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Geoacoustic Physical Modeling Elastic Parabolic Equation 1 (GPM EPE1) Experiment: Measurement Report and Acoustic Data

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14. ABSTRACT

Researchers in the NRL Acoustics Division performed a tank experiment at the NRL Shallow Water Acoustic Laboratory in April 2004 to verify the predictions of elastic parabolic equation models for acoustic propagation. The experiment employed a sheet of elastic material (PVC) to replicate an elastic ocean bottom. The recorded data are suitable for testing methods of inverting for the acoustical properties of the material. This report gives an overview of the experiment, describes the acoustic source and receiver placements, presents displays of the raw time series and transfer function data, and is designed to allow a user to select and obtain data for analysis. Included on the compact disc are a brief report on the laboratory measurement of material properties of PVC samples, a description of the data file formats, Matlab scripts for reading the data files, and the acoustic data files themselves.

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Parabolic equation; Elastic media; Acoustic propagation; Geoacoustic inversion; Physical modeling

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Geoacoustic Physical Modeling Elastic Parabolic Equation 1 (GPM EPE1) Experiment: Measurement Report and Acoustic Data

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Introduction

The Naval Research Laboratory (NRL) has recently performed experiments with scale models of the ocean bottom under the Geoacoustic Physical Modeling (GPM) project. These experiments have been designed to verify the predictions of acoustic scattering and propagation models. In 2003 and 2004, the experiments Rough Surface Scattering 1 (GPM RSS1), Subsurface Imaging 1 (GPM SI1), Elastic Parabolic Equation 1 (GPM EPE1), and Rough Surface Scattering 2 (GPM RSS2) have been performed. The EPE1 experiment, described in this report, was performed at the Shallow Water Acoustic Laboratory in NRL/Washington DC Building 71 in April 2004 and employed a flat PVC sheet (4' x 4' x 4'') from San Diego Plastics. A rough PVC surface from an unknown manufacturer was used in the other experiments. The RSS2 experiment is documented under a separate NRL Memorandum Report [1]. The point of contact for the SI1 experiment is Dr. Dennis Lindwall of NRL/Stennis Space Center (Code 7430).

The EPE1 experiment was designed to measure the acoustic propagation in a simulated waveguide with an elastic bottom in the frequency band 100-300 kHz, in order to verify the predictions of elastic parabolic equation codes developed at the Naval Research Laboratory [2,3]. Two samples of PVC Type 1 Gray material (nominally 38mm x 38mm x 19mm) from San Diego Plastics were analyzed for acoustic properties in the band 300 kHz to 1.5 MHz by Professor De-Hua Han, Director of the Rock Physics Lab at the University of Houston. A summary of the estimated results at 300 kHz is given in Table 1 – this is at the lower limit of the frequency band for lab analysis and the lab analysis report, included on the CD in the file 'PVCanalysis_sdpied.pdf', should be consulted for more information[1]. For information on the accuracy and frequency dependence of the parameters given in Table 1, see the lab analysis report. The acoustic parameters of the water in the tank are sound speed[2] = 1482 m/s and density = 1.00 g/cc.

Parameter	Value
Density (kg/m^3)	1378
Compressional Speed (m/s)	2290
Compressional Attenuation (dB/m/kHz)	0.33
Shear Speed (m/s)	1050
Shear Attenuation (dB/m/kHz)	1.0

Table 1: Estimated properties of the PVC material at 300 kHz.

[1] Note that the frequency band for the lab analysis (300 kHz to 1.5 MHz) is higher than the frequency band for the acoustic tank experiment (100 kHz to 300 kHz). The lab analysis was restricted to a higher band because of the difficulty of finding an acoustic source that could produce the needed sound level without ringing. Lab analysis at 100 kHz to 300 kHz is scheduled for 2005 with newly purchased sources. The higher frequency results allow for plausible extrapolation to the lower frequency result, but the effect of any resulting error depends on the specific application.

[2] The temperature may have varied a degree or so around 20 deg C, which creates a range of values of roughly 1481-1483 m/s.

This report consists of four main sections to help the user of the database in understanding and reading the experimental data. The four sections are:

- Experimental Summary
- Acoustic Data Format
- Matlab IO m-scripts
- Appendix A. Acoustic Data Overview

The Experimental Summary provides reference tables for the acoustic data files and their associated source and receiver positions. The Acoustic Data Format section briefly discusses the general aspects of the data configuration and the relevant information a user will need to process the data files. The Matlab section details the m-scripts that can be used to read and manipulate the binary data. Finally, Appendix A provides time and frequency graphs for each data set. This should help the user identify specific experimental runs for processing and manipulation.

Experimental Summary

A series of 10 experimental runs were conducted to study shallow water sound propagation over an elastic bottom. For the first series of runs the PVC sheet was suspended horizontally[3] at a depth of 15 cm, parallel to the air-water interface. The spherical, omni-directional source hydrophone was placed at depths of 7.50 cm and 14.55 cm, and the receiver hydrophone, of identical manufacture to the source, was moved in both horizontal and vertical directions in a range 25 cm to 135 cm from the edge of the sheet (see Figure 1). Moving the receiver in vertical and horizontal directions and collecting data at equally spaced positions produced vertical and horizontal virtual apertures. A time series obtained for a particular source/receiver position is referred to as a "record"; the number of records a data file is simply the number of receiver positions included in the file. Each data set along with the associated file name is detailed in Table 2.

For the second set of experimental runs, the PVC sheet was slanted, sloping from 15.05 cm to 4.95 cm below the water surface end to end. The source hydrophone was placed at depths of 6.90 cm and 13.55 cm at a horizontal position of 15 cm and the receiver was placed at horizontal positions between 25 cm and 135 cm in virtual horizontal, vertical, and slanted apertures (see Figure 2). Each data set along with the associated file name is detailed in Table 3.

[3] There was a nominal 2 mm difference between the horizontal position of a corner and its opposite.

