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ABSTRACT

An experiment was conducted near borehole 6010 off the New Jersey coast as part of the DARPA ACT II experiment in 1993. Several of the tow tracks of the sound source coincided with tracks from the 1988 Hudson Canyon experiment. For this experiment major differences from 1988 were the accuracy and sampling of the range data, the available sound source which dictated the use of pulses as opposed to CW, and the low signal transmit power at the lower frequencies. Horizontal wavenumber spectra were computed at 100 Hz for this experiment and compared with SAFARI calculations. However the 100 Hz signal levels were problematic and consequently the low received signal to noise ratio precluded meaningful analysis. At the higher frequencies the coarseness of the range sampling, although adequate for signal transmission studies, would be aliased in synthetic aperture processing. Despite these problems, these results underline the robustness of this horizontal wavenumber estimation technique.

INTRODUCTION

The major thrust of this work was the analysis of data from the 1993 ACT II experiment to determine horizontal wavenumber spectra for comparison with the 1998 results. The experiment was performed near latitude 39 03' N, longitude 72 57' W on the New Jersey continental shelf near borehole 6010. The 1993 sound transmission measurements used an HX 189 sound source and at low frequencies had a much lower signal-to-noise ratio than the 1988 data obtained with a J15-3A source. The results were quite different from those calculated with SAFARI using the bottom model derived from the 1988 data (reference 4). In the 1993 experiment the ranges were derived from differential GPS sampled every 30 seconds as opposed to the 1988, more accurate, radar-transponder measurements made every 5 seconds. Sustained transmission of multiple, high-level tones was not possible with the 1993 source, so it was pulsed in order to transmit higher source levels. Also, in 1988 the ship was operated using a single propeller so as to maintain a low speed; this was not possible in 1993 and consequently the ship's speed over ground, while fine for measuring transmission loss, was faster than optimal for synthetic aperture processing. One result of this was that at 100 Hz the acoustic field was sampled only every half-wavelength. It is believed that the lack of agreement between the two experiments is due to the sub-optimal sampling of the range and pressure field and the poor signal-to-noise at 100 Hz for the 1993 data.

NAVIGATION

The track of the ship during TL3 is shown in figure 1 taken from reference 1. The ranges in ACT II were measured using a differential GPS system. Two systems recorded data: one MacIntosh-based which recorded navigation information every two minutes, and one PC-based which recorded navigation information and bottom depth approximately every 30 seconds. Because the range to the hydrophone array (derived from the navigation) is critical to the success of the Hankel transform method of analysis, the more rapidly sampled PC data was chosen. A plot of range between the source and the array as a function of time is shown in figure 2.

The ranges were fitted with a smoothing spline, and the speed of approach to the SEACAL array was calculated and shown in Figure 3. Both the speed derived from the GPS data as well as the speed from the splined data are shown in this figure; the agreement is so good that they appear as one curve. The rationale behind smoothing the range data is that the ship was navigated as well as possible to achieve a constant speed. High frequency variations in speed are therefore probably due to things such as movement of the ship's GPS antenna due to roll, and to errors in the differential corrections to the GPS signal. This spline fit was then used to interpolate to get the ranges at the times of the acoustic pulses.

The difference between the spline fit and the GPS data shows the fit is good: there is a scatter of about +/- 3 meters between the smoothed spline data and the measured GPS data from the beginning of TL3 at about 0100 until CPA with the SEACAL array at 0123.

ACOUSTIC SIGNALS

Ten frequencies (100, 150, 200, 300, 400, 600, 700, 800, 900, 1000 Hz) were broadcast sequentially in two sets, with a 2.5 second repetition rate for frequencies below 500 Hz and a 5 second repetition rate for frequencies above 500 Hz (Fig 4). This figure shows the low signal-to-noise ratio at 100 Hz; progressively better at higher frequencies. Figure 5 is a plot of the relative sound pressure level at 100 Hz for channel 15 at a hydrophone depth of 61.7 meters. As the ship approached the array, high-pressure spikes developed (after 1.32 hours and levels above -40 dB in figure 5); these data were removed before the signal was analyzed. Since the source was pulsed at successive frequencies, the received signal filtered at a particular frequency consists of peaks corresponding to times when that frequency was broadcast followed by dips corresponding to noise when that frequency was off. Figure 6 is an expanded portion of figure 5 about times from 1.03 to 1.055. The *'s represent levels automatically picked by the analysis program as representative levels for each pulse. Figure 7 shows the results of a SAFARI run for 100 Hz at a hydrophone depth of 61.7 meters, and Figure 8 shows the SAFARI data superimposed on the experimental data.

ANALYSIS TECHNIQUE

A Fourier transform was taken of the raw data to extract only the signal at 100 Hz (figures 5 and 6). One value from each peak (* values in fig. 6) of the resulting series was saved. This resulted in a series of complex pressures (quadrature components of the pressure) vs. time. Separately for channel 15 only, a sequence of values within +/- 2 dB of a manually-selected level on each peak was similarly saved. The smoothing spline previously fitted to the ranges was used to assign a range to each value of time in these series. The resulting pressure as a function of range is shown in figure 9 for 100 Hz and channel 15. The lower (solid) curve is for the hand-picked data; the upper (dotted) curve (very noisy at short ranges) is the result from the automatic peak picking. The two curves agree well for ranges greater than 500 meters. In order to avoid contaminating the data with noise, the analysis procedure discarded data points for levels above -40 dB.

An additional transform over range was then taken in order to compute the wavenumber spectrum of the field. Details of this technique can be found in Frisk et al (1984). In this case, the modified routine of Press et al (1988) was substituted for the Fourier-Bessel Transform.

DISCUSSION

In order for the Hankel transform technique to succeed, several points are critical. One is that the clocks controlling both the source and the digitizer in the SEACAL array must be precise enough so that any slip in phase between the clocks corresponds to a slip in range of only a fraction of an acoustic wavelength over the time it takes to transit a leg. The other is that the range between the source and the hydrophone array must be measured to a fraction of an acoustic wavelength.

The source was controlled by a precision oscillator, and the output of a precision oscillator was recorded on one of the data channels of the SEACAL. Thus the timing requirement should be satisfied if the appropriate correction factors are applied.

The lowest frequency used for this experiment was 100 Hz, which corresponds to a wavelength of about 15 meters. The average ship speed as derived from the GPS data was about three meters per second. Thus the acoustic field was sampled about every seven meters, or about twice each wavelength at 100 Hz. At 150 Hz, the wavelength is about 10 meters, so the field was sampled somewhat less than twice a wavelength. This means, in general, that for this data the Hankel analysis cannot be done at frequencies above 100 Hz. The sampling is perhaps marginal for the 100 Hz data, and aliasing effects may be observed.

The ship speed of slightly less than 3 meters per second resulted in about 80 meters of ship movement between navigation fixes (Figure 10). This range difference between fixes is larger than one would like for deriving ranges for pings which are about 7 meters apart. As previously described, a smoothing spline was fitted through these range points and used to interpolate the range of each ping.

In 1988, with the acoustic tones mixed together and continuous, the field was sampled about every 1/3 meter and it was easy to interpolate the pressure data onto an equal-spaced grid for the analysis. The ACT II data was sampled only every 7 meters, about 1/2 wavelength at 100 Hz, which made interpolation difficult. It was thus decided to use a routine published by Press et al (1988) for the analysis of non-equally-spaced data, and this routine was modified to handle the complex (quadrature components of the) pressures as a function of range. Results of the output of this new routine (ASPER) are shown in Figure 11, and of the old one (PT_HANK) in Figure(12). The resulting peaks are similar, but the background noise levels are dramatically improved for ASPER.

The wavenumber spectra for the SAFARI model are given in Figure 13. A comparison between the SAFARI and ASPER results shows that several of the peaks in the horizontal wavenumber spectrum agree if the ASPER values are decreased (shifted to the left) by about 0.05. However, spurious peaks are observed at wavenumbers greater than the water wavenumber. These may be due to aliasing as a consequence of inaccuracies in measuring and interpolating the range, and in interpolating the pressure field. Because of this, and the poor signal-to-noise, additional corrections to account for the shift in the peaks were not performed.

Figure 14 is a plot of horizontal wavenumber and depth with the colors representing relative modal levels in dB and figure 15 is the same in a 3-D projection. Superficially this looks like results from the 1988 experiment. There is a dominant series of 5 peaks in depth just above kr=0.4, and a somewhat less apparent series of 4 peaks just below kr=0.45. However, the fundamental mode (one peak) appears to be missing. Also, the symmetry in the figure about a vertical axis between the double lines at a wavenumber of about kr=0.47 is reminiscent of aliasing. The modal shapes are less apparent in the results from the Hankel transform, Figure 16.

CONCLUSIONS

The difficulty in determining the wavenumber spectra from the 1993 data (as compared to the 1988 data) was due to the low signal-to-noise ratio, the less accurate ranging derived from the navigation, and the pulsed source which sampled the acoustic field only every 1/2 wavelength. However, this data set, particularly at the higher frequencies where there is better signal-to-noise, was quite suitable for studying frequency-dependent transmission loss effects (where the precise phase of the signal is not important). Such analysis has been performed and has provided an interesting comparison with transmission loss results derived from the 1988 experiment.

