ACOUSTIC SOURCE LOCALIZATION WITH ENVIRONMENTAL UNCERTAINTY

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1. INTRODUCTION

This paper applies a nonlinear Bayesian formulation to study uncertainty in ocean acoustic source localization due to uncertainty in the knowledge of ocean environmental properties (water-column sound-speed profile and seabed geoacoustic parameters). Localization uncertainty is quantified in terms of probability ambiguity surfaces (PAS), which consist of joint marginal probability distributions for source range and depth integrated over uncertain environmental parameters. The integration is carried out using Metropolis Gibbs' sampling for environmental parameters and two-dimensional heat-bath Gibbs' sampling for source range and depth to provide efficient sampling over complicated source search spaces with many isolated local maxima [1]. The approach is illustrated for acoustic data recorded on a hydrophone array in a shallow-water environment in the Mediterranean Sea where previous geoacoustic studies have been carried out [2]. Localization uncertainty is considered as a function of the level of uncertainty in the prior information for environmental properties.

2. EXPERIMENT

The PROSIM shallow-water geoacoustic experiment was carried out by the NATO Undersea Research Centre in the Mediterranean Sea off the west coast of Italy near Elba Island [2]. The experiment consisted of recording acoustic signals from a transducer towed at approximately 10-m depth along a track with nearly range-independent bathymetry (water depth: 132 m). The source emitted a 0.5-s linear frequency-modulated signal over the band 300–800 Hz every ~0.25 km along the track. The signals were received at a bottom-moored vertical line array (VLA) of 48 hydrophones which spanned from 26–120-m depth with 2-m sensor spacing. The water-column sound-speed profile (SSP) measured during the experiment consisted of a weakly downward-refracting gradient that varied from about 1520 to 1510 m/s.

The environment and source parameters that comprise the model for Bayesian focalization are illustrated in Fig. 1. The acoustic source is at depth z and range r from the VLA in water of depth D. The SSP is represented by four sound-speed parameters c_1–c_4 at depths of 0, 10, 50, and D m. The geoacoustic parameters include the thickness h of an upper sediment layer with sound speed c_s, density ρ_s, and attenuation α_s, overlying a semi-infinite basement with sound speed c_b, density ρ_b, and attenuation α_b.

Geoacoustic inversion was applied previously to the PROSIM data for a source range of approximately 3.95 km, employing 11 frequencies at 50-Hz intervals over the 300–800-Hz source band [2]. The signal-to-noise ratio (SNR) for the data was approximately 30 dB, although the effective signal-to-noise ratio (ESNR), which also accounts for theory error, varied from about 7 to 0 dB over the band. The prior information for the geoacoustic parameters consisted of uniform distributions over wide parameter bounds representing essentially no knowledge of seabed properties. The geoacoustic inversion results from [2] are given as marginal probability distributions in Fig. 2.

3. RESULTS

This section considers the dependence of source localization uncertainty distributions on the prior information (uncertainties) of environmental parameters. Fig. 3 compares PASs computed for measured data at source ranges of approximately 3.1, 4.2, 5.3, and 6.3 km, with four different states of environmental information consisting of uniform prior distributions with: wide prior bounds for both geoacoustic and SSP parameters (top row of Fig. 3); wide bounds for geoacoustic parameters and narrow bounds for SSP parameters (second row); narrow bounds for geoacoustic parameters and wide bounds for SSP parameters (third row); and narrow bounds for both geoacoustic and SSP parameters (bottom row). The wide geoacoustic bounds are identical with the prior bounds used

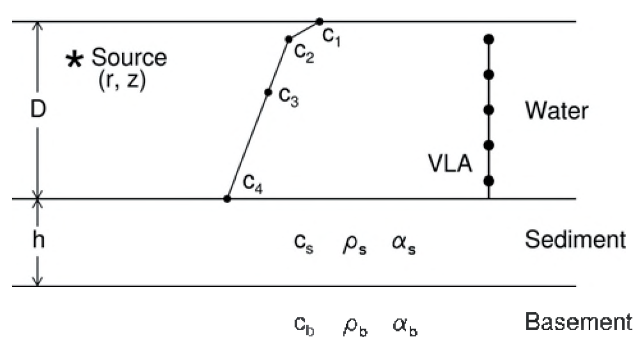

Fig. 1. Schematic diagram of experiment configuration and environmental parameters (defined in text).

