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COMPARISON OF MEASURED AND PREDICTED PURE TONE PROPAGATION LEVELS FROM JAPE-1: AN EVALUATION OF THE PERFORMANCE OF ASOPRAT.

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ABSTRACT

Joint Acoustic Propagation Experiment Phase One (JAPE-1) short range propagation data has been used to evaluate the performance of the Advanced Sound Propagation in the Atmosphere (ASOPRAT) prediction code. The pure tone short range data has been Fourier analyzed giving the propagated pressure levels as a function of frequency. Meteorological profiles measured at the experimental site were used as input for the acoustic prediction routine ASOPRAT. Predicted and measured propagation levels are compared in decibels (dB) relative to one of the measurement positions for receivers on the line passing between the two thirty meter towers. Agreement between predicted and measured levels is very good. Source strength data has not been available so the comparisons show good agreement as to the shape of the propagation loss curve not necessarily the propagation levels.

INTRODUCTION

During JAPE-1, short range acoustic propagation data was gathered in which the source was a speaker emitting a pure tone. The data was gathered by MIT Lincoln Laboratory microphones located between the two source towers and in some cases by the French-German Research Institute of Saint Louis (ISL) microphones located about the South tower. The set up for the microphone data to be discussed is shown in Fig. 1. ISL data exists for only one of the data sets used in this paper. Fourier analysis of the measured time series is used to find the acoustic propagation levels for a particular frequency.

Along with the acoustic data, meteorological data was also taken. Using the data, sound-speed profiles can be calculated and used to predict the acoustic propagation levels. This met-data was used in ASOPRAT to predict the propagation levels. The levels predicted by ASOPRAT were then compared to the measured levels.

Analysis of four data sets will be included in this paper. Figure 2 shows the effective sound speeds ($c_{ef} = c + w$, c is the sound speed and w is the component of the wind along the direction of propagation) for the four data sets. For data sets 001102 and

057102 the source height is 30m. For data sets 025102 and 061102 the source height is 2m. For each of the source heights there is one effective sound speed profile in Fig. 2 that is upward refracting and one that is downward refracting. In choosing the data to be discussed, the source height and effective sound speed profile were considered, not which tower the source was located in. The propagation will be determined by the wind direction and the sound speed profile. One disadvantage of using these four sets is that the measured data does not cover the same range. For the two data sets with the source on the South tower, 057102 and 061102, there are no measurements closer than 500m, while for data set 025102 there is no data past 500m from the source.

DATA ANALYSIS

Figure (3a) shows one example of the pressure time series measured in the short range experiments. Figure 3b shows the Fourier analyzed signal for this time series. The MIT data was low pass filtered at 670Hz so there are no measured signals above 650Hz.

The data files containing the time series are very large. The analysis was done on a workstation equipped with both 'C' and Fortran compilers. A sample size of 2048 points was used as this represents about 1 second of data. An unwindowed FFT was performed on the data and the power spectrum calculated. To arrive at the dB levels shown in Fig. 3b the power spectrum of a 1/3 octave band was summed to get p^2. The dB level is given by

$$\mathrm{dB} = 10.0 \log_{10} (p^2). \qquad (1)$$

Equation (1) represents the dB level at a particular frequency at one time. Figure 3b was produced by displaying the dB levels of a single frequency for consecutive one second samples.

The length of time each frequency signal was broadcast is readily apparent in Fig. 3b. It is also evident that the propagation level over that time changes. In order to arrive at a level that can be compared to theory an average propagation level was found. Each of the broadcast signals in Fig. 3b was summed and divided by the broadcast length providing an average level over the broadcast. This is the level that will be used in the comparison to theoretical predictions.

ASOPRAT

ASOPRAT is an outdoor acoustic propagation routine that has been developed by the Physical Acoustics Research Group of the Department of Physics and Astronomy at the University of Mississippi (PARGUM). A meteorological profile is read by the code which is used to construct a sound speed profile and a wind speed profile along the direction of propagation. The wind and sound speed profiles are used in raytracing calculations or in Fast Field Program (FFP) calculations to predict the level of an acoustic signal.