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3. Frisk, G.V, Lynch, J.F., "Shallow Water Waveguide Characterization Using the Hankel Transform," J. Acoust. Soc Am. 76:205 (1984)

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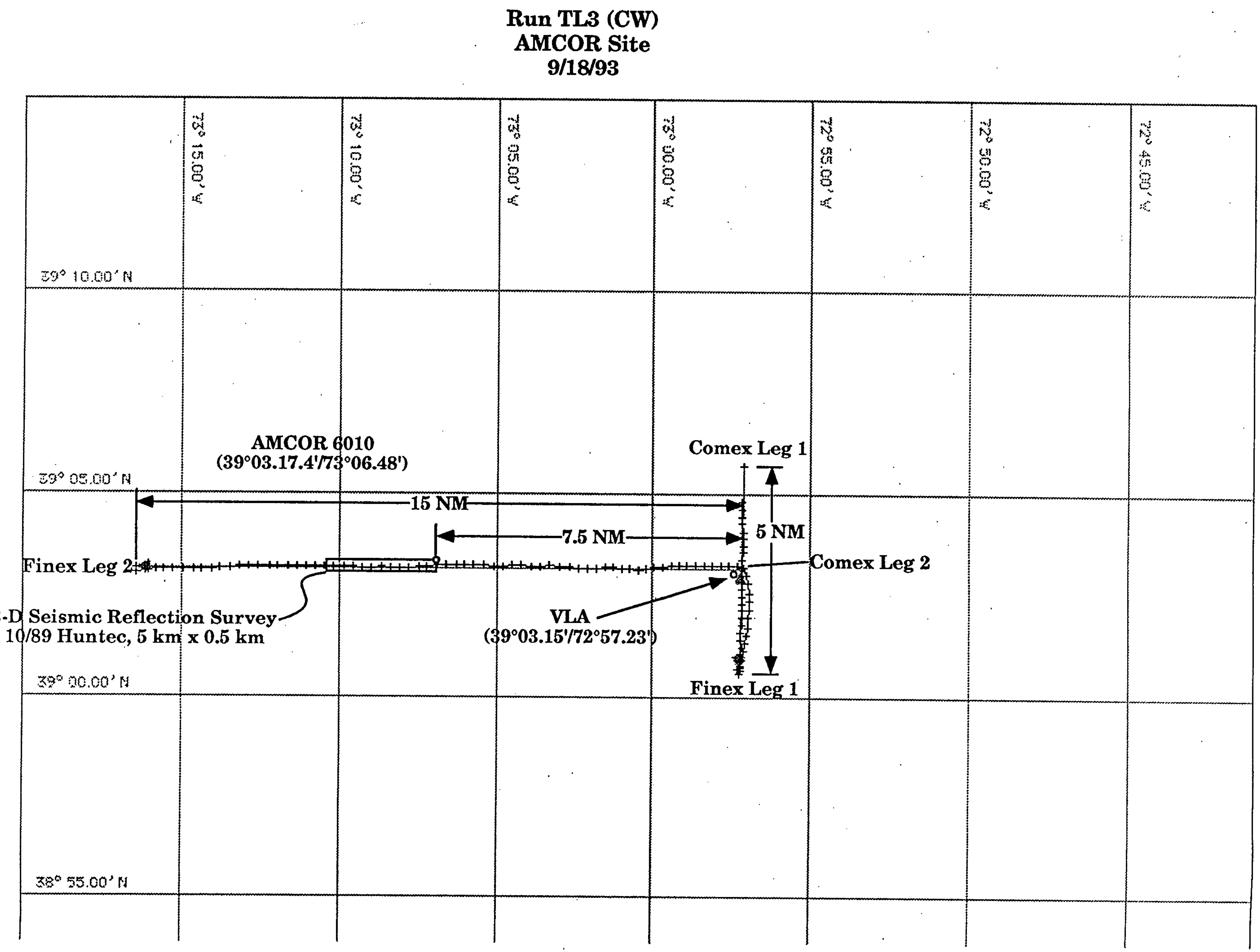

Figure 1. Figure from ref 1. showing ship's track during TL3.

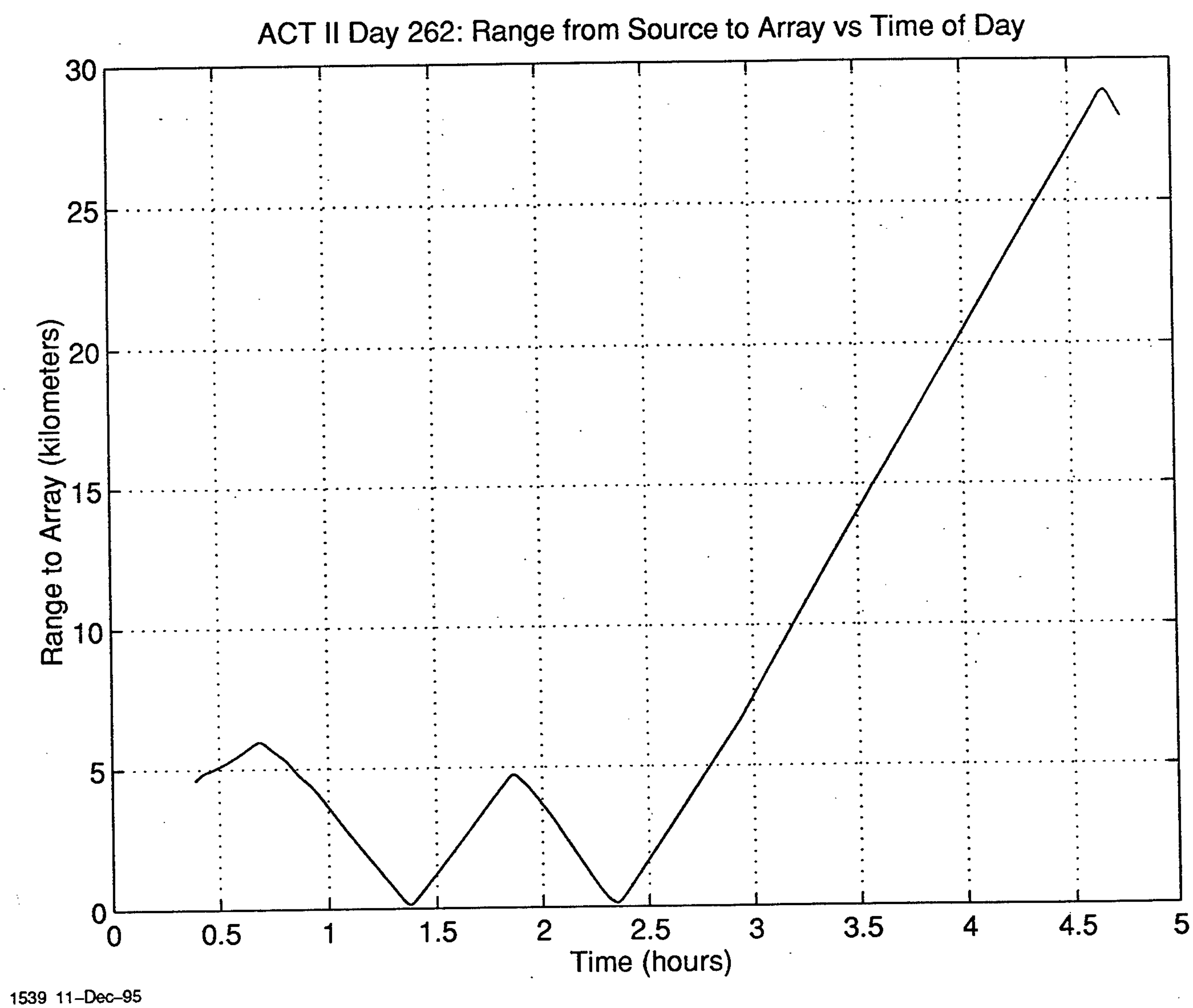

Figure 2. Range between source and SEACAL array as function of time-of-day.

