NOAA Technical Memorandum NESDIS 34

SATELLITE OBSERVATION OF GREAT LAKES ICE: WINTER 1986-87

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UNITED STATES DEPARTMENT OF COMMERCE / National Oceanic and Atmospheric Administration / National Environmental Satellite, Data, and Information Service

NOAA Technical Memorandum NESDIS Series

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SATELLITE OBSERVATION OF GREAT LAKES ICE: WINTER 1986-1987

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Interactive Processing Branch

Washington, D.C.
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CONTENTS

FIGURES

SATELLITE OBSERVATION OF GREAT LAKES ICE: WINTER 1986-87

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ABSTRACT

This report gives a descriptive view of the ice season along with analyzed charts derived from various data sources. During the ice season, ice conditions on the Great Lakes and Lake St. Clair were monitored using satellite imagery. The formation, movement, decay, and dissipation of the lake ice was observed from December 1986 through April 1987. Air temperatures were a contributing factor to ice formation and decay. Wind speeds and directions were a factor in ice movement and dissipation.

INTRODUCTION

This publication is a summarization of the 1986-87 Great Lakes ice season. It monitors the formation and melt of ice from mid-December through mid-April. The purpose of this paper is to describe the progression of the ice season as the surrounding atmospheric conditions influenced the growth, movement, and dissipation of the ice. Ice formation and decay was influenced by increasing and decreasing air temperatures throughout the season. Ice movement was mostly a result of changing wind speeds and directions. The first ice occurred in the northern bays of Lake Superior around mid-December. The last ice of the season was located in the North Channel of Lake Huron around mid-April. Based on the Great Lakes climatology, this ice season was among the light ice years with the total percentage of ice growth near a minimum. Lakes Erie and Ontario were especially lighter than normal. Local daily mean weather conditions for stations surrounding the lakes were used to monitor atmospheric conditions.

DATA SOURCES

SATELLITES

Most of the data used for the analyses were from NOAA's Polar-Orbiting Satellites. One of the primary sensors on board is the Advanced Very High Resolution Radiometer (AVHRR). The AVHRR is a five channel scanning radiometer with a resolution of 1.1 km at nadir. All AVHRR data depicted were from the visible channel which is sensitive to energy between 0.58 um and 0.68 um. Other satellite data were gathered by the Geostationary Operational Environmental Satellite (GOES). The primary sensor on board this satellite is the Visible and Infrared Spin Scan Radiometer (VISSR) which is sensitive to radiation between 0.55 um and 0.75 um in the visible spectrum and 10.5 um and 12.5 um in the infrared. The resolution for VISSR is 1 km in the visible and 8 km in the infrared. All GOES data used are from the VISSR visible channel.

CLIMATOLOGY DATA

Local Climatology data were obtained from stations surrounding the lakes. These data were provided by the National Climatic Data Center in Asheville, North Carolina.Especially useful were the daily average air temperatures and the daily resultant wind speeds and directions.

ANALYSIS CHARTS

The Great Lakes Composite Ice Analysis charts are produced by the Navy/NOAA Joint Ice Center located in Suitland, Maryland. The data sources used to produce the analysis include NOAA's polar orbiting and GOES satellite data, U.S. Coast Guard ship and shore station reports, and meteorological conditions from various weather stations surrounding the lakes.

SUMMARY OF ICE GENERATION, MOVEMENT, AND DECAY

LAKE SUPERIOR ICE CYCLE

Average air temperatures across Lake Superior (FIGURE 1) remained near freezing during the first half of December. Ice was discernable in the northern half of Black and Nipigon Bays on satellite imagery starting December 9. Clouds prevented lake observation during much of the second half of December; however, ice could be seen in the Ashland Bay area on December 21. There was also fast ice detected in Duluth Harbor (FIGURE A-1). Air temperatures over the lake during the first half of January were unseasonably warm. This warming resulted in a less than normal amount of ice formation. Areas containing significant ice cover were northern Black and Nipigon Bays, Duluth Harbor, and Ashland Bay (FIGURE A-2).

On January 23, the air temperature dropped from -12°C to -25°C over a period of three days. This prompted new ice formation around the Apostle Islands and along the coast to Duluth (FIGUREA-4). This ice extended approximately 10 nm lakeward. Thin shore ice was also seen along Keweenaw Pennninsula. Temperatures were below freezing at Marquette since January 16, therefore the ice here and around Munising had reached a greater thickness than other surrounding areas. In addition to Whitefish Bay, the area between Isle Royal and Thunder Bay were 70 percent covered with thin ice. Toward the end of January the average temperature in the southwestern basin of the lake was about -6°C. Local off shore winds caused advection of the newly formed ice into warmer waters and resulted in light melting by the end of the month.

Air temperatures were slightly below freezing at the beginning of February, but quickly rose to an unseasonable 11°C over the next few days. This resulted in extensive melting over the lake during the remainder of the week (FIGURE A-5). The lake was only 20 percent ice covered at the end of the second week of February. Great Lakes climatology indicate that this amount is much less than the seasonal mean for this period. During the next seven days air temperatures fluctuated a bit but resulted in very little changes in the ice conditions. Whitefish Bay began melting during the fourth week of February in response to southeasterly winds and higher air temperatures. The winds drove the coastal ice between Marquette and Whitefish Bay into warmer waters where it completely melted. The amount of ice in Thunder Bay was reduced to approximately 70 percent as a result of the atmospheric conditions mentioned above (FIGURE A-6).

Toward the end of February the growth rate of the ice in Whitefish Bay decreased significantly. At the beginning of March, the seasonal breakup of the land fast ice was in full swing. Lake ice remained only in the northern Bays, Duluth Harbor, the Apostle Islands, and Whitefish Bay (FIGURE A-8). By March 10, in response to temperatures up to 12°C, the ice in Thunder Bay diminished to a 20 percent coverage while the other bays remained 90 percent to one hundred percent ice covered (FIGURE A-9). After mid-March the air temperature averaged around 4°C, resulting in additional melt throughout the lake.

During the last week of March, air temperatures decreased drastically. This cooling was due to a high-pressure system located just north of the lake which generated cold northwesterly winds. These weather conditions resulted in a temporary lag of the melt season. Temperatures continued to decrease through the end of March; however, there was no significant formation of ice. This was due mainly to wind induced mixing of the open water areas bringing warmer water upward from the lake's bottom preventing surface ice formation. This is a common occurrence during late March. At the end of the month the only ice remaining in the lake was in the northern bays with light concentrations in Black and Nipigon Bays. There was also coastal ice in eastern Whitefish Bay and Duluth Harbor (FIGURE A-11). These upper coastal areas are usually the last to completely melt.

The extreme low temperature for the month of April occurred during the first week. The seasonal climatic change was evident by the second week. Temperatures remained above freezing for more than three days and significant melting had taken place. The only ice remaining in the lake was in Black and Nipigon Bays. Surface water temperatures were now averaging 4°C. By April 18, the lake was ice free with the exception of the northern section of Black Bay which was ice free by the end of the month.

In summary, the first ice on Lake Superior occurred around December 10. The maximum extent of ice for the season occurred around January 30 with 30 percent of the lake containing ice. The lake was ice free by April 30. The total number of days ice remained on the lake was 127. According to climatology, Lake Superior's average maximum ice coverage is approximately 90 percent to 100 percent, leaving this season among the light or mild ice years.

LAKE MICHIGAN ICE CYCLE

Air temperatures at Green Bay and the surrounding areas of lake Michigan (FIGURE 2) dropped below freezing during the third week of November. They remained below freezing until the second week of December. During this period, the average air temperature was -19°C, which was the extreme low for the month. By December 16, thin ice had formed throughout the lower end of Green Bay. Ice continued to increase in thickness in these areas and along the northern coast of the bay (FIGURE A-2). Green Bay was covered with ice of 0-10 cm thickness by December 30. Air temperatures increased throughout the month and remained just above freezing during this period. Ice growth was delayed in the usual areas of ice formation because of the warm air temperatures.

The average air temperature was near 1°C for the first two weeks of January, the minimum temperature was near -4°C. The lake was not visible during this period due to extensive overcast associated with low-pressure systems passing through the area. Strong winds associated with the systems drove most of the newly formed ice in Green Bay against the coast. This caused increased ice thickness in these areas. Green Bay and the northwestern coast were the only areas visible on satellite imagery.

Two weeks later, ice was seen along the southwestern coast from Milwaukee to Chicago and extended approximately 16 km from the shore. This new formation of ice resulted from 15-25 knot northeasterly winds and decreasing air temperatures averaging near -8.5°C. Ice was also discernable in the northern lake from the Straits of Mackinac to Beaver Island. The Traverse Bays were also ice covered. Very thin ice extended down to Manitou Island and hugged the coast from Door Peninsula down to Chicago and around to Gary, Indiana. New ice grew along the east coast from Muskegon to St. Joseph in response to decreasing temperatures and northeasterly winds (FIGURE A-4).

During the last week of January, the winds shifted to 30 knot easterlies. This wind shift caused a crack in the ice along the southeastern coast which later increase to a 8 km wide lead. The lake was now 30 percent ice covered with most of the ice located in Green Bay and the northern basin with a thin strip along the western coast. This was the maximum extent of ice cover for the season.

February brought warmer temperatures to the southern half of the lake, which were accompanied by a southwesterly wind flow. These meteorological conditions caused the newly formed ice in southern lake Michigan to melt, leaving the lake 25 percent ice covered. The only ice remaining in the lake was in Green Bay and the northern coastal areas extending into the Straits of Mackinac

(FIGURE A-5).

A lead was created along the northern coast of Green Bay from just south of Big Bay DeNoc to Cedar River. This was in response to a temporary increase in air temperature accompanied by westerly winds. This was believed to be the beginning of the melt season for Green Bay. The lake was only 25 percent ice covered at the end of February and already into its melt season. When compared to our climatological data, it appears to be among the light ice years. The lake was about one month ahead of the normal onset of the melt season.

The average air temperature for the first week of March was -1.5°C with winds from the west. These off-shore winds increased the width of the lead along the coast of northern Green Bay. The lead extended across the bay and downward along the western coast. The coldest days of the month occurred during the next five days. This cold outbreak of polar air caused new ice to form in the northern lake and in the lead mentioned above. Much of the new ice was confined to Little Traverse Bay. The area north of Beaver Island continued to increase in thickness. This growth of ice extended into the Straits of Mackinac and also over to the northeastern area of the lake (FIGURE A-8).

During the first week of March, average air temperatures were warmer than normal in the northern basin of the lake and increased to 14°C by March 7. These temperatures led to an increase in the rate of melt. By March 10, the only ice remaining in the lake was confined to the northeastern coastal basin, extending into the Straits of Mackinac, and ending at Beaver Island. Green Bay was 85 percent ice covered with 40 percent of the ice in its melting stage (FIGURE A-9). For the next ten days, temperatures were below freezing at Green Bay, Wisconsin. This caused a temporary lag in the melt season. By March 21, the temperatures rose again and the ice near the straits were reduced to small scattered floes. A continuous warming trend melted the ice at the mouth of Green Bay and the winds helped to deteriorate the ice at the Straits of Mackinac. At the end of March, ice was still present in the lower and upper coastal areas of Green Bay. By April 10, the lake was completely ice free (FIGURE A-12).

The ice season on Lake Michigan began around mid-December and ended around April 10, a total of 114 ice days. The normal maximum extent of ice coverage for this lake is 40 percent to 50 percent during an ice season. This season's coverage was 30 percent, occurring near January 30.

LAKE HURON ICE CYCLE

Average air temperatures over Lake Huron (FIGURE 3) were below freezing after November 20. Coastal ice was seen in Saginaw Bay, Georgian Bay, and North Channel from satellite imagery by December 20. Air temperatures at Flint and Alpena rose above freezing during the remainder of the month. Temperatures as high as 16 degrees above normal were recorded in these areas which lead to considerable melting of the newly formed ice mentioned above.

