MODEL-BASED HYDROACOUSTIC BLOCKAGE ASSESSMENT AND DEVELOPMENT OF AN EXPLOSIVE SOURCE DATABASE

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ABSTRACT

We are continuing the development of the Hydroacoustic Blockage Assessment Tool (HABAT) which is designed for use by analysts to predict which hydroacoustic monitoring stations 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 tool presents the analyst with a map of the world, and plots raypath blockages from stations to sources. The analyst inputs source locations and blockage criteria, and the tool returns a list of blockage status from all source locations to all hydroacoustic stations. We are currently using the tool in an assessment of blockage criteria for simple direct-path arrivals. Hydroacoustic data, predominantly from earthquake sources, are read in and assessed for blockage at all available stations. Several measures are taken. First, can the event be observed at a station above background noise? Second, can we establish backazimuth from the station to the source? Third, how large is the decibel drop at one station relative to other stations? These observational results are then compared with model estimates to identify the best set of blockage criteria and used to create a set of blockage maps for each station. The model-based estimates are currently limited by the coarse bathymetry of existing databases and by the limitations inherent in the raytrace method. In collaboration with BBN Inc., the Hydroacoustic Coverage Assessment Model (HydroCAM) that generates the blockage files that serve as input to HABAT, is being extended to include high-resolution bathymetry databases in key areas that increase model-based blockage assessment reliability. An important aspect of this capability is to eventually include reflected T-phases where they reliably occur and to identify the associated reflectors.

To assess how well any given hydroacoustic discriminant works in separating earthquake and in-water explosion populations it is necessary to have both a database of reference earthquake events and of reference in-water explosive events. Although reference earthquake events are readily available, explosive reference events are not. Consequently, building an in-water explosion reference database requires the compilation of events from many sources spanning a long period of time. We have developed a database of small implosive and explosive reference events from the 2003 Indian Ocean Cruise data. These events were recorded at some or all of the IMS Indian Ocean hydroacoustic stations: Diego Garcia, Cape Leeuwin, and Crozet Island. We have also reviewed many historical large in-water explosions and identified five that have adequate source information and can be positively associated to the hydrophone recordings. The five events are: Cannikin, Longshot, CHASE-3, CHASE-5, and IITRI-1. Of these, the first two are nuclear tests on land but near water. The latter three are in-water conventional explosive events with yields from ten to hundreds of tons TNT equivalent.

OBJECTIVE

The 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 this: 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. 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. Currently, research is focused on the development of a blockage assessment software tool. The tool is envisioned to develop into a sophisticated and unifying package that optimally and automatically assesses both model and data based blockage predictions in all ocean basins, for all National Data Center (NDC) stations, and accounting for reflected phases (Pulli et al., 2000). Currently, we have focused our efforts on the Diego Garcia, Cape Leeuwin and Crozet Island hydroacoustic stations in the Indian Ocean.

RESEARCH ACCOMPLISHED

We have continued the development of the Hydroacoustic Blockage Assessment Tool (HABAT) which employs a model-based approach to assess blockage from source events to hydroacoustic monitoring stations. HABAT is a stand-alone, platform independent, JAVA tool which allows the user to predict which hydroacoustic monitoring stations can be used in discrimination analysis for any particular event. The code uses the HydroCAM output "path", travel time and attenuation files as input. The "path" files can be either source-centered, indicating the area illuminated by the source, or station-centered, indicating the area visible to the station. The user then defines a series of points of interest, typically stations for the source-centered path case, or potential sources for the station-centered case.

