WEATHER AND HEIGHT OF NOCTURNAL MIGRATION IN EASTCENTRAL ALBERTA: A RADAR STUDY

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INTRODUCTION

Birds migrating in still air would benefit by flying high. As the density of air decreases with height the speed of migrating birds increases (through a decrease in drag), but the power required to fly at those higher speeds also increases (Pennycuick, 1969). The advantage of flying high at high speed is the reduction of flight time. When birds are migrating in the atmosphere where calm conditions rarely prevail, the greater cruising speeds at higher altitudes also reduce interference from winds aloft, but this advantage may be offset when unfavorable winds are stronger aloft than at the surface.

High-altitude migration also facilitates the maintenance of heat and water balance of migrants. Birds can get rid of excess body heat generated by flying, through convection (air flowing over exposed skin) or evaporation of water in the lungs. The latter method might result in gradual dehydration during long flights. The low ambient temperatures at higher altitudes facilitate convective heat loss and reduce respiratory water loss (Pennycuick, 1969; Hart and Berger, 1972). As the air temperature decreases with height at an average rate of about 2°C per 1,000 ft (6.6° C per km), relatively small changes in the height of the birds result in considerable changes in ambient temperature.

The oxygen pressure decreases with height and Pennycuick (1969) considers the theoretical optimal flight height to be that altitude at which there is still sufficient oxygen to maintain the "maximum-range speed" (the air speed at which birds fly during migration).

In still air birds would thus presumably fly at high altitudes that would be determined by air density, temperature and particularly oxygen pressure. As those heights would be largely the result of physiological and aeronautical characteristics of the birds, they would probably vary for different species. During actual migration in the atmosphere, however, weather factors may seriously influence the flight height.

Our study on the subject was initiated when it became evident that information on height would enhance the operational usefulness of routine bird migration forecasts at Canadian Forces Base (CFB) Cold Lake, Alberta (Blokpoel, 1973). The present report describes the results of a qualitative analysis of the height distribution of night migrants in fall 1969 and spring 1970 and of the influence of certain weather factors on that distribution.

METHODS AND MATERIALS

Bird data

A. Data on the height of bird movements were obtained by filming an A-scope of a vertically aimed 3-cm M33C track radar, with its range adjusted to 18,000 ft (5,490 m). The site of the radar was the Primrose Lake Evaluation Range (PLER), about 30 mi (48 km) north of CFB Cold Lake (54°24′N, 110°17′W) in eastcentral Alberta.

Birds flying through the vertical radar beam produced echoes (so-called "bird spikes") on the A-scope, at ranges representing the altitude at which they were flying. The radar could not detect any target at a range of less than 1,200 ft (370 m). Further information on the M33C radar was given by Blokpoel (1971a).

Black-and-white, 16-mm, time-lapse films were taken of the screen from shortly after sunset to early morning or late night during fall 1969 and spring 1970. Each frame was exposed for six seconds. Solman (1969) described the technique for making time-lapse films of radar displays.

The 16-mm radar films were "read" using a Boscar film analyser, which permitted the data to be punched on paper tape. A computer was programmed to print out the hourly number of echoes for each 200-foot (60-m) height band.

B. During both migration seasons time-lapse films were taken of the Plan Position Indicator screen of a 23-cm surveillance radar near Cold Lake, with its maximum range set at 60 n mi (111 km). Richardson and Gunn (1971) gave some details of that radar. Those radar films provided information on the density and direction of bird movements in the Cold Lake area.

Weather Data

During each night of radar observations a radio-sonde was released at PLER, usually about one to two hours before midnight, providing data on temperature, relative humidity, pressure, and wind speed and direction for upper air layers.

All weather reports for CFB Cold Lake and weather maps (surface, 850 mB and 700 mB) prepared by the Meteorological Office at CFB Cold Lake were made available to us. A meteorologist determined the tops and ceilings (i.e. the undersides) of clouds over PLER from the radiosonde data and the other weather information. He considered the accuracy of those estimates to be generally within ±500 ft (150m).

All heights given are above ground level and all times are Mountain Daylight Time (=MST + 1).

ANALYSIS AND INTERPRETATION OF ECHOES

The problem of the widening radar beam

A problem with the vertical beam method is that the radar beam widens with range. Thus, when the beam is aimed straight up, it contains more space at higher altitudes than at lower heights and counts for different height bands have to be corrected to make them comparable.

Blokpoel (1971a) made M33C radar films at PLER in fall 1968 and developed a method to determine quantitatively the height distribution of migrants from echo counts for the different height bands. That method was based on a comparison of radar data and simultaneous visual observations (obtained by watching the moon, as described by Lowery, 1951). It was based on a few experimental data and a few assumptions. Attempts in fall 1969 and spring 1970 to obtain more experimental data failed almost completely due to unusually long spells of cloudy weather which made moon watching largely impossible. The few data obtained yielded confusing and inconclusive results (possibly because the radar detected not only birds but insects as well). It appeared not justified to use the quantitative method that was used for a preliminary analysis of the fall 1968 radar data (Blokpoel, 1971b).

No calibration tests were carried out for the M33C radar, so no beam pattern was established, and it was thus impossible to calculate correction factors that could be applied on the echo counts for the different height bands. We used the original uncorrected echo numbers, which do not give the true height distribution of the birds. From those uncorrected echo counts we calculated the percent of echoes per 200-ft (60-m) height bands, and the heights below which 50%, 75%, and 90% of the echoes appeared.

