BAYESIAN OCEAN ACOUSTIC SOURCE TRACK WITH ENVIRONMENTAL UNCERTAINTY

Stan E. Dosso and Michael J. Wilmut
School of Earth and Ocean Sciences, University of Victoria, Victoria BC Canada V8W 3P6, sdosso@uvic.ca

1. INTRODUCTION

This paper considers matched-field tracking of a moving acoustic source in the ocean when acoustical properties of the environment (water column and seabed) are poorly known. The goal is not simply to estimate source locations but to determine track uncertainty distributions, thereby quantifying the information content of the tracking process. A Bayesian formulation [1, 2] is applied in which source and environmental parameters are considered unknown random variables constrained by noisy acoustic data and by prior information on parameter values (e.g., physical limits for environmental properties) and on inter-parameter relationships (limits on source velocity). Source information is extracted from the posterior probability density (PPD) by integrating over unknown environmental parameters to obtain a time-ordered series of joint marginal probability surfaces over source range and depth. Given the strong nonlinearity of the localization problem, marginal PPDs are computed numerically using efficient Markov-chain Monte Carlo (MCMC) methods, including Metropolis-Hastings sampling over environmental parameters (rotated into principal components and applying linearized proposal distributions) and heat-bath Gibbs sampling over source locations [1, 2]. The approach is illustrated here using acoustic data collected in the Mediterranean Sea, with tracking information content considered as a function of data quantity (number of time samples).

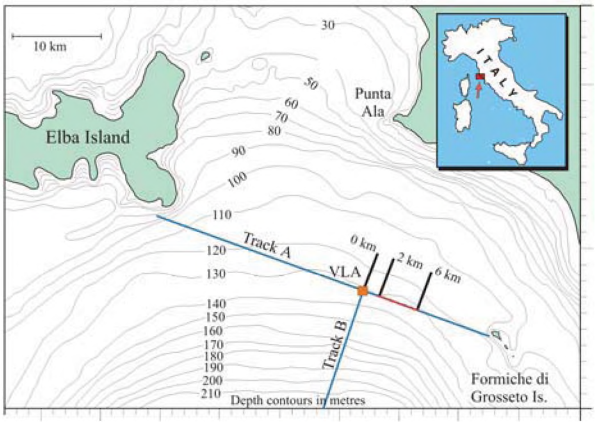

Fig. 1. Location of acoustic experiment.

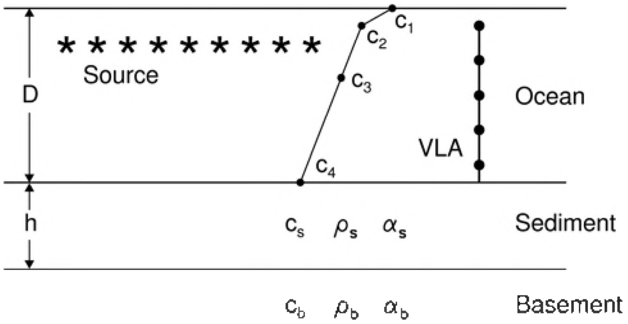

Fig. 2. Experiment geometry and model parameters.

2. RESULTS

The acoustic experiment considered in this paper was carried out in 130 m of water off the west coast of Italy (near Elba Island) in the Mediterranean Sea (see Fig. 1). Acoustic data were measured at a vertical sensor array consisting of 24 hydrophones at 4-m spacing from 26- to 118-m depth. A ship-towed acoustic source (transducer) at a depth of 12 m transmitted a linear frequency-modulated "chirp" signal every ~0.25 km along a radial track from approximately 2-6 km range. Complex (frequency-domain) acoustic fields at 300 Hz are considered here for source tracking, with a signal-to-noise ratio of approximately 0 dB.

The unknown environment and source parameters considered in the tracking problem are illustrated in Fig. 2. Seabed 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. The water depth is D, and the water-column sound-speed profile is represented by four parameters c_1–c_4 at depths of 0, 10, 50, and D m. Wide uniform prior distributions (search intervals) are assumed for all parameters.

For efficiency sake, most source tracking algorithms operate in a sequential mode in which the component data sets of a series of acoustic measurements collected at a sequence of times are each inverted independently for the source location at that particular time. However, the total data information content is maximized by simultaneous inversion of all data sets for a sequence of source locations. This is particularly true for source tracking in an unknown environment, since simultaneous inversion brings all data information to bear on constraining environmental parameters, which in turn leads to better estimation of source locations. Further, applying constraints

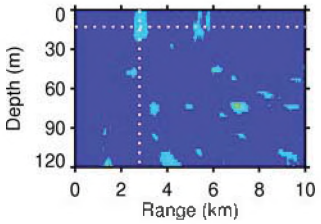

Fig. 3. Joint marginal probability distribution computed for a single source location at the start of the track. Dotted lines indicate the true source ranges and depths.

