R, 18 log R, 22 log R, and 24 log R, are considered to estimate the SL value at the pile driving location and eventually to compute 120 dB distance.

[8] Estimation assumes the spreading loss parameter to be 20 log R. Consideration of different parameters is discussed in the following sections.

Figure 88 shows five possible situations of SPL values for the bucket dredging operation with varying ranges up to 10 km based on the worst case measurement: the red curve indicates the SPL using the transmission loss with 16 log R; the magenta curve indicates the SPL using the transmission loss with 18 log R; the blue curve indicates the SPL using the transmission loss with 20 log R; the cyan curve indicates the SPL using the transmission loss with 22 log R; and the green curve indicates the SPL using the transmission loss with 24 log R.

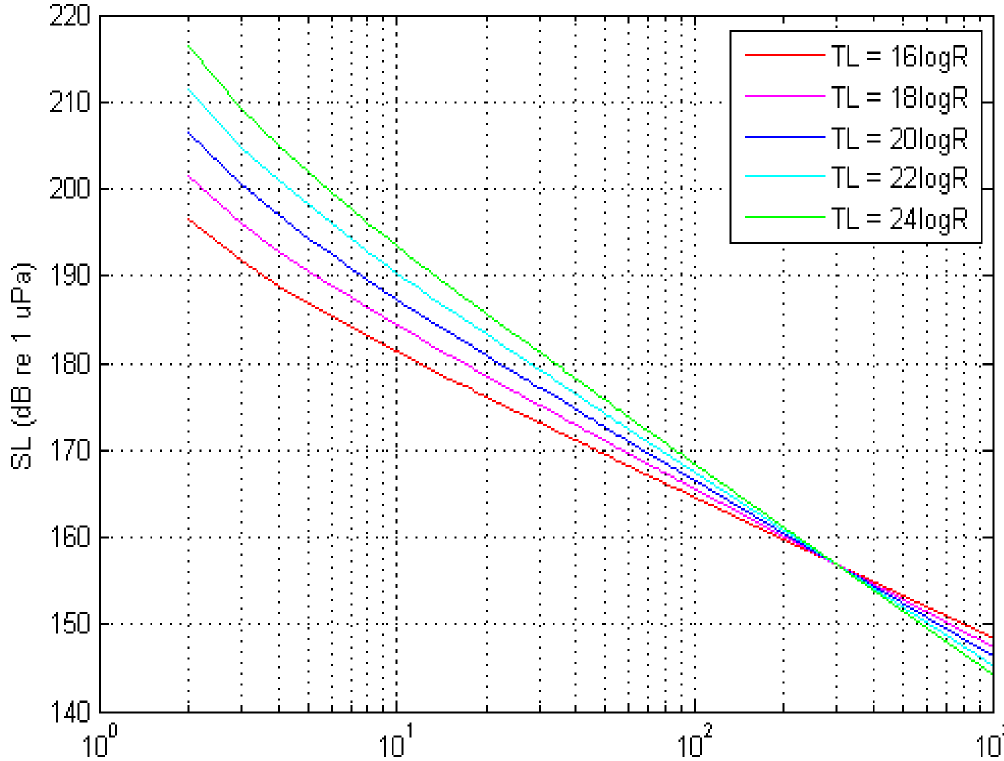


Figure 88. Consideration of Different Transmission Loss Configurations (Bucket Dredging)

The estimated SL's and range to 160 dB for different transmission loss configurations are listed in the **Table 49**. In this worst case situation, the nominal transmission configuration (20 log R) provides the estimated range to 160 dB to be 21 m, but it can possibly range between 19.2 m and 22.3 m.

Table 49. Estimated Source Levels and 160 dB Distances (Bucket Dredging)

Transmission Loss	Estimated SL [dB re 1μPa]	Estimated 160 dB Distance [m]
16 log R	180.5	19.2
18 log R	183.5	20.2
20 log R	186.4	21.0
22 log R	189.4	21.7
24 log R	192.4	22.3

3.4.3 Hand Hammer

Two hand hammer impact sessions were collected on September 29, 2008 and the summary of the analysis is shown in **Table 50**.

For the worst case, the range to 160 dB was estimated to be 3.89 m based on SPL value with RMS computation, but it can be as long as 25.62 m when it is derived from instantaneous peak pressure.

Table 50. Summary of Data Analysis (Hand Hammer)

Data Field	Values
Sampling Date & Time	09/29/2008, 08:18:54 ~ 08:26:01
Total Count of Hand Hammer Impacts	28
Average Source Level [dB]	168.3473
Max/Min Source Level [dB]	171.78 / 161.59
Average Sound Pressure Level [dB]	120.05
Max/Min Sound Pressure Level [dB]	124.67 / 109.42
Average Instantaneous Peak Pressure [dB]	135.74
Max/Min Instantaneous Peak Pressure [dB]	139.92 / 128.31
Average Range to Source [m]	287.39
Max/Min Range to Source [m]	408.36 / 225.45
Estimated 160 dB Distance (Worst Case) [m] Based on SPL (RMS)	3.89
Estimated 160 dB Distance (Worst Case) [m] Based on Instantaneous Peak Pressure	25.62

3.4.3.1 Data Collection and Sampling Area

During the data collection, two separate sessions were recorded with the distance between 225.45 and 408.36 m at high tide levels between 29.8916 and 30.1391 ft. **Table 51** shows both sessions in detail.

Table 51. Data Collection Log (Hand Hammer)

SLM Data			Avisoft Data					Comments
File name	Start time	Stop time	File name	Start time	Stop time	Start offset	End offset	
831_DATA_100.xls	8:12:00	8:25:25	T0000039.wav	8:15:57	8:19:57	02:57	03:07	
				8:15:57	8:19:57	03:12	03:18	
831_DATA_101.xls	8:25:49	8:30:23	T0000043.wav	8:25:52	8:29:52	00:01	00:09	Peak of tide, range 473 m

The sampling locations during hand hammer impacts were logged with a GPS that was synchronized with acoustic data collection. **Figure 89** shows the relative positions of the hand hammer and the sampling locations. The yellow push pin icon refers to the location of pile driving site (N 61°15'4.941", W 149°52'56.875") and the two light green tracks indicate the data collection locations.

Figure 89. Aerial Map of Sample Location and Pile Driving Site (Hand Hammer)

3.4.3.2 Data Processing and Analysis

The sound pressure levels for the hand hammer impact ranged from 109.42 to 124.67 dB re 1μPa during the recording session. Their equivalent instantaneous peak pressures ranged from 128.31 to 139.92 dB re 1μPa.

The 28 individual impacts from two raw time series of recorded data are shown in **Figure 90** were processed to produce sound pressure levels with RMS computation and the instantaneous peak pressures. The range to 160 dB was derived for both instances.

Sound pressure levels of all measured hand hammer impacts and their estimated source levels are shown in the order they were measured in **Figure 91**.

As noted above, tide level significantly affects the propagation of sound energy (the higher the tide, the more efficient the transmission of the sound energy). As illustrated in **Figure 92**, tide levels during two recording sessions were relatively high (29.9~30.2 ft).

One-third octave spectrum averaged over all measured hand hammer impacts is shown in **Figure 93**. The spectral energy is mostly focused over the 5 kHz band. The trend of spectral energy distribution is consistent throughout the measurement.

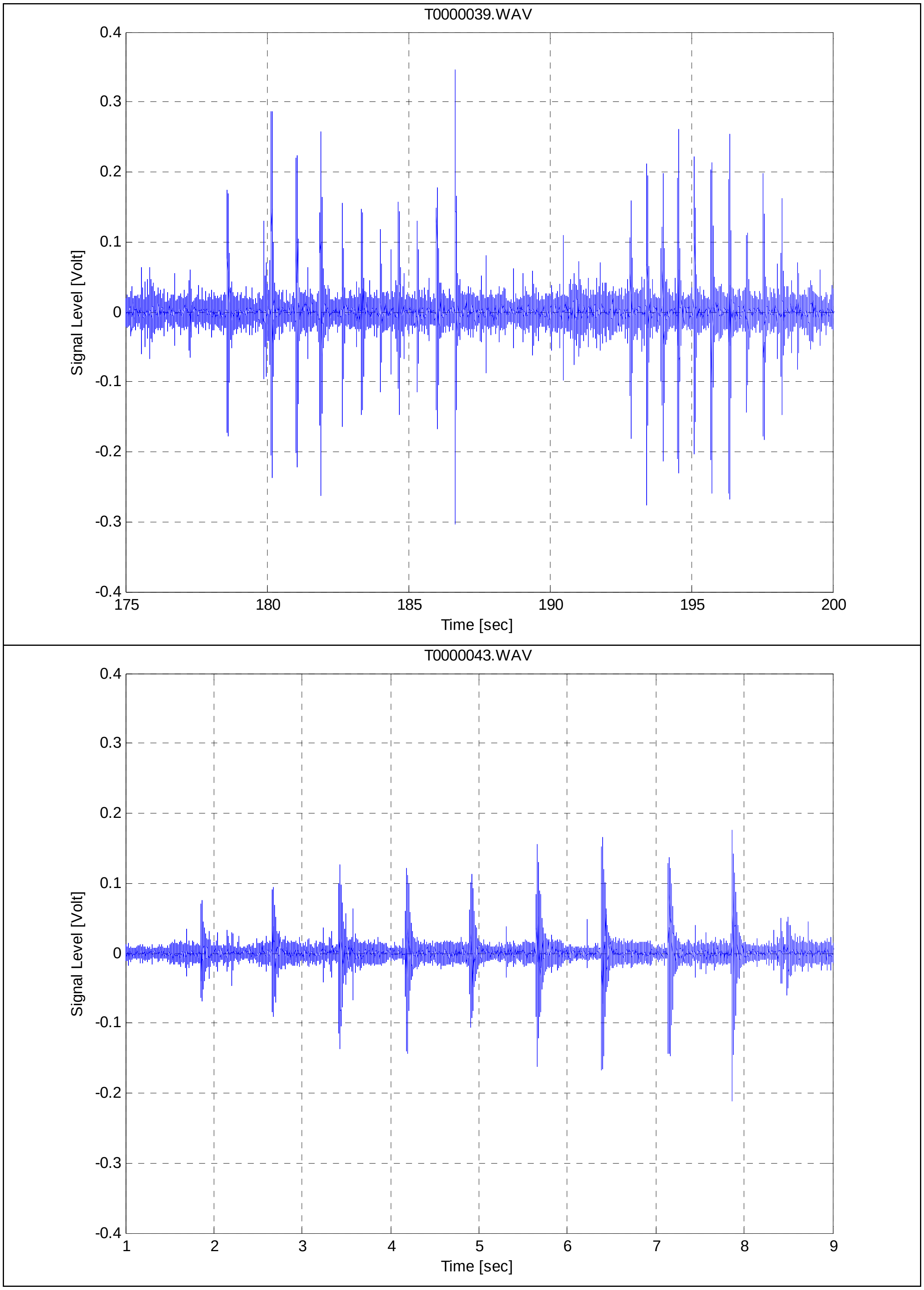


Figure 90. Raw Time Series of Hand Hammer Impacts

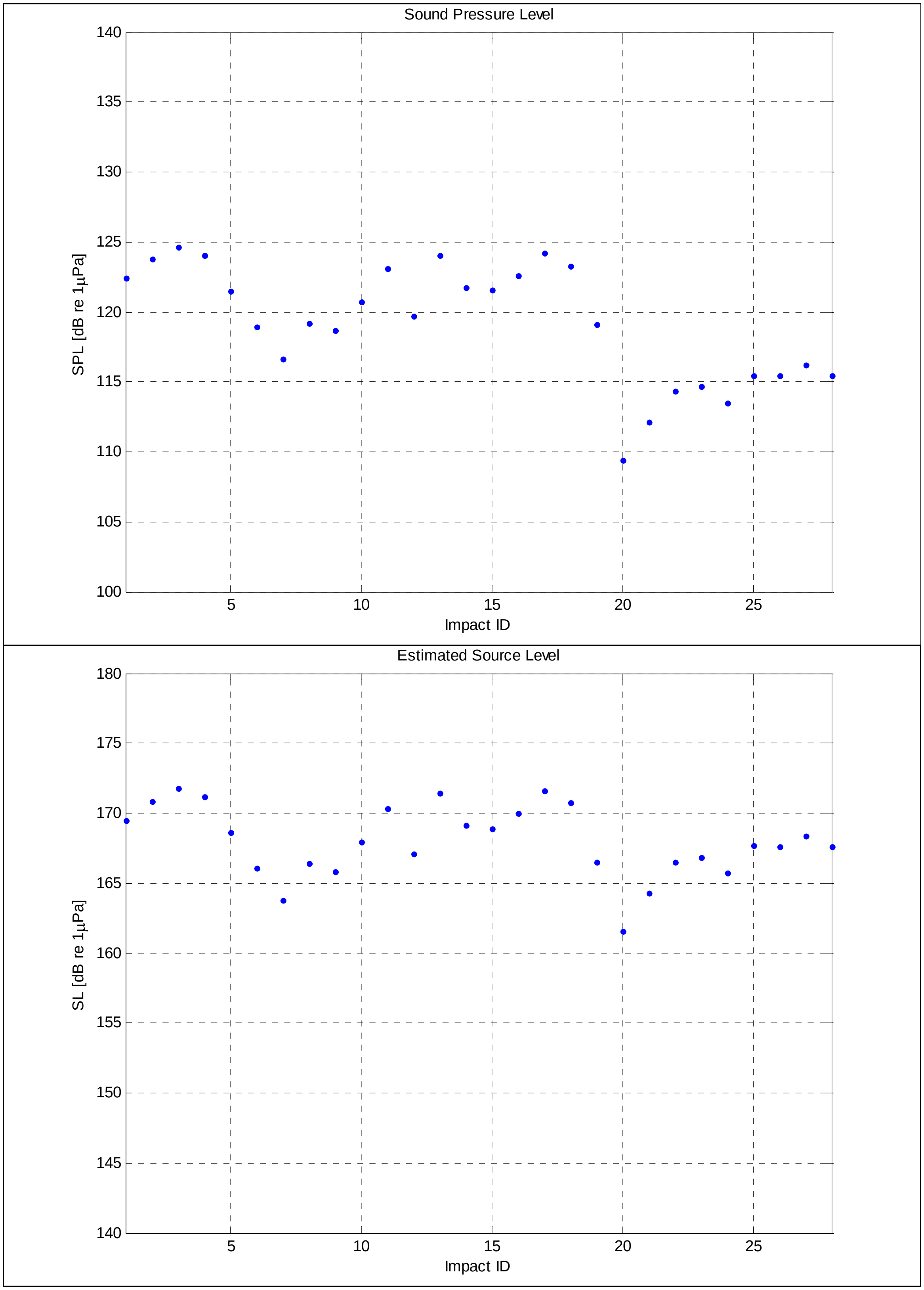


Figure 91. Sound Pressure Level and Estimated Source Level (Hand Hammer)

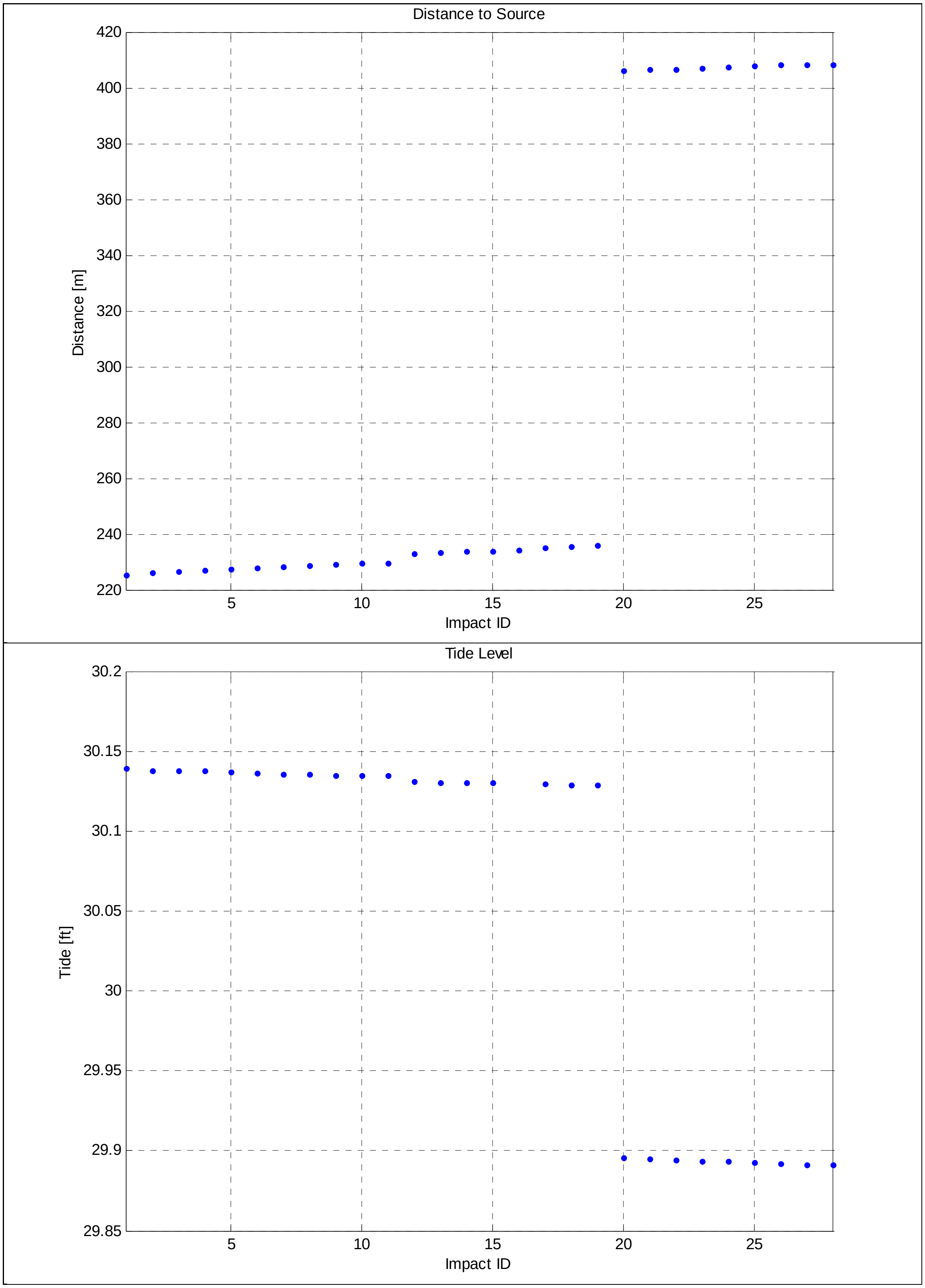


Figure 92. Distance to Source and Tide Level (Hand Hammer)

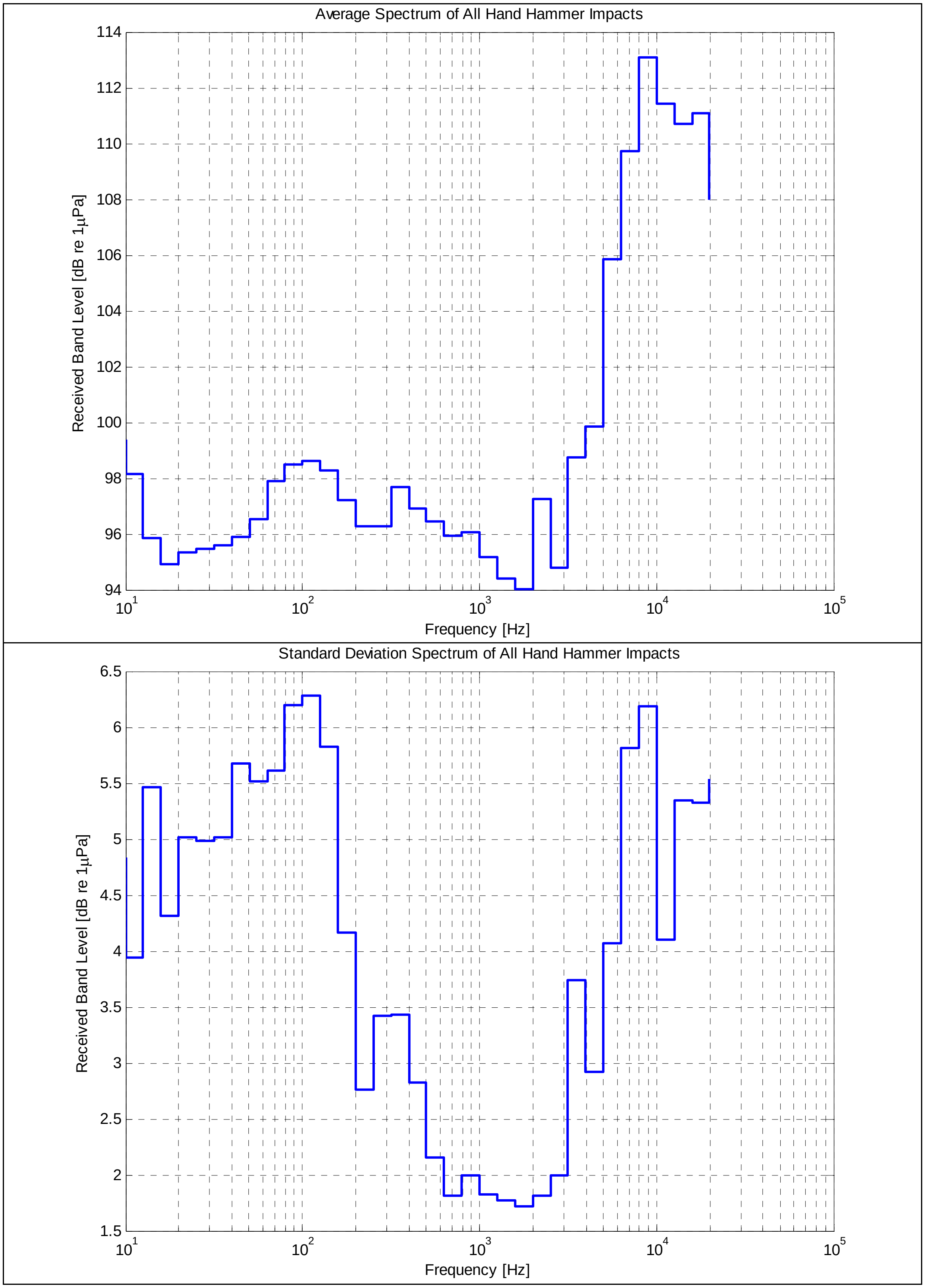


Figure 93. Average Spectrum and Standard Deviation (Hand Hammer)

3.4.3.3 Worst Case Analysis

As mentioned above, computing the sound energy of the impact, a typical calculation is based on RMS value for the pulse duration of the impact. The result of this SPL computation is greatly dependent on the pulse duration that is averaged relative to RMS. Longer pulse durations produce lower SPL's. A more conservative method of computing the worst case can be based on the instantaneous peak pressure without averaging.

When all SPL's are converted to SL's, assuming spherical spreading transmission loss for the distance from the pile driving site, the incident with the maximum value of SL is used for the worst case analysis. This sample is considered the loudest incident among all the measured impacts in terms of RMS-based SPL values (**Table 52**). This event occurred at 08:18:58.05 on September 29, 2008 and the range to 160 dB SPL is estimated to be 3.89 m from the pile driving site.

The other perspective of the worst case incident based on the instantaneous peak pressure was measured at 08:25:57.66 on September 29, 2008. Using a different instance and its 160 dB peak pressure distance is estimated to be 25.62 m from the pile driving site (**Table 52**).

Table 52. Summary of Worst Case Analysis (Hand Hammer)

Data Field	Values
Data File Name for Peak Pressure	T0000043.WAV
Range to Source [m]	407.7665
Date & Time of Peak Pressure	09/29/2008, 08:25:57.66
Time Offset in File [sec]	5.66
Instantaneous Peak Pressure [dB]	135.96
Estimated 160 dB Distance (Worst Case) [m] Based on Instantaneous Peak Pressure	25.62
Data File Name for Max SPL	T0000039.wav
Date & Time of Max SPL	09/29/2008, 08:18:58.05
Time Offset in File [sec]	181.05
Range to Source [m]	226.68
Sound Pressure Level [dB]	124.67
Pulse Duration [sec]	0.13
Estimated Source Level [dB]	171.78
Estimated 160 dB Distance (Worst Case) [m] Based on SPL (RMS)	3.89

A nominal transmission loss configuration of 20 log R was used to calculate SL values, although the actual transmission loss is a function of many complicated environmental variables. Thus, different possibilities of transmission loss, such as 16 log R, 18 log R, 22 log R, and 24 log R, are considered to estimate the SL value at the pile driving location and eventually to compute 120 dB distance.

Figure 94 shows five possible situations of SPL values for the hand hammer with varying ranges up to 10 km based on the worst case measurement: the red curve indicates the SPL using the transmission loss with 16 log R; the magenta curve indicates the SPL using the transmission loss with 18 log R; the blue curve indicates the SPL using the transmission loss with 20 log R; the cyan curve indicates the SPL using the transmission loss with 22 log R; and the green curve indicates the SPL using the transmission loss with 24 log R.

