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# HIGH-RESOLUTION RADAR

## PART III, SEA CLUTTER

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## ABSTRACT

The use of a short-pulse, high-resolution radar for the study of sea clutter indicates the presence of a set of parameters — velocity, wavelength, and period — which are properties of the echoes displayed by the radar. The B-scope response indicates a moving, wavelike pattern directly; for radar aspects perpendicular to the wave-fronts, a range-time plot of radar echoes as seen on the A-scope trace also indicates wavelike motion. These parameters of the radar echoes resemble those of the ocean waves, and within the limits of the data taken, their similarity is illustrated. As a result of the range-time study using both horizontal and vertical polarizations, certain differences in echo properties are illustrated as a function of polarization.

## PROBLEM STATUS

This is an interim report; work on this problem is continuing.

## AUTHORIZATION

NRL Problem R02-12  
Projects NR 412-000, NR 412-003, NL 430-014-1,  
and NO 051-631  
Bureau Nos. EL-43001 and B4-f-246-9-56

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## HIGH-RESOLUTION RADAR

### PART III - SEA CLUTTER

#### INTRODUCTION

One of the properties of a high-resolution, millimicrosecond, pulsed radar is its ability to display targets separated in range by several feet. With such a radar, sea clutter has been observed to be made up of a series of discrete echoes. This report is concerned with the range-time relationship of these discrete echoes as found in the reduction of data taken on a field trip with a millimicrosecond radar. The location involved in this trip was an ocean site one mile north of Boca Raton, Florida.

#### ELECTRONIC EQUIPMENT

The radar used for this study was an experimental short-pulse model designed and built by the High Resolution Branch of the Radar Division, U.S. Naval Research Laboratory. Some of the properties of the radar are listed below:

Frequency	9375 Mc
Pulse Length	0.008 microseconds
Peak Power	15 kw
RF Amplifier	X-band TWT
IF Amplifier	2 S-band TWT
IF Bandwidth	200 Mc
Video Bandwidth	100 Mc
Antennas	6-foot (section of parabola of revolution). Horizontal beamwidth: 1.2 degrees 8-foot (full parabola of revolution). Beamwidth: 0.9 degrees
PRF	1800 per second
Display	A-scope, B-scope, delayed sweep, range gated.
Dynamic Range	20 db

#### METEOROLOGICAL AND OCEANOGRAPHIC EQUIPMENT

The following systems were required to present a history of wave heights and direction, and wind velocity and directions. The topographical movies of the waves were used along with recorded optical sightings to determine wave-front directions.

Wind-measuring equipment consisted of an AN/UMQ-5 wind gauge. This tape-recording instrument was operated continuously day and night, its tape output indicating both velocity and direction for the local wind. The sensing element for this wind gauge was located on top of the operating tower, 130 feet above sea level.

Wave-measuring equipment consisted of a 25-foot model of the Beach Erosion Board's step-resistance ocean wave gauge. The sensing element, or staff, was pile mounted in 25 feet of water at a point 400 yards from the beach, directly in front of the operating tower. This instrument was also a tape-recording unit, and was operated continuously in such a manner as to sample the waves for a two-minute period out of each hour. In addition to the automatic operating features of two minutes per hour, manual controls permitted simultaneous operation of the wave gauge with the radar for specific tests.

Motion-picture equipment used to record the data analyzed in this report consisted of several modified 16-mm cameras. For tests conducted in daylight, a camera looking at the radar-illuminated area was motor driven in frame-synchronism with a camera looking at the radar echoes. Movies taken of the topography of the ocean will be termed "visual" pictures and movies taken of the radar response will be termed "radar" pictures for the remainder of this report.

#### OPERATIONAL PROCEDURE

The radar used for these tests was tower mounted on an ocean beach in such a manner as to permit operation with antenna heights of 27 to 113 feet, and to permit approximately 180 degrees of azimuth scan when looking at the ocean. Study of radar sea clutter was thus possible for grazing angles from  $1/2$  to 6 degrees and for near-trough aspects around to head-on aspects of the wave fronts. Operating conditions did not permit looking at the back of the waves with the radar.

A movie camera positioned on the antenna platform permitted photographs of the area under radar surveillance when light conditions were suitable. The lens for this camera was chosen to cover a field of view as nearly equivalent as possible to the area illuminated by the radar beam. By using synchronous motors to drive this camera and another which is looking at the scope output of the radar, it was possible to secure simultaneous pictures of the waves being studied and of the radar echoes from those waves. Pictures of the A-scope were taken at a rate of five frames per second and of the B-scope, at one frame per scan, two scans per second.

For strong waves that appeared to have a visual moving pattern, the B-scope response of this short-pulse radar system gave an indication of this moving pattern. Figure 1 shows five frames of a sequence of movies taken to illustrate this motion, and Fig. 2 is a picture of an equivalent A-scope trace. Delayed short-range sweeps were used.

