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AUTUMNAL BIRD MIGRATION OVER MIAMI STUDIED BY RADAR: A POSSIBLE TEST OF THE WIND DRIFT HYPOTHESIS

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Radar observations of nocturnal bird migration have produced conflicting evidence regarding the ability of birds to compensate for wind drift (see Eastwood, 1967 for a review). In North America, Drury and Keith (1962) and Drury and Nisbet (1964), working on Cape Cod, and Richardson (1972) observing in the Canadian Maritime provinces, reported that passerines and shorebirds usually fly at some angle to the wind, and on some nights appear to maintain a constant direction of movement despite shifts in the direction and speed of the wind. Williams et al. (1972, 1974), utilizing tracking radars and radio tracking, reported that birds are certainly capable of such compensation on flights of 20 to 30 miles. Gauthreaux and Able (1970) reported that, in the south-eastern United States, passerine migrants, far from compensating for the wind, use wind as an orientation cue and fly with it. Able (1973, 1974) reported that only passerines fly with the wind, whereas shorebirds and waterfowl appear to fly on courses independent of wind direction.

The different results obtained in these North American investigations may be due to the simultaneous observation of several different migratory routes at any one site, to differences in the behavior of migrants at different latitudes, or to differences in behavior of birds on coastal vs. inland migration routes. In addition, at latitudes above the Tropic of Cancer, birds do not usually initiate migration until winds are favorable for their preferred flight direction, and thus it is rarely possible to distinguish between goal-oriented and down-wind flight for heavy migration nights.

During the fall of 1973 we conducted radar observations of nocturnal bird migration at Miami, Florida which combined several conditions not previously investigated in the study of nocturnal migration. The site was both coastal and in the south-eastern United States. We apparently observed a single migratory route, and preferred flight direction and wind direction differed significantly even on nights of heavy migration.

METHODS

Our observations of bird migration were made with the U.S. Weather Bureau WSR-57 radar of the National Hurricane Center, Coral Gables, Florida (near Miami). The WSR-57 is a 500 kW peak power, 10 cm wavelength meteorological radar with a fully steerable conical beam measuring 2° at the 3 db points. The instrument is described more completely by Gauthreaux (1970). Observations were made nightly from 29 September 1973 to 12 October 1973, except on 4 October 1973. Observations usually started at 2350 GMT (near local sunset) and continued until 0400. Data were obtained from the radar by rotating the antenna at a constant angle of elevation (from 2° to 7°) while making a time exposure of the Plan Position Indicator (PPI) display with a Polaroid camera. The length of the exposure varied from 2 to 6 minutes with most exposures lasting for 5 minutes. The shutter of the camera was opened for 3 minutes, closed for one minute and opened for one minute; moving targets thus produced a streak on the film with a dot at one end showing the direction of motion. Speed of movement of the target relative to the ground was calculated from the distance it moved (length of the streak) and the exposure time for the photograph. The radar at the National Hurricane Center receives extremely heavy use during the fall hurricane (and bird migration) season. For this reason we were able to make one or two time exposures per hour.

Weather conditions at hourly intervals and winds aloft at 0000 and 1200 hrs GMT were obtained at the Center.

Gauthreaux (1970) and Able (1973 and 1974) distinguish between "passerine" radar echoes which produce a fine mist on the PPI screen and dot echoes which produce measurable tracks. We will use their terminology, although air airspeed analysis indicates that many dot echoes are probably groups of passerine birds.

The density of bird migration seen on the PPI photographs was scored as none, light, moderate, or heavy on an arbitrary scale similar to that employed by Gauthreaux (1970). Due to severe time limitations on our use of the radar, it was not possible to use systematically stepped attenuation (see Gauthreaux, 1970) and, thus, our density estimates are limited by saturation of the PPI screen. The direction of movement, altitude, and speed of all measurable dot echoes were determined for all photographs. These measurments gave us the velocity of a bird relative to the surface of the earth (V_g). For some analyses it was desirable to determine the speed with which a bird was moving through the air (airspeed) and the direction in which it oriented its body in flight (heading). The airspeed and heading of a bird constitute its air velocity (V_a) which was calculated by vector subtraction of V_g and the velocity of the wind (V_w) measured by radiosonde balloon at the altitude of the bird recorded at 0000 GMT the same night. In all except three photographs this was within 4 hrs of our observations.

