HYDROACOUSTIC BLOCKAGE CALIBRATION FOR DISCRIMINATION

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ABSTRACT

The core focus of this hydroacoustic research is to develop a better understanding of hydroacoustic blockage to better predict those stations that can be used in discrimination analysis for any particular event. The research involves two approaches: 1) model-based assessment of blockage and 2) ground-truth data-based assessment of blockage. The goal is to reliably determine all hydroacoustic stations that can be brought to bear on a discrimination analysis from any event location in the world's oceans. An important aspect of this capability is to include reflected T-phases where they reliably occur since reflected T-phases can allow station utilization when the direct path is otherwise completely blocked. We have conceptually designed an approach to automate assessment procedures that will allow both model-based and data-based methodologies to be utilized and in the future, integrated. We have modified the HydroCAM model-based network assessment code to include variable density bathymetry grids. This will improve the reliability of model-based blockage assessment as dense bathymetry grids are added to the bathymetry database where available and needed. We are also running the HydroCAM code to produce blockage grids in the Indian Ocean for many different blockage criteria. We have been building the database necessary to begin the data driven assessment of blockage. At present, the database is accumulating earthquake events within the Indian Ocean basin as recorded at Diego Garcia and Cape Leeuwin. Over 130 events from 2001 and 2002 have been loaded. Now earthquake event data is automatically loaded into the Lawrence Livermore National Laboratory database at 1-hour record lengths to accommodate future reflection phase analysis. Future work will focus on the utilization of reflected T-phases, the automated use of model-based blockage grids, and the enhancement and use of the data-based method for blockage assessment in the Indian Ocean. The analysis methodology will then be applied to other ocean basins to eventually include all ocean basins for a full worldwide blockage assessment capability.

OBJECTIVE

The ultimate objective of this research is to enhance discrimination capabilities for events located in the world's oceans. Two research and development efforts are needed to achieve the stated objective: 1) improvement in discrimination algorithms and their joint statistical application to events and 2) development of an automated and accurate blockage prediction capability that will identify all stations and phases (direct and reflected) from a given event that will have adequate signal to be used in a discrimination analysis. More emphasis will be put on the first R&D need in the future. This paper will focus on the progress made on the 2^{nd} R&D need.

The strategy for improving blockage prediction in the world's oceans is to improve model-based prediction of blockage and to develop a ground-truth database of reference events to assess blockage. This two-pronged approach emulates the approach taken in seismic monitoring and to the extent that seismic tools and know-how can be utilized in hydroacoustic blockage assessment, they will. Improving model-based blockage prediction entails, first and foremost, improving resolution of the bathymetry databases used in blockage calculations. The BBN Inc. developed code, HydroCAM (Hydroacoustic Coverage Assessment Model), is in use at the National Data Center (NDC) and is the basis for all model-based grid file calculations. Improving HydroCAM's blockage modeling capability starts with improving the bathymetry databases the blockage calculations are based upon. Research has focused on developing the capability in HydroCAM to utilize variable resolution bathymetry data and hence incorporate high-resolution "spotlight" bathymetry databases into the overall bathymetry data utilized in blockage calculations.

Research has also focused on specifying the form and function of the blockage assessment software tool. The software tool is envisioned to develop into a sophisticated and unifying package that optimally and automatically assesses both model-based and data-based blockage predictions in all ocean basins and for all NDC stations. The tool development begins in FY03 by developing the model-based element of the tool. The model-based software tool effort focuses on the Diego Garcia station in the Indian Ocean and uses a suite of blockage grids produced by HydroCAM to assess blockage.

The ground-truth element of blockage assessment has begun with the assembly and delivery of an earthquake event database recorded at Diego Garcia Station in the Indian Ocean and implementation of an automated event-loading schema. The assembly of a database test bed will be the focus of this component through FY03 and into FY04. Future plans call for integration of the database element with the blockage assessment software tool. An important issue in building ground-truth databases is the understanding of ground-truth sources and the limitations of each in providing broadband blockage information and accurate source locations. For example, earthquakes will be the dominant component of database events but their limited bandwidth (nominally 1-15 Hz) and fundamental location difficulties (de Groot-Hedlin, 2001) require another class of events to fill the bandwidth and location accuracy gaps. The database will seek to include sources of all types to span the monitoring bandwidth.

