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William Whitney
Poway, CA

Dear Bill:

It has been quite a long while since we have been in touch, in spite of the fact that I frequently recall your many contributions, both ashore and at sea. The trigger for this note is a surge of interest in tracking whales - arising out of the Navy's making SOSUS array outputs available for unclassified use (although specific array locations are still secret). In this context I have taken the liberty of pulling out of my files a copy of a note that you wrote many years ago presenting range and depth tracks from sperm whale clicks.

I have given a copy to Mark McDonald - a recent SIO geophysics graduate - who is working with NOAA scientists on whale behavior. It has provided a significant data point concerning the depths to which these animals go. It was certainly an interesting by-product of the sound propagation and ambient noise work that you were doing at the time. Mark may drop you a line one of these days to let you know what is going on.

I have recalled your expertise recently as we have been overtaken by a transducer problem that you would probably have foreseen. You may recall that we devised a "precision transponder", really a repeater, that, in principle, lets us turn a signal around and send it back without losing track of the phase information - and thus we can, with high S/N, determine travel times quite accurately by cross-correlating the reply with the transmitted signal. The problem is that when one wants significant output level from the transponder, the conventional matching network and the transducer characteristics introduce differing phase shifts across the band (~4 kHz centered at 16), and the correlation process gives unreliable results. If you have any ideas about how to cope with this, give me a call.

Sally joins me in sending our best to both you and Valerie. If you are in the area, please drop by, we would enjoy visiting with you. We are in the same house on La Jolla Shores Drive where we have been all these years.

Sincerely,

Fred

Fred.

cc. Mark McDonald

Observations of Sperm Whale Sounds from Great Depths

Abstract: Localization in depth and range of "clicks" typical of Sperm Whales were made using two hydrophones and a surface reflection. One hydrophone was mounted on the bottom of FLIP (91.5 meters deep) and the other suspended 900 meters below FLIP. Source depths as deep as 2500 meters and ranges to 10,800 meters were observed.

Bill Whitney was a scientist and development engineer with considerable expertise in ocean acoustics. He held various positions in MPL from about 1950 to 1982.

In the month of March 1967, the Marine Physical Laboratory of the Scripps Institution of Oceanography, using the research platform FLIP, was involved in a series of acoustic experiments approximately 200 miles south of Oahu, Hawaii. During the course of these experiments and apart from the primary objective of the expedition it became apparent that localization in range and depth could be made for sources of certain fish sounds (clicks) and that the depths of these sources were of the order of 450 meters or more. Magnetic tape recordings were made and documented for later analysis at the laboratory. The analysis of these records showed that the sounds, typical of Sperm Whales, did at times originate at depths far greater than our in situ estimate and greater than depths previously reported for these whales (1). Our analyses show depths as great as 2500 meters. The techniques used in acquiring and analyzing these data have produced many exciting questions pertaining to the sounds generated by Sperm Whales and other bio-acoustic sources. However, the scope of this paper will be limited to three areas of interest:

1. The documentation of technique.
2. New information concerning the depth capability of Sperm Whales.
3. Some comments regarding spectrum and source-level related to the aspect of these sources.

The locations of the sources of sounds were made by measuring the arrival-time differences between signals received at a hydrophone located at the bottom of FLIP, i.e., 91.5 meters below the sea surface and at a hydrophone located below FLIP and 900 meters below the sea surface. Normally two hydrophones would not provide enough information to solve this problem. However, since these sounds were very short "clicks" the surface reflections were evident at both hydrophones. This additional information allows one to solve the problem for range and depth. Due to the cylindrical symmetry of the hydrophone arrangement azimuthal information was not obtained. The arrival-time differences obtained by measurements were converted to path-differences assuming a constant sound velocity for the ocean. Two sets of hyperbolas were plotted via the University of California, San Diego computer. These two sets of hyperbolas constituted a coordinate system upon which the source points were located. One set had the shallow hydrophone at one focus and the deep hydrophone at the other focus with the path difference between direct arrivals a constant along any one curve. The other set had the deep hydrophone at one focus and its image in the surface at the other focus with the path difference between the direct and surface-reflected arrivals a constant along any one curve.

It was decided that a track of a single source of these clicks would be a desirable feature of the analysis. However, the nominal repetition period for these clicks was the order of 1/2 sec and when consideration was made for multiple arrivals and multiple sources it became apparent that analysis in real time was not possible where a sequence of events was to be observed. Therefore the original data were re-recorded at high speed allowing about 12 min of data to be inspected per reel. This recording was then played back at a 16:1 reduction in speed and the two hydrophone channels displayed on a multi-channel oscillograph. This display allowed us to sort out the pattern of arrivals identified with a single source even though several sources were present. Further, by timing this slow-speed playback of the data the spectrum of individual clicks could be realized.

Twelve minute samples of the data were taken and analyzed; the most significant of these analyses is shown in Fig. 1. Other sources were evident during this run at shallower depths and closer ranges but were omitted for clarity. The sequential points in Fig. 1 represent approximately 30 sec intervals of plotted real time starting with point no. 1 at 2300 meters depth and continuing for about 11 min to point no. 22 where the source stopped prior to the end of the run. The animal maintained a repetition period of about 600 ms nearly continuously for the entire period of 11 min.

Three factors enter into the accuracy of this presentation. First the accuracy of the measurement of the time differences. Second the axis of the hydrophone pair may be tilted. And third, the ocean does not have a characteristic sound velocity independent of depth.

The accuracy to which we could measure time differences was judged to be of the order of 1 ms or approximately 1.5 meters of path difference. This leads to an error of approximately $\pm$ 10% in both range and depth in the vicinity of points no. 7 and 8 in Fig. 1. The expedition logs for the period of these recordings show zero wire angle on the line to the deep hydrophone so we can assume that the pair was not tilted. A computer solution was made for the path differences that would exist for a bilinear approximation to the sound velocity profile that was obtained during the expedition, for a source in the vicinity of points 2 and 3 of Fig. 1, i.e., at a range of 7900 meters and depth of 2500 meters. The differences between these path differences and the path differences for a constant velocity ocean was significantly less than the path difference error indicated above. From these considerations we can conclude that the accuracy of the data presented here depends primarily on the ability to measure arrival time differences and is of the order of magnitude stated above.

Another interesting portion of the data showed the peak received level increasing to a maximum then decreasing, first on the shallow hydrophone then on the deep hydrophone. The change in level amounted to about 12 dB and can best be explained if the source is of finite extent and possesses a directional characteristic. This property assigned to a source which is diving and turning would produce the observed level change. The source was plotted at 107 meters in depth and 1200 meters in range. The spectrum was obtained for both high level portions and low level portions of the record. These spectra show a significant reduction in the high frequency components for the low level pulses, i.e., those pulses that were received when the source was turned away from the receiver. This change in spectrum would probably mask any attempt to relate spectrum changes to other parameters, for example, changes in depth. Calculations of absolute source levels for the above and other portions of the data resulted in a spread of values between 75 and 100 dB re 1 μbar for the peak levels received.

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Xerox copy to Schevill (02-4-25)

References and Notes

1. Bruce C. Heezen, Deep Sea Research, 4, 105 (1957).

2. This work was supported by ONR, Code 466 and NavShipSystems Command, Code 1622. The author expresses his appreciation for the attention given to this work by Drs. F. N. Spiess and V. C. Anderson of MPL and the stimulating discussion and encouragement given by Dr. W. E. Schevill of WHOI.

Figure Caption

1. Sperm Whale track.