BSCE 18/ WP 7 REVISED
Copenhagen May 1986

BIRD HAZARD WARNING USING NEXT GENERATION WEATHER RADAR

Captain Russell P. DeFusco, United States Air Force
Dr. Ronald P. Larkin, Illinois Natural History Survey
Dr. Douglas B. Quine, Illinois Natural History Survey

HQ Air Force Engineering and Services Center
Tyndall AFB, Florida 32403-6001

Abstract

United States Air Force Bird-Aircraft Strike Hazard (BASH) Team is sponsoring research to utilize an algorithm designed to detect birds on the nation-wide Next Generation Weather Radar (NEXRAD) system currently being developed. A phased approach to the task of algorithm development separates flying radar targets into several classes: waterfowl, passerines, blackbird roosts, gulls, raptors, bats, and insects. Data was collected for all classes and a draft algorithm was prepared for waterfowl in the first phase. A second phase is underway to test the waterfowl algorithm and to draft and compare a migratory passerine algorithm. Research has confirmed that the NEXRAD system can distinguish the different classes of targets and can distinguish birds from weather. Ultimately this system will provide real-time bird hazard warning information on a continent-wide scale.

I. Introduction

A comprehensive new system of weather radars, termed the Next Generation Weather Radar (NEXRAD) is being built in the United States. The NEXRAD system (Figure 1) is designed with the goal of identifying dangerous and economically significant weather patterns automatically, including tornadoes, hurricanes, hail, and flood-producing rains. In 1982, the Bird Aircraft Strike Hazard Team at Tyndall Air Force Base began to investigate the possibility that this powerful radar system could be used to identify birds also. This paper will discuss the potential of the NEXRAD radar system to warn pilots automatically of potentially hazardous flying birds.

Research to determine the feasibility of automatic recognition of birds and to program such ability into the NEXRAD system is being carried out by the Illinois Natural History Survey in Champaign, Illinois, USA.

In the remainder of the paper we describe the essentials of the NEXRAD radar system and its capabilities, show the appearance of some bird targets and weather targets on NEXRAD, touch upon the real time warning aspect of the project and finish with a film of "Ring Angels" on a NEXRAD-like radar.

The Next Generation Weather Radar System presently is in the advanced stages of prototype development, scheduled to be completed in the early 1990's. NEXRAD will be based on a large S-band pulsed Doppler radar with a narrow beam and great power (1 megawatt) and sensitivity (90 dB dynamic range). This radar is pictured as the Radar Data Acquisition Subsystem of NEXRAD. It is important that there are two other subsystems in NEXRAD, the Radar Products Generation Subsystem and the Principal User Processor Subsystem. NEXRAD is designed to be heavily computerized, and all displays of NEXRAD information available to users are derived from computer displays. For automatic processing of weather data, large computer programs are being written to analyze the digital NEXRAD weather data while the data are being acquired and make decisions on hazardous winds and rain. NEXRAD processing will also be available for making decisions on bird targets within the range of NEXRAD radars; because birds usually avoid severe weather, we expect that considerable processing time will be available when severe weather is absent.

NEXRAD radars (about 170 of them) will provide coverage of a large part of the Continental United States. A few other NEXRAD radars will be located at U.S. military installations and NATO facilities outside the Continental United States.

II. Bird Targets on NEXRAD Prototype Radars

Large Doppler radars, similar in characteristics to NEXRAD, are used for meteorological research in several places in the United States. Here we present color images of flying birds on some of these research radars and show that the NEXRAD radar certainly will be able to detect birds and that distinguishing birds from weather is possible.

NEXRAD can detect birds out to remarkable distances. For instance, calculations show that a single Herring Gull would be visible as a faint target at a distance of 450 km. It is clear that other factors, such as interfering ground clutter and the curvature of the earth, are more important then sensitivity in determining NEXRAD's range in detecting birds of this size.

Echos of song birds during migration often extend out to beyond 100 km on NEXRAD images.

In Figure 2, velocities of migrating birds are visible covering much of the New England region. The radar at the center of this image is located at the Massachusetts Institute of Technology and all of the radar echoes appearing on the map are migrating birds. The radar measures the radial velocity of the birds and, because the birds are flying in a southerly direction in the fall, birds on the top half of the image are receding away from it. The speed of these targets, which includes the speed of the wind, is about 13 meters per second.

Sometimes birds appear as complete sheets on these NEXRAD images (Figure 3). The migrants in this image taken from the Air Force Geophysical Laboratory also in Massachusetts, appear in all directions. Because the 4° elevation of the radar slants up through the dense layer of migrating birds, and because the wind is exhibiting shear with altitude, the velocities show that the directions of the higher birds are different from the directions of the lower ones. Note the small cloud somewhat higher than the bird images, to the southwest. The targets in this photograph were more than half waterfowl. This is known from wingbeat records and tracks of individual birds taken concurrently with a small tracking radar unit operated by the Illinois Natural History Survey and co-located with the NEXRAD prototype radar.

