Array element localization using ship noise

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I. INTRODUCTION

Array element localization (AEL) involves accurate localization of the sensors of an acoustic array using measured travel times between the receivers and a number of sources. The inversion is typically based on the acoustic ray tracing equations, and has been applied to a variety of experimental source and receiver geometries [1], [2]. AEL is usually carried out using impulsive sources that produce recorded time series which contain identifiable acoustic arrivals. The continuous nature of broadband sources such as ships makes direct observation of coherent arrivals difficult; however, relative arrival times can be extracted from recordings of a noise source by cross-correlating the time series of spatially separated hydrophone pairs.

In this work, relative acoustic arrival times are extracted from broadband noise recordings of a surface ship and used in AEL inversion to estimate the receiver locations of a vertical line array (VLA), accounting for uncertainties in the source locations. The inversion uses the method of regularization [4] to combine information from the data with prior estimates and uncertainties of the source and receiver positions. Estimates of the posterior positional errors are obtained by a Monte-Carlo appraisal procedure [5].

II. EXPERIMENT AND INVERSION METHOD

In October 2003 a scientific cruise in the northern Gulf of Mexico was undertaken to collect acoustic data for gas hydrate research. A bottom-moored VLA consisting of 16 hydrophones spaced at 12.5 m intervals was deployed from the ship and allowed to freefall to the seafloor in ~800 m of water. Six second samples of acoustic data were recorded at several ship positions as it transited along radial track lines centered over the array position, first towing an impulsive source (water gun), and then with no sound source except the survey ship. Due to large correlated timing errors and badly clipped direct arrivals, the towed-source data were not suitable for AEL inversion; therefore, a method was devised to use the ship noise for this purpose.

The inversion method is based on a least-squares approach, whereby the model that best fits the data is found by iteratively solving a system of equations consisting of a locally linear approximation to the acoustic ray equations. Including both source and receiver positions as unknowns in the inversion leads to an ill-conditioned problem which can be overcome by including regularization terms that impose constraints on the solution based on prior information about the model. In this case, the prior information includes initial estimates and uncertainties of source and receiver positions based on the deployment procedure, and the expectation that the array shape and source tracks are smooth functions of position.

Relative acoustic travel times were extracted from band-pass filtered recordings of the ship noise by cross-correlating the signals of pairs of receivers over the same time interval. The maxima of the cross-correlation functions correspond to the time differences between the direct arrivals of coherent acoustic energy at the hydrophones.

III. RESULTS

Relative travel time data were picked from the cross-correlation functions of 13 hydrophone pairs, derived from recordings of ship noise obtained at 64 locations along two orthogonal tracks. Samples of acoustic pressure data recorded at the array are shown in Fig. 1(a), and the cross-correlation functions derived from them are shown in Fig. 1(b). The errors on the travel time picks (Fig. 1(c)) were estimated to be 0.2 ms based on the width of the cross-correlation peaks. The uncertainties in the prior source positions were assumed to be 15 m in x and y, and 3 m in z. Large uncertainties (1000 m in x and y, and 100 m in z) were used for the hydrophone positions. The inversion was initialized from the GPS position where the array was dropped overboard, and converged to the final solution after 7 iterations. The data misfit for the final model was more than a factor of 20 smaller than the initial estimate. The inversion relocated the array ~44 m southeast of its deployment position. The recovered

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hydrophone depths are consistent with the known bathymetry at this location to less than 1 m, and the inter-element hydrophone spacing is in excellent agreement with the nominal values (within 0.1 m). The AEL solution indicates that the top hydrophone of the array is deflected ~5.5 m towards the south-southeasterly direction (Figs. 2(a) and (b)) which is consistent with the average direction of the bottom current obtained from an acoustic Doppler current profiler mounted at the base of the array. Non-linear estimates of the position errors were obtained by a Monte-Carlo appraisal that involved 500 iterations of the inversion with random Gaussian noise added to the data, starting model, and prior position estimates. Figs. 2(c) and (d) show the absolute and relative (with translation and rotation errors removed) position errors estimated by this procedure indicating a high degree of confidence in the final solution. The translation correction co-locates the centroids of the inverted array solutions and the true solution; hence, the errors are close to zero near the middle hydrophone of the array and increase toward the ends.

IV. CONCLUSION

In this paper, an AEL inversion method was described that uses relative acoustic arrival times derived from recordings of ship noise. The inversion produced a solution for the VLA location and shape that is consistent with available information.

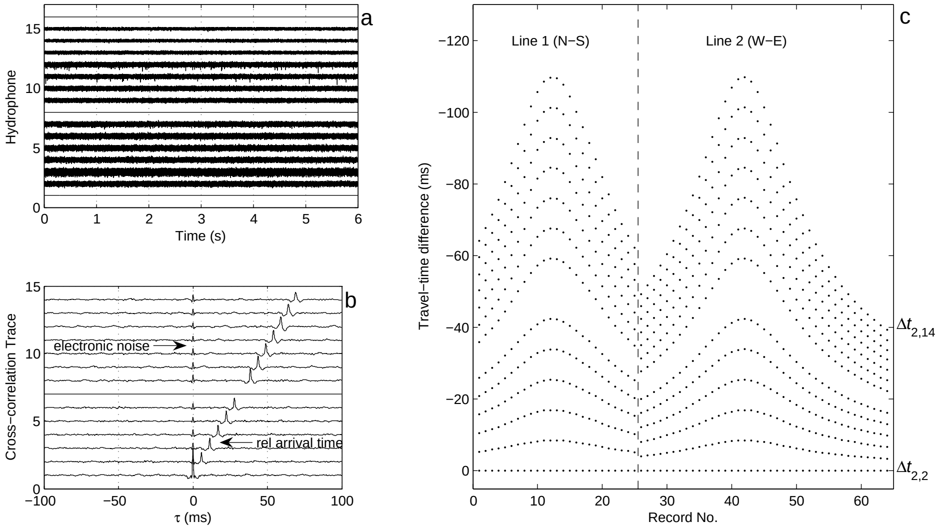

Fig. 1. (a) Time-series of ship noise (hydrophones 1, 8, and 16 zeroed due to poor data). (b) Cross-correlation functions showing the time delay between direct arrivals for each hydrophone pair (hydrophone numbers increment from the bottom of the array). (c) Relative travel-time picks from cross-correlation functions for all hydrophone pairs and both ship track lines.

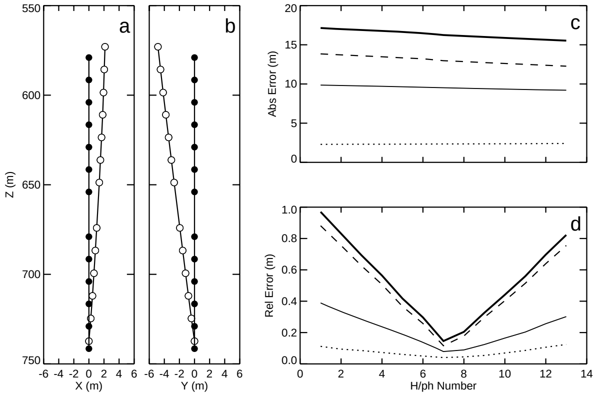

Fig. 2. Panels (a) and (b) show the prior estimates (solid circles) and inversion results (open circles) for the array shape in x and y (relative to bottom hydrophone). Absolute (c) and relative (d) uncertainties of hydrophone locations in x, y, z and $R=[x^2+y^2]^{1/2}$ are indicated by solid, dashed, dotted and heavy solid lines, respectively.

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