NOAA Technical Memorandum NESS 118

DEPARTMENT OF COMMERCE ★ UNITED STATES OF AMERICA ★

SATELLITE OBSERVATIONS OF GREAT LAKES ICE: 1979-80

Washington, D.C.
July 1983

U.S. DEPARTMENT OF COMMERCE / National Oceanic and Atmospheric Administration / National Environmental Satellite, Data, and Information Service

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NESS 79 Publications and Final Reports on Contracts and Grants, NESS-1975. National Environmental Satellite Service, June 1976, 10 pp. (PB-258-450/AS)

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NESS 84 Winter Snow-Cover Maps of North America and Eurasia From Satellite Records, 1966-1976. Michael Matson, March 1977, 28 pp. (PB-267-393/AS)

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SATELLITE OBSERVATIONS OF GREAT LAKES ICE: 1979-80

Sharolyn Reed Young

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UNITED STATES
DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary

National Oceanic and
Atmospheric Administration
John V. Byrne, Administrator

National Environmental Satellite,
Data, and Information Service
John H. McElroy, Acting
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SATELLITE OBSERVATION OF GREAT LAKES ICE: WINTER 1979-80

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ABSTRACT. Ice conditions on the five Great Lakes and Lake St. Clair were monitored from satellite imagery. The formation, movement, and dissipation of lake ice were traced from December 1979 to April 1980. Wind speeds and directions were correlated with ice movement, and air temperatures were related to ice formation and decay.

INTRODUCTION

This report of the 1979-80 ice season on the Great Lakes monitors the development of ice from mid-December until May. Maximum extent of ice occurred between February 5 and March 14 for all the lakes. Unlike the 1978-79 ice season, Lake Onatrio had a normal ice season. The maximum ice extent was 35 percent coverage as opposed to 80 percent for the previous ice season. Local daily mean weather conditions for stations surrounding the lakes are used. Air temperatures at these stations are correlated with ice formation and degeneration. Ice movement is a function of wind speed and direction.

DATA SOURCES

Satellites

Most of the data were gathered by the Geostationary Operational Environmental Satellite (GOES). The primary sensor onboard is the Visible and Spin Scan Radiometer (VISSR) which is sensitive to visible radiation between 0.55 and 0.75 um and infrared radiation between 10.5 and 12.5 um. Resolution for VISSR is 1 km in the visible and 8 km in the infrared. All GOES data are from the VISSR visible channel.

The remaining data were gathered by NOAA's other operational satellite, TIROS-N. TIROS-N is the first in a series of NOAA's third-generation polar orbiting satellites. The primary sensor onboard is the Advanced Very High Resolution Radiometer (AVHRR). AVHRR is a five-channel scanning radiometer with resolution of 1.1 km at nadir. All TIROS-N data depicted in 1979 are from the AVHRR visible channel which is sensitive to energy between 0.55 and 0.9 um. All TIROS-N data depicted in 1980 are from the AVHRR visible channel which is sensitive to energy between 0.58 -0.61 um.

Other Sources

Local climatological data were observed at Chicago, Ill.; Alpena, Detroit, Flint, Grand Rapids, Marquette, and Sault Ste. Marie, Michigan; Duluth, Minn.; Buffalo, Rochester, and Syracuse, N.Y.; Cleveland and Toledo, Ohio; Erie, Pa.; and Green Bay and Milwaukee, Wis. The Environmental Data and Information Service (EDIS) in Asheville, N.C., provided these data. Especially useful were the daily average air temperature and daily resultant wind speed and direction.

SUMMARY OF THE ICE GENERATION, MOVEMENT, AND DECAY

LAKE SUPERIOR ICE COVERAGE: 1979-80

Air temperatures across Lake Superior (figure 1) were below freezing on November 27. Satellite imagery on December 28 showed ice in Black and Nipigon Bays. Twelve days later on January 10, medium fast ice was visible on Thunder Bay as well as the other two bays mentioned above. Temperatures remained below freezing throughout the remainder of January. Cloud coverage from January 10 through January 30 made viewing of the lakes impossible. Northwesterly winds throughout the month prompted fast ice development on all the shores of the lake.