We now turn our attention from the general appearance of widespread bird hazards on NEXRAD radars to the potential methods of distinguishing such bird targets from other targets such as weather. Although insects, moving ocean waves, and other kinds of targets must also be discriminated from birds, distinguishing precipitation, clouds, and other weather echos is more important than attempting to assess bird hazards using these radars. As shown in Figures 4 and 5, weather often has distinctive characteristics on radar. These post-cold-front clouds are rather uniform patches of echo extending to rather high altitudes. Often their echos on radar are much stronger than echos of birds because clouds fill huge regions with water, whereas birds package their water in feathery bundles. Clouds also move at the speed of the wind and pay little attention to time of day, topography, or the appropriate migratory direction, unlike birds.

In Figures 6 and 7, images of bird show the opposite characteristics; they are inhomogeneous (a characteristic we have begun to call "stipple"), less intense in their echos, and sometimes following topographic features or other aspects of the underlying geography. Birds also fly with a velocity different from that of the background wind velocity.

In this discussion we have been considering birds as targets and weather as "noise" against which the bird targets should be recognized. However, we can also look at this from the opposite point of view. Most computer programs running at NEXRAD radar sites will be concerned with the recognition of weather targets and will consider targets other than weather to be "noise." In our analysis of bird targets on these radars, we have concluded that many of the methods for automatically recognizing weather features on NEXRAD radars will often be troubled and will sometimes report incorrect results, due to bird targets. In Figure 8 we see an image taken with the research radar operated by the Illinois State Water Survey and the University of Chicago. This image is complex, with a mesoscale structure including precipitation echos to the southeast and a small frontal system extending diagonally across the center of the display toward the northwest. The region of interest in this image is on a line extending from about 045° to about 235°. Note that there is considerable shear along this line. Targets close to the radar, and therefore at low altitudes, are moving away; whereas targets farther out (at high altitudes) are approaching. The opposite is true along the 045° line from the center.

Large differences in wind at different altitudes constitute wind shear. In some situations, such shear can be hazardous to aircraft; however, in this particular situation the "wind shear" is actually "bird shear," due to birds flying in different directions at different altitudes. Thus, we see that bird targets can generate misleading results from weather recognition schemes that do not take the nature of the targets into account.

III. Real Time Recognition of Birds on NEXRAD

The Illinois Natural History Survey is presently engaged in writing computerized procedures, called algorithms, to allow NEXRAD radars to automatically discriminate birds from other targets and to estimate their densities. Presently, a concentrated effort is being made to provide recognition of migrating passerines and waterfowl and of the larger local movements of waterfowl. In future years, this will be expanded to include coasting and roosting movements of gulls and movements of starlings and blackbirds to and from large winter roosts. Unfortunately, NEXRAD radars will be unlikely to detect single flying birds nor to detect birds flying at treetop altitude or lower. Therefore, some classes of bird hazards, such as individual hunting or migrating raptors, will remain undetected and unreported by NEXRAD systems. Nevertheless, warnings of other kinds of bird targets described above should be given in an automatic and timely fashion, with data available about every 15 minutes.

Output from the NEXRAD computers will consist of both printed text messages and images on sophisticated color displays such as those seen in the Figures for this paper. Our present idea is that the NEXRAD radars will report bird hazards with reference to large geographical areas, not pinpoint locations, and to estimate the degree of hazard in different altitude strata over these regions. The U.S. Air Force has the responsibility for communicating future warnings from such summaries to pilots in the air and before takeoff.

IV. Ring Angels on Doppler Weather Radar

Winter roosts of starlings and blackbirds are an important hazard. Large numbers of these birds, up to millions but usually tens or hundreds of thousands, roost together in sheltered areas for extended periods during the winter. In early morning, they take off in massed fashion, with pulses or waves of birds leaving the roost and other pulses following a minute or more later. The clusters present a distinct hazard.

Images taken during a morning in early December in Champaign, Illinois at the Illinois State Water Survey show almost no targets at all before dawn. Operating the radar "on the deck" at minimal elevation, the images show buildings, highways, and hills, but no moving targets except scattered specks. A few minutes later, (Figure 9) we see about 100,000 starlings leaving a roost 10 km north of Willard Airport. Flying in calm conditions, the birds depart almost uniformly in all directions and one can clearly see the waves of departing birds. They are flying at about 50 meters altitude AGL. The birds fly 30 km or more to their feeding areas, returning in smaller, but still hazardous, groups in late afternoon.

One notices that there appear to be fewer moving targets to the South in this "bull's eye" pattern than in the north part. This is because the small cities of Champaign and Urbana have tall targets, namely buildings, and the average speed of a small target such as a bird and a large target such as a building is nearly zero.

These results are encouraging because they demonstrate the potential of NEXRAD Doppler weather radars to observe clear bird hazards even at very low altitude.

Figure 1. NEXRAD (Next Generation Weather Radar) logo.

