THE JOURNAL OF THE ACOUSTICAL SOCIETY OF KOREA VOL.23, NO.2E 2004. 6 pp. 68~73

# Modeling Environmental Effects on Detection Performances for Variable Depth Sonars in the East Sea of Korea

Young-Nam Na*, Chang-Bong Cho*, Sang-Kyu Han**
*Agency for Defense Development, **STX Radarsys.
(Received Jun 17 2004; Revised August 4 2004; accepted August 16 2004)

## Abstract

In the East Sea of Korea, the ocean environments are known to have strong variations in space and time. Their effects are very important factors in sound propagation and sonar performance. We consider the environmental factors such as eddies and thermal fronts affecting underwater sound propagation and target detection performance by sonars. Unfortunately, however, the detailed structure of eddies is usually difficult to understand by using the sea surface temperatures from infrared images alone or a few profiles from the CTD (conductivity, temperature and depth) castings. The temperature fields of eddy and thermal front are simulated with typical patterns of those obtained from several observations. This paper delivers the overviews of environments and acoustic models with their simulation results on sonar performance.

***Keywords***: *Environmental effect, Eddy, Front, Propagation loss, Detection performance*

## I. Introduction

To establish and operate the early-warning systems (for example, towed array sonars) in waters against hostile underwater targets, the prediction of the acoustic fields and detection ranges is one of the most important issues. Typical water environments affecting the acoustic propagation include water mass variation, bottom sediment distribution, and topography. In particular, most vertical and horizontal variations of water mass in the East Sea are caused by eddies and thermal fronts which vary with time and space. Their effects are very important factors in the operations of variable depth sonars for long-range detection. Recently, some studies have been focused on the relationship between oceanic variability and sound propagation in the East Sea[1,2]. Figure 1 is an example showing the fact that how ocean environments affect the sonar operation depths. The source, which radiates CW signal of 100Hz, is assumed to be at 100m depth and 50km range within the eddy. The simulations are performed up to 120km range. The existence of a typical eddy makes the convergence zones form in lower depths and thus the sonar should be operated in lower depths compared to in ordinary cases.

In this paper we describe an environment model for simulating meso-scale phenomena in waters, i.e., eddies and fronts. We also deliver a brief scheme of an acoustic model employed. The input parameters for the acoustic

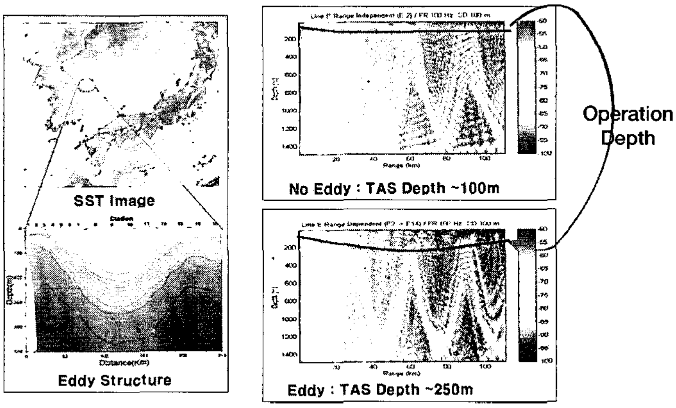

Figure 1. Eddy effects on acoustic waves propagation.

---

Corresponding author: Young-Nam Na (ynna@add.re.kr)
Agency for Defense Development
645-600 P.O.Box 18, Chinhae, Kyung-Nam, Republic of Korea

model are environmental data such as topography, temperature fields, bottom properties, ambient noises from acoustic sensor, and sonar parameters. The model may provide information such as detection ranges both of own ship and target, convergence zones, and optimum depth for sonar operation. Finally, we present some simulated results of eddies and fronts with a realized system for operational purpose.

## II. Environmental Model

### 2.1. Environmental Data.

Oceanic environmental data for acoustic model are topography, temperature fields, bottom properties, and ambient noises which obtained from *in-situ* observation, database or environmental modeling (simulation). *In-situ* observation data are temperature profiles observed from the expendable bathythermograph system MK-8E, positioning data interfaced with GPS and ambient noises measured by acoustic sensor.

