THE METEOROLOGY OF LAKE HAZEN,

ELLESMERE ISLAND, N.W.T.

based on observations made
during the International
Geophysical Year 1957-58

by

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Figure 1.
Frontispiece

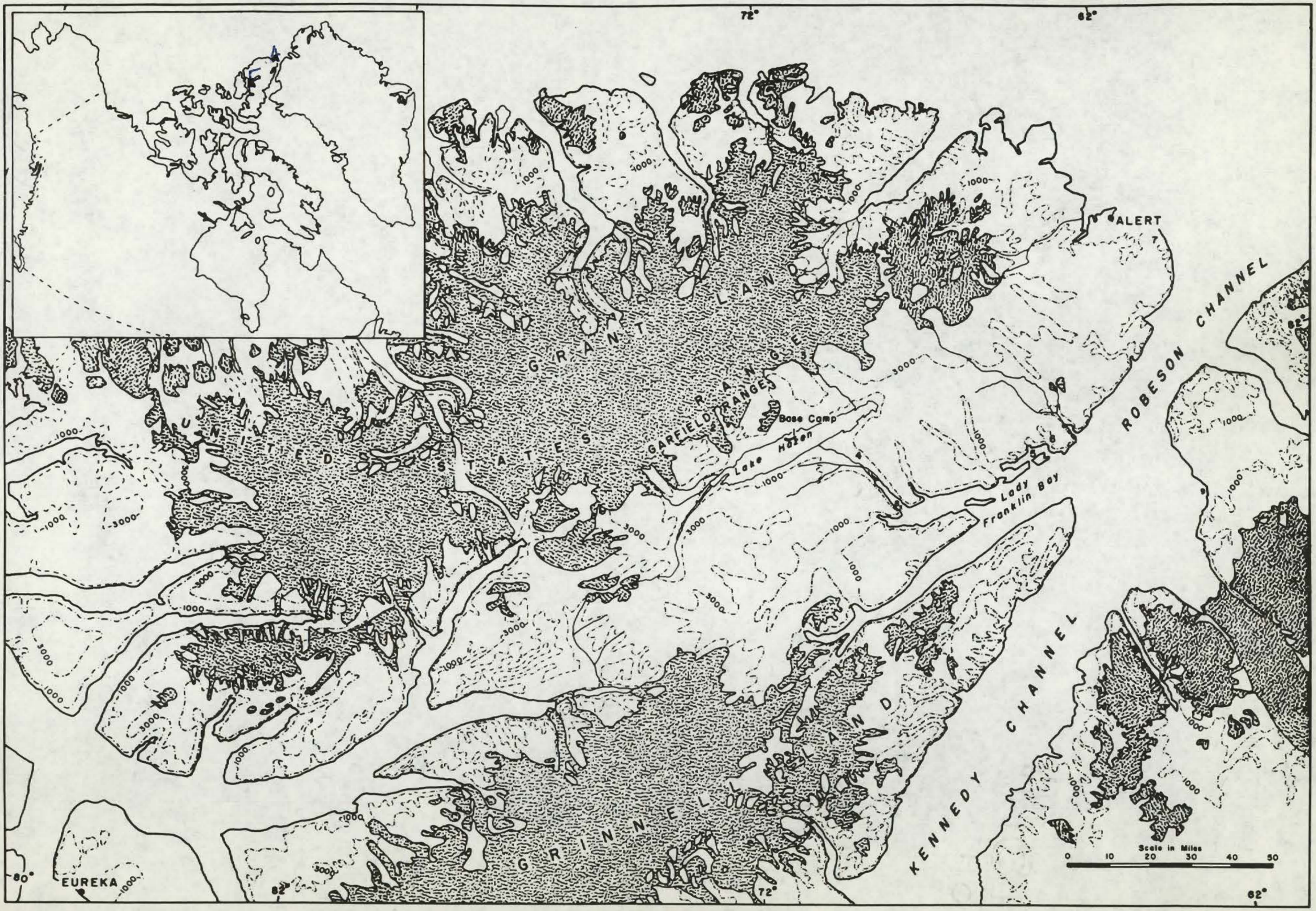
LOCATION MAP.

The positions of Alert and Eureka are indicated on the inset map of Arctic North America by initials.

Land-ice areas are stippled.

Key to locations on the main map:

1. John's Island.
2. Henrietta Nesmith Glacier.
3. Gilman Glacier.
4. Ruggles River.
5. Discovery Harbour.
6. Fort Conger.
7. Floeberg Beach.
8. Chandler Fiord.
9. Thank God Harbour, Polaris Bay.



GRANT LAND
UNITED STATES RANGE
GARFIELD RANGE
GRINNELL LAND
ROBESON CHANNEL
KENNEDY CHANNEL
ALERT
EUREKA
Base Camp
Lake Hazen
Lady Franklin Bay
Scale in Miles
0 10 20 30 40 50
72°
62°
82°
80°
1000
3000

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She told me that in the "Arctic Regions", as they call some places a long way north, where the Great Bear lies all across the heavens, and no sun is up, for whole months at a time, and yet where people will go exploring, out of pure contradiction, and for the sake of novelty, and love of being frozen - that here they always had such winters as we were having now. It never ceased to freeze, she said; and it never ceased to snow; except when it was too cold; and then, all the air was choked with glittering spikes; and a man's skin might come off him, before he could ask the reason. Nevertheless the people there (although the snow was fifty feet deep, and all their breath fell behind them frozen, like a log of wood dropped from their shoulders), yet they managed to get along, and make the time of the year to each other, by a little cleverness.

R. D. Blackmore, Lorna Doone.

PREFACE

This is the first of two studies of the weather and climate of the Lake Hazen area. The basis for the work is the records of surface weather which were collected there between August 1957 and August 1958 as part of the Canadian International Geophysical Year Expedition to the area. The present account considers these observations and their implications. It is hoped to follow it with a study of the synoptic climatology of Northern Ellesmere during the same period, and to complete the work with a local forecast study of the Lake Hazen area. In this first part synoptic conditions are discussed only by implication; no synoptic map appears in the report and none were used in its preparation. To this extent, therefore, some of the conclusions drawn from the observations are liable to be modified later when synoptic conditions have been taken into consideration; this later study is the only justification for their present omission. Certain aspects of the climate, in particular the magnitude and importance of the diurnal fluctuation, receive little attention here but are being analysed by J. M. Powell as part of his study of the bioclimatology and plant ecology of the area.

Unlike similar reports from many other expeditions, the actual observations are not reproduced here. Instead the various elements have been analysed separately to bring out what appeared to the writer to be the most significant features. In this respect frequent comparisons have been made with conditions at Alert and Eureka during the same period. Those requiring the actual record will find it on microfilm at the Canadian Meteorological Branch in Toronto.

First among the acknowledgments must be my thanks to the Defence Research Board of Canada, sponsors of the expedition, for enabling me to take part in such a happy and rewarding enterprise. I am grateful to Dr. H. Appleman, Dr. G. Hattersley-Smith and the McGraw-Hill Book Co. Inc. for permission to reproduce Figs. 24 , 13 , and 4 respectively. The Meteorological Branch have given much assistance, particularly by the provision of the synoptic data from Alert and Eureka. I acknowledge with thanks the advice of Mr. B. Sagar, whose study of glacial-meteorological conditions on the Gilman Glacier will appear shortly. Miss Mona Macfarlane and Miss Cynthia Wilson contributed advice on statistical technique. My thanks also go to Mrs. B. Knill and Miss Pamela Russell for their care in the final typing and the re-drawing of the illustrations respectively. Miss Nora Corley, Librarian of the Arctic Institute of North America gave much assistance in tracing copies of some of the references in Chapter I. My debt to Dr. Svenn Orvig of McGill University at all stages of this work has been very great.

My greatest debt of thanks, however, is to my three colleagues, C. R. Harington, J. M. Powell and D. I. Smith who, with myself, were responsible for collecting the observational data at Lake Hazen. The care which they devoted to this work has made the task of analysis much easier; I can only trust that this report justifies their efforts.

C. I. J.

CHAPTER I

PREVIOUS METEOROLOGICAL RECORDS FROM THE VICINITY OF NORTHERN ELLESMERE ISLAND

Until the last decade or so, scientific material concerning the Queen Elizabeth Islands has been derived almost entirely from the work of expeditions. Some of these, it is true, went to the area only in attempts to discover new lands, to traverse the mythical "open polar sea", or to reach the North Pole itself, but several expeditions also made careful and detailed scientific observations. At least two such meteorological records are still of interest and value in the study of the climate of the northern part of Ellesmere Island.

The credit for the discovery of Ellesmere Island in the modern era is usually given to William Baffin and his ship the "Discovery" which, in 1616, reached the southern end of Smith Sound in latitude 77° 22' N. and then went on to discover Lancaster and Jones Sounds further south. This amazing voyage, in a ship of only 55 tons, was not repeated until 1818, when Cdr. John Ross followed a similar route with H.M.S. "Isabella" and "Alexander".[1]

[1] Much of the material in this chapter is based on Taylor's memoir on "Geographical Discovery and Exploration in the Queen Elizabeth Islands." (52) which, as with his account of the physical geography of the area, contains an excellent bibliography. References to the meteorological literature are based on a study of the works cited. The sites of some of the bases and winter quarters will be found on the Location Map, Fig.1.

Meanwhile Baffin's claims to discovery had become generally discredited; Barrington's map (5), with its inscription "Baffin's Bay, according to the relation of W. Baffin in 1616, but not now believed", actually appeared while Ross was at sea.

For the most of the nineteenth century, interest in what was to become the Canadian Arctic focussed primarily on the search for the Northwest Passage, both directly and also indirectly through the Franklin Search expeditions. Sustained interest in Ellesmere Island did not come until attempts to reach the North Pole succeeded the quest for the Passage. Parry and Franklin both used Lancaster Sound as their route into the islands. Of the many relief expeditions sent in search of Franklin, which contributed so much to geographical knowledge, only two ventured into Smith Sound. Commander E. A. Inglefield reached a latitude of 78° 21' N. in August 1852, but then immediately returned south and passed into Lancaster Sound. Much more important was the expedition sent by the United States Navy under the command of Dr. E. K. Kane, 1853-55. Kane believed that Franklin had turned northwards up Wellington Channel on the west side of Devon Island, and had become trapped by ice in the polar sea. Kane's belief that the Smith Sound route would lead to this open polar sea was incorrect, but his small party of eighteen men not only opened up what Peary later termed "the American route to the Pole" but undertook a series of detailed scientific observations for a considerable period after the "Advance" became frozen in the ice of Van Rensselaer Bay, Greenland, at the northern end of Smith Sound, 78° 37' N. 70° 53' W. Although Taylor quotes Kane as saying that "there never was, and I trust never will be, a party worse armed for the encounter of a second Arctic winter"[1] they were well provided with scientific equipment. The discussion of the record which was published later by the Smithsonian Institution (37) remarked that the party possessed thirty-six mercurial thermometers from the National Observatory in Washington, together with four maximum and four minimum thermometers and no fewer than two dozen spirit thermometers, including two standards with registers 36 inches long. Although these thermometers were not so accurate as those of today, particularly at low temperatures, this was recognised at the time and considerable care was taken to correct the errors. Even in more recent times, the thermometers used in the Antarctic at Little America III in 1940 were such that temperatures could not be measured more accurately than to within 2° F. (23)

The admiration which may be felt for the hourly record of temperature so faithfully maintained from September 1853 until January 1855 can be extended to the wind record also, although here no anemometer was available and wind speed was estimated according to a scale similar to the Beaufort scale. Pressure was also measured, and notes made of precipitation type

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[1] He could not see into the future and contemplate the horrors of Greely's third winter at Cape Sabine.

and amount, together with incidental details of such features as optical phenomena and the strength of light during the winter.

As the meteorological records of the expedition are fairly easy of access, in the Contributions to Knowledge of the Smithsonian Institution, only a short abstract is presented here. It should be noted that Taylor's remark (52, p.58) that after August, 1854, "Kane's expedition lost all connection with science and exploration and devoted all its efforts to the struggle for survival" is not true of the meteorological programme which continued until January 1855. It is also important to note that although Schott (who was responsible for the analysis of the results) discussed the records in the belief that wind directions had been referred to Magnetic North, he later discovered that they were taken in the True directions. As True North is approximately East-Southeast Magnetic, this has a considerable effect on the records.

Table I

Mean Monthly Temperatures at Van Rensselaer Harbour
78° 37' N., 70° 53' W. (°F.)

1853	Sept.	17.16	1854	Jly.	38.19
	Oct.	1.62		Aug.	31.82
	Nov.	- 22.39		Sep.	9.74
	Dec.	- 25.46		Oct.	- 8.78
1854	Jan.	- 29.21		Nov.	- 21.52
	Feb.	- 32.65		Dec.	- 36.79
	Mar.	- 36.79	1855	Jan.	- 27.23
	Apr.	- 7.69		Feb.	- 20.22
	May	13.45		Mar.*	- 32.98
	Jun.	30.12		Apr.*	- 13.01

* taken at sea after leaving Van Rensselaer Harbour

Schott summed up the wind records in the words "The calms greatly predominate, there being during the year more hours of calm (5063) than of wind from any direction (3697) - a circumstance quite characteristic of the locality." (37)

The next expedition to the area was that led by Dr. Israel Hayes in 1860-61. Its purposes were not, however, to join in the search for Franklin but, in the words of the foreword to the scientific results of the expedition (33) were

> to extend the exploration of Dr. Kane towards the north and to make such observations of a scientific character as might tend to increase the existing knowledge of the Physical Geography, Meteorology and Natural History of the region within the Arctic Circle, including the coasts and islands on either side of Smith's Straits". (p.viii)

Behind this lay Hayes' intention to prove the existence of the open polar sea. Like Kane's expedition, their ship "United States" wintered on the west coast of Greenland at Port Foulke in latitude 78° 18' N., 73° 00' W., "twenty miles south of the latitude of Rensselaer Harbour..... and distant from it by the coast line about fifty-five statute miles." (33, p. viii)

Like Kane also, Hayes ensured that a detailed programme of meteorological observations were carried out at Port Foulke, and the results were again discussed by C. A. Schott in the Smithsonian

Contributions to Knowledge. The principal feature which emerged from a comparison of the two records was the much greater mildness of Port Foulke. One might at first be tempted to attribute this merely to the vagaries of weather from year to year, but Schott's explanation seems both reasonable and significant:

> "The locality may be said to be, climatologically, an anomalous one, as it is fully under the immediate influence of the upper north water and the smaller water areas of Smith Strait. The sea, here, does not freeze over entirely during the winter, but presents large patches of open water which exercise a powerful influence over the climate of this region. Dr. Hayes remarked that during the winter of 1860-61, the open sea could always be found a few miles to the westward of his anchorage........ This contrast in climate cannot be better illustrated than by stating the fact of the temperature simultaneously recorded on March 18, 19, 20, 21 1861 at Port Foulke and at Van Rensselaer Harbour, then revisited by Dr. Hayes, at the former place it was -24°.7 and the latter -50°.7 as observed by him........" (33, p.167)

Schott was correct in terming this the upper north water, although the existence and exact location of this relatively ice-free area later became confused. Dunbar (26, pp.58-9) pointed out that the "north water" was sometimes referred to in the literature as existing in the northern part of Baffin Bay, and at other times as being in the southern part of Smith Sound. It was in the latter area that Hayes encountered it, as did the present author during the Lake Hazen expedition. Flying across Smith Sound towards Bache Peninsula in late May 1958, the author observed that the sea was practically clear of ice over an area of many square miles, with only an occasional iceberg. This was a year which was bad for navigation along the Smith Sound route and, when the Lake Hazen party returned south on board the U.S.S. "Atka" the following August, considerable difficulty was experienced in breaking through drift ice in the same general area.

The scientific equipment of the Hayes expedition was similar to that taken by Dr. Kane. The expedition carried about two dozen thermometers of different kinds and according to Schott:

> ..... near the (magnetic) observatory a suitable shelter was also erected for the thermometers. These....... were mostly filled with spirits of wine..... (and) were observed, with the other instruments, each hour during the whole twenty-four every seventh day, and three times a day in the interval. In addition to these observations the temperature was noted every second hour by a thermometer suspended from a pole on the ice."' (33)

Table II
Mean Temperature Port Foulke 78° 18' N., 73° 00' W. 1860-61
(°F.)

1860	Sep.	22.56
	Oct.	7.46
	Nov.	- 2.96
	Dec.	- 13.18
1861	Jan.	- 25.97
	Feb.	- 24.63
	Mar.	- 22.41
	Apr.	- 9.95
	May	+ 24.81
	Jun.	34.52
	Jly.	40.53
	Aug.	(36.07)

Lowest temperature - 45.4, January 25; highest temperature + 61.0, July 5. The "United States" reached Port Foulke on September 3 1860 and broke free on July 14; Schott used the figures taken on board, duly corrected, to assist in estimating the means for July and August.

Table III
Seasonal Mean Temperatures

	Port Foulke 78° 18' N. 73° 00' W.	Van Rensselaer Harbour 78° 37' N., 70° 53' W.
Spring	- 3.19	- 10.59
Summer	(+ 36.82)	+ 33.38
Autumn	- 11.01	- 4.03
Winter	- 21.22	- 28.59
Year	+ 5.86	- 2.46

Schott says that northeast winds were observed 47 per cent of the time, calms 27 per cent, southwest winds 17 per cent and winds from other directions averaged 1½ per cent.

The first expedition to winter in the approximate latitude of Lake Hazen was the expedition in the steamer "Polaris" 1871 - 3. This was organised by C. F. Hall in an attempt to reach the North Pole. The expedition met with little but misfortune. Hall himself died of apoplexy soon after arriving at the winter quarters in Thank God Harbour, Polaris Bay, on the west coast of Greenland, 81° 36' N., 62° 15' W., and the ship was nipped by the ice and eventually had to be abandoned close to the sites of the Kane and Hayes expeditions' winter quarters the following year.

Like these other expeditions, however, the party at Polaris Bay made detailed scientific observations and a similar abstract of temperature is presented in Table IV.

Table IV
Temperatures at Polaris Bay, Greenland 81° 36' N., 62° 15' W.
1871 - 2
(°F.)

	Max.	Min.	Mean.
1860 Sep.	31.0	- 14.1	-23.25
Oct.	16.0	- 19.0	- 1.37
Nov.	15.1	- 25.9	- 8.65
Dec.	15.6	- 30.3	- 15.79
1861 Jan.	4.4	- 45.5	- 22.23
Feb.	6.8	- 42.4	- 23.28
Mar.	4.6	- 45.2	- -23.47
Apr.	19.6	- -33.2	- 7.77
May	32.6	- 9.7	16.81
Jun.	48.6	25.6	36.44
Jly.	53.0	32.4	39.58
Aug.	52.4	25.6	35.91

The wind record obtained by anemometric measurements, instead of by estimation, showed an interesting preponderance of winds from the directions between north and northeast. [1]

The records discussed in the accounts of these expeditions, while interesting and also valuable to a limited extent, are from areas to the south of northern Ellesmere Island, or from the Greenland coast, or both.

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The scientific results of this expedition (6) are as interesting and rewarding of study as those from the earlier expeditions. The Arctic Bibliography reference (53, entry 18,388), which lists a copy in the Hydrographic Office of the U.S. Navy, is apparently incorrect. With the help of the Librarian of the Arctic Institute of North America, however, a copy was eventually found in the library of Dartmouth College, Hanover, N.H. This, unlike the copy in the Library of Congress, is available for loan.

However the two expeditions which followed them up the Smith Sound route, the British Admiralty expedition under Nares and the American Polar Year expedition (also known as the Lady Franklin Bay expedition) led by Greely, both wintered on the Ellesmere coast north of 80° latitude, and the records from the "Discovery" and from Fort Conger are of considerable relevance to the consideration of the climate at Lake Hazen.

The purpose of the Nares expedition was clearly set out in his sailing orders by the Admiralty: "..... the scope and primary object..... should be to attain the highest northern latitude, and, if possible, to reach the North Pole, and from winter quarters to explore the adjacent coasts....." (46, p.xi) The quest for the Pole was all-important, and it is not therefore surprising that the greater part of Nares' account (46) was devoted to the exploration from H.M.S. "Alert", which wintered at Floeberg Beach, not far from the present site of Alert weather station. Nares' second ship, the "Discovery" had, however, been left behind in Lady Franklin Bay (Discovery Harbour), in case the "Alert" was nipped by the ice in her adventurous journey northwards. This was a wise precaution, as even today icebreakers rarely attempt to reach Alert through Robeson Channel, but it did relegate the "Discovery" to a minor role in the expedition. This was keenly felt at the time by the crew, and compared to the considerable literature concerning the "Alert", the only comprehensive account of the events in Discovery Harbour is contained in Captain Stephenson's log, sent to Nares on the "Alert" as opportunity arose, and later printed in the volume (LVI) of the Parliamentary papers of 1877 (30) devoted to the expedition.[1]

The monthly means and extremes from Discovery Harbour are collected in Nares' account (46 pp. 354-5) and are reproduced here, with the data from the "Alert" Floeberg Beach as a comparison.

Table V

Temperature at Discovery Harbour 81° 45' N., 65° W.
and Floeberg Beach 82° 25' N., 61° 30' W.
(°F.)

	Discovery Harbour			Floeberg Beach		
	Max.	Min.	Mean	Max.	Min.	Mean
Aug. 1875-6	41.0	26.0	32.72	44.0	24.5	31.9
Sep. 1875	43.0	2.4	18.5	36.5	- 0.2	15.6
Oct.	21.5	- 39.0	- 9.8	21.2	- 32.2	- 5.0
Nov.	19.0	- 46.0	- 18.4	23.0	- 45.7	- 16.8
Dec.	26.0	- 54.0	- 24.5	35.0	- 46.5	- 22.1
Jan. 1876	- 13.0	- 63.0	- 40.6	8.5	- 59.2	- 32.9
Feb.	+ 2.0	- 62.0	- 35.0	- 2.0	- 66.5	- 38.0
Mar.	- 8.0	- 70.8	- 37.1	- 8.0	- 73.8	- 39.8
Apr.	+ 13.0	- 42.5	- 17.3	+ 15.0	- 46.5	- 18.0
May	33.6	- 20.5	+ 10.0	32.5	- 14.9	+ 11.2
Jun.	41.0	+ 16.5	32.5	44.0	+ 18.2	32.5
Jly.	46.3	29.6	37.2	50.0	29.0	38.4

Many significant remarks, however, were made by Stephenson in his log and are worth quoting verbatim. Nares noted in his account that "after the 20th August the temperature of the air remained steadily below freezing point for the winter." (46 pp. 115-6) The two ships reached Discovery Harbour on the 25th, and Stephenson continued in his log:

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1 A shorter note, also by Stephenson, appeared in the Proceedings of the Royal Geographical Society XXl, 1876.

14. The thermometer stand has been landed and erected five feet from the ground. The meteorological records that are regularly taken and registered just before midnight by Dr. Belgrave Ninnis (the surgeon) will add much to the store of knowledge gained by this link of the expedition. (30 p.46.)

18. The weather during September has been decidedly warm and muggy on the whole, particularly to those who have had manual labour to perform, but singularly devoid of sunshine - so gloomy that we have been unable to obtain any (solar) observations. (p.46.)

October 1875

39. The weather during October has been fine, but the temperature very variable. We have experienced no winds to speak of. The adjoining hills and opposite coast of Grinnell Land have been observed quite free of snow, which indicate they have been visited by the usual autumn gales. (p.47)

November 1875

46. November has been decidedly a dark and gloomy month[1]...... There has been no wind to speak of. (p.42)

54. The temperature has been very variable throughout the month, at times almost warm enough to dispense with fires; the warmest day was the 9th, 19° ..... (p.48)

December 1875

60. December has been very dark, hazy and thick. The moon rose on the 6th and set on the 20th, appearing like a great grease spot nearly the whole of that duration. On two days only were lunar distances obtained. The hazy state of the weather and the intense cold during the latter part preventing other observations. On the 4th we experienced a gale from the S.W. (true) lasting from 1 a.m. to 6 a.m. Temperature 26°, and on the 7th it was very squally from the eastward, temperature -5°, accompanied on both occasions by a deal of snow drift. These are the strongest breezes we have yet experienced, but they were by no means cold. (p.48)

69. The mercury was frozen between the 19th and 28th inclusive (p.49)

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1 Stephenson meant this as a meteorological remark; it was not prompted solely by the absence of the sun.

January 1876

73. The month of January has been remarkably fine and clear, intensely cold but no wind...... At noon on the 28th we were able to read on the floe a few lines from the leading article of the "Times". (p.50)

February 1876

83. The month of February has been rather gloomy, owing to the increased daylight and no sun. (p.51)

89. On the 4th, during the middle watch, a gale sprung up from the N.E., with a falling barometer; the wind veering all round the compass in heavy squalls. The atmosphere was so laden with snow drift, that the observations of the declinometer were discontinued for a time,[1] being unable to get out of the ship during the most of the day. It lasted with more or less violence till the night of the 5th, when it blew itself out in fitful gusts, leaving the atmosphere very thick, overcast, and the hills quite barren of snow. This was a regular arctic gale........ The temperature varying between -12° and $+2^{\circ}$. Even the dogs looked miserable. These are the only two days during the winter we have been prevented by the weather from morning inspection and prayers outside the ship. (p.51)

96. .... The temperature was -30°. It is difficult to make the men understand that though the sun is about to return it is not warm enough to go outside in their shirt sleeves at present.

March 1876

106. March was ushered in with a bright sun, but severe cold. Between the 1st and the 14th the mean temperature was -49°, and just before midnight of the 3rd the minimum showed -70.5° – I believe the coldest ever recorded.[2] (p.52)

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[1] Drifting and blowing snow seem to occur at lower windspeeds than in more southerly latitudes, because of the fine, powdery composition of the snow. Experience at Lake Hazen showed that drifting usually occurred whenever the wind rose to four or five miles an hour, and blowing snow was usually recorded at wind speeds above 10 m.p.h.

[2] It was on March 3rd that Nares recorded -73.75° F. at Floeberg Beach.

108. The officers have taken daily long walks in search of game...... In some instances 26 miles have been accomplished, with the temperature - 52°.....

121. From our well sheltered position I am unable to give any opinion of the prevailing winds during the winter. (p.53.)

May 1876

30. From our arrival (at Polaris Bay, Greenland, on foot) on the 12th to the 15th we experienced a heavy blow from the northward. On the 16th the barometer fell from 30.30 to 29.76, accompanied by a whole gale from the same direction with a deal of snowdrift, confining us all to our tents.

June 1876

7. We have experienced during the latter part of May and the beginning of June ~~thick,~~ muggy weather, with a continued fall of snow which has thawed rapidly. (p.58)

9. On the 8th inst. a stream of water about nine feet broad was observed for the first time running down the ravine abreast of the ship. (p.58)

July 1876.

24. On the 5th and 7th instant we had heavy falls of rain, the first since our arrival in this harbour.

In his account to the Royal Geographical Society (51) Stephenson observed that "I consider the winter by far the most agreeable part of the whole period spent in the Arctic. For 109 days out of the 135, we had the stars shining brightly at mid-day. The ship was very warm and comfortable."

Considering the record above and in Nares' account, and the temperature means and extremes in Table IV, the general picture of the climate is one in which winter was very cold, judged merely by temperature.

Its effects were, however, ameliorated by the light winds which were usual. Occasional gales were always possible and were always accompanied by a steep rise in temperature. Summer, the melt-season, came abruptly, but was not particularly warm, there being a considerable amount of cloud. Precipitation throughout the year was light and little rain was recorded. It is significant that this summary may be applied in practically every detail to the description of weather at Lake Hazen in 1957-58. The only major difference emerging from Stephenson's log is that the early part of the winter was much more cloudy and "muggy" than the clear and crisp conditions at Lake Hazen from mid-October onwards.

Five years or so after the Nares expedition, the Lady Franklin Bay Expedition led by Greely set up its First Polar Year station in Discovery Harbour, naming its base Fort Conger. The story of the expedition, as told in Greely's account "Three Years of Arctic Service" (32) is one of the most heroic stories of polar exploration and misfortune ever written.

The accompanying summary of meteorological observations is taken from Greely's account. The complete meteorological records, together with other results of a very comprehensive scientific programme were published separately (31). In the latter work the heights above sea-level of the instruments are recorded. The mercury barometer used for most of the pressure observations was 24.2 feet above sea-level and a constant correction of 0.030 inches was applied to all readings to give the sea-level pressure (31, p.90). The thermometers were exposed in an instrument shelter and were 34.4 ft. above mean sea-level and 5 feet above the ground.

Like Stephenson on the "Discovery", Greely made pertinent meteorological remarks in his journal and in "Three Years of Arctic Service" and a selection of these follow, all taken from the latter account.

Table VI

Temperatures at Fort Conger 1881-3
(The location is practically identical with Discovery Harbour, Table V) (°F)

	Max.	Min.	Mean.
August, 1881	45.9	- 15.6	33.3
September	30.0	- 10.4	-10.9
October	- 9.0	- 31.1	- 9.2
November	- 3.0	- 43.0	- 24.5
December	-10.0	- 52.2	- 32.0
January, 1882	- 9.5	- 58.2	- 38.3
February	-10.0	- 62.1	- 46.5
March	- 7.0	- 46.8	-29.9
April	+ 13.9	- 42.1	- 8.6
May	35.8	+ 1.1	+ 17.4
June	53.0	12.7	33.1
July	50.3	30.0	36.8
August	47.8	22.8	35.3
September	27.4	- 0.7	-18.1
October	-14.0	- 23.5	- 7.7
November	- 1.1	- 46.0	- 28.0
December	+ 5.5	- 43.9	- 27.8
January 1883	-18.0	- 50.6	- 35.8
February	- 5.0	- 56.5	- 38.9
March	+20.0	- 49.1	- 17.9
April	6.6	- 37.3	- 14.8
May	32.3	- 13.0	+ 14.8
June	39.6	22.7	32.4
July	52.4	28.8	37.2

The observations as to the pressure of the atmosphere, temperature and dew-point of the air, direction and force of the wind, quantity, kind and movement of the clouds, the aurora and the state of the weather, were made hourly after the vicinity of Fort Conger was reached.
(32, i, p.124)

The temperature given in the narrative are corrected from tests with frozen mercury, that metal being assumed to solidify at a temperature of - 37.9°F. (- 38.8°C.)..... Some of our alcohol thermometers were so unreliable that they were never used.

Some excellent standard thermometers....... were made for the expedition..... Their error at freezing mercury proved inconsiderable, less than a degree Fahrenheit.

Our thermometers were exposed in a large wooden shelter of Louvre pattern, four feet square and seven high, which was situated about forty yards northwest of the house. The instruments were fastened to a sheet-iron drum, so made as to revolve, which was shielded by another small shelter, made after the Louvre pattern, of galvanised iron.

The anenometers and wind-vane were placed on the ridge-pole of the main building where the exposure was excellent.

The number of observations made and recorded each day were as follows: meteorological 234; tidal 28; magnetical 264 - aggregating 526..... (i.132)

On December 16th our mean temperature for the day was for the first time lower than - 40°, being - 40.9° (- 40.5°C.) corrected. (i. 169)

The 16th of January was a day long remembered at Conger. My journal says "We have had today the most violent storm I have ever experienced, except a hurricane on the summit of Mount Washington." The barometer commenced falling .05 in. hourly at 7 a.m. with calm, cloudy weather. I watched the barometer hourly, the fall increasing until it reached .10 inch an hour at 11 a.m. with a southwest wind of eighteen miles. Observations were then made every fifteen minutes. An hour later the barometer had fallen another tenth of an inch, and the wind, which suddenly changed to the northeast, attained a velocity of over 50 miles an hour. The air was so full of snow that I ordered the temperature observations to be made by two strong men together, and the tide reading by two others. It was with difficulty that they succeeded in reaching the instruments. It took six of the best men with ropes to make the 1 p.m. reading, when the wind was blowing steadily at 52 miles from the northeast, in which quarter it remained. At 2 p.m. the barometer still fell with the same rapidity, and the wind had attained a velocity of 62 miles. It was quite impossible to quit the house, and a thermometer was read just outside the southwest door..... (i. 181)

The highest registered wind was at 2.15 p.m. northeast, sixty-five miles per hour, but about 2.40 p.m. the wind, which had been blowing steadily, changed into violent gusts, which probably reached eighty or ninety miles an hour. The anemometer spindle broke off, and the cups blew several miles into the harbour before they caught and stopped. At 3 p.m. the barometer was 29.028, a fall of over half an inch (.504 inch) (i. 182). The general principle that storms do not occur at very low temperatures is sound, and it is equally obvious that during storms the temperature rises rapidly and that observers in the field overrate the velocity of cold, cutting winds. The wind blowing fifty-two miles an hour in this storm, at a temperature of - 13° (- 25°C.) is probably unparalleled.[1] Other memorable winds at low temperatures occurred January 23 1882, thirty-four miles at - 25.2° (- 31.8°C.) and March 6 1882, east, twenty-one miles at - 27.2° (- 32.9°C.) (i.182)

For the first time during our experiences, it would now be possible to cut blocks of snow and build a snow house.[2]

At 10 p.m. February 16th (1882) the mercurial thermometers thawed out, after having been frozen continuously for sixteen days and five hours. This is the longest period on record during which mercury has remained frozen. The "Alert" in 1876 experienced a similar spell of cold, during which the mercury was solid for twelve continuous days. The longest period of similar temperatures by Kane's record is but five days. (i.192)

1

It is not, however, a very exceptional feature at Alert. Exactly 76 years later, at 1200 G.M.T. observation on January 16 1958 the wind was blowing at 55 m.p.h. in a temperature of - 13.1°F. At the 2100 G.M.T. observation on the following day the wind was 85 m.p.h. and the temperature - 5.0°F. Even these conditions were moderate, however, when compared to those experienced by the Mawson expedition to Terre Adelie in the Antarctic in 1911. To quote Mawson's account (43) "Temperatures as low as - 28°F...... were experienced in hurricane winds, which blew at a velocity occasionally exceeding one hundred miles an hour." Mean wind speeds of over ninety miles an hour were recorded over 24-hour periods and the mean wind speeds during the three months of March, April and May were 49, 51.5 and 60.7 m.p.h. respectively.

2

This experience was identical to that at Lake Hazen. In the early part of the winter the snow was so dry and powdery that snow blocks could not be cut from the snow lying on the ground and were difficult to make by compacting the snow by hand. After the January gale the compaction was so great that a spade was preferable to a snow knife in cutting the blocks. See p. 87-88.

> The cold weather just passed has been remarkable for its duration as well as its severity, the mean temperature for thirty-five days, January 20th to February 24th inclusive, has been - 47.1° (- 43.9°C.) During this time the mercury has been solid frozen except for sixty-seven hours. (i.194)

It was Greely's expedition which first travelled up the Ruggles River and discovered Lake Hazen, and considerable interest attaches to Greely's remarks on the journey he made in the summer of 1882 along the southern side of the Lake:

> The weather during the day (June 29 1882) was excessively hot, and we suffered extremely. The attached thermometer of the aneroid barometer, which was carried always in the shade, stood at 74° (23.3°C.) and the exposed thermometer, though swung repeatedly for seven minutes in the air, could not be got to read lower than 73° (22.8°C.) This temperature was certainly a very remarkable one to be encountered in such a high latitude, but I am confident as to its reliability within one or two degrees (i.385)
>
> At 4 p.m. (on the same day) the temperature of the air was 67° (19.4°C.) in the shade. In order to determine it correctly, I plunged the thermometer in the river,[1] and was surprised at the temperature being 45° (7.2°C.) The only inference to be drawn is that the river must flow a long distance from the supply of snow which feeds it. The thermometer, after being taken from the river and carefully wiped, rose slowly in the shade to 64° (17.8°C.) which must be accepted as correct. The very high temperature of the air today explains the temperature of the river and we cannot do otherwise than believe that the temperature of the interior of Grinnell Land must be considerably higher in summer and correspondingly lower in winter, than the coast regions.[2] (i.386)

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1 The river in question is the Cobb river, a fairly short stream draining the Greely-Hazen plateau and flowing into Lake Hazen.

2 Greely mentions in a footnote that the maximum on the same day at Fort Conger was 51.2° (10.7°C.) which was the highest ever experienced there except for the 53° (11.7°C.) two days later.

Like Stephenson's record, the preceding account contains much of relevance to the record from Lake Hazen for 1957-8. The long periods of extremely low temperatures were repeated, and in particular the storm of January 17-18, 1958, seventy-six years after the one recorded by Greely, had many of the same characteristics and was equally memorable.

The return of the Greely expedition marked the end of meteorological interest in the area of Ellesmere Island for over half a century. Almost the only exceptions to this are the records from the two winters which the "Fram" spent in the area, at Fram Havn on the Ellesmere coast opposite Etah and at Harbour Fiord on the south coast, and also the records kept at the Royal Canadian Mounted Police posts at Craig Harbour and, for a short time, at Bache Peninsula. Exploration of the area continued, and Fort Conger was visited by many parties, including Peary on two occasions. Lake Hazen was visited in 1914 by Ekblaw and two Eskimos of Macmillan's expedition and again in 1935 (the date is printed wrongly in Taylor's account) by Stallworthy and Moore.[1] Stallworthy stayed at the lake for two weeks during late April and early May, while Moore re-discovered and ascended the Gilman Glacier and climbed Mount Oxford in the United States Range. Stallworthy's attention was however entirely occupied with fishing for dog-food and little of scientific value, in meteorology at least, resulted.

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[1] Taylor's account (52) contains the references for all these sources.

So the position remained until the end of the Second World War, when advances in techniques of meteorological analysis, the advent of long-range aircraft, and a new perspective in continental defence caused the meteorological services of Canada and the United States to collaborate in the establishment of five new weather stations in the Queen Elizabeth Islands, two of which, Alert and Eureka, were on Ellesmere Island. Eureka on the west coast, 80° 00' N., 85° 56' W., and eight feet above sea-level, was established in the summer of 1947. Alert, the last of the five "Joint Weather Stations" to be established (1950), is located on the north coast in latitude 82° 30' N. and longtitude 62° 20' W. at a height of 218 feet above sea-level. The records from these two stations will be considered in later chapters to provide direct comparisons with conditions at Lake Hazen.

CHAPTER II

SITE AND INSTRUMENTATION

Even after the Joint Weather Stations at Alert, Eureka and elsewhere in the Queen Elizabeth Islands had been established, considerable gaps remained in the meteorological network north of the Canadian mainland. One instance of this was the lack of a station in the vicinity of Victoria Island, in the Western Arctic, a gap which was recently partially filled by the establishment of a new station at Sach's Harbour on Banks Island.

The principal objection, however, to the present distribution of stations is that they are almost without exception all in coastal locations and thus only partially represent the climate of the island on which they are situated. The reasons for their location on tidewater are simple and reasonable. With the exception of Alert, Isachsen and Mould Bay, all the weather stations are normally visited each year by supply ships or icebreakers, which bring in the heavy equipment and supplies for the next twelve months. Even in the cases where establishment and maintenance has had to be undertaken entirely by air transport, proximity to the sea was important in the original location of the station because it meant that an ice airstrip was available for the aircraft before the land strip at each station was built. Perhaps more important is the fact that it is the upper-air soundings which are the vital part of the raison d'etre of the High Arctic stations. The significance of these soundings for the meteorological analysis in mid-latitudes, and for military and civil air operations in the Arctic itself, is greater than that of the surface observations taken in areas where, away from the station itself, the country is practically uninhabited. The exact location of an upper-air station is not important, and therefore it was reasonable that the more recent stations should be located close to tidewater; for the earlier stations, established before Arctic flying became routine, there was no choice.

Despite these practical considerations, there are many reasons why an inland record from one of the larger islands is of value. One recent report which discusses the "Temperatures of Northern North America" (36) was prepared in connection with problems encountered by the U.S. Signal Corps in the storage and use of dry batteries. Hogue, its author, remarks on the reliability of the data, "The least degree of reliability is in the interiors of Greenland, Iceland and islands of the Canadian Arctic Archipelago, where stations are almost entirely lacking." (36 p.2) From this small practical problem one may turn to point to the usefulness of such an inland record in the consideration of the budgets and régimes of the inland ice masses which cover much of the interiors of several islands.

These are a few of the factors behind the desire to obtain a 12-month record of the surface weather at Lake Hazen. The immediate cause was the decision to mount an expedition "to make detailed glaciological, seismic, gravimetric and other geophysical and climatological studies on the ice cap to the north of Lake Hazen" (10 p.l.) during the International Geophysical Year 1957-58. This expedition was part of the Canadian glaciological programme (44, pp. 48-54) and thus the expedition is classified under Section IX (Glaciology) of the I.G.Y. programme. It must be stressed, however, that the surface records at Lake Hazen were collected in as close a manner as possible to the methods used at a normal weather station and there was no bias towards the special problems of glacial meteorology.

I. SITE

The choice of the station site was not determined by the requirements of the meteorological programme. The station was designed as a base camp for the ice-cap operations, and also as a centre for botanical, zoological, archaeological and other studies in the area; the suitability of the base for meteorological observations was thus only one of several considerations in its location. All aircraft landings had to be made on the frozen lake surface; it was therefore desirable that the station should be situated close to the lakeshore to receive supplies as they arrived. Communication with the ice-cap was almost as much by foot and dog-team as by aircraft; the site had therefore to be on the north side of the lake. It was originally intended (10) to establish the base close to the Henrietta Nesmith Glacier. When, however, it became apparent that access to the ice-cap by that route was impractical, the location was moved about twelve miles or so along the shore to the vicinity of John's Island. Final choice of the site was not made until the arrival of the first members of the expedition in the first aircraft.

These considerations inevitably affected the record which was obtained, just as local conditions in some measure influence the record at every meteorological station. The choice of the Lake Hazen trough, a long, low valley between the 3500-feet high mountains of the Garfield Range and the higher mountains and ice-cap behind the Range to the north, and the Greely-Hazen Plateau on the south, meant that the station was in the bottom of a gigantic frost-hollow, with winter temperatures which, on the basis of the 1957-58 record, are probably some of the coldest experienced in an ice-free area of North America. It also meant that winds, apart from katabatic flow, from the quadrant between west and north were likely to be under-represented, as the mountains rose up only a few miles from the site. The presence of a large water body in the area for a considerable period after the air temperature had fallen below freezing in the fall gave rise to cloud conditions which were peculiar to the vicinity of the lake; on several occasions the sun could be observed shining on distant hills when a dense layer of strato-cumulus enveloped the lake and its immediate vicinity. This effect was reversed in the summer when the ice-covered surface or the cold water probably kept temperatures at the station several degrees lower than would have been experienced some distance away.

The position of the station can be seen from Figs. 1 and 2. Although necessarily chosen in a few minutes when the ground was still snow-covered, the station site is one of the finest anywhere close to the lake shores from the point of view of a living site. A small circular rise, approximately fifty yards in diameter, it is formed of fluvio-glacial deposit of sands and gravels which permits rapid drainage of surface moisture, in contrast to the marshy areas immediately to the northeast. At about 12 feet above the level of the Lake (approximately 522 feet above sea-level) and only thirty yards from its edge, it was in an excellent position for receiving supplies and obtaining fresh water.

It was also a satisfactory site for a weather station. If it is granted that the station had to be established in the shadow of the Garfield Range[1] and in the general vicinity of Lake Hazen, then the exposure of the site was quite acceptable. The buildings, two Attwell shelters and other smaller tents, etc., were low and the wind suffered little check from any direction, particularly at the level of the 40-foot anemometer and also at those of the three totalising anemometers about

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1 A phrase which here is literally true, as in spring and fall the mountains prevented the station from recording as much sunshine as sky conditions would allow.

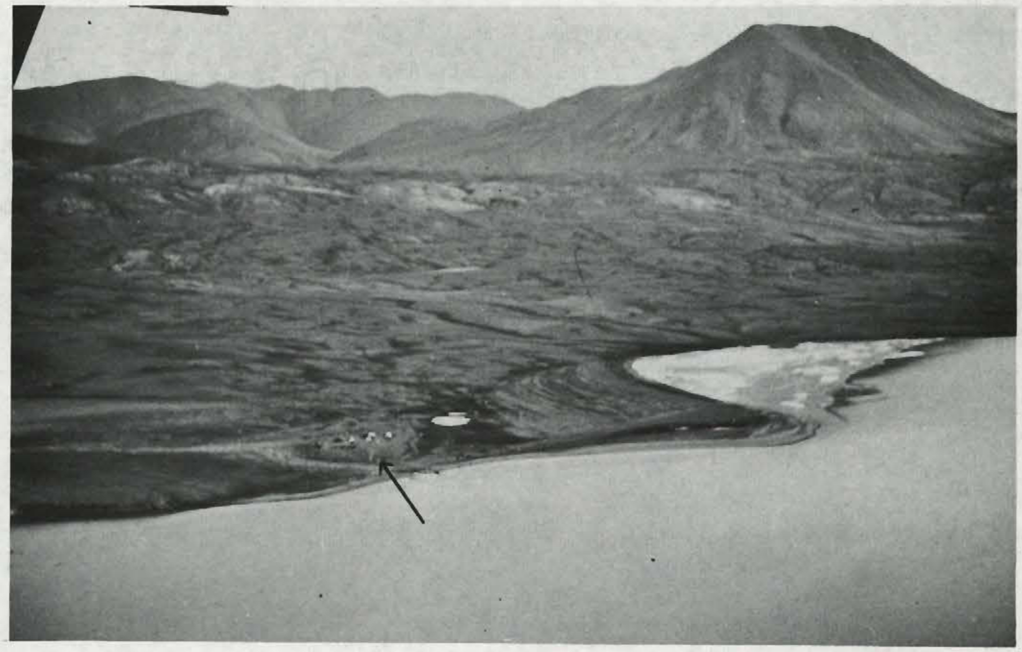

Fig. 2. Hazen Base Camp.

fifty yards to the northeast. The very low windspeeds and the appearance of several preferred directions are almost certainly features characteristic of the Lake Hazen trough and are not due to the poor location of the weather station.

Having thus discussed the limitations of the station, some mention of the limitations of the observers is necessary. All the observations were taken by four research students from the Department of Geography of McGill University, with the author in nominal charge of the meteorological programme. Two observers, including the author, had spent several weeks during the summer of 1957 at Knob Lake, the first-order weather station in Labrador-Ungava which is maintained by McGill University. Neither of the other observers had had formal experience at a weather station before arriving at Lake Hazen. The absence of any prolonged training among the four observers is perhaps most apparent in the minor details of the actual record; although every effort was made to correct errors as they arose, a check of the daily sheet, particularly during the first few months, shows many slips in detail. To give an example of their nature, precipitation might be entered as "S" (i.e. moderate snow) when the prevailing visibility was better than 5/8 mile, thus defining it as "light" or "very light". It also possibly affected the estimation of cloud heights and the correct description of their type. This source of error, however, is not considered to be greater than would be the case at regular weather stations where cloud heights etc. are estimated, and in particular great care was taken when the ceiling was below about 3000 ft. because of the importance for aircraft operation. [1]

Although the correct methods of reading the various instruments were soon learnt, one aspect of what Brooks and Carruthers (7, p.7) call the "personal equation" of the observer must be mentioned. They point out that certain systematic errors tend to arise because, for instance, an observer when mentally dividing a thermometer scale into tenths of a degree often has certain "preferred values"; he may practically never record .3 or .7 or so on. These and similar sources of error, if not avoided at Lake Hazen, were usually in the minds of the observers, and this is the best that can be hoped for. [2] Each observer did undoubtedly have certain predilections which are reflected in the record: one, for instance, might have a habit of recognising more cloud layers in a confused sky cover than another; a third might attempt to record cirriform cloud at what he estimated to be the nearest thousand feet, whereas the fourth preferred to think in intervals of 5,000 feet at altitudes of 20,000 ft. or above. None of these things, it is believed, detract materially from the value of the record, and on the credit side the author is glad to be able to work with material

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1 A copy of the Abridged International Cloud Atlas (55) did not arrive until May 1958. However, an elementary introduction to cloud recognition appears in the syllabus for most degrees in geography and, with the help of the fairly detailed descriptions given in MANOBS (15, p.12) there was little difficulty in interpreting the sky and no heart-searching when the Atlas eventually arrived.

2 Chapter VI contains a study of such tendencies by the observers at Lake Hazen.

collected by observers who maintained a keen interest in the observations and a fairly stern discipline in their collection (e.g. in taking them exactly on the hour) throughout the twelve months. The exact period in question was from 0000 G.M.T. August 20-21 (7 p.m. August 20, E.S.T.) 1957 until 1200 G.M.T. (7 a.m. E.S.T.) August 11 1958. Only two observations were missed during that time, both of them in the first week of observations. It should be noted that the "Climatological Day" referred to in subsequent discussion is that adopted by the Canadian Meteorological Branch, and ends with the 1200 G.M.T. observation.

Mention of the times of observation leads to a discussion of the times used in the records. The approximate co-ordinates of the station are 81°49'N., 71°18'W., in the Eastern Standard Time Zone. Local noon was thus some 15 minutes before noon on the Eastern Standard Meridian of 75°W., and approximately 4h. 45m. after noon on the zero meridian at Greenwich. The three-hourly observations were taken at 0000, 0300, 0600, 0900, 1200, 1500, 1800 and 2100 G.M.T. and "local standard time", as used in the record, is Eastern Standard Time.

Although the times of observations were thus the normal ones in Canada, observations at 0000, 0600, 1200 and 1800 being termed "main synoptic" and the others "intermediate synoptic", there is one important feature of the Lake Hazen records which must, within the last decade or so, be very unusual. The expedition, not equipped with any accurate chronometers, was dependent on obtaining time-checks from the broadcast time-signals (WWV in Washington D.C. and WWVH in Hawaii being the two most commonly received at Lake Hazen.) Unfortunately the generators which provided the low-tension power for the radio failed at the end of September 1957 and, for a variety of reasons, replacements for them did not arrive until late in March 1958. Throughout the intervening six-month period it was possible only to get three reasonably accurate time checks. One of these was on November 13 1957, when all available batteries were used in series in an attempt to gain the necessary 12 volts for the radio. In the six weeks from the end of September "local time", that is, the time shown by the clocks at Lake Hazen and on which the meteorological observations were based, had fallen 20 minutes behind Eastern Standard Time. This experiment with the radio was not repeated, as it blew most of the spare fuses and also it was felt that such small reserves of power as were available should be kept in case of a real emergency. The expedition was supplied with short-range V.H.F. transceivers by parachute drop in December 1957, but not till February 25 1958 was it possible to use them to obtain a time check from a passing aircraft. On that date local time was 1 h. 48 m. behind Eastern Standard Time. Although there is no guarantee that the error in the clocks at Lake Hazen was always in the same direction (i.e. that they always lost and never gained), it seems likely that this was the case and so the error in late February was probably the largest in the period. A further time check was obtained on March 14, with only a small error of seven minutes (again a lag), and the new generators arrived on March 29.

As far as the weather records are concerned, it must be remembered that the sun was continuously below the horizon for the greater part of the period involved (at that latitude from October 16 until February 28); diurnal fluctuations are therefore practically negligible. Much more important is the fact that the observations were taken, for all practical purposes, three hours apart. Each of the accumulated errors was corrected in a single step (e.g. the 2100 G.M.T. observation on February 25 followed 1 h. 12 m. after the "1800 G.M.T. " observation.) There seems no reason to try and correct the record for this time lag in the same way as has been necessary, for instance, for the auroral observations which were taken on behalf of the I.G.Y. Auroral Centre in Ottawa. [1]

The final feature about the station itself which must be mentioned, apart from the instrumentation, is the building itself. The basic units of the Base Camp were two green Attwell shelters, consisting of two layers of canvas stretched over a wooden framework, with a layer of insulating material between the layers of canvas. Doors, each with a large window, are at each end. For the greater part of the year, one of these was used as an unheated store and the observers lived and worked in the other. On one end of each was erected half a Jamesway shelter, thus making it impossible

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1 Reference to the daily sheet for February 17 1958 will show that on that date an attempt was made to obtain an astronomical time check. It was not used as a new reference point at the time, but should others have occasion to correct the times, it may be of assistance.

to see out of the window at that end. On the other end of the living hut there was erected a storm porch, consisting of a large tarpaulin stretched over a framework of aluminum spars. This porch was in position from mid-September until early May and thus during that period the Attwell was effectively windowless. This was obviously not an ideal condition for a weather station, but was made necessary by the intense cold of the winter. A three-hourly synoptic programme requires that a constant check be kept on the weather, particularly with regard to times of precipitation, and it was therefore laid down that the state of the sky should be checked at least once an hour. If this seems too long a period, it must be remembered that the swift variations in conditions typical of mid-latitudes only rarely occur in the High Arctic and the hourly checks were found to be adequate, particularly as they were normally considerably augmented during "daylight" hours by the comings and goings of the other members of the party.

II. INSTRUMENTATION

The Measurement of Temperature. As with all such measurements at official weather stations in Canada, the temperatures at Lake Hazen were recorded in degrees Fahrenheit. The latter scale is preferable for meteorological work as the scale interval means that the accuracy to one decimal place is practically the same as that to two places on the Celsius scale.

The quality of the thermometers with which the expedition was supplied was excellent; their number was unfortunately small. It had been intended to bring in a number of spare thermometers in the projected October re-supply. However, as already mentioned, the aircraft could not reach Lake Hazen and so the only spare of satisfactory accuracy from late August (after one minimum was broken on the second day of observations) until April 30 was one maximum. The breakage of any of the thermometers, and particularly of the very fragile minimum, would have affected the value of the entire meteorological programme to a very serious extent. The desirability of having at least three spare thermometers of each type cannot be stressed too strongly.

The thermometers used for the measurement of air temperature were mounted in a Stevenson Screen supplied by the Meteorological Branch of the Department of Transport. It is specified as follows:

> 2.3.2. The M.S.C. standard screen...... is a double louvred box with interior dimensions 19½" x 11" x 20½". The roof is constructed of ¾" hard asbestos cement board and provided with an air space. The entire screen is given a coat of aluminum paint and then covered with exterior white enamel. The door is arranged to open downwards. (14, p.5)

The screen should be erected so that the thermometers are at a height between 4½ and 6 ft. (1.25 - 2 m.) above the ground. This means that the base of the Canadian screen is normally 3 ft. 9 ins. above the ground. When the advance party arrived at Lake Hazen in the spring of 1957 the ground was of course frozen hard and the supports were not therefore buried to any depth. Thus the base of the screen was approximately 5 ft. 3 ins. above ground level; the thermometer bulbs were, however, still well within the limits mentioned above.

The screen was erected at the southern end of the station site and so arranged that its door faced north. The position of the screen and its relation to other buildings can be seen from Fig 3. There was no motor psychrometer attached and so the screen is described as "unventilated."

Because of an unusual number of breakages at the ice-cap station during the summer of 1957, which had used up all available spares, the usual "ordinary" thermometers for the measurement of dry- and wet-bulb temperatures were not available when observations began. A sling psychrometer was, however, available with accurate correction cards for both thermometers. The latter were removed from the sling and mounted in the screen in the same way as with ordinary thermometers. They were replaced by the usual type on May 8, and detailed notes of such changes, breakages, etc. were entered in the daily sheets.

The specification of the M.S.C. ordinary thermometers, which is essentially valid for the sling type also, is:

> 3.3.1. The M.S.C. ordinary thermometers are sheathless mercury filled thermometers with a cylindrical bulb graduated in degrees Fahrenheit and are useable from − 38° F. to 120° F. The overall length is 12" and the stem is provided with a button on the top to facilitate mounting. The space above the mercury contains nitrogen and an expansion chamber at the top allows the temperature to be raised to 160° F. without damage. (14, p.9)

Temperatures fell on many occasions during the winter below the freezing-point of mercury. As was seen in Chapter I the early expeditions usually left their thermometers in the screen whether the mercury was liquid or frozen. However, to quote MANOBS :

> 7.1.4. .... If left exposed, there is a danger that, if the temperature falls below the freezing point of the liquid used, gas may be entrapped in the column due to shrinkage of the column from the walls of the thermometer tube. (15, p.44)

The shortage of thermometers at the base meant that no such risks could be taken and therefore every effort was made to comply with the requirement that "..... mercury..... thermometers shall be moved indoors when the temperature falls within 3° of their freezing-point" (15, pp. 43-44) although this meant that humidity measurements could not be made below about - 35° F.

The specifications of the maximum and minimum thermometers used at Lake Hazen are as follows:

> 3.5.2. The M.S.C. maximum registering thermometers, Series 5, are unsheathed mercury thermometers of 13 inches in length and provided with a cylindrical bulb and a button on the stem for mounting. The thermometers cover the range from - 38° to 120° F. The space above the mercury column is evacuated. (14,p.11)

> 3.6.2. The M.S.C. minimum thermometers Series 5 are unsheathed and filled with clear absolute ethyl alcohol and calibrated over the range - 90° to 110°F. The overall length is 13 inches and it is provided with a cylindrical bulb. The etchings on the stem are filled with black waterproof filler. The index is about ½" in length and is designed to be drawn back by the meniscus of the retreating alcohol column (14, p.15)

Both these thermometers, when used in the screen, are mounted in aluminum sheaths by means of rubber grommets. The maximum, like the other mercury thermometers, was removed from the screen when the temperature fell below about - 35° F. In such cases the Meteorological Branch recommend that "frequent readings of dry bulb temperature should be made and the highest observed temperature taken as the maximum during the interval under

Fig. 3. Low Cloud over Lake Hazen, September 1957.

consideration. A thermograph record, if available, may also be used to determine the maximum temperature". (15, pp. 44-5) The dry-bulb temperature, in such circumstances, is of course the end of the spirit column of the minimum thermometer. While, however, this practice may be satisfactory at most weather stations when the period of freezing mercury is relatively short, "frequent readings" of temperature when the mercury was frozen sometimes for days and weeks at a time was impractical and, lacking a thermograph calibrated to such temperatures, the maxima are missing from the Lake Hazen record during these periods.

As far as the humidity measurements are concerned, the vapour pressure of the atmosphere is very small at such low temperatures (see Fig. 4) and the dew-point and relative humidity are of less importance than at higher temperatures. However it is desirable that any further winter measurements at Lake Hazen, if a permanent weather station were established there, should be taken by means of thermometers of the mercury-thallium type (14, pp. 9-10 & Fig. 3) which do not freeze until the temperature falls to - 78°F.

All the thermometers supplied by the Meteorological Branch had been calibrated according to its normal practice. They are placed in a large alcohol-filled chamber in which the temperature can be controlled to 1/100 of a degree Fahrenheit and the temperature is checked against a platinum resistance thermometer. Correction cards were supplied giving an accuracy within 0.1°F.

Soil temperatures were measured by means of thermistors at three sites adjacent to the station which were excavated to a maximum depth of three feet, a few inches below the active layer of the permafrost. The results of this programme will be discussed separately by J. M. Powell. During the summer of 1958 a thermometer was also exposed with its bulb covered by $\frac{1}{4}$ inch or so of soil a short distance from the Stevenson screen (Fig.5). This thermometer was read at 6-hourly intervals and the figures entered on the sheets in the space normally used for grass minima. For part of the time the thermometer used was an ordinary M.S.C. mercury thermometer such as has been described earlier; much of the record, however, was obtained from an uncorrected and rather unreliable alcohol thermometer calibrated in degrees Celsius. The latter temperatures are probably not more accurate than 1^{o}C., but this gives an adequate measure of the diurnal range at the soil surface.

A continuous record of temperature and humidity was obtained by means of a Short and Mason thermo-hygrograph with a speed of one revolution of the drum in seven days. It was not a very satisfactory instrument for arctic work, as it was designed only for limits 0^{o} - 100^{o}F. and it could be modified only down to - 25^{o}F. Continuous records of humidity are also difficult to obtain at low temperatures.

Precipitation. The aids for the measurement of precipitation consisted of two items only: a wooden snow rule (M.S.C. Type 2) 36 inches in

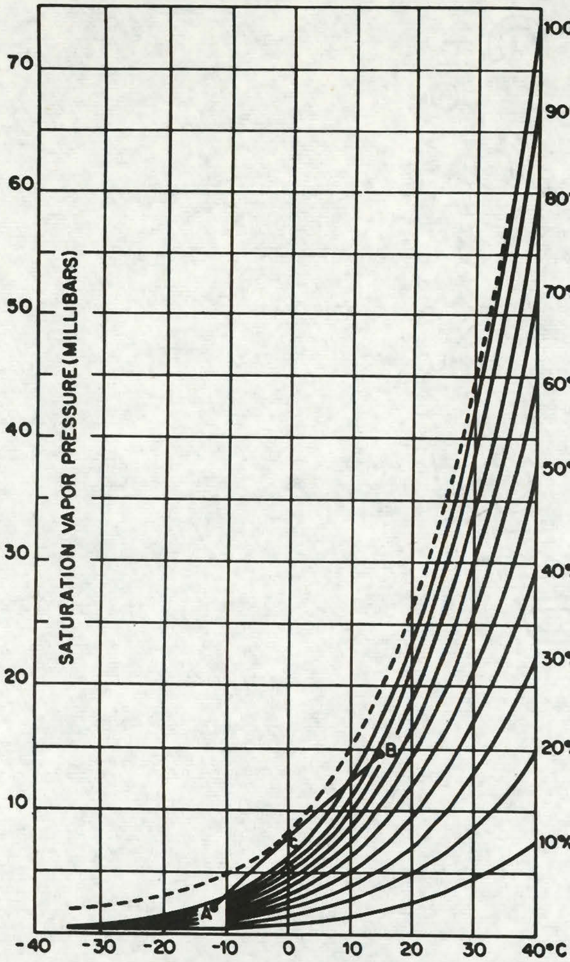

Fig. 4. Relation between vapour pressure and air temperature for standard values of relative humidity. The heavy curve represents saturation with respect to water. The pecked curve indicates supersaturation corresponding to 0.5 g of liquid water per cubic metre. The line ACB has no significance in the present context. (By permission from <u>Weather Analysis and Forecasting</u>, by S. Petterssen; Copyright, 1956, McGraw-Hill Book Co. Inc.)

