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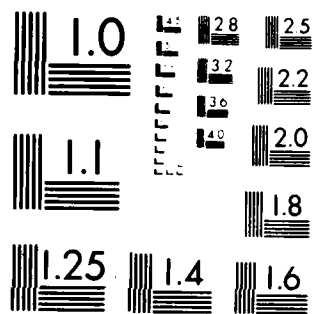
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DETERMINATION OF THE
ORIENTATION AND GAIN OF
HORIZONTAL GEOPHONES USED
IN OCEAN BOTTOM SEISMOMETERS

by

Ules. S. Wade
Clive R.B. Lister

Office of Naval Research
Contract N-00014-75-C-0502
MOD P00021
Project NR 083-012

Reference M81-06
March 1981

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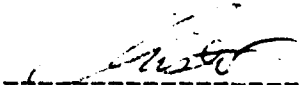
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Determination of the orientation and gain of horizontal
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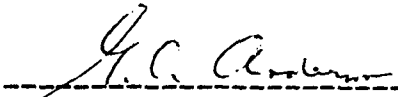
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C. R. B. Lister
Principal Investigator

Reference MB1-06
March 1981



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INTRODUCTION

In both explosion and earthquake marine seismology, the information contained in orthogonal horizontal geophones has not been fully utilized due to a lack of an accurate technique for obtaining radial and transverse horizontal ground motion. There is little work in the literature where particle orbits have been calculated for OBS arrivals. One approach commonly used is to find the mean azimuthal angles of arrival of the seismic energy with respect to one of the horizontal components. This is done using the relative amplitudes of the two horizontal seismograms over the first few cycles of a direct P-wave. However, this method is unsatisfactory for most present ocean bottom experiments. It is critically dependent upon accurate knowledge of each channel's gain and sensor sensitivity. Relative channel gains are often not accurately known, while the direction of arrival of P-wave energy is subject to variations caused by lateral velocity anomalies. Recently, Cheung and Clowes (1978) oriented a single horizontal by the direct P-wave method to construct SV-component record sections for refracted shear wave velocities.

The simplest orientation scheme is the inclusion of 'magnetic jelly bottles' in the instrument as described by Francis (1977). A magnet is suspended by a thread inside a plastic bottle of warm liquid jelly, and the bottle is insulated and attached to the OBS prior to launch. The thermal time constant is such that the jelly does not set until after the instrument has landed, thus recording the orientation of the OBS.

A more complicated scheme (Matteboni and Solomon, 1977) involves the rotation about a vertical axis of a horizontal-axis coil exposed to the earth's magnetic field and the simultaneous rotation of a horizontal-axis reference coil that revolves just above a permanent magnet. Through a feedback circuit, the magnet is rotated until the signals from the two coils are 90 degrees out of phase so that a pointer attached to the magnet indicates bottom orientation of the instrument.

EXPERIMENTAL PROCEDURE

The data used for this study are from an experiment entitled Seismarray. A small array of five OBS's was deployed in the northeast Pacific on a gently sloping plain west of the Queen Charlotte Islands. A circular shot line was centered on a moored buoy radar transponder, and an 8 degree shooting interval was maintained at a radius of 10 kilometers. All shot points were first located with respect to the buoy but their azimuths were calculated relative to the true position of OBS 3, the instrument used for this study (figure 1). Ranges were corrected by ray tracing through a water column velocity model. Examples of the arrivals near the null points are shown in figures 2 and 3.

The 4.5 hertz L 15 B Mark Products geophones were triaxially mounted in a spherical-shell boat. This boat floated on a thin layer of viscous silicone oil in the lower half of the buoyant spherical pressure case and was leveled by a small moveable counter weight. The mounting plate was molded out of rigid plastic to assure uniform orthogonality. The data were recorded in analog form on magnetic tape and later digitized at a sample spacing of 0.01 seconds in real time. Before analog-to-digital conversion, each channel was passed through a 50 hertz (real time) anti-aliasing filter and a 4-pole 20 hertz notch filter to eliminate the noise induced by vibration of the tape drive motor. The signals passed through a calibrated and matched 3-channel variable-gain amplifier to achieve a maximum 10 volt excursion prior to digitization.

To increase the dynamic range of the magnetic tape recording in the OBS, the data were compressed by a bi-polar square root circuit (Lister and Lewis, 1976). A sine wave processed in this manner is decomposed into a fundamental plus an exponentially decreasing sum of the odd harmonics. However, the analog playback head shifts the phases of the lower harmonics and thus distorts the original waveform. A carefully constructed digital filter was applied to the data to correct both phase and amplitude distortions, and restore waveform fidelity. The mechanics and electronics of the University of Washington OBS package are described in detail by Lister and Lewis (1976) and by Johnson et al (1977).