Because the results of the calculations did not represent the true situation we could not draw any conclusion regarding the height distribution during hours when only a few echoes were counted. However, with large numbers of echoes per hour certain height distributions were very obvious despite the shortcomings just mentioned. As we could not examine the height distribution quantitatively, we decided on a qualitative approach using only nights during which there were at least 50 bird echoes per hour during the period of peak heights.

The problem of insect echoes

A. Airborne insects in general

Density, height distribution, and species composition of airborne insects have been studied by several authors (e.g. Coad, 1931; Glick, 1939 and 1957; Williams, 1940; and Johnson, 1963). Those and other studies were reviewed by Johnson (1969).

In general only small and very small insects are found at greater heights. From the findings of Coad (1931), Glick (1939, 1957, 1960), Freeman (1945), Williams (1958), and Johnson (1969) we conclude that insects the size of a housefly (*Musca domestica*) or larger are very rarely found at heights greater than 1,000 ft (300 m).

Although we know of no published studies on airborne insects over the boreal forest in Canada, many insects were probably present in the sky when the radar films were taken at PLER.

B. Insect detection by M33C radar

Airborne insects can be detected by radar (e.g. LaGrone et al., 1964; Glover et al., 1966). To determine range to which the M33C radar was capable of detecting insects, different sized insects were tracked with the radar and their maximum ranges recorded. Insects of various sizes were caught, dosed with ethylacetate and each tied to one end of a long nylon string. The other end was attached to a helium-filled balloon. Long nylon string was used to give good separation between the insect target and the balloon, because the balloon itself would give a small echo. Lock-on to the insect was facilitated by the use of strips of colored paper attached to the nylon string close to the insect. The paper material did not produce any noticeable echo itself but permitted easy manual tracking using the periscope system of the M33C radar (Blokpoel, 1971a).

A night-moth (*Samia columbia*) with a wingspan of about 2.4 in (6.0 cm) was tracked to a maximum range of about 3,900 ft (1,190 m), two bumble bees (*Bombus* sp.) up to about 2,550 and 3,150 ft (780 and 960 m) and two honey bees (*Apis mellifera*) up to about 2,250 to 2,400 ft (685-730m). Tests with still smaller insects were unsuccessful. We used a small bee (Halictidae) the size of a housefly (about 0.3 in; 8 mm) but during three such tests the insect echo was always smaller than the ground-clutter. It seemed likely that the maximum detection range for insects the size of a housefly would not be greater than about 1,800 to 2,100 ft (550 to 640 m).

C. Elimination of the problem of insect echoes

The effect of weather factors on the height distribution of airborne insects has been studied by Glick (1939), Williams (1940), Wellington (1945), Glick and Noble (1961), and Johnson (1969). Temperature appeared to be an important factor. Wellington (1945) conducted experiments and noticed "that any insect cooled below its minimum flight temperature invariably folded its wings in the normal rest position." We concluded from the studies by Wellington (1945), Taylor (1963), and Lewis and Taylor (1965) that for most insects the size of a housefly the minimum flight temperature is 10°C. The exceptions are the Noctuids (with minimum flight temperatures between 1°C and 2°C), and the Neuroptera (6.1°C). Noctuids fly below the minimum height of 1,200 ft (370 m) at which the M33C begins to detect targets (Williams, 1958). The Neuroptera fly mainly early in the night (Lewis and Taylor, 1965).

As insects of the size of a housefly or larger are rarely found flying above 1,000 ft (300 m) and would not be flying at ambient temperatures lower than 10°C, we eliminated the problem of insect echoes by selecting those nights when the 10°C level (at the hour of peak heights) was at or below 1,200 ft (370 m), the minimum height at which the M33C can detect targets. Two nights with the 10°C level at 1,300 ft (400 m) and 1,400 ft (430 m) were analysed as well. Those nights were 8-9 May and 7-8 May, respectively.

A total of 14 nights fulfilled both the condition for insect-free data and the minimum number of 50 echoes per hour during the period of peak heights. The following results pertain to those 14 nights.

RESULTS

Height distribution

The height distribution of birds flying above 1,200 ft (370m) varied during the course of a night, as exemplified in Figs. 1 and 2, which show the height distribution (in percent) of the hourly numbers of bird echoes.

On both nights, average flight altitudes increased, peaked, and decreased during the period with radar observations. On one night, flight altitudes remained more or less the same for 5 hours before dropping (Fig. 1), but on the other night flight altitudes decreased after having reached their peak (Fig. 2). The hour during which the median flight altitudes reach their peak is considered as the peak hour (2300-2400, Fig. 1; 2300-2400, Fig. 2).

On the other 12 nights one of two patterns of nightly height distribution was observed: (1) on five nights average flight altitudes increased, remained near the same height for 2 to 6 hours, then decreased, and (2) on seven nights average flight altitudes increased for 1 to 6 hours, then decreased for 2 to 7 hours.

Peak hours usually occurred before midnight:

2100 - 2200: 3 nights

2200 - 2300: 3 nights

2300 - 2400: 6 nights

0000 - 0100: 1 night

0100 - 0200: 1 night

As expected, the uncorrected numbers of bird echoes during the course of a night generally followed the height distribution pattern. Hourly numbers of echoes increased during the evening to a maximum that generally coincided (within one or two hours) with the peak hour; the hourly numbers of echoes decreased thereafter, more or less rapidly, and they were generally below 50 early in the morning (e.g. Fig. 1).

For the 14 nights we studied, the maximum altitudes ranged from 4,600 to 12,400 ft (1,400 to 3,780 m). In general, birds migrated at considerably greater altitude in fall than in spring. However, due to our small sample (six nights in spring and eight in fall) and the differences in weather conditions between the nights in fall and the nights in spring, the height differences could not be tested for significance.

