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RADC-TR-68-188
Final Report

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SEA CLUTTER INVESTIGATION (U)

J. L. Ahearn
Naval Research Laboratory

TECHNICAL REPORT NO. RADC-TR-68-188
June 1968

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SEA CLUTTER INVESTIGATION (U)

J. L. Ahearn

Naval Research Laboratory

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FOREWORD

This document is the final report by the Naval Research Laboratory, Washington, D. C., under USAF MIPR FD2310-7-0015, 673A System, with Rome Air Development Center, Griffiss Air Force Base, New York. Mr. Kenneth Stiefvater (EMATS) was the RADC Project Engineer.

Assistance by the Air Force with the essential groundwork and assembly of equipment, as well as support for the experimental phase of the study, is greatly appreciated. The author also wishes to acknowledge the help of Mr. Stiefvater, and Messrs. D. C. Rohlfs, W. C. Headrick, and F. E. Wyman of NRL.

This work is classified SECRET because it is concerned with techniques for use in present and future OHD applications. It contains no classified material extracted from other classified reports.

This technical report has been reviewed and is approved.

Approved: Kenneth C Stiefvater
KENNETH C. STIEFVATER
Project Engineer

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WILLIAM T. POPE
Acting Chief
Surveillance and
Control Division

FOR THE COMMANDER: Irving J Gabelman
IRVING J. GABELMAN
Chief, Advanced Studies Group

SECRET ABSTRACT

(S) The report contains spectral measurements of backscatter return from the surface of the sea via ionospheric paths. Data was also taken of the return spectra of land and land-sea boundaries. The data was taken in conjunction with the operation of the high power Madre OHD radar at Randle Cliff, Maryland. The results show that it is not possible to classify the sea clutter into components due to the reflecting surface and the refracting ionosphere. The conclusion reached is that the ionospheric movement is the dominant form and accounts for most of the backscatter spectral composition.

EVALUATION

(U) This program is one in a continuing effort under System 673A to investigate phenomena and promising techniques for use in present and future OHD application.

(S) The objective of this effort was to study, investigate and run experimental tests to determine the coefficient of OHD backscatter clutter from sea water using the high power Madre radar at Randle Cliff, Maryland. The areas of investigation consisted of clutter, amplitude, and doppler spectrum functions of various operational variables such as: operating frequency, range, mode, azimuth, pulse width, etc. Using these measurements, attempts were made to separate the returned spectrum into components due to the reflecting surface (the sea) and the refracting ionosphere.

(S) Experimental data was obtained looking at the backscatter from the sea alone, a land sea boundary, and at land masses only. In looking at the sea clutter only, an LST ship was used to sail on a predetermined course to act as a target and record the condition of the sea. Experimental data was also taken during sunrise periods when OHD signals undergo their most drastic fluctuations.

(S) The processing equipment used for the most part on this program was the analog processor with 25 dB dynamic range and 1/10 cycle analysis resolution. It was anticipated at the outset to use the new 60 dB dynamic range digital processor with 0.037 cycle spectral analysis capability. However, the equipment was late in being delivered and consequently, only used briefly.

(S) The conclusion reached is that it is not possible to classify the sea clutter into components due to reflecting surface and refracting ionosphere. The ionospheric movement is seen as the dominant factor and accounts for most of the backscatter spectrums composition.

(U) Additional information relating to this effort was reported in ARPA meeting proceedings of 17-18 May 67, in a paper entitled "Some Skywave Radar Constraints." It was also published as NRL report 1811 in Oct 1967.

Kenneth C. Stiefvater
KENNETH C. STIEFVATER

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I. INTRODUCTION

(S) This investigation has been concerned with the spectral measurement of backscatter returns from the surface of the ocean via ionospheric paths. Some data was also taken of the return spectra from land-sea boundaries. The data has been taken in conjunction with the operation of the high-power Madre OHD radar at Randle Cliff, Maryland.

(S) A sufficient body of spectral data should enable one to determine the ultimate limits of MTI methods when applied to HF radar operation where the backscatter itself has spectral components in the same frequency region as targets with low apparent doppler. Such data will aid in planning radar defense systems against the SLBM threat. The data will also provide information for HF OTH operation against maneuvering aircraft and those which are travelling nearly broadside to the radar beam. In addition, there is the possibility of detecting moving ships beyond line-of-sight via an ionospheric mode. Such MTI detections will be possible only when the backscatter spectral width is narrow (approximately 1 Hz or less).

II. BACKGROUND

(S) Over-the-horizon detection systems can use backscatter clutter rejection techniques employing fixed-width rejection filters centered on the fundamental and the harmonics of the operating PRF. Most of the Madre work has been with such filters, and only targets with dopplers above 5 Hz have been displayed. This 5 Hz doppler corresponds to a 75-knot target for operation at a 19 MHz transmitting frequency. A better understanding of the clutter variability both in amplitude and frequency content may enable OTH radar designers to use adaptive filtering techniques to reject only where the clutter is and thus maximize available doppler for targets. The system regularly detects Polaris missile launches from the Cape Kennedy area, a distance in excess of 600 nmi over the ground from the radar site at Randle Cliff, Md. During the early part of the Polaris test program the detections were of pad-launched vehicles. As the program moved along and missiles were installed and test fired from the Polaris submarines, the detections were against missiles launched from the submarine's silo while cruising submerged off Cape Kennedy.

(S) The Madre experimental radar is a coherent pulse doppler monostatic system with 4.6 megawatt peak and 100 KW average power operating in the frequency range 10-27 MHz. It makes over-the-horizon detections via an ionospheric path and thus overcomes the inherent line-of-sight range limitation. In the receiving section of the system crystal comb rejection filters are used to eliminate the backscatter components of the signal. The crystal comb filters have fixed notches at the PRF lines which have a 1 Hz width 60 dB down and 12 Hz width 3 dB down. The present crystal comb filters have sections centered on 100 KC (corresponds to 0 doppler) and at points $\pm$ 0.5 Hz and $\pm$ 1 Hz from the 100 KC point which corresponds to 0 doppler. These notches are set on a large number of the PRF harmonics. Table I shows radial velocity in knots for various wavelengths, all for a doppler of 1 Hz.

f (MHz)	λ (Meters)	V (Knots)	fd (Hz)
5	60	58.2	1
10	30	29.1	1
20	15	14.6	1
30	10	9.7	1
40	7.5	7.3	1

Table I

A. Processing Equipment

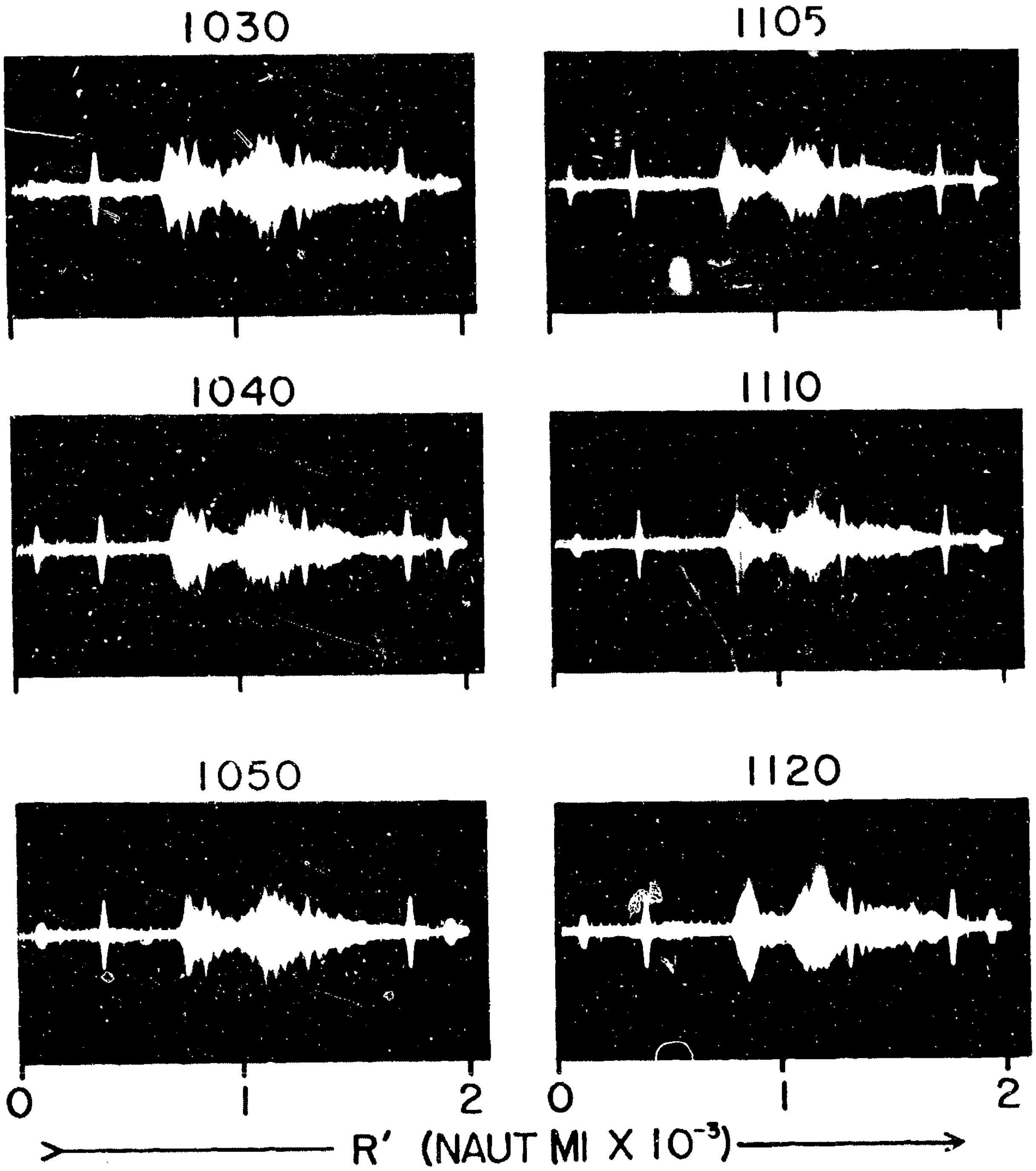
(S) During the first part of this study the spectral data was obtained with a drum analog processor and analysis filtering system of about 25 dB dynamic range and 1/10 cycle analysis resolution. Our original plan called for analysis via the 60 dB dynamic range digital processing equipment developed by GE with ARPA funding. This equipment was not available for the type of spectral analysis required by this study until the fall of 1967. Details of the 60 dB digital processor may be found in NRL Memorandum Report 1787. For operation in a spectral analysis mode the resolution bandwidth can be narrower than the analog processor, i.e., .037 Hz vs 0.1 Hz, and, of course, there is approximately 35 dB increase in dynamic range with the digital processor.