The lake was only five percent ice covered at the beginning of January. However, on January 16 temperatures were down to -16°C, which was the extreme low for the month. This cold weather lead to extensive ice formation throughout the lake (FIGURE A-4). Saginaw Bay and North Channel became 100 percent ice covered. Coastal extended 16 km lakeward around the entire lake. The ice in northeastern Georgian Bay was a mixture of thick and thin fast ice along the coast. During the remainder of January, air temperatures remained slightly below zero. These temperatures were periodically accompanied by strong northeasterly winds which drove the ice shoreward from Saugeen Peninsula down to Sarnia.

Warmer air temperatures dominated the beginning of February. Temperatures up to 20 degrees above normal were reported at Alpena. Southeasterly winds reaching 40 knots drove ice into warmer waters resulting in extensive melt. Georgian Bay was reduced from 50 percent to 20 percent ice coverage (FIGURE A-5). Ice in the southern basin of the lake was reduced to 10 percent with ice remaining only along the eastern shore.

By mid-February very cold weather prevailed throughout the region. Temperatures dropped to -29°C which was 13 degrees below normal. These low temperatures caused extensive ice growth over much of the lake (FIGURE A-7). On February 23 the lake was 40 percent ice covered. This was the maximum extent of ice cover for the season. Georgian Bay was 80 percent ice covered, North Channel and Saginaw Bay were each 90 percent ice covered, and the lower southern basin of the lake was 40 percent ice covered. Ice surrounded the entire coast except in the areas near Harbor Beach and either side of Saginaw Bay (FIGURE A-7).

On February 24, temperatures began to increase and averaged near 22°C by the end of the month. These warm temperatures contributed to the decrease in the rate of ice growth throughout the lake. From February 25 to February 28, southeasterly winds transported the ice away from the coast from north of Kincardine down to Goderich. The warmer temperatures plus the wave action of the ice free areas surrounding the ice caused rapid melt of the remainding ice.

Temperatures continued to increase during the first week of March and by the beginning of the second week Georgian Bay had lost 50 percent to 60 percent of its ice cover. Temperatures of up to 14°C were reported during that week. Around mid-March, air temperatures decreased to -5°C and remained below freezing until March 18. Coastal ice remained in Georgian Bay and also in areas along the southern basin. Other areas maintaining ice coverage were the Straits of Mackinac, North Channel, and Saginaw Bay (FIGURE A-10). Temperatures gradually increased throughout the remainder of the month, and by March 29 reached 11°C.

North Channel and Saginaw Bay were the only areas in the lake with ice at the beginning of April. Both areas were 70 percent covered with deteriorating ice and small broken floes. This lake was reduced to 20 percent coverage by April 10 with ice remaining only in North Channel (FIGURE A-12). Lake Huron was ice free by April 15.

The ice season on Lake Huron began on December 20 and lasted until April 15, a total of 120 ice covered days. The maximum extent of ice coverage was 40 percent which occurred around February 24. The normal maximum coverage is 60 percent to 70 percent occuring in late February.

ICE CYCLE ON LAKE ERIE

Air temperatures dropped below freezing over most of Lake Erie (FIGURE 4) during the first week of December. During the following week, temperatures remained near freezing but increased toward the end of the month. The first two weeks of January were much like December with unseasonably warm temperatures. These conditions prevented ice formation. Temperatures up to five degrees above normal were recorded in mid-January. The ice cycle on Lake Erie was now behind the normal seasonal freeze-up. Areas that are normally open water in this lake usually occur only during the months of December and April. Freeze-up normally begins during the third week of December.

The first ice on the lake formed during the last week of January in response to below freezing temperatures and northeasterly winds. Air temperatures over most of the lake were between -18°C and -14°C, and caused rapid ice formation over 40 percent of the lake's surface. Ice occupied the entire western end of the lake west of Point Pelee (FIGURE A-4).

During the first ten days of February, the air temperatures fluctuated. These and other atmospheric conditions caused rapid changes in the ice on the lake. The second half of February was more typical of a normal freeze-up season. There was evidence of new ice forming over most of the lake. The only area which remained open was in the eastern lake just east of Erie, Pennsylvania. This open area extended over to the coast of Dunkirk and stretched 20 nm lakeward (FIGURE A-6).

Over 95 percent of the lake was frozen by February 25. This was the maximum extent of ice cover for the season (FIGURE A-7). February ended with a warming trend. Air temperatures increased to near 10°C with 12-15 knot east-northeasterly winds. These meteorological conditions caused the opening of a narrow coastal lead along the northern lake which extended from Port Stanley to Buffalo (FIGURE A-8). The opening of this lead, coupled with the warming trend, contributed to the onset of the melt season.

Air temperatures continued to increase during the first week of March. Twenty knot northerly winds caused the lead mentioned above to increase in width. New polynas and leads also formed in the basin west of Point Pelee. Lake Erie's rapid response to surrounding atmospheric conditions was evident during the next few days of March. Temperatures rose to 14°C with 20 knot southeasterly winds. These conditions resulted in a 90 percent melt of the lake's ice coverage (FIGURE A-9). Ice now remained only in the southwestern portion of the lake with coastal ice surrounding the lake from Sandusky to Fairport. There was also a long tongue of ice which stretched across the lake from Lorain to the northern coast. The temperatures returned to near freezing over the next few days but did not slow down the melt season. The lake was ice free by March 17 (FIGURE A-10).

The ice season on Lake Erie began around January 24 and lasted until March 17, a total of 58 days. The maximum extent of ice coverage was 95 percent which occurred around February 24. The normal maximum coverage is 90 percent to 100 percent which occurs during February.

LAKE ST. CLAIR ICE CYCLE

Lake St. Clair (FIGURE 4) had no significant ice formation until January 24 when surrounding air temperatures decreased to -16°C. The entire lake was frozen with thin ice by January 26 (FIGURE A-4). The lake remained frozen throughout the month of February, with ice reaching thickness of 35 cm in some coastal areas.

Average temperatures were above freezing during the last week of February and the general wind direction was south-southeast at 35 knots. Eighty percent of the lake was open water at the end of the first week of March (FIGURE A-9). Coastal ice remained in the northeastern areas of the lake between New Baltimore and Chatman, Ontario. A few days later the coastal ice was advected southward into warmer waters while the thicker ice remained in the mouth of the Detroit River (FIGURE A-10).

During the next five days surface winds played a major role in advecting the remaining coastal ice into the open water. Ice lingered in the northern basin until the end of March. The lake was ice free by March 31.

The ice season for Lake St. Clair began on January 24 and ended on March 31, a total of 65 days. The maximum extent of ice coverage for this lake was 100 percent which occurred around January 27. This is normal for Lake St. Clair.

LAKE ONTARIO ICE CYCLE

Lake Ontario (FIGURE 5) is a deep lake with a small surface area to depth ratio. During a normal freeze-up season, ice formation is usually confined to the shallow coastal areas with the deep middle basin remaining open throughout December. Temperatures at Rochester and Syracuse remained near freezing throughout December and into the first week of January. The second half of January was accompanied by colder temperatures which helped to condition the coastal waters for ice formation.

The first ice on the lake occurred during the third week of January after five days of northeasterly winds accompanied by temperatures between -9°C and -4°C (FIGURE A-4). Ice was confined to the coastal areas, south of the Bay of Quinte, throughout the remainder of January and into February. Following an outbreak of cold polar air, new ice formed in the northern coastal areas from the Bay of Quinte to Stony Point. Four days later, ice formation between these two points continued southward beyond Prince Edward Peninsula over to the coast just east of Oswego (FIGURE A-6). The lake was now 30 percent ice covered, which was the maximum extent of ice for the season.

During the last few days of February, 18-20 knot winds caused a southward advection of the ice. This ice soon melted due to increasing air temperatures and wave interaction (FIGURE A-8). By March 3, coastal ice remained only in the northeastern lake. This ice lingered in the lake until March 9 when air temperatures reached 19°C at surrounding weather stations.On March 10, the lake was ice free (FIGURE A-9).

The ice season for Lake Ontario began on February 13 and ended on March 10, a total of 33 days. The maximum extent of ice coverage was 30 percent which occurred around February 24. This was normal for Lake Ontario.

CONCLUSION

This ice season was among the very light ice years. Lakes Superior and Michigan reached a seasonal maximum of 30 percent ice coverage during late January. The maximum extent of ice for these two lakes normally occur in late February reaching approximately 75 percent coverage. Lakes Huron and Ontario reached 40 percent and 30 percent maximum ice coverage, respectively. The season's total ice coverage for these two lakes were also below normal. Lakes Erie and St. Clair attained their normal maximum ice coverages of 90 percent to 95 percent but the ice thickness was significantly less than normal. Consequently, the ice melted sooner, resulting in a very short ice season for these two lakes. Air temperatures were the controlling factor in determining ice formation and thickness throughout the lakes. The ice did not reach normal thickness due to unseasonably warm temperatures which occured throughout the ice season. The result was a quick freeze-up and melt season for all the lakes.

APPENDIX

FIGURES 1-5. Bathymetric and Geographic Location Charts.

FIGURES A-1 Through A-30. Composite Great Lakes Ice Analysis Charts for December 16, 1986, through April 28, 1987.

FIGURE A-14. Place Names On The Great Lakes.

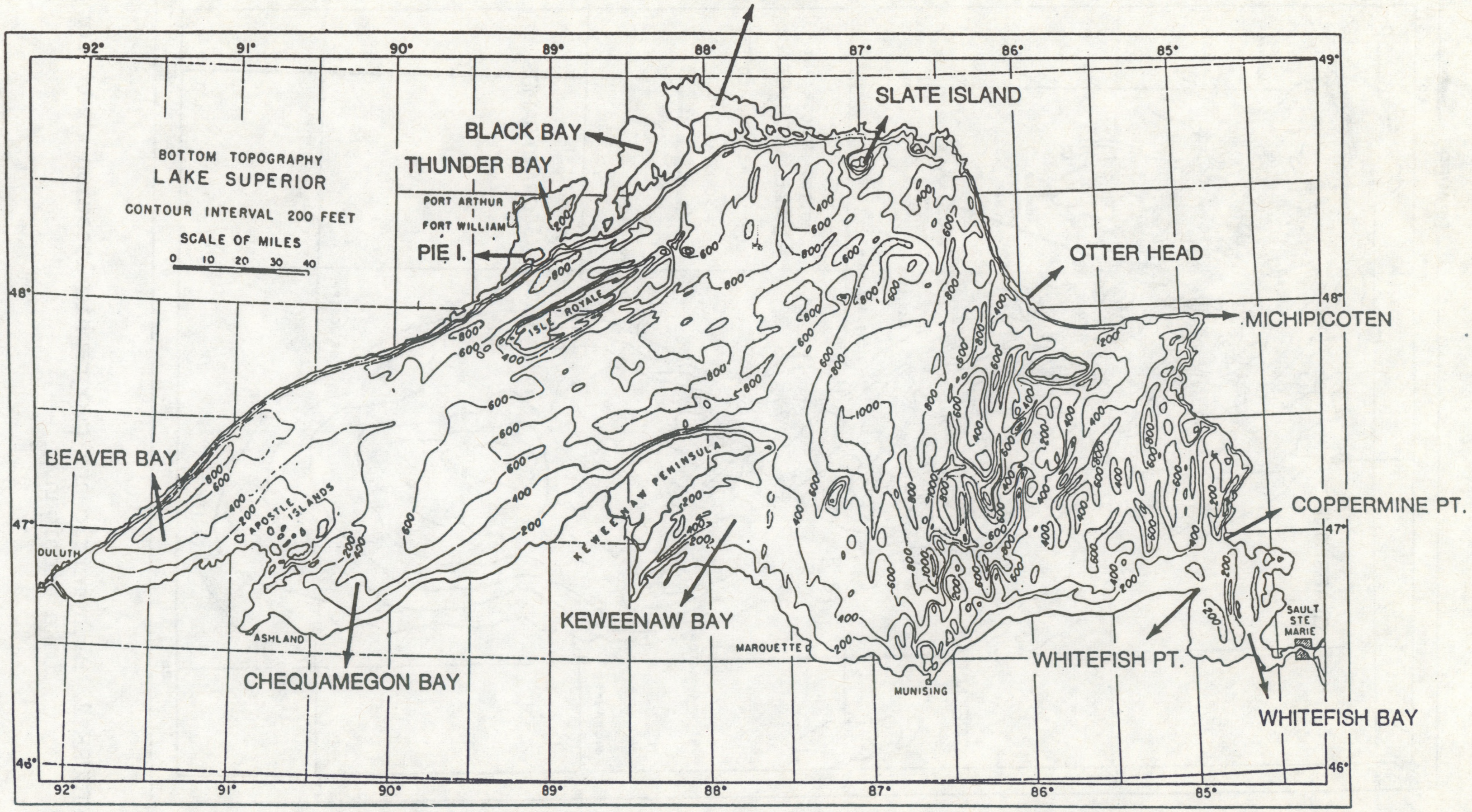

FIGURE 1. Bathymetric and geographic location chart for Lake Superior.