ASOPRAT employs either a raytrace or an FFP calculation when needed. Raytracing is used first as it is much faster, especially when multiple frequencies are being run. The ground is treated as an impedance surface. The Attenborough four parameter impedance model is used to calculate the impedance. The raytrace function will attempt to locate rays leaving the source that meet at the receiver. It only uses the four most intense rays to calculate the propagation level, two direct rays and two one bounce rays, if they exist. No multiple bounce rays are considered. The Fast Field Program is used if raytracing cannot find any rays that reach the receiver (shadow zone) or when a focus occurs at the receiver.

When raytracing fails a Fast Field Program (FFP) is used to complete the prediction. The FFP calculation must be done separately for each frequency. The calculations take longer than the raytrace calculation. As the calculation involves spatial FFT's, finding the propagated level at a set of specific points is impractical. For the purposes of the paper, however, the FFP can be run once using the maximum range and the output of the calculation for each position out to the maximum range saved. This calculation uses the effective sound speed and the impedance ground to get the prediction.

COMPARISON

Predicted acoustic propagation levels are shown along with the measured levels from the JAPE-1 measurement in Figs. 4-7. The measured acoustic level will depend on the source level of the signal. At this time we have no information on the source levels for any data we have analyzed. In the figures, the level at one of the receivers has been used as a reference level for all other points. In Fig. 4 the ISL microphone at 800m from the North Tower was used as all of the measured data shown has a value there. In Fig. 5 the microphone at 100m from the North Tower is used as the raytrace calculation and is not valid for any of the microphones further away. Both Figs. 6 and 7 use the microphone at 500m as this is the closest microphone to the source on the South Tower.

Except for a few points, the predictions of ASOPRAT's raytrace and FFP calculations are very close to the measured values. For the sources located at 2m above the ground the raytrace calculation fails at a very short range. In these cases the FFP will be the main means of prediction. With the source at a height of 30m raytrace worked well out to 900m for the upward refracting 057102 and for all of the data for the downward refracting 001102 data set.

The comparisons shown in Figs. 4-7 show very good agreement between the measured and predicted propagation levels. There is very good agreement between the shapes of the predicted propagation curves and the measured data for Figs. 5-7. In Fig. 4 there is quite a discrepancy between the shape of the theory and the data. This is the only set of data with an appreciable cross-wind present. At this time ASOPRAT does not take into account cross-winds.

In comparing the actual measured and predicted propagation levels a common reference point was needed. As was discussed earlier the reference point was arbitrarily chosen to be one of the microphones. With this in mind the measured and predicted levels again compare very well except for data set 001102. Note however that by using a microphone that is a distance away from the source as a reference some of the effects of turbulence may be canceled. For example if the reference point is a shadow zone the underprediction of the sound level will not be seen due to normalization to the higher than expected shadow level.

CONCLUSION

Comparison of the JAPE-1 pure tone acoustic data to predictions from ASOPRAT shows very good agreement. The shape of the calculated propagation loss curves agreed very well with the data. As there is no source level data the comparisons use one of the data points as a reference for the dB representation. This did allow for the easier comparison of the shape of the propagation loss curve. However, the very good agreement between the measured and predicted levels may be invalid. The worst agreement is seen in the data set with the largest cross-wind.

For future work, the source levels will be needed to determine the proper reference levels. It would be preferred to have the data collected by the WES group. This would provide data spaced at 100m over a full kilometer regardless of the location of the source. It might be useful to try and estimate the met-profile at the time each data set was acquired. This may be done with a code provided by Dr. A. K. Blackadar at Pennsylvania State University. This could provide met-profiles which better describe the propagating medium.