After January 30, fast ice was visible in the southwestern reaches of Keweenaw Bay. Fast ice was also seen on the eastern edges of the basin near Michipicoten and eastern points north of Sault Ste. Marie. A composite ice analysis showed fast ice appearing east of the Keweenaw Peninsula. Fast ice extended east of Keweenaw Bay and entirely covered Whitefish Bay. It extended 64 km to the north of Coppermine Point. The ice in Black, Thunder, and Nipigon Bays increased to 100 percent thick ice. Thin ice surrounded the northwestern edges of Isle Royale. This thin ice stretched from northwest of Isle Royale to Pie Island and southwest to Grand Marais in eastern Minnesota.

Air temperatures at Duluth, Marquette, and Sault Ste. Marie were all below freezing almost every day in February. This cold weather was reflected in Lake Superior's ice coverage as early as February 1. Figures A-8 through A-13 show the rapid growth of ice. Maximum extent of ice for Lake Superior occurred during February 1-8. Thin ice completely covered the eastern half of the lake.

On February 12, after a day of brisk northwesterly winds, a lead developed along the entire northern shore. This lead appeared to be refreezing as seen from TIROS-N satellite imagery of February 13 (figure A-15). Pack ice with narrow fractures containing new thin ice filled the western half of the lake. On February 14, A thick pack of the ice appeared to have separated and drifted northeast of Isle Royale. By February 21, open water was on three-fourths of the eastern half of the lake. By February 26, open water was visible from Duluth to Otter Head and Marquette to Pie Island. By March 6, the only open water was an area that was greater than 40 meters in length and 35 meters in width in the eastern lake about 64 km north of Munsing.

Several days of cold west winds above 10 knots were responsible for leads which refroze along the entire north shore, eastward of Isle Royale, the Apostle Island, and to the south and east of the Keweenaw Peninsula. West winds prevailed along the northern shore through March 14. Temperatures, though warming, remained below freezing. Fast ice broke into floes and was deposited on the southern shore by the winds. A large fractured ice pack could be seen piled on the northern side of the Keweenaw Peninsula. Clouds covered the southern edge of the eastern lake, but fast ice and wind distributed floes appeared in Chequamegon Bay and the southern side of Beaver Bay.

Record high temperatures of 3°C at both Duluth and Marquette around March 20 combined with increased length of the solar day to cause extensive ice melts. An excellent GOES satellite image of March 30 shows open water from Duluth to Pie Island to Marquette. Loose ice floes were wind distributed north of Chequamegon Bay past Whitefish Bay, north and east of Michipicoten Island. All northern bays remained frozen. Satellite imagery of April 5 showed the lake ice free except for the bays and inlets. Persistent cloud cover prevented observations from April 6 to April 20. Satellite imagery of April 21 showed that the only ice remaining in the lake was thin ice in Black and Nipigon Bays. By May 5, the lake was ice free.

The ice season on Lake Superior began about December 28 and ended May 5, a total of 130 days. Maximum ice coverage of approximately 95 percent occurred around March 14. Maximum ice cover, though short lived, occurred a full two weeks ahead of normal.

LAKE MICHIGAN ICE COVERAGE: 1979-80

On Lake Michigan (figure 2), ice was first detected in the southern tip of Green Bay on December 28. Air temperatures were below freezing until December 25. By January 8, thin fast ice appeared on the northern shore of the lake. Green Bay was 70 percent covered with thin ice. January 10-19 was a period of rising and falling air temperatures. The winds were from the west at 8-10 knots. This brief period of changing weather caused ice to form continuously and melt along the western shore from Port Washington to Chicago. After January 19, air temperatures fell below freezing. The fast ice extended approximately 16 km from the shore. Fast ice also cvered the Straits of Mackinac from Petoskey, Michigan to Manistique, Wisconsin.

Persistent cloud cover during the month of February made viewing the lake difficult. Satellite imagery of February 26 showed that Green Bay was completely covered (figure A-18). Ice of 70-90 percent concentration extended along the western shore southward and near Gary, Indiana. From February 29 to March 6, the average air temperature was around -8° accompanied by cold northerly winds which developed into low, stationary clouds over the lake.

