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14. ABSTRACT
The Naval Air Development Center has been conducting over-water flight trials of passive Infrared mapping systems as part of an ASW program to study the possibility of detecting submarines by the effects they produce on the surface of the water. It has been found that submarines operating at shallow depths under conditions of low sea state produce wakes that may persist for several hours. In addition, as by-products of these studies, infrared pictures of many beautiful oceanographic and meteorological phenomena have been recorded, and are presented here. It appears that passive infrared mapping systems may have significant military value for detecting, tracking and classifying maritime targets and significant scientific value as oceanographic and meteorological tools.

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MARITIME APPLICATIONS OF INFRARED MAPPING SYSTEMS

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The Naval Air Development Center has been conducting over-water flight trials of passive infrared mapping systems as part of an ASW program to study the possibility of detecting submarines by the effects they produce on the surface of the water. It has been found that submarines operating at shallow depths under conditions of low sea state produce wakes that may persist for several hours. In addition, as by-products of these studies, infrared pictures of many beautiful oceanographic and meteorological phenomena have been recorded, and are presented here. It appears that passive infrared mapping systems may have significant military value for detecting, tracking and classifying maritime targets and significant scientific value as oceanographic and meteorological tools.

I. INTRODUCTION

The Naval Air Development Center has been conducting over-water flight trials of passive infrared mapping systems as part of an ASW program to study the possibility of detecting submerged submarines by detecting effects they may produce on the surface of the water. In conducting these investigations tens of thousands of square miles of ocean surface have been mapped. While infrared pictures of ships, submarines, and their wakes were being obtained, infrared pictures of many beautiful oceanographic and meteorological phenomena were recorded. The purpose of this paper is to present samples of these results to demonstrate military and scientific maritime applications of infrared mapping systems. This paper will consist of a description of a typical infrared equipment used in conducting these studies, a brief résumé of results obtained against submarines and ships, and a description of results that appear to be significant in the fields of physical oceanography and atmospheric physics.

II. DESCRIPTION OF EQUIPMENT

The three infrared equipments used to obtain the results to be described were built by HRB-Singer, Incorporated and are designated the AN/AAD-2, AN/AAR-9, and Reconofax Camera. Because of their great similarity the design of only one will be described.

Figure 1 illustrates the optical system of the AN/AAD-2 infrared mapping set which was designed originally for use in U. S. Army Signal Corps drone aircraft. It operates in the following manner. A small portion of the infrared radiation emitted or reflected by the objects under surveillance is intercepted by the plane 45^{o}-angle scanning mirror, which is mounted on a rotating shaft whose axis is parallel to the flight path of the aircraft. As this mirror rotates at a rate of 100 revolutions per second, radiant energy from each object point along a line perpendicular to the flight path is sampled sequentially and focused by means of a parabolic mirror onto a cooled infrared detector. The electrical signal generated

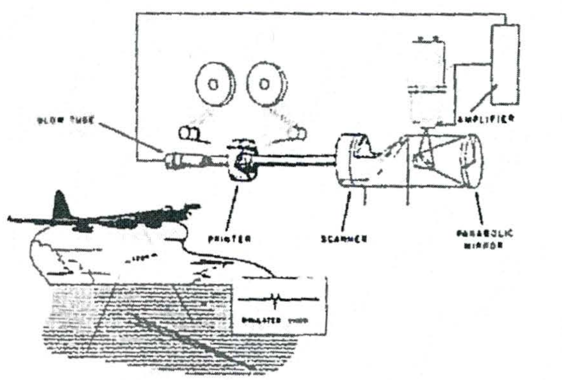

Fig. 1. Optical system of AN/AAD-2 infrared mapping set.

in the detector is amplified and passed on to a glow tube which emits light whose intensity is proportional to the electrical signal impressed upon it. Light from the flow tube is focused to a small spot by means of a microscope objective, which is also mounted on the rotating shaft. The intensity-modulated spot of light scans across a piece of slowly advancing photographic film in synchronism with the scanning mirror. As the aircraft advances, a 120° field of view of the terrain below is swept out by the scanner and recorded on photographic film in the form of a continuous strip map.

The diameter of the parabolic mirror is 3.25 in., with a focal length of 6 in. The sizes of detectors used range in sensitive area from 0.25 mm^2 to 12 mm^2. In this project the most common size used in the AN/AAD-2 was 6.25 mm^2 which yields an instantaneous angular field of view of about 1°. This detector size was chosen to provide an optimum tradeoff between thermal resolution and spatial resolution for the types of submarine wake targets anticipated. Figure 2 shows the AN/AAD-2 installed in the closed-off bomb bay of a P2V aircraft. Figure 3 illustrates the observer's station in the same aircraft. The item of principal interest here is an Ansco KD-14(XA-3) camera-processor-viewer in which video information from the scanner is printed on photographic film by means of an intensity-modulated cathode ray tube, processed continuously by a two-solution "arrested development" technique, and presented to the observer on a back-lighted

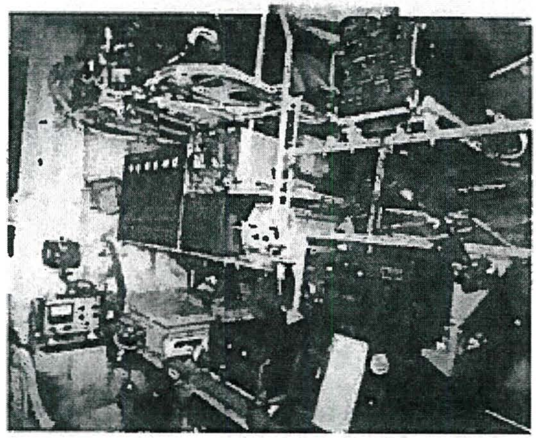

Fig. 3. Installation of AN/AAD-2 accessories in after-section of P2V aircraft. KD-14(XA-3) camera-processor-viewer appears in right foreground.

viewer with a typical total delay time of about 15 seconds.

Figure 4 shows the AN/AAD-2 with some of the detectors it has been modified to accept. Copper- and mercury-doped germanium detectors with integral helium-nitrogen double dewars are shown. Also illustrated are liquid-nitrogen-cooled lead selenide, p-type gold doped germanium, indium antimonide detectors, and a zinc-activated germanium-silicon-alloy detector which was designed to operate at temperatures achievable with pumped-over solid nitrogen. To date, the best results have been obtained with a liquid-helium-cooled Raytheon copper doped germanium

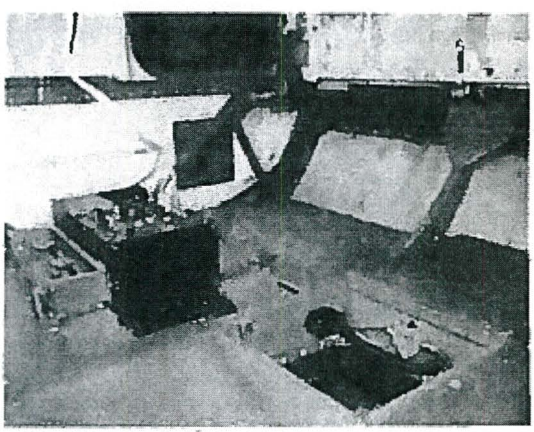

Fig. 2. Installation of AN/AAD-2 in closed-off bomb bay of a P2V aircraft.