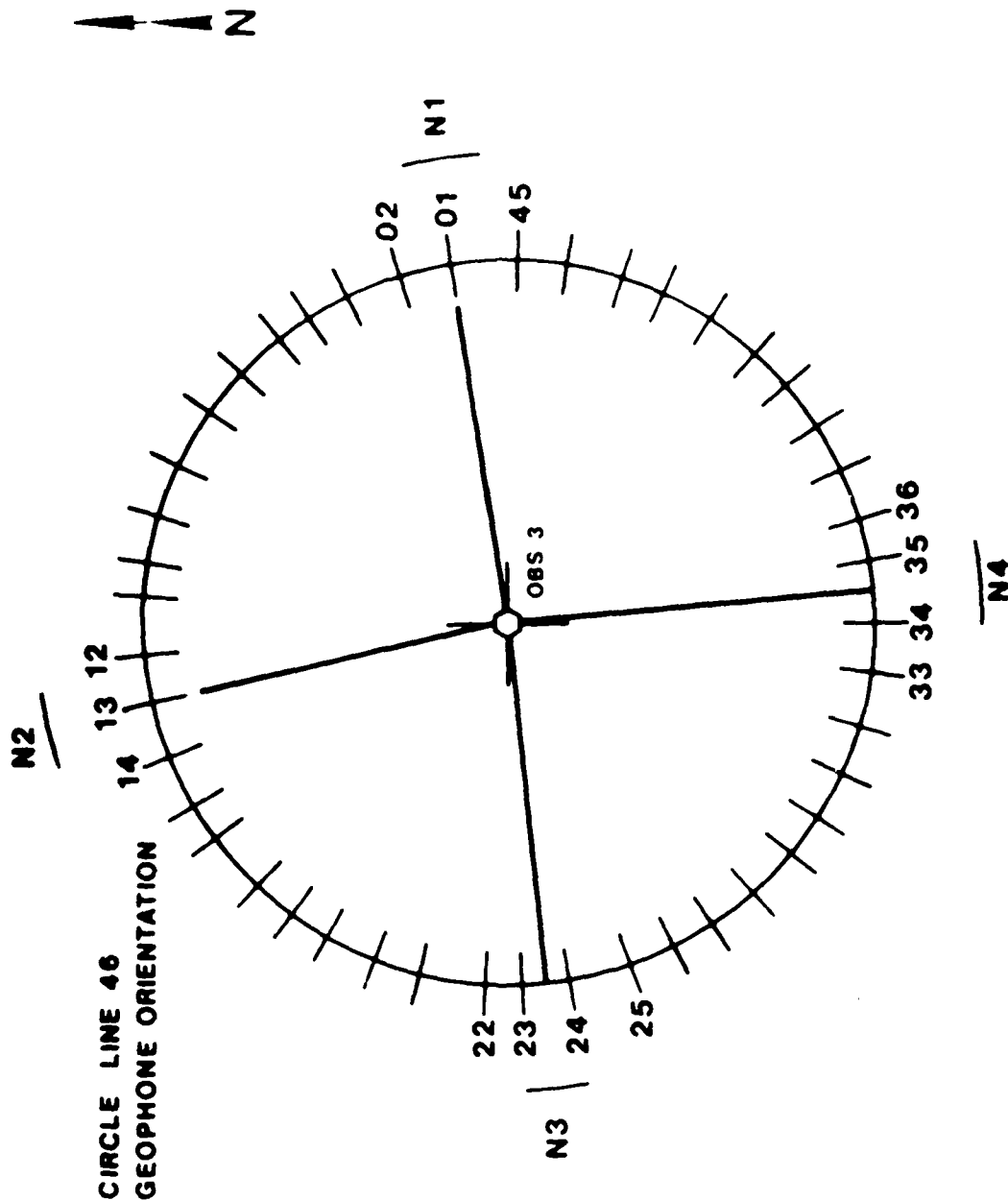


FIGURE 1. Azimuthal refraction shot pattern centered on OBS 3. Null groups 1 through 4 are displayed with shot numbers. Radial lines are tentative horizontal geophone orientation based on data in figures 2 and 3.

