WATCHING MIGRATION BY RADAR

By DAVID LACK
(*Edward Grey Institute, Oxford*)

HISTORY

SO FAR AS I know, the first time that radar echoes were definitely identified as coming from birds was in the spring of 1940, when an experimental equipment on a wavelength of 50 cm. at Christchurch, Hampshire, detected gulls (*Larus* spp.) (Shire, 1958). Unidentified echoes, some of them doubtless from large birds, were reported on 150 cm. equipment round the British coasts during the ensuing year, but the next identified records appear to be those of R. G. Finnis, who between 11th August and 11th November 1941 regularly plotted a migration of Herons (*Ardea cinerea*) by radar over Tobruk (Stanford, 1954). In September 1941, echoes from sea-birds for the first time became a serious operational nuisance, on the newly developed 10 cm. equipment (Lack and Varley, 1945, who also refer to other early records). During the war years, only large birds were usually detected,

continued ...

though a big roost of Starlings (*Sturnus vulgaris*), repeatedly disturbed by V1 bombs passing over it, caused a scare that the enemy had invented a new form of radar jamming. The only other migration plotted in this period was of raptors in the Suez area in October 1945 (Goodwin, 1947).

Thereafter the ornithological problem was allowed to languish for more than a decade, though in the latter part of this time, both in Britain and U.S.A., radar equipments much stronger in power than those used during the war were regularly plotting bird-migration, unknown both to the operators and to the investigating scientists who ascribed the echoes in question to unidentified meteorological phenomena ("angels"). I am, however, indebted to Dr. Stuart Smith for an overlooked record, in this period, of a hard-weather south-westward movement of Lapwings (*Vanellus vanellus*) detected by the airport radar on Jersey, Channel Islands, and confirmed visually on 26th January 1952 (Graham, 1953). Three years later Lapwings were tracked by radar at Zürich Airport (Hoffmann, 1956), and the next year Sutter (1957ab) not only showed convincingly that "angels" recorded on radar at Zürich Airport were echoes from migratory Passerine birds, but by thorough and imaginative techniques explored the possibilities of this new tool in the study of migration: his speeded-up films of a radar display with migration in progress provided a sensation at the International Ornithological Congress at Helsinki in 1958. Harper (1957, 1958), working independently in England, also established that "angels" were echoes from migratory birds, while for some further references see Lack (1958) and Tedd and Lack (1958). From 1955 onward, the Royal Radar Establishment, and later the Research Branch of R.A.F. Fighter Command, collected regular records of "angels" on their new high-powered equipment, at first by operators' reports and later by repeated photographs, and this material they generously put at my disposal for analysis, while also allowing me to watch at their stations.

THE ILLUSTRATIONS

Good photographs of "angel" displays have been published for radar equipments of lower power by Sutter (1957 ab) and Harper (1958), and some for high-power R.A.F. equipment by Tedd and Lack (1958), one of which is reproduced here, as plate 48a, by kind permission of the Air Ministry and the Royal Society (in whose *Proceedings* it appeared). The other photographs shown here were supplied by the Royal Radar Establishment through Mr. H. K. Sutcliffe, to whom I am extremely grateful, and, of these, plates 45b and 46b have previously appeared in *The Ibis* and are reproduced by the editor's permission. All these pictures are Crown Copyright. They demonstrate better than a lengthly description in words what bird migration looks like on a radar display, and though movement is absent, bird-echoes do not move at a visible rate on the scale used, so at any one moment the human observer does not see more than what is shown here.

On the plan-position display, all radar echoes appear as bright points of light against a dark ground. Each is in its correct geographical position with respect to other echoes, and the range from the station is indicated by concentric rings. Not all the photographs have been reproduced here on the same scale, but the scale is readily seen because the bright rings in all the photographs on plates 45, 46 and 47 are 50 miles apart, while the fainter rings on plates 45a, 46b, 47 and 48b are 10 miles apart; plate 48a, without range-rings, has a scale at the bottom. All the plates have been arranged with north at the top.

