An Oceanic Mass Migration of Land Birds

Every fall millions of songbirds and small shorebirds leave the east coast of North America for the Caribbean and South America. Their difficult journey has now been followed with the aid of radar

by Timothy C. Williams and Janet M. Williams

For about two months after the summer visitors leave the beaches of New England and the Canadian Maritime Provinces those areas experience a far more massive departure that goes unnoticed by most of the remaining inhabitants. More than 100 million birds, most of them fairly small, cross those shores on their annual flight southward over the Atlantic from eastern North America to the Caribbean and South America. A patient observer with a powerful pair of binoculars might see a few of the birds as they traverse the face of a full moon or pass through a beam of light pointed upward at night, but for the most part the participants in the migration cannot be seen directly. With the aid of John M. Teal and John W. Kanwisher of the Woods Hole Oceanographic Institution, Leonard C. Ireland of the Bermuda Biological Station and others we have exploited a network of radars to observe the behavior of the birds. The studies have yielded much information about this remarkable migration and have indicated why some birds succeed at it and others, which seem to be out over the ocean by mistake or misfortune, perish in large numbers.

The birds we have observed by radar along the Atlantic coast during the last week of September and the first half of October are most likely shorebirds (such as sandpipers and plovers) and small songbirds (such as warblers). The vast majority of the birds begin their journey at night, after a cold-front weather system has moved southeast over the coast. If you stand in a quiet area of Cape Cod early of an October evening with a brisk northwest wind at your back, you can hear great numbers of small birds calling to one another as they pass overhead. If you then were to go to any of the three large radar installations on the Cape (Air Force surveillance, air-traffic control or weather radar), you would find the center portion of the screen filled with small bright dots moving in a roughly southeasterly direction.

Such a radar screen represents a map of the area surveyed by the apparatus; north is at the top, and the distance of an object from the radar installation is indicated by concentric range rings at intervals representing about 10 kilometers. The location of any object detected is represented on the screen by a bright dot. The radars to which we had access displayed each object in this way from once to 15 times per minute.

In order to record information from the radar screen we made time-exposure photographs. Any slowly moving object such as a bird would show up in the photograph as a series of small dots or as a streak. By briefly closing and then reopening the shutter toward the end of the time exposure we could ascertain the direction of motion of the bird. By measuring the length of the streak, and therefore the distance traveled, we could (knowing the duration of the time exposure) compute the speed of the bird. The number of birds detected per unit of area served as a basis for estimating the density of migration, which we classified in four categories: no movement, light migration, moderate migration and heavy migration. Most of the radar units could also estimate the altitude of birds from the angle of elevation of the radar beam and the distance of the birds from the radar.

We began our research on these southerly migrations by observing birds as they moved over Cape Cod. Like William H. Drury and Ian C. T. Nisbet of the Massachusetts Audubon Society before us, we were fascinated by the great numbers of birds (up to 12 million per night) that left Cape Cod moving southeast toward the middle of the Atlantic. To determine what happened to these birds we watched from radars on the islands of Bermuda and Antigua. We found that many but not all of the birds continued flying southeast over Bermuda but arrived in the Caribbean flying southwest. Land birds and most shorebirds would have no chance to land during that flight of more than 3,000 kilometers. Moreover, they could not navigate by following coastlines or other landmarks; some other system of guidance was necessary.

