CHARACTERIZATION AND UTILIZATION OF HYDROACOUSTIC SIGNALS REFLECTED FROM CONTINENTS AND BATHYMETRIC FEATURES

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ABSTRACT

The objective of this research is to establish an understanding of the hydroacoustic signals that reflect from continents and bathymetric features so that these signals may be utilized as part of the hydroacoustic component of CTBT monitoring. This understanding is important because long-range propagation modeling predicts that some direct source-receiver paths are either blocked by bathymetric features or do not exist because of horizontal refraction. In these cases, reflections may be the only observable signal from a source, and may provide important information for localization and source type estimation.

In our research we have identified, acquired, and analyzed numerous historical and contemporary databases of hydroacoustic signals for sources with known origins. These include the Chase ship scuttling exercises in the 1960's and 70's; French nuclear tests in the southwest Pacific; the Japanese crustal exploration explosions in 1996; and signals generated during the May 1999 Ascension Island experiment. Results to date indicate that hydroacoustic reflections can be consistently seen at specific receivers for repeated events in a given source area. For example, the Chase explosions off the US eastern seaboard produced signals that reflected off the Guianna Plateau off the coast of South America and were recorded at Ascension Island. The locations of these reflecting features can be determined either from their arrival times at multiple receivers or by beamforming hydroacoustic array data (when available) and combining the back azimuth estimation with the time difference between the direct and reflected signals. Reflections that are 30 dB lower in power than the direct arrivals can be seen from the Japanese exploration explosions recorded at WAKE, but only for the largest events. For the smaller events with lower SNR, these reflections are below the ambient noise and hence not observed.

Information about the source also appears to be preserved in the reflected signals. For example, both the direct and reflected signals from the Chase 22 explosion recorded at Ascension show spectral scalloping in the band 5-30 Hz, unlike the signals from the nearby Chase 21 explosion, which have smoother spectra.

Key Words: Hydroacoustics, reflections, long-range propagation, bearing estimation

OBJECTIVE

The objective of this research is to establish an understanding of the hydroacoustic signals that reflect from continents and bathymetric features so that these signals may be utilized as part of the hydroacoustic component of CTBT monitoring. This understanding is important because long-range propagation modeling predicts that some direct source-receiver paths are either blocked by bathymetric features or do not exist because of horizontal refraction. In these cases, reflections may be the only observable signal from a source, and may provide important information for localization and source type estimation.

RESEARCH ACCOMPLISHED

Databases Examined

We have examined numerous historical and contemporary databases of hydroacoustic signals for sources with known origins. Historical data were provided to us by LLNL and AFTAC, and include:

- The Chase ship scuttling explosions of the 1960's and 70's which occurred in both the Atlantic and Pacific Oceans. These include Chase 2, 3, 4, 5, 7, 12, 16, 17, 18, 19, 20, 21, & 22.
- Nuclear tests in the Aleutians, such as Longshot in 1965 and Milrow in 1969.
- The IITRI explosions conducted off the coast of California in 1968.
- French nuclear tests conducted in the south Pacific from 1971-78.

These historical databases have the advantage that the sources were large and thus produced large signals, but in many cases the direct arrivals are clipped because of the limited dynamic range of the old analog recording systems. In addition, station and origin information is often difficult to track down for these events. Instrument calibration factors are generally not available. The authors would appreciate hearing from anyone with information or references on the Chase explosions.

Contemporary databases examined include:

- The French nuclear tests conducted at Mururoa during 1996-96.
- The Japanese ocean crustal exploration explosions in September 1996
- The Ascension Island airgun experiment of May 1999

These contemporary databases were obtained online at the PIDC and AFTAC via AutoDRM requests.

Examples

Because hydroacoustic signals propagate at relatively low speeds (~1.49 km/sec), can propagate for long distances, and still retain high-frequency information (on the order of 100 Hz), data streams that include reflections can be very large (on the order of an hour). A convenient way of examining and processing this data is to transform the time series to an envelope. The data are first rectified, then smoothed, and then resampled to a frequency on the order of the length of the smoothing window. Smoothing windows are typically 1-second long. The data can also be bandpass filtered before processing to examine the relative spectral contribution between the direct and reflected signals. Shipping noise and electrical interference often contaminate the signals, and bandpass filtering is often necessary to mitigate these effects.

