

Sound levels associated with pile installation in waters offshore from Piltun Bay, Northeast Sakhalin Island

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ABSTRACT

Sound levels from impulsive sounds associated with onshore pile installation were recorded in 2009 in the offshore waters adjacent to Piltun Bay, Northeast Sakhalin Island, Russia. As in 2008, pile installation included several steps: 1) a hole was drilled to near full deployment depth leaving loose material in place, 2) a pile was put in the hole and vibrated to depth, 3) the pile was driven to design resistance using a pile-driving hammer. Only the pile-driving step led to measureable sound levels in the offshore waters.

An array of acoustic recorders measured sound levels as in previous years. In 2009, supplemental recorders were installed to further characterize the sound field. Sufficient acoustic data were collected to enable development of a model to estimate the sound levels in the immediate offshore area. Sound levels between 99 and 134 dB re 1 μ Pa (rms) were detected in a limited area directly offshore of the construction site. Sound levels were on the order of 110 dB re 1 μ Pa (rms) or less, 7 and 11 km north and south of the installation site, respectively.

Whale distribution data and whale behavior data were also collected during pile installation, as part of the Western Gray Whale monitoring program. Vladimirov et al. (2010), report whale densities in the Piltun Feeding Area as substantially higher in 2009 compared with 2008. This included observations immediately offshore from the pile installation activity.

KEYWORDS: ACOUSTICS, MODELLING, MONITORING

INTRODUCTION

The Sakhalin-1 project is located offshore Northeast Sakhalin Island in the vicinity of the feeding areas of Western Gray Whales (WGW). The consortium is operated by Exxon Neftegas Limited (ENL). ENL cosponsors the Western Gray Whale monitoring program along with Sakhalin Energy Investment Company, operators of the Sakhalin-2 project.

In 2008 and 2009, ENL installed piles at the Odoptu-North construction site for foundation support for operations such as drilling of extended reach wells from shore to develop the offshore Odoptu field without the use of an offshore platform. Pile installation involved drilling a hole leaving the loose material in place, vibrating the pile into the hole, and pile driving to design resistance. The only step with the potential to affect sound levels offshore is the pile-driving step.

In 2008, logs show that no pile driving occurred between July 5 and September 9 (Figure 1a). In 2009, pile installation took place between April 8 and September 12 (Figure 1b). Pile installation occurred during the day and for discrete time periods (i.e., not continuous during the day). No pile-driving operations occurred at night.

Figure 1c is a plot of pile installation time by day and illustrates clearly the period of time that pile installation activities were occurring; the plot shows that for the majority of the period, pile installation was performed for less than 3 hours/day. Pile installation was conducted for more than 4 hours/day for only 7 days and pile installation was never conducted for more than 5 hours/day. The average daily duty-cycle over the period is approximately 2.25 hours/day (~10%).

In 2009 a comprehensive monitoring program was executed in the Odoptu area with the goal of monitoring autonomously (and, for a limited dataset, in real-time) the acoustic signature of low frequency impulsive acoustic signals generated onshore during foundation pile driving and recorded in the waters adjacent to the Odoptu construction site.

METHODS

In both 2008 and 2009, acoustic measurements were taken during the western gray whale feeding season by several Autonomous Underwater Acoustic Recorders (AUAR) deployed at a number of fixed offshore locations as part of the WGW Monitoring Program (Figure 2). AUAR deployment stations in the Odoptu area are shown in Figure 3. In 2009, additional temporary buoys were deployed at several locations for short periods of time (days) to characterize the sound field more completely (Figure 4). Figure 4 shows a map of the Odoptu area with the location of the annual WGW acoustic monitoring stations A9, Odoptu-N-10, Odoptu-N-20, Odoptu-S-10, Odoptu-S-20 and locations where additional temporary recorders (AUAR, mini-AUAR) and the Mollusk-07 vertical array were deployed. Mini-AUARs were sequentially deployed at locations T.1 to T.6, P.1 to P.6, and R.1 to R.5. To monitor sound from pile installation in real time, digital transmitting AUARs (DT-AUAR) buoys were deployed at Odoptu-N-10 and Odoptu-N-20 stations from June 15 to September 14, 2009.

Measurements from AUAR stations were used to assess sound pressure levels when pile installation took place and provide a basis to estimate the sound pressure field. Data from the additional recorders was used to construct a propagation model for the Odoptu area.

RESULTS

Temporal Analysis of Acoustic Data

The following describes the temporal characteristics of the low-frequency pulses generated by pile-installation activities at the Odoptu site and measured synchronously at the stations indicated in Figure 3. Figure 5 shows a time series approximately 10 seconds long recorded at the Odoptu-N-10 and Odoptu-N-20 stations at 14:45 on June 17, 2009. These plots demonstrate that the impulses were produced at a repetition rate of approximately 1.5 blows/second which is in line with the operational blow rate (Delmag D62-22 diesel pile hammer, 1.2-1.7 blows/second). Figure 5 shows that at the Odoptu-N-10 station the peak pressure reaches ~10 Pa (~140 dB re 1 μ Pa), and ~5 Pa (~139 dB re 1 μ Pa) at the Odoptu-N-20 station. The plot shows that the acoustic impulse from a hammer strike arrives at the Odoptu-N-10 station first and a second or two later reaches the Odoptu-N-20 station.

Figure 6 shows five pile blows as recorded for one of the loudest piles on all the stations in the Odoptu area. This illustrates clearly the change in transmission loss with distance from the Odoptu site and depth at the monitoring location and shows that the impulses can not be seen above the ambient noise at station A10 to the north and Odoptu-PA-B to the south.

These Figures suggest that energy transferred through the pile couples into the ground and propagates in a form of a low frequency impulse, thereafter coupling into the water; thus the area adjacent to the Odoptu camp is effectively ensonified. The low frequency pulses generated by pile installation at the Odoptu site were recorded at the A9, Odoptu-N-10, Odoptu-N-20, Odoptu-S-10, and Odoptu-S-20 stations. The pulses could only be seen in favorable weather and low ambient noise conditions at the Odoptu-PA-B station (southernmost station). The pulses were not found in the acoustic recordings for the A10 station (north).

Figure 7 gives a plot of the distribution of RMS sound pressure level (SPL_{rms}) and sound exposure level (SEL) for all the piles analyzed during the 2009 field season. This plot shows that maximum SPL_{rms} and SEL values vary significantly from pile to pile due to pile location and characteristics and the subsurface conditions near the pile.

SPL_{rms} is computed within the 90% energy window

$$SPL_{rms} = 20 \log_{10} \sqrt{\left(\frac{\sum (P_i^2 dt)}{T_{imp(90\%)}} \right)}$$

SEL is computed within the 90% energy window:

$$SEL = 10 \log_{10} \left(\sum_{T_{imp(90\%)}} (P_i^2 dt) \right)$$

$$dt = \frac{1}{f_d}$$

Where: P_i is the pressure time series.
 T_{imp} is the time duration of the impulse containing 90% of the impulse energy. (i.e. the time at which 5% of the impulse energy has been accumulated to the time when 95% of the impulse energy has been accumulated)
 f_d is the sample rate.

Spectral analysis

The data from almost all the piles has been analyzed. The following summarizes the type of information for a single pile and is representative of what will be developed for a subset of piles. Figure 8a shows sonograms from a single pile taken from different recording stations (Figure 3). For each installation of a pile, sound level generally (though not always) increased over the pile driving step as the pile neared completion. This is shown in Figure 8b as SPL and SEL increase over the installation of a pile. Figure 8c shows the data in 1/3 octave bands at each of the monitoring stations.

Propagation models

A numerical propagation model was constructed using the data collected from both the fixed and temporary AUAR and mini-AUAR recordings during the installation of several piles (Figure 4). This model was iteratively calibrated against actual acoustic data, and was modified to show the effect of a permafrost layer. Figure 9 shows the results from the modeling of one loud pile and one quiet pile. Estimation of these sound fields will enable assignment of a sound level to a given geographic position and enable prediction of sound levels as a function of location and time.