GEOPHONE ORIENTATION DIRECT WATER WAVE

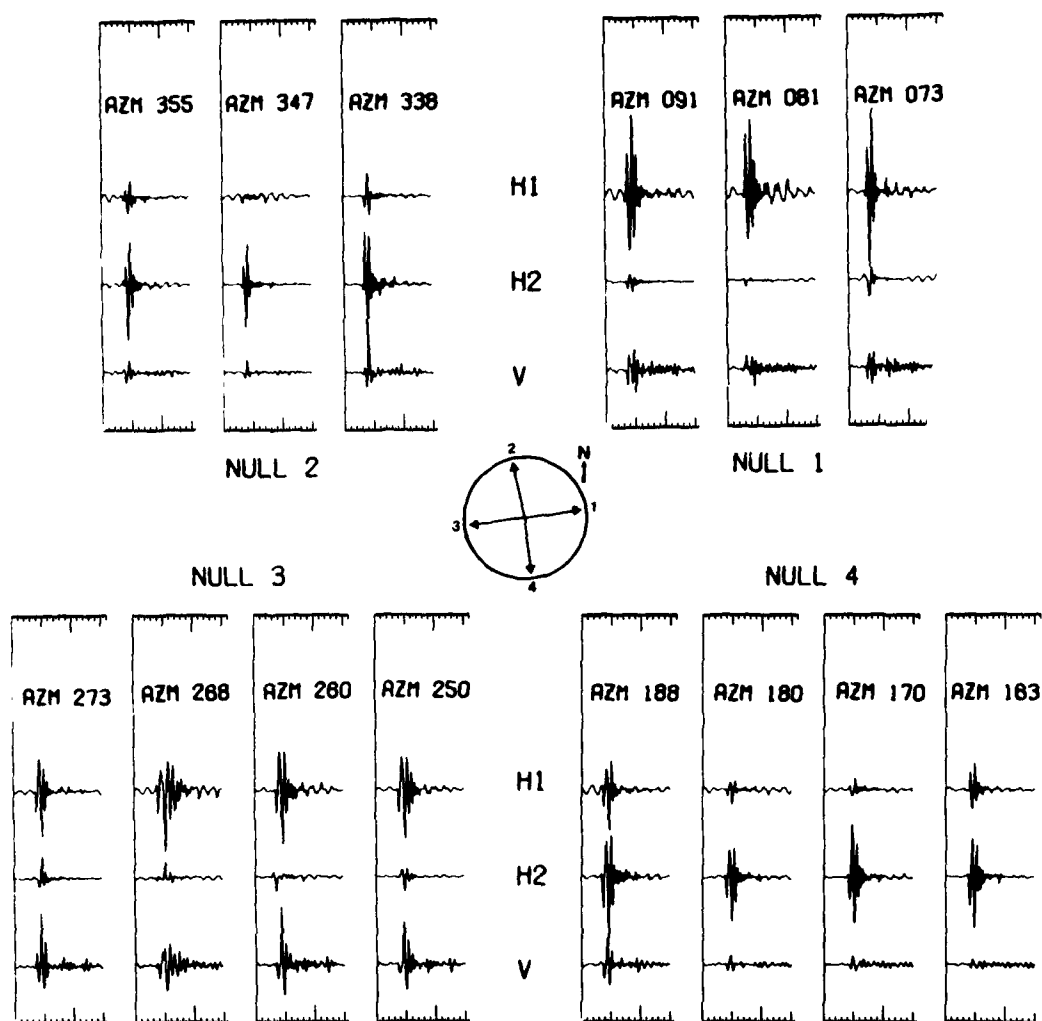


FIGURE 2. Three component seismograms displaying the first 1.5 seconds of direct water wave arrival for all four null groups. A constant gain factor is used for all traces.

GEOPHONE ORIENTATION FIRST BOUNCE WATER WAVE

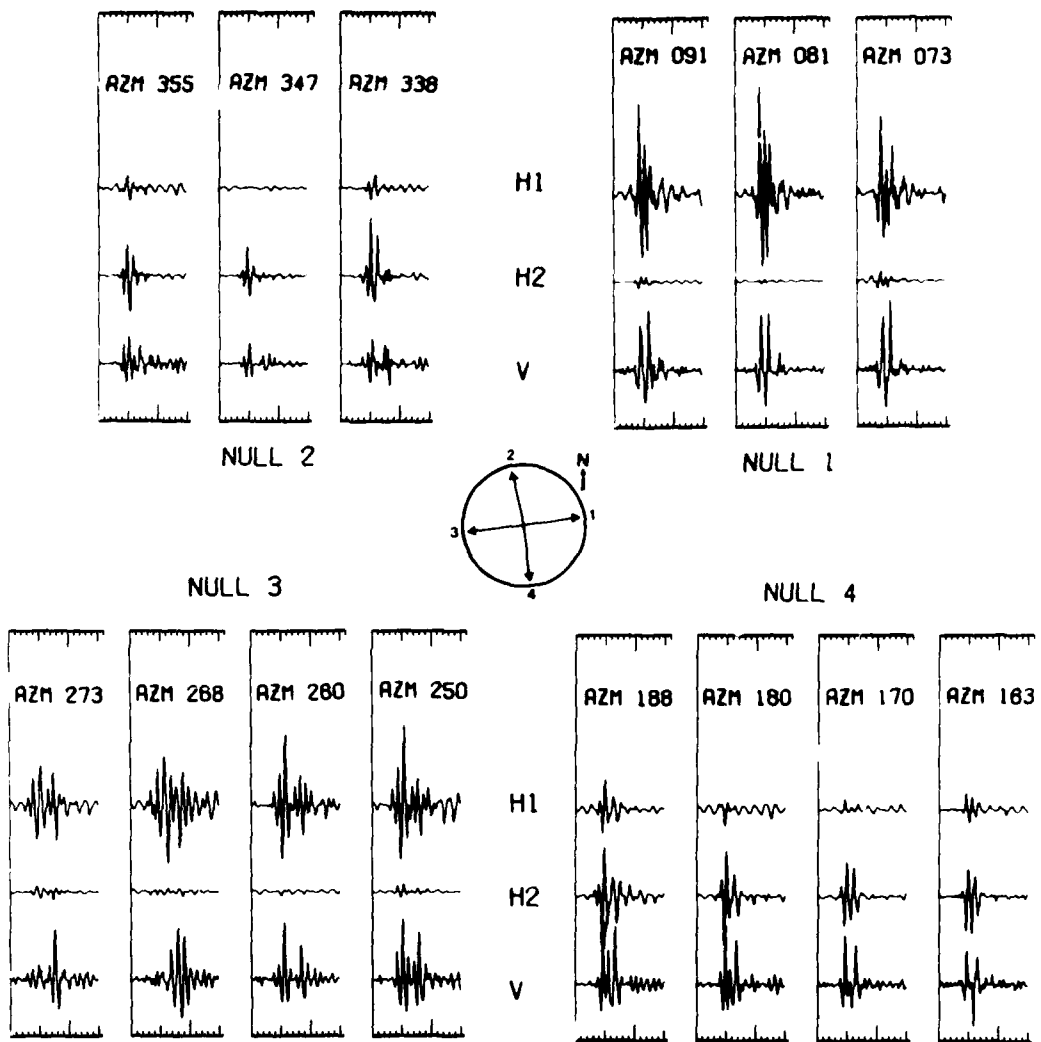


FIGURE 3. Same as figure 2 using first bounce water wave arrival.

