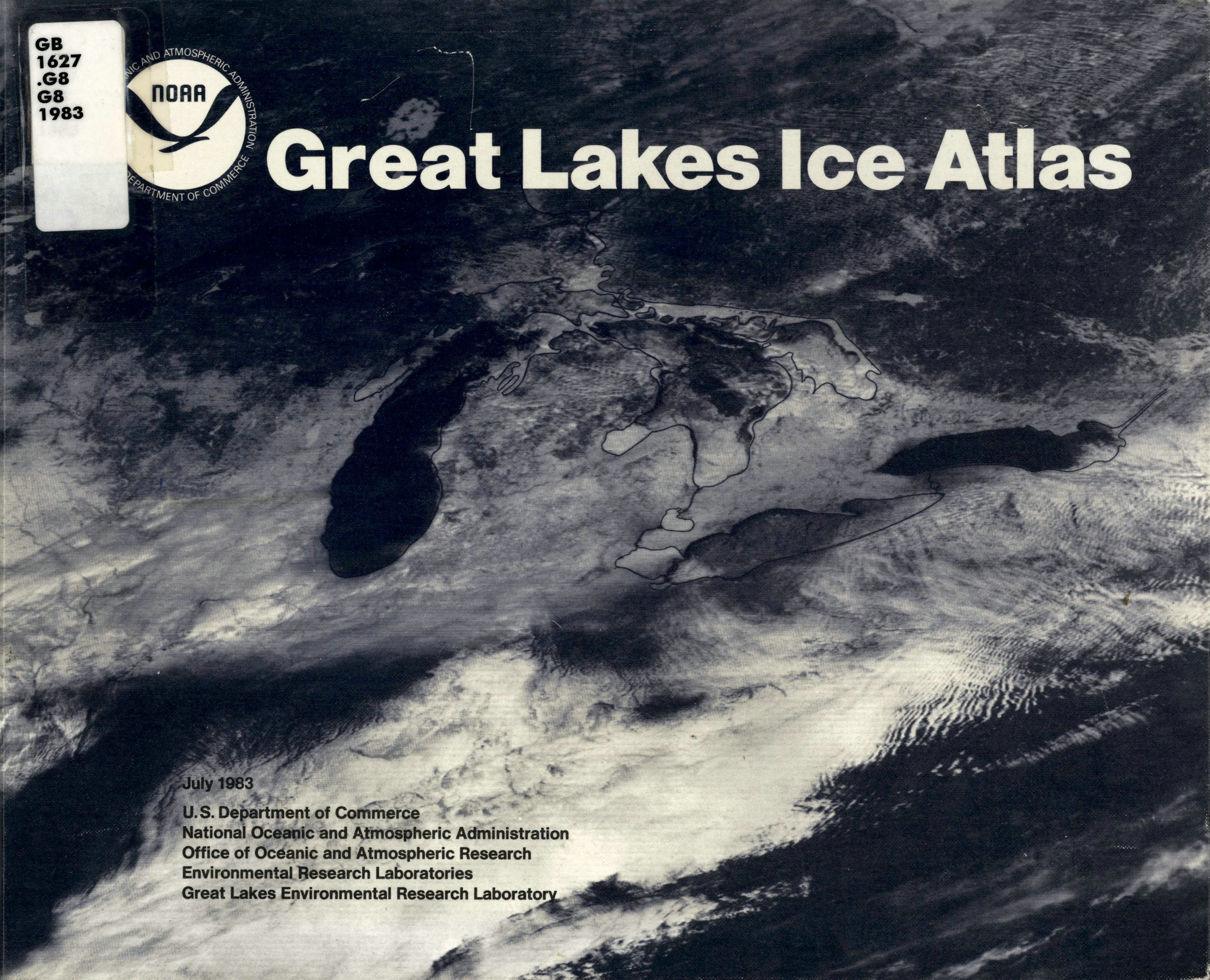
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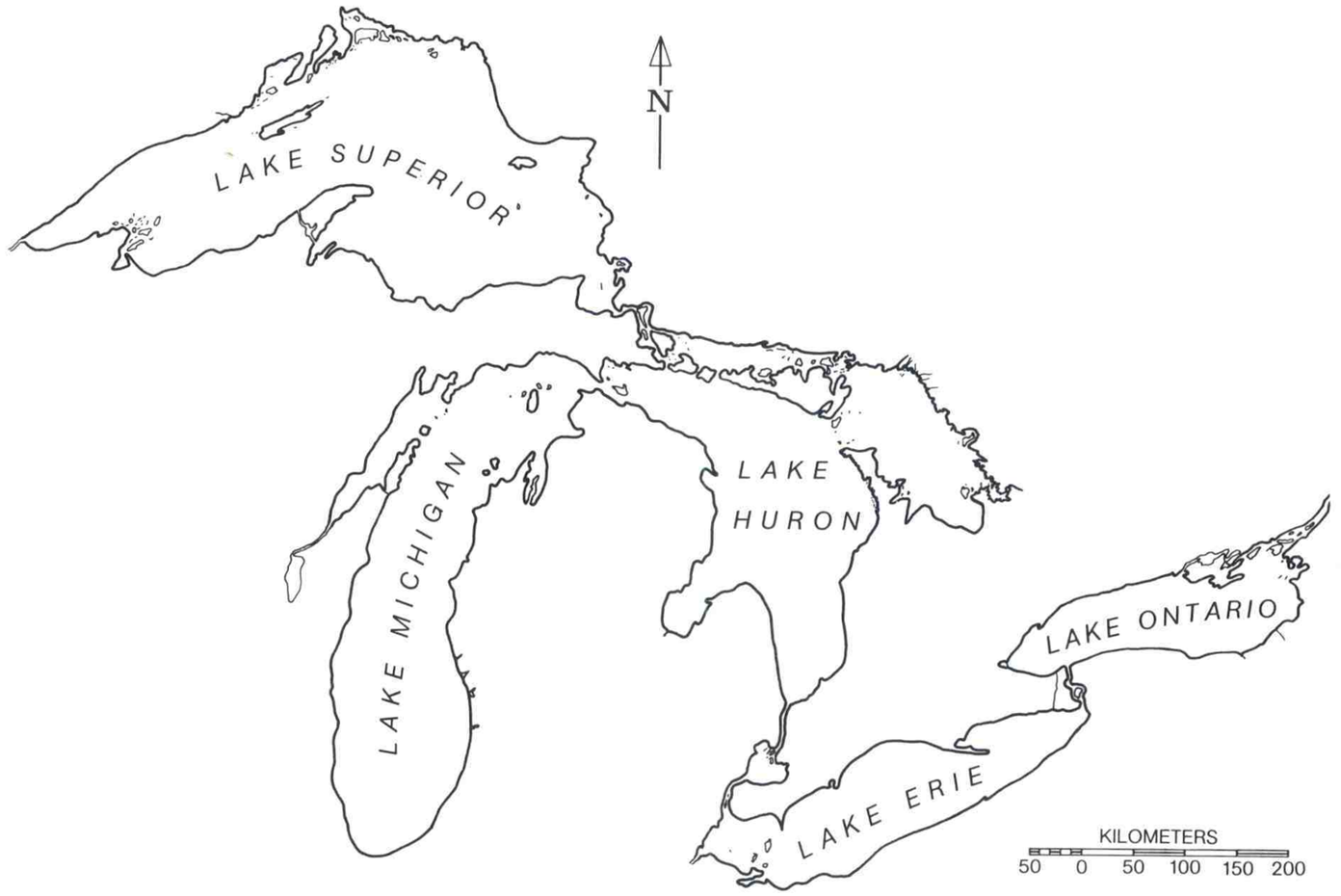
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Great Lakes Ice Atlas

R. A. ASSEL, F. H. QUINN, G. A. LESHKEVICH, and S. J. BOLSENGA



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** With the exception of plate 19, plates ending in letter "B" have normal ice cover and observation density.
*** Plate 19 contains monthly normal ice cover.

NOAA GREAT LAKES ICE ATLAS

by

R. A. Assel, F. H. Quinn, G. A. Leshkevich, and S. J. Bolsenga

GLERL Contribution No. 299

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ABSTRACT

Over 2,800 historic Great Lakes ice charts spanning 20 winters (1960-79) were digitized and converted to discrete 5-by-5-km grid cells. This data set was analyzed to produce a series of 46 plates, including 9 for each of the 5 Great Lakes with one extra plate for Lake Michigan. The plates portray charts of maximum, minimum, and normal ice concentration patterns and observation density for nine semimonthly periods beginning the last half of December and ending the last half of April. The percent of the surface area covered by ice was calculated for each ice chart and summarized in tabular format. In addition, a 10-year data set of ice thickness in the nearshore zone of the Great Lakes, i.e., primarily in bays and harbors, is presented to identify ice thickness ranges and ice statigraphic patterns for the Great Lakes Region. To complete this Atlas, air temperatures at 25 stations on the perimeter of the Great Lakes for an 80-winter period (1898-1977) were used to classify winter severity into five severity classes, based on freezing degree-days. Winter severity trends for the pre- and post-ice concentration climatology periods are identified on an annual and semimonthly time scale for individual stations and for lakewide averages.

1. INTRODUCTION

The Laurentian Great Lakes, shown in figure 1, are one of the major natural resources of North America. Within their drainage basin live one-eighth the population of the the United States and one-third the population of Canada. Economically, the area contributes approximately 20 percent of the United States' and 33 percent of Canada's gross national products. The area is, therefore, extremely sensitive, both socially and economically, to factors that impact upon the Great Lakes.

One of the major physical features of the lakes is the annual ice sheet that covers all or portions of each of the lakes during winter. The ice modifies the climate, producing the fruit growing zones, and affects winter temperature and precipitation patterns. It provides for varied recreational use, such as ice fishing and ice boating. The ice cover also has a major impact on the economy by impeding and eventually stopping commercial navigation, interfering with hydropower production and cooling water intakes, and damaging shore structures.

This Atlas was developed to update an earlier analysis (Rondy, 1969) of the formation, growth, and decay of the Great Lakes ice sheets for a broad spectrum of users. These include governmental users such as the National Weather Service and the U.S. Army Corps of Engineers; industrial users such as the Great Lakes shipping industry, the power utilities, and consulting engineers; marine resource decisionmakers; and the general public. The Winter Navigation Demonstration Program, authorized by Congress in 1970 and completed in 1979, gave major impetus to Great Lakes ice studies. Many of the data used in this Atlas were collected under the auspices of this program. The operational ice flights conducted by the Ice Branch of the Canadian Atmospheric Environment Service were the other main source of data.

The three major sections of this Atlas focus upon ice-cover concentration, ice thickness at nearshore locations along the lakes, and winter temperature severity. Ice charts portray the maximum, minimum, and normal ice concentrations on each lake for the period of record in half-month intervals. The thickness data provide corollary information on the range of ice thickness that can be expected around the perimeter of the lakes. Winter temperature severity values are given for 25 stations along the perimeter of the lakes to place the ice concentration values in the perspective of the air temperature regime during the data collection period and the temperature regime from 1898 to 1959, for which ice-cover data were not available.

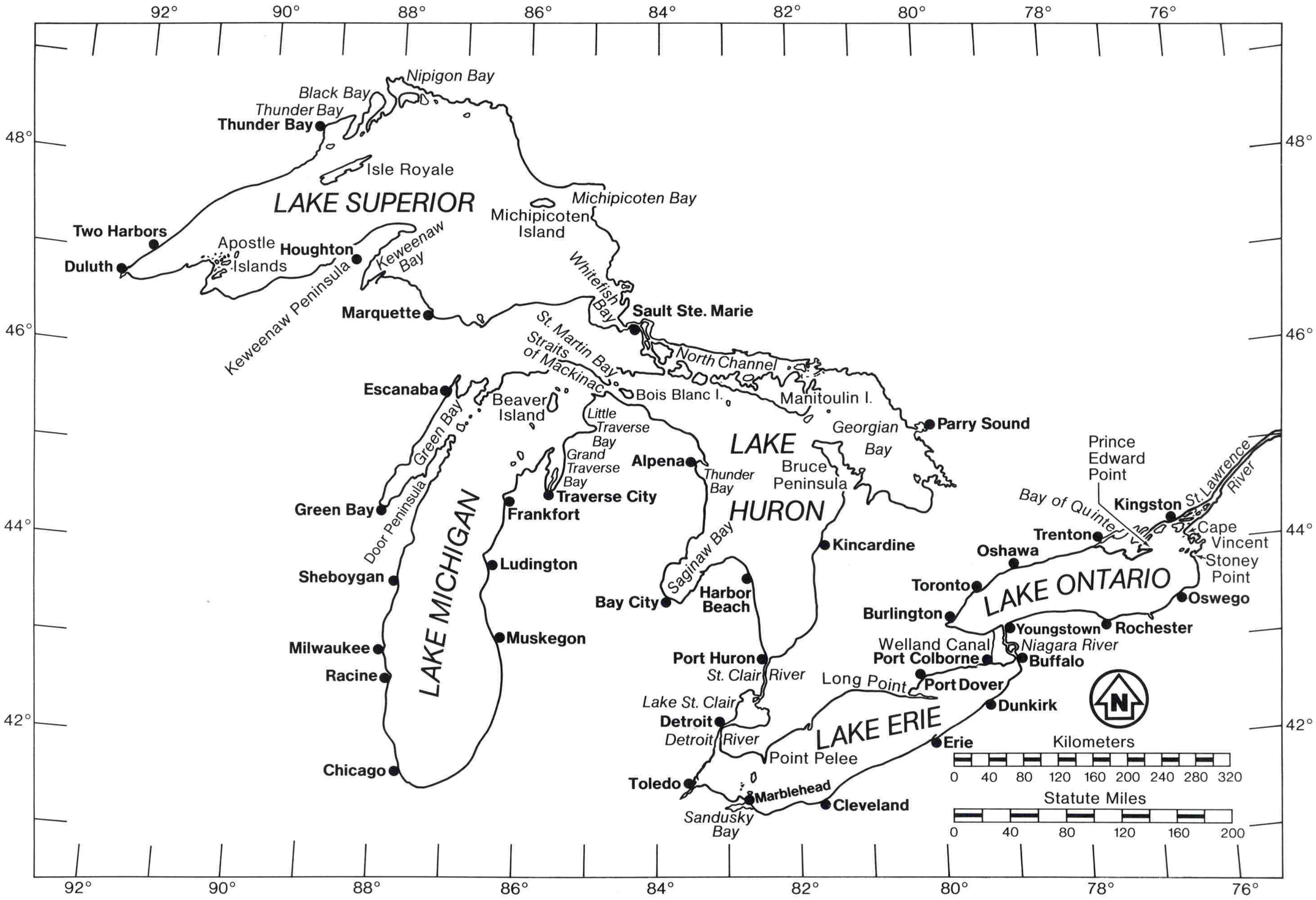


FIGURE 1. Place names on the Great Lakes.

2. ICE-COVER CONCENTRATION CLIMATOLOGY

2.1 Basic Data and Analysis Procedures

Ice charts depicting the distribution pattern of ice concentration and other ice-cover characteristics provided a 20-winter data set (1960-79) from which a digital ice concentration data base was abstracted. The ice charts in this data set were made largely from visual aerial ice reconnaissance overflights and, to a lesser extent, from side looking airborne radar (SLAR) overflights of the Great Lakes. In the case of the visual ice reconnaissance charts, trained ice observers recorded visually observed ice conditions on a base map in a systematic manner. Flight altitudes ranged from 2,000 to 10,000 ft. SLAR overflights were started in the 1970s and flight altitude was usually 10,000 ft. The SLAR signal was used to produce gray-tone images that correspond to the amount of backscattered radiation from the ice. Ice charts were produced by overlaying a base map on the SLAR image and making visual interpretations of ice concentration and other ice characteristics from the SLAR image.

Over 2,800 of these historic ice charts have been used in this study. Sources for these data include Environment Canada, Atmospheric Environment Service; the U.S. Coast Guard; the National Aeronautics and Space Administration; the Great Lakes Environmental Research Laboratory and its predecessor, the Lake Survey Center, National Ocean Survey; and Lake Survey District, U.S. Army Corps of Engineers.

Ice concentration, i.e., the percent of a unit surface area covered by ice, was abstracted from the original ice charts and recorded in 10-percent increments from open water to 100-percent ice cover. An electronic digitizer coupled to a computer was used to abstract, code, record, and transpose the ice concentration information from the original ice charts to discrete 5-by-5-km grid cells in rectangular cartesian coordinates. The data set for each lake was partitioned into half-month intervals. This interval was selected because it was the smallest averaging period for which there were sufficient data for analysis. The number of ice charts, number of grid cells, and the relative amount of data available for analysis of each lake for each half-month period are given in table 1. The time series of ice concentration data for each grid cell were analyzed for maximum and minimum values of ice concentration. Subperiod ice concentrations were then averaged during years with multiple observations. The average, median, and mode ice concentrations and the number of years of observations were then calculated for the time series at each grid cell. Ice charts depicting ice-cover distribution patterns for average, median, and mode ice concentration over the nine semimonthly periods were produced to evaluate which of these three statistics should be used to define the normal ice cover. It was subjectively determined that the median ice concentration patterns provided the most coherent pattern of the progression of ice-cover formation and decay over the winter season. Therefore, the normal ice cover portrayed in this Atlas is defined by the median ice concentration, which is an estimate of the 50-percent point of the ice concentration probability distribution for each grid cell for a given half-month period.

TABLE 1.—Ice-cover data base

Part I. Number of ice charts and total number of ice concentration observations used in the ice-cover climatological analysis.

Lake	Number of ice charts	Number of grid cells	Total data
Superior	618	3,195	1,974,510
Michigan	489	2,224	1,087,536
Huron	845	2,308	1,950,260
St. Clair-Erie	565	1,041	588,165
Ontario	307	739	226,873
TOTAL	2,824	9,507	5,827,344

Part II. Average percent of lake observed each period for years with data.

Period	Superior	Michigan	Huron	St. Clair	Erie	Ontario
Dec. 16-31	47	11	52	86	56	39
Jan. 1-15	34	23	52	88	69	35
Jan. 16-31	54	31	60	93	78	56
Feb. 1-14	56	35	64	90	77	59
Feb. 15-28	58	29	68	92	78	56
Mar. 1-15	75	45	81	94	85	59
Mar. 16-31	74	36	77	87	86	53
Apr. 1-15	73	31	75	93	79	61
Apr. 16-30	62	18	64	90	49	28

Part III. Percent of years with data.

Period	Superior	Michigan*	Huron	St. Clair	Erie	Ontario
Dec. 16-31	65	58	60	45	55	50
Jan. 1-15	85	63	85	75	70	75
Jan. 16-31	95	74	95	90	95	95
Feb. 1-14	90	90	95	90	90	85
Feb. 15-28	85	79	85	85	85	85
Mar. 1-15	100	100	100	95	95	85
Mar. 16-31	100	95	100	95	90	90
Apr. 1-15	95	79	95	60	85	85
Apr. 16-30	60	37	60	15	45	45

*100 percent is equal to 19 years of data for Lake Michigan and 20 years for all other lakes.

2.2 Ice Charts

A series of nine plates for each of the five Great Lakes (with one extra plate showing monthly normals for Lake Michigan), portrays ice charts of maximum, minimum, and normal ice concentration and the observational density from the last half of December through the last half of April (plates 1-46). Lake St. Clair data are shown on Lake Erie plates. The ice concentrations have been grouped into the five standard classes (Rondy, 1969) of

1. Open water—A large area of freely navigable water in which lake ice could be present in concentrations of less than one-tenth.
2. Very open pack—Pack ice in which the concentration is one- to three-tenths and water preponderates over ice.
3. Open pack—Pack ice in which the concentration is four- to six-tenths, with many leads and polynyas and the floes are generally not in contact with one another.
4. Close pack—Pack ice in which the ice concentration is seven- to nine-tenths, composed of floes mostly in contact.
5. Consolidated pack—Pack ice in which the concentration is ten-tenths and the floes are frozen together.

The observation density has been grouped into the following classes:

1. First quartile—Zero to five years of data.
2. Second quartile—Six to ten years of data.
3. Third quartile—Eleven to fifteen years of data.
4. Fourth quartile—Sixteen to twenty years of data.

The maximum and minimum ice charts define the variability and limits of the Great Lakes ice cover during each half-month period for the 20-year period (1960-79). Normal ice concentration distribution patterns from one half-month period to the next define the usual progression of ice cover during the winter. In a few instances in small areas, this progression showed discontinuities, which were usually subjectively edited.

The percent of the lake's surface covered by ice is commonly used to characterize the extent of ice on the Great Lakes. Table 2 presents the percentage of ice-covered lake surface for each of the nine half-month periods for the maximum, minimum, and normal ice charts.

2.3 Ice Characteristics by Lake

Because ice-cover characteristics are related to the physical characteristics of the Great Lakes, the variability over the period of record and normal seasonal progression of ice cover over the nine half-month periods are discussed within the context of the physical dimensions and location of each Great Lake. In particular, each lake's surface area, water volume, mean depth, length, breadth, and bathymetry are summarized in the following discussion of ice-cover characteristics.

TABLE 2.—The percent of ice cover on each Great Lake and Lake St. Clair for semimonthly periods for maximum, minimum, and normal ice-cover concentration

Period	Superior	Michigan	Huron	St. Clair	Erie	Ontario
Dec. 16-31						
Maximum	17	*	46	96	64	17
Minimum	0	*	1	1	0	0
Normal	2	*	7	60	9	2
Jan. 1-15						
Maximum	63	37	75	99	100	28
Minimum	1	3	6	2	0	1
Normal	8	18	25	88	36	8
Jan. 16-31						
Maximum	89	66	95	100	100	52
Minimum	1	2	8	6	0	0
Normal	12	18	30	93	65	7
Feb. 1-14						
Maximum	95	77	99	100	100	84
Minimum	2	7	13	3	1	5
Normal	38	24	56	93	90	19
Feb. 15-28						
Maximum	100	88	99	100	100	91
Minimum	7	11	13	3	2	5
Normal	75	45	68	91	90	24
Mar. 1-15						
Maximum	100	82	98	100	99	51
Minimum	3	4	9	0	0	2
Normal	67	25	53	74	64	10
Mar. 16-31						
Maximum	98	57	97	97	94	28
Minimum	2	0	7	0	0	0
Normal	51	16	41	11	26	6
Apr. 1-15						
Maximum	95	31	90	79	84	18
Minimum	1	0	1	0	0	0
Normal	10	6	22	0	10	2
Apr. 16-30						
Maximum	78	*	44	23	17	0
Minimum	4	*	1	0	0	0
Normal	8	*	9	0	3	0

*Insufficient data to calculate percent of lake surface ice covered.

2.3.1 Lake Superior

Lake Superior is the largest, the northernmost, and the westernmost of the Great Lakes. This lake spans 7° of longitude, 85°W to 92°W, and 2.5° of latitude, 46.5°N to 49°N. Its length (563 km) and breadth (257 km) make its wind fetch the largest of any on the Great Lakes. Its volume (12,230 km^3) is second only to that of Lake Baikal in the Soviet Union. This large water volume, combined with a large surface area (82,100 km^2), results in a mean lake depth of 149 m. Lake Superior's bathymetry is shown in figure 2. The deepest sounding (405 m) is located in the southeastern part of the lake. The Keweenaw Peninsula, along the southern shore, protrudes many kilometers into the lake. This peninsula and a prominent subsurface north-south ridge approximately 150-180 m deep effectively divide the lake into eastern and western lake basins. Although the bottom of the eastern basin is characterized by a system of north-south trending valleys and ridges, the bathymetry of the western basin is relatively smooth. Water depths drop off much more gradually along the southern shore than along the northern and eastern shores. Prominent features in the western lake basin include the Apostle Islands and the associated shoal area in the western end of the lake, the deep trough along the northwestern shore and Isle Royal, and the three large bays along the north-central shore. Whitefish Bay at the eastern end of the lake, Keweenaw Bay at the base of the Keweenaw Peninsula, and Michipicoten Island and Michipicoten Bay along the eastern shore are prominent features in the eastern lake basin.

The large differences in Lake Superior ice cover portrayed in maximum and minimum ice charts are indicators of the interannual variability of the ice-cover concentration over the 20-year period (1960-79). Ice concentrations vary from open water to 90 to 100-percent ice cover over the lake for most of the nine half-month periods. However, the maximum ice charts for the last half of December and both halves of January show a persistent area of open water in early winter. This area of open water extends over virtually the entire lake in December, the eastern half of the lake during January 1-15, and smaller areas in the eastern lake basin during January 16-31. The maximum ice chart for the last half of April also shows a persistent area of open water in the northeastern quadrant of Lake Superior during the ice breakup period. The minimum ice charts show that there are also persistent areas of ice cover. These areas are located in the shore zone of Lake Superior and include Thunder, Black, and Nipigon Bays along the north shore; the Apostle Islands and portions of the southern shore from Duluth, Minn., to the Keweenaw Peninsula; Keweenaw Bay; portions of the southern shore to, and including, Whitefish Bay; and Michipicoten Bay along the northeastern shore. There is no doubt of the climatological persistence of ice cover in these areas. It is clear, however (from the minimum ice charts), that ice-cover duration in shore areas of the Apostle Islands and Thunder, Black, and Nipigon Bays is greater than in other shore locations, such as Whitefish and Keweenaw Bays.

Ice cover, as shown on normal ice charts, is usually confined to bays and harbors and the perimeter of Lake Superior through the end of January. Ice cover in these shore areas increases in concentration, but there is little lakeward advance of the ice boundary until February. These areas include the western tip of the lake; the Apostle Islands; the three large bays along the northern shore (Thunder, Black, and Nipigon Bays); and Whitefish, Keweenaw and Michipicoten Bays. During the first half of February, ice forms in the western basin of the lake. In the eastern basin, during this time period, ice extends some 20-40 km away from shore in an arc from the Keweenaw Peninsula to Michipicoten Island. Normally, the mid-lake area of the eastern lake basin first develops an extensive ice cover during February 15-28. Ice formation continues through the end of March, although ice cover also begins to be lost during the month of March. The ice cover is reduced from 75 percent during the second half of February to 51 percent during the second half of March. Much of the loss in ice extent during this time and earlier in the winter can be attributed to wind action, which induces vertical mixing of warmer waters to the surface and results in ice melt. The wind also transports the ice to windward lake shores. The interaction of these two wind effects decreases ice concentrations along lee open-lake areas and deeper areas of the lake, including portions of the northwestern shore and eastern lake basin, and increases ice concentration and rafted ice along the windward southern lake shores. The ice cover in mid-lake areas is dissipated during and prior to the first half of April. The lake is only 10-percent ice covered during April 1-15. During the last half of April, the remaining ice is once more confined primarily to bays, harbors, and the southern shore of the lake.

Ice charts for January 1-15 and April 16-30 were edited to reflect a logical progression of ice cover in the western lake basin where incoherent ice patterns were indicated in the original analysis because of the low number of observations.

2.3.2 Lake Michigan

Lake Michigan is second to Lake Superior in water volume—4,920 km^3. It is the third largest of the Great Lakes in terms of both surface area (57,750 km^2) and mean depth (85 m). The length axis of the lake is 494 km and spans 4° of latitude, 42°N to 46°N. Its breadth is 190 km and spans 3° of longitude, 85°W to 88°W. Lake Michigan has four major bathymetric regions (seen in figure 3): a southern basin, a central basin, a northeastern basin, and Green Bay. The southern basin extends from the southern end of the lake to a sill running across the lake approximately from Sheboygan, Wis., to Ludington, Mich. The deepest area of the southern basin is located in the mid-lake area east of Racine, Wis., and is from 150 to 200 m deep. Bottom topography is relatively smooth and water depths gradually decrease going shoreward from mid-lake areas. The limits of the second basin are more difficult to define. It starts north of the sill area noted above and gradually blends into the northeastern basin, which for practical purposes starts with the islands along the northeastern shore. Bathymetry in the central basin is more irregular than that in the southern basin, and water depth ranges from 250 to 280 m in the deepest area of the central basin, the mid-lake area off of Frankfort, Mich. Bathymetry in the northeastern basin is characterized by many north-south trending ridges and troughs. Other prominent features in this basin include two shoal areas, one from Beaver Island to the Straits of Mackinac and a second along the northern shoreline, and two large embayments, Grand

LAKE DEPTH LEGEND

- LESS THAN 20 METERS
- 20–39 METERS
- 40–59 METERS
- 60–99 METERS
- 100–200 METERS
- GREATER THAN 200 METERS

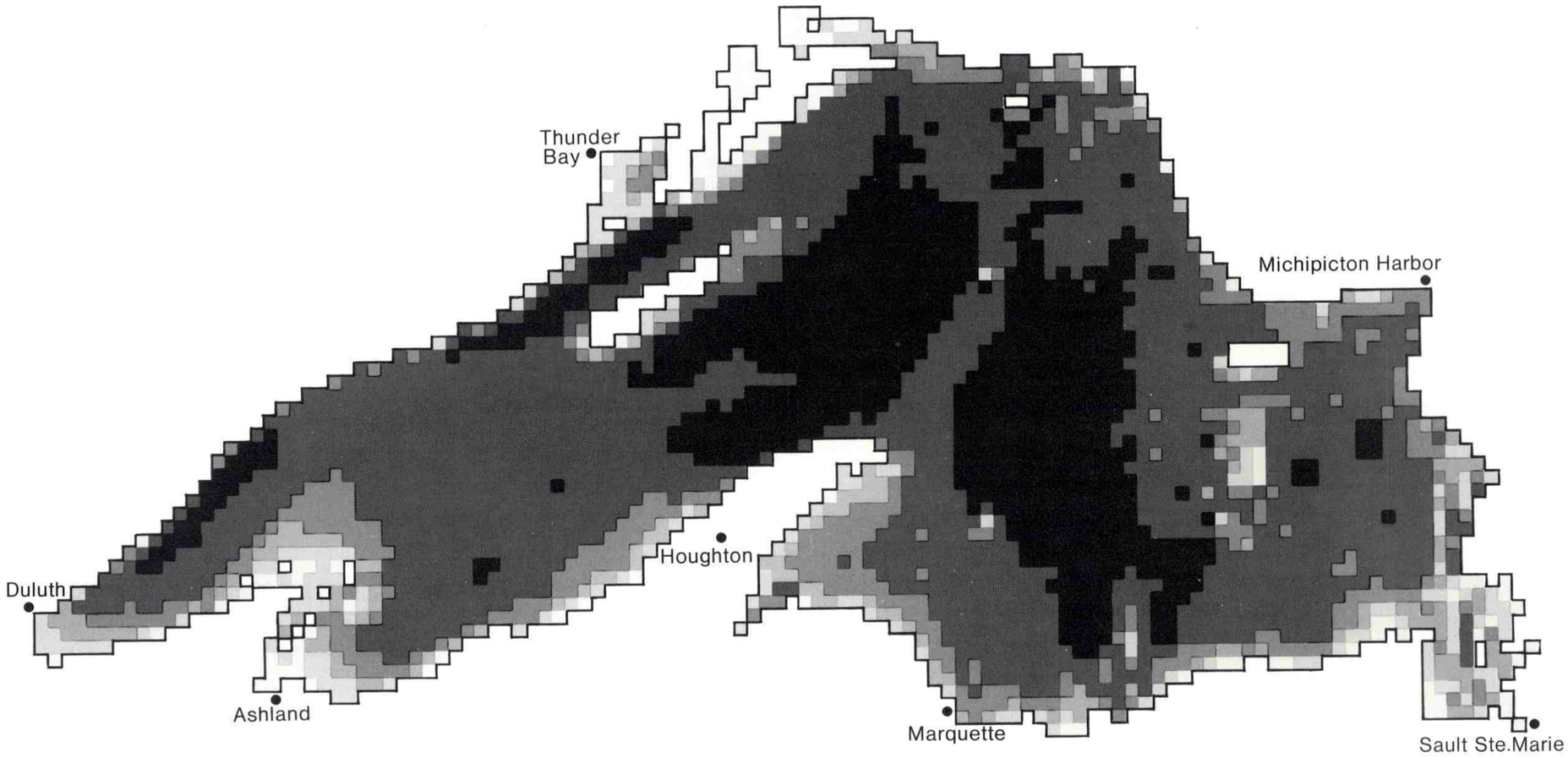


FIGURE 2. Lake Superior bathymetry

LAKE DEPTH LEGEND

- LESS THAN 20 METERS
- 20–39 METERS
- 40–59 METERS
- 60–99 METERS
- 100–200 METERS
- GREATER THAN 200 METERS

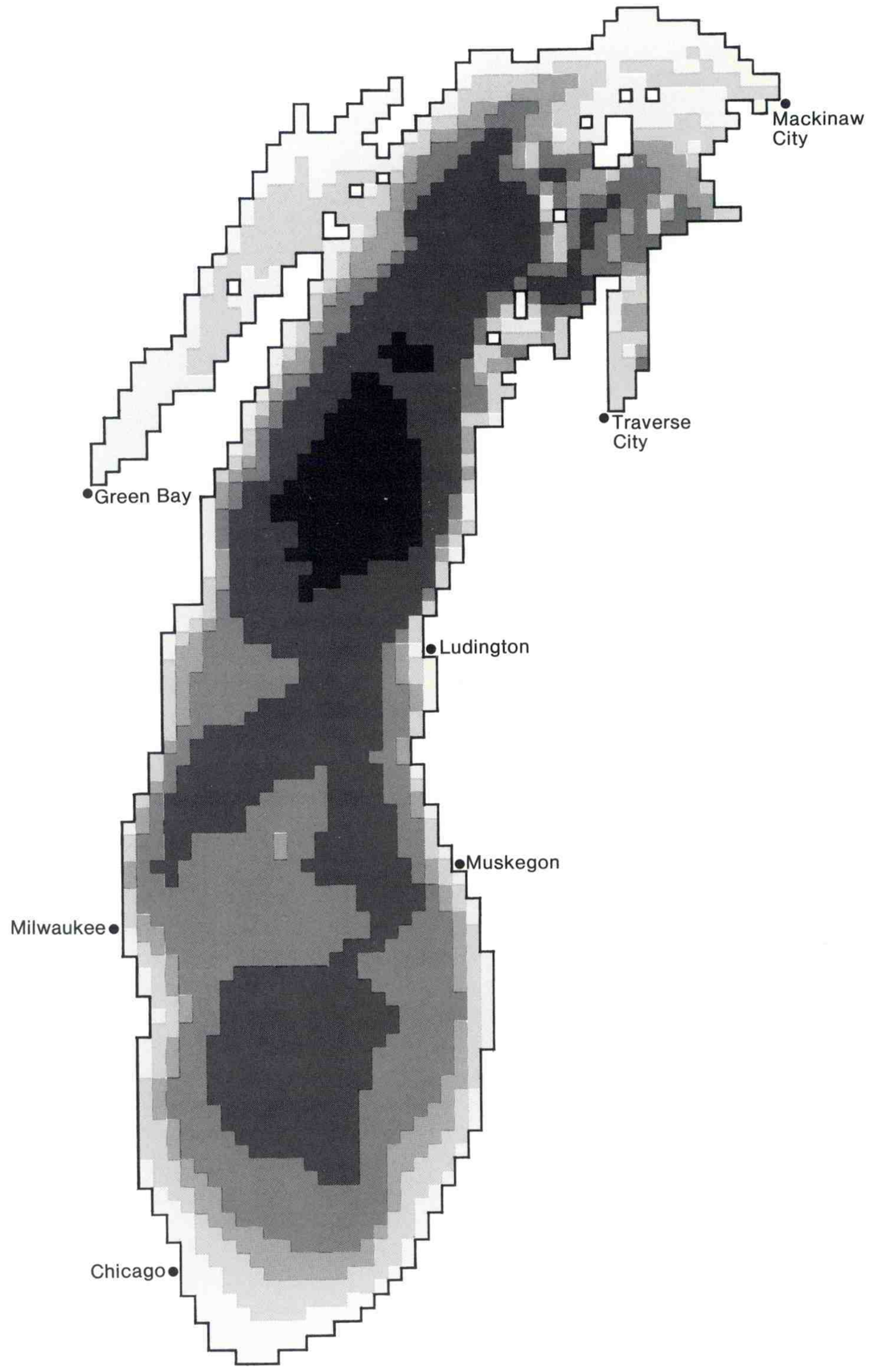


FIGURE 3. Lake Michigan bathymetry

Traverse and Little Traverse Bays. Deepest waters in this northeastern basin are less than 150 m. Green Bay, with maximum depths of less than 50 m, is the shallowest of the four bathymetric regions of Lake Michigan. It is separated from the main lake by the Door Peninsula and by islands north of this peninsula.

Because of the low observation density in Lake Michigan, particularly in the southern part of the lake, ice distribution patterns are discontinuous at times. Discontinuities were not removed from the minimum and maximum ice charts, but small areas of several of the normal ice charts were edited to portray a more coherent picture of the seasonal ice distribution pattern. In addition, monthly normal ice charts were produced for comparison.

The maximum and minimum ice charts indicate that ice concentrations varied over the period of record from open water to 70 to 100-percent ice cover over most grid cells for a majority of the nine half-month periods. Exceptions to this pattern occur in the deeper mid-lake areas, in bays, and in the Straits of Mackinac.

Persistent open water occupies virtually the entire lake excluding the lake perimeter and Green Bay during December 16-31. The open water area is gradually reduced in January and the first half of February as it retreats toward the middle of the lake and southward. It is at a minimum during February 15-28 and March 1-15, occupying only portions of the southern lake basin. From March 16-31 to April 16-30, the open water area expands northward and toward the shores until it occupies almost the entire lake south and west of the southern end of Beaver Island.

Green Bay, Grand Traverse Bay, Little Traverse Bay, and the Straits of Mackinac develop persistent ice covers. The ice cover in the southern and northern ends of Green Bay lasts longest (from December 16-31 to April 16-30), followed in duration by ice cover in the Straits of Mackinac (February 1-28) and, of shortest duration, Grand Traverse and Little Traverse Bay (February 15-28).

Ice cover normally forms first in the northern shallow areas of the lake, including Green Bay and the Straits of Mackinac to Beaver Island. The normal ice charts for January and the first half of February show that ice cover next forms in other shallow and restricted areas along the perimeter of the lake. Green Bay and the Straits of Mackinac normally form 100-percent ice cover during this time. The largest increase in ice extent takes place during the last half of February; the 45-percent ice cover developed by the end of that period is the maximum extent for the winter season. During that period and into March 1-15, ice formation in mid-lake areas is possible over the entire north-south extent of the lake. Below-freezing air temperatures gradually recede northward in March, ending the period of ice formation on the southern two-thirds of the lake during the first half of the month. The ice formation period ends during the last half of March for the northern third of the lake. Throughout the winter, ice in mid-lake areas is susceptible to winds, which tend to move the ice cover east across the lake because the prevailing winds are westerly. This can cause considerable shipping problems, particularly in spring, as ice becomes rafted and hummocked at harbor entrances and extends into the lake along the windward lake shore. The greatest decrease in ice cover occurs during March 1-15, as ice covers recede northward and shoreward from mid-lake areas. By April 1-15, the lake is normally only 6-percent ice covered and the bulk of the ice is located in Green Bay, the Straits of Mackinac to Beaver Island, and Grand Traverse and Little Traverse Bays. Extensive ice cover can endure in these areas through the end of April.

2.3.3 Lake Huron

Lake Huron has a water volume of 3,537 km^3, making it the third largest water mass of the Great Lakes. Its 59,500 km^2 of surface area is second only to Lake Superior. Its mean depth of 59 m places it behind Lakes Superior, Michigan, and Ontario in this respect. Lake Huron has a breadth of 294 km and a length of some 331 km. Its perimeter spans 3° of latitude, 43°N to 46°N, and 4° of longitude, 80°W to 84°W.

This lake is divided into three basins (figure 4): the eastern basin, composed of Georgian Bay and the North Channel; the central basin, including the lake proper north of a line from Alpena, Mich., to Kincardine, Ont.; and the southern basin, south of that line. Prominent features of the southern basin include Saginaw Bay, Thunder Bay, and bathymetry that is smooth and less than 50 m in depth near shore and, for the most part, less than 100 m in mid-lake areas. The central basin is the deepest and has the most complex bottom topography of the three basins. Water depths of 100-200 m are not uncommon, and the maximum sounding is 229 m. Other features of this basin include shallow areas in the Straits of Mackinac to Bois Blanc Island and along the perimeter of the lake and Manitoulin Island. The eastern basin, like the southern basin, is composed of water less than 100 m deep over most of its area and less than 50 m deep along the shore.

The maximum ice-cover chart for December 16-31 shows large areas of open water in the deeper areas of all three Lake Huron basins. During the first half of January, persistent open water areas have receded primarily to the mid-lake region of the central lake basin. And by the second half of January, with the exceptions of several small patches of open water in the central lake basin, there are no persistent areas of open water. A few patches of open water appear lakeward of Thunder Bay during the first half of April. By the second half of April, open water persists in most of the central lake basin, the northern end of Georgian Bay, and the northwestern section of the southern lake basin.

Areas of the lake that have persistent ice cover include Saginaw Bay, the eastern and northern shorelines of Georgian Bay, the North Channel, and portions of the Straits of Mackinac. Persistent ice cover in Saginaw Bay lasts 3 months, from the last half of December through the first half of March. There is shore ice on the North Channel by the first half of January and ice over the remainder of that area starting January 16-31. Persistent ice cover remains over virtually all of the North Channel through the second half of March and in some shore areas through the first half of April. Ice endures in the shore region of Georgian Bay from January 1-15 through March 16-31. In the Straits of Mackinac, i.e., St. Martin Bay to the north and the lake between Bois Blanc Island and the mainland to the south, persistent ice lasts only during the month of February.

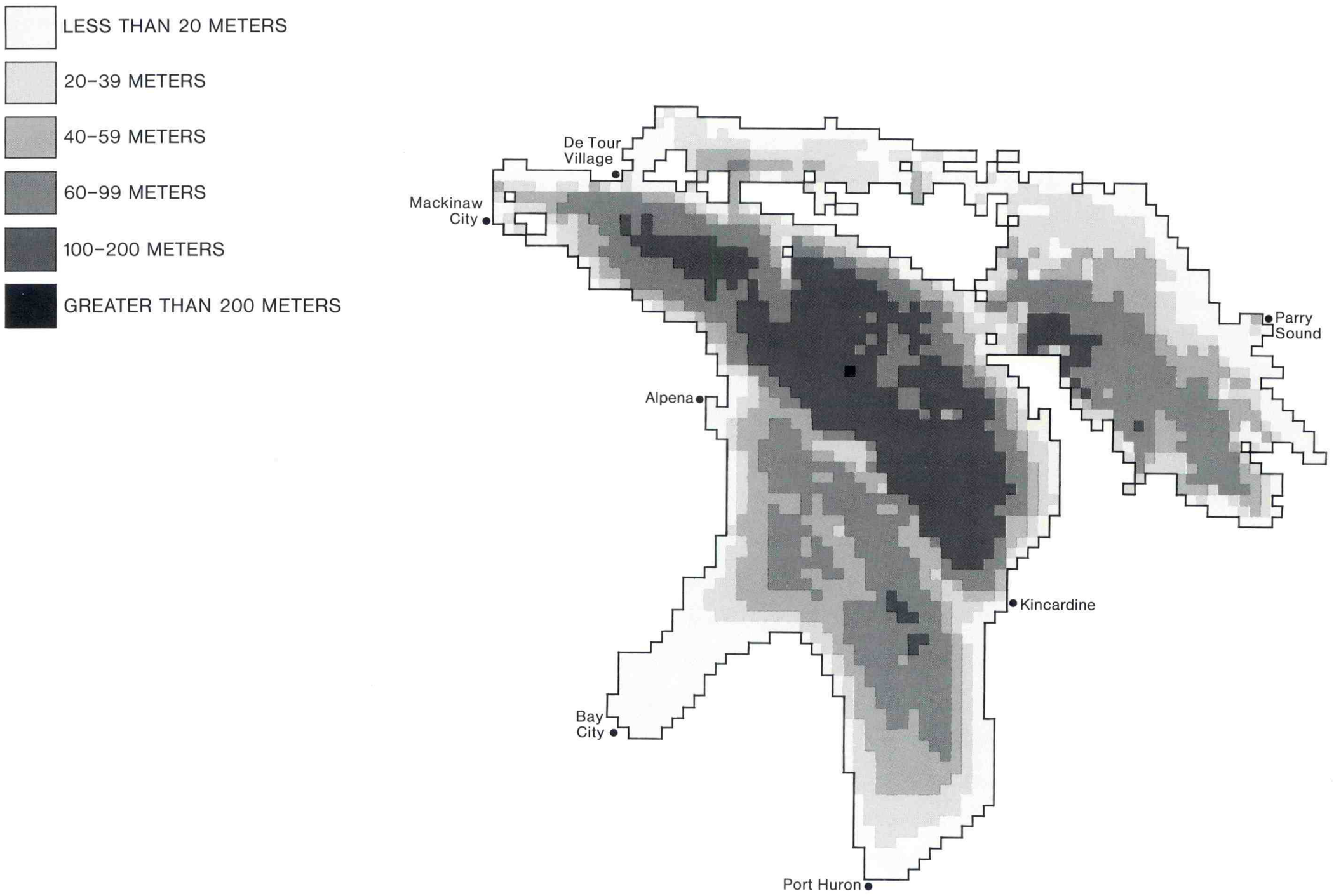


FIGURE 4. Lake Huron bathymetry

In areas of Lake Huron not mentioned above, ice concentration has been observed to vary over the 20-year period (1960-79) from open water to 70 to 100-percent ice covered for each half-month period.

The ice cover normally increases in extent on Lake Huron through the end of February, when it reaches its greatest areal coverage. The ice cover then recedes in March and April and usually covers only 9 percent of the lake's surface the second half of April. During December 16-31, there is ice cover in Saginaw Bay, Thunder Bay, the North Channel, Georgian Bay, St. Martin Bay, and the Straits of Mackinac. In the first half of January, Saginaw Bay becomes 100-percent ice covered and the North Channel, the Straits of Mackinac, and Thunder Bay 90 to 100-percent ice covered. Shore ice is present along the perimeter of the lake. Ice cover in bays along the perimeter of the lake continues to increase in concentration and extent during the second half of January, but the mid-lake area still remains ice free. The North Channel usually is 100-percent ice covered and remains frozen over from the second half of January through the first half of April. During the first half of February, the Straits of Mackinac form a 100-percent ice cover, and the greater part of Georgian Bay is 90-percent ice covered. During the second half of February, the lake is 68-percent ice covered, and the only extensive area of open water is located in the deeper part of the open lake, west of the Bruce Peninsula. The southern end of the lake to Harbor Beach, Mich., is primarily 90-percent ice covered at this time. During March and April, ice concentration decreases, and the area of open water in the deeper part of the lake expands to encompass virtually the entire lake, excluding protected embayments. Saginaw Bay normally loses its 100-percent ice cover during the last half of March, and the Straits of Mackinac usually lose their 100-percent ice cover during April 1-15. The bulk of the remaining ice cover in the first half of April is located in the North Channel, Georgian Bay, and along the windward shores of the southern end of the lake. Ice covers in these areas dissipate during the second half of April and early May.

2.3.4 Lake St. Clair

Although Lake St. Clair is not one of the five Great Lakes, it is usually included in discussions of the Great Lakes because it is an important part of the Great Lakes system.

Lake St. Clair has a volume of 4 km^3 and a surface area of 1,113 km^2, thus giving it a mean depth of 3.6 m. It has a length of 42 km and a breadth of 39 km. Several large islands are located at the northern end of the lake where the St. Clair River delta feeds into Lake St. Clair. With the exception of a navigation channel, the maximum depth of the lake is 6 m.

Lake St. Clair's ice concentration variation over the period of record is large, owing to its shallow depth. The minimum ice charts show that, along the eastern lake shore, persistent ice cover occurs only in January and February. Maximum ice charts show that persistent open water does not occur until after mid-April, when it covers most of the lake. Ice concentration varies from open water to 100-percent ice cover during most half-month periods.

Normal ice charts show that the lake usually has near-100-percent ice cover in January and February. Ice covers are reduced during March 1-15 and 90 to 100-percent ice concentration is located in the eastern half of the lake at this time. By the second half of March, the bulk of the remaining ice cover is located along the southeastern shore. The lake is usually ice free during the first half of April.

2.3.5 Lake Erie

Lake Erie, with a volume of 483 km^3 and a mean depth of only 19 m, has the smallest volume and is the shallowest of the five Great Lakes. With a surface area of 25,657 km^2, Lake Erie has a length of 388 km and a breadth of 92 km, and spans 4° of longitude, 79°W to 83°W, and approximately 1.5° of latitude, 41.5°N to 43°N.

This lake, as shown in figure 5, is divided into three basins. The western basin, extending from the western end of the lake to Point Pelee, is separated from the central basin by an escarpment that extends from Point Pelee to Marblehead, Ohio. This is the shallowest basin, with water depths of 18 m or less. Prominent features include the islands between Point Pelee and Marblehead, Ohio; the mouth of the Detroit River and Sandusky Bay. The central lake basin extends eastward from Point Pelee to Long Point, where a ridge extends lakeward from the base of Long Point across the lake to Erie, Pa. Bottom depths in the central basin range from under 10 m near shore to 24 m in mid-lake areas. The eastern basin extends from Long Point to the eastern end of the lake and is the deepest of the three basins. The deepest area is located in the mid-lake region between Erie, Pa., and Dunkirk, N.Y., where water depth typically ranges from 36 m to 55 m and the deepest sounding is 64 m. East of Dunkirk, N.Y., mid-lake water depths range from 18 m to 36 m. Prominent features in the eastern lake basin include the head of the Niagara River, which is the natural outlet of Lake Erie; the Welland Canal, used for shipping between Lakes Erie and Ontario; the New York State Barge Canal; and, since 1964, an ice boom structure placed at the head of the Niagara River to aid in controlling ice and its potential harmful effect on hydroelectric installations on that river.

The small mean depth of Lake Erie and associated small thermal reserve provides this Great Lake with the most rapid response to changing atmospheric conditions. Ice cover extends over 90 percent of Lake Erie's surface most winters, and the ice-cover variability over the period of record is the largest of any of the five Great Lakes. Only during the last half of December and during April are there any persistent areas of open water as shown on the maximum ice charts. In December these areas occupy the southern lake shore and eastern end of Lake Erie. In the last half of April, persistent open water occupies virtually the entire lake west of Long Point. Areas of ice cover occur only sporadically on minimum ice charts during January and February. Ice-cover concentration has been observed to vary from open water to 90 to 100-percent concentration over most of the nine half-month periods over most of the lake.

The normal ice charts show that ice cover usually develops in the western end of Lake Erie, west of Point Pelee, in the last half of December. During

the first half of January, the west end of the lake is over 90-percent ice covered, and extensive ice formation takes place in the central lake basin between Point Pelee and Long Point. The eastern basin is primarily ice free. Ice forms over the entire lake surface during the second half of January, and the mid-lake basin usually becomes 70 to 90-percent ice covered during this period. The eastern lake basin is usually 40 to 60-percent ice covered at this time. During February the entire lake normally develops a 90 to 100-percent ice cover. In late winter and in spring, under the influence of the prevailing winds, the ice cover usually first recedes from the western end of the lake and northern shores, and these open water areas gradually expand eastward and southward across the lake. During March 1-15 the western lake basin and the western half of the central basin usually have 40 to 60-percent ice concentration, and the rest of the lake is primarily covered by 70 to 90-percent ice concentration. In the last half of March, the open water areas include the entire western end of the lake as well as the western half of the central basin and the northern shore in the vicinity of Long Point. These open water areas advance farther eastward during April 1-15 to include most of the lake except the area east of Erie, Pa., and primarily along, and lakeward of, the southeastern shore. Ice cover along this southeastern shore area is further reduced in extent the second half of April, and most of the remaining ice is located east of Port Colborne, Ont. The wind can cause considerable rafting of ice cover in the eastern end of the lake, resulting in rafted ice that lasts past the end of April and well into May some years. This rafted ice can also cause considerable navigation problems in spring.

2.3.6 Lake Ontario

Lake Ontario is the second most southerly and the most easterly of the Great Lakes. Its long axis is approximately parallel to the prevailing winds. (This is also the case with Lakes Erie and Superior.) This lake has the second largest mean depth (86 m) and the smallest surface area (19,000 km^2) of the five Great Lakes. With a volume of 1,634 km^3, Lake Ontario is, in effect, a very large heat reservoir with a small opening for heat exchange with the atmosphere. Lake Ontario spans nearly 4° of longitude, 76°W to 80°W, and lies almost entirely between 43°N and 44°N latitude. It has a breadth of 85 km and a length of 311 km.

The bottom of Lake Ontario is divided into two basins by an indistinct sill that extends northward from Rochester, N.Y. (figure 6). There is a coherent pattern to the depth contours of both eastern and western basins, with depths dropping off rather abruptly along the southern shore and more gradually along the northern shore to the deeper regions of the lake. The western basin has a small area with depths in excess of 180 m, while the eastern basin has a much larger area with water depths also in excess of 180 m. Prominent features in the western basin include the mouth of the Niagara River and an associated large area of shallow water in the shore zone from the river mouth to the western end of the lake. The prominent feature in the eastern basin is the extensive area of islands, embayments, and shallow water located in the northeastern quadrant of the lake where the lake empties into the St. Lawrence River.

The maximum ice charts show that Lake Ontario has relatively large persistent open water areas every half-month period except February 1-14 and February 15-28. Areas of persistent open water cover the entire lake during December 16-31 and are gradually reduced in extent during January so that they occur lakeward from the northwestern shore and in the southeastern quadrant of the lake during the last half of January. During the first half of March, much of the lake west of Rochester, N.Y., has persistent open water. During March 16-31, the open water expands eastward to include most of the lake west of a line from Trenton, Ont., to Oswego, N.Y. The remaining lake area east of this line has persistent open water by the second half of April. However, because of the low observation density during April 16-31, the open water shown for the bay and harbor areas in the northeastern section of the lake is questionable.

In sharp contrast to the prevalence of persistent open water, the areas of persistent ice cover, as shown on minimum ice charts, are small and occur primarily during February. During January 1-15, all of February, and the first half of March, the main area of ice cover includes the Bay of Quinte and, during February, embayments and sections of the open lake east of a line from Stony Point to Cape Vincent, N.Y. Ice concentrations over the rest of the lake, excluding the areas of climatic persistence discussed above, for most half-month periods have a variability of open water to 70-percent or greater ice cover, over the period of record.

Normally, ice cover first forms in the Bay of Quinte and the embayments along the northeastern shore. By the last half of December, a good portion of the Bay of Quinte is already frozen over. By the last half of January, the protected shore areas in an arc from Prince Edward Point to Stony Point are 90 to 100-percent ice covered, and ice of lower concentrations extends lakeward from these areas. Shore ice also forms from Burlington, Ont., to the mouth of the Niagara River at Youngstown, N.Y., and other shallow areas around the perimeter of the lake. By the first half of February, the lake is almost 20-percent ice covered, and shore ice now lines the perimeter of the lake except for one reach from Burlington, Ont., northward to the vicinity of Oshawa, Ont. By the second half of February, ice cover is near its maximum extent; at that time it covers about 24 percent of the lake's surface. The ice has not advanced significantly lakeward from its February 1-14 position, but has consolidated in these areas. The first half of March brings a reduction in the ice cover, and only 10 percent of the lake is now ice covered, with most of the ice located along the eastern shoreline and in the northeastern section of the lake north of a line from Prince Edward Point to Stony Point. During the second half of the month, ice covers recede shoreward from these areas, although the embayments remain frozen over. By the first half of April, the embayments are no longer 100-percent ice covered, and the lake is now only 2-percent ice covered. The lake is ice free by the second half of April, although some shore ice might still remain.

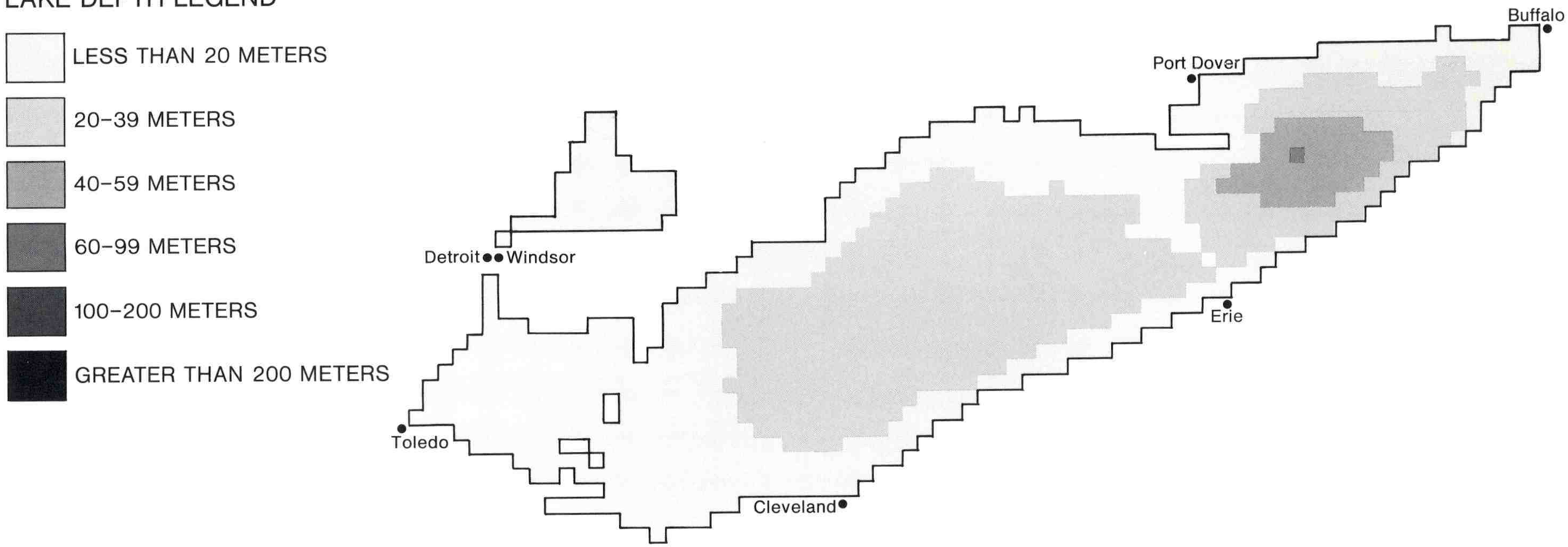


FIGURE 5. Lake Erie and Lake St. Clair bathymetry

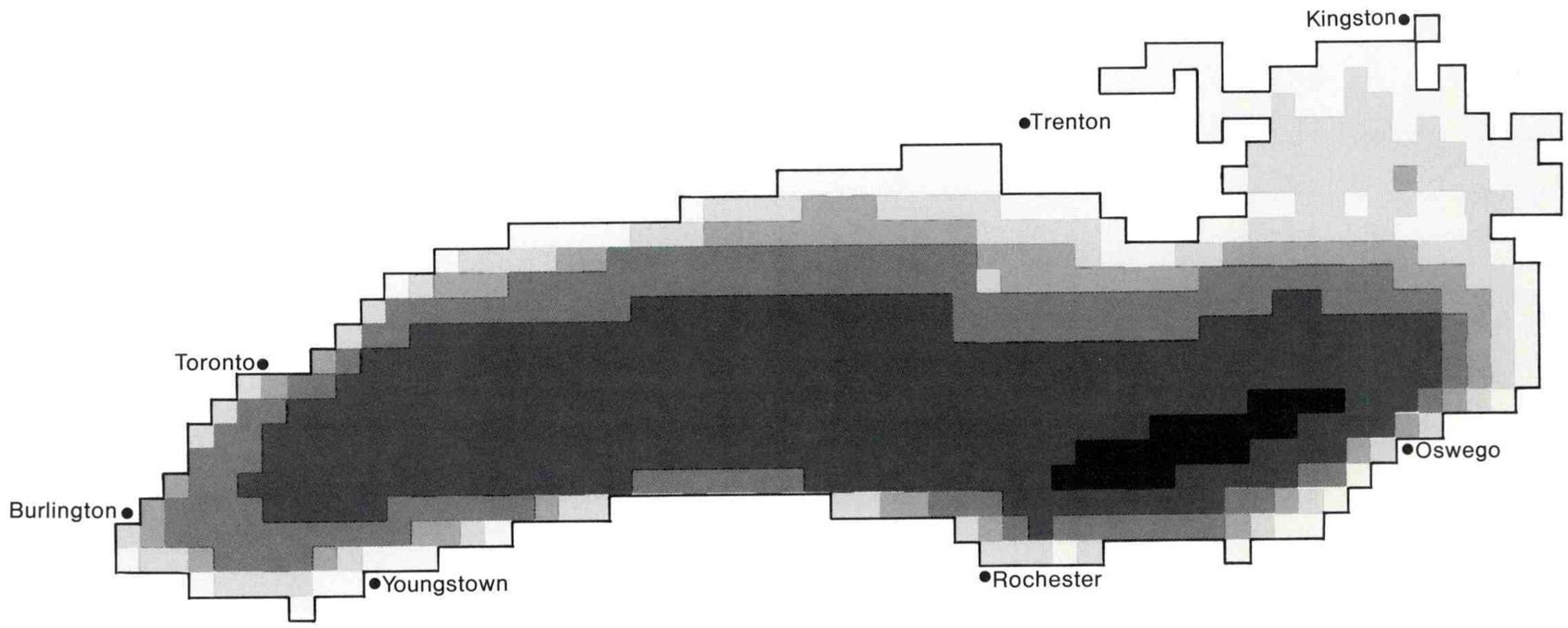


FIGURE 6. Lake Ontario bathymetry

3. ICE THICKNESS AT NEARSHORE LOCATIONS

Synoptic information on ice thickness in the Great Lakes is exceedingly sparse. Boring the ice by hand and measuring the thickness of ice at individual locations is the only viable technique currently available for such studies. Since an observer must traverse the ice surface for such measurements, observations are usually limited to nearshore areas for both safety and practicality. For these reasons, this Atlas does not contain a regional description of ice thickness in mid-lake areas of the Great Lakes. However, as an aid to winter navigation on the Great Lakes in the 1970's, the United States Coast Guard and Canadian Coast Guard (1978) annually published a *Guide to Great Lakes Ice Navigation,* which does contain an operational description of mid-lake ice conditions and ice thicknesses for the Great Lakes.

For this description, data from a nearshore ice thickness measurement network were collected during the period 1967-68 through 1976-77. Observers at over 30 locations selected an offshore site, that was characterized by a normally stable ice cover. Weekly measurements were then made by boring a hole through the ice and measuring ice thicknesses with a specially designed ruler. Measurements of the amount of clear ice and white ice were made by noting the ice interface locations at the ruler (visual sighting through the borehole). A complete description of the methodology and the data are given by Sleator (1978).

A location map of stations selected for this analysis on the basis of period of record, reliability of the observations, geographic location, and completeness of each winter's record is given in figure 7. In figures 8-11, two traces are shown for each station. The envelope curve indicates the mean ice thickness for all ice types for the period of record. The inner curve indicates mean thicknesses of clear ice only. Differences between the two curves indicate the amount of "white" ice. White ice is here defined as ice commonly referred to as snow-ice, refrozen slush, slush curd, pancake, brash, and ball ice.

North to south variations in ice thicknesses are illustrated by the curves for De Tour, Mich.; Mackinaw City, Mich.; Alpena, Mich.; Saginaw Bay; Lake St. Clair; Brest Bay; and Marblehead, Ohio, (figure 8). The progression is not consistent owing to localized factors, but amounts of both total and white ice decrease from north to south. Local variability in ice thickness is generally apparent as indicated by data from the two Saginaw Bay locations.

A west to east comparison shows little change in total ice thickness between Muskegon Lake, Lake St. Clair, Marine Lake, and North Pond (figure 9). Similarities between white ice amounts at locations with similar exposure to prevailing winds are evident (i.e., Muskegon Lake and North Pond, Lake St. Clair and Marine Lake). This is perhaps because of the differences between windward and leeward accumulations of blowing snow or drifting ice. Another west-east comparison, among stations at nearly the same latitude, is possible by comparing data from Duluth, Minn.; Ashland, Wis.; Munising, Mich.; Tahquamenon Bay; and Point Iroquois (figure 10). Total ice thickness generally decreases from west to east, but white ice thickness generally increases. The higher total ice thicknesses at Duluth, Minn., and Ashland, Wis., are possibly a result of cold air temperatures produced by prevailing winds passing over the relatively cool land masses to the north and west. Higher white ice amounts at the eastern end of the lake are possibly due to greater snowfall amounts at those locations caused by increased moisture content of air masses as they pass from west to east over the often ice-free central portions of the lake. Local variability is again shown by a comparison of data from Tahquamenon Bay and Point Iroquois.

The importance of localized meteorological conditions in nearshore ice formation is illustrated by a comparison of the average ice thickness at two stations separated by less than 32 km. Portage Lake is a large inland lake, and L'Anse Bay is a large bay of Lake Superior. The L'Anse Bay site is normally windswept and nearly snow free. Portage Lake is protected from similar high winds, allowing significant amounts of snow to accumulate. Average annual snowfall is approximately 300 cm for the L'Anse Bay site and approximately 430 cm for the Portage Lake site. It has been estimated that temperatures at the two sites would be similar, with slightly lower values possible at Portage Lake. Differences between white ice quantities at the two locations are dramatic (figure 11). For the period of record, white ice accounted for 60 percent of the total ice on Portage Lake and only 16 percent on Keweenaw Bay. The differences emphasize the degree of caution necessary in extrapolating known ice conditions at one location to another nearby location. Estimates are possible, but accuracy is largely determined by accurate estimates of attendant meteorological conditions.

The problem of extrapolating ice data from one station to another is further compounded by yearly variability in the ice cover at the station from which data are available. Total ice thickness curves for a station on Lake Ontario are shown in figure 12. The wide range in the dates of occurrence of first and last measurable ice is particularly evident and not unusual for stations in the network. Bilello (1977) shows similar variations in ice decay patterns for the Canadian Arctic and furnishes evidence that these conditions could be mathematically modeled with appropriate meteorological data.

Maximum ice thicknesses for the year of greatest ice growth and the year of least ice growth are shown in table 3. These data indicate no clear-cut dependence on geographical position. The average maximum thickness is 74 cm at maximum ice growth and 30 cm at minimum ice growth. Those values compare favorably with averages for a larger 32-station network (72 cm and 32 cm), indicating that the stations selected are reasonably representative of maximum ice thicknesses in the Great Lakes Basin.

FIGURE 7. Nearshore ice thickness station locations.

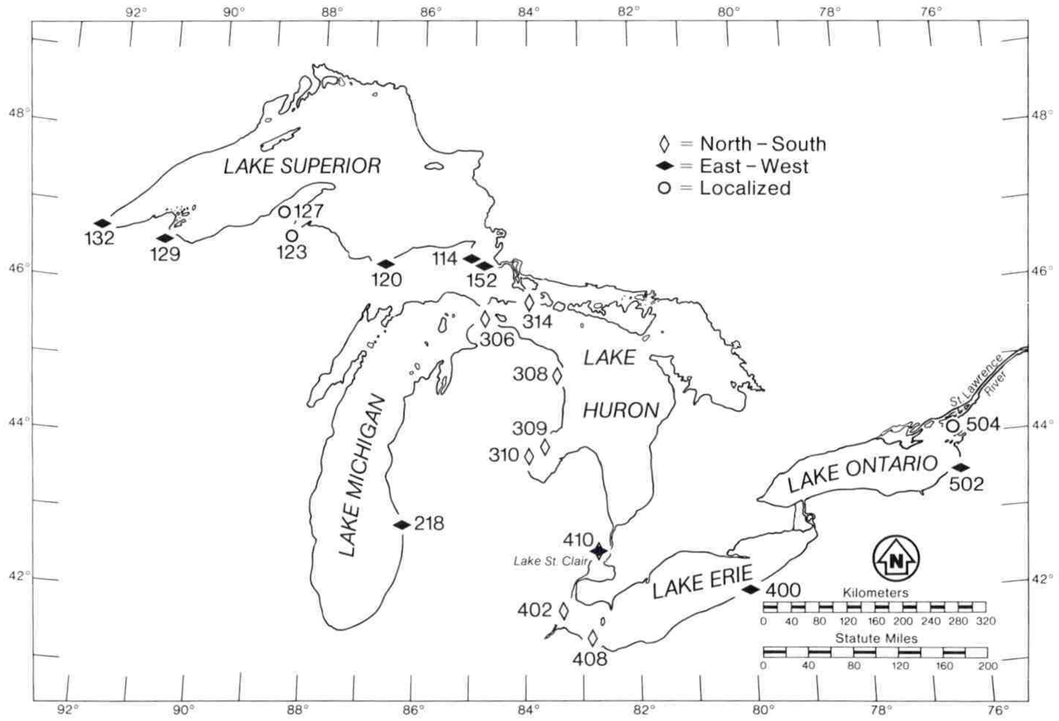


TABLE 3.—Maximum ice thicknesses for selected nearshore stations during the year of maximum ice accretion (high) and during the year of minimum ice accretion (low)

Station number	Station name	Maximum ice thickness (cm) Low	High
402	Brest Bay	15	61
129	Chequamegon Bay	53	99
314	De Tour	58	84
132	Duluth	56	84
410	Lake St. Clair	5	49
123	Lanse Bay	25	61
306	Mackinaw City	33	96
408	Marblehead	11	71
400	Marine Lake	13	61
218	Muskegon Lake	23	46
502	North Pond	35	67
152	Point Iroquois	28	73
309	Point Lookout	20	81
127	Portage Lake	44	63
120	South Bay	43	68
114	Tahquamenon Bay	25	76
308	Thunder Bay	15	92
310	Wigwam Bay	40	87
504	Wilson Bay	28	87

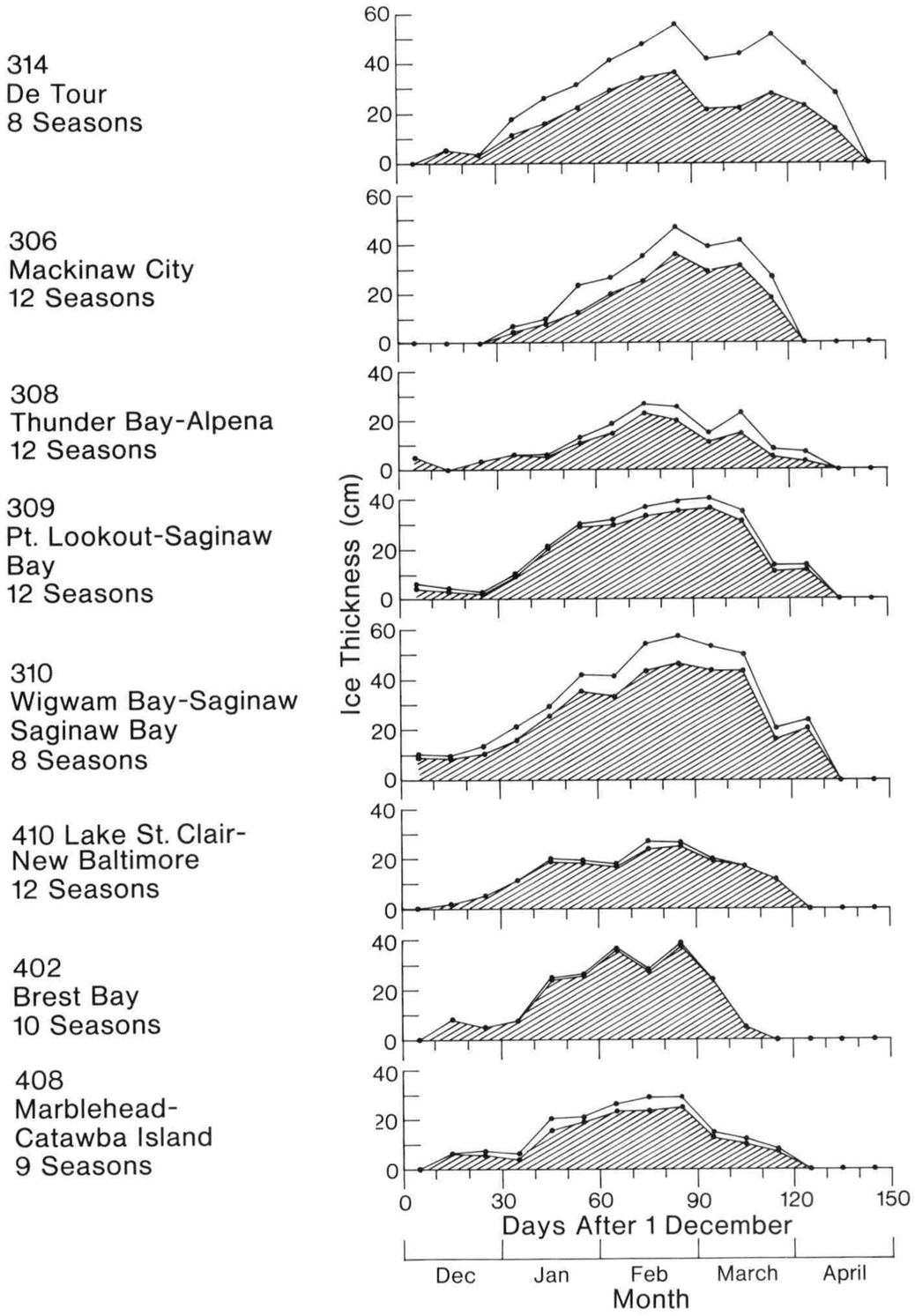


FIGURE 8. Mean ice thickness vs. time for the period of record at stations located on a north (De Tour)-to-south (Marblehead) line over the Great Lake Basin.

218
Muskegon Lake-
Snug Harbor
6 Seasons

410
Lake St. Clair-New
Baltimore
12 Seasons

400
Marine Lake-Erie
Harbor
11 Seasons

502
North Pond
11 Seasons

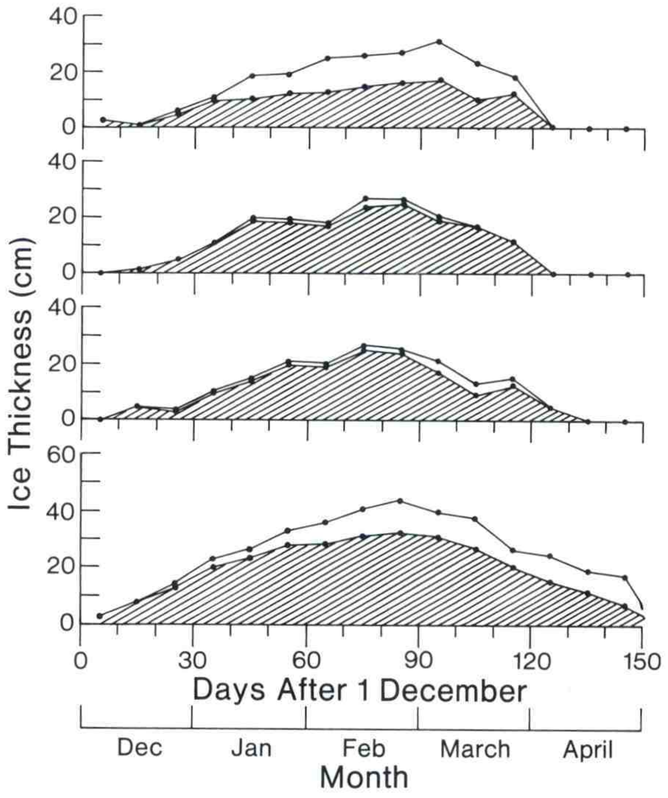


FIGURE 9. **Mean ice thickness vs. time for the period of record at stations located on a west (Muskegon)-to-east (North Pond) line over the Great Lakes Basin.**

132
Duluth Harbor
12 Seasons

129
Chequamegon Bay-
Ashland
12 Seasons

120
South Bay-Munising
11 Seasons

114
Tahquamenon Bay
8 Seasons

152
Point Iroquois
10 Seasons

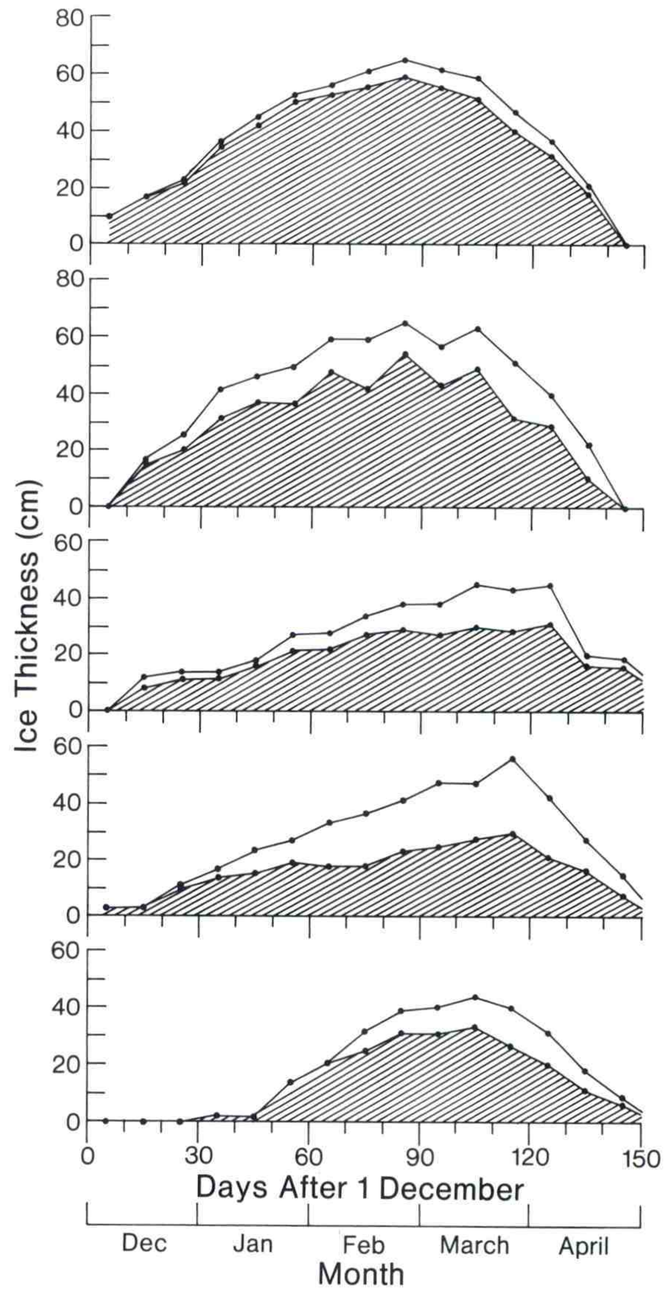


FIGURE 10. **Mean ice thickness vs. time for the period of record at stations located on a west (Duluth)-to-east (Pt. Iroquois) line over the Lake Superior Basin.**

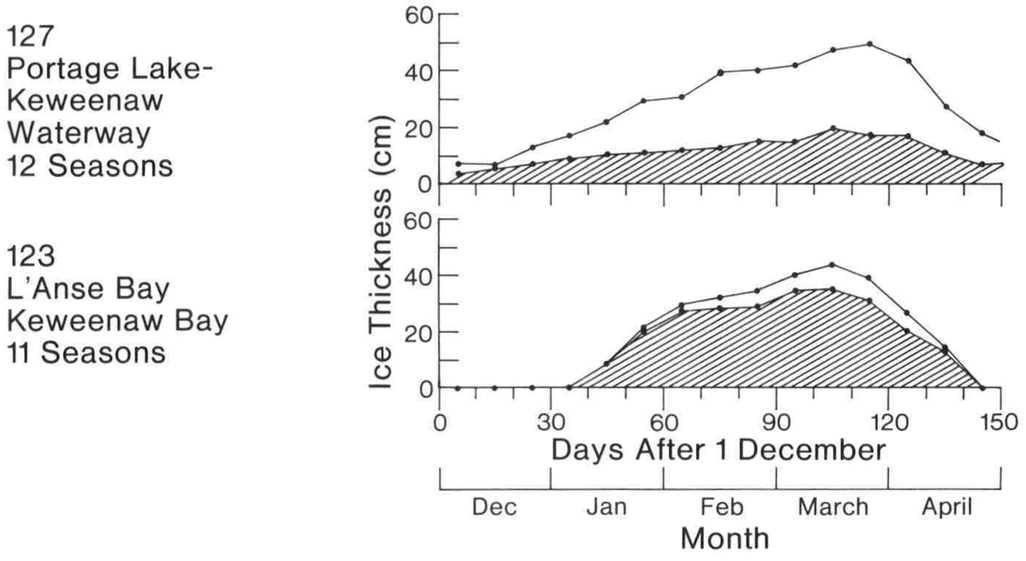


FIGURE 11. **Comparison of mean "white" ice amounts for the period of record at two stations located within 32 km of each other. Differences in "white" ice are due to localized meteorological conditions.**

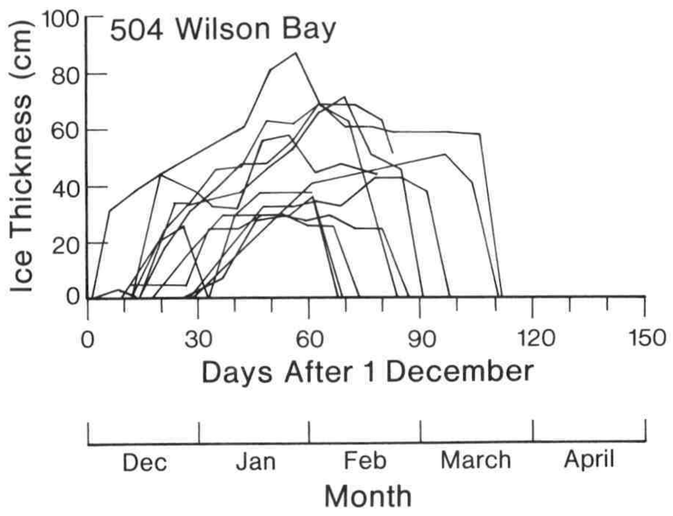


FIGURE 12. **Total ice thickness curves for Wilson Bay Lake Ontario. Note the wide range of first and last ice dates.**

4. WINTER SEVERITY

4.1 Freezing Degree-Days

The degree-day concept is frequently used to classify winter severity. A freezing degree-day (FDD) is defined as the difference between 0°C and the average of the daily maximum and daily minimum temperatures. For example, if the average temperature is −4°C, 4 FDD's are accumulated for that date. And if the average daily air temperature is 6°C, then a negative 6 FDD's are accumulated for that date. A summation of FDD's is usually started in the autumn when daily air temperatures fall below 0°C and is continued until April of the following year. The maximum FDD accumulation usually occurs in March as daily average air temperatures start to rise above 0°C and negative FDD's begin to be added to the summation during that month. The annual maximum FDD accumulation is used as an index of winter severity.

A degree-day and temperature data base 80 winters in length (1898-1977) for 25 stations on the perimeter of the Great Lakes has been described by Assel (1980a). Portions of this data base were used to define winter severity and to examine the distribution of winters classified as "mild" and "severe" at each station for the 80-winter period (Assel, 1980b). The classification scheme used the cumulative frequency distribution (CD) of the annual maximum FDD accumulation at each station to characterize the winter as "severe," the upper 5 percent of the CD; "severer than normal," the next 15 percent of the CD; "normal," the 60 percent mid-range of the CD; "milder than normal," the next 15 percent of the CD; and "mild," the lowest 5 percent of the CD.

The following patterns in FDD's and winter severity were identified in that study: The 25-station average of maximum FDD's CD revealed a cooling trend from 1898 to 1918, a warming trend from 1918 to 1958, and a second cooling trend from 1958 through 1977. The majority of the severe winters occurred during the two cooling trends, and the majority of the mild winters occurred during the warming trend. This is in significant agreement with the period covered by this Atlas (1960-79), when the Great Lakes experienced one extreme in winter severity (severe winters) but not the other extreme (mild winters).

Although the FDD data base used in this Atlas goes through 1977, studies by Diaz (1980) and DeWitt et al. (1980) using average monthly air temperatures for December, January, and February have shown that the 1978 and 1979 winters were of comparable severity to 1977. In fact, the three consecutive winters of 1977, 1978, and 1979 make a unique combination and rank among the three most severe consecutive winters on record.

4.2 Lake Average Trends in Winter Severity

The average FDD value for all stations on the perimeter of each Great Lake is used to index lakewide trends in winter severity. Lake averages of annual maximum FDD values for the winters between 1898 and 1977 are used to classify winter severity for each lake. Lake averages of running weekly accumulations are used (1) to compare seasonal accumulations of FDD's for the pre- and post-ice climatology period by use of the mean value for each period and (2) to examine the climatology of seasonal FDD distributions by comparing an 80-winter mean (1898-1977) to the average of the four coldest and four warmest winters occurring during the same 80-winter period.

The climatology of the seasonal FDD's is illustrated in figure 13 for each lake. From this figure it can be seen that there has been considerable variation in the seasonal FDD accumulation during the 80-winter period. Comparing the mean FDD values before (1898-1959) and during (1960-77) the period of ice-cover climatology, it is evident that the climatology period had a greater FDD accumulation and therefore colder winters. (See figure 14.) Trends in above-normal winter severity and below-normal winter severity are shown in figure 15 for the period 1960-79. Of these 20 winters, there were at least three and perhaps as many as five winters during which all five Great Lakes had severe or severer than normal winters, including the winters of 1963, 1970, 1977, and perhaps 1978 and 1979. FDD's for the 1978 and 1979 winters for all 25 stations have not been calculated; but, as noted earlier, indications from other studies (Diaz, 1980) show these winters to be comparable in severity to 1977. Other winters of greater than normal severity for individual lakes include 1971 and 1972 for Lake Superior, 1962 and 1965 for Lake Michigan, and 1961 for Lake Erie. Winters of less than normal severity (milder than normal or mild) include the 1966 winter for Lake Ontario; 1973 and 1975 for Lakes Ontario, Erie, and Huron; and 1975 for Lake Michigan. The lake average winter severity FDD class limits are given in table 4.

TABLE 4.—Statistics of lake average maximum annual freezing degree-days (1898-1977) and lower boundaries of winter severity classes

Lake	Value of FDD's (°C)			Severity class lower boundary*			
	High	Mean	Low	MN(5%)	N(20%)	SN(80%)	S(95%)
Superior	1,523	1,100	654	720	951	1,289	1,422
Michigan	1,029	563	243	306	445	699	904
Huron	1,086	611	275	321	471	721	934
Erie	696	326	73	106	220	430	629
Ontario	873	461	145	201	345	591	729

*MN, milder than normal; N, normal; SN, Severer than normal; S, severe.

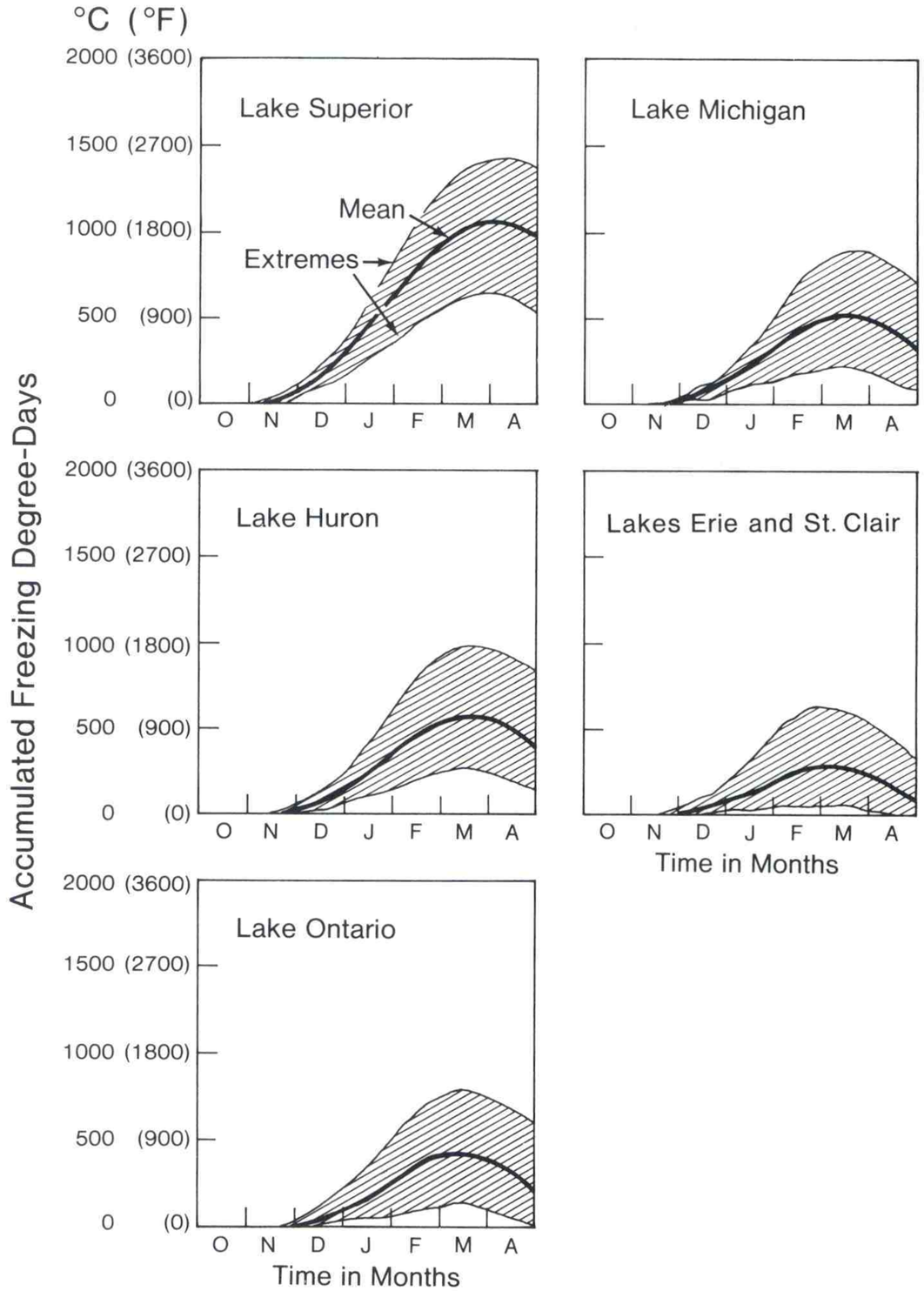


FIGURE 13. Eighty-winter mean and four-winter extremes of lake-averaged freezing degree-days by lake.

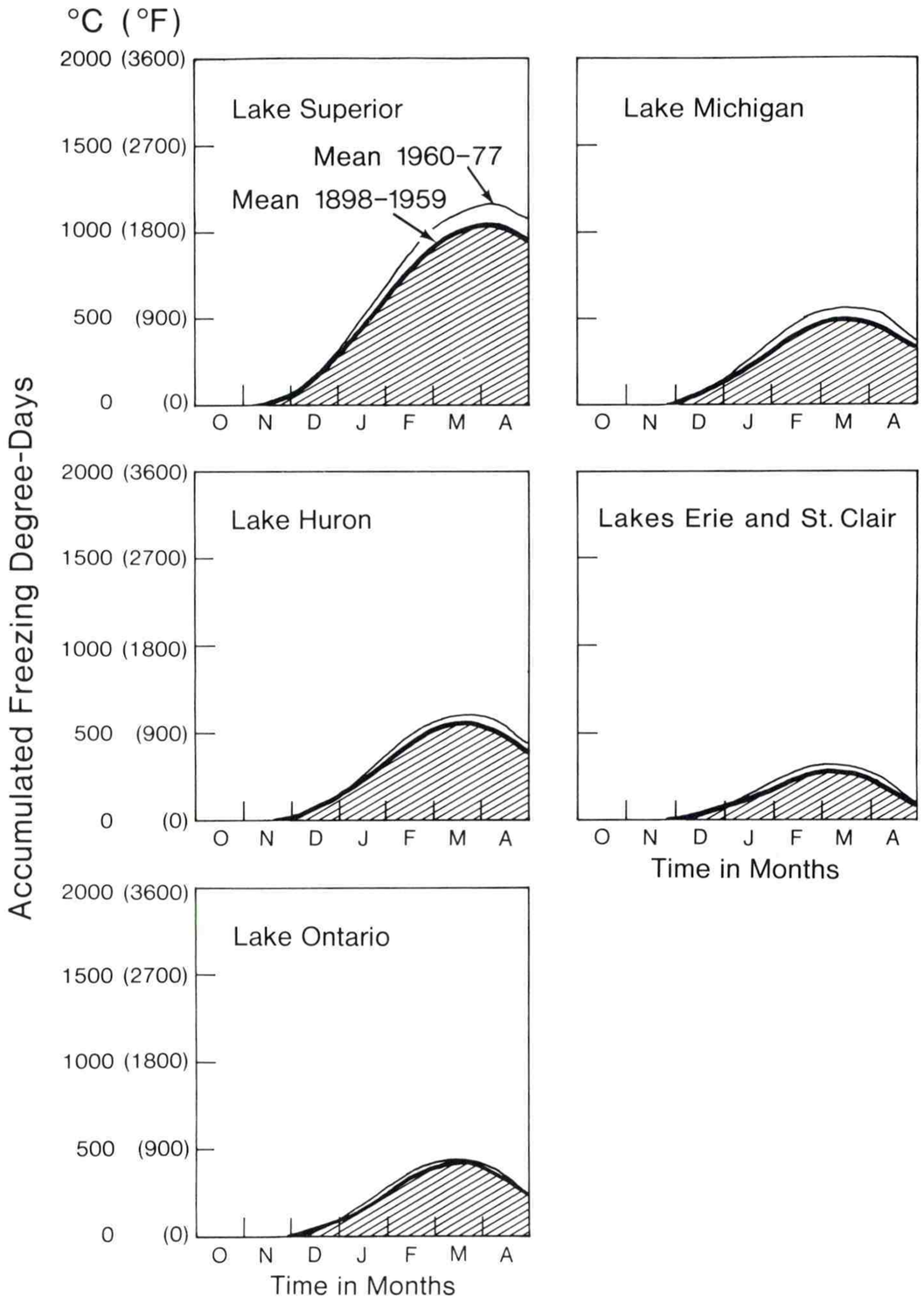


FIGURE 14. Mean freezing degree-day values before (1898-1959) and during (1960-77) the period of the ice-cover climatology by lake.

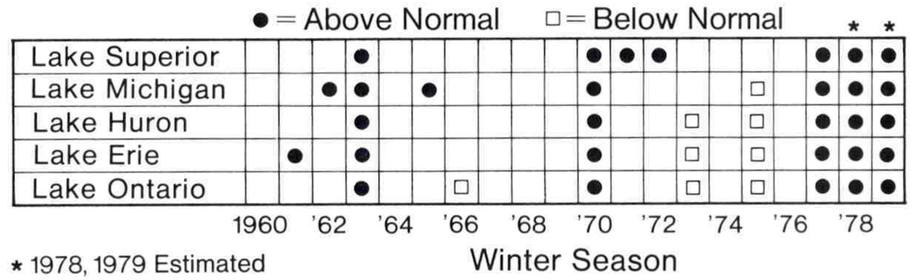


FIGURE 15. Distribution of winters with above-and below-normal severity (1960-79)

4.3 Regional and Seasonal Trends in Winter Severity

Just as the annual maximum FDD values have been used to characterize winter severity for an entire winter season, FDD's accumulated each half-month period during the winter are useful indicators of winter severity on a subseasonal time scale and are useful for comparison with ice charts for the same half-month periods.

The normal FDD accumulation for each of 14 half-month periods, October 1-15 to April 16-30, was defined by the 80-winter mean (1898-1977) as given in table 5. Deviations from normal, defined as the difference between the 18-year mean (1960-77) and the 80-year mean, are used to evaluate anomalies during the period of the ice-cover climatology and are given in table 6.

The first half-month period during which the average air temperatures are less than 0°C is significant, because it initiates the period of potential ice formation. The first positive FDD accumulations normally occur during November 1-15 at a majority of the 25 temperature stations. Lake Superior, where first accumulations normally start October 16-31, and Cleveland, Ohio, where first accumulations normally occur November 16-30, provide exceptions to the general pattern. Average FDD accumulations during the initial half-month period of positive accumulations are under 10 FDD's.

The coldest period in the winter is January 16-31 for Lake Superior and the western shore of Lake Michigan. In other areas, FDD accumulations during January 16-31 and February 1-14 are within 5 FDD's of one another, so either of these half-month periods could be considered the coldest period of the winter. FDD accumulations during the coldest period are less than 100 FDD's for Lake Erie, most of Lake Ontario, and southern portions of Lakes Michigan and Huron; FDD's for the remainder of Lakes Michigan and Huron vary from 100 FDD's to 160 FDD's; FDD's on Lake Superior are between 150 and 250 FDD's at most locations. The last half-month period with average air temperatures below 0°C is important, because it marks the end of the period

of ice formation. The last half-month of positive FDD accumulation occurs February 15-18 for much of Lake Erie and the southern tip of Lake Michigan. The last half-month of positive FDD's occurs March 1-15 for other stations south of the 45th parallel and March 16-31 for stations north of the 45th parallel.

From table 6, it can be seen that the mean FDD's for the 1960-77 winters were greater than the 80-year mean (negative anomalies) over all of the Great Lakes during the early winter when temperatures are normally coldest. Thus, during the coldest portion of the winter, temperatures were in general lower during the 1960-77 winters compared to the 80-winter mean. Another trend shown in table 6 is of positive anomalies for stations along the shores of Lakes Erie and Ontario for much of February, March, and April. These positive anomalies indicate milder temperatures in the mid-to-late winter and spring for portions of Lakes Erie and Ontario compared to the 80-winter mean.

Because air temperature is one of the most important factors affecting ice formation, it is possible to relate the climatic potential for ice formation to FDD accumulation. Thus, the climatic potential for ice-cover formation was greater during the early winter for the winters of the ice-cover climatology as evidenced by the above-normal FDD values for December 16-31, January 1-15, and January 16-31. Similiarly, the below-normal FDD's over much of Lakes Erie and Ontario for February, the first half of March, and all of April represent a decrease in climatic potential for ice-cover formation for those lakes.

These trends in ice-cover formation potential are important because they indicate that the ice-cover climatology analysis may have had a natural climatic bias that tends to produce greater ice concentrations for the early winter period than the long term mean of the past 80 winters (1898-1977).

