Improving the Water Column Representation

Paul W. Maassel
VisiTech, Ltd
3107 N. 18th Street
Arlington, VA 22201

Richard Schaffer
Sean Cullen
Gerry Stueve
Lockheed Martin Information Systems
37 North Ave.
Burlington, MA 01803

Chris Scannell
Joseph Collins
Naval Research Laboratory
Code 5580
4555 Overlook Ave., SW
Washington, DC 20375

Nicholas Kim
HydroQual, Inc.
1 Lethbridge Plaza
Mahwah, NJ 07430

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ABSTRACT: *The representation of the undersea environment has often been ignored, or at best static, or pre-calculated in distributed simulation. This paper details the efforts of a multidisciplinary team who have implemented a dynamic ocean model and sensor response in the Joint Semi-Automated Forces (JSAF) architecture. A variant of the Princeton Ocean Model was run off the North Carolina coast to provide the dynamic environment. The Shallow Water Acoustic Toolset (PC-SWAT) that modeled the AQS-14 sonar solved the sonar equation. A CORBA interface to JSAF was developed to replace the pre-calculated look-up tables with real-time sensor information. This system was demonstrated in April 2000 at the Naval Research laboratory and will be used in the Naval War College's Fleet Battle Experiment-Hotel in August 2000.*

Background

Semi-Automated Forces (SAF) heritage with Army tank training systems has led to a long evolution of improvements to the environmental models used by land platforms. Soil trafficability, urban areas, man-made and natural objects can all be represented in state of the art SAF systems. One of the latest improvements is dynamic terrain that allows for deformations to the terrain skin due to run-time simulate events.. The percentage of terrain that changes during a simulation is likely a very small percentage of the entire terrain skin.

Aviation has been played in SAF for nearly as long as the land systems. The atmosphere has usually been represented by a homogeneous clear sky that allows for optimal propagation of sensors. The technology to bring the atmospheric environment into the SAF architecture was developed in the Synthetic Theater of War (STOW) Advanced Concept Technology Demonstration (ACTD). The Total Atmospheric and Oceanographic Server (TAOS) was developed as a means to serve the dynamic environment to the distributed SAF stations and was used to provide dynamic atmospheric conditions based on pre-computed, time-stamped data sets. The grid structure used to deliver the atmosphere provided variably spaced vertical layers; however, the lateral dimensions in all the layers were homogeneous, rectilinear boxes.

SAF development has often sidestepped dynamic acoustic interactions for maritime systems. Unlike Army, Navy came late to the SAF community; thus, demands for a complete maritime environment were not made or met. Further, Navy trains in classified mode, making development and testing more difficult. Lastly, the undersea environment, like the atmosphere, is highly dynamic, particularly in coastal regions, where uniform, rectilinear grids are not adequate for representing tactically significant parameters. Many of these reasons for not implementing a water column model for acoustic sensors in SAF are being eliminated through the support of the Naval Research Laboratory (NRL) and the Office of Naval Research (ONR). The Ocean, Atmosphere, and Space Department has taken the lead in funding research efforts to answer the question of how much environment is enough.

The NRL, code 5580, Advanced Information Technology Branch has led a team of ocean modelers (HydroQual), acousticians (Scientific Solutions, Inc.), SAF developers (Lockheed Martin Information Systems), and systems engineers (VisiTech, Ltd.) in researching how much environmental information is needed to model acoustic sensors in the littoral water column. The methodology they developed is directly applicable to environmental domains other than ocean. The fundamental process begins with using well validated models to develop a finely resolved environment. That environment is tested for decorrelation times and lengths. Models that represent the physical effects the control system behavior are then run through this synthetic natural environment. These results are also tested for decorrelation time and lengths. This second set of decorrelations provides the tactically relevant temporal and spatial scales that must be represented in the simulatoin.

This team analyzed the temporal and spatial decorrelation times in the New York Bight and presented this work at the Fall Simulation Interoperability Workshop (SIW). The next steps in the program were to construct an ocean model for the Onslow Bay area off Camp LeJeune, NC, extended the JSAF application to work with an acoustic sensor service, and integrated an existing shallow water acoustic model with JSAF. The remainder of the paper presents how these steps were taken and reports results from our work thus far.

