REVERBERATION MODEL-DATA COMPARISONS AND ESTIMATED SCATTERING STRENGTHS IN THE VICINITY OF THE TREX13 SITE

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Abstract:
During the 2013 Target and Reverberation Experiment (TREX13) reverberation and target echo data were collected using a fixed source and fixed horizontal array deployed in shallow water in the Gulf of Mexico. Various pulses in the 1.8 to 3.6 kHz frequency band were sent, day and night over a 4-week period, and an extensive analysis of the reverberation data and environmental measurements made. Results by various authors were collected in the recent TREX13 Special Issue of the IEEE Journal of Oceanic Engineering. Ellis et al. used a normal-mode Reverberation and Target Echo model [IEEE JOE, 42, 344–361, 2017] to perform model-data comparisons and extract a scattering strength (based on Lambert's rule) along the relatively-flat Reverberation Track. The beams of the horizontal array, can be steered at all azimuths, so in this paper we look at model-data comparisons along other radials, using a different scattering function. As well as propagation effects, the model takes into consideration the frequency and angular dependence of the beam patterns, so an estimate of the range and azimuthal dependence of the scattering can be extracted. Scattering anomalies point to regions where additional environmental measurements would be worthwhile.

Keywords: *TREX Experiment, reverberation, range-dependent modelling, normal modes, scattering functions, Gulf of Mexico, towed array*

1. INTRODUCTION

TREX was a series of Target and Reverberation Experiments sponsored by the US Office of Naval Research (ONR) in the Gulf of Mexico off Panama City, Florida, USA. Their unique feature was a fixed source and fixed receivers deployed in about 20 m of water, with the acoustic experiments being complemented by an extensive set of environmental measurements. These measurements were to facilitate the understanding of the underlying reverberation and clutter mechanisms, and to support quantitative modelling. The reverberation experiments were primarily organized by the Applied Physics Laboratory at the University of Washington (APL/UW). Extensive environmental measurements were made before, during, and after the main experiment. Results from various authors have been collected in a Special Issue of the IEEE Journal of Oceanic Engineering [1].

The main focus was the reverberation experiments, where various pulses in the 1.8 to 3.6 kHz frequency band were sent, day and night for about four weeks in April and May 2013, and received on a horizontal line array. An extensive analysis of the reverberation data has been made by Yang et al. [2]. Modelling efforts by Ellis et al. [3] concentrated on interpretation of the data, calibration of the matched filter output, and estimation of scattering strengths. For that work a normal-mode Reverberation and Target Echo model was used to perform model-data comparisons and extract a scattering strength (based on Lambert's rule) along the relatively-flat Reverberation Track.

The beams of the horizontal array, can be steered at all azimuths, so in this paper model-data comparisons are made along other radials, using a different scattering function. As well as propagation effects, the model takes into consideration the frequency and angular dependence of the beam patterns, so an estimate of the range and azimuthal dependence of the scattering can be extracted. Scattering anomalies point to regions where additional environmental measurements would be worthwhile.

2. TREX OVERVIEW

Figure 1 shows the TREX13 site and deployments. The source and FORA triplet array [4] were fixed near the bottom in about 20 m water, moored to research vessel *R/V Sharp*. The data were received on the 48-element array deployed horizontally in a fixed position about 2.1 m above the bottom. Each of the elements were triplets, so the "left-right" ambiguity was resolved, and beams could be formed in the full 360° azimuth. The 0.2-m spacing between the elements made the aliasing frequency about 3.8 kHz for a sound speed of 1525 m/s. At half-wavelength spacing the 48 elements can be used to produce approximately 96 independent beams, though generally more were processed.

The omnidirectional ITC-2015 source, also fixed, was deployed nearby, 1.2 m above the bottom. Typical pulses were CWs at 1.9, 2.7, and 3.6 kHz, and LFMs in the bands 1.9–2.0, 2.7–2.8, 3.4–3.5, 1.8–2.7, and 2.7–3.6 kHz. The pulses were 1 s duration and 10% Tukey-shaded at each end. The source levels varied slightly over the band, but were roughly 197 dB re 1μPa at 1 m, and produced reverberation which dropped into the noise after 5 to 10 s, depending on conditions.