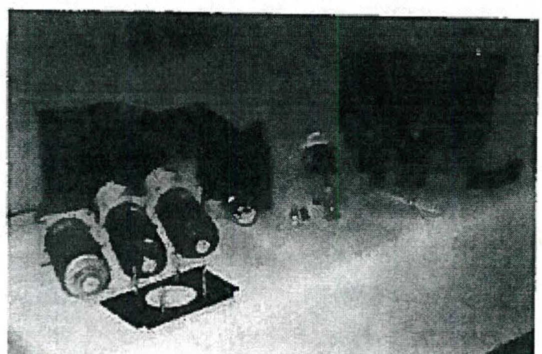

Fig. 4. Infrared detectors used with the AN/AAD-2. From left to right are shown Ge:Cu, Ge:Hg, Ge:Cu, GeSi:Zn, InSb, Ge:Au, PbSe and Ge:Au types mounted in a variety of dewars.

detector which is sensitive throughout the infrared spectrum to a long-wavelength cutoff of 14 μ. Among the nitrogen-cooled detectors, which yield an order of magnitude lower sensitivity, Philco photovoltaic indium antimonide and Minneapolis-Honeywell photoconductive indium antimonide have yielded the best results.

III. DETECTION AND TRACKING OF SUBMARINES

When employing the helium-cooled detectors, the AN/ AAD-2 has demonstrated a consistent ability to record wakes from submarines operating at keel depths as great as 65 ft in seas as high as state 4. On a few occasions wakes from submarines operating normally at depths as great as 130 ft have been recorded. If the submarine's operation is abnormal in any of several ways, detectable surface effects are often produced. For example, if the submarine is leaking air, a slick-like wake is produced; if the submarine is operating out of hydrostatic trim with a bow-down attitude of more than a few degrees, a line of readily detectable, nearly circular upwellings is produced. The pumping of bilges and ballast tanks often produces detectable surface effects.

In general, the persistence of these wakes appears to be primarily a function of sea state. In calm seas, wakes as long as 22 mi and as old as 3 hours have been recorded; in state 4 seas they have been observed to dissipate within 10 minutes.

Figure 5 shows a submarine's hot snorkel and wake as recorded at night by the AN/ AAD-2. In this, as in subsequent pictures, effectively warm targets are represented as light and effectively cold ones as dark. The next three pictures form a series of views of the same area of ocean over a time interval of 1 1/ 2 hours. Figure 6 shows the wake of a snorkelling submarine. Figure 7 shows the same wake 18 minutes after the submarine had secured its snorkel and dived to a greater depth. The abrupt termination of the wake indicates the point of submergence of the submarine. Beyond this point can be seen a series of patches produced on the surface of the water by a deliberate discharge of oil from the submerged submarine. Figure 8 was recorded 84 minutes after the submarine dived. The wake from the snorkelling submarine still appears virtually unchanged. The oil patch has broadened with time.

Figure 9 shows the finely etched wake generated by a submarine operating normally at a keel depth of 130 ft recorded 50 minutes after the submarine had passed along the center line of the area shown. As has been indicated earlier, such wakes are recorded only occasionally. A number of activities in the United States, Canada, and the United Kingdom are studying effects produced by completely submerged submarines with intentions of predicting under what oceanographic conditions they are produced and of improving methods by which they may be detected.

IV. SURVEILLANCE AND CLASSIFICATION OF MARITIME TARGETS

Another maritime application of infrared mapping systems that appears to have military significance is the passive nighttime surveillance and classification of potentially hostile vessels.

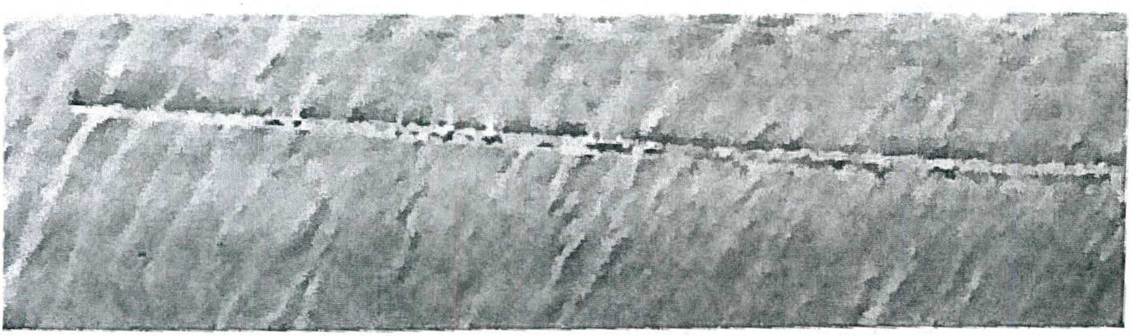

Fig. 5. Hot submarine snorkel and wake recorded by AN/AAD-2. Date: 15 Mar 1962; Time: 1939 R; Coordinates: 24°00'N, 83°45'W; Aircraft altitude: 1300 ft; Detector: Ge:Cu, circular, 2.8-mm diameter; Length of area shown: 1.0 n mi.

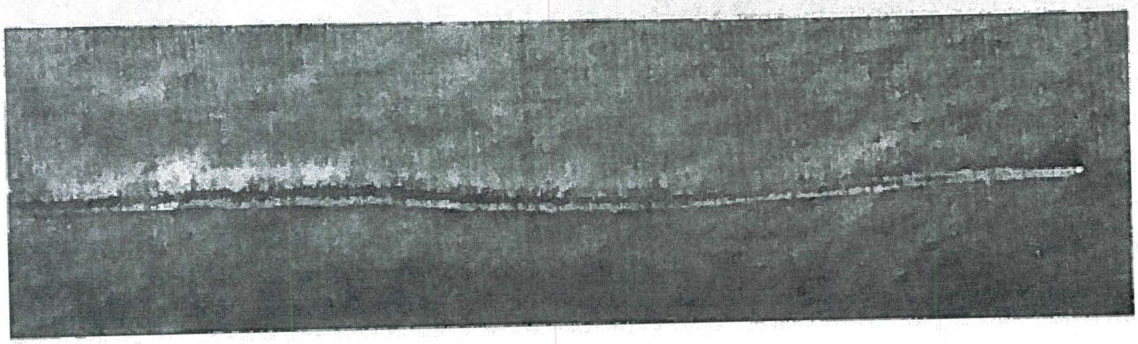

Fig. 6. Hot submarine snorkel and wake recorded by AN/AAD-2. Date: 8 Aug 1962; Time: 2301 Q; Coordinates: $40^{o}29'$N, $71^{o}40'$W; Aircraft altitude: 2500 ft; Detector: Ge:Cu, circular, 2.8-mm diameter; Length of area shown: 2.8 n mi.