TABLE 5.—Mean semimonthly freezing degree-day accumulations for the 80-winter period 1898-1977

Lake location	October		November		December		January		February		March		April	
	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Lake Superior														
Thunder Bay, Ont.	0	3	25	69	138	183	203	237	208	148	120	67	− 2	− 62
Houghton, Mich.	0	1	11	36	82	117	134	163	155	118	94	45	− 17	− 80
Duluth, Minn.	0	3	22	65	129	170	188	214	184	129	96	44	− 24	− 80
Marquette, Mich.	0	0	7	29	70	100	117	142	133	96	73	27	− 27	− 80
Sault Ste. Marie, Mich.	0	0	8	32	82	121	138	170	165	123	98	48	− 14	− 79
Lake Michigan														
Escanaba, Mich.	0	1	5	23	66	101	118	146	137	98	74	28	− 25	− 81
Traverse City, Mich.	0	0	3	11	40	66	79	101	104	75	49	− 2	− 51	−111
Green Bay, Wis.	0	0	6	25	71	111	128	147	131	87	50	− 6	− 63	−125
Muskegon, Mich.	0	0	1	5	26	45	56	73	77	46	15	− 30	− 76	−112
Milwaukee, Wis.	0	0	3	12	46	74	86	101	86	49	12	− 35	− 77	−122
Chicago, Ill.	0	0	1	8	32	52	59	70	58	24	− 16	− 63	− 85	− 80
Lake Huron														
Parry Sound, Ont.	0	0	5	24	74	119	132	158	156	111	81	27	− 32	− 99
Alpena, Mich.	0	0	4	15	48	80	92	118	120	87	63	15	− 37	− 95
Bay City, Mich.	0	0	1	8	35	61	70	89	85	55	23	− 33	− 79	−123
Port Huron, Mich.	0	0	1	6	31	51	63	79	78	47	13	− 34	− 75	−112
Lakes Erie and St. Clair														
Buffalo, N.Y.	0	0	1	6	25	44	52	70	72	45	13	− 31	− 65	−103
Port Dover, Ont.	0	0	1	7	32	56	67	85	86	56	26	− 22	− 65	−113
Detroit, Mich.	0	0	1	5	25	45	51	65	64	34	− 3	− 51	− 84	− 92
Erie, Pa.	0	0	1	4	17	31	37	53	57	34	− 1	− 43	− 65	− 73
Toledo, Ohio.	0	0	1	7	26	46	50	60	57	27	− 11	− 57	− 78	− 81
Cleveland, Ohio.	0	0	0	4	18	33	37	48	48	22	− 15	− 52	− 60	− 59
Lake Ontario														
Kingston, Ont.	0	0	2	11	51	91	105	128	124	82	50	0	− 56	−112
Toronto, Ont.	0	0	1	6	29	51	61	82	80	50	20	− 28	− 73	−113
Oswego, N.Y.	0	0	1	4	29	52	61	77	79	49	19	− 28	− 65	−107
Rochester, N.Y.	0	0	1	6	26	47	54	70	72	44	12	− 38	− 74	−109

TABLE 6.—Deviation of 1960-77 mean of semimonthly freezing degree-day accumulations from the long term mean (1898-1977)

Lake location	October 1	October 2	November 1	November 2	December 1	December 2	January 1	January 2	February 1	February 2	March 1	March 2	April 1	April 2
Lake Superior														
Thunder Bay, Ont.	− 0.1	1.8	− 2.0	− 4.9	− 2.8	−18.3	−29.0	− 8.6	− 3.6	−13.8	4.6	− 7.1	2.6	4.4
Houghton, Mich.	0	0.9	− 2.8	− 2.0	− 5.8	−13.6	−21.9	− 7.5	0.4	− 6.3	5.4	−11.0	−10.4	− 5.1
Duluth, Minn.	0	1.9	− 2.5	− 0.9	− 4.7	−15.9	−32.9	−15.5	0.6	− 5.3	4.4	−10.5	− 5.1	0
Marquette, Mich.	0	− 0.3	− 5.9	−10.7	−10.7	−25.8	−41.8	−21.9	−13.5	−16.6	− 6.0	−18.9	−14.9	− 0.3
Sault Ste. Marie, Mich.	0	0	− 1.1	3.4	3.4	−17.3	−18.7	− 1.6	− 1.1	0.5	9.7	− 5.2	− 5.3	6.9
Lake Michigan														
Escanaba, Mich.	0	1.0	0.3	3.3	8.9	− 0.8	−17.2	0.3	6.3	1.9	11.8	− 3.9	− 3.2	3.4
Traverse City, Mich.	0	0	0.3	0.6	0.7	−13.8	−25.6	−12.7	−11.3	−10.6	− 0.4	−11.2	− 2.0	12.4
Green Bay, Wis.	0	0	− 1.1	− 0.1	− 1.9	−18.9	−30.4	− 9.4	2.1	0	5.4	− 8.4	− 0.5	9.2
Muskegon, Mich.	0	0	− 0.5	− 0.7	1.4	− 8.7	−18.6	− 7.8	− 1.8	0.3	8.7	− 1.6	1.6	16.4
Milwaukee, Wis.	0	0	− 0.2	− 0.5	1.3	−14.4	−30.1	−18.8	− 1.1	4.7	0.1	−15.0	− 3.3	5.9
Chicago, Ill.	0	0	− 1.3	0.6	− 1.2	−15.0	−35.4	−24.4	− 6.2	− 5.4	4.8	− 5.9	17.2	52.1
Lake Huron														
Parry Sound, Ont.	0	− 0.1	0.4	4.6	2.0	−18.8	−19.1	−10.3	− 4.9	− 3.9	1.4	− 9.7	−10.1	2.1
Alpena, Mich.	0	− 0.1	− 0.2	− 1.4	− 5.2	−19.2	−29.2	−16.9	−10.4	− 5.8	0.8	− 8.9	− 4.9	9.6
Bay City, Mich.	0	0	− 0.3	1.9	2.6	− 5.4	−22.6	−10.4	− 2.3	0	7.7	−11.7	− 5.7	20.1
Port Huron, Mich.	0	0	− 0.2	2.6	7.8	0	−11.7	− 1.5	7.6	9.6	13.6	1.0	5.3	15.7
Lakes Erie and St. Clair														
Buffalo, N.Y.	0	0	0.2	0.9	0.2	−11.3	−22.1	− 9.7	− 4.3	0.8	5.7	− 5.5	5.8	28.2
Port Dover, Ont.	0	0	− 0.1	2.7	6.4	− 3.2	−10.4	− 6.1	3.2	7.1	10.8	− 6.6	− 2.6	8.2
Detroit, Mich.	0	− 1.0	1.3	2.6	4.8	2.2	−14.4	− 1.2	6.1	10.4	13.4	0.6	8.4	− 2.4
Erie, Pa.	0	0	0.2	1.4	1.4	− 6.7	−23.8	−12.2	−10.6	− 2.7	4.0	− 9.8	5.1	30.6
Toledo, Ohio.	0	0	− 1.1	0.9	− 3.9	−15.2	−34.7	−18.3	− 8.8	− 3.8	4.1	− 8.6	15.8	48.3
Cleveland, Ohio.	0	0	− 0.5	1.4	0.7	− 7.1	−28.4	−13.4	− 7.7	1.2	6.3	− 7.3	14.9	32.1
Lake Ontario														
Kingston, Ont.	0	0	− 0.3	3.4	2.2	−20.6	−17.0	− 1.2	1.2	2.0	6.6	− 2.1	− 0.9	8.6
Toronto, Ont.	0	0	− 0.3	3.7	6.4	− 1.3	−14.8	− 3.7	8.2	8.9	13.9	0.2	8.9	6.7
Oswego, N.Y.	0	0	0.8	1.4	7.7	− 5.6	−11.3	− 4.1	0.6	6.1	10.0	− 4.6	3.4	12.2
Rochester, N.Y.	0	0	0.4	0.8	4.7	− 7.5	−20.6	− 8.0	− 3.1	2.0	6.7	− 9.5	2.3	23.6

Oct. 1 = October 1-15
Oct. 2 = October 16-31
Nov. 1 = November 1-15
Nov. 2 = November 16-30
Dec. 1 = December 1-15
Dec. 2 = December 16-31
Jan. 1 = January 1-15
Jan. 2 = January 16-31
Feb. 1 = February 1-14
Feb. 2 = February 15-28
Mar. 1 = March 1-15
Mar. 2 = March 16-31
Apr. 1 = April 1-15
Apr. 2 = April 16-30

5. ACKNOWLEDGMENTS

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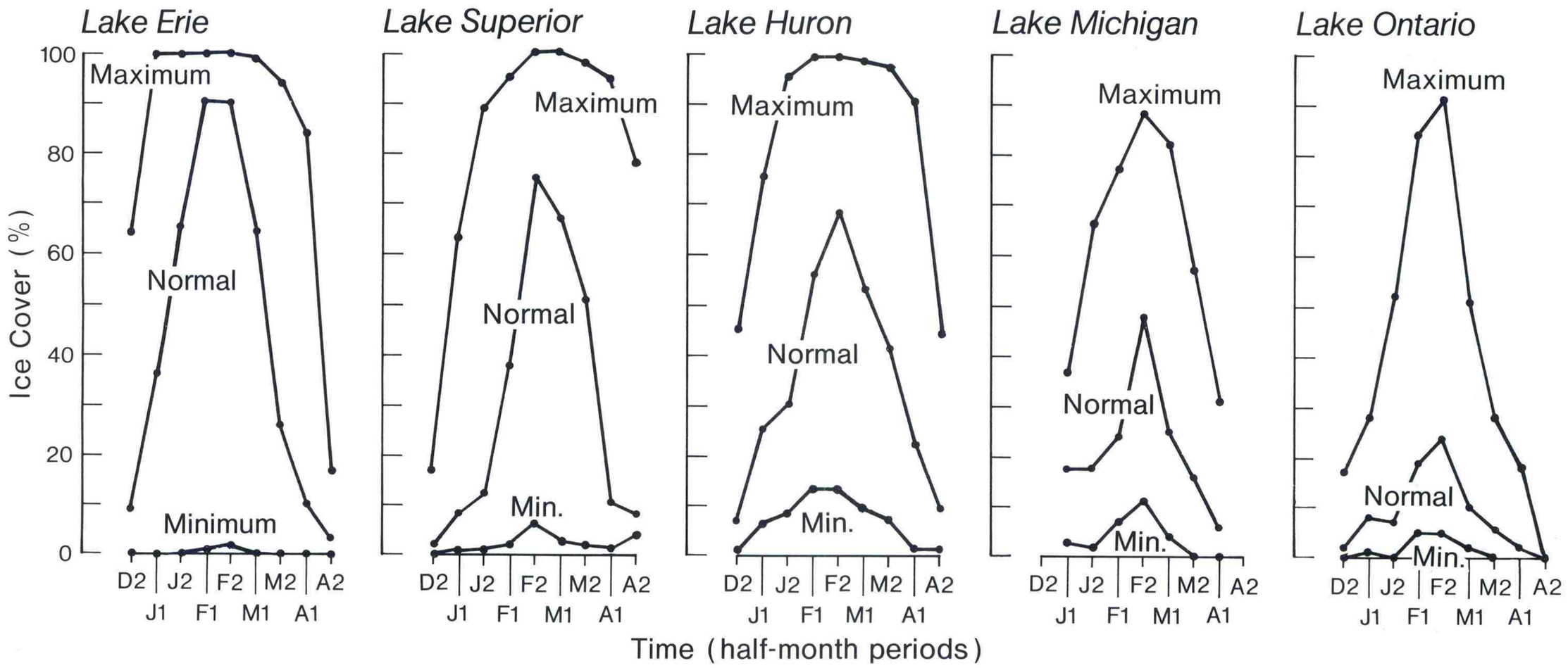
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ICE COVER PLATES



Ice charts for maximum, minimum, and normal ice concentration distribution patterns are given in plates 1–46 by lake for the nine half-month periods starting December 16–31 (D2) and ending April 16–30 (A2). The half-month ice cover statistics given in table 2 are shown in graphical form above and are arranged in descending order of normal percent ice cover for the five Great Lakes.

EXTREMES IN ICE COVER

DECEMBER 16–31
1960–1979

LAKE SUPERIOR

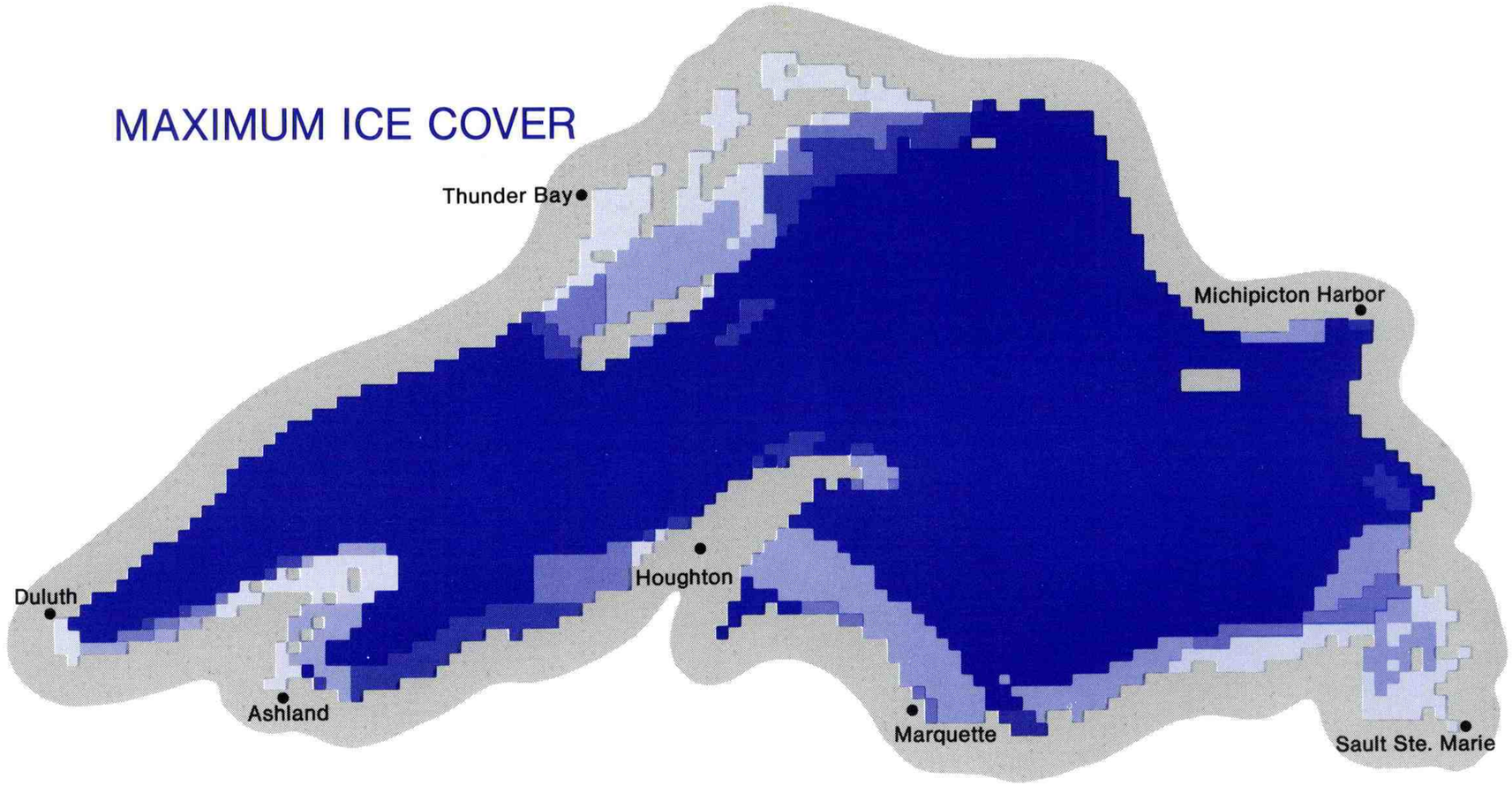
Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

ICE COVER LEGEND

- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

MAXIMUM ICE COVER



MINIMUM ICE COVER



PLATE 1A

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER AND OBSERVATION DENSITY

DECEMBER 16–31

1960–1979

LAKE SUPERIOR

Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

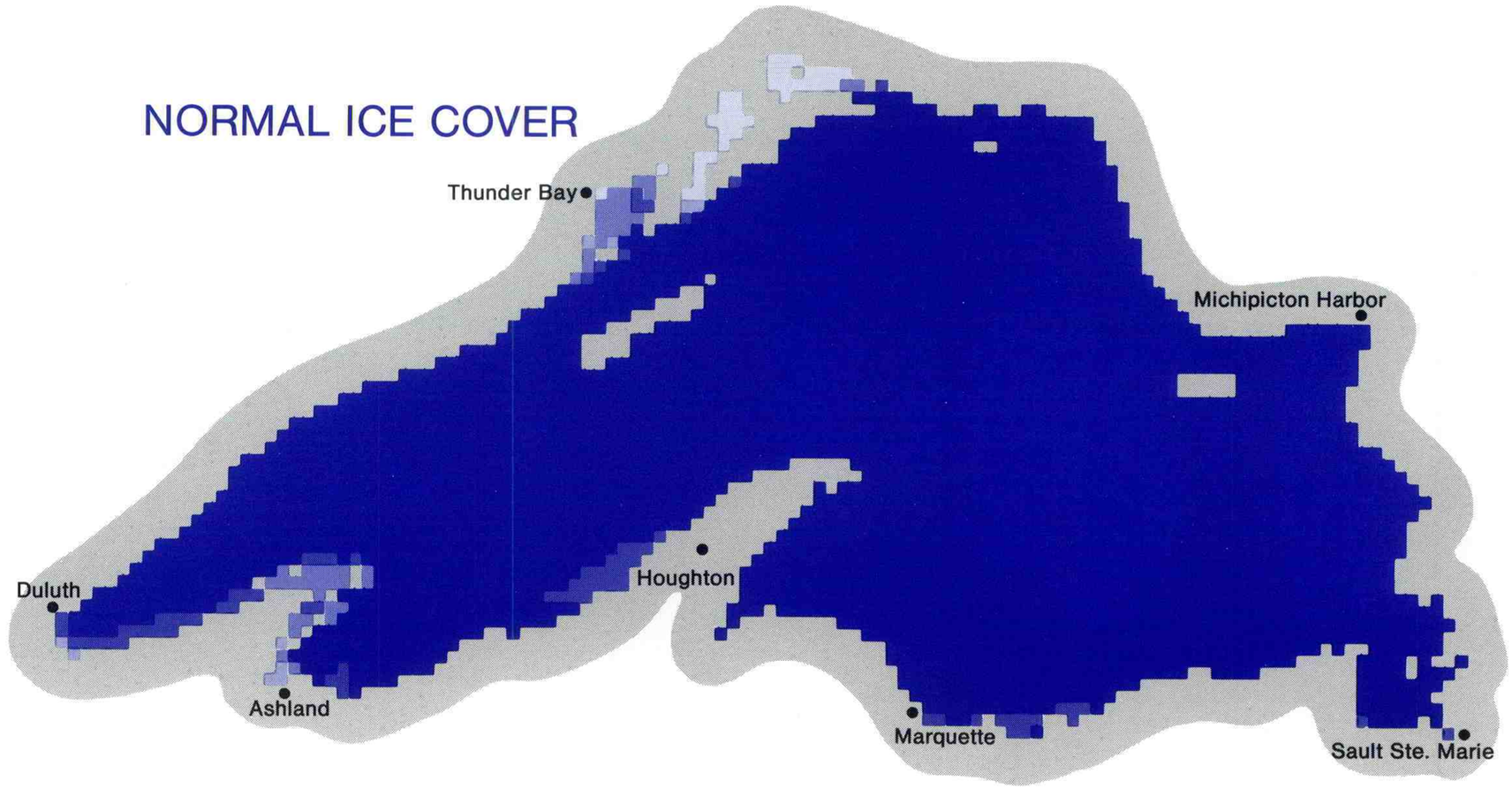
OBSERVATION LEGEND

- FIRST QUARTILE
  0 to 5 years of data
- SECOND QUARTILE
  6 to 10 years of data
- THIRD QUARTILE
  11 to 15 years of data
- FOURTH QUARTILE
  16 to 20 years of data

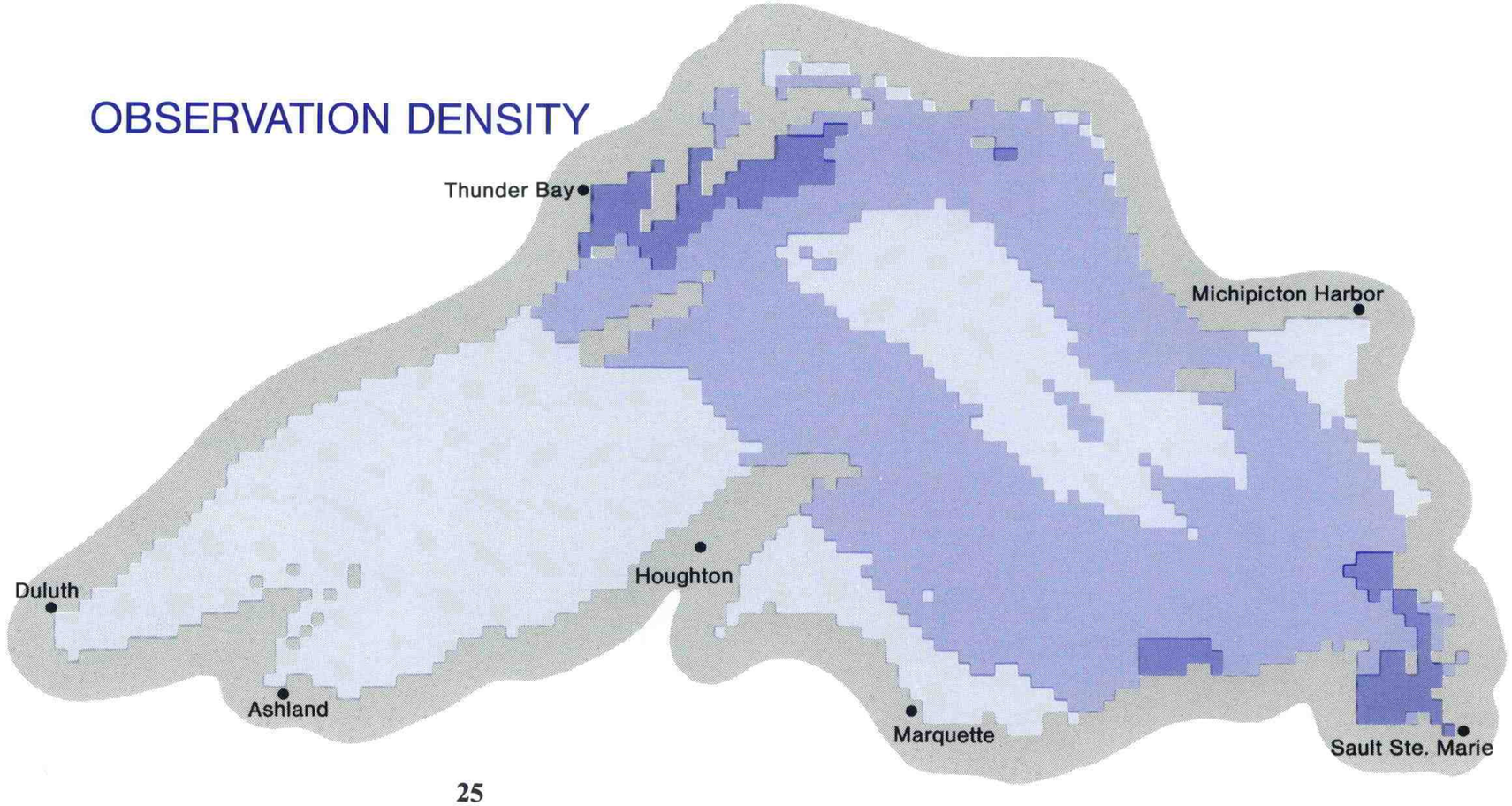
PLATE 1B

U.S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER



OBSERVATION DENSITY



EXTREMES IN ICE COVER

JANUARY 1–15
1960–1979

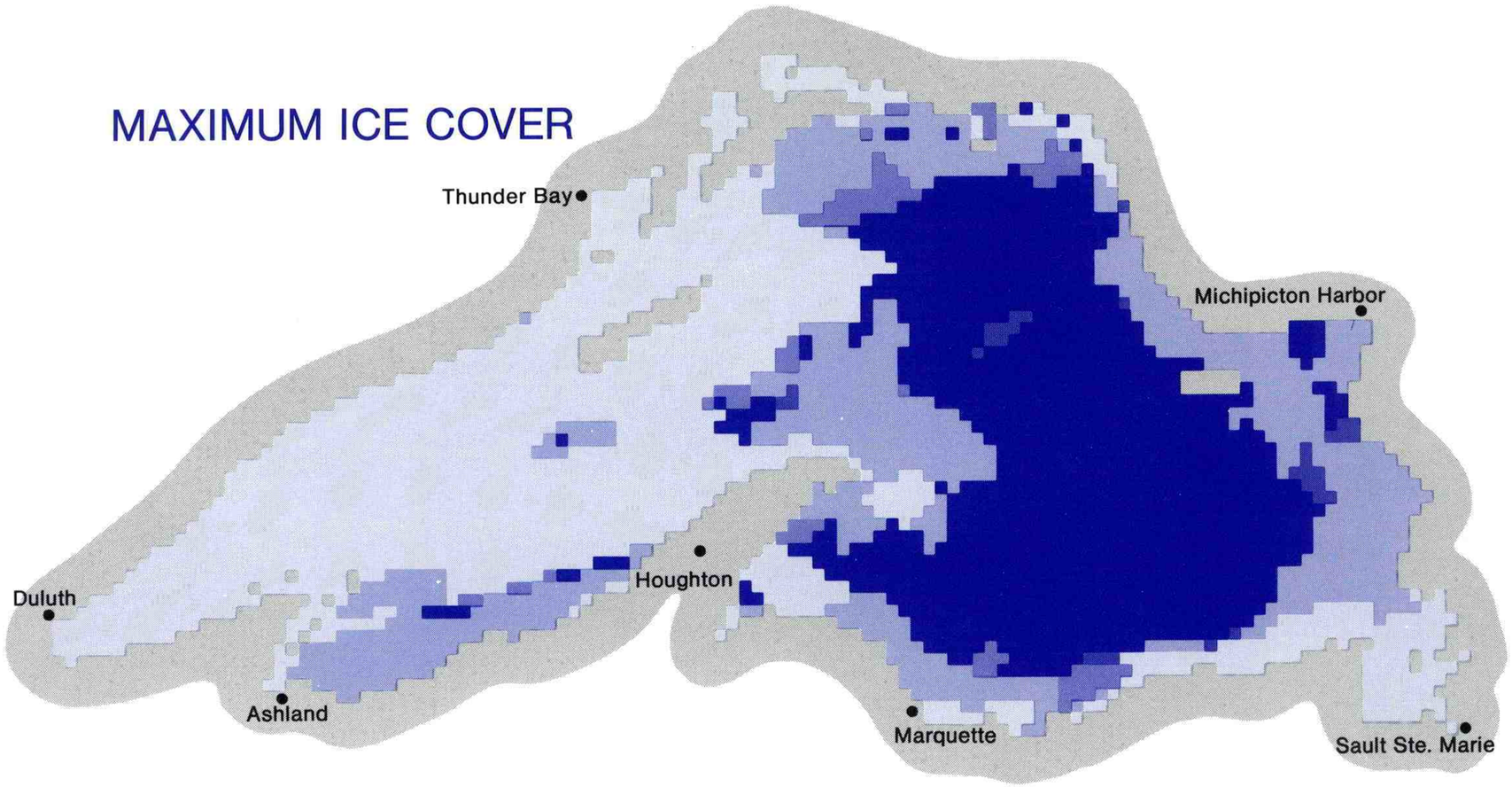
LAKE SUPERIOR

Kilometers
0 20 40 60 80 100
0 10 20 30 40 50 60
Statute Miles

ICE COVER LEGEND

- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

MAXIMUM ICE COVER



MINIMUM ICE COVER

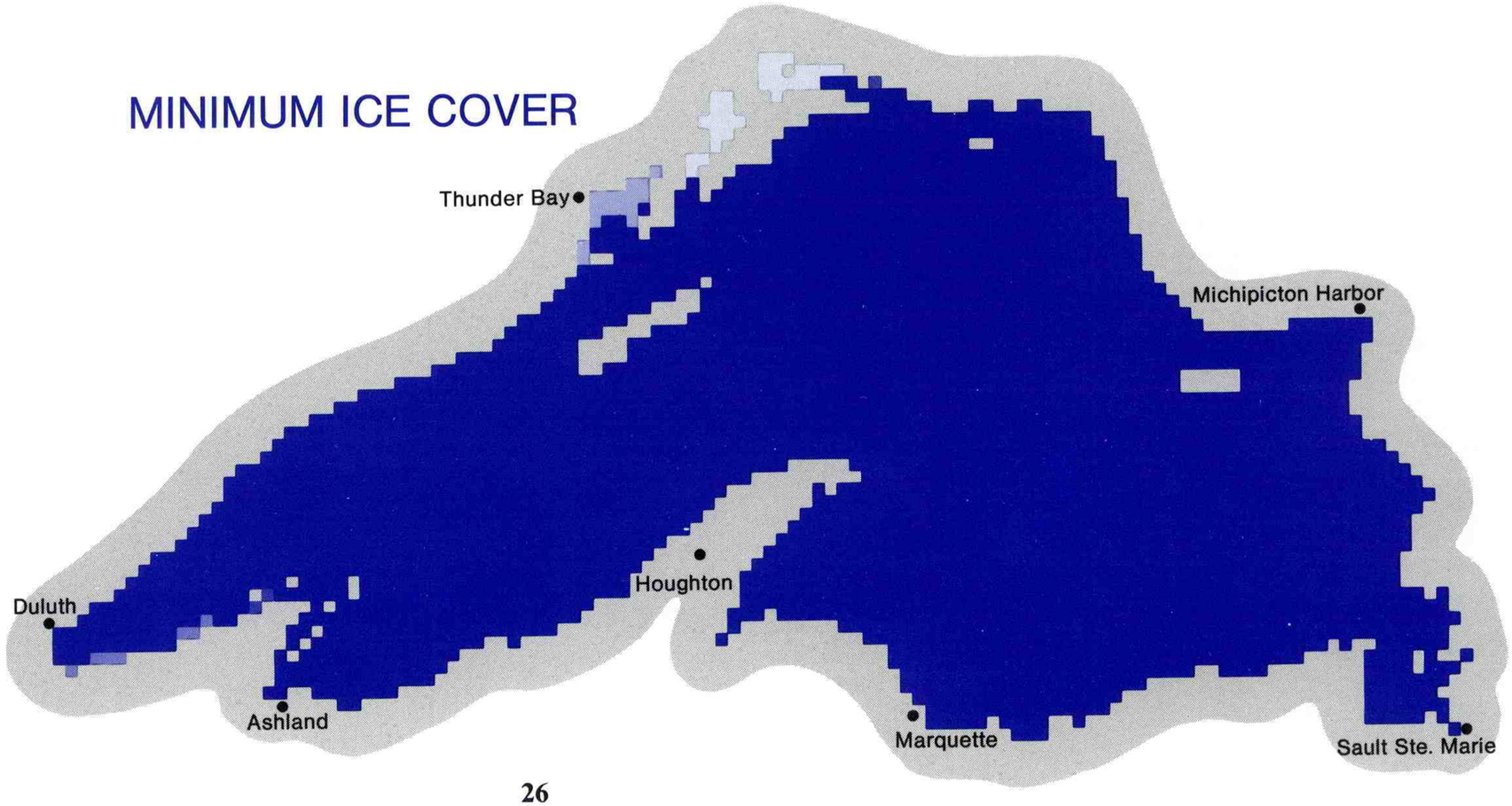


PLATE 2A

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER AND OBSERVATION DENSITY

JANUARY 1–15
1960–1979

LAKE SUPERIOR

Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

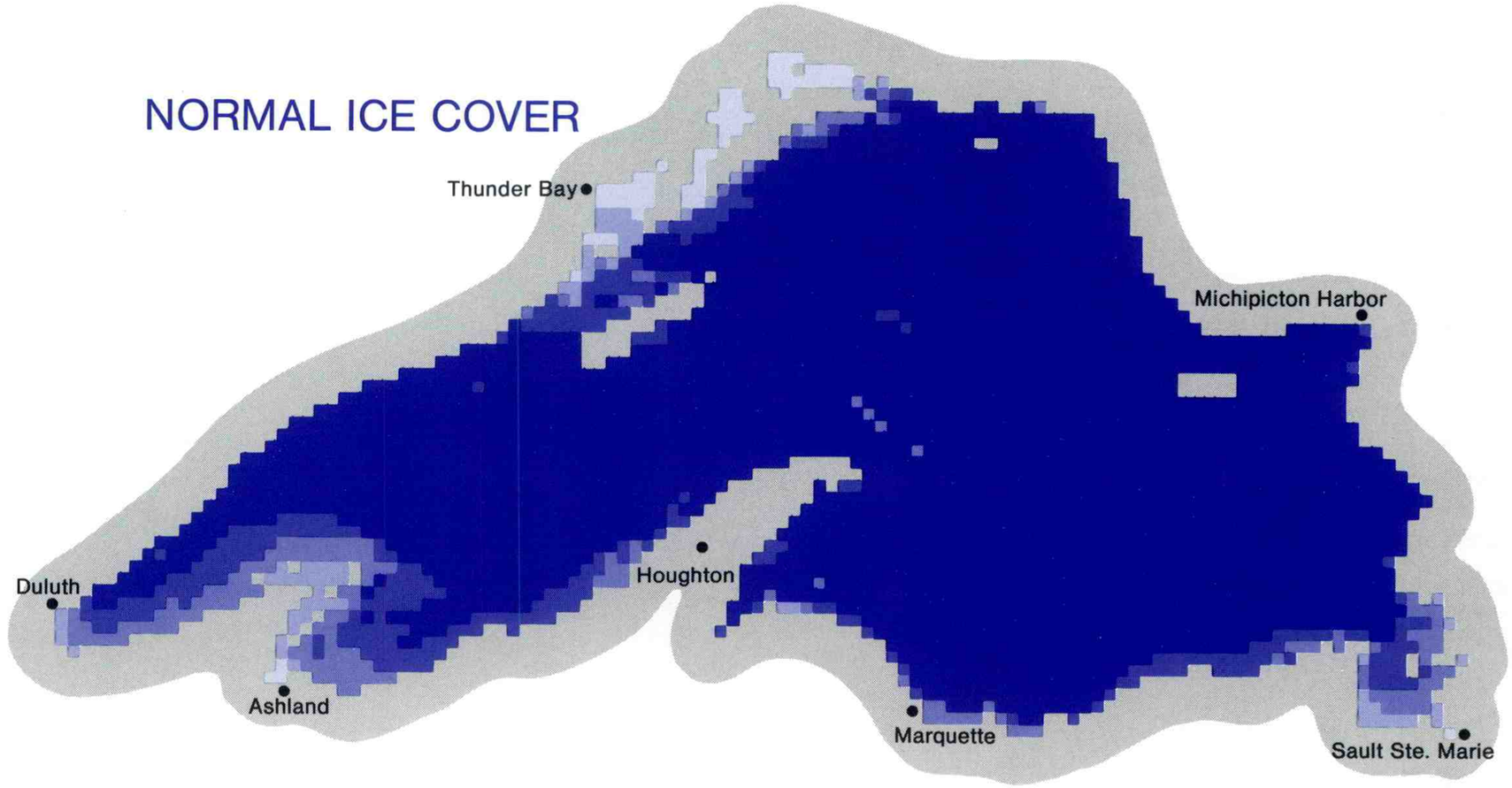
OBSERVATION LEGEND

- FIRST QUARTILE
  0 to 5 years of data
- SECOND QUARTILE
  6 to 10 years of data
- THIRD QUARTILE
  11 to 15 years of data
- FOURTH QUARTILE
  16 to 20 years of data

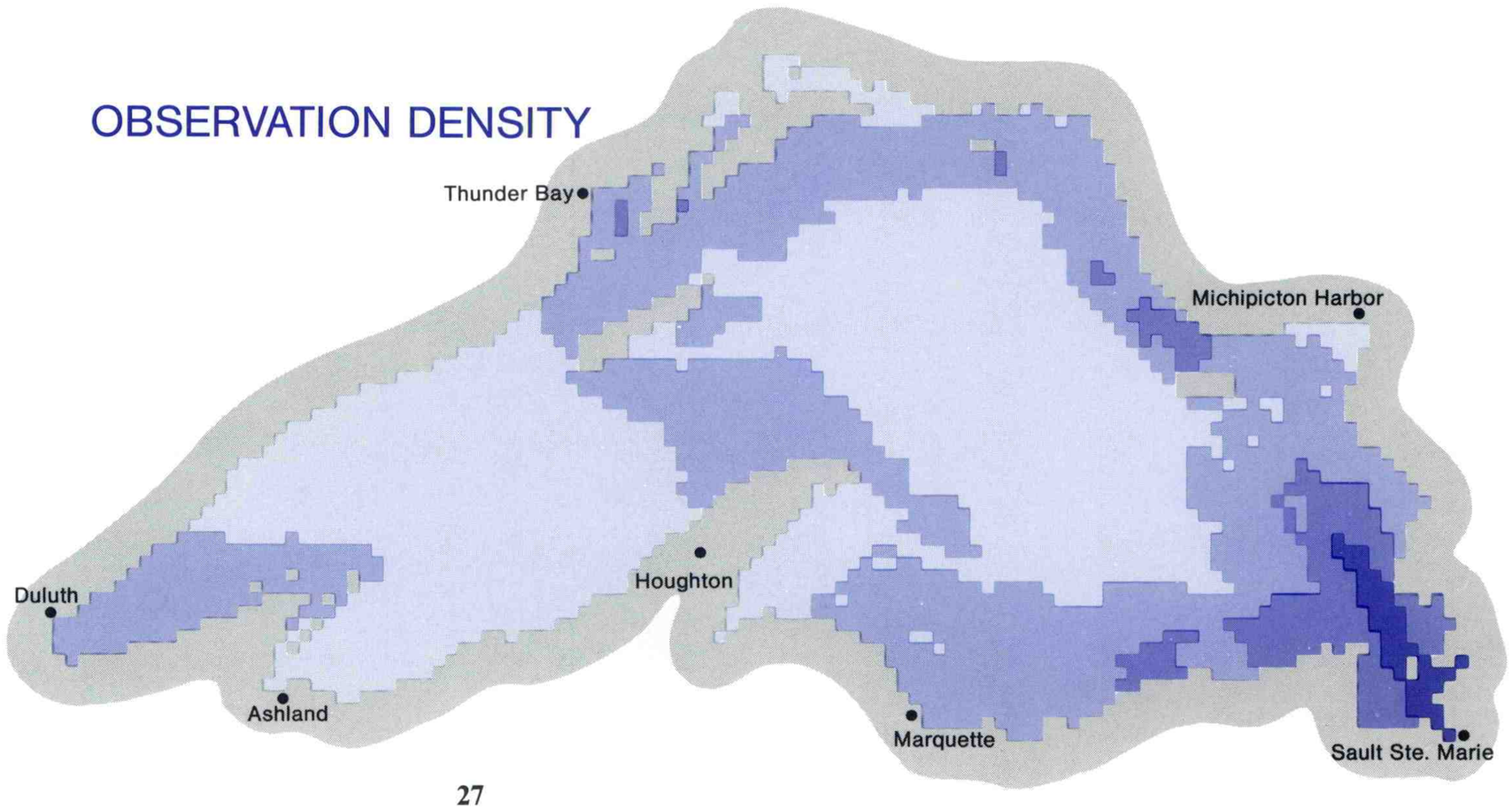
PLATE 2B

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER



OBSERVATION DENSITY



EXTREMES IN ICE COVER

JANUARY 16–31
1960–1979

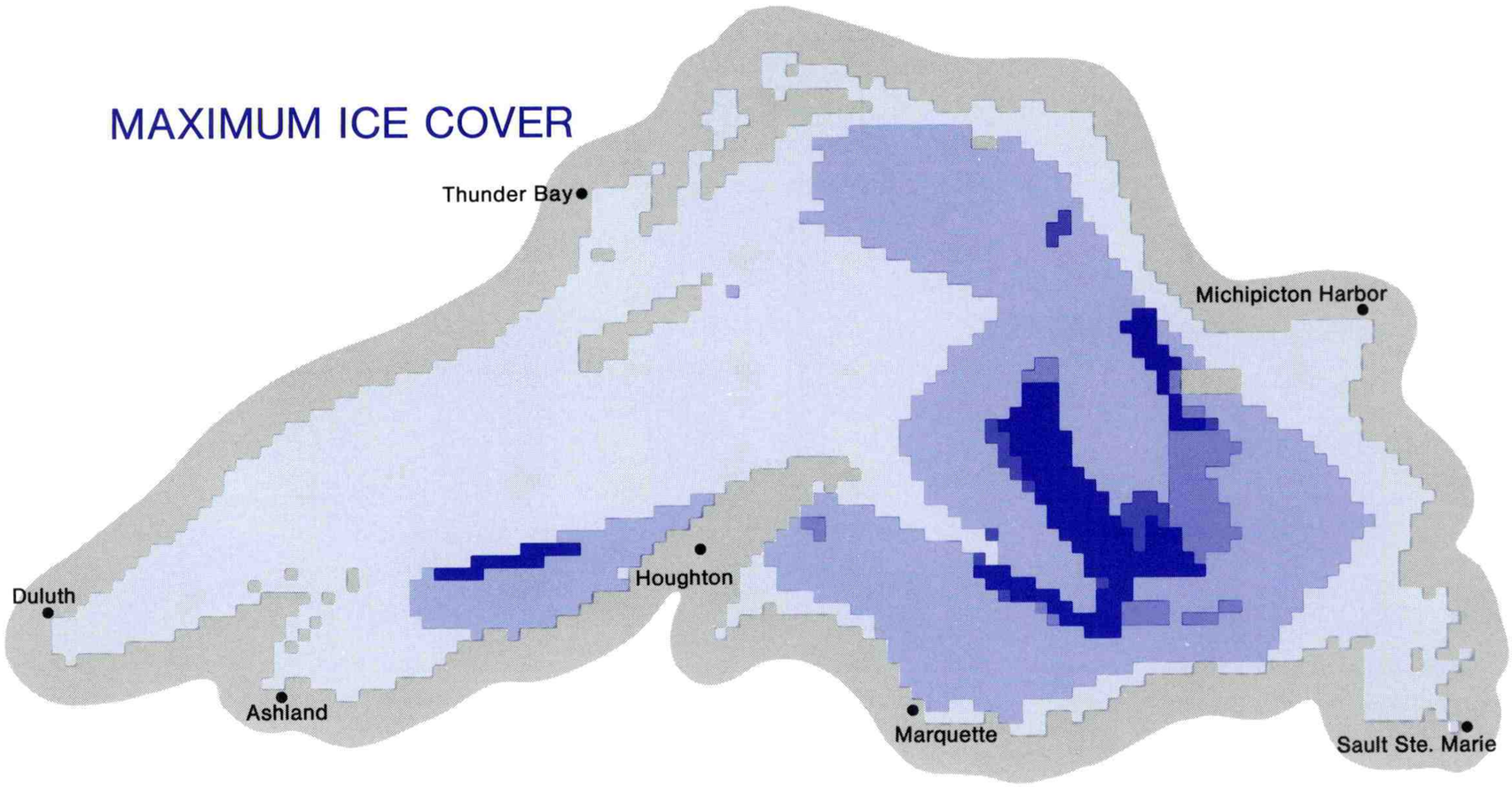
LAKE SUPERIOR

Kilometers
0 20 40 60 80 100
0 10 20 30 40 50 60
Statute Miles

ICE COVER LEGEND

- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

MAXIMUM ICE COVER



MINIMUM ICE COVER

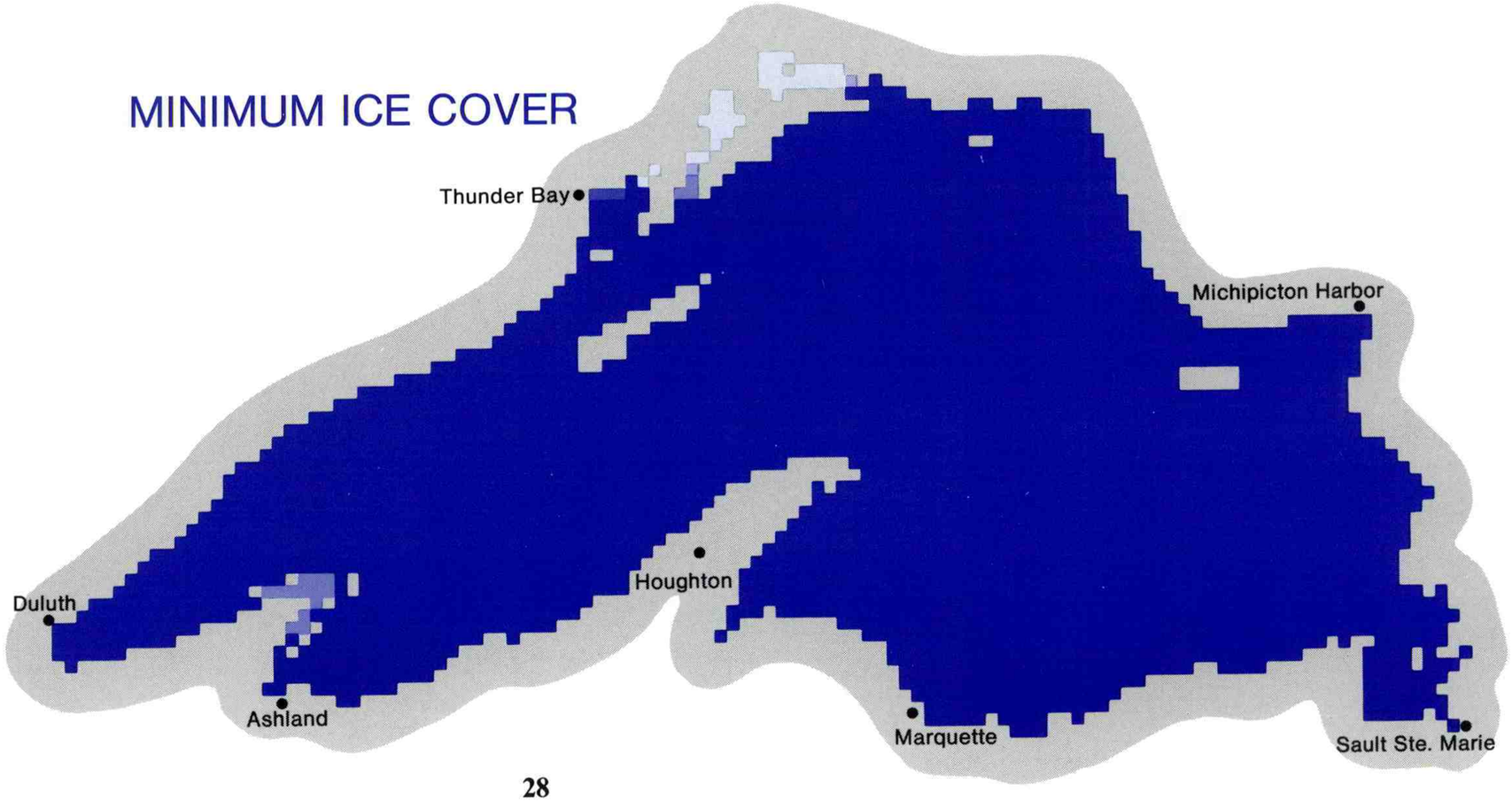


PLATE 3A

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER AND OBSERVATION DENSITY

JANUARY 16–31
1960–1979

LAKE SUPERIOR

Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

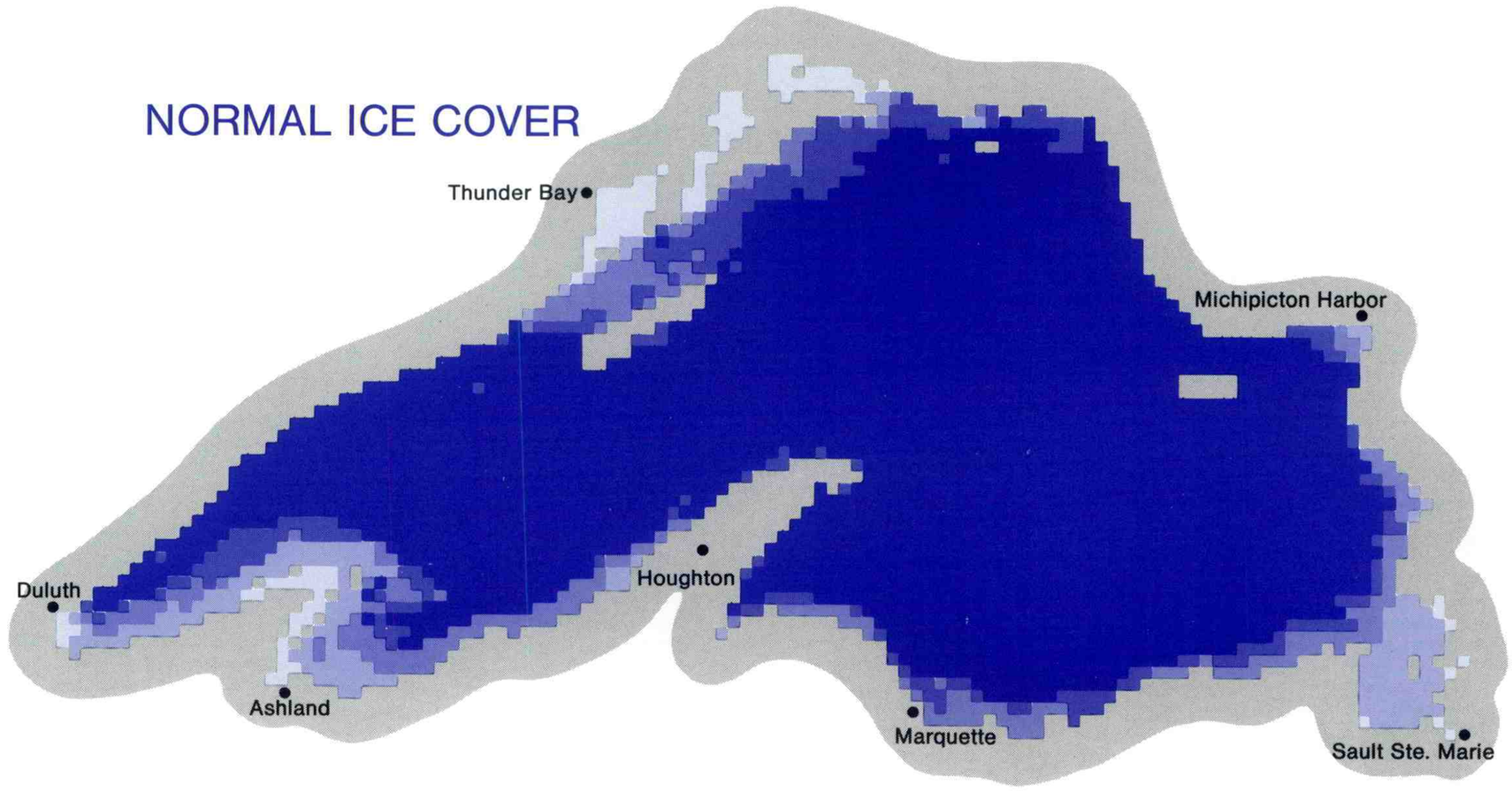
OBSERVATION LEGEND

- FIRST QUARTILE
  0 to 5 years of data
- SECOND QUARTILE
  6 to 10 years of data
- THIRD QUARTILE
  11 to 15 years of data
- FOURTH QUARTILE
  16 to 20 years of data

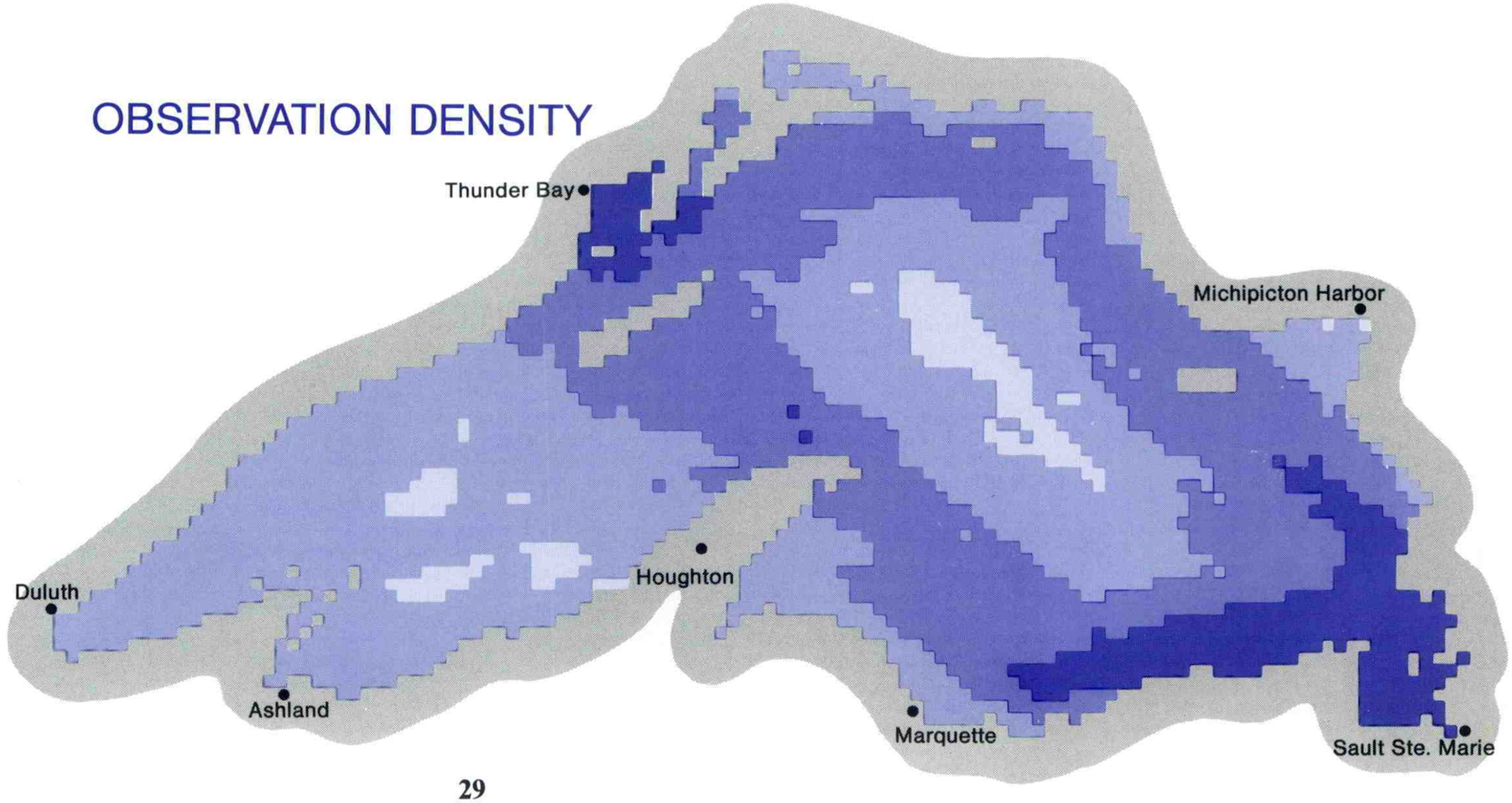
PLATE 3B

U.S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER



OBSERVATION DENSITY



EXTREMES IN ICE COVER

FEBRUARY 1–14
1960–1979

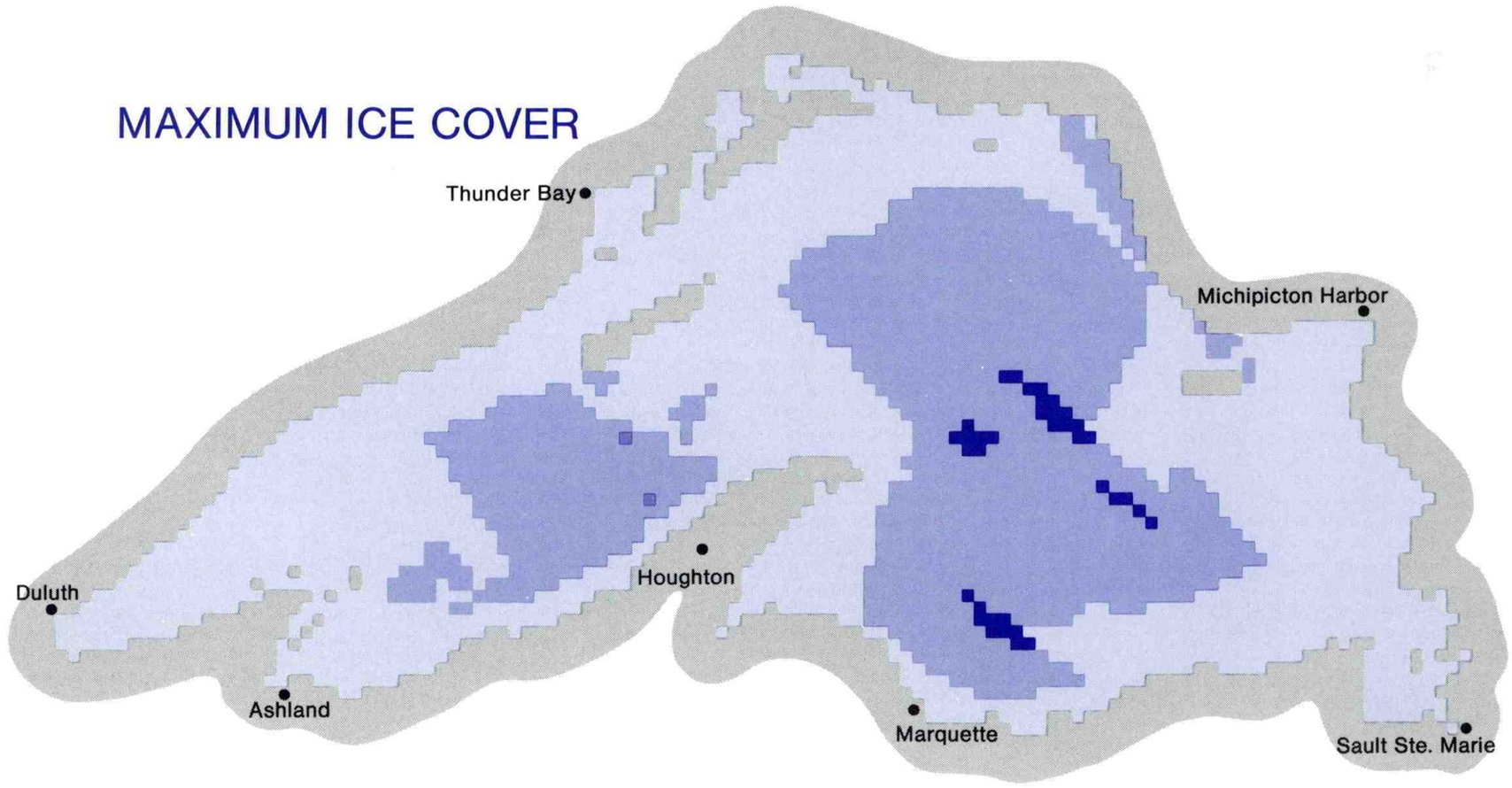
LAKE SUPERIOR

Kilometers
0 20 40 60 80 100
0 10 20 30 40 50 60
Statute Miles

ICE COVER LEGEND

- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

MAXIMUM ICE COVER



MINIMUM ICE COVER

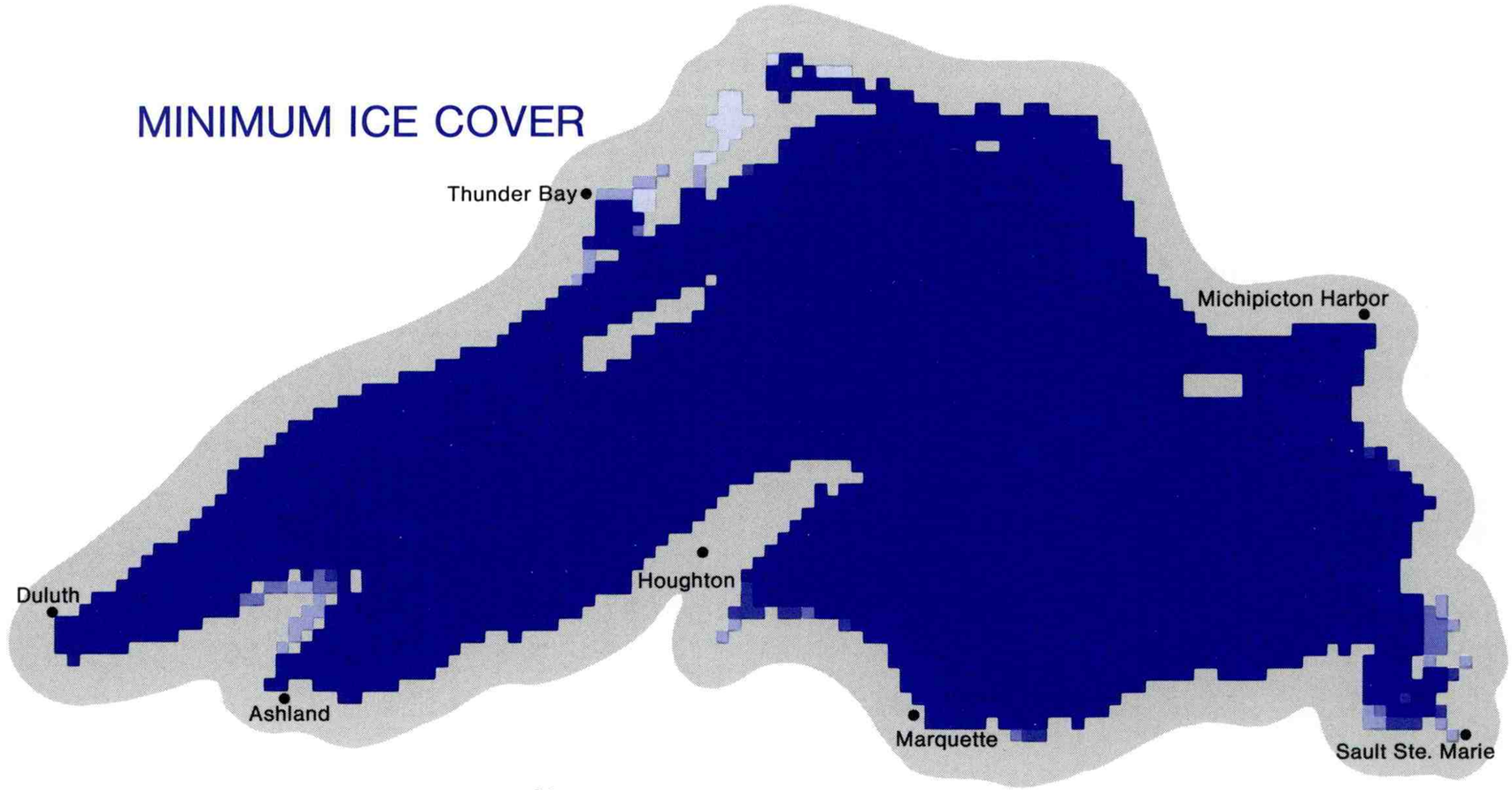


PLATE 4A

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER AND OBSERVATION DENSITY

FEBRUARY 1–14
1960–1979

LAKE SUPERIOR

Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

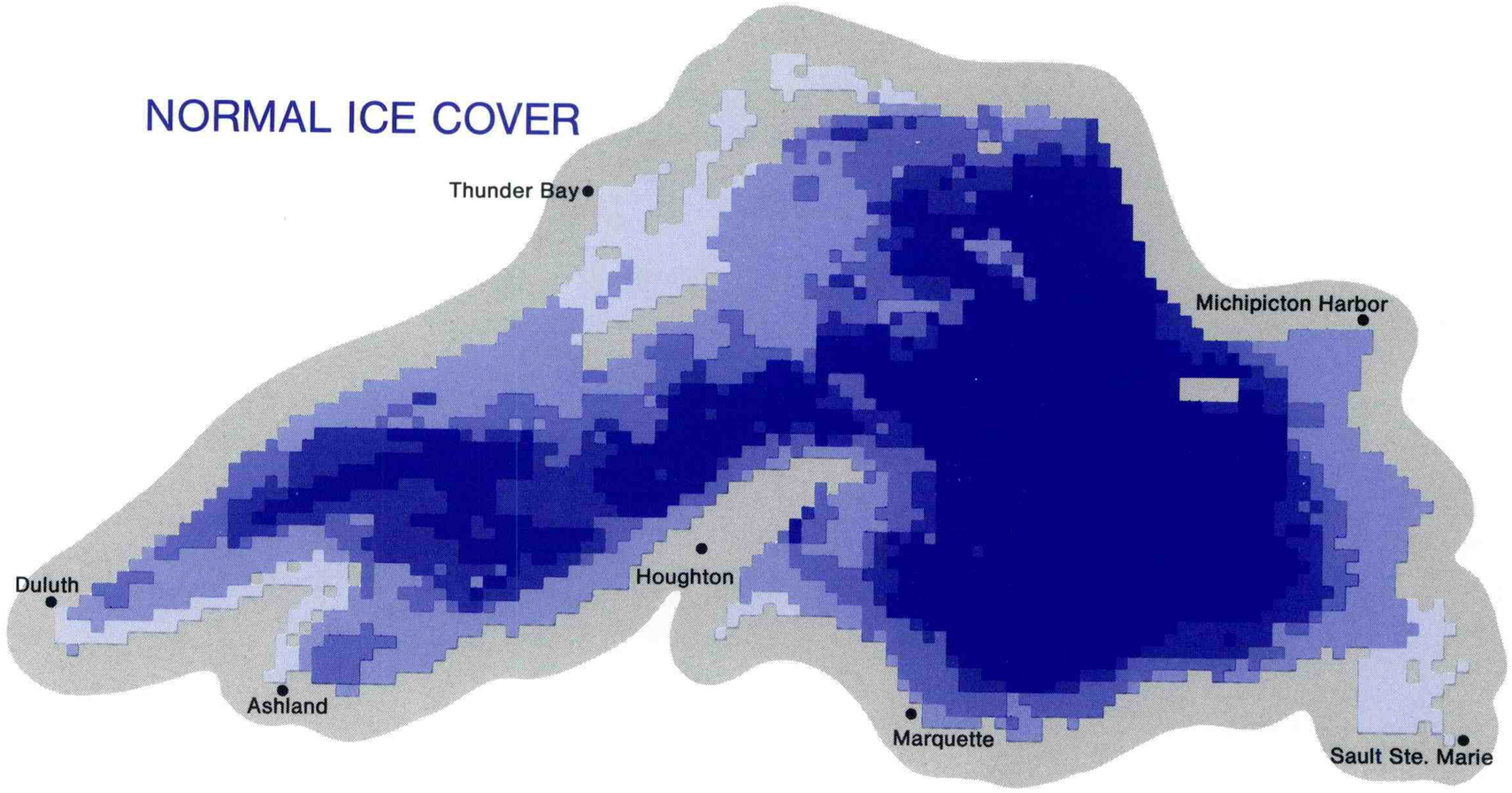
OBSERVATION LEGEND

- FIRST QUARTILE
  0 to 5 years of data
- SECOND QUARTILE
  6 to 10 years of data
- THIRD QUARTILE
  11 to 15 years of data
- FOURTH QUARTILE
  16 to 20 years of data

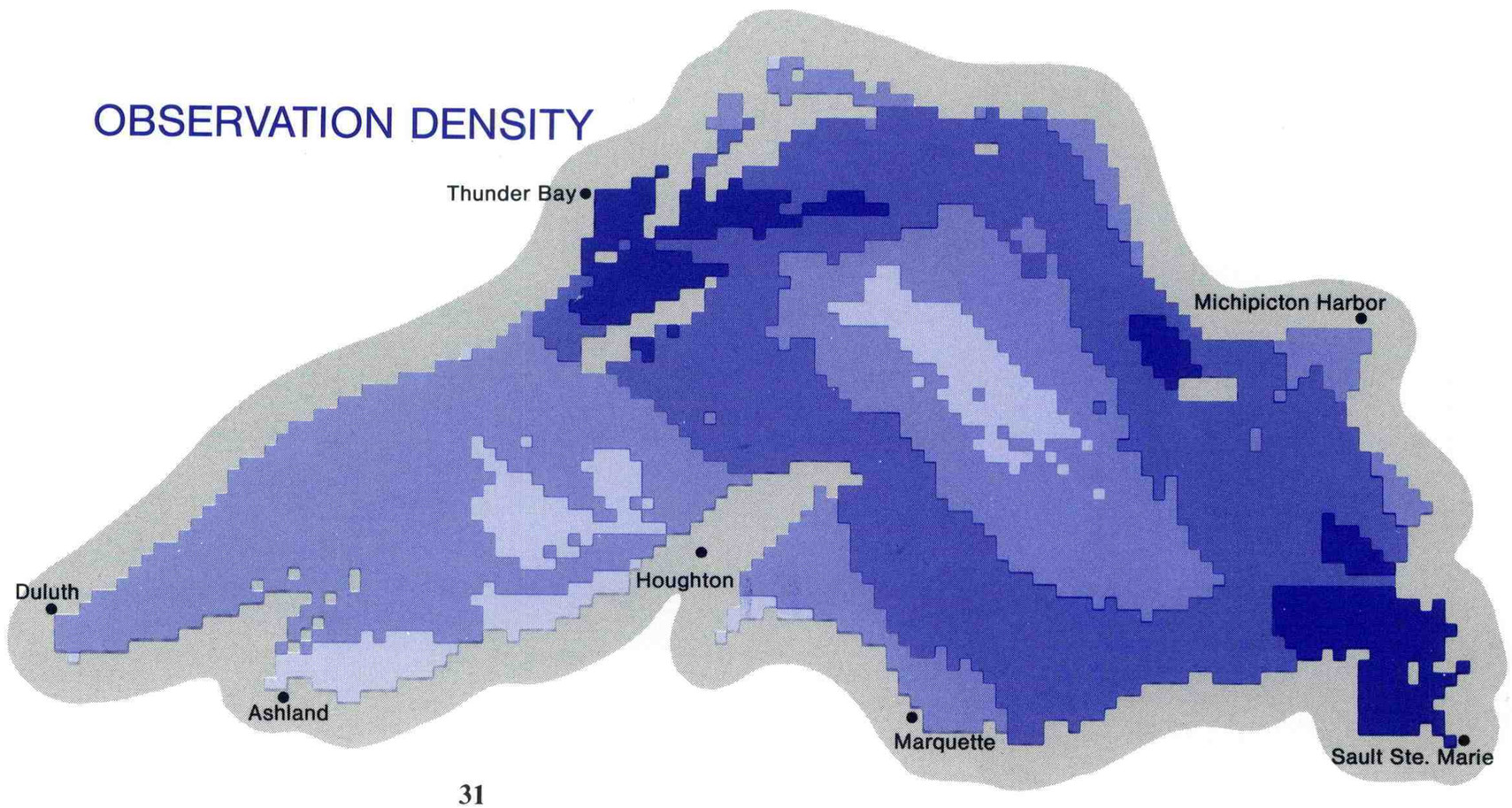
PLATE 4B

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER



OBSERVATION DENSITY



EXTREMES IN ICE COVER

FEBRUARY 15–28
1960–1979

LAKE SUPERIOR

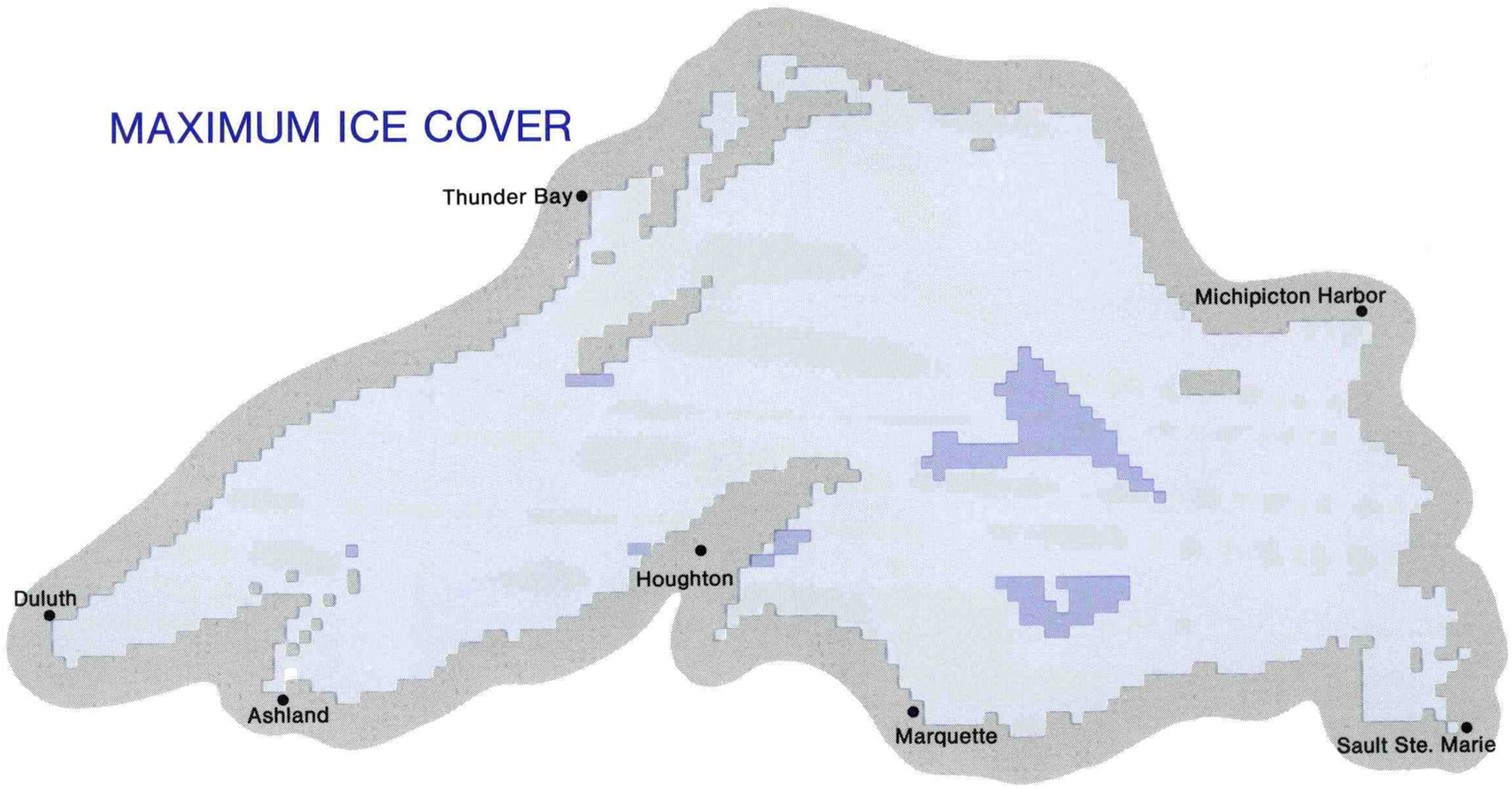
Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

ICE COVER LEGEND

- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

MAXIMUM ICE COVER



MINIMUM ICE COVER

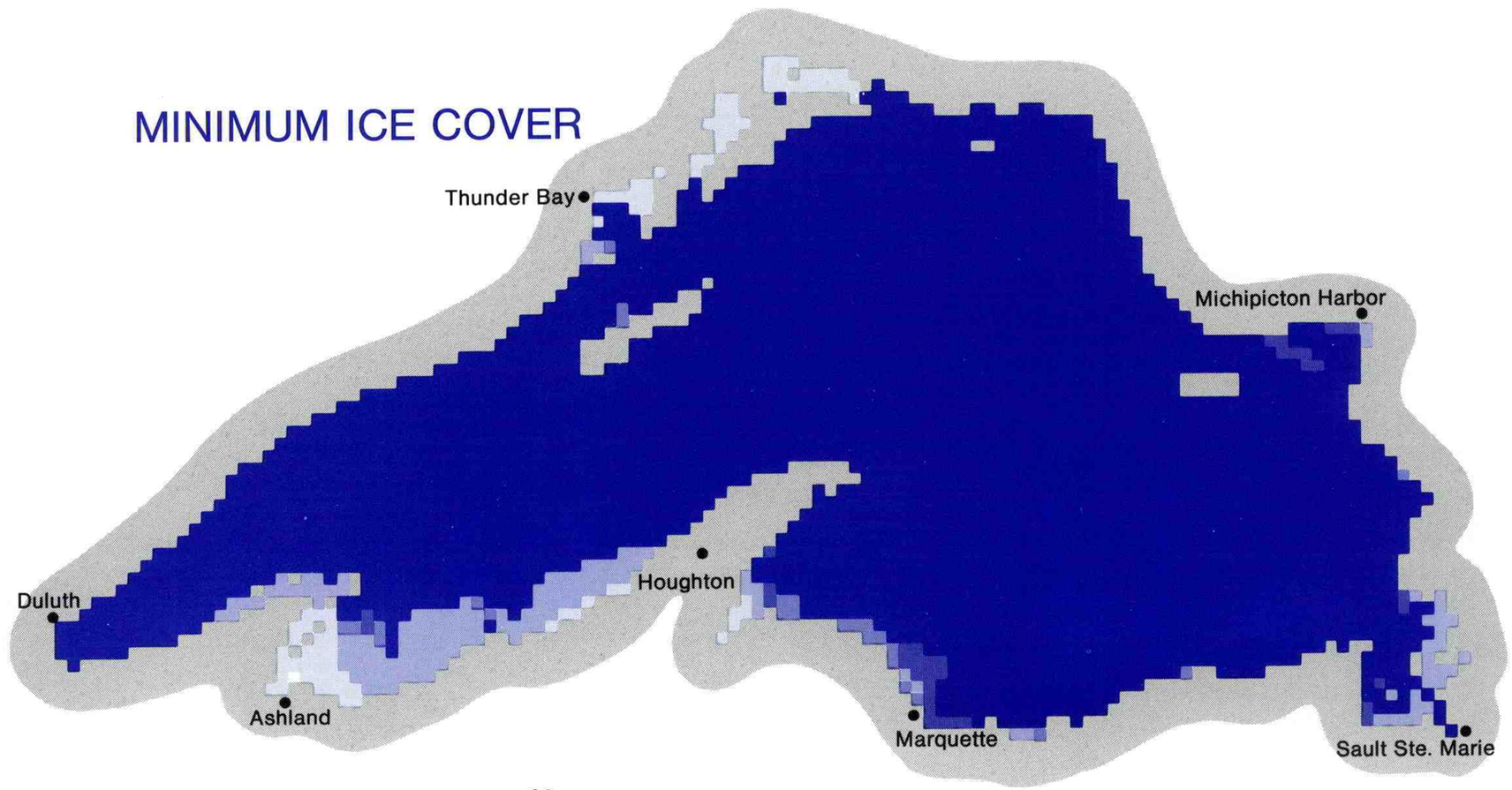


PLATE 5A

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER AND OBSERVATION DENSITY

FEBRUARY 15–28
1960–1979

LAKE SUPERIOR

Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

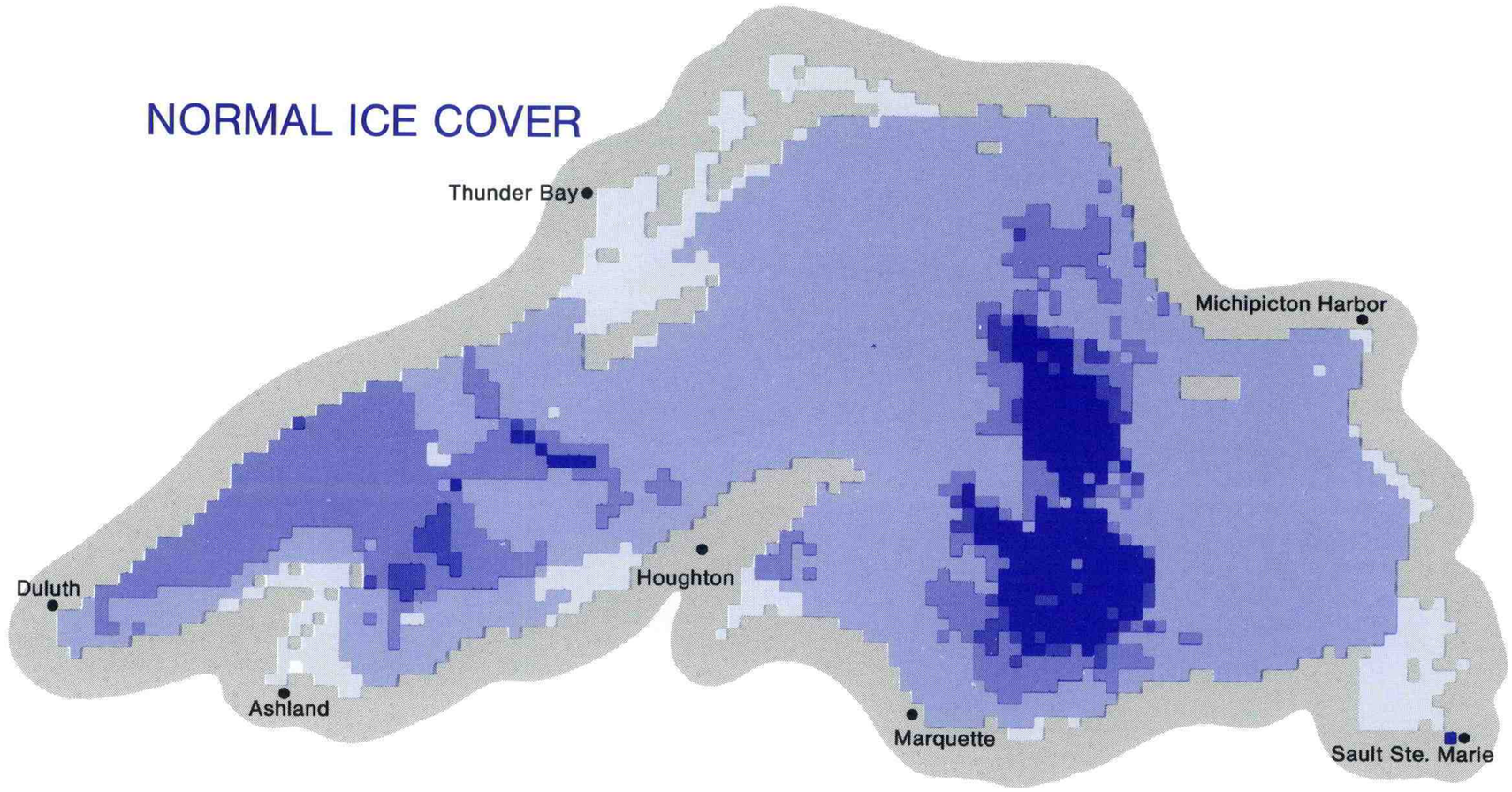
OBSERVATION LEGEND

- FIRST QUARTILE
  0 to 5 years of data
- SECOND QUARTILE
  6 to 10 years of data
- THIRD QUARTILE
  11 to 15 years of data
- FOURTH QUARTILE
  16 to 20 years of data

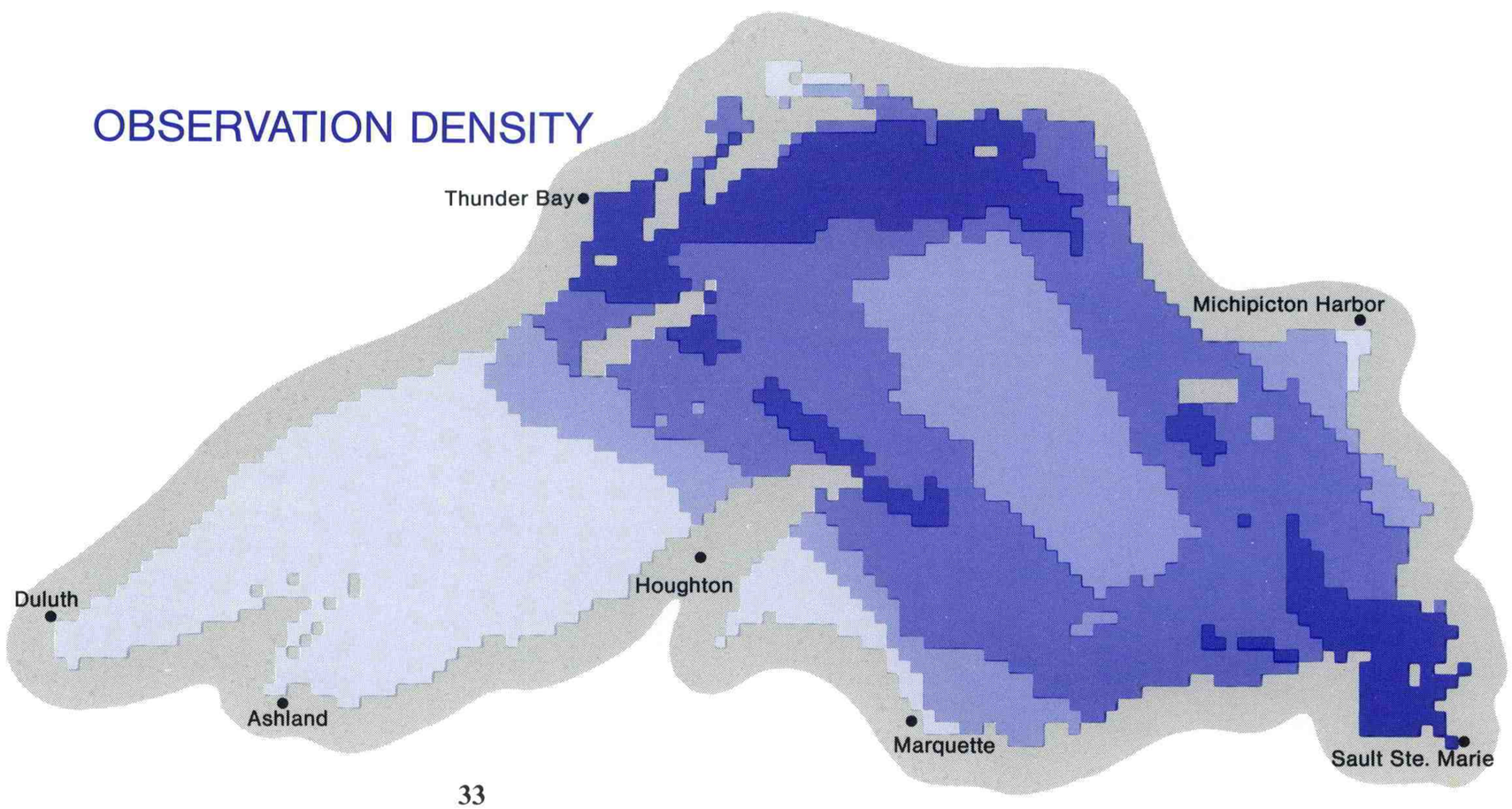
PLATE 5B

U.S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER



OBSERVATION DENSITY



EXTREMES IN ICE COVER

MARCH 1–15
1960–1979

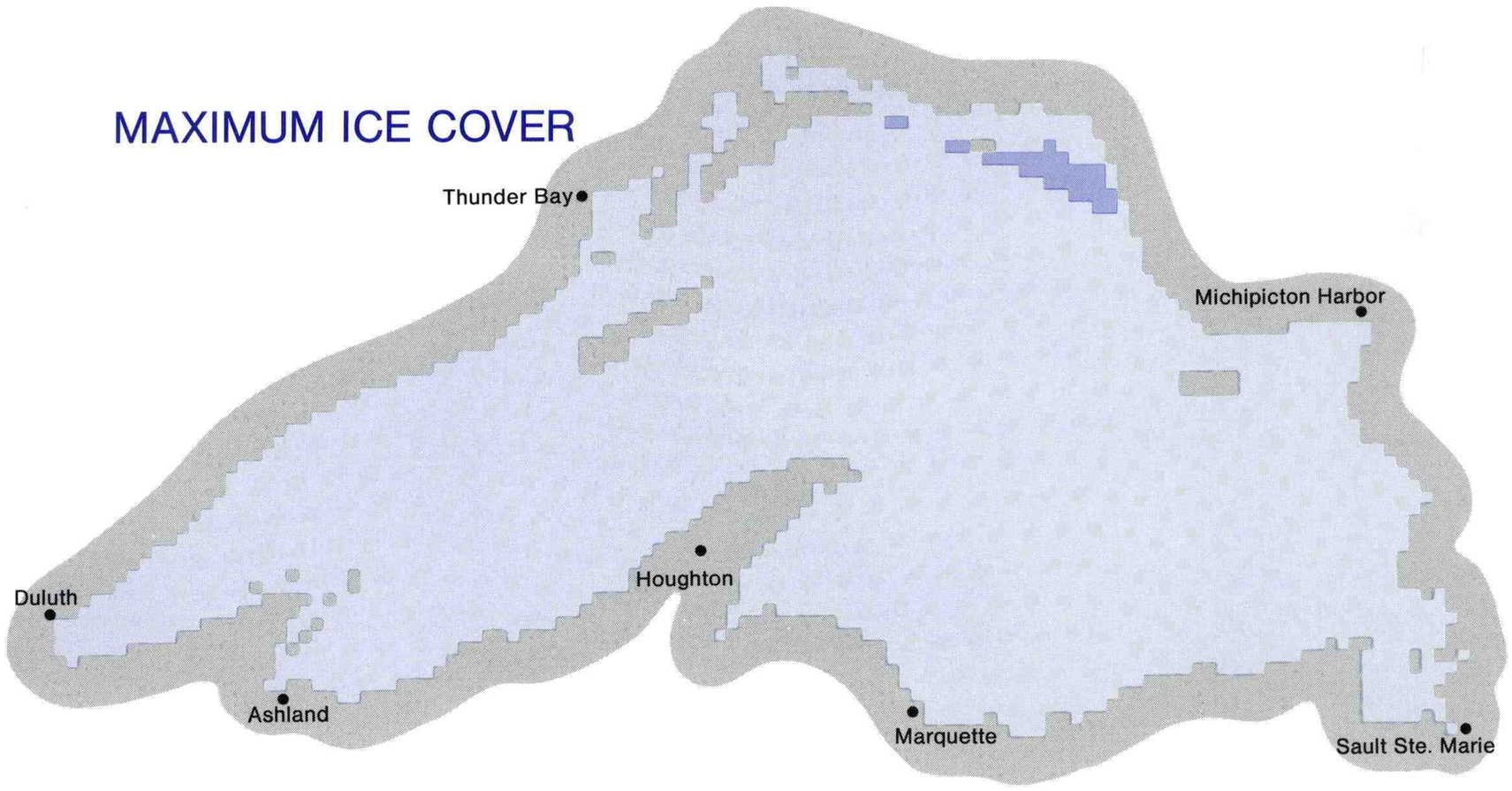
LAKE SUPERIOR

Kilometers
0 20 40 60 80 100
0 10 20 30 40 50 60
Statute Miles

ICE COVER LEGEND

- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

MAXIMUM ICE COVER



MINIMUM ICE COVER

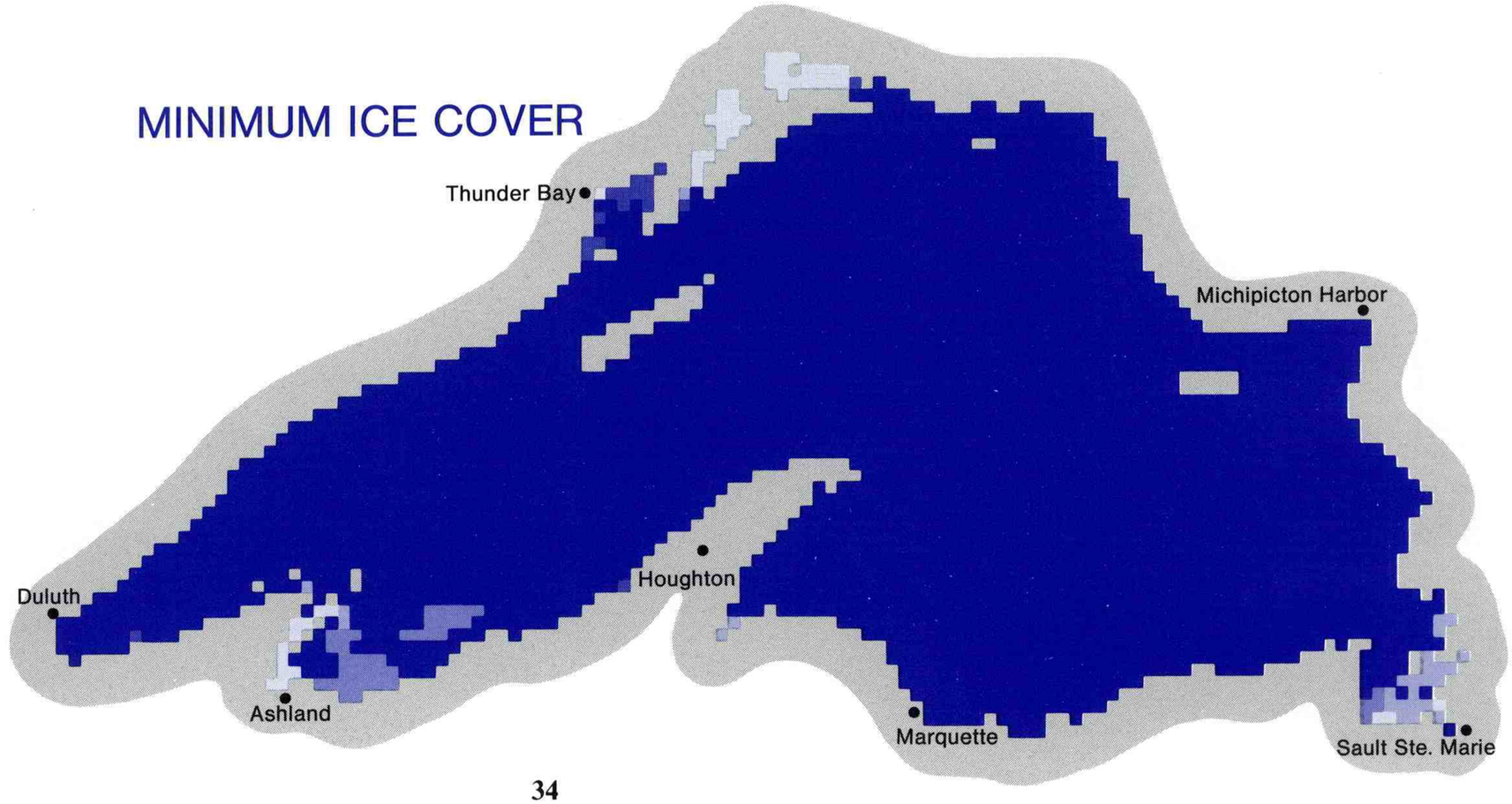


PLATE 6A

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER AND OBSERVATION DENSITY

MARCH 1–15
1960–1979

LAKE SUPERIOR

Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

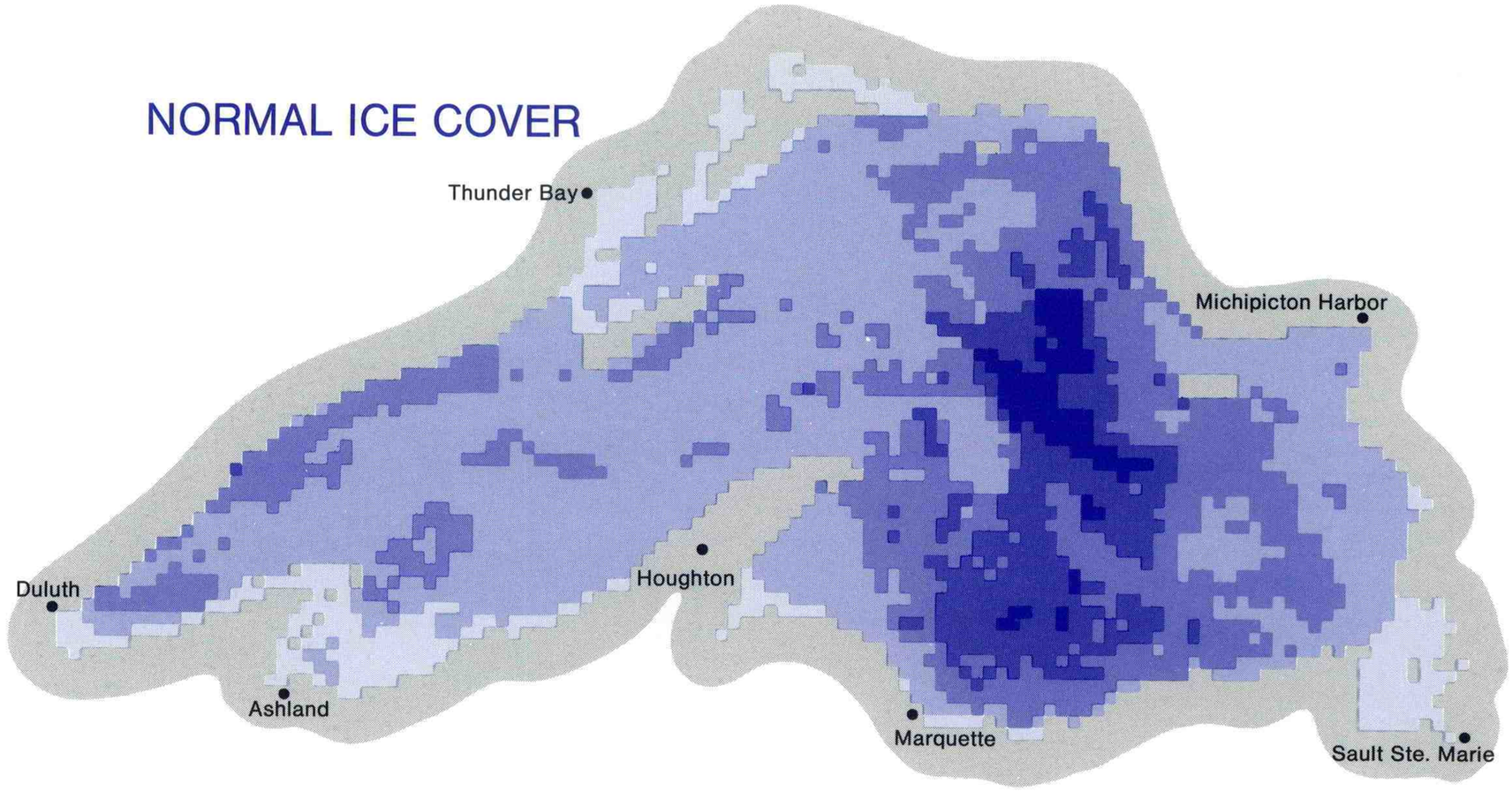
OBSERVATION LEGEND

- FIRST QUARTILE
  0 to 5 years of data
- SECOND QUARTILE
  6 to 10 years of data
- THIRD QUARTILE
  11 to 15 years of data
- FOURTH QUARTILE
  16 to 20 years of data

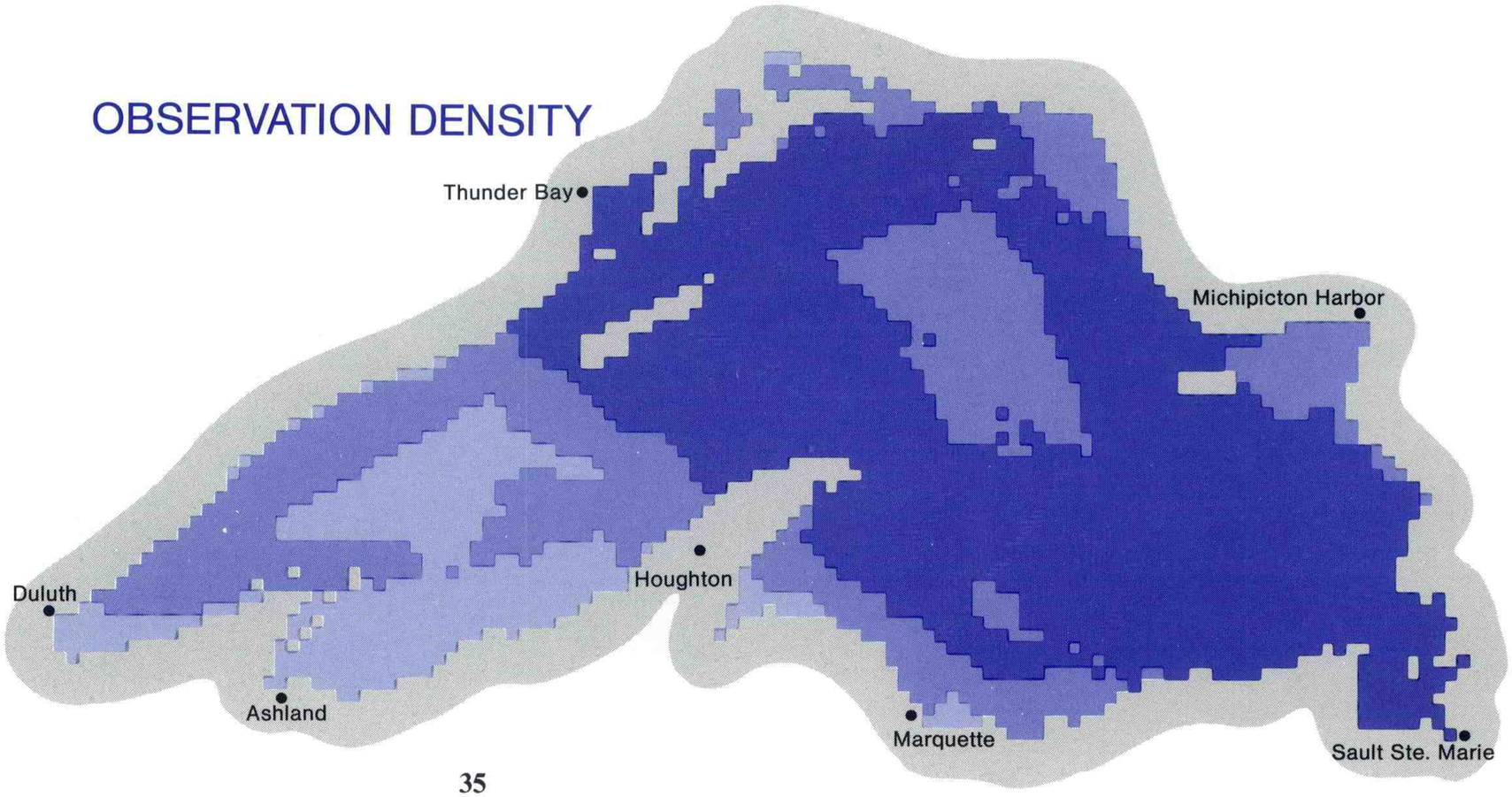
PLATE 6B

U.S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER



OBSERVATION DENSITY



EXTREMES IN ICE COVER

MARCH 16–31
1960–1979

LAKE SUPERIOR

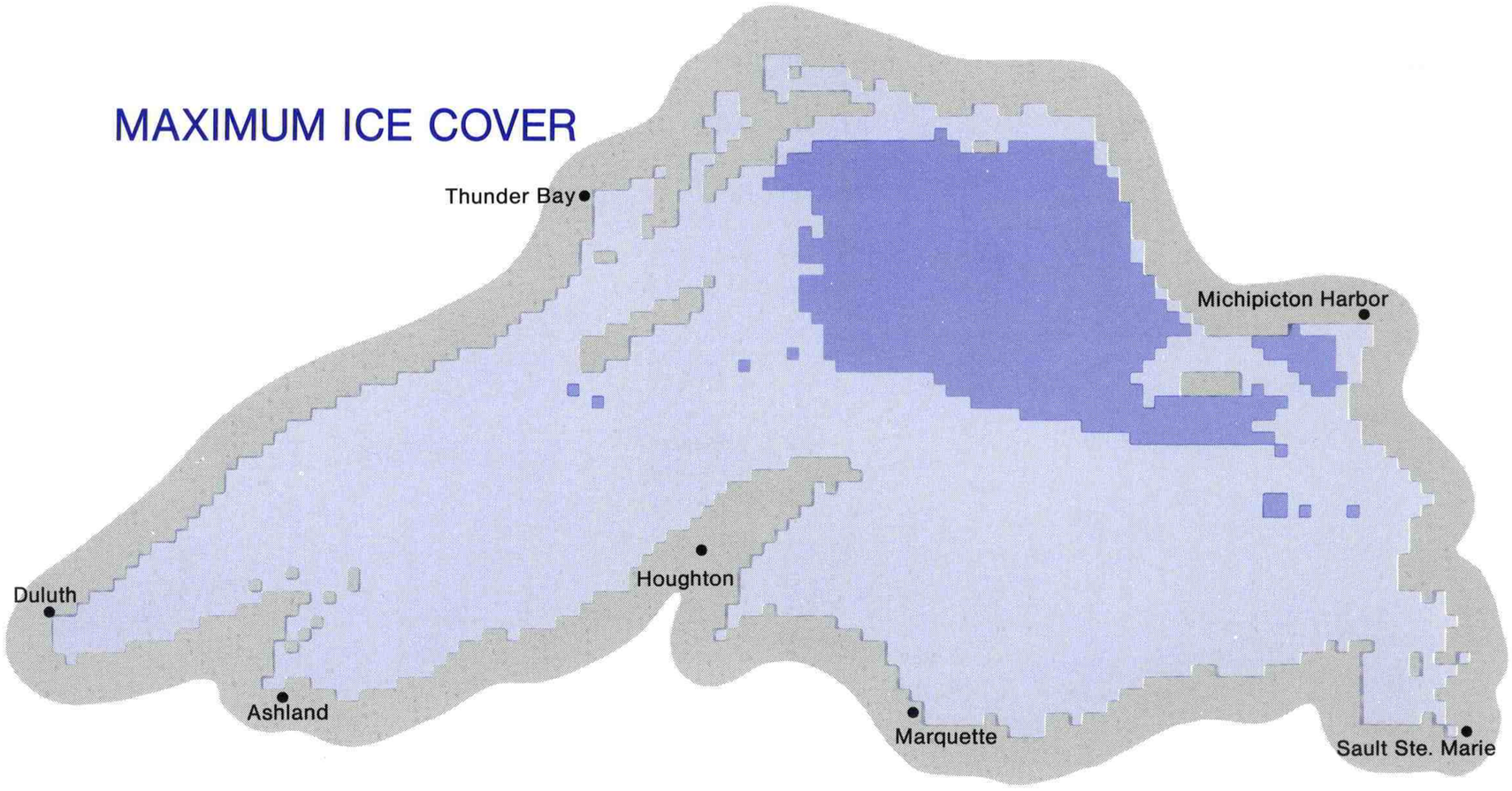
Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