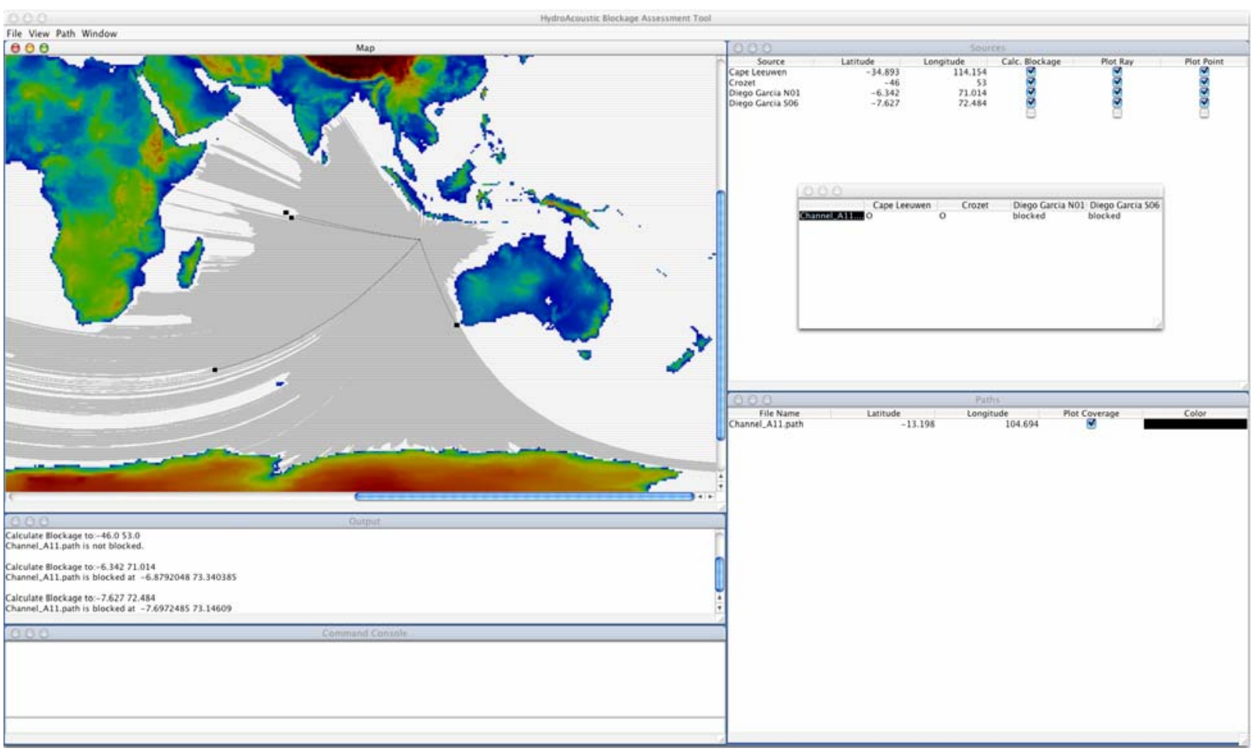

Figure 1. The HABAT tool user interface, showing the coverage map for source (A11) to the Cape Leeuwin, Crozet Island, Diego Garcia North, Diego Garcia South hydroacoustic stations in the Indian Ocean.

The user interface to the blockage assessment tool is shown in Figure 1. The tool is divided into several panels, including a scalable map of all input sources and monitoring stations with optional plotting of the coverage estimate, raypaths, travel time and attenuation contours. In the example above, a coverage map for source location (A11) from the 2003 Indian Ocean cruise is plotted, along with raypaths between the source and the Indian Ocean stations (Diego Garcia, Cape Leeuwin, and Crozet Island). The panel below the map shows an assessment of blockage to each station from a given source in list format. The rightmost panels are editable tables of station point locations (top) and source path locations (bottom). The tool provides an analysis for specific user-specified blockage criteria given in depth cutoff criteria. A 1,000 m cutoff criteria, for example, means that a specific source-receiver path is considered blocked if bathymetry above 1,000 m is encountered anywhere along the path. The coverage estimate shown in Figure 1 was based on the simple assumption that the source is blocked if the bathymetry cuts the sound channel axis. For that criteria, the prediction is that the source will be blocked at both Diego Garcia North and South, but visible at Cape Leeuwin and Crozet.

