COMPARISON OF MEASURED REVERBERATION AND TRANSMISSION LOSS DATA WITH MODELED RESULTS ON THE WEST FLORIDA CONTINENTAL SHELF

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Abstract Acoustic data from the September, 1992 Area Characterization Test (ACT I) are compared to ADAM (Advanced Development Acoustic Model) output. Conduct of harsh shallow water acoustic exercises, and data interpretation mandates that critical path environmental variables are understood. Sediment, bathymetry, temperature, salinity, and wind speed measurements, augmented with archival geophysical data provide input to ADAM, a shallow water range dependent boundary and volume reverberation model. This affords a state-of-the-art depiction of shallow water prediction capability.

Measured transmission loss in the 50-100Hz, 100-200Hz, 200-400Hz and 400-800Hz frequency bands are compared to predictions from the Gaussian beam module in ADAM. This methodology will also validate the area geoacoustic characterization by comparing modeled and measured bottom loss. Average reverberation level in the 200-400Hz and 400-800Hz bands from explosive sources and the vertical array top hydrophone at separations from 6 to 13 nm along upslope and downslope propagation paths are compared to ADAM predictions.

1. Introduction

Transmission loss and reverberation acoustic data were collected as part of the DARPA sponsored Area Characterization Test (ACT I) conducted September 18 through 27, 1992 on the West Florida Shelf in an area known as Florida Middle Ground (fig. 1). This test was an active acoustic exercise designed to measure acoustic parameters in a shallow water site containing an extensively defined environment. This site, considered a harsh environment not only because of its highly bottom interactive acoustic nature but also because it has the potential for considerable environmental variability.

Effective use of resources for conduct of any acoustic exercise and for adequate interpretation of results demands attention to environmental parameters as part of a critical path to be followed. This includes an environmental assessment for survey design, hardware engineering and environmental data collection for acoustic data processing, analysis and unambiguous interpretation of the acoustic data. Minimizing failures due to unanticipated environmental variability and maximizing acoustic data utility mandates that critical environmental variables be understood. In the past, many experiments have been postponed or canceled due to unanticipated meteorological events such as tropical cyclones or large scale extra tropical frontal passages while the failure to adequately account for the effect of currents has degraded the success of other tests due to unsuccessful equipment deployment/retrieval or noise contaminated acoustic data. Even intense biological noise in cetacean mating areas has caused catastrophic exercise failure. On the

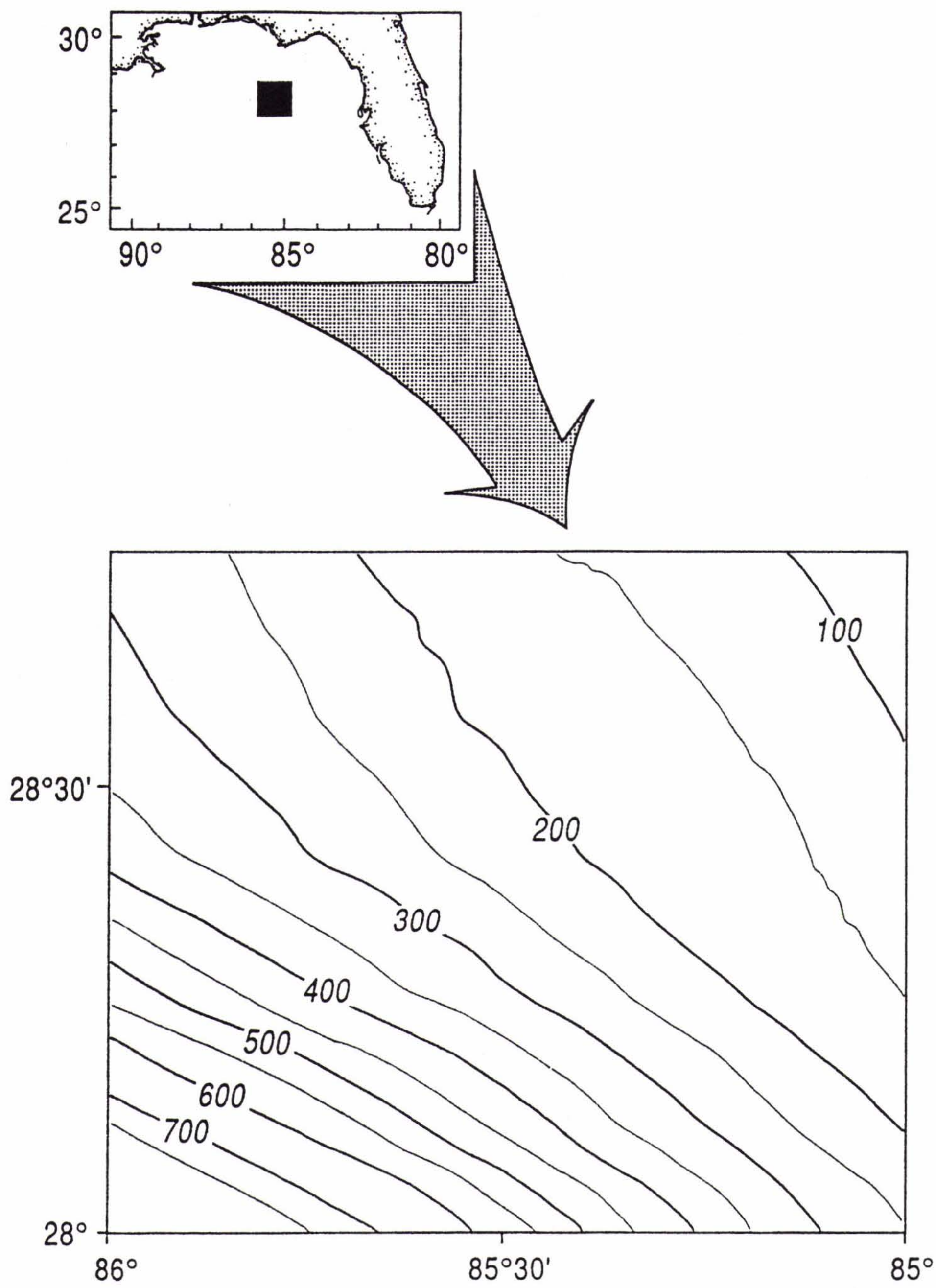

Figure 1. Location of the ACT I exercise area.

other hand, successful tests results can be enhanced by judicious site selection. For instance, while the extent and type of reverberation domination and bottom loss is highly site dependent, the environmental data sets necessary to quantify them are prohibitively expensive to acquire. For ACT I, an a-priori knowledge of the degree of bottom limitation as well as sea floor surface and subsurface characteristics was acquired by locating pre-existing seismic data sets . Array design incorporated a detailed description of expected current speeds, the sound speed field and geologic/geoacoustic character of the seafloor for type of fairing, seafloor anchoring requirements, determination of source to receiver geometries and array element placement.

Shallow continental shelves and their associated slopes present the acoustician and tactical planner with an environmental challenge found in few deep water environments. Their characteristically highly bottom interactive properties can result in high reverberation levels. A key issue today is our ability to predict bottom reverberation levels in these harsh environments where the often large geographical variability in both bottom types and oceanographic variability exacerbates the problem. The Advanced Development Acoustic Model (ADAM) shallow water reverberation code was designed to address this void by producing accurate reverberation predictions in these technically challenging environments. The comprehensive environmental and acoustic ACT I data set gives us the opportunity to begin evaluating that capability. It will be illustrated that the physics embedded in ADAM is capable of providing a close match of reverberation levels in selected frequency bands to the measurements when the environment is adequately defined.

2. Methods

2.1 Environment

The ACT I environmental assessment was a primary tool used in exercise site selection. The assessment took into account the possibility of loop current excursions onto the continental shelf and resulted in the incorporation of two current meters into the VLA system to quantify array deformation. The upslope and downslope acoustic paths used during the exercise were planned along pre-existing literature documented seismic lines so that the ACT I site and track geometry is supported with geoacoustic data in the vicinity. The availability of this data removes some of the uncertainty in assigning causative factors to reverberation and bottom loss results. Based on the assessed potential for environmental variability, a robust suite of environmental measurements were made. As shown in figure 2, these include bathymetry, sediment samples, temperature/salinity of the water column, current speed/direction at the acoustic array locations and meteorological conditions. These measurements, augmented with archival seismic data, cores and additional high resolution bathymetric soundings provide a coherent description of the temporal and spatial variability during the exercise.