RESEARCH ACCOMPLISHED

The primary research focus in FY03 was on implementing a basic model-based blockage calibration capability at Diego Garcia and developing the database for a future data-based blockage capability. This section outlines the accomplishments on both the model-based and data-based approaches.

The model-based research and development has focused on extending the modeling capability of HydroCAM and on developing a basic software tool that can be used to access a suite of blockage grid files (based on different blockage criteria) produced by HydroCAM. The critical shortcoming in current HydroCAM blockage modeling accuracy can be blamed on the coarseness of the present-day worldwide bathymetry databases. The nominal wavelengths in the hydroacoustic-monitoring band are about 15 meters to 1.5 km whereas the current average resolution of the ocean surface slope and topography with satellite altimetry is 24 km (Smith and Sandwell, 1997). It would seem unlikely that worldwide bathymetry databases will be at the resolution needed for accurate hydroacoustic model-based blockage prediction anytime soon. The prospect for improving bathymetry databases, however, is not so grim. The vast majority of the world's ocean basin area is at depths well below the sound channel and consequently poor bathymetry resolution is not a factor in blockage prediction. Instead, accurate blockage prediction hinges on augmenting the worldwide database with high-resolution (nominally 200 meters from ship soundings) bathymetry in "spotlight regions" like island arcs, atolls, and ridges. Such data has been collected in many spotlight regions making the task one of integrating variable resolution databases and modifying HydroCAM to work with variable density meshes. During FY03 HydroCAM was modified to work with variable density meshes as shown in Figure 1. The fundamental modifications in the code algorithms have been completed and, as of this writing, testing is underway with a high-resolution database in the vicinity of Wake Island.