System Components

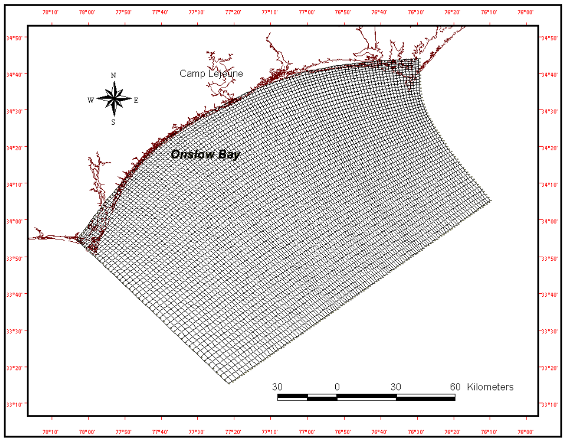

Figure 1.1. The Curvilinear Grid of Onslow Bay off Camp Lejeune, NC.

Modeling Onslow Bay

Onslow Bay bathymetry is represented in the Camp LeJeune database generated by the Joint Countermine Operational Simulation (JCOS) ACTD. This Compact Terrain Database (CTDB) served as the starting point for our Ocean Modeling at HydroQual, Inc.

The Camp LeJeune database did not include bottom type attribution that describes the sea floor. Examples of attributions are Fine Sand, Coarse Sand, Sandy Gravel, Gravelly Sand, Mud, etc. Bottom attribution is important for Mine hunting sonar frequencies, as sonar system performance is critically sensitive to backscatter, which varies with bottom type. For example, a rocky bottom is more difficult to hunt than a sandy one. Any simulation of mine or countermine operations in coastal waters must include bottom type. In operational planning, search areas and asset allocations are often based primarily on what is known about the characteristics of the bottom For the April demonstration a homogeneous bottom type was used. This limited the team's ability to examine the PCSWAT response to bottom attribution changes, but allowed an early test of the other portions of the dynamic water column environment. In Fleet Battle Experiment-Hotel[1] (FBE-H), the database will include appropriate bottom attribution in the bathymetry in the MCM area of operations.

An orthogonal curvilinear grid[2] was developed for the Onslow Bay area (Figure 1.1). This type of grid structure is typically used by hydrodynamicists as a means of providing the highest resolution only where it is needed. The grid has 50 cells offshore direction and 120 cells along shore direction. The horizontal grid spacing ranges from 1 km inshore to 2.5 km offshore locations. The model domain covers approximately 100 by 150 km area. Vertical resolution is accomplished by employing equally spaced 11 sigma levels so that the model adequately resolves the important physical processes in the vertical plane. These 11 sigma levels represent equal fractions of water depth for each grid so that deep water and shallow water has same number of vertical layers. A numerical ocean model, Estuarine, Coastal, and Ocean Model (ECOM), was run to produce three-dimensional time-varying ocean environment. The model requires initialization data and updated forcing data to run long periods of time. At the Open ocean boundary, forcing data are extractred from NOAA's Coastal Ocean Forecast System (COFS) archives. NOAA's COFS archives provide hourly sea surface elevations and daily horizonal and vertical temperature/salinity information along the Onslow Bay model boundaries. Atmospheric forcing data such as spatially varying wind speed and direction, air temperature, barometric pressure, and relative humidity are provided by NOAA's National Environmental Center for Modeling (NCEP) archives. NCEP's meteorological model, Eta, archived these parameters for every three hours. Figure 1.2 shows the inputs and outputs from the ECOM model.

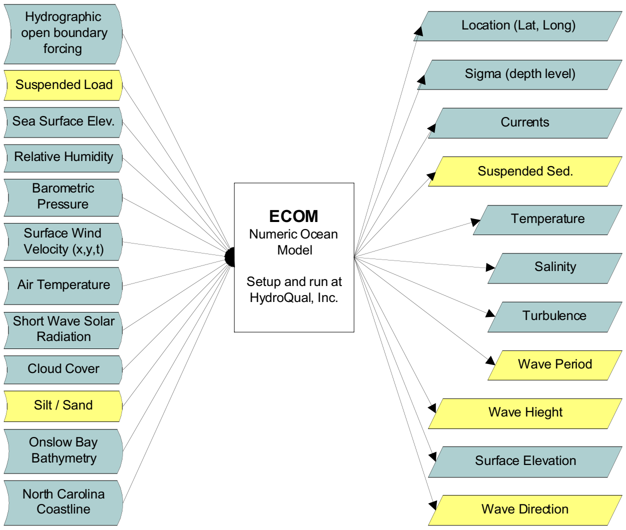

Figure 1.2. The inputs and outputs of the ECOM Ocean Model. Yellow boxes indicate data that were not used for this event.