As shown in figure 2, the transmission loss and reverberation measurements chosen for a comparison to modeled results were made in a sloping environment.

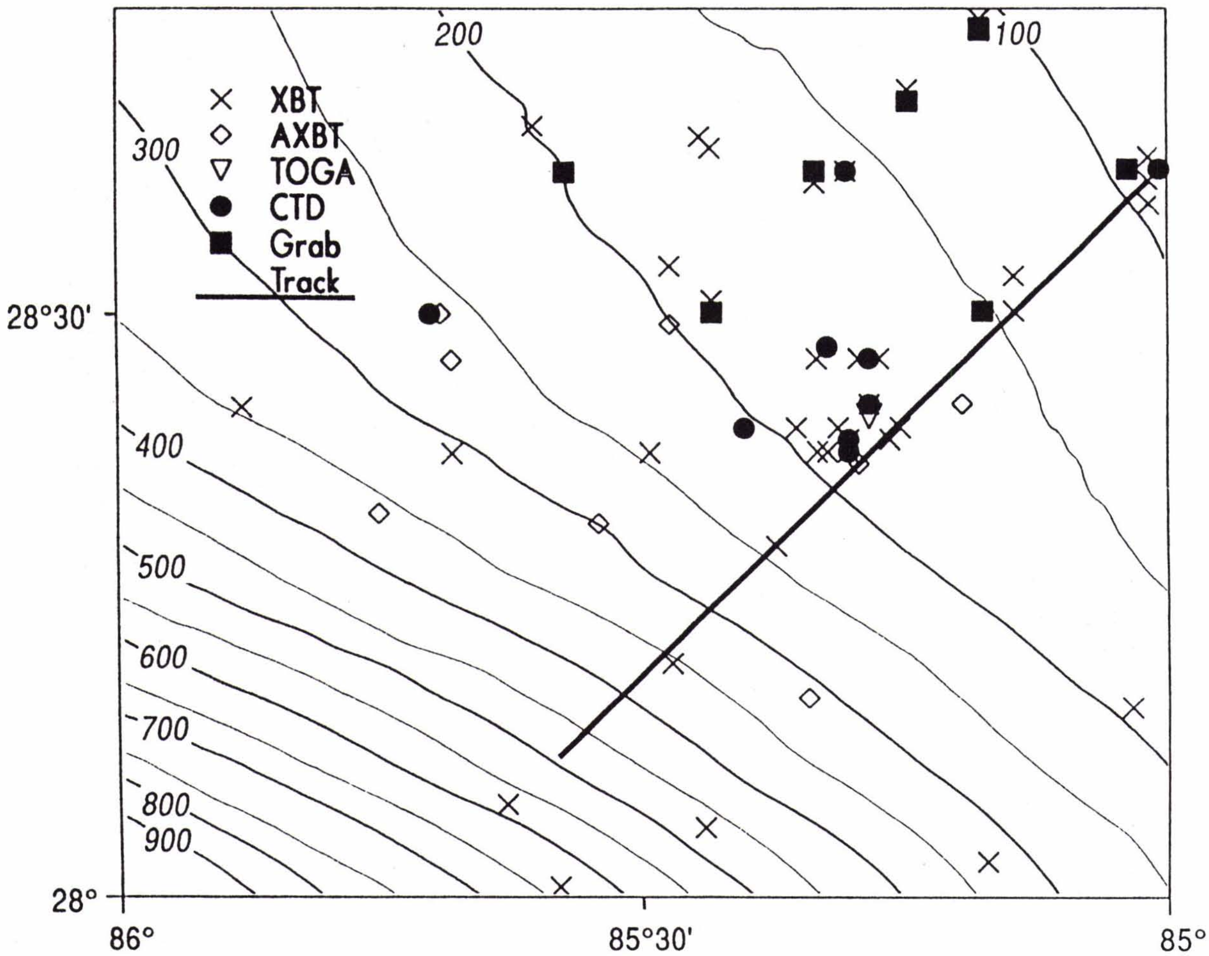

Figure 2. Location of environmental measurements and propagation path relative to the seafloor bathymetry in the ACT I exercise area.

The receiver was located at 28°23' N, 85°18' W about half way along the TL 3 propagation track. The sea floor in the upslope direction has a slope about .14° and the downslope direction has a slope about 0.46°. The vertical line array is located at a depth of 188 m.

2.1.1 Sound Speed To address possible sound speed variability due to the presence of the Loop Current, eddies shed by this highly variable current or other dynamic processes, a set of 71 water column profiles were collected over the entire test area. Figure 3 presents a composite of the sound speed variability along the TL 3 track. The higher sound speeds shown at depths below 100 m resulted from temperature differences of 3°C, with the warmer water located at the northern end of the track. The currents at 78 m water depth recorded by the current meter on the vertical array are primarily to the north to northeast at 10 cm/s whereas those at 188 m depths recorded by the meter on the horizontal line array are to the southeast at 5 cm/s. This southeast flow at depths close to where the sound speed variability occurs appears to be cooler offshore water moving to the southeast with a subsurface warm water filament extending northwestward from the nearshore. This variability is possibly a result of a relaxation effect from Hurricane Andrew's passage through the Gulf of Mexico one week prior to test commencement. Because model comparisons were made with data close to the receiver and the sound speed variability experienced was near bottom and remained downward refracting, it was determined that one profile taken from a position near the vertical line array would be adequate for this short range comparison.

2.1.2 Ambient Noise The possibility of high ambient noise levels due to surface shipping, petrochemical extraction and biologics was reduced by the location of the test. Mitchell and Levinson (1990) reported a high correlation of wind speeds of ≥5 m/s with near bottom noise data for frequencies as low as 25 Hz at a deep ocean site in the Pacific. During ACT I, in-situ wind speed and direction measurements were collected utilizing a meteorological buoy moored approximately 5 nm from the vertical line array Past experience has shown that meteorological conditions can vary significantly over distances of much less than 100 nm. This calls into question the adequacy of land based or distant weather buoy meteorological data alone for the analysis of acoustic data. Average wind speeds during the TL-3 were below 5 m/s, with levels closer to 2 m/s .

2.1.3 Geology and Geophysics Water depths recorded during the TL-3 run varied between 83 m and 480 m. The seafloor in this region is gently dipping, relatively hard, and smooth. Bathymetry contours run approximately northwest-southeast, with shallow water to the northeast. The VLA is located at approximately the shelf edge with depths just shoal of 200m. While only a minimal amount of 3.5 kHz data was collected, all data records show a sharp reflection from the water-sediment interface with virtually no sub-bottom penetration. All 7 sediment grab samples were similar and consisted of greenish-gray sandy material. The sediment grain size analysis classified these samples as a sandy-silt or sand-silt-clay. Sample 2 (shallowest water depth, 90m) contained a variety of shell and coral fragments that were not present in other samples. Evaluation of seafloor properties suggest that it is homogeneous (void of stratification), with a smooth water-

