AZIMUTHAL DEPENDENCE OF HYDROACOUSTIC BLOCKAGE AT DIEGO GARCIA AND IMPLICATIONS FOR DISCRIMINATION

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ABSTRACT

An understanding of hydroacoustic blockage around bathymetric features serves many purposes in ocean monitoring. These include the planning of station placement, estimation of network detection thresholds, and the evaluation of evasion scenarios. Our early estimates of hydroacoustic blockage in the Indian Ocean (Pulli and Upton, 2001) utilized ray based propagation models and binary blockage estimates based on a variety of environmental criteria. These models predicted, for example, that T-waves from events along the Sumatran Arch would not be seen at the north array of Diego Garcia. However, once actual data were accumulated for the Diego Garcia arrays, observations showed that paths that were predicted to be blocked were actually attenuated, often by approximately 30 dB. Possible mechanisms for this process include diffraction around the island, refraction, and perhaps acoustic-to-seismic-to-acoustic conversion.

In order to better under the azimuthal and frequency dependence of blockage around Diego Garcia, we have accumulated a dataset of earthquake sources located around the atoll and recorded by both the north and south arrays. The goal is to assemble a virtual array of sources for high-resolution studies. For example, events to the west of Diego Garcia include those occurring along the Carlsberg Ridge and Chagos Archipelago. A typical blockage value from the north to the south arrays is approximately 30 db. To the east of Diego Garcia, the recent sequence of events along Sumatra provides a vast amount of data for analysis. Blockage estimates here are about 25 dB. To the south of Diego, events along the Mid-Indian Ridge are used. For each event, the spectrum of the T-wave recorded on the north and south arrays is measured and compared.

To understand the implications of these measurements for detection and discrimination, we combine these measurements with our studies of T-wave amplitudes (sound pressure levels) versus seismic magnitude (Pulli et al., 2005). These studies indicate a near-linear trend of 15 dB/Mw. Broadband background noise levels at Diego North are approximately 90–95 dB and at Diego South they are 95–100 dB. Combining these measurements with an average blockage value of 30 dB, we estimate that blocked signals from events along the Sumatran arch can still be detected if the event is at least magnitude 4.5. Spectral decay of T-waves averages 1.5 dB/Hz above 1 Hz. Hence, by 30 Hz, the high frequencies of the blocked signals at the minimum detection level will be below the noise. Discriminants based on the ratio of high-frequency to low-frequency energy will thus not work for these small events. However, bubble-pulse frequencies are typically lower than 10 Hz, so cepstral parameters may still be able to separate underwater explosions from nonexplosions using these low amplitude blocked signals.

OBJECTIVES

The overall objective of this effort is to improve our understanding of the effects of bathymetric blockage and reflection on hydroacoustic signals and to use this understanding to assess the effects on hydroacoustic signal discrimination. The specific tasks include the following:

- A study of the azimuthal and frequency dependence of blockage at Diego Garcia using virtual arrays of earthquake sources surrounding the atoll.
- The identification of prominent bathymetric reflectors in the Indian, Atlantic and Pacific Oceans using both contemporary and historic hydroacoustic data.
- The selection of a specific source-reflector-receiver scenario which will be used to model and analyze the reflection process; this effort is being conducted in conjunction with Lawrence Livermore National Laboratory.
- An analysis of the effects of blockage and reflection on the hydroacoustic discrimination process.

RESEARCH ACCOMPLISHED

Introduction

During the first few months of this effort, we have focused on the task of determining the azimuthal and frequency dependence of blockage at Diego Garcia. An understanding of hydroacoustic blockage around bathymetric features serves many purposes in ocean monitoring. These include the planning of station placement, estimation of network detection thresholds, and the evaluation of evasion scenarios. Our early estimates of hydroacoustic blockage in the Indian Ocean (Pulli and Upton, 2001) utilized ray based propagation models and binary blockage estimates based on a variety of environmental criteria. However, once actual data were accumulated and analyzed for the Diego Garcia arrays, observations showed that the blockage process was more complicated and could not be predicted by these simple models. Possible mechanisms for this process include diffraction around the island, refraction, and perhaps acoustic-to-seismic-to-acoustic conversion.