We considered all species of migrants together, and the variability in the nightly patterns might be partly due to behavioral characteristics of specific groups of migrants. That was probably the case on 26-27 September 1969 (Fig. 1) when a few birds were still flying above 6,000 ft (1,830 m) early in the morning (0500-0600), while many had already begun to descend (lower average flight levels and a small number of echoes). While passerine migrants probably stopped migrating towards the end of the night, other birds such as waders and waterfowl were perhaps continuing their flight.

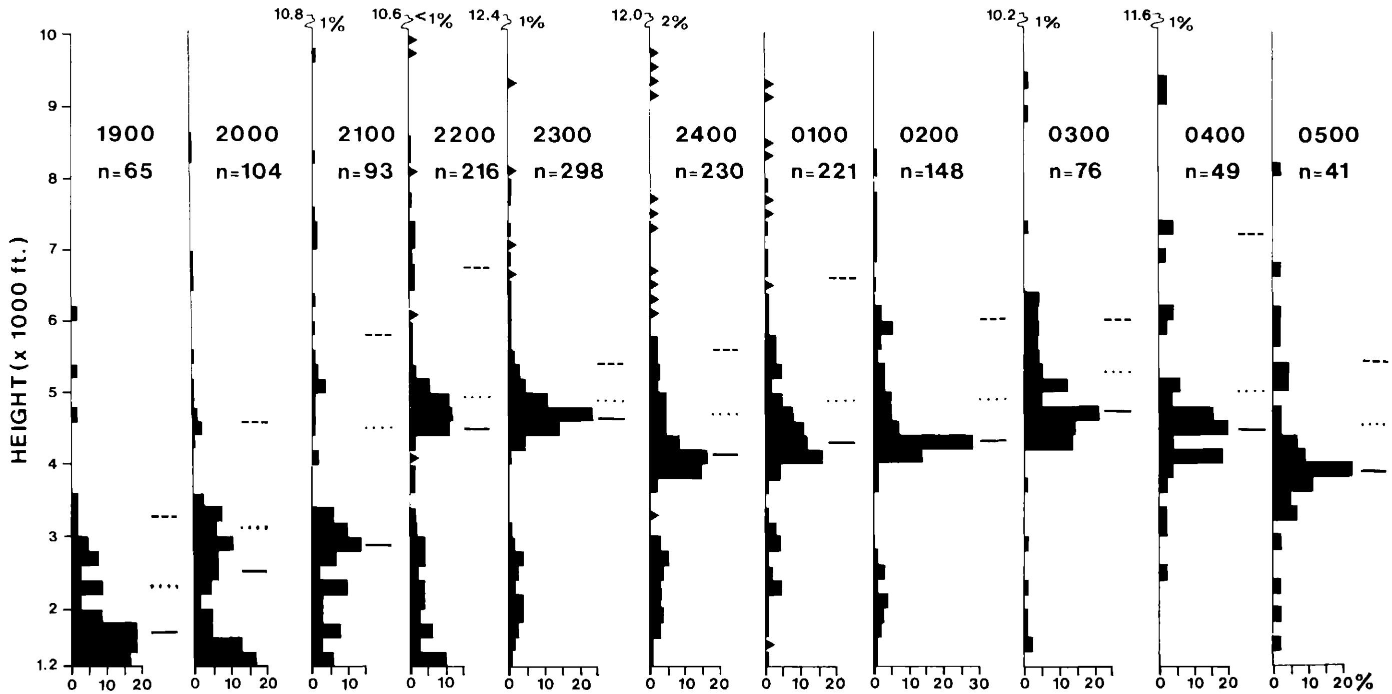

FIGURE 1. Height distribution of night migrants at Primrose Lake, Alberta, on 26-27 September 1969 at one-hour intervals. The beginnings of the one-hour periods are shown. The number of echoes observed during each one-hour period are shown as n. The heights below which 90, 75 and 50% of the echoes occurred are indicated by broken, dotted and solid lines, respectively. ▶ indicates less than 1%.

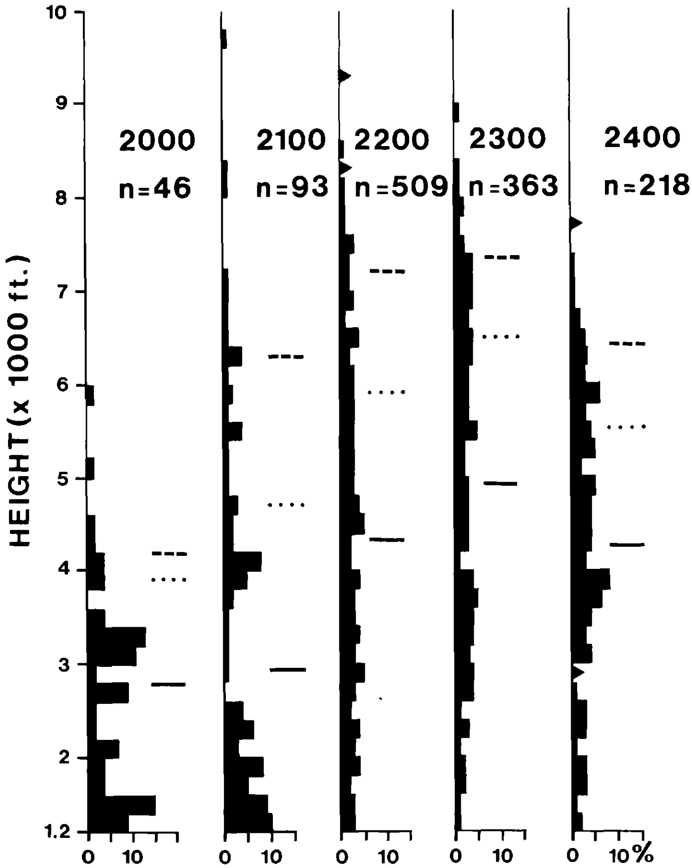

FIGURE 2. Height distribution of night migrants at Primrose Lake, Alberta, on 7-8 May 1970 at one-hour intervals. Symbols as in Figure 1.