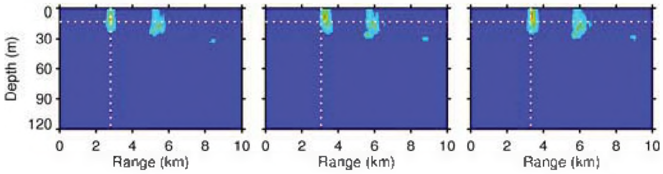

Fig. 4. Joint marginal probability distributions computed for the first 3 source locations along the track. Dotted lines indicate the true source ranges and depths.

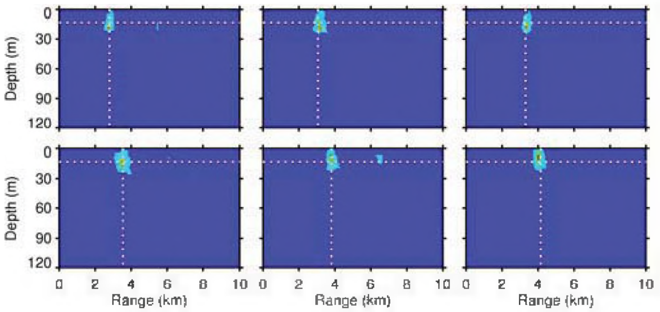

Fig. 5. Joint marginal probability distributions computed for ther first 6 source locations along the track. Dotted lines indicate the true source ranges and depths.

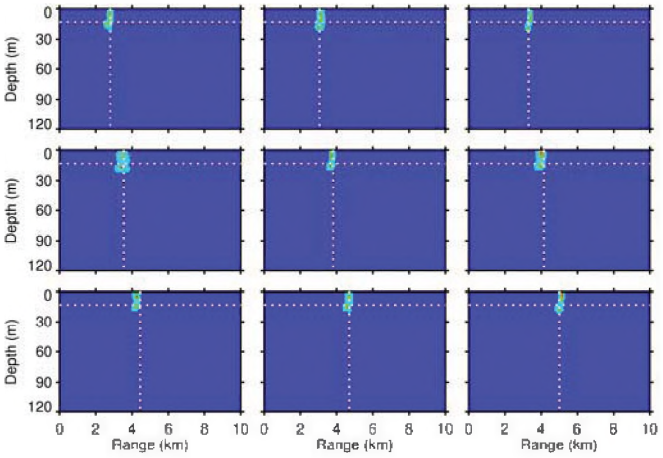

Fig. 6. Joint marginal probability distributions computed for 9 source locations along the track. Dotted lines indicate the true source ranges and depths.

on the maximum horizontal and radial source velocity as prior information provides a link between the various source locations along the track. This has the effect that each source location along the track is constrained by all of the recorded acoustic data, not just the data measured while the source was at that particular location.

The advantages of simultaneous inversion are illustrated in Figs. 3-6. Figure 3 shows the joint marginal probability distribution over source range and depth for the first source location along the track computed by inverting the acoustic data for the first source transmission (i.e., integrating the PPD over unknown environmental parameters via MCMC), with prior limits of 10 and 0.2 m/s for source horizontal and vertical velocity. Although a region of elevated probability (above the background) is associated with the true source location, there are many such local maxima, several with higher probabilities than that at the true location. Hence, the data information content is not sufficient for reliable localization in this case, given data noise and environmental uncertainties. Figure 4 shows marginal probability distributions for three source locations computed by inverting the first three source transmissions. The highest probability peak occurs at the true source location for each transmissions, with only two other local maxima in probability, indicating reasonably reliable localization/tracking. Of particular note is the substantial improvement in localization for the first source position over that shown in Fig. 3 for a single transmission. This improvement results from the fact that, in simultaneous inversion with source velocity constraints, the acoustic data for the second and third source transmissions help constrain the source location at the time of the first transmission. This effect is further illustrated in Figs. 5 and 6, which show localization marginal probability distributions computed for six and nine source transmissions, respectively. In each case the ability to localize/track the acoustic source at early times along the track is substantially improved by data collected at later times (which, of course, also leads to improved results at later times). This improvement is only possible through simultaneous inversion.

ACKNOWLEDGEMENTS

The authors thank Dr. Peter Nielsen of the NATO Undersea Research Centre (NURC) for providing the Mediterranean Sea acoustic data.

REFERENCES

[1] Dosso, S.E. and M. J. Wilmut, 2008. Uncertainty estimation in simultaneous Bayesian tracking and environmental inversion. J. Acoust. Soc. Am., **124**, 82-97.

[2] Dosso, S.E. and M. J. Wilmut, 2009. Comparison of focalization and marginalization for Bayesian tracking in an uncertain ocean environment. J. Acoust. Soc. Am., **125**, 717-722.