In addition to measurement of complete tracks in each photograph, we estimated the modal direction of dot echo and "passerine" movements by eye. The direction of movement for dense "passerine" migrations was estimated by utilizing the short pulse (1 μ sec) of the radar which greatly reduced the effective range of the radar but showed a large number of fine, short, overlapping tracks probably from slow flying passerine migrants (speeds for these tracks could not be accurately determined). In some PPI photographs taken at 4 μ sec pulse length it was possible to estimate the direction of migration at ranges of 20 to 25 miles where the large number of overlapping radar echoes did not totally saturate the radar screen.

RESULTS

Bird migration observed on radar at Miami was unusually constant in magnitude and direction during the period of our observations. Every night of observation at Miami we recorded either moderate or heavy migration at some time, and as shown in Figure 1 the movement of birds was almost entirely restricted to the sector 150° to 210°. At no time did cold fronts penetrate nearer than 300 miles north of Miami.

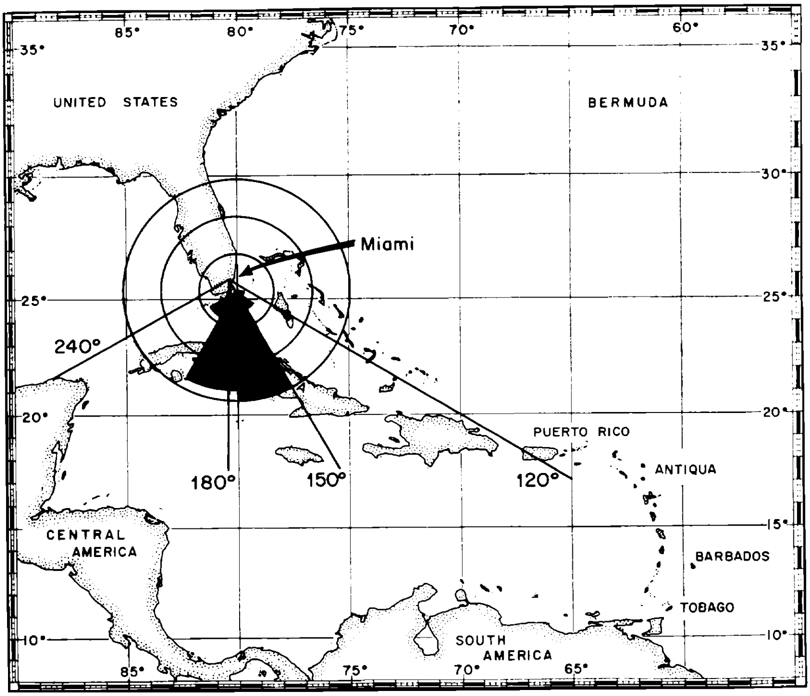

FIGURE 1. Possible destinations of migrants detected by radar at Miami, Florida. Circular histogram shows distribution of all measurable tracks. Each ring indicates 100 tracks in a 30 wide sector. (Note center of histogram is displaced southward for clarity.) Other geographical locations and several compass courses from Miami mentioned in the text are also shown.

The mean altitude of migration over Miami was considerably greater than that observed at northern sites (see Eastwood, 1967; Richardson, 1972; Williams et al., 1974). Figure 2 presents the altitude range for moderate and heavy migrations for all nights

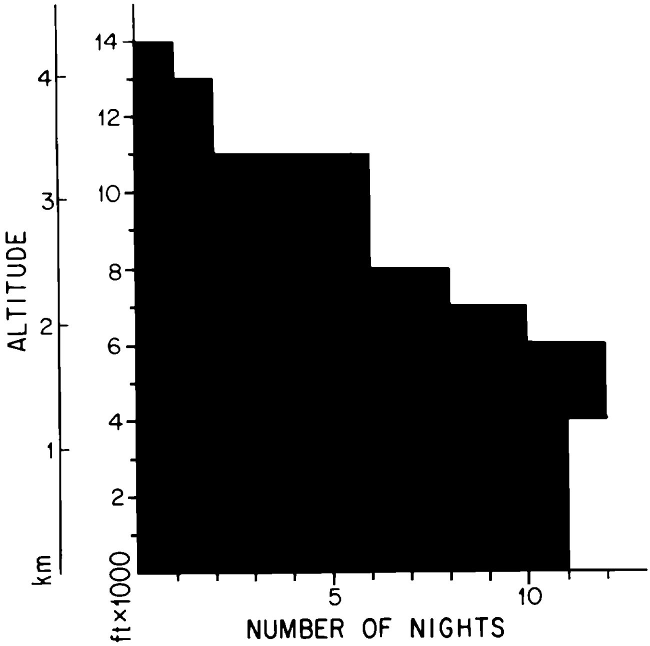

FIGURE 2. Range of altitudes for each night of moderate and heavy migration. Bars indicate number of nights when large numbers of radar targets were detected within a 1,000-ft altitude range. Altitudes below 3,000 ft may be over-represented due to ground return.

