APPENDIX A
ACOUSTIC MODELLING OF SEISMIC SOURCES

APPENDIX A:

ACOUSTIC MODELING OF SEISMIC ACOUSTIC SOURCES AND SCALING FACTORS FOR SHALLOW WATER[1]

For the proposed survey off New Jersey, a smaller energy source than the full airgun array available on the R/V *Langseth* would be sufficient to collect the desired geophysical data. Previously conducted calibration studies of the *Langseth*'s airgun arrays, however, can still inform the modeling process used to develop mitigation radii for the currently proposed survey.

Acoustic Source Description

This 3-D seismic data acquisition project would use two airgun subarrays that would be fired alternately as the ship progresses along track (one subarray would be towed on the port side and the other on the starboard side). Each airgun subarray would consist of four airguns (total volume 700 in^3). The subarrays would use subsets of the linear arrays or "strings" composed of Bolt 1500LL and Bolt 1900LLX airguns that are carried by the R/V *Langseth* (Figure A1): four airguns in one string would be fired simultaneously, and the other six airguns on the string would be inactive. The subarray tow depth would be either 4.5 m (desired tow depth) or 6 m (in case of weather degradation). The subarray would be fired roughly every 5.4 s. At each shot, a brief (~0.1 s) pulse of sound would be emitted, with silence in the intervening periods. This signal attenuates as it moves away from the source, decreasing in amplitude and increasing in signal duration.

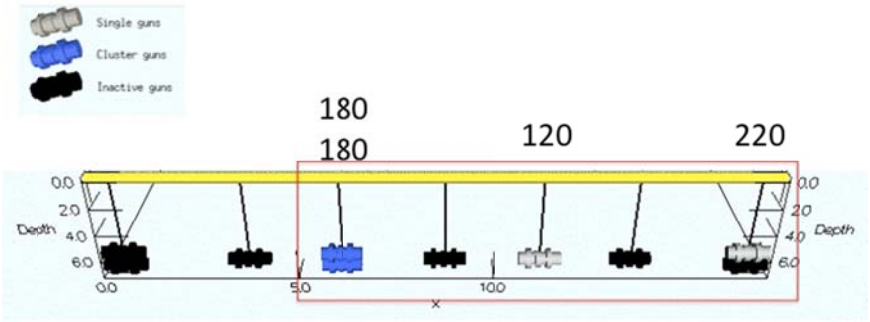

FIGURE A1. Four-airgun subset of one string that would be used as a 700-in^3 subarray for the proposed survey (individual volumes are indicated).

Four-Airgun Subarray Specifications

Energy Source	1950-psi Bolt airguns with volumes 120–220 in^3, arranged in one string of four operating airguns
Towing depth of energy source	4.5 m or 6 m
Source output (downward), 4.5 m	0-pk is 240.4 dB re 1 µPa · m; pk-pk is 246.3 dB re 1 µPa · m
Source output (downward), 6 m	0-pk is 240.4 dB re 1 µPa · m; pk-pk is 246.7 dB re 1 µPa · m
Air discharge volume	~700 in^3
Dominant frequency components	0–188 Hz

Because the actual source originates from 4 airguns rather than a single point source, the highest sound levels measurable at any location in the water is less than the nominal source level. In addition, the effective source level for sound propagating in near-horizontal directions would be substantially lower

[1] Helene Carton, Ph.D., L-DEO.

than the nominal source level applicable to downward propagation because of the directional nature of the sound from the airgun array.

Modeling and Scaling Factors

Propagation measurements were obtained in shallow water for the *Langseth*'s 18-gun, 3300-in^3 (2-string) array towed at 6 m depth, in both crossline (athwartship) and inline (fore and aft) directions. Results were presented in Diebold et al. (2010), and part of their Figures 5 and 8 are reproduced here (Figure A2). The crossline measurements, which were obtained at ranges ~2 km to ~14.5 km, are shown along with the 95th percentile fit (Figure A1, top panel). This allows extrapolation for ranges <2 km and >14.5 km, providing 150 dB SEL, 170 dB SEL and 180 dB SEL distances of 15.28 km, 1097 m, and 294 m, respectively. Note that the short ranges were better sampled in inline direction including by the 6-km long MCS streamer (Figure A2, bottom panel). The measured 170-dB SEL level is at 370-m distance in inline direction, well under the extrapolated value of 1097 m in crossline direction, and the measured 180-dB SEL level is at 140-m distance in inline direction, also less than the extrapolated value of 294 m in crossline direction. Overall, received levels are ~5 dB lower inline than they are crossline, which results from the directivity of the array (the 2-string array being spatially more extended in fore and aft than athwartship directions). Mitigation radii based on the crossline measurements are thus the more conservative ones and are therefore proposed to be used as the basis for the mitigation zone for the proposed activity.