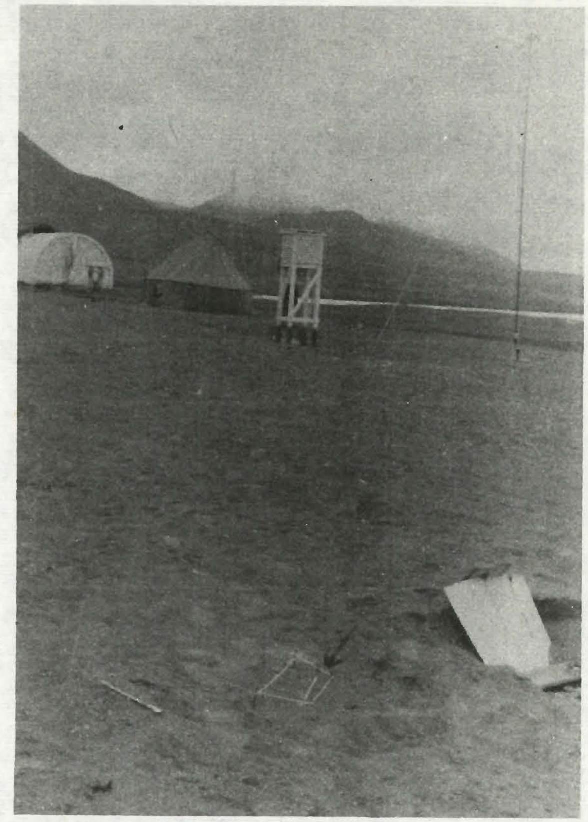

Fig. 5. Soil Surface Thermometer.

length, and a cylindrical rain gauge with a collecting area of 10 square inches.[1] A glass measuring graduate accompanied the gauge. Once again it is recommended that a spare glass graduate be supplied on future expeditions to insure against breakage. The copper raingauge was erected a satisfactory distance from obstructions (Fig 23) and was moved once, a matter of some fifteen yards.

The Meteorological Branch recommend that:

> 5.8.2. .... The amount of snowfall which has fallen in a given period shall be determined by measuring and averaging the depth of snow in several places. Snow depth shall be measured in tenths of inches.....
> 5.8.2.1. ...... The snowfall shall be divided by ten to obtain the water equivalent of the snow. (15, p.30)

The snowfall which is recorded in column 25 of the daily sheets and used in this study as the precipitation amount was not measured in this way, one of the few major departures from Meteorological Branch practice. Instead the raingauge, with its collecting funnel removed, was left outside during the winter, and the water equivalent of the snow collected in it was multiplied by ten to obtain an estimate of the snowfall.

The major objection to this practice is, of course, the liability to under-recording because of eddying round the rim of the precipitation can. This undoubtedly occurs, but the other method also has disadvantages, particularly when the snow is drifting, and it is generally agreed that there is as yet no completely satisfactory method of recording snowfall amounts. The principal objection to the standard method is that at Lake

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[1] This is described in the handbook "How to Measure Rainfall". (12)

Hazen the amount of precipitation which fell in any 6-hour period was usually very small, with rare exceptions mainly when the temperature was close to freezing-point. It was extremely difficult to measure these very small falls accurately with a snow rule. At Lake Hazen, however, the usual windspeeds were so light (two-thirds of all the 3-hourly observations in the months of November and December 1957 and February and March 1958 were calms) that the errors introduced by eddying were very much less than would normally be the case. The problem is discussed at greater length in Chapter V. An important source of error, which has received little attention, is the problem of under-recording due to a too short time interval between observations. This also will be discussed later.

Snow depth was measured with the rule at frequent intervals and entered in column 30 of the daily sheets; it thus serves as a useful check on the gauge measurements.

<u>Wind</u>. The instrument used for the measurement of wind speed at Lake Hazen was a three cup Cassella electrical recording anemometer. This was mounted on a steel mast so that the cups were approximately 41 feet above the ground. This 40-foot anemometer was immediately adjacent to the weather station (Fig. 6) and about four times as high as the buildings, so that exposure was excellent. The recording instrument inside the station consisted of a chart on a revolving drum on which a mark was made for every twentieth of a mile of wind run. From the interval between these

marks the windspeed could be measured at any time. The record was for most of the year kept on a drum which made one revolution every seven days. When extra charts became necessary, however, it was found that the model had been discontinued and it was therefore converted to take daily traces for the rest of the period.

Trouble was experienced during the winter because the anemometer did not record at very low temperatures. The reason for this is not clear. It would seem unlikely that the grease in the instrument freze, as the cups continued to turn, and the problem is probably that of increasing resistance in the leads or connections affected by very low temperatures (below - 25°F.) Contact points may also have become frosted up, but this is also unlikely as the anemometer functioned intermittently during periods of relatively milder weather (e.g. about - 15° to - 20°F.) although the temperature never approached freezing-point. As the low temperatures at which the record is missing were invariably associated with low windspeeds, it was found quite satisfactory to estimate speeds when it was not operating. Wind direction was obtained from flags on the mast, one of which was of very light nylon, or by the windchill effect on the observer's face at speeds below about 3 m.p.h.

In addition to the standard anemometers at 40 feet, three totalising anemometers were installed in December 1957 at a site adjacent to the station at heights above the ground of 1 ft., 3 ft., and 10 ft. (Fig. 6) These were read each day immediately prior to the 1200 G.M.T. observation and thus

Fig. 6. Anemometers

L. to R.: 3ft., 1ft., 10ft. and, on
Camp rise, 40 ft.

TABLE VII

COMPARISON OF SEA-LEVEL CORRECTION AND BAROGRAPH

(during change-over to standard method)

	G.M.T.	Barograph	3-hr. Change	Sea-Level Pressure	3-hr. Change
Dec. 9	0600	994.0 mbs.		1018.1 mbs.	
	0900	994.0	0	1018.2	0.1 mbs.
	1200	993.7	-0.3 mbs.	1017.7	-0.5
	1500	992.6	-1.1	1016.3	-1.4
	1800	991.1	-1.5	1015.0	-1.3
	2100	990.4	-0.7	1014.2	-0.8

give a record of the daily run of wind at these levels.

Pressure. The primary instrument used for the measurement of pressure was a Type C Patterson fixed cistern barometer (number 319), giving a reading in millibars and of the type used at regular weather stations in Canada. Its detailed specification is described in the manual "Pressure Measurements with Mercury Barometers" (17). It was mounted on the inside of the north wall of the Attwell shelter. The framework was not so firm as is desirable, but no other location was possible. The barometer was not exposed to extremes of temperature within the period of the record and no direct sunlight reached the instrument at any time after it was mounted in position.

The height of the station (522 ft. plus or minus 12 feet) was not known until a few days before regular observations began. The barometer was therefore not equipped with correction cards for station pressure or sea-level reduction, and these did not arrive until the parachute drop in mid-December. In the intervening period such corrections were made by means of the methods outlined in the Smithsonian Meteorological Tables (38, Table 48, pp 204-5). The arrival of the official cards showed that the method used had been fairly accurate, and the monthly mean pressures are probably correct to within a millibar. Table VII shows the comparison between the barograph trace and the sea-level pressure during the change-over to the official cards. It suggests a reasonable level of accuracy and it has not been thought necessary to recalculate the pressures in the earlier period.

A continuous record of pressure was kept by means of a M.S.C.barograph. This instrument, in which the drum makes one revolution every three days, was one of the most satisfying instruments supplied to the expedition. Many others, including the barometer, functioned equally well, but all continuously recording instruments are liable to faults and it is a pleasure to record that the barograph operated excellently. If one has a criticism, it is only that it could be improved by allowing an extra $\frac{1}{4}$ inch or so of clearance between the top of the rotating drum and the perspex cover: occasionally the chart-retaining pin had a tendency to scrape the cover, stopping the revolution of the drum.

Sunshine. It is unfortunate that the most suitable instrument for the recording of bright sunshine was not available at Lake Hazen. The Meteorological Branch have adapted the standard Campbell-Stokes recorder to enable a 24-hour record to be obtained at high-latitude stations. The detailed description of the instrument, consisting essentially of two ordinary recorders mounted back to back, will be found in the manual Sunshine Recorders (18). A recorder of this type was, however, not available for either the base camp at Lake Hazen or the ice-cap station on the Gilman Glacier, where it would have been even more valuable.

The instrument actually used at Lake Hazen from the return of the sun in March 1958 until the end of observations in August was an adaptation of a single Campbell-Stokes recorder using the standard 4-inch sphere to record for 24 hours. The photograph (Fig. 7) gives a better impression of the instrument than any verbal description. Standard cards were not available until May 8th, and had to be improvised before that date.

It is inevitable that dissatisfaction should be felt concerning the sunshine records. Although sunshine is not one of the primary parameters measured at every weather station, it is an element of great importance at high latitudes, both in itself for botanical and similar studies, and indirectly because empirical methods exist which enable insolation to be estimated fairly accurately if the duration of sunshine is known. The record is probably not unsatisfactory once the standard cards became available, but it is particularly regrettable that they were not to be had at the time when they would have been most useful. When the sun is high in the sky it will burn on a clear day through any reasonable card, but when it is low in the sky (or thinly veiled with cloud), this is not the case.

Insolation. During the summer of 1958 both the ice-cap station and the base camp were equipped with the recently-designed Cassella actinograph, giving a continuous record on daily traces by means of a bimetallic strip (Fig. 8)

The design of the instrument makes it particularly suitable for use in difficult conditions, as it is small and the transparent sphere is well protected against breakage during transport. It has, however, at least two faults which could be rectified in later models. The recording pen is unnecessarily complicated - the ink is supplied through a tube of very small bore which cannot be cleared when it clogs. The pen arm had to be replaced during the summer by a simple nib system taken from a spare hygrograph. This gave a satisfactory trace and seems much more preferable.

The second fault is the absence of a spare drying element. The element is screwed into the side of the instrument and must be removed at frequent intervals for drying. While this is being done the instrument is no longer air tight and moisture is liable to condense on the inside.

Clouds. Cloud height and type were normally observed by visual estimates, but the station was equipped with two instrumental aids. Although upper winds were not measured by either sonde or pilot balloon, because of the proximity of Alert, ceiling balloon equipment was available.

The equipment is described in the manual Ceiling Balloon Equipment (19). It consists of a supply of hydrogen (at Lake Hazen this was supplied in three cylinders each containing about 200 cu. ft), a filling device, and a quantity of 3-inch red rubber balloons which, when correctly inflated, rise at 460 ft. per minute. The equipment was installed in a shelter constructed of dog-food boxes and, except for the hydrogen, was brought indoors during the winter night. The equipment operated satisfactorily throughout the period.

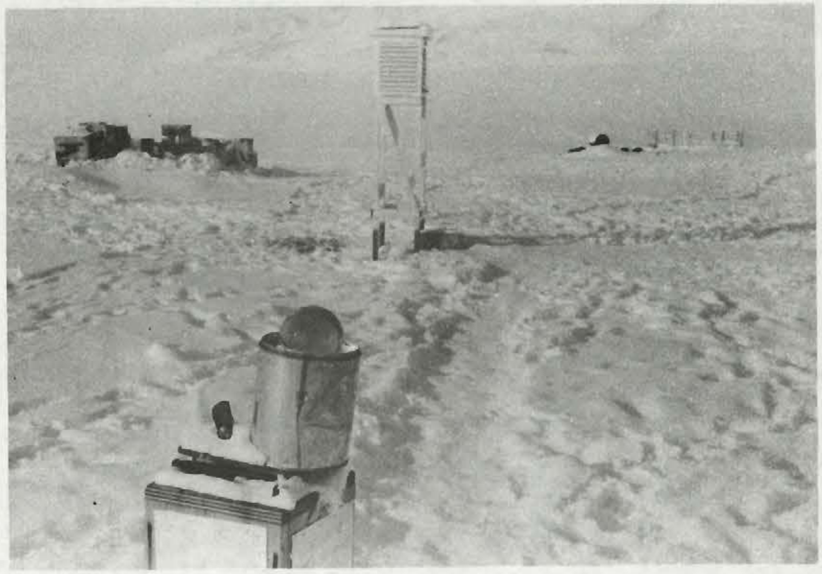

Fig. 7. Sunshine Recorder.

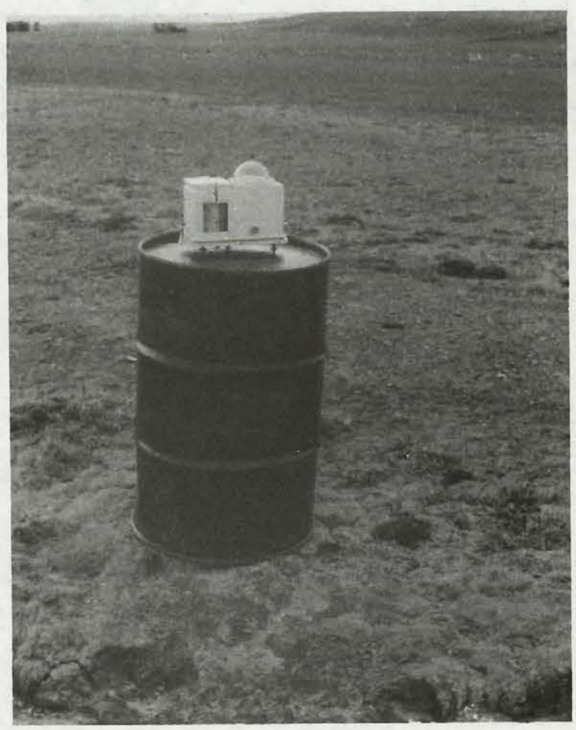

Fig. 8. Casella Actinograph.

Also available were a Type D Ceiling Projector and a Type A clinometer. These items and their operation are described in two Meteorological Branch circulars (16 & 20). They consist essentially of an automobile spotlight which is mounted on a post to throw a vertical beam upwards, and a clinometer which measures the elevation of the reflection on the cloud base from a fixed distance away, the height of the cloud being given by a simple tan function.

The purpose of the Type D Projector, as described in Circular 2042, is "..... to provide an inexpensive method of determining ceiling heights significant to aviation, at off-Airways stations and small airstrips." Within that category Lake Hazen is undoubtedly grouped. Unfortunately the equipment assumes a 110 v. A.C. power source, from which the power is stepped down to 7.5 v. A.C. by a transformer on the post just below the lamp. The internal resistance of the leads meant that a 6 v. D.C. battery such as was available at Lake Hazen was unable to light the lamp unless it was placed on the ground immediately beneath the lamp, with only about 3 ft. of connection. Thus not only was it impossible to site the lamp at the far end of the base line (500 or 1000 ft. from the camp) as is normal practice, but it was impossible even to have the lamp just outside the hut and the battery inside (with the observer going to the far end of the base-line.) The battery had to be taken out for each observation and then quickly returned indoors before the electrolyte froze. Little regret was felt, therefore, when the equipment was rendered entirely useless by the failure of power supplies.

Undoubtedly the idea of a simple and portable projector is of great value to the pioneer fringe of aviation in the north and elsewhere, but in assuming a 110 v. A.C. power source exclusively, the design negates its purpose.

The clinometer is also capable of improvement. It was used regularly during the winter for measuring the elevation of auroral forms. Again the idea was a good one, but one must ask whether it is necessary that the clinometer should be so heavy. There seems no reason why it should not be made from a light alloy instead of from steel: considerable effort is required to keep the eyepiece close to the eye and the clinometer aligned in the correct position with one hand while the instrument is locked with the other. It also seems unnecessary that the lock should be on a left-handed thread: several times the locking key was nearly lost in the snow before the observers became accustomed to the reversed thread.

The Weather Record. The weather observations at Lake Hazen were entered on the sheets of the Meteorological Branch "Synoptic Weather Record", form 2311, an example of which, reduced in size appears in Fig. 9. The "Monthly Climatological Summary", form 2301, was also completed regularly. These records are available for consultation at the Head Office of the Meteorological Branch in Toronto. In order that as much as possible of the meteorological information obtained at Lake Hazen could be easily accessible in one place, as many observations as possible were entered on these daily sheets. Thus the "Notes" (column 71) contain, at appropriate seasons, details of the times of occurrence of aurora, duration of sunshine, run of wind at various levels, daily variations in the level of Lake Hazen and miscellaneous other observations.

Before the failure of power supplies for the radio, attempts were made to transmit observations regularly to Thule and Resolute Bay. The reports were therefore coded into 5-figure groups on the daily sheets and this was continued for the sake of completeness throughout the period of observations. They provide additional information, particularly the "ww" and "W" (present and past weather) groups, and also the groups in which the cloud types are described in detail.

During the summer, in addition to the 3-hourly programme, many aviation observations were taken for the benefit of visiting or passing aircraft. These were also entered on the daily synoptic sheet, together with simultaneous observations at some of the Joint Weather Stations, particularly Alert and Eureka, which in themselves provide many interesting comparisons.

SYNOPTIC WEATHER RECORD

COPY Fig. 9.

STATION: LAKE HAZEN PROV. N.W.T. DATE FROM APRIL 26 1958 TO 27 1958

1. BAROMETER, TEMPERATURE and PRECIPITATION READINGS	1500 Z	2100 Z	0300 Z	0900 Z
2. Barograph Reading	1005.2	1003.8	1001.5	997.7
3. 3-hour Character and Amount	⌒ 0.7	～ 1.0	⌒ 1.5	⌒ 1.9
4. Attached Thermometer	56	57	51	54
5. Barometer as read	1004.3	1003.0	1000.0	996.5
6. Total Correction	+0.7	+0.6	+1.2	+0.9
7. Station Pressure	1005.0	1003.6	1001.2	997.4
8. Reduction to Sea Level	22.4	22.5	22.4	22.3
9. Sea Level Pressure	1027.4	1026.1	1023.6	1019.7
10. Dry-Bulb Temperature	-24.5 -24.0	-21.4 -21.1	-25.2 -24.8	-25.2 -24.8
11. Wet-Bulb Temperature	-24.5 -24.0	-21.2 -20.9	-25.2 -24.8	-25.3 -24.9
12. Depression	0.0 0.0	-0.2 -0.2	0.0 0.0	+0.1 +0.1
13. Dew Point Temperature	-30	-24	-31	-33
14. Relative Humidity	72	85	72	65
15.				
16.				
	1800 Z	**0000 Z**	**0600 Z**	**1200 Z**
2. Barograph Reading	1004.8	1003.0	999.5	995.7
3. 3-hour Character and Amount	⌒ 0.4	⌒ 0.9	⌒ 1.9	⌒ 1.9
4. Attached Thermometer	57	50	54	57
5. Barometer as read	1004.0	1001.4	998.4	994.9
6. Total Correction	+0.6	+1.3	+0.9	+0.6
7. Station Pressure	1004.6	1002.7	999.3	995.5
8. Reduction to Sea Level	22.5	22.4	22.3	22.2
9. Sea Level Pressure	1027.1	1025.1	1021.6	1017.7
10. Dry-Bulb Temperature	-19.2 -18.9	-24.0 -23.6	-29.3 -28.7	-20.0 -19.7
11. Wet-Bulb Temperature	-19.0 -18.7	-24.0 -23.6	-29.3 -28.7	-20.0 -19.7
12. Depression	-0.2 -0.2	0.0 0.0	0.0 0.0	0.0 0.0
13. Dew Point Temperature	-21	-30	-35	-25
14. Relative Humidity	90	72	72	77
15.				
16.				
17. Maximum	-16.6 -16.7	-11.5 -11.7	-22.0 -22.0	-19.9 -19.9 (-19.7)
18. Maximum-check after resetting	-18.7 -18.8	-22.0 -22.0	-28.3 -28.2	-19.9 -19.9
19. 24-hour Maximum	X	X	X	-11.7
20. Minimum	-26.2 -25.7	-24.7 -24.2	-33.2 -38.7	-33.5 -33.0
21. Minimum-check after resetting	-20.6 -20.2	-23.9 -23.4	-29.0 -28.5	-21.0 -20.6
22. 24-hour Minimum	X		X	X
23. Grass Minimum	– –	– –	– –	– –
24. Rainfall	X 0	X 0	X 0	X 0
25. Actual Snowfall and ÷ 10	0 0	0 0	0 0	0 0
26. Total 6-hour Precipitation	0	0	0	0
27. 24-hour Rainfall	X	X	X	X 0
28. 24-hour Snowfall and ÷ 10	X		X	0 0
29. Total 24-hour Precipitation	X	0	X	0
30. Total depth of Snow on Ground	12	12	12	12
31. (T-12) Temperature 12 hours prev.	-27.5	-24.6	-18.9	-23.6
32. (T0) Current Temperature	-18.9	-23.6	-28.7	-19.7
33. Sum (T-12+T0)	-46.4	-48.2	-47.6	-43.3
34. Mean (Sum ÷ 2)	-23.2	-24.1	-23.8	-21.7

Date (LST) 35	Hour EST 36	G.M.T. 37	Ceiling (hundreds of feet) 38	Visibility (miles) 39	Weather and Obstructions to Vision 40	Sea-level Pressure (mb) 41	Dew Point (°F) 42	Wind Direction (16 pts.) 43	Wind Speed (mph) 44	Station Pressure (mb) 45	Corr. Dry Bulb (°F) 46	Corr. Wet Bulb (°F) 47	Relative Humidity (%) 48	Total Opacity 49	Total Amount 50	Lowest Layer Opacity 51	Amt 52	Type 53	Height 54	2nd Layer Opacity 55	Amt 56	Type 57	Height 58	Sum Amt 59	3rd Layer Opacity 60	Amt 61	Type 62	Height 63	Sum Amt 64	4th Layer Opacity 65	Amt 66	Type 67	Height 68	Observer 69
26	10	15		35		1027.4	-30	↗	07	1005.0	-24.0	-24.0	72	0	0		0				0			0		0			0		0			CRH
26	13	18		35		1027.1	-21	↑	01	1004.6	-18.9	-18.7	90	0	0		0				0			0		0			0		0			CRH
26	16	21		30		1026.1	-24	↗	01	1003.6	-21.1	-20.9	85	0	0		0				0			0		0			0		0			DIS
26	19	00		25		1025.1	-30	↓	03	1002.7	-23.6	-23.6	72	0	0	0	0																	CIJ
26	22	03		40		1023.6	-31		C	1001.2	-24.8	-24.8	72	0	1	0	1	Ac	150					1					1					CIJ
27	01	06		40		1021.6	-35		C	999.3	-28.7	-28.7	72	0	1	0	1	Ac	150	0	1	C₁	200	1		0			1		0			JMP
27	04	09		40		1019.7	-33		C	997.4	-24.8	-24.9	65	1	2	1	1	Ac	120	0	1	Ac	160	2	0	1	C₁	200	2		0			JMP
27	07	12		40		1017.7	-25	↙	02	995.5	-19.7	-19.7	77	0	1	0	1	Ac	160		0			1		0			1		0			JMP

CODED SYNOPTIC REPORTS

Hour GMT	(II) iii	N dd ff (50 43 44)	VV ww W (39 40 72)	PPP TT (41 46)	Nh CL h CM CH (51—68)	TdTd app (42 3)	(99 ppp)	7 RR Rt s (26 72 30)	Whole Inches	8 Ns C hshs (51—68)	8 Ns C hshs (51—68)	8 Ns C hshs (51—68)	9 SpSp spsp (71)	2 HsGsHs σ3	3R24R24R24R24 (29)	4 TxTx TnTn (17—22)
15	Lake Hazen	02206	85010	27476	00900	70807										12 | 24
18	"	01801	85020	27181	00900	79704									X	4(83)65
21	"	02401	83020	26179	00900	76710										12 | 18
00	"	03603	82020	25176	00900	70709										48865
03	"	10000	86020	23675	10930	69715										24 | 24
06	"	10000	86030	21671	10951	65719				81365					X	48865
09	"	20000	86020	19775	20971	67719										↓ (24) | 12
12	"	10402	86010	17780	10940	75719				81366			90412			48867

NOTES

Unusual clouds, visibility, humidity, pressure changes; floods, frosts, freeze-up and break-up of lakes, rivers and harbours; wind damage; optical phenomena, etc.

Bright sunshine 19.0 hrs.

0530 Superior mirage very well developed on opposite shore of Lake to S.W.

0700 Only wind at 40'

INSTRUMENT DEFECTS

	Anemometers 1'	3'	10'	40'
Readings	3650.9	4821.0	4697.4	
24-hr totals	32.5	38.5	39.1	30.8 (see note)

INSTRUMENT CHANGES: Anemometer operating 0800 L.S.T.

DURATION OF WEATHER

Thunderstorms and Precipitation: Type	Times (LST) of Beginning	Ending	Thunderstorms and Precipitation: Type	Times (LST) of Beginning	Ending	Obstructions to Vision: Type	Times (LST) of Beginning	Ending

SUMMARY FOR THE CLIMATOLOGICAL DAY

(24 hours through to 1200Z observation of following day unless noted*. Entries in columns 77, 78 and 97-101 are for the date based on LST shown in column 74).

Day of the Month 74	Temperature: Maximum 24 hours ending 1200Z 75	Minimum 24 hours ending 0000Z 76	Rel. Humidity: Maximum % 77	Minimum % 78	6-Hour Total Amount 1800Z 79	0000Z 80	0600Z 81	1200Z 82	24-Hour Amount Rainfall (R, RW, L, ZR, ZL, A) 83	Snowfall (S, SW, E, EW, SP, SG, IC) 84	Total 85	Depth of Snow on the Ground (inches) (see line 30 of previous date) 86	Day with	Freezing Temperature (see Col. 76) 87	Thunderstorms 88	Liquid: Rain or Drizzle 89	Freezing: Rain or Drizzle 90	Frozen: Hail 91	Snow (S, SW, E, EW, SP, SG, IC) 92	Fog, Ice Fog (vis. less than ½ mile) 93	Smoke or Haze 94	Dust, Blowing Dust, Blowing Sand 95	Blowing Snow 96	Winds of 32 or more m.p.h. 97	39 or more m.p.h. 98	Peak Wind Gust Direction (use wind arrows) 99	Speed m.p.h. 100	Time to nearest hour LST 101
26	-11.7	-35.2			0	0	0	0	0	0	0	12	NO		✗	✗	✗	✗	✗	✗	✗	✓	✓	✓	✗			
													YES	✓														

(Peak wind gust: leave blank if gust does not exceed 18 m.p.h.)

METEOROLOGICAL BRANCH - DEPARTMENT OF TRANSPORT - CANADA

Form 2311

CERTIFIED CORRECT [signature] O.I.C.

CHAPTER III

TEMPERATURE

The method chosen of demonstrating the implications of the records of temperature, wind and other parameters at Lake Hazen is that of a fairly detailed comparison with conditions at the permanent weather stations of Alert and Eureka during the same period. Detailed, that is, in the climatological sense, involving the weather of the year as a whole. Fluctuations of the order of a day or so will be considered in the section on synoptic climatology.

The comparative method has several advantages. The data from Alert and Eureka were made readily available through the courtesy of the Meteorological Branch, in the form of microfilmed copies of the daily synoptic sheets. The stations themselves are sufficiently close to Lake Hazen to share, on most occasions, the same synoptic situations. Most important, comparison with these two coastal locations enables a fair assessment to be made of the influence of the Lake Hazen station's inland position on the weather which it experiences.

Figure 10 shows the essential temperature means at Lake Hazen in the usual form of annual curves; the data from which it is plotted appears

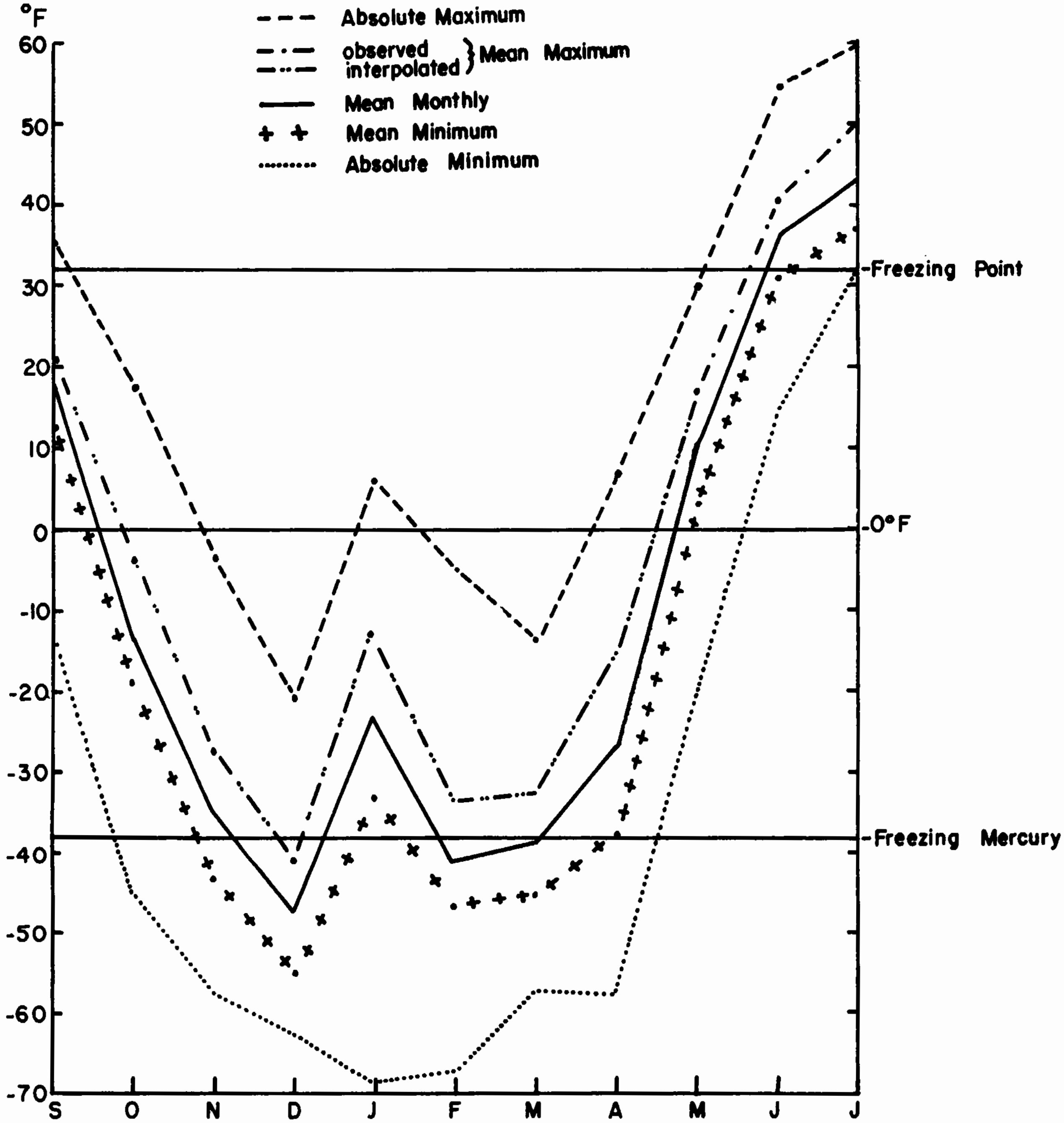

Fig. 10. Monthly Mean Temperatures, Lake Hazen, September 1957 - July 1958.

in Appendix A. "Annual", here as elsewhere, must be taken to mean the period from August 1957 to August 1958 although in fact no mean data for August were available as observations were only taken during the last ten days of August 1957 and the first ten days of August 1958.[1] It is probable that August, being a snow-free summer month, has mean temperatures very similar to those of June. The highest temperature recorded in early August 1958, 54.3°F., helps to confirm this.

The graph is also incomplete in that mean maximum temperatures are not available from the record from October through April. In each of these seven months, temperatures below the freezing-point of mercury meant that accurate maxima could not be obtained on a daily basis, although even in December, the coldest month, the temperature did rise above - 38°F. long enough for the probable absolute maximum for the month to be determined. The mean maximum values for these winter months have therefore been interpolated. The mean temperature for the month is defined, according to Canadian practice, as half the sum of the mean daily maximum and the mean daily minimum. During the winter months, however, the mean temperature was taken as the mean of the dry-bulb temperatures at the four main synoptic observations, separately summed and averaged. This dry-bulb mean is usually very close (within a few decimal places) to the orthodox monthly mean temperature and thus a reasonable estimate of the mean monthly maximum can be obtained by plotting it the same number of degrees above the monthly dry-bulb mean as the mean monthly minimum is below it.

---

[1] Even if the periods had overlapped slightly, it would of course be unrealistic to mean together portions of the same month in different years.

The curves of temperature in Fig. 10 are very far from what might be considered climatologically normal. Summer, making allowance for the absence of August data, is probably fairly typical and the spring warming and fall cooling progress fairly steadily. In winter, however, the warmth of January 1958 is in sharp contrast to the very cold December which preceded it and to the two months which followed. Only the curve of absolute minimum temperatures reached its lowest point in January when - 68.5°F. was recorded on January 4.

Considering this annual curve in more detail, Fig. 11 shows the ten-day running means of mean daily temperature at Lake Hazen, Alert and Eureka throughout the observational period (with the exception that no data for Eureka in August 1957 are available.) The values of the mean temperature were calculated by meaning the dry-bulb temperatures at each of the eight main and intermediate synoptic observations. These were grouped into ten-day running means with the value plotted on the fifth day in the series.

The choice of a ten-day period enables each of the three principal influences on the temperature curve to be recognised separately. In order of decreasing importance these are:

(1) The annual cycle of insolation, responsible for the broad pattern of summer warmth and winter cold.

(2) The major synoptic disturbances which give rise to fluctuations on this major curve. At this latitude they are expressed for the greater part of the year as warming trends.

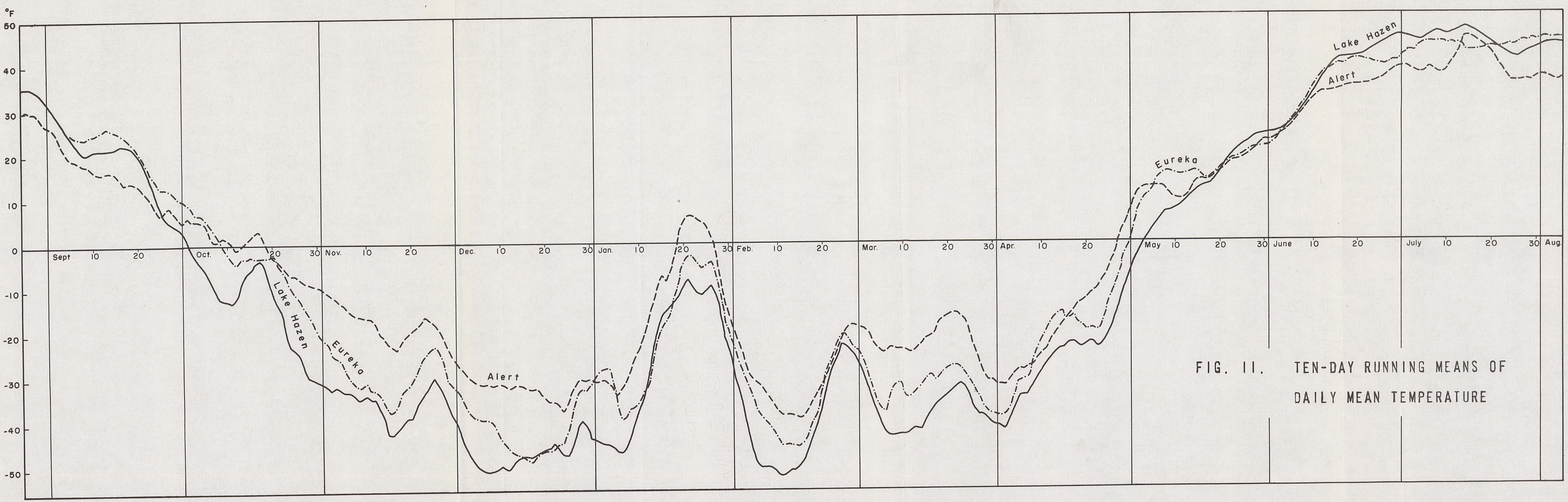

FIG. 11. TEN-DAY RUNNING MEANS OF DAILY MEAN TEMPERATURE

(3) The local position of each station which causes the temperature curve at one to be several degrees higher or lower than at another, the sign and amount varying with the season.

Each of these influences will now be considered separately.

THE ANNUAL CYCLE OF INSOLATION

Although the sun's apparent progression northwards in summer and southwards in winter is perfectly regular, at the latitude of northern Ellesmere Island the annual cycle of insolation is not that of a regular wave, with a definite maximum in summer and minimum in winter. The summer maximum is present, but the fact that the sun is below the horizon at Lake Hazen approximately from October 16 until February 28 means that the insolation cycle is of the form , with receipts for a large part of the winter being for all practical purposes nil. Thus whereas in mid-latitudes the time when the curve of winter temperature should be at its lowest is in January, just before insolation begins to exceed radiational loss, this minimum is postponed, in normal circumstances, until February or March. At Floeberg Beach, as was seen in Chapter I, the coldest temperatures experienced by Nares in the winter of 1875-76 were in early March, with a maximum for the month of -8° F., and a minimum of -74° F. As the altitude of the sun in summer declines rapidly after reaching its solstice, a similar delay in reaching the maximum, produced by the continuous daylight, is not of such importance, and the apex of the temperature curve, on theoretical considerations involving insolation alone, is probably in middle or late July in northern Ellesmere Island. The expected annual cycle, on these assumptions, would thus show a gradual cooling for eight or nine months of the year, followed by a rapid rise to the summer peak. In so far as data is available, and omitting the other influences on the curve, this pattern can be demonstrated in the three curves in Figure 11 for 1957-58.

Comparing the two ends of the curve with each other, it would appear that the decline in daily mean temperatures during August is fairly slow, as contrasted to the fall in subsequent months. This is probably the usual situation, although it seems that the summer of 1957 was, if anything, somewhat warmer than that of 1958 at Lake Hazen and so the 9 °F difference between the ten-day mean on August 6 1958 and that on the 25th of the month in the previous year might be somewhat greater in average conditions.

With the beginning of September, however, the mean temperature at Lake Hazen reached freezing-point and thereafter the fall in temperature continued, with minor interruptions, until the first week in December. By September 8 the ten-day mean at Lake Hazen was slightly above 20°F. and on the 25th had reached 10°. At this point the mean at Alert, which during the summer appears to be continuously below that at Lake Hazen, reversed its position. Soon afterwards Alert became, in mean values, warmer also than Eureka and these relative positions continued for most of the rest of the winter.

The general rate of cooling continued until the end of October by which time the ten-day mean at Lake Hazen was $-31^{\circ}F$. This was ten degrees colder than at Eureka and over twenty degrees colder than at Alert. At this point the cooling rate at Lake Hazen slackened, but the other two stations continued to decline rapidly so that by November 14, the ten day means at both Eureka and Lake Hazen were between -30° and $-35^{\circ}F$.; at Alert they were slightly below $-20^{\circ}F$.

A warming tendency affecting all the stations in the latter part of November was followed in early December by renewed and rapid cooling, which ceased at Lake Hazen by December 8 when the ten-day mean dipped below $-50^{\circ}F$., a temperature recorded on only one day throughout the whole winter at Alert. Eureka reached its coldest mean temperature of the first part of the winter on December 17, when the ten-day mean was $-48.5^{\circ}F$. Alert dipped to $-37^{\circ}F$. on December 24.

Thereafter, although the absolute winter maximum was recorded at Lake Hazen in early January, the mean temperature rose slightly in the first few days of 1958 and then increased very rapidly to a peak in the last third of the month. A fall to the more usual low values was not completed until the middle of February and it was again followed by dynamical warming in the latter part of that month, so that it is difficult to be certain whether temperatures in mid-February did fall to their seasonal low before warming set in. It seems likely, however, that they did, and this enables another reference point to be established on the annual temperature curve as related to insolation and radiation. It will be seen that the ten-day means dropped in mid-February to values only slightly lower than (at Eureka not quite so low as) those recorded in early December. This implies that by early December the principal radiational loss from the ground surface has been effected. Heat loss will continue to take place as long as there is a thermal gradient between air, snow and permafrost, but it takes place at a much slower rate. Thus, although the coldest temperatures might, from a consideration of the annual insolation cycle, be expected to occur in late February or March, the slow rate of radiative cooling from mid-December onwards means that synoptic disturbances will usually be much more important in determining the exact date on which the lowest temperatures are recorded. This date might be at any time from late December onwards. This is probably especially true inland, where the ground is frozen throughout the year at no great distance below the surface and is thus a poor source of radiative heat. On the coast the presence of relatively warm water below the surface ice provides a radiative source which would continue to be of significance for a longer period, reaching a minimum when the ice thickness is at its greatest.

At the end of February temperatures again began to fall rapidly, but before they could reach their seasonal minima, the fall was interrupted by synoptic events. These were short-lived, and temperatures again began to drop in the latter part of March but their fall was this time limited by the growing significance of the incoming solar radiation, and thereafter all stations shared in a general and, on the whole, very regular warming phase which lasted until and after the thaw in early June.

It should perhaps be pointed out that cooling in the latter part of March is cooling towards the seasonal minima, i.e. that it is not a case of the seasonal warming beginning in the early part of the month and being interrupted by synoptic events. The only source of cold air which could cause a fall of 10°F. in a ten-day running mean at temperatures as low as those experienced in northern Ellesmere Island would be the Greenland ice-sheet and, on the evidence of the station records alone it seems that this source is relatively unimportant. The subject must be considered in more detail in the section on synoptic climatology, but it seems unlikely that an easterly flow around the northern part of a depression, which is the only way cold air from Greenland could reach the stations, could have such a pronounced effect over a period as long as ten days. Katabatic flow, of course, may be discounted as it is impossible that such a surge of cold air, by nature very shallow and flowing under the influence of gravity, would have such a similar effect on all three weather stations. It is, on the other hand, relatively easy to provide for advective warming influences to cause a rise in temperature; they evidently did so in January with much greater force and are all the more likely as temperatures rise in more southerly latitudes.

Of particular relevance to the preceding hypotheses is Longley's study (39) of the ten-year record at Resolute. Although the present study was practically completed before Longley's paper was considered, both the technique of analysis and the conclusions reached are remarkably similar. Longley also shows the significance of dynamic influences (which, considering a relatively long period, he terms "non-cyclic") and concludes that at Resolute "the time of minimum temperature may be any time between 15 January and 8 March." (39, p.461) At Resolute the sun is only absent between November 6 and February 5, so that at Lake Hazen the period when the minimum is likely to occur in any year may reasonably be extended at least two weeks in each direction.

Longley extended his study to consider the six-hour temperature changes during the winter, which represent diurnal fluctuations and hence the direct effect of insolational heating. He found that

> the effect of the returning sun is noticeable after 20 February although the heating effect may not be great enough to compensate for the radiation from the earth before 1 March. Before the end of the first ten days of March the sun's heat has definitely begun to cause the mean temperature to rise." (39, p.463)

Thus the lag at Resolute between the reappearance of the sun and its effect becoming apparent in daily mean temperatures appears to be about two or three weeks. If it is legitimate to expect a similar lag at Lake Hazen, then the effect may be expected to become noticeable some time after the middle of March, probably in the last ten days of the month. From Fig. 11 it can be seen that the effect apparently commenced at the beginning of April according to the convention of the ten-day mean. Longley's study thus seems to provide confirmation of the conclusions which had been drawn from a consideration of the three curves in Fig. 11 alone.

The most striking feature in the rise of temperature which occurred between April 1 and June 10 is the regularity with which it occurred and the close similarity of the temperature curves at all three stations. It is clear from this that the insolational control on air temperature is the most effective in this period. Synoptic events can accelerate the rise in temperature slightly; they can delay it to a less extent. Local differences are also at a minimum, with the solid ground still being snow-covered and the depth of the sea ice at a maximum.

Although the shape of the Lake Hazen curve seems to suggest that this warming trend continued unchanged until at least the later part of June, the flattening of the curve at Alert points to the change which took place in the relative importance of the controls after the air temperature reached freezing-point. When the snow has gone from the land surface, contrasts between coastal and inland sites tend to increase in relative importance. Eureka, although on tidewater, is relatively landlocked compared to Alert and therefore shares part of the Lake Hazen regime. Even at Lake Hazen, however, the nearness of an extensive ice and water body has important effects. Thus in summer the importance of direct solar control on air temperature is considerably modified at all three stations and it is impossible to tell from the curves when the theoretical maximum might be expected. It is evident, however, that such a maximum would give a ten-day mean above 50°F. and it is synoptic and local circumstances which cause the curves to be lower than this value. It is probable that such conditions of more direct solar control on summer temperature existed at Lake Hazen in 1957, when the early summer was reported to have been marked by much finer weather than that of 1958. Even in 1958 a more regular curve might have been obtained at Lake Hazen if the screen had been situated several miles from the lake instead of about thirty yards from its shore.

The solar control on air temperature, then, is most clearly shown during spring and fall, when the sun's elevation is changing rapidly. At these times, although synoptic disturbances cause minor fluctuations in the curve at all three stations, the rise or fall of daily mean temperature is remarkably steady. Local differences are also weak in the spring and early fall, although they increase in importance as mean temperatures decrease. At the other seasons of the year, by contrast, solar influences are liable to considerable modification by the other two controls. In winter, as was shown earlier, the radiative loss from the ground is slow, and synoptic influences are relatively much more significant, while local influences are also marked, as the wide gap between mean temperatures at Alert and Lake Hazen clearly shows. In summer synoptic disturbances are always likely to invade the area, while the differences in weather conditions between coast and interior are very great, perhaps more so than emerges from a consideration of temperature alone.

DYNAMICAL INFLUENCES

The effects on air temperature brought about by the advection of warmer or colder air from distant areas is part of the broad synoptic climatology of the Arctic which will be considered later; here only the magnitude of the effects of synoptic disturbances which are clearly recognisable in the curves of mean temperature will be considered.

Referring once more to Fig. 11, the first major advective influence which can be detected in the observational period is the warming which took place in mid-October, at a time when, as was concluded in the previous section, solar control is at its strongest. The effects were felt in varying degrees at all three stations, being most marked at Lake Hazen, where the mean temperature had fallen very rapidly in the preceding two weeks. The ten-day mean rose from -13°F. on October 11 to -3.5°F. on the 17th; at Alert the rise was only about half that amount, and at Eureka the effect of the warm advection was only to arrest the cooling trend for about a week.

A similar and rather longer warming period occurred during the second half of November. This time the shape of the curves at all three stations was similar, although the warming took effect later and disappeared earlier at Alert than at the other two stations, where mean temperatures were very much colder.

A brief and rather ill-defined warming trend at the end of December 1957 was followed by the remarkable events of January 1958. In considering this great anomaly in regional temperature it is important to remember that such conditions are in fact unique within the period of observational records. The freezing rain recorded at Alert on January 23-24, when the maximum temperature there reached 32.3°F. is not only the only time rain has been recorded in January in the Queen Elizabeth Islands but is the only known instance north of the Canadian mainland. Thus, while it is of very great significance in indicating the maximum amount of dynamical warming which is possible at these latitudes in mid-winter, it must not be viewed as something which is likely to happen in any winter.

As far as the actual magnitude of the changes is concerned, the ten-day mean at Lake Hazen on January 6 was - 46.7°F.; on January 21, two weeks later, it was - 8.0°F., a rise of 38.7°F. or nearly 2.6°F. a day in ten-day means. At Alert on January 5 the ten-day mean was - 33.7°F.; on January 21 it was +6.1°F., a rise of 39.8°F. or 2.5°F. a day and at Eureka on January 6 the ten-day mean was - 39.1°F., rising 36.4°F. to - 2.7°F. on the 21st. The winter temperature of northern Ellesmere Island became for a brief period a close approximation to the seasonal normals of Winnipeg or Saskatoon, 2500 miles to the south.

The swift rise in temperature caused by the invasion of warm air was followed by an equally swift fall as its influence diminished and conditions reverted to normal. The ten-day means at Lake Hazen fell by forty degrees in the eleven days from January 26 to February 6. In terms of actual temperatures the decrease was even more abrupt. On January 30 the maximum for the day was - 1.0°F. at Lake Hazen; from February 2 until February 17 only one dry-bulb temperature above - 40°F. was recorded. This serves to illustrate the very ephemeral effect which individual dynamical disturbances have on the winter climate of the High Arctic, however intense they may be. The rise in air temperature caused a rise in soil temperature near the surface as Powell's studies indicate,[1] but a few days of near 0°F. temperatures are insignificant when compared to the rapidity with which the heat is radiated again into the arctic night. Thus the ten-day means reached their coldest value of the winter at Lake Hazen on February 11 (- 51.7°F.); the coldest temperature of the observational period at Alert was recorded two days later (- 50.9°F.) and Eureka's coldest of - 61.7°F. occurred on the 19th.

By this time, however, another warming trend was beginning which rose rapidly to a peak of about - 20°F. at all three stations in late February and then fell swiftly again. On this occasion temperatures did not fall as low as before, and synoptic events continued to moderate winter temperatures until the spring rise in temperature began at the beginning of April. Thereafter the purely dynamical control decreased in relative and absolute importance. In spring, as in the fall, its effects were on the whole only strong enough to modify slightly the change in temperature. Thus at Lake Hazen from April 1 till June 1 no ten-day mean temperature was more than 1°F. below the previous high and although the same is not true of the other stations, Eureka in particular, the general pattern is the same.

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1 Personal communication

In the summer the situation is more complex. Synoptic events, as was mentioned earlier, were influential in causing temperatures to be lower than would have been the case if insolation had been the sole factor involved, but the synoptic effects are of a different type to those which are important in winter. It is not simply that they are more important in causing falls in temperature instead of rises. More important is the way in which the control is exerted. The thermal changes in winter were caused by the physical advection of large amounts of warm air. In summer also warm air arrives from the south, but it contains much more moisture than in winter and so tends to give rise to a dense cloud cover. At all three stations it was the presence of a cloud cover restricting insolation which was the main cause of the relatively cool temperatures. This is very well illustrated by comparing Fig. 11 with the sunshine totals in late July in Fig. 37. At Alert this question of atmospheric humidity is particularly important; the much lower temperatures are due to a considerable extent to the prevalence of fogs, from which Lake Hazen especially was relatively free during the summer.

LOCAL INFLUENCES ON THE TEMPERATURE CURVE

The final control on air temperature, the local and regional situation of the stations, is much more straightforward, although this does not mean it is any less important to this study.

To be able to assess these local influences it is of course essential to know the conditions at the station sites. Their relative positions are shown in the Location Map (Fig. 1); Lake Hazen is about 220 miles from Eureka and 100 from Alert. Alert weather station is situated at 218 feet[1] above sea-level, about a mile inland from the head of Dumb Bell Bay, with the Arctic Ocean to the north, generally low land around the station, and the mountains of Grant Land rising behind a few miles to the south. The station elevation at Eureka is only eight feet above sea-level and it is situated on Slidre Fiord, an arm of Eureka Sound, itself a much greater fiord system connecting with the Arctic Ocean. The three sites are thus very different from each other: Alert on an exposed coast, Eureka close to sea-level, but sheltered by land surrounding the fiord system, and Lake Hazen, 522 feet above sea-level in the Lake Hazen trough and in the shadow of the Garfield Range.

Whereas summer temperatures at Eureka and Lake Hazen are, on the evidence of a single year, very much the same in terms of mean values, Alert is considerably colder and it was not until late September that the Alert and Lake Hazen curves intersected. They did not meet again until the beginning of the following summer. In late September the separation between the curves at Eureka and Lake Hazen also became distinct and this too, with a few exceptions, continued until the following summer. Of considerable interest is the halt in the fall of temperature which both Eureka and Lake Hazen experience in the latter two thirds of September,

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[1] Some references give 205 ft.

but in which Alert does not share. In the preliminary reports on the Lake Hazen data (See, e.g. (9)) the author attributed this delay at Lake Hazen to the presence of open water in the vicinity of the station after the air temperature had fallen below freezing. The relative warmth of the lake was, it was assumed in the preliminary report, responsible for causing the low and generally complete cloud cover in the vicinity of the lake (see Chapters VIII and X and Fig. 3) and for preventing screen temperatures, measured only thirty yards from and 12 feet above the lake, from falling below about 20°F. until the lake itself froze over.

This still appears to be a reasonable hypothesis and it appears from Fig. 11 that the same happened at Eureka also. Thus Slidre Fiord froze over completely on September 14 (as noted in the daily sheet at Eureka) and the temperature began to fall rapidly a few days later. Lake Hazen did not freeze over completely until about September 24 (9) and hence the fall was delayed several days. At Alert the Arctic Ocean is rarely free of ice to any extent and the fall in temperature was more regular.

In November and December, when synoptic disturbances did not have an appreciable effect on temperature, the difference in mean temperatures between the stations increased to between 15° and 20°F. As each plot in

Fig. 11 represents the mean value of eighty observations over a ten-day period, the very great differences between coast and interior are apparent. One reason is the frost-hollow site of the Lake Hazen station: cool air drains down the mountains and tends to collect over the lake. In this respect, therefore, Lake Hazen is not perhaps representative of the more exposed situations inland. However it seems true also that the interior receives much less wind than the coast and calm conditions do much to help the development of an intense inversion. Eureka also has a frost-hollow site in the bottom of the fiord, which accounts for its temperatures being much lower than those at Alert; it is, however, much windier than Lake Hazen and this helps to explain why mean temperatures do not fall quite so low as they do inland.

At times of dynamical warming, the difference between the three mean temperatures becomes closer, although the differences are greater than a cursory study of Fig. 11 would suggest. Thus throughout the fall in temperature in late January and early February, when the Alert and Lake Hazen curves appear to be close together, the ten-day mean at Lake Hazen was always at least 5°F. colder than that at Alert.

The unusual fluctuations in temperature at the three stations during the spring warming are not immediately explicable in terms of local differences and it is perhaps preferable to defer consideration of them until the synoptic climatology is taken into account. The three stations shared practically the same ten-day mean temperature on May 20 and from then until temperatures rose above freezing in the first half of June the three curves remained close together. After the thaw, however, they separated again, and on the whole Lake Hazen was a few degrees warmer than Eureka and about seven degrees warmer than Alert. Alert's summer weather is a mixture of fog, low cloud and occasional periods of fine weather. Eureka and Lake Hazen, less liable to these fluctuations, might be rather warmer were it not for the presence of relatively cold ice or water nearby.

To express quantitatively the differences between the stations during the observational period, Fig. 11 was sampled to derive comparative temperatures at Alert and Eureka for different temperature groups at Lake Hazen. The temperatures at each of the permanent stations were placed in groups according to five-degree intervals at Lake Hazen and each group was meaned. These means, and the difference of the mean from the mid-point of the corresponding temperature group at Lake Hazen, are set out in Table VIII. The groups naturally vary considerably in size, with only four observations at Lake Hazen falling in the ranges 35° to 40°F. and 30° to 35°F., while there were as many as 36 observations in the group 40° to 45°, this being the usual ten-day mean temperature throughout the summer of 1958. The data are clearly too sparse for any valid regression lines to be derived from the differences. However, they do present more clearly some of the features which have been discussed qualitatively in the preceding pages. Thus the difference between Alert and Lake Hazen is always negative at temperatures above 15°F. and always positive below 5°F., the difference generally increasing with lower temperatures. Eureka temperatures always tend to be warmer than those at Lake Hazen, although the differences are fairly small at temperatures of 15°F. and above.

TABLE VIII

COMPARISON OF TEN-DAY RUNNING MEANS AT LAKE HAZEN, ALERT AND EUREKA

Temperature groups Lake Hazen	Mean of Temperatures at Eureka	Mean of Temperatures at Alert	Differences from mid-point of Lake Hazen groups at Eureka	Differences from mid-point of Lake Hazen groups at Alert
45 to 50	42.8	40.4	+0.3	- 2.1
40 to 45	42.2	36.3	+0.3	- 6.2
35 to 40	38.0	31.8	+0.5	- 5.7
30 to 35	33.3	29.3	+0.8	- 3.2
25 to 30	27.8	25.4	+0.3	- 2.1
20 to 25	23.0	18.2	+0.5	- 4.3
15 to 20	17.6	14.7	+0.1	- 2.8
10 to 15	14.5	12.5	+2.0	0
5 to 10	14.2	9.6	+7.1	+ 2.1
- 0 to 5	11.1	9.1	+8.6	+ 6.6
- 5 to 0	- 4.6	8.3	+7.1	+10.8
- 10 to - 5	- 1.2	4.3	+6.3	+11.8
- 15 to - 10	- 5.4	- 0.1	+7.1	+12.6
- 20 to - 15	- 14.0	- 6.9	+3.5	+10.6
- 25 to - 20	- 18.6	- 13.1	+3.9	+ 9.4
- 30 to - 25	- 22.3	- 18.6	+5.2	+ 8.9
- 35 to - 30	- 27.6	- 18.2	+4.9	+14.3
- 40 to - 35	- 33.3	- 24.6	+4.2	+12.9
- 45 to - 40	- 34.7	- 27.9	+7.8	+14.6
- 50 to - 45	- 41.8	- 33.2	+5.7	+14.3
- 55 to - 50	- 43.2	- 34.8	+9.1	+17.7

DAILY MAXIMA AND MINIMA

The main interest in the temperature extremes at Lake Hazen concerns the maxima in summer and the minima in winter and this is true both for absolute extremes and for daily values.

The principal feature of the daily maximum temperatures at Lake Hazen is their very small variability throughout the summer. Between June 1 1958 and the end of observations on August 10 there were only four occasions on which a daily maximum differed from the previous day's value by more than 5°F., compared to twenty-one such occasions at Eureka and thirteen at Alert, several of these last being changes of maximum temperature of 10° to 15°F. from one day to the next. Nearly half the daily maxima at Lake Hazen during that period were between 50° and 55°.

Daily minimum temperatures were usually very similar at all three stations during the summer of 1958, tending to fall in the range 30° to 40°F. and usually above freezing-point. In winter, however, the differences between the stations were almost always considerable, with Alert having the highest and Lake Hazen the lowest minima. Variation from day to day was quite large, but from October 20 1957 until the end of that year the daily minimum at Alert was higher than that Lake Hazen on every occasion.

Table IX shows these differences in winter minima very strikingly. On only 35 days out of the 355 in the observational period did the temperature at Alert not fall below freezing-point, compared to 61 days at Lake Hazen. The main feature, however, is the frequency of very low temperatures recorded at the inland site by comparison with the permanent stations, particularly its nearer neighbour. Thus on exactly one-third of the days in the year temperatures below the freezing-point of mercury were experienced at Lake Hazen and temperatures below - 50°F. were recorded on 73 days or the equivalent of more than ten weeks.

TABLE IX

FREQUENCIES OF TEMPERATURES BELOW VARIOUS LIMITS

(Alert and Lake Hazen: August 21 1957 to August 10 1958; Eureka: September 1 1957 to August 10 1958)

LIMITS	LAKE HAZEN		EUREKA		ALERT	
	Days in Range	In and Below Range	Days in Range	In and Below Range	Days in Range	In and Below Range
Below 32.5°F. ≠	294	-	289	-	320	-
0 to - 20	38	225	33	204	62	206
- 20 to - 40	66	187	88	171	115	144
- 40 to - 50	48	121	57	83	28	29
- 50 to - 60	63	73	24	26	1	1
Below - 60	10	10	2	2	0	0

≠ Because of the method of rounding-off used in the Meteorological Branch, freezing temperatures are considered as all temperatures below 32.5°F.

To obtain quantitative measurements of the day to day variation in extreme temperatures at Lake Hazen as compared to the coast, the variance of the daily change was computed for three periods of fifty days during the observational period. The periods were selected to show the conditions during three periods of particular interest at Lake Hazen: the period after the first snow in the fall, when temperatures were continuously decreasing, and the two periods in mid-winter and mid-summer respectively. The results of the evaluation are set out in Table X.

Considering the summer period first, the significant feature is the very low values of variance for both maximum and minimum temperatures. If conditions during 1958 were representative of a longer period, then these low values of variance may be of considerable use as a forecasting aid. This question will be taken up in more detail in the third part of this study. For both the maxima and minima the variance is less at the inland station than on the coast, although Alert's minimum temperature also appears to be highly conservative from one day to the next.

TABLE X

VARIANCE OF THE DIFFERENCE BETWEEN SUCCESSIVE MAXIMUM AND MINIMUM TEMPERATURES

Station	Sep. 4 – Oct. 23 1957		Feb.3 – Mar.24 1958	Jun.20 – Aug.8 1958	
	Var. of M_x	Var. of M_n	Var. of M_n	Var. of M_x	Var. of M_n
Lake Hazen	28.638	48.488	57.142	12.158	5.634
Eureka	28.899	89.969	66.878	35.212	9.520
Alert	41.822	52.090	35.428	32.110	6.053

Conditions in mid-winter show one feature which is not to be found in either the fall or summer data. Daily fluctuation of temperature is considerably less at Alert than it is at Lake Hazen. This is, of course, because of the warmer temperatures which were experienced there throughout the winter. Whenever significant dynamical warming took place over northern Ellesmere Island the amplitude of the fluctuation was much greater at Lake Hazen than at Alert. The variance is even greater at Eureka and the author would suggest that this is because the considerable fluctuations from day to day at Eureka probably reflect both major and minor dynamical influences into the area. At Lake Hazen, by contrast, the minor synoptic disturbances passed by with little or no effect on weather conditions.[1] Thus before such values of variance, or the standard deviations which are derived from them, can be used as local forecast aids, it will be necessary to plot the distribution curves of the values of the day-to-day changes from which the variance has been computed. At Lake Hazen in mid-winter such a distribution curve would probably show a cluster of very small differences and two other clusters some distance away caused by the rise and fall of extreme temperatures during major synoptic invasions. This, however, will be deferred until a later section of this study.