Oceanic database consists of topography with 1-minute grid, bottom properties with 20' grid, and monthly temperature profile with 10-minute. However, shallow water always has some degree of horizontal variability such as eddies and thermal fronts along or across the acoustic paths which strongly influence the acoustic fields. Eddies have typical dimensions of 100~200km in radius and 150~200m in thickness in the East Sea of Korea[3]. Thermal fronts also appear to be critical restrictions to sonar operation. Unfortunately, the structure of eddy or thermal front is usually difficult to understand by using the sea surface temperature alone from satellites or a few conventional CTD castings. We attempt to simulate temperature fields using typical patterns of those obtained from several observations. The simulation factors on eddy and thermal front are the center position, radius (width), thickness, and ratio of those.

Figure 2 gives an example of eddy variations over a year. The eddy was observed in 1992 along the section between Ulneung Island and Mukho harbor in the East Coast[4]. In March, the eddy developed most largely decayed thereafter, and its symmetry broke in August. This type of meso-scale eddies typically persist for several months.

### 2.2. Environmental Model

Among eddies or fronts of various temporal and spatial scales, we focus on those of meso-scale because they make dominant factor in deciding the sonar operation depths for long-range (typically a hundred kilometers) detection.

The first step to form the model is to analyze and to categorize typical eddies and fronts in the East Sea. We could obtain five basic types about them from which we can deduce many varieties to simulate the real environments.

The second step is to choose proper parameters from deduced variations on eddies and fronts. These parameters are center position, radius, width, thickness and strength. The strength could be expressed as horizontal gradients of eddies or fronts. The maximum horizontal and vertical ranges are limited to 200km and 400m, respectively.

The third step is to apply an objective analysis to model the distributions of temperature or sound speed in range

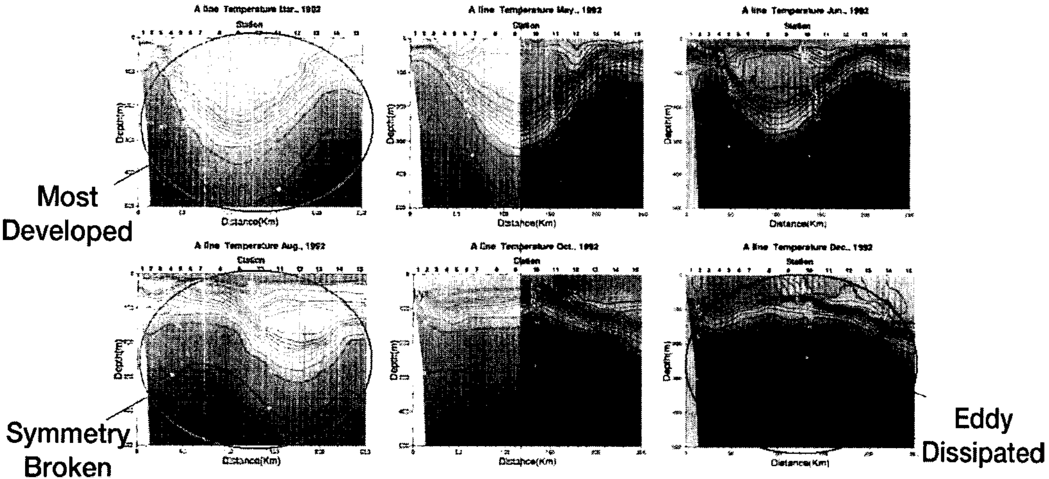

Figure 2. An example of eddy variation over a year.

and depth. For confirmation purpose, model outputs need to be displayed in graphics. The following is a basic relation for the environmental model[5].

$$X_{Ai} = X_{Bi} + K\sum_{k=1}^{k=P}\left(Y_k - X_{Bk}\right), K = B\left(B + R\right)^{-1}, \quad i = 1, 2, 3, \ldots, N \tag{1}$$

where, $\mathbf{X_A}$ = analyzed value, $X_B$ = background value, $\mathbb{Y}$ =observed value, **K** =weight matrix, **B** = covariance matrix of background error, **R** =covariance matrix of observation error, k = observation point and i =grid point.

