Autonomous Wide Aperture Cluster for Surveillance (AWACS)

John Joseph
Department of Oceanography
Ocean Acoustics Laboratory
Naval Postgraduate School
Monterey, CA 93943
Phone: (831) 656-7994 fax: (831) 656-7970 email: jejoseph@nps.edu

Grant Number: N0001408WR20133

LONG-TERM GOAL

A five year effort led by the Ocean Acoustical Services and Instrumentation Systems (OASIS), Inc., AWACS is a multi-disciplined team effort comprised of a number of collaborating academic and scientific institutions, fleet operation support communities and manufacturers of ocean sensors and platforms. The long-term goal of the AWACS program has been to develop an undersea surveillance system consisting of a cluster of autonomous vehicles for use in complex littoral shallow water environments. The vehicles will be capable of sampling oceanographic, bottom and acoustic features in a local environment and, as a networked cluster, will collectively feed adaptive sampling and search algorithms leading to improved detection, classification and localization (DCL) of quiet targets.

The Naval Postgraduate School (NPS) contribution has been focused on development, implementation and validation of a quasi-real time environment, transmission and ambient noise estimation system that will assimilate data retrieved by a cluster of vehicles to recursively improve estimates of ocean, bottom and acoustic parameters with reduced error variances in the volume of interest, thereby improving probability of detection while reducing false alarm rates.

OBJECTIVES

A number of specific technical objectives have been identified to support the long-term AWACS goal stated above:

- Explore limits and capabilities of REMUS Towed and Hull-Mounted Array Systems to detect, classify and localize quiet targets

- Evaluate current and develop new methods and capabilities of adaptive sampling, adaptive search and data assimilation techniques to optimize ocean, acoustic and geoacoustic estimations

- Develop mobile sources for in-situ transmission loss measurements and DCL testing

- Explore the limits of signal processing with emphasis on dynamic array control using a cluster of REMUS vehicles for adaptive DCL of quiet targets based on improving probability of detection and reduced false alarm rate

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
30 SEP 2008	**Annual**	**00-00-2008 to 00-00-2008**

4. TITLE AND SUBTITLE **Autonomous Wide Aperture Cluster For Surveillance (AWACS)**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Postgraduate School,Ocean Acoustics Laboratory,Department of Oceanography,Monterey,CA,93943**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
code 1 only

14. ABSTRACT
A five year effort led by the Ocean Acoustical Services and Instrumentation Systems (OASIS), Inc., AWACS is a multi-disciplined team effort comprised of a number of collaborating academic and scientific institutions, fleet operation support communities and manufacturers of ocean sensors and platforms. The long-term goal of the AWACS program has been to develop an undersea surveillance system consisting of a cluster of autonomous vehicles for use in complex littoral shallow water environments. The vehicles will be capable of sampling oceanographic, bottom and acoustic features in a local environment and, as a networked cluster, will collectively feed adaptive sampling and search algorithms leading to improved detection, classification and localization (DCL) of quiet targets.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**7**	

- Explore and develop vehicle command and control methods based on adaptive environmental and acoustic sensing, and models of vehicle and cluster behavior

The NPS effort to develop an environmental and acoustic estimation system support all the objectives above with particular emphasis on applying adaptive sampling and search techniques based on local ocean, acoustic and geoacoustic conditions to improve probability of detection of quiet targets.

APPROACH

This multi-year program has been based on an extensive build-test-build approach in which AWACS components and algorithms are designed, built, tested and evaluated; then redesigned and rebuilt based on test results. Hypotheses have been formulated, tested and revised or reformulated based on models and measurements. Over time, components and algorithms are incrementally integrated with continued testing and adjustments made as the entire system matures.

NPS efforts for 2008 were focused primarily on further improvements and retesting of algorithms for its environment and acoustic estimation system in an "at-sea" environment. The at-sea tests were conducted during the New Shelf Break Test 2008 (NEST-08) in late May and early June in the New England Bight south of Rhode Island. It was the same geographic location as the NEST-07 test conducted in late May 2007 which has provided an opportunity to make direct comparisons between the two data sets.

