Geoacoustic Inversion Techniques Workshop

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LONG TERM GOALS

The lack of high-resolution geophysical databases places severe limitations on the performance of present day active and passive sonar prediction systems that operate in shallow water. The long term goal of this work is to develop and assess effective inversion methods for estimating geoacoustic properties in shallow water environments.

OBJECTIVES

The geoacoustic properties of the ocean bottom, including sound speed profiles, densities, attenuations and sediment layer depths, have a significant effect on sound propagation in shallow water. Over the past 10 years researchers in ocean acoustics have developed geoacoustic inversion techniques that have been used successfully in various applications to estimate geoacoustic model parameters. However, a significant question remains about the accuracy and the reliability of the estimated values. To address these questions, the first geoacoustic benchmarking workshop was held in June 1997, sponsored by ONR (Tolstoy, Chapman and Brooke, 1998). This workshop began the process of evaluating inversion techniques. The initial tests in Workshop '97 were applied to range-independent shallow water environments. Such environments are not generally characteristic of real shallow water environments, but the workshop developed an approach that proved very successful in comparing the performance of specific inversion methods. The objective of the present Geoacoustic Inversion Techniques Workshop is to move the process to the next stage: evaluate the capabilities of present day geoacoustic inversion methods for estimating geoacoustic model parameters in range-dependent environments.

APPROACH

Following the approach in Workshop'97, a benchmarking workshop was organized for evaluation of geoacoustic inversion methods against test cases for specific range-dependent environments. The format of the workshop was a blind test: participants were provided acoustic fields for specific geoacoustic environments, but were not given the model parameters that were used to generate the fields. The task for the participants was to invert the synthetic data to estimate the unknown model parameters. In order to calibrate the forward models used in the inversions, participants were provided a calibration case for which the model parameters were known. The workshop involved three stages: (1) generate a set of test case geoacoustic environments for range-dependent shallow water scenarios; (2) calculate and validate the acoustic fields for the test case environments using state of the art numerical acoustic propagation models; (3) design and apply a metric for comparison of the estimated

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14. ABSTRACT
The lack of high-resolution geophysical databases places severe limitations on the performance of present day active and passive sonar prediction systems that operate in shallow water. The long term goal of this work is to develop and assess effective inversion methods for estimating geoacoustic properties in shallow water environments.

15. SUBJECT TERMS

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solutions for the geoacoustic model parameters. The task of planning and organizing the workshop was carried out by Stan Chinbing and Dave King at NRL Stennis, and Ross Chapman at the University of Victoria. Richard Evans, SAIC, was contracted by NRL to generate the synthetic field data.

1. **Geoacoustic test cases** (Chapman): Three test cases were generated to provide realistic models of shallow water geoacoustic environments. The cases were designed to be increasingly complex, a relatively straightforward case that most present day inversion methods should be able to solve, and two other cases of increasing complexity in order to evaluate the capabilities and limitations of the methods. In order of complexity, the cases were: (1) a monotonic slope; (2) a continental shelf environment consisting of a slope rising onto a shelf; and (3) an intrusion of different sediment material in a shallow water waveguide. The last case presented the most difficult environment: range dependent geoacoustics. The geoacoustic profiles were designed as N-layer models, with unknown number of layers and unknown (homogeneous) parameter values in each layer. A simple method based on sediment particle size was used to generate the velocities, densities and attenuations in each layer (Bachman, 1989; Richardson and Briggs, 1993). The number of layers and the layer thickness was chosen randomly to create a total sediment thickness of about 30 m.

2. **Synthetic data** (Evans, Chinbing and King): The acoustic fields for each test case were calculated by Richard Evans using the coupled normal mode model, COUPLE. As in Workshop '97, the data were provided for two types of receiver geometries:

   (1) vertical arrays with 1-m spacing from 20 m to 80 m. This information was provided every 500 m, from 500 to 5000 m;

   (2) horizontal arrays at 25 m and 85 m, with data every 5 m from 50 m to 5000 m.

   The fields were calculated for a broad band of frequencies: δf = 1 Hz from 25 to 199 Hz, and δf = 5 Hz from 200 to 500 Hz.