Whale distribution

Preliminary analyses of data collected as part of the joint ENL-SEIC WGW monitoring program indicate that, in 2008, whale densities were low throughout the feeding season in the Piltun Feeding Area (Vladimirov 2009). Recall that piles were not installed between July 5 and September 9, 2008. Whale densities in the Piltun Area were higher in 2009 than in 2008 and included increased densities immediately offshore from the construction site (Vladimirov 2010). Whale distribution and behavior data are being analyzed using multivariate techniques to further understand the potential link between onshore pile installation activities (sound exposure) and the abundance, location, and behavior of whales.

SUMMARY AND CONCLUSIONS

ENL sponsored a significant monitoring effort associated with the construction activities at the Odoptu North site in 2009. Efforts were aimed at gaining a better understanding of the propagation of impulsive sounds generated by the onshore pile driving.

A summary of the data analyses and models are presented in this paper, although further analyses are still underway. Future work will focus on understanding the factors that control propagation in the area and may include effects of a patchy permafrost layer in the area.

The ensonification maps show that propagation of impulses from pile-driving is highly directional toward the east and sound levels drop off rapidly toward the north and south. This would tend to limit exposure of feeding gray whales to elevated sound levels. Sound levels within the feeding area from analyzed piles suggest sound pressure levels between 134.3 to 98.7 dB re 1 μ Pa (rms) which are below levels believed to cause significant behavioral reactions in 10% of feeding gray whales for impulse sounds (Malme et al. 1988). The data set collected in 2009 can be used to verify whale behavioral thresholds for pile driving sounds.

Whale densities directly offshore of the pile driving station were higher during 2009 than during 2008 when no pile driving occurred between July 5 and September 9. In addition, whale densities in the overall Piltun feeding area were higher in 2009 compared to 2008, with levels comparable to 2007 data (when no ENL construction or pile-driving activities took place). Plans for multivariate analyses that combine acoustics, abundance, and behavioral data, and which build upon past analytical frameworks (Gailey et al. 2007) are underway to further investigate the effects that sound from pile installation activities may have on western gray whales.

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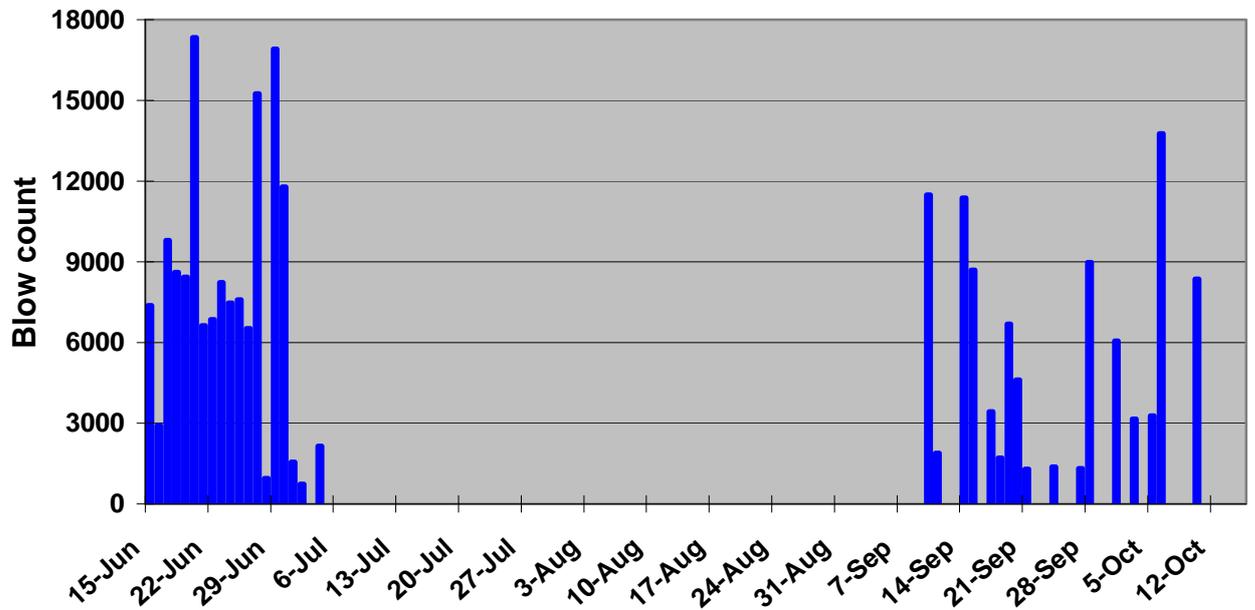


Figure 1(a): Pile-installation hit count per day (from machine logbooks) at the Odoptu site in 2008

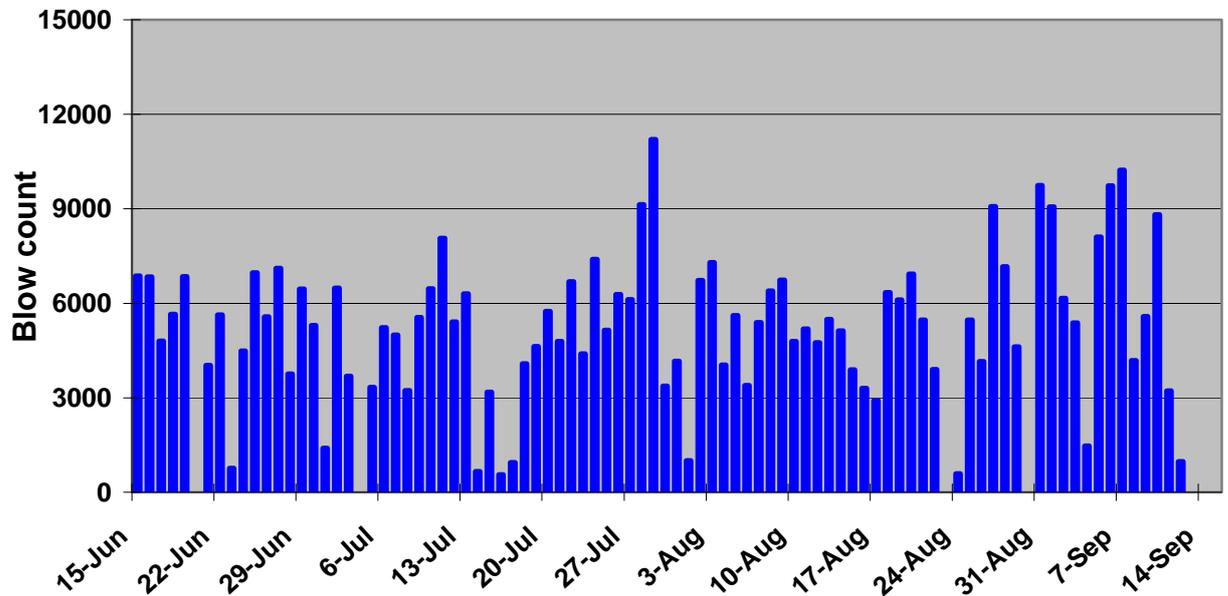


Figure 1(b): Pile-installation hit count per day (from machine logbooks) at the Odoptu site in summer 2009