The majority of tests were conducted to show characteristics of radar sea clutter as azimuth, range, and grazing angle were varied, looking mainly into oncoming waves. Some study was made of trough and near-trough aspects when this was possible. As many different sea states were studied as weather conditions and time permitted. Ranges from just beyond the surf out to 3000 yards were used for these radar clutter studies. Some tests were conducted on waves passing the pile-mounted wave gauge located 400 yards from the beach, to permit comparison of radar returns with simultaneous records taken with the wave gauge. A special study was made of waves passing between two marker stakes placed in line with the antenna just beyond the surf. The purpose of this test was to compare visually measured crest velocity with radar echo velocity.

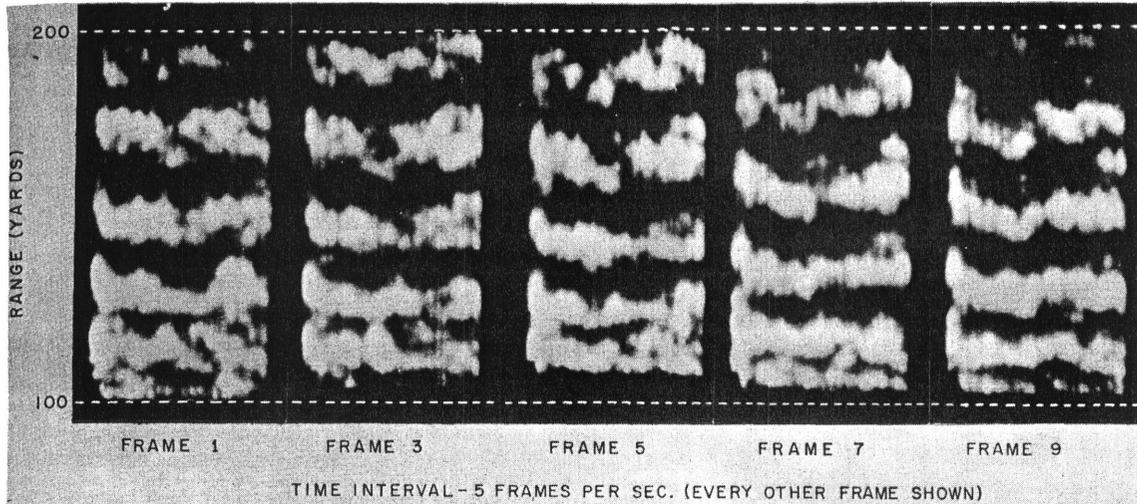


Fig. 1 - B-scope response 10-degree scan

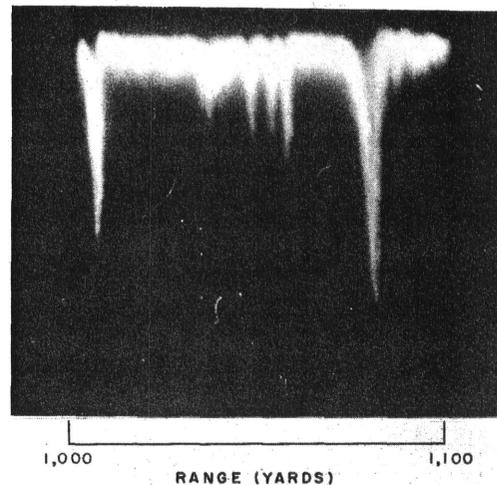


Fig. 2 - A-scope response 100-yard sweep

#### DATA PROCESSING

In the optical pictures of waves taken during radar operation, range uncertainty prevented wave-to-echo correlation on any but a statistical basis. From the movies of the A-scope showing clutter echoes, the range of each readable echo was measured to its sharp peak value. These ranges were plotted as points in the y-direction, while frame number was plotted in the x-direction. Each frame was equivalent to a time interval of  $1/5$  of a second. Figure 3 shows a point-plot of this type, with a "best-fit" line drawn through the apparent pattern of the plot to indicate "average" velocity for the echo trains. As a method of adding information on echo-pulse length to the plots, each readable echo was then plotted as a line in the y-direction proportional in length to the A-scope echo length. This bar-type of plot presented a better pattern for long-time slope determination, while the point-plots revealed short-time (on the order of four or five seconds) slopes of lesser value than the long-time "average" values. Figure 4 illustrates the bar-type of plot derived from the same data used for Fig. 3. Figure 5 is another plot, illustrating conditions that failed to produce a clear pattern.