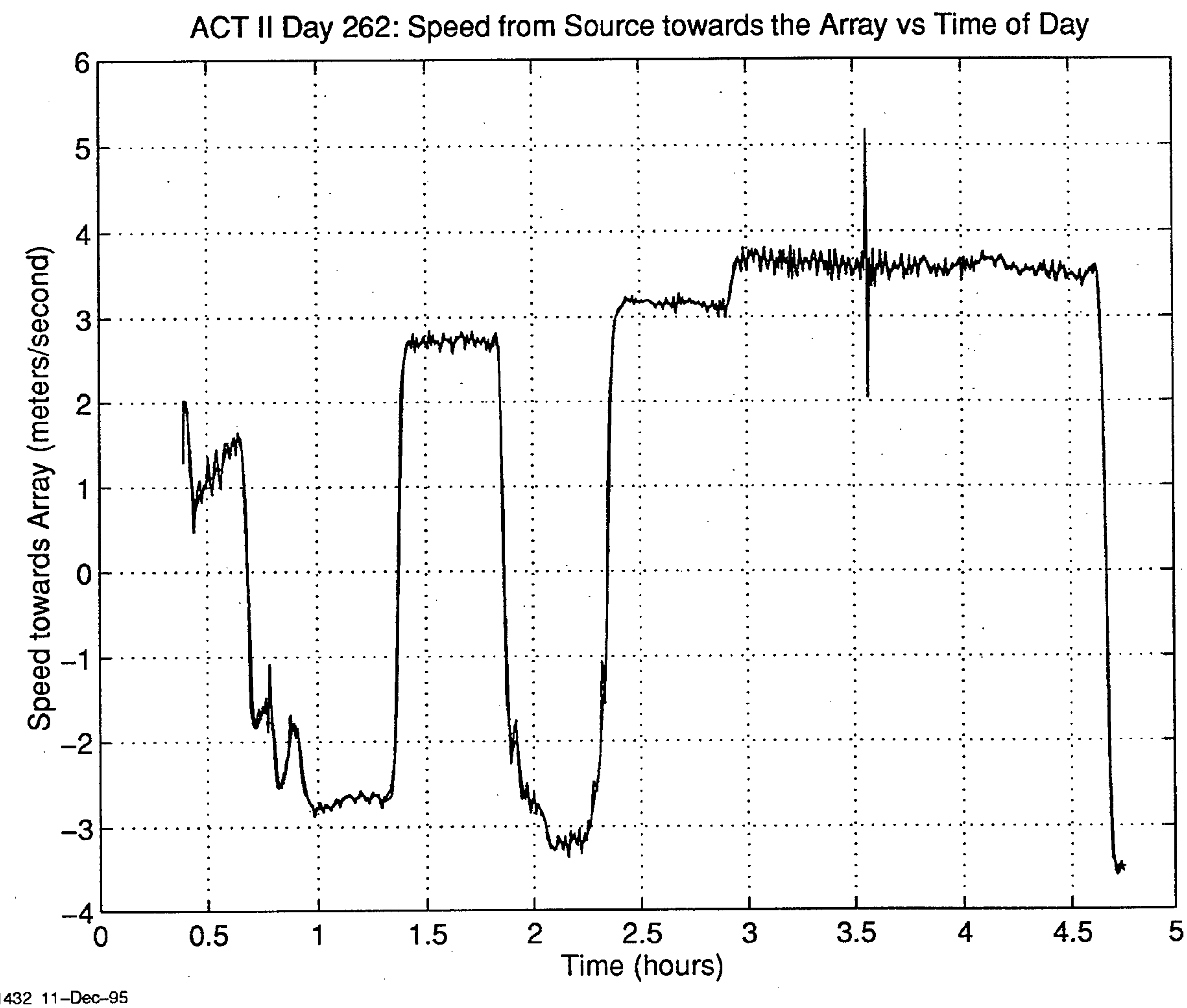

Figure 3. Speed of acoustic source (ship) towards (-) and away from (+) the SEACAL array. Both the smoothed-spline speed and the raw-GPS speed are shown.

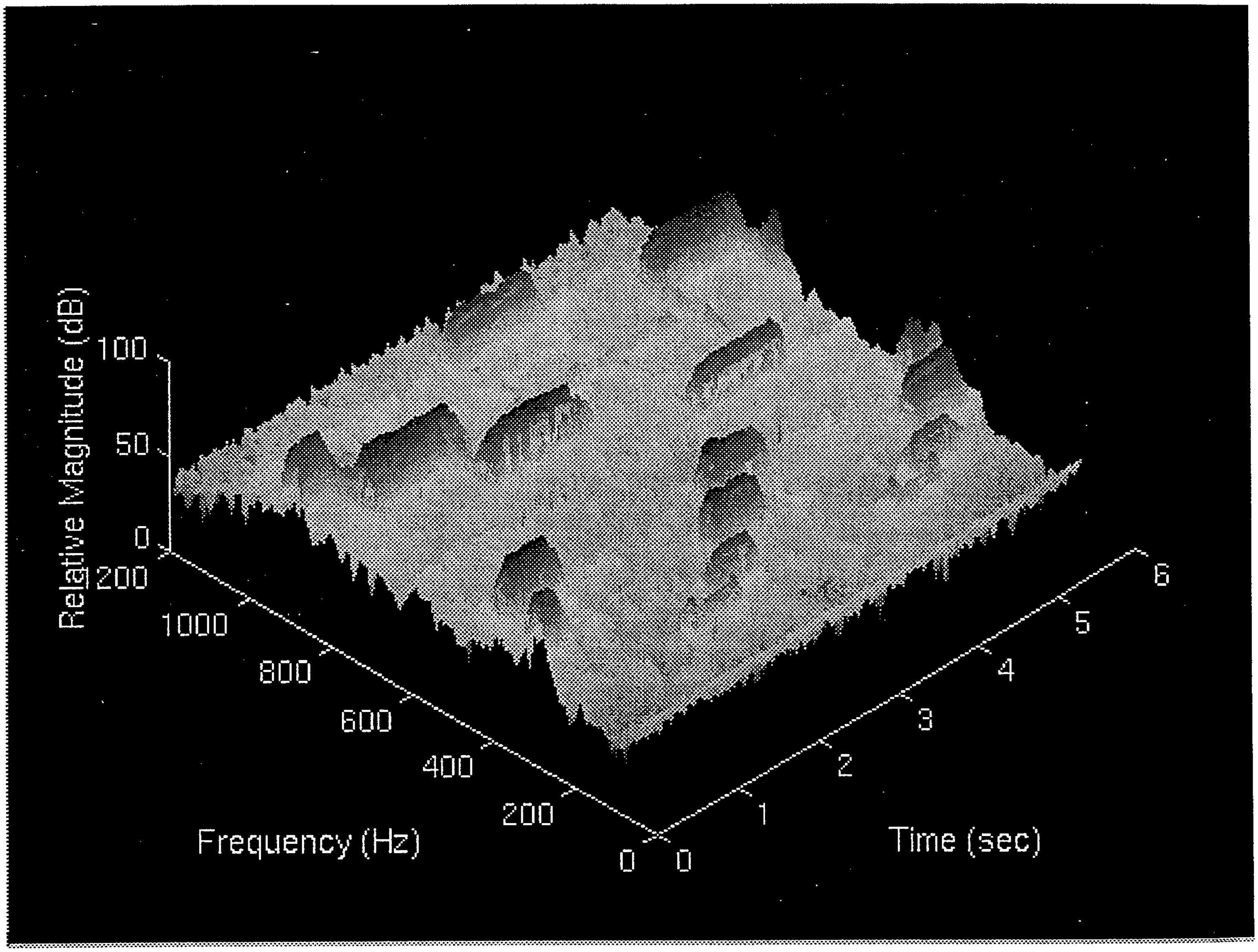

Figure 4. Spectrogram of the sequence of tones broadcast during TL3: received signal level as a function of frequency and time. The poor S/N below 200 Hz was due to poor transponder response. Above that frequency the good S/N would be suitable for transmission loss analysis.

