Recognizing bird targets on next generation weather radar

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RECOGNIZING BIRD TARGETS ON NEXT GENERATION WEATHER RADAR

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Summary

By 1994, the present weather radars within the United States and at some overseas sites will have been replaced with a network of advanced Doppler radars, the Next Generation Weather Radar (NEXRAD). This paper discusses the final specifications of NEXRAD with respect to its performance in detecting and recognizing bird targets hazardous to aircraft. Techniques are outlined for automatically discriminating bird echoes from echoes caused by weather and for testing the performance of the automatic discrimination.

I. Introduction

A network of large Doppler weather radars is being built to cover the United States and some overseas locations. Because it will completely replace weather radars from the 1950s, it is termed Next Generation Weather Radar (NEXRAD). Although designed to detect weather phenomena, NEXRAD inevitably detects many bird targets as well. In this paper we discuss the characteristics of these large weather radars, their potential to detect various kinds of bird targets, and the status of efforts at the Illinois Natural History Survey (INHS) to implement recognition of bird targets in computer software.

Background information on the general characteristics of NEXRAD and illustrations of the appearance of migratory bird movements on NEXRAD are given in the proceedings of the 18th Bird Strike Committee Europe (DeFusco, et al., 1986).

II. Schedule of NEXRAD installation

A vendor has been selected for the NEXRAD system and final validation testing has just begun:

1988	Installation and final testing of first NEXRAD prototype unit
1990-1991	Installation of units 2-11
1992-1994	Installation of units 12-135, with more units available optionally

III. Characteristics of NEXRAD pertaining to bird targets

Most of NEXRAD's specifications are typical for a large weather radar (Joint Systems Project Office, 1984). The 10-cm wavelength of the radar penetrates cloud or haze yet backscatters strongly off bird targets. This wavelength, however, causes quantitative errors in estimation of the size of bird targets because 10 cm is similar in size to some birds and to body parts of birds.

NEXRAD has ample power and sensitivity for detecting birds at great range (DeFusco, et al., 1986). Birds (and insects) generate strong echoes whenever they fly in view of the radar and are not obscured by nearby ground targets. In some cases, however, NEXRAD electronics will suppress the echoes, as described below. Doppler velocity information on NEXRAD will be available to a range of 230 km, the maximum range over which we expect to be able to analyze bird echoes, although information on echo strength will be available out to 460 km.

NEXRAD projects a narrow 1-degree "pencil beam" that localizes targets in height as well as geographically. However the radar is designed for weather targets and does not permit fine resolution of targets close together in space. For this reason, NEXRAD can follow movements of large numbers or flocks of birds but cannot paint the fine structure of such flocks nor follow small flocks or individual birds. In measuring target velocity, NEXRAD allows 250-m resolution in range over its entire 230-km region of coverage for birds. For measurement of echo strength, the resolution widens to 1 km. As shown in Figure 1, NEXRAD paints with a broad brush (at 60 km the beam is 1 km wide).

NEXRAD radars will be located to provide good coverage for weather targets. In most cases, these sites will also provide good coverage for birds, unless the birds are (1) obscured by large ground targets, (2) so low and distant as to be obscured by the curvature of the earth, or (3) above the radar at elevation angles over about 15 degrees. Ground targets can often obscure such low-flying bird hazards as gulls and blackbirds (Figure 2).

To decrease the possibility that ground clutter would be mistaken for weather echoes, NEXRAD includes two types of clutter-rejection. In some cases, the clutter-rejection also rejects bird targets. In the first, a two-dimensional map of ground clutter is maintained continuously. Stationary targets at low altitude over this map are rejected by a mechanism similar to the circuitry of a classical Moving Target Indicator (MTI). (Stationary targets outside or distinctly above ground clutter are not rejected.) In the second type of clutter rejection, dot-echoes are rejected by a rather complex scheme that searches for single 250-m resolution cells that are much stronger than neighboring cells. Such cells are replaced by their weaker neighbors. In this manner, such isolated targets as aircraft, broadcast towers, single birds, or flocks much under 250 m in size are filtered out of the NEXRAD data. The dot-echo filtering can be switched off but present methods of measuring weather phenomena malfunction when dot-echoes remain in the data.