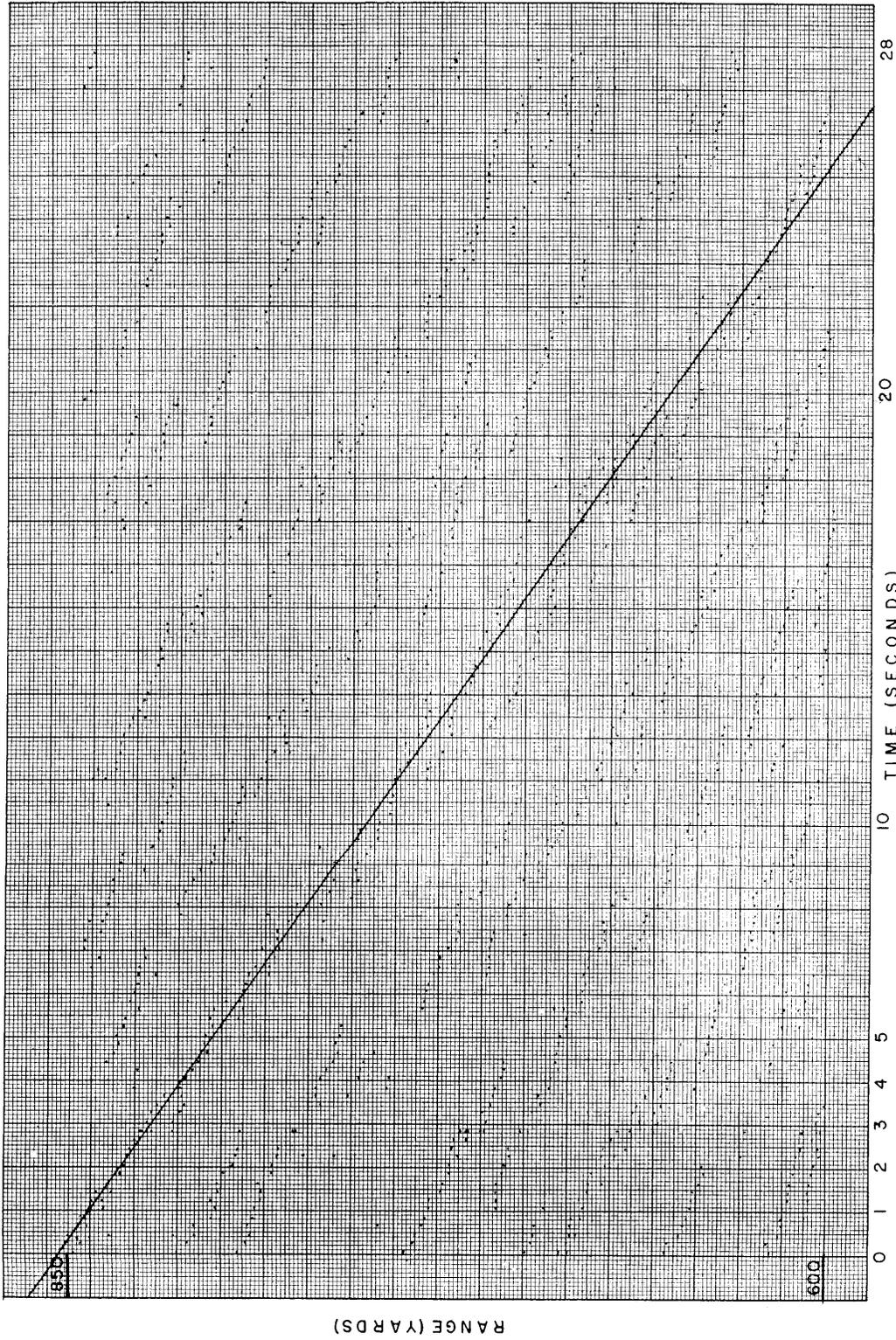


Fig. 3 - Range-time point plot

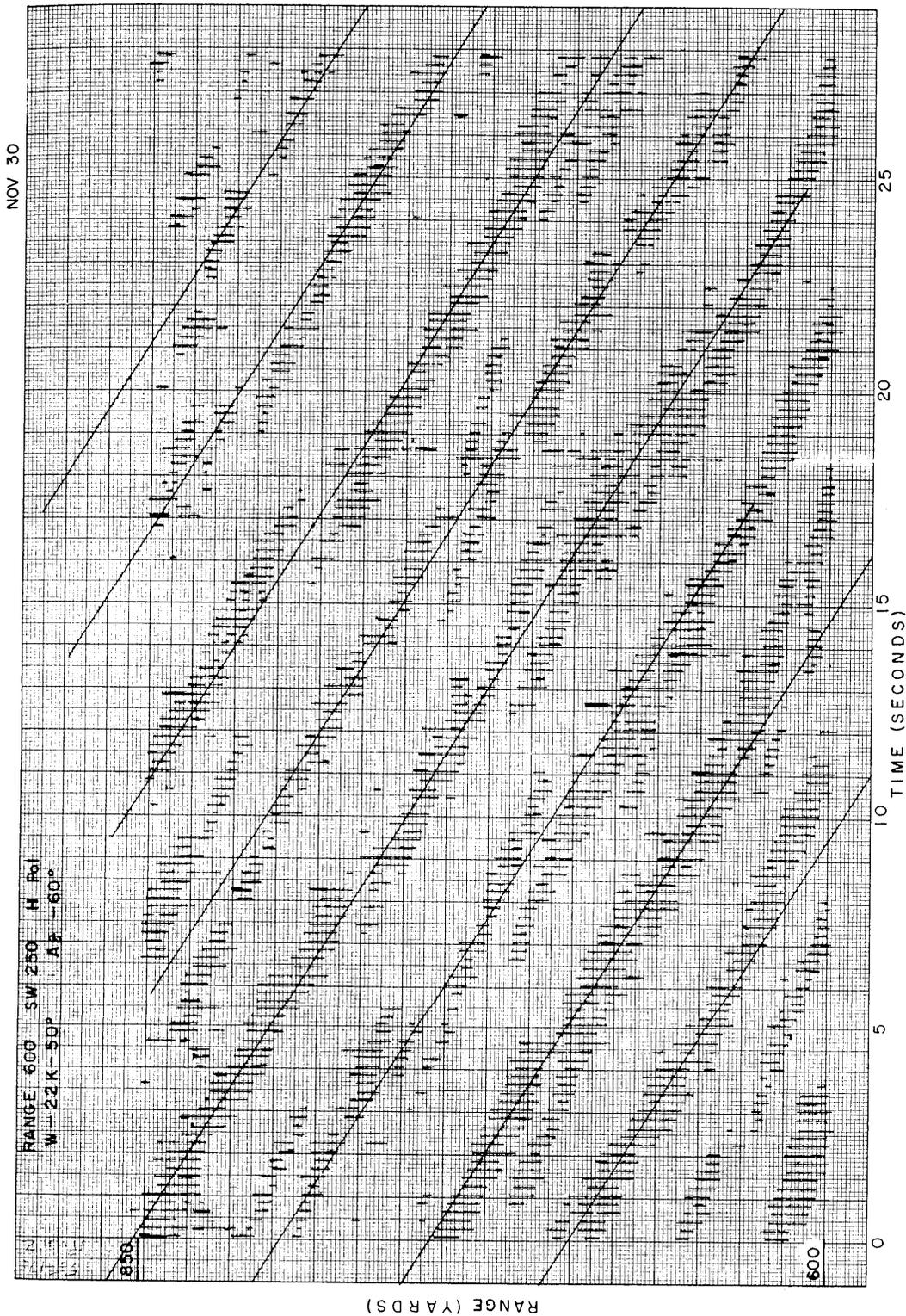


Fig. 4 - Range-time bar plot

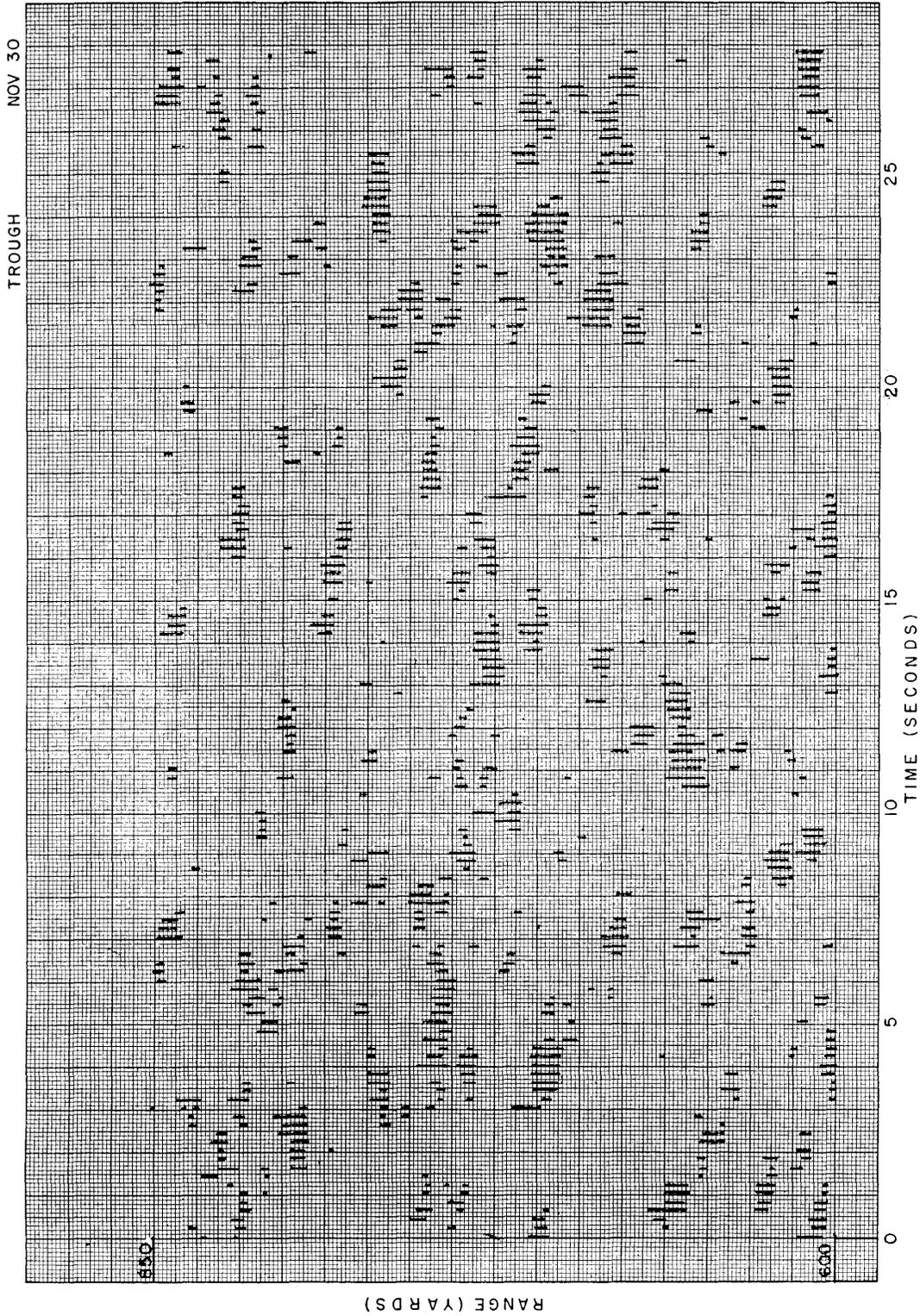


Fig. 5 - Range-time bar plot (no pattern)

Plots were made of this range-time relationship of the radar echoes for waves near the two marker stakes and an "average" velocity, period, and wavelength of the pattern was determined. Optical pictures of the wave crests moving from stake to stake furnished the data required to determine velocity, wavelength, and period for the waves associated with these crests. Since the wave gauge data furnished a period for the existing sea state, the range-time plots for waves passing the wave gauge were used to derive a period value for comparison.

An effort was made, where possible, to process data to indicate the nature of the echo velocity as a function of range from the beach and of wave height. Consideration was given to data which would indicate any significant difference between horizontal and vertical polarization.

