2027

NRL Report 6881

pwind-Downwind-Crosswind Sea-Clutter Measurements

JOHN C. DALEY, JOHN T. RANSONE, JR., JOSEPH A. BURKETT,
AND JAMES R. DUNCAN

Wave Propagation Branch
Electronics Division

April 14, 1969

APPROVED FOR PUBLIC
RELEASE - DISTRIBUTION
UNLIMITED

NAVAL RESEARCH LABORATORY
Washington, D.C.

CONTENTS

Abstract	ii
Problem Status	ii
Authorization	ii
INTRODUCTION	1
INSTRUMENTATION	1
DATA COLLECTION AND PROCESSING	3
DATA PRESENTATION	4
DEPENDENCE OF SEA CLUTTER ON WIND DIRECTION	5
CONCLUSIONS	14
REFERENCES	14

ABSTRACT

The initial processing and analysis of radar backscatter data recorded off the coast of San Juan, Puerto Rico, in July 1965 have been completed. This data constituted part of a study conducted in conjunction with the Applied Physics Laboratory (APL) of Johns Hopkins University to determine the scattering mechanism involved in the generation of sea clutter. The NRL WV-2 instrumented aircraft was used in this experiment with its four-frequency, pulsed radar system and a surface vessel equipped and staffed by APL for the purpose of gathering sea-surface data in the form of stereophotographs and wave-buoy measurements.

Radar returns were collected nearly simultaneously on four frequencies –428 MHz, 1228 MHz, 4455 MHz, and 8910 MHz–for both linear and cross polarizations. In the course of these measurements, sea clutter was recorded in the upwind, downwind, and crosswind directions. The ratios of the upwind-to-downwind and upwind-to-crosswind returns were investigated as functions of the incident angle, the polarization, the radar wavelength, and the gross surface parameters of wind velocity and wave height. The upwind/downwind ratio is shown to decrease with increasing angle and surface roughness. Horizontal polarization is more sensitive to wind direction than vertical polarization. The short wavelengths are more sensitive to wind direction than the long wavelengths. The upwind/crosswind ratio remains significant as the short wavelengths for the roughest sea encountered at Puerto Rico. The results provide estimates of the upwind-downwind-crosswind relations as functions of the above parameters over an angular region of 4 to 90 degrees (vertical incidence) and from calm sea conditions to moderately rough conditions characterized by 5- to 7-ft wave heights and 10- to 20-knot winds.

PROBLEM STATUS

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

AUTHORIZATION

NRL Problem R02-37
Project A31533/652/69R00801020

Manuscript submitted December 24, 1968.

UPWIND-DOWNWIND-CROSSWIND SEA-CLUTTER MEASUREMENTS

INTRODUCTION

From July 13 to 29, 1965, the Wave Propagation Branch, Electronics Division, NRL, in conjunction with the Applied Physics Laboratory (APL) of Johns Hopkins University, conducted an extensive sea-clutter-measurement program off the coast of San Juan, Puerto Rico. Using the WV-2 instrumented aircraft with its four-frequency (4FR) radar system, the NRL group obtained radar backscatter statistics at four radar wavelengths, for both linear and cross polarizations, for a variety of surface conditions. Due to the vast amount of data recorded, it is desirable to express the results of the program in a series of reports. The first report of this series (1) described the instrumentation, experimental procedure, and data processing system and included amplitude measurements of the normalized radar cross section σ_0 as a function of radar wavelength, incident angle, and surface conditions for the linear polarizations (vertical and horizontal) in the upwind direction. This report will treat the effect on clutter amplitude of downwind and crosswind orientations. A later report will provide the results obtained for the cross-polarized returns.

INSTRUMENTATION

The 4FR pulsed radar and its antenna system have been described in previous NRL reports (1,2), so that only a brief description need be given here. The system transmits in the sequence shown in Fig. 1–P band (428 MHz), X band (8910 MHz), L band (1228 MHz), and C band (4455 MHz), alternately on vertical and horizontal polarization, and receives both the vertical and horizontal components of the return. The reception sequence indicates that both the direct and the cross-polarized returns are recorded. It is seen that a total of 16 signal amplitude components are recorded – eight on direct polarizations and eight on the cross polarizations.

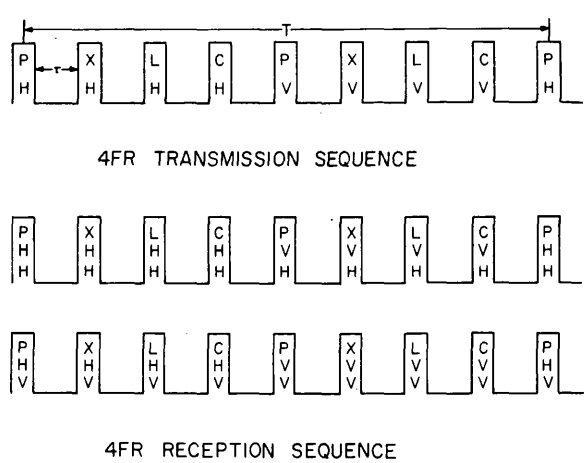

Fig. 1 - Pulse train

A simplified block diagram of the receiving system is shown in Fig. 2. The receiving system consists of four i-f amplifiers (37 Mc) through which all the radars are multiplexed on a time-share basis. Two of the amplifiers are fed by the horizontally polarized signal, and two are fed by the vertically polarized signal. One of these is a logarithmic (log) strip whose output is detected square law and provides a pulse-to-pulse measure of the amplitude in the range gate. The second of these is a linear (lin) strip whose output is hard clipped to eliminate amplitude fluctuations and provides a measure of instantaneous signal phase. A similar log-lin pair of receivers exists for the vertically polarized returns. The output of each detector is range gated, digitally quantized to 128 levels (7 bits), and recorded on magnetic tape at the pulse repetition rate. Formating circuitry separates the various frequency and polarization combinations and assigns to each a definite position to allow later identification.

