AUTUMNAL BIRD MIGRATION OVER ANTIGUA, W. I.

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Tracking and weather radars have been found useful in the study of bird migration, as they give information on the altitude as well as the horizontal distribution of targets (Williams et al., 1972; Gauthreaux, 1971). Unlike search radars which have a broad vertical beam and which can be rotated only horizontally, the tracking and weather radars have a narrow beam of radar energy which can be moved in three dimensions. During the fall of 1970 and 1971, we used both tracking and weather radars to study patterns of migration over the island of Antigua in the West Indies. This was part of a study of bird migration over the North Atlantic Ocean with simultaneous observations being made on Bermuda, at Wallops Island, Virginia, and at Cape Cod, Massachusetts. Richardson (pers. comm.) made simultaneous observations with search and height finding radar on Puerto Rico. We know of no previous radar studies of bird migration in the Caribbean area.

MATERIALS AND METHODS

Two radars were used on Antigua: the FPQ-6 of the U. S. A. F. Eastern Test Range and the weather radar at Coolidge Airfield. The FPQ-6 is a 5 megawatt, 5 cm wavelength radar with a beam width of 0.4° (3db points). This radar can automatically track an individual target; the position and altitude of the target are stored digitally on magnetic tape and also displayed on an x-y recorder for real time analysis. Tracking data presented in this paper are from a computer printout of the magnetic tape with corrections for curvature of the earth. A radar signature of tech target (Automatic Gain Control (AGC) level) corresponding to changes in radar cross section of the target was recorded on a strip chart. (See Williams et al., 1972, for details of these techniques.) The Mitsubishi weather radar, located at the Coolidge Airfield meteorological station, is a 400 kilowatt, 10 cm radar with a beam width of 1.90° (3db points). It cannot be used to track but can give information on horizontal and altitudinal distribution of migration on its video display, the Plan Position Indicator (PPI).

Observations were made with the FPQ-6 radar from 28 September through 14 October 1970. Our use of this instrument was limited by other projects with higher priority. Observations were made between 10:00 and 17:00 local time for periods ranging from one to five hours. From 24 September to 16 October 1971 we made two hour observations at the weather radar at about 10:00, 13:00, and 18:00 each day. In 1971 we obtained only four tracks from the FPQ-6 and a computer malfunction in recording has prevented us from extracting useful data from these tracks. Neither radar was operational at night or over weekends.

The procedure for collecting data was essentially the same for both radars and involved taking a time lapse Polaroid photograph of the PPI scope while the radar antenna was rotating. When using the FPQ-6, which rotated at about one rpm, the camera shutter was left open for two revolutions, closed for the third, and reopened for the final revolution. A moving target produced a series of two dots followed at an interval by a third dot that indicated the direction of target movement. With the weather radar (rpm = 6), the camera shutter was left open for five minutes, closed for one, and then reopened for one more minute. These photographs showed streaks with a dot at the end, indicating the direction of movement. For both radars the entire length of the streak or dots indicated the distance covered by the target from initial shutter opening to final closing and, thus, the speed of the target. To determine the altitude, density, and direction of migration, a series of pictures was made at different angles of elevation of the antenna, usually between 2° and 10°. Because the beam of the FPQ-6 radar is narrow, the range of a target on the PPI scope was a good measure of its altitude. For example, a target observed at 30 km range at an angle of elevation of 5° would have been at an altitude of 2620 $\pm$ 220 m. (See Bellrose and Graber, 1963, for an explanation of this technique.) Altitudes estimated with the weather radar were more uncertain because of its wider beam.

Selection of targets for the tracking radar was performed as follows. An area of maximum bird migration density was determined from the PPI photographs. The radar beam was directed into this area and usually tracked the first target that appeared. We rejected birds which would soon fly out of range of the radar or birds whose radar signature indicated soaring rather than flappling flight. Soaring birds were rejected due to the large numbers of Frigate birds (*Fregata magnificens*) often in the area.

Ground observations of cloud cover were obtained from the meteorological station on Antigua. These observations often reflected highly localized weather conditions, and weather satellite pictures were used to determine the extent of cloud cover over larger areas. The velocity and heading of winds aloft were obtained from a radiosonde sent up at noon five days a week. The radiosonde was launched from a point within one mile of the radars we used.