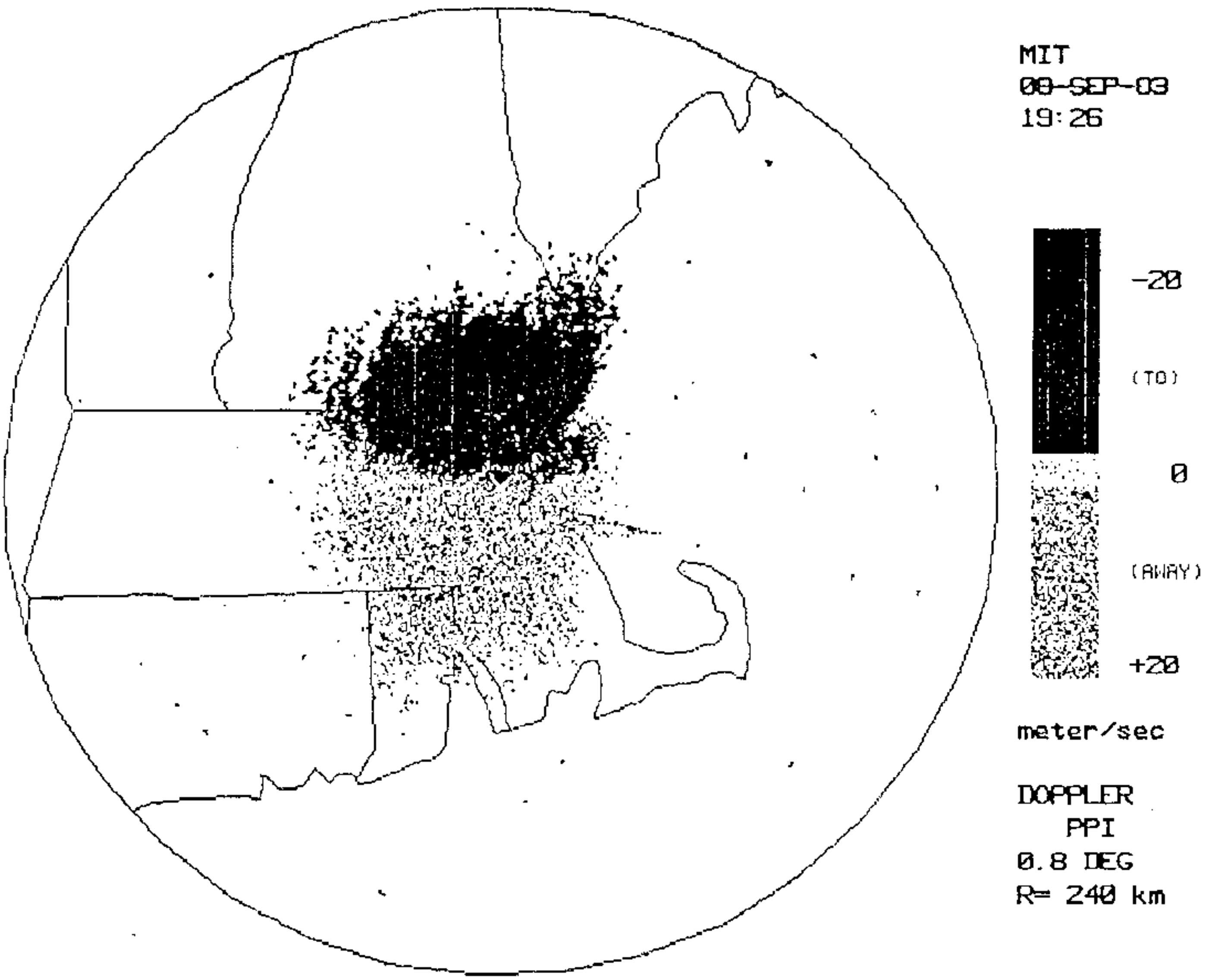


Figure 2. PPI (Plan Position Indicator) of migrating birds flying south over New England. The legend on the right in each of the PPI displays in this paper provides information in the following format:
Radar location (MIT), Date (8-Sep-83), Time (19:26), a bar graph indicating the color codes, the units of data recorded (meter/second), the type of data (Doppler), the type of display (PPI), the elevation angle of the radar beam (0 `), and the range from the center to the perimeter of the display (240 km).