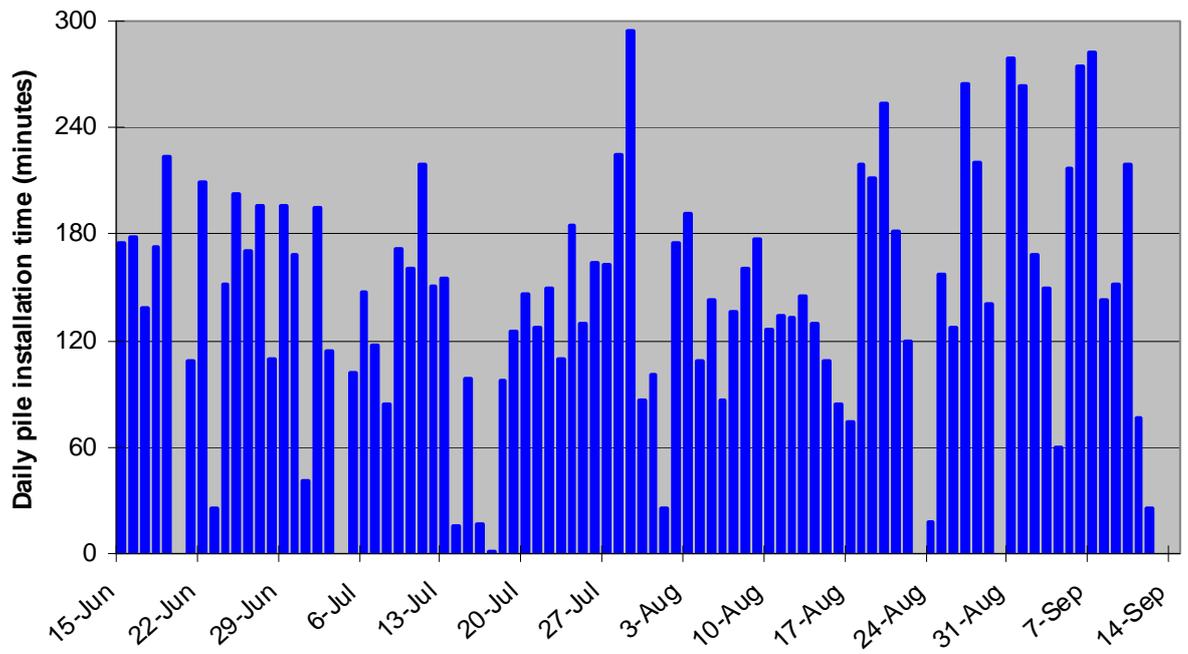


Figure 1(c): Total (non-continuous) pile-installation time per day (from machine logbooks) at the Odoptu site in summer 2009

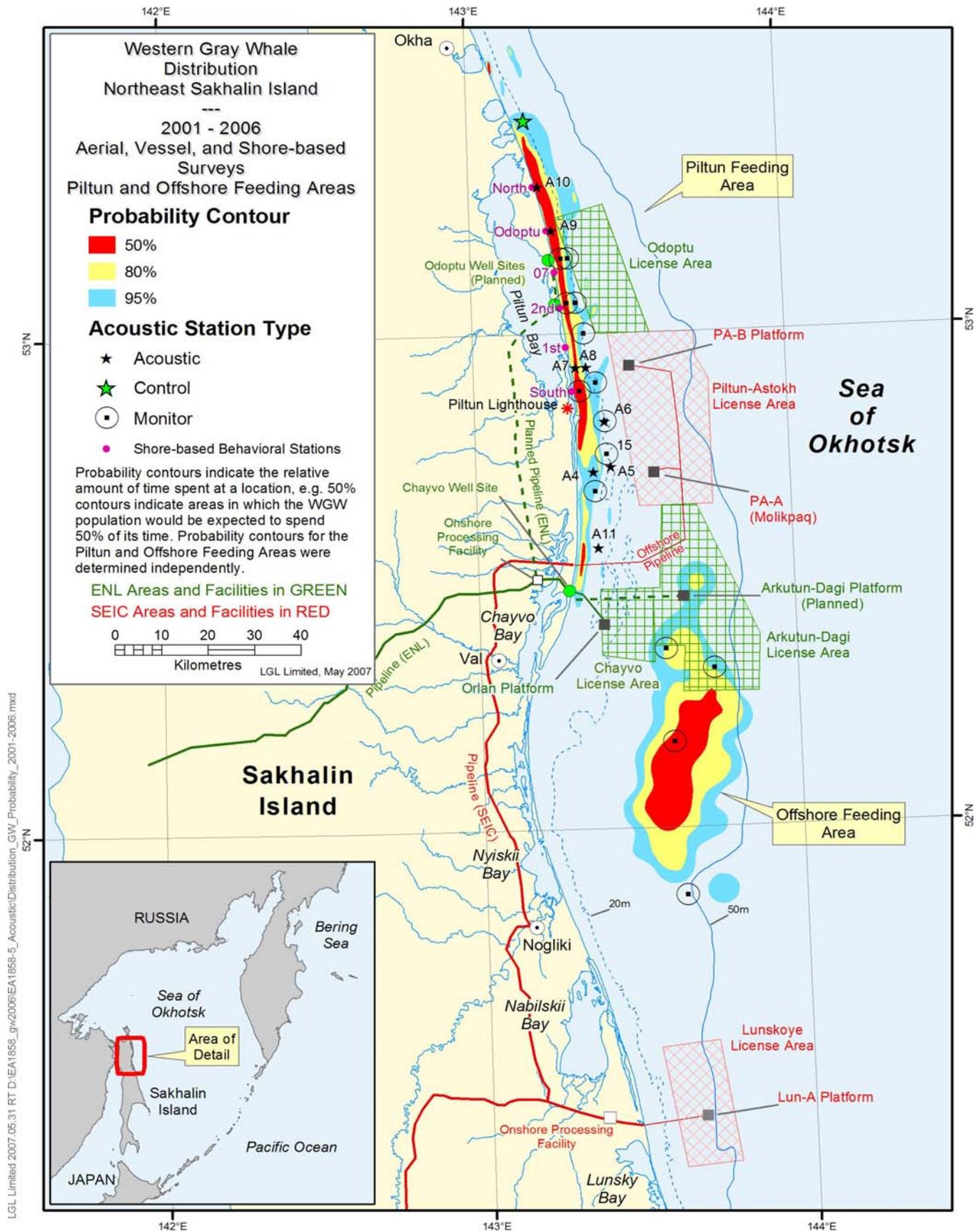


Figure 2: Map showing the western gray whale distribution (2001-2006) and AUAR deployment locations