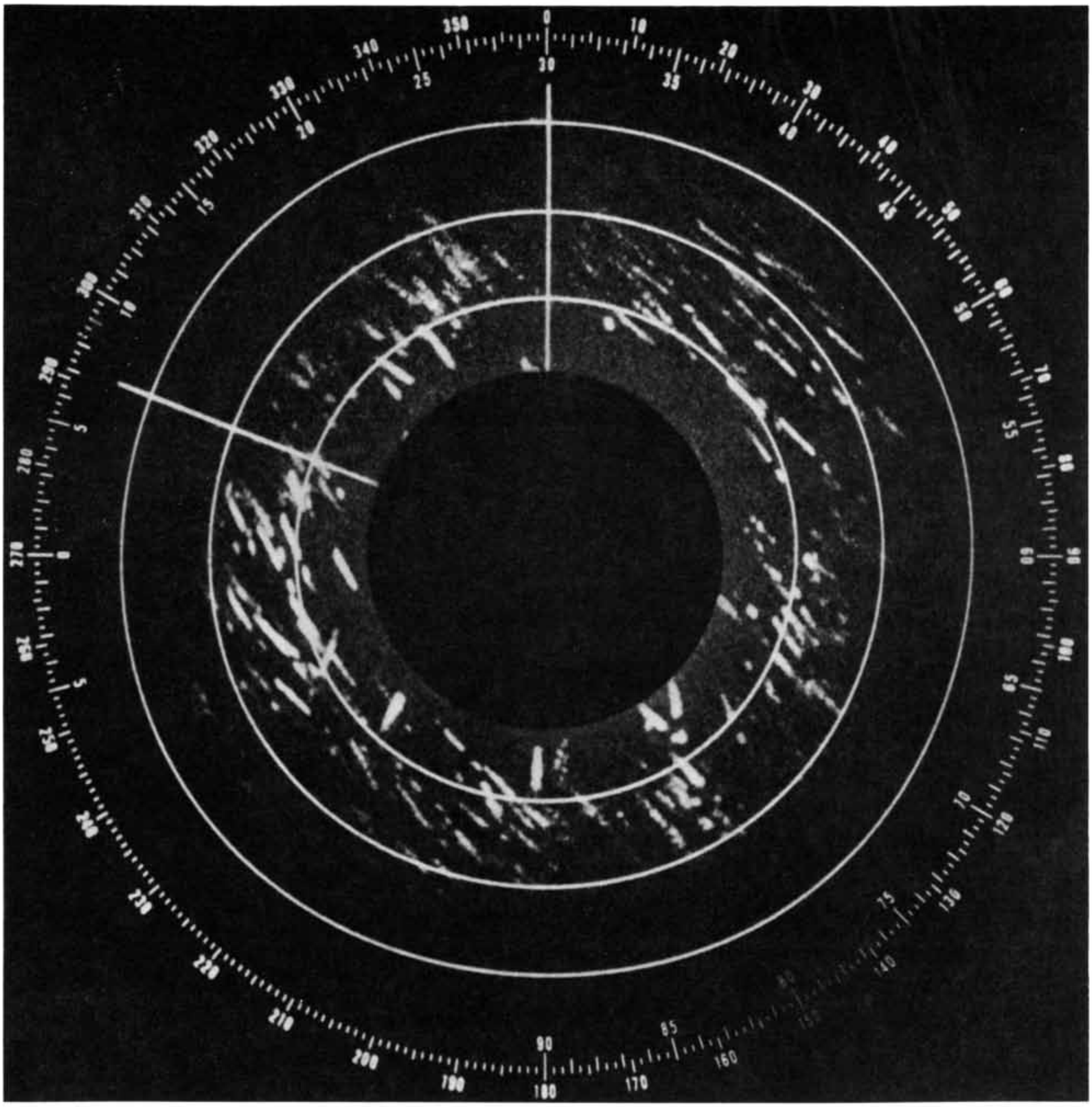
The only way we could study the movement of the birds while they were over water was with radars at coastal sites and on islands and ships along the route. These observations had to be made simultaneously with similar radars and under similar conditions. Therefore during the last week of September and the first two weeks of October for six years we enlisted the cooperation of six national governments, four Federal agencies, the Woods Hole Oceanographic Institution and a large number of our friends and students to man as many as nine radar stations along the route of the migration.

The basic patterns of migration that we found appear to involve at least two routes from North America to South America. On one route the birds follow the coast southwest to the vicinity of Florida and then turn southeast to move along the Caribbean islands. The second route involves birds leaving the coast from at least as far north as Nova Scotia and as far south as Virginia, and thereafter moving southeast (a direction of flight observed from ships in all the areas of the Atlantic we studied). We suppose the birds turn in the area of the Sargasso Sea (approximately the southern limit of our observations) as they encounter the northeast trade winds. Aided by those winds, they move in a southwesterly direction over the region occupied by the Caribbean islands.

At all the radar sites we found that the migrations proceeded in waves. Several days would pass with little or no activity, and then for a day or two birds would move in large numbers. The intervals between periods of migratory activity became longer as one moved away from the coast. At coastal sites some movement could almost always be observed at night. At Bermuda we encountered occasional periods without migration, and in the Caribbean several days often passed with no migrants being observed.

By plotting the data obtained by radar on a series of photographs made from weather satellites operated by the National Oceanic and Atmospheric Administration (NOAA) one can establish a correlation between migratory activity and the state of the weather. An example is provided by the satellite photographs for October 3 through October 6, 1973 [*see illustration on page 173*]. On the first day a departure of birds from the North American coast was beginning. A cold front had just moved offshore from Cape Cod to Florida. As the cloud patterns show, the front crossed the shoreline between Cape Cod and Halifax. Coastal radars recorded heavy movements of birds that night. Birds were moving both along the coast and offshore.

By October 4 the frontal system had become stationary between Bermuda and the coast. Birds observed from a ship penetrated the frontal system all day, moving southeast and reaching the Bermuda area by midafternoon. On October 5 these birds were between Bermuda and the Caribbean. At Bermuda



MIGRATING BIRDS show up as white streaks on this photograph of a radar screen on the Caribbean island of Antigua. North is at the top. The white rings represent 10-kilometer intervals from the radar station. The center of the display is blacked out to prevent overexposure of the photograph from ground clutter. The photograph is a five-minute time exposure, in which the largest concentration of streaks representing birds is in the range circles from 20 to 45 kilometers. A dot at the end of a streak, caused by briefly closing the shutter of the camera, shows direction of movement. The white line at the left shows the angle of elevation of the radar beam, which was intersecting a layer of birds at altitudes of from three to six kilometers. Most of the birds were moving southeast; a few were moving southwest.

ATLANTIC MIGRANTS, drawn to a common scale, are portrayed. Included are three shorebirds, the Hudsonian godwit (*a*), the American golden plover (*b*) and the white-rumped sandpiper (*c*), and one songbird, the blackpoll warbler (*d*). Perhaps half of the migrants are songbirds. An indication of the scale is provided by the warbler, which in life is from 4.5 to 5.5 inches long and weighs less than an ounce.

the movement had shifted from southeasterly to southerly (possibly reflecting birds moving south from Halifax the previous night). Bird movements at the ship, which was about 400 kilometers behind (northwest of) the weather front, appeared to be scattered in all directions, although the density of birds was scored as being heavy.

