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Potential Impact of Long-Life Environmental Sonobuoys on Active ASW

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ABSTRACT

The focus of military activity has recently shifted from large area engagements to regional conflicts. Consequently, Naval maritime operations continue to evolve toward littoral warfare in complicated shallow-water, near-shore environments. This evolution requires new sensors, advanced Concept of Operations, and improved data-analysis capabilities, among others. Planning operations in these harsh-environment areas is difficult because accurate predictions of tactical sensor performance depend on detailed knowledge of local environmental conditions. Tactical mission planning is thus seldom optimal or efficient - often resulting in coverage gaps, increased risk, and reduced mission success. The U.S. Navy is exploring extended-life environmental sonobuoy concepts to better characterize the littoral environment. Some designs contain a thermistor string to measure ocean temperatures and hydrophones to measure ambient noise. This type of complex sonobuoy would be far more expensive than a traditional single-measurement expendible bathythermograph but it could provide a more thorough environmental assessment. This paper examines the trade-off between increased sensor cost and improved ASW performance, in terms of area coverage and probability of detection. For this trade-off analysis, temperature data from the Sea of Japan were used along with a realistic dynamic ambient noise field from archival data and a noise statistical model. Several notional environmental buoys were then simulated to drift through the area and collect data over several days. The analysis shows that a drifting extended-life environmental sonobuoy field can provide significant improvement in environmental characterization, tactical planning, and ASW detection performance.

INTRODUCTION

Naval operations continue to evolve toward Littoral Warfare as military action shifts to regional conflicts. To accomplish this evolution, new navigation, sensor, and data-analysis capabilities are needed to support operations in the highly variable and complicated near-shore waters of the littoral environment. Antisubmarine Warfare (ASW) is often conducted in shallow-water areas, where subsurface enemies pose a constant threat, and where knowledge of ocean thermal data and ambient noise levels is critical, but lacking. Planning operations in these harsh-environment areas is difficult because accurate predictions of sensor performance depend on detailed knowledge of the local conditions. Tactical mission planning is thus seldom optimal or efficient, often resulting in coverage gaps and increased risk. According to the U.S. Navy, "*Air ASW tactical execution, especially in littoral seas, requires in-situ environmental updates for preflight mission planning. In the conduct of ASW operations, an urgent need for explicit knowledge of environmental variables is required to optimize the effectiveness of operational acoustic sensors, as well as acoustic sensors in development.*" One solution is to deploy more environmental sensors (*e.g.,* Airborne eXpendable BathyThermograph; AXBTs) but this reduces time on-station available for the tactical mission.

The Naval Air Systems Command has considered new ways to better characterize the littoral environment. One possibility is a new or upgraded extended-life sonobuoy with a thermistor string to measure ocean temperatures at fixed depths while drifting through an area. Additional sensors, like hydrophones to monitor the changing ambient noise field, are also possible alternatives. A new space-time sampling capability, like this, would be more expensive than a traditional single-shot, point measurement AXBT but it would provide valuable additional data for littoral environmental characterization. There would be many new requirements to meet and issues to solve for such a new device, like increased electrical power, survivability, communications, processing, data rate, drift rate, new Concept of Operations, etc. In addition, since higher resolution temperature fields would lead to better acoustic characterizations, there would be an opportunity to deploy complicated tactical buoy patterns that could be adapted to the environmental complexity and provide increased detection performance.

The increased unit cost would drive the need for an environmental decision aid to determine the minimum number and optimal deployment locations of environmental buoys to meet performance objectives. A prototype decision aid that addresses this issue has been developed and is reported in the Oceans '09 Biloxi Conference Proceedings. That capability, called SPOTS (Sensor Placement for Optimal Temperature Sampling) produces sampling patterns for AXBTs that are adapted to oceanographic conditions for optimal performance. Recent SPOTS results show that a few well-placed AXBTs can significantly improve temperature accuracy compared to larger numbers of gridded measurements.

Optimizing tactical buoy patterns for multistatic sensors has been addressed in several projects. The current accepted Fleet solution is called ASPECT. A recent research effort produced SCOUT (Sensor Coordination for Optimal Utilization and Tactics), which uses genetic algorithms to design non-standard buoy patterns and irregular "ping" intervals for monostatic and multistatic sonobuoy fields. Some results of this work are reported in the Oceans '09 Biloxi Conference Proceedings. They show that standard patterns are grossly ineffective in inhomogeneous environments where 36-60% improvements in detection performance are achieved with SCOUT and that 8-16 sonobuoys with SCOUT placement can perform as well as 32 regularly spaced sonobuoys.

