GEOACOUSTIC INVERSION OF MEDITERRANEAN SEA DATA

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BACKGROUND

Determining seabed geoacoustic properties from measured ocean acoustic fields is a challenging nonlinear inverse problem with no direct solution. Typically, global search methods, such as simulated annealing and genetic algorithms, have been applied to provide a practical solution. Recently, a hybrid inversion algorithm which combines the local (gradient-based) downhill simplex method with simulated annealing has been developed and shown to be more effective than global searches alone [1,2]. In this paper, the hybrid inversion, referred to as simplex simulated annealing (SSA) is applied to invert measured acoustic fields [3] for geoacoustic properties at at a site off the west coast of Italy where previous acoustic and geophysical studies have been performed [4,5].

EXPERIMENT AND INVERSION

Figure 1 shows the location of the acoustic experiment, referred to as PROSIM'97. Acoustic fields were recorded on a 48-sensor vertical line array (VLA) due to a swept-frequency source (300–850 Hz) towed at a nominal depth of 12 m over a series of tracks. In this paper, data recorded while the source was towed over a 10-km section of relatively constant water depth is analyzed (Fig. 1). Environmental parameters such as ocean sound speed and current velocity were recorded throughout the experiment; however, the precise bathymetry along the source track was poorly constrained due to experimental difficulties.

Based on the known geology, the seabed was modelled as a sediment layer overlying a semi-infinite basement with parameters consisting of the sediment thickness h, sediment and basement sound speeds c_s and c_b, source range and depth r and z, array tilt ψ, and water depth at source and receiver D_1 and D_2. The geoacoustic parameters were estimated using matched-field inversion which determines the set of model-parameter values that minimizes the mismatch between the measured acoustic fields and modeled replica fields computed using a numerical propagation model. The measure of the mismatch used here is based on the (normalized) Bartlett correlator for a broad-band signal:

$$E(\mathbf{m}) = 1 - \frac{1}{F} \sum_{i=1}^{F} \frac{|\mathbf{p}(f_i) \cdot \mathbf{p}^*(\mathbf{m}, f_i)|^2}{|\mathbf{p}(f_i)|^2\, |\mathbf{p}(\mathbf{m}, f_i)|^2}, \tag{1}$$

where $\mathbf{p}(f_i)$ is a vector of acoustic pressures measured at the VLA at a frequency f_i, $\mathbf{p}(\mathbf{m},f_i)$ is a vector of replica pressures computed for a model $\mathbf{m}$, and F is the number of frequencies. With the normalization applied in Eq. (1), the mismatch has a value $E \in [0, 1]$, with zero indicating a perfect match. The replica acoustic fields were generated using an adiabatic normal-mode acoustic propagation model known as PROSIM. The mismatch was minimized using SSA, a hybrid inversion algorithm that incorporates the local downhill simplex method into a fast simulated annealing global search [1,2].

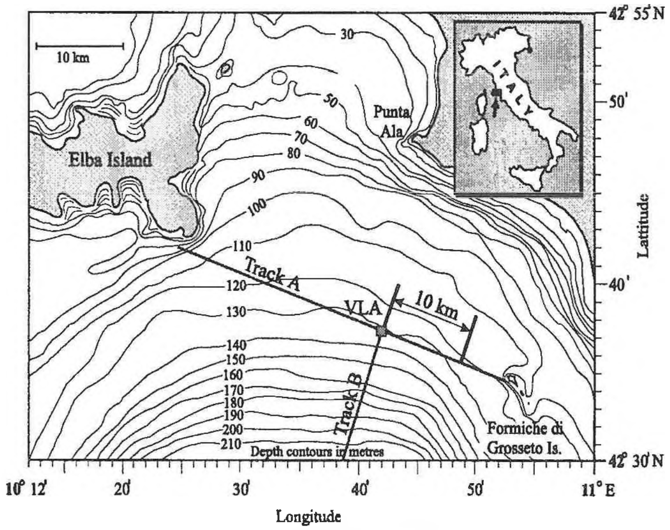

Fig. 1 Experiment site and ship tracks.

Acoustic data for 17 ranges from 0.7–10 km along the source track were selected for inversion. The goal of inverting data from multiple ranges was not to determine a range-dependent geoacoustic model, but rather to consider a large enough number of independent measurements to provide an indication of the consistency of the inversion results for the various model parameters. Several independent SSA inversions were carried out for the acoustic data at each range, for a total of 52 inversions (each inversion required approximately 3 hours on a 500-MHz DEC Alpha workstation). Figure 2 shows the model parameters determined in all inversions plotted as a function of the source longitude, with the inversion results that produced the lowest mismatch at each range connected by a solid line.

