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NAVAL ARCTIC OPERATIONS HANDBOOK

PART I. GENERAL INFORMATION

DEPARTMENT OF THE NAVY

SERIAL NO.

NAVAL ARCTIC OPERATIONS HANDBOOK

PART I. GENERAL INFORMATION

Prepared by the Arctic and Cold Weather Coordinating Committee of the Office of the Chief of Naval Operations

(Revised 1950)

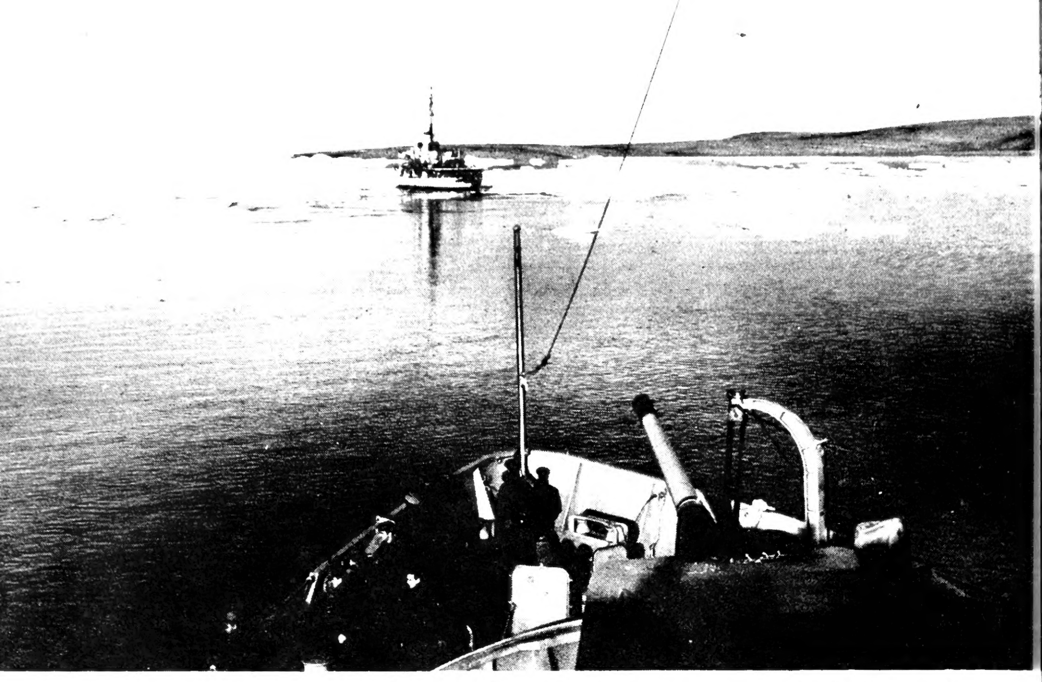
DEPARTMENT OF THE NAVY ★ ★ ★ ★ 1949

GENERAL NOTE

Naval Arctic Operations Handbook is published for the information and guidance of all concerned. It is presented in two volumes, Part I being a compilation of general information, and Part II lessons learned during the conduct of operations in the polar regions and in areas where the extremes of cold weather have been encountered.

It is desired that commanders of task forces, commanding officers, and others in command of operations in the high latitudes submit data and recommendations for incorporation into subsequent editions of the handbook. Thus naval skill in these operations will develop in a continuing and orderly manner.

In time our arctic and cold weather experiences will become doctrine, to the end that polar naval operations can be planned and conducted routinely. Basic doctrines will be included in the proper USF publications at some future date.



Top—Icebreakers at Cape Sheridan, Ellesmere Island, summer of 1948, farthest north 82°34' N., 62°22' W.

Bottom—Central group of TF68 en route Bay of Whales, Antarctica, January 1947, farthest south, 78°30' S., 163°30' W.

W. M. Dunkle

CONTENTS

PART I

PART II

PREFACE

Part I of *Naval Arctic Operations Handbook* is intended to be a source of general information—nature of past and probable future naval operations in the Arctic, geography, climate, and weather, status of various areas in international law, clothing and personal equipment, health, survival, and a selected bibliography as a guide for further reading and study. Appendix A is a discussion of the climate of Antarctica and is included herein for reference when operations are conducted in the ocean areas around the southernmost continent.

The reader will note some repetition of data in the various chapters of Parts I and II. This is not done for emphasis. It has been found desirable in some instances in order to permit a more effective and readable presentation of the subjects of the several chapters involved. Therefore, the handbook will serve as a ready book of reference as well.

Source material for this manual is from notes derived from arctic literature—reports and books of the explorers and polar scientists, operation plans and reports, manuals, hydrographic publications, pilot charts, and ice atlases.

GLOSSARY OF TERMS

This selected glossary is limited to definitions helpful for an understanding of this handbook. More extensive glossaries are included in various Hydrographic Office publications. HO Study No. 103, *A Functional Glossary of Ice Terminology,* has been prepared in order to standardize ice terminology and to provide a convenient means for describing ice features and related characteristics. Refer also to Selected Bibliography, chapter 7, this handbook.

Ablation—Surface removal of ice or snow by evaporation.

Arctic Pack (Polar Pack)—The ice cover of the north polar basin or Arctic Sea (also called Arctic "Ocean").

Barrier—The cliffed edge of shelf ice. (See *Shelf Ice.*)

Bay Ice.—Fast, level ice formed in an embayment.

Belt—A relatively narrow band of sea-ice of any variety.

Berg—A large mass of land ice which has broken away from its parent formation on the coast and either floats in the sea or is stranded on a shoal; a berg is tabular if derived from shelf ice, irregular if derived from glacial ice.

Bergybit—A medium-sized piece or cake of glacier ice, heavy floe, or hummocky pack ice washed clear of snow and floating in the sea.

Beset—Situation of a ship or small craft when so closely surrounded by sea-ice that control is lost.

Big Clearing—A large area of open water, other than a lead, encompassed by fields or floes of pack ice; also polynya.

Bit—A single piece of brash or of ice less than two feet in diameter. Note: compare with *Glacon, Cake, Floe,* and *Block.*

Blizzard—Snow storm in polar regions in which fine snow drifts so high and thick that it is impossible to tell whether sky is clear or clouded.

Block—A small piece of ice ranging in size from 6 to 30 feet across.

Brash—Small ice fragments less than 6 feet across; the wreckage of other forms of sea-ice.

Broken Ice—Sea-ice consisting of scattered cakes and floes covering five-tenths to seven-tenths of the sea surface.

Cake—A term of general meaning used in reference to individual pieces of pack ice.

Calving—The breaking away of ice from its parent berg, glacier, or shelf ice formation.

Channel—Lead (lane).

Close Ice—Ice so closely packed that it covers seven-tenths to nine-tenths of the sea surface and virtually all sea water openings are obscure.

Close Pack—Close ice or pack composed mostly of cakes in contact. (See fig. 11.)

Coast or Coastal Ice (Fast Ice)—A stretch of ice, broken or unbroken, either stranded in shoal water, attached to the shore, or held fast in position of growth in embayments by glaciers or glacier systems.

Conglomerated Ice—Various forms of floating ice compacted into one mass.

Consolidated Pack—An ice area containing the heaviest forms of sea ice and entirely devoid of water spaces.

Crevasse—A rift or fissure in a glacier, shelf ice, or other land-ice formation.

Cul-de-sac—Blind lead.

Deadman—A large timber buried in the ground, snow, or ice to which a mooring line can be attached for securing a ship. (See HO 551.)

Drift Ice—Loose, very open pack where water predominates over ice; floating ice; any ice that has drifted from its place of origin.

Erosion—Destruction of sea-ice by the action of waves and weather.

Fast Ice—See *Coast Ice.*

Field Ice—The largest connected areas of sea-ice, ranging from several to scores of miles wide; also ice field.

Floe—An area of sea-ice consisting of a single unbroken piece of ice or many large consolidated pieces; small floe, 30 to 600 feet across; medium floe, 600 to 3,000 feet across; giant floe, 3,000 feet to 5 or more miles across.

Floeberg—A mass of thick, heavily hummocked sea-ice usually detached from its parent floe.

Frost Smoke—A mist or thick fog rising from sea surface when the relatively warmer water is exposed to an air temperature much below freezing; steam fog; arctic smoke.

Giant Floe—See *Floe.*

Glacier—A massive body of land-formed ice moving slowly down a mountainside or valley.

Glacial (Glacier) Ice—Ice which originates from glaciers.

Glacon—A piece of sea-ice ranging in size from brash to medium floe (6 to 2,000 feet across).

Grease Ice—Slush ice formed from the congelation of ice crystals in the early stages of freezing.

Growler—A small piece of dense glacier ice usually green in color and barely showing above the water.

Growler Ice—An accumulation of growlers.

Heavy Ice—Any pack ice more than 10 feet thick.

Hummocked Ice—Ice piled haphazardly into the form of a short ridge or hillock.

Ice Barrier—See *Barrier.*

Iceberg—See *Berg.*

Ice Blink—A yellowish-white glare on the underside of extensive cloud areas created by light reflected from ice-covered surfaces.

Ice Cap—An ice sheet of vast extent covering the topographic features of a continental land mass.

Ice Field—See *Field.*

Ice Foot—A wall or belt of fast sea-ice formed along a shore not subject to rise and fall of tides.

Ice Sky—See *Ice Blink.*

Land Sky—Dark streaks, patches, or a grayness on the underside of extensive cloud areas due to the absence of reflected light from bare ground.

Lead (Lane)—A long, narrow but navigable water passage in pack ice.

Medium Floe—See *Floe.*

Nipped—As applied to a ship, caught and held tightly by sea-ice under pressure.

Nunatak—An isolated hill or mountain of bare rock rising above the surrounding ice sheet.

Open Water—Sea areas less than one-tenth covered with floating ice.

Pack Ice (The Pack)—Any large area of floating sea-ice driven closely together. (See *Arctic Pack.*)

Pancake Ice—Piece of newly formed sea-ice about 1 to 6 feet in diameter.

Permafrost—Permanently frozen soil, rock or bedrock.

Polar Ice—The thickest and heaviest form of pack ice more than 1 year old.

Polynya—See *Big Clearing.*

Pool—Polynya; sometimes used to mean a depression on ice floes filled with water as result of summer thaw.

Pressure Ice—A general term for ice displaced vertically by pressure resulting from action of wind, tide, temperature change, etc.

Rafted Ice—A type of pressure ice formed by one cake over-riding another.

Ram—A horizontal extension of floe or berg below its waterline.

Rotten Ice—Old ice in an advanced stage of disintegration as result of melting.

Sastrugi—Wavelike ridges of hard snow formed on a level surface by the action of the wind with axes of the ridges at right angles to the prevailing direction of the wind.

Scattered Ice—Ice that covers less than one-half of the sea surface.

Sea Ice—A general term for all forms of ice encountered on the surface of the sea.

Seracs—Ice pinnacles on a glacier.

Shelf Ice—A thick, glacial ice formation extending from the land but attached thereto.

Shore Ice—Synonym of ***Fast*** or ***Coastal Ice.***

Shore Lead—A lead between floating ice and the shore or between floating ice and fast ice.

Sikussaq—Very old ice trapped in fiords.

Slush—A general term for an accumulation of ice crystals which are either only slightly frozen together or separate.

Small Floe—See *Floe.*

Snow Blink—Similar to ice blink except that glare created by light reflected from snow-covered surfaces is white.

Storis—A regional term applied to large pieces of polar ice moving along the coasts of Greenland from the Arctic Sea.

Sky Map—The mirroring of land, snow, or ice in the clouds.

Tracking—Following the edge of pack ice.

Tundra—Stretch of mucky, treeless land covered with a variety of hardy plants, including grasses, lichens, and shrubs.

Water Sky—Dark stretches or patches of grayness on the underside of extensive cloud areas due to the absence of reflected light from open water areas.

Winter Ice—Sea-ice less than 1 year old.

Young Ice—Newly formed ice in the transitional stage of development from ice crust to winter ice.

(Top) Figure 1.—Field of Arctic or polar pack, Kane Basin. (Note pools of thaw water.
(Above) Figure 2.—Ross barrier or shelf ice (background), Bay of Whales.
(Below) Figure 3.—Irregular berg, Davis Strait.

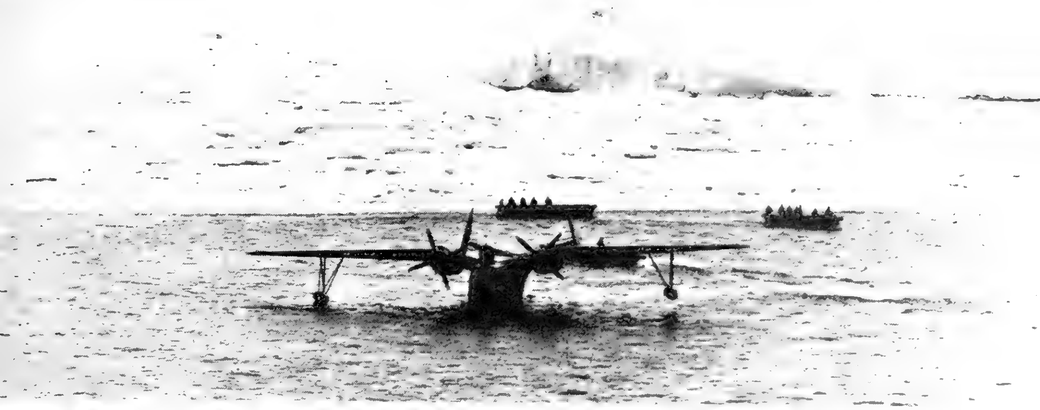
Figure 4.—Icebreaker passes tabular berg, antarctic pack.

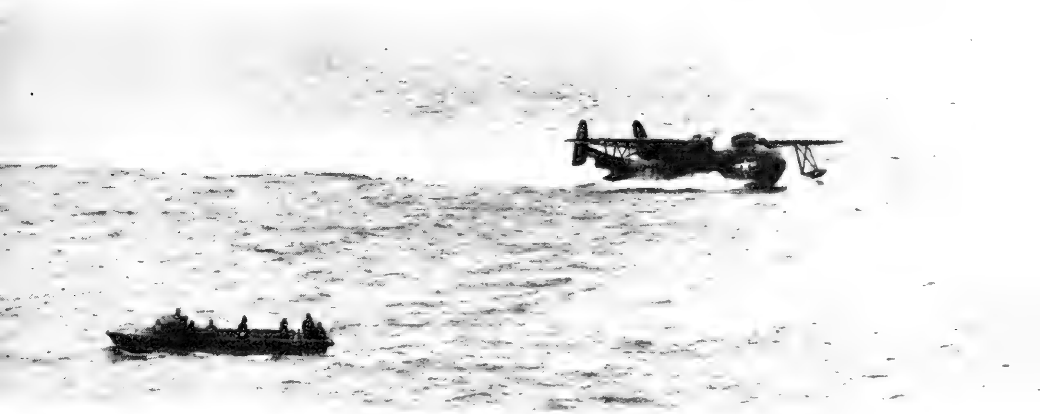
Figure 5.—Ronne's Ship—Port of Beaumont beset in ice, Neny Island Bay, Antarctic

Figure 6.—Central group of TF68 in big clearing or polynya in antarctic pack.

Figure 7.—An AV in broken ice.

(Top) Figure 8.—Glacier calving ice. Cakes of glacial ice in foreground.
(Above) Figure 9.—Icebreaker forming lead or channel in close pack.
(Below) Figure 10.—AKA's moored to fast bay ice, Bay of Whales.





(Top) Figure 11.—An area of consolidated antarctic pack.
(Above) Figure 12.—Drift ice.
(Below) Figure 13.—Glaciers, Devon Island.

Figure 14.—Grease ice.

Figure 15.—Pancake ice.

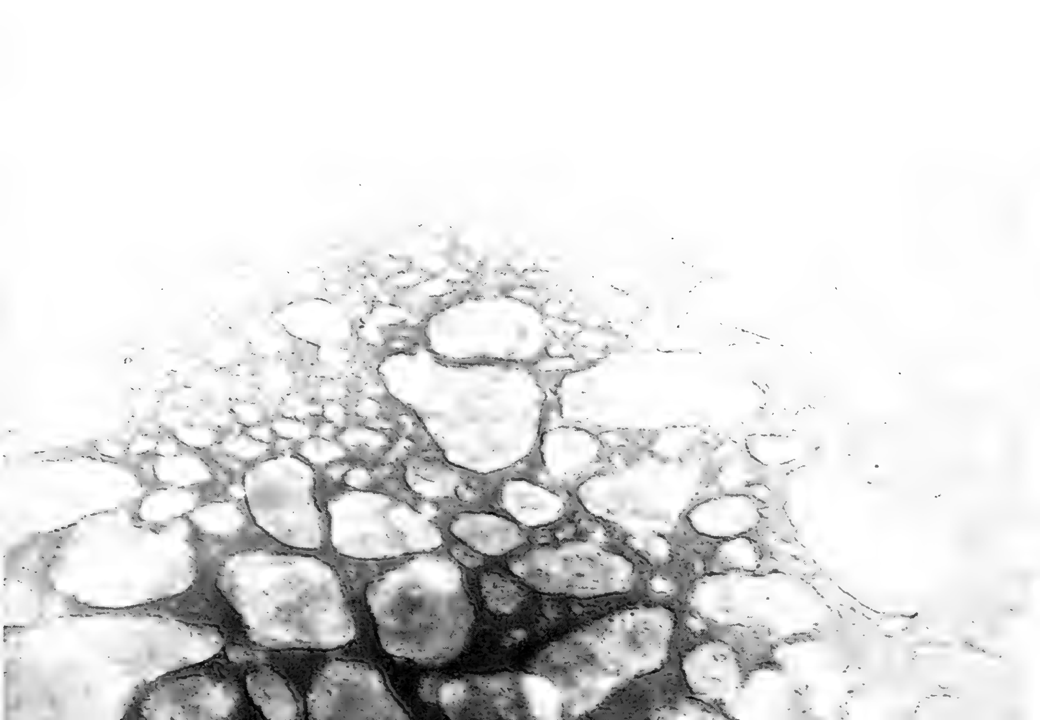


Figure 16.—Rotten scattered ice, Norwegian Bay.

Figure 17.—Scattered ice, Baffin Bay.

CHAPTER I

INTRODUCTION

"Arctic history has suffered from prejudice as well as ignorance—the two greatest hindrances to all progress."—Hayes.

HISTORICAL BACKGROUND

The story of polar exploration and discovery is largely a naval and maritime one. The first recorded voyage to the Arctic was that of Pytheas of Massilia around 330 B. C. From the earliest time through the nineteenth century the emphasis was upon geographic exploration, chiefly the search for the northeast and northwest passages which would be shorter trade routes from Europe to the Orient. Only since the first decade of the twentieth century has the emphasis been shifted to scientific discovery, exploration and exploitation of resources, and strategic development.

The United States Navy has engaged in this work for over a hundred years—since Admiral Wilkes' long journey to East Antarctica in 1839-40. The names of Wilkes, DeLong, De Haven, Kane, Schley, Peary, Byrd—all naval officers—are prominent in the history of the polar regions. Here are listed some of the highlights of these endeavors:

1839–40 —A naval squadron under Lieutenant (later Rear Admiral) Charles Wilkes discovered Wilkes Land of East Antartica and determined the continentality of the south polar region.

1850–51 —Lieutenant De Haven in the *Advance,* which was fitted out at the expense of Henry Grinnell, participated in the search for Sir John Franklin in Lancaster Sound and Wellington Channel, Canadian Arctic Archipelago.

1853–55 —Dr. Elisha Kent Kane led an expedition in the *Advance* to Smith Sound between Northwest Greenland and Ellesmere Island. Kane also established the first scientific station in the Arctic while wintering over. Officers and men of the U. S. Navy demonstrated that the Smith Sound route was the most promising for a dash to the North Pole. At the time, attainment of the pole appeared to be the most important motive for work in the far north.

1871–73 —An expedition to Smith Sound region under Charles Francis Hall was supported by public funds requested by the Secretary of the Navy. Hall was the first proponent of adopting Eskimo methods of living as a means to maintain one's health and operating capacity.

1879–81 —During the summer of 1879 the *Jeanette,* on an expedition in the Siberian sector of the Arctic Sea, commanded by Lieutenant George W. De Long, became beset in the polar pack near Wrangel Island and commenced a slow and uncertain drift toward Greenland. Then, on 12 June 1881, it sank near 77° 15′ N., 155° E. De Long and others lost their lives in the desolate Lena Delta when almost in reach of assistance. A second party under Lieutenant Melville was saved. The contributions to our understanding of the polar sea which these brave men made are still basic.

1884 —On 22 June, Captain W. S. Schley rescued the Greeley expedition to Ellesmere Island (First International Circum-polar Year, 1882-83).

1886 —In this year Peary (Commander Robert Edwin Peary; later Rear Admiral) began his long arctic career with a first visit to northern Greenland. His expeditions were all privately conducted and financed.

1891–92 —On 4 July 1892, Peary reached Northeast Greenland across the inland ice plateau, discovering Independence Bay and Peary Land.

1893–95 —Peary made his second crossing of the ice plateau in April 1895.

1896–97 —Peary visited Greenland and brought back the famous York meteorite (50 tons), largest in the world, which he had found in 1894 in the Cape York district.

1898–1902—Peary made his first attempt to reach the North Pole in February 1902.

1905–06 —Peary, on his first Roosevelt expedition to northernmost Ellesmere Island, Cape Sheridan district, claimed to have reached latitude 87° 06′ N. in this second attempt to reach the North Pole.

1908–09 —Peary's second Roosevelt expedition to Cape Sheridan was successful. By virtue of a remarkably well organized operation he reached the North Pole on 6 April 1909.

1913–17 —Donald MacMillan (Commander USNR) headed an expedition to Northwest Greenland and Ellesmere

Figure 1–1.—Peary discovers North Pole April 6, 1909.

Figure 1–2.—Byrd—first to fly over the North Pole in an airplane.

Island in search of new land in the Arctic Sea to the west of Cape Columbia.

1925 —Richard E. Byrd (now Rear Admiral, Ret.) flew over Ellesmere Island and Northwest Greenland in connection with MacMillan's second arctic expedition.

1926 —On 9 May, Byrd flew from Spitsbergen to the North Pole and returned in 15½ hours. He was the first to fly over the North Pole in an airplane.

1928–30 —First Byrd expedition (privately financed) to Little America, Antarctica. On 29 November 1929, Byrd flew from his base over the South Pole in a flight of 19 hours duration.

1933–35 —Second Byrd expedition (privately financed) to Antarctica.

1939–41 —Third Byrd expedition (U. S. Antarctic Service, Interior Department) to Little America and Marguerite Bay.

1942–45 —Various war operations in the Aleutians, Bering Sea, Greenland and Barents Seas.

1944 —First Point Barrow supply expedition (Barex) in support of Naval Petroleum Reserve No. 4. This now is an annual expedition conducted in August. In 1948 five AKA's, two LST's and one icebreaker participated, delivering close to 30,000 short tons of supplies and equipment to Point Barrow and Barter Island in the Beaufort Sea.

1946 —Cold weather cruise, *Operation Frostbite,* of a carrier task group in Davis Strait.

1946 —*Operation Nanook* to Thule, Northwest Greenland and Canadian Arctic Archipelago (Melville Island, Cornwallis Island, Ellesmere Island, etc.) in support of Canadian-American weather stations. This has be-

Figure 1–3.—Summer scene. Dumbbell Bay, Ellesmere Island, 450 miles from North Pole.

come an annual summer operation. In 1948, ships of TF80 reached 82°34′ N. latitude near Cape Sheridan where Peary's cairn (1906) was found. Later an icebreaker reached Slidre Fiord on Eureka Sound.

The two icebreakers returned to Boston via Prince Regent Inlet, Fury and Hecla Strait, Hudson Bay, and Hudson Strait.

1946–47 —Fourth Byrd expedition (*Operation Highjump*, U. S. Navy) to Antarctica. Largest exploring expedition in history.

1947–48 —Two Navy icebreakers conducted a reconnaissance of East Antarctica, the Bay of Whales and Palmer Peninsula.

CHARACTER OF RECENT COLD WEATHER OPERATIONS

During the middle of the 1940's, it became evident that the course of any future war would be further northward. Implications of arctic geography on world strategy and national security

Figure 1–4.—Summer scene. The Fury & Hecla Strait first transited by ship, summer of 1948.

Figure 1–5.—Summer scene [illegible] Norwegian Bay.

are evident from an examination of a polar orthographic projection made of the Northern Hemisphere. Our approaches must be guarded in the Aleutians, in Alaska, and in the complex of islands of the Greenland Sea—Iceland, Greenland and Spitsbergen. This strategic concept is not new. It was William Henry Seward, Secretary of State in President Lincoln's cabinet, who consummated the Alaska purchase and made a futile effort toward purchase of Greenland and Iceland.

In the winter of 1946 (March 10-21) *Operation Frostbite* was conducted in Davis Strait using a small carrier task group formed around the U. S. S. *Midway* (CVB41). This cruise was valuable in revealing the nature of problems associated with the operation of carrier aircraft in cold weather areas. The findings and recommendations of a special group of observers have been recorded in a Bureau of Aeronautics report. (See ch. 7.) The general opinion expressed by observers on this operation was:

"The aircraft, equipment, procedures, technical orders, technical notes, and other existing instructions are satisfactory for conditions of temperatures and winds considerably more rigorous than the conditions which can be tolerated by the deck personnel. Certain modifications are necessary to the aircraft, equipment, and technique to increase cold-weather carrier operational efficiency and to lower the limits imposed by temperature and wind conditions.

"With improvement of aircraft and equipment as indicated in the recommendation of the report, and by adherence to Bureau objectives and procedures, and what is more important, with additional training in cold weather operations at frequent and regular intervals, carrier operations can be conducted at as low temperatures as will be found in (ice-free) areas where a task group or force may be ordered to operate with only a slight reduction in efficiency and probably no decrease in aircraft complement."

During the summer of 1946 (July-September) Task Force 68, consisting of an AV, AKA, AG (icebreaker), SS and various aircraft, conducted "Operation Nanook" in waters around Greenland and among islands of the Canadian Archipelago. This operation, a resupply expedition, has been continued annually in fulfillment of the Navy's commitment for establishing and supporting of weather stations, which are maintained in the Arctic through combined American-Canadian and American-Danish efforts. New stations have been established in succeeding years. Valuable scientific observations, both afloat and ashore, are being made. During the summers of 1947 and 1948 icebreakers reached the Lincoln Sea, Slidre Fiord on Eureka Sound, and Victoria

Figure 1-6.—Summer scene. St. Patrick Bay, Ellesmere Island.

Island. In the summer of 1948 the icebreakers returned to Boston by way of Prince Regent Inlet, Fury and Hecla Strait, Foxe Basin, and Hudson Strait. Two "firsts" are credited to our forces: farthest north afloat in the Western Hemisphere, and transit of Fury and Hecla Strait. The latter resulted in the opening of a long sought route to the Canadian Arctic.

Following completion of *Operation Nanook,* the task force commander was directed to plan and prepare for *Operation Highjump* to Antarctica. The numerous ships (CV, AV, AO, AKA, AGC, SS) assigned to the force departed for their stations in December 1946. It consisted of three groups: one operating in the Palmer Peninsula—Weddell Sea sector; one in the Ross Sea sector; and one in the Wilkes Land—Queen Maud Land sector. Thus, the continent was circumnavigated in the short period of 2½ months. The valuable achievements of this exploring expedition can only be grasped and appreciated by a study of the comprehensive report submitted by the task force.

Probably the most significant lesson learned during *Operation Highjump* was that extended operations of 13 ships, 8,000 miles from their bases, were highly successful without the necessity of special preparations and special training and that our materiel and ship equipage performed satisfactorily, in most instances, to the extreme conditions encountered. These conditions were near to what might be expected in various sea-land areas in the arctic and subarctic regions during a large part of the year.

For many years the Navy has assisted in the protection of the seal fishery around the Pribilof Islands in the Bering Sea, and has participated in the logistic support of the islands.

The Point Barrow resupply expedition (Barex) is conducted annually in August in the Beaufort Sea in logistic support of

Figure 1–7.—Summer scene. Beach at Resolute Bay.

Figure 1-8.—Summer scene. Bridport Inlet, Dundas Peninsula, Melville Island.

operations at the Naval Petroleum Reserve No. 4. This is a small-scale amphibious operation growing in scope and importance each succeeding year.

In the late fall of 1948 a task fleet exercise was conducted in the North Atlantic around Newfoundland; in the late winter of 1948-49 another task fleet engaged in a similar exercise in the Gulf of Alaska around Kodiak Island. In February and March 1949 icebreakers operated in the pack ice of Davis Strait and Bering Sea. Nome, Alaska, was reached for the first time by ship during the winter.

The Navy may be called upon at any time of the year to assist in the rescue of airmen as routine arctic flights increase.

The Navy has peacetime missions which require operations on a small scale in the far north. Likewise, as a part of naval policy, the Navy is ever ready to operate any place on the surface of the globe where ships can be navigated. The frontispiece indicates that this can be done in a north-south direction through more than 161 degrees of latitude. Naval aircraft operating from ships and temporary bases, established and supported by ships, can easily extend the operations to the poles themselves. Submarines can conduct limited operations in scattered pack ice and beneath it. Amphibious ships can support activities of forces ashore in those areas which are navigable.

BASIC PRINCIPLES AND LIMITATIONS

Naval operations conducted under arctic conditions follow the same basic principles as do operations under other conditions. The differences lie in tactical and logistical limitations imposed by the climatic conditions and weather, by variations in the application of standard principles, and by the special equipment, training, techniques and procedures necessary to overcome the limitations.

The principal limitations upon sea operations are navigability, sea-ice, and extreme cold. Northern seas are navigation nightmares—high nebulosity, fog, drift ice, icebergs, pack ice, rough seas, cold water, low-surface air temperatures, sudden and long-continuing storms, and few recognizable land marks.

Civil and military flying in the Arctic have become routine. Most cold weather flight difficulties occur on the ground. Uncertain weather, formation of snow and ice on airplane surfaces, rescue and survival, and lack of adequate conventional navigational aids are the principal limitations.

In the case of military operations in the Arctic, the significant limitations are lack of transportation facilities, difficult and unfavorable terrain, and extremes of climate both in summer and winter.

MAJOR PROBLEMS

Operations of land, air, and naval forces in the polar regions, even on a limited scale, involve the solution of many problems of environmental adjustment, training, construction, ship building, logistics, research and design. The adaptation of men and machines, on a mass scale, to arctic conditions will be a long and tedious process. That some progress is being made is reassuring,

Figure 1–9.—Summer scene. Goose Fiord, Ellesmere Island.

Figure 1–10.—Summer scene. Dundas Harbor, Devon Island.

but only a concerted effort of science, technology and colonization will produce lasting and significant results.

Major problems for the Navy are the adaptation of existing ships and equipment to conditions, including extreme cold, for which they were not designed initially, and the maintenance of ship readiness and personnel efficiency while in the high latitudes. New ships and equipment are being designed for extreme climatic conditions in addition to standard and other special requirements. New materials of basic industries (steel, rubber, plastics, textiles, food, petroleum products, etc.) must be developed to replace conventional materials, the physical behavior of which becomes modified to the point of unreliability or uselessness at extremely low temperatures. Prevention of icing of upper works of ships and de-icing of exposed equipment are problems in need of solution.

Major problems in connection with military aviation in cold weather areas are ground maintenance of aircraft, rapid engine starting, erection of aircraft shelters, solution of manifold and complex materiel problems, prevention of ice formation on aircraft structures, protection of personnel, rescue and survival, construction and logistic support of airfields and bases, expense and difficulties of establishment and maintenance of adequate facilities including navigational aids and early warning radar nets, and military protection and security.

Four major problems present themselves for solution in the conduct of winter warfare on land, regardless of geographic area, under conditions of snow, ice, mud, and extreme cold, that are likely to be encountered at various times of the year above the thirty-fifth parallel in the Northern Hemisphere. These are (1) keeping men and animals warm and comfortable, (2) transportation of troops across snow and ice, (3) transportation and preservation of supplies and equipment, and (4) prevention of malfunctioning of weapons, ammunition, and equipment. Men are subject to chilling, frostbite, freezing, and at certain seasons snow blindness. When cold, they are less alert and consequently incapable of performing tasks in the usual time under conditions prevailing in temperate climates. Ordinary wheeled vehicles are

Figure 1–11.—AKA serves Pribilof Islands, Bering Sea.

useless on snow, muskeg, and the muck of the barren lands and northern tundras. Special winterized tracked vehicles and sled trains are required. Consequently, all cross-country travel is slow and uncertain during the winter, but almost impossible during summer except on highways. Vehicle motors require special starting and maintenance techniques; lubricants stiffen; gasoline and chemicals vaporize less readily; condensation of moisture in fuel tanks and carburetors occurs and turns to ice at temperature below freezing; water jackets freeze; steel parts break more easily; storage batteries lose capacity; frost fogs lenses of optical instruments and windshields of vehicles.

Arctic clothing, equipment, and arms make 300-pound sloths of average size airborne soldiers. Sufficient cold weather exercises have been conducted to prove the feasibility of limited, small-scale military operations over snow-covered terrain. Large scale transpolar military expeditions present difficult problems. The difficulties of mass airborne and land operations in subzero weather and over rugged arctic terrain are so great that they may never be solved. Large scale attrition type combat, therefore, does not appear a reasonable possibility, but highly mobile small striking forces may play an important role in arctic warfare.

Standard construction practices employed in temperate climates must be modified for permafrost conditions in the Arctic. The few roads, railroads, and structures built there in the past have sustained serious damage because of the destructive action of the permafrost which had been ignored or miscalculated in the original design. A thorough understanding of permafrost is, therefore, an important part of the planning of each engineering project.

Each service has an artcic and cold weather materiel program required for discharge of its respective responsibilities in war or peace. That for the Navy Department was approved by the Secretary of the Navy on 9 September 1948. It should be carefully studied by all personnel charged with research and development, materiel, and operational problems.

IMPORTANCE OF ARCTIC REGIONS

The trend of history is that successive wars become more global and more universal. No future war is likely to be restricted to a single locale. Because the Arctic is the central area of most of the earth's land masses, and since its nature is largely that of a mediterranean sea, naval operations will be of utmost importance.

Joint and combined operations of specialized character will be certain. For national security certain of these far northern strategic areas must, if necessary, be defended. As peacetime missions, the armed services must be capable of supporting weather and other arctic stations and of assisting with the development and securing of potential economic resources of our northern territories.

Across the Arctic Sea are the shortest air routes between the United States, Europe, and Asia. Earlier "over the top" operations were very difficult in the past because of the vast expanses of relatively unexplored territory, the absence of satisfactory landing places, and the lack of weather information. Now, with the availability of powerful, long range airplanes and suitable electronic equipment and more knowledge and experience in the Arctic, the big push of polar development is emerging.

The pitchblende of arctic and subarctic Canada, the oil of arctic Alaska and Canada, the iron of Labrador, the fisheries of southern Alaska and the Grand Banks, the furs of Canada, the timber of Alaska and Canada, the cryolite and lead of Greenland, the coals of Spitsbergen, and the rich vegetation capable of supporting hordes of arctic animals are among the treasures which will serve our continent in years to come and be vital to it in any future war.

Lastly, the arctic regions are important as a source of weather and scientific data essential to the welfare of a peaceful and thrifty world.

SUMMARY

Weather is not a barrier to limited scale operations on ground and sea, or in the air, in the Arctic. Success in living and working there is predicated on knowledge and use of area conditions, plus forethought, skill, courage, and endurance. This is no different than the requirements for successful living anywhere. Fuel and shelter are prime considerations in all operations on land.

Aviation in the Arctic can now perform its functions routinely the year round if provided with the same adequate bases, installations, facilities, and logistic support essential to any type of continuing operation, large or small, anywhere. Valuable resources await further exploration and development. The arctic regions are slowly evolving as a new crossroads of the world—possibly in time to be compared in importance with the Mediterranean Sea and the Panama Canal.

All personnel of the Navy require knowledge of the Arctic and training in arctic operations. Experience can only be gained by extending our peacetime training and operations northward.

Planning for such arctic operations must be more exacting and detailed than for operations in the temperate zones where the hazards are less.

CHAPTER 2

GEOGRAPHIC CHARACTER OF ARCTIC AND SUBARCTIC REGIONS

"Within the Arctic Circle lies a vast domain of prairies, lakes, forests, mountains, and pack ice."—Stefansson.

The term arctic is generally associated with ideas of cold, snow, and high latitudes. The detail and validity of the meaning of the word varies from person to person depending on knowledge, experience and specific interests in the region. There are a number of commonly used definitions, each valid in its own right and useful in a particular function.

For purposes of fleet operations, the Navy considers the Arctic to be those water areas on which ice acts either as a barrier to all navigation, or as a hindrance. The term thus defined does not relate to static global areas. It refers to conditions which may persist or exist from time to time in a number of areas in the high latitudes.

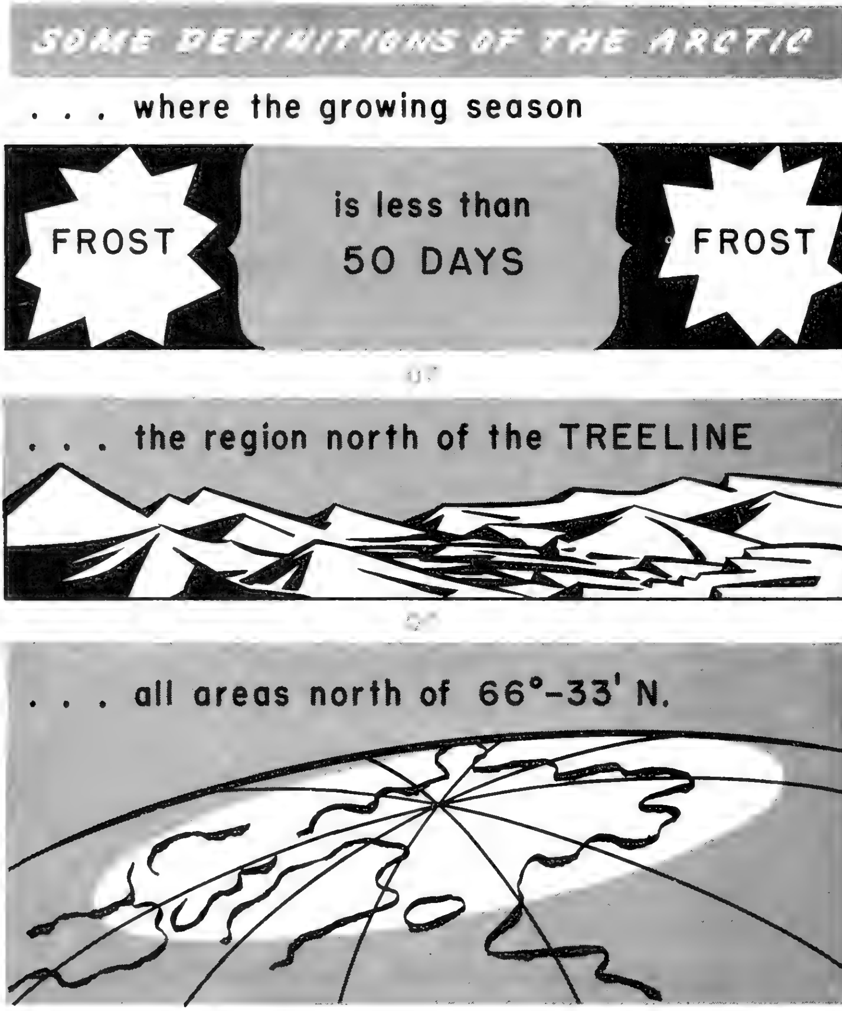


Figure 2–1.—Some definitions of the arctic region.

Many definitions use climate as a criterion to delimit the polar areas. Based on temperature, the Arctic is defined as:

1. The area lying north of the boundary fixed by the isotherm of 50° F. (10° C.) for the warmest month, or the isotherm of 14° F. (minus 10° C.) for the coldest month.

2. Areas having a mean annual temperature of 32° F. or below.

3. All areas where the sum of the average temperature in degrees centigrade of the warmest month plus one-tenth of the

temperature of the coldest month is less than 9° C. (This definition is the Nordenskjold-Wall formula used by the Soviets for defining the Arctic.)

Agronomists frequently define the region on the basis of the length of growing season. Thus all areas having less than 50 days between frosts are considered Arctic.

Botanists define it as the region north of the treeline, a boundary which approximates the 50° F. summer isotherm; or as the areas in which trees will not grow because of the cold, excluding other inhibiting factors such as poor soil, lack of water, and excessive winds.

Figure 2–2.—Sharp sounds can be heard at ten miles.

The astronomical definition, used in navigation and in understanding the seasonal variations in the length of daylight and darkness, places within the Arctic all areas north of parallel 66° 33′ N.—the difference between 90° and the maximum northerly declination of the sun.

There are other definitions based on such factors as extent of permafrost and windchill.

The subarctic is defined by the temperature factor as the areas where the mean temperature for less than 4 months of the year is higher than 50° F. (10° C.) and the mean temperature of the coldest month is less than 32° F. (0° C.) It should be noted that minimum temperatures are often lower there than in areas farther to the north. This does not mean that all subarctic areas are colder than arctic areas. Some areas included in the subarctic have average winter temperatures falling so slightly below 32° F. that they are characteristically non-Arctic, such as Iceland where Reykjavik has an average temperature for the coldest month about like that of Philadelphia.

COMMON CHARACTERISTICS

Regardless of the criteria used for the various definitions, there are certain characteristics common to the region. These are:

1. Short cool summers.
2. Long cold winters.
3. Low annual mean temperature (23° F. or minus 5° C.).
4. Long periods of semi-darkness.
5. Periods of continual daylight and darkness.
6. Absence of forests.
7. Freezing in winter of lakes, rivers, bays, and parts of the sea.
8. Scant precipitation.
9. Low absolute humidity.
10. Low evaporation rate.
11. Moist soils when thawed.
12. Presence of permanently frozen ground.
13. High windchill factor.
14. High latitude position.

Other phenomena found in the Arctic include the aurora borealis, mirage, increased visual and auditory perception, glare, fog, and the magnetic pole.

In the matter of darkness it should be noted that, although there is no direct sunshine in the winter above 74° N. latitude, there are long periods of moonlight, with the snow and ice acting as good reflectors for the light from stars, the aurora, and the moon. However, the reflected light is diffused and as there are no clear shadows it is difficult to judge size and shape of objects. Under such conditions, fliers have trouble in judging the surface of the ground.

The aurora borealis is a useful source of winter light but it is not regular and dependable. The area of maximum frequency is oval-shaped around the northern geographical and magnetic poles. Discussion of the effect of aurora upon communications is included in chapter 3, Part II.

The long summer daylight does not mean that there is good visibility. Fog is especially prevalent in the spring and summer. The fog is mainly along the coasts where the warmer continental air passes over the cold arctic waters, and is frequently concentrated in the lower levels, a few feet above the surface. Fog is also produced by communities and encampments of men, by power plants and airplanes. In the Mackenzie delta area, the *black fog* occurs, especially in March, making flying very hazardous. Some fogs are made up of frost flakes or spicules. Another visibility problem is that of mirage. Due to the differential density of air, light cannot pass through the boundary between the layer of cold air along the surface and the warmer air above. The surface of the ground is obscured and images are inverted.

Glare is a common problem during the period when the sun is above the horizon and the sky is overcast. On sea-ice or on snow-covered land everything looks equally white. Eye strain and snow blindness come from an attempt to distinguish features in this general whiteness. (Rest the eyes by viewing regularly any marked contrasts that may exist—particularly areas of open water.)

In the absence of fog, the degree of visibility is very great. Normal horizontal visibility in the Arctic is 50 miles, and under special conditions visibility for 150 miles is possible. This poses a military problem of concealment.

Sound travels with great clarity in the dry, cold air. Sharp sounds can be distinctly heard at distances of 10 miles or over.

The areas having these general characteristics of the Arctic and Subarctic include northern Alaska. the northern two-thirds of Canada and Labrador, Greenland, Iceland, the northern portions of Scandinavia in the Lapp country, the northern sections of the Soviet Union, including the lower basins of the famous north-flowing rivers (Ob, Yenisei, Lena), and all of the islands and seas north of these mainlands.

PREDOMINANCE OF THE ARCTIC SEA

Looking at the top of the world, the Arctic Sea (also referred to as Arctic Ocean) is seen to be an arm or gulf of the Atlantic Ocean, joined to it by the wide strait of the Norwegian and Greenland Seas. Unlike the impression gained from a world map on the Mercator projection, the Arctic Sea is comparatively small in area. The two great land masses of the Eastern and Western Hemispheres are separated by relatively short distances across this mediterranean. Great circle flight routes between major power centers lie over the Arctic. In economic terms, however, the uses of these routes have been *shortcuts to nowhere* up to the present time.

In general, the peoples of the two hemispheres consider the value and use of the arctic basin on quite dissimilar bases. The Soviet Union, needing an outlet for the interior of the continent, is looking north and is using the seas bordering the central basin as a seasonal supply route. Russian interest in her northern sections has been active for many decades, emphasized by the early explorations of Bering and more lately by the establishment of an Arctic Institute in 1928. North America, on the other hand, has an abundance of temperate zone harbors, and, therefore, has felt little need to be concerned with the Arctic except in terms of exploration and exploitation on a relatively minor scale. Only in very recent times has there been any concerted effort to "know" the Arctic. In part, this effort was promoted by a realization that the polar basin is an area of junction and not separation of the two hemisphere continents.

The Arctic Sea, as the center of the north polar region, is the dominating feature. Its position gives it significance with relation to the lands bordering it. These lands are characteristically cold, desolate areas strongly influenced by the ice-covered central maritime basin.

TOPOGRAPHY

The lands in the far north are made up mainly of pre-Cambrian rocks, most of which have been metamorphosed. These ancient and resistant rocks form the great shield areas of Finland and Scandinavia, eastern Canada, and eastern Siberia. Between the shield areas are younger sedimentary deposits. In general, the lands are mainly mountain, plateau or rolling upland areas of greater or lesser height. The main highland areas are the central Siberian plateau from the Yenisei to the Lena, the Novaya Zemlya mountains, the mountains of Spitsbergen, the Greenland ranges, the mountains of the eastern Canadian arctic islands, the Yukon-Mackenzie highland, the Brooks Range of northern Alaska, and the mountains of southern Alaska. There are few extensive lowlands. Small areas of low, relatively flat ground are found in the Canadian Eastern Arctic, the Mackenzie Basin, and far northern and central Alaska. The most prominent plains are those of Eurasia in northern Siberia, and in northern Russia west of the Urals.

Most of the land of the arctic regions is underlain by permanently frozen ground or permafrost. This phenomenon is a product of both past and present climatic conditions and is defined as any soil, rock or bedrock which has had a temperature below freezing throughout two or more years. Frozen ground containing little or no ice is called dry permafrost, usually associated with areas of sandy or coarse grained material which is well drained. It offers few problems in construction engineering since its properties are similar to those of unfrozen ground. Frozen ground with a high moisture content, usually in the form of ice crystals or lenses, requires special construction methods.

PERMAFROST

Permafrost is found in most of Alaska, northern Canada and the Canadian archipelago, Greenland, and as far south as northern Mongolia and Manchuria. It reaches farther south in the eastern sections of the continents than in the western parts. The thickness varies from a narrow wedge at the southern edge to depths of several hundred feet in northern Alaska and reputedly over 1,000 feet in northeast Siberia.

There are many factors that appear to be related to the formation of permafrost. A low annual mean temperature (minus 4° to minus 6° C.) can produce and maintain permafrost. Its first occurrence was probably during the excessive chilling caused by the Pleistocene ice ages, about a million years ago. Inconclusive evidence suggests that the permafrost layer is thickest in the areas which were not glaciated during the ice age. Although the relationship with the ice age is not entirely clear, permafrost is related to current climatic conditions. For example, at Port Nelson on Hudson Bay after a lake was drained, the ground froze to a depth of 8 feet the first year, to 20 feet the second year, and in the third year the permafrost reached a depth of 30 feet, the average depth for the area.

The layer above the permafrost is usually subject to thawing in the summer. This is called the active layer and its depth depends upon the annual mean temperature, the surface exposure, the heat distribution and composition of the ground, and the vegetation cover. Moss or peat act as insulators to limit the depth of the active layer. If this cover is removed or the ground is disturbed, the thawing will be increased and the active layer will become thicker. Heavy snow cover and water bodies act as insulators against the cold, and the underlying permafrost will be at a deeper level or nonexistent. Thus the bottom surface of the active layer and the top of the permafrost layer are quite irregular, frequently having little relationship to the ground topography.

Permafrost is impermeable to water. During the summer, a considerable amount of the surface water percolates through the thawed active layer. As the ground freezes in the winter from the top downward, the water continues to flow in the unfrozen layer which gradually becomes more restricted and the water becomes subject to hydrostatic pressure. In many cases, the water under pressure is forced to the surface where it may form seepages and ice sheets, icing-mounds, blisters or bursts. Or, the water may become frozen within the active layer in large solid masses, sheets, wedges, veins, lenses or minute grains causing a swelling of the surface of the ground. In a few instances, when the water was strongly mineralized, it has remained in a fluid state although the surrounding ground was frozen. Water exists below the permafrost layer. It is always fluid, and usually is under considerable pressure.