HORIZONTAL ORIENTATION

The technique is based on the geometrical partitioning of energy between the triaxial components. Any incident wave is recorded on the vertical (V), horizontal number 1 (H1), and horizontal number 2 (H2) channels. The root mean squared (RMS) power ratio, $H1/H2$, is a function of the projected angle ϕ_1 , and is independent of the angle of vertical incidence θ (figure 4). This ratio is equal to the tangent of ϕ_1 (equation 1)

$$\text{RMS}(H1)/\text{RMS}(H2) = \text{RMS}_{\text{ray}} \sin \theta \cos \phi_1 / \text{RMS}_{\text{ray}} \sin \theta \sin \phi_1 = \tan \phi_1 \quad (1)$$

A null in the arrival amplitude occurs when the geophone axis is perpendicular to the source direction. As the null axis of H1 is approached, the left hand side of equation 1 approaches zero. Thus, a linear regression fit to RMS power ratios as a function of source azimuth will specify the null azimuth.

The plot of the tangent function is compared to the linear least squares fit through 10 tangent points in figure 5. The correlation coefficient of the fit is 0.990. The crossing of linear regression lines to the left and to the right of a null point will intersect the ordinate at -0.04 (figure 5). Our method confirms this behavior for all null groups, with two presented in figure 6. In this figure the filled circles are mean RMS power ratios, $H1/H2$, for the first half second of the water wave arrival. The filled squares are the same data after subtraction of mean RMS background noise. The linear regression lines for the squares intersect below the zero ordinate and define the null point for geophone H1. The regression lines for the circles intersect within 2 degrees of the above (table 1). Ratios greater than one are due to gain differences between channels.

The maximum amplitude in an arrival is a good approximation for the RMS power in it. Points are plotted for both the amplitude ratio and the RMS power ratio for groups 2 and 4 in figures 7 and 8. The filled circles are mean RMS power ratios while the crosses are amplitude ratios. The main drawback to the amplitude approximation is the difficulty in correcting for ambient noise. The summary of null point crossings for both direct and first bounce water waves are given in table 1.

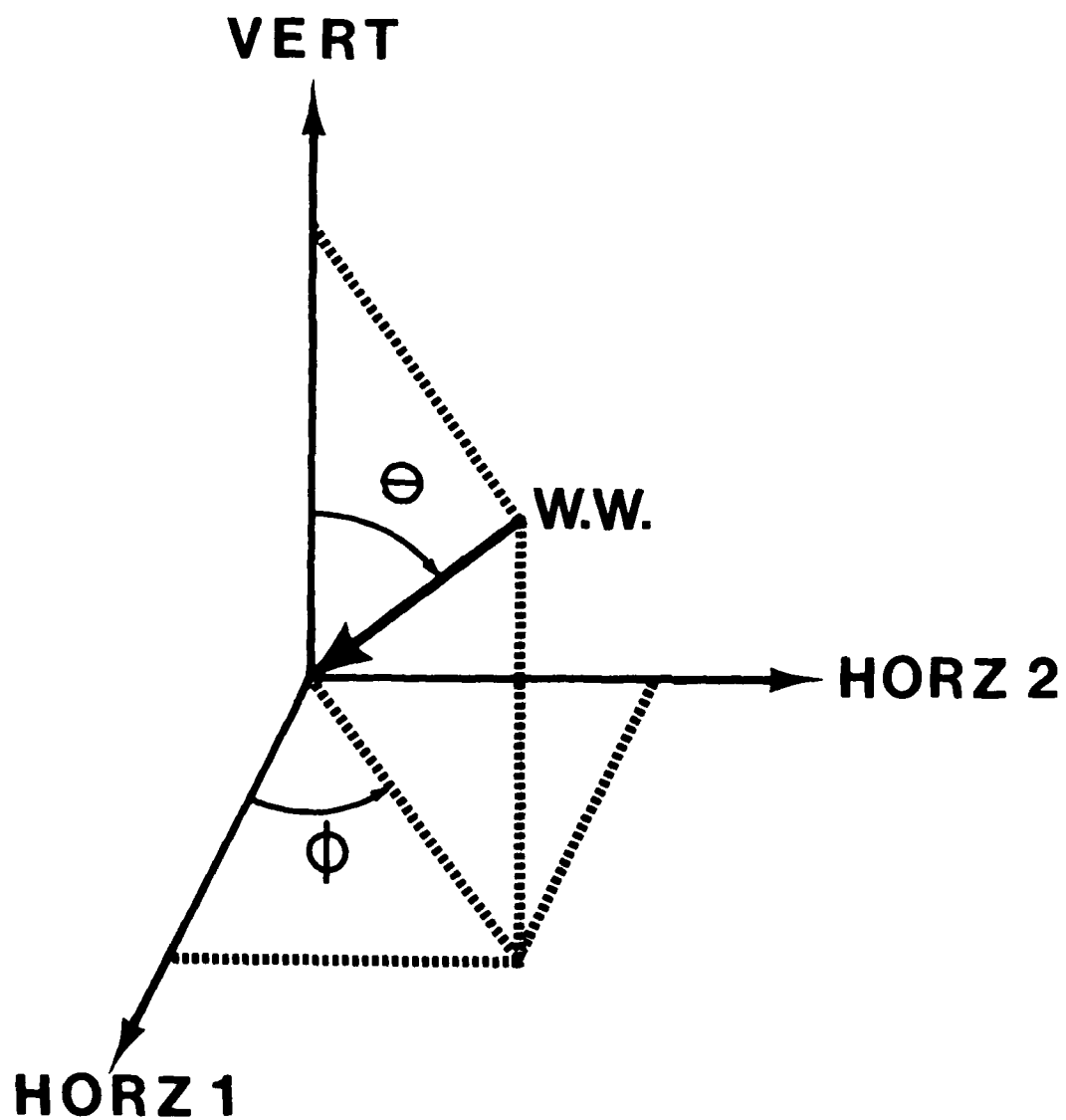


FIGURE 4. Triaxial partitioning of an incoming water wave.