3. SOME REVERBERATION DATA

In this paper, we use data processed by Yang [2], with uniformly-weighted beams steered every degree of azimuth, except for 5 degrees near each endfire where the triplet processing [5] was potentially inaccurate. For the results here, beams at 3° intervals were selected.

For each beam, the frequency-domain processing gave a reverberation estimate at time intervals of (bandwidth)$^{-1}$. To smooth the fluctuations of an individual ping for display, the intensity over 19 time points was averaged using with a Hann window.

A few pings with low noise and low volume reverberation from fish were selected from overnight Run 79 (May 9–10) and Run 124 (May 15–16). For these deployments, the array heading was 353°T. For Run 79 there were 4 LFMs of interest, each ping of the same type being repeated every 6 minutes. For Run 124 there were two 900-Hz bandwidth LFMs which alternated every 40 s.

Figure 2 shows the reverberation from a 1.8–2.7 kHz LFM on a polar plot, superimposed on bathymetric contours spaced at 2 m intervals. For the overlay, the beams are mapped into azimuth, and time is mapped into range. The data for each beam have been flattened by multiplying by $(\text{time})^3$, which is slightly less than the reverberation dropoff. This allows a reduced dynamic range for the colour scale, so more features to be seen. Note the high reverberation near the shoreline (white bathymetric contours to the northeast of the array); the reverberation from it also appears faintly on the ambiguous beams to the northwest. Many other scattering features can be seen.

Figure 3 shows the flattened reverberation at short time from the 2.7–3.6 kHz LFM for a selection of beams to the southeast of the array in the general direction of the Reverberation Track (upper plot), and for a selection of beams to the west of the array (lower plot). The reverberation to the southeast (upper plot) is associated with the sand waves of the detailed bathymetry [3, 2]; Figure 4 illustrates the correlation along the Reverberation Track from previous analysis. The reverberation to the west (lower plot of Figure 3) shows similar structure, but the reverberation "peaks and valleys" are closer together, and not so obvious.

4. DATA-MODEL COMPARISON

The Target and Reverberation Model [3] was used to compare with the data. It is a bistatic range-dependent reverberation model that uses adiabatic normal modes for propagation and an empirical function for the scattering. Ray-mode analogies are used to obtain the grazing angles for the scattering function. In [3] the scattering function used was Lambert's rule: $S_b(\theta, \theta') = \mu_2 \sin\theta \sin\theta'$, where the θs are the incident and scattered grazing angles. Figure 4 (left) shows