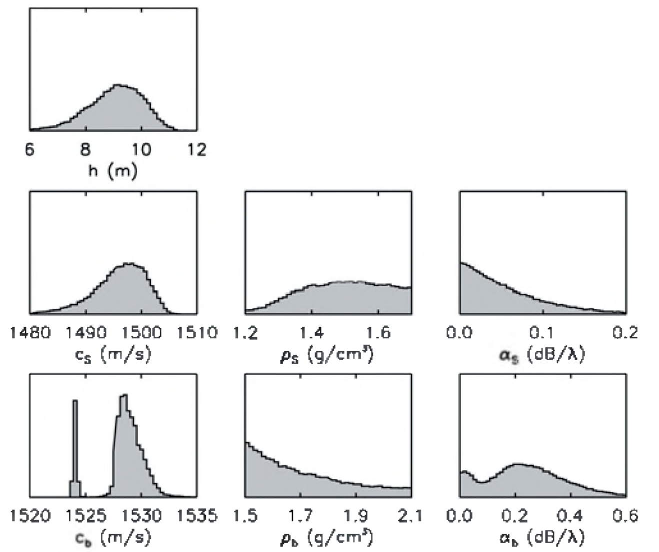

Fig. 2. Marginal probability distibutions from geoacoustic inversion.

in the earlier geoacoustic inversion [2], and represent essentially no knowledge of the seabed properties. The narrow geoacoustic bounds are taken to be the 95% credibility interval from the geoacoustic inversion results shown in Fig. 2, and represent the typical state of seabed information available for localization from a previous geoacoustic inversion survey in a given region. The wide and narrow SSP bounds consist of intervals 10 m/s and 2 m/s wide, respectively, with the measured sound-speed values at or near the centre of the interval.

The acoustic data used in the Bayesian focalization consist of the complex pressure recorded at a single frequency of 300 Hz, with random Gaussian-distributed errors added to the measured data to reduce the SNR to –3 dB. In addition to the additive Gaussian errors, the data uncertainties also include theory error resulting from the limitations of the model parameterization and numerical propagation model.

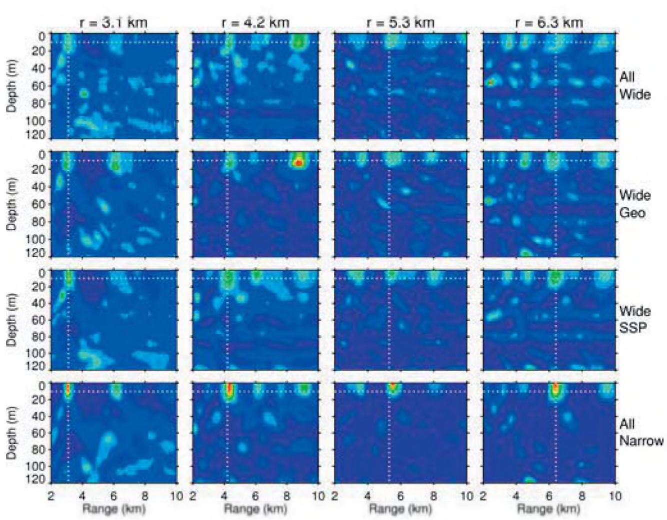

Fig. 3. PASs for various source ranges (indicated by column labels) and levels of prior information (row labels), including combinations of narrow and wide bounds for geoacoustic and SSP parameters. Dotted lines indicate the true source depth and range.

Figure 3 shows that a region of elevated probability is associated with the true source location in all cases. However, localization results are poor for the two cases involving wide geoacoustic parameter bounds. Localization is improved for the case of narrow geoacoustic and wide SSP bounds, although the true location is not unambiguous. Finally, for narrow geoacoustic and SSP bounds, Bayesian focalization provides good localization with small uncertainties for all four source ranges.

It is important to note that the good localization results obtained for the narrow environmental bounds do not indicate that any and all environmental models within these bounds suffice for localization. Rather, the Bayesian focalization samples parameter combinations within the prior that are consistent with the acoustic data. To illustrate this point, Fig. 4 compares the PAS for the source at 4.3-km range computed via integration over narrow environmental bounds to PASs computed for three cases in which geoacoustic and SSP parameters were drawn at random from the narrow bounds and held fixed. Each of the fixed-environment cases yield poor localization results.

REFERENCES

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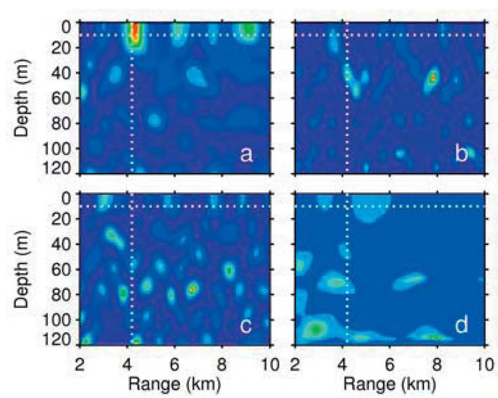

Fig. 4. (a) PAS for source at 4.2-km range from Bayesian focalization over narrow prior uncertainty bounds. (b)–(d) PASs for fixed environmental parameters drawn at random from narrow uncertainty bounds.