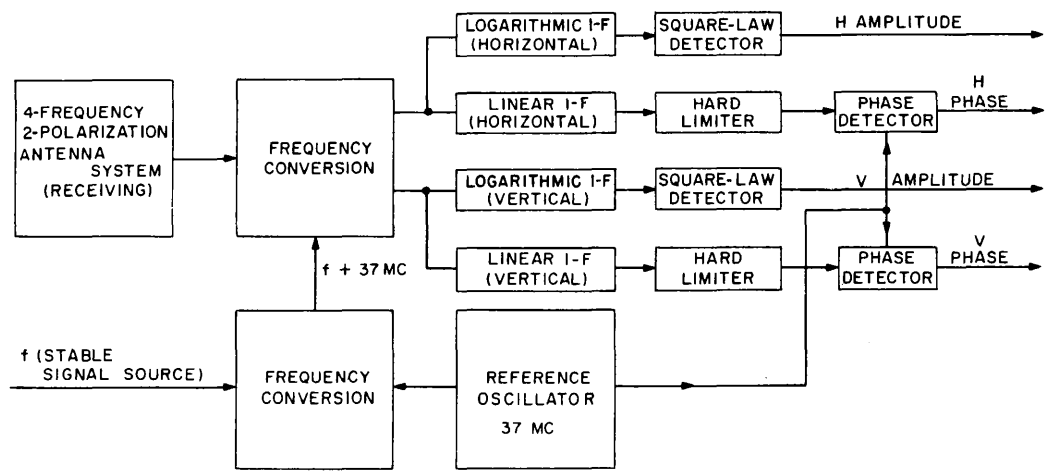

Fig. 2 - Four-frequency receiving system

The system also features common antenna pointing through 100 degrees of elevation. The X- and C-band antennas are parabolas mounted side by side in the radome on the underside of the aircraft. This pair is mounted back to back with the P- and L-band crossed dipole antennas. Both antenna pairs are colinear so that the X and C bands illuminate the same area; likewise, the P and L bands illuminate the same area, although the P-band beam is larger and actually includes the area illuminated by the L-band beam. The antennas are stabilized in roll and pitch; they can sector scan through 315 degrees of azimuth and turn through 100 degrees of elevation. The electrical characteristics of the antenna and the principal parameters of the radar system are given in Table 1. The 4FR system allows many choices of the radar parameters. The values used for these parameters during the July program were prf = 788, pulse width = 0.25 μ sec, and range-gate width = 50 nsec.

The received clutter power is absolutely calibrated by referencing it to the power returned from aluminum spheres dropped from the aircraft. The spheres are dropped singly and manually tracked by the radar. Good estimates of the sphere cross section are obtained by recording the backscatter from several spheres for each wavelength. Since the antenna pairs are concentric, the X- and C-band wavelengths are calibrated simultaneously and likewise the L- and P-band wavelengths.

versus time, in terms of the 10%, 50% (median), and 90% percentiles of successive cumulative probability distributions. A typical plot is illustrated in Fig. 4, for one X_{VV} of the 16 amplitude components ordinarily recorded during each run. The data are initially plotted against an arbitrary decibel scale on the left. This scale is calibrated by the sphere measurement to provide the values of the normalized cross section σ_0 scale to the right. The return is referenced to the oceanographic data, since the position of the surface vessel is marked by the sharp increase in signal toward the end of the run. To study σ_0 as a function of other parameters, the median value of σ_0 was determined from plots, such as this one, through the region of interest, usually near the surface vessel. These values were tabulated on all frequencies and polarizations for each data run and represent the median value of σ_0 observed over a 20- to 30-second time interval. Over 200 data runs were recorded during the July 1965 period, with from 1 to 6 angle settings per run. With 16 signal amplitude components available for processing, a vast amount of data has been generated, which provide a comprehensive description of the signals returned from the sea surface.

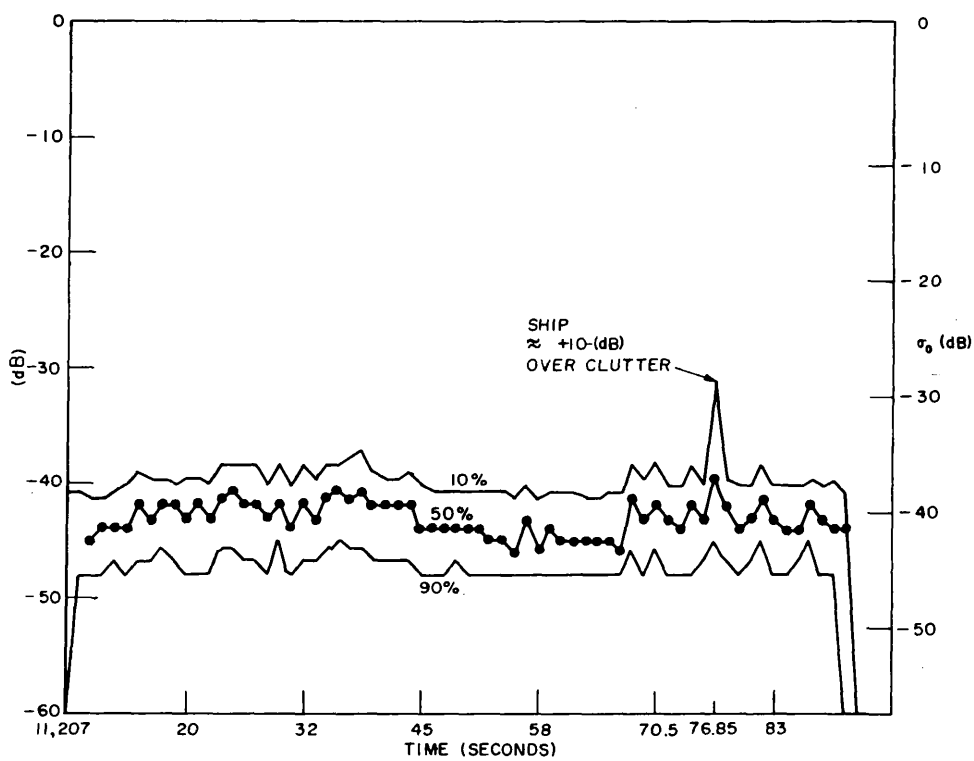

Fig. 4 - Sample median plot. Run 170 was made on July 29, 1965, with θ = 20 degrees, polarization = VV, and frequency = X.

DATA PRESENTATION

The study of the long-term median values reveals the expected variation in σ_0 with wind direction at moderate angles, as well as run-to-run differences for σ_0 in the same direction. While small run-to-run differences may be attributed to receiver stability, larger effects are due to the nonstationary nature of the sea surface. In particular, the short wavelengths (X and C bands) are most sensitive to upwind-downwind-crosswind

relations and to short-term fluctuations in the wind velocity. To estimate these effects, the median σ_0 value was tabulated, when available, at each angle for the upwind-downwind-crosswind directions over all available surface conditions. These conditions are described by gross estimates of average wind velocity and wave height made by APL observers at various intervals throughout the day. The roughness scale ranges from moderate conditions of up to 20-knot winds and 5- to 7-ft wave heights to natural slick conditions. Detailed descriptions of each day are given in Table 2.

The dependence of clutter amplitude on wind direction is conveniently expressed as the ratios σ_0 (upwind) $/\sigma_0$ (downwind), and σ_0 (upwind)$/\sigma_0$ (crosswind) in decibels. As discussed above, a long-term median value was determined in each direction for a given sea state. From these data, the above ratios were calculated and plotted in Figs. 5 to 12 as a function of angle for each direct polarization and frequency combination and for each operating day. The curves are plotted in approximate order of decreasing roughness, with the curve from the roughest day on the top of the page. The plots also include previously published data on X and C bands obtained on December 9 and 10, 1964 (2). Curves for July 27, 1965, were omitted because natural slick and "confused" sea conditions resulted in upwind and downwind directions being undefinable.

