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ANALYSIS OF SHALLOW WATER EXPERIMENTAL ACOUSTIC DATA INCLUDING NORMAL MODE MODEL COMPARISONS

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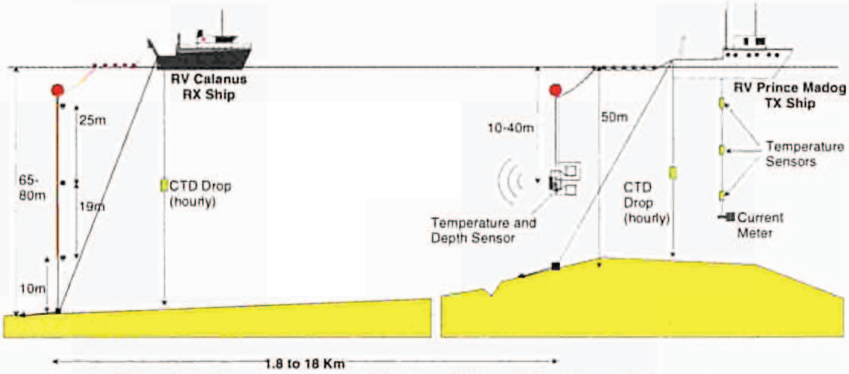
As part of a propagation model validation exercise experimental acoustic and oceanographic data was collected from a shallow-water, long-range channel, off the west coast of Scotland. Temporal variability effects in this channel were assessed through visual inspection of stacked plots, each of which displays 120 echo records. From such data an average impulse response for the channel, at a variety of ranges, was established. The average impulse response was compared with simulations performed using the fast broadband normal mode model developed in the EC MAST III PROSIM project. Comparative results are presented.

1. THE EXPERIMENT

The aim of the CEC MAST III project PROSIM (PROpagation channel SIMulator) was to develop a software channel model simulator that would be able to predict the effect of a broadband audio frequency source (0.4 to 1.5 kHz), in shallow-water acoustic channels at realistic long ranges. An important application is in the area of underwater communications where a better understanding of environmental parameters, and how they affect the communication channel, will improve the performance of such equipment.

An integral part of the PROSIM project were seagoing experiments designed to collect acoustic and oceanographic data for use in model validation. The data to be presented in this paper was obtained from experiments performed in the Clyde, 10 km to the west of Troon harbour on the west coast of Scotland. In typical water depths of 70 m and at a variety of ranges between 0.5 and 15 km bistatic acoustic propagation experiments were performed using two research vessels acting as transmit and receive platforms. A variety of acoustic signatures were used in these experiments, such as CW pulses of varying pulse length and frequency, as well as linear FM sweeps of varying bandwidth. Selected data sets from the Clyde experiments can be made available to EC researchers through the British Oceanographic Data Centre.

The results presented in this paper all use matched filtered versions of chirp data. This enables the fine structure of the multipath signals to be detected. As well as acoustic data, the data recorder also logged IRIG B time code derived from a GPS receiver. This allowed precise time-stamping of all our data sets. Both transmit and receive ships were accurately time synced.



An illustration of the cross section of the Firth of Clyde trials site, showing the source and receiver geometry, is shown in Fig. 1. CTD drops were recorded at hourly intervals, on both ships, for the duration of the experiments.

Fig. 1. Illustration of the of the Clyde trials area.

A Hanning weighted chirp of bandwidth 1 to 8 kHz with a pulse-duration of one second was transmitted. The source pulse was transmitted every 35 seconds over a period of 70 minutes giving a total of 120 pulses for each track. The maximum source level was 205 dB ref. 1μ Pa at 1 m. These experiments were repeated at ranges of approximately 2, 5 and 10 km and with a source depth of either 34 m (deep source) or 15 m (shallow source). The three hydrophones were set at water depths of approximately 11, 35 and 55 m. Depth sensors were attached at the projector and at each hydrophone.

Pulse compression was achieved by correlating with a normalised 1 to 8 kHz chirp replica of the transmit waveform and adjusting the result to take account of the Hanning weighting on the source pulse and the projector sensitivity gains. Typically, a 1.5 second section of matched filtered data was used in order to examine the arrival time structure of the multipath. In order to allow the noise and any early low level multipaths to be observed, the start point of the data section was set to start approximately 0.4 s prior to the maximum level of the matched filtered data.