Plate 45a shows an eastward emigration of moderate size from East Anglia in March at 0400 hours, i.e. near the end of the night movement. The large bright echoes on the left of the picture are mainly from land, while those from migrating birds are smaller points, in a dense mass near the station, and extending from it fairly densely to 50 miles and in more scattered form to 80 miles. Plate 45b, a picture of the same movement taken at 22.00 hours, which is near to the peak time for nocturnal departures seaward in spring, shows an extremely heavy eastward emigration, with bird-echoes extending in the north-east to 130 miles from the station. Plate 46a, again of the same display, was taken at 06.00 hours next morning, when the nocturnal emigration had nearly ceased and the morning emigration was under way. The latter movement was of moderate size, with echoes to about 70 miles in the north-east. Note particularly the sharp boundary running from north-east to south-west in the bottom right-hand part of the display, with many bird-echoes to the east of it but hardly any to the west of it. This line is that of the coast, and the effect, as I interpret it, is due to many migrants flying over the land so low as to be out of radar range, and then rising higher, into radar range, on putting out to sea. This effect was often seen on spring mornings, and a drawing from another photograph in Lack (1959, Pt. 2) shows both the Suffolk coast and the Wash outlined in this way. The effect was never seen at night ,when eastward-moving echoes were usually as dense over the land as out to sea. This presumably means that migrants leaving at night immediately rise high while over the land.

Plate 46b, taken at 21.00 hours in mid-November, shows to the east of the station a typical immigration of moderate extent. The birds involved in this movement presumably took off after dusk from northern Holland, travelling just south of west. There were, as usual, few echoes to the north of the station because, owing to the Heligoland Bight, there is no land immediately north of Holland from which birds could come. This is the characteristic pattern for westward movements in autumn, by day and night, except that there are not infrequently more echoes to the south of the band shown in plate 46b. The picture is very different for the south-westward immigrations in autumn, which are usually densest to the north-east of the station, but I have no

photographs of these. Plate 46b also shows a moderate number of bird-echoes over the land.

Rain also gives radar echoes, and plate 47a taken at 17.30 hours on 30th March 1958, of the same display as plates 45 and 46a, shows many birds moving E.N.E. to the north of a cold front. Plate 47b, again of the same display but enlarged, was taken at 09.45 hours next day. The centre of the station is blacked out, the opaque bright smears are from rain, and the remaining echoes are from birds. This was a time-exposure, so that each bird-echo appears not as a dot, as in previous pictures, but as a line, this representing successive positions of the same echo and thus showing the track of the bird, though not the direction in which it moved along it. Most of the echoes over the land between west and south of the station were moving N.E., and most of those out to sea between north and east of the station beyond a range of 45 miles were moving E.N.E.; these were the remains of a typical morning emigration. But out to sea inside 45 miles from the station was a dense group of echoes moving about W.N.W. The comparatively short range at which they ceased to be detected suggests that the birds concerned were flying lower than those on the eastward emigration (but they could not have been really close to the waves, or they would have been out of radar range). I earlier postulated (Lack, 1959) that this north-westward movement was part of the big drifted arrival of Continental night-migrants into eastern Britain in the period concerned (Ferguson-Lees, 1958), but observations in late March 1959 showed that north-westward arrivals also occur at this season with westerly winds when drift from the Continent can be excluded, finches (*Carduelis* spp.) and Meadow Pipits (*Anthus pratensis*) probably being involved. Hence my early conclusion that this was an instance of down-wind drift must unfortunately be regarded as unproven, though it may well have been correct.

Plate 48a, taken at a different radar station, was a ½-hour time-exposure, and shows bird-echoes moving north-east out to sea, also a large belt of rain which was travelling 10 degrees east of north; hence the birds were not moving directly away from the rain. While directions can be obtained photographically by a time exposure, and on an actual display by tracking individual echoes, they are most quickly obtained on the present type of radar equipment in another way. The glow from each echo persists for some time, so that previous positions of the same echo are normally visible as a "tail" to the main echo in the direction from which it has come. After-glow tails are not easily photographed, but can be seen in the enlarged portion of a radar display in plate 48b. The birds are arriving west in June and are presumably Lapwings (*Vanellus vanellus*).

MAIN ORNITHOLOGICAL FINDINGS

The following are some of the main ornithological findings so

far, most of which are being published in detail in *The Ibis* (Lack, 1959), while others have not yet been written up.

(1) Radar confirms that the migration visible by day may be not merely incomplete but also unrepresentative of what is passing overhead. For instance, depending mainly on the wind, sometimes much and sometimes nothing was visible of the big eastward emigrations from Norfolk on April mornings in 1958. Further, the direction of migrants flying within visual range is sometimes different from that of birds migrating high up. It follows that great caution is needed in interpreting results from visible migration.