Targets intermediate between discrete dot-echoes and diffuse or spatially extended bird movements include important hazards to aircraft: birds or bats entering or departing roosts, coasting movements of gulls, large flocks of waterfowl, and sometimes migrating raptors. Figures 3 and 4 illustrate the effect of dot-echo filtering on one such kind of intermediate target, namely flocks of Canada Geese. The dot-echo filtering obviously reduces clutter. However many of the smaller flocks are also filtered out of the image or flicker on and off with successive sweeps of the radar. Larger flocks (Figure 5) prove steady, prominent NEXRAD targets.

Although NEXRAD is computer-controlled and can be programmed to move its antenna in arbitrarily complex patterns, its scanning strategies will be simple, at least during its first years. As NEXRAD searches for bird targets, the antenna will usually move in

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360-degree sweeps in azimuth at increments of one degree in elevation. The maximum elevation will be about 15 degrees.

Both operational and research radars in use today rely on linearly polarized beams. Weather radars normally employ horizontal polarization; tracking radars often employ vertical polarization. In contrast, NEXRAD has a circularly polarized beam. Because circular polarization reflects poorly off flat surfaces, we expect echoes from ground targets, aircraft fuselages, and other surfaces to be attenuated on NEXRAD relative to echoes from cloud droplets, precipitation, and other weather targets. Bird targets are complex in shape and intermediate in size between ground targets and water drops. Bird targets can be expected to suffer some diminution of echo return because of the circular polarization; however, the degree of the effect of diminution of the echo remains open to speculation, as does the sensitivity of this effect to body size, target aspect, and the distribution of bird targets in space. We know of no radar studies of birds in which circular polarization was used. Based on primitive theoretical considerations, we expect that a few dB of echo loss will be incurred because of NEXRAD's circular polarization. Such loss would be a minor factor.

In addition to echo strength and radial velocity of targets, NEXRAD estimates the width of the Doppler spectrum. This estimate should provide an indication of how much the speed of the target varies during the time the 1-degree radar beam scans across the target. Ideally, this spectrum estimate approaches quantitative measurement of the second moment of a sample of the target velocity. The electronic methods used to estimate spectral width in Doppler radars are still in the development stage and presently produce imperfect but useful estimates of variability. We expect spectral width to be greater on average for bird targets than for weather targets. The INHS and the Illinois State Water Survey have been cooperating in studies of spectral width.

IV. Techniques for discriminating birds from other NEXRAD targets

The INHS is developing an algorithm[1] for discriminating birds from other targets such as weather and insects (Mueller and Larkin, 1985). The algorithm will be incorporated into the NEXRAD system after it is completed and is shown to be reliable. Discrimination of target types by the Bird Hazard Algorithm cannot be accomplished using one simple criterion but rather must use a combination of

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[1] An algorithm is a precise procedure for carrying out a task. In this case, the task is recognizing bird targets on NEXRAD and algorithms are coded in a special language called NEXRAD Algorithm Enunciation Language (Joint Systems Project Office 1984, see also Appendix). In fact, the Bird Hazard Algorithm will be implemented as a small number of separate NEXRAD algorithms.

salient echo characteristics. We have identified several salient characteristics, which we call diagnostic variables. Because data on the actual appearance of birds on NEXRAD radars will not be available until about 1989, we rely on data from other similar radars in studies of possible diagnostic variables. The radars, data from which appear in our earlier BSCE contribution (DeFusco, et al. 1986), are Doppler weather radars designed for research. They closely resemble the NEXRAD specifications with the significant exception of linear rather than circular polarization.

The diagnostic variables presently number eleven (Table 1; see also Larkin and Quine, 1987). For some of them (e.g. Date) we can rely on information from published studies of bird movements as well as from long-term data sets available at the INHS and elsewhere. For others (e.g. Spectral Width), considerable basic research must be carried out before we shall have sufficient understanding to use the variable.

