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RADAR OBSERVATION OF INSECTS - MOSQUITOES

by

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ABSTRACT

For several years studies of insect behavior have been made with data obtained from a 16 GHz radar. Tests were conducted at several sites over the coastal lowlands of New Jersey and over a region of high plains and low mountains in Oklahoma. In one area, a salt marsh in New Jersey, extensive ground tests on insect numbers were run during periods of radar operation. These ground tests were combined with laboratory data on expected insect backscatter to arrive at an extremely convincing model of the insect origin of most "Dot Angels." The radar studies give a great deal of insight into the buildup and dispersal of insect swarms, since radar can "follow" insects where other means of trapping and observation cannot. In particular, new data are available on large-scale behavior as a function of wind and topography.

* Mr. Downing was with the Monmouth County (N.J.) Mosquito Extermination Commission when this research was performed.

INTRODUCTION

"Dot Angels" have been observed for many years and their contribution to radar clutter is well documented [1] - [4]. These airborne clutter returns become increasingly bothersome at higher frequencies. This paper reports on a program undertaken to evaluate degradation of radar performance and to ascertain the insect origin of these phenomena. These requirements were met by using a radar as a remote sensor of insect behavior. In particular, the early work (1969) at Fort Monmouth, New Jersey [5] showed an extremely close correlation with crepuscular insect (especially mosquito) activity; this in turn prompted further work in the extreme insect environment over Lower New York Bay. Since a literature search produced no data on mosquito returns at our radar frequency, 16 GHz, laboratory measurements were made [6] which were then extrapolated to expected radar returns [7] (these are consistent with work at longer wavelengths and with larger insects [8]). These, in turn, were used in comparing radar displays of mosquito-prolific New Jersey salt marshes with "Ground-Truth" based on insect trapping. These three New Jersey locations are shown in Figure 1. The radar was sited at the arrow point in each case. These points are each at the center of a circle showing the maximum radar range. The New York Bay/Sandy Hook location (top) has concentric circles of 10 kilometer and 15 kilometer radii. The longer range version of the radar was used in a second series of tests. The Fort Monmouth/Shark River location (center) and the Salt Marsh/Manahawkin Bay location (bottom) used the radar with 10 kilometer maximum range.

Additional data, taken at Fort Sill (Lawton), Oklahoma checked the consistency of the insect theory when extended from the coastal lowland to the Great Plains, Figure 2. Fort Sill is adjacent to and north of Lawton.

RADAR DISPLAY CHARACTERISTICS

The radar used in the program was the AN/MPQ-4 Mortar Locator. In normal operation, a narrow beam is mechanically scanned alternately across a lower and upper beam position. These beam positions fill the same arbitrary 24° (425 mil) azimuth angle and are separated by about 2° in elevation. Either or both beams may be presented on the range/azimuth/intensity or "B scope" display. This is illustrated in Figure 3 [9]. In this paper, only single beam data are reported. The full 24° azimuth coverage is always displayed. However, the range may be "full" or in 20% increments. The lower beam may be arbitrarily positioned from -5.625° (100 mil) to +11.25° (200 mil).

The next two figures compare the "B" display with photographs of the area illuminated by the radar. In addition they show how insect returns can mask other targets and illustrate insect - precipitation differences. Data were taken at Fort Sill. Figure 4 shows the radar display with light, medium, and heavy airborne clutter. This sequence proceeds clockwise from the photograph of the water tower. This water tower, plus some associate structures, appears as the target echo near the center of each of these radar displays. These are in a northerly direction about one mile from the radar site. The photograph of the water tower also shows the lush grass in the foreground. The spring had been extremely wet and in normal years this grass would have dried out well before the date of the photograph (May 16). The medium and heavy clutter situation were recorded, respectively, at 2100 and 2226 on May 16. (All times of this report are CDT.) Sunset was at 2021 and this increase was typical of the after-sunset buildup observed in similar, extremely hot and humid evenings in the Atlantic coastal area. A similar buildup had been observed at Fort Sill during daytime operations, and increased activity corresponds to increasing temperature. The light clutter situation was recorded at 1300 on the following day. We were plagued by an extreme number of mosquitoes, most of them enormous, during this evening of very high radar clutter. We captured 3 insects intact, and these were later identified as 2 *Psorophora ciliata* and 1 *Aedes nigromaculis*.¹ It is interesting to note that the *Psorophora* is far larger than the *Culex pipiens* for which the 1 km single insect range for this radar was calculated [6], [7]. The *Aedes* probably blew in from several miles to the south where there are abundant slickspots [10]. These radar displays are all in a mode showing a maximum range of about 2.3 miles (3.7 km).

Figure 5 is shown as an example of a different type of clutter; clutter of obvious meteorological origin (these data were taken with a display of about ten miles (16 km) in range). This is due to condensed moisture which was in the clouds but did not reach the ground. This area of the radar display was clear at the lower elevations. There is, however, some airborne biological clutter along the bottom of the radar displays. This comparison of clutter type can also be made by comparing this figure with the subsequent figures where the insects appear at greater ranges. The radar displays are presented with corresponding photographs of the cloud cover. The radar beam was at maximum elevation, 200 mils (11.25°), and slices the photographs about half way between the horizon and the top of the photograph. The left hand data were taken in a northerly direction and show the water tower of Figure 3. All data were taken at about 2008, 40 minutes before sunset on June 27.

¹R. Ostergaard, private communication

TEMPERATURE EFFECTS

It was not difficult to separate temperature effects from other factors. Figure 6 gives an extreme example of the variation in insect activity with temperature. The two exposures show maximum return on each of two succeeding days, April 26 and 27, 1970, and with identical radar settings. The radar was at Fort Monmouth. The day to day temperature drop corresponds to a decrease in activity from moderate to low. The displayed range was 10 km.