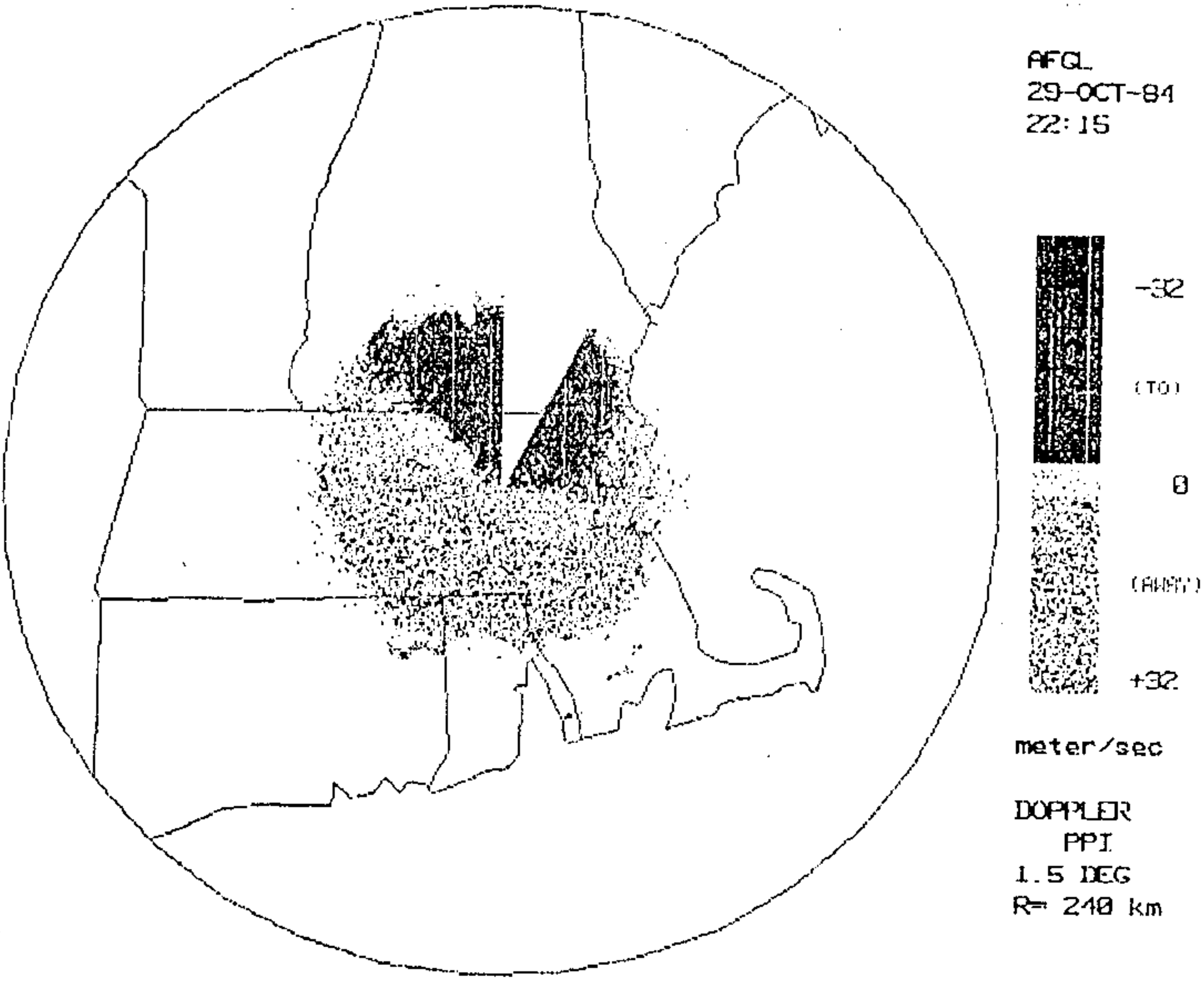


Figure 3. PPI of birds flying south over New England (see text for details). Data were not collected between 0° and 30° (N-NNE).