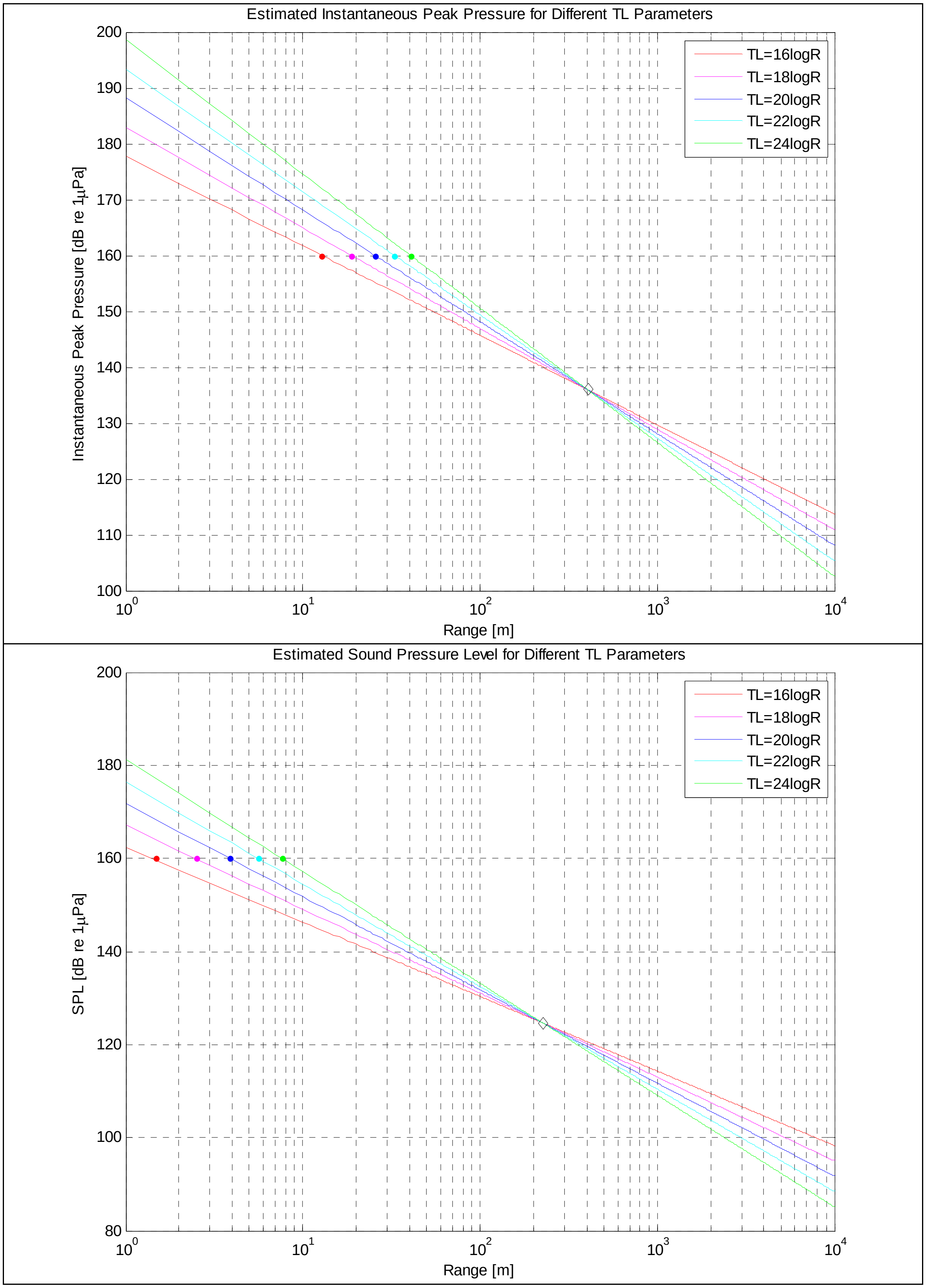


Figure 94. Consideration of Different Transmission Loss Configuration (Hand Hammer)

The estimated 160 dB peak pressure distances and 160 dB SPL distances for five different transmission loss configurations are listed in **Table 53**.

Table 53. Estimated 160 dB Distances of Instantaneous Peak Pressures and Sound Pressure Levels (Hand Hammer)

Transmission Loss	Est. 160 dB Distance [m] Based on Inst. Peak Pressure	Est. 160 dB Distance [m] Based on SPL (RMS)
16 log R	12.83	1.49
18 log R	18.84	2.52
20 log R	25.62	3.89
22 log R	32.95	5.64
24 log R	40.63	7.66

3.4.4 Survey Vessel

3.4.4.1 Data Collection and Sampling Area

During the data collection, one survey vessel session was recorded with the approximate distance between 10 and 20 m under the tide level of 18.66 ft and wind speed of 3.20 m/s (**Table 54**).

Table 54. Summary of Data Analysis (Survey Vessel)

Data Field	Values
Sampling Date & Time	09/29/2008, 10:57:14 ~ 10:57:46
Total Recording Time [sec]	33
Average Sound Pressure Level [dB]	128.61
Max/Min Sound Pressure Level [dB]	131.90 / 126.72
Average Instantaneous Peak Pressure [dB]	161.59
Max/Min Instantaneous Peak Pressure [dB]	162.74 / 159.73
Estimated Range to Survey Vessel [m]	10~20
Average Tide [ft]	18.66
Average Wind Speed [m/s]	3.21

Table 55 shows the recording session details.

Table 55. Data Collection Log (Survey Vessel)

SLM Data			Avisoft Data					Comments
File name	Start time	Stop time	File name	Start time	Stop time	Start offset	End offset	
831_DATA_110.xls	10:57:14	10:57:47	T0000061.wav	10:57:08	10:57:50	0:00	0:42	Survey boat passing 10-20 m away

3.4.4.2 Data Processing and Analysis

The sound pressure level and peak pressure for the survey vessel ranged from 126.72 to 131.90 dB re 1μPa during the recording session. Their equivalent instantaneous peak pressures ranged from 159.73 to 162.74 dB re 1μPa.

Figure 95 shows the LZF field and LZpeak field of SLM data. They are equivalent to the 1/8 sec RMS processing of SPL and the instantaneous peak pressure, respectively.

One-third octave spectrum averaged over the recording session for vessel traffic is shown in **Figure 96**. This data is from LZeq field of SLM data. Although LZeq is 1 sec RMS based SPL value unlike LZF (1/8 sec RMS), overall energy distribution should be very similar.

High spectral energy levels below 100 Hz and over 1 kHz are observed in the **Figure 96**. The standard deviation stays very small.

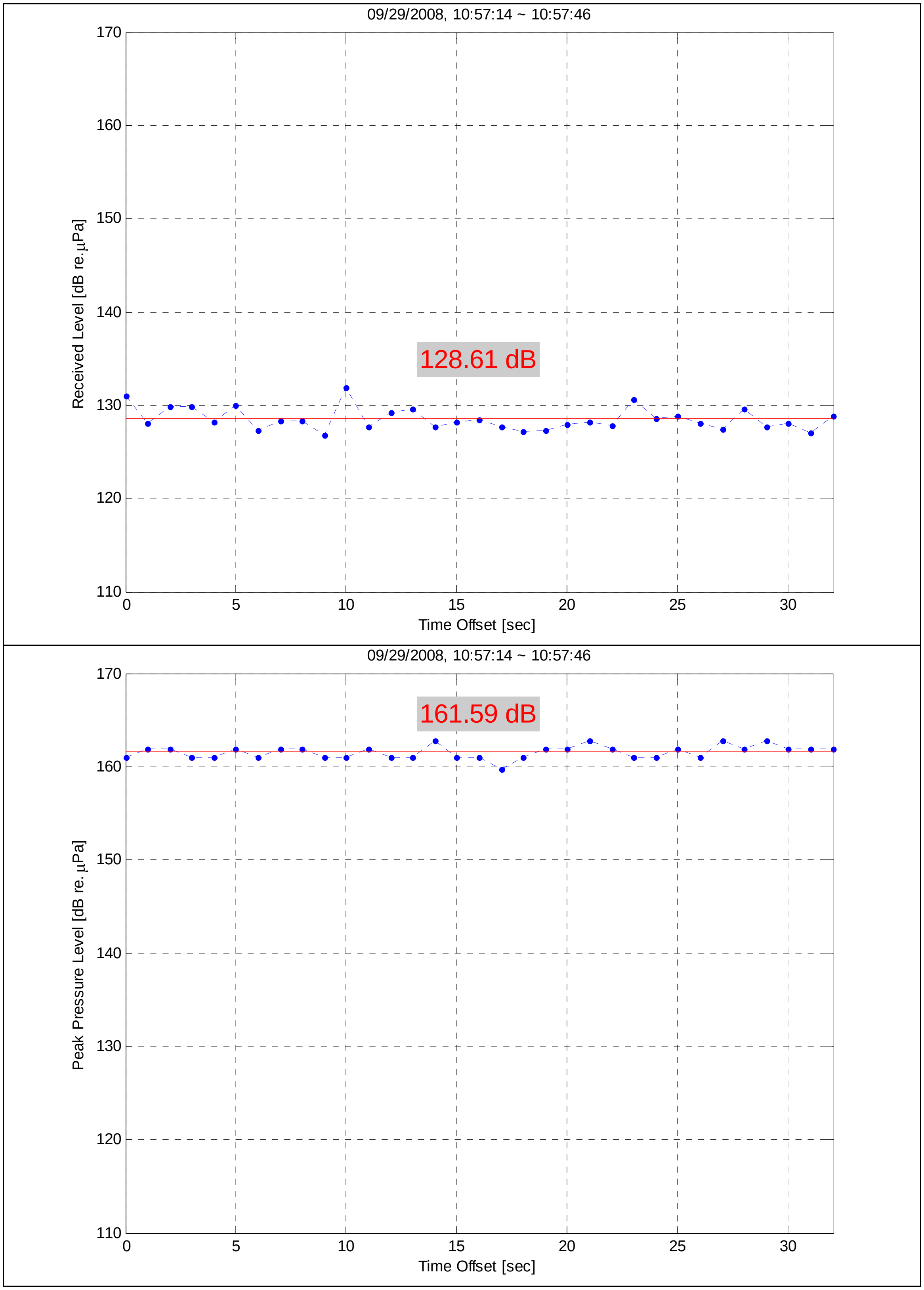


Figure 95. Noise Level of Survey Vessel in Sound Pressure Level and Peak Pressure

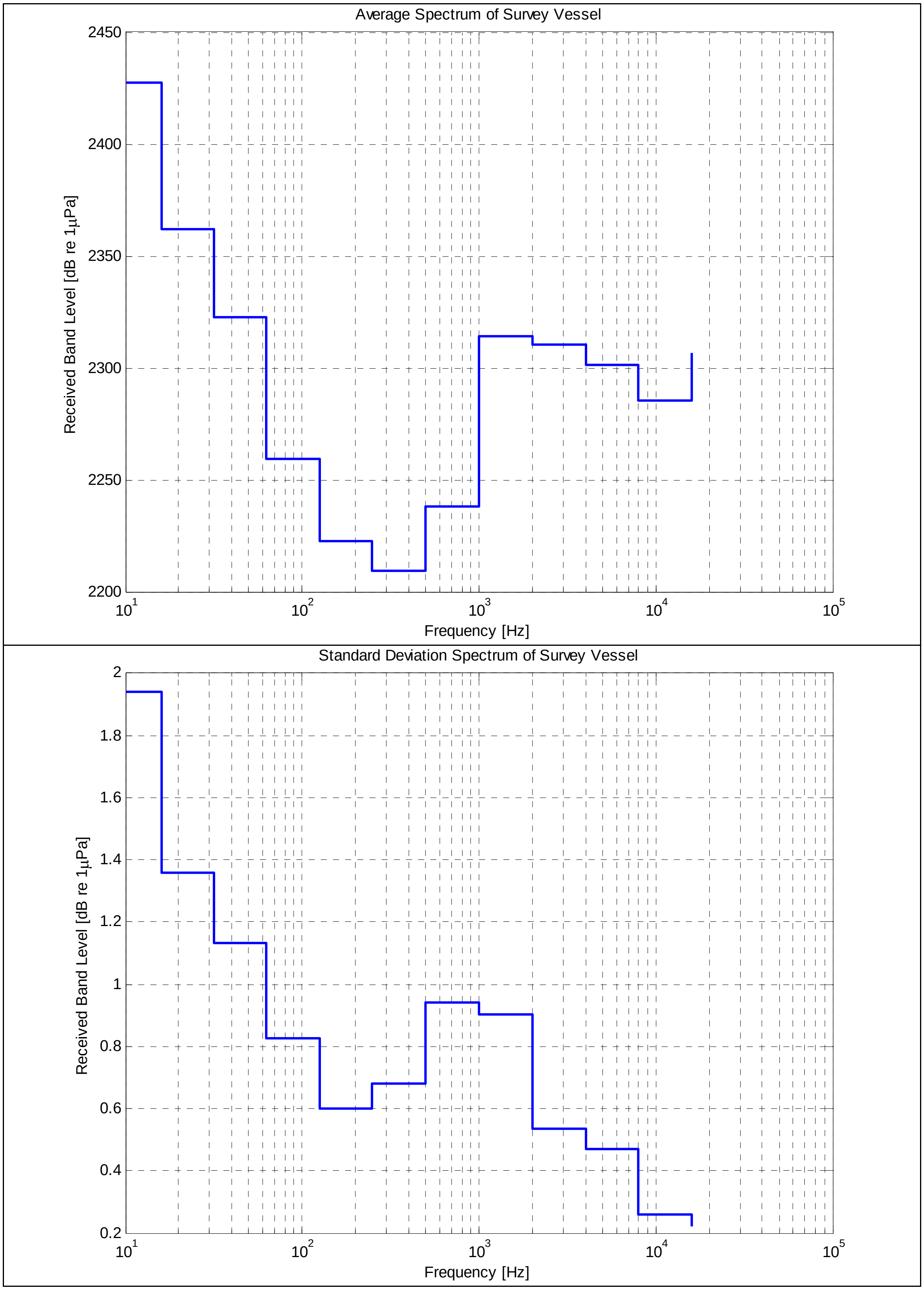


Figure 96. Average Spectrum and Standard Deviation

3.4.4.3 Worst Case Analysis

In computing the sound energy of the impact, a typical calculation is based on RMS value for the pulse duration of the impact. The result of this SPL computation is greatly dependent on the pulse duration that is averaged relative to RMS. The longer pulse duration, the lower SPL is. However, a more conservative method of the worst case computation can be based on the instantaneous peak pressure without averaging process.

The exact distance to the survey boat is not known, but the best estimation ranges from10 to 20 m according to the field notes by the system operator at the time of the incident. **Figure 97** illustrates the estimated SL's for the different possible distances. The plot on the left is the maximum possible SL of the survey vessel based on the measurement of maximum peak pressure, and the plot on the right is the maximum possible SL based on the measurement of SPL's; both show five different transmission loss configurations.

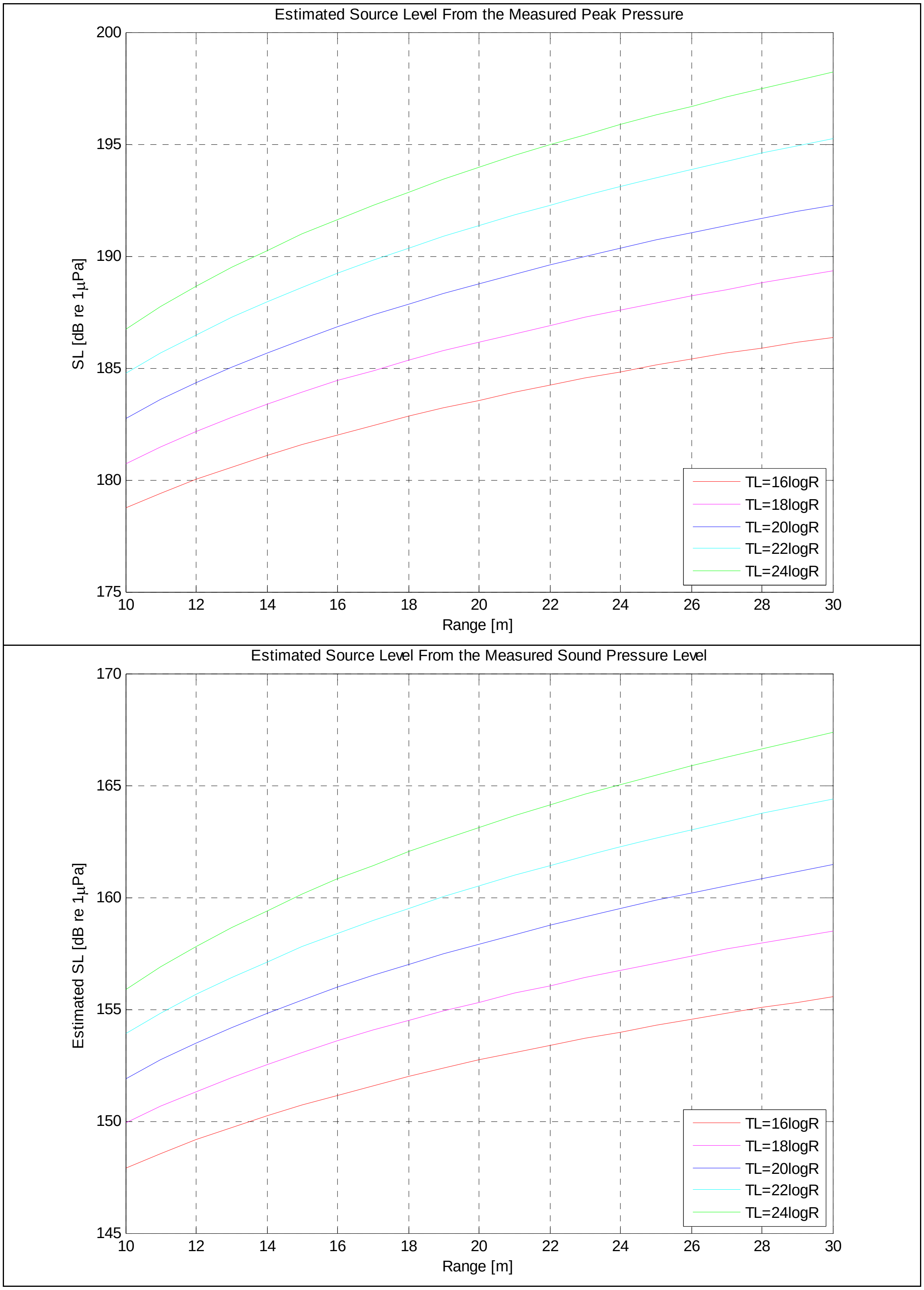


Figure 97. Estimated Source Level for Different Ranges in SPL and Peak Pressure

4. Noise Attenuation Measures

There have been several noise attenuation measures proposed to reduce the impact of noise on marine mammals during pile driving operations. In a recent report by LGL Alaska [17] there was a survey of potential mitigation tools to reduce the disturbance to beluga whales by the proposed Knik Arm crossing bridge. In this report, there were six areas described. In a follow-on report by PND Engineering [18], the practicality of each of these measures was assessed. Utilizing these resources, **Table 56** provides a summary of these findings relative to the Port of Anchorage Marine Terminal Redevelopment Project.

Based on the research conducted and summarized above, the approach that has the greatest potential for noise reduction could be the noise curtain / Gunderboom approach. On the Gunderboom website (www.gunderboom.com) they report:

> *As part of the California Department of Transportation (CalTrans) Pile Installation Demonstration Project conducted in 2000, Gunderboom worked with CalTrans to test noise attenuation systems. Measured at 100 feet from the largest piles ever used in a hammer pile driving operation, the Gunderboom SAS™ reduced sound wave intensity by up to 85 percent.*

However, this technology has not been deployed in conditions similar to Knik Arm and would require further research to fully understand the expected benefits.

Table 56. Summary of Potential Noise Attenuation Measures and Their Utility to POA Expansion

Mitigation Measure	Description	Utility
Physical Barriers	Construct a physical barrier around the pile driving activity that would keep belugas at a safe distance	Construction is not practical in the severe conditions found in the Cook Inlet
Acoustic Deterrents	Use sound to deter or harass the belugas, directing their path away from the pile driving; utilize soft-start techniques to alert belugas and give them the opportunity to avoid the area	Using sound to deter marine mammals has not proven successful; soft-start techniques are already in use with existing POA pile driving
Non-acoustic Deterrents	Use rubber bullets or blunt tipped arrows to redirect the belugas away from pile driving	These methods have not proven to be successful with sea lions on Columbia River
Noise Reduction	The following methods were described in the LGL Report [17]: • *Pile driver silencer*—a steel frame filled with foam surrounded by a rigid casing used to reduce in-air sounds from pile driving. • *Bubble Curtain*—perforated rubber or plastic pipe lying on the seafloor and encircling the pile. Compressed air pumped through the perforations creates a stream of bubbles from the base of the pile to the surface that helps to attenuate underwater sound propagation. • *Gunderboom® Sound Attenuating System™*—a double-walled fabric barrier surrounding the pile and used in conjunction with a bubble curtain to confine the bubbles and help attenuate sound propagation. (www.gunderboom.com) • *Cofferdam*—an enclosure usually constructed of sheet piles constructed around the work location. Water may be either pumped out of the cofferdam or left in place. Pumping water out of the cofferdam further decreases noise propagation into surrounding waters. • *Decoupling Sound Sources*—repositioning of sound-producing equipment to reduce or eliminate the sound path into the water (e.g., placing generators located on the deck of a pile-driving barge onto used tires to reduce propagation of sound into the water).	• *Pile driver silencer*—utility of this approach is unknown • *Bubble Curtain*—perforated rubber or plastic pipe lying on the seafloor and encircling the pile. Compressed air pumped through the perforations creates a stream of bubbles from the base of the pile to the surface that helps to attenuate underwater sound propagation. • *Gunderboom® Sound Attenuating System™*—During the field testing in California, the system proved to be expensive. Gunderboom, Inc is currently working on a less expensive alternative that will be more competitive with unconfined systems • *Cofferdam*—Cofferdams can be expensive and more harmful than the intended pile driving [18] *Decoupling Sound Sources*—this is not likely to be the primary source of the noise; currently POA Expansion has equipment on shore and data analysis included herein shows there is no measurable sound transmission through sediment to the water
Timing and Location of Construction Activity	Time construction activities to minimize pile driving during times when belugas are likely to be present	POA Expansion is currently using this approach
Monitoring and Shut-down Procedures	Utilize observers to watch for belugas and shutting down pile driving operations when they are present	POA Expansion is currently using this approach

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Appendix A: Underwater Noise Survey Plan 2008

Underwater Noise Survey Plan 2008

Port of Anchorage
Marine Terminal Redevelopment Project

AUGUST 2008

Prepared for:

United States Department of Transportation
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Underwater Noise Survey Plan 2008

Port of Anchorage
Marine Terminal Redevelopment Project

Table of Contents

1. Introduction

The Port of Anchorage (Port) serves 80 percent of Alaska's population and transports 90 percent of the consumer goods in Alaska. It is the major gateway for Alaska's water-borne commerce and a vital element of the regional economy, generating more than $750 million each year. To keep pace with the future trends in the shipping industry, the Port is undergoing construction to accommodate larger ships, develop larger barge berths, and improve and expand cruise ship facilities. As part of the Marine Terminal Redevelopment Project (Project), construction is planned for the next several years. To prevent and minimize adverse impacts to marine mammals, underwater noise surveys and beluga whale monitoring are required during in-water Port construction activities, including pile driving, dredging, vessel traffic and dockside activities.

Representatives of the Port of Anchorage (POA) have received an Incidental Harassment Authorization (IHA) permit from the National Marine Fisheries Service (NMFS) dated July 15, 2008 for the 2008 construction season for small take authorizations under the Marine Mammal Protection Act (MMPA) for incidental taking of Cook Inlet Beluga Whales. The POA must comply with the terms of the IHA as well as the mitigation measures stipulated in the US Army Corps of Engineers (USACE) permit number POA-2003-502-N (August 10, 2007). Specific permit conditions will be discussed in Section 1.1.

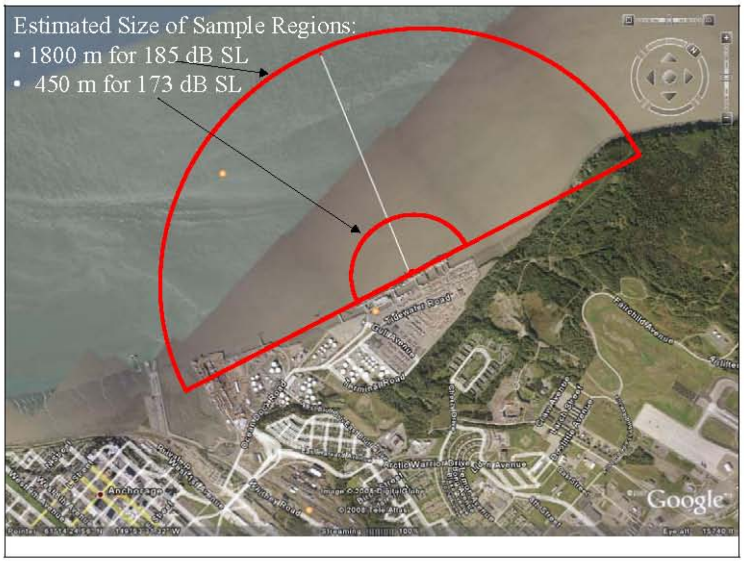
Integrated Concepts and Research Corporation (ICRC) procured the services of Alaska Native Technologies, LLC (ANT) to develop this Noise Survey Plan (Plan). The Plan is written in accordance with the IHA and USACE permits and details procedures for conducting the noise survey during pile driving activities, and coordination with beluga whale observers, construction crews, and other Port operations personnel. Implementation of the Plan will occur only after NMFS approval.

1.1 Permit Requirements

The following conditions specified in the NMFS and USACE permits are applicable to this Underwater Noise Survey Plan:

- Carry out a one-time acoustic monitoring study upon commencement of in-water pile driving. The study will confirm or identify harassment isopleths for all types of piles used, including open-cell sheet piles and 36-inch steel piles, and the "stabbing" process. The acoustic study proposal shall be approved by NMFS prior to the start of seasonal in-water pile driving.
- Collaborate with the concurrent beluga whale monitoring program to correlate construction noise with beluga whale presence, absence, or change in behavior.
- Conduct underwater noise surveys to verify the 190, 180, and 160 dB re 1 microPascal (µPa) root mean square (RMS) isopleths from pile driving activities, and determine the 120 dB isopleth for vibratory pile driving.
- Prior to the start of seasonal pile driving activities, the Port of Anchorage shall require construction supervisors and crews, the marine mammal monitoring team, the acoustical monitoring team, and all project managers to attend a briefing on

responsibilities of each party, defining chains of command, discussing communication procedures, providing overview of monitoring purposes, and reviewing operational procedures regarding beluga whales.



Projected sample area based on estimated transmission loss for 173 and 185 dB SL vibratory hammers

- A "*soft start*" technique shall be used at the beginning of each day's in-water pile driving activities or if pile driving has ceased for more than one hour to allow any marine mammal that may be in the immediate area to leave before pile driving reaches full energy. The soft start requires subcontractors to initiate noise from vibratory hammers for 15 seconds at reduced energy followed by a one-minute waiting period. The procedure will be repeated two additional times. If an impact hammer is used, contractors will be required to provide an initial set of three strikes from the impact hammer at 40 percent energy, followed by a one-minute waiting period, then two subsequent three strike sets.
- If marine mammals are sighted within or approaching the safety or harassment zones prior to commencement of pile driving, operations shall be delayed until the animals move outside the zones in order to avoid take exceedence.
- Pile driving shall not occur when weather conditions restrict clear, visible detection of all waters within harassment zones. Such conditions that can impair sightability include, but are not limited to, fog and rough sea state.