GROUND-TRUTH, CREPUSCULAR BUILDUP AND SWARMING

Extensive radar data were taken and the results compared with actual insect catches in the summers of 1970 and 1971 at a site on the tidal marshes about one kilometer inland from Manahawkin Bay in Ocean County, New Jersey. The radar was placed on a bridge, locally known as "The Bridge That Goes Nowhere," which is reached from a northwesterly direction by a straight, well-graveled road. Figure 7 shows the radar emplaced on this bridge. The photograph also shows a "boat trap" headed upstream. A map of the area is shown in Figure 8 [11]. A bend in the road and tree line of low hardwoods are about 1500 meters along the road from the bridge. The tidal salt marsh extends at least one kilometer in all directions except toward the east, where a small arm of the bay, Turtle Cove, comes to about 600 meters from the radar location. Beyond the bay, a narrow barrier beach, Long Beach Island, forms the margin of the Atlantic Ocean. Minimum range to the ocean is about 4500 meters. The angular measurements were rather arbitrary, being based on an excellent boresight on a tower at the Barnegat exit of the Garden State Parkway, a distance of 9750 meters, or very nearly the maximum range displayed on the particular radar. The major insect observed is *Aedes sollicitans*, the rather infamous Jersey salt marsh mosquito. These insects emerge from the marsh at fairly predictable periods, determined primarily by the lunar high tides. Operation periods were usually planned to observe various portions of this fortnightly cycle. This map shows artifacts outlining the history of mosquito control in the area. The oldest structures that appear to be drainage canals were actually dug so that predatory fish could find access to mosquito breeding areas. Subsequently, the circular pools were dug fairly deep, so that fish could remain in the marsh. Another principal current control is larviciding by helicopter. Figure 9 shows a photograph of a truck trap used to gather insect samples for ground-truth. This view is taken from the radar on the bridge looking along the access road, which is at 6140 mils azimuth. This is one of several roads used by truck traps for frequent mosquito sampling during

the warm months. Arrangements were made with the Ocean County Mosquito Exterminating Commission to sample this road every ten or fifteen minutes whenever the radar returns were particularly interesting. Insect catches (truck and others) were sent to the Commission's headquarters, where the mosquitoes were separated and catalogued and the non-mosquito remnants were sent to Rutgers University (1970) or the Monmouth County Mosquito Exterminating Commission headquarters (1971), where they were catalogued as to number and size. Those insect data (both mosquito and non-mosquito) were used to arrive at reasonable returns from insects [5], [7]. Since the frontal area of the vehicle mounted net or trap is about .5 meter² and since runs (round trip) were in excess of two kilometers, insects were sampled in a volume of about 10³ meters³. A count of a thousand mosquitoes was typical for the more active periods giving one insect per cubic meter. Now at a distance of one kilometer, the radar's resolution cell is on the order of 5 x 10³ cm³. Most radar data were taken with a somewhat elevated beam, so the density may have been somewhat lower; however, it does follow that even at this maximum range for a single mosquito, mosquito returns of from 2 or 3 orders of magnitude above minimum detectable return should not be expected.

In addition to the truck trap, a helicopter trap [5] was used in 1970 and a boat trap was used in 1971. Both of these were basically truck traps transferred to other vehicles. The airborne trap proved extremely unwieldy with the larviciding helicopter and had to be given up after a few fairly successful runs. The boat trap was mounted on a thirteen foot "Boston Whaler" with an eighteen horsepower outboard motor. It was operated, again on demand of the radar operator, along the canal parallel to the road and in other waterways throughout the area. When operating on parallel road and canal, the truck and boat trap ran as close together (in range) as feasible.

Figure 10 compares the radar returns with weighted truck and boat trappings for the evening of August 3, 1971. Both sets show the generally seen crepuscular buildup, peaking by an hour after sunset. The first radar display, 2008 hours, shows mostly vegetation, particularly trees, from about one kilometer out on the left and a power line at the bottom center. This power line is also clearly visible along the road in Figure 9. The individual returns are from poles plus associated hardware. The several returns showing greater azimuths to the right are from guywires running over the road to poles which were further guyed out beyond the canal. Thus, this sequence of artifacts delineated the road. The second photograph was taken near the peak of the insect catches. There is a great deal of light return over much of the photograph and two distinct heavy bands which, except for the region over the road, go all the way across the radar display. This phenomenon is explained by species dependent swarming behavior. At the peak, 2030 hours, the truck trap gave a count of about 10² Chironomidae midges, to which our model gives a radar weight of 3.5 (Appendix II). The remaining 6.5 x 10² expected return was almost entirely mosquitoes, radar weight of 1. This was not an especially heavy mosquito night.

The final photograph, 2120 hours, shows complete disappearance of the very intense swarm and a more diffuse insect return. The trapping runs terminated 2115 hours, when the boat trap was damaged by one of the across-the-canal guy wires.

LAYERING AND INDIVIDUAL DOT ANGEL MOTION OVER COASTAL LOWLANDS

Figure 11 shows concentration of Dot Angels into a thin layer [12] and uniform general motion (coupled to the wind) [2], [3]. The term "atmospheric plankton" [2] seems especially appropriate here. These data were taken between 2212 and 2245 hours EDT. Sunset was at 1925 hours and the usual crepuscular buildup peaked within the next hour. This layer formed somewhat later and persisted for at least two hours. Each of these photographs is a superposition of 10 "B-scope" exposures taken at 5-second intervals. The striated appearance is thus due to the sampled paths of objects in reasonably uniform motion. The motion was toward the observer and azimuthal motion nulled at about (from) 4400 mils during most of this observation period. The two upper photographs were taken with a 150 mil (8.4375°) antenna elevation and show a slant range of about 3.3 kilometers, which also gives a layer height of 500 meters. Many other similar photographs taken during this period, and at additional azimuth angles, consistently show the same result.

Correlated motion, with or without layering, has been observed at all sites reported here and layering, probably fortuitously, has been observed everywhere except over Lower New York Bay.

A gated range, azimuth/amplitude and time display [7] was added to the radar system for use in the second series of tests at Manahawkin (1971). Figure 12 gives an idealized picture of how the radar displays the real world on both the build-in "B" display (radar screen) and on the added range gated amplitude display (recording oscilloscope). In this case the upper beam illuminates a bird in flight and the lower beam points down the center of two lines of low vegetative clutter (trees will extend into the upper beam at the shorter ranges). Note that the bird motion appears as motion on the corresponding "B" display. The target motion through the range gate is permanently recorded on a paper roll by the "range" display. Ideally, there should be one line for each scan in the given beam. The most recent line (scan) is at the top of the paper. Figure 13 shows the concurrent use of "range" and "B" displays. The 4000 mil azimuth points the radar toward the mouth of the creek. The creek bends to the left as it flows into the bay at Bay side on Figure 8 and the return on Figure 13 centered at 2 kilometers is from vegetation on this further bank. These data were taken at 2304 EDT on August 2. Sunset was at 2010 hours EDT and was followed by a buildup dominated by larger (than mosquitoes) insects. This was also apparent from stronger intensity (B-scope) and amplitude (Visicorder) displays.

