MODELING LONG-RANGE HYDROACOUSTIC REFLECTIONS IN THE ATLANTIC AND PACIFIC OCEANS

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Sponsored by the Defense Threat Reduction Agency
Arms Control Technology Division
Nuclear Treaties Branch

Contract Number DSWA01-97-C-0164

ABSTRACT

It is well known that acoustic energy that is trapped in the ocean's SOFAR channel can propagate for thousands of kilometers with little attenuation. When this energy encounters bathymetric features that intersect the SOFAR channel (e.g. islands, seamounts, and continental margins), it can be scattered and reflected back into the ocean. Historical data from many underwater explosions show large reflections arriving at receivers tens of minutes or hours after the direct arrival. If the sources of the bathymetric reflections can be identified, these reflected raypaths could then be used to improve the source localization. Spectral characteristics of the reflected signals are also similar to those of the direct arrivals and hence contain valuable information about the source. In some cases, such as when the direct source-receiver path is blocked by bathymetry, the only observable arrivals may be reflections.

Here we present a model for predicting long-range hydroacoustic reflections in the ocean. For a given source location, we use the program HydroCAM to predict ray paths, travel times and propagation losses to each potential scattering patch in the ocean. We then perform a second prediction where rays are computed from the receiver location to the scattering patches. These two results are combined to produce predictions of the bistatic ray path characteristics from the source to the scattering regions to the receiver location. We sort these calculations by time, starting with the direct arrival and extending in constant travel time ellipses out to a given time delay (e.g. 60 minutes past the direct arrival). For each travel time ellipse, we select the bathymetric features along that ellipse with slopes in the direction of propagation greater than a prescribed minimum. If these features intersect the SOFAR channel, their times and locations are stored and used to form an impulse response model of the ocean. Amplitudes are scaled by both propagation loss and an approximation to bathymetric scattering strength. This impulse response is then convolved with a model of the source time envelope to produce a synthetic waveform.

The model has been compared with recorded data for events in both the Pacific and Atlantic Oceans. For the Pacific, we modeled the signal from the IITRI underwater explosion, conducted off the coast of California on February 16, 1968. Recordings of this explosion from hydrophones off Midway Island show a prominent reflected arrival 20 minutes after the direct arrival. This corresponds with the model prediction of a reflection from the Aleutian Islands. For the Atlantic, we modeled the signal from the Chase 21 explosion off the coast of New Jersey in 1970 and recorded off Ascension Island. The reflected arrival seen in the data 9 minutes after the direct arrival corresponds with the model prediction of a reflection from the Guiana Plateau.

OBJECTIVE

Historical and contemporary hydroacoustic data from many underwater explosions and sub-sea earthquakes show large reflections arriving at receivers tens of minutes or hours after the direct arrival (Northrop, 1968). These reflections can be used for localization purposes as long as the sources of the bathymetric reflections can be identified. Spectral characteristics of the reflected signals are also similar to those of the direct arrivals and hence contain valuable information about the source. In some cases, such as when the direct source-receiver path is blocked by bathymetry, the only observable arrivals may be reflections. The objective of this work is to provide a model basis for interpreting these reflected arrivals.

The need for an understanding of hydroacoustic reflections was recognized in the recent International Workshop on Hydroacoustic Monitoring for the Comprehensive Nuclear-Test-Ban Treaty that met in Tahiti in September 1999 (Massinon, 1999). The workshop findings identify research on hydroacoustic reflections as a technical issue and recommend that an assessment be made of their utility for the hydroacoustic localization problem.

RESEARCH ACCOMPLISHED

Overview of the Model

The model we have developed can best be described as a sequence of applied steps:

