BAROMETRIC PRESSURE-PATTERNS AND SPRING BIRD MIGRATION

A. M. BAGG, *72 Fairfield Avenue, Holyoke, Mass.*

W. W. H. GUNN, *Dept. of Zoology, University of Toronto, Toronto, Ont.*

D. S. MILLER, *Fish & Wildlife Division, Ont. Dept. of Lands & Forests, Toronto, Ont.*

J. T. NICHOLS, *American Museum of Natural History, New York City, N. Y.*

WINNIFRED SMITH, *Winghaven, Route # 1, Two Rivers, Wisc.*

F. P. WOLFARTH, *133 High St., Nutley, N. J.*

AS PREPARATORY background for studies of the relation between barometric pressure-patterns and spring migration in North America east of the Rocky Mountains, this paper reviews the relevant literature and outlines current studies of the correlation and its practical applications. In setting the Rocky Mountains as a western boundary for the region under discussion, the authors recognize the distinction between migration phenomena east and west of a line approximated by the 100th meridian, as emphasized by Peterson (1948: 165–6, 233). The southern and eastern boundaries can be defined as the Gulf states and the Atlantic coast, respectively; but the northern boundary must at present be left in vague outline, roughly represented by Lat. 50° N., due to lack of pertinent data.

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INTRODUCTION

The basic concepts of modern meteorology are treated in Haynes (1947) and government or newspaper weather maps provide accompanying definitions of the terms and symbols used thereon. As a ready reference for readers unfamiliar with meteorological terms, the following greatly simplified synopsis is presented:

The modern analysis of weather is based on the concept of large moving air masses which are labelled according to their source and the type of surface

from which they have derived their characteristics of temperature and humidity: *Tropical* or *Polar*, *Continental* or *Maritime*. Within itself, an air mass retains its individual character, although it will tend to be modified, in the lower levels, by the region over which it is passing. When 2 masses of different properties (such as a warm, moist Maritime Tropical air mass and a cold, dry Continental Polar air mass) adjoin one another, they produce a boundary in which the cold air tends to push in a shallow wedge under the warm air, and the warm air rises over the cold air. A "wave" appears in the boundary and the 2 air masses tend to whirl together. This disturbance takes on a roughly circular form and creates a *depression* or *low pressure area*.

The boundary between the 2 air masses will now be represented by 2 marked surfaces of discontinuity of temperature and wind direction, radiating from a point at or near the center of the Low. Where these surfaces of discontinuity touch the earth's surface, they are called surface *fronts*. Where cold air is replacing warm air, the front is termed a *cold front* and is indicated on weather maps by a line bearing triangular points showing the direction of movement. Where warm air is replacing cold air, the front is termed a *warm front*, indicated by half-circles on the frontal line. The pronounced sector of the low pressure area lying between the cold front and the warm front is termed the *warm sector*. A frontal line with alternate triangular points and half-circles represents a *quasi-stationary front*, where the leading edge of the cold air mass is relatively stationary.

Air tends to flow towards a low pressure area (cyclone) from a high pressure area (anticyclone) but, due to the rotation of the earth, this flow occurs spirally rather than directly. In the northern hemisphere, winds blow in a clockwise direction around centers of high pressure and counterclockwise around centers of low pressure.

Several early examples might be cited to show that, for many years, ornithologists have been interested in the relation between weather conditions and spring bird migration in our temperate latitudes. For example, in discussing migrating birds, Nuttall (1832: 22–23) stated: "It is possible that at times they may be directed principally by atmospheric phenomena alone. . . . The currents of the air, in those which make extensive voyages, are sedulously employed; and hence, at certain seasons, when they are usually in motion, we find their arrival or departure accelerated by a favorable direction of the winds." Also, Thoreau (1881: 159–161) wrote in his (Concord, Mass.) Journal, under date of March 17, 1858: "A remarkably warm and pleasant day with a south or southwest wind. . . . Thus these four species of birds [Bluebird, Flicker, Robin, and Redwing] all come in one day, no doubt, to almost all parts of the town."

However, in order to understand the correlation of weather and migration

it is first of all necessary to distinguish between 2 types of migration "waves" regularly observed in the region under discussion. These are superficially somewhat similar, but actually stem from divergent meteorological conditions: (1) the *arrested wave*, checked by adverse weather, and (2) the *onrushing wave*, impelled forward by favorable conditions.