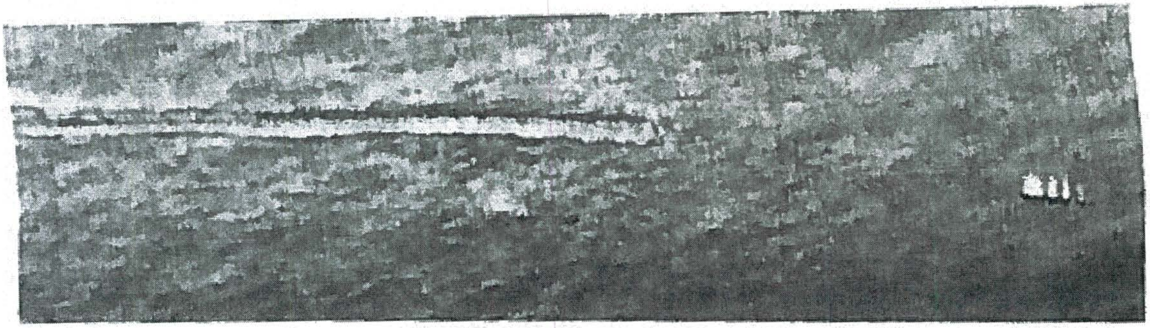

Fig. 7. Wake left by snorkelling submarine recorded by AN/AAD-2 18 min after snorkel had been secured. Wake terminates at point where submarine dived to 130 ft. Oil discharged from advancing submerged submarine appears on the right. Date: 8 Aug 1962; Time: 2329 Q; Coordinates: $40^{o}29'$N, $71^{o}40'$W; Aircraft altitude: 2500 ft; Detector: Ge:Cu, circular, 2.8-mm diameter; Length of area shown: 2.8 n mi.

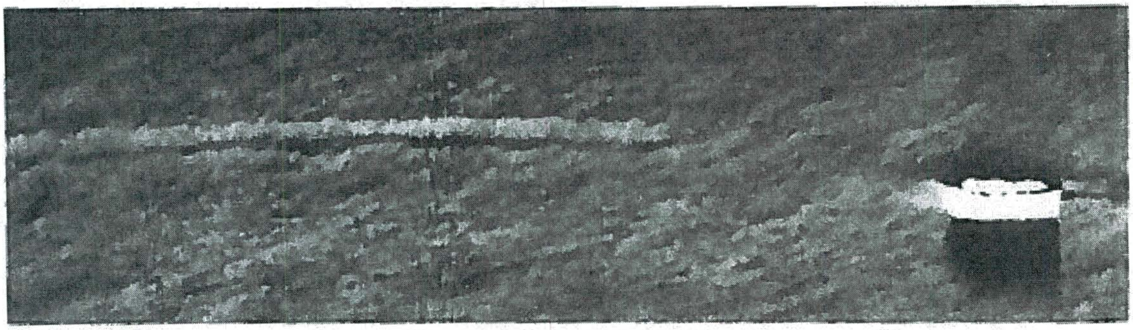

Fig. 8. Wake left by snorkelling submarine recorded by AN/AAD-2 84 min after snorkel had been secured. Spreading patch of oil appears on the right. Date: 9 Aug 1962; Time: 0035 Q; Coordinates: $40^{o}29'$N, $71^{o}40'$W; Aircraft altitude: 2500 ft; Detector: Ge:Cu, circular, 2.8-mm diameter; Length of area shown: 2.8 n mi.

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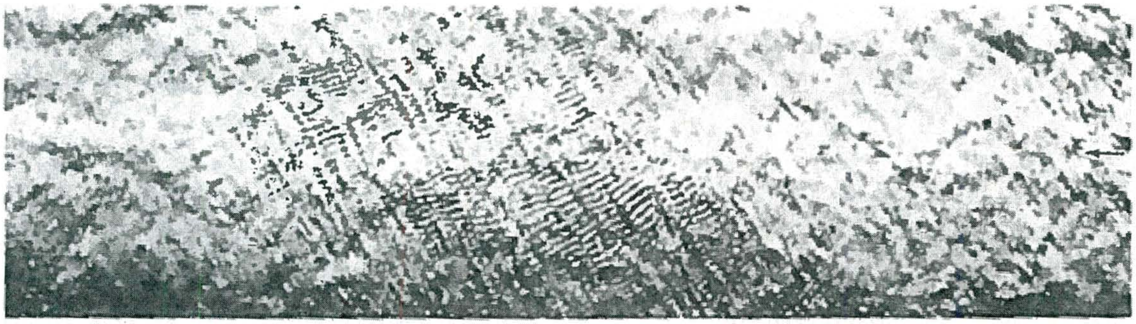

Fig. 9. Wake generated in a calm sea by a 130-ft deep normally operating submarine recorded by AN/AAD-2. Wake appears as a faint double line along the center line of the picture (at arrow). Date: 18 Jun 1962; Time: 2241 R; Coordinates: 24°10'N, 80°52'W; Aircraft altitude: 4000 ft; Detector: Ge.Cu, circular, 2.8-mm diameter; Length of area shown: 3.2 n mi.

Even when relatively large detectors yielding relatively low spatial resolution are used, the pictures recorded provide information on the dimensions of the target and the number and location of its stacks. In addition, the wake from such a vessel, which may extend many miles astern, provides information on the course of the vessel even though it may suddenly change its heading when the surveillance aircraft approaches. Figure 10, which was recorded from an altitude of 1600 ft, shows deck structure of a surfaced submarine. Typically, a portion of the after section of the hull, where the engines are located, appears relatively warm. Figure 11 shows four ships of various types in Delaware Bay. In Fig. 12 two surface craft are seen near the mouth of Delaware Bay where the appearance of the water changes abruptly.

V. APPLICATIONS TO PHYSICAL OCEANOGRAPHY

Airborne infrared mapping systems provide means for studying large areas of the ocean surface in short periods of time. Information on the bulk characteristics of the water can often be inferred from its appearance to an infrared device despite the fact that infrared radiation from only the first few thousandths of an inch of depth is received by the device.

Figure 13 is a portion of a Coast and Geodetic Survey Chart showing Loggerhead Key and Reef. Figure 14, an infrared picture of the same area, reveals a complicated water-surface thermal structure over the reef and a relatively simple structure beyond. Figure 15 is an infrared picture of Boca Grande Key. The streamlines in

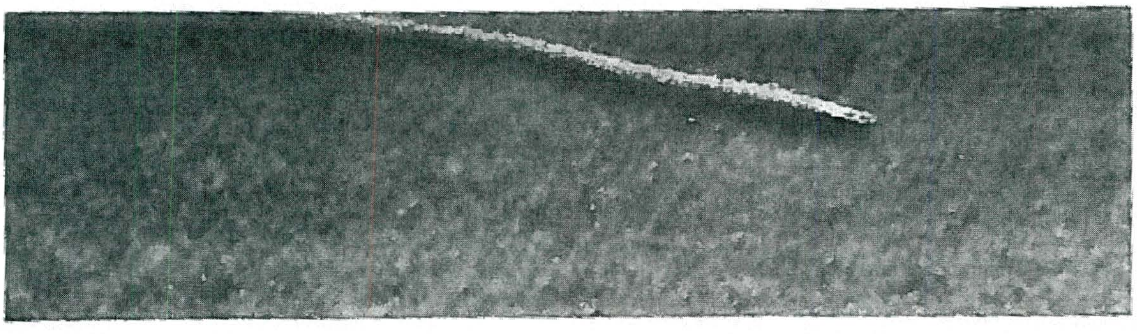

Fig. 10. Wake and surfaced submarine. Note deck structure forward and warm engine area aft. Date: Mar 1962; Time: 2127 R; Coordinates: 24°10'N, 83°55'W; Aircraft altitude: 1600 ft; Detector: Ge.Cu, circular, 2.8-mm diameter; Length of area shown: 1.0 n mi.

