Real-time environmental inversion using a network of light receiving systems

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Abstract**—*This paper reports preliminary environmental inversion results of acoustic data collected simultaneously at two receiving systems during the RADAR'07 sea trial. These receiving systems have communication capabilities that allow for transfering acoustic and telemetric data to a base station with processing capabilities in order to produce environmental estimates during the acoustic experiment. During a large part of the experiment estimates on the temperature field appear to agree with concurrent ground truth data.*

Keywords**—*REA, real-time acoustic inversion, receiver network.*

I. INTRODUCTION

The estimation of ocean parameters by means of the inversion of acoustic signals - environmental inversion - is a research topic that aroused significant interest during the 1990s, and in several occasions its viability has been demonstrated [1], [2]. Environmental inversion of acoustic signals for bottom and water column properties has been proposed in the literature as an interesting concept for complementing direct oceanographic measurements for Rapid Environmental Assessment (REA). The acoustic contribution to REA can be cast as the result of the inversion of ocean acoustic properties to be assimilated into ocean circulation models specifically tailored and calibrated to the scale of the area under observation [3]. The main question is to know to what extent acoustics may contribute to give a picture on the oceanography of a given area.

Traditional environmental inversion techniques require several adaptations in order to respond to operational requirements of REA and to effectively produce a contribution in terms of inputs to ocean circulation models: (a) the acoustic hardware must be light and handy in order to be employable in operational scenarios [4]; (b) as REA should respond to operational assessment requests on very short notice, oceanographic properties should be available short time after the reception of the acoustic signals; this requires environmental inversion concepts to be performed as a real-time application; (c) in order to earn oceanographic data more effectively, and in order to increase the spatial coverage, by simultaneously estimating multiple ocean transects instead of a single one as traditional, a network of receiving nodes can be used as this allows for collecting acoustic waves traversing the ocean in different directions. Topic (a) has been treated in the past 4 years in several occasions [5], [6].

The RADAR'07 sea trial, held during July 2007 in the sea of Tróia off the Portuguese coast, served the purpose of testing a network of receiving systems with two nodes, and perform real-time environmental inversions using that network. Each node consists of an exemplar of the Acoustic Oceanographic Buoy (AOB) [4], which uses a surface buoy and an underwater array of acoustic sensors (AOB1 with 8, and AOB2 with 16) and non-acoustic sensors. Among several other characteristics the surface buoy includes a digital storage unit for the acquired data, a wireless communications system for remote monitoring and data transmission, and GPS system. These features allow for carrying out inversions as the data can be transferred from the buoy to a platform equipped with processing capabilities before recovery. These buoys are easily deployed and recovered for their small dimensions, and since they can record their geographic coordinates they can be deployed in a free-drifting configuration.

This paper presents preliminary environmental inversion results obtained during the RADAR'07 sea trial.

II. THE RADAR'07 SEA TRIAL

The RADAR'07 took place from July 9, to July 14, 2007, off the Portuguese coast approximately

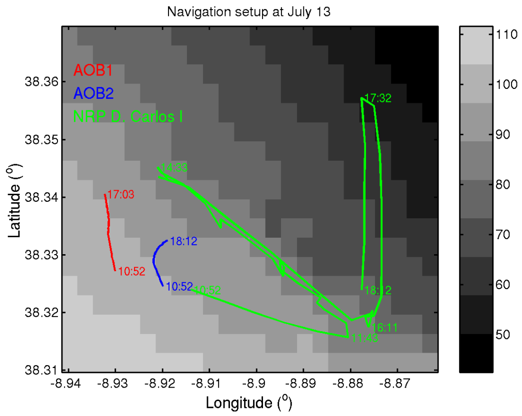

Figure 1. Navigation setup during the RADAR'07 sea trial on July 13.