Figure 1 shows waveform data for the IITRI-1 explosion of February 16, 1968 recorded at the WAKE Island array. This is an example of one of the better recordings from the historical database; the signals are not clipped or saturated, and there is little electrical interference. This was a 12-ton TNT-equivalent explosion detonated at a depth of 1825 ft near Long Beach, CA (Kos and Kennedy, 1969 report on the IITRI program, though not this particular test). The figure shows both the full waveform recording and the processed waveform envelope. Numerous reflections after the first arrival can be seen in the envelope; prominent reflections arrive approximately 2 minutes and 16 minutes after the direct.

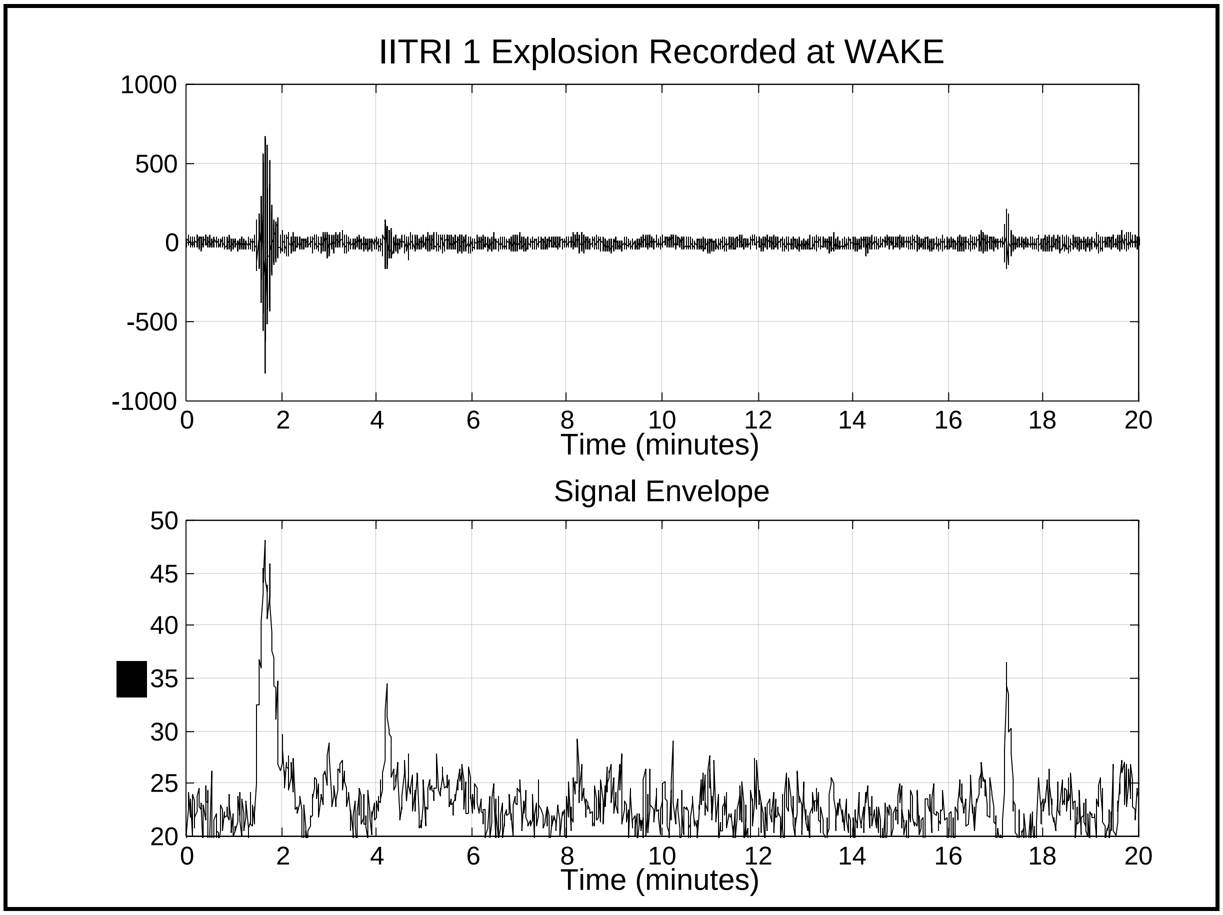

Figure 1. The IITRI-1 explosion of February 16, 1968 off Long Beach, CA recorded at WAKE Island. The full waveform recording at 200 s/sec is shown at the top. The signal is then filtered, rectified, integrated over a 1-second smoothing window, resampled at 1 s/sec, and plotted in dB at the bottom. Numerous reflections after the first arrival can be seen; prominent reflections arrive approximately 2 minutes and 15 minutes after the direct.

Figure 2 is an example from contemporary databases. The data are from one of the 138 marine seismic exploration explosions conducted off Japan in September 1996 (Brumbaugh and Le Bras, 1998). This particular explosion (Event 58) had a yield of 400 kg, and no further explosions were detonated for 1 1/2 hours (other explosions in this series were detonated every 15 minutes). Thus Event 58 provides an opportunity to examine potential reflections without having to account for additional sources which may be detonated at times on the order of the reflection delays. *Figure 2* shows the signal envelope at WAKE Island. The large direct arrival is followed by 3 arrivals within about 3 minutes and a prominent reflection 25 minutes after the direct. The amplitude of this reflection is 30 dB below that of the direct, which means that the signal-to-noise ratio must be at least 30 dB for this late reflection to be seen. Indeed, for most of the Japanese exploration explosions, which are either 20 or 40 kg (rather than 400), the signal-to-noise ratio is too low for this late reflection to show up.

