In ocean evaluation of low frequency active sonar systems

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Sonar performance measurements in the sea are always affected by uncontrollable and/or uncertain environmental conditions as sound speed variations, bottom topography or the acoustic properties of the sea floor. This paper presents a method to determine a sonar – target geometry which minimizes the uncertainty in target signal excess due to environmental variability.

An acoustic model is used to estimate the signal excess for a large number of sound speed profiles measured in the relevant area. The results are compared while searching for a target range and depth where the estimated signal excess is robust with respect to the expected variability of the sound speed profile in the actual area.

Results from sea trials will be presented, as well as simulated examples used to demonstrate the achieved robustness or sensitivity of the signal excess to environmental changes, at different test geometries.

1   Introduction

In general there is a need for quantifiable sonar performance tests carried out at sea under conditions resembling the normal working conditions for the equipment. The accuracy and reliability of such tests are frequently questioned. The limited confidence in such tests is due to acknowledged uncertainty in the environmental parameters and experienced inaccuracy of meso-scale ocean acoustic experiments.   However experimental verification of propagation models may often show good agreement for some measurements while under different conditions there is virtually no resemblance between model and reality. Also a closer look at some modelling results indicates that the sensitivity of the received signal level, to for instance the target location, may vary significantly over an actual area in the ocean. In some cases the signal excess may remain near constant over a significant depth and range interval, while only a few meters displacement may cause large deviations of the signal or reverberation levels. Similarly a small deviation in the sound speed profile may cause entirely different propagation patterns for some cases and experiment geometries while other choices of target and sonar locations may provide more robust conditions.

With this background we have developed a method of conducting experiments at sea where the uncertainty of the results are limited, quantifiable and assessable. The method is based on running an acoustic model repeatedly. Each run uses a single sampled realisation of the environment as input. This paper focuses on variations in sound speed profile. Therefore a sample sound speed profile represents a realisation of the environment. The computations are based on a selection of sound speed profiles measured within the actual area as close to the test schedule as possible. The results are then analyzed to find favourable positions for the sonar and the target.

Overall considerations and aspects of underwater sensor testing is presented in ref (1). The current paper goes into more detail on how to handle the acoustic sensitivity issues due to varying oceanography.

Section 2 presents the tools used in the analysis. Section 3 shows an example of how the method can be used to find good locations for the sonar and the target during a test. Section 5 concludes the paper.

2   Numerical tools

Two different numerical tools are used in the method of finding stable conditions for testing acoustic equipment. The main tool is Lybin, an acoustic ray trace model that estimates the signal excess in a single vertical cross-section for a given environment and sonar. The second tool is a method of presenting the sensitivity of the signal excess to environmental variation. The results are presented graphically, denoted "stability plots".

Lybin

Lybin is an acoustic ray trace model developed by Svein Mjølsnes, Norwegian Defence Logistic Organization. Ref (2) gives an overview of ray tracing and the underlying theory. The model is two-dimensional, covering depth and range. It estimates the *transmission loss*, the *reverberation level and the noise level* based on sonar data and environmental data. These data are applied to the sonar equations for estimation of *signal excess*. Detection theory (5,6) is used to find the *probability of detection* and the corresponding *detection range*. In this paper the signal excess is used.

Lybins transmission loss module was verified by NURC[1], (3). The evaluation team conclude: *"The general conclusion of this test is that the range-dependent ray-trace model LYBIN, developed by the Norwegian Navy, is indeed a valid alternative to existing propagation models in the AESS[2]. The LYBIN model has prediction accuracy similar to the GRAB 'reference' model but is considerably faster."*

Lybin was presented at the Underwater Defense Conference and Exhibition in Glasgow 2008, ref (4).

Stability plots

The idea of stability plots is to compare the signal excess results from several different Lybin-runs, and find ranges and depths where the signal excess remains nearly constant from run to run.

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[1] NATO Underwater Research Centre
[2] Allied Environmental Support System

For the purpose of finding stable acoustic conditions in an area of both spatially and temporally varying oceanography, Lybin is run using several different sound speed profiles measured in the actual area. The results from these runs are then compiled into the stability plots. One of these sound speed profiles is selected as a representative sound speed profile for the entire set of sound speed profiles. This could either be a mean of all the other sound speed profiles, or presumably better, a single measured sound speed profile, possessing some characteristics judged as *typical* for that set of sound speed profiles. In the latter case, the representative sound speed profile should be smoothed to remove measurement artifacts.