RESULTS

Figure 1 summarizes the data on migration density, altitude, direction, and speed collected from PPI photos as described above, together with direction and speed of winds at the mean altitude of the birds. The noteworthy features of these data are:

(1) The density of southward migration varied greatly from day to day. In 1970 migration density was low or zero on 5 and 6 October when heavy rains occurred over the Lesser Antilles; on these days southward movements were not seen even in gaps between squalls. This raises the possibility that birds migrating southward toward the Antilles might have detoured around the storms.

(2) Most of the birds flying southward were higher than the bulk of migrants observed at Wallops Island, Va. (1,000-2,000 m) or Bermuda (1,000-3,000 m) (Williams et al., 1972). High altitude flights have also been recorded along the eastern coast of North

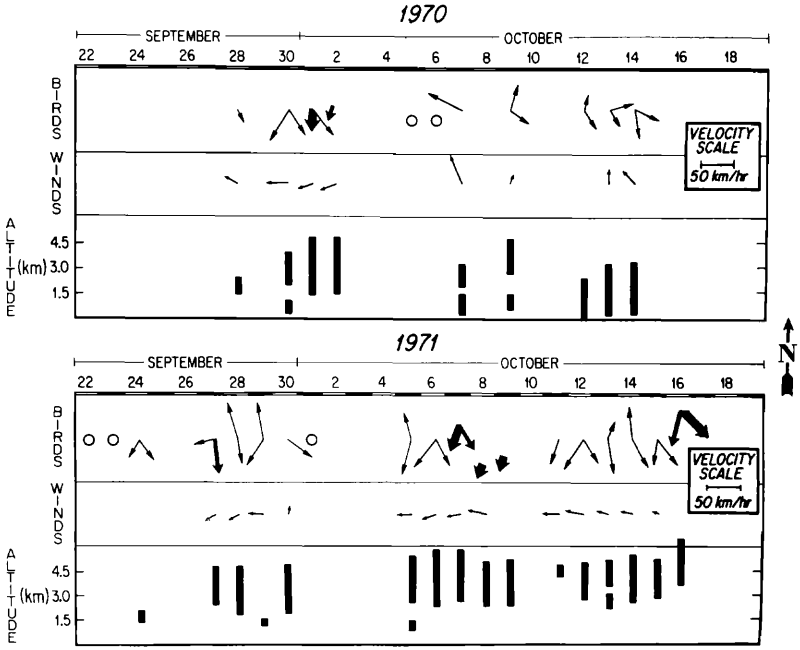

FIGURE 1. Density, altitude, and direction of migration at Antigua, with winds aloft (fall 1970 and 1971). Average velocity of the birds relative to the ground is shown in the upper portion of each diagram. Light, medium, and heavy migration densities on an arbitrary three-point scale are symbolized by broad, intermediate, and light arrows, respectively. An open circle indicates lack of bird movement. Altitude bars show the total span of altitudes for migrating birds on a particular day. Wind velocity vectors indicate the average winds at the altitudes of maximum migration density. Wind data were not available for 12 October 1970, or any weekends.

America and in Puerto Rico (Nisbet, 1963; Richardson, 1972). The mean altitude of migration at Antigua was 2,700 m with birds seen as high as 6,500 m. Few birds were recorded below 1,500 m; these targets showed no predominant direction of movement and were thought to be nonmigrating seabirds. On days when the density of migration was medium or high, most birds were recorded in a layer between 2,000 and 4,500 m. The paucity of birds flying to the south at altitudes below 2,000 m might be due to the strong SE trade winds which prevail up to 1,000-2,000 m; birds flying above these altitudes would avoid difficult crosswinds or headwinds.

(3) The general migratory movement was to the south or to the southeast. Birds were recorded flying to the north, northeast and to the northwest on nine days. This movement was always of low density; only once was the northward movement considered greater than the southward migration and only once did it occur without any southward migration. These northward headings might have been either local seabirds or migrants with a reversed orientation (Drury and Keith, 1962; Richardson, 1972).

(4) The ground speeds of the birds on days of medium to heavy migration ranged from 30 to 81 km/hr. The wind vectors in Figure 1 show that birds flying in a southerly direction rarely had a tail-wind, and in many cases there was a small headwind component. The speeds of the birds shown in Figure 1 thus represent minimal air speeds. These air speeds suggest that a large proportion of birds detected were not small passerine birds.