The azimuth/amplitude display was run while the five exposures, with five second intervals, "B" display photograph was made and shows about five seconds of running time. The range gate was at 500 meters. These returns show some temporal structure but are generally windborne, as observed for larger insects [8]. Similar display pairs were recorded at several azimuths and it was determined that the wind nulled out at about (from) 0000 mils.

Figure 14 shows decidedly non-insect motion and is given for comparison. The radar was located at the Sandy Hook (Lower New York Bay) site, as shown in Figures 18 and 19. The intensity display and simultaneous azimuth/amplitude records are part of essentially continuous data begun at 1640 hours EDT on August 25, 1971. The "B" displays show an indentation of the bay into the peninsula. The arc along the top of these displays is the further shoreline. Near land is on the left of the foreground and sea clutter (speckled appearance) is on the right. The bright bar across the bottom is due to the transmitted pulse. The lower display shows a short bright bar somewhat beyond this artifact. The upper photograph, taken tens of seconds later, shows a similar but larger bar at 300 meters, the range setting. This return is in both cases from a mass of seagulls somewhat rudely disturbed from their resting place along the near shore. The sequence shows the "flock" moving up into the beam and out into and beyond the range gate. The returns were extremely strong and the data of this figure were taken with greatly reduced I.F. gain. The gulls were quite cooperative and we made several earlier trials at higher gains. Note that in comparison to the previous figure, the birds show more intense returns, greater amplitude modulation and purposeful (dispersive) flight.

MOTION AND AGGREGATION OVER ARID HILLS

So far this paper has dealt with radar observations over the low and relatively humid New Jersey Coast. It was clearly desirable to record comparable radar data from an area with different geographic and weather characteristics; and, therefore, two series of observations were made from Fort Sill, Oklahoma [13]. Fort Sill was chosen because one of our (Fort Monmouth's) radars was there for testing and experiencing difficulty with airborne clutter (Section II of this paper). The first of these series followed an unusually wet spring: May 16-17, 1972, and the second: June 27-28, 1972 was made during the dry prairie summer. Fort Sill, Figure 15 [14], is largely in the Wichita Mountains. The radar site is at the lower right hand corner. The 0000 azimuth was chosen for bore-sighting on a convenient water tower and was very near to true north. This tower is also shown in Figures 4 and 5. Some daytime return, much of it birdlike, was recorded during both series and the diurnal variations included the twilight effects of the other locations. This activity was more intense for the days of higher activity when additional

phenomena were also seen. In the first of these, motion in a cloud-like mass, Figure 16, was observed a little over half an hour after sunset on May 16. This was at greater height and distance than the usual crepuscular effect shown by the bright areas at the bottom of the display. Both photos show the "cloud" from radar data at an elevation of 50 mils (2.8°). Radar data at zero elevation is superimposed, lightly, to show ground relief. The first (lower) "B" display shows the "cloud" over the pass between Apache Ridge on the left and Medicine Ridge shown on the right of Figure 16. The second, taken ten minutes later, shows the "cloud" to have progressed over the pass and almost to Rabbit Hill. This motion corresponds to wind from the southwest and the origin of the clutter in a region of outwashes and "Slickspots" south of the Wichita Mountains [10]. The mosquito population was extraordinarily high in the evening and they caused a great deal of discomfort to the radar operators. The insects appeared to be present in two sizes and the smaller one was subsequently identified as *Aedes nigromaculis*.¹ This animal breeds only in saline areas such as slickspots prevalent to the southwest and this capture served to verify the insect origin of this large scale clutter with large scale motion.

The second additional phenomenon observed in the more humid series is seen in Figure 17. Here a composite picture is shown at the upper right. The "landmarks" used are at the lower left, elevation 36 mils (2°) and the "aerial clutter" is given at the upper left with an elevation of 50 mils (2.8°). Referring to Figure 15, the landmarks are: Mount Scott (the highest peak in the Wichita Mountains) at the extreme radar range on the extreme right, the peaks of the hills around Brush Canyon at the center right, and Signal Mountain at the center left. The elevated data shows an aggregation of returns 425 meters (1400 ft) directly above the floor of Brush Canyon, as shown in the composite display. We conjecture that this collection occurred because of favorable moisture conditions.

LARGE SCALE MOTION OVER WATER

The concept of the salt marsh mosquito (*Aedes sollicitans*) as a migratory insect figured in the early interest which entomologists gave to this project. It was largely on the advice of two of these people² that observations were made of activity over Lower New York Bay. These were made from a site near the seaward end of Sandy Hook (Fort Hancock). Boresighting of 0000 azimuth was originally on a tower in Atlantic Highlands, but later the corresponding Verrazano Bridge angle of 2689 mils was used. North is approximately 2800 mils.

¹R. Ostergaard, private communication.

²R. Ostergaard and D. Jobbins, private communications.

The nights of September 10, (Figure 18) and September 11, (Figure 19) 1969, were particularly interesting. On September 10 the wind was blowing steadily from the northwest, about 2000 mils, at 8 to 15 knots. Figure 18 shows radar data at 1600 mils (almost into the wind) and in quadrature - 0000 mils, superimposed on a standard chart of the area [15]. The arrow lengths correspond to 4 kilometers. The land mass at the top, Staten Island, is at a minimum distance of 12 kilometers. The radar data were taken with earlier times toward the top. Corresponding data at each angle were taken with as little time lapse as possible. The radar was at 50 mils (2.8°) elevation. (Zero elevation gave excessive sea clutter.) Range marks are at 2 kilometer increments. The topmost photos were made at 1900 EDT, ten minutes before sunset. They show a few artifacts such as channel markers, but nothing airborne. (Since both directions are over water, it would not be expected that the usual twilight buildup would be observed until carried into range by the wind.) The second or middle displays were recorded at 2015 EDT. Here dense masses are beginning to appear and the more dense is toward the land mass from which the wind is blowing. The final data shown, bottom, were taken at about 2120 EDT and show a reversal in that the near quadrature direction shows high intensity at greater ranges than are seen looking into the wind. From this, it appears that the peak of activity had passed over the radar site. The data are explained by the usual diurnal insect buildup over the land mass and with this buildup observed downwind as a function of elapsed time and distance.