DEPENDENCE OF SEA CLUTTER ON WIND DIRECTION

Previous measurements (3) have shown that sea clutter is, in general, higher in the upwind direction, as opposed to downwind and crosswind. This would indicate positive values of the ratios plotted in Figs. 5 to 12, with the relation of downwind-to-crosswind clutter determined by their relation to upwind and both ratios approaching unity (0 dB) with increasing angle. While the data exhibits large variations in day-to-day comparisons, it is evident that the wind ratios in the low-angle region are functions of surface roughness, polarization, and frequency.

The largest ratios generally occur for horizontal polarization, i.e., short wavelengths. The upwind/downwind ratios are largest for the days of "moderate" roughness and approach zero for very calm and very rough conditions. Figures 13 and 14 are plots of the VV and HH polarizations wind ratios as functions of wind and wave height for the angle where the highest ratios were generally measured (i.e., θ = 10 degrees). The solid lines are medians of the short wavelengths; the dotted lines are medians of the long wavelengths. Although there is scatter, due mostly to the gross estimates of the surface conditions, some trends are discernible. On vertical polarization, Fig. 13, the maximum upwind/downwind ratios occur in the 8- to 12-knot range and 2- to 4-ft wave-height range, decreasing as sea state increases. On horizontal polarization, the upwind/downwind ratio has not yet vanished at the rougher sea states. These results are in agreement with previous measurement (4,5), showing significant wind ratios on L_{HH} during a 30-knot wind.

The upwind/crosswind ratios remain significant in both polarizations as sea state increases. This effect was also observed over rougher conditions during a recent NASA measurement program (6). It also appears that the wind ratios are inversely proportional to wavelength. The wavelength dependence is well expressed in Fig. 15, which is an average of 6 days of the data given in Figs. 5 to 12, the days with the largest values of upwind/downwind and upwind/crosswind ratios. Included in the plot is the theoretical prediction of Schooley (7), which describes the trend of the upwind/downwind ratio at the shorter wavelengths, although it does not predict high enough values for horizontal polarization. Worthy of note is the tendency toward slightly negative values at the higher angles, which has been verified (7). The wavelength dependence is apparent and in accord with expectations for the upwind/downwind case; namely, the upwind/downwind ratio, where it is significant, is large in the shorter wavelength, with the longest wavelength (P band) generally showing no significant values.

Table 2
Sea Conditions

Date	Location	Wind Velocity (knots)	Wave Height (feet)	Angles Sampled (degrees)	Qualitative Observations
July 15, 1965	10 mi NW San Juan	15-20 10-15	4-5 3-5	4-20 30-90	Rain Rain
July 19, 1965	15 mi NW San Juan	10-12 10-15	3-4 3-4	4-45 70-90	
July 23, 1965	20 mi NW San Juan	8-10 8-12	2-3 4-6	30-60 4-20, 70-90	Sea "choppy" white caps
July 22, 1965	20 mi NW San Juan	10-12 10-12	5-7 3-4	4-60 70-90	5-8-ft swells
July 16, 1965	10 mi NW San Juan	10-12 7-8 8-10 15-18	2-2.5 2-3 3-4 3-4	4-15 20, 30 45-90 80	Rain squall
July 21, 1965	20 mi NW San Juan	8-11 8-11	4-6 3-5	4 in X and C; 10 in L and P 10-90	Gusts to 12 knots
July 20, 1965	15 mi NW San Juan	7-9 10-12 10-12	2-3 2-3 2-3	5-45 60-90 4(cross-wind only)	
July 29, 1965	off Mayaguez	1-2 1-2 2-15	1-2 1-2 2-3	60-90 20-60 4-60	White caps
July 27, 1965	off Mayaguez	2-3 5-8 0-1	0.5-1 1-2 and 4-5 0.5-1	4-15 15-66 60-90	"Confused" sea-squall
July 28, 1965	off Mayaguez	0-1 3-4	0.5-1 0.5-1	4-18, 60-90 4, 34	2-ft swells Rain squall
July 27, 1965	off Mayaguez	2-3 0-1	0.5-1 0.5-1	4-20 60-90	Natural slicks
Dec. 9, 1964	50 mi east of Atlantic City,	12-15	6-10	3-90	Well-developed sea
Dec. 10, 1964	N.J.	4	2-4	5-90	Natural slicks

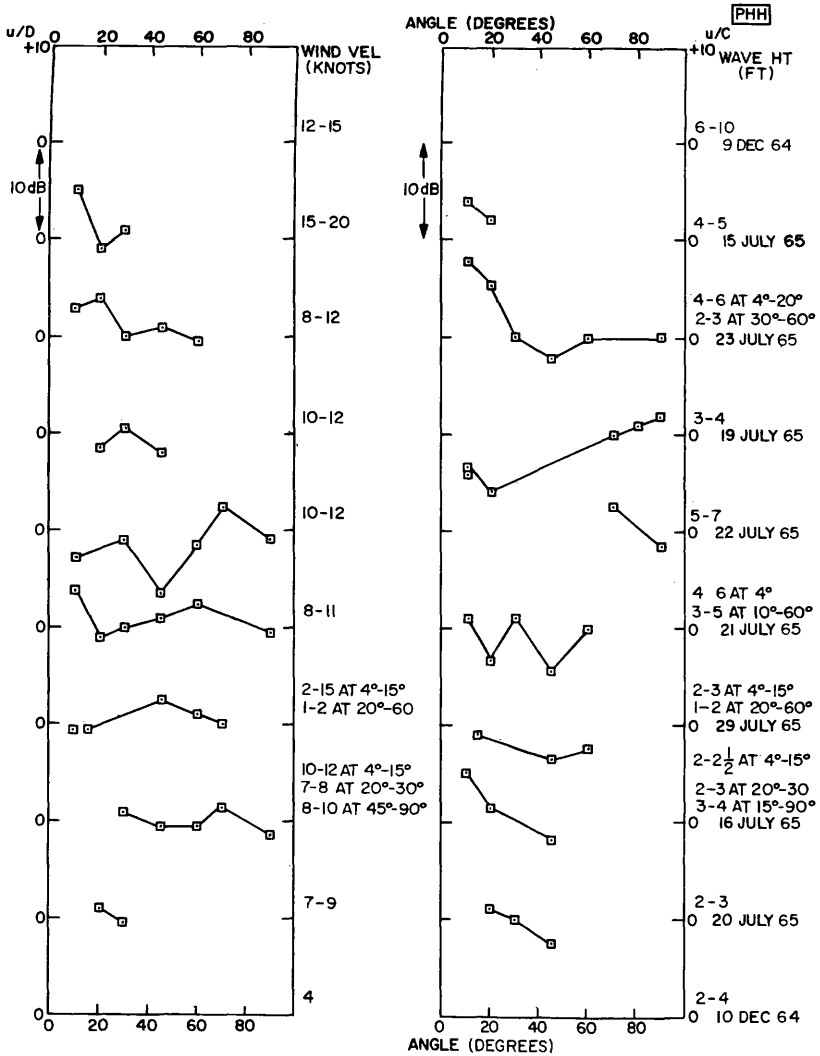

Fig. 5 - σ_0 for upwind/downwind and upwind/crosswind ratios vs angle of incidence for PHH polarization