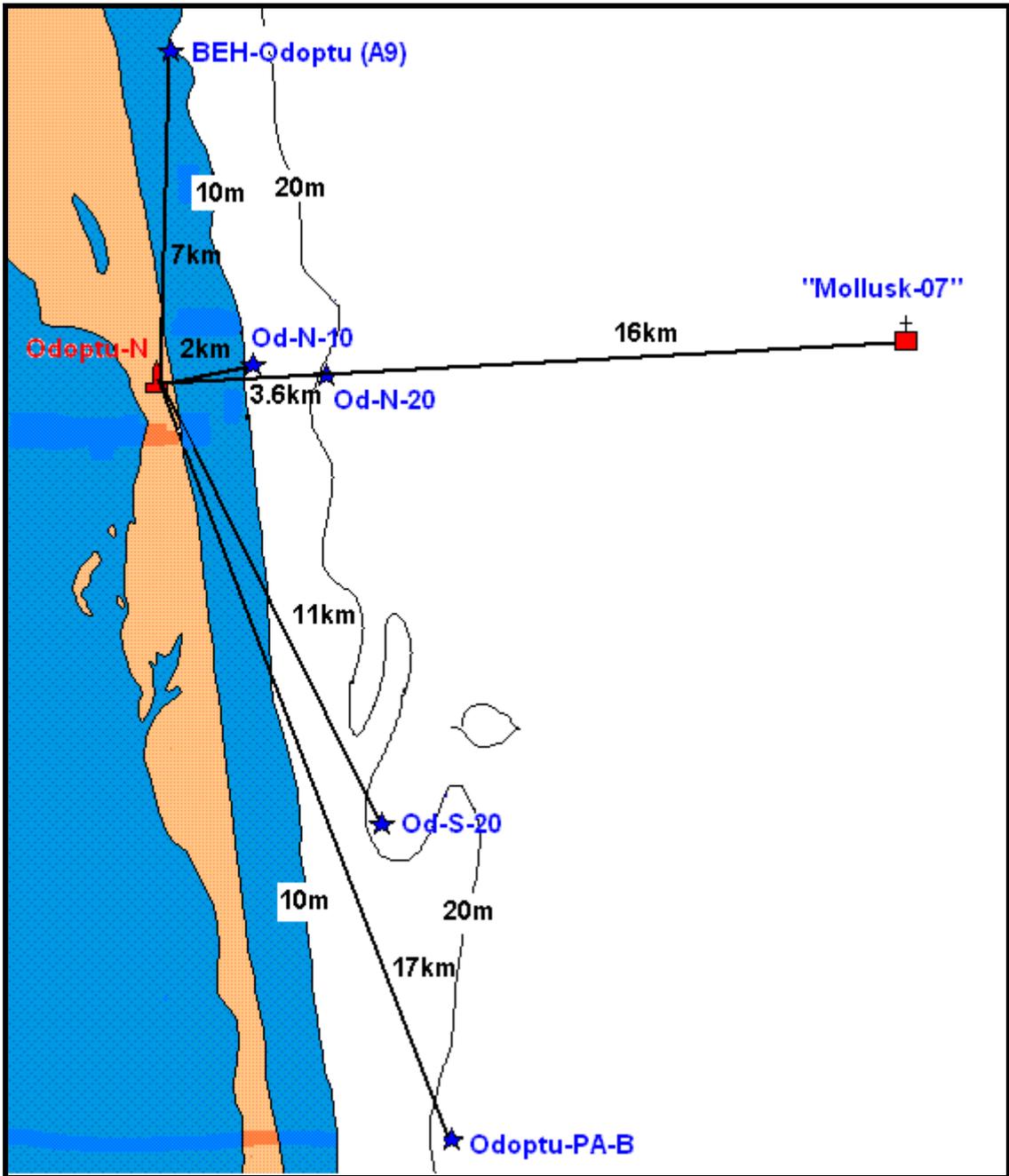


Figure 3: Location of AUAR stations in the Odoptu area and approximate sound levels at these stations during the 2008 pile-installation activities between September 10-19. Station A10 (not shown) is north from station A9.

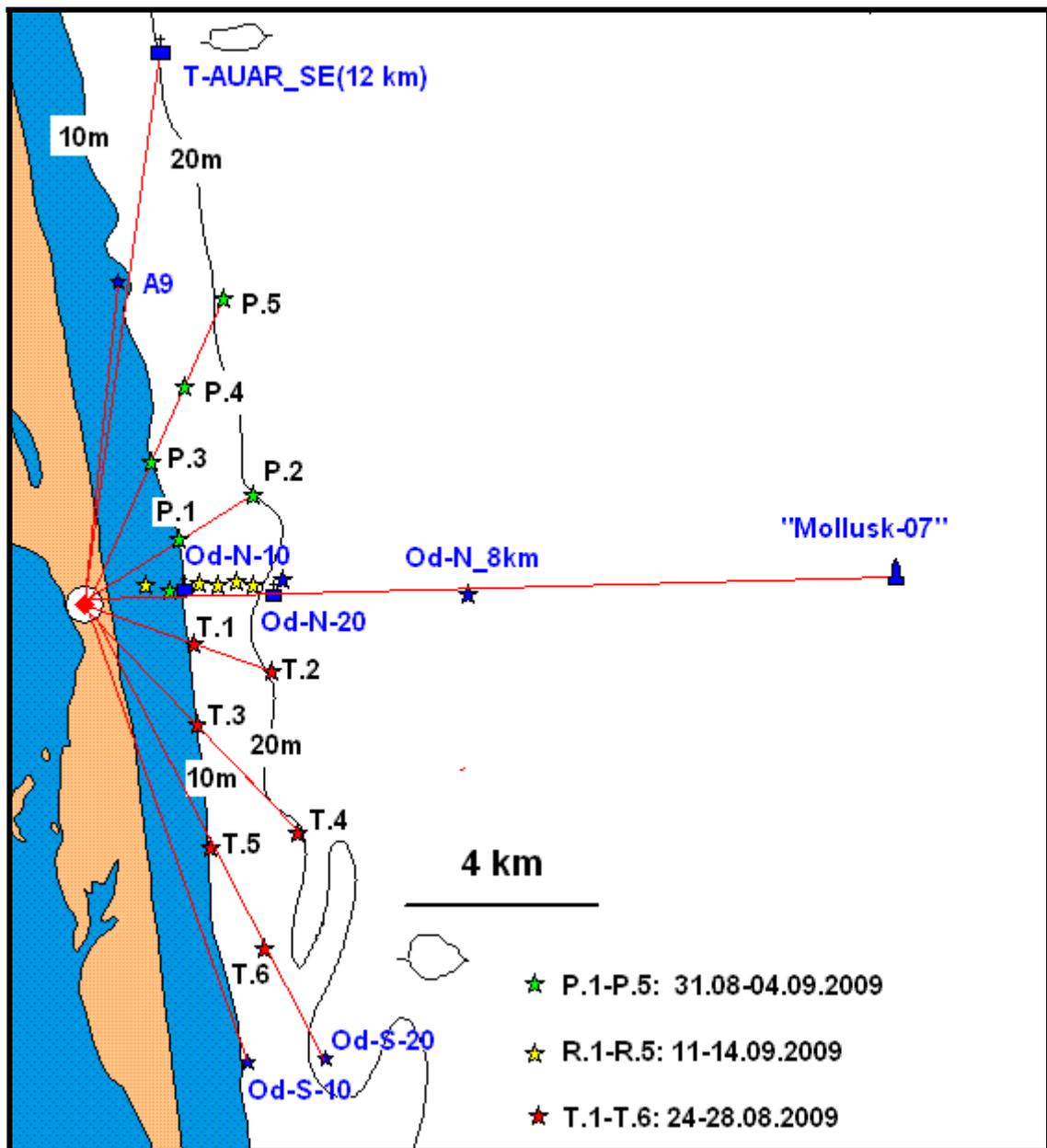


Figure 4: Map of the area with the location of the monitoring station and the profiles used for propagation studies of low frequency signals generated during pile installation at the Odoptu camp onshore in 2009. Station A10 (not shown) is north from station A9.

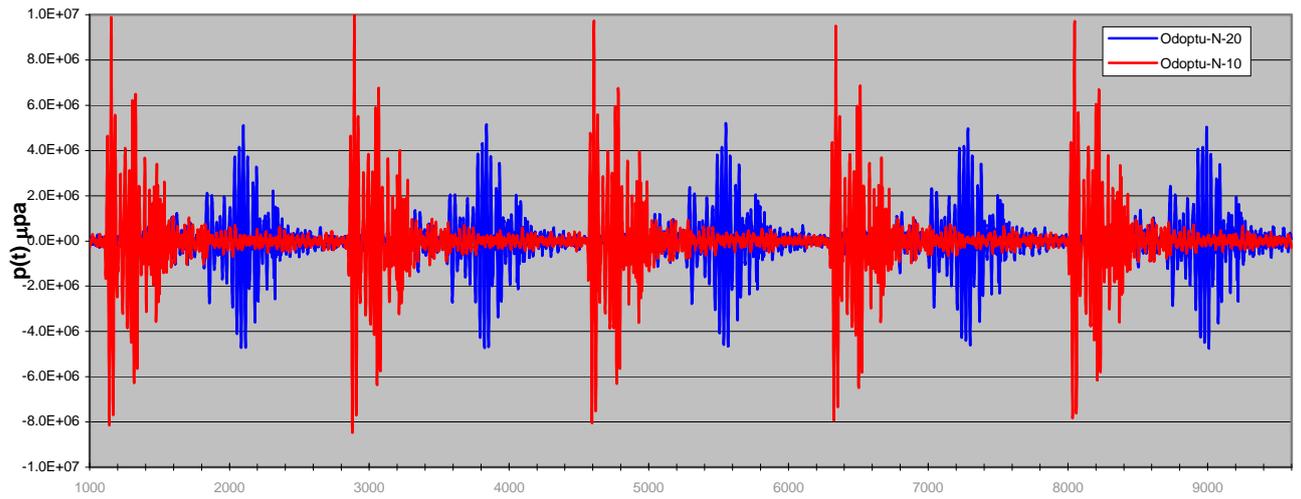


Figure 5: Plot of five pulses in the time domain for both the Odoptu-N-10 (red) and Odoptu-N-20 (blue) - 14:45 17th June 2009.