## DISCUSSION OF RESULTS

### B-Scope Echo Density

One of the differences disclosed between horizontal and vertical polarizations was the rate of change of echo density as a function of grazing angle. This is illustrated in Fig. 6, from B-scope records taken November 12, 1955. Wind from the ocean was 13 knots, and the significant wave height, measured 400 yards from the beach, was 2.9 feet. A delayed 100-yard sweep, starting at 310 yards, was used. The azimuth scan was 15 degrees, giving an illuminated area of approximately 9,000 square yards. Over a 20-frame period of time a count of each readable echo produced the averages indicated in the graph. Antenna aspect angle for these tests was perpendicular to the wave fronts, and a constant-power receiver gain relationship was assumed for the duration of the tests.

### Range Versus Velocity

In an effort to show the velocity characteristics of the A-scope response as a function of range, all of the data taken on November 30 was analyzed and plotted for the 250-yard sweep length. Figure 7 indicates a general increase in velocity with range, and Fig. 8 shows the change in water depth as a function of range from the beach. This velocity variation of the radar echoes is considered to be related to the water depth in these tests.

### Height Versus Velocity

To avoid the problem of judging the relationship of wind to waves, no effort was made to classify echo velocities as to wind values. The more direct approach was used — indicating the relationship of wave height to radar echo velocity. Since all wave-height measurements were made at the pile-mounted wave gauge 400 yards from shore, only the echo velocities derived in this range area are used in Fig. 9 to illustrate velocity spread as a function of wave height. It would appear from this plot and Fig. 7 (on velocity versus range from beach) that the apparent echo velocity was more a function of range from the beach than it was of wave height. The data processed for ranges in excess of 1500 yards from beach (not here included) indicated the possibility of a greater dependence of velocity on wave height for "deep-water" conditions. It is possible that the sample point used, 400 yards from the beach, was so close to the zero-velocity beach line that a more significant relationship between velocity and wave height was masked.

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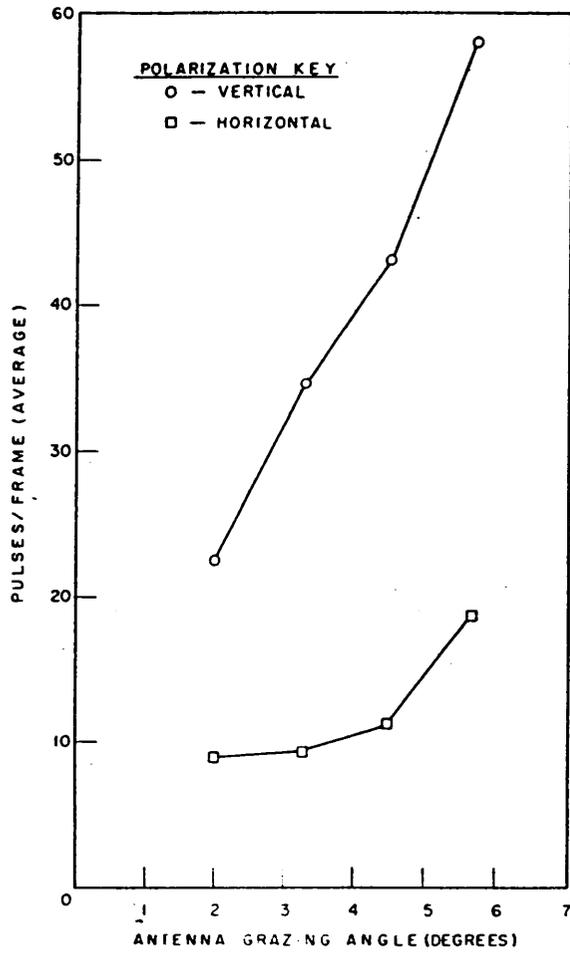