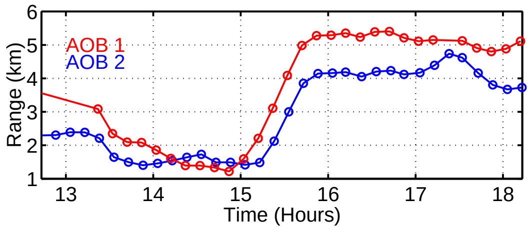

Figure 2. *Range between acoustic source and AOBs over time.*

50 km South of Lisbon, in an area with variable bathymetry, at the continental platform.

A. The experimental setup

On July 13 the two AOBs were deployed in a track with constant waterdepth. The research vessel towed the transmitting acoustic source and the AOBs drifted away from the deployment position as indicated by the GPS recordings in Fig. 1. The transmission tracks from time 10:52 to time 16:11 have a bathymetry with mild range-dependence. After, the source is towed to a position with a waterdepth decreasing down to 50 m, resulting in transmission tracks with very significant range-dependence. A waterdepth as low as 50 m may be a very severe condition in terms of modeling due to the strong interaction with the seafloor.

The source transmitted a sequence of waveforms consisting of multi-tones and linear frequency modulated chirps in different bands. Figure 2 shows the range between the acoustic source and each AOB over time according to the GPS recordings. Source depth was varied between 4 and 9 m depending on ship speed.

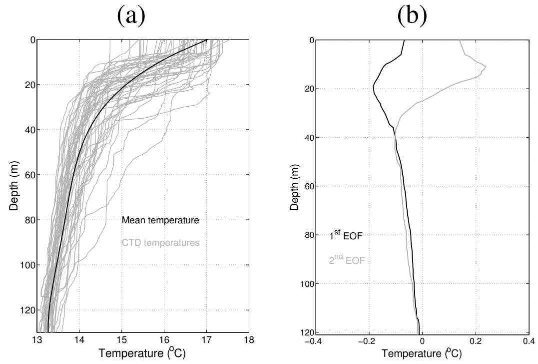

Figure 3. CTD measurements performed during the RADAR'07 sea trial: (a) Temperature profiles in gray and mean profile in thick black; (b) empirical orthogonal functions obtained from temperature profiles.

B. Oceanographic survey

Oceanographic surveys were performed during the nights over the week, using a Conductivity-Temperature-Depth (CTD) chain for measuring salinity and temperature at a pre-defined grid of points. Figure 3(a) shows the temperature measured with the CTD chain. The purpose of these temperature measurements is to obtain historical data that enter as *a priori* information into the inversion problem. The watercolumn is modeled by means of the mean temperature profile and the Empirical Orthogonal Functions (EOF) obtained from those measurements. The EOFs are shape functions that are obtained by means of a single value decomposition. A criterion selecting the most significant EOFs explaining at least 80% of the variability of the watercolumn temperature was applied, resulting in the 2 EOFs shown in Fig. 3(b). Figure 4 shows the water temperature recorded with a thermistor chain available in AOB2 during the acoustic experience of July 13. The thermistor chain consists of 16 elements, one every 4 m from 6 to 66 m depth. It can be observed how the thermocline varies over time. Also very fast variations at the surface are noticeable, which could possibly be internal waves. In the present study these data are used only for

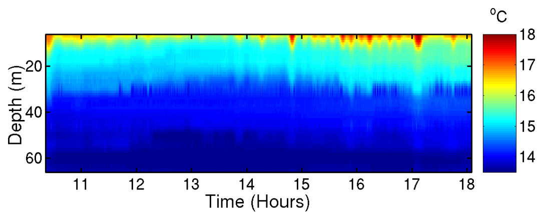

Figure 4. Temperature field recorded at AOB2 on July 13.