(2) Radar similarly confirms that the grounded night-migrants seen next morning represent a variable fraction of those which came through the area during the night. A particularly good instance of this occurred in September 1958, when on four different occasions I observed by radar fairly large south-westward arrivals from the North Sea into Norfolk during the night and morning. On the first of these movements there was a big "fall" of Continental night-migrants, many individuals and species alighting in the bushes at Blakeney Point, on the second a moderate number and variety were seen there, on the third extremely few were seen, and on the last none—though Redwings (*Turdus musicus*) and Fieldfares (*T. pilaris*) were heard at night.

(3) The density of bird-echoes on a radar display provides an objective measure of the volume of migration. This measure is on an arbitrary scale which cannot, so far as I can see, be related to the true number of birds in the air. For one thing, echoes from single birds and small flocks cannot be distinguished, nor can those from different species. There is also a gap in the radar coverage since birds flying just above the waves are not detected; and at the same time echoes from other objects, such as rain, may obscure those from birds. Otherwise, however, the radar record is complete, and this allows one to establish (a) the main patterns of migration through the year, and (b) variations in the volume of migration due to the weather and other factors. With respect to (a), it is important to have simultaneous visual observations, and my radar findings in Norfolk have been fully discussed with R. A. Richardson of Cley Bird Observatory, to whom I am most grateful.

(4) The three biggest migratory movements of the year in the southern part of the North Sea are demonstrated, by combining the results from more than one radar station, in Figs. 1, 2 and 3, prepared from photographs by Research Branch, Fighter Command, and reproduced by their permission, as well as that of the Royal Society in whose proceedings they have previously appeared. Fig. 1 shows a typical eastward emigration across the North Sea on a spring night. Note, however, that in the Pas de Calais the main movement over the land was north-east. Fig. 2, on an October morning, shows a big south-westward immigration,

but also a movement W.S.W. My own later inspection of the photographs on which this was based revealed clearly that two different movements were involved, one with a mean direction near to S.S.W., which presumably left Norway around dusk, and the other with a mean direction near to W.S.W., which presumably left northern Holland around dawn. Note that some of the birds on the S.S.W. movement passed through the Straits of Dover and evidently did not make their landfall until they reached France.

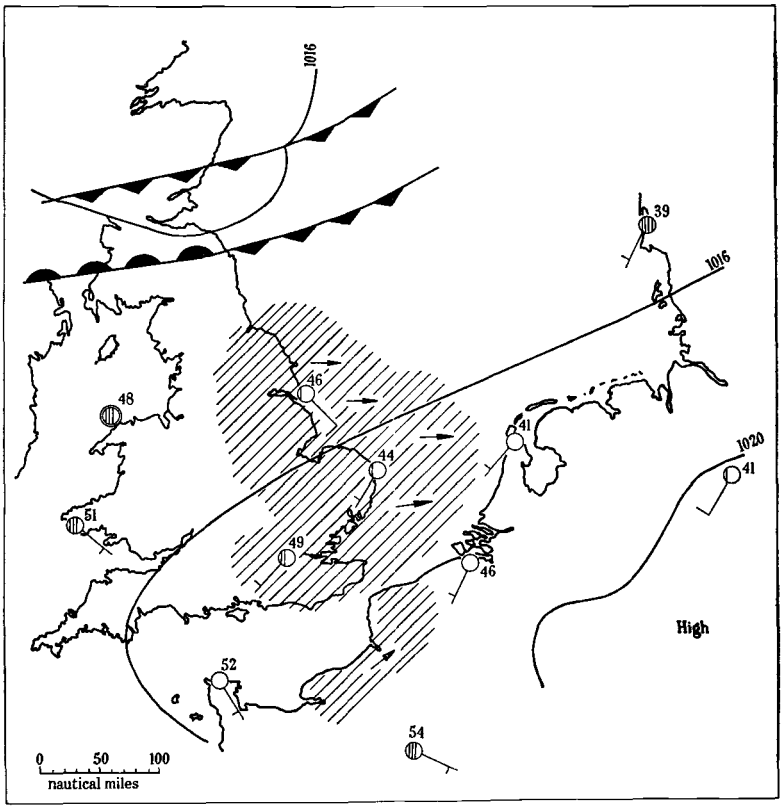

FIG. 1—A TYPICAL EASTWARD EMIGRATION IN SPRING, AT 20.00 HOURS ON 3RD MARCH 1957

For discussion see page 262.