Fig. 6 - B-scope echo density

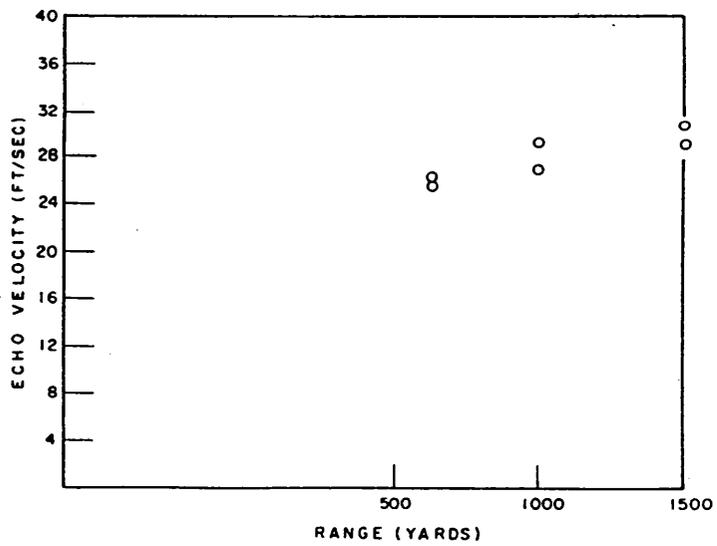


Fig. 7 - Range velocity

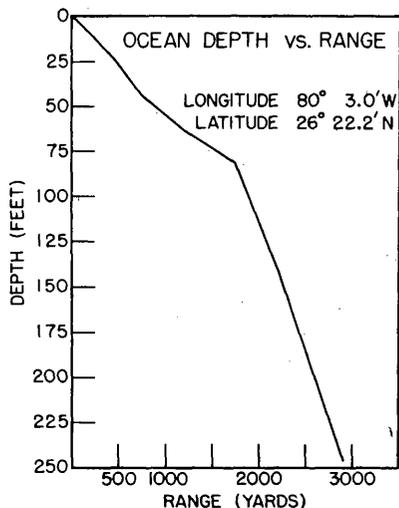


Fig. 8 - Range depth

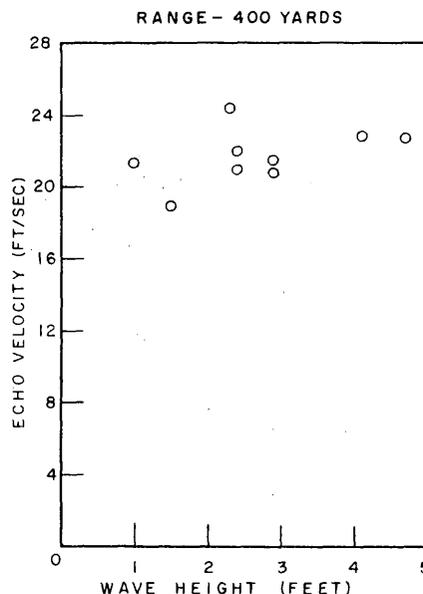


Fig. 9 - Height velocity

### Crest Velocity

A detailed study of the data taken on November 17, 1955 permitted a direct comparison of observed crest velocities with velocities derived from range-time plots of radar echoes. Since the two movie cameras used in these tests were driven in frame-synchronism, the pictures of the wave-crests moving past the marker stakes were related directly to the range-time plots made from pictures of the A-scope echoes. By plotting the marker-stake echoes as dots, the ranges of these stakes were indicated. From the movies taken of the crest motion, the time of passage (frame number) for each crest at the stakes was noted and indicated at the appropriate position on the range-time plot by an X. Figure 10 shows the comparison of crest data with radar echo data, with Table 1 showing the "average" parameters derived from this and similar plots. A radar range of 100 yards with a delayed sweep of 50 yards was used for these tests. Wind of 7 knots prevailed at the time, and the wave height measured 2.0 feet at the wave gauge 400 yards from the beach.