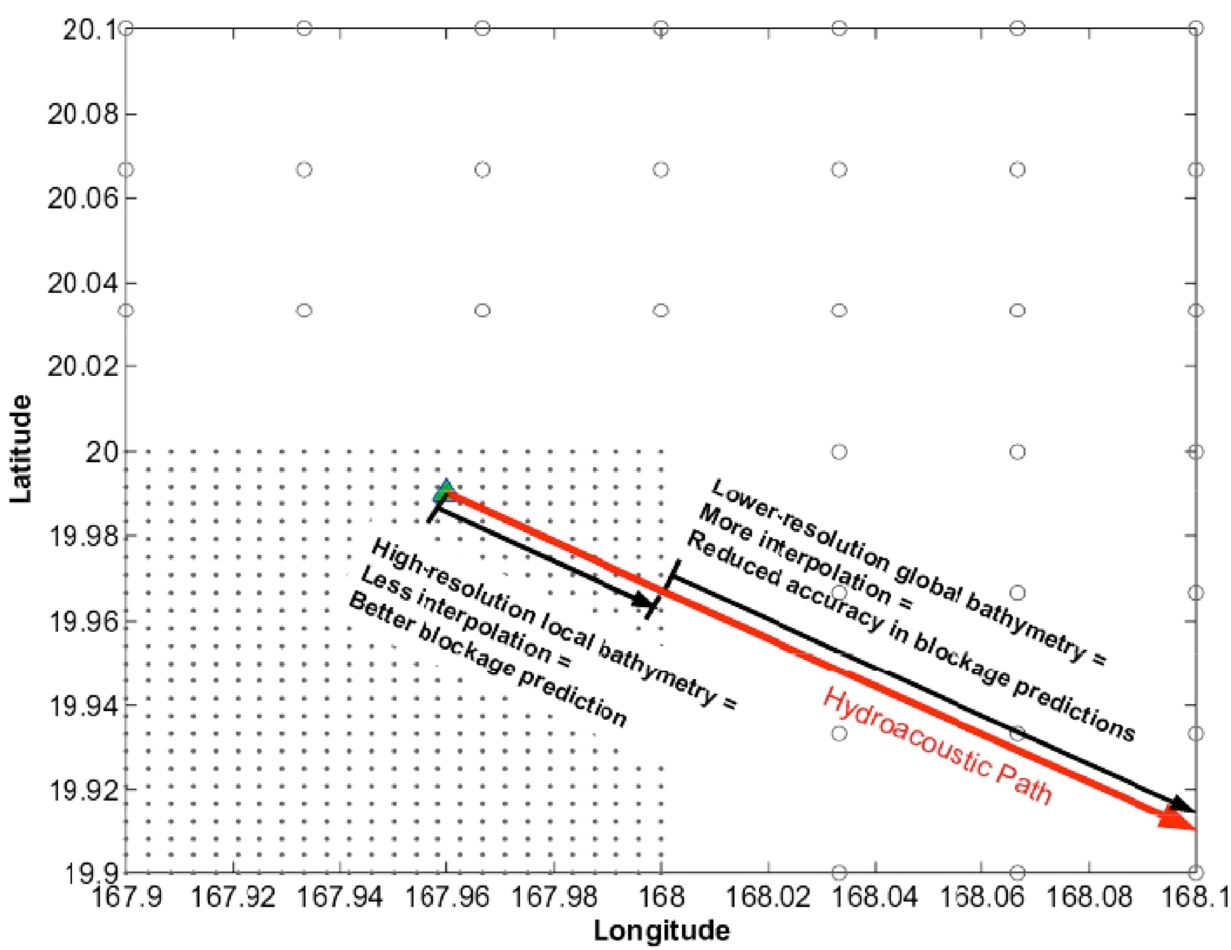

Figure 1. An illustration of the variably density grid concept with high-density grid "spotlight" areas.

The form and function of the blockage assessment tool has been specified through several generations of development. The ultimate goal of the tool will be automated assemblage of data windows containing all unblocked event phases at all stations for any given event location. The windowed phases will then be ready for analyst post-processing and discrimination analysis. A block diagram of the tool functionality is shown in Figure 2. The analysis of blockage will rely on a model component and a data component. The model component will be based on blockage grid files produced by HydroCAM. The blockage grids will be modeled using the highest resolution bathymetry database available (Smith and Sandwell) and will be recalculated whenever significant changes in relevant HydroCAM analysis algorithms or bathymetry databases occur. The data component will be based on an event database containing ground-truth source events recorded at hydroacoustic stations. The database will primarily contain earthquake source events but every attempt will be made to include as many explosive and higher frequency content events as possible. As part of the database, measurement tools will be developed that analyze the recordings to determine arrival time, back azimuth, S/N, coherence, and duration. Such measurements will be made for direct and consistent reflected phases (Pulli, 2000). Using an approach that emulates the seismic monitoring methodology to optimally make use of model and ground-truth data, the blockage assessment tool will draw on both model predictions and the database of source events. The tool will ultimately be set up for all ocean basins and all hydroacoustic monitoring station of interest.