except three when insufficient data were available to establish altitude accurately. Inspection of the distribution of winds aloft showed that birds appeared to adjust their altitude of flight to take advantage of favorable winds. On all but one of the 12 nights available for analysis, high altitude flight was recorded when upper level winds offered better tail wind components than low level winds, and low altitude flight occurred when there was no significant advantage to high altitude flight. (This point is discussed further in connection with Figure 4, below).

Figure 3, a histogram of airspeeds for all measurable dot echoes, suggests that most birds we observed were relatively slow, with airspeeds less than 30 knots, and most probably were small passerines. This conclusion is supported by the appearance of the PPI photographs we obtained. On most nights we observed the fine mist-like echoes illustrated in Gauthreaux (1970) and attributed by him and many others to passerine migration. Birds with airspeeds above 40 knots, such as waterfowl and shorebirds, appeared to make up a small proportion of the migrants we observed (see Fig. 3). We rarely detected the bright, sharply defined radar echoes attributed to these types of migrants. There were, however, a large number of relatively poorly defined, large echoes. These often made up the majority of echoes seen at about sunset and

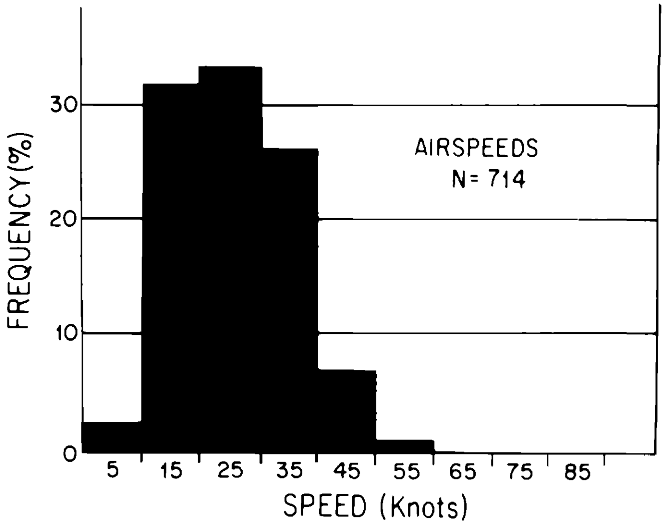

FIGURE 3. Frequency of observed airspeeds at Miami. Airspeeds were calculated from velocity relative to the ground for all measurable targets and 0000 GMT winds at the altitude of the bird. Airspeeds below 10 knots are probably due to soaring seabirds and gulls.

appeared similar to the echoes observed by Gauthreaux (1972) when diurnal flocks dispersed to the typical diffuse nocturnal passerine migration. At Miami, however, these radar echoes persisted throughout the night, suggesting flight in loose but coherent aggregations. We have not observed targets similar to these diffuse dots during our radar observations at several sites in the North Atlantic (see Williams et al., 1974) or at Buffalo, N. Y. (Williams, unpubl. data), but the diffuse dot targets seen at Miami are not artifacts of poor focus of the PPI display because the same display also produced sharply defined dot echoes.

Figure 4 presents the modal direction of both dot echo and "passerine" movement relative to the ground vs. direction of the wind plotted in the same manner as Gauthreaux and Able (1970) and Able (1973). The average measured wind speed at the altitude of "passerine" migrants was 9.8 kts (range 1 to 16 kts with only one value below 4 kts). On all but two of 12 nights wind velocity decreased with altitude from the surface to a layer of relatively still air at 12,000 to 16,000 ft. For "passerine" migration each point in Figure 4 represents the modal migration for a single night. On some nights when dot targets showed two clearly separated migratory directions, both modal directions are given in Figure 4. Data falling along the dotted line would indicate flight with the wind. Winds at the altitude of the birds during our period of observations varied from north to east, and, as shown in Figure 1, movement relative to the ground was to the south. Thus, none of our data fall on the line indicating flight with the wind, and most birds flew to the south of the wind. The correlation of "pas-