In order to better understand this process, our approach is to make blockage measurements at nearly all angles around the archipelago. To make these measurements, we are utilizing a ground-truth database of seismic events in the Indian Ocean that we have accumulated during the time period of 2000–2005 (we continue to accumulate ground truth events as they occur). This database now includes nearly 200 events (see Figure 1). Many events were added during 2005; most of these events occurred along the nearly 1000-km long aftershock zone of the December 26, 2004, Sumatra earthquake, which provides a high degree of azimuthal resolution to the east. The current azimuthal coverage for our database is shown in Figure 2.

To estimate the blockage function, we isolate the T-wave signal for each event at both the north and south array elements, then compute it's spectrum around the mode-1 arrival (peak amplitude of the signal train, window lengths typically 16 or 32 seconds; the time series are first detrended and a 30% cosine taper is applied before the FFT is computed). The spectra are then averaged over the three array elements for the north and south arrays. We define the blockage function as the difference in the spectral amplitudes between the north and south arrays. These measurements can then be utilized in other studies that are attempting to model the blockage process using an adiabatic mode parabolic equation model (AMPE) (Upton et al., 2005).

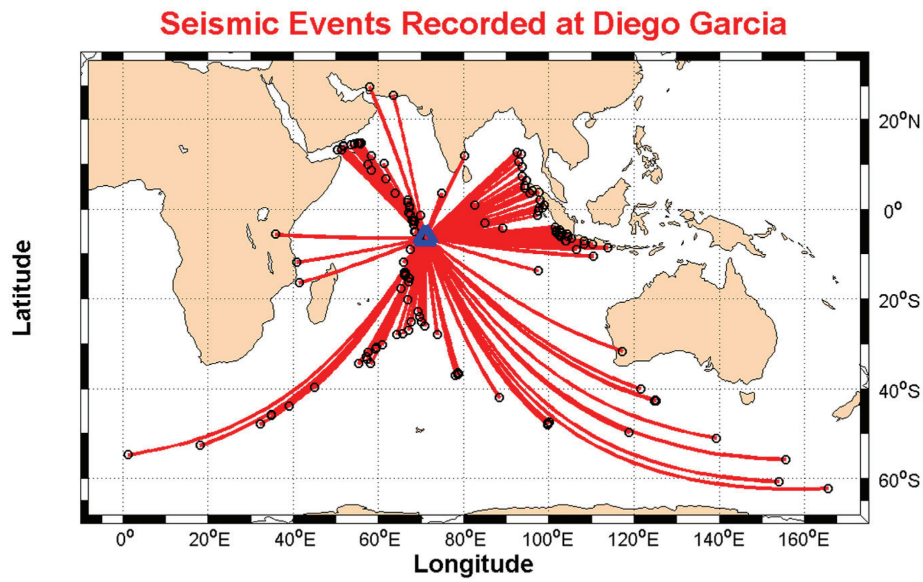

Figure 1. Locations of events in the Indian Ocean used to measure the azimuthal and frequency dependence of blockage at Diego Garcia.