   Based on this information, participants could effectively design their own experimental system using a subset of the data that were provided, within limitations that the systems should reflect realistic experimental designs. The fields were validated for each test case by Dave King at NRL Stennis using the parabolic equation code RAM, and the complete data set was posted on the workshop website: **itworkshop.nrlssc.navy.mil**.

3. **Comparison metric** (King et al): Since the inversion methods are designed to provide the best fit to the acoustic fields, this result can be obtained with many different profiles. The metric for comparison was designed to account for the non-uniqueness of the estimated geoacoustic profiles. The different estimates are compared based on the transmission losses calculated using the estimated profile for scenarios of source/receiver geometries and frequencies that were not used in the inversions.

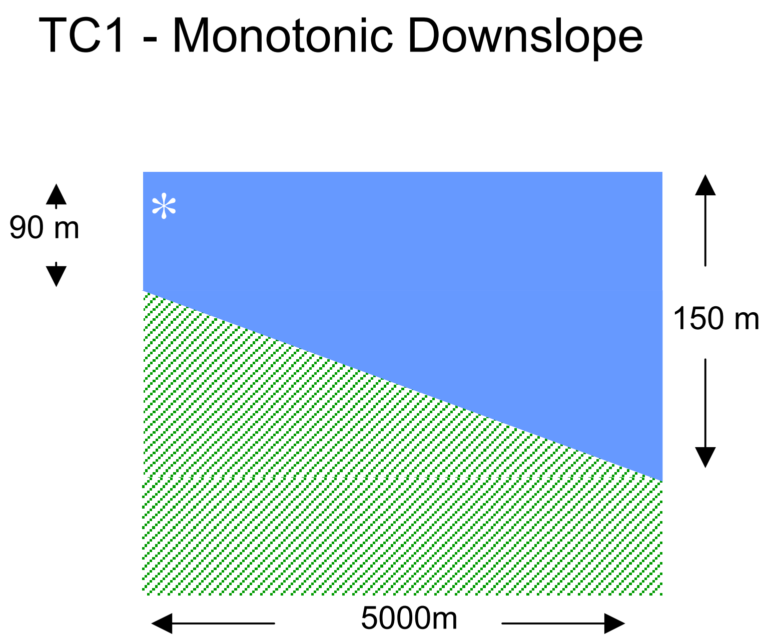

Figure 1: Test case 1 environment.