The empirically derived crossline measurements obtained for the 18-gun, 3300-in^3 array in shallow water in the Gulf of Mexico, described above, are used to derive the mitigation radii for the proposed New Jersey margin 3-D survey that would take place in June–August 2015 (Figure A3). The entire survey area would be located in shallow water (<100 m). The source for this survey would be a 4-gun, 700-in^3 subset of 1 string at 4.5- or 6-m tow depth. The differences in array volumes, airgun configuration and tow depth are accounted for by scaling factors calculated based on the deep-water L-DEO model results (shown in Figures A4 to A6).

The scaling procedure uses radii obtained from L-DEO models. Specifically, from L-DEO modeling, 150-, 170-, and 180-dB SEL isopleths for the 18-gun, 3300-in^3 array towed at 6-m depth have radii of 4500, 450, and 142 m, respectively, in deep water (Figure A3). Similarly, the 150-, 170-, and 180-dB SEL isopleths for the 4-gun, 700-in^3 subset of 2 strings array towed at 4.5 m depth have radii of 1544, 155, and 49 m, respectively, in deep water (Figure A4). Taking the ratios between both sets of deep-water radii yields scaling factors of 0.3431–0.3451. These scaling factors are then applied to the empirically derived shallow water radii for the 3300-in^3 array at 6-m tow depth, to derive radii for the suite of proposed airgun subsets. For example, when applying the scaling ratios for the 4-gun, 700-in^3 array at 4.5-m tow depth, the distances obtained are 5.24 km for 150 dB SEL (proxy for SPL 160 dB rms), 378 m for 170 dB SEL (SPL 180 dB rms), and 101 m for 180 dB SEL (SPL 190 dB rms).

The same procedure is applied for the suite of arrays:

(1) 4-gun 700 in^3 array, subset of 1 string at 4.5 m tow depth (Figure A4)

(2) 4-gun 700 in^3 array, subset of 1 string at 6 m tow depth (Figure A5)

(3) Single 40 in^3 mitigation gun at 6 m tow depth (Figure A6)

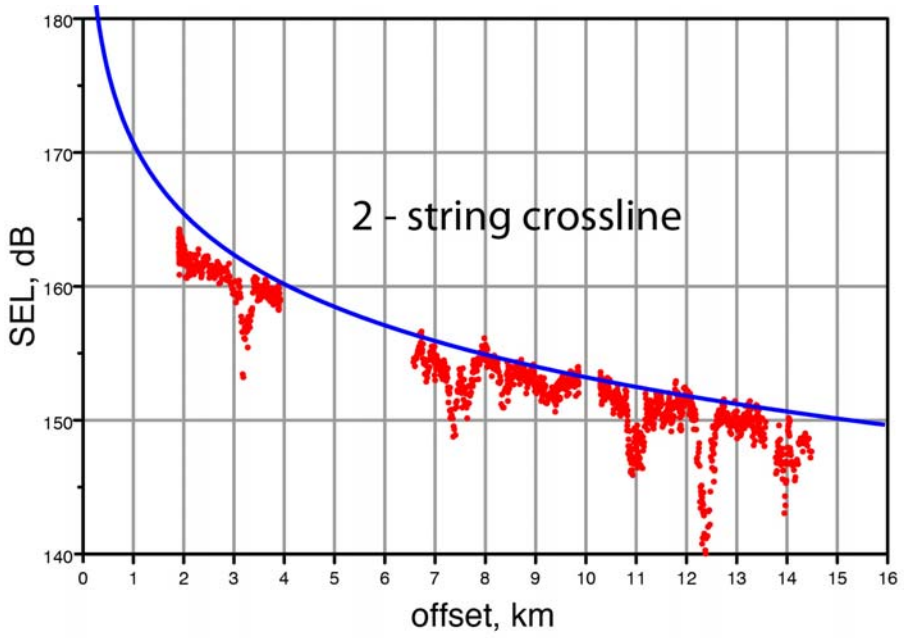

Figure 5a. Sound Exposure Levels for the crossline (side aspect) arrivals recorded along the spiral track at the shallow water calibration site, with a 95th percentile fit (using the methods described by Tolstoy et al., 2009).

