Acoustic reconstruction of ASW serials during NATO exercises

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Abstract: *NATO and its navies commit significant resources in regular exercising of anti-submarine warfare tactics conducted during at sea trials. To ensure maximum training benefit and increase lessons learned, an analysis team is deployed to conduct reconstruction of ship and submarine relative geometry throughout each exercise serial. The reconstruction highlights those time periods within which surface ships successfully maintained sonar contact on the submarine – based on the correlation between reported contact position and actual submarine position. This paper describes additional analysis performed by NATO STO CMRE in which we seek to elicit the reasons behind contact periods or lack thereof. To this end, we conduct acoustic predictions throughout an exercise area as a function of location, bearing, sonar depth, submarine depth, and submarine aspect. When combined with a geometric reconstruction of ship and submarine positions; the analysis highlights those periods in which detection is expected. In addition, we can highlight the primary reason behind detection opportunities – whether resulting from the sonar and submarine depth combination or from submarine aspect. Such analysis directly correlates sonar performance with the acoustic environment (i.e. presence of layers) and submarine tactics (depth and aspect). The paper primarily describes the methods employed and provides some representative output.*

Keywords: *Anti-Submarine Warfare, Acoustic, Reconstruction*

1. INTRODUCTION

The planning and execution of NATO exercises requires significant effort including the coordination of multiple maritime assets and personnel from many nations. Bringing together anti-submarine warfare (ASW) forces from the underwater, surface, and air domains requires a large investment from those participants together with the significant numbers of planning personnel supporting the exercise. The expense and resource requirements for these exercises are justified by their valuable training benefit. As a consequence many such exercises are specifically designed to test and indeed qualify the force readiness of various NATO maritime units.

A NATO ASW exercise, such as Dynamic Manta or Dynamic Mongoose, will be conducted over a period of several weeks. The exercise, running 24 hours a day, will be further divided into serials in which a subset of the participants (ships, aircraft, and submarines) will conduct scenarios in pursuit of a submarine. During the course of the exercise the units will be trained in the optimal use of their sonar systems in order to achieve maximum possible detection ranges. This requires an understanding of acoustic propagation pathways in the presence of range dependent sound speed profile and bathymetry.

In order to maximise training benefit, Allied Maritime Command (MARCOM) deploys the In-stride Debriefing in support of Training (IDT) team to support each exercise. Acknowledging the need for performance assessment, this team provides a consistent analysis approach allowing participants to review their performance shortly after completion of a given serial. In particular the IDT team reconstructs events during a serial having received both positional and tactical details from the participants - whether ship, aircraft, or submarine. This reconstruction, together with a tactical overview provided by suitably qualified members of the IDT team, highlights whether a submarine was detected (or not) by the various platforms and sensors pursuing it.

The analysis conducted by CMRE augments that of the IDT team with an in-depth acoustic component. Acoustic models are employed (using Bellhop [6] or ARTEMIS [3] to determine the predicted sonar range (PSR) throughout a serial taking into consideration the platform locations, submarine depth, aspect, and sonar depth in a completely range-dependent environment. Detection opportunities can be identified by comparing the reconstructed/actual submarine range in relation to the PSR. The contributing factors for the detection opportunities are then highlighted through further investigation, specifically with regard to the relative depths of the sonar and submarine, and the submarine aspect [7].

2. ACOUSTIC MODELLING FRAMEWORK

The CMRE analysis approach requires a fully range dependent acoustic model that can rapidly predict sonar performance throughout an area as a function of sonar type, sonar depth, submarine depth, and submarine aspect (due to target strength). The analysis may then compare the predicted sonar range to the actual submarine range throughout a given serial according to the reconstructed platform geometries, depths, and aspect. In order to ensure fast turnaround of the analysis, the acoustic predictions are performed overnight employing a range dependent oceanographic forecast obtained from the Copernicus web service [5]. This ensures that the actual reconstruction and analysis can be performed quickly from interpolation of the computationally intensive acoustic results that are already available.

CMRE employs the Rapid Acoustic Prediction Service (RAPS) for this work which provides a convenient service based approach allowing acoustic requests to be made from MATLAB.