This often happens on movements of this type and, on the assumption that the birds concerned came from Norway, means that they had a sea-crossing of about 600 miles. Fig. 3, on a morning in mid-December, shows a westward immigration to Norfolk and a south-westward movement along and off the Belgian coast and the Pas de Calais. It occurred during cold

weather on the Continent, so might be termed a "hard-weather" movement, though a similar pattern is often observed in late October and early November.

In addition to these three main movements, radar plotted movements off Norfolk north-westward in spring and south-east-

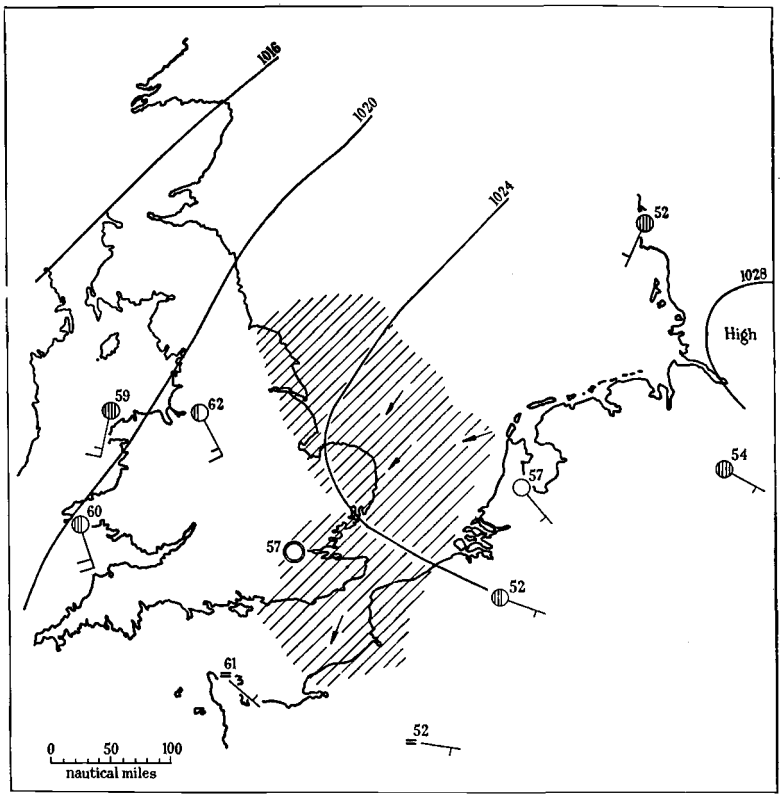

FIG. 2—A TYPICAL SOUTH-WESTWARD IMMIGRATION IN AUTUMN, AT 10.00 HOURS ON 15TH OCTOBER 1957

Two separate movements are involved here, S.S.W. and W.S.W., presumably of birds which left Scandinavia at dusk and Holland at dawn respectively (see page 263).

ward in autumn, presumably of British summer residents, but they are smaller than those of the British winter residents shown in Figs. 1-3.

(5) The amount of spring emigration from East Anglia in March and April 1956-58 was large with clear skies, light winds and warm weather, and small with rain, clouds, high wind and

cold, while it was unaffected by pressure-pattern and wind-direction as such.

(6) Nocturnal emigration usually reached its peak out to sea between 21.00 and 22.00 hours, while the morning emigration