Figure 19 depicts a comparable situation on September 11. Here the wind is fairly steady from the south. This, however, is based on motion as observed in the radar data and not direct reports of the local Coast Guard Station, as on the previous night. The two quadrature arrows of 4 kilometer length look generally into the wind, but here direction is of greater importance than relative wind speed. The first (top) radar displays were made at 1930 EDT, some twenty minutes after sunset. In the direction over land (4800) the usual crepuscular buildup has already peaked. Over water (0000) only slight clutter can be seen in addition to the artifacts presented in Figure 18 half an hour earlier on the previous day. The second, middle sets of radar data were made at 2000 hours. The overland direction shows a slight decline and buildup is seen to have occurred over water. The final photographs were made at about 2115 hours and both sets show decline. Modeling these data gives two insect sources, a close rather intense source from the lowlying woodlands of the peninsula and a more distant (minimum of 6 kilometers) and less intense source in the urbanized hills of the "Highlands."

CONCLUSIONS

The strong insect returns (angels), which occasionally plague the operation of microwave radars, become a distinct advantage when radars are used to study insect activity. Mobile "truck traps", "boat traps" and "helicopter traps" have been used to obtain insect counts which, when combined with data on the radar cross sections of small insects, verify the insect origin of most clear air airborne clutter detected by microwave radars. The temporal and special patterns of these returns both confirm and extend knowledge of insect behavior since the radar can "follow" swarms over such inaccessible places as over open water and over mountains.

Display techniques have been developed which show individual or small swarm motion within some larger cloud or mass, or which can show the overall motion over great distances. The influence of wind and terrain on insect motion and dispersal may now be determined from radar data.

ACKNOWLEDGMENTS

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APPENDIX I

CHARACTERISTICS OF THE AN/MPQ-4A RADAR
(Table 1)

Maximum Range Displayed	
Early Data	10 ⁴ meters, (6.2 mi)
Later Data	1.5 x 10 ⁴ meters, (9.3 mi)
Maximum Range, 10 ⁻³ m ² Target	10 ⁴ meters ^a
Maximum Range, 10 ⁻⁷ m ² Target	10 ³ meters, (.62 mi) ^b
Horizontal Beam Width	17.8 mil, (1°)
Vertical Beam Width	14.25 mil, (.8°)
Azimuth Scan	445 mil, (25°)
Elevation Separation of (2) Sequential Azimuth Scans	± 35 mil, (±2°)
Scan Rate	17 per second
Radiated Frequency	16 GHz (Ku band)
Radiated Wavelength	18.75 mm
Peak Radiated Power	50 KW
Pulse Repetition Frequency	
Early Data	8.6 KHz
Later Data	7 KHz
Radiated Pulse Width	.25 x 10 ⁻⁶ second
Range Increment Corresponding to Radiated Pulse Width	37.5 m, (125 ft)

^aThis figure is quite conservative.

^bThis figure is based on the line above and the conventional 4th power radar range scaling law.

APPENDIX II

SCALING INSECT SIZE AND RADAR (AN/MPQ-4A) RETURNS

Earlier workers in radar entomology studied rather large insects at wavelengths of 30 mm and longer [4], [8], [16]. Using their data would have required extrapolation to the much smaller mosquitoes, which are of most frequent occurrence and greatest interest, and to a wavelength of 18.75 mm. Since the double extrapolation was unduly risky, fundamental measurements on mosquito returns were done in the Radar Technical Area at Fort Monmouth. It should be pointed out, however, that the results are consistent with those of other researchers. The technique is described below.

Voltage Standing Wave measurements of several rehumidified dead mosquitoes, live *Culex pipiens*, and accurately sized metal spheres were used to determine corresponding reflection coefficients (ρ). These measurements were made with the standard slotted line techniques at 16 GHz [6], the discontinuities, spheres or insects, being mounted in the center of the guide on polyfoam supports.

Figure 20 shows how the expected radar returns were interpolated from results for the metal spheres. The nomograph is a straight line as the data points all lie close to the Rayleigh region asymptote. We see that the typical expected, weighted, radar returns are equivalent to a metal sphere with a cross-section πr^2 of 10^{-6}m^2 . However, these insect returns were made with the mosquitoes in the most favorable alignment. Consequently, we arbitrarily use the figure of 10^{-7}m^2 as being more typical. This is probably too conservative but is the number used throughout the program.

In Figure 21 the 10^{-7}m^2 mosquito "area" and the 10^{-7}m^2 cross-section for conducting spheres are both normalized to 1. The smooth curve is the classical radar response for the spherical metal targets at the radar frequency of 16 GHz. The histogram is averaged over insects of various lengths, e.g., from 4.5 mm to 5.5 mm for mosquito counts, scaled to the same law. Because the finite variation of insect lengths smooths out most of the fluctuations in the resonance region, only three sample sizes; 5.5 - 7 mm, 7-9 mm, and 9-12 mm, lie somewhat off (and slightly above) the corresponding optical branch. It should be noted that this figure gives expected radar returns as a function of target size, whereas the usual description [17], [18], gives the variation with the radius-wavelength ratio; the actual physical size of the target being suppressed. Thus these references show a constant return to the optical region and 4th power law in the Rayleigh region. It is obvious that, by definition, return is proportional to area (radius² for spheres, length² for insects) in the optical region and similarly the Rayleigh region is transformed from the 4th to 6th power. This gives the more directly useful curves plotted in this figure.

Table 2 gives the actual factors by which weighted insect counts were multiplied to give the estimated total radar return based on the single mosquito as the basic unit.