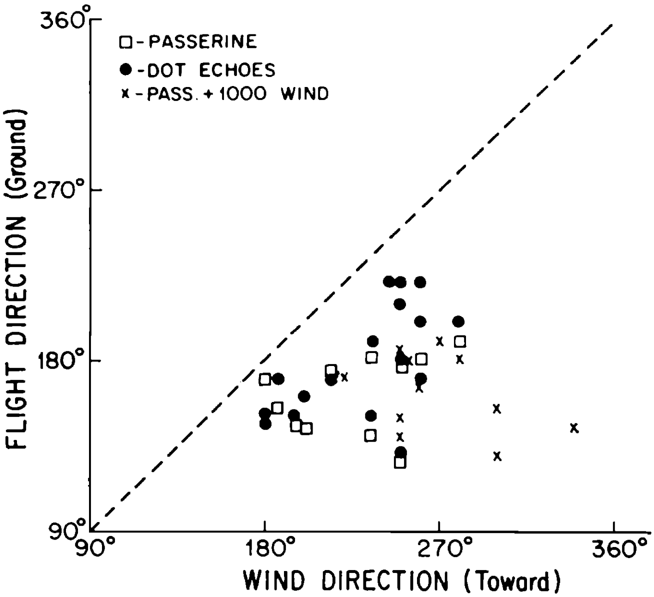

FIGURE 4. Flight direction of birds relative to the earth vs. wind direction. All directions are modal direction of movement relative to the ground as determined by inspection of all PPI photographs taken for a given night.

serine" flight and wind direction for our data was not significant (r = .36). The dot targets, like the "passerine" movements, did not move with the wind. The correlation of wind and flight direction for dot targets was significant at the 95% confidence level (r = .58), but we consider other factors such as air heading to be more important (see below). For the above analyses we have used wind velocity at the altitude of the birds. Gauthreaux and Able (1970) used winds at 1,000 ft (because most of their birds flew at less than 2,000 ft). Our data for "passerine" movements are replotted in Figure 4 using the 1,000-ft winds, and reveal a greater deviation from wind direction than when winds at the altitude of the birds are used. These plots, which would show most birds flying in cross winds or even head winds, also show the advantage of high altitude flight for birds over Miami.

From Figure 4 it is clear that few migratory birds fly with the wind at Miami. Birds still might use the wind for orientation by flying at a constant angle to the wind, but this does not appear to be the case. For this analysis and those that follow we have separated the heading of the bird (V_a) from the direction of movement relative to the ground (V_g, see above under Methods). For dot echoes the modal angle between the wind and the heading of the birds for birds flying in north winds (330° to 59°) was 25°; birds flying in east winds (60° to 120°) had a difference between modal heading and in direction of 105°. If we assume an airspeed of 25 knots for "passerine" echoes, the average difference

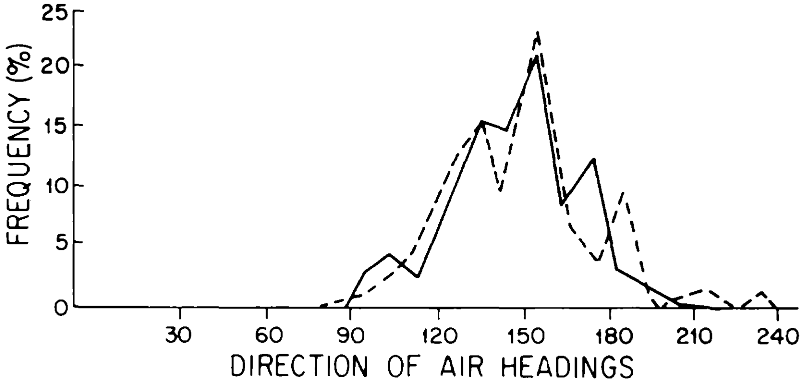

FIGURE 5. Frequency of air headings for all measurable targets at Miami. Data are divided into two groups: birds flying in north winds (330° to 59°, solid line) and birds flying in east winds (60° to 120°, dashed line). Each point represents an average for a 10° sector.

between heading and wind for these birds in east winds is 108°, and, for birds in north winds, it is 48°.

Figure 5 presents the headings of all measurable targets and strongly suggests orientation by means of constant heading for birds departing the tip of Florida. The figure presents the data divided into two groups, birds flying in north winds and birds flying in east winds. The two groups show no discernible difference in heading. As a result of this constant heading, birds flying in east winds were drifted more to the west than birds in north winds. (This may be seen in Figure 4). If birds were compensating for wind drift we would expect to see a difference in air heading for the two groups shown in Figure 4. Although our determination of the directions of "passerine" migration are averages for an entire night, the average heading of birds flying in east winds is not significantly different from the heading of birds flying in north winds. If we assume an airspeed of 25 knots for these birds, the mean heading for birds in east winds is 143° (r = 0.94, angular deviation = 19°), and for birds in north winds 146° (r = 0.98, angular deviation = 14°).