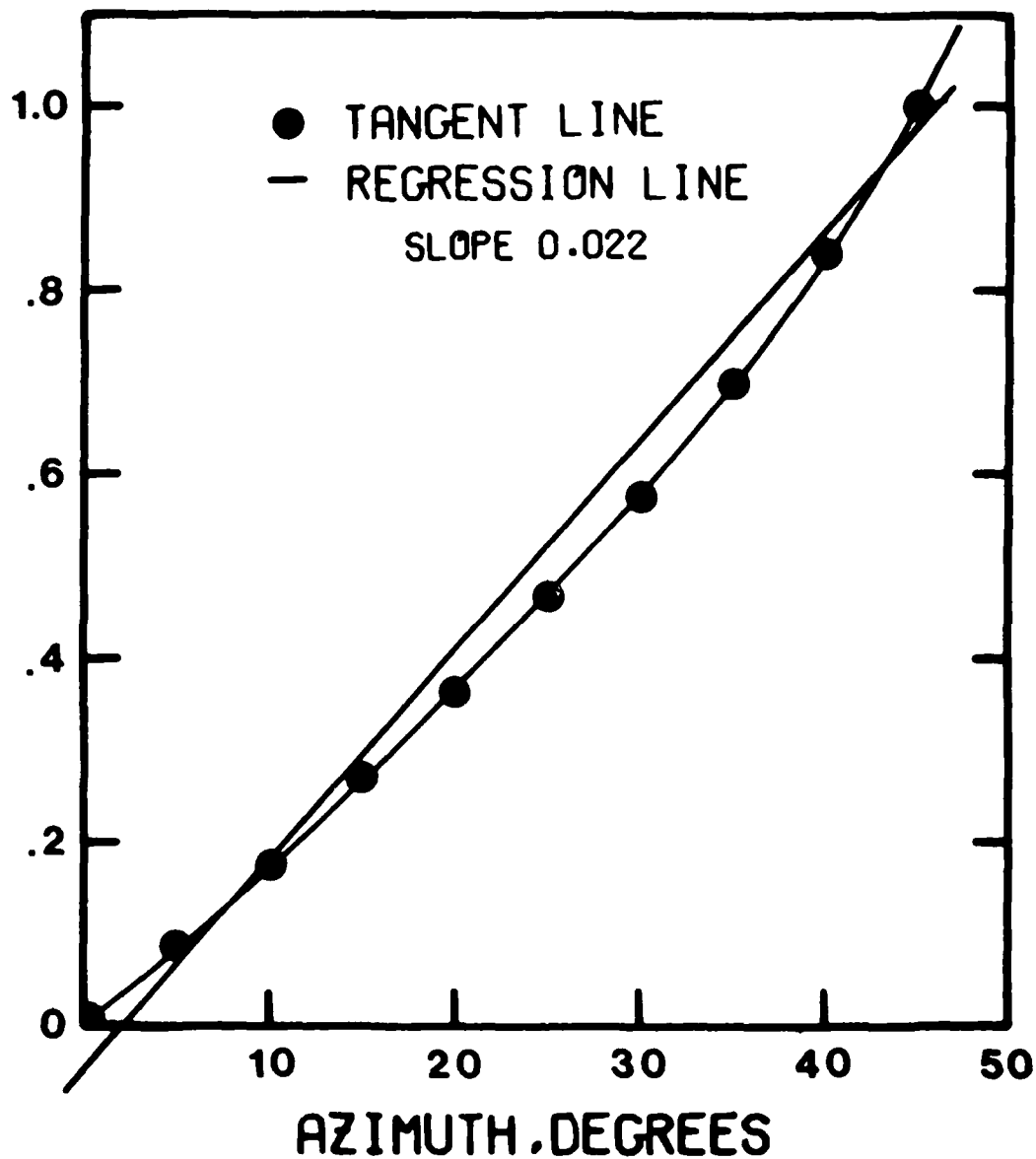


FIGURE 5. Linear least squares regression fit to tangent curve. Note below-ordinate intercept of regression line.