INSECT SIZE AND CORRESPONDING RADAR RETURN
(Table 2)

Physical Lengths (mm)	Relative Radar Return
1.5 - 2.5	.004
2.5 - 3.5	.047
3.5 - 4.5	.26
4.5 - 5.5	1.0
5.5 - 7	3.5
7 - 9	7
9 - 12	10
12 - 15	7
15 - 20	12
20 - 25	20

APPENDIX III

RADAR B SCOPE ASSAY

The cloud-like behavior of insect masses suggests the data be handled in some statistical fashion. There are a number of ways to do this operationally consistent with the form of all the other data. The technique is to prepare an overlay of little "boxes." Each box includes a small number of resolution cells mapped into the photograph of the radar display. Each box containing some target indication is given one count. This is similar to counting biological cells in extremely dilute solutions. Of course, extending the analogy, these are not dilute solutions. Those familiar with the radar art will also be aghast at the short shrift given to range effects; however, after a great deal of thought, we are convinced that these counts are monotonic with the actual returns. Figure 22 shows such a photo with two overlays, one of which is in position for the count. Most of the 1970 Manahawkin data were studied in this way and the results were a strong influence in the decision to continue the program.

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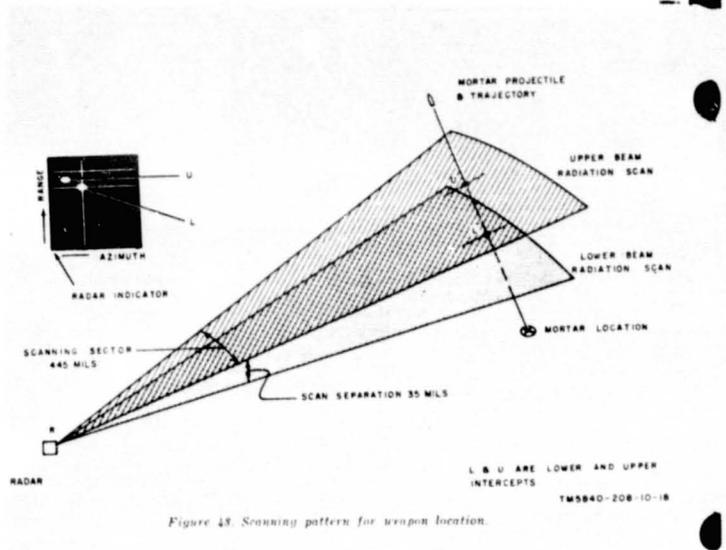


Figure 48. Scanning pattern for weapon location.

Figure 3. Radar scanning and display.

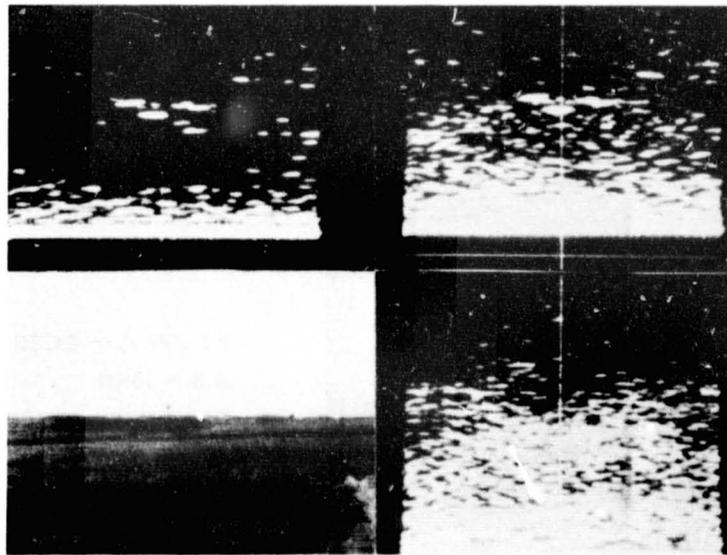


Figure 4. Radar display of insect clutter.

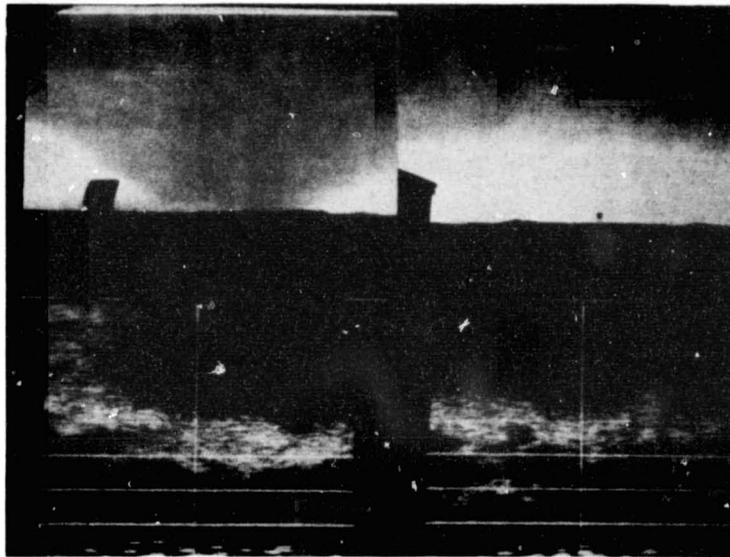
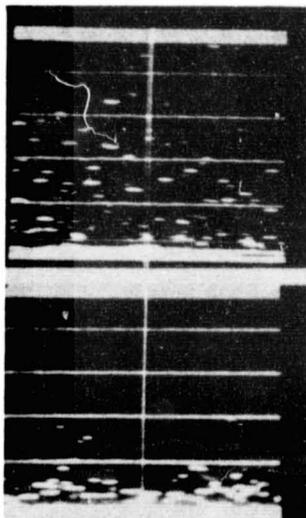


Figure 5. Radar display of weather clutter.



26 APRIL - 2037 - 62° F
 S.S. - 1845
 DAYS HIGH - 1400 - 71° F

27 APRIL - 2020 - 54° F
 S.S. - 1846
 DAYS HIGH - 0900 - 59° F

Figure 6. Variation of insect returns with temperature.