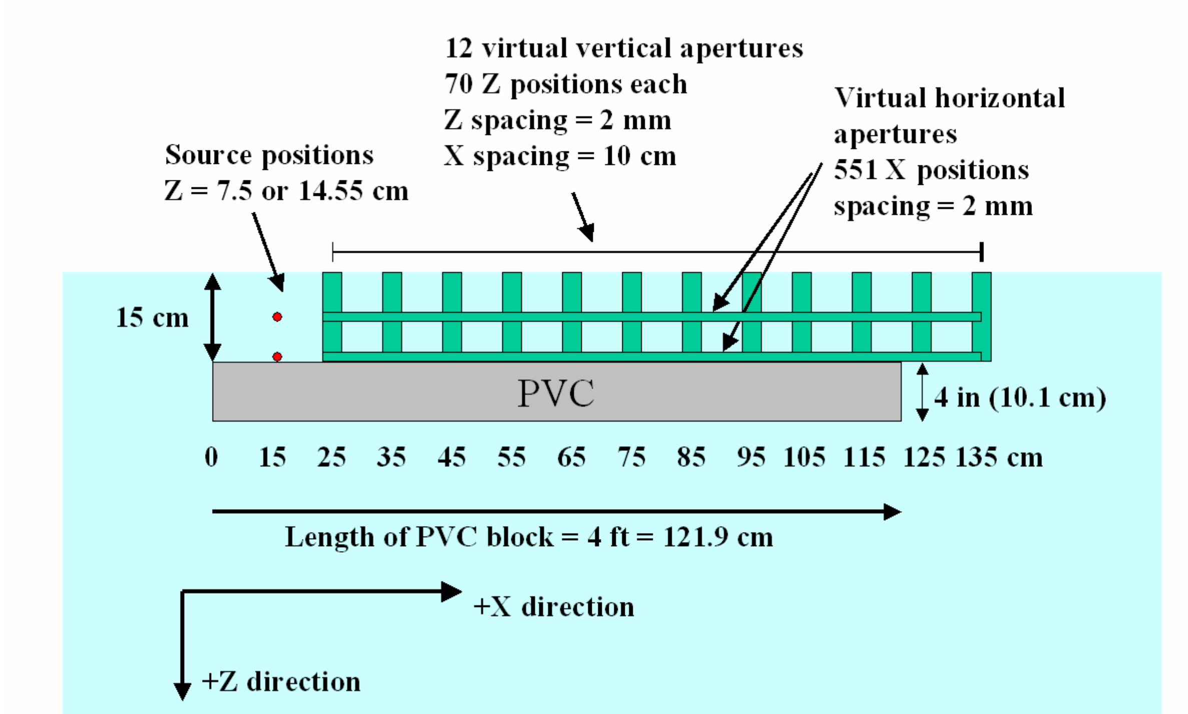

Figure 1 - Experimental setup for the runs with horizontal PVC sheet. The green bars represent the positions of the virtual apertures (multiple receiver positions). The virtual apertures were located in the nominal center of the sheet in the Y direction (the direction orthogonal to X and Z). The experimental runs with the virtual vertical apertures consist of 840 records – time series for 12 apertures of 70 positions each. The runs with the virtual horizontal apertures have 551 records. See Table 2 for the relevant data files and plots.

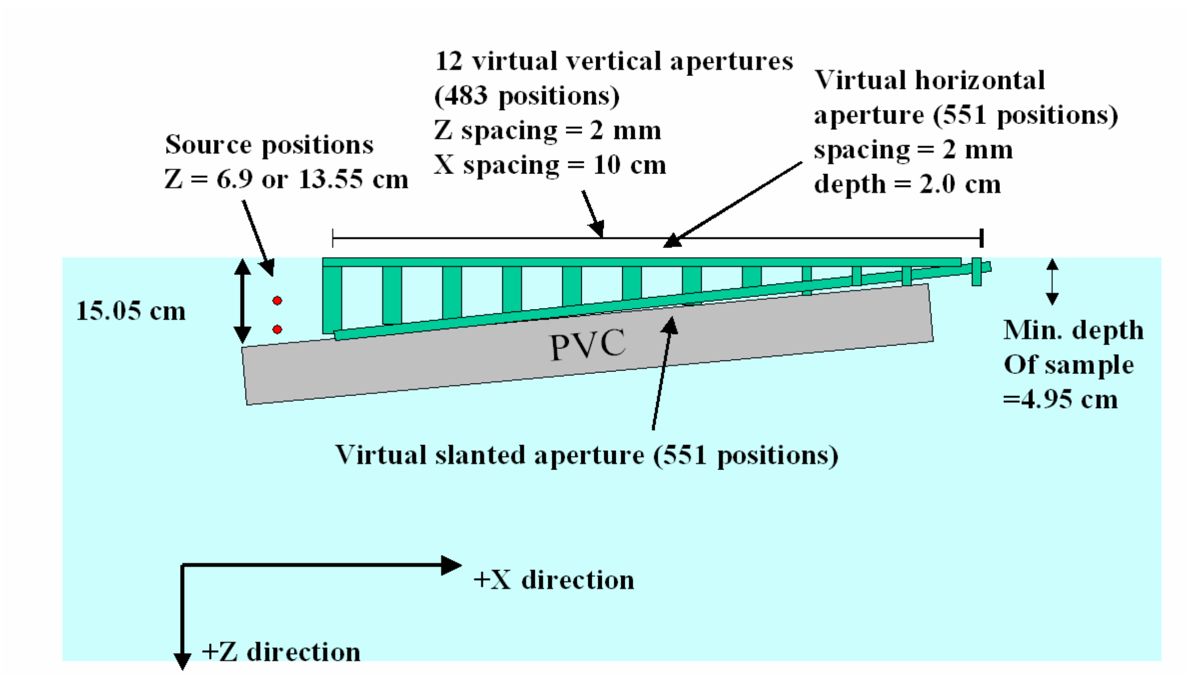

Figure 2 – Experimental setup for runs with the slanted PVC sheet. The dimensions of the sheet are the same as in Figure 1. The slant angle of the sheet is between 4.7 and 4.8 degrees relative to horizontal. The virtual horizontal and slanted apertures consist of 551 records (receiver positions) each. See Table 3 for the relevant data files and plots.

Source Depth (cm)	Receiver Depth (cm)	Receiver Pos (cm)	File Name	Figure in Appendix
7.5 (840 records)	14.55 to 0.75 by 0.2	25 to 135 by 10	pvc_hor_s_mid_r_vert_arr_a	A.1
7.5 (551 records)	14.55	25 to 135 by 0.2	pvc_hor_s_mid_ r_line_deep_c	A.2
14.55 (840 records)	14.55 to 0.75 by 0.2	25 to 135 by 10	pvc_hor_s_deep_r_vert_arr_a	A.3
14.55 (551 records)	14.55	25 to 135 by 0.2	pvc_hor_s_deep_r_line_deep _a	A.4

Table 2: Horizontal PVC 15 cm below water surface

Source Depth (cm)	Receiver Depth (cm)	Receiver Pos (cm)	File Name	Figure in Appendix
6.9 (483 records)	13.00 (maximum) to 0.6 by 0.2 at each receiver position	25 to 135 by 10	pvc_slt_s_mid_r_vert_arr_c	A.6
6.9 (551 records)	13.00 deep at 25cm to 4.13 cm deep at 135cm in diagonal line	25 to 135 by 0.2	pvc_slt_s_mid_r_line_deep_a	A.10
6.9 (551 records)	2.0	25 to 135 by 0.2	pvc_slt_s_mid_r_line_2cm_a	A.7
13.55 (483 records)	13.00 to 0.6 by 0.2 at each receiver position	25 to 135 by 10	pvc_slt_s_deep_r_vert_arr_a	A.5
13.55 (551 records)	13.00 deep at 25cm to 4.13 cm deep at 135cm in diagonal line	25 to 135 by 0.2	pvc_slt_s_deep_r_line_deep_a	A.9
13.55 (551 records)	2.0	25 to 135 by 0.2	pvc_slt_s_deep_r_line_2cm_a	A.8

Table 3: Slanted PVC 15.05 to 4.95 cm below water surface

Reference File	File Name
Time	1m_reference_time
Frequency	1m_reference_frequency

Table 4: Reference Files

Acoustic Data Format

A total of 22 acoustic data files are provided on the disk, including time and frequency files. The first 10 files, with filenames as shown above, are the “cleaned” time series recorded on the transducer at multiple positions in the water column (.cln files). The data files were “cleaned” by windowing out the scattering from the support cables and removing the data at the appropriate points on the time series. The time series in the .cln files consist of 8192 points taken at 0.5 μs sampling intervals, and are created by averaging over 100 time series acquired at each source/receiver position. The time data are recorded in units of pressure (Pascals) and the files are stored in a binary format.