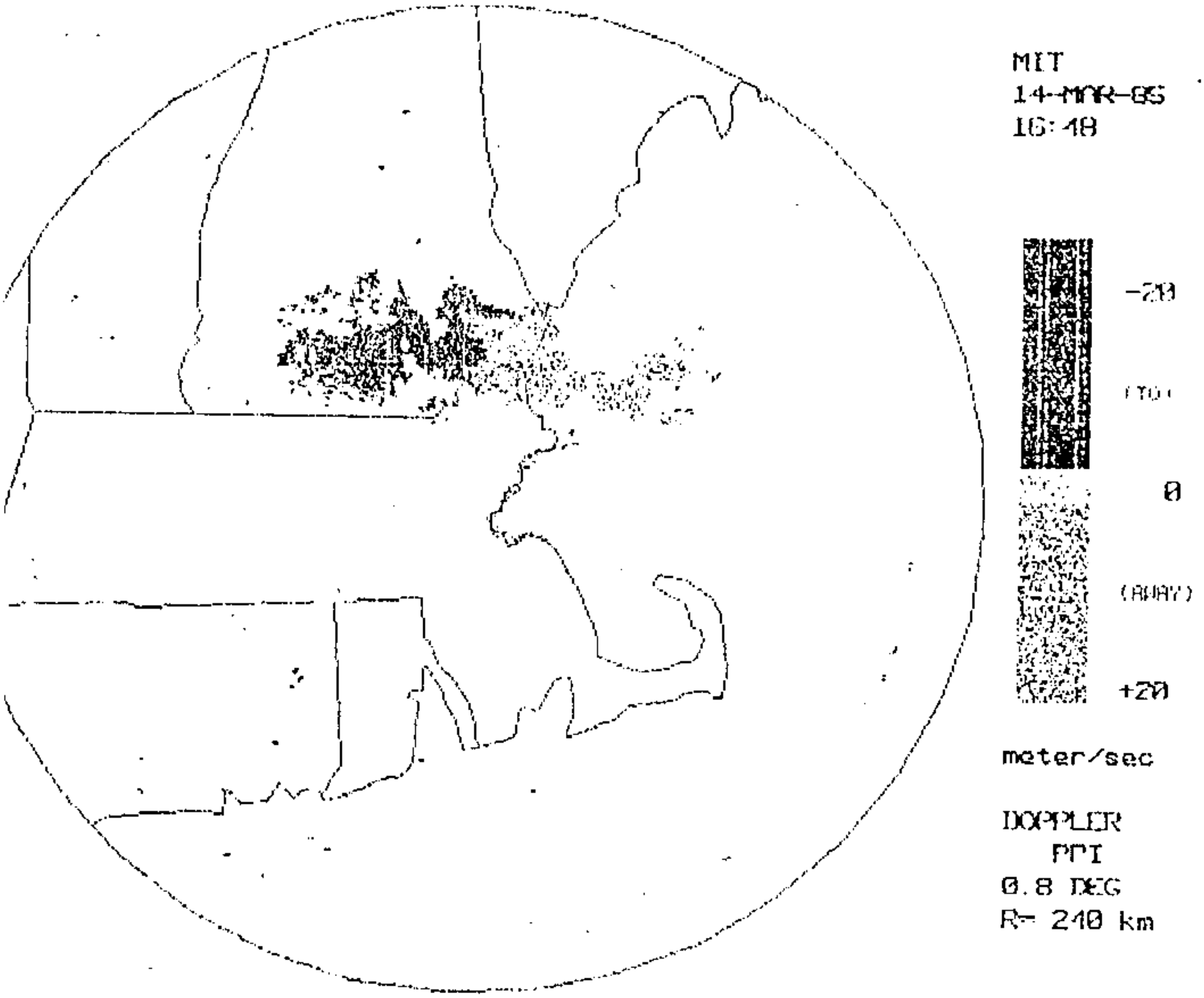


Figure 4. PPI of post-cold-front clouds passing 45 kilometers north of the radar site (see text for details).

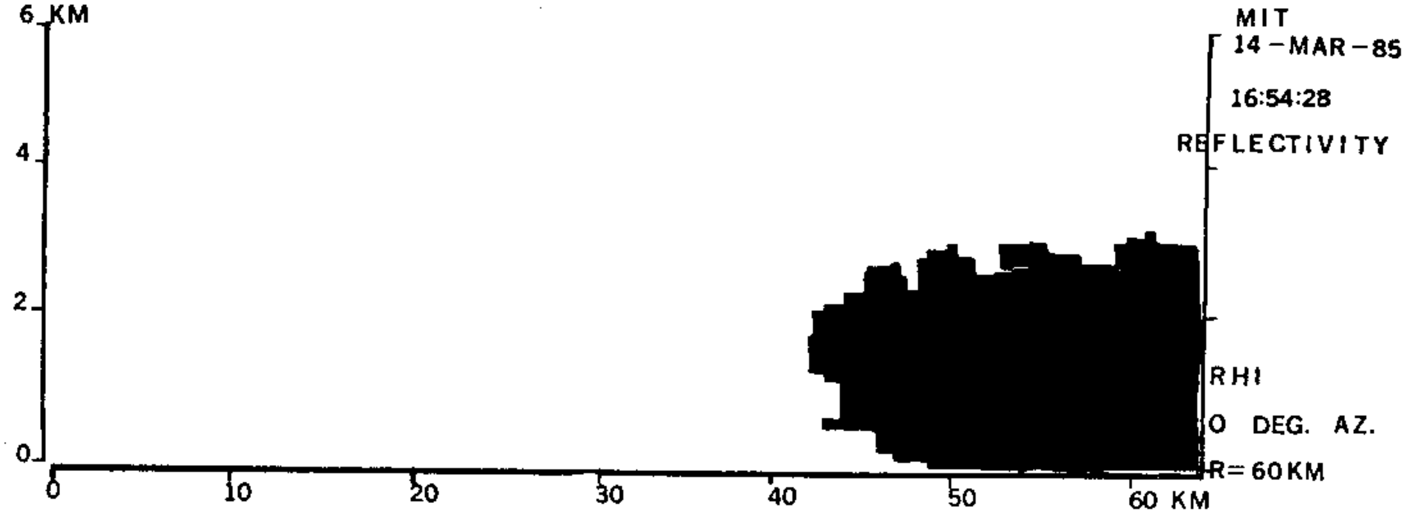


Figure 5. RHI (range height indicator). This display is a vertical cross section of the data shown in Figure 4 going towards the north. The post-cold-front clouds are seen starting at a range of 45 kilometers and extending from ground level to an altitude of 3 kilometers. Reflectivities ranged from 10 to 25 dBZ. The legend on the right in each of the RHI displays in this paper provides information in the following format:

Radar location (MIT), date (4-Mar-1985), time (16:54), type of data (reflectivity), type of display (RHI), azimuth angle of the radar beam (0°), and total range shown (60 km).