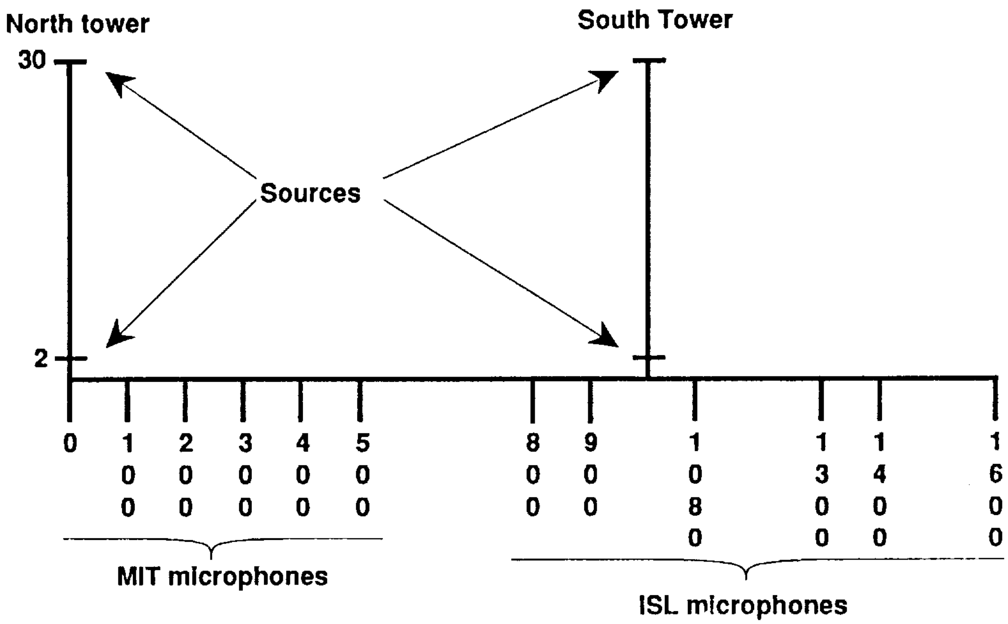

Figure 1. This figure shows the locations of the sources and microphones for the pure tone measurements.

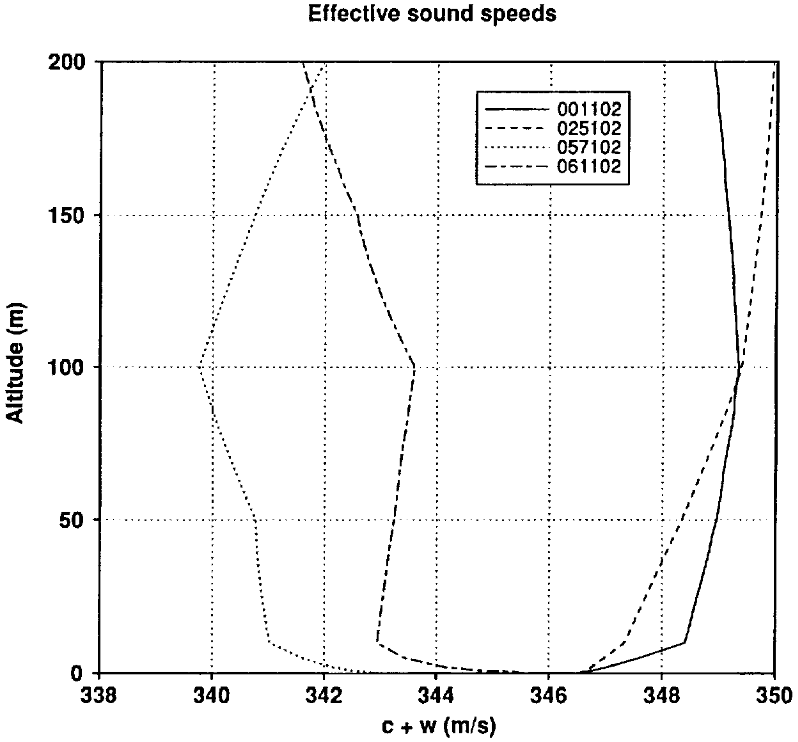

Figure 2. The effective sound speeds for the four data sets analyzed. The effective sound speed is the sum of the sound speed and the velocity component of the wind in the direction of propagation.