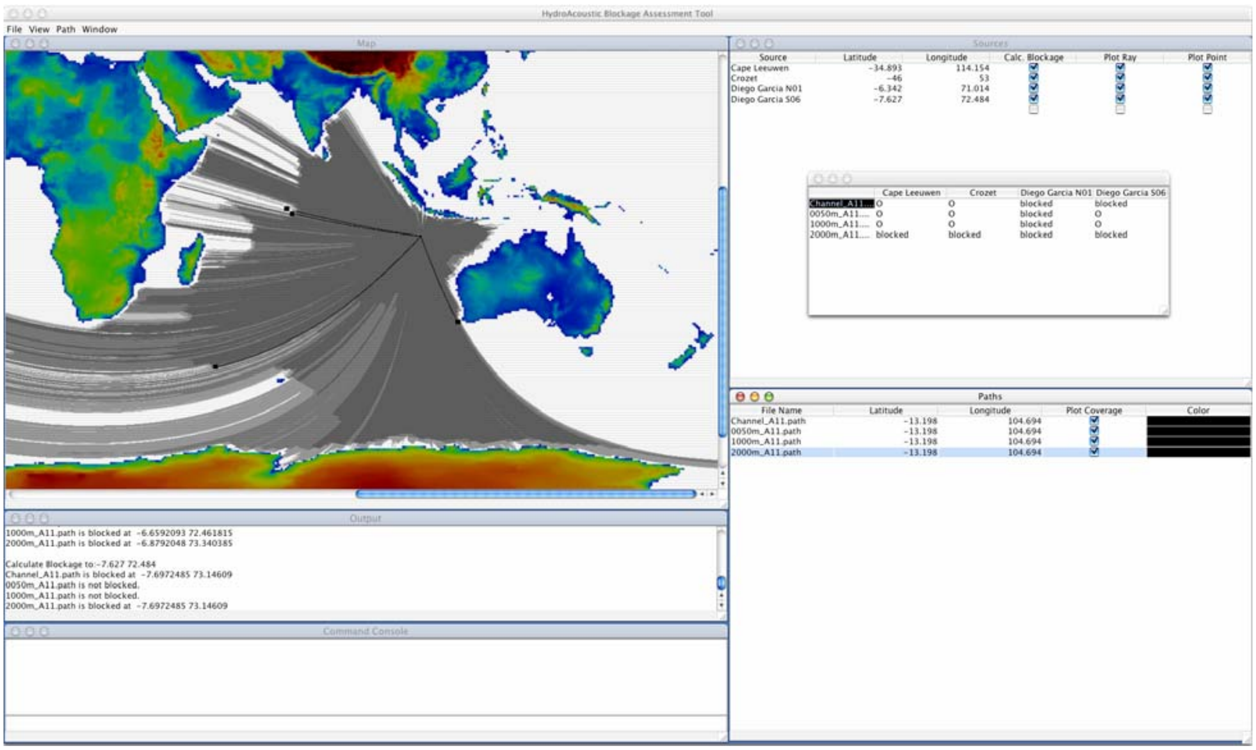

Figure 2. The user interface showing coverage maps for multiple blockage criteria. Source (A11) to Cape Leeuwin, Crozet Island, Diego Garcia North, Diego Garcia South.

Figure 2 shows the how the blockage prediction changes for based on different blockage criteria. In this case, path files produced by HydroCAM were based on a number of cutoff criteria from 2,000 m to sea level. In general, more blocked paths are predicted with deeper cutoff criteria. The tool is written so that an analyst can interact with multiple files simultaneously, allowing for comparison and analysis of multiple sources, stations, and blockage criteria. The coverage maps, raypaths, station and source locations can all be plotted and evaluated together or individually as desired.