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[1] This is not entirely speculation: the discussion in Chapter VII concerning the lack of strong winds at Lake Hazen by comparison with the coast deals with a similar situation.

The interesting feature of the fall period is the relatively high variances at all stations, although Lake Hazen is more conservative of both maxima and minima than either of the stations on the coast. A steady change from day to day would not be anomalous, as the mean air temperature was falling steadily throughout the period. However, the values are very much greater than would be produced by a simple radiational control and it is significant that at Lake Hazen, where the mean temperature falls farthest, the variance is the smallest. This considerable fluctuation in extreme temperatures from day to day is entirely hidden in the ten-day means of Fig. 11.

TEMPERATURES AT THE GROUND SURFACE DURING THE SUMMER OF 1958

Although the soil temperatures measured throughout the observational period by means of thermistors at depths between one foot and three feet will be discussed elsewhere by J. M. Powell, some mention may be made here of the measurements made at the soil surface with a thermometer from May 21 until regular observations ended on August 10. These temperatures may be of interest to botanists, engineers and others concerned with temperatures close to the ground.

The thermometer used for these measurements lay flat on the soil surface about five yards from the Stevenson screen (Fig. 5) with its bulb lightly covered with soil. As mentioned in Chapter II, most of the observations were taken with a thermometer correct only to within 1° or 2°C., but the nature of soil temperatures is such that errors of this amount are not so important as they are in the measurement of air temperatures.

It must be remembered that these temperatures are not minima, but only the actual temperatures at the four main synoptic observations: 1 p.m., 7 p.m., 1 a.m., and 7 a.m. E.S.T. The 1 p.m. reading was almost invariably the warmest of the day and the 1 a.m. was usually the coldest. Whilst these two times are fairly close to the theoretical optima for maxima and minima respectively, they are almost certainly seldom the actual daily extremes.

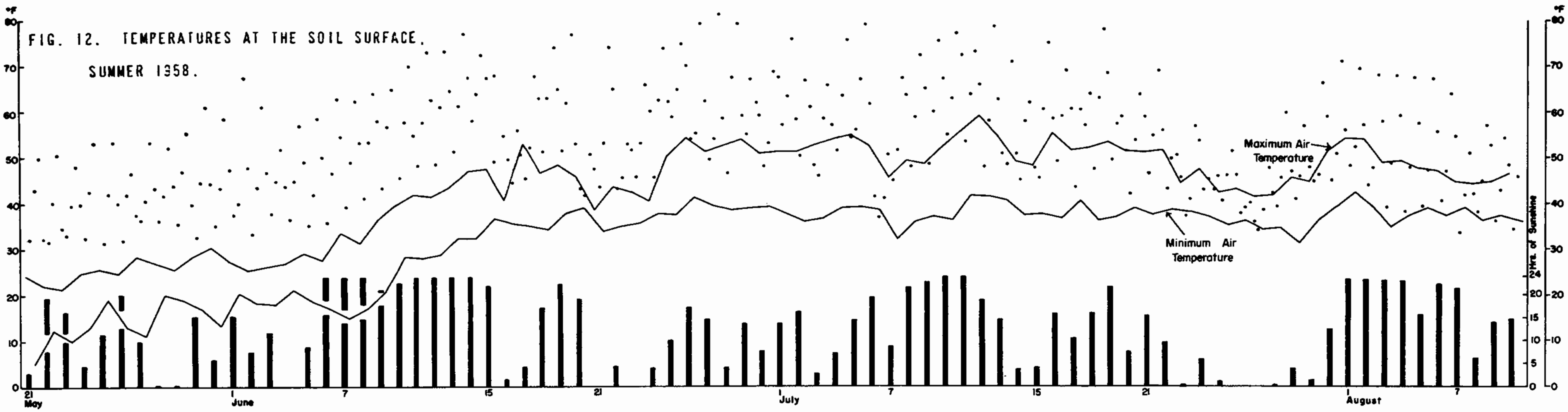
The actual observations have been plotted in Fig. 12 on the same graph as the assumed controls of the surface soil temperature: the daily sunshine and the daily maximum and minimum air temperature.

It should be noted that the thermometer was installed before the air temperature rose above freezing-point. This was possible because the camp area, apart from the immediate vicinity of the Stevenson screen had been bulldozed free of snow on May 3. Despite the presence of permafrost only a few inches down and despite the low daily minimum air temperature, the surface soil temperature did not apparently fall below about 31°F. thereafter.

The general relation of surface soil temperature to daily sunshine totals is clear enough, although a few anomalies appear to exist, probably caused by the state of the sky in the period immediately before the observation. The highs recorded at the beginning of the period were generally a little above 50°F.; they began to exceed 60°F. at the beginning of June, reached 70°F. before the middle of the month and the highest temperature of the summer, slightly more than 80°F. was recorded on June 28. Thereafter daily "maxima" were generally in the 70° to 80°F. range until the dull conditions of late July caused a considerable fall. Maxima in the early part of August were generally in the high sixties.

From May 21 until the middle of June, the soil temperature at 1 a.m. was generally five to eight degrees warmer than the maximum air temperature for the same 24-hour period. In the second half of June the highest air temperature and the lowest soil temperature were generally close to each other, and thereafter the soil "minimum" lay usually within the daily range of air temperature. Dependence on sunshine was, as might be expected, by no means so great as with maximum soil temperatures and thus the daily range at the soil surface tended to be much less on cloudy days than on clear days when the range between highest and lowest soil temperatures observed was usually of the order of 30°F.

FIG. 12. TEMPERATURES AT THE SOIL SURFACE, SUMMER 1958.



CHAPTER IV

PRECIPITATION

THE PROBLEM OF SNOW MEASUREMENT

The accurate measurement of solid precipitation is a problem which has still not been satisfactorily solved by the meteorological services of the world. Each service follows its own convention and this often gives rise to anomalies.

The essential problem is that of obtaining an adequate measurement of the water content of the solid precipitation, usually snow, which falls in a given period. The obvious way of solving the problem might seem to be the collection of the snow in a container similar to a rain gauge, and then the calculation of its water equivalent by melting and direct measurement. Several problems arise however. The density of solid precipitation is usually much less than that of rainfall and hence it is very much more likely to be affected by eddies round the top of the collecting can. Also, if the can is close to the ground, it often happens that drifting snow may be blown into it, giving a false total. Finally there is the problem of the separate measurement of snow and rain when they are falling together as sleet. This, however, is not of great concern to the present study, as a significant fall of sleet was recorded only once during the observational period, in July 1958.

The alternative approach to the problem is that currently used in Canadian practice. This is based on an assumption concerning the relation of the specific gravity of snow to that of rainfall (or, in other words, how many inches of snow are equivalent to one inch of rainfall.) The depth of newly-fallen snow is measured and this is multiplied by the specific gravity factor to give an assumed equivalent water content. In Canada the working assumption is that ten inches of newly-fallen snow has a specific gravity equal to one inch of rainfall. An observer thus measures the depth of snow with a rule, compares this with the depth at the previous observation, repeats this at several sites to obtain an average value (in particular, to make allowances for any drifting or blowing which may have taken place) and then divides this figure by ten to obtain the water equivalent. The chief disadvantages of the method may be illustrated by quoting the instructions for measurements issued to observers:

> 5.8.2. Snowfall. The amount of snow which has fallen in a given period shall be determined by measuring and averaging the depth of snow in several places. Snow depth shall be measured in tenths of inches. In so far as possible, the depth of new snow shall be measured in spots where the snow has fallen undisturbed by the wind. When the snow has been drifted by the wind, the depth of new snow in the drifts and in exposed areas shall be measured, and the observer shall then estimate the depth of snow that would have accumulated if the fall had been undisturbed by the wind, making due allowance for the relative size of the drifts and exposed areas. (15, p.30)

Measurement by this method is obviously highly subjective. The number of measurements made to obtain the average depth is left to the individual observer, and probably varies greatly according to individual conscience and prevailing weather conditions. Even with the best will in the world, however, the observer cannot hope to get better than a fair approximation when drifting has taken place. To consider "the relative size of the drifts and exposed areas" is inadequate, as the degree of compaction in drifts varies tremendously and it is not humanly possible to estimate the degree of compaction in a drift and then visualise the depth which this would represent if the snow was evenly distributed over the landscape in its newly-fallen state.

Perhaps an even more serious error is contained in the specific gravity assumption. The hypothesis that ten inches of snow is equal to one inch of rainfal is one which is open to question, particularly where snowfalls at low temperatures are frequent. This has been demonstrated on several occasions by actual comparison, and the question was investigated by B. W. Currie in 1947:

> "The average specific gravity of newly-fallen snow is assumed generally to be 0.1. As a result the rainfall equivalent of the snowfall in most regions is based on the product of this factor and the sum of the observed depths of snow in each fall. While this procedure apparently gives satisfactory values for cool climates where much of the snow falls at temperatures a few degrees above 32°F. and often in such large quantities that the upper layers help to compress the lower ones, occasional observations of the specific gravity of snowfalls at low temperatures...... have indicated that a somewhat lower value than 0.1 should be used in regions with cold climates." (22, p.150)

Currie goes on to show, as a result of his own experiments in Saskatoon, that a better water equivalent there is 0.081 (22, p.151), indicating that about twelve inches of snow is equivalent to one inch of rain in such conditions.

This liability to error is particularly significant in the Arctic, where snow most frequently falls at low temperatures, even though the falls nearer freezing-point are those which are most important for total amount. The 10 : 1 relationship probably has not even the value of being a statistical average. It should be mentioned, however, that a totally different view of the specific gravity relationship has been taken by other workers. Rae, for instance, (49, p. 16), on the basis of measurements at Resolute, suggests that the ratio in the Arctic should be nearer five to one and implicit acceptance of this view is contained in Sim's description of the climate of Eureka (50, p. 45).

The Meteorological Branch are, of course, aware of the limitations to the method, and are currently experimenting with a new type of snow gauge, mounted about six feet above the ground so as to avoid the bulk of drifting snow, and with a broad flat lip designed to minimise the eddying problem. Even here, however, the 10 : 1 relationship enters, in that the depth of snow is computed by multiplying the measured water equivalent by this factor. As it is water equivalent which is the more significant value, however, this gauge represents a much smaller liability to error.

The method adopted at Lake Hazen for measuring solid precipitation amounts was undoubtedly a makeshift one, although it would appear that the results it gave were at least as accurate as standard practice and probably much more accurate. The technique is described in Chapter II (pp.41 -42) The errors due to drifting into the can and eddying around it (probably fairly small considering that throughout the entire observational period only ten per cent of the winds recorded at 40 ft. were over 5 m.p.h.) are more than outweighed by the advantage of objectivity in measurements and in particular in the measurement of very light falls. At Lake Hazen, as elsewhere in the Arctic, falls of snow were usually light and to estimate accurately to within one-tenth of an inch, equivalent to 0.01 inches of rainfall according to convention, is well-nigh impossible.

In so far as objective snow depths are required for their own sake, these were recorded on the daily sheets by direct measurement, and the values on the last day of the month during the season with a snow cover are set out in Table XI, with the data for the two permanent stations as a comparison. The record at Lake Hazen is not, however, strictly continuous, and the reason for this helps to illustrate the problem of compaction mentioned earlier. The snow which fell on and after September 3 1957 blanketed the landscape with little drifting and, in the lack of large amounts to compress lower layers, without much compaction. After the lake froze, the density of the newly-fallen snow on its surface was found to be about 0.184 grams per cubic centimetre, later compacting slightly to 0.220 gms/cc.[1] During the storm on mid-January 1958, the snow cover was completely removed by the wind from much of the landscape (blowing sand was recorded simultaneously with blowing snow, and it left metal objects such as the rain gauge burnished bright) and it was compacted into a few dense drifts on the land and as a compact layer on the lake surface. On the lake a number of density measurements all yielded values close to 0.468 gms./cc. From the beginning of February, therefore, the depth of snow recorded in columns 30 and 86 of the daily sheets, and set out in Table XI, is that on the lake surface, the only surface from which a reasonably representative measurement could be obtained in late winter.

TABLE XI

SNOW DEPTHS ON THE LAST DAY IN EACH MONTH

(to the nearest inch)

	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	July
Lake Hazen	0	3	8	9	9	10	10	10	12	13	0	0
Eureka	0	6	7	7	7	9	9	9	9	8	0	0
Alert	0.5	11	15	16	16	14	14	11	10	8	trace	0

Before ending this discussion of the significance of the precipitation totals, mention should be made of two profiles obtained by G. Hattersley-Smith in early May. These profiles, reproduced here as Fig. 13 were taken

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[1] The author is indebted to his colleague C. R. Harington for the use of these and the following values.

	Cms.	Snow Type	Density (g/cm)	Water Equiv. (cms.)
	Sfc.			
		New	.18	.63
	3.5			
		Partly re-crystallised (1/2-2 mm.)	.21	1.78
	12.0			
		Wind pack	.45	1.80
	16.0			
		Loose platy crystals up to 1 1/2 cms.	.23	3.11
Ice	29.5		Total =	7.32 cms.

a. 300 yards from shore of lake, south of base camp, 12 May.

	Cms.	Snow Type	Density (g/cm)	Water Equiv. (cms.)
	Sfc.			
		New	.19	.95
	5.0			
		Partly re-crystallised (1-2 mm.)	.21	.99
	9.7			
		Recrystallised (up to 7 mm.)	.21	.74
	13.2			
		Wind pack	.46	2.65
	17.7			
	20.2			
		Loose platy crystals up to 1 1/2 cms.	.21	2.82
Ice	32.4		Total =	8.15 cms.

b. 100 yards from shore of lake, south of base camp, 3 May.

Fig. 13. Profiles Through the Snow Cover on Lake Hazen, May 1958
(from measurements by Dr. G. Hattersley-Smith.)

on the surface of the lake. It must be pointed out that least two factors prevent their being acceptable as representing the total water equivalent of the snowfall up to that time. First, the lake did not freeze completely until some time after the first major snowfalls of the winter and secondly, as mentioned earlier, they contain a considerable amount of snow blown off the land during the January gale. The time when this addition occurred is clearly at the layer of "wind pack", suggesting that everything below that layer was snowfall onto the lake surface after it froze and before the gale. The mean of the two measurements of this latter amount is 2.97 cms. water equivalent, or 1.17 inches. The measured precipitation in the gauge up to that date was 0.57 inches, a considerable margin of difference.

The major reason for this difference appears to be the problem of unrecorded "traces" of precipitation. Between September 3 and January 17 one hundred and eight such traces (i.e. a water equivalent less than .005 ins.) were recorded in six-hour periods, none of which contributed to the totals of measurable precipitation. If it is assumed that two traces equalled a measurable amount (0.01 ins.) then the total for the period would be 0.54 inches, practically eliminating the difference, although some of this fell before the lake froze. The author feels that this is perhaps an exaggeration: a ratio of 2½ or 3 traces to 0.01 inches might be more accurate, but the importance of the contribution of such light falls to the total precipitation is clear. During the period of sub-freezing temperatures one hundred and eighty-seven traces of precipitation were recorded, of which only fifty-eight were individual records not succeeded or followed by traces in adjoining six-hour periods. It would therefore seem that the Canadian practice, to which the Lake Hazen station adhered, of measuring precipitation every six hours should be modified in the Arctic as it causes the non-recording of a significant proportion of the annual total. A twelve-hour or daily period would seem preferable, or perhaps even the separate recording of each snowfall, where this did not continue uninterrupted for too long a period.

The desirability of altering the practice in the Arctic is made more apparent when the purpose of the precipitation measurements is considered. In mid-latitudes, where frequent showers, etc. of varying intensities are common, frequent measurements provide indications of precipitation intensity. In the Arctic, however, where almost all precipitation is light, at least by comparison with mid-latitudes, the times when precipitation is falling (recorded in column 72 of the daily sheets) combined with the total amount during 12- or even 24-hour periods would give an adequate measure of the intensity. The absolute amount of specific days, months and over the year as a whole is of considerable significance to Arctic work in botany, glaciology etc. and it is difficult to obtain this knowledge from the present practice.

THE FORMS OF ATMOSPHERIC PRECIPITATION

Although the main division of precipitation type is between liquid and solid, rain and snow, each of these generally includes more than one species. Liquid precipitation is classed into rain, drizzle, freezing rain and freezing drizzle. The distinction between rain and drizzle is defined by drop size, the one being greater and the other less than 1/50 inch in diameter; in practice they are distinguished by their behaviour in fall and in contact with the ground. Solid precipitation embraces snow, snow pellets, snow grains, ice pellets, hail and ice prisms. Of these types, hail and snow pellets were not recorded at Lake Hazen, nor was either form of freezing precipitation.

Snow is defined as:

5.4.3.1. Snow. Precipitation of mainly hexagonal ice crystals, most of which are branched (star-shaped.)
5.4.3.1.1. The branched crystals are sometimes mixed with unbranched crystals. At temperatures higher than about 23°F., the crystals are generally clustered to form snow flakes. (15, pp. 22-23)

Snow grains are defined thus:

5.4.3.3. Snow Grains. Precipitation of very small white and opaque grains of ice. These grains are fairly flat or elongated; their diameter is generally less than 1/25 of an inch. (p.23)

Thirdly are ice pellets:

5.4.3.4. Ice Pellets. Precipitation of transparent or translucent pellets of ice, which are spherical or irregular, rarely conical, and which have a diameter of 1/5 of an inch or less (p.23)

MANOBS goes on to remark that there are two main types of ice pellets; those recorded at Lake Hazen on two occasions in June 1958 would appear to be formed from "frozen raindrops, or snowflakes which have largely melted and then refrozen. The freezing usually takes place near the earth's surface."

Finally, ice prisms:

> 5.4.3.6. Ice Prisms. A fall of unbranched ice crystals, in the form or needles, columns or plates, often so tiny that they seem to be suspended in the air. These crystals may fall from a cloud or from a cloudless sky.
> 5.4.3.6.1. The crystals are visible mainly when they glitter in the sunshine (diamond dust); they may then produce a luminous pillar or other halo phenomena. This hydrometeor, which is frequent in polar regions, occurs only at very low temperatures, and in stable air masses. (pp. 23-24)

The essential feature concerning these definitions is that they are based solely on physical characteristics; the difference, for example, between snow and snow grains is not one of the relative size of the particles, but their different origin and form. The author believes that these definitions were constantly in the minds of the observers at Lake Hazen and that the entries of precipitation recorded in the synoptic sheets (especially in column 72) are very reliable.

As might be expected, there is a general relationship between temperature and the form of solid precipitation. Table XII illustrates this by showing the number of days in each month on which snow, snow grains, or ice prisms were recorded. Snow, it will be seen, is liable to fall in any month, but it is most frequent in September, October and

May, when temperatures were nearest to freezing-point, and also in January when, although air temperatures at Lake Hazen only just rose above 0°F. at the surface, observations at Alert and Eureka indicate that the free atmosphere over northern Ellesmere Island was considerably warmer. Snow grains, although recorded on only about half the number of days compared to snow, show a similar relationship, whereas the distribution of ice prisms, as might be expected, is entirely different. They are uncommon in early fall, but were observed on half or more of the days in each month from November to March inclusive. As mentioned in the specification they frequently fell out of cloudless sky. The prisms were most easily seen by the light of a flashlight beam during the sunless period and it is possible that they may have been slightly under-recorded during late winter, March and April, after the sun returned. This, as will be shown later, would not affect precipitation totals.

TABLE XII

DAYS EACH MONTH WITH VARIOUS FORMS OF PRECIPITATION

	*Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jly.
Snow	14	21	8	9	22	4	13	10	15	4	2
Snow Grains	25	11	2	2	9	5	5	0	4	0	0
Ice Prisms	2	5	17	18	20	20	15	9	7	0	0

* Includes also the latter part of August 1957

PRECIPITATION TOTALS

The quantity of precipitation measured at Lake Hazen during the observational period is summarised in Table XIII; the same data for Alert and Eureka (omitting late August 1957 at the latter station)is shown for comparative purposes.

It will be seen from column 2 of the table that precipitation at Alert was well over twice that at Eureka, which in turn recorded twice as much as did Lake Hazen. Precipitation was recorded on practically the same number of days at both the permanent stations, but at Eureka it amounted to more than a trace on only forty-nine days, compared to nearly twice as many at Alert. At Lake Hazen both the number of days with precipitation of a trace or more, and the days when it reached measurable proportions were fewer, although the relation of one to the other is practically the same as at Eureka. The difference between Eureka and Lake Hazen in precipitation amounts is not, however, as great as the wide difference in snowfall amounts (column 2 minus column 7) would imply. Eureka had 1.08 inches water equivalent more snow, according to this table, than did Lake Hazen. One reason for the difference is probably contained in the 10 : 1 relationship used at Eureka. If, following Currie (22), a 12 : 1 relationship were adopted, the difference between the two stations would be reduced to approximately 0.9 inches. More important, however, is the effect of a few heavy falls on these small

TABLE XIII

PRECIPITATION DURING 1957 - 58

Station (1)	Total (2)	Total Days Tr or More (3)	Total Days More than Tr (4)	(4) as % of (3) (5)	Total Rain (6)	(6) as % of (2) (7)	No. of Days of Rain (8)
Lake Hazen	0.98"	134	39	29.1%	0.07"	7.1%	3
Eureka	2.07"	169	49	29.0%	0.10"	4.8%	3
Alert	4.52"	171	95	55.6%	0.84"	18.6%	10

TABLE XIV

MEASURABLE PRECIPITATION BY MONTHS

(inches)

	1957 /Aug.	Sep.	Oct.	Nov.	Dec.	1958 Jan.	Feb.	Mar.	Apr.	May	Jun.	Jly.	Aug./
Lake Hazen	0	0.20	0.23	0.03	0.04	0.23	0.01	0.02	0.05	0.08	0.04	0.05	0
Eureka	-	0.96	0.36	0.05	0.10	0.31	0.05	0.04	0.02	0.08	0.03	0.07	0
Alert	0.30	1.00	0.94	0.10	0.08	0.38	0.11	0.04	0.20	0.44	0.03	0.40	0.49

/ (part)

total amounts. Comparing the precipitation during the colder months at the three stations in Table XIV it will be seen that a very great part of the excess at Eureka was received in the month of September, and that in succeeding months the relationship between the two is much closer, Lake Hazen even recording fractionally greater amounts in some months. The bulk of the precipitation at Eureka in September 1957 fell on one day, the 2nd, when the assumed water equivalent of the daily snowfall was 0.54 inches. Thus over one-quarter of the precipitation from September 1 1957 to August 10 1958 fell on a single day and sufficiently accounts for the apparently large anomaly between the stations in the "annual" figures.

At all stations, however, the pattern clearly emerges of the bulk of the precipitation falling in the first few snowfalls of winter when the temperature is still relatively high, and in the period immediately before the thaw in early June. The latter period is, on the basis of one year's observations, of less significance and this is what might be expected as most of the water bodies constituting the moisture sources are still frozen.

The very small totals recorded at Lake Hazen underline the very insignificant part played by ice prisms in the measurable precipitation, despite the frequency with which they were recorded. Normally, even if the fall was continuous over a six-hour period, the precipitation can still appeared empty and they are not recorded even as a trace. Falls greater than this have, however, been recorded elsewhere. Rae (49, p.18) quotes a record of 0.1 inches at Resolute (i.e. presumably, a water equivalent of 0.01 ins.) and quotes Kane as measuring a fall of one-quarter of an inch in six hours. While both these observations seem to be fairly reliable (Kane observed displays of paraselenae while the prisms were falling which is confirmatory evidence), on the basis of experience at Lake Hazen, when ice prisms were recorded on nearly a third of the days in the observational period, they may be neglected as sources of precipitation for all practical purposes.

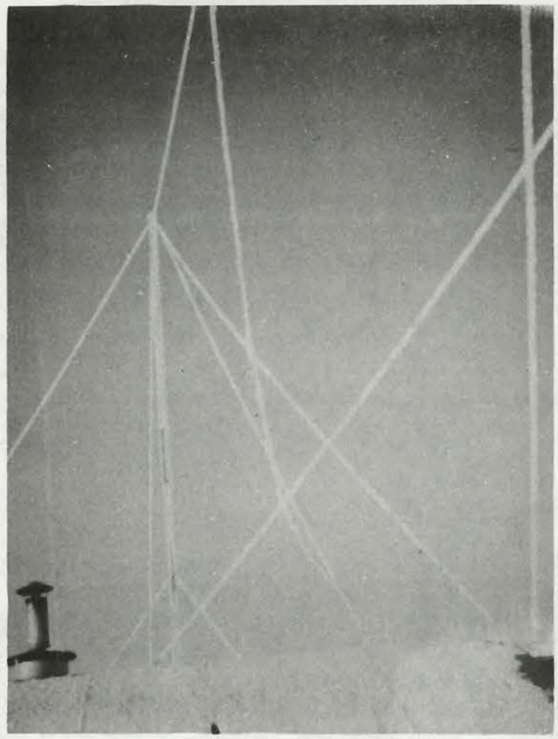
The rainfall recorded at Lake Hazen and Eureka is probably somewhat below normal. (Rae (49 p.17) suggests that nearly half the total for the year may occur as rainfall over most of the Canadian Arctic Archipelago. At Eureka the mean rainfall for the years 1948 to 1958 has been 1.04 inches, 42 per cent of the total precipitation. The summer party at Lake Hazen in 1957 measured 1.53 inches between June 12 and August 18 compared to a fall of less than a tenth of an inch in the Summer of 1958.

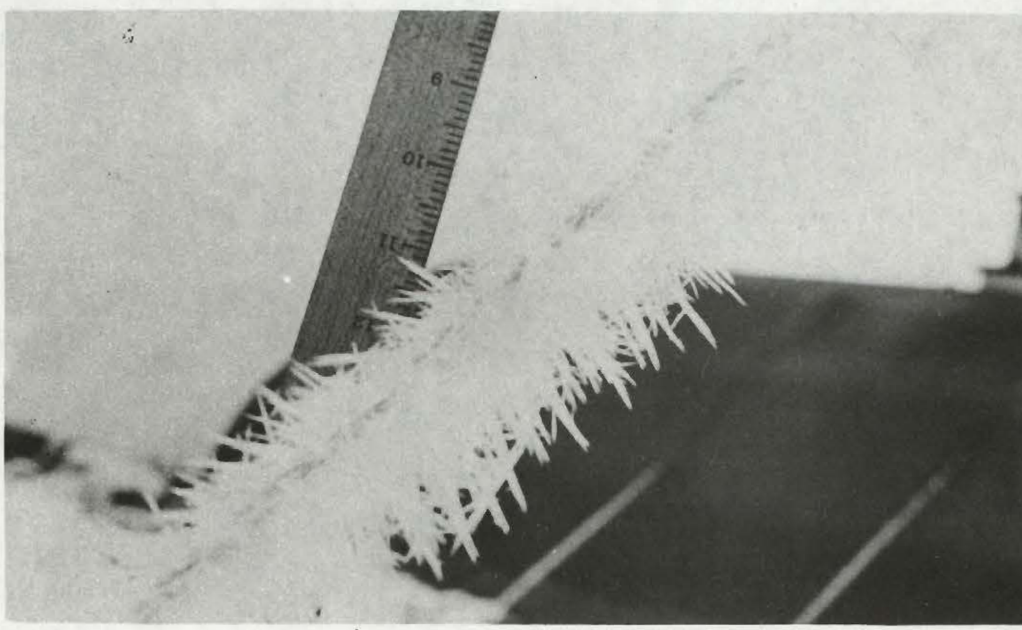
Hoar frost has frequently been cited as a significant source of precipitation in the Arctic. It is associated particularly with the "Glacial Anticyclone Theory" of W. H. Hobbs (35), in which hoar frost was assumed to be the principal, if not the only, alimentation source for the Greenland and Antarctic ice-caps. It has been pointed out, notably by Matthes (42), that the cold air which Hobbes postulates as dominating the circulation over the caps, to the complete exclusion of maritime air masses, has a very low saturation vapour pressure and would be totally inadequate to supply the moisture needed to maintain the ice sheets, even if it were not adiabatically warmed as it settles in the centre of the anticyclone.

The unacceptability of hoar frost for the Hobbs hypothesis does not, however mean that it may be neglected everywhere. Rae (49, p.17) quotes Sverdrup as estimating that rime and hoar frost may account for as much as 15 per cent of total annual precipitation in the Arctic. On the basis of observations at Lake Hazen, the author would agree with Rae that this estimate seems excessive. At the beginning of the winter, it is true, rime and frost deposition was considerable as can been seen from Figs. 14 and 15. It had to be shaken from guys, masts etc. periodically to prevent it from becoming too heavy. Once temperatures fell to the winter normals, however, rime formation decreased considerably and did not become appreciable again until temperatures rose in the spring. Figs. 16 and 17 show some of the interesting crystal forms which developed spontaneously on the cold, bare ground which had been cleared of snow by bulldozer in May. Similar features developed on the cold lake ice as the air temperature and humidity increased. Spectacular as these features are, neither they nor the very similar ones which developed in the fall can have been equivalent to any very significant amounts of water.

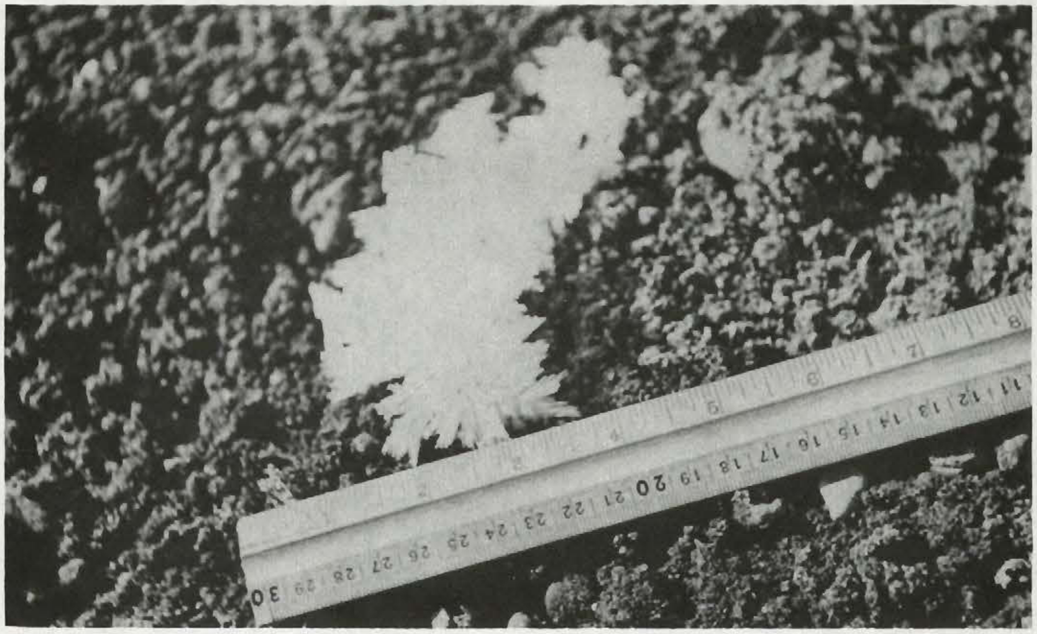
Mention should be made of thunderstorms. Rae, writing in 1951, remarked that "none have been reported from the islands north of the Parry group" (49, p.20) and a similar conclusion is implied by Petterssen, Jacobs and Haynes (48, p.69).

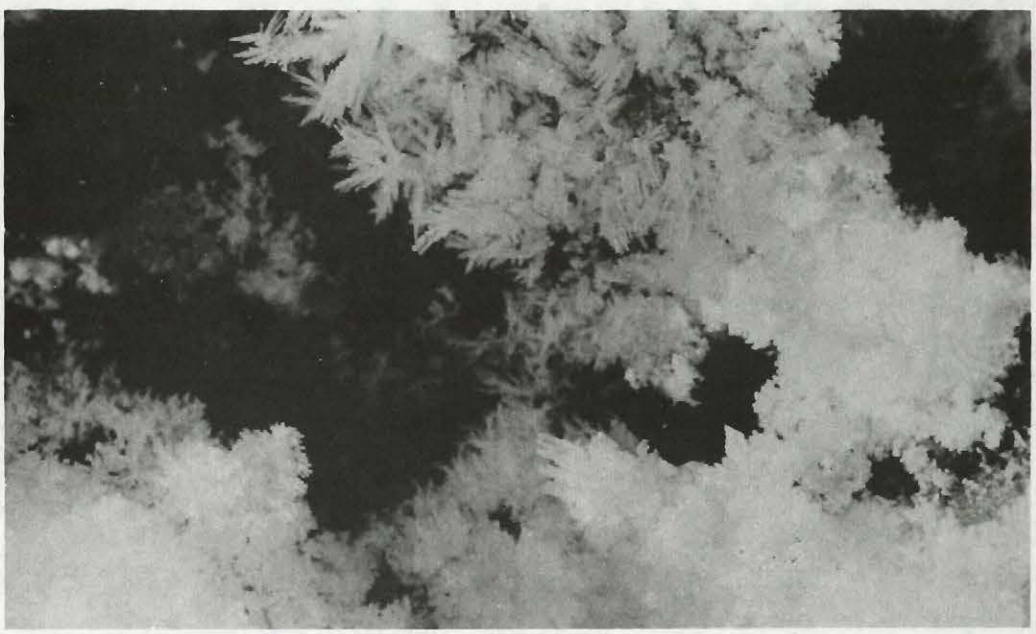
The author has no doubt, however, that a thunderstorm occurred in the environs of Lake Hazen on the evening of June 12 1958, and possibly on other occasions in the weeks previously. June 12 was the date on which the highest temperatures of the observational period was recorded (59.2°F.); it followed several days with high sunshine total (Fig. 37)





Figs. 14 & 15. Hoar Frost, Fall 1957.





Figs. 16 & 17. Spring Frost Features, 1958. "Frozen Dew."

and thus provided the most suitable local conditions for strong convective activity. Column 71 of the daily sheet for that day has the following entry "1900 - 1915 (E.S.T.). Thunder heard to S.E. A total of four rolls." No lightning was observed, but the author satisfied himself that the sound was caused by thunder and not by the only other agency which seemed possible: a fall of rock from the cliffs of John's Island in approximately the same direction. No precipitation was recorded at the station on that date but 30° of rainbow was noted in an easterly direction at 2140 E.S.T., indicating that showery precipitation, presumably of convective origin, was still occurring late in the evening at no great distance.

Figs. 18 and 19 are photographs which were taken on other occasions during the summer and show heavy cumulus over and along the Garfield Range, with most of the features of cumulonimbus clouds. It is not implied in the preceding discussion that thunderstorms are an important source of precipitation in northern Ellesmere Island as a general rule. The case was mentioned only as it seems a fairly well documented example of a phenomenon which in these latitudes appears to be fairly rare.

In view of the problems which have been raised in this chapter concerning the problem of precipitation measurement, some brief conclusion is perhaps necessary to clarify the discussion. The author believes that the total precipitation during the observational period, including that which did not reach "measurable" quantities as it fell,

Figs. 18 & 19. Cumulus and Cumulonimbus, Lake Hazen, Summer 1958.

The mountain peak in the bottom right of the lower figure is approximately 3300 feet a.s.l.

was probably close to 1.5 inches, and almost certainly did not exceed 2 inches. It would appear that the method of precipitation measurement used at Lake Hazen was preferable to the conventional method, although a specially designed snow gauge, of the type described on page 86 would have been the most suitable device.

CHAPTER V

HUMIDITY

I. THE PROBLEM OF HUMIDITY MEASUREMENT

In Chapter II reference was made (p.29) to the "personal equation" of an observer: his tendency to make systematic and repeated mistakes of the same type without being aware of it. Often the error involved is unimportant, but in certain cases it may be such as to nullify the value of the observation itself. Particularly is this so in the measurement of humidity by means of the wet- and dry-bulb psychrometer. At low temperatures the depression of the wet-bulb (in many cases a "negative" depression) is very small, often only 0.1° or 0.2°F. Any systematic mistake in estimating the tenths of a degree on the thermometers is therefore liable to cause very great errors in determining dew point, relative humidity or vapour pressure.

It had, for instance, been hoped to make use of the data from Alert at cold temperatures, but this was found to be impossible. In looking through the station records during the period it was found that one observer in particular had a tendency to round both dry- and wet-bulb readings off to the nearest half or whole degree. A quantitative check on the measurements by this observer showed that in the period from November 21 to December 31 1957, in which he took approximately half the surface observations at Alert, the uncorrected (i.e. actually observed) values of wet- and dry-bulb temperatures were grouped as follows:

Final Decimal	.0	.5	Others
No. of cases	187 (57.2%)	48 (14.7%)	92 (28.1%)

Taking the latter part of November by itself over 70 per cent of the observer's readings were in full degrees. As the temperature at that time was in the vicinity of - 20°F., where a difference of 0.1°F. in the depression changes the dewpoint by 1°F. and the relative humidity by 4 per cent, it can be seen that little reliance can be placed on the humidities so recorded which are, in fact, only the expression of the different correction factors applied to the two thermometers.

Having made criticisms of Alert, it is only just that the tendencies of the observers at Lake Hazen should be considered in the same way. The month selected was April 1958, in which temperatures were cold but not, for most of the month, below freezing mercury. The observations of the four observers were analysed separately and the results are as follows:

Observer	Number of Cases		
	.0	.5	Others
(1)	20	4	79
(2)	26	6	82
(3)	21	4	98
(4)	39	6	77
	106 (22.9%)	20 (4.3%)	336 (72.7%)

The proportion of observations in the third column is clearly much nearer 80 per cent which would theoretically be expected. The proportion of observations of .5 is, surprisingly, under-represented by all observers, while those of .0 are again too many. Only in the case of observer (4), however, is this error considerable and the author reluctantly admits that he was the person concerned. It does, however, seem possible to use the data to determine the humidity of the surface air at Lake Hazen.

II. VAPOUR PRESSURE MEASUREMENTS DURING THREE MONTHS

All studies of humidity encounter the problem of expressing the results in a form which has physical significance. The most usual expression is in terms of relative humidity, the amount of water vapour in the air as a percentage of that which it could hold at a given temperature. The possible water content of the air, however, varies very greatly according to temperature and relative humidity, unrelated to temperature, has little meaning. This problem is most important where mean figures are employed. The most acceptable form of expressing humidity content is probably as the vapour pressure: the amount of (atmospheric) pressure which the water vapour exerts, which is directly related to its mass.

Calculation of vapour pressure from the data provided by a simple psychrometer is a tedious, although straightforward, task, and it has been thought sufficient to show values during the three months in the observational period which are of particular interest for humidity. September 1957 was the cloudiest month with open water in the lake for the greater part of the time and air temperatures almost continuously below freezing. April 1958 was the only "cold" month for which sufficient data was available, the others having long periods during which the mercury thermometers had to be removed from the screen. Finally July 1958 represents a period in high summer, with the lake ice steadily melting as the month progressed.

It is important to note that it was impossible to plot the data in Figs. 20, 21 and 22 on identical graphs. The very great differences in humidity require that although the April and July graphs have the same scale, they have a different origin. Similarly April and September share the same origin, but the scale is five times larger on the April graph.

As well as plotting the vapour pressure at each of the eight daily observations during the months concerned, except on the dates in April when temperatures below freezing mercury were experienced, the daily mean temperature has been shown, and also the saturation vapour pressure (relative humidity 100 per cent) with respect to water at the daily mean temperature. The significance of the curve with respect of ice shown on the April graph will be discussed in the section on ice fog which follows. The final quantities plotted on the graph are the highest and lowest relative humidities recorded at any of the observations each day.

The most interesting feature of the September graph is the generally small saturation deficit indicated by the closeness of the individual observations to the saturation point of the daily mean temperature. Only in the first few days of the month, and particularly in the day or two before the first major snowfall on September 3, is this not the case. In general the lower the temperatures fall, the closer the vapour concentration approaches saturation, although the amount itself declines in absolute terms.

Much the same may be said of April 1958, bearing out at least part of the remark of Petterssen, Jacobs and Haynes that the Arctic "is essentially a region of high relative humidities but, because of low temperatures, it is also a region which presents only small amounts of atmospheric moisture." (48, p.71). It is the very small moisture content which is of greatest significance in the April graph and it is this which is usually offered as an excuse for the errors resulting from the difficulty of humidity measurements at low temperatures. Whether the relative humidity is 60 per cent

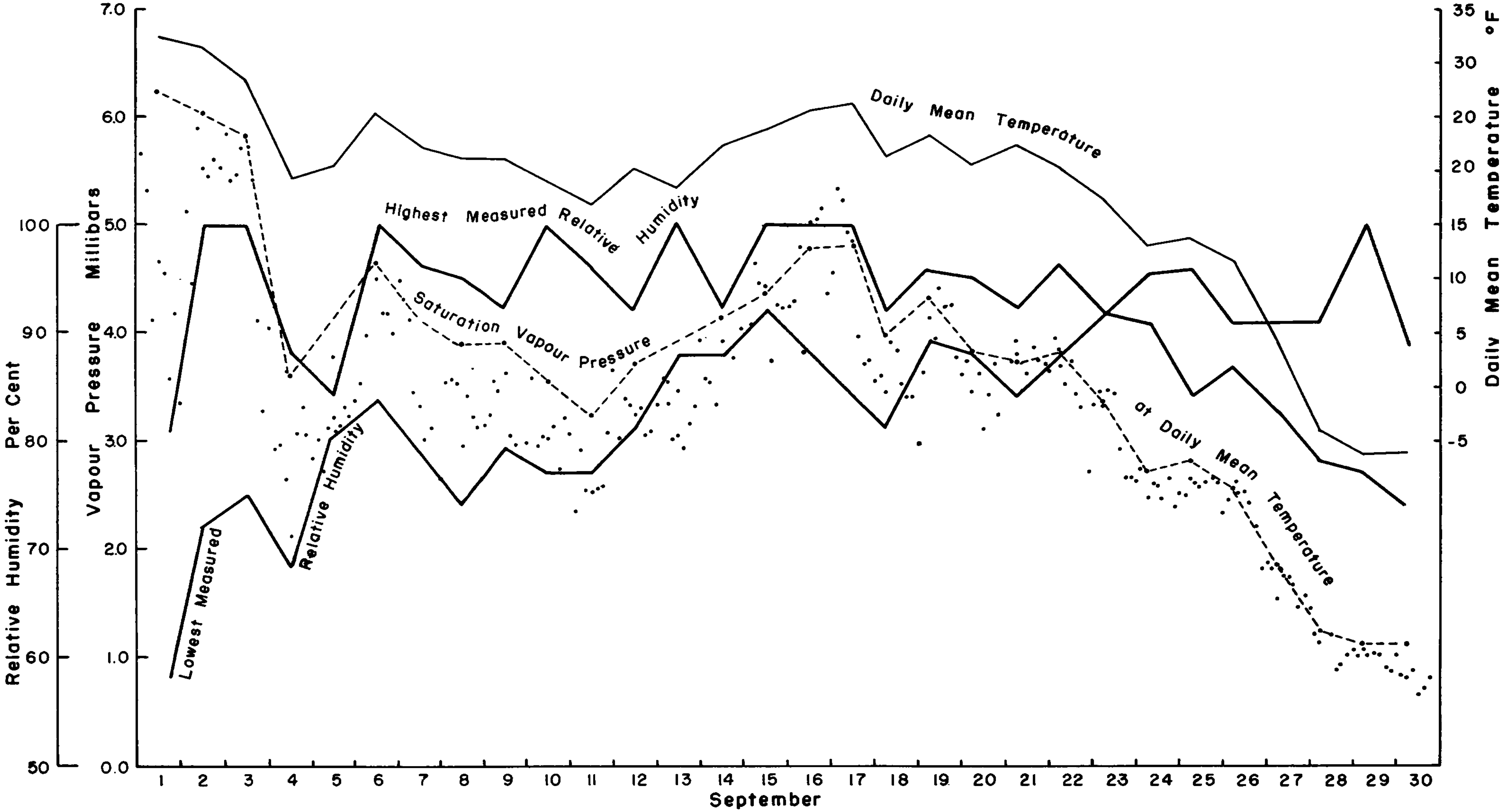


FIG. 20. VAPOUR PRESSURE: SEPTEMBER 1957

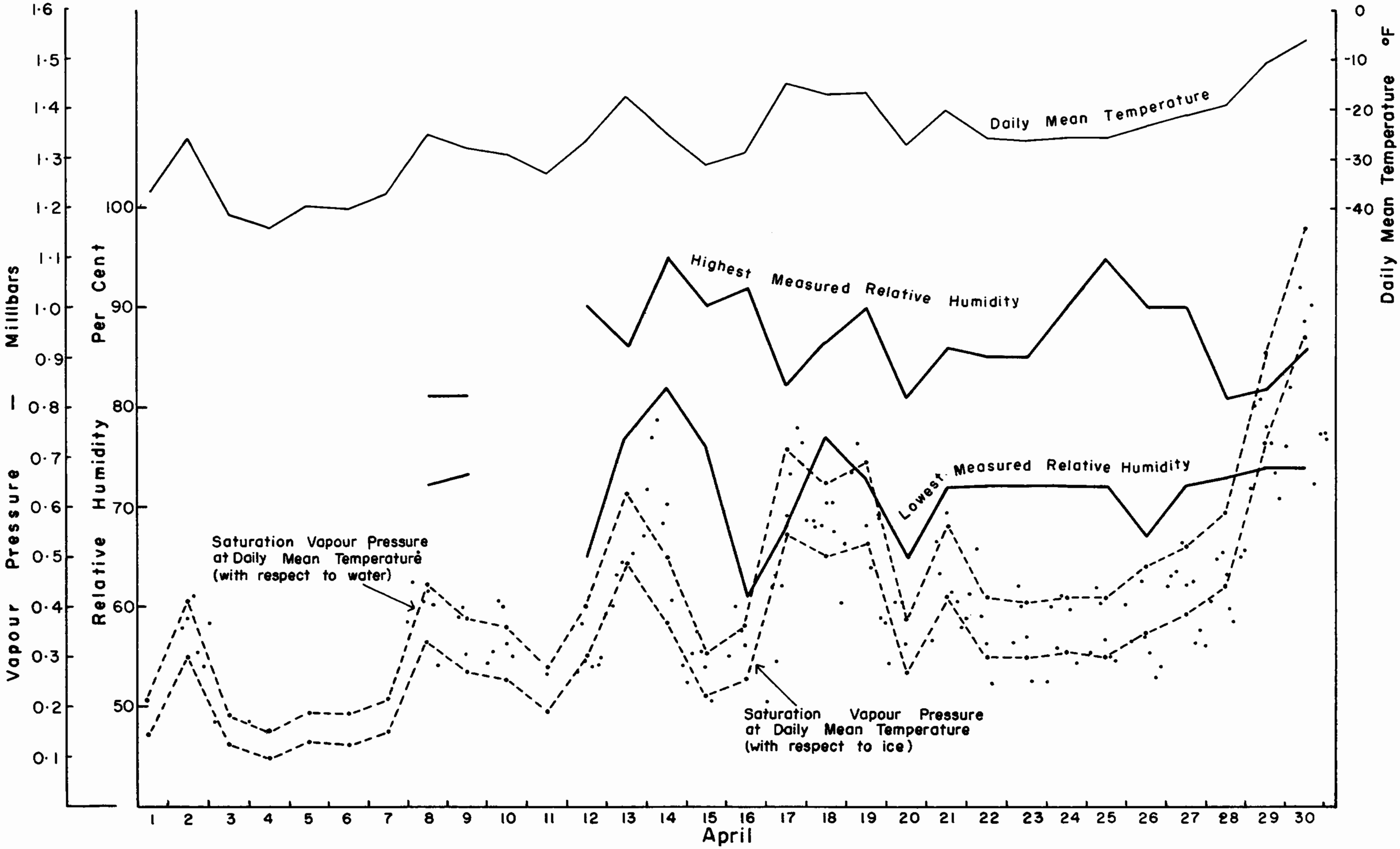


FIG. 21. VAPOUR PRESSURE: APRIL 1958

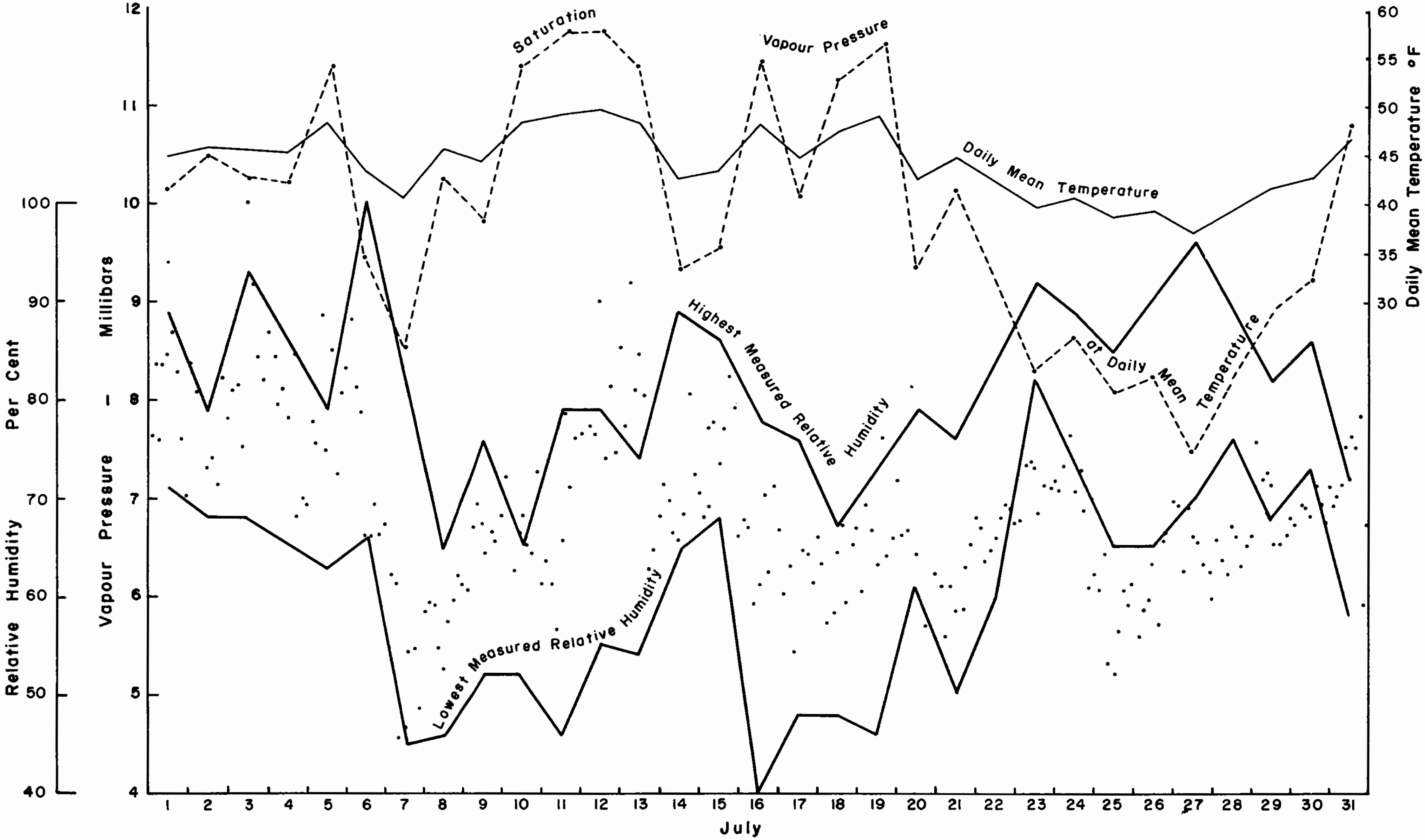


FIG. 22. VAPOUR PRESSURE: JULY 1958

or 90 per cent, it is argued, is not especially important, as the amounts of moisture in the air at either value are insignificant and, by the same token, very similar. This is illustrated in Fig. 4. Recent studies have shown, however, that the relative humidity of the air is often critical for the formation of ice fog. The latter only occurs at very low temperatures, but is of great potential importance and is considered in more detail later.

The significant feature of the July map is the relatively low vapour pressure. Although it is, of course, very much greater than the pressure in either September or April it is nevertheless very much less than the saturation pressure,and relative humidities of 50 per cent and below were recorded on several occasions during the month. Petterssen, Jacobs and Haynes consider that "the only circumstances that allow low relative humidities to occur in the Arctic are offered by strong offshore or downslope winds such as occur at the foot of a glacier or mountain." (48, p.72) There seems no reason to doubt the Lake Hazen observations, particularly at these relatively high temperatures where errors of observation are least significant and it would seem that an inland station can experience low relative humidities when direct insolational heating is at a maximum and advective influences are relatively small. It is possible that a slight increase can be detected late in the month, as the Lake ice progressively melts, but this doubtful.

Fig. 23. Ice Fog, March 1958.

III. THE FORMATION OF ICE FOG

The problem of ice fog is discussed in Chapter IX in so far as it is likely to affect aircraft operation. In recent years a considerable amount of literature has accumulated on the subject of ice fog, much of it emanating from or sponsored by the United States Air Force, which has found it to be a major problem in Arctic air operations, particularly in the interior of Alaska. The temperature, humidity and wind records from Lake Hazen suggest that it is likely to be of major importance for any possible settlement there also, although little ice fog was actually recorded during the observational period.

V. J. and M. B. Oliver, who examined conditions in Alaska, stated that:

> The ice fog which forms in the Fairbanks area can be divided into two classes: one, a persistent type, which interferes seriously with air operations; the other, a mixture of ice and water fog which forms in winter, following rapid clearing of the sky, and soon dissipates by sublimation and settling onto the colder snow surface.
>
> The persistent type of ice fog forms when the temperature falls to about -40° and persists until the temperature again rises to above -40°. If the temperature falls lower, the ice fog will become thicker and the visibility gradually decreases to zero. (47, p.24)

It is this persistent ice fog which is likely to be encountered at Lake Hazen where, as was shown in Table IX temperatures below -40°F. were recorded on one-third of the days in the year. It is therefore of considerable significance to consider the conditions under which such ice fogs are established.

The most useful study for the present purpose is that of Appleman in 1953 (4). Ice fogs, it had been observed, were most common in urban areas and in the vicinity of smoke sources. Appleman shows how, from earlier studies of condensation trail formation,

> the burning of hydrocarbon fuels, such as gasoline, kerosene, and fuel oil can either raise or lower the relative humidity of the affected enviroment, depending on the initial pressure, temperature and relative humidity of the air. (4, p.397)

The effluent produced by the burning of such fuels produces abundant nuclei which act as condensation agents for the moisture in the atmosphere provided that it is supersaturated with respect to ice. As saturation with respect to ice occurs before saturation with respect to water, the following table, reproduced from Appleman's paper, shows the critical temperatures required for saturation of the air at 1000 millibars, as a function of the relative humidity with respect to water:

TABLE XV

TEMPERATURES OF SATURATION WITH RESPECT TO ICE AT DIFFERENT RELATIVE HUMIDITIES

Relative Humidity (water)	100%	90%	60%	0%
Saturation Temperature (ice)	– 20.4	– 27.2	– 33.0	– 38.7°F.

Appleman goes on to say that:

> For fog to form as the result of the combustion of hydrocarbon fuels, it is necessary that the temperature lie below the critical value for saturation to occur as given in the table (Table XV) and also below – 22°F. in order for freezing to take place. With initially saturated air therefore, although combustion will lead to supersaturation at all temperatures below – 20.4°F., ice fog would not be expected unless the temperature were below – 22°F. If the air has an initial relative humidity of 90 per cent droplets will form at any temperature below – 27.2°F. and should immediately freeze and form an ice fog. If the initial relative humidity is 60 per cent fog will form at any temperature below – 33°F. and in completely dry air, below – 38.7°F. A graph of the temperature-relative humidity relationship, which will give rise to ice fog formation is shown as a solid curve in (Fig. 24.) In addition the – 22°C.[1] line has been drawn to indicate the maximum temperature at which liquid water droplets are likely to freeze.
>
> In the first two cases listed above (100 percent and 90 percent) the fog formed by combustion will be fairly persistent, because the unaffected air is highly supersaturated with respect to ice. In the last two cases (60 and 0 percent) this is not true..... The temperature and relative humidity relationship is shown as a dashed line in Figure (24); it represents the regions of persistent and non-persistent ice fogs. (4, p.398)

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1. Clearly a misprint for –22°F.

Thus the only reason why ice fog was recorded so seldom during the observational period was that, apart from the visit of the C-130 Hercules aircraft in March 1958, the effects of which are discussed in Chapter IX, practically the only source of hydrocarbon effluent was from the chimney of the Attwell shelter, much too small a source for the production of an ice fog of any extent. If a much larger base had been established conditions might have been very different.

The significance of Fig. 24 can be demonstrated from the graph of April vapour pressures in Fig. 21. It will be seen that the majority of the vapour concentrations lie above the curve of saturation with respect to ice, indicating supersaturation. Thus the greater part of the observations in the month of April indicated conditions likely to lead to the production of a persistent ice fog if a suitable source of hydrocarbon nuclei had been available. Under normal circumstances (i.e. allowing for the unusual conditions of January 1958) the months from November to March would have similar liabilities, and the same is true of much of October.

Wind speed must be taken into consideration in connection with ice fog, in that turbulent mixing does much to prevent the fog from forming, and the wind itself controls the direction of spread. According to a report on conditions in Alaska "Ice fog does not form or maintain itself for more than a few hours at wind speeds greater

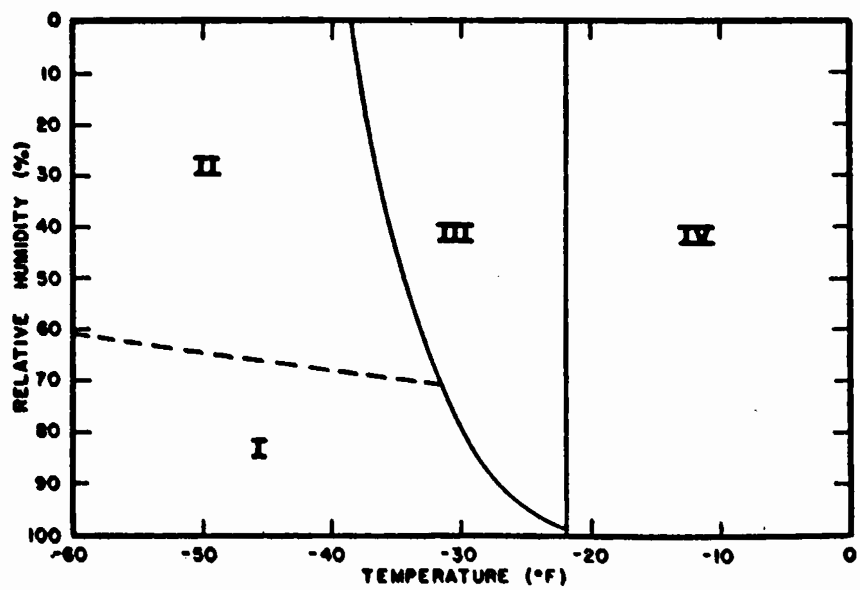


Fig. 24. Conditions Necessary for the Formation of Ice Fog.

I. **Region of persistent** ice fogs - Atmosphere supersaturated with respect to ice.
II. Region of non-persistent ice fogs - Atmosphere sub-saturated with respect to ice.
III. Region of no ice fog - Combustion causes drying of atmosphere.
IV. Region of no ice fog - Combustion causes drying of atmosphere. Droplets will not freeze.

(after Appleman)

than 3 m.p.h." (1.) This, unfortunately, brings little relief to potential conditions at Lake Hazen where it will be seen in Chapter VI that during the months of November and December 1957 and February and March 1958 two-thirds of all observations recorded absolute calm at 40 ft. and most of the remainder were of wind speeds below 5 m.p.h.

Ice fog is therefore a major meteorological factor to be considered in any projects for human occupancy of the Lake Hazen area, both at the stage of general planning and also at the level of detailed location of installations, where intelligent siting of hydrocarbon sources in relation to airstrips, buildings etc. can do much to reduce the nuisance.

CHAPTER VI

WIND

The two features of the Lake Hazen climate which are most readily appreciated by visitors to the area are the very low temperatures during the winter and the very low wind speeds which appear to be usual throughout the year. In the present chapter the wind recorded at Lake Hazen will be considered from four aspects: (a) the prevailing directions and speeds measured at the 40-feet level; (b) a comparison with similar data at Alert; (c) the vertical shear of wind close to the ground surface; (d) the effects of the wind and temperature together in the familiar physiological index of windchill.

I. WIND SPEED AND DIRECTION AT LAKE HAZEN

Speed The very low wind speeds recorded at Lake Hazen are summarised in Table XVI which shows the number of 3-hourly observations which fell into each of seven groups, together with the percentage this represents of all observations in the month. The cold winter months, omitting January, are also grouped together and compared to the record during the snow-free period.