2. DATA ANALYSIS

2.1. STACKED PLOTS

For each range, hydrophone and projector depth (shallow or deep) stacked plots of the 120 pulses for each experiment were used to give a visual indication of the channel's multipath structure. Fig. 2 gives examples of the stacked pulse series for both a 2 km and a 5 km range. Pulse number versus time is displayed with a colour bar indicating amplitude (fully calibrated) in dB. In Fig. 2a, early arrivals can be seen, one at 1.36 s before the main arrival at 1.37 s. At pulse 100, the hydrophone data is corrupted. With the 5 km plot, Fig 2b, the time dispersion of the multipaths is clearly less. In this case there are no early arrivals. The high noise level showing in the middle of the experiment is attributed to some close shipping. The first and most obvious observation from Fig. 2 is that time dispersion and reverberation decrease with increasing range. This was further validated from the results from the 10 km range data.

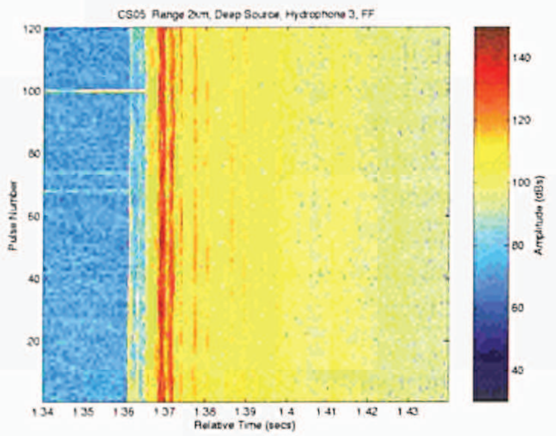


Fig. 2a. Stacked plot for 2 km range, deep source, deep hydrophone.

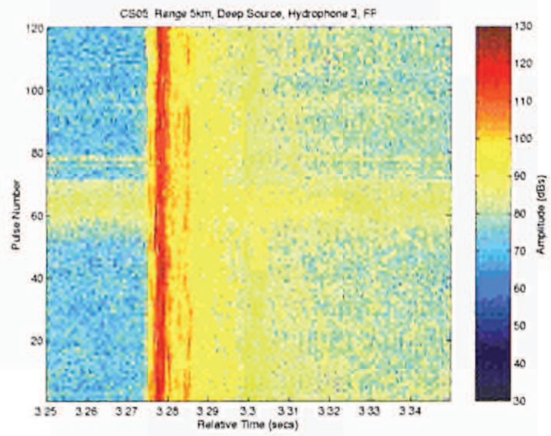


Fig. 2b. Stacked plot for 5 km range, deep source, deep hydrophone.

2.2. MEDIAN PLOT

A median for each time point over all 120 pulses is used to calculate the average impulse response for the channel. The median plot for the 2 km range (reference the stacked plot of Fig.2a) for both a 1.5 s time scale and a 0.1 s time scale are shown in Fig. 3a and Fig. 3b respectively. Fig. 3a is useful in that it shows the average noise and reverberation decay, whilst Fig. 3b helps to zoom in on the multipath structure. It is interesting to note the reverberation peak amplitude and the decay time.

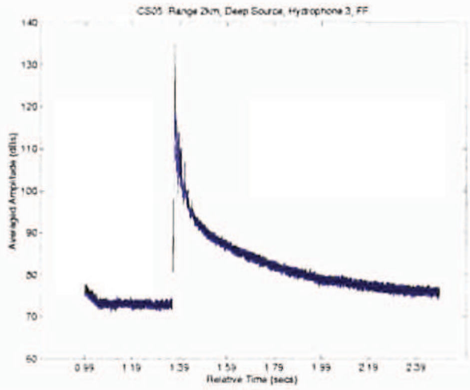


Fig. 3a. Median Plot for 2 km range, time scale 1.5 s.

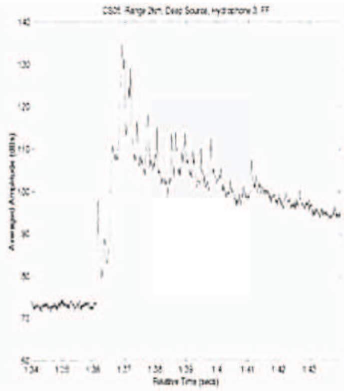


Fig. 3b. Median Plot for 2 km range, time Scale 0.1 s.

2.3. ARRIVAL TIME AND AMPLITUDE VARIABILITY OF A MULTIPATH

The multipath arrival time variability can be assessed by focusing in on individual multipaths. The median plot is used to give the average position of a particular multipath from which we can attempt a tracking operation.

Before we can track these multipaths however, the underlying noise and reverberation have to be removed. The noise is calculated as an average value obtained from a section of data positioned prior to the start of the main arrival structure. The reverberation is seen as a background signal, linearly rising in amplitude from the noise floor at a time-point roughly corresponding to the maximum level multipath and then decaying. The procedure adopted (for this first analysis) was to use a best-fit polynomial to emulate this reverberation curve. A polynomial of order 4 was found to work adequately with this data.

