APPLICATIONS MODELING--STATUS AND TRENDS

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Abstract

Numerical models support surveillance/tactical sonar requirements for acoustic information. Selection of models is based on their physics, runtime, and ability to interface with the required environmental inputs in the form of data bases. To effectively interface, a system known as the Environmental Acoustic Interactive Data System (EAIDS) is under development. EAIDS uses color graphics to show data, provides for editing, and interfaces to models selected from another system, the NORDA Acoustic Modeling Operating System (NAMOS). NAMOS interactively produces a batch job runstream on models to predict propagation loss, ambient noise, and array beamformer output. Characteristics of these research application models are detailed, as are their functions in the underwater acoustics community. Status and trends are identified. Finally, future needs in environmental data base and acoustic model development are presented including data base standardization, fluctuations, modeling, and confidence limit determination.

1. Introduction

Between the realms of pure research in underwater acoustics and what we shall term pure application, lies the area of applications research. In this paper, we review the status of applications research and attempt to perceive trends and future requirements. Before doing so, however, we shall define what is meant here by pure research, pure applications, and applications research in underwater acoustics by delineating the functions, providing examples of computer models, and describing the characteristics associated with these three terms.

Pure research models attempt to describe acoustic propagation through the use of sophisticated numerical techniques. These models are typically developed and run by research scientists. The various physical mechanisms significantly affecting acoustic propagation are incorporated in the model and often require environmental inputs far in excess of those ordinarily available, particularly with regard to boundary characteristics. Also, the availability of environmental parameters are often limited in terms of geographic coverage. One example of a pure research model is the Parabolic Equation propagation loss model, which uses a variety of numerical

algorithms to solve the parabolic approximation to the wave equation in an environment that varies with both depth and range, including the effects of multi-layered ocean bottoms which support both shear and compressional waves. A specific example of a research ambient noise model is one developed at Bell Telephone Laboratories [1,2], which employs an analytic approach to predict shipping noise for a horizontal array beam at low (i.e., surveillance) frequencies following the identification of shipping lanes and associated ships statistics and probability distributions of lanes relative to the beam, source level, and ship velocity. Pure research models usually have the following characteristics: (a) many user options, (b) results of intermediate calculations available for diagnostic and debug purposes, (c) minimal physical assumptions (compared to pure application or research application versions of the given model), (d) minimal mathematical approximations (compared to pure application or research application versions of the given models), (e) complex environmental inputs required (often requiring difficult to obtain experimental values), (f) no associated environmental data bases, (g) no configuration management [3,4], (h) large main-frame computer environment, (i) program run time is unimportant.

Pure applications models attempt to model the system performance of fleet sonars or the acoustic field in which they operate. In model developments in this area, there is a clear trend toward the use of prompts to obtain required inputs from users who, most often are naval personnel. An example of a pure application numerical model is the Integrated Command ASW Prediction System [5], (ICAPS), which provides a self-contained capability to predict acoustic detection limits for ocean environmental conditions and sonar operating modes, and represents the baseline model system for air sonar systems, being composed of a suite of environmental data bases and acoustical and tactical models. A second example is the Automated Signal Excess Prediction System [6] (ASEPS), which calculates the acoustical field for and predicts the performance of Navy surveillance systems. Pure applications models usually share the following characteristics: (a) few, if any, user options; default values are used extensively (e.g., the number of modes to be calculated in a normal mode propagation loss program would not be under user control, a coherence option would be preselected as would the range interval between predicted points in the output); (b) no information printed

for diagnostic or debug purposes; (c) many physical assumptions are made (e.g., bottom interaction is represented by a bottom loss versus grazing angle and frequency table); (d) many mathematical assumptions (e.g., asymptotic corrections may be made to ray theory in lieu of using more exact field theory due to excessive runtime for the latter); (e) automated environmental data bases retrieved by giving geographic position and month; (f) the ability to accommodate in situ data (e.g., provision for merging a shallow bathythermograph with archival deep temperature data); (g) a strong trend toward the use of configuration management; (h) multi-size computer environment including large main frames, mini-computers, desk-top calculators and programmable hand-held calculators; and (i) runtime is often of primary importance resulting in trade-offs with accuracy.