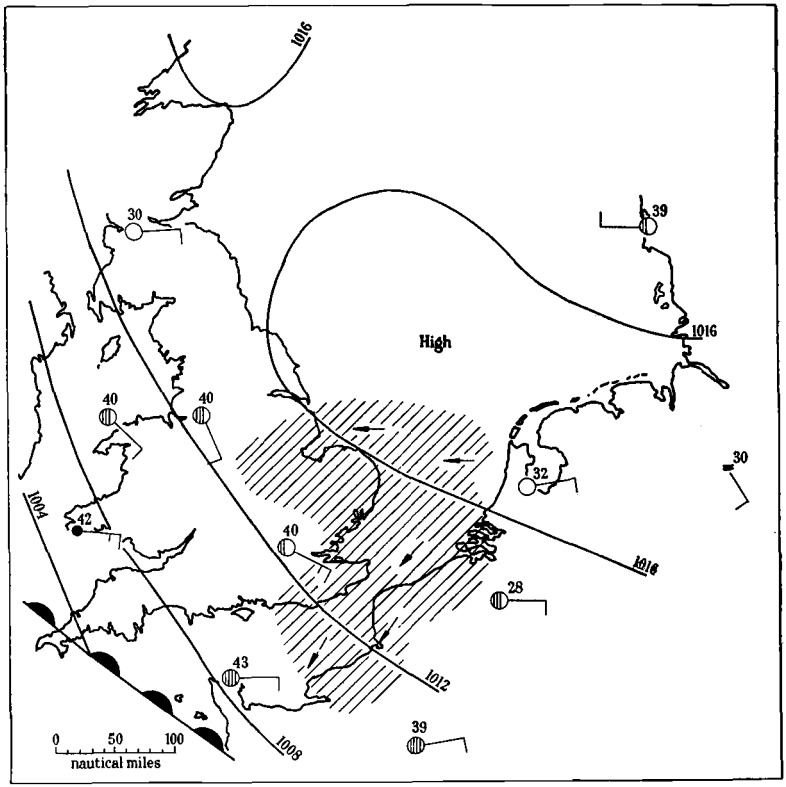

FIG. 3—TYPICAL WESTWARD AND SOUTH-WEST MOVEMENTS IN COLD WEATHER, AT 14.30 HOURS ON 12TH DECEMBER 1955
For discussion see page 263.

was usually densest about an hour after sunrise. In spring, emigration was usually much heavier by night than by day, but in autumn westward immigration was about equally dense by night and day.

(7) All night movements and nearly all day movements were on a broad front, and radar provides no support for the view that night-migrants follow coast-lines, though big coasting movements were sometimes tracked by day in autumn.

(8) An analysis of the directions of emigration over the sea in relation to the wind showed that, in clear and fairly clear weather by both day and night, the track could best be interpreted

as the resultant between a heading maintained by the bird and lateral displacement by the wind. In spring, for instance, the track was almost always north of east with a southerly wind and south of east with a northerly wind. This is the commonest type of "drift", indeed it is invariable in fine weather, but it is not the type usually responsible for big drifted "falls" at bird observatories, which seem to be associated with overcast weather.

(9) On 17th April 1958, a big evening emigration rather north of east later met widespread drizzle at sea, and thereafter no steady tracks were obtained, the birds clearly being disoriented. Under such conditions they would gradually drift down-wind (but as the wind was light and individual echoes could not be tracked for long, a down-wind drift would not have been detectable by radar). Since the birds might well be tired if they flew in this way all night, this type of drift could be responsible for big "falls" at observatories, though there is as yet no direct evidence of this.

(10) I have been personally present at a radar station during two big drift-arrivals of night-migrants into Norfolk, which is not, of course, enough to justify any generalization. As already mentioned, during the drift-arrival at the end of March 1958 many bird-echoes, presumably but by no means certainly from this movement, travelled north-west, i.e. down-wind. But the passage appeared to differ from Williamson's picture of down-wind drift in not being very close to the waves. Further, though for much of the time there was a cold front or fog at sea, it seems almost certain that the sky was clear enough to see sun or stars during part of the time when this movement occurred.

On the second movement, in the first week of September 1958, there were clear skies and south-easterly winds. The bird-echoes that I presume to have been from the drift-movement moved south-west, so the track of the birds was presumably a resultant between their normal southerly heading and the wind. The puzzling feature about this movement is not the direction taken, which was that to be expected with a laterally displaced movement, but the fact that so many of the migrants alighted on arrival, suggesting that they had come a long way. I should add that, throughout the period concerned, there were simultaneous westward arrivals corresponding to dawn and dusk departures from northern Holland, but these birds travelled high and fast, and I infer that they were waders and not the Passerines of the drifted movement.

(11) Following both big drift-arrivals, movements were tracked by radar in early April heading south-eastward and in September eastward, which must, I think, have been redetermined movements of the same birds correcting for their previous drift.