RAPS currently employs the Bellhop ray tracing model [6] with an additional reverberation component developed by CMRE. The reverberation component allows for the calculation of active sonar signal excess. The acoustic engine is installed on a powerful blade server which provides multi-core processing while allowing access from any computer on the scientific network. MATLAB scripts loop over latitude, longitude, and depth in order to analyse the acoustic performance at multiple locations throughout the exercise area. At each point transmission loss and reverberation is requested from RAPS on a number of bearings and for multiple sonar and submarine depths. This results in the determination of detection range (averaged over bearing) as a function of sonar depth, and submarine depth for a given target strength value.

For a typical serial this analysis requires many calls to the acoustic engine for each active sonar that is being considered. Each call runs Bellhop to determine transmission loss and reverberation along a number of bearings from the sonar. The signal excess is then determined from which a detection range may be obtained. A typical signal excess result is show in Fig 1. Note that we determine positive values of signal excess (dotted green line) and thereafter require a certain number of consecutive positive values in order to register a detection range. This serves to eliminate fleeting detection opportunities that are unlikely to be realized in the real world. Typical acoustic analysis results for a given location are shown in Fig 2 in which we see the sound speed profile (SSP), transmission loss along the 4 cardinal bearings, and the resulting PSR as a function of sonar and submarine depth.

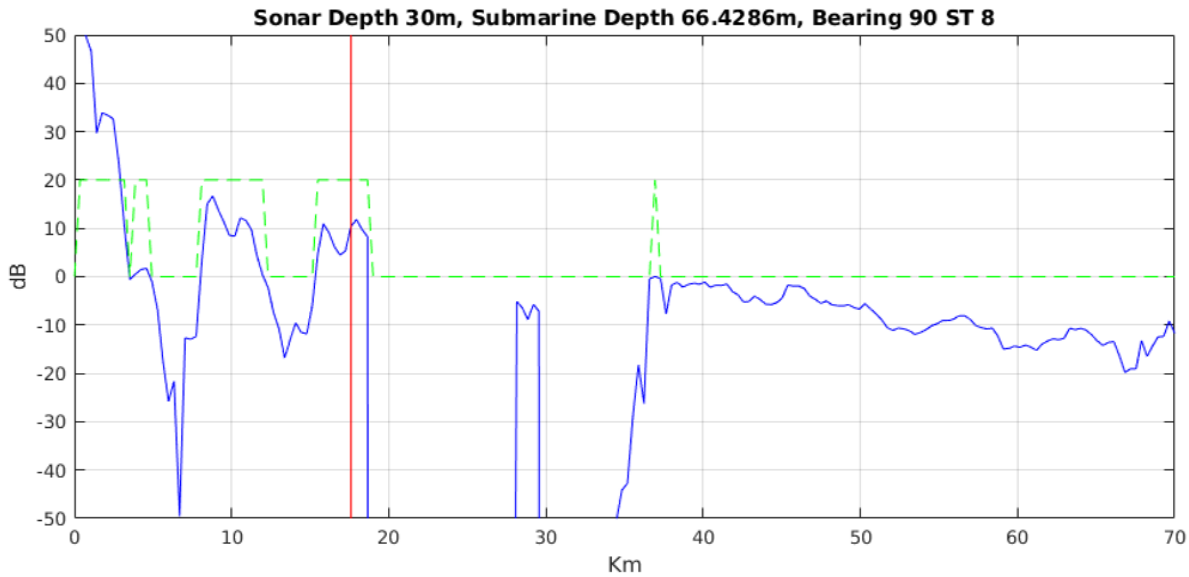

Figure 1: Signal excess versus range. Dotted green line highlights positive signal excess values. The red line indicates the calculated detection range (approximately 17 Km)

With the acoustic analysis detailed above conducted for multiple locations throughout the exercise area we may begin the process of reconstructing the geometry of the ships and submarines during a serial, i.e. a snippet of an overall exercise. Positional situational reports are provided by the IDT team in which time stamped latitude, longitude, and depth data is provided in a plain text format. These files are read by MATLAB functions in order to obtain projected coordinates in a Cartesian framework from which ranges and relative orientations may be easily determined. Generally the reconstructed platform tracks are interpolated to ensure values for all platforms at each time step - usually 60 seconds. At a given time step we can extract the PSR