Research application models are needed to predict the performance of new sonar system concepts and existing systems, to support force level studies, for experimental planning and the analysis of experimental results, to create new data bases, to assist in the evaluation of data bases and acoustic models (e.g., propagation loss or ambient noise models), and to diagnose conflicts between fleet experience and predictions of pure applications programs. An example of a research application model is the Generic Sonar Model [7], which uses a modular approach, and allows user selectable submodels to predict passive signal excess versus range or frequency, active signal excess versus range, range and bearing errors versus range, LOFAR diagrams and autocorrelation functions in an ocean environment independent of range and time. The Generic Sonar Model does not access extensive environmental data bases. Another example of a research application model is the Environmental Acoustic Interactive Data System/NORDA Acoustic Model Operating System (EAIDS/NAMOS) [8-12], which is discussed in detail below. Research applications models usually share the following characteristics: (a) many user options (almost as many as pure research models), but default values are available for many parameters and operating modes; (b) information for diagnostic or debug purposes is sparse; (c) physical assumptions are often program options (e.g., the user may select from several bottom interaction theoretical approaches); (d) the mathematical approximations are typically those of the pure research models, models which are used as building blocks in constructing the research applications model; (e) environmental selection from several data bases is the trend in research applications modeling; (f) in situ data is not utilized, however, it is likely that archival experimental environmental data files will be among the data bases automatically accessible by the model, (g) a strong trend toward the use of configuration management; (h) typically a large main-frame computer environment; (i) program run time is unimportant; (j) basic models (e.g., propagation loss, ambient noise) are decomposed into sub-model units (an example will be provided below); and (k) graphics are used extensively.

2. Status and Trends in Research Applications Modeling

Research application model development attempts to combine the automated features of pure applications models with the flexibility and options of pure research models. To examine the status and trends in research applications modeling we shall examine the features presently in EAIDS/NAMOS and those intended for implementation. EAIDS may be thought of as the system that will select, analyze, edit, and display range-dependent environmental information to be used as input to the acoustic models in NAMOS. EAIDS is fully interactive and user friendly, offering a HELP option at all critical decision points. The graphics displays are intended to assist the user in selecting and editing the environmental information. The primary tool for environmental selection, for input into a propagation loss model, is the Great Circle Path (GCP) Parameter Display as exemplified in Figure 1. In this plot, sound speed profiles, bathymetry, bottom loss type and wind speed resulting from a great circle path data extraction are displayed as a function of range. Once an environmental data retrieval has been made, the data is placed in a working file where the editing functions of deletion, insertion, and replacement may be performed and the edited results displayed. Another type of display aid is depicted in Figure 2. In this figure, an aerial view of shipping density (number of ships per one million square miles as stored in a data base of one degree square resolution), retrieved from a data base known as AUTO-HITS is presented. We note how clearly this plot indicates shipping lanes. In EAIDS this plot is produced using color graphics and the contrasts are more distinct, allowing for easier identification of shipping lanes. This plot also contains coastlines and a geographic grid. The area covered is user selectable and up to five data intervals (i.e., colors) may be selected. Other similar plots can be obtained from EAIDS for bottom loss, bathymetry, critical depth, and depth excess. Great circle paths such as O-A, O-B, O-C, can be drawn on the plot, representing possible sector boundaries for use in ambient noise model computations. Before the availability of this display aid, charts of varying scales and units were used in a very labor intensive, although inexact, process (due to the curved nature of great circle paths on Mercator grids) the aim of which was the selection of sector boundaries. Future plots will provide aerial views of sound channel axis depth, mixed layer depth, and reciprocal depth (for a variety of source depths).

The primary data bases in EAIDS are presently from a multi-parameter data base known as Auto-Ocean. In Auto-Ocean, a sound speed profile is stored for each 5° geographic square on a seasonal basis. Retrieval of these profiles along a great circle path results in a sound speed field that is too discontinuous for use by some range-dependent propagation loss models. This requires the production of interpolated profiles, which is done in EAIDS by a process known as "c-fielding." This is one example of the interfacing required between

Figure 1. Great Circle Path Parameter Display

the contents of an environmental data base and the requirements of an acoustic model. These interface requirements can be handled in either EAIDS or NAMOS.