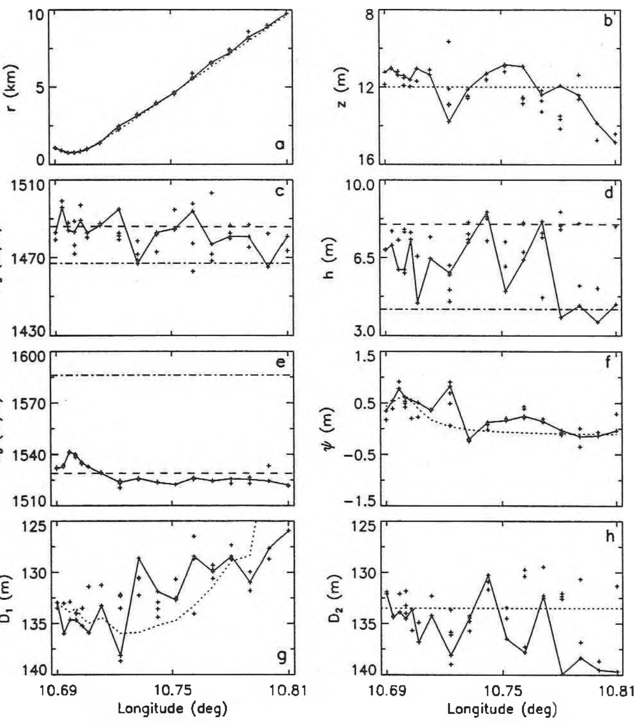

Fig. 2 SSA inversion results as a function of source longitude. Crosses represent all results, with solid lines connecting the lowest mismatch results. Dotted lines represent independent estimates (when available); dashed and dash-dotted lines represent results from Refs. [4] and [5].

The SSA inversion results for the source range r are shown in Fig. 2(a), with the dotted line representing the nominal range calculated using differential GPS measurements. The lowest-mismatch results closely track the nominal range, and the variation between inversion results at each range is small. Figure 2(b) shows the inversion results for the source depth z. The dotted line at 12 m indicates the nominal source depth. With a small number of exceptions, the inversion results are within approximately 1 m of the nominal depth, and exhibit a moderate amount of variation.

Figure 2(c)–(e) show the results for the seabed properties (sediment sound speed c_s, sediment thickness h, and basement sound speed c_b) compared to the results obtained in previous studies of the same region [4, 5]. The results for c_s generally fall between the previous results, and exhibit a moderate amount of variation from inversion to inversion. The results for h also fall between the two previous results, but with a relatively large variation. The results for c_b are in excellent agreement with the results of [4], and are highly consistent from inversion to inversion.

Figure 2(f) shows the inversion results for the array tilt ψ. The dotted line represents the estimated (relative) tilt, calculated by projecting the measured current vector onto the radial vector between the source and VLA. With the exception of a few points, the inversion results are highly consistent and are in excellent agreement with the estimated tilt.

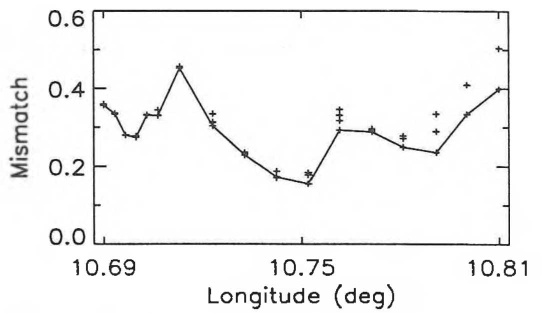

Fig. 3 Mismatches for inversion results shown in Fig. 2.

Figure 2(g) and (h) shows the inversion results for the water depth at the source and receiver D_1 and D_2, with the dotted lines representing the measured water depths. The general features of the inversion results for D_1 are in reasonably good agreement with the measured bathymetry. The inversion results for D_2 are in reasonable agreement for the first 8–10 points, but are in poorer agreement beyond. The results for both water depths D_1 and D_2 show a substantial amount of variation from inversion to inversion.

The relatively large amount of variation in the results for the sediment thickness and water depths is likely due to inter-parameter correlations that arise because the low-speed sediment layer appears similar acoustically to the water column (sound speed 1510 m/s). Correlated parameters cause difficulty in reliably estimating individual parameter values, as different parameter combinations produce very similar (low) mismatch values. The mismatches obtained by the SSA inversions of Fig. 2 ranged from 0.15–0.5, and are shown in Fig. 3.

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