(S) The analog processor aside from the comb filters cuts off doppler signals below 5 Hz, while the newer digital processor's lower cutoff is 2 Hz. In order to view backscatter spectral character, the return signals are offset by an appropriate setting of the receiver local oscillator and are displayed without any degradation. Also the crystal comb filters are bypassed so that the usually unwanted earth backscatter returns are treated the same as targets.

B. Experimental Data

(S) Figures 1 thru 8 show the backscatter amplitude-range and amplitude-frequency characteristics during the LST ship test on March 22, 1967. Time is EST.

(S) In Figures 1 and 6 calibration signals appear at 450 nmi intervals and correspond to 1 MV peak to peak signals at the radar antenna terminals. This is a nominal 50 Ω impedance point. The transmitted radiation was a



3/22/67, 19.27 MC (SECRET)

$\theta_H = 31°$, $A_z = 155°$

Fig. 1

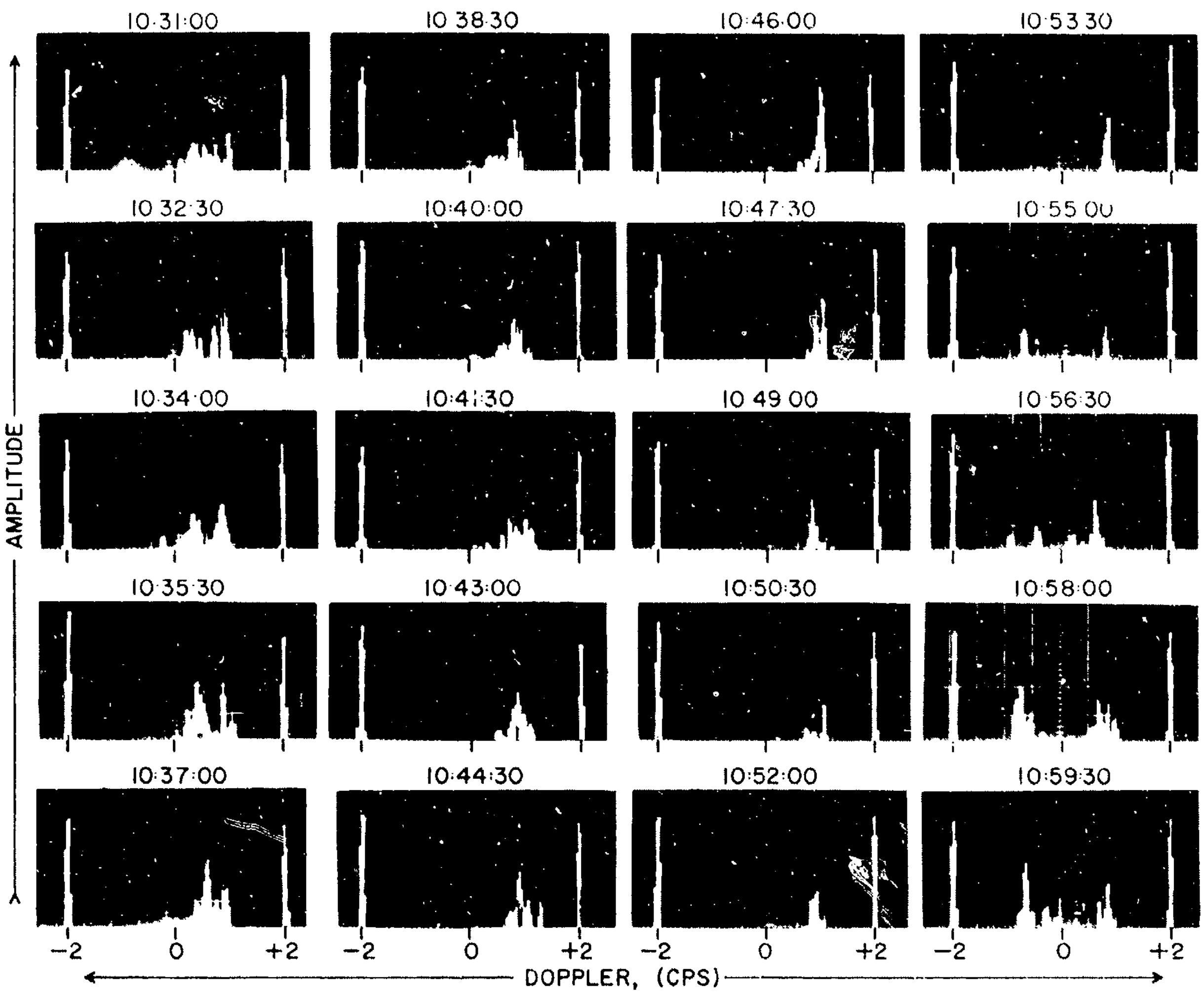
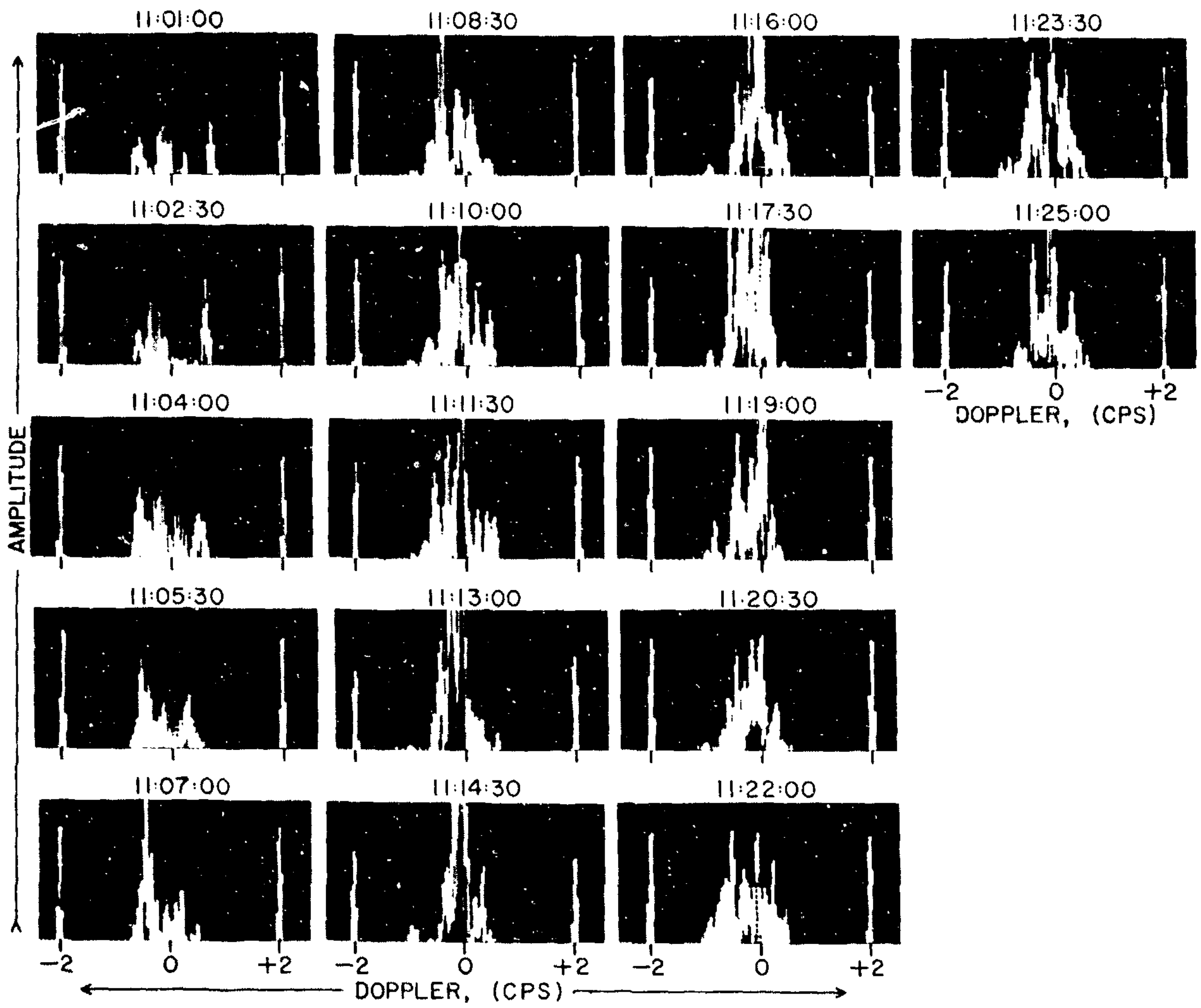