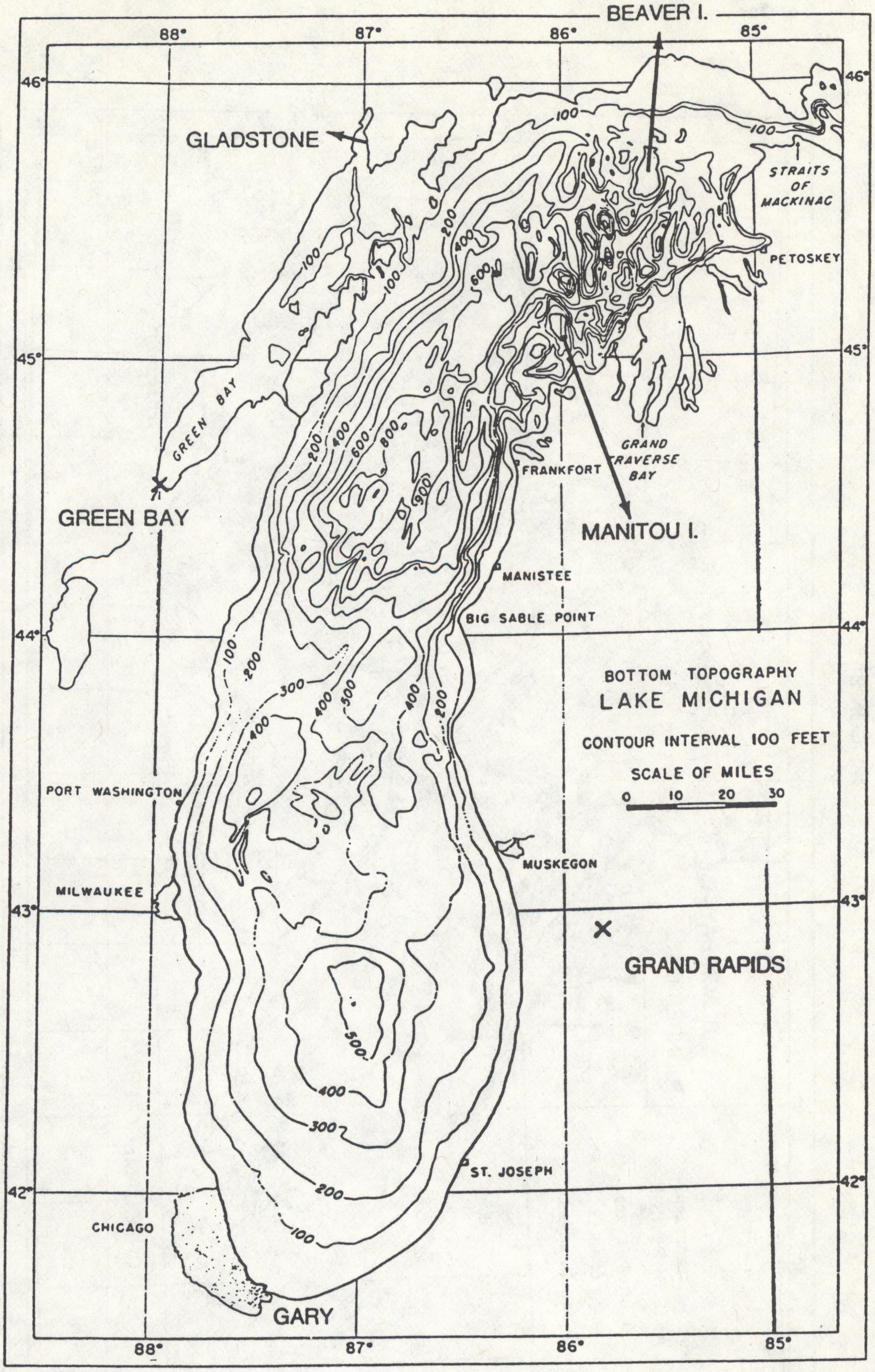

FIGURE 2. Bathymetric and geographic location chart for Lake Michigan.

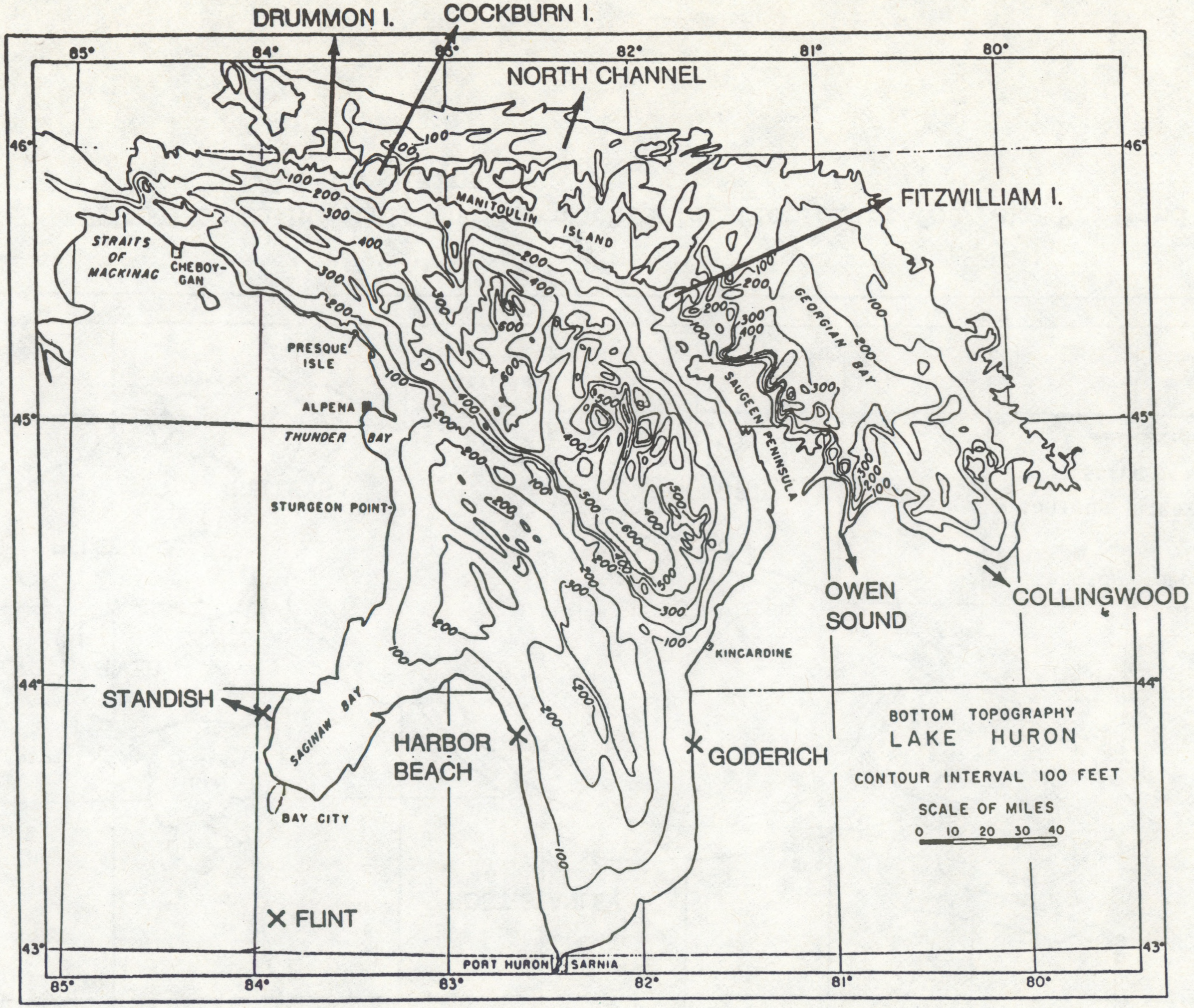

FIGURE 3. Bathymetric and geographic location chart for Lake Huron.

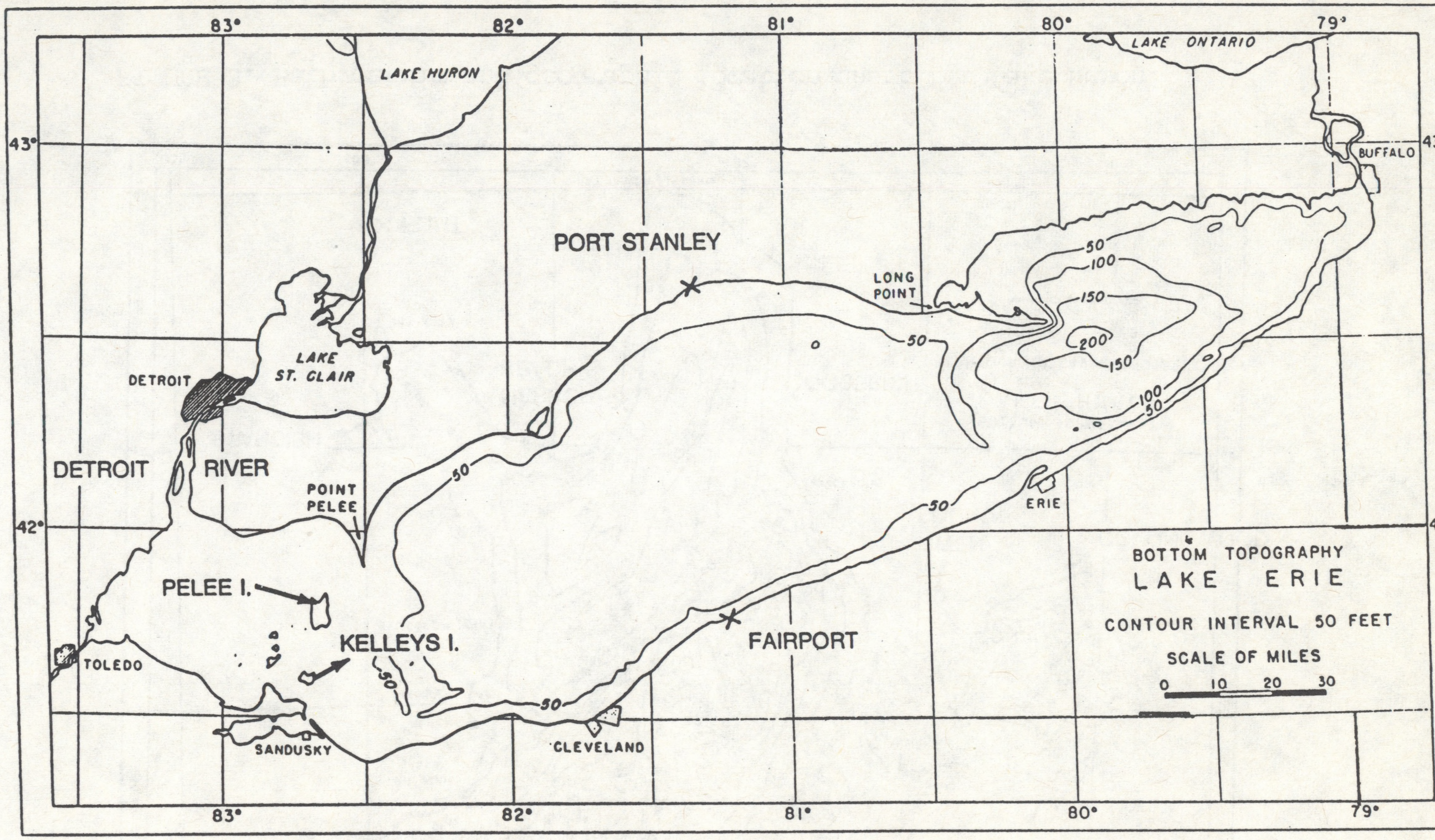

FIGURE 4. Bathymetric and geographic location chart for Lake Erie and Lake St. Claire.