Satellite imagery of March 11-15 showed the maximum ice coverage of Green Bay, which was 100 percent. Northern Lake Michigan was 70-90 percent ice covered. Southern Lake Michigan showed fast ice over much of the lower lake and open water south of Manitou Island. Fast ice formed a half circle in the southern tip of the lake from Manitou to 50 km north of Muskegon (figure A-25).

Southerly and northerly winds accompanied by above-freezing air temperatures on March 19 prompted the ice to break up and melt (figure A-26). Figure 26 shows a significant loss of ice from the March 15 satellite picture. Small floes spread throughout Mackinac Bay and ice markedly decreased on the western shore. A new lead appeared in the upper part of Green Bay. Temperatures throughout the remainder of March continued to rise at stations across the lake. By March 27, the southern half of the lake was totally ice free. The area between Washington Island and Point Detour appeared to be open water. Fast ice still lingered in the Straits of Mackinac and north of Grand Traverse Bay. Significant ice melt continued throughout the first week of April. Clouds prevented viewing of the lakes between April 6-15. On April 17, all the lake was ice free except the southeastern shore of Green Bay.

The ice season lasted about 114 days. Ice was first observed on Green Bay around December 28 and lasted until April 30. Maximum ice cover was reached around March 13 with approximately 40 percent coverage.

LAKE HURON ICE COVERAGE: 1979-80

Daily average air temperatures over Lake Huron (figure 3) fell below freezing on November 28 but rose again in December and remained above freezing throughout most of the month. By December 28, satellite GOES images showed ice in the North Channel and fast ice along the eastern coast.

On January 8, fast ice was visible along the western shore of Lake Huron. This ice continued southward into Saginaw Bay. Two days later, on January 10, the North Channel was 90 percent covered with medium ice. There was a warming trend from January 13-22 that created leads along the eastern and western coasts. Air temperatures at Alpena were as high as 3°C. Temperatures around Sault Ste. Marie dropped below -18°C on January 24 which resulted in the formation of thick ice over 90-100 percent of the North Channel. Fast ice lined the eastern coast of Georgian Bay. By January 30, the northeastern section of the bay was completely covered with ice. Thin ice covered the areas near the bay. The Straits of Mackinac also had 100 percent ice coverage. The area south of Harbor Beach was now 90 percent ice covered with a patch of open water at the tip of the lake near Port Huron.

By February 1, open water existed only in the center of the lake and measured 160 km by 200 km. Sixty percent of the ice south of Manitoulin Island consisted of medium floes. Lake Huron ice cover peaked at 95 percent on February 5 with concentrations of thick ice in the open lake. A patch of water in the center of Huron remained open from February 7-12. Higher temperatures and winds from the southwest at 2 to 10 knots formed a lead which stretched about 110 km in width and extended from Manitoulin Island down to Port Huron. The fast ice increased in thickness along the north shore due to southwesterly winds blowing against the coast.

By February 14, the lower half of the lead south of Harbor Beach and Goderich had refrozen, and the fast ice along the eastern coast was much thicker. From February 15-18, the lake was cloud covered. On February 19, in response to air temperatures 0°C - 4°C, the lead south of Harbor Beach decreased in size. The remainder of the lake was completely ice covered. During the week February 20-27, the air temperature around the lake fell. Westerly winds reduced the ice concentration along the western shore.

During the first two weeks of March, air temperatures were higher but remained below freezing. These temperatures, combined with westerly winds, thinned the ice and resulted in lead formations on the eastern shore of the lake. By March 12, the Straits of Mackinac to Harbor Beach were open. Ice remained in the bays and surrounding areas. Southwesterly winds and above freezing temperatures on March 19 and 20 opened up the central part of the lake. Leads were visible along the entire western bank of Georgian Bay. North Channel and Saginaw Bay remained 100 percent frozen.

By March 30, ice had decreased in Georgian Bay leaving only fast ice along the east shore which continued into North Channel. Ice was clustered along the eastern shore from Port Huron northward to Saugeen Peninsula. Ice in Saginaw Bay decreased rapidly by April 5 and fast ice in Georgian Bay was much thinner than previously observed. Persistent low cloudiness covered Lake Huron from April 6 - 15. On April 16, the only ice remaining in the lake was in the North Channel. There was open water throughout 80 percent of the channel and 20 percent thin ice over the remainder of the channel. On April 21, the lake was ice free.

