# Radar Ornithology and the Conservation of Migratory Birds[1]

**Sidney A. Gauthreaux, Jr.[2] and Carroll G. Belser[3]**

## Abstract

It is possible to study with surveillance radar the movements of migrating birds in the atmosphere at different spatial scales. At a spatial scale within a range of 6 kilometers, high-resolution, 3-centimeter wavelength surveillance radar (e.g. BIRDRAD) can detect the departure of migrants from different types of habitat within a few kilometers of the radar. The radar operator can also sample the flight speeds of targets in an attempt to classify birds by their velocity. At a larger spatial scale (10-60 kilometers), Doppler weather surveillance radar (WSR-88D) can be used to measure the density of birds in the radar beam as they begin a migratory movement (exodus) within 60 kilometers of the radar. Within minutes of the onset of nocturnal migration, the distribution and density of echoes in the radar beam can provide information on the geographical sources of migrants on the ground (migration stopover areas), and satellite imagery can be used to identify the topography and habitat type that characterizes these areas. At a continental scale, the national network of WSR-88D radars can be used to monitor bird migration over the United States on an hourly basis at different altitudes dependent on distance from the radar. The latter achievement is significant because it provides a means of monitoring the season-to-season and year-to-year variation in the patterns of migration at different altitudes for different geographical regions and the nation as a whole.

*Key words*: bird, conservation, habitat, migration, radar, scale, stopover areas.

## Introduction

In the early 1940s shortly after its invention, ornithologists began using radar to study the movements of birds through the atmosphere (Eastwood 1967). Investigators began using low-powered surveillance radars (airplane and marine units) to monitor the movements of birds within a range of a few kilometers of the radar in the early 1960s (Graber and Hassler 1962, Casement 1966, Flock 1972, Williams et al. 1972). Since that time, low-powered (5-25 kW) marine radars have been used to monitor bird migration and assess the impact of transmission lines, wind turbines, and other man-made structures on bird movements (Gauthreaux 1985, Cooper et al. 1991, Harmata et al. 1999, Deng and Frederick 2001) and to monitor the movements of endangered and threatened species between feeding and breeding areas (Bertram et al. 1999, Burger 2001). Researchers have also used high-powered weather and airport surveillance radars to detect migrating birds at ranges out to 240 km (Flock 1968; Gauthreaux 1970; Gauthreaux and Belser 1998, 1999; Koistinen 2000) and have used long term data sets to monitor the decline in migratory birds returning from the tropics (Gauthreaux 1992). These studies demonstrate how radar can be used in the conservation of migratory birds, and in this paper we discuss some new approaches to the conservation of migratory birds using radar ornithology.

## BIRDRAD

We currently have four projects with a radar we call BIRDRAD (bird radar). All of the projects emphasize bird movements studied at small spatial scales (within a range of 6 km) but the radar can detect large flocks of birds (migrating raptors) at ranges out to 15 km. The unit is a high resolution, marine surveillance radar (Furuno 2155 BB) with a 50 kW transceiver that transmits at 3 cm (X-band, 9415 MHz ± 30 MHz) wavelength at pulse lengths from 0.07 μsec to 1.2 μsec depending on the range selected (*fig. 1A*). The black box (BB) version eliminates the large radar monitor because the radar processor is in a flat black box mounted on a wall (*fig. 1B*) and the video display can be virtually any size non-interlaced, multi-sync personal computer monitor (CRTs as well as flat panel color LCDs with SXGA – 1280 x 1024 – resolution).

Instead of the slotted waveguide array (T-bar) antenna we use a parabolic antenna (1 m diameter) attached to the transceiver unit by a special mount (*fig. 1A*). This configuration produces a beam of 2.5º that can be elevated from 0º to 90º.

---

[1]A version of this paper was presented at the **Third International Partners in Flight Conference, March 20-24, 2002, Asilomar Conference Grounds, California.**

[2]Department of Biological Sciences, Clemson University, Clemson, South Carolina 29634-0326. E-mail: sagth@clemson.edu

[3]Department of Biological Sciences, Clemson University, Clemson, South Carolina 29634-0326.