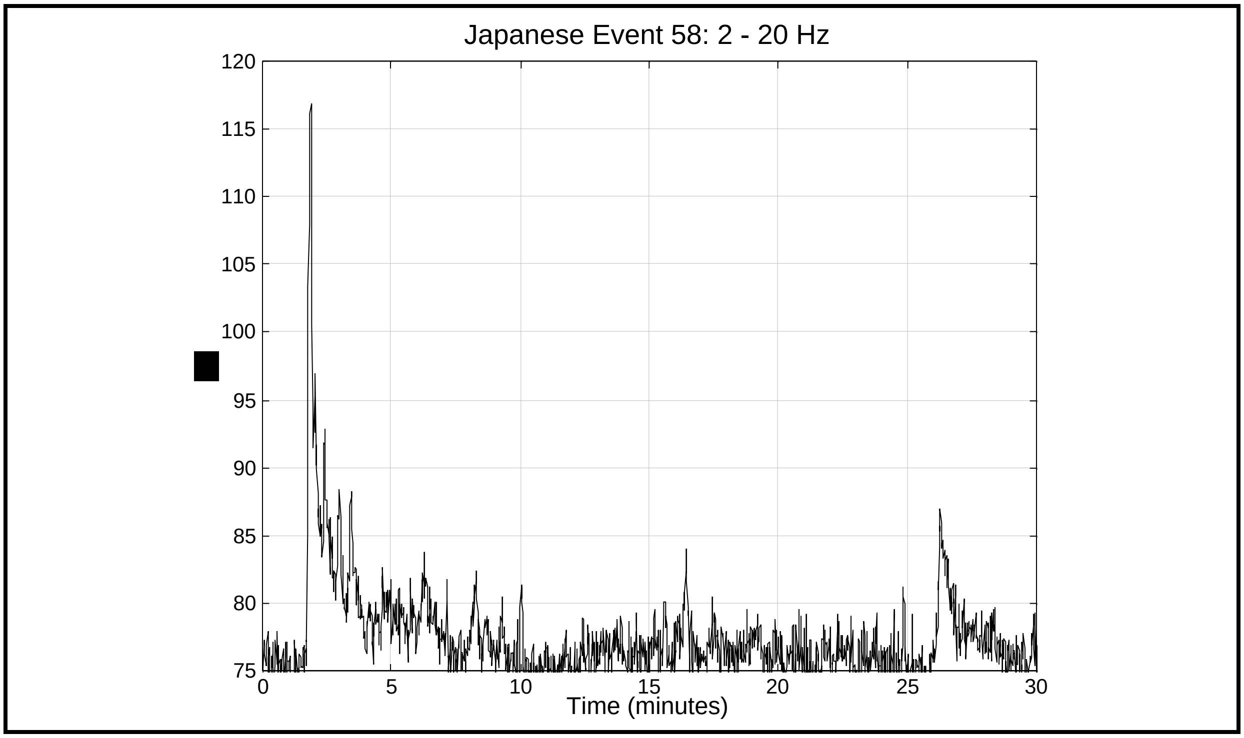

Figure 2. Envelope of the WAKE Island recording of the Japanese marine exploration explosion on September 8, 1996. The reflection, which is observed 25 minutes after the direct, is approximately 30 dB smaller than the direct and thus is only, observed for the largest of these explosions.

Localization of a Bathymetric Reflector - the Guiana Plateau

In order to gain an understanding of the nature of hydroacoustic reflections, we must be able localize and identify the bathymetric feature responsible for the signals. If enough recordings of the reflected signal are available over a range of azimuths, then we can time and locate the source, much in the same way as we locate earthquakes with a network of seismometers. However, hydroacoustic stations are sparse in distribution and the scattering properties of the bathymetric feature may not be azimuthally uniform. Reflections may often only be observed at preferential azimuths. An alternative method is possible when we have an array of recordings and can take advantage of their directional response to determine the back azimuth of the arriving signal. This back azimuth, when combined with the time difference of arrival between the direct and reflected signals, will provide both a bearing and range for localization. We now illustrate this procedure with recordings of the Chase 21 and Chase 22 explosions, detonated off the coast of New Jersey and recorded at the Ascension Island array.