The most striking feature of the table is the almost complete absence of high winds. Only on four occasions, all during August 1957, were winds over 25 m.p.h. recorded at a synoptic observation and on the overwhelming number of occasions throughout the year the wind was no more than 10 m.p.h. The number of absolute calms during the winter is quite outstanding and there can be no question of observational error here as, even when the anemometer ceased to record on the trace, the cups continued to rotate freely even during the slightest air movement which is also, at very low temperatures, readily apparent to the observer because of its chilling effect. Two out of three observations in the deep winter months were calms and winds of 5 mph. or less accounted for almost all the remaining observations. In the summer the proportion of calms was much smaller; there was almost always some air movement at 40 feet, but less than a quarter of all observations recorded winds in excess of 5 m.p.h.

These low wind speeds are in agreement with the views of Petterssen, Jacobs and Haynes concerning conditions in inland areas of the Arctic, although most of their sources were long-term records from Siberia. They emphasise, however the importance of local conditions:

> No one can examine detailed Arctic wind data from coastal and inland points without being impressed by the fact that local surface wind speed and direction are largely determined by exposure of the station (and wind instruments) and by the location of the area with respect to land and water bodies and to the regional orography. As an example of the influence of exposure, Sverdrup..... cites one case where a series of observations made between 1900 and 1902 at a station on

TABLE XVI

WIND SPEED BY MONTH AND SEASON AT LAKE HAZEN

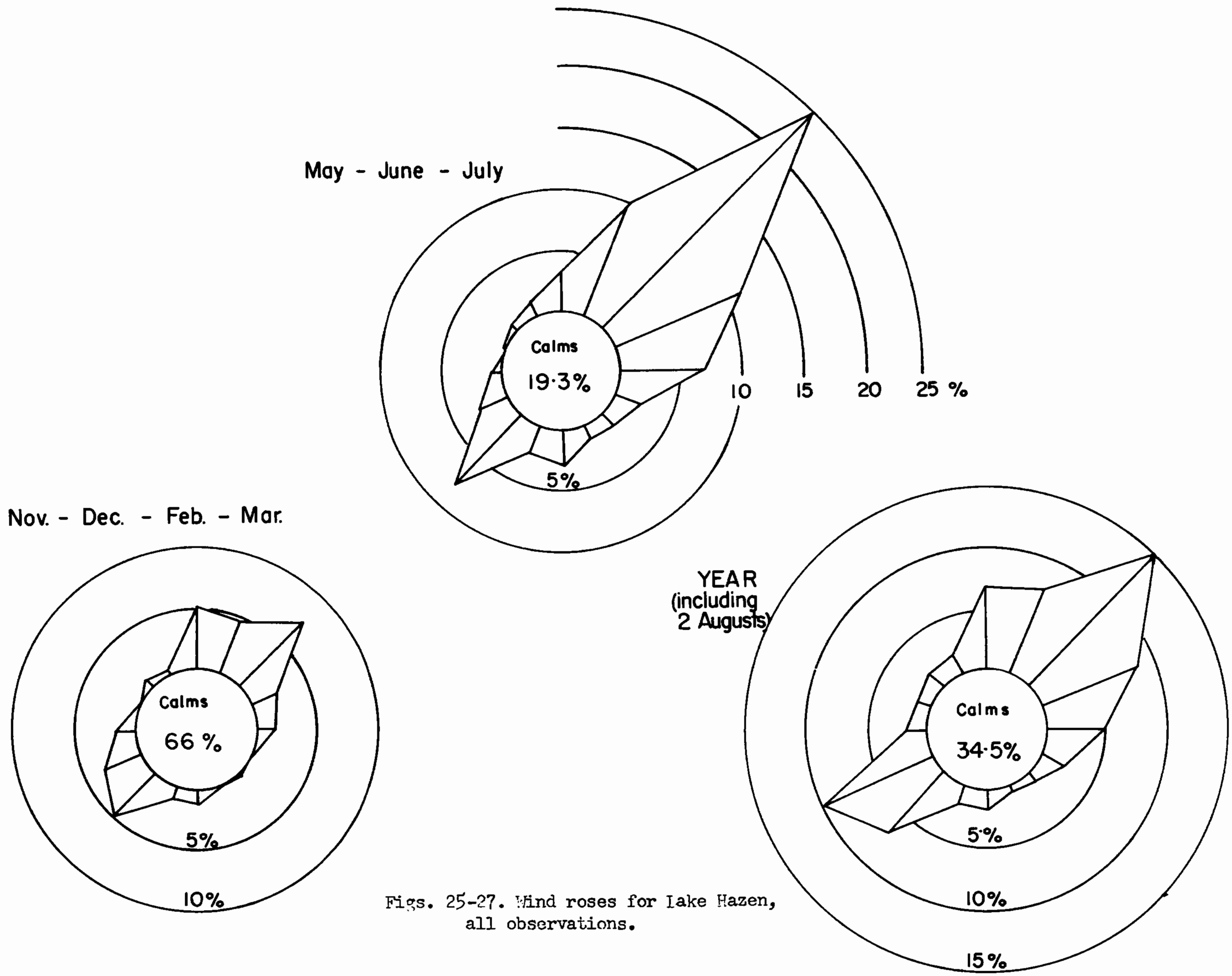
(Number and percentage of observations during each month and season based on 8 observations per day)

Month	Calm	1 - 5	6 - 10	11 - 15	16 - 20	21 - 25	Over 25
Aug. 57 ⁄	5% (5)	45% (41)	14% (13)	10% (9)	12% (11)	9% (8)	4% (4)
Sep.	8 (20)	70 (168)	18 (44)	2 (5)	1 (3)		
Oct.	33 (83)	60 (149)	6 (14)	1 (2)			
Nov.	62 (149)	38 (91)					
Dec.	70 (173)	29 (73)	1 (2)				
Jan. 58	34 (85)	56 (138)	5 (12)	1 (2)	3 (8)	1 (3)	
Feb.	62 (138)	36 (80)	3 (6)				
Mar.	72 (178)	28 (69)	0 (1)				
Apr.	40 (96)	54 (129)	5 (13)	0 (1)	0 (1)		
May	36 (90)	58 (144)	6 (14)				
Jun.	13 (30)	71 (170)	15 (37)	1 (2)	0 (1)		
Jly.	9 (23)	70 (174)	13 (33)	4 (10)	2 (6)	0 (1)	
Aug. ⁄	5 (4)	69 (55)	25 (20	1 (1)			
Nov-Dec 57 Feb-Mar 58	66% (638)	33% (313)	1% (9)				
Jun-Jly 58 2 Augusts ⁄	9% (62)	67% (440)	16% (103)	3% (22)	2% (15)	1% (9)	1% (4)

⁄ part

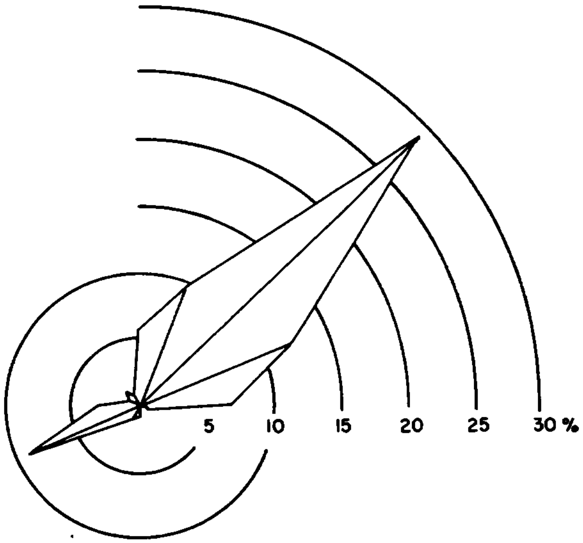
> Ellesmere Island showed an average wind speed of 11.2 m.p.h. whereas a series of observations made in the same area during the interval 1899 to 1900 gave an average wind speed of only 2.1 m.p.h. The reason for this marked difference is that the winter lodgings were located in a more sheltered location during the first year of observations than was the case during succeeding years (48, p.48)

To a certain extent this is a valid criticism, if that be the appropriate word, of the records from Lake Hazen. It has been mentioned earlier (p. 25) that the nearness of the Garfield Range would lead one to expect that winds from the quadrant between west and north would be under-recorded and this, as will be shown later, was in fact the case. However this serves also to illustrate the excellent exposure to the winds from other directions provided by the extensive flat surface of the Lake, which the low relief of John's Island did little to impede. Taking the value quoted by Geiger (29, p.393) that the effects of a wind-break are noticeable on the lee side up to thirty-five times the vertical height of the obstruction, the Lake Hazen station was within the sheltering influence of the 200-foot high cliffs at the southwestern end of the island, approximately a mile from the station, but the greater part of the island is much lower and much further away. The exposure of the instrument itself, in relation to other buildings, was excellent (Fig. 6) and on the whole it seems unlikely that the Lake Hazen record, apart from the nearness of the mountains, is unrepresentative of conditions in the neighbourhood of the lake.

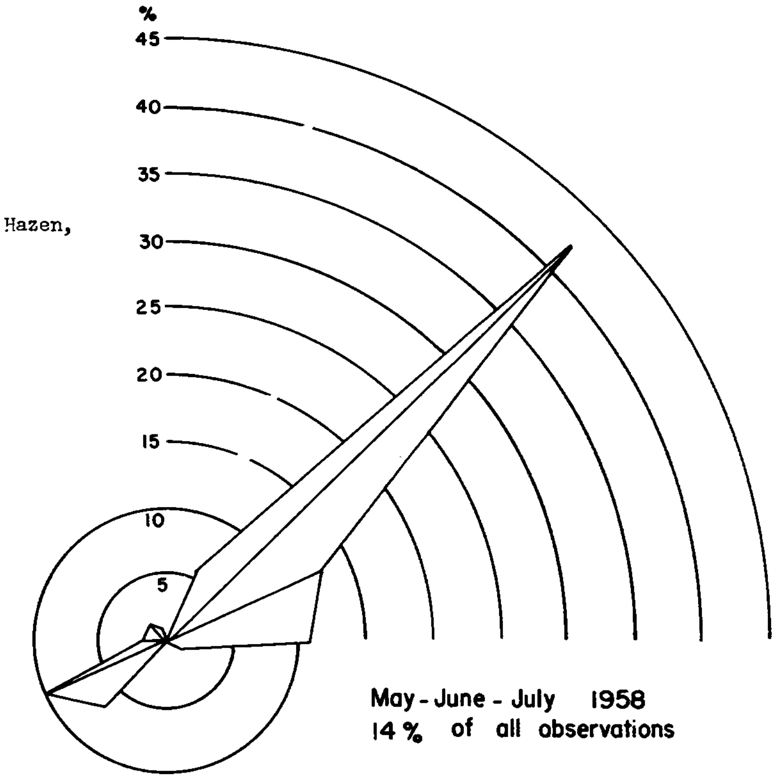


Figs. 25-27. Wind roses for Lake Hazen, all observations.

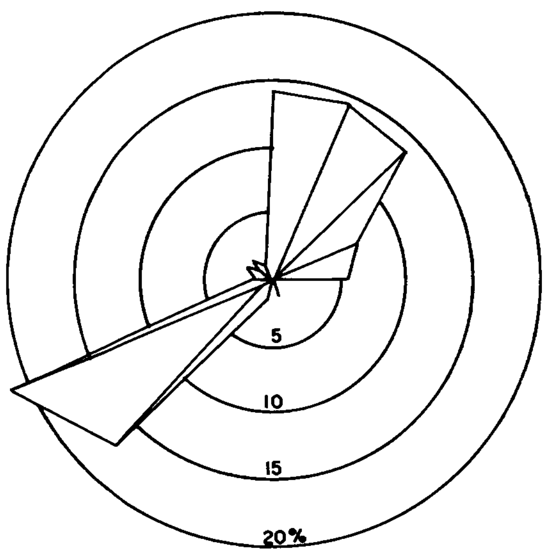
Figs. 28-30. Wind roses for Lake Hazen, winds over 5 m.p.h.



Year.
10% of all observations



May - June - July 1958
14 % of all observations



August - September 1957
19·26 % of all observations

Direction. Figs. 25, 26 and 27 show the frequency of wind direction as a percentage of observations over the whole year, and during four months in winter and three in spring and summer. In all of them the axis of prevailing wind lies along the general line of the Lake Hazen trough, although during the winter the high proportion of calms makes the question of slight importance.

Most of the data used to construct these directional roses are, however, of very light winds[1], which are of little significance for most purposes. Figs. 28, 29 and 30 have therefore been drawn using only the observations when wind speeds were greater than 5 m.p.h. It would be unrealistic to show the winter months in this fashion; instead the data for late August and September have been shown: the only time, apart from the January gale, when the wind was principally from the quadrant between south and west. The figures illustrate even more clearly the axis of the prevailing winds.

II. STRONG WINDS AT ALERT

The relatively quiescent conditions just described were not apparent on the coast of Ellesmere Island, at either Alert or Eureka. At the former

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1 According to J. M. Powell, who has made a separate analysis of the wind data in connection with his biogeographical work, calms and winds of 1 m.p.h. account for 58 per cent of all observations throughout the period of records.

station in particular, strong winds are very common, providing striking contrasts with the interior and far outweighing, in their effects on human existence, the much colder temperatures in winter at Lake Hazen.

Over the observational period, winds of 20 m.p.h. or more were recorded at Alert at 309 of the 3-hourly observations, or 11.2 per cent of the total. At Lake Hazen the number of occasions was only 29, representing 1.1 per cent of the total. Most of the latter occurred during the first few days of observations, in the latter part of August 1957. If this month is omitted from consideration, then winds of 20 m.p.h. or more were recorded on only 12 occasions, representing less than one-half of one per cent of all observations from September 1 1957 to August 10 1958.

The immense difference between the stations, and the problem of strong winds at Alert *per se*, are features of very great significance and they will be taken up in more detail in the synoptic section of this study. Here, however, it is important to point out the almost total irrelevance of conditions at Alert and Lake Hazen in the matter of wind speeds. This is demonstrated in Table XVII where conditions at Lake Hazen and Eureka are shown on occasions when the wind at Alert was 20 m.p.h. or more.

TABLE XVII

WINDS AT EUREKA AND LAKE HAZEN WHEN

WINDS AT ALERT EXCEEDED 20 M.P.H.

	EUREKA		LAKE HAZEN	
Wind (m.p.h.)	No. of Observations	%	No. of Observations	%
Calm	9	4.2	37	16.4
1 - 5	24	11.3	148	65.5
6 - 10	37	17.5	22	9.7
11 - 20	86	40.6	14	6.2
Over 20	56	26.4	5	2.2
	212	100.0	226	100.0

(Difference in totals is due to the lack of August 1957 data at Eureka.)

Strong winds at Eureka are also common, although somewhat less so than at Alert: in the period between September 1 1957 and August 10 1958 243 synoptic observations of winds of 20 m.p.h. or greater were recorded, suggesting that regional pressure patterns are at least as important as local conditions in producing strong winds. Most of the occasions when high winds did occur at Lake Hazen were associated with similar conditions at Alert and Eureka also, but much more typical were the conditions during the arrival of the summer party on April 30 1958. On that day the 1500 G.M.T. (10 a.m. E.S.T.) observations at Alert and Lake Hazen were as follows (Alert first):

> visibility: 1/8 mile in blowing snow, 30 miles; sea-level pressure: 1022.8 mbs., 1018.9 mbs., wind: southwest at 70 m.p.h., southwest at 10 m.p.h.; temperature +8.8°F., - 7.9°F.; dew point +2, - 12; relative humidity: 73 per cent, 82 per cent.[1]

III. WIND SHEAR CLOSE TO THE SURFACE

Contained in the mid-winter parachute drop were three self-totalising anemometers, recording miles and decimals of miles of wind run by means of a cumulative counter similar to the mileometer of an automobile. These, as described in Chapter II, were installed at one of the ground temperature stations, about one hundred yards northeast of the 40-foot anemometer, at

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[1] It is perhaps worth noting that the lowest cloud layer at both stations was estimated to be at 8000 ft., of possible interest where accuracy of these estimates is concerned.

heights of one, three and ten feet above the ground surface. The height above the snow surface naturally varied, but in the case of the one foot anemometer the site was generally kept free of deep snow by people taking periodic thermistor measurements.

There exists, therefore a record of the total run of wind at these levels for each 24-hour period (coinciding with the climatological day) after they were installed in mid-December. Table XVIII sets out the results in terms of the mean wind speed each month.

It had been hoped that thermistors would also be available so that detailed measurements of the heat flux between ten feet above the surface and about three feet below it could have been obtained. Thermistors were, however, available only for the soil temperature measurements. The record of wind speed does, however, give quantitative expression to several interesting features, and in particular it has enabled measurements to be made of the katabatic flow of air close to the ground and of the vertical shear of wind speed in the surface layer. Three periods will be considered here: the months of July and March 1958 which, as will be seen from Table XVIII, represent the extremes in wind speeds over months as a whole, and also a period of 35 hours during the gale of January 1958 during most of which period an hourly check was made of the anemometers.

TABLE XVIII

MEAN WIND SPEED AT THREE LEVELS

(Miles per hour)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jly.
10 ft.	2.86	1.20	0.85	1.55	1.87	2.91	3.67
3 ft.	2.76	1.20	0.96	1.57	1.74	2.70	3.50
1 ft.	2.25	0.84	0.66	1.28	1.25	2.28	3.17

The principal difference between March and July, apart from the much greater air movement in high summer, is the katabatic effect which caused the wind at three feet in March to be greater than that at ten feet. The July profile is much more "normal"; although a katabatic component must be present it is of less importance than the regional wind field.

In addition to the three self-totalising anenometers, the anemometer at forty feet also provided complete data in July and it is therefore possible to compare the run of wind at all four levels. For each day in the month, the wind at the three low levels were calculated as a percentage of that at forty feet and the mean percentages were:

1 ft.	3 ft.	10 ft.
75.2%	83.6%	84.9%

In other words the total run of wind at one foot during July was approximately three-quarters of that at forty feet on the average.

The standard deviations of these means are 13.37 per cent, 13.62 per cent and 12.02 per cent respectively.[1] These conditions, however, include five days in the month when the air movement at three feet was greater than that at forty feet, i.e. when katabatic conditions were dominant. If these five days are omitted the values become

1 ft.	3 ft.	10 ft.
70.5%	78.6%	81.9%

and the standard deviations are reduced to 8.08 per cent, 7.70 per cent and 8.49 per cent respectively. The critical value for the katabatic effect in July was a run of wind of sixty-five miles in 24 hours at the forty foot level (i.e. a mean wind speed over 24 hours of 2.7 m.p.h.) Where the total run was below this value, the air movement at three feet was always greater than that at forty feet.

It would have been interesting to calculate similar relationships in March when the balance of air flow was exactly the reverse: on only five days during the month was the air movement at ten feet greater than that at three feet. This is not possible, however, as data from the forty-foot level are not available for the whole month. Nor was it possible to find a useful expression for the flow at three feet in terms of that at ten feet since, even considering only the days when katabatic influences were dominant, the relation between the wind at three feet and that at ten feet varied between 101 per cent and 204 per cent, with a fairly broad scatter of daily values in between these extremes. This is not really

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[1] It should be noted, however, that the distribution of deviations from the mean in this and the following shears are not normally distributed.

surprising, in view of the very much smaller total air movement involved: on only two of the twenty-six "katabatic" days was the air movement at three feet equivalent to a mean wind speed of 1 m.p.h. or more and so, although the regional wind may be very light by absolute standards it prevents any simple relationship between the levels from being established. From Table XVIII, however, it is clear that the katabatic wind reaches its maximum somewhere between one foot and ten feet above the surface, being reduced close to the ground by friction and at a higher level by shearing stress due to the decrease in density of the moving air as the temperature gradient decreased away from the surface. Analysis of the daily values during March also showed how extreme the calm conditions at Lake Hazen are in winter: on four occasions the air movement at ten feet over a 24-hour period was equivalent to a mean wind speed of one-fifth of a mile per hour or less.

Remaining to be considered is the vertical shear of wind across a snow surface at relatively high speeds. During the storm of January 17 - 18 1958, the anemometers were read to the nearest mile every hour for twenty-three hourly periods, with two intervening breaks represented by 8-hour and 4-hour mean speeds. This break occurred when the storm was at its height and the short journey to the anemometers in the complete darkness and whirling snow and sand was difficult and inadvisable.[1]

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[1] It is perhaps necessary to mention that although high winds were not actually recorded at any of the synoptic observations, the wind frequently rose to 40 to 50 m.p.h. in the intervening periods.

On one occasion the reading of the one foot anemometer was abnormally high by comparison with the others, and this was followed by an abnormally low value at the next hour, indicating an error of observation. A 2-hour mean thus gives a more reliable figure for the period. Using these twenty-four observations when the wind was usually over 20 m.p.h., gradually decreasing to about 10 m.p.h. at the penultimate and 5 m.p.h. at the final observations of the series, the relationship of the air movement at 1 ft. and 3 ft. to that at 10 ft.[1] is as follows:

1 ft.	3 ft.
82.4%	92.7%

The standard deviations are 7.49 per cent and 3.66 per cent respectively.

The wind speed at three feet, it will be seen, is very close to that at ten feet: much of the reduction can be explained in terms of the greater mass of blowing snow carried along at the lower level. There is an appreciable reduction closer to the ground. This is again partly due to the still greater energy expended in carrying the blowing snow and is also, in later observations, probably an indication of increasing frictional drag: the snow cover was completely removed from much of the ground by the wind and blowing sand was carried across the surface which,

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1 The 40-foot anemometer was blown from its stand in the middle of the gale and was not replaced until calmer conditions returned.

although generally flat, also contains areas of wind eroded hummocks ("niggerheads") some distance upstream of the anemometers which might be expected to cause turbulence in the lowest layers.

IV. WINDCHILL

The windchill index, devised by Siple and later amended and interpreted by himself and others is a convenient way of collecting together the material presented in this chapter and in Chapter III. As has been pointed out by Burton and Edholm (8, p.111), the physiological implications of the windchill index are less than might at first appear. Windchill, to the man in the Arctic, is normally only fully experienced on exposed portions of the hands and face. Relative rates of windchill, however, have implications for housing, rate of fuel consumption in heating, etc., as well as in helping to decide what clothing is necessary and it remains the most widely used index of "real cold".

Fig. 31 shows windchill data for five months at Lake Hazen. The values were completed from the standard tables (see, for example, Falkowski and Hastings (27)) by taking the combination of wind and temperature at any of the eight synoptic observations which gave the highest index. September 1957 represents conditions in the fall, when winds were strong by Lake Hazen standards and when the temperature was already below freezing. The great fluctuations in December show the effect of even a light wind as compared to absolute calm conditions. January was included because of the high winds during the January gale, April to show how long winter levels of windchill continued. Finally, July represents conditions in high summer. Plotting five months on the same graph gives an impression of similarity which is very significant: most of the observations in each of the three winter months lie between 1200 and 1400 units and it is interesting to note that the worst windchill at any of the eight observations on January 4, when the absolute minimum of -68.5°F. was recorded, was exceeded the following July: the conditions were, respectively, a calm at -66°F., and a wind of 22 m.p.h. at 36°F.

To relate these values to conditions elsewhere, Fig. 32 shows similar values for Thule and Montreal. January and July data are plotted for Thule in the year 1949, a year chosen at random from the published data for that station. (54). The data from Dorval Airport in Montreal are for December 1958, a colder December than usual in the city, but one which was not especially windy. The Thule graph shows much higher values in winter than were general at Lake Hazen in the winter of 1957-58, showing that the colder temperatures at Lake Hazen are of much less significance than the higher winds common at Thule. Of greater interest, however, is the comparison between Lake Hazen and Montreal: the majority of the values at Dorval Airport fall within the same limits as the majority of those

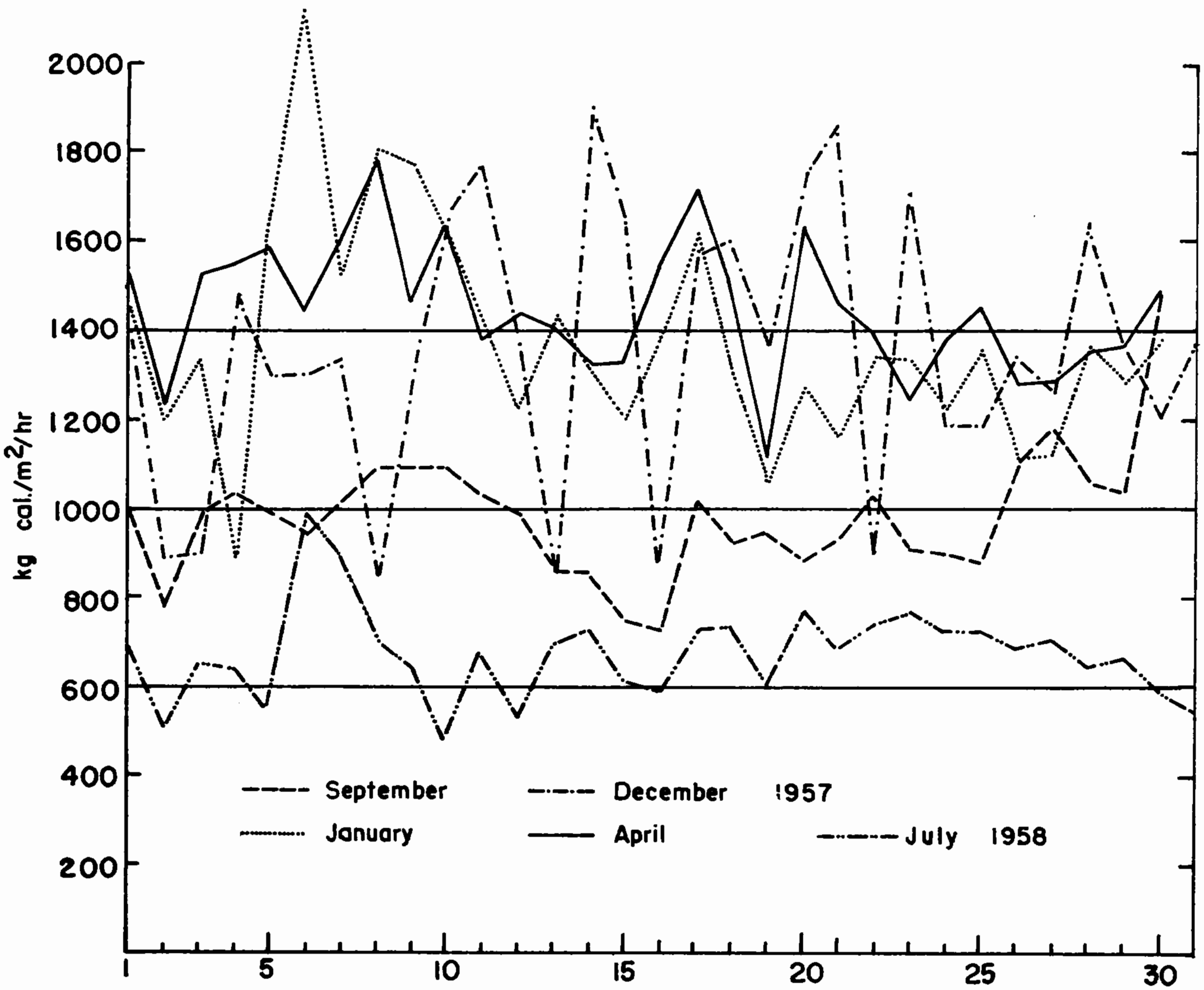


Fig. 31. Windchill at Lake Hazen 1957-58

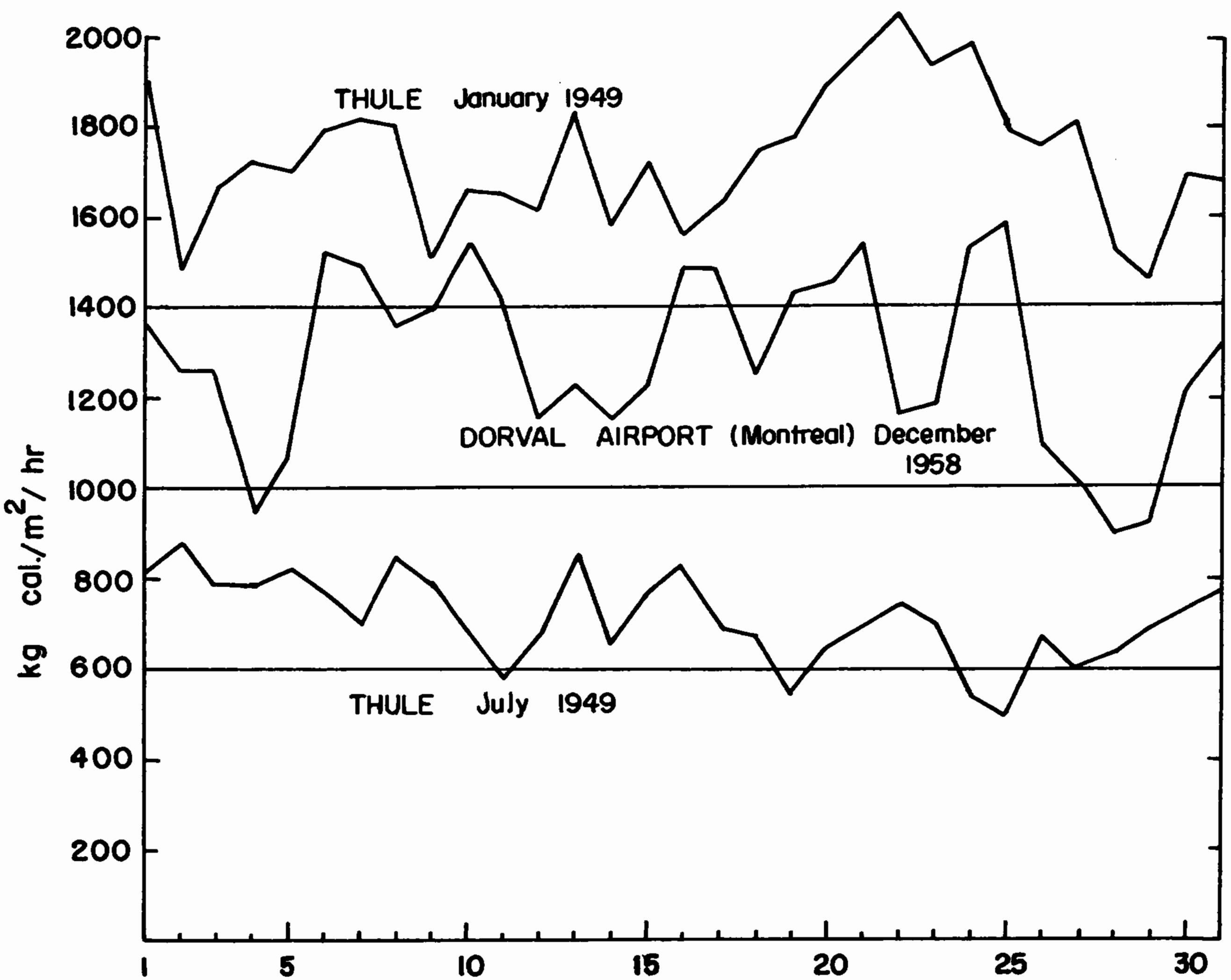


Fig. 32. Specimen Monthly Windchills at Thule and Montreal

during the winter at Lake Hazen. Whether this may be taken as an indication of the excellence of conditions at Lake Hazen or of the intolerable climate of Montreal is for others to decide. The graphs do indicate, however, that no special physiological problems, of the type that can be measured by windchill, should be encountered were a permanent settlement created at Lake Hazen. The experience of the author and his colleagues was that it is necessary to avoid breathing through the mouth as much as possible, to avoid the intensely cold air in winter from striking the lungs direct. This, of course, is equivalent to stressing the need to avoid undue physical exertion which would involve breathing through the mouth.

CHAPTER VII

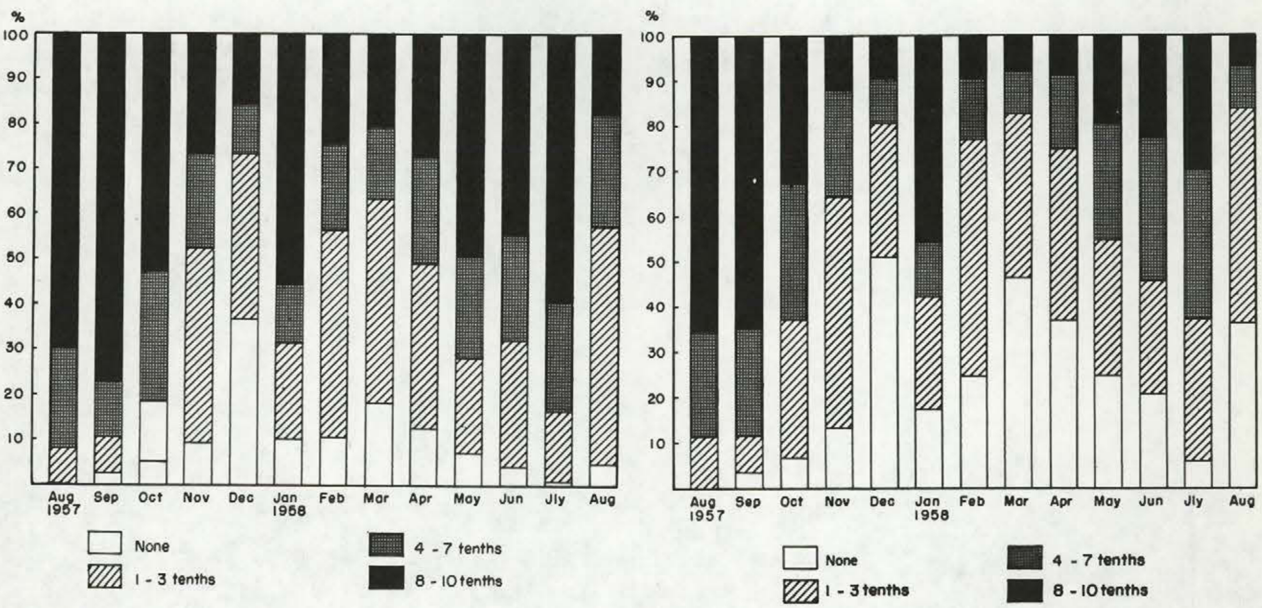
CLOUD AND VISIBILITY

The material presented in this chapter is complementary to that in Chapter IX, where the incidence of cloud and visibility combinations is presented in a way which has most significance for aircraft operations. In Chapter IX it is the height of the ceiling and the frequency of poor visibility which are important. The ceiling is defined as a cloud cover which causes six-tenths or more of the sky to be completely obscured and it is with ceiling below 2500 ft. that Chapter IX is concerned. In the present discussion the incidence of higher ceilings and of cloud and visibility conditions in general is considered not only at Lake Hazen but at Alert and Eureka also, so that the influence of the inland site of Lake Hazen may be assessed.

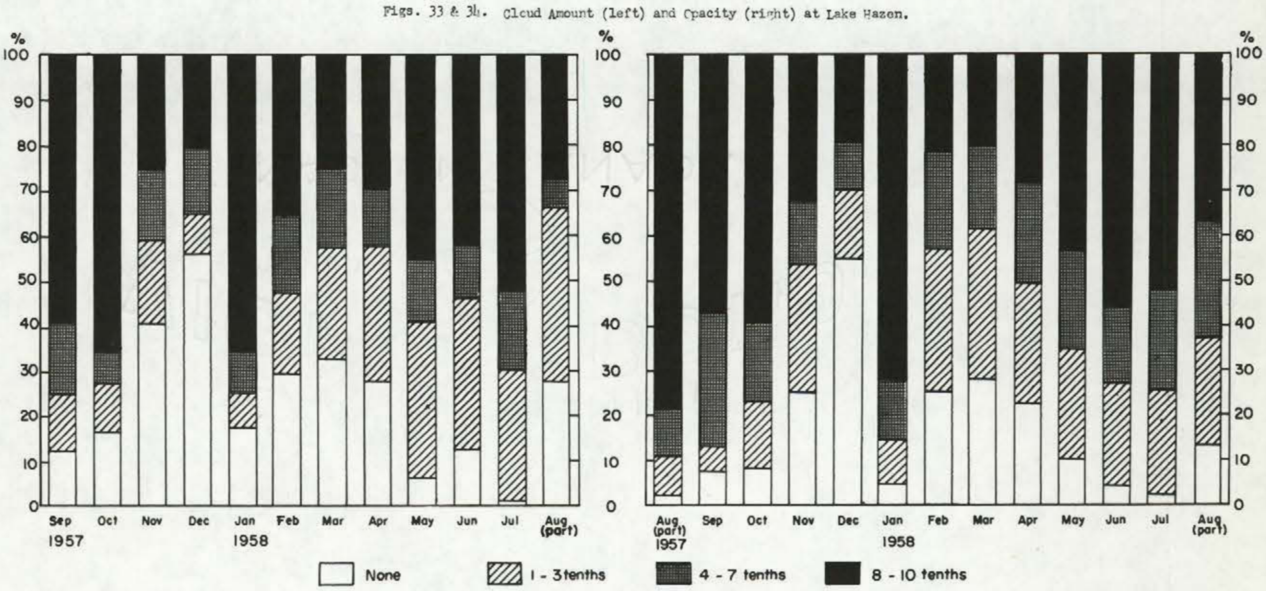
I. CLOUD

Figs. 33 and 34 show the percentages of observations in each month in which cloud amount and opacity totalled each of four different groups. In the case of the two Augusts, 1957 and 1958, the percentages are of a total of eighty-eight and eighty observations on eleven and ten days respectively. Figs. 35 and 36 show similar graphs of amount only at Alert and Eureka during similar periods. It was intended to produce graphs of opacity for these stations also, but for Alert especially the graphs of opacity and amount would have been practically identical. Throughout the period from August 21 1957 to August 10 1958, involving over 2800 3-hourly observations, the Alert record shows that on only one occasion was an observer there able to detect any difference between the amount of the cloud in the sky and its opacity. The record at Eureka indicates a much higher standard of observations, but even here the differences between amount and opacity were small when averaged over a period of a month or so and do not merit plotting separate graphs. The relative proportions are also set out in tabular form in Table XIX.

The main conclusion to be drawn from a comparison of conditions at the three stations is, rather surprisingly, the general similarity in cloud amount at Alert and Lake Hazen. If the first two groups in Table XIX are added together, the totals were usually fairly similar at the two stations, the two main exceptions being the months of September 1957, when the open lake gave high cloud amounts in the vicinity of Lake Hazen by comparison with Alert where open water is not so common so late in the year, and January 1958, when both Alert and Eureka had considerably higher totals than the inland site. Otherwise the major contrast is between Eureka and the other two stations. Except in May the sky was less than 4/10 covered on a much larger number of occasions at Eureka, and in several months the proportion of such observations rose to 45 or 50 per cent.



Figs. 33 & 34. Cloud Amount (left) and Opacity (right) at Lake Hazen.



Figs. 35 & 36. Cloud Amount at Eureka (left) and Alert (right).

If the total amounts of cloud at Alert and Lake Hazen were fairly similar during the observational period, the same is not true as far as the height and denseness of the cloud was concerned. Table XX shows the frequency of ceilings at different heights during four months. It will be seen that much of the cloud at Alert occurred at much lower levels than at Lake Hazen which, it must be remembered,is several hundred feet higher above sea-level. September 1957 again proves the exception but otherwise Lake Hazen usually either recorded no ceilings or experienced them at much greater heights than was usual at Alert. In July particularly nearly one-quarter of the observations at Alert showed ceilings at or below 2500 ft. compared to less than 1 per cent at Lake Hazen. The data perhaps indicates that while a cloud layer at heights of the order of 5,000 to 10,000 ft. may occur extensively over northern Ellesmere Island it may frequently be accompanied by a layer of much lower cloud along the coasts which is absent from the interior. Thus the summer of 1958 was a dull one, but neither a wet nor a foggy one, whereas low cloud, rain, fog, sleet and snow were common at Alert on the coast. Eureka in summer seems to resemble Lake Hazen whilst in winter it shares much of Alert's bad weather.[1]

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[1] During the relief of the summer party in 1957, J. P. Croal, on board the U.S.C.G.S. "Eastwind" in Chandler Fiord noted that "During the three days we lay at anchor in Chandler Fiord there was usually fog and low clouds in the fiord whereas at Lake Hazen 15 miles northwest and 522' above sea level the weather was generally good." (21, pp. 13 - 15)

TABLE XIX

RELATIVE CLOUD AMOUNTS AT ALERT, EUREKA AND LAKE HAZEN

(Percentage of observations)

Station	0	1-3	4-7	8-10	0	1-3	4-7	8-10
	Amount of Sky Obscured (tenths)							
	August 1957 (part)				September			
Lake Hazen	0	8.1	22.1	69.8	2.9	7.5	12.9	76.7
Eureka	-	-	-	-	12.5	11.7	17.1	58.8
Alert	2.3	8.0	11.4	78.4	7.9	15.4	20.0	56.7
	October				November			
Lake Hazen	5.7	22.6	19.0	52.8	9.6	42.9	21.3	25.8
Eureka	16.9	10.5	7.3	65.3	40.8	18.3	15.8	25.0
Alert.	8.5	14.9	17.7	58.9	25.4	28.3	14.2	32.1
	December 1957				January 1958			
Lake Hazen	36.7	36.7	10.9	15.7	10.1	21.4	13.3	55.2
Eureka	56.5	8.5	14.5	20.6	17.7	6.9	10.1	65.3
Alert	55.2	14.1	11.3	19.4	4.8	10.1	13.3	71.8
	February				March			
Lake Hazen	10.3	46.0	19.6	24.1	18.5	44.8	16.5	20.2
Eureka	29.5	17.9	17.4	35.3	32.7	25.0	16.9	25.4
Alert	25.4	32.1	21.4	21.0	28.6	33.1	18.5	19.8
	April				May			
Lake Hazen	12.9	36.3	23.8	27.1	7.3	21.0	22.6	49.2
Eureka	27.9	30.0	12.5	29.6	6.0	35.1	13.7	45.2
Alert	22.9	26.7	22.1	28.3	10.1	24.6	21.8	43.5
	June				July			
Lake Hazen	4.2	27.9	23.8	44.2	0.8	15.7	24.2	59.3
Eureka	12.5	33.8	12.1	41.7	1.2	29.0	17.7	52.0
Alert	4.2	22.9	17.5	55.4	2.4	23.4	22.6	51.6
	August 1958 (part)							
Lake Hazen	5.0	52.5	25.0	17.5				
Eureka	27.5	38.8	6.3	27.5				
Alert	13.8	23.8	23.8	38.8				

TABLE XX

CEILING FREQUENCY AT ALERT, EUREKA AND LAKE HAZEN

(Percentage of observations)

Station	Below 500'	500'-1000'	1100'-2500'	2600-5000'	Over 5000'	No Ceiling.
		September 1957				
Lake Hazen	8.3	6.3	22.9	20.8	17.5	24.2
Eureka	2.5	22.9	4.6	10.0	28.8	31.3
Alert	17.9	24.6	4.6	2.1	14.2	36.7
		December 1957				
Lake Hazen	0	0	0	1.2	12.1	86.7
Eureka	1.6	6.9	2.4	0.4	14.9	73.8
Alert	3.2	1.2	1.6	6.5	10.9	76.5
		April 1958				
Lake Hazen	0.4	0	2.5	2.1	10.4	84.6
Eureka	0	3.3	1.3	7.5	21.7	66.3
Alert	7.1	7.1	1.7	0.4	21.3	62.5
		July 1958				
Lake Hazen	0.4	0.4	0	21.0	26.2	52.0
Eureka	0	0.8	3.6	23.4	29.8	42.3
Alert	8.1	12.1	4.4	10.5	29.4	35.1

Turning from cloud amount to cloud type, Table XXI shows the frequency of observations of cloud types in three significant months, considering only the occasions when a particular type filled four-tenths or more of the sky at any observation. September was chosen because of its peculiar cloud conditions; March represents a winter month, immediately after the sun's return when the accuracy of cloud observations was likely to be higher than during the polar night, and July represents midsummer conditions.

TABLE XXI

OCCURRENCES OF CLOUD TYPES AT LAKE HAZEN COVERING FOUR-TENTHS OR MORE IN THE SKY IN A SINGLE LAYER

September 1957

Cu	St	Sc	As	Ac	Cs	Ns	Fog	Snow	Total
4	42	91	30	14	1	10	10	2	204

March 1958

Cu	St	Sc	As	Ac	Cs	Ci	Snow	Total
0	4	0	43	4	7	8	2	68

July 1958

Cu	St	Sc	As	Ac	Cs	Ci	Fog	Total
8	2	110	14	29	6	17	1	187

In September a high proportion of the dominant cloud types was composed of stratus and stratocumulus. Nearly three-quarters of the total of 204 occurrences are composed of low stratiform types. In March the situation, as might be expected, is completely different. Only on 68 occasions did single cloud layers cover four-tenths or more of the sky and only 4 of these occasions were caused by low clouds: the vast majority of occurrences were layers of altostratus. Finally in July, stratocumulus was again the dominant cloud type but conditions were very different to the previous September: stratus cloud was almost completely absent and the sky was often sufficiently clear for cirriform clouds to form a significant part of the total.

II. VISIBILITY

Table XXII sets out the relative incidences of good and bad visibilities at the three stations. In each case the figures shown represent the number of days in each month on which the lowest visibility at any of the eight synoptic observations was in each of six groups. The first four groups are those used in the ceiling-visibility summaries prepared at the Joint Weather Stations. The fifth group increases the limits to twelve miles, beyond which differences in visibility become of little significance for most purposes. The most distant marker at Lake Hazen (being equivalent to unlimited visibility) was 40 miles from the station; at Alert and Eureka similar markers would appear from the records to be at 15 and 20 miles respectively.

The principal feature which is illustrated by Table XXII is the generally poor visibility at Alert compared to Eureka or Lake Hazen. With the exception of October this is true throughout the year, but is especially marked in summer, when Lake Hazen in particular experiences almost perfect visibility. Alert is liable to very poor visibility throughout the year. Thus Alert and Lake Hazen each recorded visibilities of three-quarters of a mile or less on 14 days in September and October 1957 but over the whole observational period the figures are 58 days at Alert and 29 at Lake Hazen. At Eureka, for a slightly shorter period, the value is 33 days.

TABLE XXII

VISIBILITY AT ALERT, EUREKA AND LAKE HAZEN

(Poorest visibility each day at a synoptic observation)

Station	Miles 0 - 3/8	½ - ¾	1 - 2½	3 - 6	7 - 12	Over 12
			August 1957 (part)			
Lake Hazen	0	0	0	1	2	8
Eureka	-	-	-	-	-	-
Alert	1	2	2	3	1	2
			September			
Lake Hazen	1	5	2	9	7	6
Eureka	1	3	1	7	8	10
Alert	6	2	5	6	3	8
			October			
Lake Hazen	6	2	8	7	6	2
Eureka	6	2	8	7	6	2
Alert	1	5	5	12	4	4
			November			
Lake Hazen	2	1	3	6	14	4
Eureka	3	3	5	9	5	6
Alert	2	2	2	11	4	9
			December 1957			
Lake Hazen	0	1	3	5	14	8
Eureka	1	0	1	8	5	16
Alert	0	1	4	8	1	17
			January 1958			
Lake Hazen	2	6	2	9	11	1
Eureka	5	4	1	10	7	4
Alert	7	3	9	10	0	2
			February			
Lake Hazen	0	1	2	5	15	5
Eureka	0	2	2	11	2	11
Alert	0	2	0	8	4	14
			March			
Lake Hazen	0	0	1	5	5	20
Eureka	0	1	1	6	11	12
Alert	3	2	0	7	1	18

TABLE XXII (Cont'd)

Station	0 - 3/8	½ - ¾	1 - 2½	3 - 6	7 - 12	Over 12
			April 1958			
Lake Hazen	1	0	0	4	4	21
Eureka	1	1	2	2	12	12
Alert	3	6	0	11	2	8
			May			
Lake Hazen	0	1	0	6	4	20
Eureka	0	0	5	5	7	14
Alert	3	0	7	2	7	12
			June			
Lake Hazen	0	0	0	2	1	27
Eureka	0	0	1	2	4	23
Alert	1	2	2	2	10	13
			July			
Lake Hazen	0	0	0	1	2	28
Eureka	0	0	0	1	5	25
Alert	3	5	0	2	4	17
			August 1958 (part)			
Lake Hazen	0	0	0	0	0	10
Eureka	0	0	0	0	0	10
Alert	0	1	2	1	2	4

III. WHITE-OUTS

The problem of Arctic white-outs is one which is of considerable importance for transport in general and for aircraft operations in particular. It has recently been studied by Fritz (28) in theoretical terms and earlier by Hedine (34) and Court (24). Here is presented only the data on white-out occurrence at Lake Hazen, in the form of notes made on the synoptic sheets by the observers, together with the cloud and visibility conditions at observations close to the time at which the note was made. It is hoped to return to the question in the subsequent section on local forecasting. Observers were asked to record such conditions whenever possible, so this probably represents the majority of occurrences. One occasion, however, was certainly missed, on October 3 1957 when the author and a colleague traversed the frozen lake to the Ruggles River and back. During the morning, when a total sky cover of snow and altocumulus was being recorded at the station, white-out conditions in the middle of the lake were very bad for a time and almost caused the crossing to be abandoned. The occurrences of other white-outs follow: it should be noted that they could occur during 1957 - 58 in the immediate vicinity of Lake Hazen in the fall only after the lake had frozen and before the sun fell far below the horizon (i.e. late September to late October) and in spring any time between the return of the sun close to the horizon in mid-February until the thaw in early June.

TABLE XXIII

OCCURRENCES OF WHITE-OUT CONDITIONS AT LAKE HAZEN

(All times are approximately E.S.T.)

1958	
Feb. 27	"1100 E.S.T. Light snow grains. Visibility still some twelve miles but white-out conditions. Cloud base lowering to about 3000 ft."
	1000 obs. 10/10 altostratus at 7000 ft., very light snow grains, visibility 12 miles.
	1300 obs. 10/10 altostratus at 5000 ft., light snow grains, visibility 6 miles.
Mar 26/27	"2400, White-out conditions except where northern horizon brighter because of sun. Thick mist."
	"0700. White-out conditions in some but not all directions. Sun dimly visible."
	2200 obs. 1/10 altostratus at 7000 ft., 6/10 transparent altostratus at 12000 ft., 1/10 fog, visibility 12 miles.
	0100 obs. 7/10 stratus at 4500 ft. Visibility 6 miles in ice fog and light snow.
	0700 obs. 10/10 altostratus at 6000 ft. Visibility 4 miles in ice fog and light snow.
April 2	"1245. Partial white-out condition prevailing to east and south-east."
	1000 obs. 3/10 altostratus at 12000 ft., 4/10 transparent cirrus at 23000 ft. Visibility 20 miles.
	1300 obs. 10/10 altostratus at 12000 ft. Visibility 8 miles.
April 5	"2000-2200. White-out conditions to east."
	1900 obs. 4/10 semi-transparent altrostratus at 8000 ft., 1/10 transparent cirrus at 19000 ft., 2/10 transparent cirrus at 22000 ft. Visibility 8 miles in very light snow.
	2200 obs. 3/10 altostratus at 8000 ft. Visibility 8 miles in very light snow.

TABLE XXIII (Cont'd)

April 9.	"1000. Sun dimly visible. Tending to white-out conditions."
	1000 obs. 10/10 altostratus at 6000 ft. Visibility 13 miles
April 21.	"1400. White-out conditions during most of previous five hours.
	0700 obs. 4/10 altostratus at 7000 ft., 4/10 transparent cirrostratus at 20000 ft. Visibility 20 miles.
	1000 obs. 10/10 stratus at 2000 ft. Visibility 4½ miles in light snow.
	1300 obs. 10/10 semi-transparent stratus at 2000 ft., 2/10 transparent altocumulus at 8000 ft. Visibility 4 miles in light snow.
May 10	"0315. Tendency towards white-out conditions."
	0400 obs. 10/10 stratus at 2800 ft. Visibility 5 miles in light snow.
June 3	"0310. White-out conditions prevailing to east and southeast."
	0100 obs. 10/10 stratocumulus at 5000 ft. Visibility 15 miles in light snow.
	0400 obs. 10/10 stratocumulus at 3000 ft. Visibility 13 miles in light snow.

CHAPTER VIII

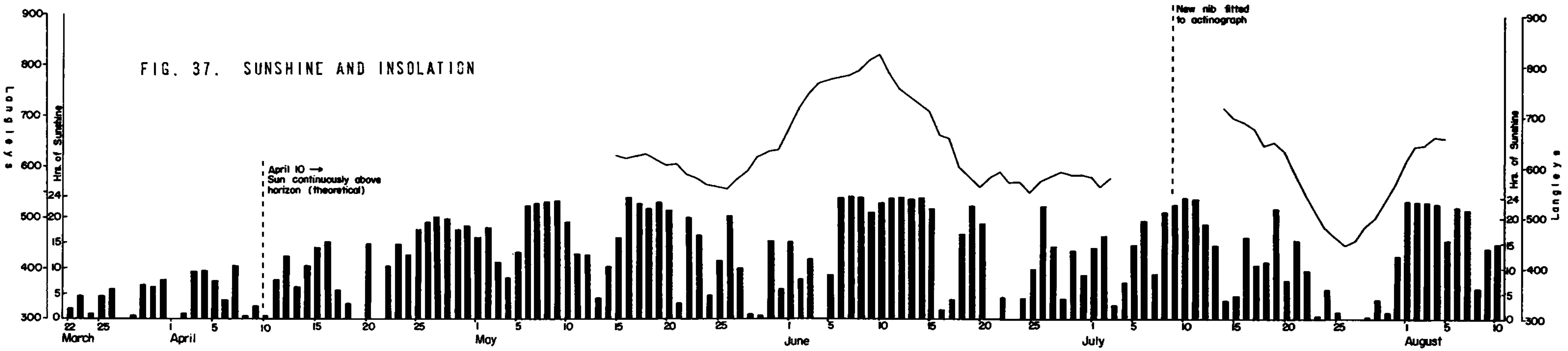
SUNSHINE AND INSOLATION

As was indicated in an earlier chapter (pp. 46-48) the records of sunshine and insolation at the base camp are far from being completely satisfactory. One reason for this, particularly in the case of sunshine totals, arises from the instrumentation; the same is also true to a certain extent for insolation, but the author must take a part of the blame in the latter case for not operating the instrument correctly. Despite these imperfections, the records are not entirely valueless and are presented here in ways which it is hoped will be useful to other workers without exaggerating the accuracy of the records.

I. SUNSHINE

Fig. 37 presents the data for both sunshine and insolation. The number of hours of bright sunshine instrumentally recorded each day has been shown in the conventional "pillar" diagram. When the sun was continuously above the horizon the trace was changed, with occasional exceptions, exactly at midnight, so that the amount shown for each day is for the 24 hours ending 2359 E.S.T.

FIG. 37. SUNSHINE AND INSOLATION



As was mentioned in Chapter II the correct cards for the sunshine recorder only became available when the summer party arrived at the end of April 1958, and so the records are most accurate for the period from May 8 onwards. One reason why only small totals were recorded in March and April was the great difficulty experienced in keeping the sphere clear of frost at temperatures well below 0°F.

At the latitude of Lake Hazen the sun is continuously above the horizon from April 10 onwards (until September 6.) This value, however, is calculated on the basis of a flat horizon at sea-level and is naturally considerably different at an inland location, particularly one close to mountains as was Lake Hazen. Only for a period of about five weeks before and five weeks after the summer solstice was the sun high enough in the sky to prevent the nearest peaks of the Garfield Range from casting any shadow. Thus the 20 hours on April 26 and the 23 hours recorded on May 8 and May 9 are probably the maximum possible on those dates, and the same is true of the high totals in early August.

On the evidence of 1958, May is the month with the highest totals of bright sunshine, with 453.4 hours, compared to 280.6 hours in April, 421.9 hours in June and 339.2 in July. It is unlikely that a normal August would be dissimilar to conditions in July. Part of the explanation for the lower figures in high summer may be found in the steadily increasing areas of open water in the lake and more particularly in neighbouring seas. The regime in 1958 was similar to that in the previous year. According to R. E. Deane "May and most of June were marked by almost perpetual sunshine at Lake Hazen. During parts of June, July and the first half of August intermittent cloudiness marred an otherwise perfect climate." (25, p.20). On several occasions in 1958 over 100 hours of continuous bright sunshine was recorded; in other periods, particularly in late July, daily sunshine totals were small and on several days no bright sunshine was recorded at all.

II. INSOLATION

The disadvantages of the Cassella actinograph have been considered in Chapter II; they are chiefly of the type to be expected with a new instrument and may easily be eliminated. Of greater importance to the present discussion was the lack of sufficient care on the part of the author in installing the instrument. In an endeavour to have the instrument operating for as long a period as possible during the summer, it was put into service without sufficient care being taken to obtain a satisfactory zero radiation line from the pen arm. This was done when the pen arm was replaced on July 9, but even then the zero line appeared to have changed somewhat when the instrument was withdrawn from service on August 10. It would appear that frequent checks (of the order of every week or so) are necessary with this instrument to ensure that an accurate zero value is obtained. This, of course, is a simple matter in mid-latitudes, where a daily zero is obtained each night, but it is more difficult when a continuous record of insolation is required during high latitude summers. The trace was changed daily at about 2120 E.S.T. and the figures of insolation are thus for the 24-hour periods ending 2120 each day. Occasional days are missing from the records, due to trouble with the pen arm.

The radiation each day was calculated throughout the period initially by assuming that the zero line was at zero on the chart until July 8 and at sixteen from July 10 until August 10. The figures obtained for the first period were not only always considerably higher than the values recorded by a similar instrument at the Gilman Glacier camp, but were often higher than the theoretical maximum for the latitude and season. The values from July 10 seemed acceptable as they were recorded.

To reduce the values for the earlier period to more representative totals, the records from the Gilman Glacier camp were used. Regular measurements of insolation did not commence on the Glacier until June 10 and thus the period available for direct comparison is limited to the period June 10 to July 8.

Whilst there was a general similarity between the records at the two stations in day to day changes, different cloud conditions on several days gave a wide range of ratios between the two sets of values and the resulting standard deviations of these ratios would have been too high for a reduction of daily values to have much significance. The technique of ten-day running means was adopted to overcome this, and the ratio of measured radiation on the Gilman Glacier to that at Lake Hazen was calculated for each of the fifteen ten-day periods available in the time of overlap. The mean ratio was 74.8 per cent (i.e. the Gilman Glacier record was only 74.8 per cent of that at Lake Hazen.) Statistical tests indicated that this value was very significant, although a number of objections may be raised to the technique. In particular, the use of ten-day running means requires that the bulk of daily observations are contained in ten of these means, but those at the beginning and end of the period are represented in a few number and the sample is thus biassed in favour of observations away from the two ends of the period.

The daily values for the period May 11 to July 8 were then grouped into ten-day running means, each of which was multiplied by .748 and these reduced running means are plotted in Fig. 37 on the fifth day of each ten-day series.

The method described above contains the implicit assumption that if both actinographs were recording accurately, they would measure equal amounts of insolation, given identical sky conditions, or, in other words, that atmospheric scattering in the 2900 ft. of altitude which separates the stations is negligible and also that multiple reflections from the glacier, mountains, the lake surface, clouds etc. are of equal magnitude at both stations. Although this assumption is not justified on theoretical grounds, the atmosphere in polar regions is almost certainly fairly free of scattering nuclei by comparison with mid-latitudes, even at an inland site in the snow-free season. The added insolation measured by the Gilman Glacier by multiple reflections between glacier and mountains and the clouds above them is probably not dissimilar to that from similar reflections between the lake, the Garfield Range and the clouds above them.

In two recent papers Mateer has provided estimates of the average insolation in Canada on cloudless days and on the basis of mean cloud conditions (40, 41). The maps in his papers are not drawn to include the whole of the Queen Elizabeth Islands, but by extrapolating from the suggested values at Resolute and occasionally at Eureka also, it would appear that the expected cloudless day insolation at Lake Hazen would be about 850 langleys per day in mid-June and about 750 langleys per day in mid-July. The average daily insolation for these months, taking account of supposed mean cloud conditions, is over 700 langleys and over 550 langleys per day respectively. These values, it can be seen from Fig. 37, agree closely with observed conditions in 1958.

Although it is regrettable that a better record was not obtained, it would appear that the ten-day means shown in Fig. 37 are a reasonable approximation of actual conditions. As such they may be of use to other workers. Botanists in particular may find the ten-day mean a convenient form of expression: by shifting the dates on the abscissa five places to the left the mean daily insolation in the ten days preceding the date plotted is represented, which should be useful in ecological and phenological studies.

CHAPTER IX

OPERATIONAL WEATHER FOR AVIATION

The problems of aircraft operation from and in the vicinity of Lake Hazen are twofold. There are the usual meteorological restrictions connected with the frequency of low ceilings, poor visibility, freezing precipitation etc., which are common to all aircraft operations everywhere, and there are also the additional problems due to the Arctic location of the area. Post-war experience, particularly after the establishment of Thule Air Force Base, Greenland, has shown that the Arctic itself places no absolute limits on aviation, although it does add considerably to the difficulties and hence to the expense of operations. In considering the specifically Arctic aspects of the present problem, comparisons with Thule have been drawn frequently. It must be emphasised that this is not done because the author feels that the meteorological conditions at the two stations are similar: they are indeed very dissimilar. Thule is used solely because, as a presently operating airfield of considerable size and importance, it provides a suitable reference point. Thus the fact that at Lake Hazen the sky was overcast below 10,000 ft. on 20 per cent of the observations in July 1958 may not seem very illuminating in itself; it becomes much more significant when it is realised that the six-year average for Thule in the same month is 39 per cent.