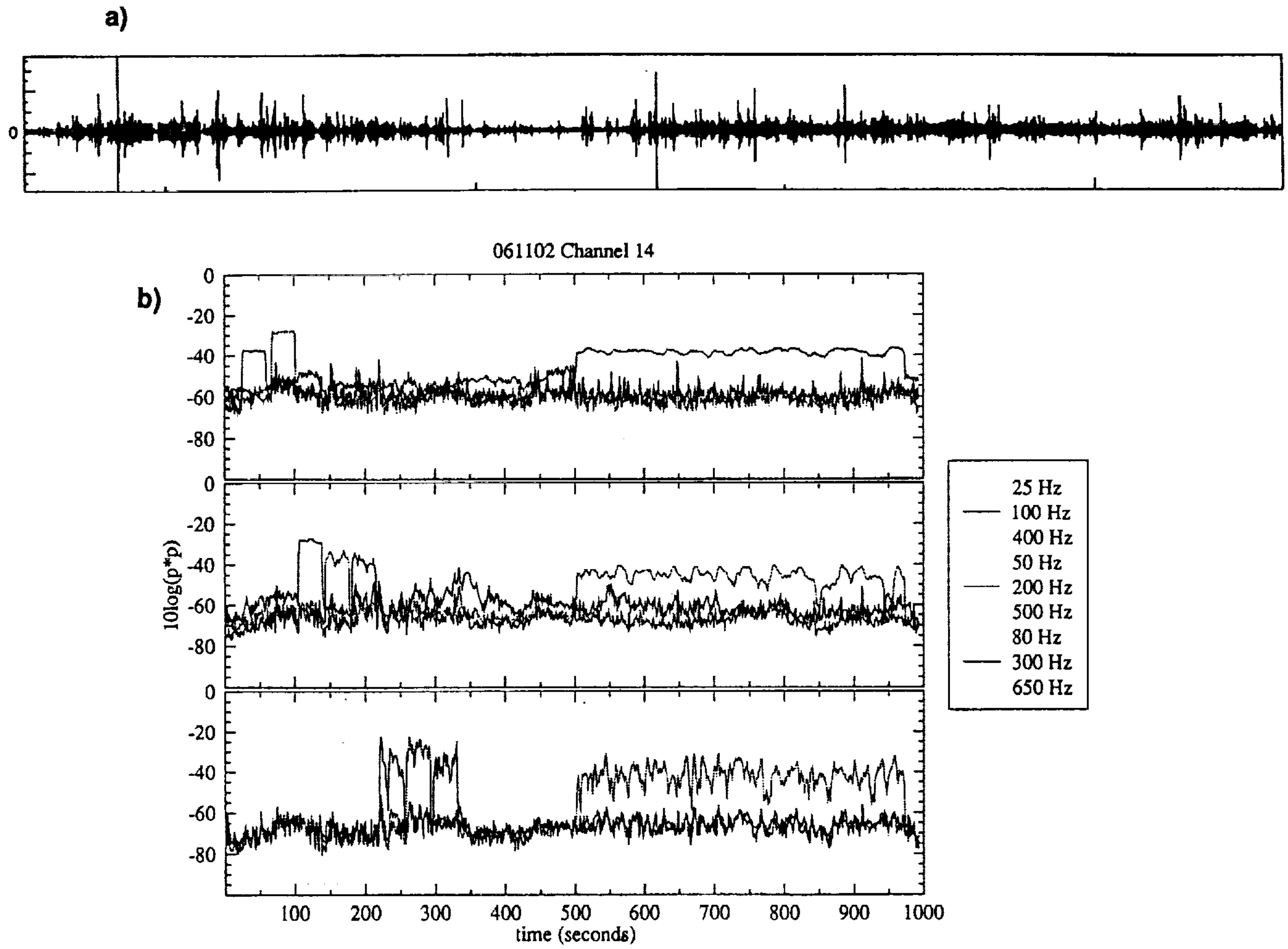

Figure 3. a) The raw time trace from channel 14 of the MIT recording for data set 061102. b) The Fourier analyzed data set for the time trace in (a).