Fig. 2

3/22/67, 19.27 MC
θ_H = 31°, A_z = 155°
RANGE GATE 805-845 NM

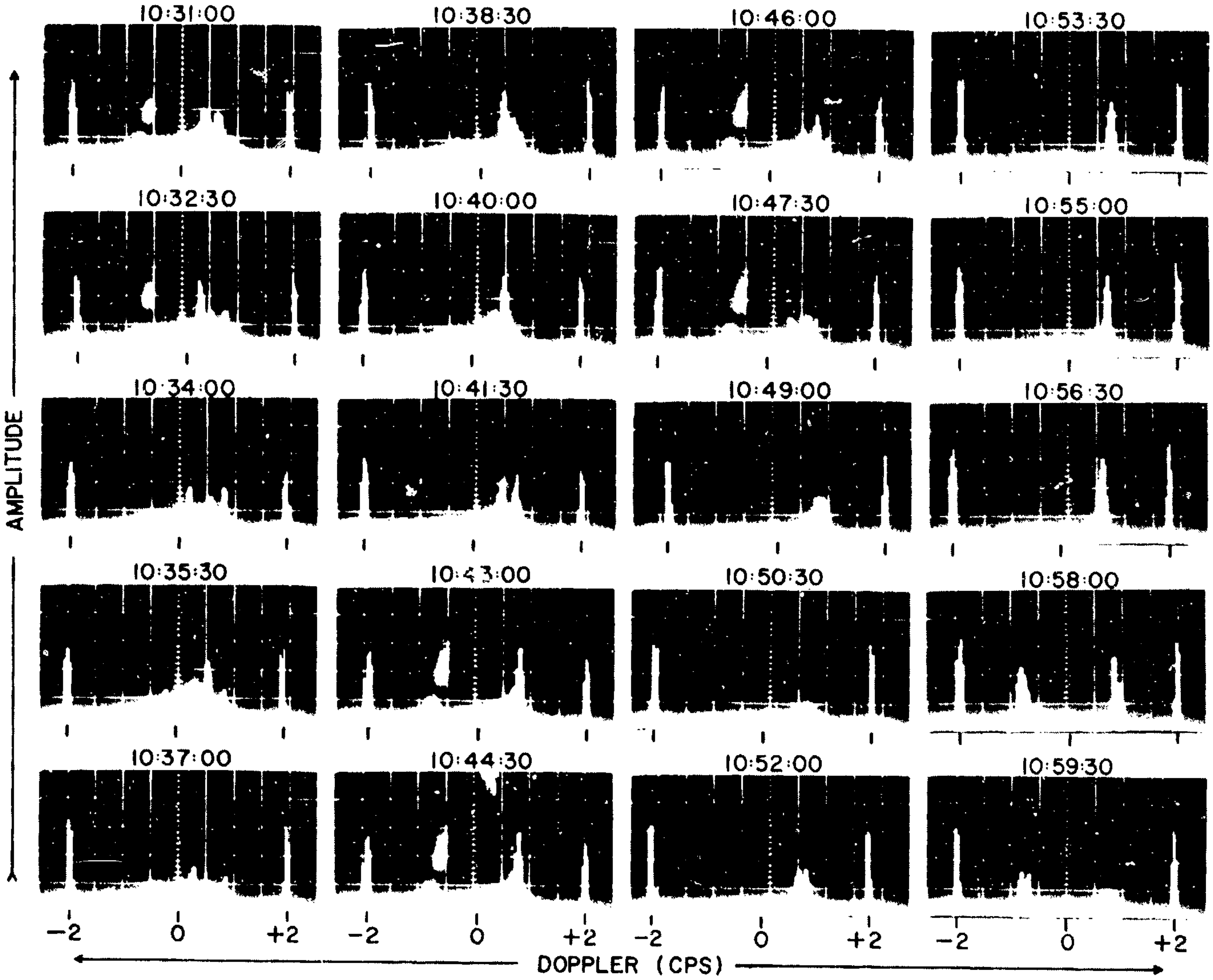
(SECRET)



3/22/67, 19.27 MC
$\theta_H = 31°$, $A_z = 155°$
RANGE GATE 805-845 NM

Fig. 3

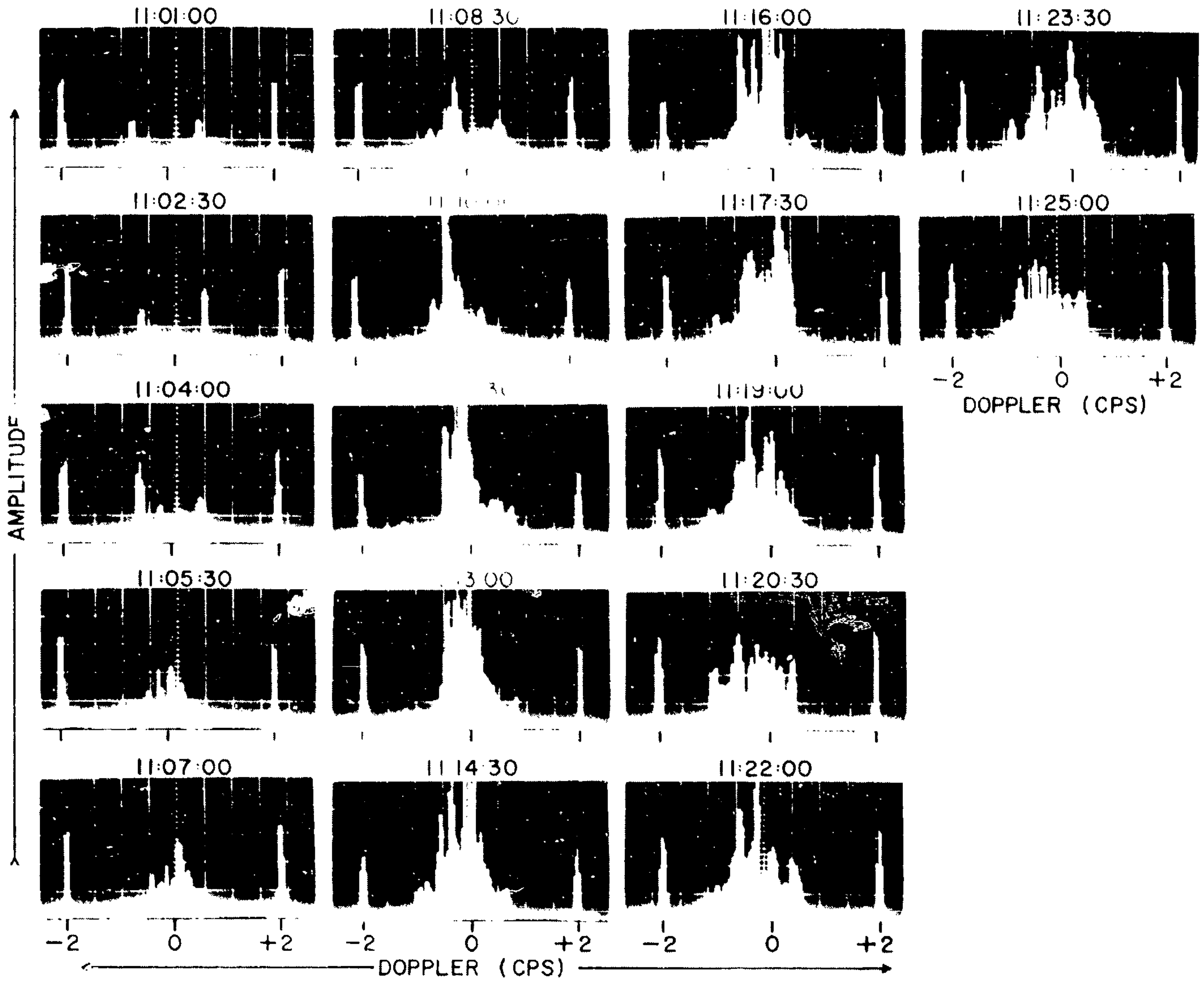
(SECRET)



(SECRET)

Fig. 4

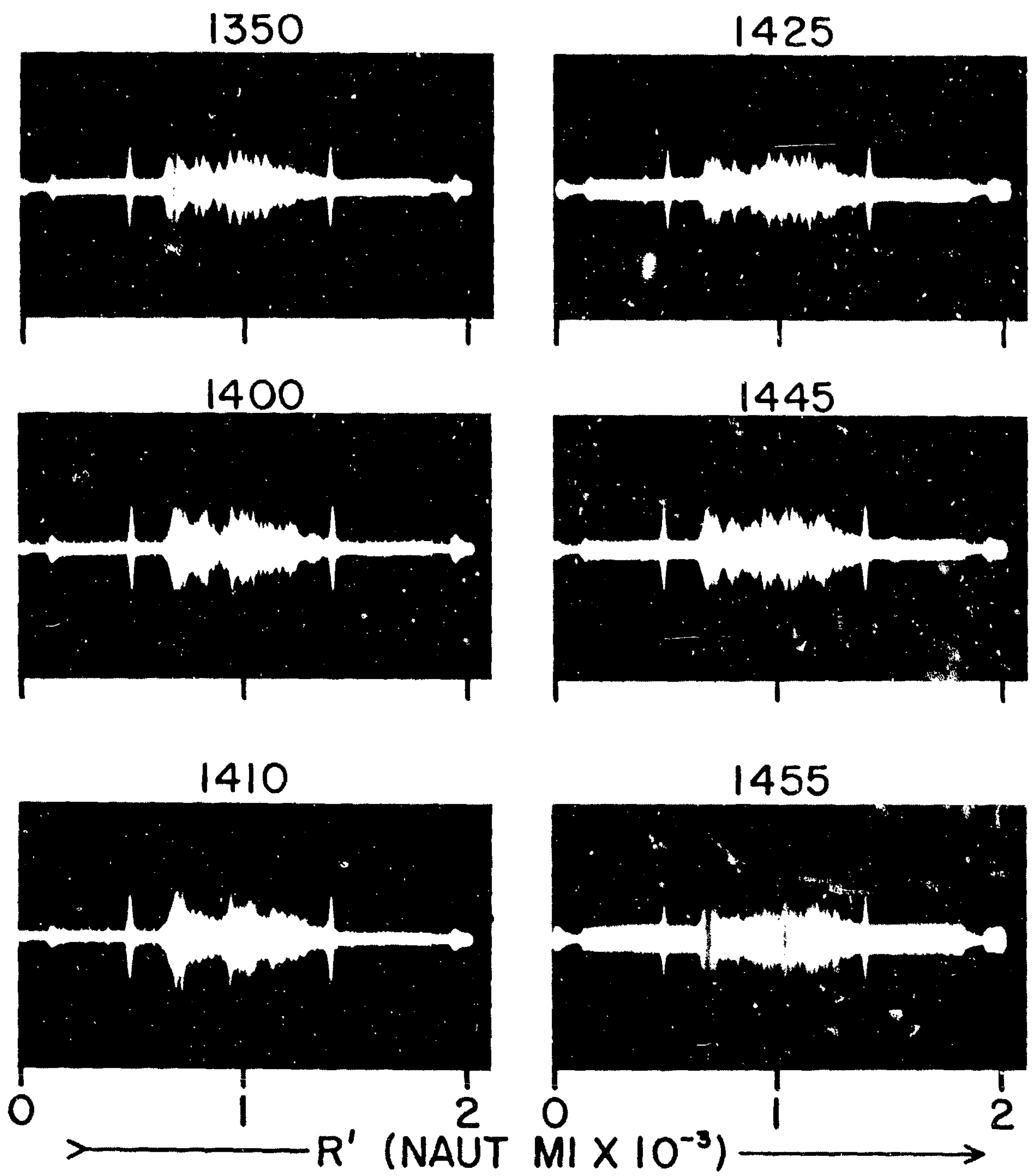
3/22/67, 19.27 MC
$\theta_H = 31°$, $A_z = 155°$
RANGE GATE 850-930 NM