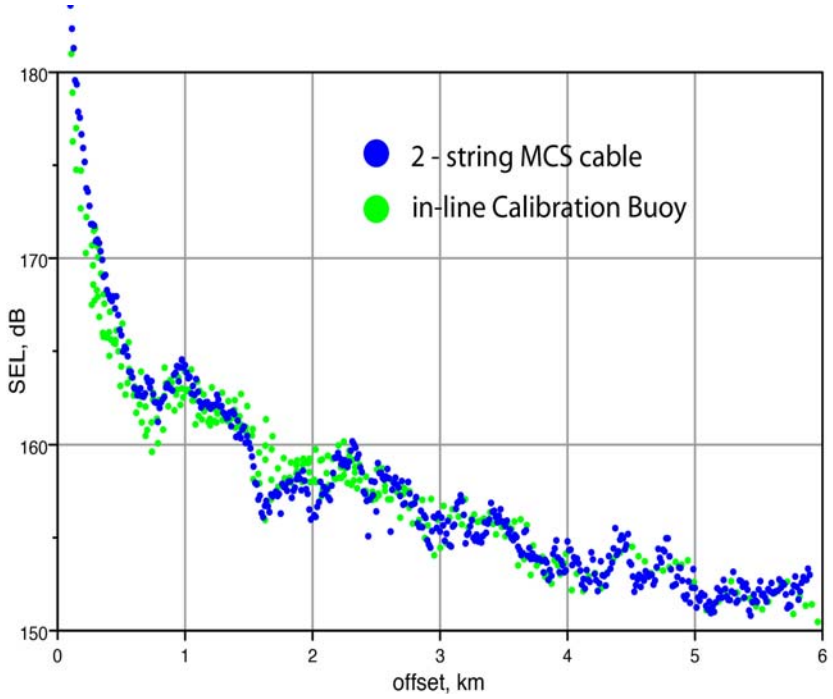

FIGURE A2. R/V *Langseth* Gulf of Mexico calibration results for the 18-gun, 3300-in^3, 2-string array at 6-m depth obtained at the shallow site (Diebold et al. 2010).