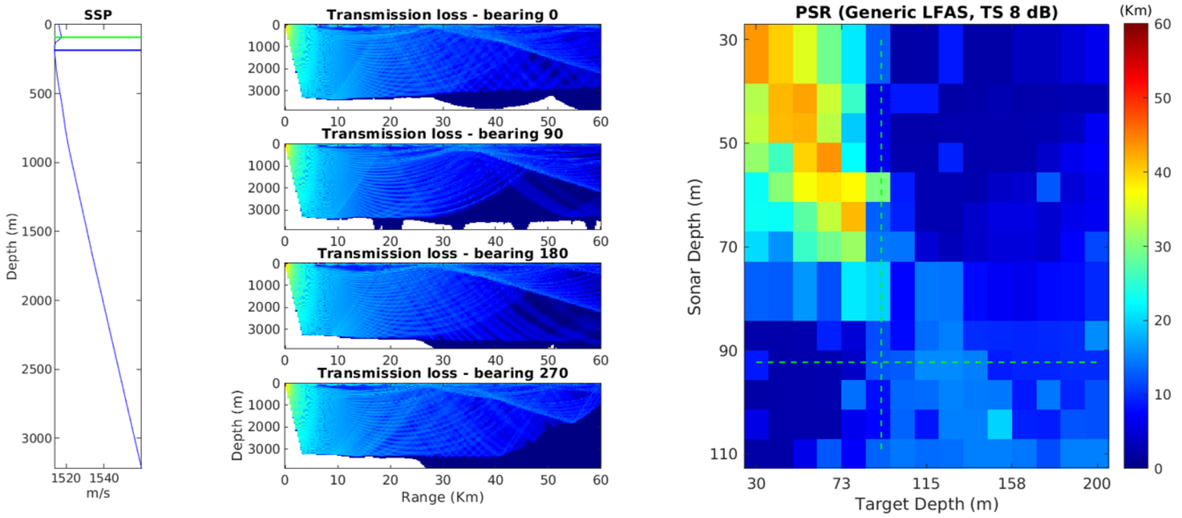

Figure 2: Typical acoustic analysis output for a single location and sonar type. Note that the green line on the SSP denotes the sonic layer depth which is also highlighted on the PSR plot (dotted green lines) in which we see the effect on performance as the sonar or submarine moves below the layer.

for the pre-calculated data given the location of the ship, the sonar depth, along with submarine depth and aspect.

The daily analysis approach may be summarized as follows:

- Download latest temperature, salinity, and waves forecast from the Copernicus service [5]
- Run RAPS acoustic engine overnight to determine PSR as a function of the following parameters
  - Sonar parameters according to the type (e.g. LFAS, HMS, Dipping).
  - Latitude, Longitude throughout exercise area (several hundred locations).
  - Bearing from sonar (4 values).
  - Sonar depth - in the case of variable depth sonar (VDS) (10 values).
  - Submarine depth (10 values).
  - Target strength value (6 values).
  - PSR results stored in a multi-dimensional MATLAB array.
- Receive platform tracks and tactical narratives from the IDT team.
- Transfer PSR arrays and tactical data to a classified network.
- Run MATLAB routines to reconstruct the serial geometry from platform data and extract relevant PSR.
- Compare PSR with actual submarine range and highlight resulting detection opportunities.

- Examine detection range for all sensor depths to determine whether current sensor depth is at or near optimal given the actual submarine depth.
- Highlight periods of increased target strength - submarine at or near broadside aspect.
- Generate summary plot (see Figure 3).
- Send the analysis back to the IDT team.

Having completed the analysis steps detailed above above we may generate the acoustic reconstruction output in the form of Fig 3. This single figure serves to provide a wealth of information to the exercise participants. Inspection of the figure provides the following insight,

- Visual comparison of predicted sonar range (shaded area) with actual submarine range (blue line).
- Detection opportunities
- Changes in submarine depth (red line) and its effect on predicted sonar range
- Effect of submarine aspect on predicted sonar range