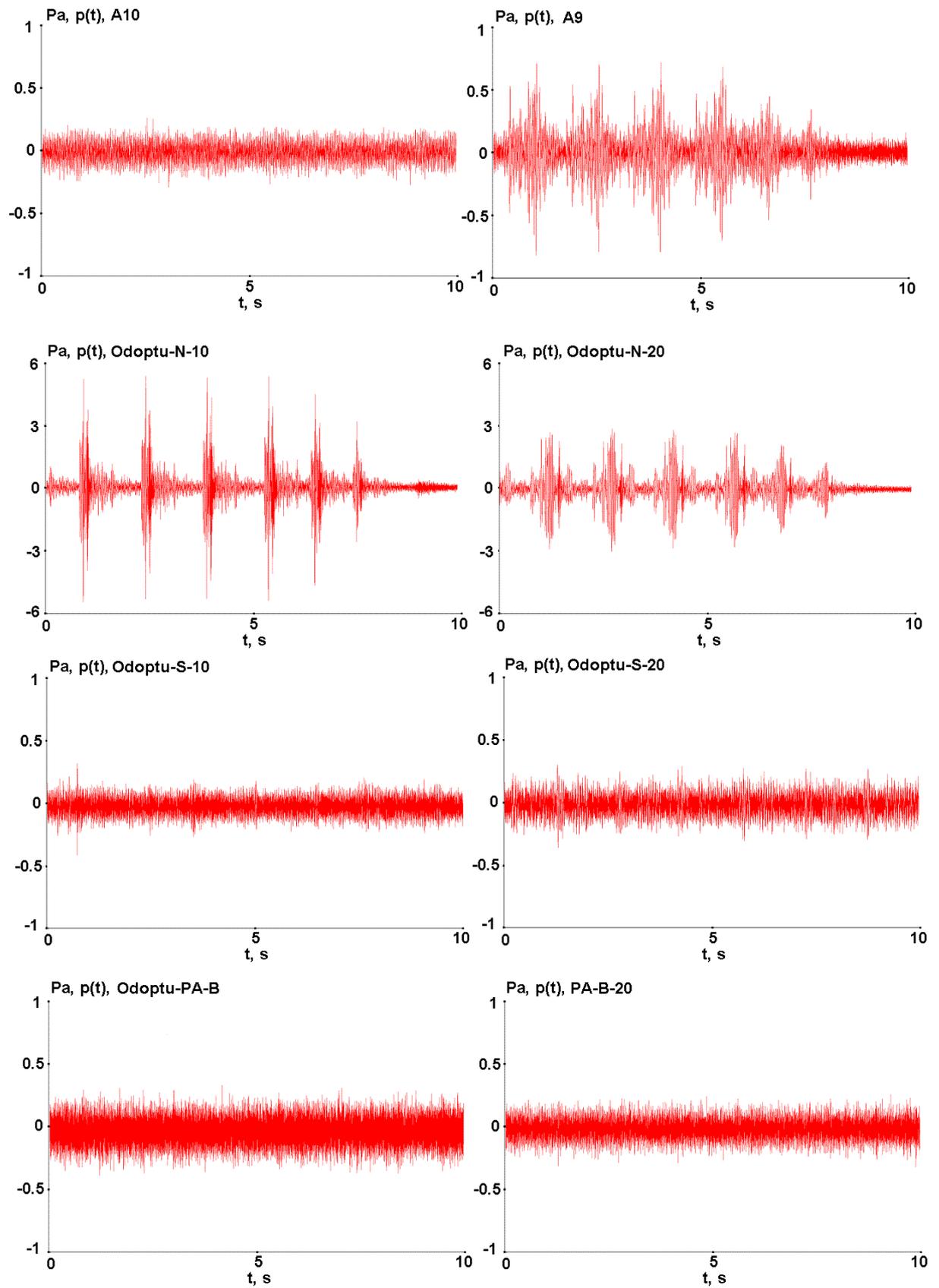


Figure 6: Acoustic pressure $p(t)$ recorded at the water bottom by AUARs deployed at the A10, A9, Odoptu-N-10, Odoptu-N-20, Odoptu-S-10, Odoptu-S-20, Odoptu-PA-B and PA-B-20 acoustic monitoring stations during the installation of one single pile at the Odoptu site.

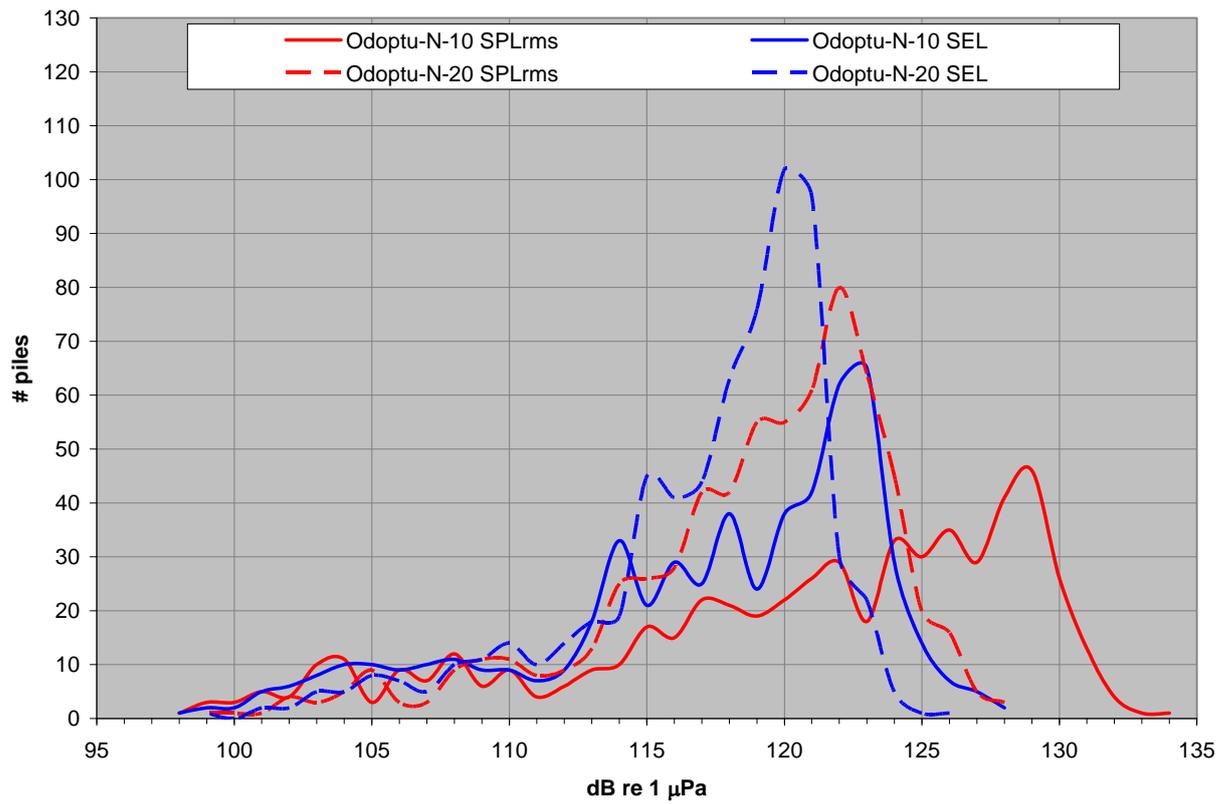


Figure 7: Distribution of maximum RMS sound pressure level and sound exposure level recorded at the water bottom by AUARs deployed at the Odoptu-N-10 and Odoptu-N-20 acoustic monitoring stations for each pile analyzed. The value at each integer represents the number of piles with a level between the integer and the next larger integer.