ICE COVER LEGEND

- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

MAXIMUM ICE COVER



MINIMUM ICE COVER

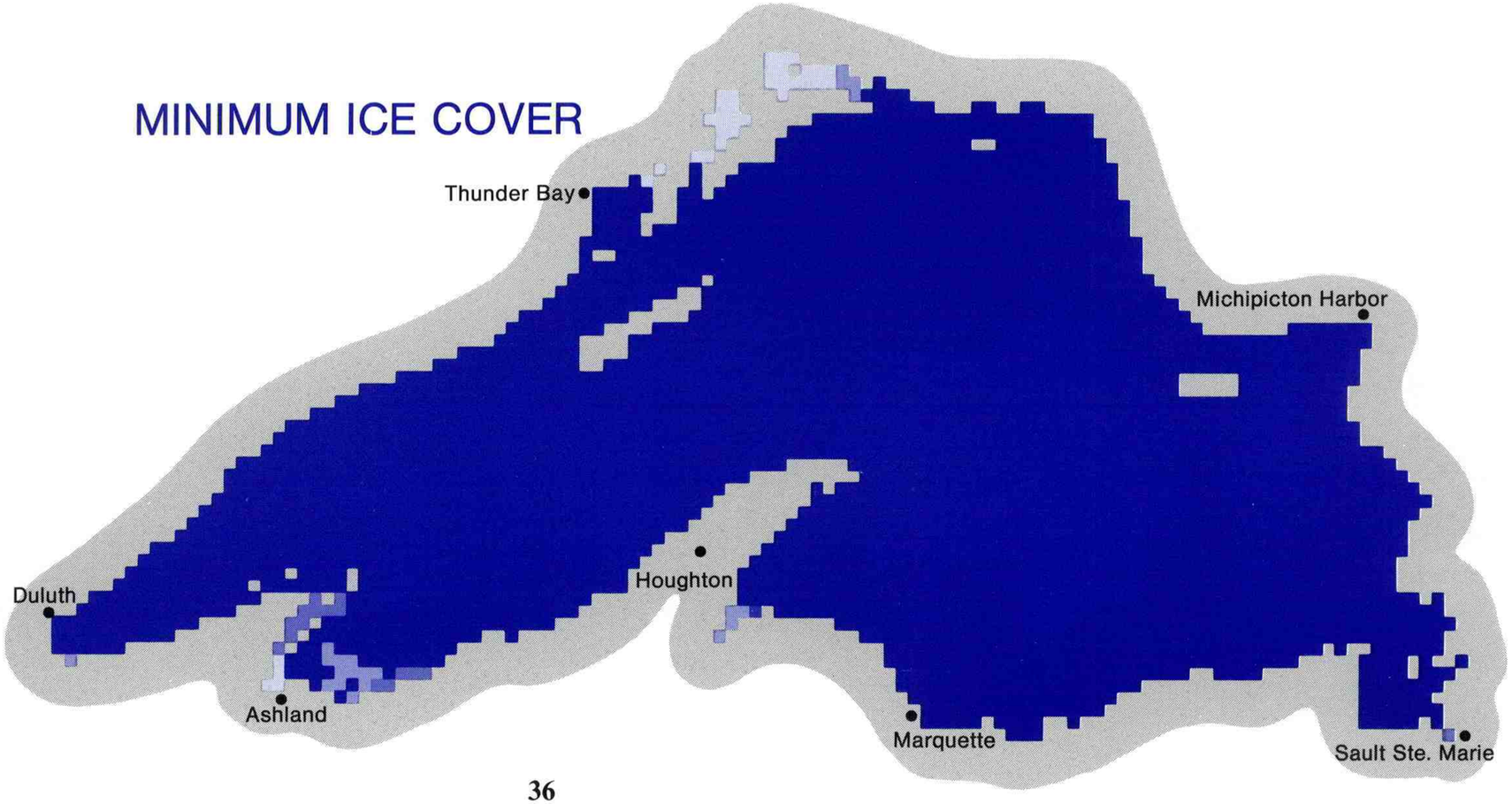


PLATE 7A

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER AND OBSERVATION DENSITY

MARCH 16–31
1960–1979

LAKE SUPERIOR

Kilometers
0 20 40 60 80 100
0 10 20 30 40 50 60
Statute Miles

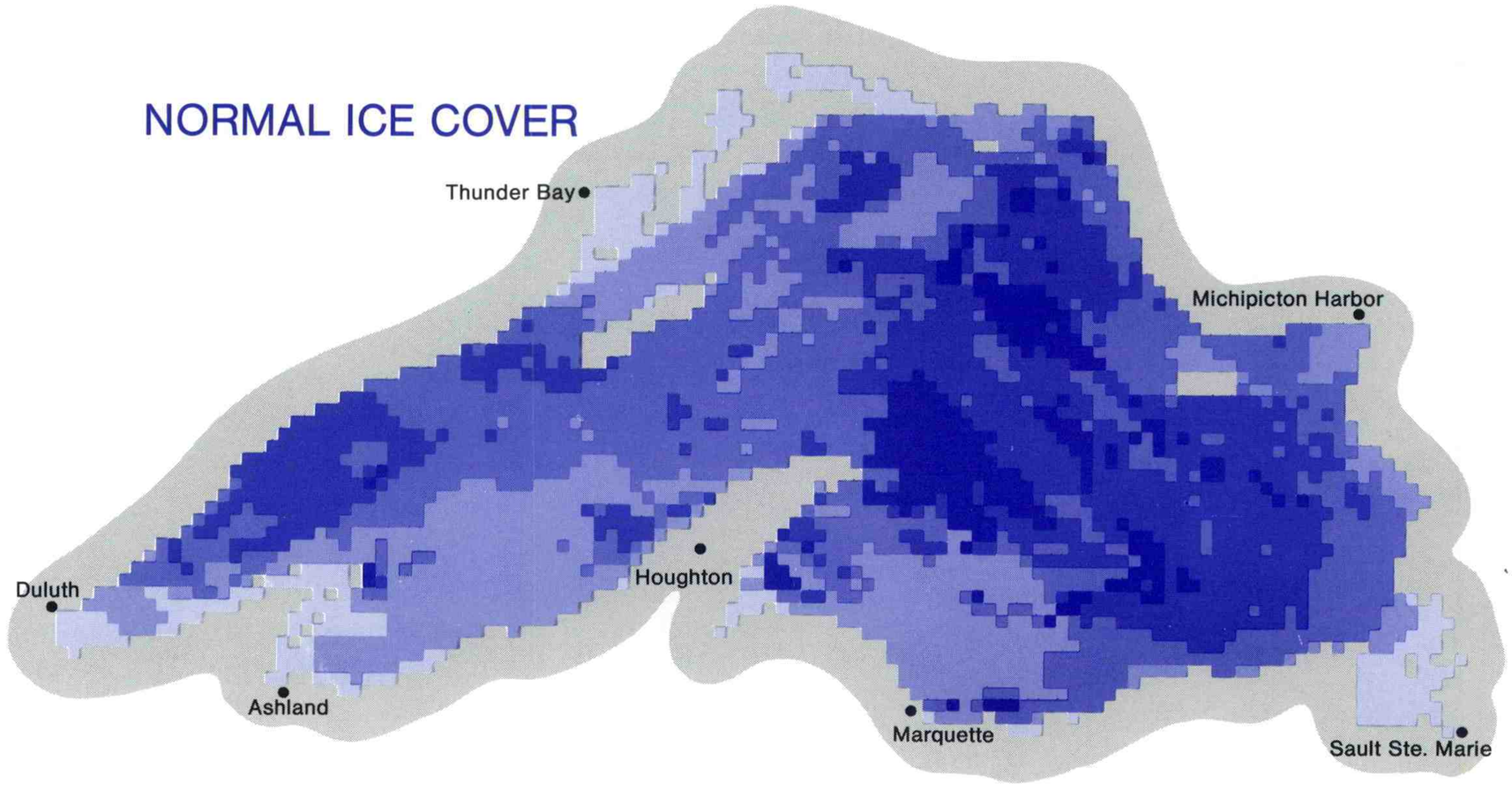
OBSERVATION LEGEND

- FIRST QUARTILE — 0 to 5 years of data
- SECOND QUARTILE — 6 to 10 years of data
- THIRD QUARTILE — 11 to 15 years of data
- FOURTH QUARTILE — 16 to 20 years of data

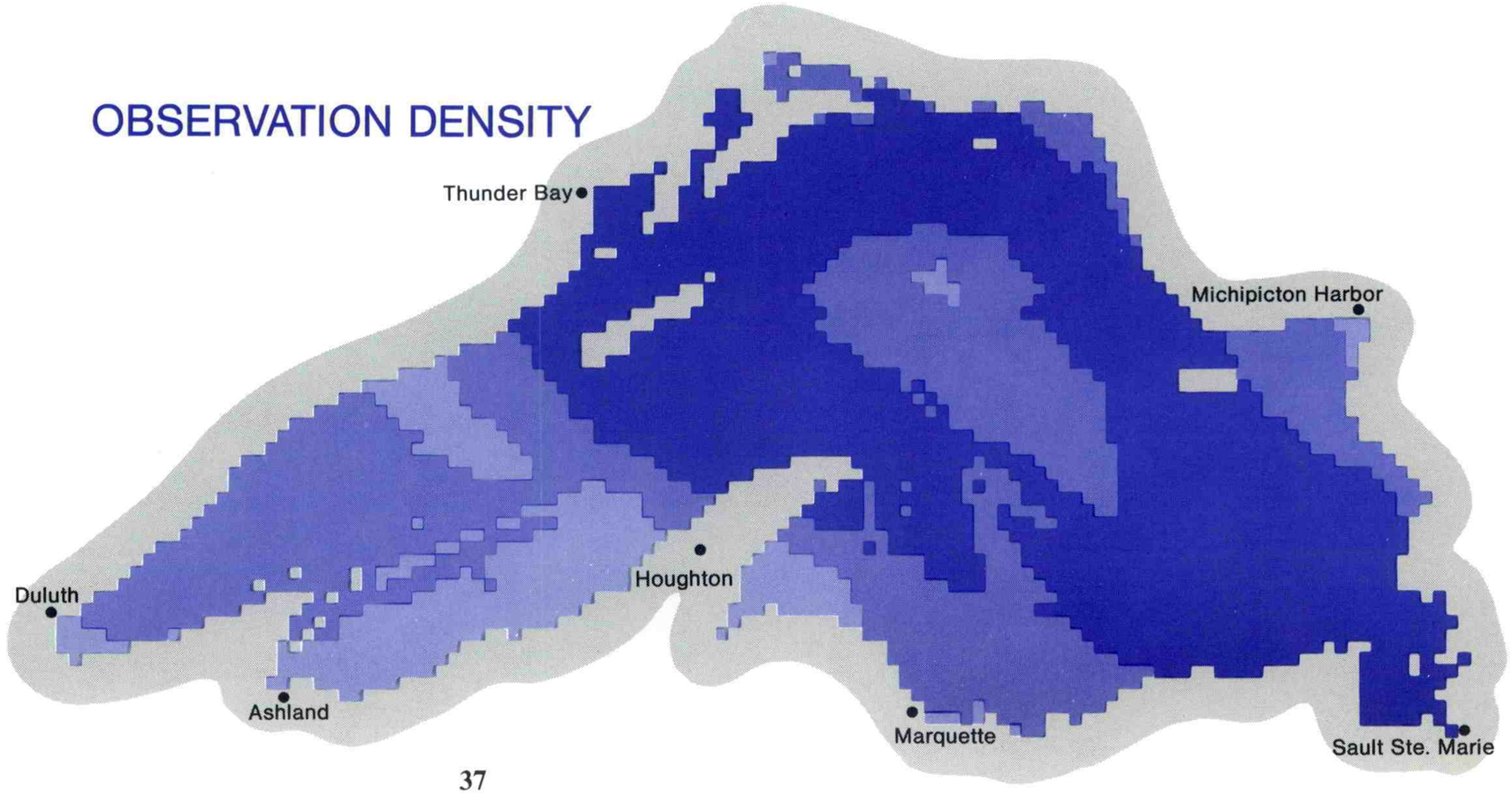
PLATE 7B

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER



OBSERVATION DENSITY



EXTREMES IN ICE COVER

APRIL 1–15
1960–1979

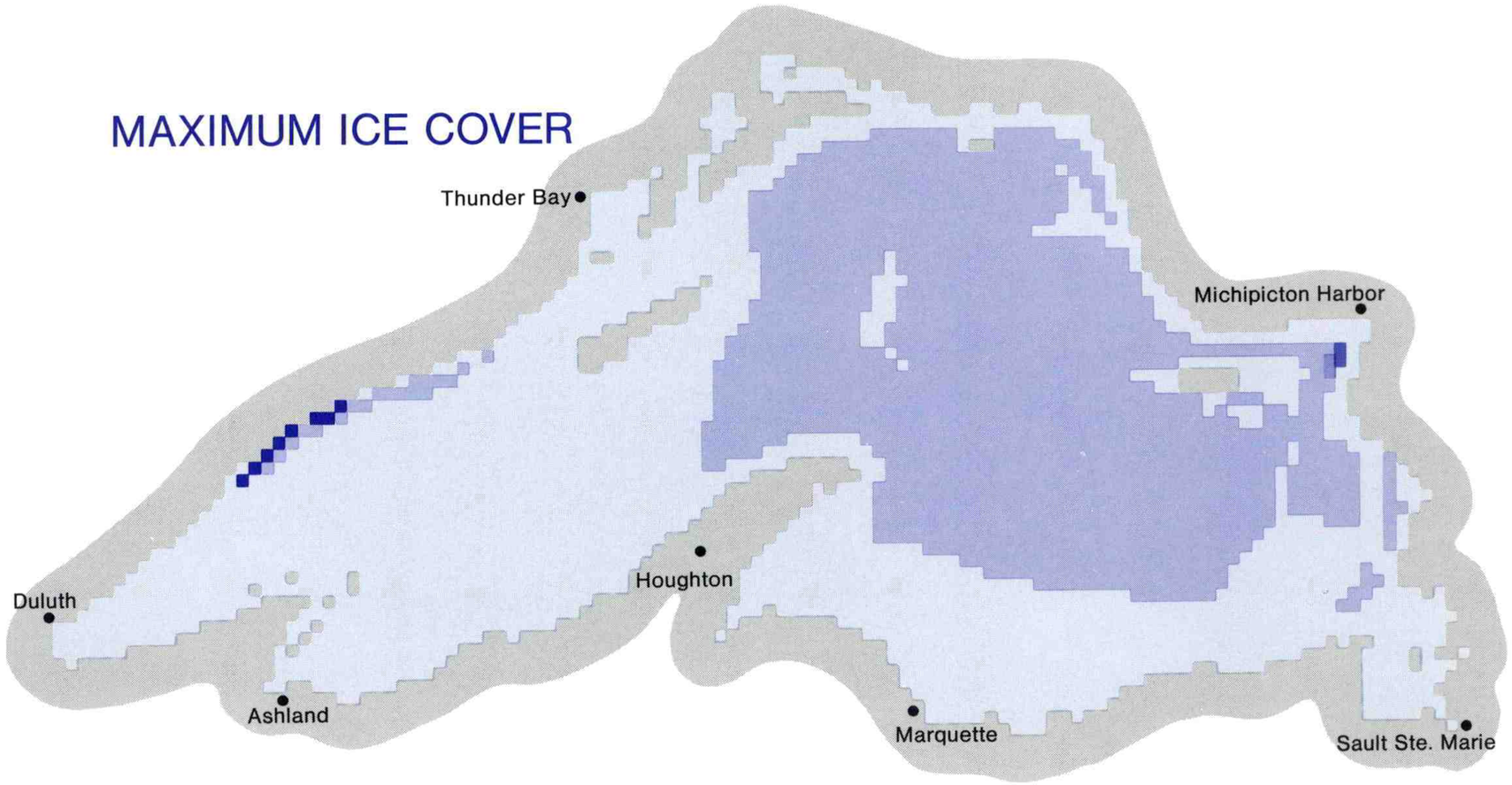
LAKE SUPERIOR

Kilometers
0 20 40 60 80 100
0 10 20 30 40 50 60
Statute Miles

ICE COVER LEGEND

- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

MAXIMUM ICE COVER



MINIMUM ICE COVER

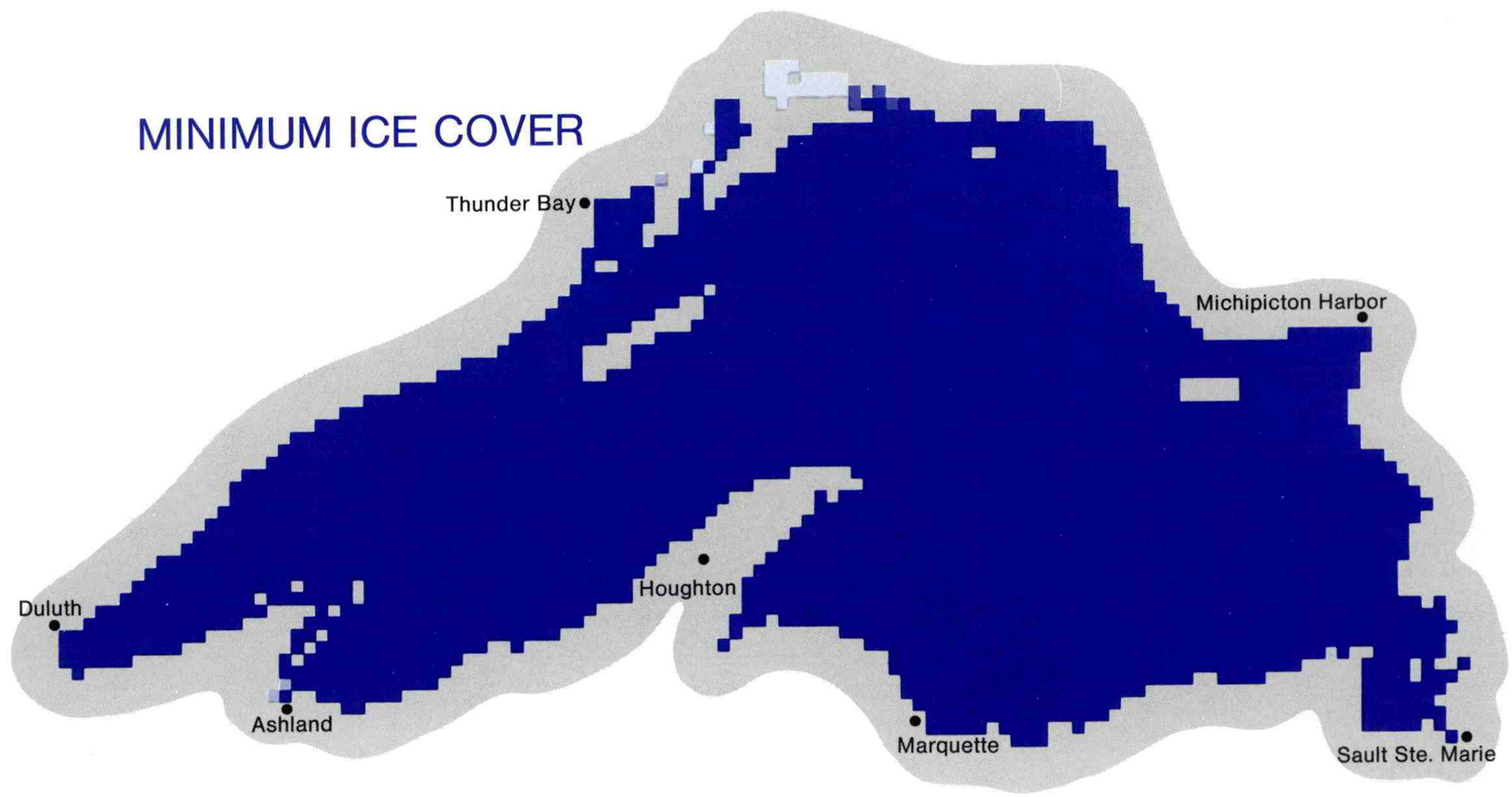


PLATE 8A

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER AND OBSERVATION DENSITY

APRIL 1–15

1960–1979

LAKE SUPERIOR

Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

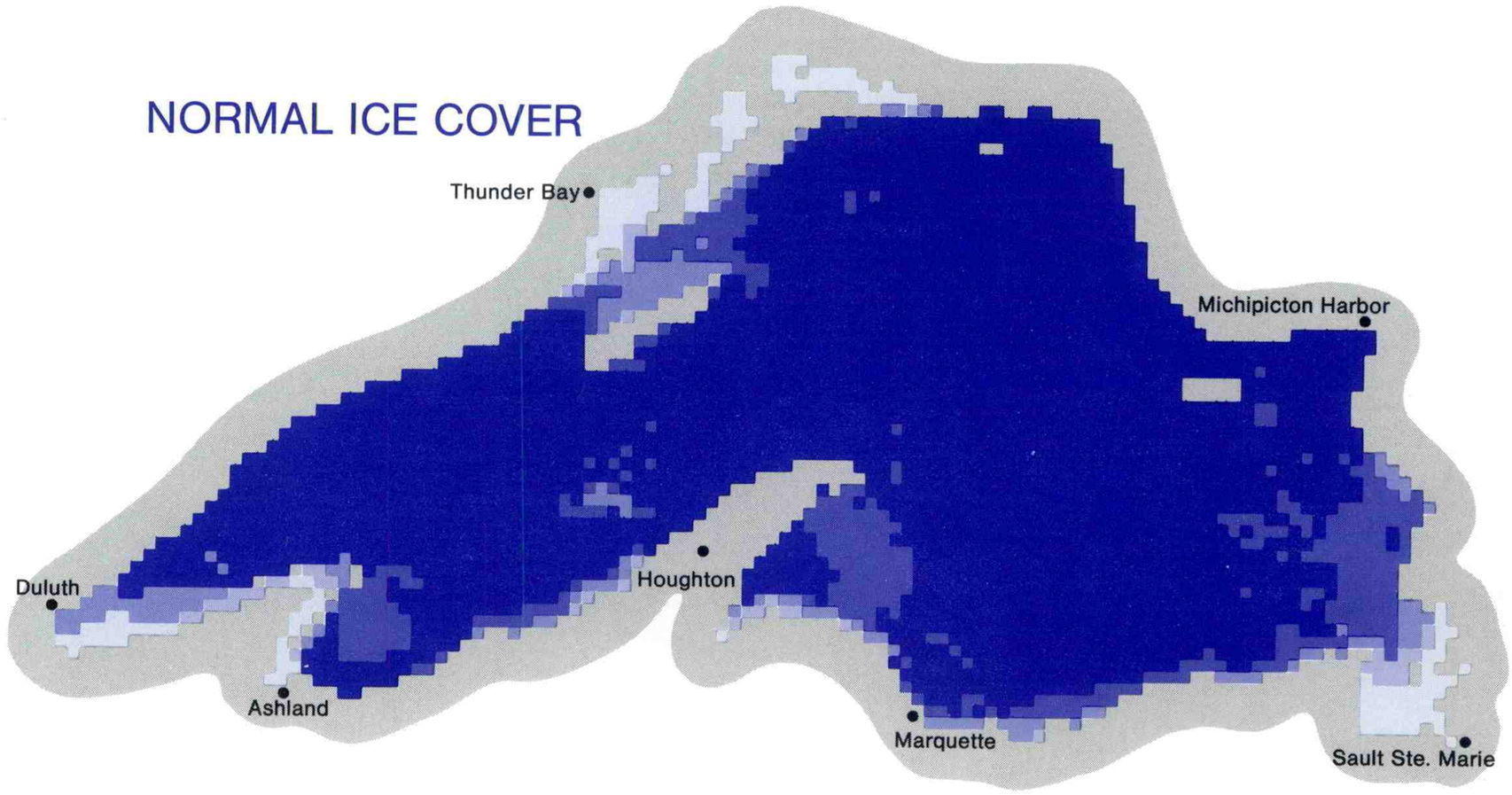
OBSERVATION LEGEND

- FIRST QUARTILE
  0 to 5 years of data
- SECOND QUARTILE
  6 to 10 years of data
- THIRD QUARTILE
  11 to 15 years of data
- FOURTH QUARTILE
  16 to 20 years of data

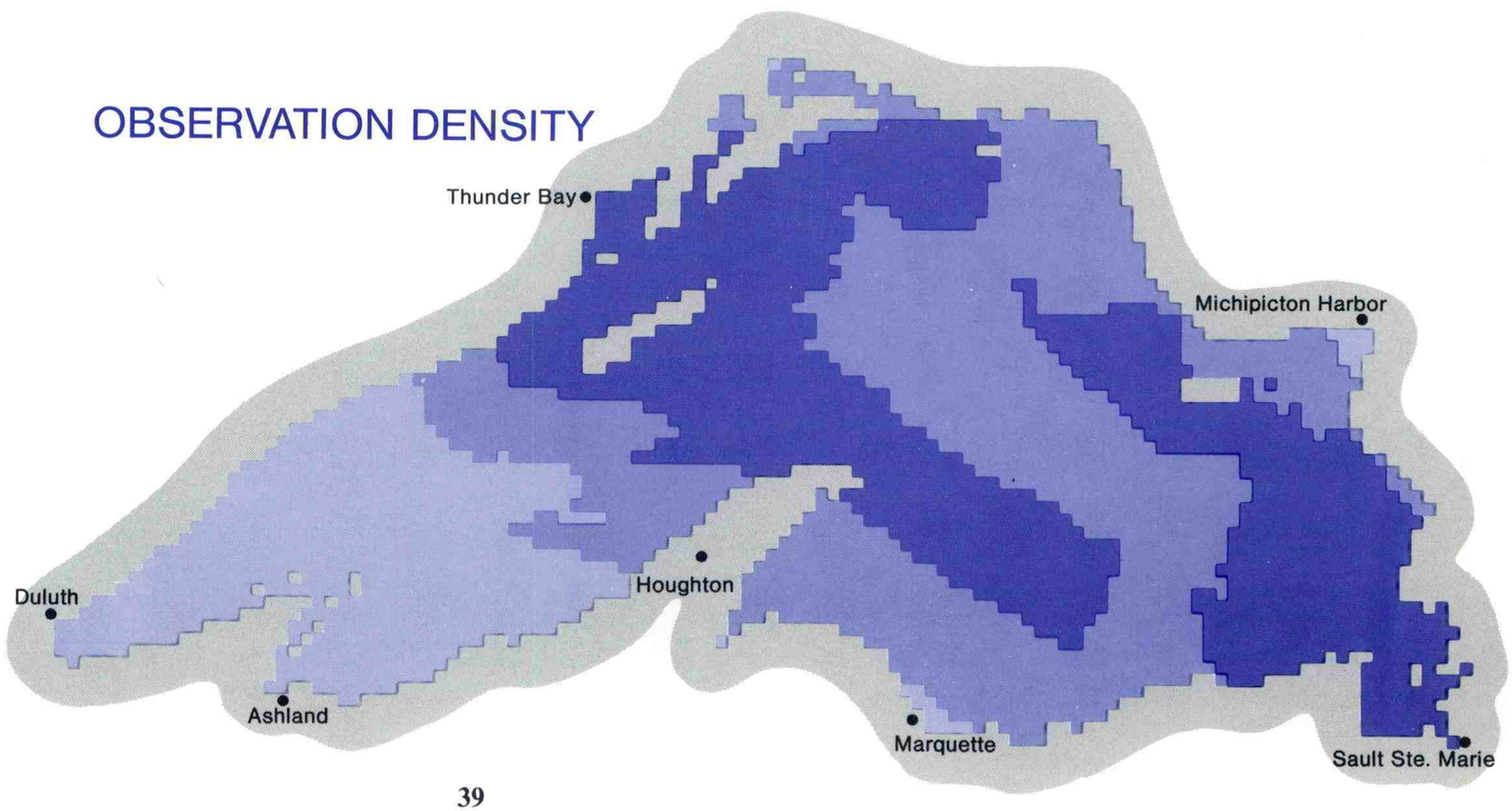
PLATE 8B

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER



OBSERVATION DENSITY



EXTREMES IN ICE COVER

APRIL 16–30
1960–1979

LAKE SUPERIOR

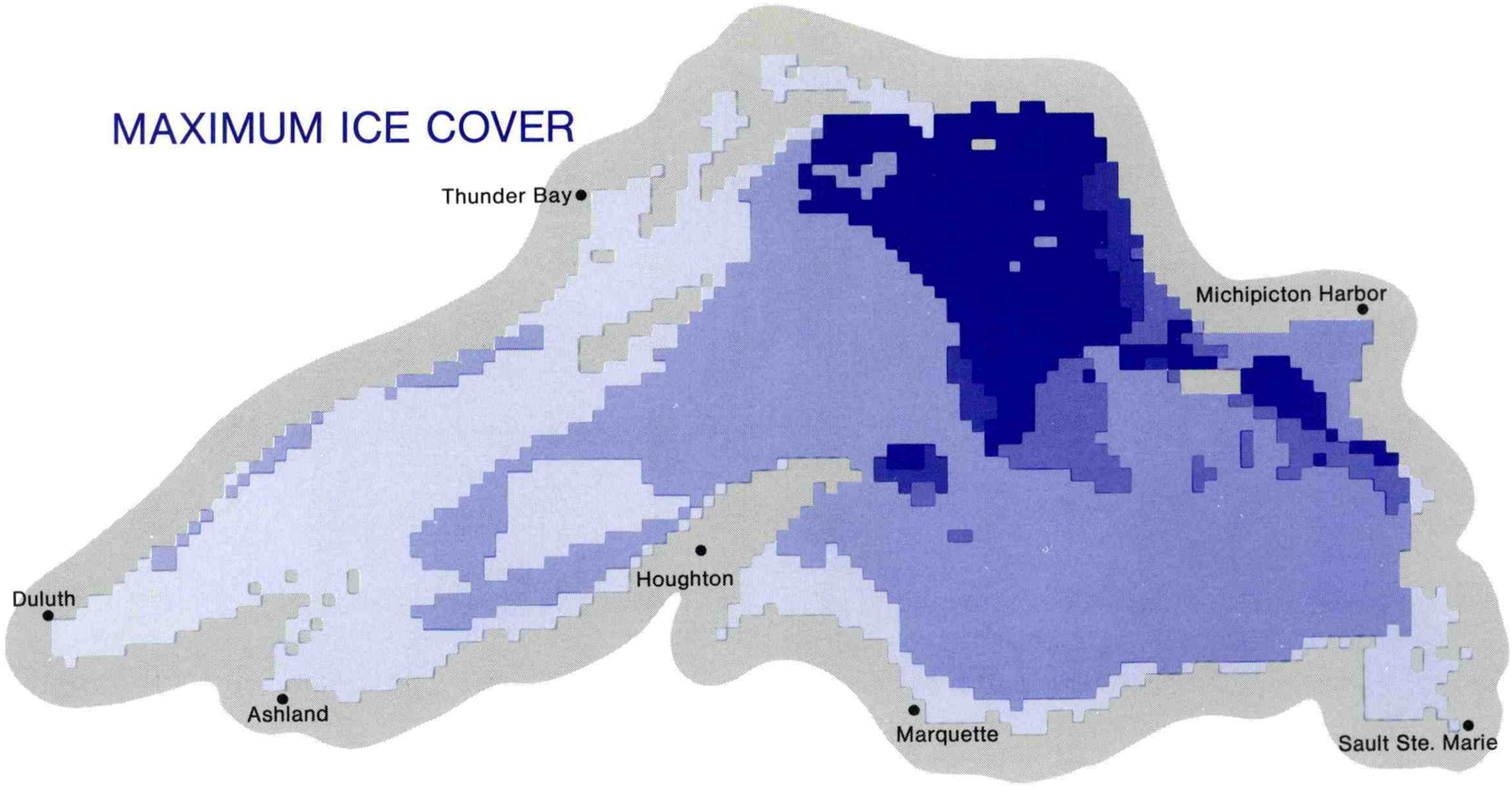
Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

ICE COVER LEGEND

- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

MAXIMUM ICE COVER



MINIMUM ICE COVER

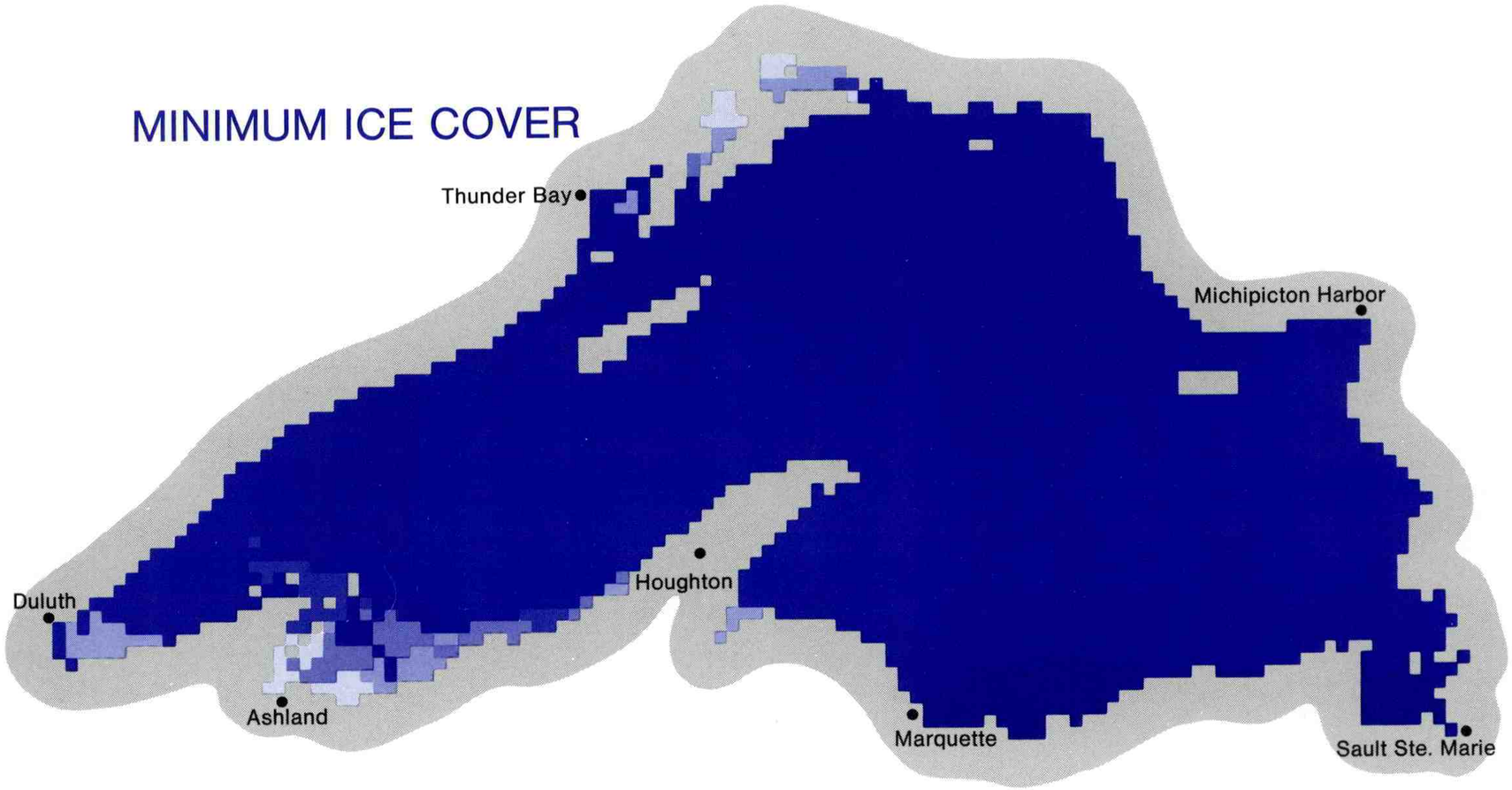


PLATE 9A

U.S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER AND OBSERVATION DENSITY

APRIL 16–30

1960–1979

LAKE SUPERIOR

Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

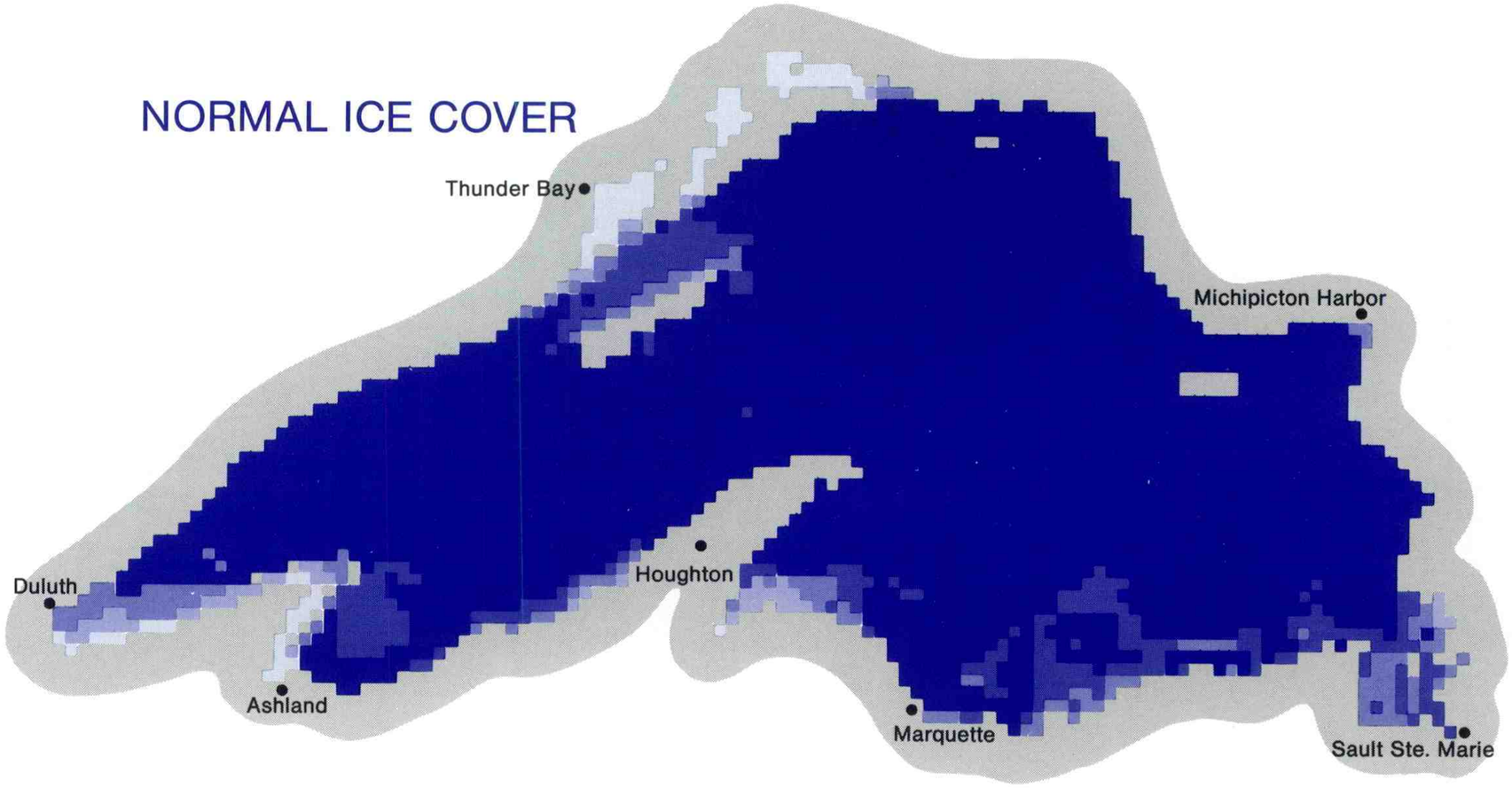
OBSERVATION LEGEND

- FIRST QUARTILE
  0 to 5 years of data
- SECOND QUARTILE
  6 to 10 years of data
- THIRD QUARTILE
  11 to 15 years of data
- FOURTH QUARTILE
  16 to 20 years of data

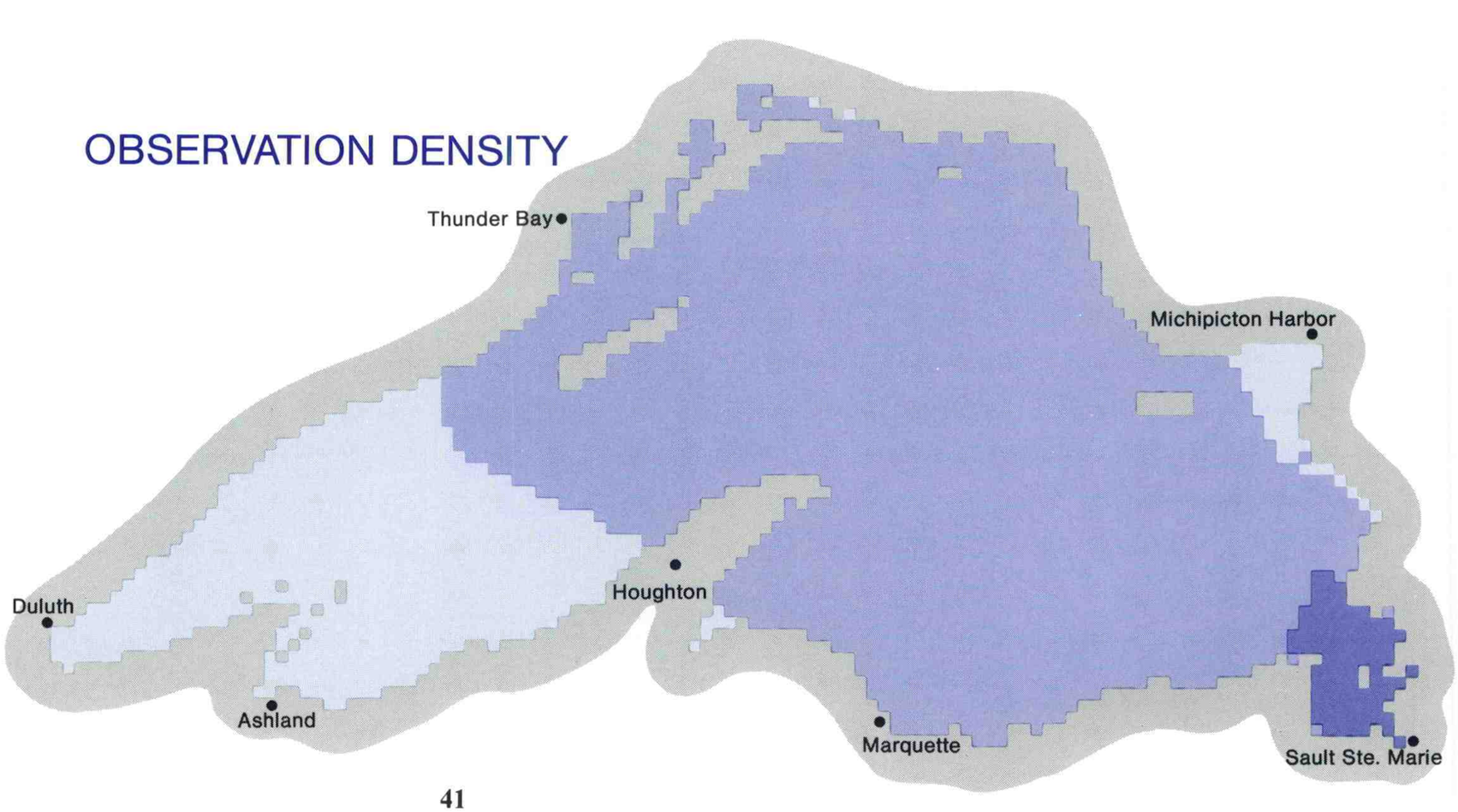
PLATE 9B

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER



OBSERVATION DENSITY



EXTREMES IN ICE COVER

DECEMBER 16–31
1960–1979

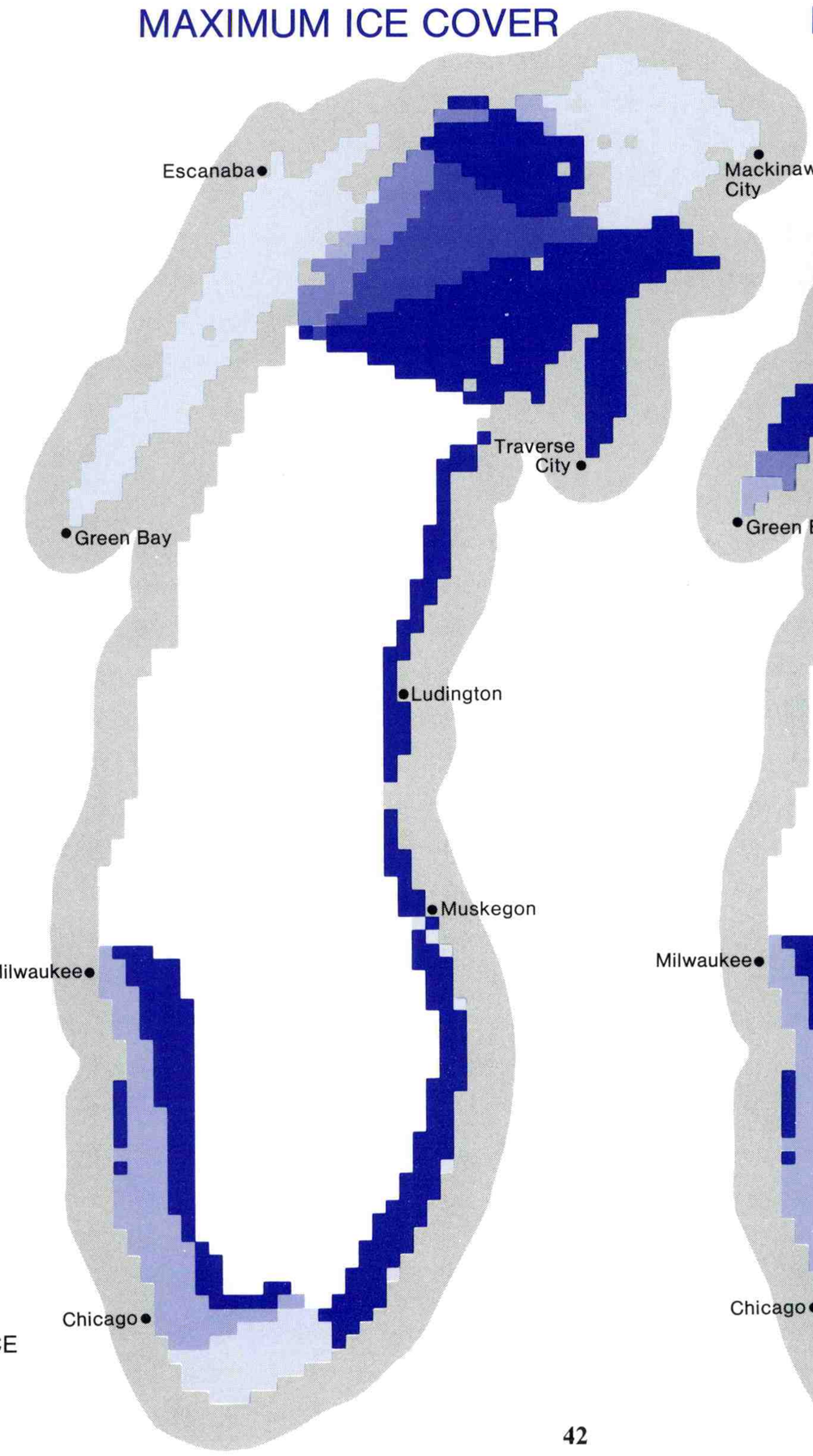
LAKE MICHIGAN

Kilometers
0 20 40 60 80 100
0 10 20 30 40 50 60
Statute Miles

ICE COVER LEGEND

- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

MAXIMUM ICE COVER



MINIMUM ICE COVER

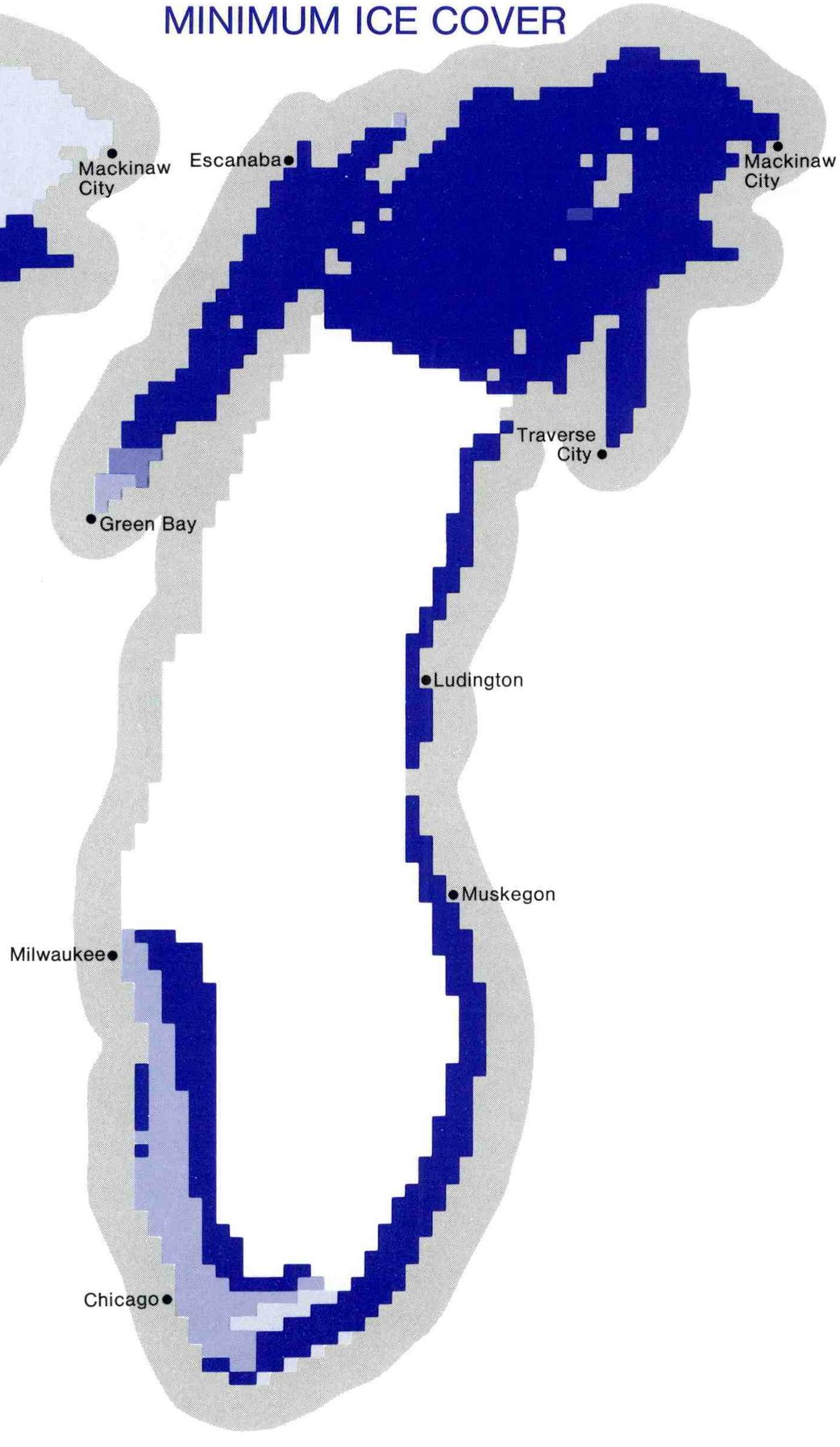


PLATE 10A

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER AND OBSERVATION DENSITY

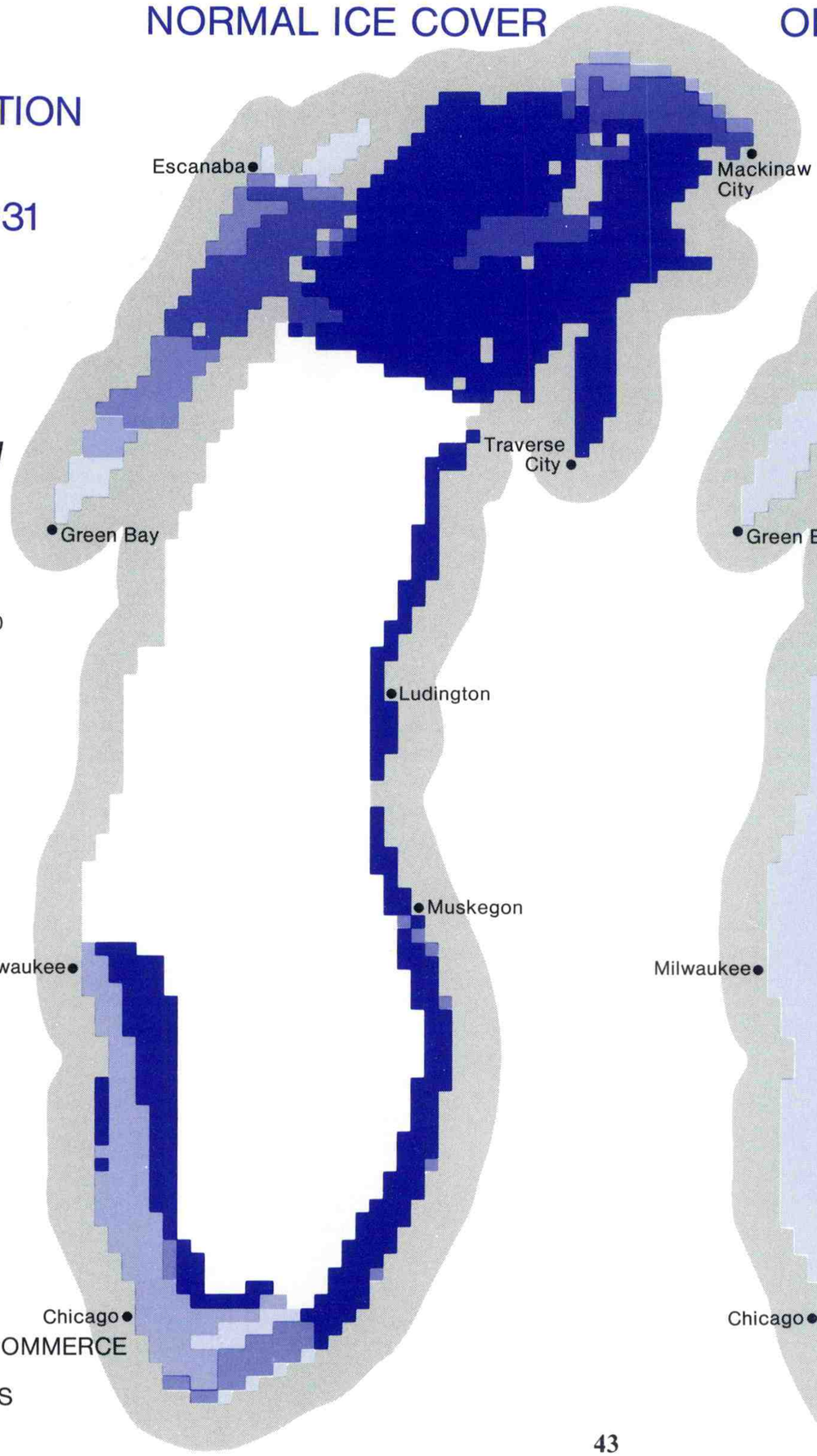
DECEMBER 16–31

1960–1979

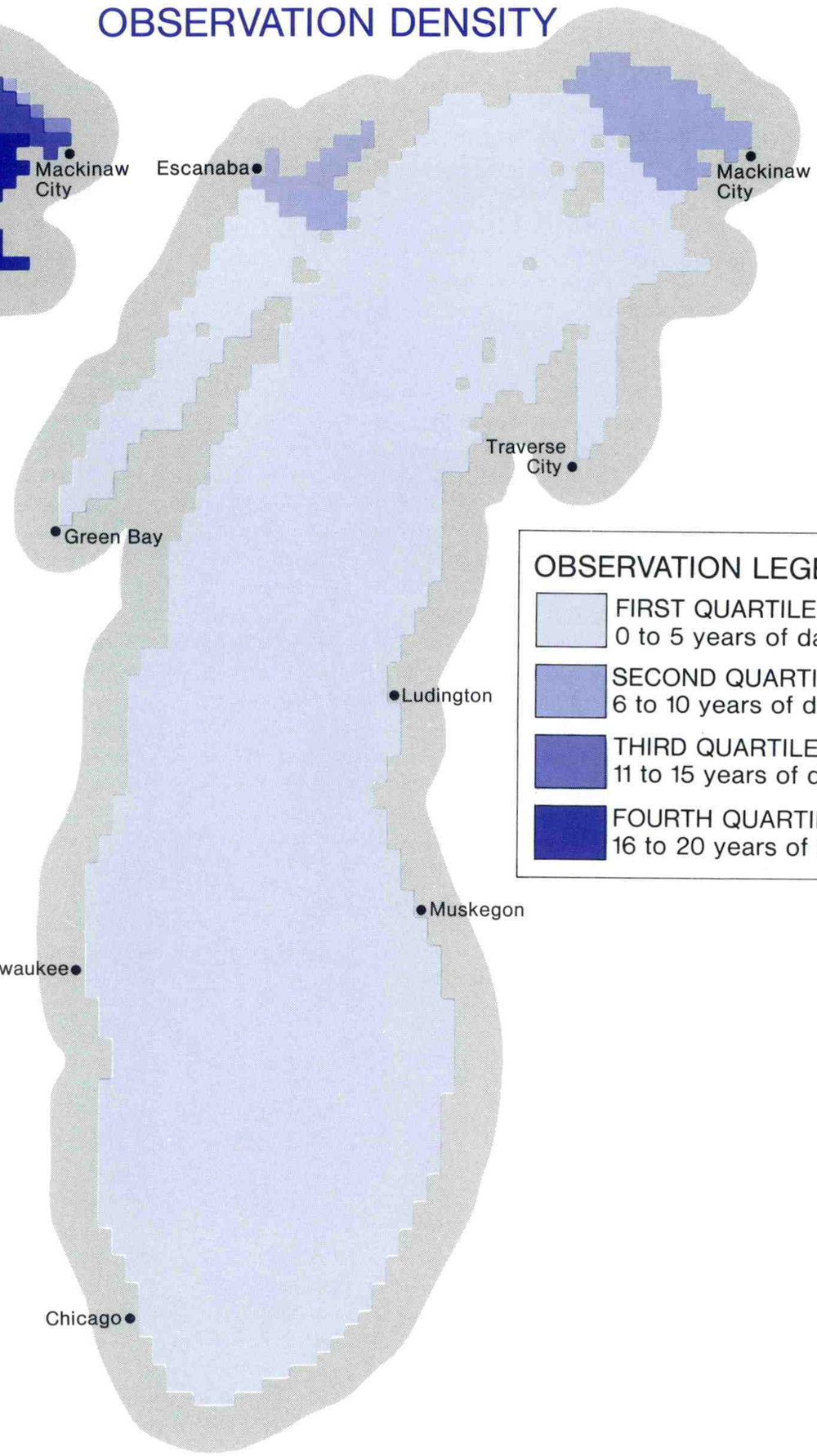
LAKE MICHIGAN

Kilometers
0 20 40 60 80 100
0 10 20 30 40 50 60
Statute Miles

NORMAL ICE COVER



OBSERVATION DENSITY



OBSERVATION LEGEND

- FIRST QUARTILE — 0 to 5 years of data
- SECOND QUARTILE — 6 to 10 years of data
- THIRD QUARTILE — 11 to 15 years of data
- FOURTH QUARTILE — 16 to 20 years of data

PLATE 10B

U.S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

EXTREMES IN ICE COVER

JANUARY 1–15

1960–1979

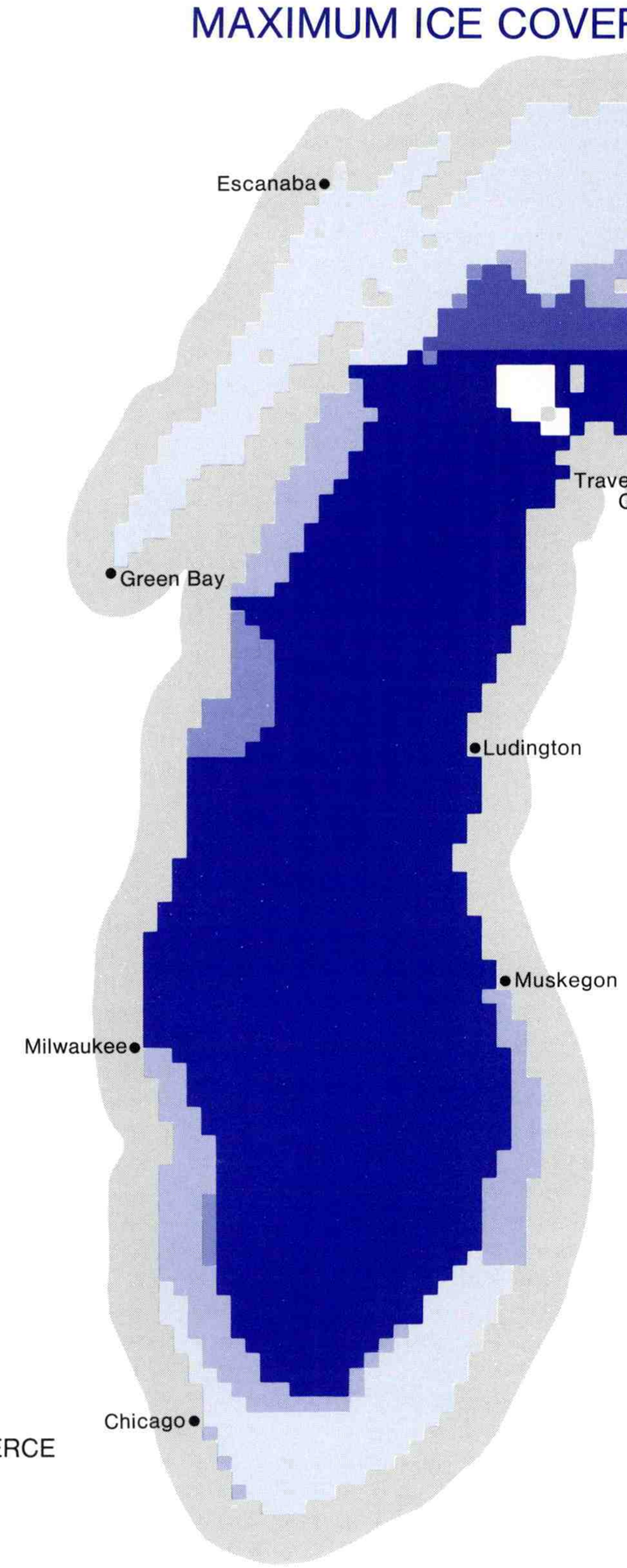
LAKE MICHIGAN

Kilometers
0 20 40 60 80 100
0 10 20 30 40 50 60
Statute Miles

ICE COVER LEGEND

- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

MAXIMUM ICE COVER



MINIMUM ICE COVER

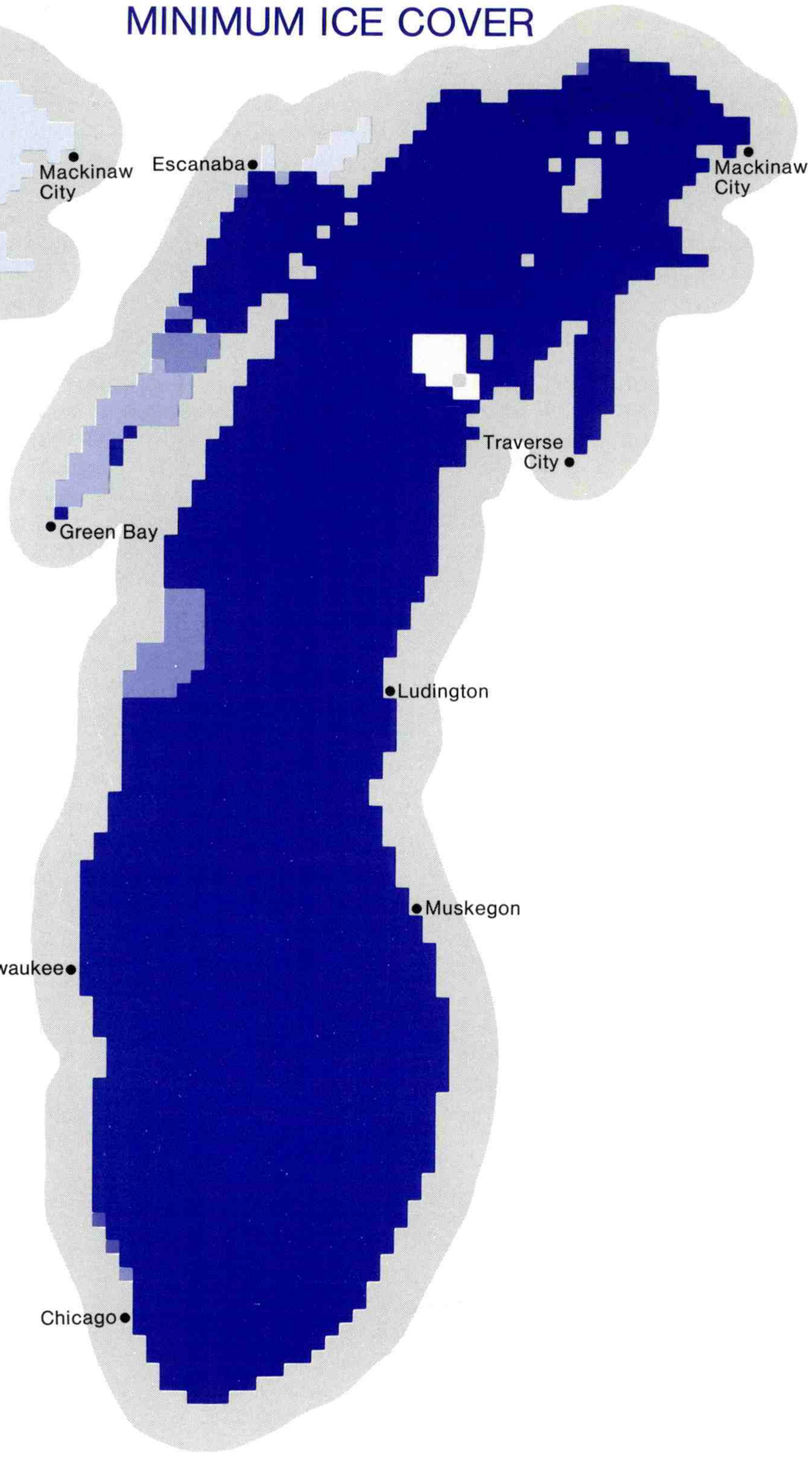


PLATE 11A

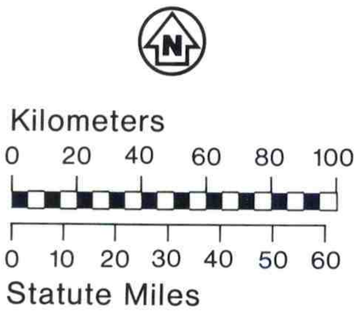
U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER AND OBSERVATION DENSITY

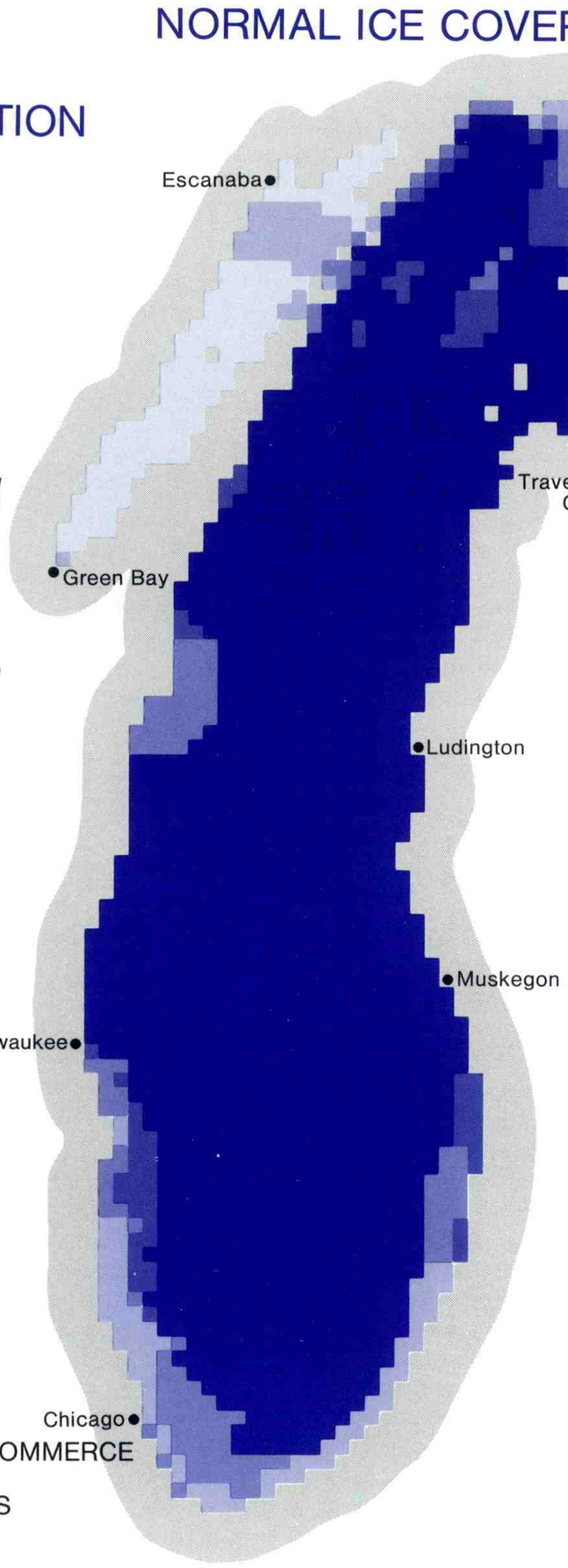
JANUARY 1–15

1960–1979

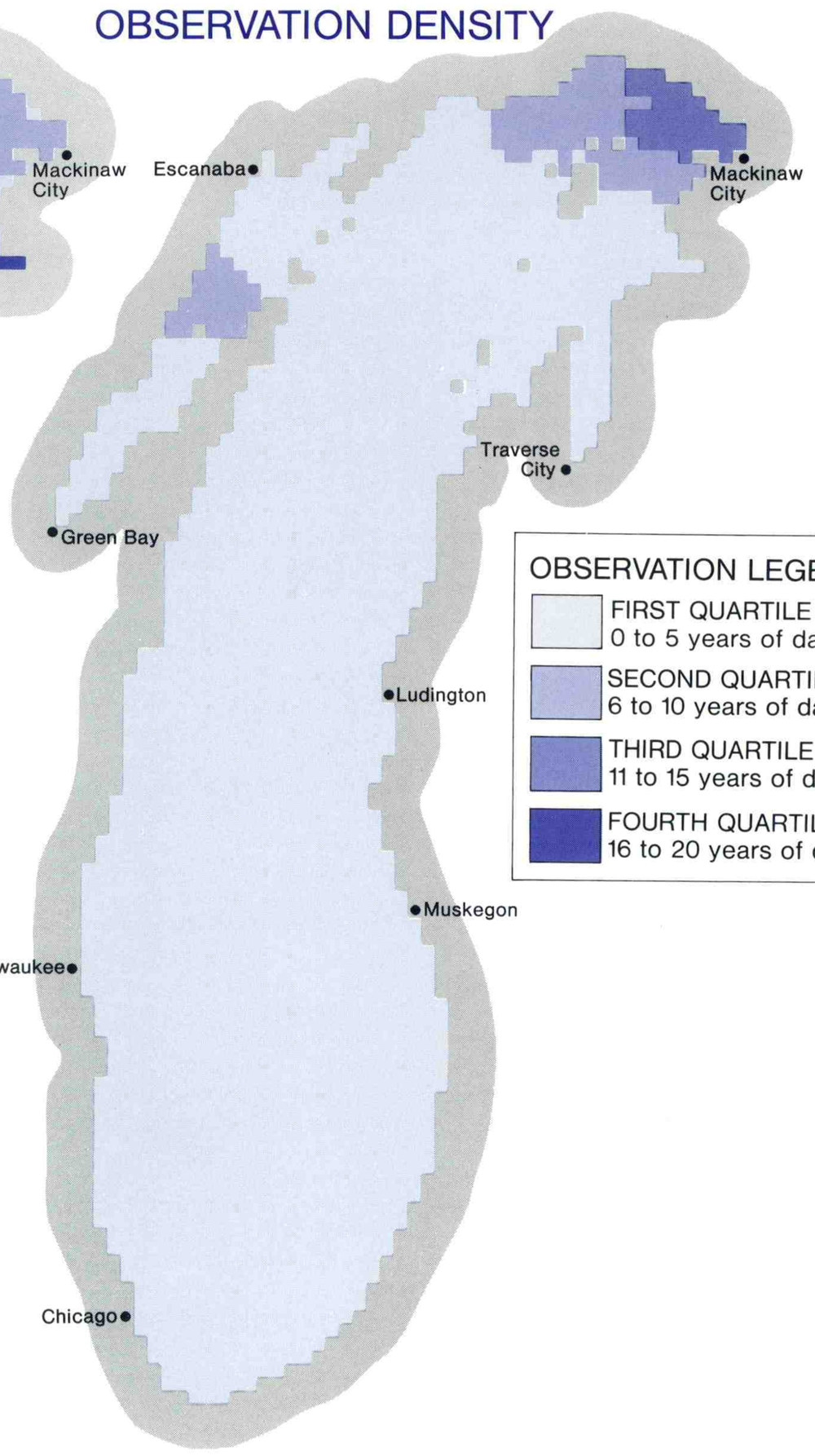
LAKE MICHIGAN



NORMAL ICE COVER



OBSERVATION DENSITY



OBSERVATION LEGEND

- FIRST QUARTILE — 0 to 5 years of data
- SECOND QUARTILE — 6 to 10 years of data
- THIRD QUARTILE — 11 to 15 years of data
- FOURTH QUARTILE — 16 to 20 years of data

PLATE 11B

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

EXTREMES IN ICE COVER

JANUARY 16–31
1960–1979

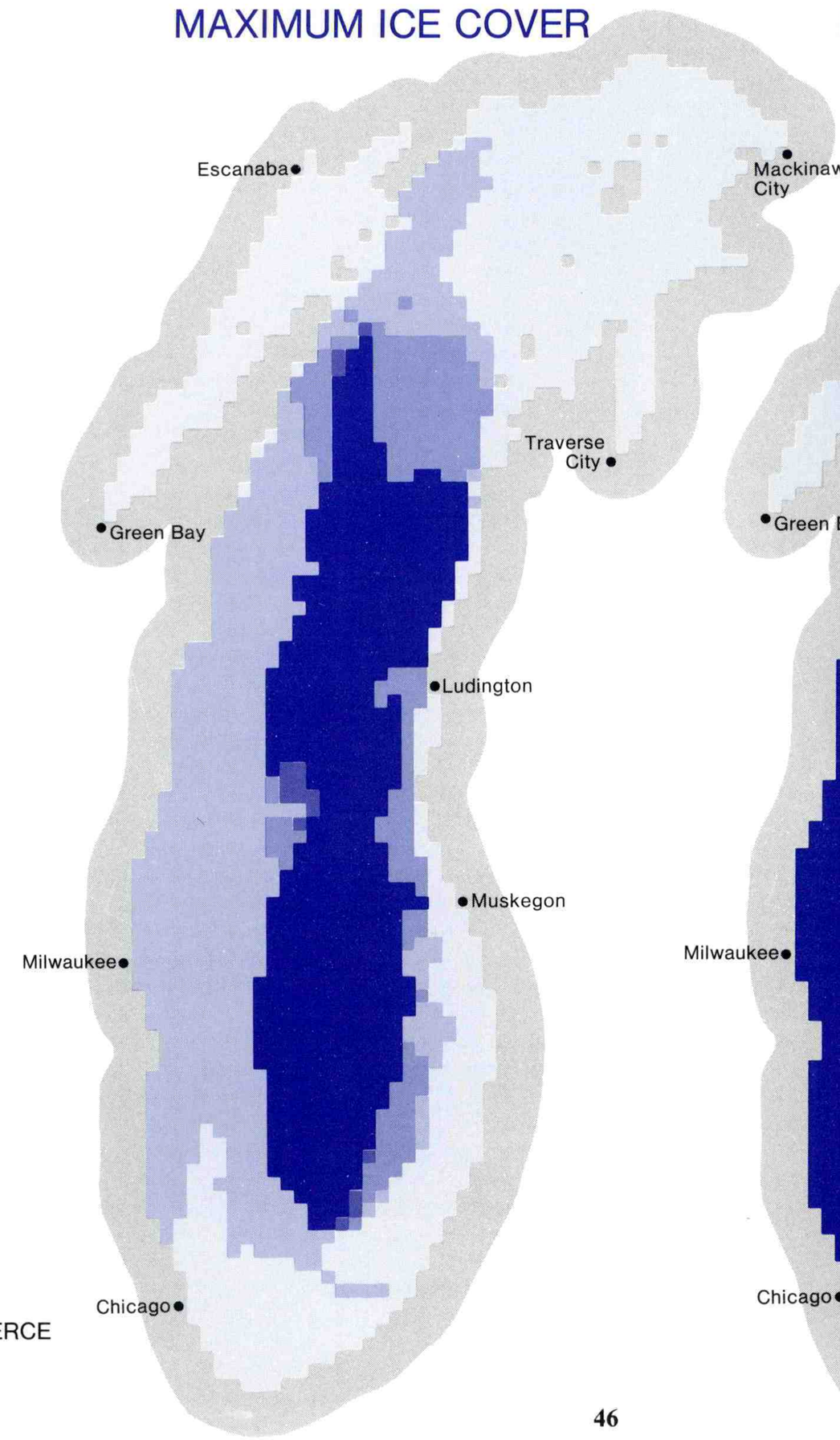
LAKE MICHIGAN

Kilometers
0 20 40 60 80 100
0 10 20 30 40 50 60
Statute Miles

ICE COVER LEGEND

- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

MAXIMUM ICE COVER



MINIMUM ICE COVER

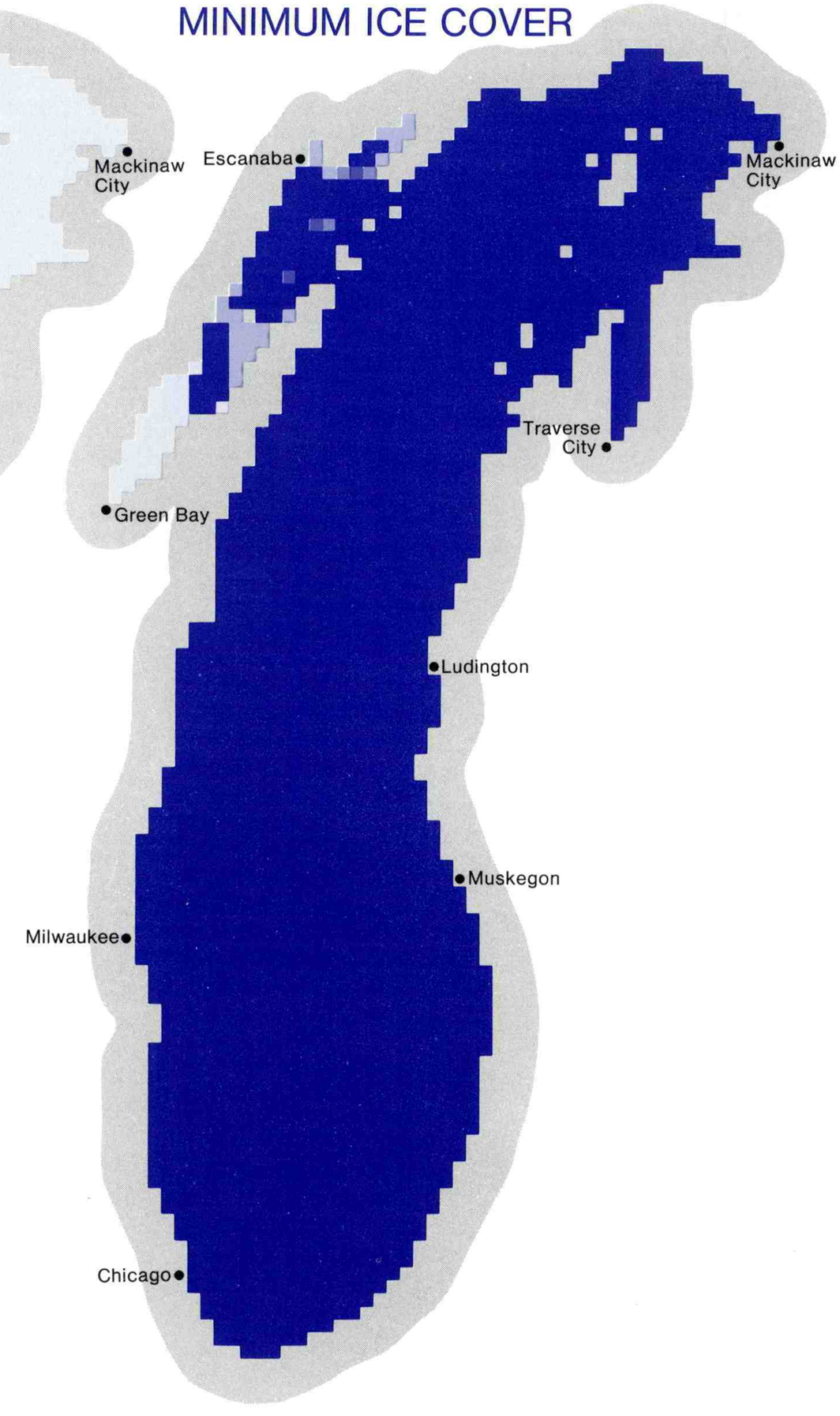


PLATE 12A

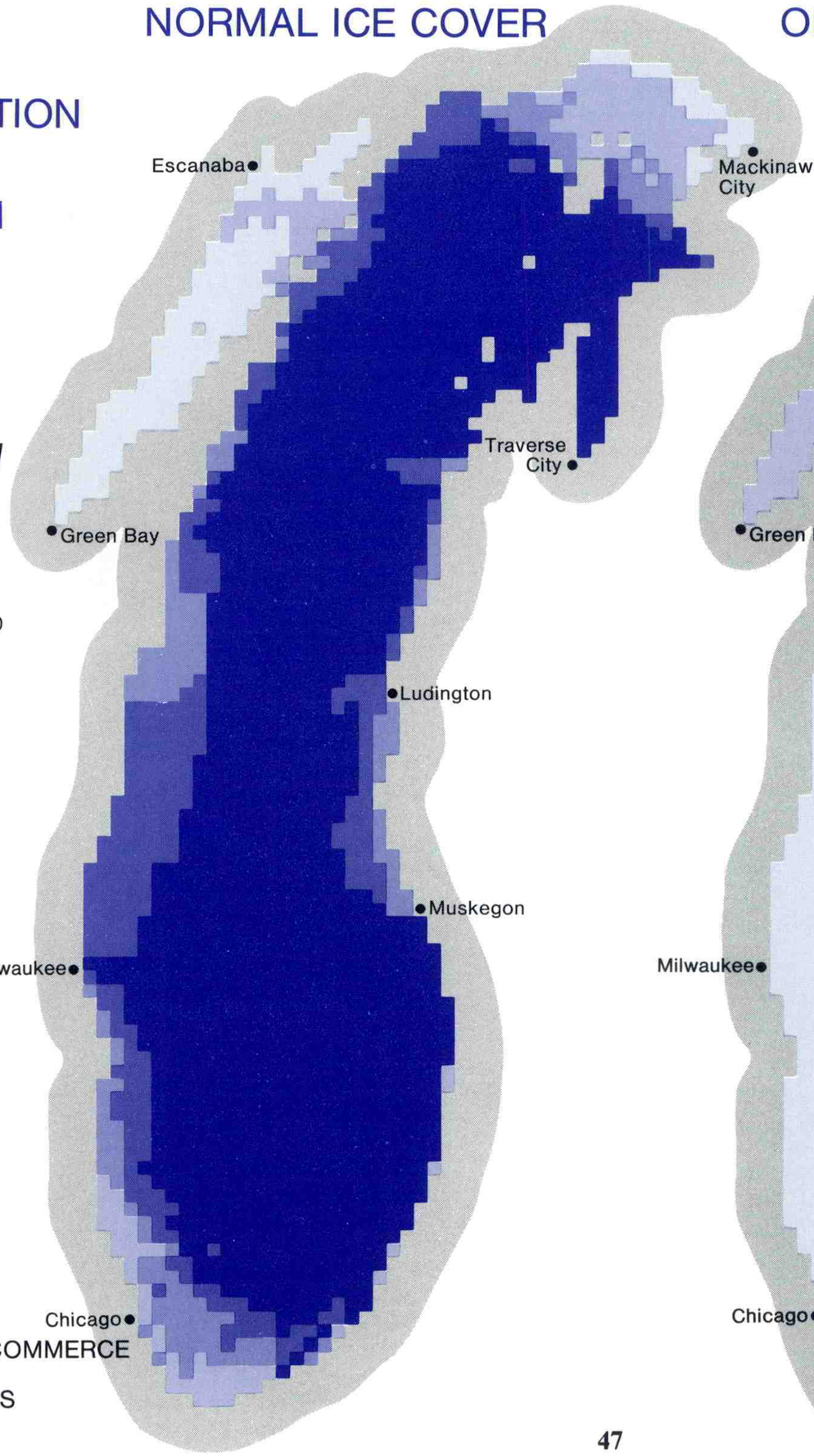
U.S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER AND OBSERVATION DENSITY

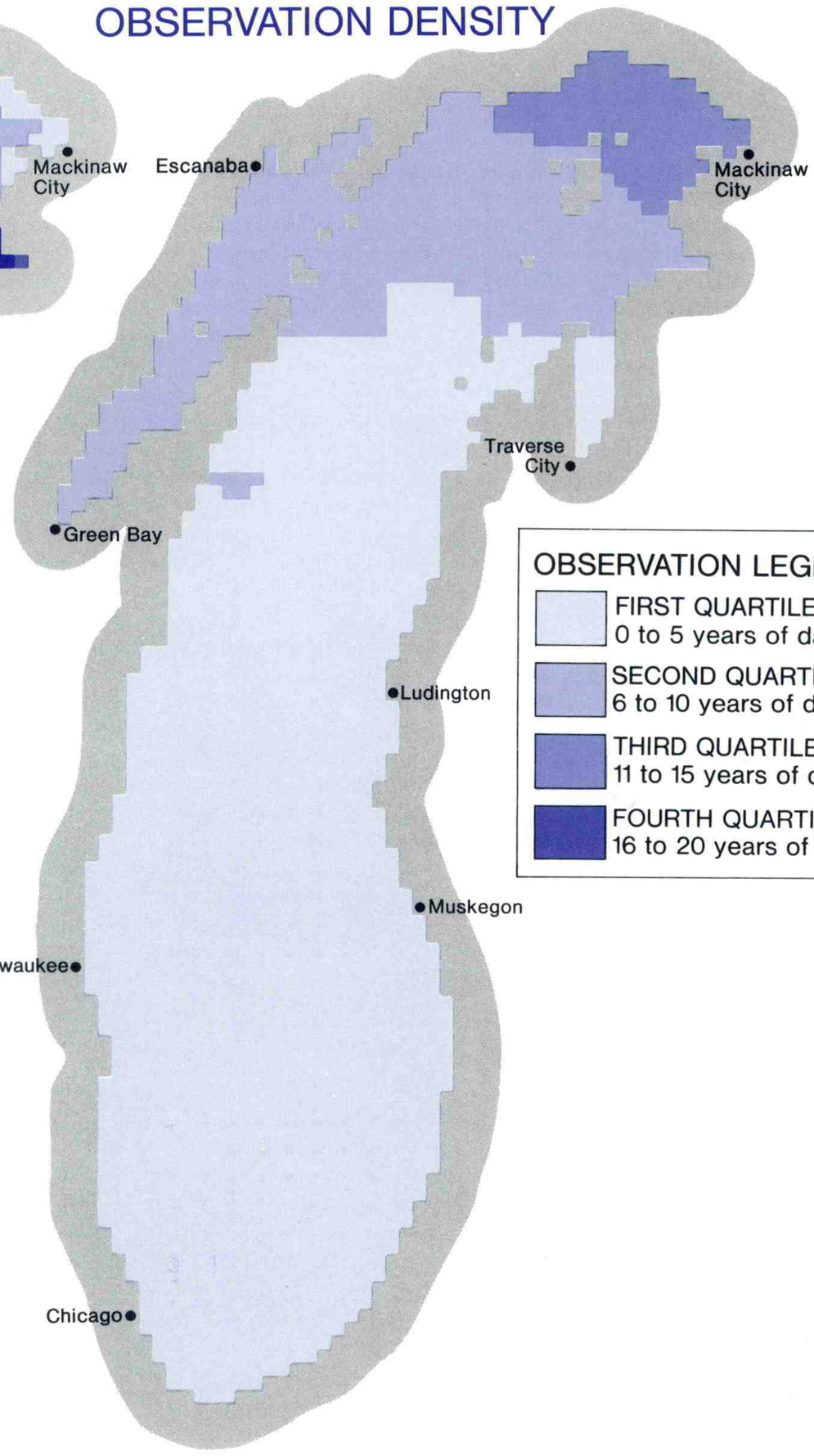
JANUARY 16–31

1960–1979

NORMAL ICE COVER



OBSERVATION DENSITY



OBSERVATION LEGEND

- FIRST QUARTILE — 0 to 5 years of data
- SECOND QUARTILE — 6 to 10 years of data
- THIRD QUARTILE — 11 to 15 years of data
- FOURTH QUARTILE — 16 to 20 years of data

LAKE MICHIGAN

Kilometers
0 20 40 60 80 100
0 10 20 30 40 50 60
Statute Miles

PLATE 12B

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

EXTREMES IN ICE COVER

FEBRUARY 1–14
1960–1979

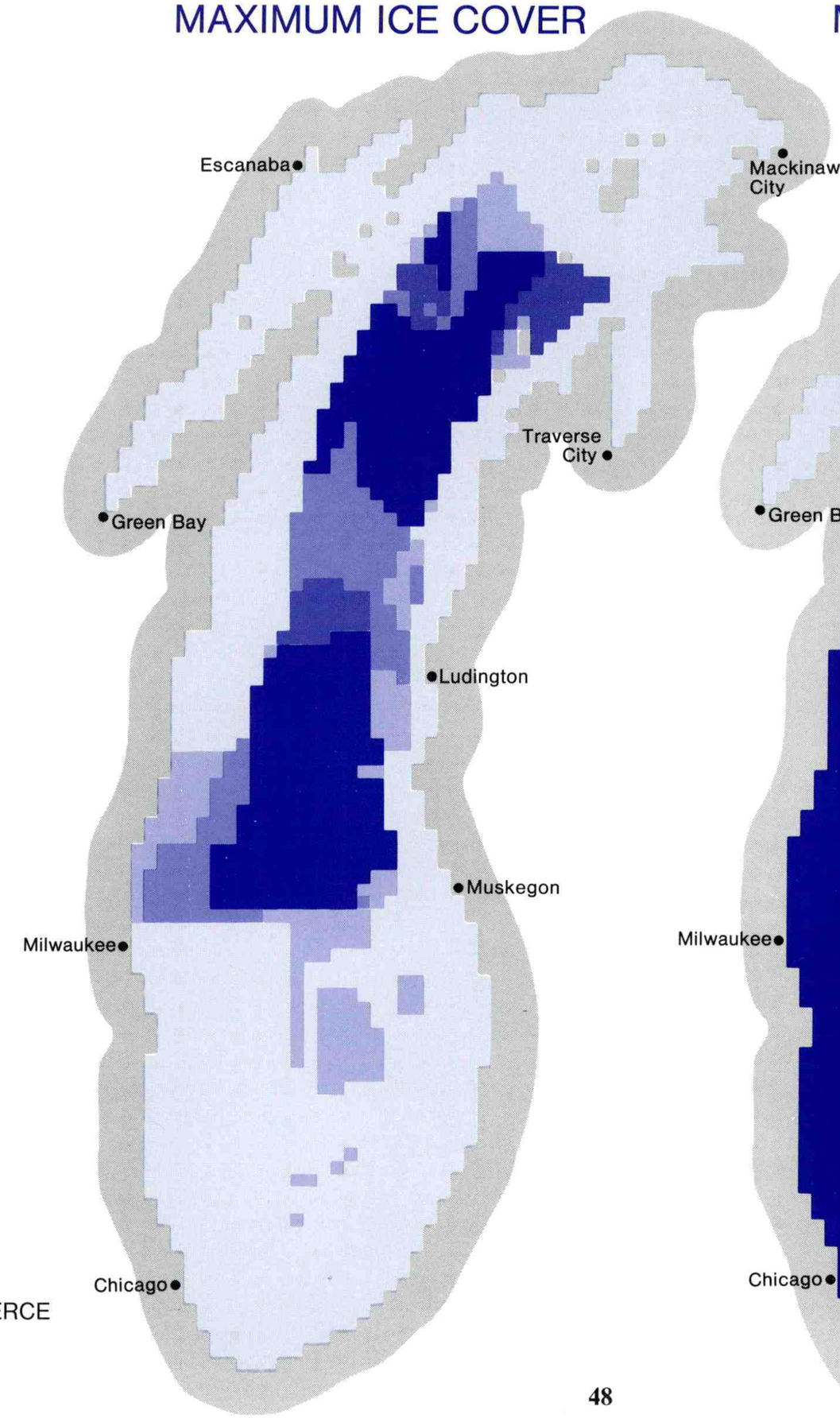
LAKE MICHIGAN

Kilometers
0 20 40 60 80 100
0 10 20 30 40 50 60
Statute Miles

ICE COVER LEGEND

- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

MAXIMUM ICE COVER



MINIMUM ICE COVER

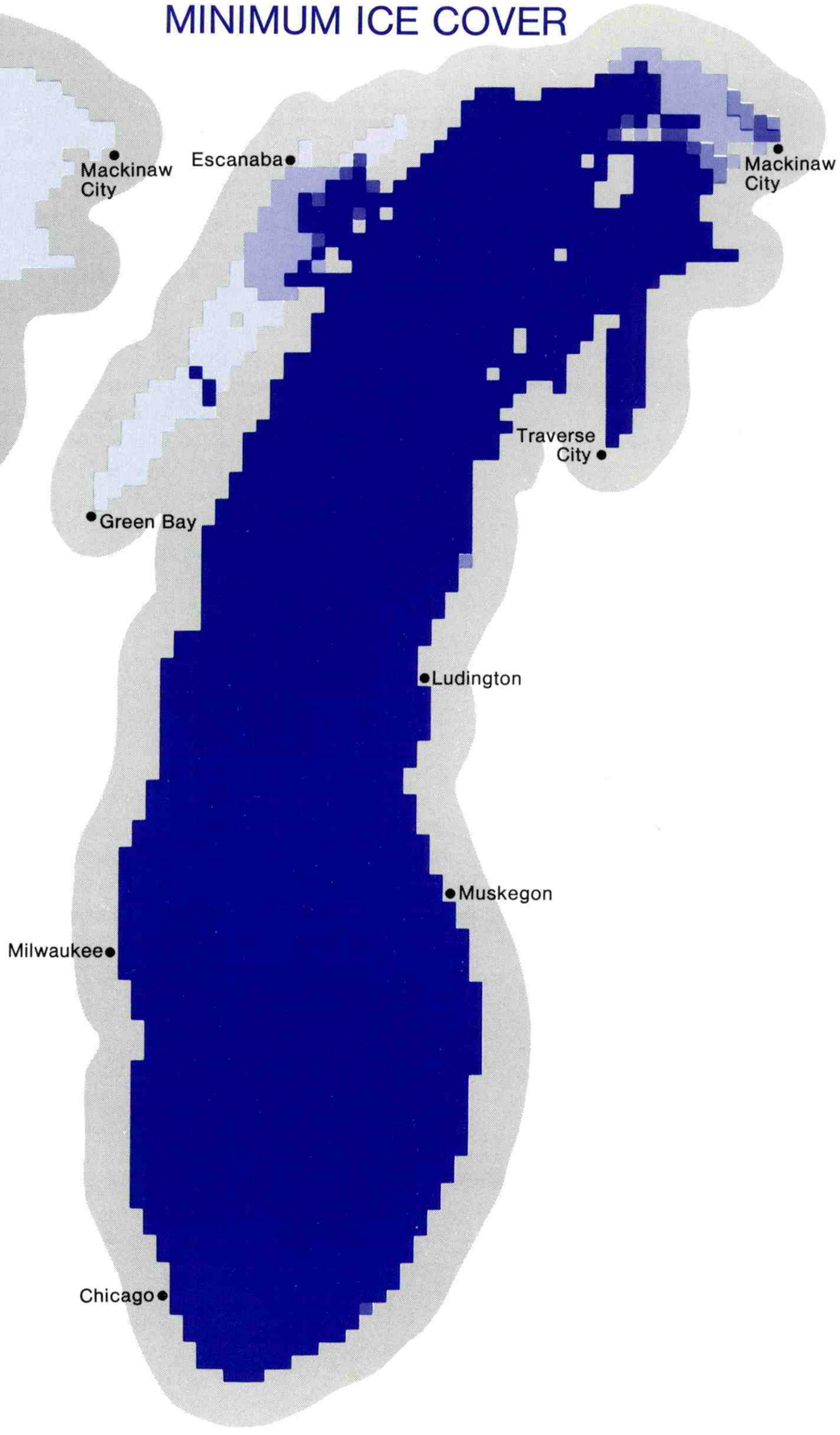


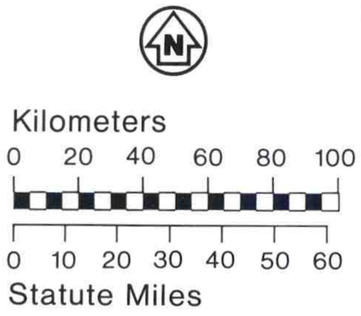
PLATE 13A

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

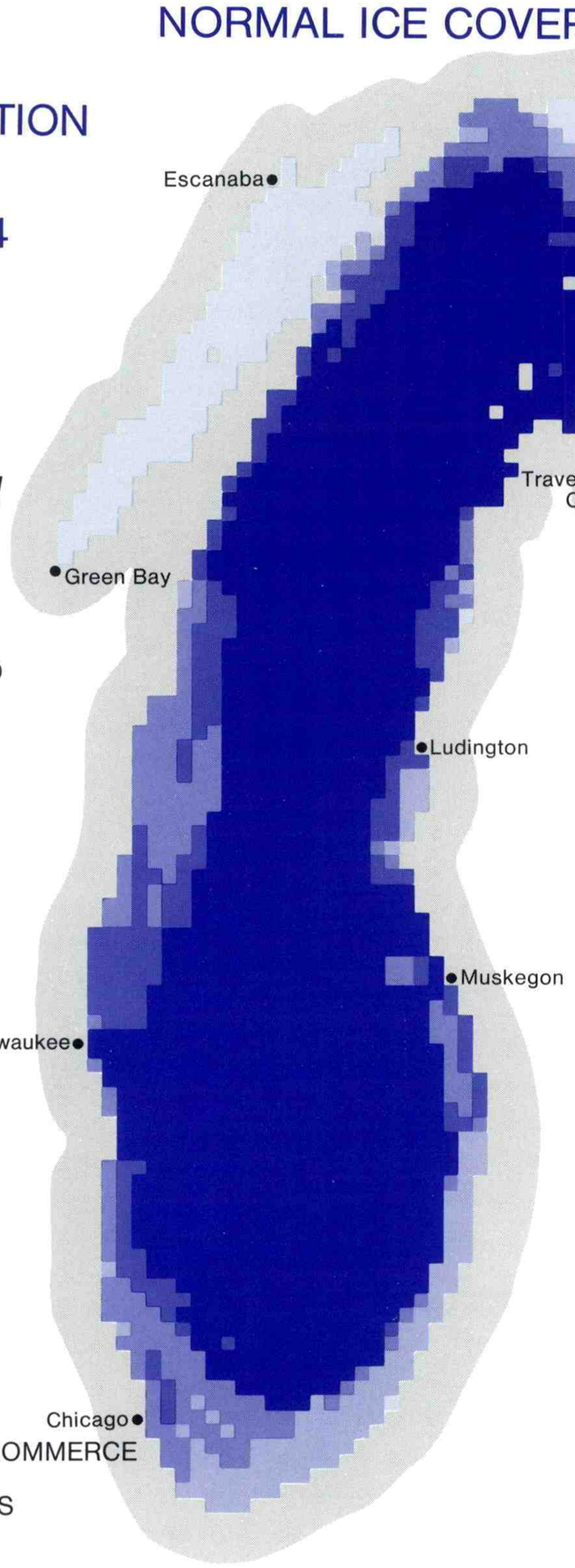
NORMAL ICE COVER AND OBSERVATION DENSITY