The ECOM model was run for sixty days (simulation time) from 1 Aug 1997. Some of the ECOM forcing data and output data are available on the internet[3]. The model results were archived in netCDF format to be accessed by JSAF. This self-describing, platform independent data format is widely used in numerical computation. The ECOM output gave eleven depth-levels for each point in the curvilinear grid. The output consists of hourly sea surface elevations and sets of three dimensional data including horizontal and vertical currents, temperature, salinity, and turbulent kinetic energy. Without appropriate bottom attribution, the suspended sediment would not be used in the PCSWAT call and was therefore not used in the environment file.

JSAF uses wave height, wave period, and wave direction to affect the kinematics of maritime platforms; however, the side scan sonar systems are towed bodies with control systems that make them relatively insensitive to these parameters. For this reasons, these sea surface parameters were not included in the environmental data file

PC-SWAT

The acoustic response of the side scan sonar was computed using the Personal Computer Shallow Water Acoustic Toolset (PCSWAT), developed by the Naval Surface Warfare Center – Panama City, Coastal Systems Station (CSS). For a give set of input data, it delivers the response of the side scan sonar to mines and mine-like objects in terms of a signal-to-noise ratio The PCSWAT Server is a multithreaded Windows® application for interfacing JSAF clients with the PCSWAT application. Data are sent to and received from the PCSWAT server by way of MICO, a Gnu Public Licensed implementation CORBA.

Using MICO, the server listens on an available port, typically 8888. The client must know ahead of time what the name/IP address of the server is and what port the server is listening on. After establishing a connection to the server, the client has four functions by which to communicate with the server. These functions are as follows:

```
void        returnSNR(
      in    SonarProjector     sonProj,
      in    SonarReceiver       sonRec,
      in    Doppler              dpplr,
      in    SonarEnvironment    snrEnv,
      in    SVPdata            svpdata,
      in    Target                 tgt,
      in    Bottom                 btm,
      out   SNR                result);


void        requestSNR(
      in    SonarProjector     sonProj,
      in    SonarReceiver       sonRec,
      in    Doppler              dpplr,
```

```
      in   SonarEnvironment   snrEnv,
      in   SVPdata           svpdata,
      in   Target                tgt,
      in   Bottom                btm,
      out  long          request_id);

long pollSNR(
      in   long          request_id);

void getSNR(
      in   long           request_id,
      out  SNR                result);
```

SNR is the signal-to-noise ratio, a key input to a detection model to determine if a mine is detectable. The method returnSNR allows the client to encapsulate and transmit all the needed parameters describing the attributes of the sonar, the environment, the sound velocity profile of the water, the bottom type, and the target's range and bearing. The server queues up the call and executes the various calls from clients on a first come, first served basis. The SNR is returned as a result. This is a blocking call for the client.

CORBA Dynamic Invocation Interface (DII) services support the ability to execute this method as a deferred synchronous call, and provides for polling and a blocking call to return the results. We found, however, that with the MICO implementation of these services, polling never returned a positive result, even when the server had clearly completed the SNR computation. A non-blocking server was necessary because of the JSAF requirement to maintain at least a two hertz rate for several behaviors and the fact that the time involved in calculating a signal to noise ratio can take approximately one second. Multiple clients simultaneously querying the server could result in unacceptable delays for the clients.

The methods requestSNR, pollSNR, and getSNR provide an alternative interface for non-blocking service calls. The method requestSNR provides the server with all of the same input information as returnSNR does. After the server receives this information it is placed in a queue and the function returns immediately providing the client a handle to the request.

The method pollSNR allows the client to check on the status of its request. Aboolean value is returned immediately that lets the client know if its request has been processed.

The method getSNR is a blocking call that returns the range and signal to noise ratio based on the parameters passed by requestSNR. If the request has not yet been processed it will wait until the server gets to that request holding the client's thread of execution hostage. Consequently, this is why it is important to first check the status of the request using pollSNR first.

The server creates a worker thread upon creation that continuously monitors the request queue for any inputs. When an input is found the server removes the request from the queue and places it into an input file for the PCSWATM.EXE program from Coastal Systems Station. PCSWATM.EXE is executed and that generates an output file. The output file is parsed for the desired range's signal to noise ratio and that information is placed into a result queue. A Mutex is used when operations are performed on the queues to prevent errors from simultaneous data access.

Since all the parameters for a request are stored individually several different clients simulating different types of sonars can all request signal to noise ratios at the same time without reconfiguring the server. MICO can handle multiple calls from several different clients at the same time, and since a handle is used for polling and retrieval of data the responsibility for retrieving a request is placed on the client.