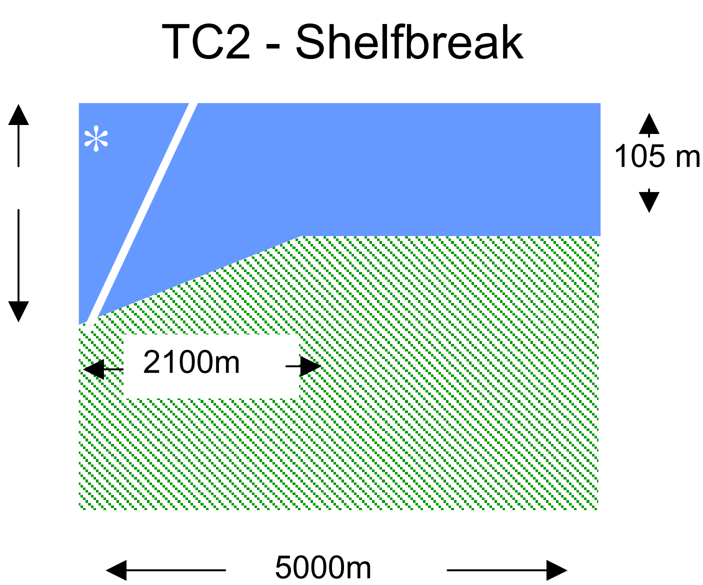

Figure 2: Test case 2 environment

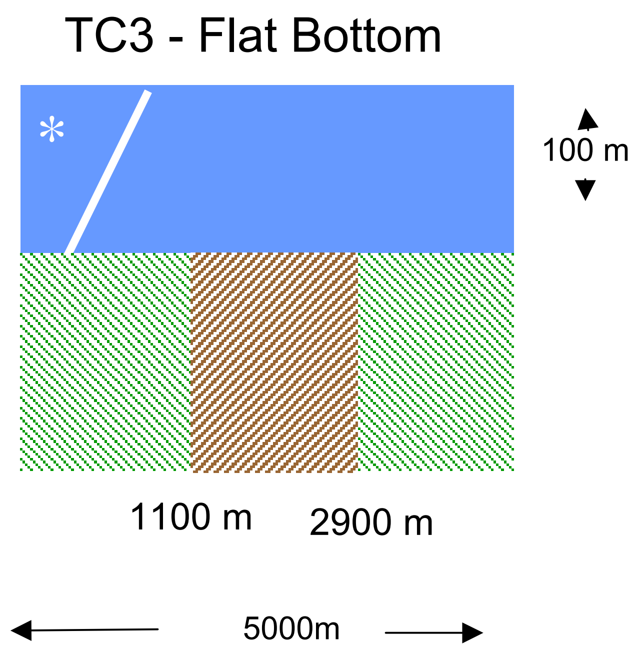

Figure 3. Geoacoustic environment for test case 3.

The workshop also included experimental data from the HEP program: reverberation data and transmission loss in 1/3 octave bands from experiments with SUS charges. These cases were relevant for the SPAWAR-sponsored participants.

WORK COMPLETED

The Geoacoustic Inversion Techniques Workshop was held at Gulfport, MS., 16-18 May, 2001. The workshop was co-sponsored by SPAWAR (Mr. K. Koehler) and ONR Ocean Acoustics. Due to time constraints in the SPAWAR schedule, the lead time for planning and preparation was very short. Participants were able to access the test case data only by mid February, so that the time available for working on the data sets was less than 4 months.

Participants were asked to describe their solutions and methods in oral presentations at the workshop, and to provide files of their estimated geoacoustic profiles for each test case before the meeting so that preliminary comparisons could be made during the workshop. The workshop was attended by about 40 – 45 researchers (from Navy labs, industries and universities) and program managers, with representation from Canada, Australia and the UK. There were 22 presentations of solutions to the test cases by participants over the three day period.

RESULTS

Full descriptions of the presentations and the comparison of the inversion results will be forthcoming in the Workshop Proceedings that will be available for distribution in December at the ASA meeting. In comparison with Workshop '97, there was a greater number of different inversion methods used to invert the test cases. Participants presented inversions using formal model-based signal processing methods (MFP); perturbative methods designed to use processed observables from the field data; methods that used transmission loss data; and specialized techniques designed to invert 'effective' parameters of BLUG-like bottom models. Among the model-based methods, several different forward models were used that proved to be effective for range-dependent environments: PE, ray theory and adiabatic normal modes.

The test cases were designed to show the capabilities and limitations of state-of-the art methods for range-dependent environments. According to this criterion, the workshop was successful in demonstrating these objectives:

1. The N-layer form of the geoacoustic model was an effective design for simulating a realistic shallow water environment and can serve as a starting point for similar exercises in the future.

2. Test cases 1 and 2: Although these cases may appear to be straightforward examples that are oversimplified, the message from the participants was that the solutions required considerable effort and insight in applying the inversion methods. *Thus, although the capability exists in the inversion methods, application of the methods is not straightforward and requires that attention of skilled operators.*

3. Test case 3: This case included range-dependent geoacoustics and it presented the greatest difficulty to the participants. Some methods were able to find the transition ranges for the intrusion, and some methods were able to invert reasonably good profiles for some part of the environment. *The results showed that the range-dependent geoacoustic environment stressed the limits of present day inversion techniques.*

IMPACT/APPLICATIONS

The workshop provided research sponsors a means for assessing the progress in research in geoacoustic inversion in order to:

1. outline future directions in research to address limitations in present day methods

2. make recommendations for transitions to operations.

For future benchmarking comparisons, the following issues were evident from the workshop:

1. The next stage should include real data examples from experiments that have been carried out in regions where extensive ground truth is available, and/or calculated test cases that include realistic noise and geological clutter in the synthetic data. The test case environments should also support shear waves. There is also a question of what kind of synthetic data to provide. An option is to calculate synthetic time series over a broad band, instead of spectral components of the field.

2. The question of meaningful estimation of the uncertainty in the estimated parameters is an important component of the inverse problem that has not been fully addressed in previous work.

3. The question of forward model accuracy is still an critical issue especially for range- dependent propagation models. Although there are many numerical models that are in widespread use, the validation process for this exercise revealed inconsistencies between COUPLE and RAM.

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