Soil that is saturated by melt-water during a part of the summer is really half afloat, and on the slopes this soil slips slowly downward. Such solifluction causes a certain amount of sorting of the material, making a striped arrangement of the soil with alternating coarser and finer particles. These stripes take the form of small irregular terraces. On level ground the form taken by the water-soaked soil is an irregular hexagonal pattern where the centers are gravel and larger stones, and the interspaces are finer sand. These are the polygonal soils of the polar areas. Vegetation commonly concentrates in the perimeters of the hexagons.

The existence of permafrost has an effect on the vegetation. The excessive moisture in the active layer above the impervious frozen ground inhibits the growth of some trees. Bogs and marshes are characteristic of wet permafrost areas. Trees with shallow roots such as the larch, spruce, tamarack, balsam poplar and dwarf birch can thrive in areas, where the active layer is as shallow as 12 to 18 inches. Jack pine has a prominent tap root, and thus cannot grow in permafrost areas. Jack pine forests are a good indication that permafrost is either very far below the surface or completely absent.

DRAINAGE

Permafrost is in part the cause of the haphazard, poorly defined drainage of much of the artic regions. The inability of the surface water to seep into the frozen ground forces a considerable amount of the scant precipitation to remain on or near the surface. Glaciation, of course, is primarily responsible for the disruption of the pattern of drainage in the vast areas that were covered by the ice sheets. There has not been sufficient time since the recession of the ice for well-defined drainage to be established. Thus, much of the relatively flat land of the Arctic is studded with innumerable shallow lakes connected by sluggish streams that seem to wander aimlessly. There are, however, some prominent rivers which flow northward into the polar basin. In Eurasia, the Ob, Yenisei and Lena are the major north-flowing rivers, the Pechora, Indigirka and Kolyma being of lesser importance. The Mackenzie river system is the largest of the North American rivers draining into the Arctic Sea. The Colville, Coppermine, Back, Thelon, Dubawnt, Kazan, Churchill, Nelson, Fort George, Great Whale, Koksoak and George rivers are some of the smaller north-flowing rivers of Arctic America.

The rivers that flow from the south present problems in the spring breakup. While the lower portions of these rivers are still ice-locked, the upper reaches are being exposed to the longer days and warmer temperatures of spring. Ice in the upper sections thaws, breaks loose, and starts moving down stream. Its progress is blocked by the still frozen lower sections, and flooding and ice-damming, are common spring occurrences. Another effect of the alinement and direction of these rivers is that, although the upper portions may be ice-free early in the summer, the rivers cannot be entered until the ice at the mouths has broken up. Local river traffic can operate in the ice-free areas, but all outside traffic must wait until the summer season has progressed northward to free the river outlets.

VEGETATION

The abundance of lakes and rivers in the northern regions might give the impression that it is an area of heavy precipitation. This is not the case. The Arctic has scant precipitation, receiving only 10 to 15 inches a year. Aridity is one of the main controlling factors in the region, together with low evaporation and low temperatures. Under such circumstances soil development is at a minimum and decay is prevented. The combination of drought, inadequate soil, frozen subsoil and short growing season produces conditions inimical to tree growth. Hence, the Arctic is essentially a treeless tundra. Clumps of trees are found in areas where soil is sufficiently deep, as on terraces, raised beaches and deltas, but they are limited in size and number.

Despite the lack of forests, the tundra is luxuriant in vegetation. There are innumerable flowering plants, mostly perennials, which burst into bloom and complete a life cycle in the short season from June to August. These plants also show adaptation to the environment in other ways; for example, they have abnormally developed subterranean stems and roots spreading laterally in the shallow layer above the permafrost; they have leathery, waxy or woolly leaves to preserve moisture like desert plants, and many are prostrate to avoid the winds and seek the protection of the snow from the extreme cold. Grass is abundant, and in many ways the meadows of the Arctic are similar to the savanna and steppe-lands. Mosses and lichens are especially numerous in the ancient shield areas. There are some 250 species of mosses.

These plants develop high osmotic pressure and, therefore, can stand low temperatures. Over 330 species of lichens have been found. Lichens are less dependent than most other plants on the type of rock or soil on which they grow because they are symbiotic, one part living on another. In the bogs and water-logged areas the sphagnum moss, peat, and sedges are the chief plants. Thus, the tundra is an area of grasses, flowering plants, heath with berry-bearing plants, mosses, and lichens, with a few stands of trees on the better soils, and patches of dwarfed prostrate willows, junipers and aspen.

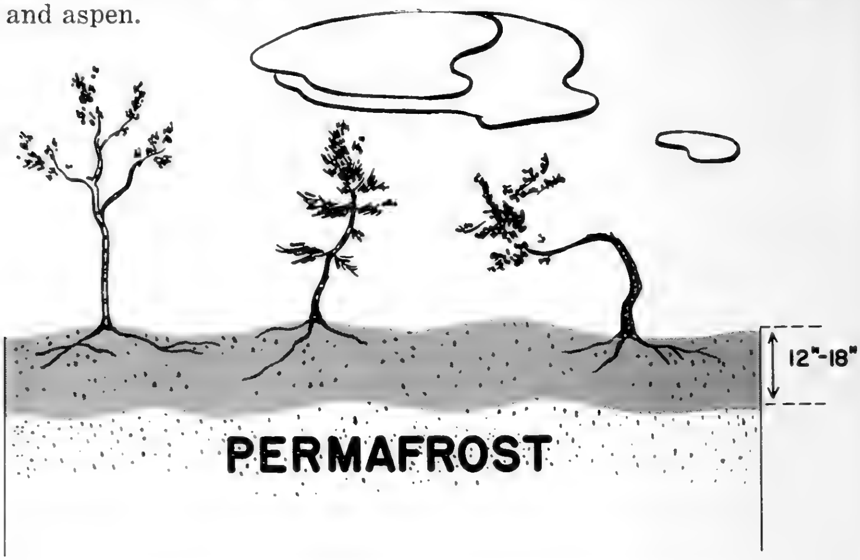


Figure 2–3.—Trees with shallow roots grow in permafrost areas.

All the plants in the tundra region have a very slow rate of growth. The size of the plants is not an indication of age, and many very small plants are 10 to 20 years old. It takes mosses 9 to 10 years to regrow after they have been grazed by migrating reindeer, because they grow only about ⅓ inch a year.

The treeline which roughly follows the July isotherm of 50° F. (10° C.) marks the northern edge of the vast coniferous forests. In North America the treeline lies along the foothills of the Brooks

Figure 2–4.—Muskeg and gravel in terrain around Resolute Bay.

Range, crosses the Mackenzie River at its delta, swings southeast across the Candian shield to Port Nelson and Fort Churchill on Hudson Bay, crosses the northern end of James Bay and the Ungava Peninsula, taking a sharp southward dip along the mountains of Labrador. In Norway, the northern limit of forests is at about the 70° N. parallel. The treeline dips southeast through the center of the Kola Peninsula, then runs almost parallel to and about 400 miles inland from the Siberian coast, trending slightly more to the south as the eastern coast is approached. The Eurasian coniferous forest is the most extensive in the world, while the Canadian forest covers more than half the Dominion.

The coniferous forest or taiga, as it is called in Siberia, is composed of several species of pines, firs, spruces, birches and larches. On the whole, the forests are not a mixture of all the species, but the trees tend to segregate into more or less solid stands of single species. The trees group themselves mainly on the basis of their ability to adapt local conditions of moisture, temperature, exposure and soil. To some extent, the different trees are indicators of particular soil, water and temperature factors.

Black spruce, for example, will grow in swampy areas and is found as far north as the treeline. It will also thrive on dry soils, but is frequently pushed out by faster growing trees. Larch is one of the hardiest of the forest trees and grows to the very northern limit of trees. This northern limit is not a clear cut line.

Toward the northern edge the trees grow farther apart, with grasses, mosses and shrubs covering the ground between the trees. The forests have a parklike appearance. Farther north there are still fewer trees. Some of the trees such as the spruce, birch, and

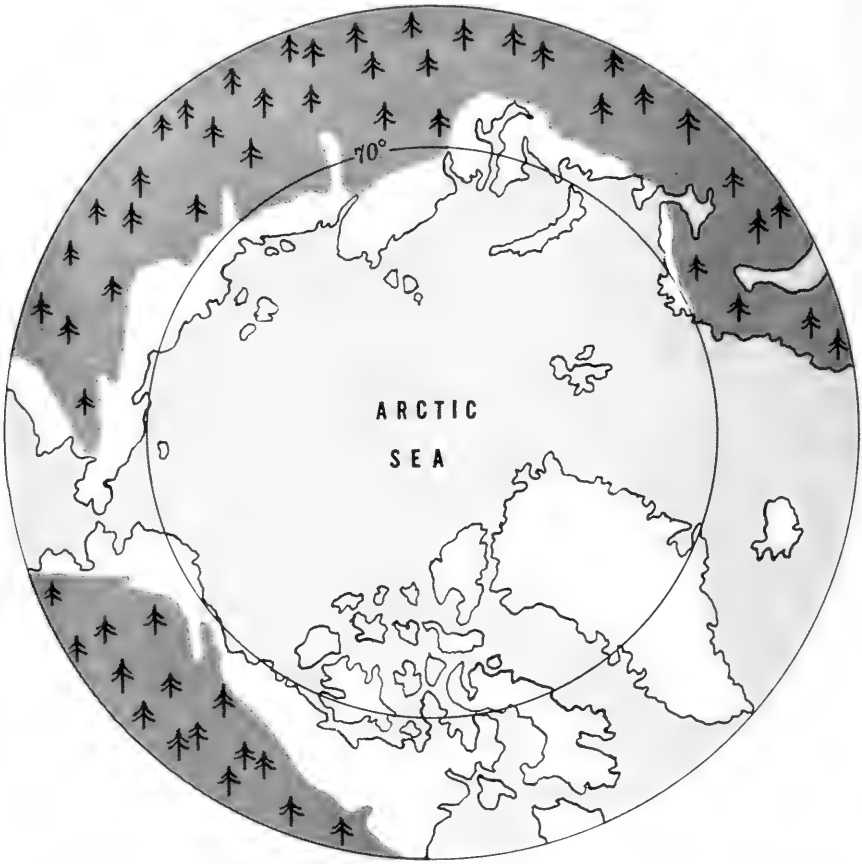


Figure 2–5.—The treeline.

fir become dwarfed and stunted. More of the area is covered by shrubs and thickets of willows and alders, especially the margins along the rivers and lakes. North of the limits of true forest growth these thickets of arctic willows and birches found in the lowlands make summer overland travel very difficult. Farther north these tangled masses of undergrowth die out, and are replaced by mosses and lichens.

ANIMAL LIFE

To a great extent the vegetation controls the distribution of animals. The mosses, lichens, grasses, and shrubs of the tundra provide food for the migrating herds of reindeer, caribou, and musk-oxen. The lemming, ermine, and arctic hare are found in abundance. These animals, together with the flesh-eating foxes and wolves, move northward in the summer, perhaps motivated by the appearance of the infinite number of mosquitos which breed in the water-soaked lands. The white fox, one of the most valuable of northern animals for its fur, ranges along the arctic coast, living on small birds and lemmings.

Figure 2–6.—The white fox lives on small birds and lemmings.

In winter both the arctic fox and the white fox migrate north onto the sea-ice. Here they live off partially eaten seals which the polar bear have killed and on gulls and wild duck. Wolves follow the caribou herds which are their chief source of food. The wolves range over the tundra from the tree-line to the arctic shore, rarely going out onto the sea-ice. They usually hunt alone or in pairs, and not in the much talked about multitudinous packs.

Bear are found throughout the Arctic. The polar bear, whose fur is yellowish white in color, is usually found along the coast of the continents or on the islands. They rely on seals for their food supply and therefore stay in the vicinity of the sea-ice where seals are most likely to be. Wherever the bear go, the white fox will be close behind since it depends on the polar bear to kill its food. The gulls also feed on the seal carcasses left by the bear.

The sea is particularly rich in flora and fauna, especially in protected areas and where warm water mixes with cold. These organisms, shell fish and small fish provide food for the larger animals, such as whales, seals, walrus, and the many birds.

POPULATION

Although the Arctic has been inhabited for countless ages, it is still one of the least populated regions of the world, comparable only to the deserts. It is difficult to determine the total population, since statistics are not available for the many towns and polar stations of the Soviet Union. However, the total population is small.

The people of the North live mainly along the coasts of the mainlands and the larger islands. Most of the smaller islands are uninhabited. Native activities are as intimately connected with the sea as with the land. They depend upon the products of the sea for a substantial part of their food and clothing. Caribou furnish some of these necessities, but there are too few caribou to maintain the northern population; and the migratory habits of the land animals make them a less dependable source of supplies than the fish and mammals of the sea.

Figure 2–7.—People of the North.

The natives in their culture show remarkable adaptation to their environment. Their dress, shelter, food, and mode of transportation, as well as the implements used in their daily activities, all indicate the degree to which they have made the best use of the local materials in order to live a comfortable life. The common occupations are hunting, fishing, and trapping. There are some areas, as Lapland, where reindeer herding is carried on. The Soviet Arctic is in contrast to the North American Arctic in the matter of farming and industry. Although most of the Hudson Bay Company posts and the missions have small garden plots of potatoes, radishes, carrots, and beets, some Soviet polar stations and industrial towns have extensive farms, reportedly able to feed their whole northern population.

As for industry, there is little comparison between the extensive development in the Soviet Arctic and the meager development in the Western Hemisphere. The mines at Great Slave Lake and Great Bear Lake are about the only industry of any scale in northern Canada, aside from the fishing, fur, and wood industries.

Despite the much talked about lure of the North not many people from temperate regions have found the Arctic an inviting place to live. The non-native population is mainly transitory, coming only to make a quick fortune, as in North American Arctic, or coming in response to Government orders and the "incentive bonuses" as in the Soviet Arctic. The severe climate requires that too much of an individual's time be devoted to keeping warm, dry, and nourished to allow for many economically remunerative activities. Attempts to transplant temperate zone habits and customs to the Arctic mean heavy expenditures for imported foods, implements, clothing, and equipment.

Whether or not the Arctic will one day be dotted with industrial developments seems to depend on more than mere exploration to discover the mineral wealth. Much must be done to conquer the environment and the isolation. However, the Arctic is still a most interesting place, offering endless opportunities for basic scientific research and experimentation. Its importance in world strategy and the scheme of twentieth century progress is growing.

TABLE I

Distance: Arctic Air vs. Normal Routes (Statute Miles)

Route	NORMAL ROUTE (Steamship and railroad)	Arctic air route
New York–Peiping via Seattle	9,340	6,850
New York–Tomsk via Seattle	10,600	5,625
New York–Tomsk via Hamburg	7,960	5,625
Edmonton–Tomsk via Vancouver	7,270	4,775
London–Tokyo via Montreal	11,550	5,940
London–Tokyo via Trans-Siberian	8,140	5,940
Seattle–Leningrad via New York and Hamburg	8,280	4,865

TABLE II

Distance Table

From	Across	To	Statute miles (approx.)
Geographical Center United States	Greenland	Moscow	5, 300
Do	Iceland	Berlin	4, 800
Do	West of North Pole	Irkutsk	5, 600
Do	Fairbanks	Nanking	6, 600
Do	East of North Pole	Bombay	8, 000
Washington	Greenland	Moscow	5, 000
Do	Iceland	Berlin	4, 200
Dutch Harbor	Kuriles	Vladivostok	3, 000
San Francisco	Wrangel Island	Irkutsk	5, 600
Geographical Center, Greenland	Norway	Moscow	2, 300
Tokyo	Japan Sea	Vladivostok	670
Moscow	Siberia	Anadyr	5, 000
East Cape, Siberia	Bering Strait	Nome	150
Dutch Harbor	Bering Sea	Petropavlovsk	1, 500
Fairbanks	North Pole	Moscow	4, 100
Do	Canada	New York	3, 260
Do	do	Chicago	2, 780
Do	Alaska	Seattle	1, 530
Do	Bering Sea	Yakutsk	2, 375
Do	do	Tokyo	3, 500
Anadyr	East Siberia	Vladivostok	2, 500
Tokyo	Kuriles	Petropavlovsk	1, 500

ARCTIC AND NORTHERN SEAS

The Arctic Sea fills a deep, eccentric conical basin between tw great land masses, with its center toward Alaska and its long axi from Point Barrow to Rudolf Island in Franz Josef Archipelago Although it covers about 5,000,000 square miles, it is small compared with the Pacific and Atlantic Oceans. On the surface, it appears as a gulf off the Atlantic, joined to the latter by the wide Norwegian and Greenland Seas.

However, consideration of the bottom relief shows that there are three rather distinct basins. The first and largest is the central polar basin. It extends to the rise between Spitsbergen and northeastern Greenland. The second is the Greenland Sea basin, extending from this rise to the ridge between Bear Island and Jan Mayen Island. The third, or Norwegian basin, extends southward to the Atlantic Ocean. Around the borders of the central basin local water areas have been named as separate seas, such as Barents Sea, Kara Sea, Laptev Sea, East Siberian Sea, Chukchi Sea, and Beaufort Sea.

The hydrographic survey of this sea area is not complete, but soundings which have been made indicate depths of over 15,000

Figure 2-8.—Northern seas.

feet. The deep part of the basin is egg-shaped, being nearer the Canadian and Greenland shores than the Siberian coasts. The continental shelf is well developed along the Siberian coasts from Bering Strait to the Barents Sea, having a maximum breadth of 375 miles. The shelf is very narrow along the Alaskan north coast and the Canadian archipelago. The islands of the archipelago are all on the continental shelf. However, little is known as to the water depths and submarine character of the channels and fiords in this area. The nature of the continental shelf can be seen from an examination of HO Chart 2560 (Arctic Regions).

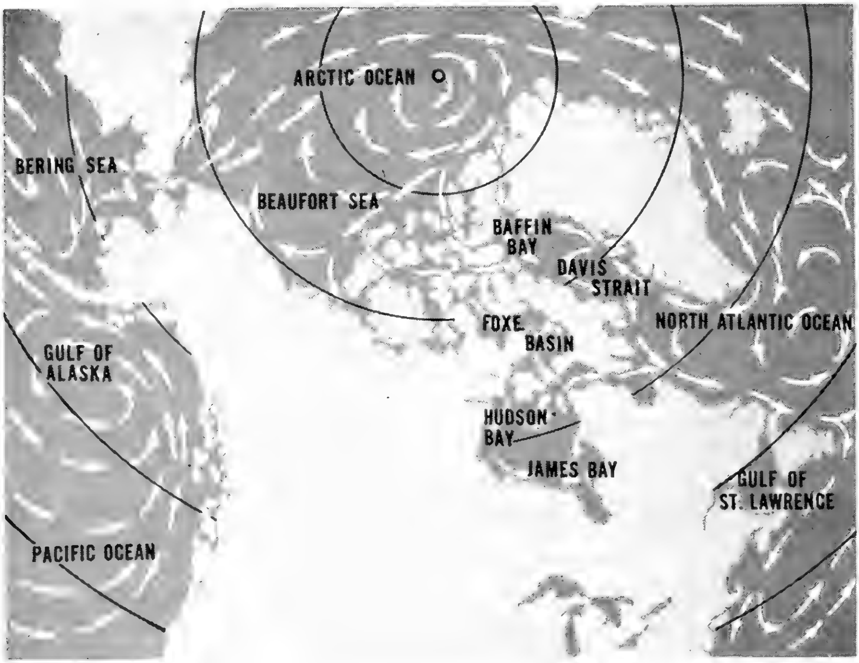


Figure 2–9.—Currents.

The Arctic Sea receives its water from two main sources, the northward flowing fresh water rivers and the highly saline current of warmer water which enters along the west coast of Spitsbergen at about middle depth, below the cold water at the surface. The water in the basin circulates in a generally clockwise direction. There are smaller currents moving eastward along the north coast of Greenland, and a large eddy some 300 miles north of the coast in the Beaufort Sea.

The principal outlet is between Spitsbergen and Greenland. The cold East Greenland current flows southward along the east coast of Greenland to Cape Farewell. Part of this current rounds the cape and flows northward along the west coast, where it is joined by a small current from the Gulf Stream. Three other outlets exist among the Canadian arctic islands. One is the narrow channel between Ellesmere Island and Greenland through Robeson Channel, Kane Basin, and Smith Sound to Baffin Bay. A second outlet is through the broad Strait, Viscount Melville Sound, and Lancaster Sound north of Baffin Island into the Bay of the same name. The third and least important outflow is through Fury and Hecla Strait to Foxe Basin and Hudson Bay.

In Baffin Bay, the northward flowing current along the west coast of Greenland curves westward in Melville Bay and merges with the outflowing polar waters which move southward along the west side of the Bay. Part of this current enters Hudson Strait and flows around the southern coast of Baffin Island, going northward along the west coast into Foxe Basin. This current joins the arctic outflow and moves counterclockwise around Foxe Basin and Hudson Bay. It flows along the south side of Hudson Strait to Davis Strait. It then merges with the southward flowing current from Baffin Bay to form the famous Labrador current, which finally mixes with the northeastward flowing Gulf Stream to the east of Newfoundland. Another outlet, but one of negligible importance, is through the Bering Strait.

Throughout much of the year, but especially during the break-up, the Labrador current and the east Greenland drift bring bergs and floes from the northern areas. It is estimated that 26 million cubic yards of ice are thus carried into the north Atlantic Ocean annually.

The circulation of the cold arctic water and the warmer Atlantic water causes considerable contrasts in the climates of the coasts along which these currents flow. Moderating influences of the relatively warm waters are also felt in northern Scandinavia. Part of the North Atlantic Drift flows along the coast past Murmansk and Kolguev Island, and northward along the west coast of Novaya Zemlya. The effect of this current is to keep the Barents Sea free of ice for several months, and to considerably moderate the climate of western Novaya Zemlya.

Tides in the far northern area are not high. Along the coasts the rise and fall varies from a few inches to 4 or 5 feet on an average. The tides are somewhat higher along the Kola Peninsula and western Soviet coasts. In the channels, fiords. and inlets the tides may reach heights of 30 feet owing to the waters piling up in the restricting narrows. The spring range is frequently two to three times greater than the mean range.

ICE

The ice conditions of the Arctic Sea vary from year to year. On the average, about 90 percent of its surface is ice-covered in winter. Most of this ice is true sea-ice and not land derived. Its forms are many and diverse, depending on its age, the influence of winds, waves, currents, and the weather. See HO 551.

Figure 2–10.—Growth of ice.

Ice begins to form on sea water of average salinity (35°/00) when the temperature reaches about 29° F. Polar seas have lower salinity and therefore freeze at higher temperatures. The first ice formed may be salt free, but the salt becomes trapped between the crystals and new ice is very salty. During the summer the surface of the ice melts and the water percolates down through the ice, carrying with it much of the salt so that ice a year old is not especially salty to the taste. On the surface of the ice, pools of fresh thaw water may accumulate in summer. The fresh water that seeps through the ice refreezes on the bottom of the ice thus causing an upward migration of debris frozen in the ice. It is not uncommon to see ice covered with rocks, shells, seaweed, and diatoms that have been brought to the surface.

Arctic ice usually grows up to 5 or 6 feet in a year. Growth continues through the summer by the addition of the new ice on the bottom of the layer. A second year may add 1 or 2 more feet to the thickness. Eight feet is about the maximum thickness of level ice, since at that point the ice acts as sufficient insulator to stop any refreezing at the bottom. Under the influences of tide, wind, current, and sea swell, the floes are pushed together or against the shores. This causes buckling, ridging, and rafting of the ice. Ice thus piled up may be 30 to 40 feet thick; and the ridges may be 100 feet high. When such pressure is released, leads and open water appear.

Ice first forms along the shore, in the bays, and at the mouths of rivers. In the fall and early winter, the polar pack which is continually in motion, coming in and moving off the shore, grinds this new ice and piles it up against the beach. When the pack moves off, a layer of new ice forms in the lead. This process continues until about the beginning of December, when the coastal ice becomes frozen fast to the bottom. This fast ice is a solid, stationary mass extending 4 to 8 miles from the shore. The fast ice is useful as a winter highway for sledges. The ice reaches a maximum thickness in April or May and then begins to crack and rot. Pools form on the surface and travel is difficult.

Between the fast ice and the pack there is a lead which intermittently opens and closes as the pack moves. Pressure ridges are formed and the grinding of the ice continues along this *flaw zone* during the winter.

Throughout the entire year approximately three-fourths of the Arctic Sea is covered by heavy pack-ice which is essentially impenetrable. During the winter, the bordering seas and bays are ice-locked and are unnavigable. The maximum extension of the heavy pack and land-fast ice is in early spring. In April and May pack-ice covers the areas along the east coast of Greenland, the Canadian archipelago, the Labrador coast, the western and northern Alaskan coasts, and the Siberian northern coast as far west as Kolguev Island. The Kara Sea, Gulf of Ob, and the Yenisei estuary are entirely ice-bound. Barents Sea is mainly ice-free except in the eastern section along the coasts of Novaya Zemlya.

In the northern end of Baffin Bay an area of open water seems to persist throughout most of the winter. This "north water" shifts in location and extent, but usually lies between Devon Island and Thule, Greenland.

Hudson Bay appears to freeze over except for wide leads. The ice begins to move out or rot in place in mid-June. By July, the bay and strait are fairly well open, as is the west coast of Greenland as far north as Etah. The west coast of Novaya Zemlya is almost ice-free by July and the ice has moved out of the southern Kara Sea. Throughout August and September the northern coasts of Siberia and the Canadian mainland, and the northwestern coast of Alaska are ice-free. Ice persists between the far northern islands of the Canadian archipelago and remains close inshore along the coast of Alaska east of Point Barrow. Heavy pack-ice remains through the summer along the northern coast of Greenland and Ellesmere Island, and areas of unnavigable pack-ice are

Figure 2-11.—Iceberg 300 feet high.

found in western Baffin Bay and Davis Strait, eastern Foxe Basin and the southern part of the Gulf of Boothia. By November the estuaries and gulfs are again unnavigable.

The White Sea begins to freeze in mid-October. In some winters fixed ice may cover the whole Sea. There is little floe ice, and polar ice only penetrates the northern section where from November to May much floating ice makes navigation dangerous. The ice breaks up and the sea is usually navigable by June, although there have been years when ice remained during the summer.

The Gulf of Ob (Obskaya Guba) is unnavigable after the first week in October. Both the Ob River and the Gulf are frozen over from November to the break-up, which begins on the river about the first of June and in the Gulf about the middle of June. Navigation is possible on the river in the first week of June; however, it is a month later before the Gulf is safe for ships.

In the beginning of October the Gulf of Yenisei freezes and the river freezes by mid-October. The break-up usually occurs on the river in the middle of June. The ice on the Gulf does not break up until mid-July.

The Lena River has a very short period during which navigation is possible. Ice covers the river from the first of October until the end of May, but the delta remains frozen until late June or July. Sometimes the river is ice-blocked throughout the year.

The break-up on the rivers is a rapid and violent event. The force of the waters flooding down the channels tears up the ice and drives it seaward at a rate of about 4 knots. Bends or constrictions in the channel cause temporary piling up of the ice. The water and bergs flood the valleys until the pressure breaks the ice barrier. In a week or less an entire river will rid itself of ice. River levels rise tremendously during the break-up, reaching heights of 70 feet or more over the winter levels.

WATER TEMPERATURE AND SALINITY

Much of the knowledge of temperatures and salinity come from the explorers and the men who made the famous drifts across the polar basin. From the Fram expedition of 1893–1896 it was learned that three layers of water exist. To a depth of 500 to 600 feet the water is cold with temperatures between 28.6° F. and 32° F. This upper layer has comparatively low salinity. Below this layer, to depths of 2,500 feet the water is more saline and warmer. This is probably the current from the Gulf Stream which

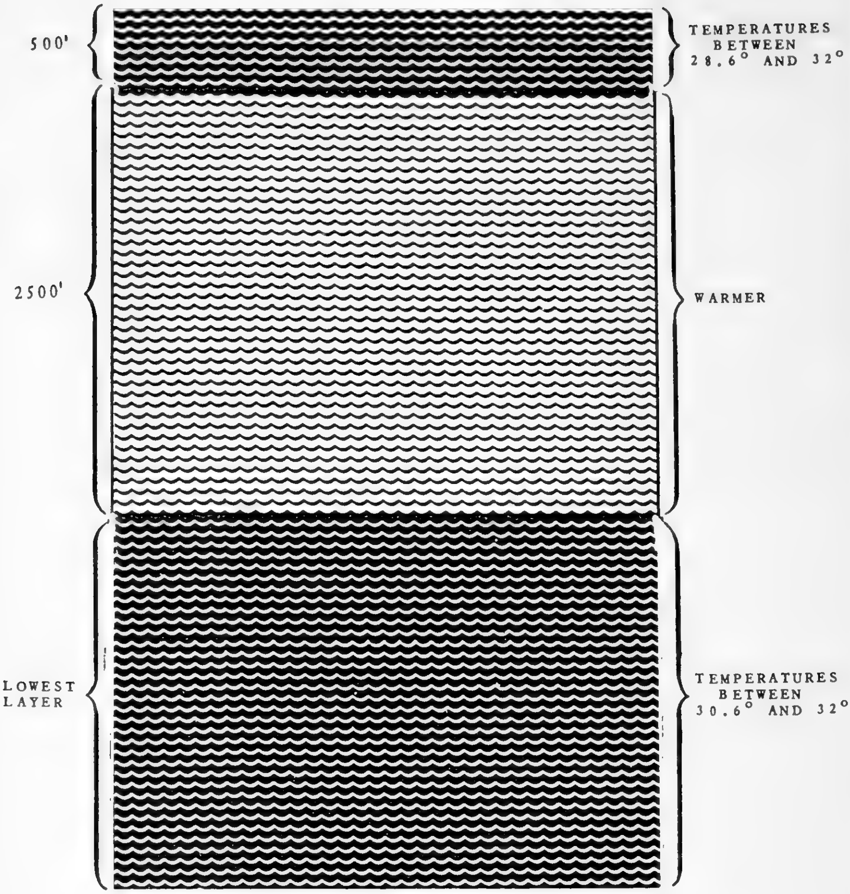


Figure 2-12.—Three layers of water.

dips under the colder arctic waters and which circulates in a counterclockwise direction. The lowest layer is again colder water, with temperatures between 30.6° F. and 32° F.

MARINE LIFE

Although the waters are cold and are ice-covered for most of the year, they are not devoid of life. Fish are abundant in the shallow seas along the continental shelf and especially at the mouths of rivers. Seals, walrus, whales, and a few sharks are found. Several kinds of shell fish, jelly fish, and shrimp are abundant. Even at considerable depths, 3,000 feet or more, diverse mollusks, larvae, medusae and crustacea are found in large numbers. These smaller forms of marine life provide the food for the walrus and seals.

There are also several varieties of seaweed found along the shoal and bank areas.

"The world's greatest fishing grounds are on the fringes of the Arctic, with life abundant throughout polar waters," Hayes writes.

GEOGRAPHY OF CANADIAN EASTERN ARCTIC

The Canadian Eastern Arctic is often defined as the area north of the treeline in Canada which is served from the Atlantic Ocean and Hudson Bay. For convenience, the region is expanded to include all the islands of the Canadian archipelago. The area includes the mainland west and north of Hudson Bay in the Keewatin District, the islands of James and Hudson Bays, the islands of the Franklin District and the mainland of northern Quebec. It contains about 700,000 square miles or 19 percent of the total area of Canada. As a distinct region, the eastern arctic presents a natural environment and a combination of problems and conditions which are dissimilar from those of the western arctic and the Mackenzie valley.

COASTAL AREAS

The coastal areas of the mainland and the islands present every possible type of shoreline development ranging from the deeply indented mountainous eastern coasts of Baffin and Ellesmere Islands to the low swampy coasts of western Hudson Bay. There are very few beaches and those that do exist are limited in extent. Small islands are numerous along the coasts of the larger islands and scattered throughout the bays.

Most maps present the arctic islands as separate and distinct units. This is not everywhere the case, however, especially in winter. The open channels become ice bridges and the islands are linked together. In fact, ice persists in some of the water areas even through the summer, as in the McClintock Channel and Victoria Strait joining Victoria, King William and Prince of Wales Islands into a common unit throughout most years. The same condition prevails in the Parry and Sverdrup Islands, essentially uniting them to Axel Heiberg Island. Along the shores of the other northern islands ice begins to form about the end of September, extending outward as the temperature lowers. The wider channels either freeze over completely or become blocked with pack ice. This effectively links the islands together and provides easy surface travel from one island to another. The winter ice, especially that lying immediately offshore, is a boon to winter travel.

Figure 2-13.—Hudson Bay area.

Along the shores of Hudson Bay and Strait the ice begins to form about late October and builds outward to a distance of 5 to 7 miles. The thickness of the ice varies. In protected inlets the ice usually is about 5 feet thick as a winter maximum. Outside these sheltered places the ice is subject to the effects of storms which may raft the ice to thicknesses of 15 to 20 feet. By November the entrance to Hudson Strait is blocked by pack ice, and although the Strait does not freeze from shore to shore the center of the channel is filled by pack ice moving both east and west with the currents. By the end of June the ice begins to break up and drift toward Hudson Strait, thus clogging the channel during most of July. The Bay and Strait are usually open to navigation during late July, August, September, and October, depending on the direction of the prevailing winds. Early November again sees this area being cut off from outside surface communication as the sea-ice begins to form.

TOPOGRAPHY

Underlying most of this area are pre-Cambrian rocks of the Canadian shield, with a belt of sedimentary rocks extending through the central arctic islands and including most of the far northern and western islands. Erosion and weathering of the pre-Cambrian rocks in general results in more rugged land forms while the sedimentary rocks result typically in level or low-relief forms.

Much of this area was glaciated during the most recent ice age which covered most of Canada with a sheet of ice several thousands of feet thick. There are today several areas of permanent ice caps. Glaciers and snow fields cover large sections of Ellesmere Island, Devon and Bylot Islands, and northeast Baffin Island. As a result of the decrease in load when the main ice sheet retreated, the land rose and ancient beach ridges and gravel terraces are now found as high as 500 or 600 feet above the present sea level. These terraced areas have proven to be valuable sites for settlements and airports, as well as being the most available source of loose, sorted material for road construction. In general, the lands subdued by glacial action have bare rounded hills of broken and frost-riven rocks separated by broad drift-covered coastal plain.

West of Hudson Bay the terrain of the drift-covered coastal plain is of low relief. The plain is about 50 miles wide at Churchill and broadens to the north, extending inland as far as Yathkyed and Baker Lakes. North of Chesterfield Inlet the land is more rugged, but to the west and east it slopes downward to the broad sandy valley of Back River and the low coast along Roes Welcome Sound. Melville Peninsula is a plateau with an abrupt drop to the west coast and a shelving, terraced slope along the central and northern sections of the east coast. West of the low coastal plain the interior plateau rises to an average altitude of 1,000 feet. Here the rolling surface is marked by rock ridges in a linear arrangement with narrow lakes occupying many of the intervening valleys.

There are countless lakes and streams forming a poorly integrated and undeveloped drainage system, due to the existence of permanently frozen ground which prevents underground drainage, and to the disruptive effects of glaciation. The three main rivers, Kazan, Dubawnt, and Thelon drain toward the northeast across the interior plateau in a general alinement with the bare rocky ridges and flow into Baker Lake and thence to Hudson Bay through Chesterfield Inlet. In many places along their courses they broaden out into lakes. Although these rivers are fairly well mapped as a result of being used as routes of exploration and penetration, they are difficult to identify from the air because of the abundance of unmapped rivers and lakes in the area.

North of Hudson Bay and to the South of Melville Peninsula lies

Southampton Island. It is the largest island in the bay. The southwestern two-thirds of the island is relatively low, flat limestone country with sloping terraces marking the ancient beaches, and broad belt of shoal ground fringing the coast. The northeastern portion is difficult of approach because it is frequently blocked by drift ice from Foxe Channel. The land in the northeast rises abruptly from the limestone plain into rugged mountains with altitudes of 1,000 to 1,500 feet. Southampton Island, together with Coates and Mansel Islands to the southeast, form the northern limit of Hudson Bay. The latter islands are of low relief.

The Ungava Peninsula lies to the east of Hudson Bay and is mainly a rolling plateau with low, bare, rocky hills, and broad valleys containing unnumbered lakes and streams. The low areas are covered with glacial fills of boulders and gravel. The plateau rises rather abruptly from a narrow coastal plain along Hudson Bay to heights of 1,000 to 2,000 feet, and slopes gradually downward to the northeast to Ungava Bay.

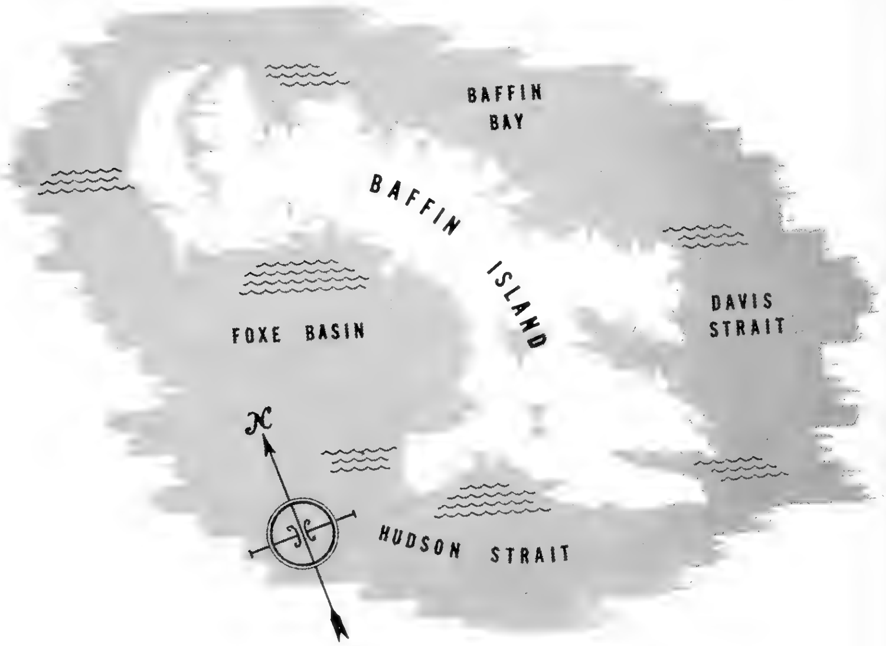


Figure 2-14.—Baffin Island, fourth largest in the world.

This plateau has been little explored and is inadequately mapped. The peninsula is fringed by many small islands. Ungava Bay indents the northeast coast. The bay is about 140 miles wide at its mouth and extends southward a similar distance. Into this bay empties the George River and the Whale River, draining the extreme eastern portion of the plateau. Between these rivers the coast is broken by three mud-filled bays. The land rises from the rocky hills of the coast to the irregular uplands. At Fort Chimo the Koksoak River enters the bay and forms banks and shoals to a distance of about 10 miles into the bay. The Koksoak is formed by the joining of the Larch and Kaniapiskau which drain the central plateau. The Leaf and Payne Rivers drain the area west of the bay. All of these rivers are characterized by extended and regular raised terraces along their courses and by numerous rapids.

Northern Labrador is mountainous with penetrating fiords, is mostly treeless, and is formed of granite and gneiss. All three coasts are hemmed in by ice the greater part of the year.

North of the Ungava Peninsula of Labrador and separated from it by Hudson Strait is Baffin Island. This is the largest of the Canadian arctic islands and has an area of 230,000 square miles making it the fourth largest island in the world. The island is long and its much indented coastline is penetrated by three sizeable bays: by Frobisher Bay and Cumberland Sound on the east coast, and by Admiralty Inlet on the northwest coast. A high, rugged mountain range of crystalline pre-Cambrian rocks rises abruptly along the eastern coast to an average height of 5,000 to 7,000 feet, with some peaks reaching heights of 10,000 feet. Permanent snowfields and icecaps in some places bury or partially cover the sharp peaks and ridges, sending long twisting glaciers down the many valleys to the sea. The east coast is deeply indented by fiords with walls rising precipitously from the water, presenting a formidable barrier. Northwestern Baffin Island, like North Somerset Island to the west, is a rolling limestone plateau surfaced by disintegrated slabs of sedimentary Paleozoic rocks. Along Admiralty Inlet and Prince Regent Inlet the plateau forms vertical walls rising 500 to 1,000 feet. Most of the interior of the southern section of the island is a rolling plateau averaging 2,000 to 3,000 feet. The southern coastal upland dips to the north and west toward the broad, lake-dotted and swampy plain west of the two large lakes, Amadjuak and Netsalik.

Devon and Ellesmere Islands are the largest of the northern group of Canadian islands lying to the north of Baffin Island. The eastern coasts are steep and rocky rising to elevations of 3,000 to 5,000 feet in the interior tablelands. Ice caps occupy many of the elevated eastern sections and numerous glaciers fill the valleys. The western portion of the islands are made up of Paleozoic sediments. These form low plains extending several miles inland to the high cliffs of the crystalline rocks which make up the eastern ranges. The tundra-covered plains provide feeding grounds for large numbers of musk-oxen, caribou and arctic hare.

Axel Heiberg Island lies west of Ellesmere Island. Unlike the other Sverdrup Islands and the Parry Islands, it has high land in the interior with a low coastal area. The other islands have low, rolling terrain characterized by elevated beaches and terraces along the shores. Most are unglaciated.

The islands of the far northern groups which are underlain by sedimentary rock have no lakes and no established drainage patterns. The very small amount of precipitation in this area is a factor in this lack of developed systems of drainage. Victoria Island is the third largest in the archipelago. The islands are separated by only a narrow channel, and are very similar in character. Much of the shoreline and the interior of Victoria Island are unsurveyed. It can be assumed that it resembles Banks Island since it is of a like geologic structure. Banks Island is a rolling plateau with elevations up to 2,900 feet in the southern part. The coast is broken by many small bays.

TABLE III

Areas of Principal Canadian Arctic Islands

Island:	*Area square miles (approx.)*
Baffin	230,000
Ellesmere	41,000
Prince of Wales	15,000
King William	6,200
Melville	20,000
Victoria	60,000
Somerset	12,000
Banks	25,000
Devon	24,000
Bylot	4,970
Cornwallis	2,590
Bathurst	7,300
Prince Patrick	6,700
Borden	4,100
Isachsen	1,000
Ellef Ringnes	3,250
Amund Ringnes	1,800
Meighen	360
Axel Heilberg	13,200
Southampton	17,800

On the whole the climate of the Canadian Eastern Arctic is relatively dry and cold. The influence of the many water areas is shown in the modification of the autumn and early winter temperatures, as compared to continental areas of similar latitudes. However, temperatures average below freezing in September. The autumn days become shorter and ice is formed on small water bodies by October. Approximately half of the total snowfall occurs in autumn, which is usually the stormiest time of the year.

Winds in gale proportions may occur at any time and coupled with low temperatures they cause considerable human discomfort through increased bodily heat loss (windchill factor). The coldest month is February at most stations. The average mean temperature is between minus 20° F. and minus 30° F., with absolute minimums going to minus 50° F. to minus 60° F. The winter is long, dark, and severe. Mean temperatures below 0° F. may be expected from November to April. Only small amounts of snow fall in the winter although it is a stormy and windy period. Because the rate of evaporation is low, the snow remains on the ground all winter except where it is swept away by the wind. Snow depth is greatest in April.

Spring comes late and is evidenced more by an increase in daylight than by a marked rise in temperature. Minimum temperatures are still low and in many cases the lowest temperatures of the year are reported in March. The water areas, now frozen, tend to intensify this cold. By June the mean temperatures average above freezing. June, July, and August are cool, with July being the warmest month. Average summer maximum temperatures are in the 50's but temperatures of 84° F. have been recorded at Chesterfield and 81° F. at Lake Harbour. A secondary snowfall maximum occurs in spring and some rain may fall in summer.

The summer is short and the frost-free growing season varies from only 29 days in the northern islands to a maximum of 67 days at Chesterfield. This short growing season and the general lack of soil minimize farming possibilities. During the summer the southern part of the eastern arctic lies under the influence of the cyclones, bringing cloudy, humid, and cool weather.

The summer is the season when fog is most prevalent, especially over the sea. It constitutes one of the greatest hazards to travel along the coastal areas. Relatively warm air from the land condenses when it contacts the cold arctic waters. Low clouds and fog may occur on as many as 15 to 25 days in any one summer month. Hudson Strait is probably the foggiest place in the Eastern Arctic. Fog is less frequent during the winter.

VEGETATION

In the short summer when there is constant daylight plants and grasses flourish wherever soil is present. Hundreds of species of plants rush through their life cycles in the 1 or 2 months when growth is possible. Lichens and mosses grow in the less favorable areas, although many sections have no vegetation cover at all. The lichens are the chief economic plants because they are the staple food of the migrating herds of caribou. There are very few plants which are edible for humans, but the wild life depends upon the vegetation, such as it is.

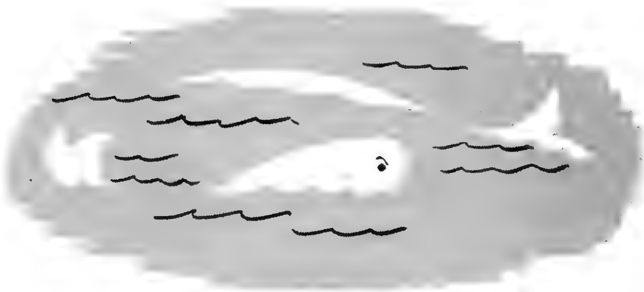


Figure 2–15.—White whales.

ANIMAL LIFE

As far as the natives are concerned, the wild life is of primary importance as a source of food, clothing, shelter, and implements. However, in the eastern arctic game is not abundant and hunting is carefully controlled for the protection of the natives. Caribou are one of the most important land animals. They range in the tundra areas west of Hudson Bay and approximately 3 million migrate between this area and the Great Slave and Great Bear Lakes. Smaller herds live on western Baffin Island in the lowlands and interior uplands. Polar caribou, a smaller species, and musk-oxen are found living on the scant vegetation of the far northern islands. The polar bear is of lesser importance, although its meat provides dog food and its fur is used for bedding and robes.

Sea mammals are a vital factor in the lives of coastal Eskimos.

Walrus are less plentiful than in earlier years, but they are the major source of dog food. The Eskimos prefer seal meat, which is their staple diet in the coastal eastern arctic. There are several species, but the ringed seal and the bearded seal are the most numerous. They feed along the coasts and in the fiords on plankton, and usually stay near the open pack ice. Whaling in the eastern arctic almost disappeared with the extinction of the larger whales. White whales and narwhal have some local importance.

Fish are not as plentiful as had at one time been supposed. Arctic char is the most common food fish and an important part of the Eskimo diet. In the spring and autumn the char are caught in the streams, but in the summer they usually go out to sea. Fish grow slowly in far northern waters and attempts to develop a fishing industry has not been successful because of the fairly rapid depletion of fish in any one area.

In the summer geese and ducks nest in the swampy areas and many birds are to be found throughout the mainland and island sections.

Fur trade is a somewhat unstable economic factor in the eastern arctic. The fur of the arctic fox is the chief export. Total fur yields, including white, blue, and red fox as well as some others, range in value from $250,000 to $700,000 annually.

RESOURCES

Detailed exploration has not been made in the Eastern Arctic to ascertain all possible mineral resources. Some deposits of nickel, copper, platinum, gold, and silver have been found along the west coast of Hudson Bay. An extensive iron ore deposit has been found recently in central Ungava, and plans are going forward for its exploitation. In the Belcher Islands iron bearing formations have been assayed as containing too much silica to make them profitable for commercial development. Some low grade coal and lignite have been a source of local fuel in northern Baffin Island but they lack commercial value. More thorough surveying and prospecting may disclose mineral wealth unknown at present to bring industry and population into this region.

HUMAN GEOGRAPHY

The present population is small, although four-fifths of the total Canadian Eskimo population live in the eastern arctic. The climate, topography, and resources have limited, and to some extent have determined, the spread and density of the population. The white population, numbering about 150, lives in the 30 or more trading posts and missions throughout the area. There are probably 5,000 to 6,000 Eskimos scattered throughout the region north of the treeline, which forms the boundary between the Indians and the Eskimo. Owing to the relative remoteness and inaccessibility of the areas in which these Eskimos live, they have been little influenced by the white man. Usually their only contact is when the Eskimos assemble at the Hudson Bay Company trading posts and at the missions, for the arrival of the annual supply ship in summer. During the rest of the year they migrate. In the winter they divide their time between fishing through the ice, hunting seals along the coast, and tending trap-lines. Their winter homes are snow-houses. The summer is usually spent near the coast or on islands where fish, seals, and walrus provide food, clothing, and fuel. Tents of skins are used in the summer camps.

The seasons not only determine the activities of the Eskimo and white population, but they also prescribe the mode of surface transportation. Summer overland travel is almost impossible in many places because of the water-logged condition of the ground and the numerous lakes. Most transportation in this season is by water, although the navigation of ships is sometimes made difficult by the prevalent fog. In the winter, the dog-team and sled are the principal means of transportation. Coastal travel is along the "highways" of coastal or littoral ice which builds out from the shore. Overland travel by sledge usually begins about December when sufficient snow has accumulated to allow the runners to glide easily.

