HOW TO USE DOPPLER WEATHER SURVEILLANCE RADAR
TO STUDY HAWK MIGRATION

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Abstract

Between 1990 and 1996, the National Weather Service (and the Department of Defense) established a national network of 150 doppler weather surveillance radars (WSR-88D). These radars readily detect migrating birds and display echoes from migrating birds within 111 km (60 nautical miles) in two image types--base reflectivity and base velocity. The reflectivity product provides information on the strength of echoes and the velocity product provides information on target radial velocity and direction of movement. Velocity information is essential for the discrimination of different types of targets (e.g., insects, small birds, large soaring birds). Targets from migrating birds can be made more distinct if the imagery is filtered with a graphics editing program. In this paper we concentrate on the use of the WSR-88D to study migrating raptors, and demonstrate that when weather surveillance radar and direct visual observations are used in combination, one technique supplements the other. Radar can provide excellent information on the distribution of migrating raptors over fairly extensive areas, only semi-quantitative data on numbers of individuals, and little information on the identity of the raptors. Direct visual observations can provide information on identification of migrating raptors and fairly accurate counts of individuals within a distance of 1.85 km (1 nautical mile).


Introduction

Historical Background

Although hawks have been detected during radar studies of bird migration (Gehring 1963, Houghton 1970, Alerstam and Ulfstrand 1972, Evans and Lathbury 1973), the studies of Houghton (1974) at Gibraltar, and Richardson (1975) in Ontario, were the first systematic studies of hawk migration using radar. Subsequently narrow-beam tracking radar was used to study the aerodynamics of raptor migration in New York (Kerlinger 1980, 1982). High-resolution marine radar (with either a parabolic antenna projecting a fixed vertical beam or a slotted wave guide array "t-bar" antenna projecting a wedge-shaped beam rotating in horizontal surveillance mode) was employed to study raptor migration in spring in south Texas and in fall at Cape May, New Jersey (Kerlinger and Gauthreaux 1984, 1985a and b, and Gauthreaux 1985). A discussion of the types of radar that have been used to study raptor migration can be found in a review by Able (1985).
In 1990 the first weather surveillance radar—1988 Doppler (WSR-88D) or Next Generation Radar (NEXRAD) was installed near Oklahoma City, Oklahoma. The new network of approximately 150 radars in the United States was completed by 1996 (Figure 1) and replaced the older network of WSR-57 and WSR-74C radars. The WSR-88D has a wavelength of 11.1 cm with a peak power of 750 kilowatts. The radar has an angular beam width of 0.96° and scans at different antenna elevations and different horizontal surveillance speeds depending on the mode of operation—either a precipitation mode or a clear air mode. In the precipitation mode there are two volume coverage pattern scans: VCP 11 scans 14 elevations in 5 minutes, and VCP 21 scans 9 elevations in 6 minutes. In the clear air mode the two volume coverage patterns scan the same five elevations in 10 minutes, but in VCP 31 a long pulse length is used and in VCP 32 a short pulse length is used.

The WSR-88D receiver captures a returned radio frequency signal (analog, $10^4$ to $10^{16}$ watts) from each resolution cell or pulse volume (1 km x 0.96°), amplifies the returned signal, and sends it to the signal processor. The signal processor transforms the analog signal into three types of basic digital data: base reflectivity (the microwave energy reflected from targets), base velocity (the component of the mean velocity of the targets moving to or from the radar antenna along a radius), and base spectrum width (a measure of the variance of radial velocity from different targets in a pulse volume). Computer processing of these basic data produces numerous meteorological products (Crum et al. 1993, Klazura and Imy 1993, and Crum and Alberty 1993).

Since 1992 the WSR-88D has been used to study bird movements in the atmosphere (e.g., Gauthreaux and Belser 1998, Russell and Gauthreaux 1998,) and a few investigators (e.g., Frank Peace) have used the equipment to study raptor migration (Beasley 1999, Byland 1999). Because of the availability of WSR-88D imagery over the Internet, it is now possible to monitor raptor migration within 60 nautical miles (111 km) of a radar station. Here, we discuss how this can be done.

Methods

Radar Data

To detect and monitor raptor migration on the WSR-88D one must have both base reflectivity and base (radial) velocity data. The best source of WSR-88D data on the Internet is WeatherTAP.com. In 2000, access to the WeatherTAP data cost $5.95 per month or $63 for a year. One can access approximately 150 individual WSR-88D sites for real-time data (base reflectivity, radial velocity, echo tops, precipitation totals, VAD wind profile, vertically integrated liquid, composite reflectivity), and national, regional, and state radar images. For each radar site it is also possible to download loops of base reflectivity and base velocity (animated GIFs of eight different images). The time span covered by the eight images depends on the frequency of imagery and is ultimately dependent on the mode of radar operation—precipitation or clear air. A software package (Animation Shop 3 by Jasc Software, Inc.) can be used to separate and save the individual GIF images for further analysis. A radar tutorial is also available at the WeatherTAP site. In addition to radar data, the site contains current weather and forecast data.