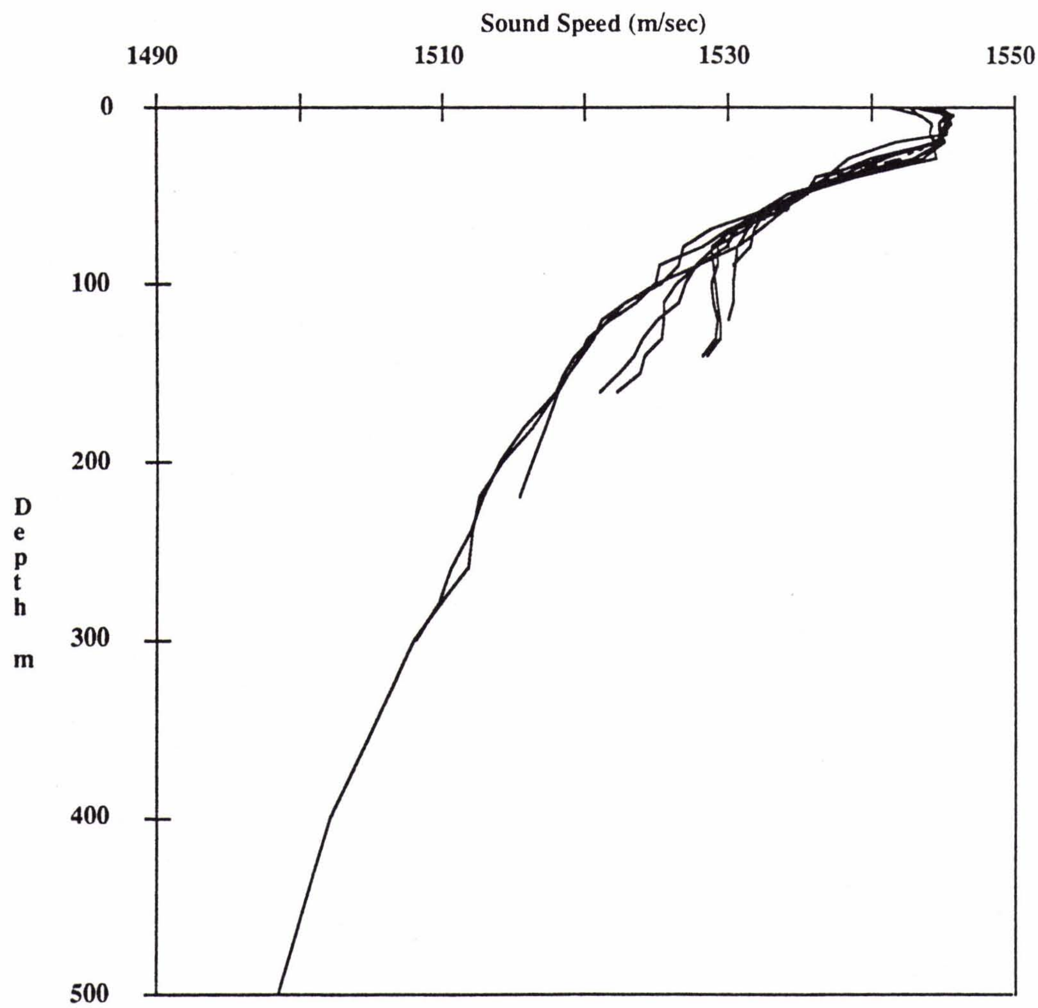

Figure 3. Sound speed profile composite along the TL 3 propagation path.

sediment interface, and a high acoustic impedance (approximately 10% higher than bottom water sound speed).

Seismic records and core data describe the sub-bottom as comprised of Pleistocene to recent sediments approximately 75 to 150 m thick. showing parallel bedding. Data from one of the near-by cores shows at least 45 m of well-sorted Pleistocene foraminiferal sand. The geoacoustic model in table 1 is derived from exercise measured surface sediment samples, the archival seismic records and archival sediment cores.

Table 1. Geoacoustic model for the ACT I exercise

Depth below sea floor (m)	Sediment sound speed (m/s)	Sediment density (g/cc)	Sediment Attenuation Constant (dB/m* kHz)
0	Vw*1.061	1.701	0.100
5	Z(0) +10.	1.711	0.099
10	Z(0) +20.	1.721	0.099
15	Z(0) +30.	1.731	0.098
20	Z(0) +39.	1.741	0.097
30	Z(0) +59.	1.761	0.096
40	Z(0) +78.	1.781	0.094
50	Z(0) +97.	1.811	0.093
60	Z(0) +116.	1.831	0.092
80	Z(0) +154.	1.871	0.089
100	Z(0) +191.	1.911	0.086
120	Z(0) +227.	1.951	0.083
140	Z(0) +263.	1.991	0.080
160	Z(0) +298.	2.031	0.078
180	Z(0) +332.	2.071	0.075
200	Z(0) +366.	2.111	0.072

The sediment sound speed at the water-sediment interface (0.0 m depth) is determined by multiplying the applicable in-situ bottom water sound speed (Vw) times the relative sediment sound speed (Vr=1.061). The sediment sound speed at standard depths in column 1 are obtained by adding the listed constant to the zero depth (Z(0)=Vw*1.061) sound speed. Sound attenuation in decibels per meter, at a given frequency and depth, is obtained by multiplying the attenuation constant for the applicable depth times the frequency in kilohertz.

2.2 Acoustic Modeling

The resulting benchmark set of environmental measurements collected during the ACT I exercise provided an opportunity for a valid comparison of acoustic transmission loss and reverberation models using precisely defined environmental input. Minimizing the environmental variability provides an excellent opportunity to assess the physics embedded in the model. The acoustic model used during this study is a variant of the Advanced Development Active Model (ADAM). The environmental measurements collected during the ACT I exercise during leg TL3 are used as inputs into ADAM to (1) validate the geoacoustic model by comparing the modeled and measured transmission loss using predictions from the Gaussian beam module embedded in ADAM with the measured values, and (2) use the validated geoacoustic model along with other exercise measurements to generate modeled vs. measured comparisons of reverberation. The average reverberation level time series measurements were collected with explosive sources and the top hydrophone of the vertical line array receiver at distance separation from 6 to 13 nm using environments along both upslope and downslope propagation paths in nominally 85 to 360 m of water. In the following sections, the model is briefly described, the transmission loss comparisons are presented, and the reverberation /model comparisons are made.

2.3 ADAM Model

ADAM is a shallow water, range dependent boundary and volume reverberation research and development model, which affords a state-of-the-art depiction of the Navy's shallow water prediction capability. This model consists of two primary parts: (1) a propagation model that is an implementation of the method of Gaussian beams as described by Cerveny et al. (1982), and (2) range-azimuthal dependent reverberation model. The salient features of the propagation model are: (1) the sound speed field is interpolated from observation points via a multivariate spline under tension which maintains the convexity of the data points, and a continuous second derivative (de Boor,1978), (2) the use of complex reflection coefficients to model bottom interaction, and (3) a global error estimator to control the Runge-Kutta-Fehlberg based ray tracing algorithm (Shampine and Watts, 1976). The other features of this reverberation model include: (1) area calculation by the reverberation model is based on a bipolar grid with modifications for azimuthal dependence, (2) the surface scattering algorithm is that of Ogden and Erskine (1992), and (3) the bottom scattering consists of a modified Lambert-McKenzie scattering law augmented with the addition of a tangent plane approximation.

3. Results

3.1 Transmission Loss Results

The transmission loss versus range calculations were made for each of four frequency bands: 50-100 Hz, 100-200 Hz, 200-400 Hz, and 400-800 Hz for both the case of the source located upslope from the receiver, and the source located downslope from the receiver. This comparison used the measurements received from the top hydrophone of the vertical line array.

Since the propagation model is a narrow band model, and the data is octave band, it was necessary to predict the transmission loss at a number of discrete frequencies, and perform a coherent average over the band of interest. A complex bottom reflection coefficient versus grazing angle function was constructed for each frequency selected using the REFLEC model (Evans, 1981), and the coherent transmission loss was calculated. In practice five frequencies were sufficient to simulate the measured data. The five frequencies selected were the highest, and lowest frequencies in the band along with three intermediate equally spaced frequencies.