Also provided are the 10 transfer functions (.xfn files) for the experiments. Fourier transforms of the windowed time files were performed to determine frequency responses for each data file. This file is stored in complex binary format. Note that the engineering convention for the complex FFT is used for these data, which is the same convention used by Matlab. The transfer functions are the convolution of the propagation response with the acoustic reference of the source-receiver separated by 1 m. The transfer function shown in Appendix A for each data set is the band-limited impulse response of the water channel and is shown as dB (re: Pa / µPa at 1 m). The binary data files store the real and imaginary parts of the transfer function in units of Pa / Pa at 1 m. To convert to Pa / µPa the data must be multiplied by 1,000,000.

Also included are the time and frequency responses for the 1 m reference file (listed in Table 4). The reference measurement was made by positioning the source and receiver 1 m apart and measuring the pressure produced from a shaped pulse. The pulse was designed specifically to be maximally flat from 100 kHz to 300 kHz. Figures 3 and 4 show the temporal and frequency responses for this 1 m reference. The data should be considered valid between 100 kHz and 300 kHz, but data above and below this band are suspect and not valid.

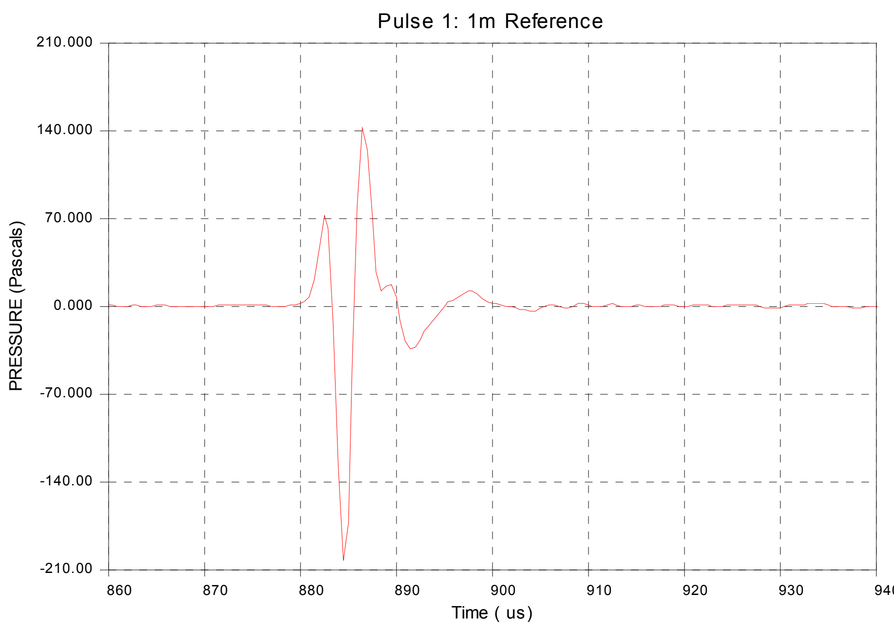

Figure 3 - Temporal response of the source/receiver separated by 1 m.

Figure 4 - Frequency response of the source/receiver separated by 1 m.

Matlab IO m-scripts

Included on the CD is a set of m-scripts that can be used to read the binary data into Matlab. Also included is a .pdf file detailing the binary format. There are two ways to read a record: (1) using the *rr* command, or (2) using the *read_record* command. The *rr* command reads data and requires more user interaction and information prompts. The *read_record* command is a basic function call that can be used in the Matlab script to read all or part of any data file.

When using the *rr* command, enter the file name at the prompt and answer the questions that follow. Time data will be found in the variable *rdata* and frequency data will be found in the variable *cdata*. To load the data using a script, type *help read_header* and help *read_record* to get the syntax to use these two function calls.

References

1. R. J. Soukup, H. J., Simpson, E. C. Porse, J. E. Summers, R. F. Gragg, "Geoacoustic Physical Modeling Rough Surface Scattering Experiment 2 (GPM RSS2): Measurement Report, Acoustic Data and Profilometry", NRL Memorandum Report 7140-04-8827 (2004).

2. M. D. Collins, "Higher-order Padé approximations for accurate and stable elastic parabolic equations with application to interface wave propagation," J. Acoust. Soc. Am. **89**, 1050-1057 (1991).

3. M. D. Collins and D.K. Dacol, "A mapping approach for handling sloping interfaces," J. Acoust. Soc. Am. **107**, 1937-1942 (2000).

Appendix A: Acoustic Data Overview

This appendix shows the data for each experimental run – one run to a page. Five graphs are included for each experimental run, including: (1) a color plot of the raw time data (upper left), (2) a color plot of the cleaned (.cln file) time data (upper right), (3) the plot of the time response for one record (middle left), (4) the plot of the frequency response vs. the noise floor for one record (lower left), and the (5) color plot of the band-limited impulse response (.xft file) of the water channel (lower right). Record numbers refer to a sequence of source/receiver positions, with the number of records depending on the experimental run (i.e., figures have different x-axis scaling when plotting against record number). For example, the record numbers in Figure A.1 refer to a set of virtual vertical apertures – the first set of records (1-70) being the aperture closest to the source, with the deepest receiver position at record 1 and the shallowest at record 70, followed by the next aperture in records 71-140, etc. For Figure A.2, the record 1 is the position in the virtual horizontal aperture nearest the source, and the last record (record 551) is the position furthest from the source.

Figure A.1 - Horizontal PVC sheet
Source position: Mid-depth (7.5 cm above sheet)
Receiver positions: 12 virtual Vertical Line Arrays (70 positions each) separated by 10 cm
Number of records = 12 x 70 = 840