The overall design of the estimation system is shown in Figure 1, with testing events shown on the left hand side of the figure corresponding to the approximate progress of algorithm development. A pair of coupled inversion Bayesian algorithms is used for the environment and transmission loss (TL) estimation. One algorithm recursively updates the ocean sound speeds using the temperature and salinity data collected through multiple sensors in near real time. The other, after ingesting the updated ocean sound speeds, upgrades the geo-acoustic parameters, including sediment compressional speed and attenuation, using the TL data. The first algorithm entails linear objective analysis. The second employs matched field processing involving an acoustic propagation model. Guided by error covariance updates for the environment in a Monte Carlo framework, a sound propagation model is used to construct TL estimates and associated error variances along selected tracks of interest following each data download. In 2008, incorporation of ambient noise (AN) modeling into the system has commenced with the goal of using directional ambient noise (AN) data from the field to update noise estimates and associated error variances. Available historical oceanographic, geologic, geoacoustic and noise data will be pre-analyzed to capture the initial uncertainties.

The estimation system runs on a desktop computer that can easily be situated aboard a research vessel where the ocean and acoustic data from autonomous underwater vehicles and other available ocean sensors such as CTD and XBT casts are retrieved. Experience from three experiments (SW06, NEST-07 and NEST-08) has shown data assimilation with this system can be performed multiple times daily. In the event recently collected data should become available after an update cycle had been run, it is easy to return the estimation system to a previous state with all prior "data history" included in order to include this new information and provide an improved depiction of the environment.

NPS, in partnership with MIT and OASIS, will also continue to develop a more sophisticated ESSE-based, fully coupled ocean and acoustic data assimilation algorithm involving the addition of a local numerical ocean model. The goal will be to exercise this coupled approach as close to real-time as possible. We envision daily, coupled data assimilation and ESSE ocean and TL forecasts by the end of CY08.

NPS, OASIS and MIT will develop and demonstrate new environmental search tools to guide spatial and temporal sampling procedures for the REMUS-based sensors in complex, dynamic littoral areas. The ultimate goal is to characterize and forecast the environment to such a level of accuracy and space-time resolution that acoustic predictions and DCL system performance of the REMUS towed array will optimize detection and minimize false-alarm rate. This approach will include pre-test optimal environmental search plans developed with a global optimization algorithm (Genetic Algorithm)