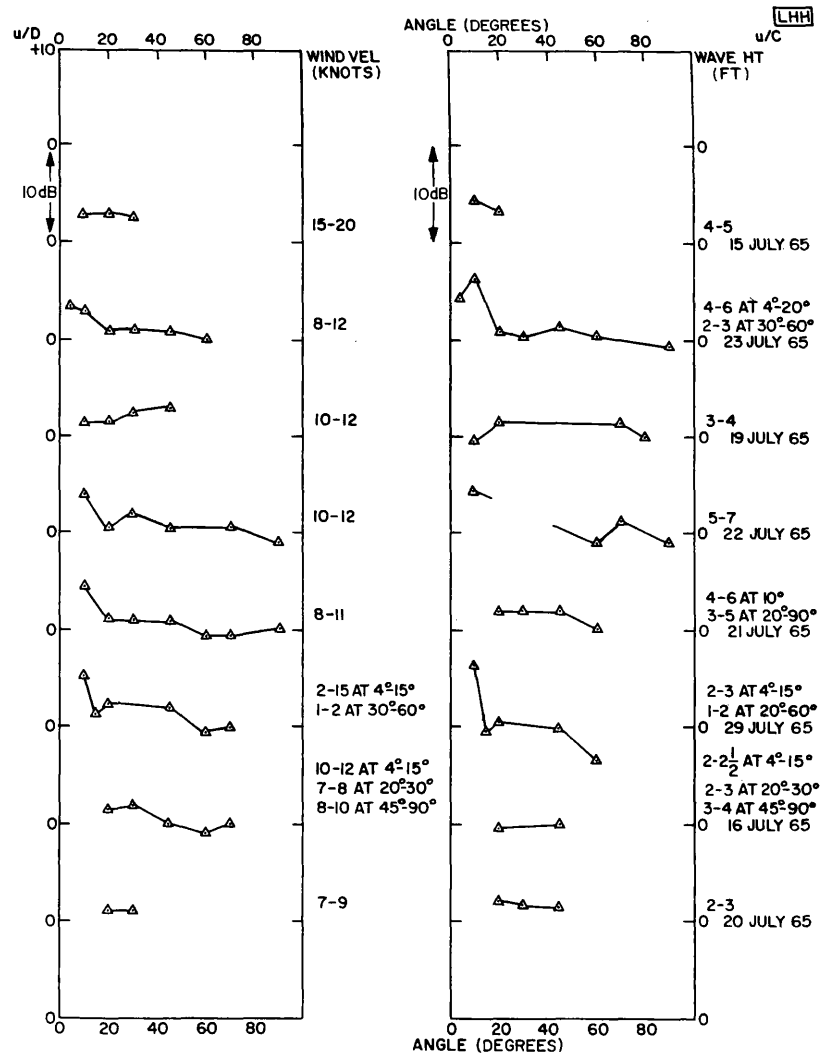

Fig. 6 - σ_0 for upwind/downwind and upwind/crosswind ratios vs angle of incidence for LHH polarization

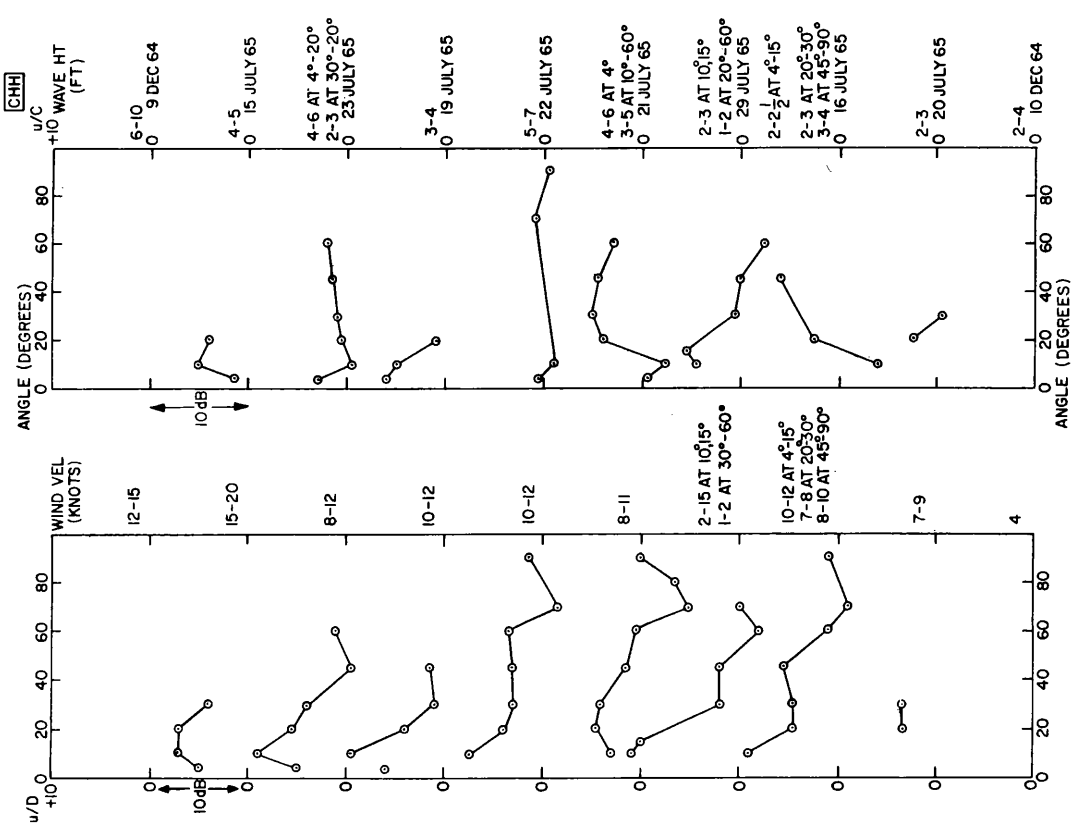

Fig. 7 - σ_0 for upwind/downwind and upwind/crosswind ratios vs angle of incidence for CHH polarization

