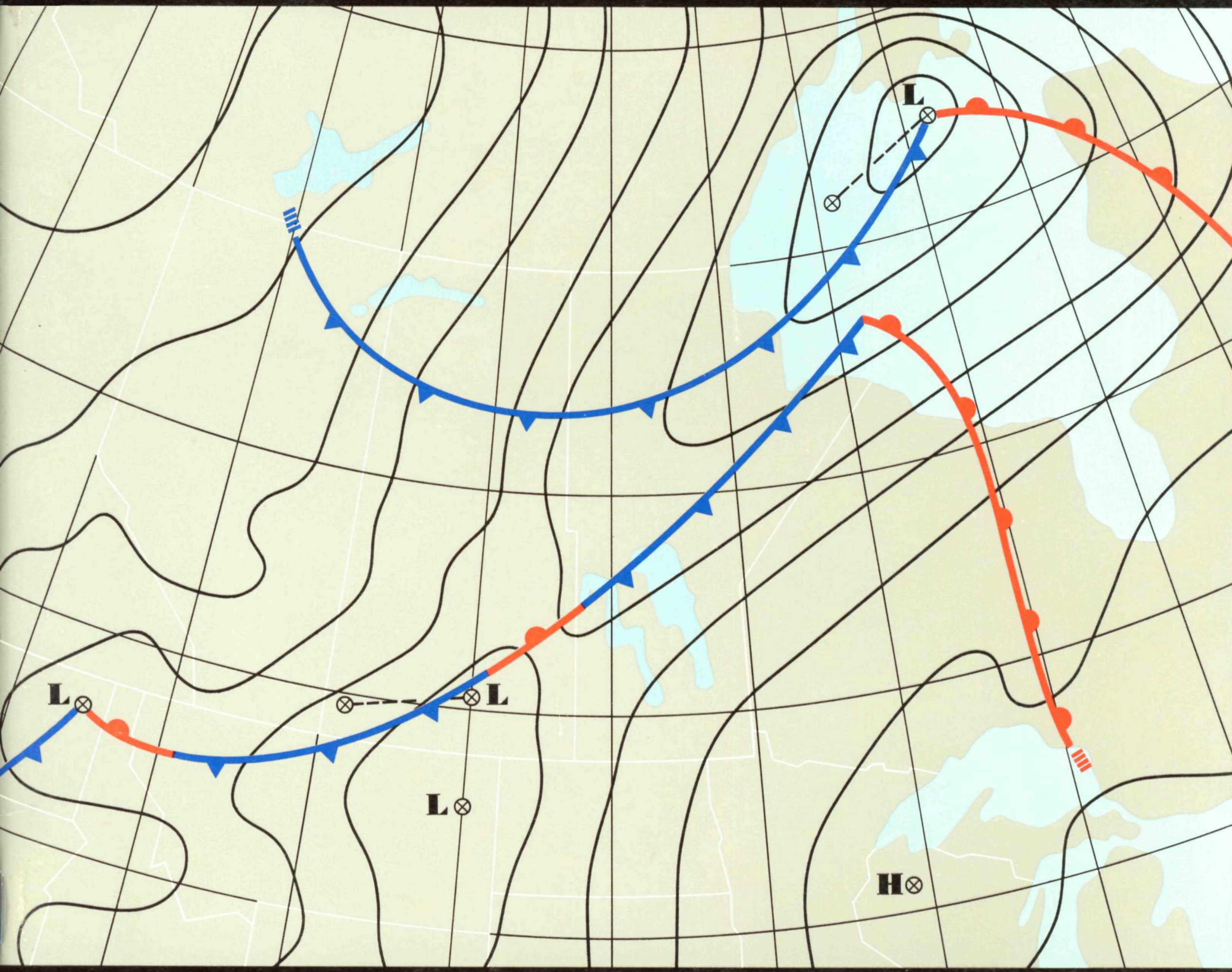
Migration of Lesser Snow and Blue Geese Part 2

by H. Blokpoel and Maureen C. Gauthier



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Environment Canada
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Migration of Lesser Snow and Blue Geese in spring across southern Manitoba

Part 2: Influence of the weather and prediction of major flights

by H. Blokpoel and Maureen C. Gauthier

Canadian Wildlife Service
Report Series Number 32

Part 1:
Distribution, chronology, directions, numbers, heights and speeds
by H. Blokpoel
Part 2:
Influence of the weather and prediction of major flights
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Contents

The authors

Hans Blokpoel received B.Sc. and M.Sc. degrees in biology from Leiden University, Holland. His work at the Fisheries Research Institute in Ymuiden, Holland, on fish behaviour with respect to towed nets had only just begun when he was drafted into the Royal Netherlands Air Force. He spent two years at the Air Staff, The Hague, working on military bird strike problems. In 1967 he came to Canada to work on contract with the Canadian Wildlife Service to develop a bird migration forecast system for Canadian Forces Base Cold Lake, Alberta. In 1968 Mr. Blokpoel became a member of the CWS staff in Saskatoon and in 1971 he was transferred to Ottawa. Radar studies of bird movements and developmental work on a bird radar for use in air traffic control operations are the main aspects of his work.

Maureen C. Gauthier obtained a B.Sc. from the University of Ottawa and an M.Sc. from McGill University where she studied the activity patterns of free-ranging striped skunks. Since then, she has worked as a seasonal naturalist for the National Parks Branch and under contract with CWS. The contract work has included study of snow goose migration, snow goose breeding ecology and food preferences of muskoxen.

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Perspective

Collisions between birds and aircraft (bird strikes) are a problem in both civil and military aviation and will continue to be so in the near future, as it is very difficult to build bird-proof aircraft. Single-engine jet fighters on high-speed low-level missions are particularly vulnerable to bird strikes as a single bird ingested into the air intake can completely ruin the engine. Multi-engine jet liners are unlikely to suffer serious bird strikes en route, but serious strikes can occur during take-off and approach. If birds do cause the crash of a big carrier (as they have done twice so far in North America), the results are catastrophic.

A near-disaster collision between a B-737 and migrating snow geese, near Winnipeg in the spring of 1969, provided the impetus for a research project at Winnipeg Airport to develop techniques for (1) detecting and warning of the spring snow goose migration and (2) predicting this annual flight.

The two standard surveillance radars used in Canada (the long-range AASR-1 and the short-range ASR-5) were found to detect flocks of geese very well. The recently introduced Bright Scan Display technique greatly facilitates bird detection. As surveillance radars do not provide height information on the bird flocks, work is now being carried out to develop a warning system using radars with height finding capabilities.

A long-term study of the spring snow goose migration was necessary for the development of a migration forecast method. The work at Winnipeg was a pilot study, and some of its results may apply to other airports as well.

Abstract

Dates of major spring migration of Lesser Snow and Blue Geese (*Anser c. caerulescens*) across Winnipeg during 1953 through 1969 were determined and examined in the light of the prevalent weather conditions. Statistically significant correlations between major migration and certain weather factors were established. These results were used as a basis for the design and testing of a simple system for predicting the dates and times of major flights of spring snow goose migration across the Winnipeg Terminal Control Area. The operational feasibility of this migration forecast method for use in air traffic control is discussed.

Résumé

On a déterminé et examiné à la lumière des conditions atmosphériques dominantes les dates du passage des Petites Oies blanches et des Oies bleues (*Anser c. caerulescens*) au-dessus de Winnipeg au cours des principales migrations printanières de 1953 à 1969 inclusivement. On a établi des corrélations statistiquement valables entre les principales migrations et certains facteurs atmosphériques. Ces résultats ont servi de base à la conception et à la vérification d'un système simple destiné à prévoir les dates et les périodes des principaux vols d'Oies blanches au-dessus de la région de contrôle terminale de Winnipeg, lors de la migration du printemps. On discute la possibilité d'employer cette méthode de prévision des migrations dans le contrôle de la circulation aérienne.

Резюме

Даты основной весенней миграции мелких белых и голубых гусей (Anser c. caerulescens) через Виннипег за период 1953-1969 г.г. были определены и исследованы в свете доминирующих метеорологических условий. Кроме того, была установлена и статистически важная взаимосвязь между основной миграцией и определенными метеорологическими факторами. Результаты проведенной работы легли в основу схемы и испытания простейшей системы предсказывания дат и времени основных полетов белых гусей при весенней миграции через конечный контрольный участок, расположенный в Виннипеге. В настоящее время обсуждается рабочая возможность использования этого метода предсказывания дат и времени миграции для контроля за движением авиатранспорта.

Introduction

The eastern populations of the Lesser Snow and Blue Goose, *Anser c. caerulescens* (snow geese), winter along the coast of the Gulf of Mexico. In spring they migrate in a north-northwesterly direction through the United States and into southern Canada. Their major staging areas are Squaw Creek, Missouri; Onawa, Iowa; Sand Lake, South Dakota; Devil's Lake, North Dakota; and southern Manitoba (Bellrose, 1968). When migrating from the plains in southern Manitoba to the coasts of James and Hudson bays, the snow geese fly in northeasterly directions, often in large flocks. Many of them cross the Terminal Control Area of Winnipeg International Airport, an area with a radius of 30 n mi (56 km) with the centre at the airport.

In spring 1969, a flock of snow geese was struck by a civil airliner 12 n mi (22 km) northeast of Winnipeg. The aircraft was seriously damaged. The Associate Committee on Bird Hazards to Aircraft of the National Research Council of Canada was asked (1) to detect and warn of this spring migration and (2) to develop techniques to predict it.

It soon appeared that the two standard surveillance radars used for Air Traffic Control in Canada could detect goose flocks very well. However, any effective warning system would require height information, not provided by the surveillance radars. A joint project of NRC and CWS resulted in a preliminary description of a bird height finding radar (Hunt and Blokpoel, 1973). That work is continuing as an NRC project (Hunt, 1973a).

During the springs of 1970, 1971 and 1972 radar films were taken at Winnipeg International Airport, experiments with height finders were carried out and visual observations were made in and around Winnipeg. The data thus obtained provided information on the directions, numbers, heights and speeds of migrating snow geese. Results for 1970 and 1971 were given in Part 1 (Blokpoel, 1974).

Here, in Part 2, we examine the influence of the weather on snow goose migration and develop and test a method for predicting major flights through the area around Winnipeg using observed weather/migration correlations.

Methods and materials

1. Visual observations of staging geese

Records were obtained from volunteers, and by making aerial and ground surveys in 1970, 1971 and 1972.

2. Visual observations of migrating geese

We made routine observations in and around Winnipeg in 1970, 1971 and 1972. In addition, volunteers reported many sightings, in 1971 and 1972 on forms we provided. Lists of observations made in spring 1972 of staging and migrating geese in North Dakota, Manitoba and northwestern Ontario are deposited in the libraries of the regional head offices of the Canadian Wildlife Service.*

Data on migrating geese before 1969 were obtained from ornithological journals and books, newspaper bird columns and note-books of bird watchers. In this way, dates of major flights over the Winnipeg area were obtained for 11 years in the period 1953 through 1969.

3. Radar observations of migrating geese

Time-lapse 16-mm films were taken of the master scope of the 23-cm AASR-1 long-range surveillance radar at Winnipeg International Airport on May 2 through 19, 1970, April 28 through May 22, 1971 and April 25 through May 12, 1972. The range was set at 60 n mi (= 69 mi = 111 km). The screen was fitted with a clock and data tab. The antenna made six revolutions per minute. Each second radar sweep was recorded on one film frame. Solman (1969) gave details of the camera setup, and the manual of the Civil Aviation Branch (Canada Department of Transport, 1967) described the AASR-1 radar.