Spring and fall offer problems to surface transportation. The snow disappears quickly in spring and the surface of the ground begins to thaw making land travel extremely difficult. At the same time the river and sea ice begin to rot and are unsafe for sled travel. But still too thick for the small schooners and boats to penetrate. The reverse of this is true in fall before the land is snow covered and while the ice is thin and newly formed. In these seasons surface transportation is virtually stopped. Air travel would seem to offer the only all-season transportation, but even this is not without spring and fall problems. Fog, overcast, and bad weather are most common in these seasons. Although floats can be used in summer and skis in winter, the difficulties of having planes properly equipped to land during the break-up and the freeze-up are serious problems in air transportation. All northern navigations are especially acute in the eastern arctic because of the proximity of the north magnetic pole area.

It should be noted that in the areas where the Eskimos have come into closest contact with the white man they have become increasingly dependent upon the white man for food, clothing, and equipment, and have adopted many of the white man's ways. The Eskimos of the Western Canadian Arctic (between 1,500 and 1,700 in number) have become most closely identified with the white man's ways and views, while those of the central mainland area remain the most primitive. The eastern arctic native falls well in between these two positions. It is in the western arctic that the fur trade has its greatest development and plays the greatest part in the native economy. The Government's attempt to interest some of these natives in reindeer herding has not been too successful.

It is a matter of military importance to have an understanding of the culture and capabilities of the Eskimos, along with major health problems endemic to the area. The natives are susceptible to trichinosis, rabies, respiratory diseases, tuberculosis, and venereal diseases.

GEOGRAPHY OF ARCTIC ALASKA AND WESTERN CANADA

In western Canada, the treeline swings north, approaching the coast at the delta of the Mackenzie River, and continuing across Alaska along the southern foothills of the Brooks Range. Using this as a delimitation of the Arctic, it is seen that only a relatively small area in western North America can be considered true arctic, as compared with the eastern portions. Most of the Yukon and Alaska are subarctic. Summer isotherms tend northwest to southeast. There is a gulf of warmth from Hudson Bay to Aklawik.

ALASKAN ARCTIC

The arctic slope of Alaska widens west of the Yukon upland region. The coastal plain is flat to gently rolling, bordered on the seaward edge by beaches and lagoons separated from the ocean by bars and spits. Numerous small islands fringe the shore. The plain is drained by many small rivers and the larger Meade, Colville, and Noatak Rivers. West of the valley of the Colville, the coastal plain is dotted by many lakes. The main settlement of this area is at Point Barrow, with smaller Eskimo villages and trading posts at Wainwright, Point Hope, and Kotzebue.

Between the arctic slope and the drainage basin of the Yukon River lies the Brooks Range. This is a relatively low mountain system in comparison with other Alaskan ranges. It rises to elevations of 9,000 to 10,000 feet in only a few peaks. The range

Figure 2–16.—The beach at Kiska.

is not a continuous chain but is made up of individual mountain groups including the De Long, Baird, Schwatka, Melville and Endicott mountains to the south, and the Franklin, Romanzof and Davidson mountains to the north. Between these groups there are low gaps forming passes both east-west and north-south. The mountains are treeless except for small willows growing in the canyons and ravines. Mosses, lichens and small plants cover most of the area.

WESTERN CANADIAN ARCTIC

The coastal plain is narrow or absent over most of the Western Canadian Arctic with the exception of the Mackenzie River valley. The delta fills an area about 125 miles long and 50 miles wide. On the east the low Caribou Hills mark the edge of the delta and on the west the plateau of the northern Yukon mountains abruptly rises from the river flats. The delta has innumerable lakes and distributaries. The main channel of the Mackenzie River keeps to the eastern side of the delta. Silt carried by the river is deposited at the mouth, thereby changing the shoreline and island detail. The banks along the channels are low and the delta is for the most part a marshy area, difficult to traverse. Separated from the delta by a narrow channel is Richards Island whose undulating, lake-dotted surface rises to 50 feet or more, considerably higher than the level of the delta. The entire area has been glaciated.

The main settlements in this section are Arctic Red River, Aklavik and Port Brabant (Tuktoyaktuk). These are small ports serving the river steamers.

Permafrost underlies the entire region, including the plateau of the Canadian shield, the sedimentary basin of the Mackenzie, and most of Alaska. The surface of the ground thaws in the summer to depths varying from 3 to 4 inches on the north slopes, and to 24 inches or more on the sunny slopes.

There is a great variation in the ice conditions along the coast from year to year. In general, the main pack breaks away from the shore ice by late May. Bering Strait is usually ice free by the first of July. Point Barrow may open up by early August, but occasionally ice remains until the first of September. The shifting winds and currents may at any time drift the pack ice in to the shore. These forces have been known to pile the ice onto the shore over the top of 75-foot bluffs, even burying Eskimo camps in a matter of a few minutes. A lead may open up in summer between the heavy pack ice of the polar basin and the shore along the whole western arctic coast. This allows limited and hazardous navigation, in great contrast to the rather active summer sea travel in the eastern arctic of North America.

The region is devoid of trees except in some of the sheltered places on the Mackenzie delta, where scrub willows and dwarf birches are found. Tundra and muskeg cover the area, with mosses and lichens on all but the most exposed rocks of the plateau and uplands.

Precipitation is light although snow cover in late winter may exceed two feet in depth, and snow may fall at any time of year. Some snow and ice persist through the summer in protected places. Visibility is poor in summer when fog and rain are common. Severe storms occur in the winter. Wind is an important factor throughout the entire year and has a high average velocity over most of the arctic coastal area of Alaska and Western Canada.

This area is of economic and strategic importance in view of a possible Naval Petroleum Reserve back of Cape Simpson, and the proximity of the Eldorado mine on Great Bear Lake, and the oil fields around Norman Wells.

For general information on petroleum development at Point Barrow refer to articles by K. Marshall Fagin in the *Petroleum Engineer* for August, September, October, and December 1947. From those articles much can be learned about this area of arctic America.

GEOGRAPHY OF NORTH AMERICAN SUBARCTIC

When the Subarctic of North America is delimited in terms of climate, as already outlined, the region extends much farther south than would normally be realized. All but the southern edge of Newfoundland is within this region, as is most of the land in Quebec, Ontario, and Manitoba. The northern half of Saskatchewan and Alberta also are subarctic as is the northeastern portion of British Columbia. The Mackenzie valley, the Yukon, central and southern Alaska, and the Aleutian Islands, form the remainder of this wide belt of coniferous forests, comparable to the taiga of Siberia. Thus about 60 percent of Canada and most of Alaska have a subarctic environment.

COASTAL AREAS

The eastern edges of the North American Subarctic are the deeply indented, rugged and mountainous coasts of Labrador and northeastern Newfoundland. High, barren ranges rise abruptly from the ocean and the fiords are deep and lined by steep, rocky cliffs.

The Labrador current which flows south along those coasts brings with it floe ice and bergs during the summer. In the winter, the coasts are blocked by heavy pack ice. The combination of ice half the year and cold water the rest of the year produces a marked influence on the environment of the shore.

Fog often covers the coastal areas, particularly in Newfoundland where the mingling of water from the Gulf Stream and the Arctic make ideal conditions for fog. Inland the weather is frequently clear even when dense fog lies along the shores.

The most striking feature of the coastal area on the west side of this subarctic region is the Aleutian Island chain. Active volcanoes and cones characterize these islands that stretch from the Alaskan Peninsula to within a few degrees of longitude of the Kamchatka Peninsula. It is one of the most active volcanic areas of the world. There are hundreds of islands of varying size in this group. Their shorelines are extremely irregular, with many deep coves and inlets.

The Aleutians, especially during the summer months, are frequently shrouded in fog due in part to the contact of the arctic waters of the Bering Sea to the north, and the warmer waters of the Japanese current to the south.

TOPOGRAPHY AND DRAINAGE

Most of this subarctic region was scraped and eroded by the vast continental glaciers of the Pleistocene. The relief is thus subdued, and vast stretches of plains characterize the central portions of the region, while the remainder, except for the valleys of the Mackenzie and Yukon Rivers, is mostly rolling plateaus and dissected uplands, with rugged mountains in southern Alaska. The soil mantel is very thin and the entire area is underlain by permafrost.

The valley of the Yukon River has many areas of flatlands, some of which are thousands of square miles in extent. The river, with its many tributaries, takes a circuitous route through the rolling mountains of the Yukon plateau and the low hills in the depression between the Brooks Range and the Alaskan Range, to empty into Norton Sound, where it is building a swampy delta. The Bering Sea coasts of Alaska are generally adjoined by lowlands. Back of the shallow Bristol Bay lie a large number of lakes at low elevation. Norton Sound is likewise surrounded by low land. Kotzebee Sound is surrounded by lagoons, barrier beaches, and flat moors. Harbor conditions throughout are unfavorable because of shallow water and of insufficient protection.

Separated from the Yukon River by the northern Rocky Mountains and the Yukon plateau, the Mackenzie River drains the eastern slope of these uplands, and flows along their foothills, receiving water from the Peace and Liard Rivers and the two vast lakes of the north, Great Slave Lake and Great Bear Lake. Because the Mackenzie has such a great latitudinal extent, there is a difference of about 3 weeks in the length of the navigation period between the northern and southern sections. Delay in the navigable season is also due to the fact that although the river ice usually breaks up in middle or late May, the ice along the shores of Great Slave Lake does not break away until early June and the lake is not ice-free until mid-June. Ice begins to form again in October in the delta. Freeze-up on the upper Mackenzie comes in mid-November and on its southern tributaries by late November.

Other than these two major systems, the rest of this subarctic region is drained by ill-defined streams which wander aimlessly over the glaciated surface, where irregularities cause numberless lakes to form. In the summer, these areas are alive with hungry mosquitoes, and the soft, water-soaked ground makes transportation overland extremely difficult or impossible.

It should be noted that the absolute extremes of cold are experienced in the Subarctic rather than the Arctic. There is no nearby ocean area to help modify the climate. The Alaskan ranges cut the Yukon and Mackenzie valleys off from the maritime western winds. The active layer of the permafrost quickly freezes during the long nights of semi-darkness of winter, and the rivers and lakes become frozen and snow-covered. In the winter, cold air from northern Greenland and the Arctic Sea sweeps across the prairie in the Baker Lake area and, under anticyclonic control, flows into the Yukon where the clear skies and stagnant air conditions promote tremendous refrigeration. Temperatures have been recorded as low as minus 76° F. at Tanana, minus 69° F. at Whitehorse, minus 74° F. at Fort Snag, and minus 78.5° F. at Good Hope. This same area experiences high summer temperatures. The range of the temperatures is extreme, with average annual ranges about 134° F.

With all this extreme low temperature, there is relatively little snowfall. Three to ten inches a month is the general average. Over much of the area the wind keeps the snow moving about, although the forests act to break the force of the wind. The heaviest drifts of snow are just south of the treeline where snow from the open tundra accumulates. The wind which carries the snow across the open areas is slowed in velocity as it strikes the forests. With less velocity its carrying power is reduced, and snow is deposited in high drifts just inside the forest area.

VEGETATION AND ANIMAL LIFE

Over most of this region there is a heavy growth of coniferous forests. These dense forests are interspersed with peat bogs and muskegs. Like the extensive taiga of the Soviet Union, these forests have been ravaged by fires and exploited by lumbermen. In the more exposed areas and in the northern fringes of the forest, the trees are smaller and more bushy. In contrast to these forested areas, the Aleutian Islands are essentially treeless. Grass, shrubs and tundra vegetation cover most of the islands, although many barren rocky areas exist without noticeable plant life.

The largest animal in the North American Subarctic is the Kodiak bear weighing from 1,200 to 1,500 pounds. However, his habitat is essentially restricted to the one island, and elsewhere the brown bear, wolves, foxes, mink, marten, beaver, and otter are common. The deer, moose, and caribou are also found in the forests.

The rivers and lakes abound with fish. The salmon fishery is of major economic importance. In the waters off the Pacific coasts there are numerous fish of commercial value such as halibut, mackerel, flounder, and Alaskan herring. Whales are somewhat less numerous since the onslaughts made upon their numbers by the early whalers. Alaska fur seals, now protected by international agreement, are fairly abundant in the Bering Sea, particularly off the Pribilof Islands. This controlled seal industry produces about 60,000 sealskins a year. In addition to the larger fish and sea animals, the ocean waters have large quantities of shrimp, crabs, clams, and small, even microscopic marine fauna.

RESOURCES

The mineral resources of this area are vast in contrast to the rather limited mineral resources of the Arctic. The gold of the Yukon is still a source of considerable yearly income. Its recovery has created much in the way of industry. It must be noted, however, that very often gold mining, especially placer mining, does not establish permanent communities because the prevailing attitude over most of the Yukon and Alaska has been to recover the gold quickly and to leave.

Another important gold mining center is at Yellowknife on the north shore of Great Slave Lake. Mining has been conducted in this location since 1934. By 1942 the yearly gold production amounted to almost 4 million dollars. During the war, however, production was almost stopped.

About 40 percent of the world's radium is produced at the Eldorado Mine on the eastern shore of Great Bear Lake. The silver-pitchblende deposits were found in 1930, but only in recent years has there been any real development. There is now a modern mining and milling plant located at this deposit. Another uranium deposit is being mined at Goldfields on Lake Athabaska.

The whole contact zone between the ancient rocks of the shield area and the recent sediments of the geosyncline appears to be rich in minerals. There are also oil fields near this contact zone.

Oil seepages in the vicinity of Fort Norman were first reported as early as 1789 by Sir Alexander Mackenzie. The first drilling was made in 1920, but not until much later was any serious effort made to develop the field. Just prior to, and during World War II, a small refinery was built at Norman Wells to serve the area. To aid in the defense of Alaska, a trail and a 4-inch pipeline were laid from Norman Wells to Whitehorse on the Yukon River, some 600 miles to the west.

Aside from the minerals and petroleum resources, the forests provide a source of natural wealth, as does the potential water-power.

HUMAN GEOGRAPHY

The coniferous forests are the home of the Indians. In scattered village communities, they subsist on their fishing, hunting, and trapping. Trading posts are their commercial centers.

Men from the more temperate zones have superimposed their culture on the native way of life in those areas where natural riches have attracted this kind of settlement. Lumbering, mining, and industry have brought many thousands of people into the Subarctic.

For a more permanent colonization of these lands, the Governments of Canada and the United States have encouraged agricultural developments. The Peace River area of Canada and the Matanuska Valley of Alaska are examples of such government subsidized agricultural experiments. Farming is laborious, however, and full of risks because of the ever-present threat of frost. Wheat, barley, oats, potatoes, and hay are grown, and in a more limited extent, garden vegetables are cultivated to supply the northern settlements. Some dairying and live stock raising is carried on, utilizing the abundant grassy meadows as summer pastures, but frequently having to rely upon imported feed in the winter.

The problem of remoteness is one factor contributing to the delay in the development of this area. The means for getting into and out of these areas are very limited. Partly in an effort to make better use of the northern lands, and the shorter route to Europe by way of Hudson Bay, a railroad was built from The Pas in Manitoba to Port Churchill. This was to be a major wheat shipping route, and tremendous elevators were built at Port Churchill to store the grain during the time when Hudson Bay and Strait were closed. It has not lived up to expectations, partly due to the fact that ships plying this route must carry extra insurance because of the ice hazard, partly because in-bound trips must be made with ballast, and partly because of the very short season in which shipping is possible. However, despite these difficulties a considerable tonnage of grain is shipped over this route.

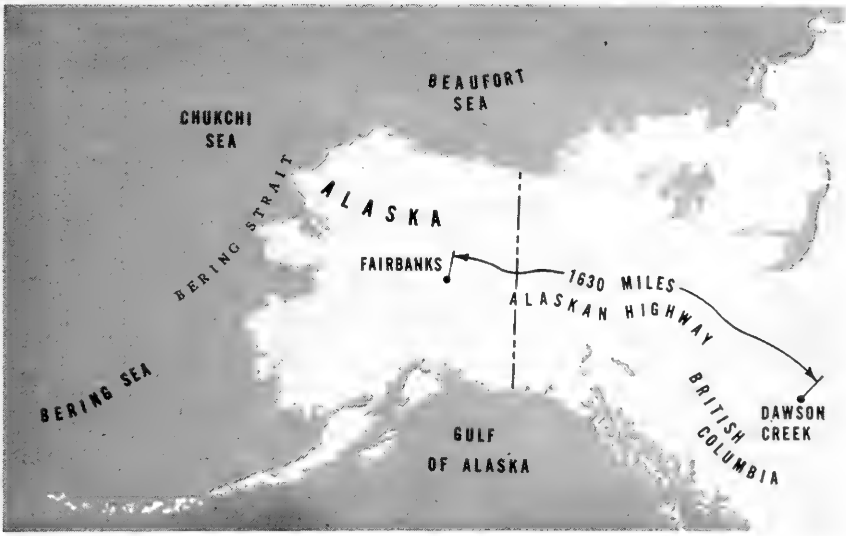


Figure 2–17.—The Alaskan Highway.

As a war measure, the Alaskan Highway was constructed by the United States to provide a safe military route into central Alaska. In 1942 the highway was built from the end of the railroad at Dawson Creek, British Columbia to Fairbanks, Alaska. The 1,630 miles of highway was rushed to completion in 8 months. Engineering problems of construction on permafrost and in areas of swamps and muskeg were given hasty consideration. The road has been put to heavy use and requires constant maintenance. Soil flow, slumping, icing, and buckling are only a few of the road troubles which clearly indicate that more study is needed in order to assure permanent and safe construction in such northern areas.

Similar problems exist along the Richardson Highway, leading from the coast into central Alaska, and along the Alaska Railroad from Anchorage to Fairbanks.

Air travel is the common means of transportation throughout most of the region. Even heavy mining and lumbering equipment is brought in by air, but the costs of such freighting make it prohibitive for all but the very large corporations. Passenger travel is probably most frequent by air since overland travel is extremely difficult in summer, due to the swampy soil conditions over much of the region.

Only by bringing life to the Arctic will the Arctic "come to life."

GEOGRAPHY OF GREENLAND, ICELAND, AND SPITSBERGEN

GREENLAND

The Danish island of Greenland is the largest island in the world, 1,650 miles long and 690 miles wide at its greatest breadth. Its interior is covered by a vast ice cap. The land surface beneath the ice is believed to be low in the center with mountain ranges along the eastern and western coasts. The eastern ranges reach heights of 11,000 feet. Ice fills the saucerlike, central basin. There are two domes on the east side of the cap, one at about 65° N. which rises to over 8,000 feet and one near 75° N. rising some 10,000 feet. From these domes the ice surface slopes gradually downward, being almost flat across the interior of the island, and becoming steep near the margins.

The ice at the edge is relatively thin with bare, rocky peaks or nunataks protruding. Glaciers flow down from the cap through the many fiords that dissect the coast. The inland ice is fed from

Figure 2–18.—Greenland, largest island in the world.

the east, and suffers loss mainly in the west. The glaciers are deeply crevassed in their lower courses and are difficult to ascend.

Surrounding the ice cap is an almost continuous ice-free coastal zone varying in width from 1 to over 100 miles. The most extensive ice-free land is on the western coast from latitude 65° N. to 69° N. and in the extreme north in Peary Land. The coastal area is very rugged, with numerous islands and bare skerries offshore. Deep fiords extend inland for miles, offering easy penetration into the island, but the fiords and the mountainous promontories make land travel along the coast almost impossible. The southern coast is especially rugged, and the east coast is fairly unapproachable because of the heavy off-lying polar pack ice.

In the north, the island has the form of a rectangle and in the south, a wedge. Thus, it is similar to the great continents with their broad shoulders in the north and narrow ends in the south.

The southern third of Greenland is a plateau inclined toward the interior zone. On the west side it may be considered to extend to a point south of Disko Bay and on the east side to very nearly the same latitude (68° N.). The land-forms are generally alpine in character. The mountains at the southern end rise in jagged ridges to over 6,500 feet. They are dissected by fiords and sounds, and furrowed by innumerable glaciers that arise from separate ice caps. On the east coast up to Angmagssalik, the principal settlement, the coastal belt practically maintains the same altitude and degree of dissection. However, the inland ice leaves only a narrow strip scarcely 3 miles wide free of ice in the extreme southeast. On the west coast from as far south as Julianehaab, there are rounded topographic forms with lesser height, mostly under 4,000 feet. Here, along a 500 mile stretch of coast, these sorrel forms prevail with few exceptions. At the same time, the ice-free land grows in width to as much as 100 miles as one proceeds northward.

At latitude 69° N. on the west coast the picture changes. In place of the narrow, transverse fiords, there appear broad, round bays, peninsulas, and islands. The topographic form here is, on the whole, that of an elevated peneplain rising to 7,000 feet or more. Disko Island is the largest in the area with an average altitude of 3,500 feet. There is no inland ice on any of these three prominent landmarks. The snow line in the marginal belt lies below 3,500 feet, but on the inland ice it rises to 5,000 feet. Boulder trains, boulder beds, and extensive ridges testify to the greater extension of the ice in former times in the lake-studded region.

Figure 2–19.—Weather station, Thule, Greenland.

The Upernivik region from Svartenhuk to Cape York is a labyrinth of skerries. The whole strip of land, here narrowed down, is broken up into a host of islands mostly of moderate height and rounded shape. Some of the sounds have depths up to 500 fathoms, whereas others are barely covered with water. A prominent feature is Melville Bay, with the inland ice reaching to the very edge of its shores at nearly every point.

A feature of the Cape York district is Smith Sound separating the large Hayes Peninsula back of Cape York from Ellesmere Island. The peninsula is a plateau 2,200 feet high divided in its central part by the deep Inglefield Gulf.

North Greenland in the west is separated from the Hayes Peninsula by the Humboldt Glacier, largest in the Arctic. The northernmost part of the island, from west to east, is divided into prominent areas not covered by inland ice, named in order: Washington Land, Nyeboe Land, Peary Land, and Prince Christian's Land. In this area several long fiords penetrate inland, the most prominent being Sherard Osborn, Victoria, Independence, and Danmark. In general the north coast is alpine in character with peaks more than 3,500 feet in the west, rising to 6,500 in some places in Peary Land in the east. One of the interesting geographical facts is the relatively ice-free nature of this northernmost land area. Rivers and lakes develop when the snow melts in summer.

The northeast section of Greenland extends from Danmark Fiord to the seventy-fourth parallel in King Christian X Land. Here and farther south to Scoresby Sound, the fiord systems introduce a new type of coastal development. In the general aspect of the coast, long stretches of out-pouring inland ice alternate with broad, ice-free areas and large nunataks in the background.

Steep walled valleys and fiords penetrate inland. The ice cap here approaches the coast more closely than in north Greenland. At latitude 81°30′ N. the snow line or lowest limit of perpetual snow lies at sea level. Winter weather prevails the year around. This is the most forbidding area of the northern hemisphere.

Central East Greenland extends from 74° N. to 68° N. The middle section is characterized by gigantic fiords, reputedly the most beautiful in the world. The Scoresby Sound fiords system penetrates more deeply than any of the others in the whole of Greenland. It is comparable to a massive river delta.

GLACIAL MOVEMENTS

Several of the immense Greenland glaciers on the West Coast (notably Jacobshavn, Tarssuktok, and the great Karajak) produce over half of the bergs that float into the North Atlantic shipping lanes. When the glaciers flowing out from the ice cap reach the sea, large pieces of the ice calve and float away. In northern Greenland where the fiords and adjacent sea are frozen over during the winter, the icebergs can float away only during the short season when the sea-ice has melted. Off Peary Land and northwest Greenland the conglomerated polar pack ice persists throughout the summer. Consequently the icebergs are forced together against the end of the glacier and produce large masses of floating land-ice. This is similar to the shelf-ice of Antarctica, yet not quite so symmetrical in shape.

As stated above, the terrain of the coastal area varies from the hummocky topography which is most extensive to the towering, serrated mountains. The entire area is underlain by permafrost. Wherever soil exists, solifluction is common. The rock areas are undergoing rapid mechanical weathering due to the freezing and thawing of seepage water. There are no important rivers, and the short streams that do exist have steep, rocky courses.

The position of Greenland brings it under the influence of cyclones and fronts, particularly in its southwestern section. The island acts as a barrier because of its height. Only very deep disturbances cross it. However, these highs and lows determine the winds on the coasts. Usually there is a down slope sliding of the air at the surface. Cold air pours off the ice plateau and funnels through the fiords. These winds may occur in the nature of violent squalls, particularly in winter. The winds are most intense and persistent when pressure changes provide gradients which accentuate and strengthen the catabatic winds.

There is heavy snowfall on the ice cap even in summer. Relative humidity is constantly high. Over the entire island there is an average precipitation of about 16 inches a year. A notable exception to this average is the extreme southern section near Ivigtut which receives over 45 inches of precipitation a year. The far northern areas, on the other hand, are quite arid. On the interior plateau and in the north several feet of snow is almost constantly blowing around on the surface. Under the influence of strong winds the snow may be lifted to over 100 feet above the ice.

Temperatures on the icecap in winter average minus 40° F. Local temperatures may go up to 0° F. or down to minus 70° F. By the time this air reaches the coastal area it usually is about minus 40° F. In the ice-free coastal areas temperatures differ noticeably between the sea border and the interior of the fiords. In spring and summer the inner sections are warm, even oppressively hot. In winter this area is colder than the outer coasts. Local temperatures differ markedly in the winter between north and south. Southern Greenland is under the influence of cyclones over the ice-free seas, while the northern areas receive the full climatic effect of the ice- and snow-covered land and sea.

The warmer, ice-free southern end of the island with its abundant rainfall supports a luxuriant vegetation. Willows, junipers, birch, and aspen grow in open stands in the valleys. Most of these are low and stunted but willows have been found reaching to 30 feet. Associated with these thickets is a thick growth of shrubs and herbs. In the open places, grass grows in the meadows. In general, the vegetation consists of small plants, mosses, and lichens. Vegetation is sparse along the cold, foggy, and wind-exposed headlands of the fiords. The vegetation toward the north, along the margins of the island is predominantly shrubs and mosses with an increasing number of meadows. Large areas are covered with heath and swamps. The uneven surface has many lakes, which swarm with mosquitoes during the summer. Even the far northern areas support hundreds of flowering plants. Off the western coast there is verdant growth of seaweed and algae.

Although most of the animal life is confined to the coastal margins, foxes and birds have been found on the inland ice. The numbers and varieties of animals increase toward the north. This is due to the abundance of pasture areas and the relative safety from man. Reindeer, musk-oxen, wolves, foxes, lemmings, and ermine

Figure 2-20.—Summer scene. Holsteinsborg, Greenland.

are among the animals found. There are many birds along the coasts. The sea animals are also varied and numerous. In the north are found the Greenland whale, narwhal, whitefish, walrus, bearded seal, and polar bear. The hooded seal, Greenland seal, humpbacked whale, bottle-nosed whale, finback whale, and swordfish are found in the south. Smaller fish are abundant along the southern coasts.

Greenland is rich in scientifically interesting mineral deposits, but these are not of particular economic interest. However, no complete surveys have been made to ascertain the full mineral wealth. Denmark has been doing some surveying. In southwestern Greenland at Ivigtut a large deposit of cryolite has been mined for many years. This is an important source of a necessary flux in the production of aluminum. Some iron has been found along the west coast occurring in basalt. Recently lead deposits have been discovered. The trade items, in addition to cryolite, are fish, fur and graphite. Marine resources continue to be the foundation of Greenland's economy. The trade is mainly with Copenhagen.

There are approximately 20,000 people living on Greenland, of which some 19,500 are natives and 500 are Danes. The Greenlanders spend most of their time in hunting and fishing. There is some sheep farming in the southern districts. Most of the population is in the southern and southwestern areas.

The Danish government maintains a strict control over the area through its Government Board in Copenhagen, and has a trade monopoly to keep the natives from being exploited.

ICELAND

Iceland lies on the southern edge of the arctic region and in many ways it resembles the more temperate regions. The name gives an improper impression. In reality, the main feature of the island is the prevalence of volcanoes and hot springs.

COASTAL AREAS

The coasts of Iceland are of two distinct types. That of the northern two-thirds of the island is rocky, deeply penetrated by fiords, and marked by high seaward-facing cliffs. Shallow deltas have been formed at the heads of the fiords and along their sides where tributary streams reach the sea. Characteristically these deltas have been altered by marine action, and bars with shallow lagoons have been formed.

The southern coast is smooth in outline and has many stretches of sand and shingle shore. Lagoons and offshore bars are common. The character of this coast is probably due to the debris-laden melt waters from nearby glaciers. There are few harbors along this coast.

Occasionally the ice-drift from the north approaches the northern Icelandic coasts. When it does it not only constitutes a hazard to navigation and the fisheries, but it has a marked effect on the weather conditions throughout the island. The irregularity with which the ice appears makes it difficult to predict its occurrence. There have been long periods that were relatively free of ice. In those years when the ice appears, it is usually in sufficient quantity by April or May to hinder navigation. The ice is first seen off the northwest peninsula in December. It is carried along the north coast by the prevailing eastward current. Ice is rare on the southeast, south, and west coasts.

The coasts of Iceland offer many good natural anchorages especially in the fiords of the west, north and east coasts. The southern coast has few indentations and no anchorages of importance. The chief port is Reykjavik which handles most of Iceland's foreign trade. It acts as the collecting and distributing center. Nearby is the port of Hafnarfjoraur. There are six other ports which can be considered of major importance: Siglufjoraur, Vestmannaeyjar, Akureyri, Neskaupstaour, Seyoisfjorour, and Isafjorour. Most of the other harbors are fishing ports and stations.

TOPOGRAPHY

The lack of harbors along the southern coast seems to be related to the heavy sedimentation from the glacial waters. About one-eighth of Iceland is covered by glaciers, of which Vatnajokull in the southeastern section of the island is the largest.

The land surface shows a marked contrast between the features developed on the older rocks of the northwestern and eastern sections and those on the younger rocks of the central part of the island. The land forms of the older rocks are due mainly to erosion whereas the land forms of the sands, ashes and overlying lavas of the central zone are the result of earthquakes and rock accumulation. About one-quarter of the whole area of Iceland is sand and stone desert, and one-eighth is covered with lava. The central part of Iceland is built of younger accumulations of volcanic products. This process is still going on and there are several volcanoes which have been active in historic times. Volcanoes exist even under the glaciers, and in the sea off southwest Iceland.

Iceland is mainly a tableland with an average elevation of 2,500 to 3,000 feet. There are narrow borders of coastal lands and very small plains in the south and west. Very little of the island can be said to be lowlands. The highlands are considerably dissected by many valleys which cut into the tablelands from all sides. Flat-topped, steep-sided land forms characterize most of the area. Mountains rise above the general level as prominent features of the central zone. The slopes of the peaks and tablelands are covered by frost-riven, rocks, loose and angular. A common phenomenon seen in the higher areas is the arrangements of stones in ring enclosing mud. Also, stones in the pebbly flat areas may be sorted into rings with larger stones encircling smaller ones. Much of the grassland and the central desert area is covered by the hummocky surface. These features are a result of frost action and the permafrost which exists in some of the higher areas.

Over the whole of the island the soil is fairly uniform, being derived from the basic igneous rocks. On the highlands and on the desert regions near the glaciers, the soil has little organic matter. Nearer sea level the humus layer is thicker. In general, the soil is of poor quality.

DRAINAGE

The many constantly melting glaciers and the high rainfall of Iceland produce great run-off and rivers are numerous. In the rather extensive central desert, water is lacking because the water sinks into the porous and fractured lavas and volcanic deposits. Subsurface drainage from this area appears at the surface as springs along the desert borders. Both the sediment-laden glacial rivers and the clear nonglacial rivers are for the most part unnavigable because of their steep gradient, torrential currents and their shallow depths in the lowlands. In the dry summer, the clear rivers become small but the glacial rivers carry two to three times their normal volume of water. Lakes and waterfalls are common. The potentialities of the waterfalls for power are being increasingly utilized.

CLIMATE

Iceland is characteristically cool in summer and mild in winter. The North Atlantic Drift is mainly responsible for the winter mildness of the southern and western coasts. The coldest month in the coastal areas is February, with average temperatures ranging between 25° F. and 30° F. The warmest month is July with averages of from 48° F. to 51° F. Absolute extreme low temperature has been recorded at minus 21° F., and an extreme high at 87° F. Winter is mild for the latitude. However, the interior upland has average temperatures of below freezing for the 7 months from October to April.

The relative humidity is high throughout the year, while the absolute humidity is low, especially in winter.

Fog and poor visibility along the coasts are a considerable hindrance to navigation. Sea fog is most prevalent in summer but seldom penetrates inland or up the fiords. In the fiords, radiation fog and sea smoke are most common.

In general the climate of Iceland is damp. Evaporation is slow and the wet, cold, windy winter weather is unpleasant. The total precipitation varies from over 85 inches on the southern coast to less than 12 inches in parts of the northern coast. The coastal lowlands receive frequent snow fall during the winter, especially in the northeast peninsular area. Strong winds along the coast sweep most of the snow away, leaving large patches of bare ground.

VEGETATION

Most of Iceland is without a continuous mantle of vegetation. Even in the low coastal districts there are large areas of barren rocks, stony and sand deserts, and lava flows. Over half the island has no vegetation, while the other half is covered chiefly with grasses. There are no true forests, but birch bushes and dwarf willows are found in some places.

In the interior lava and sand desert area there are only scattered plants except in the locations of springs. In these cases are found dwarf willows, grasses, and sedges.

RESOURCES

Iceland is not especially rich in commercially important minerals. Only sulphur and Iceland spar are exported. The sulphur is recovered from deposits on or near the surface as Krisuvik and in the Myvatn district. The Iceland spar, which is a transparent variety of calcite used in optical instruments to provide polarized light, is found at Helgustaoir. The greater part of the world supply comes from this deposit.

Small deposits of lignite, peat and bog iron ore are found, but these are exploited only for local consumption.

HUMAN GEOGRAPHY

Almost all of the 120,000 people in Iceland live along the coasts, while three-fifths of the island is uninhabited. About a third of the total population live in or near the capital, Reykjavik.

The chief occupation of the people is in the fishing industry. Fishing grounds extend around the entire island. The productivity of the various grounds varies with the seasons, and causes a certain amount of migration on the part of the fishermen. The fishing grounds of the southwest and west are profitable in the early months, those in the southeast and south in May and June, and those in the north are fished in late summer and autumn. The chief catch is cod, although considerable quantities of coal fish, haddock and herring are obtained.

Agriculture is of less importance in the national economy. Only limited land of suitable quality is available. The rigorous climate and the infertile soil combine to make farming a very restricted activity, confined mainly to the valley bottoms along the coastal areas. Hay production predominates, with some cultivation of sturdy root crops such as potatoes and turnips.

The main land use is in pastures. Sheep raising is widespread, and cattle and horses are raised in large numbers. Of rather unique economic importance is the eider duck farming which has developed into quite an industry in Iceland.

Because the inhabited areas of Iceland form a ring around the coasts of the island and the central portion is devoid of people, the transportation system has developed mainly along the coastal plains and coastwise along the shores. Air transportation and sea routes to Europe and England have been highly developed to overcome the general isolation of Iceland.

SPITSBERGEN (Svalbard)

The islands of the Svalbard Archipelago lie on the continental shelf. West Spitsbergen is the main island, 235 miles long and 130 miles wide. It is wedge-shaped with the point toward the south. The coasts are deeply indented by fiords with Bell Sound, Ice Fiord, Wijde Fiord, and Kings Bay being the largest. The other islands surround it. The long, narrow Prince Charles Foreland lies to the west; Barents and Edge Islands lie to the southeast. Northeast Land is separated from the main island by the deep, narrow Hinlopen Strait. A little farther to the east lie Hope Island and the small islands of King Karls Land.

Spitsbergen lies about 450 miles to the north of Norway on the great circle air route between the vital centers of Soviet Russia and the United States. Table IV includes distances from Longyear City on Advent Bay to various places.

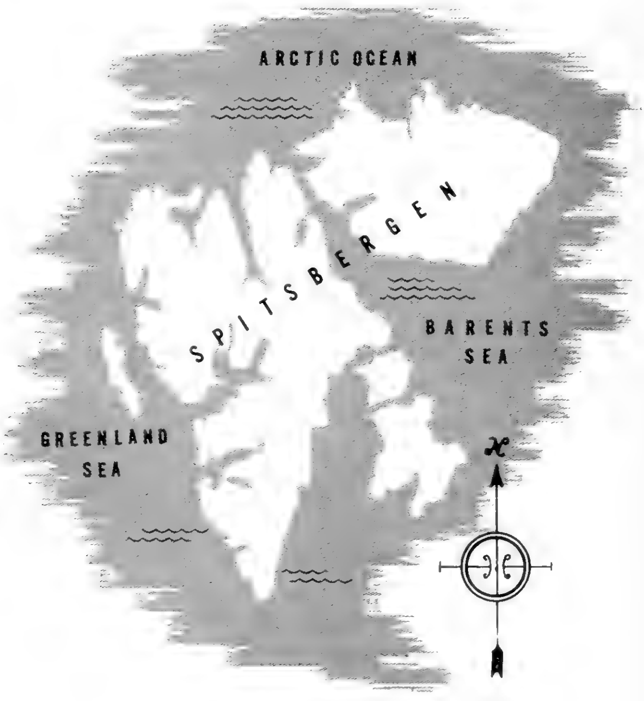


Figure 2–21.—Spitsbergen.

TABLE IV

Distance from Longyear City

To:	Distance (nautical miles)
Kola Gulf, White Sea	760
Archangel, U. S. S. R.	930
Dickson Island, Mouth of the Yenisei	930
Eyja Fiord, Iceland	930
Reykjavik, Iceland	1,100
Oslo, Norway	1,100
Helsinki, Finland	1,100
Bear Island	230
Jan Mayen Island	570
Murmansk, U. S. S. R.	625
Leningrad, U. S. S. R.	1,125
Stockholm, Sweden	1,136
Cape Farewell, Greenland	1,567
London, England	1,640
Montreal, Canada	2,745
Boston, Massachusetts	2,880
Seattle, Washington	3,095

TOPOGRAPHY

The coastal areas are a series of narrow crested mountains separated by fiords in which glaciers reach down to the sea. A notable feature of the coasts is the level plain and foreland area which lies between 70 and 100 feet above the sea. The mountains are not high, the highest being Hornsundtind of less than 5,000 feet. The interior plateaus rarely exceed 2,000 feet. The contrast between the western coastal mountains and the interior plateau is due to the geology. The west is a zone of folded rock whereas the interior is mainly horizontal strata. The slopes of the mountains and the massive tablelike land forms are covered with broken rock. The plateau is covered with ice and snow under which is a mantle of rock debris.

Within recent geologic time volcanic action has taken place. Thick diabase dikes and intrusions, and lava fields are found. In the northwest, along a prominent fault line, volcanic cones and hot springs occur.

ICE CONDITIONS

Alpine glaciers are numerous in the valleys of the western mountains. The tongues coalesce in many places to form fairly extensive ice fields. The glaciers are small and too low to create many icebergs. The interior is partially ice-covered, the ice being thicker and more continuous in the northeast sections.

Spitsbergen is underlain by permanently frozen ground and the surface is characterized by frost-broken rocks, polygonal soil, and solifluction. The land has been little modified by water erosion. The streams are small, and they flow in the wide glaciated valleys.

The sea-ice conditions, as well as the distribution of land ice, point to the fact that Spitsbergen is a place where arctic and more temperate climates meet. The northeast groups of islands are subject to the extreme polar influences. Polar ice floes come in from the east. Stor Fiord and Hinlopen Strait are often ice-blocked and inaccessible even in summer. On the other hand, the west coast receives the benefits of the remnants of the North Atlantic Drift. This current keeps Whaler Bay open, and the harbors of the west coast are accessible for 4 months or more.

CLIMATE

The mean annual temperature of Spitsbergen is between 14° F. and 18° F. During the short summer the mean temperature is above freezing. The temperature of the warmest month is about 40° F. However, temperatures between 50° F. and 60° F. are not uncommon, particularly when warm foehn winds are blowing. At such a time the ground may thaw to depths of 2 feet.

The fiords of the west coast freeze over in late December, but January is frequently a warmer month than December. The coldest periods are in February and March, when the long dark winter is about over. The mean temperature of the coldest month is about minus 10° F. Temperatures above freezing may occur in any month, and midwinter thaws are not uncommon. The variations of winter temperatures, especially the daily ranges, are much greater than those of summer which maintains a fairly uniform warmth.

Spitsbergen feels the effects of the passing high and low pressure areas which come from the North European Sea and travel south or west of the islands. These bring winds from all directions, the velocity of which is highly variable. The mixture of warm sea air and cold land air produces frequent fog along the west coasts. This coast also receives a more abundant precipitation than the inland area. The eastern side of the islands is dry, colder and clearer, especially in winter.

ANIMAL LIFE AND VEGETATION

The low temperatures and exposed position of the outer coasts retard or prohibit plant growth. The more protected interiors of the fiords support abundant vegetation. On the flat uplands there are moors and swamps in the depressions. The slopes are covered by a wide range of flowering and woody plants. Tundra plants and grasses cover the wide lowlands. These polar pastures are the feeding grounds for reindeer.

The bird life is divided according to whether the habitat is on the coast or inland. Sea birds are much more abundant than those of the interior. They breed in summer along the coasts and migrate southward in winter. The gulls, ducks, geese, and terns each have a definite nesting place. The inland birds, snow buntings, gulls, geese and ptarmigans, nest in places inaccessible to the foxes.

Most hunting is controlled in Spitsbergen by the Norwegian Government in an attempt to replenish the animal population. The eastern parts of the country are the home of many herds of reindeer, the polar bear, and the arctic fox.

Sea mammals include whales and seals, both of which have been hunted for hundreds of years. Fishing and whaling have decreased in recent years.

RESOURCES AND INDUSTRY

Coal is one of the most important natural resources of Spitsbergen. It is estimated that the fields contain 9 billion tons of coal. The deposits have been known since the early 1600's when the coal was used locally by the whalers, but systematic mining dates back only to 1905. At that time, an English company began the exploitation. Since then, Norwegian, Swedish, Soviet and Dutch mines have opened.

Although coal of several geologic ages is found, the Tertiary beds are the most abundant and accessible. These seams are nearly horizontal and run from one fiord to another. The coal is of generally good quality. Mining is not a simple matter. The severe climate, the frozen ground, and the short season in which navigation is possible all add to the difficulties.

In addition to coal, some gypsum, asbestos, iron ore, and marble are found.

The total population is about 2,700, concentrated mainly on the southwest coast of West Spitsbergen.

GEOGRAPHY OF THE FENNO-SCANNIAN ARCTIC

Characteristic arctic conditions prevail only in a narrow strip along the northern Scandinavian coast, and in the mountainous or plateau interior of Norway and northernmost Sweden and Finland. Most of this area is considered to be in Lapland. Moderating influences along the western side of the continent of Europe push the arctic boundary far to the north.

The coast of northern Norway shows a general alinement of rugged, steepsided peninsulas and deep fiords oriented north and south. Innumerable mountainous islands fringe the barren headlands. Between this outer region and the interior upland lies the more sheltered region of the fiords. Here there are birch forests, meadows and some arable land. Important food crops such as potatoes, barley, rye and berries are cultivated to supply the many fishing ports. Fish are plentiful in the fiords. The main centers of the fishing industry are Vardo, Hammerfest, Tromso, and Harstad, the latter two also being the principal ports for northern shipping.

The interior region which includes northern Sweden is relatively high and rugged (elevations up to about 5,000 feet) with many lakes and marshes. East of this mountainous section, the land of northern Finland is a rolling plateau on which the extensive Lake Inari is a prominent feature. Tundra covers most of the ridges and elevated places while scrub pine, birch and spruce grow in some of the sheltered valleys. Where it exists, the soil is thin. Like the Canadian Eastern Arctic, this is a shield area of ancient crystalline rock which has been highly disturbed and fractured. The entire area was glaciated during the ice age, leaving scoured uplands and drift-filled valleys as the dominant landscape.

The upland region receives little of the moderating climatic influences felt along the coast. Winter temperatures fall well below zero, as the recorded minus 58° F. at Karasjok shows. Cold air accumulates on the plateau and flows down the fiords creating storms along the coast in winter. The long sunless winter is brightened by fine auroral displays and brilliant moonlight. In September and October full nights of Alpine glow occur. The summer is marked by about 82 days of continuous light.

The native caribou have been replaced by the domesticated reindeer which the Lapps herd. Wolves, bears, and the smaller arctic land animals are abundant. Sea mammals and fish are numerous, although whales and walrus are more scarce than in earlier times, due to excessive hunting.

The Archeozoic rock of this area is rich in iron, copper, and sulphur. Important iron mining centers are at Kirkenes near Petsamo and at Kiruna in Sweden. Iron from Kiruna is shipped from the Baltic port of Lules in the summer and from the Norwegian port of Narvik in the winter. Fish are a very important

Figure 2-22.—Lapps and their herds of domesticated reindeer.

source of national wealth, but otherwise, the northern region offers little else in the way of resources. Timber is scarce and farming is limited to the hardier crops. There is, however, considerable potential water power in the many cascading rivers and falls.

The Lapps who inhabit this region number about 30,000. They migrated to northern Scandinavia and the Kola Peninsula, probably from the area around Lake Ladoga. Their language is a combination of Finnish, Magyar, and Estonian. The majority of the Lapps have settled along the coasts, built log cabins and become quite sedentary. Only about 4,200 to 4,500 practice transhumance or the seasonal moving of livestock from or to the mountains.

These Lapps live on the plateau during the winter, allowing their herds of reindeer to feed on the moss. They live in tents of thick sacking or blankets, rarely use reindeer skin, and eat meat, cheese, frozen milk, and berries. In the summer they come down to the coasts where the herds pasture on the grassy meadows and where the Lapps can obtain the precious commodity, salt. An added attraction of the coasts in summer is the absence of the scourge of insects that plague the uplands. Also, this change of feeding grounds enables the tundra to recover from the winter pasturing. The mountain Lapps carry on a lively summer trade in reindeer meat and skins for the Swedish markets.

Commerce and transportation are mainly by ship. The sea offers the easiest means of going from center to center since the fiords penetrate deeply into the land. Also, the land routes are forced to go over the rugged mountains or plateau areas with the fiords acting as continual breaks in the road. The sea literally unites this area, while the land divides it.

GEOGRAPHY OF THE SOVIET ARCTIC

The combined arctic and subarctic regions in the Soviet Union occupy over half of the country. Of this area, the true Arctic, treeless and cold, includes only the northernmost strip of the continent and the islands off the coast. Most of central Siberia and the northern half of European Russia lie in the subarctic zone. In many ways it is artificial to attempt to separate the two zones. The enforced development of the Arctic in the Soviet Union has made this region an integral part of the whole northern section. Although there are some definite geographic differences which mark the Soviet Arctic as a distinct region, these are insufficiently

Figure 2–23.—Murmansk and Archangel.

prominent to justify a separate consideration. For convenience and accuracy the Arctic and Subarctic will be discussed together.

COASTAL AREAS

The Kola Peninsula is an extension of the Baltic shield region of northern Scandinavia. It is a glaciated barren country with abundant lakes, several sizable rivers and at least one very important harbor, Murmansk. The coast is rugged with granite cliffs rising over 500 feet above the sea with only occasional sandy beaches at the mouths of the rivers. East of the White Sea, the North Russian plains extend along the coast to the Urals, being broken only by the Timan Hills west of Pechora River. These are relatively flat plains covered with glacial deposits in the form of moraines, eskers and drumlins. Although these are minor features of low relief, they are locally important because the gentle ridges and hills rise above the marshy, lake-covered plain. On these drier sites are located the villages and fortifications.

The Timan Hills are a branch of the Urals. The glaciated northern end of the Urals can hardly be said to break the plain, since the general topography is similar on either side of this range. East of the Urals the tundra-covered plain extends many hundreds of miles to the Yenisei. The coast is broken by several large bays including the Cheshkaya, Pechora, Baydaratskaya, the deep gulf of Obskaya, and the Gulf of Yenisei. The lower drainage basins of the Ob and Irtysh are vast bogs and swamps, subject to flooding. They become impassable quagmires in summer.

East of the Yenisei the arctic plain extends along the coast, narrowing toward the east, to the Lena River. The Khatanga, Anabar, and Olenek drain this area. Along the north coast of Taimyr Peninsula, the Biranga plateau rises some 2,000 feet, being a rather abrupt break in the coastal plain. From the Lena eastward, the coastal area is mainly a series of ranges rising over 6,000 feet, broken only by the lowlands at the mouth of the Kolyma. It should be noted that the rivers east of the Taimyr Peninsula have deltas while those to the west have estuaries.

Off the coast there are many small islands and several large island groups, including Novaya Zemlya, Severnya Zemlya or North Land, the New Siberian Islands, and Wrangel Island. Farther to the north lie the Franz Joseph Land group of islands.

The shores of the Arctic Sea are icebound for at least 5 months and the rivers for about 8 months. On the Barents Sea the port

Figure 2–24.—Length of rivers in U. S. S. R.

of Murmansk is almost ice-free, while Archangel (Arkhangelsk) on the White Sea is frozen for 140 days. This is an important factor in the northern sea route.