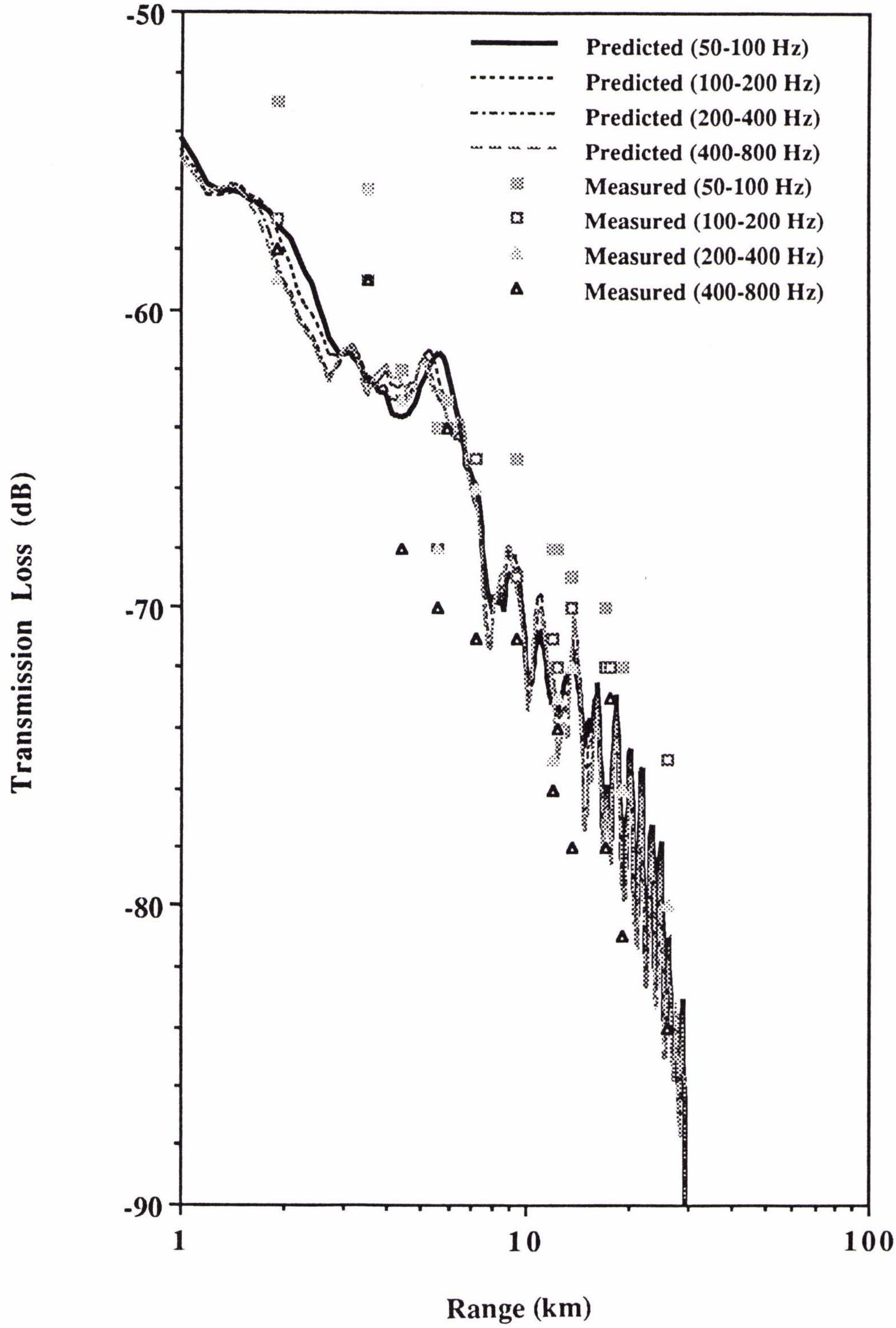

Figure 4. Plot of predicted transmission losses versus measured transmission losses for the four octave bands for the source upslope from the receiver.

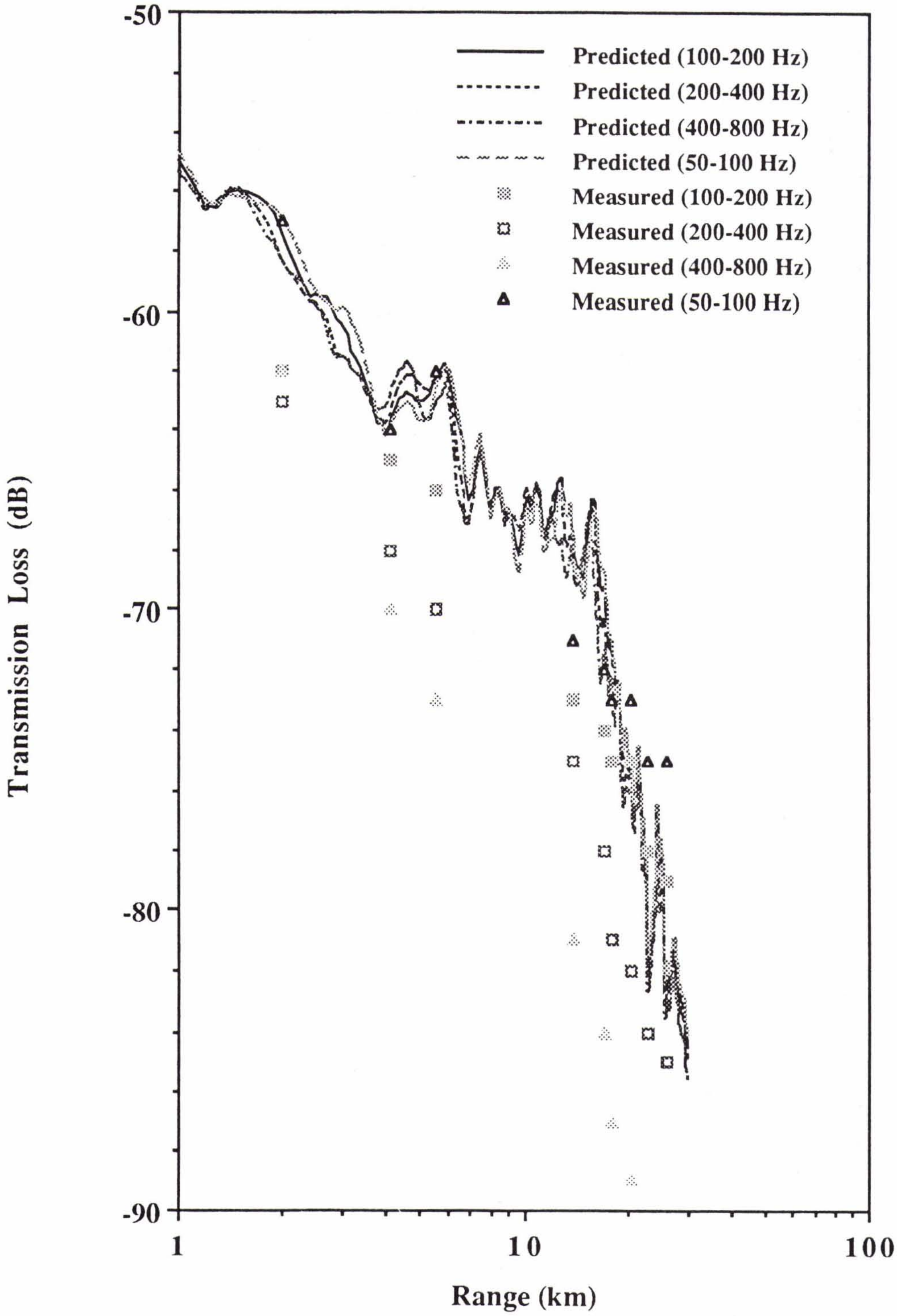

Figure 5. Plot of predicted transmission losses versus measured transmission losses for the four octave bands for the source downslope from the receiver.

Figure 4 shows the predicted transmission losses versus the measured transmission losses for each of the four octave bands for the source upslope from the receiver. The predicted losses are reasonably close to the measured losses for each of the bands. Because environmental variability for this analysis is limited to the bottom and sub-bottom properties with its attendant geoacoustic parameters, the result may be viewed as validation of the geoacoustic model.

Figure 5 shows the predicted transmission losses versus the measured transmission losses for each of the four octave bands for the source downslope from the receiver. The predicted losses show good agreement with the measured losses for the two lowest frequency bands, but at higher frequencies the predicted, and measured are significantly different. It should be noted that the trend of the predicted losses are parallel to the trend of the measured losses. This trend agreement suggests that the geoacoustic model is correct, since a change from bottom interaction would effect the trend as well as the level. The reason(s) for the differences between the predicted and observed transmission losses at the higher frequencies for only the case of the source downslope are not known.

3.2 Reverberation Results

The reverberation results presented in this section cover four source-receiver locations, and the two highest frequency bands. The locations, and frequency bands were selected based on two criteria: (1) the reverberation envelope should decay into the noise background, and (2) there must be samples of reverberation demonstrating upslope and downslope propagation. The data available at the time of this analysis which met these criteria were source upslope locations at ranges of 8.7, and 13.7 nautical miles, and source downslope locations at ranges of 6.7 and 12.4 nautical miles. For all four locations the reverberation envelopes for the 200-400 Hz and 400-800 Hz bands met these criteria.

The environmental inputs for the reverberation modeling were extracted from the exercise results. The source level was obtained by adding the measured transmission loss at a range to the peak reverberation envelope level at the same range for each source receiver location (including those not included in this analysis) and averaging the resultant. The coefficients in the Lambert McKenzie law were modified such that the angle associated with the predominate path at 5 nmi had a scattering strength equal to the observed scattering strength. The variance of the sea floor was set at 3 cm based on the lack of surface structure observed on the 3.5 kHz sub-bottom profile record, and the few shell samples of this size obtained as part of the environmental measurements. Because the theoretical value of source level was not used, the model-data comparison results should be viewed as relative.