As the snow geese migrate in spring in northeasterly directions, in large flocks

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Table 1
Weather records for Pilot Mound and Winnipeg during major waves of spring snow goose migration, 1953 through 1972

	Pilot Mound*			Winnipeg		
Weather factors	Frequency of reading	Actual values during migration	10-yr normal values	Frequency of reading	Actual values during migration	10-yr normal values
Temperature†	6-hourly	1959–72	1960–69	Hourly	1953–72	1957–66‡
Relative humidity†	6-hourly	1959–72	1960–69	Hourly	1953–72	1953–62§
Pressure	6-hourly	1959–72	—	Hourly	1953–72	—
Surface wind‖	Hourly	1959–72	1960–69	Hourly	1953–72	1960–69
Geostrophic wind	—	—	—	6-hourly	1961–72	1960–69
Opacity	6-hourly	1959–72	—	Hourly	1953–72	—
Precipitation	Continuous	1959–72	1960–69	Continuous	1953–72	1960–69¶

*Records of weather data at Pilot Mound were available from 1959.
†Measured at about 5 ft(1.5 m) above the ground.
‡Based upon linear extrapolation between the hourly monthly means of April and May for the 10-yr period (Canada Department of Transport, 1968).
§Based upon linear extrapolation between the hourly monthly means for April and May of wet bulb and dry bulb temperatures for the 10-yr period (Canada Department of Transport, 1968).
‖Measured at about 20 ft(6 m) above the ground.
¶Data for 1967 not available.

and at altitudes of up to more than 5,000 ft (1,524 m), one would expect the echoes of the goose flocks to be relatively big, non-fluctuating, moving at a steady speed and on a straight course in directions between north and east, and visible for many miles on the screen. All echoes with these characteristics were considered "goose echoes". See Appendix 1 for arguments that more than 90% of the "goose echoes" were indeed caused by migrating snow geese. Filmed records of the radar display during late April and much of May provided a complete record of periods when the geese were and were not flying within radar range.

Directions of "goose echoes" on the 1970 films were determined by projecting the radar film on a sheet of paper and manually tracking with a pencil the paths of a representative number of echoes. Directions for the 1971 and 1972 data were obtained in the same way using a Vanguard Film Analyser with a sheet of transparent material (Mylar) taped to the ground-glass projection screen.

Total annual numbers of "goose echoes" for the spring migrations of 1970, 1971 and 1972 were estimated by running the radar film and counting the total number per hour crossing a straight line, the length and position of which were varied to best fit the direction, spread and visibility of the echoes during that hour and thus intercept the largest number of echoes. Counts were usually made every second hour.

4. Weather data

4.1. Synoptic weather

For 1953 through 1969 we used 6-hourly surface weather maps for days when geese were reported migrating. For 1970 through 1972 (May 1–17) we used 6-hourly surface maps and twice daily 850 mB and 700 mB maps.

4.2. Weather factors at Winnipeg and Pilot Mound

Years for which weather data were used are given in Table 1. Since we used readily available weather data to calculate 10-yr normals for several weather factors, these periods were not always the same for each factor.

Weather data recorded 6-hourly were used only if the time of record occurred during migration or within 2 hr of the beginning or end of a period of migration.

At an average ground speed of 45 mph (72 km/hr), migrating snow geese would take about 2 hr to fly from the staging grounds near Pilot Mound to Winnipeg. For this reason, Pilot Mound weather factors during the departure periods of major waves were those recorded 2 hr previous to the corresponding periods of migratory flight over the Winnipeg area.

5. Terminology

All times given in this report are Central Standard Time (CST) and all directions are in degrees azimuth, True North being 360° or 0°. The direction of the wind indicates from where the wind blows; the direction of the birds, their apparent destination. Heights were always given in feet: 1,000 ft = 304.8 m, and precipitation in inches: 1 in. = 2.54 cm. Speeds are expressed in miles per hour (mph): 1 mph = 1.609 km/hr. U.S. customary units were used in the tables and figures, but in the text the equivalent units of the Système International d'Unités (metric) are given as well.

Influence of the weather

1. Distribution and chronology

The eastern populations of snow geese winter along the coast of the Gulf of Mexico and breed in the eastern Canadian Arctic. The spring migration corridors through the United States were described by Bellrose (1968). The distribution and chronology in North Dakota and Manitoba have immediate bearing on the migration over Winnipeg and are described here.

Snow goose sightings in North Dakota and southern Manitoba during spring 1972 are plotted in Fig. 1, to give an idea of the geographical distribution of the spring migration.

In North Dakota, the geese generally migrate through the Oakes – Valley City area to their major staging grounds at Devil's Lake, with most birds arriving during the first 2 wk of April (H. K. Nelson, pers. comm.). From Devil's Lake, the geese gradually move north and northwest into northern North Dakota and southern Manitoba. Mass exodus from the Devil's Lake area usually takes place towards the end of April (L. Grinde, H. K. Nelson and O. Swenson, pers. comm.).

When moving from North Dakota to southern Manitoba, the geese appear to fly either west or east of the Turtle Mountains. In recent years, the numbers passing to the west seem to be increasing (L. Grinde, pers. comm.). G. Cockle, J. J. Janz and A. Meyers (pers. comm.) reported a great increase in goose numbers in 1972 for the westernmost part of southern Manitoba. Grinde suggested that this westward shift was due to the increase in fall tillage in the Cando area of North Dakota resulting in a lack of feed for the geese.

In southern Manitoba, the major staging areas in recent years have been between Cartwright and Windygates, with the largest concentrations near Pilot Mound, Crystal City and Snowflake. Since 1965, increasing numbers have been reported from the Boissevain–Hartney–Souris area. Blokpoel (1974) briefly reviewed the known shifts in Manitoba staging areas over the past forty years.

Observations for 1970, 1971 and 1972 showed the geese arrived in southern Manitoba by mid April. Their numbers gradually built up and reached a peak toward the end of April (Bidlake, Cockle, Hatch, Palmer, Reese, Ryder, pers. comm.).

The geese left southern Manitoba and extreme northern North Dakota during the first 2 wk of May. Detailed observations of major migration across southern Manitoba during 1953 through 1969 are given in Appendix 2. From these data, a list (Table 2) was compiled of periods for which we felt sure that major migration over the Winnipeg area (within a 60 n mi (111 km) radius of Winnipeg) had taken place. A "major migration wave" was numerically defined as at least 15 flocks or 3,000 birds per day. Where appropriate numerical data were unavailable, statements such as "peak migration" or "the main flight" (App. 2) were used in their place. Although reported directions over the Winnipeg area varied from north through east, most were northeasterly. As Winnipeg is at a bearing of about 48° from the Pilot Mound staging grounds, it seemed likely that a large proportion of the geese observed over Winnipeg came from this area.

For some years, the dates of both the departures from Devil's Lake and the flights over Winnipeg were known (Table 3). There was seldom overlap in the dates of departure from Devil's Lake and of migration wave over the Winnipeg area.

From these observations we concluded that (1) the great majority of the snow geese observed migrating over the Winnipeg area in the first half of May came from a staging area north or northwest of Devil's Lake, probably in the vicinity of Pilot Mound, and (2) a very small proportion of the migrants over Winnipeg in 1967 might have come in a direct flight from Devil's Lake.

Table 2
Dates of known major waves of spring snow goose migration over the Winnipeg area, 1953 through 1969

Wave	Year	Date	Time (CST)
1	1953	May 4	0800–2300
2	1953	May 6	0800–1700
3	1956	May 12	0800–1100
4	1956	May 12	2000–2300
5	1956	May 14	0800–1300
6	1959	May 7	0800–1100
7	1959	May 7	2000–2300
8	1961	May 7	0800–1100
9	1961	May 12	0800–1700
10	1961	May 13	0800–1100
11	1962	May 12	1100–1400
12	1962	May 15	2200–2300
13	1963	May 14	1700–2100
14	1964	May 5	0800–1700
15	1964	May 10	0800–1700
16	1965	May 10	0800–2300
17	1965	May 11	0900–1200
18	1966	May 16	1300–1700
19	1968	May 9	0800–1100
20	1968	May 9	1800–2300
21	1969	May 5	0800–1700
22	1969	May 6	0800–1700
23	1969	May 12	0600–1100

Table 3
Dates of departure of major waves of spring snow goose migration from the Devil's Lake area and of major snow goose migration over the Winnipeg area, 1963 through 1967

Year	Departures from Devil's Lake*	Major migration over Winnipeg area
1963	April 23–26†	May 14
1964	April 18 – May 2†	May 5, 10
1965	April 25 – May 1†	May 10, 11
1966	May 2 – 10†	May 16
1967	April 30 – May 13†	May 11–16†

*H. K. Nelson (pers. comm.).
†Exact date(s) unknown.

2. Migration waves and weather

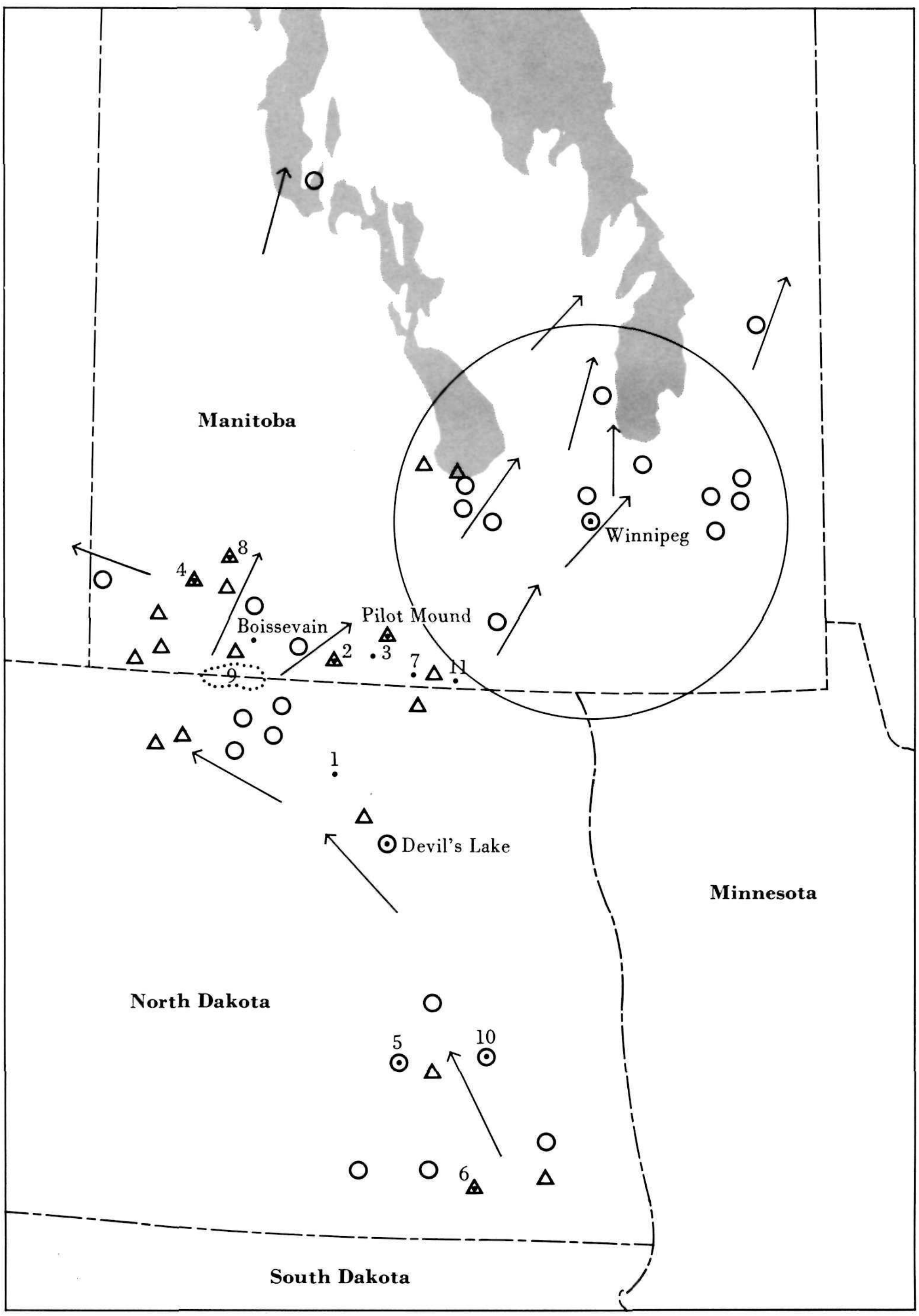
To determine to what extent weather was responsible for the initiation of migratory flights, we examined both the synoptic weather patterns and individual weather factors.