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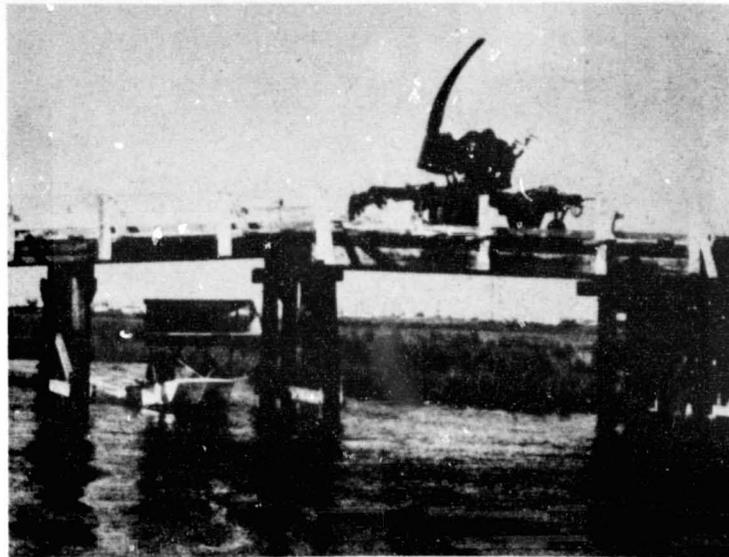


Figure 7. Radar and boat trap, Manahawkin, New Jersey.

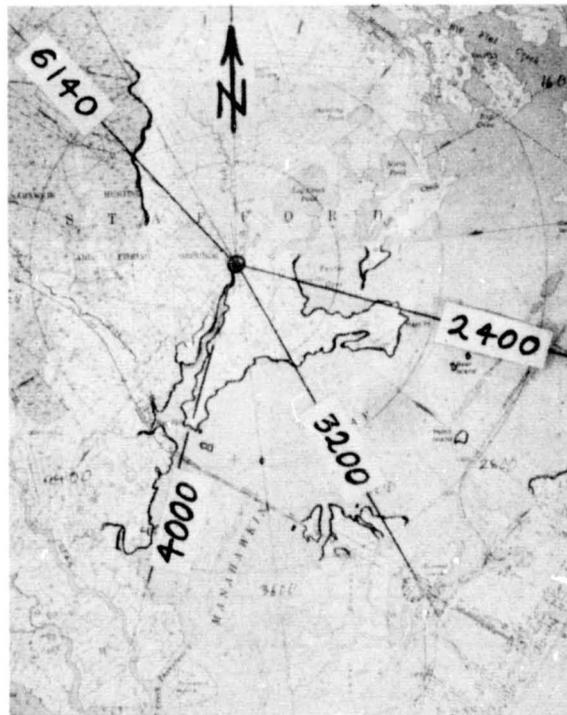


Figure 8. Map of Manahawkin area.



Figure 9. Truck trap, Manahawkin.

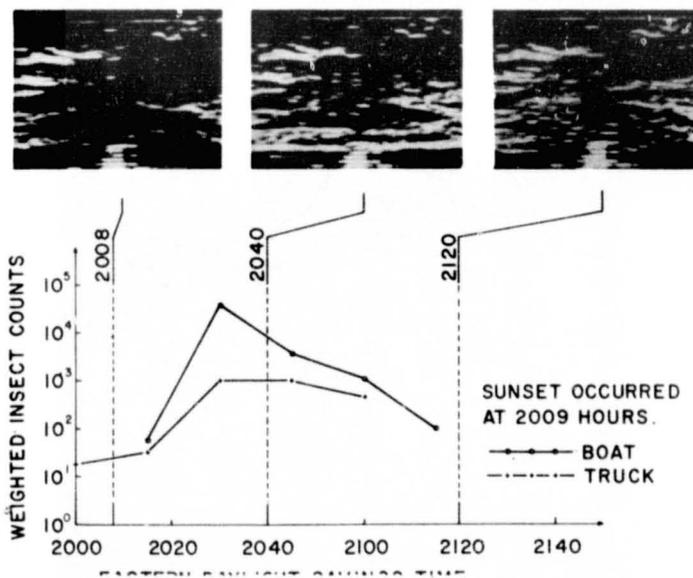


Figure 10. Comparison of truck and boat trappings with radar display, Manahawkin.

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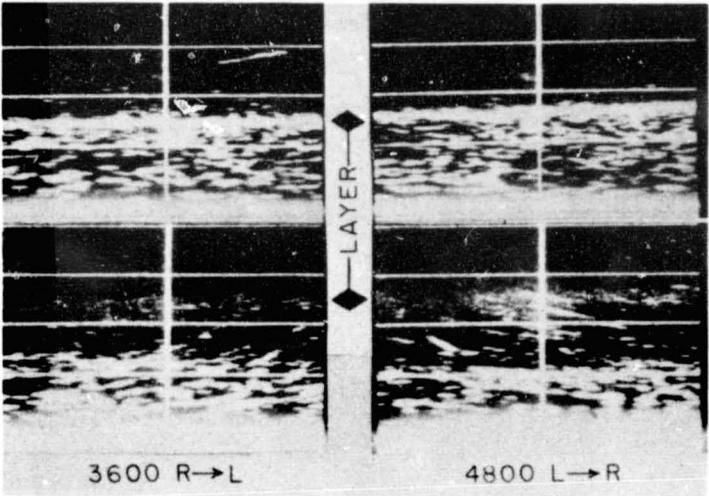


Figure 11. Radar displays showing layering and wind drift, Manahawkin.

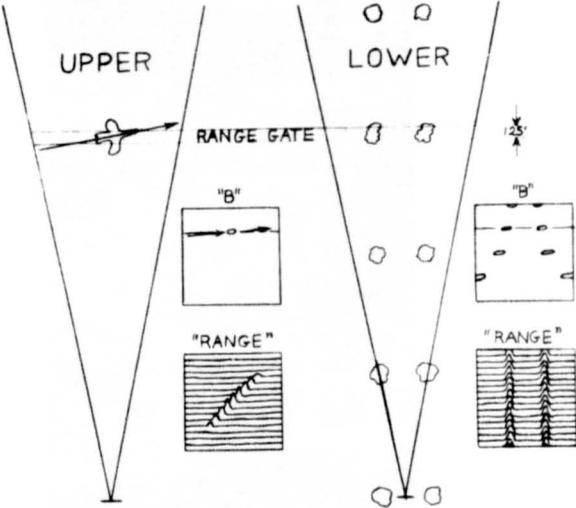


Figure 12. Comparison of "B" and Range Gated Display.