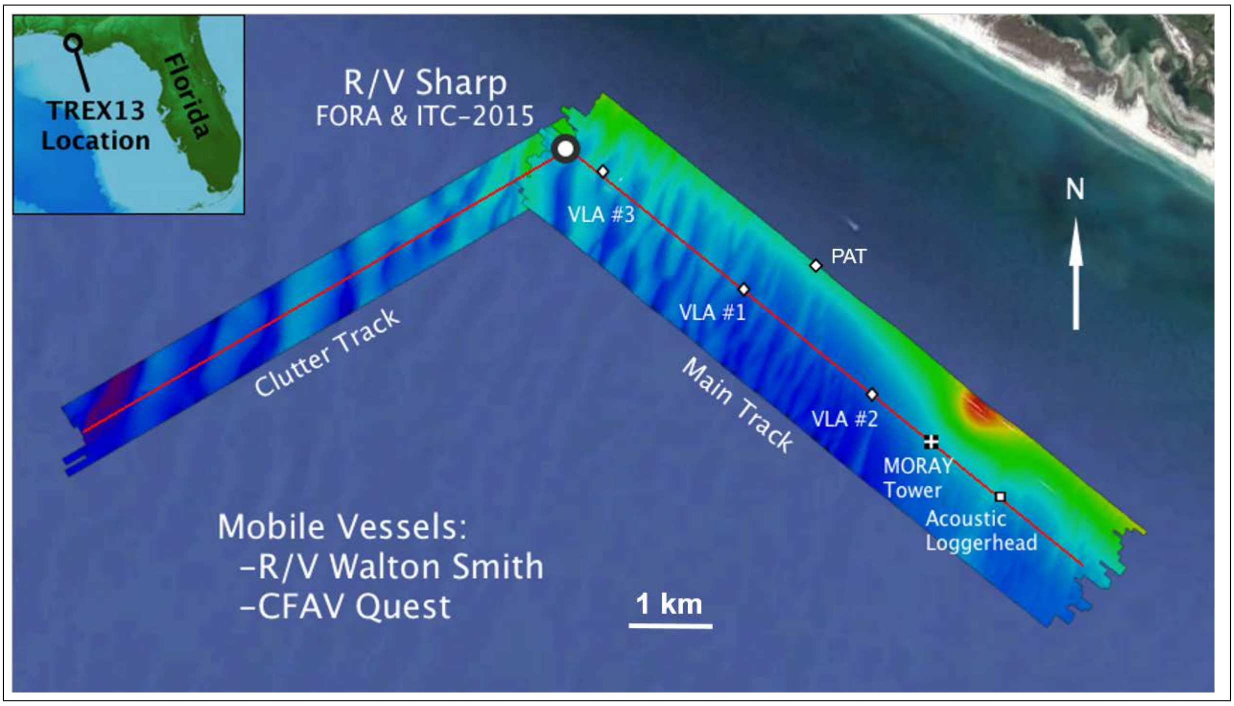

Fig. 1: TREX site showing bathymetry and deployments. The ITC-2015 source and FORA horizontal array are fixed near the bottom in about 20 m water. Water depths range from 12 m (red) to 21 m (dark blue). The Main Track is about 7 km and of nearly constant depth; sand dunes are 1–2 m in height, and several hundred meters apart.

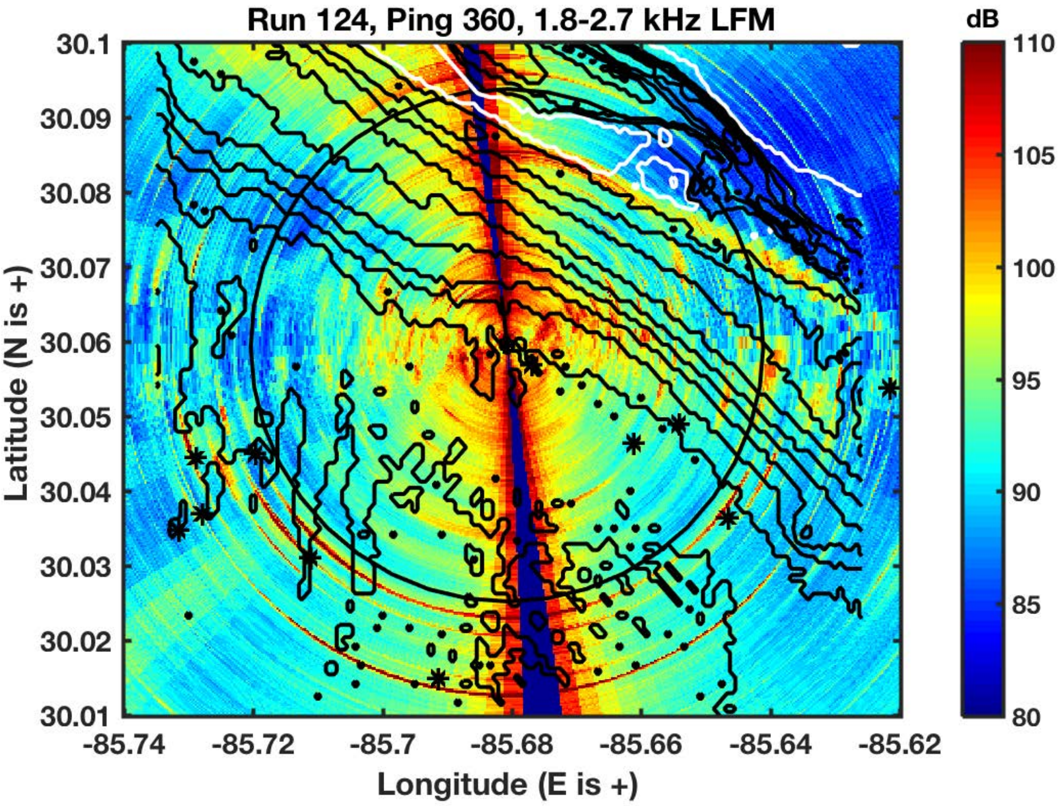

Fig. 2: Polar plot of flattened reverberation for one ping the 1.8-2.7 kHz pulse in Run 124. The source and receiver are at the centre, and the circle corresponds to a time of 5 s (3.8 km).