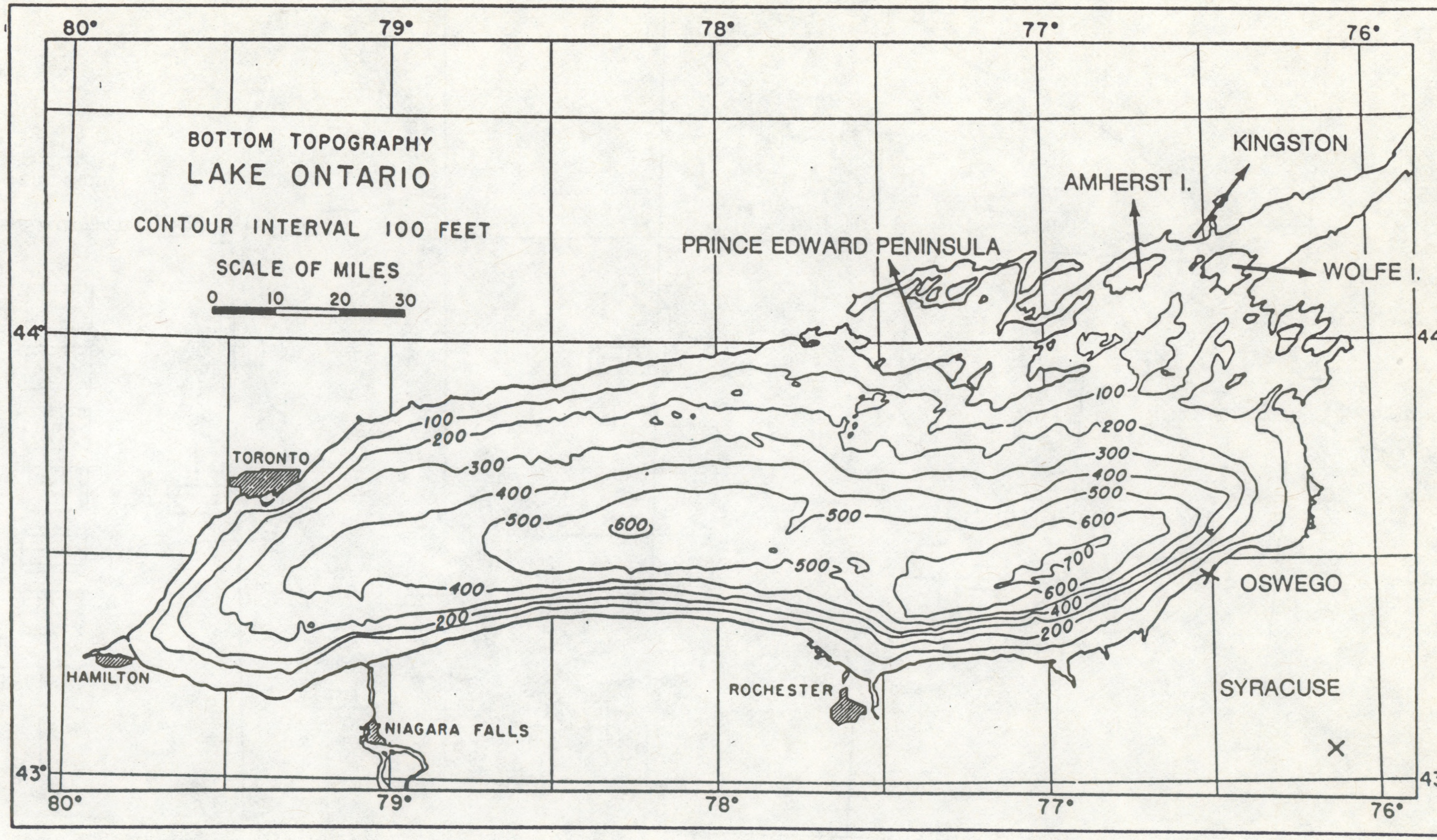

FIGURE 5. Bathymetric and geographic location chart for Lake Ontario.

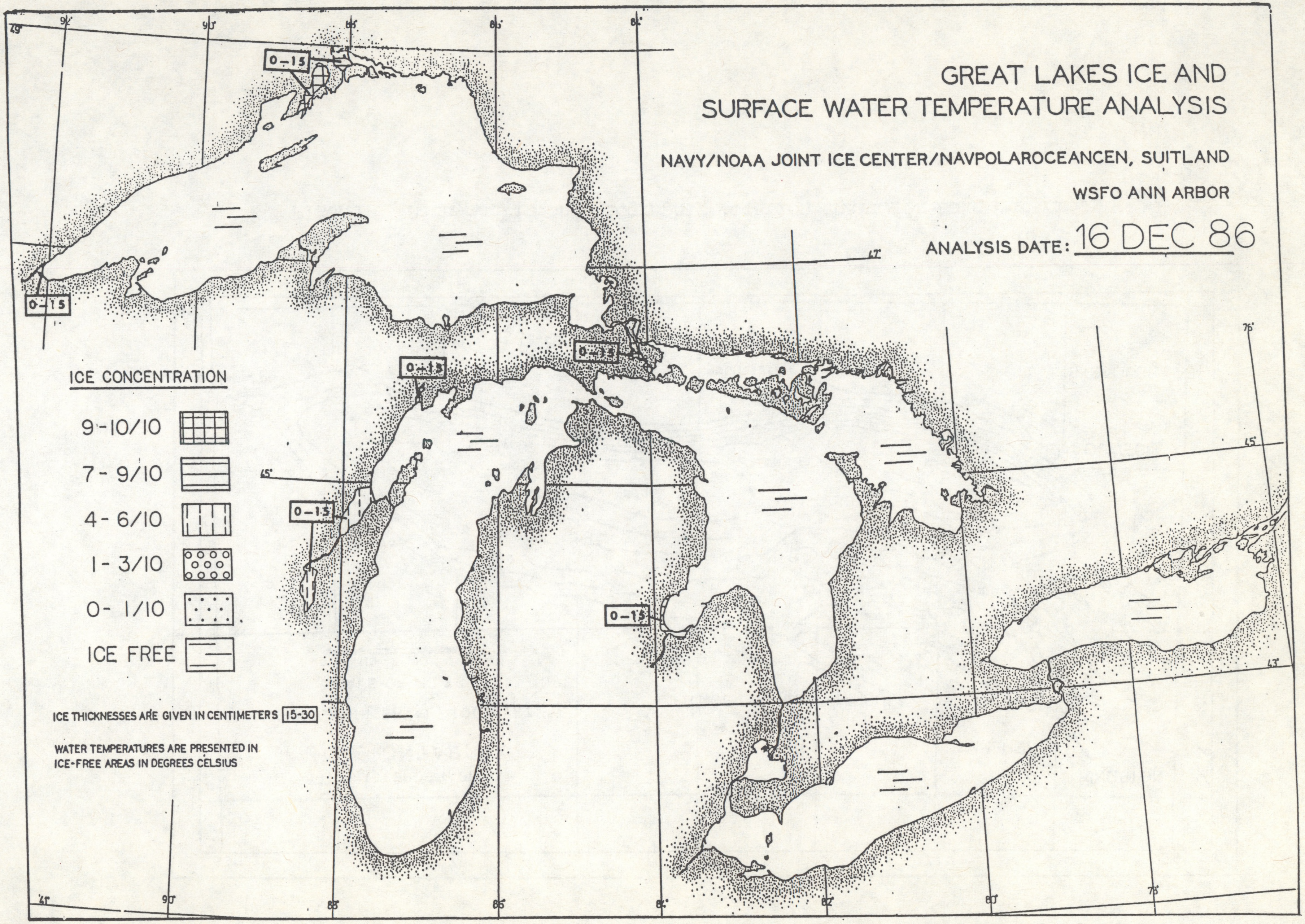

FIGURE A-1. COMPOSITE ICE CHART for 16 December 86.

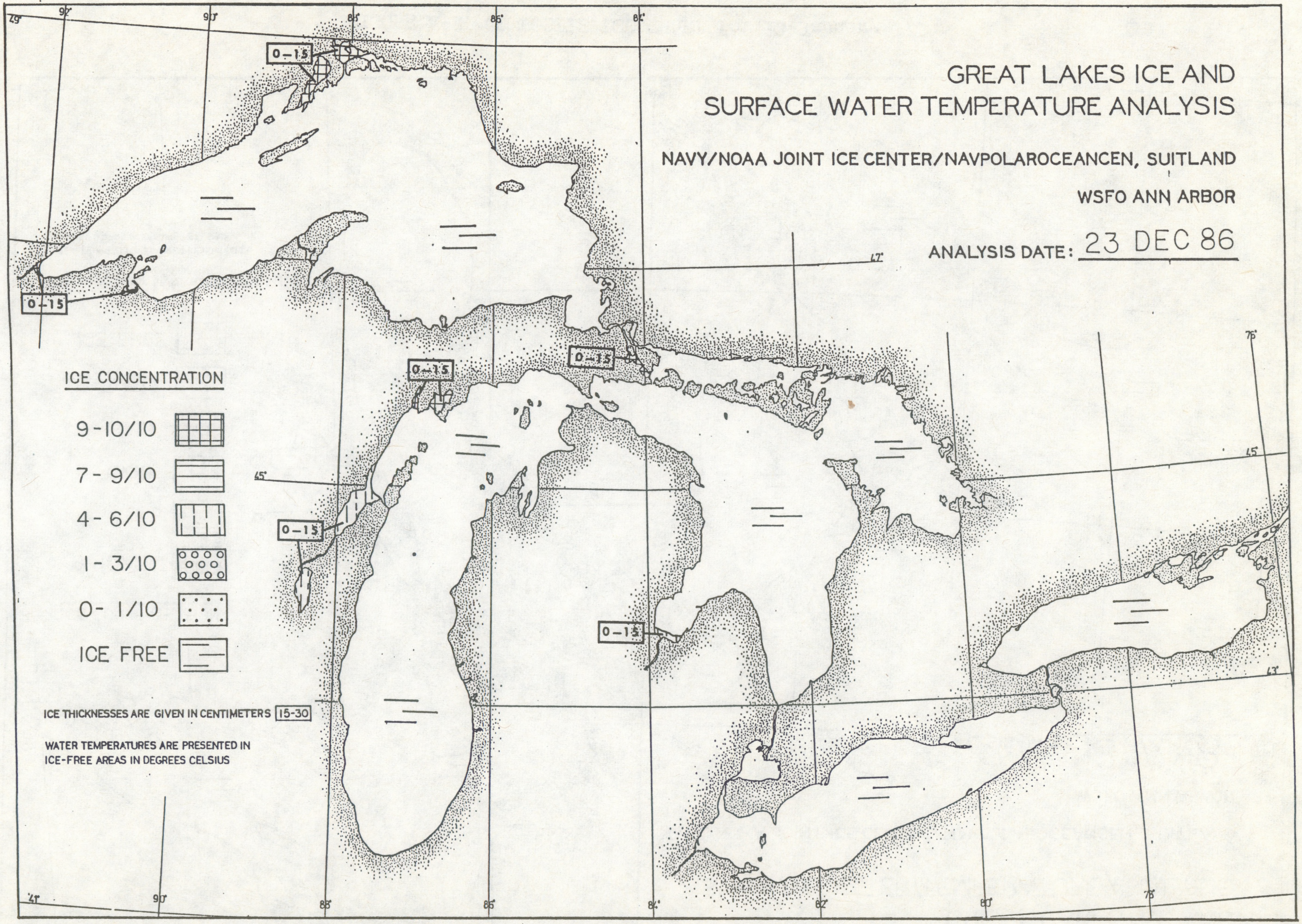

FIGURE A-2. COMPOSITE ICE CHART for 23 December 86.