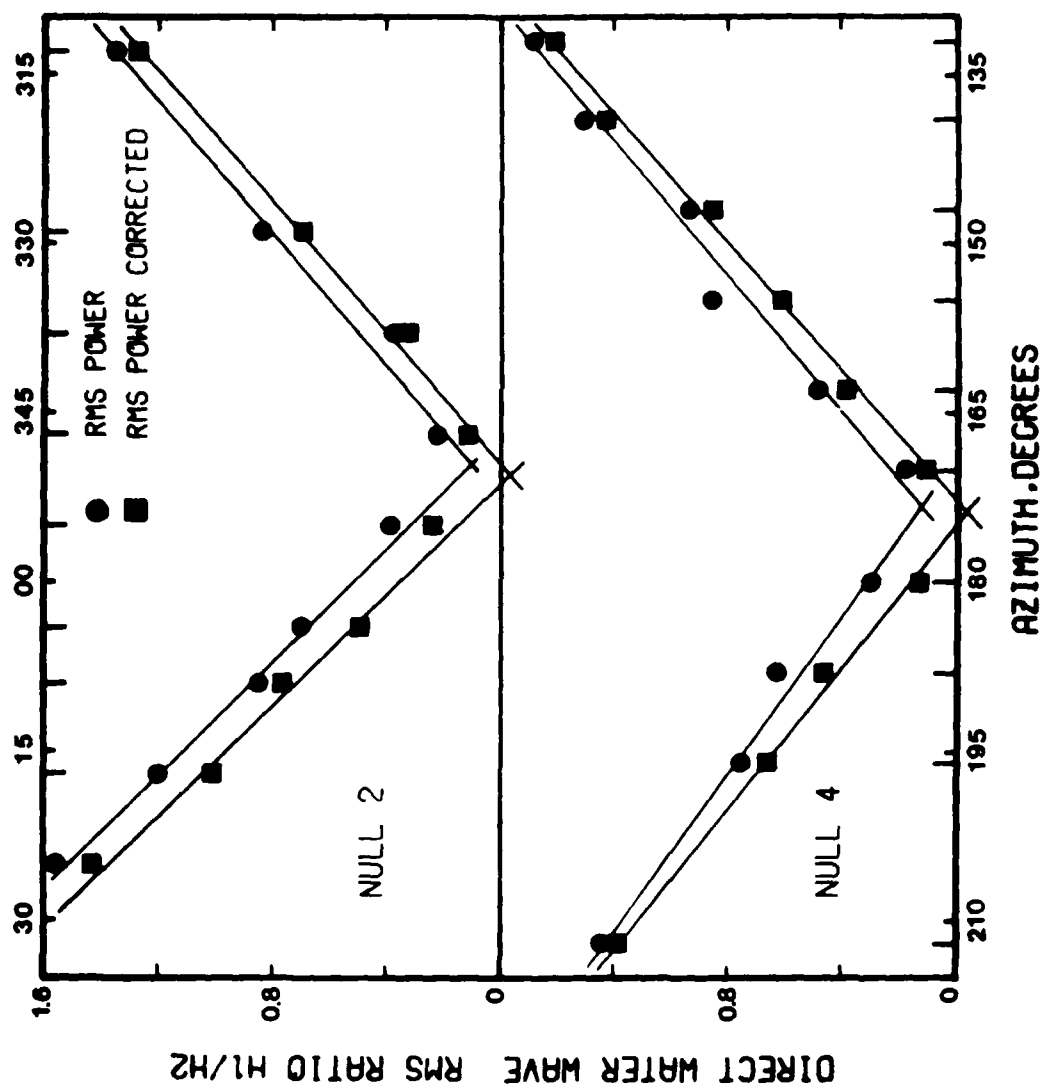


FIGURE 6. Comparison of the regression fits to RMS power ratio and RMS power corrected ratio data using nulls 1 and 2. See text for detailed discussion.