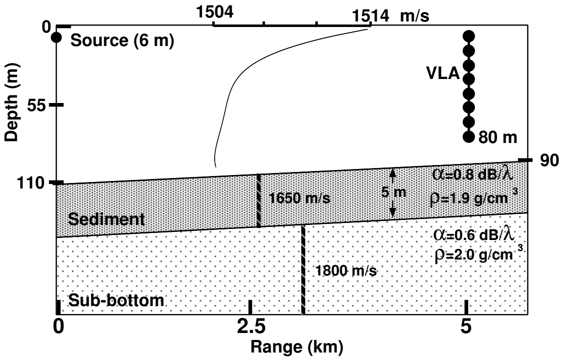

Figure 5. Baseline environmental model used for environmental inversion.

comparison with the acoustic inversion results, but these could eventually be used to feed the inversion process over time.

III. Experimental results

A. The environmental model

Figure 5 shows the baseline environmental model used for the environmental inversion. It consists of a three layer model with watercolumn, sediment layer, and sub-bottom. The watercolumn is modeled in terms of sound-speed according to the mean temperature profile, EOFs and mean salinity obtained from the oceanographic survey, and the properties for sediment and sub-bottom are respectively values typically found for sand and gravel. The waterdepth is based on the segmentation of the archival bathymetric information along the source-receiver cross sections at each time. For the purpose of inversion the parameter set consists of EOF coefficients α_1 and α_2, sediment parameters (sound velocity, density, thickness), sub-bottom sound velocity, and geometric parameters (source depth, receiver depth, array tilt). The parameters have different numbers of quantization step depending on the search interval resulting in a search space with dimension $\approx 4\times10^{13}$. Forward models are computed using the normal-mode acoustic propagation model C-SNAP [7].

B. The objective function

The environmental inversions are based on a Matched-Field Processing (MFP) technique [8]. Forward models for candidate parameter solutions are computed in order to obtain replica fields. These replica fields are compared to the acoustic field observation in order maximize the match. As direct inversion is not possible, the inversion problem is posed as a global optimization problem. The comparison between field and replicas is performed by means of the Bartlett processor, given as

$$P(\underline{\theta}) = \sum_{k=1}^{K} \underline{H}^H(\underline{\theta},\omega_k)\hat{\mathbf{C}}_{YY}(\omega_k)\underline{H}(\underline{\theta},\omega_k), \quad (1)$$

where K is the number of discrete frequencies ω_k considered, $\underline{H}(\underline{\theta},\omega_k)$ is the replica for the candidate parameter vector $\underline{\theta}$, and $\mathbf{C}_{YY}(\omega_k)$ is the sample spectral density matrix obtained by $\hat{\mathbf{C}}_{YY} = \frac{1}{N}\sum_{n=1}^{N}\mathbf{Y}_n\mathbf{Y}_n^H$. The present case considers tones with frequencies 500, 550, 600, 650, 700, and 800 Hz (hence $K = 6$), and a temporal window of 48 s divided into intervals of 1 s (hence $N = 48$). The parameter vector $\underline{\theta}$ that maximizes P gives is the solution of the optimization problem. The search is performed using a genetic algorithm (GA).

C. The computer network

The computer network used during the RADAR'07 sea trial integrated a data server, two dual processor processing nodes, laptops being used as workstations, and the two AOBs, all communicating through standars network protocols such as the file transfer protocol (FTP) or others. Two carry out the network environmental inversions in real time a software was writted in `MATLAB`. This software lists the data files available in the selected AOB and downloads data files containing the sequence to be inverted. As the transissions are precisely scheduled, it is accurately known which data files have to be downloaded. The beginning of the time series is detected and extracted. Then based on the GPS recordings of both research vessel and AOB position, a segment of the bathymetry is generated. The next step is to launch a GA that generates candidate models. These models are distributed to the processing nodes, which compute the forward models in order to obtain the replicas, and yield the results of the comparison between replicas and data.