The difference between the two is well illustrated by a passage from Batchelder (1882: 252), who analyzed weather's relation to the northward course of a "tidal wave" of birds observed consecutively at Washington, D. C., New York City, and Boston, Mass. He interpreted the correlation as follows: "The vast number of birds [noted at Washington] was doubtless due to the cold and rainy weather that prevailed, checking the progress of the migration beyond the latitude of Washington [arrested wave]. When the weather changed, the gradually accumulated throng was let loose, and rushed in a great [onrushing] wave towards the northern breeding grounds. In the vicinity of New York . . . after prolonged cold and wet weather a change came on the morning of May 20, and with the pleasant weather the rush of birds began. Almost all the Warblers and Thrushes were in great numbers, and continued very abundant at least throughout the following day. In the latitude of Boston birds had been unusually scarce for some days. The change to clear and warmer weather took place about noon of the 21st, and before the rain ceased the rush of birds had begun. All day long the smaller birds came in unheard of numbers, stopping awhile to feed, and then hurrying on [onrushing wave]. The next morning the host was even greater, and the trees fairly swarmed with Warblers. Before noon of that day most of the birds had passed on, but for a day or two afterward the number of loiterers was sufficient to be noticeable. . . ."

Among more recent authorities, both types of waves are implicit in statements by Cruickshank (1942: 39–40), Griscom (1945: 103) and Nichols (1948: 126, 130). A specific modification of this correlation is given by Nice (1937: 55), who writes of the Song Sparrow: "The early migration is absolutely dependent upon a warm wave the last of February or the first of March, but the main migration is only relatively dependent on a rise in temperature. Severe cold waves stop migration short."

The above analyses have emphasized significant temperature-rise and a southerly wind as the meteorological key to the onrushing wave. As a working formula, that emphasis has been most useful in anticipating occasions of noteworthy vernal movement. Generally speaking, however, ornithologists have paid very little attention to the study of the barometric pressure-patterns which produce the warm waves which, in turn, favor migratory movement in spring. Since it is this particular aspect which has been, in recent years, the subject of investigation by the authors, it consequently seems fitting to present the following references which treat the problem.

Early North American References (1888–1937)

In his "Report on Bird Migration in the Mississippi Valley in the Years 1884 and 1885", Cooke (1888: 16–25) included a section entitled "Relation of Migration to Barometric Pressure and Temperature". This section presents a detailed "record of the relation of migration to atmospheric conditions for the seven days from March 19 to 25, 1884, contrasted with a week's migration in May". Discussing the period of March 19–25, 1884, Cooke described a situation (since found to be typical, in a general way, of that season of the year) in which the center of a low pressure area is moving from "the southern Rocky Mountain region" progressively northeastward through North Platte (Nebraska), Yankton (S. Dakota), St. Paul (Minn.) and Marquette (Mich.). He describes the night of March 21 as being "a night of much migration", but one in which the movements took place "only to the east of the low pressure area; for it is a law of atmospheric circulation that the winds are attracted from the south, not directly toward the center of the low pressure area, but toward places to the east of it in the same direction that it is moving, while the winds which it attracts from the north move toward places to the west or behind it. Migration, therefore, would be looked for in vain to the south, west, or north [of the low pressure center]. . . . It is well to bear in mind that all these birds were migrating on a rapidly falling barometer, hence in the face of what is usually considered a sign of an approaching storm".

Before leaving Cooke, there are two further passages which are of importance in subsequent discussion: First: "Since it is known that low pressure is generally accompanied by clouds and rain, while areas of high pressure are cloudless, it would be naturally supposed that migration would take place during high pressure; but, as has already been stated, the area of low pressure attracts a south wind and the increased warmth more than overbalances the cloudiness. Fully 60 per cent of the spring migration of 1884 took place in cloudy weather". Second: Describing an instance in May in which there seemed "to have been a regular though not rapid advance . . . with N. and NW. wind", Cooke was led to the inference that "during the latter part of migration there is no night so unfavorable but that some migration takes place".

In reporting on the 1902 spring migration at Rochester, N. Y., Eaton (1904: 344) observed that "the greatest bird wave of the season . . . occurred on the 3rd of May . . . a perfect day, warm and sunny, following a low cyclonic center moving from the southwest and culminating in a shower during the night". Eaton added that "during the warbler season of 1903 there was no decided southwest cyclonic storm and no remarkable warbler wave". Moreover, Eaton (1910: 67) made this significant general observation: "There can be no doubt that the arrival of birds with us depends upon the temperature and probably upon the winds. With the advance of a low cyclonic center from the southwest, bringing high temperature to western New York in March, April or May, there is sure to be a bird wave which corresponds in magnitude to the warm weather wave which undoubtedly brought it. Many facts seem to show that the birds of western and northern New York are mostly immigrants from the southwest, and the warm weather as well as the prevailing winds of this region also come from that direction. The warm weather at least furnishes the favorable conditions which induce them to migrate. These are no more an agreeable temperature than an abundance of food and favoring winds to aid their arduous passage".

