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4pSP1. Sampling methods for uncertainty quantification in source localization and geoacoustic inversion in the ocean

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Iterative and sequential Bayesian filtering approaches have been successfully employed for the estimation of select features of received acoustic signals - namely, arrival times and amplitudes of paths that have interacted with the propagation medium. These are subsequently utilized in source localization and environmental property estimation. Sequential filtering has the advantage of relating multipath arrival times across spatially separated hydrophones of a receiving array, providing "tighter" estimates of arrival times and amplitudes and, thus, probability densities with a reduced "spread" in inversion. We here present a new implementation of linearization of the relationship that links source location, water depth, and sound speed to the received sound field using arrival time estimates extracted with sequential filtering from time-series received at an array of phones in the ocean.

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ARRIVAL TIME ESTIMATION AND INVERSION

Localization of a sound source and estimation of propagation medium properties from time-series recorded at arrays of hydrophones are important problems in ocean acoustics for both defense purposes and environmental studies. Localization results by using arrival times extracted with a particle filtering method have been presented in Jain and Michalopoulou (2009), Yardim et al. (2011), Michalopoulou et al. (2012), and Michalopoulou and Jain (2012). This method has been shown to lead to better source location estimates than approaches relying on non-sequential arrival time estimation.

In this paper we present a method for sound speed estimation by first using sequential filtering for arrival time extraction. With the estimated multipath arrival times as input, we design a linearization approach that inverts for sound speed using Empirical Orthogonal Functions (EOFs), extending the approach of Michalopoulou and Ma (2005). The Jacobian matrix that is necessary for the linearization process contains time derivatives with respect to coefficients of these EOFs in addition to those with respect to source range, source depth, water column depth, and time of transmission.

Specifically, linearization inversion methods for sound speed estimation are challenging. Sound speed typically varies with depth (rarely is the profile a true isovelocity one). Sometimes, instead of inverting for a complete sound speed profile (ssp), a bias between an assumed and a “true” profile is estimated, as shown in Dosso et al. (1998). A more comprehensive inversion would involve several parameters for the unknown sound speed, reflecting its change with depth. Parameterization of profiles with EOFs, however, allows us to invert for EOF coefficients rather than sound speed directly. Specifically, we follow the approach and notation of Ma (2001) towards this goal.

We start by describing the water column sound speed profile as:

$$ c = c_m + \sum_i \mu_i v_i, \quad (1) $$

where $c_m$ is a mean ssp vector calculated from a number of available ssp measurements and $v_i$ is the $i$th eigenvector of the sound speed covariance matrix. Here, we consider for the inversion $i = 1, 2, 3$. Once coefficients $\mu_i$, $i = 1, 2, 3$, are retrieved, they can be used in Equation 1 to form the complete ssp.

We form the Jacobian matrix via which arrival times and unknown parameters are related by setting up the problem as a quasi-linear system. We use the PDFs of the arrival times extracted with particle filtering to generate PDFs of the unknown parameters (source location, water column depth, ssp EOF coefficients, and time of transmission). As mentioned above, these arrival times are estimated with the approach of Jain and Michalopoulou (2009) and Michalopoulou and Jain (2012). These PDFs are more realistic and elaborate than simple Gaussian distributions that are typically assumed for the statistical description of measured arrival times.

Estimated PDFs at the output of the inverse method are shown in Figs. 1 and 2 for source range and coefficient $\mu_1$, respectively. The true values for the parameters are 223 m and -60. The modes of the PDFs are very close to those values, indicating the potential of the method for accurate localization and environmental inversion with simultaneous uncertainty quantification.

Although, in this work we validated the method by applying it to synthetic data, we are currently implementing such an inversion approach for source localization and water depth and sound speed estimation with Shallow Water 06 data. Preliminary results are very promising, as demonstrated via a comparison of estimates obtained with the new technique to benchmark values and estimates from other approaches.
FIGURE 1: PDF of source range using arrival times extracted via particle filtering and EOFs for modeling sound speed.

FIGURE 2: PDF of coefficient $\mu_1$ using arrival times extracted via particle filtering and EOFs for modeling sound speed.

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