The PPI data discussed above indicated the general patterns of migration; the FPQ-6 tracking radar gave detailed data on the flight paths of a relatively small number of birds. These data were not included in Figure 1. The accuracy of this tracking radar has not been determined for bird targets. Our discussions with radar engineers indicate that the greatest errors are to be expected from "ducting" or a departure of the radar beam from a straight path causing angular errors of up to 0.06° for the FPQ-6. (In extreme cases errors 10 times this value have been recorded.) This would result in an altitude and position error of 80 m for a target of 80 km or 40 m at 40 km.

Figure 2 presents all bird tracks longer than 6 km; this represents 17 of the 26 tracks we obtained in 1970. Each track is accompanied by a vector indicating the air velocity of the bird. Table 1 gives ground speed, wind speed and direction, air speed, and altitude of each track shown in Figure 2. The tracks show no indication that the birds were reacting to either Antigua or the nearby island of Barbuda. Only two tracks (13A, 2A) showed a significant change in course, and most tracks tended to maintain altitude. Birds 2A and 2C descended as they approached large rain clouds (detected by the radar). Bird 28B descended, but there are indications from the irregular radar signature (see below) that this was not a migrant bird.

All the birds tracked were heading to the south or southeast with the exception of 6A and 7A heading north, 2B heading northwest, and 2C heading southwest. As with the PPI data discussed above, birds heading to the south often flew with crosswinds.

One of the advantages of tracking radar is the possibility of identifying the birds tracked. This can be accomplished by two techniques: accurate measurement of the air speed of the bird, and the radar "signature" or regular changes in the radar cross section of the targets. Bruderer (1971) and Bruderer and Steidinger (1972) have used these parameters to identify more than 50 "radar species" with a small fire control radar in Switzerland. The problem is to identify these radar signatures with species or genera of birds. We had an opportunity to identify visually target 1A when it passed over the radar site at an altitude of 4,200 m. Although not clearly resolved at this range, it appeared to be a small or medium-sized shorebird flying alone with a wing-beat frequency of about 7 Hz. The radar signature for this target was quasi-periodic with components of 7 and 14 Hz. The higher frequency component was probably a harmonic of the wing-beat frequency which became prominent at certain angles with respect to the radar beam.