Smith (1917) remarked that "there seems to be ample justification for the statement that in Central Illinois there is a high degree of correlation between the flights of night migrants [in spring] and the meteorological conditions involved in the near approach from the West of an area of low barometric pressure with the accompanying rise in temperature and southerly winds". Possibly with an eye to more general application, Smith (1918) repeated this statement, but without mention of central Illinois.

For the period 1919–1937 there is surprisingly little to be found on this aspect of migration

in the North American literature. The pressure-pattern relationship is given virtually no consideration, while winds, *per se*, unless exceptionally strong, are generally regarded as having little or no relation to time or direction of migration, the latter conclusion being reached chiefly on the basis of local observations rather than from a survey of the meteorological picture for the continent as a whole.

The question arises: why has the whole subject involved in these published findings been, until very recently, so largely overlooked? In the opinion of the authors, at least three factors appear to have contributed to this situation. First, numerous professional ornithologists were interested in the physiological mechanism which induced the state of unrest which, in turn, appeared to precede and accompany actual migration. Thus, experimental investigation tended toward such research as that carried out by Rowan (1929 *et seq.*) and Kendeigh (1934) on climatic factors. Second, while over 40 years ago Wood (1906: 156) remarked that "... enough study of the weather maps has been done at this Museum [University of Michigan Museum of Zoology] to show that 'bird waves' can be predicted with some certainty", the amateur field ornithologist was neither equipped with, nor educated in the use of, meteorological maps to employ the above discoveries to advantage in his avocation. Nor, as pointed out above, was he encouraged by the literature of the day to support Wood's views. Third, the science of meteorology itself is greatly advanced today in knowledge, techniques and availability over what it was during the years preceding World War II.

European References

This paper is concerned primarily with the region of North America east of the Rocky Mountains. However, it appears worthwhile to consider whether the type of pressure-pattern first outlined by Cooke favors spring migration elsewhere in the Northern Hemisphere. There is evidence from European findings, for example, to support this contention. As early as 1832, Nuttall (1832: 27) wrote interestingly of an instance of the arrested wave in the Mediterranean region in which adverse winds precipitated numbers of migrant Quail on Islands of the Archipelago, "where they wait, sometimes for weeks, the arrival of a propitious gale to terminate their journey. . . ."

Walter (1908: 365–6), in discussing a paper by Marek of Hungary, stated that Marek had compared "known migrations of the woodcock in Europe with the weather charts of the same dates and had found that, aside from minor deviations, these birds migrate from anticyclonic areas of high barometric pressure to cyclonic areas of low barometric pressure".

Eagle Clarke (1912) devoted considerable attention to "the meteorology of bird-migration", with particular reference to the British Isles and Western Europe. Due perhaps to the moderating climatic influence of warm ocean currents, migration flyways appear to be more complex there than in eastern North America, with considerable west-east spring movement in evidence as well as south-north flights. Nevertheless, Clarke showed that favorable conditions for south-north flights to and through Great Britain and neighboring regions of the Continent of Europe are such that there is a "High" to the east or southeast of these areas and a "Low" to the west or northwest of them. He used maps of barometric pressure to illustrate favorable and unfavorable conditions. He believed that the clear weather of a high pressure system prevailing in the area in which the movement has its origin is a prerequisite to the great "rushes". However, in regard to winds, he took a strong position later echoed by numerous other writers on the subject: "... Their direction, apart from the weather condition to which they are due, has no influence whatever on the [migratory] movements".

Thomson (1926), in reviewing European findings to that date, stated Clarke's views and summarized the work of 2 meteorologists, Hegyfoky and Defant. Hegyfoky found spring migration into Hungary "favored by high barometric pressure and rising temperature in the region passed through, these conditions being commonly present when there is a depression

over northwestern Europe". Similarly, Defant found "a close correlation . . . between [spring] immigration into Austria and high barometric pressure over the Balkan peninsula"; but, while he recognized the attendant existence of a pressure gradient falling from east to west in the Mediterranean region, he did not emphasize the importance of the northwestern depression. After noting that the correlation with a high pressure area was similar to that found by Clarke, Thomson is then careful to say: "Defant, however, differs from Eagle Clarke in attaching direct importance also to favorable winds".