The estimated noise and reverberation, the background level, is removed from the pulse data to leave the multipaths. A moving window is then used to find the time of arrival of each multipath. A multipath is found if there is a maximum within the window that is a few dBs greater than the average. The difference between the average and the multipath peak can be altered to obtain the main multipaths. Once the average position of the multipaths is established a database is created with the times of these multipaths. The maximum point within the window and its corresponding time are recorded. The amplitude and time variability can then be observed for each multipath.

Fig. 4a shows the estimated background level and the marked multipaths. Fig. 4b shows how the tracked paths can be marked on the stacked plot. Some paths cannot be followed, as in the case of the third path in Fig. 4b with an average time of 1.366s.

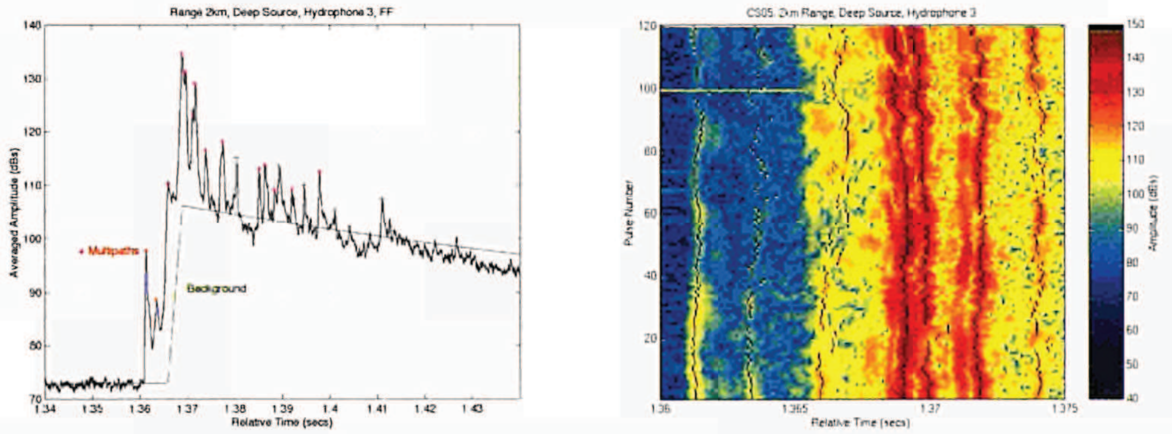


Fig. 4a. Real data with estimated background and marked multipaths. *Fig. 4b. Stacked plot (0.015 s scale) marking the tracked multipaths.*

Fig. 5 shows the time variability of the main paths, the strongest path is shown in red. Each line is plotted with the mean about a y-grid line. The spacing between the y-axis grid lines is 1 ms. The annotation on the right hand side enables the path to be compared with the path in the stacked plot image.

Fig. 6 shows the amplitude variability. The median amplitude of each path has been removed from the data so that the variability, in dB, can be displayed. Each path is plotted on the y-axis grid line. The offset between the y-axis grid lines is 20 dB.

3. MODEL DATA COMPARISON

The PROSIM broadband normal mode model [1] was run with a number of experimental chirp pulse scenarios in order to establish how well the model and the real data were in agreement. Certain inputs to the model are explicitly known. These include the geometrical configurations: ranges, water depths, source and hydrophone depths etc. The bathymetry of the track was obtained from ship echosounder data.

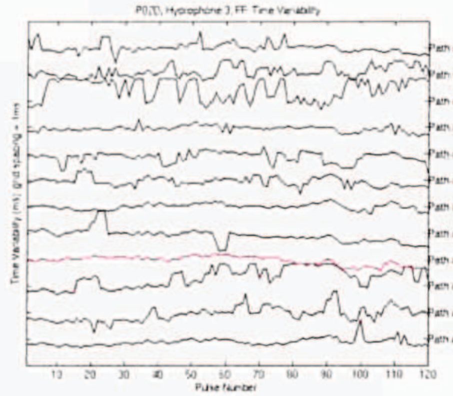


Fig. 5. Time variability of the paths. Main path in red.

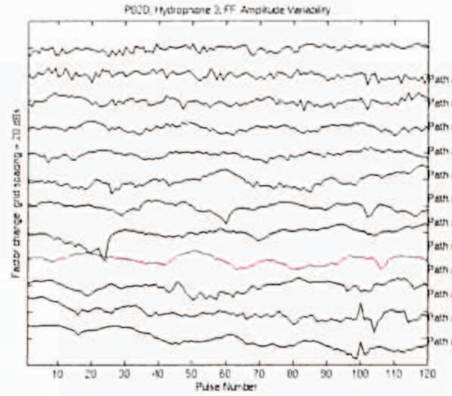


Fig. 6. Amplitude variability of the paths. Main path in red.