Figures 6 through 13 show the predicted versus measured reverberation envelopes for the 6.7 nmi source downslope of the receiver in the 200-400 Hz band (Figure 6), and the 400-800 Hz band (Figure 7), the 8.7 nmi source upslope of the receiver in the 200-400 Hz band (Figure 8), and the 400-800 Hz band (Figure 9), the 12.4 nmi source downslope of the receiver in the 200-400 Hz band (Figure 10), and the 400-800 Hz band (Figure 11), and the 13.7 nmi source upslope of the receiver in the 200-400 Hz band (Figure 12), and the 400-800 Hz band (Figure 13). Each

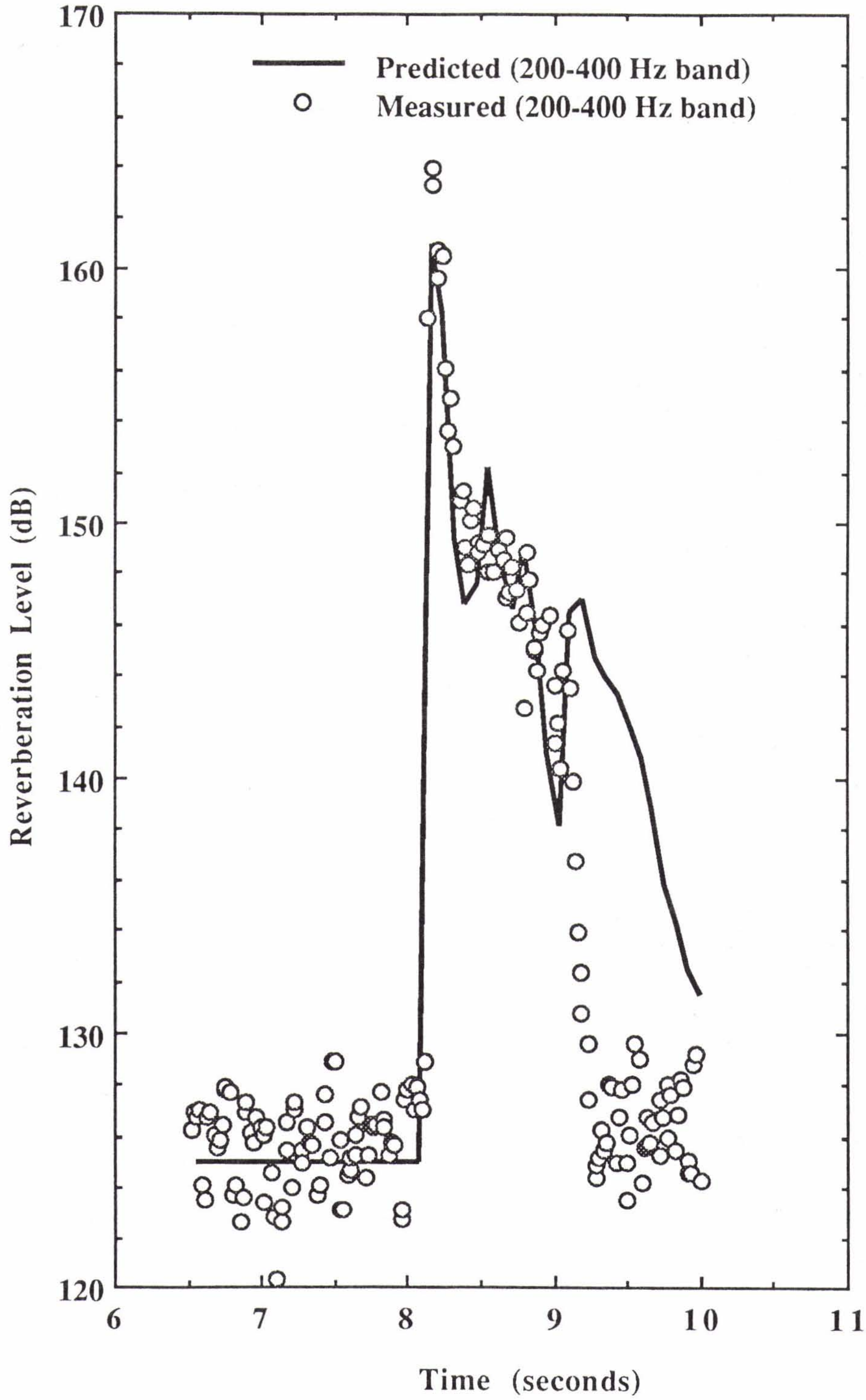

Figure 6. Plot of predicted reverberation envelope versus measured reverberation envelope for the source 6.7 nmi downslope from the receiver for the 200-400 Hz octave band.

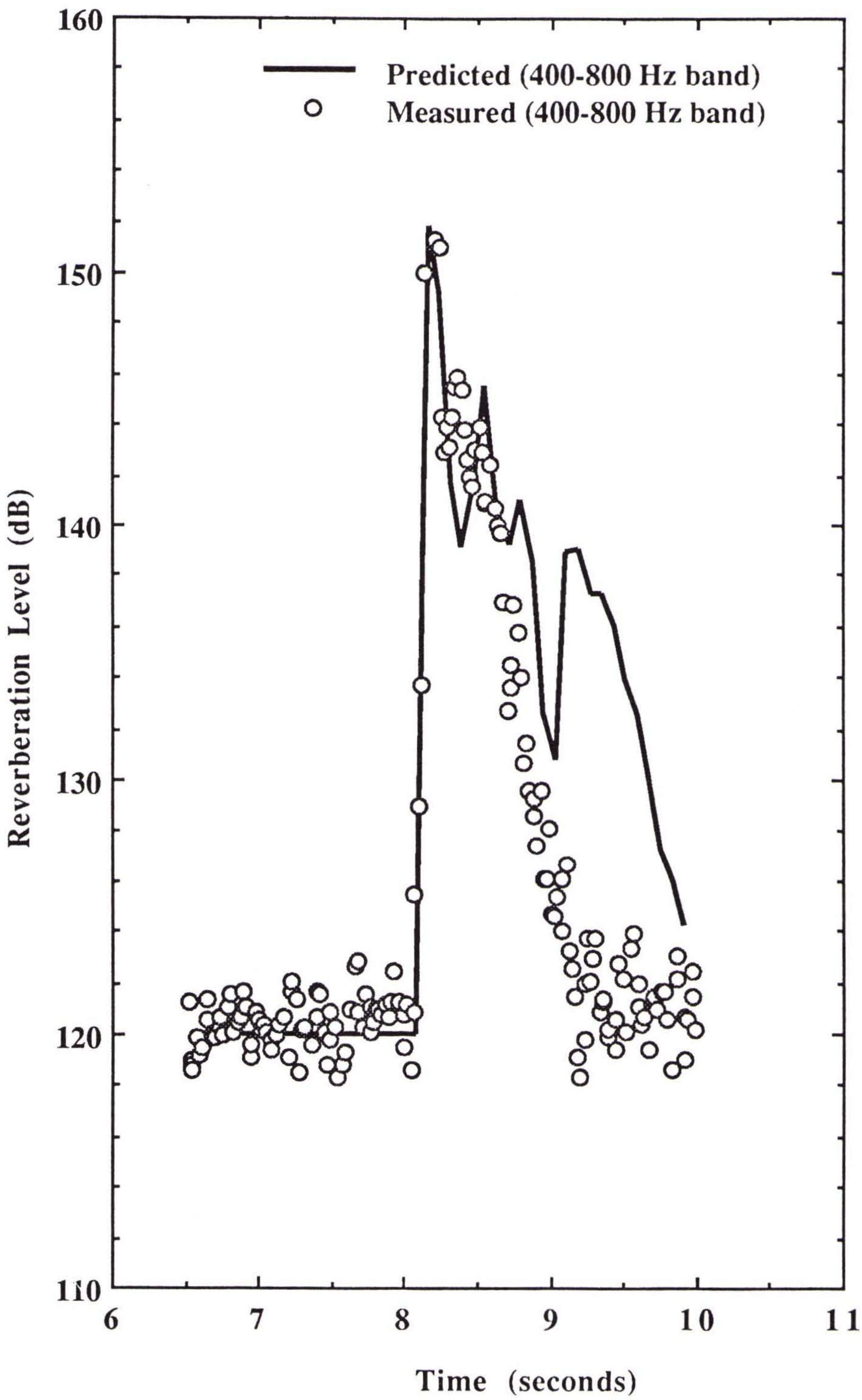

Figure 7. Plot of predicted reverberation envelope versus measured reverberation envelope for the source 6.7 nmi downslope from the receiver for the 400-800 Hz octave band.