A planned EAIDS capability is the construction of special purpose or refined data bases from massive data bases of raw observations. For example, a data base of bathythermograph and salinity-temperature-depth (STD) data can be used to identify representative profiles in a given area, calculate statistical characteristics of profiles in a given area or retrieve profiles according to access keys such as geographic area, month, or experiment name. This will require additional plot capabilities such as overplots, min-max envelopes, and locations of profile measurements on an aerial view and various data processing algorithms.

Environmental data from at-sea exercises will be stored in EAIDS and retrievable by several access keys. Corresponding acoustic data will also be stored for comparison with model results in NAMOS.

NAMOS is the system in which the user sets up an interactive runstream for subsequent batch processing of acoustic models. After batch

processing, model results are returned to the user terminal for further display and analysis in the interactive mode.

At the present time, two range-dependent propagation loss models are available in NAMOS, ASTRAL and Parabolic Equation. Either may be used to calculate transmission loss along radials for use by an ambient noise model over pre-selected sectors. The various decisions regarding models, sectors, radials, data bases, and source and receiver characteristics such as frequency, source depth, receiver depth, beam patterns, etc., are made following prompts from the program. The series of decisions is saved in a working file so that if only slight changes are required for additional model runs, one need not go through the entire menu again but may go directly to the parameters requiring changes and effect those changes. NAMOS has looping controls that allow for runs involving several frequencies, source and receiver depths over several radials to be set up in a single interactive runstream. This is a great time saver when one is operating in the "production" mode and requires, for example, horizontal directional noise estimates at a given position for 25, 50, and 100 hertz at receiver depths of 25, 50, 100, and 200 meters.

Figure 2. South Atlantic Ship Density. Season: Austral Summer (Jan, Feb, Mar)

Although not yet available in NAMOS, one highly desirable feature in research application models in the modular decomposition of the basic models (e.g., propagation loss, ambient noise, reverberation) into independent sub-models. The Generic Sonar Model does have basic models in decomposed form. Table 1 gives the basic sub-models which constitute a typical propagation loss model.

TABLE 1. Sub-Models of a Typical Propagation Loss Model

Sound Speed Model
 Surface Reflection Coefficient Model
 Bottom Reflection Coefficient Model
 Bottom Phase Shift Model
 Volume Attenuation Model
 Source Level Model
 Filter Equalizer Model
 Transmitter Beam Pattern Model
 Receiver Beam Pattern Model
 Eigenray (or Eigenmode) Model
 Pressure Model

The roles of the sub-models are as follows: (a) Sound Speed Model--includes earth curvature correction and a choice of several curve fitting techniques; (b) Surface Reflection Coefficient Model--pressure ratio of a reflected acoustic wave to an incident wave at the ocean surface; (c)

Bottom Reflection Coefficient Model--pressure ratio of a reflected acoustic wave to an incident wave at the ocean bottom; (d) Bottom Phase Shift Model--phase change of an acoustic wave as it reflects off the ocean bottom; (e) Volume Attenuation Model--determination of the absorption coefficient; (f) Source Level Model--pressure levels and spectra for narrow band and broad band sources, respectively, referred to a specified range from the source; (g) Filter Equalizer Model--filter the signal at the receiver; (h) Transmitter Beam Patterns Model--determine the ratio of pressure transmitted in a particular direction, to the pressure transmitted along the acoustic axis, all measurements being referred to a common distance from the array; (i) Receiver Beam Pattern Model--predict the ratio of voltage produced by a plane wave received in a certain direction, to the voltage produced by a plane wave of equal strength received along the acoustic axis; (j) Eigenray Model--solve the reduced wave equation by the use of rays that join the source to the receiver; (k) Pressure Model--multiplies the source level, transmitter and receiver beam patterns, and filter equalizer by eigenray pressure amplitudes, sums the multipath contributions, and stores the resulting pressure amplitudes. The models available for selected sub-models in the Generic Sonar Model are given in Table 2. Any combination of these sub-models may be selected to effectively construct a new propagation loss model. Thus, the MGS bottom reflection coefficient