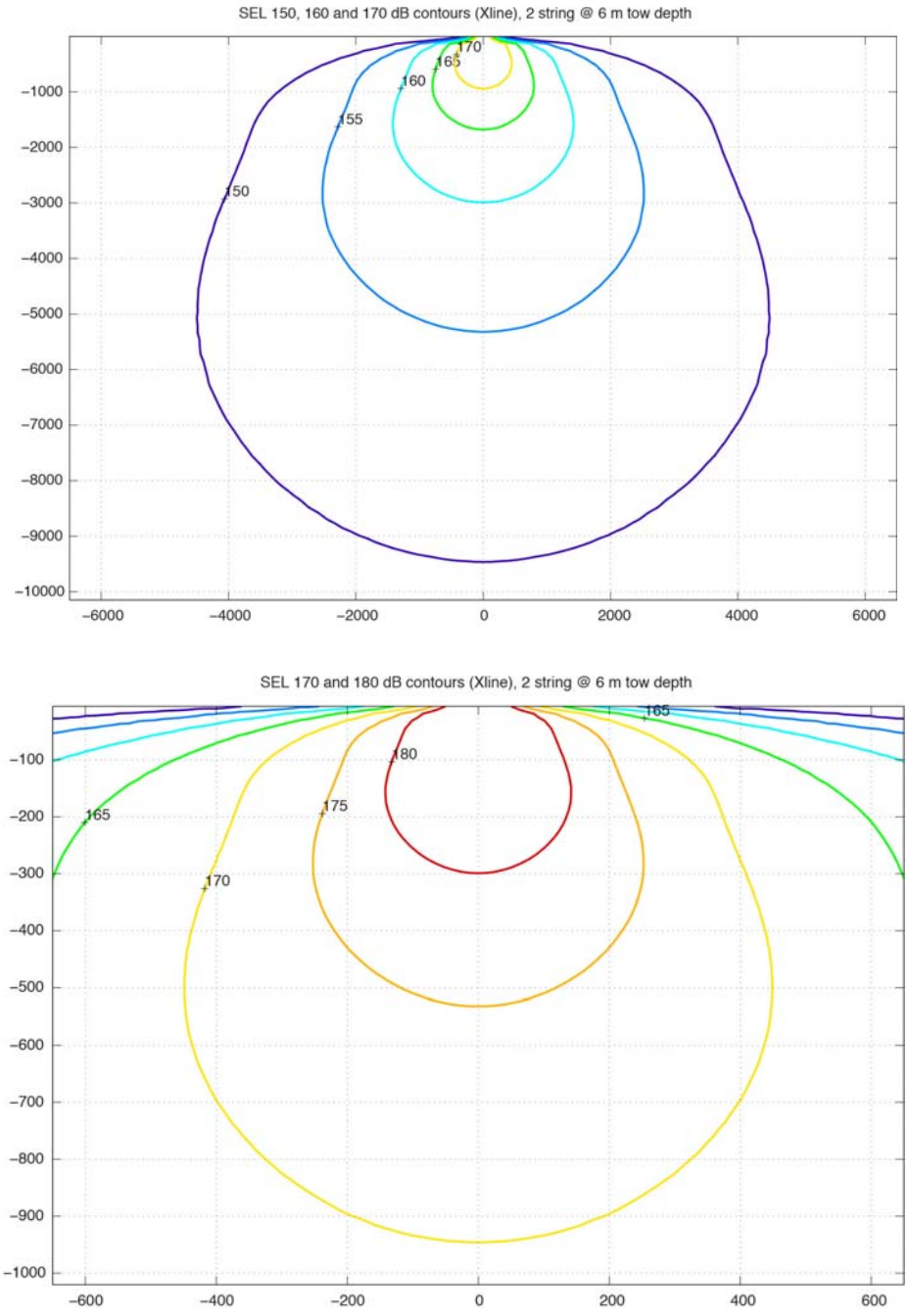

FIGURE A3. Deep-water model results for the 18-gun, 3300-in^3, 2-string array at 6-m tow depth, the configuration that was used to collect calibration measurements presented in Figure 2. The 150-dB SEL, 170-dB SEL, and 180-dB SEL (proxies for SPLs of 160, 180, and 190 dB rms[2]) distances can be read at 4500 m, 450 m, and 142 m.

[2] Sound sources are primarily described in sound pressure level (SPL) units. SPL is often referred to as rms or "root mean square" pressure, averaged over the pulse duration. Sound exposure level (SEL) is a measure of the received energy in a pulse and represents the SPL that would be measured if the pulse energy were spread evenly across a 1-s period.