Thomson (1936), reviewing subsequent (1926–1935) findings on weather influences, quoted Schenk who, following up Marek's earlier work, investigated the spring migration of the Woodcock (*Scolopax rusticola*) into Hungary in relation to weather conditions. "He [Schenk] found that the chief movements coincide with, or quickly follow northwesterly cyclonic conditions (depression in the region of England), possibly because there is then fine weather (with warm air currents from the south) over the Mediterranean."

While further investigation was carried on in Europe, notably in Finland by Palmgren (1937), the tendency has been to deal with aspects of migration outside the immediate scope of this paper.

Recent North American References (1938–1948)

During recent years improved U. S. Weather Bureau maps became available to the North American public, and certain newspapers began printing simplified versions of such maps. Some radio stations issued not only weather forecasts, but also detailed descriptions of prevailing pressure-patterns and the various meteorological factors involved. Finally, quite a few ornithologists received meteorological training during the course of their World War II service. Thus new availabilities and techniques paved the way for the rediscovery of earlier findings and permitted their practical application. The forerunner of this trend may be said to be McMillan (1938), who brought a new and refreshing outlook to the subject. An experienced airline pilot well versed in the latest meteorological techniques of the day, he emphasized the fact that wind and temperature conditions at ground level may differ widely from those prevailing at the levels of flight; hence, conditions aloft must be considered in any true picture of migratory flight.

He further propounded "the general hypothesis that, whenever possible, migrating birds ride the wind" and that by utilizing "the spinning cyclonic and anti-cyclonic areas" (i.e., Lows and Highs) they "are riding the natural fly-ways of the world". This concept has found more recent expression in Landsberg (1948: 709), who says: "To the meteorologist, it looks as if some . . . migratory birds had developed a rather remarkable system of what is called in modern aviation 'pressure-pattern flying'. This is the system which takes advantage of the maximum possible amount of tail wind in long-distance flights. . . . If powerful modern aircraft, for reasons of economy and safety, adopt the system of pressure-pattern flying, it seems reasonable that birds, which are much more dependent upon assistance offered by these air currents, would follow the path of least resistance."

While we agree with the suggestion that many migrants avail themselves

of "pressure-pattern flying", the following statement by McMillan (1938) appears to be somewhat of an over-simplification: "Spring and the birds came early in 1938. Was one the cause and the other the effect? Why not say that both are effects of the same cause—that the influx of tropical air came early this year? The birds migrate and the wind migrates. . . ." This seems to be a confusion of short-term meteorological factors with longer-term climatology. For example, similar barometric patterns may occur in the eastern United States in November and March, both of them producing an influx of warm, southwesterly air, but only in March do these patterns coincide with a northward flight of birds.

In the region of the states bordering on the Gulf of Mexico, where the influx of tropical air first makes itself evident, interesting facts came to light more or less as a by-product of the recent studies of migration routes in the region of the Gulf. Burleigh (1944: 337–8) pointed out that spring migrants were observed along the Gulf Coast of Mississippi only when grounded by inclement weather. This point was treated more fully by both Williams and Lowery. Williams (1945: 108) indicated that few or no migrants are to be seen on the Gulf Coast in fine spring weather, but the "sudden appearance of the migrants will occur (and occur invariably) *at any hour of the day when bad weather comes.*" Lowery (1945: 92) said: "During clear weather, trans-Gulf migrants that do not breed on the Gulf coast or in the lower Mississippi River valley proceed inland several hundred miles before coming down. That stretch of coast which one might suppose to be teeming day after day during the spring with multitudes of migrants . . . is, in actuality, *during fine weather*, an 'ornithological vacuum' so far as many migrants are concerned. . . . *During inclement weather*, however, all trans-Gulf migrants are precipitated on the first available land. . . ."

That this "bad" or "inclement" weather in fact represented the arrival of a cold front from the northwest was amply demonstrated by Lowery (1946: 178) who described in careful detail the sequence of meteorological and ornithological events which take place when a cold front cuts off the influx of tropical air and grounds northbound migrants. Both Williams and Lowery are describing extreme examples of the arrested wave. It is interesting to compare these descriptions with the example quoted earlier from Nuttall (1832) regarding migrant Quail in the Mediterranean region.

In regard to the northward departure of migrants from the Gulf states, Lowery (1945: 97) stated: "Migrants which arrive on the Gulf coast are not so completely fatigued as to require long periods of rest before advancing northward. . . . Should the weather clear on the morning following the passage of a polar front, the concentrations are usually maintained throughout the first day. On the second day, however, only a few are found. . . ." This statement is of particular importance since it permits the determination of the

barometric pressure-pattern characteristic of the onrushing wave at the inception of its northward movement from the Gulf states. Thus, with the eastward passage of the High, whose leading edge was represented by the cold front, the situation gradually becomes more favorable for the resumption of a northward flow of tropical air. When the High is supplemented by a Low originating over the southwestern states and moving northeastward, then the influx of tropical air over the eastern part of the United States is greatly intensified, and, as determined by observers working independently in the north-central and northeastern United States and southern Canada, it is under these conditions that bird waves may be expected in their regions.