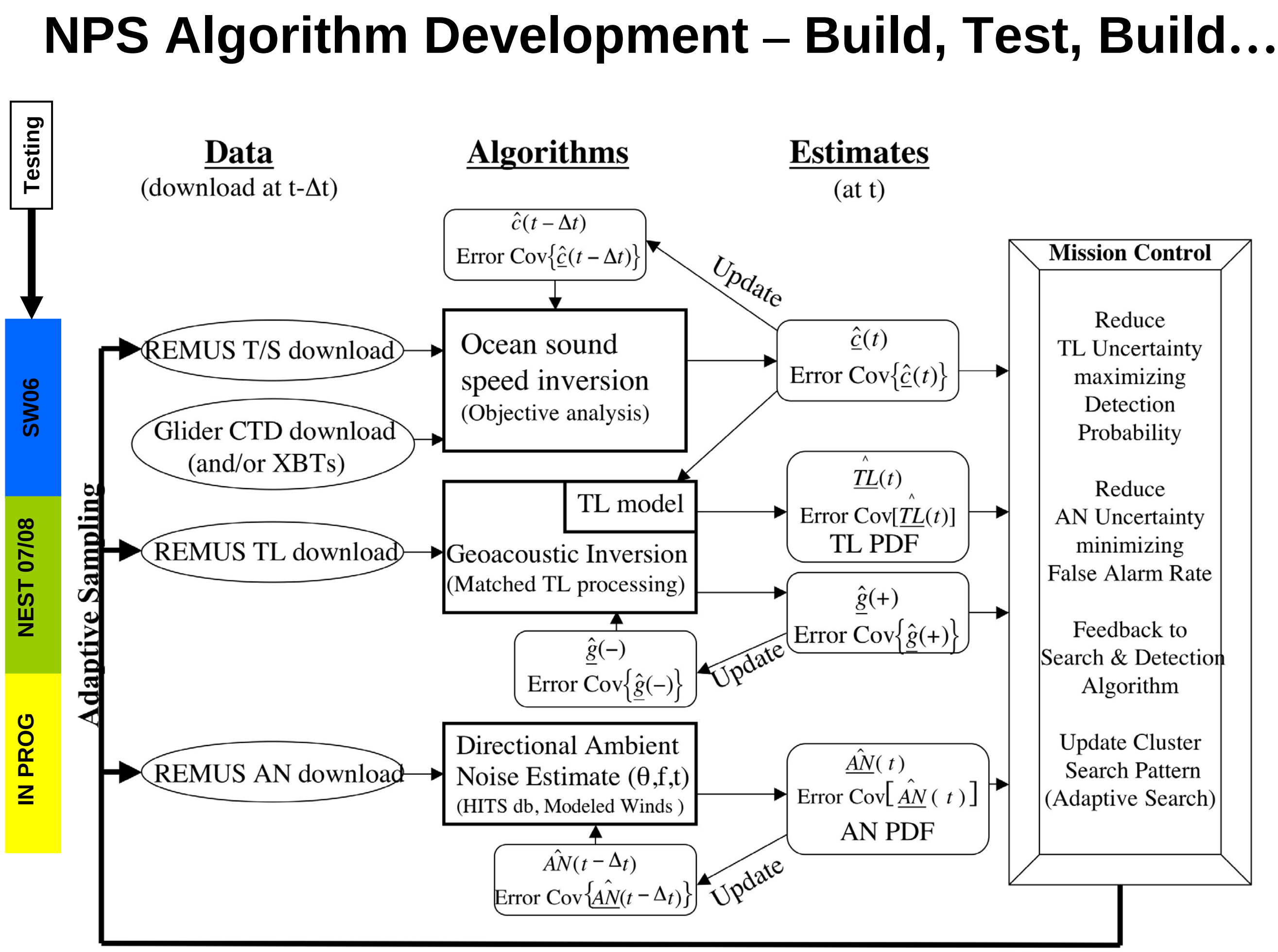

Figure 1. Block diagram of a quasi real-time environment and acoustic estimation system that transfers uncertainty information to mission planning. In the diagram, $\hat{c}$, $\hat{g}$, $\hat{TL}$ and $\hat{AN}$ denote estimates of ocean sound speed, geo-acoustic parameters, transmission loss and ambient noise, respectively. General progress of testing during at-sea experiments are shown at left with initial objective analysis and acoustic predictions tested during Shallow Water 2006. Improved versions were retested during NEST-07 and NEST-08, with geoacoustic models added to the system. Efforts to include ambient noise estimates have recently commenced in late FY08.

applied to the environmental data available. Uncertainty maps, coupled with the local bathymetry and dynamic ocean models, will be used to develop new optimal sampling and search approaches.

WORK COMPLETED

Through collaboration in other ONR-sponsored experiments, the AWACS team has leveraged opportunities to test progress of its developing systems and algorithms while contributing to the overall goals of the experiments. In the fall of 2007, a new 6.3 program (PLUS-INP) was announced that is expected to build upon the efforts of 6.1 programs such as AWACS and PLUS-net. With many of the AWACS team members present at the PLUS-INP kickoff meeting held in Orlando in November, the meeting also served as an informal planning meeting for the May NEST-08 at-sea test. In May 2008, NPS results from AWACS were included in the brief for the PLUS-INP Environmental Sensing and Adaptation team.

A significant event for this project was the at-sea testing conducted during NEST-08 which took place 28 May -06 Jun 2008 aboard RV HUGH R SHARP. This test took place in the same location as the NEST-07 test which was conducted one year earlier in late May 2007. While it might be expected that the oceanographic conditions would be similar, there were significant differences. During NEST-08, the ocean conditions were more dynamic with the foot of the front pushing farther onto the shelf than what was seen in NEST-07. As a result, the sound speed minimum was found generally near 25m throughout NEST-08 whereas it was typically found near 45m in NEST-07, which is close to the climatological mean. These differences demonstrate the importance of knowing the physical environment in near real time to accurately characterize the acoustic environment in order to optimize the effectiveness of passive receivers.

As a result of the NEST-07 test, the algorithms used in NEST-08 to generate TL predictions were modified to have more utility for mission planners. With mobile sources being used in the at-sea tests, it made sense to depict directional TL predictions around passive receiver locations for various source/receiver depth combinations to give mission planners a complete view of the acoustic environment. In order to generate a horizontal depiction around a fixed receiver location, TL predictions were made along multiple radials, typically 5-15 degrees apart. Using the Principle of Reciprocity, TL for a fixed receiver and a moving source (at a fixed depth) is calculated along each radial with a single TL model run, saving significant calculation time. The information is then merged into a 360-degree view of TL out to a user-selected range for a given source and receiver combination. Figures 2 and 3 show predicted directional TL fields examples for source/receiver combinations of 20m/25m and 61m/25m for a receiver located at 40.25N 71.00W for 1200Z on 31-May-2008 during NEST-08. The process is repeated for as many receiver depth and/or locations as needed, giving a 3D characterization of the TL field.