- Develop a *Sound Index* to accurately represent noise levels from pile driving and other Port operations, including dockside activities, vessel traffic, dredging, and docking. The evaluation shall characterize current baseline operations noise levels at the Port of Anchorage and develop an engineering report that identifies structural and operational noise reduction measures, if necessary, to minimize the baseline operational noise levels at the expanded Port to the maximum extent practicable.

1.2 Underwater Sound Descriptors

Sound is a physical phenomenon consisting of minute vibrations that travel through a medium, such as air or water. Sound is generally characterized by several variables, including frequency and intensity. Frequency describes the sound's pitch and is measured in Hertz (Hz), while intensity describes the sound's loudness and is measured in decibels (dB). Decibels are measured using a logarithmic scale.

The method commonly used to quantify airborne sounds consists of evaluating all frequencies of a sound according to a weighting system which reflects that human hearing is less sensitive at low frequencies and extremely high frequencies than at the mid-range frequencies. This is called A-weighting, and the decibel level measured is called the A-weighted sound level (dBA). A filtering method to reflect hearing of marine mammals such as whales has not been developed for regulatory purposes. Therefore, sound levels underwater are not weighted and measure the entire frequency range of interest. In the case of marine construction work, the frequency range of interest is 10 to 10,000 Hz.

Several descriptors are used to describe underwater sounds. Two common descriptors are the instantaneous peak sound pressure level (dB PEAK) and the Root Mean Square (dB RMS) pressure level during the pulse or over a defined averaging period. The peak pressure is the instantaneous maximum or minimum overpressure observed during each pulse or sound event and is presented in Pascals (Pa) or decibels (dB) referenced to a pressure of 1 micro Pascal (μPa).

The RMS level is the square root of the energy divided by a defined time period. The duration of a single pulse will be defined as the averaging period for impact pile driving. The RMS or sound pressure level (SPL) average period is not sensitive to continuous sounds from vibratory pile installation, so a period of about 1/8 of a second will be appropriate for evaluating impacts to marine mammals. Other researchers have used longer periods for vibratory driving, but offered no justification. The "impulse" setting of a sound level meter uses 35-millisecond (ms) time averaging. This provides a good approximation of the RMS averaged over the duration of a pulse, since most pile driving impact pulses last about 40 to 60 ms. This proposed monitoring plan will provide RMS levels for various pulse durations to ensure the appropriate levels are used to assess impacts to marine mammals.

Transmission loss (TL) under water is the decrease in acoustic intensity as an acoustic pressure wave propagates out from a source. Transmission loss parameters vary with frequency, temperature, sea conditions, source and receiver depth, water chemistry, and bottom composition and topography. For this survey, TL will be calculated based on results of underwater sound measurements for several hydrophone positions both close and distant from the pile installation activity.

2. Project Objectives

To prevent and minimize adverse impacts to marine mammals, underwater noise surveys and beluga whale monitoring are required during MTR Project activities, including pile driving, pile stabbing, construction, dockside activities, vessel traffic, and dredging. The noise survey is to be conducted over a period of approximately five to seven days in order to appropriately capture representative noise measurements of pile driving test and existing Port operations. The survey is expected to begin mid-September 2008, in coordination with the MTR Project construction subcontractor, QAP, and their schedule for in-water pile driving.

3. Methodology

To successfully implement an Underwater Noise Survey Plan, it is necessary to have the following:

- A sampling strategy that provides sufficient coverage within the MTR Project footprint (See Section 4);
- Sensors that can sufficiently provide the acoustic, bathymetric, thermal, and location accuracy needed to provide the data that will be used to provide a sound index;
- Personnel that have field experience for hydro-acoustic data collection;
- Analysis tools to properly analyze and graphically report the sound index;
- Coordination with both the pile-driving and whale observation activities, including the ability to immediately communicate with both groups; and
- Maritime support sufficient to provide rapid response of sensors.

3.1 Briefing

Prior to beginning activities, ANT will coordinate with ICRC's Construction Group to attend the weekly subcontractors meeting.

During the underwater noise survey, ANT personnel will attend the subcontractor's daily safety meeting. All personnel involved in the daily activities will coordinate survey operations with QAP's and ICRC's Safety Managers.

Depending on the tide schedule at the survey site, ANT personnel will launch the boat and arrive at the survey site at least one hour prior to high tide to prepare for monitoring.

3.2 Coordination

Coordination between the noise survey vessel, construction crew, POA personnel, marine mammal observers, and ICRC staff will be conducted using hand-held radios. It is imperative that the noise survey vessel remains in constant contact with the construction crew or ICRC personnel to be appraised of the start and stop times of the pile driving, types of pile, depths of pile, and location.

ANT will have one technician on the noise survey vessel that will operate the hydro-acoustic recording devices and other necessary equipment, and coordinate with the on-shore personnel, vessel operators, and marine mammal observers. The boat will be operated by Terrasond, a company with extensive experience in working in the arduous conditions associated with Knik Arm.

3.3 Equipment

ANT will provide all equipment required for the noise survey, as described in the following sections.

3.3.1 Boat

Terrasond has two vessels available for rapid response: the M/V Jella Sea and the MV Hick Up. Each vessel can be transported by trailer on surface streets and deployed directly from the Port. These vessels have been used previously in the Upper Cook Inlet for data collection activities and have proven to be safe and reliable in this environment. Two people aboard each vessel will conduct acoustic sampling: the vessel operator and the acoustician.

Each vessel provides a Differential GPS with NMEA port and a depth sounder. These vessels also provide 110 VAC power through DC to AC invertors. The acoustic equipment will be located in an enclosed cabin so that data collection will not be hampered by rain. Both vessels have VHF radios to provide communications with the pile driving crew on shore.

3.3.2 Recording

The passive hydro-acoustic monitoring equipment that has been selected for this survey is consistent with the acoustic equipment used during prior beluga whale noise studies (Blackwell & Greene, 2002; NMFS, 2007). The following acoustic sampling equipment will be used:

- Calibrated hydrophone capable of recording from 1 Hz to 25 kHz (Reson TC4034)
- Signal amplifier, providing up to 94 dB additional signal strength (Stanford Research Model SR560)
- Data collection system that provides the capability of 14-bit samples up to 2,000,000 samples per second and stores the data in 10 second intervals in time-stamped files (Adlink DAQ-2010)
- Nautical charting software to provide immediate reference of the sensor during data collection and assist with sensor positioning and localization of additional noise sources such as vessel traffic in the sample region
- Matlab data analysis software for quick-look analysis on the water to confirm system operation and provide immediate noise levels

The hydrophone will be attached to a weight between 5 and 20 pounds, and manually lowered into the water. ANT will have several different weights, so that adjustments in the field can be made if necessary. Hydrophone depth will be set at 10 m, unless the water is too shallow, in which case the hydrophone will be placed at half the available depth. A depth reading will be taken with the recording vessel's depth sounder before all sound-generating devices (engine, generator, depth sounder) on the vessel are turned off and the vessel begins its drift. Power on the vessel will be 110 VAC provided through power inversion from 12V marine-grade batteries.

During the data collection operation, range information from all known noise sources will be stored in a log file. The log file provides time-stamped entries that identify acoustic events as they are occurring. At a minimum, the start and stop of pile-driving activities will be noted, as well as the location, name, and size of any vessels passing through the area. A range finder will be used to determine the distance between the data collection vessels and vessels passing through the area. Annotations on the electronic chart will also be made and this data will be stored with the log files through screen captures.

3.3.3 Differential GPS

A differential GPS is installed on each vessel proposed for maritime support. Either the Trimble DSM-212 or the CSI MBX-3 Beacon Receiver will be used to provide D-GPS data. Both of these devices provide an NMEA output for the nautical charting software. The GPS will be used to reset the clock on the data collection system prior to data collection each day, in order to mitigate clock drift.

3.3.4 Depth Sounder

Depth information will be collected and monitored using Raymarine Model L365 depth sounder.

3.3.5 Water Temperature

Temperature data will be continuously collected using an Applied Microsystems CTD (conductivity-temperature-depth) sensor deployed to the same depth as the acoustic sensor. Data is time-stamped as it is collected.

The internal clock will be synchronized with the GPS at the beginning of each day to mitigate clock drift.

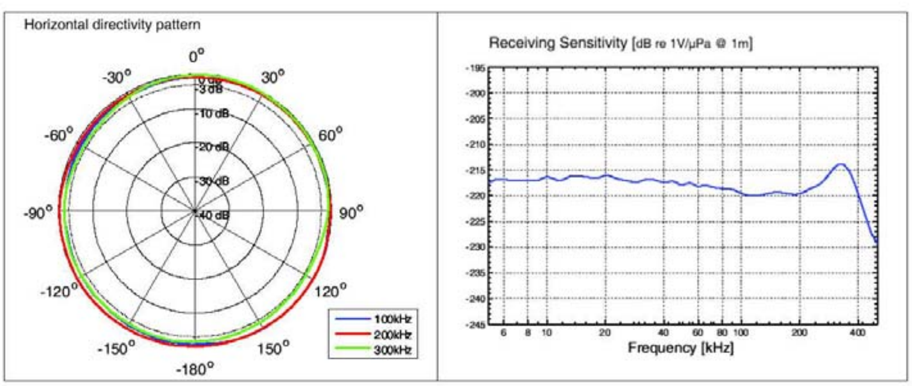
3.3.6 Laser Range Finder

To determine the range from the data collection vessel to other passing vessels and other surface-borne acoustic sources, a Bushnell Yardage Pro Trophy Laser Rangefinder will be used. This rangefinder provides distance accuracy of 1 m to 800 m.

3.3.7 Sensor Calibration

All hydro-acoustic sensors were individually calibrated from the manufacturers in a well-controlled environment. Additional calibration is not necessary to perform the noise survey. The directivity pattern and the receiving sensitivity of Reson hydrophone TC4034 are shown in the figure below.

Reson Hydrophone TS4034 Directivity and Sensitivity Curves



4. Sampling Protocol and Techniques

To create the required sound-index and the associated acoustic isopleths, passive acoustic measurements will need to be taken during a variety of activities, including pile driving, dockside activities, vessel traffic in the channel, dredging, and docking activities. Furthermore, sampling must be done for each type of piling and pile installation technique.

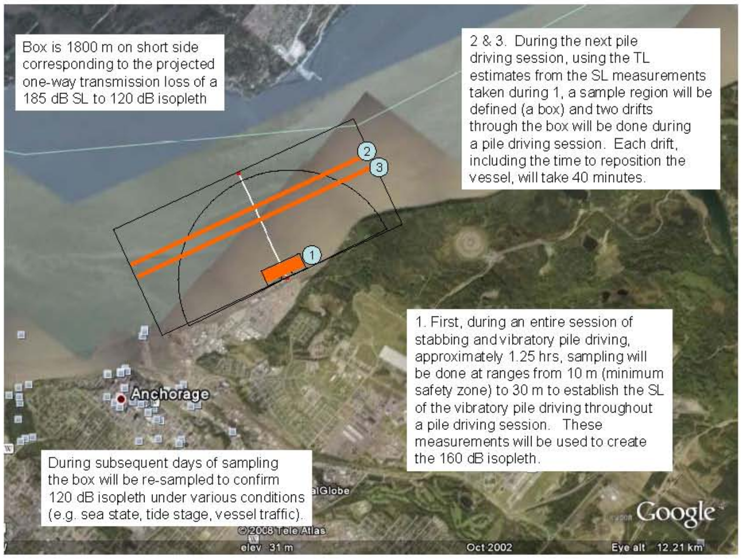
Sampling must be done at multiple locations to produce the required 190, 180, 160, and 120 dB isopleths. Sampling will occur from a drifting vessel, utilizing the tides and currents to move through the sample area. Since data collection would be performed from drifting vessel, the measurements will be performed in 10 sec increments with each increment "stamped" with corresponding GPS time and coordinates. The sample area for each isopleth will be determined based on the estimated Source Level (SL) of each pile driving method. The SPL measured at the receiver is affected by the TL from spherical spreading (20 log R) and attenuation from absorption loss (NA), related using the equation

$$SPL = SL - TL$$

$$TL = 20 \log R - NA$$

For example, assuming an SL of the vibratory hammer equals to 185 dB, the distance to 160 dB isopleth could be approximately estimated at 18 m. Hence the sample area for 160 dB isopleth for vibratory hammer will be located approximately between 10~30 meters distance from the pile.

Sampling Strategy



The Figure immediately above outlines the "little-box"-"big-box" approach that will be used for sampling. First, the small sampling region ("small-box") immediately in the vicinity of the pile driving is used to determine the SL of the pile driver and identify the 190 dB (if applicable), 180 dB, and 160 dB isopleths. This sampling will occur throughout an entire session to determine if there is a change in the SL with pile depth. With this information, the sample region for the 120 dB isopleths ("big-box") will be estimated. The big-box will then be repeatedly sampled throughout the week to determine the full extent of the 120 dB isopleths and to document other noise sources, as well as ambient noise.

Accordingly, during the first session of pile driving (approximately 75 to 90 minutes), the sampling will be done at ranges 10 m (safety zone) to 30 meters (more than twice the predicted range). Collected data will be analyzed to determine SL of the pile driving and to create 160 dB isopleth. The boundaries of the sample region will be then calculated based on the obtained SL values. During the consecutive pile driving sessions, the data will be collected with the boat drifting between the boundaries of big-box sample region. Estimated time for drift session is approximately 40 minutes (20 minutes through the box, another 20 minutes to reposition for the next drift), thus approximately 2 drift tracks will be possible for each pile driving session. Collected data will be analyzed to determine and to verify 120 dB isopleth under various conditions. If the initial big-box sample region does not contain the 120 dB isopleths, it will be expanded until the 120 dB isopleths can be determined.

Note that our initial estimates for the vibratory hammer's SL is less then 190 dB, so the 190 dB isopleths for this operation would not be applicable. Furthermore, the 180 dB isopleth will be located approximately 2 m from the source. Measuring sound pressure level at this distance might be inappropriate due to various factors (acoustic far-field restrictions, equipment deployment complexity, safety requirements). In such case the theoretical location of 180 dB isopleth could be empirically derived from the SPL data recorded at larger distances based on estimated TL values.

According to the IHA and USACE permits, impact pile driving may not take place within two hours on either side of low tide; therefore, ANT will measure other Port operation activities (docking, dredging, vessel activities, other construction activities) and ambient noise levels during low tides.

Each day that the pile driving noise is sampled, a hydrophone that is acoustically isolated from the survey vessel will be deployed at mid-water depth and the vessel will be shut down and allowed to drift past the MTR Project site at various ranges from shore within the sample region. The minimum range to the pile driving activity will be 10 meters to provide a safety zone near the pile-driving activity. The drift rate will depend on the tides and currents. Appendix A provides estimates of currents in the sampling region for September 2008 (http://tidesand**currents**.noaa.gov/**currents**08*)*. A differential GPS will be used to acquire position information. Acoustic data will be collected at 10-second intervals and each 10-second file will be tagged with GPS-synchronized time and location for later isopleth creation. The peak pressure and sound pressure level (RMS) will be calculated from recorded data using custom-developed signal processing Matlab scripts. Nautical chart software on the vessel will be used to track the vessel position and assist with positioning so that the sample region will be optimally sampled. Isopleths will be refined daily by increasing the number of samples in the region and compensating for variability that is detected.

All noise sources will be catalogued during collection. A laser rangefinder will be used to measure distance to vessels that pass through the sample area. At the conculsion of the project the required isopleths will be reviewed by an ANT marine mammal expert and then provided to ICRC in the final report.

4.1 Stabbing

Due to the short duration of the pile driving "stabbing" process and due to unknown SL values, creating isopleths for this operation would require multiple repetition of "stabbing" with each individual pile. Since this approach is not feasible, the first session of pile "stabbing" will be used to estimate corresponding SL. Based on the calculated SL values, the theoretical distance to each isopleth will be estimated. These distances will be then used to determine recording locations for the consecutive pile "stabbing" operations. The recorded SPL values at these locations will be used to verify the estimated isopleths distances.

Since "stabbing" operations are performed at reduced vibratory hammer energy, it is estimated that the SL for this operation may be less then 180 dB. In this case only 160 dB, and 120 dB isopleths would be determined for "stabbing" operation.

4.2 Vibratory Pile Driving

The SL for vibratory hammers can range from 173 dB to 185 dB re 1 micro Pascal (μPa) RMS, depending on the pile driving equipment being used (Hawkins, 2006; Illingworth & Rodkin, 2001; Abbott & Bing-Sawyer, 2002). Given the TL values provided above, a 120 dB isopleths for a 185 dB SL vibratory hammer would be 1800 m from the source. If the SL of the vibratory hammer is 173 dB, then the 120 dB isopleths are approximately 450 m from the source. This estimate is also affected by sediment load, salinity, bathymetry, water temperature, and other ambient noise sources in the region. Much of Upper Cook Inlet is generally a poor acoustic environment because of its shallow depth, sand/mud bottoms, and high background noise from currents and glacier silt (Blackwell and Green, 2002). It is expected that the sample region required to meet the 190 dB, 180 dB, 160 dB, and 120 dB isopleths is closer to smaller than the ranges mentioned above.

Vibratory pile installation produces continuous sounds, which are not sensitive to the RMS averaging time window selected, unlike impulse sounds. The commonly accepted 1/8 second average tie will be used to measure the RMS for vibratory pile driving.

4.3 Impact Pile Driving

At the moment the impact pile driving is not anticipated to be required during the Port of Anchorage expansion operations. In case is impact pile driving will be required, the corresponding measurements (similar to vibratory pile driving measurements described above) will be performed to establish locations for 190, 180 and 160 dB isopleths.

Underwater sound levels from impact pile driving are much higher in amplitude and shorter in duration than vibratory sound levels. For this reason, safety zones will be greater and will require considerably more measurements to establish.

Impact pile driving generates transient noise events of varying duration. For this reason, the "impulse" setting that utilizes a commonly accepted 35-milliseconds (ms) time average that encompasses at least 95% of the signal's energy will be used for describing sound pressure levels for this type of pile driving. Duration of impact pile driving sounds is typically 50 to 100 ms, with most energy contained within about 50 ms. The RMS measured with the impulse setting will closely approximate this pulse over the duration.

5.0 Data Analysis

The peak pressure and sound pressure level (RMS) will be measured in real time using an SLM or calculated with equivalent MatLab script, and recorded on a datasheet. Sampled calibrated tap recordings will be analyzed using Real Time Analyzers (RTA) or calculated with equivalent MatLab script to provide detailed acoustical analyses of selected pile installation sounds. Waveforms (time pressure analysis), frequency spectra (narrow band and 1/3 octave band), and accumulation of sound energy can be provided from this type of analysis.

6.0 Reporting

Preliminary noise survey data consisting of peak and RMS sound pressure levels will be made available verbally at the end of each measurement day. Following approval by ICRC, ANT will produce a report documenting the results of the noise surveys for pile driving and other Port activities. ANT will also include any beluga whale activities observed in the MTR Project footprint during the noise surveys.

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Cook Inlet Currents – Anchorage Shipdock – September 2008

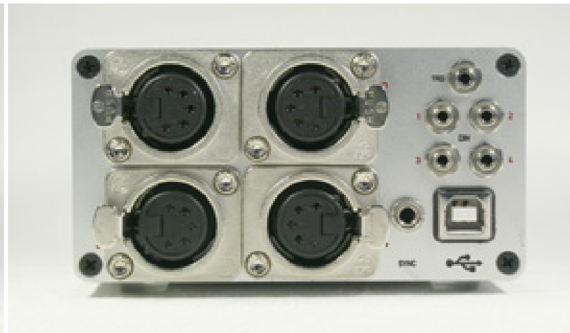
	Slack Water	Maximum Current		Slack Water	Maximum Current		Slack Water	Maximum Current		Slack Water	Maximum Current		Slack Water	Maximum Current	
	Time	Time	Veloc	Time	Time	Veloc	Time	Time	Veloc	Time	Time	Veloc	Time	Time	Veloc
	h.m.	h.m.	knots	h.m.	h.m.	knots	h.m.	h.m.	knots	h.m.	h.m.	knots	h.m.	h.m.	knots
1	420	630	5.5	1014	1152	-5.6	1639	1842	5.7	2232					
2		10	-5.8	501	700	5.6	1054	1227	-5.4	1719	1913	5.6	2308		
3		45	-5.7	542	734	5.5	1134	1303	-5.1	1758	1947	5.3	2343		
4		120	-5.4	623	811	5.1	1213	1340	-4.6	1838	2025	4.8			
5	17	158	-5	706	851	4.6	1254	1419	-4.1	1920	2106	4.1			
6	53	239	-4.5	753	935	3.9	1338	1503	-3.4	2009	2152	3.3			
7	133	327	-3.8	850	1025	3.1	1433	1554	-2.7	2112	2244	2.6			
8	225	420	-3.2	958	1120	2.4	1544	1651	-2.2	2225	2340	2.1			
9	342	519	-2.8	1108	1220	2.1	1702	1756	-1.8		1933	-1.4		2047	-1.7
10	503	628	-2.6		800	-2.4		901	-2.5	1211	1331	2		1418	2
11		152	1.9	613	944	-3	1306	1623	2.8	1907	2214	-2.9			
12	130	429	2.5	711	1013	-3.5	1354	1656	3.4	1953	2238	-3.4			
13	215	421	3.2	801	941	-4.1	1436	1647	4	2032	2203	-4.1			
14	256	446	4	844	1017	-4.6	1515	1707	4.5	2107	2237	-4.7			
15	334	524	4.8	924	1055	-5	1552	1742	5	2140	2314	-5.4			
16	411	603	5.4	1002	1134	-5.3	1628	1820	5.4	2212	2352	-5.8			
17	448	644	5.8	1040	1213	-5.4	1704	1900	5.6	2245					
18		31	-6	527	725	5.9	1120	1253	-5.2	1742	1940	5.5	2319		
19		112	-5.9	609	808	5.7	1203	1335	-4.9	1823	2024	5.1	2358		
20		155	-5.6	657	854	5.1	1251	1421	-4.2	1911	2111	4.5			
21	43	244	-5	753	945	4.4	1347	1514	-3.6	2012	2204	3.8			
22	140	341	-4.4	901	1043	3.7	1456	1615	-3	2128	2304	3.1			
23	256	444	-3.8	1015	1146	3.1	1614	1723	-2.7	2246					
24		9	2.7	423	556	-3.5	1125	1303	3	1727	2039	-2.9	2355		
25		133	2.7	540	853	-3.7	1227	1538	3.6	1830	2128	-3.8			
26	55	358	3.6	646	942	-4.3	1322	1625	4.3	1923	2207	-4.5			
27	147	444	4.4	743	1019	-4.8	1410	1704	4.8	2008	2236	-5			
28	233	524	5	831	1041	-5	1453	1735	5	2048	2244	-5.4			
29	315	553	5.3	914	1058	-5.2	1534	1747	5.2	2125	2308	-5.6			
30	355	608	5.5	953	1126	-5.2	1612	1809	5.2	2200	2339	-5.8			

Appendix B: Avisoft UltraSoundGate 416H

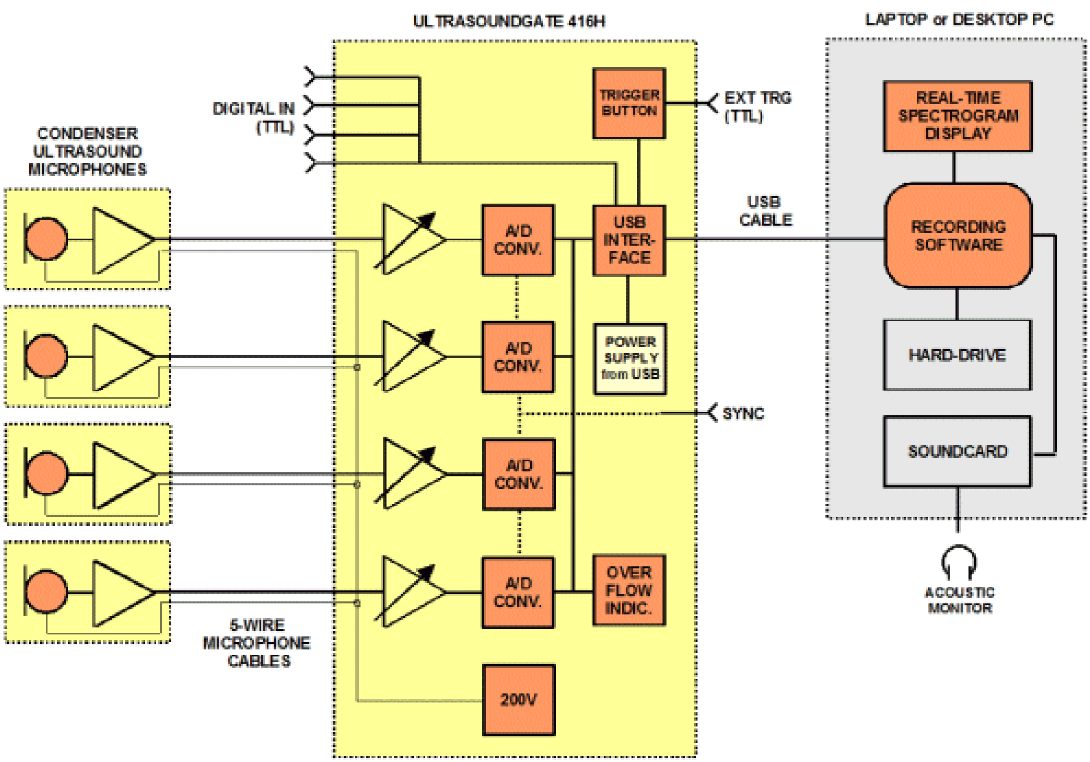
Appendix B: Avisoft UltraSoundGate 416H

Ultrasound recording interface with 4 balanced analog inputs, USB 2.0 interface, recording software and water-proof transport case.