For example, in following such movements in New Jersey, one of us (Wolfarth) observed as early as 1940 the favorable influence of a High centered off the Middle Atlantic coast. The relation between this observation and Lowery's (1946) is apparent, since they both look to a pressure-gradient falling from east to west to accompany northward movement. Similarly, on the basis of her own ornithological and meteorological observations, begun in 1946 at Two Rivers, Wisconsin, another of the present writers (Smith) deduced that noteworthy spring migration may be expected in a given area when that area is, or was during the preceding night, in the warm sector of a Low.

From his own observations in Massachusetts in 1947, coupled with migration data contributed by other observers, Bagg (1948: 147), stated that spring migration into New England and adjacent sections of the northeastern states is stimulated by a pressure-pattern in which "high pressure is moving eastward off the southeast U. S. coast, while a low pressure area is moving into the Great Lakes region after having originated in the vicinity of Kansas and Colorado", the clockwise effect of the High having set in motion a northeastward flow of tropical Gulf air, that flow being subsequently intensified by the counter-clockwise effect of the Low.

Gunn (1948), studied the relation between pressure-patterns and records of migration at Point Pelee for the years 1937–1947 and found that the type of pressure-pattern favorable to New England was equally favorable to the Lake Erie region. Crocker and Gunn (MS.), studying in some detail the meteorological background of the exceedingly early arrival of a wave of insectivorous migrants observed in the Lake Erie and Western Lake Ontario region during the period April 5–7, 1947, attributed the arrival of the wave in this region to the intense cyclonic disturbance which arose in the southwestern states and whose center passed to the northwest of the region, as was first suggested by Mayfield (1947: 153–154).

One consequence of this varied, independent research has been the pooling of ideas and observations by the co-authors that made possible the joint study of spring migration in 1948 along a broad front. It also brought about a search of the literature resulting in the historical background for the subject, as

outlined above. Since each and every one of the references quoted appears to represent an individual approach to the same fundamental principles regarding the relationship between barometric pressure-patterns and spring bird migration, and since these principles are supported by meteorological and ornithological data obtained during the spring of 1948, it is therefore deemed possible to draw up a working hypothesis for the analysis and prediction of spring migration flights.

Hypothesis

1. In the region under consideration, northward movement of migrants in late winter and spring will normally begin under conditions of a barometric gradient falling from east to west and of southerly winds typical of the westward portion of a high pressure area (clockwise circulation) moving off to the east or southeast.

2. When the high pressure area is supplemented by a low pressure area (counterclockwise circulation) originating in the southwest and moving northeastward, the influx of warm, moist tropical air is extended and intensified; concurrently, the northward movement of migrants assumes the proportions of a pronounced onrushing wave in the warm sector of the low pressure area.

3. The intensity of the onrushing wave and the distance advanced by it are likely to be proportional to the depth of the Low and the extent of its northeastward progress.

4. Expressed in terms of "fronts", it may be said more simply: during the period of spring migration, pronounced movement will take place into or through a given region during the interval between the passage of a warm front through that region and the subsequent arrival of a cold front.

5. Cloudiness and rain are likely to be encountered by the onrushing wave as the cold front approaches from the west or northwest. If still in motion when overtaken by the cold front, the onrushing wave will be grounded and thus form an arrested wave until the meteorological cycle is complete and a further advance takes place.

6. An onrushing wave may also be grounded if it encounters a quasi-stationary front intersecting its line of flight.

7. The above relationships, while always of major significance in spring, may be less absolute in character during the later part of spring migration than during the earlier part.

Something should be said concerning the species of migratory birds to which this hypothesis directly applies. Studies so far have shown that a great many migrants do fit into this category and moreover, have failed to indicate any exceptions, although research is needed to determine the exact meteorological factors involved in the spring migrations of certain groups of birds such as: owls; pelagic birds; shore-birds that are chiefly littoral in their passage; other

species, like the Evening Grosbeak (*Hesperiphona vespertina*), whose spring migration may not follow the general south-to-north trend. While recognizing the possibility of such exceptions as these, the authors believe that the above hypothesis does apply to the vast majority of spring migrants in the region considered.

