Improving Anti-Submarine Warfare Sonar Performance Modelling using BLUElink Forecast Environmental Data

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Abstract- **The underwater environment is often complex and highly variable in space and time, making it difficult to model the detection performance of anti-submarine warfare (ASW) sonar systems. Furthermore, the environment can result in complex active sonar data displays that are difficult to interpret. The performance of the sonar system can be enhanced by understanding and exploiting knowledge about the underwater environment. This paper illustrates how relevant and timely environmental data from the BLUElink ocean model can be used to improve sonar performance modelling and assist the sonar operator interpret complex sonar data displays.**

I. Introduction

The underwater environment is complex and highly variable in space and time, making it difficult to model the detection performance of anti-submarine warfare (ASW) sonar systems. Furthermore, the environment often results in a complex and changing active sonar display with much clutter, making the sonar data difficult and time consuming to interpret.

The Australian Maritime Doctrine [1] states that "Oceanography plays a vital role in undersea warfare, not only for submarines themselves, but also for anti-submarine and mine warfare forces…these units require not only an extensive knowledge of the water mass in which they are operating but also the means to analyse the prevailing conditions and predict sensor and weapon performance."

Conventional sonar performance prediction tools use limited *in-situ* data which provide a single measure of the environment for one physical location and time. This includes expendable bathythermographs (XBTs) which provide a single measure of the ocean temperature profile. This is commonly referred to as "range-independence" where there is no spatial variation and the ocean parameters only vary as a function of depth. In many scenarios, these environmental inputs are limited in their accuracy and usefulness as they fail to capture the highly variable and changing ocean environment. Therefore it is more desirable to use "range-dependent" environmental inputs as they capture the spatial variation of the ocean properties in depth, range and azimuth. This paper will illustrate how relevant and timely environmental data provided by the BLUElink ocean model can improve sonar performance modelling and increase the sonar operator's environmental awareness, and its impact on sonar performance.

A concept demonstrator has been developed at the Defence Science and Technology Organisation (DSTO) with the focus on assisting the operator to interpret the sonar picture through distinguishing echoes and potential targets from environmental clutter by providing more accurate and timely modelled sonar performance and environmental data to the operator. This demonstrator has been successfully trialled on at-sea data for both an active towed array system and hull-mounted sonar systems and has shown the improvement using range-dependent BLUElink environment inputs compared with spatially-independent *in-situ* measurements.

II. Background

BLUElink Ocean Model

The BLUElink project [2] is an Australian Government initiative between the Bureau of Meteorology, Royal Australian Navy (RAN) and Commonwealth Scientific and Industrial Research Organisation (CSIRO). BLUElink uses climatology databases, satellite remote sensing and measured at-sea data as inputs, and performs modelling to produce three-dimensional ocean forecasts and hindcasts for environmental parameters including ocean currents, wind stress, temperature and salinity (which can be combined to obtain sound speed). The Relocatable Ocean Atmosphere Model (ROAM) also being developed by the BLUElink project is a limited-area high resolution model, which can be run for areas of interest. It is nested within the global model, and has sufficient resolution to accurately resolve smaller-scale, short-lived ocean circulation features including fronts and eddies which can dramatically influence sonar system performance.

Fig. 1 shows an example of the types of outputs that are produced by BLUElink. The figure illustrates a time snapshot of the sea surface temperature variability off the east cost of Australia. BLUElink is capable of capturing the position and movement of currents and eddies, and can also identify ocean frontal boundaries. This is useful to sonar performance modelling as refraction and scattering of energy can occur at these boundaries, which can severely affect acoustic propagation.

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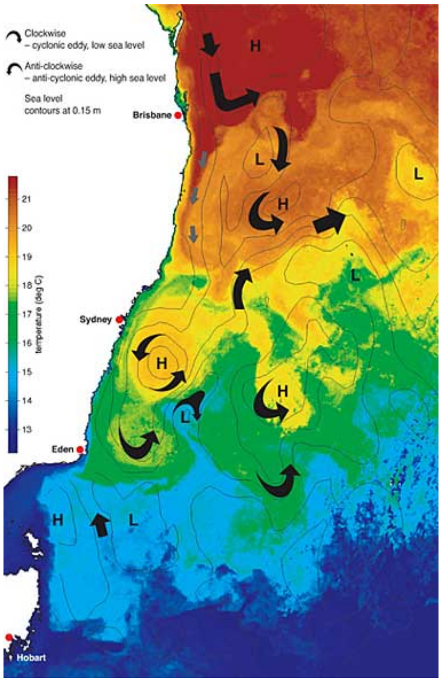

Figure 1. Example of BLUElink sea surface temperature data.