3/22/67, 19.27 MC
θ_H=31°, A_z=155°
RANGE GATE 850-930 NM

Fig. 5

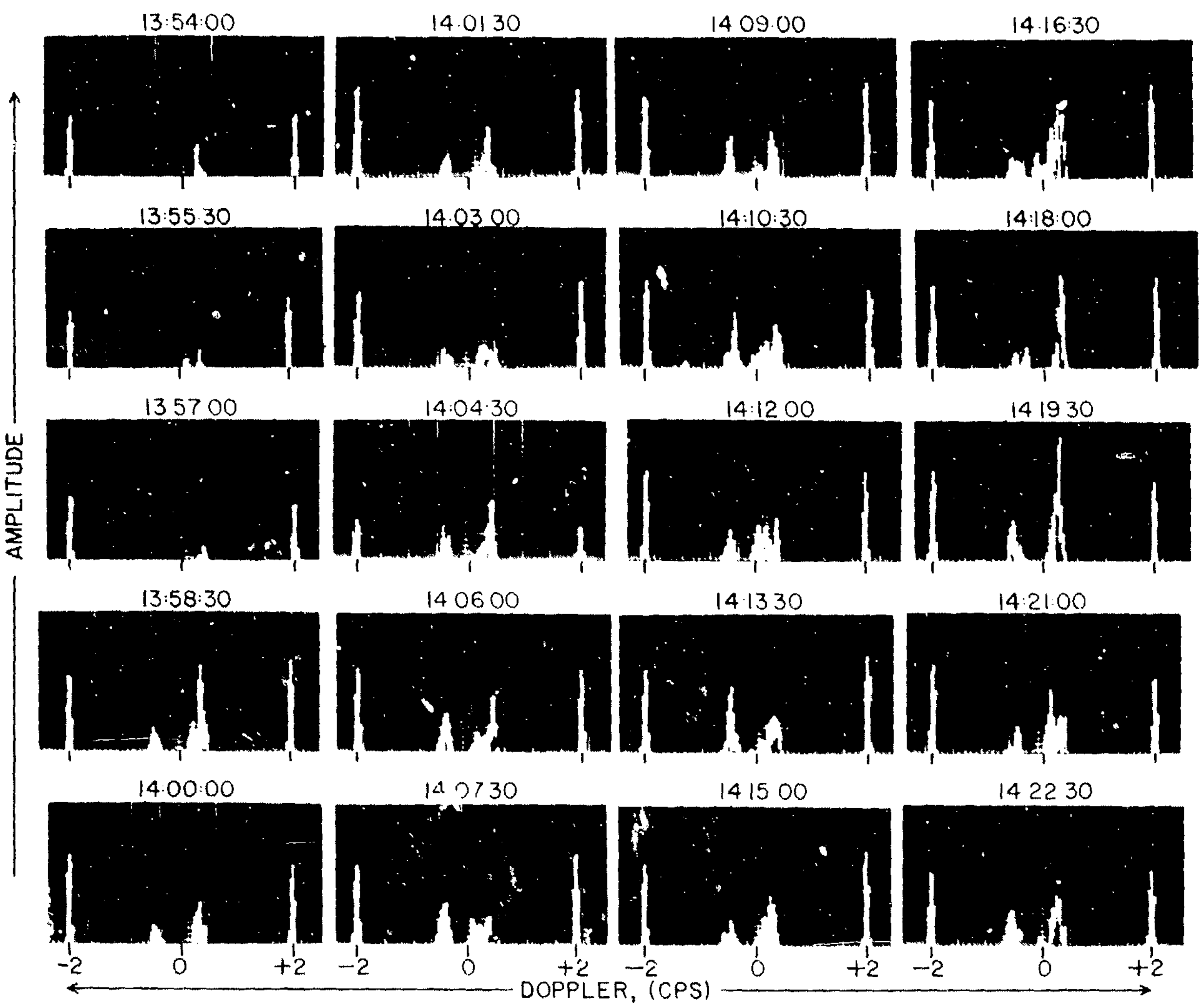
(SECRET)



3/22/67, 15.53 MC
$\theta_H = 37°$; $A_z = 155°$

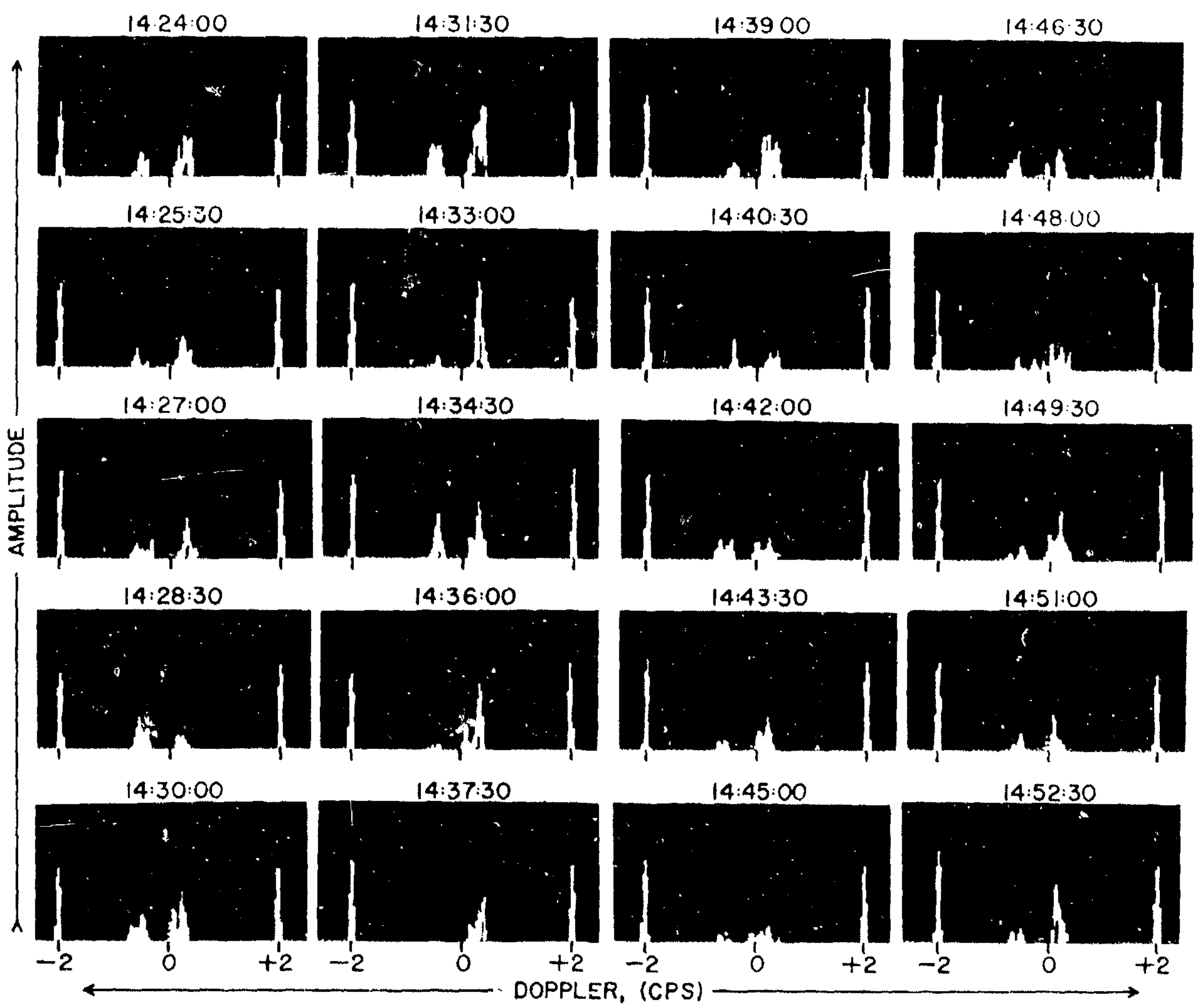
(SECRET)

Fig. 6



3/22/67, 15.53 MC
$\theta_H = 37°$, $A_z = 155°$
RANGE GATE 880-920 NM

Fig. 7 (SECRET)



3/22/67, 15.53 MC
$\theta_H = 37°$, $A_z = 155°$
RANGE GATE 880–920 NM

(SECRET)

Fig. 8

300 microsecond cosine squared pulse. During the time interval covered by Figures 1 thru 5, the LST was cruising approximately broadside to the radar beam at a ground range of 889 nmi from the Madre radar site. Figures 2 and 3 show spectral scans at 90 second intervals from a range gate covering 805 to 845 nmi. This range gate does not cover the LST's position. However, the position is covered by Figures 4 and 5. Two synthesizers are used to provide calibration signals 2 cycles above and 2 cycles below the carrier. Resolution is 1/10 cycle and the calibration level corresponds to a 4.9 X $10^7 m^2$ at 890 nmi. The analyzer storage time is 20 seconds.

(S) Figures 7 and 8 show spectral scans taken during the afternoon of 22 March. The transmitted frequency was lowered to 15.53 Mc to maintain coverage of the LST position. At 14:14 EST, the LST was at a point 859 nmi ground range from the radar. Prior to 14:14 the ship was moving along a radial toward the radar site (bow aspect), at 14:14 it turned 90° and proceeded east presenting a broadside view. The ship continued on the broadside course until 1630 when it again turned 90° and proceeded on a radial away from the radar site. For both of these figures a 5.6 X $10^7 m^2$ target at 900 nmi would present the same level signal as the calibration. In all the spectral scans a signal 20 dB below the calibration level, corresponding to a $\sigma \approx 5 \times 10^5 m^2$, would just be visible.

(S) During the period prior to 14:14 when the LST was cruising along a radial toward Washington, its doppler would be about 0.8 cycles on the high side of the carrier. Nothing like this shows on Figure 7. Model measurements by Mr. Joseph Green of ITT-EPL on a Fletcher-class destroyer show a $\sigma \approx 7 \times 10^3$ at bow aspect using vertical polarization for an equivalent HF frequency of 7.41 Mc. Values for the LST should be within a few dB of the destroyer measurements. From these figures it appears that the LST was probably 20 dB lower in cross-section than our minimum detectable σ.