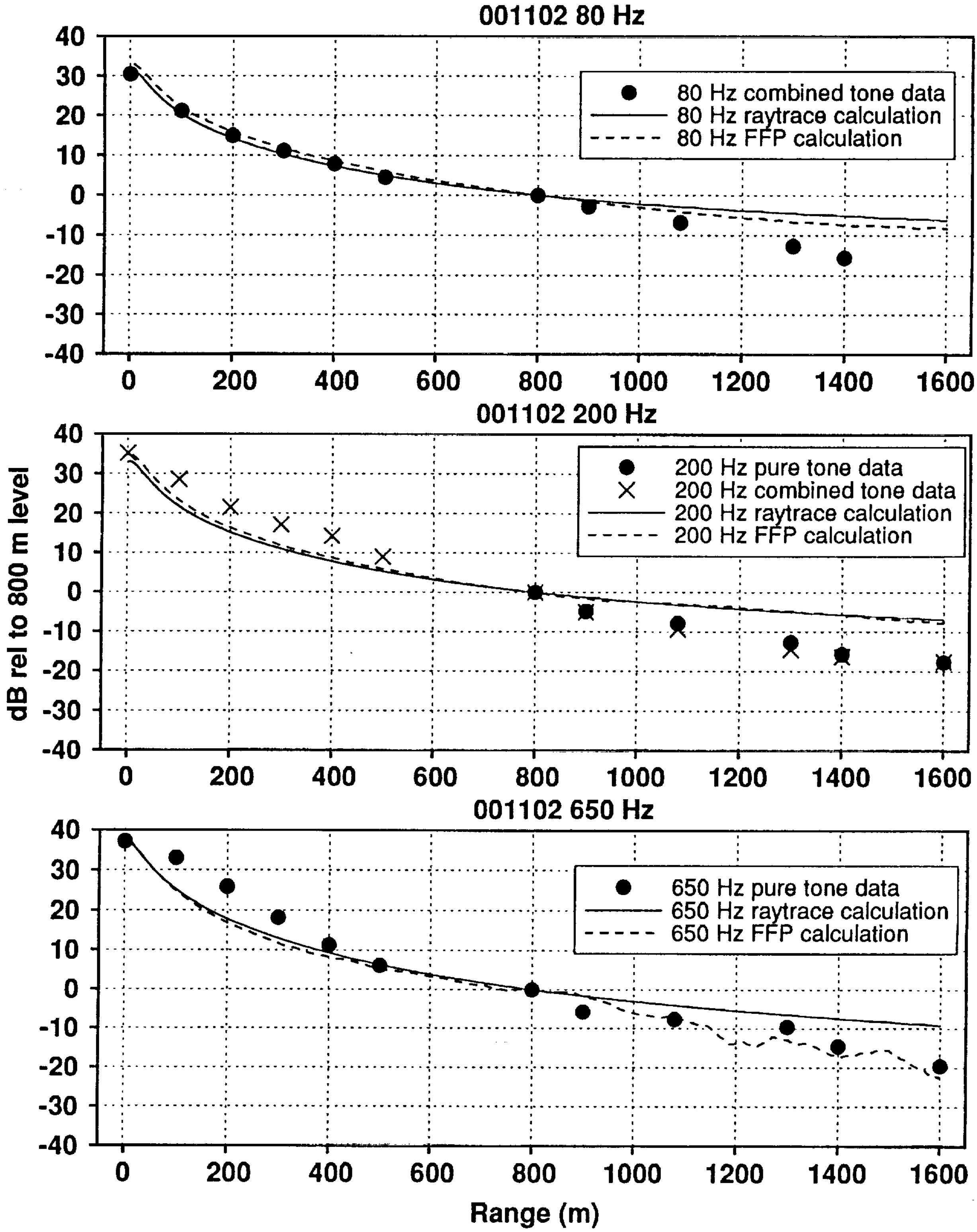

Figure 4. Comparison of ASOPRAT predictions and measured propagation levels for data set 001102.