Concept Demonstrator

Typically a sonar operator will view a plan position indicator (PPI) display on their sonar console which displays active sonar returns in range and azimuth. These displays can often be very cluttered and the task of distinguishing potential targets from environmental clutter is very difficult.

The concept demonstrator was developed to assist the operator in interpreting the sonar picture by displaying modelled sonar system performance data (e.g. probability of detection, bottom reverberation and total reverberation), together with relevant environmental data (e.g. bathymetry, sound velocity and sediment type), To allow easy comparison with the sonar data PPI, the modelled performance data is displayed as a PPI overlaying the environmental data. A snapshot of the demonstrator displaying modelled probability of detection (red-blue colour scheme) as an overlay to bathymetry (white-black colour scheme) is shown in Fig 2.

The demonstrator allows active sonar returns to be correlated with bathymetric features such as canyon walls, seamounts or slopes. Sonar returns due to ocean features can then be more quickly and easily identified or discarded through the use of and association with the bathymetry databases and performance modelling.

Using the modelled probability of detection, the operator can also assess the likelihood of the returns being a target of interest. Alternatively the operator can use the modelling to identify areas of higher probability of detection which may lead to more alerted detection opportunities.

These displays are automatically updated in real time, utilizing automatic feeds of latitude and longitude from the ownship and heading, as well as depth and transmit mode information from the sonar, avoiding the need to manually run the sonar performance models offline.

The above mentioned measures of sonar system performance and associated environmental parameters are standard in the ASW domain. Detailed information on calculating sonar system performance will not be discussed in this paper but further information can be found in [3, 4].

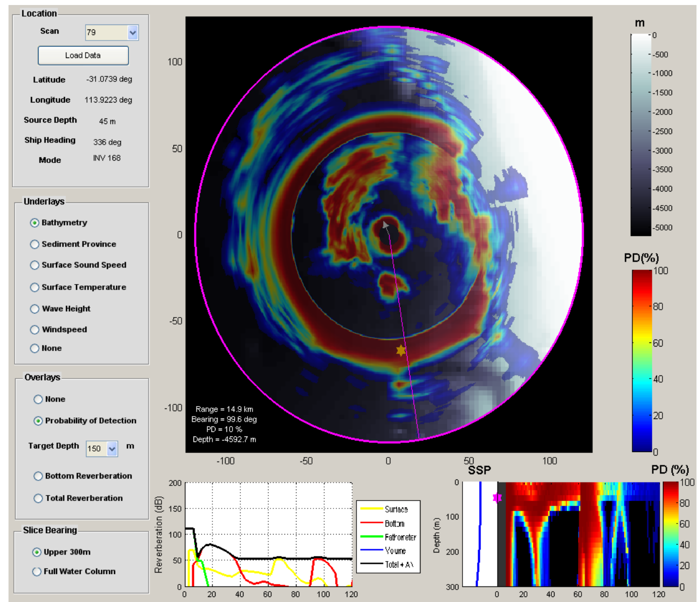

Figure 2. Example screenshot of the concept demonstrator showing PPI of probability of detection overlying bathymetry.

III. RESULTS

The concept demonstrator has been used to conduct post-trial analysis including sonar performance modelling for several at-sea trials data sets. This paper uses data and shows results from a sea trial which was conducted in deep water (>5000 m) off Western Australia in July 2003. During the trial an active towed array system was used to detect an echo-repeater simulating the returns from a submarine target. The trial was set up such that the range between the active sonar system platform and the echo-repeater target increased over time, and hence the sonar PPI commences with a small range scale and slowly expands outwards to the sonar's maximum available range scale.