As the model employs the adiabatic approximation for range dependent environments, the environment was divided into a number of segments of constant water depth (with 4 m increment), see Fig. 8. Fig. 7 indicated the measured sound speed profile for 6 of the tracks, providing information on the typical amount of variability observed.

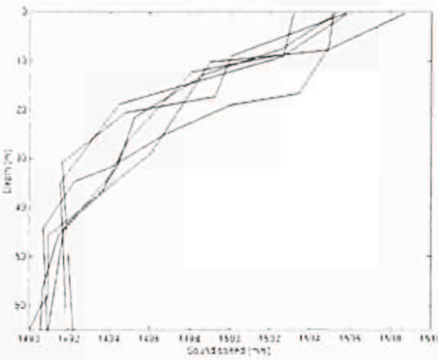


Fig. 7. Approximate sound speed profiles used for the model (6 tracks).

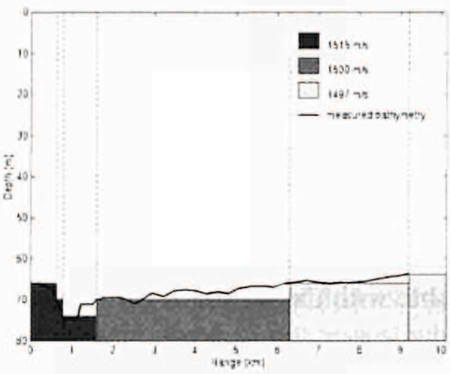


Fig. 8. Measured bathymetry and constant water depth segments.

The normal mode model assumes the bottom to consist of sediment overlying a homogeneous sub-bottom. The BLUG database and geological maps indicate that the Clyde sediment was 20 m of silt and clay. At 4.5 kHz penetration would be limited to about 10 m. The sediment type has a sound speed variation of between 1450 and 1575 ms^{-1} [2].

The model was run with upper sediment sound speed c within these ranges. Fig. 9 shows the calculated signals for the 2 km, deep source/middle hydrophone experiment, for upper sediment sound speed values of 1505, 1515, 1525 and 1535 ms^{-1}. Also plotted are the corresponding average matched filtered measured signals, both with and without background (i.e. reverberation plus noise). The measured and predicted signals are time aligned. Comparing both the amplitudes and the time dispersions of the measured and modelled signals, it can be concluded that the best match between model output and measurements is obtained for an upper sediment sound speed in between 1515 and 1525 ms^{-1}.

A similar analysis was performed for the 5 km and the 10 km experiments.

In order to optimise the model results, for these longer ranges, it was necessary to build in a range-dependence to the upper sediment sound speed, see Fig. 8.

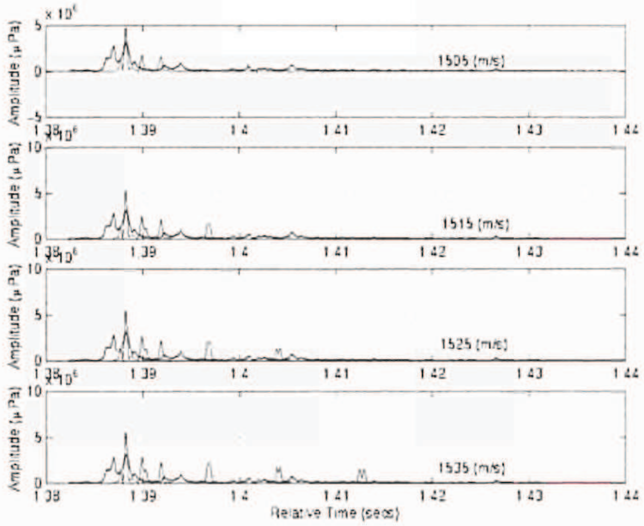


Fig. 9. Measured (red with background; black without) and modelled signals for c = 1505, 1515, 1525 and 1535 ms^{-1}.

In these cases the model and real data were seen to match well if the upper sound speed was set to a somewhat lower value (1500 and 1497 ms^{-1}, respectively). The results from this model comparison work have shown that an optimal match can be determined between measured and modelled data if the correct value of upper sediment sound speed is used. A variation of only a few ms^{-1} results in a rapid decrease in the match between modelled and measured signals. However, even at the optimal sound speed there is still always going to be a deviation in the precise shape of the signals.

An important point to note was that the propagation appeared to be governed primarily by the geo-acoustic properties closest to the receiver.

4. CONCLUSIONS

In this paper we have shown plots indicating typical time variability effects for experiments performed in the Clyde. A typical impulse response, at a number of ranges has subsequently been calculated. It has been shown that if care is taken in the choice of top sediment sound speed then results from the PROSIM model for typical impulse response are comparable with the real data.

5. ACKNOWLEDGEMENTS

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