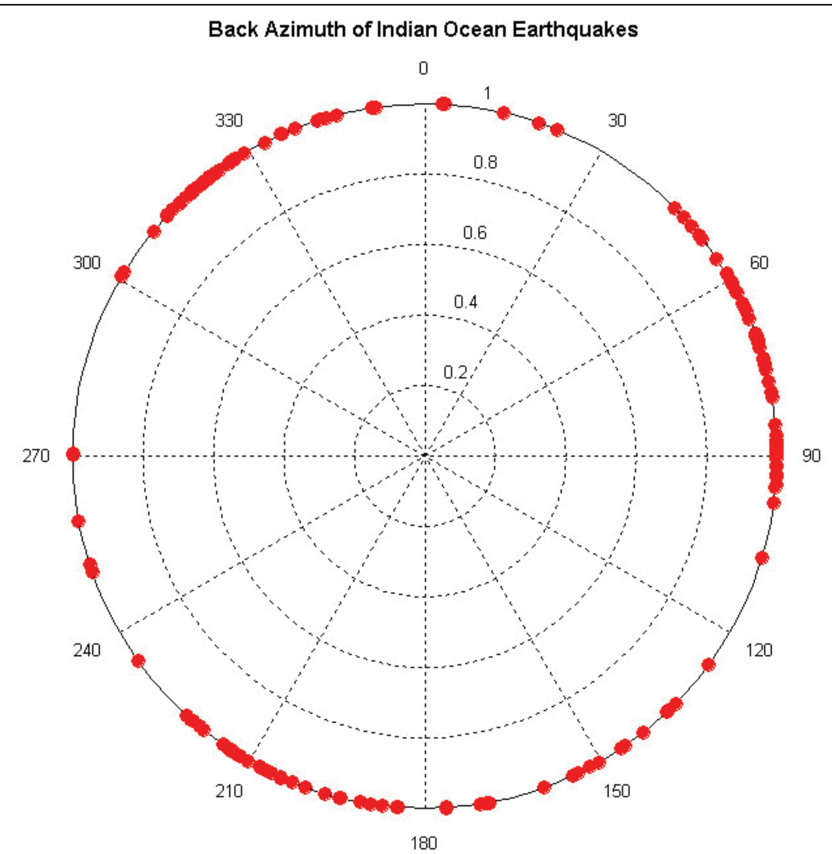

Figure 2. Azimuthal coverage of events and blockage estimates at Diego Garcia.

Examples of Blockage at Diego Garcia – East and West Sources

We now illustrate some blockage measurements at Diego Garcia using signals from the east and west of the atoll. The first example uses the T-wave signals generated by the great Sumatran earthquake of December 26, 2004. Hydroacoustic waveforms for this event recorded at Diego Garcia are shown in Figure 3. In this case, the T-wave signal at the north array is partially blocked by the atoll. In Figure 4, we show the spectra of these T-waves, and the estimate of the blockage function is approximately –32 dB over the frequency band of 5–40 Hz.