- For a given source location, we use the program HydroCAM (Farrell et al, 1997) to predict ray paths, travel times, and propagation losses to each potential scattering patch for a given ocean basin.
- Then, a second prediction is made where rays are computed from the receiver to each of these scattering patches.
- These two calculations are combined to produce predictions of the bistatic ray path characteristics from the source to the scattering regions and then to the receiver location.
- Next we sort these calculations by time, starting with the direct arrival and extending in constant travel time ellipses out to a given time delay (e.g. 60 minutes past the direct arrival).
- For each travel time ellipse, we select the bathymetric features along that ellipse with slopes in the direction of propagation greater than a prescribed minimum. The determination of slope, although simple in concept, was actually rather difficult to implement because of the relatively low resolution of available bathymetry for an entire ocean. We settled on a measure of the total relief (difference between maximum and minimum depths) of a given patch as an approximation to the actual slope.
- By combining the ray paths that correspond to the selected patches, we obtain an impulse response model of the ocean for the given source-receiver configuration.
- Each bathymetric feature will only reflect hydroacoustic energy if it penetrates the SOFAR channel axis where the energy is propagating. This is illustrated conceptually in Figure 1. The measure we use of this scattering strength is the difference between the bathymetric feature depth and the depth of the sound channel axis at this point. An arctangent function is used for the model (Figure 2). SOFAR channel depths were obtained from the "Database Description for the Master Generalized Digital Environment Model (GDEM), Version 5.0". SOFAR channel data are generally not available at the same resolution as bathymetry data, so a 2-D interpolation must be made before the two databases can be compared.
- Amplitudes for each path are then scaled by both propagation loss and attenuation.
- Finally, the impulse response model is convolved with a source model based on the envelope of the direct arrival.

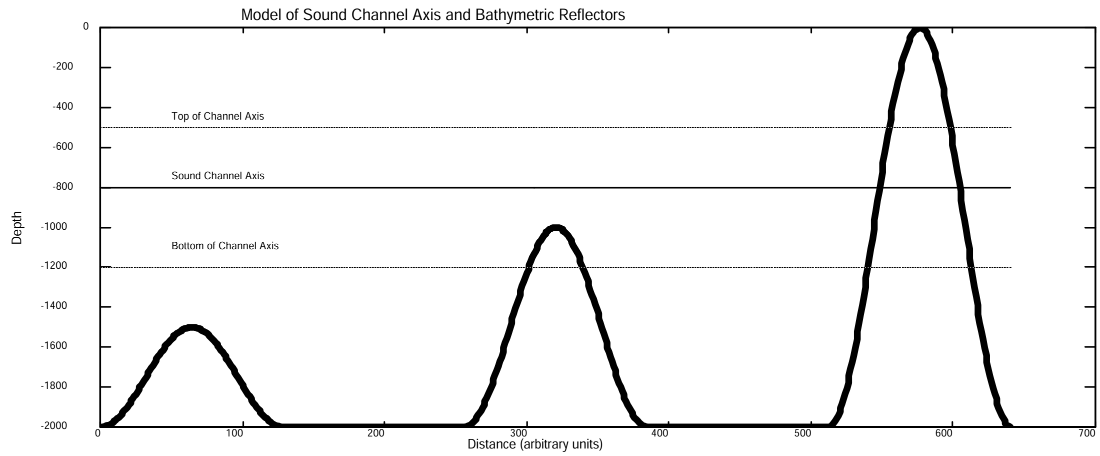

Figure 1. Conceptual model of three bathymetric features and their relationship to the sound channel axis (SCA). The feature on the left is below the sound channel and will not reflect energy in the sound channel. The feature in the middle penetrates the lower range of the sound channel and will reflect some energy. The feature on the right (e.g. an island) spans the entire sound channel and will efficiently reflect the energy.

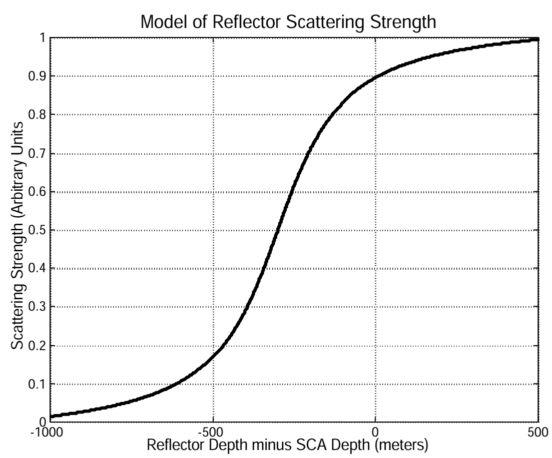

Figure 2. Model for scattering strength of a bathymetric feature versus its depth with respect to the SCA. Features which are well below the SCA will not reflect hydroacoustic energy, whereas features near or above the SCA will reflect energy. This is modeled with an arctangent function.

Pacific Example

Our first application of the model will be for the IITRI underwater explosion recorded at the hydrophone off Midway Island (see Figure 3). This explosion occurred on February 16, 1968 and was located in deep water off the coast of San Diego. The direct arrival is recorded at Midway at a travel time of 60 minutes; a prominent reflection can be seen arriving 15 minutes later.

