Generating Acoustic Provinces for the U.S. Navy's Low Frequency Bottom Loss Database Using Geographic Information Systems

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Abstract- **The U.S. Navy's Low Frequency Bottom Loss (LFBL) database is released and maintained by the Naval Oceanographic Office (NAVOCEANO) and used as an environmental input to many of the Navy-standard tactical decision aids. It is designed to support the Navy's operational requirements in determining the nature of the interaction of 20 – 1000 Hz acoustic energy with the sea bottom. The general methodology of generating shallow-water LFBL databases was described in a previous paper. [Harvey, D.W., Lowrie, A., and Filipczyk, R. D., Oceans '02 MTS/IEE Volume 1, pages 358-362.] LFBL is based on acoustic and seismic measurements performed at-sea by NAVOCEANO survey teams and subsequent geo-acoustic inversions of the measured data using the Navy Standard Parabolic Equation (NSPE) model and the resources of the Navy Department of Defense Supercomputing Resource Center (Navy DSRC). LFBL is composed of a global database that is available worldwide and four regional databases for which additional acoustic and geological measurements were made. The global and regional databases use different parameter sets to describe bottom interactions. In the global database, a set of 10 parameters is used to describe an effective one-layer bottom. In the regional databases the bottom is parameterized using a set of effective acoustic layers described by sound speed, density, and attenuation at the top and bottom of each layer. The acoustic properties of the effective layers may not correspond to the actual density, sound speed, or attenuation of the physical bottom at a given location, but collectively, they are found to accurately predict acoustic propagation of bottom-interacting sound paths, and the values are constrained in the geo-acoustic inversion to geologically reasonable values. Hence, the regional databases are also known as "N-Layer" databases. Starting with LFBL Version 11.1, LFBL has also included error metrics in the regional databases to indicate the degree of confidence for the values therein in order to provide improved guidance for operational decision-making. For both the global and regional databases, the geographic region is divided into provinces over which it is assumed that the sub-bottom acoustic parameters are constant, even if the sub-bottom layer depths in the N-Layer regions vary. The sub-bottom layer depths are determined from geological interpretation of acoustic two-way travel times using data gathered concurrent with, but with independent equipment from, the acoustic transmission loss (TL) measurements. A new technique has been devised for determining province boundaries in the regional databases using geographic information systems (GIS). In brief, rough provinces are sketched out by geologists at NAVOCEANO. The locations of the TL measurements are added onto this map, and colored lines (dubbed "geo-acoustic connections") are drawn between the TL measurements to indicate how accurately the inverted parameters from one measurement predict the results of the other. The province boundaries are then adjusted to include (as much as possible) only measurements whose inverted parameters accurately predict TL at the other measurement sites within the province. Parameters are chosen for a given province by selecting the parameter set within the province that produces the best confidence metrics.**

I. INTRODUCTION

The U.S. Navy requires accurate, high-resolution, and reliable data to meet its operational goals. Predicting and modeling sonar performance, for example, requires accurate acoustic propagation models together with accurate information about the ocean surface, water column, and ocean bottom. A key environmental input required by Navy tactical decision aids to calculate the underwater acoustic field in the 20 – 1000 Hz frequency range is the Low Frequency Bottom Loss (LFBL) database, released and maintained by the Naval Oceanographic Office (NAVOCEANO). The database is updated as additional information about the ocean bottom is gathered. This paper describes a technique that improves the manner in which a certain aspect of the database (province boundaries) is determined.

Detailed information on how NAVOCEANO has built recent versions of LFBL can be found in an earlier paper by Harvey, Lowrie, and Filipczyk [1]. Section II gives a brief summary of the data model and database generation technique, concentrating on the features and processes of relevance to the province boundary generation technique.

Section III describes the technique that leverages the use of geographic information system (GIS) technology with the expertise of NAVOCEANO geologists to improve the determination of acoustic province boundaries.

Section IV lists some conclusions and potential on-going work.

II. OVERVIEW OF THE LFBL DATABASE

The LFBL database is in fact a collection of databases: a global database and four regional databases.

In the global database, the acoustic interaction with the bottom is modeled by a single bottom layer described by ten parameters. This model is deemed adequate in deep-water areas with more limited acoustic bottom interaction and higher-angle ray paths.