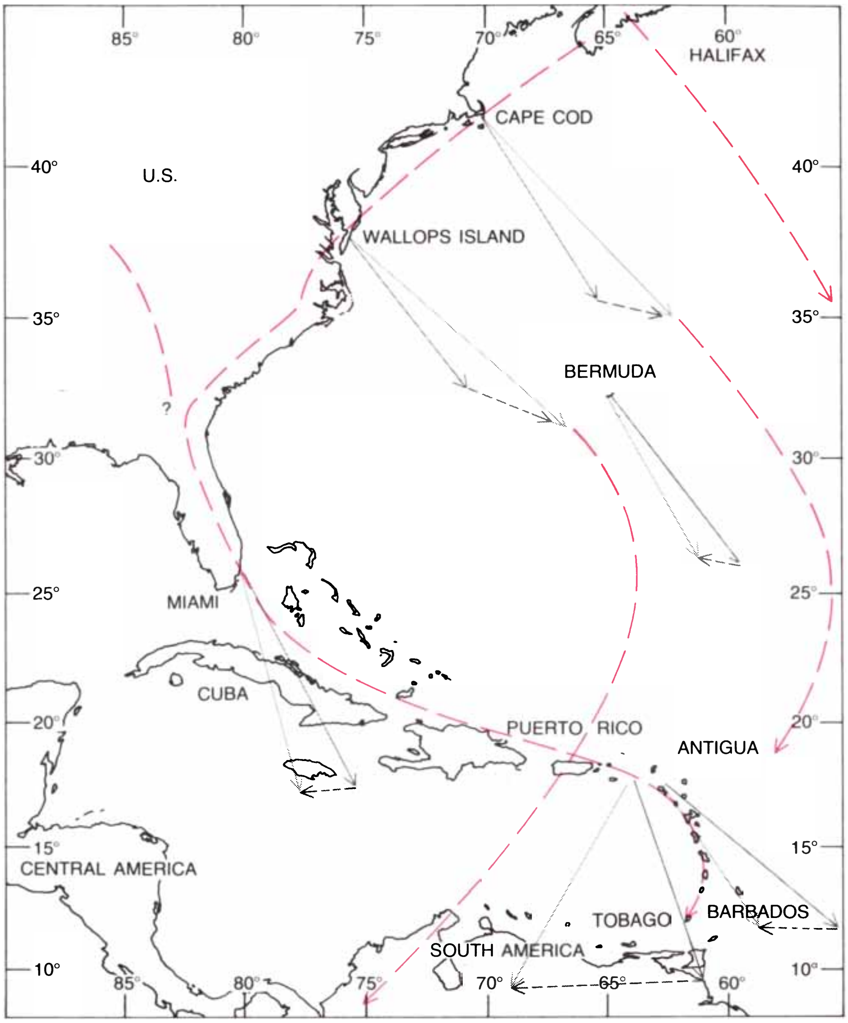
On October 6 the wave of migration reached the Caribbean, with heavy movements reported at Antigua during the day and at Barbados during the evening. The total time of flight from North America to Antigua was about 64 hours and to Barbados about 72.

The timing of this migration is typical of the data we have been able to gather. Departures from the coast are triggered by favorable flight conditions behind a cold front. The significant feature of the weather is strong northwest winds, which help the birds to move from the coast to the area of Bermuda in an average of only 18 hours. Radar indicates that few birds land on Bermuda; the great majority of them continue southeast over the island, usually in light and variable winds, until they reach the area of the Sargasso Sea, where they encounter the northeast trade winds that assist them in reaching the Caribbean. This second part of the journey is much slower than the first; the birds appear to fly for about 48 hours between Bermuda and Antigua. The radars at Antigua indicate that, as at Bermuda, few of the birds land; instead most of them seem to continue flying for another 18 hours to reach South America. The total time of nonstop flight over the ocean hence appears to be 86 hours, plus or minus 12.

To the best of our knowledge this migration is the longest (in both time and distance) nonstop flight known for small birds. It also seems to take place at the greatest height above the ground of any bird migration. From radar observations we found that the densest migrations from the North American coast to Bermuda are at an altitude of two kilometers (about 6,500 feet) or somewhat less, although some birds are detected at five kilometers (about 16,000 feet). At Bermuda a different pattern begins. Most birds fly at an altitude of from one to two kilometers. By the time they reach Antigua they are up between three and six kilometers, and on some days the radar showed significant numbers of birds flying over the island at 6.5 kilometers (21,000 feet). Although we made many fewer observations at Barbados and Tobago, it appeared that the birds were by then dropping in altitude, until at Tobago we recorded no birds above 800 meters. Evidently in approaching the South American coast the birds come down gradually in preparation for landing.

Birds at an altitude of six kilometers above Antigua are flying in air at a temperature of zero degrees Celsius, and the air has only about half as much oxygen as air at sea level. The advantage of flying at such heights seems to be that it puts the birds in a region of favorable wind conditions. We plotted the average wind velocity at various altitudes on the days when we detected moderate or heavy migrations at Antigua at an average altitude above 4.2 kilometers. The average direction of bird movement on those days was southeast. Our data for altitudes below four kilometers showed strong east-southeast winds, which were avoided by the high-flying birds.

Physiologically flight at such altitudes is made possible by the distinctive respiratory system of birds. The system embodies a number of adaptations for flight, but in this connection the crucial one is the countercurrent flow of blood and air in the bird's lung. It is the key to the bird's ability to extract oxygen efficiently and so to fly at high altitudes.