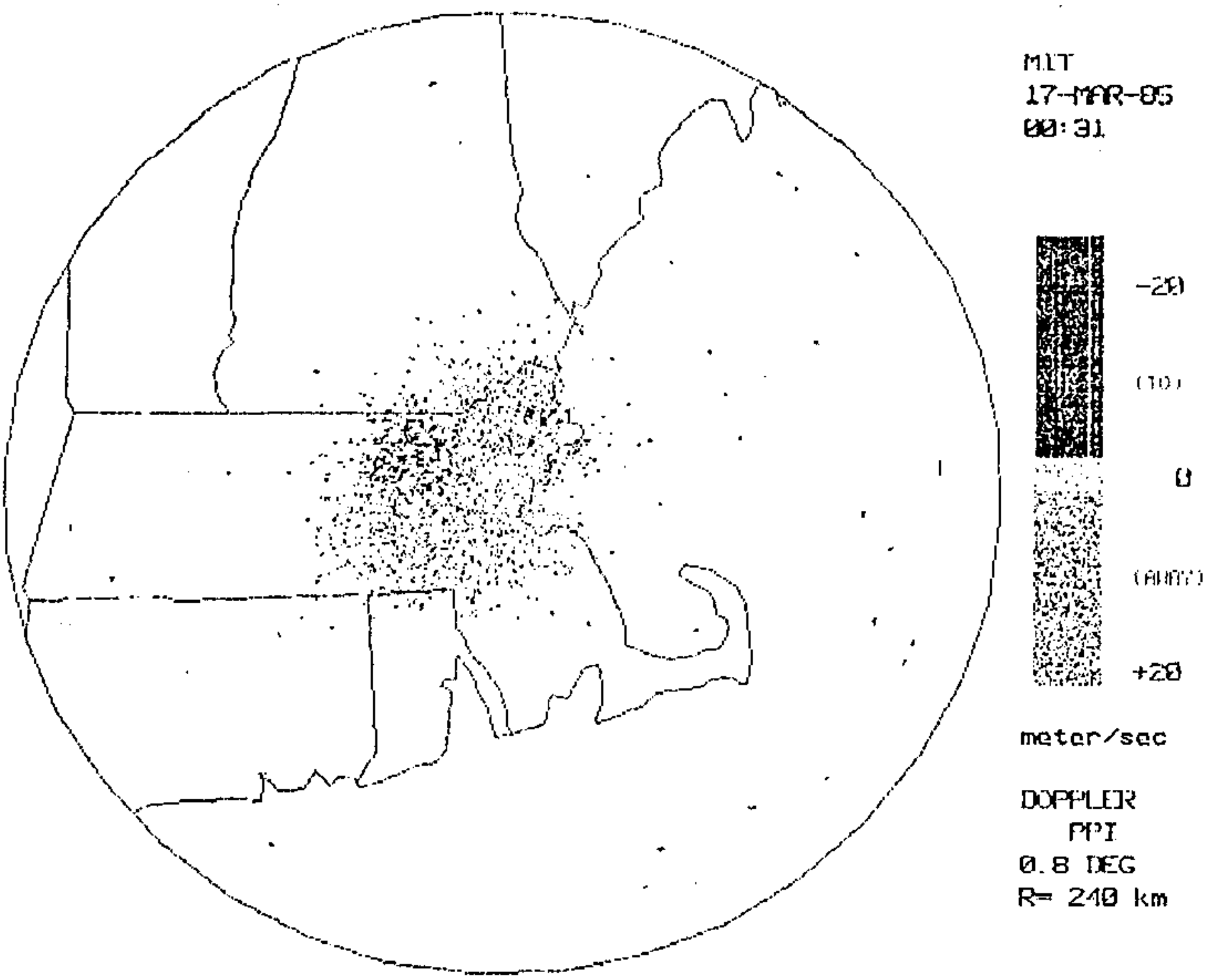
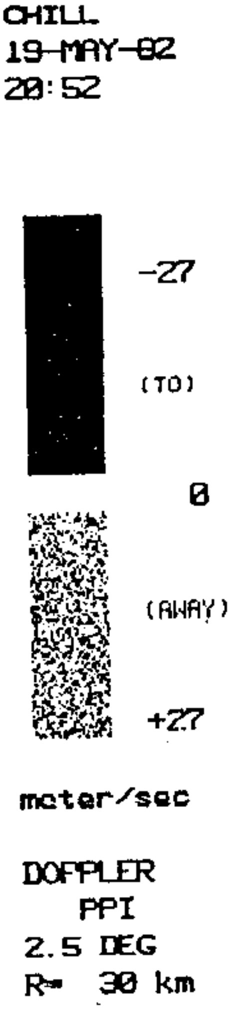


Figure 6. PPI showing characteristically inhomogeneous echos from migrating birds (see text for details).