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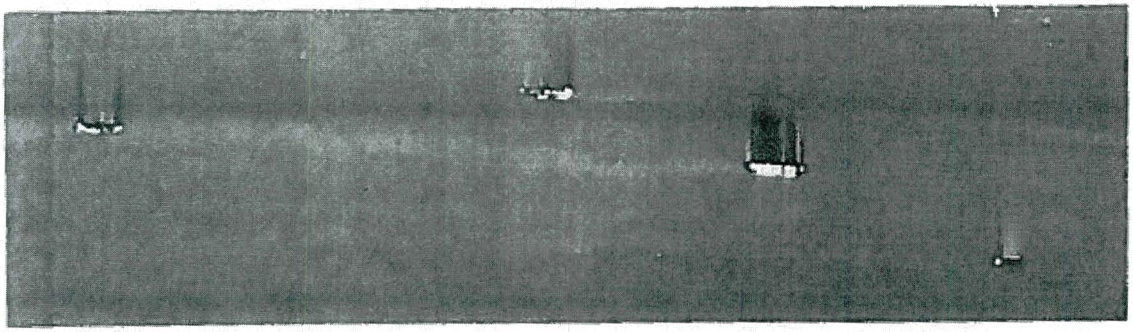

Fig. 11. Four ships and wakes in Delaware Bay recorded by AN/AAD-2. Date: 18 Jan 1962; Time: 1953 R; Coordinates: 38°58'N, 75°06'W; Aircraft altitude: 2100 ft; Detector: InSb, square, 2.5 by 2.5 mm; Length of area shown: 2.1 n mi.

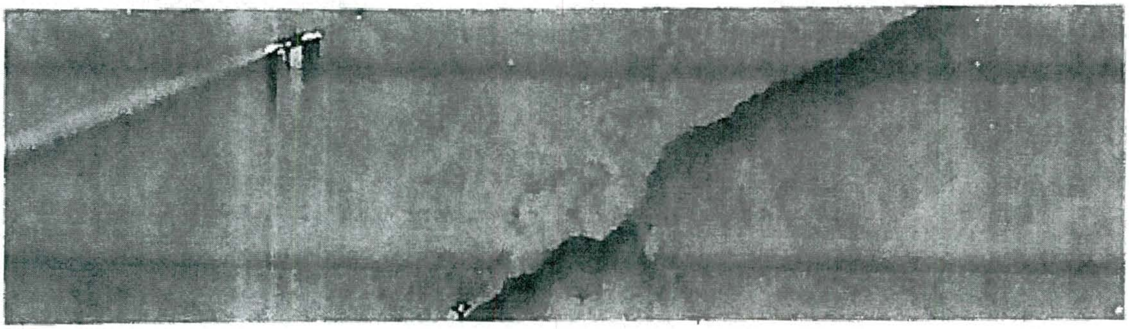

Fig. 12. Boat and ship with wake at mouth of Delaware Bay recorded by AN/AAD-2. Date: 18 Jan 1962; Time: 1956 R; Coordinates: 38°49'N, 75°01'W; Aircraft altitude: 2100 ft; Detector: InSb, square, 2.5 by 2.5 mm; Length of area shown: 2.1 n mi.

the water indicate the direction of a strong current flowing past the island. Figure 16 is a portion of a chart showing this island. Figure 17 shows apparent temperature contours in Barnegat Bay which seem to correlate with bottom contours shown on the chart of the corresponding area (Fig. 18).

Figure 19 illustrates a current shear near the sea buoy at the end of the main ship channel out of Key West. A discontinuity in the wake left by a surfaced submarine, which had just emerged from the channel, is evident along the shear line. Figure 20 shows the cold, fresh water efflux of Takanassee Lake (at Long Branch, New Jersey) riding on the more dense salt water of the Atlantic Ocean and being drawn in a southeasterly direction by the ebbing tidal current. Figure 21 was recorded over Chesapeake Bay Bridge (near Annapolis, Maryland) during a time of tidal flood current. Wakes from the bridge piers are seen extending upstream. The array of many fine parallel lines which intersect the bridge at an angle of about 20° are streaks aligned with the wind. "Wind shadows" cast on the water surface by the bridge piers are aligned with the wind streaks.

Figure 22 illustrates a "cold front" in the ocean which was recorded on a night when there was ice floating in New York harbor while water temperatures of 68 to 75°F were reported in the Gulf Stream, 230 mi to the southeast. A surfaced submarine on a southeasterly heading had just emerged into the warmer waters when this picture was recorded about 140 mi east-southeast of New York City. This picture has suggested the use of infrared mapping devices for monitoring under-

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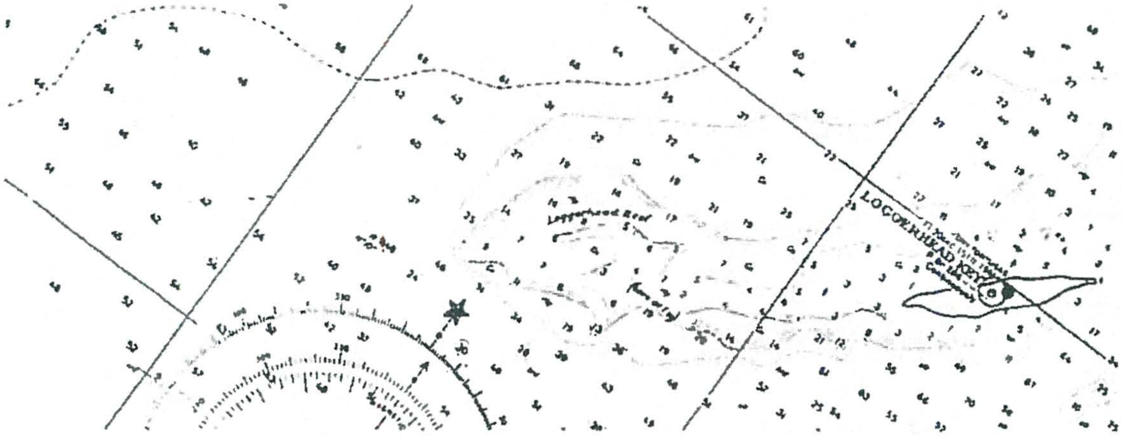

Fig. 13. Portion of Coast and Geodetic Survey Chart No. 585 showing Loggerhead Key and Loggerhead Reef. Depths are given in feet.

Fig. 14. Infrared picture of Loggerhead Key and surrounding waters recorded by AN/AAD-2. Date: 15 Mar 1962 Time: 1833 R; Coordinates: 24°38'N, 82°56'W; Aircraft altitude: 4500 ft; Detector: Ge:Cu, circular, 2.8-mm diameter; Length of area shown: 4.2 n mi.