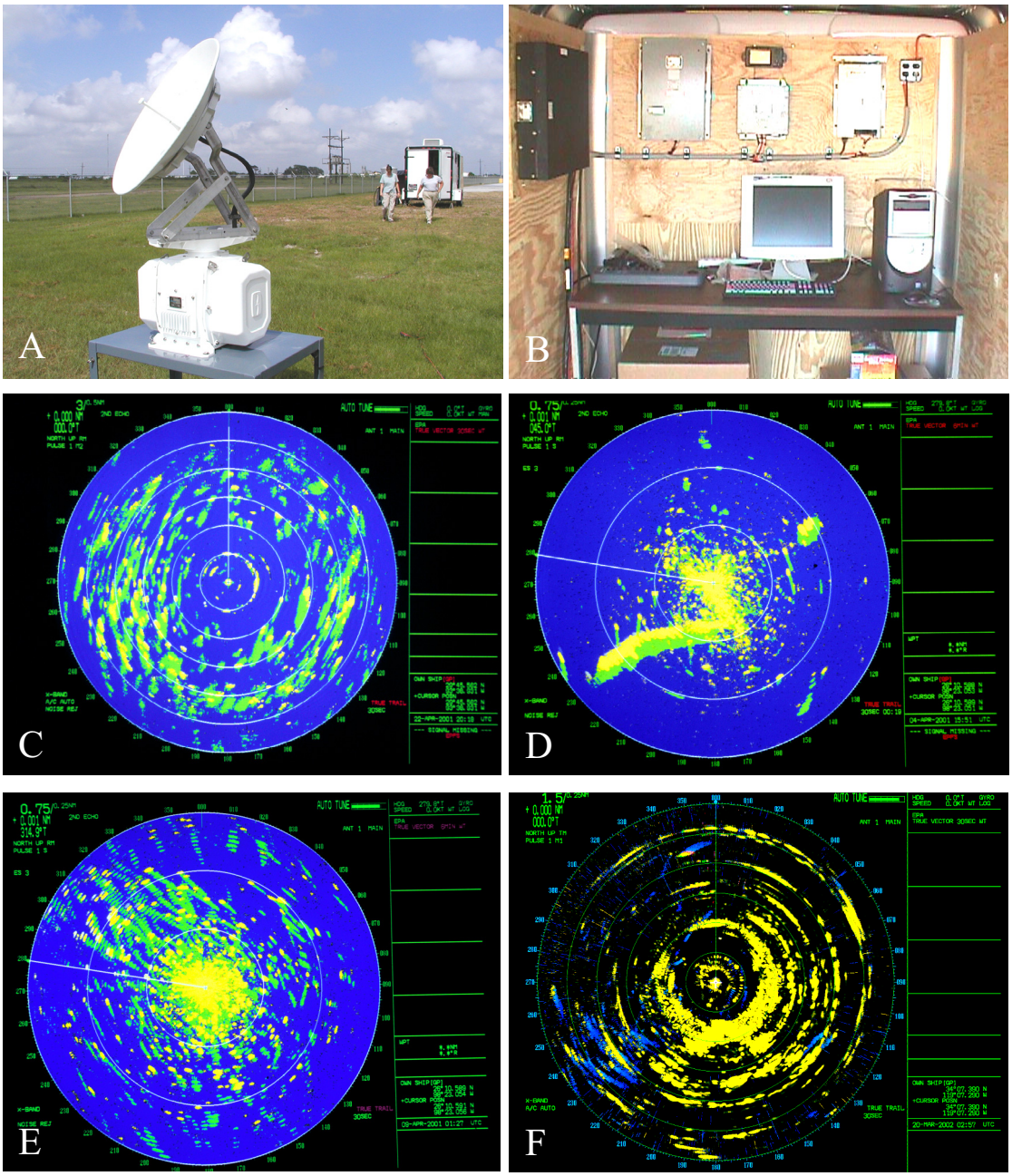


**Figure 1—** The high-resolution surveillance radar BIRDRAD. (A) The parabolic antenna-antenna mount-transceiver attached to metal cart. The transceiver is connected to the radar processor and electrical power with an 18.2 m cable; (B) the black box radar processor is attached to the left wall of the utility trailer and other power packs (e.g., rectifier) and a GPS display are mounted on the forward wall. The radar display controller keyboard, the personal computer, and monitor are on the desktop; (C) a radar image (5.6 km or 3 nautical mile range and 30° antenna elevation) showing the arrival of flocks of trans-Gulf migrants over the southwestern Louisiana coast on 22 April 2001 at 20:19 UTC; (D) a radar image (1.42 km or 0.75 nautical mile range and 22° antenna elevation) showing a stream of migrating raptors during the glide phase over Bentsen-Rio Grande Valley State Park, Texas on 4 April 2001 at 15:51 UTC; (E) a radar image (1.42 km range and 22° antenna elevation) showing the beginning of an exodus of migrants from Bentsen-Rio Grande Valley State Park, Texas on the evening of 9 April 2001 at 01:27 UTC. More bird targets are departing from the area just north of the radar site (above center) where trees have thicker foliage than from the area just south of the radar site (below center) where trees have less foliage and are dying; (F) a radar image (2.84 km or 1.5 nautical mile range and 10° antenna elevation) showing the departure of waterfowl from wetlands to the lower left of the display at Pt. Mugu Naval Air Station, Ventura, CA. In images C-E the echo trail color is green; in image F the echo trail color is blue. Echo-trails are set for 30 sec.

Moving targets on the radar display are readily detected because of the radar's echo-trail feature. The current position of a target is shown in one color while the previous positions of the target are shown in a different color (*figs. 1C-F*). Echo-trail duration can be selected from 30 sec to continuous. Because targets may leave the radar beam before 30 sec or enter the beam after the start of a 30 sec sample, it is not possible to determine the speed of movement from echo trails. It is also possible to plot manually the speed and direction of 10 individual targets on the display using an electronic plotting aid (EPA). A target is marked and then after a period of time (at least 30 sec) the