AREA OF MIGRATION from North America to the Caribbean and South America appears based on radar observations from Halifax, Cape Cod, Wallops Island, Bermuda, Miami, Puerto Rico, Antigua, Barbados and Tobago. The broken colored lines indicate two sets of possible migratory routes, one for birds flying along or near the North American coast and the other for birds making most of the trip over the ocean. (The data for Puerto Rico are derived from observations by W. J. Richardson of Environmental Research Associates in Toronto.) The gray lines forming triangles show the relation of the wind to the heading and track of the birds. In each case the broken line shows the direction of the wind (with the relative wind speed indicated by the length of the line), the dark gray line represents the average heading of the birds and the light gray line shows their average track. The birds consistently have a southeasterly heading, but the trade winds that blow from the northeast in the Caribbean create a drift that has the effect of turning the migrating birds toward the southwest as they approach their destination.

Observations made both visually (with the aid of binoculars) and by radar from ships at sea yielded a much clearer picture of how the birds behave during their long flight over the ocean and also indicated what kinds of birds might be making the flight. In order to follow our discussion of these results one needs to be clear about the distinction between a bird's track and its heading. If a bird is flying in a wind, the

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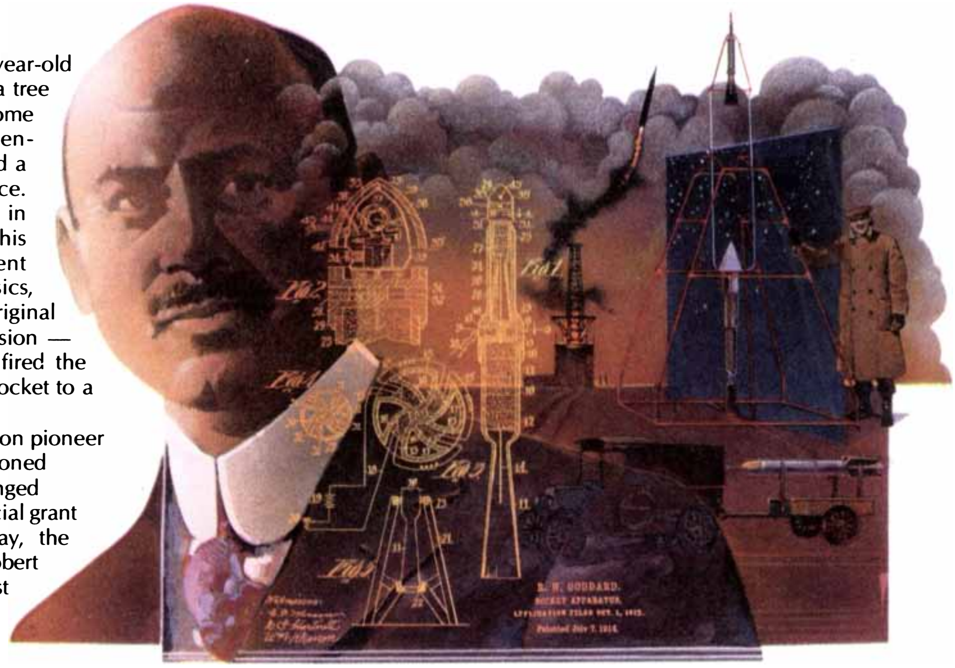