Verification of the actual kinds of airborne targets that produce a given region of echo on a large radar is especially important in developing a Bird Hazard Algorithm. We need to be certain which of several kinds of bird and weather targets produce the echoes. Among bird targets, the degree of hazard to aviation depends upon the kind and number of birds present in the air. Whenever possible, therefore, we have deployed ground observers with binoculars to identify and count birds while the radar operates (Figure 5). At night and when birds fly at high altitudes, we have used an INHS transportable tracking radar dedicated to detailed counting and, when possible, identification, of biological targets (Figure 6). With the tracker, we can identify broad classes of targets via wingbeat signatures and using telescopes and a radar-mounted spotlight.

The Bird Hazard Algorithm attempts to distinguish among five classes of radar echoes: weather, insects, migratory movements of mixed species of birds, migratory movements of waterfowl, and local movements of waterfowl. Other target types (for example, blackbirds and gulls) will be added when we have enough data. At least some of the five classes of echoes differ from one another on each of the diagnostic variables. Although a particular diagnostic variable may provide little or no help in making a decision about one class of echo, it may be helpful for another class. For instance, one finds time of day of no help in deciding whether a region of echo is generated by weather but most helpful in deciding whether the echo is generated by migratory passerines.

The computations that automatically distinguish among the classes of echoes rely on a matrix of probability functions, one function for each class of echo for each diagnostic variable. Figure 7 illustrates the data that support the probability functions. An example of a probability function appears in Figure 8. When a diagnostic variable is not helpful for a class of echo, that function equals 1.0. For each echo region, the computer evaluates the matrix of functions and for each class of echo it calculates the joint probability across the diagnostic variables. If the computation succeeds, at least one joint probability will be nonzero and that of the correct class of echo will be larger than the others, thereby identifying the echo.

Although the calculation of 11 statistics on an echo region and subsequent evaluation of 55 to 75 functions seem laborious, the NEXRAD computer will not complain. To illustrate, we can process a an echo region of about 25,000 cells in under 10 seconds, on a minicomputer slower than the one NEXRAD uses.

V. Method of testing the Bird Hazard Algorithm

Because bird targets are in some ways poorly known on 10-cm weather radars and because of the complexity of the algorithm, we subject actual bird echoes to a working computer-coded algorithm. The researcher outlines regions of echo from known targets on a color Plan Position Indicator (PPI) image, using an interactive graphic display (Figure 9). After a region of interest is selected in this way, the computer stores a priori target identification with the description of the region. Computation of the diagnostic variables then proceeds automatically and the resulting joint probability scores are compared with the a priori identification to evaluate the success of the Bird Hazard Algorithm in categorizing the target.

Further work with these algorithms will consist of collecting data to construct and refine probability distributions, extending the algorithm to other classes of bird hazards such as blackbirds and gulls, devising methods to find interesting regions of echo and delineate them automatically for submission to the algorithm, and describing such site-specific diagnostic variables as geographic features and migration timetables.

VI. Acknowledgements

Data were gathered for this research at the U.S. Air Force Geophysics Laboratory, Illinois State Water Survey, Massachusetts Institute of Technology, and National Center for Atmospheric Research. Information on the NEXRAD radar system was provided by the NEXRAD Joint System Project Office. David Brunkow, Eugene Mueller, and Donald Staggs of the Illinois State Water Survey gave indispensible advice and technical help.

The U.S. Air Force and the U.S. Fish and Wildlife Service funded the research. We particularly appreciate the knowledgeable assistance and encouragement of Captain Russell DeFusco.

VII. References

DeFusco, R.P., Larkin R.P. and Quine, D.B. 1986. Bird hazard warning using next generation weather radar. Proceedings of the 18th Bird Strike Committee Europe, Copenhagen, 26-30 May 1986.

Joint Systems Project Office for NEXRAD, 1984. NEXRAD Technical Requirements (NTR). Document R400A-SP-203 (reprinted, May 1985).

Larkin, R.P. and Quine, D.B. 1987. Report on bird movement data. Contract DACA-86-D-001 to the University of Illinois by the U.S. Army Construction Engineering Research Laboratory.

Mueller, E.A. and Larkin, R.P. 1985. Insects observed using dual-polarization radar. Journal of Atmospheric and Oceanic Technology, 2:49-54.