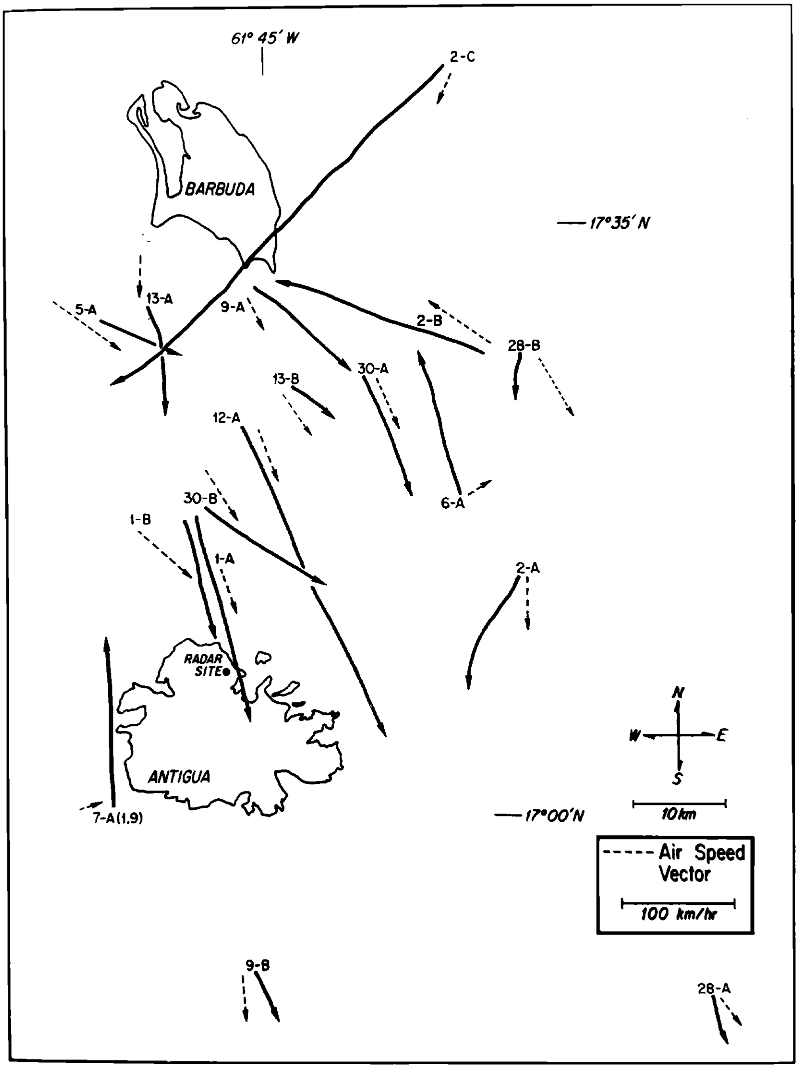

FIGURE 2. Birds tracked at Antigua by FPQ-6 radar, 28 September through 13 October 1970. Figure includes all tracks over 6 km. Tracks are identified by number and letter which usually appear at the beginning of each track (number = day of month, letter distinguishes consecutive tracks on same day). A vector indicating the birds' air speed is given for each track.

Radar signatures were taken on all birds except those tracked on 2 October. The fundamental frequency of the radar signature for all bird tracks shown in Figure 2 is given in Table 1. With the exception of track 12A which showed the irregular fluctuations characteristic of flocks, all birds tracked gave the regular, coherent radar signatures of single targets (see Bruderer, 1971; Williams et al.,

TABLE 1. Data for bird tracks given in Figure 2.

Track No.	Average Ground Speed (km/hr)	Wind[a] Speed (km/hr.)	Wind[a] Direction 0° = N	Air Speed (km/hr.)	Altitude Max–Min (m) (m)	Signature (Hertz)	Signature type (see text)
28A	16	18	127°	32	2,650–2,200	6	Continuous
28B	38	33	115°	58	850–400		Soaring
30A	42	7	127°	49	3,800–3,750	7	Continuous
30B	50	24	322°	51	5,650-5,300	8	Continuous
1A	49	11	167°	40	4,400–4,000	7	Bursts
1B	53	33	74°	62	4,100–4,000	7	Continuous
2A	65	27	52°	45	4,600–4,100	——[b]	
2B	88	26	72°	68	3,150–2,700	——[b]	
2C	53	28	70°	30	3,300–2,900	——[b]	
5A	37	40	137°	76	2,150–2,050		Irregular
6A	47	20	138°	46	2,100–1,900	14	Continuous
7A	52	22	250°	51	2,100–1,950	14	Continuous
9A	38	14	252°	32	3,750–3,700	10	Continuous
9B	40	15	244°	43	5,950–4,800	10	Continuous
12A	40	9	176°	50	3,600–2,750	12	Bursts
13A	27	10	191°	35	4,150–3,850	8	Continuous
13B	43	12	218°	43	4,650–4,650	9	Bursts

[a]Wind taken by radiosonde at radar site at average altitude of the bird

[b]No signatures available for these tracks.

1972, for a discussion of radar signatures). A total of 21 radar signatures was obtained; of these 12 consisted of continuous (amosts sinusoidal) fluctuations of 5 to 11 Hz, and two were records of the same type but with frequencies of 14 Hz. (As mentioned above, these might be double the wing-beat rate.) The second group of signatures was similar to the first except that the fluctuations came in bursts of 4 to 8 beats followed by a pause of about 0.5 sec as though the birds had set their wings briefly. Five such signatures varied from 7 to 11 Hz during the bursts. The signatures of track 28B corresponded to those of large soaring birds tracked with similar radars at Wallops Island, Va. (Williams et al., 1972). The air speeds of the birds ranged from 35 to 55 km/hr (Table 1). The limited data on wing-beat rate compiled by Greenewalt (1962) and our own observations indicate that the birds we tracked were probably not small passerine birds. The air speeds seem low for most waterfowl and large shorebirds. The most likely candidates thus appear to be small shorebirds, perhaps terns or small waders, or large passerines. If would be surprising to find such species flying singly.