DISCUSSION

Miami is situated near the tip of the Florida peninsula, a 400-mile projection of the North American east coast into the Atlantic Ocean (see Figure 1). A bird taking the route via Florida to South America, as opposed to the overland routes around the Gulf of Mexico, shortens its flight by approximately 1,500 mi (50%). The nearly constant migration over Miami may be explained by the importance of this peninsula for birds leaving both the central and eastern United States. The low variability in direction of migration is understandable if one examines the consequences of departure on various courses from Miami as illustrated in Figure 1. Courses west of 240° are clearly inefficient routes to South

America and courses east of 120° would take birds into the Atlantic against strong east winds; a course departing Miami east of 120° would miss South America completely (although it would pass through the Lesser Antilles).

In many ways bird migration over Miami is similar to that observed with radar from Caribbean Islands; flight above 5,000 ft is common, dot echoes with low airspeeds suggesting passerine migrants are frequently seen, and birds rarely fly with the wind (Hilditch et al., 1973; Williams et al., 1974; Richardson, 1976). This behavior contrasts with observations of bird migration in other areas of the southeastern United States. Gauthreaux (1971, 1974) and Able (1973, 1974) used WSR-57 radars and simultaneously watched birds pass through a ceilometer light beam in Louisiana, Georgia, and South Carolina. They reported most birds migrating below 2,000 ft with dot echoes showing high airspeeds characteristic of shorebirds and waterfowl (see Able, 1974, p. 225), and all of these studies reported passerine birds flying with the wind, often in apparently inappropriate directions. Stoddard and Norris (1967), who collected birds killed at a 1,000-ft high television tower in northern Florida, also reported most passerine migrants appeared to fly with the wind. Since our studies did not use direct visual observations, we cannot positively identify passerine migrants. However, the time of year, the large numbers of low airspeed targets, the diffuse dot echoes, the low altitude observations at 1 μ sec pulse length, and the frequent appearance of "passerine" echoes all suggest that at least a significant proportion of the birds we detected were passerines. We therefore tentatively conclude that the orientation techniques used by birds over Miami during the period of our studies are different from those of birds, especially passerine migrants, in the other southeastern United States. This conclusion is supported by the large scale moon-watching studies of Lowery and Newman (1966) conducted at the same time of year during four nights over much of the United States. They reported that migration direction in the southern states was variable and often with the prevailing wind, but in Florida "most of the migration is remarkably in line with the slant of the peninsula, regardless of the direction of the wind" (Lowery and Newman, 1966: 578).

Examination of global wind patterns (see Neiburger et al., 1973: 123) reveals that orientation by down-wind flight must be rejected by avian migrants that penetrate the zone of constant easterly winds below the Tropic of Cancer if these birds are to make progress to the south. Even if birds departed Florida on the infrequent north winds they would almost certainly face cross winds only a few hundred miles south.

Our data also contrast with the report of Drury and Nisbet (1964) of birds maintaining a constant direction relative to the ground during changes in wind. For all birds we observed, it appears that orientation is accomplished by maintenance of a constant heading and flight at altitudes with favorable winds.

Thus, it appears that the differences in orientation with respect to wind that have been reported by Richardson (1972), Drury and Nisbet (1964), and Williams et al. (1972) on the one hand, and the down-wind flight reported by Gauthreaux (1971), Gauthreaux and Able (1970), and Able (1974) on the other, may be due to their observations of migrations with fundamentally different behaviors. Birds departing the New England and Canadian coasts for a long overwater flight or southwest movement down the U. S. coast will almost certainly have to penetrate areas of unfavorable winds to complete successfully their migration. Birds in the central and southern states can afford to wait for the occurrence of favorable winds (northwest in the fall and southeast in the spring) when confronted with unfavorable winds; for them down-wind flight is adaptive, for birds on other routes it might well prove fatal.

SUMMARY

Radar observations of bird migration over Miami, Florida during the fall of 1973 revealed intense movements to the south or southeast on all nights. Both mist-like and dot echoes were detected on most nights. Analysis of airspeeds of dot echoes indicated that many slow flying birds appeared to form loose aggregations when departing the Florida coast. Birds rarely flew with the wind, neither was there evidence of compensation for wind drift; instead both slow and rapidly flying birds appeared to maintain a constant heading without regard for the direction of the wind.

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