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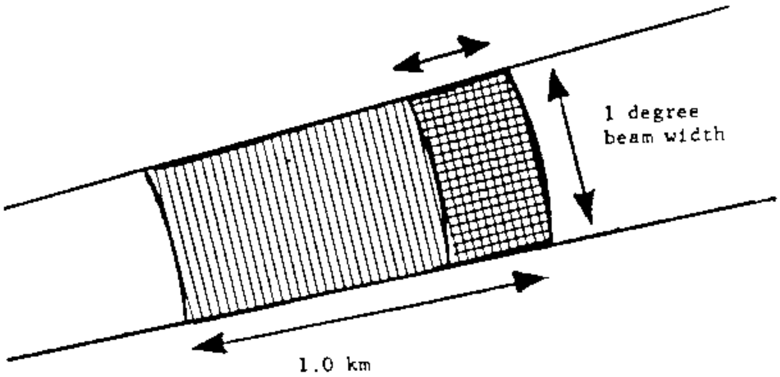
TABLE 1. Diagnostic variables presently in use.

Coverage	Per cent of the echo region filled by targets
Date	Date of the data
Habitat	Codes for large habitat regions: oceans, wetlands, deserts, etc.
Height AGL	Distance from the ground, km
Reflectivity	Echo strength in decibels relative to a standard amount of water suspended evenly in air
Spectral width	Width of the Doppler spectrum, m/s
Stipple in reflectivity	In dB/km, see below
Stipple in velocity	In 1/ms, see below
Stipple in width	In 1/ms, see below
Time of day	Time relative to sunrise and sunset
Velocity	Radial speed, m/s

Note on stipple variables: Cloud, snow, and rain are composed of many tiny scatterers distributed rather evenly throughout the pulse volume of the radar and usually varying only moderately between adjacent pulse volumes. Bird echoes and sometimes insect echoes, on the other hand, are composed of fewer larger scatterers, so that variability occurs from one pulse volume to the next. Stipple measures the "roughness" of the echo region by taking the average of the first derivative of the relevant unit along radial samples of the echo region.

FIGURE 1. Size of a NEXRAD pulse volume.



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ALTITUDE ABOVE RADAR (m)

FIGURE 2. Low-height coverage of the NEXRAD beam.

(Note that X and Y axis scales differ.)