target is marked again and the following data are generated on the display: range, and speed and direction of movement. The radar is also integrated with a Geographical Positioning System (GPS) so that the latitude and longitude of targets under the control unit cursor can be easily determined. All pertinent radar data (e.g., mode, pulse length, echo-trail length, date, time, and GPS coordinates) are displayed as alpha-numerics in the image. Additional characteristics of the Furuno 2155 BB can be found at the Furuno web site (http://www.furuno.-com/).

We record radar images with a frame grabbing board (Foresight Imaging HI*DEF Accura) in a Pentium processor personal computer. Auto-SYNC software automatically configures the HI*DEF Accura board to the radar analog video source and the software also enables individual image capture at original resolution (SXGA – 1280 x 1024). Images are saved in a bitmap file format. We are currently using BIRDRAD to monitor the arrival of trans-Gulf migrants on the northern coast of the Gulf of Mexico (*fig. 1C*), the migration of raptors through south Texas in the spring (*fig. 1D*) and South Carolina in the fall, the exodus of migrants from different types of habitat (*fig. 1E*), and bird movements in the vicinity of military airfields (*fig. 1F*). The benefits of using BIRDRAD to study the movements of birds through the atmosphere outweigh the costs. The radar unit is less expensive (about $30,000 US) than larger more powerful surveillance radars and can be easily moved from location to location and operated on a gasoline generator. Because of the high resolution of the radar (short pulse length and narrow beam width) we can often see the shapes of large flocks and can estimate altitudes of targets. The echo trail and EPA plotting features provide detailed data on the direction and speed of target movement. By using a frame grabber we do not need to photograph the video display. Ground clutter (radar echoes returned from stationary ground objects) can sometimes dominate a display, but it is still possible to detect moving targets (*fig. 1F*). The radar would be more useful if it displayed quantitatively the reflectivity of targets, had moving target indicator (MTI) circuitry that displayed only moving targets without stationary ground clutter, and provided radial velocity of targets. However these features would greatly increase the cost of the radar.