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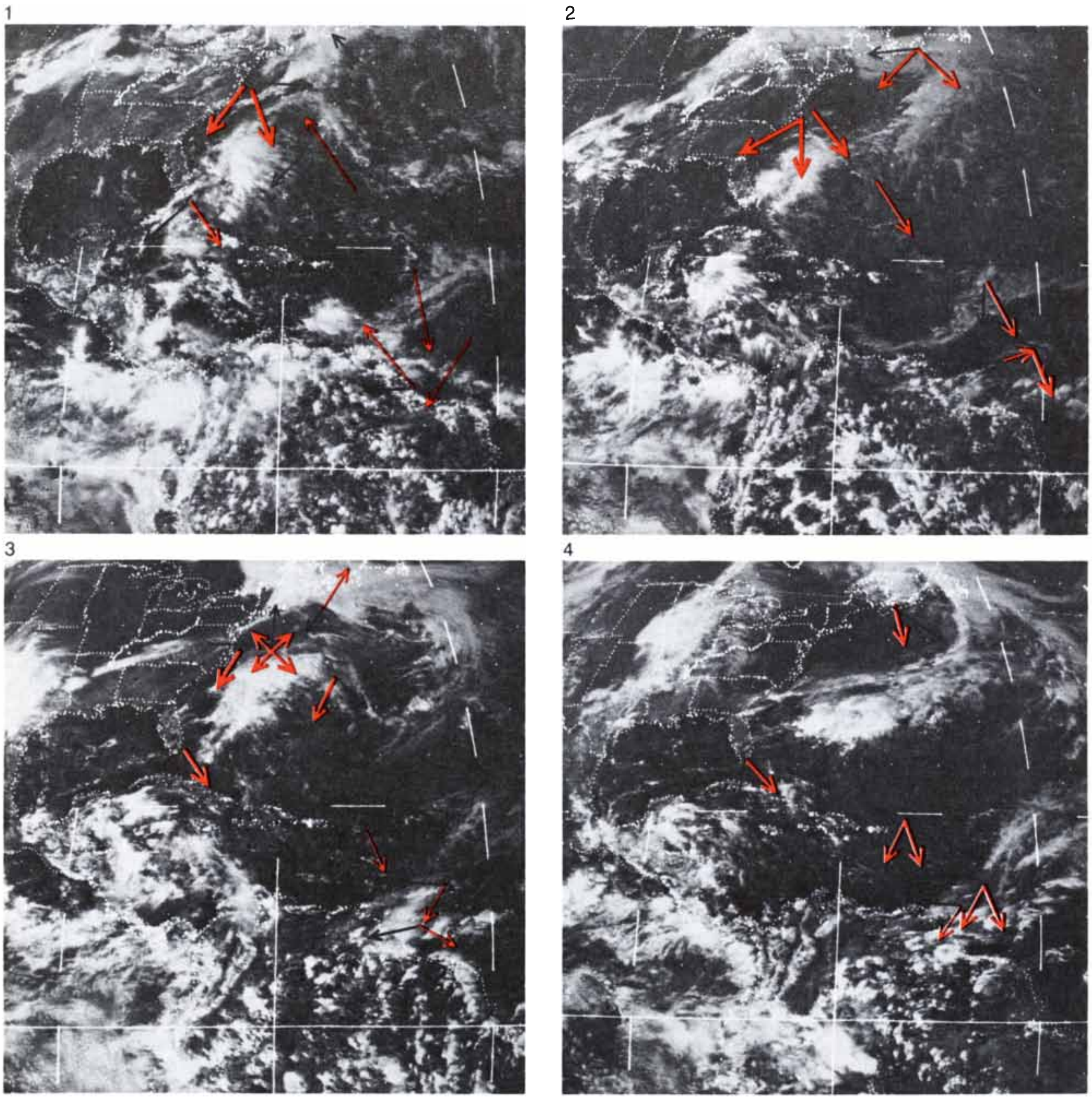
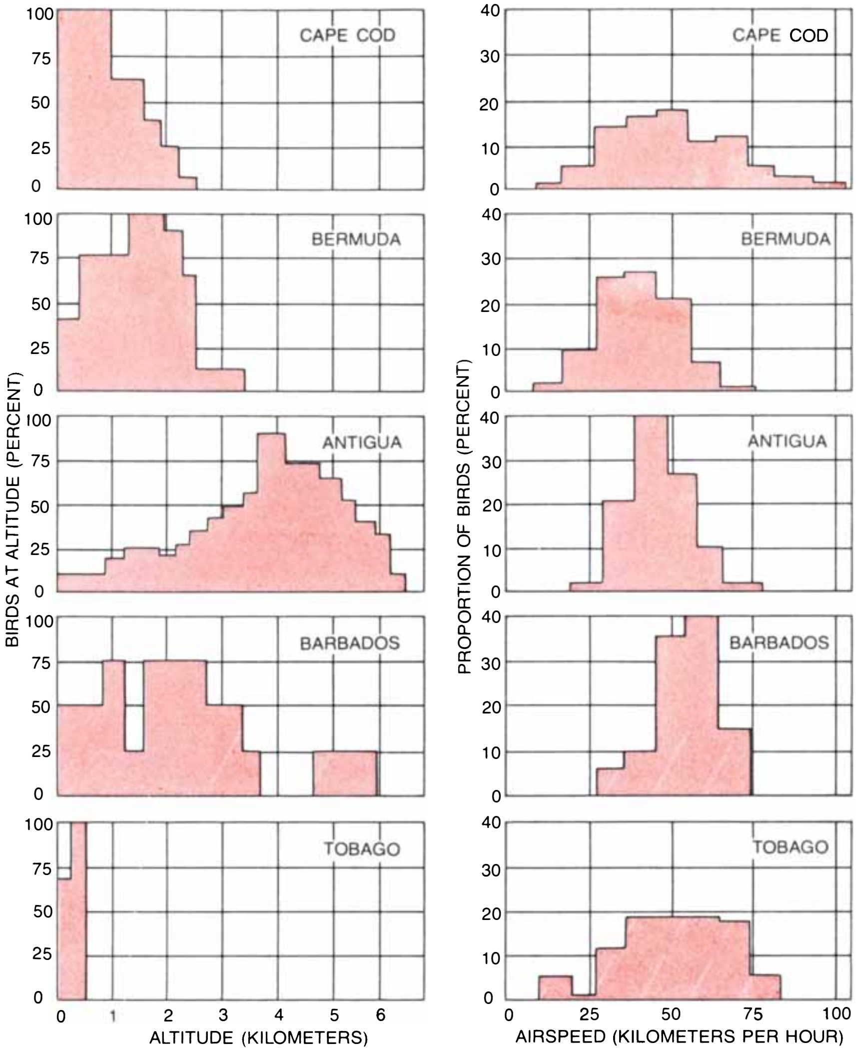
movement shown on a radar screen (the track) does not necessarily correspond to the direction in which the bird is orienting its body (the heading). The wind introduces drift, that is, it blows the bird to the downwind side of its heading.

Another factor to be taken into account is the bird's airspeed, which is of course the speed of its flight through the air. Airspeed and heading are calculated from our radar data by means of the direction and speed of the wind as determined by a weather balloon at the altitude of the bird. In order to distinguish the behavior of birds from their drift caused by the winds we have plotted both track and heading for observations of bird migrations at sea. Following the lead of Ronald P. Larkin of Rockefeller University, who analyzed the first two years of these observations at sea, we have divided all the observations from ships into periods of consistent migratory behavior.

A plot of these data on a map reveals four rather different categories of behavior [*see top illustration on page 175*]. The first category consists of the periods when no significant amount of migration is detected. The second consists of birds with headings from south to southeast and tracks that are southerly. These birds, if they continued the pattern, would be likely to reach South America. The third category consists of groups of birds that appear to be disoriented.