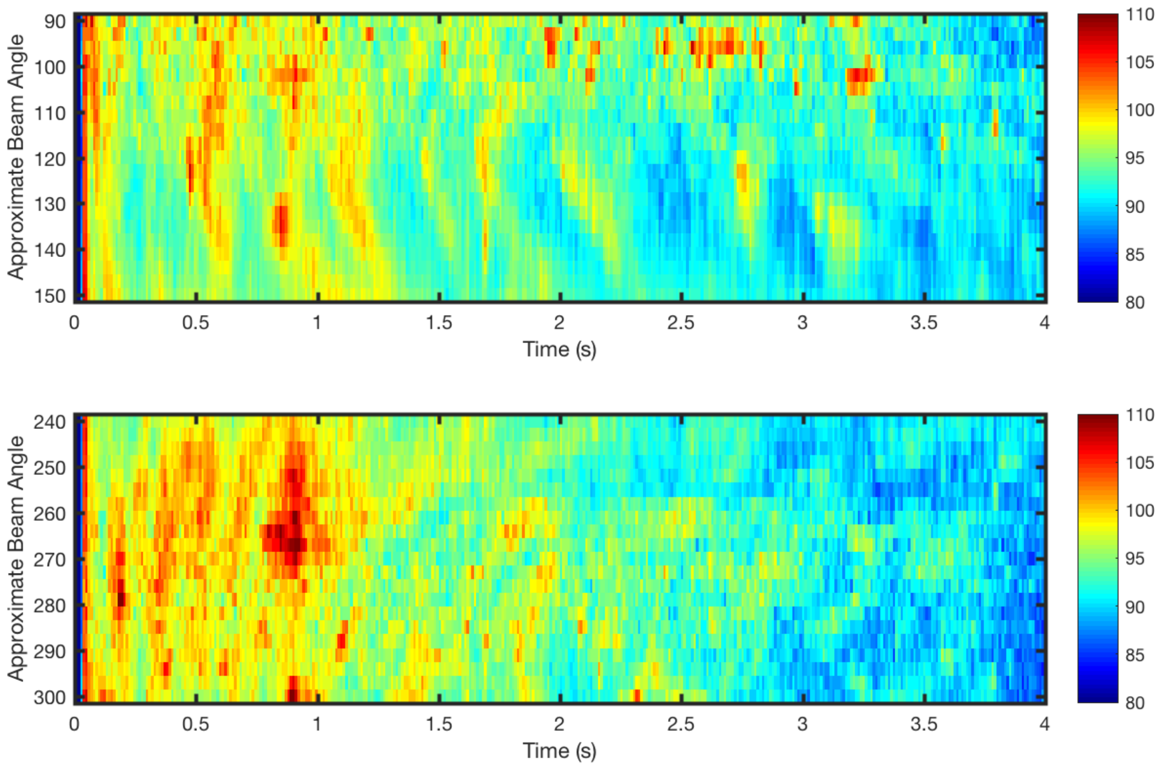

Fig. 3: Plot of reverberation from the 1.8–2.7 kHz LFM for a selection of beams: in the vicinity of the Reverberation Track (upper), and to the west of the array (lower).