D. Environmental inversion results

This section reports on the inversion results obtained with acoustic data received simultaneously on both AOBs. The primary objective of these inversions is to follow the variation of the temperature in the watercolumn in different ocean transects. Fig. 6 shows EOF coefficient estimates obtained with AOB1 and Fig. 7 shows those obtained with AOB2. It can be observed that until time 15:00 the

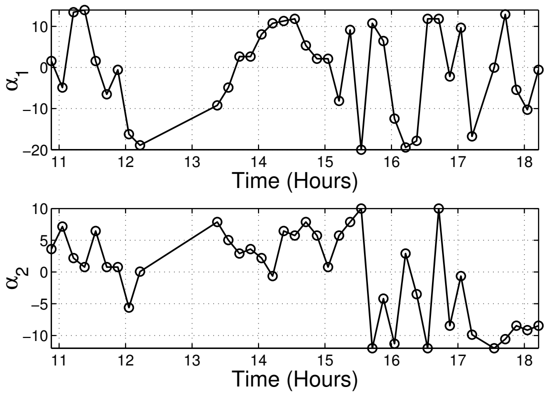

Figure 6. EOF coeficient estmates obtained by inversion of the acoustic data collected with AOB1.

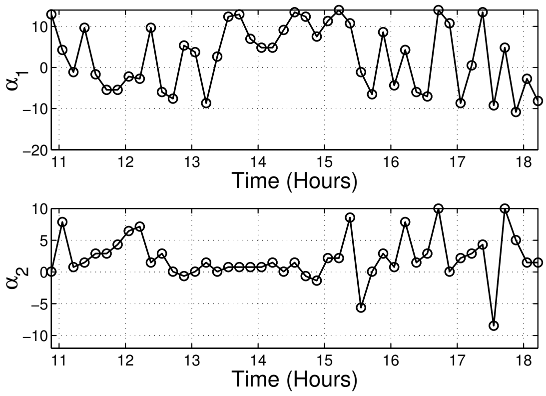

Figure 7. EOF coeficient estmates obtained by inversion of the acoustic data collected with AOB2.

estimates of both coefficients α_1 and α_2 in general behave quite smooth and stable. Then the behavior completely changes as the coefficients become very unstable. This change happens at the same time as the thermistor temperature field in Fig. 4 exhibits very fast variations close to the surface. This is only a conjecture, since evaluating the inversion performance without a large amount of concurrent ground truth data is difficult. Figure 8 shows the temperature profiles obtained with the two data sets. It is interesting to compare those results over time, and verify that there is a consistent resemblance in the behavior of the estimated temperature profiles over time. This is acceptable since most of the time the propagation tracks do not significantly differ in terms of direction and source to receiver range is reduced until time 15:00.

IV. Conclusions

In this paper two novel aspects in environmental inversion by means of acoustic inversions are explored. One is the possibility of increasing the spatial coverage by using a network of acoustic receiving systems, and the other is the extension of an environmental inversion concept to a real-time application. These features could be included into the environmental inversion concept thanks to the design of the Acoustic Oceanographic Buoy meeting high operational requirements.

This experiment may represent an important step towards the demonstration on the feasibility of the acoustic REA concept in real operational scenarios.

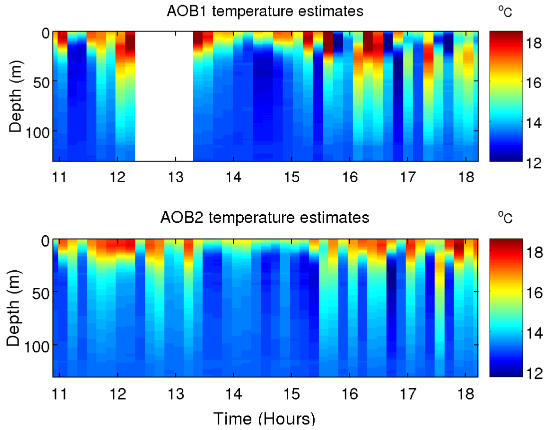

Figure 8. Estimated temperature profiles.

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