## WSR-88D (Doppler Weather Surveillance Radar)

We currently have two projects that use the WSR-88D. One emphasizes the mapping of migration stopover areas throughout the United States and monitoring input to and output from those areas. The other concerns mapping the distribution and abundance patterns of migration over the United States based on data from the national network of WSR-88D stations. The WSR-88D (referred to as NEXRAD for next generation radar during the developmental and early operational years) has a peak transmitter power of 750 kW and a frequency range of 2.7 GHz to 3.0 GHz (10.3-11.1 cm or S band). The antenna is 9 m and the beam width is 0.96º with pulse widths of 1.57 μsec to 4.5-5.0 μsec. The characteristics of bird echoes on the WSR-88D and its use for studying bird movements can be found in Gauthreaux and Belser (1998, 1999).

### *Migration Stopover Areas*

We use two WSR-88D products: base reflectivity and base velocity images to detect migration stopover areas during spring and fall. The base velocity image shows the radial velocity of radar echoes and is used with winds aloft data to distinguish birds from other reflectors in the atmosphere. The 2-5 reflectivity images that show the beginning of bird migration on a given night and are free of obscuring precipitation or other radar interference within 120 km of the radar are compiled for further processing. Generally from 8 to 17 nights per site per year meet the above criteria. The reflectivity images are then processed to emphasize areas of high relative bird density (birds $km^{-3}$) and the resulting imagery is converted to rectangular raster and imported into ArcInfo. The map showing important migration stopover areas is then compared with land cover maps based on classified Landsat data (*figs. 2A* and *B*).

Preliminary findings suggest that most stopover areas along the Gulf and Atlantic Coasts are associated with floodplain topography and upland areas are used less. Forested wetlands are used almost exclusively as important stopover areas and extensive pine flatlands are rarely used (Gauthreaux, unpubl. data).