Another Internet site for WSR-88D data is WSI Intellicast (www.intellicast.com). Although the site is an excellent source of WSR-88D base reflectivity imagery, the
Figure 1. The distribution of WSR-88D radars in the continental United States. The coverage pattern for a radar is the distance at which the center of the radar beam reaches an altitude of 10,000 feet (3048 m) when the beam is elevated by 0.5°. Blockage by buildings and mountains will modify this coverage.
"base velocity" image shows storm relative mean radial velocity (SRMRV) instead of base velocity and is unsuitable for studies of bird movements. The SRMRV product provides an estimate of the mean radial velocity with the storm motion removed. We have noted that this algorithm can alter the actual direction of bird movements in the imagery. Moreover, SRMV is only available when the radar is in "precipitation mode" and not available in "clear air mode."

Filtering of WSR-88D Images

Because the WSR-88D is extremely sensitive, it can detect dust and smoke particles as well as insects and birds in the atmosphere. Occasionally high numbers of weak targets in a base reflectivity image obscure the targets of interest, and it is necessary to filter the radar image so that the desirable targets are more evident. We recommend the use of Paint Shop Pro 6 (Jasc Software, Inc.) to accomplish this task. Once the GIF image file is opened in the application, choose the Colors menu and click on Edit Palette. Once the Edit Palette frame is opened, the "dropper" tool can be used to select the color to be filtered in the radar image and that color is highlighted in the Edit Palette frame. When the highlighted color in the Edit Palette frame is double clicked a new Color frame appears with the original color highlighted. A new color selected in the Color frame will replace the original color. If the background color of the image is black, click on the black square, and the original color will be changed to black. If the background color is white, then white should be selected. If the color change is satisfactory, click OK and the change will be saved.

Base velocity or radial velocity information is very important for the determination of target identity. Targets with a component of their velocity moving toward the radar have negative radial velocity codes because their range is decreasing. Targets with a component of their velocity moving away from the radar have positive radial velocities because their range is increasing. The radial velocity of a target flying along a radial to or from the radar antenna is true ground speed. The radial velocity of a target flying at 60° relative to a radial is only 50 per cent of true ground speed, while the radial velocity of a target flying perpendicular to the radial is zero.

The radial velocities of migrating birds are higher than those of insects, dust, and smoke particles. If targets are moving against the wind or moving faster than a tailwind, they are likely birds. When slower moving targets are numerous they can obscure targets of interest in base velocity images. In such cases we routinely filter the images in an effort to enhance the appearance of targets of higher velocity. The filtration process is the same as that for filtering reflectivity images.

Results

A demonstration of filtering base reflectivity images can be found in Figure 2. The upper image is unfiltered and shows a Corpus Christi, TX, WSR-88D base reflectivity display for 26 September 1998 at 18:31 UTC (13:31 CDT). The radar is operating in precipitation mode (VCP 21) and shows numerous reflectors in the atmosphere. Note that the relative reflectivity scale begins at 5 dBZ. It is difficult to see the stronger targets produced by migrating raptors because of the abundance of targets of lower reflectivity. The lower image of Figure 2 shows the display after all targets of 5-15 dBZ have been filtered using the Paint Shop Pro procedure. The echoes from streams of migrating raptors are clearly evident and extend out to nearly 60 nautical miles (111
Figure 2. Base reflectivity image of Corpus Christi, TX WSR-88D on 26 September 1998 at 18:31 UTC. Upper image unfiltered and lower image filtered.
kilometers) to the NNE and SW. Range rings are at 30 nm (55 km) intervals and radial markers are every 30° of azimuth.

The imagery in Figure 3 shows the base velocity data that corresponds to the base reflectivity data in the imagery of Figure 2. The upper image of Figure 3 is not filtered and all velocity categories are displayed. In the lower image the bins for 0 to 10 knots (0 to 18.5 km hr⁻¹) and -1 to -10 knots (-1.9 to -18.5 km hr⁻¹) have been filtered. Once the slow moving targets have been eliminated, the streams of migrating raptors are clearly delineated as they move from NNE to SW. Compare the filtered (lower) images in Figures 2 and 3.