I would in conclusion stress that experience and judgement are needed in observing and interpreting radar data, just as they are

needed for all other forms of bird-watching, and I would not want the reader to think that, because a new and highly technical tool of research is being used, the conclusions based on it are infallible. Difficulties in observation arise particularly when two movements take place simultaneously, and difficulties in interpretation in relating the radar record to the ornithological situation.

SUMMARY

After a brief history of bird-detection by radar, photographs of bird-echoes under different conditions are described, and the main ornithological findings so far are reviewed.

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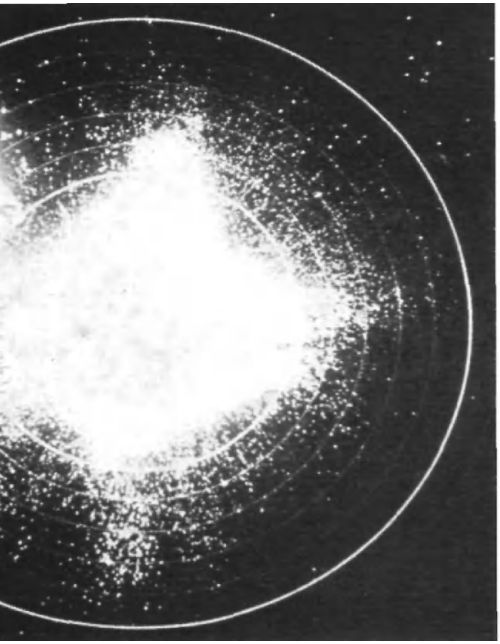

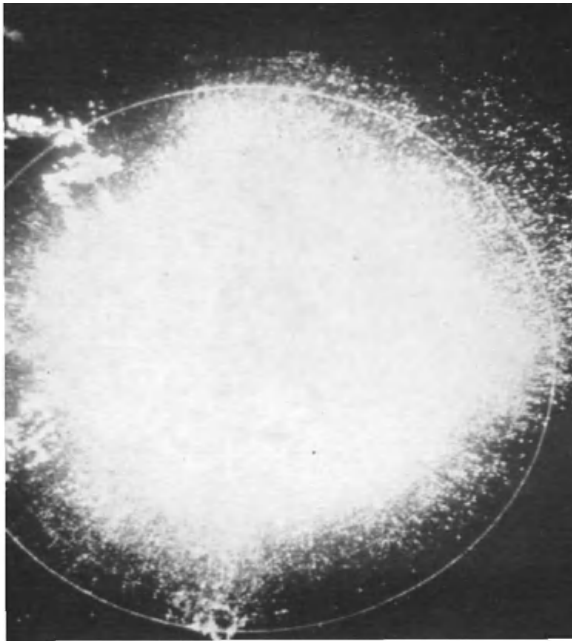

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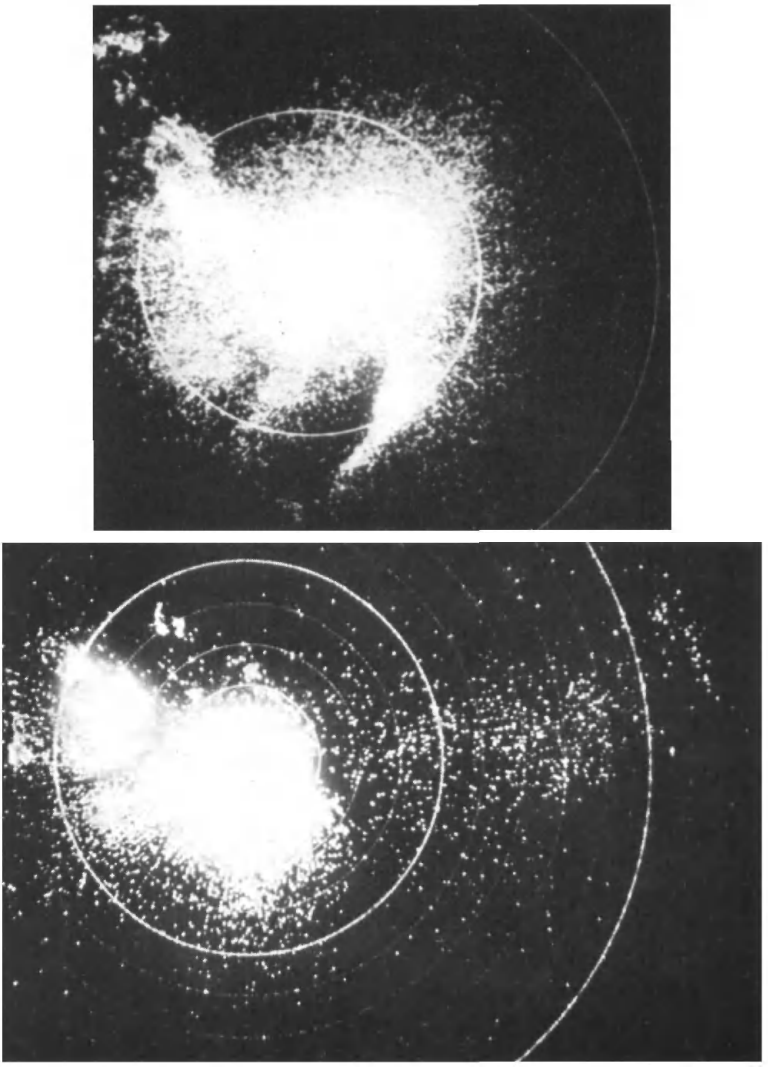
MIGRATION ON RADAR: (a) MODERATE NIGHT EMIGRATION IN MARCH, and (b) DENSE NIGHT EMIGRATION IN MARCH