The bathymetric feature finder was run for a travel time window of between 55 and 100 minutes, which should include reflected arrivals corresponding to the available data. The algorithm identified 241 possible bathymetric features, shown on the map in Figure 4. A histogram of the feature depth is shown in Figure 5. Most features are located at depths of between 750 and 1500 meters. A histogram of the sound channel axis depth in the Pacific is shown in Figure 5, where it can be seen that the sound channel axis occurs mostly at depths of between 600 and 1200 meters. Hence many of the identified bathymetric features should reflect hydroacoustic energy from the SOFAR channel.

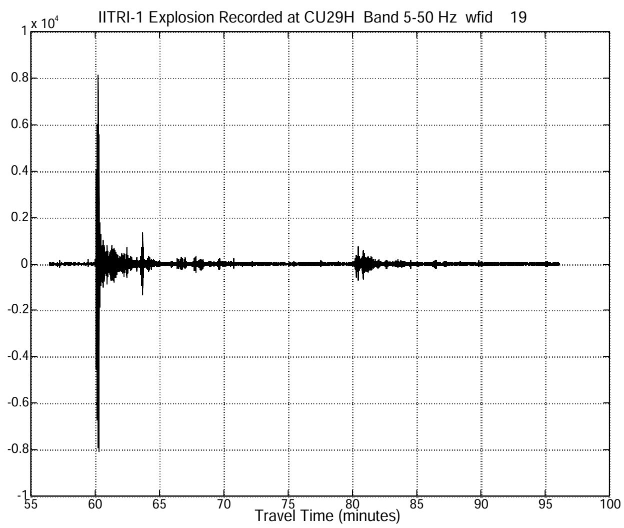

Figure 3. Recording of the IITRI underwater explosion at station Midway.

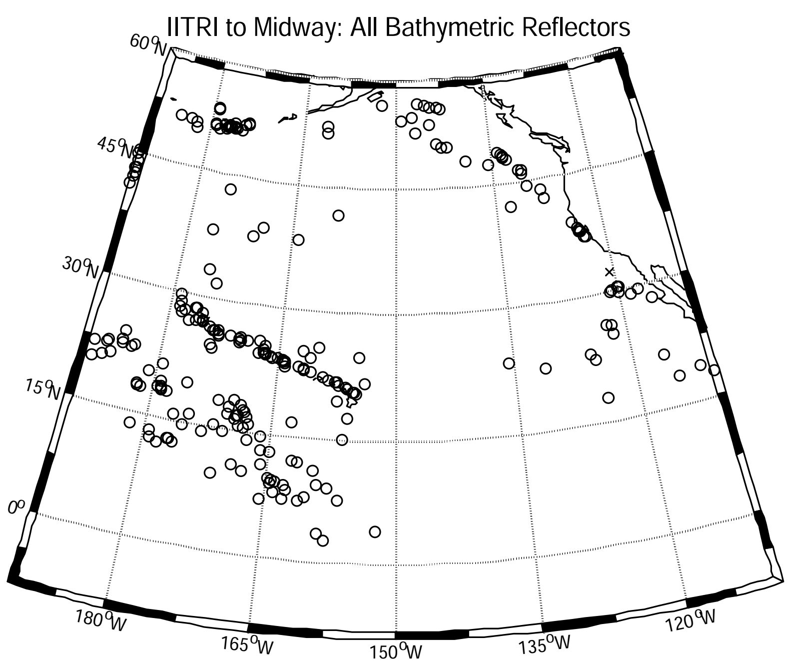

Figure 4. Map of bathymetric reflectors for the case the IITRI explosion recorded at Midway.