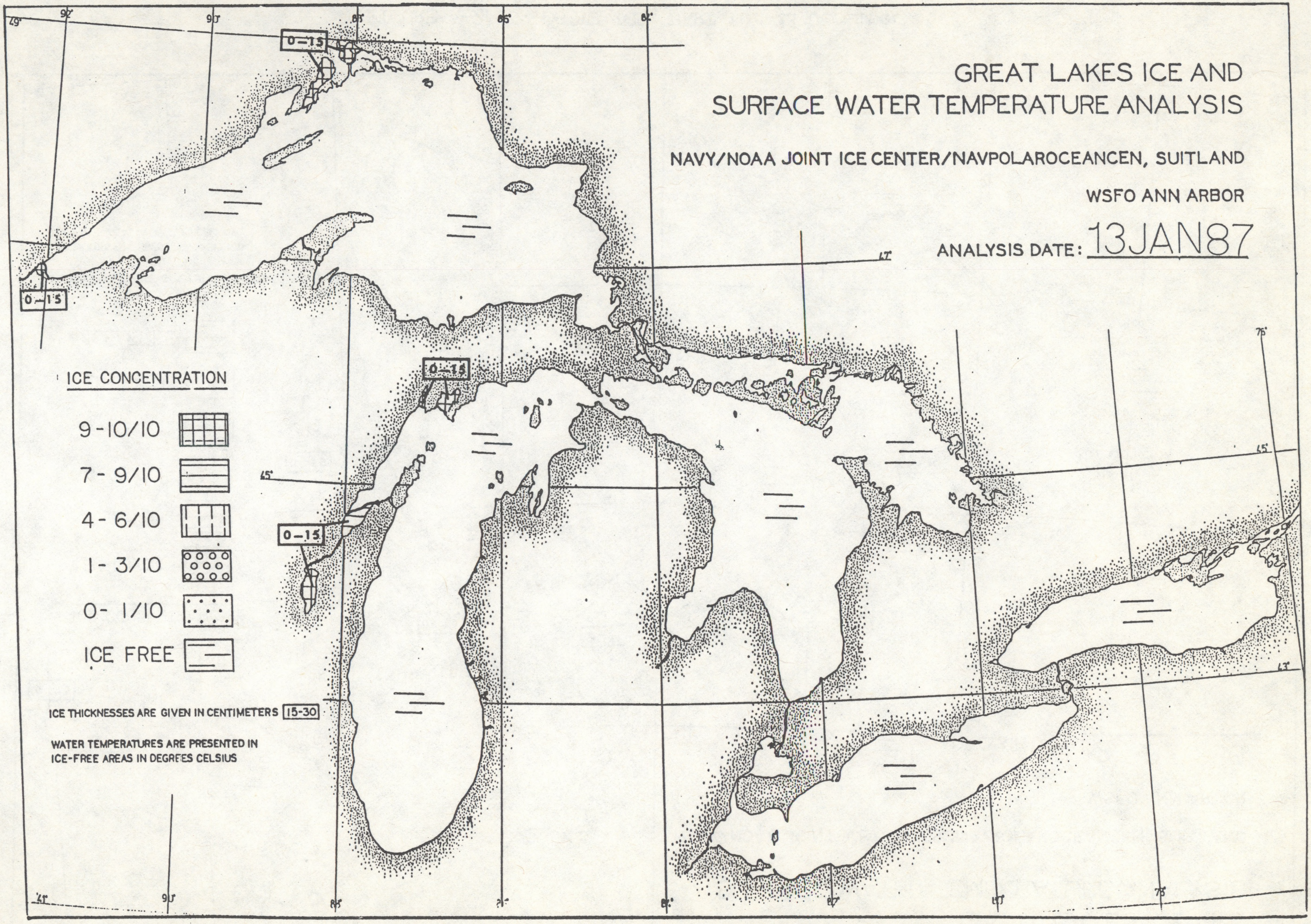

FIGURE A-3. COMPOSITE ICE CHART for 13 January 87.

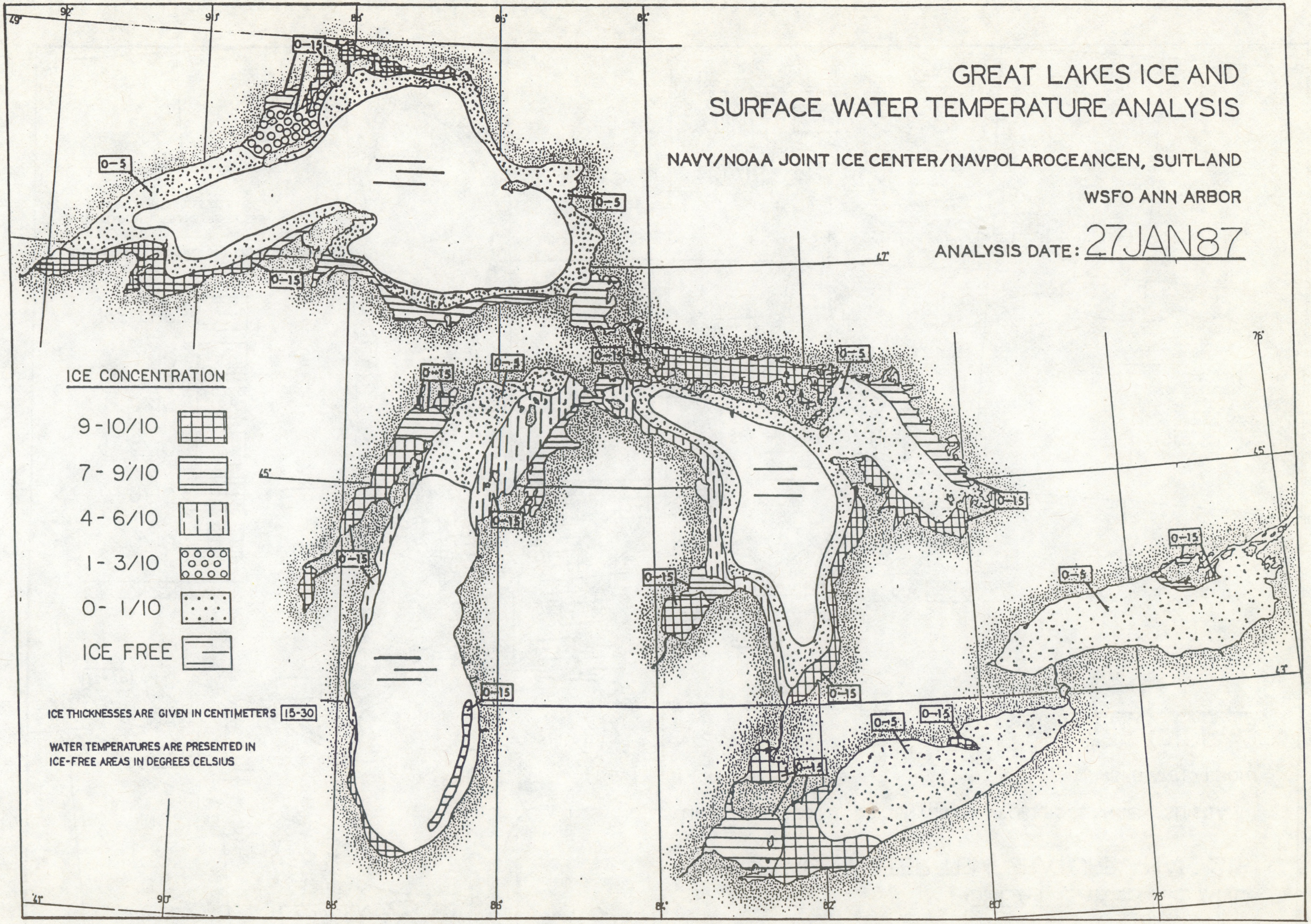

FIGURE A-4. COMPOSITE ICE CHART for 27 January 87.

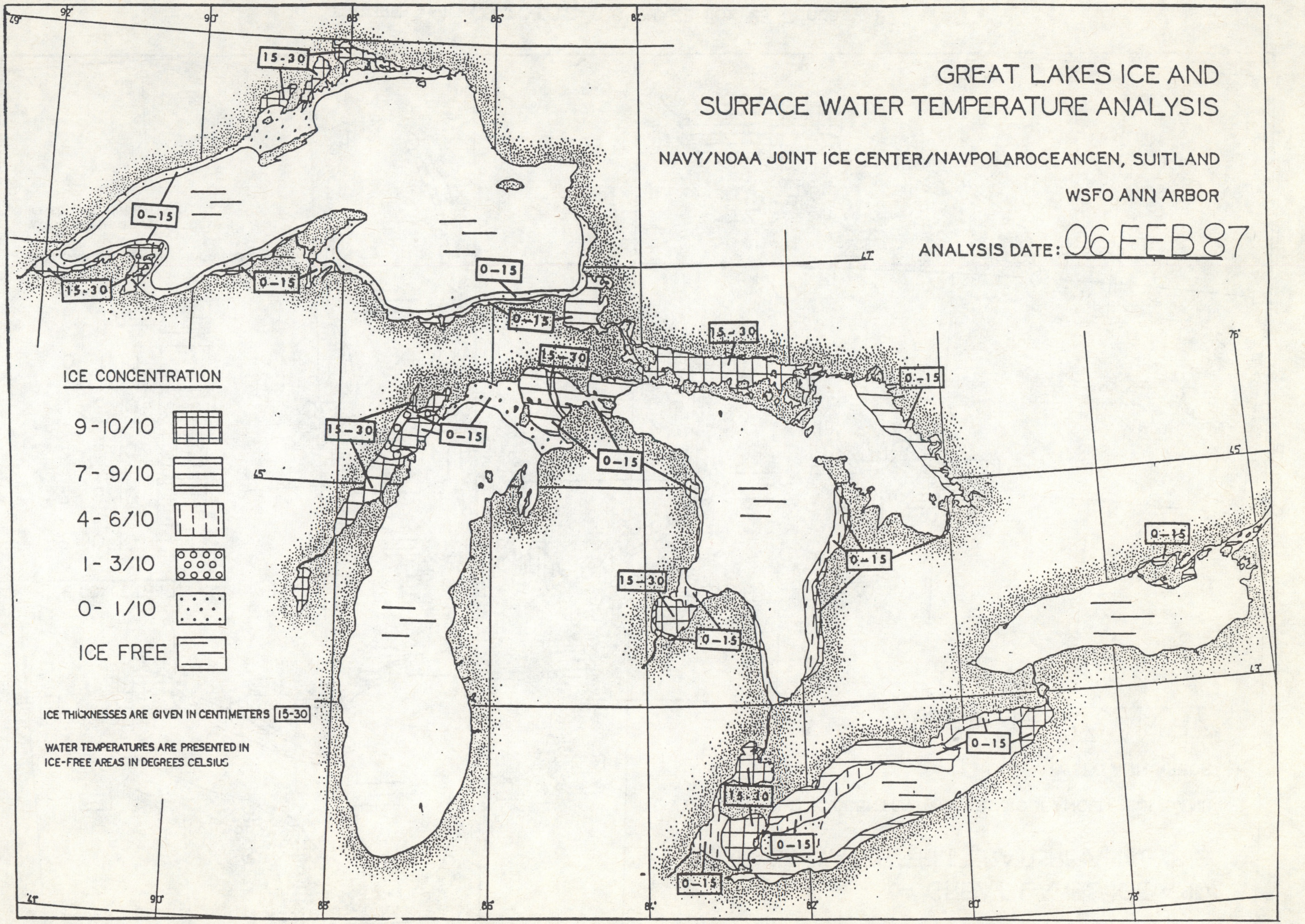

FIGURE A-5. COMPOSITE ICE CHART for 06 February 87.