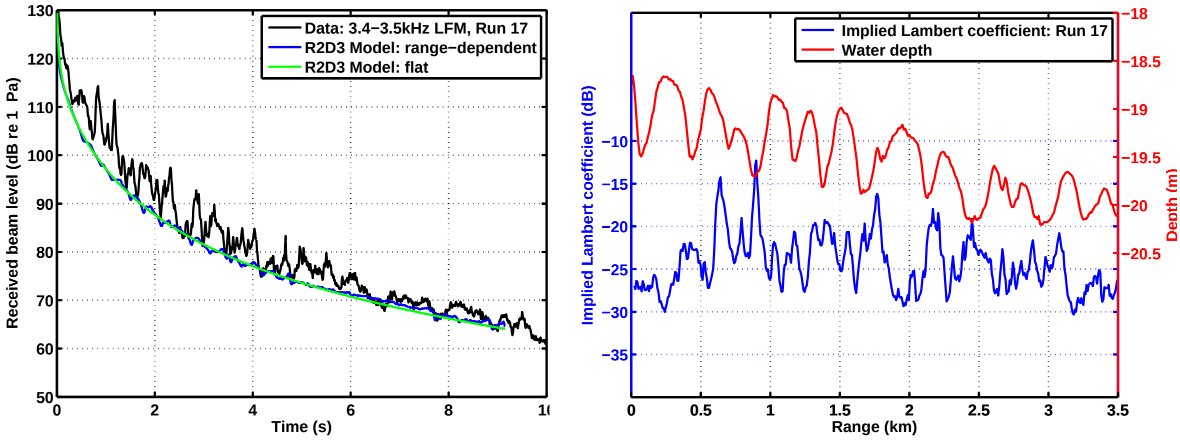

Fig. 4: (Left) Model-data comparison along the Reverberation Track for an earlier data set, and (right) the implied scattering strength compared with the bathymetry.

a model-data comparison along the Reverberation Track from that earlier work using a constant Lambert coefficient, along with the implied scattering strength (right) required to fit the data.

In this paper a different scattering function is used: $S_b(\theta, \theta') = \mu_3(\sin\theta \sin\theta')^{3/2}$, which gives a reverberation decay of $r^{-3.5}$ for Pekeris environment [6], and provides better agreement with the slope of the measured data [7].

From a TREX13 Workshop, a "Strawman" environment was proposed (B.T. Hefner, Private communication, Sept. 2016) with water depth 19.6 m, constant water sound speed 1525 m/s, and a bottom halfspace with sound speed 1660 m/s, and density ratio 1.9. The bottom attenuation had a wide variance, and 0.5 dB/m-kHz was used here. The bathymetry from a NOAA database which has ~90 m resolution was used for the calculations in this paper.

Figures 5 and 6 show model–data comparisons in two frequency bands for four beam angles (one in each quadrant). For the calculations, a constant scattering strength was used at each frequency. For the 1.8–2.7 kHz LFM a value of $\mu_3 = -21$ dB provided a reasonable fit for three of the beams (Figure 5). The model calculations did not include background noise which may be affecting the data at the longer times shown. For the 2.7–3.6 kHz LFM, a stronger scattering coefficient $\mu_3 = -16$ dB was needed. Again, it provides a reasonable fit (Figure 6) to the lower envelope of the data in three of the quadrants, but also falls too low for the beam looking shoreward to the northeast.

The cause of this is not known: it could be increased scattering due to the bottom or surface; it could be that the bathymetry is in error; or it could be that the modes near cutoff are beaming into the bottom causing sub-bottom volume scattering that is not included in the model. Figure 7 shows reverberation on a beam looking shoreward for 4 frequency bands. At 4 s there is a quick drop off of reverberation. There may be a frequency-dependent mode cutoff, with the lower frequencies being cut off a little earlier.

5. DISCUSSION AND SUMMARY

The directional dependence of the towed array, along with the time resolution of the reverberation, make it a very useful tool for Rapid Environmental Assessment and surveying an area [8], identifying features for further investigation.

The previous analysis of the TREX13 reverberation data concentrated on the Reverberation Track. Using high-resolution bathymetry, spikes in the reverberation along the Reverberation Track were shown to be correlated troughs in the sand dunes.