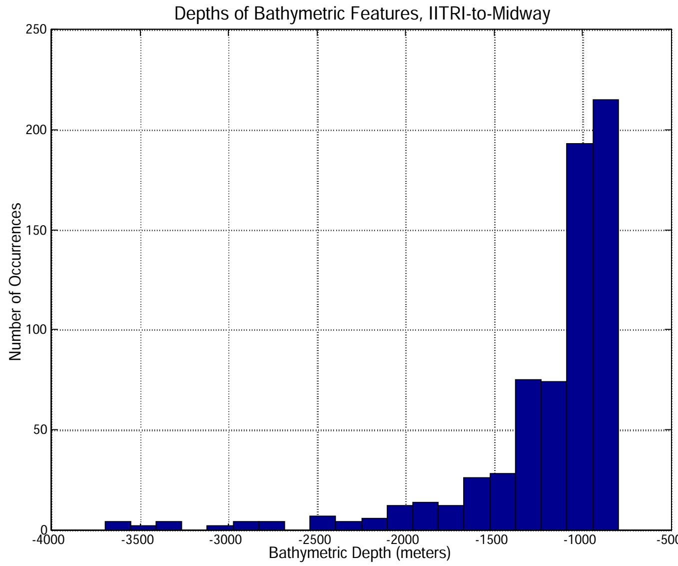

Figure 5. Histogram of bathymetric feature depths in the Pacific for the IITRI to Midway case.

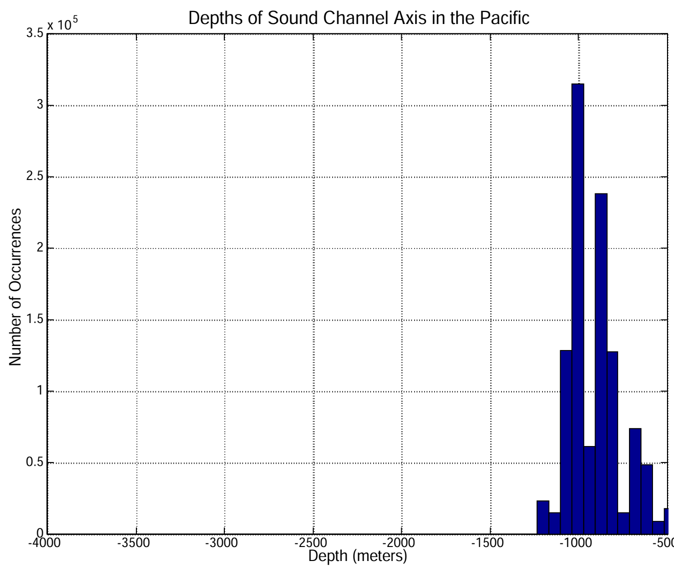

Figure 6. Histogram of sound channel axis depths in the Pacific.

Figure 7 shows the impulse response model derived from the bathymetry analysis. The amplitude corresponding to each scatterer has been scaled with the function shown in Figure 2 as well as with geometrical spreading and attenuation. After the direct arrival at 60 minutes, there is a decaying sequence of impulses with large reflections at 64 minutes and 80 minutes. Figure 8 shows the final output of the model where the impulse response has been convolved with a source envelope model.

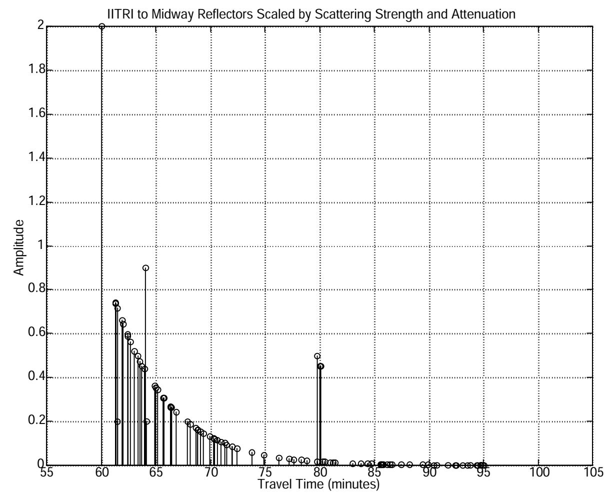

Figure 7. Impulse response model of the Pacific for the case of IITRI to Midway Island.