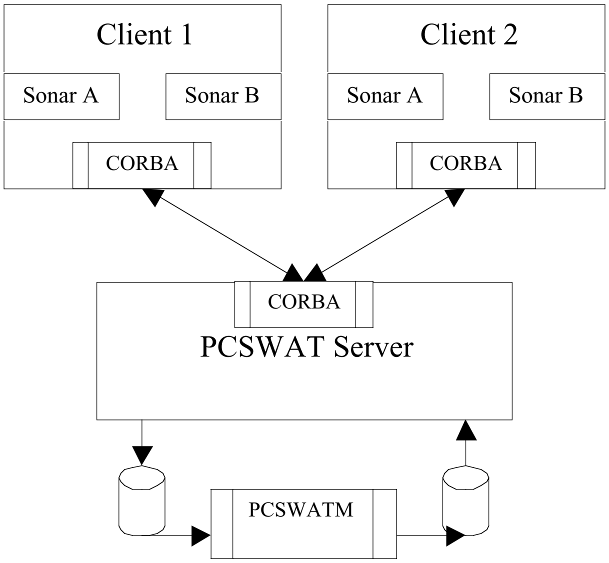

Figure 2 The PC-SWAT acoustic sensor server

A simplified PCSWAT server has been tested with up to twenty test clients making a request and then waiting for a response. The simplified server didn’t actually invoke the PCSWATM software but instead returned a default range and signal to noise ratio. This allowed the server to rapidly receive and respond to multiple clients and ensure that no deadlock conditions existed between the two threads. The PCSWAT server performed well with this free implementation of MICO proving it to be a viable solution for cross platform communication.

JSAF

When JCOS was originally developed, it used sets of look-up tables to determine the performance of mines and countermine systems. Because of the cost of computing large sets of these tables for differing environmental conditions, the simulation typically used only one set of tables for a single execution. Thus there was no change in performance with different locations in the operational space or for the duration of the operation. To permit the simulation to respond to the temporal and spatial variability that characterizes the littoral regions, it was desirable to replace the tables with a data server and an effects server. PCSWAT was thus developed into the effects server.. If no PC-SWAT model is available the look-up table is used for the sonar sensor. Only the AQS-14 sonar is currently modeled in the team's version PC-SWAT.

The client was integrated into JSAF 4.9 with a library called libpcswat. This library takes as parameters both the name of the server machine and the port that it is running on. MICO is initialized and libpcswat exposes a function for requesting a signal to noise ratio. The SNR request function is passed a callback that is invoked upon discovery of the completed request. Libpcswat is periodically ticked and during this time a call to the PCSWAT server is made to check on the status of any requests made. If a request is ready, getSNR is called to retrieve the data and that is then passed on to the callback function. Checks are also made before the callback is invoked to ensure the vehicle that made the request is still alive.

TAOS

The role of data server was filled by TAOS. TAOS 1.2[4] currently inputs data in two primary formats both developed by the World Meteorological Organization[5]: Gridded Binary data (GRIB) and Binary Universal Form for the Representation of meteorological data (BUFR). A large number of historical environmental datasets is available in these formats through the services of the Master Environmental Library (Mel), a data broker developed under sponsorship of the Defense Modeling and Simulation Office (DMSO[6].

The output of the HydroQual ECOM model could have been translated into BUFR format (essentially a list of locations with the associated parameter values at those locations) to be ingested into a TAOS environmental database. While BUFR is an easy way to read data, there are problems associated in searching the data efficiently. Gridded data is readily searched; however, GRIB format could assumes a regular, rectilinear grid and the hydrodynamic data is produced on an orthologonal curvilinear grid.. Thus, each readily available format presented problems.

We chose, instead, to extend TAOS so that it could read the non-uniform grid, but search the data efficiently., TAOS reads the grid as though it were in the usual, uniform format. At the same time the data required to transform the locations stored in TAOS to the appropriate locations on the orthogonal curvilinear grid was stored in a file that was pre-distributed as static data to each SAF station. TAOS would receive and process the information as though it were in the known GRIB format. SAF stations would received the data from TAOS, but ignore the location, transforming it to the correct position using the information in the pre-distributed file.

This technique was chosen for a few reasons. Most importantly, the orthogonal curvilinear grid developed by HydroQual is customized for the particular region of interest. Secondly, the environmental information is best represented on a grid, as opposed to a series of measurements made at arbitrary locations. On a grid, algorithms can be used, based on parameter values at neighboring grid cells, to interpolate over the various environmental parameters. Another a gridded representation is that many of the algorithms and their underlying data structures had already been developed for grids during unit testing of the SAF stations.