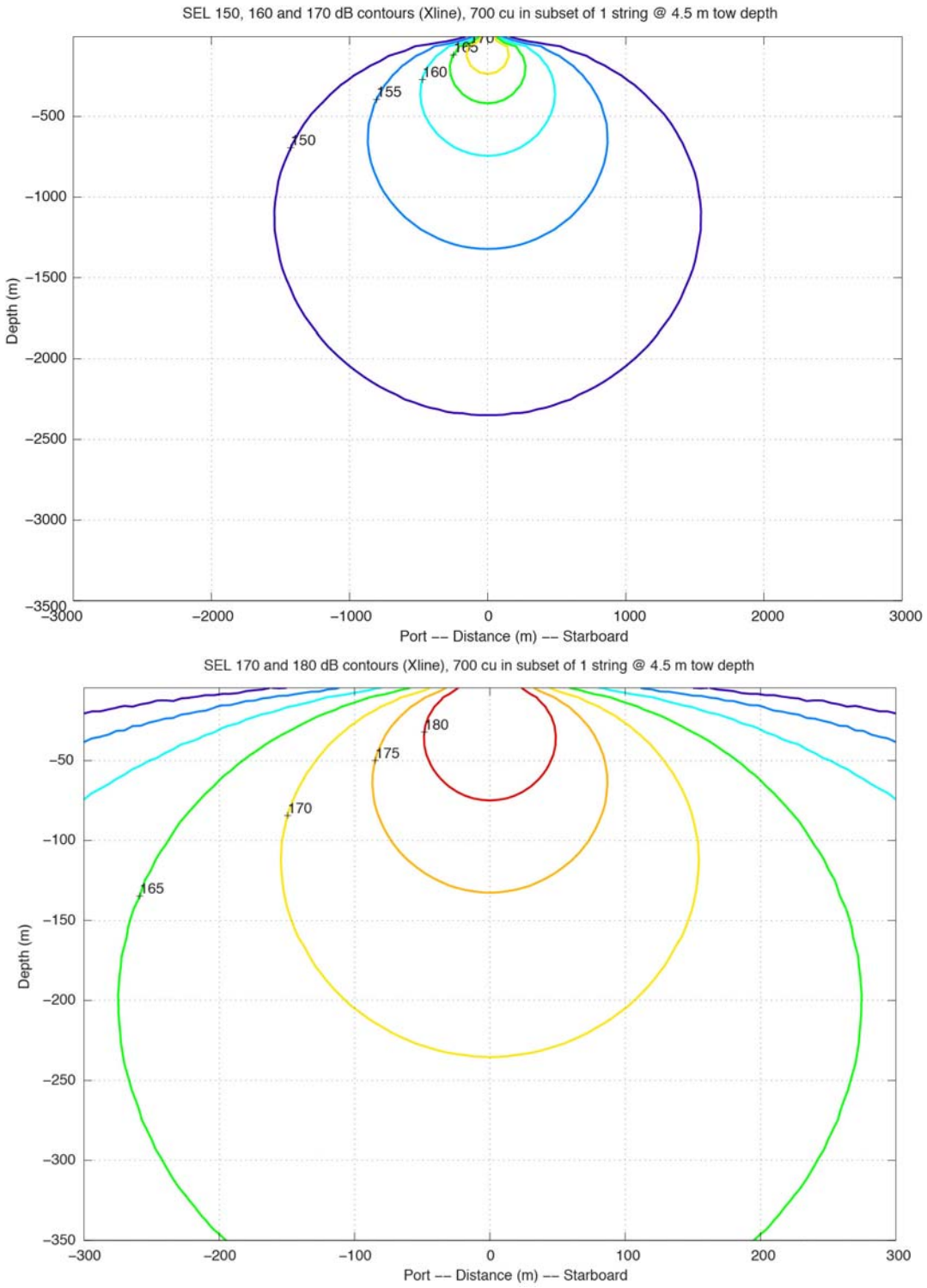

FIGURE A4. Deep-water model results for the 4-gun, 700-in^3 subset of 1-string array at 4.5-m tow depth that could be used for the NJ margin 3D survey. The 150-dB SEL, 170-dB SEL, and 180-dB SEL distances can be read at 1544 m, 155 m, and 49 m, respectively.