(S) The scan pictures do show spectral configurations. In Figures 2 and 4 there are times when the spectra has single and double peaks. The double peak separation is about 1.5 Hz with one peak above and one below the carrier. In Figures 7 and 8 the double-peak separation is about 0.8 Hz. The ship reported wave heights 3-4 feet with periods 7-8 seconds during the data period represented by Figures 1-8. The wind direction was approximately at right-angles to the radial from the radar site. After 11:00 EST the gates were close to the front edge of the backscatter which may account for the filled-in character of the spectral scans. Under these conditions slow-moving targets (apparent doppler < 1 Hz) will be difficult to detect.

(S) If one assumes there are sea waves travelling radially to the antenna, both approaching and receding in this large patch of ocean surface, simple theory predicts a large reflection when the sea wavelength $L = \frac{\lambda}{2}$ (λ = radio wavelength). Under these conditions the separation of the approaching and receding spectral peaks would be $\Delta f = 2\sqrt{\frac{g}{\pi\lambda}}$

From the data:

At 19.27 Mc, Δf = 0.9 Hz

while at 15.53 Mc, Δf = 0.8 Hz

(S) The apparent agreement between experiment and theory at 15.53 Mc should be treated cautiously because there is nothing that prohibits the ionosphere itself from behaving similarly to the ocean surface and with comparable statistics.

(S) Figure 9 shows a series of spectral scans of the backscatter during a sunrise period. The returns were from the ocean surface. This data shows a strong tendency for the spectrum appearing on the high side of the carrier, corresponding to approach doppler. With time the spectral width decreases and its position moves closer to the carrier. As the scatter moved closer in range, the gated position was moved to correspond to the position of maximum backscatter amplitude. The spectrum width remains at about 1.5 Hz for about 20 minutes before narrowing down to a cycle or less.

(S) Another set of spectral data is shwon in Figures 10-17. In this case the processing system is the new 60 dB dynamic range digital equipment. Again the backscatter amplitude range prints show returns from the surface of the ocean and the range of the spectral sample points may be noted. The spike below +3 Hz is an undesirable 60-cycle component which has folded back into the spectral analysis region of interest. Calibration spikes above and below the carrier appear in each print. During the morning there are some double peaked spectra with separations of approximately 1 Hz. The noise level for each scan on Figure 11 corresponds to a signal at the input to the receiver of about 40 μV peak to peak. This corresponds to a cross section of 9.7 X $10^3 m^2$. For this calculation the range is taken as 1575 nmi and only spreading loss has been considered. At 1726 GMT there is a low level line at -1.9 Hz at a 60 μV level. The line is 1.1 Hz below the lower spectral peak and corresponds to a $1\frac{1}{4}$-knot target. This level signal corresponds to a cross section of 22 X $10^3 m^2$. Figure 12 is a composite doppler time picture of the same time period covered by Figure 11. The double-peak character is evident as well as spectral differences between the sample range positions.

(S) In Figures 14 and 15 the noise level is about 40 μV. A signal at this level and at the range of the sample (818 nmi) would correspond to a target of cross section 687 m^2 if only spreading loss is assumed. For an estimated path loss of 10 dB the cross section would be 6870 m^2. Again the composite doppler time analysis on Figures 16 and 17 exhibits the longer time movements in the spectral composition of the backscatter return.

(S) Some calculations were made to determine the backscatter cross section coefficient σ_0 (cross section per unit intercepted area) for the data taken during 12/20/67. Table II summarizes the results.

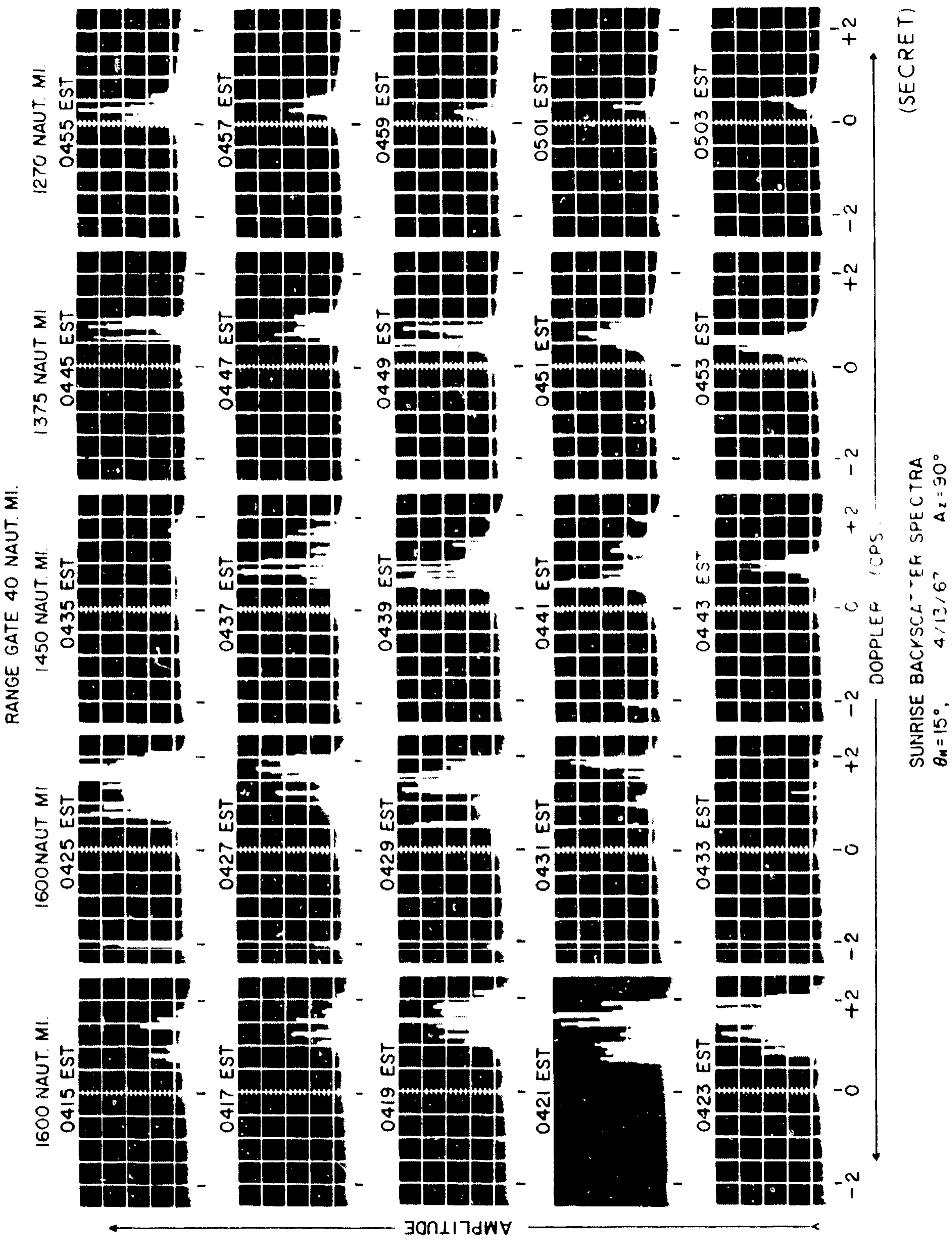

RANGE GATE 40 NAUT. MI.
1600 NAUT. MI.
1600 NAUT. MI.
1450 NAUT. MI.
1375 NAUT. MI.
1270 NAUT. MI.
0415 EST
0417 EST
0419 EST
0421 EST
0423 EST
0425 EST
0427 EST
0429 EST
0431 EST
0433 EST
0435 EST
0437 EST
0439 EST
0441 EST
0443 EST
0445 EST
0447 EST
0449 EST
0451 EST
0453 EST
0455 EST
0457 EST
0459 EST
0501 EST
0503 EST
-2
0
+2
DOPPLER (CPS)
AMPLITUDE
(SECRET)
SUNRISE BACKSCATTER SPECTRA
$\theta_H = 15°$, 4/13/67 Az = 90°