XBT measurements of the *in-situ* temperature profiles were taken at various times during the trial and BLUElink hindcasts of sea surface temperature were also obtained post-trial. A plot of the sea surface temperature during the trial is displayed in Fig. 3. The red box in Fig. 3 indicates the location of the trial area. It can be seen that there is significant variability in the sea surface temperature throughout the exercise area. Unlike ROAM data, the lower resolution BLUElink hindcasts are only available as single snapshots of the day and hence some temporal variation in the data can be expected.

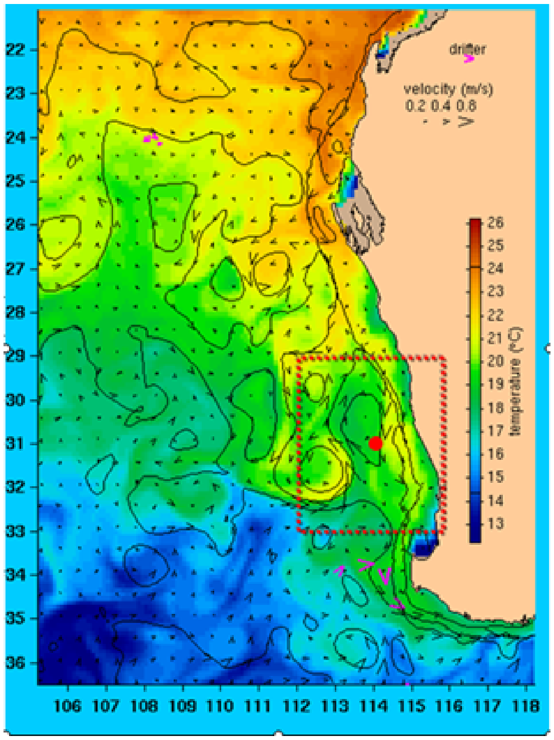

Figure 3. BLUElink hindcasts of sea surface temperature for the trials area off Western Australia (as indicated by the red-dashed box).

As part of the trial reconstruction, sonar performance modelling was conducted using three different assumptions for the sound speed profile input parameters:

i) Range-independent XBT: Assumed a range-independent sound speed by taking the closest available measured XBT in time and ownship position, and assuming it constant over the entire exercise area.

ii) Range-independent BLUElink: Assumed a range-independent sound speed by taking the closest BLUElink prediction in time and ownship position, and assuming it constant over the entire exercise area.

iii) Range-dependent BLUElink: Assumed the sound speed varied with position by taking the full range-dependent BLUElink predictions available for the time and area of the trial.

Similar assumptions were made for windspeed, although the measured data was 10 knots for all of the considered trials data, whereas the BLUElink predictions estimated the windspeed to be between 10 and 11 knots, therefore any difference between assumptions was not a significant factor in the sonar performance modelling. For all three assumptions, range-dependent bathymetry and sediment properties were used in the performance modelling.

Fig 4 shows a comparison of the measured XBT and BLUElink predicted sound speed profiles for two instances during the trial. Fig. 4(a) displays good correlation between the measured XBT and BLUElink predictions which both show an initial mixed layer (surface duct) down to approximately 40 m, and then a channel down to 80 m. Fig. 4(b) shows less correlation between the measured XBT and BLUElink predictions. In this case, the BLUElink prediction is again showing the surface duct and channel, whereas the measured XBT shows a generally downward refracting sound speed profile. This difference is likely to be due to either a resolution or location accuracy issue in the BLUElink modelling prediction.