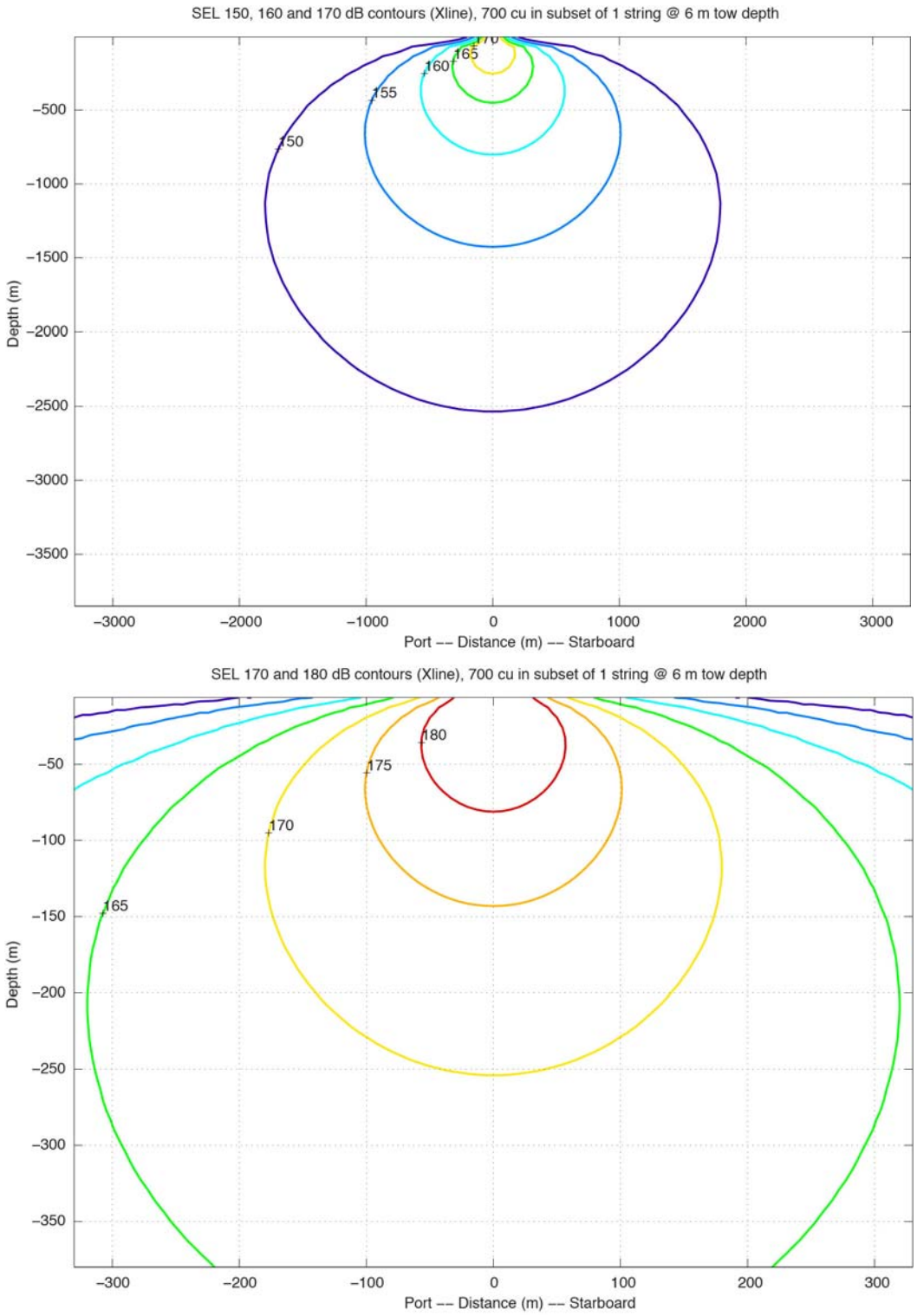

FIGURE A5. Deep-water model results for the 4-gun, 700-in^3 subset of 1-string array at 6m tow depth that could be used for the NJ margin 3-D survey. The 150-dB SEL, 170-dB SEL, and 180-dB SEL distances can be read at 1797 m, 180 m, and 57 m, respectively.

