GEOACOUSTIC INVERSION OF NOISE FROM SHIPS-OF-OPPORTUNITY WITH UNKNOWN POSITION

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1. INTRODUCTION

The use of noise from ships-of-opportunity for geoacoustic inversion [1-3] can provide several practical advantages: it allows for unobtrusive geoacoustic characterization, a dedicated ship is not required, and additional acoustic sources are not introduced to the marine environment. Use of ship-noise, however, does not allow for control of factors such as source frequency content and position, and supporting data on ship positions may be unavailable or inaccurate. This paper presents results from matched-field geoacoustic inversion (MFI) of noise from a quiet research ship (position known) and from a merchant ship (position unknown) recorded on a horizontal line array (HLA) deployed on the seafloor in shallow water. A Bayesian inversion method [4] is employed; this provides quantitative estimates of model parameters and their uncertainties, and allows for meaningful comparisons of results from different data sets. Ship-noise inversion results are compared with previous results from inversion of controlled-source data collected in the same experiment.

2. METHOD

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

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

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

$$E(\mathbf{m}) = N \sum_{f=1}^{F} \sum_{j=1}^{J} \log_e B_{fj}(\mathbf{m}),$$

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

$$B_{fj}(\mathbf{m}) = \mathrm{Tr}\left\{\mathbf{C}_{fj}\right\} - \left[\mathbf{d}_{fj}^{\dagger}(\mathbf{m})\mathbf{C}_{fj}\mathbf{d}_{fj}(\mathbf{m})\right] \Big/ \left|\mathbf{d}_{fj}(\mathbf{m})\right|^{2}.$$

Here Tr{•} represents the matrix trace, the dagger represents conjugate transpose, $\mathbf{d}_{fj}(\mathbf{m})$ is the replica acoustic field and $\mathbf{C}_{fj}$ is the data cross-spectral density matrix (CSDM) at the fth frequency and jth data segment (defined by the ensemble average over K time-series snapshots [3]).

With a priori unknown ship position, the ship track is first estimated by simultaneous optimization (minimization of $E(\mathbf{m})$) over environment parameters and source positions. The ASSA hybrid search algorithm [5] is used, with source positions searched over a range-depth grid, and track constraints applied to ship velocity. Bayesian MFI is subsequently employed, with small a priori source position uncertainties centred on the optimal track.

3. RESULTS

Acoustic data were collected using the FFI research array (a 900-m HLA with 18 sensors spaced at 10-m to 160-m intervals) deployed on the seabed at water depth 280 m in a relatively flat area of the Barents Sea. First considered is noise from the R/V H U SVERDRUP II in transit along a track (speed 5 kn) starting at the north end of the array and extending radially outward to range 6 km at a bearing of 30° relative to the array endfire-north. Data from a controlled source towed along this track have previously been used for inversion [6].

3.1 Research-ship noise

Noise from the research ship was processed at three frequency lines within 40-145 Hz at signal-to-noise ratio (SNR) of 5 dB and lower. CSDM estimates were formed for five data segments each at two ranges, each 18-s segment from ten 50%-overlapping data snapshots. Inversions were run for a two-layer model of Quaternary sediment (constant-gradient sound speed upper layer over homogenous lower layer) with seven unknown geoacoustic parameters. Small a priori uncertainties were applied to water depth, source depth, and ship range and bearing (offsets from known track). The ORCA normal-mode model [7] was used to compute replica fields.

Fig. 1 shows marginal PPDs for four geoacoustic model parameters from inversion of controlled-source data and ship-noise at source-array ranges of 1.5 km, Figs. 1(a) and 1(b), and 5.1 km, Figs. 1(c) and 1(d). Figs. 1(a) and 1(b) show in general good consistency between marginal PPDs for the geoacoustic parameters from the controlled-source data and ship-noise, with parameters well defined by both data types. Mean parameter estimates (with mean-deviation uncertainties) from controlled-source data and ship-noise are 1510±21 m/s and 1507±23 m/s for sound speed at top of sediment (c_1), 1753±13 m/s and 1737±43 m/s for sound speed of the lower layer (c_2), and 2.0±0.2 g/cm^3 and 1.7±0.2 g/cm^3 for upper layer density (ρ_1). These values compare well with reference geophysical data. The 5.1-km ship-noise, Fig. 1(d), resolved only an average sound speed of the upper layer. (For further discussion of results, see [3].)