Here we have taken a look at other bearings using beams of the FORA array. Similar patterns in the reverberation are seen to the west of the source-receiver. However, more detailed bathymetry

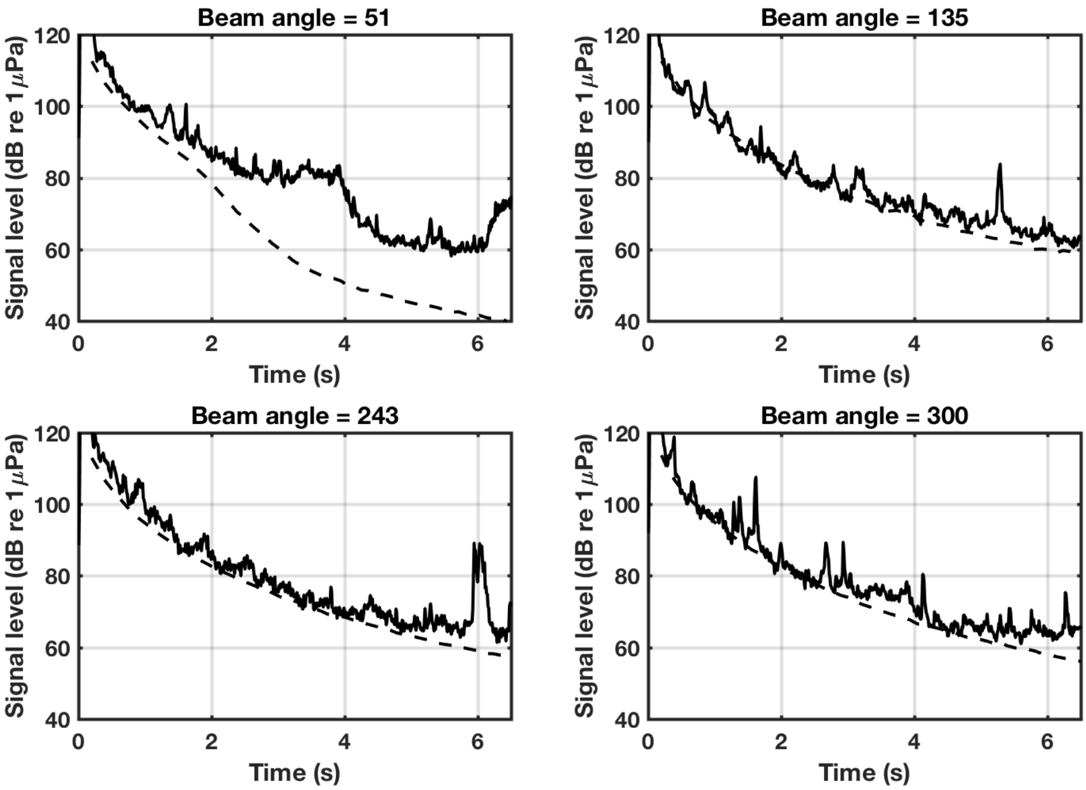

Fig. 5: Model-data comparison on selected beam angles for 1.8–2.7 kHz LFM.