FEBRUARY 1–14
1960–1979

LAKE MICHIGAN



NORMAL ICE COVER



OBSERVATION DENSITY

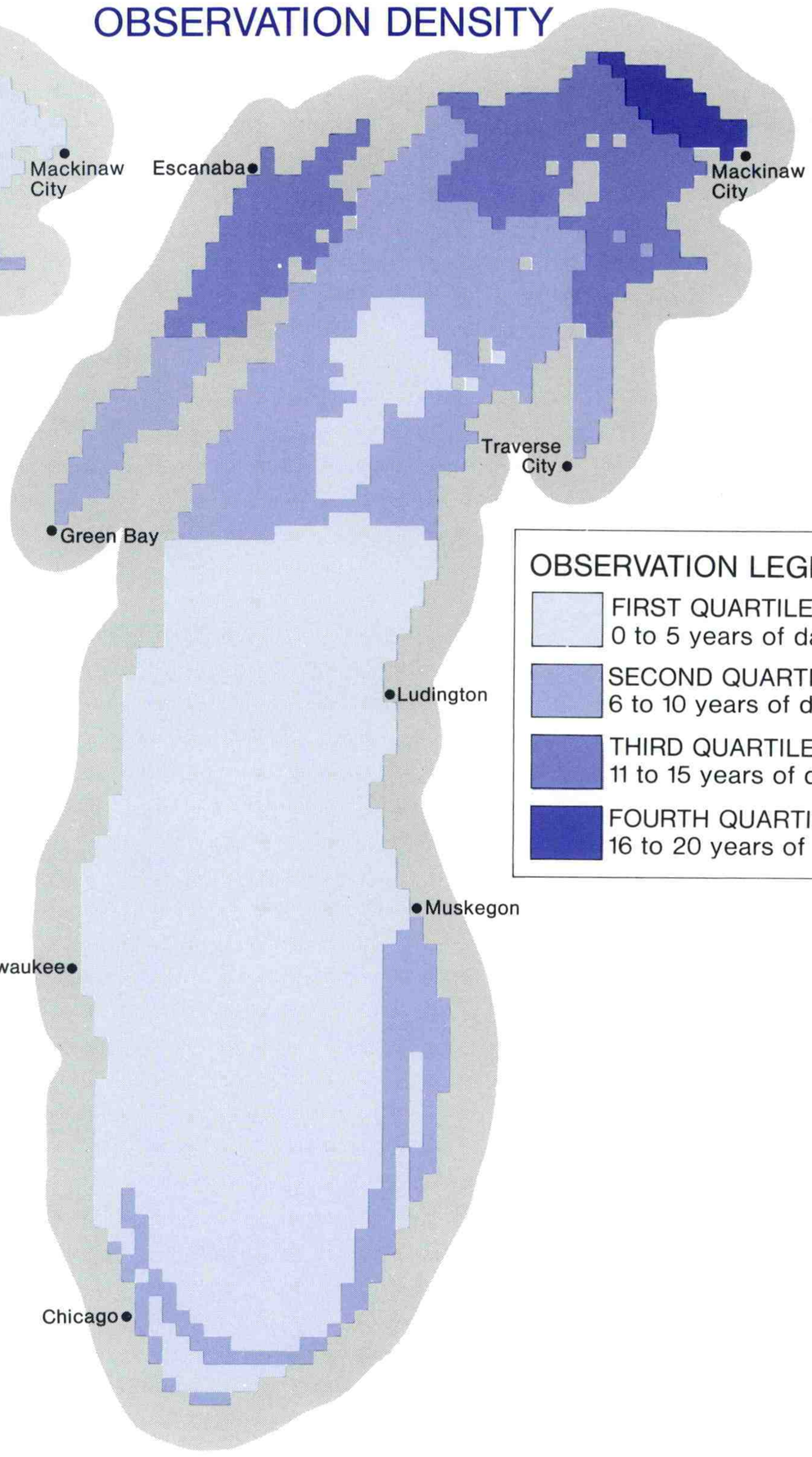


PLATE 13B

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

EXTREMES IN ICE COVER

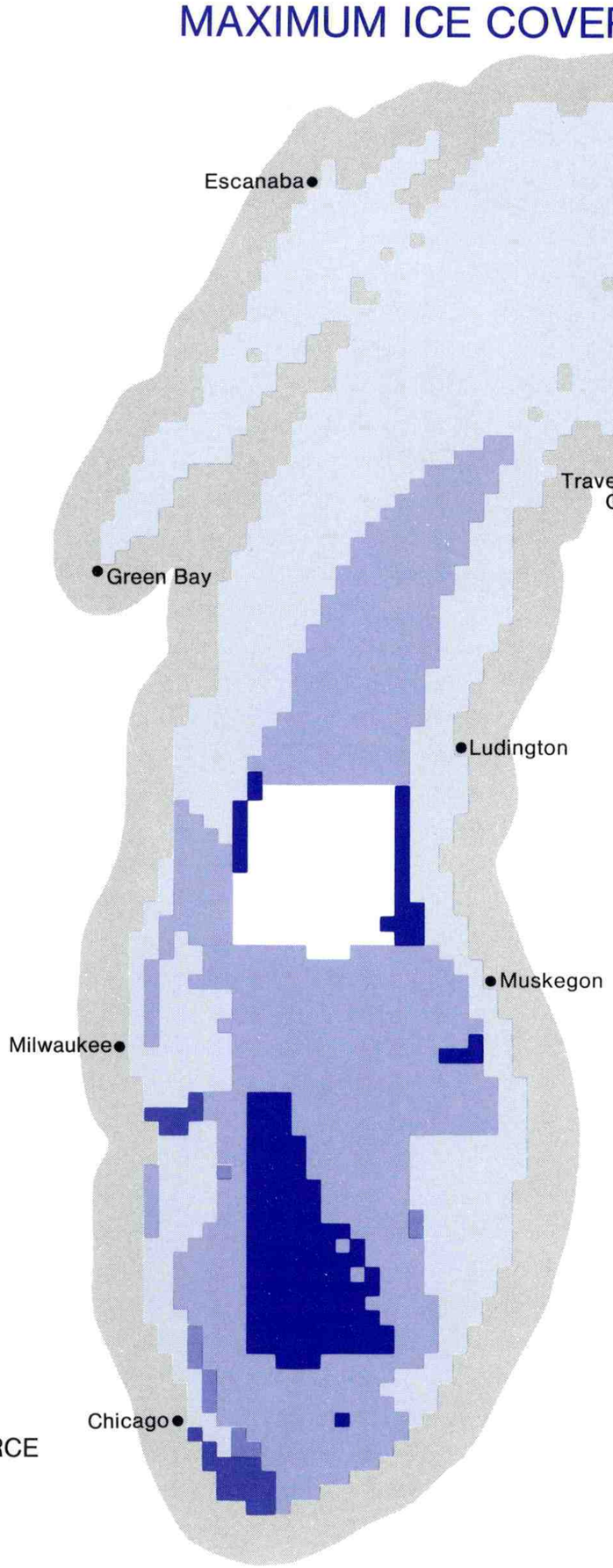
FEBRUARY 15–28
1960–1979

LAKE MICHIGAN

Kilometers
0 20 40 60 80 100
0 10 20 30 40 50 60
Statute Miles

ICE COVER LEGEND
- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

MAXIMUM ICE COVER



MINIMUM ICE COVER

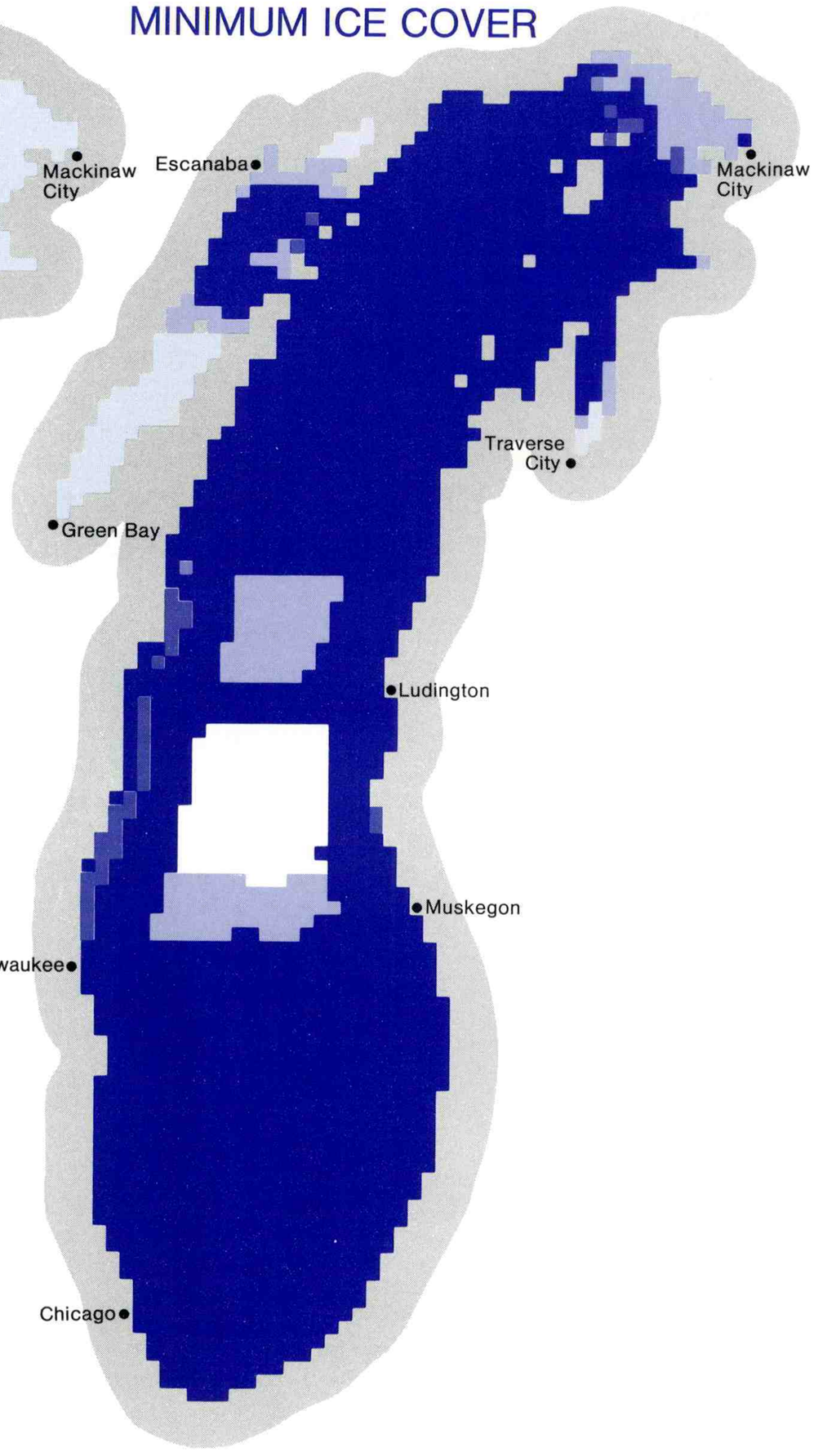


PLATE 14A

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER AND OBSERVATION DENSITY

FEBRUARY 15–28

1960–1979

NORMAL ICE COVER

OBSERVATION DENSITY

LAKE MICHIGAN

Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

Escanaba
Mackinaw City
Traverse City
Green Bay
Ludington
Muskegon
Milwaukee
Chicago

OBSERVATION LEGEND

- FIRST QUARTILE — 0 to 5 years of data
- SECOND QUARTILE — 6 to 10 years of data
- THIRD QUARTILE — 11 to 15 years of data
- FOURTH QUARTILE — 16 to 20 years of data

PLATE 14B

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

EXTREMES IN ICE COVER

MARCH 1–15
1960–1979

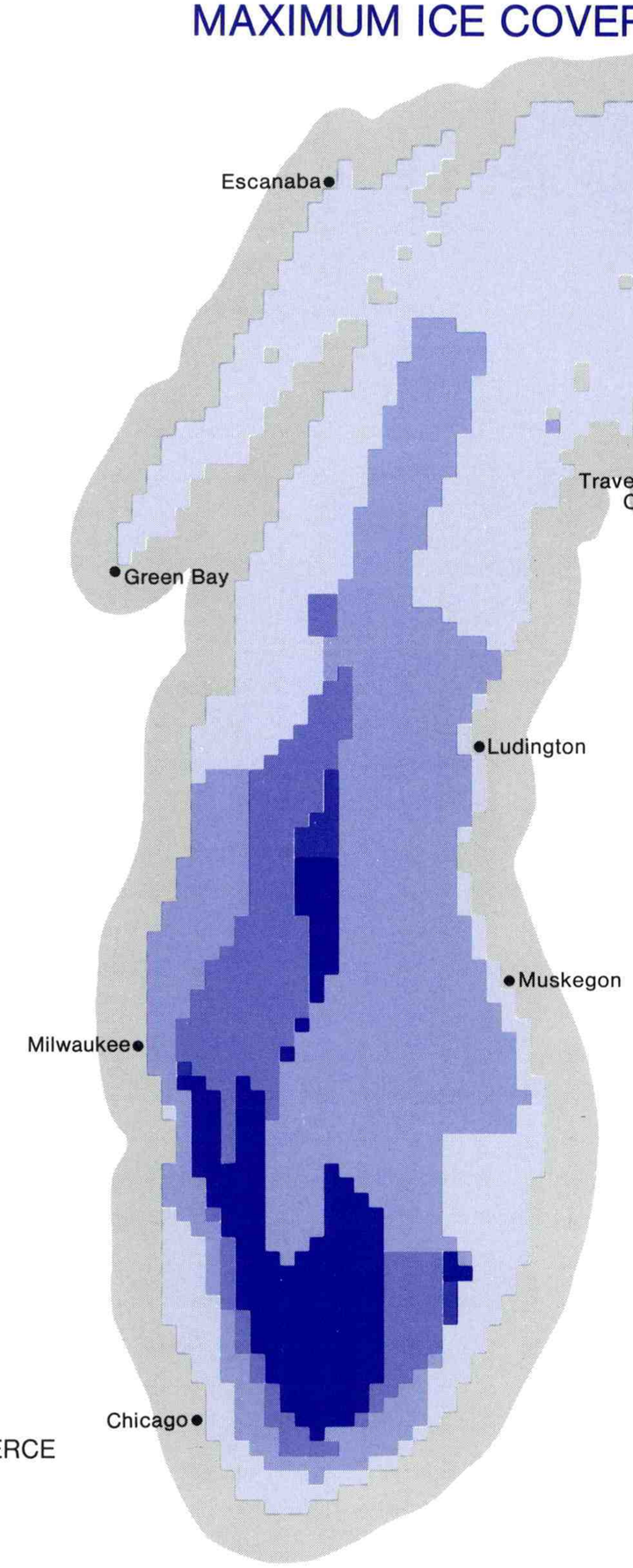
LAKE MICHIGAN

Kilometers
0 20 40 60 80 100
0 10 20 30 40 50 60
Statute Miles

ICE COVER LEGEND

- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

MAXIMUM ICE COVER



MINIMUM ICE COVER

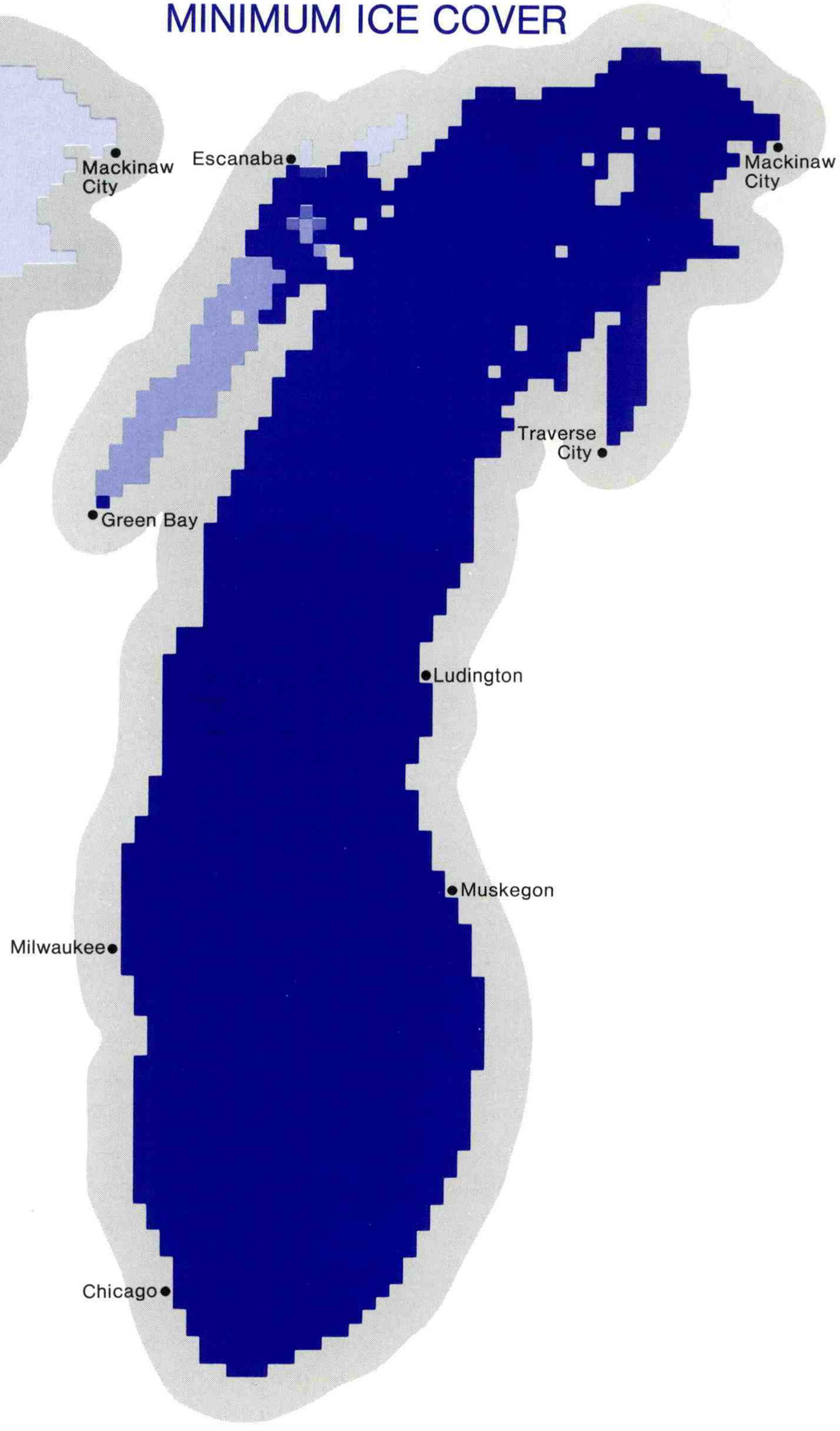


PLATE 15A

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

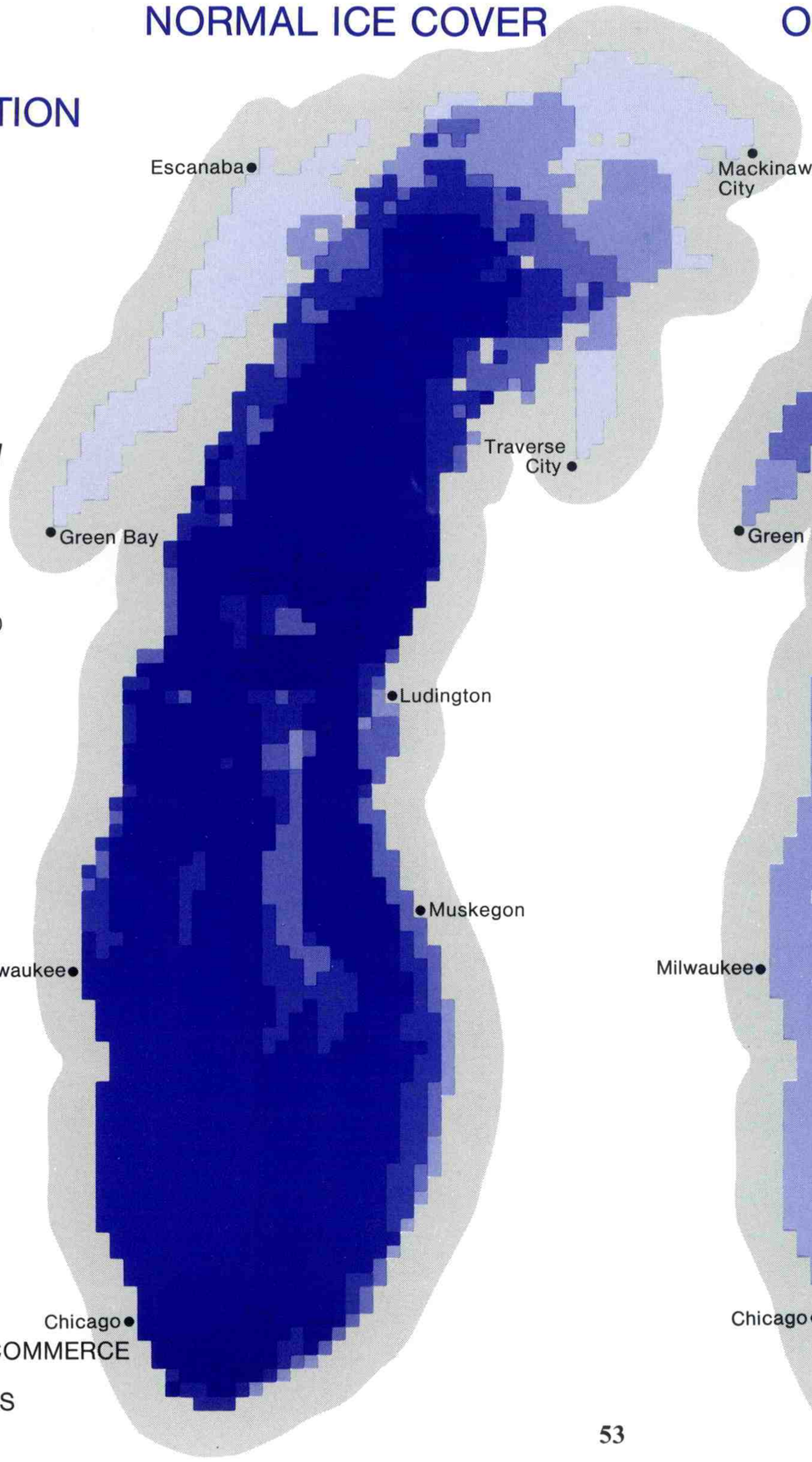
NORMAL ICE COVER AND OBSERVATION DENSITY

MARCH 1–15
1960–1979

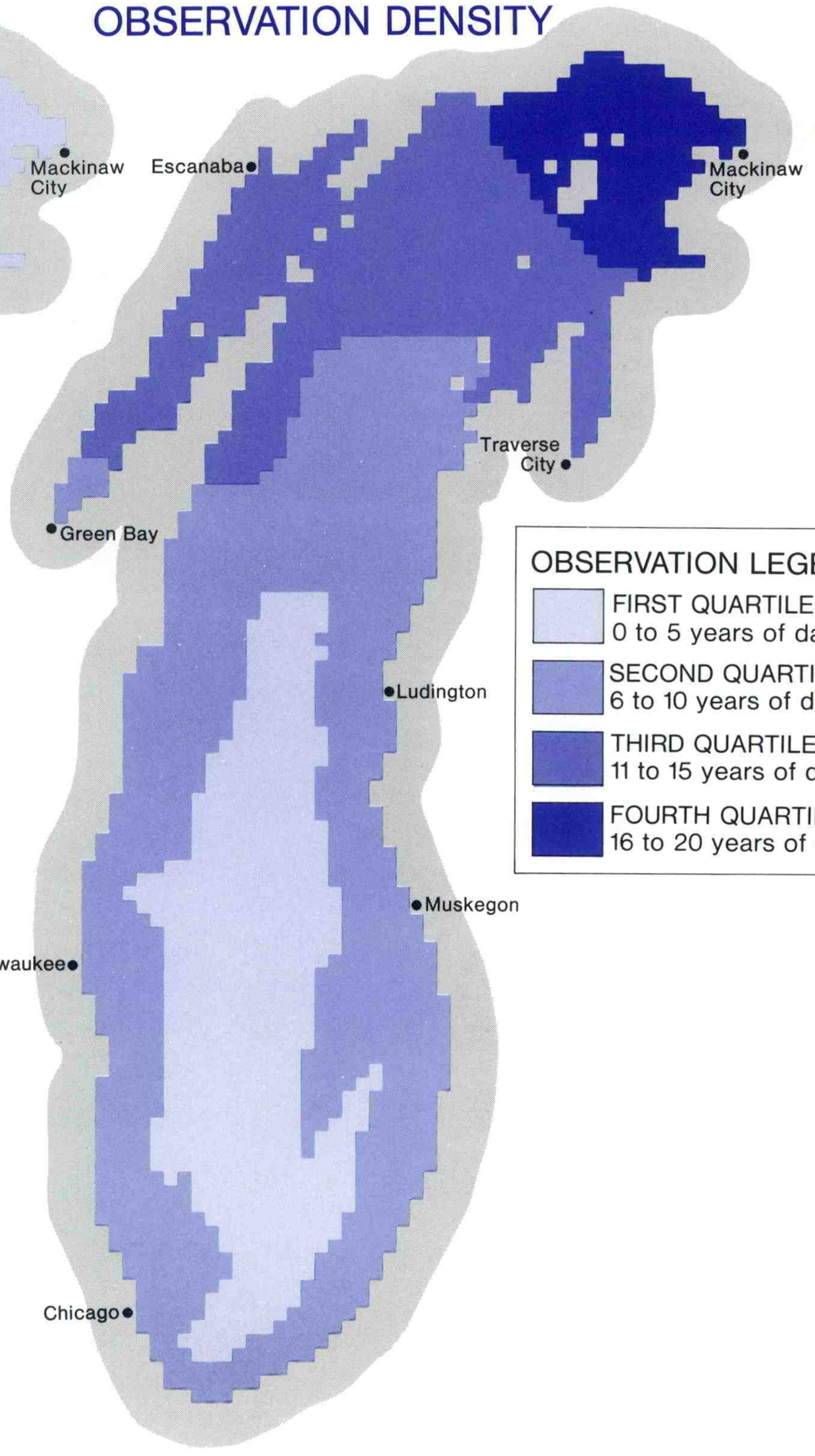
LAKE MICHIGAN

Kilometers
0 20 40 60 80 100
0 10 20 30 40 50 60
Statute Miles

NORMAL ICE COVER



OBSERVATION DENSITY



OBSERVATION LEGEND

- FIRST QUARTILE — 0 to 5 years of data
- SECOND QUARTILE — 6 to 10 years of data
- THIRD QUARTILE — 11 to 15 years of data
- FOURTH QUARTILE — 16 to 20 years of data

PLATE 15B

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

EXTREMES IN ICE COVER

MARCH 16–31
1960–1979

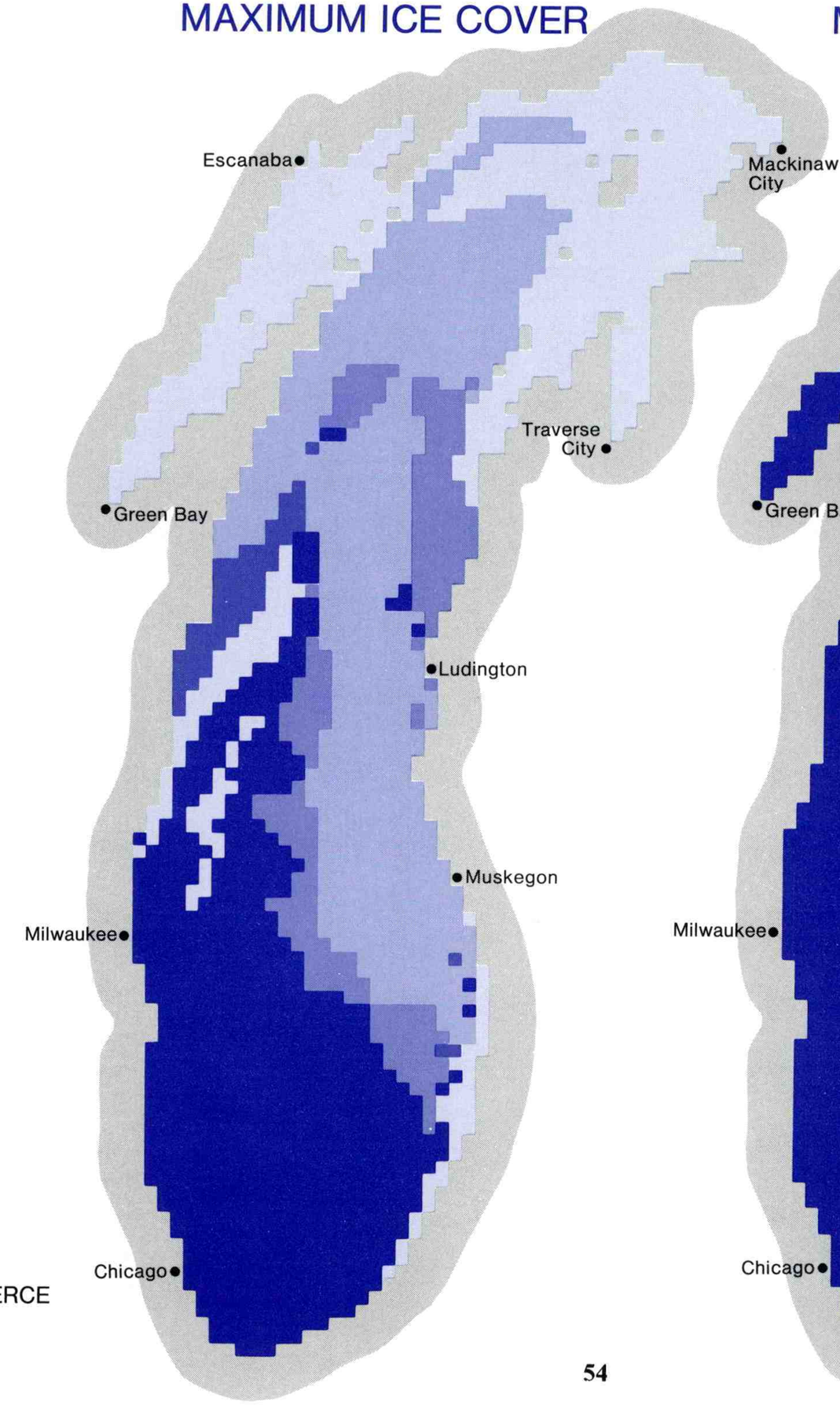
LAKE MICHIGAN

Kilometers
0 20 40 60 80 100
0 10 20 30 40 50 60
Statute Miles

ICE COVER LEGEND

- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

MAXIMUM ICE COVER



MINIMUM ICE COVER

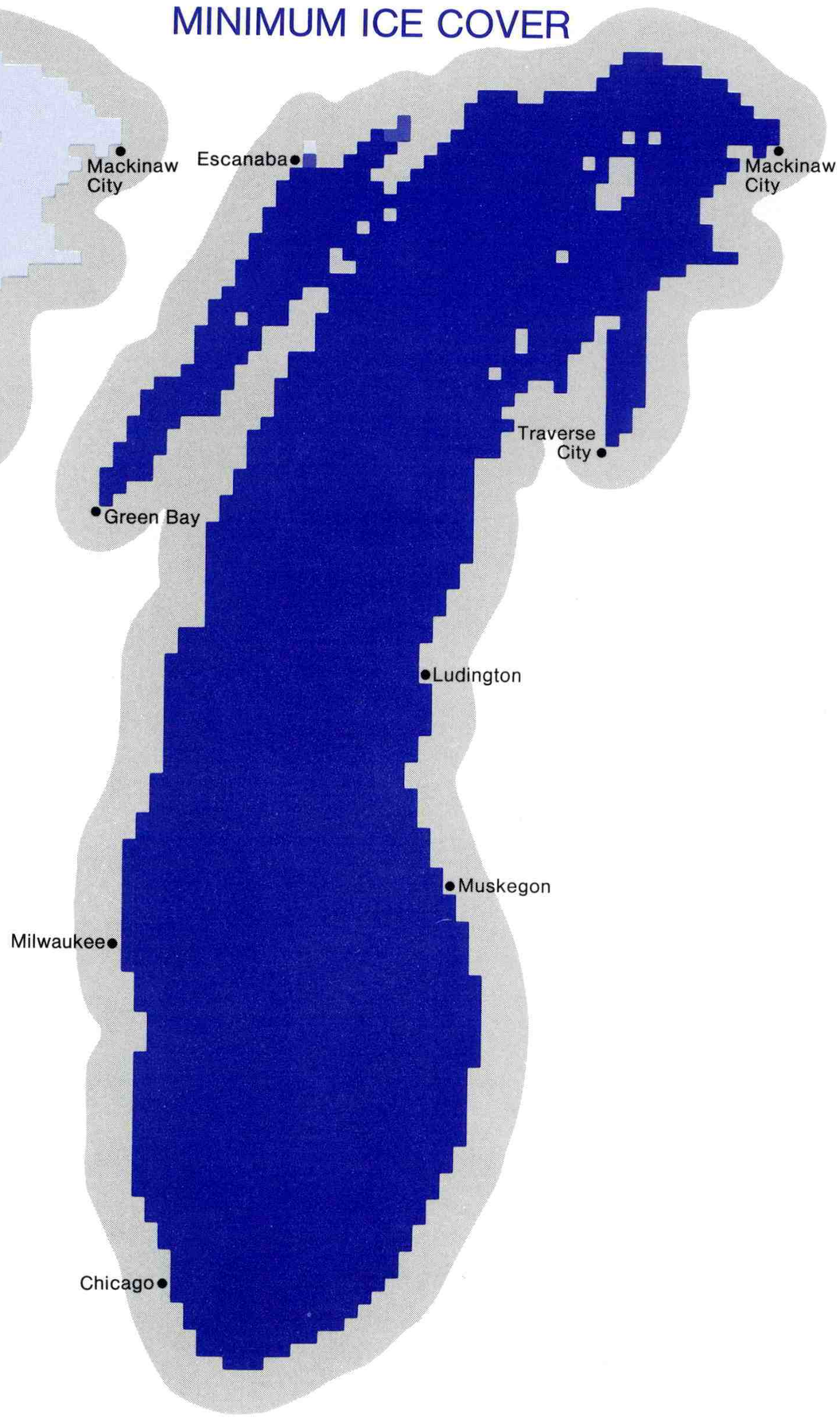


PLATE 16A

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER AND OBSERVATION DENSITY

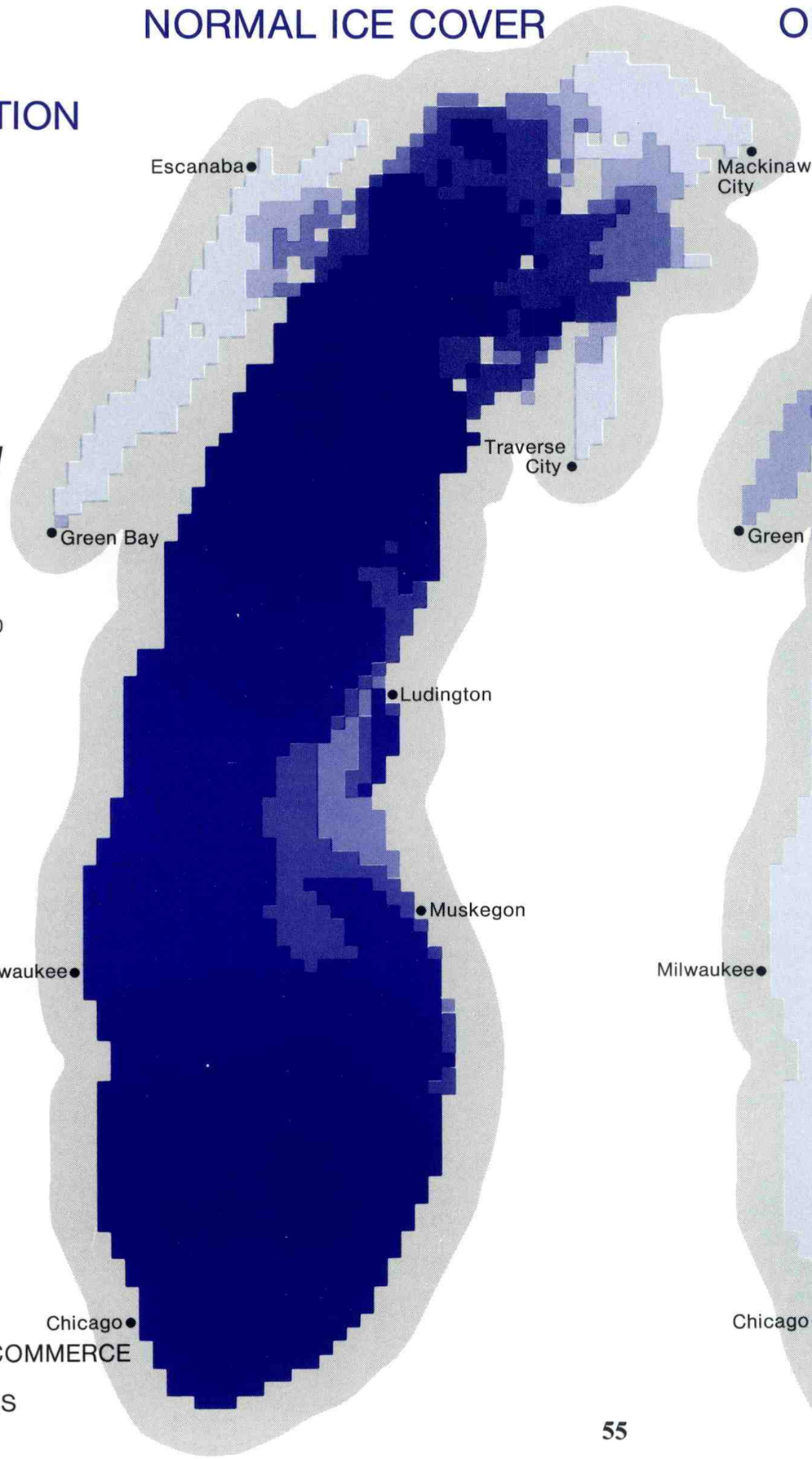
MARCH 16–31
1960–1979

LAKE MICHIGAN

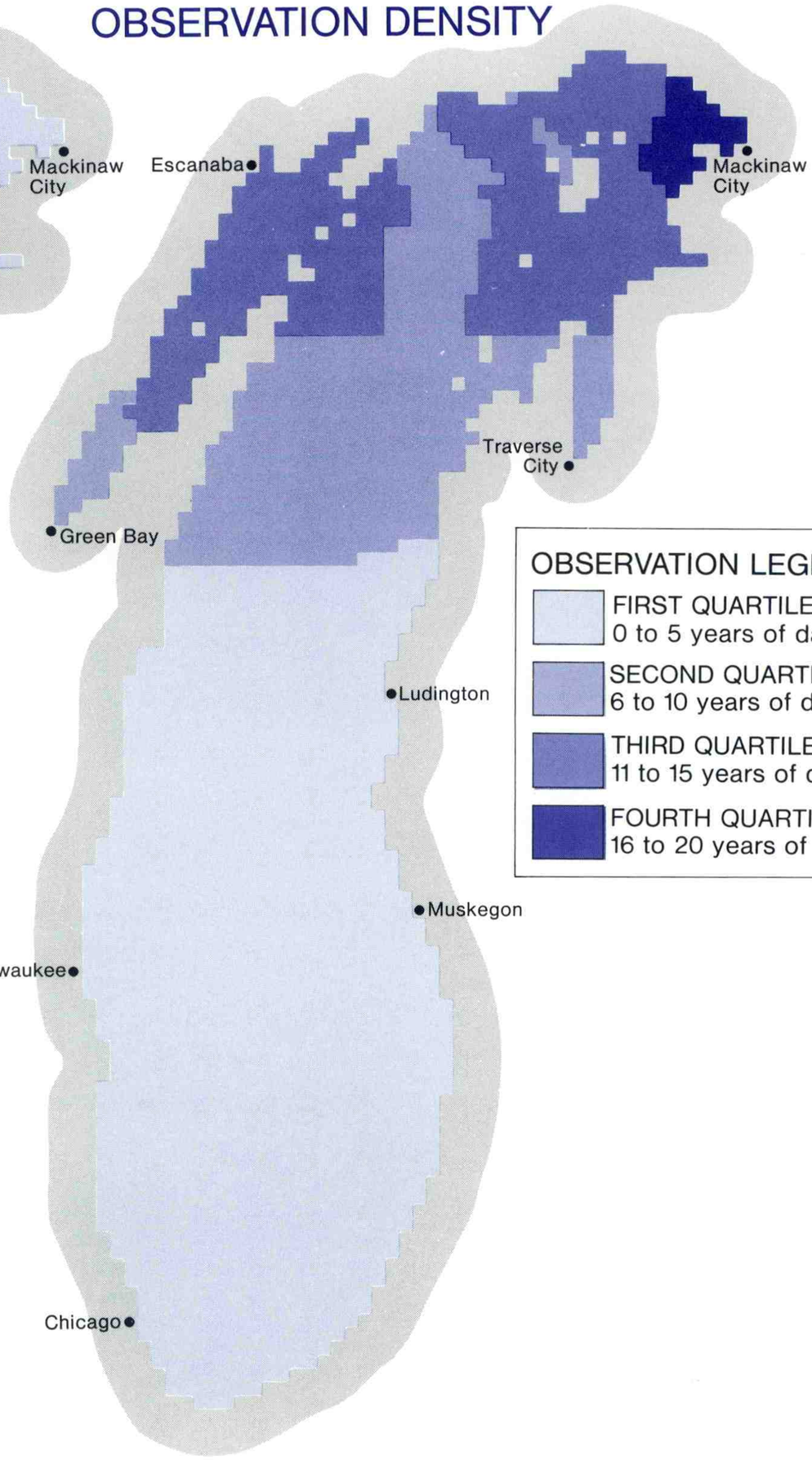
Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

NORMAL ICE COVER



OBSERVATION DENSITY



OBSERVATION LEGEND

- FIRST QUARTILE — 0 to 5 years of data
- SECOND QUARTILE — 6 to 10 years of data
- THIRD QUARTILE — 11 to 15 years of data
- FOURTH QUARTILE — 16 to 20 years of data

PLATE 16B

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

EXTREMES IN ICE COVER

APRIL 1–15
1960–1979

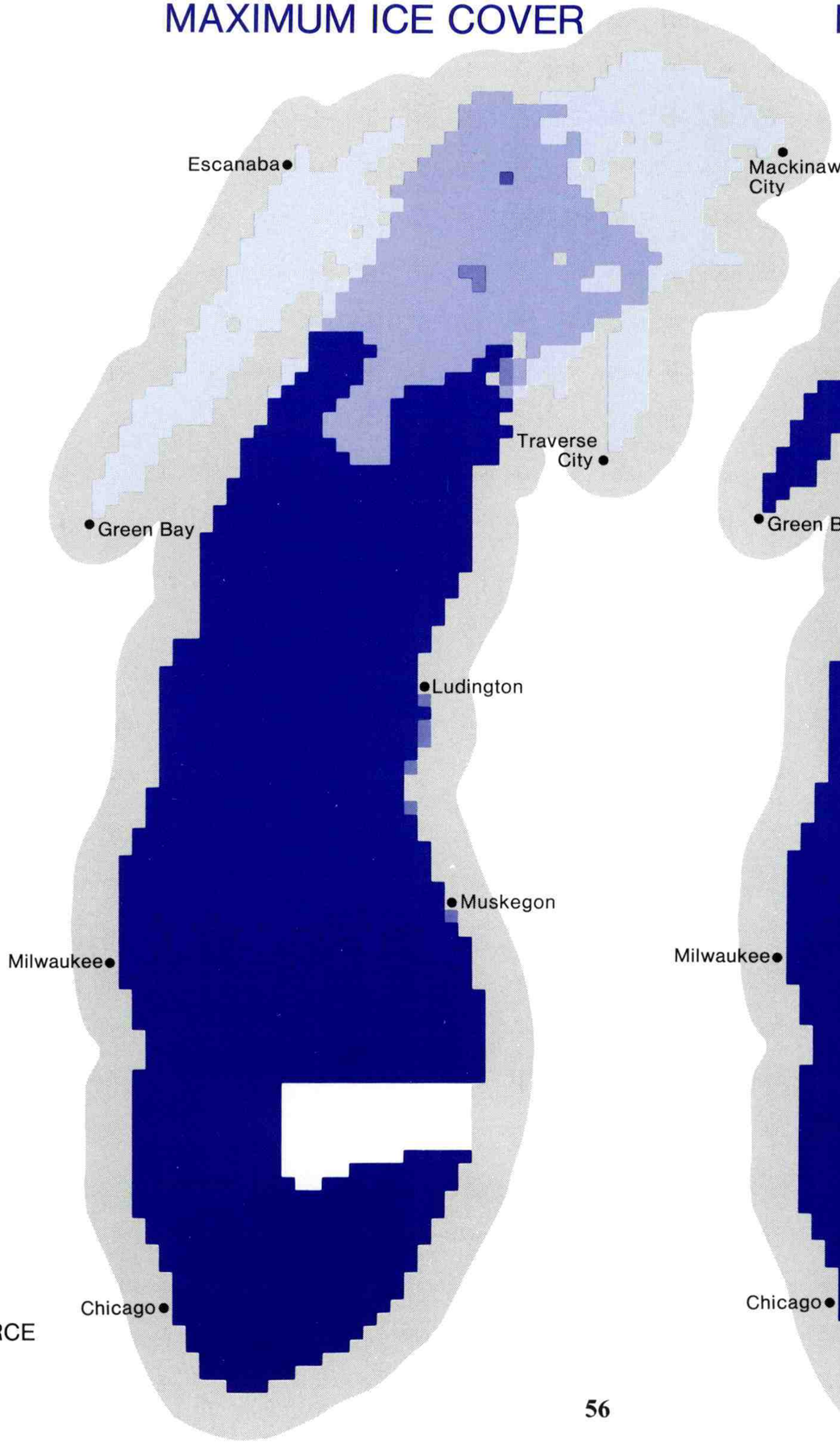
LAKE MICHIGAN

Kilometers
0 20 40 60 80 100
0 10 20 30 40 50 60
Statute Miles

ICE COVER LEGEND

- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

MAXIMUM ICE COVER



MINIMUM ICE COVER

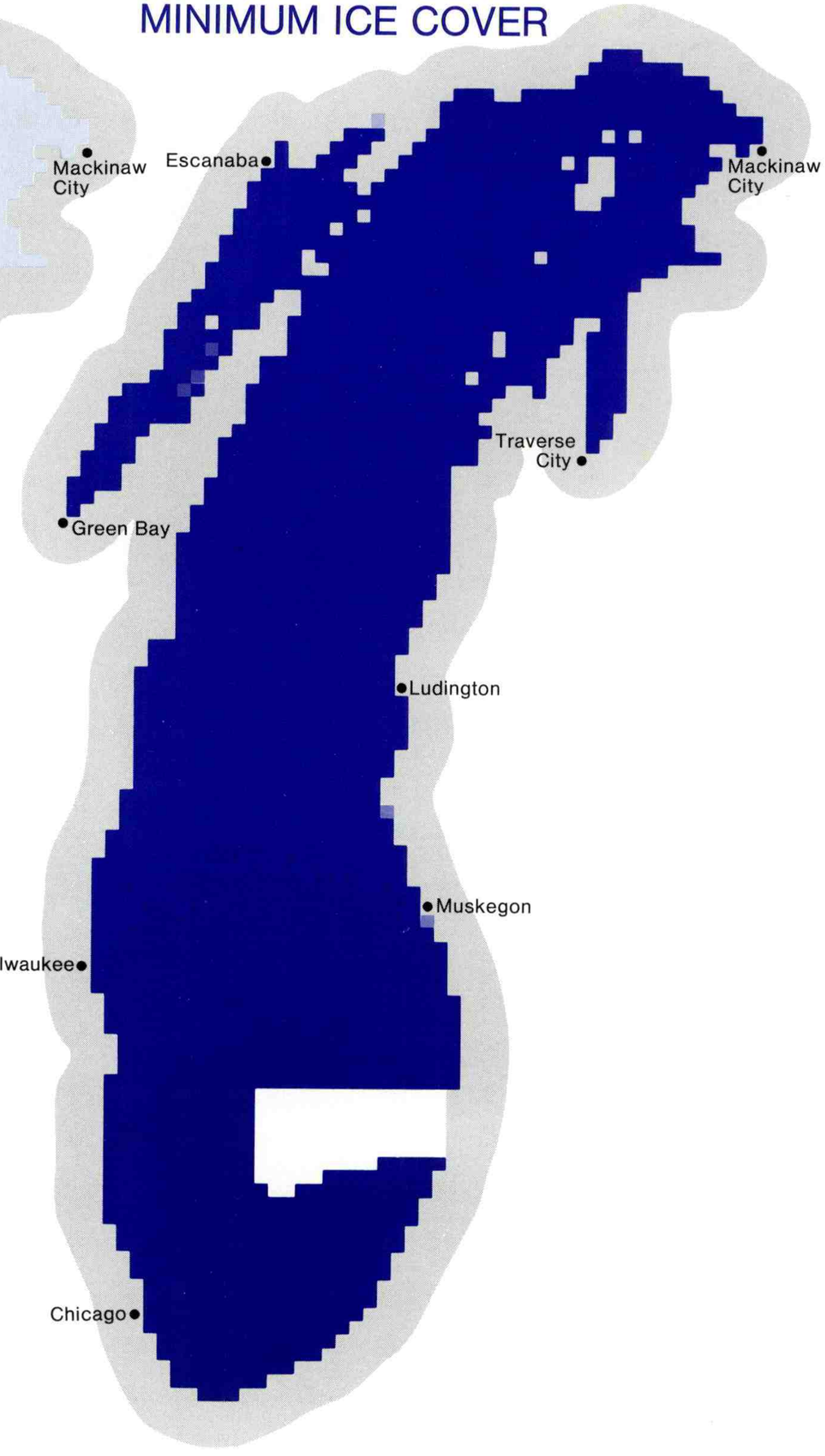


PLATE 17A

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

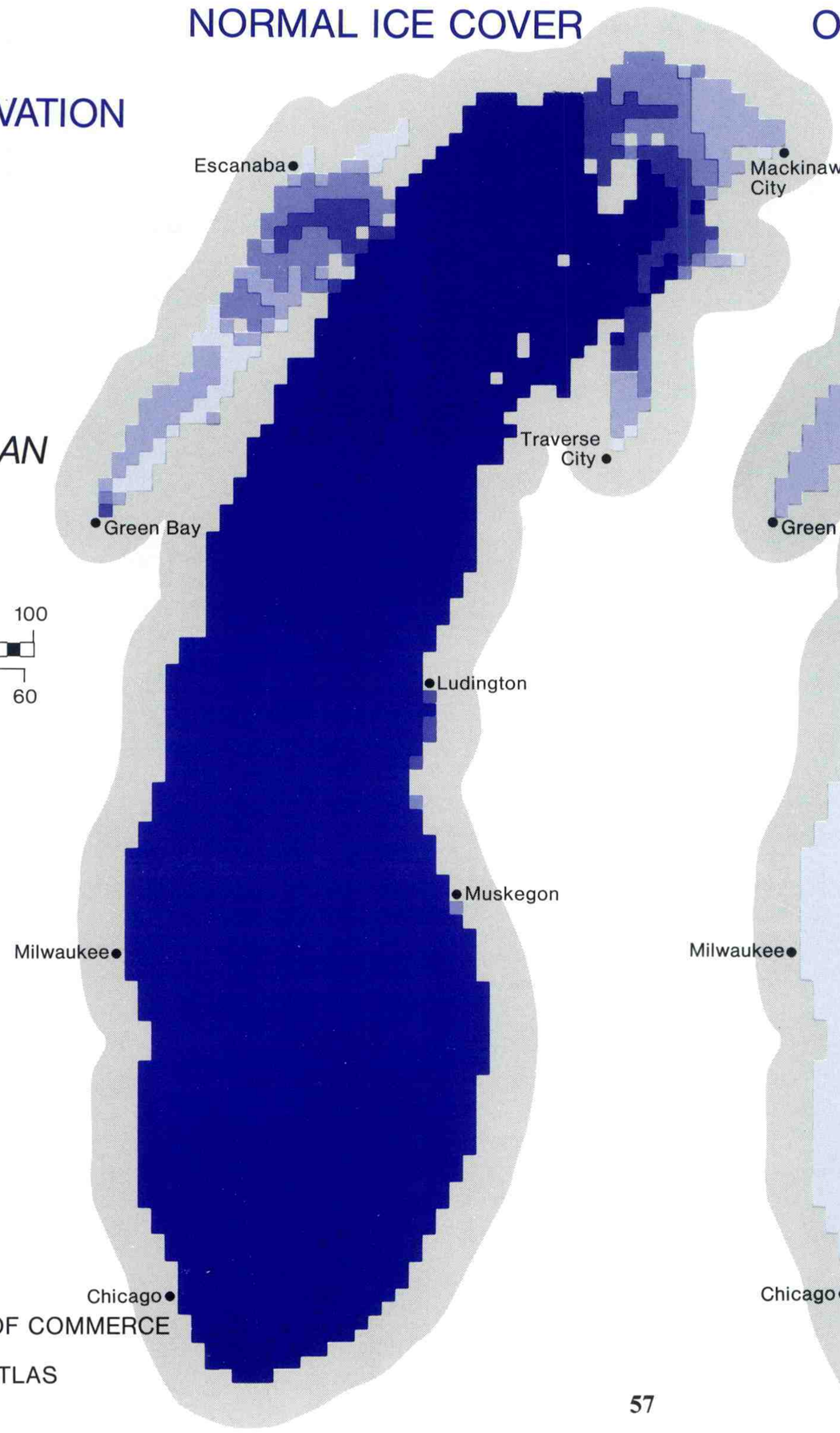
NORMAL ICE COVER AND OBSERVATION DENSITY

APRIL 1–15
1969–1979

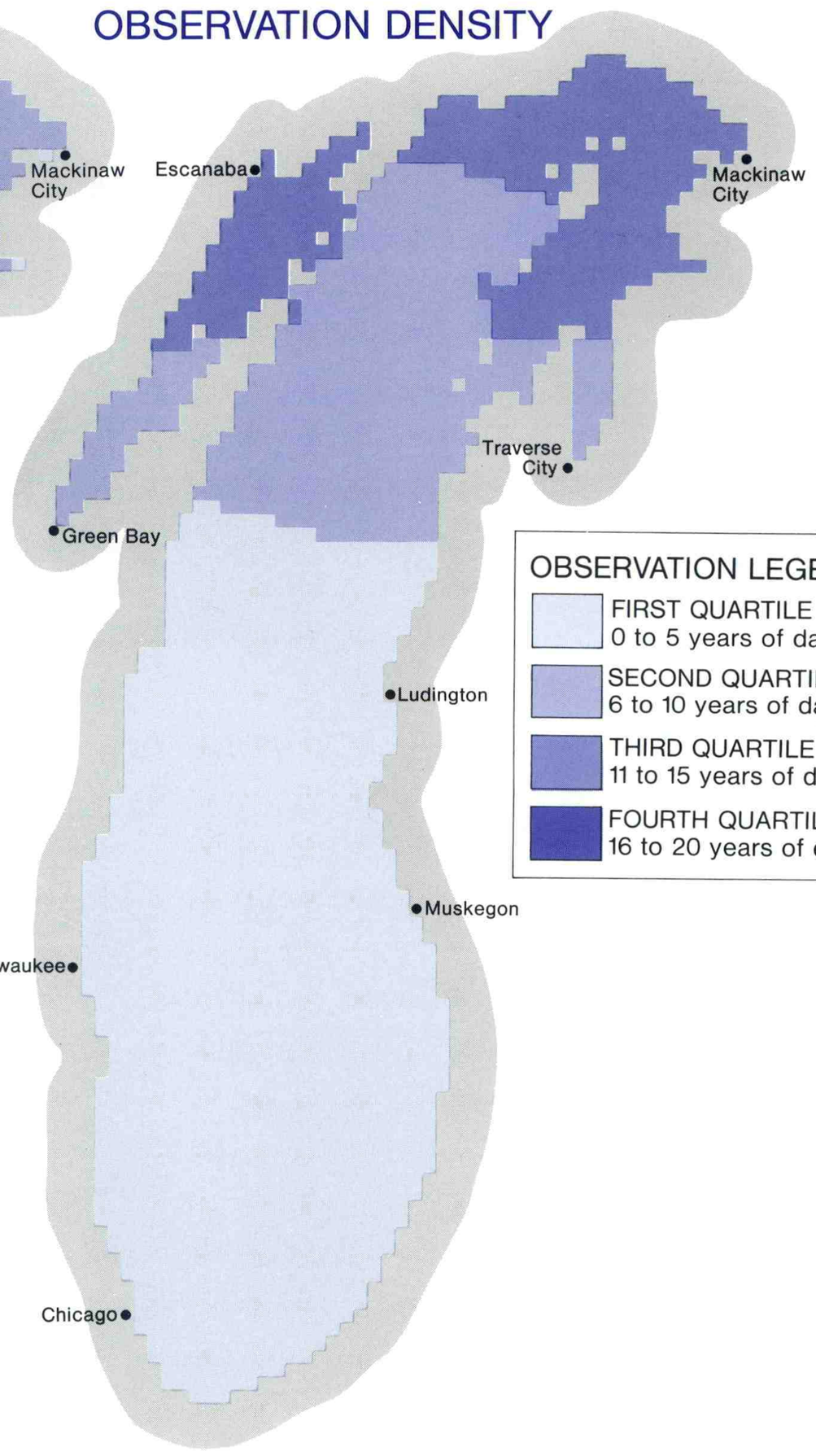
LAKE MICHIGAN

Kilometers
0 20 40 60 80 100
0 10 20 30 40 50 60
Statute Miles

NORMAL ICE COVER



OBSERVATION DENSITY



OBSERVATION LEGEND

- FIRST QUARTILE — 0 to 5 years of data
- SECOND QUARTILE — 6 to 10 years of data
- THIRD QUARTILE — 11 to 15 years of data
- FOURTH QUARTILE — 16 to 20 years of data

PLATE 17B

U.S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

EXTREMES IN ICE COVER

APRIL 16–30
1960–1979

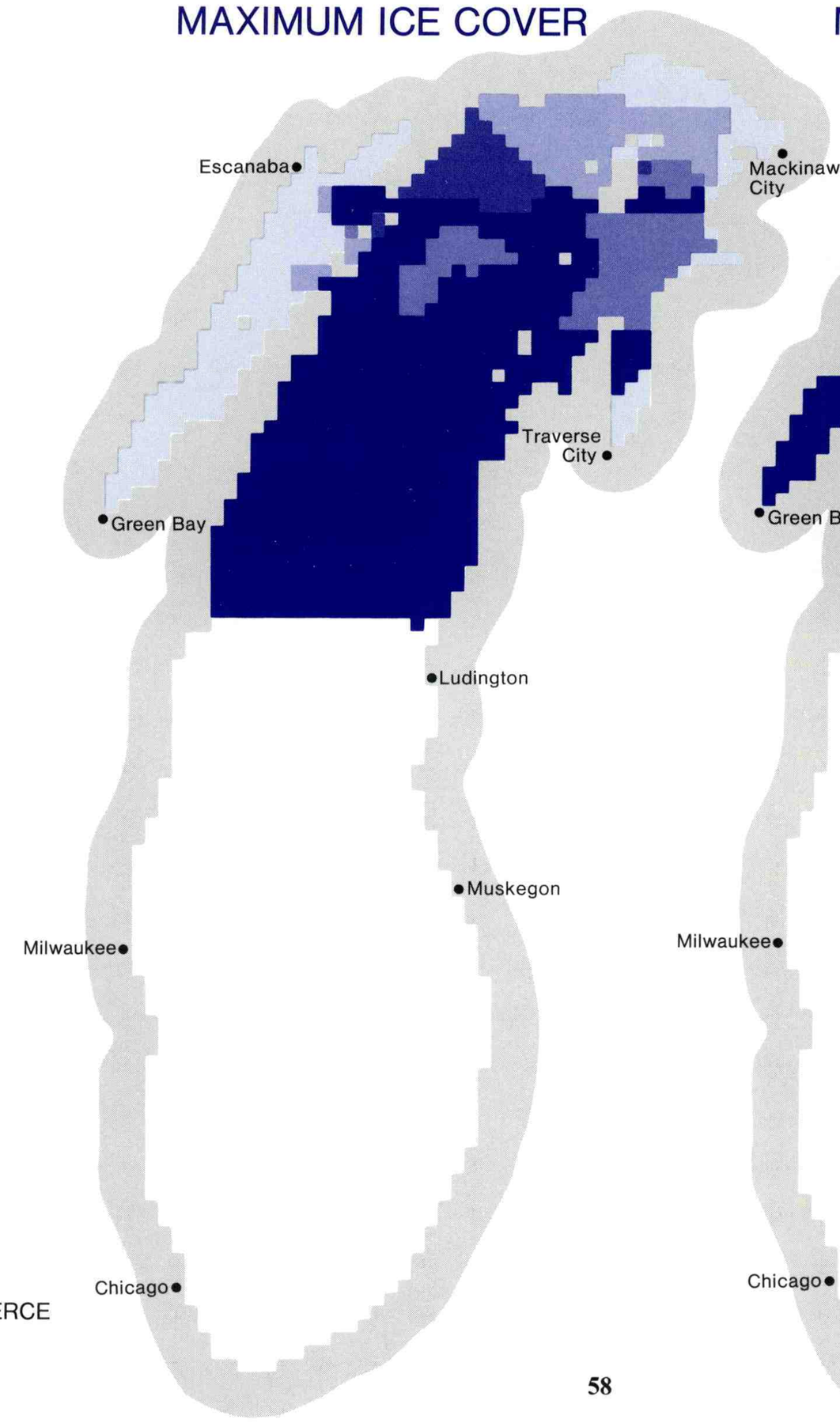
LAKE MICHIGAN

Kilometers
0 20 40 60 80 100
0 10 20 30 40 50 60
Statute Miles

ICE COVER LEGEND

- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

MAXIMUM ICE COVER



MINIMUM ICE COVER

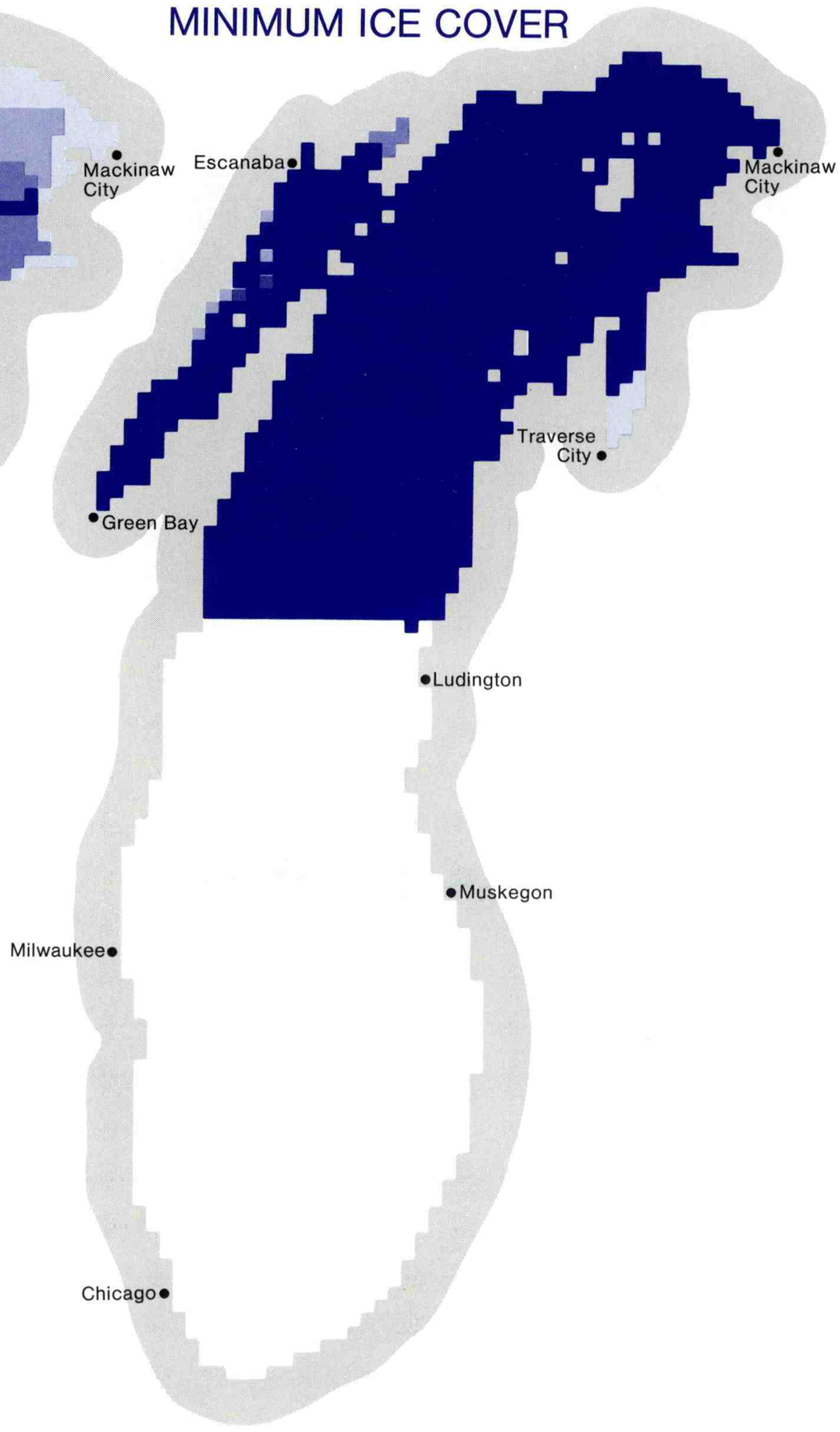


PLATE 18A

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

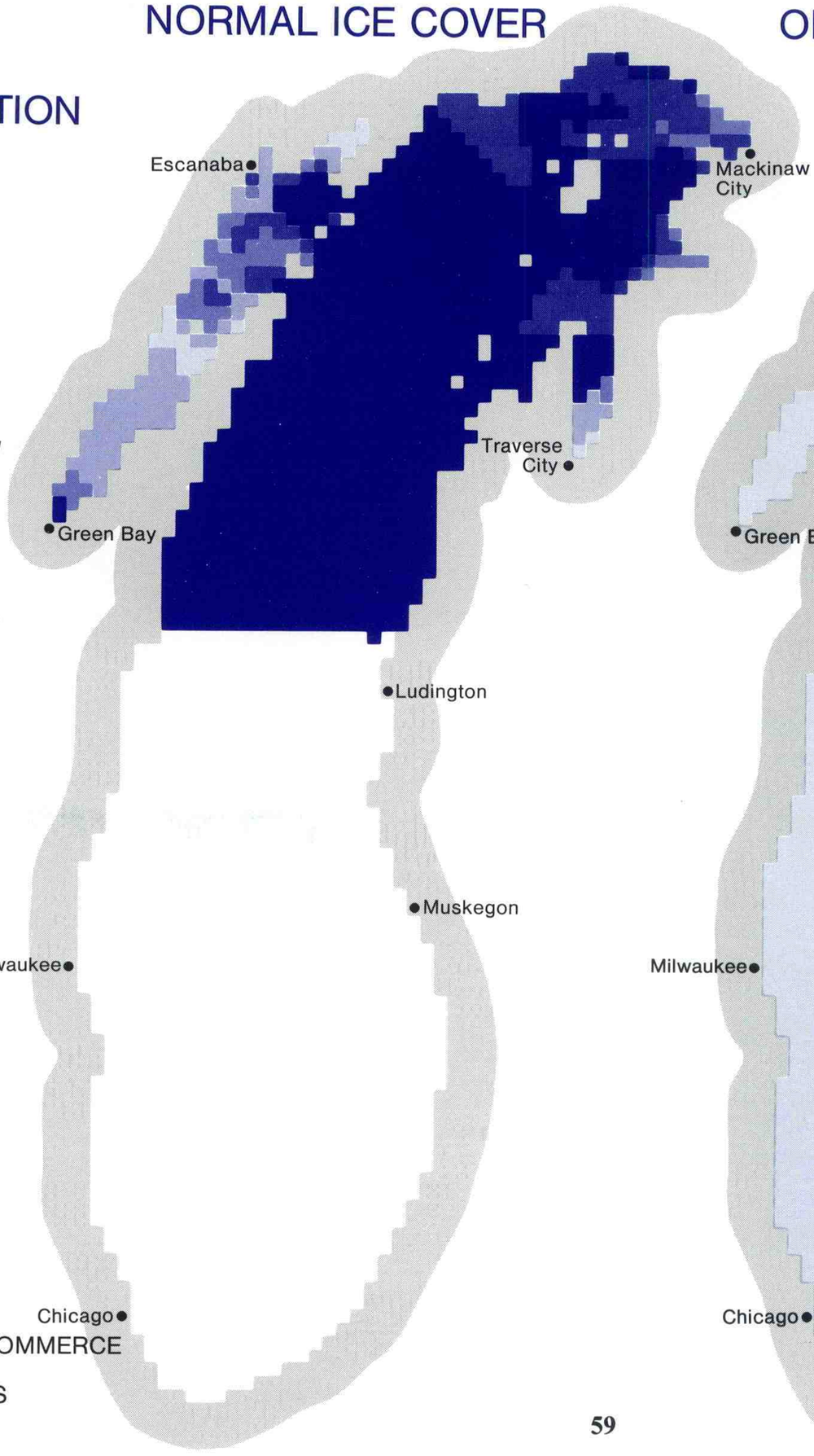
NORMAL ICE COVER AND OBSERVATION DENSITY

APRIL 16–30
1960–1979

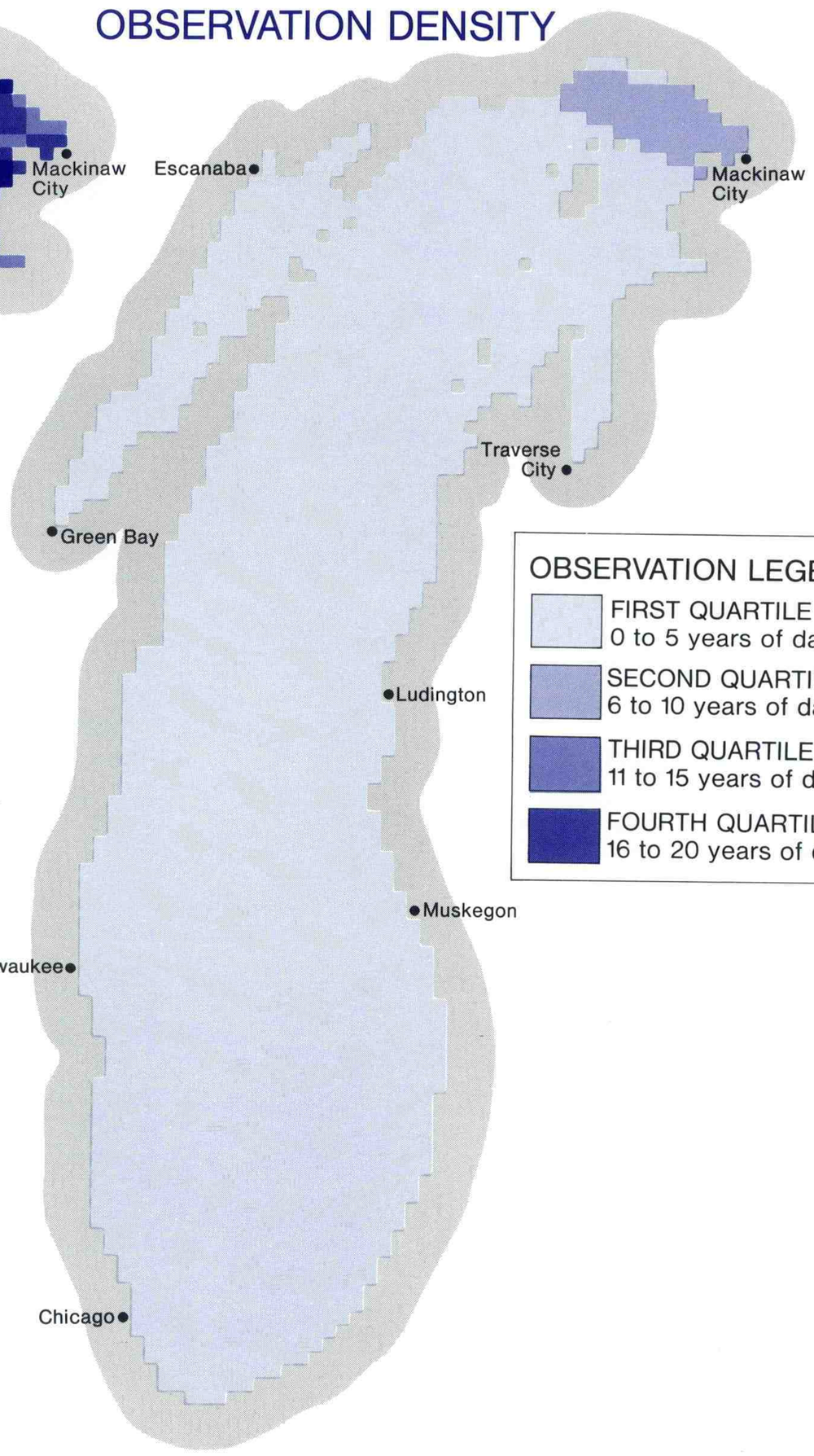
LAKE MICHIGAN

Kilometers
0 20 40 60 80 100
0 10 20 30 40 50 60
Statute Miles

NORMAL ICE COVER



OBSERVATION DENSITY



OBSERVATION LEGEND

- FIRST QUARTILE — 0 to 5 years of data
- SECOND QUARTILE — 6 to 10 years of data
- THIRD QUARTILE — 11 to 15 years of data
- FOURTH QUARTILE — 16 to 20 years of data

PLATE 18B

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

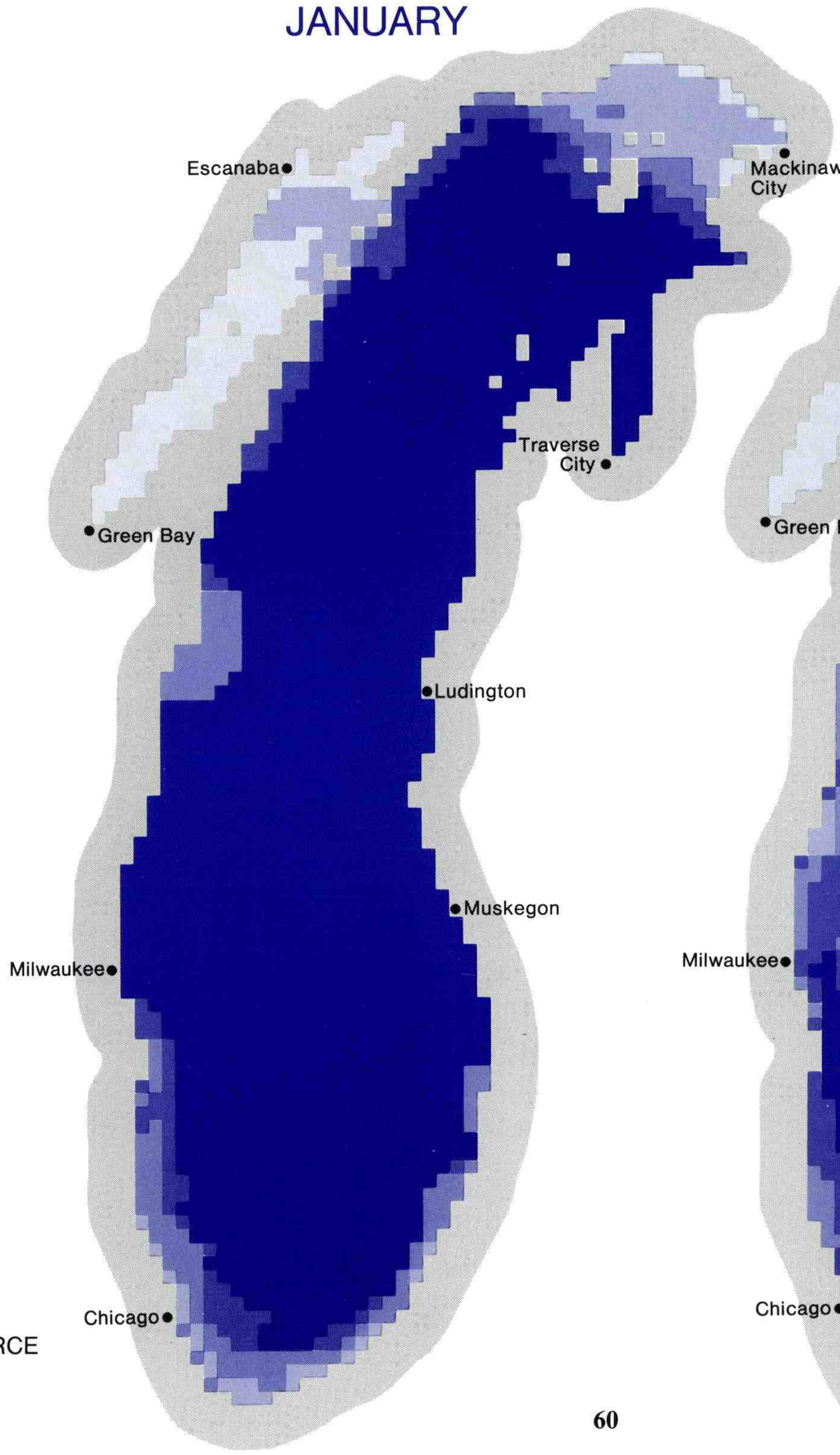
MONTHLY NORMAL ICE COVER
1960–1979

LAKE MICHIGAN

Kilometers
0 20 40 60 80 100
0 10 20 30 40 50 60
Statute Miles

ICE COVER LEGEND
- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

JANUARY



FEBRUARY

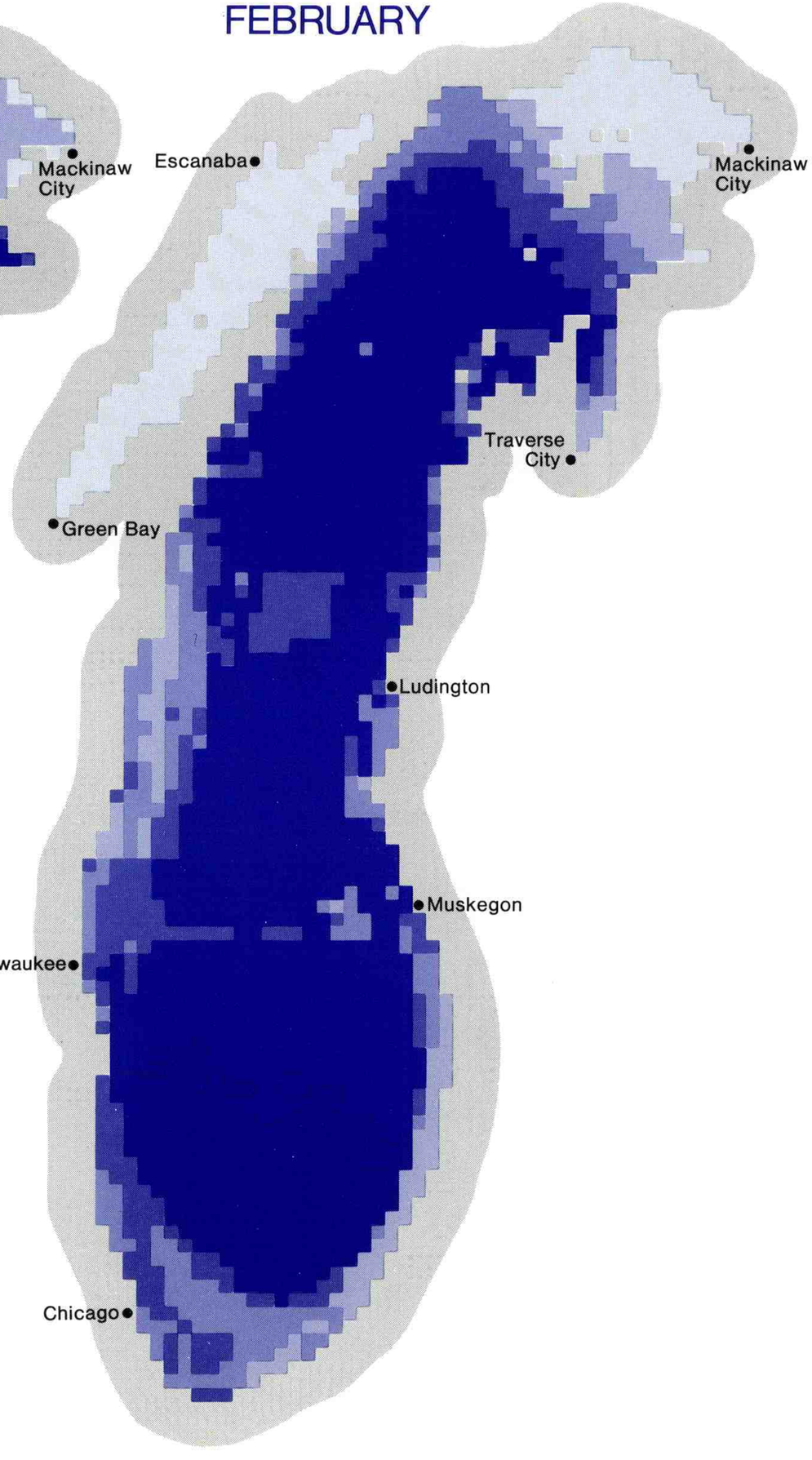
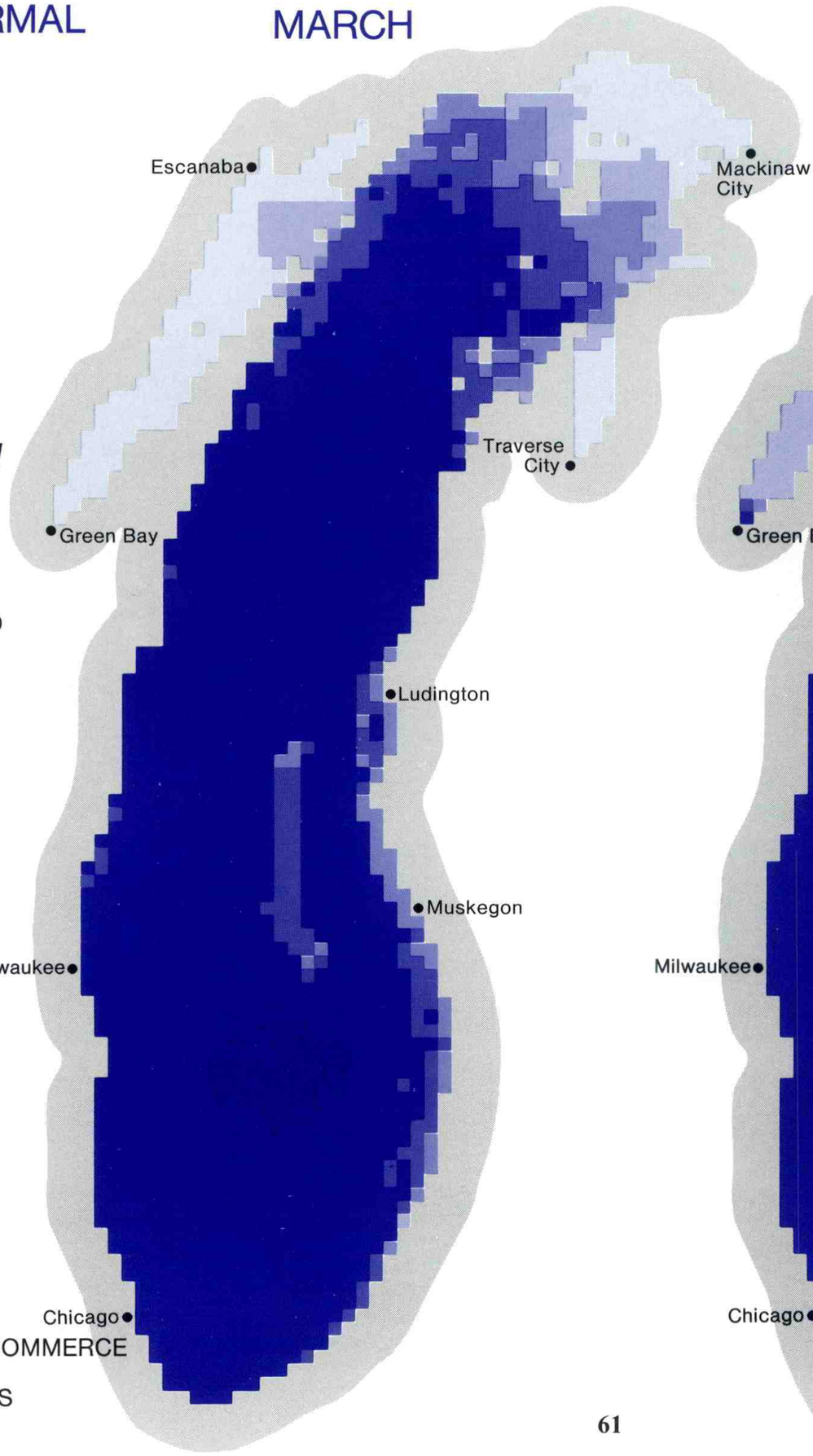


PLATE 19A

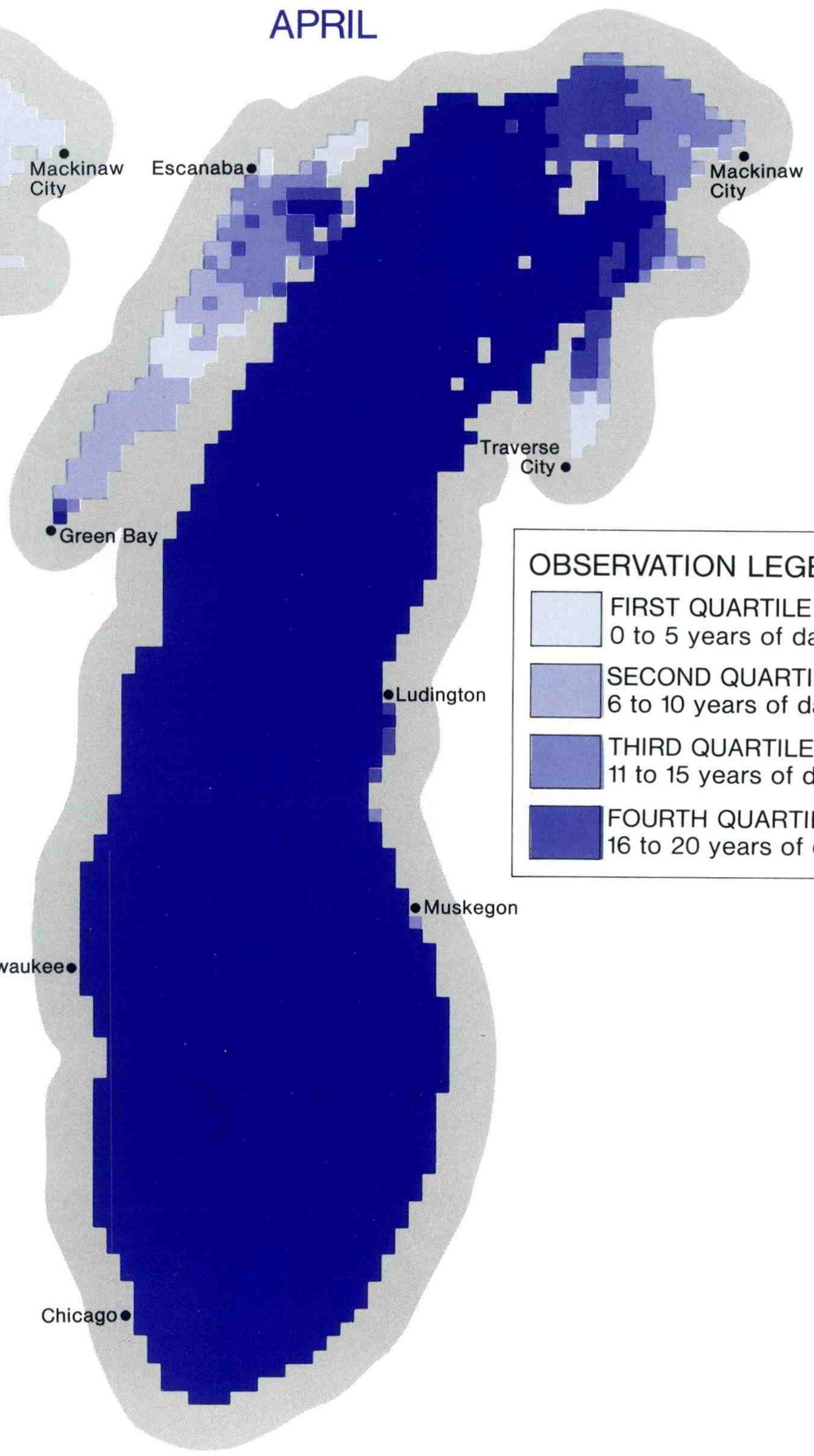
U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

MONTHLY NORMAL ICE COVER
1960–1979

MARCH



APRIL



LAKE MICHIGAN

Kilometers
0 20 40 60 80 100
0 10 20 30 40 50 60
Statute Miles

OBSERVATION LEGEND

- FIRST QUARTILE — 0 to 5 years of data
- SECOND QUARTILE — 6 to 10 years of data
- THIRD QUARTILE — 11 to 15 years of data
- FOURTH QUARTILE — 16 to 20 years of data

PLATE 19B

U.S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

EXTREMES IN ICE COVER

DECEMBER 16–31

1960–1979

LAKE HURON

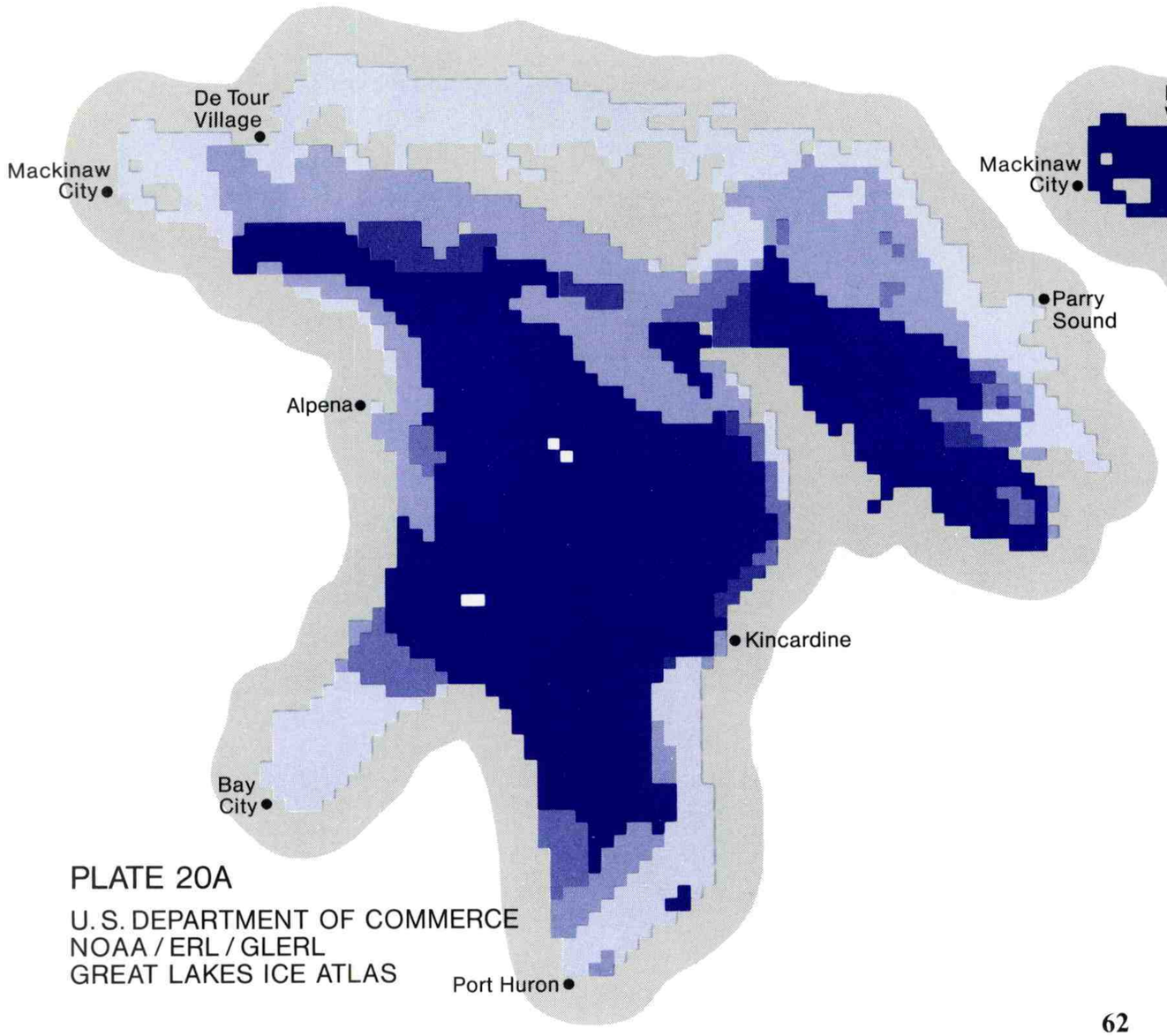
Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