At a large number of airfields in Canada, where there are first-order weather stations taking hourly aviation observations in addition to main synoptics, there is completed a "Monthly Summary of Operational Weather", Form 2369, which shows diagrammatically and quantitatively the periods of time during each month when ceilings and visibilities are below certain limits. The limits chosen vary slightly from station to station. To provide a quick and graphic way of showing similar conditions at Lake Hazen in 1957-58, this summary has been completed for the whole period of observations from the synoptic records. Two points much be emphasised concerning these summaries which, reduced in size, are reproduced as Figs. 38 to 50. Firstly, they are completed from the synoptic sheets which specifically record ceiling and visibility only at 3-hour intervals. The symbols at the remaining observations were interpolated from a study of the synoptic record, taking account (a) of the general weather conditions over the period considered, (b) the times during which precipitation fell (recorded in column 72 of the synoptic sheets) and (c) comments by the observers in the Notes (column 71), bearing in mind that an effort was made to check the prevailing weather conditions at least once an hour. Undoubtedly some accuracies must be present, but they may be expect to cancel each other over a period of a month, and the usefulness of such a method of presentation was felt to outweigh any minor errors. The second feature of importance is that common to most of the present study: the record is for one year only and is not necessarily indicative of mean conditions.

The limits chosen are those in use at Churchill, Manitoba. They were selected because Churchill is a sub-Arctic airfield which is used by many who may be interested in the operational aspects of the Lake Hazen weather. Resolute would have been a more suitable choice, but aviation observations are not taken on a regular basis there and so Form 2369 is not completed.

As will be seen from Figs. 38 to 50 the weather at Lake Hazen was grouped into six combinations of ceiling and visibility, as follows:

	Ceiling (ft.)	Vsby. (mls.)		Vsby. (mls.)	Ceiling (ft.)
(1)	0-100	with 0 or more	or	0-3/8	with 0 or more
(2)	200	with ½ or more	or	½ - ¾	with 200 or more
(3)	300-400	with 1 or more	or	1	with 300-400
(4)	500-900	with 1 or more	or	1 - 2½	with 500 or more
(5)	1000-2400	with 3 or more	or	3 or more	with 1000-2400
(6)	2500 or more	with 3 or more	or	3 or more	with 2500 or more

Using the Churchill standards had one important weakness. The mountains of the Garfield Range clost to Lake Hazen were approximately 2800 ft. above the level of the lake; it would therefore have been preferable to raise the upper level in group (5) to at least 3000 ft. It is assumed, however, that any possible airstrip designed to handle a regular flow of traffic would be sited at a considerable distance from the mountains, either at the north-west end of the lake, or better still on the south side of it where, although terrain conditions are difficult, high mountains are absent and tidewater is closer, a factor of some importance for the supply of such an installation.

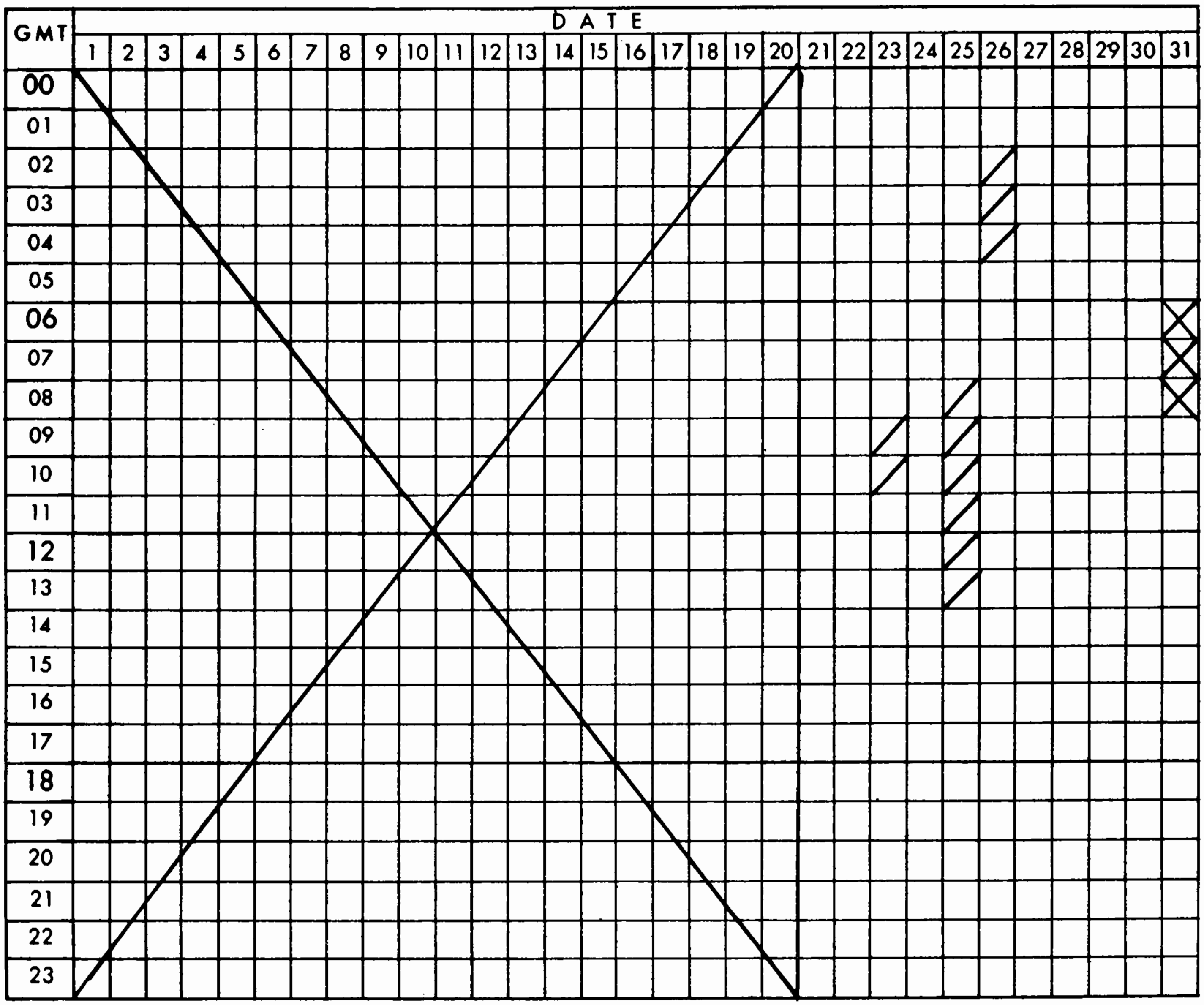
Form 2369

METEOROLOGICAL DIVISION - DEPARTMENT OF TRANSPORT - CANADA

MONTHLY SUMMARY OF OPERATIONAL WEATHER

Airport LAKE HAZEN, N.W.T. Month AUGUST (21 - 31) 1957

RANGES	SYMBOL	CEILING AND VISIBILITY COMBINATIONS							PERCENTAGE OF TIME	
		CIGS. (ft.)	with	VSBYS. (mi.)	or	VSBYS. (mi.)	with	CIGS. (ft.)	IN RANGE	IN and BELOW RANGE
1		0 - 100	with	0 or more	or	0 - 3/8	with	0 or more		
2		200	with	½ or more	or	½ - 3/4	with	200 or more		
3		300 - 400	with	1 or more	or	1	with	300 - 400		
4		500 - 900	with	1 or more	or	1 - 2½	with	500 or more		
5		1000 - 2400	with	3 or more	or	3 or more	with	1000 - 2400		
6		2500 or more	with	3 or more	or	3 or more	with	2500 or more		100.0



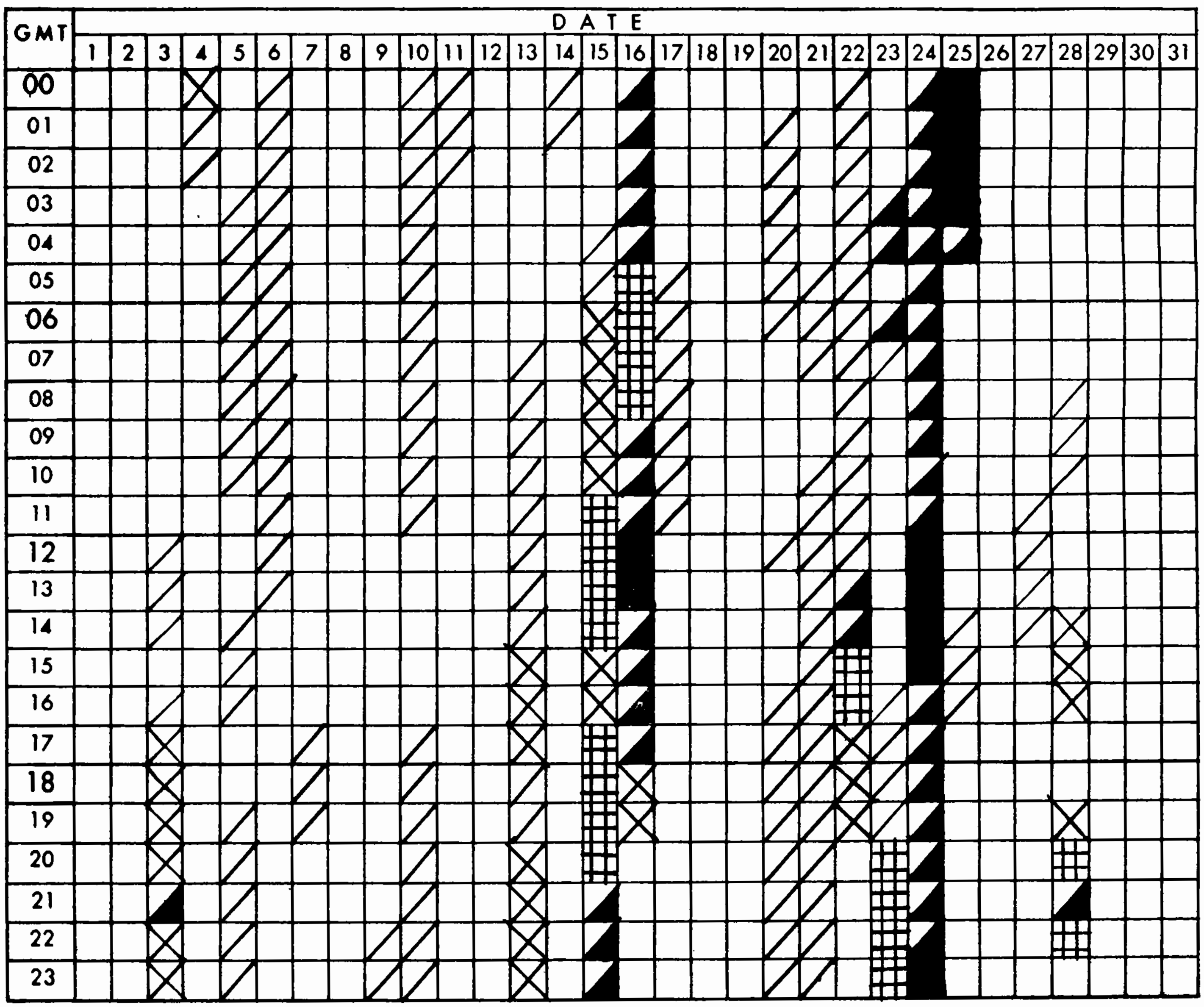
Form 2369

METEOROLOGICAL DIVISION – DEPARTMENT OF TRANSPORT – CANADA

MONTHLY SUMMARY OF OPERATIONAL WEATHER

Airport LAKE HAZEN, N.W.T. Month SEPTEMBER 19 57

RANGES	SYMBOL	CEILING AND VISIBILITY COMBINATIONS: CIGS. (ft.)	with	VSBYS. (mi.)	or	VSBYS. (mi.)	with	CIGS. (ft.)	PERCENTAGE OF TIME: IN RANGE	IN and BELOW RANGE
1		0 - 100	with	0 or more	or	0 - 3/8	with	0 or more	1.5	1.5
2		200	with	½ or more	or	½ - 3/4	with	200 or more	5.7	7.2
3		300 - 400	with	1 or more	or	1	with	300 - 400	2.8	10.0
4		500 - 900	with	1 or more	or	1 - 2½	with	500 or more	4.2	14.2
5		1000 - 2400	with	3 or more	or	3 or more	with	1000 - 2400	18.6	32.8
6		2500 or more	with	3 or more	or	3 or more	with	2500 or more	67.2	100.0



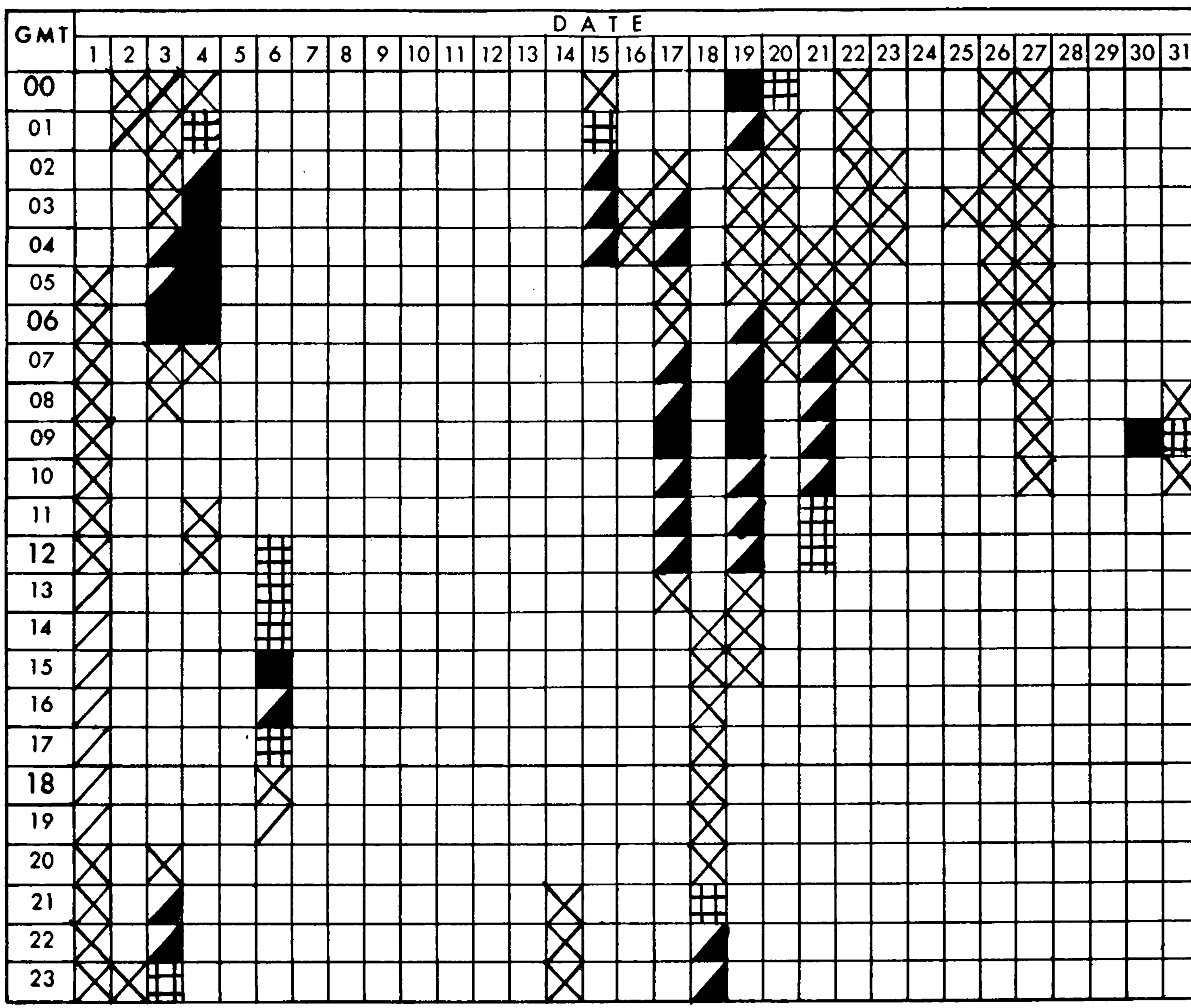
Form 2369

METEOROLOGICAL DIVISION - DEPARTMENT OF TRANSPORT - CANADA

MONTHLY SUMMARY OF OPERATIONAL WEATHER

Airport LAKE HAZEN, N.W.T. Month OCTOBER 1957

RANGES	SYMBOL	CEILING AND VISIBILITY COMBINATIONS							PERCENTAGE OF TIME	
		CIGS. (ft.)	with	VSBYS. (mi.)	or	VSBYS. (mi.)	with	CIGS. (ft.)	IN RANGE	IN and BELOW RANGE
1		0 - 100	with	0 or more	or	0 - 3/8	with	0 or more	1.5	1.5
2		200	with	½ or more	or	½ - 3/4	with	200 or more	3.9	5.4
3		300 - 400	with	1 or more	or	1	with	300 - 400	1.6	7.0
4		500 - 900	with	1 or more	or	1 - 2½	with	500 or more	12.5	19.5
5		1000 - 2400	with	3 or more	or	3 or more	with	1000 - 2400	1.1	20.6
6		2500 or more	with	3 or more	or	3 or more	with	2500 or more	79.4	100.0



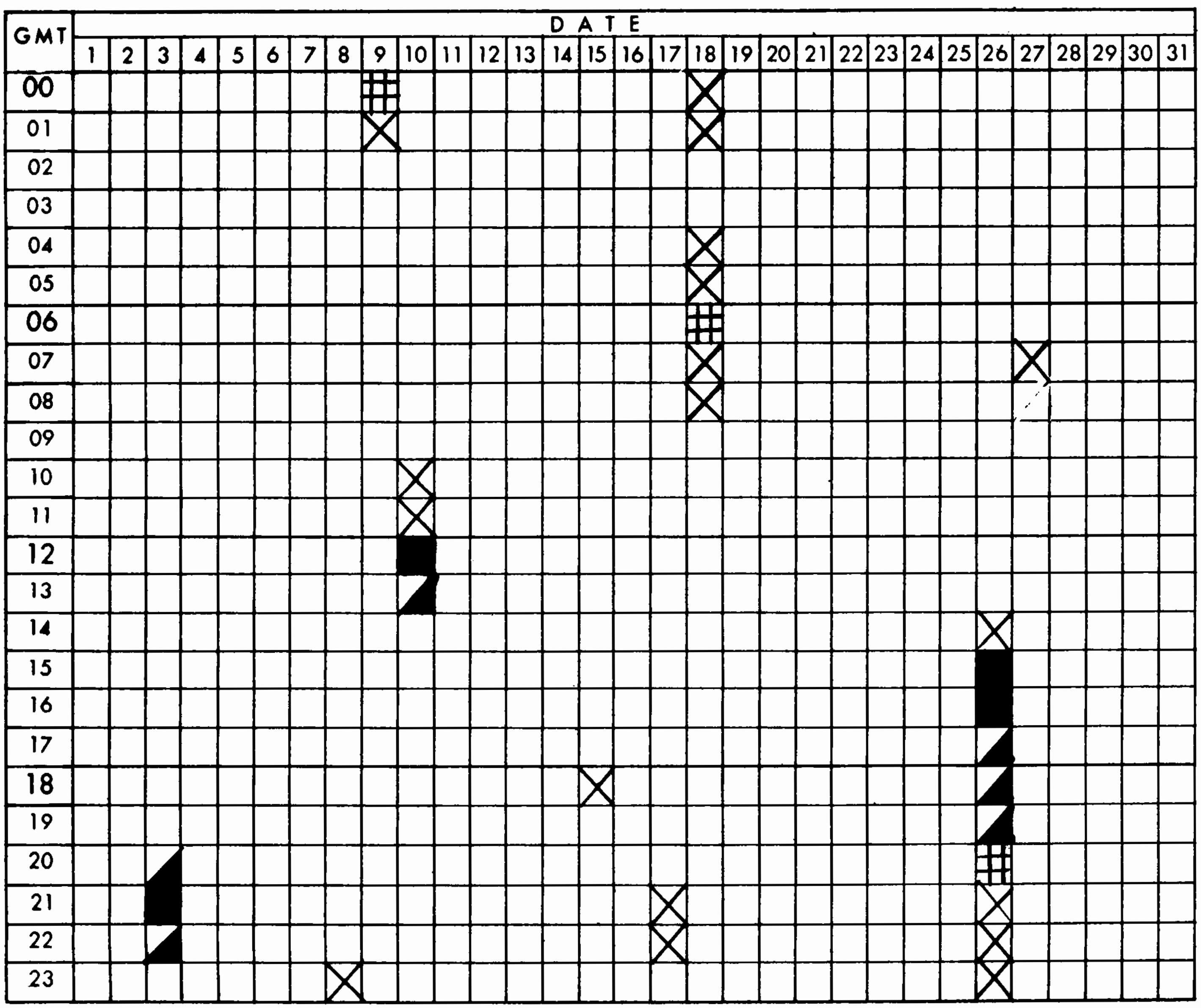
Form 2369

METEOROLOGICAL DIVISION - DEPARTMENT OF TRANSPORT - CANADA

MONTHLY SUMMARY OF OPERATIONAL WEATHER

Airport LAKE HAZEN, N.W.T. Month NOVEMBER 1957

RANGES	SYMBOL	CEILING AND VISIBILITY COMBINATIONS: CIGS. (ft.)	with	VSBYS. (mi.)	or	VSBYS. (mi.)	with	CIGS. (ft.)	PERCENTAGE OF TIME: IN RANGE	IN and BELOW RANGE
1		0 - 100	with	0 or more	or	0 - 3/8	with	0 or more	0.6	0.6
2		200	with	½ or more	or	½ - 3/4	with	200 or more	0.8	1.4
3		300 - 400	with	1 or more	or	1	with	300 - 400	0.4	1.8
4		500 - 900	with	1 or more	or	1 - 2½	with	500 or more	2.5	4.3
5		1000 - 2400	with	3 or more	or	3 or more	with	1000 - 2400	0.0	4.3
6		2500 or more	with	3 or more	or	3 or more	with	2500 or more	95.7	100.0



Form 2369

METEOROLOGICAL DIVISION - DEPARTMENT OF TRANSPORT - CANADA

MONTHLY SUMMARY OF OPERATIONAL WEATHER

Airport LAKE HAZEN, N.W.T. Month DECEMBER 1957

RANGES	SYMBOL	CIGS. (ft.)	with	VSBYS. (mi.)	or	VSBYS. (mi.)	with	CIGS. (ft.)	PERCENTAGE OF TIME IN RANGE	PERCENTAGE OF TIME IN and BELOW RANGE
1		0 - 100	with	0 or more	or	0 - 3/8	with	0 or more	0.0	0.0
2		200	with	½ or more	or	½ - 3/4	with	200 or more	0.4	0.4
3		300 - 400	with	1 or more	or	1	with	300 - 400	1.1	1.5
4		500 - 900	with	1 or more	or	1 - 2½	with	500 or more	2.7	4.2
5		1000 - 2400	with	3 or more	or	3 or more	with	1000 - 2400	0.0	4.2
6		2500 or more	with	3 or more	or	3 or more	with	2500 or more	95.8	100.0

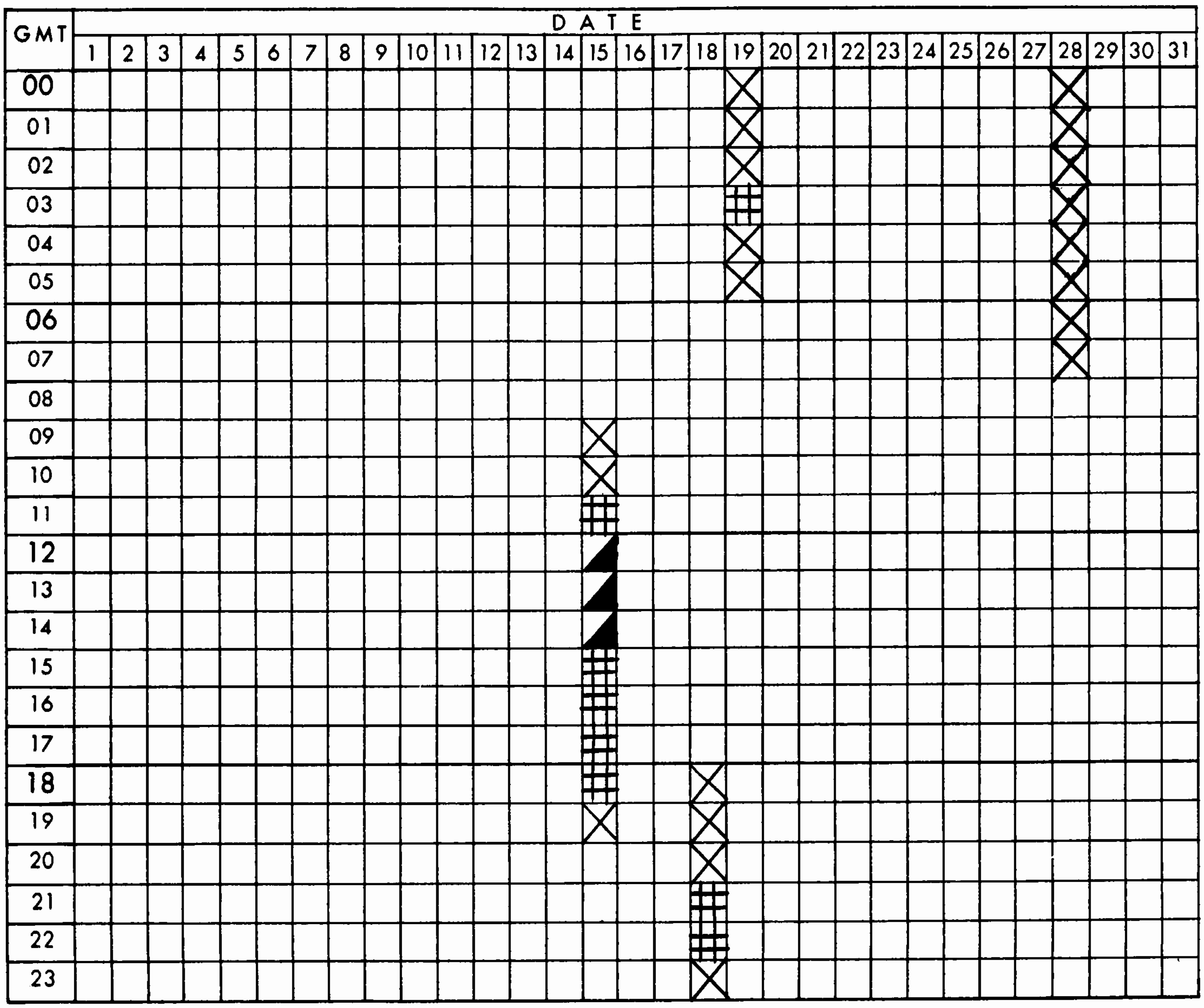


Fig. 43

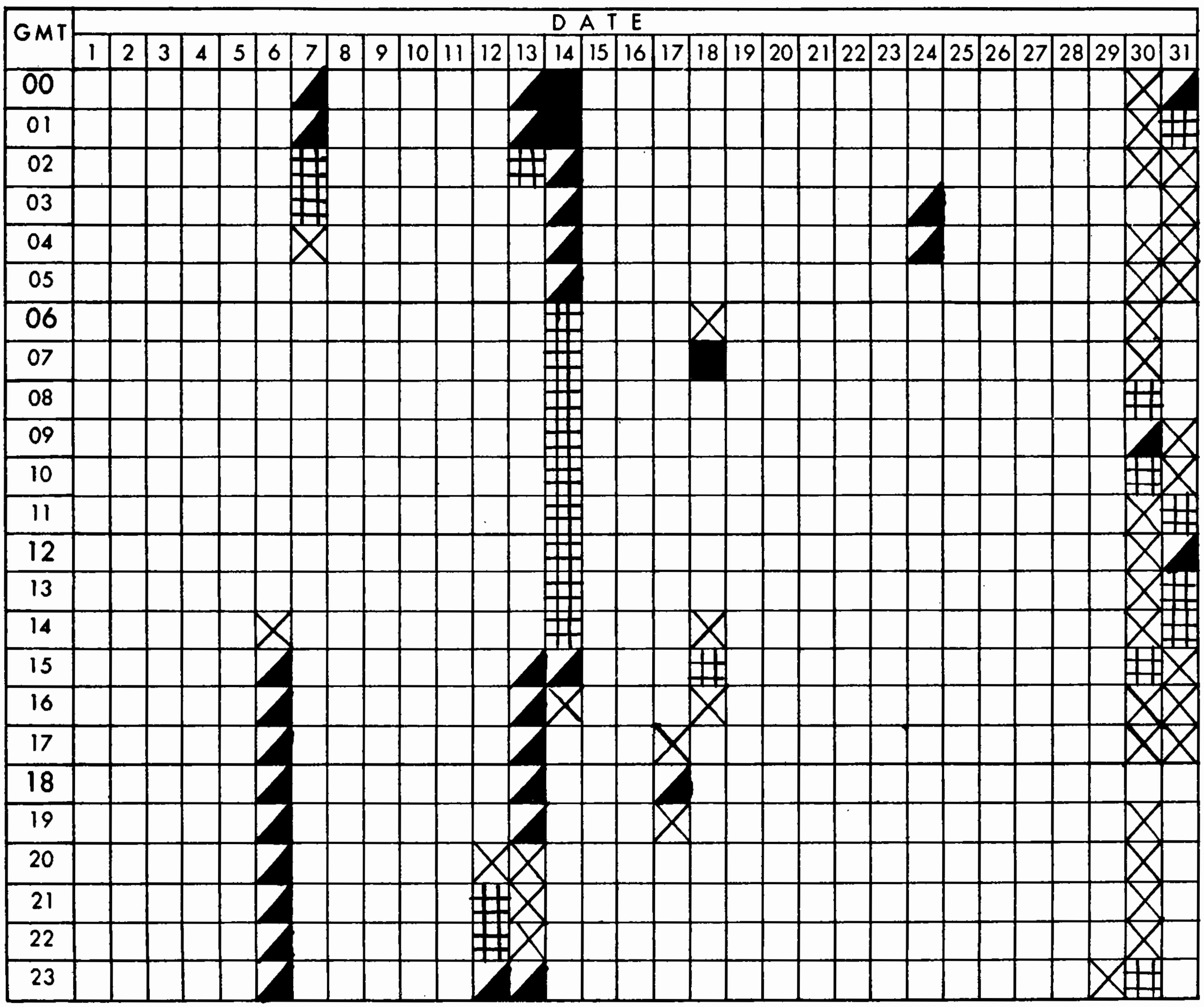
Form 2369

METEOROLOGICAL DIVISION – DEPARTMENT OF TRANSPORT – CANADA

MONTHLY SUMMARY OF OPERATIONAL WEATHER

Airport LAKE HAZEN, N.W.T. Month JANUARY 1958

RANGES	SYMBOL	CEILING AND VISIBILITY COMBINATIONS							PERCENTAGE OF TIME	
		CIGS. (ft.)	with	VSBYS. (mi.)	or	VSBYS. (mi.)	with	CIGS. (ft.)	IN RANGE	IN and BELOW RANGE
1	■	0 - 100	with	0 or more	or	0 - 3/8	with	0 or more	0.4	0.4
2	◢	200	with	½ or more	or	½ - 3/4	with	200 or more	4.2	4.6
3	⊞	300 - 400	with	1 or more	or	1	with	300 - 400	3.1	7.7
4	☒	500 - 900	with	1 or more	or	1 - 2½	with	500 or more	5.1	12.8
5	⁄	1000 - 2400	with	3 or more	or	3 or more	with	1000 - 2400	0.0	12.8
6		2500 or more	with	3 or more	or	3 or more	with	2500 or more	87.2	100.0



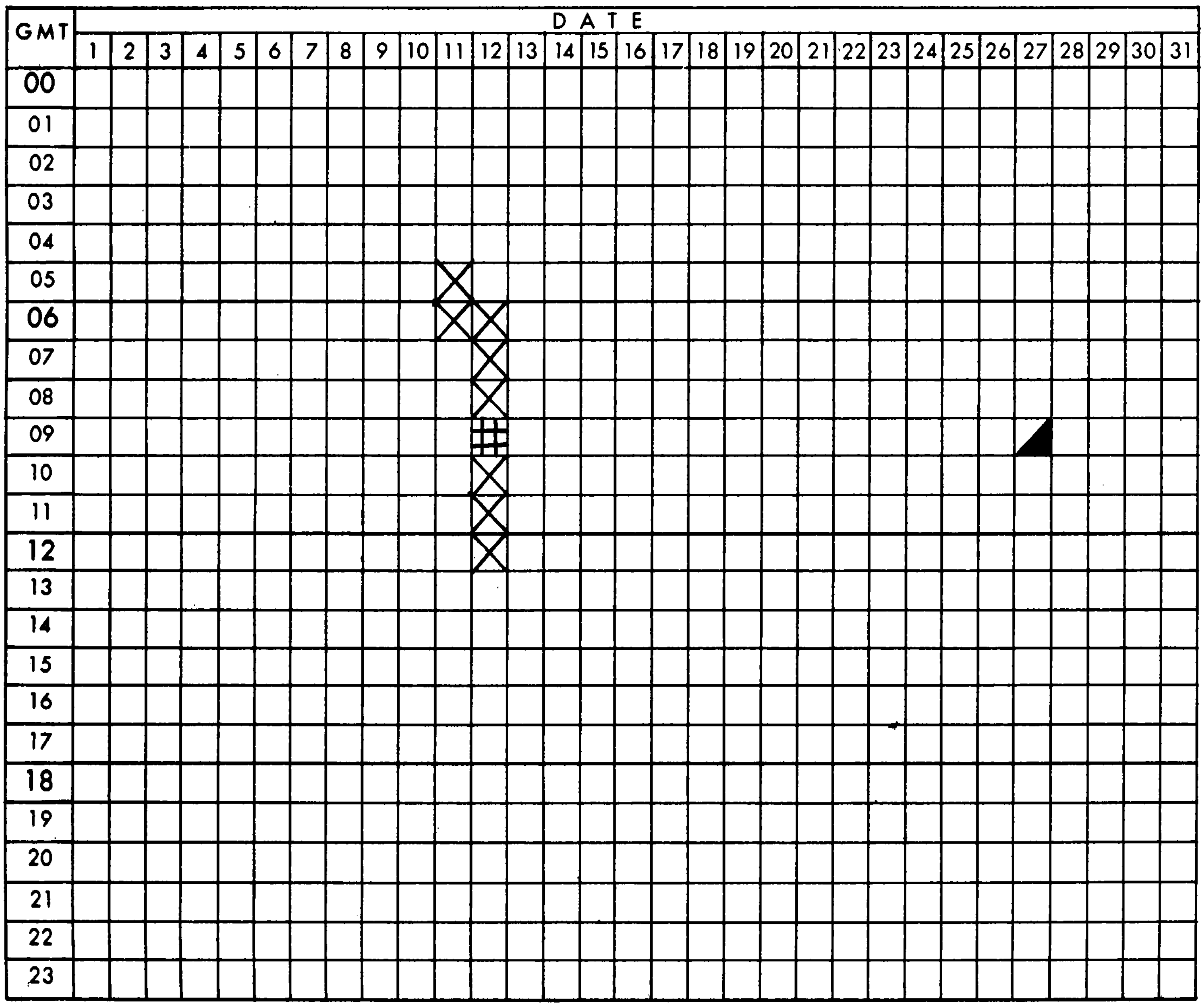
Form 2369

METEOROLOGICAL DIVISION - DEPARTMENT OF TRANSPORT - CANADA

MONTHLY SUMMARY OF OPERATIONAL WEATHER

Airport LAKE HAZEN, N.W.T. Month FEBRUARY 1958

RANGES	SYMBOL	CIGS. (ft.)	with	VSBYS. (mi.)	or	VSBYS. (mi.)	with	CIGS. (ft.)	PERCENTAGE OF TIME IN RANGE	PERCENTAGE OF TIME IN and BELOW RANGE
1		0 - 100	with	0 or more	or	0 - 3/8	with	0 or more	0.0	0.0
2		200	with	½ or more	or	½ - 3/4	with	200 or more	0.2	0.2
3		300 - 400	with	1 or more	or	1	with	300 - 400	0.2	0.4
4		500 - 900	with	1 or more	or	1 - 2½	with	500 or more	1.2	1.6
5		1000 - 2400	with	3 or more	or	3 or more	with	1000 - 2400	0.0	1.6
6		2500 or more	with	3 or more	or	3 or more	with	2500 or more	98.4	100.0



Form 2369

METEOROLOGICAL DIVISION – DEPARTMENT OF TRANSPORT – CANADA

MONTHLY SUMMARY OF OPERATIONAL WEATHER

Airport LAKE HAZEN, N.W.T Month MARCH 1958

RANGES	SYMBOL	CEILING AND VISIBILITY COMBINATIONS							PERCENTAGE OF TIME	
		CIGS. (ft.)	with	VSBYS. (mi.)	or	VSBYS. (mi.)	with	CIGS. (ft.)	IN RANGE	IN and BELOW RANGE
1	■	0 - 100	with	0 or more	or	0 - 3/8	with	0 or more	0.0	0.0
2	◩	200	with	½ or more	or	½ - 3/4	with	200 or more	0.0	0.0
3	#	300 - 400	with	1 or more	or	1	with	300 - 400	0.1	0.1
4	X	500 - 900	with	1 or more	or	1 - 2½	with	500 or more	0.5	0.6
5	/	1000 - 2400	with	3 or more	or	3 or more	with	1000 - 2400	0.0	0.6
6		2500 or more	with	3 or more	or	3 or more	with	2500 or more	99.4	100.0

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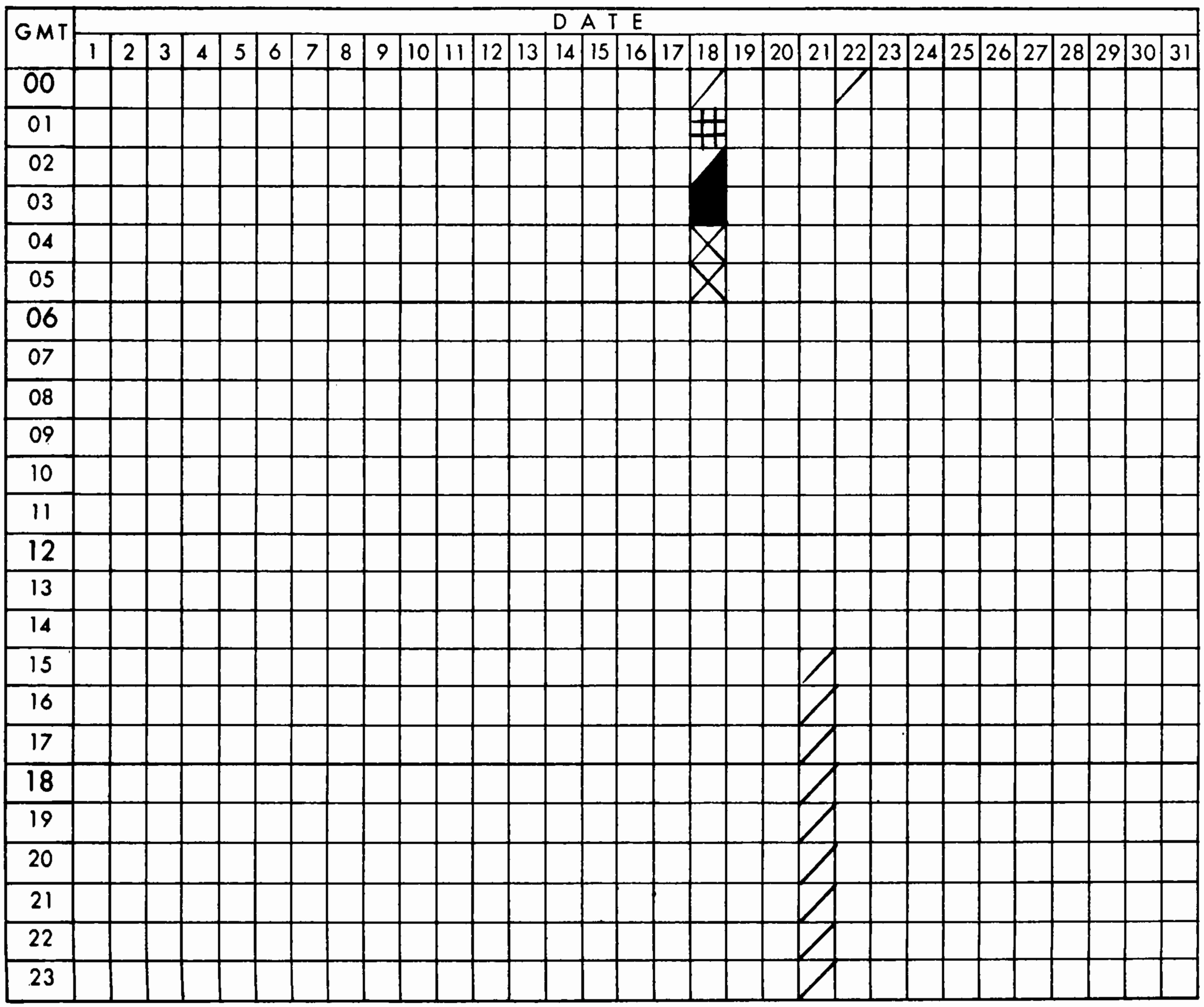
Form 2369

METEOROLOGICAL DIVISION – DEPARTMENT OF TRANSPORT – CANADA

MONTHLY SUMMARY OF OPERATIONAL WEATHER

Airport LAKE HAZEN, N.W.T. Month APRIL 19 58

RANGES	SYMBOL	CEILING AND VISIBILITY COMBINATIONS							PERCENTAGE OF TIME	
		CIGS. (ft.)	with	VSBYS. (mi.)	or	VSBYS. (mi.)	with	CIGS. (ft.)	IN RANGE	IN and BELOW RANGE
1		0 - 100	with	0 or more	or	0 - 3/8	with	0 or more	0.1	0.1
2		200	with	½ or more	or	½ - 3/4	with	200 or more	0.1	0.2
3		300 - 400	with	1 or more	or	1	with	300 - 400	0.1	0.3
4		500 - 900	with	1 or more	or	1 - 2½	with	500 or more	0.3	0.6
5		1000 - 2400	with	3 or more	or	3 or more	with	1000 - 2400	1.5	2.1
6		2500 or more	with	3 or more	or	3 or more	with	2500 or more	97.9	100.0



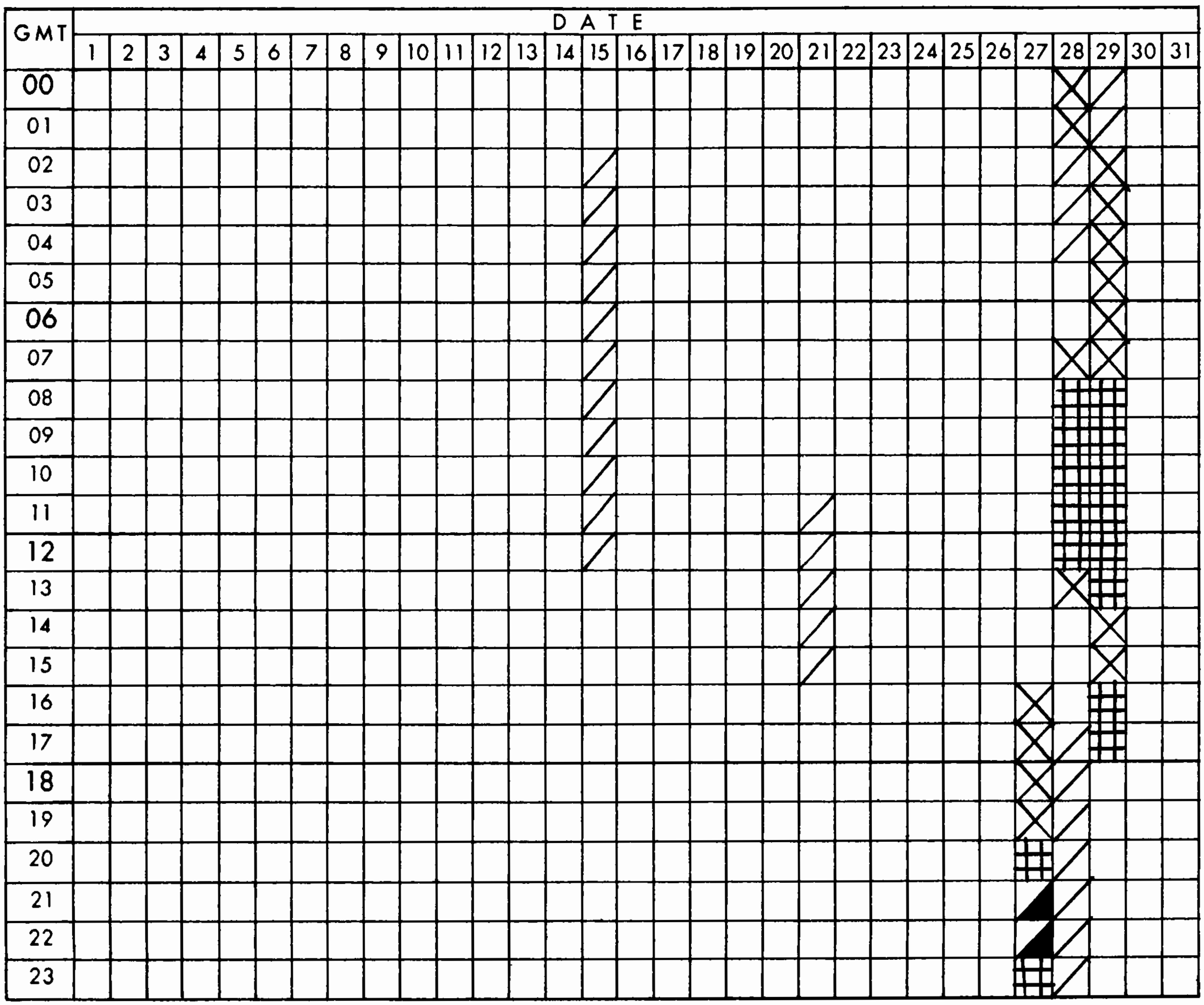
Form 2369

METEOROLOGICAL DIVISION - DEPARTMENT OF TRANSPORT - CANADA

MONTHLY SUMMARY OF OPERATIONAL WEATHER

Airport LAKE HAZEN, N.W.T. Month MAY 1958

RANGES	SYMBOL	CEILING AND VISIBILITY COMBINATIONS							PERCENTAGE OF TIME	
		CIGS. (ft.)	with	VSBYS. (mi.)	or	VSBYS. (mi.)	with	CIGS. (ft.)	IN RANGE	IN and BELOW RANGE
1		0 - 100	with	0 or more	or	0 - 3/8	with	0 or more	0.0	0.0
2		200	with	½ or more	or	½ - 3/4	with	200 or more	0.3	0.3
3		300 - 400	with	1 or more	or	1	with	300 - 400	2.0	2.3
4		500 - 900	with	1 or more	or	1 - 2½	with	500 or more	2.2	4.5
5		1000 - 2400	with	3 or more	or	3 or more	with	1000 - 2400	3.8	8.3
6		2500 or more	with	3 or more	or	3 or more	with	2500 or more	91.7	100.0



Form 236

METEOROLOGICAL DIVISION - DEPARTMENT OF TRANSPORT - CANADA

MONTHLY SUMMARY OF OPERATIONAL WEATHER

Airport LAKE HAZEN, N.W.T. Month JUNE 19 58

RANGES	SYMBOL	CIGS. (ft.)	with	VSBYS. (mi.)	or	VSBYS. (mi.)	with	CIGS. (ft.)	PERCENTAGE OF TIME IN RANGE	PERCENTAGE OF TIME IN and BELOW RANGE
1	■	0 - 100	with	0 or more	or	0 - 3/8	with	0 or more	0.0	0.0
2	◩	200	with	½ or more	or	½ - 3/4	with	200 or more	0.0	0.0
3	▦	300 - 400	with	1 or more	or	1	with	300 - 400	0.0	0.0
4	☒	500 - 900	with	1 or more	or	1 - 2½	with	500 or more	0.0	0.0
5	/	1000 - 2400	with	3 or more	or	3 or more	with	1000 - 2400	0.8	0.8
6		2500 or more	with	3 or more	or	3 or more	with	2500 or more	99.2	100.0

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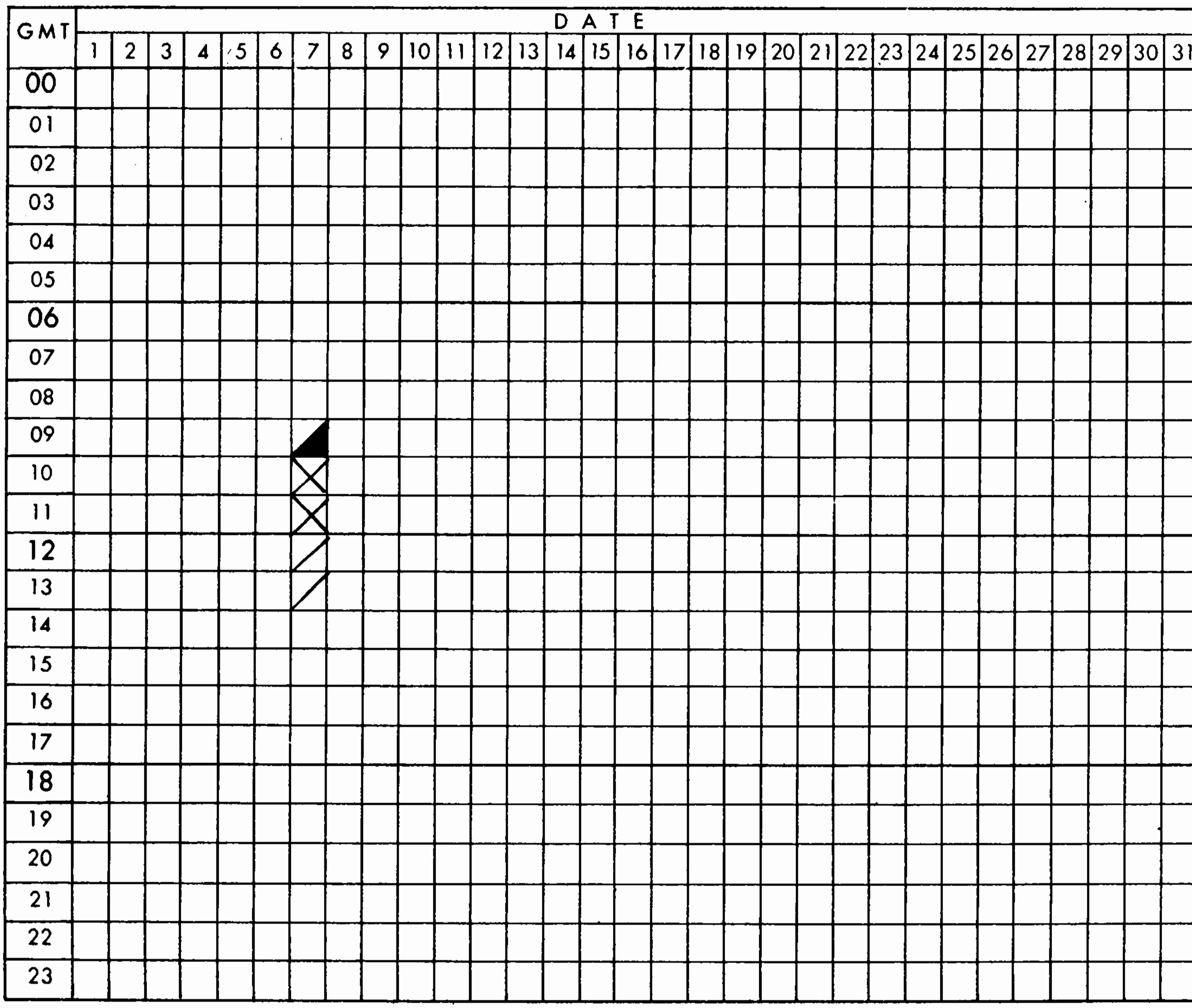
Form 2369

METEOROLOGICAL DIVISION - DEPARTMENT OF TRANSPORT - CANADA

MONTHLY SUMMARY OF OPERATIONAL WEATHER

Airport LAKE HAZEN, N.W.T. Month JULY 1958

RANGES	SYMBOL	CEILING AND VISIBILITY COMBINATIONS								PERCENTAGE OF TIME	
		CIGS. (ft.)	with	VSBYS. (mi.)	or	VSBYS. (mi.)	with	CIGS. (ft.)		IN RANGE	IN and BELOW RANGE
1		0 - 100	with	0 or more	or	0 - 3/8	with	0 or more		0.0	0.0
2		200	with	½ or more	or	½ - 3/4	with	200 or more		0.1	0.1
3		300 - 400	with	1 or more	or	1	with	300 - 400		0.0	0.1
4		500 - 900	with	1 or more	or	1 - 2½	with	500 or more		0.3	0.4
5		1000 - 2400	with	3 or more	or	3 or more	with	1000 - 2400		0.3	0.7
6		2500 or more	with	3 or more	or	3 or more	with	2500 or more		99.3	100.0



Form 2369

METEOROLOGICAL DIVISION – DEPARTMENT OF TRANSPORT – CANADA

MONTHLY SUMMARY OF OPERATIONAL WEATHER

Airport LAKE HAZEN, N.W.T. Month AUGUST (1 – 10) 19 58

RANGES	SYMBOL	CEILING AND VISIBILITY COMBINATIONS							PERCENTAGE OF TIME	
		CIGS. (ft.)	with	VSBYS. (mi.)	or	VSBYS. (mi.)	with	CIGS. (ft.)	IN RANGE	IN and BELOW RANGE
1	[filled black square]	0 – 100	with	0 or more	or	0 – 3/8	with	0 or more		
2	[half-filled square]	200	with	½ or more	or	½ – 3/4	with	200 or more		
3	[grid pattern]	300 – 400	with	1 or more	or	1	with	300 – 400		
4	[crossed square]	500 – 900	with	1 or more	or	1 – 2½	with	500 or more		
5	[single diagonal]	1000 – 2400	with	3 or more	or	3 or more	with	1000 – 2400		
6		2500 or more	with	3 or more	or	3 or more	with	2500 or more		100.0

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Little of importance can be seen in the record during the latter part of August 1957. Weather conditions were generally good and low cloud was present at only a few of the observations. Conditions in the following month, however, were the worst of the entire observational period. The reason for this has been touched upon several times elsewhere in this study: the presence of a relatively warm body of open water, in this particular year (1957), after the air temperature fell below freezing point produced cloud conditions peculiar to Lake Hazen (although frequent at coastal localities) and these persisted until late in September. Thus at 10% of the hourly checks the weather was in groups 1, 2 or 3, and occasions when conditions were "2500 or better with 3 miles or more" existed for only about two-thirds of the month. It may well be that such conditions would be acceptable by comparison with more southerly latitudes. The author, during 12 months at Lake Hazen, came to regard "bad weather" as any visibility under 15 miles or cloud base below 5,000 ft. or wind above 10 m.p.h., but September was certainly the worst month for operational weather throughout the period of observations. It was, furthermore, fairly certainly typical of normal conditions at that time of the year. Complete thawing of the lake ice apparently does not occur every year (it almost certainly did not occur in 1958) but at least a modified form of the lake's influence on cloud cover may be expected as a regular feature of the fall climate.

The most striking feature of the figure for October is the much greater frequency of observations in group (4) (12.5 percent of the total) and the much smaller proportion in group (5) by comparison with September. This is because weather conditions in the former group usually occur with poor visibility (1 - $2\frac{1}{2}$ miles) and not low ceiling (500 - 900 ft.) as the determining feature. Group (5), by contrast, assumes good visibility and is solely determined by cloud height. Thus the September observations reflect the low cloud over the lake; those in October in large measure express the poor visibility experienced during snowfall which was, relative to the rest of the year, quite considerable.

In October the proportion of observations in Group (6) was practically 80 per cent; in November it reached 90 per cent and, except for January 1958 remained above that figure throughout the remaining months of observations. Little can really be said about the months of November and December: they show, on a modified scale, the same pattern as October, neither of them having ceilings between 1000 and 2,400 ft. without visibility criteria (almost always when snow was falling) requiring that a lower category than group (5) be used. As precipitation, in measurable amounts at least, was very rare, it follows that the restrictions on operational weather were also small.

January 1958 was, of course, far from typical of the weather conditions to be expected in a normal January at Lake Hazen. It is, however, of considerable significance in showing the effect of completely atypical synoptic conditions during the winter: such conditions would yield practically the same result in any month from November to March. The principal conclusion to be drawn is perhaps how small the total effect was. When operational weather was limited, conditions were usually very bad, with visibilities of a mile or less, but group (6) only just failed to contain 90 per cent of all observations.

The exceptional conditions continued to be experienced at Lake Hazen until the end of the month. On February 1, however, they ended abruptly and conditions reverted to the pattern of November and December for the rest of the winter. Little again need be said of the three months, February, March and April, in all of which 97 per cent of all observations were in Group (6).

Similar conditions extended into May and continued indeed for most of that month. As temperatures rose steadily they came, in late May, close to freezing point again and so the period of poor operational weather at the end of the month occurred during the last significant snowfall of the year.

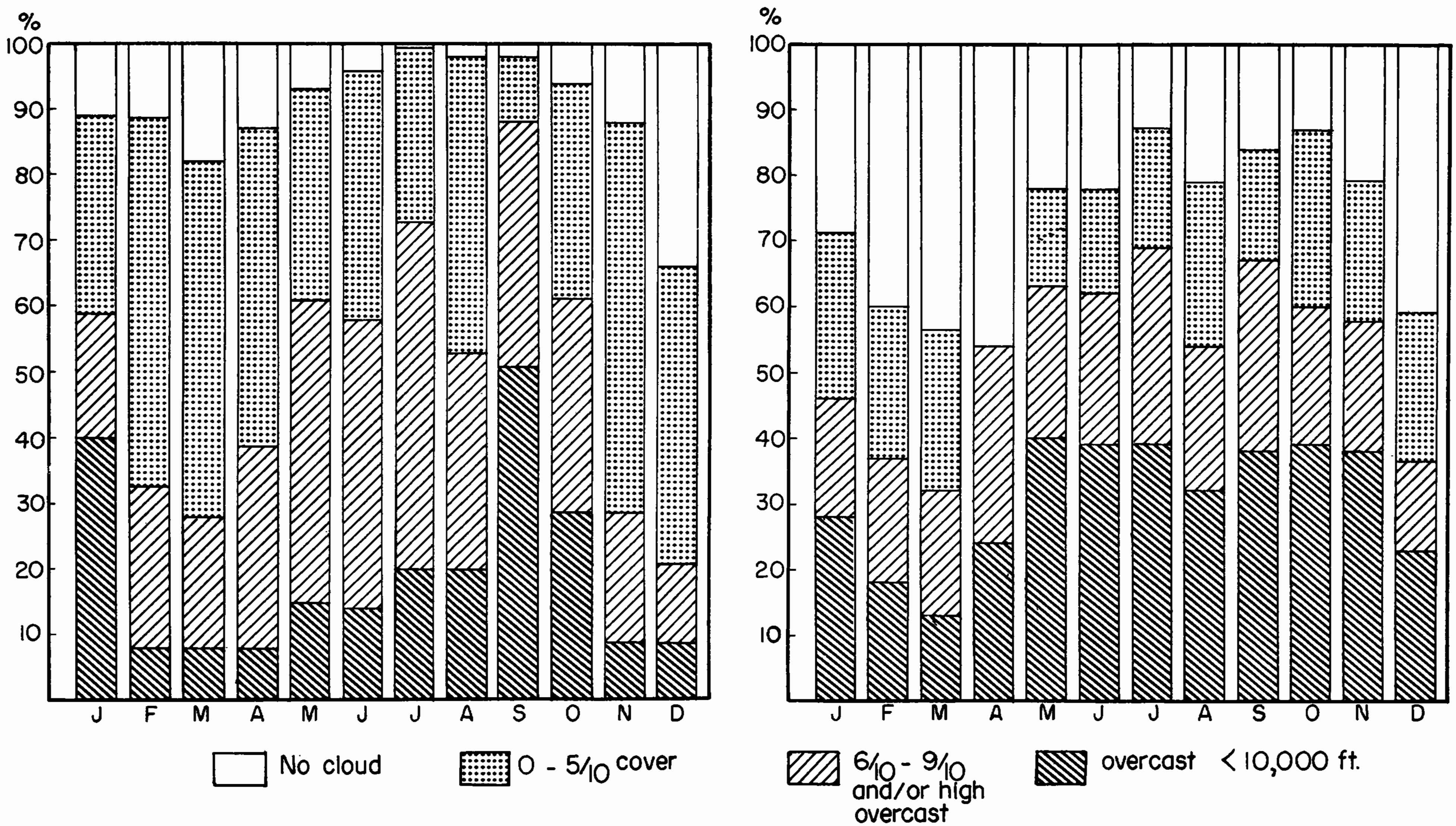
June and July were both practically perfect months, each having over 99 per cent of observations in group (6). The summer was apparently dull compared to that of 1957, but ceilings were seldon lower than 5,000 ft. No limitations to operations were experienced in the first ten days of August 1958.