While this paper has been confined to spring migration, because it is felt that autumn migration requires a separate study, the authors concur with the recent statement by Landsberg (1948) that any hypothesis of bird migration "should include a very careful analysis of . . . patterns of atmospheric currents."

To illustrate the relation between barometric pressure-patterns and spring migration in eastern North America, the authors chose one of several periods of notable migration observed in the northern states and southern Ontario during the spring of 1948: April 18–22. This particular example was selected because the favorable pattern affected in succession from west to east all regions that the authors had under personal observation. The authors would add, and emphasize, that while the following example involves only one 5-day period, neither the evolution of the barometric pressure-pattern nor the accompanying evidences of migration differ fundamentally from what the authors have found in other situations that they have studied individually. To cite one case, Bagg's faith in the above hypotheses is based on his studies of the meteorological backgrounds of the following occasions of either notable influx or diurnal migration at Holyoke, Mass: March 25, April 6, 12, 27, May 12, 1947; March 16, 22, April 20–21, May 10, 1948; March 22, 27, 1949.

The figures (1–2) represent simplified versions of the U. S. Weather Bureau 1.30 A.M. and 1.30 P.M. maps for the period of April 17–21. For the sake of clarity, the data on these figures are confined to simple indications of: (1) the positions of the High and Low centers at the particular times involved; (2) their attendant frontal systems; (3) general trend of wind direction (large arrows); (4) a few of the isobaric lines, connecting localities of equal barometric pressure, to indicate not only the positions, but also the general outlines, of the Highs and Lows; (5) the path of the Low center on April 20–21, its position at six-hour intervals being denoted by the dark squares.

April 17, P.M.: High pressure is centered over the eastern Great Lakes with northerly winds prevailing on its eastern periphery, the leading edge of cold air moving southward through Georgia. The clockwise flow of air around this High is bringing southerly winds, and a warm front, to the Prairie states.

April 18, A.M.: The High center has moved eastward to New York and southern New England, the dotted line on the figure indicating the southerly limit of freezing temperatures at 1.30 A.M., E.S.T., on this date.

April 18, P.M.: The High center is moving off the southeastern coast of New England, and the pressure gradient falls from this center along an east-west line through the eastern half of the U. S. to a shallow Low over Nebraska. A warm front is entering Wisconsin.

April 19, A.M.: The High is centered just east of New England. The Low over Nebraska has deepened, and the warm front now extends from northern Wisconsin to Lake Ontario. The warm sector, behind this front, includes the vicinity of Two Rivers, Wis., and the greater part of lower Michigan.

At Winghaven, located on the west shore of Lake Michigan, 10 miles north of Two Rivers, Wisconsin, the day of outstanding migration during April, 1948, was the 19th (Smith). Eight new species for the year were listed on this date

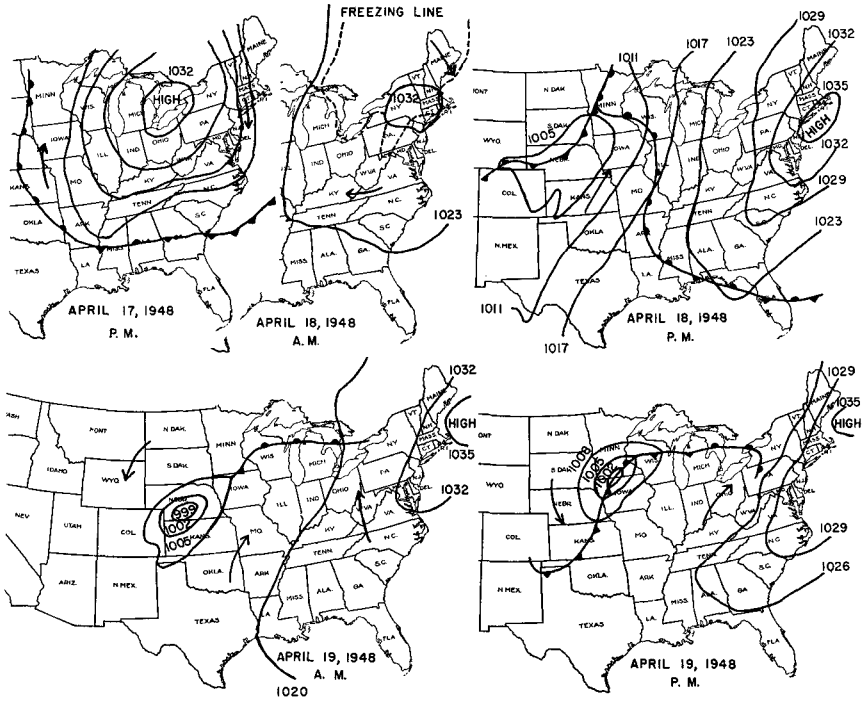

FIG. 1. Weather maps from April 17–19, 1948 (see text for explanation).