PHYSIOGRAPHY

In general the arctic and subarctic regions of the Soviet Union can be divided into five physiographic provinces. The coastal plains described above are the tundra area. Between the Soviet or western part of these plains and the Siberian part lie the Urals and the extensive west Siberian plain, drained by the Ob and the Taz. East of the Yenisei is the central Siberian plateau. This is an area of crystalline rock extending to the Lena River. The three Tunguska rivers dissect the southern and western part of the plateau. The upland regions rise to over 3,000 feet in some places. East of the plateau is the region of the Siberian ranges, an area of rough ånd broken terrain, partially glaciated, and reaching to heights over 9,000 feet.

A physical map of the Soviet shows the predominance of two features: the vast plains and the long rivers. The rivers which drain the arctic and subarctic regions are very long. The Yenisei System is over 3,500 miles in length, the Lena 2,700 miles, the Ob 2,500 miles. Also, most of these rivers are very broad. The Yenisei, for example, has over 3,000 miles of navigable waterway and is over 20 miles wide at the mouth. It is 4 miles across at Igarka, a port just north of the Arctic Circle, 400 miles from the mouth. Fair-sized river boats can navigate as far as Krasnoyarsk. The rivers are vital links in the transportation system although even the large rivers freeze in the winter and are icebound 6 to 8 months in the subarctic and over 8 months in the Arctic.

The Siberian rivers have been used for local traffic for as long as the area has been settled, but only recently have they figured in the transportation system of the whole Soviet Union. There are no interconnecting canals and not much has been done to develop these routes. However, the increased shipping along the northern sea route has added new importance to both the Siberian rivers and the arctic ports. Active interest in this route came with the establishment in 1932 by the Soviet government of the Northern Sea Route Administration (Glavesmorptut). It was in this year that the first vessel, the 1,400-ton Sibiriakov, made the voyage from Archangel to the Bering Strait in a little more than 2 months.

The northern sea route has become an important component of the Soviet trade pattern. The arctic fleet includes over 120 vessels and 40 icebreakers. In the 100 days of open season a considerable cargo tonnage is moved. Thousands of tons of freight now move over this route rather than using the over-loaded Trans-Siberian Railway. Timber, fur, and minerals are shipped from the ports along the Ob, Yenisei, Lena, Kolyma and Indigirka. New ports have been opened such as Dikson, Dudinka, Igarka, Nordvik, Tiksi, and Ambarchik. Dock facilities are being improved and mechanized. To assist in the planning and operation of this sea route, over 100 polar stations and more than 50 weather stations have been established, with regular flights patrolling the route to provide ice and weather information.

CLIMATE

The major handicap to the northern sea route and the commerce on the Siberian and western rivers is the long period when ice makes traffic impossible. This, of course, reflects the cold winter temperatures which prevail over most of this vast area. The temperature in January almost everywhere is consistently below 32° F. The winter temperatures decrease from the southwest to the northeast. The *cold pole* center of the Northern Hemisphere is in the middle near Verkhoyansk. It is an arctic paradox that man finds it easier here to withstand the extremely low temperatures than some of the less extreme western temperatures, because in the east the air is dry and usually calm.

The low precipitation, low evaporation, and low temperatures are controlling factors. The short summer, even with 24-hour daylight, does not provide enough heat to thaw more than the top few inches of the ground and the subsoil remains frozen. The freezing and thawing of the surface arches it into little hillocks. There are many areas where no soil exists. On these rocky places reindeer moss is found. In some areas, as between the Pechora River and the Urals, stunted willow and birch brush grows to about 3 feet in height. The lower areas are swampy and the drainage is poor, mainly because of the underlying impervious layer of permafrost. In the short summer the many polar flowers relieve the drabness of the tundra, grasses flourish in the meadows, and the patches of heath produce abundant berries.

ANIMAL LIFE AND VEGETATION

The animal life of the tundra includes reindeer, white fox, white partridge, lemming, and arctic fox. These animals and the forest animals, which prey on the gulls and ducks, move northward in the summer.

The subarctic zone is the region of ash-gray soils or podsol, and of the coniferous forests or taiga. The upper layer of the soil consists of gray, sandy particles leached by percolating water of most of the iron hydroxides and humus. These substances and the finer clay particles form a darker layer below the surface. Leaching takes place despite the fact that the area receives relatively little rainfall; melting snow, a low evaporation rate, and cold soils account for the depletion of the top layer.

At the northern edge of the coniferous forest the birch and conifers are dwarfed and stunted. Toward the south where the snowfall is greater and the winds are less strong, firs, larches, spruces and pines flourish. Fires have burned out extensive areas and where new growth has started up, the birch is usually the first to get established.

In some areas, as around Archangel and in the central Ob basin, the sandy soil is waterlogged due to the presence of a hard pan layer below the surface, which prevents downward percolation of water. Peat-bogs take the place of forests in these areas. These bogs, similar to the muskeg swamps of northern Canada, offer serious problems to road and railroad construction.

There is a more varied animal life in the forest than in the tundra. Berries provide food for the small animals and rodents which in turn provide food for the birds of prey and carnivorous animals. The wolf, lynx, and fox inhabit the forest, together with the marten and ermine. These animals move north in summer, following their food supply and avoiding the hordes of mosquitoes that breed in the water-soaked soil. The fur-bearing animals of the tundra and forest areas are the basis of an important occupation and source of income. Although haphazard hunting and trapping are prohibited, special breeding and trapping stations have been established.

Underlying essentially all of the tundra and taiga is a layer of frozen ground with ice filling all the spaces between the particles of soil and rock. The lower Ob, the Indigirka and Kolyma flow along beds of ice in both summer and winter. The depth of the permafrost varies, being narrower in the south and up to depths of over 1,000 feet, as at Kazhevnikov Bay in Northern Yakutia. The problems of construction, mining, and farming in permafrost areas in the development of the Soviet northland focused attention on the need for planned study. As a result, the Institute for the Study of Frozen Soil was established in 1930.

RESOURCES AND INDUSTRY

Despite the rigors of the climate and difficulties imposed by other characteristics of the arctic and subarctic environments, the Soviet Union has been active in supporting a program of exploration, exploitation and colonization of these regions. As a result, much is known of the potential wealth of these areas.

Geologic investigations of the tundra and the taiga of the Yenisei and Lena basins have shown that a large coal field exists in the area of the Tunguska River, a tributary of the Yenisei. Estimates indicate that it contains 400,000 million tons. At Norilsk, near Igarka on the Lower Tunguska, some mining is going on to provide coal for the ships using the Northern Sea route and for river steamers. There is also a deposit of nickel ore near Norilsk that is being worked. Another arctic coal field is on the Vorkuta, a tributary of the Pechora. This coal is of good quality and makes excellent coke.

On another tributary of the Pechora an oil field has been found. Here on the Ukhta in 1936 oil wells and a refinery were installed.

Near here are radio active wells, believed to be the only known possible source of uranium in the Soviet Arctic. To the east at Nordvik another rich oil field has been discovered.

In the Kola Peninsula, titanium and vanadium are being recovered from the iron-ores. Some low-grade nickel ores have been found. At Petsamo, which formerly belonged to Finland, nickel deposits have been mined for many years.

Deposits of alluvial or placer gold are found along many of the rivers of the northeast. Along the Indigirka and Kolyma these deposits are being worked. To provide an outlet for this production a road has been built to Nagaeva on the Sea of Okhotsk.

Vital to the agricultural development of the Soviet Union is a supply of phosphates. The discovery in 1926 of a huge mountain of apatite, a calcium phosphate, on the Kola Peninsula, is providing an abundant and continuing supply. A center of this production is at Kirovsk.

The coniferous forests support a vast timber industry. The forests of the northwest are the most productive, but Siberian forests are also being exploited. Together with the sawmills, wood-chemical combines have been established as at Archangel. These produce newsprint, wallpaper and wall board.

The industries that have been created in the Soviet northlands have made it necessary to develop agriculture in these areas to provide food for the thousands of people who work in the mines, quarries, mills and ports. Before the introduction of this new economy, the tundra was the home of small bands of nomadic people subsisting by hunting, fishing, and herding reindeer. They migrated south in the winter to the edge of the forests and moved north again in the summer. The Soviet Government now controls the movement of these peoples and the herding of the reindeer in an attempt to prevent misuse of the grazing grounds and to convert the people to a sedentary life. With government help, settlements have been established to grow fodder crops in the river valleys. At Tiksi, Norilsk, and Dudinka are grown fields of cabbage and potatoes, as well as beets, lettuce, radishes, and tobacco. Some barley, oats, and spring wheat are produced and cattle, pigs, rabbits, and poultry are kept. Hothouses are used to grow the fresh vegetables. These, and the sheds for the animals, are electrically heated and lighted. Electricity is also used to heat the soil for the less hardy plants. Although production is small and the methods are complicated, supplies of fresh vegetables and milk are provided locally for each major settlement.

In the clearings of the forest area, especially in the west, agriculture has developed. Cereals, potatoes and vegetables are being grown. Meadows and pastures are being used to support dairy herds. Apple growing has been introduced in Siberia and considerable production has resulted from these orchards where the trees grow horizontally close to the ground to get protection from the cold by the snow cover and to avoid wind damage.

Agriculture is neither extensive nor a primary occupation in either the arctic or subarctic areas. However, it forms an interesting and necessary part of the economy and life of the region.

The population of the Soviet Northland is sparse. Efforts to settle the area have not resulted in a great influx of people. The settlements that now exist are of three types: the villages of the nomads whose chief occupation is hunting and fishing; the permanent settlements of the state farms and herds, the sawmills, mines, and ports; and the polar stations.

There are few roads connecting these settlements although attempts are being made to build roads from the north to tie into the system along the Trans-Siberian Railroad. The rivers are used as summer highways and the dog team and reindeer sledge are the winter modes of transportation. The airplane offers the only other means of transportation and is hindered by fog, difficulties of navigation, and lack of suitable landing areas.

ISOLATED ISLANDS OF GEOGRAPHIC SIGNIFICANCE

In this section are briefly described certain isolated arctic islands of geographical and possible strategic interest—Jan Mayen, Bear, Novaya Zemlya, Vaigach, Franz Josef Archipelago, New Siberian Islands, and Wrangel.

To the east of Central East Greenland lies Jan Mayen Island, almost the smallest of arctic islands. Due to the high inactive Beerenberg volcano (7,680 feet high), this island has a landscape visible from afar and serves as an unmistakable landmark in a sea area in which there are few. The generally poor, sandy, and lava soil, the high winds, and low summer temperatures permit but scanty plant life. Lying at the limit of the pack ice, it has frequent fogs.

"Jan Mayen Island is tiny, only 34 miles long, generally narrow, and so particularly narrow at its center that it nearly has a dumbbell shape. There is nothing remarkable about it except an inactive volcano that is perhaps the most remarkable in the world,

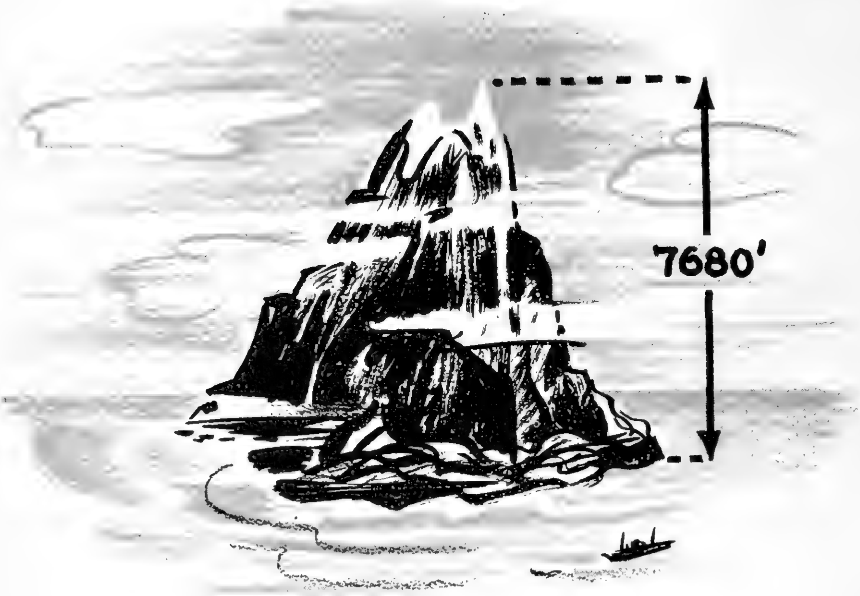


Figure 2–25.—Jan Mayen Island.

rising, as it does, from the shore steeply to greater heights than any other mountain that stands by the sea," Stefansson writes of it.

Bear Island is situated 160 miles south of Spitsbergen in latitude 74°30′ N. It has very changeable weather and is beaten by a heavy surf since it is along the storm path of the North European Sea. It is almost constantly shrouded in fog. July mean temperature is 40° F. There are no harbors. Drift ice surrounds the island about half the year. The northern two-thirds is a plain with a 100-foot high cliffed coast, gradually rising to 400 feet. Adjoining the plain is a high plateau which falls off in the South to the sea in vertical walls as much as 1,200 feet high. It has been estimated that coal deposits to the amount of 200 million tons are on the island.

Vaigach is a small rectangular island lying near 70° N., 60° E. It is separated from the Soviet mainland by the narrow Yugor Shar, one of the three straits leading from the Barents Sea into the Kara Sea.

Novaya Zemlya to the northward is a long, narrow double island. It is separated at latitude 74°30′ N. by the fiordlike strait called

Matochkin Shar. At this strait the width of the island is 60 miles. Together, Vaigach Island and Novaya Zemlya are 650 miles long with an area of 37,000 square miles (fig. 40).

In view of the length and narrowness of Novaya Zemlya, the coast stands out as the most prominent element in the landscape. Along the western side there often is found a low foreland in front of the steep flanks of the mountains. The western coast of the north island is indented by deep bays. On the east side, the general outline of the coast is more uniform.

The southern island of Novaya Zemlya up to its central part is low and flat. From the somewhat higher ridges of the western coast, the land slopes off to plateaus, usually less than 700 feet high. Here are found many lakes and rivers, but no glaciers. In the northern half of the southern island and southern half of the northern island, from Gooseland to Admiralty Peninsula, the whole land rises to greater heights reaching nearly 4,000 feet in the vicinity of Matochkin Shar. Deep, often ravinelike transverse

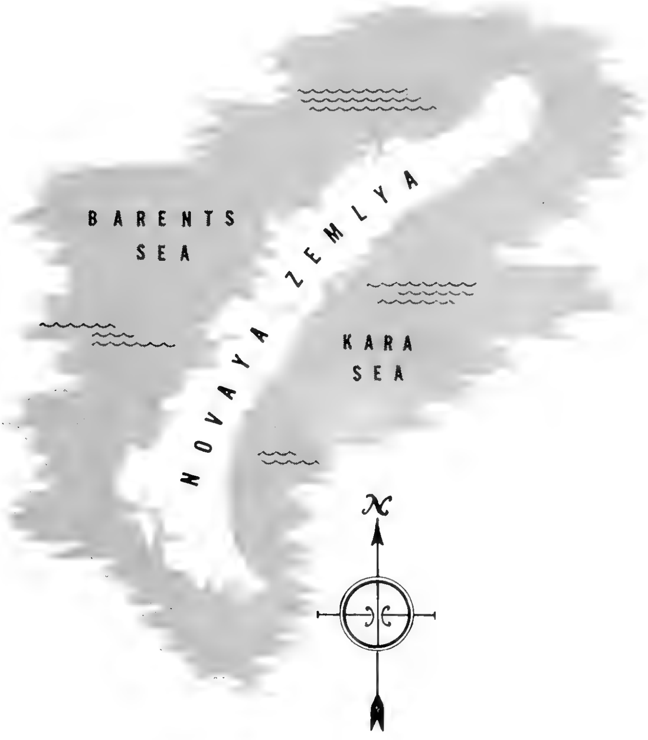


Figure 2–26.—Novaya Zemlya.

valleys and fiords cut into the land from both sides. Abreast the Admiralty Peninsula inland ice appears. This constitutes the third major subdivision of Novaya Zemlya and rises to a height of 2,000 feet with the highest parts lying in the east.

Thus, the island system of Vaigach and Novaya Zemlya rises like a wall between the Barents and Kara Seas. The Barents Sea, on the west side, has wide and open communication with the North European or Norwegian Sea from which it receives off-shoots of the North Atlantic Drift. The Kara Sea, on the east side of the "wall," forms a cul-de-sac of the west Siberian coastal sea. It has been fittingly described as an ice cellar.

Figure 2–27.—Franz Josef Archipelago.

Anthracite coal and copper are found on Novaya Zemlya. There are immense quantities of arctic birds—guillemots, auks, petrels, gulls, geese and ducks. Both the Barents and Kara Seas abound in crabs, fishes, and sea mammals, especially seals. Among the land animals found are the arctic fox, polar bears, and reindeer. The inland waters contain fish, including various species of salmon which are of economic importance. For several centuries, Russians have come here each season for hunting and fishing.

Franz Josef Archipelago, consisting of many small islands with a total area of 65,000 square miles, lies between 79°45′ N. and 81°50′ N. It is twice as long east and west as it is north and south. Most of the islands are plateaus covered by ice caps or island ice. In the north the plateaus are about 1,000 feet high, and in the southeast 2,500 feet high. Fogs are frequent. Mean temperature in July is 32° to 34° F. Weather is clear in winter with lowest mean in the order of minus 22° F. The absolute minimum is near minus 50° F. There is little precipitation. Animal life is sparse. Resources are nil. Sites for airfields are available. There is no question about capability of Soviets operating aircraft there.

The New Siberian Islands lie off the east Siberian coast. The archipelago consists of four major and a number of minor islands. The largest and highest is the western island, Koletroi. The eastern island, Novaya Sibir, is less than 350 feet in elevation. The strata of these islands contain the remains of various prehistoric animals which had their normal habitats in warmer climes. The vegetation is poor in species and in growth. The formation is that of dry tundra. The temperature is lower in all months than at the mouth of the Lena River.

To the northeast of the New Siberian Islands, there lies a group of small islands near the edge of the continental shelf. The largest is Bennett Island in latitude 76°40′ N. It is a rocky plateau, ice-covered, with an area of only 75 square miles.

Farther to the east stands Wrangel Island, Soviet sentinel of Bering Strait and East Siberia. It is difficult to reach by ordinary ship during the normal summer season. It is 1,800 square miles in area, 80 miles long, with greatest width 30 miles. It is generally mountainous, hilly and scantily covered with tundra. The elevation of the highest mountain is 2,500 to 3,000 feet. There are sites available for airfields.

Nicholas II Land (Lenin Land or North Land on some maps) is a small archipelago lying at 80° N., 100° E. to the north of Cape Chelyuskin on the Taimyr Peninsula.

SUMMARY

Geography is developing as an increasingly important science. So little is known of the geography of the Arctic, that it is covered here in some detail to give the reader a general picture of these vast areas.

The Arctic is cold, but the coldest spots in the Northern Hemisphere are not in the Arctic. It is a barren and desolate land, but in places vegetation, animals, birds, insects, and fish abound. It is windy, but chiefly in localized areas. It rains and snows heavily, but only in spots. It is not unfriendly if one knows, understands, and respects it.

Figure 2–28.—World's northernmost city.

Table V is a summary of geographical data worth remembering.

TABLE V

Summary of Geographical Areas

Location:		*Areas (Goode's Atlas)*
Alaska	square miles	580,000
Greenland	do	837,000
Greenland Icecap	do	708,000
Hudson Bay (850 miles long by 520 miles broad)	do	472,000
Spitsbergen	do	25,000
Franz Josef Archipelago	do	65,000
U. S. S. R. Arctic	do	5,570,000
Disko Island, Greenland	do	3,006
Wrangel Island	do	1,800
Novaya Zemlya	do	35,100
Iceland	do	39,700
Land Area draining into Arctic Ocean	do	8,000,000
Alaska	do	586,000
Canadian Arctic	do	1,000,000
Northwest Territories	do	1,309,600
Lenaland, east of Yenisei	do	3,750,000
Heartland, west of Yenisei	do	4,250,000
Asiatic Portion, U. S. S. R.	do	7,346,000
Mackenzie River (total length)	miles	2,525
Lena River (total length)	do	2,700
Yenisei River (total length)	do	3,500
Yukon River (total length)	do	2,100
Arctic Sea	square miles	5,500,000
Atlantic Ocean	do	31,500,000
Pacific Ocean	do	64,000,000
Mediterranean Sea	do	1,100,000

Summary of Geographical Locations

Location:	*Situation*
Northernmost point of American continent is on Boothia Peninsula and is situated at	72° N., 95° W.
Northernmost point of Alaska is Point Barrow at	71°24′ N., 156°22′ W.
Northernmost point of land in Western Hemisphere is Cape Morris Jessup at	83°39′ N., 34° W.
Northernmost point of land in Eastern Hemisphere is on Rudolph Island at	81°50′ N., 60° E.
Northernmost point of Eurasian continent is Cape Chelyuskin at	78° N., 105° E.
Hammerfest, Norway, world's northernmost city, at	70° N., 24° E.

Mileage chart of Greenland

North-south length of Greenland	miles	1,650
Greatest width in Greenland at 77° N.	do	690
Nearest land to the North Pole is in Greenland	do	439

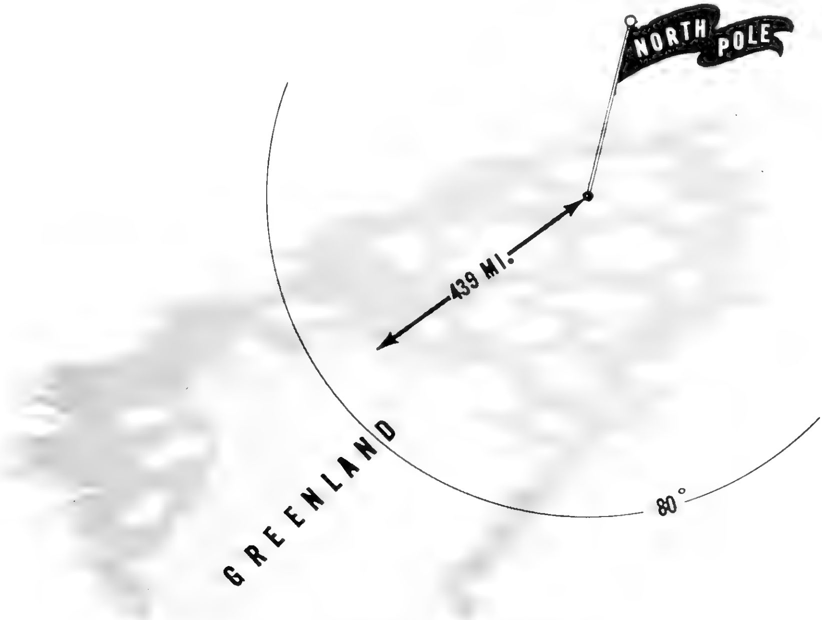


Figure 2–29.—Nearest land to the North Pole.

Circumference of polar circle	miles	8,460
Distance polar circle from pole	do	1,410

CHAPTER 3

CLIMATE AND THE WEATHER

"Weather is now an item of major importance in planning and executing naval surface, air, and amphibious operations."—Admiral Halsey.

Weather is one of the principal factors limiting naval operations in the Arctic. In view of the small amount of available data upon which to establish firm conclusions, the following may be subject to some revision, when more complete information is forthcoming. The word *season* as used in this chapter has its literal astronomical meaning.

The two prominent controls of arctic weather are (1) the Arctic Anticyclone, and (2) the extension of the semipermanent Icelandic

Figure 3–1.—Common track for low-pressure centers.

low pressure area into the Barents and Kara Seas. Separating these two pressure areas is the *Atlantic Arctic Front* along which the cyclonic disturbances in these regions are most likely to develop.

During the winter months, the center of the Arctic Anticyclone lies in the vicinity of 80° N., 165° E. The Icelandic low pressure area extends northeastward from Iceland to beyond northern Novaya Zemlya. Its central axis is marked by the mean position of the Atlantic Arctic Front, which extends intermittently along the northern Siberian coast to 170° W. longitude. There is a rather uniform and quiet situation over the polar basin. At this season, an almost continuous succession of cyclones is to be noted along the Arctic Front, between Bear Island and Novaya Zemlya. East of Novaya Zemlya, the disturbances decrease in intensity and dissipate so that few storms penetrate along the east Siberian coast. Surface winds are prevalent from the westerly direction along the Siberian coast; easterly over the central arctic regions and most of Greenland; and north to northwest over the Canadian archipelago.

During the spring months, the winter pattern of mean pressure is continued with little change. The Arctic Anticyclone shifts slightly eastward to the 180th meridian and the central pressure continues high. Pressures are slightly higher in the Icelandic low pressure cells and fewer intense cyclones develop or move along the Atlantic Arctic Front. With the eastward shift of the Arctic Anticyclone, the winds become more variable along the northern Alaskan coast.

During the summer months, the pressure gradients are weakest over the entire arctic region, and the winds are quite variable. A separate anticyclonic center occurs to the east of Greenland, while the principal Arctic Anticyclone continues its eastward movement along the eightieth parallel, to approximately the 150°-155° W. meridians, but with greatly diminished intensity. Winds are prevailingly northeasterly along the Alaskan and Siberian coasts, and north to northwest over the Canadian archipelago. While few in number, cyclonic storms may penetrate any section of the arctic at this season. The weather in the Canadian archipelago is dominated by semi-permanent cyclonic activity with centers located in Baffin Bay and northwest of Ellesmere Island.

The low pressure center which is semi-permanent over Baffin Bay is a natural result of the blocking effect of the Greenland plateau on the migratory storm centers moving in from the west and southwest. Most of these migratory centers originate as waves on the North American Polar Front. Some, however, result from the regeneration of old Pacific Ocean occluded systems, while a few are developed from various low pressure centers connected with the Aleutian Low.

The most common track of low pressure centers approaching Baffin Bay in summer is produced by migratory centers originating in southern Canada, east of the Rocky Mountains. These centers move eastward and occlude in the area immediately to the west of Hudson Bay, then gradually curve northeastward across Hudson Bay and extreme northern Quebec, and finally move across Baffin Island and over Baffin Bay. The area of major deepening of low pressure centers on the above course is in the vicinity of and just to the west of Hudson Bay. Hence, the slowest forward movement of the centers is in this area.

The speed of advance after leaving the Hudson Bay region is approximately 25 knots, gradually slowing to 5 to 15 knots over Baffin Bay, where the blocking effect of the high altitudes of the plateau of Greenland is felt. The migratory lows which develop as regenerations of old Pacific occluded systems originate in western Alberta Province, along the eastern side of the Canadian Rockies. During the summer these centers move directly eastward, near 60° N., into the area west of Hudson Bay. From this position paths vary widely, some centers being forced south-southeastward across the eastern Great Lakes, some proceeding directly eastward into the Labrador-Davis Strait region, and some curving northeastward across Baffin Island and over Baffin Bay.

In the latter part of August and in early September, the trajectory of these lows across the central part of Canada shifts farther to the south, due to the gradual increase in size of the high pressure cells centered to the northwest of Canada. The northernmost track of low pressure centers moving into the Baffin Bay region is across the Canadian archipelago. These lows originate as waves on the Arctic Front or as developments off the Aleutian Low, which is separated into several small centers during the summer months. The average speed of these lows is 20 to 25 knots, except to the south of the Ellesmere Low, where they tend to intensify and thence move eastward more slowly, eventually stagnating in Baffin Bay.

By the time migratory low pressure centers arrive in the Baffin Bay area, the frontal systems connected therewith are usually in the form of well developed occlusions. When these occlusions reach the Greenland coast, they are blocked on the surface by the edge of the cold high pressure cell over the inland ice cap and are either forced aloft or dissipated.

Frontal weather affects the North American arctic more frequently in summer and early fall than in other seasons, but even in summer non-frontal processes predominate. As mentioned above, fronts encountered are generally of the occluded type, although open wave cyclones may also be observed.

During the fall months, there is an increase in cyclonic activity along the Arctic Front, which extends from southern Greenland, through Iceland, off the northern coast of Norway, over southern Novaya Zemlya and across the Taimyr Peninsula. Winds are prevailingly westerly south of the front and prevailingly easterly north of the front. The Arctic Anticyclone continues relatively weak and is centered in its easternmost position along the 80th parallel on the meridian of 140° W. longitude. The transposal of this center to near the Siberian border takes place simultaneously with the freezing over of the East Siberian and Laptev Seas in early winter.

Generally speaking, air masses are classified according to source and recent life history. The simplest method of designating them allows for four types, which apply to all parts of the earth. These four broad types are:

cP: continental polar.

mP: maritime polar.

cT: continental tropical.

mT: maritime tropical.

However, in a discussion of air masses over a particular region, it is desirable to use a more specialized scheme. This is because air from different geographical regions of the same general type assumes characteristics peculiar to the source region, which help materially in analysis and forecasting. For example, polar air which has lain for days over the almost unbroken pack ice north of Bering Strait, in the total darkness of winter, will show, in general, marked similarity to a mass of polar air from the subpolar plateau of Outer Mongolia. But in the arctic air, in addition to the strong inversion of temperature in the lower 5,000-foot layer, there will be found, in most cases, a characteristic 500-foot layer at the very surface, in which the temperature falls rapidly with height and the surface layer shows higher humidity. At the same time, at the top of the troposphere (at about 30,000 feet), the temperature will be somewhat lower than at the same altitude in the subpolar air. So it is customary to differentiate the two types of air by adding the following types to the above classifications:

cA: continental arctic.

mA: maritime arctic.

By adding the letter W (warm) or K (cold) to any of the above types, it can be shown whether the air is *warm* or *cold* with respect to the surface over which it is moving (*stable* or *unstable*).

Thus in the arctic and subarctic regions we have the following types, together with the general source region and the season or seasons of occurrence:

Table VI

Main Source Regions of Arctic Air Masses

Type	Main Source Region	Season of Occurrence
mAK	Greenland-Spitsbergen	Entire year except July and August.
cAK	Novaya Zemlya-Canadian Archipelago-Pole	Entire year except July and August.
mPK	North Atlantic	Entire Year.
cPK	Scandinavia-Siberia North	Northern Winter (September-June).
mPW	Atlantic and Pacific (around 50° lat.)	Northern winter.
cPW	Ukraine-Mongolia	Northern spring, summer, and fall.
mTW	Azores (Middle Atlantic) Anticyclone	Entire year.

In summer the distinction between polar maritime, polar continental, and arctic air almost disappears due to the nearly uniform surface conditions over the arctic and subarctic. The frozen ground over the continents thaws, at least at the surface, under the influence of continual sunshine or daylight; the snow melts from the glaciers and pack ice, the ice melts from the lake areas, and the water area in the polar basin or Arctic Sea increases markedly. Thus, the whole polar area becomes one of mild, humid, semimaritime activity. Temperatures are uniformly between freezing and 50° F. Occasionally, higher temperatures occur under the influence of strong importation from the south, or of strong insolation in favored localities.

Diurnal ranges, horizontal differences, and inter-diurnal variabilities are slight. The latitudinal and continental influence is at a minimum. Only the effect of elevation is increased due to the greater humidity and lack of inversion, the former increasing the lapse rate and blanketing the lowlands from excessive outgoing radiation and the latter removing the anomaly, so common in the arctic winter, of having pools of cold air in the hollows while hill or mountain tops are 20°, 30°, and even 40° warmer.

If any contrast exists in the Arctic in summer, it is between the air over the pack ice at near 32° F. and the subarctic zone on the one hand, and the air over the warm Atlantic water on the other hand, where temperatures average 20° or 30° higher in July and August. This contrast is destroyed frequently when small, but sometimes intense, cyclonic storms invade the polar basin, temporarily displacing the Arctic Front. Also, at any time during the summer a mass of mAK air can build up some place in the Arctic and move down over the Canadian islands or the Norwegian and Barents Seas, giving summer snowstorms, freezing temperatures, icing and fog to those parts.

WINTER CONDITIONS

In winter, that is from September to June, the arctic air masses form over the polar basin: The continental type over the solid-pack ice north of Bering Strait, an area about half the size of the United States; and the maritime arctic air over the Atlantic side of the polar basin where a larger percentage of water exists and where the water is relatively warm with respect to the sea-ice present. The continental polar air masses come mainly from the Siberian Anticyclone, which is a northern extension of the warm central Asiatic Anticyclone, although distinctly not the warm type itself.

Unstable maritime polar air masses are formed in the North Atlantic during the entire year. The front between these masses and the continental polar or arctic air from Canada, Greenland, or Scandinavia is subject to the greatest storm activity in the Northern Hemisphere. Here is experienced the worst flying weather to be found on any of the north polar routes, if not on the whole earth.

The more stable types of both polar and maritime air come from middle latitudes (around 45°–55° N.) in North America or Central Asia, the Atlantic or Pacific. Being warm-core the masses tend to stagnate in the regions where they are formed so that the invasion of these masses into the polar regions is rare. Whatever air of this type existing in the arctic or subarctic regions comes rather by a slow process of extension of the area of the warm anticyclones from southerly regions into the higher latitudes, as in the fall or "Indian Summer" in central Canada, or in Siberia.

About the only type of Pacific air that is found in the Arctic, and that only rarely when a deep cyclone is centered in the Bering Sea, is mPW air from the northern extension of the Hawaiian High, which pours across the high ranges of the Alaskan coast into the interior valleys. Occasionally, the stable continental air drains down from the plateaus of the Rockies or of Mongolia, into the arctic prairies of Canada or Siberia for weeks at a time, even in December or January. This condition gives perfect CAVU weather over a vast area, with temperatures perhaps 20° to 30° above normal, thus reversing the normal condition when midwinter is a season of little flying activity.

Stable maritime air sometimes persists for long periods along the coasts. In such cases aviation is hampered by surface fogs or stratus, although such weather may be ideal for long distance flights if fog-free terminals are available. Tropical air aloft invades the Arctic only on rare occasions, and only in the Atlantic sector, coming from the Azores high in advance of an unusually deep low. Surface tropical air would be even more rare north of 60° N.

The temperature distribution in individual air masses in the Arctic tends to be more uniform than in the temperate zones, but less homogeneous than the tropical air masses. In the fall and spring with rapidly moving of cold types of air masses, the coldest air may be just behind the front, so that extreme cold is coincident with the most stormy weather conditions such as strong gusty winds, rain, snow, and blizzards. The cold in such cases may preclude human activity even though the turbulence associated with the front keeps the temperature from dropping to 50° to 60° below zero, as it does in stagnant air masses. Usually if the wind is at all strong, the temperature will be above 20° below zero.

Exceptions to this rule will be noted in places like Wrangel Island, where local drainage off of the continent may give temperatures of minus 40° F. with strong winds. In the middle of the winter (December through February), on the other hand, the coldest air is to be found a day or more after the frontal passage, even in rapidly moving air masses, since turbulence in the frontal zone is about the only *warming* influence to be found in the Arctic at that season.

WIND CIRCULATION OF THE NORTH POLAR REGION

From the limited data available, a generalized picture of the wind system of the north polar region can be constructed. Of primary importance is the anticyclonic circulation. As little *winds-aloft* data are available for the areas north of the eightieth parallel, conclusion about the upper-wind circulation in the Polar Anticyclone can be based, to a limited extent, on the knowledge of the circulation in anticyclones of lower latitudes.

The Polar Anticyclone, as is the case with the continental anticyclone of winter in lower latitudes, is dependent on a net loss of heat. However, in the case of the continental anticyclone of lower latitudes, sufficient insolation is received during the warmer half of the year to not only end its existence, but even to replace it with low pressure. In the summer the Polar Anticyclone is not destroyed but pressures are considerably reduced by the added insolation. During the long winter little heat is received from the sun, and there is a continual loss of heat through radiation, with the result that there is a piling up of cold, heavy air. When a sufficient amount of air has accumulated at the North Pole so that a balance no longer exists, a gradual flow of air out of this cold air dome takes place. While the direction of this outflowing air is at first from the north, it soon assumes an easterly component, due to the rotation of the earth. Velocities associated with the central core of this arctic air mass would be small. It is believed that the vertical extent of high pressure is not great in the polar anticyclone and that above the first few kilometers the pressure field is probably reversed, with low pressure present. If the above assertion is true, the motion of the air in the Polar Anticyclone above the first few kilometers must be anticlockwise or westerly about the North Pole, with a slight component in the direction of the Pole to compensate for the loss of air at the lowest levels.

While there is a more or less steady flow of air out of this cold air dome, the process is greatly accelerated at times by the passage along its periphery of areas of low pressure which upset the balance and induce large masses of the cold air to break away from the parent mass and move out of the polar region along certain well-defined continual paths.

Those periodic mass outbreaks of cold air are not limited to the lowest levels, but embrace the entire troposphere, disrupting the shallow easterly circulation of the lower levels and also the westerly circulation above 6,000 feet. At times low pressure

Figure 3–2.—Blizzard.

centers will invade the region usually occupied by the Polar Anticyclone with attendant gales and stormy weather. Incursions such as these would be more numerous in the summer when the anticyclone is weakest, and when it has been depleted by mass outbreaks of cold air into lower latitudes.

As we mentioned earlier, areas of low pressure pass along the periphery of the cold air mass and certain areas are zones of greatest frequency. One such zone lies along the Atlantic Arctic Front. In this zone there is no well-pronounced prevailing direction and winds are strong and variable. This front marks the mean southern boundary of the arctic air mass. It extends from the vicinity of southern Greenland northeastward into the Barents Sea and beyond, changing its mean position with the progression of the seasons. Another such active region exists along the Pacific Arctic Front which extends from Alaska to eastern Siberia, passing through the Bering Sea. In addition there are two regions with winds of monsoon character, one in Siberia and the other in Alaska. Of local consequence are katabatic winds. These winds are caused by the downrush of cold air from higher elevations. The passage of a low may provide the necessary pressure gradient to set such winds into motion. These winds frequently reach gale force. If the area is snow-covered, the turbulent action of the winds will carry the snow dust aloft to such heights as to blot out the sun. Winds of this character can occur along the entire outer portion of the arctic basin, where there are elevations or mountains from which the cold air can sweep. They are known to occur along the deeply indented coast of Norway, at Wrangel Island, and in the Aleutians.

Local winds in the Alaska region are known as *williwaws, takas,* or *kniks.* Their strength is greatest in the months when the temperature contrast between the land areas and the open water is the largest. The critical velocity marking the beginning of sufficient turbulence to carry the snow dust aloft is about 11 m. p. h. At about 18 m. p. h. the turbulence is great enough to carry sufficient snow dust aloft to reduce the visibility to a point presenting a landing hazard to aircraft.

REGIONAL WIND SYSTEMS

The first region to be discussed is that portion of Siberia east of the Verkhoyansk Mountains. The wind system of this region is monsoonal in character. During the colder months, from September through March, a ridge of high pressure is present over eastern Siberia and southerly winds prevail along the northern portion, blowing out from the cold land surface toward the Arctic Sea. These southerly winds are strongest along the north coastal areas, while in the interior the winds are light with long periods of calm.

For instance, at Verkhoyansk in the interior, during February to May there is practically no surface wind. Even in October and November the surface winds are light, while at Tiksi Bay, on the coast, the average wind velocity is about 12 m. p. h. except during March and April when the average drops to between 6 and 7 m. p. h. At Verkhoyansk the frequency of gales is greatest during the months of June, July, and August with an average of two or three per month. During these latter months the thermal low pressure system shows greatest development over the interior. Along the coast the frequency of gales is least during these same summer months, Tiksi Bay having an average of one per month from April through September. During the colder months when the anticyclone is well developed over the continent there are no gales in the interior at Verkhoyansk, but during these same months at Tiksi Bay the frequency is greatest. From October

Figure 3–3.—Winter wind system of Siberia east of Verkhoyansk Mountains.

through May there is an average of about four gales each month. At Verkhoyansk the monsoonal character is also reflected in the winds aloft.

In the winter at 3,000 feet, 56 percent of the observed directions are south to southwest at about 10 m. p. h. At 10,000 feet the quadrant having the greatest percentage is to the southwest with 37 percent. Low pressure areas seldom invade this continental area of eastern Siberia because of the uninterrupted strength of the anticyclone. Any cyclonic activity is fairly well confined to the region between the Polar Anticyclone and the ridge of high pressure in eastern Siberia. The passage of cyclones in the region referred to above would affect the wind system along the northern quadrant of the Siberian anticyclone. Northwest winds follow in the wake of these cyclones and this could account for the fact that of the observed winds at 10,000 feet at Verkhoyansk 19 percent are northwest.

There is insufficient information about conditions above to draw any conclusions, but from the few available observations it appears that practically all directions are represented. At 3,000 feet southerly winds are less predominant in spring; 30 percent are south to southwest at 11 m. p. h. There is a secondary direction of greatest frequency from the northeast to north-northeast of 25 percent. At 10,000 feet, in spring, 50 percent are from that 90° quadrant from south-southwest to west-northwest, while 40 percent are from that 90° quadrant from north to east at about 12 m. p. h. At this elevation those winds having the least frequency are those with a southeasterly component. Summer brings a reversal of the wind flow, at which time the thermal low develops over the interior and winds become northerly at Verkhoyansk.

At 3,000 feet 30 percent are north-northeast to east-northeast with a secondary maximum of frequency from south-southwest to west-southwest. At 10,000 feet, however, 55 percent prevail from the northwest to northeast, and at 20,000 feet 64 percent are west to north. The great depth of the northerly current in summer is no doubt dependent upon the fact that at that time Verkhoyansk is located along the pressure gradient between the relatively high pressure of the polar region and the low pressure of the Asiatic continent. Autumn again brings southwesterly winds at 3,000 feet with 55 percent south-southwest to west. A gradual veering of the wind takes place with elevation, and at 10,000 feet 46 percent of the observed winds are from southwest to west-northwest at 14 m. p. h.

Here Bering Strait and the land areas immediately to the east and west, being low in elevation, present no obstacle to the free interchange of air between the arctic basin and the region of the Bering Sea. During the winter there is a prevailing northerly wind through this region. This northerly flow of cold air replenishes the air lost through the flow of air from the Bering Sea into the Pacific Ocean during the winter season, at which time the Aleutian Low is well pronounced. The surface winds and upper winds at Nome, Alaska, confirm this. Sixty percent of the surface winds at Nome are from north to east-northeast at about 10 m. p. h. and continue from that quadrant up to 6,000 feet. At 10,000 to 13,000 feet the winds back to a northerly quadrant and about 50 percent are from that direction with an average velocity of 24 m. p. h.

Autumn winds at Nome are similar to those in winter, with 64 percent of the surface winds from the quadrant between north-northwest and east-northeast averaging 8 m. p. h. At 10,000 feet 55 percent of the winds fall in that segment between north and northeast, with an average velocity of 21 m. p. h. However, in spring and summer when the Aleutian pressure system is less pronounced and farthest south, there is no such marked prevalence in direction aloft as there is in fall and winter. It can be said that there is a noticeable absence of southerly winds at 10,000 to 13,000 feet, all other directions being represented.

The wind regime of Alaska, like that of eastern Siberia, is to some extent monsoonal in character. In the warmest months a thermal low develops over the interior of Alaska whereas in winter high pressures are present. As a result winter winds at Fairbanks are regulated by the Alaskan and polar high pressure systems and by the proximity of the Aleutian low pressure system to the south. Surface winds at Fairbanks are light as that settlement is located in a sheltered valley. The average winter surface velocity is between 4 and 5 m. p. h.

Immediately above the surface at 1,500 feet 71 percent are east-northeast to east-southeast at 13 m. p. h. But with increasing height there is a veering of the wind and at 10,000 feet 43 percent are south to west-southwest at 21 m. p. h. At 13,000 feet winds from the south to northwest at 22 m. p. h. have the greatest frequency.

Winds of spring at Fairbanks, like those of winter, veer from the southeast at 14 m. p. h. at 3,000 feet, to southwest at 19 m. p. h. at 13,000 feet. This would indicate that, whereas the low pressure at the surface is centered to the southwest of Fairbanks, at 13,000 feet the lower pressures are found to the northwest.

In summer high pressures replace the low pressures of winter in the Gulf of Alaska and the warmed Alaskan interior produces a thermal low. The net result produces decreasing pressures across Alaska toward the north. The pressure system also does not change as much with elevation as at other seasons. Consequently, there is no great turning of the wind with increasing elevation. Prevailing winds at Fairbanks in summer, therefore, are southwesterly at about 16 m. p. h. at all levels. This is slightly less than the average at other seasons.

The progression from summer to autumn brings the greatest change at the 3,000-foot level with a shift of the prevailing wind direction from southwest to southeast and a slight increase in velocity from 14 m. p. h. in summer to 17 m. p. h. in autumn. While there is practically no change in direction in the 6,000 to 13,000-foot layer, there is a slight increase in velocity from 16 to 20 m. p. h. for the prevailing southwesterly wind. It can be said that the greatest seasonal variation in the wind at Fairbanks takes place below 6,000 feet, with little change above that level. This would indicate that mean surface pressure changes from season to season, although well pronounced, are not reflected to any height and that the relative pressure distribution above 6,000 feet is rather constant throughout the year.

WINTER WINDS AT POINT BARROW

Winter winds at Point Barrow are almost entirely dominated by the Polar Anticyclone. Northeast to east winds prevail up to at least 13,000 feet. However, the frequency percentage decreases with height from 48 percent at the surface to 30 percent at 13,000 feet. The average surface velocity is 14 m. p. h. From 3,000 to 13,000 feet the average velocity remains about 27 m. p. h. for these east to northeast winds. The change from winter to spring causes the winds aloft at Barrow to veer about 22° with little change in surface wind direction. The velocity likewise does not vary greatly from winter to spring except that, whereas in winter there is slight increase in velocity for the prevailing direction from 25 m. p. h. at 3,000 feet to 29 m. p. h. at 10,000 feet, there is a slight decrease in the velocity with elevation in the spring.

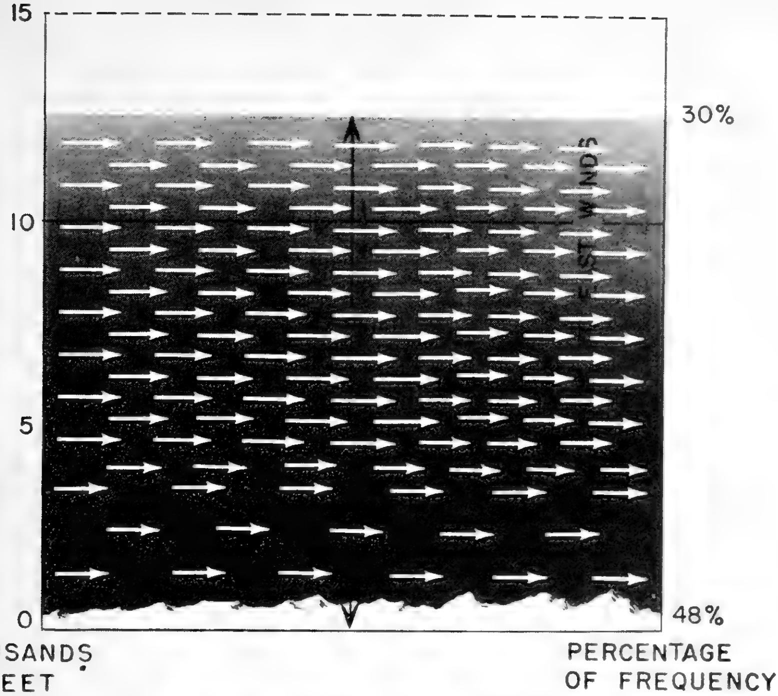


Figure 3–4.—Winter winds at Point Barrow.

Summer brings the greatest departure from the polar anticyclonic wind pattern at Point Barrow. At the surface, easterly winds still prevail but a secondary maximum of greatest frequency exists from the west to southwest. Aloft the direction of greatest frequency becomes southwest to west from 3,000 to 10,000 feet. At 13,000 feet there is no particular quadrant of greatest frequency, except that the greatest percentage of wind has a westerly component. At 13,000 feet those winds having the greatest westerly component are the strongest, reaching about 22 m. p. h. The easterly winds have the least velocity. Easterly winds are again predominant in the fall, however, with 58 percent of the surface wind coming from the east-northeast to the southeast at 16 m. p. h. At 3,000 and 6,000 feet those winds having the greatest frequency, accounting for 45 percent of the total, are from east-northeast to southeast with an average velocity of 24 m. p. h. At 10,000 feet the dominance of easterly winds is less pronounced, while at 13,000 feet there is a small weight of prevalence in favor of west to northwest winds at 21 m. p. h.

The frequency of gales in Alaska is similar to that of eastern Siberia. In the interior the season of greatest frequency is summer. Along the coast the season of greatest frequency is winter. Coastal stations have a greater annual frequency than inland stations. Point Barrow on the north coast has an average of 18.7 gales a year, while Fairbanks in the interior has an average of only 0.9. Wrangel Island has an annual average of 50.4 gales. From May through August there is an average of two each month. The season of low average at Wrangel Island is associated with the summer, at which time the Polar Anticyclone is weakest and the Aleutian Low is dissipated. During the colder months from September to April the average monthly frequency is between five and six. At this season the Polar Anticyclone is present and the Aleutian Low is well developed.