Figure 3 shows the envelopes of the recordings at Ascension for the two events. The signals consist of a strong direct arrival and a prominent reflected arrival (or set of arrivals) about 8 minutes later. Since recordings are available for five array elements (and the array geometry is know), we can window each arrival and beamform (stack) the envelopes based on the theoretical travel time differences between array elements. In this case, we used a propagation velocity of 1.49 km/sec. *Figure 4* shows the beam amplitudes as a function of azimuth for the direct and reflected arrivals. The back azimuth of the direct arrivals is 319 deg. This matches the back azimuth computed from the known source location and provides a point of confirmation of the method. The back azimuth of the reflected arrival is 290 deg. The travel time from the source origin to the measured reflected arrival defines a travel distance and thus an ellipse of possible locations of the reflecting features. When this ellipse is combined with the back azimuth projection, we find that this intersection is at the site of the Guiana Plateau off the coast of Brazil.

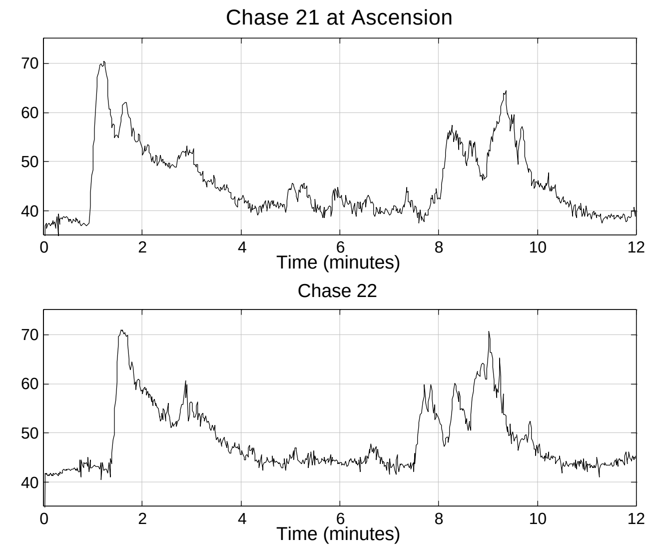

Figure 3. Envelope of the Ascension Island recording of the Chase 21 and Chase 22 ship scuttling explosions off the coast of New Jersey. The signals contain both a direct arrival and a strong reflected arrival about 8 minutes later.