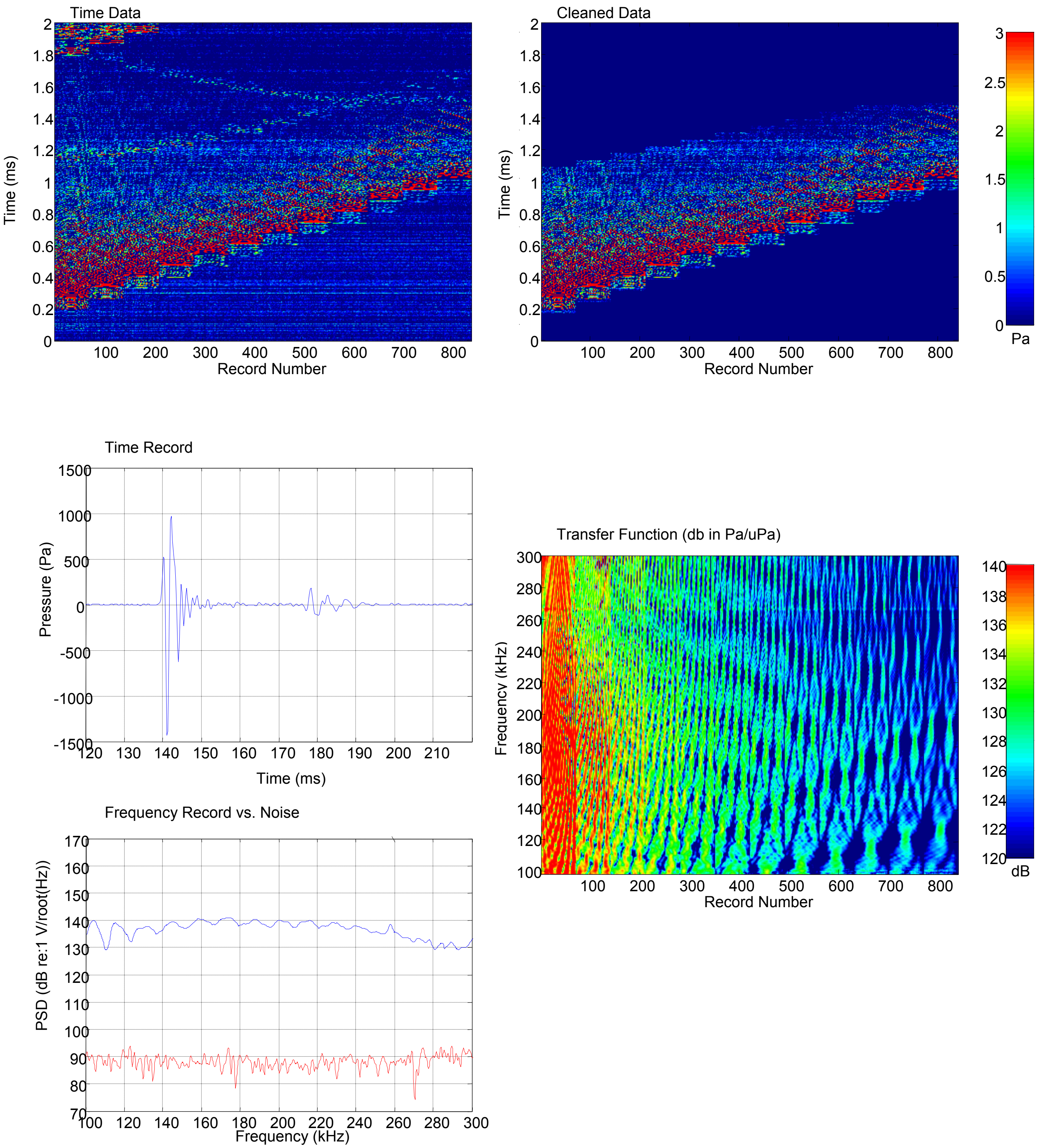

Figure A.2 - Horizontal PVC sheet
Source position: Mid-depth (7.5 cm above sheet)
Receiver positions: 1 virtual Horizontal Line Array (551 positions) 0.65 cm above sheet
Number of records = 551

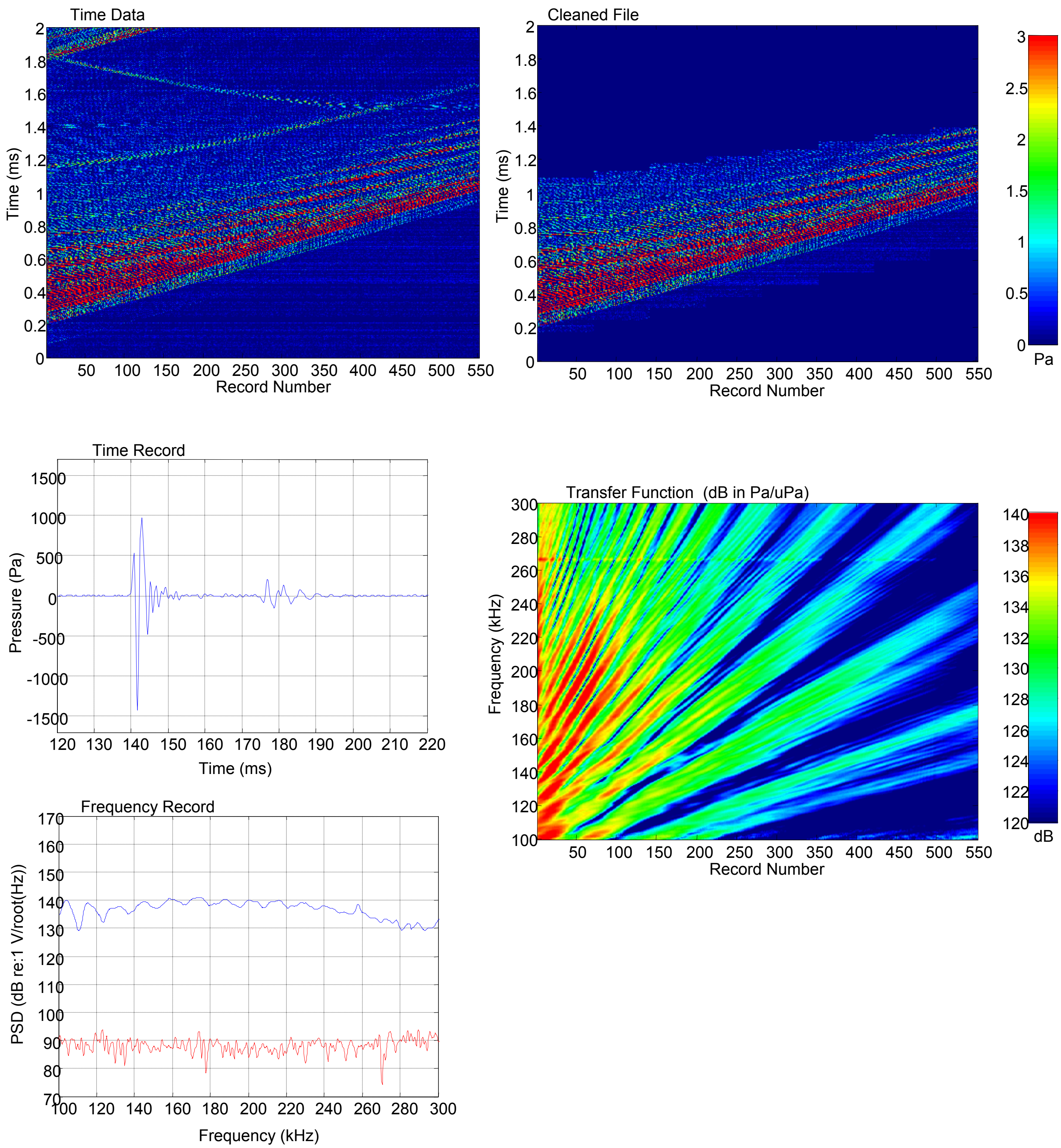

Figure A.3 - Horizontal PVC sheet
Source position: Deep-depth (0.65 cm above sheet)
Receiver positions: 12 virtual Vertical Line Arrays (70 positions each) separated by 10 cm
Number of records = 12 x 70 = 840