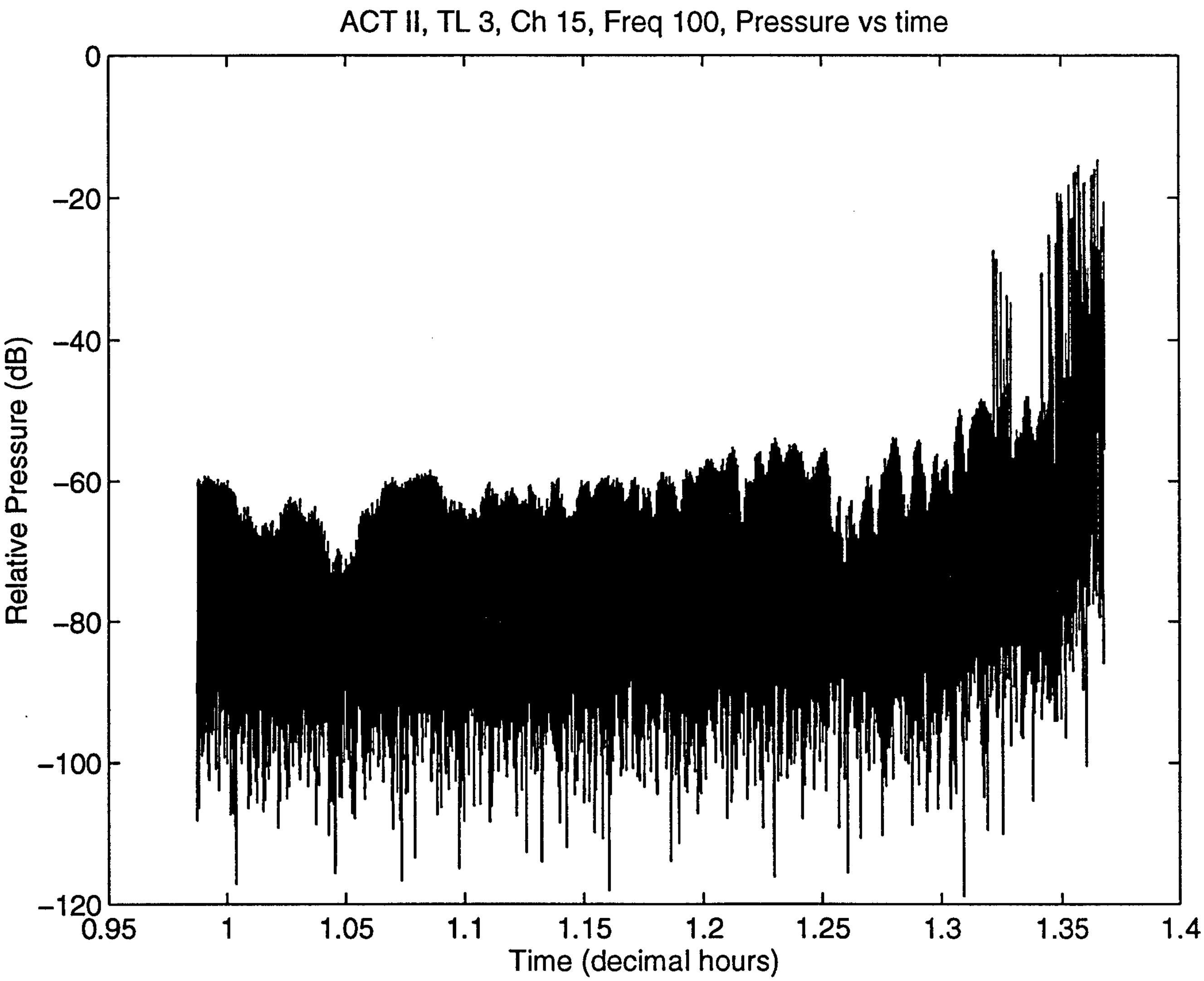

Figure 5. Relative sound pressure level from SEACAL channel 15 at 61.7 meters depth.

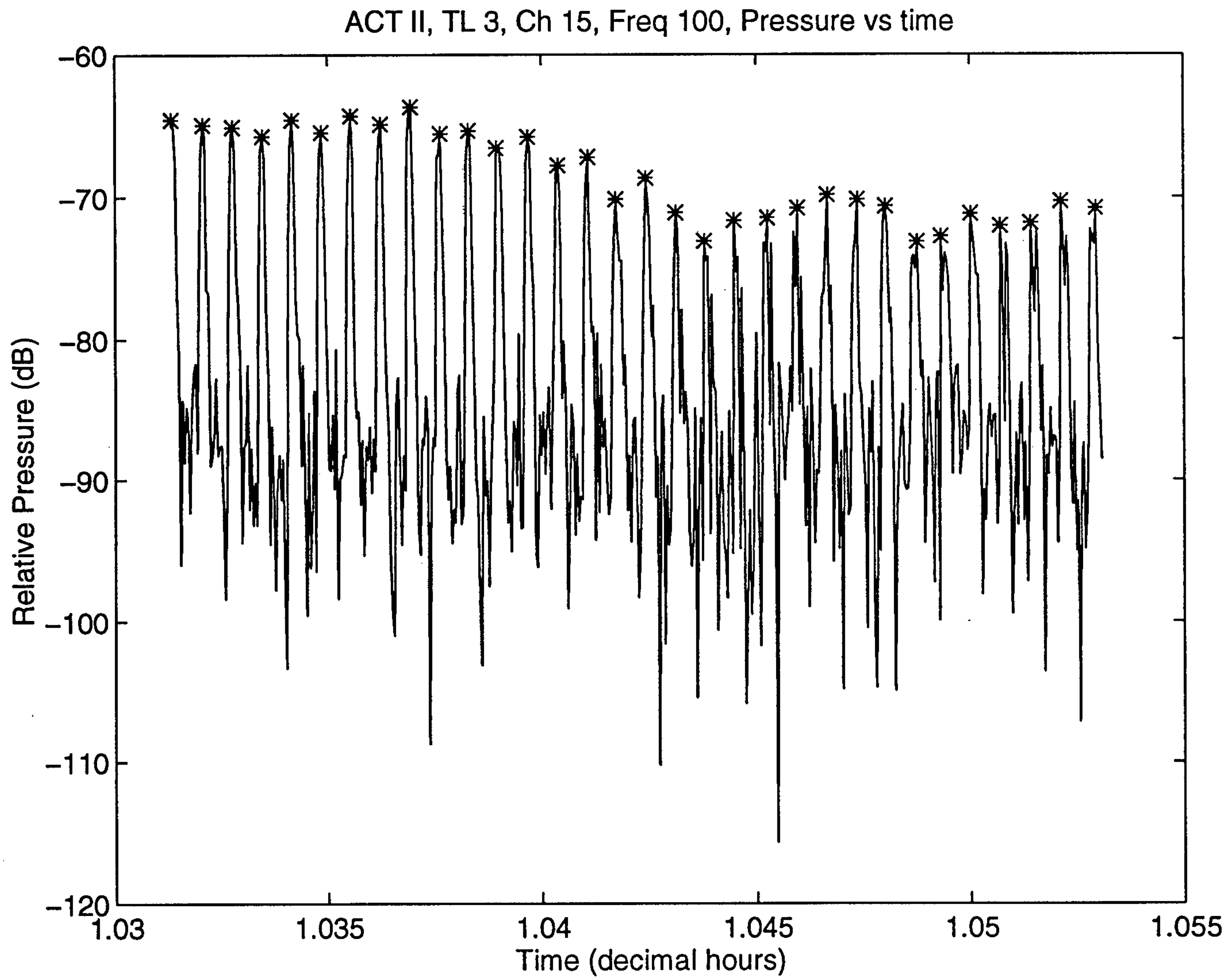

Figure 6. Expanded view of Figure 5 for the time interval 1.03 to 1.055 hours.

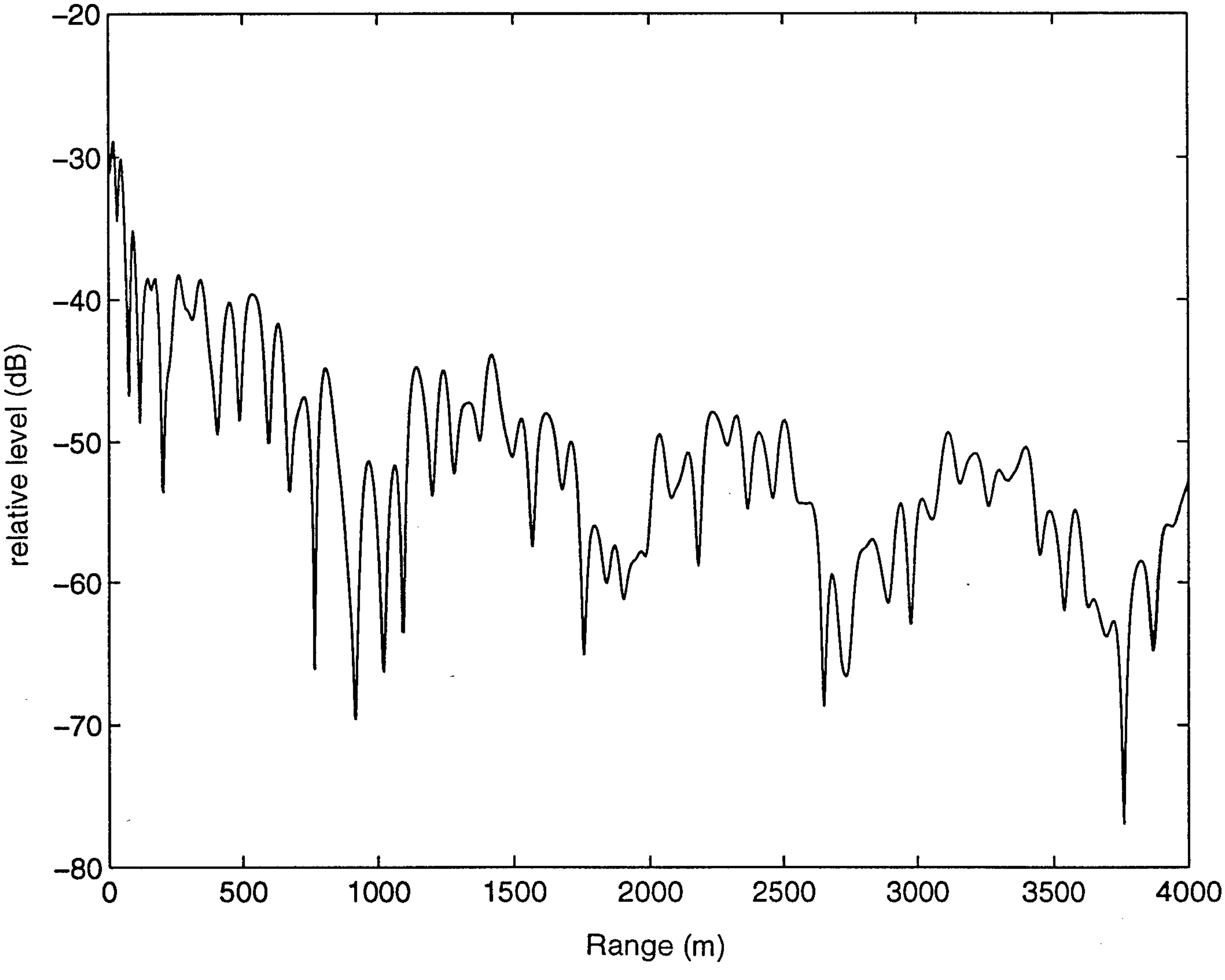

Figure 7. SAFARI output: magnitude of the pressure in dB as a function of range in meters.