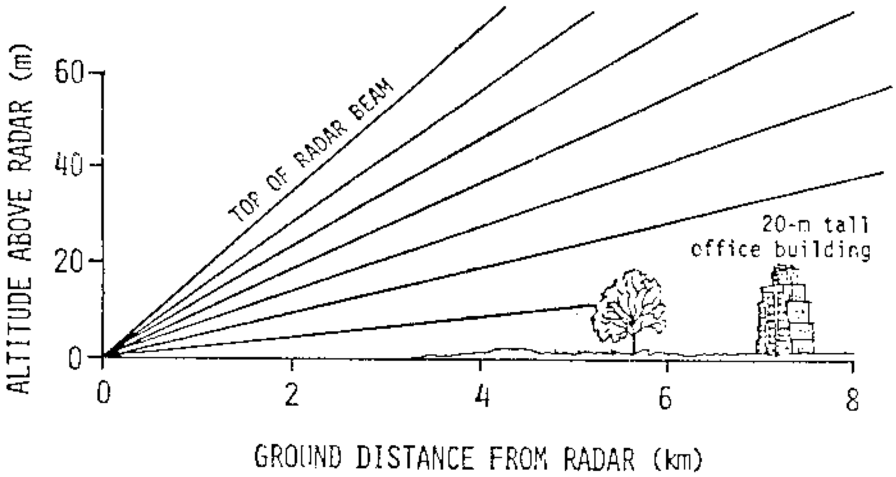
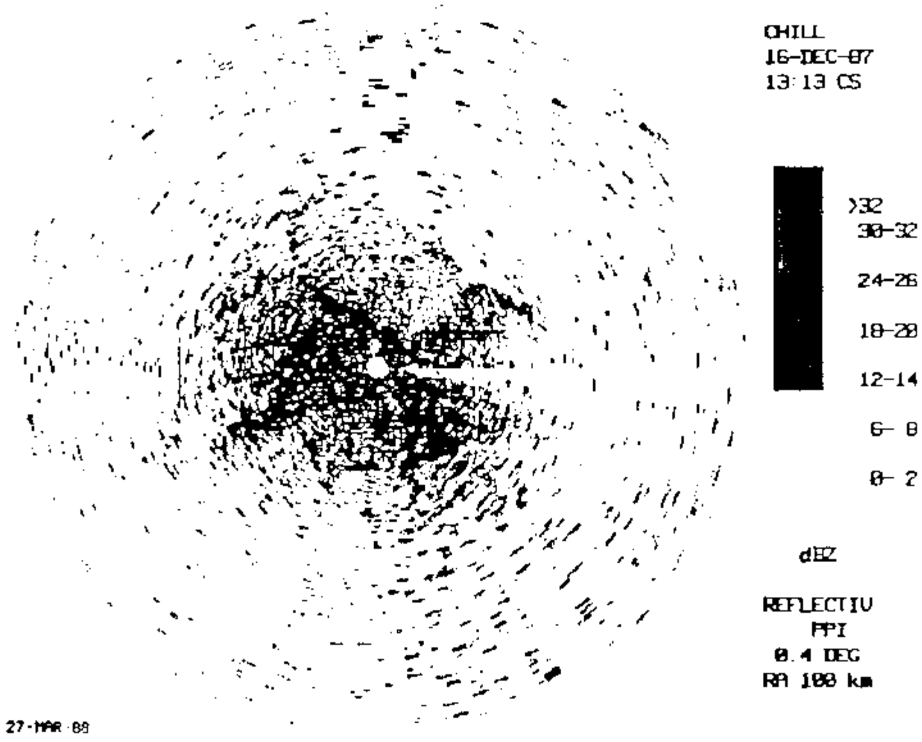


FIGURE 3. PPI of goose flocks from research radar.

The data were taken on 16 December 1987 with the CHILL radar of the Illinois State Water Survey using a gate spacing of 150 m for both echo strength and velocity. Dot-echoes have not been suppressed. Compare with Figure 4.



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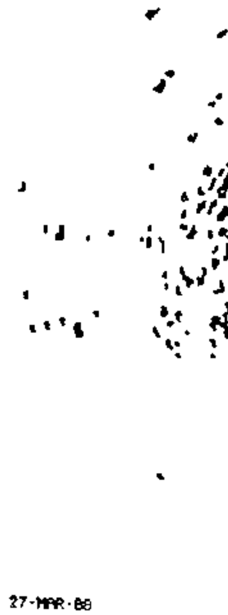


FIGURE 4. ' PPI of goose flocks as seen on NEXRAD.

The data of Figure 3 were processed to produce a close approximation of NEXRAD's gate spacings of 250 m in velocity and NEXRAD's dot-echo suppression.