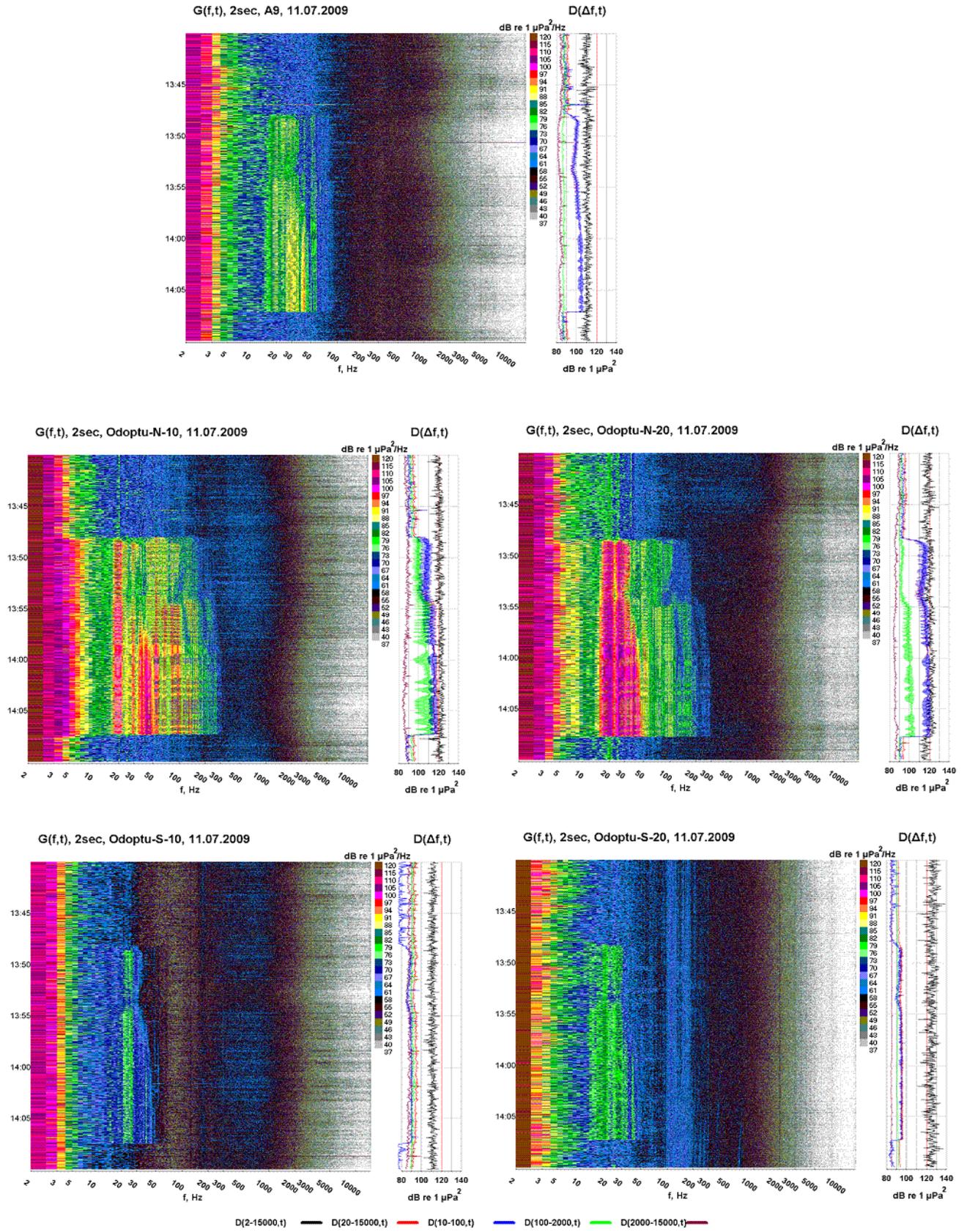


Figure 8(a): Sonograms $G(f,t)$ of data recorded at the water bottom by AUARs deployed at the A9, Odoptu-N-10, Odoptu-N-20, Odoptu-S-10, and Odoptu-S-20 acoustic monitoring stations.

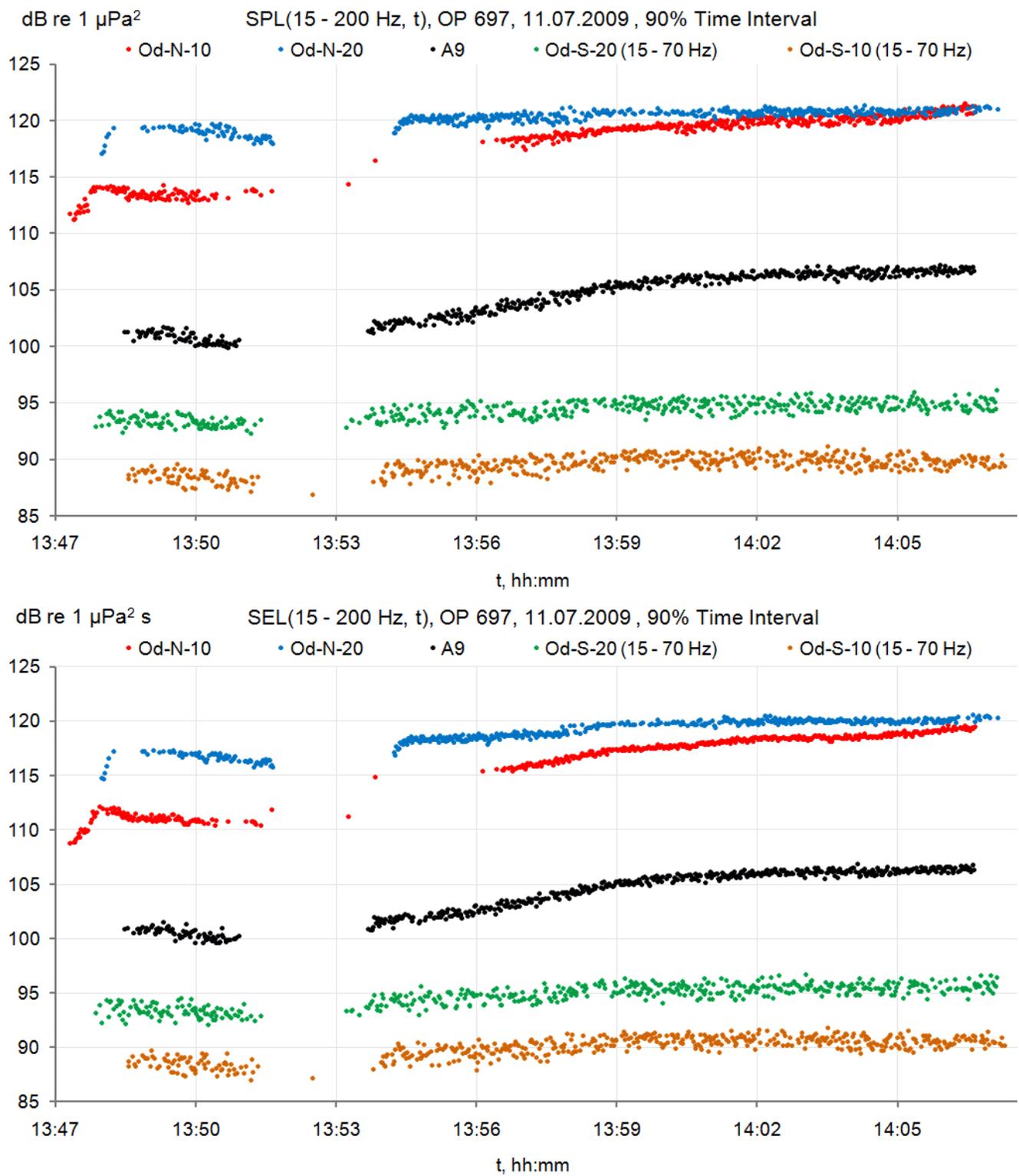


Figure 8(b): Plots of SPL & SEL (15 Hz-200 Hz – unless otherwise noted) recorded at the water bottom by AUARs deployed at the A9, Odoptu-N-10, Odoptu-N-20, Odoptu-S-10, and Odoptu-S-20 acoustic monitoring stations during installation of one single pile at the Odoptu site.