OVER NORTHERN CANADA

Little is known of the upper-wind regime of northern Canada. The elevation of the many islands of the Canadian archipelago is not great. The area is covered with ice and snow a great portion of the year. An extension of the Polar Anticyclone extends down over this region. A steady flow of air out of this high pressure area continues throughout most of the year, being greatest in winter when the anticyclone is most highly developed. As a result, winds across the Hudson Bay region are northwesterly in winter. The depth of this northwesterly current is reflected in the winds aloft at Port Harrison. Northwesterly winds are most frequent up to the limit of observational data at 13,000 feet. Progressing from winter to summer the Polar Anticyclone and its Canadian extension gradually weaken, so that the northwesterly surface winds do not penetrate as far south as Port Harrison. Aloft, however, there is still a prevalence of northwesterly wind at 6,000 to 13,000 feet, although the velocities are not as great. There are no data as to the number of gales in this region. But in the colder months of the year, during the presence of high pressure there would be few gales. In the warmer months the weakened anticyclone would allow cyclones to invade this region, with attendant gales.

The ice-covered region of Greenland, because of its high elevation and great size, exerts a considerable influence on the wind flow in its vicinity. The wind circulation in close proximity resembles that of an anticyclone. At Etah, in northwest Greenland, during the winter, the prevailing winds, from the surface to 3,000 feet, are east to northeast, flowing down from the ice cap. Between 6,000 and 13,000 feet there is a shift to south and southeast, with the circulation in relation to the island resembling that found around an anticyclone. This same circulation scheme of winds off the ice cap at low levels, with south to southeast winds above 6,000 feet, holds true for spring and summer. In autumn the prevalence of air flow from the northeast continues up to 10,000 feet, and at 13,000 feet becomes northwest to north.

The wind scheme at Mount Evans is similar to that at Etah as both are on the western side of Greenland. The lowest level of air at Mount Evans has an easterly component coming from the ice cap. Above 3,000 feet the wind assumes a southerly component at all seasons. A short summer record of winds-aloft data was obtained at a station on the ice cap in central Greenland. At this season the region of highest pressure in the Arctic is located off the northwest coast of Greenland, and the region of lowest pressure is to the east, at Baffin Island. On the surface of the ice cap as a consequence, 70 percent of the wind is from the east-northeast to south-southeast. This prevalence of easterly wind continues above the ice cap to a depth of at least 17,000 feet. Too much reliability cannot be placed on the record because of its shortness. At East Station, on the east coast of Greenland, there is a high percentage of calm at the surface, a maximum in the summer of 88 percent and a minimum in the autumn of 26 percent. Light easterly winds persist for the remaining time. Immediately above the surface layer a northwesterly wind prevails, and the analogy of Greenland's wind system to that of an anticyclone is again demonstrated.

Reykjavik, off the southeast coast of Greenland, is in a region of cyclogenesis and the wind regime should be a variable one. During the winter, Reykjavik is in the central portion of the statistical low pressure system. Southeasterly winds prevail in the first 3,000 feet of atmosphere. At 6,000 feet there is no prevailing wind, and at 10,000 feet and 13,000 feet westerly winds prevail. In the spring this statistical low has moved eastward and decreased in intensity, and the prevailing wind at Reykjavik is northwesterly. Above the surface easterly winds prevail up to 10,000 feet and at 13,000 feet northerly winds prevail. In the summer the pressure in the Polar Anticyclone is highest to the northeast of Greenland and the prevalence of the deep current of northerly wind in evidence at East Station in Greenland extends eastward as far as Reykjavik. This current of north wind exists from the surface up to at least 13,000 feet. Likewise in autumn northerly winds prevail from 3,000 to 13,000 feet.

Observations made during the Wordie expeditions to northwest Greenland in 1937, and to the Canadian Arctic in 1938, confirm other observational data to the effect that the highest wind velocities are found at or immediately below the tropopause. The height of the tropopause for one observation was found at 37,750 feet, while the maximum wind velocity occurred at 32,150 feet. The maximum velocity at this elevation was 34 m. p. h. The height of the maximum wind velocity and likewise the height of the tropopause was found to vary with the surface pressure. During the presence of low pressure areas the maximum velocity occurred at lower elevations, from 26,250 feet to 31,150 feet, and in high pressure areas from 32,800 feet to 37,750 feet. In comparison with data collected at other seasons the maximum velocities are found to occur about 10,000 feet lower in the winter than in the summer.

WIDELY DIFFERENT SYSTEMS

A comparison of the winds-aloft regimes at Tikhaja in Franz Joseph Land and at Tromso, Norway, affords a good example of the widely different systems that exist on either side of the Atlantic Arctic Front. Tikhaja, near the 80th parallel, lies to the north of the front and its wind system is largely governed by the Polar Anticyclone. Tromso, on the seventieth parallel, lies south of the front and its wind circulation is governed by the Icelandic Low. However, the wind system at Tikhaja is also influenced by the latter low. Northeasterly winds are prevalent up to 13,000 feet at Tikhaja for all seasons except summer. In summer at the surface 32 percent of the time it is calm and 34 percent of the time the winds are north to east. Above the surface layer, in summer, there is no marked prevalence from any direction. The Icelandic low pressure system is practically nonexistent in the summer and the Polar Anticyclone is weak. For all seasons at Tromso, south of the front, there is a prevalence of southerly wind, shifting to southwesterly above 3,000 feet and extending up to 10,000 feet. At 13,000 feet there is no direction of greatest frequency. Velocities from 1,600 to 10,000 feet are slightly higher at Tikhaja, the average being between 12 and 18 m. p. h., while at Tromso averages are from 10 to 18 m. p. h. At 13,000 feet the average is slightly higher at Tromso.

In the winter the surface winds at Dikson Island, in the Kara

Sea, prevail from the south with a secondary maximum from the northeast. This would seem to indicate a conflict between the outflow from the continental anticyclone and the Polar Anticyclone. At no great distance above the surface the air flow is largely from the northeast and remains in that quadrant up to at least 13,000 feet. During the spring months the prevailing winds aloft are easterly. In the summer surface winds are northerly and flow into the heat low of the continent, but above 1,600 feet and continuing up to 13,000 feet the prevailing winds are southerly. During autumn there is a return of easterly winds aloft. The average wind velocities aloft are greatest in summer, blowing from 16 to 22 m. p. h., while velocities in winter range from 14 to 18 m. p. h. Surface wind velocities are greatest in winter, and the occurrence of gales is likewise highest then, averaging nine per month, against an average of three per month during the summer, for a yearly total of 80.

A summary of the winds-aloft data gathered on the Norwegian north polar expedition in the *Maud* follows. The data were gathered in the years 1918–1925, between latitudes 77°33′ N. and 70° 43′ N., and between longitudes 105°40′ E. and 175°15′ W.

For all seasons, combined surface winds showed the greatest frequency from northeast to southeast with 51 percent of all observed winds from that quadrant. The average velocity of these prevalent winds was 9 m. p. h. At 3,000 feet all wind directions are about equally represented, except for north and northwest which have about half the percentage of other directions. The velocity, as well as the prevalence, is least for these north and northwest winds, being 16 m. p. h. with southeast winds having the greatest velocity, 19 m. p. h. At 6,000 feet the situation is similar to that at 3,000 feet, except that westerly winds have a slight edge in percentage. At 13,000 feet the weight of prevalence of west and southwest wind increases but all other directions are still well represented. Velocities at this level are least for southeast winds at 17 m. p. h., and greatest for west winds at 22 m. p. h. At 20,000 feet the weight of prevalence of west and southwest winds increases to a combined total of 33 percent, southeast being the least with 5 percent, and all other directions averaging 11 percent each. Velocities at 20,000 feet are greatest for west and northwest at 25 m. p. h. and least for southeast at 19 m. p. h.

From an average surface velocity of 7.8 m. p. h. there is a sharp increase to 17.4 m. p. h. at 3,000 feet above sea level. From 3,000 to 26,000 feet the rate of increase, while at first very small, becomes progressively greater. At 26,000 feet the highest average velocity is reached, 34 m. p. h. The upper limit of the troposphere is also found at about 26,000 feet and is evidently associated with the maximum wind. Average velocities at all elevations are greater in the winter than in the summer, the average difference between the two seasons being 2.5 m. p. h. At 16,000 feet the difference is greatest, 6.3 m. p. h., and at 23,000 feet the difference is least, 1.6 m. p. h.

SUMMARY OF WINDS

There are certain factors that should be considered in regard to the evaluation of the wind regime of any region. As is well known, there are shifts in the climatic scheme of the earth. As a rule these shifts are relatively small but in some years they are large and affect the climate of a region materially. These larger climatic shifts may amount to as much as several hundred miles, so that the average seasonal temperature at a given point may equal that usually experienced at a point several hundred miles to the north or south.

Naturally any climatic shift involves the wind system of a given region. The degree of change in the wind system may be so great that the wind system of one year would differ widely from that of another. Such climatic shifts do occur along the margins of the arctic basin. The desirability of long observational records is thus demonstrated, to give increasing value to a statistical study of climatological data.

Another factor affecting the representativeness of wind data is the cloudiness factor associated with wind direction. In certain areas of the Arctic, winds from one direction will bring clear skies, and as a consequence winds-aloft data gathered at such times will extend to high altitudes. Winds from other quadrants will bring low cloudiness and observations will be limited.

Some of the conclusions set forth in this discussion of the arctic wind scheme have been based on records of short duration and weighted in favor of those winds associated with clear skies. These conclusions err in proportion to the unrepresentative character of the data. However, it is believed that the data are such as to justify the statement that the conclusions set forth herein do approximate the actual conditions.

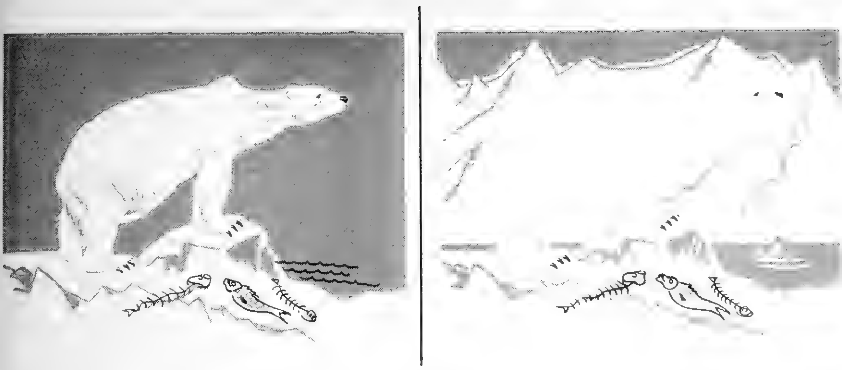


Figure 3–5.—Visibility.

VISIBILITY IN THE ARCTIC

The problem of visibility in the Arctic is extremely complex. The air is very transparent. The records of many travelers are replete with accounts of the extreme range of visibility. It is not uncommon to see dark mountains 100 miles distant. On the other hand, the lack of contrast, particularly where all surface objects are covered with new snow, results in the inability to distinguish objects close at hand. The traveler may easily fall into a crevasse which he is unable to see in midday. The black nose and claws of a polar bear may be seen clearly before it is possible to see any outline of the animal, because the yellowish white of the fur blends with snow-covered background.

The frequent well-marked temperature inversions of the arctic region explain the many accounts of mirages. Objects that are known to be below the horizon are not infrequently visible as mirages; and the periods of daytime and twilight are lengthened as the normal index of refraction is altered. The inversions may also interfere with the identification of landmarks through distortion, and the estimation of vertical distances is made much more difficult.

In winter the poorest visibility is indicated in the vicinity of Cape Chelyuskin. Improved visibility conditions are to be found to the west in the neighborhood of Murmansk, and to the east in the neighborhood of Uelen and Anadyr. Visibility conditions are better in the spring, particularly over inland stations. The section with the poorest visibility continues to be the Kara Sea. During the summer and fall the conditions are better over the inland stations than over the coastal stations. But again, the poorest conditions are to be found in the Kara and eastern Barents Sea regions. The very short record for Franz Josef Land indicates that visibility conditions are much poorer at Tikhaja Bay in the south than at Rudolph Island in the extreme north.

Limitations to visibility in the arctic region are primarily fogs, blowing snow, and local smoke. The different types of fogs are considered in the next section. Local smoke is serious only in the vicinity of the larger towns, and often occurs with the shallow radiation fogs of winter.

Blowing snow constitutes a much more serious hazard to flying in the Arctic than in more temperate latitudes. By comparison, the snow is dry and consists of fine particles. It is easily picked up by gentle or moderate winds and is drifted into the hollows, leaving the higher elevations bare. Winds of 9 to 14 m. p. h. will raise the snow a few feet off the ground, and the blowing snow will obscure surface objects such as rocks and runway markers. Winds of 15 m. p. h. or higher will raise the snow to consider-

Figure 3–6.—Blowing snow.

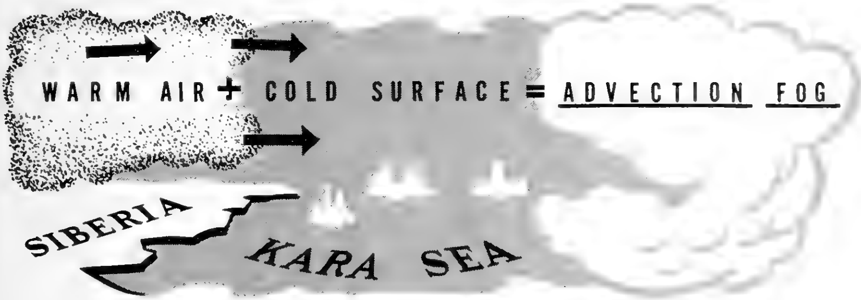


Figure 3–7.—Advection fogs.

able heights, obscuring buildings, radio masts, and other high objects. With high winds all traffic becomes impossible. The driven snow penetrates all types of buildings and equipment. The natives remain in their huts until the *urga,* as the blizzards are known, have blown over. These storms explain the poor visibility recorded at Chelyuskin in the colder months. The location of this station exposes it to frequent winds of sufficient velocity to cause almost continually blowing snow.

FOG

In many respects fog is the most important of the weather elements limiting aviation in the arctic regions. Over a large portion of the northern seas, fog may be expected to occur 90 or more days each year, and over small areas as many as 180 or more days each year. Any analysis of fog in the Arctic is rendered difficult due to the carelessness in defining and recording fog and to the lack of observational reports over large areas.

Two types of fog are frequent in the Arctic. The most common type is advection fog, formed when relatively warm air moves over a cold surface. A further condition is a fairly stable stratification of the air which would limit the increment of visible water vapor to the lowest layers of the atmosphere. Turbulence, whether convective or frontal in nature, is conducive to the formation of clouds but not of fog. The areas where conditions are most favorable for the formation of advection fog are the open waters of the Kara, Laptev, East Siberian, and Chukchi Seas during the summer. Fifteen to 20 days monthly with sea fog during the summer are normal in these areas, and 20 to 25 days are not uncommon. In adverse years 30 days with fog may be recorded. The frequency of the summer sea fogs diminishes rapidly from the coast line inland, and diminishes less rapidly over the pack ice.

It will be noted from the data that the summer fogs are less frequent over the Barents and Norwegian Seas. This is due to the more turbulent nature of the lower atmosphere over these seas, resulting in less fog and more low clouds.

Little is known about the frequency of fogs north of the mainland of North America. It is probable that fog is only slightly less frequent over the Beaufort Sea than over the Chukchi Sea, and that fog north of the Canadian archipelago and Greenland is comparable to that over the central pack ice. In the summer the advantages of inland terminals over coastal points exposed to the sea fogs may be summed up in stating that fog is three to five times more frequent over the open water of the Arctic than over inland river ports, and many times more frequent than over interior highland stations.

Fogs are reported to occur in some localities when a sea breeze carries moist air from the sea over the land. Such a condition must be considered unusual, because the sea breezes are most frequent in summer when the land is much warmer than the ocean, and the turbulence in the cooled air passing over the warm land results in the formation of strato-cumulus clouds. However, there are days in the spring and fall when the land could be colder than the open water of the neighboring sea, and fogs result from the passage of moist air currents from the sea to land. The area

Figure 3-8.—Radiation fogs.

where this type of fog is most likely to occur is the outer islands of the Canadian archipelago, particularly Prince Patrick, Borden and Meighen Islands. Here the prevailing winds are northwest (from sea to land) at all seasons of the year. The fogs do not penetrate far inland, and localities 20 miles from the coast are relatively free of fog. Unlike other areas in the Arctic, the periods of maximum frequency of fog in the outer islands of the Canadian archipelago would be spring and fall.

The second type of fog of major importance in the Arctic are the radiation fogs of winter. These fogs form readily under inversion in very cold weather and are caused by the cooling of the lowest layer of air in contact with the ground surface. Cooling by radiation takes place most rapidly over the land areas and least rapidly over open water. The fogs that are formed are generally thin and shallow. They occur most frequently along river bottoms where the air drainage is poor and the air movement sluggish. The locale of most frequent occurrence appears to be in the lower Lena River valley in Siberia and the lower Mackenzie River valley in North America. They are also quite frequent in the Yukon valley and the valleys of the principal northward-flowing rivers of central and eastern Siberia. Radiation fogs are also common over the pack ice during very cold weather.

Over the river valleys and over the pack ice, these fogs may be expected from 8 to 12 days monthly during the winter. In more adverse years the number of days with radiation fogs may be doubled. In a few localities, such as the lower Mackenzie in the vicinity of Aklavik, early morning radiation fogs may be expected 20 to 25 days monthly during the coldest months. It should be stressed that these *frost fogs* do not present as serious an obstacle to aviation as do the *water fogs*. They are generally thin fogs, so that contrasting objects can be distinguished on the surface directly beneath the airplane. It is only in the brief interval when the airplane is passing through the thin fog layer that visibility is seriously reduced. With experience, landings and take-offs can be made with safety through the shallow frost-fogs.

Of considerable interest but of minor importance is the occurrence of *steam fogs,* also known as *arctic smoke*. They are formed by *steaming* from open water surface during extremely cold weather, occurring most frequently over rivers, unfrozen lakes, and open leads in the arctic seas. Such *steam fogs* are generally shallow and are quickly dispersed by wind. However, they may at times be sufficiently dense to obscure landing fields adjacent to

Figure 3–9.—Fog trails.

open water or to obscure landmarks along the airlines. Over the Arctic Ocean they serve the very important purpose of advising the traveler of the presence of open water. They are most noticeable when the temperature contrast between water and air is the greatest, i. e., at extremely low temperatures. In some places *steam fogs* are so frequent during cold weather as to be a natural part of the landscape. For example, Reykjavik, meaning "Smoky Bay," derives its name from the fact that steam fogs arise from the abnormally warm waters of the bay during extremely cold weather.

Of special interest is the fact that *fog trails* are left by airplanes when traveling through the very cold atmosphere of arctic regions. Canadian fliers have reported fog trails 18 miles long in the lower Mackenzie district. Various factors enter into the formation of these fog trails: the amount of condensation nuclei in the exhaust gases; the formation of water vapor in the exhaust gases; the lower pressures set up by the airfoils; and the turbulence set up by the rapidly moving airplanes. It is possible for one airplane to follow another by means of its fog trail.

The summer sea fogs occur most frequently with easterly winds over the portions of the Arctic north of the Siberian coast. The explanation may be offered that the stable condition necessary for fog formation exists with easterly winds. It was noted from the upper air observations taken on the *Maud* that the temperature inversion aloft existed most frequently with easterly winds and that warm air aloft was carried over the arctic seas in a southeasterly current. The westerly winds were generally uniformly cold at all levels. During the summer, fog occurred most frequently at all but two of the stations with winds from the north to east. The two exceptions were the stations on Great Liakhov Island and Bulun. The latter is an interior station and the former showed considerable variability due to the adjacent land masses.

During the fall and winter, the fogs appeared to occur most frequently with south or southwest winds. This would indicate that the stable conditions in which the fog occurs are associated more frequently in this portion of the arctic region with the great Asiatic Anticyclone than with the Arctic Anticyclone. However, considerable variability may be expected from year to year with the varying strength of the two anticyclonic systems.

Fogs are not to be expected in summer with offshore winds, as a rule. The offshore winds are generally dry and are not cooled sufficiently to cause the formation of fog.

Summer fogs are most frequent with light winds, but may occur with winds of high velocity under favorable conditions. Since they are advection fogs, they do not form readily in calm weather. The opposite is true of the mists or *frost fogs* of the winter season. These latter are radiation fogs and form most readily in calm weather or with very light winds. High winds are very unfavorable for the formation or continuation of fog in the colder months of the year.

Fogs in the arctic region are more frequent in the late night and early morning hours than at any other time. In discussing the fogs of the Kara Sea region, Vize has noted that the maximum frequency of fogs occurs at midnight or in the hours immediately following, and that the minimum frequency occurs at noon or in the hours immediately following. This agrees closely with experience of the *Maud* in the East Siberian Sea.

Data on the diurnal distribution of mist, or frost fogs, are not so conclusive, but indicate a similar distribution to the summer advection fogs. The data from Aklavik indicate that frost fogs are much more frequent in the early morning than at noon or in the evening. It is the common practice in these regions to limit aviation activities to the late morning or afternoon hours. It is particularly important that all flights terminating in the lower Mackenzie, the Yukon, or the Lower Lena River valleys during the winter season be so planned that they are completed at midday or in the afternoon.

CLOUDINESS

In general, cloudiness over the arctic regions is greatest in summer and fall and least in winter and spring. This statement should be modified slightly when dealing with specific locations. Those localities in the Arctic Ocean or under the immediate influence of the ocean circulation will have the maximum cloudiness in midsummer. Those localities under the influence of the adjacent continents will have the maximum cloudiness in early autumn, with a secondary maximum in early summer.

In the warmer months of the year cloudiness shows a maximum during the daylight hours and a minimum during the night hours. In some months the trend may be reversed and the maximum cloudiness will occur at night. This may be due to the occurrence of fog at night, but further observations are necessary to verify the present data—observations taken over wide areas simultaneously. During the winter half-year the observed diurnal variation is largely due to conditions of the light, more clouds being observed in the daytime or twilight hours than are observed at night.

The character of the cloud deck is quite different over the Arctic Ocean than over more temperate latitudes. Stratus clouds are by far the most frequent type observed. They cover the sky completely and seem to merge with the snow or ice-covered landscape at the skyline. In the summer and fall the stratus clouds will constitute from 70 percent to 80 percent of all clouds observed. In the winter and spring they are not quite so frequent, making from 45 percent to 60 percent of all cloud types observed. These proportions apply only to conditions over the Arctic Ocean or adjacent seas. Along the coast lines the stratus clouds are slightly less frequent and have a tendency to be more broken up by convective currents, with an increase in the percentage of stratocumulus type of cloud being reported. In the winter, altostratus and cirrostratus clouds are frequently recorded. At this season the clouds are thin; during daylight hours the disk of the sun can frequently be observed through the clouds.

Cloudless days are uncommon in the Arctic. Days with zero- to two-tenths coverage usually occur with the greatest frequency during February and March, although the number of such days in a winter period will total no more than 3 to 10. The greater number of clear days will naturally occur over those areas where anticyclonic conditions are most likely to prevail. Thus the expectancy of clear days is greatest over the interior of the arctic basin, with the lower Mackenzie valley and the lower Lena and Yana River valleys running second. Clear days are least frequent over the Barents and Kara Seas and relatively infrequent over the Chukchi Sea. Cloudy days, those with eight- to ten-tenths coverage, are most frequent over the arctic basin in summer. From May to October they will run between 18 and 24 a month over most of the area. There are a few more cloudy days over

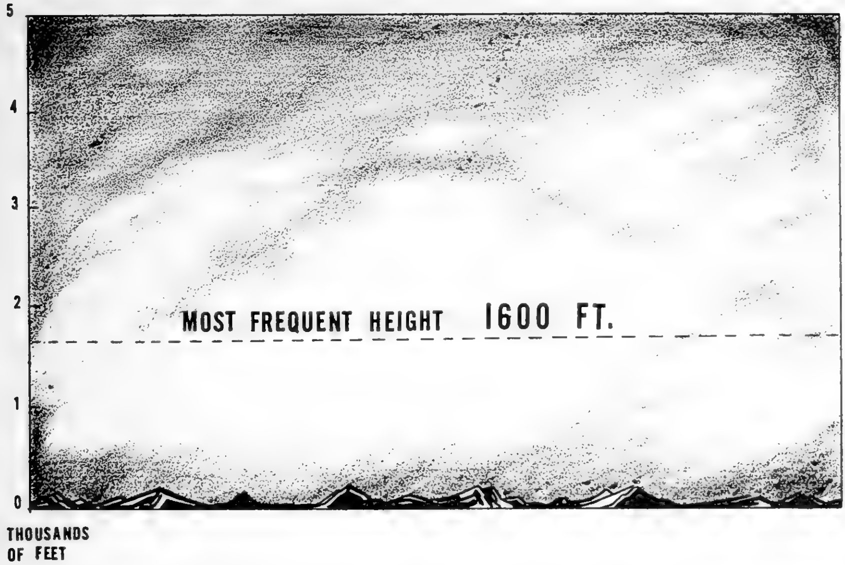


Figure 3–10.—Cloud heights are lower in the Arctic.

the pack ice than over the coastal areas. In winter the number of cloudy days will generally run between 6 and 12 a month, the greater number occurring in the same areas as the least number of clear days.

The conditions described apply only to the arctic basin and the adjacent coastal areas. In the interior of the continents within the arctic zone cloudiness is appreciably different. In particular the summer cloudiness is much less, with few cloudy or overcast days, but with a large proportion of partly cloudy days. The clouds are mostly of a cumuliform nature, as contrasted to the stratus clouds of the arctic basin. In winter the cloudiness of these interior sections is largely governed by their location with respect to the moving cyclonic disturbances. Those localities near the paths of the disturbances will have a high percentage of cloudiness with a large number of cloudy days. Other localities far removed from the paths of storms will have less cloudiness, with a larger number of clear or partly cloudy days.

Cloud heights are lower in the Arctic than in the temperate latitudes. The most frequent type of cloud, the stratus clouds, will be found anywhere between zero and 5,000 feet. The observations on the *Maud* indicated that the most frequent height is below 1,600 feet. However, the measurement of the ceilings were made only when a kite flight or a pilot balloon observation was practicable. With very low clouds in summer, the kites became iced and were forced down so that, in general, measurements of the ceiling could not be made. From other sources it is indicated that the height of stratus clouds is frequently found between 600 and 1,000 feet. Stratocumulus may be expected most frequently at around 5,000 feet; and, as mentioned previously, they are more frequent over the coast than over the sea. Altocumulus have an average height of 10,000 feet and altostratus about 13,000 feet. The various types of cirrus clouds are encountered between 15,000 and 30,000 feet.

CEILINGS

The average height of the various types of clouds has been noted above. Data on ceilings are difficult to find and are not too reliable.

Low ceilings are most frequent over the Kara Sea area. Over

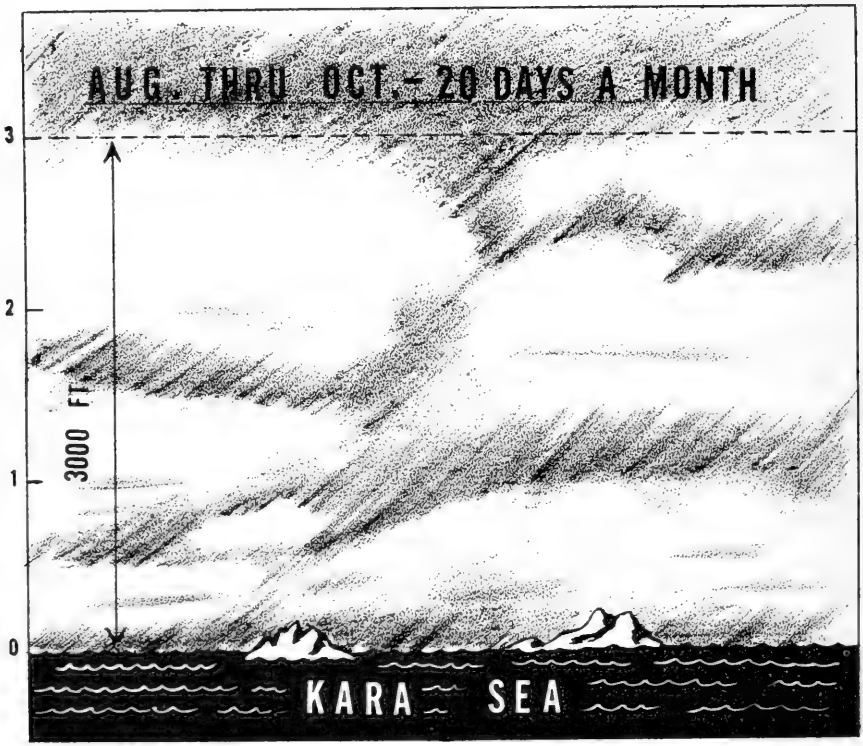


Figure 3-11.—Low ceilings over Kara Sea region.

the central polar or arctic basin they occur most frequently in the late summer and autumn. Ceilings less than 3,000 feet may be expected on 20 days a month in the Kara Sea region from August through October, and on about 15 days a month in early summer and late autumn. The best season is late winter and early spring, with approximately 10 days a month having low ceilings. In the Laptev, East Siberian, and Chukchi Sea areas the number of days with low ceilings will average about 5 less each season than over the Kara Sea area. The conditions over the Barents Sea are similar to those over the Kara Sea. Data for the American portion of the Arctic are not available. Conditions over the northern Alaskan coast and near the mouth of the Mackenzie River should be similar to conditions along the Siberian coast from the mouth of the Lena River eastward.

Slightly different conditions are shown by taking the occurrences of very low ceilings (less than 600 feet). The poorest conditions in midwinter and early spring are to be found in the Kara Sea region, but in late spring the area of most frequent very low ceilings shifts to the extreme northeast of Siberia. Uelen shows the poorest conditions in April, while in May the poor conditions extend from Wrangel Island to Cape Navarin. July and August are the poorest months of the region as a whole, taking into account the occurrence of ceilings less than 600 feet. In July the record at Cape Navarin shows more than 15 days with ceilings less than 600 feet. In the interior, the occurrence of low ceilings is not an important factor.

TEMPERATURE

The most common misconceptions of the Arctic are that the land areas are covered with eternal ice and snow; that there is everlasting winter with intense cold; and that with the everlastingness of winter there is an absence of summer and lack of vegetation. Greenland is a striking example of an ice-covered land possessing these qualities and from it the rest of the north has been pictured by analogy. The high elevation of Greenland and the rather heavy precipitation it receives are two factors which highly favor glaciation. In general, however, other arctic lands possess neither of these characteristics. Over a large portion of the Arctic the scanty snows melt rapidly with the approach of summer. Otherwise, glaciers would soon form. Most of what little snow does fall is soon swept by the wind into gullies and into the lee of

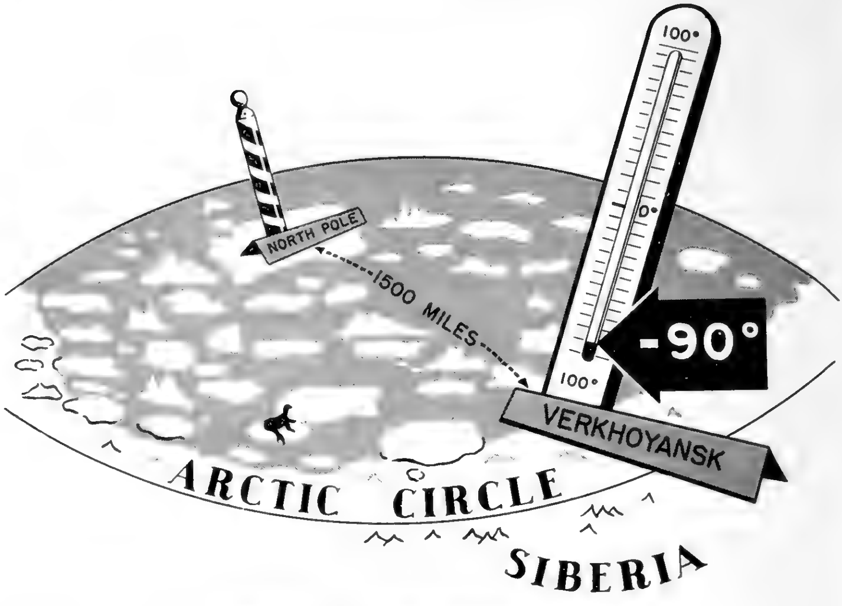


Figure 3–12.—Coldest recorded temperature.

the hills so that more than three-fourths of the arctic lands are comparatively free of snow at all seasons.

Next, considering the intense cold, it has been shown that temperatures below minus 60° F. are not possible at the North Pole, lying as it does at the center of a deep basin. At Herschel Island, off the north coast of Canada, the absolute minimum over a long period has been minus 54°. The lowest official temperature ever recorded in North America, minus 78.5° F., was registered at Fort Good Hope, several hundred miles to the south. Even at Havre, Mont., an extreme temperature of minus 68° F. or 8° F. colder than is theoretically possible at the North Pole, has been recorded. The coldest observed temperature on the surface of the earth was recorded at Verkhoyansk, near the Arctic Circle in eastern Siberia, well over 1,500 miles from the geographic pole. Until a few years ago this station enjoyed the doubtful honor of experiencing colder winter weather than any other known place in the world. Theoretically only the South Pole is colder. In 1929 a station was opened in the Oimekon River district, some 400 miles southeast of Verkhoyansk, and from the brief record available it is noted that the winter temperatures have consistently averaged lower than those for the same time at Verkhoyansk. The lowest reading at the new station is minus 85° F., only 5° from the record of minus 90° found at Verkhoyansk. It is not at all improbable that a lower record will be established at this new station.

On the other hand, there is always a summer in the Arctic with lúsh vegetation in places, the presence of birds, and the hum of millions of insects. The myriads of mosquitoes can and do cause more distress than the cold. Not infrequent complaints of the summer heat are voiced. A maximum of 100° F. in the shade has been recorded above the arctic circle, and maximum 80° F. to 90° F. at stations not on the coast are the rule rather than the exception. Even with the lower maxima farther north, the high relative humidity produces oppressive conditions. Then, too, the heavy clothing necessary for protection against the insects adds to the general discomfort. Whereas native clothing is much more satisfactory in winter, the clothing of the white man is better than that of the Eskimo for summer use.

TEMPERATURE CURVE TYPES

A huge variety of climatic conditions are encountered in these regions. Areas adjacent to one another are found to have widely different climatic characteristics, determined by latitude, marine influence, and topography. A study of annual temperature curves reveals three well defined types—*maritime, coastal,* and *continental:*

1. In the Arctic Sea the temperature in June, July, and August deviates very slightly from the freezing point, thus producing a flat curve in summer. Likewise in winter there is a flatness to the curve, but this time the temperature stays around minus 30° F.

2. The coastal climate closely resembles the maritime, with the year consisting primarily of a long cold winter and a short cool summer similar to fall or spring as experienced on the continent. The annual curve has the same winter characteristics as that of the Arctic Sea but there is a seasonal maximum in July during summer. The mean summer temperature, however, remains under 50° F.

3. The arctic continental climate is characterized by very low winter temperatures with a pronounced winter minimum, and high summer temperatures with a highly pronounced summer maximum. Here the annual ranges of mean temperature may be as much as 80° F. to 100° F.

The winter and summer temperatures are of especial interest and will be discussed more fully.

The prominent feature of the winter temperature at arctic stations in the vicinity of the coast is that the temperatures remain nearly constant for a considerable length of time. The coldest month of the year, on the average, is not January, but February. For many stations it is March, and in some years even April has a lower mean than January. Bear Island is one case in particular which shows this tendency. The high pressure cell in the Arctic Sea has become well developed by late winter and as the mean position of the arctic front shifts southward conditions favorable to the producing of these low temperatures as late as March and April are found.

On the European continent there is no mountain barrier near the coast and the warm North Atlantic Drift has a marked influence on the temperature of central and northwestern Europe. The prevailing westerly winds carry the oceanic influence far inland. In the south, on the other hand, the prevailing northeast winds originate in the heart of the continent and consequently are quite cold. These facts account for the marked northwest to southeast trend of the winter isotherms in Russia and western ana central Siberia. The temperature decreases with marked uniformity as one advances toward northeastern Siberia. until the region around Verkhoyansk, known as the *cold pole* or center of extreme cold of the northern hemisphere, is reached. Here the January average is minus 58° F., and never in this month has the temperature risen higher than 2° F. above zero. The absolute minimum of minus 90° F. is the lowest reading ever taken of the surface of the earth. With a July average of 60° F. the annual mean range of 118° F. is the greatest for any station. Also, the absolute range is the largest ever recorded, from minus 90° F. to 90° F. above, or 180° F.

That this area should have the most extreme winters known to man is readily understood from its geographical location. The heat of the North Atlantic cannot penetrate the 3,000 miles of frozen continent; the Pacific Ocean has no appreciable effect, since ranges of hills intervene and winds are prevailingly offshore; the ice-covered Arctic Ocean certainly cannot ameliorate the harsh conditions; and the lofty ranges of central Asia check any influence from the warm Indian Ocean far to the south. The characteristic *lag* of seasons, so highly pronounced on the arctic coast and conspicuous at any locality with maritime influence, is almost totally absent. The temperature curve follows more nearly that of insolation, and April is as warm as October. In the interior of Canada the same characteristics are evident, but since the area is not comparable to the vastness of the Siberian continent, the feature is less pronounced.

The Siberian winter is by no means as unpleasant as its extreme temperatures might suggest. The air is often calm and the skies clear. Danger to man or beast occurs only when the *wild buran* or *purga* blows. These fearful blizzards also occur in the interior of Canada.

As has already been noted, average temperatures near the central polar basin are higher than in the interior. That the maritime effect of the ice-covered sea could produce the large differences observed is not logical and the explanation lies in the physical characteristics of the land. With no hills or trees of any consequence to act as frictional resistance to the wind, more freedom of movement is allowed. This produces a greater degree of mixing in the surface layers which transport warmer air to the surface.

Irregularities of the winter isotherms in the polar sea are produced by the influence of the Atlantic and Pacific Oceans. In the North Atlantic the isotherms are pushed far northward and here is found the greatest positive anomaly of temperature in the world (the greatest departure from the latitudinal average). The winter temperatures in the vicinity of Bering Strait are influenced by the open waters of the Bering Sea. North of the Strait the influence is limited to a rather small area with large local differences occurring with different wind directions. Northerly and especially northeasterly winds bring temperatures characteristic of the ice-covered sea, while southeasterly winds transport air with a much higher temperature.

The temperature inversions noted in all arctic regions are especially prominent over the pack ice in the polar sea. The diurnal variation during the dark season is, as would be expected, rather irregular. From the available data it is discovered that the maximum occurs at night hours and the minimum in the middle of the day. Again it is the wind which accounts for the irregularity. Any slight increase in wind, regardless of direction, will produce a considerable rise in temperature by the process of mixing. Since the diurnal variation of wind is largely dependent on the diurnal variation of pressure it is possible to set up definite relations which exist among temperature, wind, and pressure.

Small temperature variability in summer is a characteristic

Figure 3–13.—Breaking up pack ice.

common to all stations in the inner polar areas. The temperatures in the pack ice never deviate far from the freezing point. The diurnal ranges are smaller and the interdiurnal changes are less in summer than in any other season. Warm air from inland is often transported a considerable distance from the coast, but in passing over the icy waters it is cooled so effectively by contact with the ice that a sharp inversion is formed. Thus, the warm air current flows at some distance from the ground and has practically no influence on the surface temperature. Considerably higher temperatures are found on the coast and the transition from coastal to maritime conditions takes place within a very short distance. However, this characteristic holds for the surface layers only and is not found at higher levels. The discontinuity, therefore, represents only a quasifront and is of no consequence to the circulation of the atmosphere.

The warmest month in the Arctic over both land and sea areas is, with but few exceptions, July. However, the August temperature chart is representative of summer conditions. It is highly probable that everywhere in the Arctic Ocean the average temperature for July is within a few tenths of a degree of the freezing point, whereas in June and August the average is slightly below 30° F.

The highest temperature observed on the *Fram* expedition was 39.2° F. in June, 1896, and observers on the *Maud* found an absolute maximum of 38.3° F. in June, 1923. That both values occurred in June is probably explained by the fact that maximum cloudiness in this area occurs in July and August. At coastal sta-

Figure 3–14.—Warmest month in the Arctic.

tions much higher readings are found and maxima near 70° F. are quite common. Still greater maxima are recorded at inland stations, and temperatures above 90° F. are the rule at stations near the arctic circle which are a considerable distance from the sea.

There are two features worthy of note which characterize the summer temperatures in the polar sea: (1) The temperature is near freezing everywhere with no variation with latitude and (2) again independent of latitude, the first day with a maximum temperature and the first day with a mean temperature of 32° F. or higher is nearly the same in all sections except those under the influence of warm winds from the south.

PRECIPITATION

There are two significant factors which make it extremely difficult to obtain satisfactory measurements of precipitation in the Arctic: (1) The fine ice needles of winter precipitation are very easily blown across the rain gage opening and (2) during snow storms it is difficult to determine whether the snow is falling or is being blown up from the surface. Another obstacle is determining the number of days with a measurable amount of precipitation. On extremely cold days the snow is very fine, and there are many days when precipitation is so slight that it cannot be measured but is present nevertheless. A striking example is found in records of the Norwegian north polar expedition. At Goose Fiord, Ellesmere Island, eleven days in April were recorded on which precipitation occurred, but the total for the month showed only 0.2 mm. or slightly less than 0.01 inch. On the North American continent the number of days with precipitation is determined from the days on which 0.01 inch or more is measured. Other stations use days with 0.1 mm. or more, while still other stations have tabulated all the days when precipitation occurred.

In the arctic and subarctic regions the inadequacy of the records permit only broad and general statements regarding yearly averages and seasonal distribution. The time of year of maximum precipitation varies with the prominence of marine or continental influence. It is a well known fact that snowfall is extremely light and stations in continental areas have maximum precipitation in late summer, indicating that a large percent of the yearly total falls as rain.

On the whole, amount of precipitation received at land stations is rather uniform, which is as might be expected in countries of monotonous relief. This is especially true in the north central portion of Siberia. Variation of the annual amounts from year to year is also slight. Snowfall varies more than rainfall, especially where it is comparatively scarce. Depth of snow for any month may exceed four times the average fall, whereas rain seldom exceeds twice the normal amount.

Although the amount of precipitation along the arctic coast is small, the ground remains soaked for a long period in summer. Underground drainage is prevented by the permanently frozen subsoil. Even though somewhat larger amounts of precipitation are received farther south at inland stations, the summer temperatures are so much higher that drought conditions become manifest.

The amount of precipitation decreases considerably toward the North Pole, especially in winter. In precipitation, as in temperature, interzonal differences are apparent. In the Canadian archipelago and on the north coast of Asia summer precipitation is greater than that of winter, but in the North Sea low pressure area, between the east coast of Greenland and Novaya Zemlya, averages are greater in winter than in summer. In the region of the foregoing low and the low pressure spur in Baffin Bay the annual amounts of precipitation are greater than in the other regions of equal geographical latitude.

Snow may fall in every month and rain falls only in June, July, August, and September. May has, on the whole, the greatest number of days with precipitation and the midwinter months the smallest. The contrast between conditions in summer and winter appear to be greater over the pack ice than at the coast.

No diurnal variation was found in winter in the pack ice but in other seasons of the year the probability of precipitation appears to be greater at night than in the daytime. The difference is especially great in spring, but apparently there is no satisfactory explanation of this feature. It was also found that the probability of precipitation was greater with northerly than with southerly winds. This is also true of the coast as the land elevations would favor precipitation with onshore winds.

The frequency of precipitation varies, in general, with the total precipitation. Koeppe suggests that at least two-thirds of the Dominion of Canada probably has fewer than 80 days per year with measurable amounts (0.01 inch or more). This area embraces nearly all the arctic region of North America. The number of days with precipitation in the Canadian archipelago is particularly small in winter. A maximum frequency occurs in the region of the North Sea Low in October and November, while on the Asiatic Russian north coast the maximum appears in September, though the period of heaviest precipitation is more generally July and August.

FORECASTING AIDS

The following remarks relative to forecasting the weather in the Canadian archipelago were extracted from reports submitted by naval aerologists who have served with task forces operating in the area.

The rules of forecasting used in middle latitudes can be considered of consequence, but cannot be completely relied upon for forecasting in the Canadian Arctic. Single station observations, aided by a general circulation pattern, must be the basis of present forecasting in this area. First-hand experience is of prime importance as local influences are a major factor and vary widely from place to place within the area.

Forecasts covering periods of 18 to 24 hours are the maximum lengths found to have a satisfactory degree of reliability, because of the extent to which forecasts depend upon single station analysis and local observations. By use of the few synoptic reports available in the Canadian archipelago, weather can be forecast in a general way, but without experience in the area itself and without greater facilities than are now present, detailed conditions cannot be determined for longer periods in advance. The use of *persistence* forecasting, that is observing the trend of weather toward improving or deteriorating conditions, cannot be relied upon except for a period of a very few hours, and then only in a very general way.

WEATHER SCHEDULES

1. Radio Washington cannot normally be copied in most arctic areas, and the best information available comes from Dorval, Canada (VFN), or Westover Field, Mass. (WSO).

2. One or two radiomen should be assigned the primary responsibility for copying weather schedules. A radioman who is familiar with the methods of broadcast peculiar to weather schedules understands what is required of him and obtains a more complete coverage than would an unindoctrinated radioman.

WINDS

1. Wind direction and velocity are often of great aid in forecasting visibility conditions, but use of winds in forecasting must be tempered by a thorough consideration of any land mass effects in the vicinity. With a steady flow from the south, poor visibility can be expected in the Canadian archipelago in summer. This is due to cooling of the warm, humid air which moves in from the south to temperatures less than its condensation point, resulting in fog. Even with velocities in excess of 25 knots fog will not dissipate before a steady flow from the south.

2. Winds slowly veering from north to southeast or south indicate the passage of a high pressure ridge across the observing station. This gradual shift is usually accompanied by a decrease in velocity to less than 10 knots as the peak of the wedge approaches. It is an indication that a well developed occlusion is moving into the area when the wind slowly veers to the southeast, and then remains in that direction while gradually increasing in velocity as the barometric pressure decreases. If the wind-veer continues into the southwest, with or without an increase in velocity, it is an indication that a cold front is approaching from the northwest, preceding an arctic air mass outbreak from the Beaufort Sea area.

3. A wind shift into the north or northwest with a cold frontal passage is not an indication of clearing behind the front. The air masses behind cold fronts which move across the Canadian archipelago are shallow, and thus the clouds behind the fronts are more stratiform than cumuliform, having very little vertical development. Here also, when occlusions are encountered, the cessation of precipitation is not rapid, due to the fact that the occlusions moving across the archipelago are mature, and the moist air has been transported completely around the northern tip of the occlusion.

CLOUDS

1. Very often the low stratus overcast prevalent in the maritime air of the Canadian archipelago obscures all higher clouds, and only by use of radiosonde soundings can their presence be detected. However, it is very rare that there is not an occasional break in the low stratus, and through these breaks the higher clouds can be observed for short periods of time, if they are present.

2. There are two situations in which the normally prevalent low stratus can be expected to be absent. One is on the front side, near the middle of high pressure ridges, where there is marked divergent circulation. The other, less frequent, is in the relatively dry continental arctic air moving southeast from the Beaufort Sea area, prior to its picking up moisture in the maritime archipelago. This second situation is due partly to divergence, although the lack of moisture in the air mass in general is the major factor.

3. Broken layers of altocumulus clouds, usually mixed with much altostratus, are present a long distance behind fronts in the arctic areas. This is due to the usual shallowness and great homogeneity of the air masses behind the fronts in the Arctic. The broken layers of clouds are connected either with cold fronts or occlusions that are part of the systems that stagnate in the Baffin Bay area in summer. In autumn they lie to the north of the cold fronts that develop between the polar air masses of central Canada and the arctic air masses formed over the ice pack to the north and west of Canada. The distance behind fronts to which the middle clouds extend varies greatly, and no definite statement can be made without further observation.

4. Very low stratus, only a few hundred feet above sea level, forms on the sides of hills, due to the radiation effect in combination with the high moisture content of the air near the surface. Moisture is supplied during the summer months by the continuous melting of the top of the permafrost layer. Since continuous observations could not be made in any of the areas where this stratus formed, it was not possible to establish any criteria for the formation and dissipation of these clouds.

PRECIPITATION AND FOG

1. Throughout July, and until the latter part of August, drizzle type rain was the prevailing form of precipitation encountered. Commencing in the latter part of August, and from then on until completion of the operation, as the warming effect of the sun lessened and the autumn season replaced summer, temperatures decreased and snow, instead of rain, become the common form of precipitation.

2. The type of precipitation experienced was largely in the form of intermittent drizzle, and in almost all cases precipitation was

light. This was to be expected as there was little vertical development in clouds of the sort that produce precipitation of the showery type, nearly all clouds being stratiform in character.

3. In forecasting the beginning and ending of precipitation in connection with the passage of occluded fronts, it must be remembered that occlusions moving into the eastern part of the Canadian Arctic are well developed and mature by the time they reach this area; hence, rain shields extend well forward of the front and also far to the rear of the front, near the tip of the occlusion. The extension of the rain shield to the rear of the front is a result of well developed cyclonic circulation around the tip of the occlusion, to the north. Rain shields usually diminish in size after the occlusion has matured and has slowed in its forward movement. In the Canadian archipelago this does not occur until approaching Baffin Bay.