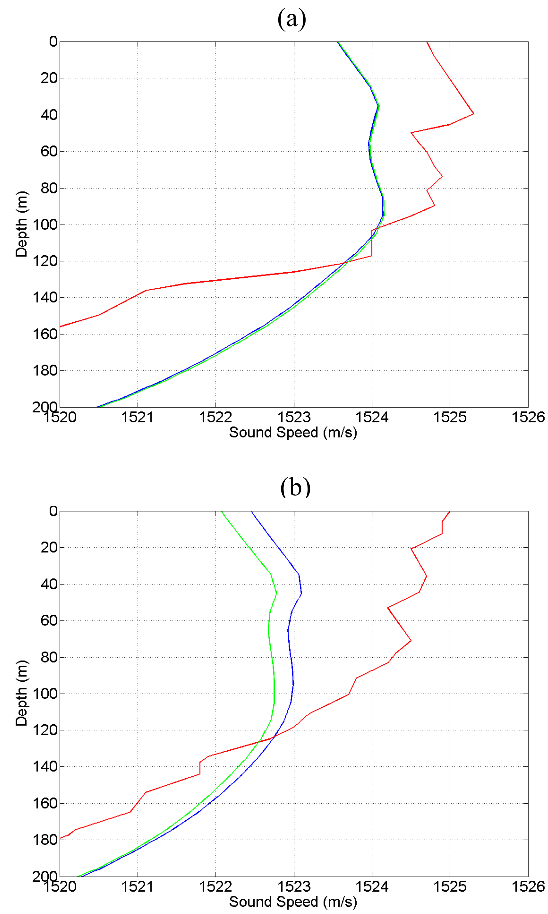

Figure 4. Comparison of sound speed profiles for two sonar pings during the trial where the BLUElink prediction at the ownship location is shown in blue, the closest measured XBT from the ownship location in red and the BLUElink prediction at the closest XBT measurement is plotted in green.

Fig. 5 shows PPI plots of the probability of detection for three selected pings (out of the 82 pings conducted across the 3.5 hours of trials data) using the three types of sound speed profile assumptions as inputs into the sonar performance model; range-independent XBT (left), range-independent BLUElink (centre) and range-dependent BLUElink (right).

In Fig. 5(a) and (b), the overlay of probability of detection extends only to the interior circle which indicates the size of the range scale employed at the time of the ping relative to the sonar's maximum range scale.

The small black square on the PPI figures denotes the position of the actual target and the green star set in the black square indicates a successful detection was made by the sonar operator for that active sonar ping.