The annual proportions (of a total of 8,532 hours) within the different groups are as follows:

(1): 0.35%; (2): 1.36%; (3): 0.90%; (4): 2.75%; (5): 2.46%; (6) 92.09%

Another way of presenting the flying weather is presented in Figs. 51 and 52. The first of these, prepared by Anstey on the basis of a six-year record at Thule is designed to show the total sky cover. The lowest category, overcast below 10,000 ft., is of less significance for aircraft operation than the monthly summary of operational weather already discussed. Provided an airstrip is equipped with a minimum of navigational aids, such as a radio beacon, overcast at 10,000 feet is of little significance, at least for landing and taking-off.

The comparison between Lake Hazen and Thule in this way is not, however, without interest. On the one hand it is evident that some cloud was observed at a much larger number of observations than is usual at Thule. The complete absence of cloud at such a large proportion of the monthly observations over a six-year period seems surprising for, although Thule is close to the Greenland ice sheet, it is also in a coastal situation. It is, however, of less account than the second feature: the much smaller proportion of time when conditions were "broken or high overcast" or "low overcast" at Lake Hazen as compared to Thule. Only in the months of January and September was the record at all similar.



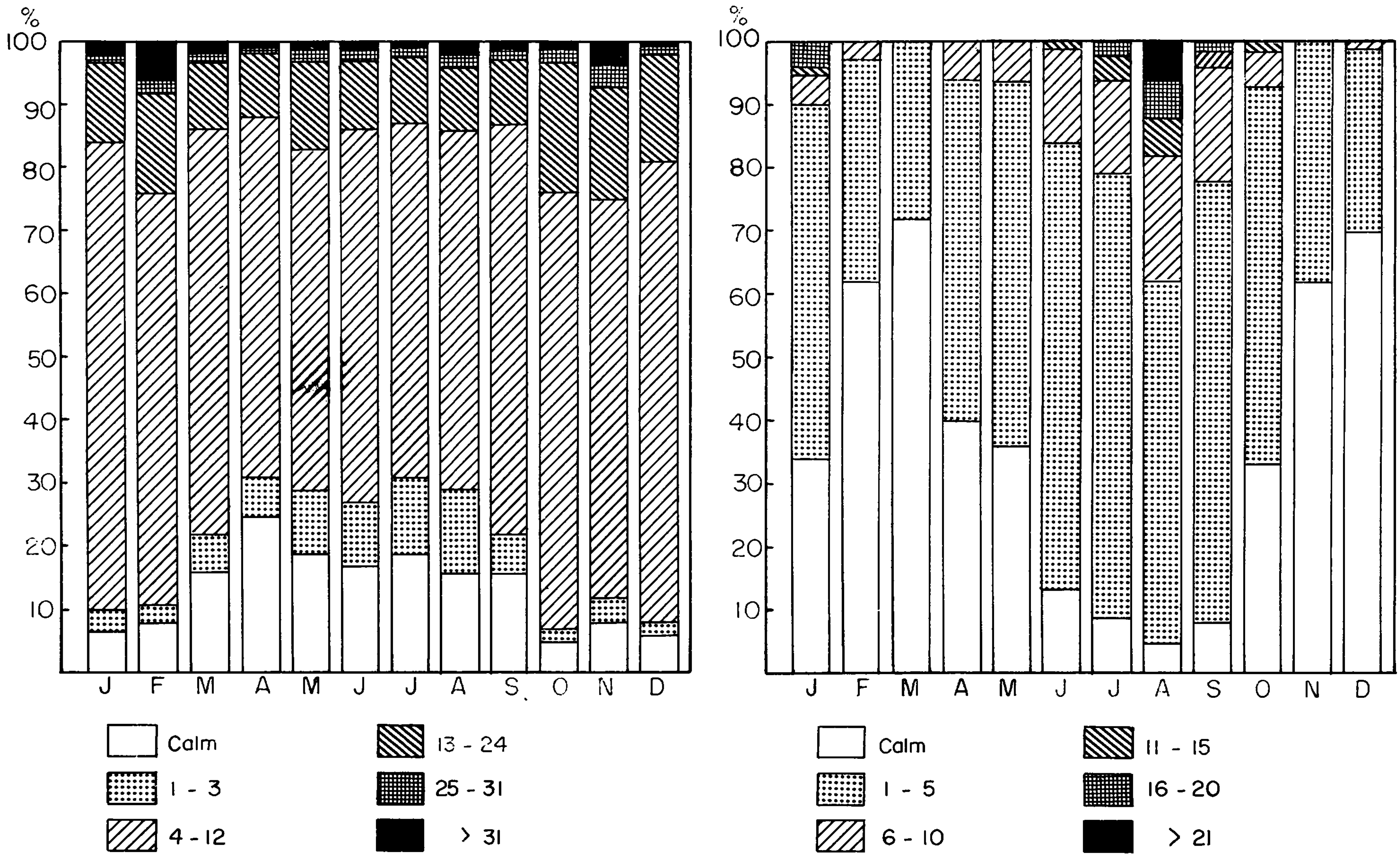
Figs. 51 & 52. Sky Conditions at Lake Hazen (left) and Thule (right.) Data for Thule is from Anstey (2) and is the mean of a six-year record. Lake Hazen data is for 1957-58 and combines the observations during parts of two Augusts.

Turning from cloudiness and visibility to wind, Figs. 28, 29 and 30 already considered in Chapter VI provide most of the necessary information. Although the proximity of the Lake Hazen station to the Garfield Range must be taken into consideration it is probable that the roses are fairly representative of wind direction in the Lake Hazen trough and it seems unlikely that a station situated, for instance, on the Greely-Hazen plateau, would show appreciable differences.

Another comparison with Thule is provided in Figs. 53 and 54. Thule is notorious for its occasional strong winds and it must be reiterated that the only justification for a comparison of the two stations is that Thule is already an operational airport of considerable importance.

It will be noticed that the wind speeds are not grouped identically in the two diagrams. The lowest classification of wind, as opposed to calms, includes winds up to 5 m.p.h. at Lake Hazen, but only up to 3 m.p.h. at Thule. In all other groups, however, each division represents a much higher wind speed at Thule than at Lake Hazen. Thus the fourth group represents wind speeds of 25 to 31 m.p.h. at Thule but only of 16 to 20 m.p.h. at Lake Hazen. Even despite this bias, a comparison of the two diagrams clearly demonstrates the very much lower wind speeds at Lake Hazen.

Low temperatures, of course, affect aircraft operations in many



Figs. 53 & 54. Wind at Thule (left) and Lake Hazen (right). Data for Thule is from Anstey (2) and is the mean of a six-year record. Lake Hazen data is for 1957-58 and combines the observations during parts of two Augusts.

ways, such as maintenance, refuelling operations, etc. The subject is therefore worth considering.

At Lake Hazen in 1957-58 temperatures of -60°F. and below were recorded on ten days, and temperatures below -50°F. on seventy-three days. In view of the very abnormal conditions during January 1958 it would seem that temperatures below -60°F. might be experienced for a much longer period, perhaps up to thirty days, in extreme years and the probable absolute minimum must be close to the Canadian record of -81°F. Thus, for winter operations, a cloud point pour point specification even lower than -60°F. would be desirable and perhaps essential. It may here be mentioned in passing that the fuel used at Lake Hazen in 1957-58 - diesel oil, naptha and M.T. gas seemed completely satisfactory. If it is impossible to obtain oils with such very low temperature specifications, it may be remembered that storage in large 15,000 gallon tanks, such as are used at Resolute, would cause the temperature of the oil to fall much more slowly than in 55-gallon drums, and also that a possible storage site exists in the lake itself where, below the relatively thin surface cover of ice, the temperature is always slightly above freezing-point. These, however, are problems with which this study is not directly concerned.

Another problem of indirect meteorological significance is that of biting insects during the short summer. This, apparently, is not a problem which is encountered at Thule. To quote Anstey:

> There is no local problem from mosquitoes, biting flies or midges, as is common in south Greenland. While several species of insects have been reported in the Thule area during the summer season - June through August - they do not necessitate the use of repellents or protective nets. (2, p. 13)

This happy state of affairs is by no means true of the Lake Hazen area, where the much greater extent of plant cover, and possibly greater soil moisture, nourished considerable numbers of mosquitoes in the summers of 1957 and 1958. In 1957, according to the summer party, they were a nuisance for only about three weeks. In 1958, however, they arrived in force in late June and only decreased in numbers in early August. They were a considerable nuisance to both men and dogs, particularly the latter, and repellents were used extensively.

It is not proposed to add to the discussion of white-outs presented in Chapter VII, but some extra consideration is necessary of ice fog which, in the author's opinion, is a factor which might prove critical if a permanent airstrip were contemplated, particularly if it were to handle regular traffic. The problem was considered from the meteorological aspect in Chapter V and here only the implications for aircraft operation are discussed.

Mitchell recently showed that the warm-up and take-off of aircraft can be of tremendous importance in moisture production which is critical for ice fog formation. Thus, at air temperatures near -40°F., and with an initial relative humidity with respect to water of 80 per cent, the moisture produced by four F-86F aircraft taking off at the same time would create sufficient fog to close the field. Similar conditions would be produced by one B-50 and "a B-47 or B-36 aircraft can temporarily maintain a dense runway fog despite the presence of ambient wind drifts or 1 of 2 ft./sec." (45, p. 207, footnote).

Similar conditions were actually experienced at Lake Hazen on the occasion of the visit of the first supply aircraft on March 29, 1958. On that day the inversion was established in practically type conditions: temperatures varied between -40° and -50°F., the total run of wind in 24 hours at forty feet was only 3.6 miles (a mean wind speed of 0.15 m.p.h.), and on several occasions during the day superior mirages or the Fata Morgana were recorded.

To quote the Notes in the daily sheet for that day:

"...... snow blown up by aircraft at 1500 and again 1645 had completely dispersed by 2100, although at 1900 visibility was still restricted to 1 - 2 miles in S.E."

It should be mentioned that the airstrip was approximately half a mile from the weather station and the general visibility at 1900 E.S.T. was 22 miles.

At that time the observer, as also the author, believed that the reduction in visibility was due to soft snow being thrown up by the propellers, as undoubtedly did occur to some extent, particularly when the aircraft landed and reversed propellers: it was lost to sight in a whirling cloud of snow for at least a minute. The latter, however, cleared rapidly and it seems obvious from Mitchell's account, and from Appleman's analysis of the meteorological factors involved (4) that the turbo-prop engines of the C-130 had produced an ice fog of very considerable intensity.

The tremendous depth of the winter inversion covering Lake Hazen under normal conditions, and the almost total absence of air movement in the surface layers cannot be stressed too strongly. Mitchell's observations are therefore particularly pertinent:

> With regard to the planning of new installations, the following points can be ...... made:
>
> (1) Selection of new air base sites should be such that topographic depressions are avoided where Arctic air can stagnate, and such that drainage winds do not place them down wind of other centres of population.
>
> (2) Bases themselves should be laid out such that the runways are upwind of, and as far removed as practical from, the other base facilities. The runways should also be at a higher elevation than the other facilities whenever terrain permits.

> (3) The buildings .... and other facilities of the base should be designed to emit a minimum of water vapour except at high elevations above runway level or down wind of the runway area, (45, pp. 207-9)

It is possible that such conditions would be fulfilled if a base were established close to the lake and the airstrip were constructed on the higher ground behind. It is suggested, however, that a series of practical tests, preferably in the early spring, could be made with aircraft to test the probable effects.

A further potential problem is suggested by a recent paper of Appleman (3) who examined a case of fog formation at Goose Bay, Labrador, apparently formed by the landing of a number of F-86 jet aircraft. This, he showed, was not due to the formation of ice fog, since the surface and 950 mb. temperatures were about 10°F. and 0.°F. respectively. This fog, he showed, was caused by the production of smoke and nuclei by the engines of the jet aircraft. Normally, these nuclei would be rapidly dispersed, even by a light wind, but at Goose Bay on the day in question the wind fell from three knots to a calm. The responsible conditions which Appleman concluded were necessary for such fogs: stability in the lower atmosphere, calm or very light winds and high relative humidities, are again likely to be encountered at Lake Hazen in the spring and in the fall.

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APPENDIX A

STATISTICAL SUMMARY

1. Temperature °F.

Month	Max.	Min.	Mean	Mean Max.	Mean Min.
Aug 1957	(42.6)	(30.6)	-	-	-
Sep	35.6	-12.0	17.9	20.9	14.9
Oct	17.7	-45.1	-11.8	(- 3.8)	-19.8
Nov	- 3.4	-57.4	-35.1	(-27.4)	-42.8
Dec	-20.2	-62.9	-47.7	(-40.6)	-54.8
Jan 1958	+ 5.5	-68.5	-23.9	(-15.0)	-32.8
Feb	- 4.6	-66.8	-41.0	(-33.5)	-48.5
Mar	-13.9	-56.5	-38.7	(-32.4)	-45.0
Apr	+ 7.4	-57.8	-26.2	(-15.0)	-37.4
May	30.5	-18.1	+10.8	+17.8	+ 3.8
Jun	54.4	+15.4	36.0	41.5	30.4
Jly	59.2	32.3	43.8	50.1	37.5
Aug	(54.3)	(35.0)	-	-	-

The August data refers to the period of regular observations, i.e. Aug. 21 to Aug. 31 1957 and Aug. 1 to Aug. 10 1958. Mean maxima for the winter months have been interpolated by a method described in the text. The suggested mean temperature for the year August 1957 - August 1958 is - 6.0°F.

2. Wind

Mean Wind Speed at 3 Levels (m.p.h.)

	Jan	Feb	Mar	Apr	May	Jun	Jly
10 ft.	2.86	1.20	0.85	1.55	1.87	2.91	3.67
3 ft.	2.76	1.20	0.96	1.57	1.74	2.70	3.50
1 ft.	2.25	0.84	0.66	1.28	1.25	2.28	3.17

3. Precipitation (ins.)

	1957 Aug	Sep	Oct	Nov	Dec	1958 Jan	Feb	Mar
Rain	(0)	0	0	0	0	0	0	0
Snow	(Tr)	0.20	0.23	0.03	0.04	0.23	0.01	0.02
Total	(Tr)	0.20	0.23	0.03	0.04	0.23	0.01	0.02

	Apr	May	Jun	Jly	Aug
Rain	0	0	0.04	0.03	(0)
Snow	0.05	0.08	0	0.02	(0)
Total	0.05	0.08	0.04	0.05	(0)

Total for 11 months + 21 days = 0.98 inches.

4. Pressure (sea-level mbs.)

	1957 Sep	Oct	Nov	Dec	1958 Jan	Feb	Mar
Max	1027.6	1027.0	1034.5	1040.7	1042.0	1046.3	1057.3
Min	1002.7	990.5	1001.0	984.2	996.5	997.2	1009.7
Mean	1014.4	1006.5	1017.4	1017.5	1015.8	1022.9	1031.2

	Apr	May	Jun	Jly
Max	1044.0	1037.7	1036.1	1024.7
Min	988.1	1007.6	1006.2	997.1
Mean	1021.0	1021.5	1019.5	1016.2

5. Comparison of Temperatures at Alert, Eureka and Lake Hazen

	Lake Hazen	Alert		Eureka	
	Mean	Mean 57-58	Mean 50-58	Mean 57-58	Mean 47-58
Aug. 57	-	34.2	33.6	37.2	37.9
Sep	17.9	14.1	15.2	21.1	19.7
Oct	-11.8	- 0.1	- 3.4	- 2.7	- 6.8
Nov	-35.1	-18.0	-15.6	-29.3	-22.8
Dec	-47.7	-32.1	-22.9	-41.7	-32.9
Jan. 58	-23.9	-13.0	-26.1	-19.9	-34.8
Feb	-41.0	-30.8	-27.9	-34.3	-36.4
Mar	-38.7	-22.6	-26.5	-33.3	-33.5
Apr	-26.2	-17.3	-10.7	-20.5	-16.7
May	+10.8	+14.9	+11.5	+15.8	+14.3
Jun	36.0	31.6	31.7	35.4	37.0
Jly	43.8	39.4	39.5	43.5	42.2
Aug	-	34.3	33.6	40.1	37.9

OPERATION HAZEN

THE METEOROLOGY OF LAKE HAZEN, N.W.T.

Based on Observations made during the International Geophysical Year 1957-58

II. SYNOPTIC INFLUENCES ON SURFACE WEATHER

III. A GUIDE TO LOCAL FORECASTING IN THE LAKE HAZEN AREA

IV. AN ANNOTATED BIBLIOGRAPHY ON THE METEOROLOGY OF ELLESMERE ISLAND

by

C. I. Jackson

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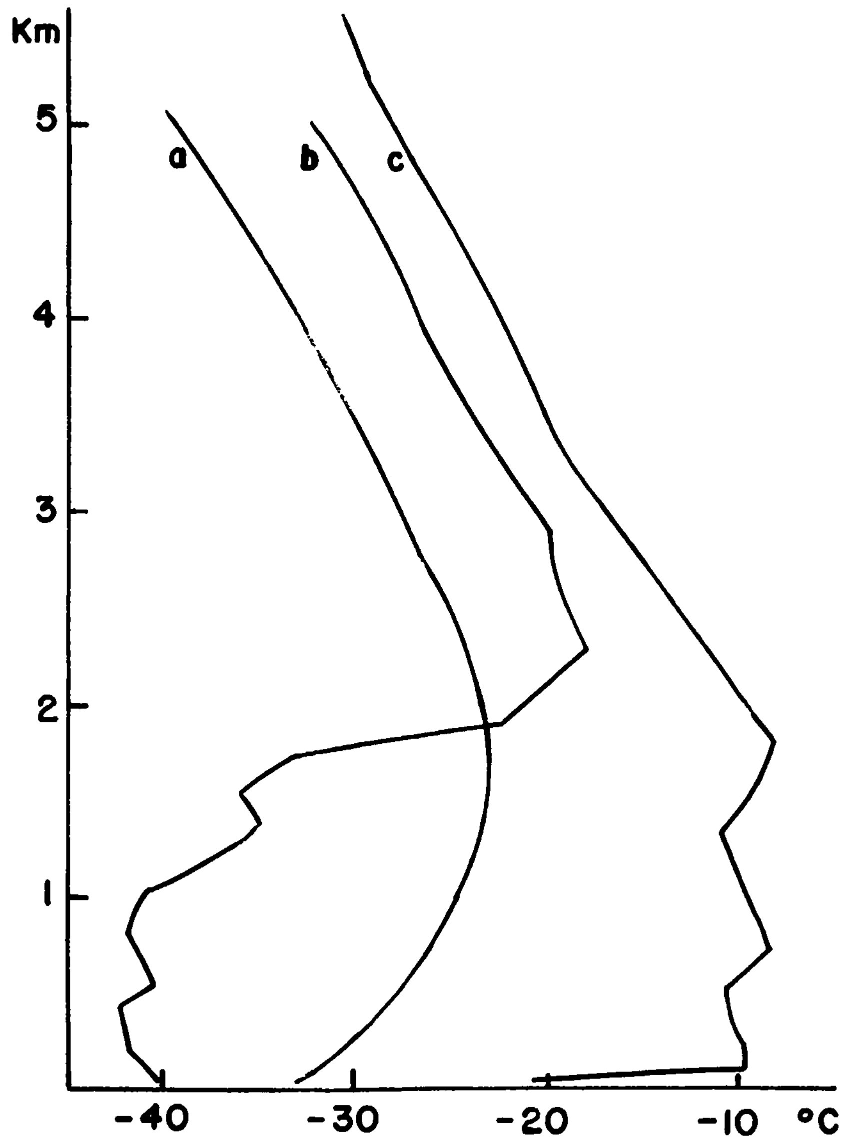

Fig. 55. Soundings at Alert.

a. January mean 1951-53.
b. 1200 Z, January 6 1958.
c. 0000Z, January 23 1958.

PREFACE TO PART II

This discussion of the influence of synoptic events on surface weather in northern Ellesmere Island in 1957-58 depends even more on illustrative material than did the study of the surface observations contained in Part I. Some restrictions have been necessary, however, in the number of figures, and it is for this reason that no synoptic maps are reproduced. Their absence must not be taken as an indication of their unimportance. It is felt that synoptic maps are available fairly widely, whereas the soundings and hodographs for Alert, which are of equal importance to the discussion, are not available in published form and have therefore been reproduced here in preference to the synoptic maps.

Several map series are available for reference. Probably the best is the U.S. Weather Bureau's Synoptic Weather Maps, Daily Series, Part I, Northern Hemisphere Sea Level and 500 Millibar Charts. These are prepared from checked data several months in arrears and were not available for the I.G.Y. period at the time this study was prepared. The Deutsche Wetterdienst publishes a daily series of weather maps based on unchecked data, including analyses at the surface and 500 mbs. on a polar projection for 0000 G.M.T. These were used in combination with the twice daily surface and 500 mb. charts prepared by the Arctic Forecast Team of the

Canadian Meteorological Service at Edmonton, Alta., (the "Edmonton Series"), and reference was also made to the operational analyses (surface, 750 and 500 mb. and frontal contour) prepared by the Central Analysis Office at Dorval Airport, Montreal.

Because much of the present report concerns upper-air data, use has been made of the Celsius and Absolute (Kelvin) temperature scales in addition to the Fahrenheit. An attempt has been made to lessen possible confusion by including Celsius equivalents of all Fahrenheit temperatures used in this section. The conventional abbreviation "Z" is used to indicate Greenwich Mean Time.

The numbering of pages, chapters, tables and figures is continuous with Part I, and frequent reference is made to material in that section. The references however, are numbered separately in each section.

I am grateful to my colleagues Mr. B. W. Boville, Captain C. W. Cook, U.S.A.F. and Dr. S. Orvig for their help and advice.

C.I.J.

CHAPTER X

SYNOPTIC INFLUENCES ON SURFACE WEATHER

I. INTRODUCTION

The discussion of the station records at Lake Hazen, Alert and Eureka contained in Part I did not include a discussion of the weather of northern Ellesmere Island from the synoptic aspect. Certain features were attributed, in the absence of any other likely explanation, to synoptic events, usually involving the advection of warmer air into the region. While, however, it may have been possible to recognise those synoptic events which did have an effect on the weather at Lake Hazen and the other stations, there undoubtedly also existed a number of interesting synoptic situations which had little or no effect on surface weather and passed unnoticed in the analysis of the observations.

In the present section, therefore, the primary purpose is to investigate the synoptic conditions of different periods to discover how far and in what ways events in the lower troposphere - below 500 mbs. - affected surface weather. Particular attention must naturally be given to periods which were shown in Part I to be of importance in this respect, but other periods, when the synoptic contribution to weather appeared less significant at the surface, must also be studied to arrive at tentative conclusions about the critical conditions for a substantial modification of surface conditions.

It will be remembered that the most unusual feature of the mid-winter weather - of the entire observational period, in fact - was the unusually warm temperatures recorded at all three stations during January 1957. It has been shown by Thomas and Titus (15) that the extremes recorded that month were all-time records at many stations in the Canadian Arctic, and some discussion of synoptic activity during that period would be essential in any analysis of the weather of northern Ellesmere Island. The fact that these conditions were so abnormal is, however, of considerable importance from the climatic as well as the meteorological aspect: the conditions of January 1958 are valuable indications of the degree of influence which can be exerted on the midwinter climate of the High Arctic by warm air advection.

Of considerable interest also is a synoptic study of a winter month in which few such warming trends were in evidence at the surface. At Lake Hazen, as can be seen from Fig. 11 (Part I), December 1957 is the most suitable choice: a month in which the mean temperature at Lake Hazen was -47.7° F., compared to -23.9° F. in January 1958.

Much of the subsequent discussion is concerned with the specification of the required conditions for an appreciable rise in surface temperature. The treatment of the data therefore is primarily by means of the three-dimensional temperature field rather than with the pressure or wind field. Surface winds, it will be shown, are of critical importance, but at Lake Hazen in particular their relation to regional wind fields in the free air is not a simple one.

It is necessary to pause at this point to show that the philosophy of analysis, while similar to that of mid-latitude climatology, is comparatively novel in the Arctic. The purpose, as has been made clear already, is to explain surface weather. This is ultimately the purpose of much of mid-latitude meteorology and climatology: the interpretation and explanation of observed surface conditions, leading to their prognosis. In the Arctic, however, where most of the land area is uninhabited, there has been, apart from aviational aspects, very little economic demand for a forecast of surface conditions, and hence little need to write a climatology of surface weather. Some accounts do exist (e.g. Rae (11) and Sim (14)) but most have been based on station statistics with little or no attempt at a consideration of dynamic climatology.

While, therefore, there is a growing literature on the dynamic climatology of the Arctic it is of a special kind, concerned with the average behaviour of the systems themselves, rather than with a consideration of their effects on surface weather. This is, of course, a comment rather than a criticism; as far as present scientific and economic needs are concerned, such a treatment is the most desirable, but there is certainly a place for studies of the present type also.

One of the best examples of this type of approach is The Arctic Circulation by Hare and Orvig (6). This, as stated in the preface, "is a review of the climatology of the northern atmospheric circulation from sea-level up to 30 km." In showing the need for such a study the authors argue that

> .....the view that the arctic circulation can be permanently neglected by the meteorologist is untenable ..... The operational significance of arctic weather for trans-polar flights is unarguable. Even without this, however, we must remind ourselves that the arctic is still the necessary hemispheric energy sink, about whose radiative behaviour we know very little. The arctic climates, moreover, have been those most affected by secular climatic variation in the recent geological past, and by the more recent fluctuations of the past half-century. ...... Research into the general circulation should obviously comprehend these changes, and thus cannot possibly exclude the arctic regions. Presumably the same is true of the antarctic. (6, pp. 2-3.)

It is significant that there is no mention of the fact that a knowledge of dynamic climatology will assist in the interpretation of surface weather and climate. Although the student of such conditions can, of course, derive a considerable amount of assistance from <u>The Arctic Circulation</u> and similar works, they are not primarily concerned with the solution of his problems.

The point of view which is here being pressed has been mentioned also by Keegan (7). In discussing "The Wintertime Circulation in the Arctic Troposphere" he was, like Hare and Orvig, primarily concerned with the climatology of the systems themselves. However he concluded his study with the remarks

> Over the Pole itself the circulation is as complicated as at mid-latitudes. All varieties of circulation are present from deep lows to blocking highs. There are periods of persistence as well as those of great synoptic variability. One big problem is whether there is a systematic relationship between circulation and surface weather. The IGY network may help to solve this problem. (7, p. 31.)

The purpose of the present study could not be better expressed.

In explaining why the present method of analysis differs from that of recent authors, it is finally necessary to mention the work of Belmont on lower tropospheric inversions, which he studied from a large number of soundings at T-3 from June 1952 to April 1954 (1). About 1100 ascents were used in the study; the treatment was statistical and the purpose was to type the inversions according to their physical appearance on a graph of height against temperature, and then to show the frequency and significance of the various types.

Inversions are, of course, as common a feature of the upper-air soundings at Alert and Eureka as they are of T-3, and it was hoped that Belmont's technique might prove applicable in the present study. However it seems to have several drawbacks for such a purpose. The principal one is that although steepness of lapse rate was considered to some extent in the typing of the inversions, neither the surface temperature nor the maximum temperature in the sounding were considered in absolute terms. Thus the temperature at the warmest point of the inversion might be -25°C. or -5°C. but the typing of the inversion, based solely on the change of temperature with height, remains the same. In the present study this is unsatisfactory, as the implications for surface weather are very different and, in a broader context, it may be queried whether such a simple differentiation between soundings has much physical significance. This may perhaps best be illustrated from Fig. 55. The regular curve represents the mean conditions for the month of January, based on three years' data at Alert (5). The two soundings represent individual ascents in January 1958. That for January 23 shows much warmer conditions than normal throughout the lowest 5 km. It represents, in fact, the period of warm air advection over northern Ellesmere Island which produced, a day or two later, the unique temperatures discussed by Thomas and Titus (15). Yet it would be classified on the Belmont system as type 031, which is the most common sounding, especially in winter. Similarly the ascent for January 6 would be typed as 231 which is, according to Belmont, a relatively rare form (less than 1 per cent of all cases over T-3.) This may be true of Alert, although the present study has suggested that it is not infrequent, but its abnormality is as nothing compared to the sounding of January 23 which, lacking any absolute temperature criteria, would have gone unnoticed in a statistical analysis based on the ABC typing method alone.

With these preliminaries, the weather of northern Ellesmere Island during December 1957 and January 1958 may now be considered. In general the upper air ascents at Alert have been used in preference to those at Eureka. The differences between Lake Hazen and Alert, which were shown to be so marked at the surface, are unlikely to extend far into the free atmosphere, particularly in winter. On some occasions the relative nearness of Alert (100 miles) to Lake Hazen as compared to Eureka (220 miles) is of significance in the sounding. In general the discussion progresses from the general to the particular, beginning with a consideration of the variation of potential temperature during each month. The form of the daily soundings are then considered in relation to surface and synoptic conditions, and finally hodographs are used to show the levels at which advection is significant at different times.[1]

II. MIDWINTER SYNOPTIC ACTIVITY

A. December 1957 According to the Meteorological Branch:

> December mean temperatures were well below normal throughout the Northwest Territories. The greatest deficiency was thirteen degrees at Holman Island, and Coppermine was next with twelve degrees. Stations on the shores of Great Slave Lake had deficiencies of about one degree but the remaining stations in the Territories reported deficiencies ranging from four to ten degrees.
>
> Precipitation was irregularly distributed in the Northwest Territories in December. ...... On the Arctic Archipelago there was no pattern evident and the range was from a trace of precipitation at Isachsen to two and a half times the normal fall at Frobisher Bay. (3, p.2.)

The low temperatures referred to above were very evident at Lake Hazen. On only 5 out of a possible 124 occasions was the temperature sufficiently far above the freezing point of mercury to risk placing the mercury thermometers in the screen at a main synoptic observation. Temperatures of - 50°F. (- 45.6°C.) or below were recorded on all but three days in the month. Conditions, one might have said, were almost constantly those associated with little synoptic activity and the intense development of the Arctic inversion. The month was, in fact,

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[1] Those unfamiliar with hodograph analysis will find a clear discussion of its implications by Petterssen (10, Vol. 1, pp. 101-103.)

characterised by high index conditions, with strong westerlies lying rather north of their usual position over North America, but having little effect on the High Arctic. The only major exception to this pattern of constant and intense cold occurred in a period beginning on the 15th, when the temperature rose to - 20.2°F. (- 29.0°C.) and then fell rapidly to a minimum of - 56.8°F. (- 49.3°C.) followed by a similar rise on the 17th, this time to - 27.3°F. (- 32.9°C.), both cases being associated with measureable snowfall. These periods, December 15-16 and 18-19, were the only occasions on which the mercury thermometers were in use during the month.

These occasions on which the extremely cold temperatures were somewhat ameliorated beg interesting questions in themselves. Thus on the broad scale the month of December 1957 must be investigated to answer the question "What are the conditions which lead to the establishment and maintenance of intensely cold temperatures at the surface ?", that of January 1958 to solve the problem of the required conditions for their complete absence. The fluctuations of mid-December may therefore be of some interest as indicating conditions which initiated warmer temperatures but were either insufficient or not continued long enough to have anything but a brief influence on surface weather.

A general picture of the thermal variation throughout the lower troposphere can be derived from a study of Fig. 56 which shows the variation of potential temperature at the standard pressure levels up to 500 mbs. and also the actual surface temperatures at Alert and Lake Hazen. The upper-air data is for Alert and is taken from the "Radiosonde and Rawinsonde Checked Data" section of the U.S. Weather Bureau's Northern Hemisphere Data Tabulations (17). The only advantage in using potential rather than actual temperatures at the standard levels for the present purpose is that it enables the curves at the different levels to be clearly distinguished from each other: actual curves continually intersect and it is difficult to appreciate the change at all levels simultaneously. The values of potential temperatures are therefore significant only in the fluctuation of the curves about the mean values for the different levels. This mean value is based on about 245 ascents at Alert in the years 1950-53 and is the average of the separate means for ascents at 0300 Z and 1500 Z, published in the Climatological Summary for Alert (5).[1] Each of the twice daily (now at 0000 Z and 1200 Z) ascents are plotted in the diagram.

The chief feature of the pattern is the contrast at 850, 700 and 500 mbs. between the first third of the month and the remaining period. Potential temperatures were considerably above normal for at least a week at all levels. This was a clearly defined and on the whole regular variation, whereas during the rest of the month temperatures fluctuated fairly frequently about the three-year mean, with perhaps

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[1] The differences between the two means is, during the sunless months of December and January, rarely more than 0.2°C. at any of these lower levels.

a tendency to be rather colder than normal at 700 mbs. What is of more significance, however, is that surface conditions appear to be almost totally unrelated to the temperature fluctuations in the free atmosphere, with the exception of the abrupt rise at the very end of the month. This, it was suggested in Part I, was rather to be expected at Lake Hazen; it is more surprising to find the surface temperature at Alert, so very consistently warmer than at Lake Hazen, apparently equally independent of the tropospheric fluctuations.

Besides raising several interesting questions concerning the relationship of conditions in the troposphere to those at the surface, Fig. 56 also contains much of significance as regards the relationship between Alert and Lake Hazen. Each of them, it is apparent from the actual temperatures, are at the base of fairly deep inversions (the actual mean temperatures 1950-53 over Alert at 850 and 700 mbs. were - 23.7°C. and - 25.9°C. respectively). Yet, as Part I showed, there is a considerable and persistent temperature difference between the coastal and inland sites. The first half of December illustrates this clearly, the temperatures at Lake Hazen being consistently five or ten degrees centigrade or more below Alert. In the latter part of the month, however, the temperature at Lake Hazen fluctuated considerably. On several occasions it approached that at Alert; only twice, however, did it exceed the latter and in each case it appears that a rise at Alert was only delayed by comparison with Lake

Hazen. Particularly interesting are the occasions when coast and interior recorded almost identical surface temperatures.

A study of Fig. 56 thus suggests several hypotheses which should be examined in more detail:

(1) Despite the considerable warming of the troposphere, at least within the limits 500 to 850 mbs., there was no perceptible effect at the surface.

(2) Conditions at Alert were favourable for the maintenance of remarkably constant temperature conditions at the surface, which were colder than the 1950-53 average.

(3) At Lake Hazen there was similarly no disturbance of the thermal conditions during the first half of the month, but thereafter occasional fluctuations occurred, their maximum effect being the elimination of differences in temperature between Lake Hazen and Alert.

Considering the events of the month in more detail, the sounding at Alert at 0000 Z on December 2 1957 is shown in Fig.57. This, as can be seen from Fig.56, was the time immediately before the atmosphere began to be affected by warming and when negative potential temperature anomalies varied from about 8°C. at 700 mbs. to 2.5°C. at 850 mbs. The sounding, it will be seen, passed through a generally isothermal atmosphere. A small inversion bulge was present, with its apex at - 27.5°C. at 850 m. (911 mbs.) This bulge, though small, was lower than the mean position at about 1500 m. The main feature of the sounding, however, is the small variation in temperature along the vertical and also the absence of strong winds. Values of wind speed are plotted in metres per second along the ascent. As might be expected the hodograph shows nothing of significance. Winds are plotted, here and in succeeding hodographs, in metres per second at 500 m. intervals from the surface to 3000 m. (700 mbs.) and at 1000 m. intervals from there up to 5000 m. Winds at all levels, as the sounding has already indicated, were sluggish and no significant advection is evident or to be expected.

Such a pattern accords well with the synoptic map. At the surface, the Canadian - Alaskan sector of the polar area had practically uniform pressure with an extensive but weak high pressure system extending from eastern Siberia to central Greenland.

By the 4th the increase in temperature was evident throughout the lower troposphere. The temperature at the apex of the bulge had risen by about 5.5°C. in two days and a considerable part of the sounding below three kilometres was now warmer than - 30°C. The shape of the sounding is more what is implied by the term "inversion". There was a rapid increase in temperature from a minimum at the surface up to about 300 m. and then a slow increase up to about 1000 m. This, however, had not taken on its form by radiational cooling of the lower part of the atmosphere with a normal lapse rate above: the Alert surface temperature remained almost constant during the two days (and, as Fig 56 shows, for a long time thereafter) and it is the atmosphere itself which was warmed. This warming, it is clear, in the absence of radiational heating at the surface, must have been caused either by advection in the horizontal plane or by adiabatic warming of subsiding air. From the wind speeds plotted on the sounding and on the hodograph it is apparent that there had been no warm air advection on a sufficient scale and the rise in temperature must therefore be due to subsidence. Extension of the hodograph above 5 km. shows that there is a marked increase in wind speeds up to the tropopause and that it is, in fact, colder air which is being brought in at these levels. This warming due to subsidence is in accordance with the views of Schumacher concerning the maintenance of the inversion over Maudheim in the Antarctic:

> During the polar winter we usually find the highest temperatures of the atmosphere at the top of the surface inversion. It is evident that this layer suffers a net loss of heat energy from radiation and, possibly also from heat transfer, meaning that the inversion layer serves as a source of heat for a greater part of the atmosphere. Wexler (1936), considering radiation only, came to the conclusion that the layer is gradually cooled, attaining the structure of an isothermal layer of increasing thickness. By successive soundings from a maritime polar air mass moving into continental regions he showed that cooling from the surface created a temperature distribution in accordance with his theoretical considerations. However, we have seen above that over polar regions the mean temperature of the lower troposphere shows small month to month variation during winter. This applies especially to the two antarctic stations, Maudheim and Little America, but also in the Arctic the cooling appears to be of another order of magnitude than that which should be expected from radiative loss of heat. Thus, Wexler found that an initial temperature of some - 25°C. at the top of the inversion layer might be lowered by some 10 degrees centigrade in about a fortnight, assuming calm, cloudless conditions. To some extent, advection of warmer air may compensate the loss of heat,

> but at least in polar anticyclones this effect must be of minor importance. The only possibility left is adiabatic heating due to subsidence, which accordingly seems to play an important role in determining the temperature distribution during winter in the lower part of the polar atmosphere. (13, pp.35-36.)

In this case it has done more than maintain lower tropospheric temperatures; it has raised them considerably above seasonal normals.

The problem of why the surface was not affected by this tropospheric warming immediately becomes much clearer. Stability requirements will prevent the warmer air aloft from reaching the ground without the aid of mechanical turbulence and this turbulence is absent in the calm conditions of a polar anticyclone. Nor is the descending and warming air likely to cause clouds to develop which are the alternative method enabling warmth to reach the surface from the atmosphere, by long wave radiation from the relatively warm cloud layer.

These conditions reached their best development on December 6. The sounding indicates considerable warmth at about 850 mbs. with temperatures not far below freezing. Humidities, however, in this subsiding air, were very low also, and were only A15 per cent at 850 mbs., A16 per cent at 700 mbs. and A20 per cent at 500 mbs.[1]

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[1] These humidities, expressed with respect to water saturation, are preceded by the letter 'A' in the data sheets to indicate that the humidity element in the sonde was "motorboating" at these levels, as it was not designed to record such low humidities; the values have therefore been interpolated.

Throughout this period, therefore, the surface temperature at Alert and, at a lower value at Lake Hazen also, remained virtually constant. Despite the ideal conditions for radiation, temperatures did not fall appreciably and this has been explained in Part I: by December the principal heat loss from the ground has been effected and thereafter the seasonal temperature fall is only very small. Conditions in the free atmosphere were unusually warm, but the nature of this warming, adiabatic heating of subsiding air, was such as to prevent its effects from reaching the ground surface. Finally, it is evident that the form of the inversion cannot be considered without account being taken of actual temperatures and past history.

This period was interesting as an example of warmth but little wind. The next, from about the 10th to the 15th, is an example of appreciable surface winds but a generally cold lower troposphere.

The sounding for 0000 Z on December 11 shows a rather irregular form, with the bulge gradually decreasing in temperature after its maximum a few days earlier. The temperature at the surface was about - 35°C. as it had been throughout the preceding ten days. The hodograph shows little of significance below 500 mbs.; if anything, colder air was blowing from the southeast. The synoptic map was also unexciting. Ellesmere Island was between a high (1028 mbs.) over the Pole and a low (1012 mbs.) east of Devon Island. Weak gradients were found at 500 mbs.

Little change is evident in the sounding for December 13: the lower troposphere was once again approaching the almost isothermal conditions of December 1. By 0000 Z on the 14th, in fact, the sounding was essentially isothermal between 300 m. and 2500 m. The wind hodograph for the 13th is again unrevealing: the apparent warm air advection was of little significance as the sounding shows. More significant were the developments in the synoptic pattern with the usually broad dispersal of isobars contracting as a depression moved northwards along the west Greenland coast. As it happened this filled rapidly, but another moved northeastwards behind it into central Greenland, creating a deep cyclonic vortex there and strong pressure gradients over northern Ellesmere Island. The resulting surface winds were sufficient to overcome the "nival" inversion at the ground both at Alert and Lake Hazen. The winds, however, were not blowing in a warm lower troposphere and hence the form of the sounding on the 15th. The hodograph does suggest that some warm air advection was taking place, but it is clear that the principal effect of the wind was to raise the temperature of the surface layer by mechanical mixing.

It would seem that similar causes were responsible for the rise in temperature at Lake Hazen also, although there were certain differences of scale. In particular, the winds recorded at the surface were very much lighter than those at Alert. At the latter station the effect of the winds was abrupt: at 2100 Z on the 14th the winds were calm and the temperature - 35.5°F. (- 37.5°C.);

three hours later, at the time of the sounding, the winds were north-northwest at 45 m.p.h. and the temperature was - 22.3°F. (- 30.2°C.) At Lake Hazen the highest recorded wind at an observation was only 10 m.p.h. (southwest) but, as Fig.56 indicates, this was sufficient to overcome the surface inversion and eliminate the differences between coast and interior at 1200 Z on the 15th.

It would seem, therefore, that only a very light wind is necessary to remove the inversion when, as in the period preceding December 15, the temperature gradient just above the surface at Lake Hazen is very steep. It will be seen that the much greater fluctuations at Lake Hazen as compared to Alert are only a function of the former's initially much colder temperatures. It is clear also that mechanical turbulence, even on a relatively small scale, can "roll up" a surface inversion very effectively, but that the actual rise in surface temperature is dependent on the temperature of the free air.

As the low moved across Greenland, gradients slackened and, with surface winds dropping again, the inversion was rapidly re-established. During the course of the next few days the coldness of the surface gradually affected a deeper layer of the atmosphere so that by the 18th there was a fairly constant increase of temperature with height from - 36°C. at the surface to - 25°C. at 1200 m.

At this time there occurred another period of warming at the surface, once again much more marked at Lake Hazen than Alert. This time the winds at the inland station were extremely light, one or two miles per hour, and a layer of medium cloud persisted giving fairly continuous light snow. It appears that in this case it was the cloud and precipitation which were of more significance in raising the temperature. Light winds were also recorded on the 20th, but they did not prevent the temperature falling again as the sky cleared and the snow was replaced by ice prisms.

The next significant event was the advection of warmer air aloft, as demonstrated in the sounding for December 20. This never reached the surface, but it is nevertheless interesting for its own sake, as the source area of the warm air appears to have been the Norwegian Sea: the 500 mb. map shows a small high pressure system centred over Nord and a low south of Thule with warm temperatures at Nord and Alert but not, interestingly, at Eureka. Thus at Alert at 0000 Z on the 21st the 700 mb. temperature was - 19.8°C.; at Eureka it was - 32.8°C. A day later the values were - 25.9°C. and - 33°C.: the warm air aloft never reached Eureka. This feature will be discussed in another example later; it seems, however, to be a factor of considerable importance and may indicate a major contrast in regime between northern Ellesmere Island and the southern part, which is to a much greater extent under the influence of systems in the Baffin Bay-Davis Strait area.

These events, meanwhile, went unnoticed at the surface, except that a certain amount of cloud was recorded during this period. Much more cloud, however, was recorded in the next synoptic development. This was caused by the extension northwards of a warm tongue of air over Baffin Bay and Greenland, not quite reaching northern Ellesmere Island at its strongest. The significance of the air was mainly in its humidity, which was considerably higher than the usual low values aloft and it is the associated cloud which apparently caused the rise in temperature at Lake Hazen. There seems almost to be a direct and immediate relationship between temperature and cloud amount on the 24th and 25th: - 34°F. (- 37°C.) with a snow-obscured sky at 1500 Z, - 39°F. (- 39°C.) with six-tenths cloud at 2100 Z, - 40° with two-tenths at 0300 Z, - 34°F. (- 37°C.) with ten-tenths at 0900 Z.

The final feature of interest is of course the rise in temperature at all levels in the last two days of the month. The sounding for 0000 Z on the 30th shows that the atmosphere below 500 mbs. was very cold throughout. The maximum temperature, at about 500 m. was only - 32°C. and the surface temperature at Alert was unusually cold. Twelve hours later, the form of the sounding had been transformed. The steady rise of temperature up to about 500 m. had been replaced by a shallow nival inversion and between this and about 4 km. temperatures had risen considerably. The change is explained by a comparison of the hodograph and the frontal contour chart. The hodograph shows no advection of any kind below about 1000 m., but from this level up to about 4000 m. there is evidence of considerable warm air advection from the west. This was associated with a low pressure centre with a well-developed warm front which had passed Isachsen at the surface by 1200 Z on the 30th.

By 0000 Z on the 31st the effects of the warming had reached the surface at Alert, aided by overcast skies, but more particularly by strong winds which completely destroyed the inversion. At Lake Hazen there were no appreciable winds; the warming at the surface took place much more slowly and was of much less significance than at Alert. It would therefore appear to be almost entirely due to long-wave radiation from the clouds associated with this warm invasion and is thus in contrast to the other fluctuations of late December which, as shown earlier, produced much greater temperature changes at the inland station.

The weather of December 1957 provides illustrations of a considerable number of different synoptic factors, which had very different effects on surface weather. A summary of their implications will, however, be deferred until conditions in the following month have been analysed in a similar way.

B. January 1958 The Meteorological Branch summarised the weather of January 1958 in the High Arctic as follows:

> The most outstanding weather event in January in the Northwest Territories occurred from the 20th to the 24th when an invasion of warm air covered Ellesmere Island. As a result new record high temperatures were established at almost all the stations on the eastern part of the Arctic Archipelago. The most interesting of these records was the maximum of 32 degrees reported at Alert on the 24th. This was not only a new record for January, but was higher than

> the record high temperatures for all months from November to April, inclusive. The high of 30 degrees at Eureka and of 40 degrees at Arctic Bay were also new records for the period November to April; the latter record going back 21 years. January mean temperatures were close to normal at Aklavik and Clyde but all other stations in the Northwest Territories reported excesses ranging to sixteen degrees in the Arctic Archipelago and to 17 degrees in the area around Great Slave Lake.
>
> As usual the distribution of precipitation over the Northwest Territories was quite irregular .... On the Arctic Archipelago a few stations had precipitation deficiencies, but most had excesses. Of these the greatest was at Mould Bay which had about six times the normal fall while Holman Island and Frobisher both reported snowfall over four times the normal (4, p.2.)

The weather over northern Ellesmere Island was indeed unique within the period of records: the Meteorological Branch had to go back to 1919 to find a January in which Canadian stations reported such abnormalities of temperature, almost thirty years before the Joint Weather Stations were established.

The contrast to the previous month is admirably demonstrated by Fig. 58. In December the magnitude of the potential temperature fluctuation at the standard levels was fairly small except for the warming trend in the early part of the month. In the atmosphere as at the surface it was the general pattern rather than the day to day variations which was striking. In Fig. 58 however, it is the changes which are of most importance; there is in fact little evidence of any general pattern. Not much can be said about conditions over the month as a whole, except that one feature is true of all levels. For approximately the first week of the month the surface and standard pressure levels were colder, generally much colder, than the 1951-53 mean. Thereafter they became much warmer and, although temperatures began to drop in the middle of the month, new developments raised them to even higher values later. The climax of this trend was reached about the 24th and the free air had practically reached its mean condition by the end of the month.

At Alert some of the warmth which had been brought in during the last days of December was apparent in the early part of the new year. Fairly strong winds aloft, however, had by 0000 Z on the 1st established "normal" lapse rates down to about 1500 m. above the surface, with an isothermal layer below. This isothermal condition was apparently caused by mechanical turbulence in fairly strong winds and by the 2nd the sounding was beginning to cool through an extensive depth while still preserving a mixing layer down to the surface. At the ground there was a marked but easily explicable contrast between Alert and Lake Hazen. At the former, it was pointed out, the warmth of late December was brought to the surface principally by the winds of up to gale force. As, however, the free air cooled, so the temperatures at the surface fell also. At Lake Hazen, with little or no wind in this period, the warmth was due to radiation from a warm cloud layer. Overcast skies continued until about 0000 Z on the 3rd, and thus the less marked increase of temperature at the inland station continued up to that time.

Once the skies cleared, however, surface temperatures fell very rapidly, so that the coldest temperature of the winter, - 68.5°F. (- 55.8°C.), was recorded at Lake Hazen late on the 4th. A little earlier, at 0000 Z on the 4th, the sounding at Alert showed that the cooling had extended throughout the lower troposphere, resulting in a practically isothermal sounding with no point warmer than about - 38°C. - unusually cold conditions and probably an indication of the state to which the lower troposphere tends in winter at this latitude when radiational cooling is the dominant control. The inversion was practically eliminated at Alert.

The sounding at 0000 Z on the 5th was very similar although there had been a slight rise of temperature at about 2500 m. Synoptic developments were of more significance. A low over Goose Bay had extended its influence northwards into Baffin Bay and a separate centre (central pressure 984 mbs.) had developed over Thule. Fairly strong gradients existed between there and Alert where the pressure was 1012 mbs. The light northeast winds which this pattern brought to Alert were associated with continuous snow and low cloud. At Lake Hazen, by contrast, skies were generally clear, winds were practically calm, and the temperature remained below - 60°F. (- 51.1°C.)

A day later the rise in temperature at 2500 m. had become quite marked. Winds were quite strong throughout the sounding but the lowest layers still remained cold. The hodograph demonstrates the cause of this rise in temperature admirably; warm air was being advected from the northeast, particularly at about 1500 to 2000 m. The surface synoptic map shows a complex cyclonic circulation round a major centre over Greenland and Iceland (952 mbs.) and minor centres over Ungava (976 mbs.) and Denmark (984 mbs.) This warm advection was similar to that which reached northern Ellesmere Island about December 20th. On this occasion, as before, the warming effects were associated with precipitation and overcast skies.

On the 7th the sounding was still of the same general pattern, although the slowness with which the warm advection reached the lowest layers is interesting. This may well be an orographic effect: the fairly high land in the extreme north of Greenland acts as a barrier to the warm air from the Norwegian Sea which can thus only arrive at Alert at altitudes above about 1500 m. By the 8th, when the whole of the lower troposphere had been warmed, the winds at the surface were light and so the warm advection had little effect on surface weather except so far as snowfall is concerned: light snow was recorded continuously at Alert from 0445 Z on the 4th until 1400 Z on the 7th.

There were signs on the 9th that this circulation was breaking down: that the lower troposphere was once again cooling towards isothermal conditions. Generally straight isobars crossed northern Ellesmere Island at the surface from Scandinavia to the Bering Strait between high pressure north of Novaya Zemlya and a low over southeast Greenland. At 500 mbs. there was an extensive circulation around a low in Baffin Bay, but no connection with the Norwegian Sea.

The hodograph shows nothing of significance. If anything, the warmer air had been replaced by colder air at a slightly higher level blowing from the Greenland ice-cap in the southeast.

The sounding for January 10, however, shows that a radical change had taken place. The temperature at the surface had remained constant during the previous day, and for about another twenty-four hours afterwards. But in the free air the temperature rose quickly and appreciably, with the bulge about - 12°C. at 1500 m. The upper circulation had reverted to flow from the Norwegian Sea across northern Greenland and Ellesmere Island. The hodograph confirms the presence of the warm air and suggests that it was being advected in a fairly narrow layer about 1500 to 2000 m.

The principal change on the 11th was that the lowest layers of the troposphere had become as warm as those above. Winds at both Alert and Lake Hazen were light, however, and surface temperatures rose only slowly. Later, however, the sky became overcast at Alert, snow began to fall and moderate winds were recorded. The temperature rose rapidly, reaching - 14°C. by 0000 Z on the 12th, by which time the supply of warm air from the Norwegian Sea had been cut off and the troposphere was already beginning to cool again. At Lake Hazen the winds continued light as usual, but they did exist and, with snow and fairly low cloud, helped to cause a similar rise in temperature, although much less than at Alert.

The gale of mid-January must now be considered. This was responsible for the only winds over 20 m.p.h. recorded between August 1957 and July 1958 at Lake Hazen. Its effect at that station were much more extreme than the actual wind speeds suggest. Snow had lain practically undisturbed since the winter began; it was now removed completely from much of the landscape and piled into compact drifts, and the soil beneath the snow was also blown. Much of the station equipment was buried beneath these drifts, a radio mast was blown down and, although other structural damage was negligible, the effects of the gale were such that the possibility of its recurrence once or twice a winter is a factor of some importance for any installation in the area.

The principal feature of the surface synoptic map is a very strong anticyclonic cell (central pressure 1048 mbs. at 1200 Z January 17) over Baffin Island, Baffin Bay and west Greenland. Its influence, as indicated by anticyclonically curved isobars, extended from the Pole to the Great Lakes. Coincident with this there was a slowly moving low pressure system of Alaskan origin which by 1200 Z on the 17th was centred (992 mbs.) about 83°N., 160°W., north of Alaska and west of the Queen Elizabeth Islands. Hence there were strong gradients over the Islands - there was a difference of over 30 mbs. between the sea-level pressures at Isachsen and Thule - and the 50 to 80 m.p.h. winds recorded at Alert at this time were hardly surprising.

What is surprising is the long delay before the high winds made their appearance at the surface at Lake Hazen. Winds with a west or southwest origin were blowing at Alert by 0600 Z on the 16th and from then onwards they remained strong. Visibility was seldom as good as half a mile, blowing snow was continuous and usually formed the ceiling, and the lowest wind at the surface between then and 1500 Z on the 18th at an observation was 40 m.p.h. At Lake Hazen, however, the daily weather record for the twenty-four hours between 1200 Z on the 16th and 1200 Z on the 17th showed no sign of these events. A considerable amount of medium cloud was present and temperatures were relatively high (- 24°F. to - 16°F. or - 31°C. to - 27°C.) Winds, however, were very light, the 24-hour run at 40 feet being equivalent to a mean wind speed of only 2.06 m.p.h. They were also consistently opposite to the regional gradient, being north or north-northeast.

A comparison of the 1200 Z observations on the 17th sums up the contrasts:

Alert: Visibility 1/8th mile in blowing snow: wind S.W. 50 m.p.h.; temperature - 3.7°F.; clear skies.

Lake Hazen: Visibility 8 miles; wind calm; temperature - 16.0°F; 10/10 overcast at 10,000 ft.

Eureka: Visibility zero in blowing snow; wind S.S.E. at 40 m.p.h.; temperature - 8.0°F.; sky obscured by blowing snow.

Not for another four and a half hours did the gale reach the surface at Lake Hazen, when the temperature suddenly jumped to 0°F. (- 18°C.) and winds of 10 to 15 m.p.h. from the southwest established themselves. The wind speed at Alert had by now reached 80 to 90 m.p.h. Maximum winds at Lake Hazen came about twelve hours later, with speeds of 37 to 40 m.p.h. timed over three-minute periods. At about this time the anemometer was blown from the 40 foot mast and could not be replaced until after the gale. Winds were estimated and the 10 ft. anemometer, read hourly during this period, indicated that the estimates were fairly accurate.

The soundings for Alert during the height of the gale are missing, which is understandable and their lack is not so important as at other times. It is clear that the surface inversion disappeared, although the Eureka sounding for 0000 Z on the 18th suggests that it was replaced by a more or less isothermal layer rather than by a "normal" lapse rate. The air, blowing from far to the south, was warm, although perhaps not so warm as that of Norwegian Sea origin.

What emerges from this discussion, concerning the possibility of severe gales at Lake Hazen? On the synoptic scale it is clear that the surface pattern was unusual: the anticyclone was centred in an area which is a particularly favoured area for cyclonic centres, and Hare and Orvig (6, 115-19) have drawn attention to the very low frequency of anticyclonic centres over the Canadian Archipelago and the Labrador Sea. The system was not only unusually located, it was exceptionally intense, and the steep gradients along its margins were enhanced by the low pressure system north of Alaska. The strong winds over Ellesmere Island are thus no problem; it would have been unusual if they had not been reported. Much more difficult to explain is why the arrival of the gale should have been delayed so long at Lake Hazen and why the velocities were so much less than on the coasts. Local relief may partly explain the latter, although the trend of the physiography helps to funnel southwest winds along the Lake Hazen trough. The author is naturally hesitant to suggest that winds must reach 90 m.p.h. at Alert before they become moderate in strength at Lake Hazen. There does, however, seem to be some evidence from other occasions during the winter that these very strong winds of 70 to 90 m.p.h. at Alert seldom blow stronger than 10 to 15 m.p.h. at the inland station. Otherwise the phenomenon can only be properly investigated by a longer record at Lake Hazen, including at least pilot balloon and preferably rawinsonde ascents. A reconnaissance party in the early summer of 1959 reported that profiles through the snow on the lake and the Gilman Glacier suggested that there had been a similar gale early in the 1958-59 winter. Otherwise there was no evidence of strong winds.

The gale of mid-January and the resulting warm temperatures were, however, only a preliminary to the abnormally high temperatures in the period from January 23 to 25, particularly on the coast. This is another period in which the warmth of northern Ellesmere Island can be interpreted in terms of the broader synoptic pattern.

The unusual synoptic conditions have been described by O'Connor (9). The major influence affecting the Arctic Islands at this time was:

> .....the block in Davis Strait when monthly mean 700 mb. heights averaged 520 feet above normal..... This block predominated during the second half of the month, when it developed to near-record proportions.
>
> . . . .
>
> On a 5-day basis the Davis Strait block reached its maximum intensity at 700 mbs. of about 1,500 feet above normal in the January 18-22 period. On a hemispheric basis this was probably second in intensity only to the record anomaly of + 1,600 feet in the same area during the 5-day period February 19-23 1947. (9, pp.11 and 13.)

The effect of this blocking pattern on the lower troposphere at Alert is clearly demonstrated by the graph of potential temperature, Fig. 58. The 850 mb. potential temperature at 0000 Z on January 24 was 25°A. above normal and smaller anomalies were recorded at higher levels. The soundings for 0000 Z on the 22nd, 23rd and 24th show the advance of warm air. The temperature at 500 mbs. rose by 9°C. and the height of the surface by 530 feet between the 22nd and the 23rd. The temperature below about 2 km. was about - 20°C. on the 22nd, - 10°C. on the 23rd and at 937 mbs. on the 24th it was 3.7°C. above freezing.

Surface temperatures at Alert rose by almost the same extent, although a lack of wind at the ground in the period preceding the sounding for the 23rd accounts for the maintenance of the temperature of the previous day. At Lake Hazen, however, temperatures did not equal the 5.5°F. (- 14.7°C.) of the previous week, the maximum of 3.3°F. (- 15.9°C.) occuring twice on the 25th. The rise, from about - 30°F. (- 34°C.) appears once again to have been at least as much a function of radiation from cloud and falling snow as of mechanical mixing by surface winds. Winds of up to 6 m.p.h. were recorded during this period but the 24-hour run at 40 feet from 1200 Z on the 24th to the 25th was only marginally above a mean wind of 2 m.p.h. Meanwhile winds of 20 to 40 m.p.h. were being continuously recorded at Alert.

Temperatures remained high until the end of the month and snowfall was considerable. Of particular interest was the relatively high snowfall at the end of the month at Lake Hazen. This, as the hodograph for 0000 Z on the 30th indicates, appears to have been associated once again with the advection of warm air from the east or northeast - from the Norwegian Sea. 0.13 inches water equivalent were recorded in about 48 hours, or over 13 per cent of the measureable precipitation recorded during the period of observations at Lake Hazen. The Alert total in this period was much less, but a probable explanation of this is that strong winds were once again present on the coast and much of the new snow may have gone unnoticed during the blowing snow which was reported throughout the period.

C. Conclusions From the preceding discussion several tentative conclusions may be drawn concerning the effect of the events in the lower troposphere on surface weather conditions in midwinter. Most of these conclusions are not new; they have been suggested or proved for other localities in the Arctic or Antarctic. One or two, however, are more unexpected and all have relevance to the problem of local forecasting in northern Ellesmere Island.

1. As an answer to a question posed earlier, it appears that the required conditions for the development and maintenance of very cold temperatures at the surface during the sunless period are clear skies and calms or light surface winds. The temperature of the free air, even a short distance above the ground, appears to be of very much less significance.

2. Conversely, the conditions required for a significant rise in surface temperature in midwinter are either overcast skies, especially associated with snowfall, or moderate or strong winds at the surface. In the former case the rise in temperature is affected by long-wave radiation from warm clouds or falling snow and takes place relatively slowly. Surface winds cause mechanical turbulence and thus mix the lowest layers with the warmer air aloft. This latter process is rapid and effective, but the magnitude of the temperature change is dependent on the temperature of the free air; when the sounding is cold over a fairly deep layer the wind can have little effect.

3. Once the skies clear or the wind drops, temperatures fall very rapidly at the surface.

4. The causes of a rise in temperature in the free air - horizontal or vertical motion - are very important as far as the effect on surface weather is concerned. Warming of subsiding air, as exemplified by conditions in early December 1957, is associated with clear, calm, anticyclonic conditions, light surface winds and, in subsiding and drying air, little cloud formation. Lacking either cloud or appreciable surface wind it is thus relatively difficult for the warmth of the subsiding air to reach the ground. Warm air advected horizontally, however, is frequently associated with strong surface pressure gradients and is generally cooling and therefore more likely to produce clouds and precipitation.