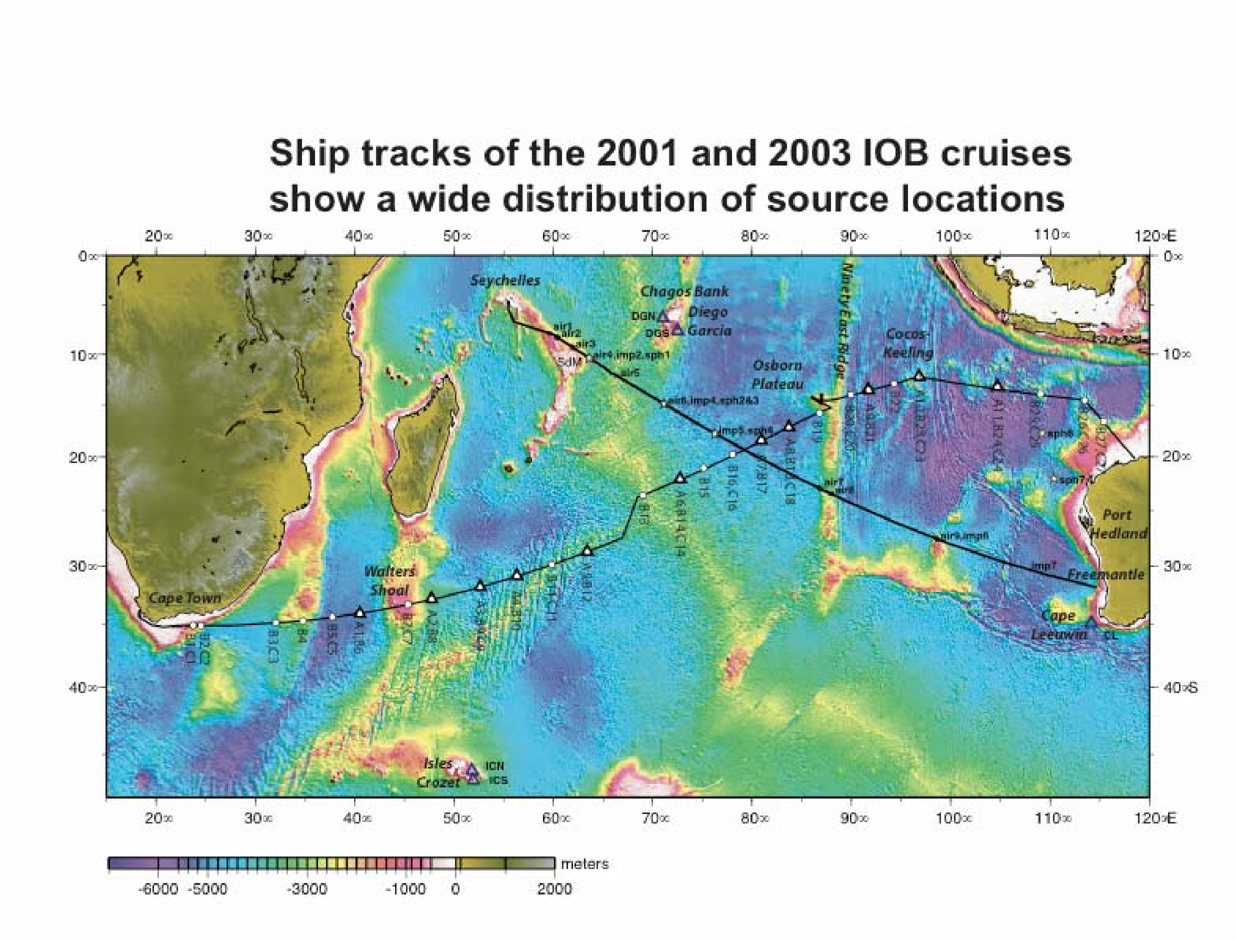

Figure 3. The Indian Ocean basin map shows the ship track of the 2001 cruise (Seychelles –Freemantle) and the 2003 cruise (Cape Town – Darwin) and the locations of all SUS, sphere, and airgun sources.