The electrical power issue is being examined by the authors under a new research effort called SWEM (Sonobuoy Wave Energy Module) in which new technology is being developed to harvest kinetic energy from ocean waves and convert to electrical energy. There are many engineering challenges to be overcome. They include achieving adequate efficiency, performing well in all sea states, adapting to changing wave conditions, fitting in a fraction of the volume of a sonobuoy casing, surviving in rough seas, and being cost effective. That work is in an early research and development phase.

This paper addresses the potential tactical value of drifting thermistor-string data to support active sonar predictions and performance. We assume that a SPOTS capability is available to determine the best initial deployment locations and that a SCOUT capability is available to locate tactical buoys in optimal locations. We further assume that a SWEM capability would allow a 12-day operational life. These simulation results could help determine if a thermistor string on a new extended-life environmental sonobuoy has sufficient value to justify further research or a new development program.

ENVIRONMENTAL ANALYSIS

The analysis is based on AXBT data collected on 17 February, 23 February, and 1 March 1999 in the Sea of Japan, near the east coast of Korea. During each water-sampling flight about 44 measurements were made on an approximate 15-min grid (between 35.75 and 37.75 deg N and from near the coast to 130.5 deg E) and then assimilated into climatology using a standard set of optimal interpolation routines to produce temperature nowcasts throughout the water column. The spatial covariance distance for assimilation is often assumed to be the Rosby radius at the latitude of the measurement. In this analysis, for this dynamic enclosed sea, a smaller distance (approximately 20 km) is used. This smaller value is based on previous analysis in this region.

Fig. 1 shows results between 36 and 38 deg N at 100-m water depth between 129.7 and 130.7 deg E on each of the three days, with temperature contours ranging from 4 to 12 deg C. Korea is colored gray and the exact AXBT deployment sites are shown by the nearly gridded sets of white dots. The sampling density is sufficiently high that we consider these nowcasts to be "ground-truth" for comparison with other sampling schemes.

The temperature structure changes dramatically with depth (not shown) and over time during this 12-day period. The large central warm core on 17 Feb shrinks in size and becomes less intense over time. We consider two questions: first, how well would these complicated temperature fields be represented by a small number of long-life drifting thermistor strings compared to a small number of fixed pont and time AXBT measurements; and second, are the environmental effects significant enough to improve tactical detection performance?

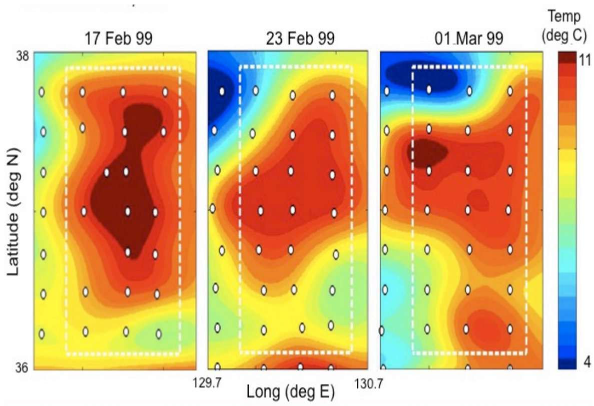

Figure 1. Ground-truth water temperatures at 100-m depth on 17 Feb (left), 23 Feb (center), and 1 Mar (right).

The first question (sub-sampling) is addressed in Fig. 2 where we compare nowcasts from 3 AXBTs (right) and 3 hypothetical SWEM-powered buoys with thermistor strings (center) on 1 Mar. For simplicity, the conceptual extended-life drifting buoy system is called SWEM and for ease of comparison, the ground truth result for 1 Mar, already shown in Fig. 1, is repeated here (left). These nowcasts are for a 100-m depth, span 4 to 11 deg C, and are computed as follows.

For the AXBT assimilation, we assume that 3 measurements were made on a straight flight path along 130.25 deg E at 36.0, 36.75, and 37.5 deg N just prior to conducting a tactical mission on 1 Mar. The AXBT nowcast shows that at the 2 southern locations, the measurements were warmer than climatology, which produces so-called bulls-eye patterns, as shown by the circular orange areas. The northern AXBT is in rather cold water. The unsampled area between the central and northern AXBTs is much colder than ground-truth.

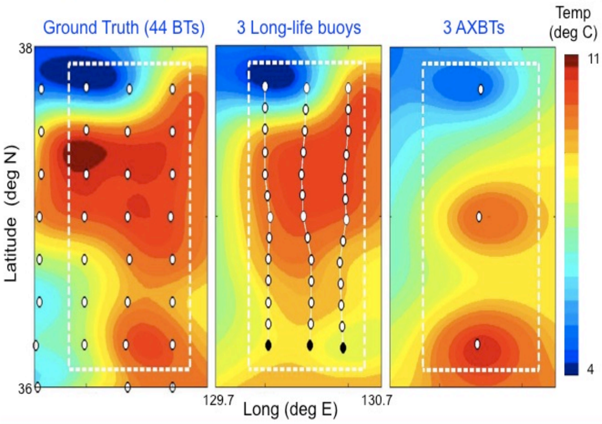

Figure 2. Temperature assimilation results at 100-m depth on 1 Mar for ground-truth (left), 3 SWEM buoys (center), and 3 AXBTs (right).