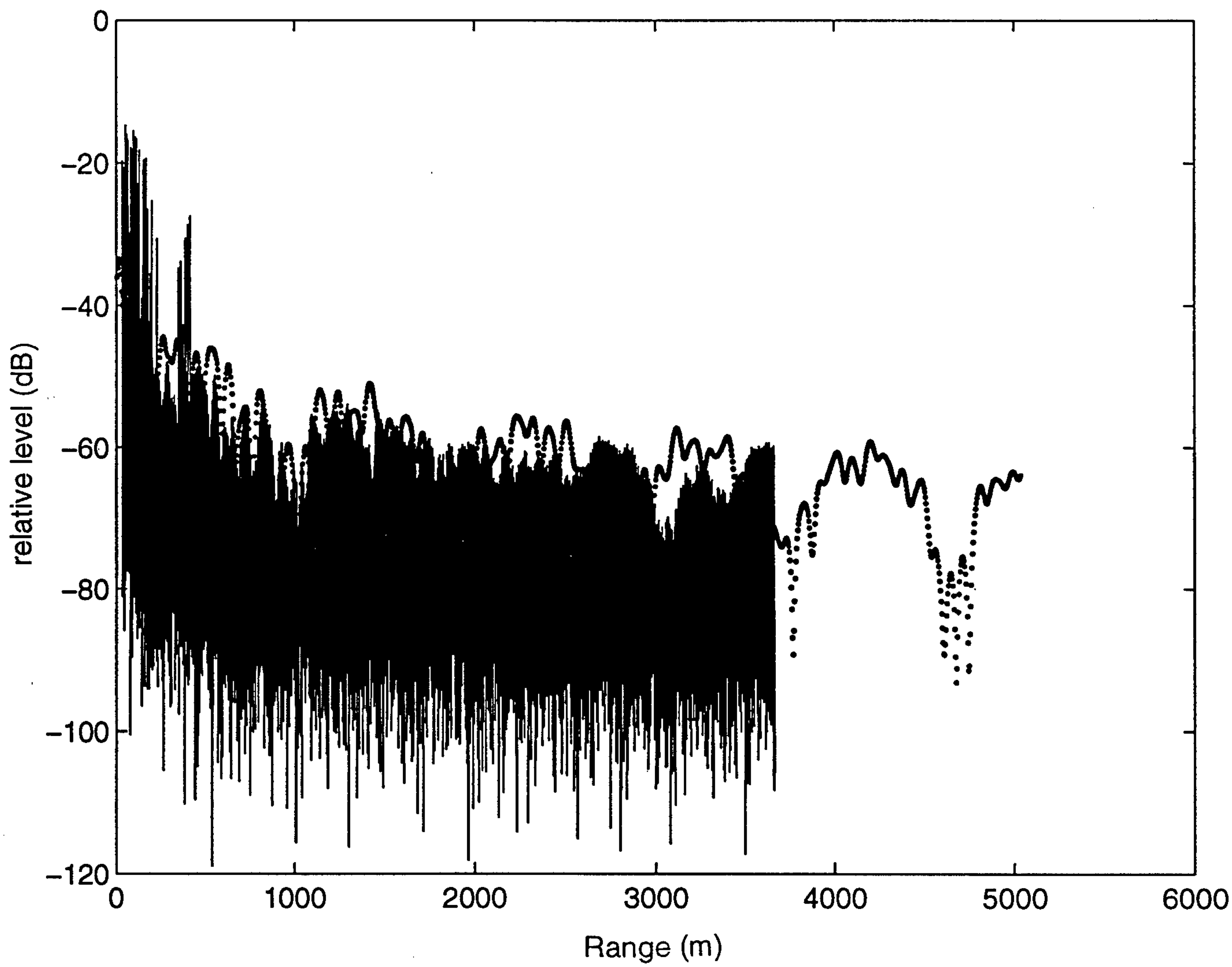

Figure 8. Comparison of the relative pressure levels in dB from SAFARI (dotted) and the experiment (solid) vs. range.

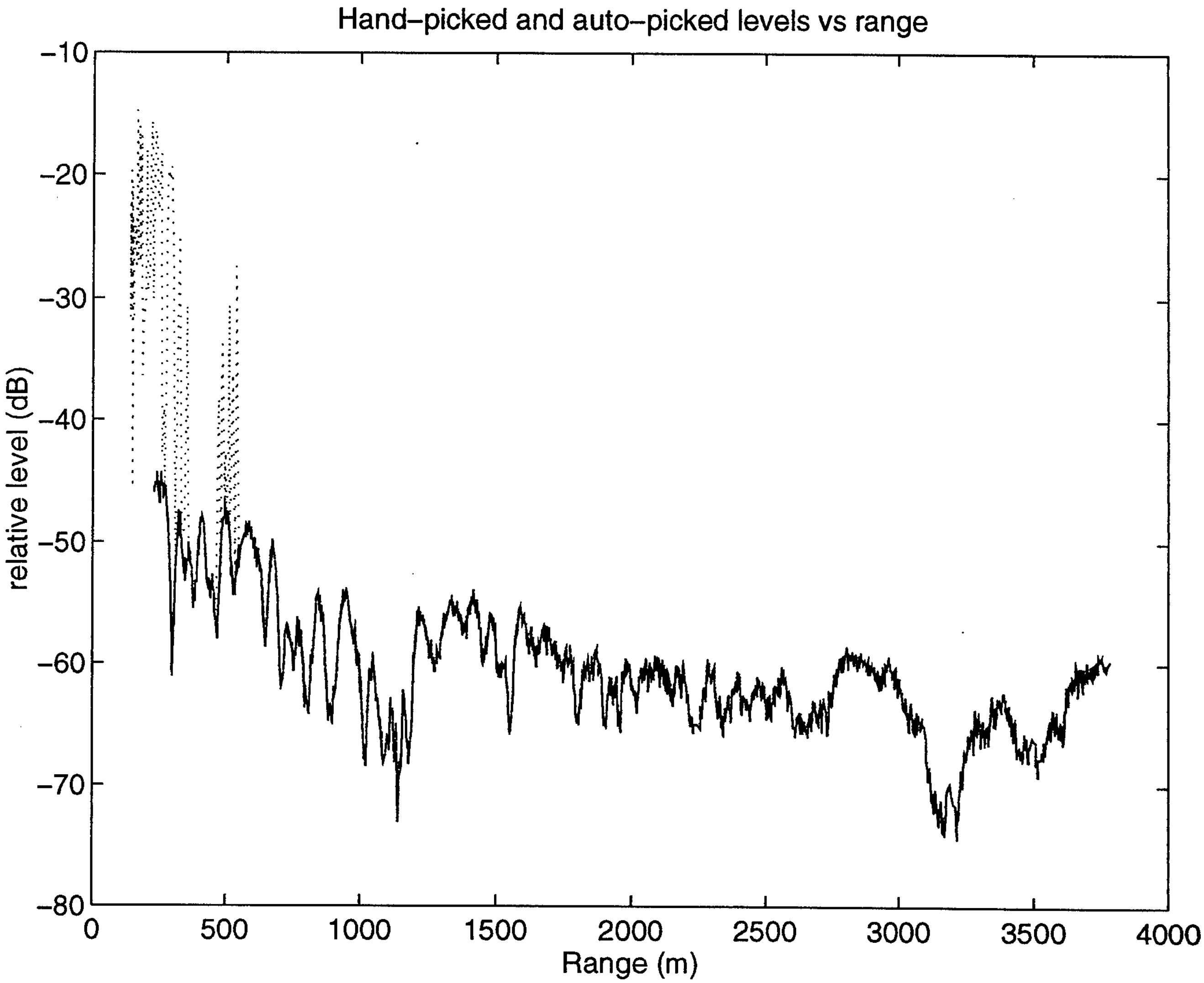

Figure 9. Magnitude of the pressure as a function of range. The lower, black curve is the result of the hand-picked data; the upper (red) curve (noisy near short ranges) is the result of the automatic peak-picker.