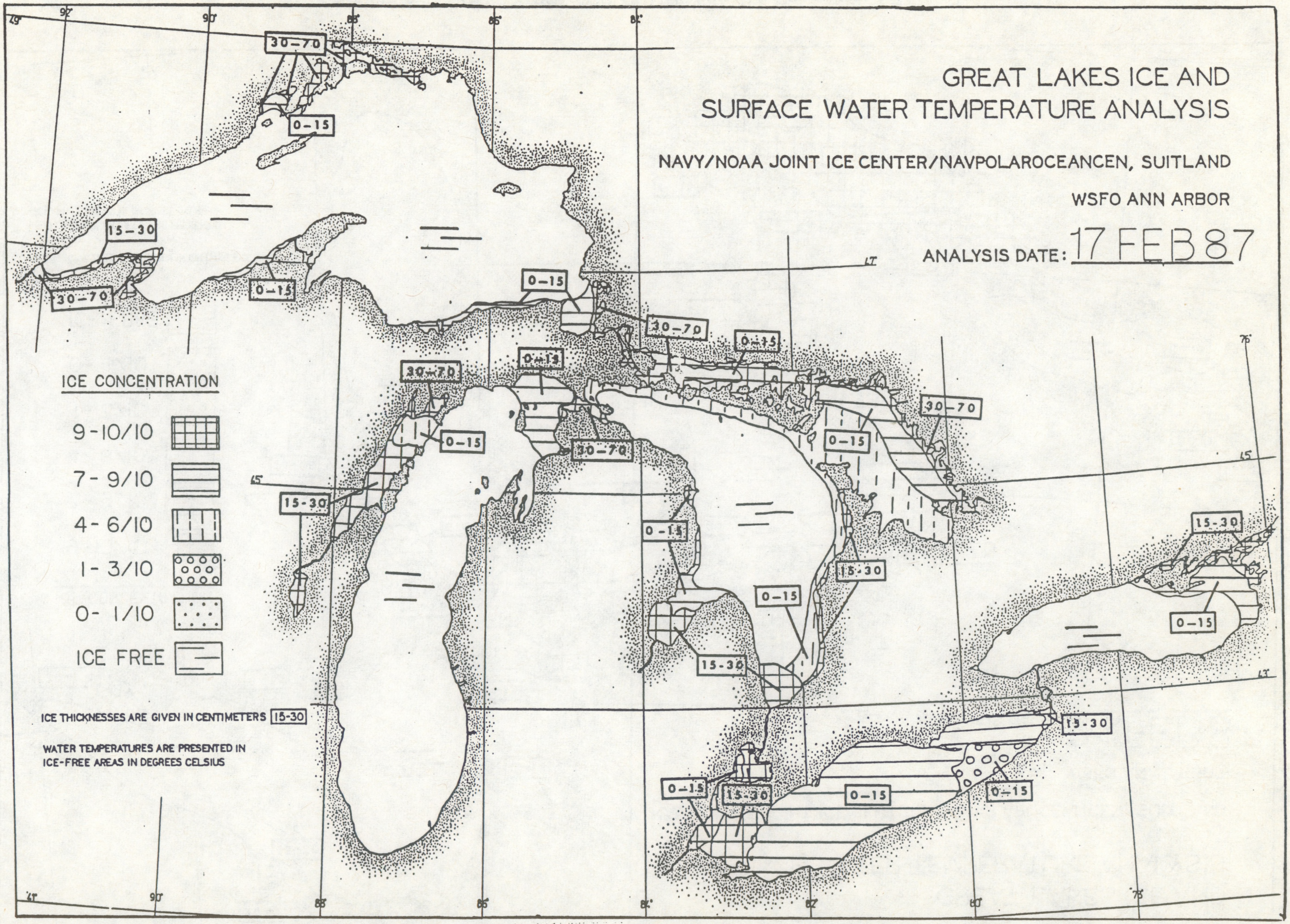

FIGURE A-6. COMPOSITE ICE CHART FOR 17 February 87.

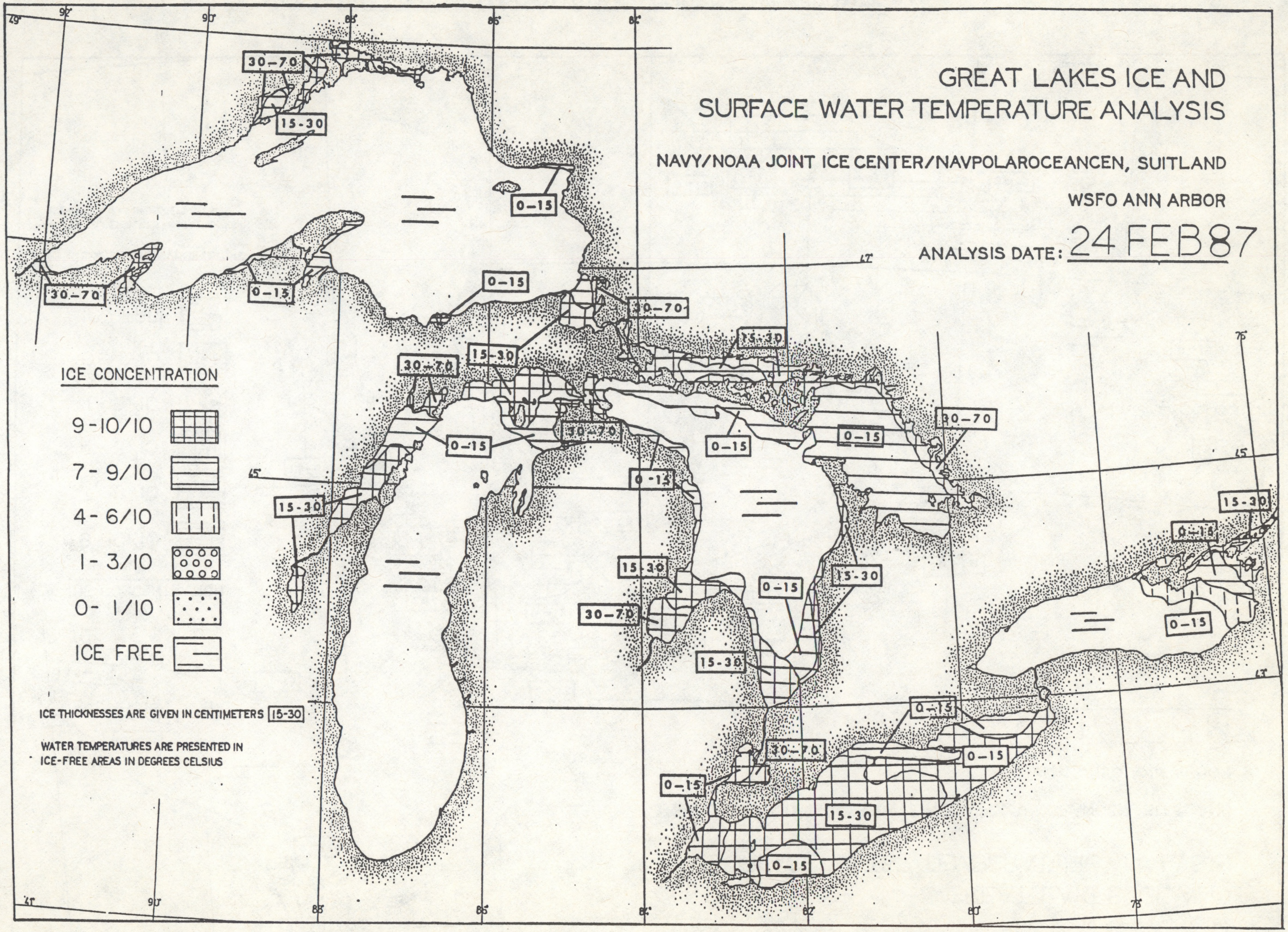

FIGURE A-7. COMPOSITE ICE CHART for 24 February 87.

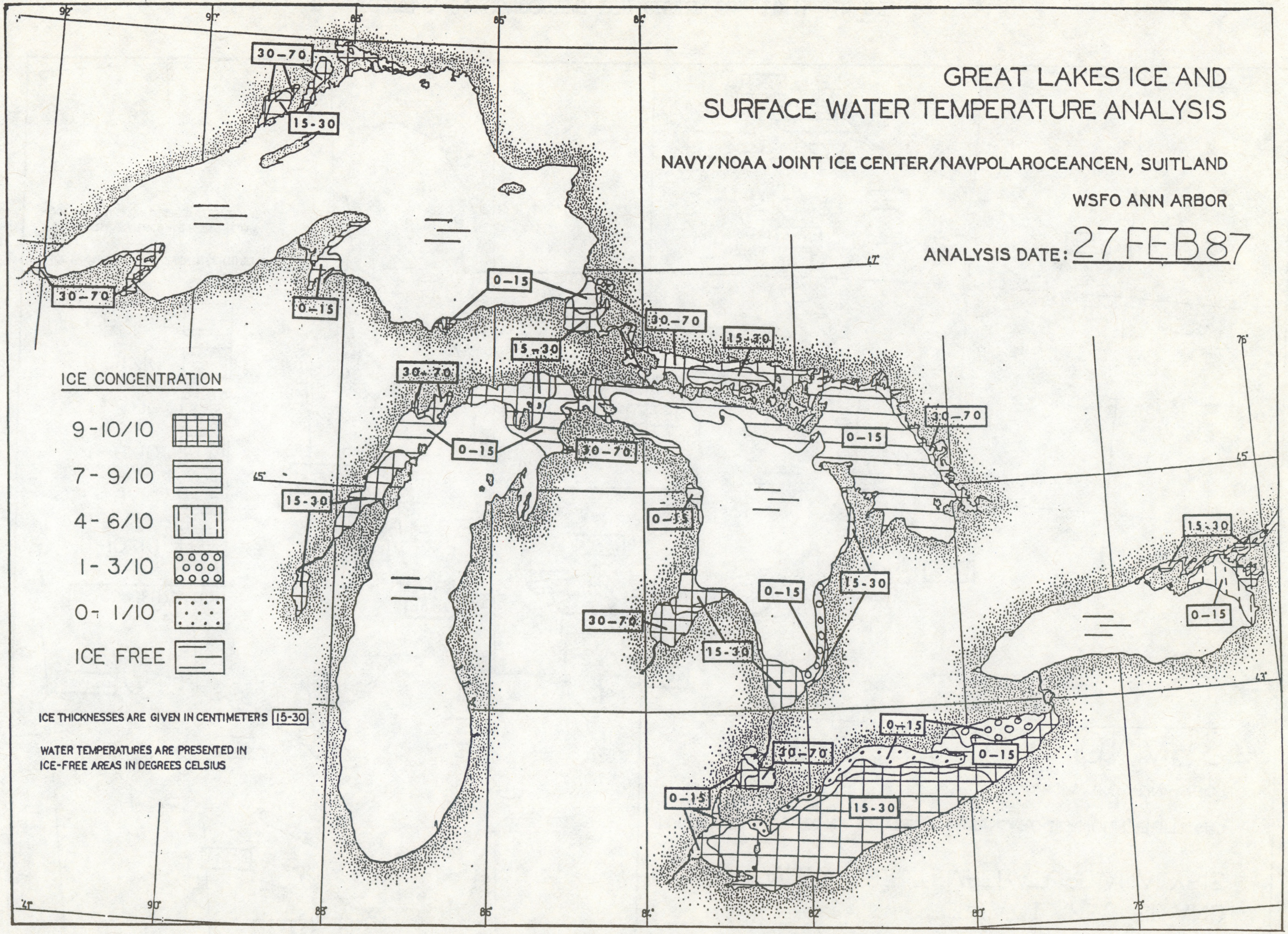

FIGURE A-8. COMPOSITE ICE CHART for 27 February 87.