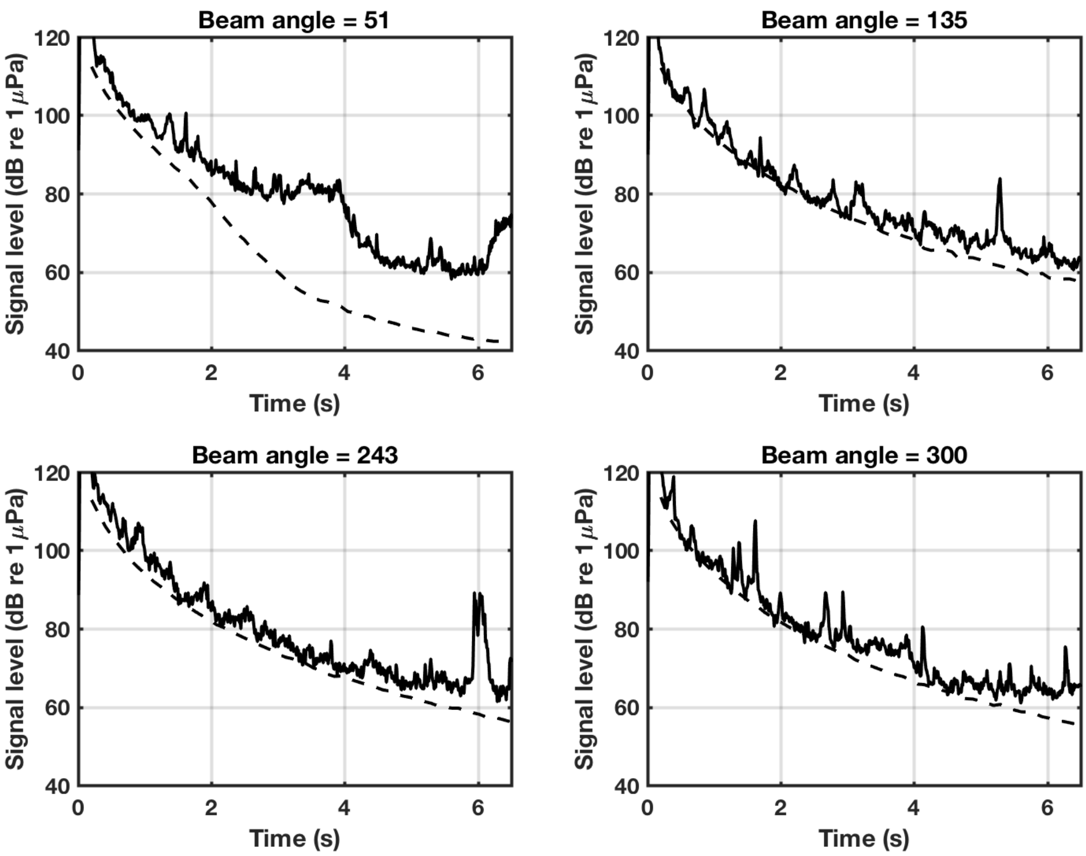

Fig. 6: Model-data comparison on selected beam angles for 2.7–3.6 kHz LFM.

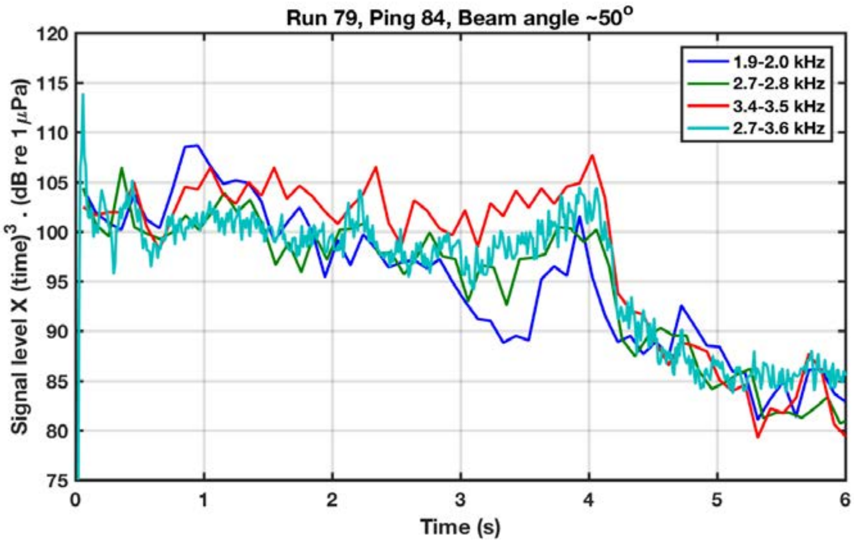

Fig. 7: Comparison of reverberation at different frequencies for shoreward beam.

would be needed to make a correlation.

Initial estimates of the bottom Lambert scattering strength were made in Ref. [3]. There seems to be some indication that the reverberation fits a $\sin^3\theta$ backscattering law which gives a $r^{-3.5}$ range dependence. This is midway between the commonly used $\sin^2\theta$ of Lambert's rule, and the low-angle $\sin^4\theta$ given by perturbation theory. The physics-based scattering function from perturbation theory should be incorporated into the model, and used with estimates of the roughness scattering parameters obtained along the Reverberation Track.

As discussed near the end of the previous section, the behaviour of the scattering near the shore is interesting and requires more investigation.

Work is continuing to look at the data in more detail, and to refine the model predictions.

Model-data differences point to regions where additional environmental measurements would be worthwhile.

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