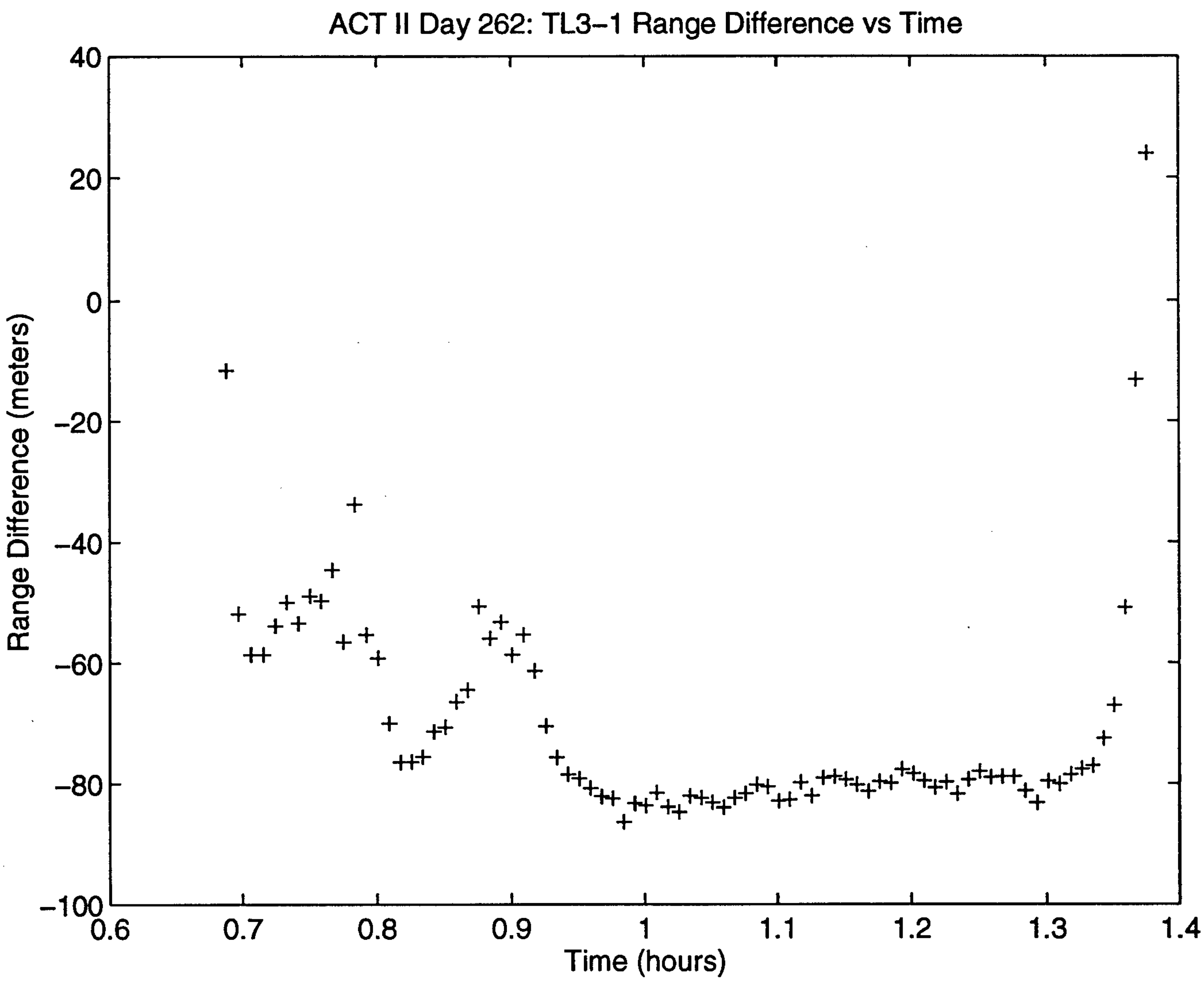

Figure 10. Range difference from source to the array between successive fixes 30 seconds apart. The constant value from about time 1.0 to 1.3 occured during the run; the variation after time 1.3 occurred as the ship approached CPA

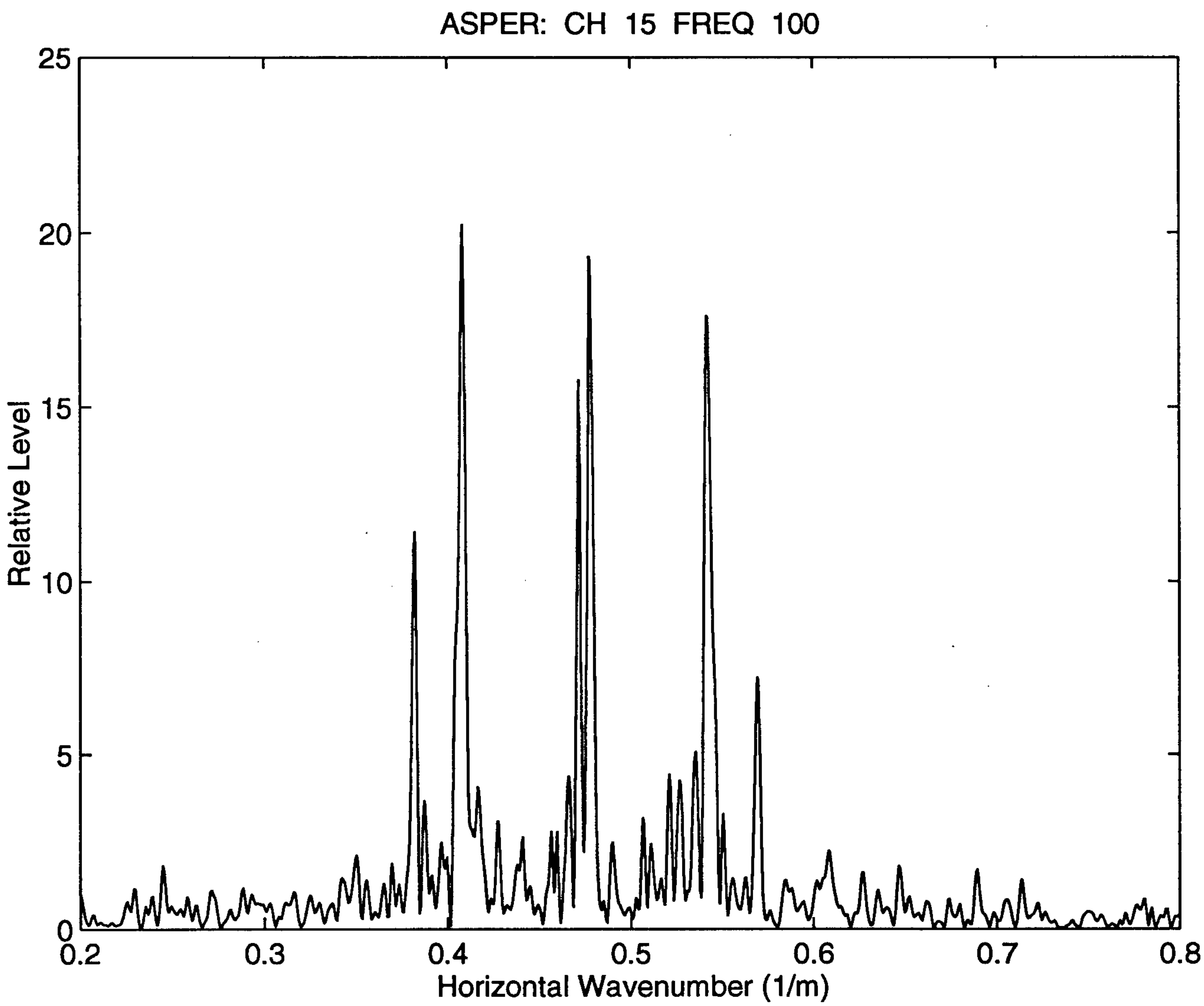

Figure 11. Wavenumber spectrum from ASPER.