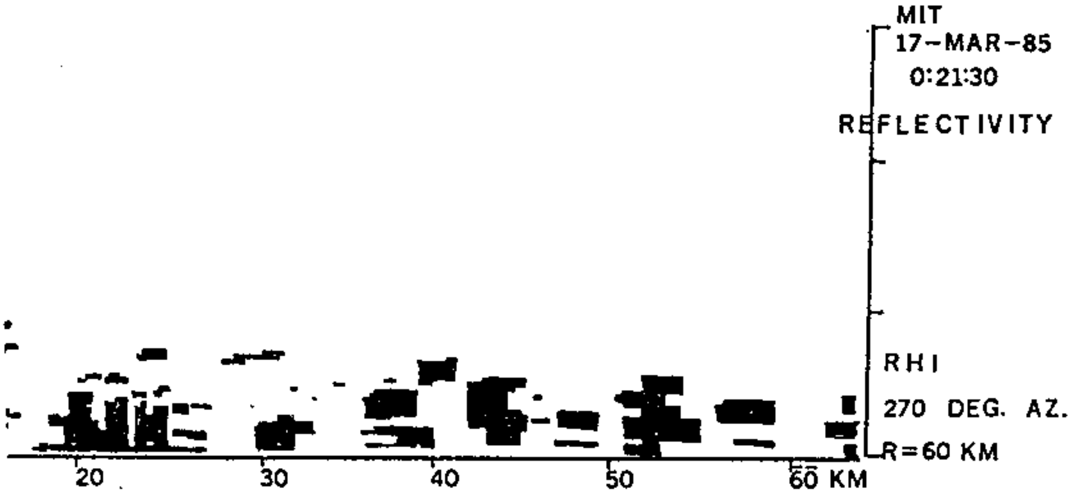


Figure 7. RHI showing a vertical cross section towards the west of the birds shown in Figure 6. Reflectivities ranged from 10 to 20 dBZ.