Figures 1 and 2 also illustrate another aspect of height distribution. During 2300-2400 on 26 September 1969 (Fig. 1), there was a concentration of echoes from about 4,200 to about 5,600 ft (1,220 to 1,710 m). The situation for 2200-2300 and 2300-2400 on 7 May 1970 (Fig. 2) shows a rather even distribution of the echoes from 1,200 to 8,400 ft (370 to 2,560 m) without any obvious concentrations or gaps. The two figures represent two extreme situations (nights with and without concentration layers), and there were intermediate situations among the 12 other nights. We were unable to arrive at suitable quantitative criteria to define a "concentration layer." Thus, we present the height distributions of uncorrected numbers of echoes and discuss their relation to upper air weather factors in a qualitative manner.

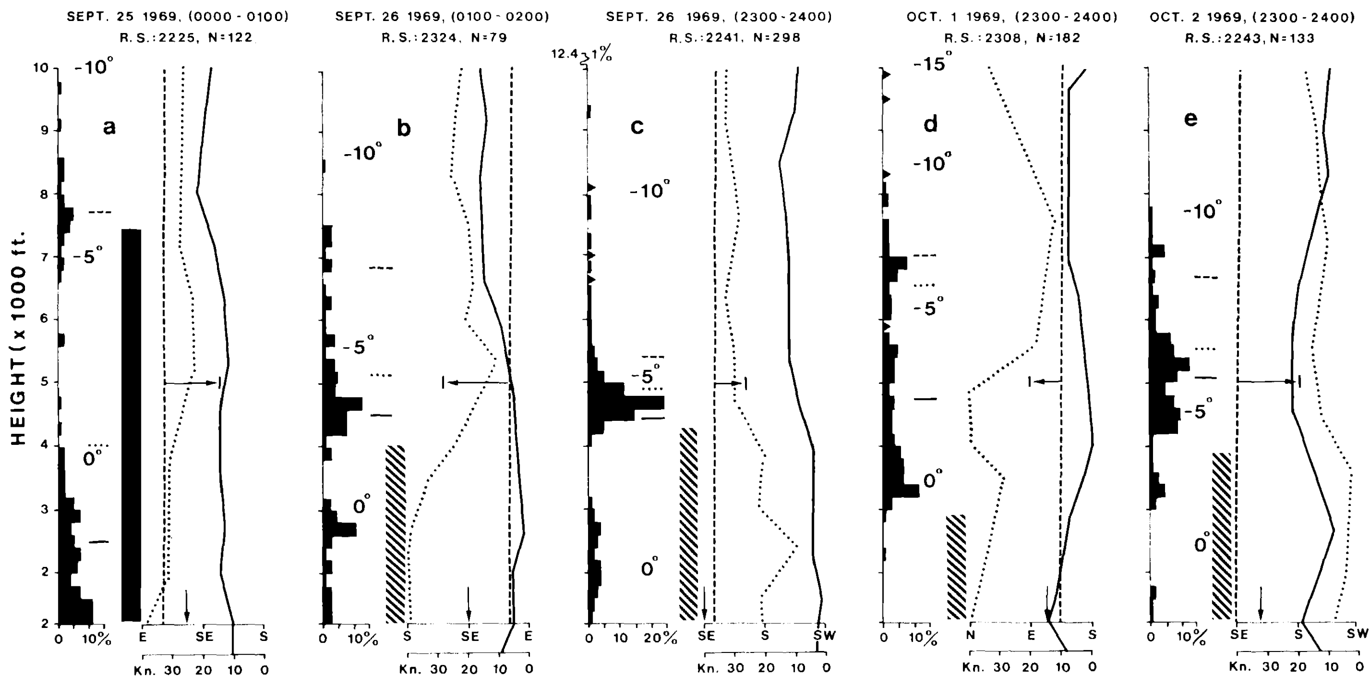

FIGURE 3. Height distribution of night migrants at Primrose Lake, Alberta, and upper air weather factors. R.S.: release time of radiosonde. The heights below which 90, 75 and 50% of the echoes occurred are indicated as in Fig. 1. ▶ indicates less than 1%. The vertical bars indicate amount and height of clouds. The vertical broken lines show the most used direction of migration. The vertical dotted lines give the direction to which the wind blows and the solid lines the wind speed. See text for further explanation.