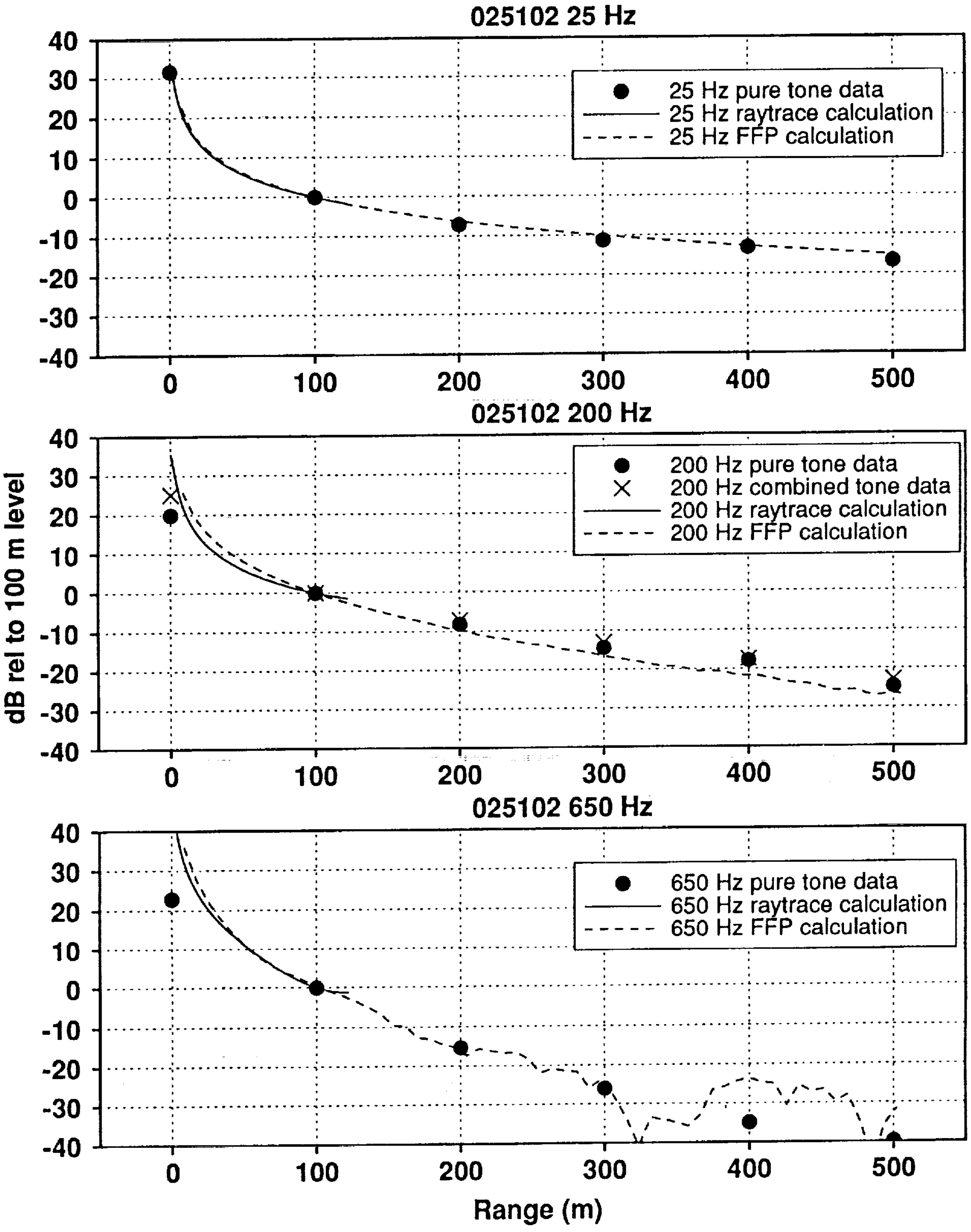

Figure 5. Comparison of ASOPRAT predictions and measured propagation levels for data set 025102.