UltraSoundGate 416H, front view



UltraSoundGate 416H, front view



Functional principle of the UltraSoundGate 416H

Number of channels	4 (4 separate A/D converters)
ADC type	Delta-Sigma architecture with integrated adaptive anti-aliasing filter
Resolution	16 bit or 8 bit
Maximum aggregate sample rate	4 x 750 kHz / 16 bit
Sample rates [kHz]	750, 500, 375, 300, 250, 214, 187.5, 166.6, 150, 125, 100, 75, 62.5, 50
Frequency response (-3dB, external input without mic)	20 Hz - 370 kHz
Acoustic monitor output	no
Overload indicator (red LED)	yes
Peak level meter (4 LEDs)	no
Input sensitivity (max trim)	-43.2dBV = -41 dBu = 6.9 mVrms
Input sensitivity (min trim)	-3.2dBV = -1 dBu = 0.69 Vrms
Input sensitivity (max trim) step gain option	-31.8 dBV = -29 dBu = 25.6 mVrms
Input sensitivity (min trim) step gain option	2.1 dBV = 4 dBu = 1.28 Vrms
Gain adjustment potentiometer	40 dB continuous range (standard) or 33 dB range with three dB increments (optional)
Input impedance	50 kOhm
Analog input connectors	female XLR-5 sockets
Other inputs	external trigger (TTL-compatible), 4 digital inputs (TTL-compatible), SYNC in/out
Computer interface	USB 2.0, isochronous high-speed mode
Physical USB connection	standard B-type USB socket
Maximum power supply current (drawn from the USB)	500 mA
Housing	compact aluminum enclosure
Physical dimensions (W/H/D) in mm	103 x 56 x 165
Weight	600 g
Included software	Avisoft-RECORDER USGH, version 3.4 for Windows XP and Vista

Appendix C: Larson Davis Model 831 Sound Level Meter

Appendix C: Larson Davis Model 831 Sound Level Meter

- Precision integrating sound level meter, ANSI S1.4 type 1, IEC 61672 class 1
- Single measurement range from 20 to 140 dB SPL
- 120 MB standard data memory, expands up to 2GB
- 160 x 240 graphic LCD display with backlight and icon driven user interface
- Elastomeric illuminated keypad with “Quiet Touch” tactile action
- Detectors: linear, slow, fast, impulse, peak
- Frequency weighting: A, C, Z
- Peak frequency weighting: A, C, Z
- Ln statistics (L0.01 through L99.99 available) and Histogram tables
- Measurement or Interval History stores statistics with every run or by time interval
- Exceedance History with programmable length and triggers
- Jack for AC/DC output or Headset microphone and speaker
- Voice annotation recording with playback, from headset or measurement microphone
- Digital audio recording of events and interval start
- Detachable preamplifier with up to 30m (100 feet) microphone extension cable (full scale to 20 kHz)
- – AA batteries provides up to 12 hours of battery life
- Dust tight (IP53), durable plastic case with tripod mount and lanyard
- USB 2.0 peripheral full-speed port
- AUX control connector for USB Mass Storage, Cellular & Dialup Modems and future devices
- AC and DC signal output connector, 2.5 mm phone jack
- Utility software included for setup, control and high speed data download, application software available
- Field-upgradeable firmware

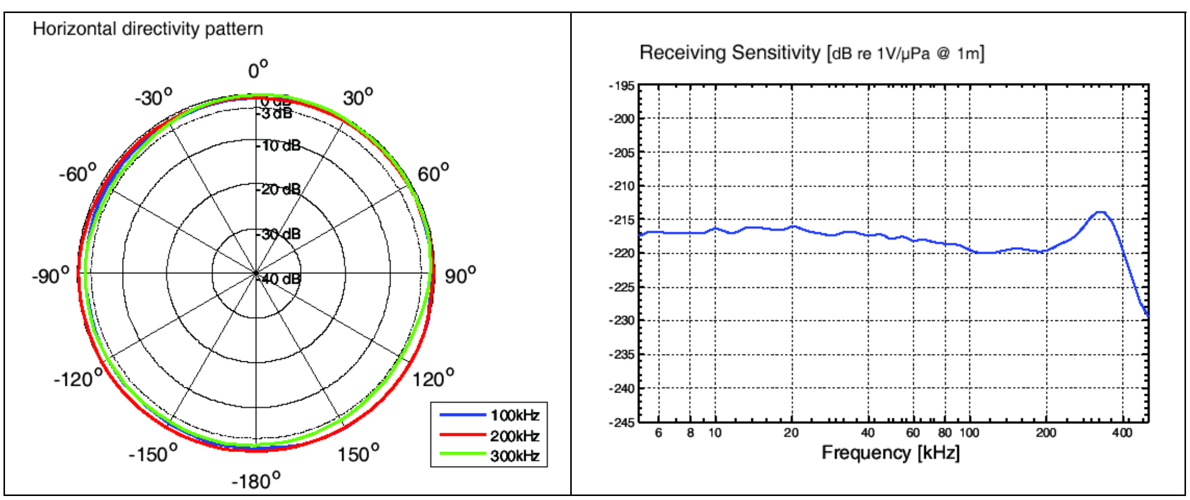
Appendix D: Reson TC4013 Hydrophone

Appendix D: Reson TC4013 Hydrophone

Technical Specification:

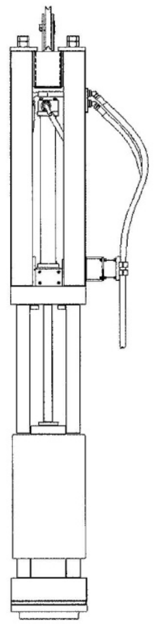
- Usable Frequency range: 1Hz to 470kHz (+3, -10dB)
- Linear Frequency range: 1Hz to 250kHz (+2, -4dB)
- Receiving Sensitivity: (re 1V/µPa) -218dB ±3dB (at 250Hz)
- Horizontal directivity: Omni directional ±2dB (at 100 kHz)
- Transmitting sensitivity: 122dB ±3dB (typical) re 1µPa/V at 1m at 100kHz
- Vertical directivity: >270° ±3dB (at 300kHz)
- Nominal Capacitance: 3nF
- Operating Depth: 900m
- Survival Depth: 1000m
- Operating Temperature range: -2°C to +80°C
- Storage Temperature range: -40°C to +80°C
- Weight incl. cable,(in air): 1.6 kg
- Cable (length and type): Standard 10m shielded pair DSS-2MIL-C915.
- Optional cable length available on request
- Encapsulating Material: Special formulated NBR
- Metal body: Alu-bronze - AlCu10Ni5Fe4
- Connector type: BNC

The directivity pattern and the receiving sensitivity:



Appendix E: J&M Model 115 Impact Hammer

The J&M Model 115 Hydraulic Impact Hammer



Engineered for long-term investment value and maximum ownership utilization

- All J&M hydraulic impact hammers operate with a patented 100% hydraulic, infinitely variable stroke control system. On the J&M hammers, you will find no troublesome electrical connections, fragile sensors or complex computer controls.
- All J&M hydraulic impact hammers have a super-tough, single-piece, ferro-chromium alloy forged ram to eliminate segmental ram separation or ram point failures.
- All J&M hydraulic impact hammers utilize a time-proven and ultra-rugged 4-column tensioned cable connected design.
- All J&M hydraulic impact hammers have a patented hydraulic ram cycle control system that eliminates energy-robbing backpressure and ensures maximum energy to the pile.
- All J&M hammers are built with hard-chromed columns and self-lubricating nylon ram bearings to minimize friction and maximize transferred energy.
- Supplied with environment friendly non-toxic biodegradable hydraulic oil.
- Remote electric pendant control includes engine speed control for fuel efficiency and emergency engine stop for personnel safety. Duplicate full-function controls on panel eliminate downtime from accidental damage.
- Optional radio remote control provides total operator freedom of movement.
- Highest quality Dennison gear pump in time proven reliable open-loop hydraulic system ensure maximum efficiency, maximum reliability and simpler, quicker unit serviceability.
- Optional digital radio energy monitoring system measures and records delivered energy for every blow but does not effect the otherwise 100% hydraulic control and operating system.

HAMMER		POWER UNIT	
Ram weight	11,500 lbs (5216 kg)	Engine	Caterpillar 3116TA
Maximum stroke	4 ft (1219 mm)	Power	200 HP (149 kW)
Rated energy	46,000 ft-lbs (62 kJ)	Operating speed	2,400 rpm (2400 rpm)
Blow rate @ maximum energy	45 bpm (45 bpm)	Drive pressure	2,500 psi (172 bar)
Minimum stroke	1 ft (305 mm)	Drive flow	100 gpm (380 lpm)
Hammer weight(1)	17,000 lbs (7711 kg)	Stroke system pressure	2,500 psi (172 bar)
Operating weight(2)	20,050 lbs (9094 kg)	Stroke system flow	10 gpm (38 lpm)
Hammer length(1)	19' 10" (6044 mm)	Weight (w/ full fluid & fuel)	9,400 lb (4265 kg)
Operating length(2)	22' 1" (6730 mm)	Length	126 in (3200 mm)
Width	26 in (660 mm)	Width	60 in (1525 mm)
Depth	36 in (914 mm)	Height	76 in (1930 mm)
Hydraulic hose length	100 ft (30 m)	Hydraulic reservoir	275 gal (1040 l)
Hydraulic hose weight	850 lbs (385 kg)	Fuel capacity	122 gal (460 l)

NOTES

1) Bare hammer weight and length only. No hoses or helmet are included.
2) Includes 14" square concrete helmet only. No hoses are included. See hose weight listed separately.

FOUNDATION EQUIPMENT

1601 Banksville Road Pittsburgh Pa 15216-3205

PH: 866-462-PART / 412-341-8190 / 412-720-5175

E-Mail: info@jandm-usa.com FAX: 412-341-8192

I. GENERAL INFORMATION

A. GENERAL DESCRIPTION

The J&M Model 115 Hydraulic Hammer is a Free-Fall hammer. The ram is lifted by the hydraulic actuator and then allowed to free-fall, impacting the pile. The hammer has been designed to provide maximum flexibility by enabling the contractor to vary the energy range of the hammer to suit job conditions. The 115 hammer design incorporates an all hydraulic control system, with no electrical or electronic controls used, to ensure reliability and field serviceability. Further, without the need for vulnerable umbilical cords, this unit is readily adaptable to alternate hydraulic power sources.

The 115 hammer is normally powered by the same Model 175 power unit that powers J&M Vibratory Hammers and J&M Earth Augers. This permits the contractor to use a single power unit on jobs where both the Impact Hammer and a Vibratory Hammer or Auger are needed. The Hammer can also be powered by any source providing the required flow, pressure, cooling and filtration. The 115 Hydraulic Hammer delivers 46,000 ft-lbs (6359.7 Kg-M) of energy at its full stroke of 4'-0" (1.2M) at a blow rate of 40 blows per minute.

B. MAJOR COMPONENTS

The hammer system consists of 8 major components (Fig. 1) page I-4:

- Hydraulic Actuator
- Ram
- Guide Structure
- Lifting Bale
- Drive Cap
- Controls
- Interconnecting Hoses
- Power Unit

Hydraulic Actuator

The hammer is driven by the hydraulic actuator. The actuator is coupled to the ram using a shock absorbing, self aligning, connection. Hydraulic oil flows from the power unit, at pressure, to the actuator which accelerates the ram upward. Attached to the ram is a trip bar which activates a trip valve after the ram has risen a predetermined distance. Activation of the trip valve stops the flow of oil to the actuator. The ram then decelerates and free falls to impact the pile. Power unit energy is stored in a hydraulic accumulator while the ram is falling.

I. GENERAL INFORMATION

B. MAJOR COMPONENTS (CONTINUED)

Ram

The ram is a one piece high strength steel forging. The one piece construction of the ram eliminates slack in the driving system and provides maximum energy transfer to the pile. The one piece construction also eliminates the dangers of structural failure known to exist in rams constructed of separate segments. High performance, non-metallic, bearings, retained within the ram, prevent guide column wear and reduces maintenance and lubrication requirements. The shock and vibration, generated when the ram impacts the pile, are isolated from the hydraulic actuator by an elastomeric, self aligning, coupling.

Guide Structure

The guide structure consists of tubular steel guide columns and connection plates. The guide columns serve to guide the ram and provide the rigidity required to allow the driving of batter piles. Guide columns, connecting plates and lifting bale are held together by tensioned wire ropes which run from the base plate to the top of the lifting bale. These cables provide a resilient means of connection and eliminate the need for keys or bolted connections. The hammer is designed to fit in 26" x 8" rail leads produced by J&M and other manufacturers. The connecting plates provide mounting points for the lead guide rails necessary for J&M leads and various other hammer guidance systems.

Lifting Bale

The lifting bale surrounds and protects the hydraulic actuator and hoses from damage and is the attachment point for the lifting sheave. Two energy storing hydraulic accumulators are mounted to, and protected by, the lifting bale. Incorporated in the lifting bale design are the connection flanges for the hydraulic supply hoses, and a shock absorbing hose support.

Drive Cap Assembly

Striking energy of the ram is transmitted to the pile through the three elements of the drive cap assembly. The ram impacts the forged steel striker block which self aligns and self centers within the lower connecting plate. Ram energy is transferred through cushion material into the DCB-X drive cap base. The DCB-X serves to retain the cushion material, Guide the piling, and adapt to various styles of J&M piling inserts. Piling inserts adapt the hammer to most popular types of piling and retain additional cushion material when required.

I. GENERAL INFORMATION

B. MAJOR COMPONENTS (CONTINUED)

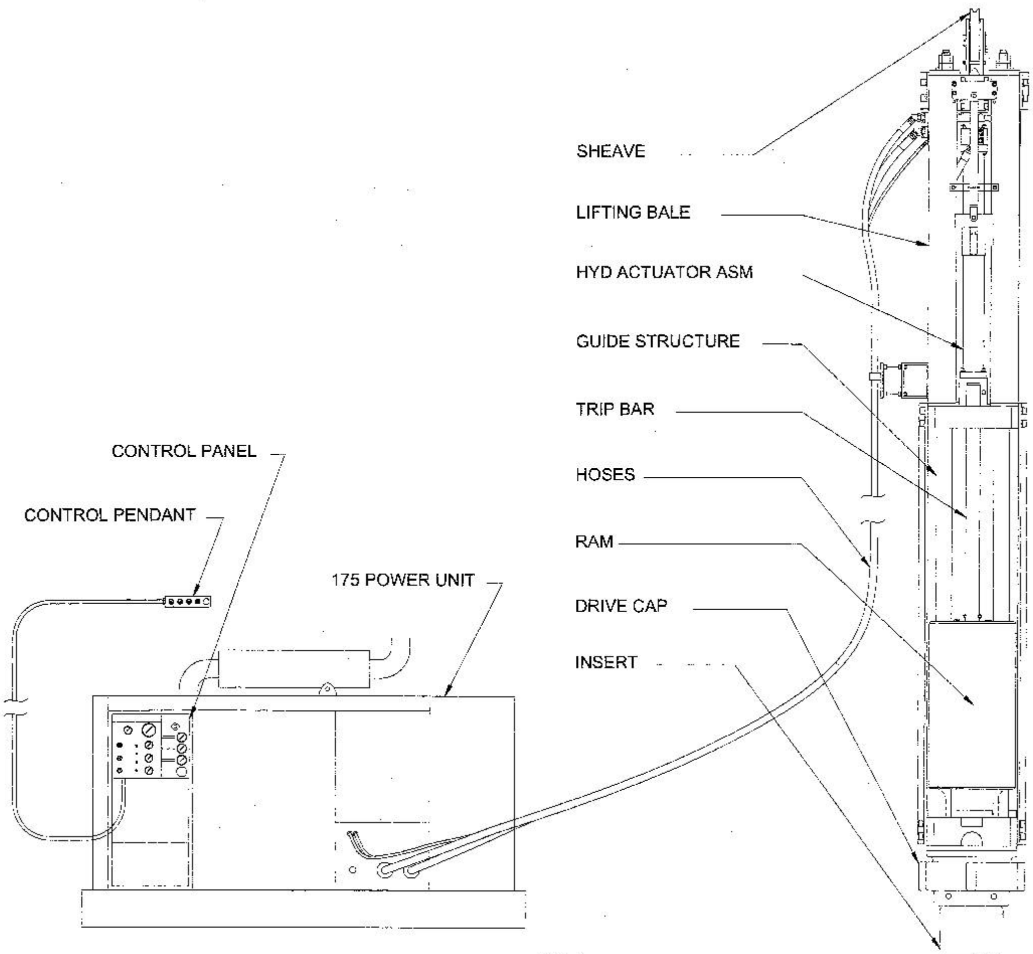


FIG 1

I-4

I. GENERAL INFORMATION

C. SPECIFICATIONS

Working Specifications	
Designation	J&M Model 115
Maximum stroke	4'-0" (1.2 Meter)
Rated energy @ maximum stroke	46,000 ft-lbs (62.4 kN-m)
Blow rate @ maximum stroke	45 bpm
Minimum stroke	1' (0.3 Meter)
Rated energy @ minimum stroke	11,500 ft-lbs (15 kN-m)
Blow rate @ minimum stroke	75 bpm
Weights and Dimensions	
Ram weight	11,500 lbs (5,215 kg)
Hammer weight (bare)*	18,900 lbs (8,573 kg)*
Complete operating weight with cap*,**	21,500 lbs (9,752 kg)**
Length (bare)**	19'-9" (6014 mm)
Complete operating length with cap**	22'-4" (6815 mm)**
Width (without guides)	26" (660 mm)
Depth	36" (914 mm)
Depth centerline to back	18" (457 mm)
Depth centerline to front	18" (457 mm)
Hydraulic hose length (standard)	100' (30 m)

*Weight includes one half of hydraulic hoses.
**Set up for 26" leads and 14" square concrete pile.

Power Unit	
Designation	J&M Model 175
Engine	CAT 3116DITA
Max. power	175 HP (130 kW)
Operating speed	2400 rpm
Max. drive pressure	2,500 psi (172 bar)
Drive flow	93 gpm (378 lpm)
Stroke control pressure	1,000 psi (69 bar)
Stroke control flow	10 gpm (38 lpm)
Weight	8,500 lbs (3856 kg)*
Length	126" (320 cm)
Width	60" (152 cm)
Height	75.5" (192 cm)

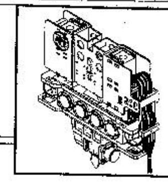
I-5

Appendix F: APE Model 200 Vibratory Hammer

OPERATION / MAINTENANCE MANUAL

MODEL 200, 200T & 200-6 VIBRATORY DRIVER WITH MODEL 630 POWER UNIT

7032 SOUTH 196th - KENT, WA 98032 - (253) 872-0141 / FAX (253) 872-8710



I. GENERAL INFORMATION (Continued...)

I-3. General Description of Model 200 Vibro

The **APE Model 200**, 200T & 200-6 is a variable frequency vibratory pile driver/extractor designed to drive and extract all types of piles including sheet, pipe, timber, concrete, H-beam, I-beam and steel plates. In addition, the vibrator can be used for soil compaction, installing well casings and installation of tiebacks and wick drains.

The Model 200, 200T, 200-6 is especially suited for driving or extracting piles that are near buildings or other structures. This is because the Model 200, 200T & 200-6 vibrates at higher frequencies and thus is less damaging to surrounding soils.

The three major parts to the Model 200 are as follows:

A.) The Suppressor housing.
B.) The Gearbox.
C.) The Clamping Attachment,

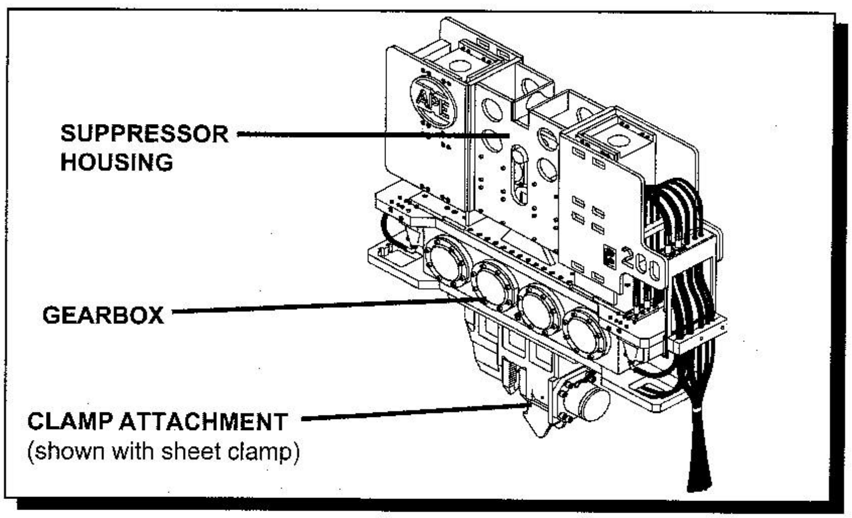


Figure 1-B. General Description of 200, 200T & 200-6 Vibro

Note: The 200 and 200T have four eccentrics while the 200-6 has six eccentrics.

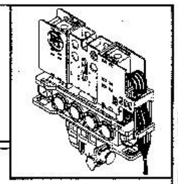
AMERICAN PILEDRIVING EQUIPMENT, INC.

APE

OPERATION / MAINTENANCE MANUAL

MODEL 200, 200T & 200-6 VIBRATORY DRIVER WITH MODEL 630 POWER UNIT

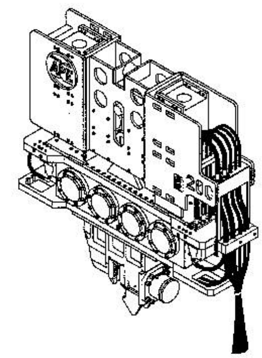
7032 SOUTH 196th - KENT, WA 98032 - (253) 872-0141 / FAX (253) 872-8710



I. GENERAL INFORMATION (Continued...)

I-2. Machine Specifications

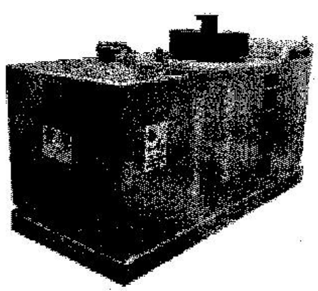
I-2A. Model 200, 200T & 200-6 Vibro - (Table 1-A.)



Specifications	Units Imperial/SI	200	200T	200-6
Eccentric Moment	in-lbs/kg-m	4,400/500	5,200/600	6,600/760
Drive Force	ton/kN	202/1,797	239/2,212	303/2,700
Frequency	cpm/hz	1,650/27.5	1,650/27.5	1,650/27.5
Centrifugal Force	ton/kN	170/1,693	201/2002	255/2002
Amplitude w/o attachment	in/mm	1.17/29.7	1.3/33	1.44/36.5
Pile Gripping Force	ton/kN	250/2,491	250/2,491	250/2,491
Caisson Gripping Force	ton/kN	500/4,982	500/4,982	500/4,982
Line Pull For Extraction	ton/kN	150/1,494	150/1,494	150/1,494
Hydraulic Hose Length	feet/meter	150/45.7	150/45.7	150/45.7
Suspended Weight Without Clamp	lbs/kg	13,500/6,123	13,800/6,259	18,000/8,164
Length	in/mm	14/355	14/355	14/355
Width at Throat	in/mm	101/2,560	101/2,560	150/3,810
Height w/o Clamp	in/mm	106/2,692	106/2,692	106/2,692

* Add 2200 lbs. to suspended weight when using bias weights.
** Frequency is adjustable at control panel or hand held pendant.

I-2B. Model 630 Power Unit - (Table 1-B.)