ICE COVER LEGEND

- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

MAXIMUM ICE COVER



MINIMUM ICE COVER

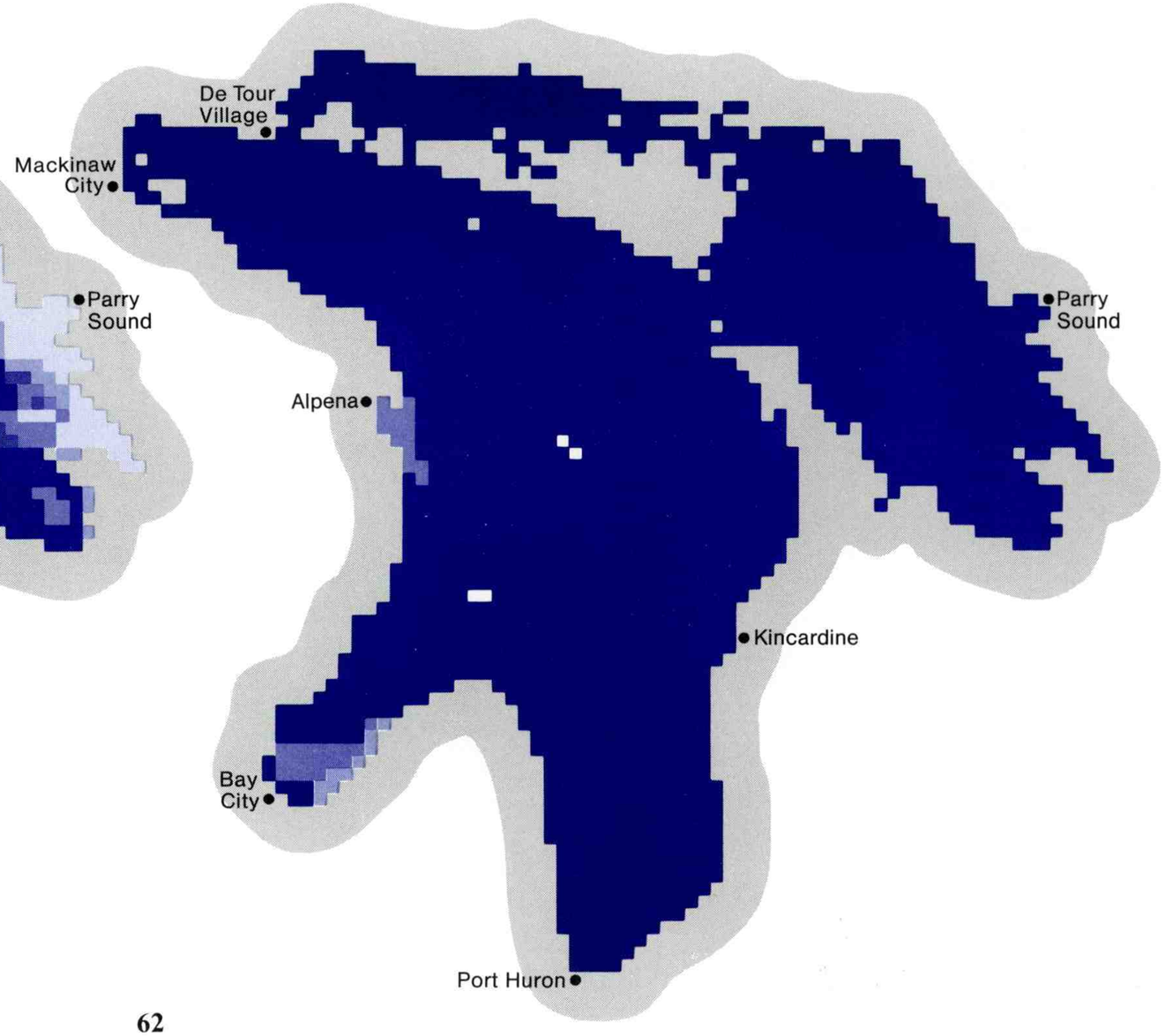


PLATE 20A

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER AND OBSERVATION DENSITY

DECEMBER 16–31

1960–1979

LAKE HURON

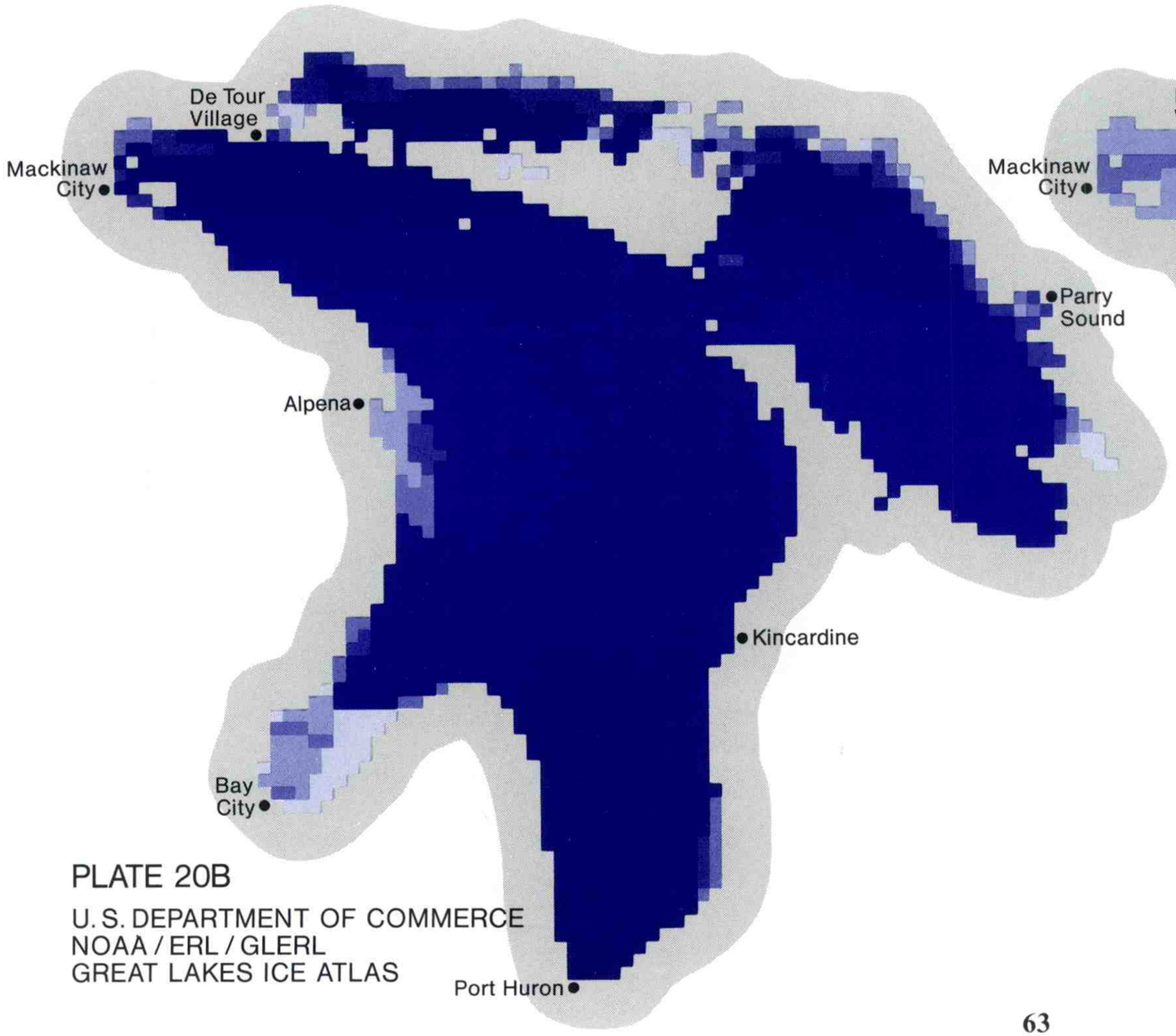
Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

OBSERVATION LEGEND

- FIRST QUARTILE
  0 to 5 years of data
- SECOND QUARTILE
  6 to 10 years of data
- THIRD QUARTILE
  11 to 15 years of data
- FOURTH QUARTILE
  16 to 20 years of data

NORMAL ICE COVER



OBSERVATION DENSITY

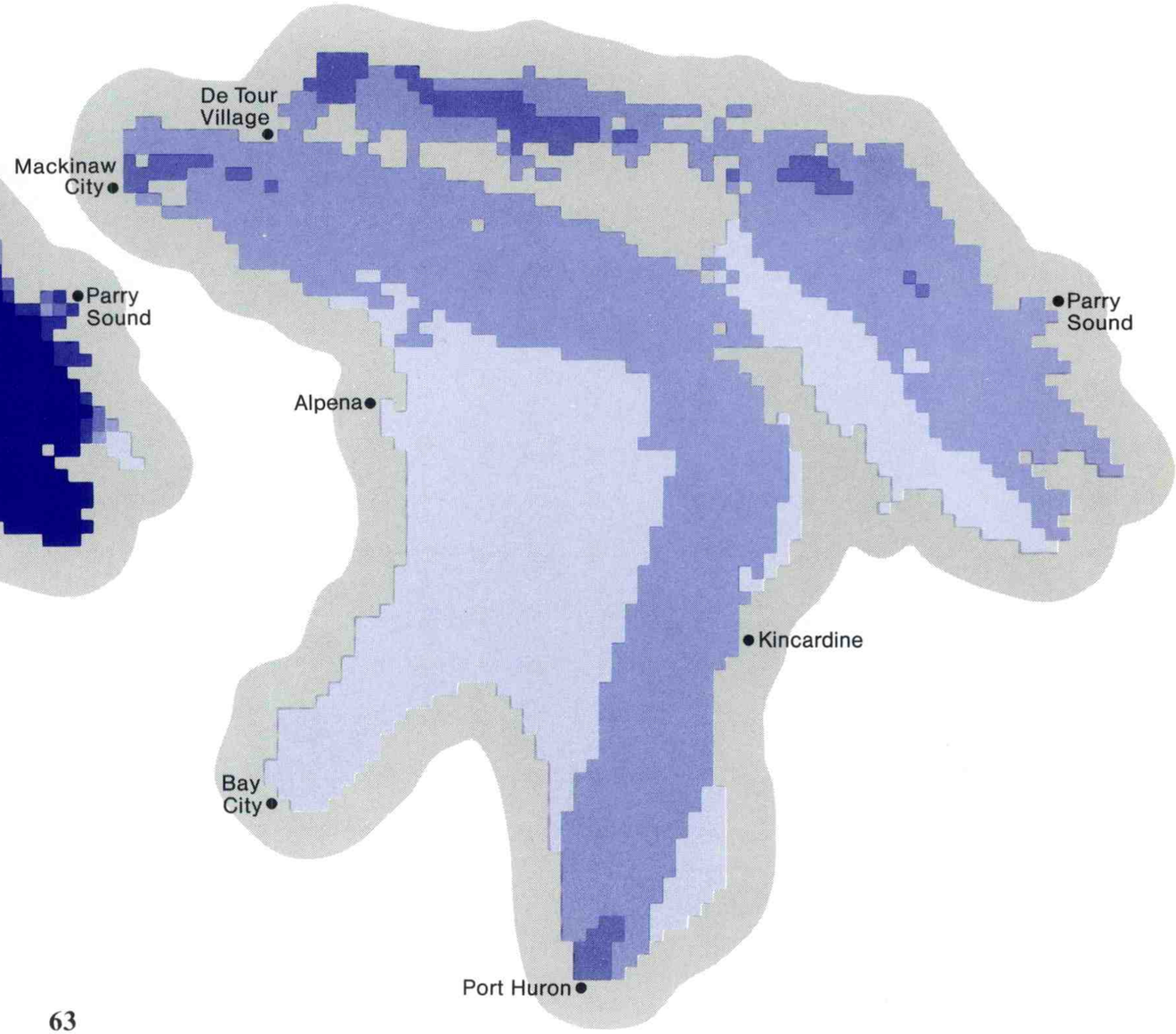


PLATE 20B

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

EXTREMES IN ICE COVER

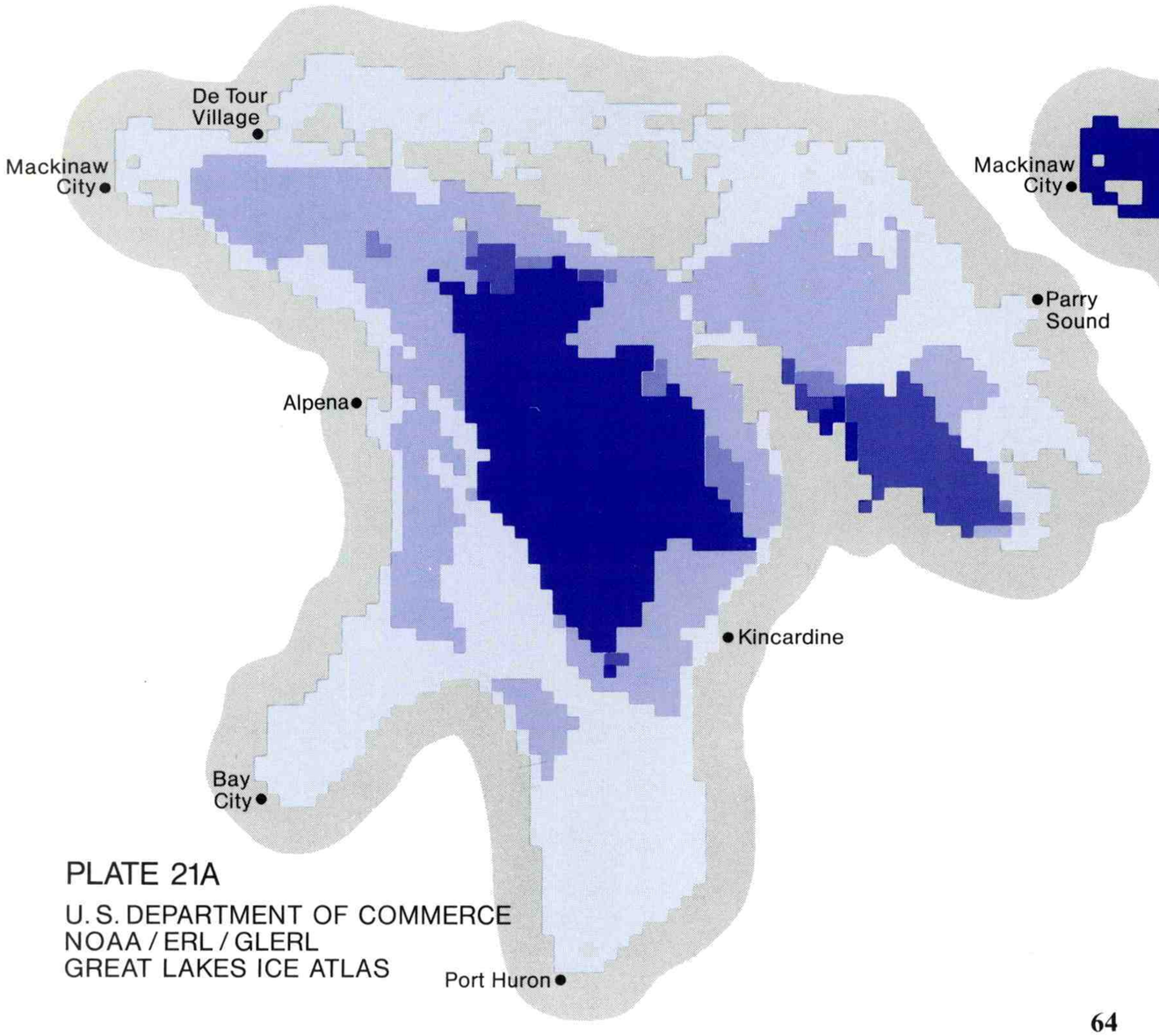
JANUARY 1–15
1960–1979

LAKE HURON

Kilometers
0 20 40 60 80 100
0 10 20 30 40 50 60
Statute Miles

ICE COVER LEGEND
- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

MAXIMUM ICE COVER



MINIMUM ICE COVER

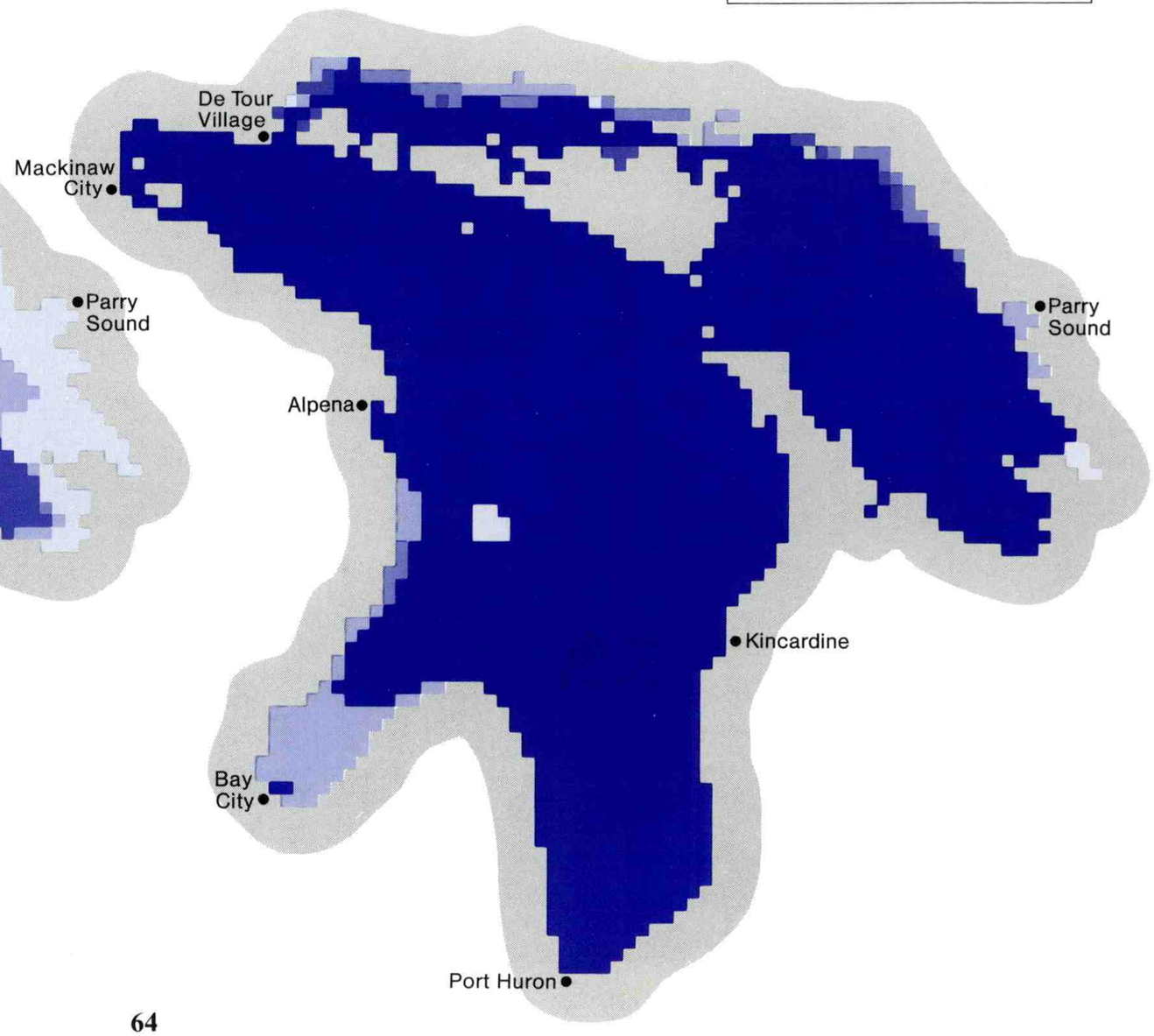


PLATE 21A

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER AND OBSERVATION DENSITY

JANUARY 1–15

1960–1979

LAKE HURON

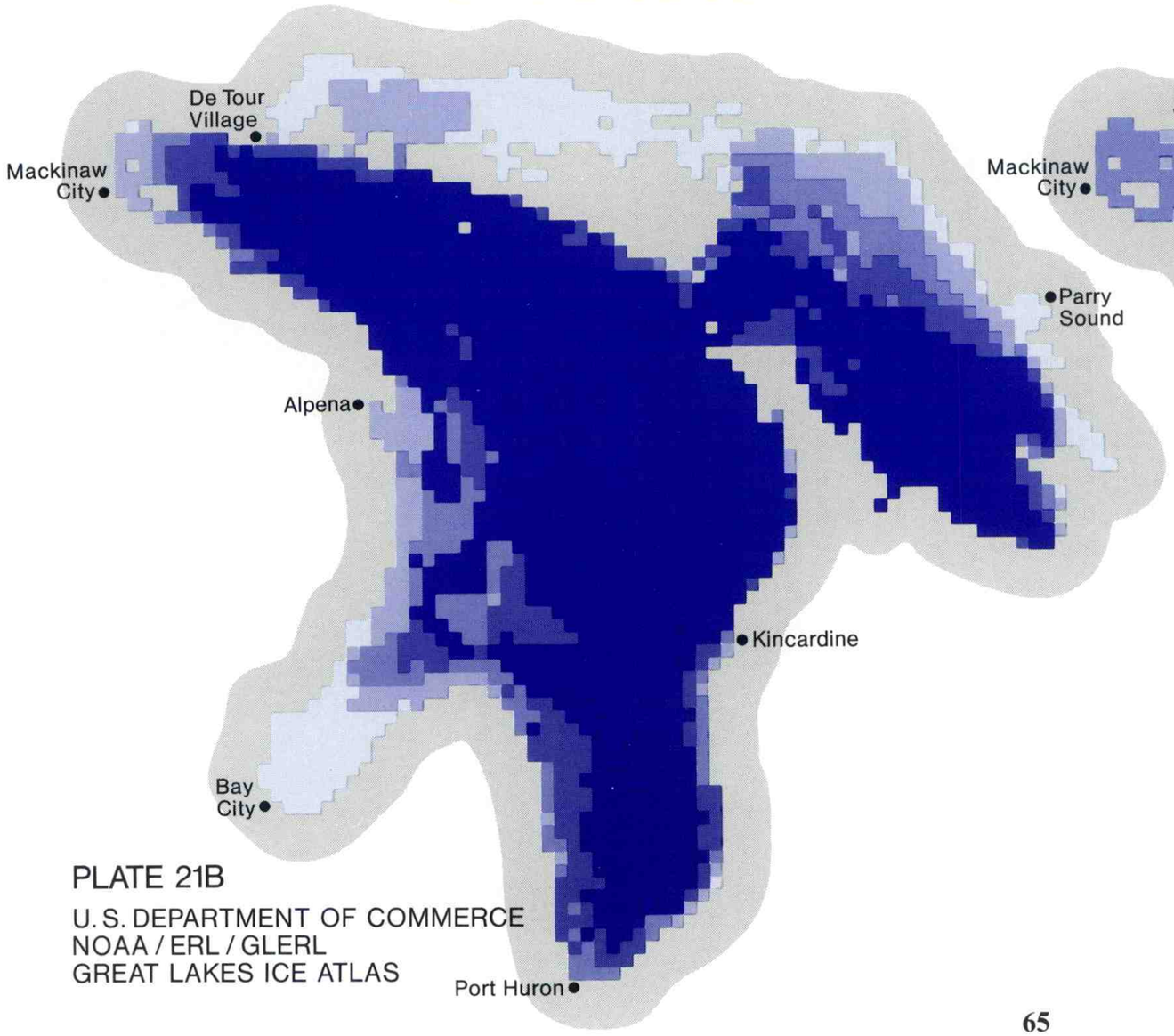
Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

OBSERVATION LEGEND

- FIRST QUARTILE
  0 to 5 years of data
- SECOND QUARTILE
  6 to 10 years of data
- THIRD QUARTILE
  11 to 15 years of data
- FOURTH QUARTILE
  16 to 20 years of data

NORMAL ICE COVER



OBSERVATION DENSITY

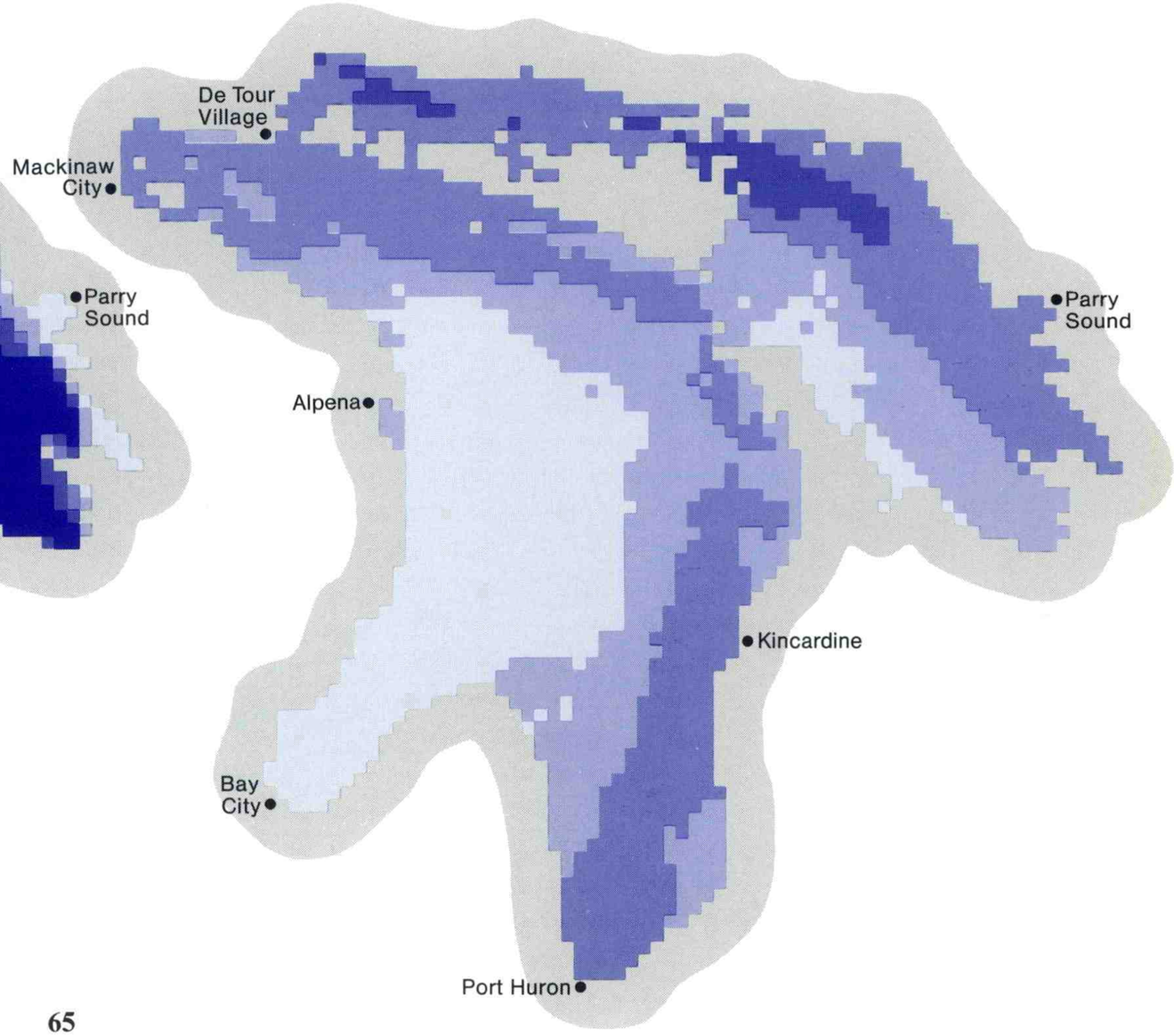


PLATE 21B

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

EXTREMES IN ICE COVER

JANUARY 16–31

1960–1979

LAKE HURON

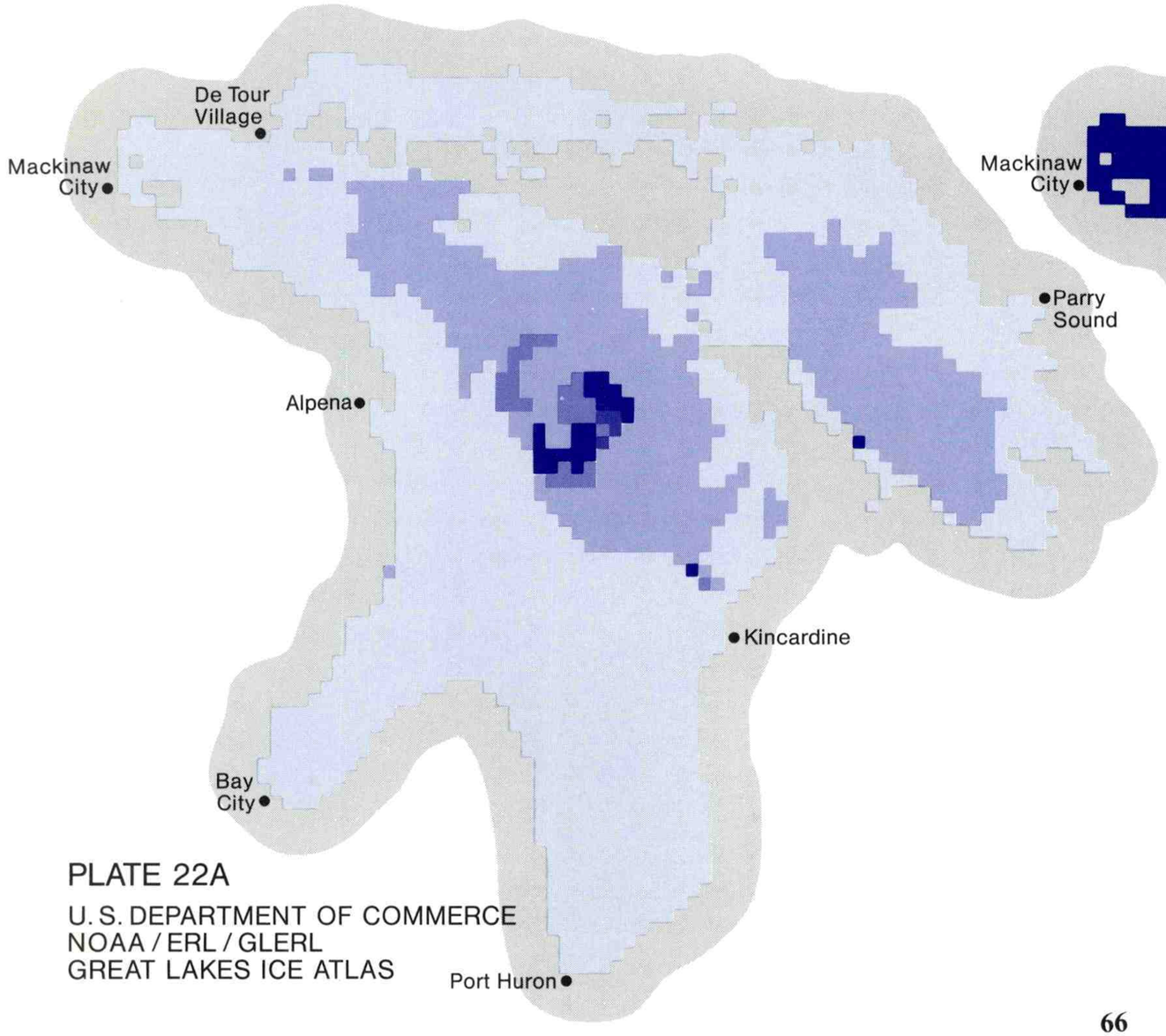
Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

ICE COVER LEGEND

- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

MAXIMUM ICE COVER



MINIMUM ICE COVER

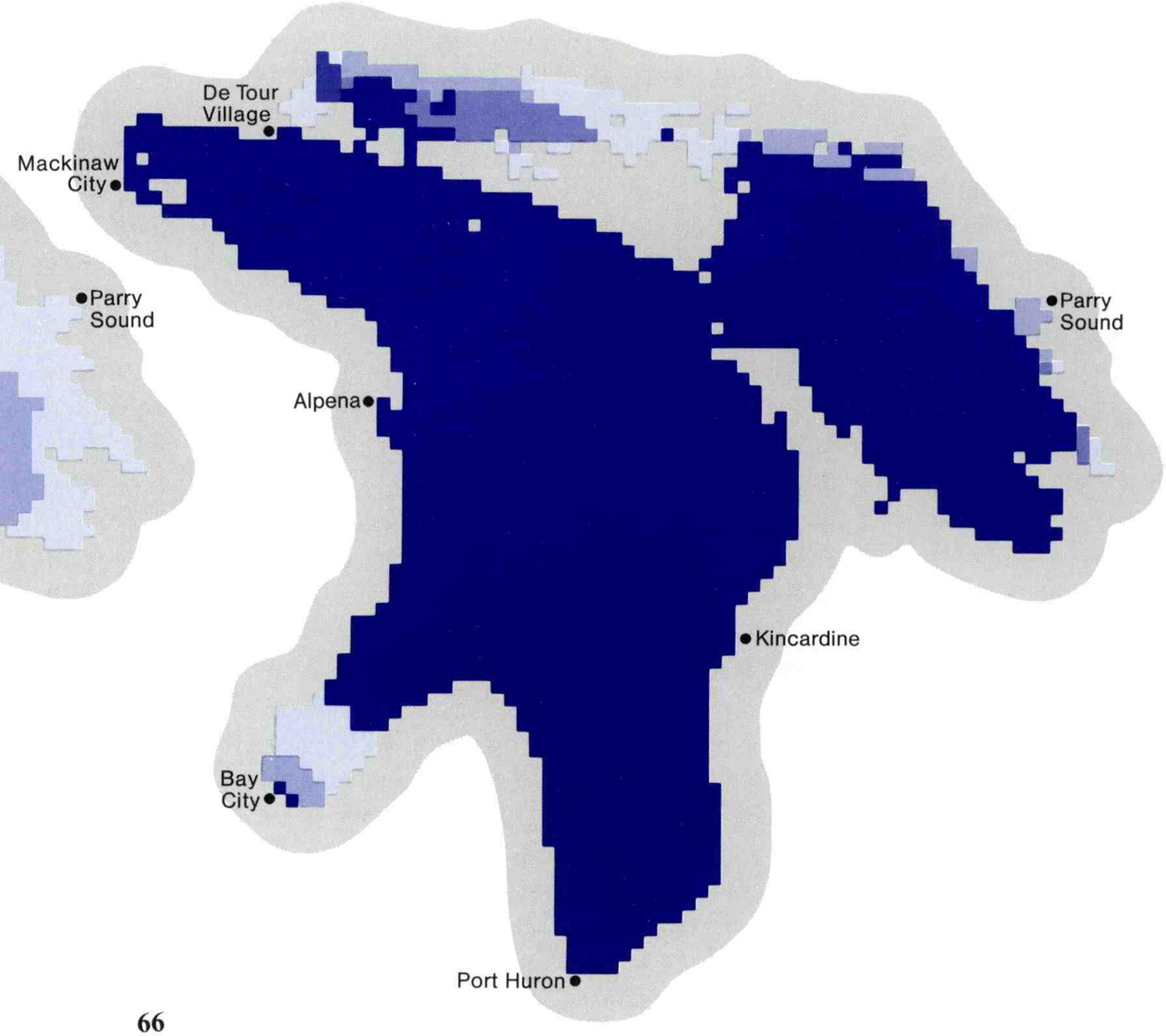


PLATE 22A

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER AND OBSERVATION DENSITY

JANUARY 16–31

1960–1979

LAKE HURON

Kilometers
0 20 40 60 80 100

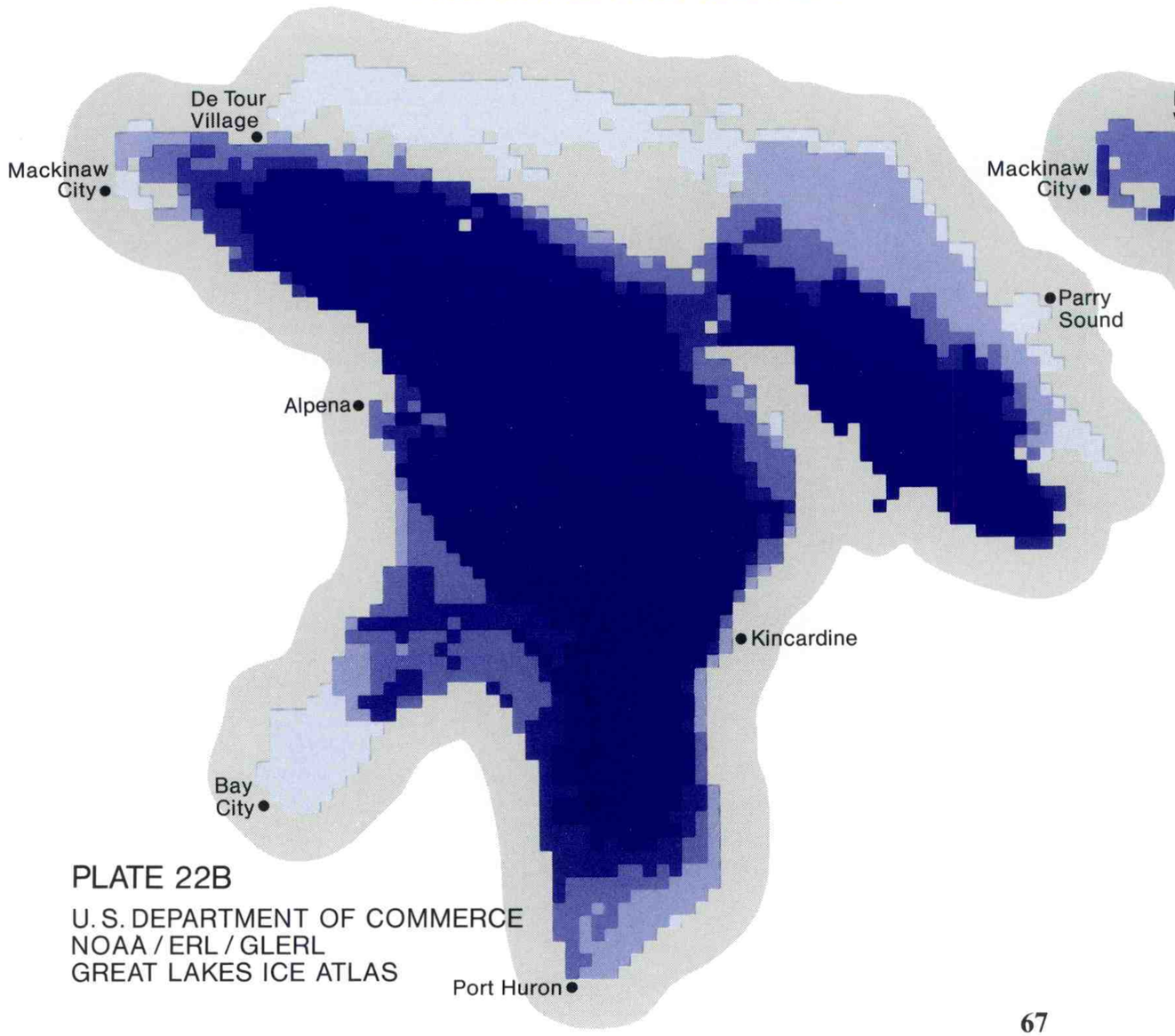
0 10 20 30 40 50 60
Statute Miles

OBSERVATION LEGEND

- FIRST QUARTILE
  0 to 5 years of data
- SECOND QUARTILE
  6 to 10 years of data
- THIRD QUARTILE
  11 to 15 years of data
- FOURTH QUARTILE
  16 to 20 years of data

NORMAL ICE COVER

OBSERVATION DENSITY



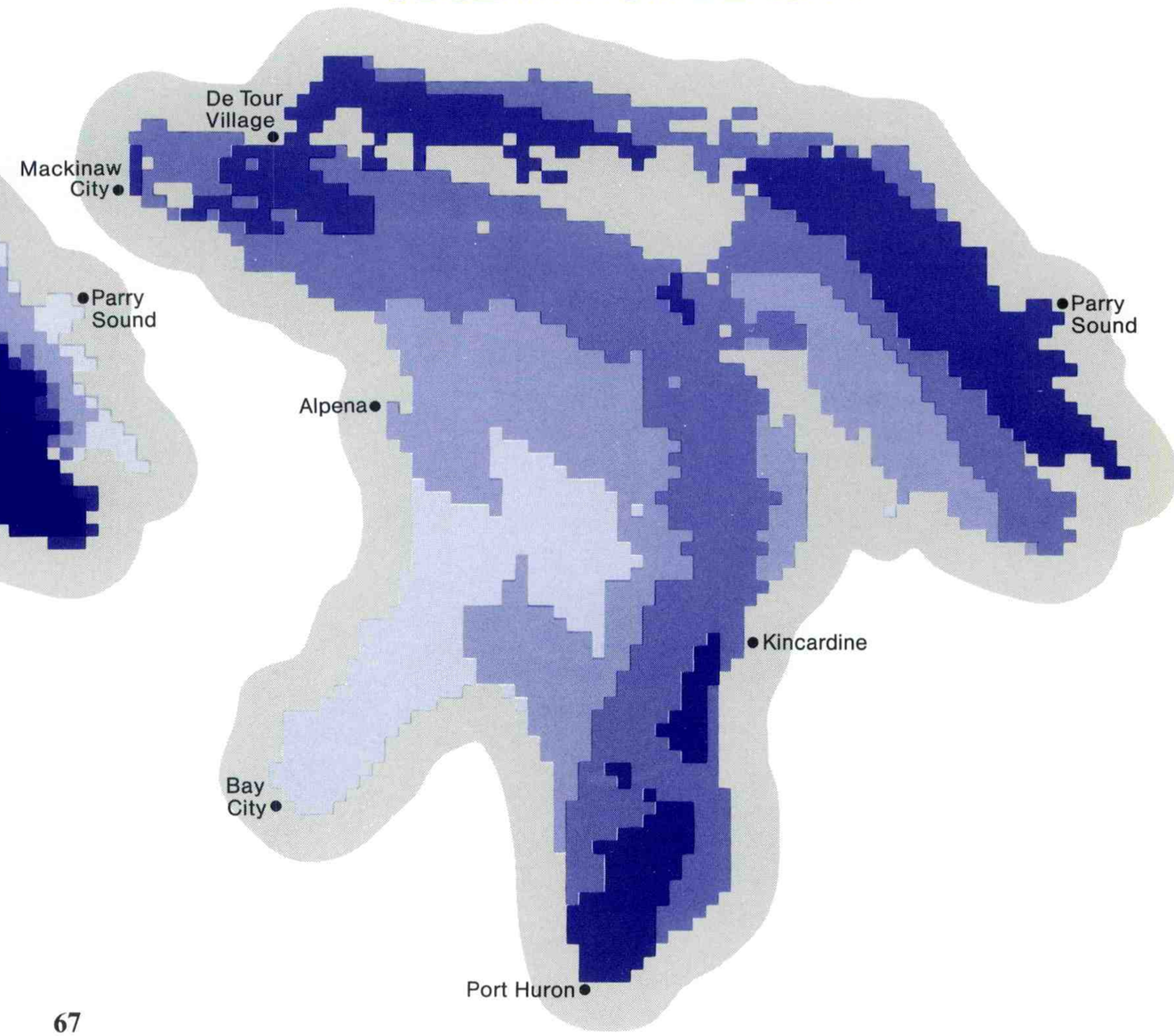


PLATE 22B

U.S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

EXTREMES IN ICE COVER

FEBRUARY 1–14
1960–1979

LAKE HURON

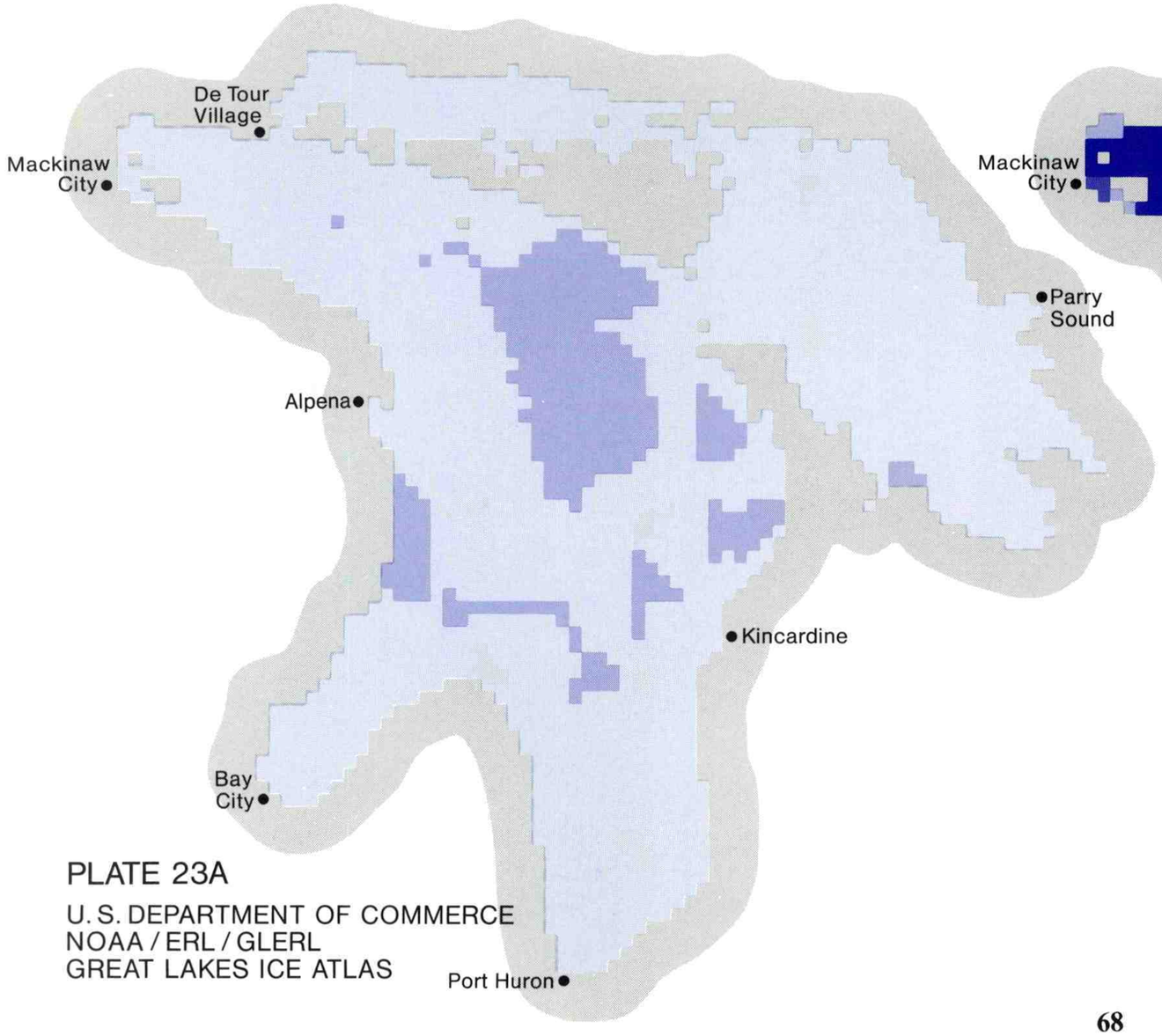
Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

ICE COVER LEGEND

- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

MAXIMUM ICE COVER



MINIMUM ICE COVER

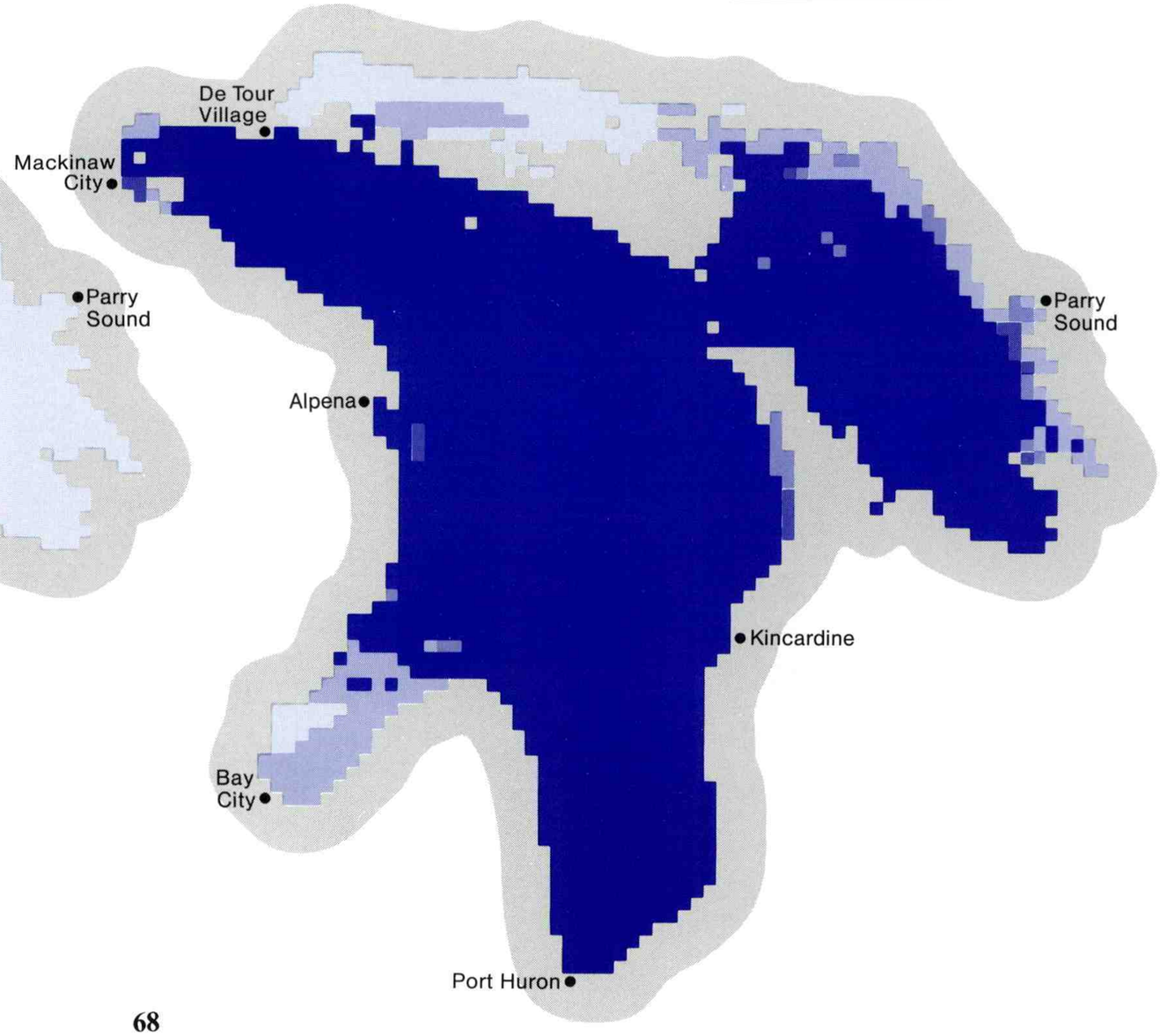


PLATE 23A

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER AND OBSERVATION DENSITY

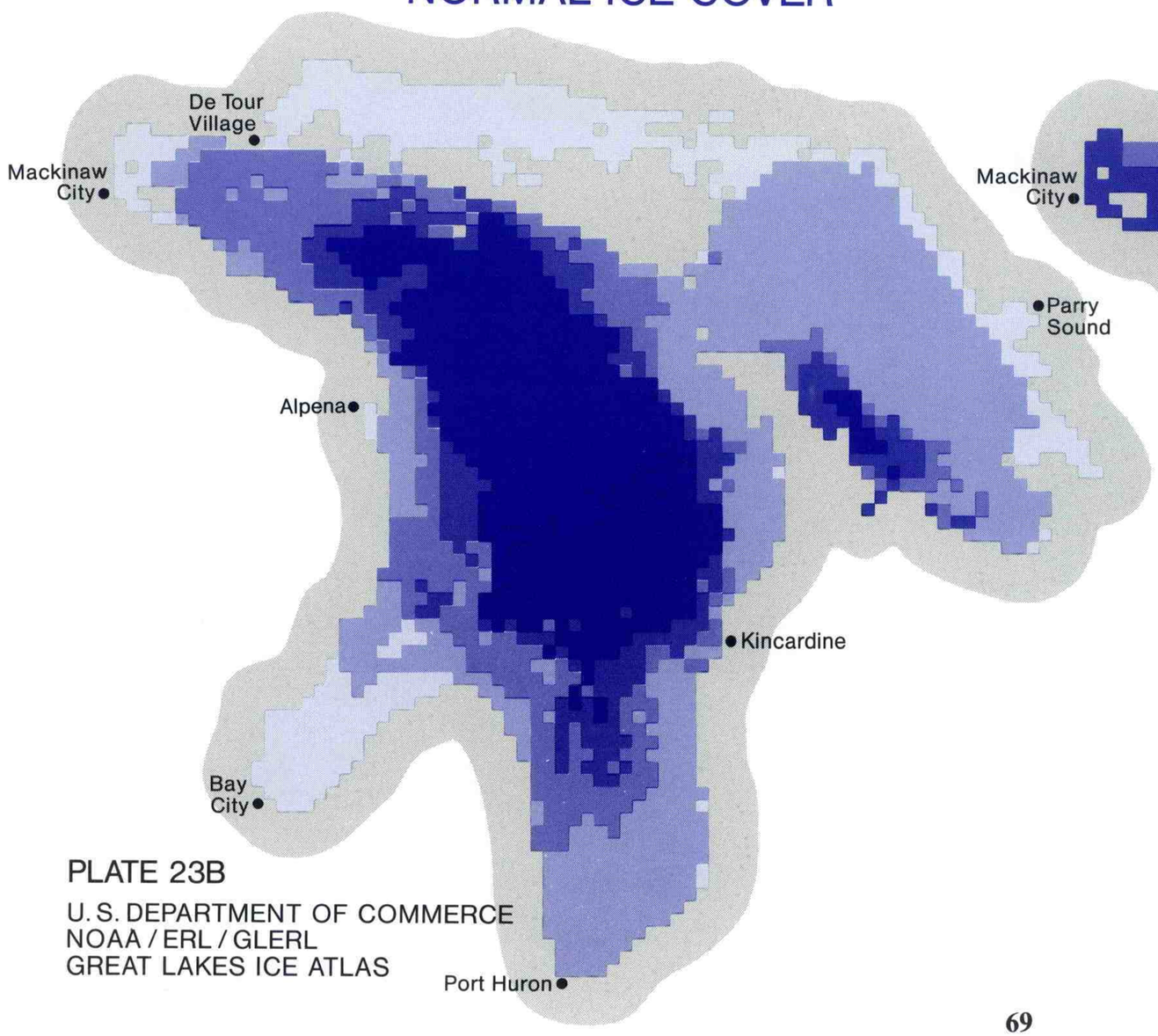
FEBRUARY 1–14
1960–1979

LAKE HURON

Kilometers
0 20 40 60 80 100
0 10 20 30 40 50 60
Statute Miles

OBSERVATION LEGEND
- FIRST QUARTILE — 0 to 5 years of data
- SECOND QUARTILE — 6 to 10 years of data
- THIRD QUARTILE — 11 to 15 years of data
- FOURTH QUARTILE — 16 to 20 years of data

NORMAL ICE COVER



OBSERVATION DENSITY

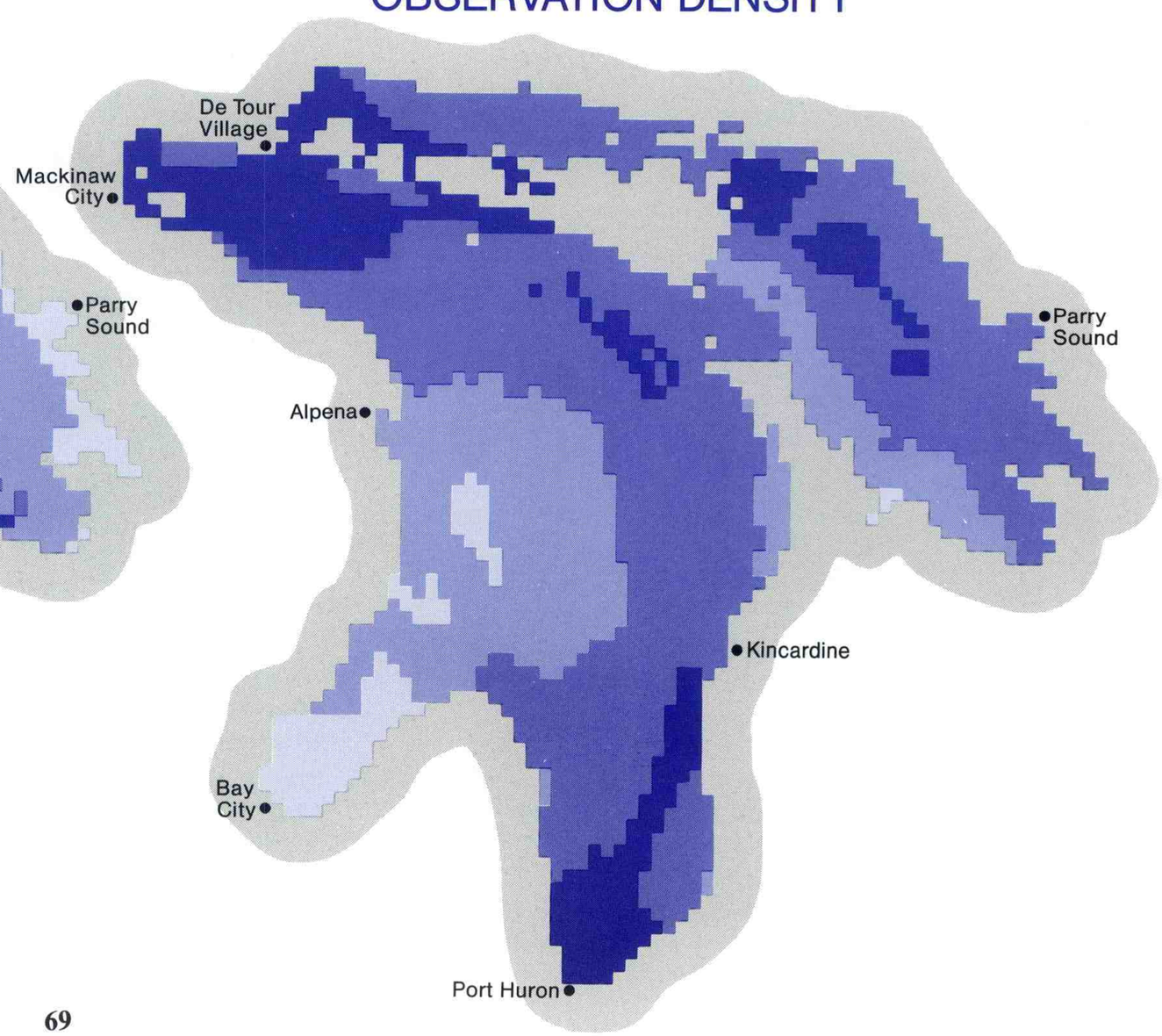


PLATE 23B

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

EXTREMES IN ICE COVER

FEBRUARY 15–28

1960–1979

LAKE HURON

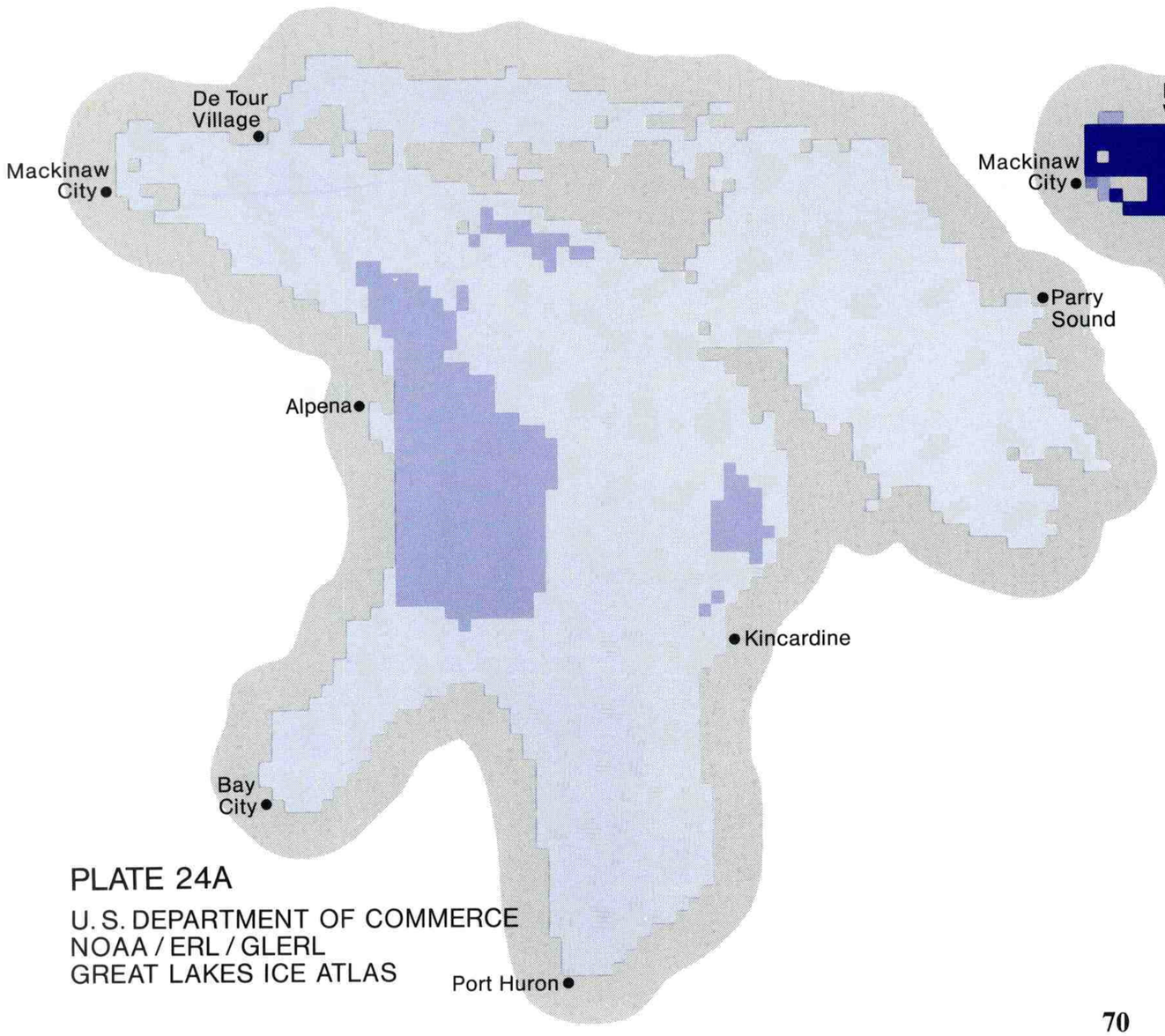
Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

ICE COVER LEGEND

- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

MAXIMUM ICE COVER



MINIMUM ICE COVER

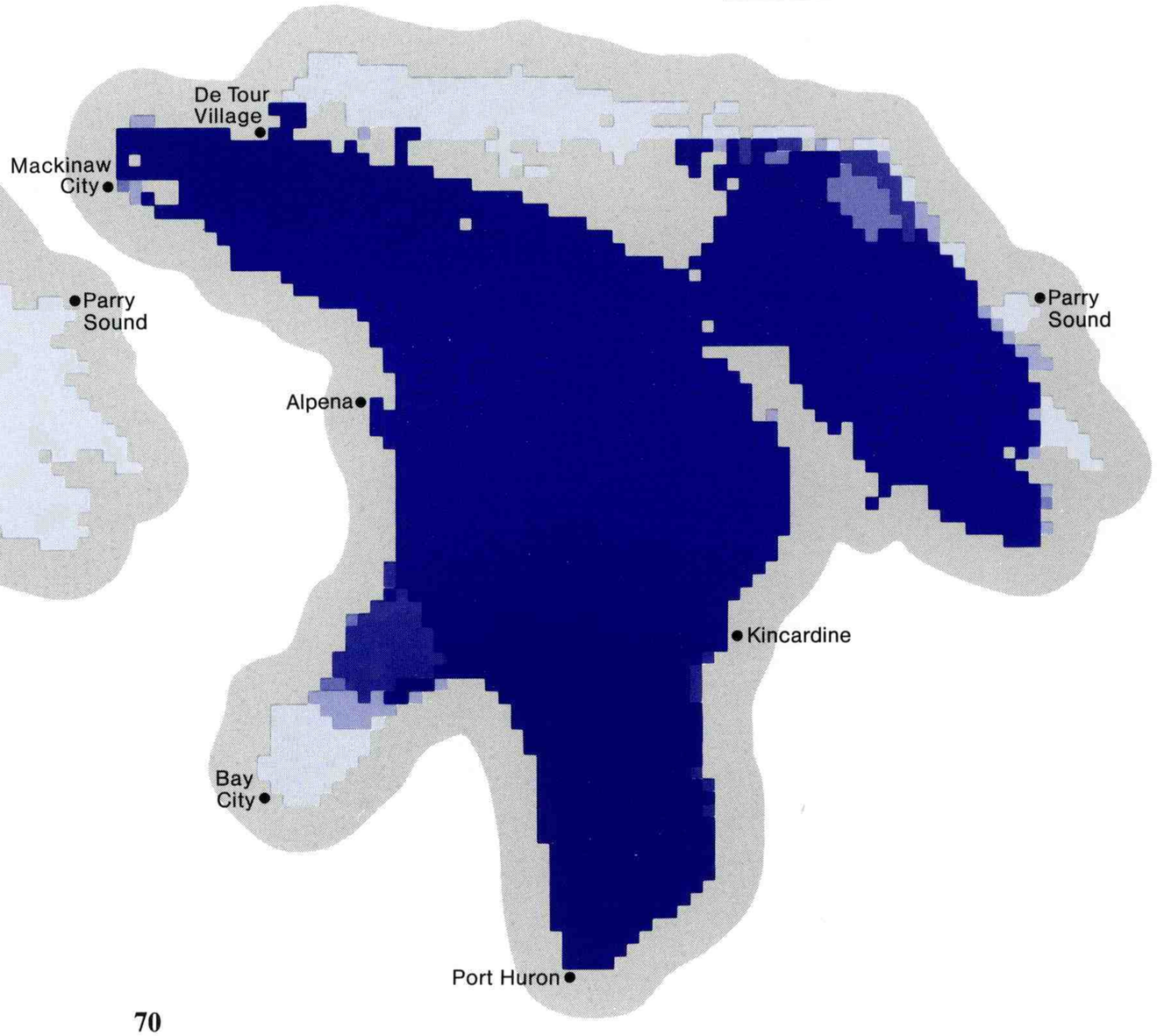


PLATE 24A

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER AND OBSERVATION DENSITY

FEBRUARY 15–28

1960–1979

LAKE HURON

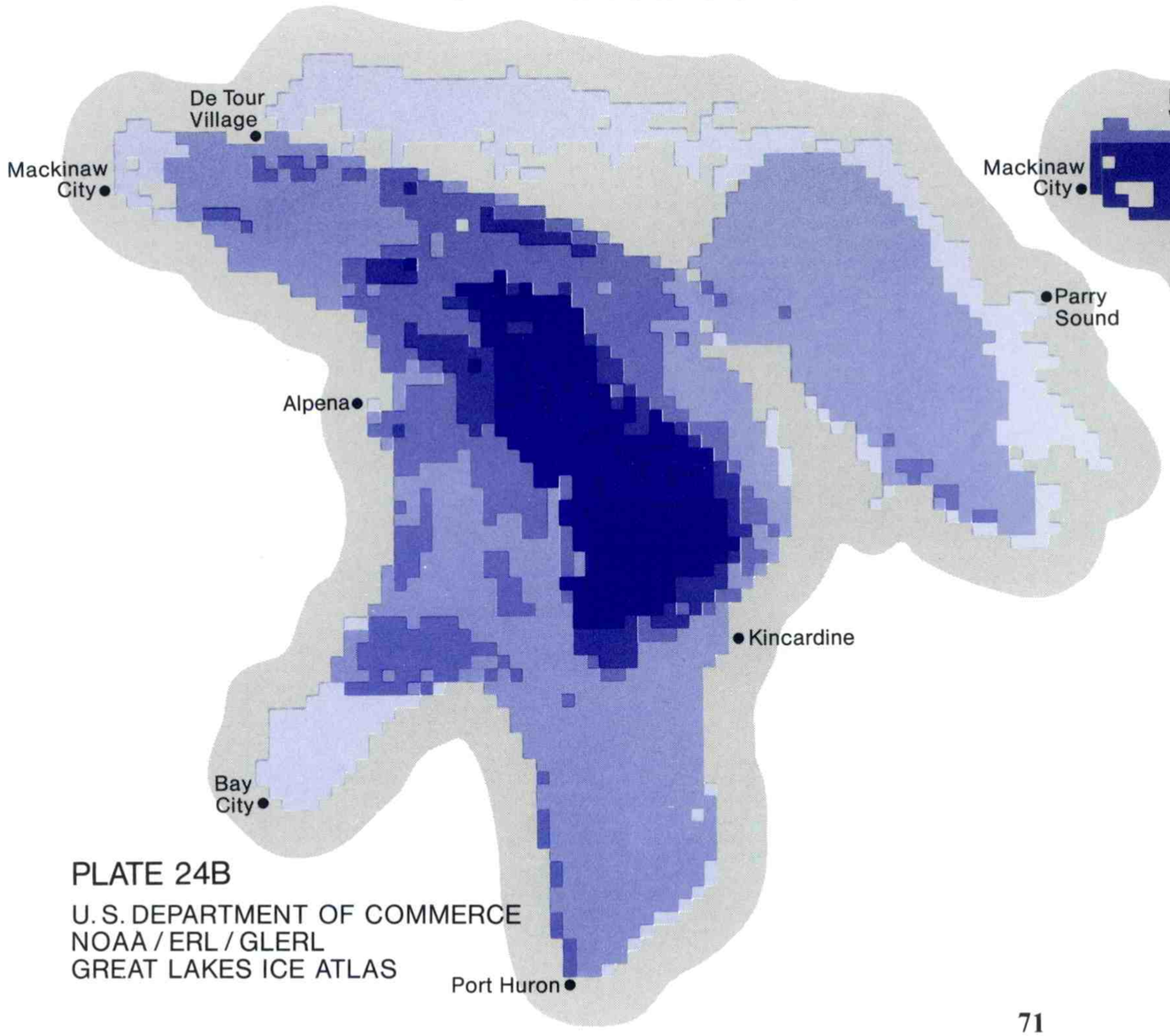
Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

OBSERVATION LEGEND

- FIRST QUARTILE
  0 to 5 years of data
- SECOND QUARTILE
  6 to 10 years of data
- THIRD QUARTILE
  11 to 15 years of data
- FOURTH QUARTILE
  16 to 20 years of data

NORMAL ICE COVER



OBSERVATION DENSITY

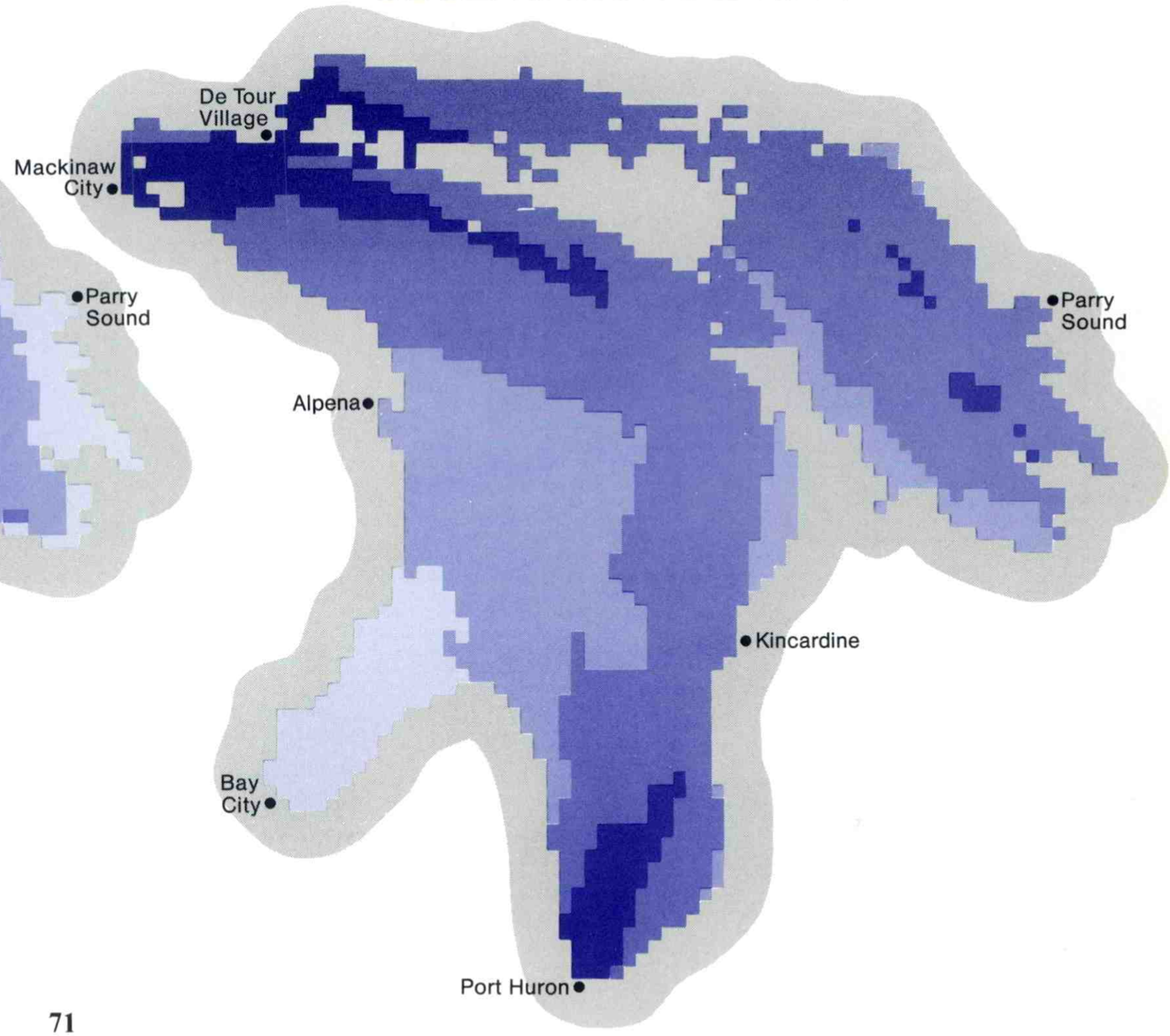


PLATE 24B

U.S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

EXTREMES IN ICE COVER

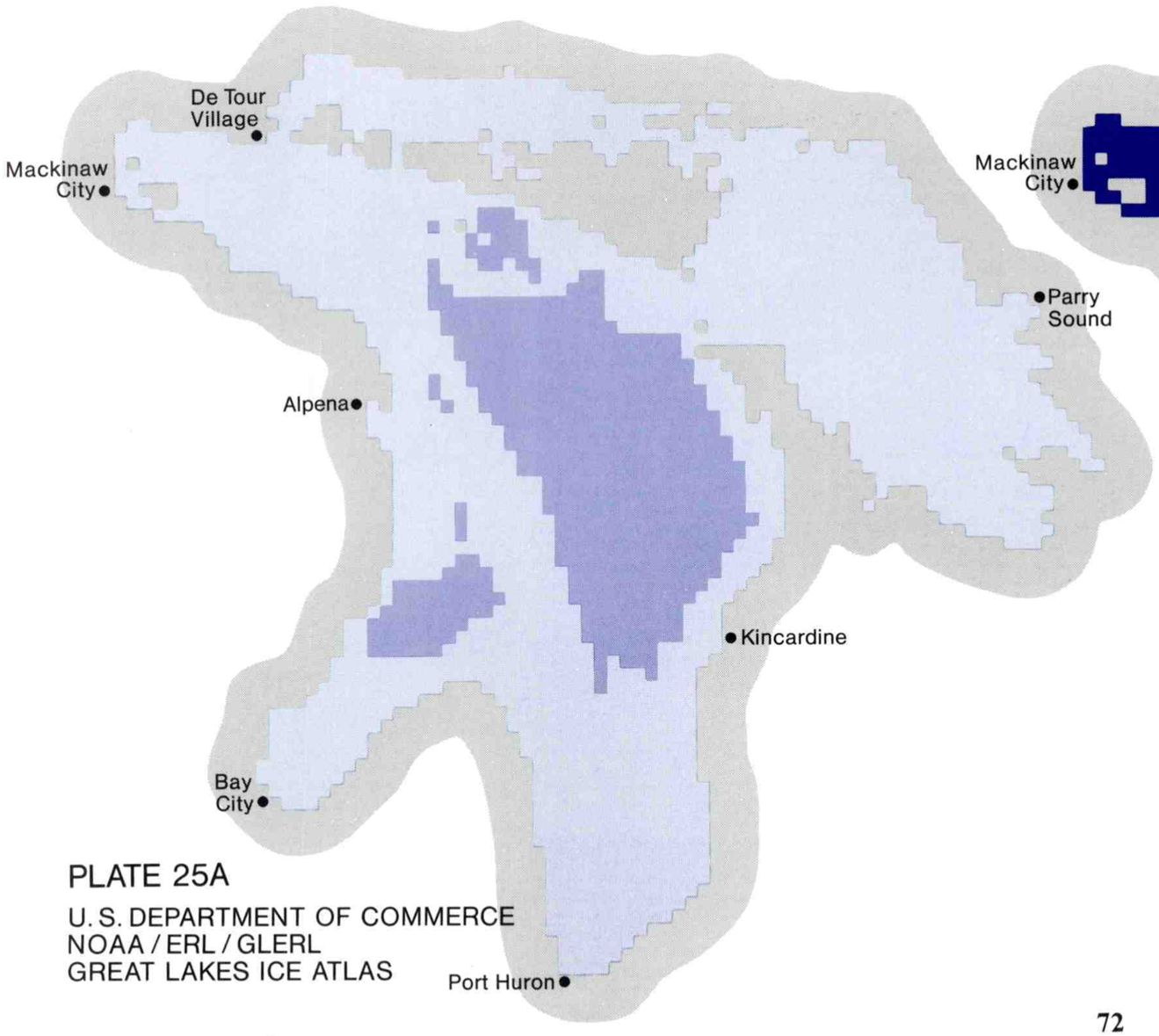
MARCH 1–15
1960–1979

LAKE HURON

Kilometers
0 20 40 60 80 100
0 10 20 30 40 50 60
Statute Miles

ICE COVER LEGEND
- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

MAXIMUM ICE COVER



MINIMUM ICE COVER

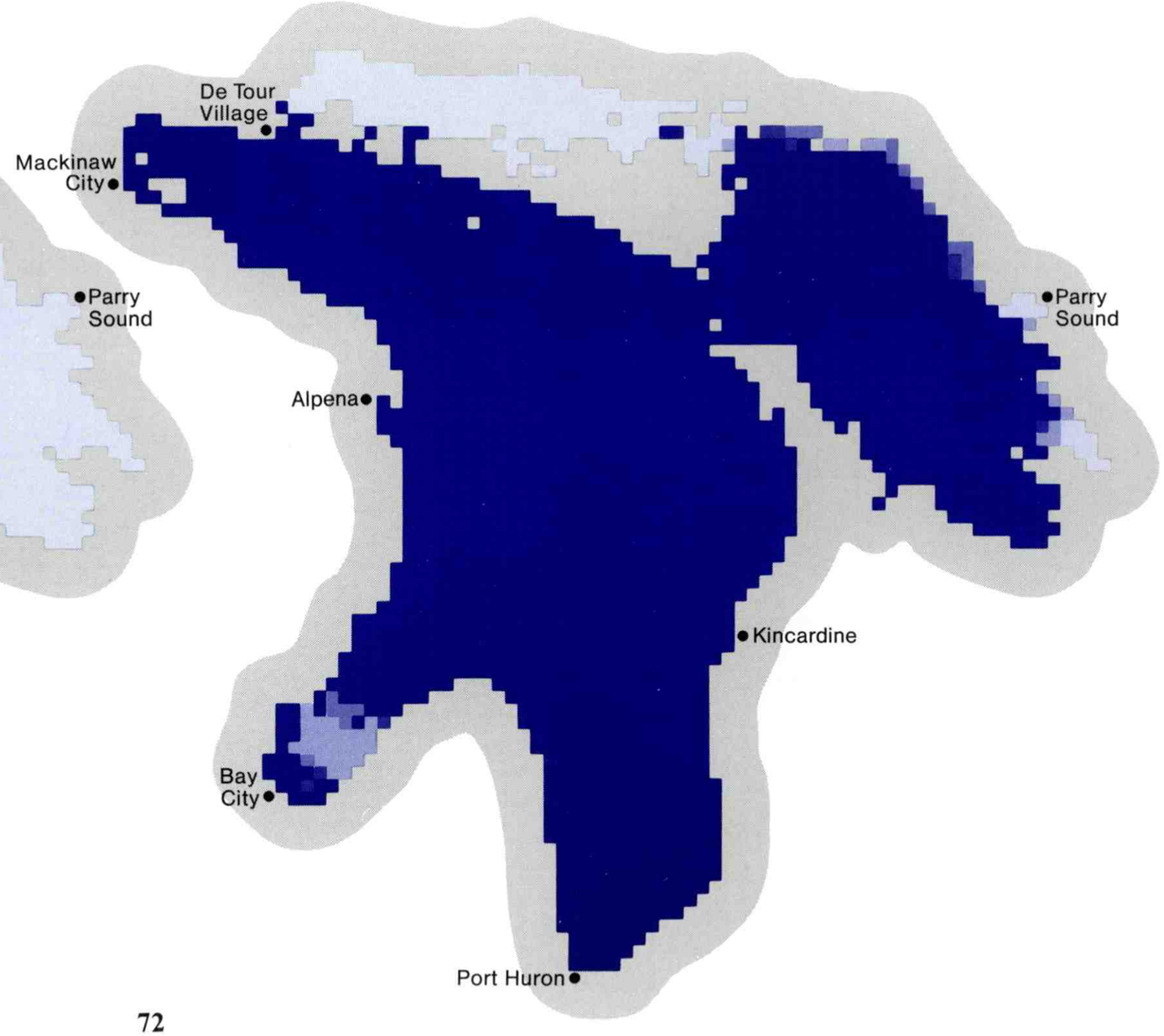


PLATE 25A

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER AND OBSERVATION DENSITY

MARCH 1–15

1960–1979

LAKE HURON

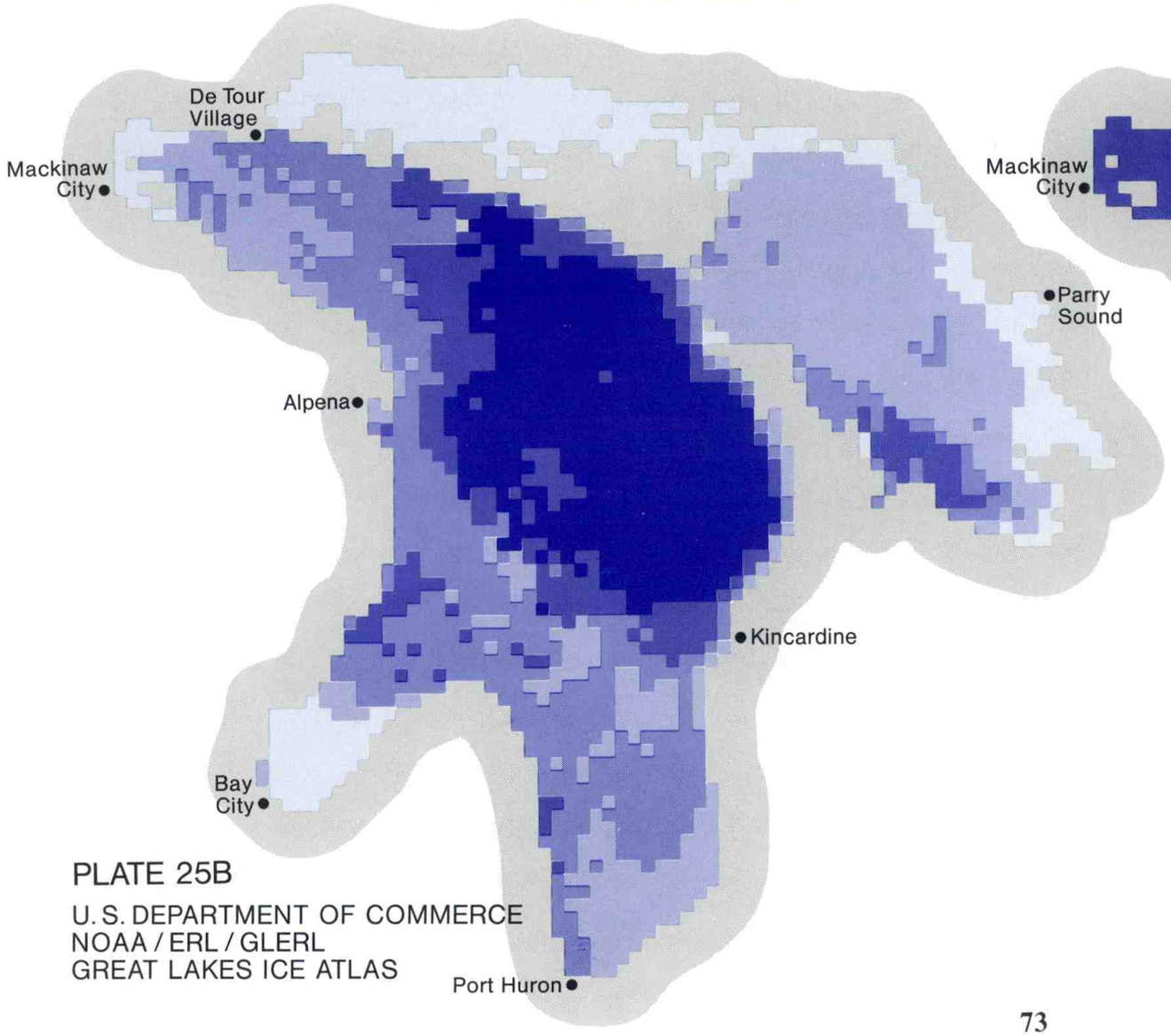
Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

OBSERVATION LEGEND

- FIRST QUARTILE
  0 to 5 years of data
- SECOND QUARTILE
  6 to 10 years of data
- THIRD QUARTILE
  11 to 15 years of data
- FOURTH QUARTILE
  16 to 20 years of data

NORMAL ICE COVER



OBSERVATION DENSITY

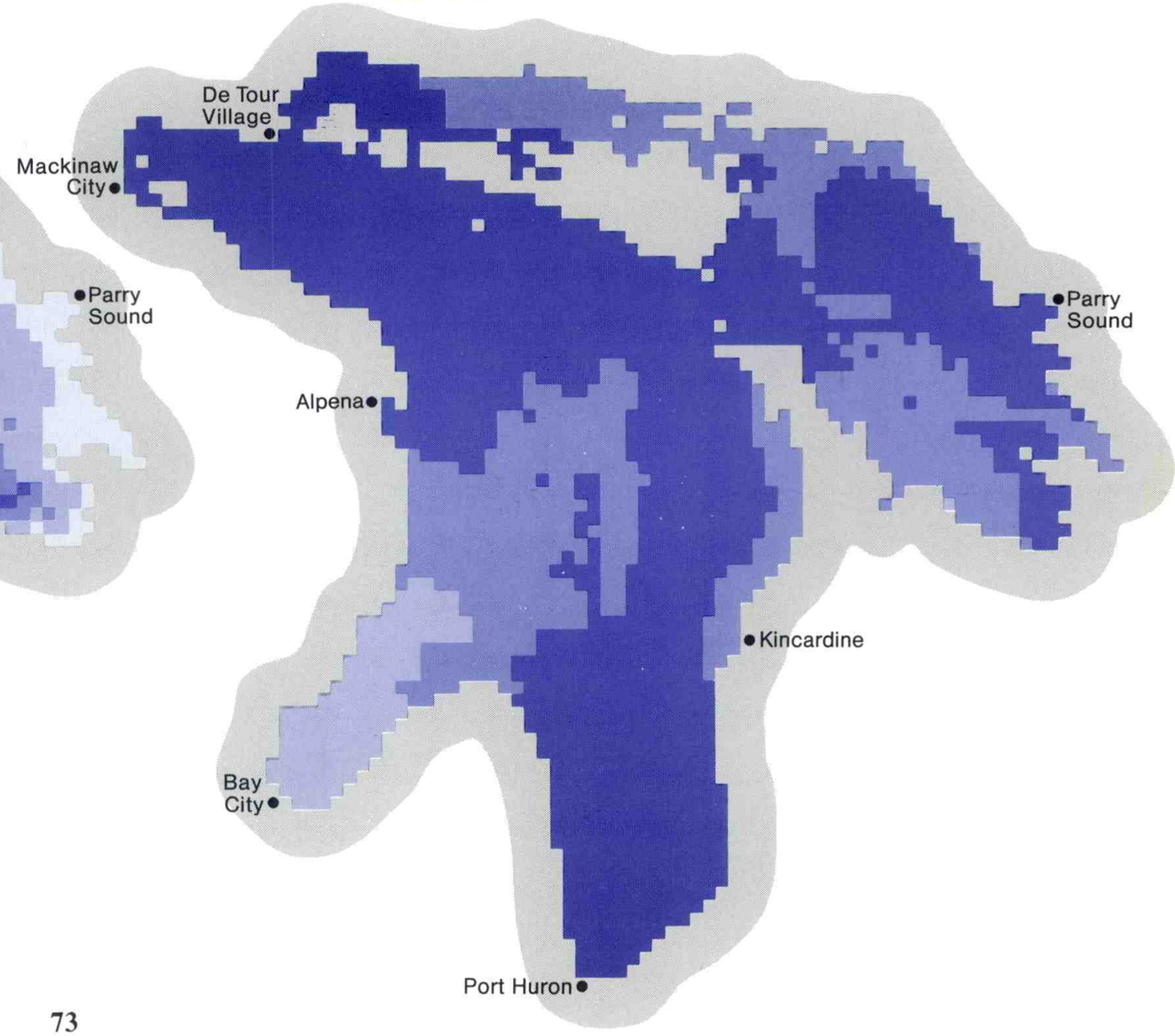


PLATE 25B

U.S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

EXTREMES IN ICE COVER

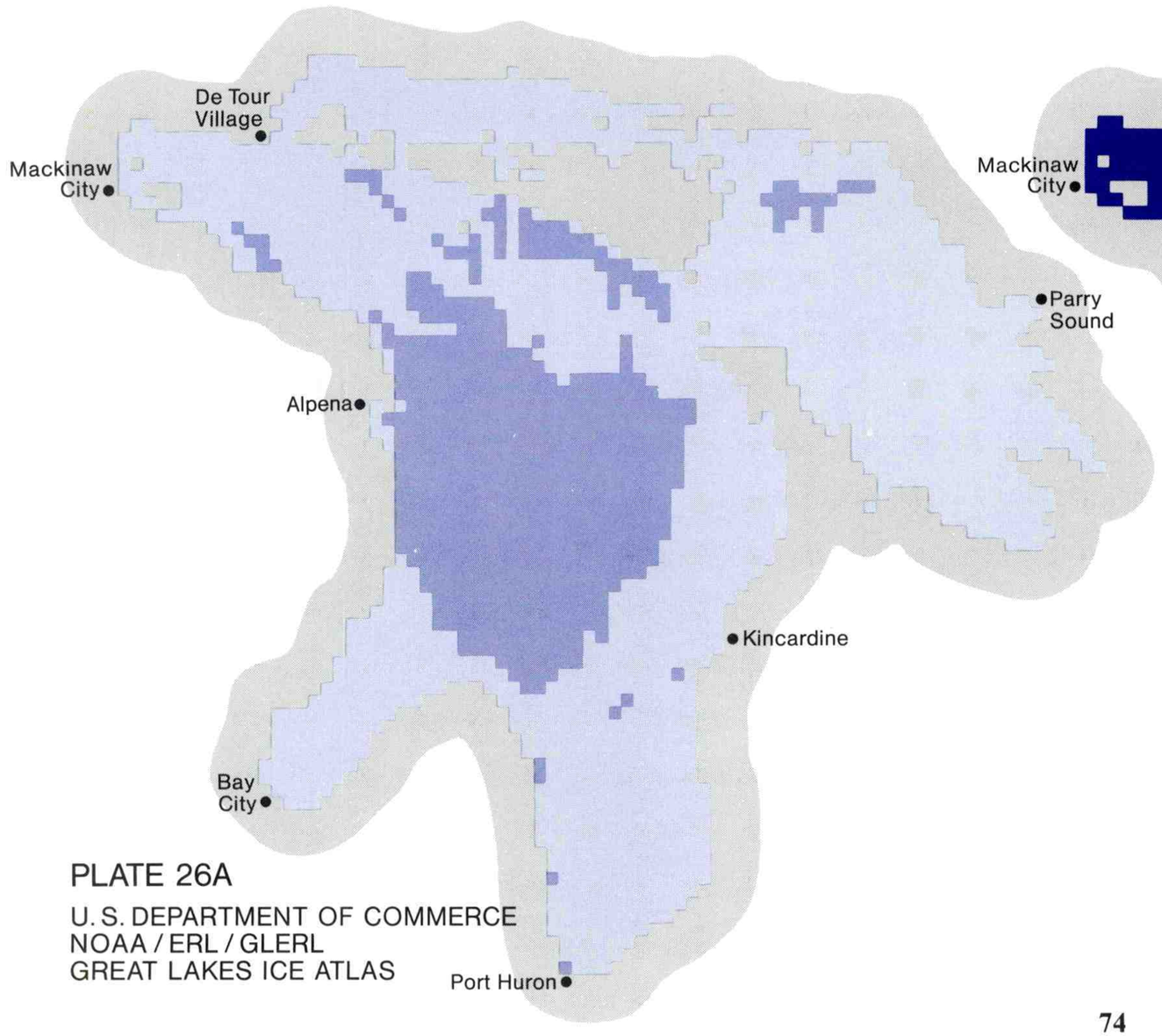
MARCH 16–31
1960–1979

LAKE HURON

Kilometers
0 20 40 60 80 100
0 10 20 30 40 50 60
Statute Miles

ICE COVER LEGEND
- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

MAXIMUM ICE COVER



MINIMUM ICE COVER

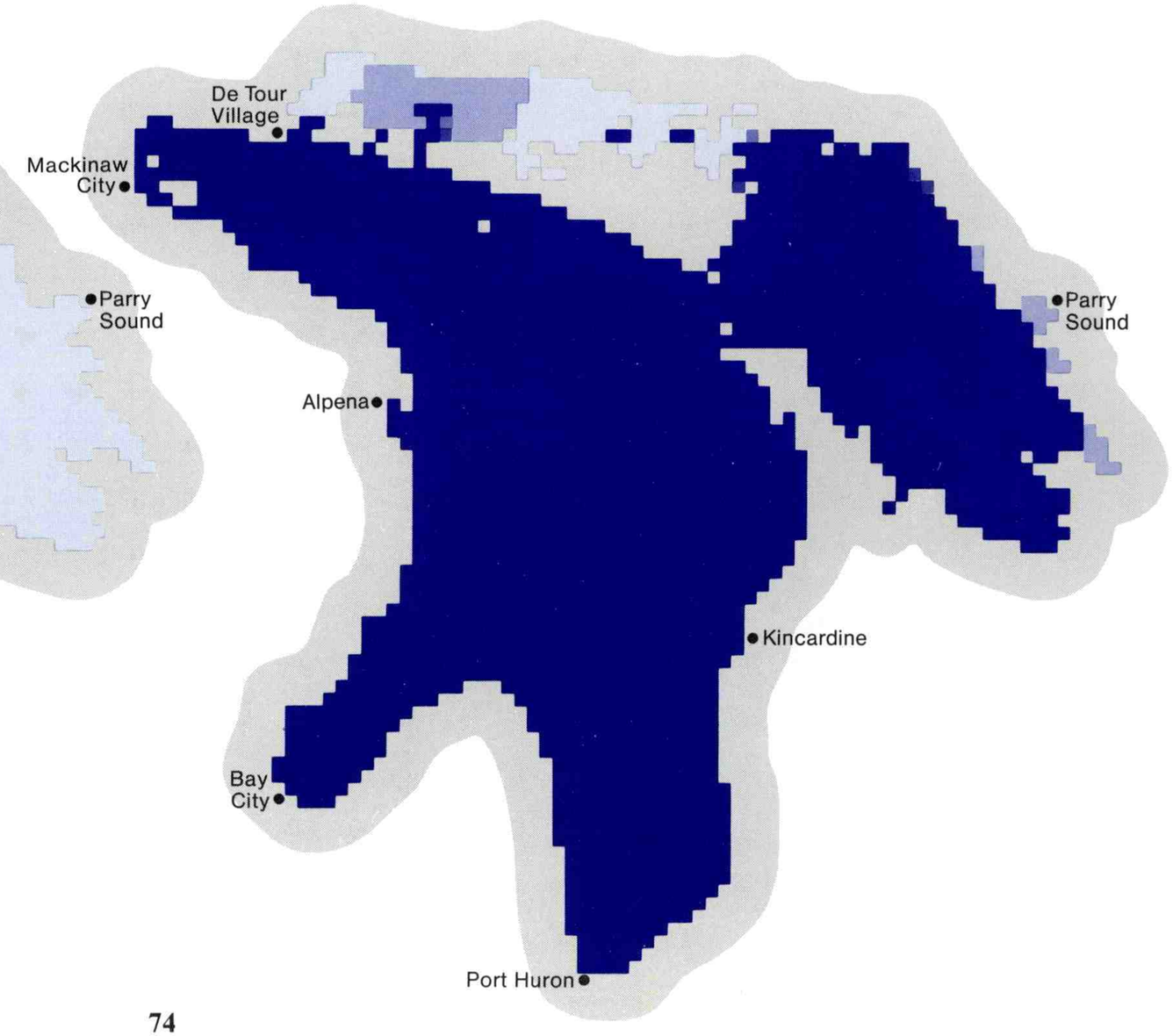


PLATE 26A

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER AND OBSERVATION DENSITY

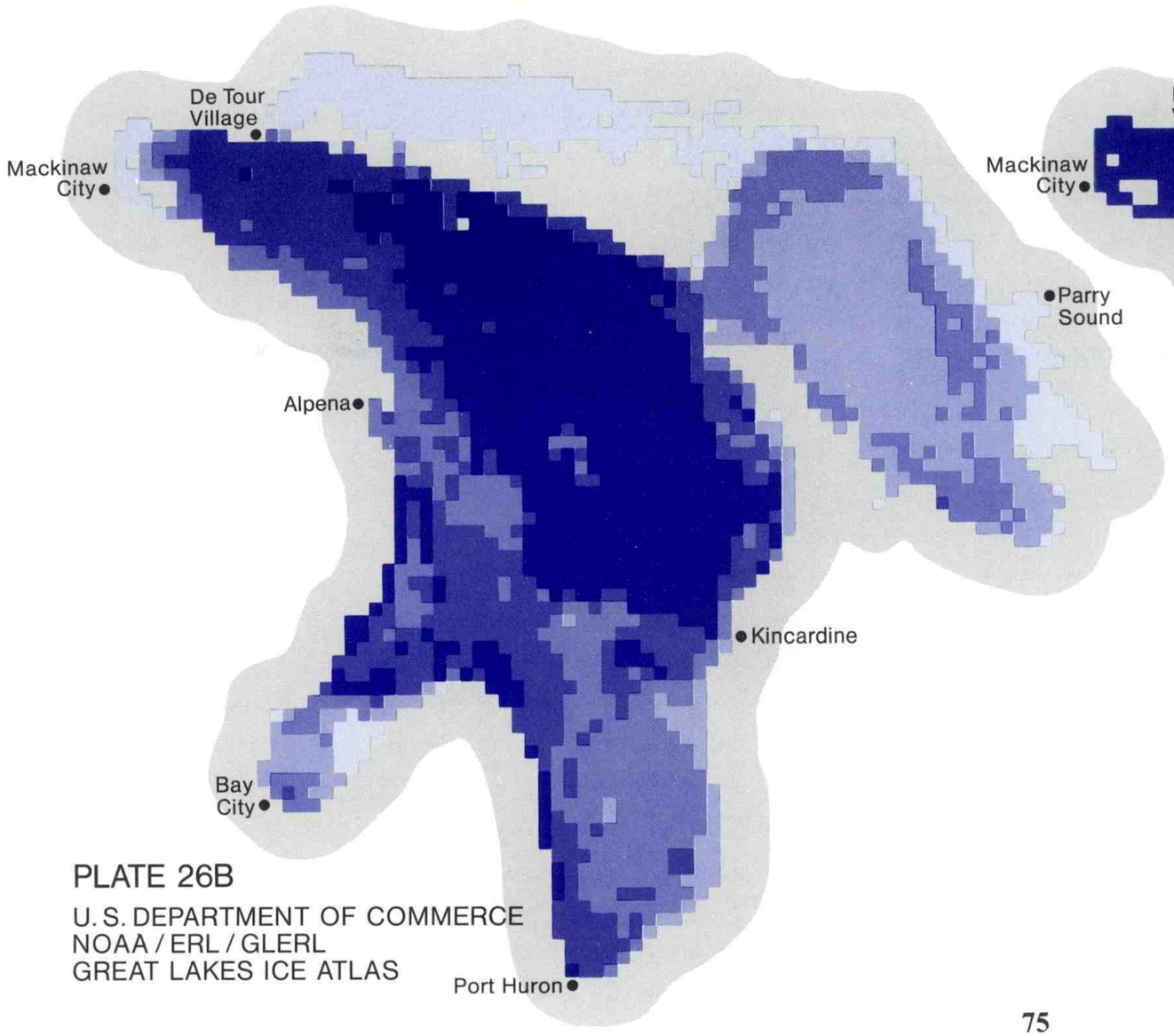
MARCH 16–31
1960–1979

LAKE HURON

Kilometers
0 20 40 60 80 100
0 10 20 30 40 50 60
Statute Miles

OBSERVATION LEGEND
- FIRST QUARTILE 0 to 5 years of data
- SECOND QUARTILE 6 to 10 years of data
- THIRD QUARTILE 11 to 15 years of data
- FOURTH QUARTILE 16 to 20 years of data