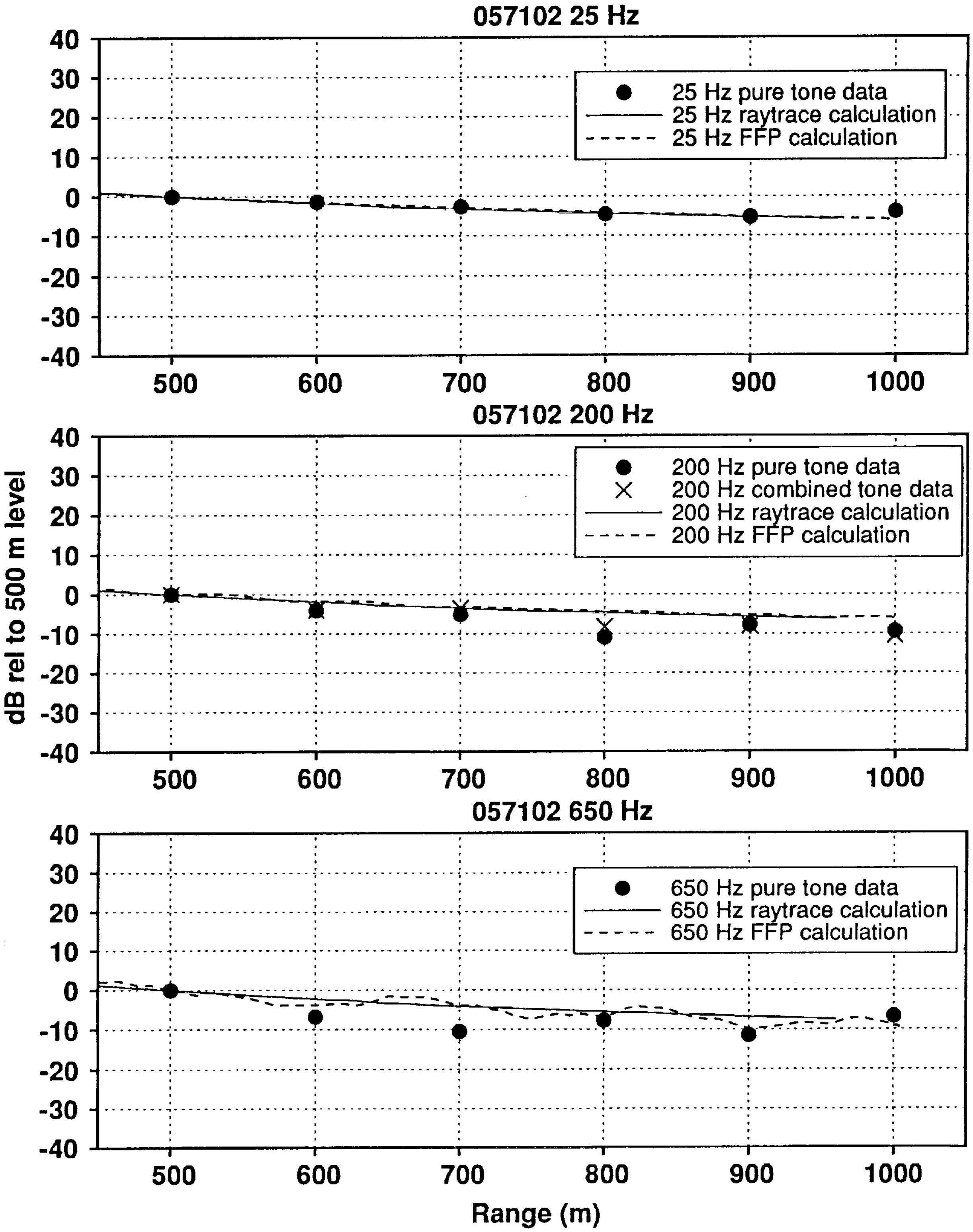

Figure 6. Comparison of ASOPRAT predictions and measured propagation levels for data set 057102.