2.1. Synoptic weather

The association of mass migratory flights with the movement of weather sys-

Figure 1
Geographic distribution of selected sightings of snow geese in North Dakota and southern Manitoba during the spring migration of 1972. Sightings within 10 mi of those shown in the figure were not plotted for the sake of clarity. The circle delineates the Winnipeg area (radius 69 mi)

Figure 1



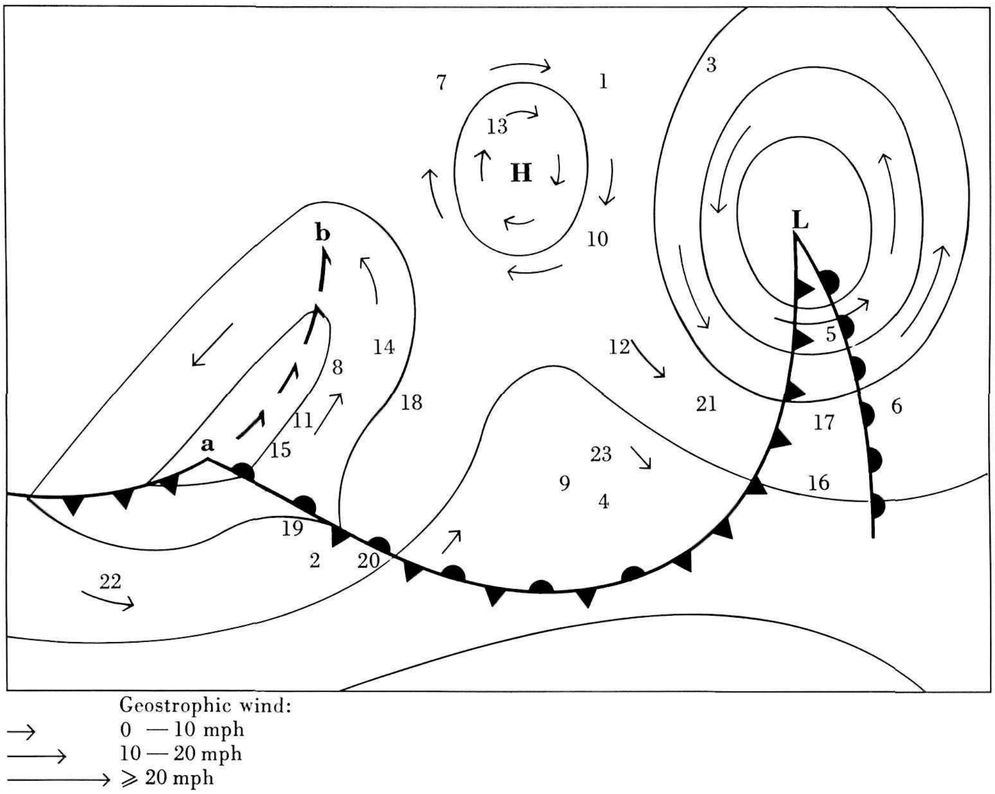
- △ Staging ⩾ 10,000 birds
- ○ Migrating ⩾ 3,000 birds
- • Town or city
- ↗ General direction of migration

1 Cando
2 Cartwright
3 Crystal City
4 Hartney
5 Jamestown
6 Oakes
7 Snowflake
8 Souris
9 Turtle Mountains
10 Valley City
11 Windygates

Scale: 1 in. = 61 mi.

Figure 2
Generalized weather map showing the approximate position of Winnipeg in relation to highs, lows and fronts during 23 major waves of spring snow goose migration over the Winnipeg area, 1953 through 1969

Figure 2



tems would provide a simple means to predict the timing of the spring migration over the Winnipeg area. Several authors have found that bird migration is associated with weather systems, such as cold fronts, warm fronts, pressure systems and broad wind patterns.

To depict the synoptic weather conditions during which the 23 migration waves over the Winnipeg area occurred, we used a generalized weather map (Fig. 2) similar to those used by Curtis (1969) and Richardson and Gunn (1971). The map depicts the normal spatial and directional relationships between fronts, winds and pressure systems.

Figure 2 shows a trough of warm air aloft (from a to b) to the left, with moderate upper air winds as indicated by the arrows. The arrows show the approximate speed and direction of the geostrophic wind at 4,000 ft (1,220 m) above sea level (asl), which is 3,200 ft (975 m) above ground level (agl) at Winnipeg. At this height, the wind is not influenced by the earth's surface and wind directions are then parallel to the isobars. To the right is a deep low (L) accompanied by strong winds, blowing counter-clockwise around it. The high (H) in the middle is characterized by moderate clockwise winds and by light winds very close to the centre. South of this high along the quasi-stationary front the winds are light and variable. For further information on synoptic weather descriptions, the reader is referred to standard textbooks such as *Weather Ways* (Canada Department of Transport, 1966).

By analysis of the 6-hourly surface maps for days of migration waves, we plotted on the generalized weather map that location of Winnipeg which best corresponded with the prevailing synoptic conditions during the wave. We chose Winnipeg rather than Pilot Mound because upper air wind data were available for Winnipeg, which helped greatly in estimating the proper location on the generalized weather map.

The geese migrated under a large variety of weather conditions: to the southwest of a low (22), to the northwest of a low (3), to the east side of a trough of warm air aloft (8, 11, 14, 15 and 18), in the vicinity of a quasi-stationary front (2, 19, 20), on almost all sides of a high (1, 7, 10, 13), in the light and variable winds in areas without active weather systems (4, 9, 23), behind a strong cold front (12, 21), in a warm sector (5, 16, 17) and just in front of a warm sector (6).

As the analysis of the synoptic weather situations provided few useful cues for predicting periods of migration, individual weather factors both at the staging grounds and at Winnipeg were examined.

2.2. Weather factors at the staging grounds

An operational migration prediction system at Winnipeg Airport using weather at the staging grounds would be the most useful, as this would provide a 2-hr interval between the predicted time of take-off and the actual presence of the geese over Winnipeg and so allow for alternative air traffic control procedures to be put into effect. Although the geese staging in southern Manitoba and northern North Dakota were widely scattered, their main concentration was within the Pilot Mound – Crystal City–Snowflake–Windygates area (Blokpoel, 1974). Pilot Mound weather records were used to represent the weather on the staging grounds as it was the only weather station within the area reporting hourly wind speeds and directions.

The main results of our analysis of individual weather factors at Pilot Mound and the occurrence of major waves of mi-

Table 4
Summary of results of analysis of weather factors at Pilot Mound and 18 major waves of spring snow goose migration over the Winnipeg area, 1959 through 1969

Weather factor		Preference for and avoidance of individual weather factors during departure from the Pilot Mound staging grounds
Temperature		None
Relative humidity		None
Pressure		None
Cloud cover		None
Precipitation		Avoidance of precipitation*
Surface wind direction	tail	Preference for tail wind*
	side	Avoidance of side wind*
	head	Avoidance of head wind*
Surface wind speed	tail	Preference for less than normal speed*
	side	Preference for less than normal speed
	head	Preference for less than normal speed

*Statistically significant ($P<0.05$).

Note:
There were no statistically significant linear correlations between the weather factors (relative to normal) during departure and the dates of migration waves. (In other words the response of the geese to the weather factors did not significantly change with the progression of the migration season).

gration over the Winnipeg area are summarized in Table 4. A more detailed account is as follows:

2.2.1. Temperature

The geese departed from the Pilot Mound area with hourly surface temperatures varying from 30.1°F (−1.0°C) through 70.2°F (21.2°C). The average temperatures for the 18 take-off periods ranged from 30.1°F (−1.0°C) through 59.4°F (15.2°C) with a mean of 49.6°F (9.8°C). The average normal temperatures during the departure periods varied from 33.9°F (1.1°C) to 58.6°F (14.8°C) with an average of 46.3°F (7.9°C). The mean temperatures during the take-off periods were on average 3.3F° (1.9C°) higher than normal. However, the differences between the mean departure temperatures and the mean normal temperatures varied considerably—from −11.2F° (−4.1C°) to +13.8F° (+4.0C°).

There was no statistically significant linear correlation between date of migration wave and temperature with respect to normal. Response of the geese to temperature with respect to normal did not change with progression of the migration season.

2.2.2. Relative humidity

The hourly surface relative humidities during take-off periods ranged from 30.0% through 94.0%. Geese departed under average relative humidities of 30.0% through 93.0%, with an average of 67.3%. The averages of normal relative humidity readings during the departure periods of the geese varied from 50.5% to 87.5%, with an average of 69.1%. Thus, on the whole, departures occurred with slightly lower-than-normal relative humidities on the staging grounds. However, the mean relative humidities for the individual take-off periods varied considerably from the normal means —from −42.1% to +18.0%.

We found no statistically significant linear correlation between the date of migration wave and the relative humidity with respect to normal.

2.2.3. Pressure

The average barometric pressures at the surface during the migration wave departures varied from 944.7mB through 972.3 mB (mean 956.6 mB). No trend with the progression of the migration season was evident. No data were available to assess the effect of pressure tendency.

2.2.4. Cloud cover

The geese began their migration with the average total opacity (calculated for each departure period and measured on the 0–10 scale) ranging from 0 through 9 (mean 3.6). No trend with the progression of the migration season was evident.

2.2.5. Precipitation

A very light 5-min shower was the only precipitation during the 18 periods of departure from the Pilot Mound area for which weather data were available. This was significantly less than the normal precipitation value for these periods (sign test, $P<0.001$, $N = 18$).

2.2.6. Wind direction

Surface winds during the waves were classed as head wind (360° through 090°), tail wind (180° through 270°) or side wind (all others). For each wave we calculated the time percentages of head, side and tail winds. We also calculated the normal time percentages of the wind classes for the hours that the waves occurred. The results showed pronounced differences between the actual and normal percentages (Table 5). Most (71%) of the surface winds during the departures were tail winds. Side winds occurred 18% of the time and head winds only 11% of the time. The preference for tail wind and avoidance of head and side winds were statistically significant (sign test; $P<0.05$ and $N = 18$ in all three cases).

We plotted the time percentage for each wind direction class against the date of the wave, but found no statistically significant linear correlations.

2.2.7. Wind speed

Average surface wind speeds during departures varied considerably among the three wind direction classes: 6.6 mph (10.6 km/hr) (head wind), 9.8 mph (15.8 km/hr) (side) and 11.8 mph (19.0 km/hr) (tail). Normal wind speeds were higher and varied much less (Table 5). The geese appeared to prefer less-than-normal speeds, particularly in the case of head and side winds. However, when tested (sign test), this preference for lower wind speeds was statistically significant ($P<0.05$, N = 16) only in the case of tail winds. The difference between average actual and normal wind speed in the side wind class was marginally significant ($P=0.055$, N = 10), while that for the head wind class could not be tested as the sample was too small (N = 4).

We plotted the average wind speed during the departure periods (calculated for each of the three wind classes) against the date of the wave. There were no statistically significant linear correlations.

Table 5
Average wind directions and speeds at the surface at Pilot Mound during the departure periods of major waves of spring snow goose migration from the Pilot Mound area, 1959 through 1969

	Wind direction* (time %)			Wind speed (mph)		
	Head	Side	Tail	Head	Side	Tail
Actual	11	18	71	6.6	9.8	11.8
Normal	35	34	31	11.0	14.2	14.8
Difference†	S	S	S	—	NS	S

*Wind classification: head, north through east; tail, south through west; side, all others.

†S: difference between actual and normal statistically significant at 5% level (sign test applied to the data for the individual waves); NS: not significant.

Table 6
Summary of results of analysis of weather factors at Winnipeg and major waves of spring snow goose migration over the Winnipeg area, 1953 through 1969

Weather factor		Preference for and avoidance of individual weather factors during migration over the Winnipeg area
Temperature		None
Relative humidity		None
Pressure		None
Cloud cover		None
Precipitation		Avoidance of precipitation*
Surface wind direction	tail	Preference for tail wind
	side	Preference for side wind
	head	Avoidance of head wind*
Surface wind speed	tail	Preference for less than normal speed
	side	Preference for less than normal speed*
	head	Preference for less than normal speed*
Geostrophic wind direction	tail	Preference for tail wind
	side	None
	head	Avoidance of head wind*
Geostrophic wind speed	tail	Preference for less than normal speed
	side	Preference for less than normal speed
	head	Preference for less than normal speed

*Statistically significant ($P<0.05$).

Note:
Only temperature and relative humidity showed a statistically significant linear correlation with the dates of migration waves.