NORMAL ICE COVER



OBSERVATION DENSITY

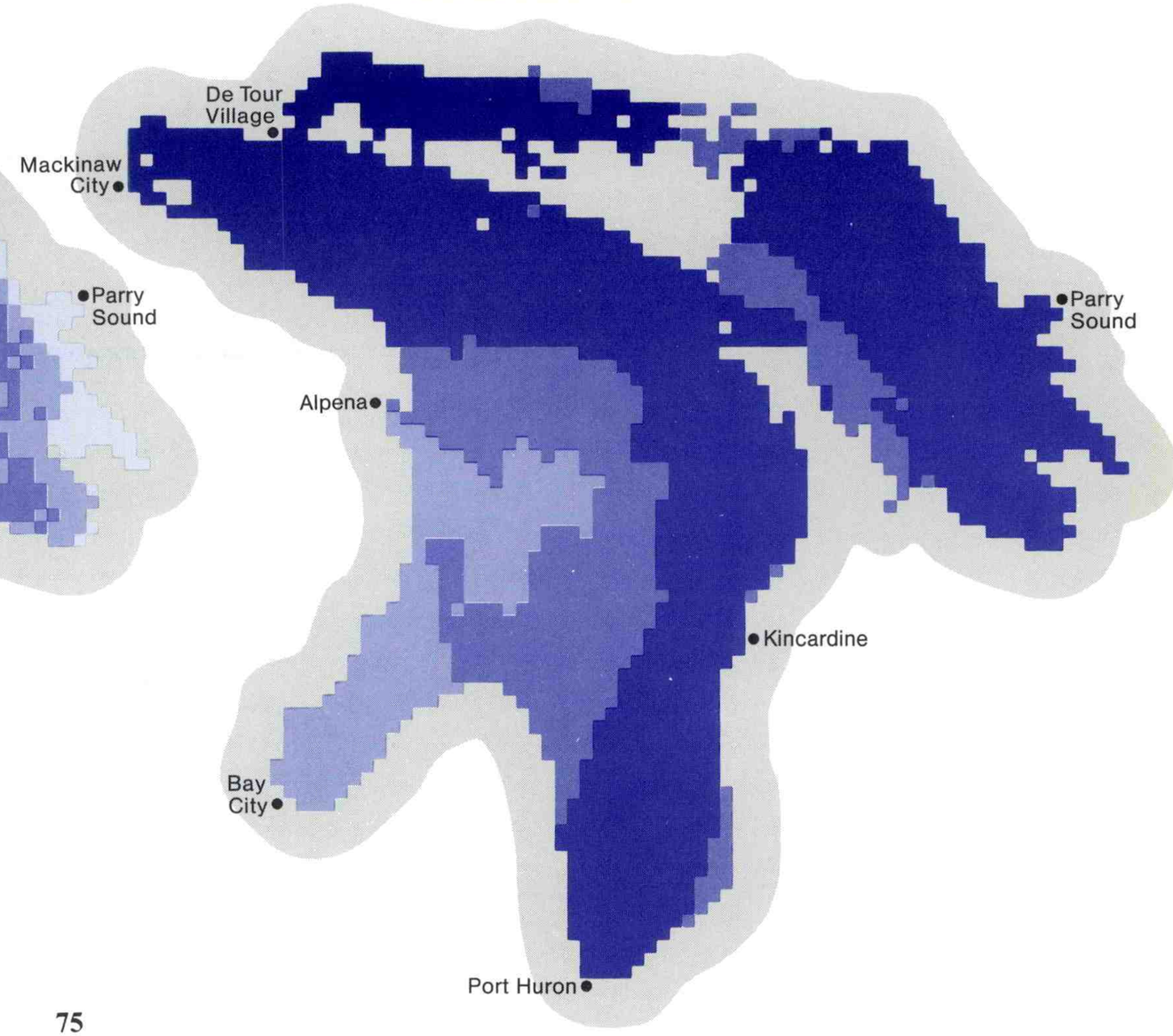


PLATE 26B

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

EXTREMES IN ICE COVER

APRIL 1–15
1960–1979

LAKE HURON

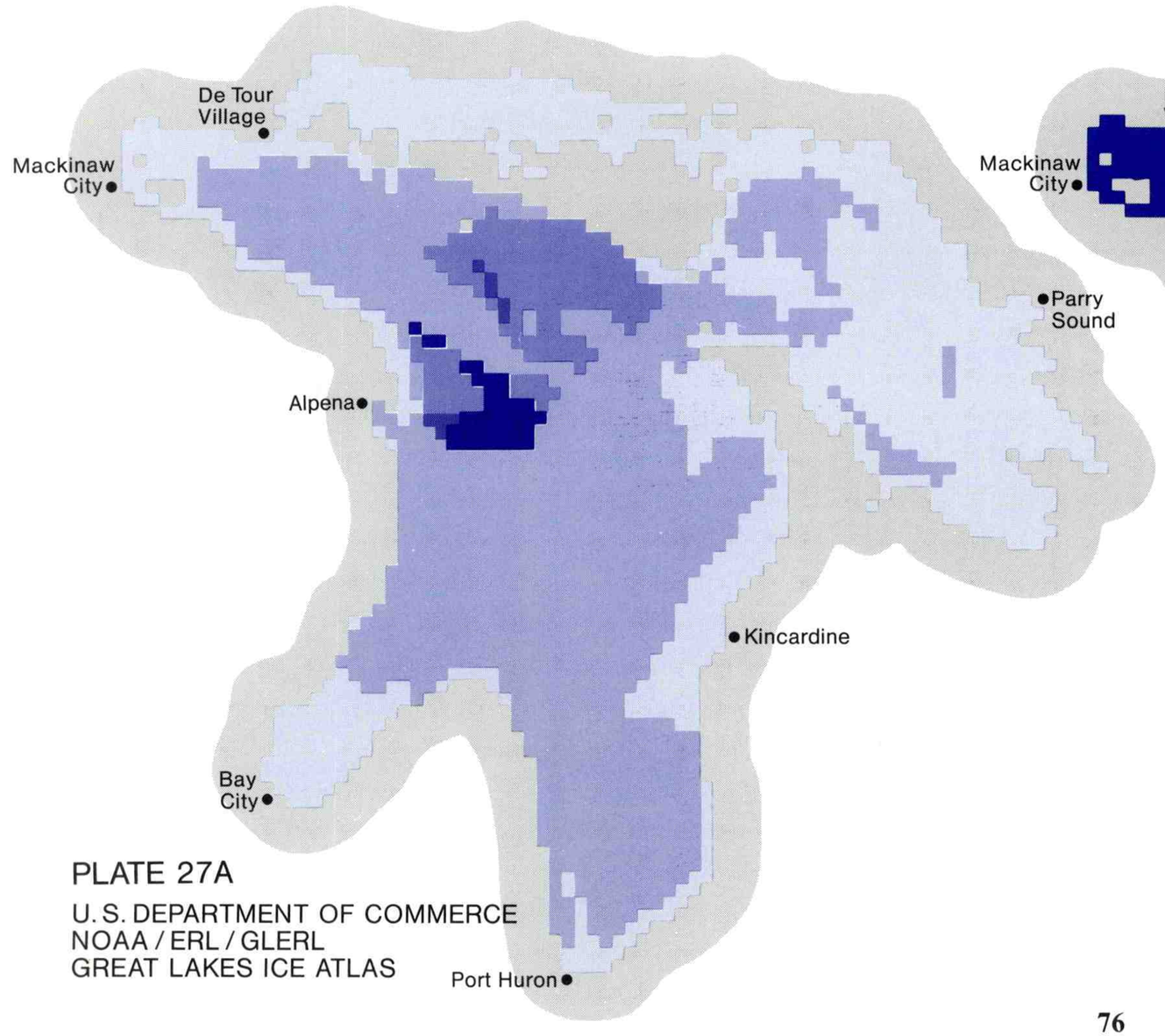
Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

ICE COVER LEGEND

- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

MAXIMUM ICE COVER



MINIMUM ICE COVER

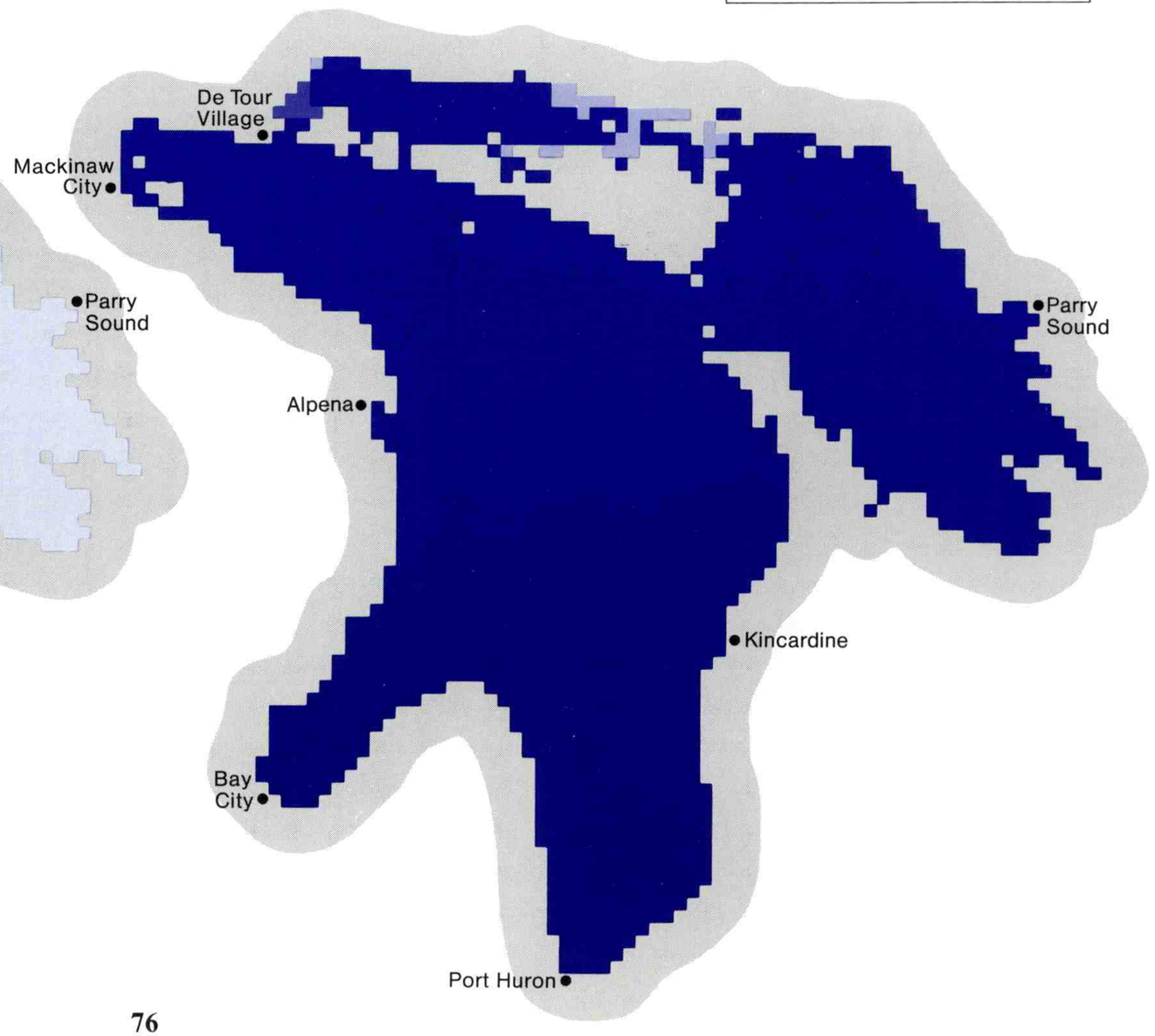


PLATE 27A

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER AND OBSERVATION DENSITY

APRIL 1–15

1960–1979

LAKE HURON

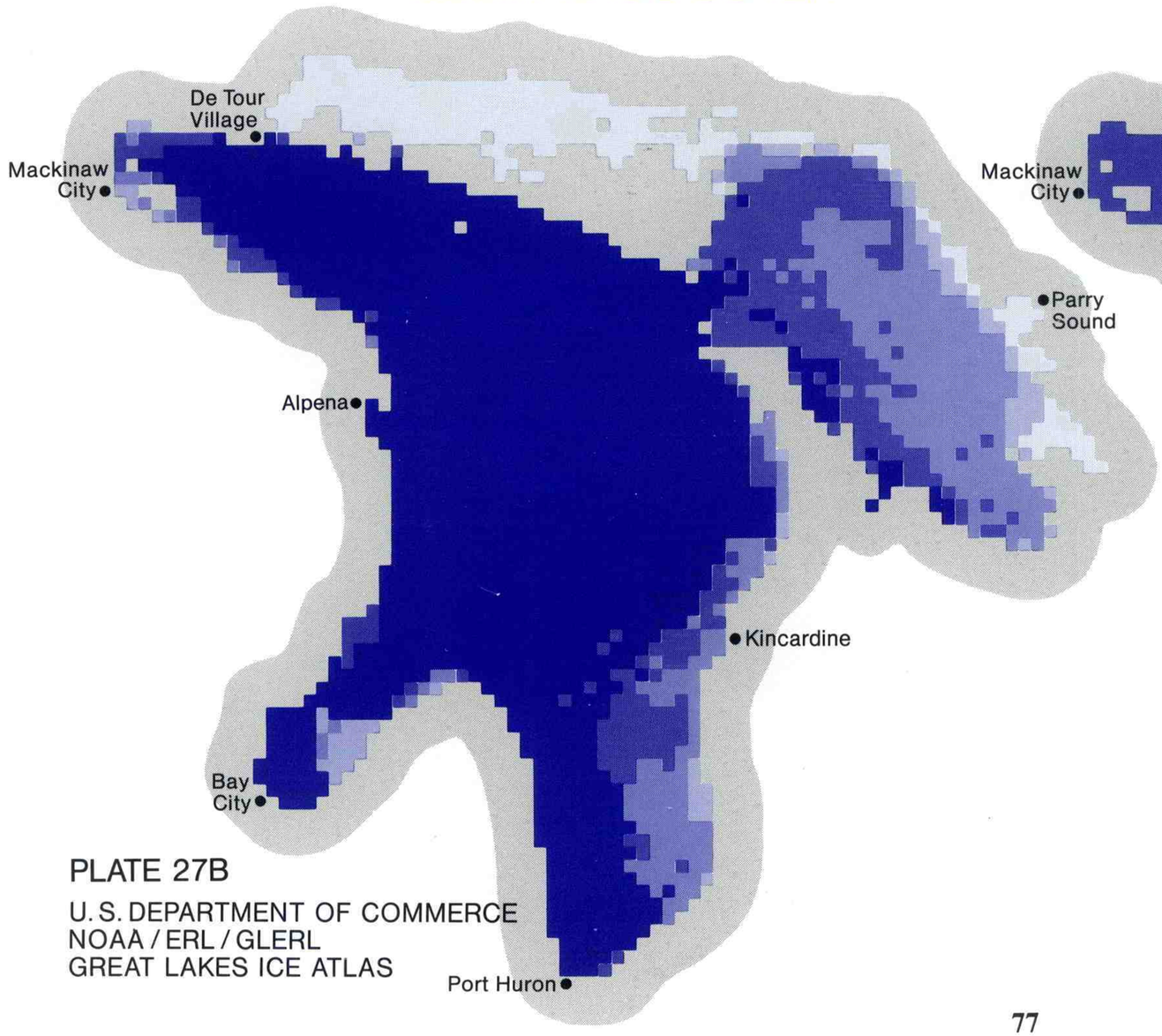
Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

OBSERVATION LEGEND

- FIRST QUARTILE
  0 to 5 years of data
- SECOND QUARTILE
  6 to 10 years of data
- THIRD QUARTILE
  11 to 15 years of data
- FOURTH QUARTILE
  16 to 20 years of data

NORMAL ICE COVER



OBSERVATION DENSITY

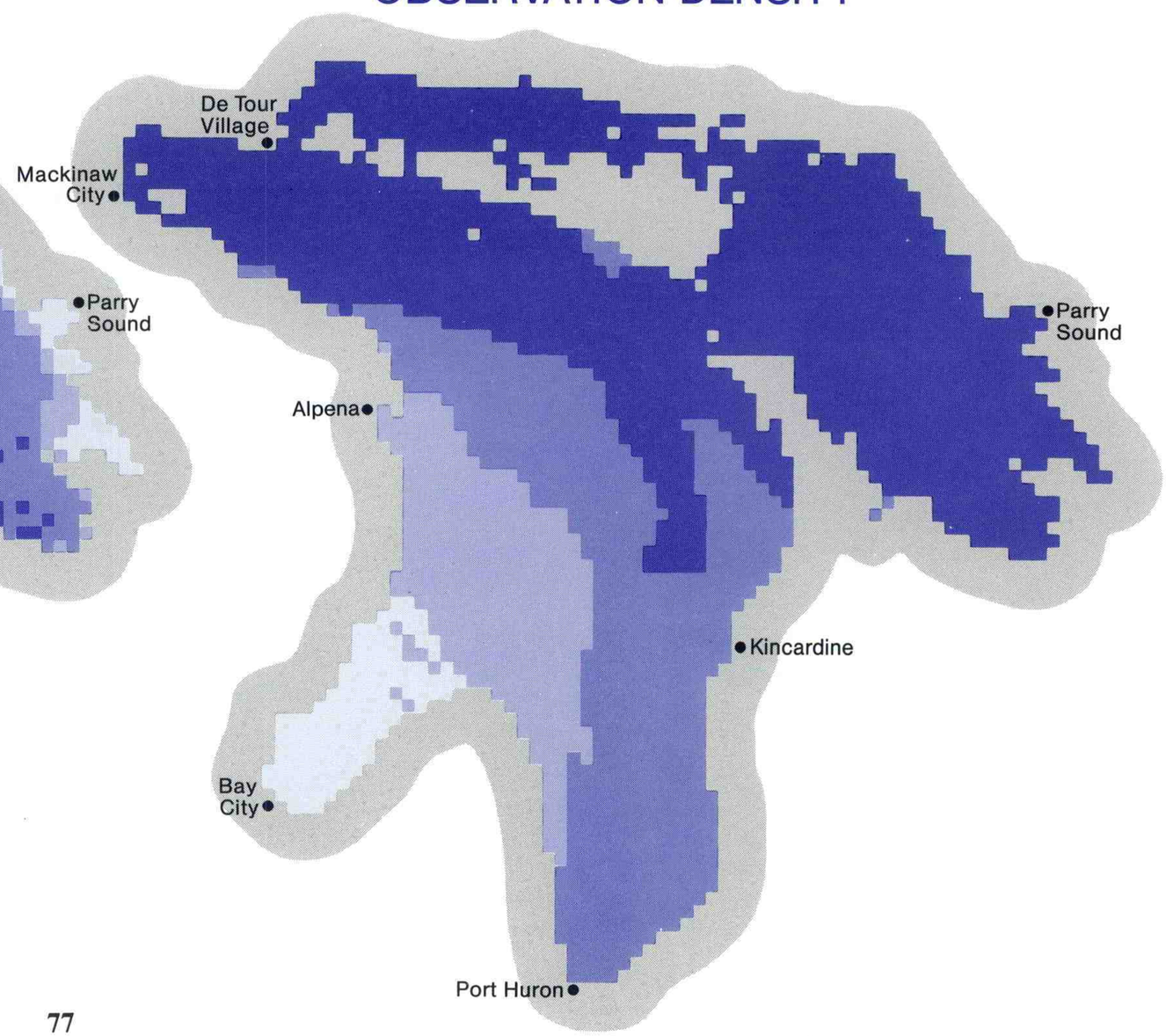


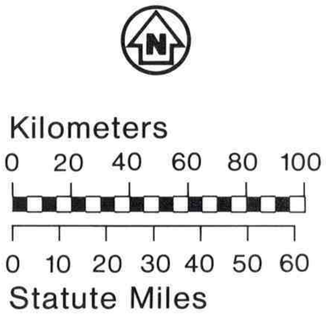
PLATE 27B

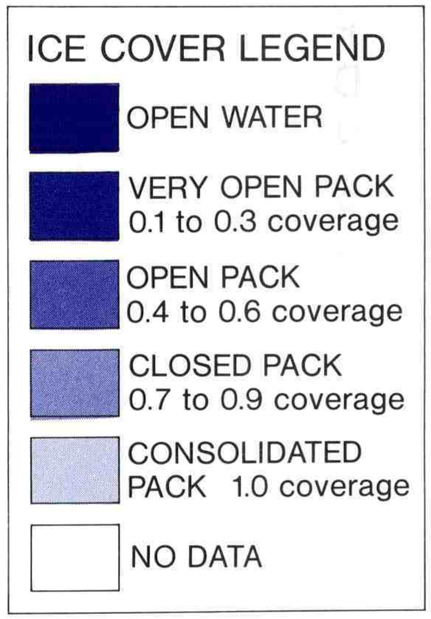
U.S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

EXTREMES IN ICE COVER

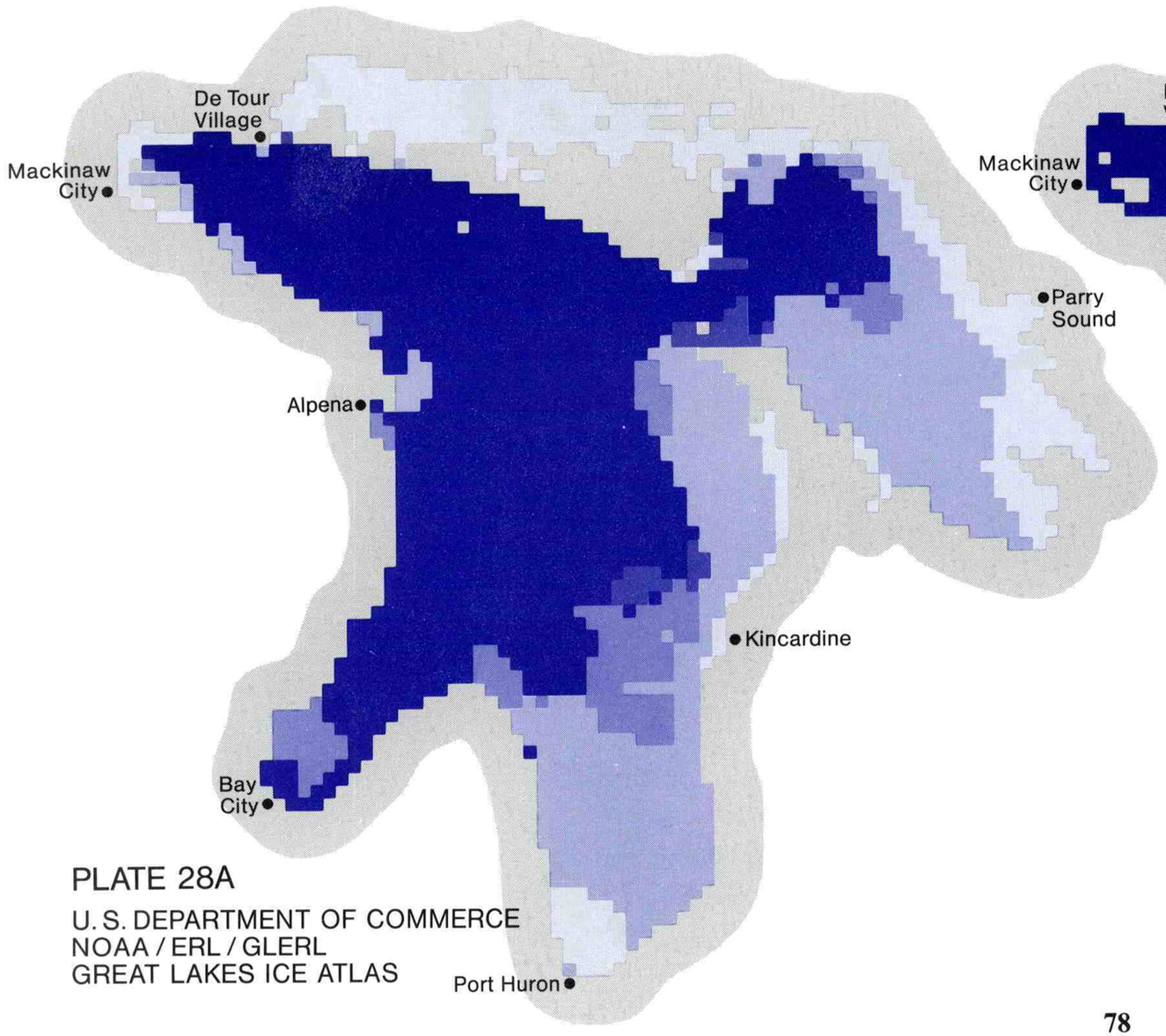
APRIL 16–30
1960–1979

LAKE HURON





MAXIMUM ICE COVER



MINIMUM ICE COVER

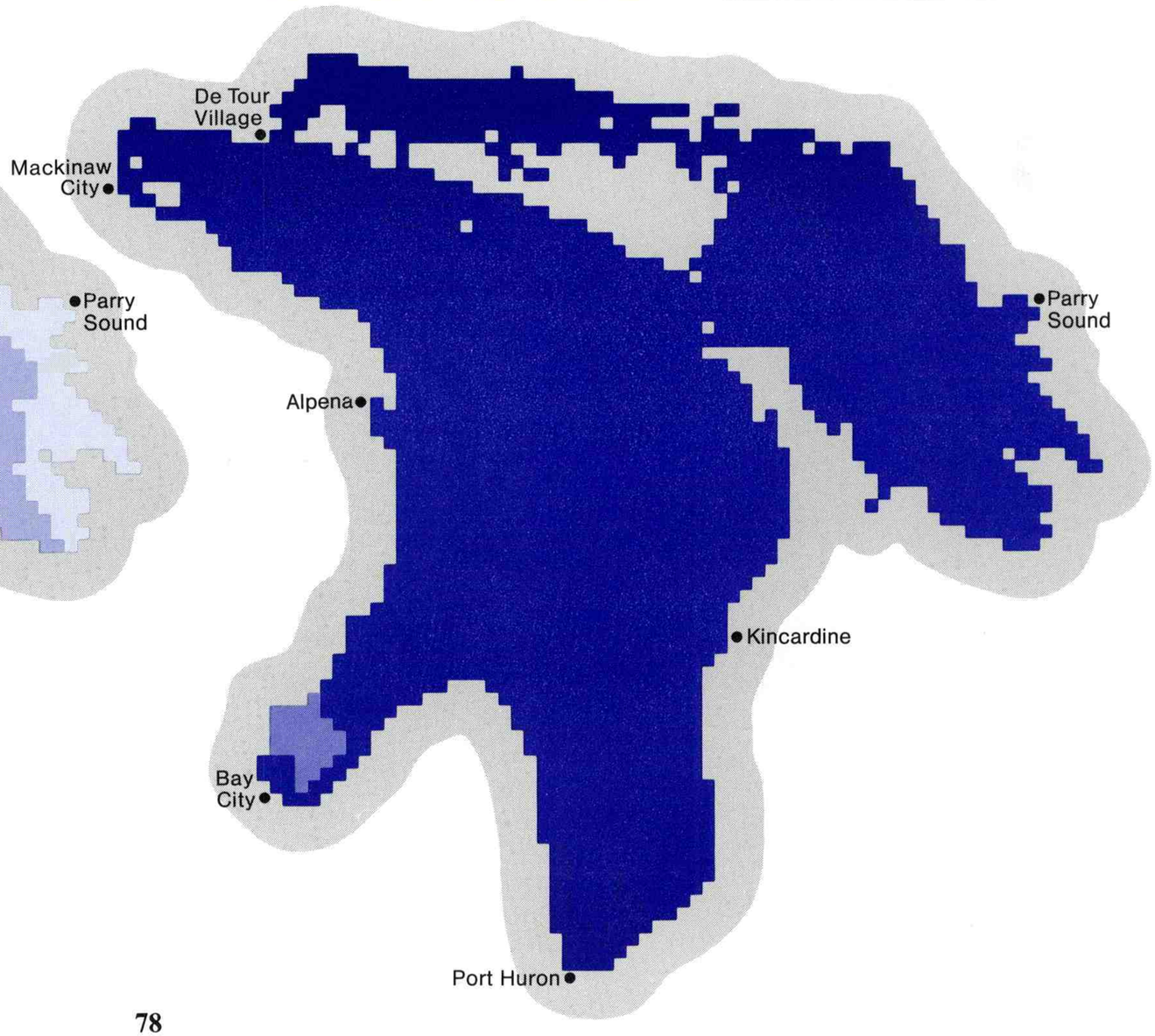


PLATE 28A

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER AND OBSERVATION DENSITY

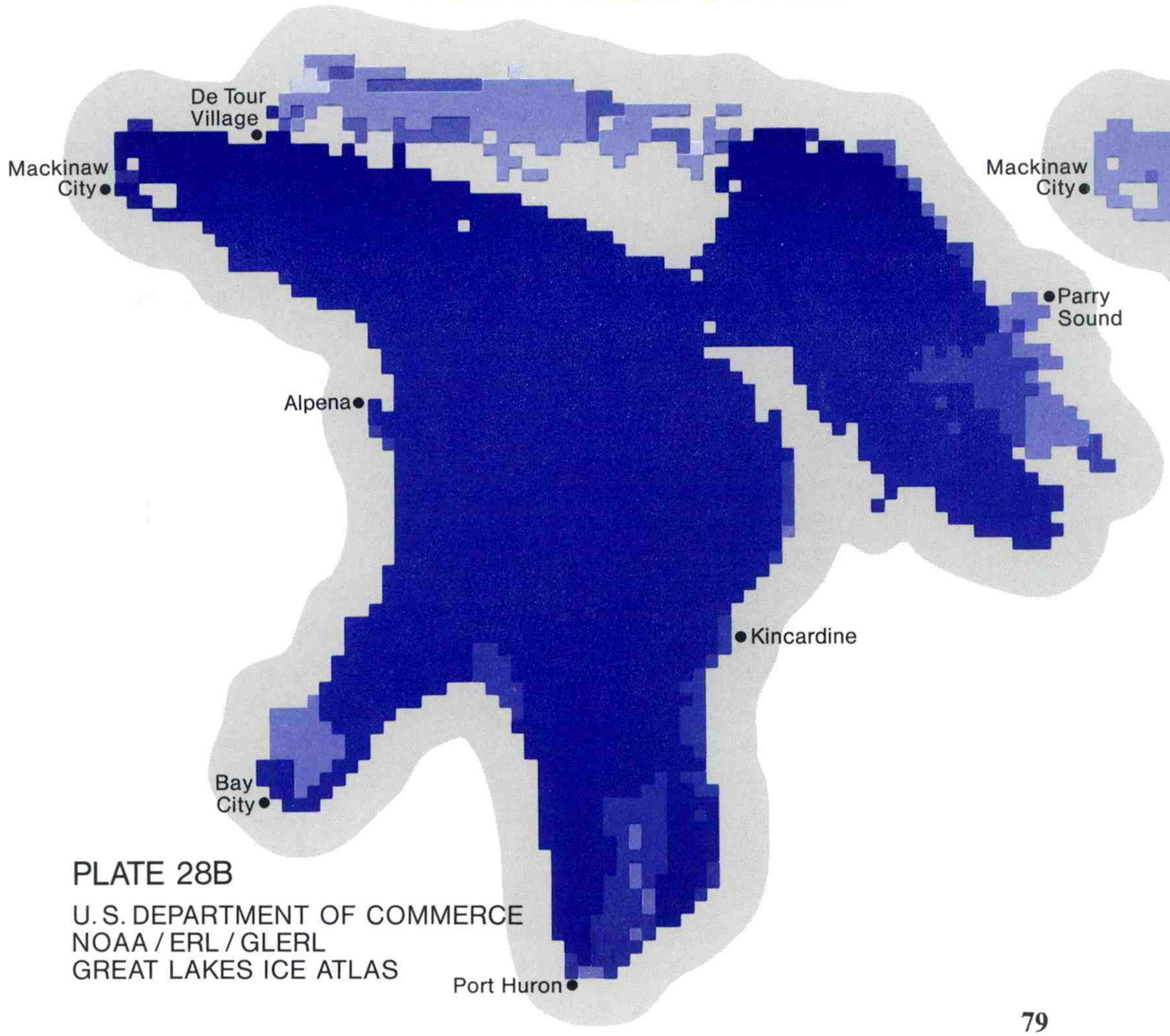
APRIL 16–30
1960–1979

LAKE HURON

Kilometers
0 20 40 60 80 100
0 10 20 30 40 50 60
Statute Miles

OBSERVATION LEGEND
- FIRST QUARTILE 0 to 5 years of data
- SECOND QUARTILE 6 to 10 years of data
- THIRD QUARTILE 11 to 15 years of data
- FOURTH QUARTILE 16 to 20 years of data

NORMAL ICE COVER



OBSERVATION DENSITY

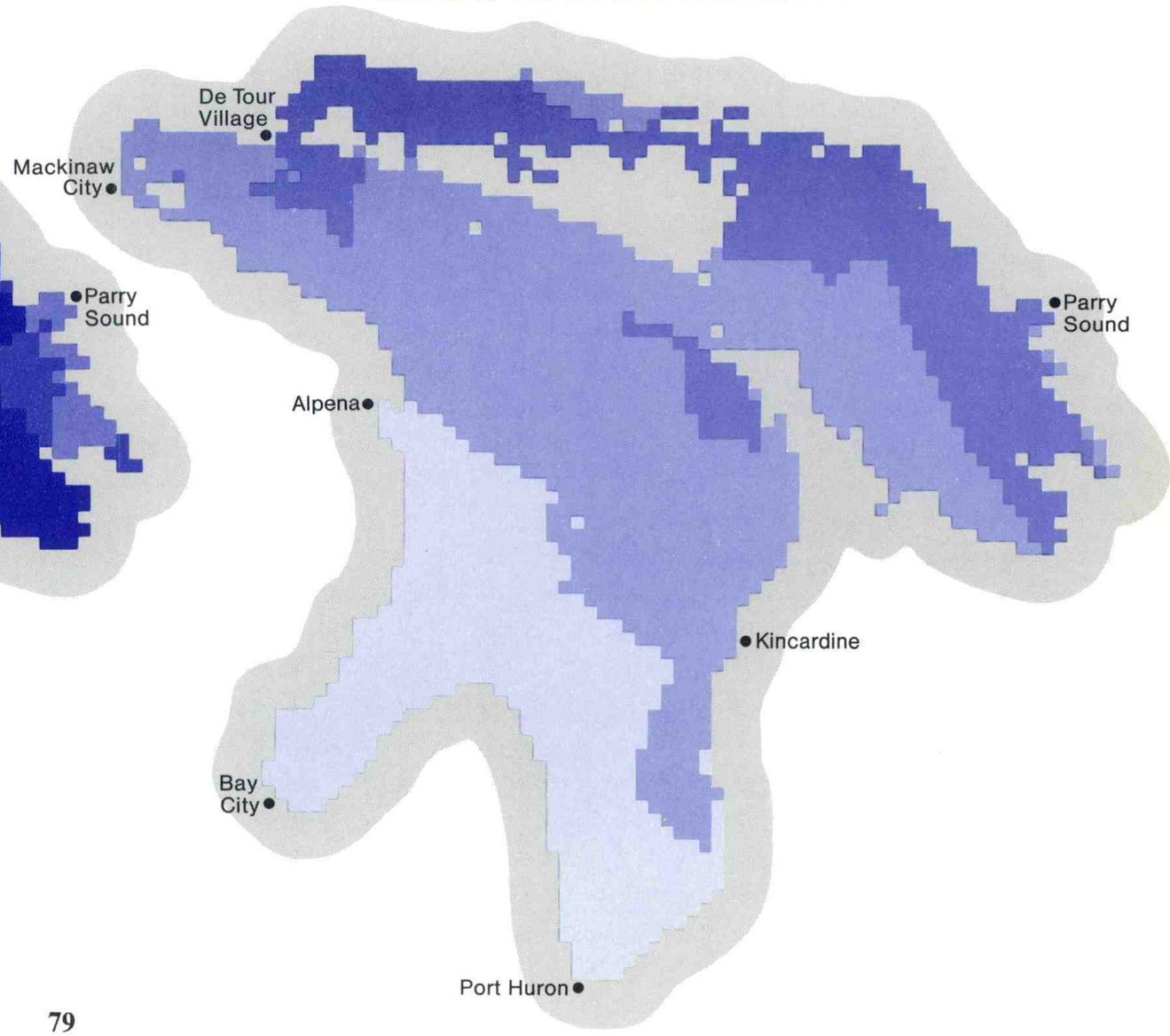


PLATE 28B

U.S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

EXTREMES IN ICE COVER

DECEMBER 16–31

1969–1979

LAKES ERIE & ST. CLAIR



Kilometers

0 20 40 60 80 100

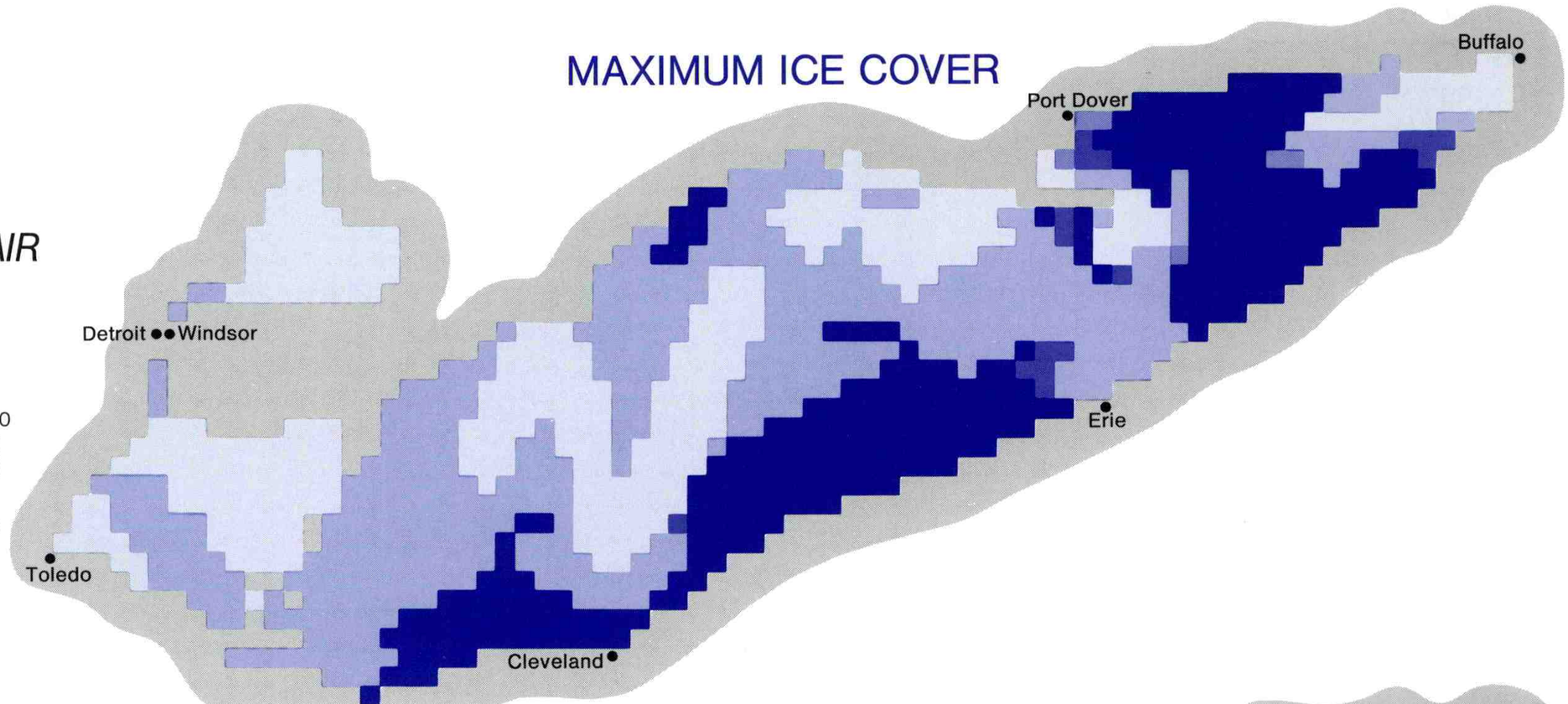
0 10 20 30 40 50 60

Statute Miles

ICE COVER LEGEND

- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

MAXIMUM ICE COVER



MINIMUM ICE COVER

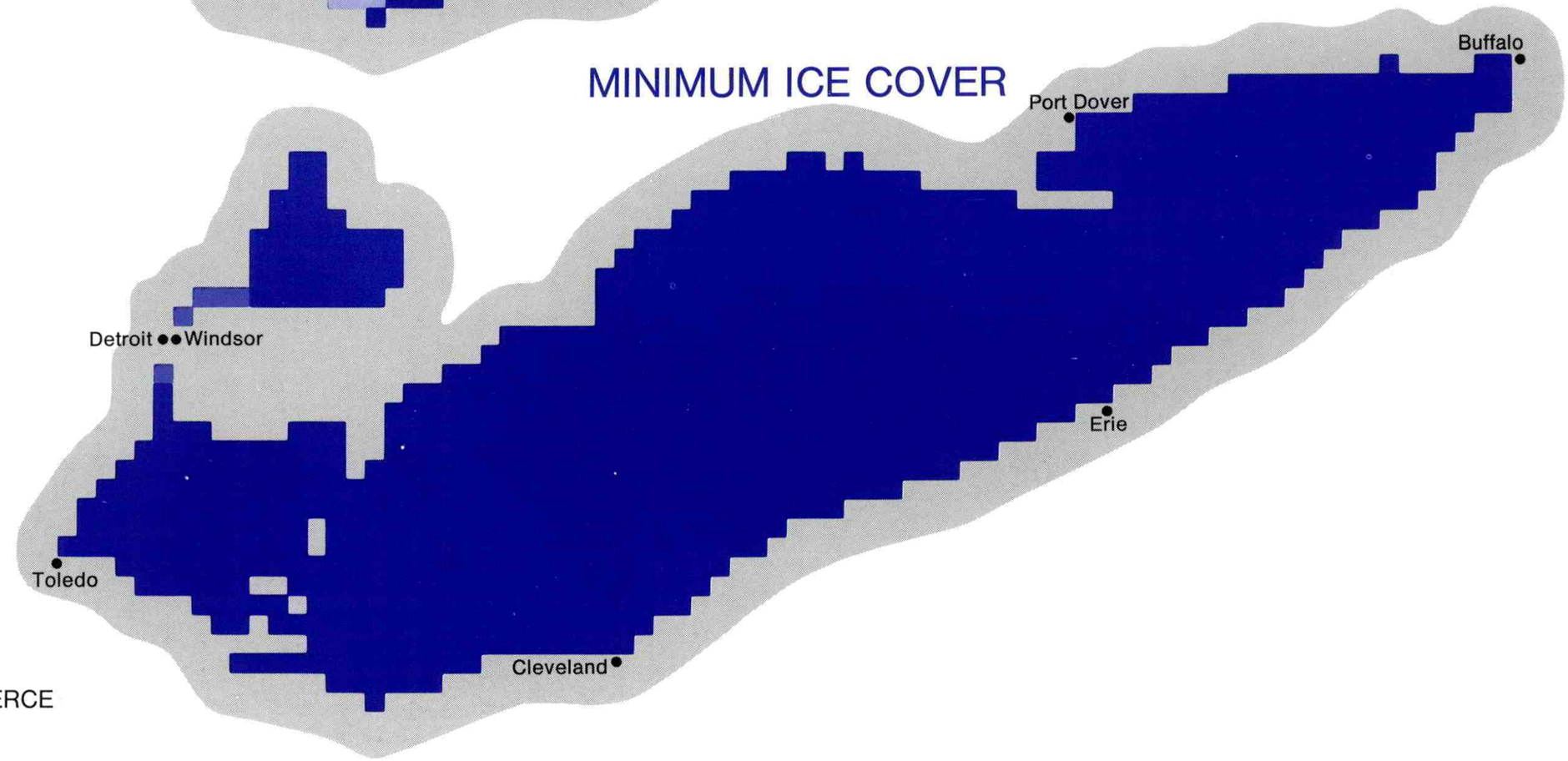


PLATE 29A

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER AND OBSERVATION DENSITY

DECEMBER 16–31

1960–1979

LAKES ERIE & ST. CLAIR

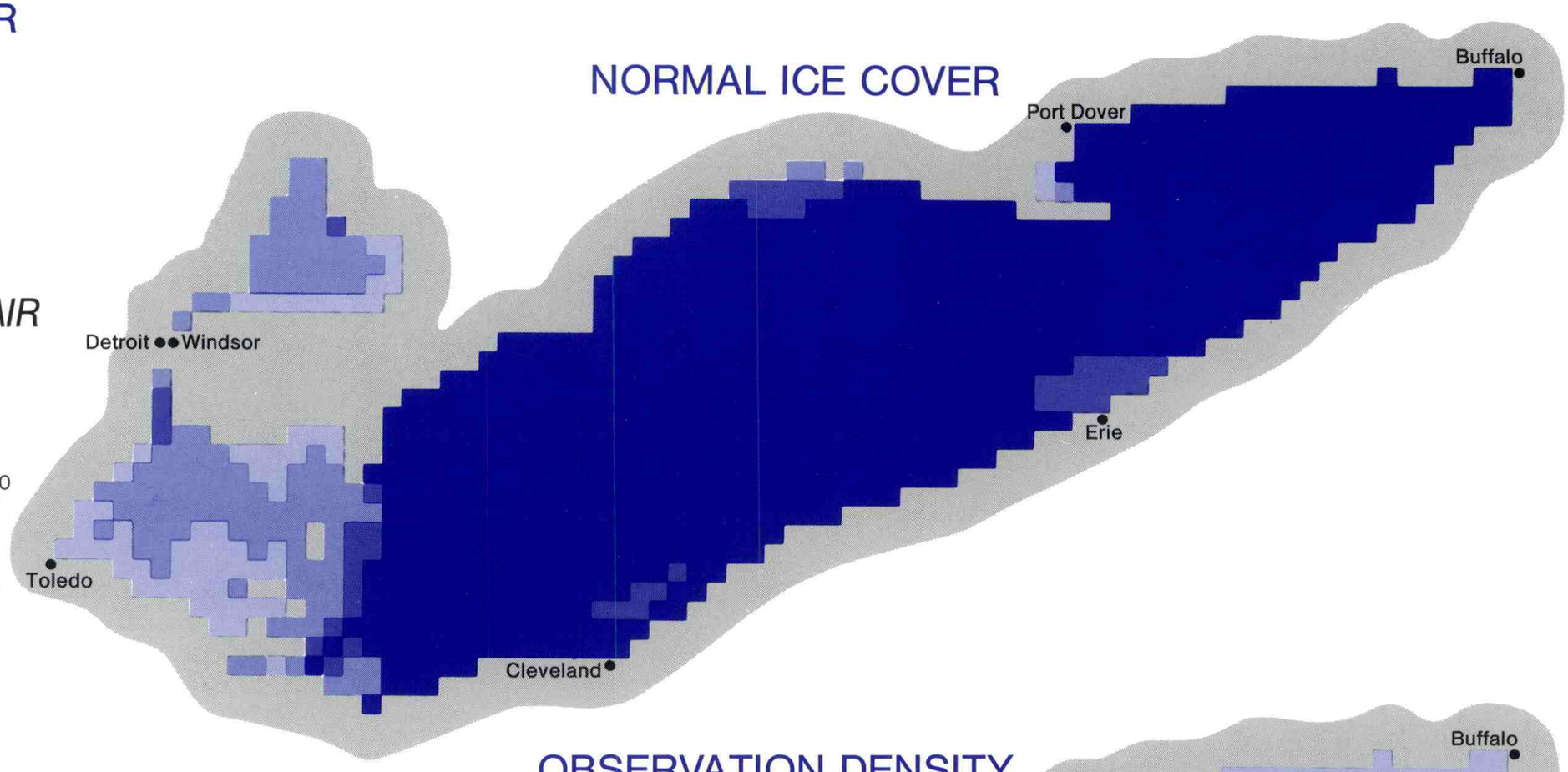
Kilometers

0 20 40 60 80 100

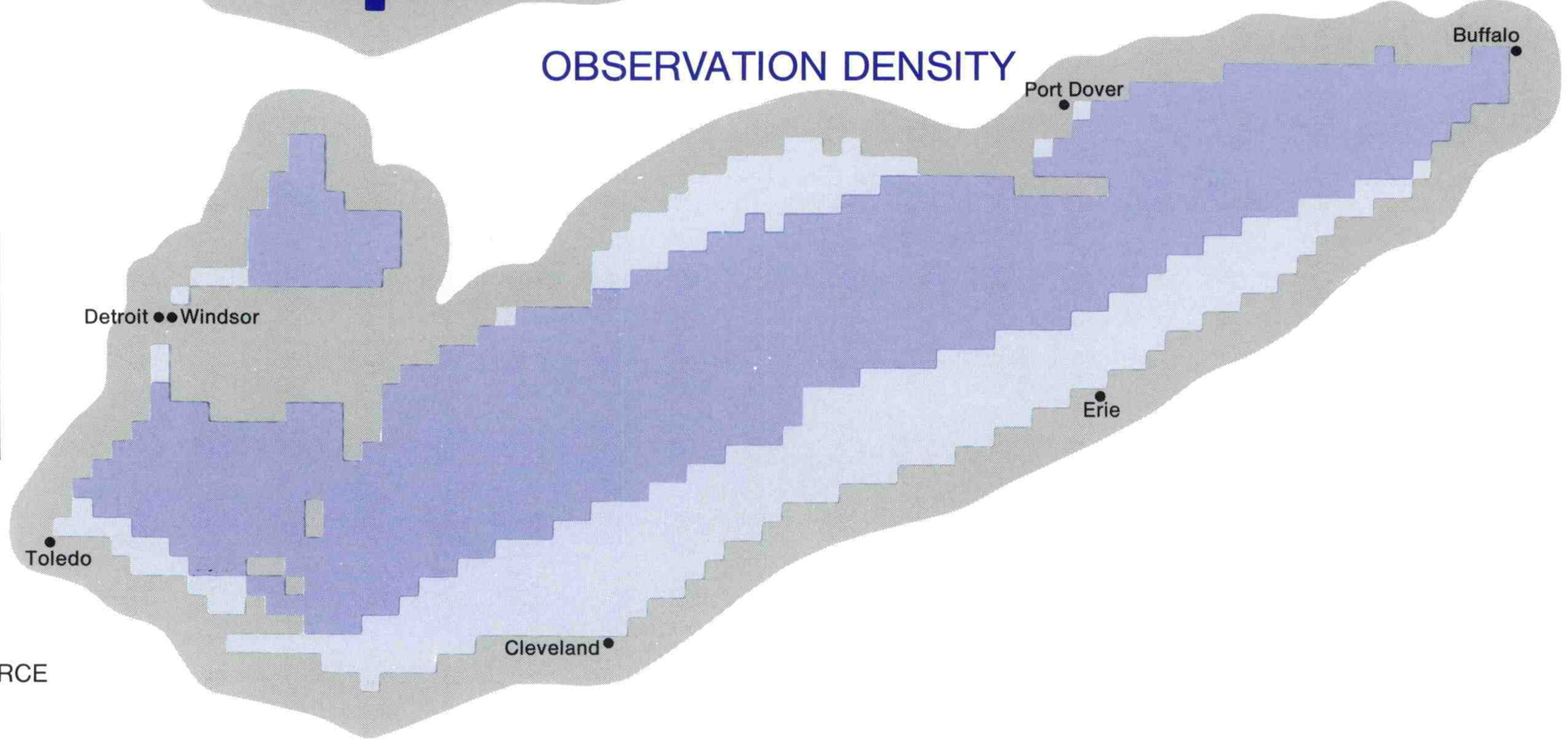
0 10 20 30 40 50 60

Statute Miles

NORMAL ICE COVER



OBSERVATION DENSITY



OBSERVATION LEGEND

- FIRST QUARTILE — 0 to 5 years of data
- SECOND QUARTILE — 6 to 10 years of data
- THIRD QUARTILE — 11 to 15 years of data
- FOURTH QUARTILE — 16 to 20 years of data

PLATE 29B

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

EXTREMES IN ICE COVER

JANUARY 1–15
1960–1979

LAKES ERIE & ST. CLAIR

Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

ICE COVER LEGEND

- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

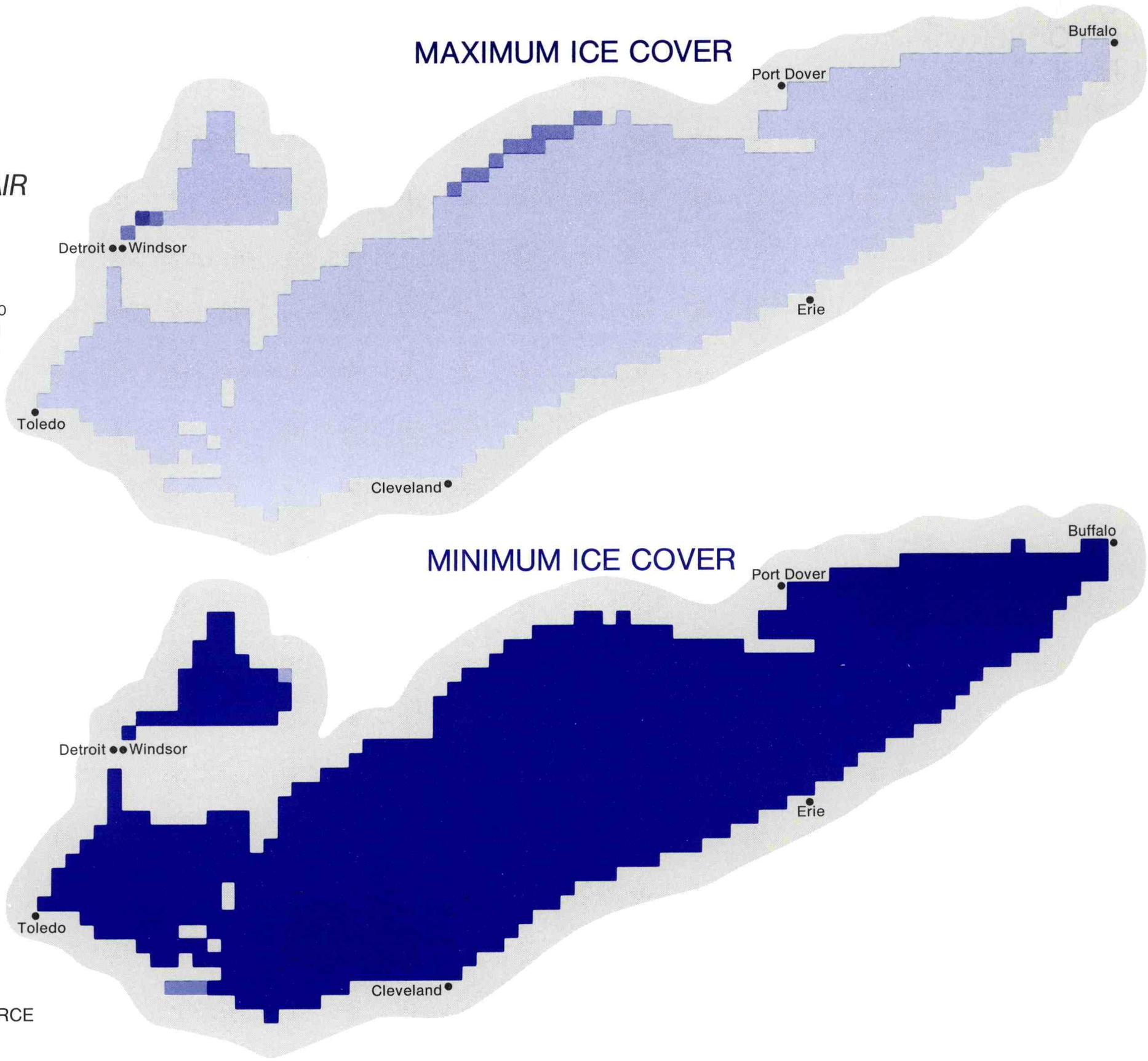


PLATE 30A

U.S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER AND OBSERVATION DENSITY

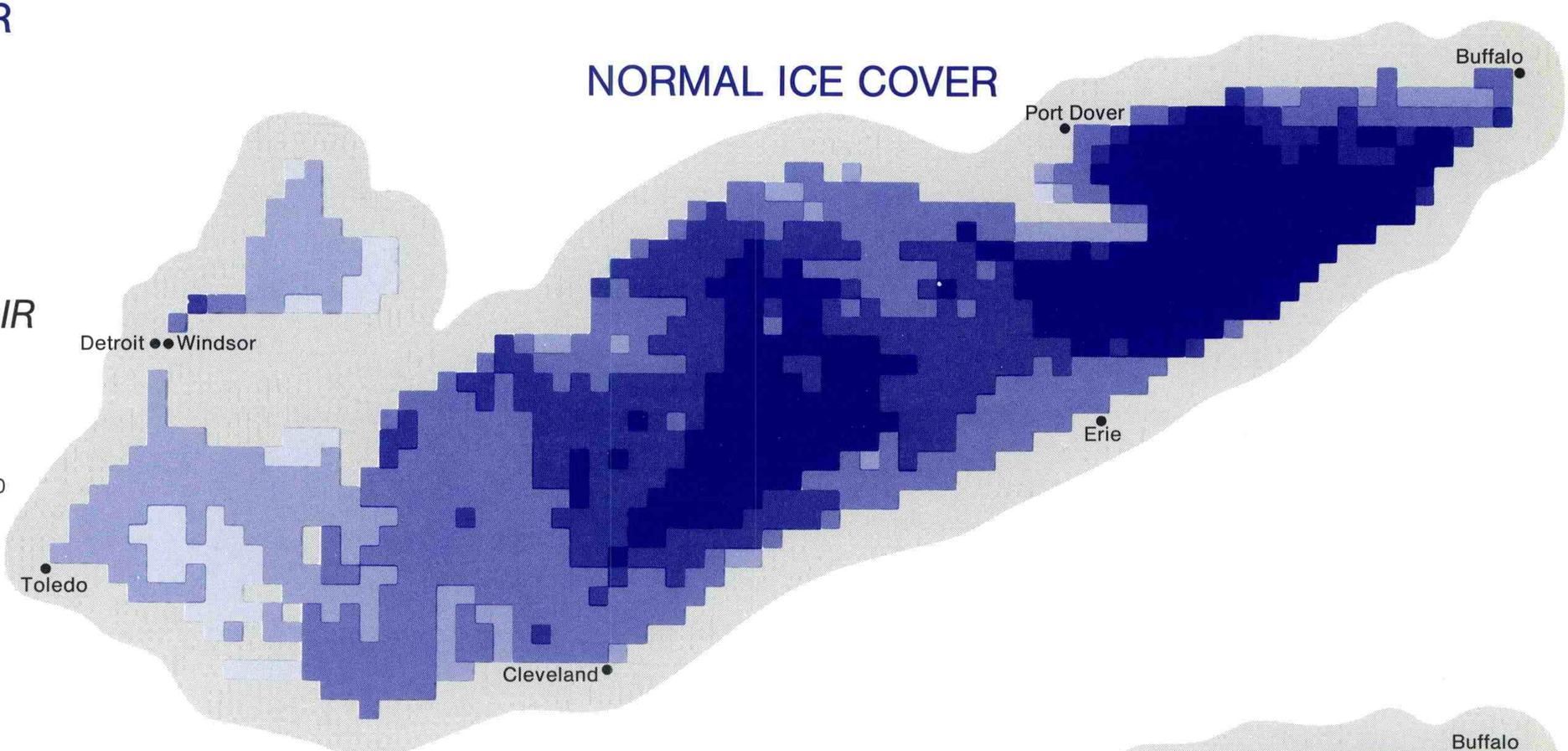
JANUARY 1–15
1960–1979

LAKES ERIE & ST. CLAIR

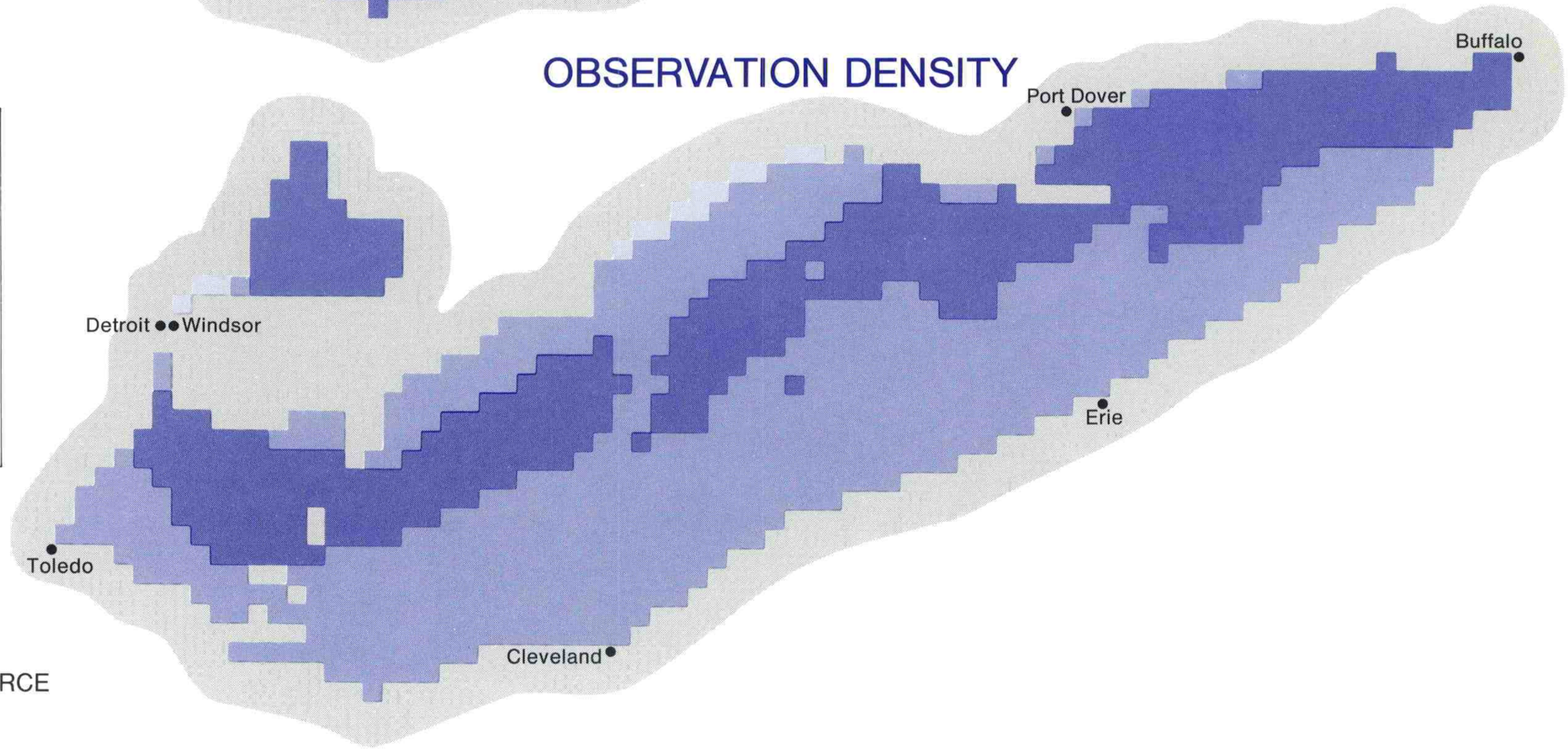
Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

NORMAL ICE COVER



OBSERVATION DENSITY



OBSERVATION LEGEND

- FIRST QUARTILE — 0 to 5 years of data
- SECOND QUARTILE — 6 to 10 years of data
- THIRD QUARTILE — 11 to 15 years of data
- FOURTH QUARTILE — 16 to 20 years of data

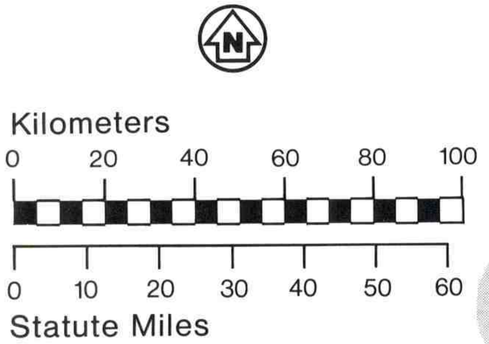
PLATE 30B

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

EXTREMES IN ICE COVER

JANUARY 16–31
1960–1979

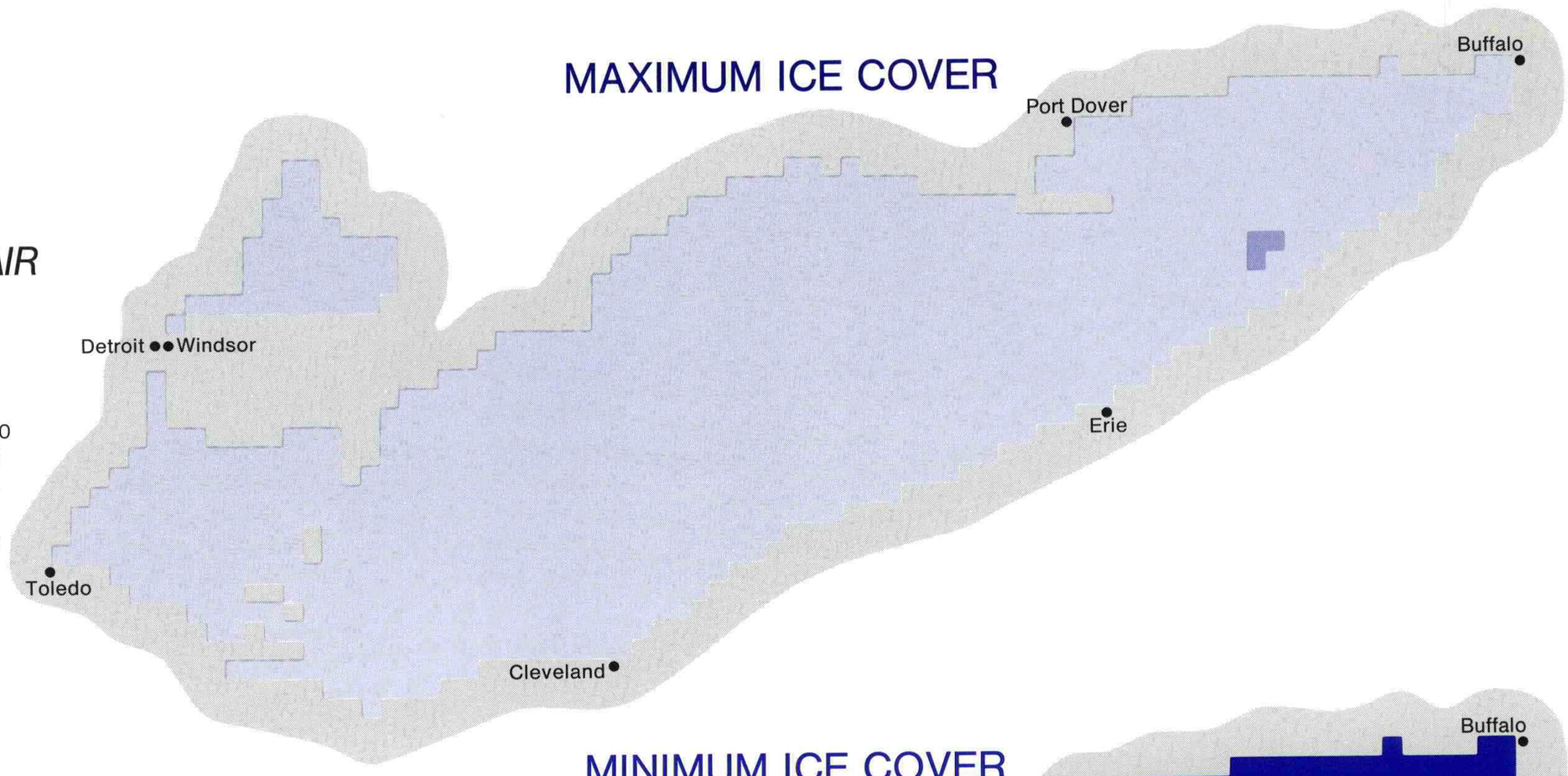
LAKES ERIE & ST. CLAIR



ICE COVER LEGEND

- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

MAXIMUM ICE COVER



MINIMUM ICE COVER

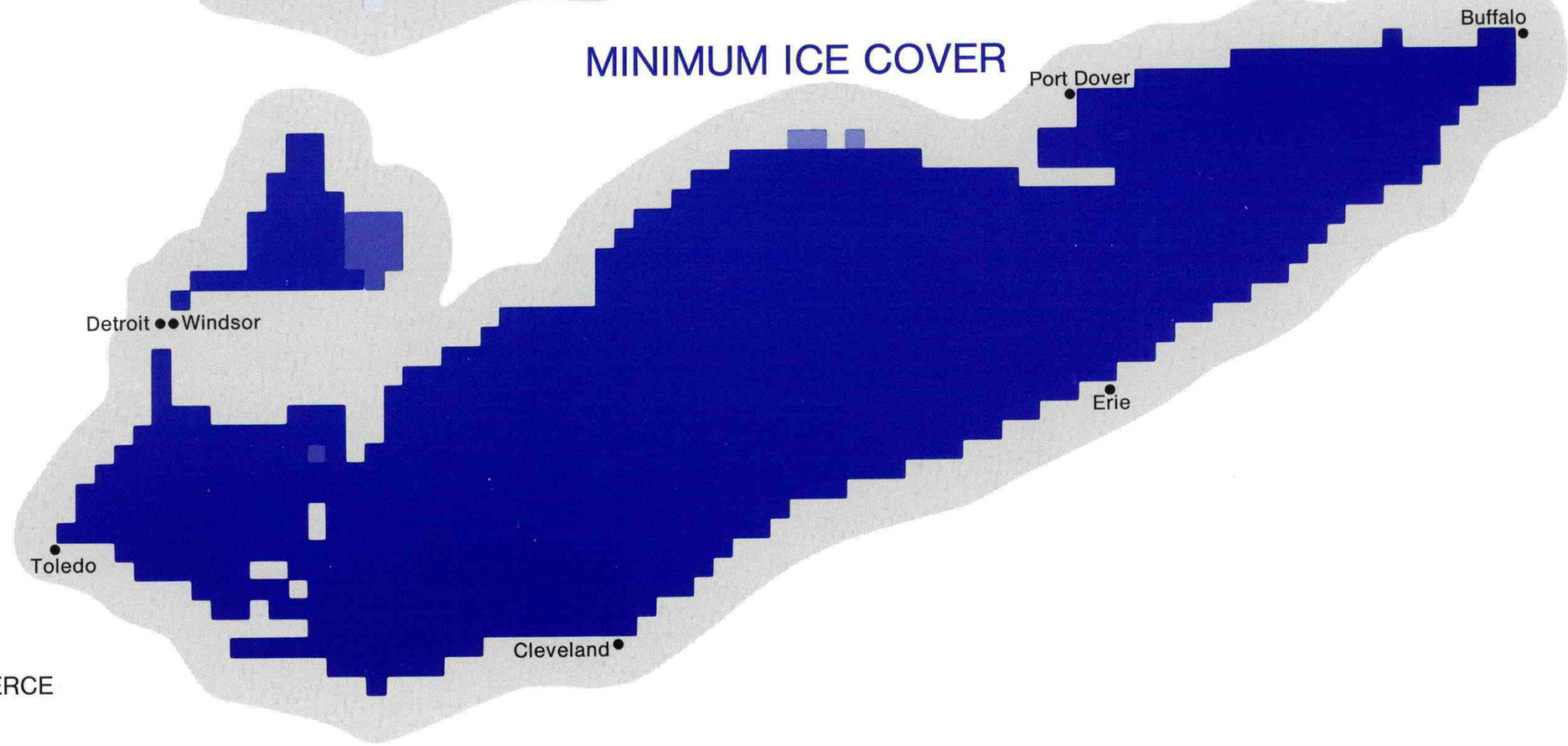


PLATE 31A

U.S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER AND OBSERVATION DENSITY

JANUARY 16–31

1960–1979

LAKES ERIE & ST. CLAIR



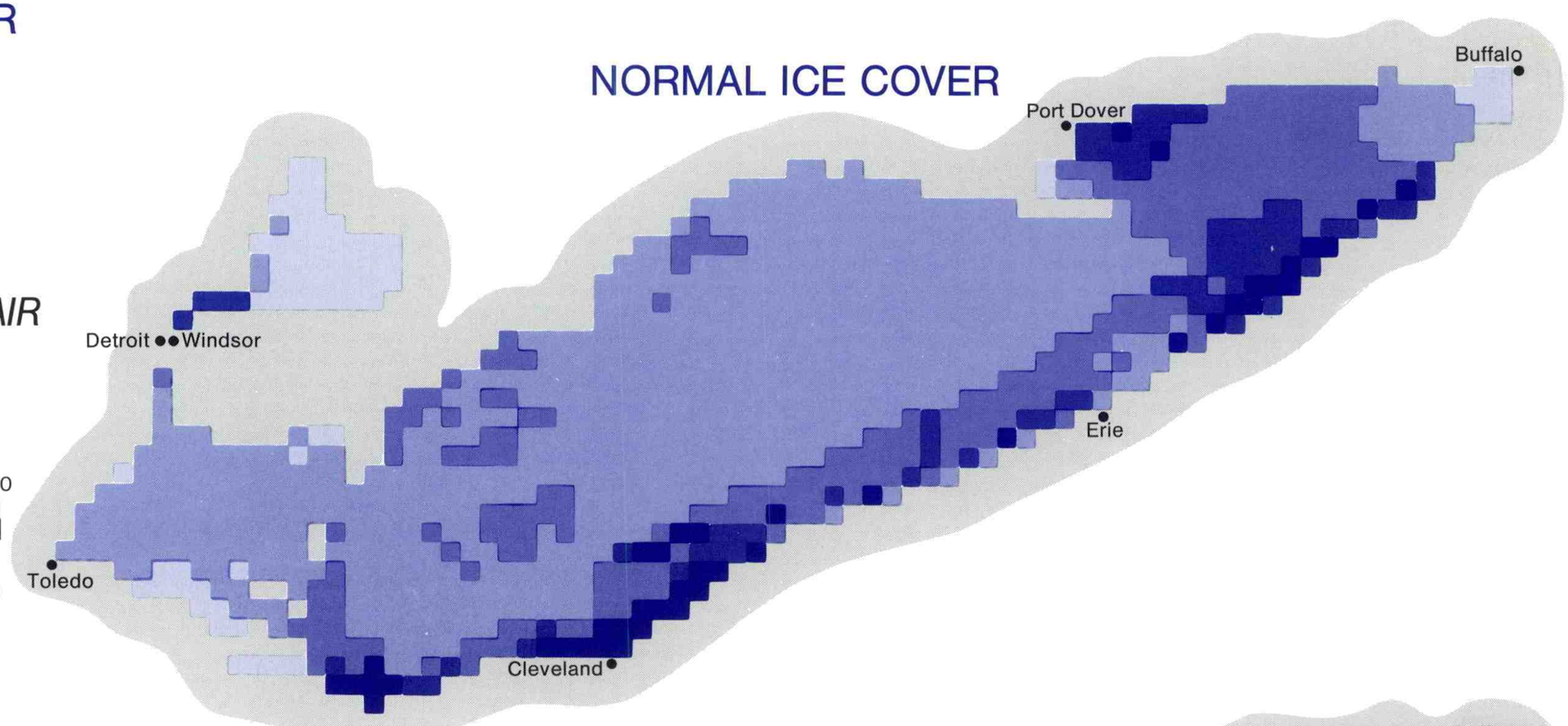
Kilometers

0 20 40 60 80 100

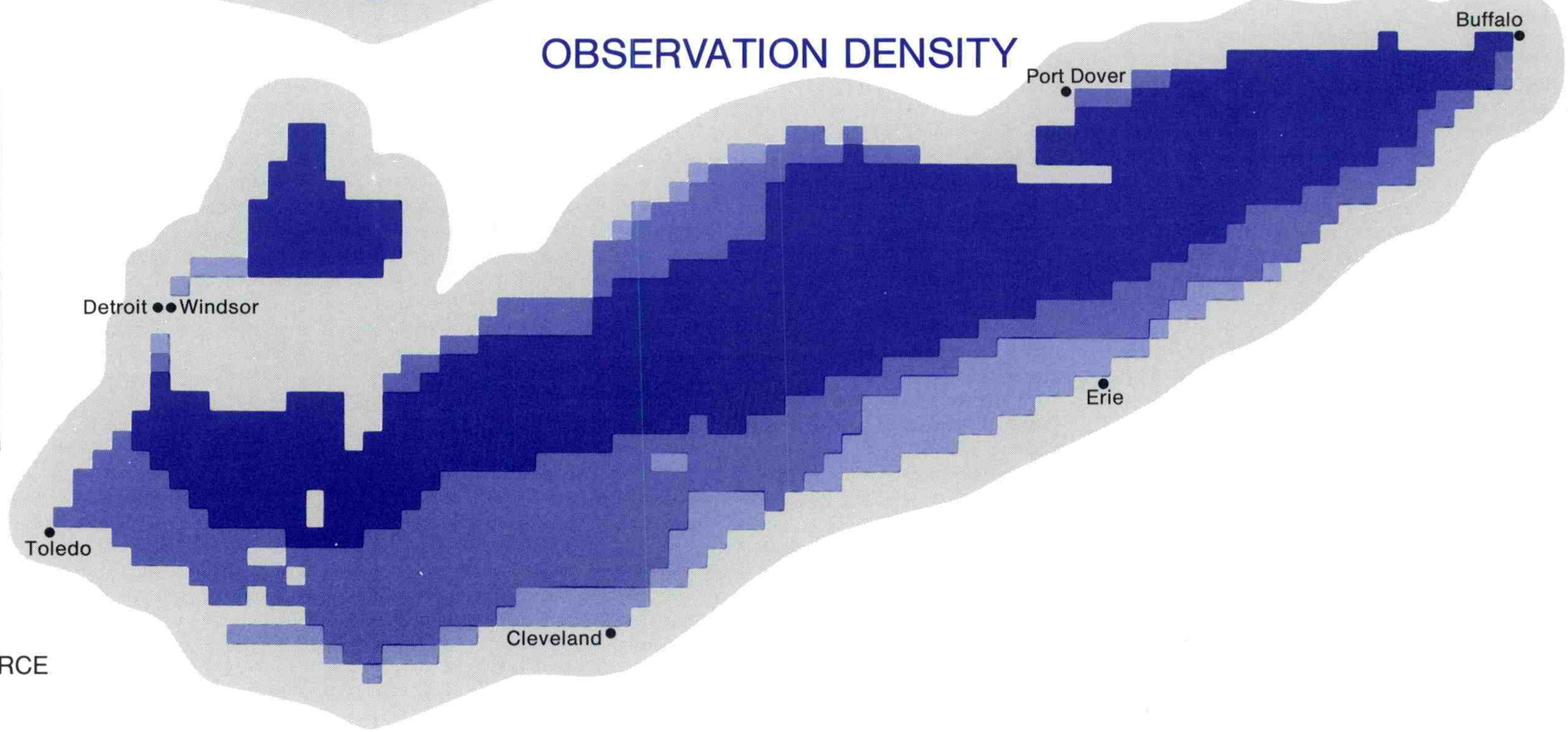
0 10 20 30 40 50 60

Statute Miles

NORMAL ICE COVER



OBSERVATION DENSITY



OBSERVATION LEGEND

- FIRST QUARTILE
  0 to 5 years of data
- SECOND QUARTILE
  6 to 10 years of data
- THIRD QUARTILE
  11 to 15 years of data
- FOURTH QUARTILE
  16 to 20 years of data

PLATE 31B

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

EXTREMES IN ICE COVER

FEBRUARY 1–14
1960–1979

LAKES ERIE & ST. CLAIR

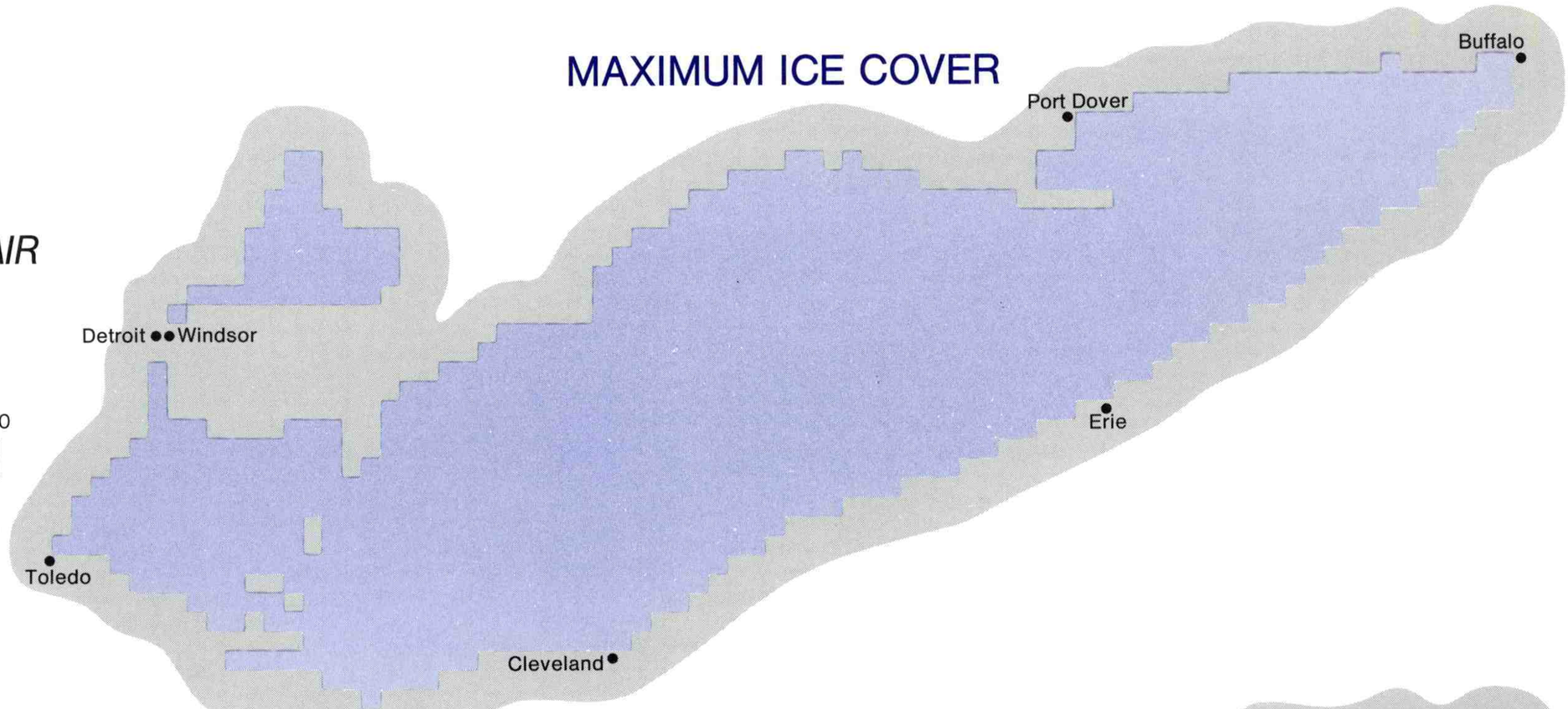
Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

ICE COVER LEGEND

- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

MAXIMUM ICE COVER



MINIMUM ICE COVER

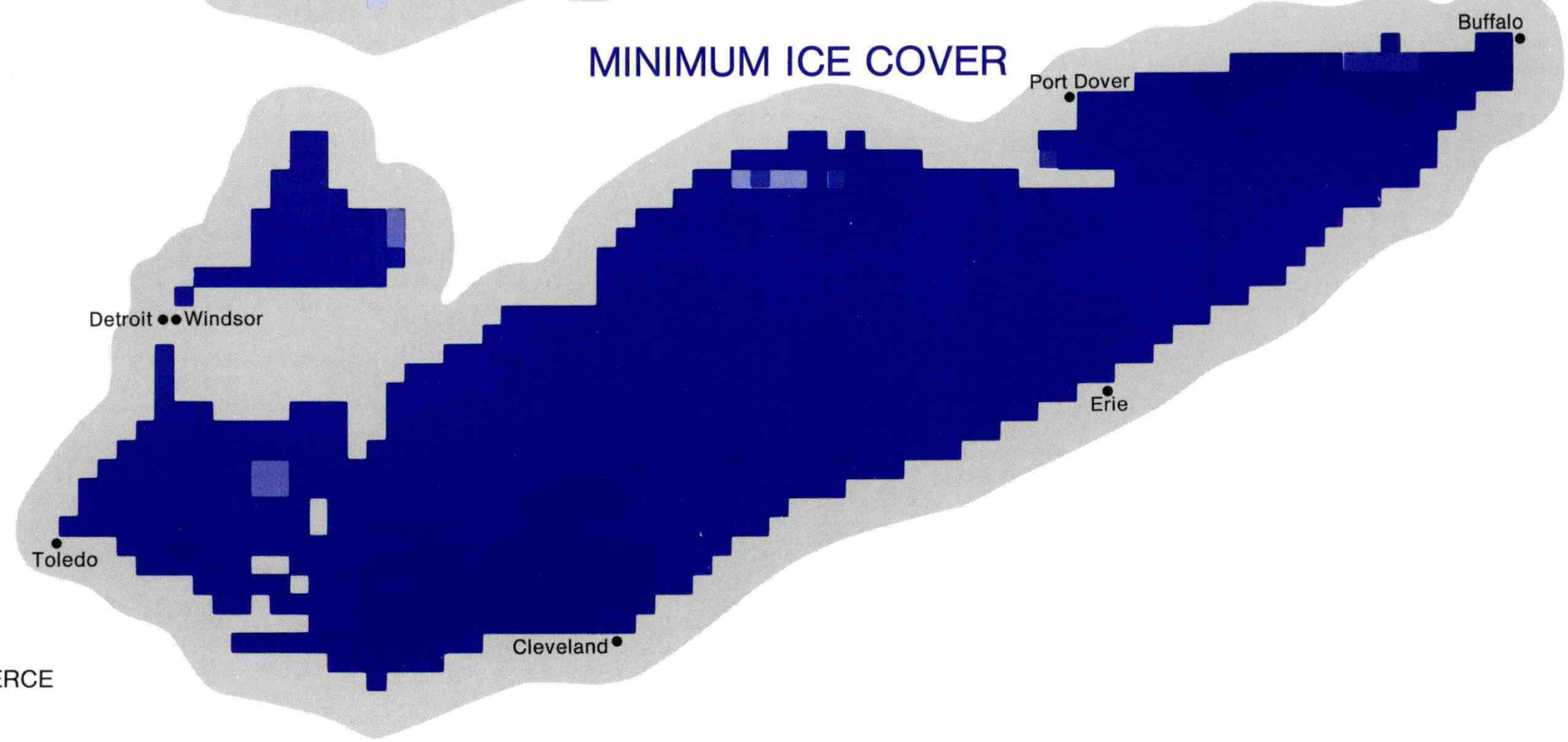


PLATE 32A

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER AND OBSERVATION DENSITY

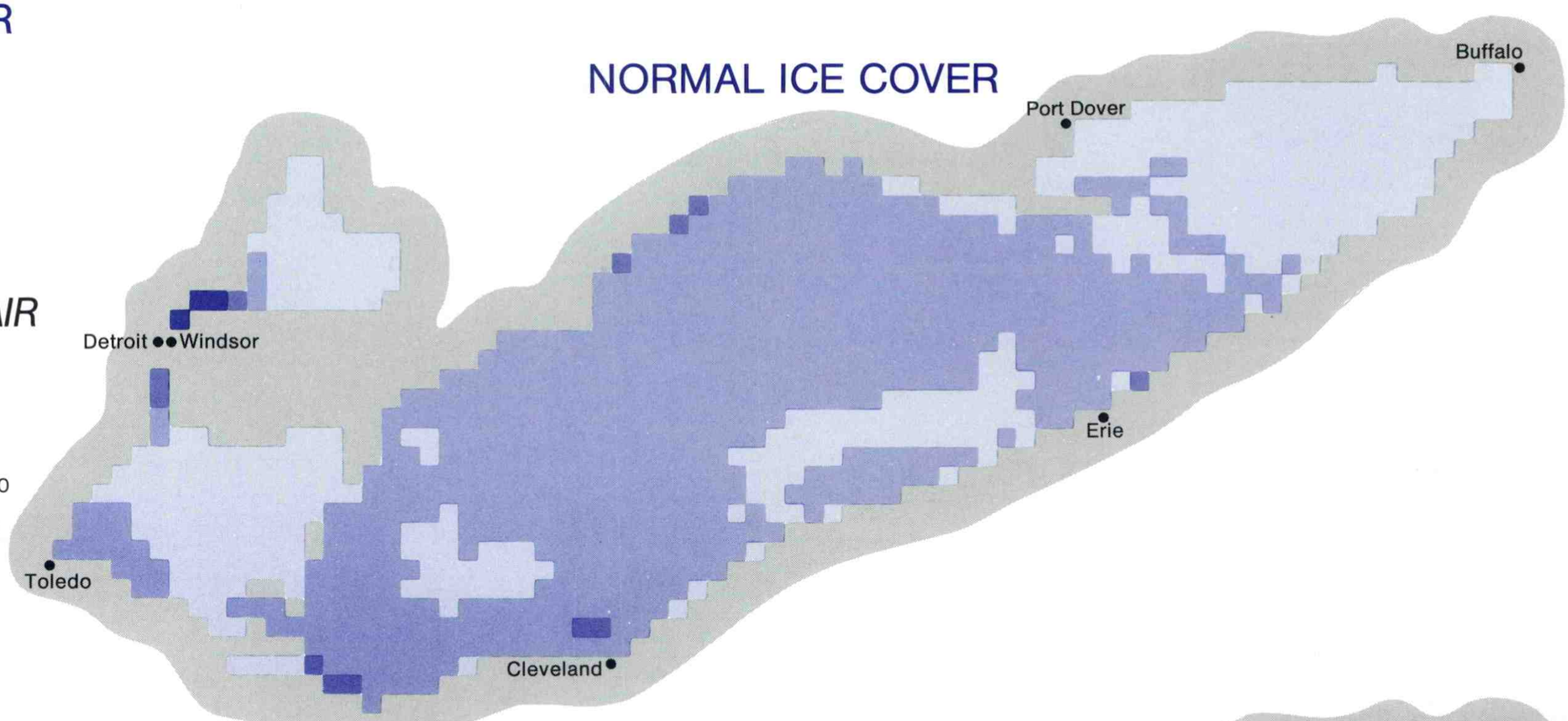
FEBRUARY 1–14
1960–1979

LAKES ERIE & ST. CLAIR

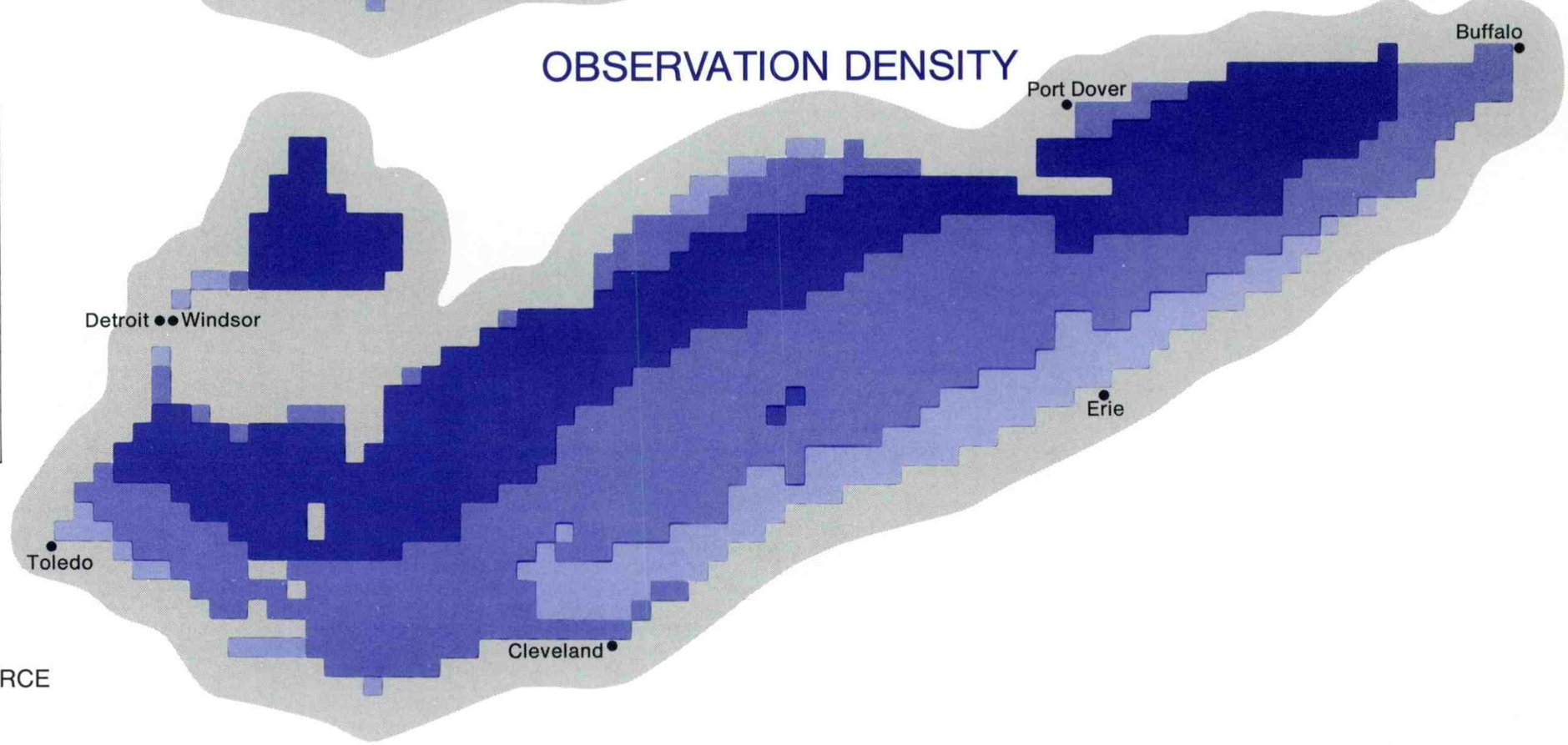
Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

NORMAL ICE COVER



OBSERVATION DENSITY



OBSERVATION LEGEND

- FIRST QUARTILE
  0 to 5 years of data
- SECOND QUARTILE
  6 to 10 years of data
- THIRD QUARTILE
  11 to 15 years of data
- FOURTH QUARTILE
  16 to 20 years of data

PLATE 32B

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

EXTREMES IN ICE COVER

FEBRUARY 15–28
1960–1979

LAKES ERIE & ST. CLAIR



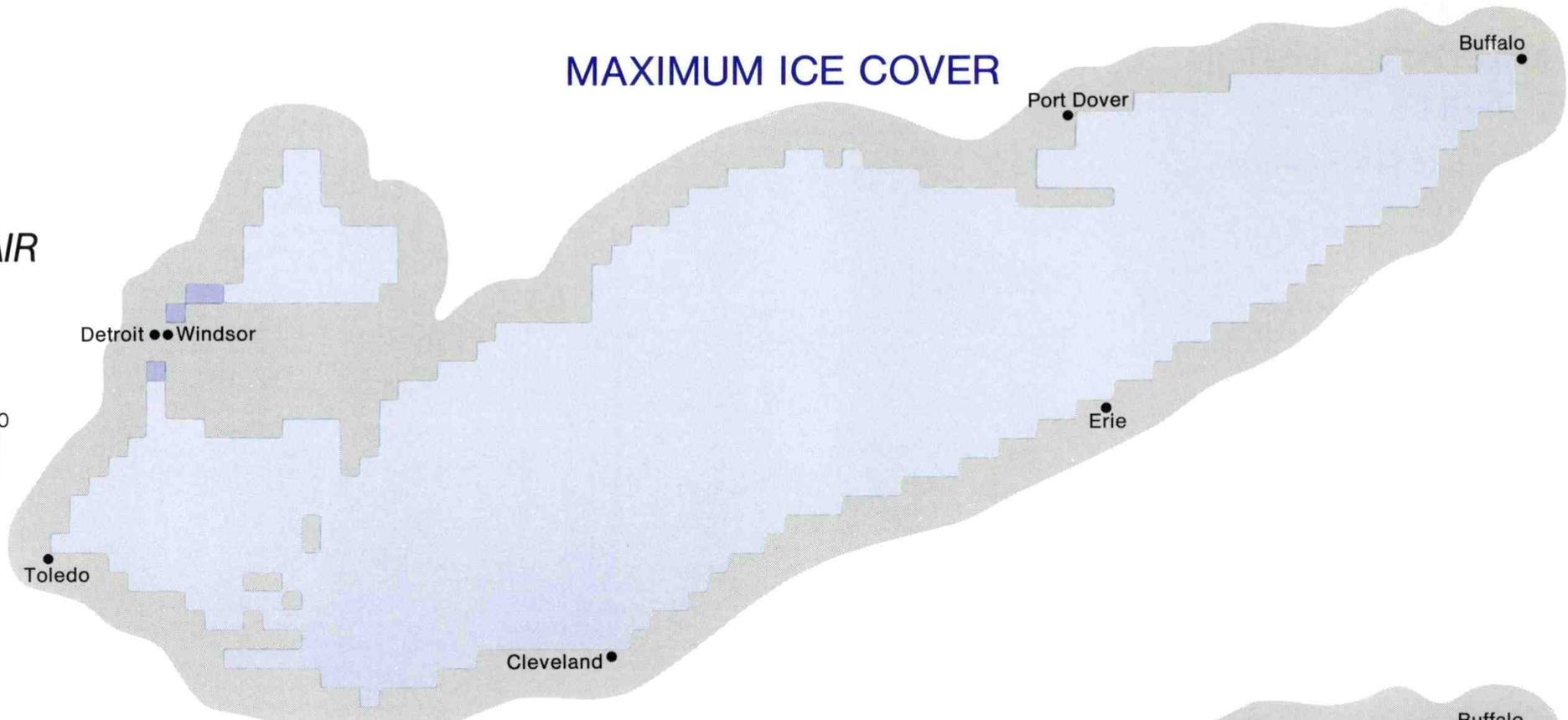
Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