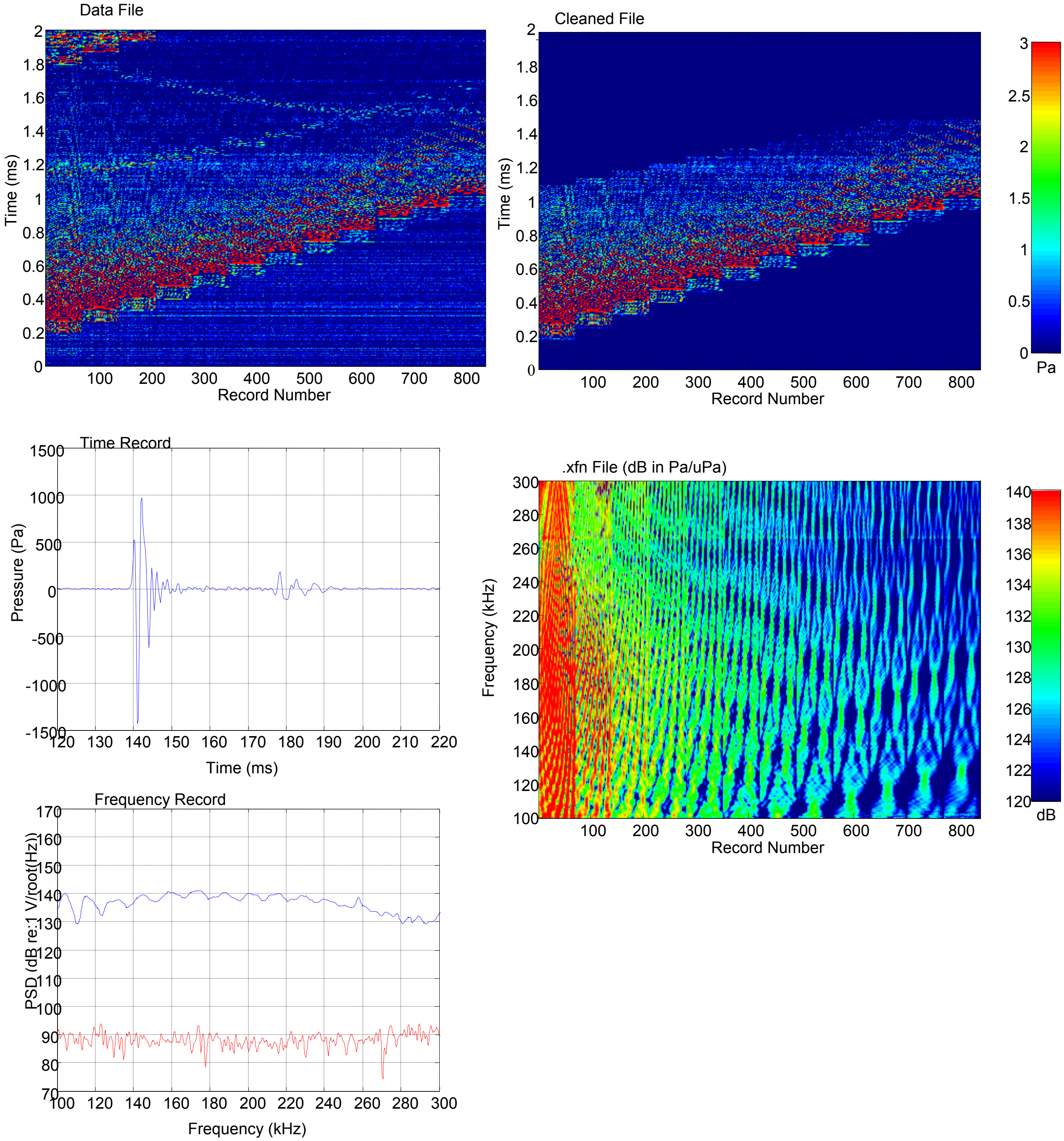

Figure A.4 - Horizontal PVC sheet
Source position: Deep-depth (0.65 cm above sheet)
Receiver positions: 1 virtual Horizontal Line Array (551 positions) 0.65 cm above sheet
Number of records = 551

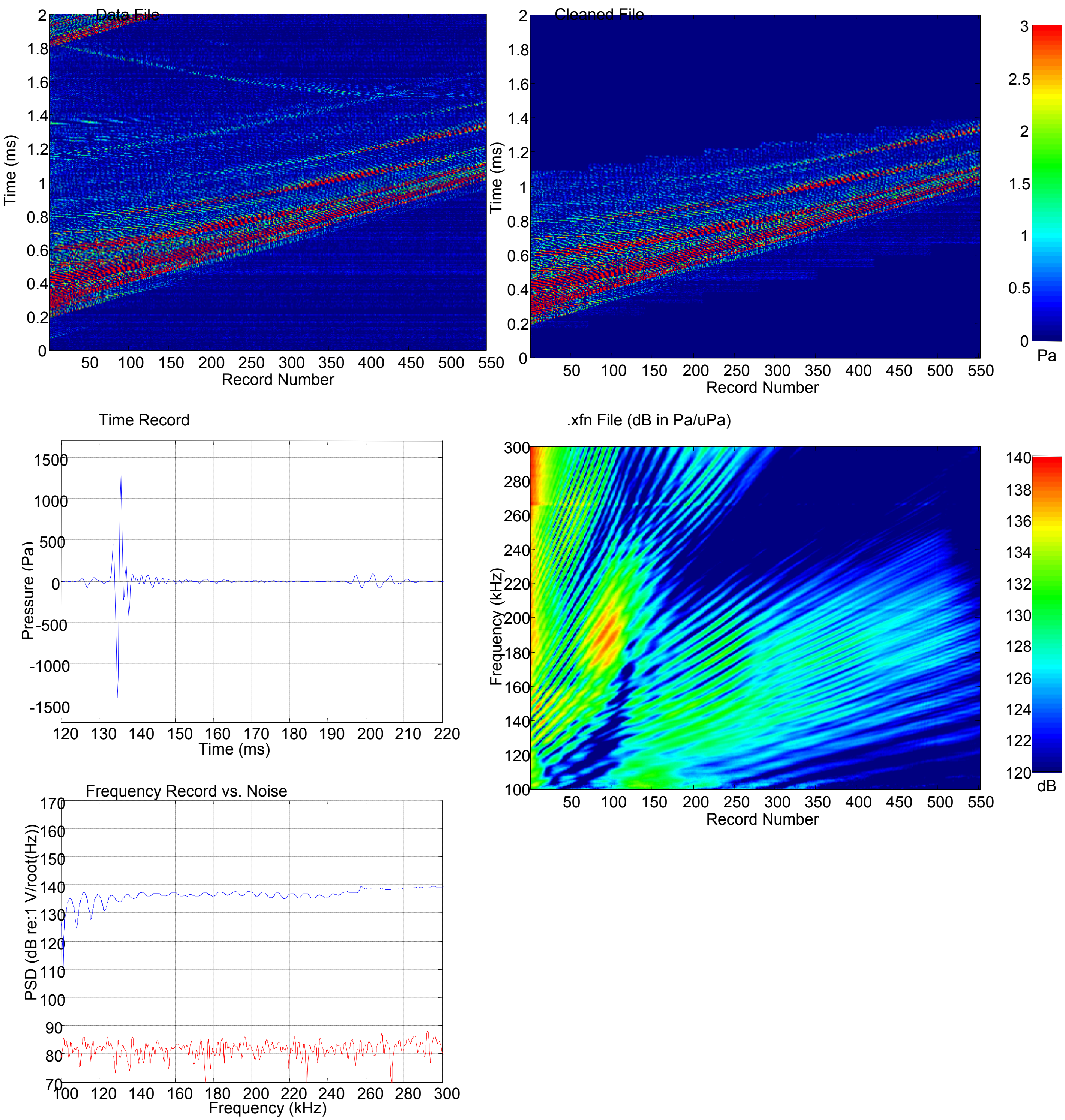

Figure A.5 - Slanted PVC Sheet
Source position: Deep-depth (0.65 cm above sheet)
Receiver: 12 virtual Vertical Line Arrays separated by 10 cm. Number of positions per vertical line array varies. Number of records = 483