2.3. Weather factors at Winnipeg

Although the Pilot Mound weather data showed a few significant correlations useful to predict migratory flights, we felt it pertinent to examine the weather factors at Winnipeg in view of the possibility that once a flight is initiated by favourable weather, it might be terminated by unfavourable weather at any point along its route.

The main results of our analysis of individual weather factors at Winnipeg and the occurrence of major waves of migration over the Winnipeg area are summarized in Table 6. A more detailed account is as follows:

2.3.1. Temperature

The surface temperature during the migration waves varied considerably. Geese were reported migrating with surface temperatures at Winnipeg as low as 30.0°F (−1.1°C) and as high as 87.4°F (30.8°C). The average temperatures during the migration waves varied from 41.5°F (5.3°C) to 80.0°F (26.7°C) with a mean of 54.9°F (12.7°C). The average normal temperatures for the periods that the geese were flying varied much less. The extremes were 47.9°F (8.3°C) and 61.0°F (16.1°C) and the mean was 52.8°F (11.6°C). Thus on the whole, major waves occurred with surface

Figure 3
Linear correlation between surface temperature at Winnipeg (relative to normal) and date of major waves of spring snow goose migration over the Winnipeg area, 1953 through 1969

Figure 4
Linear correlation between surface relative humidity at Winnipeg (relative to normal) and date of major waves of spring snow goose migration over the Winnipeg area, 1953 through 1969

temperatures at Winnipeg that were only 2.1F° (1.1C°) higher than normal. However, the differences between mean temperatures for the individual waves and their corresponding normal values varied from −10.3F° (−6.2C°) through +27.5F° (+15.2C°). There was a statistically significant linear correlation between the temperature (with respect to normal) on days of waves and the date on which the wave occurred (Fig. 3).

2.3.2. Relative humidity

The surface relative humidity ranged from 27.0% through 94.0% during the migratory waves. The average relative humidity readings during these waves varied from 35.7% through 82.0%, with a mean of 58.7%. The corresponding normal values ranged from 43.0% to 64.8%, with a mean of 55.1%. Thus, the migration waves occurred with relative humidities that were in general slightly higher than normal. Yet, the differences between the means of the relative humidities during the waves and their corresponding normal values ranged from −17.4% through +34.0%.

There was a significant linear correlation between the relative humidity (with respect to normal) and the date on which the wave occurred (Fig. 4).

2.3.3. Pressure and pressure tendency

Snow geese were observed migrating with surface barometric pressures ranging from 969.8 mB through 1000.6 mB. The average barometric pressures during the migration waves varied from 972.1 mB through 1000.4 mB, with a mean of 984.0 mB. There was no trend with the progression of the migration season. During the 23 waves of migration, pressure tendencies fell 14 times (61%), rose 5 times (22%), and rose then fell 4 times (17%). All waves with rising barometric pressure occurred rather late in the season (May 9 through 13).

2.3.4. Cloud cover

Snow geese were observed to migrate under all conditions of opacity, measured

Figure 3

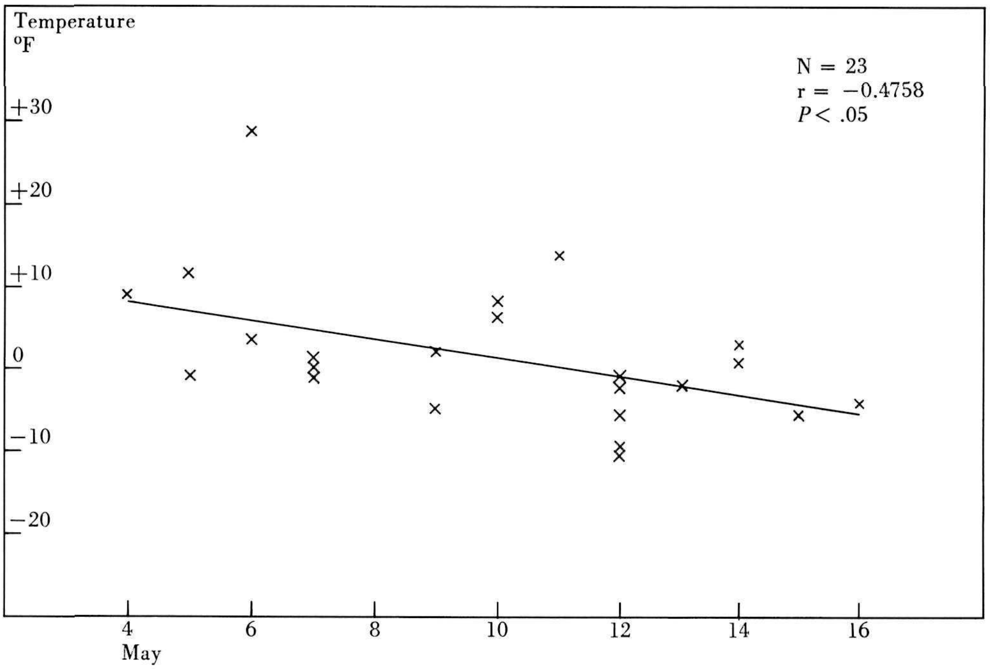
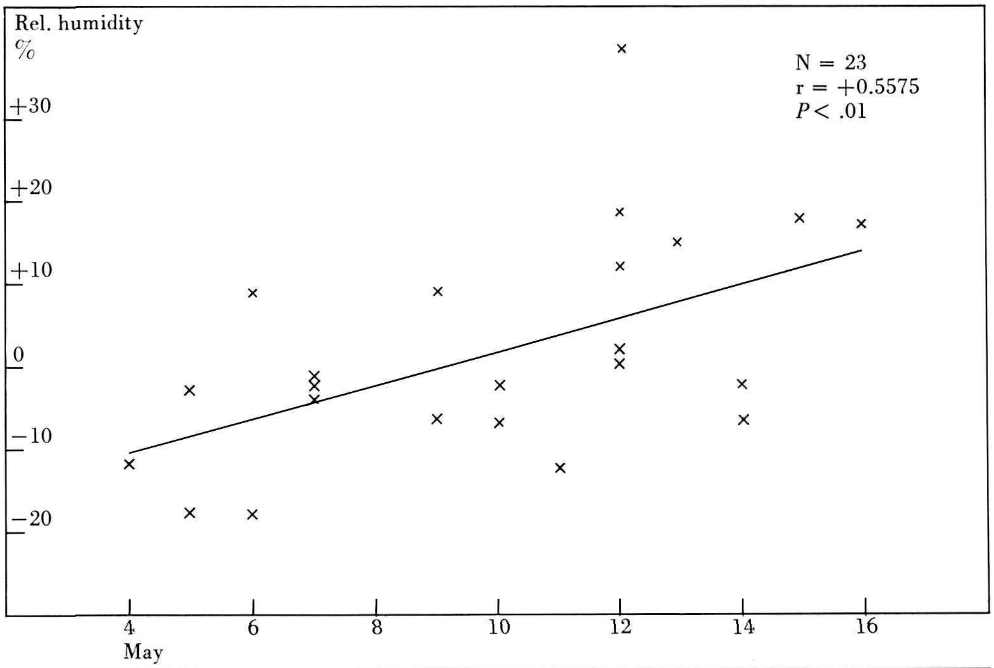


Figure 4



on the 0–10 scale. Averaged opacities for wave periods ranged from 1 through 10, with a mean of 5.0. No trend with the progression of the migration season was evident.

2.3.5. Precipitation

Precipitation occurred during only four waves, and varied from very light drizzle to thunderstorm (Table 7). In those four cases, precipitation lasted 58%, 47%, 20% and 37% of the time of passage of the waves. The amount of precipitation during the waves was significantly less than normal (sign test, $P<0.001$, N = 23). We found no trend with progression of the migration season.

Table 7
Precipitation during major waves of spring snow goose migration over the Winnipeg area, 1953 through 1969*

	Precipitation over the Winnipeg area			
			Duration	
Migration wave period	Type	Accumulation (in.)	Hr	% of migration wave
May 12, 1962, 1100–1400	L—	tr	1 hr 45 min	58
May 10, 1964, 0800–1700	RW—, RW–, RW, T	0.11	4 hr 13 min	47
May 9, 1968, 1800–2300	RW—	tr	1 hr	20
May 6, 1969, 0800–1700	RW—, RW–, RW, A–, T	0.15	3 hr 20 min	37

*Legend for symbols:
A– light hail
L— very light drizzle
RW moderate rain shower
RW– light rain shower
RW— very light rain shower
T thunderstorm
tr trace

2.3.6. Surface wind

Surface winds during the waves were again classed as head wind (360° through 090°), tail wind (180° through 270°) or side wind (all others). For each wave we calculated the time percentages of head, side and tail winds. We also calculated the normal time percentage of the wind classes for the hours that the waves occurred. The results showed pronounced differences between the actual and normal percentages (Table 8). The geese appeared to avoid head winds and to fly with side and especially tail winds. However, using the sign test, only the difference for the head wind category was statistically significant (i.e. the geese avoided head winds) ($P<0.05$, N = 23).

High percentages of head winds occurred mainly towards the end of the migration season (May 12–16), but we found no statistically significant linear correlation between time percentage of head winds and date with major migration. No such correlations for side and tail wind classes were found either.

Average wind speeds during major flights varied with the wind direction classes: 8.4 mph (13.5 km/hr) (head wind), 10.4 mph (16.7 km/hr) (side) and 12.6 mph (20.0 km/hr) (tail) (Table 8). The normal wind speeds varied much less: 13.3 mph (21.4 km/hr) (head), 14.1 mph (22.7 km/hr) (side) and 14.2 mph (22.8 km/hr) (tail). Applying the sign test to the differences between actual and normal wind speeds, we found statistically significant differences for the head and side wind classes ($P<0.05$, N = 8 and $P<0.05$, N = 16). In other words, when flying with side or head winds, the geese flew with lower than normal wind speeds.

Table 8
Average wind directions and speeds at the surface at Winnipeg during major waves of spring snow goose migration over the Winnipeg area, 1953 through 1969

	Wind direction* (time %)			Wind speed (mph)		
	Head	Side	Tail	Head	Side	Tail
Actual	17	41	42	8.4	10.4	12.6
Normal	37	34	29	13.3	14.1	14.2
Difference†	S	NS	NS	S	S	NS

*Wind classification: head, north through east; tail, south through west; side, all others.

†S: difference between actual and normal statistically significant at 5% level (sign test applied to the data for the individual waves); NS: not significant.

Average wind speeds during the waves showed no statistically significant linear correlations with progression of the migration season.

2.3.7. Geostrophic wind

Surface winds are not necessarily indicative of the wind conditions at the birds' flight altitude. Although the heights at which the snow geese migrated over the Winnipeg area were unknown, the geostrophic winds (3,200 ft agl, 975 m agl) were considered to provide further information concerning the actual wind conditions during the migration waves.

The 6-hourly geostrophic winds were dealt with in the same manner as the surface winds (Table 9). Only the time per-

Table 9
Average wind directions and speeds at the geostrophic level over Winnipeg during major waves of spring snow goose migration over the Winnipeg area, 1961 through 1969

	Wind direction* (time %)			Wind speed (mph)		
	Head	Side	Tail	Head	Side	Tail
Actual	10	37	53	9.5	17.9	20.8
Normal†	25	48	27	19.2	20.2	23.6
Difference†	S	NS	NS	NS	NS	—

*Wind classification: head, north through east; tail, south through west; side, all others.

†S: difference between actual and normal statistically significant at 5% level (sign test applied to the data for the individual waves); NS: not significant.

centage of flights with head wind conditions was significantly less frequent than normal (sign test, $P<0.05$, N = 15).

The migration flights occurred during less-than-normal average wind speed conditions, particularly with head winds, where actual wind speeds were less than half the normal values. Nevertheless, the differences were not significant, possibly due to sample size (N = 7 for side winds, N = 9 for tail winds) and the weakness of the sign test employed. (No test was possible on the speeds in the head wind class, N = 2.)

We found no statistically significant linear correlation between date of wave and time percentage (per wind direction class), nor between date of wave and average wind speed (per wind direction class).