TABLE 2. Choices Available for Selected Sub-Models in the Generic Sonar Model

Ocean Sound Speed Models:	
CONGRATS Ocean Sound Speed Model	
Constant Gradient Ocean Sound Speed Model	
Linear Ocean Sound Speed Model	
Spline Ocean Sound Speed Model	
FACT Ocean Sound Speed Model	
RAYMODE Ocean Sound Speed Model	
Bottom Reflection Coefficient Models:	
Table Bottom Reflection Coefficient Model	
Rayleigh Bottom Reflection Coefficient Model	
NUC Bottom Reflection Coefficient Model	
MGS Bottom Reflection Coefficient Model	
FNOC Bottom Reflection Coefficient Model	
Eigenray Models:	
Multipath Expansion Eigenray Model	
FACT Eigenray Model	
Generate Eigenray Model	
RAYMODE Eigenray Model	
AMOS Eigenray Model	

model (normally unavailable in the FACT propagation loss model) may be used with the FACT Ocean Sound Speed and FACT Eigenray models. This gives the user far more flexibility than if given the undecomposed versions of basic acoustic models. This flexibility is particularly useful in the process of model evaluation where normally when two models differ, it is not known how much of the difference is due to the physical mechanisms associated with each sub-model. With the sub-models available, all but the eigenray models, for instance, may be chosen to be identical and the eigenray models thereby compared. Similarly, the sensitivity of a given eigenray model to various bottom reflection coefficient models may be determined.

Once the batch acoustic runs have been made and the results returned to the user terminal, several post-analyses and display options are planned. These include various signal processing functions (e.g., FFTs of the complex pressure field to simulate array processing of the signal field, auto- and cross-correlations of signal and noise fields, spectral analyses) and statistical analyses (e.g., estimates of signal and noise decorrelation times and distances, probability density functions, moments). These analyses would be performed on the mean and fluctuating components of signal and noise fields. Display options will show the analyses results and include, as examples, mean $\pm$ standard deviation of transmission loss versus range (or ambient noise versus angle or time), fluctuation histograms, and spectral levels versus frequency or wavenumber. Other plots will be of transmission loss contours on depth versus range or frequency versus range plots. Other plots will permit the comparison of acoustic model results with those of other models or with experimental data values. All the above functions and plots are to be generated in the interactive mode.

Two other topics of great importance to EAIDS/NAMOS and to research application models in general are the use of data base management systems (DBMS) and configuration management techniques. DBMS is essential if data bases are to be used with the flexibility demanded by the variety of problems to be solved by research applications programs. Solutions of these problems require data bases retrieved by keyed access and the need for them to be edited and updated. Commercial DBMS have the advantages of good documentation and system maintenance; many DBMS permit portability between several computer systems.

Research applications programs are exceedingly complex due to the large numbers and types of data bases and models, the interfaces between them, and the various analyses and graphics functions, all in an interactive environment. This complexity demands the use of configuration management practices to and assure proper identification of different versions, controls program alterations, and assures adequate documentation (which includes a functional description, system/subsystem specification, program specification, data base specification, user's manual, program maintenance manual, and test plan). Using configuration management techniques, model development progresses in a controlled manner, essential changes are accommodated in an orderly fashion, and test and evaluation are integral components of the system development.

3. Future Requirements for Research Applications Models and Pure Applications Models

Pure applications models are typically predictors of mean levels as functions of range (or time). Fluctuations have usually been eliminated through the use of methods such as incoherent phase addition or range averaging. In the applications environment, this may be valid due to the integration times associated with some sonar systems. In other cases, the approach is invalid and has been used to simplify the tactical decision-making process (e.g., smooth propagation loss curves are easier to interpret than those with detailed structure occurring on several range scales). The contrast is exemplified in Figure 3 in which the same propagation loss model (RAYMODE) has produced two results from the same input data, one due to incoherent phase addition, the other from coherent phase addition.