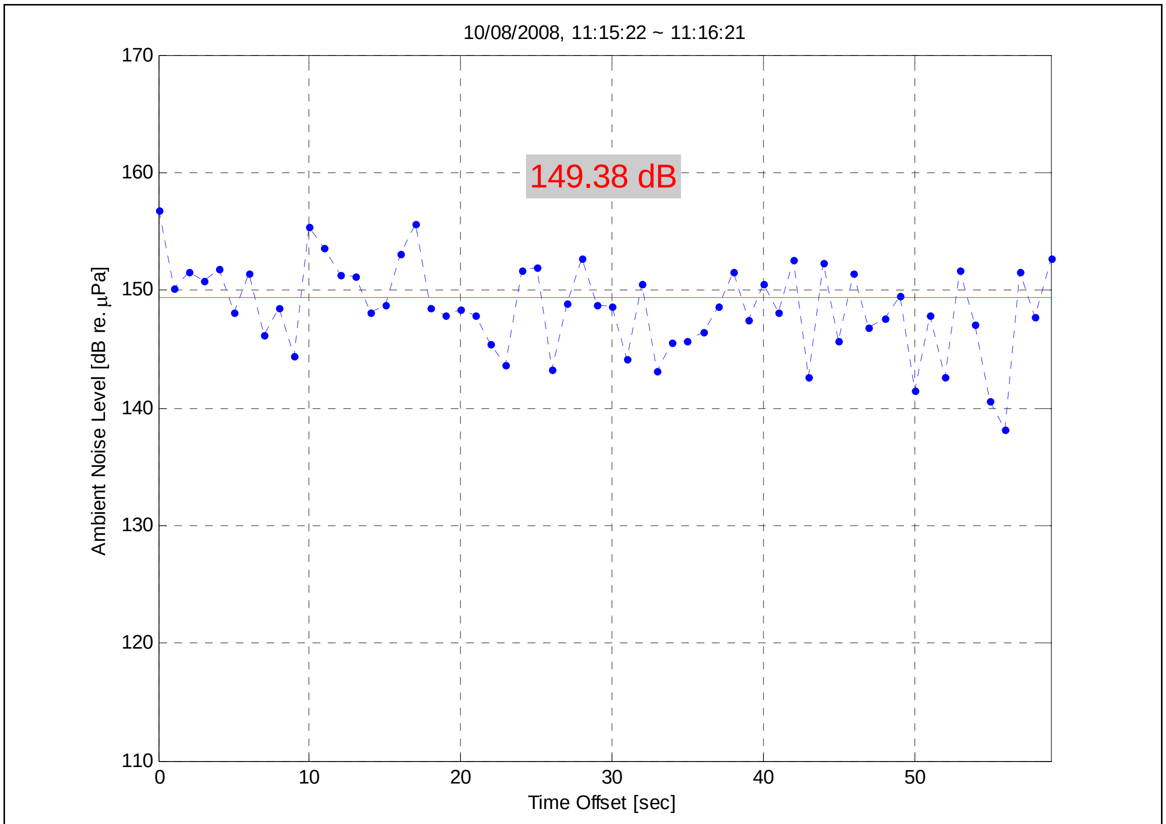


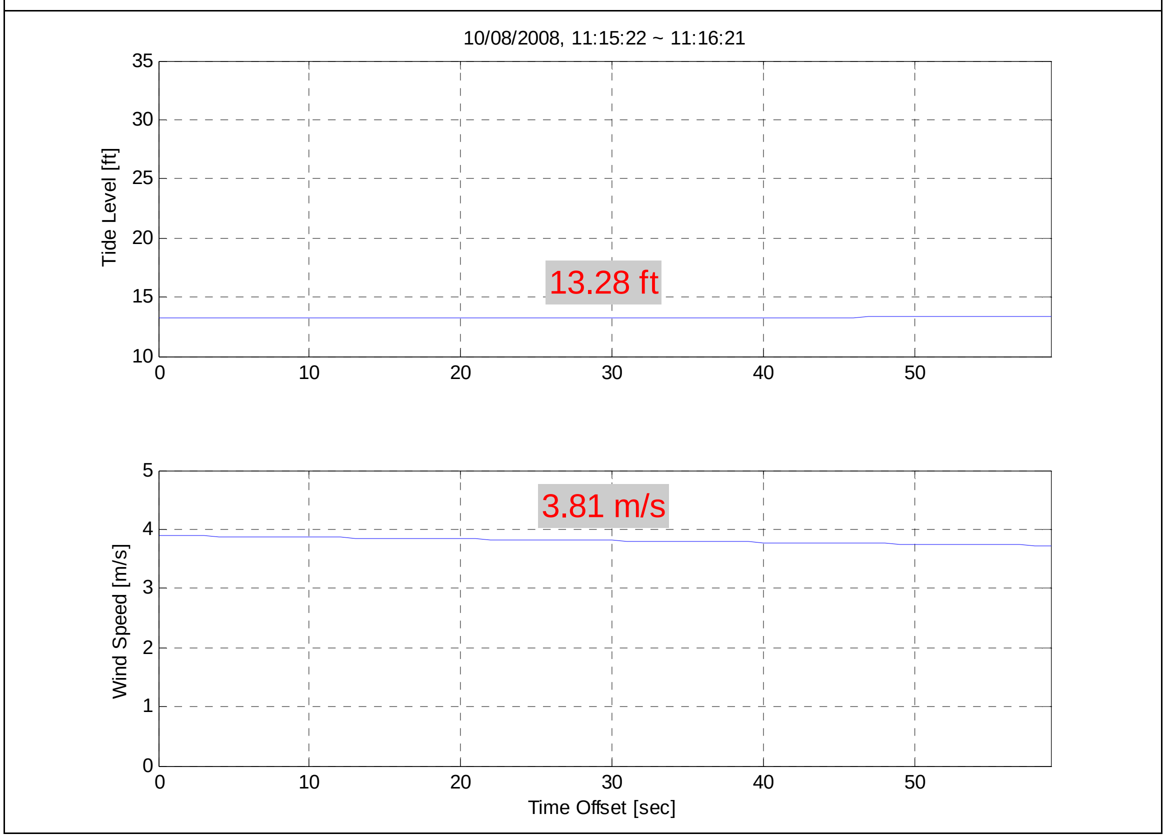
	Model 630
Engine	Caterpillar C-16
Maximum Power	630 HP (470 kW)
Operating Speed	800 to 2350 rpm
Maximum Drive Pressure	4,800 psi (331 bar)
Maximum Hyd. Flow-Forward	0 to 180 gpm (682 lpm)
Maximum Hyd. Flow-Reverse	0 to 180 gpm (682 lpm)
Clamp Pressure	4,800 psi (331 bar)
Clamp Pump Flow @ 2200 rpm	6.5 gpm (25 lpm)
Weight	20,000 lbs (9,071 kg)
Length	156 " (3,962 mm)
Width	72" (1,829 mm)
Height	101" (2,565 mm)

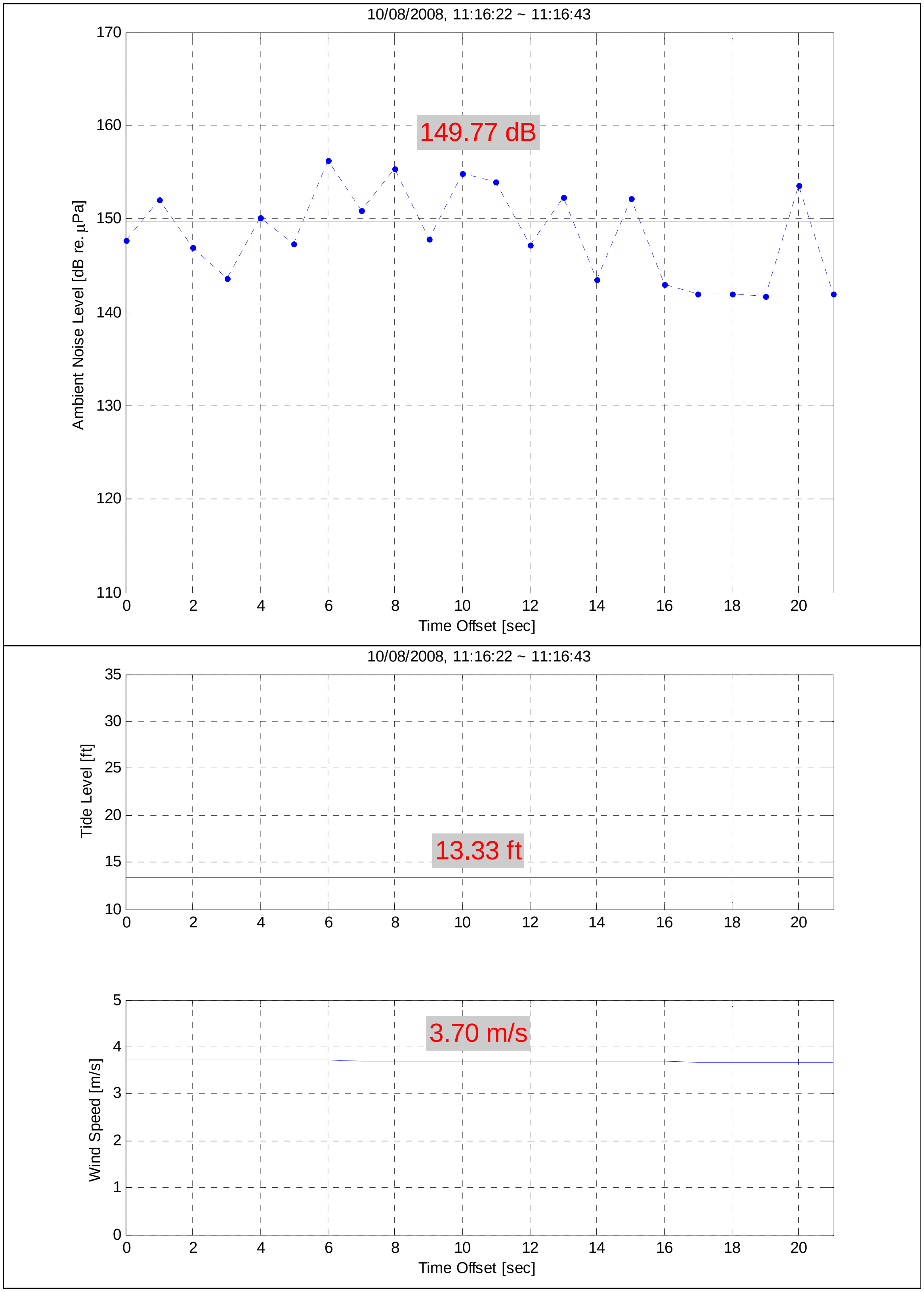
**Dimensions may vary depending on the year and model.
Consult the factory for certifications on unit being used.**

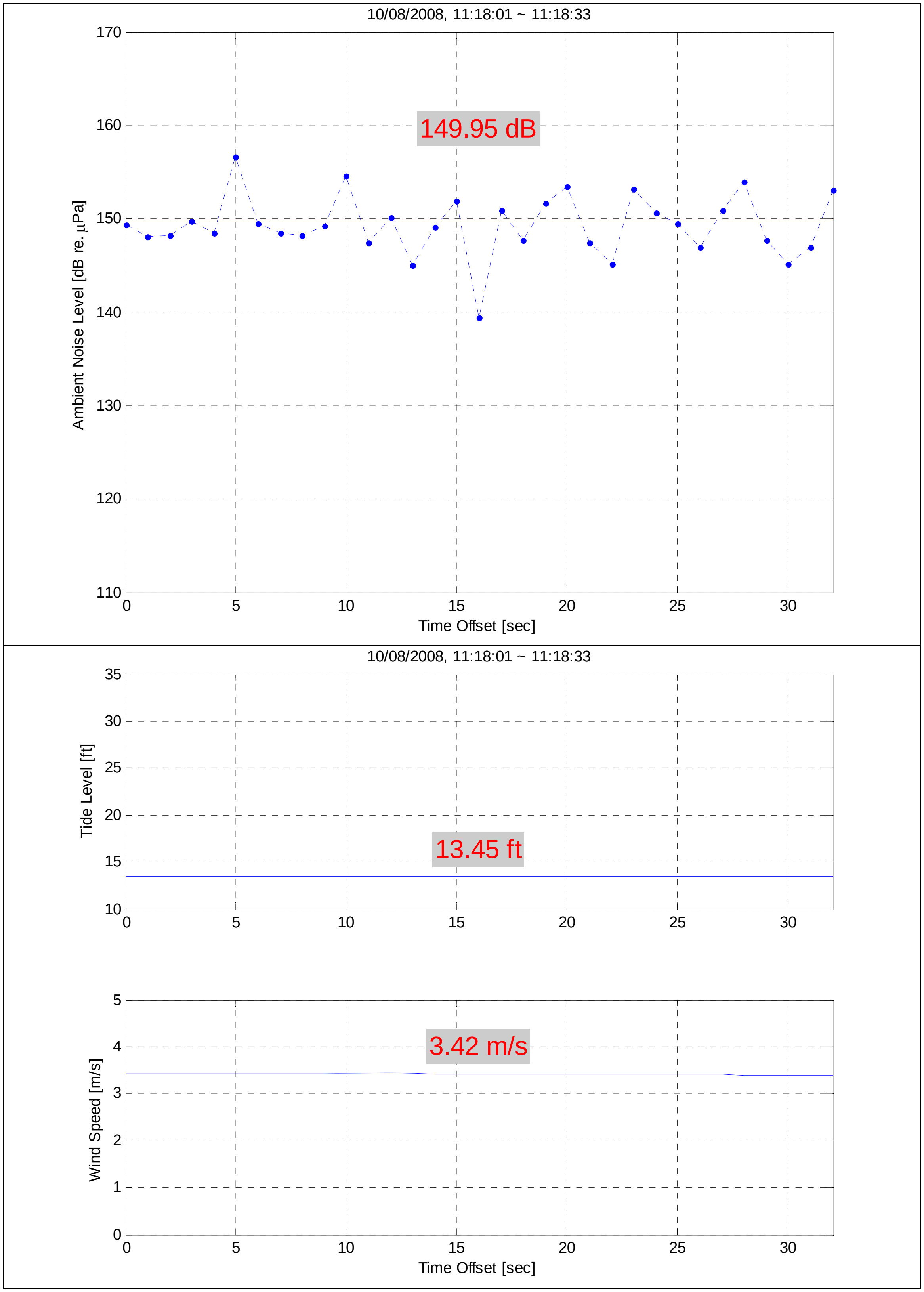
Page 1-2

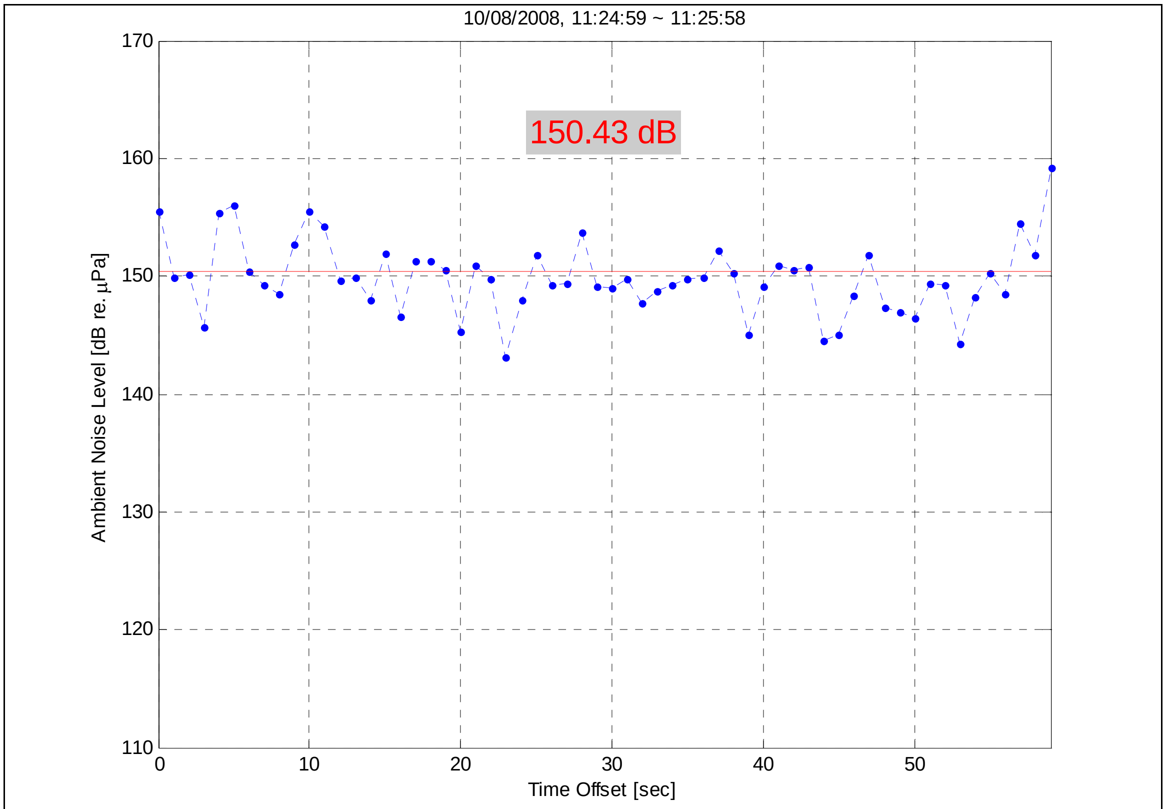
Appendix G: Background Noise vs Tide / Wind Speed

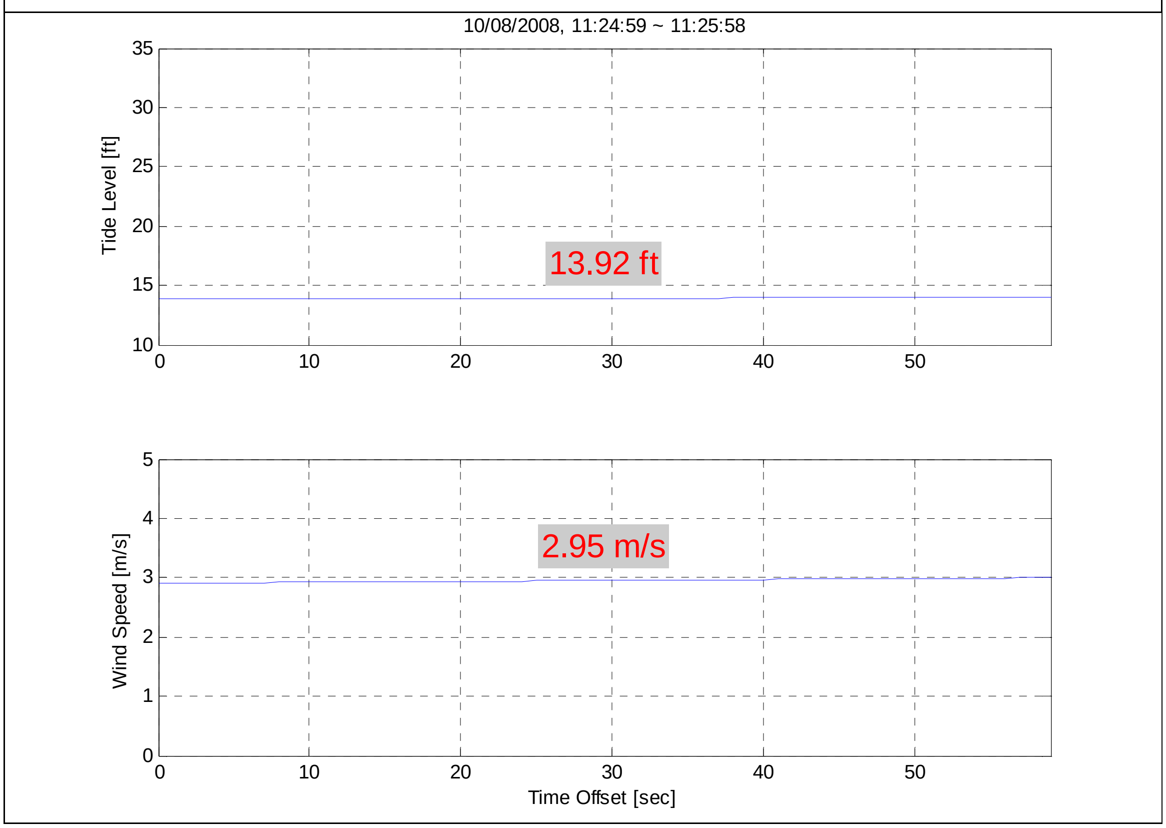

10/08/2008, 11:15:22 ~ 11:16:21
149.38 dB
Ambient Noise Level [dB re. µPa]
170
160
150
140
130
120
110
0
10
20
30
40
50
Time Offset [sec]

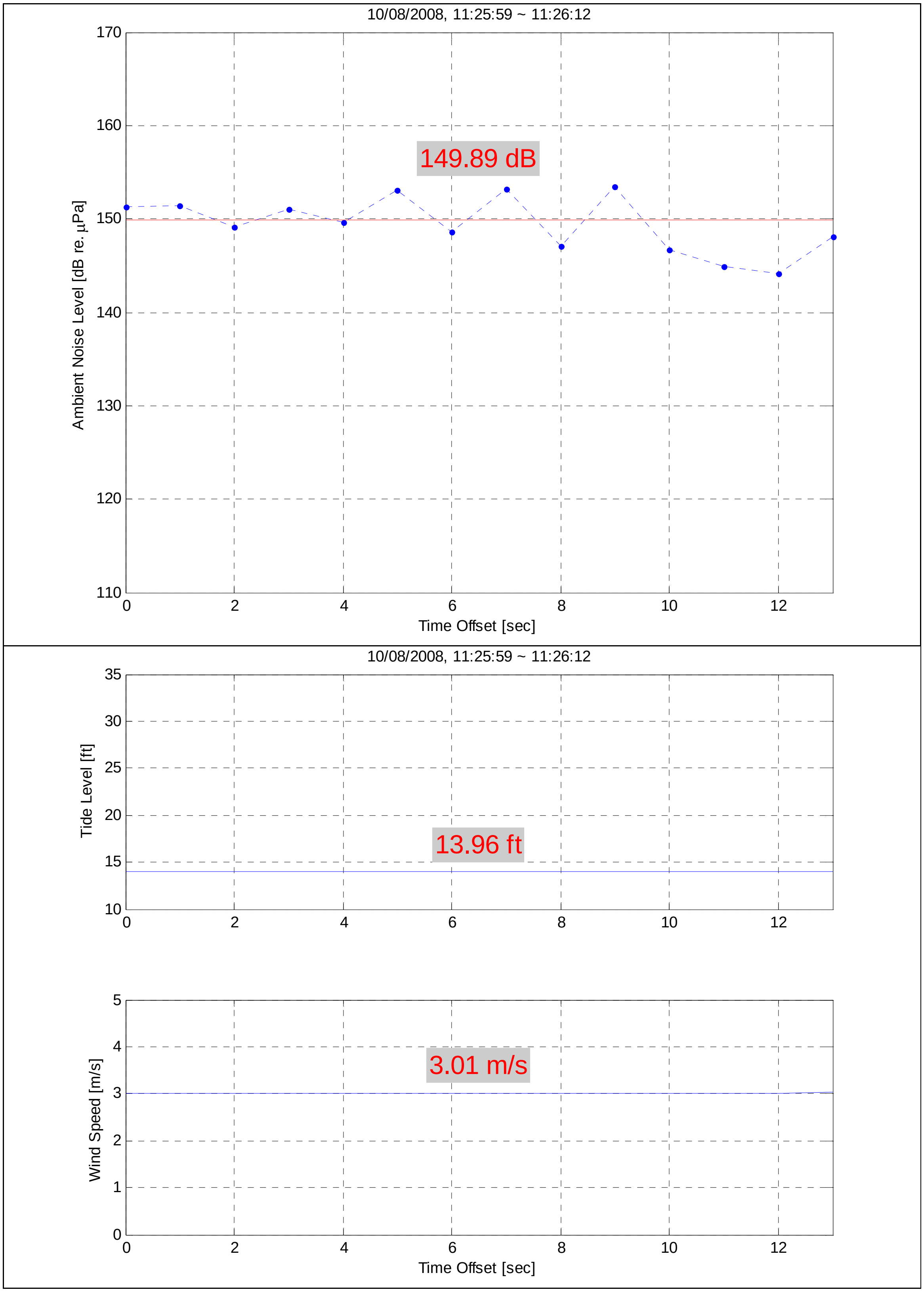

10/08/2008, 11:15:22 ~ 11:16:21
13.28 ft
Tide Level [ft]
35
30
25
20
15
10
0
10
20
30
40
50
3.81 m/s
Wind Speed [m/s]
5
4
3
2
1
0
0
10
20
30
40
50
Time Offset [sec]

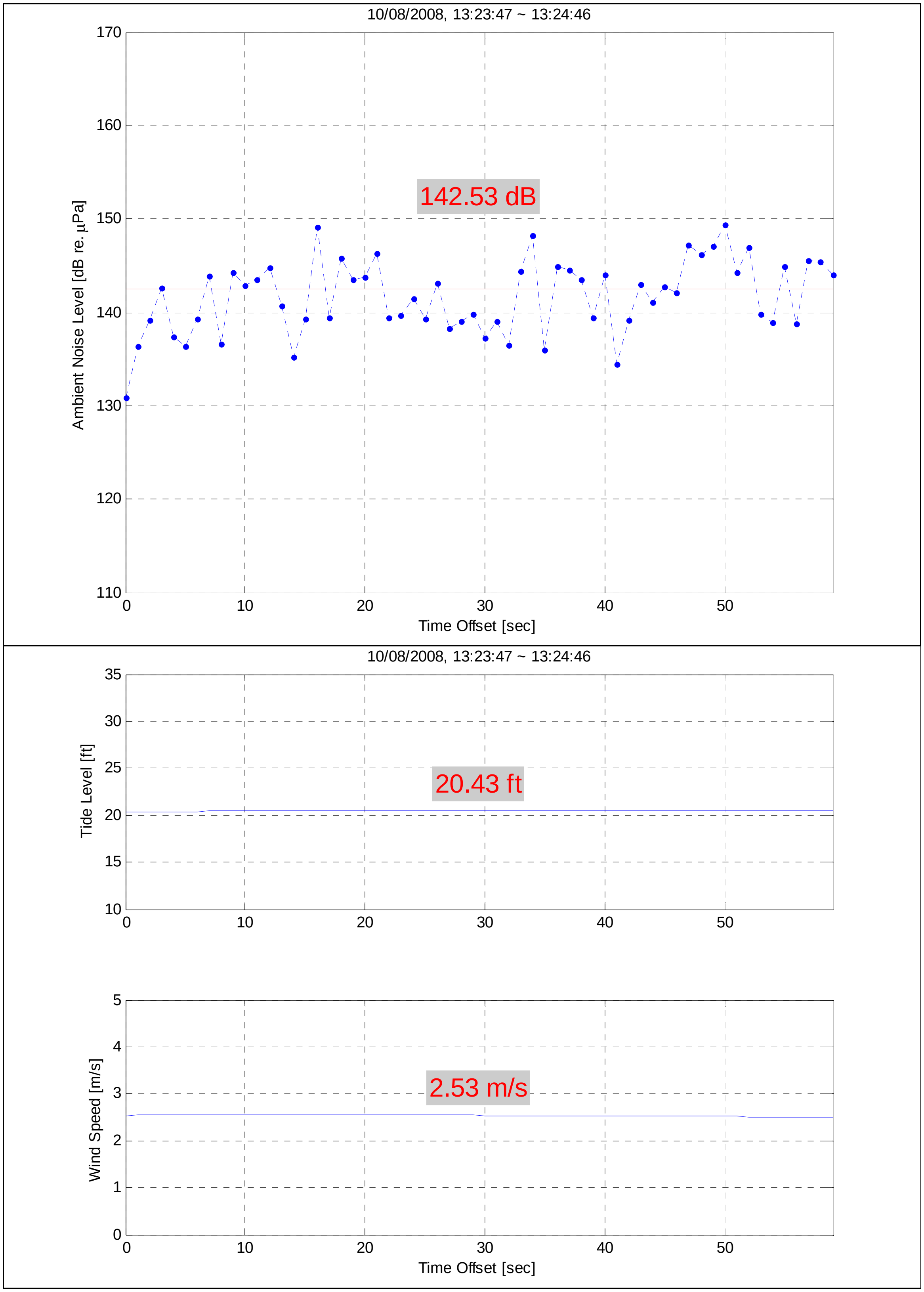

10/08/2008, 11:16:22 ~ 11:16:43
149.77 dB
Ambient Noise Level [dB re. µPa]
170
160
150
140
130
120
110
0 2 4 6 8 10 12 14 16 18 20
Time Offset [sec]
10/08/2008, 11:16:22 ~ 11:16:43
13.33 ft
Tide Level [ft]
35
30
25
20
15
10
0 2 4 6 8 10 12 14 16 18 20
3.70 m/s
Wind Speed [m/s]
5
4
3
2
1
0
0 2 4 6 8 10 12 14 16 18 20
Time Offset [sec]