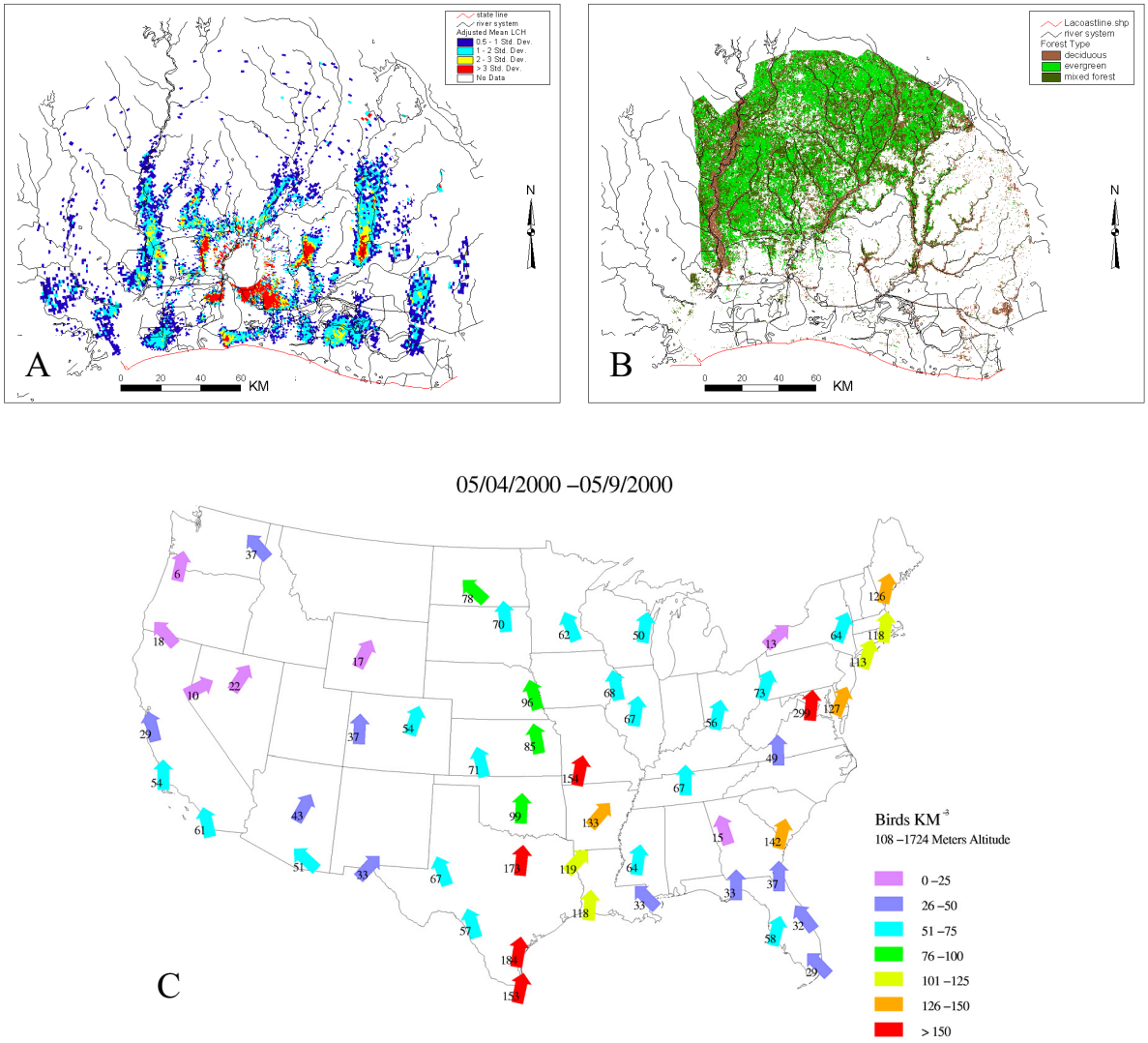


**Figure 2—** WSR-88D migration projects. (A) migration stopover areas based on radar data from southwestern Louisiana collected during spring migration from 1998 through 2001. All the pixels represent bird densities at least 0.5 standard deviations above the mean, (B) classified forest type from LANDSAT data showing deciduous forested wetlands (brown), evergreen pine forest (light green) and mixed deciduous and pine forest (dark green). Migration stopover areas are associated with the floodplain forest, (C) national migration map for the nights 4-9 May 2000 showing the mean density and direction of migration between 108 and 1724 m above ground level. The colors represent mean numbers of birds km$^{-3}$ (see text for additional details).

## *Mapping Patterns of Migration over the United States*

To construct national migration maps of the relative density and direction of bird migration for each night during spring and fall we used two WSR-88D products—base reflectivity and base velocity images. Images were collected each night between 2-3 hours after sunset and near the peak of a night's migration from each of 70 WSR-88D stations near weather stations that measured winds aloft, because winds aloft data were necessary for subsequent processing of radar imagery. Each station reflectivity image was previewed to eliminate those containing obscuring weather or other interference. To determine the extent of insect contamination or other aerial plankton in an image, we used winds aloft data. The tabular wind data from the atmospheric sounding (radiosonde) were converted to raster GIS to produce a wind base velocity product, and this product was used to threshold the radar base velocity raster data. If the mean radial velocity of a resolution cell (pixel) did not exceed a threshold of 10 knots above the radial velocity of the wind, the resolution cell was eliminated. The surviving radar base velocity raster data (containing velocities appropriate for birds) were used to mask the radar base

reflectivity data so that only reflectivity resolution cells containing velocities defined as birds were selected. We then used velocity to infer direction by finding the direction of maximum outgoing velocity within an altitudinal zone (*table 1*) and then calculating the mean number of birds $km^{-3}$ in a 30° wedge centered on that direction. In the map an arrow shows the direction of migration for a radar station, and the color of the arrow indicates the average number of birds $km^{-3}$ in the 30° wedge (*fig. 2C*). As the radar beam moves out from the location of the radar it samples increasing altitudes. Because of the expansion of the radar beam, its tilt, and the curvature of the earth, at increasing ranges the altitudinal strata sampled by the radar beam overlap (*table 1*). Because of this we generate a migration map for each altitudinal zone.

**Table 1—** *The altitudes sampled by the WSR-88D with a 0.96° beam width when the antenna is tilted 0.5° above the horizontal.*

| Range from radar | Altitudes sampled (AAH)[a] |
|---|---|
| antenna to 40 km | antenna height to 754 m |
| 40 km to 80 km | 108 m to 1724 m |
| 80 km to 120 km | 431 m to 2909 m |
| 120 km to160 km | 970 m to 4309 m |

[a]Above radar level

The use of a standardized procedure to generate national migration maps based on radar data will not only document the temporal and spatial patterns of migration for four altitudinal zones nationwide but also permit quantitative season-to-season and year-to-year comparisons among different regions of the United States (Gauthreaux et al. 2003). In the long term the maps can be used to monitor the health of the North American bird migration system.