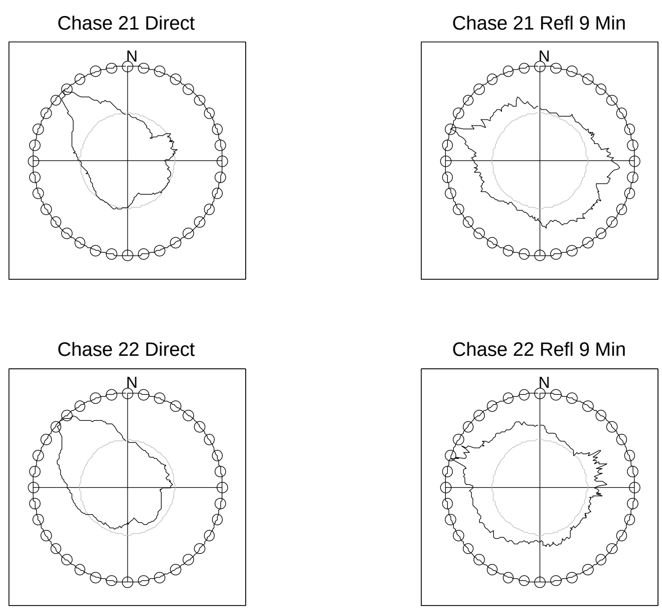

Figure 4. Bearing scans at the Ascension Island array for the Chase21 (top) and Chase 22 (bottom) explosions off the coast of New Jersey. For both recordings, the back azimuth computed for the direct arrival (319 deg) points to the known source locations. For the reflected arrivals 9 minutes later, the back azimuth (290 deg) points to the Guiana Plateau.

Spectral Characteristics of Reflected Hydroacoustic Signals

One of the reasons why an understanding of hydroacoustic reflections is important is that in some circumstances, these reflections may be the only observed signal. For example, the direct signal may be blocked by bathymetry or its ray path may be refracted away from a receiving station. The localization procedure described above provides us with a means of identifying and utilizing the reflected ray path, but an additional question is "what information about the source is contained in the reflected signals"?

Let us first examine the spectra of the arrivals at WAKE Island for the IITRI underwater explosion first shown *in Figure 1*. In this example, both the direct and reflected arrivals are clear and simple, unlike the reflected arrivals for the Chase explosions shown earlier. *Figure 5* shows the spectra of the direct arrival and the reflected arrival observed some 16 minutes later. Modulation of the spectra are caused by the interference of the primary explosion with the signals generated by the bubble pulses. Although the peaks and valleys of each spectra do not always track identically, it is apparent that the spectra of both arrivals are indicative of an underwater explosion. The differences in the spectra may be explained by the additional interference effect of complex reflection at the scattering bathymetric feature.