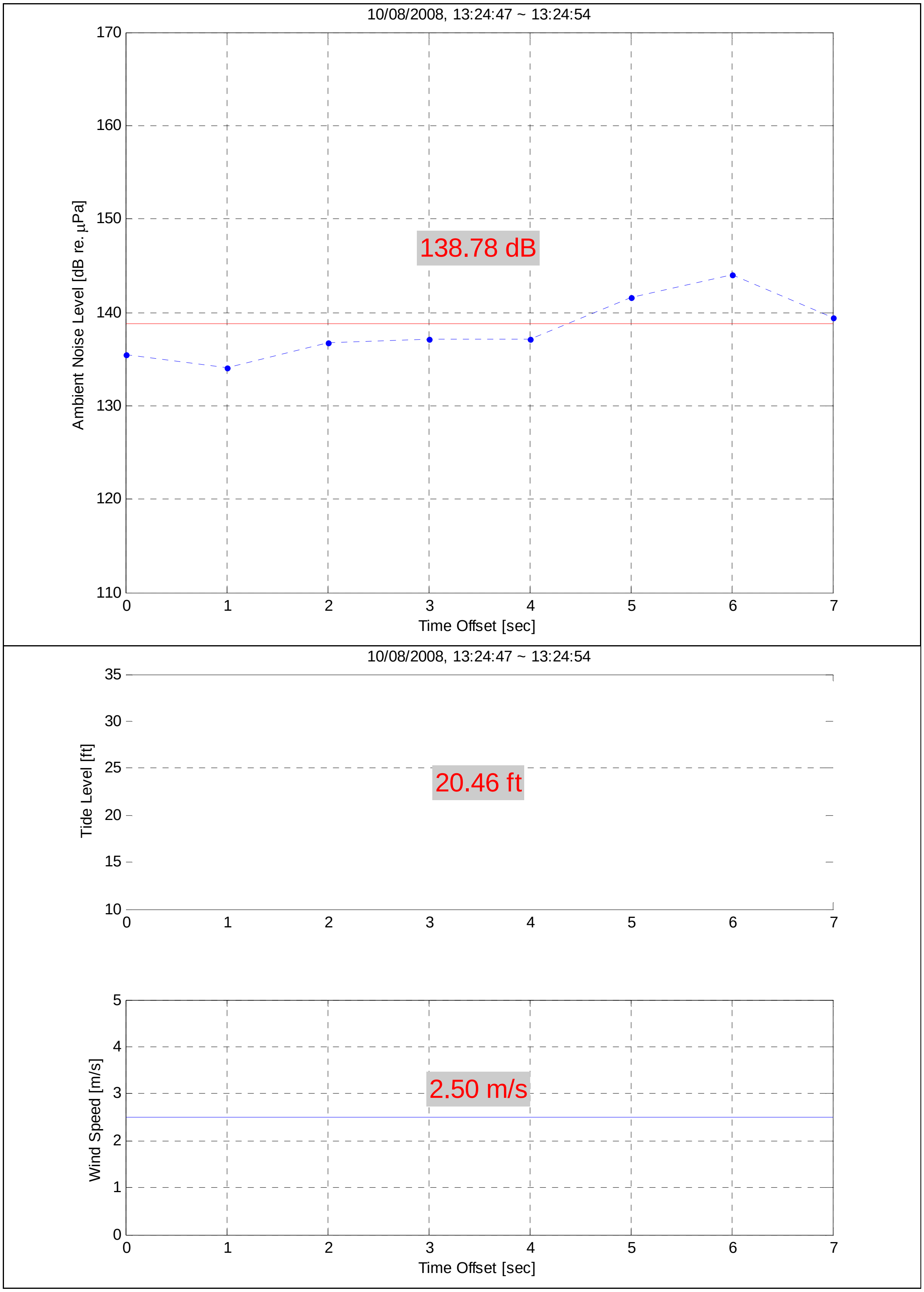

10/08/2008, 11:18:01 ~ 11:18:33
149.95 dB
Ambient Noise Level [dB re. µPa]
Time Offset [sec]
10/08/2008, 11:18:01 ~ 11:18:33
13.45 ft
Tide Level [ft]
3.42 m/s
Wind Speed [m/s]
Time Offset [sec]

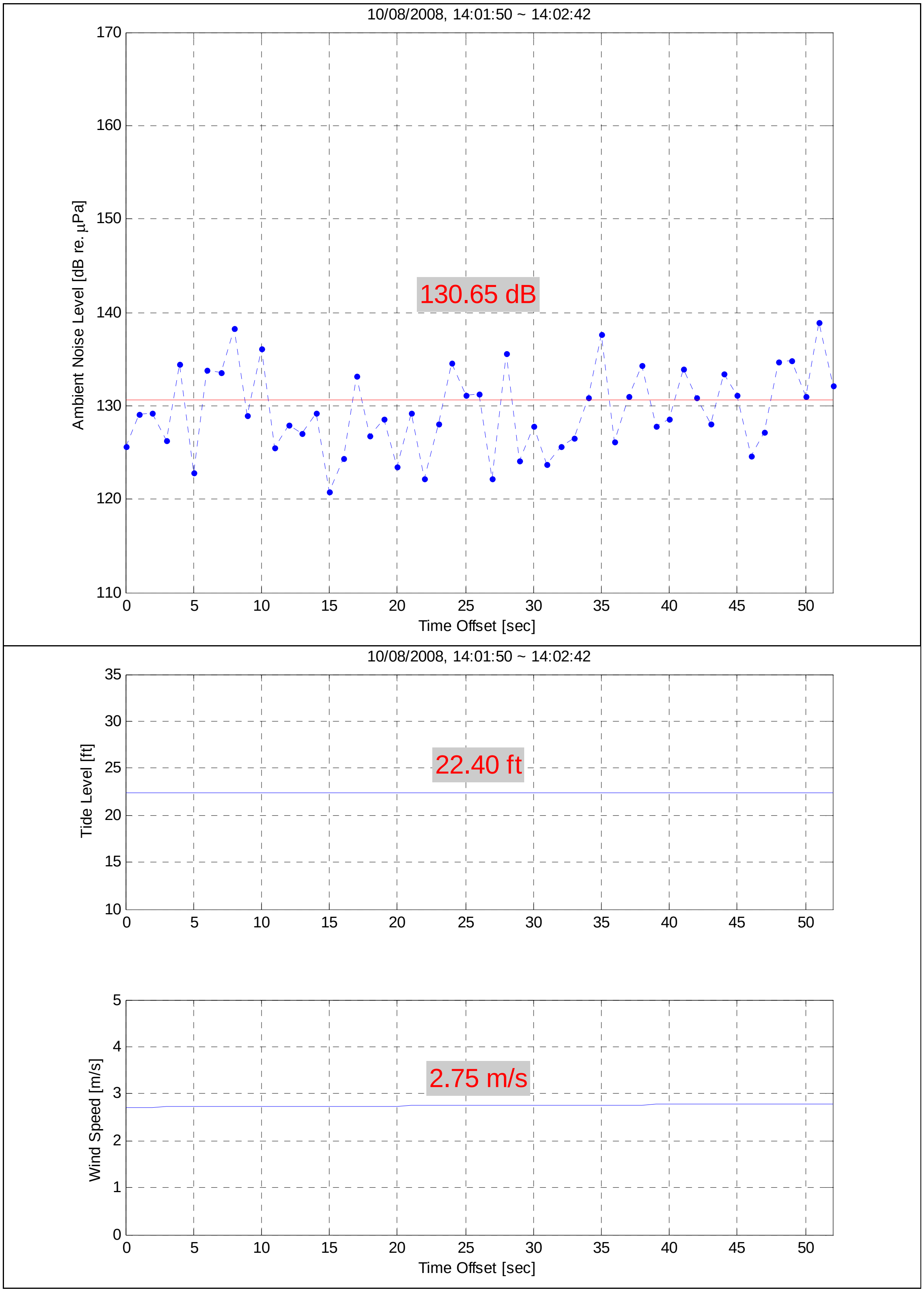

10/08/2008, 11:24:59 ~ 11:25:58
150.43 dB
Ambient Noise Level [dB re. µPa]
Time Offset [sec]
170
160
150
140
130
120
110
0
10
20
30
40
50

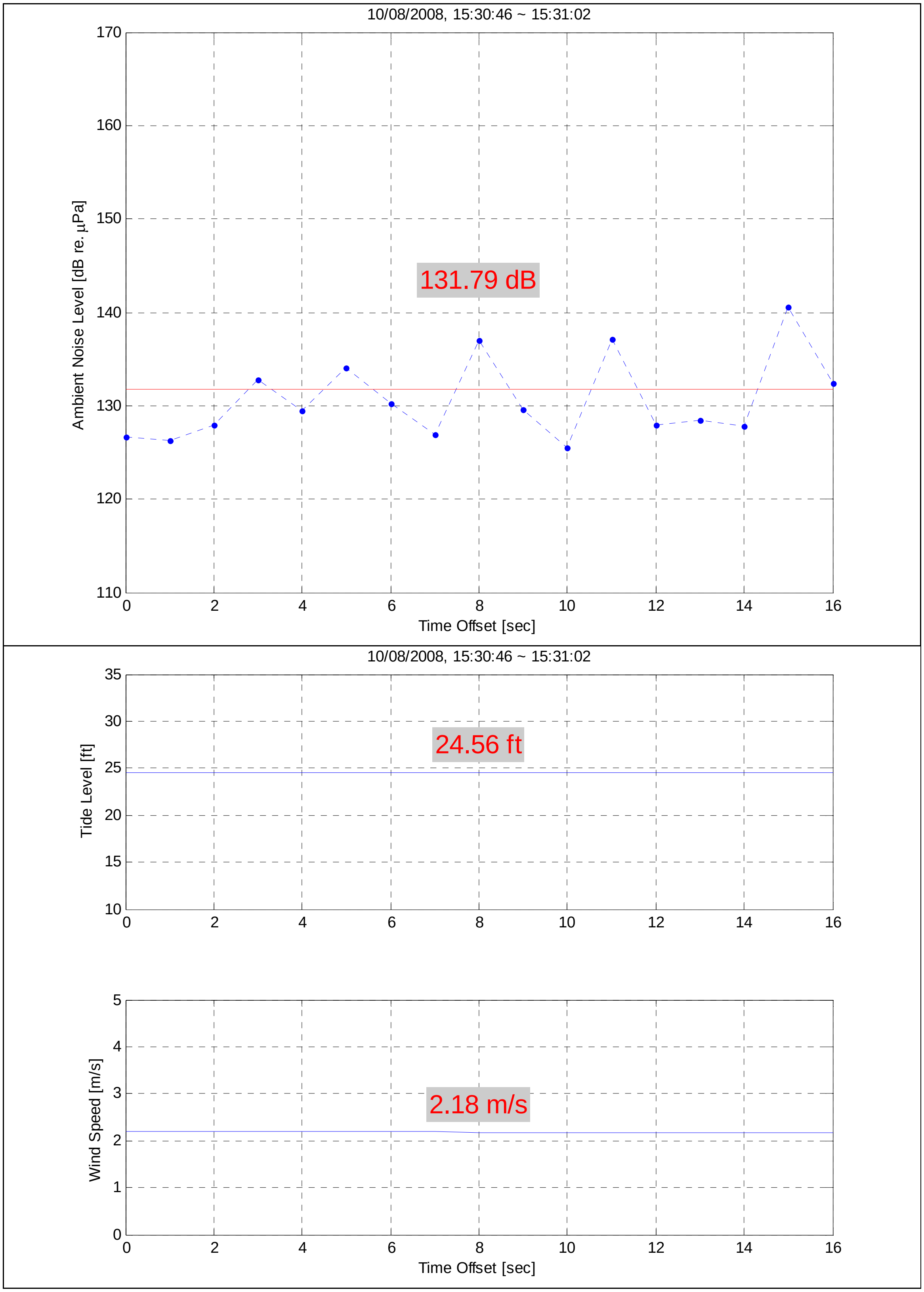

10/08/2008, 11:24:59 ~ 11:25:58
13.92 ft
Tide Level [ft]
35
30
25
20
15
10
2.95 m/s
Wind Speed [m/s]
5
4
3
2
1
0
0
10
20
30
40
50
Time Offset [sec]

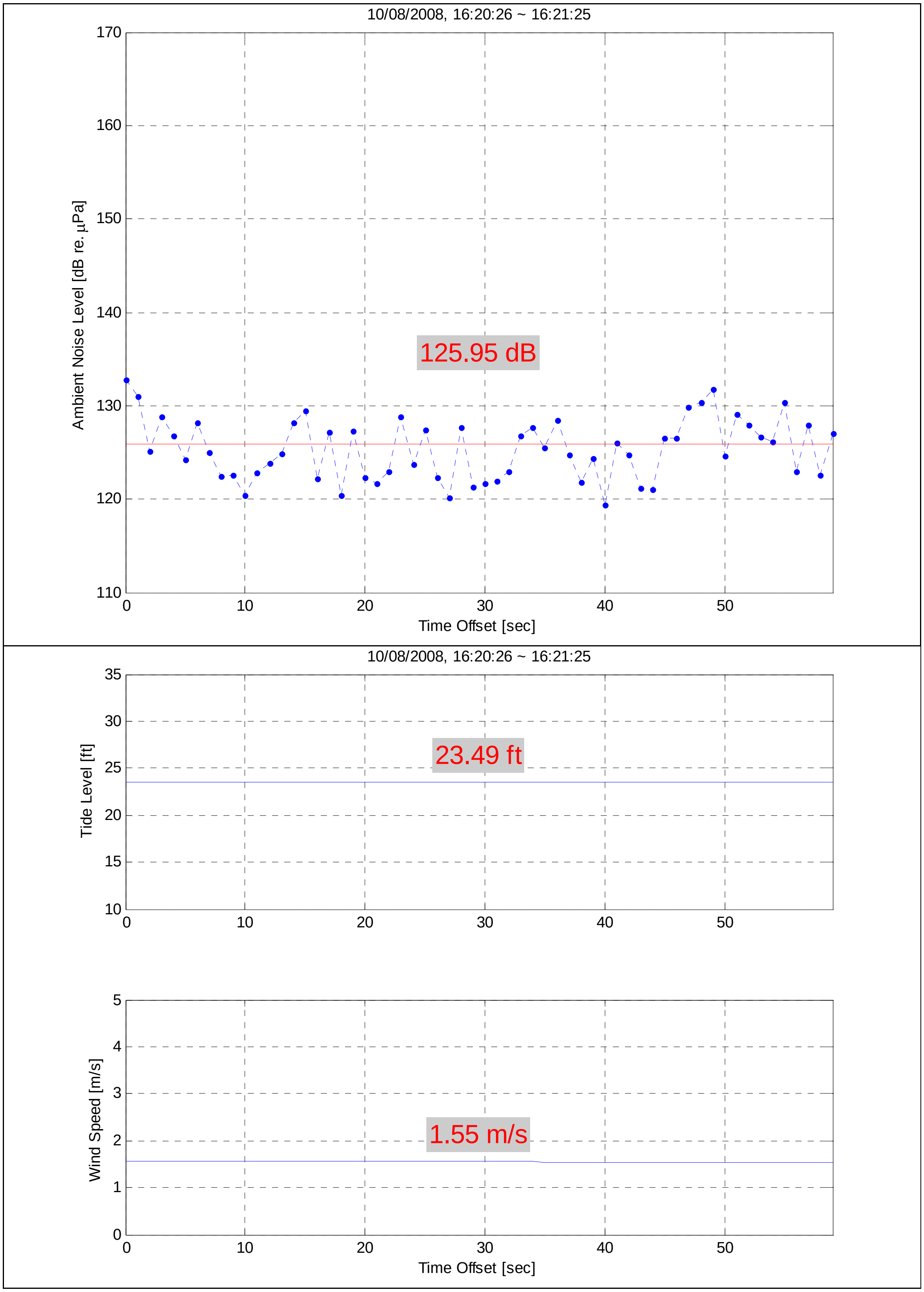

10/08/2008, 11:25:59 ~ 11:26:12
149.89 dB
Ambient Noise Level [dB re. µPa]
Time Offset [sec]
10/08/2008, 11:25:59 ~ 11:26:12
13.96 ft
Tide Level [ft]
3.01 m/s
Wind Speed [m/s]
Time Offset [sec]

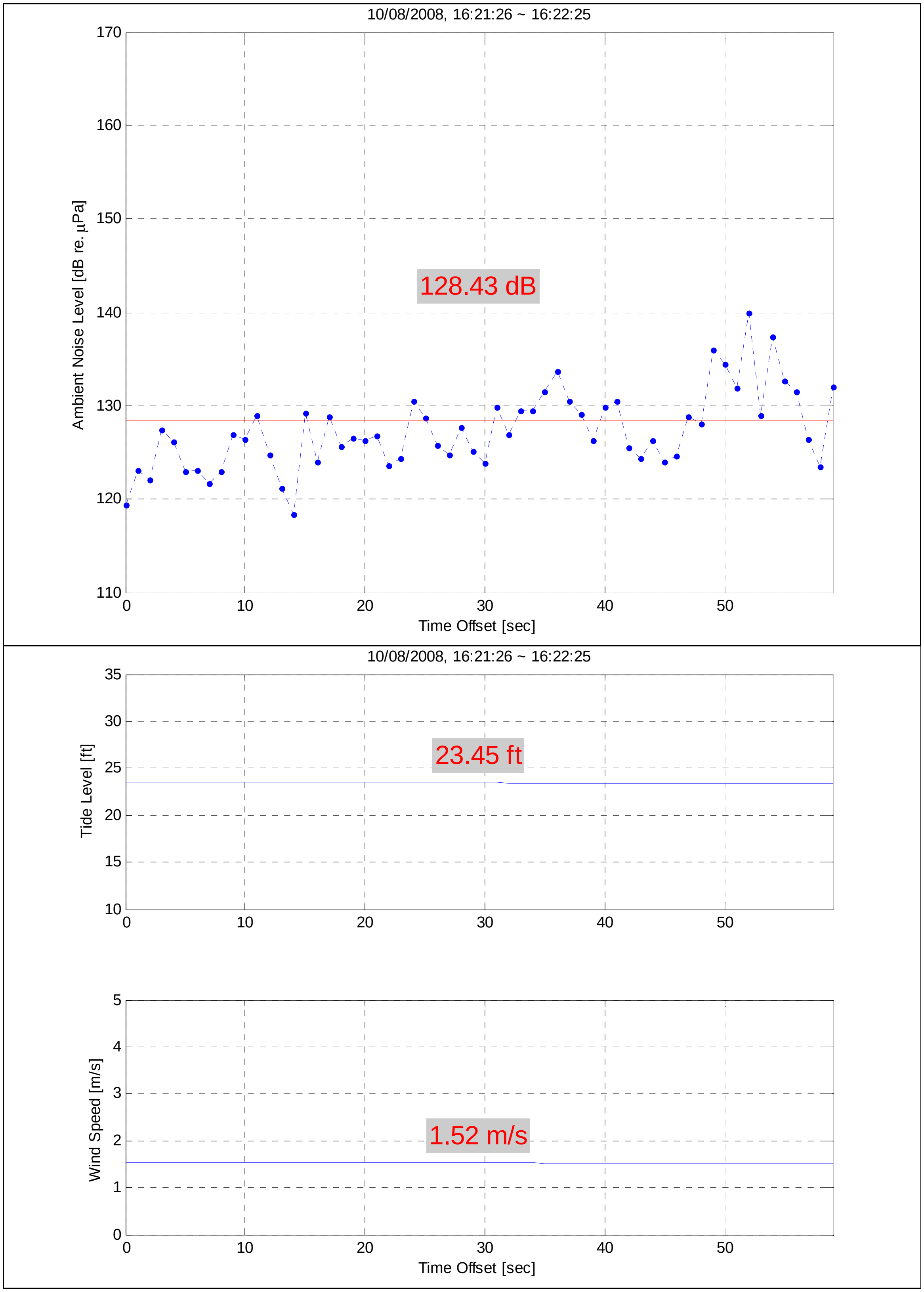

10/08/2008, 13:23:47 ~ 13:24:46
142.53 dB
Ambient Noise Level [dB re. μPa]
170
160
150
140
130
120
110
0
10
20
30
40
50
Time Offset [sec]
10/08/2008, 13:23:47 ~ 13:24:46
20.43 ft
Tide Level [ft]
35
30
25
20
15
10
2.53 m/s
Wind Speed [m/s]
5
4
3
2
1
0
Time Offset [sec]

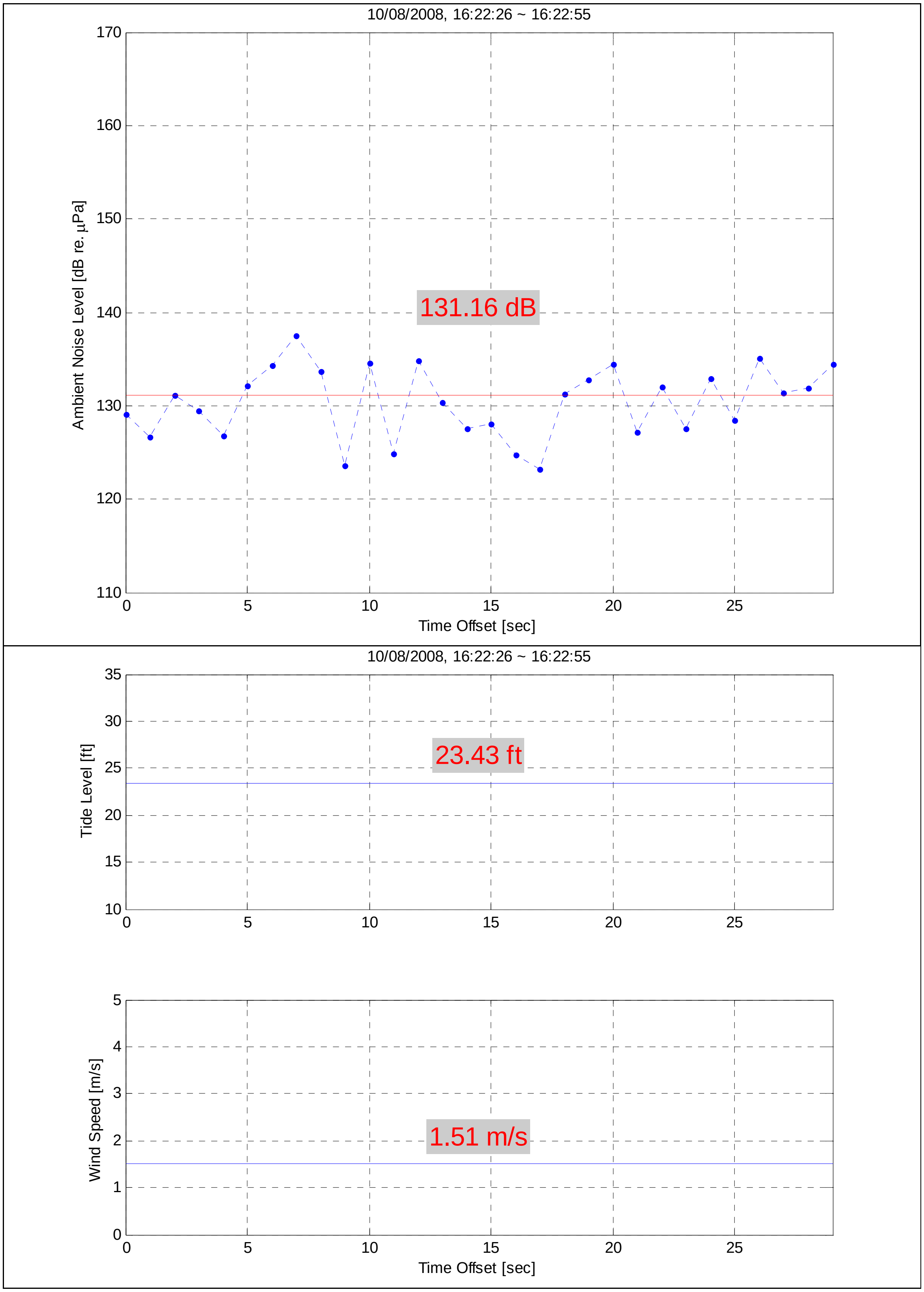

10/08/2008, 13:24:47 ~ 13:24:54
Ambient Noise Level [dB re. µPa]
138.78 dB
170
160
150
140
130
120
110
0
1
2
3
4
5
6
7
Time Offset [sec]
10/08/2008, 13:24:47 ~ 13:24:54
Tide Level [ft]
20.46 ft
35
30
25
20
15
10
Wind Speed [m/s]
2.50 m/s
5
4
3
2
1
0
Time Offset [sec]

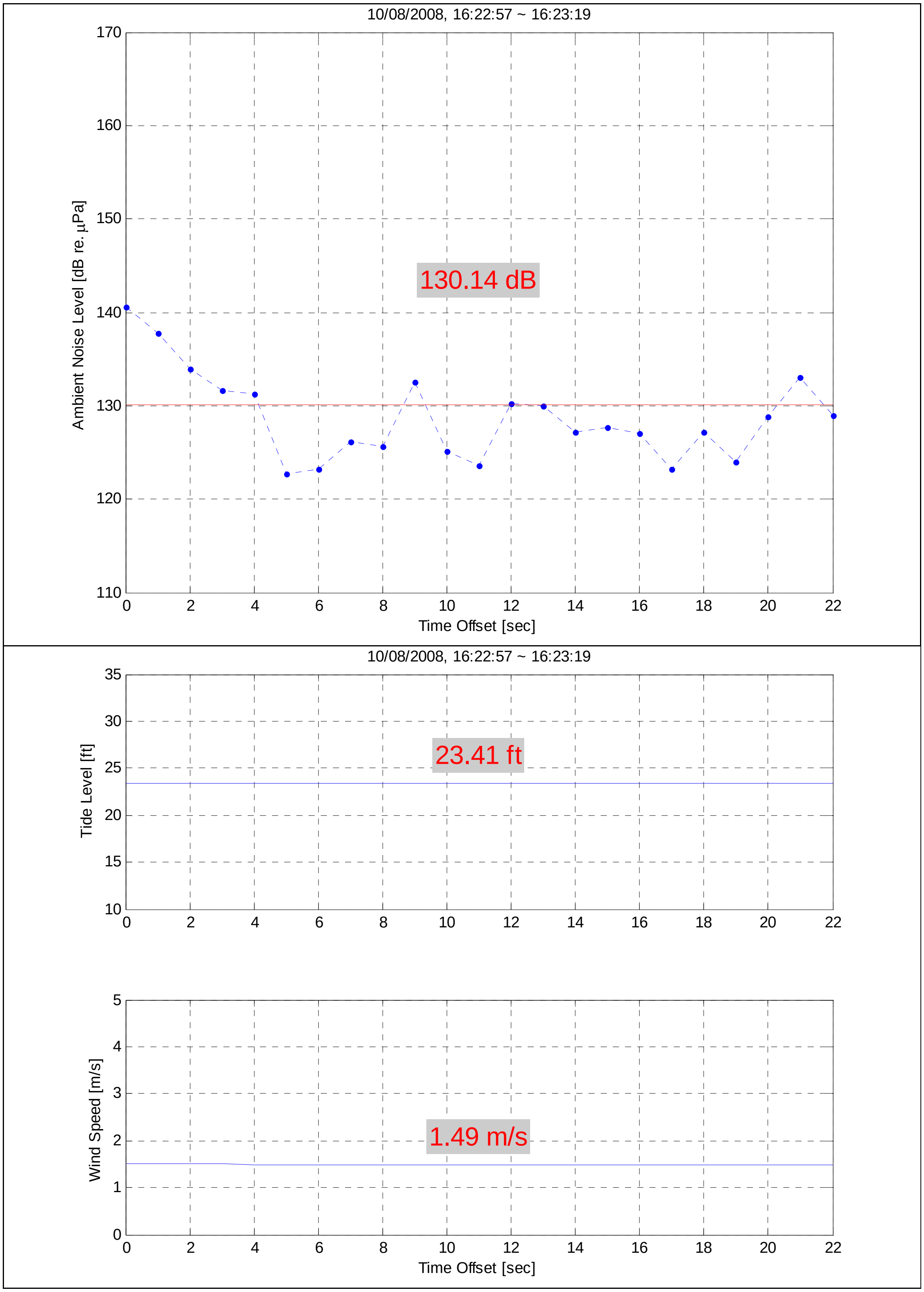

10/08/2008, 14:01:50 ~ 14:02:42
Ambient Noise Level [dB re. µPa]
130.65 dB
Time Offset [sec]
10/08/2008, 14:01:50 ~ 14:02:42
Tide Level [ft]
22.40 ft
Wind Speed [m/s]
2.75 m/s
Time Offset [sec]