PROGRESS OF MIGRATION during four days in October, 1973, is plotted on weather-satellite photographs made by the National Oceanic and Atmospheric Administration (NOAA). The colored arrows represent the average track of a bird migration, and the thickness of an arrow indicates whether the migration was light, medium or heavy. The black arrows show the wind direction at the altitude of the birds; the longer the arrow, the higher the average wind speed. A migration began October 3 under typical conditions (*1*), after a cold front had just moved offshore from Cape Cod to Florida. The accompanying northwest winds aided the birds. By the next day (*2*) the frontal system was stationary between Bermuda and the coast, and most of the birds had reached Bermuda. Once past Bermuda (*3 and 4*) they encountered the northeast trade winds that shifted them toward their destinations in the Caribbean and South America. The birds were at Barbados by the fourth day after about 72 hours of flight. The total time of nonstop flight over the ocean was about 86 hours.



ALTITUDE AND SPEED of migrating birds, as ascertained by radar observations, are charted. The plot of altitude (*left*) shows the percent of birds found at given altitudes during times of moderate or heavy migration. The average altitude reaches a peak at Antigua and then declines as the birds approach their destination. The plot of airspeed (*right*) shows the percent of birds detected at each speed. The loss of both the faster and the slower birds between Cape Cod and Antigua suggests that only certain species are adapted to this long migration. The number flying at less than 50 kilometers per hour suggests that many of the birds are small songbirds.

Their headings are widely scattered, and any net progress of a group is largely attributable to drift caused by the wind. The calculated airspeeds of these birds are generally quite low, less than 20 kilometers per hour. It appears unlikely that any significant proportion of the birds in this category would reach the Caribbean or South America if they persisted in poorly oriented flight at low speed. The last category consists of birds that are apparently trying to move in a direction other than toward the Caribbean.

We could not discern a statistically significant tendency for these four types of behavior to be grouped in any area of the Atlantic we studied. We therefore concluded that some factor other than geography must have been determining the categories of behavior we observed from the ships. If one plots the same data on a diagram of the predominant weather patterns at a given time, a clearer picture emerges.

A typical weather system for which we made such a plot consisted of a low-pressure center or hurricane, a moving cold front, a stationary front and two high-pressure air masses, one subtropical and the other (northwest of the frontal system) representing air that had just moved off the North American continent [*see bottom illustration on opposite page*]. The migratory patterns differed according to the weather. In the area around the subtropical high we found only migrants with headings to the south or southeast; they were making effective progress toward the Caribbean. Groups of birds with scattered headings were found only northwest of frontal systems or south and east of low-pressure centers. A common factor in both cases is that the disoriented birds have recently experienced strong offshore winds. It is in these areas also that we found most of the birds with an average airspeed of less than 20 kilometers per hour.

Based on this analysis we can tentatively classify birds observed over the Atlantic as true migrants if they have penetrated the frontal system that initiated their departure and as unsuccessful migrants if they are observed in a high-pressure center northwest of a frontal system or in a low-pressure system. (Some true migrants will occasionally turn up in the second category, usually because the observation was made near the North American coast when the birds had not yet penetrated the frontal system.) It is probable that the unsuccessful migrants are birds that would normally migrate over land but have been blown out to sea.

A heading that is generally southeast is typical of the true migrants, regardless of whether the radar that detects them is coastal, island-based or on a ship. Nevertheless, it is not always easy to identify the true migrants because of the frequent simultaneous occurrence of two or more patterns of migratory behavior, particularly at the large coastal or island-based radars. Therefore at each site we separated groups of birds on the basis of track direction and then computed the average heading of each group. Although the average heading of all migrants at Cape Cod, Wallops Island, Miami and Bermuda was to the southeast, the analysis at Antigua is probably the most important one. There we divided the birds into two groups: those that were moving along the Antilles to the southeast and those that were arriving from the Atlantic moving southwest. In spite of this arbitrary division the average heading of both groups was to the southeast; the difference in track direction was due to the fact that the birds were flying in different wind conditions.

The analysis of headings suggests that a remarkably simple guidance system is adequate for this 3,000-kilometer flight. Once birds leave the coast of North America they maintain a constant compass heading to the southeast until they reach the coast of South America. It apparently is not necessary for them to change this heading; the shift from a southeast track to a southwest one is accomplished for them when they encounter the northeast trade winds in the area of the Sargasso Sea. A substantial body of experimental evidence supports the notion that a bird can establish and maintain a compass heading on the basis of the sun, the stars or the magnetic field of the earth.