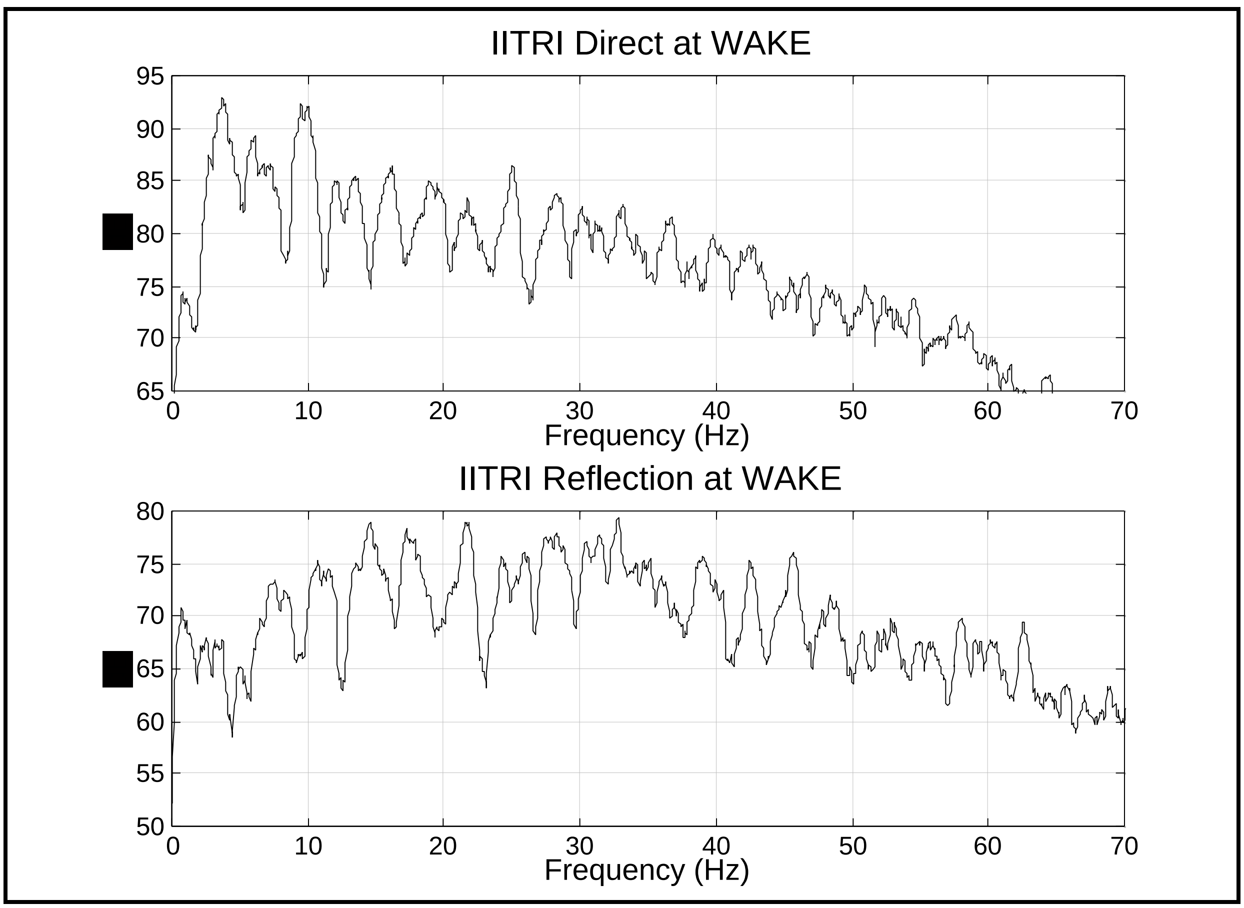

Figure 5. Spectra of the direct (top) and reflected arrival at WAKE Island for the IITRI underwater explosion off the coast of Long Beach, CA.

Figure 6 shows another example, this time for the Chase 22 explosion recorded at Ascension Island. Here we use the time-frequency representation to illustrate the similarity of spectral features because the arrivals are not cleanly separated, and in the case of the reflected arrival, actually consists of three separate signals. In this case, the spectral modulation is remarkably similar for the arrivals. Additionally, note that the spectra of the scattered energy after the direct arrival and between the reflected arrivals also maintain these same spectral features.