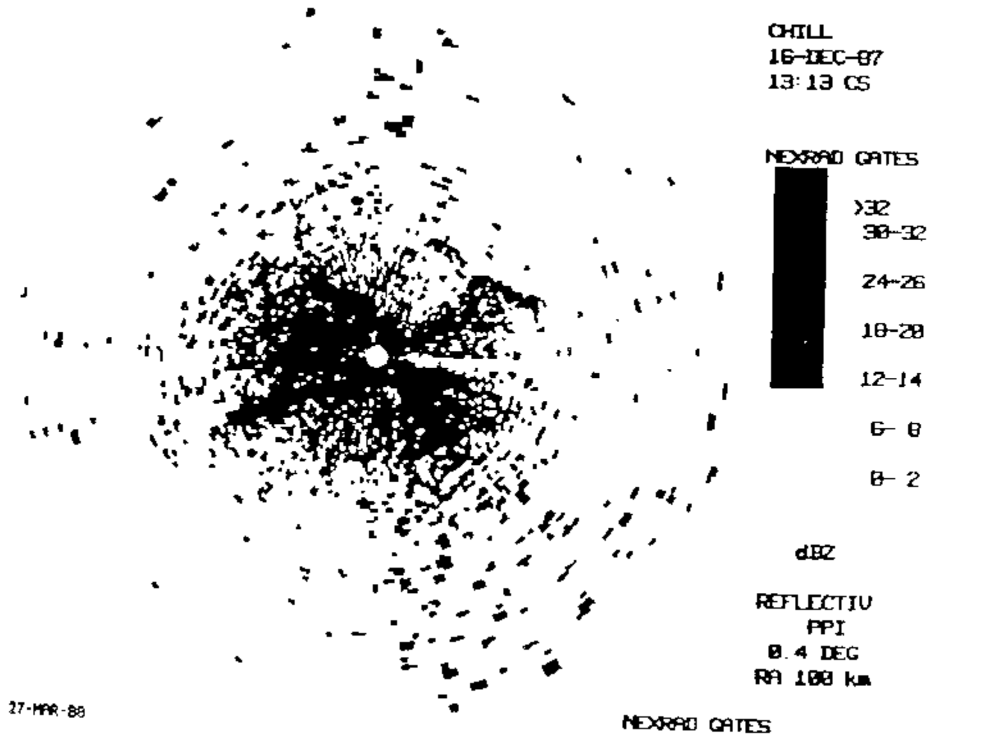


FIGURE 5. Spatial spans of flocks of Canada Geese.

Data were taken by observers with binoculars counting geese (N about 20,000) at Champaign, Illinois. The geese were migrating from Horicon, Wisconsin to southern parts of Illinois and neighboring areas. Spans assume geese flew with their bodies spaced at 3-m intervals.

16 Dec 1987

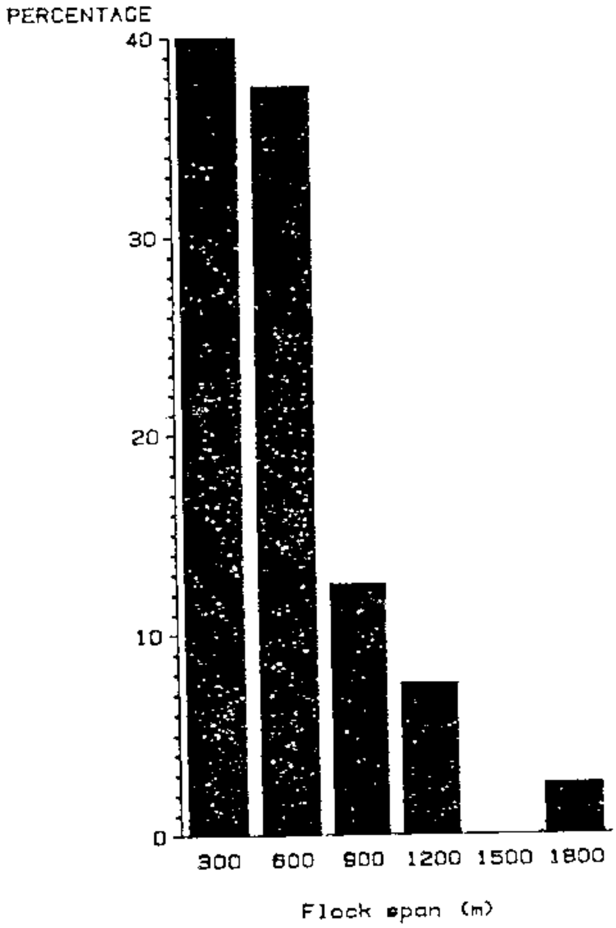


FIGURE 6. Il

FIGURE 6. Illinois Natural History Survey 3-cm tracking radar.