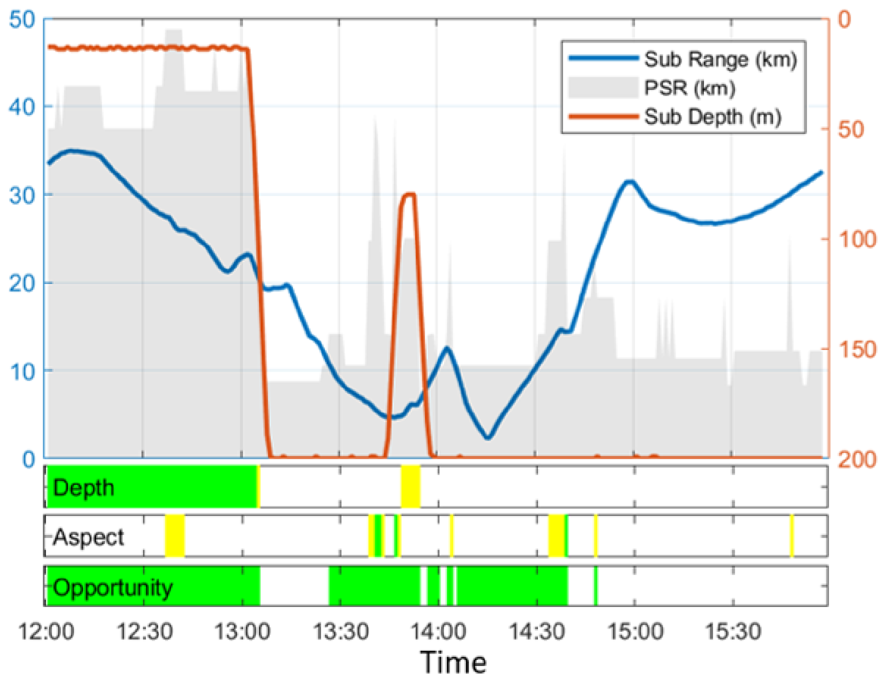

Figure 3: Example output showing submarine range and depth, PSR, detection opportunities, and contributing factors.

3. ENVIRONMENTAL ANALYSIS

In addition to providing immediate support to the IDT team and exercise participants we also wish to leverage the acoustic and tactical data for further research within the decision support project at CMRE. To this end we are interested in extracting correlations between observed sonar performance and the prevailing environmental conditions. This requires an automatic characterisation of the environmnet through a determination of layer depths. This may be performed by inspection of the temperature, salinity, and resulting sound speed profiles according to the following definitions. This analysis is performed throughout an exercise area leveraging range dependent temperature and salinity data in netCDF format. Note that the sound speed profile is calculated from the temperature and salinity profiles using the Chen-Millero formula [1].

- Sonic layer depth - depth of near surface maximum in SSP [4].
- Number of ducts - number of minimums in the sound speed profile.
- Shallow sound channel - depth of first minimum in SSP.
- Deep sound channel - depth of deepest minimum in SSP.
- Mixed layer depth f(temperature) - depth at which the temperature changes by 0.2 degrees from the value at $10m$ [2].
- Mixed layer depth f(density) - depth at which the density changes by 0.03 $kg.m^{-3}$ from the value at $10m$ [2].
- Convergence zone possibility - requires the presence of a sound channel and that the sound speed at the sea bed is greater than that at the surface.

An example sound speed profile including a sonic layer depth and sound channel is shown in Figure 4.

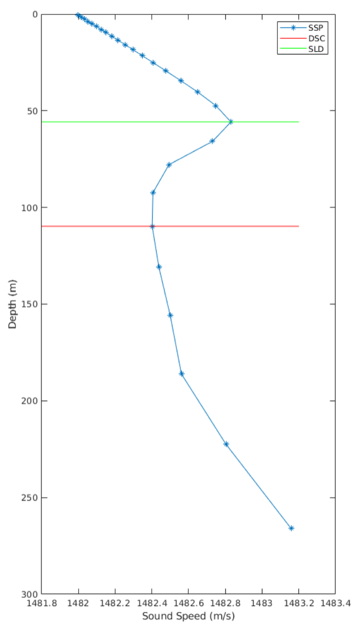

Figure 4: Example sound speed profile showing the sonic layer depth and channel depth

Determining the above parameters throughout an area allows for a visual inspection of the variation in underwater environmental conditions and further analysis of its effect on acoustic propagation. Example variation in mixed layer depth and sonic layer depth is shown in Fig 5.