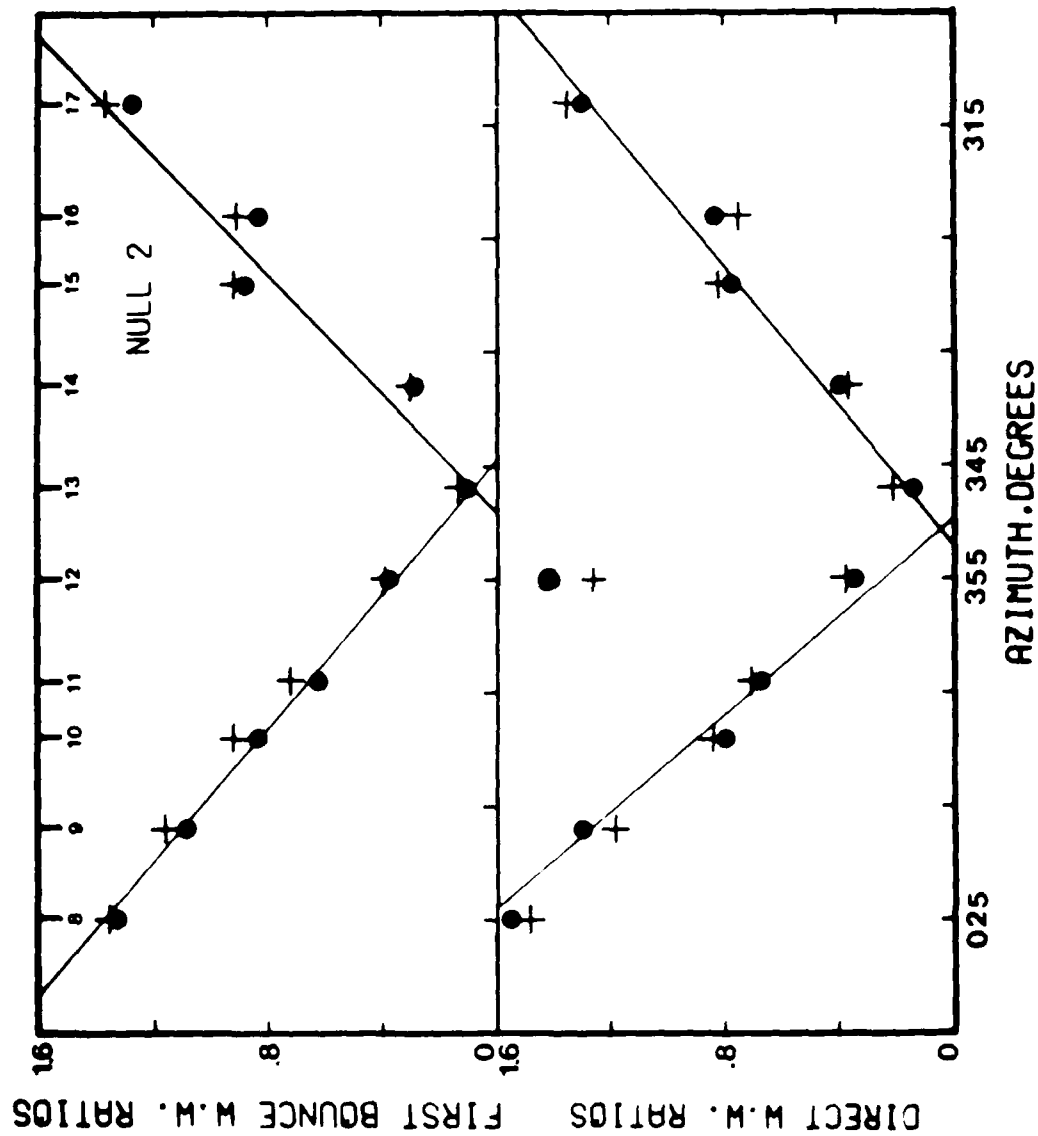


FIGURE 7. A point by point comparison between RMS power ratios (filled circles) and maximum amplitude ratios (crosses) for null 2. Regression lines fitted to RMS power ratio.

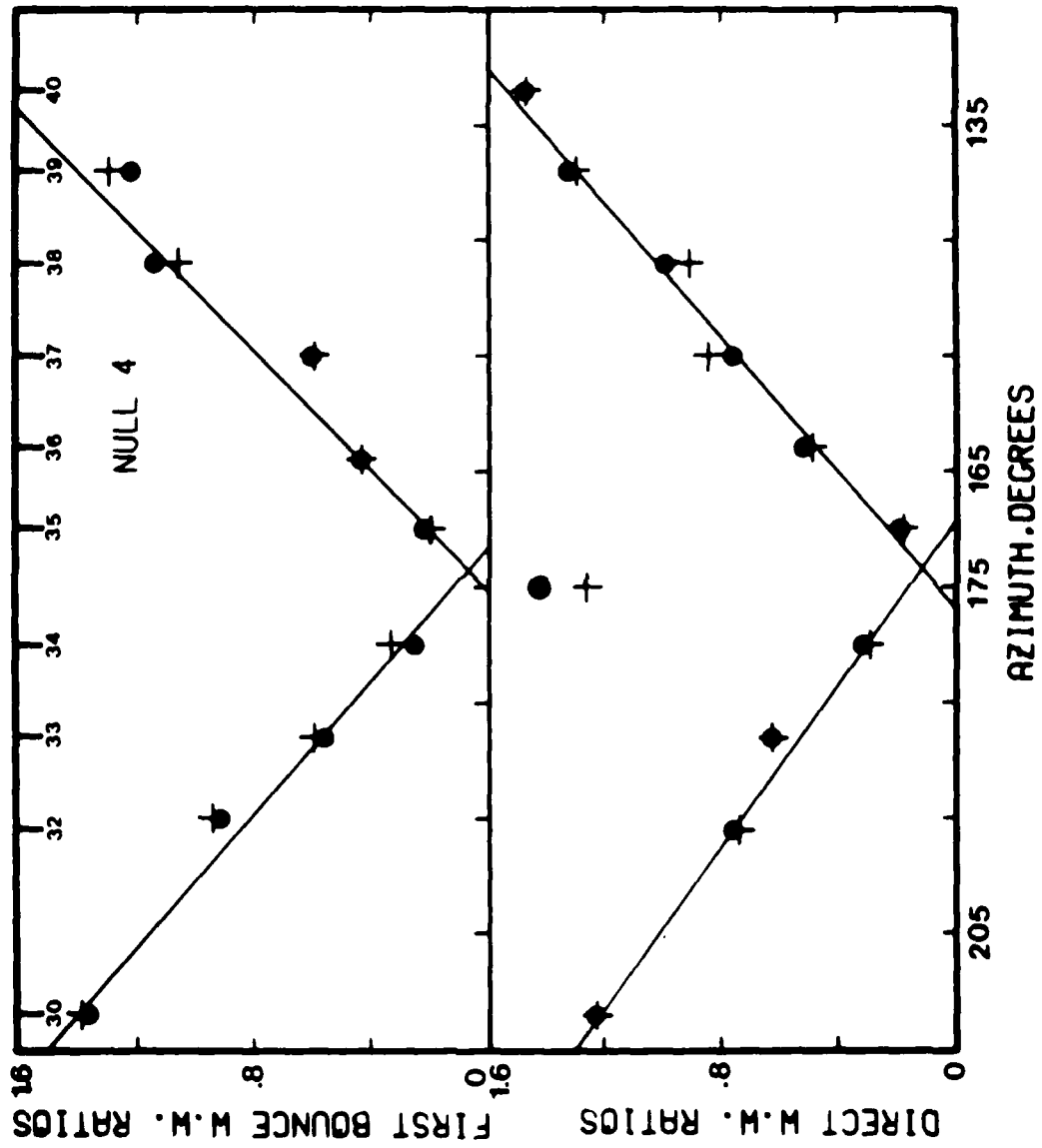


FIGURE 8. Same as figure 7 for null 4 data.