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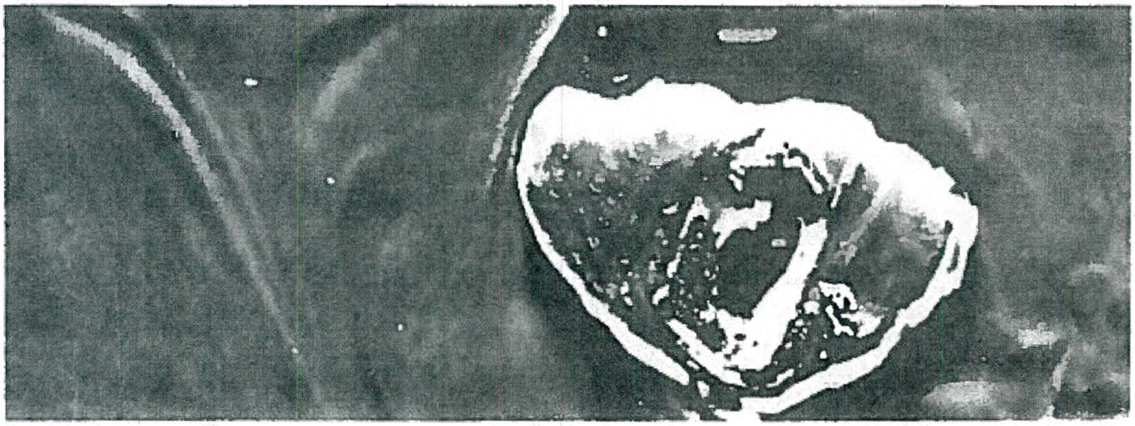

Fig. 15. Infrared picture of Boca Grande Key and surrounding waters recorded by AN/AAD-2. Date: 15 Mar 1962; Time: 2222 R; Coordinates: 24°32'N, 82°00'W; Aircraft altitude: 1900 ft; Detector: Ge:Cu, circular, 2.8-mm diameter; Length of area shown: 0.9 n mi.

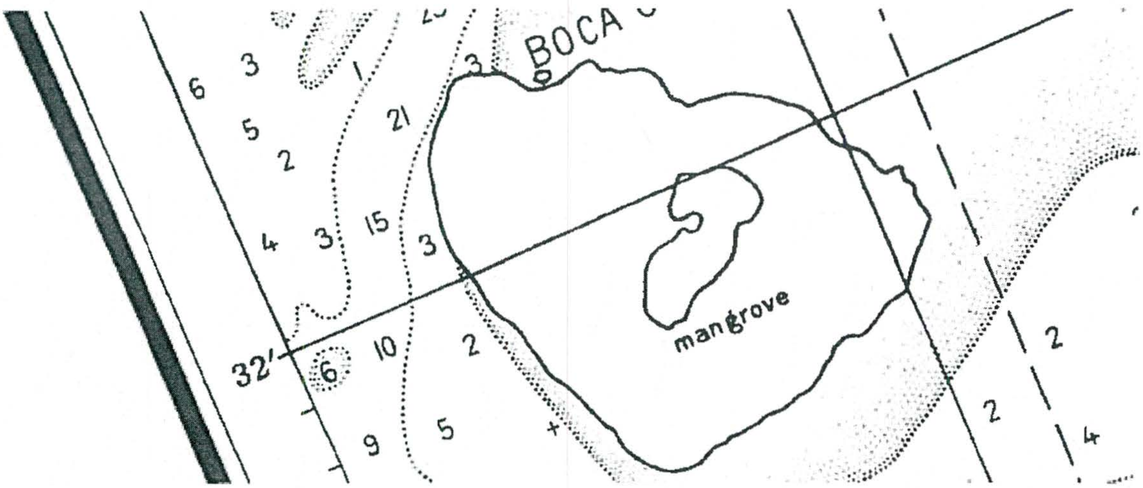

Fig. 16. Portion of Coast and Geodetic Survey Chart No. 584 showing Boca Grande Key.

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Fig. 17. Thermal contours in Barnegat Bay recorded by Reconofax Camera installed in Cessna 310-B aircraft of HRB-Singer, Inc. Date: 20 May 1959; Time: 2300 Q; Coordinates: 39°48'N, 74°11'W; Aircraft altitude: 5000 ft; Detector: Ge:Au (p-type), circular, 2.0-mm diameter; Length of area shown: 4.5 n mi.

Fig. 18. Portion of Coast and Geodetic Survey Chart No. 1216 showing bottom contours in Barnegat Bay.

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Fig. 19. Current shear, surfaced submarine, and wake at end of main ship channel out of Key West, Florida recorded by AN/AAD-2. Date: 12 Mar 1962; Time: 2003 R; Coordinates: $24^{\circ}28'$N, $81^{\circ}48'$W; Aircraft altitude: 3000 ft; Detector: Ge:Cu, circular, 2.8-mm diameter; Length of area shown: 3.0 n mi.

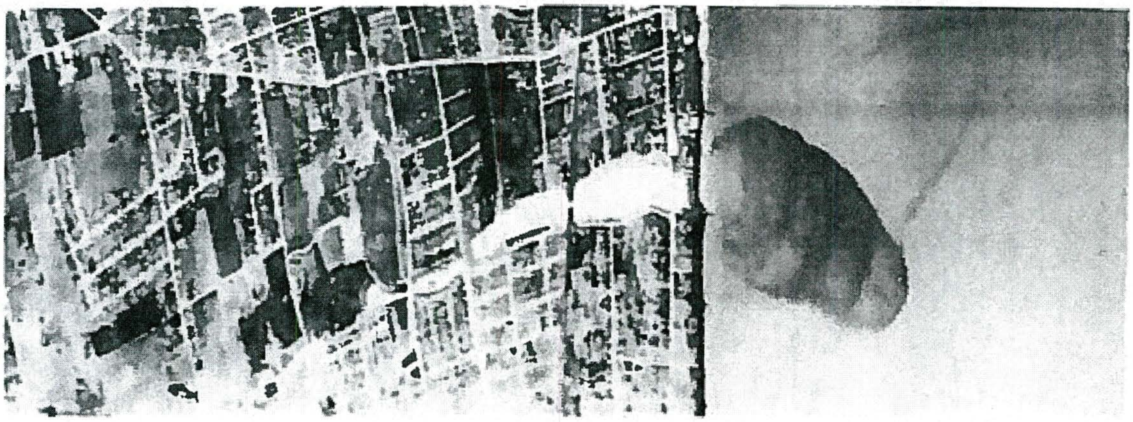

Fig. 20. Cold fresh water efflux from Takanassee Lake into the Atlantic Ocean recorded by AN/AAD-2. Date: 3 Apr 1961; Time: 2306 R; Coordinates: $40^{\circ}17'$N, $74^{\circ}00'$W; Aircraft altitude: 2200 ft; Detector: Ge:Au (p-type), circular, 2.0-mm diameter; Length of area shown: 2.0 n mi.