The stability plot shows the *stability parameter*, SP, given by:

$$SP(r,z) = \frac{1}{N} \sum_{i=1}^{N} step(|SE_r(r,z) - SE_i(r,z)| - T) \quad (2)$$

$SE_r(r,z)$ is the modelled signal excess at range *r* and depth *z*, measured in dB, using the representative sound speed profile. $SE_i(r,z)$ is the modelled signal excess for the i-th sound speed profile in the set. *N* denotes the size of the set. *T* is a set threshold, for example 3dB as used in this work. *step()* denotes the unit step function taking the value 1 for positive arguments and 0 elsewhere. *SP(r,z)* is therefore a two-dimensional matrix of values between 0 and 1. The value of a single element is simply the fraction of cases that has a signal excess deviation from the typical case, lower than the selected threshold. Thus, an element takes the value 1 if the complete set of sound speed profiles results in a signal excess difference less than the selected threshold. The value 0.5 indicates that half the set of sound speed profiles results in a low signal excess difference. Figure 2 shows an example of the stability plot. The red areas represent areas where 100% of the runs resulted in signal excess values within a margin of *T* from the signal excess computed using the representative sound speed profile. Simply spelled, red areas are stable, blue areas are unstable.
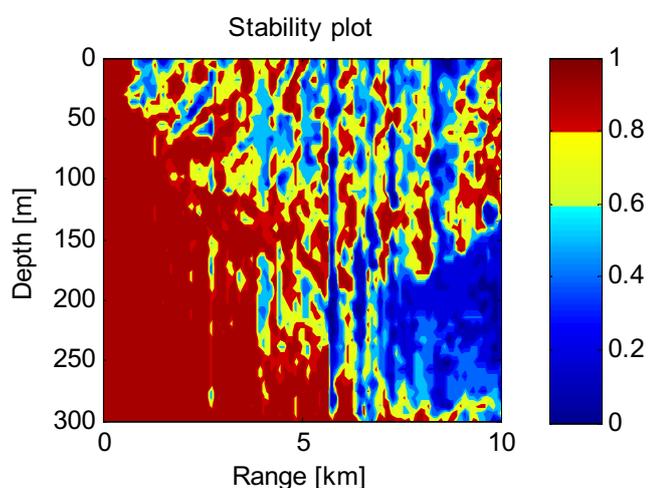

Figure 2   *Stability plot for a set of sound speed profiles. The sonar is at 25m depth.*

3 Results

The task of finding a stable environment for testing of the acoustic equipment is divided into two parts. First, a historically stable area must be found. Areas prone to oceanographic fronts or strong variations in terrain should be avoided. Second, just prior to the testing of the equipment, oceanographic measurements should be made to find the most stable region in that area *and* the relative positions of the equipment resulting in the most stable conditions. This paper is focused on the second part.

In the present example, a monostatic sonar is tested using a stationary, artificial test target (echo repeater). During the test, the distance between the sonar and the target is kept constant by letting the sonar vessel encircle the target. Three geometric parameters remain to be determined, in order to gain stable conditions for the test; sonar depth and target depth and range (distance from sonar vessel).