The bright rings are 50 miles and the faint rings 10 miles apart; every photograph has north at the top. The large echoes on the left are mainly from land; the bird-echoes are the small points of light which form a dense mass near the station and are more scattered further out. Both pictures are of the same eastward emigration, (b) at the peak and (a) six hours later near the end of the night (see page 260).



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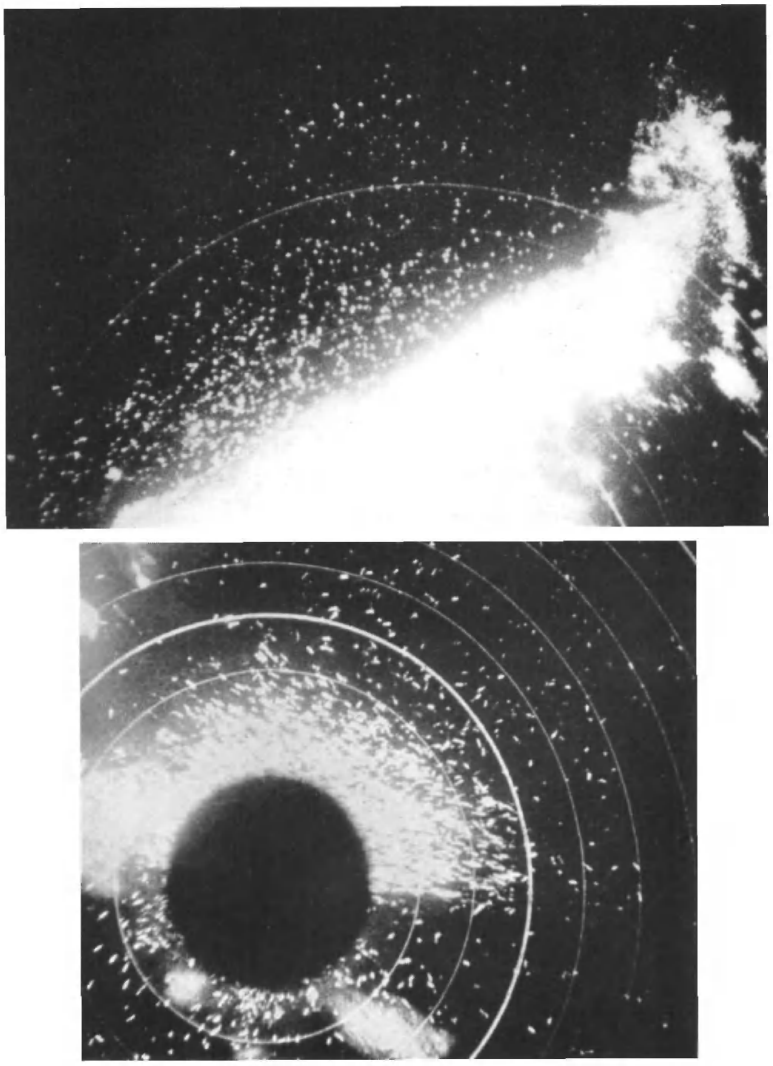
MIGRATION ON RADAR: (a) MODERATE MORNING EMIGRATION IN MARCH, and (b) MODERATE WESTWARD IMMIGRATION ON A NOVEMBER NIGHT