## Acknowledgments

Radar work at the Clemson University Radar Ornithology Laboratory is supported by the Department of Defense, Legacy Resource Management Program and the Department of the Navy, Naval Facilities Engineering Command Headquarters. Houston Audubon Society provided initial funding for our WSR-88D work along the northeastern Gulf coast of Texas. We wish to thank D. Van Blaricom and A. Cunningham for their work on the file format of the WSR-88D products, development of computer programs and GIS work. We appreciate the helpful reviewer comments from D. Bonter and R. Millikin.

## Literature Cited

Bertram, D. F., L. Cowen, and A. E. Burger. 1999. **Use of radar for monitoring colonial burrow-nesting seabirds.** Journal of Field Ornithology 70: 145-157.

Burger, A. E. 2001. U**sing radar to estimate populations and assess habitat associations of marbled murrelets.** Journal of Wildlife Management 65: 696-715.

Casement, M. B. 1966. **Migration across the Mediterranean observed by radar**. Ibis 108: 461-491.

Cooper B. A., R. H. Day, R. J. Ritchie, and C. L. Cranor. 1991. **An improved marine radar system for studies of bird migration.** Journal of Field Ornithology 62: 367-377.

Deng, J., and P. Frederick. 2001. **Nocturnal flight behavior of waterbirds in close proximity to a transmission power-line in the Florida Everglades.** Waterbirds 24: 419-424.

Eastwood, E. 1967. **Radar ornithology.** London: Methuen; 278 p.

Flock, W. L. 1968. **Monitoring bird movements by radar.** IEEE Spectrum 5:62-66.

Flock, W. L. 1972. **Flight safety aspects of precision radar near air bases in bird-aircraft collision avoidance.** Technical Report No. AFWL-TR-72-25. Kirkland Air Force Base, NM: Air Force Weapons Laboratory, Air Force Systems Command; 66 p.

Gauthreaux, S. A., Jr. 1970. **Weather radar quantification of bird migration.** BioScience 20: 17-20.

Gauthreaux, S. A., Jr. 1985. **Radar, electro-optical, and visual methods of studying bird flight near transmission lines.** EPRI EA-4120, Palo Alto, CA: Electric Power Research Institute; 76 p.

Gauthreaux, S. A., Jr. 1992. **The use of weather radar to monitor long term patterns of trans-Gulf migration in spring.** In: J. M. Hagan and D. W. Johnston, editors. Ecology and conservation of neotropical migrant landbirds. Washington, DC: Smithsonian Institution Press; 96-100.

Gauthreaux, S. A., Jr. and C. G. Belser. 1998. **Displays of bird movements on the WSR-88D: Patterns and quantification.** Weather and Forecasting 13: 453-464.

Gauthreaux, S. A., Jr. and C. G. Belser. 1999. **Reply to Black and Donaldson.** Weather and Forecasting 14: 1041-1042.

Gauthreaux, S. A., Jr., C. G. Belser, and D. Van Blaricom. 2003. **Using a network of WSR88-D weather surveillance radars to define patterns of bird migration at large spatial scales.** In: P. Berthold, E. Gwinner, and E. Sonnenschein, editors. Avian Migration. Germany: Springer-Verlag; 335-345.

Graber, R. R. and S. S. Hassler. 1962. **The effectiveness of aircraft-type (APS) radar in etecting birds**. Wilson Bulletin 74: 367-380.

Harmata, A. R., K. M. Podruzny, J. R. Zelenak, and M. L. Morrison. 1999. **Using marine surveillance radar to study bird movements and impact assessment.** Wildlife Society Bulletin 27: 44-52.

Koistinen, J. 2000. **Bird migration patterns on weather radars.** Physics and Chemistry of the Earth (B) 25: 1185-1193.

Williams, T. C., J. Settel, P. O'Mahoney, and J. M. Williams. 1972. **An ornithological radar.** American Birds 26: 555-557.