The final step is to merge the modeled data into existing typical data at the specified time and section. That is, over the water column, the modeled data form the upper part of 400m and the typical data (monthly averaged sound speeds in grid) do the remaining. The historical data, which are averaged over all observation time in some area, generally do not show major features of meso-scale phenomena such as eddies and fronts. Hence, this kind of environmental modeling is expected to make a great contribution to develop tactical or operational plans with high performance sonars that are dedicated to detecting underwater targets of long range. Figure 3 gives model results of an eddy and a front changing some of their parameters.

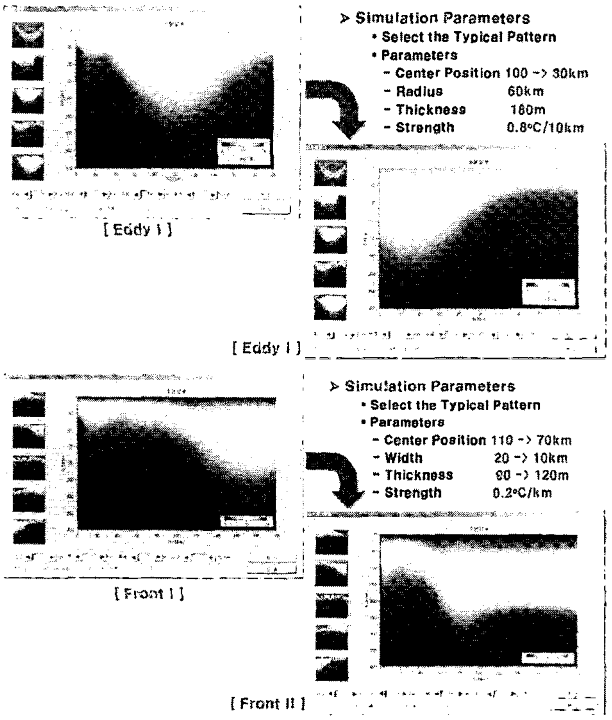

*Figure 3.* Model results of an eddy and a front changing some of their parameters.

## III. Acoustic Model Optimization

We employ a scheme based on the Gaussian beam tracing method. The idea starts from the fact that a ray should be considered as statistically varying curve with Gaussian statistics. This leads informally to associating a Gaussian intensity distribution with each ray, the ray becoming the central ray of a Gaussian beam[6].

In order for an acoustic model to be applicable in naval operations, it should be optimized to obtain computation time as well as accuracy. The optimized grid numbers are 201 in range and 301 in depth, respectively. The maximum launch angle is variable within +/-70°. The most crucial factor affecting the accuracy of the results is total beam number, which should be inevitably varied with frequency. We applied the following criteria in determining the proper number[7].

$$N_{beam} = \alpha + \left|\alpha - \beta\right| / A, \tag{5}$$

where, $\alpha, \beta$ =ray angle in radian, the coefficient $A = \left(c/6fr\right)^{1/2}$, c=sound speed(m/sec), f=frequency(Hz) and r=maximum range(m).

Since the BELLHOP-RD adopts a kind of Gaussian beams along ray paths instead of traditional delta function, the accuracy could be affected by weighting function applied. In general, delta function causes unreasonable shadow and convergence zones. We considered three functions: Gaussian beam bundle (GBB), geometric beam (GEO), and simple Gaussian beam (SGB). After many simulations over the wide frequency ranges and comparisons with the RAM, we employed the GBB as a weight function along each ray path.

We also gave it a little modification to the model inputs. Once sound speed profiles are fed into the model, they are interpolated by conventional schemes. Conventional methods such as spline often lead to artificial spikes where temperature or sound speed varies sharply with depth. We introduced new method of interpolation, Akima spline [8], which is known to be valid even at the worst case when properties face high variations.