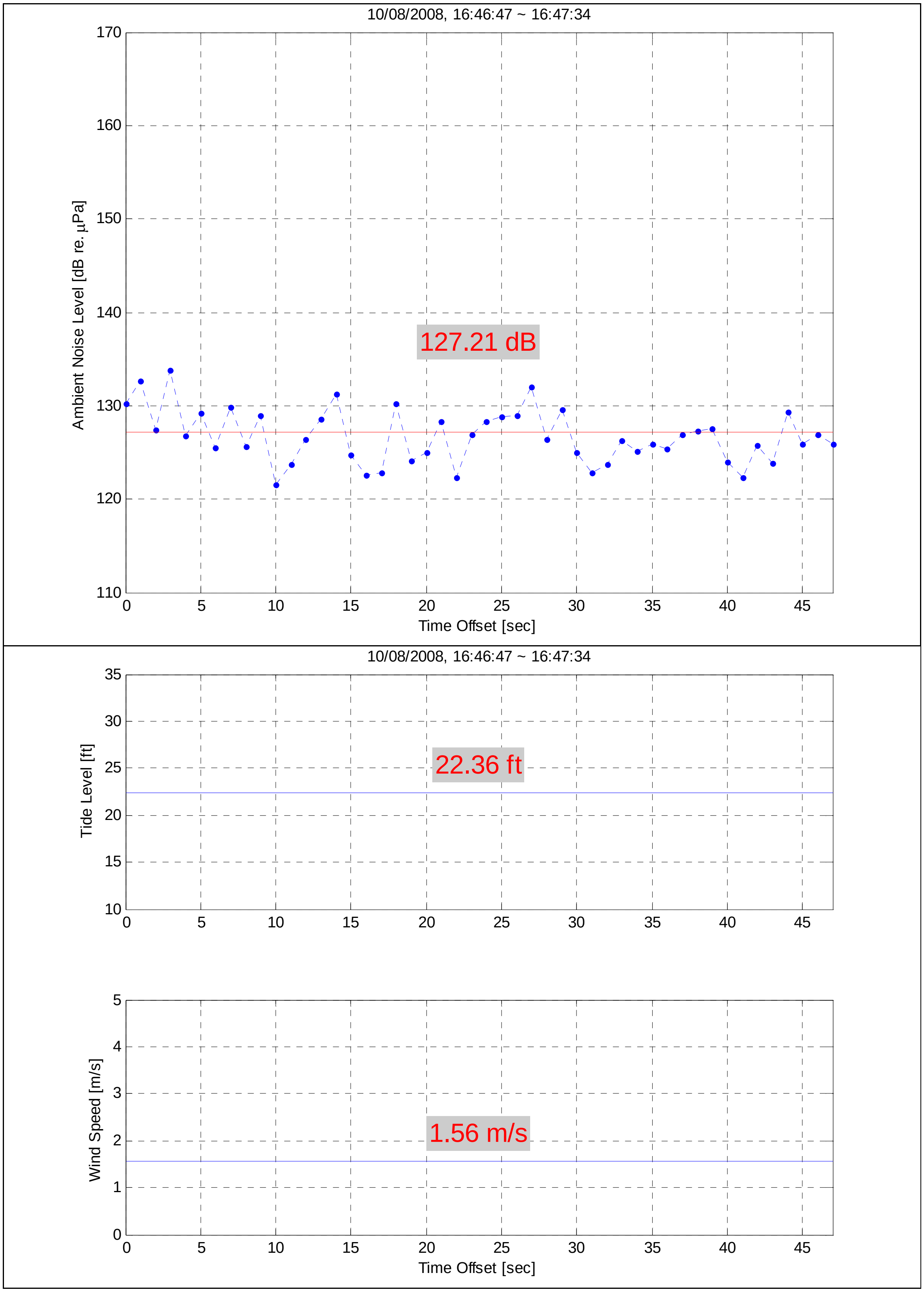

10/08/2008, 15:30:46 ~ 15:31:02
Ambient Noise Level [dB re. µPa]
131.79 dB
Time Offset [sec]
10/08/2008, 15:30:46 ~ 15:31:02
Tide Level [ft]
24.56 ft
Wind Speed [m/s]
2.18 m/s
Time Offset [sec]

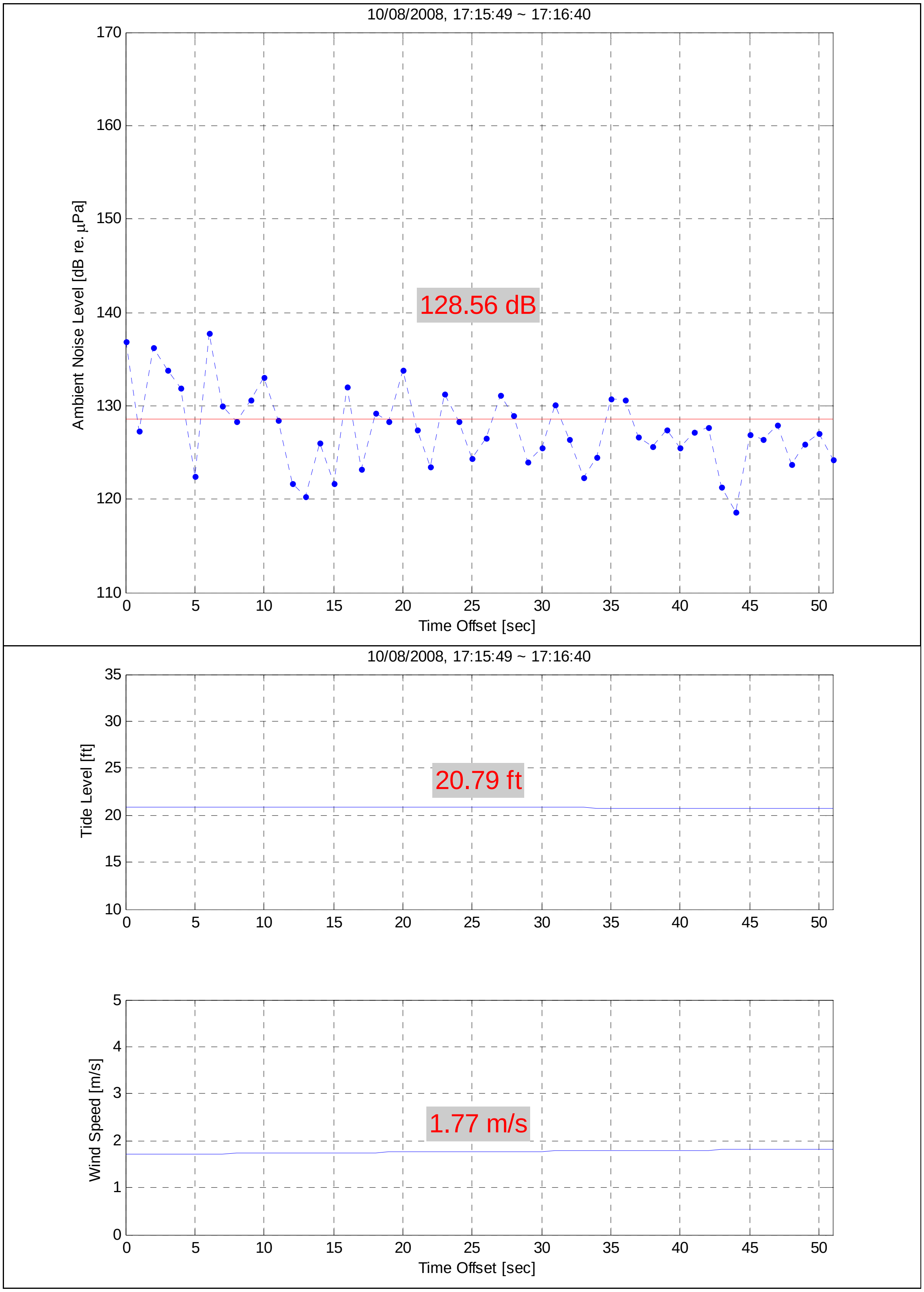

10/08/2008, 16:20:26 ~ 16:21:25
Ambient Noise Level [dB re. µPa]
125.95 dB
Time Offset [sec]
10/08/2008, 16:20:26 ~ 16:21:25
Tide Level [ft]
23.49 ft
Wind Speed [m/s]
1.55 m/s
Time Offset [sec]

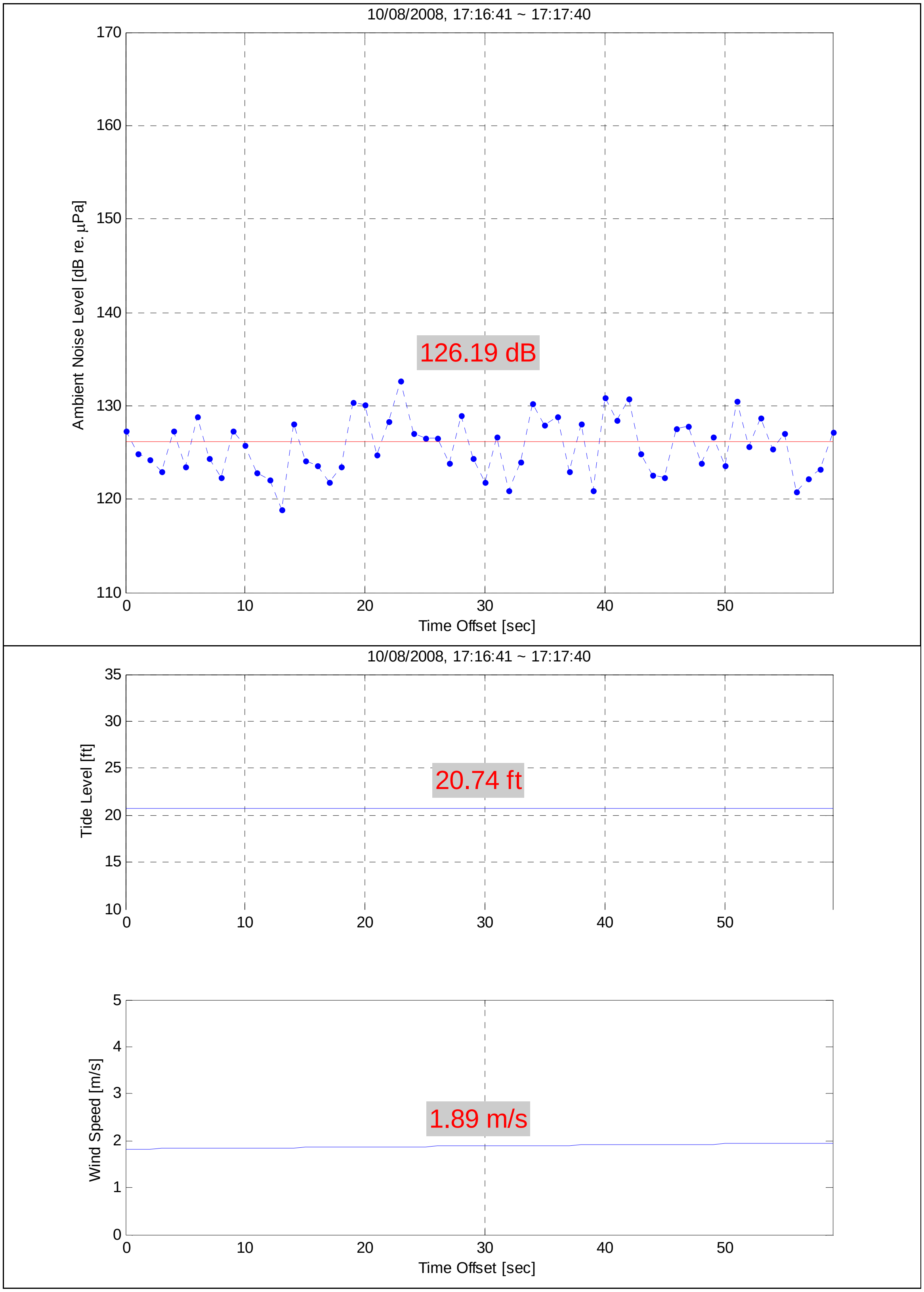

10/08/2008, 16:21:26 ~ 16:22:25
128.43 dB
Ambient Noise Level [dB re. µPa]
Time Offset [sec]
10/08/2008, 16:21:26 ~ 16:22:25
23.45 ft
Tide Level [ft]
1.52 m/s
Wind Speed [m/s]
Time Offset [sec]

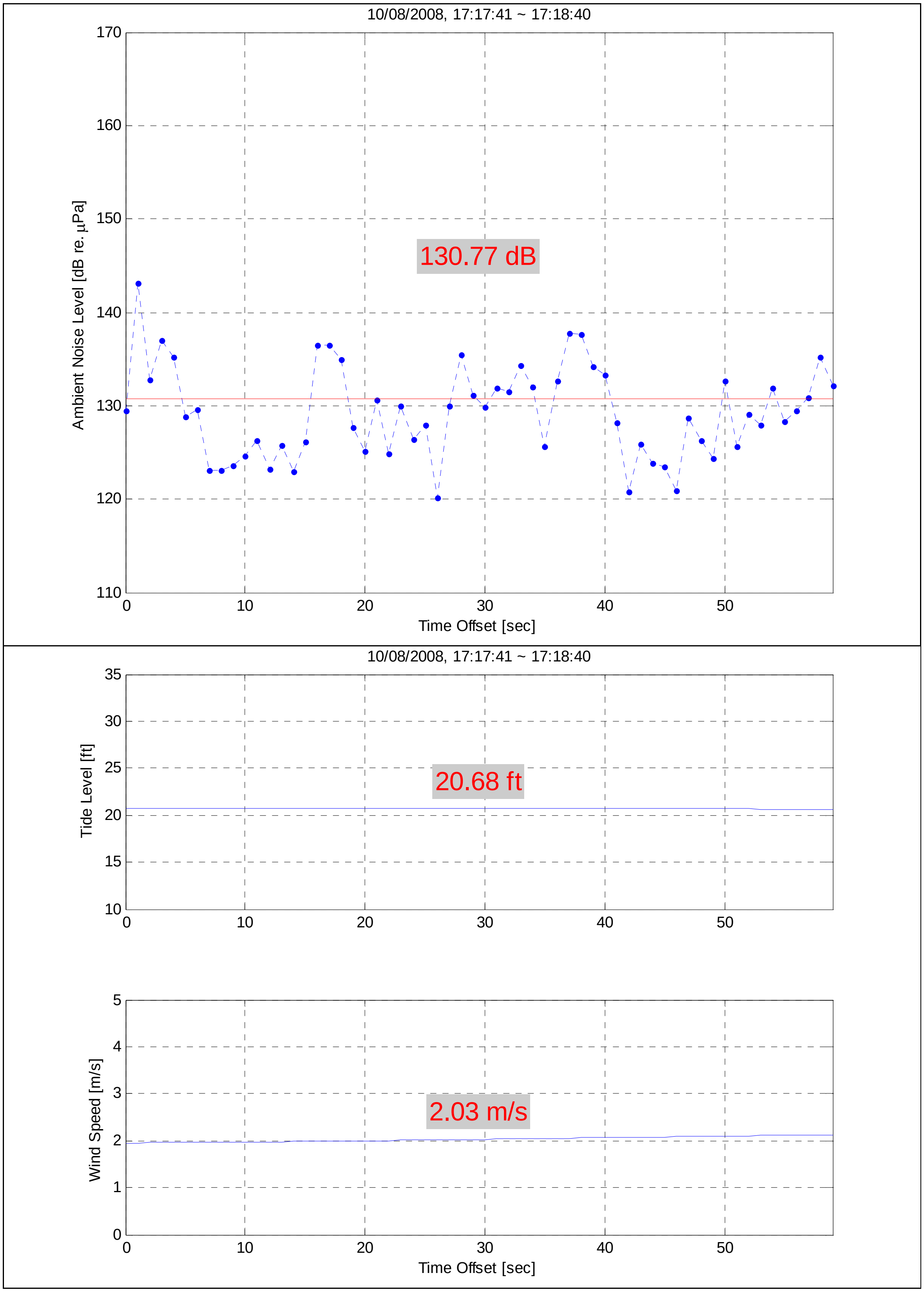

10/08/2008, 16:22:26 ~ 16:22:55
Ambient Noise Level [dB re. µPa]
131.16 dB
Time Offset [sec]
10/08/2008, 16:22:26 ~ 16:22:55
Tide Level [ft]
23.43 ft
Wind Speed [m/s]
1.51 m/s
Time Offset [sec]

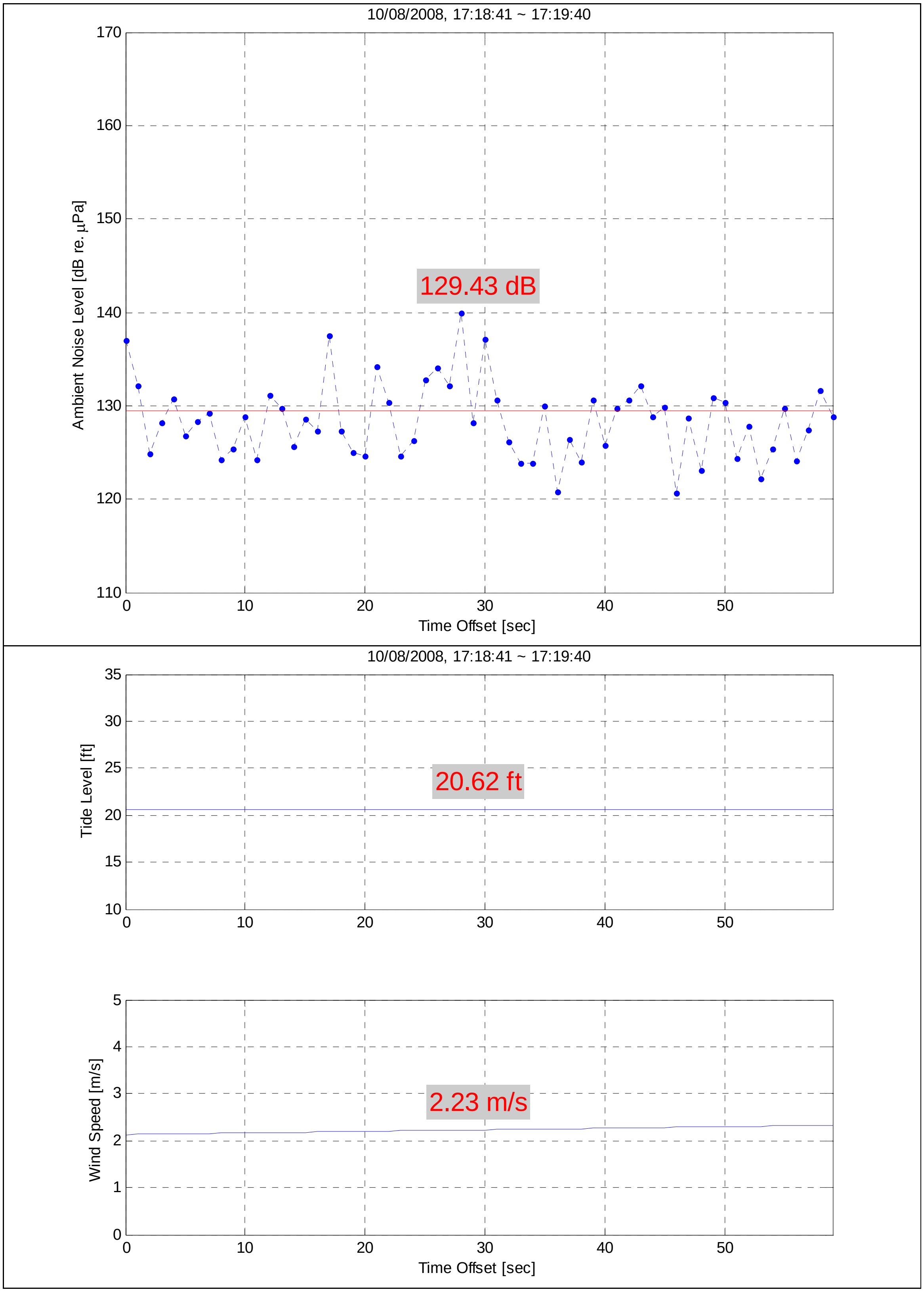

10/08/2008, 16:22:57 ~ 16:23:19
Ambient Noise Level [dB re. µPa]
130.14 dB
Time Offset [sec]
10/08/2008, 16:22:57 ~ 16:23:19
Tide Level [ft]
23.41 ft
Wind Speed [m/s]
1.49 m/s
Time Offset [sec]

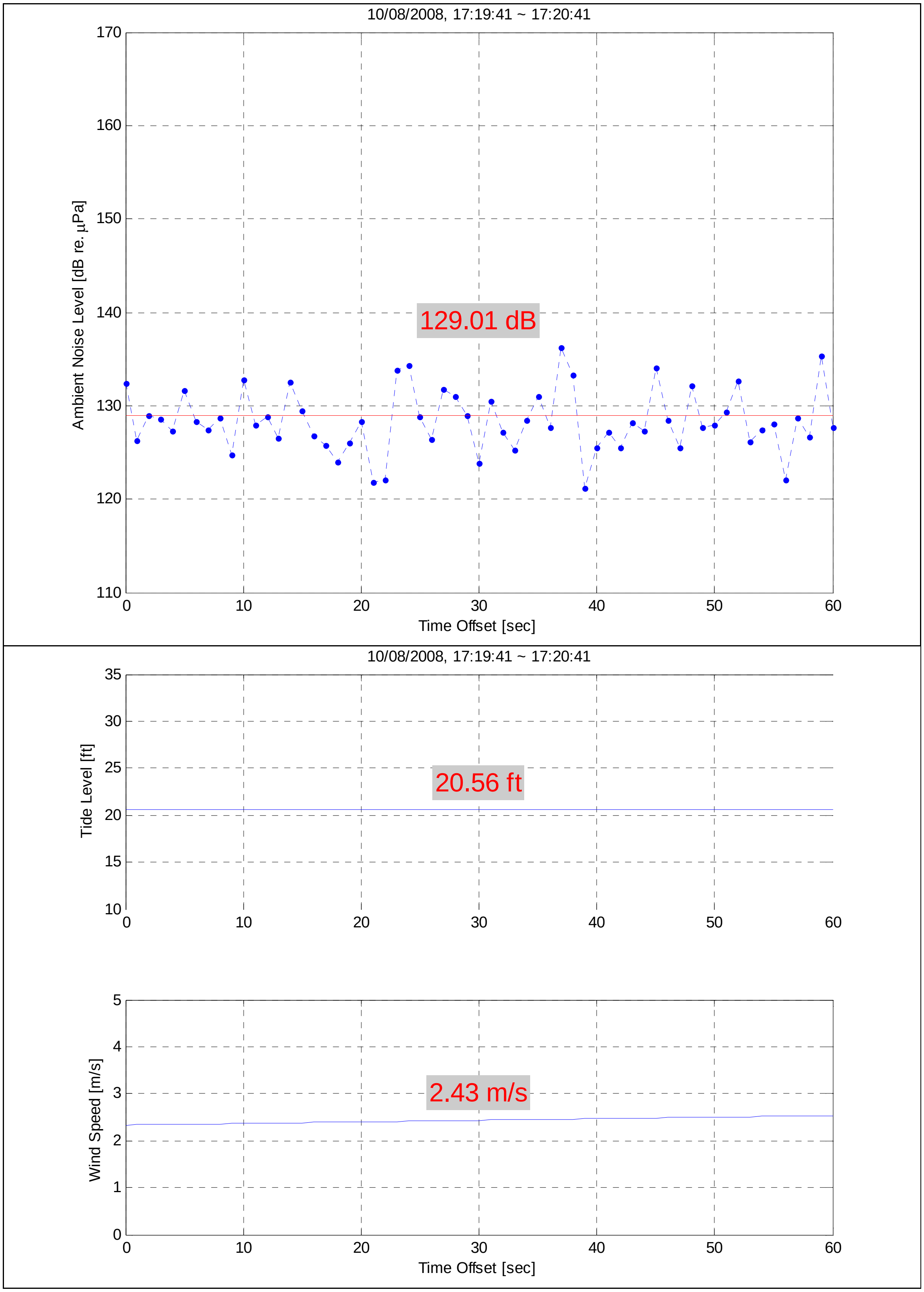

10/08/2008, 16:46:47 ~ 16:47:34
Ambient Noise Level [dB re. µPa]
170
160
150
140
130
120
110
127.21 dB
0
5
10
15
20
25
30
35
40
45
Time Offset [sec]
10/08/2008, 16:46:47 ~ 16:47:34
Tide Level [ft]
35
30
25
20
15
10
22.36 ft
Wind Speed [m/s]
5
4
3
2
1
0
1.56 m/s
Time Offset [sec]