The regional databases cover four specific shallow-water regions of the world. In these regions, the global database is inappropriate for operational use. Here, the bottom is modeled by a series of layers with varying thicknesses. The sound speed, density, and attenuation are given at the top and bottom of each layer. This parameterization gives the regional databases the name "N-Layer." The remainder of this paper will be concerned only with these N-Layer databases.

LFBL N-Layer databases are built using acoustic and seismic data collected by at-sea NAVOCEANO survey teams. Two types of surveys are performed: acoustic surveys, whose purpose is to measure acoustic transmission loss (TL) as well as very high-resolution sub-bottom two-way travel time (TWTT) data along specific predetermined paths (known as "stations"), and a seismic-only survey, whose purpose is to collect TWTT data over the entire region. The seismic data are interpreted by NAVOCEANO geologists to identify significant layer depths. These depth maps are then gridded to provide coverage at any point in the region. Fig. 1 illustrates how the two surveys would differ in coverage in a given ocean region.

TL data are collected by anchoring a collection of hydrophones at different depths at a predetermined location and then sailing away from the receivers along a predetermined bearing, detonating explosive sources at intervals. The hydrophones record the TL for each shot. Seismic data are then collected as the ship returns to collect the hydrophone array.

The acoustic TL data are checked for quality and consistency and then inverted for the N-Layer parameters using the Navy Standard Parabolic Equation (NSPE) model. The inversion is constrained to providing physically realistic bottom properties. The extremely computationally intensive inversions are performed using the Navy Department of Defense Supercomputing Resource Center (Navy DSRC), also located on the NAVOCEANO campus.

Since the bottom parameters (sound speed, density, and attenuation) are determined by geo-acoustic inversion, the values may not correspond to the actual properties at that location. Rather, they represent an effective set of parameters that accurately predicts the measured TL at that location.

Each regional database (and, for that matter, the global database) is divided into provinces. The N-Layer parameters are assumed to have the same values throughout a given province, though the layer thicknesses independently vary. When the database is queried for bottom properties at a given location *(x, y)*, the extraction routine determines the province *P* in which *(x, y)* is found and then returns the sound speeds, densities, and attenuations of the province *P* and the layer depths from the gridded seismic database at *(x, y)*. The technique for determining the boundaries of these provinces is described in the next section.

Starting with LFBL Version 11.1, each N-Layer province has an associated set of error metrics. These are meant to characterize the error in predicted TL that would be expected to result from sampling the parameters within the province at a random location. Two quantitative metrics are stored for each province: the mean and standard deviation of the RMS errors between the measured TL and that modeled by NSPE using the database values for all stations in a province (excluding the station whose parameters are used to characterize the province).