Fluctuations are usually addressed by a very simple model. Given a mean value of signal excess as determined by a complicated pure applications model using sophisticated data bases, acoustic models and sonar system characteristics, the fluctuations of the signal excess are likely to be modeled as a Gaussian distribution, with a standard deviation invariant with frequency or geographic position. Thus, unsophisticated fluctuations models are used for even those scenarios in which it is the acoustic fluctuations that limit the ability to detect or track a target. We note that it is well within the state-of-the-art to improve our fluctuations models, particularly if the fluctuations of acoustic output parameters

Figure 3. Raymode Propagation Loss Model Predictions Using Coherent and Incoherent Phase Addition of Ray Paths for Identical Inputs

are empirically determined. The rigorous approach of determining the sensitivity of output acoustic parameters to fluctuations of environmental inputs and then using the statistics of the input fluctuations is an extremely difficult problem due to inadequate modeling of many of the physical mechanisms involved and the drastic effect such modeling would have on runtime. It is, however, important to examine the sensitivity of models to input variability, thereby using this information to develop good investment strategies with regard to basic research requirements and data base developments and upgrades. We note that research applications models provide excellent test beds for the development of fluctuations models.

Related to the question of fluctuations modeling is the question of confidence limits on acoustic predictions. An example is: given that a model has predicted a maximum detection range of 12 km based on mean value modeling, at the 90% confidence limit, will the maximum detection range vary over narrow limits (e.g., between 11 and 13 km) or over wide limits (between 4 and 16 km)? Clearly, tactics might be dramatically affected depending on the answer. Once again, what is required is fluctuations modeling. We note that the detection envelope at a given confidence level will be determined by spatial and temporal fluctuations of the components of the acoustic field and the characteristics of the sonar and its signal processor.

An alternative to the development of predictions of fluctuations is to instead predict the envelope of the mean field using environmental input variable statistics. Thus, for example, one would use the knowledge that a given high frequency (1000 Hz) bottom loss versus grazing angle curve has an associated standard deviation of the approximately 3 dB to shift the bottom loss curve

to higher and lower values for determination of the envelopes of the acoustic output. For other variables, new data bases would be necessary (e.g., twentieth and eightieth percentiles of wind speed in addition to median values). In this manner, the range of possible mean values could be determined at a given confidence level (with respect to the environmental input parameters).

Even pure research models of propagation loss assume the environment to be time invariant. Further, some physical mechanisms of possible importance are neglected. An example is the effect of internal waves on the boundary of a surface duct (a time varying phenomenon) on the acoustic field in the duct and leakage from the duct. A statistical treatment of bottom roughness and layering at frequencies above a few hundred hertz also bears investigation by the research community to determine if replacement of homogeneous bottom loss provinces and associated reflectivity curves by a (statistical) geoaoustic model is warranted.

A final issue for pure applications models is the standardization of data bases and algorithms for prediction of the acoustic field (insofar as allowed by) computer hardware resources and type of sonar signal processing utilized. Until recently, developers of pure applications models would often also develop their own environmental data bases. This results in different sonar predictions for a given operational scenario, often on the same ship. This, in turn, causes confusion and uncertain tactical decision making. Although the selection of environmental data bases across various sonar system configurations is difficult, it is possible if data base specifications based on system operational requirements are generated. Also involved are considerations such as data base maintenance, level of documentation, provisions for upgrades and sensitivity analyses. Research applications models should prove particularly useful for the evaluation and comparison of data bases.

4. Summary and Conclusions

We have defined three model types: pure research models, pure applications models, and research applications models. Research applications models have been shown to combine flexibility through the editing of data bases and the decomposition of acoustic models (e.g., propagation loss) into their basic elements. These models are typically interactive and utilize modern graphics capabilities. They are capable of the high productivity of pure applications models through automatic data base retrievals. The complexity of these models necessitates the use of data base management systems and configuration management techniques. Examples from the Generic Sonar Model and EAIDS/NAMOS have been given to illustrate the status and trends in this modeling area.

Looking toward the future, the need for sophisticated fluctuations models is identified due to a broad class of scenarios for which fluctuations rather than mean levels drive the probabilities associated with detection and tracking. The

need for confidence limits for acoustic predictions has long been requested by the user community; several approaches to the fulfillment of this requirement have been offered. Finally the need for data base standardization is identified and some issues related to its achievement have been listed.

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