Sound speed measurements

The sound speed profiles used in this study was measured in November 2007, along lines using a towed CTD. The ten lines were approximately 27km length with 5km separation between the lines, see figure 3. Each star in figure 3 corresponds to a single sound speed profile. The red stars indicate positions suitable for performing the acoustic tests due to homogenous sound speed profiles. In the following analyses these seven sound speed profiles are used. The measurements resulted in a total of 170 sound speed profiles. Figure 4 presents all the measured sound speed profiles. Figure 5 shows a filled contour plot as a function of range and depth for line nr 5.
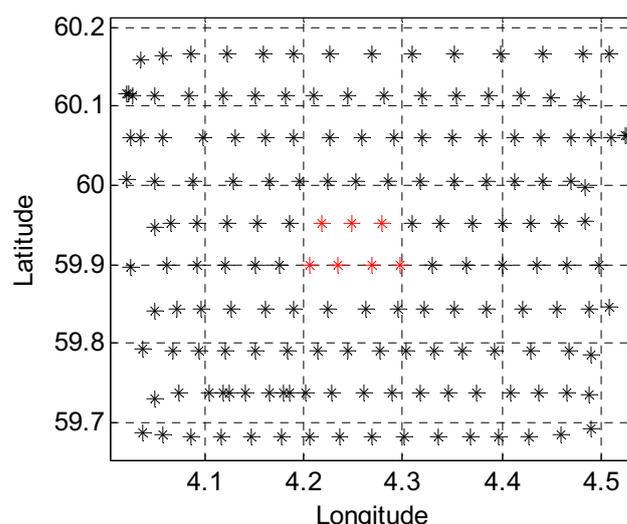

Figure 3   *Positions of the sound speed measurements made. The coordinates are presented in decimal degrees. The sound speed profiles were measured along east-west oriented lines.*
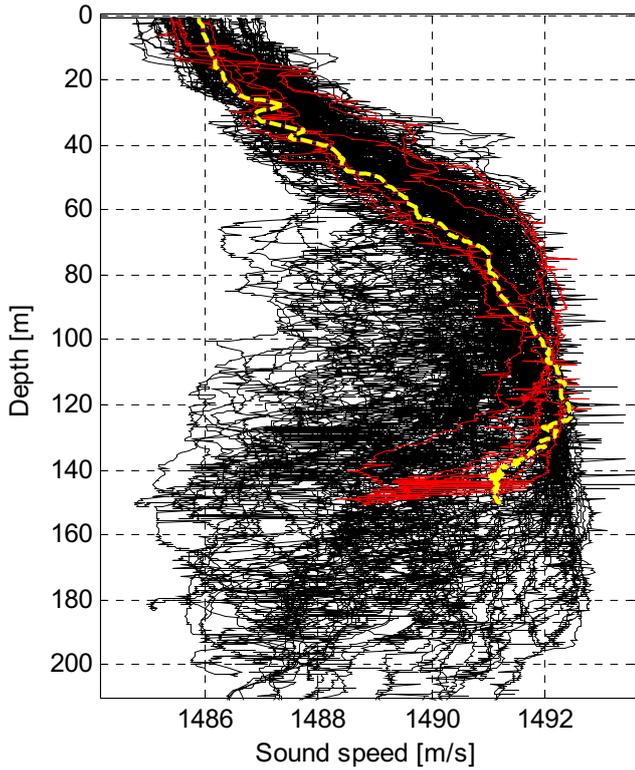
Figure 4   *170 sound speed profiles. Notice the strong variations below 60m depth compared to above 60m depth. The red curves are the sound speed profiles measured in the positions indicated by the red stars in figure 3. The yellow curve depicts the selected and smoothed representative sound speed profile.*
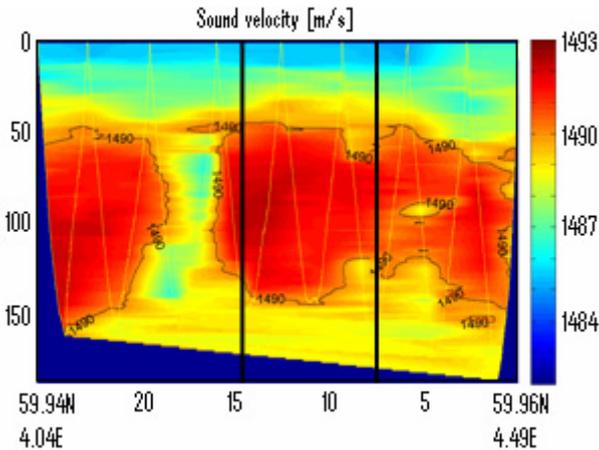

Figure 5   *Sound speed as a function of depth and range from west to east along line 5 (Line 1n in figure 3 is furthest to the north). The preferred area is between the two black vertical lines.*

Stability plot

The threshold, *T*, see equation (1), for determining the stability parameter was set to 3dB. Figure 6 shows a stability plot for the sonar at 50m depth. The red areas indicate range - depth pairs with stable signal excess, and therefore suitable positions for the target. Figure 7 shows

the stability picture when the sonar is at 5m depth. Both cases show reasonably large areas for robust measurements. This is however not always the case. Figure 8 shows a stability plot using a set of sound speed profiles measured in April 2008. In this case the target should be deeper than 60m in order to ensure stability.