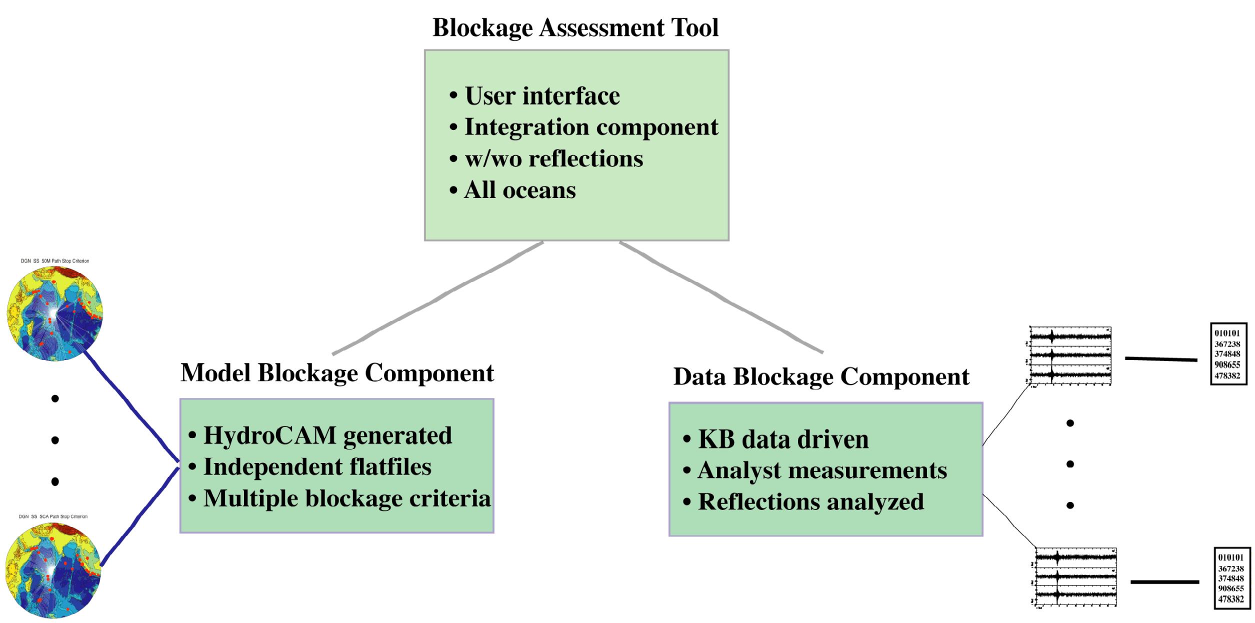

Figure 2. The conceptual flow and functionality of the blockage assessment tool.

A research database of hydroacoustic events has been developed that currently consists of 132 Indian Ocean area events recorded at Diego Garcia and at Cape Leeuwin. The waveform records are 1-hour in duration to accommodate future processing and analysis of reflected phases. Figure 3 maps the distribution of events compiled to present; all are earthquakes. Clearly the database is of adequate event density in the region of Java and Sumatra to begin to be useful in defining blockage to Diego Garcia from those areas. Although it is straightforward to accumulate and automate earthquake source events into a database and, in time, build a dense event dataset, the shortcomings of an earthquake ground-truth database are clear. For one, the location of the origin of the T-phase associated with the event is uncertain in two ways: 1) in the earthquake bulletin itself and 2) in where on the ocean floor the seismic energy converts to acoustic energy. The other problem with earthquake source events is that the signal bandwidth is about 1-15 Hz but the monitoring band is 1-100 Hz. Consequently, blockage mapping at higher frequencies, if different, will not be accounted for. It will be important to include accurately located high frequency events in the database to better understand the conditions under which earthquake-based event blockage predictions become unreliable for mapping high frequency event blockage. A major challenge will be to populate the database with higher frequency source events. Imploding spheres (Harben, 2000) and Navy explosive charges used in the 2001 Indian Ocean cruise and in the 2003 Indian Ocean cruise have been identified and will be loaded into the database.