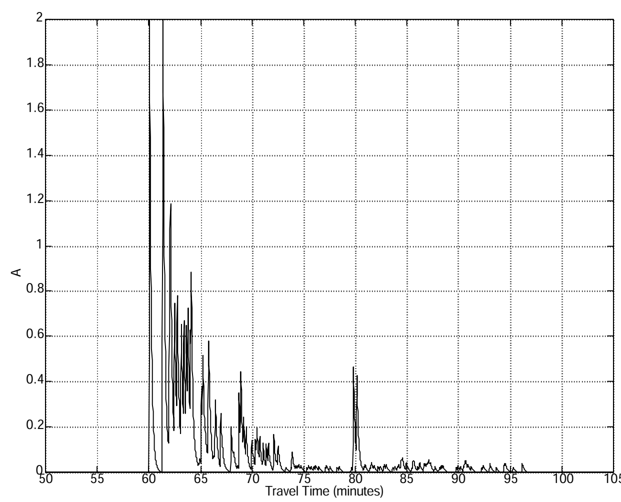

Figure 8. Impulse response model convolved with a model of the source

Atlantic Example

Our second application of the model is for the Chase21 explosion recorded at Ascension Island. This event, which occurred on June 25, 1970, was a ship-scuttling explosion on the continental shelf off the coast of New Jersey at a depth of 540 ft. The explosive charge was 614.5 tons. Although the explosion occurred above the SOFAR channel depth, energy was trapped in the channel and excellent recordings were obtained at the Ascension hydrophone array. The recording made at Ascension station FS27 is shown in Figure 9. A prominent feature of this signal is the presumed set of reflected arrivals, which are seen at a travel time of between 95 and 97 minutes. Our previous studies of this arrival indicate that the Guiana Plateau, a bathymetric feature off the northeast coast of South America, is the source of this reflected energy. A smaller reflection arrives at a travel time of approximately 102 minutes.

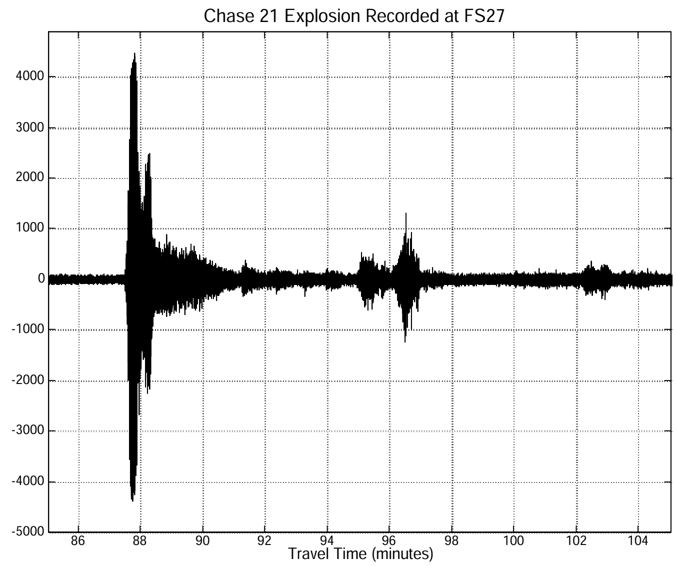

Figure 9. Hydroacoustic recording of the Chase 21 explosion at Ascension Island

The bathymetric feature finder was run for a travel time window of between 85 and 115 minutes, which should include reflected arrivals corresponding to the available data. The algorithm identified 309 possible bathymetric features, shown on the map in Figure 10. A histogram of the feature depth is also shown in Figure 11. Most features are located at depths of between 2000 and 4000 meters. A histogram of the sound channel axis depth in the Atlantic is shown in Figure 12, where it can be seen that the sound channel axis occurs mostly at depths of between 500 and 1200 meters. Hence only a few of the identified bathymetric features will reflect hydroacoustic energy from the SOFAR channel.

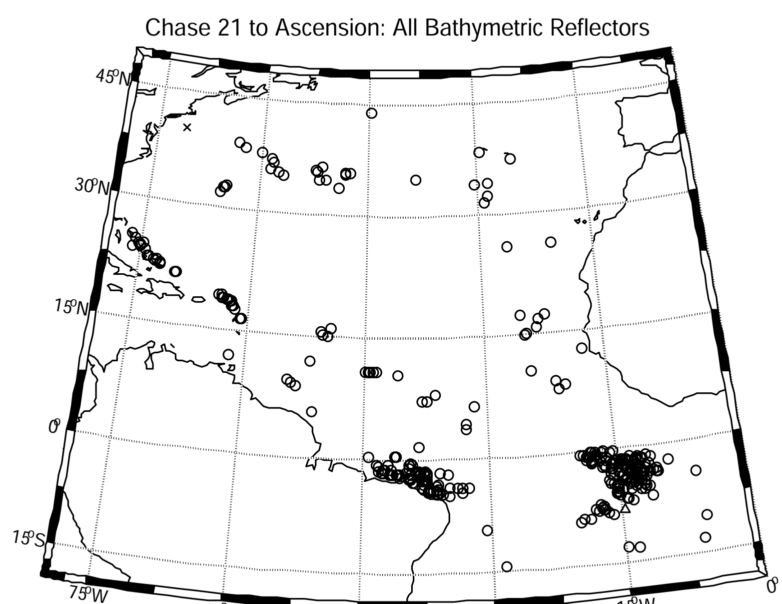

Figure 10. Bathymetric features in the equatorial Atlantic Ocean for the case of Chase21 to Ascension Island.