4. In forecasting the duration of precipitation after the passage of a cold front, it is important to note that the slope of the cold front is usually very gradual, since the outbreaks of arctic air from the northwest are very shallow. As a result of the gradual slope, the rain shields extend farther to the rear than in a middle latitude cold front with a steeper slope. The rain in these cases is more of a steady type, rather than showery. A rain shield extending 75 miles behind the cold front is not unusual; and beyond that, stratocumulus clouds often extend as much as 200 miles behind the front.

5. With a strong southerly flow, warm, moist air is carried north across considerable latitude and is subjected to cooling from below when it passes over the maritime Canadian archipelago. This results in the formation of fog, when the temperature of the air is lowered to the dew point or below. With strong winds, mixing occurs in the lower layer of air, and the effect of this is to intensify the fog. It has been observed that with southerly winds of from 20 to 30 knots, the fog is decidedly more dense than with winds of from 10 to 20 knots.

6. There are times, although relatively few, when precipitation is of the shower type rather than of the drizzle type. An analysis of the stability characteristics of the air mass involved will give an indication of the type of precipitation to be expected in the Arctic as elsewhere. Continental arctic air masses move into the

area from the northwest and their surface layers are warmed as they move over the Canadian archipelago. The archipelago, with its maritime characteristics in summer, in much warmer than the ice pack source region of the summer arctic air masses. The warming in the lower layer of air results in a steep lapse rate in that layer, and hence instability.

PRESSURE

1. Pressure tendency cannot be relied upon as an aid in forecasting except in very few instances in the Canadian Arctic. In the western and northern portions of the operating area, weak pressure gradients were found, and these gave little indication as to the orientation of isobars, because of the absence of reporting stations.

2. In the summer, when pressure gradients are weak, local land mass effects, rather than the general pressure field, are the major influences on wind direction. This does not apply in the cyclonic circulation of northern Baffin Bay, a large area of open water, with a normally steeper gradient than is found to the west.

3. In autumn, late August and September, the high pressure cell to the northwest of the archipelago, centered over the Beaufort Sea, becomes more pronounced. This results in a somewhat steeper pressure gradient across the archipelago. Hence, a northerly wind on the east side of the high cell prevails across the archipelago.

4. In the eastern part of the Canadian Arctic, when migratory storms move from the southwest toward Baffin Bay, the steepness of the pressure tendency provides a good indication of the intensity of the approaching lows. It follows that, in these pressure systems, the sharper the fall and subsequent rise of pressure, the greater will be the velocity of the accompanying winds.

5. During the summer months, except in the cyclonic circulation of Baffin Bay, rise and fall of barometric pressure was of practically no value in forecasting. In autumn, as the pressure field becomes more pronounced, a certain amount of reliability can be placed on pressure tendency, but not to the extent of that in middle latitudes.

SUMMARY

Our knowledge of arctic climate is based on sparse records even though collected at various places over a period of many years. More than in most other geographic areas, the success of a given operation and indeed the very safety of the unit depend on accurate and timely forecasts of weather. The data contained herein can form one of the bases for consideration in planning arctic operations. Included as appendix A is a brief description of Antarctic climate as understood at this time. It is to serve as reference matter for personnel connected with exploring expeditions to Antarctica.

TABLE VII

Place Names for Weather Tables

Place:	*Area*
Archangel	U. S. S. R., White Sea.
Cape Chelyuskin	U. S. S. R., Taimyr Peninsula.
Dickson Island	U. S. S. R., Kara Sea.
Kola	U. S. S. R., Kola Peninsula.
Okhotsk	U. S. S. R., East Siberia.
Tiksi Bay	U. S. S. R., Laptev Sea.
Vaigach Island	U. S. S. R., Kara Sea.
Verkhoyansk	U. S. S. R., East Siberia.
Wrangel Island	U. S. S. R., Chukchi Sea.
Yugor Strait	U. S. S. R., Novaya Zemlya.
Anchorage	Alaska, Cook Inlet.
Dutch Harbor	Alaska, Aleutian Islands.
Fairbanks	Alaska, Central.
Juneau	Alaska, Inland Passage.
Point Barrow	Alaska, Arctic.
St. Paul Island	Alaska, Bering Sea.
Aklavik	Canada, Yukon Territory.
Barrow Strait	Canada, Northwest Passage.
Churchill	Canada, Hudson Bay.
Craig Harbour	Canada, Ellesmere Island.
Fort Resolution	Canada, Great Slave Lake.
Herschel Island	Canada, Beaufort Sea.
Lake Harbour	Canada, Hudson Strait.
Pond Inlet	Canada, Baffin Island.
Tromso	Norway.
Vardo	Do.
Bear Island	Norwegian Sea.
Jan Mayen Island	Greenland Sea.
Green Harbour	Spitsbergen.
Angmagssalik	Greenland, East Central.
Etah	Greenland, Northwest.
Godhavn	Greenland, West Central.
Ice Cap (Interior Greenland)	Greenland.
Ivigtut	Greenland, Southwest.
Godthaab	Do.
Thule (North Star Bay)	Greenland, Northwest.
Upernivik	Greenland, West Central.

Table VIII

Mean Monthly and Annual Temperatures (° F.) with Extremes

Place	January	March	May	July	September	November	Annual	Absolute Maximum	Absolute Minimum
Archangel	8.1	17.4	41.4	59.5	45.7	21.4	32.3	94	−49
Cape Chelyuskin	−24.4	−26.4	15.0	34.9	27.9	−9.0	4.9	67	−50
Dickson Island	−13.5	−10.8	17.2	40.3	35.4	1.2	11.8	73	−55
Kola	11.3	17.4	38.1	54.5	42.6	20.5	30.7		−39
Okhotsk	−10.3	6.4	34.9	54.3	46.4	5.4	22.5	78	−50
Vaigach Island	3.1	−.6	22.5	42.2	38.1	18.9	20.7	79	−44
Verkhoyansk	−58.2	−23.8	36.3	60.3	36.1	−34.1	3.3	94	−90
Wrangel Island	−10.7	−10.1	16.7	37.0	28.5	1.4	10.8	65	−50
Yugor Strait	−1.0	−2.2	21.8	43.0	38.3	15.6	19.2	78	−47
Anchorage	11.3	22.3	44.8	57.0	47.8	22.5	34.6	84	−36
Dutch Harbor	32.1	34.1	40.7	51.3	48.5	36.4	40.4	80	5
Fairbanks	−11.2	9.5	46.9	60.1	43.6	4.1	26.1	99	−66
Juneau	27.7	33.7	47.7	56.7	50.4	35.7	42.2	89	−15
Point Barrow	−16.2	−14.8	19.6	40.0	31.6	−.3	10.2	78	−56
St. Paul Island	21.8	26.6	33.4	45.2	44.7	32.8	33.8	64	−26
Aklavik	−21.4	−7.0	30.6	55.5	37.6	−5.9	15.0	85	−56
Barrow Strait	−31.5	−21.1	15.6	37.9	21.9	−8.3	2.7		
Churchill	−18.9	−6.2	29.1	52.9	41.0	6.8	17.7	96	−57
Craig Harbour	−22.1	−14.4	15.4	40.5	28.6	−2.9	7.0	60	−49
Fort Resolution	−16.9	−1.7	40.0	60.2	45.5	8.3	23.0	90	−63
Herschel Island	−22.0	−12.1	19.2	44.1	31.3	−6.1	10.2	69	−52
Lake Harbour	−15.4	−4.9	27.7	44.0	35.0	12.4	16.4	74	−45
Pond Inlet	−29.2	−21.9	23.4	42.2	30.0	−4.2	7.2	77	−54
Tromso	26.2	26.4	38.8	51.8	44.2	30.4	36.3	82	−1
Vardo	22.1	23.5	35.1	47.7	43.2	28.2	33.3	78	−11
Bear Island	15.1	12.2	27.9	39.6	35.4	20.7	25.2		
Jan Mayen	22.8	20.7	29.7	40.5	38.1	27.0	29.8	59	−2
Green Harbour	3.2	−2.2	23.4	41.7	32.2	10.9	18.5	60	−57
Angmagssalik	17.6	18.9	33.8	44.8	37.6	23.0	29.1	77	−26
Etah	−14.2	−7.4	22.6		25.2	4.5		60	−30
Ice Cap Greenland	−33.2	−30.1	14.9	37.8	16.5	−18.9	−1.8		
Godhavn	2.1	3.7	30.6	45.5	36.5	20.7	23.0	63	−28
Godthaab	14.4	18.5	33.4	43.7	37.8	23.7	28.6	76	−20
Ivigtut	18.7	23.9	40.1	49.8	41.0	26.8	33.4	86	−20
Thule	−20.6	−15.2	23.0	40.5	28.0	−.4	9.1		
Upernivik	−7.2	−6.3	25.2	40.8	33.4	14.2	16.5	69	−44

TABLE IX

Average Number of Gales Per Month and Year

Place	January	March	May	July	September	November	Annual
Archangel	2.4	1.6	1.8	0.7	1.9	2.4	19.7
Cape Chelyuskin	5.0	1.0	2.0	3.0	0	6.0	38.0
Dickson Island	11.0	10.0	6.0	3.0	4.0	8.0	80.0
Kola	4.0	4.0	3.0	2.0	2.0	5.0	36.0
Okhotsk	0	1.0	1.0	1.0	4.0	1.0	15.0
Tiksi Bay	7.0	2.1	1.4	1.1	1.0	3.6	28.8
Vaigach	5.0	5.0	4.0	2.0	2.0	6.0	49.0
Verkhoyansk	0	0	1.0	2.0	1.0	0	10.0
Wrangel	7.9	3.0	2.3	2.6	4.8	5.0	50.4
Yugor Strait	7.0	6.0	4.0	1.0	3.0	7.0	54.0
Fairbanks	.5	.1	.1	0	0	0	.9
Nome	3.8	2.7	.6	.3	1.0	1.4	20.6
Point Barrow	2.2	.4	1.0	1.2	2.4	2.8	18.7
St. Paul Island	12.6	7.2	3.0	.2	5.6	10.5	74.0
Tromso	2.0	1.0	.2	0	.2	2.0	10.0
Vardo	6.0	6.0	2.0	.5	3.0	5.0	44.0
Jan Maven	5.2	3.6	2.1	.2	2.0	4.5	32.9
Green Harbour	1.0	1.0	.3	0	.7	.6	8.0

TABLE X

Average Surface Wind Velocity and Direction

Place	January	March	May	July	September	November	Annual
Archangel	11.9 SE	10.6 SE	10.2 NW	8.7 NW	10.7 SW	12.4 SW	10.3
Dickson Island	19 S	17 S	15 NE	14 NE	16 S	17 S	17.0
Kola	9.8 SW	8.7 SW	9.2 SW	9.0 N	8.1 SW	9.8 SW	8.9
Okhotsk	9.8 N	8.1 N	8.9 SE	8.9 SE	8.7 N	11.9 N	9.4
Tiksi Bay	17.0 SW	6.7 SW	9.6 NE	8.9 NE	11.6 W	10.1 SW	10.1
Vaigach	18.1	16.6	15.4	14.5	15.4	20.4	16.6
Verkhoyansk	1.1 SW	1.6 SW	6.0 NE	5.4 NE	3.1 SW	1.3 SW	3.2
Wrangel	15.0 NE	9.2 N	9.2 NE	9.6 E	13.4 N	15.0 N	11.7
Yugor Strait	20 S	18 S	16 NE	13 NE	16 S	20 S	17.0
Dutch Harbor	5.4 SE	13.0 SE	10.1 SE	11.2 SE	11.6 SE	8.5 NW	9.7
Fairbanks	3.4 N	4.6 N	6.5 NE	5.9 SW	5.2 NE	3.9 N	4.9
Nome	9.8 NE	9.3 NE	7.7 NE	8.6 W	9.9 N	8.8 NE	9.1
Point Barrow	10.0 NE	11.2 NE	11.4 NE	12.5 SW	14.1 NE	11.7 NE	11.8
St. Paul Island	19.4 NE	17.4 NE	13.9 NE	10.9 S	15.8 NW	18.6 N	15.9
Tromso	12.7 SW	11.9 SW	8.2 NE	8.2 NE	8.2 W	11.2 SW	10.1
Vardo	21.6 SW	20.9 SW	15.7 NW	13.4 NW	17.1 NW	20.9 SW	18.3
Jan Mayen	20.8 NNW	18.1 NW	12.5 E	11.9 E	16.0 E	19.0 ENE	16.7

TABLE XI

Average Number of Days with Fog Per Month and Year

NOTE.—At numerous places in table below years of record are few indicating only trend of situation.

Place	January	March	May	July	September	November	Annual
Dickson Island	5.5	7.9	4.9	22.9	10.5	5.2	152.2
Kola	.7	.2	1.0	3.1	1.9	1.6	16.1
Tiksi Bay	3.7	4.4	5.3	9.0	4.6	1.0	66.1
Verkhoyansk	3.4	.6	.6	1.5	4.1	1.8	25.9
Wrangel	1.6	4.6	12.2	21.4	10.8	3.8	113.5
Yugor Strait	4.5	6.2	9.1	19.6	14.1	4.5	123.8
Aklavik	19.6	27.6	2.0	2.2	21.2	15.6	165.6
Tromso	1.0	.8	1.0	2.0	2.0	1.0	14.0
Vardo	0	0	1.0	6.0	1.0	0	18.0
Green Harbour	.1	.1	.4	4.0	1.0	0	13.0
Bear Island	1.1	2.7	6.7	18.7	12.0	3.3	82.0
Jan Mayen	1.9	3.2	3.3	12.8	5.9	1.8	58.3
Angmagssalik	1.0	1.0	7.0	9.0	4.0	2.0	48.0
Godhavn	9.0	11.0	15.0	17.0	8.0	3.0	127.0
Godthaab	1.0	1.0	7.0	13.0	7.0	1.0	61.0
Ivigtut	.2	.4	2.0	6.0	3.0	1.0	26.0
Upernivik	2.0	2.0	5.0	11.0	2.0	1.0	47.0
Churchill	1.0	*	1.0	2.0	1.0	*	13.0
Craig Harbour	*	1.0	0	2.0	1.0	*	9.0
Lake Harbour	2.0	1.0	2.0	5.0	2.0	3.0	30.0
Pond Inlet	1.0	*	*	*	*	2.0	9.0
Dutch Harbor	.9	.9	2.5	3.5	1.8	0	18.4
Fairbanks	17.2	11.6	.8	2.4	3.2	6.1	68.0
Nome	5.3	5.2	5.0	8.1	4.4	3.2	67.2
Point Barrow	5.0	2.3	7.5	15.0	5.4	2.7	82.6
St. Paul Island	1.7	2.8	6.9	7.0	2.8	1.5	52.2

* Less than 1 day.

Table XII

Mean Monthly and Annual Number of Days with Precipitation 0.01 Inches or More

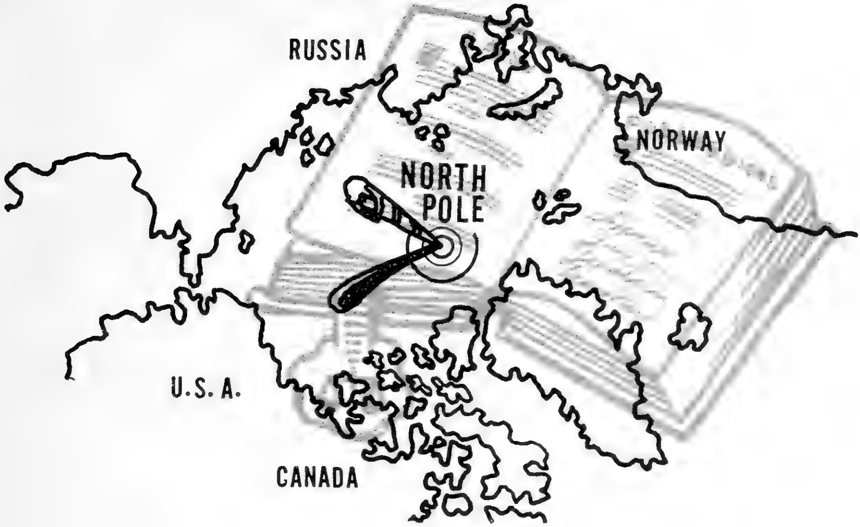
Place	January	March	May	July	September	November	Annual
Archangel	16	13	12	12	15	17	171
Cape Chelyuskin	8	3	4	12	15	13	121
Dickson Island	8	10	10	12	17	13	142
Kola	13	12	16	15	18	17	179
Tiksi Bay	9	7	4	11	14	9	108
Vaigach	14	11	9	12	15	14	151
Verkhoyansk*	6	4	4	8	6	8	73
Wrangel	8	7	8	10	10	8	102
Yugor Strait	13	11	12	12	19	16	165
Vardo	14	16	11	9	14	16	157
Bear Island	14	14	12	7	14	14	140
Jan Mayen	19	15	11	11	15	17	174
Green Harbour	12	12	7	6	9	11	114
Anchorage	7	5	6	10	13	7	97
Dutch Harbor	22	20	19	13	18	21	219
Fairbanks	10	5	9	13	10	10	110
Juneau	18	18	18	17	20	20	221
Nome	11	9	7	13	16	9	132
Point Barrow	1	1	1	7	6	2	34
St. Paul Island	18	16	13	17	21	20	204
Aklavik	6	4	6	9	11	6	81
Churchill	4	5	7	10	12	10	101
Craig Harbour	5	5	7	6	7	8	73
Lake Harbour	5	6	8	9	8	11	91
Pond Inlet	3	2	2	6	4	4	43
Etah*	6	6	3	......	6	14	64
Godthaab*	13	13	10	10	13	13	142
Ivigtut*	12	12	10	9	13	12	131
Thule*	1	7	3	6	10	8	......
Upernivik*	4	6	7	7	10	10	84

* 0.1 mm. (0.004 in.) or more.

TABLE XIII

Mean Monthly and Annual Cloudiness (Tenths)

Place	January	March	May	July	September	November	Annual
Archangel	8.1	8.1	7.0	7.1	8.1	8.6	7.7
Cape Chelyuskin	5.6	4.2	8.0	8.1	9.2	7.6	7.4
Dickson Island	6.2	6.0	8.2	7.7	8.8	7.6	7.5
Kola	7.0	6.0	7.2	7.5	7.7	7.7	7.3
Vaigach	7.2	6.4	8.1	7.3	8.3	8.3	7.6
Verkhoyansk	3.4	3.3	6.1	6.4	6.6	4.6	5.1
Wrangel	5.5	5.0	7.9	7.2	8.1	6.7	6.7
Yugor Strait	7.0	6.3	8.4	7.5	8.6	8.3	7.6
Tromso	6.5	6.0	6.8	6.6	7.6	7.0	6.6
Vardo	7.6	7.2	7.6	7.2	7.7	8.0	7.5
Bear Island	8.2	8.2	9.0	8.7	9.0	8.6	8.6
Jan Mayen	8.4	7.9	8.2	9.0	8.1	8.3	8.3
Green Harbour	6.2	5.8	6.6	7.0	7.6	6.1	6.6
Aklavik	4.1	4.3	4.5	6.0	7.0	5.8	5.4
Churchill	4.5	3.8	5.6	5.0	5.9	5.6	5.2
Craig Harbour	3.9	5.0	6.0	6.2	7.8	5.6	5.8
Lake Harbour	4.8	4.8	6.7	6.4	6.4	6.5	5.9
Pond Inlet	3.6	4.0	4.8	4.8	7.0	5.2	4.9
Dutch Harbor	7.6	7.4	8.0	7.7	8.0	7.5	7.7
Fairbanks	5.2	4.9	6.9	6.6	7.2	6.1	6.1
Nome	5.4	5.0	6.2	7.9	6.8	5.2	6.2
Point Barrow	4.2	3.1	7.1	6.2	8.2	4.7	5.6
St. Paul Island	7.8	7.4	8.8	9.4	8.4	8.1	8.3
Angmagssalik	6.7	6.1	6.3	5.6	6.3	6.7	6.2
Godhavn	6.9	6.3	6.7	6.3	6.0	7.1	6.4
Godthaab	7.3	6.8	6.8	6.6	6.8	6.6	6.9
Ivigtut	5.8	5.5	6.0	5.8	6.2	5.6	5.8
Upernivik	4.4	4.5	6.6	6.3	7.1	7.1	6.0



CHAPTER 4

THE LAW AND ARCTIC POSSESSIONS

"We cannot say that the sovereignty of all the known lands in the Arctic is definitely settled internationally. We can say, however, that the sovereignty of substantially all of these territories is now either definitely known or definitely claimed."—David William Hunter.

Unlike antarctic topography, there is no land mass of continental or subcontinental size in the north polar region. The latter area contains relatively few islands and consists chiefly of a vast ice-covered sea girdled by continental land. That portion of the ice cap resting on the sea is in motion. As a consequence, the area that may be subjected to sovereignty is very limited.

There are three general divisions in this discussion of the legal problems of the arctic region:

1. The problem of sovereignty in the region.

2. The territorial claims of the various nations.

3. United States international agreements which have been set up for activity in the region.

SOVEREIGNTY

The present high development of aircraft as a means for transporting persons, equipment, and supplies, and the capacity of modern medicine and science to sustain human life and activity in areas of climatic extremes have endowed the north polar regions with great political and military significance for the nations of the northern hemisphere. Consequently, the governments of these states are becoming increasingly concerned with the question of sovereignty in the region.

In this connection, the problem of occupation is paramount. The established law in this regard was concisely set forth in the Isle of Palms arbitration. The court held that, according to the view that has prevailed since the nineteenth century, discovery gives only an inchoate title to territory. The title of discovery must be completed within a reasonable period by the effective occupation of the region claimed to be discovered, before sovereignty is vested in the discovering state.

The problem of sovereignty in the Arctic is complicated by the fact that, in addition to land and ice areas resting on land, there is a second type of area (ice resting on the sea) on which men can build habitations and live for an indefinite period of time while carrying on activities normally pursued on land. In this sense, it could be argued that men might permanently occupy such areas, and that they are, therefore, susceptible to sovereignty. Logical as this may appear, such an argument has no legal validity. In law, an effective occupation is more than a matter of the nature of the habitations and activities in a given area. Above all, the area itself must be stationary and capable of having permanent and clearly ascertainable boundaries. The natural movement of

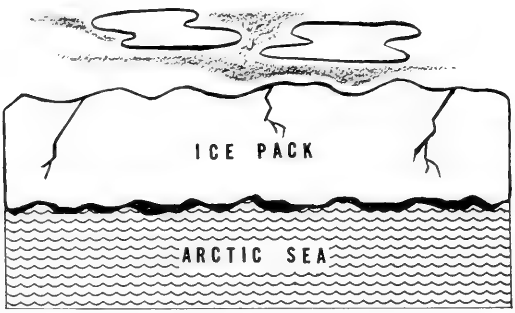


Figure 4–1.—Ice areas resting on the sea have no permanent boundaries.

ice areas resting on the sea makes any clearly defined territorial delimitation impossible. Any occupation of such areas would be too precarious and shifting to give good title. The legal rules which recognize the freedom of the high seas naturally apply also to a moving and shifting substance like the Arctic Ocean ice areas. Consequently, the most authoritative opinion is that the right of sovereignty over such ice areas is denied by international law. It was for this reason that the United States made no claim to the North Pole on the basis of Peary's discovery in 1909.

Until recently there was some doubt that occupation of ice areas resting on land was legally possible—but for a different reason. Some publicists and some governments (including the United States) held that climatic conditions prevented any occupation of these regions from being really effective. When Captain Amundsen made his arctic flight in 1926, he was authorized by the Norwegian Government to take possession of any land discovered, but was specifically denied authority to take possession of any ice areas resting on the sea. In reply to a Norwegian note concerning Amundsen's discoveries, Secretary of State Hughes said:

> "Today, if an explorer is able to ascertain the existence of lands still unknown to civilization, his act of so-called discovery, coupled with a formal taking of possession, would have no significance, save as he might herald the advent of the settler; and where for climatic or other reasons actual settlement would be an impossibility, as in the case of the polar regions, such conduct on his part would afford frail support for a reasonable claim of sovereignty."

For this reason the United States would not recognize Norway's sovereignty in the polar area on the basis of the discoveries made by Amundsen.

To argue, as Secretary Hughes did over 20 years ago, that the ice cover resting on land is not susceptible to sovereignty because of the impossibility of establishing and maintaining effective establishments in such areas, is, of course, no longer a valid argument. States do now claim sovereignty to various areas of this kind and the claims are recognized as valid by the family of nations. When the rule (that climate ipso facto prevented any truly effective occupation) was formulated, the whole question of legal rights in the region was, by and large, an academic one. As a matter of actual fact, man did lack the capacity to make use of the region as an area of transit or of residence. The airplane was a vehicle of limited range and trans-polar flights were still in the future. The capacity of medicine and science, not only to sustain

Figure 4–2.—The Sector Principle—"regions of attraction"

life under such trying conditions but to make it reasonably tolerable and practical, was still unrealized. Under such circumstances, climate did prevent any occupation from being an effective one. The recent prodigious advances in science, medicine, and aeronautics, however, now enable man to overcome the obstacle of climate and extreme cold. Claims to sovereignty can no longer be questioned solely on the ground that the occupation is ineffective because of climate.

As it became evident that in polar regions effective occupation would be difficult to realize, and claims of sovereignty over polar areas would thus remain inchoate, new theories were advanced from time to time, in an effort to circumvent the occupational requirement. One theory offered the substitute principle that sovereignty ought to attach to littoral states according to the *region of attraction* doctrine. This principle, known as the Sector Principle, has been strongly advocated as a solution to the problem in the north polar regions. According to this principle, the extreme eastern and western meridians bounding the territory of countries adjacent to the arctic circle are projected to the North Pole. These pie-shaped segments are considered as belonging to the littoral states as *regions of attraction* of such states.

The man generally credited with having called attention to this principle for the first time was P. Poirer, a Canadian Senator. In the Canadian Senate, on 20 February 1907, he recommended that Canada should declare it had taken possession of the lands and islands lying between its northern coast and the North Pole. This proposal was not adopted by the Canadian Government, although the Canadian sector claim has been made on other occasions.

Strongest support for the Sector Principle has come from the Soviet Union. In a decree dated 15 April 1926 the Central Executive Committee expressed itself in favor of the principle and laid claim to lands and islands lying within the Soviet sector. Soviet claims are discussed below.

The United States has not accepted the Sector Principle or the wider theory of regions of attraction. Acceptance of the theory with respect to the Arctic would lend strong weight to acceptance of Chilean, Argentine, and other claims in the Antarctic, for which the United States has proposed some form of international control.

CLAIMS

Although the law governing claims to territory appears to be crystallized it is not to be assumed that all applications of it are equally well settled. There are certain areas where there is no longer any question as to which state is sovereign. There are other areas over which a state claims sovereignty but, for the time being at least, other states neither object to nor acquiesce in the claim. In other words, not enough time has yet elapsed since the crystallization of the law to allow for a definitive application of the law in all areas. Consequently, governments interested in the polar regions can, with more or less reasonable certainty, expect to become involved in complicated diplomatic negotiations and disputes, particularly with regard to areas not clearly and exclusively within the orbit of a given country. For this reason, some discussion of arctic claims should be included.

CANADA

There can be no doubt that the Canadian government considers that Canada has sovereignty over the islands lying above its northern or Arctic coast. This has been indicated by official action in various ways. In 1921, for example, Canada informed the Danish Government that any discoveries which Knud Rasmussen might make on his journey across Arctic America would not be recognized by the Canadian Government as a basis for any territorial claims by Denmark.

Figure 4–3.—Hunting and fishing in certain portions of Northwest Territories.

In June 1925 the Canadian Parliament passed a law providing that scientists and explorers wishing to work in the Northwest Territories must have a Canadian permit. The Northwest Territories, as defined in Canadian law, include the so-called District of Franklin which embraces the Canadian arctic islands.

A third example of those official actions clearly indicating Canada's claim to sovereignty over its northern islands is to be found in the Canadian game laws. In certain portions of the Northwest Territories, hunting and fishing are reserved to Eskimos, Indians, and half-breeds. One of the areas reserved to these people is the *Arctic Islands Preserve* which approximately coincides with the District of Franklin and, as stated above, includes the islands in the vast archipelago to the north of Canada. The regulations now in force with regard to hunting and fishing in the Arctic Island Preserve are found in an Order in Council of 15 May 1929

No state has seriously questioned Canada's claim to sovereignty over these islands. Academically, one might raise the question as to whether Canada is really in effective occupation. Canada does exercise control over the area to the exclusion of all other states, which activity is the basic test of sovereignty. Such manifestations of authority as those discussed above do effect an adequate satisfaction of the needs of the sovereign in that particular area, and seem, therefore, to constitute an effective occupation.

The following can also be offered as evidence of the strong control that Canada maintains over her Arctic:

1. The Canadian official sponsorship of the 1913–18 Arctic expedition, which made it necessary for Stefansson to return funds he had previously solicited from various sources in the United States.

2. Payment by the Canadian Government in 1930 of $67,000 to Otto Sverdrup in recognition of his discoveries, claimed by Canada.

3. The maintenance of posts throughout the inhabited area by the Royal Canadian Mounted Police and the patrols periodically made by police officers into the uninhabited areas. The enforcement of these officers of Canadian law among the resident native and white inhabitants.

4. The various services afforded by the Canadian Department of Health and Welfare in the area. These include payments in assistance of mission hospitals established in the area and payment to missions for all patients receiving treatment, and the provision of medical and dental service to all residents of the area needing such attention who are encountered in the annual arctic patrols.

5. Payment of *baby bonus,* one of the social services maintained by the Canadian Government, to Eskimos and other residents of the Canadian Arctic. The baby bonus funds are administered by the Department of Health and Welfare.

6. Command of all weather stations established jointly by the United States and Canada in the Canadian Arctic is reserved for Canadian Government employees.

UNITED STATES

It is now a certainty that there is no land mass of any significance between Alaska and the North Pole. Consequently the United States has had no occasion to make any territorial claims in the so called United States Sector. However, official pronouncements have been made indicating that, should any discoveries be made in the area, the Government would take the position that they came under our sovereignty. For example, when the Naval Com-

Figure 4–4.—Payment of baby bonus.

mittee of the House of Representatives was discussing the question of sending the airship *Shenandoah* to the polar regions (19 January 1924). Mr. Denby, Secretary of the Navy, said that the flight was being undertaken partly because there was an unknown area of 1,000,000 square miles north of Alaska, and that it was "highly desirable that the United States should know what is in that region." The Secretary went on to say, "If there is in that region land, either habitable or not, it should be the property of the United States." The weather flights now being made by the United States, the establishment of weather stations, and the recent trips of public vessels to the Arctic have not been made the basis for any claims by the United States to territory in the arctic regions.

SOVIET UNION

The government of the Soviet Union has categorically laid claim to all lands, known and unknown, lying north of the northern coast of Russian Siberia. A decree of 15 April 1926, mentioned previously, states that lands and islands are considered to be Soviet territory when they lie between the northern coast of the Soviet Union and the North Pole, in the region limited by the meridian 32°4′35″ E., cutting the east side of the Vaidaguba, through the triangular mark on Cape Kekursky, and by the meridian 168°49′30″ W., cutting the middle of the sound separating the Ratmanov and the Krusenstern Islands.

Since the United States and Canada have allowed all their claims to Wrangel Island to lapse, and since the Russians are in physical possession in the Soviet Arctic Sector, Franz Josef Land merits brief mention.

The archipelago has long been the scene of Norwegian sealing and other types of hunting expeditions. Whatever settlements the Norwegians made were seasonal and of too limited a scope to have the characteristics of effective occupation. No serious claim to sovereignty could be made by Norway on the basis of these settlements.

The Soviet Union made a claim to sovereignty over the archipelago in 1928. By a decree of 7 March 1929, funds were provided for a radio station and a geo-physical station on Franz Josef Land. On 28 July 1929, the flag of the Soviet Union was hoisted on Hooker Island and other ceremonies appropriate to the taking of possession were performed. Since that time the Soviets have expanded their occupation. For all practical pur-

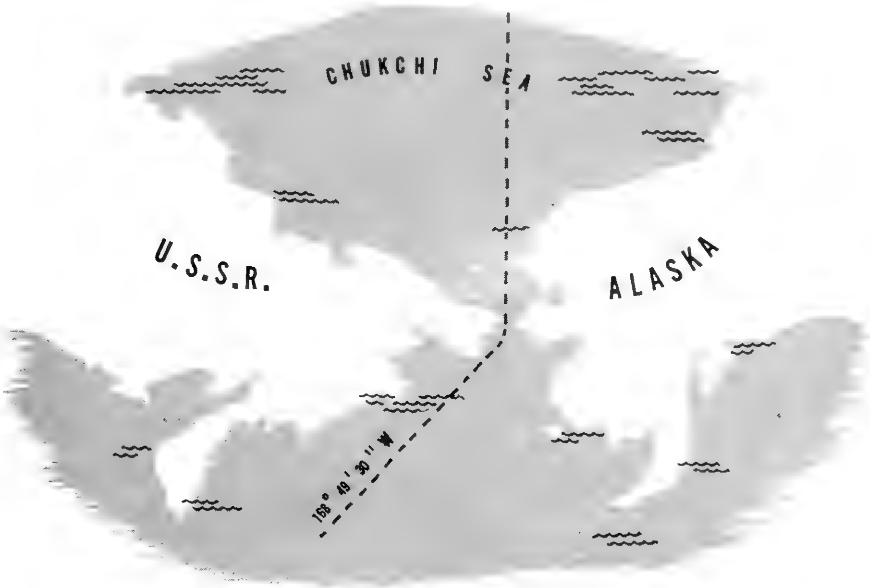


Figure 4–5.—Boundary between U. S. A. and U. S. S. R.

poses no government any longer seriously questions the sovereignty over the archipelago.

The treaty between the United States and Russia of 1867 has provided a special argument, from the Russian point of view, to the validity of the sector principle. This treaty stipulated that the boundary between the two states should be the meridian 168°49′30″ W., in the Bering Sea, and it was stated with regard to this boundary that it "continues to the north in a straight line without limitation until it disappears in the Arctic." In further support of the sector principle favoring Soviet claims is the treaty of 1825 between Russia and Great Britain relating to the boundary line between Alaska and Canada, where the expression is used that the meridian 141° W. should be the boundary line "right up to the Arctic" (*jusqu's la Mer Glacial*).

DENMARK

For some years Norway and Denmark made conflicting claims to Greenland. Denmark claimed all of the area, while Norway laid claim to Eastern Greenland on the basis of various settlements which the Norwegians had made there.

Down to 1931 no power disputed the Danish claim to all of Greenland. On 10 July of that year a royal Norwegian decree placed Eastern Greenland (territory between 71°30′ N. and 75°40′ N.) under Norwegian sovereignty. On 12 July 1932, a second decree making claim to Southeast Greenland (Territory between 60°30′ N. and 63°40′ N.) was promulgated by the Norwegian Government, while the question of Eastern Greenland was before the Permanent Court of International Justice. This second claim was also placed before the court.

On 5 April 1933, the Permanent Court handed down its decision that Denmark has a valid title to sovereignty over all of Greenland. The court said that in the East Greenland Agreement of 1925 Norway had recognized Danish sovereignty and therefore the 10 July 1931 Norwegian decree of occupation and sovereignty was void.

Although the Norwegians had established settlements in Eastern Greenland, these existed at the sufferance of Denmark, so to speak, on the basis of the Agreement of 1924. Because of this, the court concluded that the Danish claim was clearly the superior one, although the Norwegians might have been more active in the business of erecting settlements. The court went on to say that, "It is impossible to read the records of the decisions in cases as to territorial sovereignty without observing that in many cases the tribunal has been satisfied with very little in the way of the actual exercise of sovereign rights, provided that the other state could not make out a superior claim. This is particularly true in the case of claims to sovereignty over areas in thinly populated or unsettled countries."

On 7 April 1933 (2 days after the court's decision was handed down) Norway revoked the decree of 12 July 1932 by which claim had been made to Southeast Greenland. This revocation and the court's decision in the Eastern Greenland case firmly established Denmark's claim to all of Greenland.

Denmark has made no claims under the sector principle.

NORWAY

The two Norwegian possessions in the Arctic region are Spitsbergen (Svalbard Archipelago) and Jan Mayen Island. The latter island is a desolate area of 144 square miles lying about 300 miles north of Iceland. The Norwegian Meteorological Institute established a weather station there in 1921. Otherwise Jan Mayen is uninhabited. No one disputes Norway's claim to sovereignty over the island, and they are in possession.

The Svalbard archipelago was discovered by Norsemen in 1194 and rediscovered by Barents in 1596. The islands have long been the resort of whalers of several nations. Periodically since 1261, Norway has asserted claim to the islands. From 1870 on, this claim has been asserted with increasing insistency because Norwegian explorations have discovered rich outcropping seams of coal—a mineral which Norway lacks. There are also large deposits of low-grade iron ore and gypsum. Signs of oil have been reported.

Down to 1921, the Norwegian claim was questioned by other states wishing to exploit the area. The prize was a good one and the competitors important. Possibly more to keep a rival from winning this prize than for any other reason, the interested powers relinquished all claims by a treaty signed in Paris on 9 February 1921. In this treaty, the United States, Great Britain, Denmark, France, Italy, Japan, the Netherlands, and Sweden agreed that Norway was sovereign over the archipelago. The Soviet Union, then not in a position to be a signatory, has since declared its recognition of Norwegian sovereignty.

Norway has made no claims under the Sector Principle.

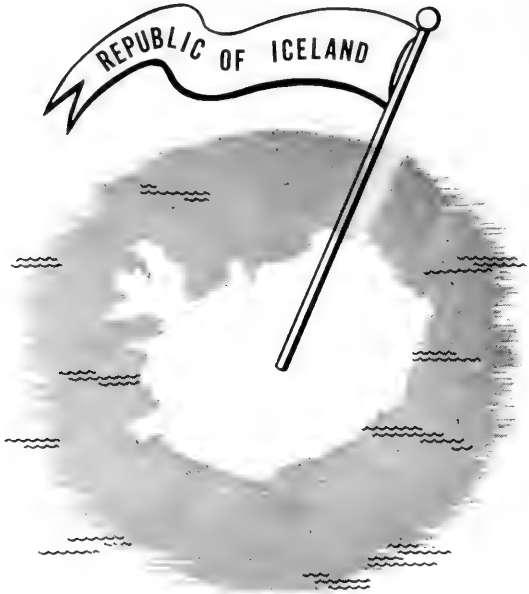


Figure 4–6.—The Republic of Iceland.

ICELAND

When Norway separated from Denmark in 1814, Iceland remained under Denmark. In 1918, the Danish Government acknowledged Iceland as a sovereign state, united with Denmark only in that the Danish king was also king of Iceland.

When Germany occupied Denmark, the Icelandic Parliament (Althing) voted in May, 1941, to terminate the union with Denmark. A regent was elected to assume the functions of the King and it was resolved that a republican constitution be adopted as soon as the union ceases. In May of 1944, the people of Iceland severed the last tenuous bond to Denmark by terminating the regency. The Icelandic Parliament formally proclaimed Iceland to be an independent republic, and the regent, Sveinn Bjoernsson, was elected President of Iceland.

Iceland claims no territory in the Arctic.

FINLAND

By the treaty of Dorpat, dated 14 October 1920, Finland was given an Arctic frontier, but this is a very short one. In the Finnish sector of the Arctic there is no land other than a small part of Svalbard (Spitsbergen) belonging to Norway.

INTERNATIONAL AGREEMENTS

As was pointed out earlier in this chapter, the United States lays claim to no territory in the arctic region other than Alaska, nor does it endorse the Sector Principle. Under modern conditions, possessions in the region are of great value, particularly to a major power, for defense as well as other reasons. The United States satisfies its defense requirements by means of agreements with other governments rather than by seeking possessions of its own to be utilized in this manner. Following is a brief discussion of the United States agreements with Denmark, Canada, and Iceland.

AGREEMENT RELATING TO THE DEFENSE OF GREENLAND

When German forces invaded and occupied Denmark in April, 1940, it opened the way for possible German occupation of Denmark's possession, Greenland, and its utilization as a base for operations against North America. Under the pressure of this threat, the local authorities in Greenland adopted a resolution (3 May 1940) expressing the hope that, for as long as Greenland remains cut off from the mother country, the United States Government would keep in mind Greenland's exposed position.

There was no question of the fact that the defense of Greenland against attack by a non-American power was essential to the preservation of the peace and security of the American continent and a matter of vital concern to our country. There was no practical way in which an agreement with the Danish home government could be made because of the German occupation. However, the 1940 resolution of the Greenland authorities did offer a practical, legal basis for negotiation. In view of this extraordinary political situation, the Danish Ambassador felt himself to be free and competent to enter into an agreement with the United States in the name of his King, although lacking specific authorization to do so. In short, it was felt that the King was no longer a free agent. The Danish Ambassador and Secretary Hull signed an agreement concerning the defense of Greenland on 9 April 1941.

In the treaty the United States Government specifically reiterated its recognition of and respect for Danish sovereignty over Greenland. Recognizing that Greenland might be "converted into a point of aggression" against this continent, we accepted the responsibility for assisting Greenland in the maintenance of its security. The agreement gives us the right to construct, maintain, and operate such landing fields, seaplane facilities, and radio and meteorological installations as are considered necessary for the defense of the area. This grant included the right to do any and all things necessary to insure the efficient operation, maintenance, and protection of the facilities and fortifications installed.

Denmark retained sovereignty over all defense areas leased by the United States, but the latter has jurisdiction over such areas and the persons therein for as "long as this agreement shall remain in force." This agreement remains in force "until it is agreed that the present dangers to the peace and security of the American continent have passed." At such time, any modification or termination of the agreement is to be the subject of consultation of the two governments. After due consultation, either party may serve notice of its intention to terminate the agreement, and it shall cease to be in force "at the expiration of 12 months after such notice shall have been received" by the other party.

The treaty is still in force. A little over a year ago, the Danish Government indicated its intention to initiate consultation with the view to terminating the agreement. The discussions are currently in progress and the future of United States rights in Greenland remains unsettled.

Formal diplomatic clearance for visits of United States ships to Greenland is not required when the visit is in connection with the defense of Greenland or other related activities. It is, however, the practice of the Navy Department through the Department of State to keep the Government of Denmark informed of our activities in and around Greenland.

DEFENSE ARRANGEMENTS WITH CANADA

On the basis of the Ogdensburg Agreement (18 August 1940) the Governments of the United States and Canada established a Permanent Joint Board on Defense. This board is charged with the responsibility of making studies on sea, land, and air problems, including personnel and material. Its over-all mission is to consider, in the broad sense, the defense of the northern half of the western hemisphere.

In the interest of efficiency and economy, each Government has decided that its national defense establishment shall, to the extent authorized by law, continue to collaborate for peacetime joint security purposes. The collaboration will necessarily be limited and will be based on the following principles:

1. Interchange of selected individuals so as to increase the fa-

miliarity of each country's defense establishment with that of the other country.

2. General cooperation and exchange of observers in connection with exercises and with the development and tests of materiel of common interest.

3. Encouragement of common designs and standards in arms, equipment, organization, methods of training, and new developments. As certain United Kingdom standards have long been in use in Canada, no radical change is contemplated or practicable, and the application of this principle will be gradual.

4. Mutual and reciprocal availability of military, naval, and air facilities in each country; this principle to be applied as may be agreed in specific instances. Reciprocally each country will continue to provide with a minimum of formality for the transit through its territory and its territorial waters of military aircraft and public vessels of the other country.

5. As an underlying principle all cooperative arrangements will be without impairment of the control of either country over all activities in its territory.

While in this, as in many other matters of mutual concern, there is an identity of view and interest between the two countries, the decision of each has been taken independently, in continuation of the practice developed since the establishment of the Joint Defense Board in 1940. No treaty, executive agreement, or contractual obligations has been entered into. Each country will determine the extent of its practical collaboration in respect of each and all of the foregoing principles. Either country may at any time discontinue collaboration on any or all of them. Neither country will take any action inconsistent with the Charter of the United Nations. The Charter remains the cornerstone of the foreign policy of each.

AGREEMENT WITH ICELAND

On 11 July 1941, the United States entered into an agreement with Iceland to station American troops on the island. These troops were withdrawn after the defense agreement was terminated in October, 1946.

A new agreement was signed on 7 October 1946, under which provision was made for interim use of Keflavik airport. The agreement "shall continue in effect until the obligation of the Government of the United States to maintain control of agencies in Germany shall have been fulfilled; provided, however, that at any time after the lapse of 5 years from the coming into force of the present agreement, the Keflavik airport will continue to be available for use by aircraft operated by or on behalf of the Government of the United States. The special character of these aircraft and their personnel will be respected as far as customs, immigration, and other formalities are concerned. No landing fees shall be charged such aircraft.

It should be noted that the agreement above does not apply to entry by United States naval ships. Formal diplomatic clearance is required for such visits to ports in Iceland.

SUMMARY

This chapter is included so that our position in the Arctic will be known, under the terms of international agreements and of accepted principles of international law. In areas over which Canada and Denmark have clearly recognized sovereignty, United States forces must be careful of their actions and statements, less infringements and misunderstandings occur.

It is recognized that these possessions are vital in the defense of the approaches to the American continent. That our position there should remain clear and indisputable is evident. Therefore, it is mandatory that personnel of the Navy respect the laws, rights, and position of the sovereign powers here as in any other part of the world.

CHAPTER 5

CLOTHING AND PERSONAL EQUIPMENT

"It is quite a mistake to suppose that one becomes hardened to the cold; however, one becomes expert in keeping oneself warm."—Scott.

"Keep dry is the first law of the North."—Carlson.

The arctic winter is not very different from the winters in northern Wyoming, Montana, or the Dakotas—except that it lasts longer. Some parts of the Arctic, of course, are much worse and every part is always subject to extremes of climate. If the few basic principles are known and applied it is possible to live and work in the Arctic without serious trouble, and still be comparatively comfortable.

CONSERVE BODY HEAT

The first problem facing men assigned to duty in the Arctic is adaptation to cold. The main objective is to keep comfortably warm. If that is not done, energy is wasted and it will be impossible to work or perform a duty or task assigned. The first lesson is to learn to conserve body heat which can be lost extremely fast to the cold surrounding air. There are two ways which will help to attain comfort and save body energy. One is proper wearing and use of the special clothing provided; the other is acclimatization or becoming accustomed to a colder environment than normally desirable. The success of the first depends on adaptation; the success of the second depends on how well body machinery adjusts itself to the cold.

Actually, the body is very much like a gas engine. The food eaten is the gas. When this food energy is burned by the different tissues in the body, such as the muscles or the brain, about 20 percent of the energy is used in doing work and about 80 percent is liberated as heat—just about the same ratio as that of an engine. The lungs are the carburetor, intake, and exhaust through which oxygen is drawn in, mixed with the blood, and the waste gas (carbon dioxide) eliminated. The heart and blood are the fuel pump and line; they force the absorbed food and oxygen through

Figure 5–1.—Avoid perspiration (loosen clothing or remove coat).

the body under different pressures. The surface of the body is the radiator and, like any other radiator, the bigger the surface in proportion to the thickness, the faster the loss of heat. So the arms and legs (especially the hands, feet, fingers, and toes) and other extremities such as the ears, nose, and chin are remarkably efficient radiators.

The *thermostatic control* of the body heat is more complicated than in an engine. This is roughly how it works: when exercising or working it is necessary for the body to burn more "gas" (food energy). More air is needed and the lungs simulate a supercharger; breathing is faster and deeper. More heat is generated and the "radiator" is taxed heavily. It is not possible to suddenly increase the radiating surface, but water can be poured on the outside of an overheated radiator, similar to the early practice of pouring water on the radiator of an Old Model T after climbing a hill. The body does this by means of perspiration. But perspiration in the arctic cold is liable to freeze—either on the skin or in the underclothes—and then the body may also freeze.

One of the first principles to learn is to avoid perspiration. Loosen the clothing or take some off, layer by layer, while work is in progress, replacing them layer by layer as body activity is reduced. Remember that uncontrolled perspiration may prove disastrous because it leads to freezing in low temperatures.

Remember, too, that the cold, outside air rapidly sucks heat from the body. Heat pours out like a stream running down hill. The thermostat in this case controls the amount of heat reaching the radiator by reducing the supply and slowing the rate of flow. That is, the small blood vessels near the skin shut down and the blood thickens so that it does not flow as fast. In this way, the skin temperature is lowered and the body may feel cold. The cold skin in itself is a poor conductor and less heat is lost from it than from the warm skin.

SEASONAL CLOTHING FOR THE ARCTIC

Away from the coast, summer temperatures in ice-free regions of the North are sufficiently high to make the wearing of winter clothing or even woolen uniforms decidedly uncomfortable. However, even with high temperatures complete body covering is necessary for protection against the hordes of mosquitoes and biting flies.

In the interior, if a special summer outfit is lacking, wear windproofs over light underwear. An extra shirt and pair of trousers are a useful addition to the kit. As insurance against cold spells, also include a sweater or warm jacket. Coastal regions usually are colder than the interior and require warmer clothing than is normally worn inland.

Since most summer travel is over wet ground, the best foot gear is the shoepac. Wear wool socks in summer as in winter and carry spares so that the feet can be kept dry and clean.

In all coastal areas of the Arctic and sub-Arctic, fog and rain or wet snow are frequent during the summer. Here, rain suits are highly desirable. In interior areas, wet-weather clothing is less necessary. But even inland, a light rain or water-repellent jacket will come in handy.