In order to evaluate blockage criteria we need to compare the model-based estimates to actual measurements. We've begun to address this using data from the 2003 Indian Ocean cruise. The 2003 cruise sailed along a track from Cape Town, South Africa to Darwin, Australia (Harben et al., 2004; Figure 3). The experiment resulted in 13 ground truth events which were detected at 1 or more of the hydroacoustic stations, including 40-50 individual waveforms of both SUS and imploding sphere sources. We measured the spectra from each of the explosive source charges at each of the Indian Ocean stations (Diego Garcia North and South, Cape Leeuwin, and Crozet Island). Figure 4 shows the observation of the SUS source from location A07 at stations DGN and DGS. Note that the signal spectra exceeds pre-event noise levels for both stations at frequencies above 30 Hz., and that the true and measured source-receiver backazimuths match within a few degrees, verifying that this source was detected at both stations. Because a non-detection of a source could be due either to blockage along the source-receiver path or attenuation of the signal over distance, it's helpful to have measurements at several stations to compare with one another. DGN and DGS are an excellent pair of stations to evaluate blockage criteria, because they are located close to one another, but are in a region with significant bathymetric features which result in very different blockage predictions for each. Thus, an event which is observed at one site should be observed at the other, unless there is a true blockage along the path. This allows us to evaluate blockage as a function of frequency and bathymetry. This is illustrated in Figure 5 for the SUS source from location A11.

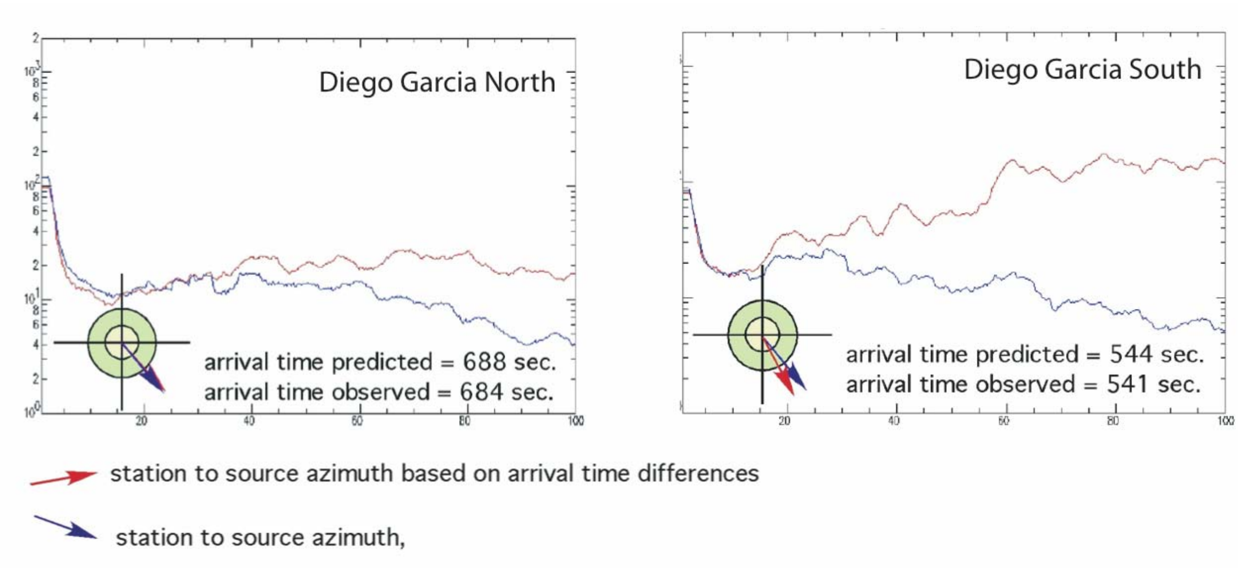

Figure 4. Spectra of the signal (red) and pre-event noise levels (blue) for the A07 SUS charge source at the Diego Garcia North and South hydroacoustic monitoring stations. The horizontal scale is frequency in Hz.