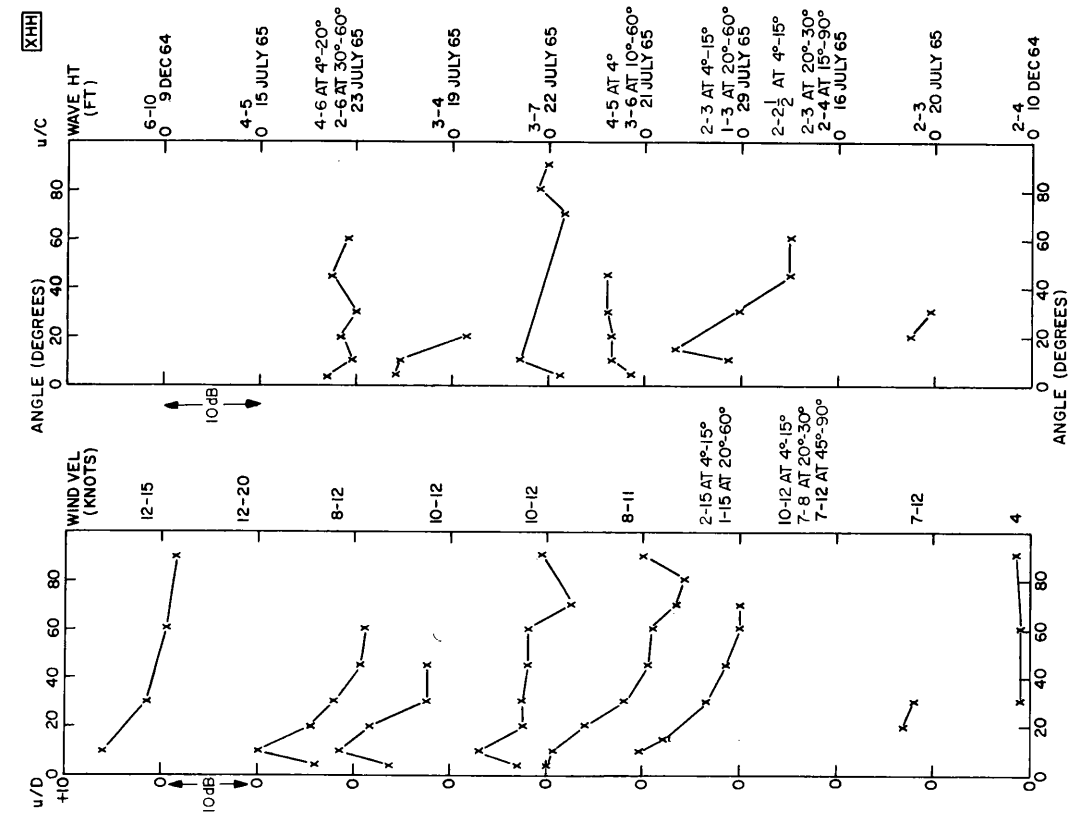

Fig. 8 - σ_0 for upwind/downwind and upwind/crosswind ratios vs angle of incidence for XHH polarization

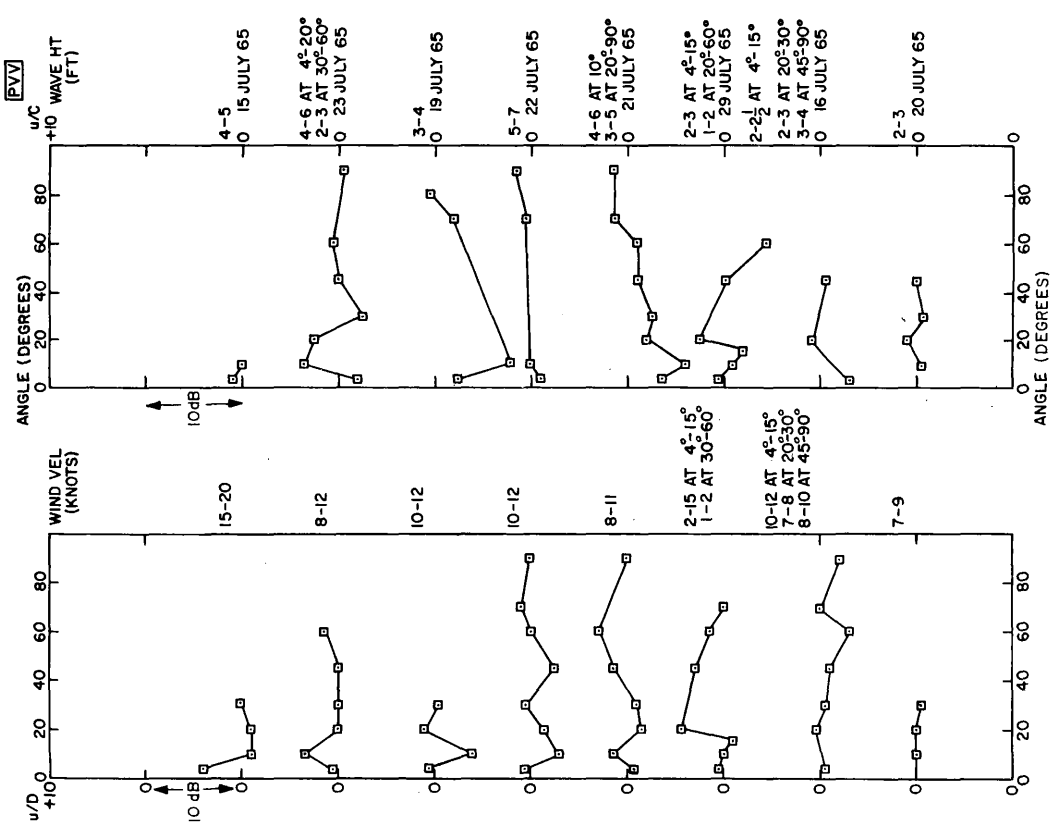

Fig. 9 - σ_0 for upwind/downwind and upwind/crosswind ratios vs angle of incidence for PVV polarization