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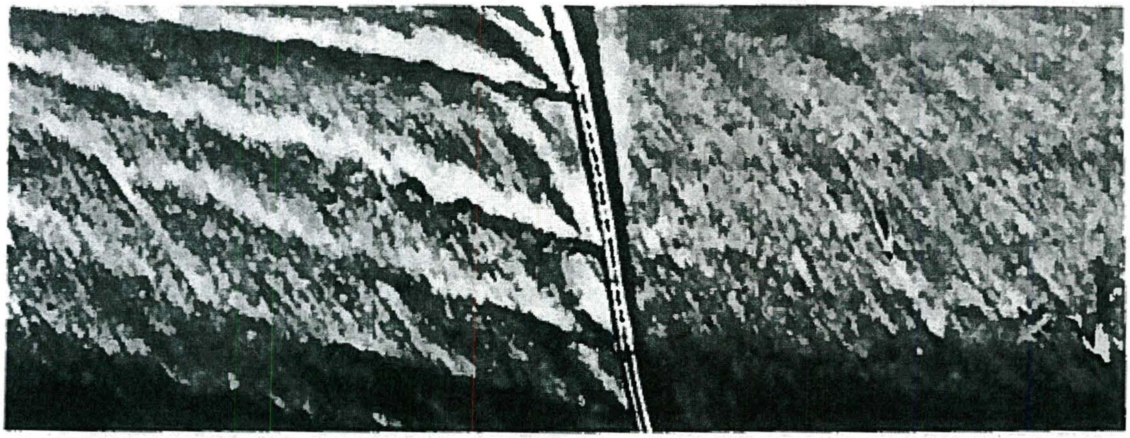

Fig. 21 Chesapeake Bay Bridge, wakes and wind shadows from bridge piers, and wind streaks recorded by AN/AAD-2. Date: 10 July 1962; Time: 2201 Q;Coordinates: 38°59'N, 76°23'W; Aircraft altitude: 1000 ft; Detector: Ge:Cu, circular, 2.8-mm diameter; Length of area shown: 0.9 n mi.

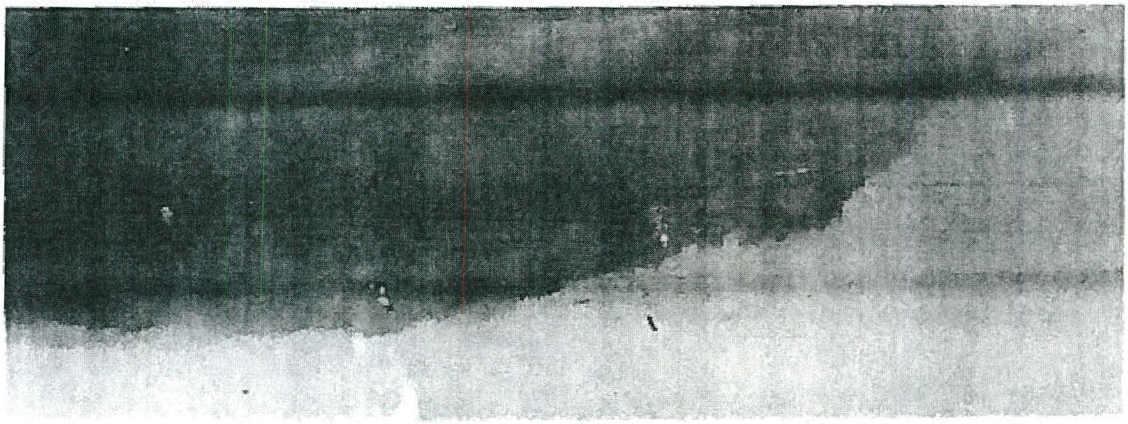

Fig. 22. Ocean "cold front" and surfaced submarine recorded by AN/AAD-2. Date: 14 Feb 1961; Time: 1900 R; Coordinates: 39°52'N, 71°29'W; Aircraft altitude: 1300 ft; Detector: Ge: Au (p-type), circular, 2.0-mm diameter; Length of area shown: 1.4 n mi.

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sea "weather" conditions both from the military point of view of making sonar predictions and from the commercial point of view of predicting the migration of fishes and other sea animals.

Figure 23 shows what is probably a thin layer of cold, relatively salt-free water from melting ice flowing over warmer — but more dense — salt water. A periscope-depth submarine is passing through the area shown and apparently has punched a line of warm holes in the cold layer but is leaving only a faint slick-like wake in the warmer region.

Figure 24 shows a rough sea in the daytime. The whitecaps appear bright by reflected sunlight. Figure 25 shows whitecaps and a line of demarcation between thermally distinct water masses in a rough sea on a cold night. The whitecaps appear as cold, black specks.

The structure resembling a mountain ridge in Figure 26 is believed to be the surface manifestation of an internal wave — a vertical fluctuation of the thermocline propagating through a density-stratified sea. It was recorded on seven aircraft passes over the area and calculated to be advancing relative to other references in the water at a speed of 0.3 knot, an appropriate speed for an internal wave.

Figure 27 shows a series of "thermal steps" in the ocean. In the clearing to the right, a passing submarine has raised its periscope and is producing a puffy little cold wake after traversing the area at greater depth undetected. On the far right of Fig. 28 appears an abrupt discontinuity in the "thermal texture" of the sea surface. The character of a wake left by a surfaced submarine which had passed through the area changed abruptly across the demarcation line. Figure 29 illustrates an area of the sea which appears to be in turbulent motion although visually the sea appeared calm.

VI. APPLICATIONS TO ATMOSPHERIC PHYSICS

Against the relatively uniform background of the sea, an airborne infrared mapping system sensitive in the water vapor absorption bands can record pictures of variations in the concentration and/or temperature of atmospheric water vapor. Figure 30 was recorded on an exceptionally clear night by the AN/AAD-2 employing a lead selenide detector. A cold front had moved through the area and an inversion layer existed at an altitude of 3500 ft. Patterns similar to that shown were recorded continuously for 150 mi of aircraft travel in an essentially straight line path. Several times the aircraft descended deliberately below the layer; in each case the patterns disappeared and the background became uniform. Eventually, the aircraft intercepted a deck of clouds at the same altitude as the inversion layer. Figure 31 shows a few small clouds on the edge of the deck, apparently in the process of formation feeding on the accumulated water vapor.

VII. SUMMARY AND CONCLUSIONS

Airborne passive-infrared mapping systems provide a consistent capability of tracking, detecting, and classifying ships and shallow depth submarines at night, and an occasional but presently unpredictable capability against moderate-depth submarines.

In the rapidly expanding science of oceanography, airborne-infrared mapping devices are well suited for use as instruments which permit studying vast areas of the oceans in relatively

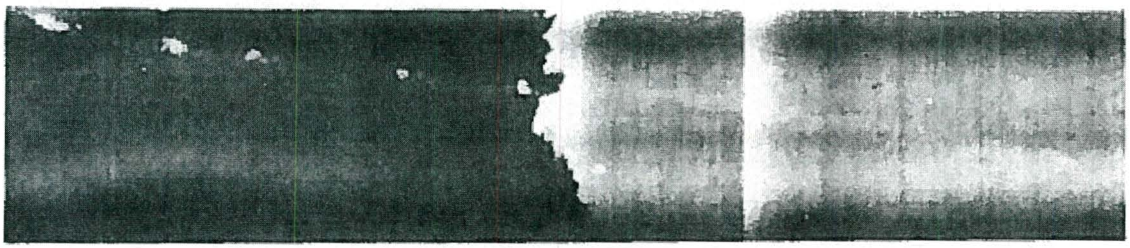

Fig. 23. Layer of cold water flowing over warm water and wake of a periscope depth submarine recorded by AN/AAR-9 installed in a USAF B-50 aircraft. Date: 25 Mar 1959; Time: 2020 R; Coordinates: 39°15'N, 70°45'W; Aircraft altitude: 1000 ft; Detector: PbTe, square, 1.0 by 1.0 mm; Length of area shown: 1.1 n mi.

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short periods of time. Correlation of results obtained by this method and other methods of obtaining oceanographic data has been demonstrated.

Infrared mapping devices should prove to be of value in the science of meteorology in studying distributions of atmospheric water vapor and the dynamics of cloud formation.