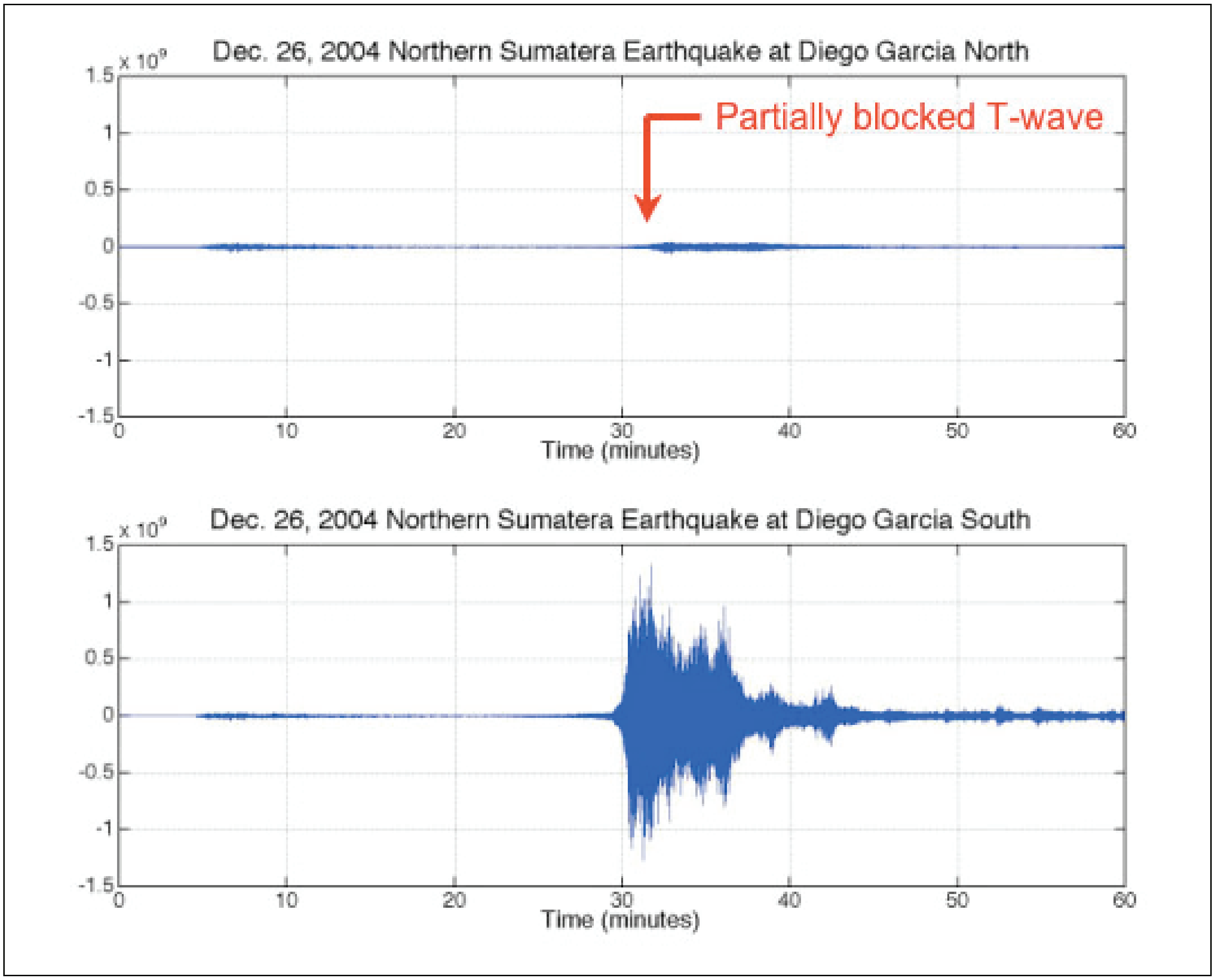

Figure 3. Hydroacoustic waveforms for the December 26, 2004, Sumatra earthquake recorded at Diego Garcia North (top) and South (bottom). The T-wave signal at the north station is partially blocked, but because the event was so large, the signal-to-noise ratio of the partially blocked signal is also large and enables an accurate measurement of blockage.

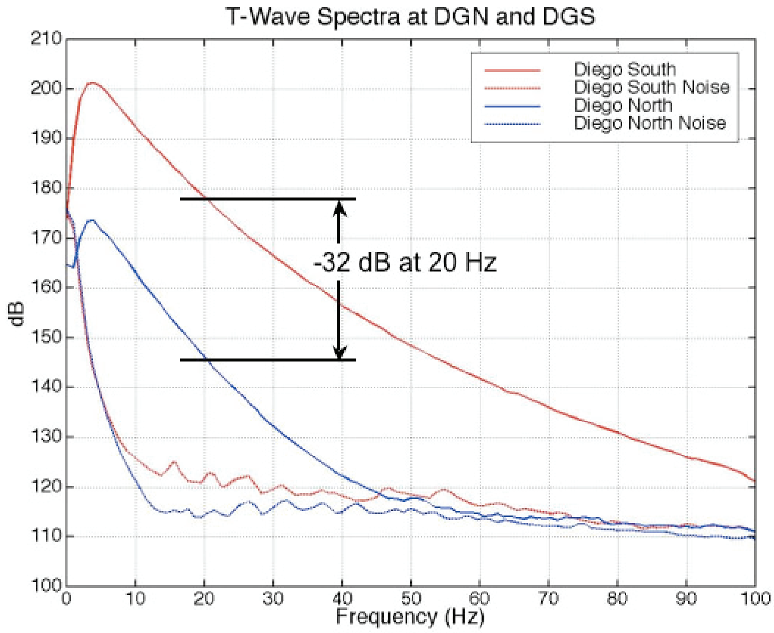

Figure 4. Spectra of T-waves for the December 26, 2004, Sumatra earthquake recorded at Diego Garcia north and south arrays. There is a near-constant –32 dB difference in the signals (blockage) as a function of frequency.

Our second example is from the west of Diego Garcia; the event occurred on July 25, 2002, on the Chagos Archipelago. T-waves from this event at Diego Garcia are shown in Figure 5. Here we see the opposite effect from what was shown previously; here, the south station is partially blocked. The spectra of the T-waves are shown in Figure 6. From this direction, the blockage is approximately –20 db, lower than from the opposite side.