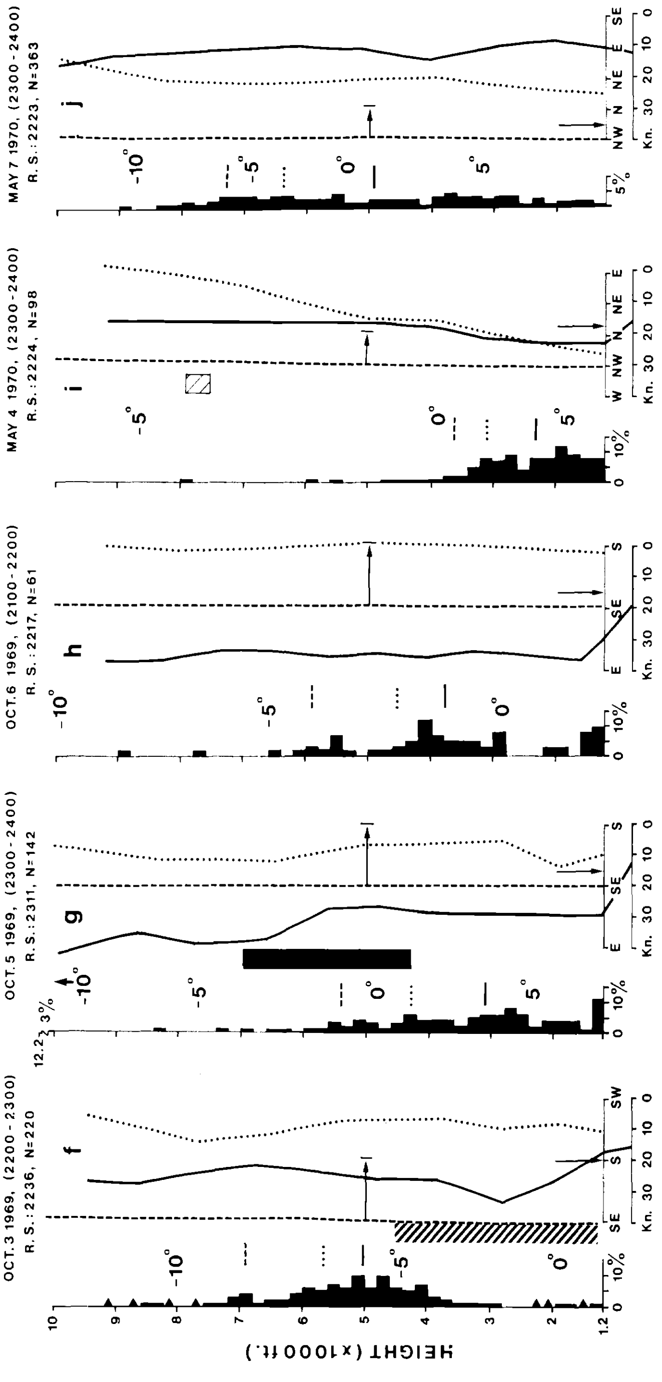
OCT.3 1969, (2200-2300)
R. S.: 2236, N=220
f
OCT.5 1969, (2300-2400)
R. S.: 2311, N=142
g
OCT.6 1969, (2100-2200)
R. S.: 2217, N=61
h
MAY 4 1970, (2300-2400)
R. S.: 2224, N=98
i
MAY 7 1970, (2300-2400)
R. S.: 2223, N=363
j
HEIGHT (x1000 ft.)
Kn.

Fig. 3. Cont'd.

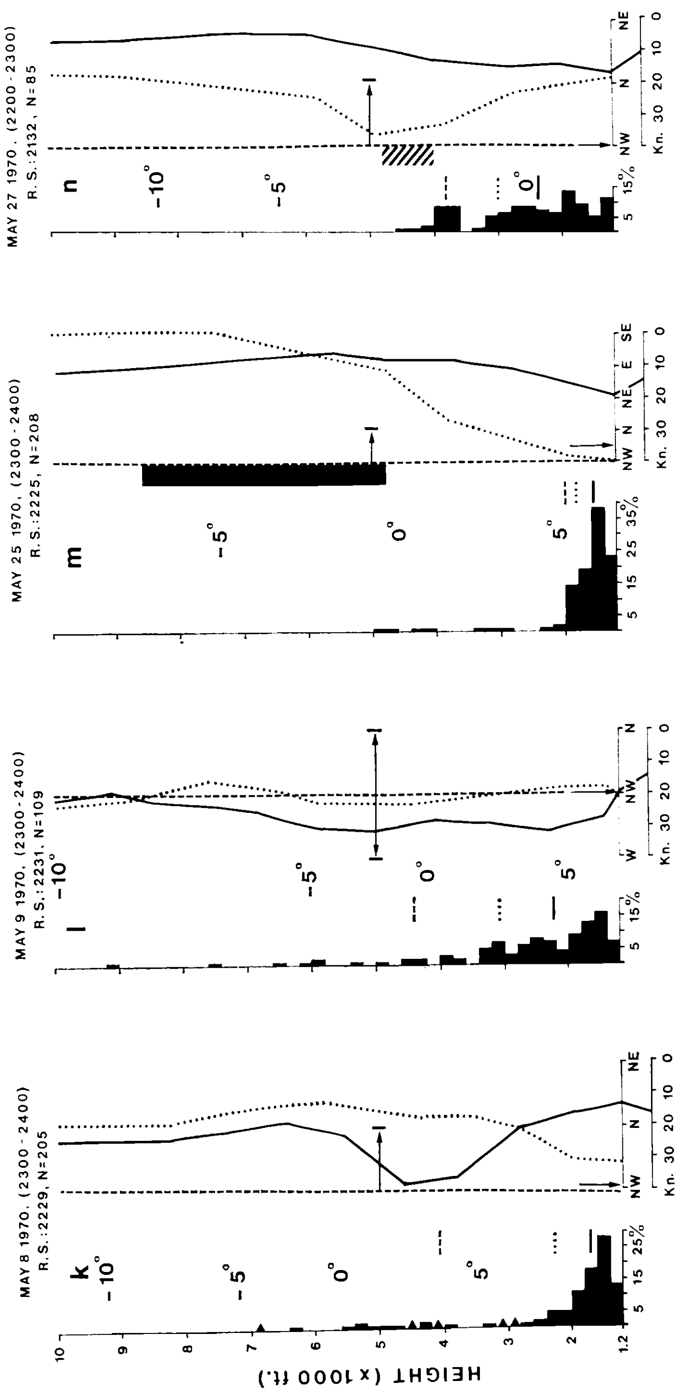
MAY 8 1970, (2300 - 2400) R.S.:2229, N=205
k
MAY 9 1970, (2300 - 2400) R.S.:2231, N=109
l
MAY 25 1970, (2300 - 2400) R.S.:2225, N=208
m
MAY 27 1970, (2200 - 2300) R.S.:2132, N=85
n
HEIGHT (x 1000 ft.)
Kn.