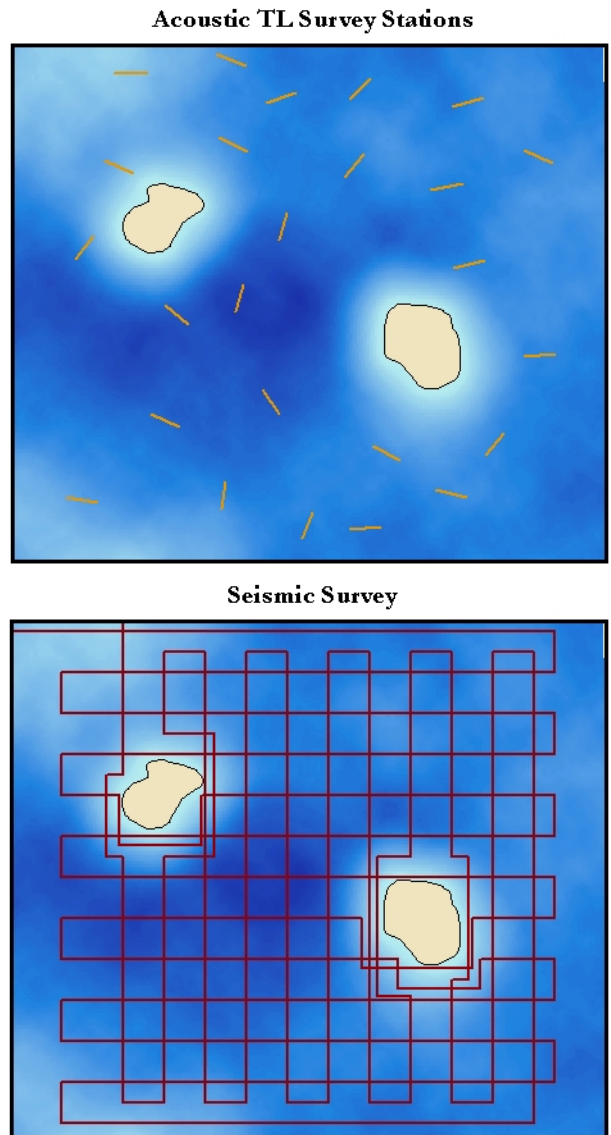**Acoustic TL Survey Stations**

Seismic Survey

Fig. 1: In LFBL data collection, acoustic TL data are gathered at specific pre-determined stations along with very high-resolution seismic data (top); regional seismic data are collected in a separate survey (bottom).

III. DETERMINING PROVINCE BOUNDARIES

A new process has recently been developed by NAVOCEANO scientists for choosing optimal province boundaries. The goal was to produce province maps in a more systematic manner and base these maps even more firmly on sound geological reasoning.

Initially, NAVOCEANO geologists draw a rough province map based on expected significant variation in bottom composition or properties. This map represents the starting set of province boundaries and will be subject to modification from the subsequent analysis of measured acoustic data.

The initial rough map is ingested into a geographic information system (GIS) along with the locations of the TL measurements (the "stations" referred to earlier), as illustrated in Fig. 2. Recall that each station has an associated set of N-Layer parameters calculated by geo-acoustic inversion.

To describe the process, we first consider two stations, a "subject" station and and "object" station. The two stations might belong in the same province if the bottom parameters in the subject station accurately model the TL at the object station. That is, if the "connection" between the two stations is good. The fitness of a connection is defined by a cost function: the RMS difference between the TL measured at the object station and the TL modeled using the bottom parameters from the subject station. A lower cost indicates a better connection. Ideally, a province will contain only stations whose connections have low cost. (There is also a connection cost for the same two stations when the roles of the stations are switched: the subject station becomes the object and the object becomes the subject. Call this the "complementary" connection.) Connection costs need not be calculated between each pair of stations: if the stations are very distant, it is unlikely that they will be in the same province.

Fig. 2: Geologists' initial estimation of province boundaries with TL survey locations overlaid.

The connection costs are visualized using a GIS. A database is created whose entries are connections, geographically represented as a line between the subject and object stations. The database entries have connection cost as an attribute, so that the GIS can display the connections on a map, color-coded by cost. In our work, low-cost connections were dashed green lines and higher cost connections were solid yellow, orange, or red lines. (The low-cost connection representation was a dashed line so that a high-cost complementary connection will be visible.) A province should ideally contain only green connection lines. Red connections lines should always cut through province boundaries.

Additional constraints are that each station must be entirely contained within a single province since the inversion is assumed to have a single set of acoustic parameters over the length of the acoustic measurement and that each province must have at least two stations to allow for metric calculations.

Beginning with the rough province map (as in Fig. 2), the boundaries are altered based on the connection costs and the other constraints described in the previous paragraph. This alteration may involve provinces being split or joined as deemed appropriate. The decisions are not always clear-cut; for example, a station may have poor connections with all its neighbors. Nevertheless, the process as a whole is quite systematic and relatively rapid.

To illustrate, consider Fig. 3, which shows the northwest portion of Fig. 2 with the connections filled in. All the connections around the island have low costs, indicating that they all belong in a single province. However, many of the connections cross the boundaries of the rough province, which includes the island, and none are entirely within the province to the southwest. The province boundaries therefore must be remapped. A number of solutions are possible. The one shown in Fig. 3, where the entire northwest section of the region is joined in a single province, seems the simplest. The contour follows the overall shape of the rough map around the island but extends it farther out.

Note also in Fig. 2 or Fig. 3 that in the rough province map the southernmost station is in a province by itself, which is not allowed. The connections in Fig. 3 indicate that the station might belong in the same province as the two stations directly to its north.