(a) Ping 31

(b) Ping 70

(c) Ping 82

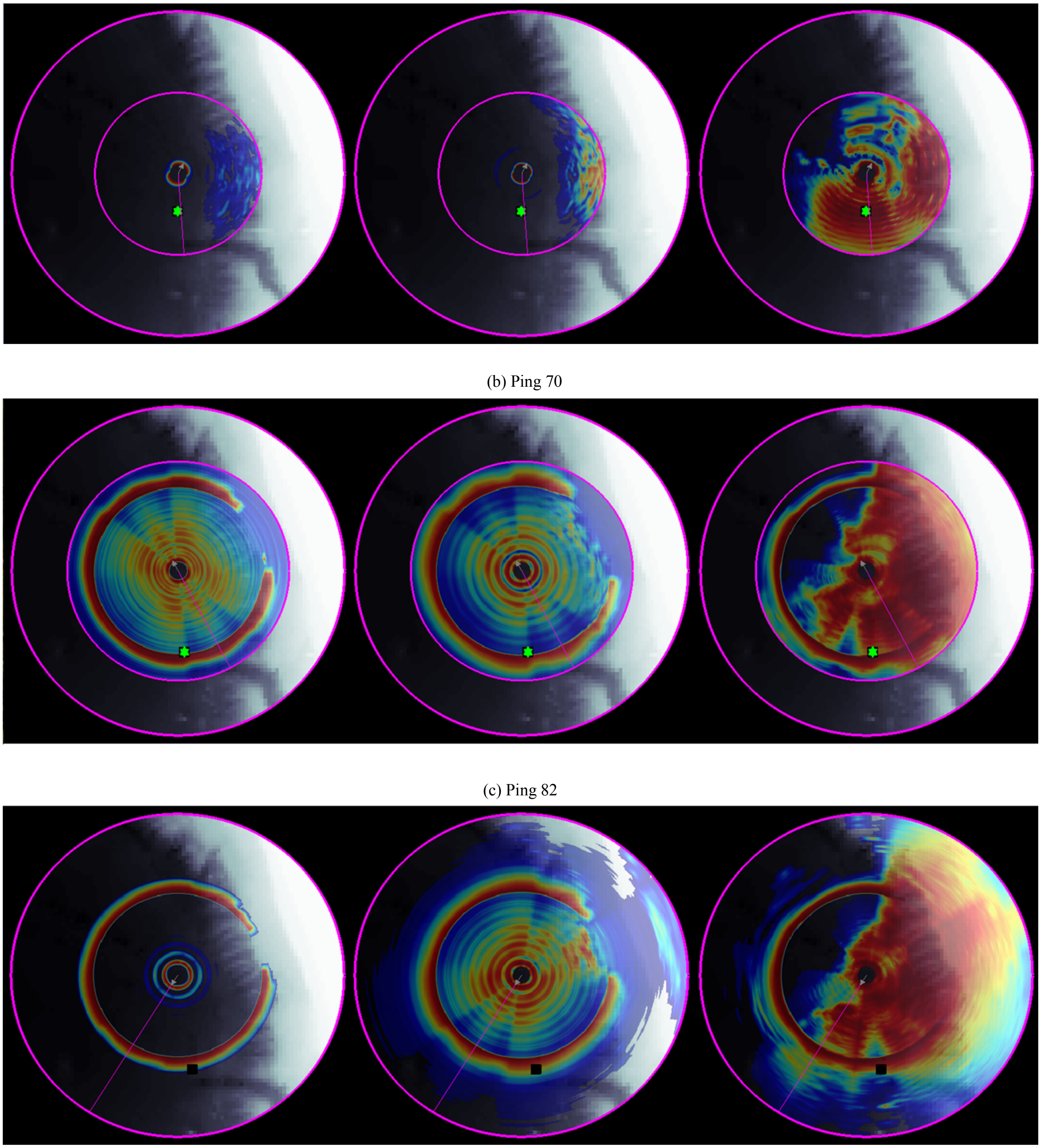

Figure 5. PPI of modelled probability of detection at a single target depth for selected pings during the trial using various environmental inputs (from left to right); range-independent XBT, range-independent BLUElink and range-dependent BLUElink. The small black square denotes the position of the actual target and the green star set in the black square indicates a successful detection was made by the sonar operator for that active sonar ping.

In Fig. 5(c) where there is simply a black square without a star the sonar operator did not detect the target for that ping. In each PPI plot, the sonar transmit direction for the current ping is indicated by the pink radial line, however the majority of the pings were conducted in a "search mode" which has wide transmit beams.

Fig. 5(a) summarises the sonar performance modelling results for Ping 31 of the trial in which the operator successfully called the target at a bearing of 175̊. The range-dependent BLUElink modelling shows a high probability of detection to the south which is consistent with the at-sea data. The range-independent modelling using the XBT and BLUElink correlate well with each other but both show virtually no modelled detection opportunities for all ranges and azimuth which is inconsistent with the observed at-sea data.

All three plots in Fig. 5(b) show the presence of a convergence zone for Ping 70. However the range of the target is just short of the convergence zone. Only the range-dependent BLUElink modelling predicts any significant probability of detection for this target location. Again there is good correlation between the XBT and the range-independent BLUElink modelled results.

Fig. 5(c) shows the PPI plots for Ping 82 of the trial where the target has passed through the convergence zone. The XBT data predicts some intermittent detection opportunities close to the ownship and a strong convergence zone further out, but no detection opportunities in between. The range-independent BLUElink modelling shows intermittent opportunities out to the convergence zone, while the range-dependent BLUElink results show high probability of detection out to and beyond the convergence zone east and south of the ownship position (which includes the target location).

The PPI plots presented in Fig. 5 are useful in summarising the change in sonar performance modelling results with azimuth for a single target depth. It can be clearly seen that the sonar performance modelling using the full range-dependent BLUElink data is capable of capturing the spatial dependence in the sound speed profiles which can result in significant changes to the modelled probability of detection. This is particularly observed by comparing the range-independent BLUElink modelled results with the range-dependent BLUElink data in Fig. 5, which have the same sound speed profile at the centre point (ownship location), but varies spatially elsewhere.

To better understand the acoustics and propagation paths that are occurring, one also needs to consider the depth variation in the modelled results, particularly as there are significant surface ducts and channels present, which are influencing the propagation. However this analysis is outside the scope of the paper.