Fig. 3. Cont'd,

Influence of weather factors

Figure 3 shows the height distributions of the bird echoes during the first hour of peak height with at least 50 echoes. Each night is identified by a letter (a through n). The date, hour, time of radio-sonde release (R.S.), uncorrected number of echoes during the hour (n) and the percentage height distribution are indicated for each night.

For bird echoes over 10,000 ft (3,050 m) Figure 3 shows (a) the maximum height and (b) the percentage of all echoes above 10,000 ft (3,050 m). The 90, 75, and 50% levels are indicated as in Figures 1 and 2.

Figure 3 also shows the general direction of migration of the birds as obtained from radar films taken of the surveillance radar near Cold Lake (indicated by a vertical arrow at the bottom of the figure). The most used direction of heavy migration (as given by Richardson and Gunn, 1971, p 42) is shown by a vertical broken line. The Cold Lake radar showed heavy migration on all 14 nights. Horizontal arrows show the range of "following winds" (i.e. 45° on either or both sides of this typical, or most used, direction).

Figure 3 shows for each night the following weather factors: (a) temperature (5°C, 0°C, −5°C, −10°C, and −15°C levels), (b) cloud cover (the heights indicated by columns and the density by shadings of the columns; solid black: 10/10, heavily streaked: 8/10 and 9/10, and lightly streaked: 1/10 to 5/10), (c) wind direction (a dotted line showing the direction to which the wind blows), and (d) wind speed in knots (solid line); 1 knot (kn) = 1.852 km/hr. The wind scale at the bottom also shows the speed of the surface wind (where it is intersected by the solid line).

Pressure

Air pressures at ground level varied during the migration seasons, the largest differences being 20 mB in fall (918 to 938 mB) and 12 mB in spring (927 to 939 mB). As pressure decreases with height, we can correlate the altitudinal distribution of birds and the pressure values: there were nights when birds were spread out over several thousands of feet (Fig. 3 d, f, g, h, and j) when pressure values varied from 888 to 605 mB; during some other nights, many birds were concentrated, either at low levels (Fig. 3 i, k to n) at pressures from 909 to 799 mB, or at higher altitudes (Fig. 3 a, b, c, and e) at pressures from 807 to 638 mB. The birds, as a group, did not appear to prefer certain air pressures.

Temperature

Birds flew higher in fall than in spring although the temperatures aloft were much lower in fall. In fall the highest flying birds were exposed to temperatures as low as −15°C (Fig. 3 d). On six out of the eight nights in fall more than 10% of the echoes were reported at temperatures lower than −5°C (Fig. 3 a, b, c, d, e, and f) and on two of those nights (Fig. 3 e and f) more than 50% of the echoes were recorded below −5°C. In spring birds flew with higher ambient temperatures (e.g. Fig. 3 k: mainly from about

10° to 7°C; Fig. 3 m: mainly from about 6° to 5°C).

On nights with a wide height distribution birds flew with a wide range of temperatures, the greatest range running from about 10 to −10°C (Fig. 3 j). Our data do not indicate that the birds, as a group, had a temperature preference.

Relative humidity

Birds flew at relative humidities that differed greatly from night to night. Birds that were concentrated high above ground level (Fig. 3 a, b, c, and e) flew at RH's ranging from 40 to 90%. Birds concentrated at low altitude (Fig. 3 k and m) flew at RH's from 35 to 40% and from 50 to 55%. On the other hand, during nights when birds had no preferred heights (Fig. 3 g and j), they flew at RH's varying from 70 to 100% and 35 to 60%. Relative humidity itself did not appear to have any influence on the height distribution of the birds.

Clouds

Three nights had completely overcast skies (Fig. 3 a, g, and m). Two nights had cloud banks with ceilings of at least 4,000 ft (1,220 m); on one of those nights (Fig. 3 m), the birds remained below them, but on the other night (Fig. 3 g), the birds appeared to spread well into the clouds with an occasional bird flying above them. The third night (Fig. 3 a), had solid overcast from the surface up to about 7,400 ft (2,260 m) and most birds flew in the clouds at altitudes of up to 4,000 ft (1,220 m). Another group flew just above and between the cloud tops, with only a few sporadic birds between 4,000 and 7,400 ft (1,200 and 2,260 m).

Another six nights had 8/10 or 9/10 cloud cover (Fig. 3 b, c, d, e, f, and n). On five of those nights cloud ceilings were below 1,200 ft (365m) and the tops were at heights of just under 3,000 ft (910 m) to just over 4,000 ft (1,220 m). On those nights relatively few birds were flying in the clouds and most birds were flying above the clouds. During the last night (Fig. 3 n) the cloud layer extended from 4,000 to 4,800 ft (1,220 to 1,460 m) and most birds were flying below it.