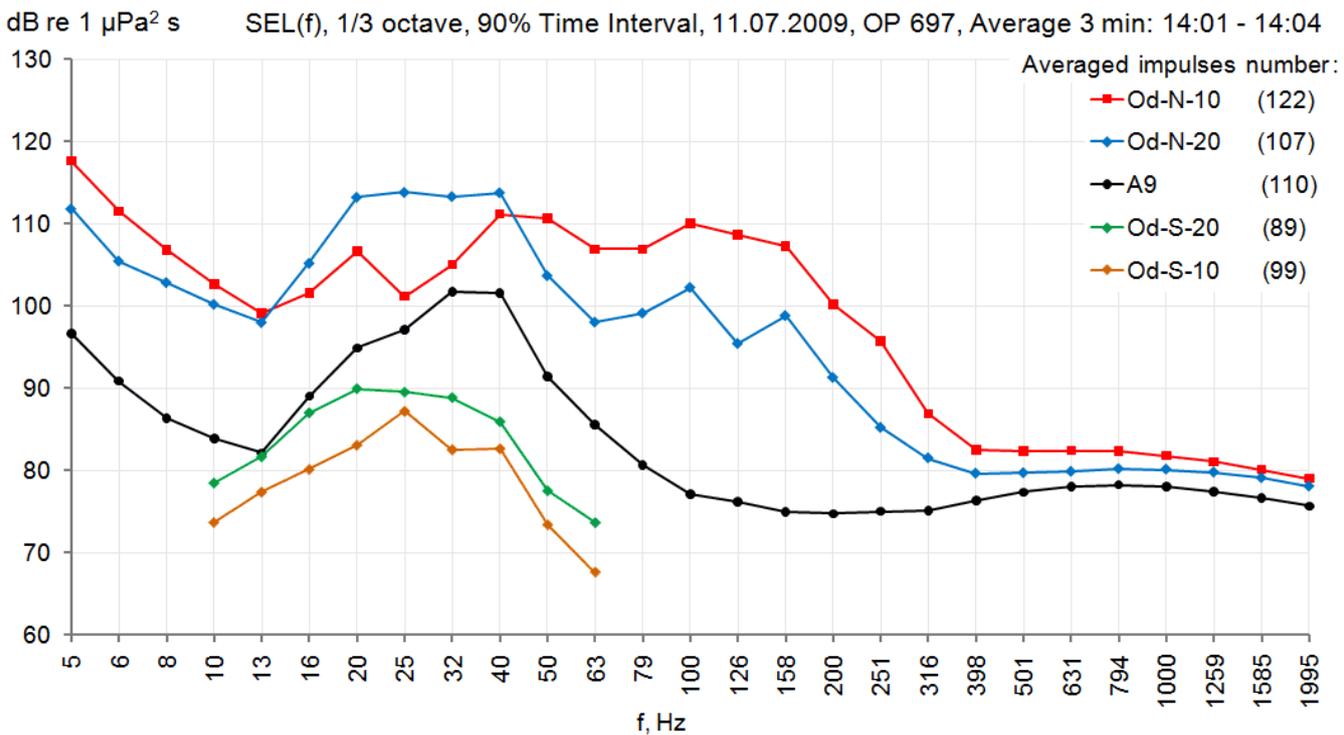
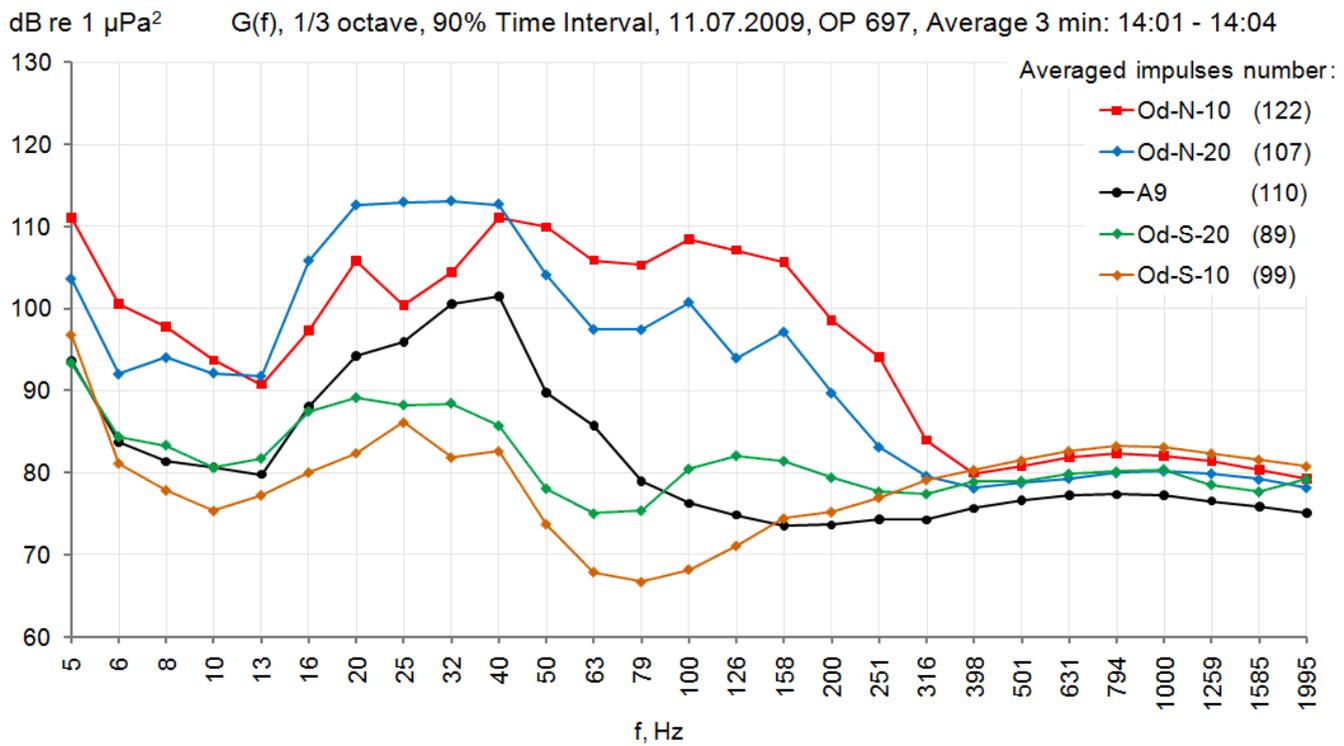


Figure 8(c): Plots of one third octave spectra (15 Hz-200 Hz – unless otherwise noted) recorded at the water bottom by AUARs deployed at the A9, Odoptu-N-10, Odoptu-N-20, Odoptu-S-10 and Odoptu-S-20 acoustic monitoring stations during installation of one single pile at the Odoptu site.