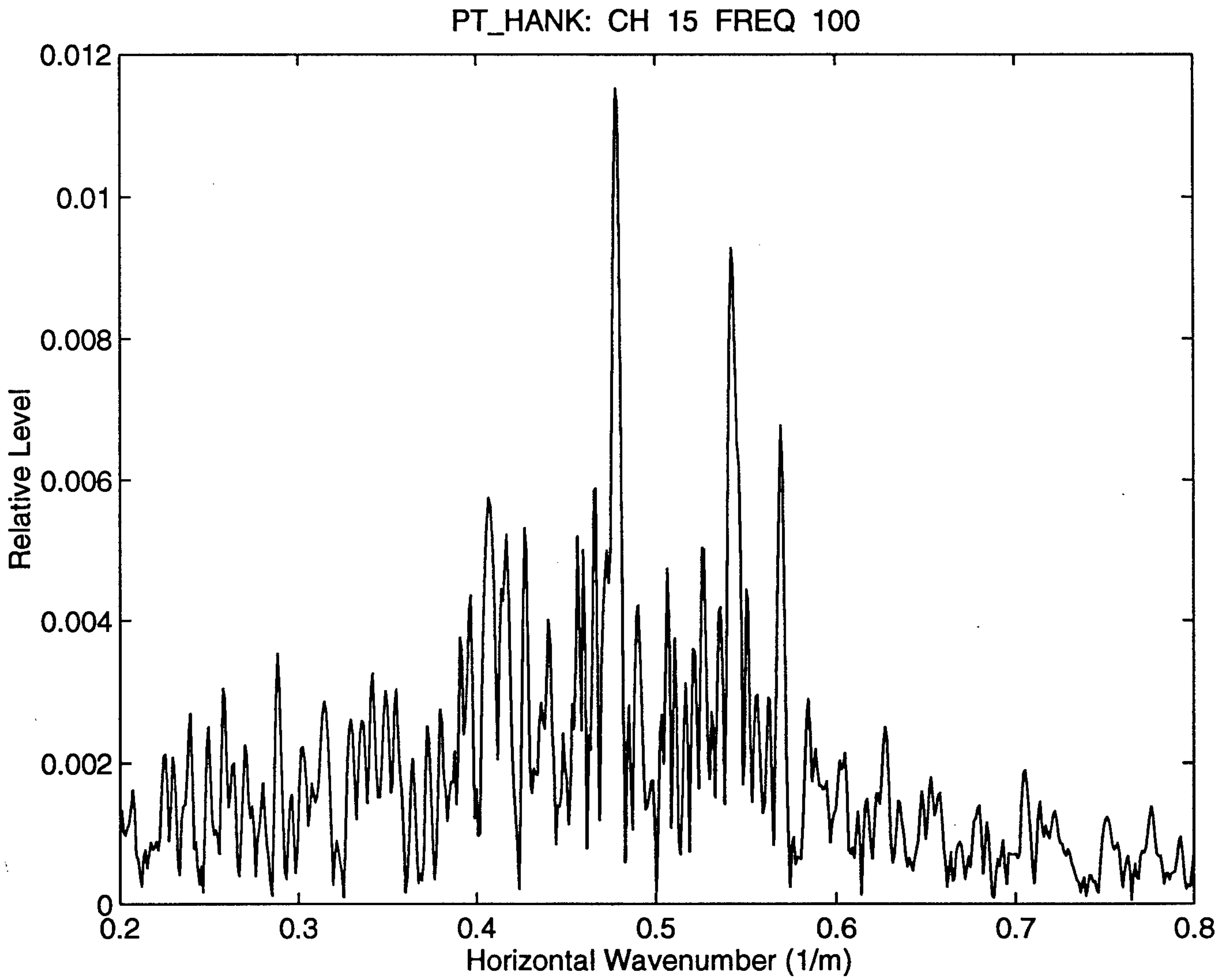

Figure 12. Wavenumber spectrum from PT_HANK

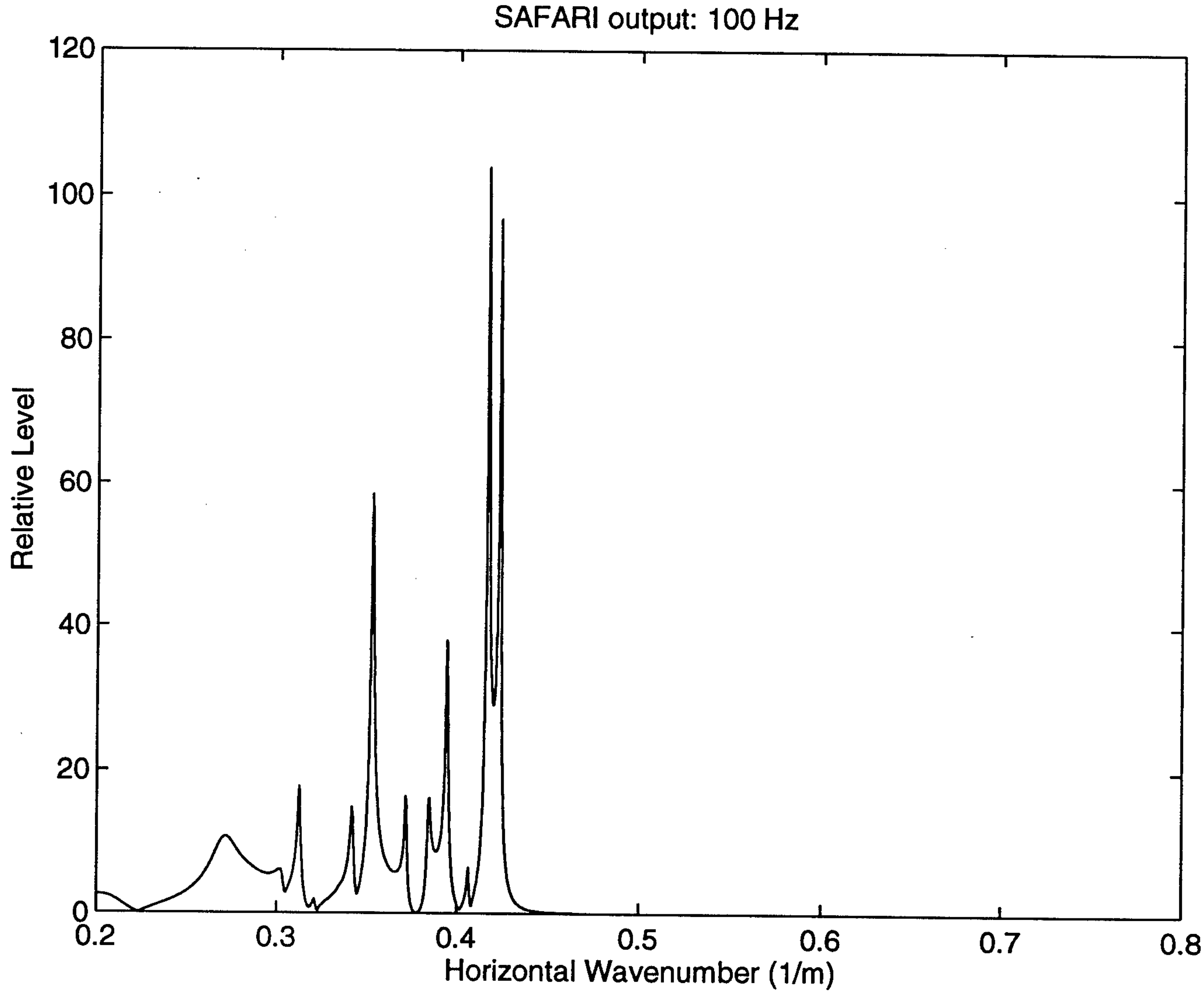

Figure 13. Theoretical wavenumber spectrum from SAFARI

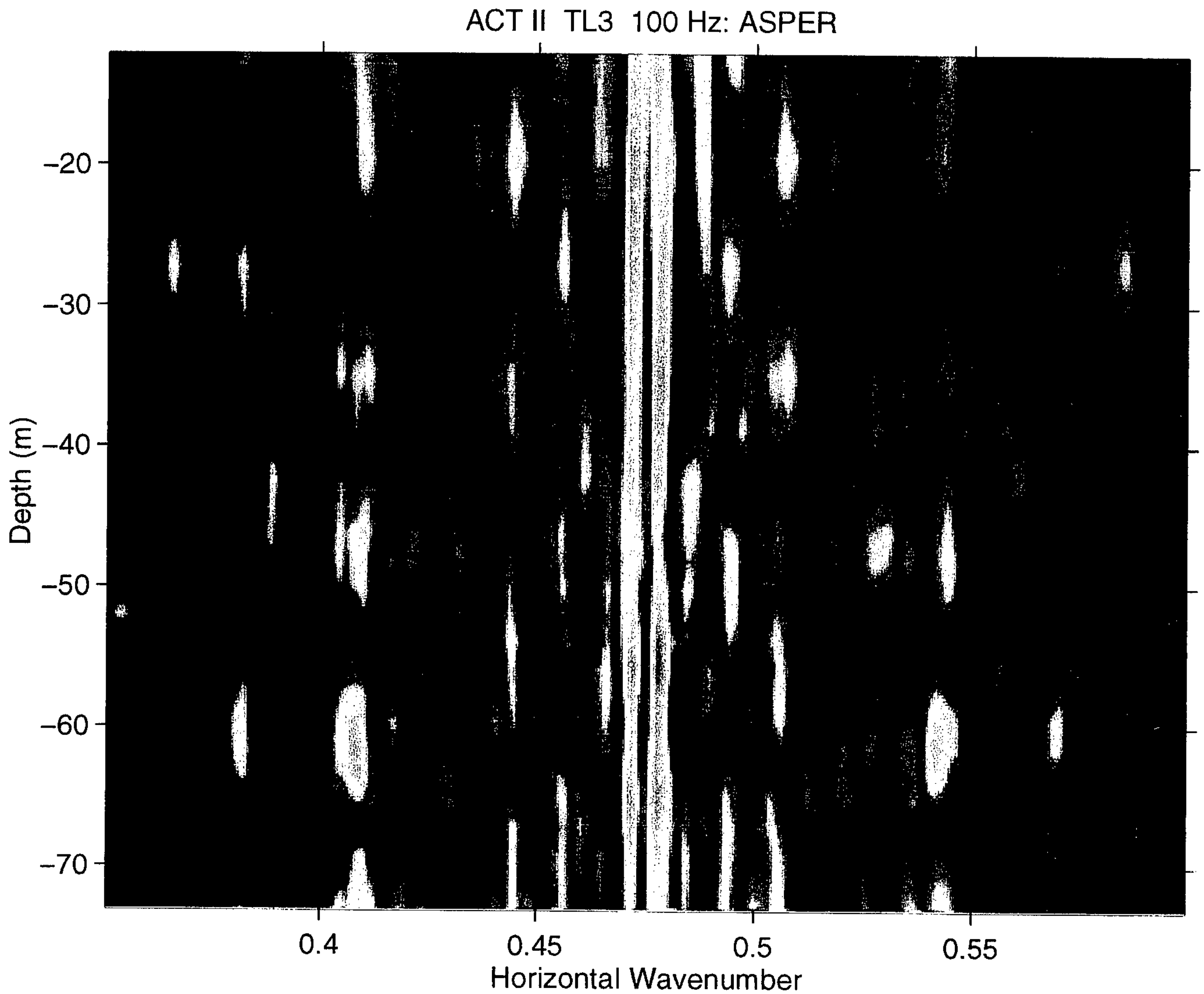

Figure 14. Relative modal level in dB as function of depth and wavenumber spectrum (from ASPER).