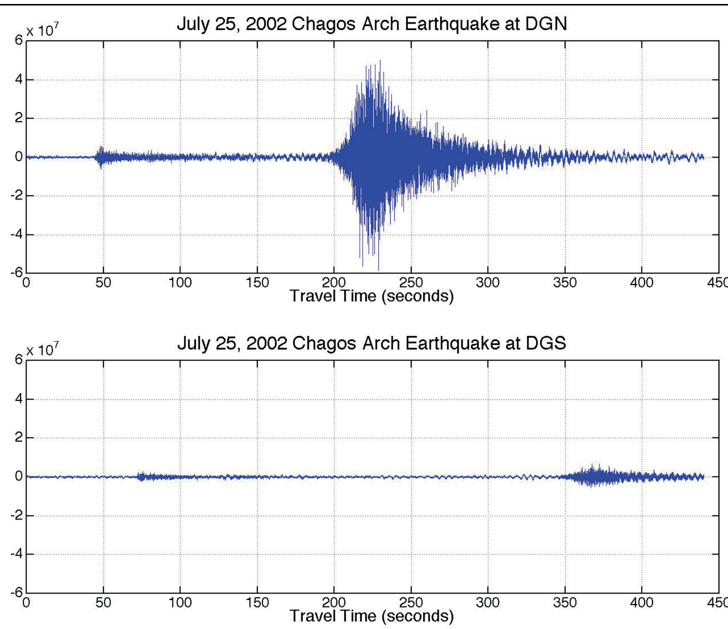

Figure 5. Hydroacoustic waveforms for the July 25, 2002, earthquake on the Chagos Archipelago, recorded at Diego Garcia North (top) and South (bottom). The T-wave signal at the south station is partially blocked.