3. Discussion

3.1. Nature of the data

3.1.1. Limitations of this study

The limitations of our study were (1) incomplete staging data, (2) incomplete migration data, (3) incomplete weather data, and (4) the small sample size.

Incomplete staging data

We could not be certain that all geese seen over the Winnipeg area had departed from the Pilot Mound area. The Pilot Mound weather data might not have been representative of the take-off weather for all migration waves. However, as detailed in the chapter on distribution and chronology, it seemed reasonable to assume that most geese over Winnipeg had indeed come from the Pilot Mound area.

Incomplete migration data

There was only a certain number of days and hours during which we were reasonably sure that major migration occurred. Often, the times were approximate, as in cases where the reporter mentioned only "all day" or "morning" (See App. 2). We did not know if waves other than the reported ones occurred. Furthermore, for 6 yr (even as recently as 1967) there were no definitive reports of major migration. The qualitative description of the numbers of migrating geese made it impossible to scale the migration density, and we had to use arbitrary criteria to decide whether or not major migration had occurred.

Incomplete weather data

Upper air wind data for Winnipeg during 1953 through 1959 were unavailable. There were no upper air wind records for Pilot Mound. Records of surface weather at Pilot Mound dated back only as far as 1959 and entries were 6-hourly, with the exception of hourly wind values.

Small sample size

We used a simple univariate analysis for nine weather factors because of the sample size (23 migration waves). Nisbet and Drury (1968), Richardson and Haight (1970) and Able (1973) discussed the advantages and disadvantages of uni- and multi-variate analysis of the effects of weather on bird migration. The statistically significant correlations between single weather factors and waves of migration may be causal or spurious. For example, in Table 5, we found that departing birds significantly preferred tail winds and avoided head and side winds. However, a biologically significant (i.e. real) preference for tail winds might well result in a statistically significant, yet spurious, avoidance of side and head winds, or conversely, a biologically significant avoidance of head and side winds might result in a statistically significant apparent preference for tail winds that the geese do not actually possess.

3.1.2. Advantages of this study

Advantages of our study were that we were dealing, for the most part, with a single species which migrated in an unusual direction (northeasterly) and rather late in the season when compared with other species of waterfowl. The snow geese were easily identified and their migration took them over a large settled area with many reporting bird watchers.

3.2. Comparison with results of others

The influence of synoptic weather and weather factors on migration has been studied by many authors in both Europe and North America (for reviews and discussions, see Lack, 1960; Nisbet and Drury, 1968; Richardson and Gunn, 1971; Schüz, 1971; and Able, 1973). Our discussion is limited to spring migration over inland North America.

Bagg *et al.* (1950) proposed a working hypothesis for the analysis and prediction of spring migratory flights in North America: ". . . 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". This means that major flights will occur in association with warm following winds with a high to the east and/or a low to the west, as was confirmed by several authors (e.g., Hochbaum, 1967, for southern Manitoba and Richardson, 1966, for southern Ontario). Richardson and Haight (1970) found that spring migration departures of the Common Starling (*Sturnus vulgaris*) from roosts in southern Ontario took place in a northeasterly direction and with tail winds. All but one heavy flight occurred just ahead of, in, or just behind the warm sectors associated with approaching cold fronts. Curtis (1969), working in Wisconsin, reported heavy migration departures under a variety of synoptic conditions: just to the west of a high, further west of a high and in the warm sector. Heavy migration also occurred with northeasterly winds associated with the northern portion of a low and with the light northerly winds at the east side of a high. Heavy spring migration in east-central Alberta is usually in a northwesterly direction and occurs with following winds (Richardson and Gunn, 1971). These authors reported heavy migration under quite a variety of synoptic situations, but mainly to the southwest of a high and/or just ahead of a warm front.

The use of a generalized weather map helps to visualize the influence of weather systems, but we found that the actual synoptic weather conditions were often more complicated than is indicated on our simplified weather map. In a few cases it was difficult to determine what part of our map would best represent the actual weather situation at Winnipeg. Twelve (52%) of the 23 waves we studied occurred in or just ahead of a warm sector, near or on the east side of an occluded front, or on the west side of a high. Thus, although many geese flew under the classic "favourable" weather conditions, many waves occurred with other synoptic situations and it therefore seemed unlikely that synoptic weather would be very useful for predicting all major snow goose migration.

Regarding *wind direction*, we found a strong preference for tail winds and/or avoidance of head and side winds. This agrees with the findings of Raynor (1956), Richardson (1966), Bellrose (1967), Curtis (1969), Richardson and Haight (1970) and Richardson and Gunn (1971).

When departing with tail winds, the snow geese showed a statistically significant preference for lower than normal *wind speeds*. Such a preference was not expected, because it would be more economical for the birds to fly with strong tail winds. No correlation between the density of passerine migration and wind speed was reported by Richardson (1966), Richardson and Haight (1970) and Richardson and Gunn (1971). Bellrose (1967) reported that waterfowl selected for winds above 25 kn (46 km), whereas small birds preferred to fly with winds below 15 kn (28 km). Our results and those of Bellrose are not in agreement, and it may be that the mathematically significant correlation that we found is not the result of a real biological preference of the geese for lower-than-average wind speeds.

As far as *temperature* is concerned, Raynor (1956) and Curtis (1969) found no correlation between migration departures and temperature changes. Richardson (1966) found evidence that mass migration occurs only when the temperature is above a limiting value, and that above that value wind direction exerts the main influence on the volume of migration. This was also reported by Bellrose (1967), who wrote: "Strong winds within 45 degrees of a following wind appear to be more important than temperature in triggering a wave of migrating waterfowl. Yet the temperature level must be above the threshold required for motivating individual species and segments of waterfowl populations." Although the Winnipeg temperature with respect to normal fluctuated strongly, it became on average lower as the migration season progressed. This might indicate that such a temperature threshold decreases later in the season, probably because the birds develop higher motivation to migrate.

We found a significant positive linear correlation between *relative humidity* at Winnipeg on days with migration and progression of the migration season. This may have occurred because there was also a significant trend for the Winnipeg temperatures on migration days to become lower than normal as the season progressed. Furthermore, migration with head winds occurred mainly late in the season (although this trend was not significant). These results suggested that the geese flew with a warm, and thus relatively dry, southwesterly air flow in the beginning of the season, whereas later on they also migrated despite a more northerly air flow with lower temperature and higher relative humidity. Richardson (1966) found that increasing relative humidity was somewhat correlated with major waves of migration in southern Ontario, but this "could hardly help both to start and to stop a mass movement". Starling migration departures in southern Ontario showed no correlation with relative humidity (Richardson and Haight, 1970). A correlation between low humidity and high intensity of northwest migration was reported by Richardson and Gunn (1971). This correlation persisted when only nights with following southeast wind were considered. It was also not the result of intercorrelation of humidity and temperature or pressure trend, which suggested "that these birds may be using low humidity as an indicator of the preferred time for NW migration".

More than 60% of the waves of snow goose migration occurred with falling *pressure trend*. Raynor (1956) reported a slight relationship between flights and falling pressures, but considered pressure as such to be of no importance. Richardson and Gunn (1971) found that the correlation between falling pressure and higher migration density disappeared when only nights with following winds were considered. "If birds were reacting to pressure changes *per se*, one would expect the correlation to persist, since not all nights with following winds . . . have similar pressure trends" (Richardson and Gunn, 1971).

Prediction of major flights

We found that the geese departed and migrated with less-than-normal *precipitation*. These results agree with those of Richardson (1966) and Curtis (1969).

The snow geese migrated with *cloud cover* conditions varying from clear to completely overcast. Similar results were obtained by Richardson (1966), Richardson and Haight (1970) and Richardson and Gunn (1971). Curtis (1969) reported departures of nocturnally migrating passerines under all cloud cover conditions, but mainly with clear skies.

It appears that for spring migration over inland North America, surface wind direction is the most important single weather factor, and it is likely that this factor will be the best predictor of heavy migration.

1. Introduction

In the previous section, we found significant correlations between migration waves and several weather factors. As we could not determine which weather factors were biologically or merely statistically significant, we used all statistically significant correlations to predict migration waves.

Prediction of migration over the Winnipeg Terminal Control Area required the identification of two phases: departure from the staging grounds and continuation of the flight over the Winnipeg area. A period of favourable weather conditions at Pilot Mound should be followed, 2 hr later, by a major wave over the Winnipeg area, provided the Winnipeg weather is favourable. Conversely, no migration would be expected over the Winnipeg area during favourable weather unless favourable conditions had prevailed at the staging grounds 2 hr earlier.

The geese presumably staged in the Pilot Mound area covering about 40 by 15 mi (64 by 24 km). To allow time for weather changes to affect the whole Pilot Mound staging area, we used periods beginning 1 hr before the first readings of favourable conditions and ending 1 hr after the last favourable reading as the periods with good take-off weather at Pilot Mound.

When examining the weather records for Pilot Mound and Winnipeg, we arbitrarily decided that three consecutive hourly readings of favourable weather were the minimum period for prediction of heavy migration. Results of this and other studies showed the direction of the surface wind to be the most useful factor for predicting heavy migration. Thus we considered the surface wind direction at Pilot Mound as the most important factor: the duration of a wave would be at most as long as the period with tail winds at Pilot Mound. Any period with tail winds at Pilot Mound would be followed, 2 hr later, by an equally long period of major migration over Winnipeg, provided all other weather factors, both at Pilot Mound and at Winnipeg, were favourable. These other weather factors would shorten the period of predicted migration only for the time that they were unfavourable.

Complete records of the 1970, 1971 and 1972 spring snow goose migrations were obtained by continuous filming of the Winnipeg AASR-1 surveillance radar (see "Methods and materials"). A wave of major migration on radar was arbitrarily defined as any continuous period of migration during which at least 200 "goose echoes" were estimated to cross the screen, and the hourly numbers of "goose echoes" totalled 20 or more (an interval of 1 or 2 hr with less than 20 echoes would not break a wave).

The procedure we followed was largely trial and error: we designed a prediction model based on our findings, tested it on the data for 1970, redesigned it and repeated the procedure for the 1971 and 1972 data.

2. Testing of first model on the 1970 data

Based on the migration/weather relations for 1953 through 1969, the following forecast model for the 24-hr day was developed. Heavy snow goose migration over the Winnipeg area would be expected if:

A. the day was in the period May 4–16 (Table 2)

B. the Pilot Mound weather, 2 hr previously, was as follows:
- a. direction of surface wind: tail wind (south through west)
- b. speed of surface tail wind: below normal
- c. precipitation: less than normal

C. the Winnipeg weather was as follows:
- a. temperature: above normal before May 12 and below normal thereafter
- b. relative humidity: below normal before May 9 and above normal thereafter
- c. direction of surface wind: tail or side wind (side winds are all winds that are neither head winds, i.e., north through east, nor tail winds)
- d. speed of surface side wind: less than normal
- e. direction of geostrophic wind: tail or side wind
- f. precipitation: less than normal

The periods of snow goose migration during spring 1970 as obtained from the filmed radar display are given in Fig. 5a. The first wave of migration occurred on May 6, 0600 to 2000 hr (assuming that the wave continued during the period 0800–1100 hr for which we have no radar data) and the only other wave took place from May 15, 2100 hr through May 17, 0900 hr (assuming the wave continued during the 1-hr period no radar data were available). The 9-day period between these two waves is the longest ever reported (Table 2). The previous latest date of major migration was May 16, whereas in spring 1970 heavy migration occurred May 17.

To evaluate the accuracy of the migration predictions, we calculated two values: the number of hours of actual heavy migration correctly predicted and the number of hours of predicted heavy migration that materialized.

Using only periods with reliable data, 26% of the hours of actual heavy migration were predicted, and 100% of the hours of predicted heavy migration materialized.

Predicted heavy migration that did not materialize:
There was a considerable movement of "goose echoes" on May 6, 0600–2100 hr. Radar interference began at 2100 hr and continued through the night of May 6/7, making it impossible to determine if the migration wave continued (Fig. 5a).