In general, the BELLHOP-RD, which is based on the ray theory, is known to be valid in high frequency. The models based on other schemes (for example normal theory or parabolic equation) give accurate solutions but have critical limitations in high frequency mainly because computation time increases by geometrical series[8]. To apply the BELLHOP-RD to low frequency problems, we should examine the conditions at which it is valid. We compared propagation losses by the BELLHOP-RD with those by a parabolic equation based model (RAM) in deep and shallow environments. Figure 4 gives an example at 250 Hz in the East Sea of Korea. The source is assumed to be 200m, the lower edge of the sharp thermocline. We can see that major features match very well in the two distributions. The main objective of this model is to give the optimum sonar depth to guarantee the maximum detection performance in the given environment. The BELLHOP-RD proves to be proper because it gives results very quick results within an acceptable error bound. On the contrary, a parabolic equation based model(RAM) is very hard to be operational mainly because its computation time increases in power series as frequency increases in spite it is known to give accurate results.

## IV. Simulation of Environmental Effects

### 4.1. Model Implementation into a sonar Performance Prediction System

The environmental and acoustic models are implemented into the system ASADE-T (Analysis Software of Acoustic Detection Environments for Towed Array Sonars). The missions of the ASADE-T are to provide solutions to the following questions.

- At which depth should the sonars be operated to keep their performance the best in given source and environmental conditions?
- To which direction would the sonars show best performance?
- What is the situation now with own ship and targets?
- What is possible detection range in given source and receiver conditions?

In order to answer the questions above, the system firstly prepares environmental data that serve as an input for the acoustic model. The data consist of three categories of real time, database and simulation. Real time data come from the own ship equipment such as expendable bathythermograph, global positioning system, and sonars. Database are inherently averaged ones based on historical observation and are constructed to give typical values in each grid point. They contain temperatures, sound speeds, geoacoustic parameters, and water depths. Simulations are made to get more realistic environments with eddies or fronts whose existence may be critical consideration on sonar operation.

As the second stage, the system gives tactical information such as directional patterns of ambient noise, propagation loss, signal excess, and detection probability. Same analogy is applied to get information for counter detection environments, where we assume the source be the radiation noises of the own ship.

The final results from the ASADE-T are detection ranges for given source-receiver configuration, optimum sonar depth for best performance, and convergence zones. All the processes are easily handled through graphic user interface. The system has a function of tactical briefing in which major results are summarized from the inputs to the outputs.

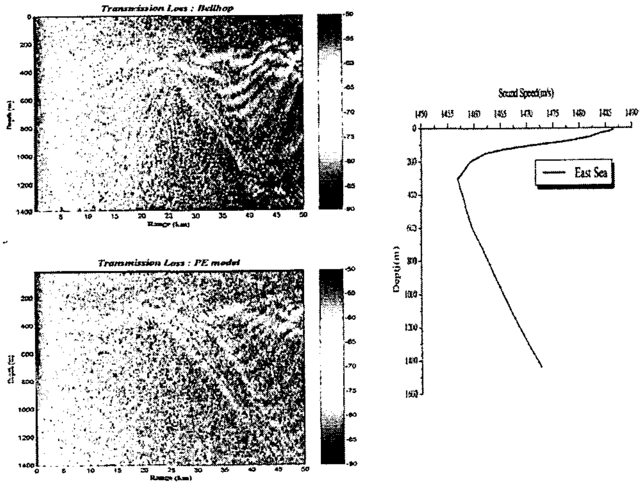

Figure 4. An example of propagation losses at 250Hz in the East Sea of Korea.

### 4.2. Simulation of Environmental Effects with Eddies and Fronts

Figure 5 gives simulation results when an eddy is located between the source and the receiver. The left picture is obtained assuming the eddy to be centered at range 100km and to have a radius of 60km. (See Figure 3 for more details.) The source is assumed to be located at depth 150m and to have frequency 120Hz. Meanwhile, the second eddy(right picture) is obtained by moving its center position to the left and by decreasing the thickness from

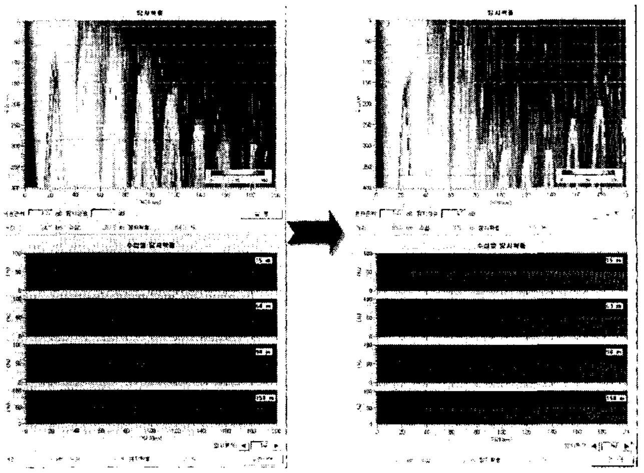

Figure 5. Examples of sonar performance variations according to eddy changes.