Several geoacoustic models were tested as part of the estimation system in NEST-07. Of these, the model based on the Evans and Carey IEEE paper (1998) proved most promising when comparing measured versus predicted TL taken during the test. A JASA Express Letter by Dediu, Siegmann and Carey (July 2007) describes an updated version of the Evan/Carey work based on data from SW06. A geoacoustic model based on this work has been incorporated into the NPS estimation system. By applying inversion methods, it is expected that a range dependent geoacoustic model can be based on differences in measured versus predicted TL.

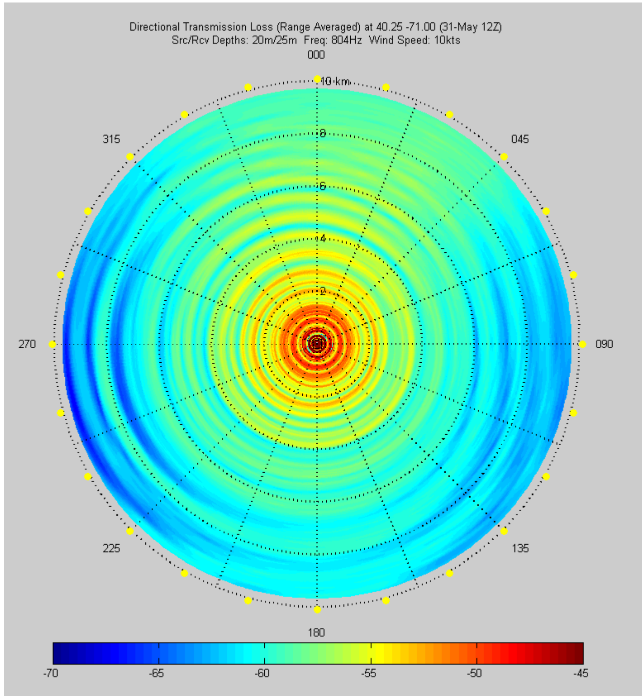

Figure 2. Example of directional transmission loss for a fixed receiver at 40.25N 71.00W and 25m depth with a source at 20m depth on 31-May-2008 at 1200Z taken from NEST-08. The source and receiver are near the sound channel axis.

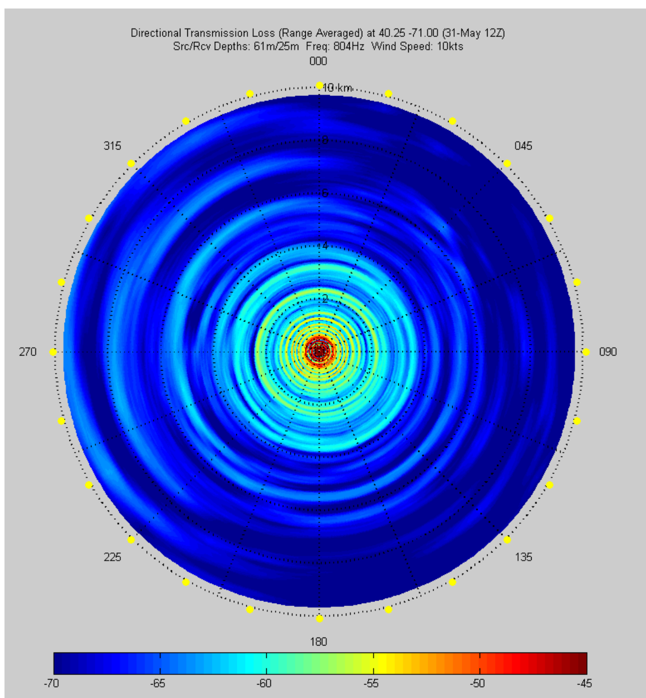

Figure 3. Example of directional transmission loss for a fixed receiver at 40.25N 71.00W and 25m depth with a source at 61m depth on 31-May-2008 at 1200Z taken from NEST-08. The receiver is near the sound channel axis while the source is well below it.