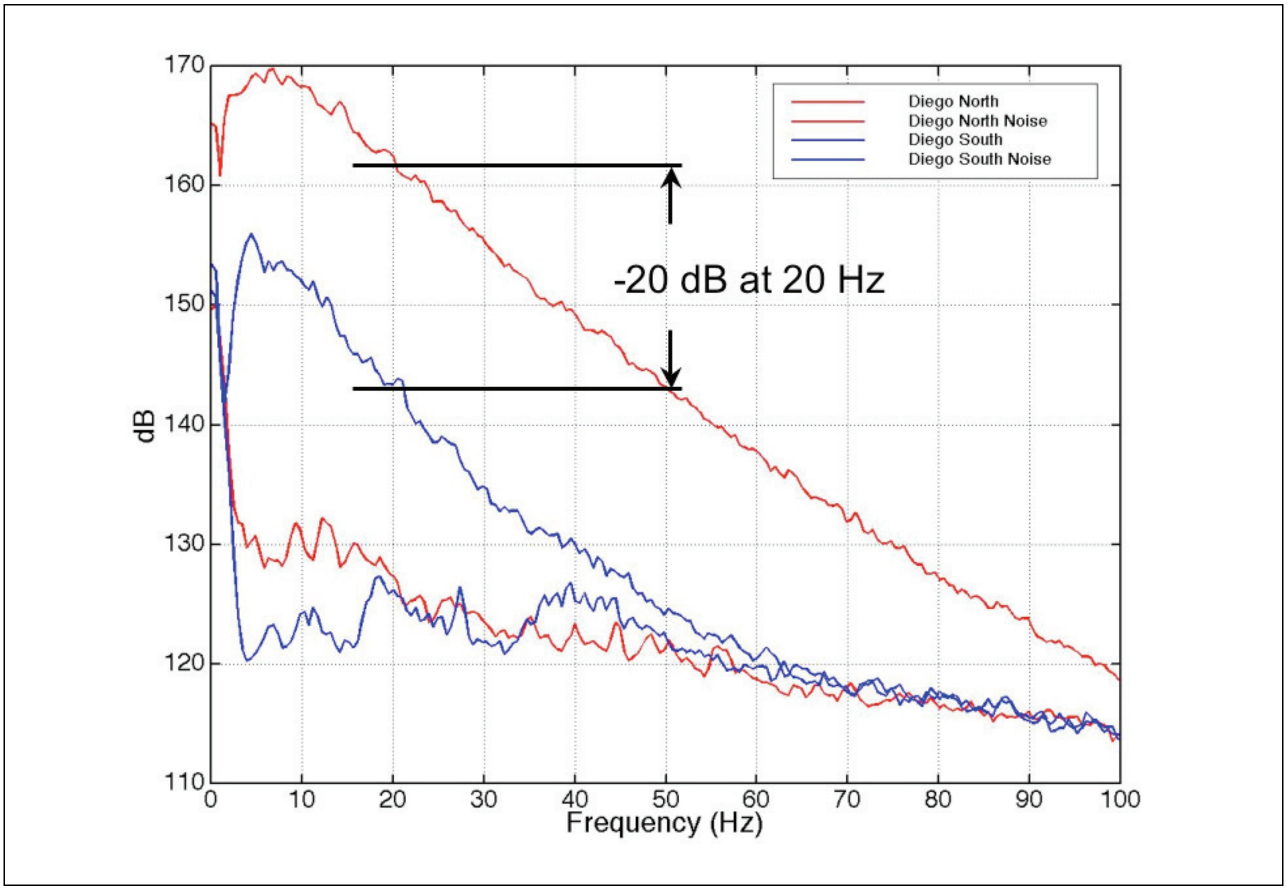

Figure 6. Spectra of T-waves for the July 25, 2002, Chagos Archipelago earthquake recorded at Diego Garcia north and south arrays. There is a near-constant –20 dB difference in the signals (blockage) as a function of frequency. Blockage in this direction (west-to-east) is lower than in the east-to-west direction.

Azimuthal Dependence

To date, we have performed the high-resolution blockage estimates using a group of earthquake sources in the Sumatra area. A map of these events is shown in Figure 7. For now, we have grouped the events into three categories: northern, central, and southern Sumatran events. The computed blockage functions for these three areas are shown in Figure 8. The general trend is for the blockage to decrease from north to south. For the northern group of events, the blockage averages 30 dB. For the central events, the blockage averages 26 dB. For the southern events, the blockage averages 23 dB.