Actual heavy migration that was not predicted:
A. On May 6, 0600–1700 hr, geese left with stronger-than-average tail winds.
B. On May 16, the geese left the staging area with a west wind from 0000 to 1800 hr, with the exception of the period 1100 to 1500 hr when the winds varied between west and northwest (i.e., generally a side wind). Geese continued to depart during this interval of less favourable wind conditions.
C. A wave of migration occurred on May 16, with the Winnipeg surface temperature above normal, the relative humidity below normal and the speed of the surface side wind above normal.
D. The guidelines did not allow predictions after May 16. Had we predicted for May 17, we would have made errors because (a) the geese departed with stronger-than-normal tail winds, and (b) all heavy migration for spring 1970 was completed by 0900 hr on that day (Fig. 5a).

To assess the usefulness of a particular weather factor for predicting heavy migration, we used an arbitrary guideline: a weather factor causing an error of 3 or more consecutive hours in the prediction period is eliminated. Speed of surface tail wind at Pilot Mound and temperature, relative humidity and speed of surface side wind at Winnipeg were eliminated on this basis.

3. Testing of revised model on the 1971 data

The prediction model was modified to agree with the findings of our analysis of the 1970 prediction results. The following criteria were used to predict the 1971 spring migration. Heavy snow goose migration over the Winnipeg area would be expected if:
A. the day was in the period May 4–17
B. the Pilot Mound weather, 2 hr previously, was as follows:
   a. direction of surface wind: tail wind
   b. precipitation: less than normal
C. the Winnipeg weather was as follows:
   a. direction of surface wind: tail or side wind
   b. direction of geostrophic wind: tail or side wind
   c. precipitation: less than normal
D. late in the season (May 16), intervals of not more than 4 hr of northwesterly winds at the staging grounds during a period of favourable winds will not arrest major departures.

The predicted and actual snow goose migration flights during spring 1971 are shown in Fig. 5b. The first wave occurred on May 2, earlier than the dates given in Table 2 and, as such, not within the prediction period (May 4–17). At the end of the season, there were two predicted waves (on May 14 and May 14/15) that did not materialize because most geese had already left the area. In practice, one would not predict a wave for May 14/15 if there were apparently not enough geese left on the staging grounds to realize the predicted wave. We therefore disregarded the wave on May 14/15 in our calculations of the accuracy of the predictions. Using only periods with reliable data, 65% of the hours of actual heavy migration were predicted, and 79% of the hours of predicted heavy migration materialized.

Predicted heavy migration that did not materialize:
A. Lack of data for the 0300–0800 hr period on May 4 made it impossible to determine if a wave had occurred on May 4, 0300–1300 hr.
B. During the period 1500–1800 hr on May 12, we were at the end of a wave, and apparently at the end of any major migration for spring 1971. This also explains why there were no waves on May 14 and May 14/15.

Actual heavy migration that was not predicted:
A. The guidelines did not allow predictions before May 4, the earliest date previously reported. Had we predicted for May 2 and 3, we would have made errors due to (a) geese departing from the staging area with southeast wind, and (b) geese continuing their migration over the Winnipeg area despite northeast geostrophic winds at 6 mph (10 km/hr).
B. The geese left the staging area with southeast winds on May 6, 0400–0700 hr; May 8, 2000–2200 hr; and May 11/12, 2200–2400 hr.

The data for 1970 and 1971 showed that the geese took off with southeast side winds. The statistically significant avoidance of side winds during take-off, Table 5, is apparently not biologically significant, at least for southeasterly winds. This agrees with observations on migrating snow geese by Hochbaum (1967, p. 170–171), who wrote: "Though both spring and fall migrations of waterfowl generally occur with a favouring wind, they do not always do so. The Lesser Snow and Blue Geese, going to the northeast, are often seen migrating with a cross wind at the same time that many other migrants are travelling northwest with the southeast wind on their tails."

4. Testing of revised model on the 1972 data

Using the criterion that factors which cause errors of at least 3 hr will be omitted or modified, we changed the 1971 prediction model before we tested it on the 1972 data. These changes were:

A. major flights can be expected in the period May 2–17

B. a light (6 mph, 10 km/hr) geostrophic head wind at Winnipeg will not halt a wave of migration

C. the snow geese will leave the Pilot Mound staging grounds with southeast winds.

The actual and predicted periods of major migration in spring 1972 are given in Fig. 5c. Filming of the radar screen ended on May 12, 0900 hr, and we therefore did not predict for the time thereafter.

Using only periods with reliable data, 85% of the hours of actual heavy migration were predicted and 75% of the hours of predicted heavy migration materialized.

Predicted heavy migration that did not materialize:

A. There was no heavy migration on May 7, 0200–0600 hr and May 9, 1600–1900 hr (see Fig. 5c and note that there was light migration). We have no explanation for these errors other than that the geese preferred to take off during certain times of the day, at least under normal weather conditions, such as prevailed during spring 1972. This is discussed in the next section.

B. The other major errors (May 11/12, 2300–0300 hr and May 12, 0100–0900 hr) were due to the fact that most geese had already left the staging areas. Visual observations in and around Winnipeg (see "Methods and materials") confirmed this and also showed that no heavy migration occurred after May 10. Radar filming stopped on May 12, 0900 hr.

Actual heavy migration that was not predicted:

A. Geese flew despite a light (3–10 mph, 5–16 km/hr) surface head wind at Winnipeg on May 7, 1400–1900 hr and on May 8, 0800–1000 hr.

B. Departures from the staging ground occurred with very light (2.5 mph, 4 km/hr) head winds at Pilot Mound on May 8, 1800–2100 hr. This 3-hr period of less-than-optimal wind conditions was an interval in a much longer period of southwest winds.

Based on these findings we suggest the following system for predicting waves of spring snow goose migration over the Winnipeg area:

A. the day is in the period May 2–17

B. the Pilot Mound weather, 2 hr previously, is as follows:
- a. direction of surface wind: tail or southeast wind
- b. precipitation: less than normal

C. the Winnipeg weather is as follows:
- a. direction of surface wind: tail wind, side wind, or a head wind of not more than 7 mph (11 km/hr).
- b. direction of geostrophic wind: tail wind, side wind, or a head wind of not more than 6 mph (10 km/hr).
- c. precipitation: less than normal

D. late in the season (May 16), intervals of not more than 4 hr of unfavourable northwesterly winds at the staging ground during a period of favourable winds will not arrest major departures

E. in the middle of the season, intervals of not more than 3 hr of light (2.5 mph, 4 km/hr) head winds at the staging grounds during a period of favourable winds will not arrest major departures

F. in normal years, the birds prefer to take off from the staging grounds in the very early morning and the early evening. In abnormal years, when migration has been delayed by bad weather for a long time, massive departures can take place any time of the day or night. (This will be discussed in greater detail in the following section).

5. Discussion

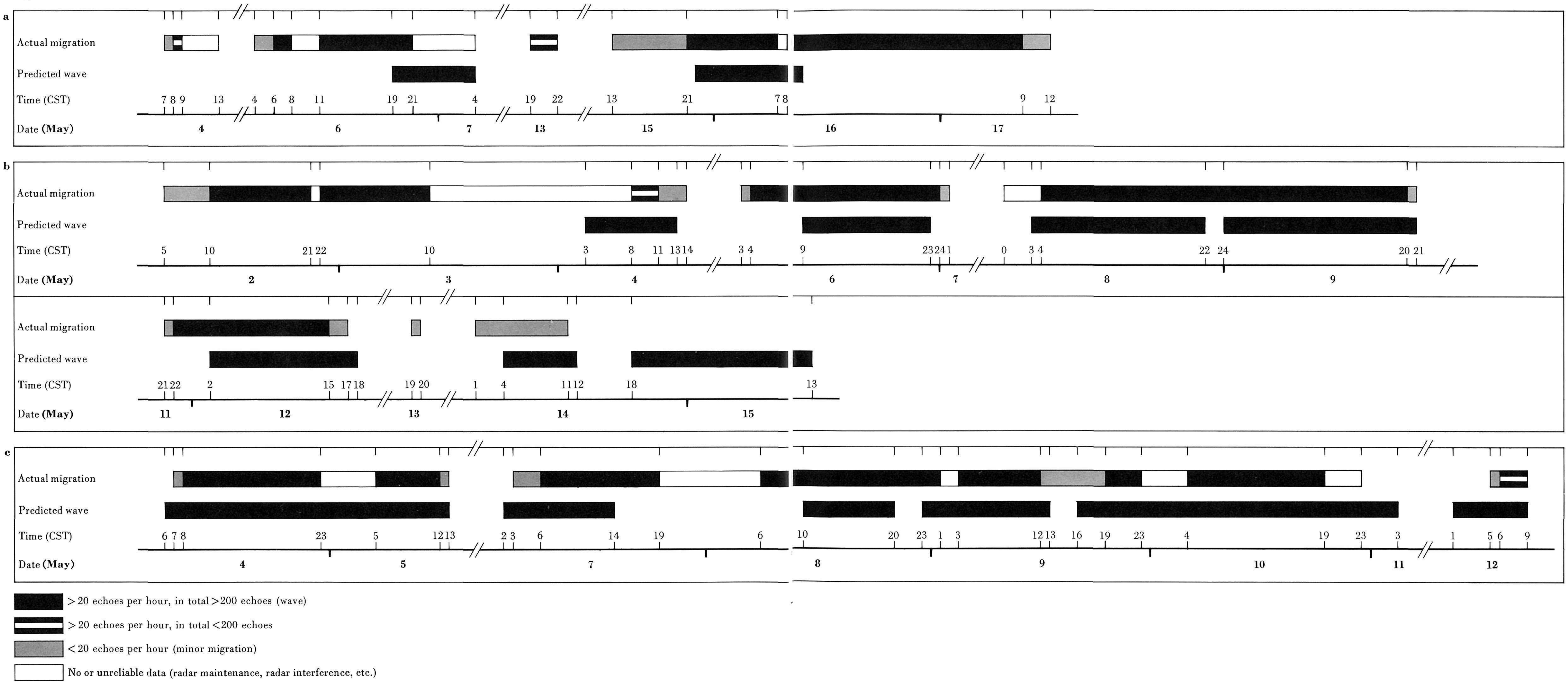
Initially, nine weather factors were used to predict the major waves of spring migration of snow geese. Although all nine weather factors were statistically significant with respect to heavy migration, we did not know which ones were of biological significance. The direction of the surface wind at Pilot Mound was assumed to be the most important factor. When we found that certain factors caused us to err seriously in our predictions, we eliminated or modified them. In this way we arrived at a simple forecast system that produced increasingly accurate results. The weather factors which gave the best prediction results were surface wind and precipitation both at Pilot Mound and at Winnipeg, and geostrophic wind at Winnipeg. However, we do not know whether the surface wind at the Pilot Mound staging area caused massive departures or if another associated meteorological factor was the main stimulus.

Major departures occurred with southeast winds at Pilot Mound. This happened on several occasions, and as snow goose migration with southeast winds had been reported in the literature as well, we changed the prediction model accordingly.

The forecast system was used to predict the periods during which large numbers of geese would move across the Winnipeg area. It could not be further refined to predict the numbers of flocks per unit surface area at a certain hour within that period. Typically, a wave gradually built up to a peak and then gradually subsided, although on some occasions the beginning or end of the wave was very abrupt. In order to get rid of the low-level beginnings and endings of waves and of all other low intensity movements, we decided that waves should have at least 20 "goose echoes" per hour and total over 200 "goose echoes". But even so, the hourly numbers of "goose echoes" varied from 20 to as many as 240. Furthermore, the geese appeared to have two preferred take-off periods: the very early morning (the first few hours after sunrise) and the early evening

Figure 5
Periods of actual and predicted major waves of spring snow goose migration over the Winnipeg area in (a) 1970, (b) 1971 and (c) 1972

Figure 5



(the last 2 or 3 hr before sunset). Numbers of "goose echoes" often peaked in the morning (between 0800 and 1200 hr), reached a low in the afternoon and peaked again in the late evening. Thus during waves lasting for one or more days, there were often a few peaks in numbers of "goose echoes".

The trend for the snow geese to take off in peak numbers at certain times of the day was more obvious in 1971 and 1972 than in 1970 when migration was unusually late, due to a long delay caused by very bad weather. Bellrose (1967) reported that snow geese appeared to depart from the Louisiana coastal marshes in the hours immediately following sunset. Our snow goose data for Manitoba fitted somewhat better with Bellrose's comments for Canada Geese: "Departures usually occur either in the hour before sunset and in the early hours of the night, or in the hour prior to sunrise and for 2 hours after sunrise". A flight safety leaflet issued by the Canada Department of Transport (undated) says that waterfowl migrating in spring normally leave the staging areas between dusk and midnight and during the first 3 hr after dawn, but that they may leave at any hour of the day or night, particularly after long periods of poor weather for migration.