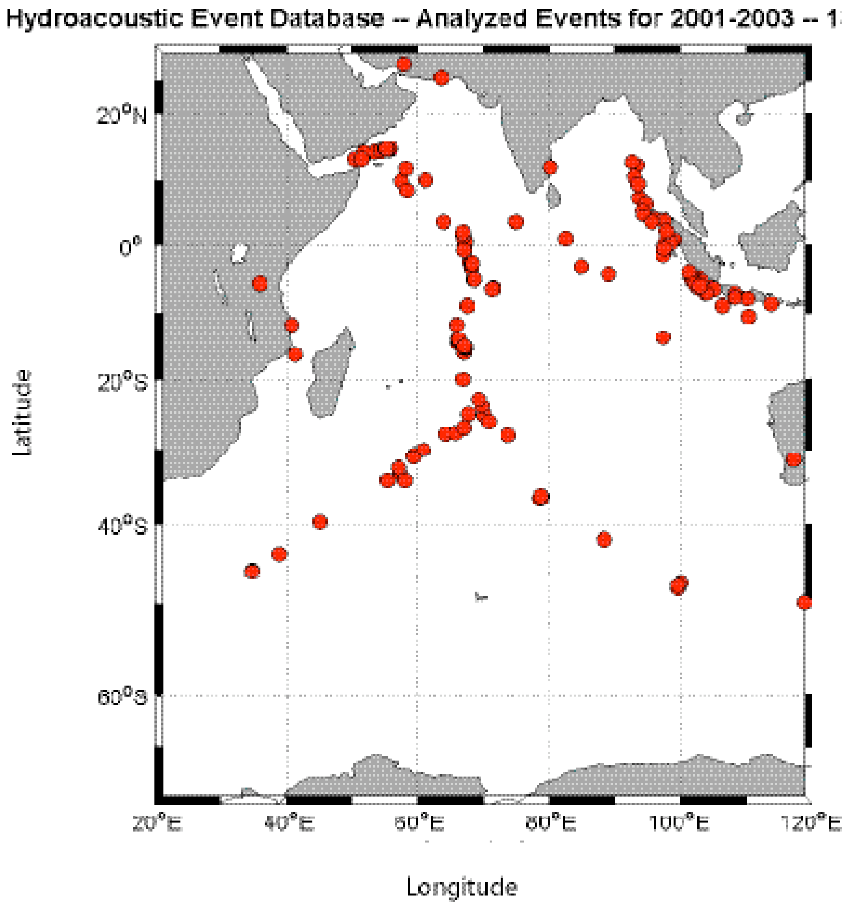

Figure 3. Research database of events in the Indian Ocean recorded at Diego Garcia and Cape Leeuwin

Although the database mapped in the previous figure was manually selected and loaded, future earthquake events will be loaded automatically as part of the overall development and growth of the LLNL seismic (and hydroacoustic) event database. An initial region has been specified for trial use and is currently being evaluated. The region is shown in Figure 4. All earthquake magnitudes greater than 4.5 and within the bounds of the Figure will be loaded and become part of the hydroacoustic event database. Earthquakes of that size and greater have reliably resulted in relatively high S/N direct-path T-phases. In the Java trench region the minimum magnitude was chosen as 5.0 to limit events from this very high-seismicity region. All records include an hour record starting shortly before the predicted T-phase arrival time. This is to include a time record long enough to record most reflected phases also. Reflected phases will ultimately be measured in identical ways to the direct T-phase arrival.

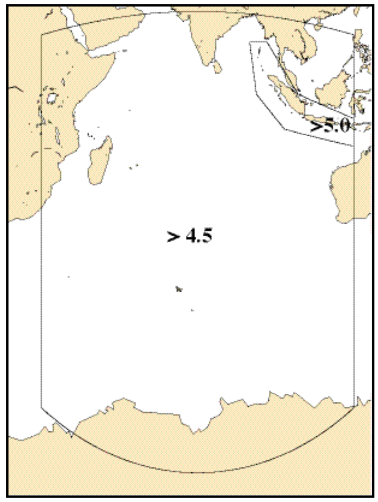

Figure 4. All events greater than magnitude 4.5 in the Indian Ocean and greater than 5.0 in the Java trench region (to limit event numbers in this high-seismicity area) will be automatically loaded into the LLNL research database.

CONCLUSIONS AND RECOMMENDATIONS

Blockage is not an on-off phenomenon. Rather, it is a frequency dependent loss of S/N and coherency due primarily to bathymetric obstacles in the source-receiver transmission path. Accurate assessment of blockage requires either a very sophisticated model prediction capability or an extremely rich ground-truth database. We have neither. Consequently, the research focus is on using crude modeling and a sparse ground-truth database in an optimal way, while steadily improving both capabilities. The focus in FY03 has been on the development of a basic software tool to analyze blockage using blockage grid files produced by HydroCAM and a suite of blockage criteria. Work has also focused on populating a ground truth database in the Indian Ocean. Future work will build on this, expanding model-based analysis and ground truth database development to all ocean basins while developing an integrated software tool that provides an optimal blockage predictive capability given the model and database limitations.

Hydroacoustic monitoring is generally considered secondary to seismic monitoring for meeting current requirements. Hydroacoustic monitoring can be exploited in new ways when used in synergy with other technologies for special types of events and has an important and unique niche to fill in the big event monitoring picture. Research in new analysis, processing and utilization of hydroacoustic assets (such as the new International Monitoring System hydroacoustic triads) should lead, not lag, new requirements.

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