The main advantage of this approach over pre-distributing the entire set of ECOM outputs as a flat file is that the ECOM model can be run “in-stride” with the simulation. When run in-stride, the ECOM model is driven by real-time fleet weather forecasts. In this way the outputs of the ECOM model can be simultaneously distributed to the SAF stations as a “now-cast” representation of the current water column environment.

These extensions to TAOS have been completed and are being tested for use in FBE-H in August 2000.

Results

The system components were brought together in April, 2000, at the Naval Research Laboratory for a system integration test. A number of problems were discovered with the system components, but the overall process and concept proved sound.

The output of the ECOM model was imported to the AVS visualization package at the NRL VR-Laboratory[7]. The netCDF file was transformed into the appropriate AVS format and display in the VR-Lab's GROTTO using 3D computer graphics. A selection of these images may be found on the project's website.[8]

The PC-SWAT model exhibited some instability, returning nonsense values that were traced back to a bug in the SWAT architecture. This has been corrected for the FBE-H use.

The integration test was hampered the fact that the terrain database on which the SAF entites move did not have ocean bottom type attributes. There were not sufficient resources to develop and deploy bottom attribution features for the Camp Jejune database for this integration. A homogenous bottom type was assumed for the experiment. A bottom attribution feature is scheduled to be created for the area off Panama City, FL, in time for the August exercises..

A set of comparisons were performed between versions of the software that used the original data tables and the newly developed data and effects servers. Performance of the AQS-14 responded appropriately to the dynamic environment introduced by the servers. Further tests and comparison with live data will be needed to validate the model's performance.

The use of servers is particularly valuable when trying to maintain consistency of system performance across a group of federated sensor models. Because TAOS can handle atmospheric and water column data, the coordinated environmental conditions can be served across the federation. By providing acoustic servers, multiple sensors can interpret the served data in a consistent manner by polling the same server as demonstrated. The TAOS server provides a means to distribute data during an exercise once it is properly configured. The PC-SWAT application provides an appropriate solution for serving sensor performance to multiple sensors in the scenarios tested to this point. Separating the physics of the environment from the sensor physics is helping us add additional sensors rapidly. Because PCSWAT provides the difficult acoustic characterization, the sensor model needs only the parameters required to poll PCSWAT.

Epilogue

A similar process will be used in the Navy Warfare Development Command's (NWDC) Fleet Battle Experiment-Hotel (FBE-H) in August. Here, TAOS servers will distribute the environment to the JSAF applications that can use the environmental information generated by the ONR work. FBE-H will take place in the Gulf of Mexico, not Camp LeJeune, requiring a new terrain database to be generated with appropriate bathymetry and bottom attribution for the PC-SWAT served sonar models.

Future work will extend the investigation of "how much is enough" environmental information to other sensors, systems, and locations. We are also examining how the data required for characterizing the natural environment can be made available through operational systems in the fleet. There is considerable overlap in what is needed for tactical systems and for JSAF simulations. If consistency in data and performance specification can be developed across tactical decision systems and simulations, all maritime systems will benefit.

References

PAUL W. MAASSEL is a Vice President of VisiTech, Ltd. in Arlington, VA. He provides systems engineering services to the Department of the Navy in the Washington, DC area

RICHARD SCHAFFER is a principle investigator with Lockheed-Martin Information Systems in Burlington, MA

SEAN CULLEN is a computer scientist with Lockheed-Martin Information Systems in Burlington, MA

GERRY STUEVE is a computer scientist with Lockheed-Martin Information Systems in Washington, DC.

JOSEPH COLLINS is a research physicist with the Naval Research Laboratory in Washington, DC.

CHRISTOPHER SCANNELL received his BS in physics at Georgetown University and his MS in Electrical Engineering from Johns Hopkins University. He has worked at the Naval Research Laboratory first in the acoustics division where he participated in experiments involving ship and airplane deployed sonar devices and later in the Information Technology Division. There he has researched parallel processing paradigms, virtual reality applications and distributed simulation applications.

NICHOLAS KIM is an ocean modeler at HydroQual, Inc.

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[1] Fleet Battle Experiments are conducted by the Maritime Battle Center located aboard the Naval War College, Newport, RI. http://www.nwc.navy.mil

[2] Use of Orthogonal Curvilinear Grids for the Representation of the Littoral Ocean Environment, Blumberg et.al. SIW Spring 200 Paper No. 00S-SIW-118

[3] http://www.ait.nrl.navy.mil/ONRenvironment/

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[5] http:/www.wmo.ch/

[6] http://mel.dmso.mil/

[7] http://www.ait.nrl.navy.mil/vrlab

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[8] ref. Note #3