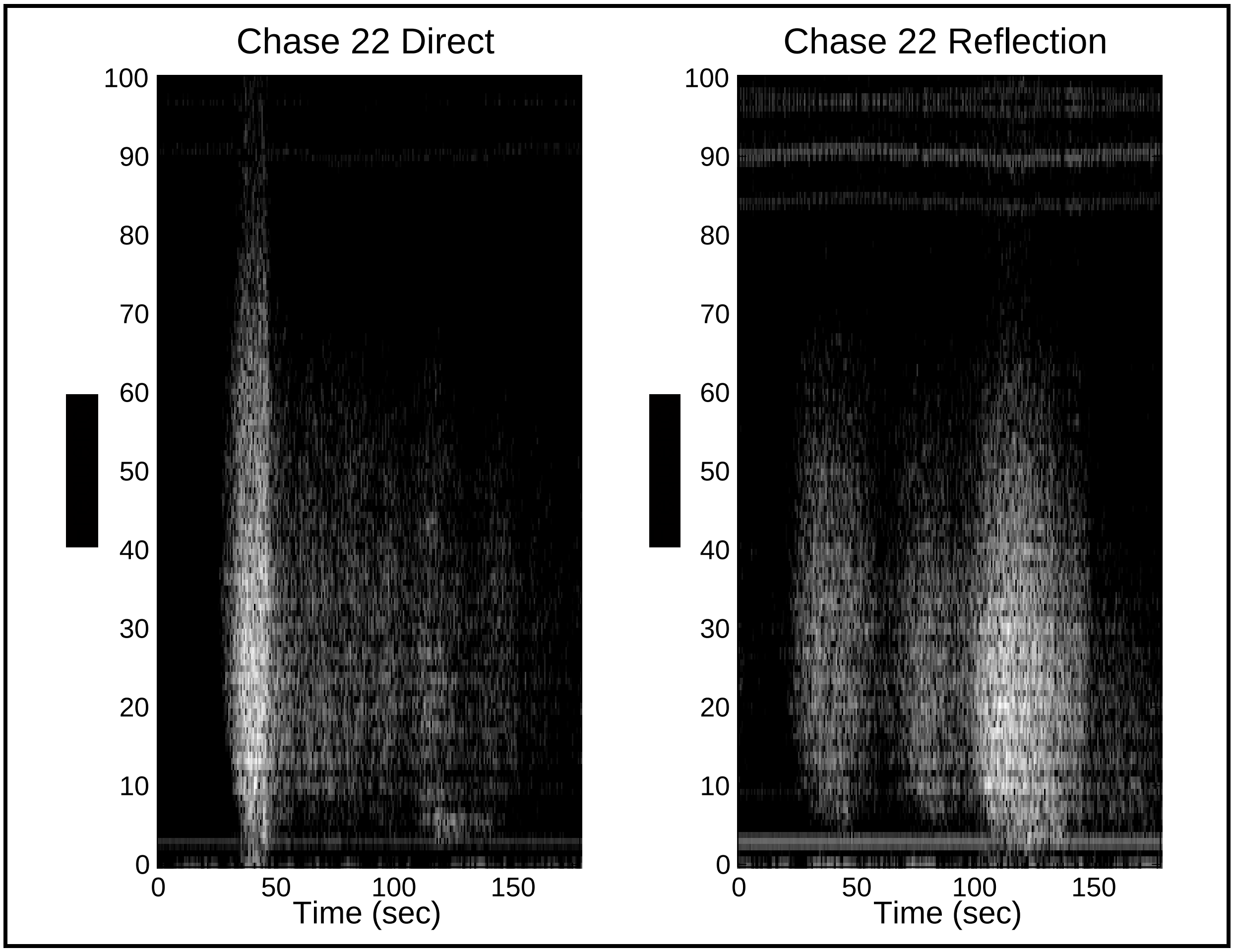

Figure 6. Time-frequency diagrams of the direct and reflected signals from the Chase 22 explosion recorded at Ascension Island. Note the similarity in spectral modulation between the two arrivals, as well as the scattered energy after the direct arrival and between the three reflected arrivals.

CONCLUSIONS AND RECOMMENDATIONS

We have examined a number of historical and contemporary recordings of underwater explosions as a means of understanding the nature of hydroacoustic reflections. We have found that reflections are observed for many source-receiver combinations, and that these reflections are visible for repeated events in the same source area. When an array recording is available, beamforming can be used to estimate the back azimuth of the arrival. This back azimuth, when combined with the travel time ellipse defined by the source and receiver locations defines a point on the globe that can be associated with the source of the reflection. An examination of the bathymetry at this location provides information on the likely features, which produce the reflection. Additionally we have found that the spectral characteristics of the source can be seen in both the direct and reflected arrivals. Our next step is to develop a simple scattering model to further explain the reflected arrivals, which will be used to predict where in a particular ocean reflected signals are likely to be produced.

REFERENCES

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