—Double-crested Cormorant (*Phalacrocorax auritus*), Shoveller (*Spatula clypeata*), Cooper's Hawk (*Accipiter cooperii*), Ring-billed Gull (*Larus delawarensis*), Bonaparte's Gull (*Larus philadelphia*), Barn Swallow (*Hirundo rustica*), White-throated Sparrow (*Zonotrichia albicollis*), Swamp Sparrow (*Melospiza georgiana*); 3 other species appeared in greater numbers—Blue-winged Teal (*Anas discors*), Redhead (*Aythya americana*), Canvas-back (*Aythya valisineria*). In Michigan, Wallace and Black (1948: 161) reported: "Over the first part of the month of April birds trickled in rather gradually, but a warm spell on the 19th and 20th speeded things up. . . ."

April 19, P.M.: The High is virtually as before. The Low center has moved to a position over the Minnesota-Iowa border, and the warm front has passed to the northeast of Toronto, placing the latter within the warm sector.

April 20, A.M.: High pressure prevails over the Atlantic seaboard, while the Low is now centered over northeastern Wisconsin. From this center, a warm front curves NE to Georgian Bay and then SE to New York City, and is about to penetrate New England.

At Toronto, the morning of the 20th produced a very pronounced influx of migrants, the best of the month (Gunn); 3 new species were noted—Upland

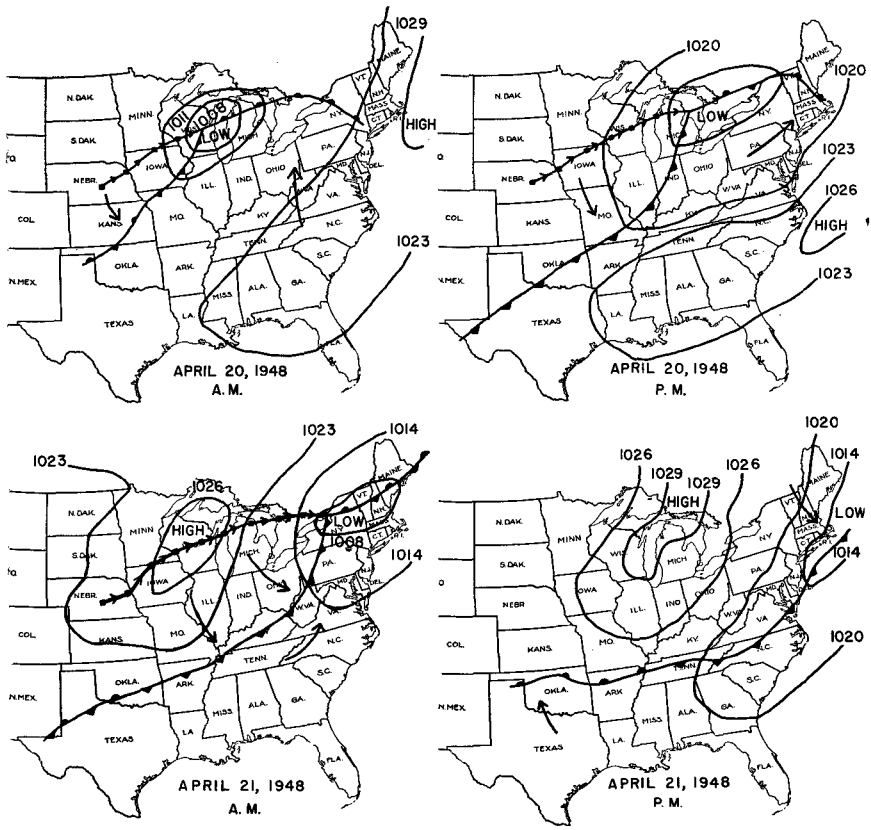

FIG. 2. Weather maps from April 20–21, 1948 (see text for explanation).