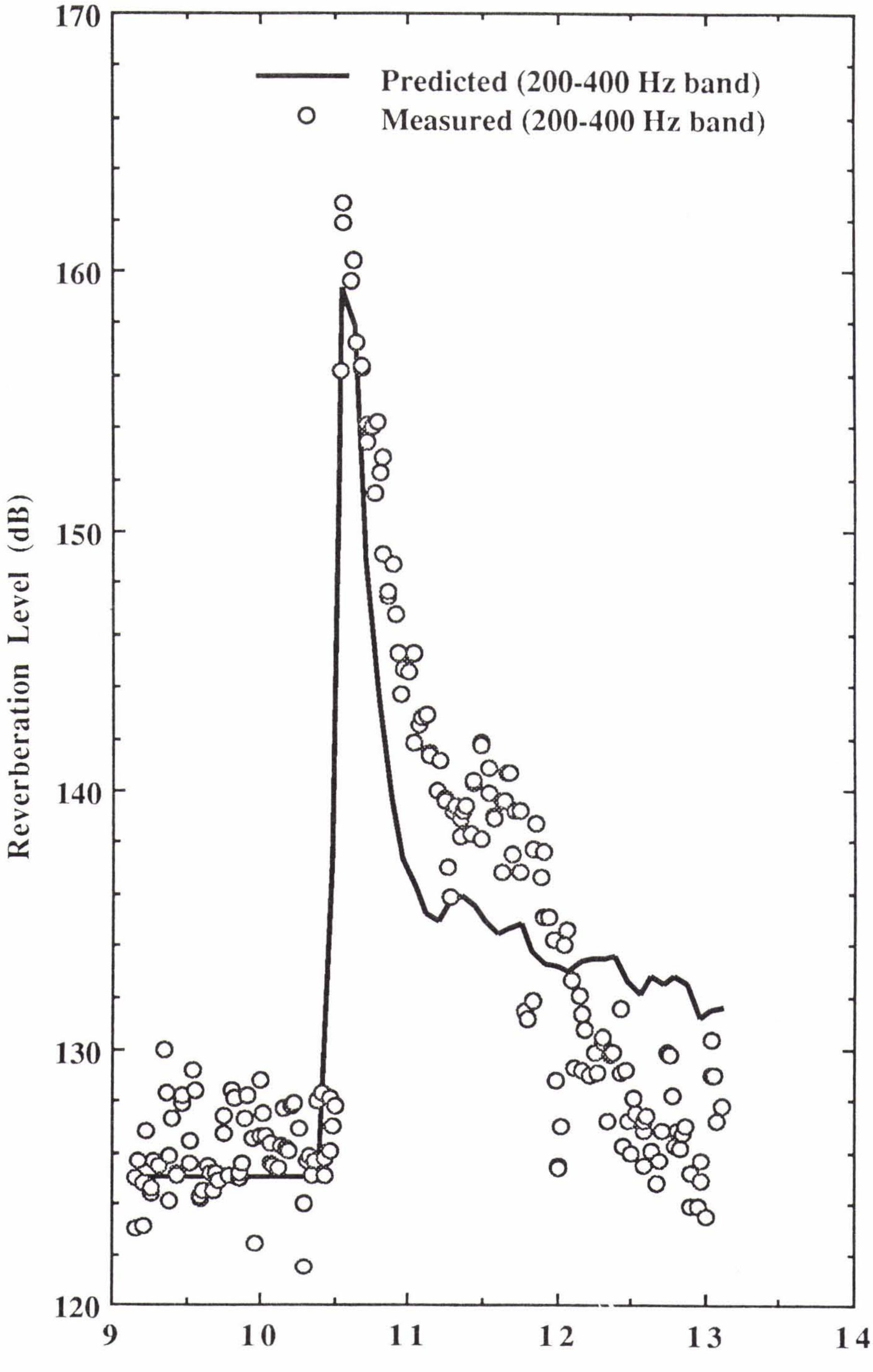

Figure 8. Plot of predicted reverberation envelope versus measured reverberation envelope for the source 8.7 nmi upslope from the receiver for the 200-400 Hz octave band.

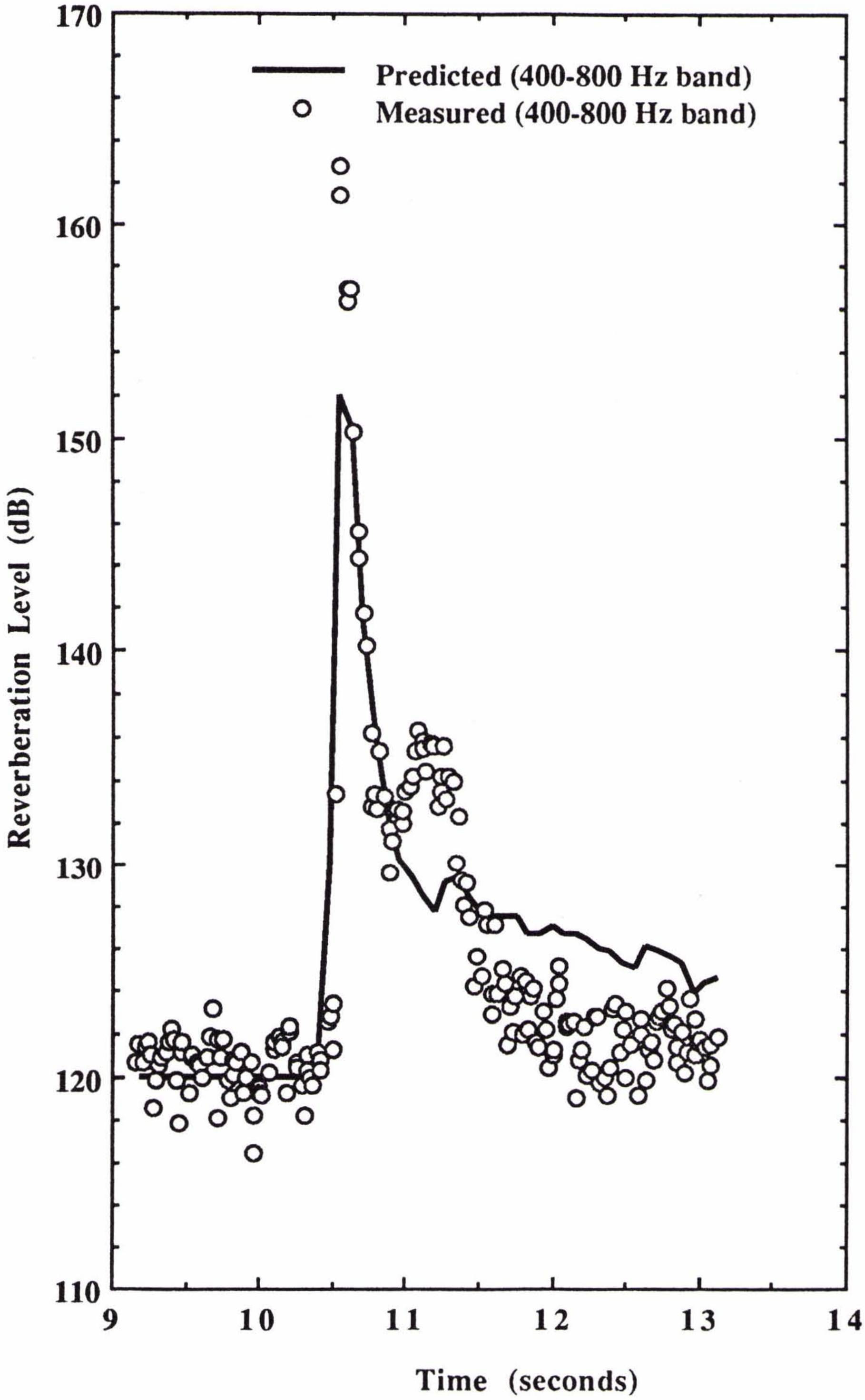

Figure 9. Plot of predicted reverberation envelope versus measured reverberation envelope for the source 8.7 nmi upslope from the receiver for the 400-800 Hz octave band.