The largest Broad-winged Hawk (Buteo platypterus) migration of the fall of 1998 at the Hazel Bazemore hawk watch near Corpus Christi occurred on 26 September. On this date 306,991 raptors were counted and 306,767 of those were Broad-winged Hawks (see report of Jeff P. Smith and Joel Simon in Beasley 1999). The raptor migration detected on this date by the WSR-88D at Corpus Christi also was the largest movement detected by the radar for the season (Figures 2 and 3).

In Figure 4, the upper image shows streams of migrating raptors displayed in the base reflectivity image from Brownsville, TX, on 4 April 2000 at 17:18 UTC (12:18 CDT). On this occasion there is relatively little return from other targets in the atmosphere (weather conditions are not favorable for the northward migration of non-soaring birds and insects), and no filtering is required. The lower image of Figure 4 shows the base velocity product that matches the base reflectivity product above. In this image we see that the streams of raptors are moving toward the NNE and against the atmospheric flow as indicated by the movement of numerous targets from NNE to SSW. On this date winds aloft from Brownsville, TX, measured with radiosonde at 12:00 UTC (07:00 CDT) between 9 m and 1090 m (30 - 3576 feet) ranged from 360° through 23° at velocities from 7 to 27 knots (13 to 50 km hr⁻¹). Twelve hours later the winds between 11 m and 1250 m (36 - 4101 feet) were still from the NE and NW at 6 to 12 knots (11 to 22.2 km hr⁻¹).

The detection of raptor movements with WSR-88D in south Texas in spring and fall is not surprising because of the great quantity of migrating raptors, but what is the situation at locations where raptor migration is not nearly as impressive? Even though hawk watches occur regularly in the upstate of South Carolina, the area is not known as a raptor migration hotspot. Despite this, we use several images to demonstrate that the WSR-88D can be used to detect raptor migration in this area and filtering of the images enhances the detection of the movements. The upper image of Figure 5 shows a base reflectivity image from the WSR-88D at the Greenville-Spartanburg Airport, SC, at 18:37 UTC (14:37 EDT) on 1 October 1999. The radar is operating in the clear air mode (VCP 32) and note that the dBZ scale starts at -28. The image shows considerable return from atmospheric targets, but most of the targets have relative reflectivity values of zero dBZ and lower. When the reflectivity values of zero dBZ and lower are filtered, streams of migrating raptors are more obvious (lower image). Although reflectivity data are useful for the detection of raptor migration, base velocity data are essential for discriminating migrating raptors from other targets in the atmosphere. Figure 6 contains base velocity data for the same date and time as the reflectivity image in Figure 5. Most of the targets have very low base velocity in Figure 6 (upper). When base velocities between -20 knots and + 20 knots (37 km hr⁻¹) are filtered, the echoes from migrating raptors are quite distinctive and are moving from
Figure 3. Base velocity image from Corpus Christi, TX WSR-88D on 26 September 1998 at 18:31 UTC. Upper image unfiltered and lower image filtered.
Figure 4. WSR-88D images Brownsville, TX WSR-88D on 4 April 2000 at 17:18 UTC. Upper image is unfiltered base reflectivity and lower image is filtered base velocity.
Figure 5. Base reflectivity image of Greer, SC WSR-88D on 1 October 1999 at 18:37 UTC. Upper image is unfiltered and lower image is filtered.
Figure 6. Base velocity image of Greer, SC WSR-88D on 1 October 1999 at 18:37 UTC. Upper image is unfiltered and lower image is filtered.
the NE toward the SW (Figure 6, lower). While observing hawk migration over a site at Clemson University on this date from 17:45-18:15 UTC (13:45-14:15 EDT), one of us (AF) recorded 255 Broad-winged Hawks, 1 Cooper's Hawk (Accipiter cooperi), 3 Sharp-shinned Hawks (A. striatus), 1 Osprey (Pandion haliaetus) and 2 Turkey Vultures (Cathartes aura) moving toward the SW.

Discussion and Conclusions

In this paper we have demonstrated that the WSR-88D can be used to study raptor migration within 60 nautical miles (111 km) of a radar station. Although the reflectivity imagery is useful in measuring the strength of echoes from targets aloft, it is the velocity product that is essential for discriminating echoes from migrating raptors from other targets in the atmosphere. When many different types of echoes are displayed the discrimination task can be made easier by filtering the imagery with a graphics editing program. Filtering of base reflectivity images makes the stronger targets more evident, and filtering of base velocity imagery enhances the display of faster moving targets. The use of WSR-88D to study raptor migration is in its developmental stages. Much more work is needed, and students of hawk migration can make a substantial contribution by using WSR-88D radar when they are counting migrating hawks.

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References