Between 23 September and 11 October 1970, Nisbet spent several hours each day searching for grounded migrants around lagoons and ponds, and in scrub and patches of trees on Antigua. The only North American migrants seen in numbers were shorebirds. Of some 2,300 shorebirds identified and counted, more than 85% belonged to five species: Semipalmated Sandpiper (*Ereunetes pusilla*) (1,050), Lesser Yellowlegs (*Totanus flavipes*) (330), Ruddy Turnstone (*Arenaria interpres*) (250), Short-billed Dowitcher (*Limnodromus griseus*) (150) and Greater Yellowlegs (*T. melanoleucus*) (140). A Least Sandpiper (*Erolia minutilla*) with dyed plumage seen on 9 October had been marked earlier in the season on the Magdalen Islands in the Gulf of St. Lawrence (R. McNeil, in litt.). The numbers of these birds in the localities studied were not constant but fluctuated greatly during the period of observation. It is possible, however, that many birds were winter residents. The only other birds seen that were certainly migrants from North America were Blue-winged Teal (*Anas discors*) (37), Blackpoll Warbler (*Dendroica striata*) (22), Barn Swallow (*Hirundo rustica*) (17), Belted Kingfisher (*Megaceryle alcyon*) (7), and Prairie Warbler (*D. discolor*) (1).

DISCUSSION

Antigua and Barbuda are the most northeasterly of the Caribbean islands. East of bearing 330° there is no land except Bermuda between these islands and the coast of North America. The directions from which birds arrive at Antigua suggest at least two principal migration routes over the mid-Atlantic Ocean. The first route would consist of birds leaving the coast of North America and flying more or less due south and then southeast along the Caribbean Islands. These birds would arrive at Antigua from the north or the northwest. The second route is one suggested by observations of Williams et al. (1972) of birds migrating over Bermuda toward the southeast. This route might contain birds that leave the North American coast flying southwest (Drury and Keith, 1963), continue in that direction until they reach the mid-Atlantic Ocean and then turn, perhaps taking advantage of favorable flying conditions, such as the trade winds, and, thus, arrive at Antigua from the northeast. Tracks recorded in other directions do not make sense in terms of long-distance migration, and may represent seabirds or herons dispersing within the Antilles.

In some respects our observations are similar to those made simultaneously by Richardson (pers. comm.) some 500 km to the west in Puerto Rico. Richardson also reports irregular fluctuations in migration density, a substantial number of birds flying at altitudes of 2,000-5,000 m, and a tendency for birds to over-fly the island and continue across the Caribbean Sea. He identified most of the dense movements as passerine-type echoes. In contrast, most of our birds apparently were nonpasserines flying east of south. The differences suggest that in 1970 nearly all of the passerines in the movements observed by Richardson passed west of Antigua. McCandless (1962) recorded a number of North American passerines as common autumn migrants in Puerto Rico. In contrast, we saw very few grounded passerines in Antigua in 1970, although they have been recorded irregularly in numbers in the Lesser Antilles (Nisbet, 1970).

Although it is difficult to make direct comparisons of bird migration data taken on different radars, certain aspects of bird migration at Antigua are clearly different from data gathered by ourselves and others on the eastern coast of North America. The greater average altitude of migration has already been mentioned. The density of migration was less than that observed either on the coast (Williams et al., 1972) or on Puerto Rico (Richardson, pers. comm.). The heaviest migration observed with the Antigua weather radar during 1970 and 1971 would correspond to the density pattern number 3 devised by Gauthreaux (1970) for the similar WSR-57 radar in Louisiana. At no time did we observe the type of radar echoes which Gauthreaux (1971) interprets as indicating passerine migration. This may well have been due to our limited period of observations or to the absence of nocturnal observations.

SUMMARY

Both tracking and weather radars on Antigua were used to study the patterns of autumnal bird migration. Both the direction and density of migration varied from day to day. Birds approaching the island from the north often flew with crosswinds. Birds migrating over Antigua flew higher than those reported in most other studies, with some flying as high as 6,500 m and few below 1,500 m. Analysis of the radar signatures and air speeds of birds followed with tracking radar indicated that these were probably not small passerine birds, but perhaps small shorebirds or large passerines. The only North American migrants seen in large numbers on the ground during the study period were shorebirds.

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