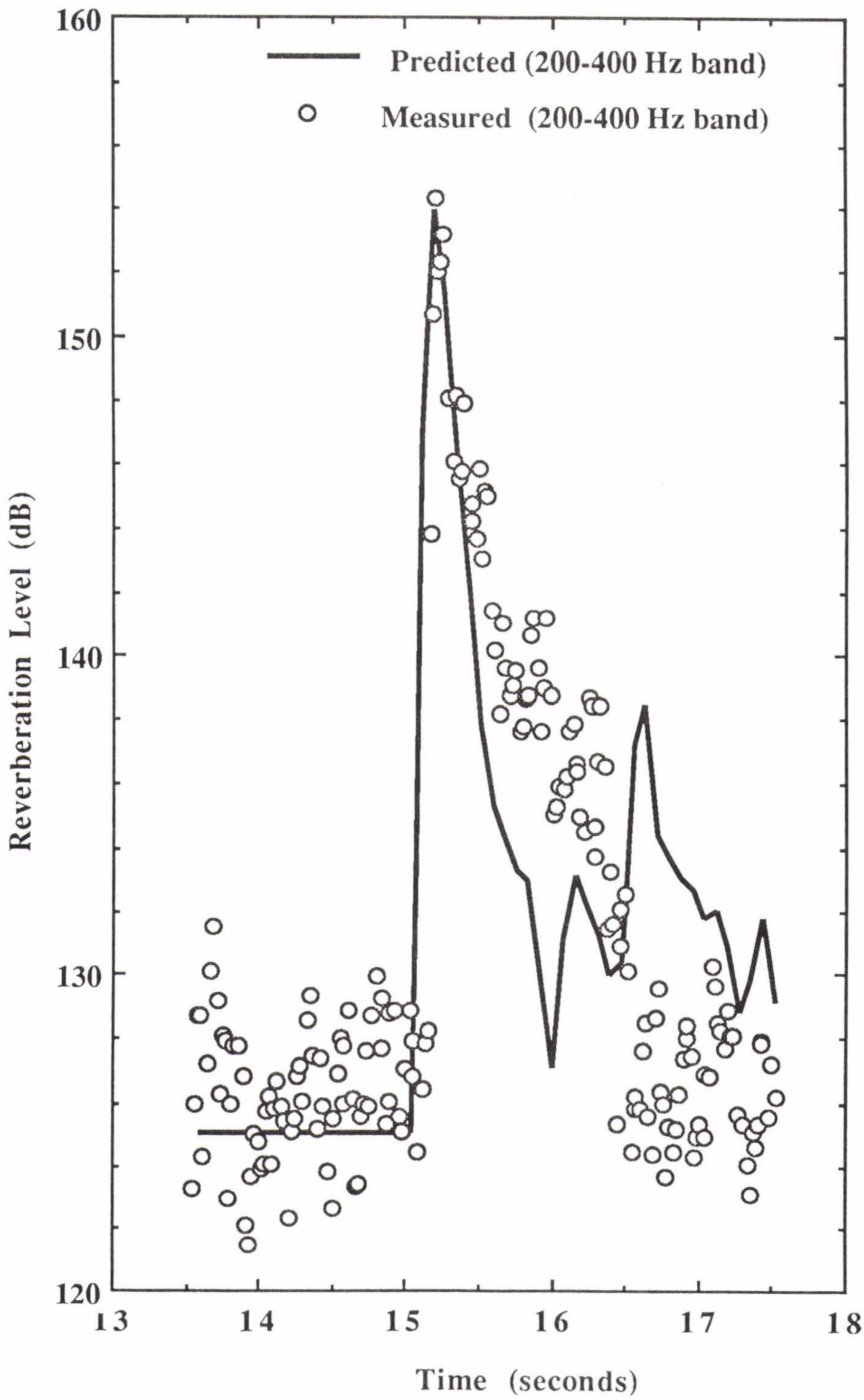

Figure 10. Plot of predicted reverberation envelope versus measured reverberation envelope for the source 12.4 nmi downslope from the receiver for the 200-400 Hz octave band.

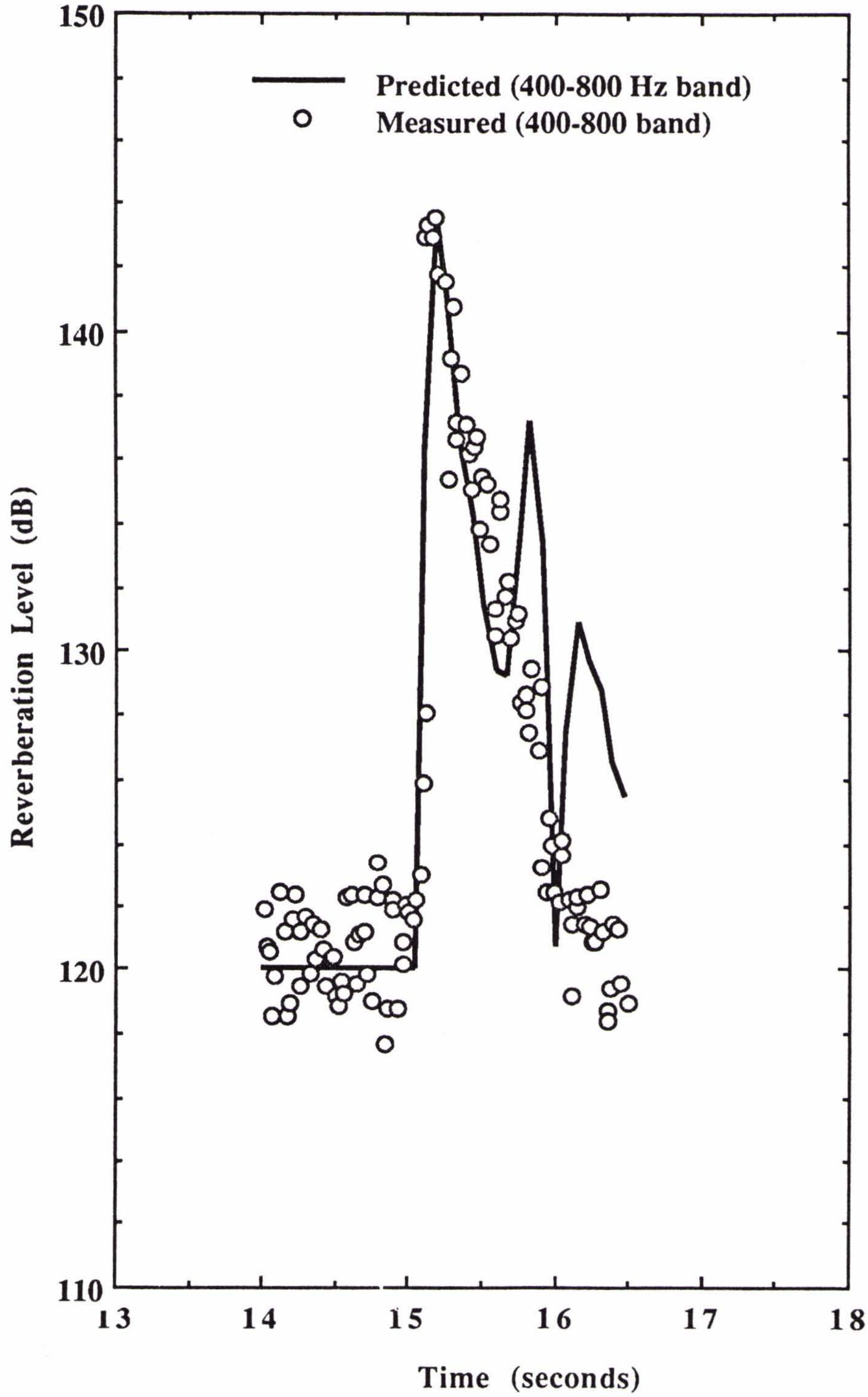

Figure 11. Plot of predicted reverberation envelope versus measured reverberation envelope for the source 12.4 nmi downslope from the receiver for the 400-800 Hz octave band.

