Geoacoustic inversion of horizontal line array ship-noise data from the Barents Sea

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I. INTRODUCTION

Recent interest in matched-field inversion (MFI) for the estimation of seabed geoacoustic model parameters has expanded from traditional use of high-level controlled sources and a vertical line array of sensors to applications including ship-noise sources with towed [1] and bottom-moored [2] horizontal line arrays (HLAs). A relevant question is the information content of such data. This paper presents results from MFI of low-frequency data from a relatively quiet surface ship recorded on a long bottom-moored HLA. Estimates of geoacoustic parameters of Quaternary sediment are obtained. A Bayesian inversion method [3],[4] is employed to provide quantitative estimates of model parameter and their uncertainties, and allow for meaningful inter-comparisons of results from different data sets. In this paper, results from inversion of ship-noise data are compared with previous results from inversion of controlled-source data collected in the same experiment.

II. INVERSION METHOD

Statistical properties of model parameters **m** can be obtained from the posterior probability density (PPD)

$$P(\mathbf{m} \mid \mathbf{d}) \propto P(\mathbf{m})\exp[-E(\mathbf{m},\mathbf{d})] \tag{1}$$

where $E(\mathbf{m},\mathbf{d})$ is the data mismatch function for data **d** and model **m**, and $P(\mathbf{m})$ the prior information. The multi-dimensional PPD is typically interpreted in terms of its integral quantities, such as the marginal probability distributions, and 95% highest probability density (HPD) credibility intervals. The integrals are evaluated by the method of fast Gibbs sampling [3],[4]. For multi-frequency acoustic data, $\mathbf{d} = \{\mathbf{d}_f, f=1, F\}$, the standard assumptions of uncorrelated complex-Gaussian distributed errors with variance ν_f at the fth frequency and unknown source amplitude and phase lead to the data mismatch function

$$E(\mathbf{m}) = \sum_{f=1}^{F} \mathrm{B}_f(\mathbf{m})/\nu_f \;, \tag{2}$$

where $B_f(\mathbf{m})$ is the Bartlett mismatch defined by

$$\mathrm{B}_f(\mathbf{m}) = \mathrm{Tr}\left\{\mathbf{C}_f\right\} - \left[\mathbf{d}_f^+(\mathbf{m})\mathbf{C}_f\mathbf{d}_f(\mathbf{m})\right] / \left|\mathbf{d}_f(\mathbf{m})\right|^2 . \tag{3}$$

In (3), Tr{•} represents the matrix trace, $^+$ represents conjugate transpose, $\mathbf{d}_f(\mathbf{m})$ is the replica acoustic field computed for model **m,** and $\mathbf{C}_f$ is the cross-spectral density matrix (CSDM) at the fth frequency defined by the ensemble average

$$\mathbf{C}_f = \frac{1}{\mathrm{K}} \sum_{k=1}^{\mathrm{K}} \mathbf{d}_{f,k}\mathbf{d}_{f,k}^+ \;. \tag{4}$$

over K time-series data segments (snapshots) $\mathbf{d}_{f,k}$.

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III. DATA AND INVERSION RESULTS

Acoustic data were collected in the Barents Sea using a 900-m, 18-sensor bottom-moored HLA (sensor spacing from 20 m to 240 m) deployed in a relatively flat area at water depth 280 m [5]. Studied here are data from a track starting at the end of the HLA and extending radially outward at a bearing of 30° relative to the array. Data from a submerged source towed along this track (transmitting five tones at frequencies 30-160 Hz) have previously been used for inversion [5]. Ship-noise data from the R/V H U SVERDRUP II recorded concurrently are considered in the following. Data was selected at four prominent frequency bins (bin width 0.3 Hz) within 25–145 Hz identified from stacked spectrograms; only bins with a positive signal-to-noise ratio (from 0 to 8 dB) and separated by 2 Hz or more from the towed source tones were included in these inversions. CSDM estimates were formed by averaging data from ten consecutive data snapshots (50% overlap) of duration 3.3 s, for a total averaging time of 18.2 s. Noise variance estimates were obtained by a procedure developed in [5]. Inversions were run for a two-layer sediment model (constant-gradient sound speed upper layer over homogenous lower layer) with seven unknown geoacoustic parameters, in addition, small search bounds were used around nominal values for water depth (D), ship range (offset dr), and bearing (b). The ORCA normal mode model [6] was used to compute replica fields. Fig. 1 presents marginal PPDs for six geoacoustic and three geometric model parameters from inversion of data at a source-array range of 1.5 km.

Fig. 1 shows generally good consistency between marginal PPDs for all geoacoustic parameters for the two data sets. Moreover, geoacoustic parameters are equally well defined by the two data sets (e.g., when measured by 95%-HPD widths). Mean parameter estimates from controlled source and ship-noise data, respectively, are 1510 m/s and 1480 m/s for sound speed at top of sediment (c_1), 1753 m/s and 1706 m/s for sound speed of the lower layer (c_2), 1623 m/s and 1585 m/s for the average sound speed in the upper layer (c_{AVE}), and 2.03 g/cm^3 and 1.92 g/cm^3 for upper layer density (ρ_1). These values compare well with reference geophysical data [5].

IV. SUMMARY

Bayesian MFI has been applied to low-frequency narrowband ship-noise data recorded on a long bottom-moored HLA in shallow water. Model parameter estimates compare reasonably well with results from inversion of controlled-source data and with prior geophysical data from the experiment site. Further research will address inversion of multiple data segments.

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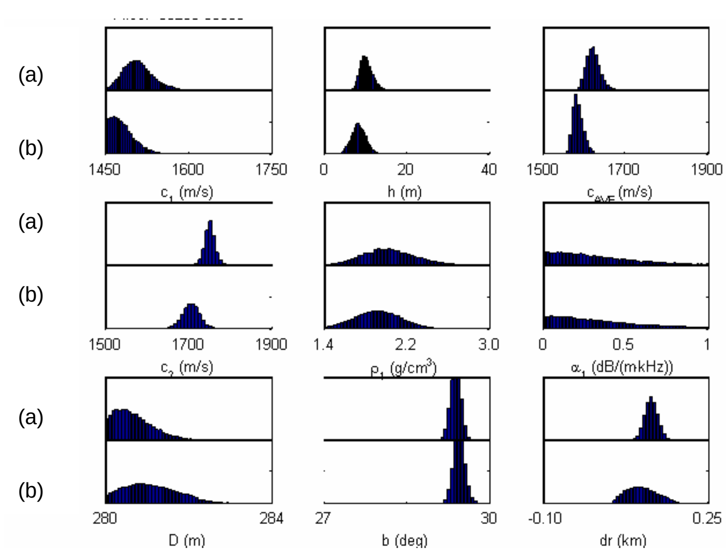

Fig. 1. Marginal PPDs for (a) towed source, and (b) narrowband ship-noise data recorded on a bottom-moored HLA. Source-array range 1.5 km.