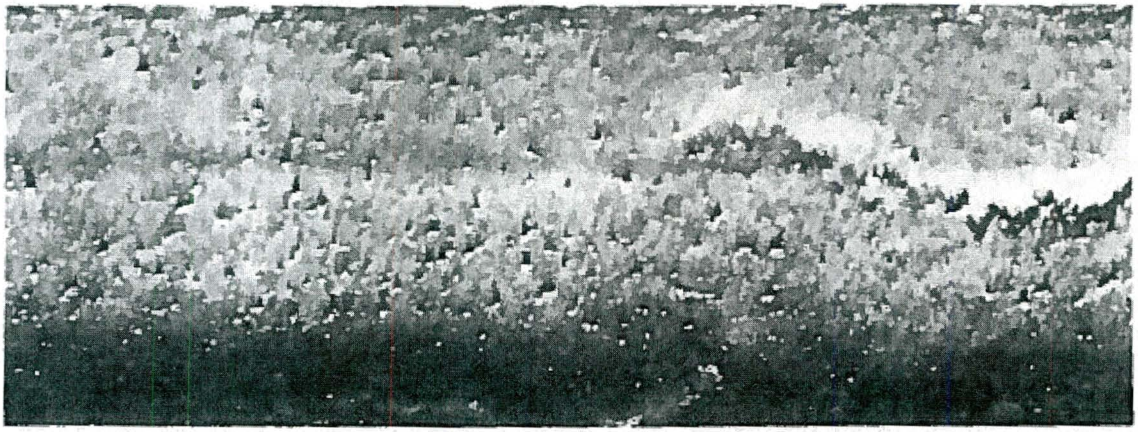

Fig. 24. Rough sea with many whitecaps recorded by AN/AAD-2. Date: 20 Feb 1962; Time: 1628 R; Coordinates: 39°00'N, 74°45'W; Aircraft altitude: 1500 ft; Detector: Ge:Cu, circular, 2.8-mm diameter; Length of area shown: 1.4 n mi.

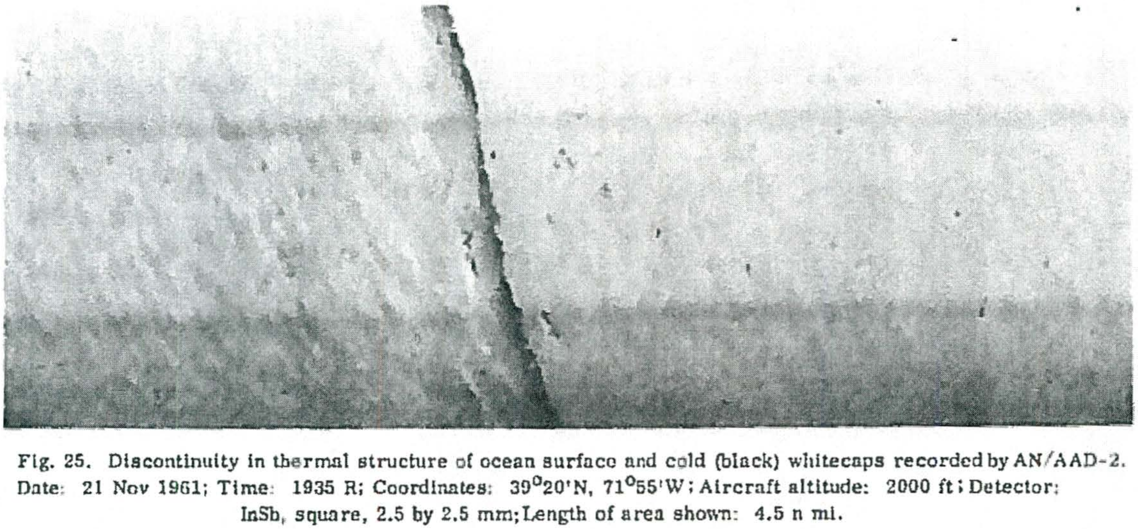

Fig. 25. Discontinuity in thermal structure of ocean surface and cold (black) whitecaps recorded by AN/AAD-2. Date: 21 Nov 1961; Time: 1935 R; Coordinates: 39°20'N, 71°55'W; Aircraft altitude: 2000 ft; Detector: InSb, square, 2.5 by 2.5 mm; Length of area shown: 4.5 n mi.

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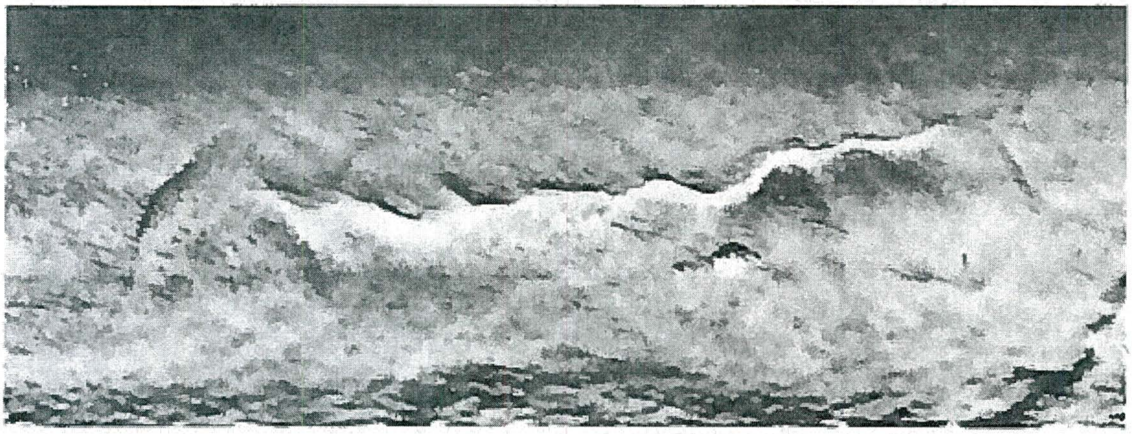

Fig. 26. Surface manifestation of an "internal wave" recorded by AN/AAD-2. Date: 4 Apr 1962; Time: 1941 R; Coordinates: 39°44'N, 71°30'W; Aircraft altitude: 2700 ft; Detector: Ge:Cu, circular, 2.8-mm diameter; Length of area shown: 3.0 n mi.

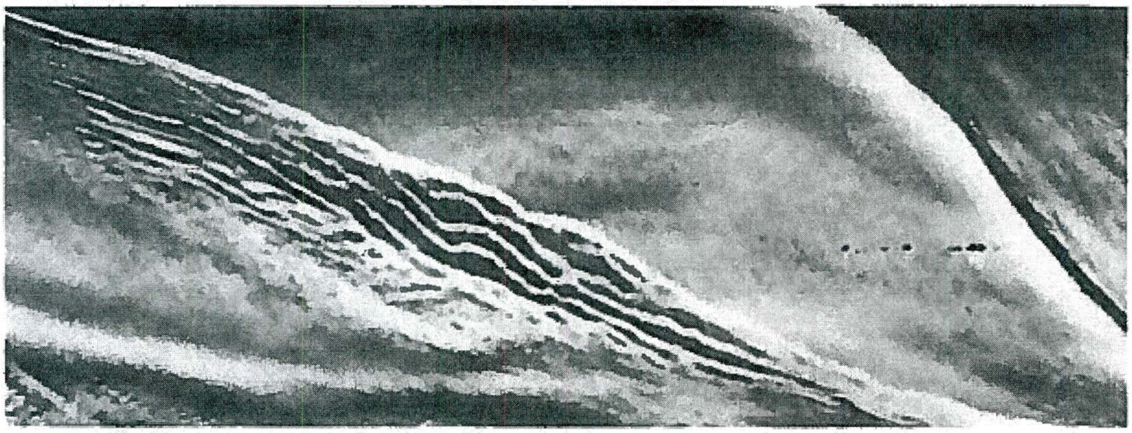

Fig. 27. "Thermal steps" in the ocean and short length of wake from a periscope depth submarine recorded by AN/AAD-2. Date: 28 Mar 1962; Time: 2139 R; Coordinates: 40°25'N, 71°53'W; Aircraft altitude: 2600 ft; Detector: Ge:Cu, circular, 2.8-mm diameter; Length of area shown: 2.0 n mi.