Fig. 9

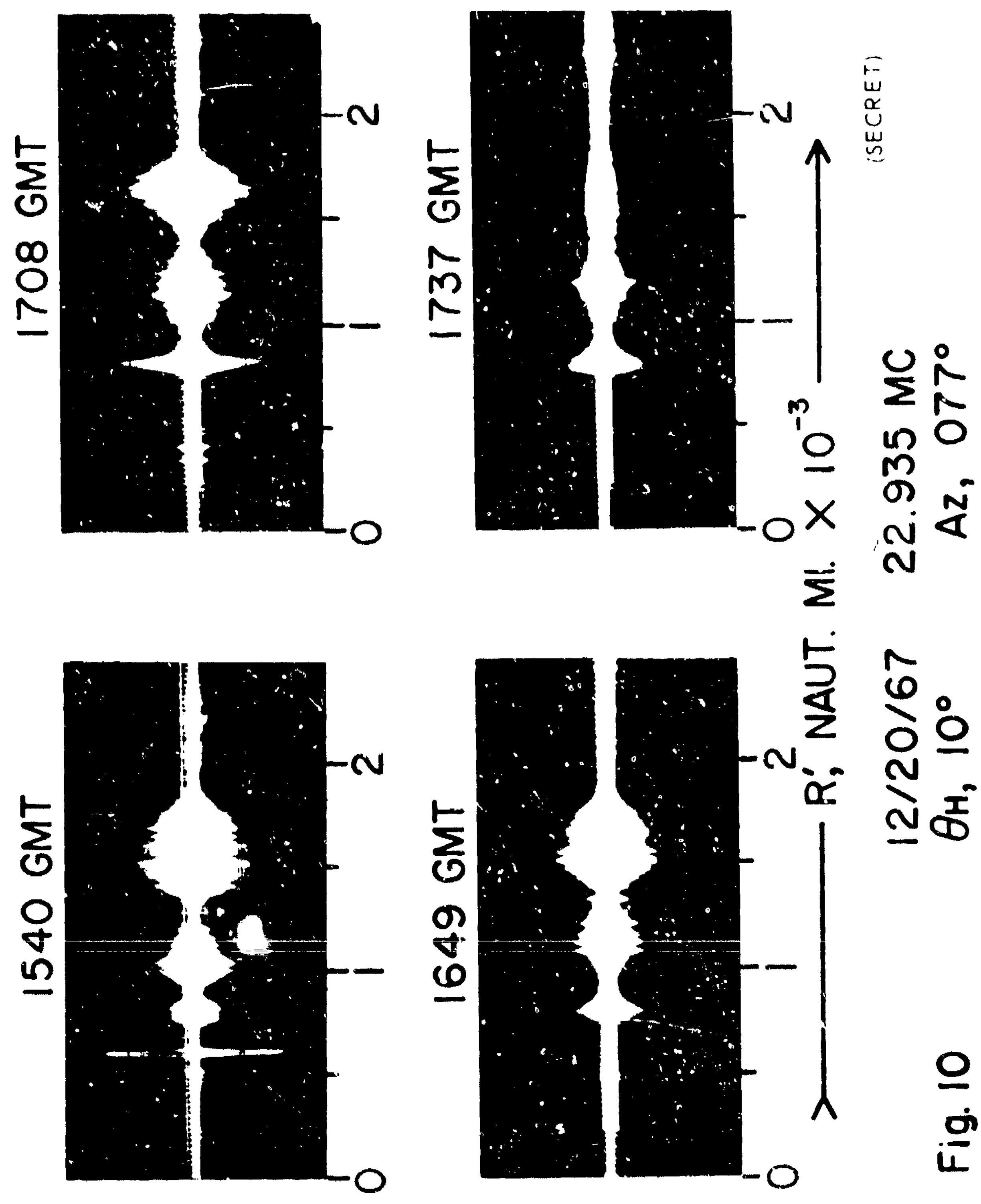
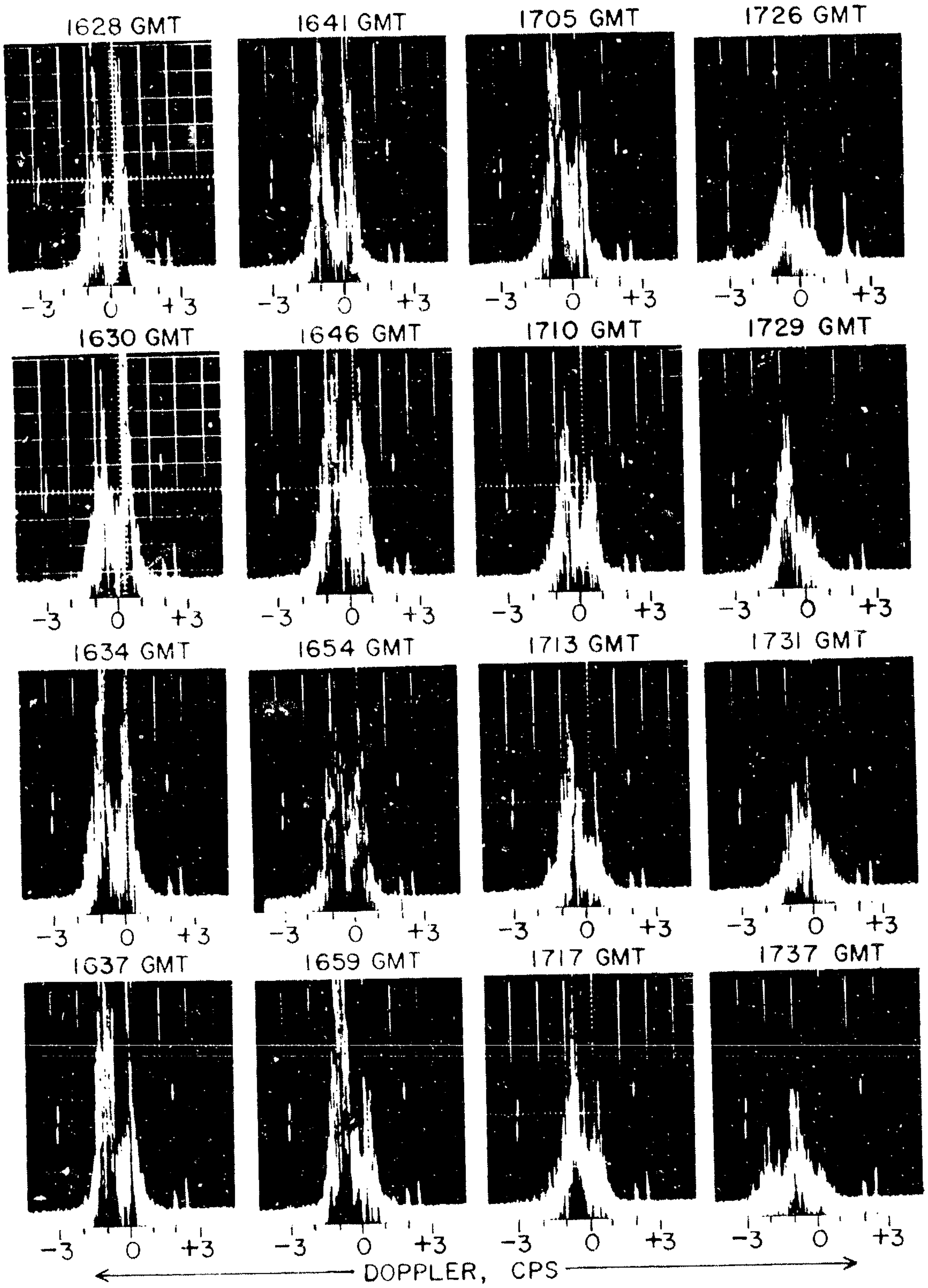

1540 GMT
1708 GMT
1649 GMT
1737 GMT
0
2
R′, NAUT. MI. × 10⁻³
12/20/67
θH, 10°
22.935 MC
Az, 077°
(SECRET)

Fig. 10



12/20/67 f, 22.935 MC
θ_H, 10° Az, 077°
SAMPLE TAKEN AT 1575 NAUT. MI.

Fig. 11

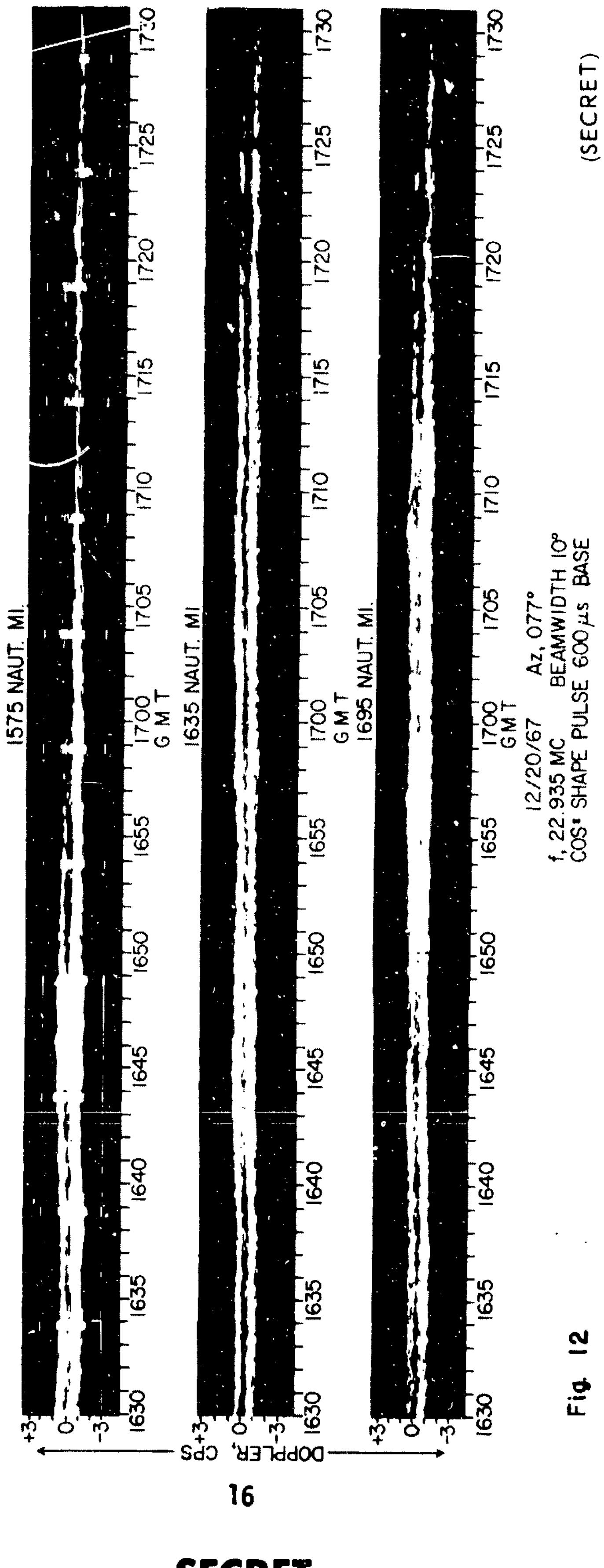
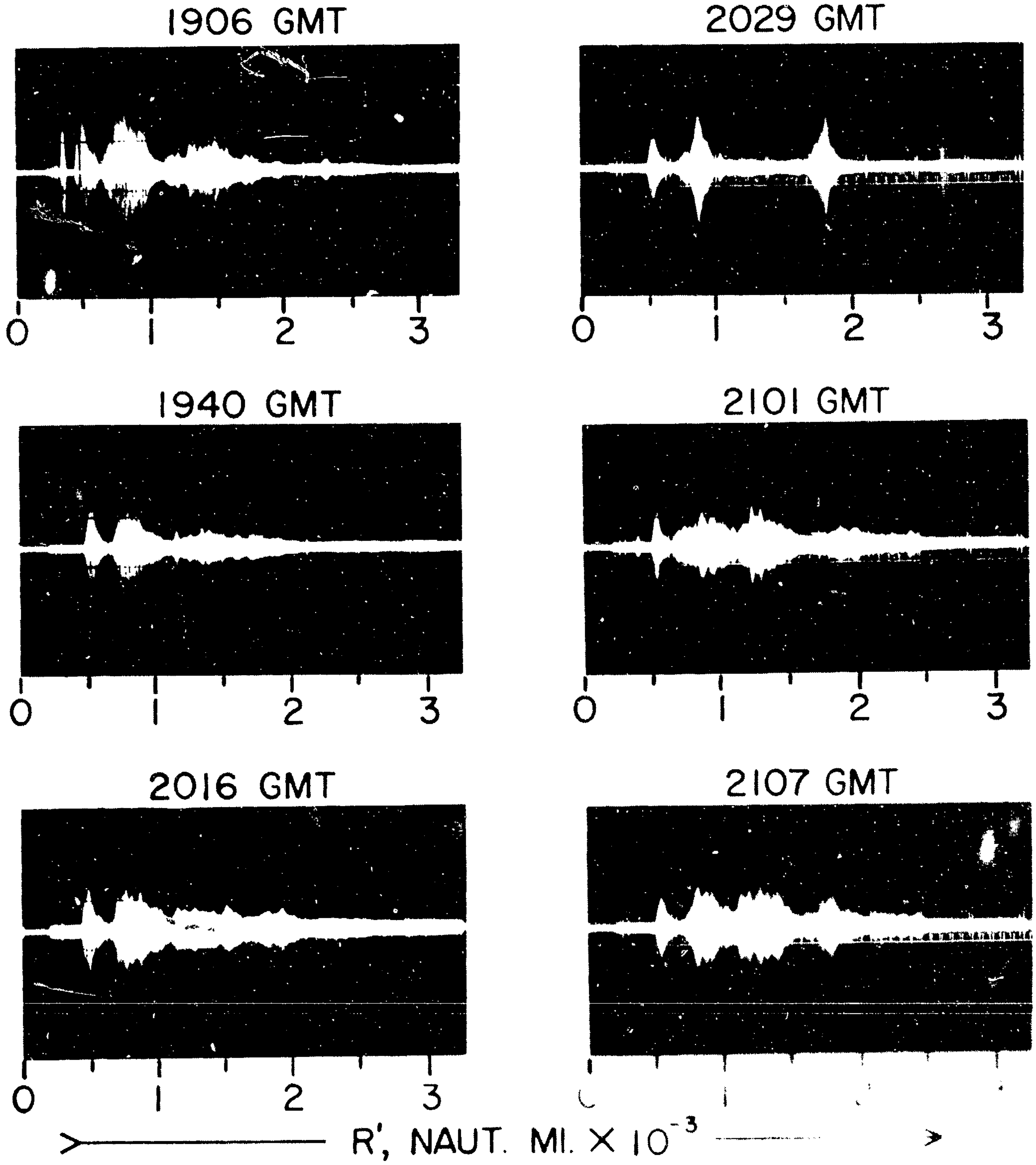