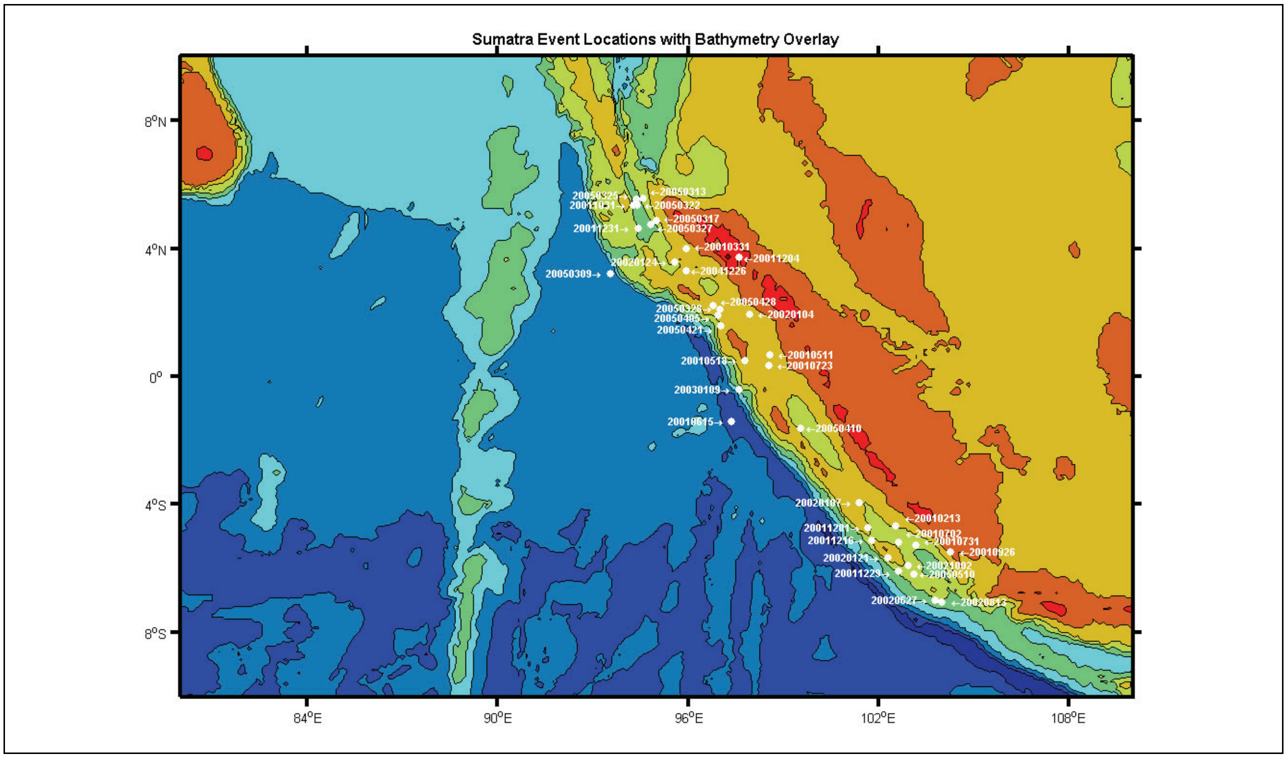

Figure 7. Map of events in the Sumatra area used to study the azimuthal dependence of blockage.

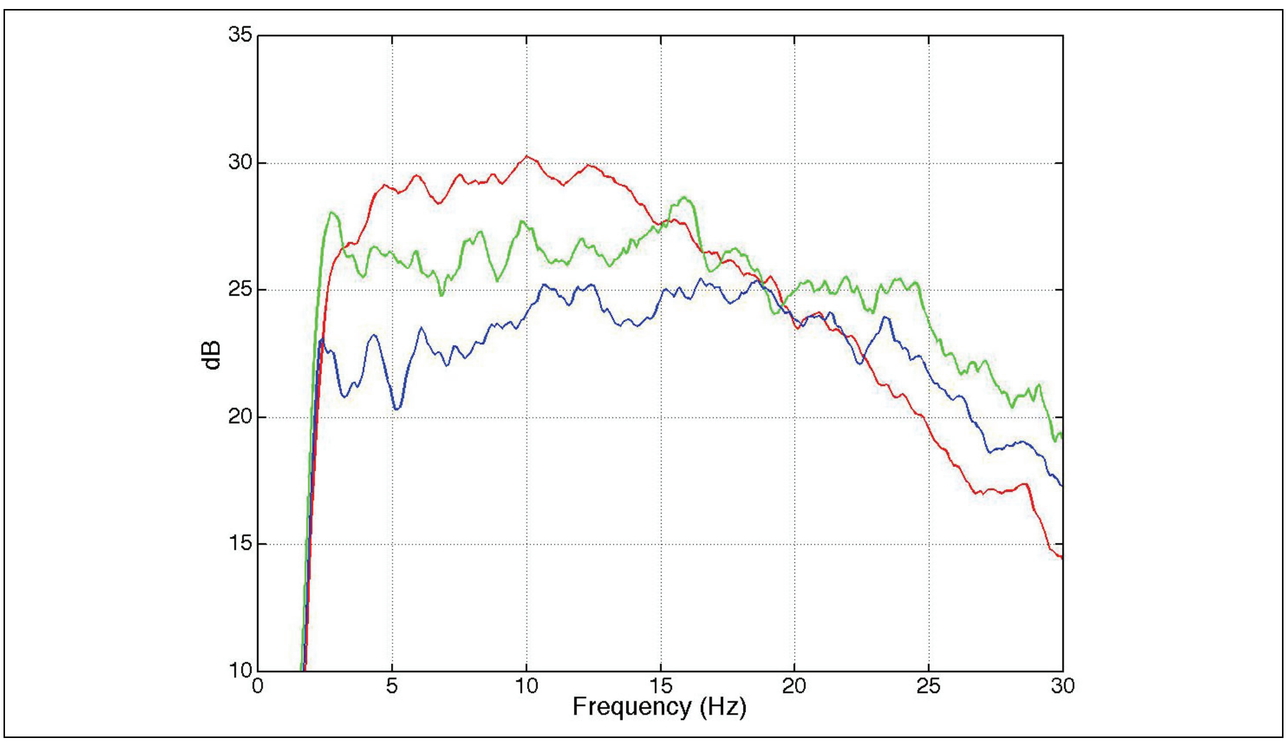

Figure 8. Blockage functions for events in the northern (red), central (green), and southern (blue) source zones of Sumatra.