USE AND CARE OF COLD WEATHER CLOTHING

The body's method of heat control is automatic. It helps one become accustomed to having a cold skin. It is an important way of controlling heat loss, but the most important factor in protecting the body from the cold is the manner in which protective clothing is used. Take a lesson from the arctic partridge, or ptarmigan; he knows how to keep warm. His fluffy feathers hold in many tiny pockets of dead air which slow down the escape of heat from his body. By raising or lowering his feathers, he can increase or decrease the amount of dead air around his body and thus make himself warmer or cooler. A human can be as comfortable in winter as a ptarmigan if he uses his clothing properly. On the other hand, if he underestimates the dangers of really cold weather and fails to use his clothing and other personal epuipment properly, he may lose a hand or a foot or even freeze to death.

GENERAL PRECAUTIONS

It is essential that every item of clothing fit properly. Each must be loose fitting—and remember that all items will probably shrink when washed. This is especially important around the joints—shoulders, elbows, hips, and knees—in view of the fact that pressure from the clothes will shut off the blood supply in the skin area where it occurs, and will make that area much more likely to freeze. However, if clothing is too large, air currents will be set up which carry heat away from the body. Remember that loosening the clothes is one easy way to cool off when a man becomes too hot from working, and closing them warms him as he grows cool.

The most important precaution in the use and care of cold weather clothing is to keep the clothing dry at all times. Water conducts heat faster than does air. Hence, wet clothing is cold clothing. Keep perspiration at a minimum. Do not wear more clothing than is necessary. It is better to underdress and be slightly cold than to overdress and perspire freely. Cold weather clothing is designed to be worn in several layers. When a man feels himself getting too warm, he should shed clothing to the point at which there is just enough to keep comfortably warm. On windy days, it is better to remove inner clothing than to take off the windproofs themselves. If a man perspires while traveling and fails to take off some clothing, he will grow cold quickly and will experience great discomfort on stopping at the end of the day's march. Anticipate the perspiration point. Remove some clothing before beginning to get wet with perspiration. *Train personnel to stay on the cool side!*

Though perspiration may not be noticeable, men perspire constantly. Regardless of the outside temperature, the body gives off through the skin about a pint of moisture a day. This is called *insensible perspiration.* There are, then, two degrees of perspiration to contend with: visible perspiration caused by exertion or overwarm clothing, and insensible perspiration, which occurs regardless of the circumstances. The moisture condenses and forms hoarfrost somewhere on the garments.

In cold weather the point of condensation may depend upon how much clothing is worn. If the dress is light, the frost either will form in the surrounding air and drift away as fog, or will form in the windproofs. When it forms on the garment, brush it off. On more heavily clad personnel, the frost will form somewhere within the layers of clothing. Later, in the warmth of a camp (unless precautions are taken) the frost will melt. Still later, when the resulting moisture is exposed to cold it will turn to ice. To deal with this problem, and keep perspiration at a minimum at all times, wear the smallest amount of clothing necessary to keep comfortable and adjust it to allow for ventilation. This will reduce the visible perspiration resulting from physical activity and warm clothing. Dressing lightly reduces perspiration. Thus, most of the frost forms on or near the outside of the garments rather than in them.

There are many little tricks to practice in keeping the body below the rapid perspiration point. Taking off gloves or wearing only the leather shell may be enough to keep cool. Pull back the sleeves from the wrists or unbutton the shirt or put the parka hood down. When wearing a belt over the parka coat, remove the belt and open the parka coat forward at the neck in order to cool the body.

Melting hoarfrost makes the clothes wet. Therefore, do not let the frost melt. Before entering a warm tent or shelter, remove the outer garments and, while they are still dry, beat and brush the frost out of them. If the stay inside is long, hang the garments inside to dry. If not, leave them outside in the cold where the remaining hoarfrost will not melt.

Figure 5-2—Shoepac.

Drying clothes is particularly difficult in crowded living quarters. To overcome this problem, hang the clothes on a rack suspended from the ceiling above the stove where the air is warmer than at stove level.

CARING FOR FOOTWEAR

Standard issue shoes with overshoes or *Arctics* are generally satisfactory for shipboard use. Footwear for shore use requires special precautions. Since it is difficult to prevent feet from perspiring, make sure the footwear does not fit tightly. Likewise, take the trouble to put on dry socks and insoles at the beginning of each day's work or march. In cold weather, moisture will condense either in the outer sock or on the inside of the boot. Frost can be beaten out of the sock, but to get it out of the boot, use a small, stiff-bristled brush. The insole should be removed as soon as the boot is taken off; otherwise, it will freeze in the boot. Insoles keep their shape better if interchanged each day.

Change socks after returning to camp. Wash both socks and insoles and dry them over the stove by hanging them near the top of the tent. Another method is to place socks next to the body while traveling. Even though the temperature is below freezing, some drying will occur. Do not attempt to dry socks in a sleeping bag unless the temperature is above zero. Leather boots should not be greased in cold weather as grease is a poor insulator and will make the boots colder. Greased boots will freeze stiff during the night. Before sleeping, spread open the uppers of the boots so that even though they may be frozen, the feet can be slipped into them the following morning.

KEEPING CLOTHES CLEAN

Oil from the body, collecting on underwear will fill the tiny air cells (the properties that make the underwear warm) in the garment. To a lesser degree, the same is true of other clothes.

Figure 5–3. The body gives off about a pint of perspiration a day.

Figure 5–4.—Hang clothes high to dry out.

Woolens should be washed in lukewarm water with a mild soap. Issue soap is too strong and is not recommended. After washing a garment, rinse it well and squeeze it to dry (laying it flat, if possible) in a warm place. Do not put the garment where it will freeze. It is especially important to wash both socks and feet frequently.

USING A SLEEPING BAG

The best material for sleeping bags is either caribou skin with the hair on or water-repellent material filled with eiderdown. The bags now being made for military use are part down and part feathers. The outer covering should be water-repellent but not waterproof. Some bags are made with two down-filled cases, one inside the other. This type also is advantageous in warm weather, since only one case need be used. The bag can be tapered toward the feet but should have plenty of room at the shoulders to allow free arm movement. Slide fasteners (zippers) should be supplemented by snap fasteners or eyelets for lacing in case the slide fasteners fail to work. The bag should have a hood and scarf attachment so that the sleeper's mouth and nose are out of the bag.

Do not sleep with the head inside the sleeping bag. Moisture from the breath will ice its interior. Wear only the minimum of clothing in the bag and never wear damp underwear. If necessary, change to dry underwear before using the sleeping bag. If dry underwear is not available, it is best to bed down in the nude. In very cold temperatures, hoarfrost cannot be removed easily. Care must be taken to keep its formation down to a minimum. Because perspiration cannot be entirely prevented, open the bag immediately upon arising and pump air in and out to remove the moist air and reduce the temperature inside the bag. Arctic bags now being issued have cotton liners which can be removed and washed, thus helping to keep the bags themselves clean. Air the bag as frequently as possible. Should the fabric become torn, repair it at once to avoid loss of feathers upon which warmth depends.

Never place the sleeping bag directly on snow or any other cold surface. Generally, a mat will be provided to place under the bag. If this is not available, spruce or fir boughs and grass make handy insulators. Before getting in the bag, puff it out by shaking it so that there will be plenty of dead-air space in the down. In mosquito country in summer, netting stretched over the head of the bag is necessary for undisturbed sleep.

FUNCTION AND DESIGN OF COLD WEATHER CLOTHING

Good clothing and its proper use are more important in cold country than anywhere else in the world. If the proper technique and equipment are used, a man can work safely and comfortably even at very low temperatures. On the other hand, subzero weather is brutal to men who are poorly equipped. *The Arctic does not treat men well.* If one underestimates the dangers and fails to wear adequate clothing, or worse, fails to use adequate clothing properly, he may suffer the loss of a hand or foot, or even risk death.

FUNCTION

The primary function of clothing is to shut in body heat and keep the body warm. Heat is transferred from a warmer object to a colder one until the temperature of the two becomes nearly the same. As insulation, clothing prevents, or rather slows down, the transfer of heat from the body to the outside air somewhat as a rubber glove prevents the jumping of electricity from a charged wire to the hand. One of the best insulators is still air. It retards the transfer of heat through it. That is why cold weather clothing is designed to hold a considerable amount of air. A soft, spongy material that holds thousands of little air cells between its fibers is better than a tightly compressed material that holds very little air. On the other hand, loose, air-holding material is not of much use as long as the air is allowed to be blown through it by the wind. For this reason an outer shell of tightly woven cotton cloth is necessary to keep the cold air out and the warm air in.

DESIGN

Not only should the material used for arctic clothing be loosely woven so it will hold plenty of air between its fibers, but it should be resilient so that it does not pack down and become compressed. Clothes must fit loosely. When they are tight, they contain little air and do not insulate effectively. Use several thin layers instead of one thick one; additional insulation will be provided by the dead air trapped between the layers, and clothing can then be removed easily to maintain comfortable body temperature. The outer layer should not only be windproof, but should also be large enough to accommodate the maximum amount of clothing that may have to be worn underneath it. Another important reason for wearing loose clothes is that tight clothes impede the circulation of blood in arms and legs. If circulation is cut off only slightly in the arms or legs, they will soon grow cold and may freeze. This point is especially important with footwear. When extra size shoes are not available, it is much better to wear but one pair of socks if a second pair means tight-fitting and uncomfortable shoes.

UNDERCLOTHING

Two-piece issue underwear is absorbent and light in weight and permits the easy escape of perspiration. Be sure that it does not bind at any point. Two-piece underwear permits the separate removal of either drawers or shirt; if a man falls through ice or wishes to strip to the waist, this is an advantage.

FOOTWEAR

Efficient footwear is probably the most important single item of winter clothing. Except for the face, feet are the parts of the body most likely to freeze. This is because shoes form a

Figure 5–5.—Spread open boots.

rather tight casing and do not allow perspiration to evaporate. Hence, shoes with linings such as felt or fleece that cannot be removed for airing or washing should not be worn.

Many types of arctic footwear have been used with success. When leather boots are worn, they should be one or two sizes larger in both width and length than for ordinary wear. They should be large enough to be worn with ¼-inch insoles and two or three pairs of light wool socks without binding the feet. The need for such large shoes is hard for an inexperienced man to understand, but it is very real. Leather boots must be carefully broken in. They are not suitable for temperatures less than about 20° F.

Mukluk boots, copied from the Eskimo, have a dry-tan leather or rubber sole, and canvas uppers extending up to just below the knees. Not being waterproof, they are not adapted for use in wet and slushy snow. However, they are excellent in extreme cold. Lace them so they do not fit tightly around the calves.

Shoepacs are a serviceable type of boot for use in wet snow. They are laced boots with rubber feet and leather uppers. They are not suitable for cold weather and should not be used in temperatures below zero. Even above 0° F., socks and insoles must be thoroughly dry in order to keep the feet warm.

The best footwear for continuously exposed occupations or on the trail at extremely low temperatures is an Eskimo mukluk made of caribou skin.

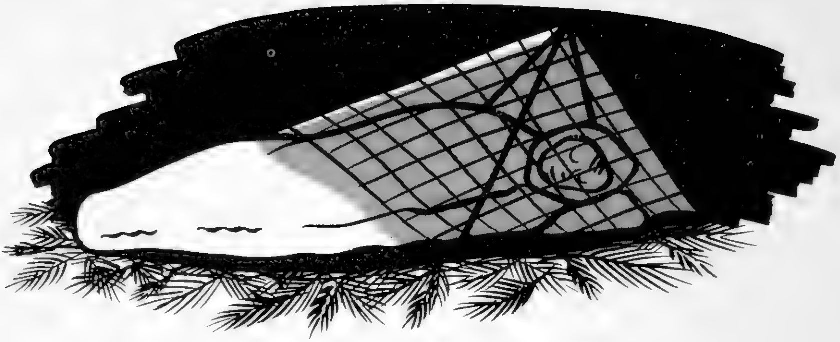


Figure 5–6.—Sleeping on fir boughs.

All arctic footwear, regardless of type, should be worn with insoles. Insoles can be made of felt, burlap, or fur. A good substitute is dry grass found throughout the Arctic. Pack the grass not only in the bottom of the boot as an insole but also around the foot for additional insulation. Insoles absorb moisture from the feet and provide additional insulation between foot and ground. This extra insulation is necessary because the socks become compressed under the weight of the body, with reduction in their ability to hold air in their fibers.

Several types of socks have been found suitable. They may be of the ordinary knitted variety or made out of blanket cloth in a design similar to that of a baby's bootee. Some men find

Figure 5–7.—Mukluks.

that jute or burlap socks worn outside the wool socks help to evaporate moisture from the feet. Take care that socks are large enough, so that when two or three pairs are worn, the outer socks are not unduly stretched. It is a good idea to have two sizes and wear the larger pair on the outside. Some men prefer cotton or rayon socks next to the flesh.

HANDWEAR

The best all-round type of handwear consists of a woolen insert mitten worn inside an outer shell mitten made of leather or windproof cloth. The shell mitten should be large enough to hold two insert mittens, although two may be needed only in very extreme temperatures. For troops, both shell and insert mittens have separate trigger fingers. Both mittens should be large enough so that the first finger can be withdrawn from the trigger finger and kept next to the others for warmth. Mittens of fur are good at extremely low temperatures.

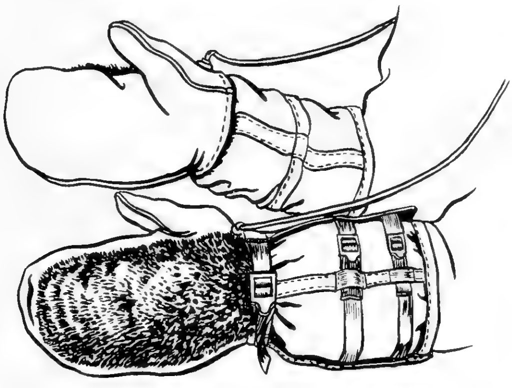


Figure 5–8.—Mittens.

For prolonged exposure without activity at very low temperatures, gauntlets made of caribou or other fur can be worn outside the woolen inserts. The chief objection to gauntlets is that snow easily collects in the gauntlet cuff.

Wristlets are recommended by some for sealing the gaps between sleeves and gloves and for work that requires the use of bare hands. In the latter case, the wristlet should cover the hand to the fingers.

Ordinarily, gloves are not suitable in temperatures below 0° F., but they are sometimes used when a fine sense of touch is necessary. Silk or rayon gloves are particularly good. Like the Eskimo, one can become accustomed, even in cold weather, to the use of bare hands provided they are warmed from time to time. In selecting gloves, go by the feel and fit rather than size.

HEADWEAR

A knitted wool helmet similar in design to a flying helmet is the best covering for the head. It should come well down over the forehead. Likewise, it should fit about the face and extend from the chin to the shirt collar. It must have a covering of windproof cloth, unless it is intended to be worn inside a parka hood. Whatever other headgear is devised, be sure it covers the ears since they are very easily frozen. It should not cover the mouth. It should be designed so that it does not press too heavily on the top of the head.

BODY CLOTHING

Ordinary heavy woolen trousers and shirt are very convenient for use in the Arctic, especially where troops are living in heated barracks much of the time. Many men with polar experience do not like sweaters because they are tight and are hard to put on and take off. A woolen vest worn over the shirt and buttoned up to the neck is very warm. The parka shape is best for the heavy outdoor garment. It is made of wool, woolpile, or fur, with windproof outer cover, slips on over the head, and has a permanently attached hood. It ought to be loose around the body, neck and shoulders, and should have drawstrings at the front of the hood and around the bottom or at the waist to permit adjustment for ventilation. Fur ruff on the hood is essential for protection of the face.

Windproofs are worth their weight in gold. They are made of smooth, tightly woven cotton cloth. They are water-repellent but are never waterproof because they must allow moisture from the skin to pass off into the atmosphere in the form of vapor. They must be large enough to fit over the maximum amount of clothing that will be worn. The trousers should have drawstrings at waist and ankles. Avoid a fly of the usual type. One about 2 inches long with a flap behind it is enough. The upper garment is of the parka type with drawstrings at the hood and at the bottom. It should extend below the hips.

Under conditions of high windchill such as may be experienced by men on flight decks of carriers or on lookout watch, face masks are an item of special gear that help withstand the rigors of the wind. It has been noted that at temperatures below minus 30° F. in wind a well-designed face mask added to the efficiency of the protection of the whole clothing assembly. However, when using a face mask, it is well to check the color of the face skin beneath to insure that freezing is not taking place.

UTILITY OF COLD WEATHER CLOTHING

The utility of winter clothing for shore based personnel, judged by experience at Point Barrow, Alaska, is summarized briefly as follows:

Arctics, shore N–2.—Durable and satisfactory in moderate weather—late spring, summer, and early fall.

Bag, sleeping, large.—Down-filled bag satisfactory for most purposes; for trail use it must be waterproof. In severest weather, furlined bag is necessary.

Boots, hip, rubber N–2.—Satisfactory only for summer use.

Cap, field, cotton, O. D., with visor.—Very satisfactory, particularly when fitted with ear flaps.

Coat, parka, winter N–1.—Satisfactory for moderate cold only. (Down to 0° F.)

Glasses, sun N–1.—Satisfactory (poloroids preferable).

Gloves, handmade, Eskimo type, wolf skin (fur inside).—Very satisfactory.

Gloves, work, N–1.—Suitable only for moderate cold.

Jacket, parka, rain N–2.—Very practical.

Jacket, winter N–1, alpaca lined with zipper.—Satisfactory during moderate cold.

Mittens, winter N–2.—Satisfactory for use separately in moderate cold or as a liner in leather mittens in cold weather.

Mittens, work, leather N–3.—Fairly satisfactory but short life.

Mukluks.—Eskimo types most satisfactory.

Net, head, mosquito.—A *must* where insects are present.

Pants, flying, quilled, down filled.—Very good for air travel or on the trail and during severe cold weather.

Pants, kersey-lined.—Durable and warm.

Parka, B–9, USAF.—Very good except in severe weather (minus 30° F.).

Parka, caribou.—Satisfactory during summer and winter.

Scarf, winter N–1.—Satisfactory during coldest periods (for moderate weather, rayon scarf preferable).

Shirts, army, O. D.—Very satisfactory.

Shoes, felt, Navy.—Most suitable yet found for cold, dry weather.

Shoes, field N–1.—Practical only for shipboard use or summer wear ashore.

Shoepac, Army—Satisfactory during spring, summer, early fall ashore. (Satisfactory for coldest weather on shipboard.)

Drawers, winter N–1.—Satisfactory.

Undershirt, winter N–1 with drawers, winter N–1.—Satisfactory.

CLOTHING EXPERIENCE DURING SUBMARINE OPERATION

The following items of standard cold weather clothing should be issued as a minimum to each man unless prescribed differently in operation orders:

1 woolen blanket.
1 pair, woolen trousers (Army issue).
1 woolen shirt (Army issue).
1 sweater, winter N–1.
1 jacket, winter N–1.
2 suits, winter underwear N–1.
2 pairs, woolen socks.

The following additional items are required for lookout, quartermasters, and others on watch topside:

1 helmet, winter N–1.
1 face mask, winter N–1.
1 pair goggles N–2.
1 pair sun glasses N–1.
1 pair mittens, N–1.
2 pair mittens, winter N–2.
1 scarf, winter N–1.
2 pair duffle socks.
2 pair insoles.

The following items should be furnished to the submarine to be kept in a pool system:

8 heavy winter coats, sheepskin lined.
16 parkas, winter N–1.
30 pairs, arctics N–1.
36 trousers, rain N–2.
36 jackets, rain N–2.
36 trousers, winter N–1.

CLOTHING EXPERIENCE DURING WINTER ICEBREAKER OPERATIONS

The utility of winter clothing for shipboard personnel may be judged by experience from recent icebreaker winter operations in the Bering Sea, summarized briefly as follows:

1. Standard issue cold weather clothing was found to be inadequate for watch standers when temperature was below 20° F. and for general wear when temperature was below 0° F.

2. Footwear was found to be inadequate for men whose duties require them to be exposed for extended times. Consensus showed the following:

a. Shoes ST#72–S–75560 do not keep feet warm under conditions below 0° F. while operating in pack ice.

b. Shoepacs were satisfactory down to 15° F.

c. Mukluks (L37–B–4247) were satisfactory in lowest temperatures down to minus 20° F. and were generally satisfactory when climbing rough snow or ice-covered terrain.

d. Flight boots (R37–B–4216) were excellent and were the unanimous choice as the ideal footwear by officers and men standing watches topside at lowest temperatures encountered. For beach parties these boots are too heavy and too warm except during severest cold weather below minus 30° F.

3. Hoods (R55–H–2500) with the fur face ruff were very satisfactory.

4. Winter trousers N–1 (55–T–62623) were satisfactory down to 0° F. However, trousers (55–T–350) were found to be warmer and less bulky.

5. For temperatures below 0° F., coverall (R55–C–3150) was used. This provides an over-all type of windbreaker and insulation for body warmth to be worn over the standard Navy jacket and dungaree trousers. It was found suitable for even greater protection when worn over a combination of jacket (R55–J–400) and winter trousers (R55–T–350). This coverall is an adequate article of clothing for exposed lookouts.

For similar operations, the icebreaker recommended that trousers (R55–T–350) be placed on the ship's allowance in place of trousers winter N–1 (55–T–62623); jackets (R55–J–400) be substituted in place of alpaca jacket (55–J–571); and hoods (R55–H–500) be provided for one hundred percent of complement.

It was also recommended that a quantity of mukluks (Larane Shoe Corp., Contract No. 155–QM–15830) equal to 150 percent of complement should be on board to be used for both watch standers and beach parties in subzero temperatures. It was found desirable that an allowance of 100 pneumatic sleeping bags (Air Force No. 8300–597100 SPE 3187A Order No. 45.2446–PF New York Rubber Co.) be provided for future winter operations. The purpose of the pneumatic bag is not for comfort, but to raise the sleeping bag above the snow enough to keep it from becoming wet or damp from snow melting due to body heat.

ISSUING SPECIAL CLOTHING

The procurement, issuing, and storing of special clothing both on shipboard and at shore based installations is of primary importance. Experience gained during past cold weather operations reveals that shipboard fitting and issue procedure has been complicated by the lack of adequate space. Sufficient space should be available in an issuing room to allow an inventory of sizes for immediate issue, to eliminate the requirement of issuing incorrect sizes pending the restocking of the issue room. Consideration should also be given to the provision of adequate space for the storing of special clothing from the standpoint of drying and keeping it dry.

In regard to issuing procedure, it is noted that, as a general rule, men do not accurately know their head, waist, chest, foot, and other body sizes. Therefore, the expedient of issuing garments on this basis is unsatisfactory. Further, fitting an individual satisfactorily with one garment and then issuing additional garments of the same size marking is unreliable, in view of the difference in garments by various manufacturers for the same size number.

The desirable method of issue would be a fitting stage, followed by an immediate issue of the same garment and later by an inspection of all personnel by division officers, to insure proper fittings. This method will involve large available stocks at one location and adequate space for fitting and issue. Close cooperation will be required by the ship's supply section and supply activity to satisfactorily handle the matter of properly outfitting ship personnel. Once fitted, men should be advised of correct sizes and this information noted in service records.

SUMMARY

Arctic clothing made available for past polar expeditions has proven generally satisfactory for shipboard use and can be adapted satisfactorily for more severe conditions encountered ashore. Standard issue items will prove adequate for summer operations. Special issue items must be provided in addition to standard items of cold weather clothing for winter operations in arctic seas.

Problems of design and standardization must be solved in order to improve clothing and simplify stock and issue thereof. All personnel must be enjoined to take care of clothing issued for cold weather operations. Commanding officers must ensure that clothing be kept dry and clean, that facilities for laundering, drying, and stowage be provided, and that clothing is properly cleaned and refurbished before turning it in to the supply depot, following completion of the operation.

Experience has shown that men can go through a process of body conditioning to endure cold weather by reducing the amount of clothing to the minimum to keep comfortable, and by being careful to remove or put on clothing when it becomes necessary to adjust to changes in temperatures. It is preferable to resort more to exercise for warmth than to wear excess clothing. It is possible to improve the body's circulation and toughen the skin of the hands and feet by controlled and careful exposure.

For additional information refer to chapter 3 of the U. S. Army publication, *Arctic Operations* (FM31–70).

Figure 5-9.—Dressed for the Arctic. Note face mask.

CHAPTER 6

HEALTH AND SURVIVAL

But the human elements of endurance and courage are the most important of all in Polar work."—Fiala.

"To be happy in the North, one must have varied interests."—MacMillan.

Arctic medicine demands the application of principles and practices that are basically the same as those in use elsewhere throughout the north temperate zones of the world. If these known facts are kept in mind and used, there is every reason for the medical aspect of any polar operation to be successful. Indeed, Navy personnel have enjoyed as good or better health during operations in the high northern and southern latitudes as in other geographic areas with less severe climates.

Good health and low morbidity rate in cold weather areas are dependent on good caloric intake of about 4,500 calories daily, warm clothing, prevention of usual respiratory ailments, adequate protection of the extremities of the body, and adoption of means to reduce motion sickness. By all means, use the facilities available to the fullest to make living comfortable.

THE EFFECT OF INTENSE COLD

To best explain the effects of cold, the following self-explanatory quotations from the writings of explorers are offered:

"Still the biting cold would have been impossible to face by anyone not fortified by an inflexible purpose. The bitter wind burned our faces, so that they cracked, and long after we got into camp each day they pained us so that we could hardly go to sleep. The Eskimos complained much, and at every camp fixed their fur clothing about their faces, waists, knees and wrists. They also complained about their noses, which I have never known them to do before. The air was as keen and bitter as steel."—Peary.

" . . . during which the furious wind kept us enveloped in driving snow." —Peary.

"The wind cuts through the warmest clothes."—Fiala.

"All sense of direction is lost in an arctic storm. The flying snow and drift are like a sand blast and blind anyone exposed to their fury."—Fiala.

Figure 6–1.—Hunters return with crab eater seal.

" . . . and to expose the hands to the frigid air for only a few seconds was painful."—Fiala.

" . . . and even 54 degrees below zero was not objectionable until a light breeze of 4 to 5 miles per hour altered this opinion."—Hayes.

"The greatest threat of the Arctic is not in low temperatures but in moisture turning to ice."—Carlson.

"Cold weather slows down everything except optimism."—U. S. Navy.

"Cold is depressing in its influence and soon enfeebles the powers of the will. At first it stimulates to action, but this vigor is quickly followed by torpidity; exertion is soon succeeded by the desire to rest."—Payer.

ENVIRONMENTAL SANITATION

Fortunately sufficient basic data about topography and meteorology are known to enable one to plan the sanitation for a given area in the North.

In the summer the usual precautions for assuring protection against the spoilage of food supplies, a pure potable water supply, and berthing, laundry, messing, housing and waste disposal facilities have proven satisfactory, both at sea and·ashore. In areas ashore, roughly south of 70° N. latitude, insect control will tax the ingenuity of those in charge, but the methods already available —screening, head-nets, DDT spray, insect repellants—will give sufficient protection and comfort.

In winter, a difference is at once noted. At sea, the problems are similar to those faced on North Atlantic duty. All food must be kept below decks since vegetables such as potatoes, lettuce, and carrots, which are occasionally kept topside, will soon spoil because of the low temperatures 20° F. to 35° F., and the almost continual wetness from fog, rain, or snow. In addition, hot drinks and extra rations will be necessary. Waste disposal will demand that outlet pipes be warmed by an increased temperature of the affluent. The ship, as a whole, will need to be winterized and comfortably heated and ventilated. Additional space for recreation and for the stowage and drying of foul and cold weather gear must be made available. Finally, the human tolerance or work feasibility for each job will need to be carefully reassessed—usual watches topside cut proportionately, special stations manned for minimum periods, and relief gun crews trained.

Ashore, the whole sanitary concept must be built about the problems arising in winter from high winds, blizzards, extreme cold, and darkness; and in summer from constant daylight, insects, varying climatic conditions, marshy tracts, and muskeg.

In addition to what is usually built into military housing, additional lighting, heat supply, and insulation will have to be furnished. Whenever possible, buildings should be connected by closed passageways, taking into consideration proper fire protection measures.

Water supply is discussed elsewhere in this chapter.

Food that can be frozen will be easily handled, but special precautions will have to be taken to protect food that may be spoiled by freezing.

The disposal of human wastes is not a serious problem so long as only a few men are involved, units are not returning to the area, or the temperature is such that waste freezes almost immediately and stays frozen. However, under conditions of extreme cold where heated shelter is not available, a personal problem will be presented, due to the possibility of freezing exposed parts. This can be solved by the proper design of arctic clothing which will incorporate such features as long skirted parkas within which the hands may be withdrawn. In connection with waste disposal, a disposal bag or 50-gallon oil drum provided with burlap liner, which is allowed to freeze and later removed to a central dump and burned with fuel oil, is an expedient method which may be used. Wherever possible, it is recommended that heated wanigan-type heads be provided and located not too far from living quarters. Freezing prevents both the danger of contamination and unpleasant odors and the frozen waste can then be collected and burned with diesel fuel in a centrally located area.

All head, bathing, and washing facilities should be heated and located as close to living quarters as possible.

Because of the difficulties in obtaining sufficient water for laundry purposes, the question of dry-cleaning clothing should be considered.

One of the most difficult things for men to get used to is a dull, monotonous life. The solution is to keep busy and to keep the

Figure 6–2.—Hunting and fishing.

mind occupied. Every form of amusement that can be provided is essential to morale and contentment. Snow sports, hunting and fishing, educational courses, hobbies, reading, movies, and various other forms of amusement should be provided at stations and outlying posts. The usual recreational facilities provided on board ship are available in the Arctic as elsewhere. At isolated posts and arctic stations, provision for amusement becomes a problem that must be met, along with others peculiar to the station. During summer cruises in the high latitudes allow as many of the personnel as possible to get ashore to satisfy their curiosity, at least.

The maintenance of a high standard of morale at arctic stations is mandatory. The principal factors are as follows: Keep men informed as to the operations at hand; provide them with a continuous estimate of the situation; maintain a good mess—men in a cold climate require a heavier caloric diet; establish a definite length of tour to be about one year, with only volunteers returning for duty; arrange for leave or rest in areas outside the Arctic.

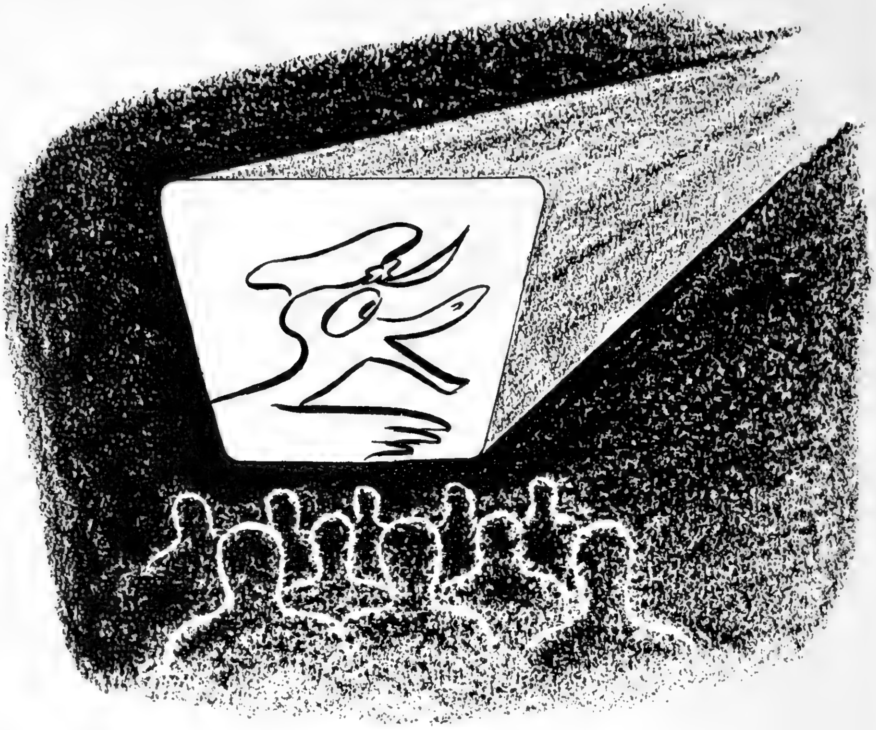


Figure 6–3—Movies.

FROSTBITE, SNOW BLINDNESS, SUNBURN

Snow blindness, frostbite, frozen extremities, trench foot, immersion foot, carbon monoxide poisoning, and insect bites are, on first sight, a rather formidable array of ailments to face. On examining each one, there is a gradual realization that each is preventable, given the proper equipment intelligently used. Large numbers of men have lived and survived in the Arctic without suffering more than minimum injury from its many hazards. At no time, however, must one relax guarding against the dangers inherent in the environment. To do so may result in a crippling illness, even death.

Snow blindness results from the action of the sun's rays in the presence of snow. Clear, bright days are not necessary, for some of the most severe cases of snowblindness have occurred on overcast days. The present goggles or sunglasses issued to service personnel will give adequate protection, if worn continuously. If these become lost or broken, the area about the bridge of the eyes may be blackened with soot or grease to cut down glare. In an emergency, satisfactory goggles may be improvised by making a mask out of a thin piece of wood or cardboard, using narrow slits for vision. A piece of cloth thin enough to see through may be worn over the eyes if nothing else is available.

If snow blindness results, ophthalmic ointment carried in the survival kit should be freely squeezed between the lids; and if possible, the eyes should be bandaged until symptoms, such as severe pain, burning of the eyes, tearing, and inability to stand light, have passed. In addition, moist, cold compresses will relieve some of the painful swelling. If mild, the symptoms usually disapper in a few days; if severe, one may be a casualty of several weeks. Personnel who have once had snow blindness are more susceptible to a recurrence during the following weeks.

Almost anyone who has lived in the Arctic has been frostbitten at one time or another during extreme weather. The prevention of frostbite demands continual awareness of the possibility when temperatures are below freezing, particularly if there is a wind. The frozen or frostbitten area–usually the face, ears, or wrists—becomes stiff, whitish, and numb. The area will rapidly regain its normal color and sensation if treated immediately by gently warming, as by placing the warm hand over the area or placing frozen fingers inside the clothing.

Brisk rubbing with or without snow is to be condemned and must not be used. Never immerse a frostbitten foot in cold kerosene or other liquid. If damage is sustained, a condition compar-

Figure 6–4.—Emergency eye protection.

Figure 6–5.—Frostbitten face.

able to a severe sunburn results, with the formation of blisters. An ointment should be applied, and the area covered with a sterile dressing. Men should be constantly on the alert in detecting the whitish or grayish discoloration of early frostbite on their companions. As most frequently frostbitten parts are those of the face, which can not be seen by the victim, it is a wise policy to work in pairs. Thus, a man can warn his companion that his face is frostbitten and first aid measures can be applied before the condition becomes severe.

In recent winter icebreaker operations, the faces of men wearing sound powered telephones for long periods at exposed stations became frostbitten. Such casualties can be avoided by wearing phones over face masks. Face masks or circular nylon scarfs should be worn by personnel exposed to strong winds below 30° F., as on the flight deck of aircraft carriers.

Freezing of the feet or hands is one of the severest penalties that a man can pay for carelessness or accidents in the Arctic. When a man's feet are frozen, he is through. Such freezing of extremities should not normally occur if the man is careful and keeps properly dressed in service-issued clothing, gloves, and footwear. Unfortunately, it is possible for men to be placed in a situation following a crash or fire, where proper clothing is not available.

The frozen parts usually are very painful at first, with the pain then giving way to numbness. The skin over the part may be white or little changed. If permanently damaged, the part will eventually turn black, the surrounding area swelling enormously, and the skin becoming a mass of large blood blisters. Above all else, the person should be placed in a shelter as soon as possible. The injured part is then warmed slowly and kept at room temperature (65° F. to 70° F.) with the remainder of the body made as warm as possible with blankets and stimulating hot drinks. Medical attention should be sought, if available. The pain may be controlled by further cooling and the administration of half of a morphine syrette every 4 hours, if available.

Figure 6–6.—Be alert for carbon monoxide poisoning.

This train of events, which in its severest form may lead to eventual amputation, is preventable.

Shoes, foot coverings, gloves, and body clothing must be kept dry, as explained in the previous chapter. This is best done by changing clothes or making camp and actually drying out clothing. Foot coverings should not be tight fitting. Any constriction of an extremity must be avoided. Tight fitting shoes should be replaced in an emergency by a makeshift covering made from available cloth materials such as parachute silk or blankets.

Immersion and trench foot result when temperatures at or just above freezing are associated with wet conditions. In addition, personnel are usually wearing constricting shoes or leggings. The constant wetness, cold, and constriction cause swelling of the extremity with a softness and discoloration of the skin. The prevention is a dry, well-fitting foot covering. Otherwise, massaging, elevating, and warming the feet will do much to prevent damage, if instituted early. Final treatment is similar to that for frozen extremities.

All personnel living in arctic shelters must be constantly on the alert for carbon monoxide poisoning. Under cold conditions, effort is usually made to keep warm, while ventilation is cut down. Coal or oil fires and engine exhaust are the usual sources of carbon monoxide poisoning. This colorless, odorless gas first affects a person by a slight headache, a feeling of drowsiness. The affected persons should either leave or be removed to other quarters, artificial respiration begun and oxygen given, if available.

TREATMENT AND EVACUATION OF CASUALTIES

A man who is wounded in the Arctic will be in grave peril of freezing. Suffering from shock and inactivity because of his wound, he may be an easy victim to the effects of cold. It is essential that he be provided quick warmth, shelter, and first aid treatment, followed by earliest evacuation back to base and medical treatment.

SURVIVAL AND EMERGENCY LIVING

Survival in the Arctic demands the intelligent use of all means at one's disposal. Every item of material and equipment that is available is capable of many uses and adaptations.

The Arctic covers a wide and varied environment of mountains, plains, swamps, and water areas, with temperatures ranging from minus 70° F. in winter to 90° F. in summer. In order to survive, much general knowledge, and a basic plan of survival are necessary. The following is given as a guide, with numerous additions suggesting themselves.

Personnel should at all times be familiar with the area in which they are operating so that, if shipwrecked, forced down in a plane, or lost from a working party or group, the greatest use is made of the environment.

First aid treatment of the injured should be accomplished first. Next, take every precaution to safeguard supplies and equipment. In no event stray far from the original position until all hope for rescue has been abandoned.

Preparation should be made to signal rescuers, build a fire, erect shelter, and ration available food to last as long as possible.

See *Polar Guide* (AFTRC 50–0–23, revised 15 June 1948) chapters 17 and 18.

FIRST AID

Injuries and sickness may occur in the Arctic as well as anywhere else. Treatment will be limited by the equipment available but improvisation and common sense will do much to help.

Shock.—This results from severe injuries, bleeding, or blast. It is recognized by a sharp, thready pulse, moist, sweaty skin, and rapid breathing. Emergency treatment demands the removal of the cause, and control of bleeding. Warmth, shelter, and the giving of warm fluids is next indicated. If severe pain exists, the contents of a morphine syrette may be administered.

Bleeding.—A tourniquet is rarely necessary. Most bleeding can be controlled by the pressure of a battle dressing. Treatment for shock is then indicated.

Wounds.—A battle dressing, or any clean dressing should be placed over the wound and firmly bandaged.

Fractures.—"Splint them where they lie" is the first maxim for fracture treatment. The important fact is that a fracture must be immobilized. Pain will become much less, once proper splinting has been performed. There are means for splinting available most everywhere. The upper or lower arm may be strapped to the body; the leg splinted by the other leg. If splinting is not performed, serious damage may result to arteries and muscles or, more important, shock will certainly ensue. Splints and bandages should not be applied too tightly for fear of impairing the circulation.

Burns.—Burn cases are treated for shock, if present. The burned area is then covered with a sterile ointment, followed by sterile dressings. Morphine can be administered to relieve the patient's pain if necessary.

(By all means, in all first aid, it must be remembered that injured personnel are very susceptible to the effects of cold. Every effort must be made to keep them warm and to get them to warm, comfortable surroundings as rapidly as possible.)

Maintenance of medical supplies.—The problem of maintaining medical supplies is complicated in cold climates by the fact that liquid drugs freeze and break in their containers. In some cases certain drug products lose their potency on freezing, although some do not and may be safely used after thawing. Experience reveals two interesting facts. First, containers which are not filled to more than 90 percent of their capacity are not likely to break upon freezing; second, metal containers of drawn construction are more resistant to bursting than those with soldered edges, or glass containers.

FUEL

The oil and gasoline available are obvious sources of heat during the period of rescue. The oil should be drained into any available container before it solidifies. Stoves are fairly easily improvised from cans.

Below the tree-line, sufficient wood will be available. On going farther north, the available fuel supply becomes less and less. Driftwood, the rare coal deposits, and dwarf willows and grasses will have to serve. To kindle a fire, gun powder, birch bark, and dry leaves will serve as a tinder.

SHELTER

For making any kind of shelter, one should first utilize the materials with which one has landed. If in a plane, any of the easily removable sections, such as the cowling, will serve for shelter construction. The cabin of a large plane will provide an excellent temporary shelter. Similar use may also be made of stranded vehicles and of boats. Trees, sod, and snow furnish building material for housing once the immediate crisis is over. See *Polar Guide,* chapter 18, pages 7 to 16 inclusive, for various improvisations of livable shelters.

The food that one arrives with should be divided into portions so that the longest possible survival is planned. Roughly, this may be figured by dividing a normal daily ration into four parts. This will add up to 800 to 1,200 calories. This ration may be supplemented by shell-fish, fish, birds, mammals, and plants that can be hunted in the area. Polar bear liver and a mushroom-like plant with a yellowish red cap are the only things that are truly poisonous.

The smaller mammals, such as lemmings, rabbits, and porcupines may be taken in snares. Musk oxen, caribou, seals, and polar bear may be shot with a rifle. Ducks, ptarmigan, geese, ravens, and owls are also to be found.

Shellfish may be dug on most shorelines or in shallow water.

When using plants, it must be remembered that the roots and inner bark will supply nourishment. Except for berries, all plants should be cooked.

If an animal or bird is caught, everything should be eaten—fat, liver, kidneys, etc.—along with the flesh. (See *Polar Guide*, ch. 18, pp. 23 to 39 inclusive.)

EMERGENCY RATIONS

Emergency rations are unfortunately limited by weight restrictions. The exact ration used will depend on the weight allotted for the purpose, anticipated survival period, and activity expected.

It is known that as low as 400 calories daily will keep a man alive for 10 days, the extra caloric requirement being made up from one's tissue. One thousand calories daily are sufficient for 20 days, and 2,000 calories are adequate for an indefinite period if there is no activity.

Weight requirements per man using a concentrated ration are roughly as follows: 400 calorie diet—0.31 lb./day; 1,000 calorie diet—0.77 lb./day; 2,000 calorie diet—1.38 lb./day.

Water will have to be supplied in quantities of one to two quarts, depending on the calories ingested, and the emergency ration unit should include, if possible, both the gasoline and the stove for resupplying water.

It is easily seen that no emergency ration may be devised that will keep personnel at more than a subsistence level. Any attempt to leave the site of original emergency is probably foolish, for it takes three to five thousand calories daily to travel in the North. In addition, it is obvious that every means to supplement one's rations off the land is of vital importance. Even though emergency rations freeze, they can be made edible by warming.

One can be heartened by the fact that both the native population and the white man have lived completely from the land in the Arctic.

CLOTHING

Clothing may be supplemented by parachute silk, blankets, cloth package material, etc. Paper may be used for insulation between layers of clothing.

If one does not have adequate foot covering, mukluks should be improvised from canvas, blankets, or parachute material. The skins of birds and mammals may also be utilized. If at all possible, loose footwear should be immediately substituted for tight shoes.

Whatever clothing is available must be carefully guarded against wetting from sweat or immersion. The clothing for each task should be planned and just enough worn to keep warm. Damp or wet clothing should be dried as soon as possible.

Figure 6–7.—Signal for rescuers.

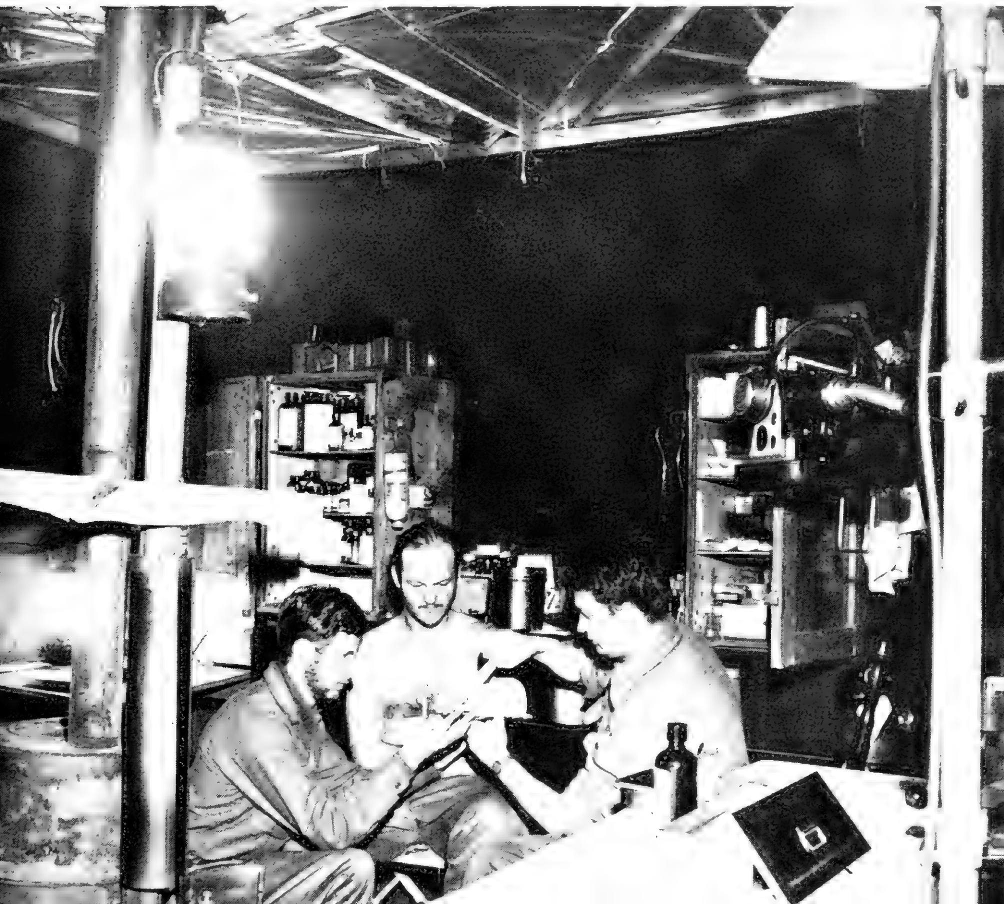
RESCUE

Rescue depends on complete cooperation between the rescuers and the persons to be rescued. The group to be rescued had best stay near the original landing point. As soon as possible, means for signalling should be ready. A well-made fire to which small quantities of water, heavy oil, grease, or rubber are added will give a thick, heavy smoke. Water gives a white smoke and the others a black smoke. Bush, boughs, or rocks may be made into 200-foot letters. Signal mirrors, the Very pistol, and smoke generator packs are additional valuable aids, but should not be used until the rescuers are in sight. (Refer to ch. 18, pp. 3 to 7 inclusive of *Polar Guide*.)

Above all, the knowledge that every effort is being made for rescue should be sufficient cause for persons in distress to continue every effort to survive.

The group planning the rescue, in addition to making adequate search plans, must be prepared to bring food, clothing, and medical

Figure 6-8.—First aid, Little America IV sick bay tent.



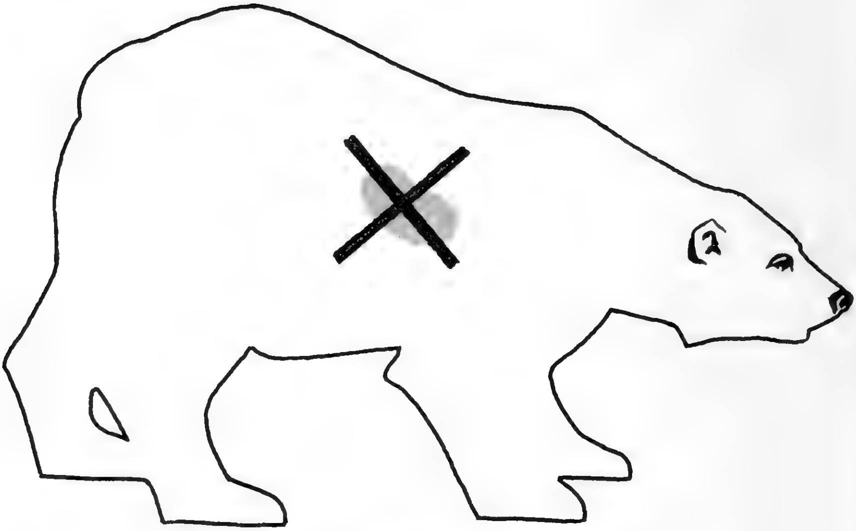


Figure 6–9.—Polar bear liver is poisonous!

aid. All of this must be droppable, if air search is contemplated. Once contact has been made, any injured or sick should be given first aid, and then evacuation performed as quickly as possible.