Lake Huron's ice season began December 28 and lasted until April 21, a total of 122 days. A maximum coverage of 95 percent ice occurred on February 5.

LAKE ST. CLAIR COVERAGE: 1979-80

Satellite imagery showed that the first ice in Lake St. Clair (figure 4), appeared on December 15 (figure A-1). Winds from the west at 3 to 16 knots compressed the ice against the coast. Thin ice covered 60 percent of the lake, and fast ice was seen along the eastern shore on January 8. There was no significant change in the ice during the next several days. Imagery from January 21 showed that thin ice now covered 70-90 percent of the basin (figure A-4).

The Detroit River connecting Lake St. Clair to Lake Erie has significant currents which hinder ice growth on Lake St. Clair. Between January 21 and 26, air temperatures were -10°C to 2°C. This resulted in the ice concentrations increasing to 100 percent ice coverage (figure A-5). The lake remained frozen until March 6 when a small lead opened on the western shore. This lead was due to a slight warming trend accompanied by 6 - 12 knot winds from the southwest (figure A-22).

On March 16, air temperatures rose above freezing causing the ice to thaw rapidly. Satellite imagery from March 19 showed a lead stretching about 8 km across the lake (figure A-26). During the next 9 days, air temperatures as high as 10°C aided in melting the remaining medium and thin ice. On March 27, only 10-20 percent of the lake contained ice. The lake was ice free on April 1.

The ice season for Lake St. Clair began December 18 and ended April 1, a total of 106 days. Maximum ice coverage occurred from January 10 through March 6.

LAKE ERIE ICE COVER: 1979-80

Air temperatures around Lake Erie (figure 4) were below freezing beginning November 29. Ice was first seen in the lake on December 15 (figure A-1). Extensive cloudiness from December 28 through January 5 obscured viewing the lake's ice coverage. Around January 8, ice could be seen in the shallow western end of the lake. Two days later, on January 10, new ice was seen in the tip of Long Point. Temperatures, up to now, had been below freezing, but a warming trend occurred from January 11-19 causing the ice concentrations to decrease. Temperatures around Toledo dropped below freezing on January 21 resultng in the formation of thicker ice which covered 40-60 percent of the lake (figure A-4).

By January 25, ice covered all the western lake and the area around Pelee and Kelleys Islands. Ice also covered the basin north of Long Point. Westerly and southwesterly winds at 10-18 knots on January 21-25 moved the ice eastward. This created two separate leads, one near Toledo along the western shore and the other between Pelee and Kelleys Islands. Temperatures from January 26 through February 1 remained well below freezing, ranging from -4°C to -11°C. Easterly winds over the next 5 days decreased the leads resulting in a concentration of 70-90 percent ice. Along the shores of Cleveland, Fairport, Erie, and Buffalo, the ice was in narrow strips resulting in about 80 percent coverage.

Lake Erie was 100 percent ice covered on February 4. Thicker ice covered Toledo to Pelee and Kelleys Islands. Ice was evident in the eastern portion of the lake. Refreezing leads lined the northern coast from Pt. Pelee to Buffalo. The area around the Long Point to Sandusky was solidly covered with ice. Near Fairport, the lake was 70 to 90 percent covered with ice (figure A-11). In response to lower temperatures, on February 8 the ice near Fairport increased in concentration and expanded northward about 30 km. Ice just beyond Pt. Erie expanded to 40 km off the coast.

From February 12-18, the lead at Port Stanley expanded southward, joining at Pelee and Kelleys Islands and ending at Cleveland (figure A-17). This extensive lead resulted from westerly winds at 11-14 knots which moved the ice eastward. Solid ice continued west of the islands. Lake Erie's maximum extent of ice coverage occurred on February 18. From February 25-29, northwesterly winds at 5 to 18 knots widened the lead at Port Stanley. The lead stretched from Detroit River eastward to Pt. Pelee and Port Stanley, ending at Buffalo. Northwesterly winds compacted the ice into the lead near Pelee and Kelleys Islands eliminating the lead (figure A-19).