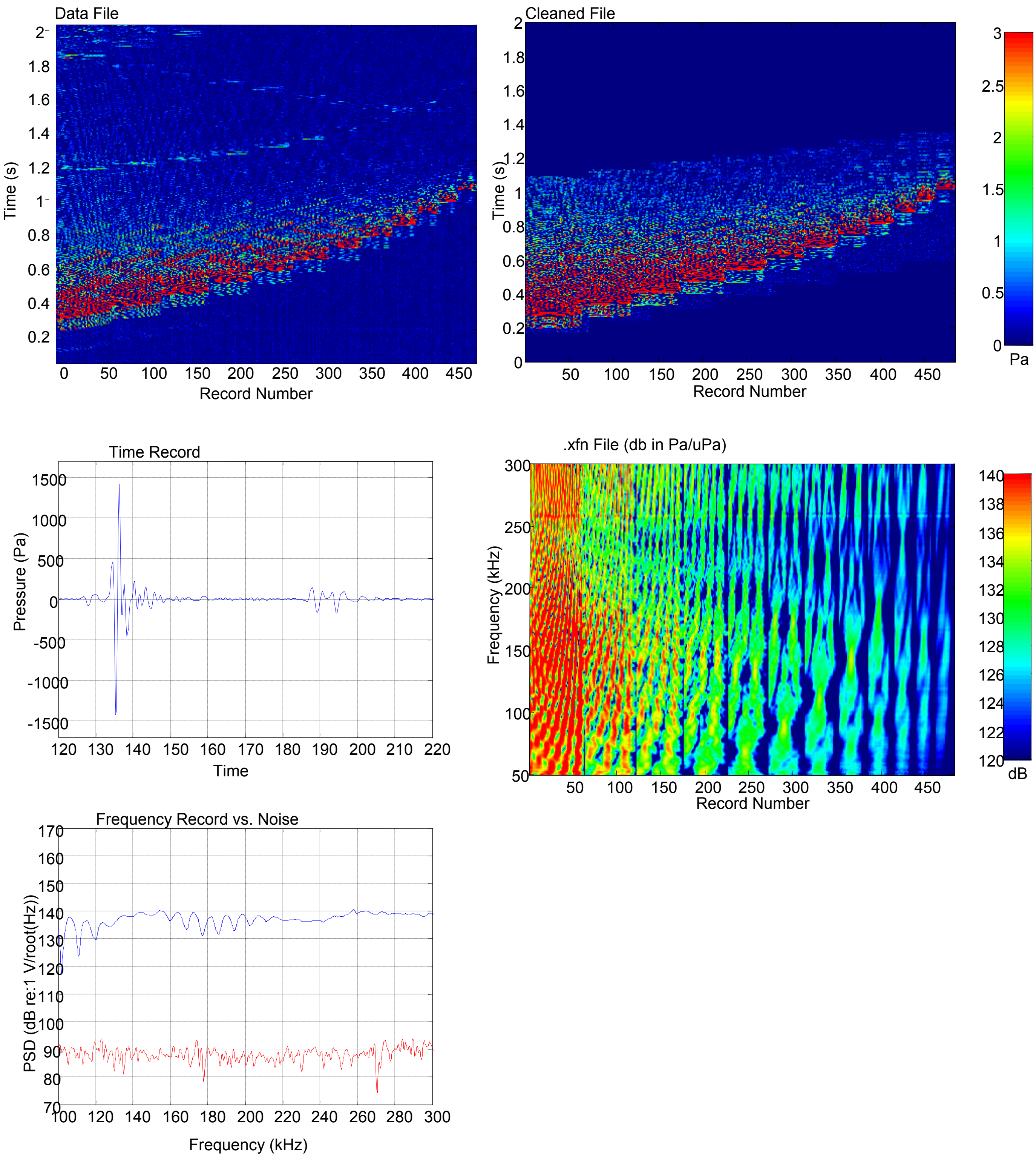

Figure A.6 - Slanted PVC Sheet
Source position: Mid-depth, 7.5 cm above sheet,
Receiver positions: 12 virtual Vertical Line Arrays separated by 10 cm. Number of positions per vertical line array varies. Number of records = 483