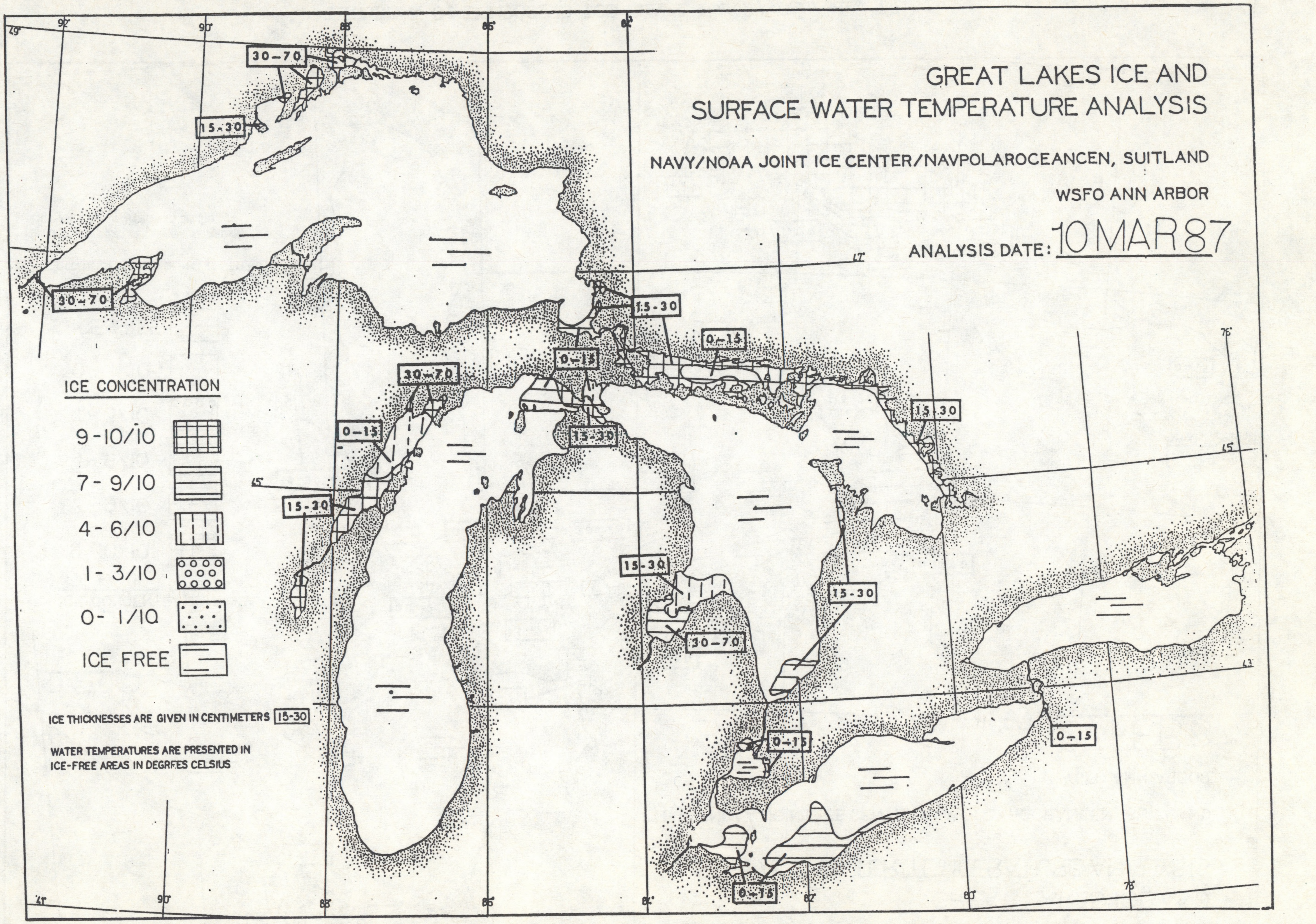

FIGURE A-9. COMPOSITE ICE CHART for 10 March 87.

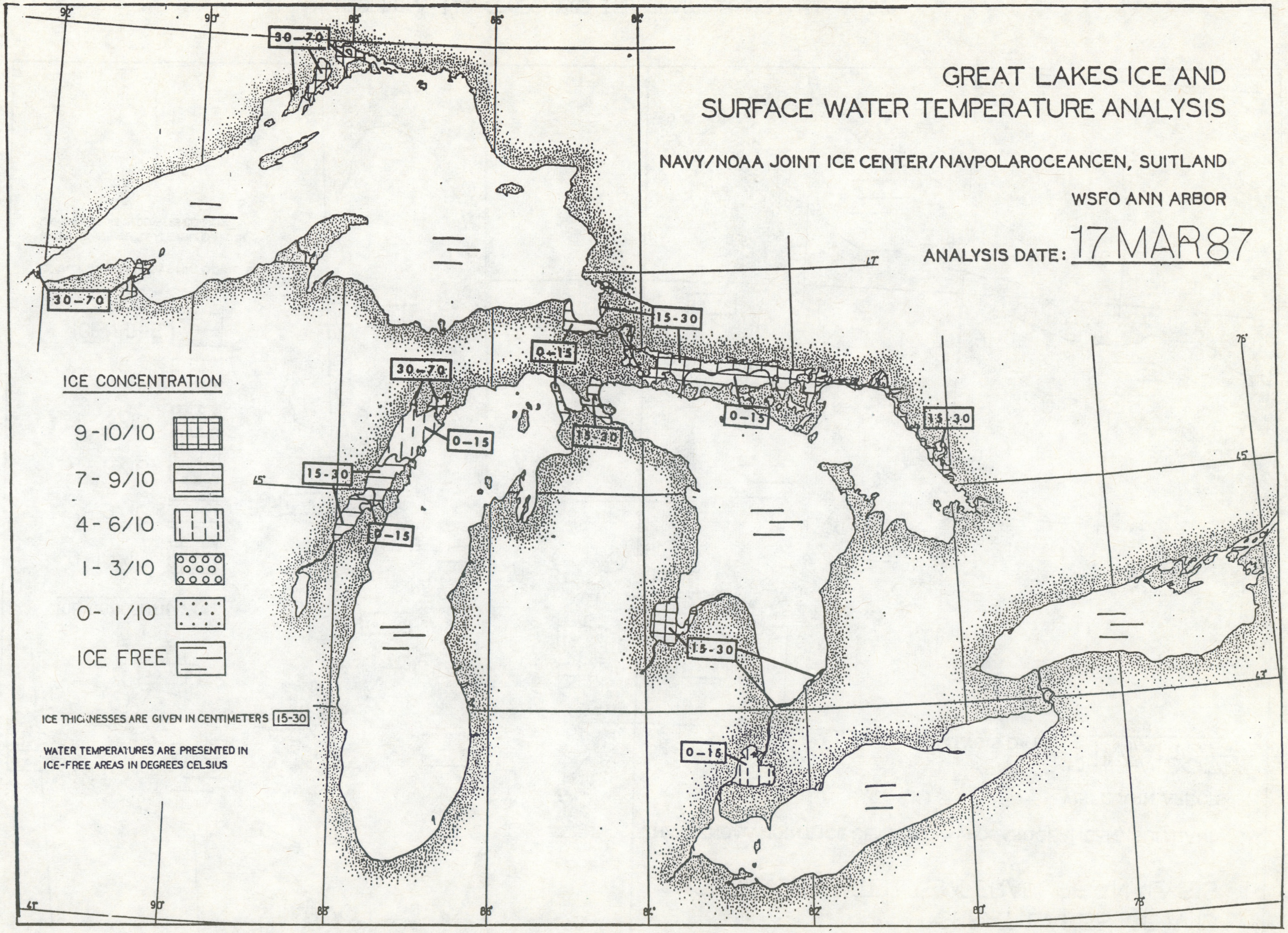

FIGURE A-10. COMPOSITE ICE CHART for 17 March 87.

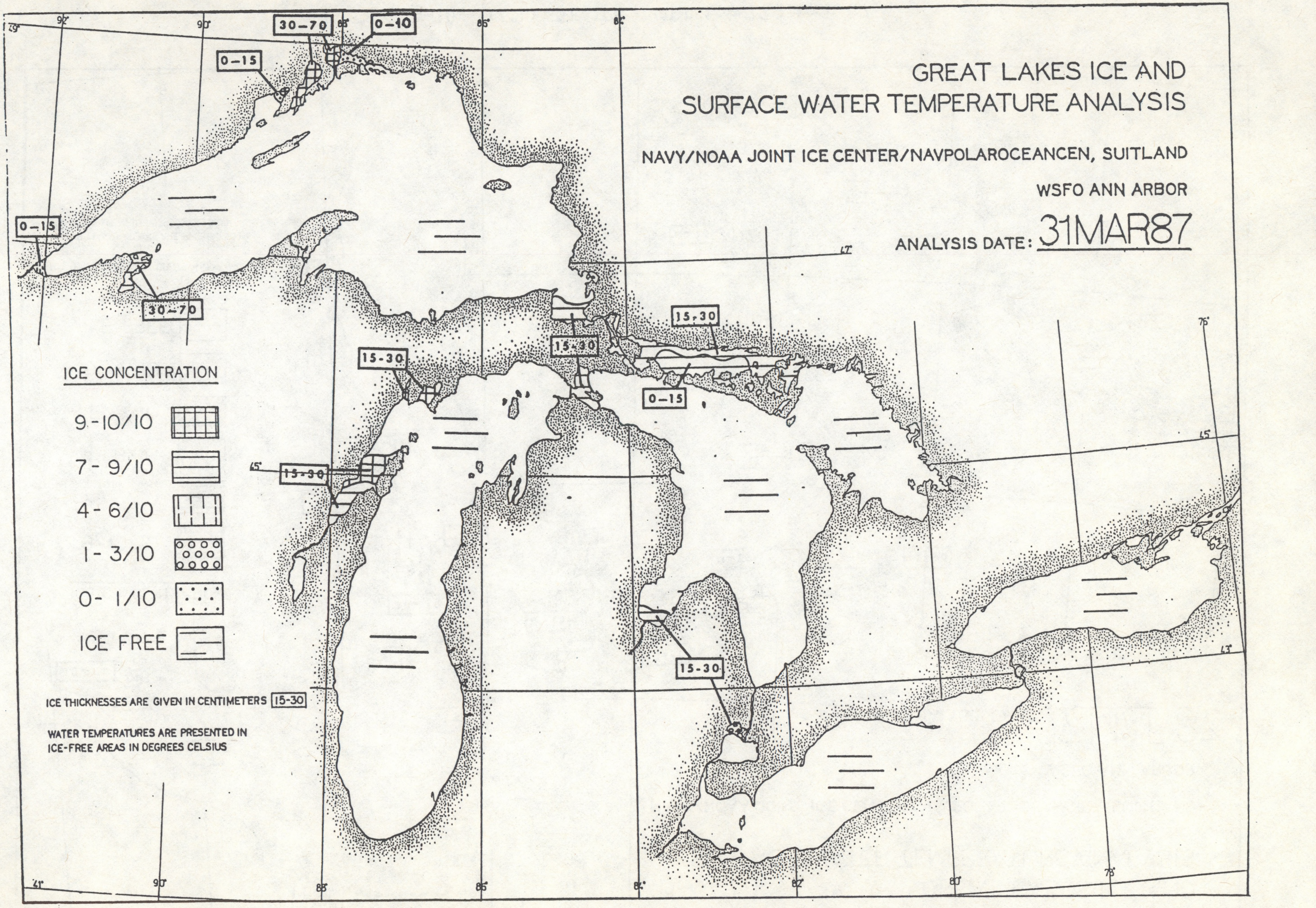

FIGURE A-11. COMPOSITE ICE CHART for 31 March 87.