The climate data show that temperatures remained below freezing through March 6. Southwesterly winds at 6 to 16 knots during this time refroze the leads in the northern basin. This resulted in thin ice covering 80 percent of the basin. Satellite data from March 6 showed the reappearance of a lead east of Pelee and Kelleys Islands. Ice in the area west of the islands was thin (figure A-22). On March 9, northerly winds at 5 to 20 knots combined with higher temperatures and resulted in new leads in the western basin (figure A-23). Two days later on March 11, satellite imagery showed a dramatic change in the ice conditions.

A very wide lead appeared in the northern half of Lake Erie because of advection under this northerly flow. A day later, the lead refroze, owing to lower temperatures. The lake appeared to be divided into two distinct portions. The southern half was totally covered with medium to thick ice and the northern half was covered with thin ice (figure A-24).

On March 15, (figure A-24) northwesterly winds blowing at 7 to 16 knots pushed the ice east and southeastward. This created wide leads from Toledo to the Detroit River and east of Pelee and Kelleys Islands. The lead also extended to Long Point (figure A-25). Air temperatures rose above freezing on March 16, reaching 10°C on March 20. The ice commenced its melting season. Satellite imagery on March 19 showed open water in the western third of the lake except near the islands (figure A-26).

Clouds covered Lake Erie from March 20-27. The lake was discernible on March 28. The lake was ice free except for the southeastern basin from Buffalo to Fairport which varied from 30-90 percent coverage of medium ice. During the next four days, the ice cover changed rapidly. The only ice left in the basin was located along the shore from Point Erie to Buffalo. Five days later on April 5, the only ice remaining in the lake was just south of Buffalo along the east coast (figure A-29). The lake was cloudy from April 5-16 and satellite data from April 17 showed the lake ice free.

The ice season on Lake Erie lasted from December 15 through April 17, a total of 124 days. The maximum extent of ice occurred on February 18 with 95 percent of the surface covered.

LAKE ONTARIO ICE COVER: 1979-80

Near the eastern end of Lake Ontario (figure 5), air temperatures at Rochester and Syracuse were generally around freezing until January 20, and then dropped to -15°C by the end of the month. Cloudiness obscured satellite viewing of the lake from January 31 to February 5. By this time, the lake had cooled sufficiently to allow ice to form in the shallow eastern portion. Satellite imagery of February 5 showed a 40-60 percent concentration of thin ice in the eastern basin between Prince Edward Peninsula and Oswego (figure A-12). Continuing low temperatures caused the strait east of Wolfe and Kingston Islands and also in Prince Edward Peninsula to become 90-100 percent ice covered (figure A-13).

Lake Ontario is a deep lake with a small surface area-to-depth ratio. This results in slow ice formation. The entire water column must be cooled to 0°C before ice can form at the surface. Although air temperatures remained around freezing from February 9 to 18, there was no significant change in the ice coverage. A brief warming trend occurred, resulting in a slight decrease in the eastern basin. On February 26, the air temperatures dropped and remained between -15°C and -2°C until March 5. During this period, low temperatures combined with winds from the southeast at 3-17 knots caused the ice in the eastern basin to expand and cover the largest area for the ice season, about 35 percent.

On March 2, 30-40 percent thin ice covered the area 65 km west of Prince Edward Peninsula and southward to Oswego (figure A-20). Four days later on March 6, above freezing temperatures caused the newly formed ice to melt. Ice remained in the northeastern basin around Amherst, Wolfe Island, and northward. Temperatures continued to rise and, by March 9, the bulk of the ice was gone. The remaining ice concentrations were reduced to about 20 percent in the northeastern basin and the tip of the western basin. On March 12, fast ice could still be seen in the western basin north of Owesgo and in the Straits of Prince Edward Peninsula.

Lake Ontario was entirely ice free on March 30 (figure A-27). The ice season began on February 5 and ended on March 30, a total of 55 days of ice coverage. The maximum extent of ice coverage was 35 percent which occurred around March 2.