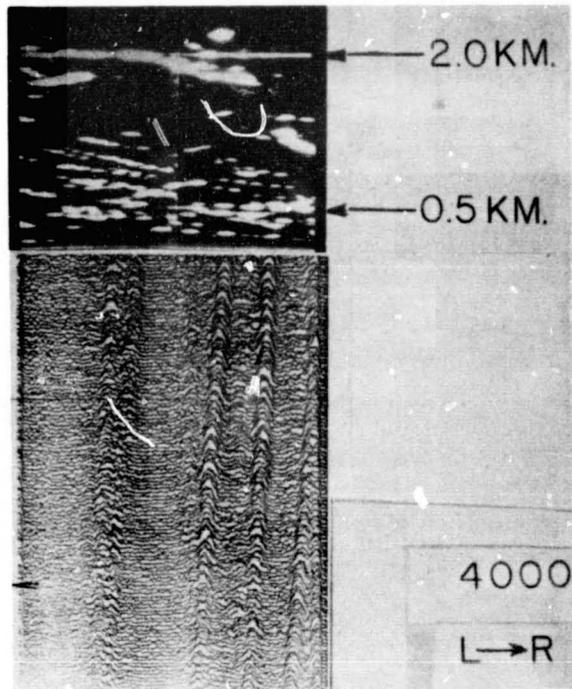


Figure 13. "B" and range gated display showing insect-like motion.

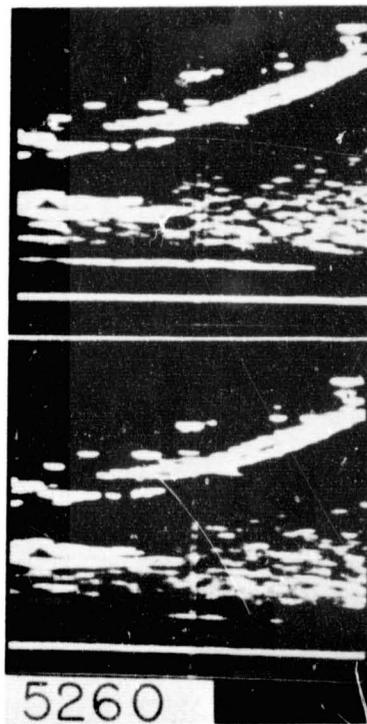


Figure 14. Range gated and "B" displays showing bird motion.

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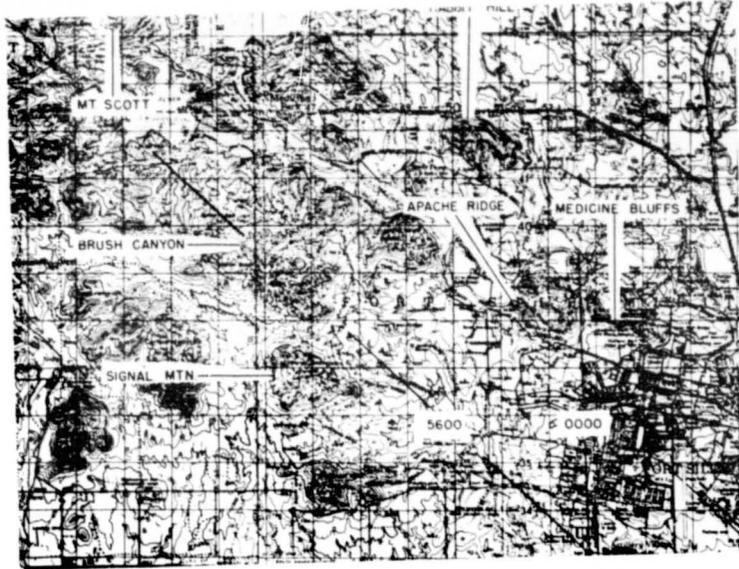


Figure 15. Map of Fort Sill.

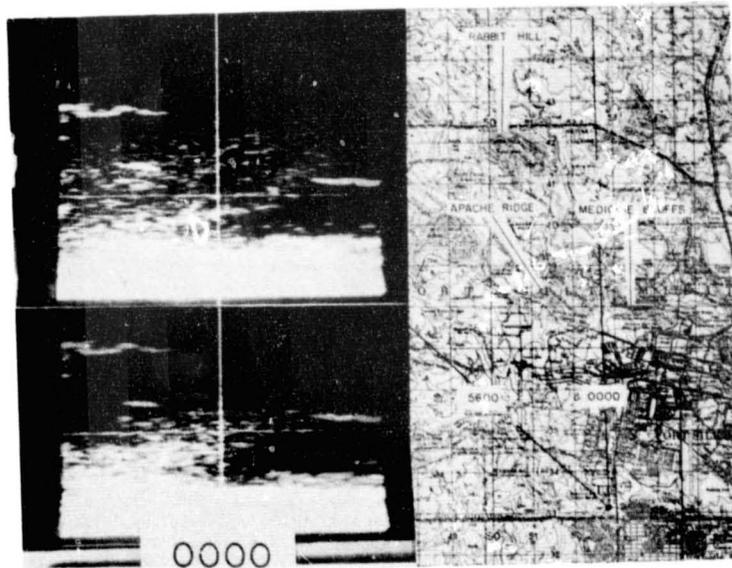


Figure 16. Cloud-like insect motion, Fort Sill.