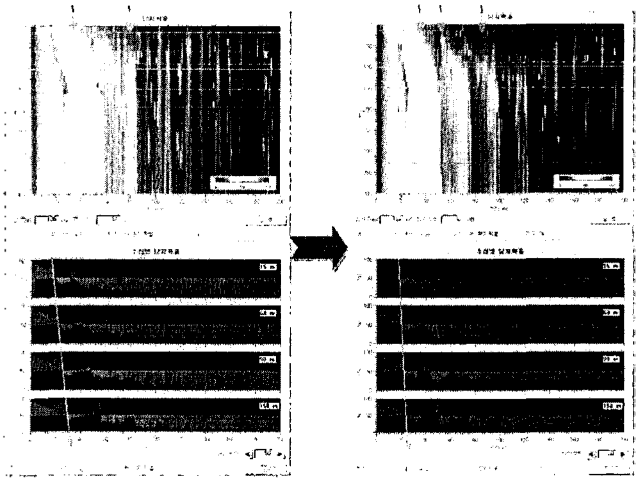

Figure 6. Examples of sonar performance variations according to front changes.

180m to 150m. The structure of eddy is simulated using an objective analysis method from a typical pattern. The range-depth distributions of detection probability (upper pictures) show noticeable difference in the two cases. When the source is located at the boundary of the eddy, we can see that the second convergence zone goes down to depth 200m, which normally develops near the surface. Succeeding convergence zones exactly follow the isothermal line of about 10°C and thus mostly lowered at ranges 100~120km. When the source is located at center of eddy, the convergence zones move into the surface and the detection probabilities increase. The lower figures show detection ranges for selected four sonar receiver depths. The ranges corresponding to the areas above the horizontal bar of each figure suggest detection with the probability of 50%. We can see that the maximum ranges in the simulation with eddy II (right) become shorter than those in eddy I (left). In the simulation, we assume the figure of merit (FOM) to be 81dB.

Simulations on thermal fronts may be activated modifying their center position, width, thickness and strength. Figure 6 presents examples of the front simulation and its effects on detection probability. In this simulation, except the strength, other parameters are changed: the center position from 110 to 70km, the radius from 20 to 10km, the thickness from 90 to 120m, and strength 0.2°C. (See Figure 3 for more details) As the front structure changes, convergence zones form in shorter interval and become weaker. As a result, detection ranges are expected to decrease in the second environment. In the two simulations, we assume the figure of merit (FOM) to be 81dB.

The system ASADE-T has been validated via tens of sea tests whose scenarios include underwater targets of

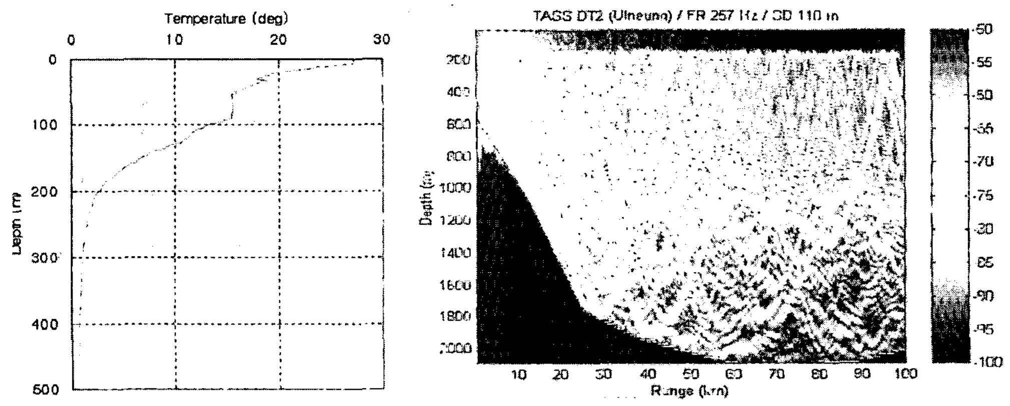

*Figure 7.* Bathythermograph data retrieved in a real sea test and propagation loss predicted.