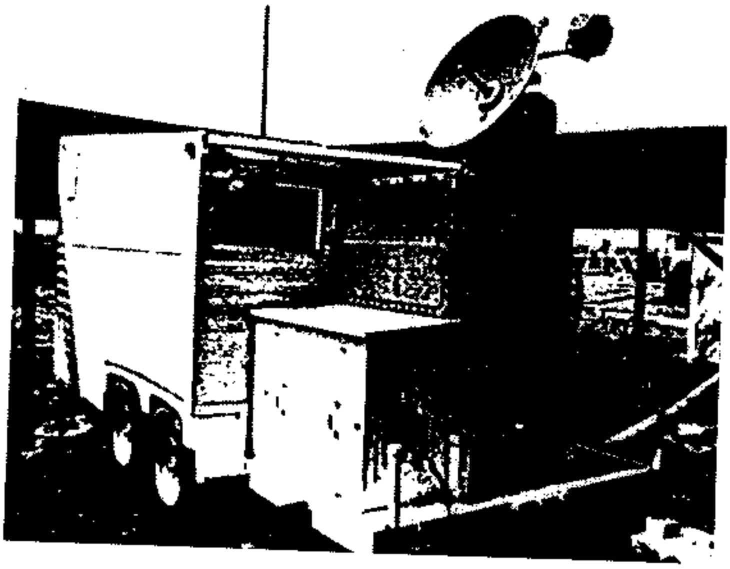


FIGURE 7. Stipple in reflectivity by target composition.

A measure of small-scale spatial variation in amount of returned radar echo for both homogeneous and composite targets. Note that a region of echo that has a score on this diagnostic variable of more than about 3 should be due to a biological target rather than to weather.

	Stipple in Reflectivity, dBZ								
	0	1	2	3	4	5	6	8	12
	N	N	N	N	N	N	N	N	N
Target composition									
All types below	.	.	1	.	.	.	.	.	.
Passerine	.	7	.	2	5	1	.	1	.
Passerine + Weather	.	.	.	.	1	.	.	.	.
Waterfowl	.	.	.	.	2	2	1	.	.
Waterfowl + Passerines	.	2	1	1	3	.	1	.	1
Waterfowl + Weather	.	.	.	.	1	.	.	.	.
Weather	1	8	17	3	.	.	.	.	.

FIGURE 8

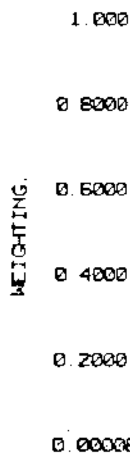


FIGURE 8. Probability distribution for the Date variable for the case of passerine migrants.