### Wave-Gauge Comparison

The analysis of records taken simultaneously by the wave gauge and radar permitted a comparative display of crest-trough positions and radar echo-train positions on the same plot. Figure 11 is an illustration of this: the top portion shows the combined data; the bottom portion shows a picture of the wave-gauge record for the period of time indicated in the plot. Wave-gauge records consisted of a continuous curve on Brush recorder tape, taken at a tape speed of 5 mm per second. This curve represented the time contour curve; crest-to-crest times were indicated and average periods were measurable for the sea state under study. Wave heights were derived from the calibration curve for the instrument.

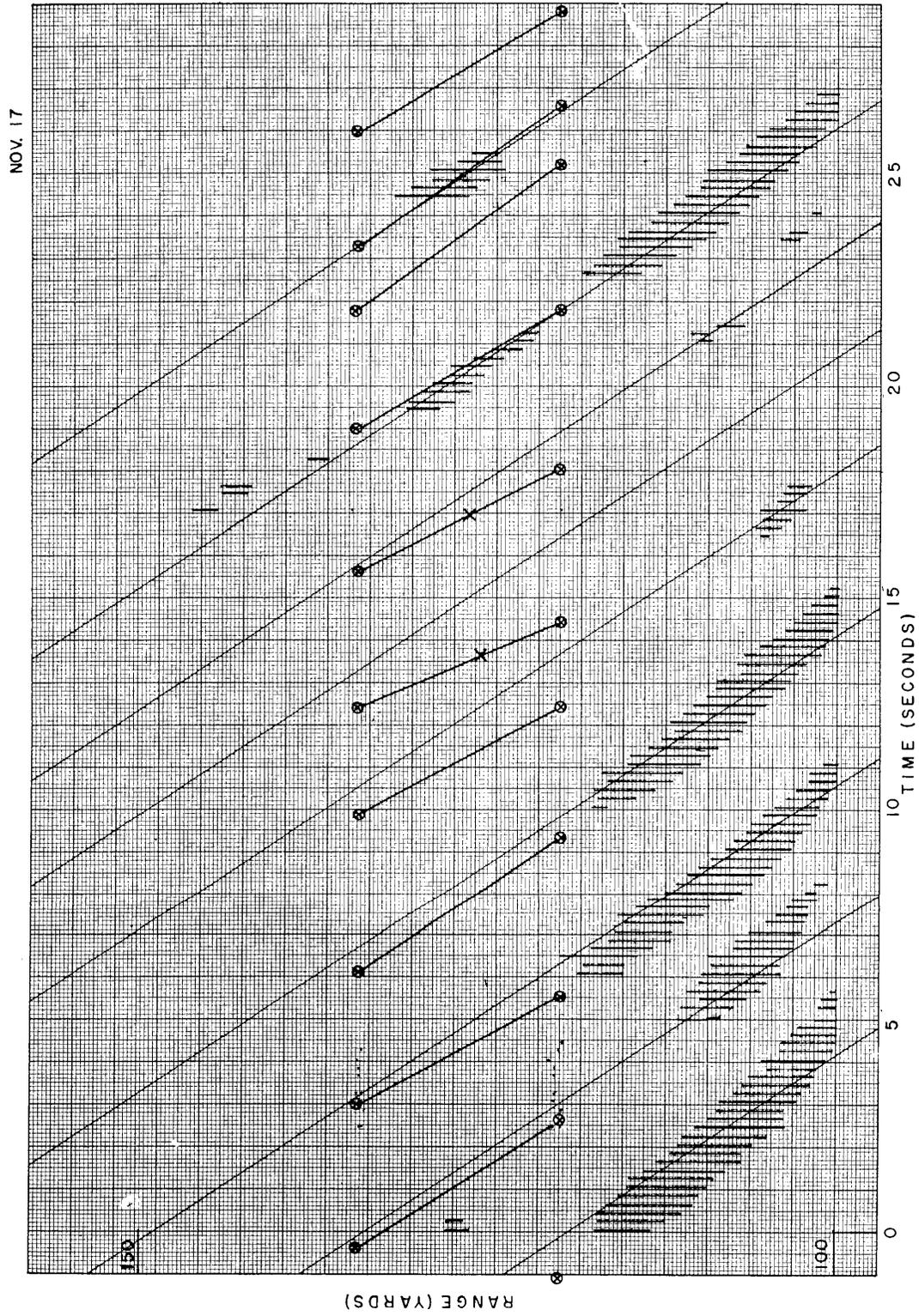


Fig. 10 - Crest-velocity study

TABLE 1  
Tabulation of Crest Velocity Study

	Velocity (ft/sec)	T (sec)	X (ft)
Radar	10.8	3.3	36
Ocean	9.9	3.3	33

In this range-time plot of radar echoes, it was found to be helpful to omit the echo from the pile supporting the wave-gauge staff, since it was much greater in amplitude than the echoes from the adjacent sea clutter. This space was used to indicate features of the waves disclosed by the wave-gauge records. After marking the wave contour curve with X's for crests and O's for troughs, these identification symbols were inserted at the proper range-time position, as shown in the top part of Fig. 11. For the majority of echo-trains that appear strongly, both beyond and inside the pile-gap in the plot, there appears to be a corresponding crest. It is to be noted that the plot of radar echoes represents energy back from a finite area on the surface of the sea. This area is determined by the 1.2-degree antenna beamwidth and the sweep length used. If a wave were to move along the edge of the area illuminated by the antenna and did not show in the wave-gauge record, a radar echo-train could appear without a matching crest in the wave-gauge record.