simulation and real submarines in the East Sea. In each test, we have predicted detection environments over the assumed scenario with historical data and compared them with the results with real data. In almost all cases, the two results have shown big differences, implying the fact that real environmental data are crucial to obtain exact tactical information. Figure 7 gives an example of bathythermograph data gathered in a real sea test and propagation loss predicted by using the temperature profile. The scenario was such that sound source kept its track along the continental slope while towed array sonar tried to detect the source in the offshore of long range. Because of the strong thermocline in the profile, all rays refract into the lower layer in the deep region after a few reflections between the surface and the bottom in the shallow region. Consequently, in this environment, it implies that the sonar operation should be made below more than 200m to detect the target. This result is a rough example based on only one profile. If we know the information about eddies or fronts (i.e., their locations, dimensions etc.), we can obtain more precise results by using the system ASADE-T.

## V. Conclusions

The tactical operation model may produce the environmental parameters affecting sound propagation and sonar performance in the East Sea of Korea. The environmental parameters considered are eddies and thermal fronts. The model successfully simulates the major patterns of eddies and fronts probably appearing in the East Sea of Korea. The model is expected to apply to tactical decisions such as the optimum depth for depth variable sonars and the search pattern to promise the best result.

## References

1. Na, Y. N., M. S. Jumg, and T. Shim, "Interference of Acoustic Signals Due to Internal Waves in Shallow Water, " *J. Acoust. Soc. Kor.*, 18(3E), 9-20, 1999.
2. Na, Y. N., Y. G. Kim, Y. S. Kim, J. S. Park, E. H. Kim, and J. H. Choi, "Considerations of Environmental Factors Affecting the Detection of Underwater Acoustic Signals in the Continental Regions of the East Coast Sea of Korea," *J. Acoust. Soc. Kor.*, 20(2E), 30-45, 2001.
3. Min, D. H., J. C. Lee, T. B. Shim, and H. S. Lee, "Eddy Distribution off the East Coast of Korea Derived from Satellite Infrared Imagery, " *J. Kor. Fish Soc.*, ***28(2)***, 145-156, 1995.
4. Annual Report of Oceanographic Observations for 1992, National Fisheries Research and Development Institute, **41**, 73-92, 1992.
5. Hartman, D. L., Objective Analysis, Univ. Washington, Department of Atmospheric Science, Course Notes, 2001.
6. F.B. Jensen, W.A. Kuperman, M.B. Porter and H. Schmidt, Computational Ocean Acoustics, pp. 168, AIP Press, 1994.
7. M.B. Porter and H. P. Bucker, "Gaussian beam tracing for computing ocean acoustic fields," J. Acoust. Soc. Am., **82**(4): 1349-1359, 1987.
8. Na, Y. N., Y. G. Kim, S. I. Kim, S. H. Lee, Y. G. Lee, C. B. Cho, and H. S. Kim, Development of Submarine Acoustic Information Management System(SAIMS 1.0), ADD Rep. NSDC-517-031109, Nov. 2003.

## [Profile]

- **Young-Nam Na**

The Journal of Acoustical Society of Korea, Vol.15, No.E3, 1996.

- **Chang-Bong Cho**

Chang Bong Cho was born in Korea in 1973. He received the B.E. degree from Kunsan National University and the M.S. degree from Seoul National University, Korea, in 1997 and 2001 respectively. Since 2003, he has been with Naval System Development Center in Agency for Defense Development, as a researcher. He is interested in the physical environment of the East Sea.

- **Sang-Kyu Han**

Sang-Kyu Han was born in Korea in 1965. He received the B.E., the M.S. and Ph.D. degrees from Hanyang University, Korea, in 1988, 1990 and 1997 respectively. He worked as a Research Scientist for Naval Postgraduate School in USA from 1999 to 2000. Since 2001, he has been with STX RadarSys Co., Ltd. in Korea as a Project Manager. His research interests are in the area of acoustic modeling and sonar signal processing.