Although radar has many advantages

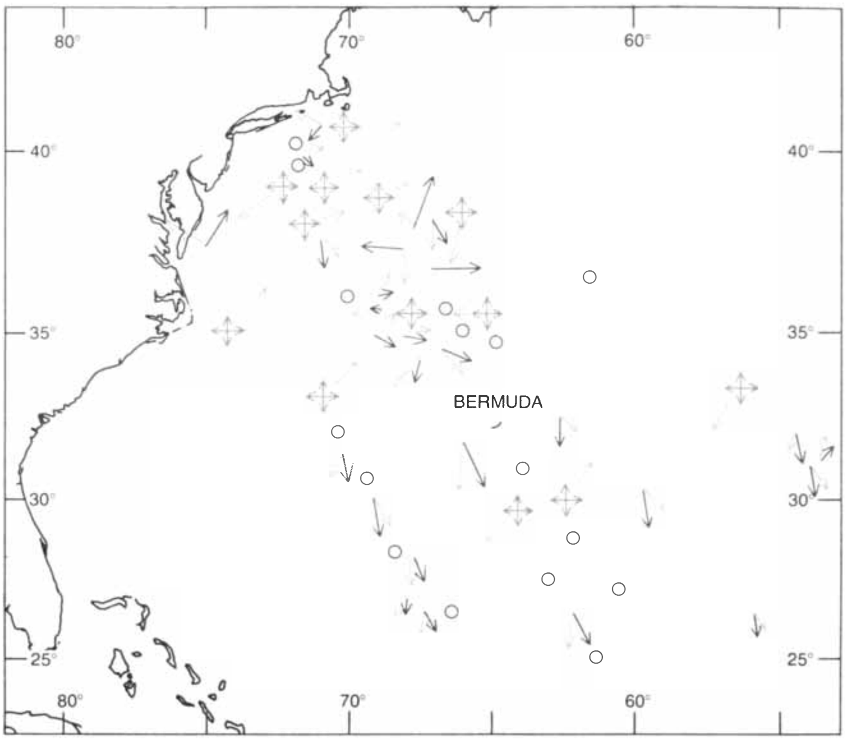
for studying the migration of birds, it does not enable us to identify the birds that are detected on the radar screen. We have gone at the question indirectly by determining the airspeed of the 4,600 or more birds we have detected by radar. At coastal sites the range of airspeeds is quite broad, but in the Caribbean it is mainly between 30 and 60 kilometers per hour. Even though airspeed is not a precise means of identifying birds, most of the birds flying at less than 45 kilometers per hour are probably small songbirds. Shorebirds and waterfowl fly faster.

Much better identifications can be made of birds that are seen passing or landing on ships. During the last two years of our shipboard observations Carol P. McClintock of the State University of New York at Buffalo undertook to obtain as many specimens as possible. Since firearms are not allowed on the ships, she resorted to live traps or a slingshot for which green grapes served as the ammunition. Her findings, together with careful observations made with binoculars, reveal that small songbirds were by far the most abundant species seen from ships in all the areas of the Atlantic we investigated.

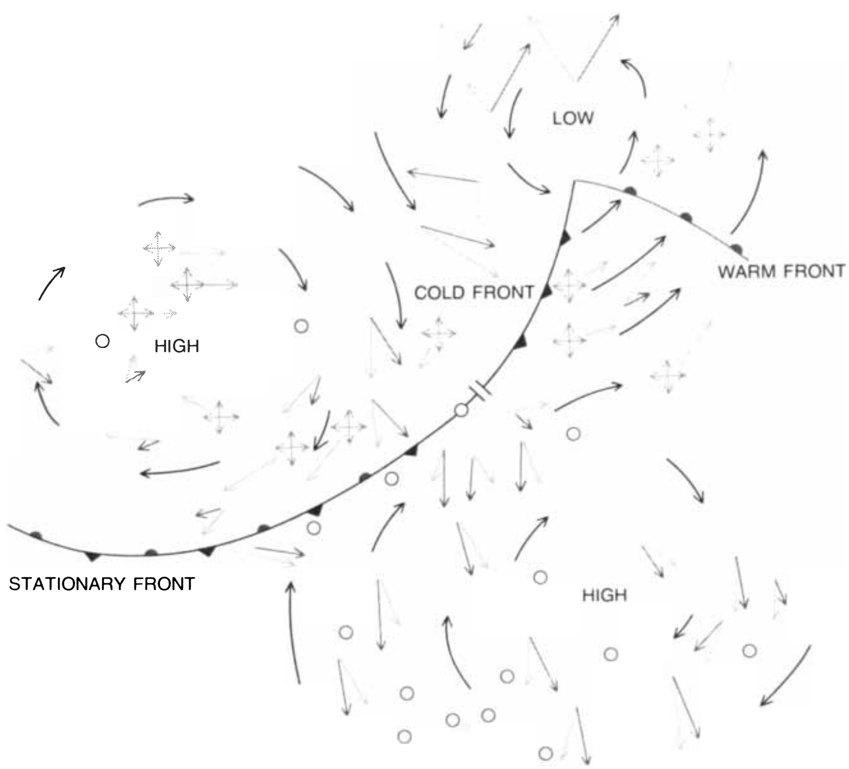
The variations in the observed distribution of songbirds appeared to reflect behavioral differences rather than physical ones. For example, warblers, sparrows and juncos are about the same size and weight, yet all but one of our observations of sparrows and juncos were confined to the area between the coast and Bermuda, and warblers were seen as far south and east as the ships traveled. We believe many of the birds we have defined as true migrants are warblers, whereas many of the birds seen wandering behind frontal systems or south of low-pressure areas (the unsuccessful migrants) are such species as sparrows and juncos, which do not migrate to the Caribbean or South America.

The Atlantic is not a hospitable place for small songbirds. During storms at sea hundreds or thousands of small birds have been seen flying around a ship, entering cabins and hitting masts or wires. At such times it seemed unlikely that many of the birds could survive for more than a few hours. Our belief that large numbers of these birds perish at sea is supported by reports from oceanographers that bird feathers are often found in the stomachs of deep-sea Atlantic fishes.