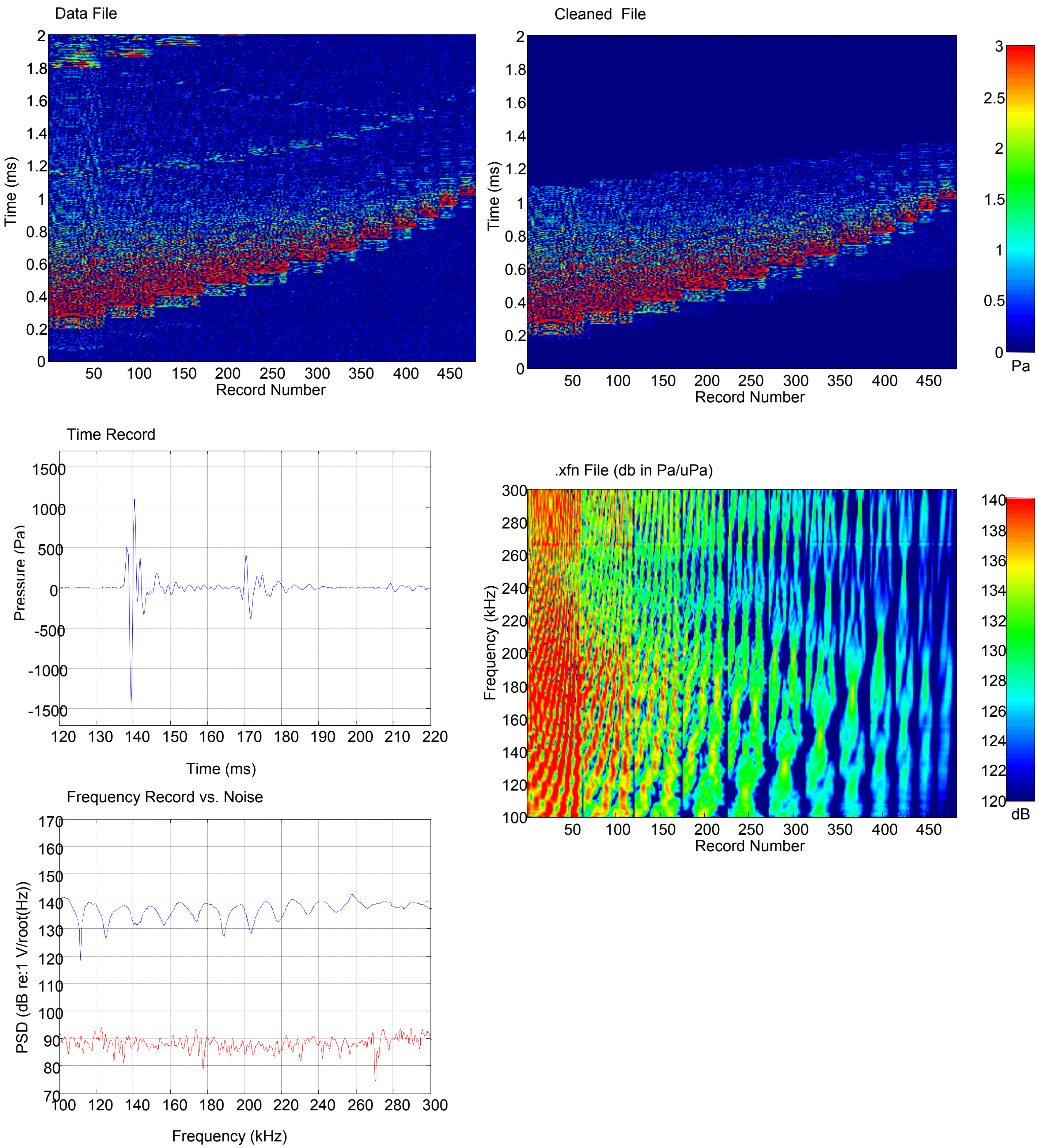

Figure A.7 - Slanted PVC sheet
Source position: Mid-depth (7.5 cm above sheet)
Receiver positions: 1 virtual Horizontal Line Array (551 positions) 2.0 cm below water surface
Number of records = 551

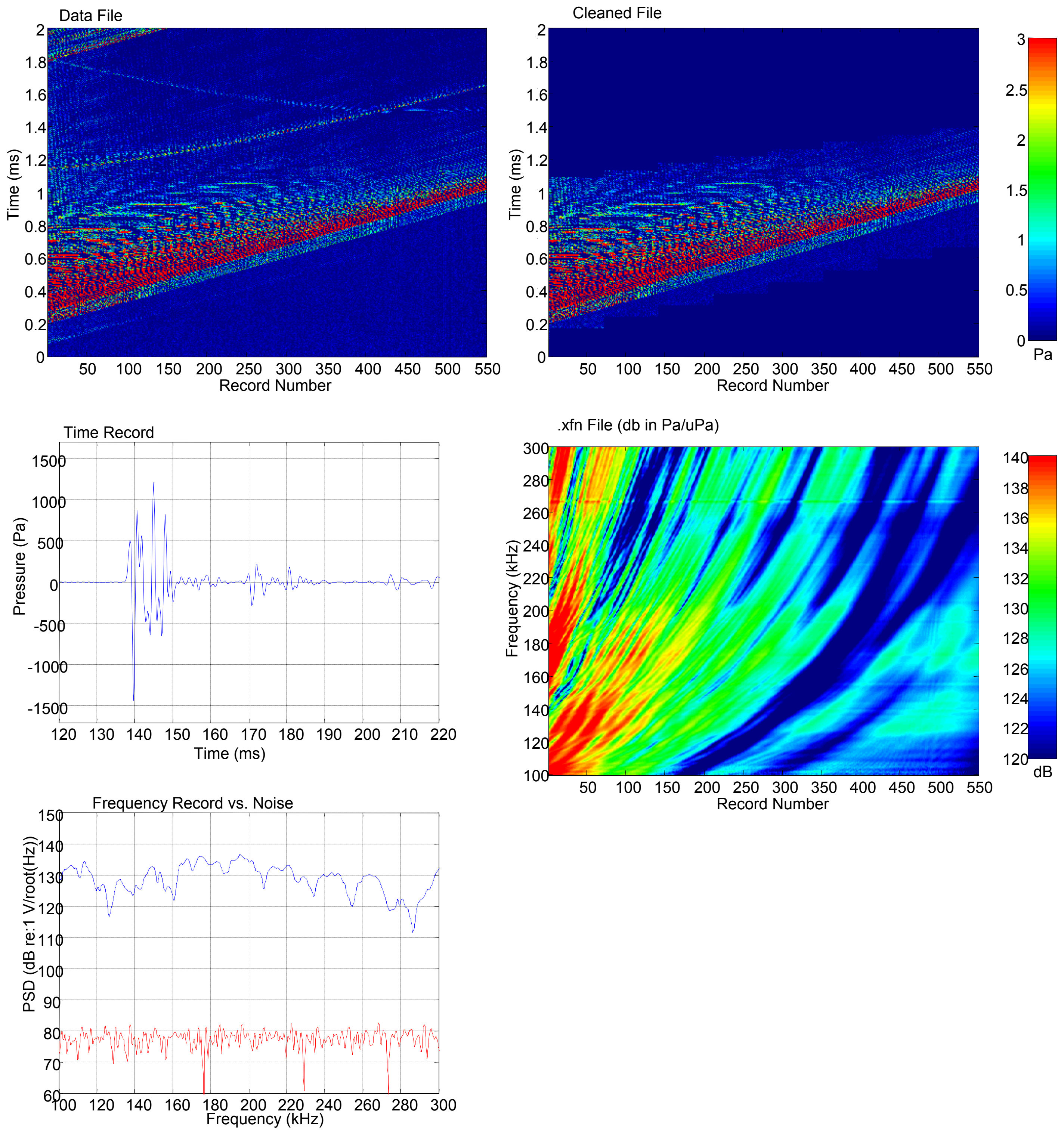

Figure A.8 - Slanted PVC Sheet
Source position: Deep-depth (0.65 cm above sheet)
Receiver positions: 1 virtual Horizontal Line Array (551 positions) 2.0 cm below water surface
Number of records = 551