To further quantify the improvement of the range-dependent BLUElink data, the modelled probability of detection has been extracted at the actual target position for each individual ping across the trial. This is displayed in Fig. 6 which also shows the pings that were successfully detected (green bars) and missed opportunities (black bars).

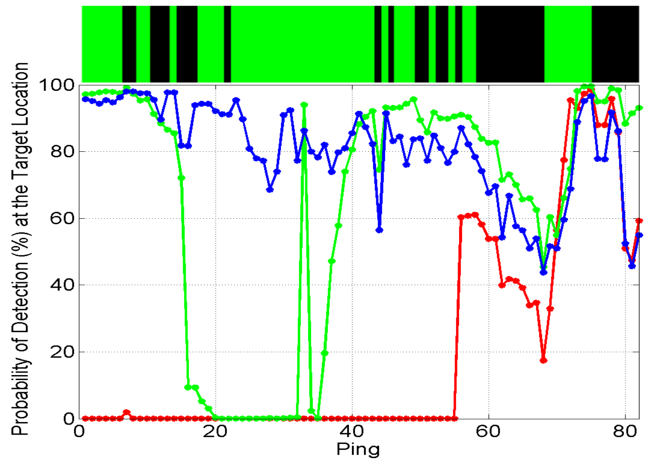

Figure 6. Probability of detection(%) at the target range and bearing for each ping of the trial for the three different types of sound speed inputs; range-independent XBT (red), range-independent BLUElink (green) and range-dependent BLUElink (blue). The upper bar displays the at-sea successful detections (green) and missed opportunities (black).

It can be seen that throughout the entire trial, high probabilities in the the range-dependent BLUElink results (blue line) correspond to green areas in the bar, and low probabilites with black areas. Thus the range-dependent BLUElink results show good correlation with the at-sea data. For pings 10-20 and pings 40 -60, the sonar operator declared intermittent detections of the targets which is consistent with fluctations in the range-dependent BLUElink modelled probability of detection.

The sonar performance modelling assumes the operators were not alerted to the location of the target and therefore detections opportunities for all pings were independent. However the at-sea data essentially consisted of alerted detections, that is, once the sonar operator correctly indentified the target, the task of maintaing the target was easier. This may explain the slight inconsistency between the range-dependent BLUElink modelling with at-sea data for pings 25 and 45 where the predicted probability of detection drops to 70% but the operator still continues to maintain contact against the target.

Note that the modelled probability of detection for the range-indepenent XBT (red) for the first fifty pings of the trial is approximately 0% which does not correlate well with the at-sea data. This difference is also observed in the range-independent BLUElink results (green) which show good correlation with the at-sea data and range-dependent BLUElink results except between pings 15 and 40. This lack of correlation is explained through further examination and comparison of the sound speed profiles for these pings which show significant spatial variation in the sound speed profiles along the radial of interest.

IV. Conclusions

The active sonar display can be complicated and contain many echo returns that may be difficult to interpret due to the complex and variable acoustic environment. Sonar employment aids that incorporate environmental and modelled data can assist an operator interpret the sonar picture and reject echoes from environmental clutters.

We conclude that the availability of more accurate range-dependent environmental data results in improved sonar performance modelling. Incorporating environmental data and modelling into sonar operator aids which are run and updated in a timely manner should lead to increased operator confidence, environmental awareness, system performance understanding and ultimately ASW capability. These improvements will be greater for sonar systems that have large detection ranges because the effects of environmental parameter variability are greater at longer ranges. The concept could also aid in mission planning by utilising environmental information such as location of ocean fronts and eddies, to position navy platforms and resources optimally to maximise sonar performance.

The ideal environmental input is likely to be a merged combination of the *in-situ* XBT measured data, which is accurate at the current ownship position, with the spatial and time-dependent BLUElink forecasts. Rapid Environmental Assessment (REA) techniques could also be used to obtain additional *in-situ* data from both dedicated environmental sensors, and from the sonar sensor itself by means of "through-the-sensor" sensing and environmental inversion techniques. For parameters such as ambient noise or reverberation levels, this additional *in-situ* data will result in improved sonar parameter estimates and therefore sonar modelling results and operator aids.

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