In addition, there was one night (Fig. 3 i) with a thin layer of light clouds at high altitude which did not appear to have any effect on the birds' height distribution.

We conclude that when there are low clouds, most birds fly above them. When clouds are higher, birds either stay below or fly partially into them.

Wind direction and wind speed

Heavy nocturnal migration in the Cold Lake area usually occurs with following winds (Richardson and Gunn, 1971). As mentioned earlier, all 14 nights considered had at least 50 echoes during the hour shown in Fig. 3, and the surveillance radar at Cold Lake confirmed that migration was heavy on all 14 nights (density of 5 or more on the 0-8 density scale, described by Richardson and Gunn, 1971). Thus we expected that most migrants on the 14 nights would fly at heights with tail winds or at least following winds (i.e. within 45° of the birds' most used direction, assuming that was their preferred direction).

On the four nights without clouds (Fig. 3 h, j, k, and l) there was one night with a very wide altitudinal distribution of echoes (Fig. 3 j), one with concentration at low altitude (Fig. 3 k) and two nights showing a somewhat intermediate situation (Fig. 3 h and l).

On 8-9 May 1970 (Fig. 3 k) the wind was very favorable up to 2,000 ft (610 m), remained following up to 3,000 ft (910 m), and became less favorable at still greater altitudes. Most of the birds were below 2,000 ft (610 m), although there were scattered echoes up to 6,400 ft (1,950 m).

On 7-8 May 1970 (Fig. 3 j) the wind direction was unfavorable all the way up to 10,000 ft (3,050 m), with wind speeds of 10 to 14 kn (19 to 26 km/hr). The wide altitudinal distribution indicates that some birds continued to climb to great heights in the absence of a height band with favorable wind conditions.

On 6-7 October 1969 (Fig 3 h), winds deviated almost 45° from the preferred direction of migration and were strong (over 30 kn, 56 km/hr). The wide altitudinal distribution indicates that several birds continued to climb on this night with wind conditions that were only marginally favorable.

On 9-10 May 1970 (Fig. 3 l) the wind direction was very favorable all the way up to 10,000 ft (3,050 m). Wind speeds between 1,400 and 6,000 ft (430 and 1,830 m) varied between 27 and 32 kn (50 and 59 km/hr). The surface wind was northwest at 15 kn (28 km/hr). Most of the birds remained at relatively low altitudes although one echo occurred at 9,200 ft (2,800 m).

Six nights had low-ceiling clouds (Fig. 3 a through f), and we examined the effect of wind direction and speed on the birds flying above the cloud tops.

On the nights 24-25, 25-26, and 26-27 September 1969 (Fig. 3 a, b, and c) the situations were somewhat similar: once the birds had climbed above the clouds they found themselves flying with good tail winds. With a few exceptions, most birds continued flying in a relatively narrow height band just above the clouds.

On 1-2 October 1969 (Fig. 3 d) the birds had unfavorable wind directions immediately above the clouds. At greater heights (4,000-4,800 ft, 1,220-1,460 m), the wind directions were worse, but wind speeds were very light (less than 5 kn, 9 km/hr). At still greater heights (5,000-8,000 ft, 1,520-2,440 m) wind directions were favorable and wind speeds were light to moderate. Figure 3 d shows a wide altitudinal distribution above the clouds and a small concentration of birds just under 7,000 ft (2,130 m) where there was a favorable combination of wind speed and wind direction. The situations on 2-3 and 3-4 October 1969 (Fig. 3 e and f) were similar in that the wind conditions above the clouds were not ideal and, as expected, many birds climbed higher.

Also, four nights had high-ceiling clouds (Fig. 3 g, i, m, and n). On 5-6 October 1969 (Fig. 3 g) the situation was confusing: the birds had favorable, very strong (> 30 kn, > 56 km/hr) winds below the clouds, yet they kept climbing well into them. We have no explanation for this. On 4-5 and 25-26 May 1970 (Fig. 3 i and m) the clouds had no effect at all, and the height distributions were largely associated with wind condition aloft. Both figures indicate that the birds flew with the best available tail winds. On 27-28 May 1970 (Fig. 3 n), almost all birds were below the clouds, with a minor concentration just below the cloud deck where the wind direction was most favorable. Most birds were flying below 3,000 ft (910 m) with slightly less favorable but still following winds.

We conclude that on clear nights the migrants over Primrose Lake flew at altitudes with the most favorable wind conditions. On cloudy nights the birds migrating above the clouds also occurred at heights where wind conditions were most favorable. On nights when there were no height bands with favorable wind conditions, the birds showed a wide altitudinal distribution.

DISCUSSION

Radar studies of height distributions of birds have been carried out by Harper (1958), Lack (1959, 1960), and Eastwood and Rider (1965) in England, by Sutter (1957a, b), Gehring (1967), Bruderer (1971) and Steidinger (1968, 1972) in Switzerland, by Bellrose and Graber (1963), Nisbet (1963), and Able (1970) in the United States, and by Richardson (1971, 1972) and Blokpoel (1971b) in Canada. Work published before about 1966 was reviewed by Eastwood (1967).

Height distribution

Our results indicate that in general migrating birds attain their peak altitude before midnight, which is in agreement with Graber and Hassler (1962), Nisbet (1963), Eastwood and Rider (1965), Able (1970), Bellrose (1971), Bruderer (1971) and Richardson (1972). Able (1970) and Bellrose (1971) reported that passerines migrating in fall climb rapidly to their maximum altitude. Richardson (1972) reported similar results for fall migrating passerines and waterfowl. We found that average flight altitudes may increase for up to six hours before peaking.