SOURCES OF WATER

Water in some form is universally present throughout the Arctic. There are innumerable lakes, rivers, and streams, which offer a safe potable supply for emergency use. Once these sources are frozen, the melting of snow or ice will be indicated. Volume for volume, ice is the best source, when obtainable, because of its greater specific gravity. Water may be obtained by the expedient of chopping through the ice over streams or lakes, but the difficulty involved does not ordinarily lend itself to emergency use.

When melting snow or ice, one must always remember to have a little water at the bottom of the utensil used for melting, otherwise the metal of the container may be melted through.

Eating unmelted snow is usually an unsatisfactory and unsafe method of allaying one's thirst.

At large installations, once water is obtained, the methods of purification are identical to those used elsewhere.

ABANDON SHIP

There is no experience in abandoning ship in seas of high latitudes. The real problems are survival in cold water until rescue arrives; proceeding by boat or across sea ice to shore; and living ashore, if possible, after land is reached.

Each ship operating in polar waters must evolve a plan of survival based on three conditions of open water, loose pack ice, or solid ice, and on equipment that is available.

As in abandoning ship in any area, calmness, leadership, and early rescue operations are essential to avoid catastrophe.

SUMMARY

Life ashore or on shipboard in the arctic regions is much like it is in other places. Surroundings will be different. Food will be of higher caloric content and will be served more frequently than normally. One will eat more confections. The clothing will be modified as required to meet the rigors of climate. There will

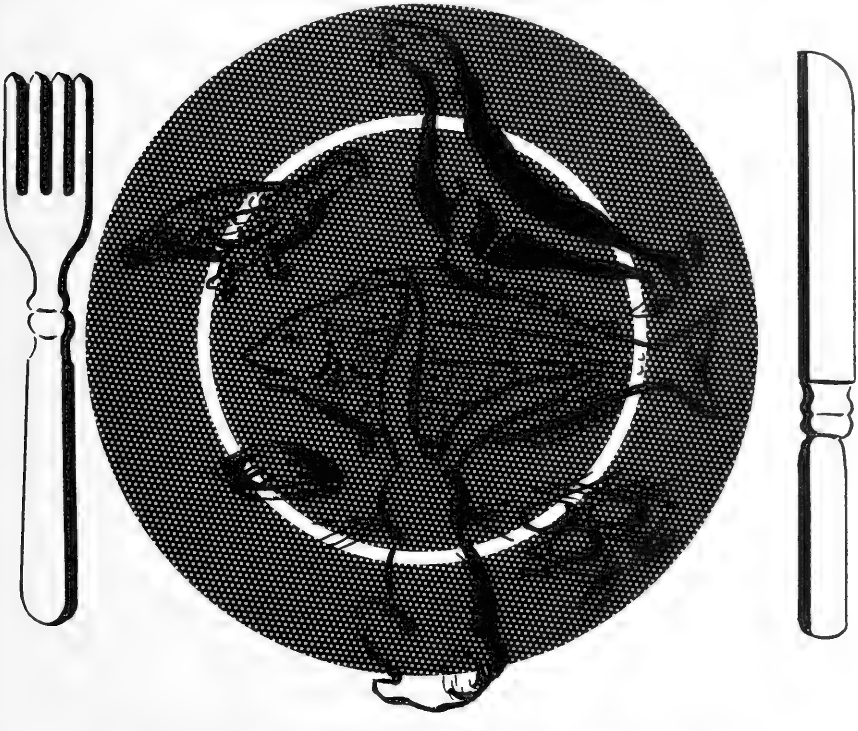


Figure 6–10.—Man can live completely from the land in the Arctic.

Figure 6-11.—Smoke signal—burning rubber.

be certain inconveniences as well as some curtailment of social and recreational activities.

It will be necessary to become adjusted to constant daylight, constant darkness, and remoteness of the areas visited. However, men in the Arctic enjoy life there and readily find ways to adapt themselves to its severe environment. Most are willing to return if the opportunity presents itself.

Men must fully understand and appreciate the fundamentals of living and survival in the polar regions. For additional information on this subject, it is suggested that the reader study chapters 6 to 9, inclusive, and chapters 17 and 18 of Air Force Publication, *Polar Guide* (AFTRC 50-0-23, revision of 15 June 1948).

CHAPTER 7

SELECTED BIBLIOGRAPHY

"I had been too much in the North to be willing to plan for an expedition by studying out of books. The trouble is the Arctic isn't anything like the books, after you get there."—Bartlett.

There is a great body of literature relating to the polar regions. Many of the books and papers were written by explorers and are either not available in libraries generally or are relatively useless insofar as applying to large-scale exploratory and naval operations in the Arctic.

The essence of the above statement by Captain "Bob" Bartlett is true. Practical experience is best always. Nevertheless, few service personnel will have had that opportunity prior to visiting the Arctic in the course of conducting naval operations there.

The manuals, guides, reports, and hydrographic publications listed herein are of recent origin and more accurately describe Arctic conditions than earlier books written for popular consumption. They are factual, represent the best service thought and experience, and should be helpful and interesting to those desirous of reading further on the subject of this handbook. It is considered that these service publications represent the very best source material available.

POLAR EXPLORATION

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The Secrets of Polar Travel	Robert E. Peary.
Polar Exploration	Andrew J. Croft.
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Across the Top of the World	Navexos P–489.
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Instructions for Use of Ice Observers Log for Aircraft.	HO Study No. 99.
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A Functional Glossary of Ice Terminology	HO Study No. 103.

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Antarctica	HO Chart 2562.
Characteristics of Antarctica Ice	HO Study No. 85.
Little America	Richard E. Byrd.

APPENDIX A

ANTARCTIC CLIMATE AND WEATHER

The antarctic continent consists of a large elevated land mass which is almost entirely covered by ice. This condition leads to formation of the permanent Antarctic Anticyclone (high pressure area) with the center located near the South Pole. This anticyclone is modified only by the semipermanent cyclones (low pressure areas) located in the Ross, Weddell, and Bellingshausen Seas. To the north of the Antarctic Circle is a belt of low pressure circling the globe which, in general, conforms to the northernmost edge of the off lying pack ice. Cyclonic storms moving from west to east in this low pressure belt tend to move directly into the semi-permanent cyclonic regions mentioned above, reenforcing the cyclonic circulation of these areas and losing their identity in doing so. (Refer to H.O Chart No. 2562 for the geographical features of Antarctica.)

A region of high pressure, as already mentioned, lies over the high Antarctic continent. The upper air descends over the polar ice cap, becomes intensely cooled, and moves outward in anticyclonic circulation toward the bordering belt of low pressure over the oceans surrounding the continent. In flowing downward from the polar plateau, these winds become southeasterly, due to the earth's rotation. They usually attain hurricane intensity, and blow drift snow high up in the air. Millions of tons of snow at low temperatures are at such times carried into the sea and play a large part in the regime of sea ice of the southern hemisphere.

Obstacles, such as the high mountains of South Victoria Land and Palmer Peninsula, produce a concentration of moving air, resulting in the high winds recorded in the McMurdo Sound and Marguerite Bay areas. Local winds of great intensity, some of which may be a reversal of the prevailing continental winds, are found in local areas, particularly where the terrain is marked by glacier valleys transverse to the flow of the prevailing air currents. Local disturbances may be confined to a relatively small area, with calm weather existing only a few miles from the area of high winds.

Figure A-1.—Map of Antarctica.

The Commonwealth Bay area is believed to be the windiest region in the world. The average wind speed for 22 consecutive months during 1911-14 was found to be 43 m.p.h. During July, 1913, a gale of 96 m.p.h. was experienced, during which an average speed of 89 m.p.h. was maintained for 12 hours. The mean speed for July was 55.6 m.p.h. During the month of August, 1913, an average speed of 80.6 m.p.h. was recorded during one 24-hour period, with gusts momentarily reaching over 100 m.p.h. The calmest month was February, 1912, with an average speed of 26.2 m.p.h.

Blizzards are very common in the Antarctic, but usually do not extend far out over the sea. They are rare during the *summer* period of November, December, and January, but are frequent during the *autumn* and *winter* months. The duration of a blizzard may be anything from a few hours to several days. The early indication of an approaching blizzard is the covering of the sky by light cirrus clouds which progressively become thicker, darker, and lower. Existing winds may steadily increase in force, or the blizzard may be preceded by a period of calm suddenly replaced by strong winds of 40 m.p.h. During the blizzard the wind holds steady in direction and carries large quantities of drift snow. Gusts of high velocity may be experienced, particularly towards the end of the disturbance. A period of calm usually follows a blizzard, after which the direction of the wind suddenly changes 180° and continues to blow with great force. This is characteristic of the passing of a cyclonic storm center.

Most blizzards are associated with northerly winds; that is, the blizzards are preceded by winds from that quarter. This is not always the case. Often a blizzard will commence without previous northerly winds and it is not until after the blizzard ceases that the wind shifts to that direction.

Large temperature increases have been noted with southeasterly blizzards, especially during the winter months; in the summer months the rise is not so marked owing to the less frequent temperature inversions. This phenomenon suggests foehn winds, and is due to adiabatic heating, the air descending from the plateau being compressed in striking terrestrial obstacles. The effect of this temperature rise is conspicuous at the mouth of the glaciers descending through the Queen Maud range.

The weather is extremely variable. Usually it changes in cycles, with the period of southerly winds lasting longer than northerly winds.

Fog is not infrequent in the region of icebergs and pack ice, and along the coasts of Antarctica. Frost smoke is common over open water areas during the autumn months.

Rain occurs frequently in the northern part and along the west coast of the Palmer Peninsula. It is rare in other parts of the continent. Precipitation is almost invariably in the form of snow or hoarfrost but the quantity deposited varies in different areas. Measurements have been of little value due to the great amount of drift swept by the winds.

Clouds are observed in great quantities in the Palmer Peninsula region, averaging eight-tenths. In the Ross Sea area the mean is seven-tenths, though cloudless skies over Marie Byrd Land are rare. Observations indicate a maximum cloud condition during the equinoctial months, with minima during the summer and winter months.

The low summer temperatures, particularly the maximum temperatures, are distinctive of Antarctica. The warmest month isotherm of 32° F. lies roughly along the Antarctic Circle except in the South Atlantic Ocean where it reaches the 60th parallel. On the western coast of Palmer Peninsula, due to the oceanic influence, average summer temperatures above the freezing point have been recorded. Winter temperatures vary in different areas, somewhat dependent upon latitude, but principally upon the frequency of southern blizzards and the presence of open water in the vicinity of the base.

The Bay of Whales region is believed to have the lowest annual temperatures (minus 10° F. to minus 15° F.) with minimum temperatures in the minus 70's being observed by each of the expeditions basing in that locality. The minimum temperature so far recorded there was minus 75° F. on 5 September 1940.

A winter sledge party camped on the Ross shelf ice near Cape McKay, Ross Island, recorded low temperatures. On 6 July 1911, the minimum of minus 77° F. was observed.

Very little is known of winter temperatures in the interior of the continent, but absence of the moderating effect of the sea is suggested by the winter temperatures recorded by Byrd at a station occupied from late March to mid-October 1934. This station was 94 miles south of the main base located at the Bay of Whales. A minimum temperature of minus 83° F. was recorded at the interior station on 21 July 1934, and the thermometer reached the lower 70's several times during the months of May, July, August, and September; temperatures were from 10° to 20° lower than those existent simultaneously at the main base at the Bay of Whales.

The outer boundary which separates the polar continental high lying over Antarctica from the polar maritime air masses of the prevailing westerlies is termed the Antarctic Front. This front varies from a maximum intensity where polar easterlies meet the westerlies, to non-existence in the vicinity of major low pressure areas where convergence destroys it. That this front exists has been well established in some cases of large wind sheer. Some characteristics are:

1. The front acts as a quasi-stationary frontal system bounding the polar high, sometimes advancing as a cold front or retreating as a warm front, and usually as boundaries of a wedge moving eastward. The weather along these fronts follows that of normal frontal systems, except on a less well developed scale.

2. The cold front has a line or zone of snow showers or squalls along which, if air mass showers are also present, become very dense. There is a wind shift across it varying from a few degrees when weak, to over 90° when well formed. A temperature drop of 5° to 7° F. has been observed across this front, though 2° to 3° is more common, and a definite change in air mass characteristics occurs.

3. As a warm front, the cloud shield is well defined, but omits the cirrus and cirrostratus forms of an ordinary system. When advancing, a well ordered layer of alto-cumulus at 8,000 to 10,000 feet is the leading edge of the shield, changing into an alto-stratus—alto-cumulus system as it lowers. Air mass weather, in the form of snow showers, usually begins before the snow shield is reached. Cirrus and cirro-stratus clouds can frequently be seen above this cloud shield, but they belong to the low pressure system that usually lies to the northwest in such cases.

4. As a quasi-stationary front, it may combine the characteristics of both a warm and a cold front, depending on the trajectory of the westerlies to the north. With over-running occurring, a narrow band of alto-cumulus clouds and a sparse line of weak snow showers exists.

5. The average location of this front is from 50 to 150 miles north of the ice pack, varying from 300 to 400 miles north as a maximum, and retreating to near the coastline as a minimum. It may retreat on to the continental plateau itself, under the influence of an extremely strong northerly circulation—but such cases are rare.

AIR MASSES

The following description of antarctic air masses was extracted from reports of naval units which operated in that area:

"The average depth of the polar air mass between the Antarctic Front and the continent varies inversely as the distance of the front from the continent increases. When the front is less than 150 miles from the continent this depth is about 8,000 to 10,000 feet, and when the front is 200 to 300 miles distant the depth is near 4,000 to 6,000 feet. This results from the seepage of the polar air from the continental plateau, downwards and outwards from its edge toward the sea. Hence, the further the front from the continent the more shallow the air mass, and, therefore, the frontal surface slope is less. The result is that for a given amount of over-running of the westerlies, the precipitation and cloud shields are wider, the further the front is from the continent, and vice versa.

"It was assumed that polar continental air (cP) on the plateau region has the ideal vertical structure of that type of air, i. e., a surface inversion (shallow during summer) with an approximately isothermal layer above the surface to a depth of 3,000 to 4,000 feet and a normal lapse rate above this layer. This air was then modified by subsidence as it sank from the plateau to sea level and by heating from below as the mean temperature of the underlying surface increased downward and outward. Thus, the air had an almost neutrally stable vertical structure at the coastline. Further travel northward over solid pack ice was accompanied by heating from below, resulting in a dry adiabatic lapse in the lower levels. The depth of this layer varied from 1,000 to 2,000 feet as a minimum, to 4,000 to 5,000 feet as a maximum, depending on the width of the pack. Immediately above this layer an inversion of 2° to 5° C. existed, formed as a result of mixing and heating from below and subsidence as the air moved northward. From this inversion to the frontal surface a slightly stable lapse rate prevailed. The strength of the inversion and the character of the lapse rate above also varied, depending on convergence or divergence due to the flow pattern. With cyclonic flow, the inversion is small and nearly isothermal and a moist adiabatic lapse rate lies above. With anticyclonic flow, the inversion is larger and deeper, with a definitely stable lapse rate above.

"The cP air of the plateau was assumed to have a low moisture content throughout, which decreased with elevation. As this air flowed downward and outward, a slight amount of moisture was added in the surface layers but it was insufficient to raise the relative humidity to more than 50 or 60 percent. The dryness aloft was accentuated by subsidence so that a sharp decrease of moisture occurred at the base of the inversion. This dryness was also accentuated by divergence when the flow pattern was anticyclonic; it was decreased by convergence when the flow was cyclonic.

"The above assumptions led to the concept of two different types of cP air; that on the continental plateau and that along the coastal area and ice pack. Since each type had different structures it was decided to name them differently; cP air was the name given that on the plateau, and the air along the coastal area and ice pack was called continental antarctic (cA).

"The above discussion has been concerned with cA air along the coast and over solid pack where there are no areas of open water. If, however, this cA air does pass over water, a rapid modification takes place similar to that occurring over the Great Lakes in winter, and to the formation of polar Atlantic air. Since this process occurs continuously with the production of large areas of an air mass intermediate between cP and that normally termed mP, and the name maritime antarctic (mA) was applied to it. The term mA is used to describe cA air that has been modified by a relatively short water trajectory, usually from 50 to 100 miles minimum and up to 500 miles maximum, beyond which it assumes properties similar to fresh mP air. The Antarctic Front is the northern boundary of this cA or mA air mass.

"The production of mA air can proceed rapidly as in the case of the direct advection from solid ice to open water or slowly through the advection of the air over open water present in the ice pack. In the latter case, this water may be open water between the fast ice and the pack, rotten pack ice, openings, and small bays. The addition of moisture from this water gradually increases the moisture content below the inversion. This continues with fracto-cumulus forming first, then gradually thickening into a layer of strato-cumulus which then develops vertically. The exact stage of development depends on the total amount of previous water travel. In estimating the total water travel of the air only the trajectory of the air in the lower 500 to 1,000 feet should be considered, which involves considerable cross-isobar movement. It is emphasized that this procedure must be considered in all cases where the trajectory of the antarctic air must be estimated.

Figure A-2.—Admiral Byrd's Tent City, Little America IV.

"At first, the strato-cumulus has bases approximately 1,500 to 2,500 feet and tops at the base of the inversion, the height of which varies with the distance of travel from the continent. With average pack composition and a travel of 150 miles across it, these tops will be 3,000 to 4,000 feet high. From these average figures the approximate stage of development from cAK to mAK can be estimated by considering that longer travel and more open water increases the height of the tops and lowers the bases, while shorter travel and less open water decreases the height of the tops and raises the bases until finally no clouds result in the extreme case. Snow showers develop higher than 6,000 feet. Convergence and divergence affects respectively augment or limit the above transformation of cAK to mAK.

"After the strato-cumulus clouds have been well developed, that is, with a total water travel of at least 50 miles, the air is considered to be mA. This mA air exists primarily in wedges extending northward from the Antarctic Anticyclone, in bubble highs developing from these wedges, and in flow paralleling the continent north of the pack over the sea. The mAK air exists in the eastern and northern sectors of the wedges and bubble highs where the flow tends northward. This air then turns southward becoming mAW in the western and southern sectors. It is characterized by a stable layer from the surface to about 500 feet and a moist adiabatic lapse rate above that to 1,500 to 3,000 feet, above which is an inversion of one degree to four Centigrade. This inversion becomes progressively lower the farther the southward travel. Above the inversion the lapse rate is very stable. Stratocumulus and stratus clouds lie beneath the inversion with ragged bases from 500 to 1,000 feet. In bubble highs these clouds frequently totally dissipate near the southern limit of the air trajectory because of the lack of the vertical convection needed to maintain these clouds. Patches of fog develop after a net southward travel of about 100 miles and become denser the farther south the air travels. The transitional area from mAK to mA to mAw occurs in the north to northwest section of the wedges and bubble highs as the air begins returning southward. Here snow showers cease and the strato-cumulus tops lower to 2,500 to 3,500 feet with bases at 1,000 to 1,500 feet.

"The opposite transitional area from Aw to mA to mAK that occurs in the south to southeast section of bubble highs is one of frequent clear skies and excellent visibility. Here patchy fog is dissipated due to heating from below and the strato-cumulus cloud deck of the mAw section frequently disappears. Maritime antarctic air flowing parallel to the continent becomes mAw upon passing over the ice pack. This change, after a distance of about 200 miles, produces dense fog which blankets the ice pack area and is frequently advected over the sea. If the fog advected over the sea has a northward trajectory, the air will be warmed from below and the fog will lift and form a stratus cloud deck after a distance of about 3 to 5 miles.

"The mP air mass that lies to the northward of the Antarctic Front is homogeneous in its east-west characteristics with a rapid north-south variation in temperature which closely corresponds to the sea surface temperature. The lapse rate is moist adiabatic to 10,000 to 15,000 feet where a small stable layer tops this moist layer. In convergence zones or where the air has an mPk classification, heavy cumulus clouds develop in the moist layer giving snow showers. These cumulus clouds frequently resemble cumulo-nimbus with flattening of tops, but on a reduced scale. They appear to be composed of super-cooled water drops through their major portion, with an ice crystal top.

"Patchy fog develops where the air becomes mPw provided there is no extremely large scale meridional flow such as is present in advance of a large low pressure area. In this latter case, the fog becomes solid advection fog and persists as long as that meridional flow exists."

WINDS

From the antarctic continent outward blowing winds prevail, and since the coast so generally trends east-west, these winds, which are always deviated to the left by the earth's rotation, generally blow from the southeasterly quadrant. Where, however, the coast trends north-south, as on the west of the Ross Sea, these winds for the same reason blow from the southwest. They are often of hurricane intensity and with gust velocities sometimes attaining to 150 or 200 miles per hour. Winds of such violence are not known elsewhere, save perhaps within a tropical cyclone. They are characterized by a noteworthy absence of humidity and an elevation of air temperature due to the adiabatic conditions.

The Antarctic Anticyclone, being due to the intense cold of the snow surface, is essentially a shallow system not more than some few thousand feet deep, and above it the general polar cyclone must exist in an intensified form. The upper winds are best shown by the movements of the clouds and by the drift of the

Figure A-3.—Icebreakers at Neny Island, Antarctica.

smoke from the volcanic Mount Erebus (13,000 feet). In the McMurdo Sound region the clouds between 10,000 and 13,000 feet and the smoke from Mount Erebus indicated prevailing winds between west and north, the opposite of the surface direction on the Ross Barrier, and associated presumably with the cyclonic circulation of the middle atmosphere. (See table II and III.)

VISIBILITY

Due to the absence of dust, solid particles, and the low moisture content of winds blowing off the antarctic continent, visibility is often unusually great and mirage effects are often experienced.

These latter will often lead the uninitiated into making serious errors from estimating distances. The most serious restrictions to visibility occur with blowing snow or when air from the leading edge of a low pressure system has sufficient trajectory over the ice packs to permit condensation of water vapor and the continuous formation of heavy fog. (See table IV.)

CLOUDINESS

Cloud cover is high throughout the area, amounting to 60 to 90 percent and increasing somewhat from December through March. Cloudiness increases and ceilings lower as one proceeds northward from the ice pack and approaches the antarctic front. At Little America, Cape Dennison, the Shackleton Ice Shelf, and on the *Gauss,* cloud covers are predominantly 60 to 70 percent, with only about 40 to 60 percent low cloud cover being experienced at Little America. Over the adjacent sea areas north of the Antarctic Circle, on the other hand, cloud covers are usually 80 to 90 percent, with about the same percentages of low broken or overcast being observed. Although no data is available relative to cloud conditions inland, it is expected that generally clear skies will prevail. The predominant cloud types are stratus and stratocumulus, which appear in over 50 percent of total observations taken at Little America, and more frequently over the adjacent water areas. Alto stratus and alto cumulus are also frequently observed. (See table V.)

TEMPERATURE

There is little to be added to what has previously been said concerning the temperature in the Antarctic. It is perhaps worth noting that there appears to be no month in which the mean air temperature reaches a temperature in excess of 32° F. It is realized that the open lake region discovered by a recent expedition tends to contradict the latter statement, but it is believed that this feature is normally perhaps caused by hot water springs. It is considered that the center of Antarctica has the coldest winters of the whole world, but there are no existing records to prove or disprove this theory. However, the winters of the Ross Sea region and the ocean coasts are not as cold as those of Siberia. (See table VI and VII.)

PRECIPITATION

There are few, if any, reliable statistics of the amount of precipitation, but it is known to be scanty, equivalent probably to not more than 5 to 10 inches of rain; it all falls as snow, mostly fine crystals, dry and powdery. The difficulty in measuring it is due to the strong winds which almost always accompany it, for the snow is whirled about and cannot settle in a gauge. Moreover, it is impossible to say how much of the snow is newly fallen from the clouds and how much has been swept up from the ice cap.

A perplexing problem is the cause of the precipitation in view of the anticyclonic conditions which prevail. That precipitation exceeds evaporation—and evaporation is certainly considerable—seems to be proved by the great glaciers that move down from the plateau and by the calving from the edge of the ice sheet of the numerous icebergs that beset the surrounding oceans. There must be considerable precipitation in the interior to feed this dispersal from the long periphery. The depressions of the westerlies provide considerable snowfall on the coasts that come within their influence, but their influence does not appear to extend far inland.

Antarctica enjoys very clear skies and long sunshine in the summer months, the sunshine traces being sometimes continuous for the whole 24 hours. In December, 1903, the Discovery station at McMurdo Sound recorded 490 hours, 66 percent of the possible duration, and in a year there were 1,725 hours, which is more than we have in the sunniest parts of England, though the sun in Antarctica was above the horizon for only 246 days. (See tables VIII and IX.)

FORECASTING AIDS

The Norwegian theory of air mass analysis and the forecasting rules and techniques derived therefrom may be applied in the antarctic areas by use of certain modifications based mainly on results of topographical influences. The observations of changes in certain weather elements were found to be of major aid in forecasting. Hence, the following paragraphs are headed according to these indicative elements.

WINDS

Due to the absence of any topographical interference over ocean areas to the gradient air flow, wind speed and direction were the most important factors in determining the positions and intensity of cyclones and anti-cyclones on the synoptic chart. The following thumb rules in relation to winds were found to be of aid in antarctic forecasting:

1. Favorable weather at Little America sets in very shortly after the surface winds shift to the south. This shift is generally accompanied by a marked drop in temperature. The shift of the wind aloft to the south likewise denoted the approach of good weather in the western portion of the Bellingshausen Sea.

2. Good weather, both at Little America and in the Bellingshausen Sea, is maintained by southerly winds aloft.

3. A wind shift from south to southwest in the Bellingshausen Sea indicated the development of a weak cold front orientated east-west near the edge of the ice pack and large areas of snow showers, accompanied by low ceilings and very poor visibility in the showers.

4. A wind shift from the prevailing direction of southeast to either east or northeast indicated the approach of a migratory low pressure center from the northwest. Within the following 18 hours, heavy fog could be expected after the warm, moist air moving southward around the leading edge of the low had had a short but sufficient trajectory over the ice pack resulting in cooling and condensation.

5. An increasing pressure gradient and resultant increasing winds will not result in dissipation of fog formed on the southeast quadrant of lows moving into the Bellingshausen Sea. In winds as high as 30 knots the fog was thinned but visibility remained less than ½ mile.

6. On and near the continent, blowing snow extending to 100 feet above the surface is common when high winds (generally above 17 knots) are blowing. It is difficult to distinguish this phenomenon from an actual snowfall when observed from the ground. Aviators flying at low altitudes should be emphatically warned that blowing snow is extremely difficult to visually differentiate from terrain and that in areas where sloping hillsides might be encountered, the only safe flight is one at sufficient altitude to be well clear of any such obstacles.

7. Wind speeds were less near the center of wedges and increased toward the edges.

8. Extreme care should be exercised in keeping a check on winds aloft, particularly in the 5,000 to 10,000-foot layer. Most high pressure wedges are relatively thin and narrow and ap-

proaching storms may be noted in winds aloft in the 10,000- to 20,000-foot layer.

9. Approaching closer than 50 miles to the continent can bring the ship under the influence of drainage flow from the ice cap. This causes an abnormally high wind for the pressure gradient present. It may be due to a tight local pressure gradient, which in turn is due to the rapid increase in depth of the polar air mass between the ship and the continent. This is a large scale katabatic or foehn wind effect and may be minimized by moving further away from the continent. The total effect is largely determined by the local topography of the continent and can be predicted in advance.

10. With a southerly wind, favorable weather will exist over a coastal area, while off shore 50 to 100 miles low status will persist with resulting poor flying conditions. In general, near the coast a southerly wind will produce 0 to 2 days of good flying weather following the passage of a migratory low.

PRESSURE

The use of pressure and pressure tendency as an aid to forecasting is, at times, misleading south of 75° latitude. This is due to the fact that most of the lows and fronts in this area are dissipating. For example, filling lows and associated bad weather approaching the Bay of Whales may result in the pressure at that location remaining steady or rising slightly. There are other instances in the antarctic areas when pressure traces may be of use in forecasting, as follows:

1. Pressure tendency is an excellent indicator of weather changes in the vicinity of 65°, the location of the track of many of the circum-continental migratory lows. As elsewhere in the world, lows and fronts are preceded by falling pressure and followed by rising pressure.

2. When the barometric trace begins to fall off rapidly in the latitudes between 60° and 70°, winds 30 to 40 knots can be expected. These winds will usually continue for a period of 12 to 24 hours after pressure begins to rise. When the barometric trace begins to level off after the rise following the passage of the low center, it can safely be expected that the winds will diminish rapidly to 16 to 24 knots.

3. Good weather conditions were found along the eastern sector of wedge lines where the southeasterly flow of dry air from the continent guaranteed good visibility and negligible cloudiness locally with CAVU weather over the coast line and continent.

4. Wedge lines between the Greenwich Meridian and 110° longitude are almost always migratory in character, moving from west to east at 15 to 20 knots.

5. In moving eastward with a high pressure wedge, barometic tendency was successfully used to judge the speed necessary to keep up with the wedge's eastward movement. A speed of 15 knots would almost always maintain a steady pressure trace and indicate that exact pace was being kept with the wedge.

CLOUDS

1. Local forecasting for short periods can be handled adequately by continuous observation of cloud conditions. The sequence of clouds is similar to that experienced in midlatitudes. The clouds associated with the Antarctic Front are very similar to those associated with the Tropical or Equatorial Front. Alto-cumulus and alto-stratus shields may be followed in 1 to 2 hours with moderate to heavy precipitation and near zero conditions. Over the ocean and ice packs, low stratus, which may obscure middle and high clouds, exists for a large percentage of the time. When forecasting for flight operations near the continent the appearance of this stratus is very deceiving. Assuming a situation where the ship is moored to land-fast ice with open water to the north, the following situation often exists: southward, looking toward the continent, the stratus and snow will blend together, appearing very white; northward, the stratus appears very dark or nearly black due to the reflection of the open water. When first observed this *water sky* appears similar to an advancing roll cloud or squall line. It is very dark and ominous and pilots will question the advisability of flight operations at the time.

However, after observing this phenomena for several hours it will be found that there is very little change and everyone will soon get used to it and, in fact, be glad to see a *water sky*, because it indicates open water, which helps greatly in navigating the ice pack. Another phenomena is *ice blink*. This is the reverse of *water sky* and is light reflected from a field of ice on the low stratus clouds. The clouds appear brighter or much whiter than the surrounding clouds. When *ice blink* appears on the horizon it is a sure indication that the ice pack will soon appear. When these two situations exist it is most difficult to estimate a ceiling. In some cases the estimate was as much as 4,000 feet in error when checked by releasing a pilot balloon.

2. The tops of most cloud formations can be reached at about

10,000 feet, except in convergence zones near low pressure areas. These clouds are usually in layers which can be predicted from radiosonde soundings or air mass considerations. Aircraft icing will exist to some degree in all of these layers.

THUMB RULES FOR LITTLE AMERICA

1. Ice fogs are common when the temperature takes a sudden drop to approximately 15° F. and the wind is moderate from the southeast.

2. Antarctic sea-smoke will obscure the front of the barrier when the temperature falls suddenly and the wind is moderate.

3. Absolutely cloudless days are experienced at Little America.

4. Visibility observations are not reliable as there are no distinguishable landmarks. Exceptional visibility of over 100 miles may be expected on clear days.

THUMB RULES FOR AREAS ADJACENT TO CONTINENT

1. During the summer months, with normal southeasterly flow of air, temperatures will remain between 27° F. and 34° F. With southerly winds and modified polar continental air reaching the area, temperatures will reach a minimum of between 20° F. and 24° F.

2. Relative humidity is of little aid in practical forecasting.

3. In summer months, periods of 6 to 9 hours of favorable weather will occur at intervals of 3 to 5 days, with periods of 24 to 36 hours of favorable flying weather occurring perhaps once in 10 days. These periods depend on the progression of the migratory lows and their effect on the high pressure ridges extending from the continent.

4. Local weather depended entirely on the air trajectory. If within 150 miles of the coast line or shelf ice, evaporation into the lower layers would give nothing more than broken strato-cumulus which would decrease gradually to clear at the coast line. If operating in excess of 150 miles from the coast, considerable shower activity could be expected with occasional closed conditions, depending on the total water travel of the air. If the ice pack was more than 150 miles from the coast with 50 to 75 miles of open water between the ice pack and shelf ice, considerable fog could be expected on the leeward side of the ice pack.

5. Most favorable weather conditions were found south of the Antarctic Front.

FORECASTING FOR FLIGHT OPERATIONS

1. Forecasting for helicopter operations is difficult at the best. For ideal operations the weather should be CAVU. Since this condition seldom exists in the Antarctic and much of the operation depends on helicopters, the aerological officer will be constantly asked, "Is it safe to fly?" To answer this query necessitates constant observations of the weather elements. Every effort must be made by the forecaster to be one jump ahead of the weather and not hesitate to advise the pilot to return to the ship if the weather appears to be closing in.

2. Too much cannot be said for the need of flight instruments in helicopters. Equipped as they are now, a pilot is nearly helpless when caught in an *antarctic white-out.* This is a condition of low stratus blending into a solid ice field, producing a situation where the horizon cannot be determined, and where the pilot has no depth of perception. The aerological officer must be especially cautious on days where a low stratus deck persists at 1,500 to 2,500 feet and a fight is to be made over an unbroken ice field. From the ship, visibility will appear very good, and conditions favorable, with icebergs and dark objects showing up very well. However, soon after takeoff, as the pilot proceeds out over the ice field, he may encounter a situation where only flat ice extends ahead of him. When dark objects, such as open water leads, icebergs, or ridges in the ice do not exist, the pilot is unable to determine the horizon. The ice and clouds seem to blend together and it is impossible to distinguish the point where one begins and the other ends.

The combination of light glare in the atmosphere, uniform clouds, and uniform surface all rendering the same color, constitute the *white-out.* Task Force 39 lost one helicopter due to this phenomenon. The pilot said, "It was like flying inside a bottle full of milk. I was so confused and so lost, it was actually a relief when we hit the ground."

GENERAL

1. The Antarctic Front is subject to wave disturbances in the exact manner and under the same conditions as those of polar fronts in the northern hemisphere. Waves forming on the Antarctic Front to the westward of the Ross Sea area generally move rapidly eastward as an open wave, then slow and occlude in the vicinity of Scott Island. The wave will then veer to the south-

east and become fully occluded in the following 12 hour period.

2. Long occluded fronts orientated in the north-south line and terminating in deep depressions are very frequently found in the Ross Sea area. They form from unstable waves on a section of the polar front in the vicinity of Australia or New Zealand.

3. Not one of the cyclones investigated that formed to the west of the 180th meridian was able to work its way through the semi-permanent high, displaced along the 120th meridian, and migrate into the Bellingshausen Sea area.

4. Low pressure centers which move into the Bellingshausen Sea are usually picked up in the vicinity of 120° and 55°.

5. When migratory low pressure centers stagnate in the Bellingshausen Sea, a new center normally develops off the northern tip of the Palmer Peninsula. The regeneration of lows north of the Palmer Peninsula cause a northward outbreak of cold continental air along the east coast of the Palmer Peninsula and behind the low as it goes into the Weddell Sea.

6. The major fronts in the Bellingshausen Sea are long occlusions, which are the remnants of waves that originate on the South Pacific polar front and develop into mature wave systems as they move southeastward. Warm and cold fronts of normal orientation extend from the occlusions.

7. Small stable waves infrequently develop on the Antarctic Front west of the Ballenys. These are found during periods in

Figure A–4.—Seals in the Bay of Whales.

which there are no other lows in the vicinity and a long quasi-stationary Antarctic Front is bounded by a large maritime polar high mass to the north. These waves normally move eastward and become absorbed by a large low of the westerlies.

TABLE I

Station Location Table

Station	Latitude °	Latitude ′	Longitude °	Longitude ′
Argentine Islands	65	15 S.	64	16 W.
Belgica Drift	69 S. to 71–30 S.		81 W. to 95 W.	
Cape Adare	71	18 S.	170	09 E.
Cape Denison	67	00 S.	142	40 E.
Debenham Islands	68	08 S.	67	06 W.
Framheim	78	38 S.	163	37 W.
"Gauss"	66	02 S.	89	54 E.
Laurie Island	60	45 S.	44	43 W.
Little America	78	34 S.	163	56 W.
McMurdo Sound	77	40 S.	166	30 E.
Port Charcot	65	03 S.	64	00 W.
Port Circoncision	65	10 S.	64	12 W.
Shackleton Shelf Ice	66	18 S.	95	01 E.
Snow Hill Island	64	22 S.	57	00 W.
Water Boat Point	64	48 S.	62	43 W.

NOTE: Refer to H. O. Chart H. O. 2562 (Antarctica).

Table II

Prevailing Wind Direction and Mean Speed in m.p.h. (Except as Noted)

Station	January	February	March	April	May	June	July	August	September	October	November	December	Years of record
Argentine Islands	S.	......	SE.	N.	N.	S.	S.	S.	S.	N.	N.	S.	1
	9	......	5	7	8	6	7	7	5	13	7	6	
Belgica Drift	E.	E.	W.	SE.	N.	W.	W.	W.	NE.	W.	E.	SE.	1
#	24	12	11	5	13	11	25	15	20	11	21	21	
Cape Adare	......	......	SE.	S.	SE.	S.	S.	S.	SE.	S.	S.	S.	1
	......	......	8	8	7	4	6	5	6	6	6	7	
Cape Denison	28	38	51	48	51	47	56	44	36	46	37	42	2
Debenham Islands	E.	E.	E.	E.	E.	SE.	NW.	SE.	E.	NW.	NW.	E.	1
	9	11	8	7	13	7	7	8	6	12	8	16	
Framheim	E.	......	......	E.	S.	E.	E.	E.	E.	E.	E.	E.	1
	8	......	......	10	6	9	10	9	10	14	11	11	
"Gauss"	E.	E.	E.	E.	E.	E.	E.	E.	E.	E.	E.	E.	1
	10	15	10	15	21	10	15	21	10	10	10	10	
Laurie Island	NW.	NW.	NW.	NW.	NW.	NW.	NW.	NW.	NW.	NW.	NW.	SE.	9–10
	10	10	14	13	12	11	12	13	13	13	12	9	
Little America, 1934	E.	SE.	E.	E.	E.	E.	SW.	S.	E.	E.	E.	E.	1
	12	13	14	14	12	11	11	8	11	13	11	9	
McMurdo Sound	E.	SE.	SE.	SE.	SE.	SE.	SE.	SE.	E.	E.	E.	E.	1–2
	9	16	18	14	16	17	17	17	15	14	13	10	
Port Charcot	NE.	NE.	NE.	S.	S.	S.	S.	NE.	NE.	S.	NE.	S.	1
Port Circoncision	NE.	NE.	NE.	NE.	N.	N.	NE.	NE.	N.	N.	NE.	......	1
	3	6	10	8	8	10	16	19	15	14	11	......	
Shackleton Shelf Ice	ESE.	ESE.	......	ESE.	ESE.	SE.	ESE.	ESE.	ESE.	ESE.	ESE.	ESE.	1
	8	11	......	12	16	15	15	6	9	19	9	5	
Snow Hill Island	SW.	SW.	SW.	SW.	SW.	SW.	SW.	SW.	SW.	SW.	SW.	SW.	1–2
	11	17	31	18	20	20	22	21	18	18	19	10	
Water Boat Point	S.	SW.	SW.	NE.	S.	SE.	S.	S.	S.	SW.	SW.	S.	1
*	0	9	13	40	20	30	7	7	5	16	9	3	

* Percentage of Observations Above Force 5, Beaufort.
# Number of Days With Less Than Force 4, Beaufort.

Table III

Number of Days on Which Gales (Winds Greater Than 34 m.p.h) Were Recorded (Except as Noted)

Station	January	February	March	April	May	June	July	August	September	October	November	December	Years of record
Argentine Islands	0	....	2	2	4	3	2	2	2	8	1	0	1
Cape Adare	11	....	5	5	5	7	6	6	6	7	6	8	1
Cape Denison#	16	13	26	26	30	30	27	29	26	30	21	12	1
Debenham Islands	4	6	3	6	10	4	3	9	6	10	5	14	1
"Gauss"	3	6	1	5	11	6	9	12	5	6	1	4	1
Laurie Island	3	11	20	17	12	12	8	21	25	17	9	6	7
Little America, 1934	0	2	5	9	5	2	3	3	6	3	1	0	1
Port Charcot*	12	9	9	8	8	10	6	12	11	12	11	7	1
Port Circoncision	1	0	5	1	0	4	11	12	12	9	4	....	1
Water Boat Point*	5	8	8	9	8	10	10	8	11	10	8	7	1

* Highest Wind Force (Beaufort) Recorded During Month.
# Number of Days With Winds Greater Than 30 m.p.h. Recorded.

Table IV

Number of Days of Fog Per Month (Except as Indicated)

Station	January	February	March	April	May	June	July	August	September	October	November	December	Years of record
Argentine Islands	2	....	0	4	3	2	1	5	5	7	0	2	1
Belgica Drift	17	22	14	26	27	28	17	25	14	23	18	13	1
Debenham Islands	2	1	2	1	1	2	0	3	1	1	0	2	1
Framheim	1	....	....	6	....	....	....	3	10	4	....	1	1
Laurie Island*	16	12	16	13	18	18	19	20	18	17	16	13	7–8
Little America, 1934	5	1	3	6	3	2	6	5	3	6	7	11	1
Port Circoncision	5	6	10	13	20	13	23	25	25	24	20	....	1
Shackleton Shelf Ice	8	1	....	0	4	8	5	1	0	1	7	13	1
Snow Hill Island	16	14	4	9	11	11	8	9	7	9	8	12	1–2

* Days of Fog or Mist.

Table V

Mean Cloud Amount in Tenths (Except as Indicated)

Station	January	February	March	April	May	June	July	August	September	October	November	December	Years of record
Argentine Islands	8.4		7.3	7.7	7.8	6.6	7.0	6.1	7.3	9.2	9.4	8.7	1
Cape Adare	6.9	7.7	7.7	7.6	6.7	4.5	5.7	5.2	6.5	5.8	5.7	6.7	2
Cape Denison	7.4	7.6	6.5	6.7	5.6	3.4	4.4	5.9	6.6	4.3	4.8	6.9	1
Debenham Islands	7.8	6.5	8.0	8.0	7.4	6.2	7.5	7.2	8.3	7.5	8.5	7.6	1
Framheim	5.2			7.2				4.5	5.8	7.5	4.3	6.9	1
"Gauss"	7.1	8.0	6.3	6.5	8.1	6.4	7.7	8.2	7.3	7.4	7.1	7.2	1
Laurie Island	9.2	9.1	9.1	8.9	7.8	7.7	7.5	7.8	8.1	8.7	9.3	9.2	14
Little America, 1934	7.7		6.8	7.7	5.5	5.7	4.2	4.7	5.7	7.1	6.3	5.9	1
McMurdo Sound	5.9	6.6	6.6	5.7	4.9	4.5	4.6	5.6	5.8	7.1	5.9	5.0	4
Port Charcot	9.2	8.3	7.9	6.8	5.9	6.3	5.9	8.3	7.5	7.4	8.7	8.0	1
Port Circoncision	9.5	7.8	8.5	7.0	8.5	7.7	7.8	8.0	8.7	8.7	8.0		1
Shackleton Shelf Ice	5.9	8.1			5.1	7.0	9.0	7.0	7.5	8.2	7.6	5.5	1
Snow Hill Island	8.8	7.7	8.7	6.7	6.7	6.1	6.2	5.7	7.3	7.3	8.4	7.6	1–2
Water Boat Point:													
Percentage of Overcast Sky	46	66	68	75	45	55	56	42	43	57	53	40	
Percentage of Sky Cover 5.0 to 9.9 tenths	36	18	13	15	29	26	24	33	40	37	42	52	
Percentage of Sky Cover 0.1 to 4.9 tenths	9	13	17	7	23	19	18	22	17	6	5	8	
Percentage of Cloudless Sky	9	3	2	3	3	0	2	3	0	0	0	0	

TABLE VI

Mean Temperature, F°

Station	January	February	March	April	May	June	July	August	September	October	November	December	Years of record
Argentine Islands	35		32	26	25	24	12	−1	12	26	28	33	1
Belgica Drift	30	30	16	11	20	4	−11	12	−2	18	20	28	1
Cape Adare	32	27	19	9	−2	−15	−12	−14	−7	−1	19	29	2
Cape Denison	30	23	10	2	−2	−6	−4	−2	−2	7	19	27	1
Debenham Islands	34	31	30	25	8	0	6	6	20	28	33	35	1
Framheim	14			−18	−32	−30	−34	−49	−30	−12	4	20	1
"Gauss"	30	26	17	4	7	0	−1	−7	0	9	20	30	1
Laurie Island	32	33	31	27	19	15	13	15	20	25	28	31	21
Little America, 1934	24	0	−14	−16	−19	−14	−37	−39	−34	−14	−2	17	1
McMurdo Sound	24	16	4	−9	−11	−12	−15	−15	−12	−2	14	25	5
Port Charcot	33	31	30	23	13	12	−3	20	23	19	32	31	1
Port Circoncision	35	34	34	23	23	20	20	22	21	28	30		1
Shackleton Shelf Ice	23	20		−3	−8	−15	−2	−5	2	9	18	25	1
Snow Hill Island	30	26	13	7	−1	−4	−5	−2	4	15	17	28	1–2
Water Boat Point	36	35	31	30	21	26	15	8	21	28	28	34	1

Table VII

Mean Maximum and Mean Minimum Temperature (Except as Noted)

Station		January	February	March	April	May	June	July	August	September	October	November	December	Years of record
Argentine Islands	Max.	39		36	30	28	27	18	5	18	30	32	36	1
	Min.	31		28	23	21	21	7	−7	5	22	23	30	
Belgica Drift	Max.	32	32	22	16	28	15	−2	22	6	23	25	32	1
	Min.	27	27	10	3	12	−6	−18	0	−11	10	11	22	
Cape Adare	Max.	37		22	16	3	−5	−1	−4	−4	5	24	36	1
	Min.	30		14	5	−11	−19	−18	−23	−19	−11	9	27	
Cape Denison	Max.	34	29	18	6	6	3	0	6	4	8	22	31	1
	Min.	25	21	10	−2	−2	−3	−8	−3	−6	−3	21	23	
Debenham Islands	Max.	39	36	34	30	14	10	18	17	25		36	40	1
	Min.	30	27	25	20	1	−10	−6	−5	13	19	26	29	
Framheim*	Max.	27			12	−4	13	9	−12	15	16	23	32	1
	Min.	1			−54	−59	−73	−66	−74	−64	−40	−18	2	
"Gauss"	Max.	34	30	23	10	11	8	6	−3	6	16	24	33	1
	Min.	24	22	10	−3	1	−9	−9	−14	−7	0	12	24	
Laurie Island	Max.	42	43	43	40	37	35	35	37	38	41	40	41	22
	Min.	24	24	18	6	−8	−18	−21	−20	−14	−3	14	22	
Little America, 1934	Max.	31	11	21	10	17	20	18	−9	−4	7.5	18	30	1
	Min.	18	−19	−45	−49	−58	−49	−65	−62	−62	−38	−26	7	
McMurdo Sound	Max.	29	20	9	−2	−5	−5	−6	−7	−5	2	19	29	4
	Min.	17	9	−2	−15	−21	−22	−24	−24	−23	−12	7	18	
Port Charcot	Max.	35	36	37	36	29	32	23	31	32	32	34	34	1
	Min.	30	27	23	10	−3	−10	−27	−4	16	2	23	27	
Port Circoncision	Max.	38	38	38	27	27	26	25	28	27	34	38		1
	Min.	33	31	30	19	19	15	14	15	16	20	23		
Shackleton Shelf Ice	Max.	33	28		2	−2	−7	7	2	7	16	26	33	1
	Min.	12	9		−9	−14	−23	−11	−12	−4	2	7	14	
Snow Hill Island	Max.	34	30	18	15	8	7	4	9	12	23	22	33	1–2
	Min.	27	21	8	0	−9	−12	−14	−13	−4	7	13	23	
Water Boat Point*	Max.	50	49	42	47	38	38	33	39	35	36	42	48	1
	Min.	27	25	20	20	4	14	−12	−16	2	14	13	27	

* **Absolute Maximum and Minimum Temperatures.**

TABLE VIII

Number of Days With Rain (Except as Noted)

Station	January	February	March	April	May	June	July	August	September	October	November	December	Years of record
Belgica Drift	4	3			4			1		2			1
Laurie Island	16	12	20	20	20	19	22	21	19	18	19	15	8
Little America, 1934	2		1	0	0	1	1	0	0	0	0	0	1
Port Circoncision	13	19	25	20	27	18	25	24	23	25	18		1
Snow Hill Island#	23	13	11	13	11	7	9	7	11	13	24	13	1–2
Water Boat Point*	5	5	8	20	3	4	1	0	0	1	0	3	1

Sum of Days With Rain and Days With Snow.
* Percent of Observations of Rain, Sleet and Hail.

TABLE IX

Number of Days With Snow

Station	January	February	March	April	May	June	July	August	September	October	November	December	Years of record
Belgica Drift	19	22	13	22	30	24	14	23	19	25	25	18	1
Framheim	5			8	1	5	3	3	5	10	8	11	1
Shackleton Shelf Ice	11	12		9	8	11	22	16	24	18	12	4	1

INDEX

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