For SWEM, we assume that on the first day of the measurement period (17 Feb), 3 SWEM buoys were deployed near the southern end of the 3 eastern-most columns of the ground-truth data. [The 3 AXBT samples are along the middle SWEM column.] We also assume about a ½ kt current flowing north so that after 12 days the SWEM buoys would be at the northern end of the ground-truth data points. We then interpolate in space and time between the AXBT measurements and simulate the temperatures that would have been measured along the 3 northern moving tracks at daily intervals. The 13 simulated SWEM buoy locations along each of the 3 tracks are shown by white dots and lines in Fig. 2 (center).

We assume a 12-day temporal covariance that weights down the data from early days (at southern positions) by more than half for the 1 Mar nowcast. Clearly the SWEM nowcast agreement with ground truth is significant, although it fails to describe the small southern warm core on 1 Mar at 36.25 deg N. In this case the SWEM samples at that latitude were simulated about 10 days earlier when that area actually contained relatively cold water (see Fig. 1 on 17 Feb).

TACTICAL ANALYSIS

The second question (environmental impact on tactical performance) is addressed in this section. The three ground-truth environments were used to predict sonar performance at 750 Hz for a notional monostatic active system with source and receiver at 300-m depth and target at 20-m depth, assuming a uniform noise distribution. The results are shown in Fig. 3 as detection range contours between 0 and 6 nmi. The indented white-outlined box is the area in which several ASW searches were simulated. The slightly reduced search-box area was chosen to avoid the shallow water areas on the continental shelf to the west and the un-sampled areas to the east. The AXBT, SWEM, and ground-truth sampling locations are overlaid as white dots.

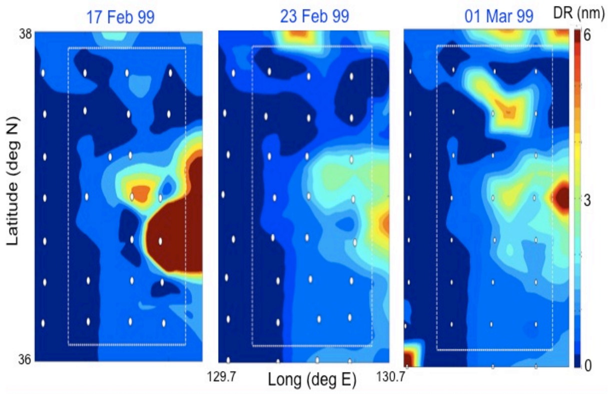

Figure 3. Ground-truth active sonar detection ramges on 17 Feb (left), 23 Feb (center), and 1 Mar (right) for source and receiver at 300-m depth and target at 20-m depth.

Fig. 3 shows that the ground-truth active sonar performance on these days is significantly non-homogenius and dynamic, which suggests that standard uniform tactical sensor patterns are not appropriate. The non-homogeneity is cause by a combination of water temperature and bottom complexities. It is not possible to interpret the multi-day changes in temperature at 100-m depth (Fig. 1) as changes in performance (Fig. 3) because the acoustic waves propagate throughout the entire vertical water column. Clearly, in this case, the temperature profile varies throughout the 12-day period. One stationary aspect that can be explained easily is the relatively better performance in the central east region. That is the deepest area and contains the sofest bottom sediments and both are good for active sonar performance.

Next we examine the effect of temperature sampling on sonar performance in a way that parallels the temperature analysis in Fig.2. Detection ranges are calculated for 3 sampling patterns, similar to Fig. 2, and shown in Fig. 4. The difference is that the 3 AXBT locations are along a SW to NE diagonal. The 3 drifting SWEM buoys clearly produce a better (*i.e.,* closer to ground-truth) acoustic representation than the 3 chosen AXBT locations, especially in the north. Part of the improvement results from the SWEM buoys being in the north near the nowcast day (1 Mar), while only one of the 3 AXBTs is in the north. However, the AXBT sampling strategy chosen is quite normal because it “covers” the area of interest on the day of interest.

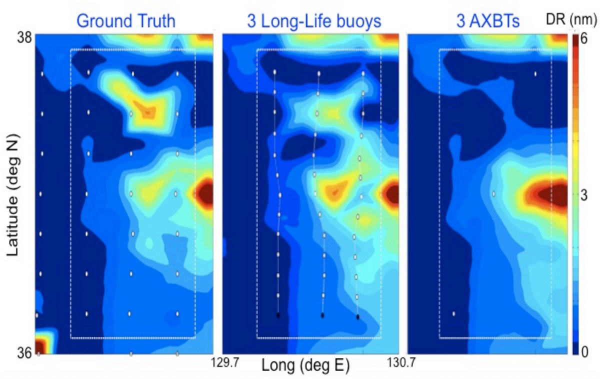

Figure 4. Detection ranges for a monostatic active system at 750 Hz with source and receiver at 300-m depth and target at 20-m depth.