5. A significant source area for warm air arriving over northern Ellesmere Island in midwinter appears to be the Norwegian Sea. Three main features are characteristic of this air:

a. The advection appears to take place above 1500 m. and especially between 1500 m. and 2000 m. suggesting that north Greenland forms an orographic barrier to the intrusion of warm air at lower levels.

b. Partly because of this feature, the warmth from such air appears to be transmitted to the ground more often by long-wave radiation from clouds or snowfall than by surface winds.

c. The snowfall associated with this warm air possibly accounts for the major part of midwinter precipitation.

It should not be necessary to stress the tentative nature of these conclusions, based as they are on a subjective analysis of only two months' data. They do seem to account, however, for most of the problems raised by the surface weather records in these months. The major problem which remains unsolved is why the wind speeds inland should be so much lighter than those recorded at Alert and Eureka. The delay of almost thirty-six hours before the arrival of the January gale at Lake Hazen is particularly surprising in view of the very steep pressure gradients.

Concerning the Arctic inversion as revealed by the sounding at Alert and, by extension, at Lake Hazen also, two comments will suffice. In the first place there seems to be evidence suggesting that in suitable conditions the lower troposphere tends towards Wexler's "ideal" sounding which, in the words of Belmont, "consisted of a surface inversion of infinitesimal thickness below an isothermal layer which extended up the resumption of the original lapse rate curve." Secondly it seems physically and practically dangerous to neglect either the actual temperatures or the immediate history of any sounding when its significance is assessed.

III. THE REMAINING PERIOD IN REVIEW

Having dealt with these two winter months in detail, the rest of the observational period may be passed over more quickly to describe the major fluctuations in the temperature curve at Lake Hazen

(Fig. 11, Part I) which were of synoptic origin.

The rise in temperature in late February was the result of a breakdown of the zonal westerlies similar to that which had occurred in the latter part of the previous month. Blocking over Davis Strait was particularly strong in the second week of February but during this time northern Ellesmere Island was under the influence of a fairly stationary cold low. About the 19th, however, this low began to retreat westwards from its earlier position over the Arctic Archipelago. The main westerly flow of mid-latitudes, diverted northwards round a high south of Iceland, was thus able to extend its influence still further north. At 0000 Z on February 19 no part of the Alert sounding was warmer than - 30°C. By the 22nd, however, a meridional pattern was well developed over eastern North America and the Atlantic. A cold trough extended southwards across the Canadian Arctic (the 500 mb. temperature at Fort Chimo at 0000 Z was - 44.3°C.) whilst a warm ridge covered Greenland and Ellesmere Island (500 mb. temperature at Alert: - 34.2°C.) The sounding at Alert shows an amazing surface inversion with a rise in temperature of almost 30°C. from - 36.3°C. at the surface (66 m. above sea-level) to - 6.7°C. at 330 m., with a maximum of - 5.0°C. at 690 m. The hodograph shows that the warm air was flowing in between 1000 m. and 3000 m.

Once again the effect on the surface temperature was delayed by the lack of a suitable agent to bring it to the ground. Such clouds as accompanied the warm air were at first unable to raise the temperature much above - 20°F. (- 29°C.) at Alert. Not until late on the 25th did the temperature rise significantly but the pattern of the fluctuations on the 25th and 26th is illuminating. Moderate winds of up to 15 m.p.h. were recorded at each observation from 1500 Z on the 25th until 0600 Z on the 26th and were associated with very low cloud and snow. The temperature rose from about - 30°F. to - 15°F. (- 34°C. to - 26°C.) Following this the sky cleared, the wind dropped and the surface temperature began to fall, The wind then came back with renewed force and the temperature rose from - 17.1°F. (- 27.3°C.) in a calm at 1200 Z to -7.3°F. (- 13.7°C.) with a wind of 23 m.p.h. at 1500 Z and - 8.3°F. (- 13.2°C.) at 35 m.p.h. at 1800 Z. The wind then dropped again and three hours later the temperature was - 20.2°F. (- 29.0°C.) , a remarkable fluctuation and one which demonstrates very well the effect of surface wind in "rolling up" an inversion.

At Lake Hazen the pattern was similar. The minimum for the six hours ending 0600 Z on February 20 was - 61.9°F. (- 52.2°C.); twenty-four hours later the temperature was above freezing mercury and remained so for the rest of the month. The rise to about - 20°F. (- 29°C.) appears to have been due to long-wave radiation from the clouds associated with the warm air. The maximum temperature of - 4.6°F. (- 20.3°C.) occurred briefly at about 0400 Z on the 26th during a 10 m.p.h. wind and between successive 3-hourly readings of -23.6°F. (- 30.9°C.) in a calm of 0300 Z and - 19.6°F. (- 28.7°C.) with a 4 m.p.h. wind at 0600 Z.

The fluctuations during March were rather different in type. Fig. 11 in Part I shows that contrasts between the three stations were at a maximum for much of the month and also that minor fluctuations at Eureka were not recorded at either Alert or Lake Hazen.

Much of the month of March was characterised by a flow of air aloft from the Alaskan area towards Ellesmere Island, frequently between high pressure over the Barren Grounds and a low over the Arctic Ocean. This Alaskan air was fairly warm but the rapid fluctuations in temperature recorded during the month were more directly associated with surface wind speeds than with the strength of the warm advection.

At Eureka there was a rise in temperature from - 39.7°F. (- 39.8°C.) at 0600 Z on the 12th to - 16.4°F. (- 26.9°C.) eighteen hours later. The wind rose to 20 m.p.h. during this period, but it appears that, as at Lake Hazen, only relatively light winds are required to raise the temperature considerably from very low values particularly when, as in the present instance, the wind is associated with an extensive and fairly low layer of cloud.

The other two stations responded differently at this time, during which a small centre of relatively low pressure (1025 mbs. in the centre) was situated to the west of Ellesmere Island. Pressure was very high throughout the North American Arctic at this time. Lake Hazen was practically cloud-free and surface wind was negligible, temperatures remained steadily below − 40°. Alert, although similarly cloud-free, experienced relatively strong winds and the temperature rose to + 10.8°F. (− 11.8°C.)

The rise in temperature later in the month was due to similar causes. From the 20th to the 23rd winds of up to 56 m.p.h. blew fairly steadily at Alert, keeping the surface temperature between − 5°F. and + 11°F. (− 21°C. and − 12°C.) By now the high over the Barren Grounds had moved to the vicinity of Thule; the flow over northern Ellesmere Island was hence generally from the west round this high. Eureka had warm air aloft on the 21st, with a rise from − 34°C. at 500 m. to − 23°C. at 750 m. but the rise in surface temperature took place more slowly with light winds, cloud and precipitation. The much smaller rise at Lake Hazen was entirely due to long-wave radiation from clouds.

In Part I it was suggested that the fall in temperature shown in Fig. 11 represented cooling towards a seasonal minimum and was not due to the advection of colder air. This has been amply proved here; the rise in temperature was not due to the return of the sun to these high latitudes, but to the arrival of synoptic disturbances from outside the region. When the effect of these diminished, the warmth was quickly radiated again.

Turning now from the effect of synoptic disturbances on surface temperature to their relation to precipitation totals, the amount of precipitation measured at Lake Hazen from August 20 1957 to August 10 1958 was 0.98 inches. Of this, 0.59 inches, or 60 per cent, fell in six periods: September 3 (0.12 ins.); September 22 (0.07 ins.); October 2-3 (0.09 ins.); October 18-19 (0.10 ins.); January 29-31 (0.13 ins.) and May 27 (0.08 ins.) The synoptic conditions during the snowfall of late January have already been discussed and the source area has been shown as the Norwegian Sea.

The snowfall of early September, the first of the winter at Lake Hazen, came from moist air moving from the west, associated with the cold front of a low pressure system crossing the Pole. Snow was particularly heavy on the west coast, because of the orographic barrier provided by the central mountains, and Eureka recorded one-quarter of its total precipitation for the 1957-58 period in twenty-four hours.

The snowfall of 0.07 ins.(water equi.) recorded at Lake Hazen on September 22 was of a different origin. A surface depression moved slowly northwards from Hudson Bay and caused frontal precipitation over Ellesmere Island. As in the earlier case, temperature and height data from the soundings at Alert and Eureka are available in the <u>Data Tabulations</u> (17) only for the standard pressure levels, so that it is impossible to follow the sequence of events in detail. The source areas of these significant snowfalls can, however, be adequately determined from successive synoptic maps.

Air moving towards Ellesmere Island from the west was again responsible for the snowfall of early October. The circumpolar westerlies immediately prior to the fall were continuous and strong over a very broad latitudinal area round a low over the Pole itself. By the 2nd this pattern was breaking down, with a large cut-off low forming over Hudson Bay, but by that time air of Alaskan or Pacific origin had reached Ellesmere Island.

This appears to have been the last significant invasion of moist air from the west in 1957. The snowfall of mid-October was derived from the Norwegian Sea, as a deep low developed in the upper air over Thule. Eureka received a slightly smaller fall than Lake Hazen and the hodograph indicates that the moist air only just reached Eureka, whereas substantial warm air advection is indicated by the Alert hodograph for October 19 (Fig. 60). The fall at Alert totalled 0.15 ins. water equivalent, although most of it fell a day or two later than at Lake Hazen.

At the end of May 1958, as air temperatures approached freezing-point, there occurred the last major snowfall of the winter. This was associated with a northward moving front, the upper air pattern again being markedly meridional, with a cold trough over eastern Canada and a warm ridge over Greenland.

It appears from the preceding discussion that in 1957-58 the principal sources of precipitation in early and late winter were frontal disturbances approaching Ellesmere Island from either the west or south, from Alaska or from Baffin Bay. In midwinter, however, these source areas appeared much less important and it has been shown that on several occasions warm and humid air from the east, not associated with frontal disturbances, was responsible for sustained and sometimes appreciable snowfall in the northern part of Ellesmere Island. This seems to be particularly important on the eastern side of the central mountains. Eureka, which in 1957-58 derived little precipitation from this source, was in a favoured location for snowfall from air masses approaching from the west.

These hypotheses have not so far been checked against the longer records at the permanent stations. Such a study would seem to be of value, and might be extended to consider the importance of Baffin Bay lows for the weather of the northern part of the island. Their effects, so marked in the latitude of Thule, appear to diminish rapidly further north. Finally it would be desirable to investigate the most frequent source areas for summer rainfall, which was negligible at Lake Hazen in 1958.

The final feature to be discussed in the present section is the very great contrast in summer precipitation totals between the Lake Hazen station and the camp on the Gilman Glacier, about twenty-five miles to the north and 3400 feet above sea-level. The glacial-meteorological records collected there during the summer of 1958 have been discussed by Sagar[1] (12) and he summarised the difference between the two stations as follows:

> Total precipitation on the Gilman Glacier was far greater than that recorded at Base Camp, comparable figures being 1.32" and 0.17" respectively. Snow accounted for 1.11" of the precipitation on the glacier and for 0.10" at Base Camp. Periods during which precipitation was recorded were the same at both observing stations indicating the influence of similar synoptic conditions. However, days on which precipitation was recorded as measureable or as a trace amount number fifty on the glacier compared to twenty-one at the base camp. (12, p.74.)

This contrast, in the period from May 18 to August 10 1958, is considerable. Precipitation on the glacier was nearly eight times that measured at the base camp and was 134 per cent of the total measured at the latter station in 1957-58. The significance of this summer precipitation for the glacier budget is outside the scope of the present investigation. It does, however, seem necessary to investigate the synoptic conditions giving rise to this precipitation and to attempt to explain why the lake station received so much less.

The greater part of the precipitation on the Gilman Glacier came in six distinct periods: May 11-13 (0.10 ins.); May 29 - June 5 (0.44 ins.); June 23-25 (0.24 ins.); June 30 - July 1 (0.29 ins.); July 3-4 (0.10 ins.) and July 12-16 (0.16 ins.)

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[1] See also a similar discussion of the 1957 records by Lotz (8).

Two falls, May 29 - June 5 and July 12-16, were from frontal disturbances moving north from Baffin Bay. Two more, May 11-13 and July 3-4, were from similar disturbances approaching from the west. On June 23-24 there was a closed low aloft approaching Ellesmere Island from the west, but no sign of a disturbance in the surface pressure field, apart from a trough on the 24th stretching northwards across the Pole from the vicinity of Thule. Synoptic conditions at the end of June and the beginning of July showed a general westerly flow in the lower troposphere, but no sign of a surface disturbance or fronts.

Measurements at the other stations during these periods are shown quantitatively in Table XXIV. Measureable falls at the former stations were so rare, however, that Sagar's comment on the similarity in the dates of precipitation is valid. Alert recorded a considerable fall during the mid-May invasion of westerly air, but otherwise there appears to have been little relationship to conditions on the glacier. The fall at the end of May and the beginning of June was associated with very low stratiform clouds which were not recorded at Lake Hazen and the snow may well have been unrelated to the Baffin Bay low. Eureka measured appreciable falls during two of the westerly invasions, but the disturbances of Baffin Bay origin apparently had a negligible effect.

It thus appears that the icecap and mountains of northern

Ellesmere Island receive a considerable amount of "summer" precipitation which is of orographic origin in the simplest sense. The moist air which rises as it reaches the mountains may be associated with frontal disturbances but these, as the stations in the surrounding lowlands show, would otherwise yield little precipitation. This orographic effect was very apparent at the Lake Hazen station, not only by the presence of such features as lenticular or heavy cumulus clouds over the mountains, but by the frequent observations of snowfall on the Garfield Range when none was recorded on the lower ground.

The discussion of synoptic conditions will be concluded at this point, although it is clear that a number of problems remain. This analysis of the relation of conditions in the free atmosphere to surface weather may, in fact, have raised more questions than it has solved. Those that remain, however, are problems which can only be attacked by a detailed study of the entire record at Alert and Eureka or by a continuing record from Lake Hazen, involving upper-air soundings.

The principal feature of interest has been the surface wind at Lake Hazen. It is apparent from the earlier discussion that the strength, and occasionally even the existence, of wind at the ground at Lake Hazen is of critical importance for the temperature in winter. Yet the main problem, why the surface wind should be so much less than that at Alert or Eureka, remains basically unsolved.

The problem might be simplified considerably if it was known to what height above the ground these relatively calm conditions continue. In this context, it is important to stress that there was little evidence of strong winds on the neighbouring mountains of the Garfield Range, which rise about 2800 feet above the level of Lake Hazen (about 3300 feet above sea-level.) The contrast between the snow-covered hills most of the winter and the stark, black slopes after the mid-January gale was very marked (2, p.16), suggesting that no strong winds, such as were frequent on the coasts, had effected these slopes earlier, and reinforcing the author's belief that the exposure of the station anemometer was satisfactory. It is interesting, and a trifle ironical, that Wilson and Markham have recently shown (96) that the ratio of surface to gradient wind at Alert is low, particularly in winter, and that Alert has a larger proportion of calms than any of the other Joint Weather Stations. The relative strength of the wind at Alert has frequently been used both here and in Part I as a contrast to conditions at Lake Hazen and a comparison with the other stations on the coasts of the Queen Elizabeth Island serves to underline the remarkable conditions at the inland station.

TABLE XXIV

PRECIPITATION ON THE GILMAN GLACIER COMPARED TO OTHER ELLESMERE ISLAND STATIONS, SUMMER 1958

Date	Precipitation (inches)			
	Gilman Glacier	Lake Hazen	Alert	Eureka
May 11-13	0.10	Tr	0.12	0.06
May 29–June 5	0.44	Tr	0.05	Tr
June 23-25	0.24	0.01	0	Tr
June 30–July 1	0.29	0.03	0	0.30
July 3-4	0.10	0.01	0	0.05
July 12-16	0.16	Tr	0	Tr
Totals	1.33	0.05	0.17	0.41

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Figure 56

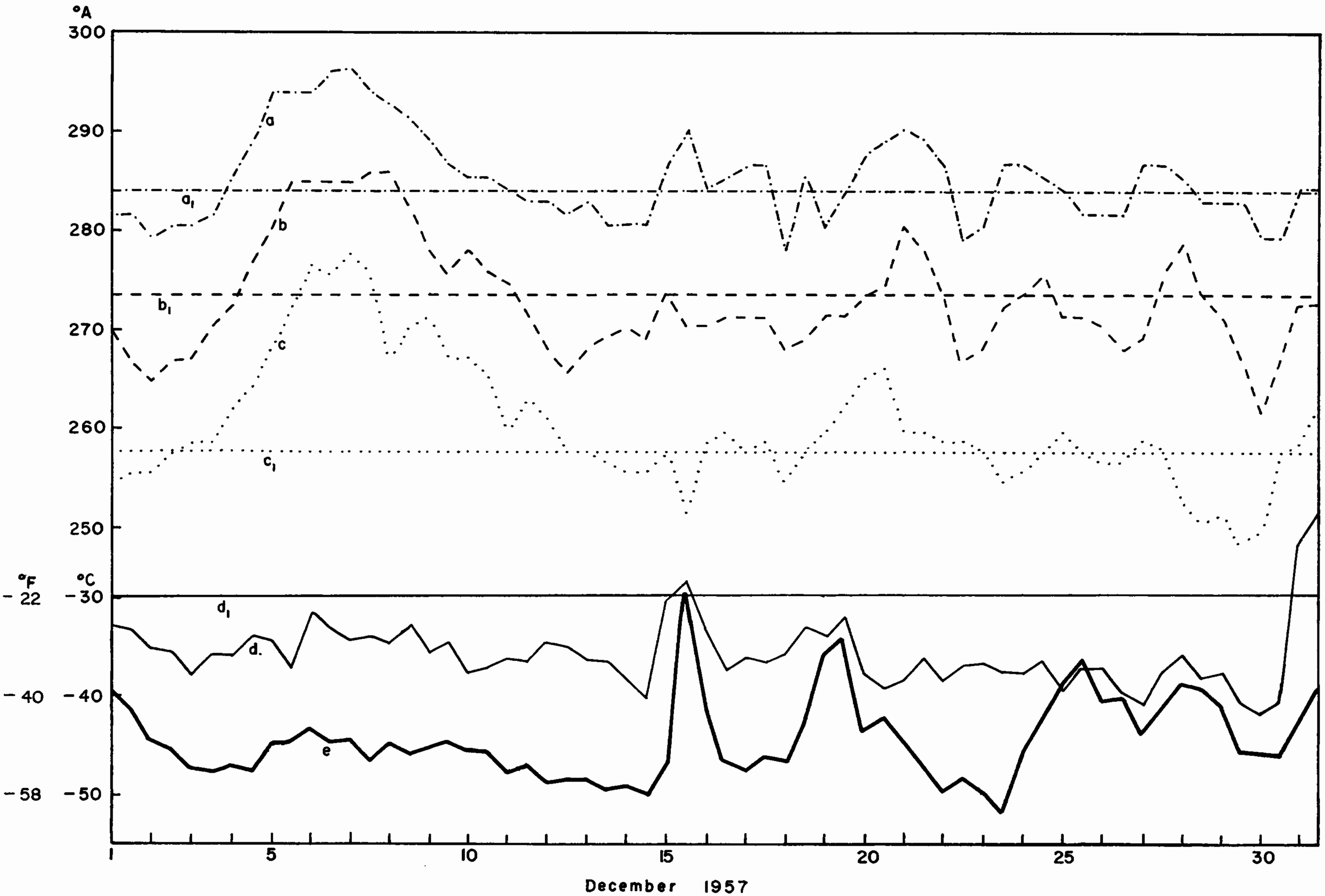
Temperatures below 500 mbs.
December 1957 at Alert.

a, b, c Represent potential temperatures (twice daily soundings) at 500, 700, and 850 mb. surfaces.

d Represents actual surface temperature at Alert.

a_1 - d_1 Are mean values 1950 - 1953.

e Is the surface temperature at Lake Hazen.



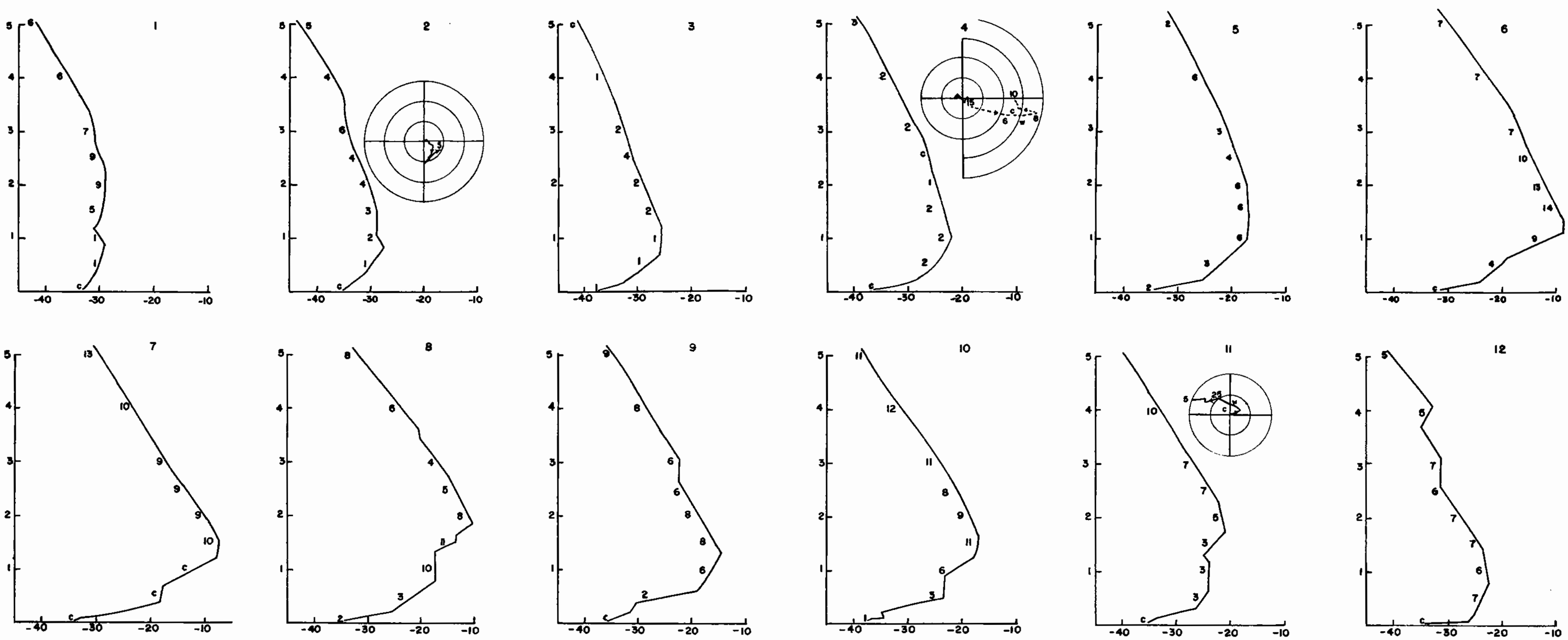
°A
300
290
280
270
260
250
°F
°C
- 22
-30
- 40
-40
- 58
-50
a
a1
b
b1
c
c1
d1
d.
e
1
5
10
15
20
25
30
December 1957

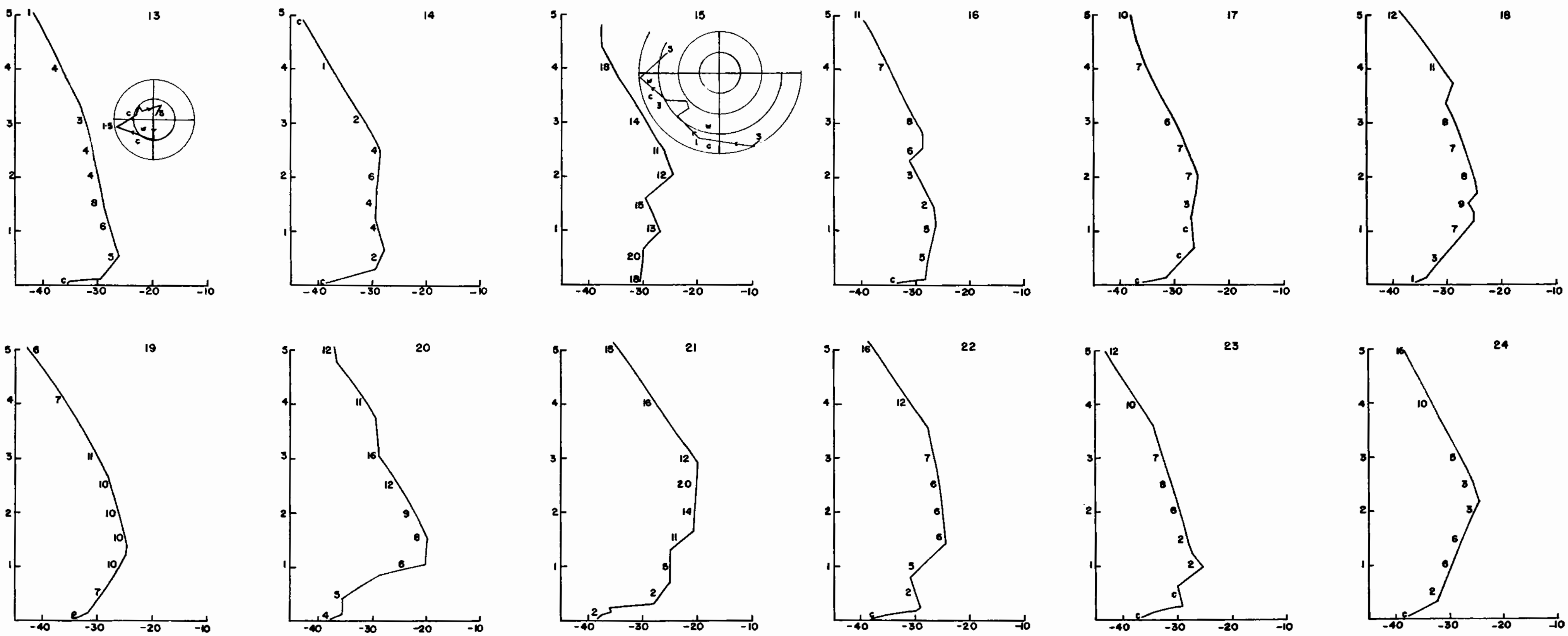
Figure 57

Temperatures and winds below 500 mbs. at 0000 G.M.T., each day, for December 1957 at Alert.

Winds are plotted along the sounding in metres per second.

On hodographs, concentric circles represent wind speeds at intervals of 5 metres per second. The thermal wind vector is drawn at 500 metre intervals to 3 kilometres and 1000 metre intervals to 5 kilometres. Warm and cold sectors are indicated.


1
2
3
4
5
6
7
8
9
10
11
12
-40
-30
-20
-10
1
2
3
4
5


13
14
15
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17
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23
24

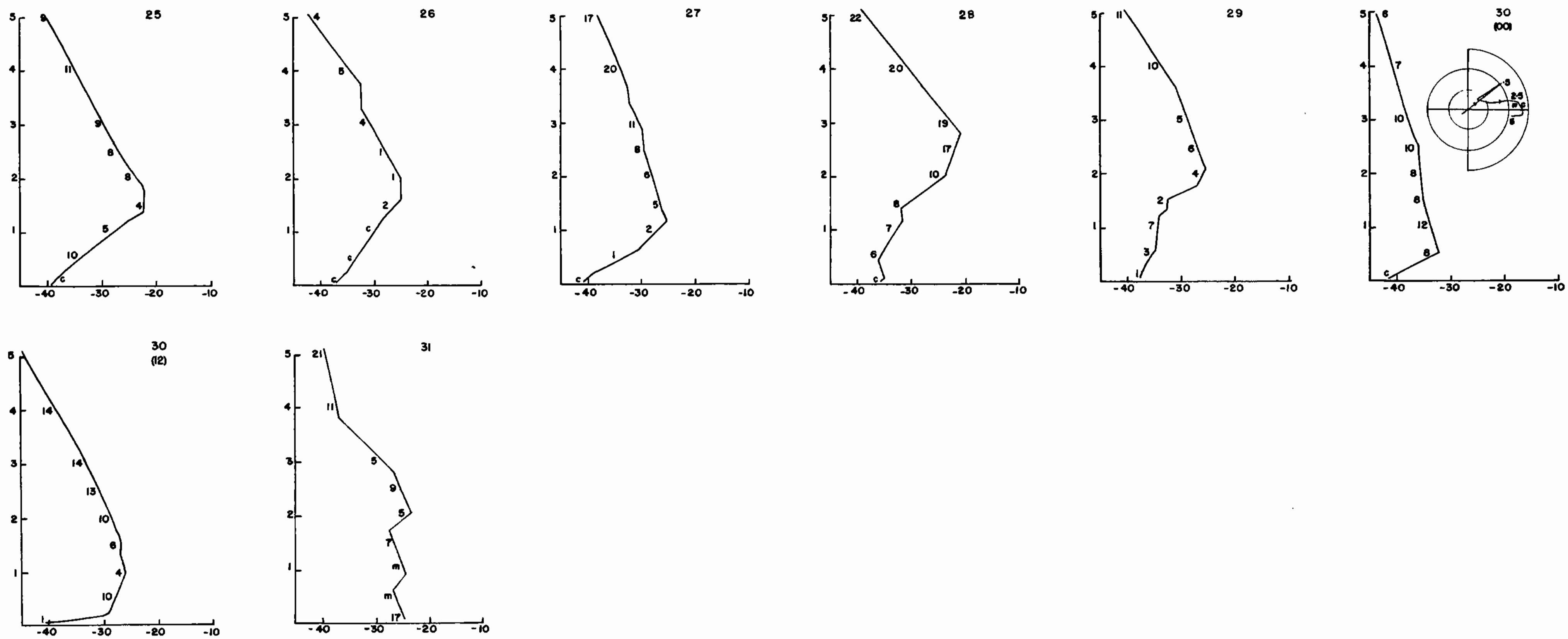
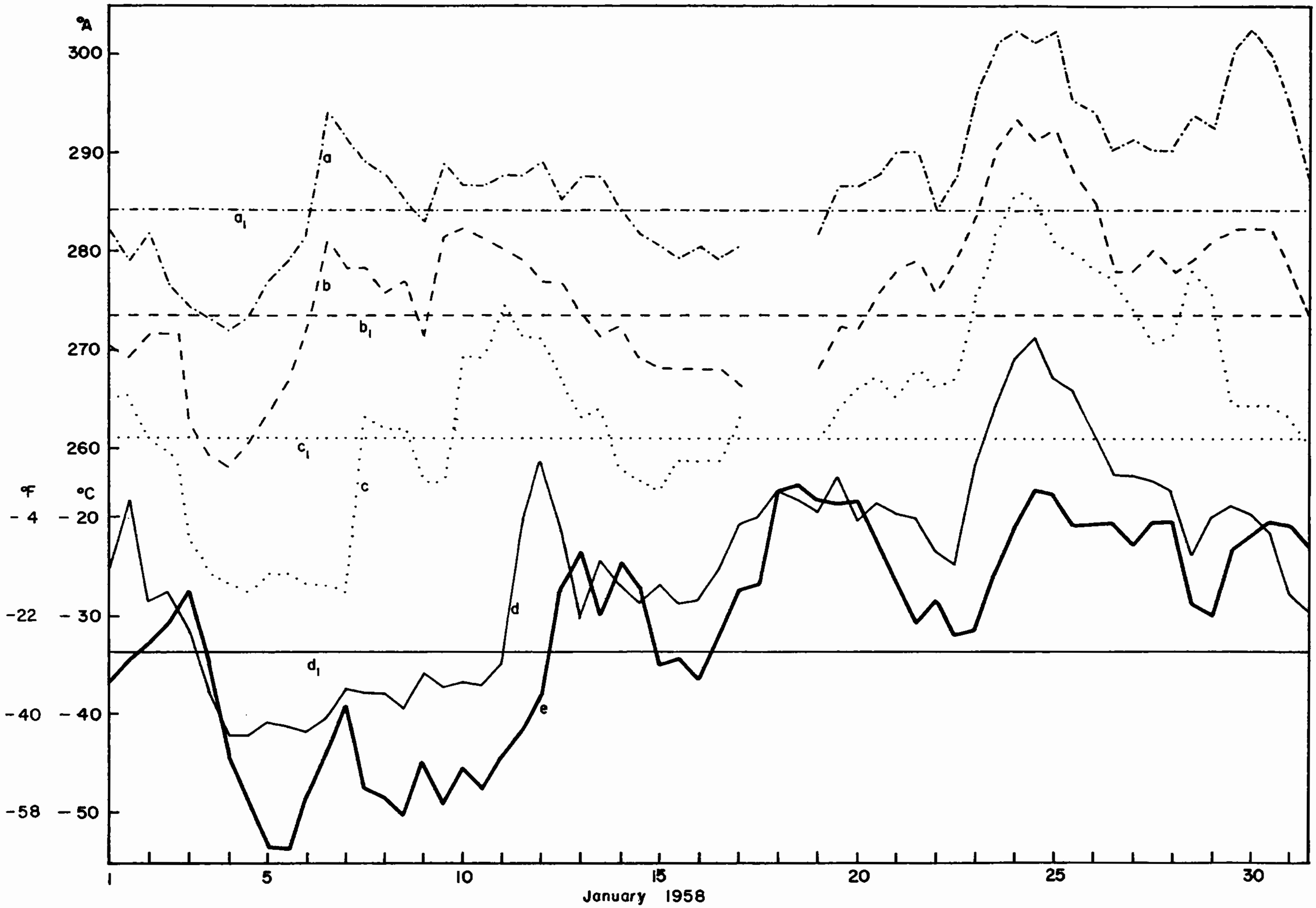

25
26
27
28
29
30
(00)
30
(12)
31

Figure 58

Temperatures below 500 mbs.
January 1958 at Alert.

a, b, c	Represent potential temperatures (twice daily soundings) at 500, 700, and 850 mb. surfaces.
d	Represents actual surface temperature at Alert.
$a_1 - d_1$	Are mean values 1951 - 1953.
e	Is the surface temperature at Lake Hazen.



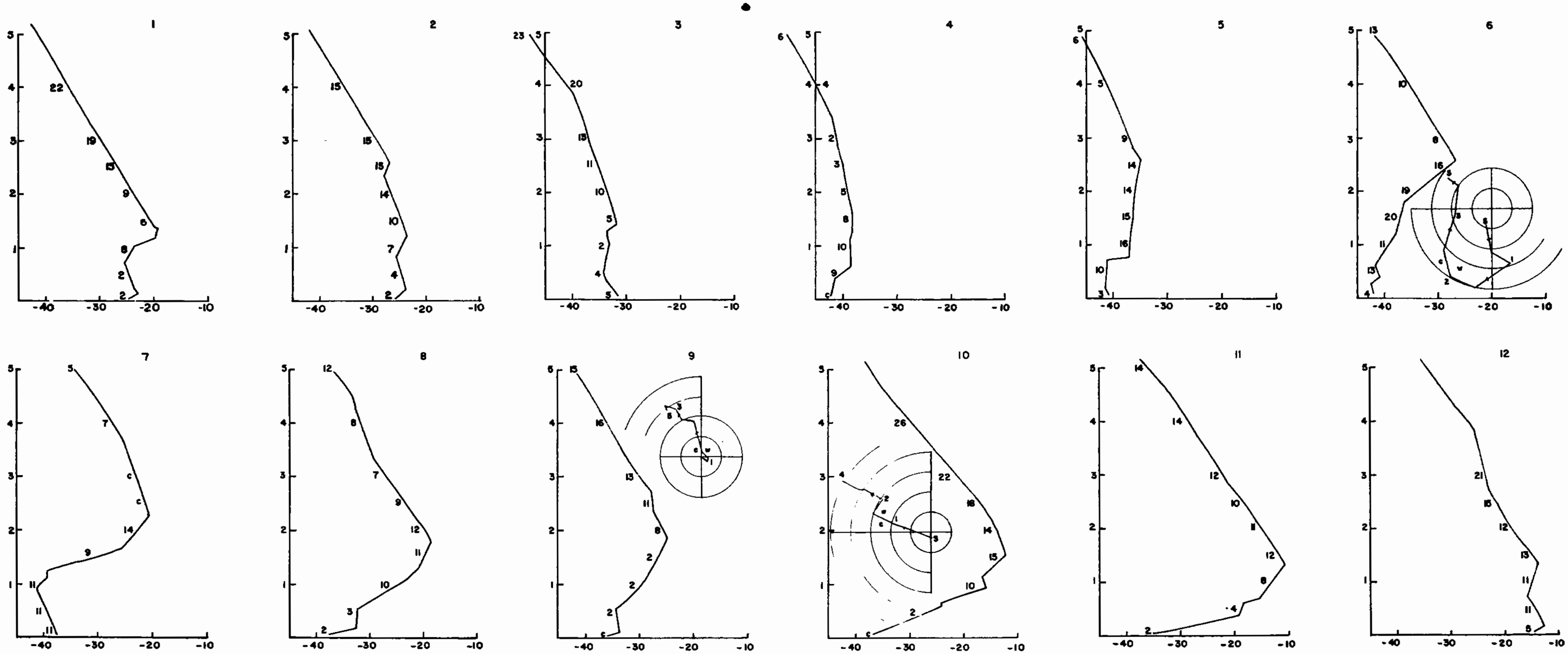
°A
300
290
280
270
260
°F
°C
- 4
- 20
-22
- 30
-40
- 40
-58
- 50
a
a1
b
b1
c
c1
d
d1
e
1
5
10
15
20
25
30
January 1958

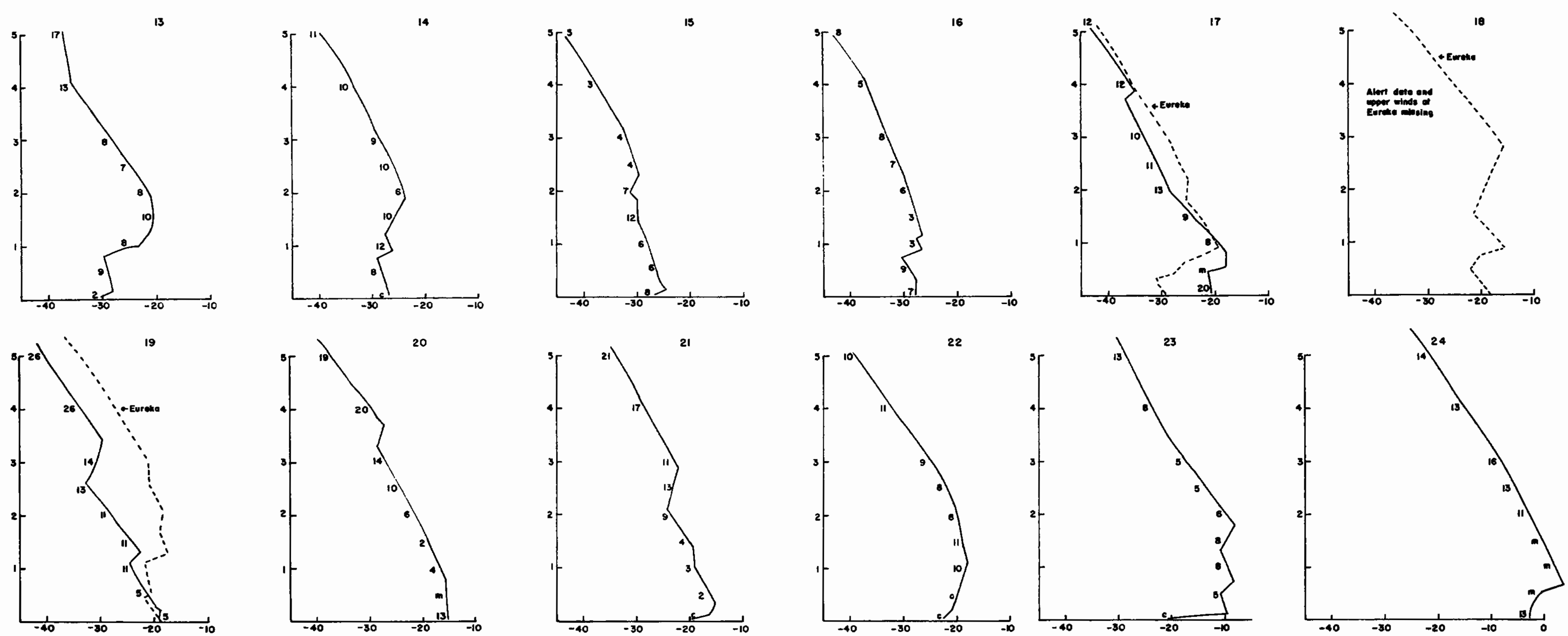
Figure 59

Temperatures and winds below 500 mbs. at 0000 G.M.T., each day, for January 1958 at Alert.

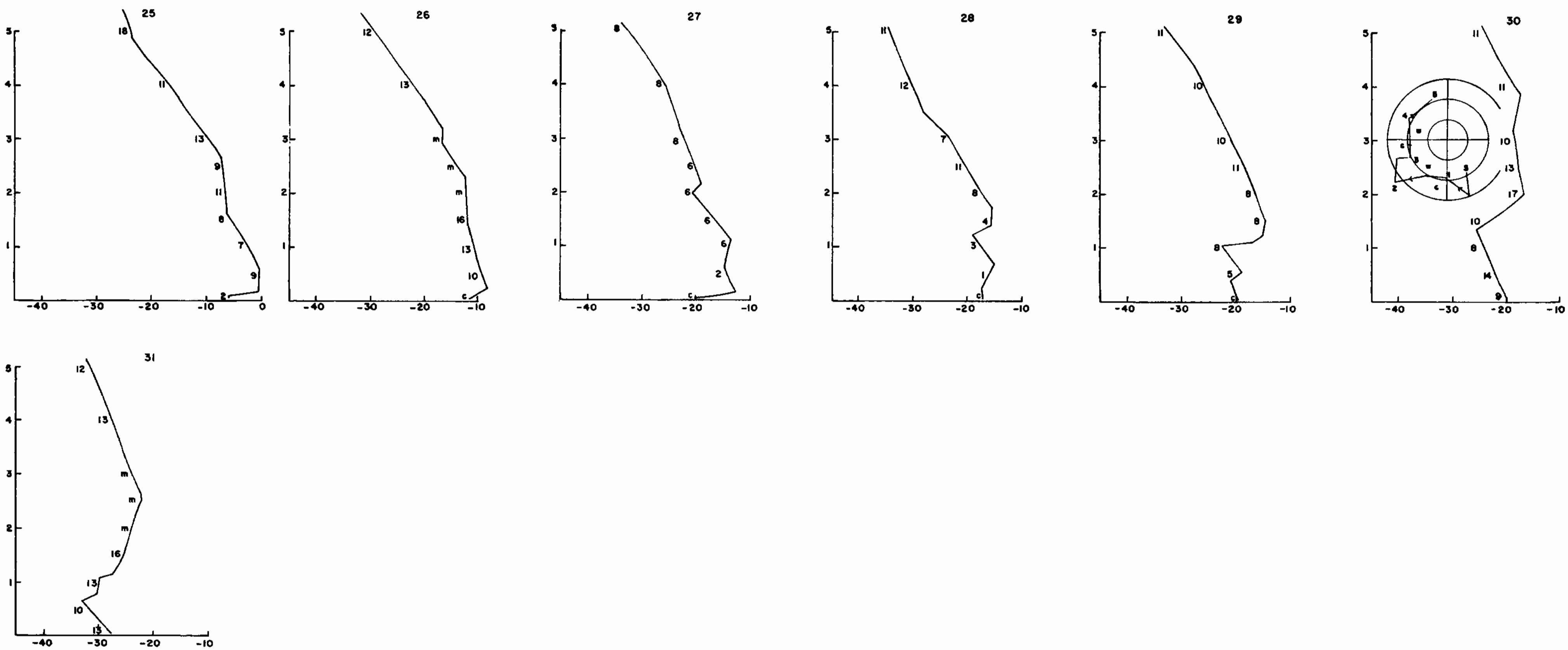
Winds are plotted along the sounding in metres per second.

On hodographs, concentric circles represent wind speeds at intervals of 5 metres per second. The thermal wind vector is drawn at 500 metre intervals to 3 kilometres and 1000 metre intervals to 5 kilometres. Warm and cold sectors are indicated.





13
14
15
16
17
18
19
20
21
22
23
24
← Eureka
Alert data and upper winds of Eureka missing


25
26
27
28
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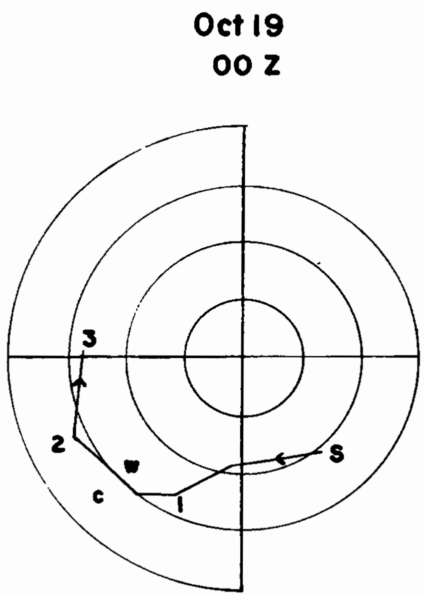
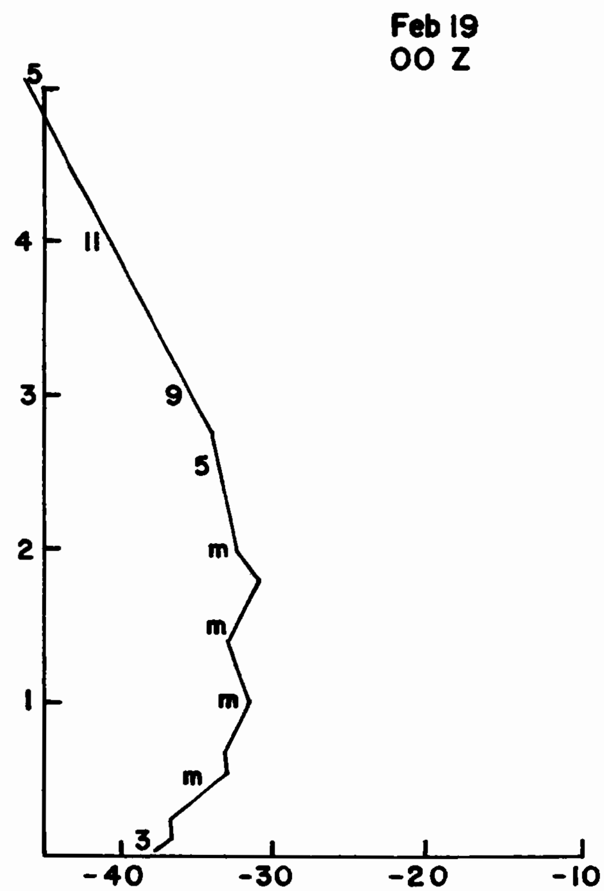
30
31

Figure 60

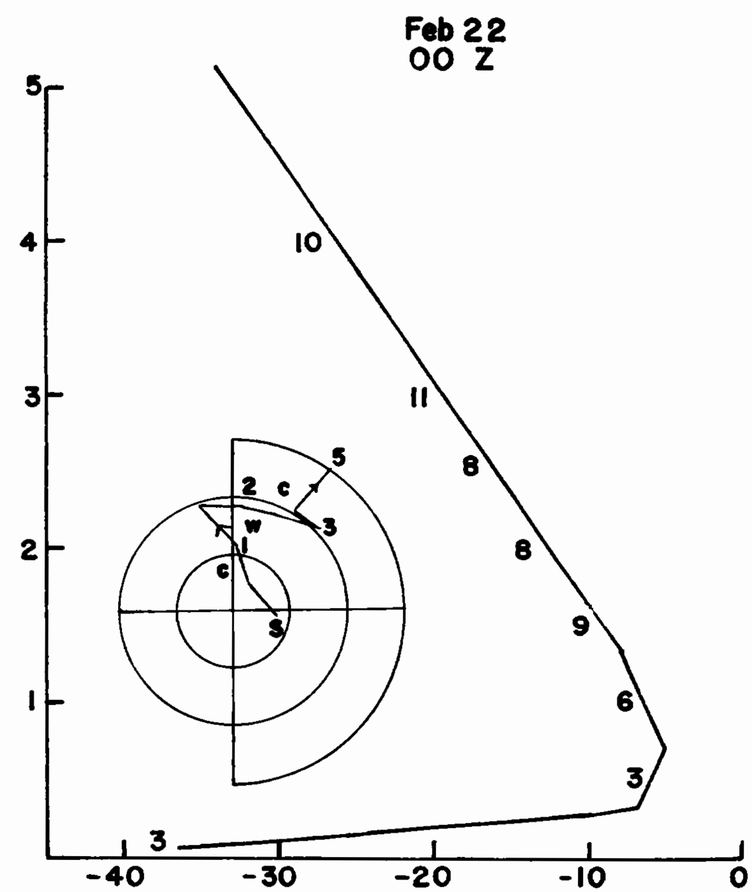
Soundings and hodographs for
Alert 1957-58.



Oct 19
00 Z
3
2
w
c
1
S



Feb 19
00 Z
5
11
9
5
m
m
m
m
3
1
2
3
4
5
-40
-30
-20
-10



Feb 22
00 Z
10
11
8
8
9
6
3
3
5
2
c
w
3
1
c
S
1
2
3
4
5
-40
-30
-20
-10
0

CHAPTER XI

A GUIDE TO LOCAL FORECASTING IN THE LAKE HAZEN AREA

I. INTRODUCTION

Forecasts prepared for specific localitites are usually of two types. Those of the first type are derived by techniques known as "objective" forecasting, in that the preparation of the forecast requires no exercise of judgment by the forecaster, but merely the application of empirical rules to meteorological data. Discussion of such models have been made by Petterssen (12) and Gringorten (9). An example of this technique, cited by Petterssen (12, vol ii, pp. 230-32) concerns the forecasting of occurrence or non-occurrence of ceilings below 600 ft. and/or visibility less than one mile at Andrews Air Force Base, Maryland. The required data for the forecast are the dew-point depression at 850 mbs. and the wind direction at 600 ft. three hours earlier, with other data being added nearer to the time for which the forecast is required. Such techniques have seldom been developed for Arctic areas, except for a few cases in Alaska, but there is some indication that they may be of considerable use for the Joint Weather Stations. The nature of weather changes at the High Arctic stations is such that there is probably already available sufficient data for the development of objective techniques giving a good degree of accuracy.

The second method of preparing local forecasts is by a combination of statistical and synoptic techniques. Here the average results of various synoptic developments: air mass movements, Grosswetterlage, etc. are analysed in the hope that the forecaster can subsequently recognise the appearance of analogous situations and forecast accordingly. A group of such studies was prepared for various Alaskan and mainland Canadian stations by the former Arctic Weather Central of the U.S. Air Force (15).

The present preliminary local forecast study for Lake Hazen fits readily into neither of these groups. Objective techniques may eventually prove helpful, particularly in connection with the problem of the surface wind, but the statistical basis for such techniques requires several years of continuous records. One objective method, however, has already been shown to be of great significance: without Appleman's investigation of the causes and forecasting of ice fogs (1) a very misleading impression of operational weather at Lake Hazen might have been formed from the 1957-58 record.

Nor is the present study at all dependent on the recognition of weather types or the use of synoptic techniques in general. The main reason why such a study is felt to be necessary is that it is believed that the application of standard synoptic techniques may cause major errors in forecasts at Lake Hazen, although the same methods may work quite satisfactorily for Alert and Eureka. The present study attempts to extract from the 1957-58 record those features which are likely to be true of most years, and to arrange them in a form which may be of use to the forecaster. Such a forecaster will, of course, derive more benefit from a single hourly report from the area than from these rules: the latter are prepared on the assumption that regular observations from Lake Hazen are not available.

Fortunately for the present purpose, the site of Lake Hazen affords considerable assistance to such a study. This is elaborated in the discussion which follows, but two examples may be mentioned. On the hemispheric scale, the latitude of northern Ellesmere Island is such that there is a long sunless period and hence a one-way exchange of heat between ground, atmosphere and space under ideal conditions. This produces cooling of the surface and it is possible to suggest dates when specific minima may be expected. This pattern is likely to be interrupted by synoptic disturbances, but the modification of the heat balance by such developments can only take place in certain ways, as were analysed in Part II. On a more local scale, it is difficult to envisage how an open lake of such size, and air temperature of 20°F., could have effects on the local climate different from those of September 1957.

Because the present study is of this type it is inevitable, and perhaps desirable, that the reader who has assimilated the preceding sections will feel that much of this section is repetitive. In some ways this is a summary of the preceding sections; nothing can be suggested as a forecasting aid, in fact, which is not contained in the earlier sections, for they contain virtually all that is known about the weather and climate in the lowlands around Lake Hazen at the present time.

The major omission from this study is that of surface wind. In the discussion of this feature at Lake Hazen in the preceding sections the apparent irrelevance of either the regional pressure gradient or conditions at Alert or Eureka was emphasized sufficiently for it to be impossible to give any suggestions here except that the probability of a flat calm in winter appears to be very great and that winds over ten miles an hour at any season are extremely rare. Perhaps the most useful suggestion that can be made is a warning against forecasting surface wind speeds at Lake Hazen on the basis of conditions elsewhere.

II TEMPERATURE

Winter Minima. The long duration of very cold temperatures in winter at Lake Hazen has received adequate treatment in earlier chapters. In a winter remarkable for the January warmth, a total of 121 days with temperature records below - 40°F. speaks for itself. It is, however, desirable to give some estimates of the approximate dates on which temperatures below various limits can be expected.

As with the other quantities discussed in this section, the problem of forecasting minimum temperatures on the basis of one year's record may appear not only impossible, but also inadvisable. It would be better, it might be argued, to present the evidence for 1957-58 without attempting to make generalisations which could conceivably do more harm than good - "A little learning is a dangerous thing." The justification in the present instance is that it has been fairly conclusively shown in preceding chapters that the winter cold of the Lake Hazen area is of local origin; apart from air drainage from the mountains into the Lake Hazen trough the cold is not brought into the area from outside. Thus if, for example, the temperature reaches - 29.2°F. by October 8, as it did in 1957, this is an expression of the radiational cooling of the snow surface and it is fairly safe to assume that synoptic influences are negligible. It is also safe to assume that when such influences are absent thereafter, the air temperature will drop to at least that level. As it happened, there followed in October 1957 a period of warming which lasted well over a fortnight and caused the daily minimum on the 19th[1] to be only - 3.1°F. However when this period ended it is significant that the temperature dropped very rapidly to a minimum of - 41.8°F. on the 25th. By making allowance for these phases of synoptic activity, therefore, it is possible to suggest from the 1957-58 data when various temperatures are to be expected.

1. 0°F. The date of the first occurrence of this temperature in winter is dependent on the date of freezing of the lake, discussed earlier. A minimum of + 12.0°F. was recorded on September 11 1957, only a week after the first snow-cover, but the temperature did not fall as low as this again until the 24th, the day the lake froze over completely. On the 26th the minimum was still as high as + 12.1°F; by the 28th it was - 10.5°F. and temperatures remained below zero for the rest of the month. Bearing in mind that the date of freezing of the lake was probably later than average, it seems fairly safe to say that temperatures below 0°F. will occur before the end of September, usually in the last week of the month.

The last date on which sub-zero temperatures occurred in 1958 was May 18. It was shown in Part I (and see later in the present section) that once the influence of direct solar radiation becomes

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[1] These dates are the climatological days of the Daily Weather Record: the minimum is for the 24 hours commencing 0000 Z on that date, the maximum for the 24 hours commencing 1200 Z.

appreciable the rise in temperature takes place very steadily (Fig. 11.) The temperature did not fall below + 10°F. after the 21st and it therefore seems likely that temperatures below 0°F. are unlikely to occur after May 20, although they are to be expected at least as late as May 10.

2. - 20°F. The first record of a minimum of - 20°F. in 1957 occurred on October 7. This was immediately after the brief relatively warm spell at the beginning of the month, the minimum on the 3rd being + 8.1°F. and on the 4th + 1.0°F. Thus in other years, particularly if the lake ice has appeared early, a temperature of - 20°F. may occur perhaps a week or so earlier, at the beginning of October. In years when October is characterised by persistent overcast the date may be delayed to about the 10th.

The last temperature below - 20°F. in 1958 was recorded on April 29. This seems to have been rather an early date, as the beginning of May was warmer than periods later in the month, and in individual years it is probable that temperatures of - 20°F. may occur during the first week of May.

3. - 40°F. This temperature, of particular interest where ice fogs are concerned, was first recorded in 1957 on October 25 and this is probably an average date, although mid-October was marked by cloud and precipitation so that - 40°F. may occasionally be recorded a few days earlier when the month is characterised by clear skies. It is interesting to note that the rapid fall in temperature, which continued steadily after the lake froze a month earlier, slowed at

this point and the temperature did not fall to - 50°F. until the second half of November.

As far as ice fogs are concerned, they may occur at temperatures above - 40°F. and are possible earlier in October, but after the 20th conditions may normally be expected to favour their formation. This condition can be expected to continue until the April of the following year. A temperature of - 41.0°F. was recorded on April 21 1958. This, however, is again the period of a rapid increase in temperature and the really acute period for ice fog formation probably ends about April 10.

4. The absolute winter minimum. The minimum of - 68.5°F. recorded at Lake Hazen on January 4 1958 was the coldest temperature recorded in Canada during the 1957-58 winter. Apparently Eureka was the only other station to record - 60°F. or below. This naturally raises questions concerning the probable absolute minimum which might be recorded over a longer period. This has practical implications for such things as fuel oil which, as mentioned in Part I (Chapter IX) tends to separate out at very cold temperatures, even the arctic-type fuel oil used at the Joint Weather Stations being graded cloud point pour point - 60°F.

It was argued in Part I that the principal heat loss from the ground and snow surface has been effected by early December and that thereafter the seasonal fall in temperature takes place slowly and is liable to considerable modification by synoptic events. Thus the coldest temperature in any particular winter may occur any time between mid-December and mid-March, when the rise in altitude of the sun above the horizon begins to affect the surface temperature. A temperature of - 60.2°F. was recorded on December 14 and one of - 57.8°F. as late as April 1.

The author is not prepared to suggest a probable absolute minimum for the area with any degree of certainty. It is conceivable that the presence of relatively warm water below the fairly thin ice cover of the lake may ultimately place a limit on the air temperature nearby which may be somewhat higher than other inland areas. But the duration of the sunless period, the long time, six weeks or so, when the ground is snow-covered before the sun sets in the fall, and the position of the lake at the foot of a mountain range and an icefield are all favourable for intense cold. It seems certain that the temperature would have fallen below - 70°F. but for the synoptic developments which began soon after the - 68.5°F. minimum was recorded. There appear to be few places more favourably located to record a temperature below the North American record of - 81.4°F. measured at Snag Airport in the Yukon in February 1947.

Winter Temperatures of - 20°F. and Above. Throughout the winter there were occasional periods when the temperature rose from - 40°F. or less to - 20°F. or even higher. Sometimes these periods lasted a few days; occasionally they were over in a matter of hours. In the very unusual month of January 1958 temperatures above - 20°F. were recorded throughout the second half of the month. A large proportion of Part II was in fact a study of what causes these fluctuations and the arguments will not be repeated here. It seems important to make clear in this section on forecasting, however, that in midwinter (i.e. when temperatures below - 40°F. are the usual minima) the only agents which can cause a rise in temperature at Lake Hazen are moderate surface winds (6-7 m.p.h. or more) or a cloud cover, particularly when it is relatively low or associated with precipitation. This may seem logical, and even somewhat obvious, but the corollaries are perhaps less apparent. Temperatures of - 20°F. or above should not be forecast in midwinter at Lake Hazen, particularly if data for the station are not available, unless it is fairly certain from current synoptic conditions that either moderate surface winds or a cloud cover exists at that station. As the author believes that at present there is no valid method of forecasting surface wind at Lake Hazen, only a fairly general cloud cover over northern Ellesmere Island can be taken as indicating that relatively warm temperatures at Lake Hazen are probable. It has been shown in earlier sections, and can easily be verified from the records, that winds of gale force at Alert and Eureka, even when associated with strong regional pressure gradients, should not be taken as evidence of moderate or strong winds at Lake Hazen.

If a cloud cover exists, then the temperature at Lake Hazen may be expected to rise slowly and steadily, the ultimate maximum temperature in these conditions probably being about 0°F. but more usually in the range - 15°to - 25°F. Once the sky clears temperatures will fall to low values again very rapidly. Temperature rises caused by turbulent mixing by surface wind will often be quasi-instantaneous if the temperature of the free air is high, but cold conditions will also be restored in a matter of hours when the wind drops.

Summer Temperatures. The maximum daily air temperature at Lake Hazen during the snow-free period appears to be a very conservative quantity and therefore, at least on the evidence of one year's data, relatively easy to forecast in general terms. Nearly half the daily maxima between June 20 and August 8, a period of fifty days, were between 50°F. and 55°F.[1] Within this period the variance (i.e. the square of the standard deviation) of the daily maximum from one day to the next was only 12.158. If this figure is representative of normal conditions then the task of forecasting daily maxima is made very much easier. If observations are available at Lake Hazen, then during the period of high summer the small standard deviation indicates that about two out of three daily maxima will be within three of four degrees Fahrenheit of the value for the previous day and almost all values will be within six or eight degrees. If observations are not available at Lake Hazen, then a forecast that the maximum will be within the range 50 to 55 degrees will have about an even chance of being correct.