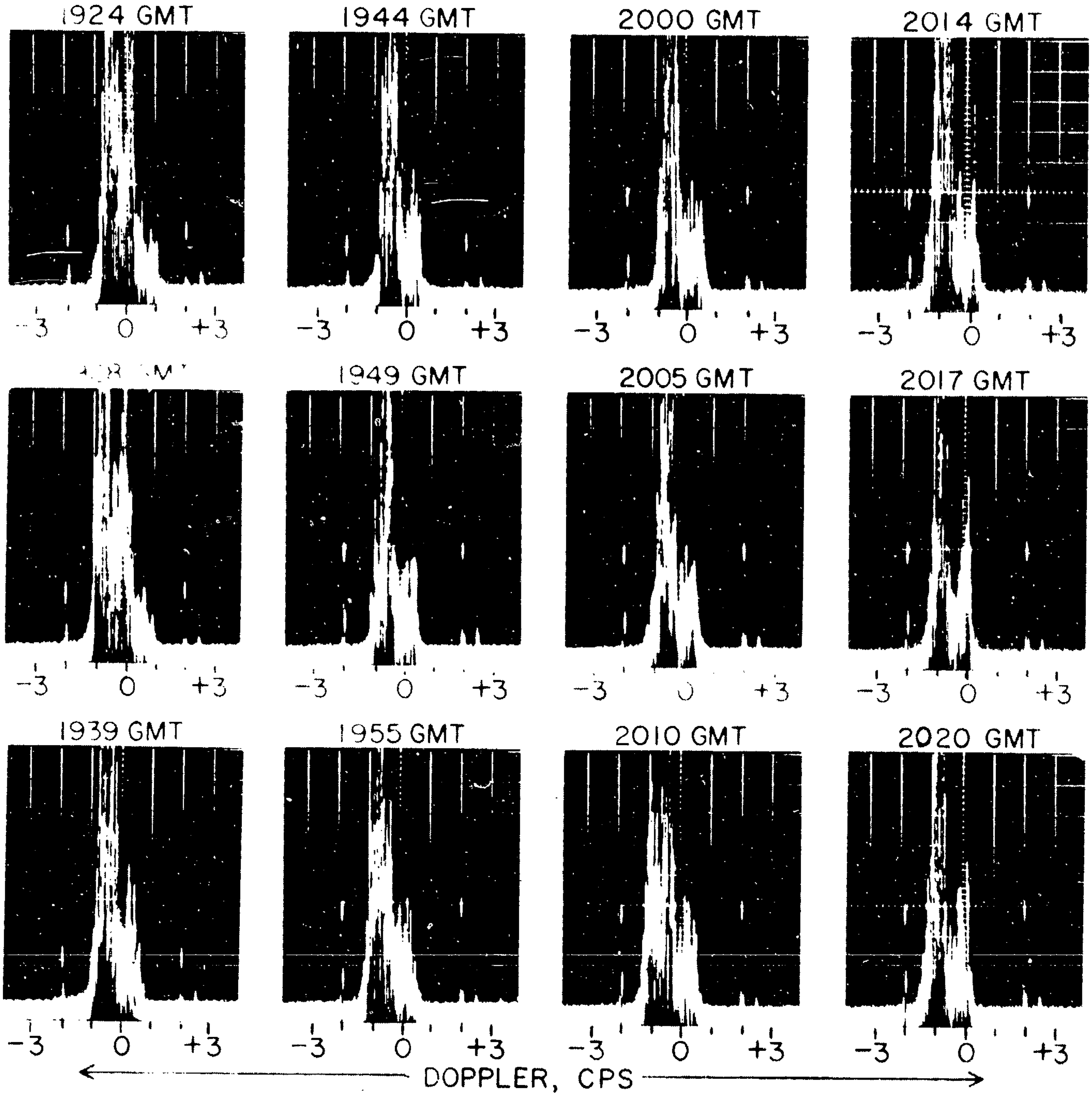
Fig. 12

(SECRET)



12/20/67 15.595 MC
θ_H, 14° Az, 077° (SECRET)

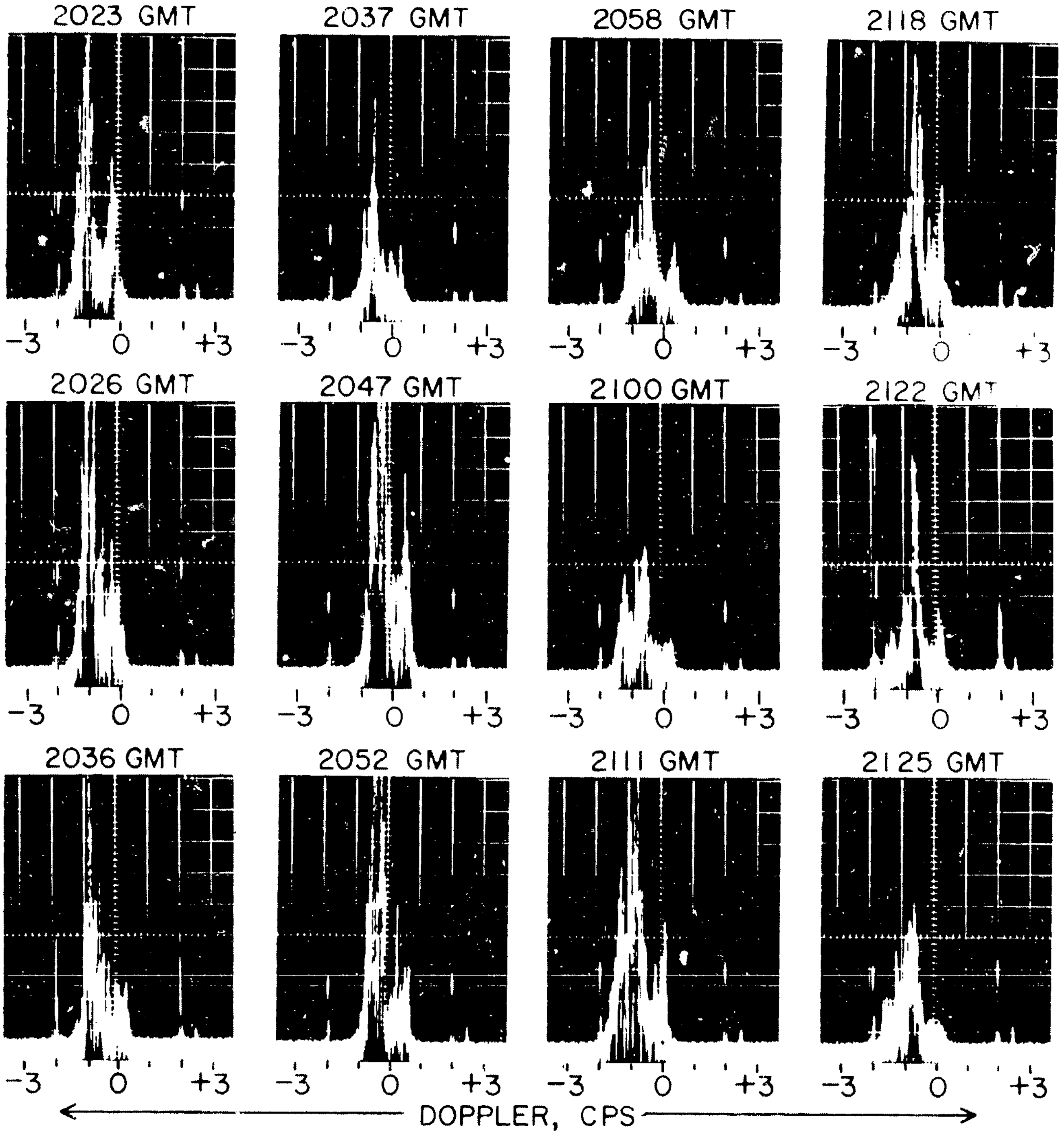
Fig. 13



12/20/67 f, 15.595 MC

θ_H, 14° Az, 077° (SECRET)

Fig. 14 SAMPLE TAKEN AT 818 NAUT. MI.



12/20/67 f, 15.595 MC (SECRET)

θ_H, 14° Az, 077°

Fig. 15 SAMPLE TAKEN AT 818 NAUT. MI.