Plover (*Bartramia longicauda*), Tree Swallow (*Iridoprocne bicolor*), Brown Thrasher (*Toxostoma rufum*),—and a marked increase in Hermit Thrushes (*Hylocichla guttata*), Golden-crowned Kinglets (*Regulus satrapa*), Savannah Sparrows (*Passerculus sandwichensis*), and White-throated Sparrows. To summarize the Toronto situation, R. M. Saunders reported (*in litt.*) that, as of May 5, 1948, there had been "nothing like a wave since April 19–20". On April 20 there was a great movement, consisting of many kinds of land birds,

in northern New Jersey and also at Hawk Mountain, Pa. (Wolfarth). In New York City, moreover, this day brought to Central Park the wave of greatest volume recorded up to that point in 1948, consisting mostly of White-throated Sparrows, many Hermit Thrushes, as well as a few Towhees (*Pipilo erythrophthalmus*) and a Northern Water-thrush (*Seiurus noveboracensis*) (Nichols). This same day, April 20, brought the greatest wave of the month to the Connecticut Valley in Mass., the significant features being good numbers of Myrtle Warblers (*Dendroica coronata*), Palm Warblers (*Dendroica palmarum*) and Ruby-crowned Kinglets (*Regulus calendula*), plus a good many Chipping Sparrows (*Spizella passerina*), White-throated Sparrows and Pine Warblers (*Dendroica pinus*) (Bagg).

April 20, P.M.: The High is now centered east of the Middle Atlantic seaboard, approximating the quasi-permanent "Bermuda high" of summer, while the Low center has moved to Lake Huron. The warm front extends from northern Vermont to Boston, while the cold front extends southwestward from the Low center.

April 21, A.M.: The Low center has moved to northern New York. A new High, moving down from the Northwest, is centered over Wisconsin. Warm, southwesterly conditions continue within the sector formed by the quasi-stationary front extending from the eastern end of Lake Ontario to the Bay of Fundy and the cold front curving southwestward from the Low center.

In the early morning of April 21 there was migration in New Jersey and Pennsylvania (Wolfarth); in New York City, White-throated Sparrows and Towhees reached their maxima for this wave, but the Hermit Thrush had fallen off in numbers (Nichols). At Talcott Mt., Conn., and Mt. Tom, Mass., the best hawk flights of the month occurred in the final 2 hours of the warm sector, which ended there with the arrival of the cold front in the late forenoon (Bagg). On April 21, moreover, eastern Massachusetts experienced a wave, including 125 Hermit Thrushes listed at Nahant (Alexander et al., 1948).

April 21, P.M.: The Low is now centered east of New England, and its attendant cold front extends from the Atlantic Ocean through Virginia, North Carolina and Tennessee. The new High prevails over the Great Lakes region, while a new warm front is moving northward through Oklahoma and Arkansas. The cycle which began on April 17 is now complete.

The 250 Palm Warblers and 1500 White-throated Sparrows which were observed in 2 eastern Massachusetts localities, Wayland and Nahant, on April 22, (Alexander et al., 1948) appear to represent migrants which entered Massachusetts during the favorable period of April 20–21, were grounded by the cold front on April 21, and then proceeded to concentrate in such areas as Wayland and Nahant, presumably remaining until the next period favorable for further migration (Bagg).

SUMMARY

This paper studies barometric pressure-pattern factors which particularly stimulate spring migration in North America east of Long. 100° W. and south of Lat. 50° N. A distinction is made between an onrushing wave of birds actively migrating and an arrested wave of grounded migrants.

Early North American references (prior to 1938), together with European findings of the same period, are cited to show what was written regarding the relation of barometric pressure-patterns to spring migration before meteorologists recognized the roles of air masses and frontal systems. These early investigations indicated that northward migration occurs in certain regions in the Northern Hemisphere when the pressure gradient falls from east to west.

Recent North American investigations (1938–1948) are described. The basic agreement prevailing among all investigations, both early and recent, leads the authors to propose several hypotheses. The most fundamental of these states that, during the period of spring migration, pronounced movement will take place into or through a given region during the interval between the passage of a warm front through that region and the subsequent arrival of a cold front.

To illustrate the mechanics of this basic hypothesis, the typical period of April 17–22, 1948, is analyzed meteorologically and ornithologically. A notable influx of migrants, which became apparent progressively eastward from Wisconsin to Massachusetts, is directly correlated with the advance and frontal development of a Low center which moved from Nebraska to the New England coast.

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LIFE MEMBER

DR. CLAYTON G. RUDD, a successful dentist of Minneapolis, has long been deeply interested in nature photography and conservation. During his early boyhood in the unspoiled prairies of western Canada he had unforgettable experiences with migrating and nesting waterfowl—among them Whooping Cranes. After graduating in dentistry at the University of Minnesota he moved to Minneapolis; but since 1932 the Teton wilderness of Wyoming has continued to lure him summer after summer, and in 1948 he finished a home near the village of Moose, in Jackson's Hole. His colored motion and still pictures, many of which are notable for their beauty, are principally of Wyoming birds, mammals, plants and scenery.