We predicted heavy flights based on weather reports. Weather forecasts are usually less detailed than weather reports, and operational predictions of goose flights based on weather forecasts would therefore be less accurate. Also, weather forecasts can be wrong, and the accuracy of a migration forecast would be, at best, no higher than that of the weather forecast.

Another problem of the bird forecast system was that we did not know when the great majority of the geese had left the staging area so that no more major flights would occur. In operational practice, the staging area could be surveyed to determine the number of geese still present. Such surveys could be made after a few waves had occurred, and could be done on the ground or, more effectively, from the air. If we had had this kind of information for the springs of 1970, 1971 and 1972, we would have predicted heavy migration with greater accuracy.

Predicting bird migration over inland North America is not new. Sieh (1958) described the forecast and advent of mass migration of waterfowl through Iowa in the fall of 1957. Spring movements of waterfowl can be predicted as well, according to Bellrose (1967) who wrote: "The occurrence of specific movements of waterfowl northward in the spring can be reasonably predicted within the parameters of migration chronology.... A strong southerly airflow, produced by areas of low pressure to the west and high pressure to the east, appears to have the greatest influence on northward migration of waterfowl." This is in good general agreement with our findings for the spring snow goose migration.

Richardson and Gunn (1971) studied nocturnal passerine migration in the spring over east-central Alberta, and Richardson (1969) reported that "...once wind direction has been used to predict migration volume at Cold Lake, the use of other weather parameters does not seem to give a statistically improved predictive ability". Based mainly on the results of Richardson and Gunn, Blokpoel (1973) developed a simple system for forecasting migration densities at Cold Lake, Alberta. He used direction and speed of the wind at the surface and at the geostrophic level at Cold Lake and the extent and duration of precipitation over the Cold Lake area. This method was very crude and had several shortcomings. Yet it is used operationally at Canadian Forces Base Cold Lake, and low-level high-speed flying exercises at night can be restricted or cancelled when high migration densities are forecast.

At Cold Lake the same weather factors were used as in Winnipeg. These two locations, both in the northern part of inland North America, have a very similar climate. In regions with other climates and/or geographic features (such as the proximity of an ocean), other weather factors may be better predictors. Nisbet and Drury (1968), working in coastal Massachusetts and using multivariate statistics, found that the density of spring migration "was significantly correlated with high and rising temperature, low and falling pressure, low but rising humidity, and the onshore (southeast) component of the wind velocity". Able (1973) studied nocturnal passerine migration in the southeastern United States using multivariate statistics. He concluded that night-to-night variability in migration density could best be explained by wind direction, change in temperature and an index of the synoptic weather situation.

6. Operational feasibility of migration forecasts

An operational migration forecast system to reduce bird hazards to civil aircraft outside the airport boundary should be accurate, reliable, practicable and economical. Ideally, the method should predict the probability of a bird strike per take-off or landing. (Most commercial operators cruise well above the migrating geese and the strike risk is therefore limited to the climb-out and descent). Bird strike probabilities can be calculated if one knows the aircraft's frontal area and its angle of climb or descent, as well as the average dimensions of the flocks, their height distribution and their density (number of flocks over 1 sq mi or km). Such calculations have been made by Gunn and Cockshutt (1966), Speirs *et al.* (1971) and Hunt (1973b). Speirs and co-workers, for example, arrived at a strike probability of about 1 in 6,500 take-offs for a DC-8 leaving Thunder Bay, Ontario, during a heavy fall migration of geese (species unknown but most likely a mixture of Canada Geese and Lesser Snow and Blue Geese). These authors all assumed for their calculations that neither the pilot tried to avoid the birds nor the birds the aircraft.

In practice, the first assumption is more or less correct. Pilots of airliners are very busy during climb-out and descent and may not notice the birds at all. Even if the geese are seen there is little time for avoidance manoeuvres due to the speed and size of the aircraft. In addition other aircraft in the vicinity may preclude evasive action in the control zone. At night observations are impossible.

Regarding the second assumption (that geese do not try to avoid aircraft), very little is published on the behaviour of migrating geese with respect to approaching aircraft. Geese that sit on the ground or on the water are readily flushed by approaching light aircraft, as has often been observed during aerial waterfowl surveys. Migrating geese may well have a strong tendency to maintain their flight direction but they do try to avoid collisions with approaching aircraft. For example, Mr. Ball reported (pers. comm.) that when flying at the same height as, but in the opposite direction to numerous flocks of migrating snow geese, the birds always detoured around his light aircraft and then continued in their original direction. In a few cases, the flocks split in two parts and rejoined after the aircraft had passed. Bellrose (1973) studied nocturnal migration from a light aircraft fitted with an extra set of landing lights. Waterfowl tried to avoid his aircraft well ahead of time, whereas small passerines often made only a last-second attempt to avoid the plane. Although geese may be successful in dodging slow aircraft, their reactions are often too slow to avoid fast planes and many serious strikes with geese have been reported, including the one with a flock of snow geese near Winnipeg on May 12, 1969, which provided the impetus for the present study. In other words, the second assumption is probably not completely correct, and hence the calculated strike probabilities are likely to be slightly overestimated. Until bird behaviour with respect to approaching aircraft has been studied under a variety of conditions, it will be impossible to arrive at reliable predictions of absolute bird strike probabilities. Relative probabilities at different times, however, are less subject to this uncertainty.

Apart from the above considerations regarding the behaviour of the birds, our migration forecast results are much too general for calculating the bird hazard in terms of strike risk. We cannot predict the number of flocks over 1 sq mi (or km), nor their height distribution, nor the average flock dimensions (goose numbers and flock formation may vary considerably from flock to flock). Without an estimate of the risk of a collision with a flock of geese, our migration forecast would serve to alert pilots and air traffic controllers, but would not provide them with sufficiently precise information to decide on alternative flight procedures (e.g. changes in angle of climb or descent, use of other runways, or cancellation of incoming and outgoing flights). Furthermore, the number of geese staging in southern Manitoba, their staging areas and their migration routes are likely to vary somewhat from year to year, and thus affect the migration forecast results.

As far as practicality at the operational level is concerned, special air traffic control procedures dealing with the various levels of strike risk would have to be formulated. In addition, there would be a requirement for suitable technical staff.

The cost-effectiveness of operational migration forecasts would be hard to determine. However, once strike probabilities can be reliably calculated, the operational cost of the system together with the revenues lost by closing the airport for a certain number of hours or days could be compared with the average costs of a collision with a flock of geese (these costs are at the present unknown, but probably very high).

In summary, it seems possible to predict major waves of spring snow goose migration over the Winnipeg Terminal Control Area with reasonable accuracy and such predictions might serve to alert pilots and air traffic controllers. It is, however, not likely that this method can be sufficiently refined to be fully satisfactory in real-time operations.

In order to minimize the risk of goose strikes during climb-out or descent, it now appears that a warning system, describing the actual migration situation in sufficient detail for appropriate action, would be the answer. Such a system could be based on the use of radar. The AASR-1 and ASR-5 surveillance radars that are now in use at Winnipeg and at most other Canadian airports are capable of detecting airborne goose flocks, but do not provide their heights. Future surveillance radars will have the capability of detecting bird flocks, but will be programmed to suppress echoes from all targets except those from aircraft. It is debatable (Richardson, 1972, 1973) to what extent echoes from large flocks of birds can be eliminated from the radar screen without also removing the echoes of slow, light aircraft and helicopters. The bird information required for a warning system could be obtained with a specially designed "bird radar" (Hunt and Blokpoel, 1973) or by modifications of and/or additions to existing and future radars (Hunt, 1973a).

Summary

A. The chronology of spring migration of Lesser Snow and Blue Geese (snow geese) in the vicinity of Winnipeg was determined, the influence of the weather was examined and the results were used to develop a method for predicting major flights (waves of migration).

B. Records of visual observations of migrating snow geese for the period 1953–69 were obtained from several sources.

C. Visual observations of staging geese during 1970, 1971 and 1972 confirmed that the majority of snow geese in southern Manitoba concentrated between Cartwright and Windygates, with the largest numbers near Pilot Mound, Crystal City and Snowflake.

D. In the springs of 1970, 1971 and 1972, time lapse films were made of the scope of the AASR-1 surveillance radar at Winnipeg International Airport. Visual observations confirmed that the great majority of "goose echoes" were caused by migrating flocks of snow geese.

E. Twelve (52%) of the 23 waves during the 1953–69 period occurred in or just ahead of a warm sector, near or on the east side of an occluded front, or on the west side of a high. The other waves occurred under a variety of synoptic weather conditions.

F. Direction and speed of the surface wind and precipitation at Pilot Mound, precipitation, direction and speed of the surface wind at Winnipeg, and direction of the geostrophic wind over Winnipeg were significantly related to major waves of spring snow goose migration over the Winnipeg area. In addition, the temperature and relative humidity at Winnipeg were significantly related to the progression of the migration season.

G. These nine weather factors were used in a simple model to predict waves of spring snow goose migration for 1970, 1971 and 1972. All predictions were based on weather reports rather than weather forecasts. Predictions for 1970 were checked against the 1970 radar data. Weather factors that caused large errors in the predictions were omitted or modified, and the revised model was used on the 1971 data. The model was further revised and used on the 1972 data.

H. The following five weather factors appeared most useful for predicting spring migration: direction of surface wind and precipitation at Pilot Mound, and direction of surface wind and of geostrophic wind and precipitation at Winnipeg.

I. The accuracy of the migration predictions improved for each year and for 1972 85% of all hours of actual heavy migration were predicted, while 75% of all hours of predicted heavy migration materialized.

J. Shortcomings and operational feasibility of the forecast model are discussed. Migration predictions could serve to alert pilots and air traffic controllers in a general way, but were too crude to allow calculations of bird strike probabilities. A real-time operational system to prevent collisions during climb-out and descent would require additional information on the three-dimensional distribution of the bird flocks. Such information can be obtained by specialized equipment.

Literature cited

Able, K. P. 1973. The role of weather variables and flight direction in determining the magnitude of nocturnal bird migration. Ecology 54:1031–1041.

Bagg, A. M., W. W. H. Gunn, D. S. Miller, J. T. Nichols, W. Smith and F. P. Wolfarth. 1950. Barometric pressure-patterns and spring bird migration. Wilson Bull. 62:5–19.

Bellrose, F. C. 1967. Establishing certain parameters of hazards to aircraft by migrating birds in the Mississippi Flyway. U.S. Department of the Interior, Bureau of Sports Fisheries and Wildlife, Washington, D.C. 74 p.

Bellrose, F. C. 1968. Waterfowl migration corridors east of the Rocky Mountains in the United States. Illinois Natur. Hist. Surv. Biol. Notes No. 61. 24 p.

Blokpoel, H. 1973. Bird migration forecasts for military air operations. Can. Wildl. Serv. Occas. Paper No. 16. 12 p.

Blokpoel, H. 1974. Migration of Lesser Snow and Blue Geese in spring across southern Manitoba. Part 1. Distribution, chronology, directions, numbers, heights and speeds. Can. Wildl. Serv. Rep. Ser. No. 28. 30 p.

Canada Department of Transport. Meteorological Branch. 1966. Weather ways. Third edition. Queen's Printer, Ottawa. 145 p.

Canada Department of Transport. Civil Aviation Branch. 1967. Air traffic control manual of equipment, part I. Radar. 254 p.

Canada Department of Transport. Meteorological Branch. 1968. Diurnal variation of dry and wet bulb temperatures at selected stations. CDS No. 2-68. 15 p.

Canada Department of Transport. Undated. Bird hazard to aircraft. Information booklet. 11 p.

Curtis, S. G. 1969. Spring migration and weather at Madison, Wisconsin. Wilson Bull. 81:235–245.

Gunn, W. W. H. and E. P. Cockshutt. 1966. Bird strike probability: strike predictions using observed bird density data. National Research Council of Canada, Associate Committee on Bird Hazards to Aircraft, Field Note 30 (revised). 13 p.