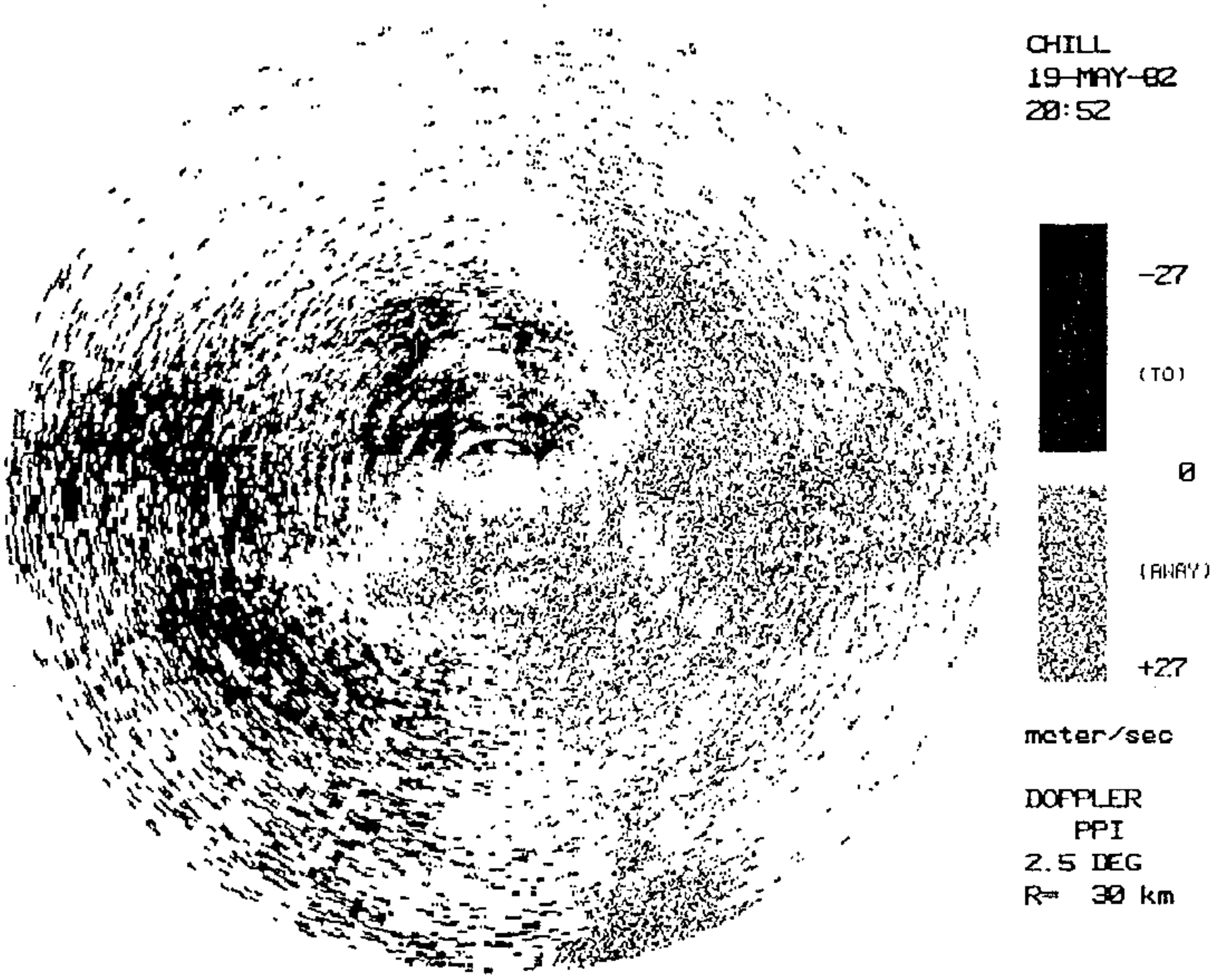


Figure 8. PPI showing "bird shear" (see text for details).

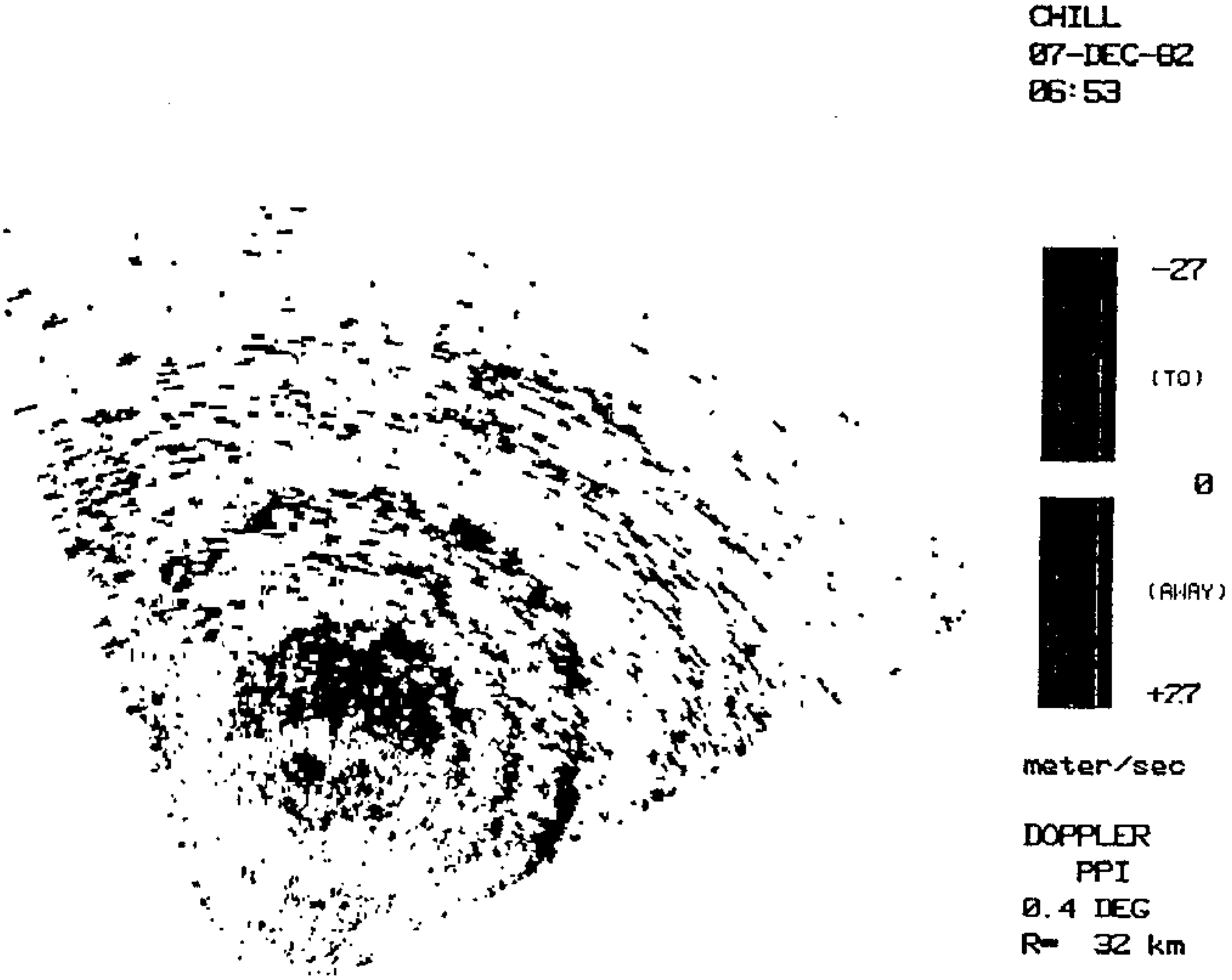


Figure 9. PPI showing approximately 100,000 starlings leaving a roost 10 kilometers north of the CHILL radar in at least 5 discrete waves. These "ring angels" are described more fully in the text.