The final, and most important, calculation comes from an assessment of the Cumulative Detection Probability (CDP) over a search period with sets of tactical monostatic active buoys in several different sub-areas of the previous figures. The following analysis is for a 6-hr search in an area from 36.5 to 37.85 deg N and 130 to 130.7 deg E (approximately 3200 nmi^2) against a 5-kt target on random patrol in this area. We used the SCOUT genetic algorithms to choose optimal (non-standard) sensor locations for 8, 16, 24, and 32 sonobuoys but adapted them differently for the distinct complexity of each environment.

We hypothesize that the most accurate performance would be achieved when SCOUT optimizes to the ground-truth environment. The prediction, and actual mission result, for that case is the ground-truth CDP. In today's non-SWEM reality, SCOUT would optimize the tactical pattern based only on the 3 AXBT measurements. The location results, with SCOUT optimization, in the ground-truth environment on 1 Mar are shown in Fig. 5 by red triangles for 16 and 24 tactical sensors. They tend to cluster in the better detection areas. The background colors are detection ranges from Fig. 4 and the white dots are the ground-truth AXBT locations, as before. Recall that the southern end of the search region is 36.5 deg N, which explains why there are no tactical buoys below that line.

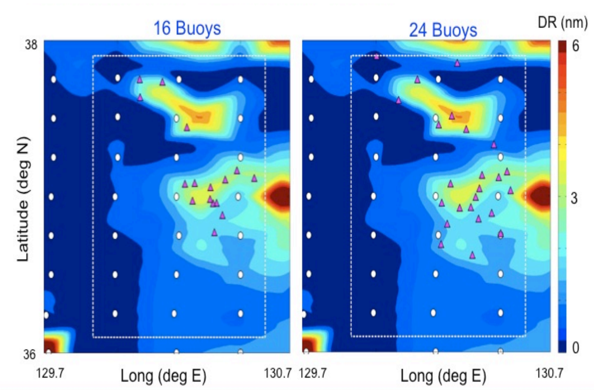

Figure 5. SCOUT optimaized sensor locations (red triangles)

These summary results are shown in Fig. 6 where CDP increases with the size of the sonobuoy field. The buoy locations were chosen according to the available temperature data (either ground-truth, 3 SWEMs, or 3 AXBTs) and then evaluated against reality; *i.e.,* ground-truth. The result for ground-truth (black line) is the highest CDP, as expected. The plan based on 3 SWEM buoys (red line) is intermediate and the plan based on 3 AXBTs gives the lowest result. Of course there are many different ways to locate 3 AXBTs in this area, so we chose several different triplets, made separate calculations, and only show the average result in Fig. 6.

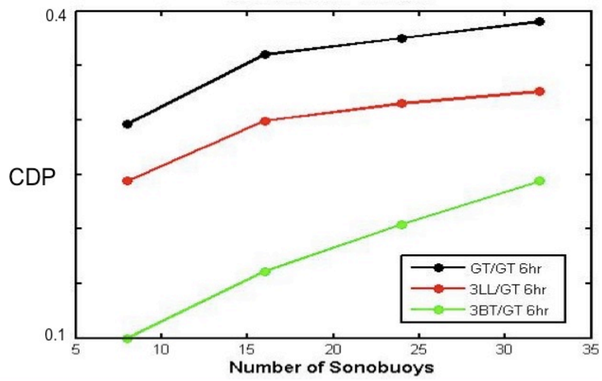

Figure 6. CDP results for 8, 16, 24, and 32 sonobuoys using ground-truth, 3 SWEM long-life, and 3AXBT environments.

SUMMARY

We studied the potential impact of drifting thermistor strings on tactical active ASW performance using real AXBT data from water-sampling flights in the Sea of Japan. The results show that data collected over the previous 12 days from 3 drifting strings can significantly improve littoral environmental and acoustic characterization when compared to 3 discrete AXBT measurements on the day of interest. The analysis is based on comparing temperature nowcasts against a ground-truth data set and then comparing acoustic performance predictions at 750 Hz and detection probabilities for various sets of sonobuoy patterns. These results support the concept of an extended life sensor based strictly on drifting temperature measurements. Future work will include a cost analysis and an attempt to determine if the performance gains are cost effective.

These results apply to summer in the Sea of Japan with 3 sensors. Generalized results will be obtained by extending the analysis to other seasons, locations, and number of sensors.

ACKNOWLEDGMENT

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