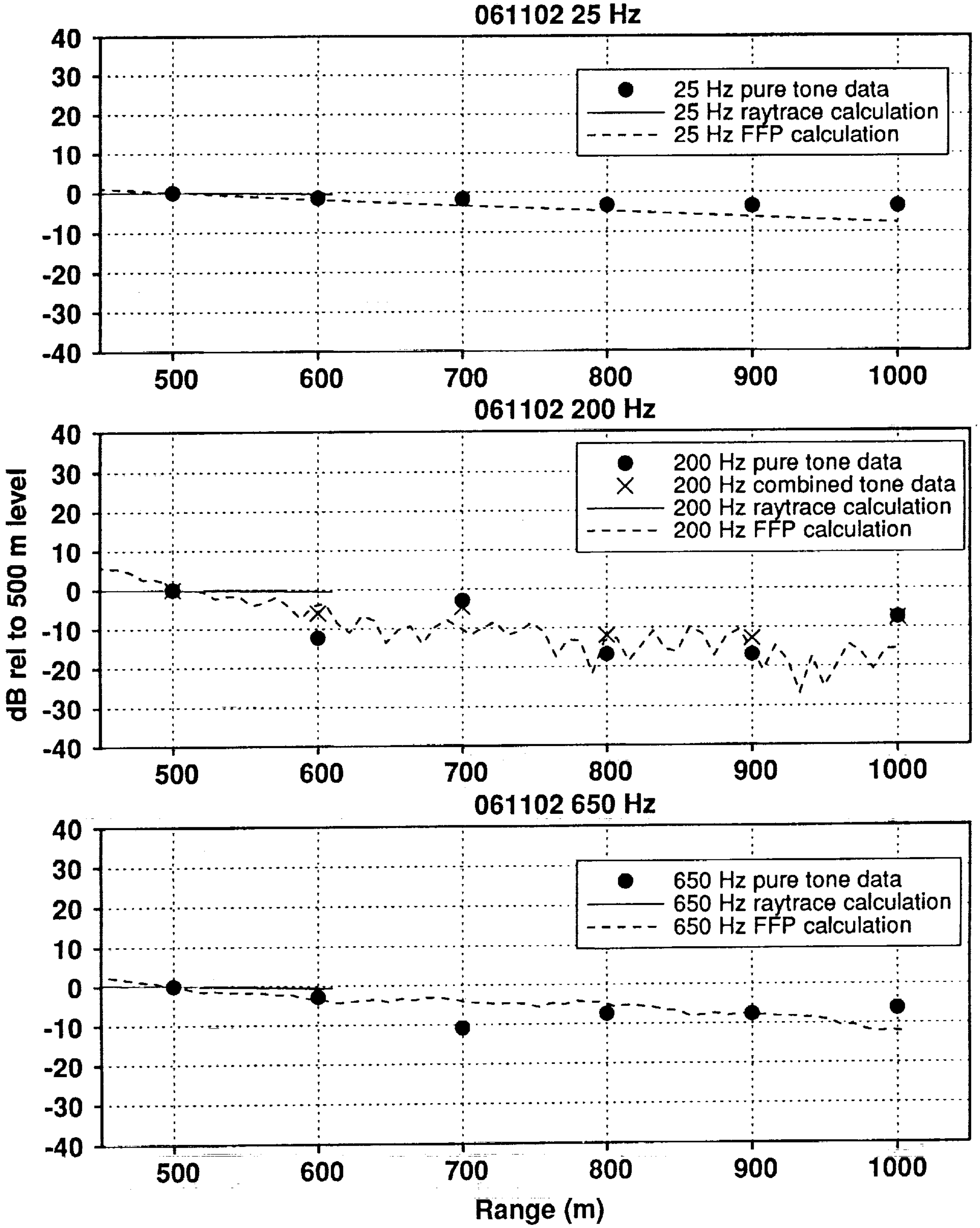

Figure 7. Comparison of ASOPRAT predictions and measured propagation levels for data set 061102.