A new 64-bit Windows Vista PC computer was purchased for use in the NEST-08 experiments. The original equipment was purchased as a 32-bit Windows XP system, and then upgraded to 64-bit Vista OS when it became available in order to take advantage of available RAM. The upgrade greatly improved overall performance, but “slowness” problems occasionally surfaced with the system that seem related to the operating system, but challenging to diagnose. With new multi-core platforms designed for Windows Vista 64-bit OS becoming common place, a new PC was purchased to increase calculation speed and provide better grid resolution as needed. The system remains very portable fitting into a single 2.5ft x 2.5ft x 3ft shipping case and relatively inexpensive using readily available commercial off the shelf components. The new system performed flawlessly during NEST-08.

Further improvement was made in the interface between components of the system. The algorithms provide more options on what types of products can be generated. The new directional TL products require many more acoustic model cycles, however this comes at a relatively small price at this stage as the NSPE RAM model runs quickly on this PC. Eventually, this may become an issue as the number of locations and receiver depths increase since the entire TL prediction process must be repeated for each of these locations and depths. For a large area, this will likely exceed the capacity of a single PC.

The effort to incorporate directional noise prediction is just beginning. A copy of the Dynamic Ambient Noise Model was requested and received from the Naval Oceanographic Office. Its performance is being evaluated. It is intended that DANM will be used to make first-guess fields for directional ambient noise and in situ noise measurements and other information about noise sources will be incorporated to provide more accurate directional noise fields. These fields can be used in conjunction with directional TL predictions to provide guidance for optimal acoustic performance for adaptive search purposes.

The fundamental approach to development of the system remains on track. The current focus areas for future work are: 1) incorporating an ocean model to eliminate the need for climatology as the initialization field, 2) complete the geoacoustic inversion effort to generate a range-dependent geoacoustic model based on differences in measured and predicted TL, 3) complete directional ambient noise estimations that are updated based on measured information and 4) make comparisons of measured vs predicted TL based on data collected during SW06, NEST-07 and NEST-08 (where possible) using the latest improvements to generate TL predictions.

Improvements to the estimation system are intended to enhance and maximize flexibility, speed of operation and automation. From a few user-provided inputs, the system generates a 3D geo-referenced grid that can be adjusted in orientation, location and resolution based on situational needs. The system is designed to support operational areas up to 30km x 30km and depths to 120m. Horizontal resolution is typically 2-4 km and vertical resolution is typically around 5 m. Data are assimilated on a 1-hourly basis assimilating data +/- 30 min hours around the stated run time.

RESULTS

The NPS effort in 2008 produced many practical improvements and improved products over the previous years efforts. At-sea testing during NEST-08 demonstrated the value of these improvements as planning tools. The system is very robust and remains portable, making it well suited for its sea-based intended purpose. The system is designed to handle data generated from a variety of ocean sensors and efficiently extracts well resolved ocean structure and bathymetry for input to TL predictions. TL predictions compare well to measured TL, but sensitivities need further investigation. Inclusion of near real time feedback to the geoacoustic model and adding an ambient noise prediction capability are in progress. Work will also continue to improve computational efficiency and automation to improve support for adaptive sampling and search decisions.

IMPACT/APPLICATIONS

An autonomous undersea surveillance system can provide persistent, large area coverage in complex, and perhaps denied environments. The AWACS concept allows "tuning" of the system in near real time to provide optimal system performance against quiet targets. Using a build-test-build development strategy allows hand-on experience with new autonomous systems; regular shake-down of system components and methodologies, and identification and fixing of potential problems as they develop. This assures AWACS matures into a robust system with proven applicability in supporting the Navy's vision for a rapid detect-to-engage capability utilizing a networked, distributed force.

RELATED PROJECTS

The AWACS team was a major participant in the Shallow Water Experiment 2006, which also involved the Littoral Environment Acoustic Research (LEAR) and the Non-Linear Internal Wave Initiative (NLIWI) groups. In 2008 and 2009, the NPS effort in AWACS will be leveraged to help development of a similar effort the ONR-sponsored PLUS-INP project. Many of the initial approaches and hypotheses will be based on lessons learned from the Capturing Uncertainty DRI in which many of the AWACS team participated.