ICE COVER LEGEND

- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

MAXIMUM ICE COVER



MINIMUM ICE COVER

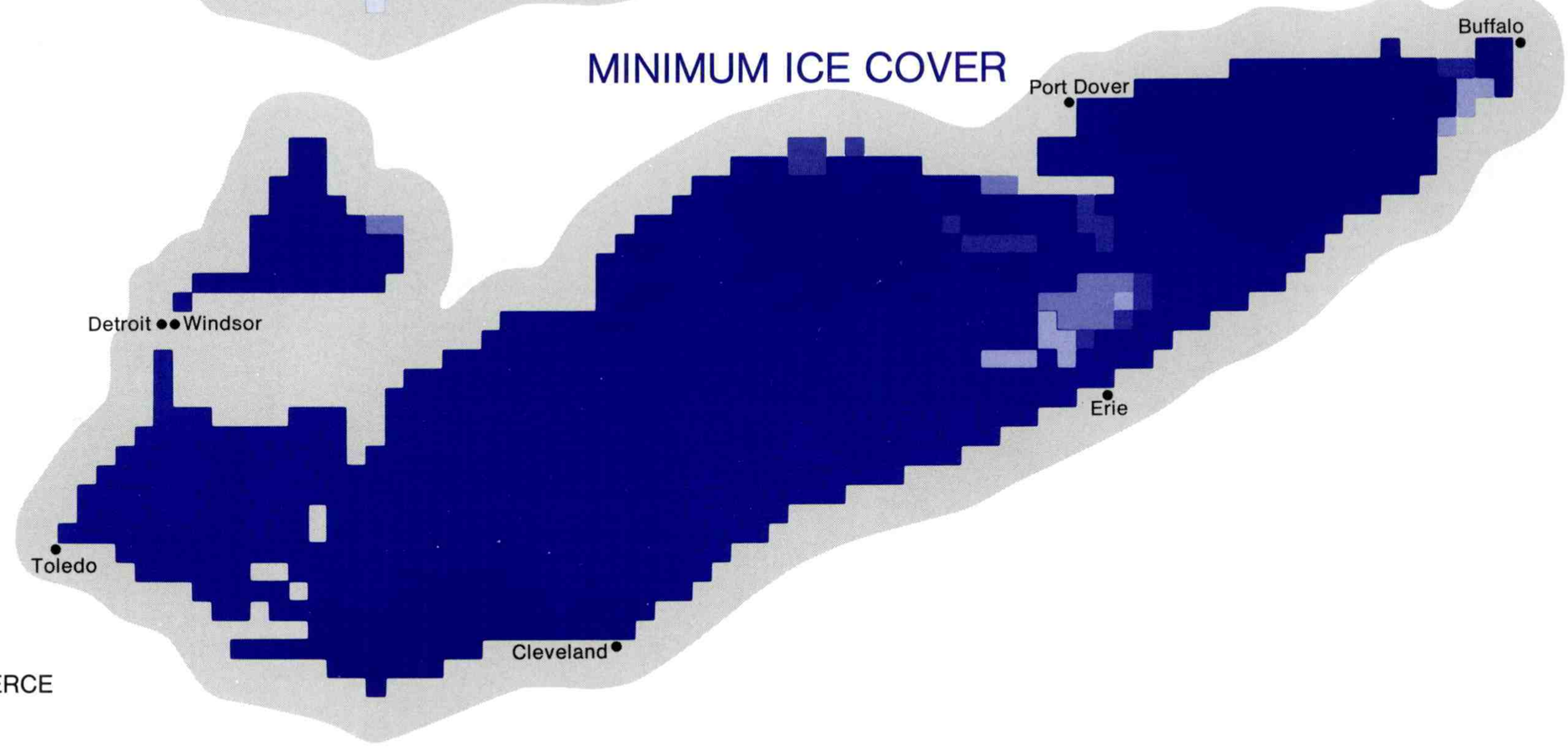


PLATE 33A

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER AND OBSERVATION DENSITY

FEBRUARY 15–28

1960–1979

LAKES ERIE & ST. CLAIR

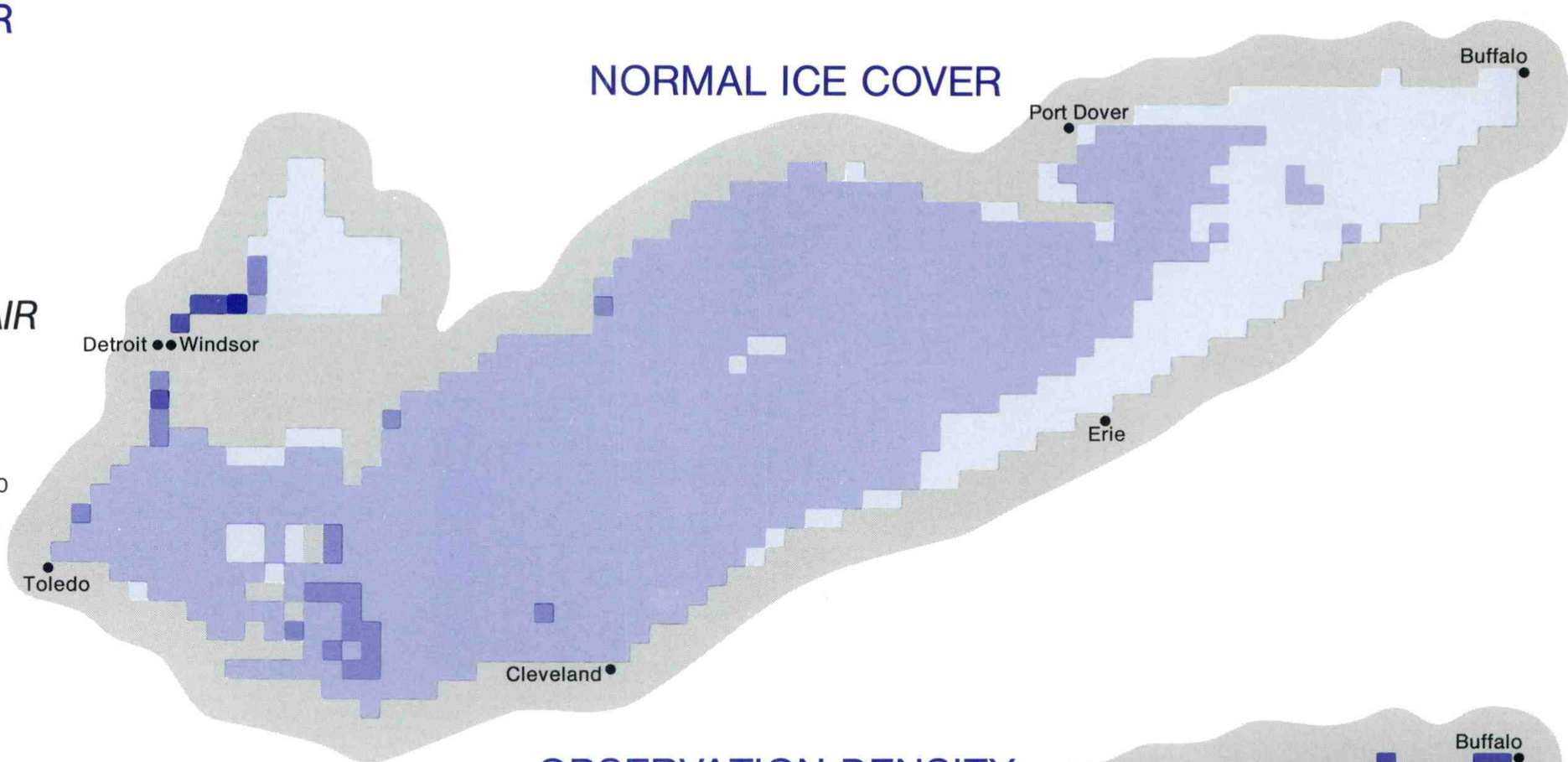
Kilometers

0 20 40 60 80 100

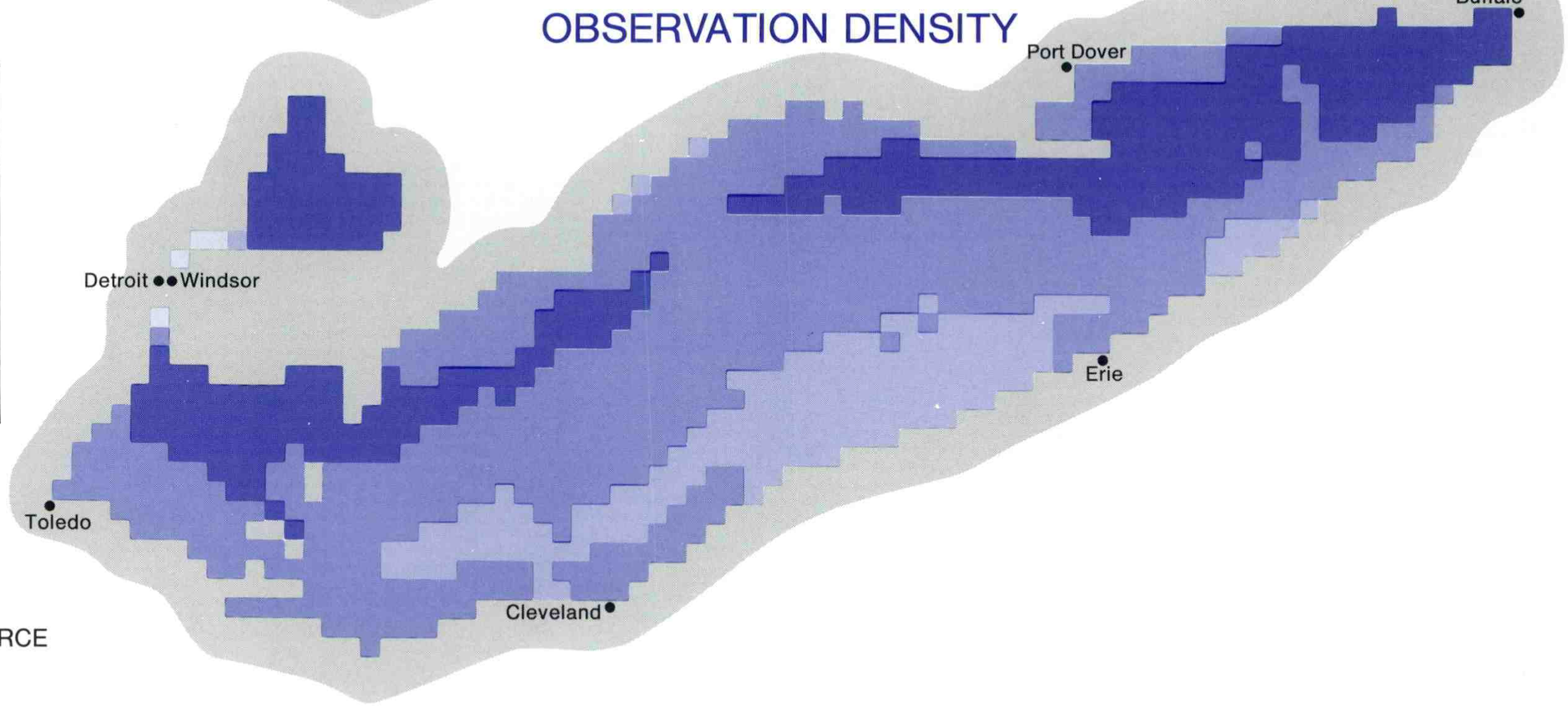
0 10 20 30 40 50 60

Statute Miles

NORMAL ICE COVER



OBSERVATION DENSITY



OBSERVATION LEGEND

- FIRST QUARTILE
  0 to 5 years of data
- SECOND QUARTILE
  6 to 10 years of data
- THIRD QUARTILE
  11 to 15 years of data
- FOURTH QUARTILE
  16 to 20 years of data

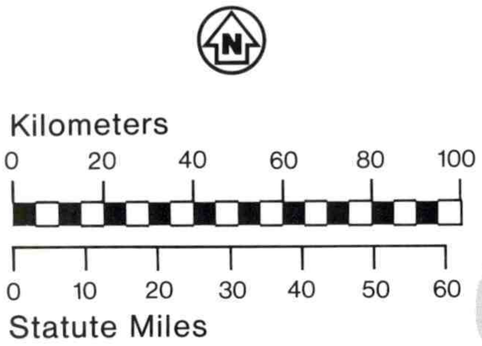
PLATE 33B

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

EXTREMES IN ICE COVER

MARCH 1–15
1960–1979

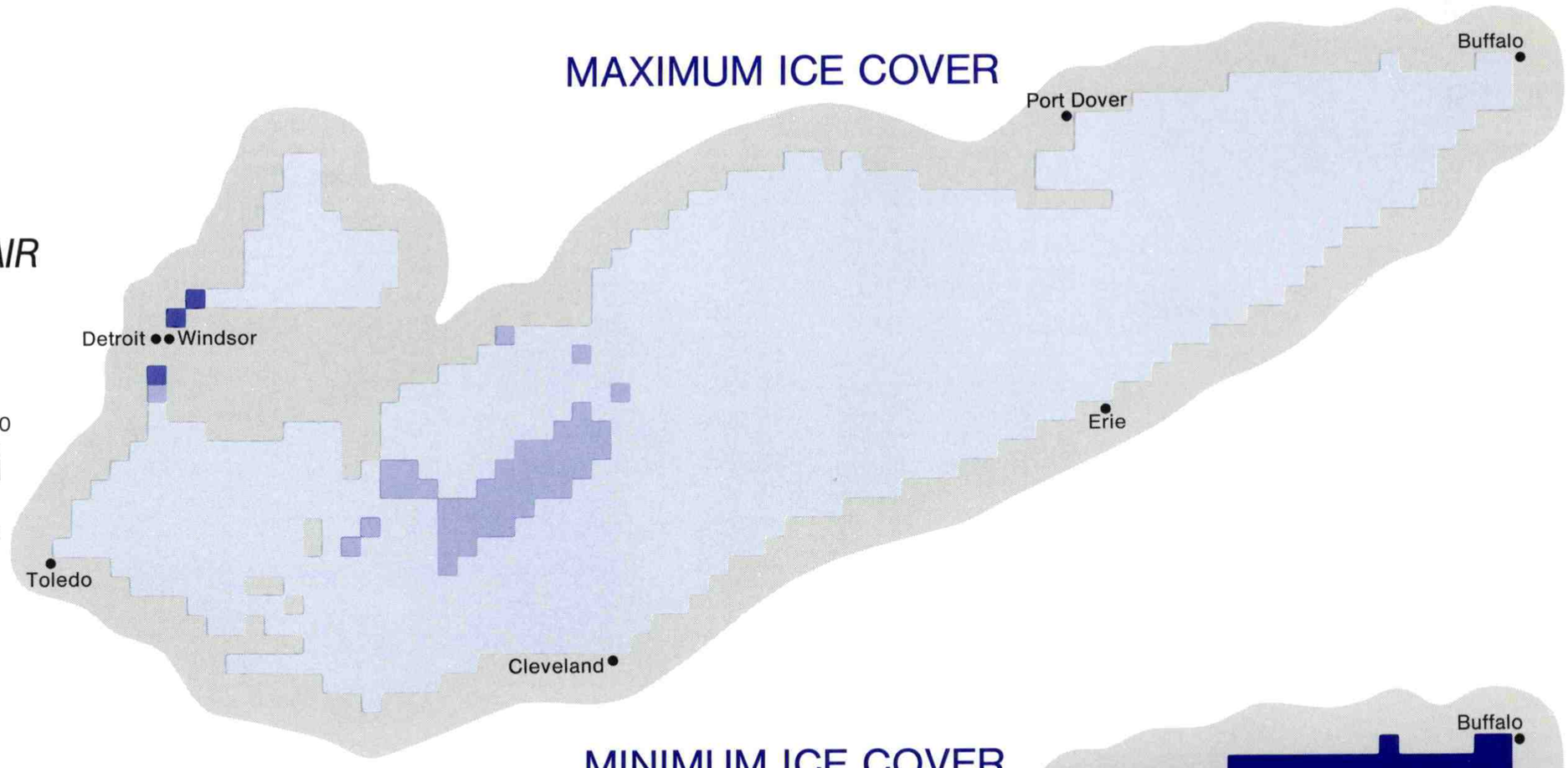
LAKES ERIE & ST. CLAIR



ICE COVER LEGEND

- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

MAXIMUM ICE COVER



MINIMUM ICE COVER

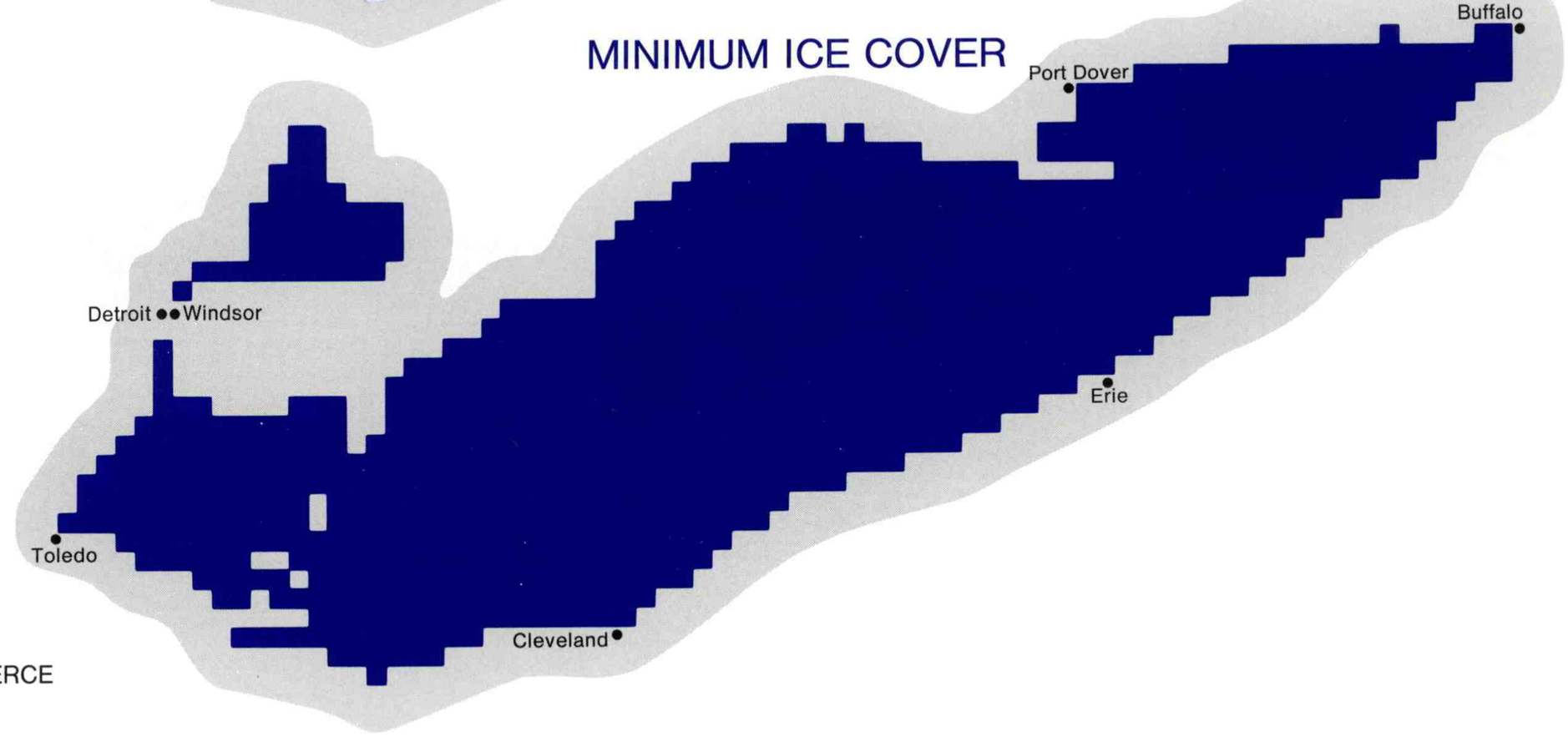


PLATE 34A

U.S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER AND OBSERVATION DENSITY

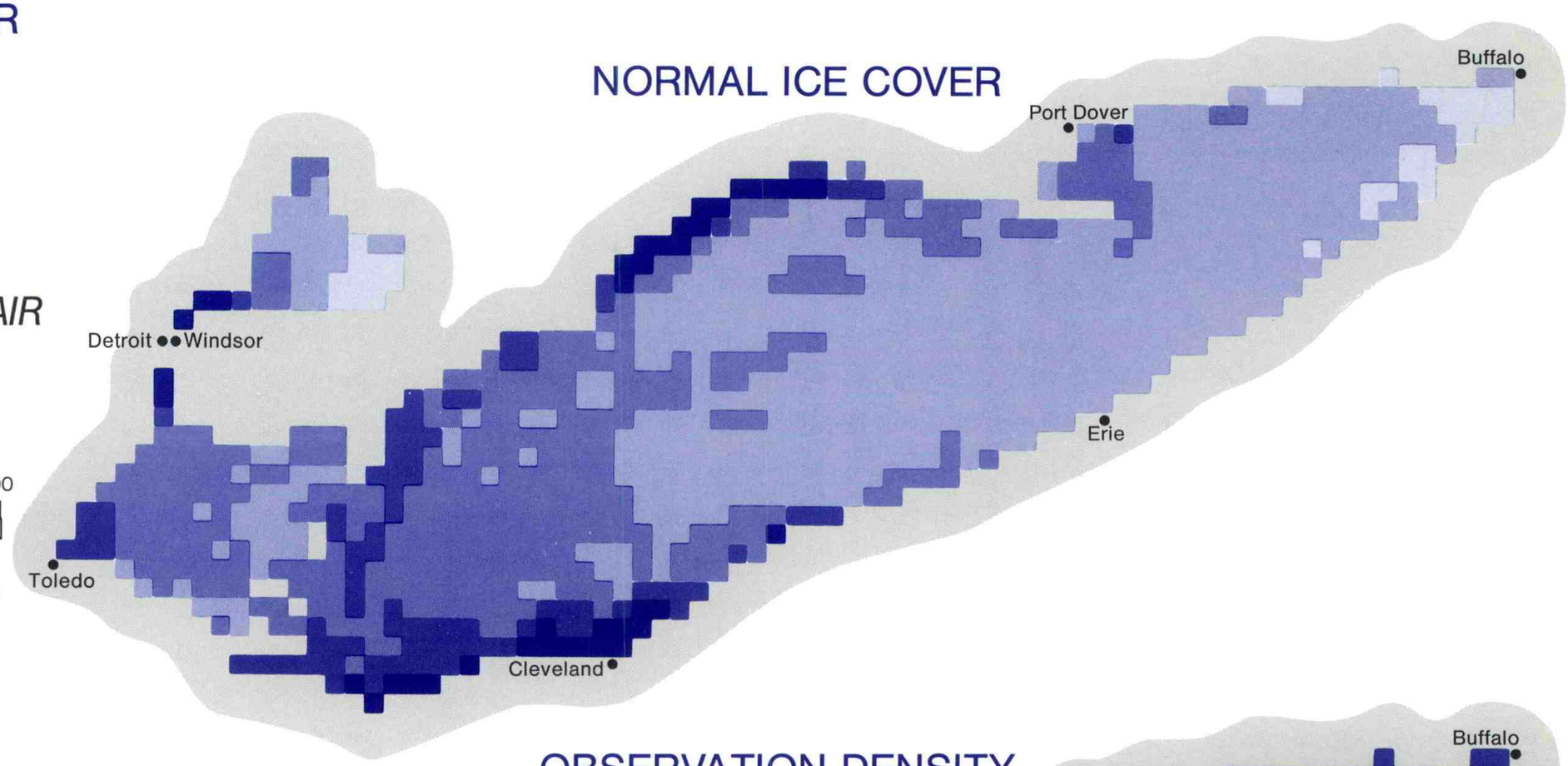
MARCH 1–15
1960–1979

LAKES ERIE & ST. CLAIR

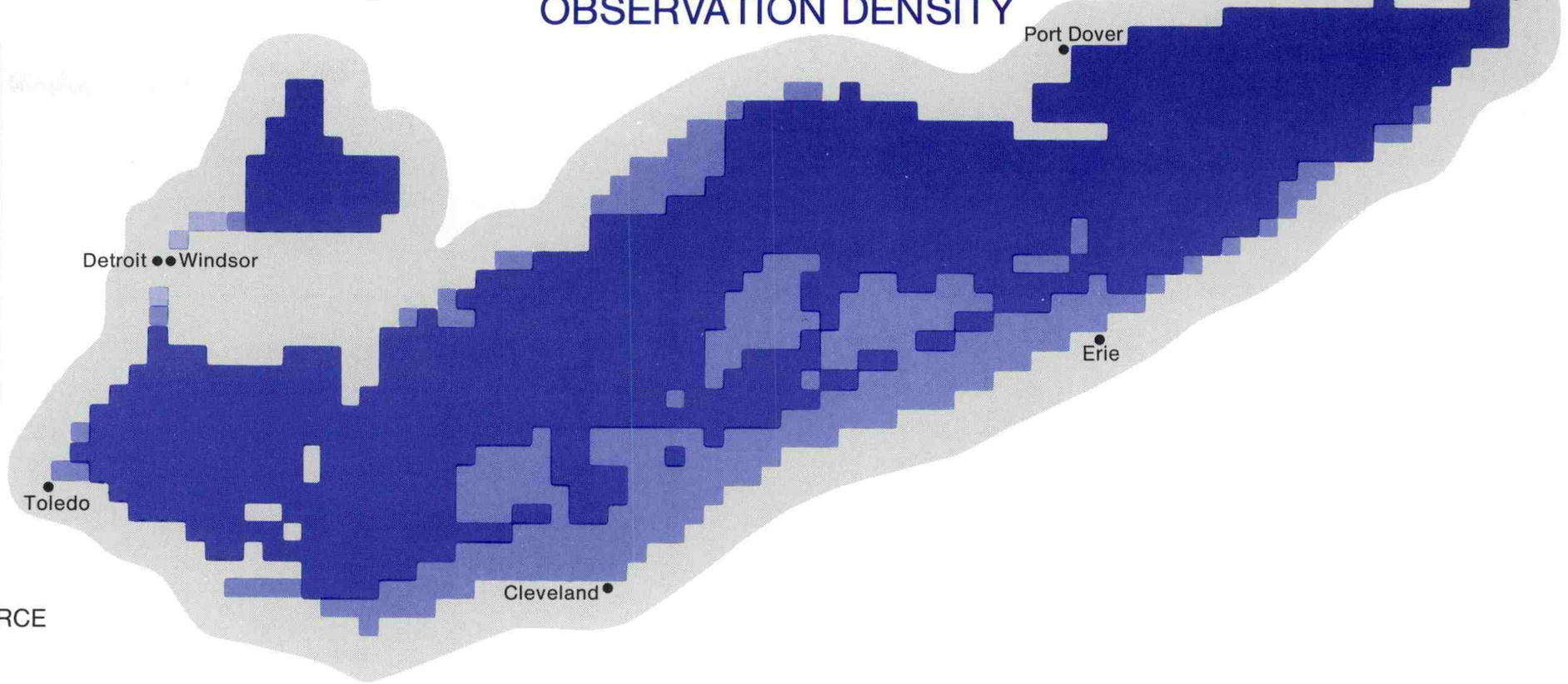
Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

NORMAL ICE COVER



OBSERVATION DENSITY



OBSERVATION LEGEND

- FIRST QUARTILE — 0 to 5 years of data
- SECOND QUARTILE — 6 to 10 years of data
- THIRD QUARTILE — 11 to 15 years of data
- FOURTH QUARTILE — 16 to 20 years of data

PLATE 34B

U.S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

EXTREMES IN ICE COVER

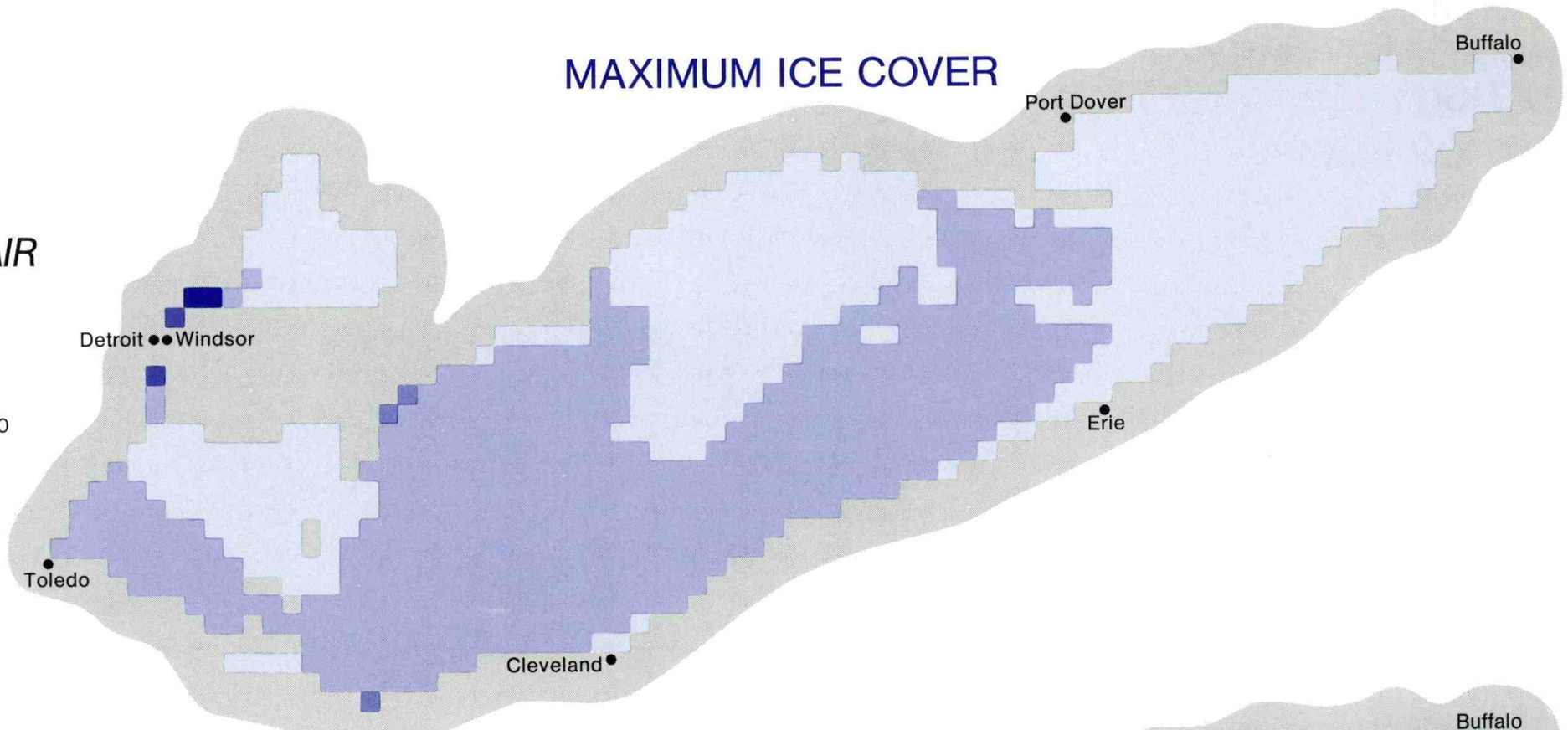
MARCH 16–31
1960–1979

LAKES ERIE & ST. CLAIR

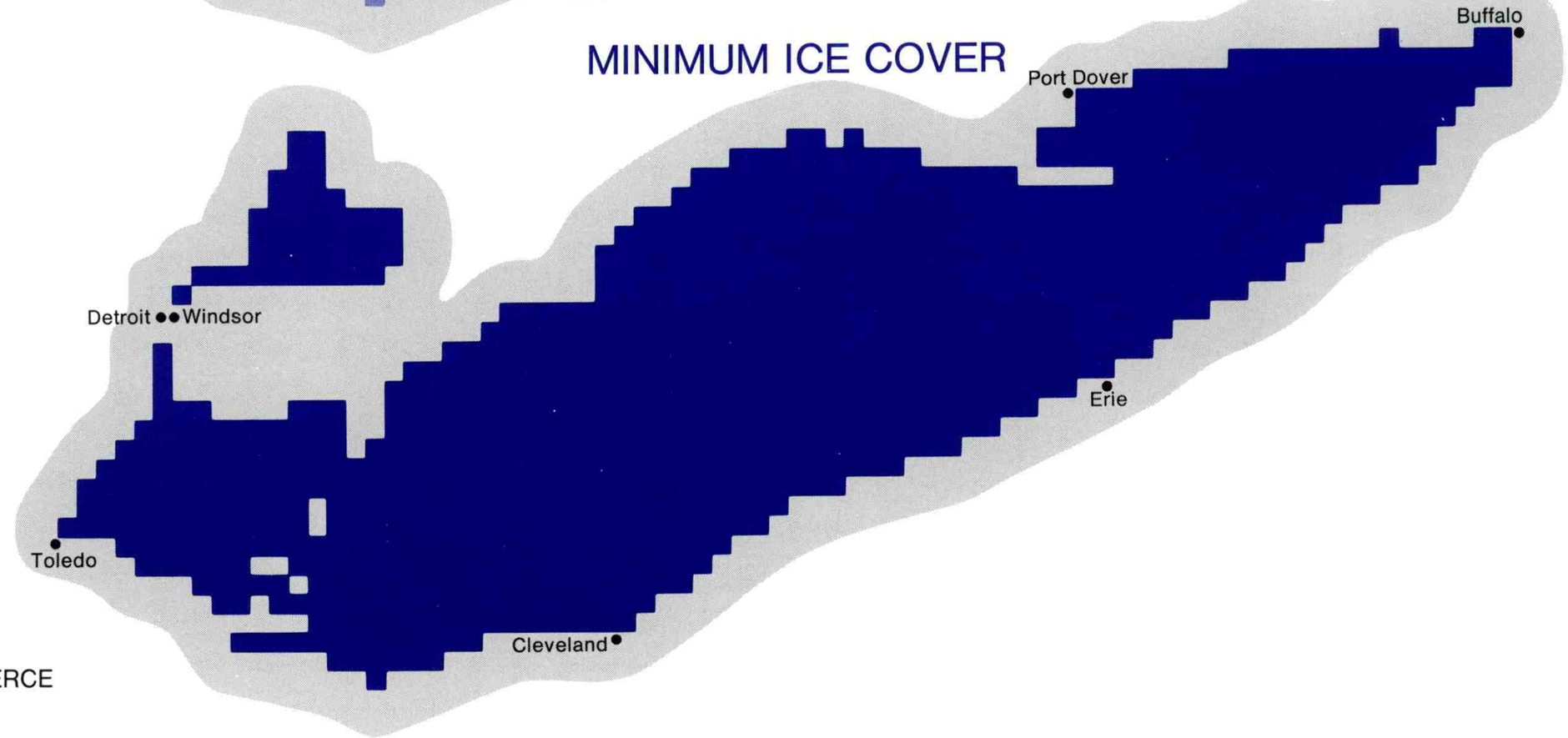
Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

MAXIMUM ICE COVER



MINIMUM ICE COVER



ICE COVER LEGEND

- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

PLATE 35A

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER AND OBSERVATION DENSITY

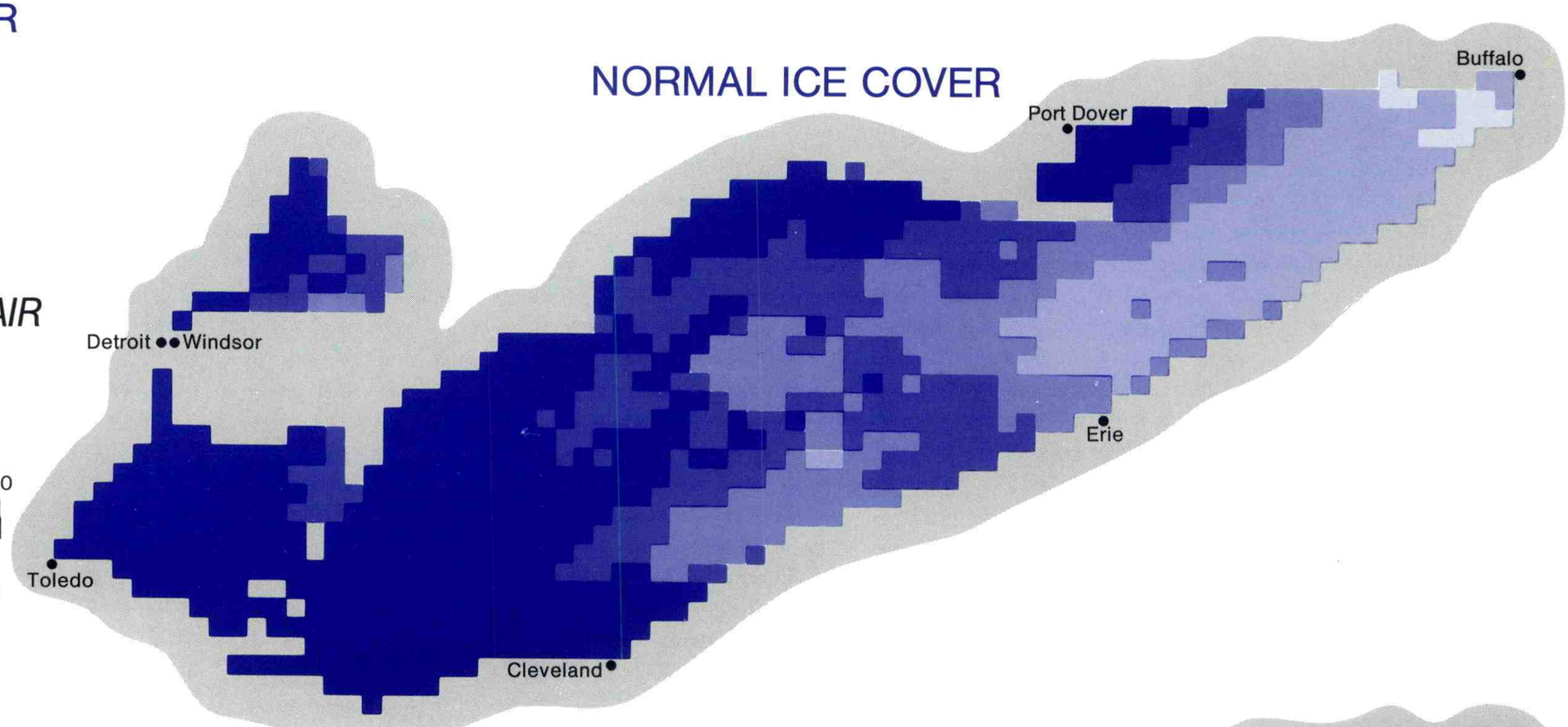
MARCH 16–31
1960–1979

LAKES ERIE & ST. CLAIR

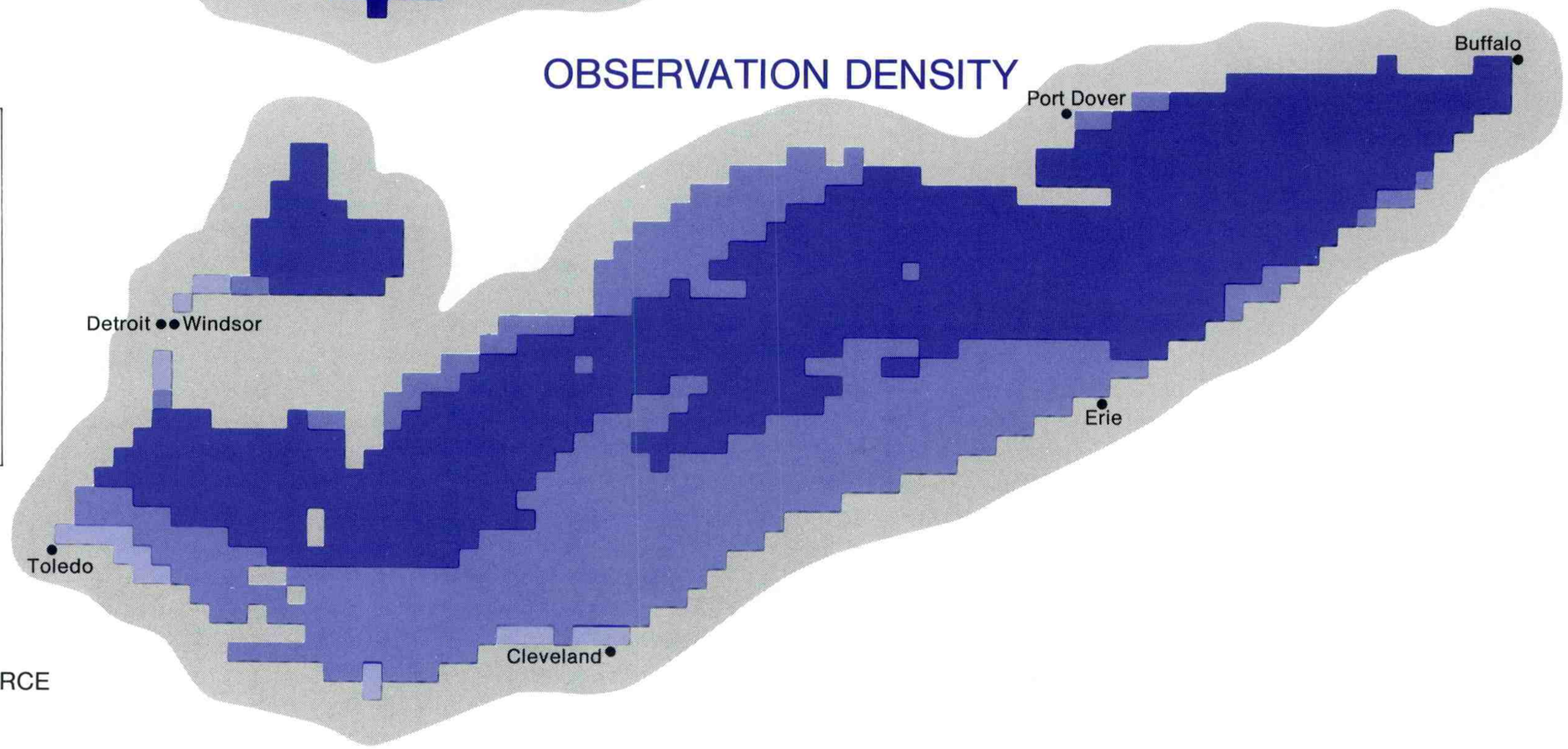
Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

NORMAL ICE COVER



OBSERVATION DENSITY



OBSERVATION LEGEND

- FIRST QUARTILE — 0 to 5 years of data
- SECOND QUARTILE — 6 to 10 years of data
- THIRD QUARTILE — 11 to 15 years of data
- FOURTH QUARTILE — 16 to 20 years of data

PLATE 35B

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

EXTREMES IN ICE COVER

APRIL 1–15
1960–1979

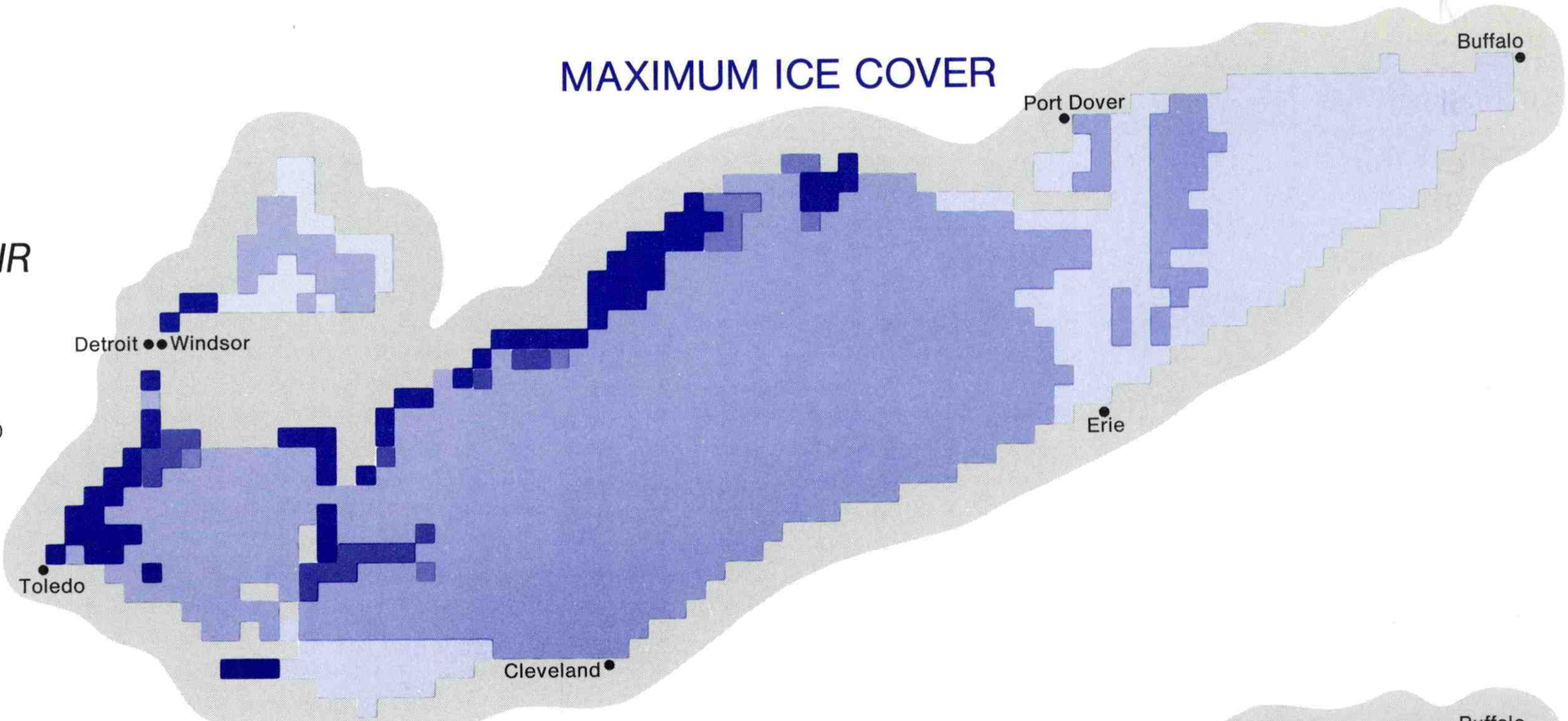
LAKES ERIE & ST. CLAIR



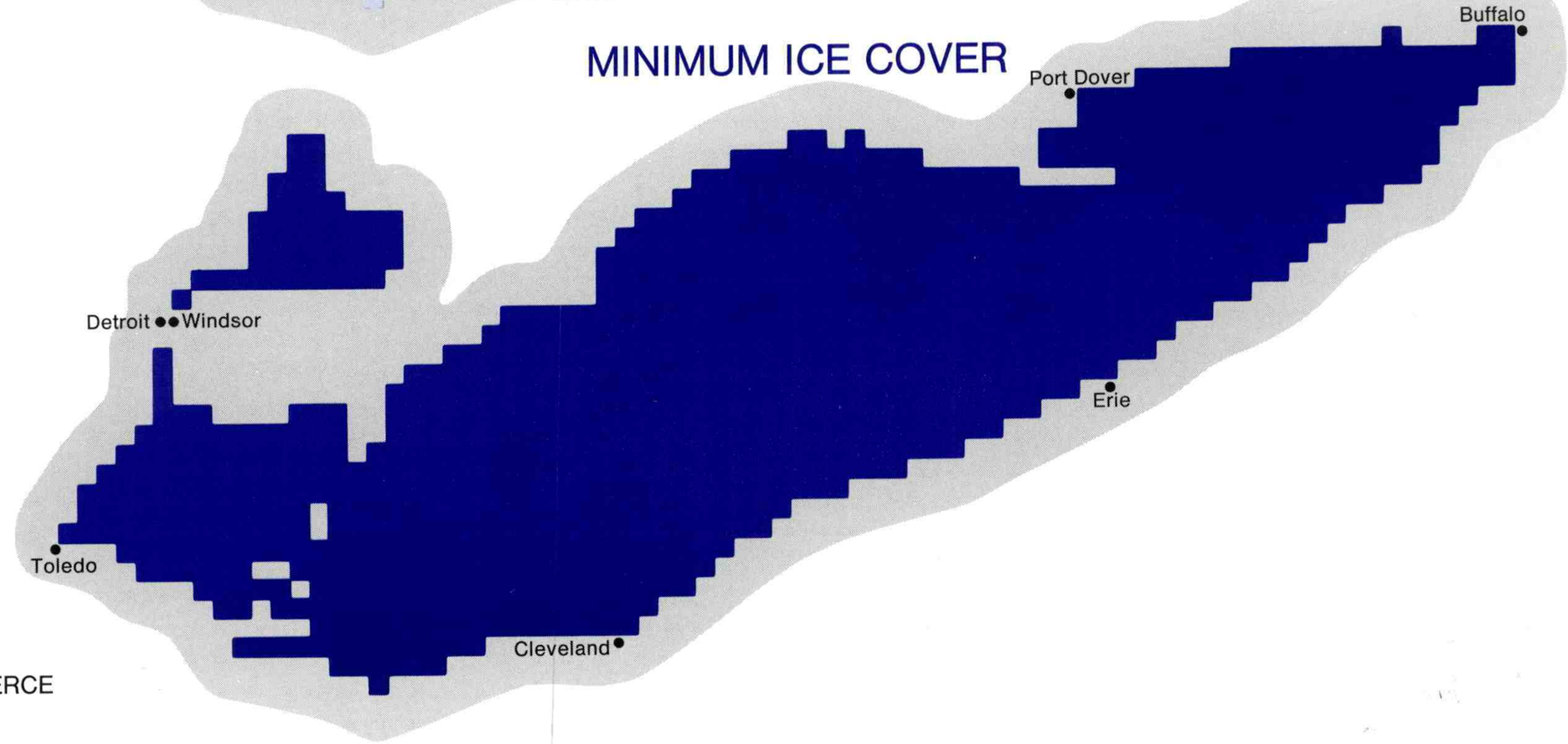
Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

MAXIMUM ICE COVER



MINIMUM ICE COVER



ICE COVER LEGEND

- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

PLATE 36A

U.S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER AND OBSERVATION DENSITY

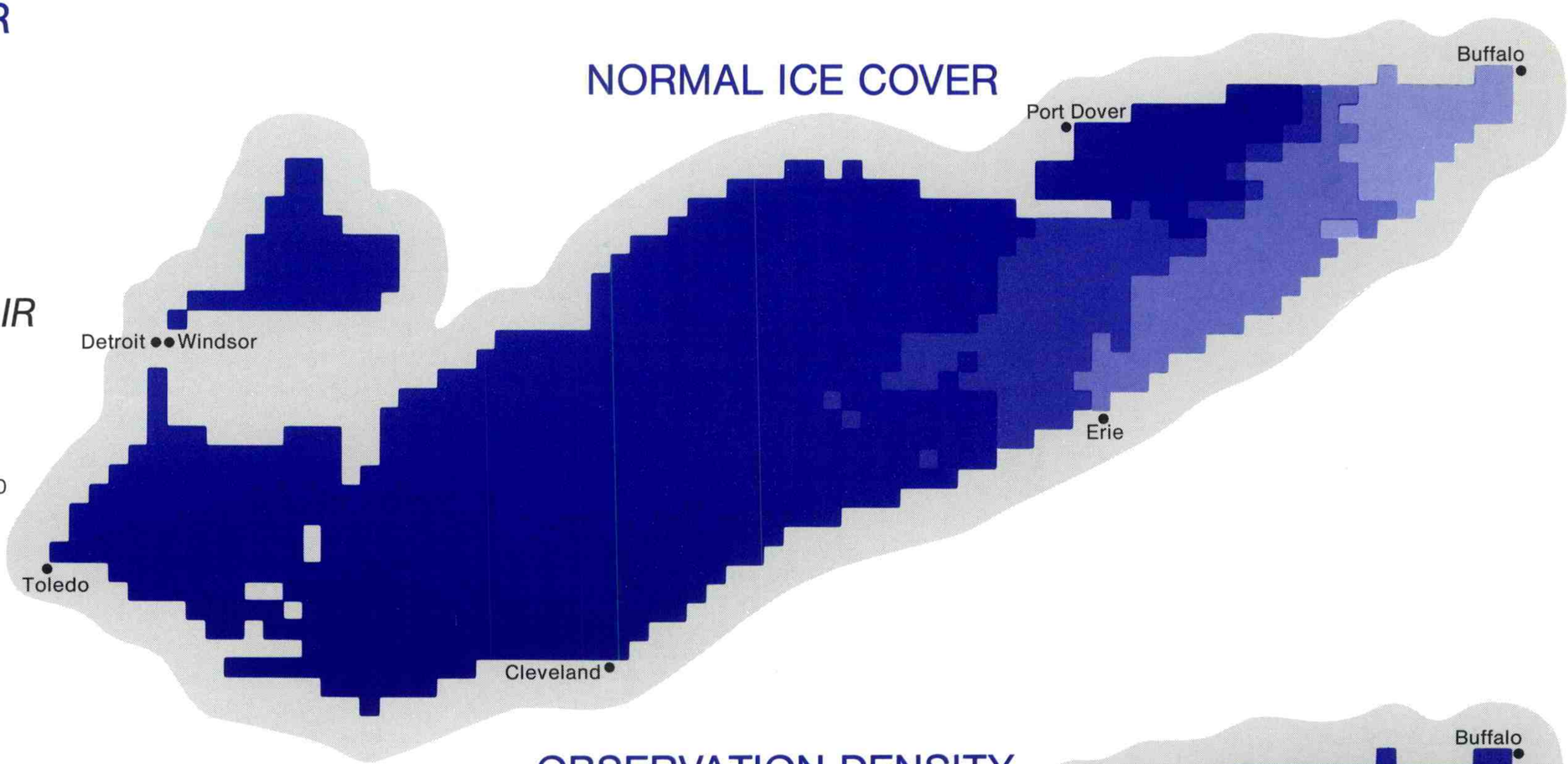
APRIL 1–15
1960–1979

LAKES ERIE & ST. CLAIR

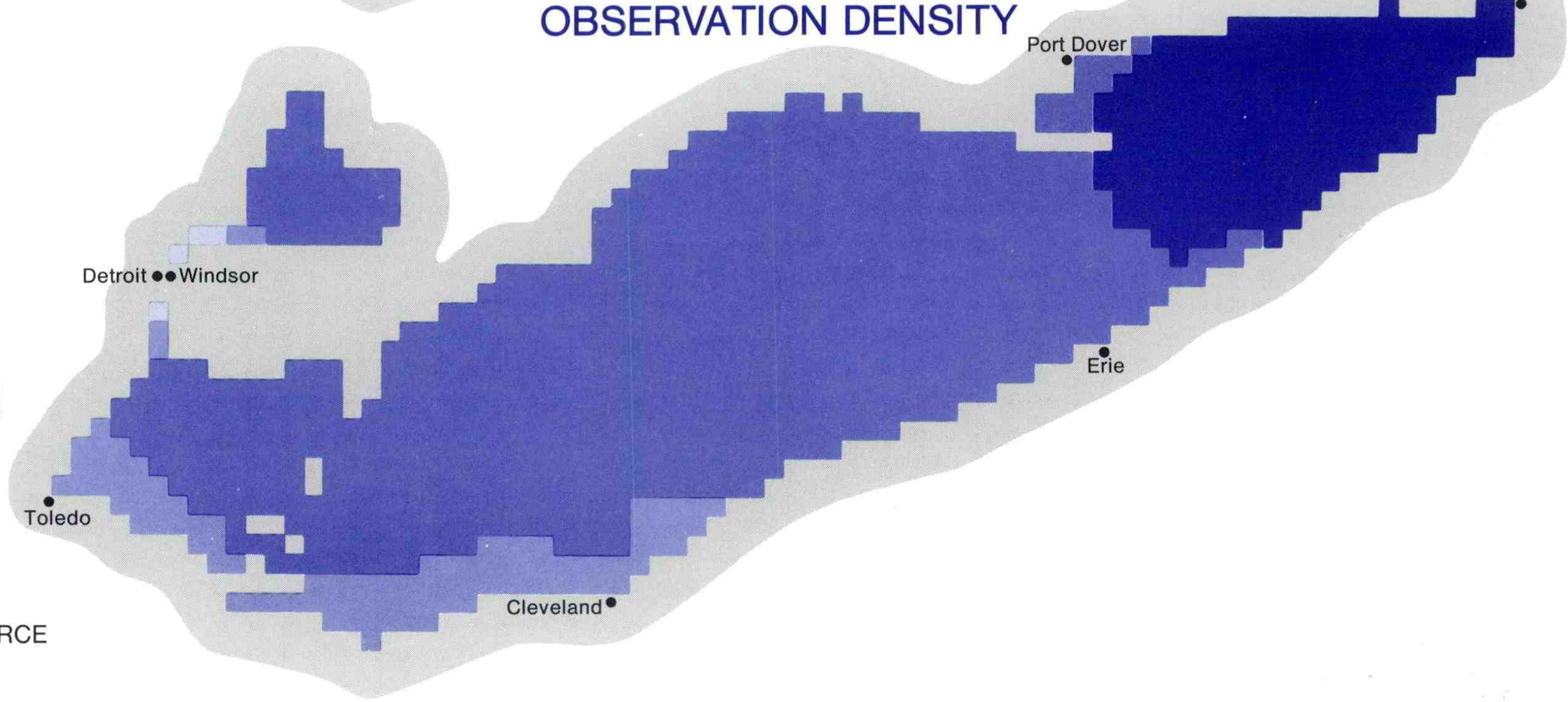
Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

NORMAL ICE COVER



OBSERVATION DENSITY



OBSERVATION LEGEND

- FIRST QUARTILE
  0 to 5 years of data
- SECOND QUARTILE
  6 to 10 years of data
- THIRD QUARTILE
  11 to 15 years of data
- FOURTH QUARTILE
  16 to 20 years of data

PLATE 36B

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

EXTREMES IN ICE COVER

APRIL 16–30
1960–1979

LAKES ERIE & ST. CLAIR



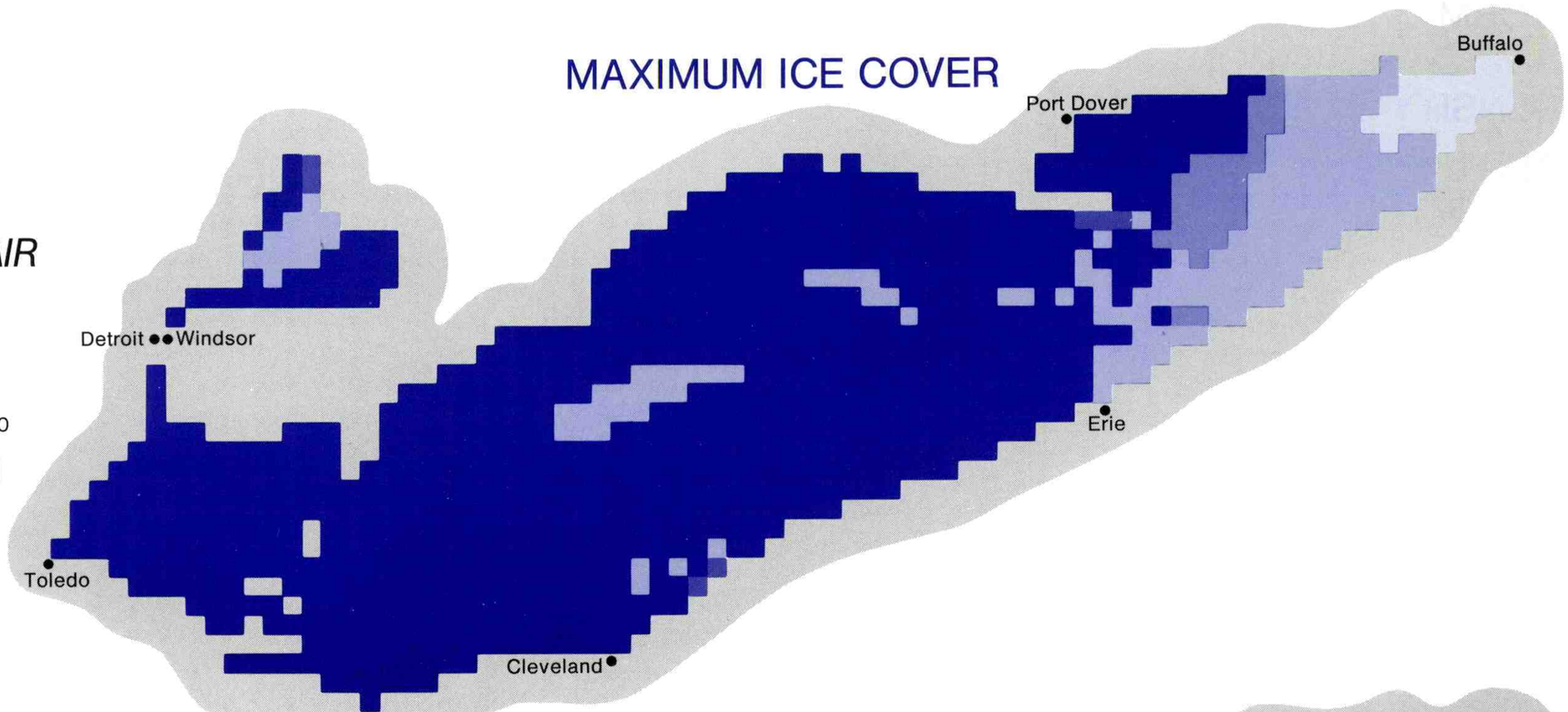
Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

ICE COVER LEGEND

- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

MAXIMUM ICE COVER



MINIMUM ICE COVER

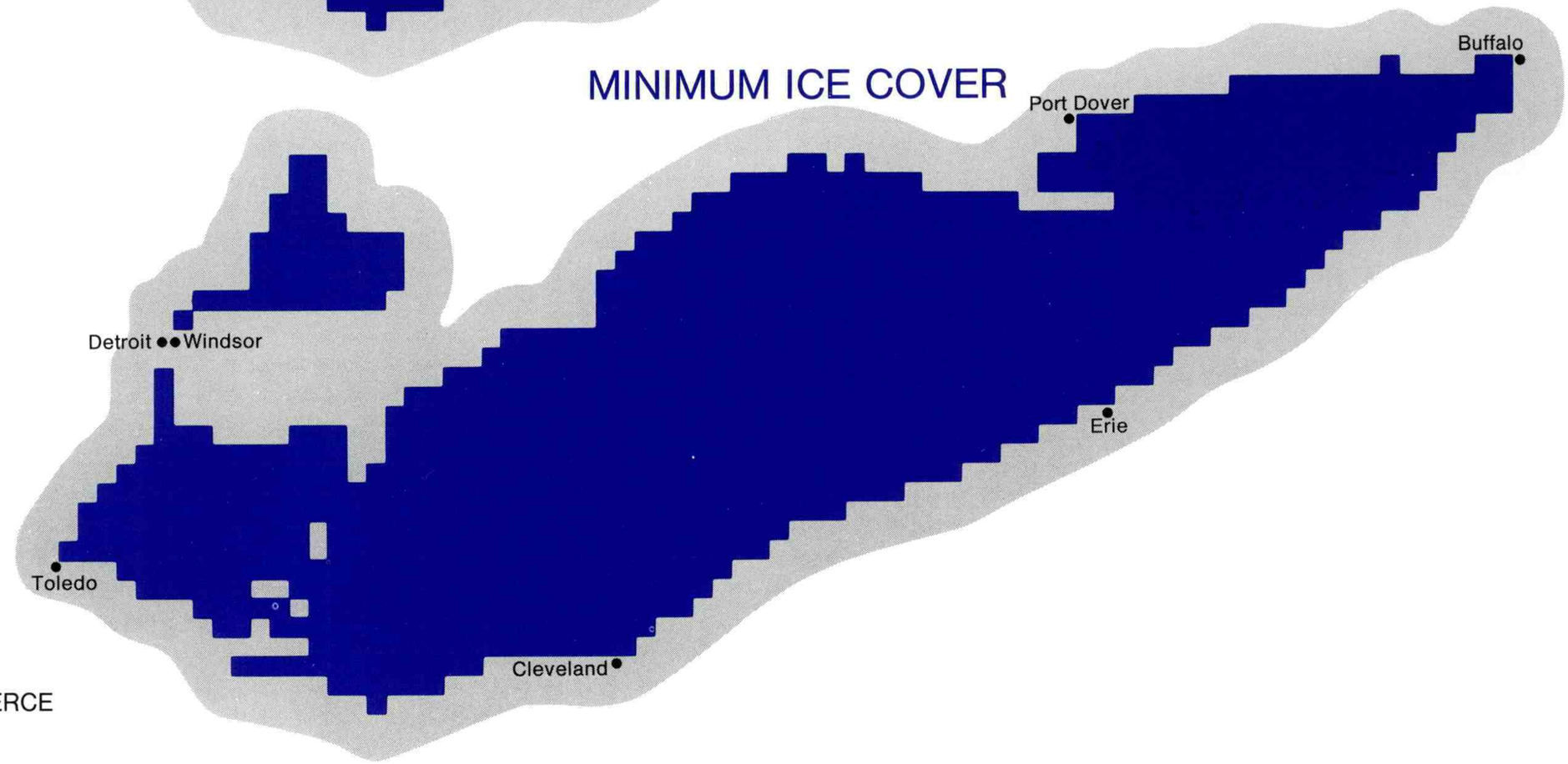


PLATE 37A

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER AND OBSERVATION DENSITY

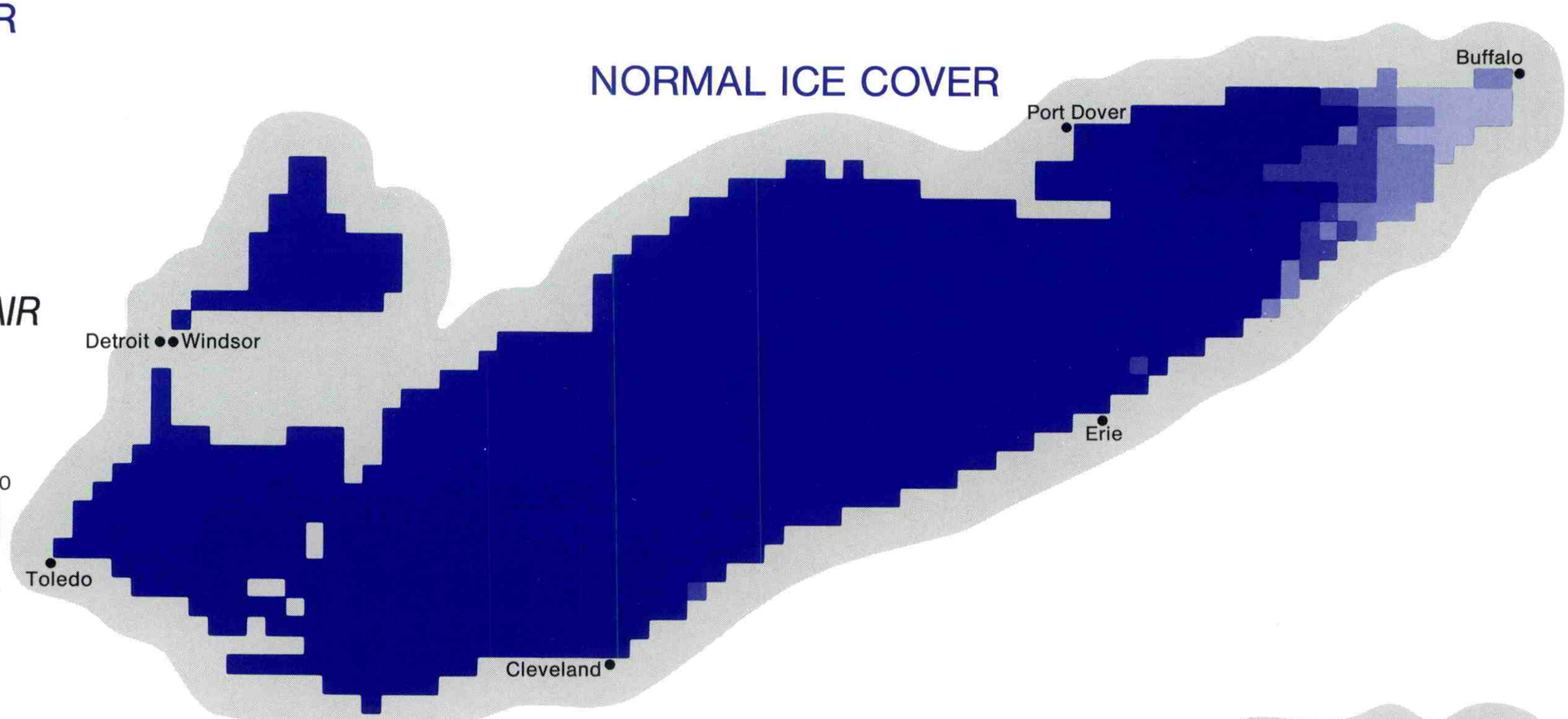
APRIL 16–30
1960–1979

LAKES ERIE & ST. CLAIR

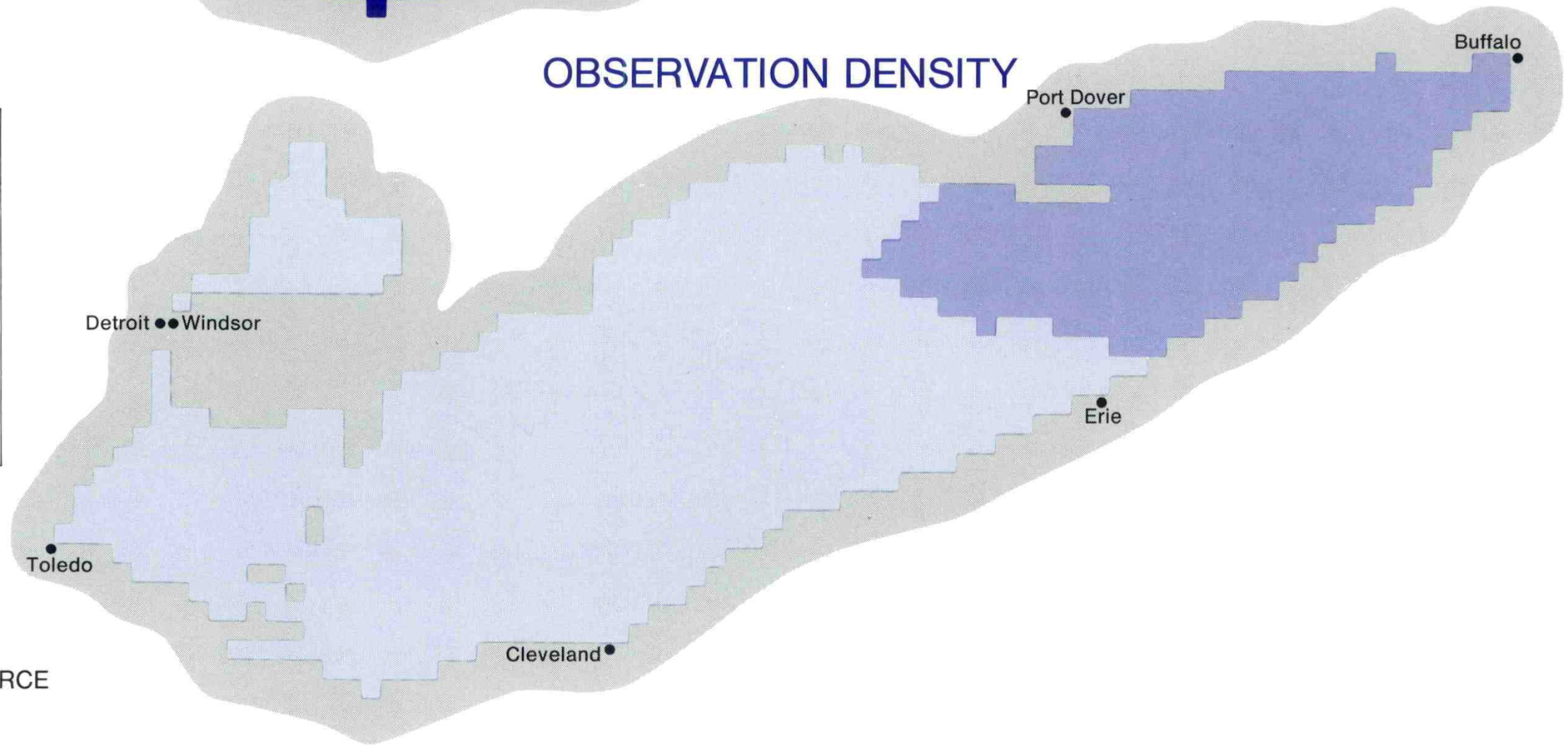
Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

NORMAL ICE COVER



OBSERVATION DENSITY



OBSERVATION LEGEND

- FIRST QUARTILE — 0 to 5 years of data
- SECOND QUARTILE — 6 to 10 years of data
- THIRD QUARTILE — 11 to 15 years of data
- FOURTH QUARTILE — 16 to 20 years of data

PLATE 37B

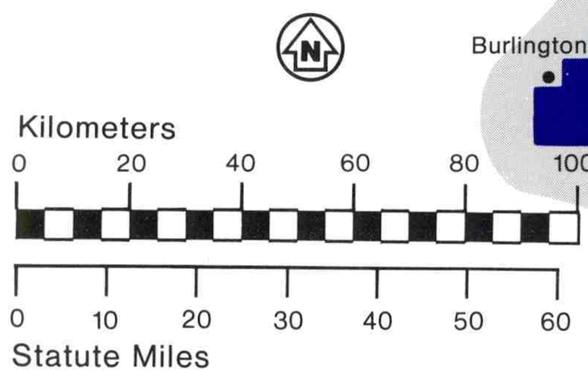
U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

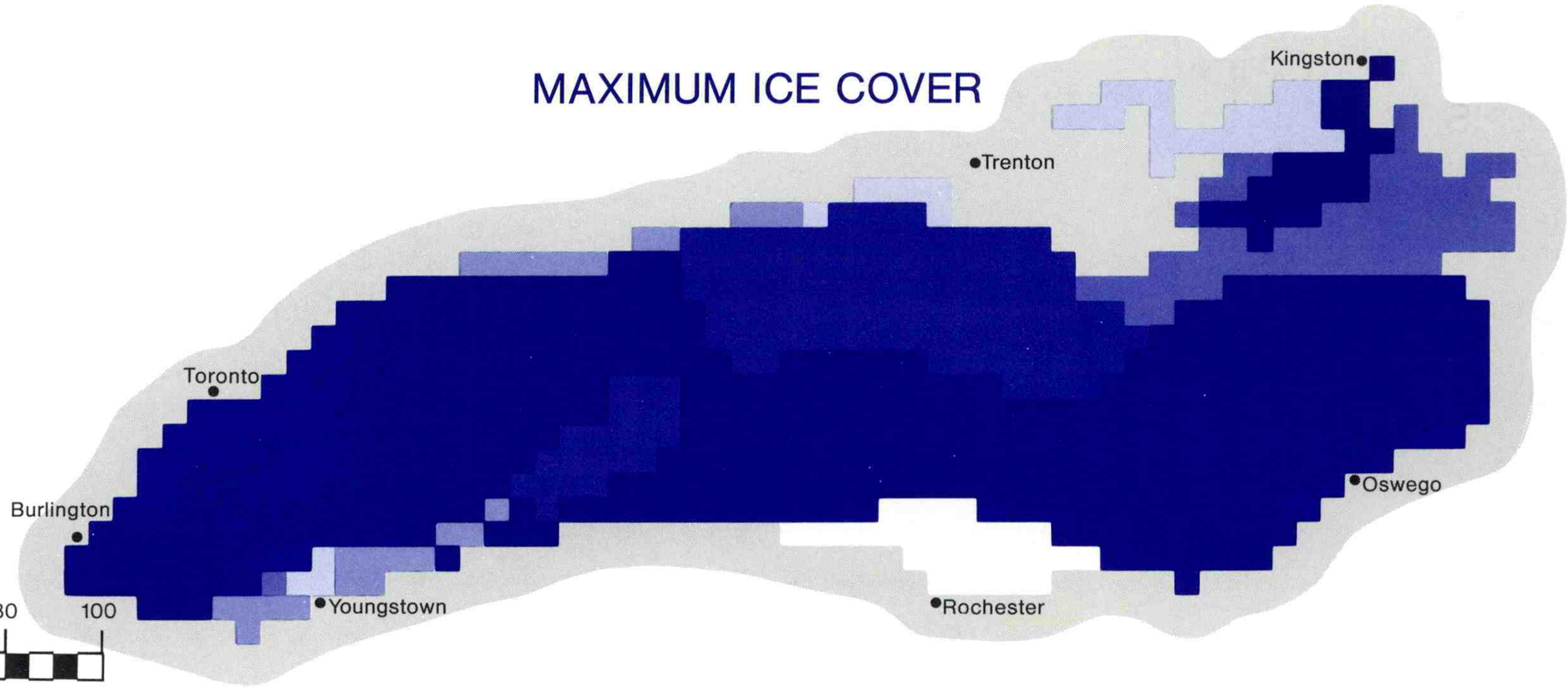
EXTREMES IN ICE COVER

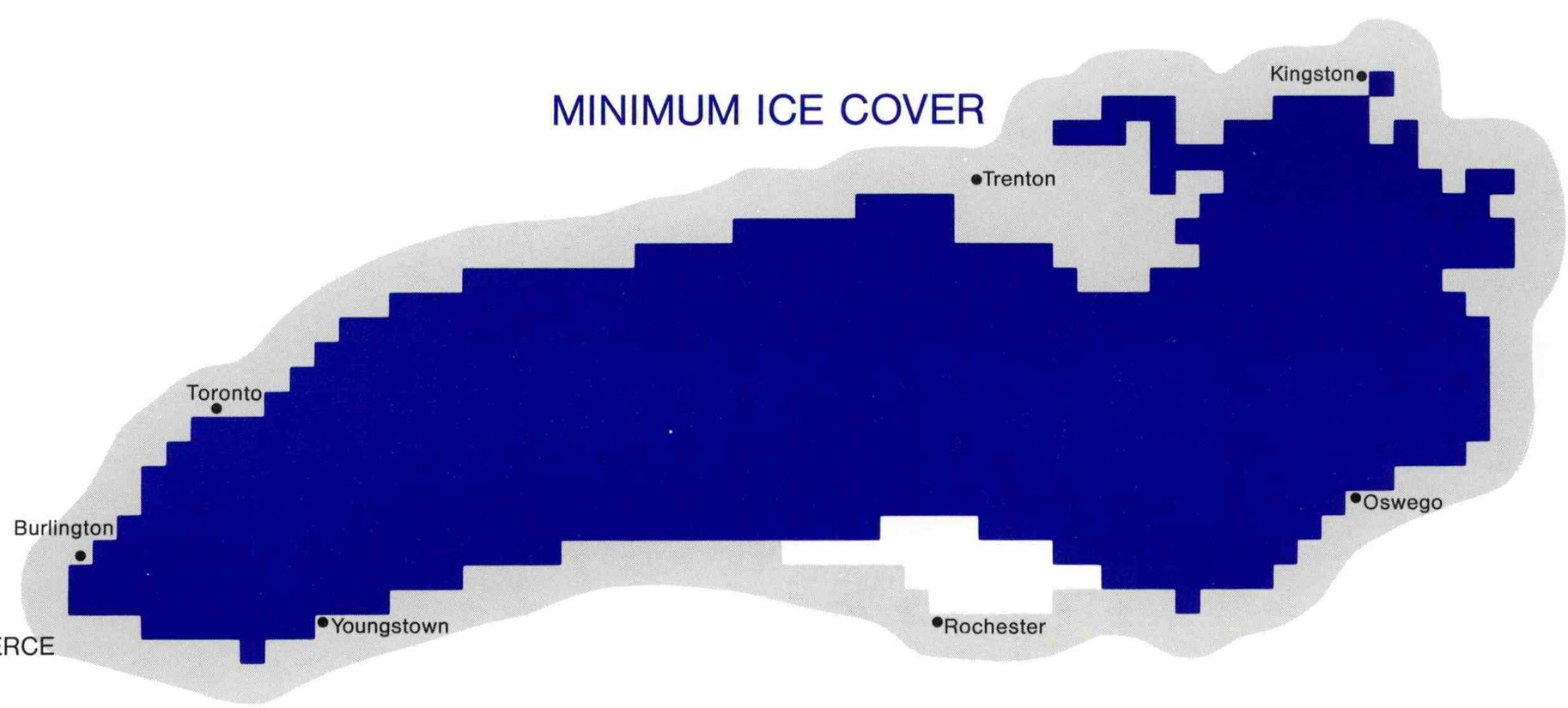
DECEMBER 16–31

1960–1979

LAKE ONTARIO







ICE COVER LEGEND

- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

PLATE 38A

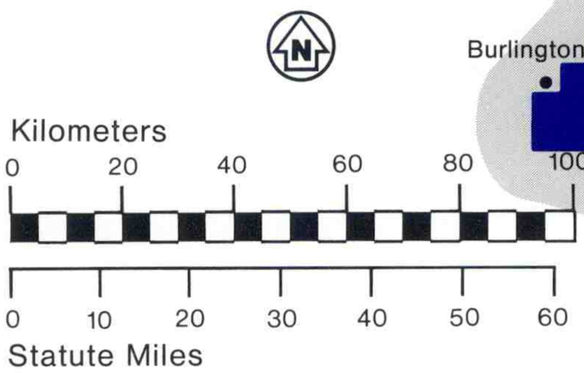
U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

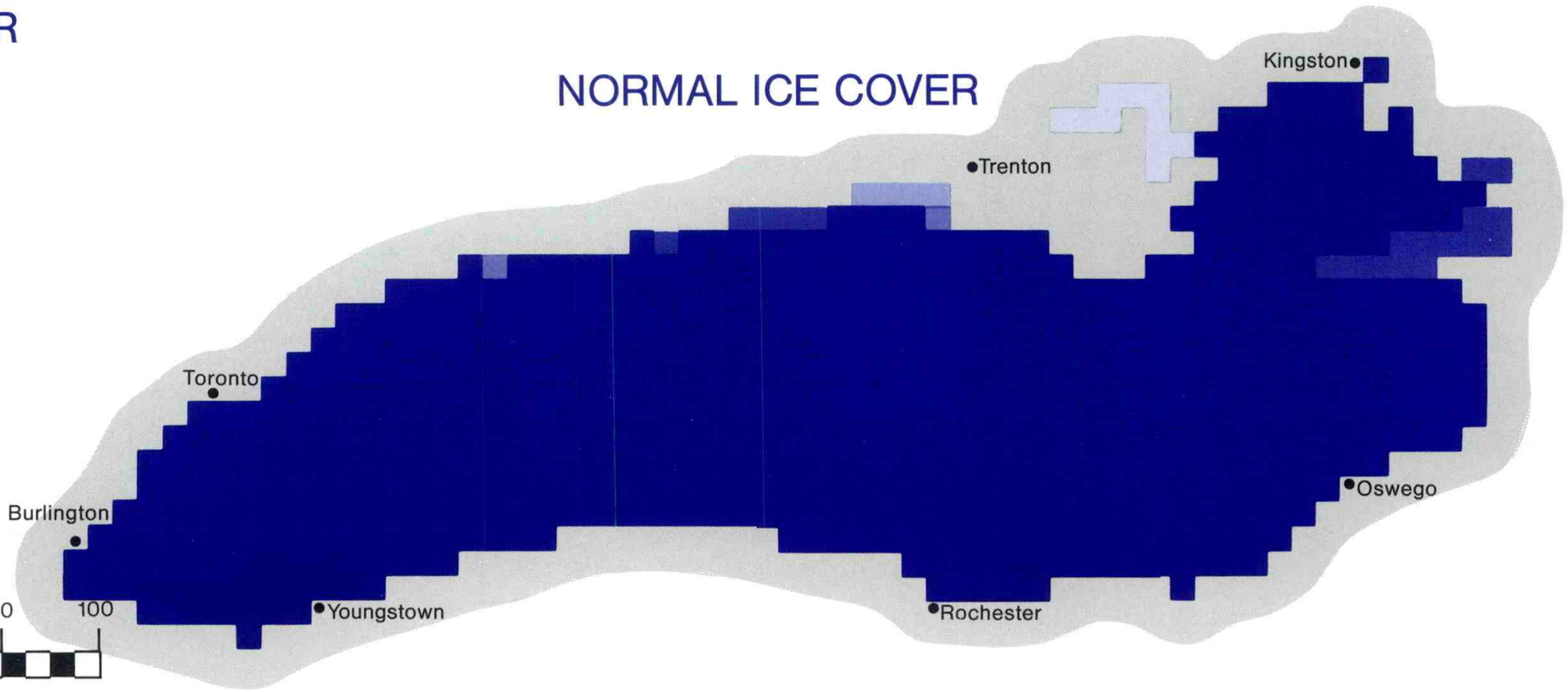
NORMAL ICE COVER AND OBSERVATION DENSITY

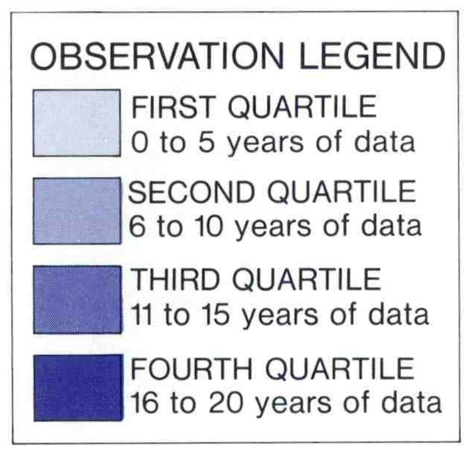
DECEMBER 16–31

1960–1979

LAKE ONTARIO







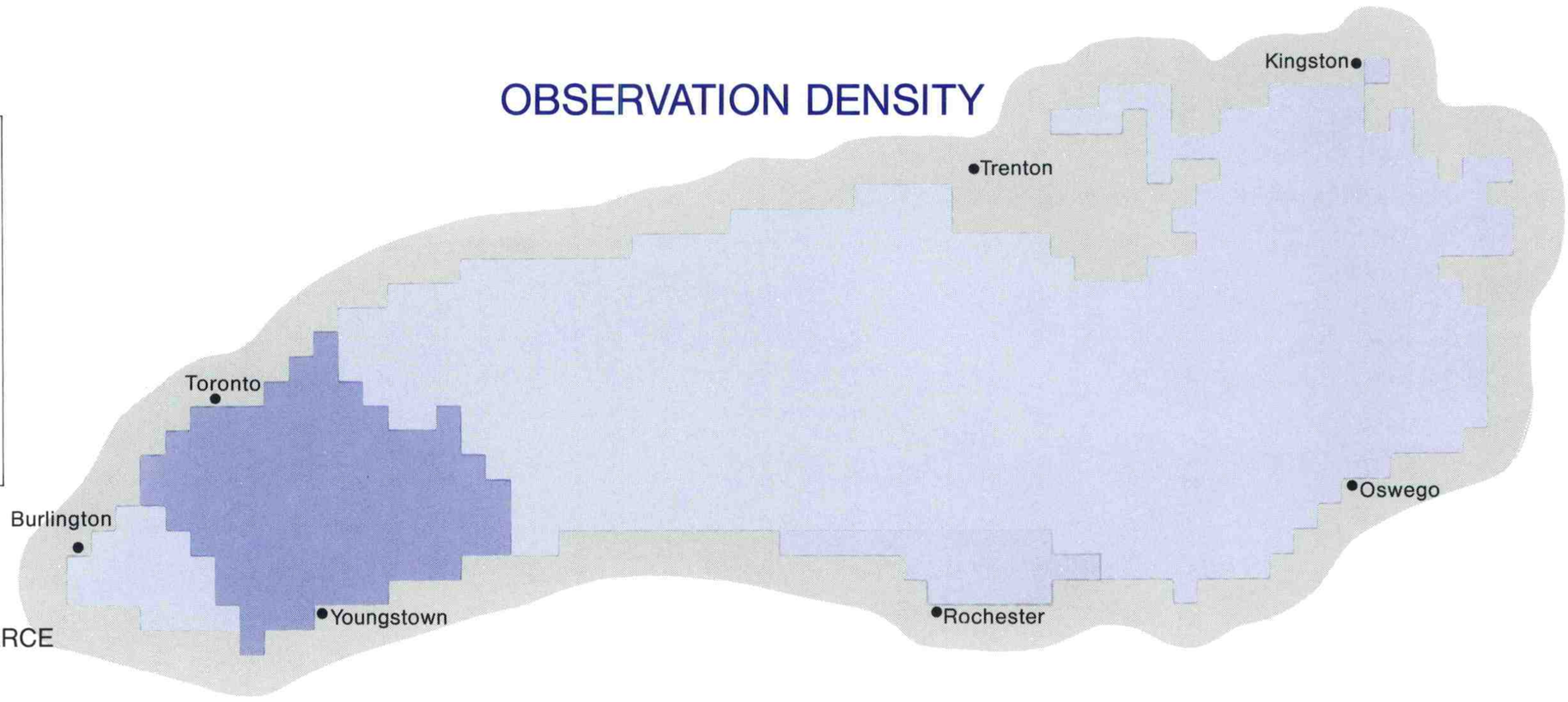


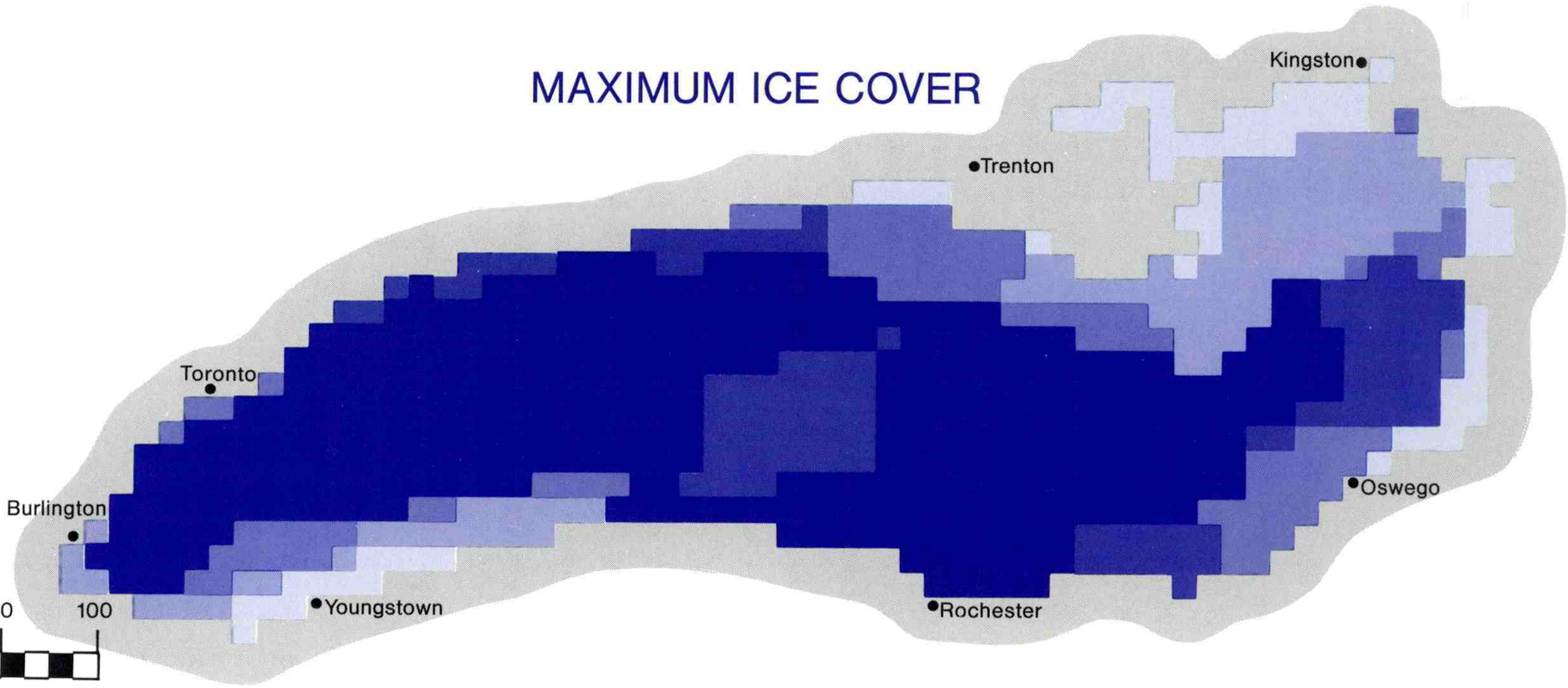
PLATE 38B

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

EXTREMES IN ICE COVER

JANUARY 1–15
1960–1979

MAXIMUM ICE COVER



LAKE ONTARIO

Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

MINIMUM ICE COVER



ICE COVER LEGEND

- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

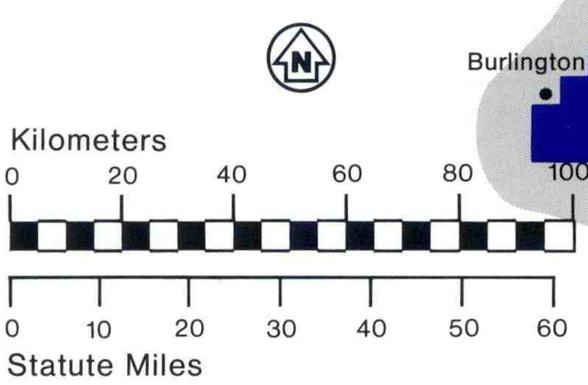
PLATE 39A

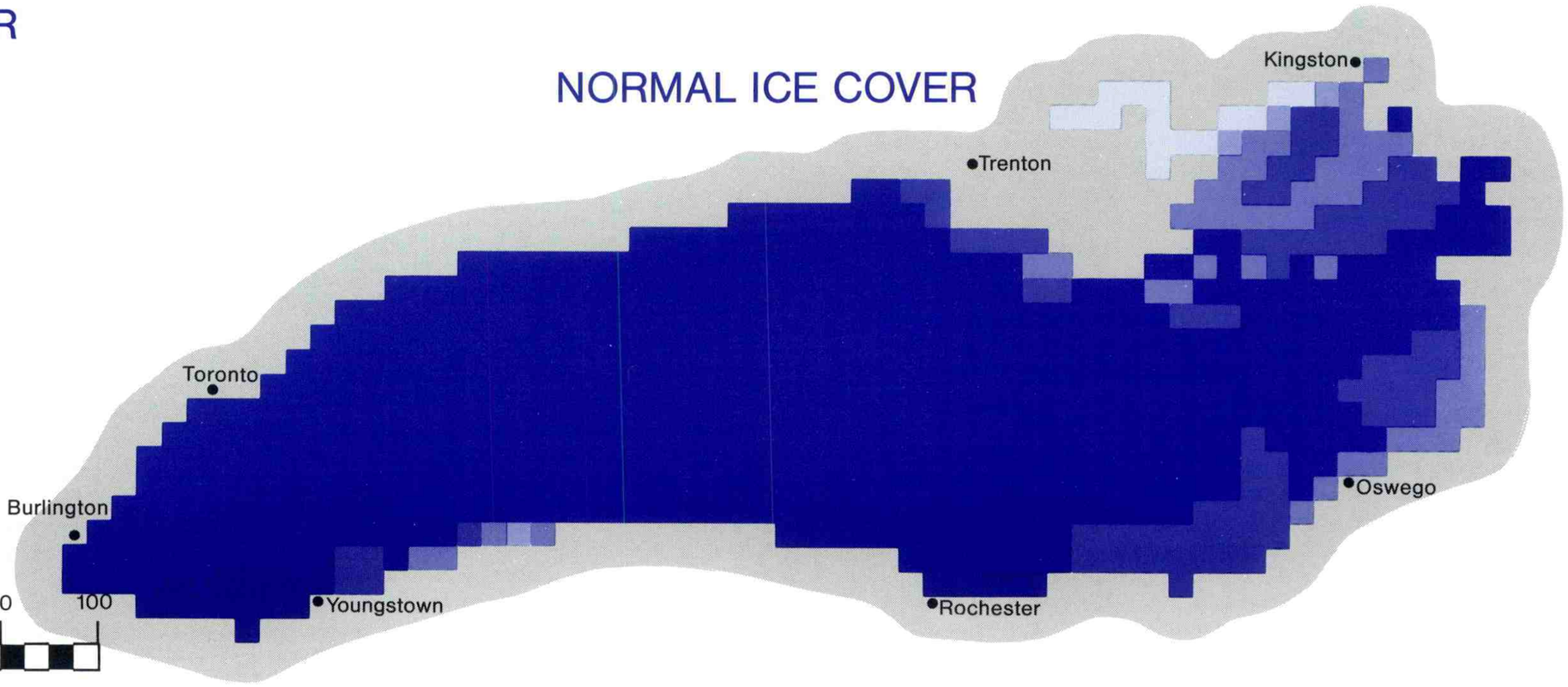
U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

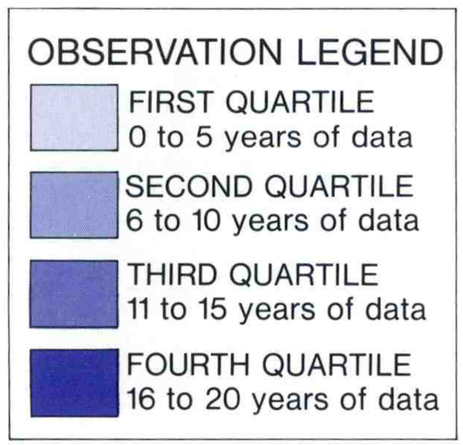
NORMAL ICE COVER AND OBSERVATION DENSITY

JANUARY 1–15
1960–1979

LAKE ONTARIO







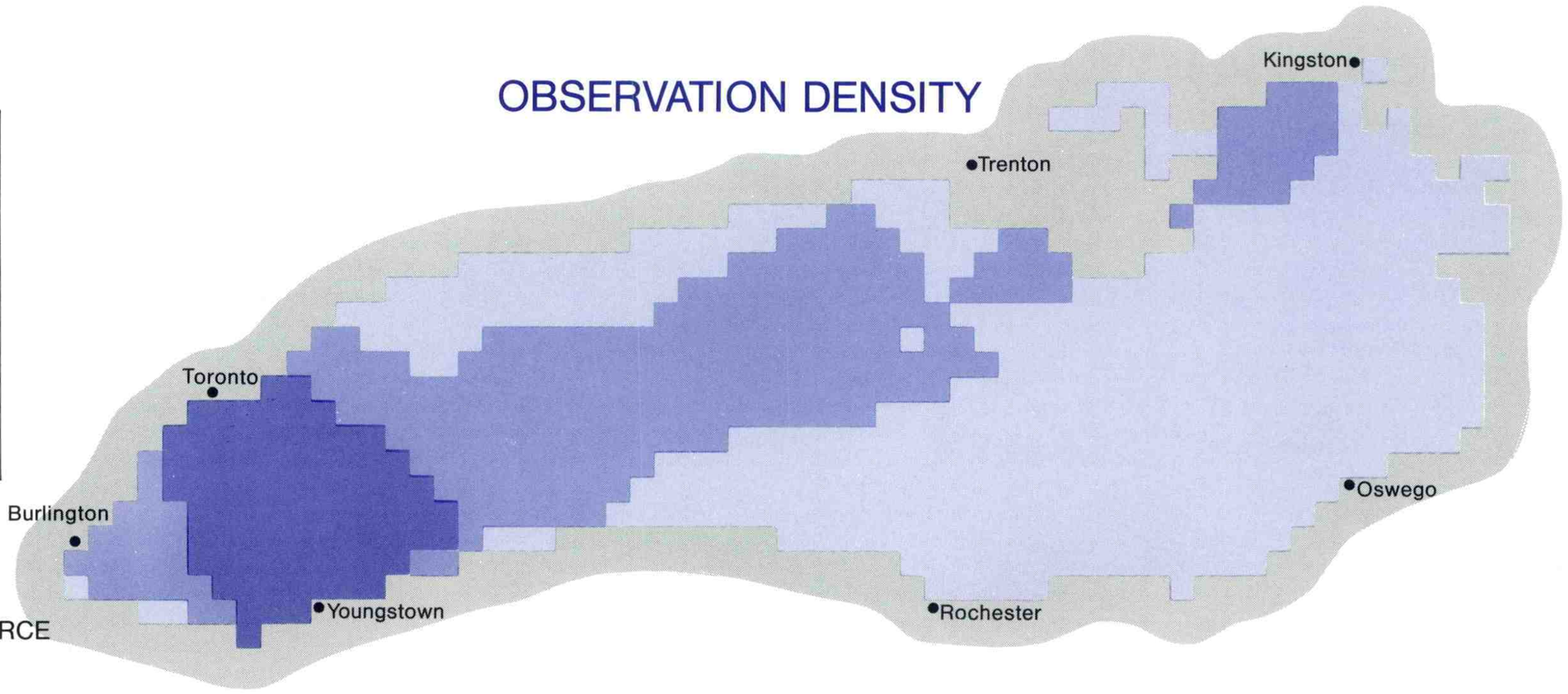


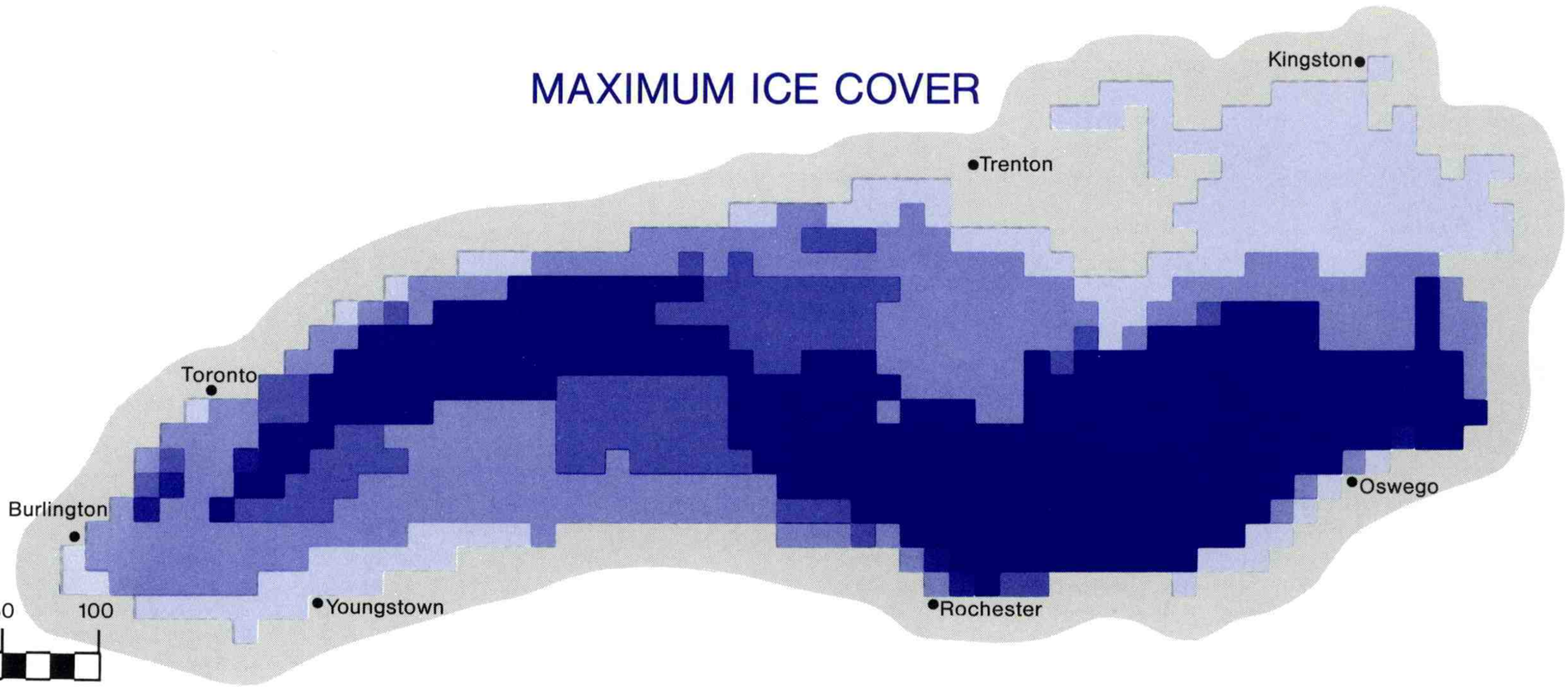
PLATE 39B

U.S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

EXTREMES IN ICE COVER

JANUARY 16–31
1960–1979

MAXIMUM ICE COVER

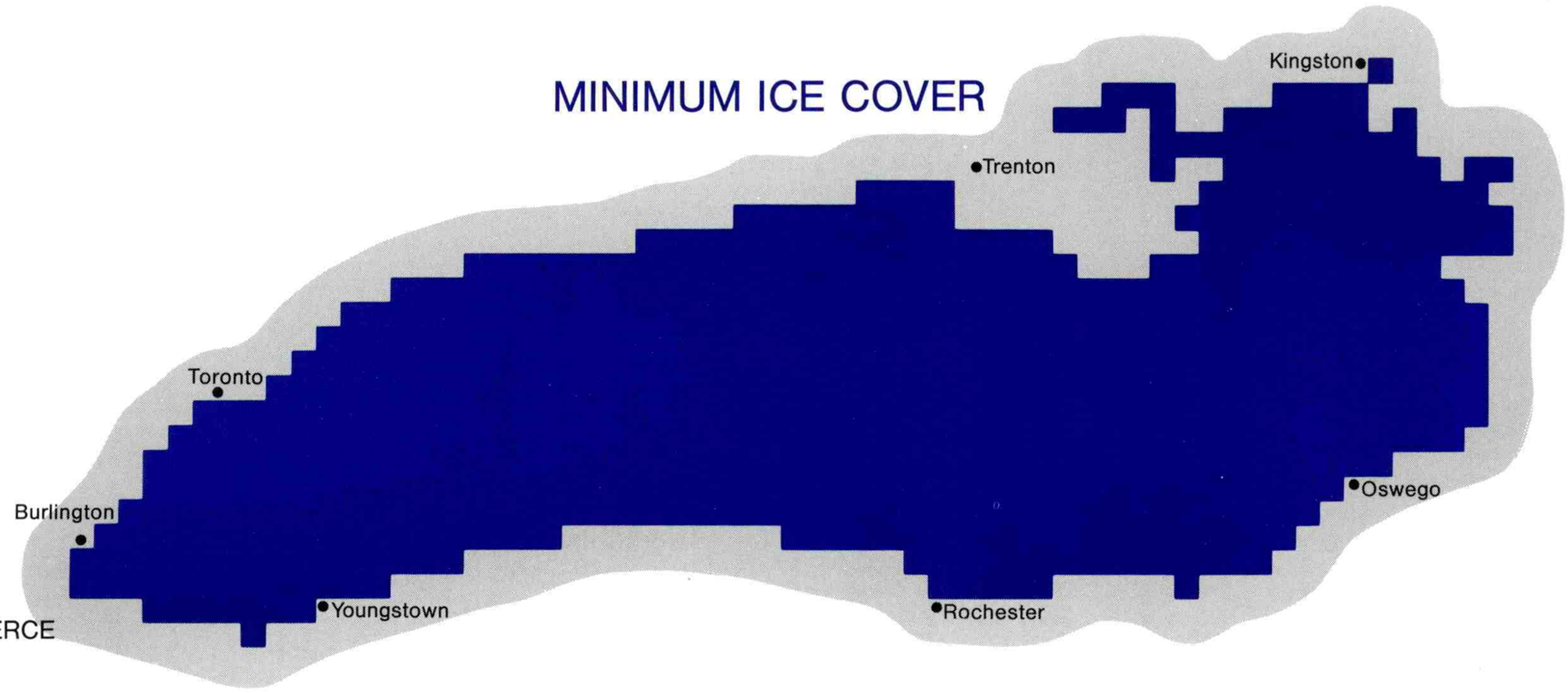


LAKE ONTARIO

Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

MINIMUM ICE COVER



ICE COVER LEGEND

- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

PLATE 40A

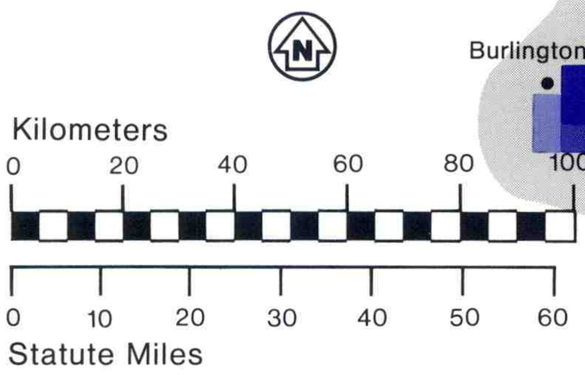
U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