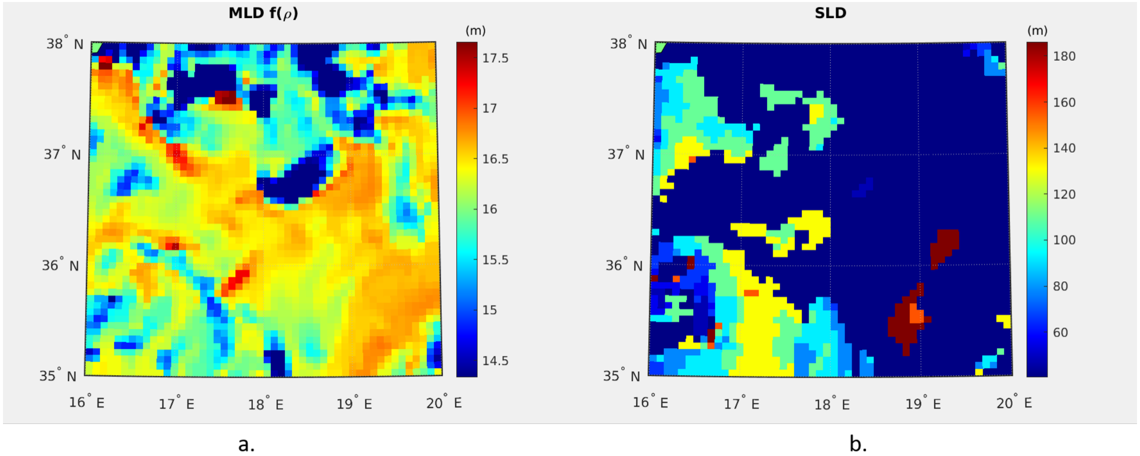

Figure 5: Example variation in mixed layer depth f (density) and sonic layer depth - (zero value if not present).

4. CONCLUSION AND FUTURE WORK

The analysis described here provides added value to the serial reconstructions conducted by the IDT team during NATO exercises. In particular we employ acoustic modelling to determine likely detection opportunities and to highlight the reasons behind them. These contributing factors can relate to the relative depth of the sonar and submarine when in the presence of strong acoustic layers. They can also highlight the effect of submarine aspect angle on detection range.

CMRE has performed this analysis during three NATO exercises each year since 2019. With the analysis conducted remotely at CMRE; there now exists a valuable data-set containing environmental forecasts, acoustic predictions, platform reconstructions, and observed detection performance. Further analysis of this data-set in 2023 will serve to quantify the performance of various sonar systems and the correlatation with environmental conditions and submarine behaviour.

5. ACKNOWLEDGEMENTS

CMRE support to NATO ASW exercises described in this paper is funded by Allied Maritime Command (MARCOM). CMRE would like to thank the IDT team for their collaboration.

This study has been conducted using E.U Copernicus Marine Service Information; https://doi.org/10.48670/moi-00016

REFERENCES

[1] ChenTung Chen and Frank J. Millero. Speed of sound in seawater at high pressures. *The Journal of the Acoustical Society of America*, 62(5):1129–1135, 11 1977.

[2] Clément de Boyer Montégut, Gurvan Madec, Albert S. Fischer, Alban Lazar, and Daniele Iudicone. Mixed layer depth over the global ocean: An examination of profile data and a profile-based climatology, 2004.

[3] C. Harrison. Adiabatic reverberation and target echo mode incoherent sum (artemis). Technical Report NURC Formal Report (FR series) NURC-FR-2011-009, NATO Undersea Research Centre, 2011.

[4] Robert W. Helber, Charlie N. Barron, Michael R. Carnes, and Robert A. Zingarelli. Evaluating the sonic layer depth relative to the mixed layer depth. *Journal of Geophysical Research: Oceans*, 113(C7), 2008.

[5] E.U. Copernicus Marine Service Information. Copernicus marine environment monitoring service. https://help.marine.copernicus.eu/en/, 2021.

[6] M Porter. The acoustics toolbox. http://oalib.hlsresearch.com/AcousticsToolbox/, 2021.

[7] NATO Science and Technology Organisation. 2022 highlights. https://www.sto.nato.int/public/2023-NATO-STO-Highlights-Web.pdf, 2022.