 [redacted]

Fig. 28. Wake of a surfaced submarine and thermally textured distinct water masses recorded by AN/AAD-2. Date: 12 Mar 1962; Time: 2119 R; Coordinates: 24°15'N, 82°05'W; Aircraft altitude: 2000 ft; Detector: Ge:Cu, circular, 2.8-mm diameter; Length of area shown: 2.0 n mi.

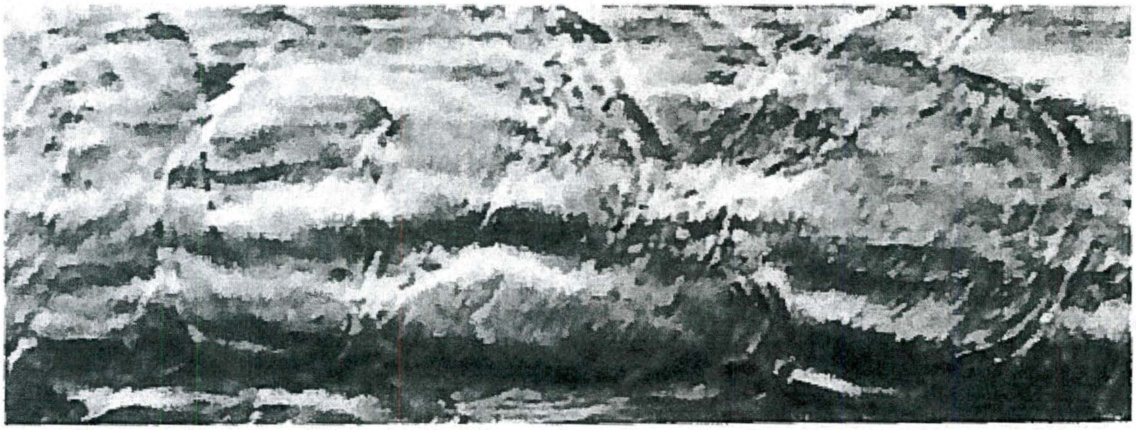

Fig. 29. Large area ocean "turbulence" in a calm sea recorded by AN/AAD-2. Date: 15 Mar 1962; Time: 1838 R; Coordinates: 24°28'N, 83°08'W; Aircraft altitude: 4500 ft; Detector: Ge:Cu, circular, 2.8-mm diameter; Length of area shown: 4.2 n mi.

[redacted]

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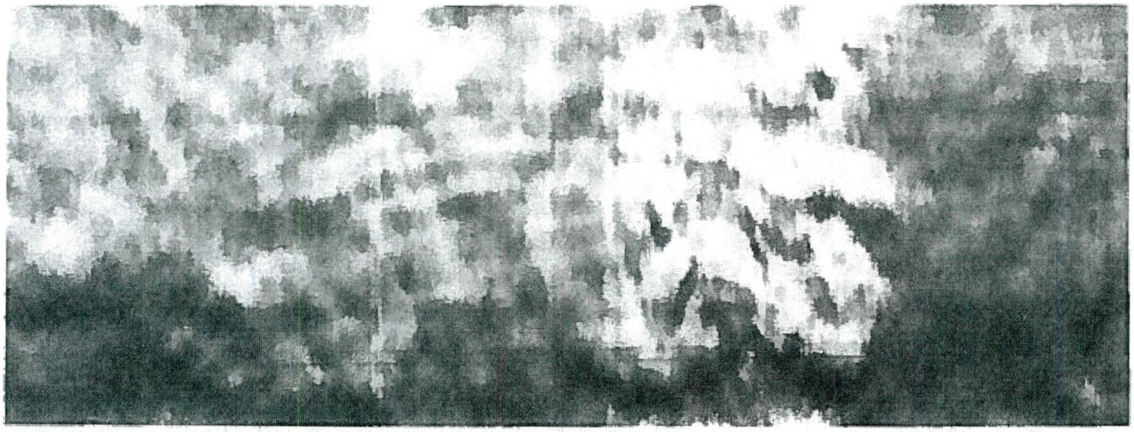

Fig. 30. Atmospheric patterns recorded over an inversion layer on a visually clear night by AN/AAD-2. Date: 1 Mar 1962; Time: 2003 R; Coordinates: 39°19'N, 72°29'W; Aircraft altitude: 7500 ft; Detector: PbSe, square, 2.5 by 2.5 mm; Length of area shown: 5.0 n mi.

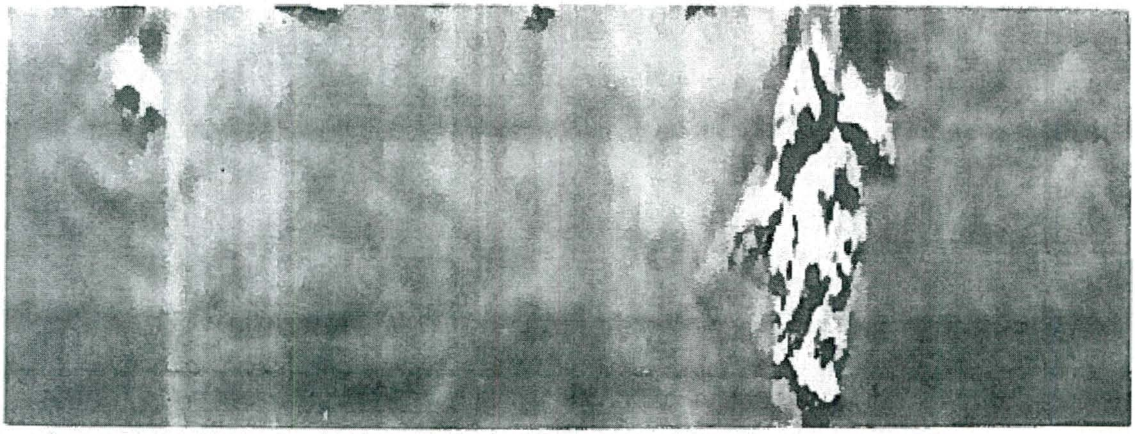

Fig. 31. Small clouds apparently in process of formation and surrounding accumulations of water vapor recorded by AN/AAD-2. Date: 1 Mar 1962; Time: 2144 R; Coordinates: 38°42'N, 71°50' W; Aircraft altitude: 6500 ft; Detector: Ge:Au (p-type), square, 2.5 by 2.5 mm; Length of area shown: 4.0 n mi.

  [redacted]