Hochbaum, H. A. 1967. Travels and traditions of waterfowl. Third printing. University of Minnesota Press, Minneapolis. 301 p.

Hunt, F. R. 1973a. Bird height finding radar — another look. Memorandum to the Associate Committee on Bird Hazards to Aircraft, National Research Council of Canada. 12 p.

Hunt, F. R. 1973b. Probability of a bird strike on an aircraft. National Research Council of Canada, Associate Committee on Bird Hazards to Aircraft, Field Note 62. 8 p.

Hunt, F. R. and H. Blokpoel. 1973. A bird height finding radar for air traffic control. A progress report. National Research Council of Canada, ERB-873. 20 p.

Kortright, F. H. 1967. The ducks, geese and swans of North America. Third edition. The Stackpole Co., Harrisburg, Pa. 476 p.

Lack, D. 1960. The influence of weather on passerine migration. A review. Auk 77:171–209.

Lawrence, A. G. 1953. Chickadee Notes 1675, Winnipeg Free Press, June 26, 1953.

Mossop, H. 1956. Chickadee Notes 72. Winnipeg Free Press, June 1, 1956.

Mossop, H. 1959. Chickadee Notes 228. Winnipeg Free Press, May 29, 1959.

Mossop, H. 1961. Chickadee Notes 331. Winnipeg Free Press, May 20, 1961.

Nero, R. W. 1962. Migration report for the Northern Great Plains Region. Audubon Field Notes 16:423–426.

Nisbet, I. C. T. and W. H. Drury, Jr. 1968. Short-term effects of weather on bird migration: a field study using multivariate statistics. Animal Behaviour 16:496–530.

Raynor, G. S. 1956. Meteorological variables and the northward movement of nocturnal land bird migrants. Auk 73:153–175.

Richardson, W. J. 1966. Weather and late spring migration of birds into southern Ontario. Wilson Bull. 78:400–414.

Richardson, W. J. 1969. Temporal variations in the volume of bird migration: a radar study in Canada. Proc. World Conference on Bird Hazards to Aircraft, Queen's University, Kingston, Ontario. p. 323–334.

Richardson, W. J. 1972. Temporal variations in the ability of individual radars in detecting birds. National Research Council of Canada, Associate Committee on Bird Hazards to Aircraft, Field Note 61. 57 p.

Richardson, W. J. 1973. Radar 'angels'. Aviation Week and Space Technology 99(22):76 (26 November 1973).

Richardson, W. J. and W. W. H. Gunn. 1971. Radar observations of bird movements in east-central Alberta. p. 53 to 68 *in* Studies of bird hazards to aircraft. Can. Wildl. Serv. Rep. Ser. No. 14.

Richardson, W. J. and M. E. Haight. 1970. Migration departures from starling roosts. Can. J. Zool. 48:31–39.

Schüz, E. 1971. Grundriss der Vogelzugskunde. Second edition. Verlag Paul Parey, Berlin. xii + 390 p.

Sieh, J. G. 1958. The forecast and advent of mass migration of waterfowl through Iowa in the fall of 1957. Iowa Bird Life 28:2–4.

Solman, V. E. F. 1969. Photography in bird control for air safety. J. Biol. Photogr. Assoc. 37:152–155.

Speirs, J. M., J. J. C. Kanitz and J. Novak. 1971. Numbers, speeds and directions of migrating geese from analysis of a radar display at Fort William, Ontario. p. 69–76 *in* Studies of bird hazards to aircraft. Can. Wildl. Serv. Rep. Ser. 14.

Appendices

Appendix 1
Identity of the "goose echoes"

Arguments that the "goose echoes" represented flocks of migrating snow geese were based on (1) simultaneous observations made at the ATC tower of "goose echoes" and the bird flocks that caused them (1970, 1971 and 1972), (2) the close agreement between the occurrence of "goose echoes" and sightings of migrating snow geese (1970, 1971 and 1972), (3) the almost total absence of other bird species that could have produced the "goose echoes" (1970, 1971 and 1972) and (4) the identification of "goose echoes" by an observer in a light aircraft that was vectored to the flocks by ATC personnel (1972).

The arguments 1, 2 and 3 for the years 1970 and 1971 were presented by Blokpoel (1974), who concluded that more than 90% of the "goose echoes" were indeed caused by snow geese.

From April 27 through May 10, 1972, W. Gemmell made routine visual observations from the Winnipeg ATC tower using binoculars and a 40X telescope. When time permitted he observed the radar screen at the ATC tower and noted whether or not the migrating flocks produced big bird echoes. At least 125 flocks (out of a total of 187 flocks seen) produced big echoes; the other 62 flocks probably produced "goose echoes" as well but either they were obscured by ground clutter or Gemmell did not have sufficient time to check them. The correlation between radar and visual observations could not be carried out quantitatively for technical and organizational reasons (Blokpoel, 1974).

Of the 187 flocks seen by Gemmell from the ATC tower, many were too far away to be identified. In some cases, birds were tentatively identified as snow geese because of the characteristic flock pattern of the species (Kortright, 1967). Identification of the flocks, their estimated directions and their radar presentation are given in Table 10. This table shows that of the 77 identified flocks flying in an estimated direction between east and north, 74 were snow geese and 3 were gulls. Of the 156 flocks that were definitely or tentatively identified as snow geese, 15 flew in directions between north and west. We do not know if these flocks were actually migrating in a northwesterly direction or were detouring the airport to avoid local air traffic.

From 1200 to 1400 hr on May 7, 1972, a Cessna 172 was vectored by ATC personnel to targets that caused "goose echoes" on their radar screen. A total of 54 target identification requests were made. In 48 (89%) cases, R. Hutchinson, the CWS observer on the aircraft, identified the targets as snow geese.

In 1972, as in 1970 and 1971, there was very close agreement between radar data and visual observations made in and around Winnipeg. (A table with 181 records of more than 965 flocks observed in 1972 in Manitoba and Ontario is deposited in the libraries of the CWS regional head offices. See "Methods and materials" section.)

From these observations we concluded that in 1972, as in 1970 and 1971, the great majority of the "goose echoes" were caused by migrating snow geese.

Table 10
Numbers of flocks, their identification and estimated direction as observed from the Winnipeg Air Traffic Control tower, May 4–10, 1972

	Visual observations				Radar observations
		Estimated directions			
Identification	No. of flocks	N to E	W to N	Unknown	No. of big bird echoes
Definitely snow geese	91	74	15	2	61
Probably snow geese	65	64	0	1	48
Canada geese	2	0	2	0	1
Mixture of Canada and snow geese	1	0	1	0	1
Unidentified waterfowl	21	21	0	0	14
Loons	3	0	3	0	
Whistling Swans	1	0	1	0	
Gulls	3	3	0	0	
Totals	187	162	22	3	125

Appendix 2
Dates of known spring migration of snow geese across southern Manitoba, 1953 through 1969

Year	Date	Time (CST)	Location	Volume of migration	Direction of migration	Source
1953	May 4	All day & into the night	St. Vital (a Winnipeg suburb)	"many flocks, 4,500 birds"	"east"	Shortt (pers. comm.)
	May 6	Morning, afternoon	St. Vital	"many flocks, 5,000+ birds	"north"	Shortt (pers. comm.)
	May 4–6		Greater Winnipeg	"the main flight"	"northeast"	Lawrence (1953)
1956	May 12	Morning, night	St. Vital	"many flocks, 4,000–5,000 birds"	"northeast"	Shortt (pers. comm.)
	May 12	Night	Winnipeg	"flock after flock"	—	Mossop (1956)
	May 12	Morning & mid-afternoon	Delta (50 mi WNW of Winnipeg)	More than 2,500 birds	"northeast"	Migration files at Delta Waterfowl Research Station
	May 14	Morning	St. Vital	3 flocks, 600 birds	"east"	Shortt (pers. comm.)
	May 14	Morning & early afternoon	Winnipeg and vicinity	14 flocks, 3,125 birds	—	Copland (pers. comm.)
1959	May 7	Morning & night	Winnipeg and vicinity	Several thousand geese	N	Mossop (1959)
1961	May 7	Morning	St. Vital	8 flocks, 1,000 birds	"northeast"	Shortt (pers. comm.)
	May 7	1030–1150	Winnipeg	3 flocks, 1,100 birds	"NNE"	Smith (pers. comm.)
	May 12	Daytime	Winnipeg	"scattered flocks"	"northeasterly"	Mossop (1961)
	May 13	Morning	Winnipeg	"flock after flock" thousands of birds	"northeasterly"	Mossop (1961)
1962	May 12	1145–1400	Winnipeg	9,000 birds	—	Nero (1962)
	May 15	2245	Winnipeg Terminal Control Area	"large flocks of waterfowl"	—	Logbook Air Traffic Control Room, Winnipeg Airport
1963	May 2	Daytime	Wawanesa (110 mi W of Winnipeg)	"thousands"	—	Hosford (pers. comm.)
	May 6	Daytime	Stonewall (15 mi N of Winnipeg)	1,300 birds	—	Hosford (pers. comm.)
	May 14	1700–2100	Headingley (3 mi W of Winnipeg)	100,000 birds	"NE"	Hosford (pers. comm.)
1964	May 5	Probably all day	Winnipeg to Treesbank (110 mi E of Winnipeg)	"large numbers, major flight"	—	Hosford (pers. comm.)
	May 6–9	Day & night	Winnipeg and vicinity	"light but steady movements"	—	Hosford (pers. comm.)
	May 8	0900–1000	Stonewall	2,000 to 3,000 birds	"NE"	Copland (pers. comm.)
	May 10	All day	Winnipeg and vicinity Dog Lake (75 mi N of Winnipeg)	"peak migration"	—	Hosford (pers. comm.)
1965	May 10	"all day & well into the night."	Winnipeg and vicinity	"peak migration"	—	Hosford (pers. comm.)
	May 10	1900–2100	Winnipeg	10,000 birds	—	McNicholl (pers. comm. to Copland)
	May 11	Morning	Winnipeg	6 flocks, 700 birds	—	Hosford (pers. comm.)
	May 11	1103	Winnipeg Terminal Control Area	"waterfowl migrating"	—	Notam 145A, Air Traffic Control Tower, Winnipeg Airport
1966	May 16	1410	Winnipeg and vicinity	"heavy waterfowl migration"	—	Notam 183A, Air Traffic Control Tower, Winnipeg Airport
	May 16	1520–1830	Stonewall	7,300 birds	"NE"	Gardner (pers. comm.)
1967	May 11	—	Winnipeg and vicinity	Possibly a heavy flight	—	Hosford (pers. comm. to Lumsden)
	May 13	0700–0900	Stonewall	"several flocks, 1,700 birds"	"NE"	Gardner (pers. comm.)
	May 16	0800	—	Heavy waterfowl migration	—	Logbook Air Traffic Control Room, Winnipeg Airport

cont'd. on page 28

Appendix 2, cont'd.

Year	Date	Time (CST)	Location	Volume of migration	Direction of migration	Source
1968	May 9	Morning	St. Vital	"many flocks, 5,000 birds"	"ENE"	Shortt (pers. comm.)
	May 9	Evening & night	Stonewall	"thousands of birds"	"N"	Gardner (pers. comm.)
1969	May 3	—	Whitemouth (about 50 mi E of Winnipeg)	"light migration"	—	Blanchard (pers. comm.)
	May 5	—	Whitemouth	"heavy migration"	—	Blanchard (pers. comm.)
	May 6	—	Richer (22 mi ESE of Winnipeg)	"heavy migration"	—	McIvor (pers. comm.)
	May 6	—	Morris–Marchand (30 mi S and SE of Winnipeg)	"first major migration"	—	Bidlake (pers. comm.)
	May 11/12	Night	Winnipeg	Unknown (heard only)	—	Townsend (pers. comm.)
	May 12	0645–0720	Winnipeg	"10,000 birds"	—	Nero (pers. comm.)
	May 12	—	W of Steinbach (22 mi SE of Winnipeg)	"second major migration"	—	Bidlake (pers. comm.)
	May 12	Morning	Shoal Lakes and Fischer Branch (40 and 82 mi NNE of Winnipeg)	About 2,600 birds	—	Townsend (pers. comm.)

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