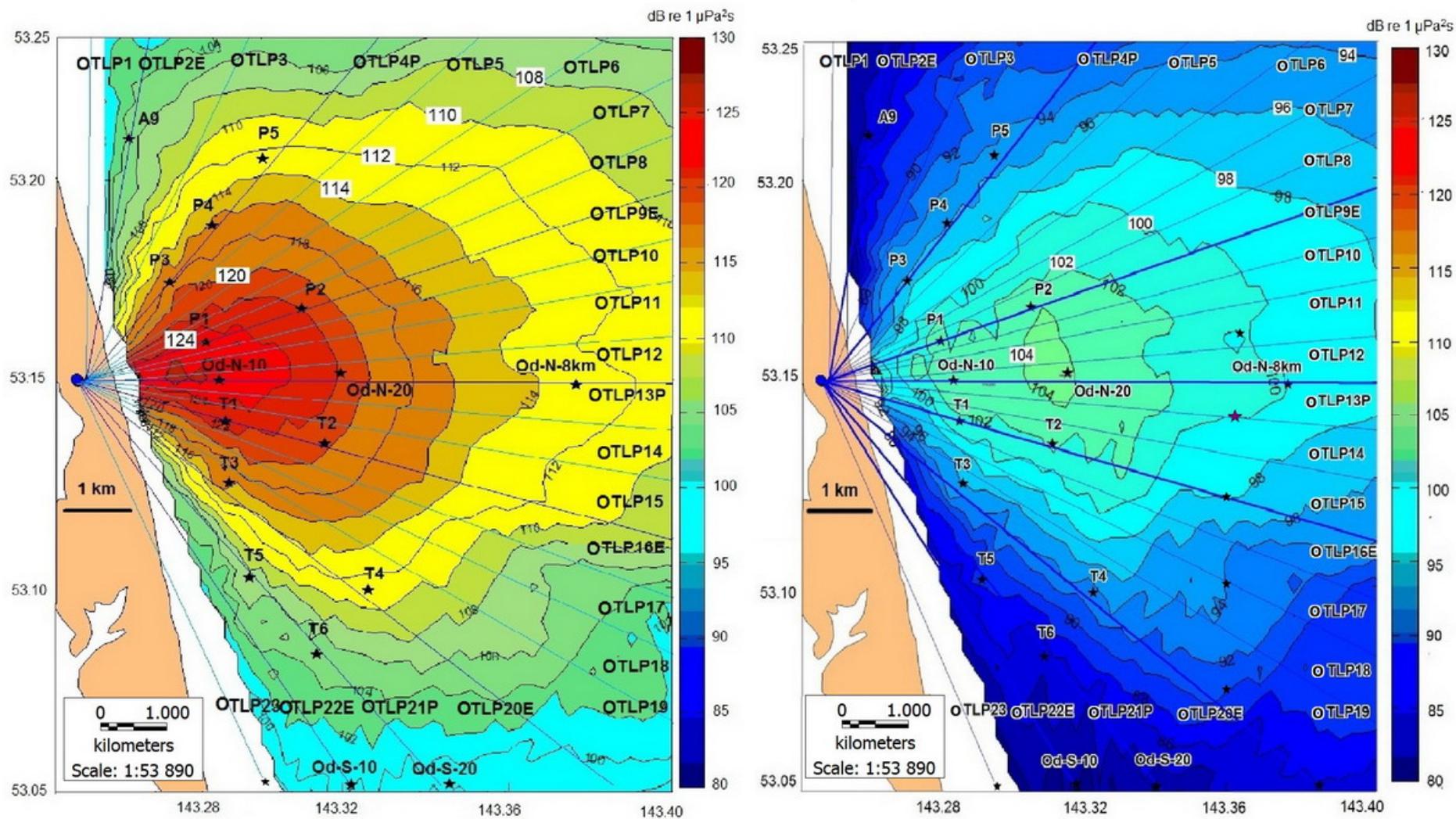


Figure 9(a): Theoretical (model-based) distribution of SEL values for one of the loudest piles (ON-270) and one of the the quietest piles (ON-510) recorded in 2009. Model based on elastic propagation and measured data using full array of buoys for calibration.

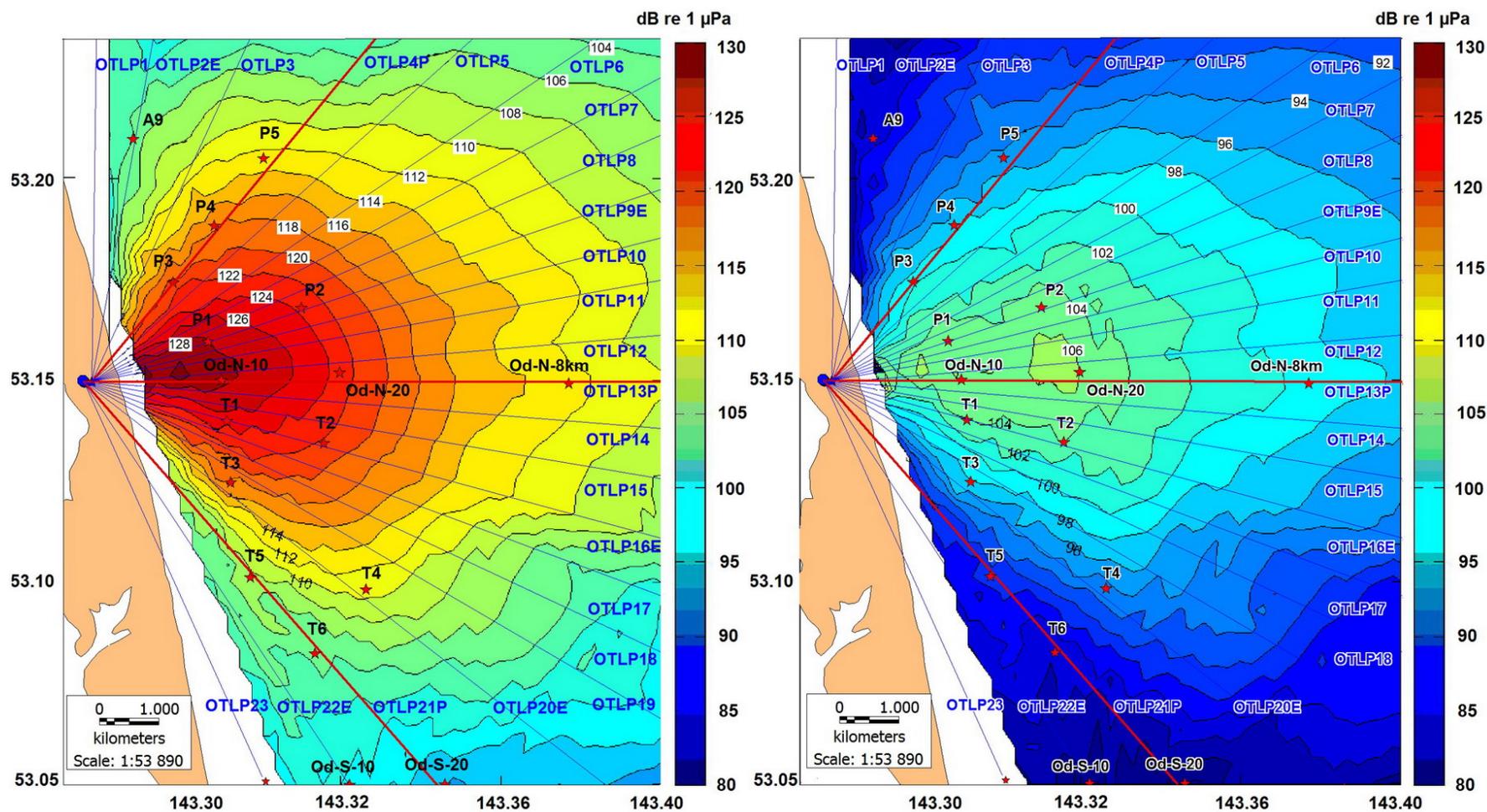


Figure 9(b): Theoretical (model-based) distribution of SPL_{rms} values for one of the loudest piles (ON-270) and one of the quietest piles (ON-510) recorded in 2009. Model based on elastic propagation and measured data using full array of buoys for calibration.