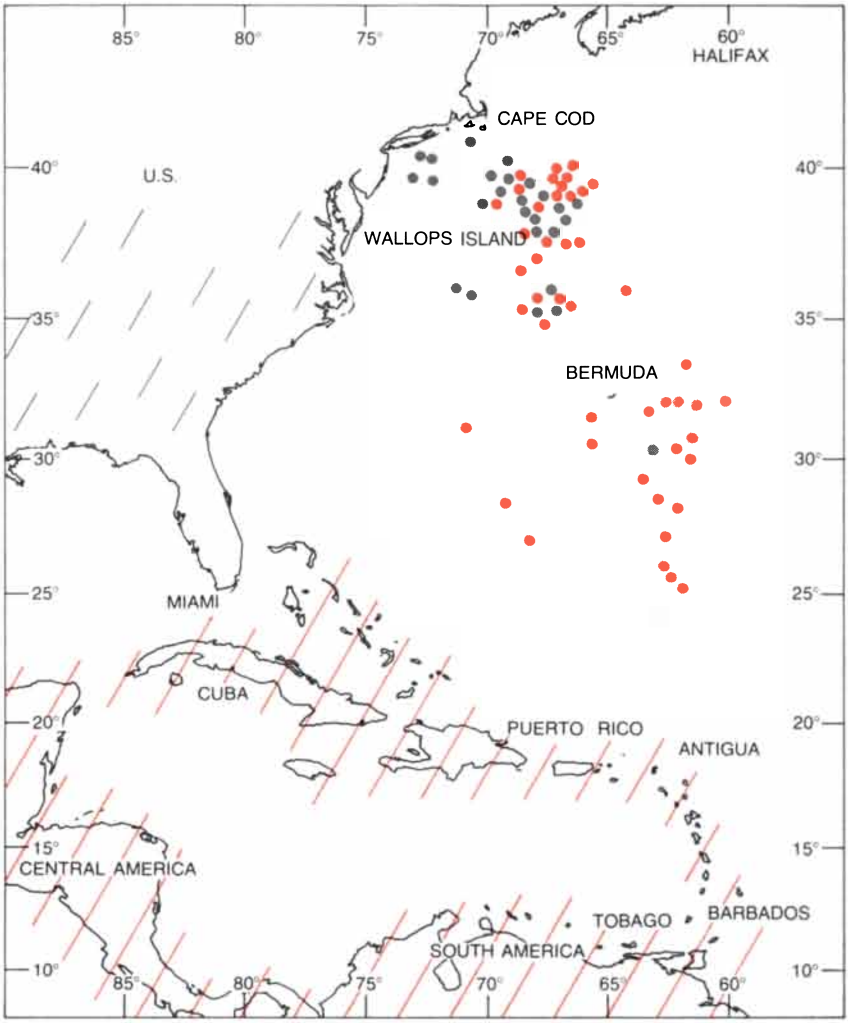
Our radar data indicate, however, that such losses arise primarily among birds that lack the behavioral adaptations for flying over the ocean. For the true migrants a relatively simple migratory strategy takes advantage of a surprisingly predictable series of weather conditions along the route. First the migrants wait on the east coast of North America until a strong cold front passes



MIGRATORY BEHAVIOR of birds over the ocean was observed by means of shipborne radar. The dark gray arrows indicate the average heading of the birds and, by the length of the arrow, the relative airspeed; the longer the arrow, the higher the average airspeed. The light gray arrows similarly indicate the average track of the birds and their average speed in relation to the ground. The open circles represent areas where no migrating land birds were seen.



EFFECT OF WEATHER on migratory behavior is indicated by plotting the data from the illustration at the top of the page on a diagram of typical weather conditions. Weather patterns are much more important than geography in influencing the behavior of migrating birds.



BIRD SIGHTINGS from ships in the western Atlantic reveal a difference between the migratory patterns of small songbirds that winter in the southern U.S. and those that winter in the Caribbean and South America. The first group, represented by gray dots and gray hatching in the wintering area, includes three types of sparrow and the slate-colored junco. The second group includes eight species of wood warbler and is represented by colored dots and hatching. Some species of warbler winter in Central and South America rather than the West Indies.

southeast over the coast and out into the Atlantic. This weather pattern not only ensures the birds favorable northwest winds during the first part of their flight but also is a remarkably good indicator of fair weather between the coast and the Sargasso Sea. Tropical storms or hurricanes approaching the North American coast usually halt the southeastward movement of cold fronts. On 93 days or nights we observed moderate or heavy movement of birds along the North American coast or at Bermuda, and on only two of those occasions did we see birds apparently flying into the path of an approaching storm.

Once the migrants have left the coast they have only to fly constantly to the southeast until they reach the Caribbean or South America; their actual track will be first to the southeast to the Sargasso Sea and then, as they encounter the trade winds, southwest until they reach their destination. As soon as they have penetrated the frontal systems near Bermuda their flight will be for the most part under clear skies with either light and variable winds or moderate, steady northeast ones.

The ocean route from Halifax to Antigua is about 2,800 kilometers (47 percent) shorter than a route by way of Florida. Moreover, birds on the ocean route take advantage of both northwest offshore winds and the northeast trade winds as tailwinds, and the route presumably is without predators. The trip does, however, require a degree of exertion that is not matched by any other vertebrate. For a man the metabolic equivalent would be to run four-minute miles for 80 hours. The avian respiratory and muscular systems show many adaptations that make such an output possible. If a blackpoll warbler were burning gasoline instead of its reserves of body fat, it could boast of getting 720,000 miles to the gallon!

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