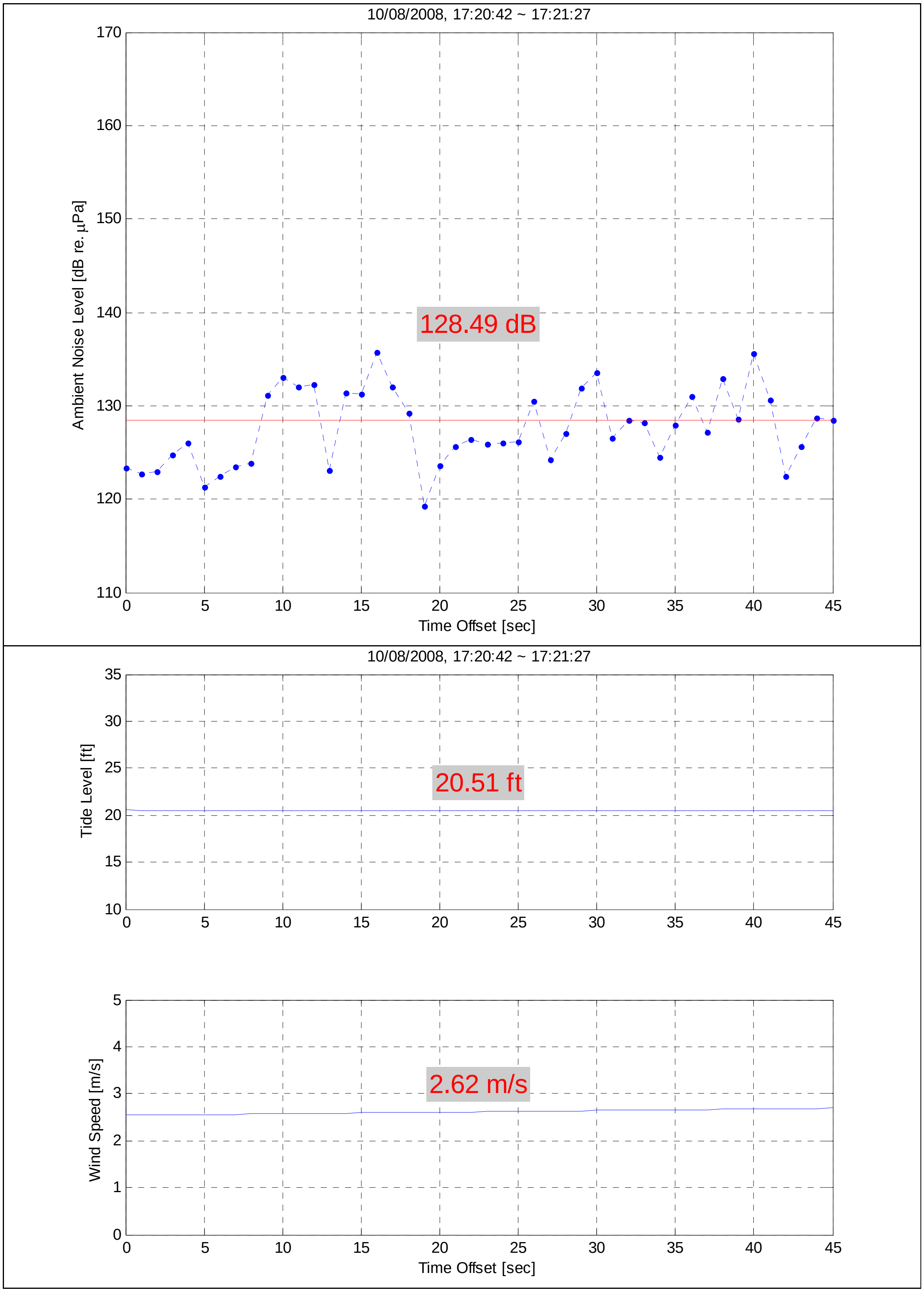

10/08/2008, 17:15:49 ~ 17:16:40
Ambient Noise Level [dB re. µPa]
128.56 dB
170
160
150
140
130
120
110
0
5
10
15
20
25
30
35
40
45
50
Time Offset [sec]
10/08/2008, 17:15:49 ~ 17:16:40
Tide Level [ft]
20.79 ft
35
30
25
20
15
10
Wind Speed [m/s]
1.77 m/s
5
4
3
2
1
0
Time Offset [sec]

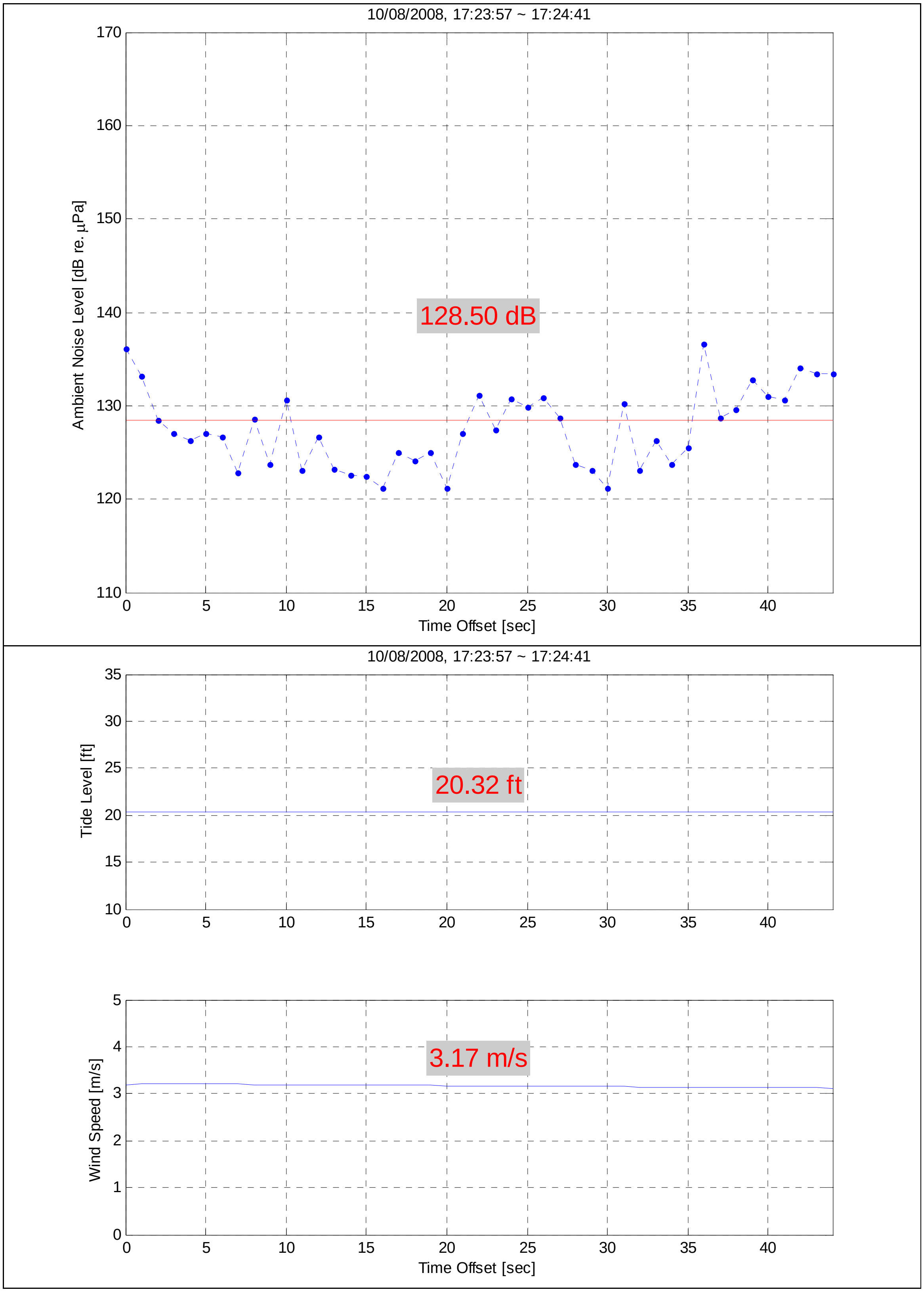

10/08/2008, 17:16:41 ~ 17:17:40
Ambient Noise Level [dB re. µPa]
170
160
150
140
130
120
110
126.19 dB
0
10
20
30
40
50
Time Offset [sec]
10/08/2008, 17:16:41 ~ 17:17:40
Tide Level [ft]
35
30
25
20
15
10
20.74 ft
Wind Speed [m/s]
5
4
3
2
1
0
1.89 m/s
Time Offset [sec]

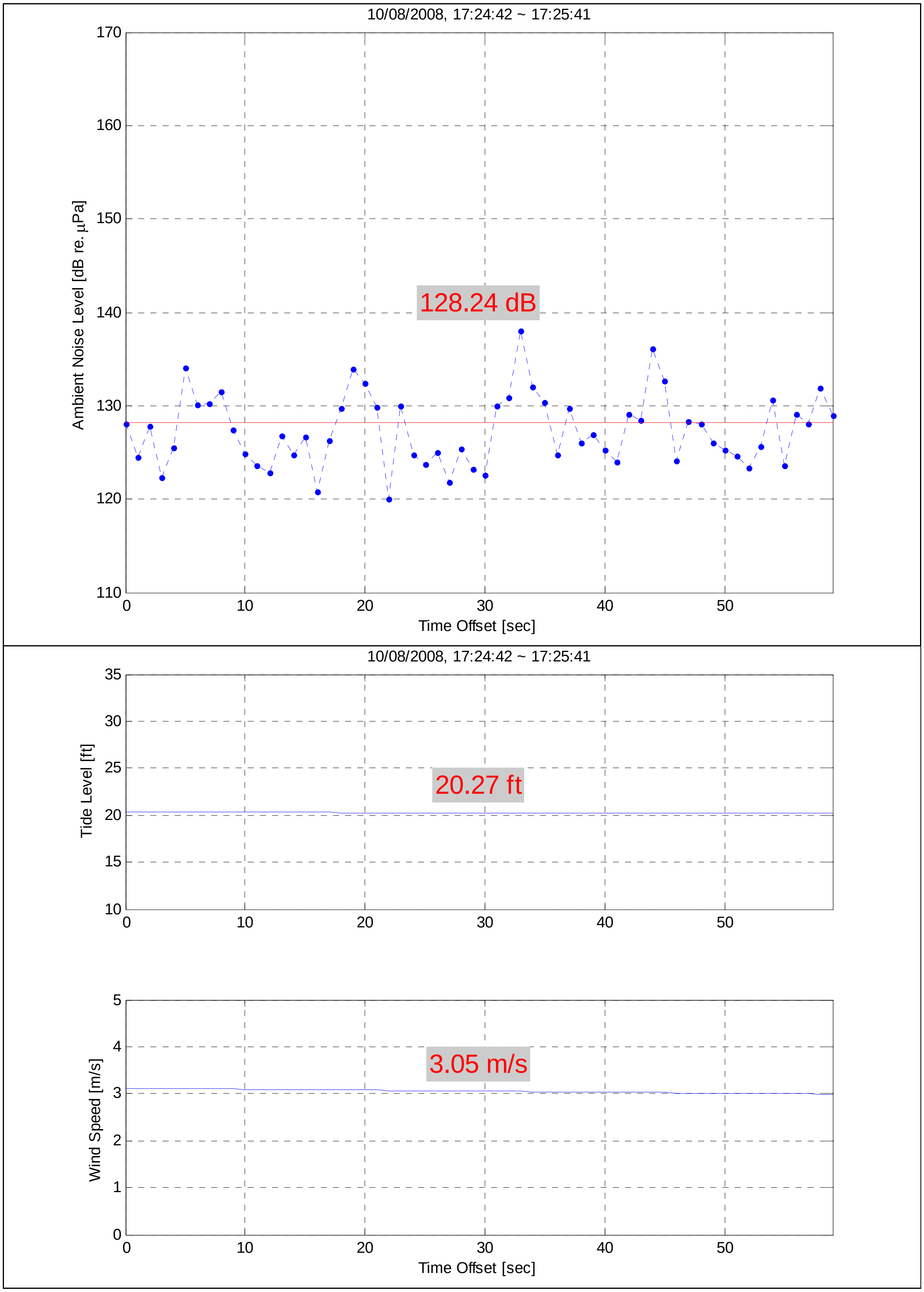

10/08/2008, 17:17:41 ~ 17:18:40
Ambient Noise Level [dB re. μPa]
130.77 dB
Time Offset [sec]
10/08/2008, 17:17:41 ~ 17:18:40
Tide Level [ft]
20.68 ft
Wind Speed [m/s]
2.03 m/s
Time Offset [sec]

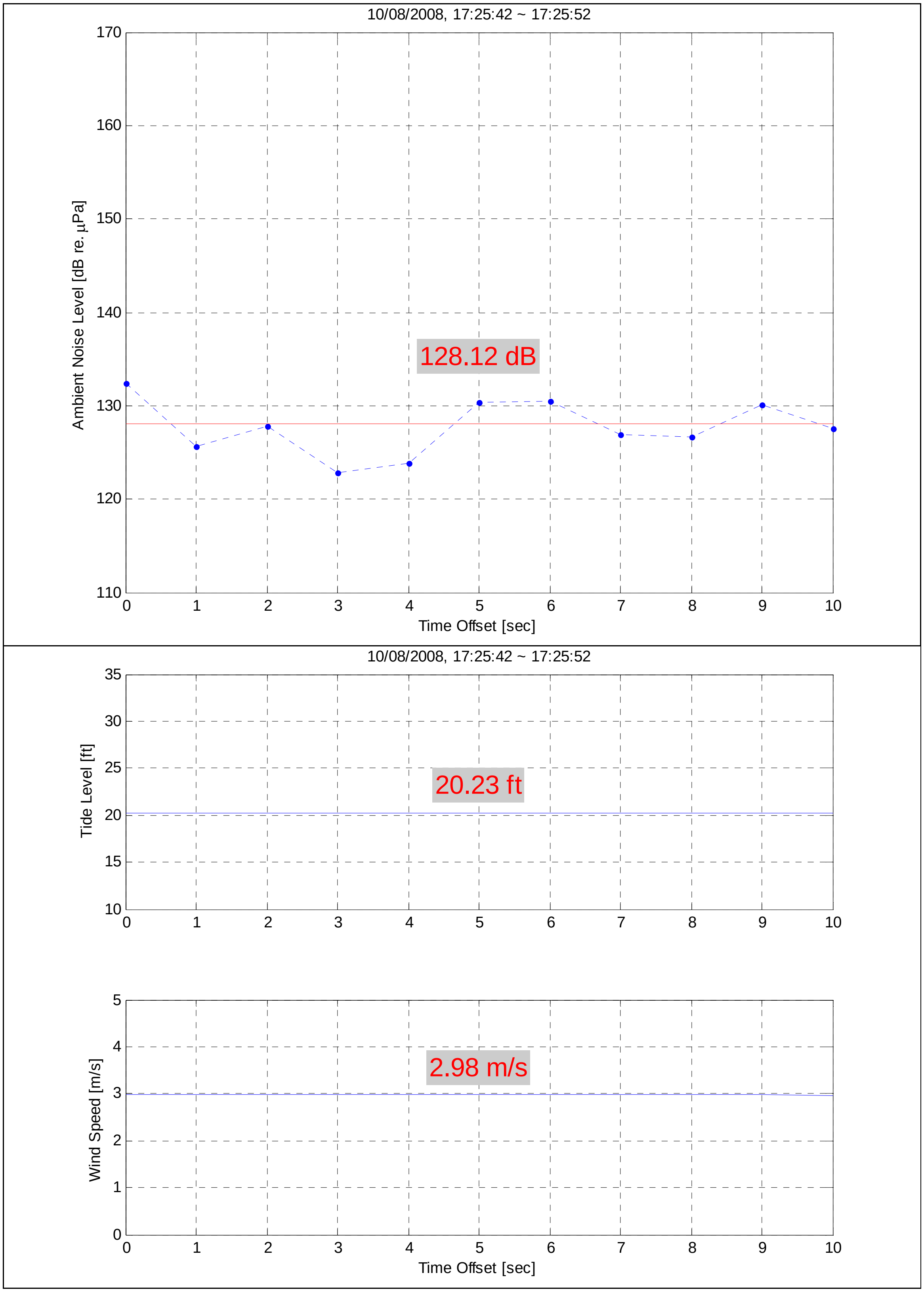

10/08/2008, 17:18:41 ~ 17:19:40
Ambient Noise Level [dB re. µPa]
129.43 dB
170
160
150
140
130
120
110
0
10
20
30
40
50
Time Offset [sec]
10/08/2008, 17:18:41 ~ 17:19:40
Tide Level [ft]
20.62 ft
35
30
25
20
15
10
Wind Speed [m/s]
2.23 m/s
5
4
3
2
1
0
Time Offset [sec]

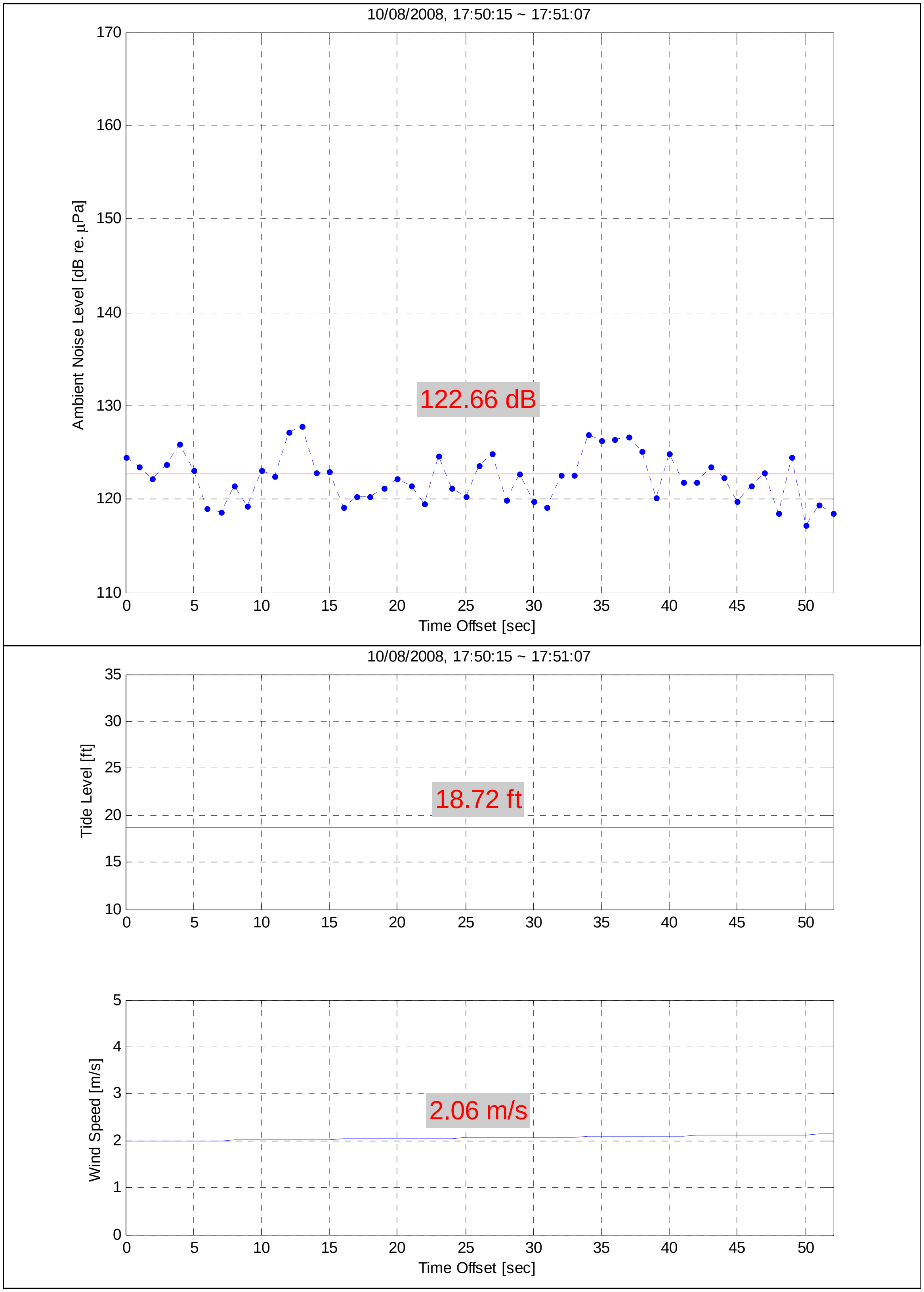

10/08/2008, 17:19:41 ~ 17:20:41
Ambient Noise Level [dB re. µPa]
170
160
150
140
130
120
110
129.01 dB
0
10
20
30
40
50
60
Time Offset [sec]
10/08/2008, 17:19:41 ~ 17:20:41
Tide Level [ft]
35
30
25
20
15
10
20.56 ft
0
10
20
30
40
50
60
Wind Speed [m/s]
5
4
3
2
1
0
2.43 m/s
0
10
20
30
40
50
60
Time Offset [sec]

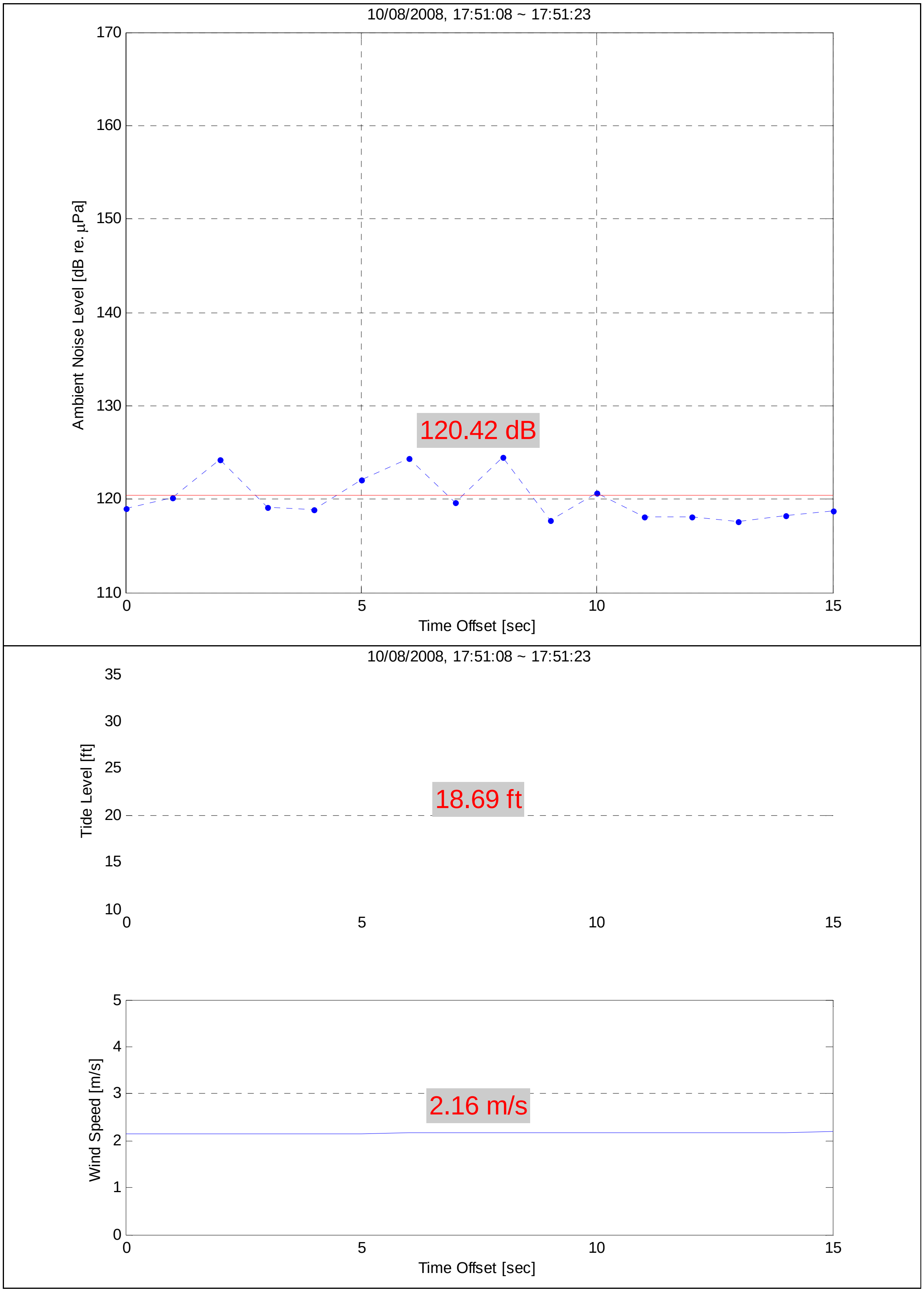

10/08/2008, 17:20:42 ~ 17:21:27
Ambient Noise Level [dB re. µPa]
128.49 dB
Time Offset [sec]
10/08/2008, 17:20:42 ~ 17:21:27
Tide Level [ft]
20.51 ft
Wind Speed [m/s]
2.62 m/s
Time Offset [sec]


10/08/2008, 17:23:57 ~ 17:24:41
Ambient Noise Level [dB re. µPa]
128.50 dB
Time Offset [sec]
10/08/2008, 17:23:57 ~ 17:24:41
Tide Level [ft]
20.32 ft
Wind Speed [m/s]
3.17 m/s
Time Offset [sec]


10/08/2008, 17:24:42 ~ 17:25:41
Ambient Noise Level [dB re. µPa]
128.24 dB
Time Offset [sec]
10/08/2008, 17:24:42 ~ 17:25:41
Tide Level [ft]
20.27 ft
Wind Speed [m/s]
3.05 m/s
Time Offset [sec]


10/08/2008, 17:25:42 ~ 17:25:52
Ambient Noise Level [dB re. µPa]
170
160
150
140
130
120
110
128.12 dB
0
1
2
3
4
5
6
7
8
9
10
Time Offset [sec]
10/08/2008, 17:25:42 ~ 17:25:52
Tide Level [ft]
35
30
25
20
15
10
20.23 ft
Wind Speed [m/s]
5
4
3
2
1
0
2.98 m/s
Time Offset [sec]


10/08/2008, 17:50:15 ~ 17:51:07
Ambient Noise Level [dB re. µPa]
170
160
150
140
130
120
110
122.66 dB
0
5
10
15
20
25
30
35
40
45
50
Time Offset [sec]
10/08/2008, 17:50:15 ~ 17:51:07
Tide Level [ft]
35
30
25
20
15
10
18.72 ft
Wind Speed [m/s]
5
4
3
2
1
0
2.06 m/s
Time Offset [sec]


10/08/2008, 17:51:08 ~ 17:51:23
Ambient Noise Level [dB re. µPa]
170
160
150
140
130
120
110
120.42 dB
0
5
10
15
Time Offset [sec]
10/08/2008, 17:51:08 ~ 17:51:23
Tide Level [ft]
35
30
25
20
15
10
18.69 ft
0
5
10
15
Wind Speed [m/s]
5
4
3
2
1
0
2.16 m/s
0
5
10
15
Time Offset [sec]