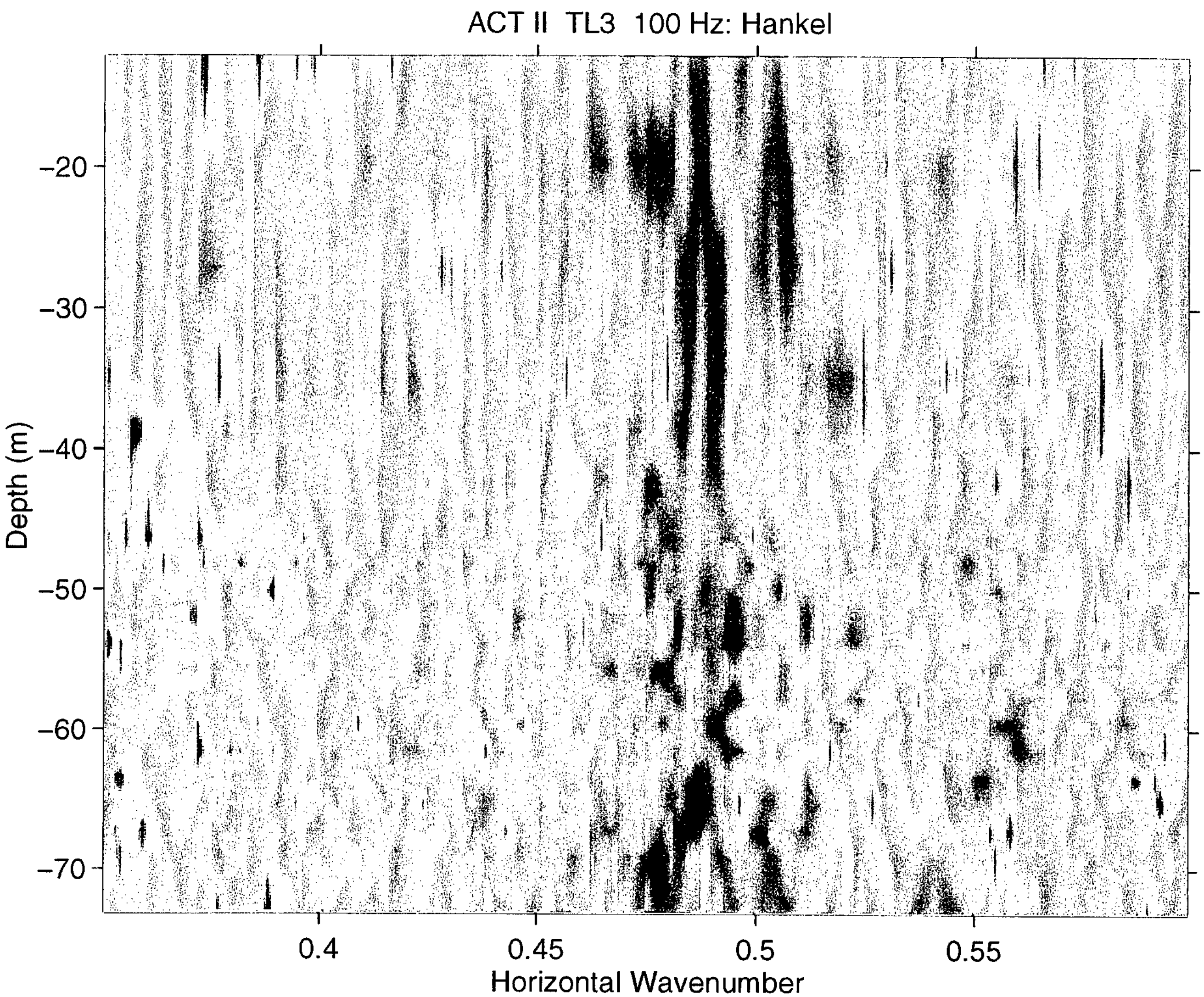

Figure 15. Relative modal level in dB as function of depth and wavenumber spectrum (from ASPER).

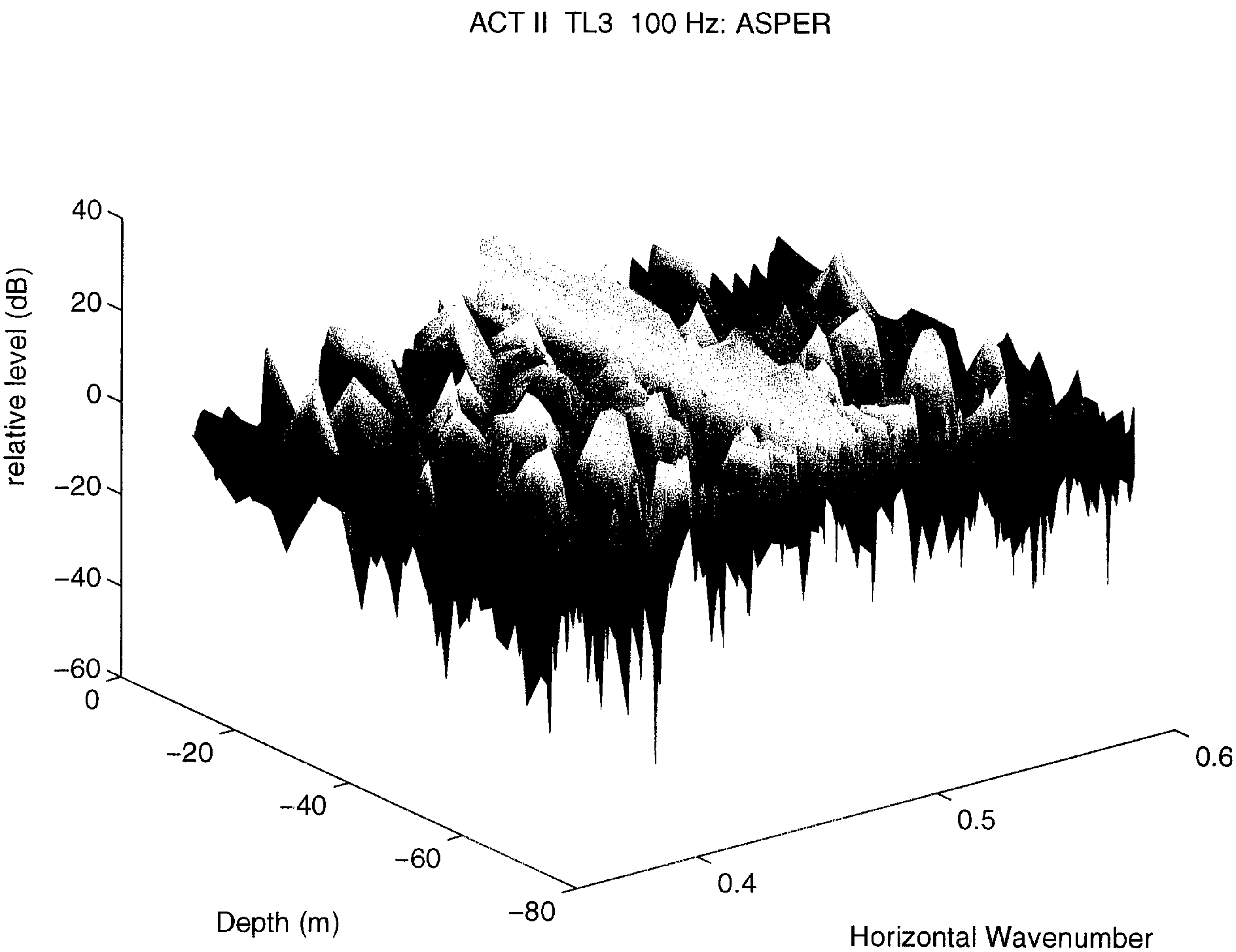

Figure 16. Relative modal level in dB as function of depth and wavenumber spectrum (from PT_HANK).