## CONCLUSIONS

When looking at sea clutter, a short-pulse high-resolution radar was found to be a useful tool in developing a set of parameters that are related to the motion associated with that sea. These parameters, derived from the echo range-time plots, are "average" velocity, period, and wavelength. They can be used to some extent, to indicate the sea state of the area in question. Direction as well as velocity can be shown from the B-scope response of such a radar for the wave motion.

Differences between horizontal and vertical polarization, as disclosed by the range-time plots of radar echoes, were slight if any for sea waves of three to five feet. For lower sea states, vertical polarization consistently produced a greater number of discrete echoes per trace.

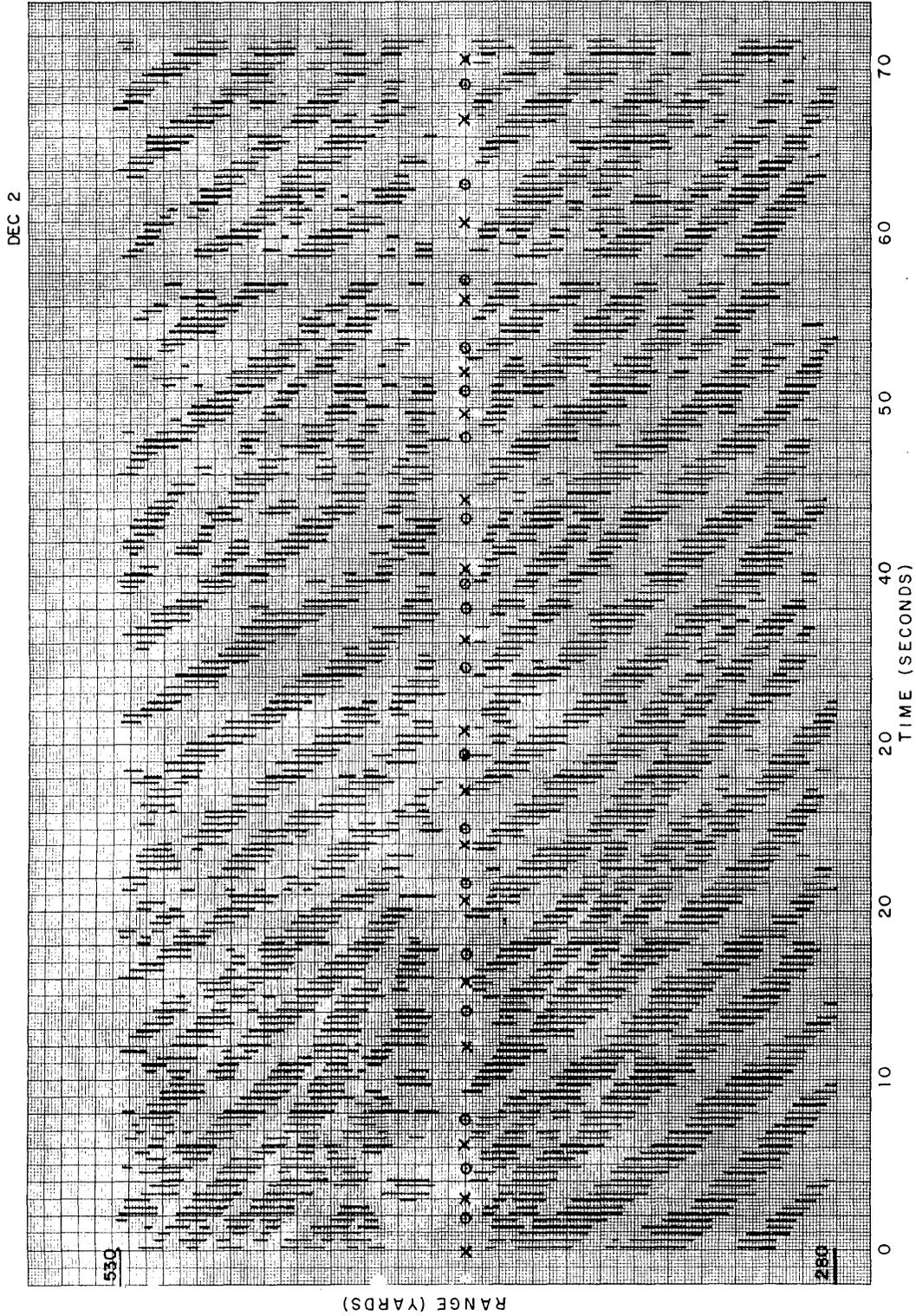


Fig. 11 - Composite of wave-gauge and radar data