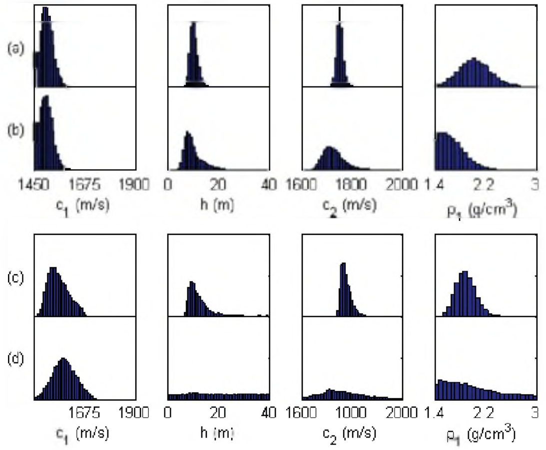

Fig. 1. Results from inversions of controlled-source data and research-ship noise. (See text for explanation).

3.2 Merchant-ship noise

Noise from a 20,000-ton product tanker in transit through the area of experiment was processed at three frequency lines within 40-120 Hz, with SNR in excess of 30 dB. Only one observation of the ship position was logged during the experiment, thus ship track parameters required estimation from the acoustic data. The optimization used eight data segments (total time 2.5 min), and established a track in the array endfire-south direction at 7.0-7.5 km range with ship velocity 15 kn. Subsequent Bayesian geoacoustic inversion used the two-layer seabed model described above, with upper sediment layer thickness constrained to 0-120 m. Results are displayed in Fig. 2 in terms of marginal PPDs for geoacoustic model parameters for inversions of data (two segments in each inversion) at range 7.4 km, Figs. 2(a) and 2(c), and 7.2 km, Figs. 2(b) and 2(d). The data did not resolve distinct upper-layer structure of the seabed, and parameter estimates represent the entire column of Quaternary sediment. Mean values (with mean-deviation uncertainties) are 1716±23 m/s for sound speed at top (c_1) and 1858±47 m/s at bottom (c_2) of sediment with an average sound speed (c_{AVE}) of 1788±14 m/s (consistent results for the two ranges).

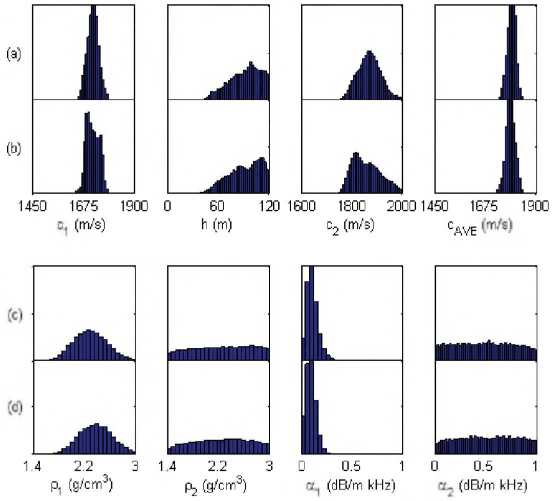

Fig. 2. Results from inversions of merchant-ship noise.

These relatively high-SNR, long-range data also resolved sediment density and attenuation reasonably well, with mean values of 2.4±0.2 g/cm^3 for density (ρ_1) and 0.11±0.04 dB/m/kHz for attenuation (α_1).

4. SUMMARY

Bayesian MFI has been applied to low-frequency narrowband ship-noise recorded on a HLA deployed on the seafloor in shallow water. Seabed geoacoustic model parameter estimates compared well with results from inversion of controlled-source data and with prior geophysical data from the experiment site. Further research is in progress to simultaneously quantify uncertainties in source track and seabed geoacoustic parameters using a Bayesian approach.

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