The rings in (a) are 50 miles and the faint rings in (b) 10 miles apart. In (a) the sharp boundary on the bottom right, with many bird-echoes to the east but few to the west, is the coast-line which shows up because diurnal migrants rise high, into radar range, before putting out to sea (see page 260). In (b) is a typical westward autumn pattern, with few echoes to the north because there is no land immediately north of Holland from which the birds can come (see page 260).



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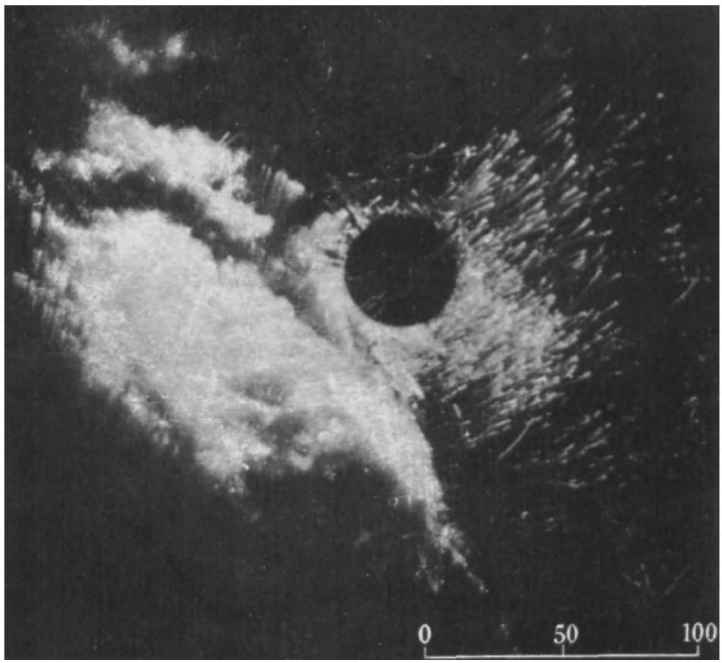
MIGRATION ON RADAR: (a) EASTWARD EMIGRATION NORTH OF COLD FRONT, and (b) WNW ARRIVAL INSIDE 45 MILES AND SPARSE NE MOVEMENT ELSEWHERE

The faint rings are 10 miles apart. In (a) the dense echoes given by rain show the position of the cold front. In (b)—taken at 09.45 hours—the centre is blacked out, the opaque smears are from rain and the rest from birds; this was a short time-exposure, so that the bird-echoes appear as direction-giving lines, not dots (see page 261); the W.N.W. movement inside 45 miles was probably drift arrival and the N.E. beyond was the remains of a morning emigration which had been much denser.



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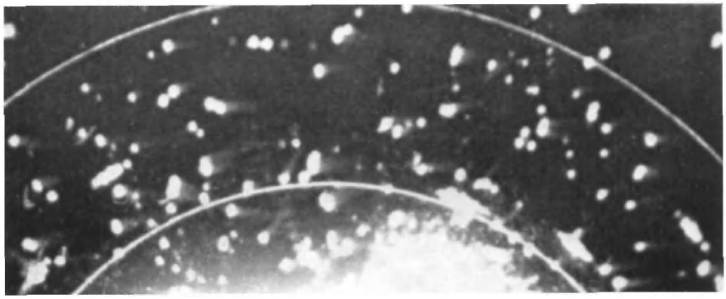

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MIGRATION ON RADAR: (a) NE DEPARTURES AND A BELT OF RAIN, and (b) ENLARGEMENT OF BIRD-ECHOES GOING WEST, TO SHOW AFTER-GLOW TAILS

In (a), a ½-hour time-exposure of spring emigration at another station, the bird-echoes appear as lines moving north-east; the rain-belt on the left was travelling 10° east of north. Directions can also be noted immediately from the after-glow tails—as shown in (b), a greatly enlarged picture (rings 10 miles apart) of a June movement, presumably of Lapwings (*Vanellus vanellus*): these tails result because the glow from each echo takes time to die away (see page 261).