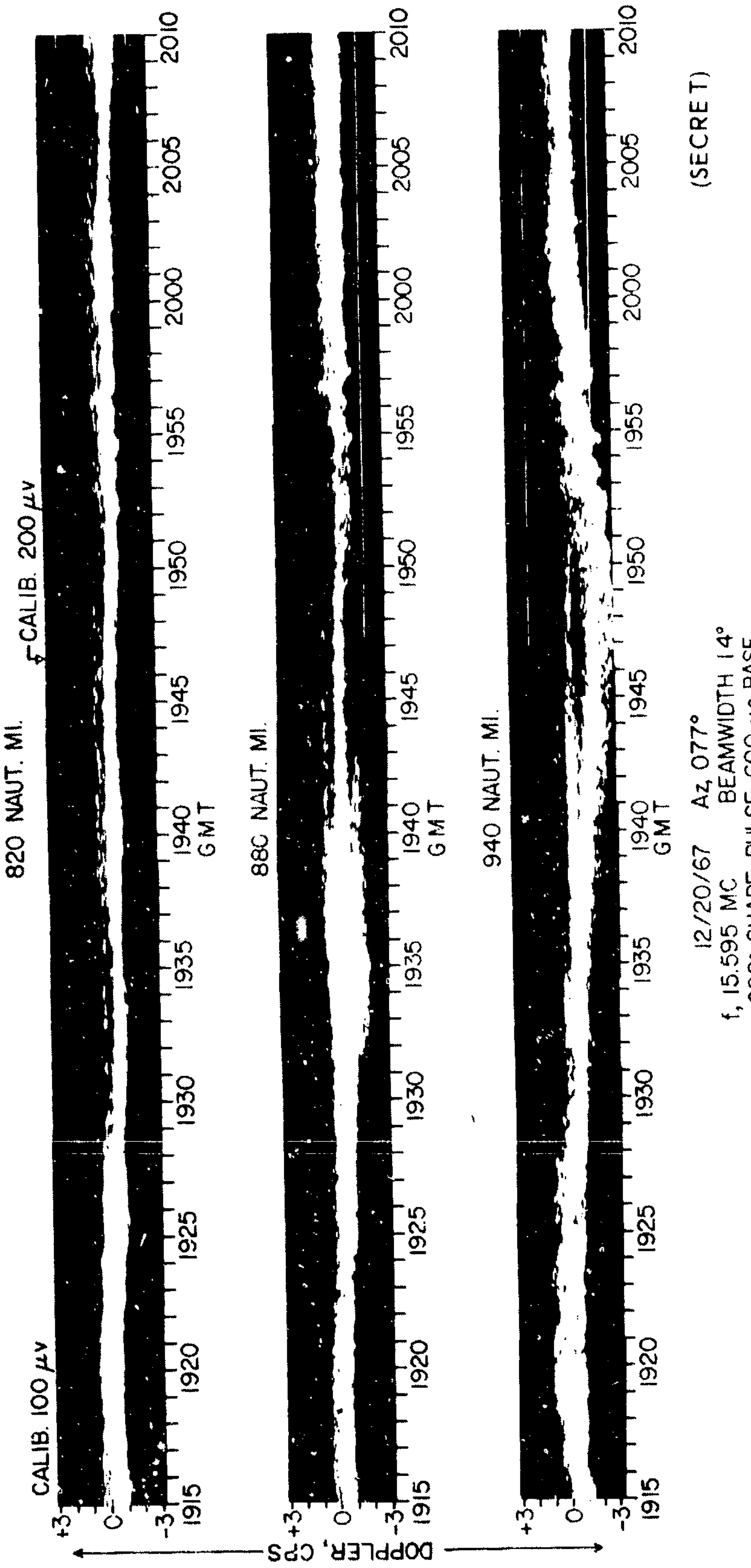

820 NAUT. MI.
CALIB. 100 μv
CALIB. 200 μv
880 NAUT. MI.
940 NAUT. MI.
+3
0
-3
DOPPLER, CPS
1915
1920
1925
1930
1935
1940
GMT
1945
1950
1955
2000
2005
2010
12/20/67 Az 077°
f, 15.595 MC BEAMWIDTH 14°
COS² SHAPE PULSE 600 μs BASE
(SECRET)

Fig. 16

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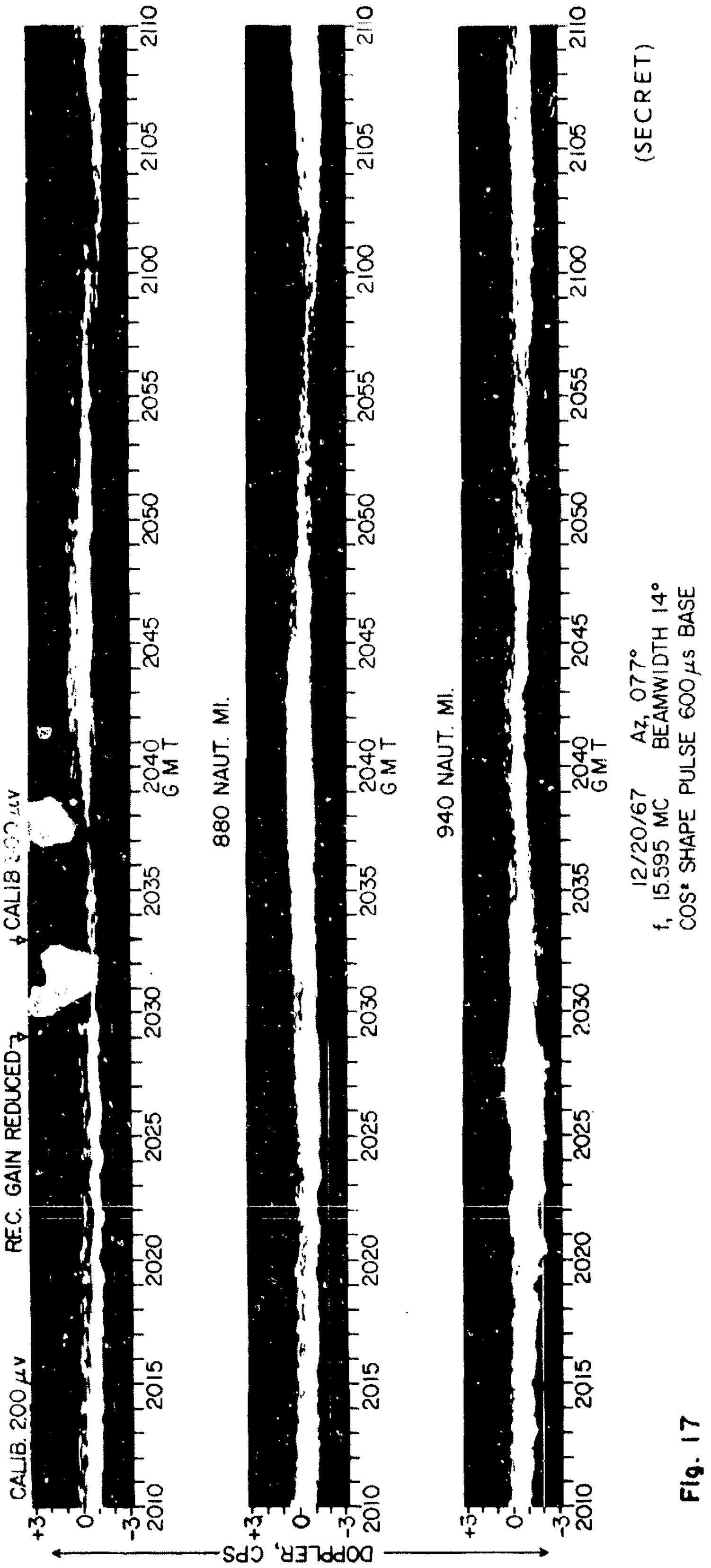

Fig. 17

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Time (GMT)	f (MHz)	Range (NM)	σ_0 m^2/m^2
1649	22.935	1500	0.55×10^{-3}
		1600	0.39×10^{-3}
1906	15.595	800	1.2×10^{-3}
		900	1.1×10^{-3}

Table II

(S) These values for σ_0 are based on backscatter amplitudes taken from Figures 10 and 13. A predicted path loss was also included since the actual path loss is unknown. The σ_0 values have a spread of about 5 dB which is reasonable. Some limited data was taken of the spectral backscatter returns from a land-sea boundary. The returns were from the coastline of the Sea of Labrador. There were no spectral characteristics which appeared to stand out examining the backscatter spectra as a function of gated range positions across this particular boundary.

(S) Other spectral data has been taken of the backscatter returns from the interior of the U.S. There are times when its spectral composition is no different than returns from the ocean surface. Double peak spectral returns appear, leading one to infer that the ionosphere may be the predominant contributor to spectral character and not the movements on the surface.

III. CONCLUSIONS

(S) This study has produced a base of backscatter spectral data which will enable intelligently attacking the problem of detecting slow moving, over-the-horizon targets in a clutter environment. It does appear that there may be times when the spectral composition is such that slow-moving targets such as ships and aircraft passing close to broadside can be detected. The minimum detectable signal for the data represented by Figures 11, 14, 15 is in the cross section region which one might expect from a destroyer of the Fletcher class. Some cooperation from the ionosphere is essential to enable one to discriminate on a spectral basis. The new 60 dB dynamic range signal processor has the essential features to provide this discrimination but it can only do this when the backscatter spectra doesn't mask the expected target spectral line. The full potential of the new processor was not utilized in this study because the equipment was not available for use until the end of the contract period. Future work will involve regular surveillance of the areas known to contain large fast ships. Ship positions will be known so that the spectral sample positions may be set accordingly.

(S) It was not possible to classify the sea clutter into components due to the reflecting surface and the refracting ionosphere. Our conclusion is that the ionospheric movement is the dominant force and accounts for most of the backscatter spectral composition.

(S) The values of σ_0 shown in Table II are consistent with σ_0 data derived from line-of-sight measurements. In general a $\sigma_0 \approx 1 \times 10^{-3}\ m^2/m^2$ is a representative value.

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9 Final Report, Oct 66—May 68

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13. ABSTRACT

(S) The report contains spectral measurements of backscatter return from the surface of the sea via ionospheric paths. Data was also taken of the return spectra of land and land-sea boundaries. The data was taken in conjunction with the operation of the high power Madre OHD radar at Randle Cliff, Maryland. The results show that it is not possible to classify the sea clutter into components due to the reflecting surface and the refracting ionosphere. The conclusion reached is that the ionospheric movement is the dominant form and accounts for most of the backscatter spectral composition.

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