TABLE 1.

Null azimuths, degrees east of north

	RMS power corrected	RMS power		Maximum amplitude		Final mean
	direct	direct	1st	direct	1st	
Null 1	081	083	082	082	082	082
Null 2	350	351	349	352	350	351
Null 3	262	260	263	259	264	262
Null 4	173	173	173	173	172	173

Final orientation of OBS 3. H1-positive axis N82 E
 plus or minus 2 degrees H2-positive axis N08 W

DETERMINATION OF RELATIVE COMPONENT GAINS

The triaxial component gains are needed in order to reconstruct particle motions. The gain of each channel is set within 5 percent of a known value. However, pre-deployment calibrations are susceptible to changes prior to the actual shooting experiment. Thus, the optimum time for calibration would be during the experiment and would include the sensors in the calibrations.

Our method uses the slopes of the mean RMS power corrected ratio (RMS-PCR) and gives a real time calibration of the two horizontal channels. Each channel will receive the same amount of energy from an arrival that bisects the two sensors ($\phi=45$ degrees), but they may not be recorded equally. The amount of recorded energy on each channel is an indication of its gain. As an example, the slope of the H1/H2 ratio regression line in figure 5 (the ideal) is 0.0222 ratio units per degree. The ratio value is 1.00 at 45 degrees which implies equal gains for channels H1 and H2. The method can be applied to the horizontal orientation data by directly reading the ratio at the azimuth 45 degrees from the nullpoint on the plots or by multiplying the slope of the regression line by 45 degrees.

The average H1/H2 RMS-PCR slope of nulls 2 and 4 (table 2) is 0.035 units per degree with a standard deviation of 0.002. The H1/H2 relative gain ratio is this slope multiplied by 45 degrees which is 1.575. For nulls 1 and 3, the H1/H2 RMS-PCR slope is 0.015 plus or minus 0.0021, and the 45 degree ratio is 0.675. The gain ratio H1/H2 multiplied by the gain ratio H2/H1 is 1.06. This is a gain determination error of 6 percent. If the 45 degree ratios are determined from the RMS power corrected plots (figure 6), the resultant error is reduced to 3 percent by eliminating the effect of the small negative intercept of the regression lines at the null points. The gain procedure can be applied to RMS power or maximum amplitude data with equally small errors (table 2).

TABLE 2.

Relative gain comparisons

	DIRECT WATER WAVE				1ST BOUNCE WATER WAVE			
	slope	gain	gain	error	slope	gain	gain	error
RMS-PCR								
ratio H1/H2	0.0150	.0021	0.675	6%	0.0149	.0018	0.671	7%
ratio H2/H1	0.0350	.0024	1.575		0.0357	.0029	1.607	
RMS POWER								
ratio H1/H2	0.0158	.0028	0.711	9%	0.0152	.0025	0.684	11%
ratio H2/H1	0.0343	.0054	1.544		0.0363	.0032	1.634	
MAX AMP								
ratio H1/H2	0.0145	.0023	0.653	5%	0.0162	.0020	0.729	13%
ratio H2/H1	0.0358	.0072	1.611		0.0345	.0010	1.553	

Gain error, % = $\frac{\text{GAIN H1/H2} - \text{GAIN H2/H1}}{\text{GAIN H1/H2}} \times 100$

The relative vertical channel gain can be calculated by first determining the water wave angle of incidence, θ , for a series of shots. The $H1/V$ RMS-PCR is given by:

$$\text{RMS}(H1)/\text{RMS}(V) * (1/\cos \phi) = \tan \theta$$

Where $(1/\cos(\phi))$ is an off $H1$ -axis weighting function for each shot. A radial shooting line will result in constant ϕ angle but varying angles of incidence, θ . The RMS-PCR ($H1/V$) is plotted versus θ and the relative gain of $H1$ to V is the ratio at θ equals 45 degrees.

CONCLUSIONS

Our method requires a full circle of special shots at direct water wave range to produce reliable geophone orientations within plus or minus 2 degrees. Also, the relative calibration of the two horizontal components is obtained accurately. Both of these pieces of information are needed to resolve seismic arrivals into their radial and transverse components. By measuring the maximum amplitude excursion contained in the water wave packets of both horizontals, one can form the ratio, amplitude $H1$ /amplitude $H2$, and plot this as a function of azimuth. The null direction is the azimuth where this ratio goes to zero. This is a simplification from using mean RMS power of an arrival in the ratio. The slope of the ratio line specifies the gain ratio for the two channels.

The value of an oriented and gain-calibrated three-component instrument is in separating the different classes of arrivals. Given 3 components and an external hydrophone the combinations are: P-waves on hydrophone, vertical and radial components; SV-waves on the vertical and radial components; and SH-waves on the transverse component. Once transformation has been made to the vertical, radial, and transverse mode, the correlation between arrivals on the different channels can be exploited fully. A further advantage of three-component ocean bottom seismometers over simpler instruments is the ability to construct seismic particle orbits. These are helpful in the identification of the different seismic phases.

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