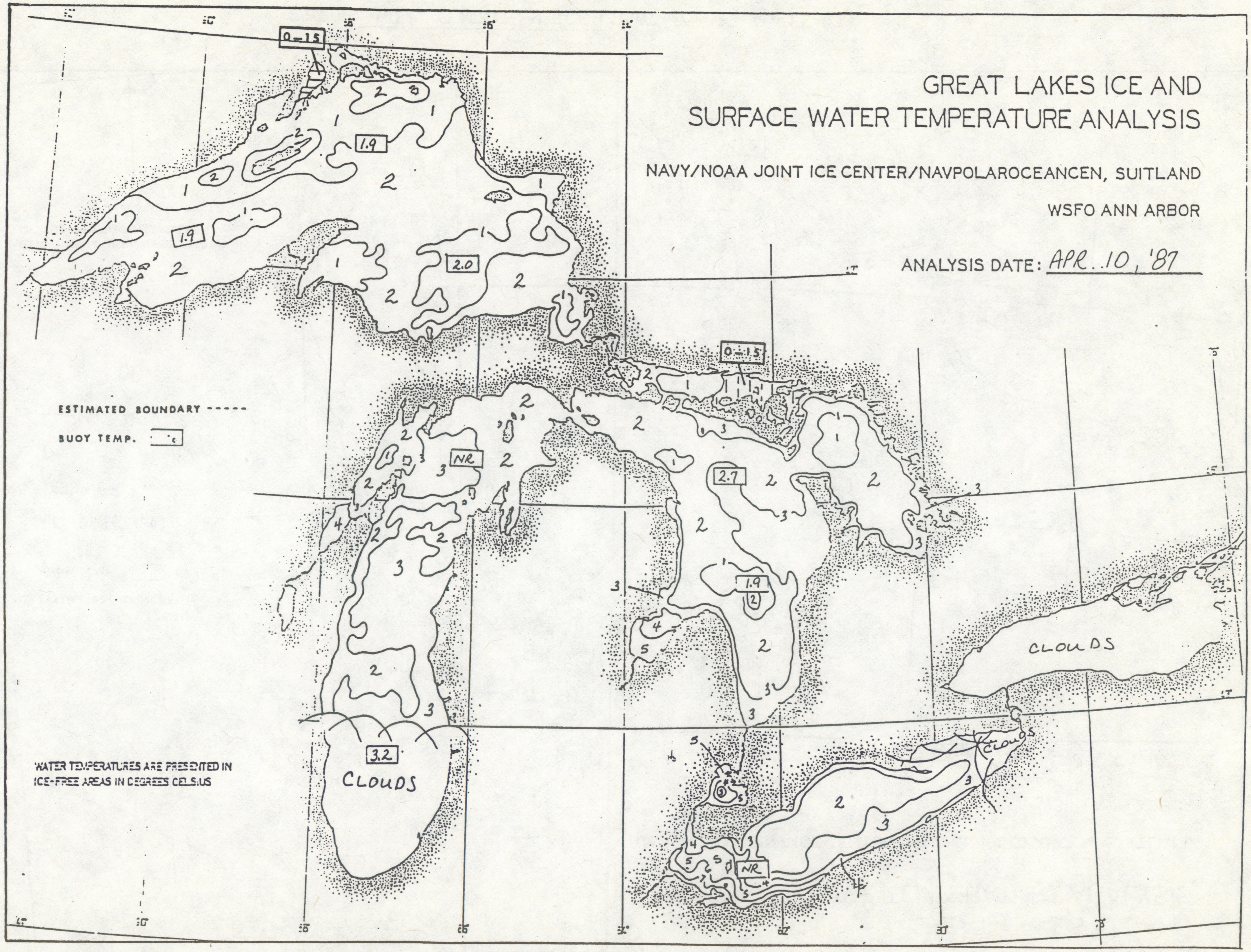

FIGURE A-12. COMPOSITE ICE CHART for 10 April 87.

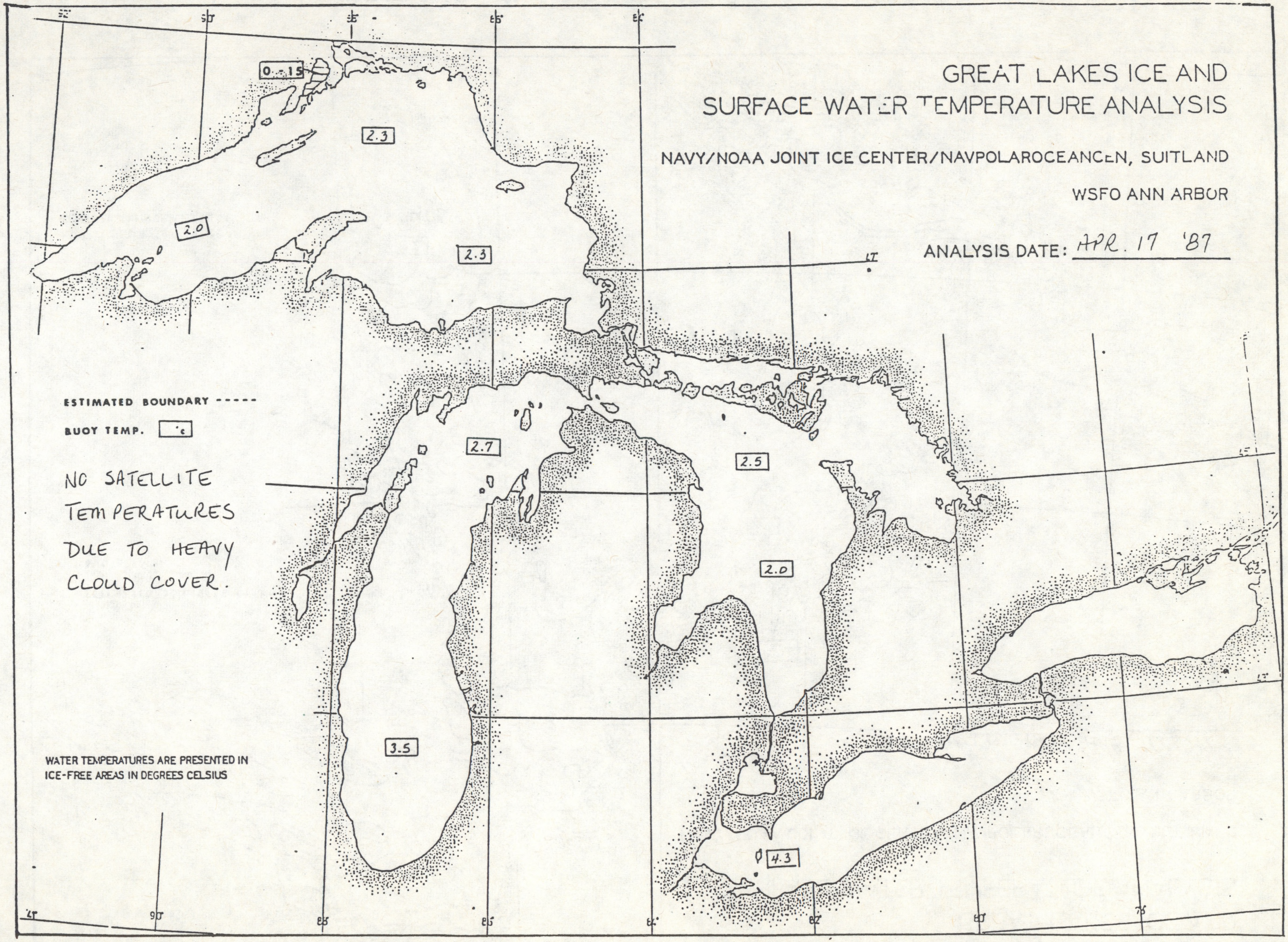

FIGURE A-13. COMPOSITE ICE CHART for 17 April 87.

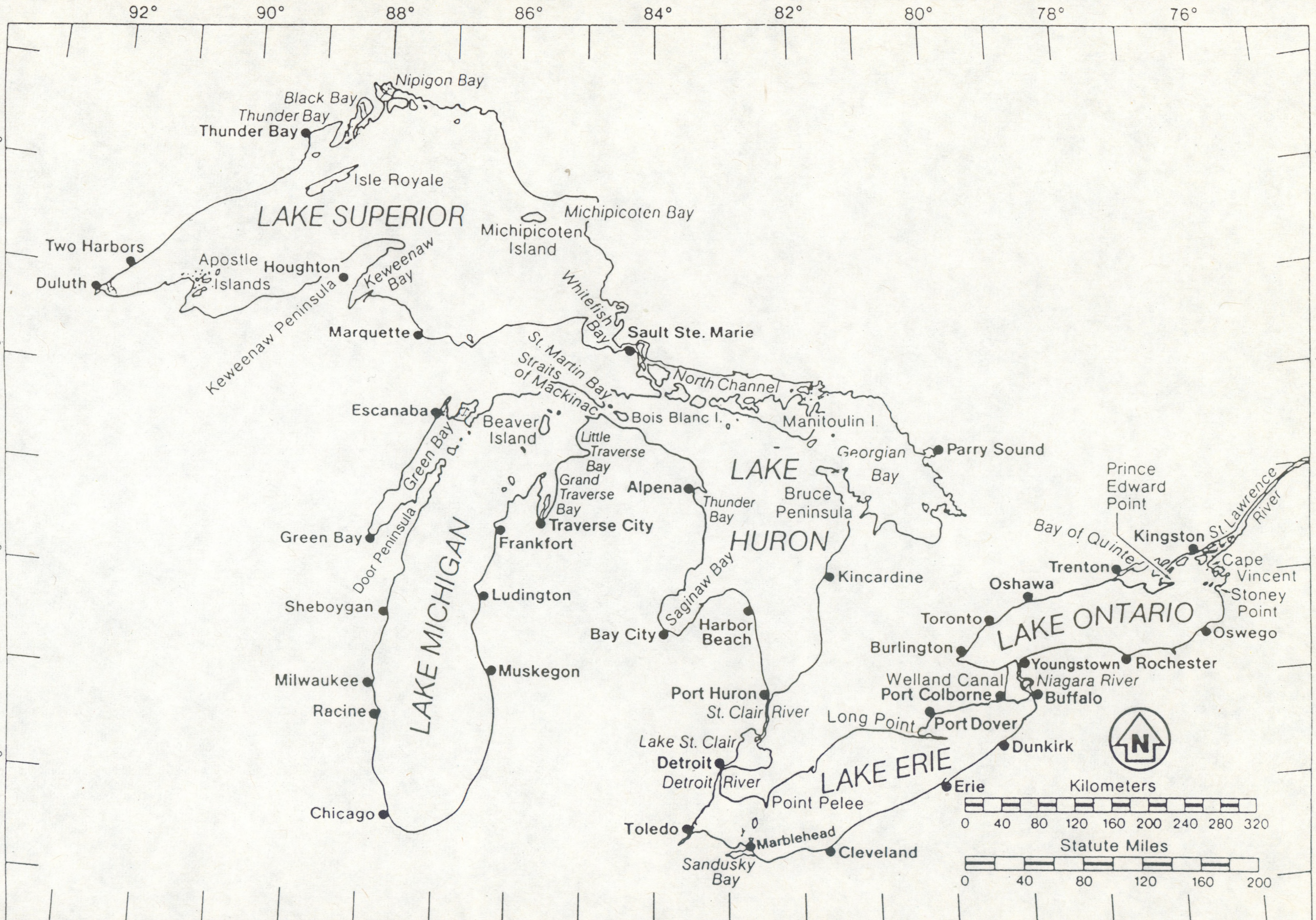

FIGURE A- 14 Place names on the Great Lakes

(Continued from inside front cover)

NOAA SCIENTIFIC AND TECHNICAL PUBLICATIONS

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