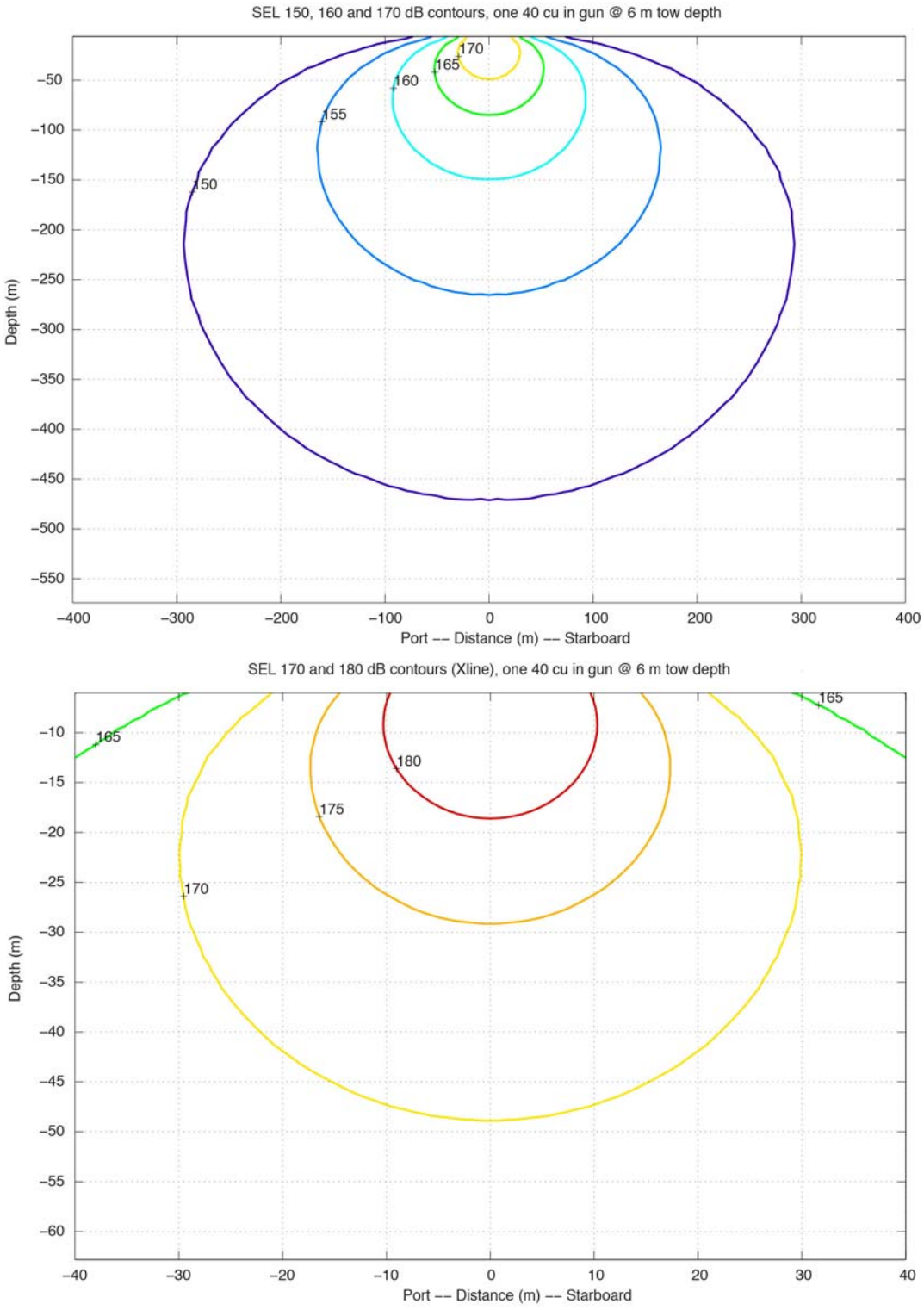

FIGURE A6. Deep-water model results for the single 40-in^3 Bolt airgun at 6-m tow depth. The 150-dB SEL, 170-dB SEL, and 180-dB SEL distances can be read at 293 m, 30 m, and 10 m, respectively.

The derived shallow water radii are presented in Table A1. The final values are reported in Table A2.

TABLE A1. Table summarizing scaling procedure applied to empirically derived shallow-water radii to derive shallow-water radii for various array subsets that could be used during the New Jersey margin 3D survey.

Calibration Study: 18-gun, 3300-in^3 @ 6-m depth	**Deep water radii (m)** (from L-DEO model results)		**Shallow Water Radii (m)** (Based on empirically-derived crossline Measurements)
	150 dB SEL: 4500		15280
	170 dB SEL: 450		1097
	180 dB SEL: 142		294
Proposed Airgun sources	**Deep water radii** (from L-DEO model results)	**Scaling factor** *[Deep-water radii for 18-gun 3300-in^3 array @ 6 m depth]*	**Shallow water radii (m)** *[Scaling factor **x** shallow water radii for 18-gun 3300 in^3 array @ 6 m depth]*
Source #1: 4-gun, 700-in^3 @ 4.5-m depth	150 dB SEL: 1544 m	0.3431	5240
	170 dB SEL: 155 m	0.3444	378
	180 dB SEL: 49 m	0.3451	101
Source #2: 4-gun, 700-in^3 @ 6-m depth	150 dB SEL: 1797 m	0.3993	6100
	170 dB SEL: 180 m	0.4000	439
	180 dB SEL: 57 m	0.4014	118
Source #3: Single 40-in^3 @ 6-m depth	150 dB SEL: 293 m	0.0651	995
	170 dB SEL: 30 m	0.0667	73
	180 dB SEL: 10 m	0.0704	21

TABLE A2. Predicted distances in meters to which sound levels ≥ 180 and 160 dB re 1 µPa$_{rms}$ would be received during the proposed 3-D survey off New Jersey, using a 4-gun, 700-in^3 subset of 1 string at 4.5- or 6-m tow depth and the 40-in^3 airgun during power-downs. Radii are based on Figures A2 to A6 and scaling described in the text and Table A1, assuming that received levels on an rms basis are, numerically, 10 dB higher than the SEL values.

		Predicted RMS Radii (m)	
Source and Volume	Water Depth	180 dB	160 dB
4-airgun subarray (700 in^3) @ 4.5 m	<100 m	378	5240
4-airgun subarray (700 in^3) @ 6 m	<100 m	439	6100
Single Bolt airgun (40 in^3) @ 6 m	<100 m	73	995