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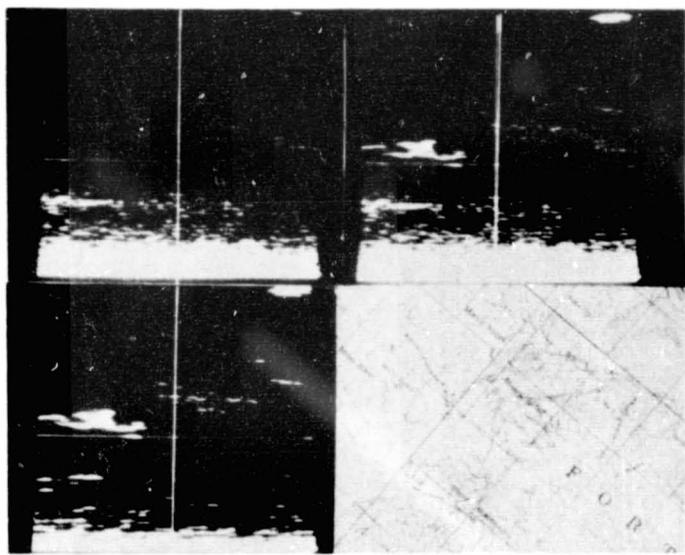


Figure 17. Localized insects, Fort Sill.

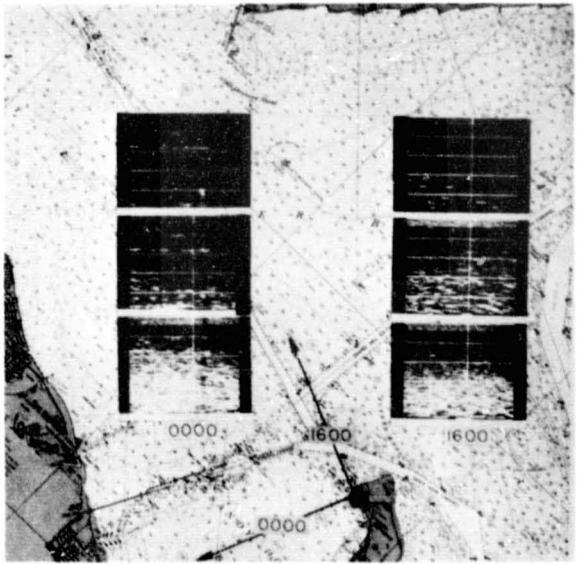


Figure 18. Insects from Staten Island observed at Sandy Hook, New Jersey.



Figure 19. Insects from Northern New Jersey observed at Sandy Hook.

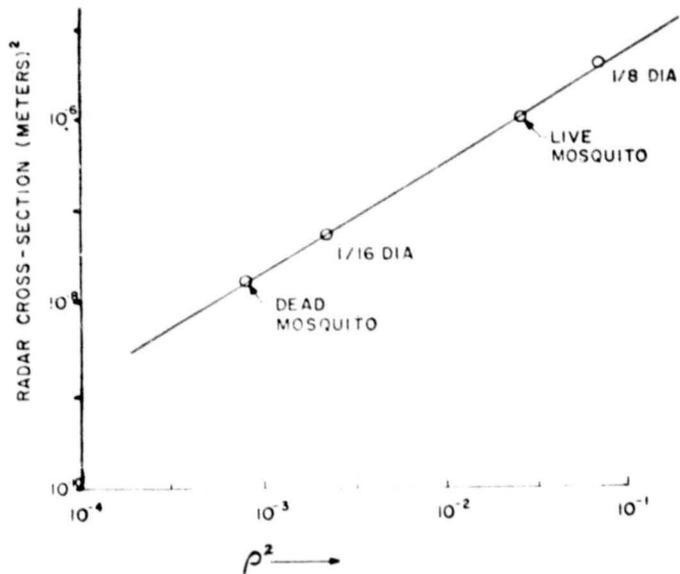


Figure 20. Waveguide measurements of Mosquito reflection coefficient at 16 GHz.

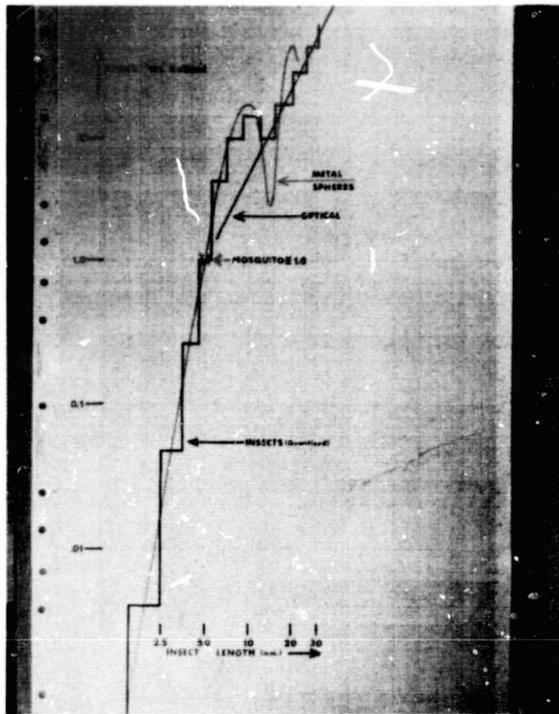


Figure 21. Determination of relative insect cross section or "weight" as a function of body length.

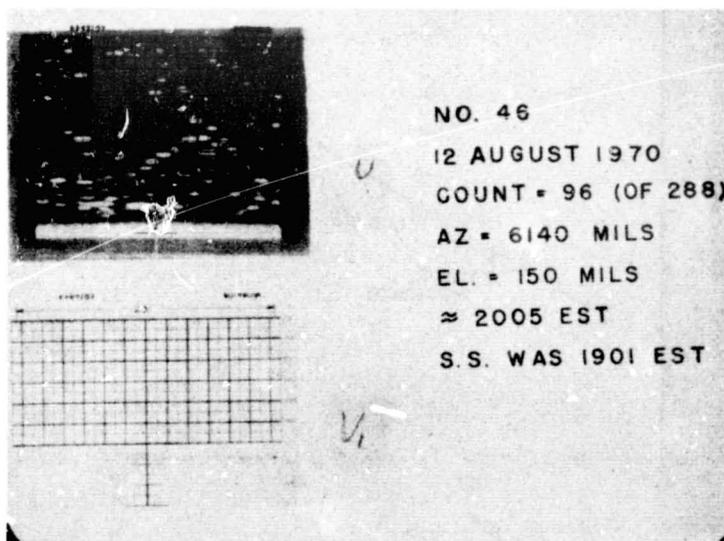


Figure 22. Grid used in radar - insect assay.