Our results show that average flight altitudes remained near peak altitude for up to six hours. On most nights flight altitudes did not begin to decrease until after midnight. This agrees in general with Graber and Hassler (1962), Eastwood and Rider (1965), Bellrose (1971), and Richardson (1972). Able (1970) reported that passerines gradually begin to descend from 2000 onwards while Nisbet (1963) and Bruderer (1971) found that the mean altitude decreases from 2200.

Our findings indicate that on most nights flight altitudes decreased gradually, as was also observed by Able (1970), Bellrose (1971), and Bruderer (1971). Graber and Hassler (1962) reported that height decreased steadily after about 0100.

Although some of the migrants were still flying at high altitude by dawn, most of the birds had settled down by that time, as was also reported by Nisbet (1963).

We noted that migrants flew higher in fall than in spring, but this difference may have been due to differences in the weather and the small sample size (six nights in spring and eight in fall). Bellrose and Graber (1963) concluded from their radar study that migrating birds flew slightly higher in fall than in spring. Lack (1960) and Eastwood and Rider (1965) found the opposite situation in England. Bellrose (1971), making observations from a light aircraft, found little difference between the altitudinal distribution of migrants in spring and in fall.

Influence of the weather

Pressure, relative humidity and temperature. Our results for 14 nights show an apparent lack of correlation between height distribution and pressure, relative humidity, and temperature. This lack of correlation may be due to the lumping of a wide range of species with different preferences with respect to these three weather factors. Bruderer (1971) reported that "the expected altitude variations according to the barometric pressure are obscured by other factors causing larger changes in flight levels." Regarding temperature, Eastwood and Rider (1965) concluded that ". . . the presence of a freezing layer appeared to impose a "ceiling" upon the birds and did so much more effectively than the presence of a cloud layer." We found that on some nights a good proportion of the birds flew well above the freezing level, particularly in fall. Bruderer (1971) reported similar findings.

Clouds. Our data show that birds do not generally migrate in clouds but fly either above or below them. This is in good general agreement with results of others. Sutter (1957a), Lack (1960), Nisbet (1963), Bellrose and Graber (1963), Bellrose (1967), Steidinger (1968), and Bruderer (1971) reported that birds fly generally above low clouds and banks of fog. When clouds are high or medium high, birds were reported to fly under them (Sutter, 1957a; Nisbet, 1963), but birds have also been recorded in or between clouds (Bellrose and Graber, 1963; Eastwood and Rider, 1965; Bellrose, 1967; Williams et al., 1972; Griffin, 1973). Able (1970) found that under solid overcast migrants were compressed into lower altitudes and that the birds did not attempt to surmount the clouds.

Wind direction and wind speed. Our findings indicate that migrants most commonly fly at heights with the most favorable wind conditions. This agrees with the results of Preston (1955), Nisbet (1963), Blokpoel (1971b), Bruderer (1971), Steidinger (1972), and Richardson (1972), but disagrees with the findings of Bellrose and Graber (1963) who concluded that "Once in migration, birds appear to be unable to detect the velocity of wind in relation to altitude. The altitudinal distribution of migrants is similar, regardless of whether winds are opposed or following." Eastwood and Rider (1965) arrived at somewhat similar conclusions: "It is hardly reasonable to expect altitude adjustment by migrant birds in response to the variations in wind speed and direction encountered during an extended flight. . . ." In 1967 Bellrose revised his earlier view, stating that migrants "select nights and altitudes having favorable directional winds and favorable wind speeds."

Our results showed the birds' preference for following winds. It is possible that on nights with following winds the birds select height bands with certain wind speeds. For example, Able (1970) reported a negative correlation between mean altitude and wind speed at 2,000 ft (610 m). Our data do not allow any conclusion in this respect because there was not a single night that had following winds all the way up, no clouds, and the wind speed varying considerably with height.

ACKNOWLEDGMENTS

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Sgt. P. P. Desfossés read the radar films and helped in the field. E. P. O'Reilly, then Director of Data Centre, made the Boscar film analyser available and developed the computer program. C. Finley, Meterological Office, CFB Cold Lake provided weather data. D. G. McCormick determined cloud heights and amounts from radio-sonde data. Dr. K. P. Able, H. Boyd, Dr. B. Bruderer, J. E. Bryant, and Dr. R. McNeil commented on the draft manuscript. P. Madore drew the figures.

SUMMARY

Height distributions of nocturnal migrants in eastcentral Alberta were observed in fall 1969 and spring 1970 using a 3-cm tracking radar with its pencil beam aimed vertically. The radar did not detect targets below 1,200 ft (370 m).

Two types of nightly height distributions were detected: average flight altitudes either increased to a peak and then immediately decreased, or they remained near peak heights for a few hours before decreasing. Peak heights were usually reached before midnight.

Height distributions varied considerably from night to night, mainly due to the weather aloft. Birds did not show preferences for a certain air pressure, temperature, or relative humidity.

When cloud ceilings were low, birds flew above the clouds, with the exception of one night when complete overcast was present up to 7,000 ft (2,130 m). On that night only few birds flew above the clouds with the majority below 4,000 ft (1,220 m). On three out of four nights with high-ceiling clouds, birds remained below the clouds; on one night, birds flew well into the clouds for no apparent reason.

On nights without clouds, most birds occurred at heights with the most favorable wind directions. If no favorable wind direc-

tions were present, birds were evenly distributed in height and flew up to great altitudes. On nights with low-ceiling clouds the same pattern was observed for migrants flying above the clouds.

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