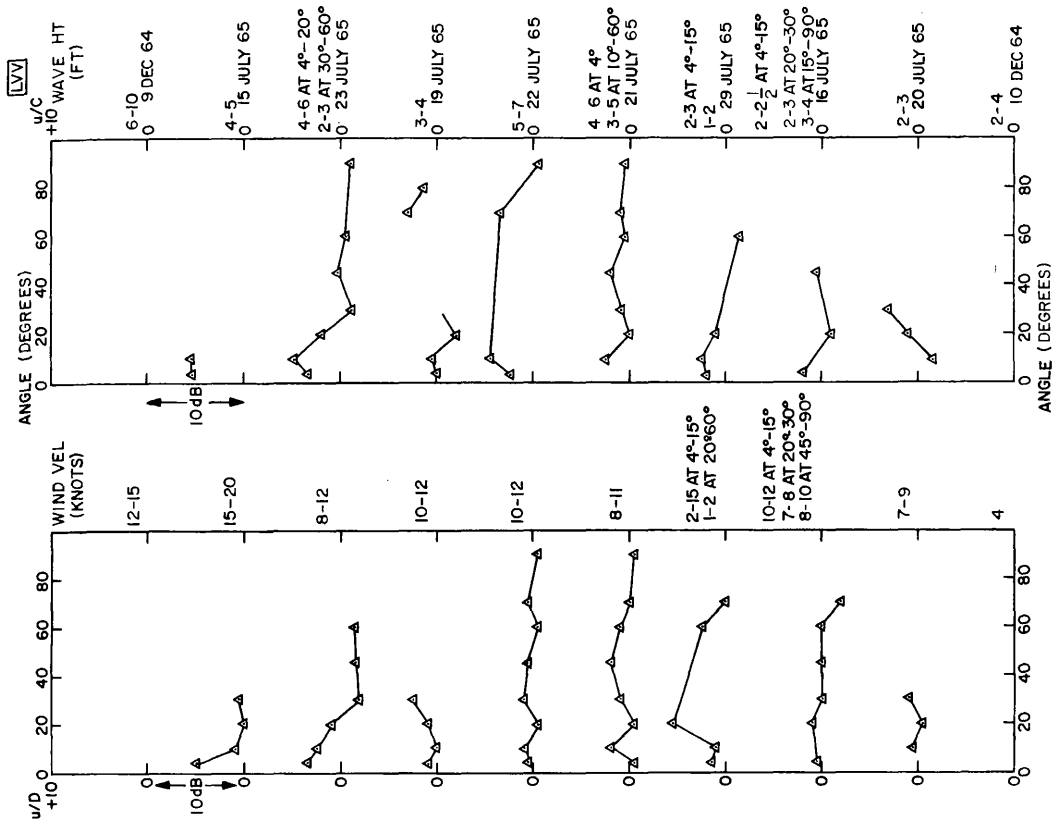

Fig. 10 - σ_0 for upwind/downwind and upwind/crosswind ratios vs angle of incidence for LVV polarization

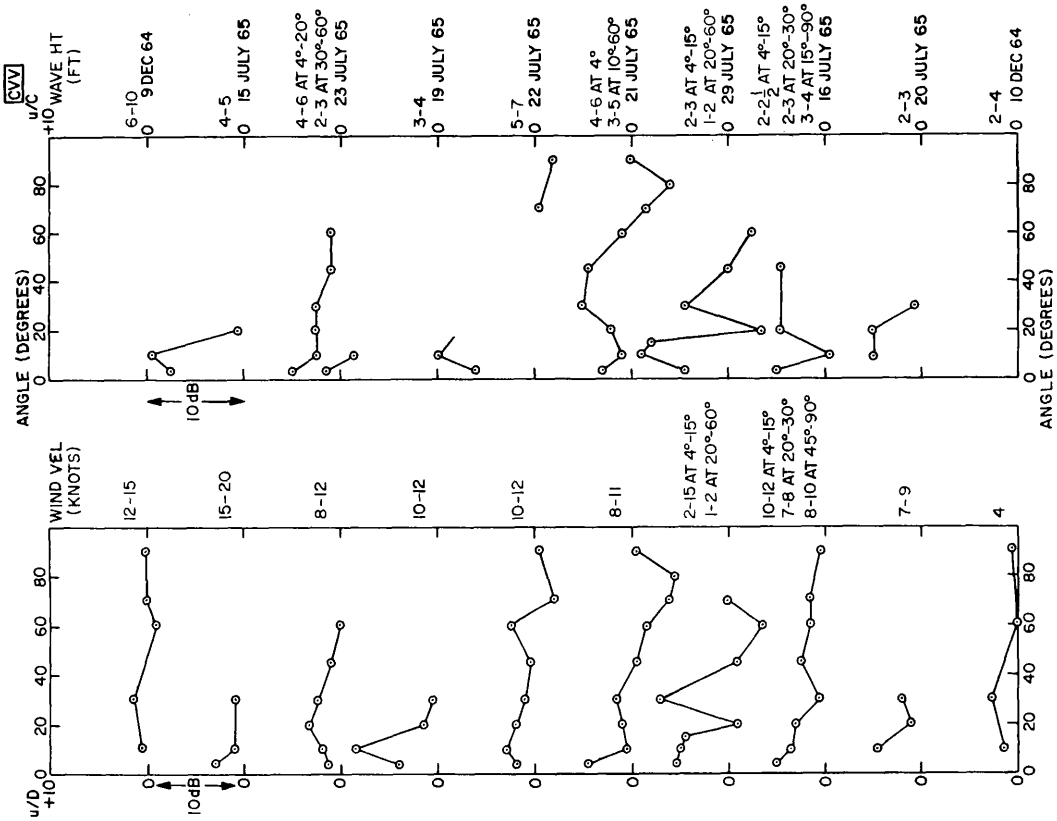

Fig. 11 - σ_0 for upwind/downwind and upwind/crosswind ratios vs angle of incidence for CVV polarization

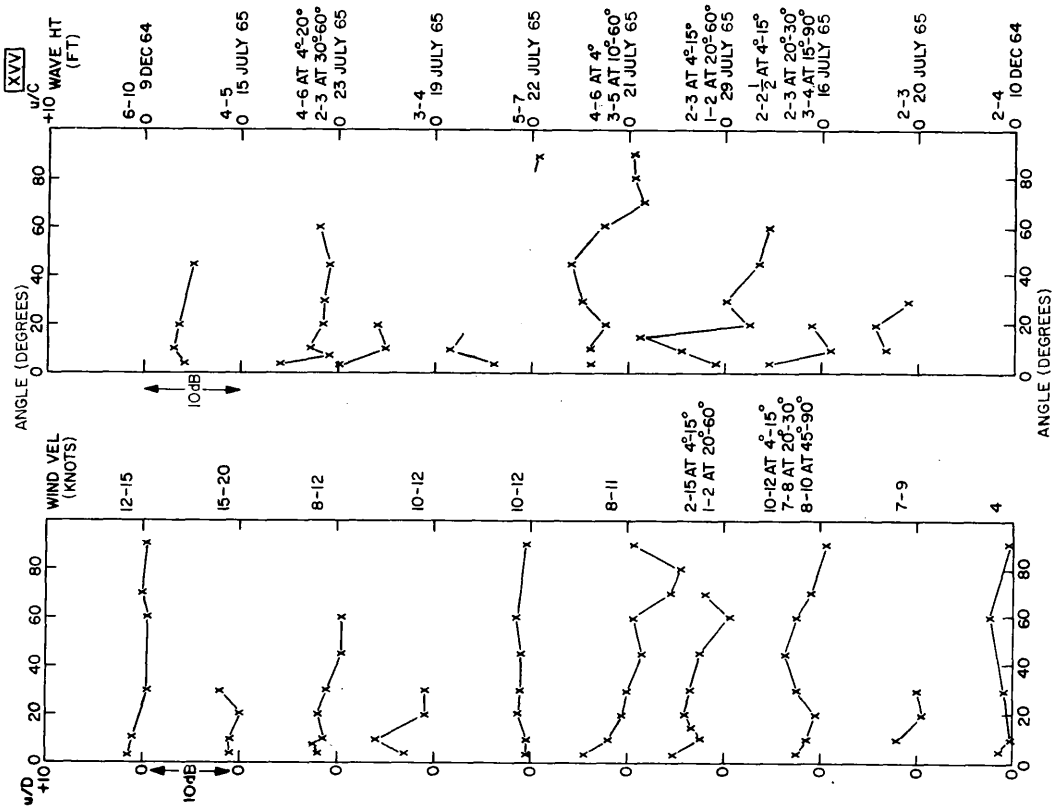

Fig. 12 - σ_0 for upwind/downwind and upwind/crosswind ratios vs angle of incidence for XVV polarization