That values for 1958 are fairly representative of normal years is suggested by a comparison with Eureka. It was shown in Part I

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[1] Not between June 1 and August 10, as stated in Part 1.

that on only four occasions from June 1 to August 10 1958 was the daily maximum on a particular day more than 5°F. higher or lower than that of the previous day, compared to twenty-one such occasions at Eureka. Examination of the same period in other years at Eureka (4) suggests that this total of 21 days in unusually high: that the summer of 1958 was characterised by larger temperature fluctuations than normal. The values for 1948 to 1955 inclusive are respectively 18, 15, 17, 10, 15, 2 and 10.

The task of forecasting summer minima is even easier. In the same fifty-day period, forty-one of the daily minima were between 35° and 40°F. The variance was only 5.634 (Part I, Table X.)[1]

Equal in importance to the actual daily minimum is the frequency of sub-freezing temperatures in summer. Here we are concerned only with temperatures as recorded in the Stevenson screen; the length of the frost-free season at ground-level is being discussed by Powell (13). In 1958 the minimum temperature rose above freezing-point for the first time on June 13; it did not fall below freezing again before records ended on August 10, although the temperature fell to 32.3°F. on the morning of July 7 during a short snowfall. The same was true of 1957 according to the advance party: the minimum temperature rose above freezing on June 12 and freezing temperatures were not recorded again until the latter part of August (5).

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[1] It should be noted that, although we are not here concerned with local forecasting at Alert and Eureka, the values of variance in these periods at these stations were similarly low, particularly at Alert where, however, daily minima were usually closer to freezing-point.

<u>The Spring Warming</u>. The author's attention has recently been drawn (by T. A. Harwood) to a note by Douglas, who as long ago as 1936 argued that on a horizontal snow surface in fine weather the incoming and outgoing radiation totals balance when the angle of incidence of the sun's rays is 25° (7, pp. 535-36.) This is of interest in the present context, as the theory was used by the Defence Research Board to decide the dates on which the summer parties should arrive at Lake Hazen in 1957 and 1958, in both cases with remarkable success.

The sun reaches an altitude of 25° at noon at latitude 80°N. about May 1 (11, Table 170, page 505). In 1958 the last temperature below - 40 F. was recorded on April 21, below - 30°F. on the 28th, below -20°F. a day later and below - 10°F. on May 1. Similar conditions were experienced in 1957.

If this rise in temperature is associated with a critical altitude of 25° of the sun, then this rapid spring warming may be expected to occur every year at about this time. Expressed another way, May 1 is the earliest date on which Lake Hazen is likely to be free of persistent very low temperatures; the first few nights in the month may be cold, but generally conditions should be very different to those of a week or two earlier.

It is always possible, of course, that synoptic disturbances may be affecting the area at this time, and overcast skies would modify this warming trend. While, however, they may prevent direct isolation from reaching the ground, they also "blanket" radiation from the snow surface and are themselves sources of long wave radiation. Very cold temperatures are therefore unlikely after May 1, whatever the state of the sky.

III CEILINGS AND VISIBILITIES

Frequency of Low Ceilings in the Fall. The greatest drawback to aircraft operation in the Lake Hazen area during the fall is the frequency of low cloud ceilings, particularly associated with the presence of an extensive area of open water in the lake itself. Conditions were summarised by the present author in a brief account of the weather from late August to the end of October, written at the station:

> (4). The most notable feature of the climate was the influence of the lake itself. It remained free of ice until late in September and up to that time had 2 important effects -
>
> (a) The relatively warm water (after the land had been snow-covered) maintained fairly warm temperatures in the surrounding air - the daily maximum temperature did not fall below 20°F. until September 24. Once the lake had frozen however there was a rapid change - the daily temperature falling 25° in 5 days, after which it recovered somewhat.
>
> (b) Until the freeze over, the lake and its surrounding area was enveloped by a localized area of low cloud - usually stratus or strato-cumulus. This has been the most significant and local climatic feature (3, p.8.)

To this general description the author would only wish to add a few quantitative details. The localised nature of the phenomenon appears to be certain: Fig. 2 in Part I was reproduced from a colour photograph of very low stratus cloud which appeared to end at the lake shore. This was, of course, exceptional;

the cloud generally extended over the whole of the Lake Hazen trough as far as could be seen from the station, but on several occasions the sun was observed shining on ground on the horizon in various directions, indicating that the overcast was controlled by and limited to the vicinity of Lake Hazen.

Forecasting cloud conditions at Lake Hazen in this period is thus the reverse of what is normal: for most of the year it is usually the case that low ceilings on the coasts are absent at the inland site. Fig. 61 shows the variation of daily cloud amount, based on the mean of eight observations each day, at Alert, Eureka and Lake Hazen. Totals, it will be seen, are generally high at all three stations, and the reason is qualitatively the same for all. On the coast the influence of the warm lake water is replaced by that of the sea which is either open or covered by a thin ice cover at this time. It will be noticed, however, that both Alert and Eureka had occasional periods of fine weather during late August and September which did not occur at Lake Hazen. Cloud amounts at the inland station averaged over five-tenths every day for more than a month.

The fluctuations at Eureka are interesting because the station site has several similarities to the I.G.Y. base at Lake Hazen. Both are very close to extensive water bodies and it might be expected that Eureka would show a similar regime to the inland site. It was shown in Part I that this is in fact the case as far as temperature is concerned: the fall in ten-day running mean temperatures (Fig. 11) was delayed at both Eureka and Lake Hazen until Slidre Fiord froze over on September 14 and Lake Hazen about September 24 1957. The reason for the occasional clear days at Eureka appears to be that the low stratus was blown away by the moderate or strong winds which were common throughout the month - the clear day on the 8th appears to have been related to moderate west winds whilst the low stratus of the day or two preceding and succeeding was associated with winds having an easterly or northerly component.

These winds cannot, of course, disperse overcast above a certain height above the ground, but it is with this relatively low cloud which is a direct result of the presence of open water that we are concerned and it seems fairly certain that its persistence at Lake Hazen is due to the absence of all but light winds. The records of ceilings at various heights from the commencement of records on August 21 until the end of September are summarised in Table XXV.

The data in Table XXV are the same as those used in the preparation of the "Monthly Summaries of Operational Weather" (Part I, Figs 38 to 50.) Here it can be seen that ceilings up to 3500 feet above the station account for almost half (45.4 per cent) of all observations in this period. As the Garfield Range rises to about 3000 ft. above the lake, and the United States Range further west is considerably higher, the significance of this low cloud can readily be appreciated. Approaching the Lake Hazen area by air at this time is therefore likely to be difficult: the approach from the east (Cape Baird) is probably the most satisfactory.

TABLE XXV

FREQUENCY OF CEILINGS DURING LATE AUGUST AND SEPTEMBER 1957

(defined as six-tenths or more of sky obscured)

Height of Ceiling	Number of 3-hourly Observations	Per Cent
Below 1000 ft.	34	10.5
1000-2000 ft.	43	13.3
2100-3500 ft.	70	21.6
3600-5000 ft.	40	12.3
Above 5000 ft.	65	20.1
No Ceiling	72	22.2

A few suggestions concerning the dates of occurrence and of greatest importance of this local cloud are possible:

1. Cloud amounts greater than are usual in the rest of the year can be expected in Northern Ellesmere Island after the middle of August. This is a general feature, related to the fall of the air temperature towards the freezing-point and the consequent decrease of saturation vapour pressures.

2. The peculiarly local cloud at Lake Hazen, which is generally very much lower than the regional cloud in (1) is probably limited to the period between the first snowfall which gives a continuous cover and the time when the lake has a continuous cover of thin ice.

a. The date of the first continuous snowfall seems likely to occur in the first week of September. The date in 1957 was September 3 and it is significant that the maximum temperature did not rise above freezing after this date. This was one day later than at Eureka, but at Alert there was snow lying throughout the last week of August. If, as seems likely, this similarity in dates between Eureka and Lake Hazen is valid in most years, Table XXVI gives snow cover data for the former station from 1948 until 1955 (the period available at the time of writing in the Monthly Record of observations (4)).

TABLE XXVI

SNOW COVER DATA FOR THE FALL, EUREKA 1948-55

1948.	Trace of snow in August. None measureable until September 12.
1949.	0.13 ins. (water-equivalent) on August 26-27.
1950.	No snow in August; first measureable amount on September 2.
1951.	0.1 inches in August and more on September 2-3.
1952.	0.23 inches on August 28.
1953.	Measureable snow apparently as early as August 23 and possibly before.
1954.	Trace in August. No measureable amount until September 18.
1955.	Trace in August; 0.1 ins. on September 1, then none until September 9.

It is apparent that there is a fairly wide range of dates, significant falls of precipitation being relatively infrequent, but it appears also that a continuous snow-cover will usually have been established by the end of the first week in September.

b. Once the water becomes a relatively warm body, its influence on the cloud cover becomes significant and appears to increase as the air temperature decreases. This continues until the lake is continuously covered by ice. The latter date probably depends on conditions during the previous summer, in determining whether the lake becomes completely ice-free or not. In 1957 the lake was clear of ice by early August (5); in 1958 it seems certain that the lake ice did not completely melt out. According to Deane (6) the reason for this is the absence of strong winds such as had occurred in the summer of 1957: air and water temperatures are apparently not important. 1957 was thus a year in which the low cloud was especially persistent and it is likely that September 24 is a fairly late date for the development of a continuous cover of ice.

Once this cover was established, the low overcast dissipated very rapidly in 1957 and this is to be expected: cloudy conditions may continue, as the first few days of October 1957 were as overcast as the previous month, but the cloud was not related to the lake water and was therefore usually much higher and much less of a hindrance to aviation. Aircraft operations are thus unlikely to be hindered by the presence of this low local cloud before the beginning of September in normal years and it is fairly certainly absent after the beginning of October.

Ceilings and Visibilities - General. For a discussion of the ceiling and visibility combinations experienced in 1957 - 58 the reader is referred to Chapter IX of Part I, and especially to Figs. 38 to 50. There it will be seen that in only three months out of the eleven for which complete records are available was the ceiling and visibility not better than"2500 feet or more with 3 miles or more" for ninety per cent of the time. Of these three months, January was exceptional, although a similar, if not so intense, warming trend in any winter month may be expected to have similar effects. In September 1957 flying weather was the worst of the whole observational period and it has been shown earlier that this is to be expected as an annual feature. Similarly the relatively frequent light snowfalls in October may be expected each year and will thus normally reduce visibility. Although full synoptic observations are not available, it is probable that relatively low ceilings are fairly frequent in late August. Low ceilings and poor visibilities are also to be expected for a short period at the end of May and early June as the temperature approaches freezing point at the surface.

These dates are largely independent of events elsewhere although, for instance, the date and intensity of the poor weather in spring will usually depend on the synoptic situation. There seems, however, to be little justification for the forecasting of low ceilings and poor visibilities at Lake Hazen on the ground that these conditions are existing or expected on the coast. It was shown in Part I. for example, that although the monthly cloud amounts at Alert and Eureka are fairly similar, a comparison of ceiling heights indicates that on many occasions, but particularly in summer, a layer of low clouds may exist along the coast but be absent from the interior.

In particular poor visibilities must not be extrapolated freely from the coast to the interior. In October, and on other occasions when continuous light snow is falling over the northern part of the island, this may be permissible, but many of the very poor visibilities on the coasts in winter are caused by blowing snow in high winds. As these winds are likely to be absent at Lake Hazen, there should be no such restriction on visibility.

White-Out. A recent bibliographical article on white-out by Harker has discussed its causes and significance in the Arctic (10). In particular, quoting from Gerdel and Diamond (8) he lists five different forms of the phenomenon:

(1) Overcast whiteout, caused by a continuous cloud cover.
(2) Water fog whiteout, produced by supercooled water droplets in the air.
(3) Ice fog whiteout, produced by ice crystals suspended in the air.
(4) Blowing-snow whiteout produced by wind-driven, wind-eroded snow.
(5) Precipitation whiteout, produced by falling snow (10, p.225.)

Each of these forms is liable to occur at Lake Hazen, although the author considers that it is inadvisable to use the term "white-out" for so many different restrictions to visibility. Considering the list in reverse order, it has already been shown that even relatively light snowfall is a considerable impediment to visibility. Blowing snow is, however, extremely rare and, although not to be neglected, the usual wind speeds at Lake Hazen are such that blowing snow is a very infrequent hazard.

Completely the reverse is true of ice fog, however, and it is for this reason that an extended discussion of this feature appeared in Part I. For an occasional aircraft, which produced its own ice fog and is therefore usually moving ahead of it, there is little problem. The amount of hydrocarbon nuclei emitted on landing is far less than when the engines are straining for take-off, so that an aircraft may land and take-off shortly afterwards without being unduly impeded. Similarly a small number of ski-equipped aircraft have considerable freedom of movement on the lake and can avoid each others' fog. The main problem is when more than one aircraft has to take off from the same airstrip within a short time; the time required for one aircraft's fog to clear naturally may be several hours in the calm conditions at Lake Hazen.

White-out caused by water droplets is, in the immediate vicinity of Lake Hazen, very restricted in the time of its occurrence. All these forms of white-out only occur when there is snow on the ground: from early September to mid-June. They will not occur during the dark portion of the sunless period:

from the end of November until mid-February. Further they will not occur during that part of September when the lake is open, for the presence of the dark water surface prevents the occurrence of white-out. Of the remaining period, temperatures for much of the time are too low for supercooled water droplets, at least of a size which would severely restrict visibility. Such water-fogs, therefore, are to be expected principally in the months of October and May.

White-outs caused by a continuous cloud cover, which is the usually accepted sense of the term, have been listed for 1957-58 at Lake Hazen in Part I (Table XXIII). Several of these were severe, with an apparently complete reduction of visibility to a few yards, but the total number of occurrences is not large and it is probably not a major problem. Forecasting of white-out at Lake Hazen should not be attempted on the basis of low stratus at Alert or Eureka, for the reasons discussed earlier (p.244); where the observations on the coast are of continuous layers of medium clouds, tending to produce white-outs at the surface, extrapolation to the interior is more justifiable.

IV ICE STRENGTH AND THICKNESS FOR AIRCRAFT OPERATION[1]

The thickness of ice on Lake Hazen is of considerable importance as the lake provides a superb surface for ski landings, and, when cleared of snow, an almost equally good surface for wheeled aircraft. Six different types of aircraft made use of the lake during "Operation Hazen". A C-130A "Hercules" landed on skis on March 29 1958 and a ski-wheeled DC-3 made frequent flights to and from the lake in May. Both of these used unprepared snow strips. C-119's made a number of flights to and from the cleared 5000 ft. strip during the spring, and a "North Star" used it in early June. Finally a float-equipped Piper Super-Cub and a Canso landed on the open water in the summer and fall. It is thus desirable to give some guides to forecasting suitable conditions for these landings, particularly on ice.

The problem consists of two main aspects: the thickness of ice required to support aircraft of varying weights and the speed with which these thicknesses are achieved. Such problems have been discussed by several authors, but notably by Sharp (14) and Assur (2). According to Assur (Supplement No.2), for regular, as opposed to emergency, operation a ski-equipped Dakota requires

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[1] The record of ice depths on Lake Hazen during 1957-58 was obtained by C. R. Harington, who has discussed them in a separate report to the Defence Research Board. This report has not been consulted by the present author.

a minimum of 14 inches of fresh-water ice if the air temperature is below 14°F., a wheeled Dakota 16½ inches and a wheeled C-119 23 inches.

According to Assur, the thickness of ice can be related to the accumulated degree-days below freezing by the formula:

$$h_i = \alpha \times 1.06 \sqrt{S}$$

where h_i = ice thickness in inches

α = a coefficient, considering snow cover, stream flow and other local conditions - 0.65 to 0.75 is suggested for medium-sized lakes with a moderate snow cover

S = Accumulated degree-days since freeze-up (°F. below freezing.)

Applying this formula to conditions at Lake Hazen in 1958, the equation worked fairly well during the first few days of freeze-up, until the end of September. Freeze-up began about September 24 and degree-days until the end of the month were approximately 157, suggesting an ice thickness of 9.3 inches (if the coefficient α is taken as 0.70.) Once formed the lake ice grew rapidly to eight inches by the end of the month. In the following month, however, the equation suggests that the ice should have increased to about 32 inches by the end of the month, whereas Harington measured 10.8 inches minimum and 15 inches maximum on the 29th (3, p.9.)[1] The

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1 Sharp's equation gives a similar error.

reason for this was apparently the snow which fell on the lake ice during October. Measurable precipitation for the month was 0.23 inches and the actual depth at the station increased from 3.4 to 8 inches. Both Sharp and Assur emphasize that snow cover affects the rate of ice formation and the constant in Assur's equation is intended to take this into consideration. However the very small compaction which the snow at Lake Hazen undergoes in the very calm conditions of the site appears to make it a better insulator than is usual and thus retards ice accretion despite the very cold air temperatures.[1]

From Assur's arguments it would thus seem that if the snow can be cleared from an airstrip on the ice as soon as it falls, then the ice will normally be thick enough for a DC-3 landing by mid-October and for a C-119 by the end of the month (actual dates may vary somewhat but if personnel are available to clear the strip they will presumably be able also to obtain and transmit data on actual thicknesses.) If, however, a landing is to be made on the lake with no preparation in the form of previous snow removal, then DC-3 landings should not be attempted until well into November: the thickness of the ice at the end of the month was still only 20 inches. By mid-November, it will be remembered, the sun has been absent for about one month.

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[1] Assur notes that "Methods are available for calculating the effect of snow cover" (2, p.3) but does not elaborate or cite references.

These ice thicknesses obtained by Harington (the depth was 30 inches by the end of December) probably represent a slow rate of development for the lake. It seems unlikely that a heavier fall would slow formation down much further, whereas a smaller fall during October would cause less insulation. 1957, it has been shown, was also probably a year when the lake froze over later than usual.

As far as the final date for aircraft operations on the ice is concerned, the limiting factor is likely to be the air temperature. According to Deane the ice thickness at maximum was 54 to 78 inches, compared to 59 to 61½ inches the previous year - the difference being attributed to the greater irregularities in snow cover in 1958 (6, p.61). In Deane's opinion, although six to ten inches of ice had melted by June 22 "the remainder was still compact and could have supported a DC-3 aircraft." (6, p.62.) In the table of thicknesses for landing selected Canadian aircraft, however, Assur (2, Supplement No 2, p.2) adds the note "In any case, suspend operations if maximum air temperature exceeds 40°F." This is because of the deterioration of the surface by slush or candling. At Lake Hazen a maximum of 41.8°F. was recorded on June 11 and the temperature reached 40°F. on every day thereafter except the 21st. June 11, it may be noted, was the departure date of the last aircraft to use the lake ice, a North Star.

If this 40°F. limit is adopted, as seems desirable particularly if the landing is to be made without detailed knowledge of actual conditions, then landings should not be attempted after June 10-12. The date may be extended a little if allowance is made for the fact that according to Deane, the snow did not melt completely from the lake surface until about June 20 (6, p. 62.)[1] but as a simple guide, if the low ground round the lake is clear of snow except in a few isolated patches, then landings on the lake should be attempted on an emergency basis only.

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[1] The date in the Daily Weather Record is June 16.

REFERENCES FOR PART III

(1) Appleman, Herbert, "The Cause and Forecasting of Ice Fogs", Bulletin of the American Meteorological Society, vol. 34 9, 1953, pp. 397-400.

(2) Assur, Andrew, Airfields on Floating Ice Sheets, for Regular and Emergency Operations, U.S. Army Corps. of Engineers, Snow, Ice and Permafrost Research Establishment, Report No. 36 January 1956 (also Supplement 2, 1956, 3 1956.)

(3) Canada, Defence Research Board, Monthly Reports of McGill University Party at Lake Hazen, Winter 1957-58, Ottawa, 1958.

(4) Canada, Department of Transport, Meteorological Branch, Monthly Record, Meteorological Observations in Canada, Toronto, in progress.

(5) Deane, Roger E., "Pleistocene Geology and Limnology", pp. 19-23 in Canada, Defence Research Board, Operation Hazen, Narrative and Preliminary Reports for the 1957 Season, Hazen 2, Ottawa 1958.

(6) Deane, Roger E., "Pleistocene Geology and Limnology", pp. 61-63 in Hattersley-Smith G, Operation Hazen, Narrative and Preliminary Reports 1957-58, Hazen 4, Canada, Defence Research Board, Ottawa, 1959.

(7) Douglas, C. K. M., "Weather in the Alps", pp. 523-37 (Appendix I) in Seligman, G., Snow Structures and Ski Fields, London, Macmillan & Co., 1936.

(8) Gerdel, R. W. and M. Diamond, White-out in Greenland, U.S. Army, Corps. of Engineers, Snow, Ice and Permafrost Research Establishment, Report No. 21, Wilmette, Ill, 1956.

(9) Gringorten, Irving I., "Methods of Objective Weather Forecasting", pp. 57-92 in Landsberg, H.E., Advances in Geophysics, Vol. 2, New York, Acadamic Press Inc., 1955.

(10) Harker, George S., "Whiteout - A Bibliographical Survey", Bulletin of the American Meteorological Society, vol. 40, 5, 1959, pp. 225-229.

(11) List, R. J., editor, Smithsonian Meteorological Tables, 6th Revised Edition, Washington D.C., Smithsonian Miscellaneous Collections, vol. 114, Publication 4014, 1951.

(12) Petterssen, Sverre, Weather Analysis and Forecasting, New York, McGraw-Hill Book Co. Inc., 1956, 2 vols.

(13) Powell, John M., Climatic Conditions Affecting Vegetation at Lake Hazen, N.W.T., a thesis to be submitted to McGill University, Montreal, in partial fulfilment of the requirements for the degree Master of Science, in preparation. *

(14) Sharp, Robert P., "Suitability of Ice for Aircraft Landings", Transactions of the American Geophysical Union, vol. 28, 1, 1947, pp. 111-19.

(15) U.S.A.F. and U.S.N. Station Forecasting Staffs, Local Forecasting Studies for Selected Alaskan and Canadian Stations, Project 4C-8, U.S. Air Force, Arctic Weather Central, 11th Weather Squadron, Elmendorf Air Force Base, Alaska, 1950.

* This thesis was completed in October, 1959.

Figure 61

Cloud amounts at Lake Hazen, Eureka, and Alert, August to September 1957.

The means of eight daily observations were plotted.

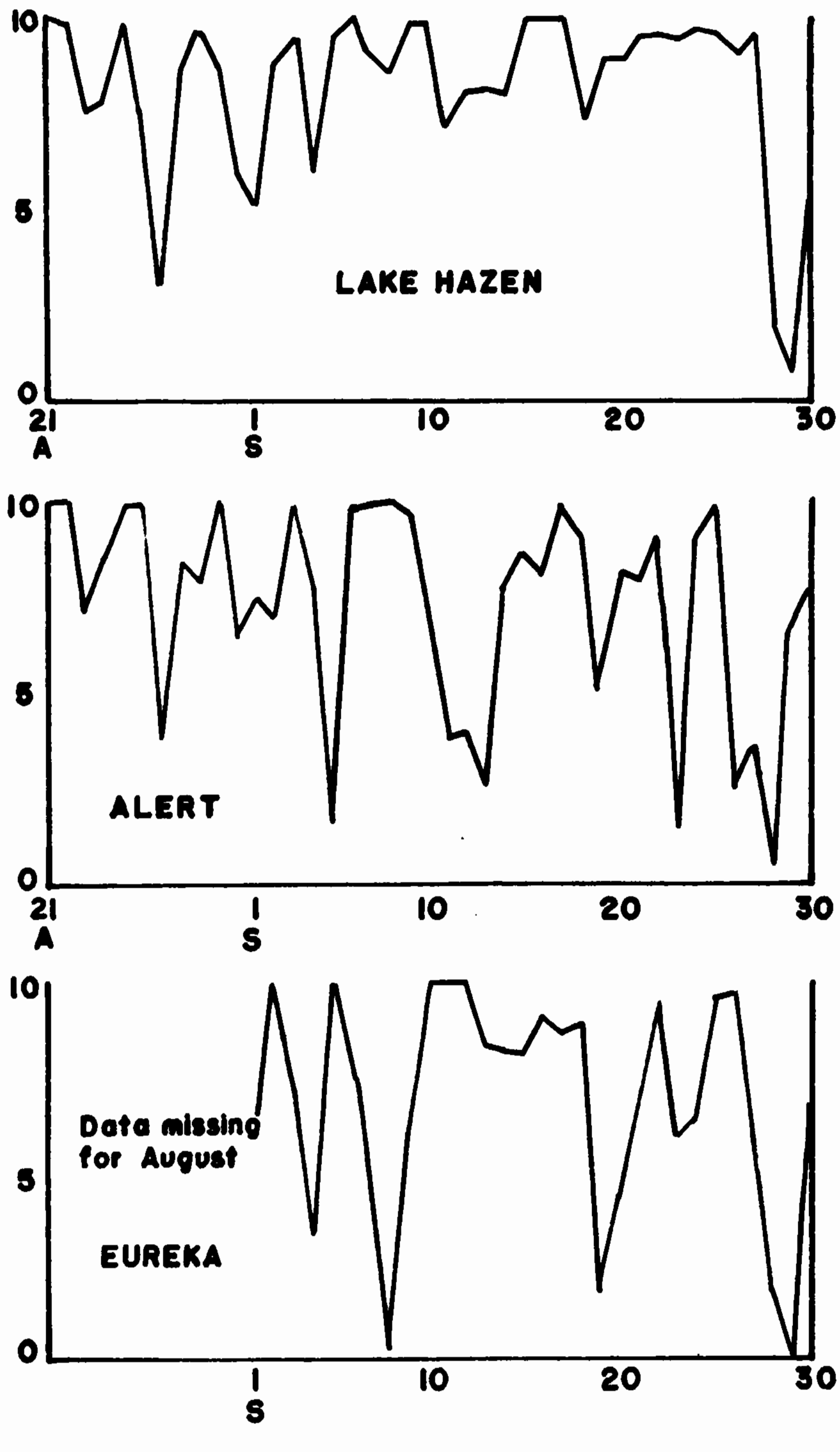

Fig 61. Cloud Amount, Aug-Sep 1957.

Figure 62

Climatological aids to forecasting
at Lake Hazen.

	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY
TEMPERATURE	MAX 47 40 35 MIN 35-40 30-35	Maximum will fall below freezing with first snow cover - about 3rd. Temps. fairly warm till lake freezes, then falling rapidly. Expect 0°F. in last week.	-20°F. sometime between 1st and 10th depending on cloud cover. -40°F. by about 25th, then more stability.	Temperatures from November till the end of March can be expected to be much the same in all months, both in the normals and in the deviations from normal. Daily temperatures below -40°F. are to be expected between the beginning of November and early April; below -50°F. between late November and the end of March; below -60°F. between mid-December and early March. The lower the temperature, the less reliable is this guide. Winter minimum (about -70°F.) may occur mid-December to mid-March. Rises in temperature during this period are associated with either surface wind or cloud/snowfall. Maxima rarely higher than -10°F.					Minima well below -50°F. at start of month; highs of 0°F. or above by end. Considerable day to day fluctuation, but general steady increase in warmth.	Spring warming continues. Little risk of temps. below -10°F. after first week or 0°F. after 20th. Daily maxima close to freezing by end of month.	Above freezing temps. by 10th. Rapid thaw and then maxima usually in mid-40's. Minima seldom below 32°F after melt. V. small day to day variation.	Maxima 50-60° in clear weather, 40-45° in prolonged overcast. Minima practically always above 32° and generally in range 37-42°.
WIND	Winds over 20 m.p.h. may be more common than in any other month and winds generally are strong by L. Hazen standards	As temperature falls winds approach the normal winter values. Winds over 5 m.p.h. only 21% of total in Sept 1957.	From October until at least mid-May, the chances of winds over 5 m.p.h. are very small and winds over 10 m.p.h. are very rare indeed. In normal winter inversions, absolute calms are usual. However, there is some evidence that strong winds are likely once or twice in a winter. They may occur in any month: quantitatively they are of little importance, but their effect in drifting and packing the uncompacted snow is very great.								Calms much less frequent after melt. Mean speed about 3 m.p.h. Winds over 10 m.p.h. still very rare	Much the same as in the previous month, although chance of moderate winds is a little greater.
CEILINGS	Early August continues conditions of July. As temperatures fall, possibility of extensive layers of Sc. etc. increases.	Very low (below 1500') ceilings frequent or continuous much of month due to open lake. Rapid clearance of low cloud after freeze-up.	Occasional very low ceilings of stratus, fog or snow, but more normally at 3-4000 feet or higher.	Throughout the winter months, clouds are usually associated with invasions of warm air and clear skies are usual at other times. Low ceilings, except in snowfall, are virtually unknown.						Gradual change from generally clear winter conditions to more cloudy summer skies.	During high summer, cloud covers 8 to 10 tenths of the sky 35 to 50% of the time. But often thin and almost always medium or high.	
VISIBILITY	Probably good visibility except during periods of rain or snow.	Liable to be impeded by snowfall. Otherwise very good. Danger of white-out after lake freezes. Sun sets for winter about Oct. 16.		Visibilities during sunless period appear to be excellent, except during snowfalls. No apparent reduction during ice prism falls. Visibilities during 1957-58 were under-recorded due to lack of illuminated markers. Almost total darkness mid-November to end of January. Sun returns about March 1.				Normally better than 12 miles from the return of the sun until late summer. Only exceptions are during precipitation. Visibilities below 2 1/2 miles extremely rare.				
ICE FOGS			Possible but not important in first part of month.	Ice fogs to be expected, given a supply of hydrocarbon nuclei, in normal weather conditions from about Oct. 20 to April 10.					Possible until end of month.			
LAKE HAZEN	In good years, lake clear of ice by early Aug. May not clear completely at all in other years. Waves up to 2·5 ft. in strong winds.	Lake remains open up to 3 weeks after air temp. falls below 32°F. After freeze-up, ice grows rapidly at first.	1957-58 → 10-15" 20" 30" 36" 42" 45" Maximum 54-78" Rate of ice development is very slow due to insulating layer of uncompacted snow. According to SIPRE, ice should have been 32 ins. instead of 10-15 ins. by the end of October — this is probably true if the ice had been kept clear of snow.								First air temp. above 40°F. about 10th. Shore leads developed by June 28 1957.	Ice unsafe for J-5 tractor after July 3 1957, for walking after 6th. Space for float-plane operation near base after 26th.

CLIMATOLOGICAL AIDS TO FORECASTING AT LAKE HAZEN

A SUMMARY

(The use of data on lake conditions obtained by C.R. Harington and R.E. Deane is gratefully acknowledged.)

CHAPTER XII

AN ANNOTATED BIBLIOGRAPHY ON THE METEOROLOGY OF ELLESMERE ISLAND

In Chapter I (Part I) the work of the various scientific expeditions of the nineteenth and twentieth centuries was reviewed to show how much, or how little, was known about the meteorology of Ellesmere Island and its vicinity before the present network of joint Canadian and United States weather stations were established. This present section is intended for the assistance of future workers in the same field, to summarise the principal sources of meteorological literature and data concerning Ellesmere Island which are available up to the middle of 1959. It is selective, in that, to a large extent, principal or the most useful sources have been cited and others neglected. Thus, for instance, the "popular" accounts of their respective expeditions written by Nares and Greely - Narrative of a Voyage to the Polar Sea and Three Years of Arctic Service - have been omitted and instead the official reports of these expeditions cited, as it is these which contain the complete meteorological data and their analysis. Similarly there are dozens of articles available on the establishment and operation of the Joint Weather Stations, but most of them are of little interest to the meteorologist.

As an aid to the location of these references, a location has been given and a reference to a major bibliographic entry has been cited, in each case with a few exceptions. The location has been given with preference to Montreal, and a large number of the references will be found there in the library of the Arctic Institute of North America. Similarly, the majority of the bibliographic references are to citations in the _Arctic Bibliography_, and workers in the United States are recommended to refer to that work for nearer locations of the various references.

Key to abbreviations of locations:

A.B. - Arctic Bibliography.

M.A.B. - Meteorological Abstracts and Bibliography.

CaMAI - Arctic Institute of North America, Montreal.

CaMM - Redpath Library of McGill University, Montreal.

DLC - the Library of Congress, Washington, D.C.

DWB - Library of the U.S. Weather Bureau, Washington, D.C.

DN-HO - U.S. Navy, Hydrographic Office, Suitland, Md.

I. BIBLIOGRAPHIES

The student of Arctic meteorology is fortunate in having available two bibliographic sources of the highest standard. They are:

(1) Tremaine, Marie, editor, Arctic Bibliography, Washington, D.C. Government Printing Office, 1953 and later, in progress. (CaMAI).

(2) Rigby, Malcolm, editor, Meteorological Abstracts and Bibliography, Boston, the American Meteorological Society, 1950 and later, in progress. (CaMM).

Each of these is such a valuable source that one cannot be preferred above the other. The Arctic Bibliography, at present in seven volumes and over 40,000 entries is the more comprehensive and therefore may occasionally cite references on the fringes of meteorology which are of use. Its indexing and cross-referencing are excellent. The other bibliography appears as a monthly, the December issue of each year being a full index of material in the other eleven issues, which are themselves individually indexed. Because of its more frequent appearance it is usually more up-to-date than the Arctic Bibliography. Each month from January to November, in addition to current listings, there is a special bibliography on a particular aspect of meteorology and two of these are of particular interest in the present context.

Another short annotated bibliography which may be of use is:

(3) Bonnlander, B. H. and A. D. Belmont, Bibliography on Polar Atmospheric Circulation, Montreal, Arctic Meteorology Research Group, McGill University, 1955. A.B. 38924 (CaMAI).

II. SOURCES OF CURRENT DATA

At present the only permanent weather stations taking regular observations are the joint Canadian-United States stations at Alert and Eureka. Copies of the surface weather records are kept on microfilm at the headquarters of the Canadian Meteorological Service (Department of Transport, Meteorological Branch) in Toronto and of the United States Weather Bureau (Department of Commerce) in Washington. For many purposes, however, the information contained in the following will be sufficient:

(4) United States, Department of Commerce, Weather Bureau, _Synoptic Weather Maps, Daily Series, Part II, Northern Hemisphere Data Tabulations, Daily Bulletin_, Asheville, N.C., in progress.

These daily bulletins, published several months in arrears, contain, for Alert and Eureka, the surface synoptic observations at 1200 G.M.T. and the details of the twice daily upper-air soundings: temperatures and heights of the standard and significant pressure levels, and humidities at the standard levels. They are published in conjunction with, but separately from:

(5) United States, Department of Commerce, Weather Bureau, _Synoptic Weather Maps, Daily Series, Part I, Northern Hemisphere Sea Level and 500 millibar charts_, Asheville, N.C., in progress.

These synoptic maps are probably the best available on a daily basis. The series covering the period of the International Geophysical Year are being delayed to ensure that only checked data are used in their compilation. Other current synoptic map series were discussed in the preface to Part II of the present study.

(6) Canada, Department of Transport, Meteorological Branch, _Monthly Weather Map, Canada_, Toronto, in progress (CaMM).

(7) Canada, Department of Transport, Meteorological Branch, _Monthly Record, Meteorological Observations in Canada_, Toronto, in progress. (CaMAI).

These two publications are complementary to each other. (6) is the earliest general summary to be published, soon after the month to which it refers. Each issue contains comments on temperature and precipitation by province and territory; maps, covering all Canada, of (a) difference from normal mean temperatures and (b) precipitation, and summaries of temperature, precipitation and sunshine records for the principal stations, including all the Joint Weather Stations.

The Monthly Record, published about three years in arrears, gives very complete summaries of the records at the various stations, on a daily basis in contrast to the monthly figures of the Monthly Weather Map. The issue for January in each year gives details of each station: position, altitude, types of observation made, and the authority maintaining the station.

III. GENERAL WORKS ON ARCTIC METEOROLOGY

(8) Kimble, George H. T. and Dorothy Good, editors, Geography of the Northlands, American Geographical Society Special Publication No. 32, New York, American Geographical Society and John Wiley and Sons, 1955. (CaMAI)

See in particular:

Hare, F. K., "Weather and Climate", pp. 55-83. Naturally very generalised, but a good introduction.

Baird, Patrick D., "Canadian Arctic Archipelago", pp. 353-71. Includes (pp. 362-63) a short section on meteorology, particularly interesting because of its suggestion that the regime of Eureka is typical of the interior of the larger low-lying islands.

(9) Rae, R.W., "Canadian Meteorology" in Encyclopaedia Arctica vol. 7, Meteorology and Oceanography, unpublished ms. July 1951 MAB 5, 3-28, (photostat - DWB).

"An excellent treatise on the history of the Canadian weather service (and previous meteorological observations and reports from the earliest days), the Arctic weather stations in Canada and the principal voyages in which Canada or Canadians participated. A detailed list of Arctic weather stations in Canada gives coordinates, elevation, length of record and names of observers. The two polar years (1882-3 and 1932-3) and the joint U.S. and Canadian Arctic network are given special attention. A description with illustrative data of the climate of various parts of the Canadian Arctic is of particular value as it contains data summarized through 1945 or 1950. Biographies of the directors from 1841 to date, a good bibliography and numerous charts add to the value of the report." M.A.B. abstract.

(10) Rae, R.W., "Climate of the Canadian Arctic Archipelago, Canada, Department of Transport, Meteorological Division, Toronto, 1951. A.B. 25333. (CaMAI).

The most useful general reference, although very much on traditional lines.

(11) Thomas, Morley K., Climatological Atlas of Canada, Canada: Department of Transport, Meteorological Division and National Research Council, Division of Building Research, NRC-3151, DBR-41, Ottawa 1953, 255 pp. A.B. 37761. (CaMAI).

A very well-produced and useful atlas which, however, naturally suffers from the lack of data on the Arctic Islands, particularly their interiors.

(12) United States Navy, Technical Assistant to the Chief of Naval Operations for Polar Projects, editor, The Dynamic North, (Op-03A3) n.p., 1956, mimeographed.

See in particular:

Hare, F.K., "Climate of the American Northlands", same item as A.B. 35167, (CaMAI).

Petterssen, Sverre, W.C. Jacobs and B. C. Haynes, "Meteorology of the Arctic" indexed in above but bound separately, (CaMAI).

Both of these monographs are rather unusual, and therefore well worth consulting. Petterssen et al. discuss several topics (esp. optical phenomena) only rarely mentioned in other general works.

IV EXPEDITIONS UP TO 1940

(arranged chronologically)

(13) Great Britain, Parliament, Journals and Proceedings of the Arctic Expedition, 1875-6 under the Command of Capt. Sir George S. Nares, R.N., K.C.B., Sessional Papers, C.1636 1877 Vol. LVI, 484 pp. (CaMAI).

Contains a very detailed account of the day-to day work of the expedition, on the *Alert*, the *Discovery*, and during the sledging trips. Is particularly valuable for the details of the winter in Discovery Harbour, which are difficult to obtain in other sources.

(14) Greely, Adolphus W., Report on the Proceedings of the Expedition to Lady Franklin Bay, Grinnel Land, Washington, 1888, 2 vols.

Although the same author's Three Years of Arctic Service is a more familiar source for this amazing expedition, the Report contains much more of scientific interest and cannot be neglected in favour of the other. The same is true of Nares' book Narrative of a Voyage to the Polar Sea which, though containing, like Three Years of Arctic Service, climatological summaries etc., has none of the detail contained in the Parliamentary Papers.

(15) Simmons, Hermann G., "Summary of the Meteorological Observations", Appendix IV, pp. 484-94 in Sverdrup, Otto, New Land, Four Years in the Arctic Regions, New York and London, Longmans Green & Co., 2 vols., 1904. (CaMAI).

Contains brief account of observations taken 1898-1902 at the different winter quarters of the "Fram". The first, Fram Havn 1898-99, was very close to Greely's winter quarters on Cape Sabine. The second, on the south coast, was near the present R.C.M.P. post at Grise Fiord. The latter two were further west on the south coast. Tables of temperature, precipitation, wind and clouds. Sverdrup's narrative contains the usual incidental references to the weather. The meteorological results of the expedition were studied in detail by Mohn, q.v.

(16) Mohn, H., "Meteorology" Vol I, part 4, in Norske videnskaps-akademi i Oslo, Report of the Second Norwegian Arctic Expedition in the Fram 1898-1902, Kristiania, 4 vols, 1907-19. A.B. 12543. (CaMAI).

(17) Cook, Dr. Frederick A., My Attainment of the Pole, New York, Polar Publishing Co., 1911, 604 pp. A.B. 3389. (CaMAI).

pp. 158-192 contain account of his crossing of Ellesmere Island from Bache Peninsula and Cape Sabine to Eureka Sound. Claims air temperatures as low as - 83°F. were recorded in late February.

(18) Peary, Robert E., Nearest the Pole, a narrative of the polar expedition of the Peary Arctic Club in the S.S. Roosevelt 1905-1906, New York, Doubleday, Page & Co., 1907, 411 pp. A.B. 13226. (CaMAI).

Contains meteorological means at Cape Sheridan 1905-1906, p.291.

(19) Macmillan, D.B., Four Years in the White North, New York and London, Harper Bros., 1918, 426 pp. A.B. 10673/4. (CaMAI).

Account of the Crocker Land Expedition 1913-17. Also contains (Appendix II, pp. 333-370) W.E. Ekblaw's account of his visit to Lake Hazen in May 1915. Little but passing references to temperatures etc. although Macmillan claims (p.322) that the expedition accomplished "Extensive work" in meteorology.

(20) Shackleton, Edward A. A., Arctic Journeys, the story of the Oxford University Ellesmere Land Expedition 1934-5, London, Hodder & Stoughton, 1937 (also New York, Farrar & Rinehart 1938). A.B.15799. (CaMAI).

An appendix (6) on "Climate" is similar to that in the article by Humphreys et al. in the Geographical Journal. This is mainly concerned with the winter at Etah. There is, however, a quotation in the narrative from Sergeant Stallworthy's account of the visit to Lake Hazen in early May 1935: "The weather during our stay at Lake Hazen had been on the whole good, but decidedly cold about midnight when the sun was shining in the north. It may be interesting here to note the variations in temperatures, which ranged from - 28° to + 30° Fahrenheit, between midnight and midday." (p.258).

(21) Shackleton, E., "Climate" in Humphreys, Noel, E. Shackleton and A. W. Moore, "Oxford University Ellesmere Land Expedition", Geographical Journal, 87, 5, 1936, pp. 385-443. A.B. 15800. (CaMAI).

Only one or two references to conditions on Ellesmere Island, most of the discussion concerning the winter quarters at Etah, Greenland. Even here they are scanty, as the British Air Ministry had advised them "not to attempt meteorological observations, on the ground that these would be valueless", remarkable advice to give to a wintering party in what is still a little-known area from a scientific standpoint.

(22) Haig-Thomas, David, "Expedition to Ellesmere Island, 1937-38", Geographical Journal, 95, 1940, pp. 265-77. A.B. 6478. (CaMAI).

Few references to weather, except that minimum crossing Ellesmere Island between Bache Peninsula and Eureka Sound in late May - early April (?) 1938 was - 52°F. A similar reference is in the same author's "Tracks in the Snow", London, Hodder & Stoughton, 1939, 292 pp. A.B. 6480.

V EXPEDITIONS SINCE 1940

(not including "Operation Hazen")

(23) Johnson, J. Peter, Jr., Information collected about the Dumbbell Bay and North Ellesmere Island regions of the Canadian Arctic Archipelago, report prepared for Geography 102, Dartmouth College, Hanover, N.H., 1952, 100 pp. A.B. 35485. (CaOGB - microfilm).

"Based on study of the literature and on the writer's observations in the Dumbbell Bay region (82°30' N. 62°05' W.) on northern Ellesmere, while participating in the establishment of the United States - Canadian weather station, Alert in spring and summer 1950. Background for establishment of such Joint Weather Stations is outlined, and a brief history given of exploration of the Ellesmere region. Geology and physiography are briefly described with emphasis on polygonal soil forms seen. Notes on climate, birds, plant life and insects etc., and mammals are given. A list of maps and of photographs (many taken by the author) follows the general, geological and biogeographical bibliographies." A.B. abstract.

(24) Bruggeman, P.F. & J.A. Calder, "Botanical Investigations in Northeast Ellesmere Island, 1951", Canadian Field-Naturalist, 67, 4, 1953, pp. 157-174. A.B. 28341. (CaMAI).

Section on "Climate", pp. 160-61. Note on general weather conditions; summary table of Nares 1875-76, Peary 1905-06 and 1908-09 and Alert 1950-51 records. Mention of thawing and freezing dates of lakes and ponds in area during summer 1951.

(25) Christie, Robert L., Geological Reconnaisance of the North Coast of Ellesmere Island, District of Franklin, Northwest Territories, Canada, Dept. of Mines and Technical Surveys, Geol. Survey of Canada, Paper 56-9, Ottawa 1957, 40 pp. + map. (CaMAI).

Climate pp. 5-6. Makes reference to means at Alert and Eureka and suggests that summer precipitation along north coast of Ellesmere Island would be considerably greater than station records. "Over 7 inches of rain fell during the melt season of 1954, and soft snow 20 to 30 inches deep in the fiords indicates a snowfall unusually great for the Arctic." Also discusses temperatures, wind direction and speed, and visibility in the area of Ward Hunt Island.

(26) Crary, A. P., "Geophysical and Oceanographic Studies" in Hattersley-Smith, G. and other members of the expedition, "Northern Ellesmere Island, 1953 and 1954, Arctic, 8, 1, 1955, pp. 3-36. A.B. 40304. (CaMAI).

Account of expedition to Ward Hunt Island. See also Christie, 1957. In Crary: p.30 "Meteorological data": "Weather observations were made twice daily near local noon and local midnight, during our entire stay. Except during short periods at the edge of the ice shelf, all observations were taken at the base camp. The following were recorded: air temperature, surface pressure, sky condition, visibility, cloud cover, and the direction and strength of the wind. During the period April 24 to September 26.1954 minimum temperatures of - 10°F. and - 3°F. were recorded in early May and late September respectively, and a maximum of 42°F. occurred in late July. The winds were remarkably constant in direction, mainly east or west, with all the heavy storms coming from the west."

(27) Barther, A. J., Report of Hydrographic Office Representative on Cooperative Investigations at Lake Hazen, Ellesmere Island, N.W.T. on 27 April 1955, 6 pp + map, typescript, n.d., n.p.

Report on ice thickness south of John's Island on date specified. Air temperature (" at 1427 R") was 2°F.

(28) Horton, Franklin, W., Report of investigations of snow cover and ice thickness at Lake Hazen and survey of bays and inlets on the east coast of Ellesmere Island, Northwest Territories, Canada, United States Air Force, Northeast Air Command, New York, 1955, 6 pp., mimeographed. A.B. 40429. (DN-HO).

"Notes on first investigation in program to identify and catalog areas in Canadian Arctic Islands and northern Greenland for use as emergency airfields. Personnel of the U.S. Air Force, Army, Navy and Canadian Defence Research Board

carried out aerial survey of southeast Ellesmere (Makinson Inlet to Cadogan Inlet); and landed on Lake Hazen in the northeast (82°N. 70°W.) in a ski-wheel C-47, April 26-27, 1955. At Lake Hazen, ice thickness and snow cover were investigated and water samples taken. Lake will support heaviest types aircraft and no take-off run need be cleared. Probably Makinson Inlet will also support heavy aircraft." A.B. abstract.

VI OPERATION HAZEN

A microfilm copy of the daily weather records (surface observations) maintained at the base camp at Lake Hazen from August 1957 until August 1958 has been deposited at the headquarters of the Canadian Meteorological Service in Toronto. The records from the ice-cap station during the summers of 1957 and 1958 are contained in the references which follow.

The principal discussion of the base camp records is the monograph The Meteorology of Lake Hazen, N.W.T. of which the present bibliography forms the fourth and final part. The first part is being published separately from the other three. Other works by the present author include:

(29) Jackson, C.I., Meteorological Observations in Ellesmere Island during the International Geophysical Year 1957-58, a paper presented to a joint meeting of the American Meteorological Society and the American Geophysical Union, Washington, D.C., May 4-7, 1959, Montreal, mineographed, 1959, 5 pp. (CaMAI).

(30) Jackson, C.I., "Coastal and Inland Weather Contrasts in the Canadian Arctic", to be published in the October 1959 issue of the Journal of Geophysical Research.*

Neither of the above contain material which is not to be found in similar form in The Meteorology of Lake Hazen, N.W.T.

The other sources of meteorological data or discussion from "Operation Hazen" which have appeared up to mid 1959 are as follows:

(31) Canada, Defence Research Board, Operation Hazen, Operational Plan for the Expedition to the Lake Hazen Area, Ellesmere Island, N.W.T. during the International Geophysical Year 1957-58, Ottawa, 1956. (CaMAI).

A short account of the general aims and logistic problems of the expedition, together with several appendices concerning natural conditions, as then known, in the Lake Hazen area, navigability of adjacent waters etc.

(32) Canada, Department of National Defence, Defence Research Board, Operation Hazen, Narrative and Preliminary Reports for the 1957 Season, Ottawa, 1958. (CaMAI).

Short accounts of all aspects of the expedition's work. See especially:

Lotz, James R., "Meteorology", pp. 32-37.

Summary of observations on the Gilman Glacier during the summer.

Lotz, James R., "Meteorological Equipment", pp. 45-52.

Notes on equipment supplied, its suitability, and recommendations for the future.

* Vol. 64, No. 10.

Deane, Roger, E., "Pleistocene Geology and Limnology", pp. 19-23.

Notes on weather at base camp during the summer (p.20).

(33) Hattersley-Smith, G., Narrative and Preliminary Reports 1957-58, Hazen 4, Canada, Department of National Defence Research Board, Ottawa, 1959.

Similar to (32) but dealing with Phases II and III of the expedition.

Short summaries by Lotz and the present author of the meteorological records from the Gilman Glacier and the Base Camp respectively.

(34) Lotz, James Robert, Glacial-Meteorological Observations in Northern Ellesmere Island during Phase I of "Operation Hazen" 1957, a report prepared for the Defence Research Board, Department of National Defence, Ottawa, Ontario, Nov. 1957, mimeographed. (CaMAI).

(35) Lotz, James Robert, Meteorological and Climatological Figures, Phase I "Operation Hazen", Northern Ellesmere Island, N.W.T., May-August, 1957, mimeographed Oct. 1957. Supp. No.1, mimeographed, Nov. 1957. (CaMAI).

The above references are complementary to each other and are bound together in the Arctic Institute Library.

(36) Lotz, James R., Preliminary Report on the Meteorological Equipment used during Phase III of "Operation Hazen", May-August 1958, 8 pages, mimeographed, Oct. 1958. (CaMAI).

(37) Lotz, James R., Meteorological and Climatological Figures, Phase III "Operation Hazen", Northern Ellesmere Island, N.W.T., May-August 1958, 81 pages, mimeographed, October 1958. (CaMAI).

(38) Lotz, James R., "Operation Hazen", Phase III, May-August 1958, Preliminary Report on the Meteorology and Micro-meteorology, Gilman Glacier Camp, 9 pp. Nov. 1958. (CaMAI).

All the above are complementary and are bound together at (CaMAI). See also Sagar.

(39) Sagar, Richard B., Glacial-Meteorological Studies in North Ellesmere Island 1958, a thesis submitted in partial fulfilment of the requirements for the degree Master of Science, McGill University, 1959, typewritten, 181 pages. (CaMM).

This is a more complete analysis than the preliminary reports by Lotz on the observations during the summer of 1958 on the Gilman Glacier.

Also in preparation at the present time is a thesis by John M. Powell entitled The Climatic Factors Affecting Vegetation in the Lake Hazen Area, Ellesmere Island, N.W.T.* This will be submitted to the Faculty of Graduate Studies and Research at McGill University (M.Sc. degree) and, if accepted, will be deposited in the Redpath Library of that university.

VII OTHER IMPORTANT REFERENCES

(40) Canada, Department of Transport, Meteorological Division, Climatological Summary, Alert, N.W.T., Canada, June 1950-December 1953, Toronto, n.d.

The most useful short summary of the Alert records. See also the similar book for Eureka (53).

* This thesis was completed in October, 1959.

(41) Canada, Department of Transport, Meteorological Division, Joint Arctic Weather Stations, Five Year Report 1946-51, Toronto, n.d.

A most valuable account of all aspects of planning and operation of the stations: by far the most useful of all that has been written on the subject. It is regrettable that further reports do not seem to have been published for later periods.

(42) Caswell, John Edwards, Arctic Frontiers: United States explorations in the Far North, Norman, Okla., Univ. of Oklahoma Press, 1956, 232 pp. M.A.B. 9.6-22. (CaMAI).

"Among the Arctic expeditions described in the 13 chapters of this popular book on U.S. explorations are those of the first International Polar Year to Lady Franklin Bay (Ch. VI) and to Point Barrow (Ch. VII), headed by General Greely and Lt. Patrick Henry Ray respectively. The information on these expeditions is unusually detailed and well documented from the point of view of the history of the organization of the Polar Year and the financing and carrying out of the expeditions and a perspective of the scientific results in various fields." - M.A.B. abstract.

(43) Caswell, John E., The Utilization of the Scientific Reports of the United States Arctic Expeditions 1850-1909, Stanford University, Technical Report No. 2, 1951, 304 pp. A.B. 21139. (DLC, Technical Information Div.)

"The developments from the work of arctic expeditions are presented by subject field in a series of essays . . . . . The scientific accomplishments of specific expeditions are recounted in detail . . . . . "SIPRE quoted by A.B.

(44) Corbel, Jean, "La Neige dans les regions hautement polaire (Canada, Groenland) au-dela du 80^{o} latitude nord", Revue de Geographie Alpine, 46, 2, 1958, pp. 343-66. M.A.B. 9.11-43. (CaMAI).

"The only land areas north of 80^{o} N. are Peary Land of N. Greenland and extreme north of Ellesmere Island and north

Axel Heiberg Island. The islands are very mountainous and rugged, and rise to 10,000 ft., whereas Peary Land is much flatter rising only to 6000 ft. Data on climate and snow cover at Eureka, Alert and Isachsen are presented and discussed in comparison with N. Greenland and Siberia. Snow occurs occasionally in winter at - 20° to - 35°C. when inversions due to advection of warmer, moister air occur. Such inversions at Alert are shown on adiabatic-type diagrams or cross sections. In summer, precipitation is more abundant and is fairly uniform, but snow cover is not uniform owing to strong winds. Eureka is driest Arctic station. Snow structure, density, wind glaciers and dunes, effect of turbulence and morphology are discussed and illustrated schematically." - M.A.B. abstract.

Anticipates some of the present author's conclusions on snowfall at low temperatures in the area. Perhaps a tendency to regard Alert as typical of the island, particular erroneous where summer snowfall is concerned: snow is rare inland during the summer except on the mountains, where it is of a different origin to that at Alert on the coast (see Part II of the present study.)

(45) Corbel, Jean, "L'Hiver dans l'Arctique Nord-Americain (de l'Alaska au Groenland)", Revue Canadienne de Geographie, x, 2-3, 1956, pp. 87-96. (CaMAI).

"The designation "Arctic" is applied to regions having more than 300 days of frost a year; in North America this includes a great part of Alaska and Canada and almost the whole of Greenland. "Sub-Arctic" designates regions having 270 to 300 days of frost yearly. The three poles of cold are situated on the Yukon-Alaska border, to the northwest of Ellesmere Island and in the centre of the Greenland ice-cap. The thermal disparity of the Davis Strait and Baffin Bay watersheds is very marked; we even speak of the Greenland Riviera. There are two zones of high humidity, one along the Pacific coast and the other along the Atlantic coast, while a dry zone extends chiefly over the Canadian Arctic archipelago. The most windy regimes are those of central Greenland and coastal Alaska. Finally, we show that it is possible for man to colonise any part of the Arctic." - Author's abstract.

The present author would prefer some other designation of the climatic "Arctic" than that of Corbel: from Table IX (Part I) of the present study it can be seen that it is possible that Lake Hazen, on the basis of 1957-58 data, would not be considered "Arctic" and, making allowance for the lack of August data, Eureka might also be marginal.

(46) Eggleston, Wilfrid, "Canada's Northernmost Island", Canadian Geographical Journal, vol. x, no. 6, 1935, pp. 289-297. A.B. 4371. (CaMAI).

Popular and, as far as meteorology is concerned, inaccurate account of Ellesmere Island. Main interest is photographs of R.C.M.P. posts at Bache peninsula, Kane Basin and Craig Harbour.

(47) Greenaway, K.R., "Experiences with Arctic flying weather", Royal Meteorological Society, Canadian Branch, Publication No. 9, Dec. 1950, 12 pp. mimeographed.

"A general account of the meteorological aspects of flying in the North American Arctic. Following a survey of weather conditions in each season, the important meteorological elements - wind speed, clouds, fog, blowing snow, temperature, turbulence and visibility - are described. Finally, the salient features to be forecast and the difficulties experienced in forecasting flying weather are discussed." - M.A.B.

(48) Lotz, James Robert, Ellesmere Island Ice Shelf Project 1959, An Outline of Meteorological and Micrometeorological Work, Montreal, Feb. 1959, mimeographed, 6 pp. (CaMAI).

Plans for work in the vicinity of Ward Hunt Island during the summer of 1959.

(49) Middleton, W.E.K., "Climate and Weather" in Bethune, W.C., Canada's Eastern Arctic; its history, resources, population and administration, Ottawa, King's Printer, 1934, 166 pp. A.B. 1507. (CaMAI).

Discusses records of weather at various northern stations including the RCMP posts at Craig Harbour and Bache Peninsula.

(50) Rae, R.W., "Joint Arctic Weather Project", Arctic, 4, 1951, pp. 18-26, A.B. 25334. (CaMAI).

An easily accessible and useful reference for the purpose, planning and establishment of the Joint Weather Stations, but the "Five-Year Report" is to be preferred if available.

(51) Simm, Victor, W., "Geographical Aspects of Weather and Climate at Eureka, Northwest Territories", Geographical Bulletin, 10, 1957, pp. 37-53. (CaMAI).

A fairly generalised account of conditions at Eureka: the Climatological Summary will probably be of more interest to the meteorologist or climatologist.

(52) Taylor, Andrew, Geographical Discovery and Exploration in the Queen Elizabeth Islands, Canada, Department of Mines and Technical Surveys, Geographical Branch, Memoir 3, Ottawa, 1955. (CaMAI).

A most valuable guide to the early history of the High Arctic Islands. A very readable account of the various voyages, with maps, their purpose, and achievements. A guide to the sources on the scientific results of the expeditions, together with a very full bibliography, makes this a most useful preliminary reference for any work on the history of scientific discovery in the area.

(53) United States, Department of Commerce, Weather Bureau, Climatological Summary, Eureka, N.W.T., New Orleans, La., 1951, 72 pp. A.B. 32636, (CaMAI).

This, together with the similar book for Alert published by the Canadian service, form the best summaries of the data from the permanent stations: they cover, however, only a relatively few years in each case.

(54) United States Air Force, Military Air Transport Service, Air Weather Service, Notes on Forecasting for Re-Supply Operations to Canadian Arctic Stations, 1951, Technical Report 105-83, 1951, 17 pp. M.A.B. 9.8-36. (DWB).

"Typical weather situations and usual weather developments at the Canadian Arctic locations Resolute Bay, Mould Bay, Isachsen, Eureka Sound and Alert Bay and at Thule on the west coast of Greenland are discussed. Particular attention is paid to special situations affecting flight operations, such as haze, cloud cover, twilight, convective and blocking effects. The study is offered as background information to forecasters assigned to the area." M.A.B. abstract.

(55) Wilson, H.P. and W.E. Markham, A Study of Arctic Surface Winds, Canada, Dept. of Transport, Meteorological Branch, CIR-2923, TEC-251, 13 May 1957, mimeographed, 14 pp. (CaMAI).

"Statistics are presented on surface winds at Resolute, Mould Bay, Isachsen, Alert and Eureka, N.W.T. The relationship between winds at the surface and at 750 metres is studied for Resolute, Eureka and Alert." - Author's abstract.

Finally, mention must be made of the records of weather collected by the posts of the Royal Canadian Mounted Police on Ellesmere Island. The present author is indebted to Mr. C. C. Boughner of the Canadian Meteorological Service for the following information on data available in the library of the Service in Toronto:

> We have observations by the R.C.M.P. at Bache Peninsula January 1931 - July 1932, October 1932 - March 1933, and at Craig Harbour September 1933 - July 1940. These were First-class Stations, listing, twice daily, pressure, temperature, humidity, wind, precipitation, and general weather conditions. The Bache Peninsula record is short and irregular; the Craig Harbour record is fairly complete for the period given. We can find no record of any reports from Kane Basin.

It is difficult to assess the reliability of the data, since there are no data to serve as a check. The stations had barographs, thermographs, and hygrographs. Temperature extremes were taken from maximum and minimum thermometers. Wind measurements were probably estimates. The Craig Harbour records give an impression of being fairly well done, and they were published in official publications.

Two R.C.M.P. posts at Bache Peninsula and Craig Harbour moved to Alexandria Fiord and Grise Fiord respectively. Since the moves, no reports have been received and we possess no records from Alexandria Fiord or Grise Fiord

. . . . .

The position of Craig Harbour given in our Monthly Record of Meteorological Observations at the time appears rather unlikely. Topographic maps of the area would indicate that the position was actually 76°12' N. 81°00' W.