Implications for Hydroacoustic Discrimination

To understand the implications of these measurements for detection and discrimination, we combine these measurements with our studies of T-wave amplitudes (sound pressure levels) versus seismic magnitude (Pulli et al., 2005). These studies indicate a near-linear trend of 15 dB/Mw. Broadband background noise levels at Diego North are approximately 90–95 dB and at Diego South they are 95–100 dB. Combining these measurements with an average blockage value of 30 dB, we estimate that blocked signals from events along the Sumatran Archipelago can still be detected if the event is at least magnitude 4.5. Spectral decay of T-waves averages 1.5 dB/Hz above 1 Hz. Hence, by 30 Hz, the high frequencies of the blocked signals at the minimum detection level will be below the noise. Discriminants based on the ratio of high-frequency to low-frequency energy will thus not work for these small events. However, bubble-pulse frequencies are typically lower than 10 Hz, so cepstral parameters may still be able to separate underwater explosions from nonexplosions using these low-amplitude blocked signals. These in-water sources have a relatively higher signal amplitude since the acoustic energy is directly coupled and is not going through the seismic-to-acoustic conversion process of T-waves.

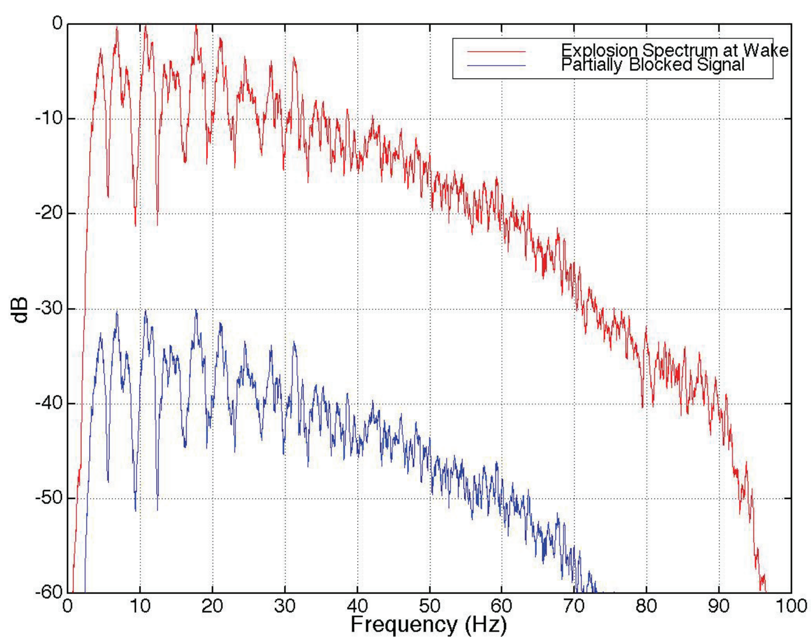

Figure 9. Hydroacoustic recording of the IITRI underwater explosion made at Wake Island (red). Note the bubble pulse and water reverberation effects in the signal below 30 Hz. The blue curve indicates the same spectrum attenuated by a 30 dB blockage function. Since signal levels are higher for in-water explosions than for sub-sea earthquakes, even blocked signals should be relatively easy to discriminate if their signal-to-noise ratio is at least 40 dB.

CONCLUSIONS AND RECOMMENDATIONS

During the first few months of this study, we have established the azimuthal dependence of blockage around Diego Garcia. In the examples shown in this paper, east-to-west, the blockage is approximately –30 dB, whereas from west-to-east the blockage is –20 dB. We also see azimuthal variations over small azimuth swaths, such as from the Sumatra area. Over the course of this program, we will evaluate the blockage's azimuthal dependence and endeavor to databases showing the complex bathymetric structure of the Chagos Archipelago. A full 360-degree survey will be presented later in this effort.

ACKNOWLEDGEMENTS

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