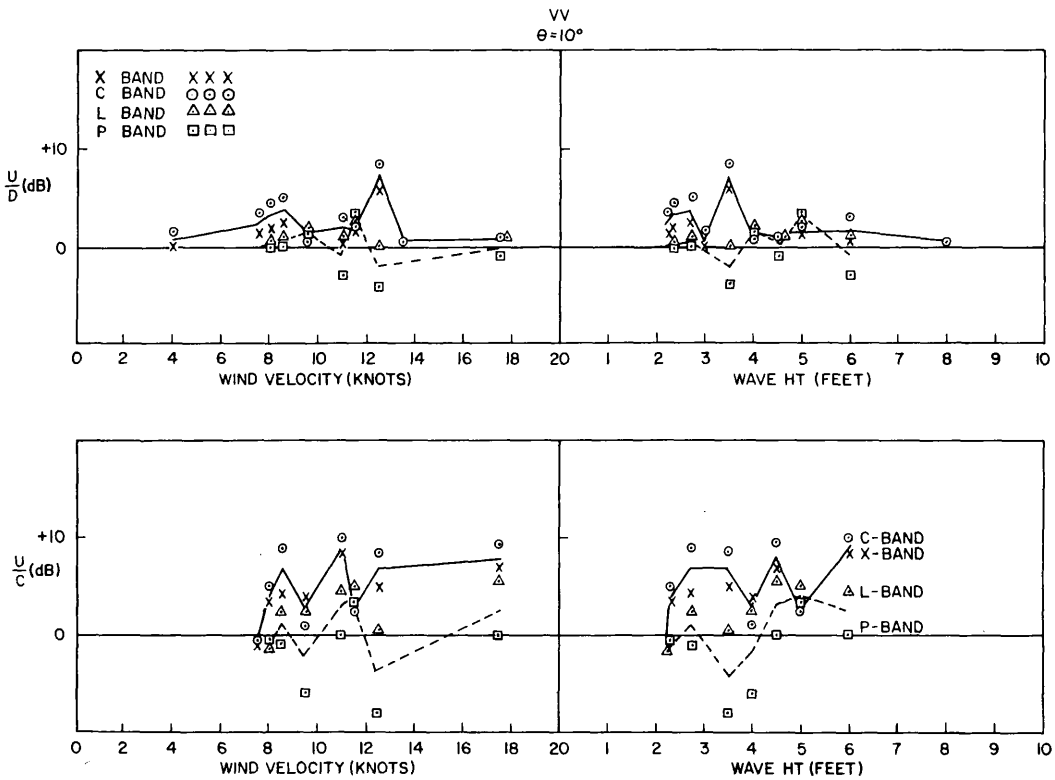

Fig. 13 - Wind ratios vs sea conditions for VV polarization and θ = 10 degrees

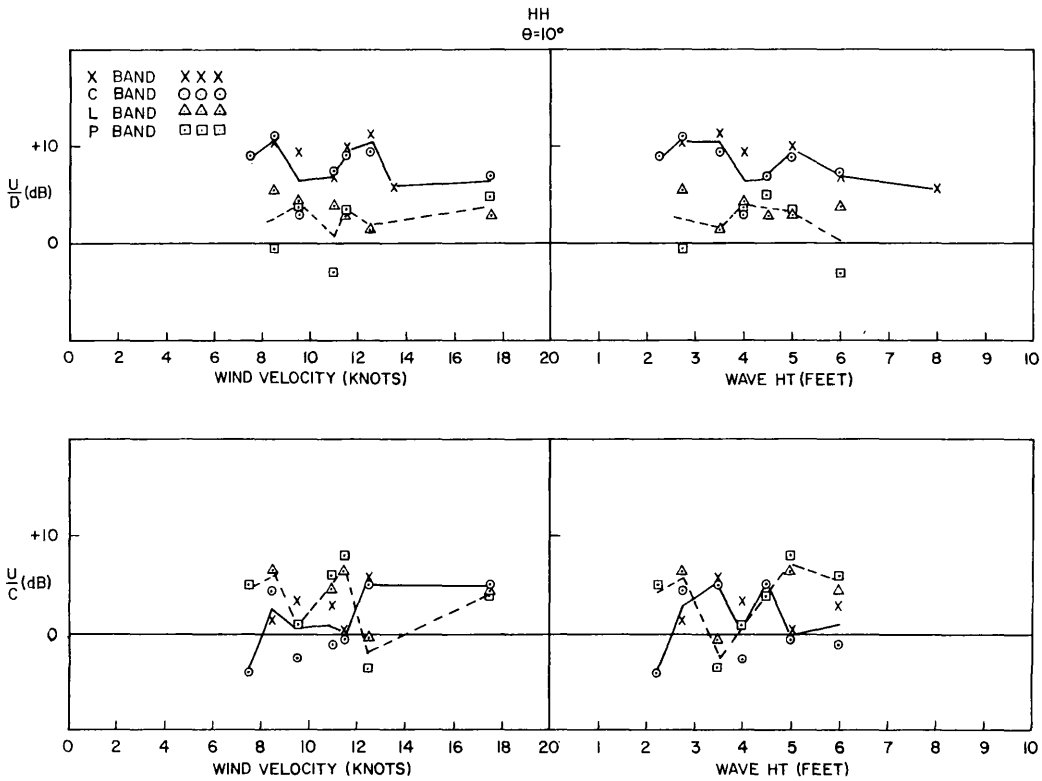

Fig. 14 - Wind ratios vs sea conditions for HH polarization and θ = 10 degrees

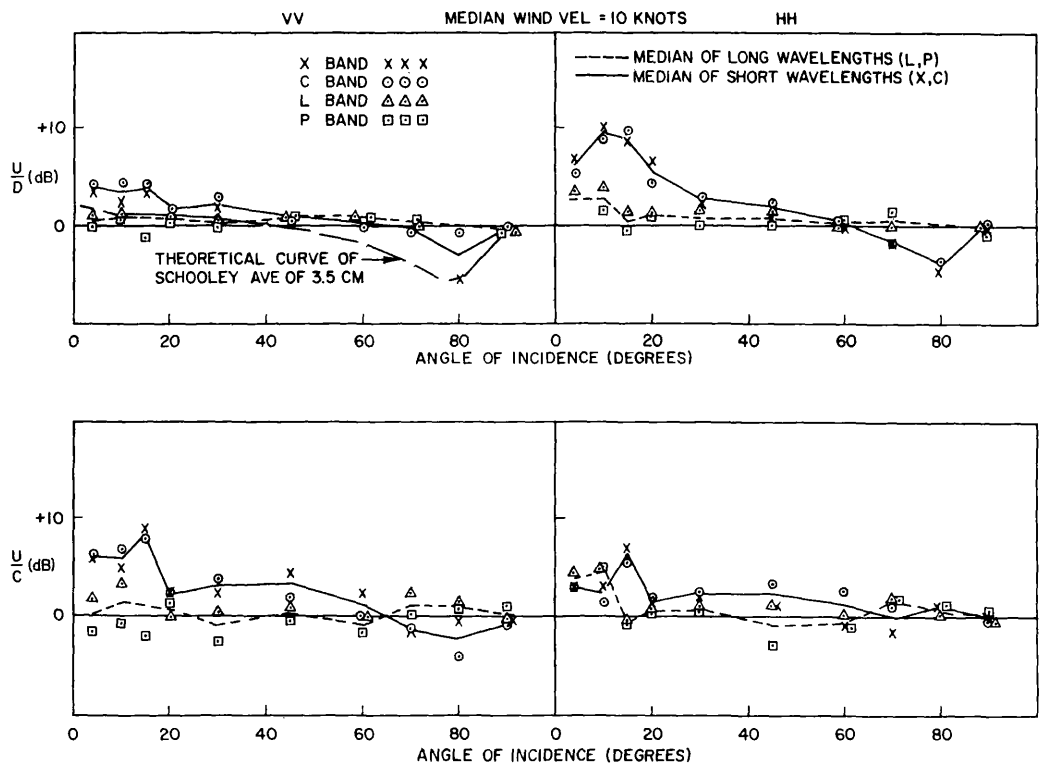

Fig. 15 - Averaged wind ratios from 6 days

The upwind/crosswind case is somewhat different. Both vertical and horizontal polarizations show significant readings in the 45- to 60-degree angular region, with vertical polarization having the higher absolute magnitudes. The wavelength dependence is similar to the upwind/downwind case at angles above 10 degrees. At θ = 10 degrees and below both the L and P bands show relatively large upwind/crosswind ratios in the horizontal polarization (see also Fig. 14). The data of Fig. 15 summarize the significant relations between upwind-downwind-crosswind clutter over six different surface conditions with a median wind velocity of 10 knots and a median wave height of 4 ft.

CONCLUSIONS

The wind characteristics of the clutter return may be summarized as follows:

1. The upwind/downwind ratio decreases with increasing angle and sea state.

2. The horizontal polarization is more sensitive to wind direction than the vertical polarization

3. The short wavelengths are more sensitive to wind direction than the long wave wavelengths.

4. The upwind/crosswind ratios remain significant for the roughest sea state encountered at Puerto Rico on both the vertical and horizontal polarizations.

5. The longest wavelength (P band = 70 cm) is practically insensitive to wind direction at angles greater than 10 degrees.

REFERENCES

1. Daley, J.C., Ransone, J.T., Jr., Burkett, J.A., and Duncan, J.R., "Sea-Clutter Measurements on Four Frequencies," NRL Report 6806, Nov. 1968

2. Daley, J.C., "Sea-Clutter Measurements at X and C Bands," NRL Letter Report 5270-18:JCD:bjg Ser 7287 of Sept. 15, 1966

3. Kerr, D.E., editor, "Propagation of Short Radio Waves," MIT Rad. Lab. Series Vol. 13, New York:McGraw-Hill, 1951

4. Macdonald, F.C., "Sea Clutter at X and L Bands," Unclassified report in "Classified Symposium Record," University of Michigan, Feb. 7-9, 1956

5. Macdonald, F.C., "The Correlation of Radar Sea Clutter on Vertical and Horizontal Polarization with Wave Height and Slope," IRE Natl. Conv. Record 4 (Part I):29-32 (1956)

6. Pierson, W.J., Jr., "On the Experimental Correlation of Radar Scatterometry Data with Sea Conditions," NYU School of Engineering and Science, Dept. of Meteorology and Oceanography, prepared for Radar Surveillance Oceanography Project, Contract NGR-33-016-117

7. Schooley, A.H., "Upwind-Downwind Ratio of Radar Return Calculated from Facet Size Statistics of a Wind-Disturbed Water Surface," Proc. IRE 50:456-461 (1962)

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* Naval Research Laboratory Washington, D.C. 20390	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