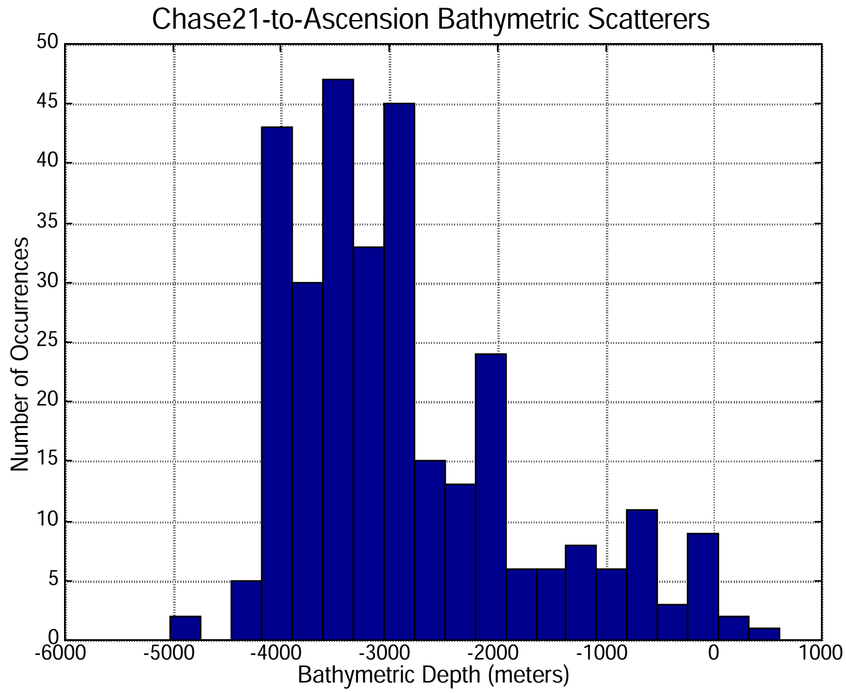

Figure 11. Histogram of bathymetric feature depth in the equatorial Atlantic for the Chase21 to Ascension case.

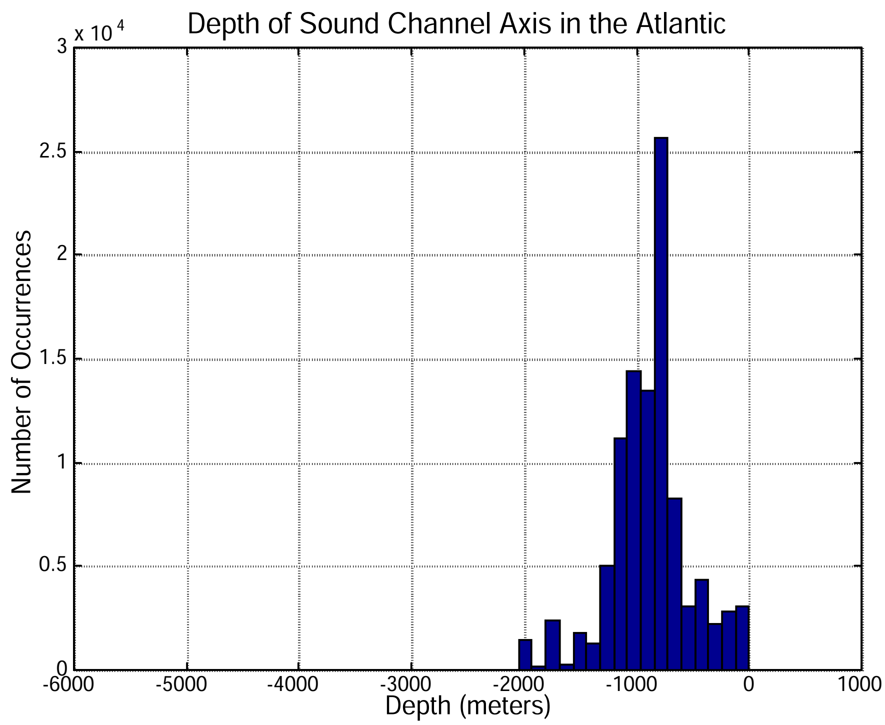

Figure 12. Histogram of sound channel axis depths in the equatorial Atlantic.