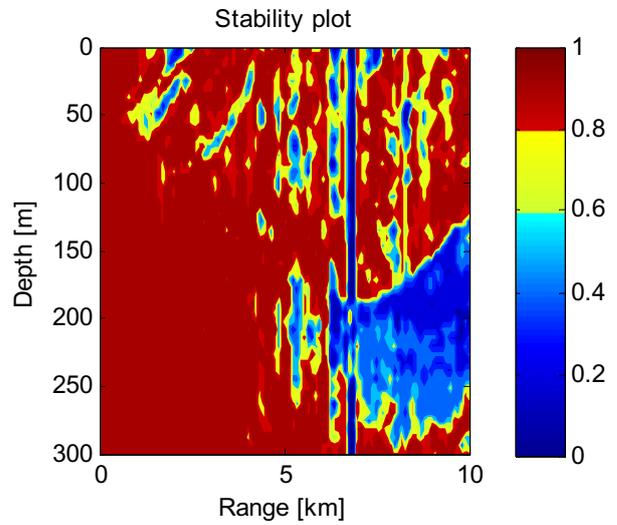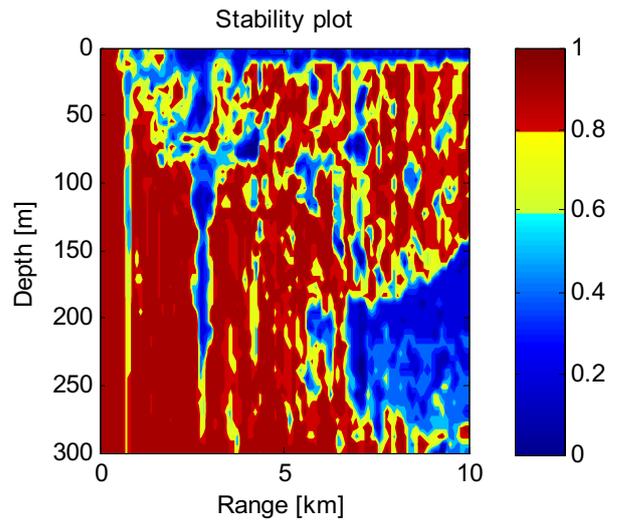

Figure 6   Stability plot for a sonar at 50m depth.

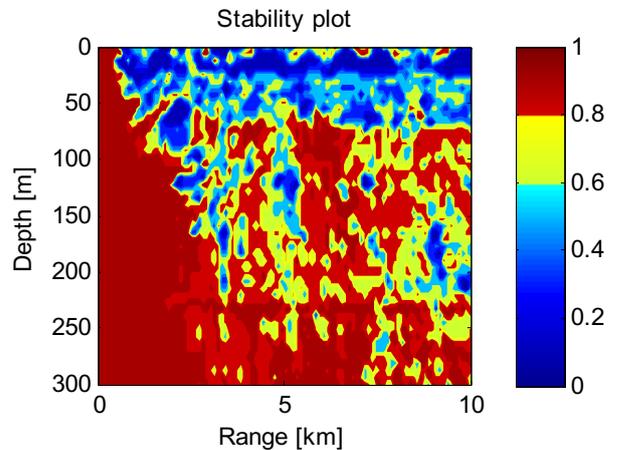

Figure 7   Stability plot for a sonar at 5m depth.

Figure 8   Stability plot for a sonar at 25m depth.

5   Conclusion

A mono-variable perturbation analysis is used to quantify the sensitivity of sonar performance measurements to temporal and spatial variations of environmental parameters with impact on the sonar performance. This analysis indicates that by a careful choice of sonar and target deployment, the sensitivity to unaccounted parameter variations may be kept within acceptable limits. Stability plots are introduced to quantify the stability of different sonar-target geometries.

Acknowledgments

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