UPWIND-DOWNWIND-CROSSWIND SEA-CLUTTER MEASUREMENTS

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

An interim report on one phase of the problem; work is continuing.

5. AUTHOR(S) *(First name, middle initial, last name)*

J.C. Daley, J.T. Ransone, Jr., J.A. Burkett, and J.R. Duncan

6. REPORT DATE April 14, 1969	7a. TOTAL NO. OF PAGES 18	7b. NO. OF REFS 7
8a. CONTRACT OR GRANT NO. NRL Problem R02-37 b. PROJECT NO. A31533/652/69R00801020 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) NRL Report 6881 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*	

10. DISTRIBUTION STATEMENT

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Department of the Navy (Naval Air Systems Command), Washington, D.C. 20360

13. ABSTRACT

The initial processing and analysis of radar backscatter data recorded off the coast of San Juan, Puerto Rico, in July 1965 have been completed. This data constituted part of a study conducted in conjunction with the Applied Physics Laboratory (APL) of Johns Hopkins University to determine the scattering mechanism involved in the generation of sea clutter. The NRL WV-2 instrumented aircraft was used in this experiment with its four-frequency, pulsed radar system and a surface vessel equipped and staffed by APL for the purpose of gathering sea-surface data in the form of stereophotographs and wave-buoy measurements.

Radar returns were collected nearly simultaneously on four frequencies—428 MHz, 1228 MHz, 4455 MHz, and 8910 MHz—for both linear and cross polarizations. In the course of these measurements, sea clutter was recorded in the upwind, downwind, and crosswind directions. The ratios of the upwind-to-downwind and upwind-to-crosswind returns were investigated as functions of the incident angle, the polarization, the radar wavelength, and the gross surface parameters of wind velocity and wave height. The upwind/downwind ratio is shown to decrease with increasing angle and surface roughness. Horizontal polarization is more sensitive to wind direction than vertical polarization. The short wavelengths are more sensitive to wind direction than the long wavelengths. The upwind/crosswind ratio remains significant as the short wavelengths for the roughest sea encountered at Puerto Rico. The results

Continues—

Security Classification

14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Sea clutter Sea-clutter scattering Sea-surface measurements Radar Oceanography						

provide estimates of the upwind-downwind-crosswind relations as functions of the above parameters over an angular region of 4 to 90 degrees (vertical incidence) and from calm sea conditions to moderately rough conditions characeterized by 5 - to 7-ft wave heights and 10 - to 20-knot winds.

DD FORM 1 NOV 65 1473 (BACK)
(PAGE 2)

Security Classification