Figure 12 shows the impulse response model derived from the bathymetry analysis. The amplitude corresponding to each scatterer has been scaled with the function shown in Figure 2 as well as with geometrical spreading and attenuation. After the direct arrival at 88 minutes, there is a sequence of six large impulses which are not seen in the data. At 95 minutes there is a cluster of arrivals which correspond to scatterers at the Guiana Plateau (Angell et al. 1998, Pulli et al. 1999). This site has been identified, using bearing analysis, as the source of the reflected arrival at Ascension. At 100 minutes there is an additional arrival, however the data show an arrival two minutes later. Figure 13 shows the final output of the model where the impulse response has been convolved with a source envelope model.

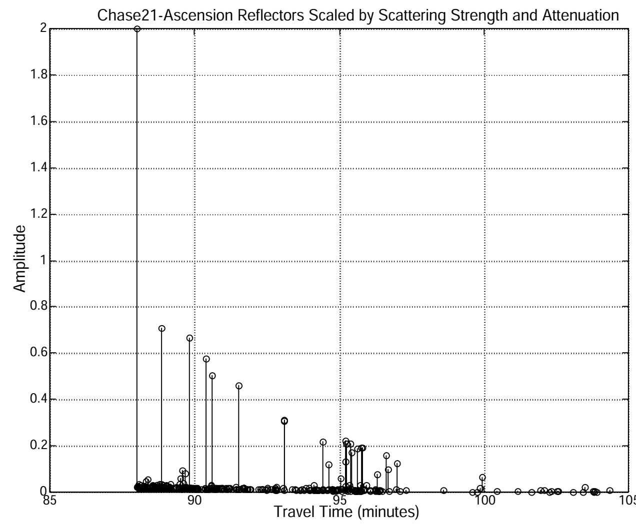

Figure 13. Impulse response model of the equatorial Atlantic for the case of Chase21 to Ascension Island. Note the cluster of arrivals at 95-96 minutes which matches those seen in the data shown in Figure 8.

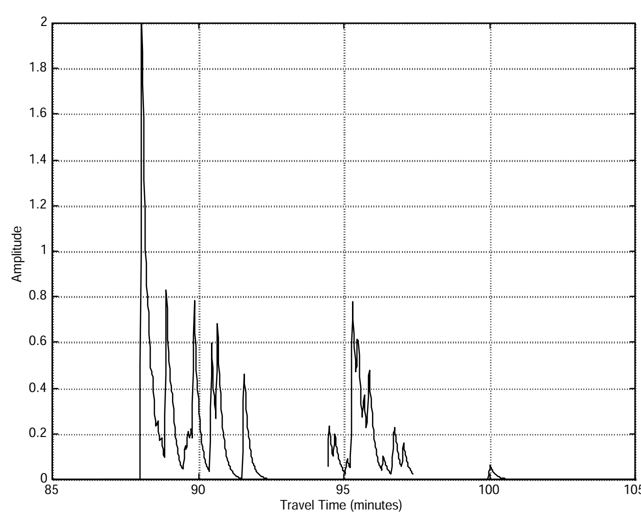

Figure 14. Impulse response model convolved with a model of the source.

CONCLUSIONS AND RECOMMENDATIONS

We have presented a model for long-range hydroacoustic reflections based on an analysis of bathymetry, slope, sound channel axis depth, travel time, and propagation loss. The model has been successfully applied to events in the Pacific and Atlantic Ocean basins. The model does not agree entirely with the data in that the model predicts more reflections than are actually observed. This is probably due to our imperfect knowledge of the actual scattering process. Improvements to the model can be accomplished with:

- Use of higher resolution bathymetry, especially in areas of known features as identified in this study.
- An analysis of slope and surface area calculations with these higher resolution bathymetric databases.
- A modeling study of reflections from bathymetric features as a function of frequency.

Key Words: Hydroacoustics, reflections, modeling, long-range propagation

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