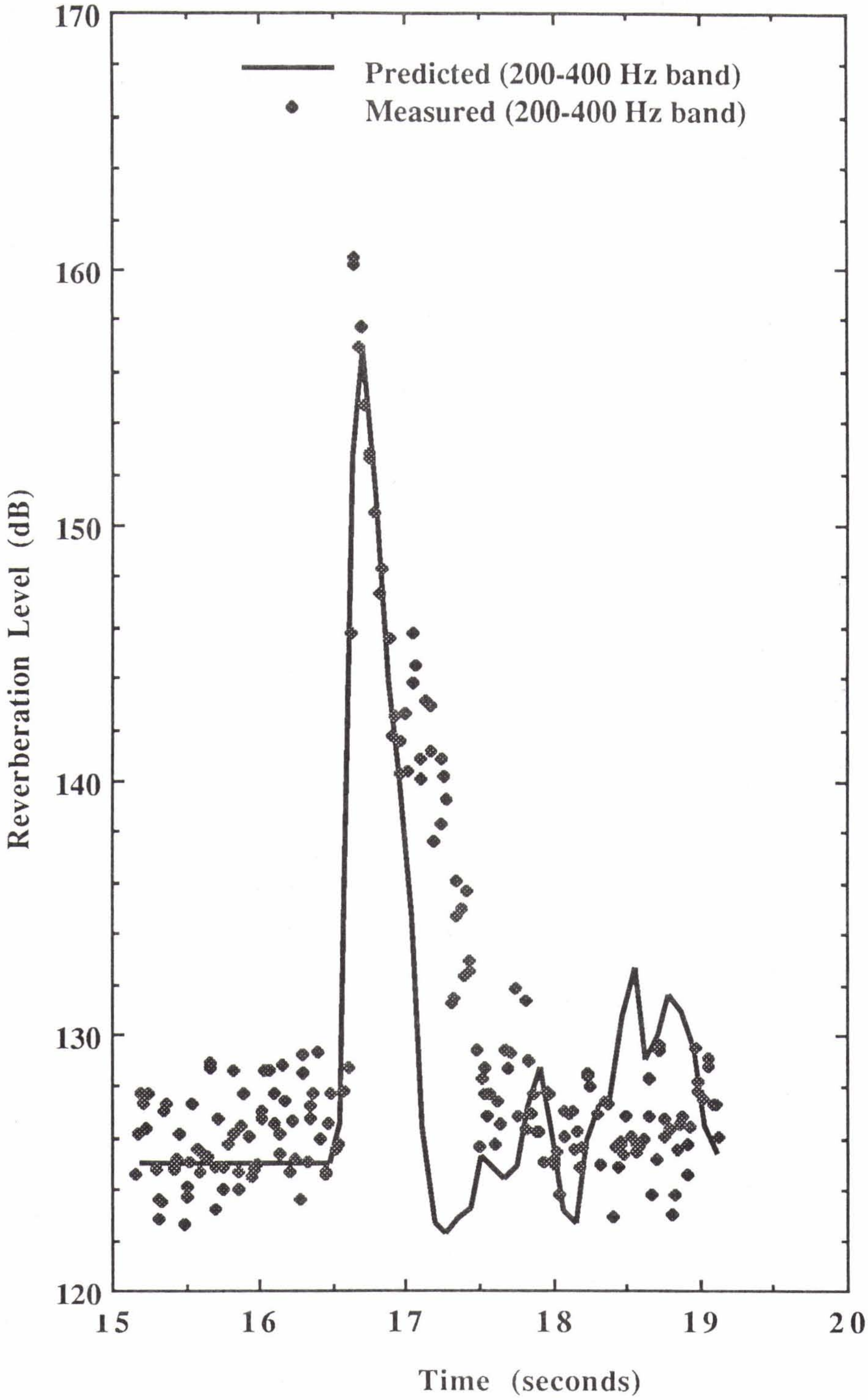

Figure 12. Plot of predicted reverberation envelope versus measured reverberation envelope for the source 13.7 nmi upslope from the receiver for the 200-400 Hz octave band.

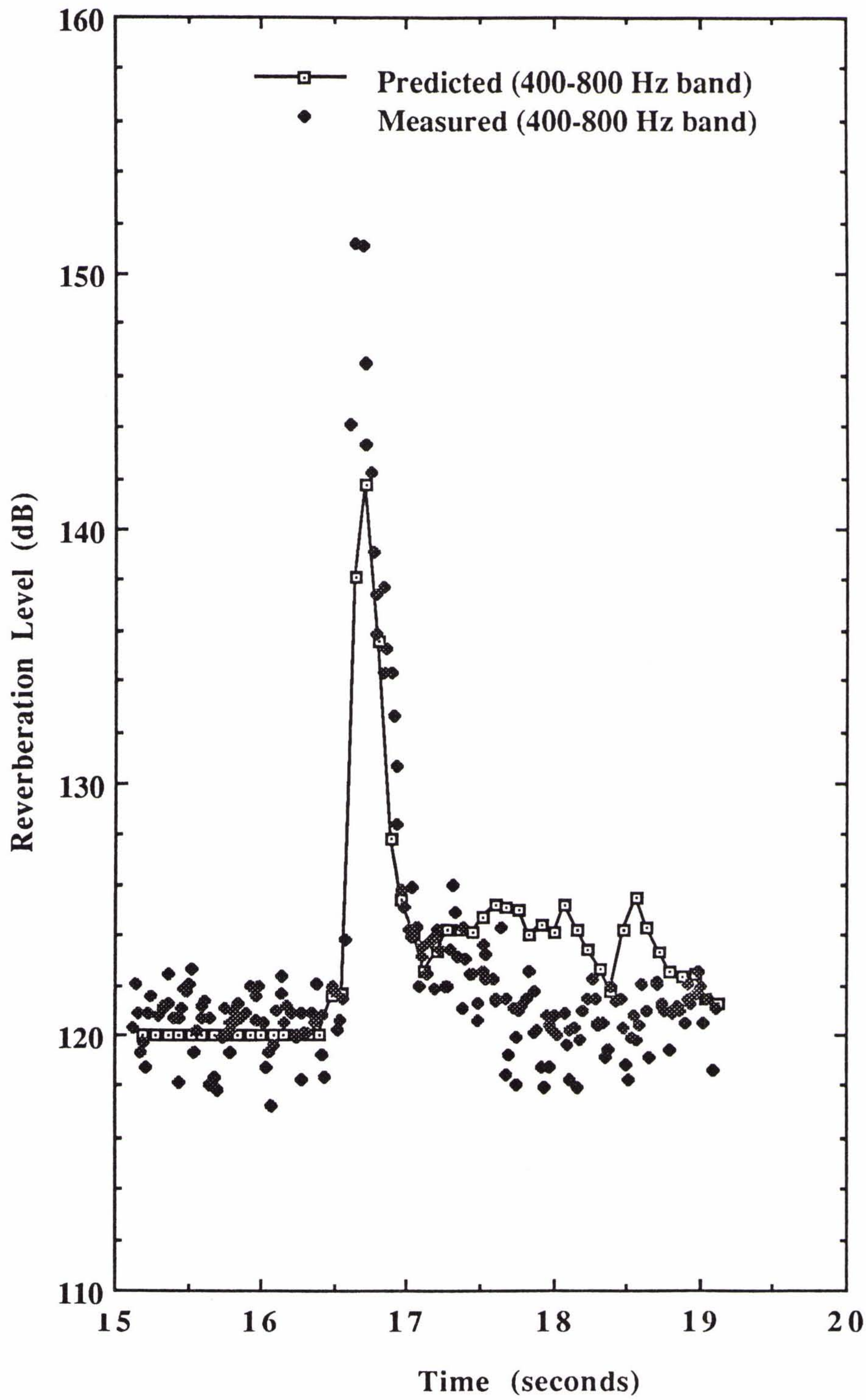

Figure 13. Plot of predicted reverberation envelope versus measured reverberation envelope for the source 13.7 nmi upslope from the receiver for the 400-800 Hz octave band.

predicted envelope is a reasonable fit to the corresponding measured envelope, even in cases where the transmission loss agreements were poor. The basic character of each envelope can be described as consisting of three parts. The first part is the specular paths composing approximately the first 100 msec, the second part is near specular scattering events generated primarily from the area forward of the receiver (model generated by the tangent plane approximation) which lasts for approximately 1 sec, and the incoherent mostly low angle reverberation returns which merge into the ambient noise.

4. Summary

Environmental variability was limited by the short ranges of the comparison. The variability seen in the sound speed profile occurs near bottom in a downward refracting scenario and does not impact to any significant degree on the propagation loss. Ambient noise was limited by low wind speeds and a site located out of major shipping lanes and fishing grounds. The geoacoustic parameters of the sub-bottom in the test area are the 1st order environmental variables that impact on the model's ability to predict propagation loss and bottom reverberation levels in this highly bottom interactive location. Results from the ADAM model show a good agreement between modeled and measured propagation loss in all but the higher frequency cases when the source was downslope of the receiver. However even in these cases the trend matched the measured data indicating that the geoacoustic model is valid for this local area and that the model can accurately predict the propagation loss. Each predicted reverberation envelope was a reasonable fit to the corresponding measured envelope, even in cases where the transmission loss agreements were poor.

5. Acknowledgements

The authors greatly acknowledge the support and guidance provided by Dr. William Carey, project manager of the multistatic active sonar for adverse environments program of the Defense Advanced Research Projects Agency (program element 62702E). The transmission loss and reverberation data was supplied in a timely manner by Mike Steele and Jim O'Connor of Bolt, Beranek and Newman, Inc.

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