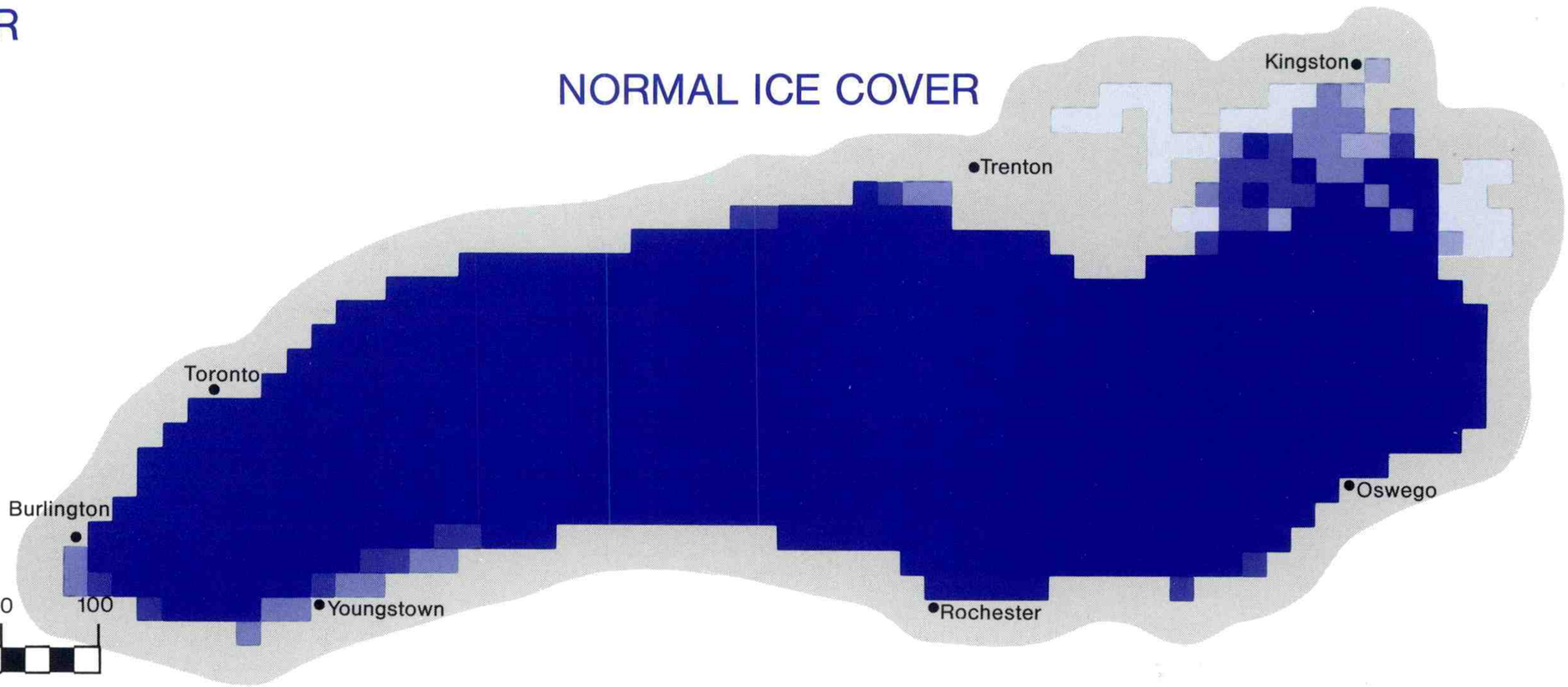
NORMAL ICE COVER AND OBSERVATION DENSITY

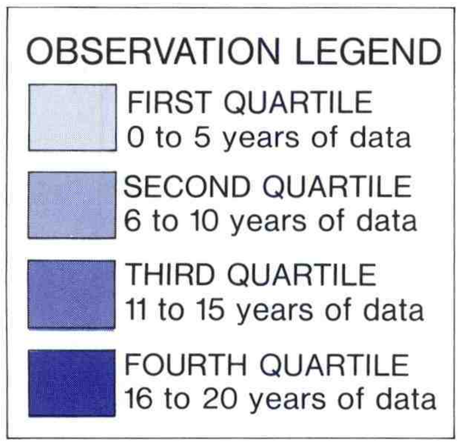
JANUARY 16–31

1960–1979

LAKE ONTARIO







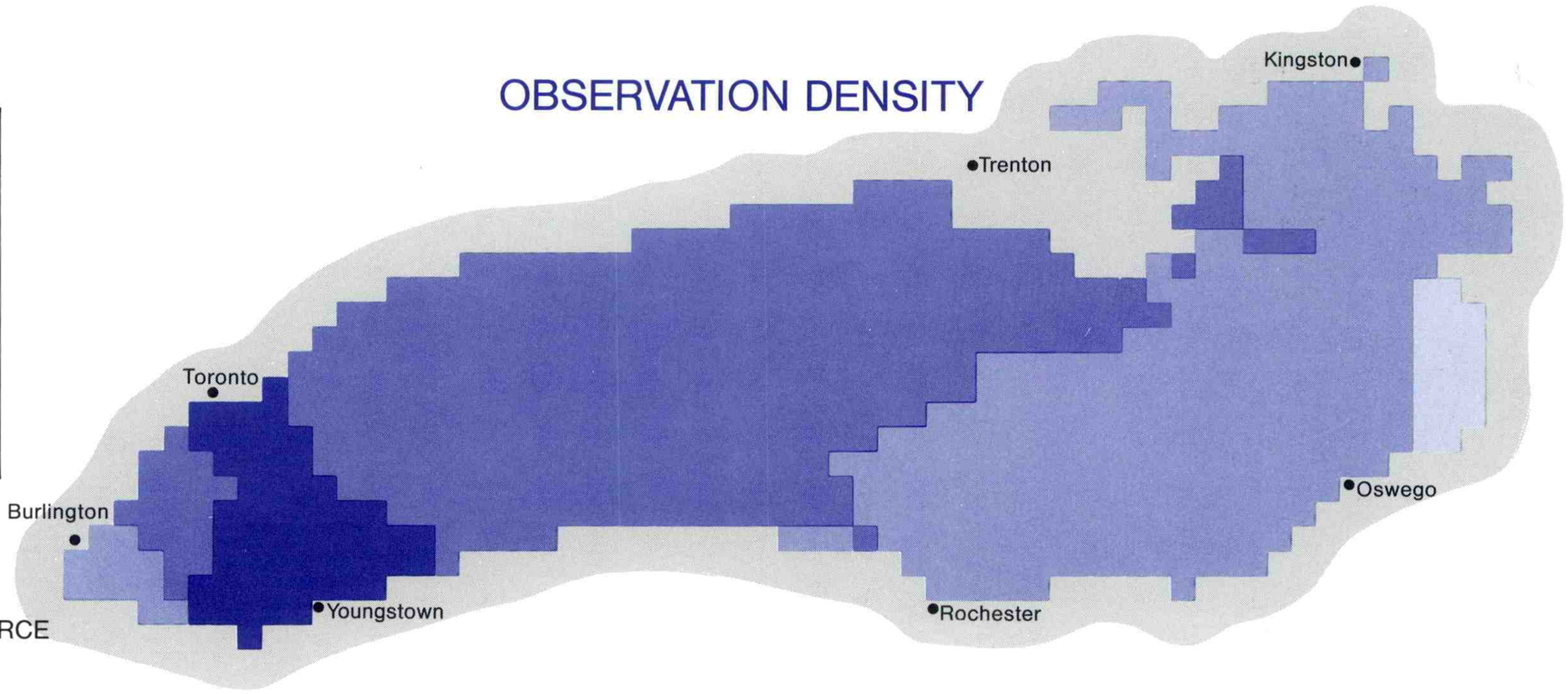


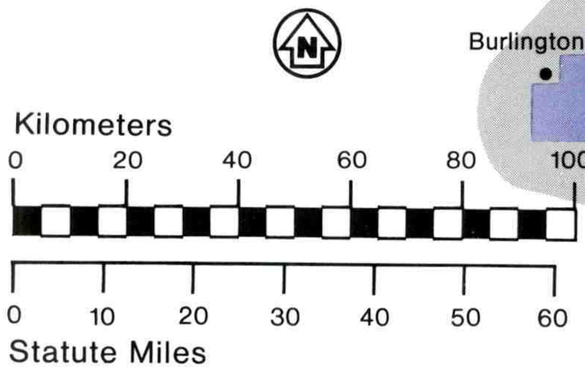
PLATE 40B

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

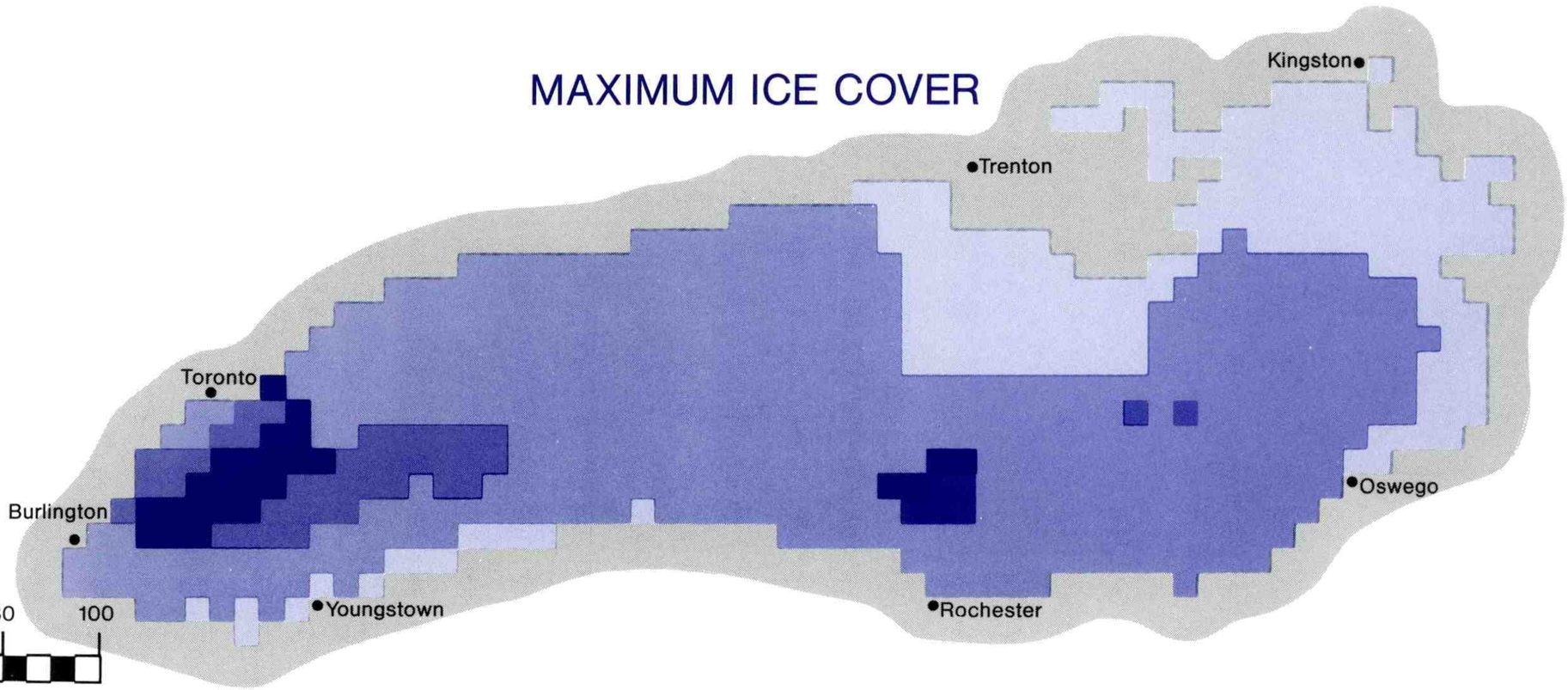
EXTREMES IN ICE COVER

FEBRUARY 1–14
1960–1979

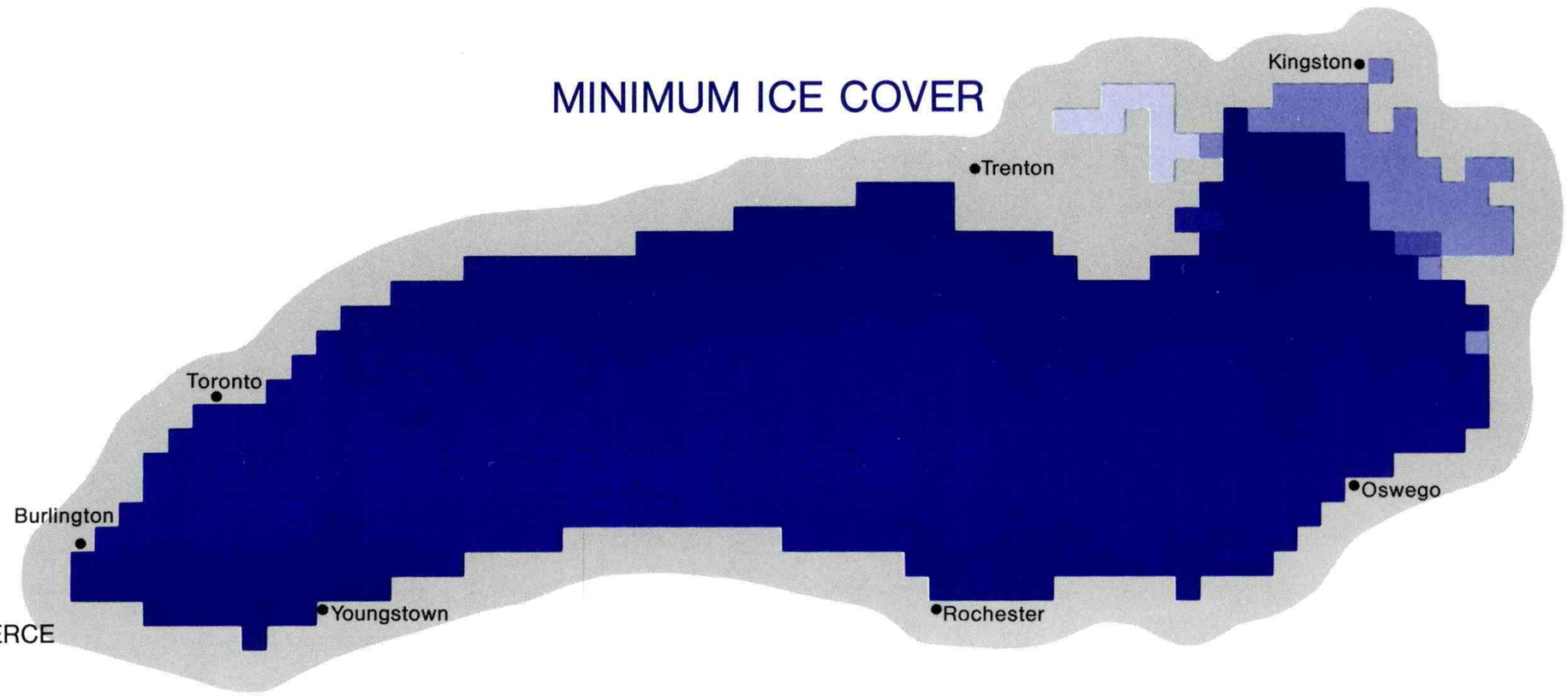
LAKE ONTARIO



MAXIMUM ICE COVER



MINIMUM ICE COVER



ICE COVER LEGEND

- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

PLATE 41A

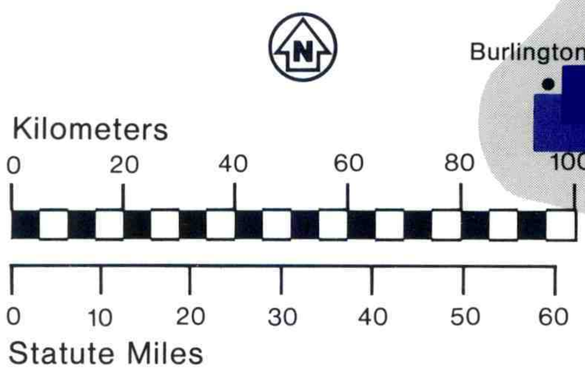
U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

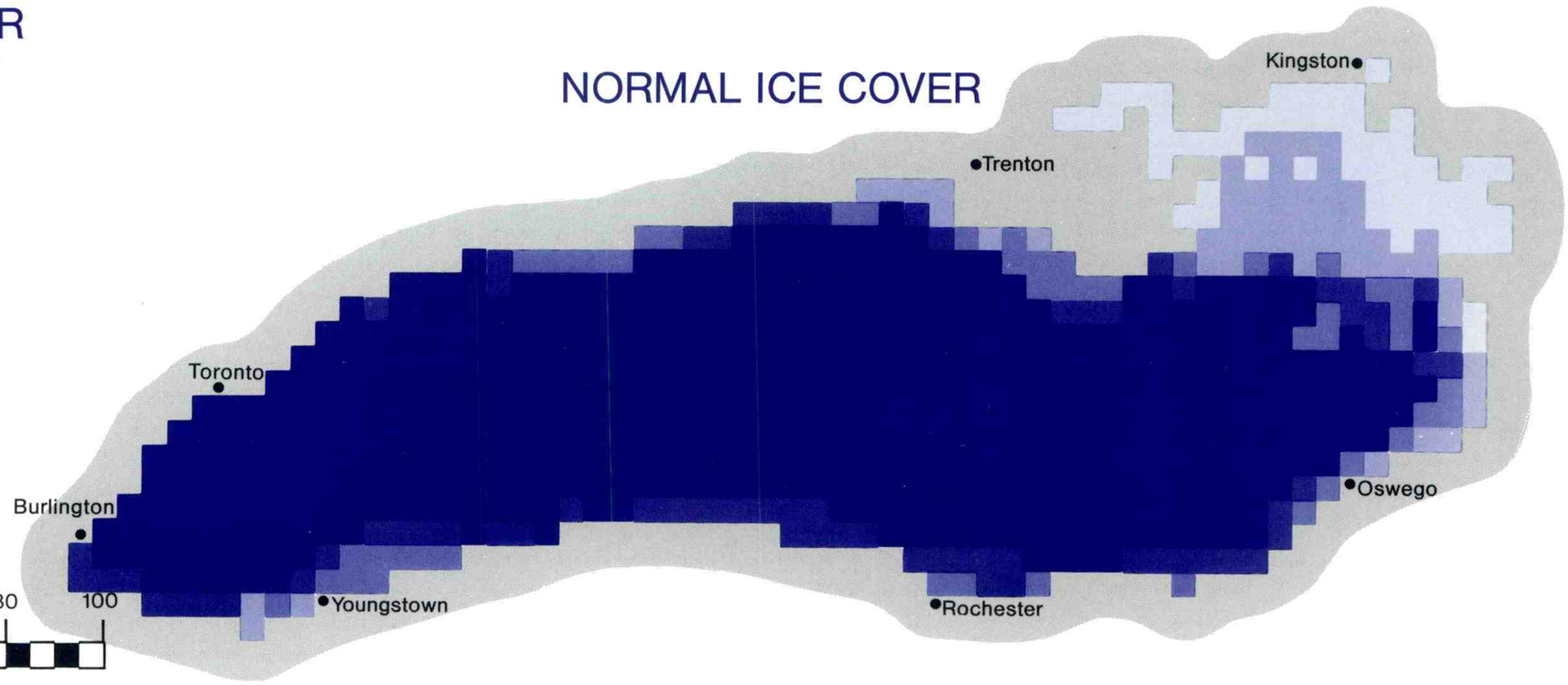
NORMAL ICE COVER AND OBSERVATION DENSITY

FEBRUARY 1–14

1960–1979

LAKE ONTARIO







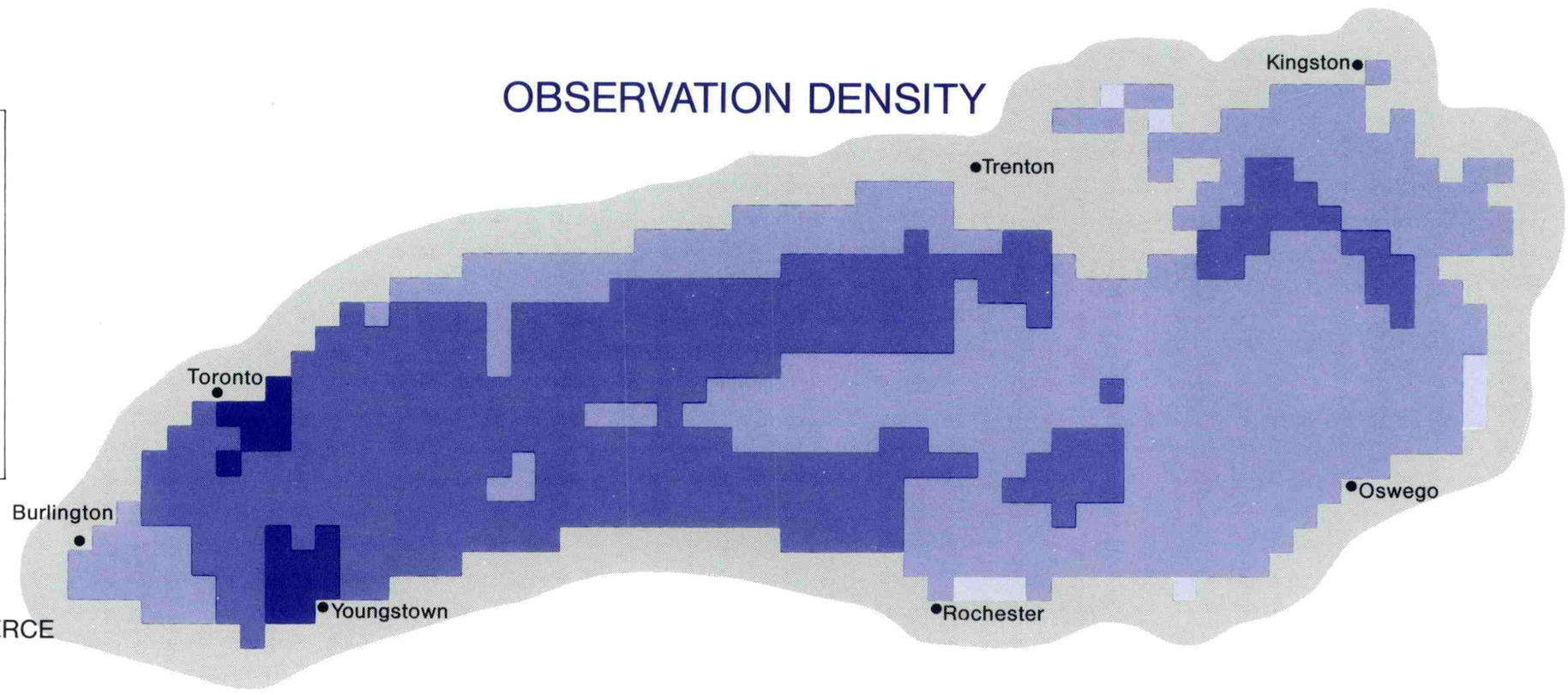


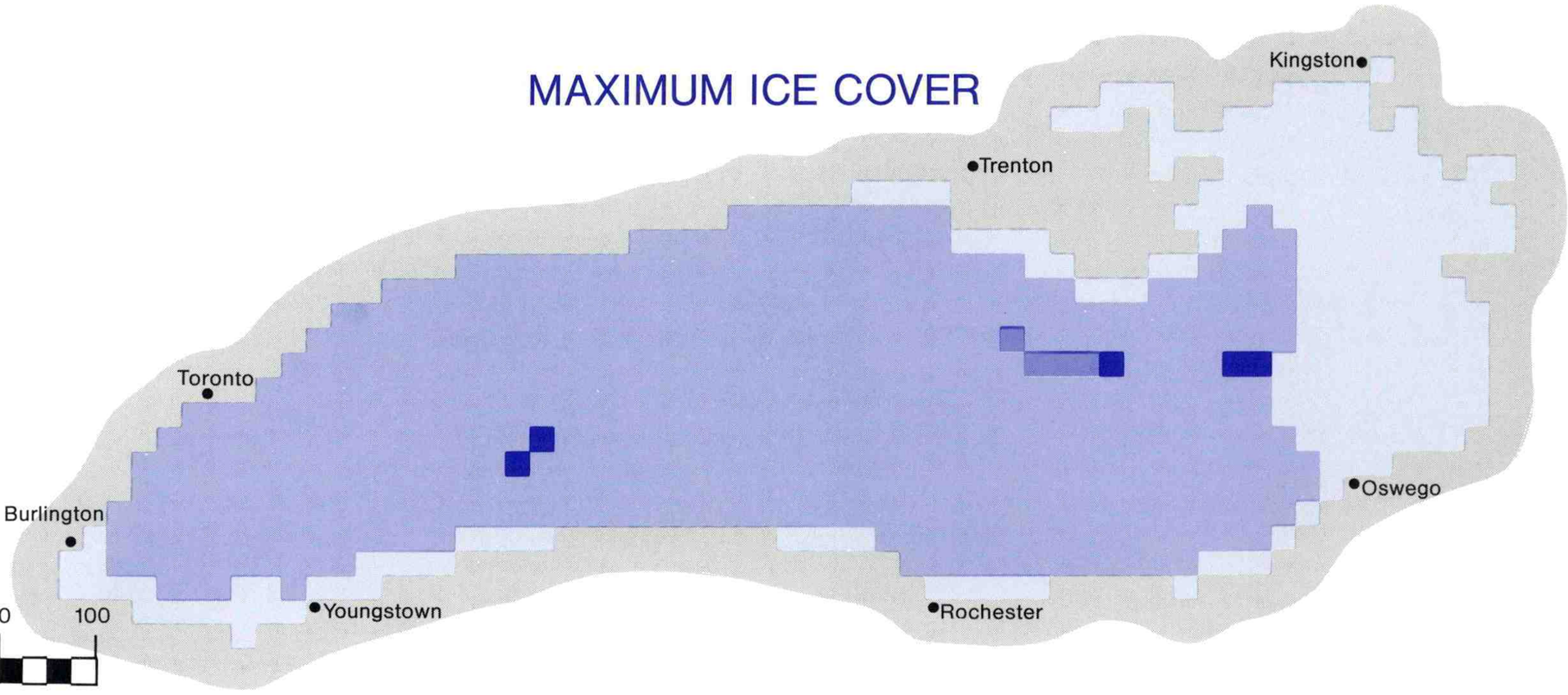
PLATE 41B

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

EXTREMES IN ICE COVER

FEBRUARY 15–28
1960–1979

MAXIMUM ICE COVER

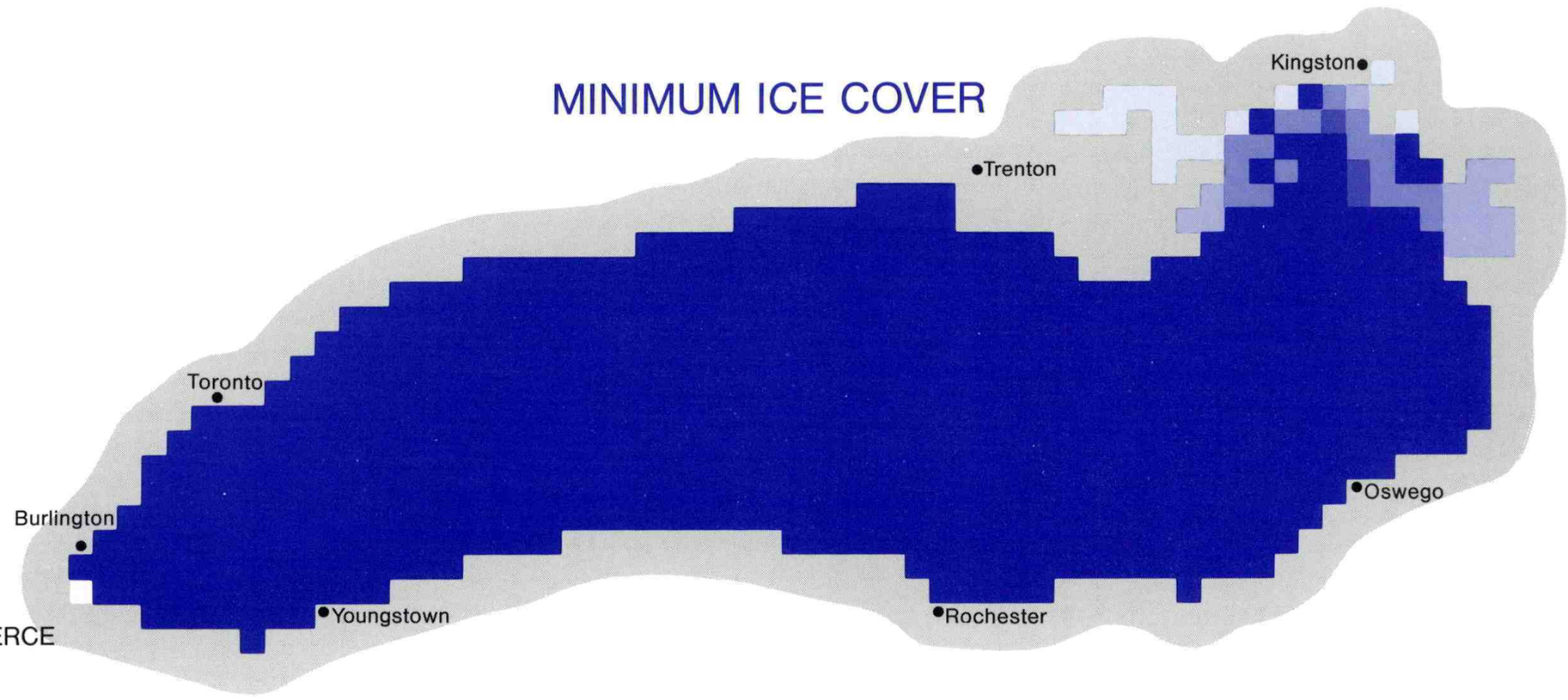


LAKE ONTARIO

Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

MINIMUM ICE COVER



ICE COVER LEGEND

- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

PLATE 42A

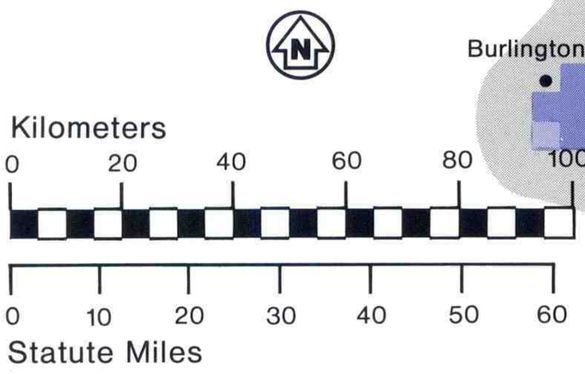
U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

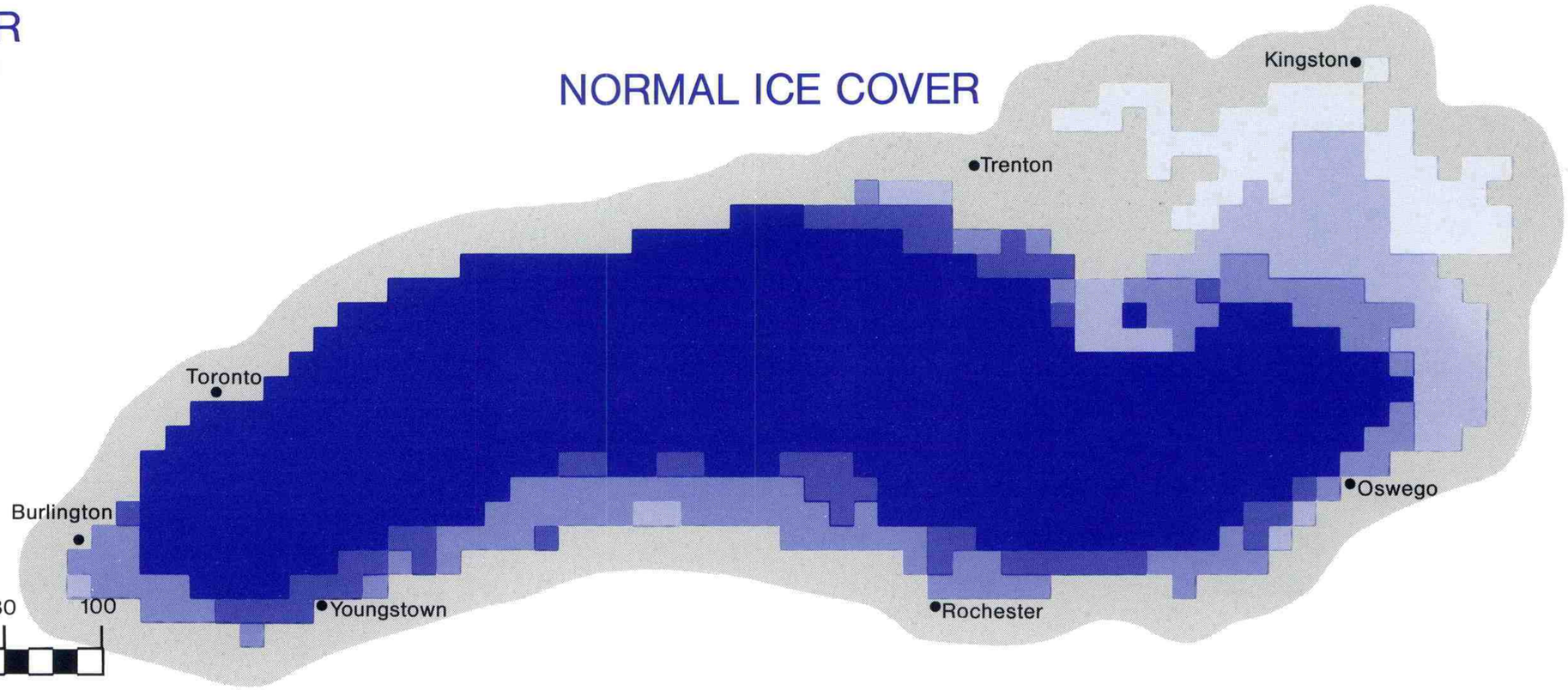
NORMAL ICE COVER AND OBSERVATION DENSITY

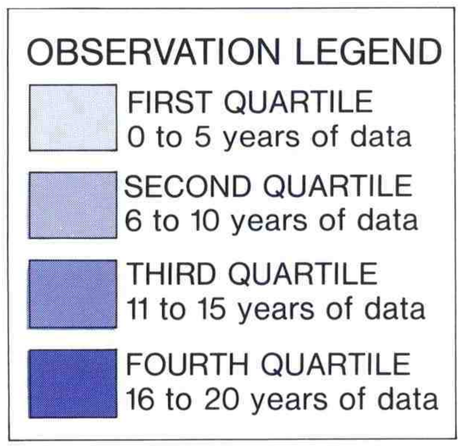
FEBRUARY 15–28

1960–1979

LAKE ONTARIO







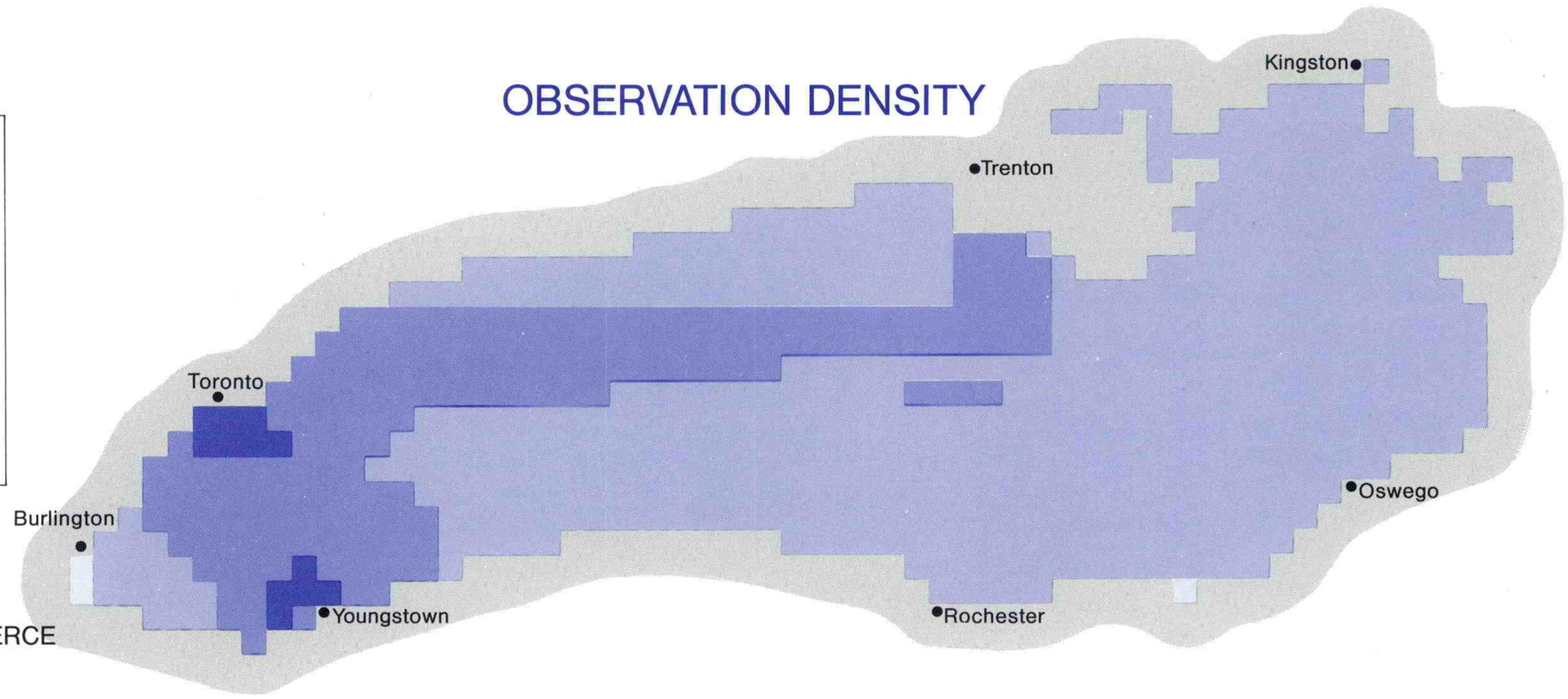


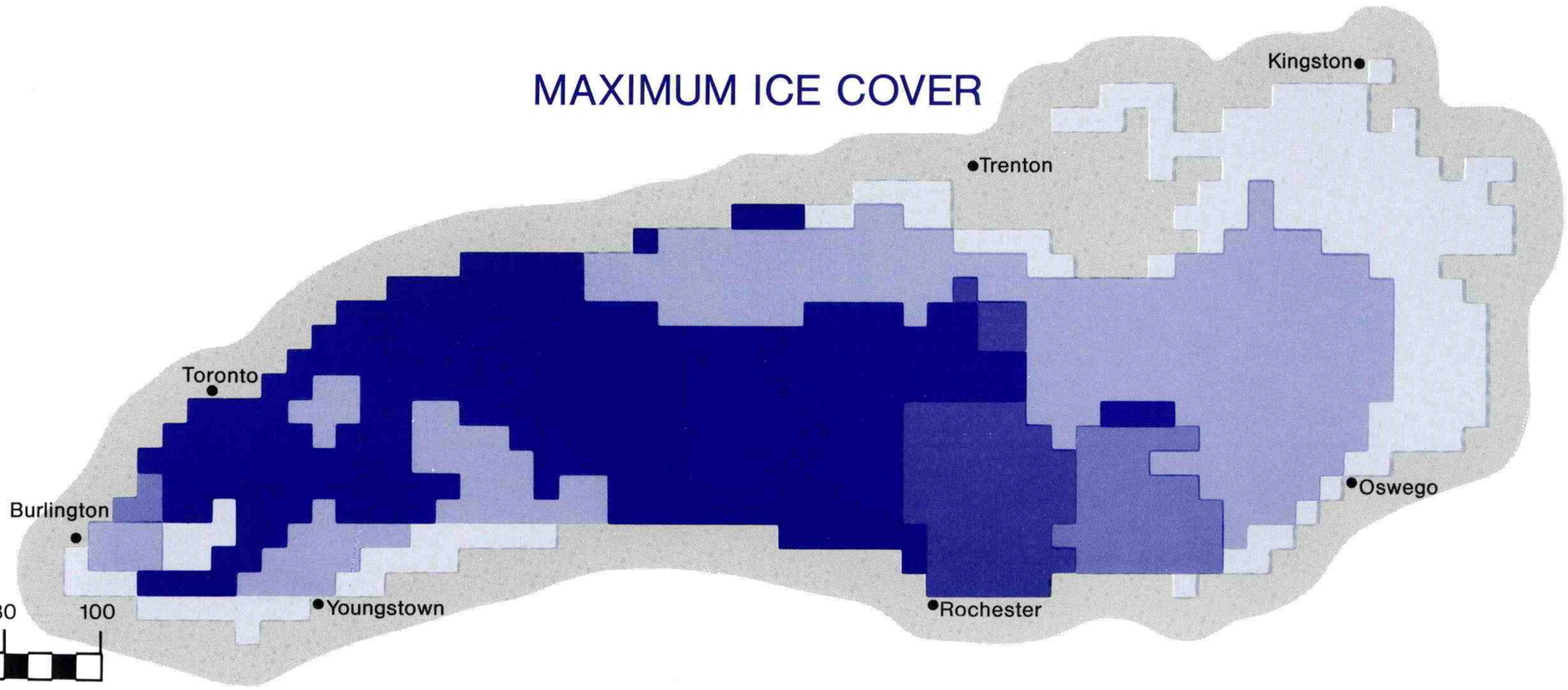
PLATE 42B

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

EXTREMES IN ICE COVER

MARCH 1–15
1960–1979

MAXIMUM ICE COVER

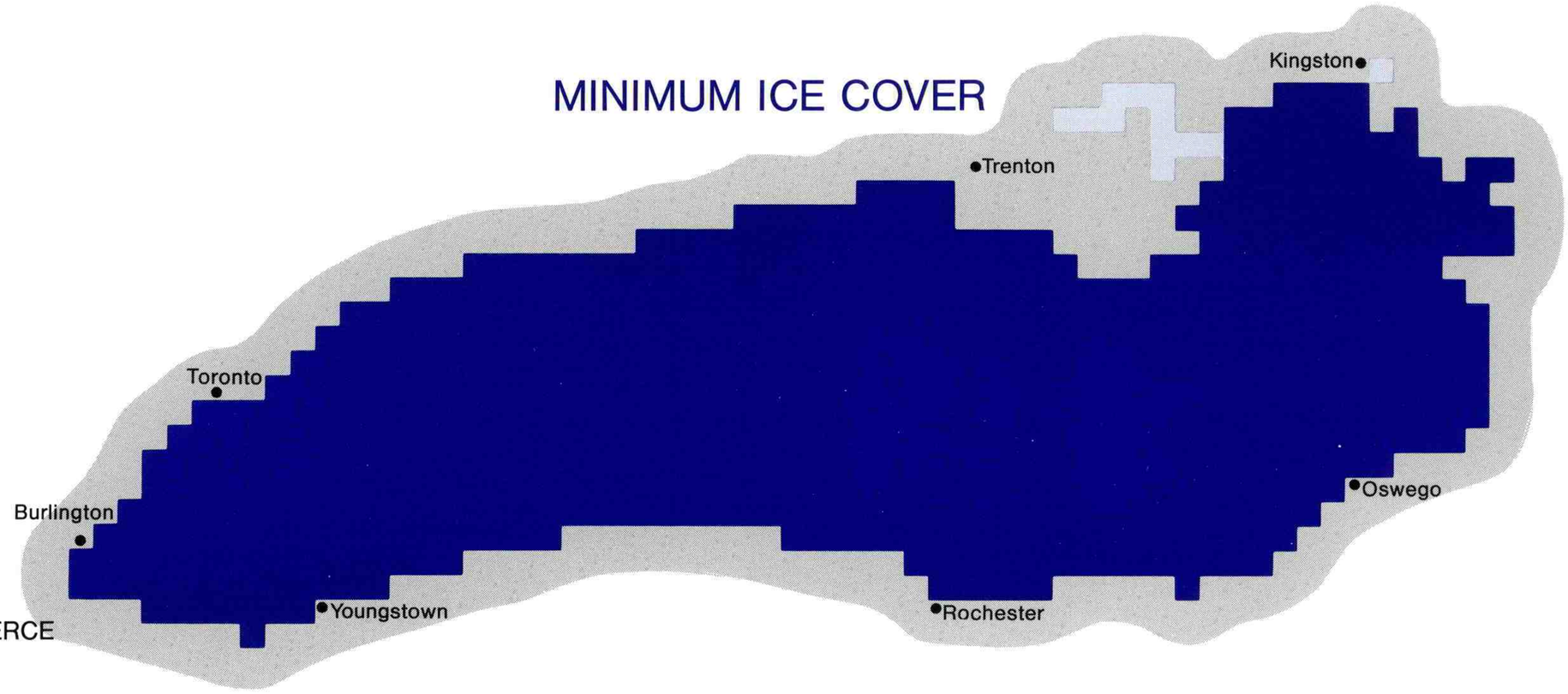


LAKE ONTARIO

Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

MINIMUM ICE COVER



ICE COVER LEGEND

- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

PLATE 43A

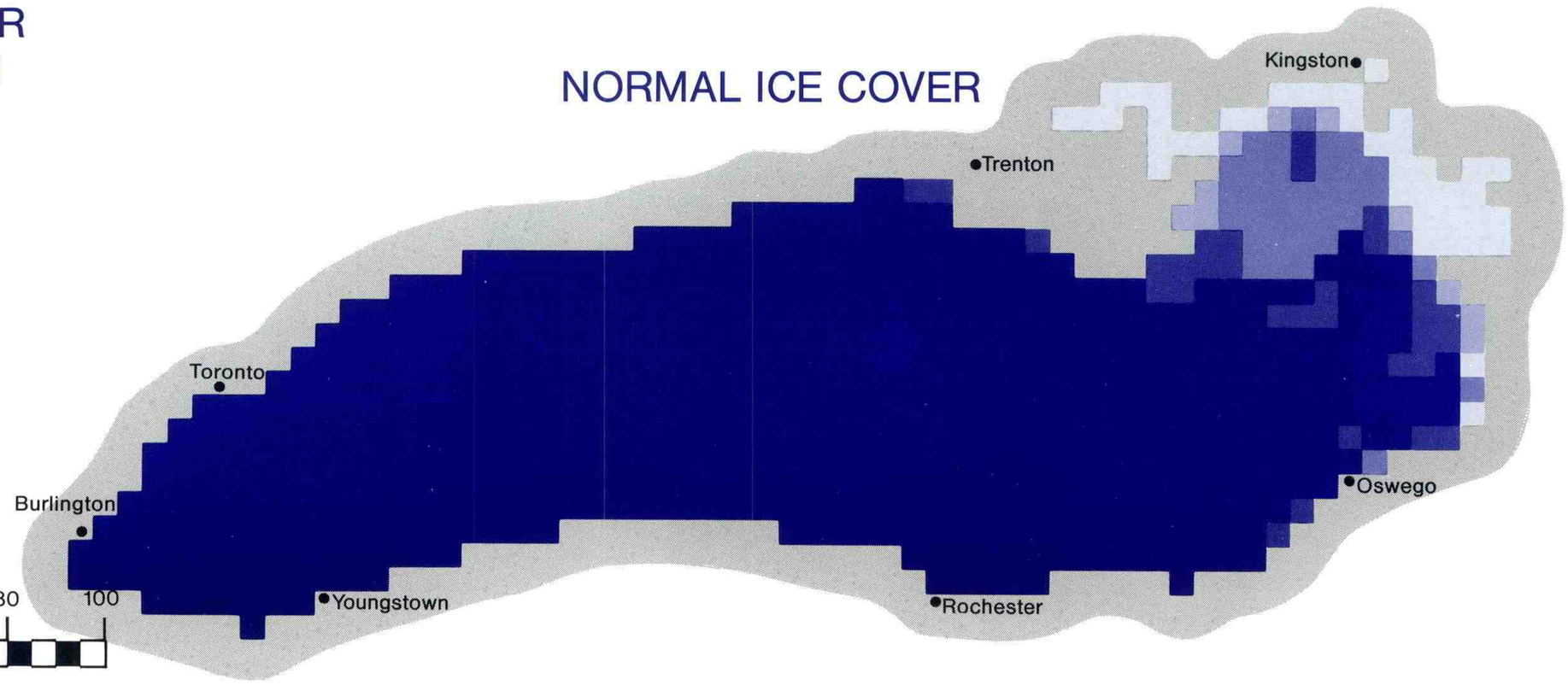
U.S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER AND OBSERVATION DENSITY

MARCH 1–15

1960–1979

NORMAL ICE COVER

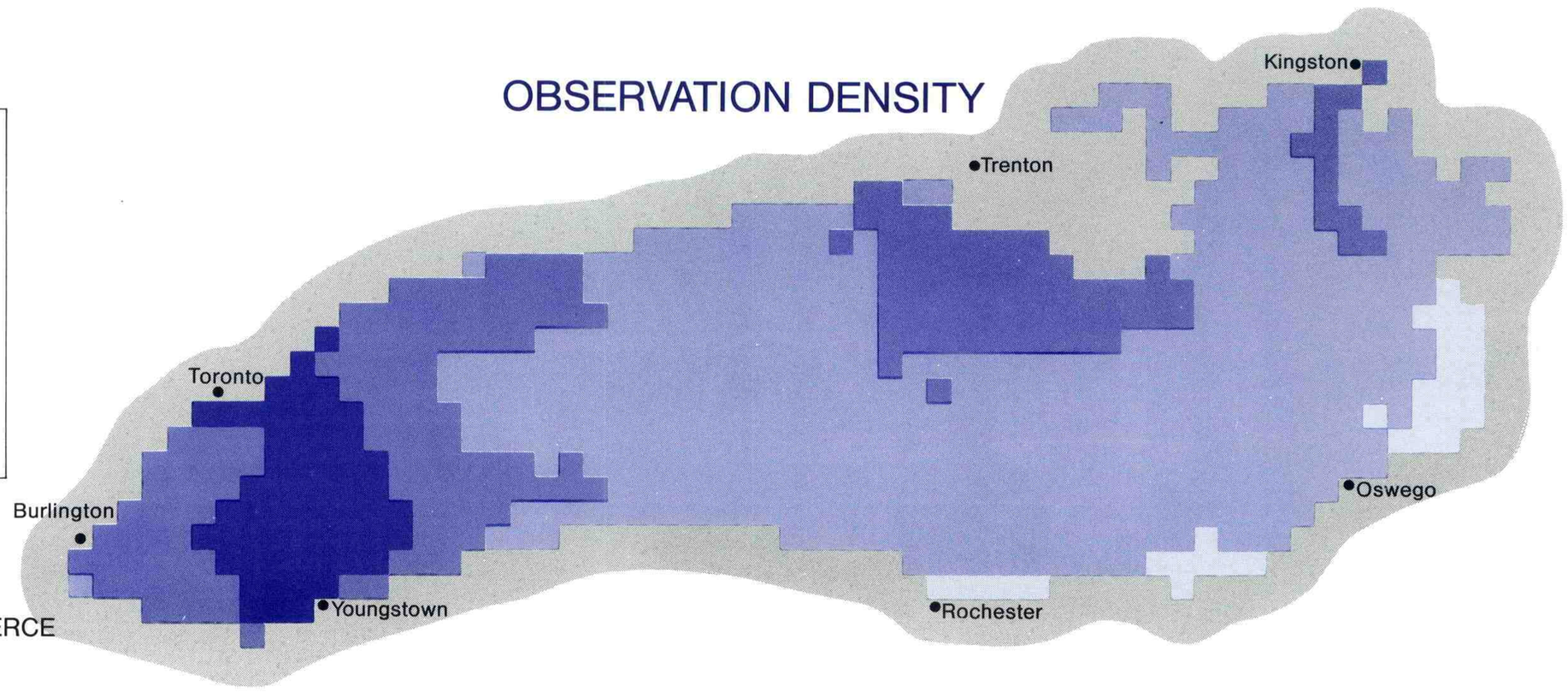


LAKE ONTARIO

Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

OBSERVATION DENSITY



OBSERVATION LEGEND

- FIRST QUARTILE — 0 to 5 years of data
- SECOND QUARTILE — 6 to 10 years of data
- THIRD QUARTILE — 11 to 15 years of data
- FOURTH QUARTILE — 16 to 20 years of data

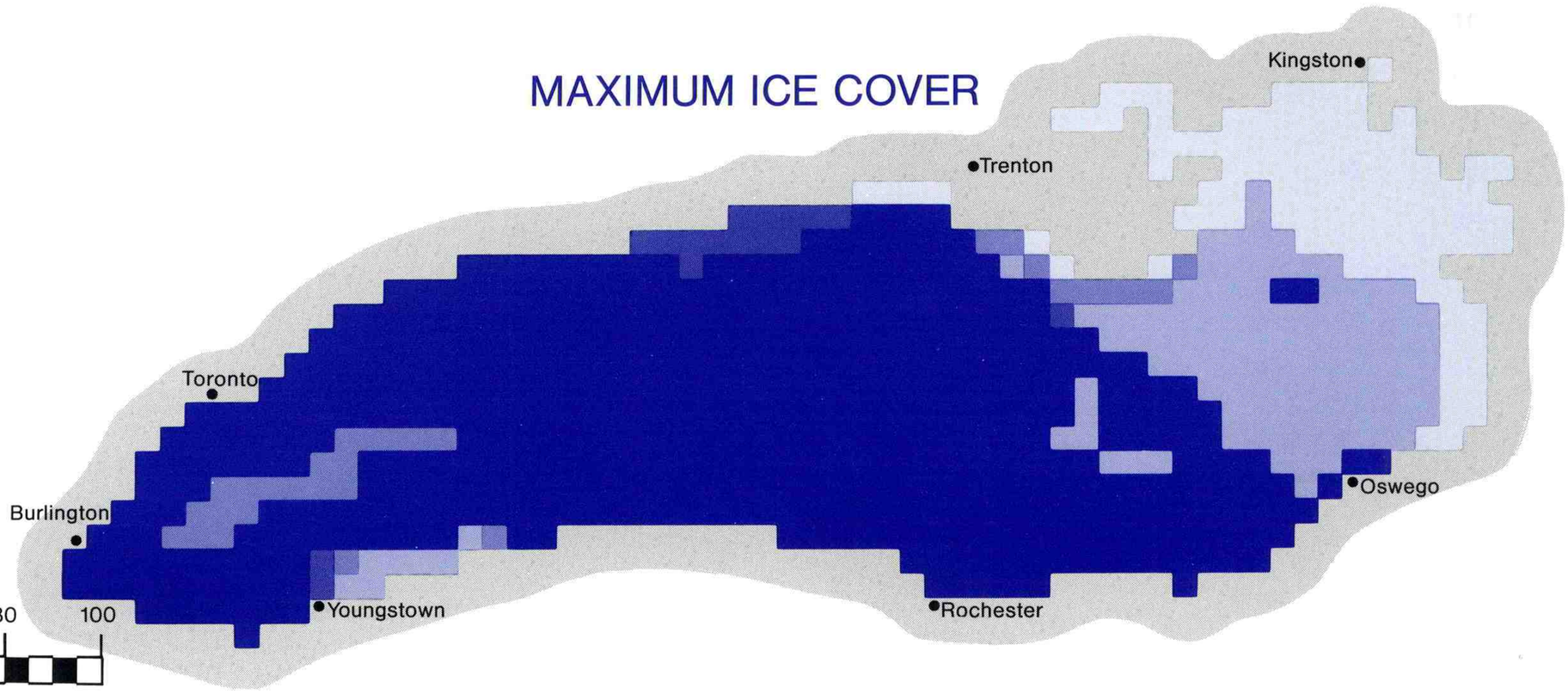
PLATE 43B

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

EXTREMES IN ICE COVER

MARCH 16–31
1960–1979

MAXIMUM ICE COVER

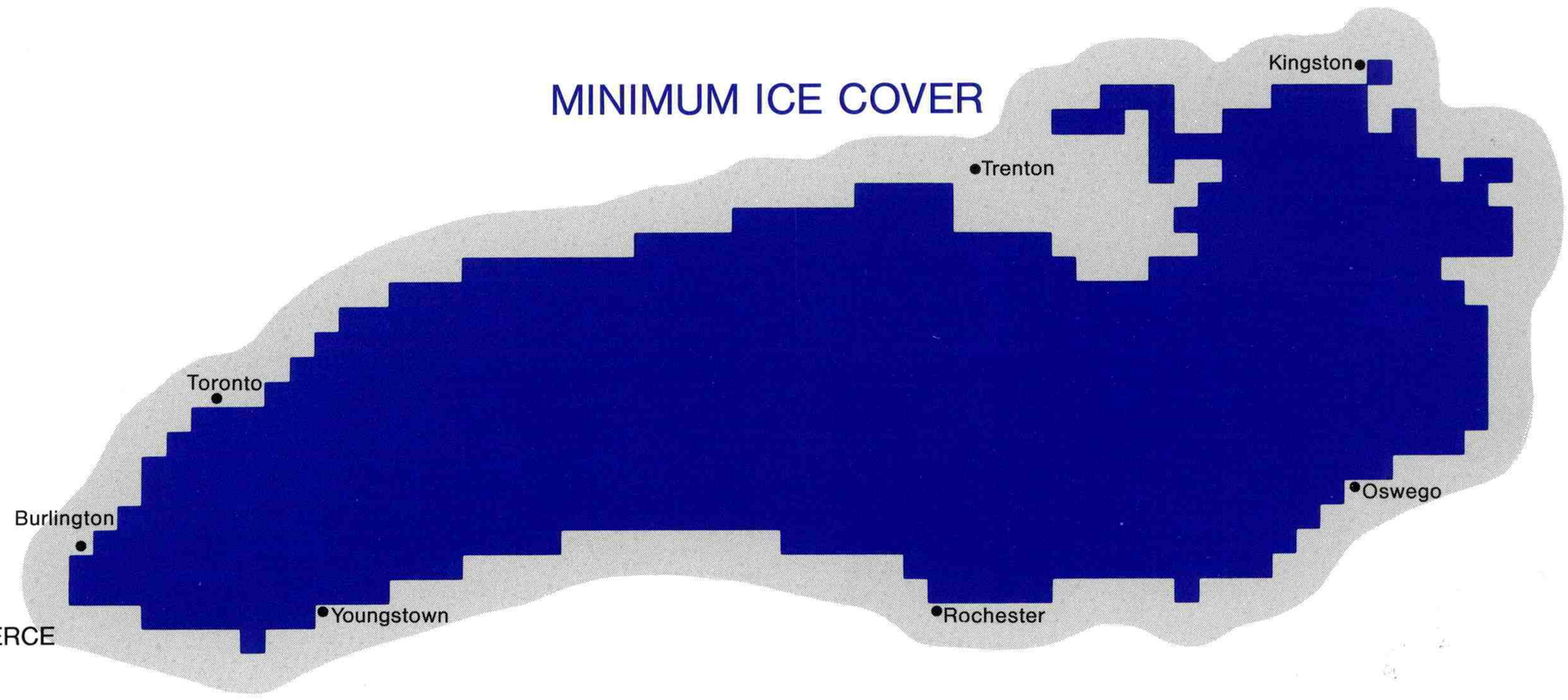


LAKE ONTARIO

Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

MINIMUM ICE COVER



ICE COVER LEGEND

- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

PLATE 44A

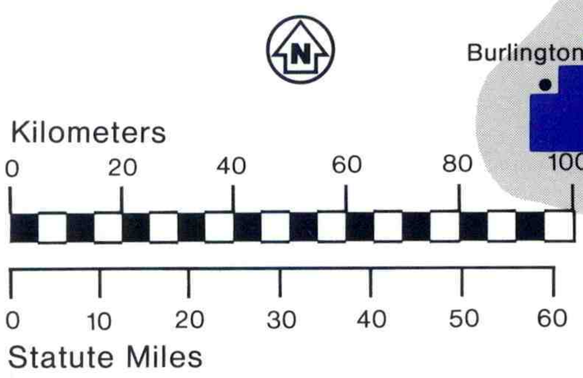
U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

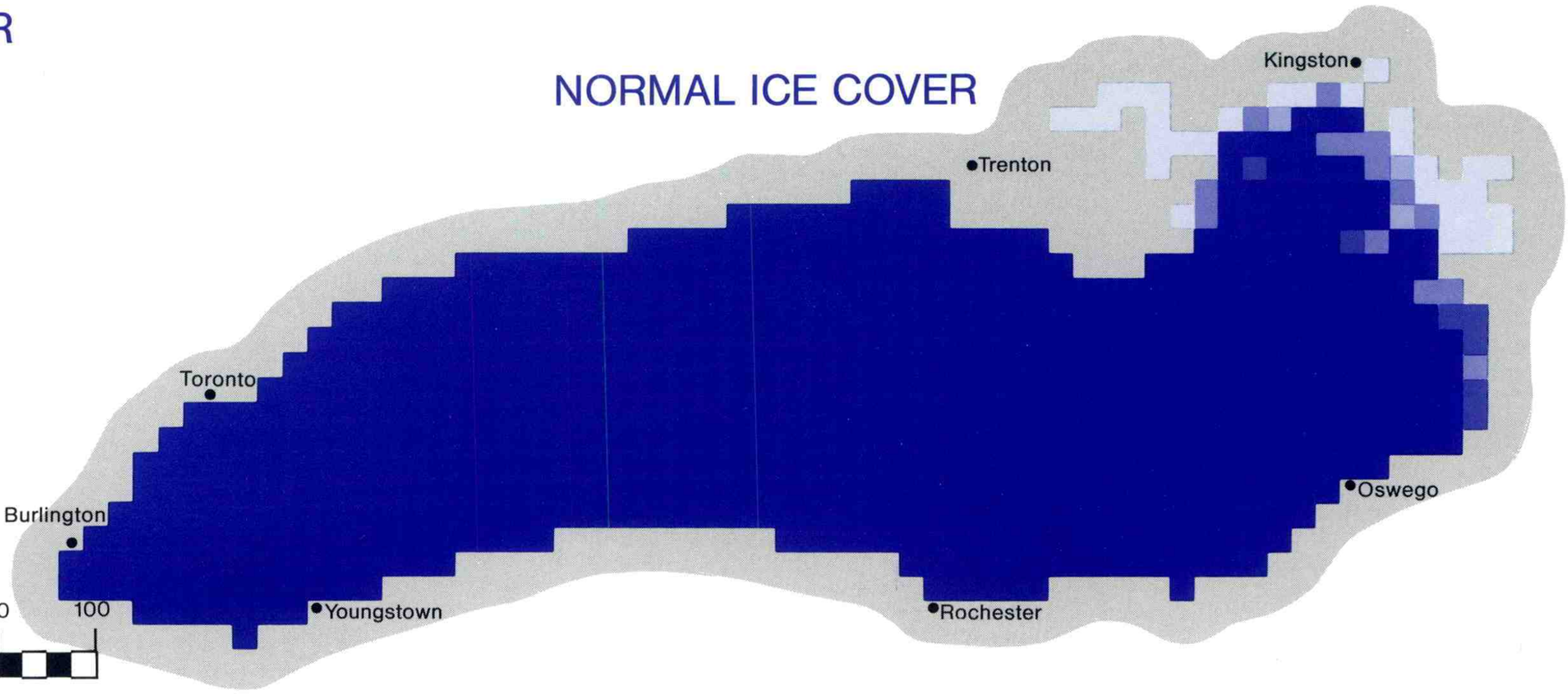
NORMAL ICE COVER AND OBSERVATION DENSITY

MARCH 16–31

1960–1979

LAKE ONTARIO







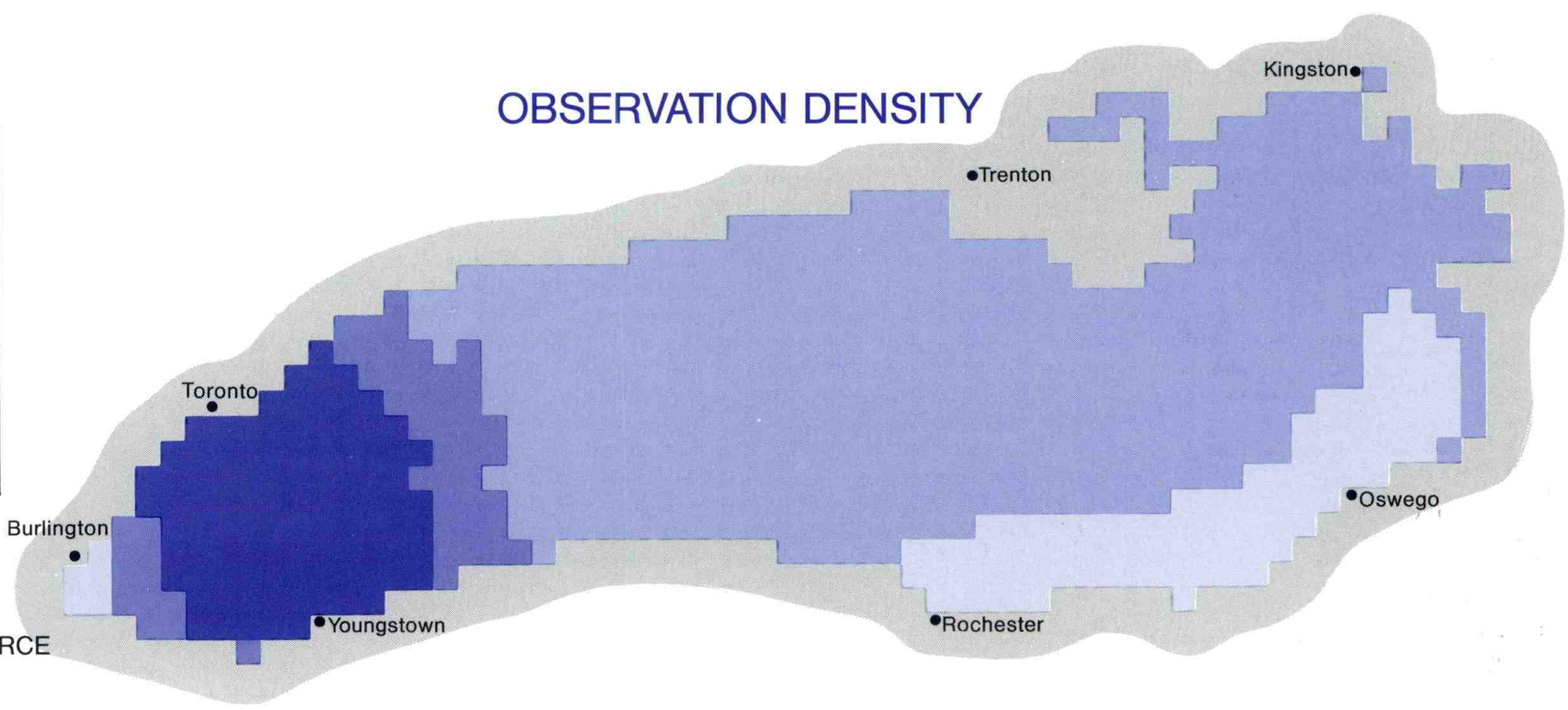


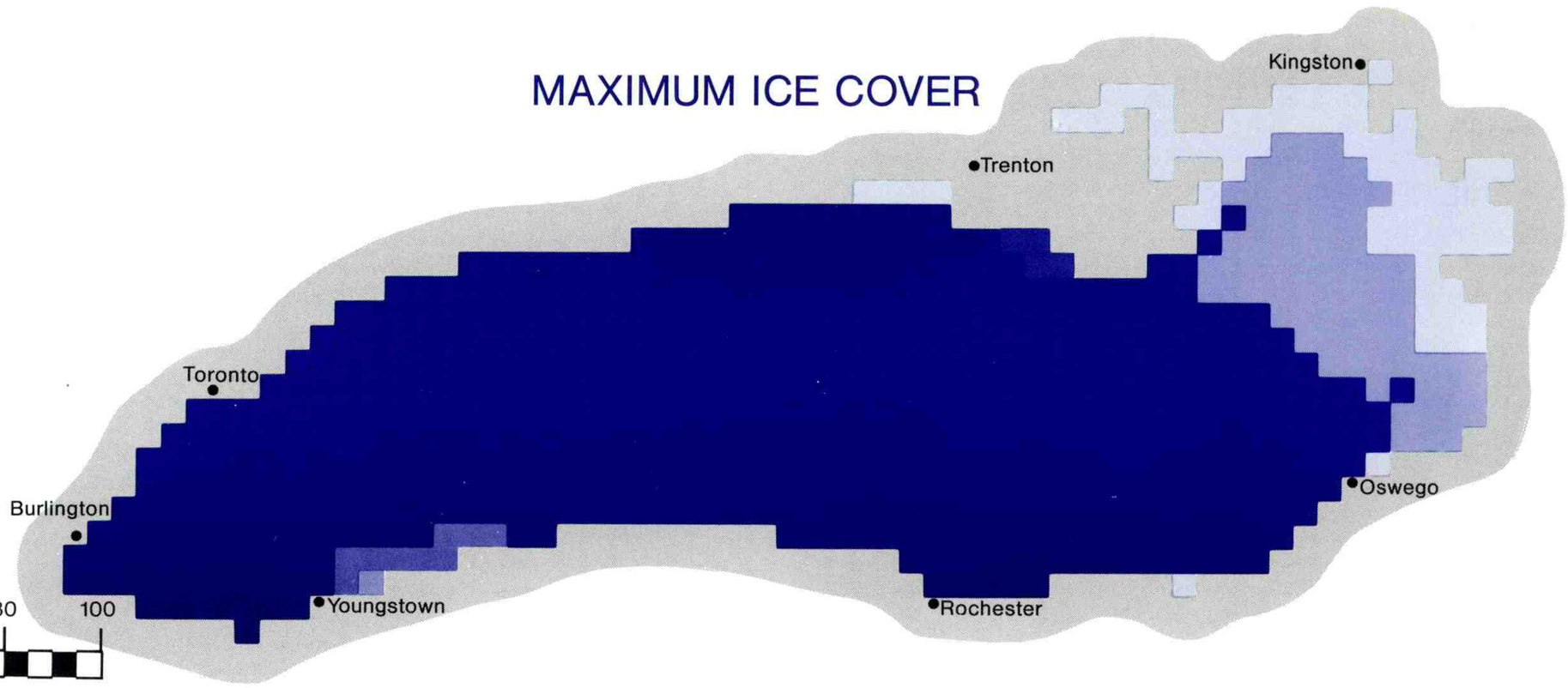
PLATE 44B

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

EXTREMES IN ICE COVER

APRIL 1–15
1960–1979

MAXIMUM ICE COVER

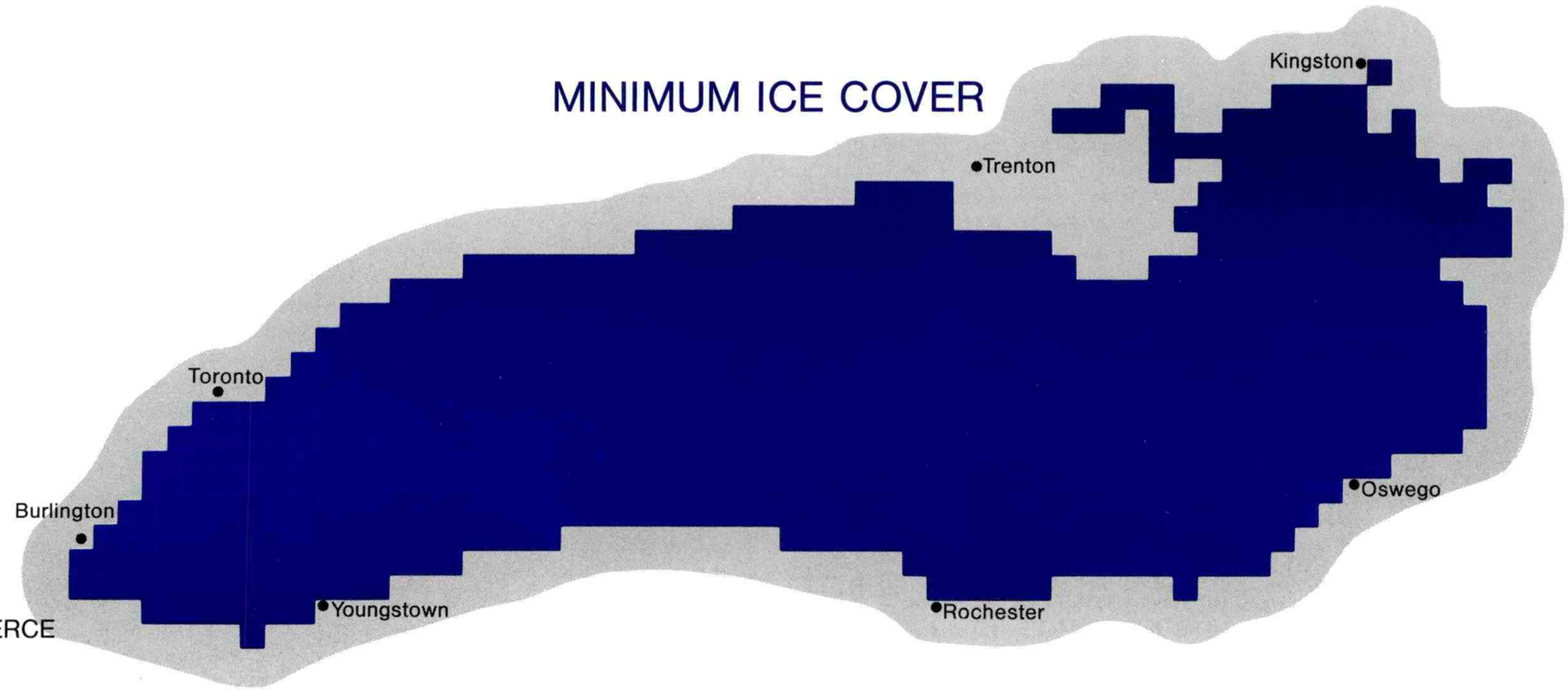


LAKE ONTARIO

Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

MINIMUM ICE COVER



ICE COVER LEGEND

- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

PLATE 45A

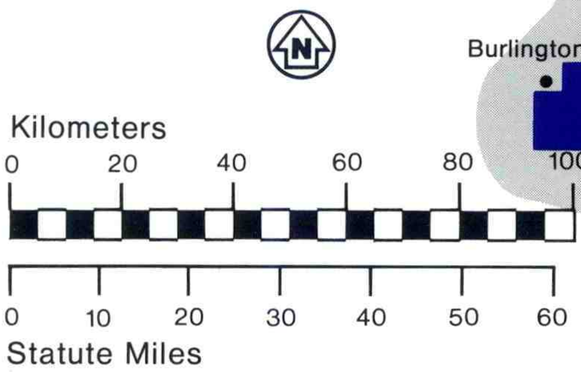
U.S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

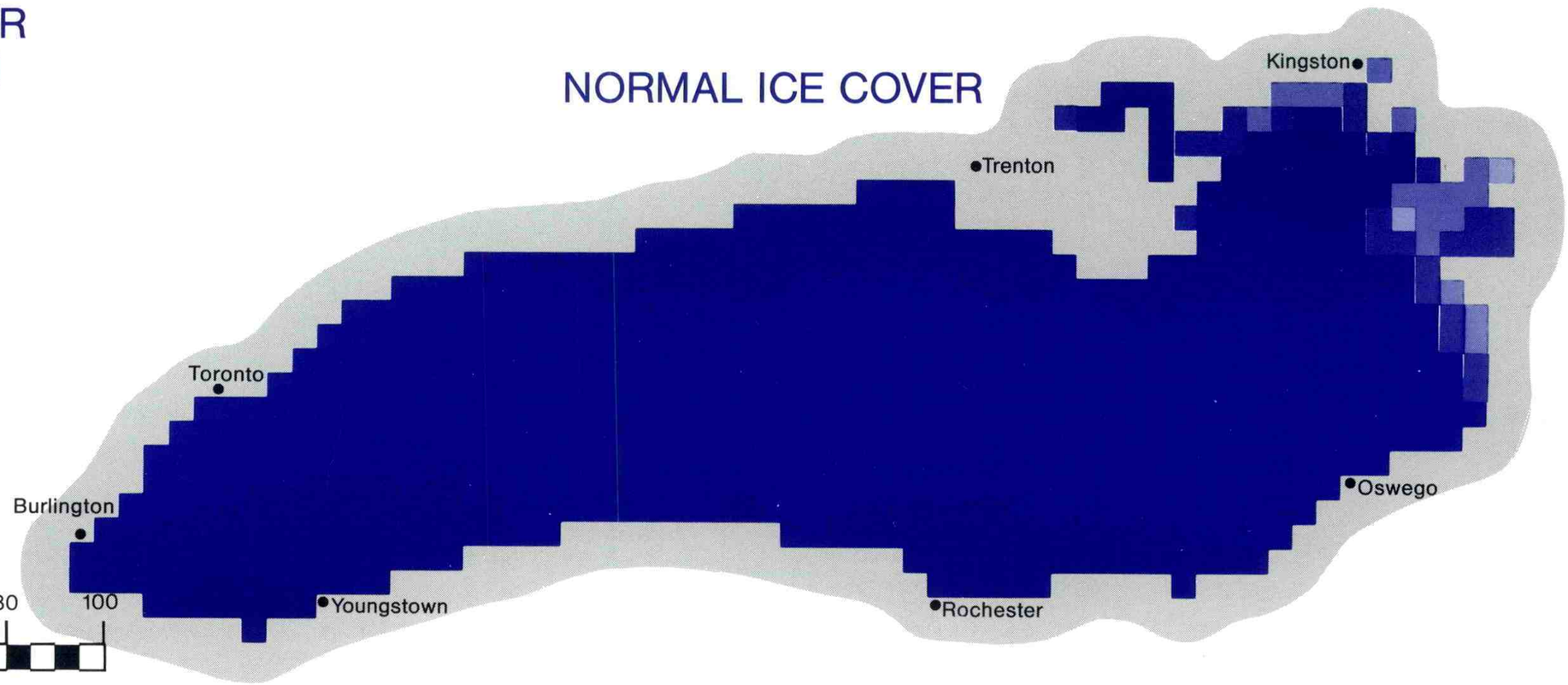
NORMAL ICE COVER AND OBSERVATION DENSITY

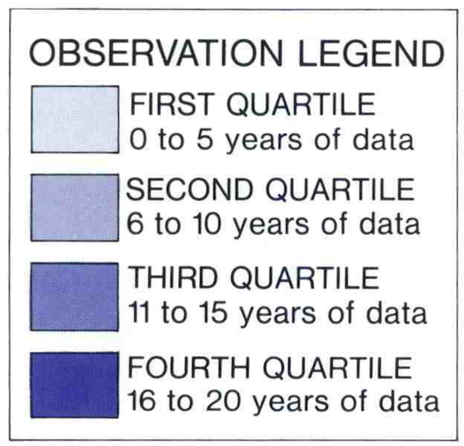
APRIL 1–15

1960–1979

LAKE ONTARIO







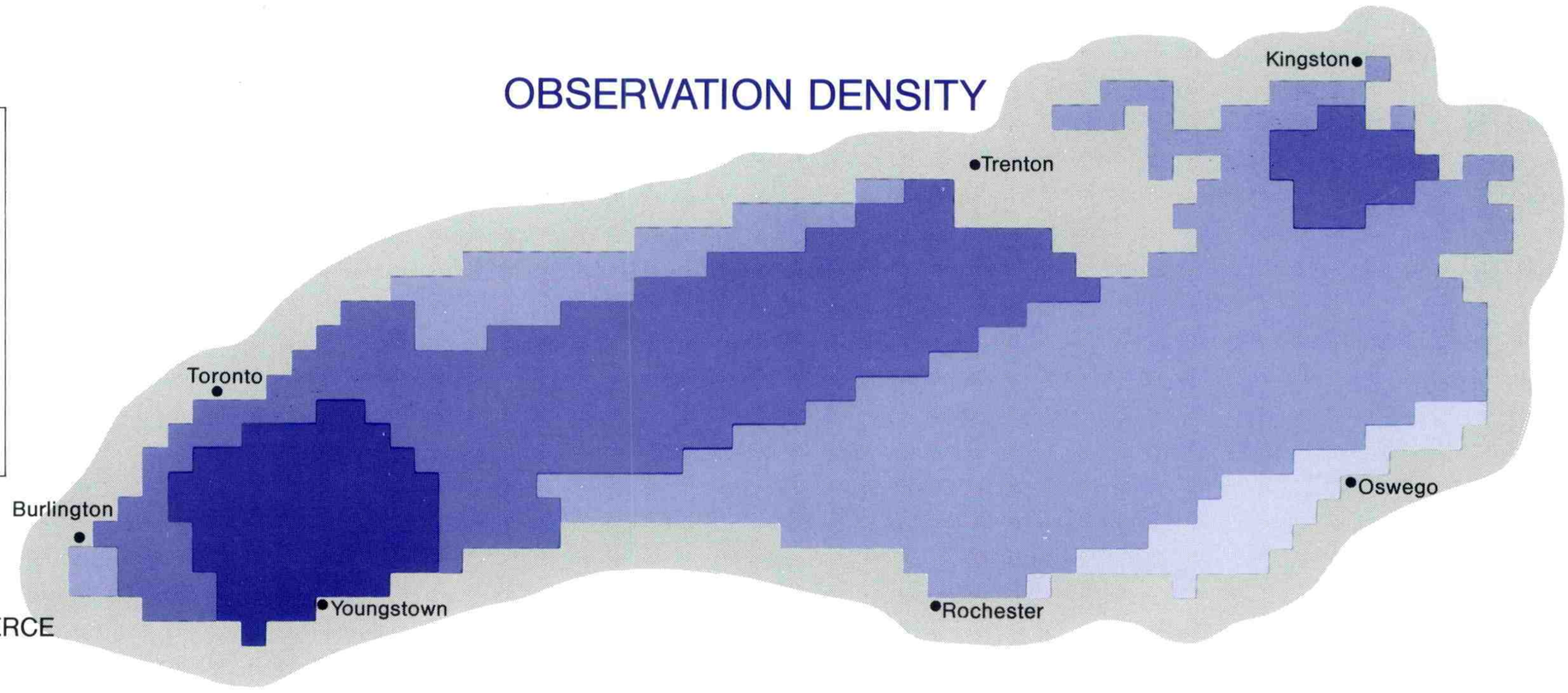


PLATE 45B

U.S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

EXTREMES IN ICE COVER

APRIL 16–30
1960–1979

LAKE ONTARIO



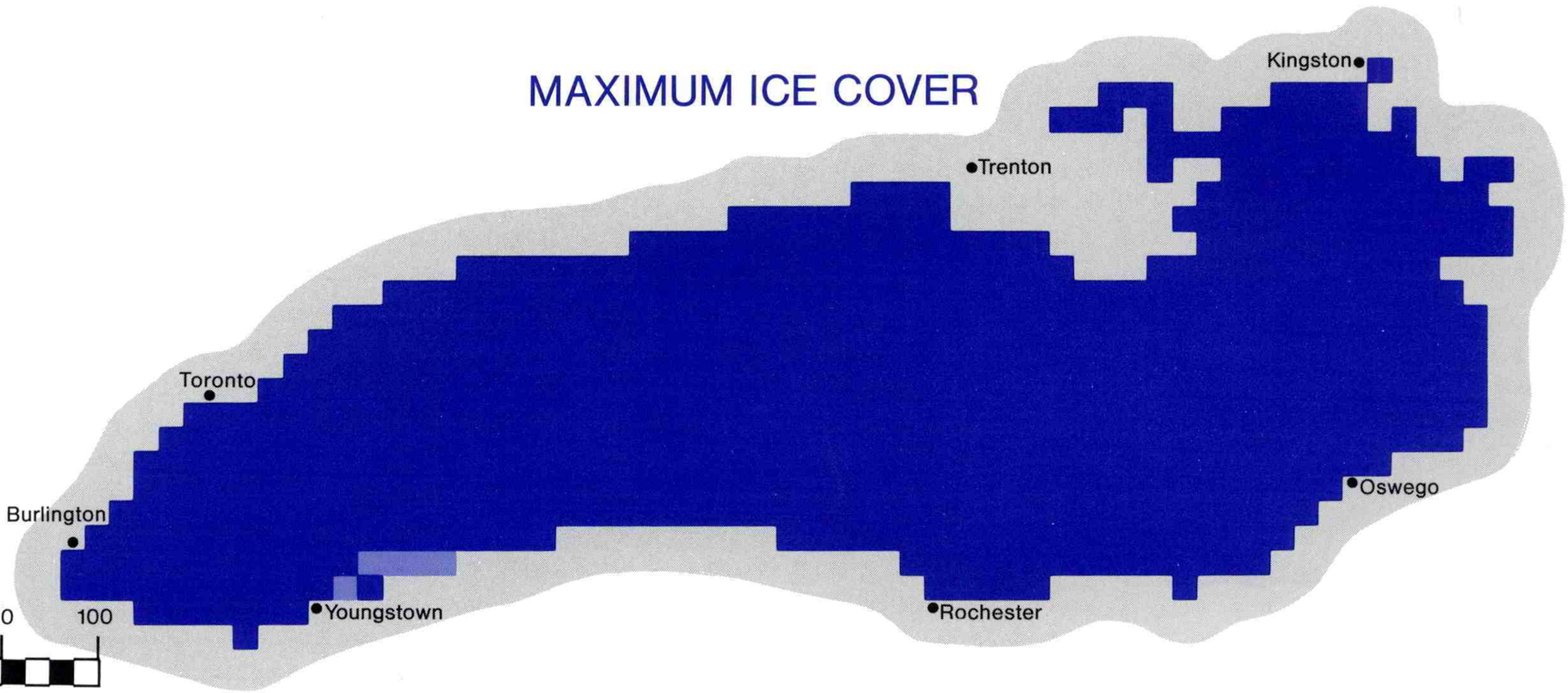
Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

ICE COVER LEGEND

- OPEN WATER
- VERY OPEN PACK 0.1 to 0.3 coverage
- OPEN PACK 0.4 to 0.6 coverage
- CLOSED PACK 0.7 to 0.9 coverage
- CONSOLIDATED PACK 1.0 coverage
- NO DATA

MAXIMUM ICE COVER



MINIMUM ICE COVER

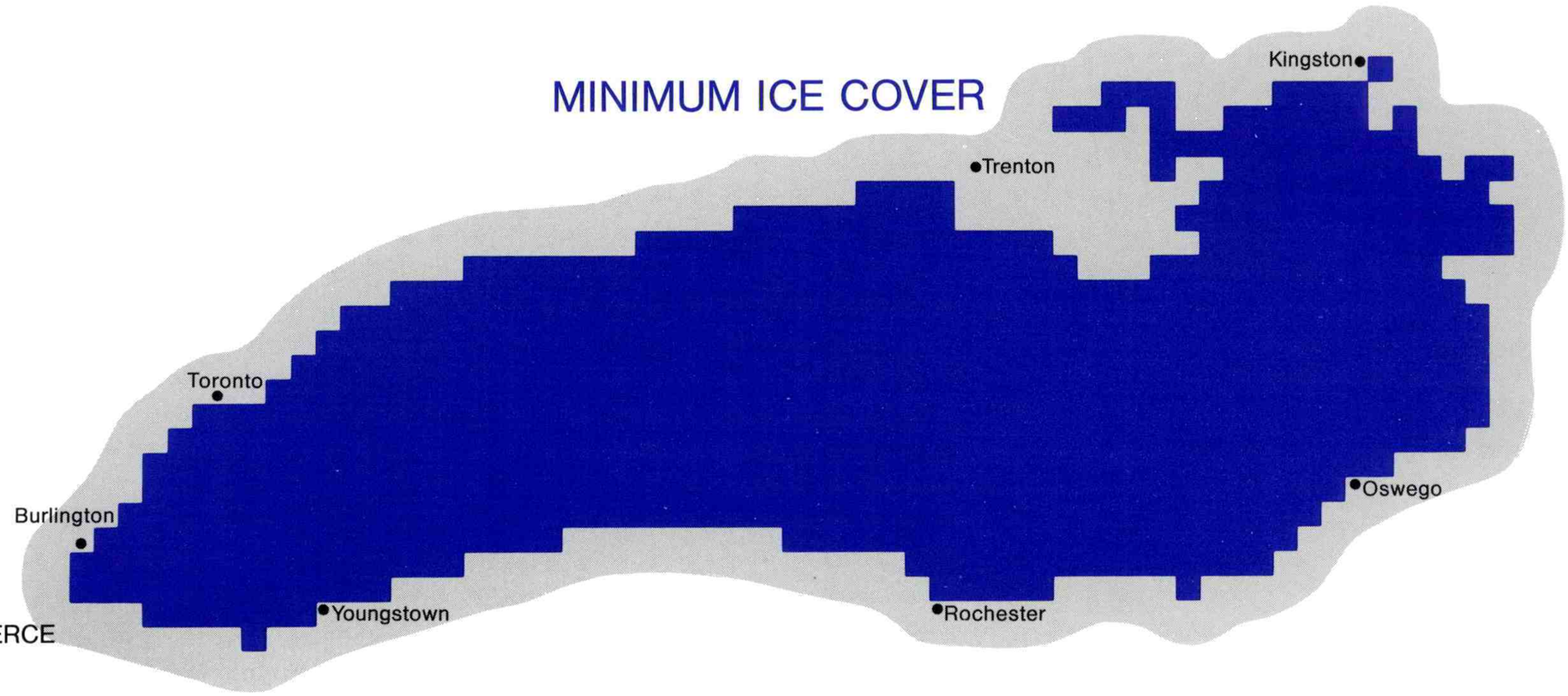


PLATE 46A

U. S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS

NORMAL ICE COVER AND OBSERVATION DENSITY

APRIL 16–30
1960–1979

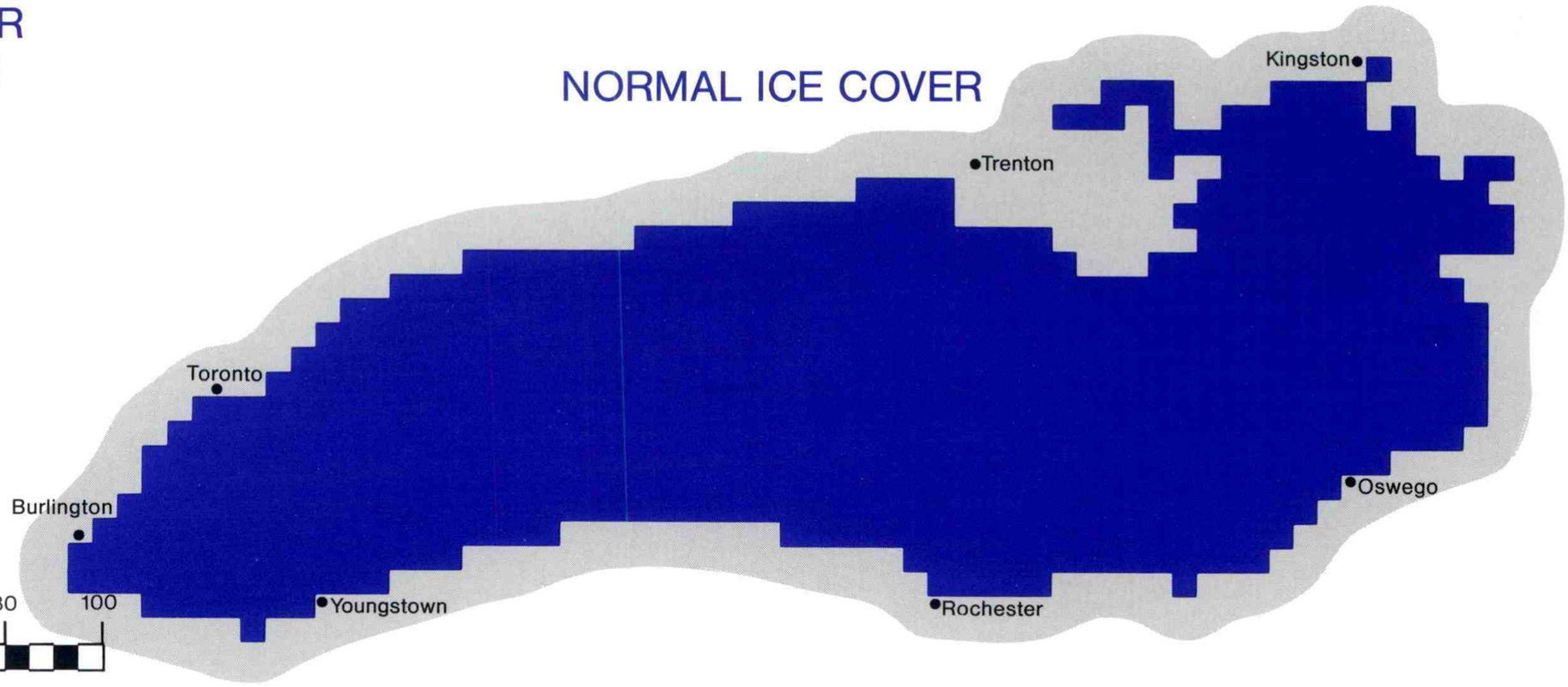
LAKE ONTARIO



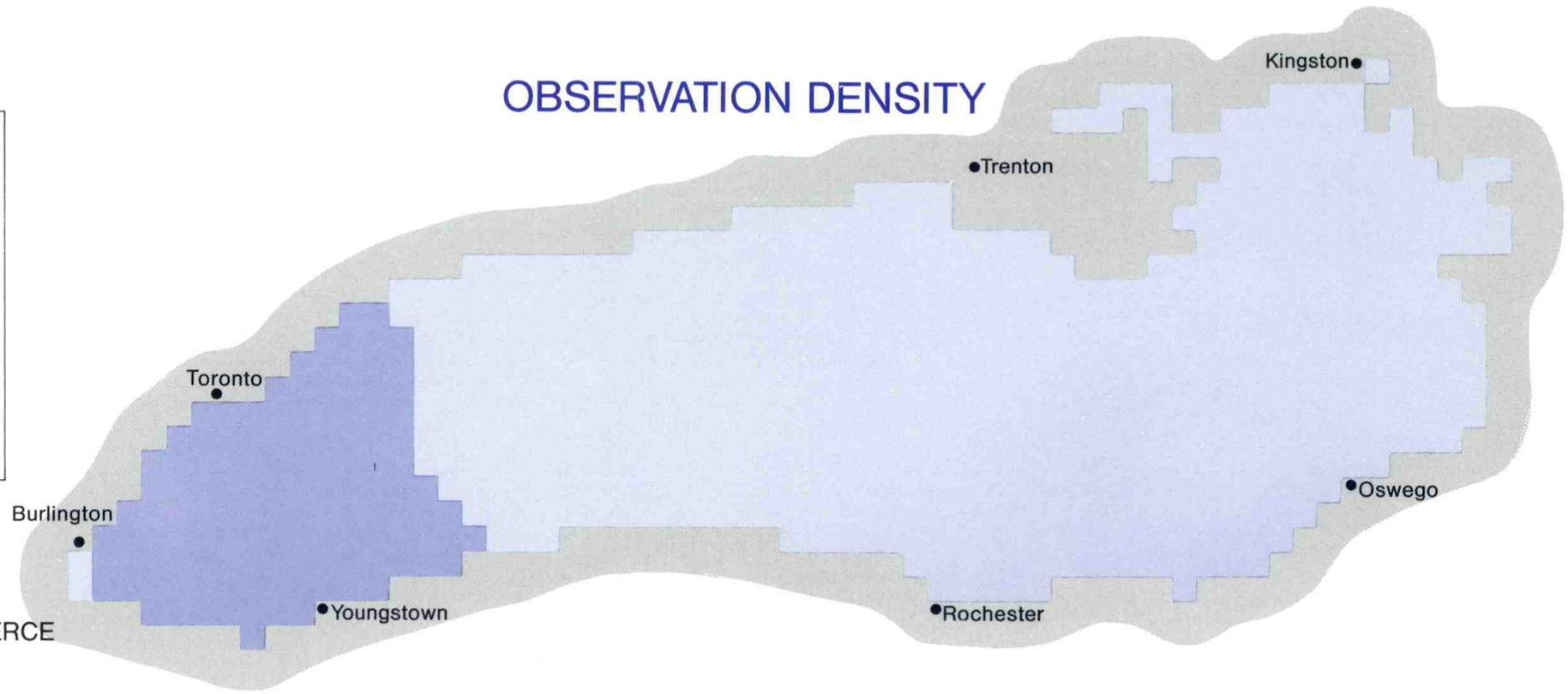
Kilometers
0 20 40 60 80 100

0 10 20 30 40 50 60
Statute Miles

NORMAL ICE COVER



OBSERVATION DENSITY



OBSERVATION LEGEND

- FIRST QUARTILE — 0 to 5 years of data
- SECOND QUARTILE — 6 to 10 years of data
- THIRD QUARTILE — 11 to 15 years of data
- FOURTH QUARTILE — 16 to 20 years of data

PLATE 46B

U.S. DEPARTMENT OF COMMERCE
NOAA / ERL / GLERL
GREAT LAKES ICE ATLAS