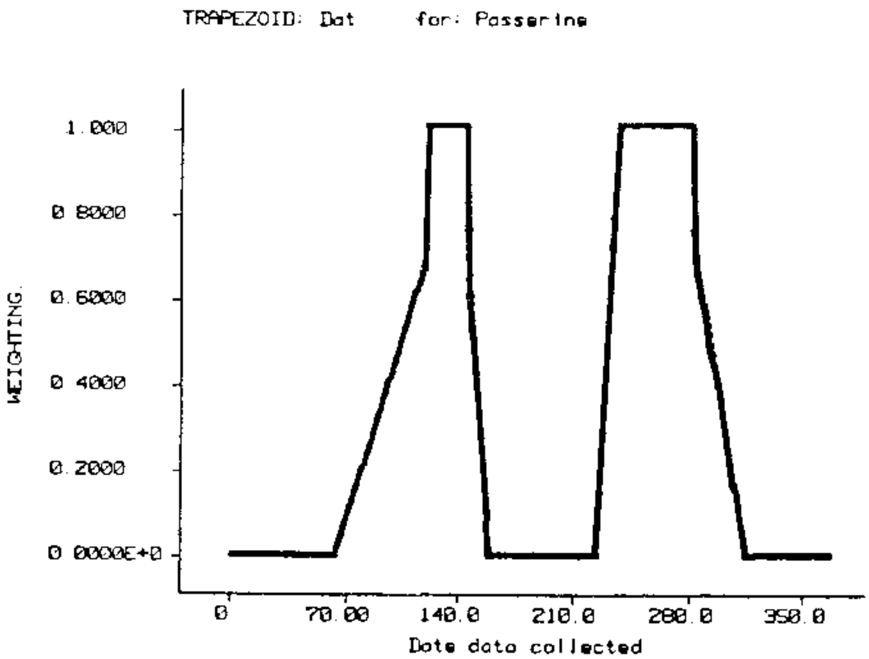
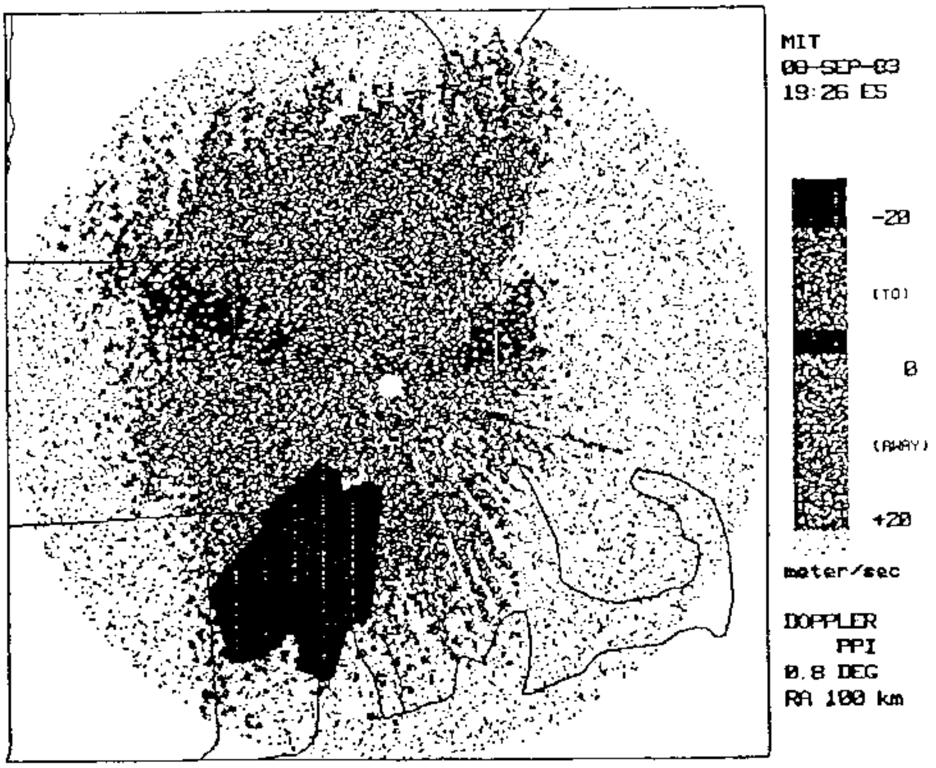


FIGURE 9. Graphical designation of a region of echo for analysis and submission to the Bird Hazard Algorithm.

The image is a monochrome rendition of a color PPI of velocity over the northeastern United States. The radar is located at the Massachusetts Institute of Technology in Cambridge, Massachusetts, at the center of the display. The rectangle is 200 km across. The irregular-shaped area of echo extending out to 40-90 km range is due to migrating birds on a night of normal fall migration. The echo is mostly passerines, but may include some insect echo as well. Echoes to the E and SE are due to tall buildings that reflect and obstruct the radar beam. A dark area to the SSW over the state of Rhode Island has been drawn by the operator to designate a region of receding birds for analysis by the Bird Hazard Algorithm.



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    IF (

    END
END DO
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APPENDIX. Example of Algorithm Enunciation Language

This fragmentary example illustrates the NEXRAD A.E.L. In the full algorithm, the terms are carefully defined prior to being used. The fragment checks to see if an echo region is undoubtedly weather; if so, the geographic area is marked to avoid a probably fruitless search for numbers of birds flying beneath what is likely to be rainclouds.

```
DO FOR ALL (ECHO SEGMENTS)
    IF (ECHO SEGMENT has elements >
                     THRESHOLD(Maximum Bird Height)) OR
        (MEAN REFLECTIVITY(Echo Segment) >
                   THRESHOLD (Bird Reflectivity)) OR
           (At least 1 POSITION (Gage Reports) is beneath this
           ECHO SEGMENT AND NOT (FLAG (No Hourly
           Accumulation) for said position)
       THEN
           Set WEATHER MAP elements beneath echo segment
    END IF
END DO
```