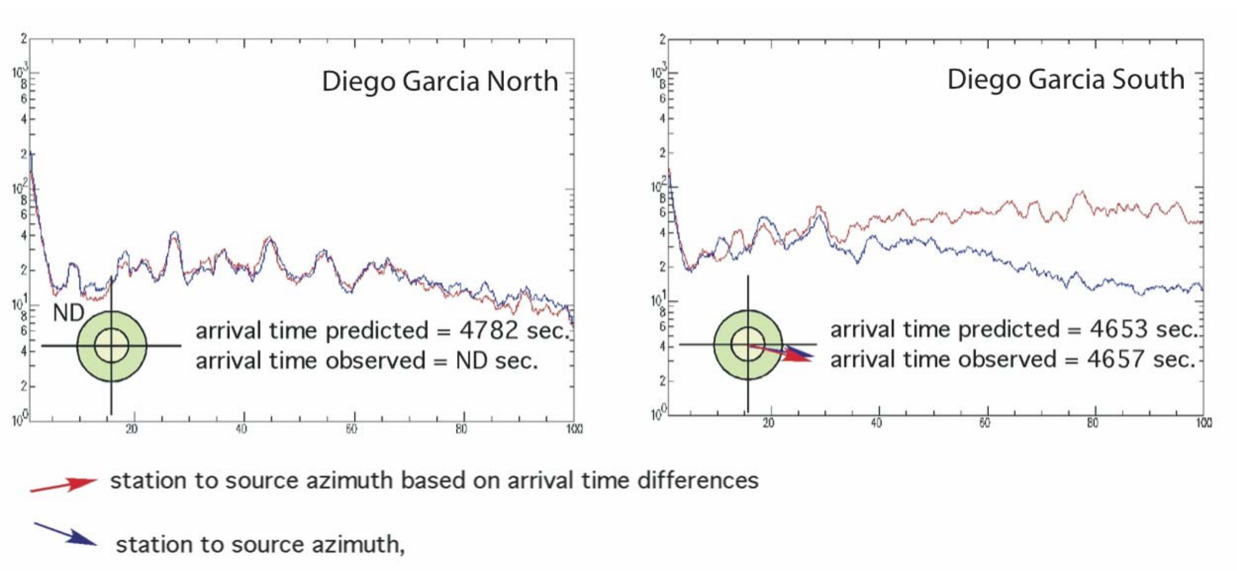

Figure 5. Spectra of the signal (red) and pre-event noise levels (blue) for the A11 SUS charge source at the Diego Garcia North and South hydroacoustic monitoring stations. The horizontal scale is frequency in Hz.

Predictions based on Different Blockage Criteria

50 m

	Cape Leeuwen	Crozet	Diego Garcia N01	Diego Garcia S06
0050m_A01....	O	O	O	O
0050m_A02....	blocked	O	O	O
0050m_A03....	O	O	O	O
0050m_A04....	O	O	O	O
0050m_A05....	blocked	O	O	O
0050m_A06....	O	O	O	O
0050m_A07....	O	O	O	blocked
0050m_A08....	O	O	O	O
0050m_A09....	O	O	blocked	O
0050m_A11....	O	O	blocked	O

1000 m

	Cape Leeuwen	Crozet	Diego Garcia N01	Diego Garcia S06
1000m_A01....	O	O	O	blocked
1000m_A02....	blocked	O	O	O
1000m_A03....	blocked	O	O	O
1000m_A04....	blocked	O	O	O
1000m_A05....	O	blocked	O	O
1000m_A06....	blocked	O	O	O
1000m_A07....	O	O	blocked	blocked
1000m_A08....	O	O	blocked	O
1000m_A09....	O	blocked	blocked	blocked
1000m_A11....	O	O	blocked	O