Once the provinces are mapped out, the province parameters are selected. Recall that each station in the province
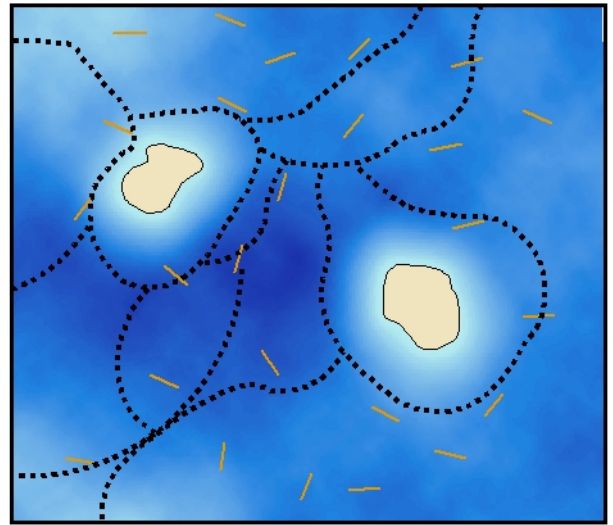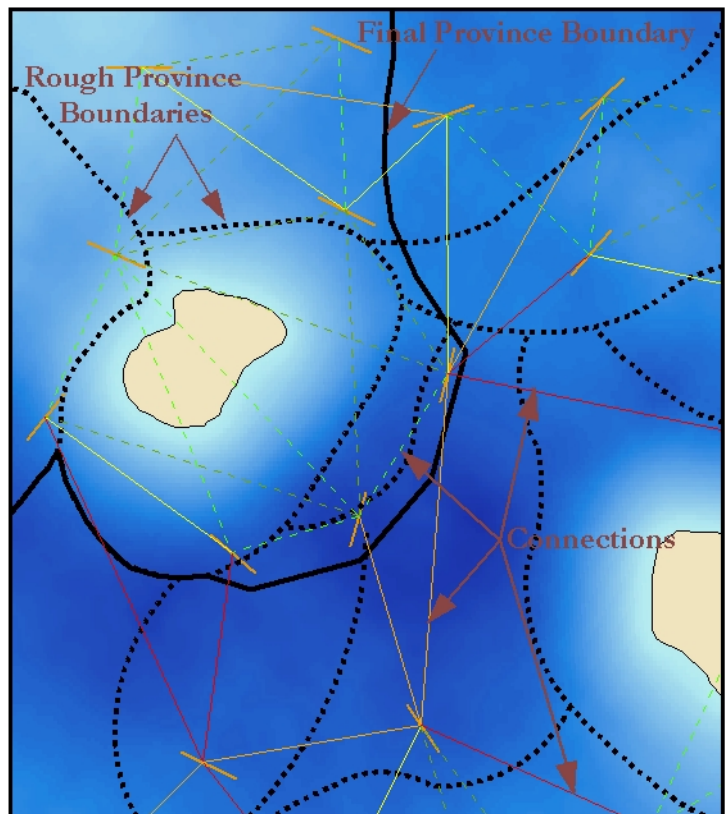

Fig. 3: Using connection fitness and GIS to modify province boundary.

has its own parameter set. To determine which set to use, one calculates metrics using the parameter set from each of the stations in the province. The parameter set that produces the lowest average metric value should be selected. The remaining stations within the province are then used to determine independent TL error metrics for the province.

IV. Conclusions

A novel method for using GIS to assist in producing LFBL province boundaries has been developed by the NAVOCEANO Acoustic Modeling and Databases Division. The method has the advantage that it more effectively leverages NAVOCEANO's geological expertise, and reduces the provincing process to a set of simple rules that should be obeyed as much as possible. However, there is still some significant latitude allowing the analyst to determine the precise position of the province boundaries.

It may be possible to further optimize the process by using a computer algorithm to investigate different groupings of stations in order to find the set that produces the best connections. Additional restrictions, such as the requirement that at least two stations must be in each province could also be algorithmically applied. With this algorithm in place, the province boundaries could be determined by adjusting the rough geologic provinces to include the station groups.

References

[1]   D.W. Harvey, A. Lowrie, and R.D. Filipczyk, R. D., "The generation of N-layered geoacoustic descriptions of the subbottom using NAVOCEANO-collected environmental data," in *Oceans '02 MTS/IEE*, vol. 1, 2002, pages 358-362.