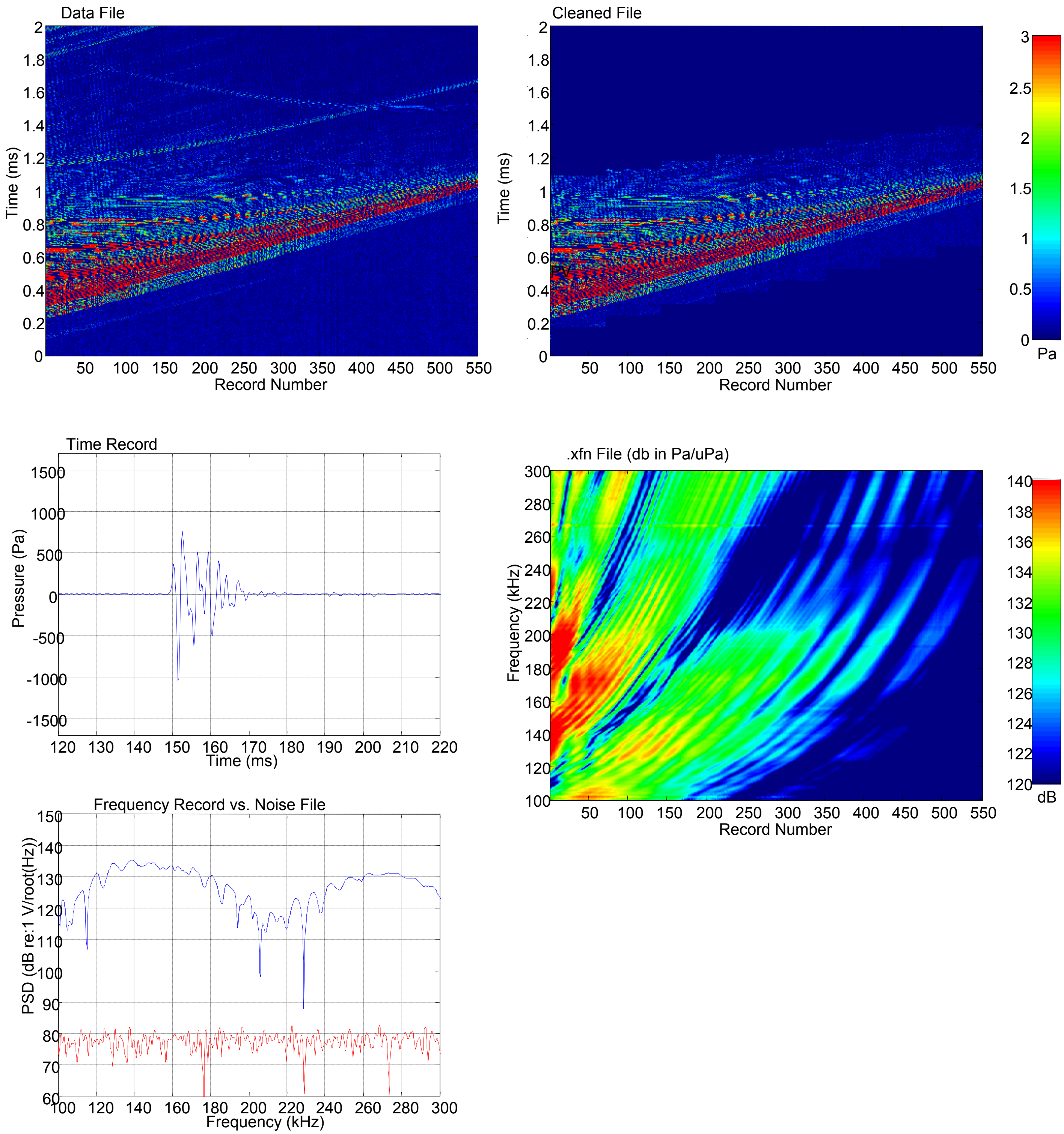

Figure A.9 - Slanted PVC sheet
Source position: Deep-depth (0.65 cm above sheet)
Receiver positions: 1 virtual Slanted Line Array (551 positions) 0.65cm above sheet
Number of records = 551

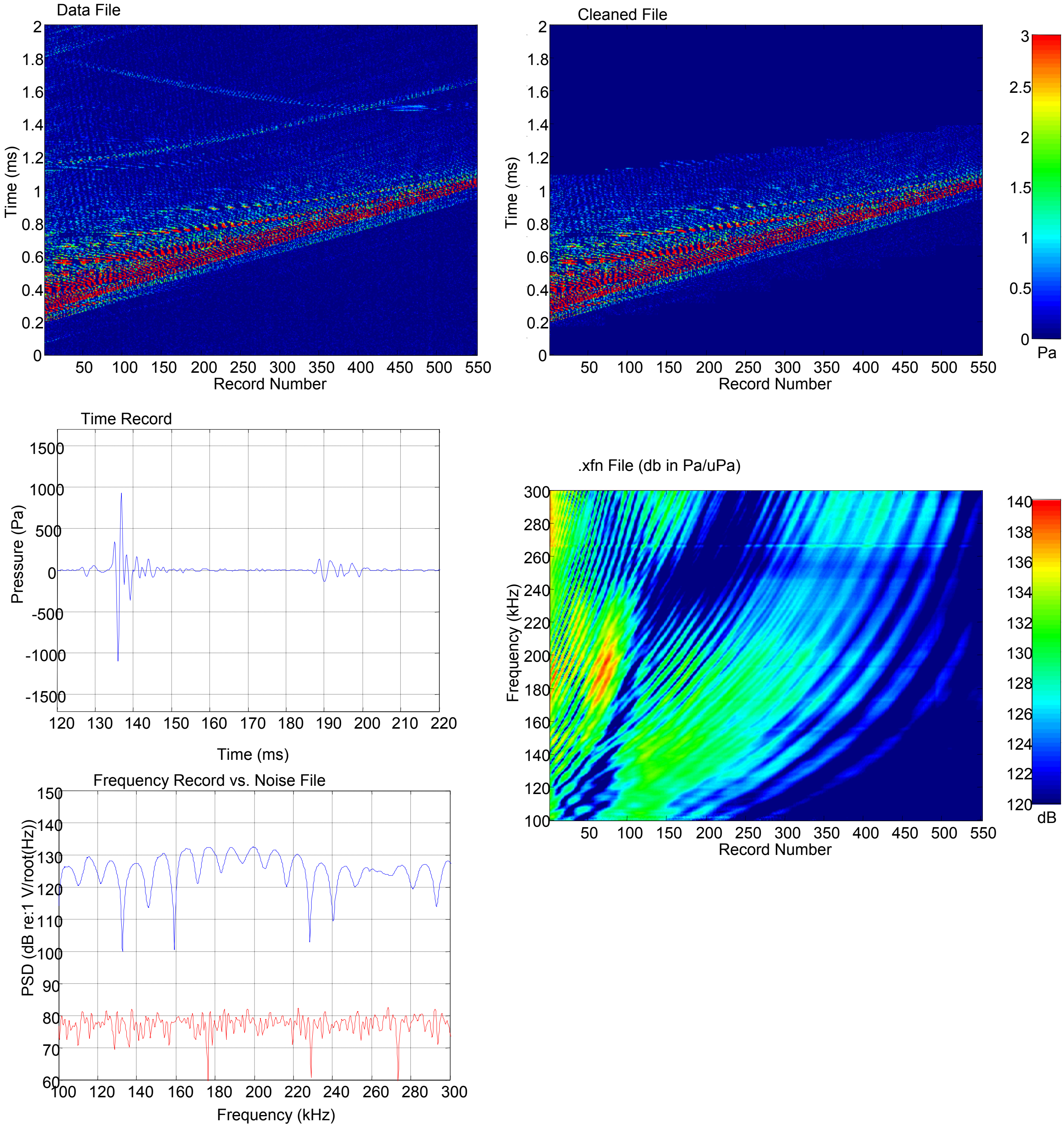

Figure A.10: Slanted PVC sheet
Source position: Mid-depth (7.5 cm above sheet)
Receiver positions: 1 virtual Slanted Line Array (551 positions) 0.65 cm above sheet
Number of records = 551