Channel

	Cape Leeuwen	Crozet	Diego Garcia N01	Diego Garcia S06
Channel_A01....	blocked	O	blocked	blocked
Channel_A02....	blocked	O	O	O
Channel_A03....	blocked	O	blocked	O
Channel_A04....	blocked	O	blocked	O
Channel_A05....	blocked	O	O	O
Channel_A06....	blocked	O	blocked	blocked
Channel_A07....	O	O	O	blocked
Channel_A08....	O	O	blocked	blocked
Channel_A09....	O	O	blocked	O
Channel_A11....	O	O	blocked	blocked

Figure 6. Blockage predictions based on various blockage criteria: (top) bathymetry < 50 m, (middle) bathymetry < 1000 m, (bottom) bathymetry cuts the sound channel axis. The names A01-A11, in the first column, refer to the source locations from the Indian Ocean cruise experiment

Figure 6 shows the several blockage predictions for the 2003 Indian Ocean Experiment sources (A01-A11) to each of the Indian Ocean hydroacoustic stations: Cape Leeuwin, Crozet, Diego Garcia North (DGN), and Diego Garcia South (DGS). Note the significant differences in the source-receiver path blockage predictions. For example, the predictions for DGN range from nearly all unblocked given the least restrictive criteria (top) to nearly all blocked given the most restrictive criteria (bottom). The actual observations are shown in Figure 7 and listed for simplicity merely as “observed” or “no-detection”. Note that none of the simple ray-based blockage criteria match all the observations. For example, DGN is best matched by the most restrictive “bathymetry cuts Channel axis” criteria: only 2 of the sources (A2 and A7) were well observed. On the other hand that criteria is far too restrictive for the nearby station DGS. Notice also, that even the least restrictive criteria predict that the path from A07 to DGS will be blocked although, in actuality, it is well observed (Figure 4). This prediction error is due to a small feature roughly 100 km from the station and is the result of the ray based nature of the calculation.

Measured

	Cape Leeuwen	Crozet	Diego Garcia ...	Diego Garcia ...
A1	ND	O	–	–
A2	O	ND	O	ND
A3	ND	ND	ND	ND
A4	ND	O	ND	O
A5	ND	O	ND	ND
A6	O	O	ND	O
A7	O	O	O	O
A8	O	O	?	O
A9	O	O	ND	O
A11	O	O	ND	O

Figure 7. Indian Ocean Experiment – source observations. (ND) no detection. (O) observed source. (?) possible detection. (–) no data. The names A1-A11, in the first column, refer to the source locations from the Indian Ocean cruise experiment. Compare to the estimates in Figure 6.

CONCLUSIONS AND RECOMMENDATIONS

We are continuing the development of the Hydroacoustic Blockage Assessment Tool and using it in conjunction with Indian Ocean data to derive a set of blockage criteria. The fundamental objective is to provide a robust prediction about which hydroacoustic monitoring stations can be used in discrimination analysis for any particular event. Currently, we are limited by the small set of ground-truth data and the limitations of ray theory in defining path-stop conditions. It is apparent that blockage is not a simple phenomenon, but as we continue to collect network data we should be able to develop coverage, propagation and attenuation maps for each of the hydroacoustic stations and develop the basic criteria for establishing blockage in the ocean at large.

REFERENCES

Harben, P. E., E. Matzel, D. K. Blackman, and D. Clarke (2004), Diego Garcia Reflections and Implosion Source Development, in *Proceedings of the 26th Seismic Research Review: Trends in Nuclear Explosion Monitoring,* LA-UR-04-5801, Vol. 2, pp. 553-562.

Pulli, J.J., Z. Upton, R. Gibson, J. Angell, T. Farrell, and R. Nadel (2000), Characterization of Reflected Arrivals and Implications for Hydroacoustic Test-Ban-Treaty Monitoring, *BBN Tech. Memor.* W1380.