ACKNOWLEDGMENTS

The author sincerely thanks Jenifer Wartha-Clark, Frances C. Holt, and Donald Wiesnet for their advice and criticisms. Gratitude is also expressed to Gail Heddinghaus who typed the manuscript.

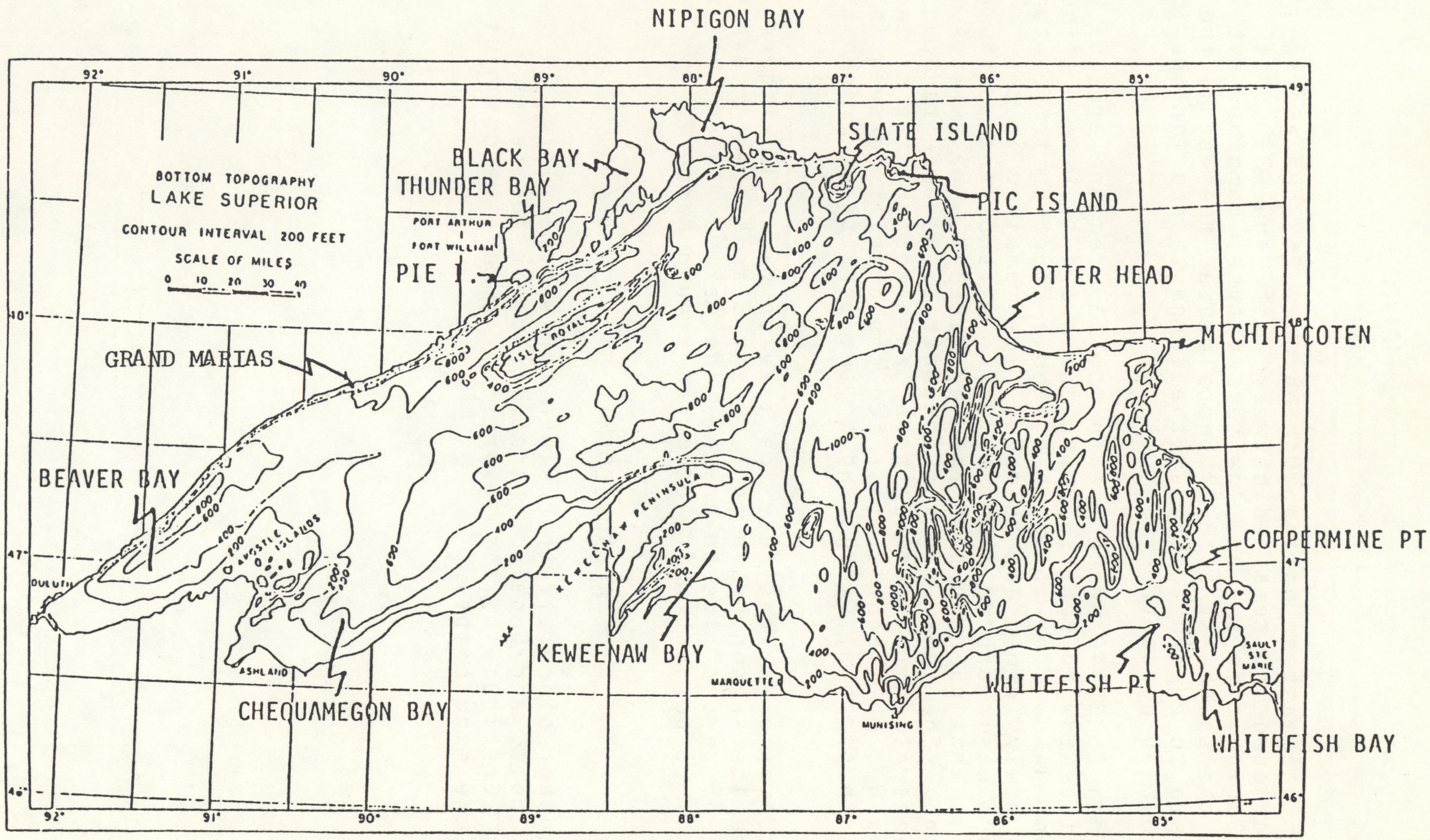


Figure 1. Bathymetric and geographic location chart for Lake Superior.

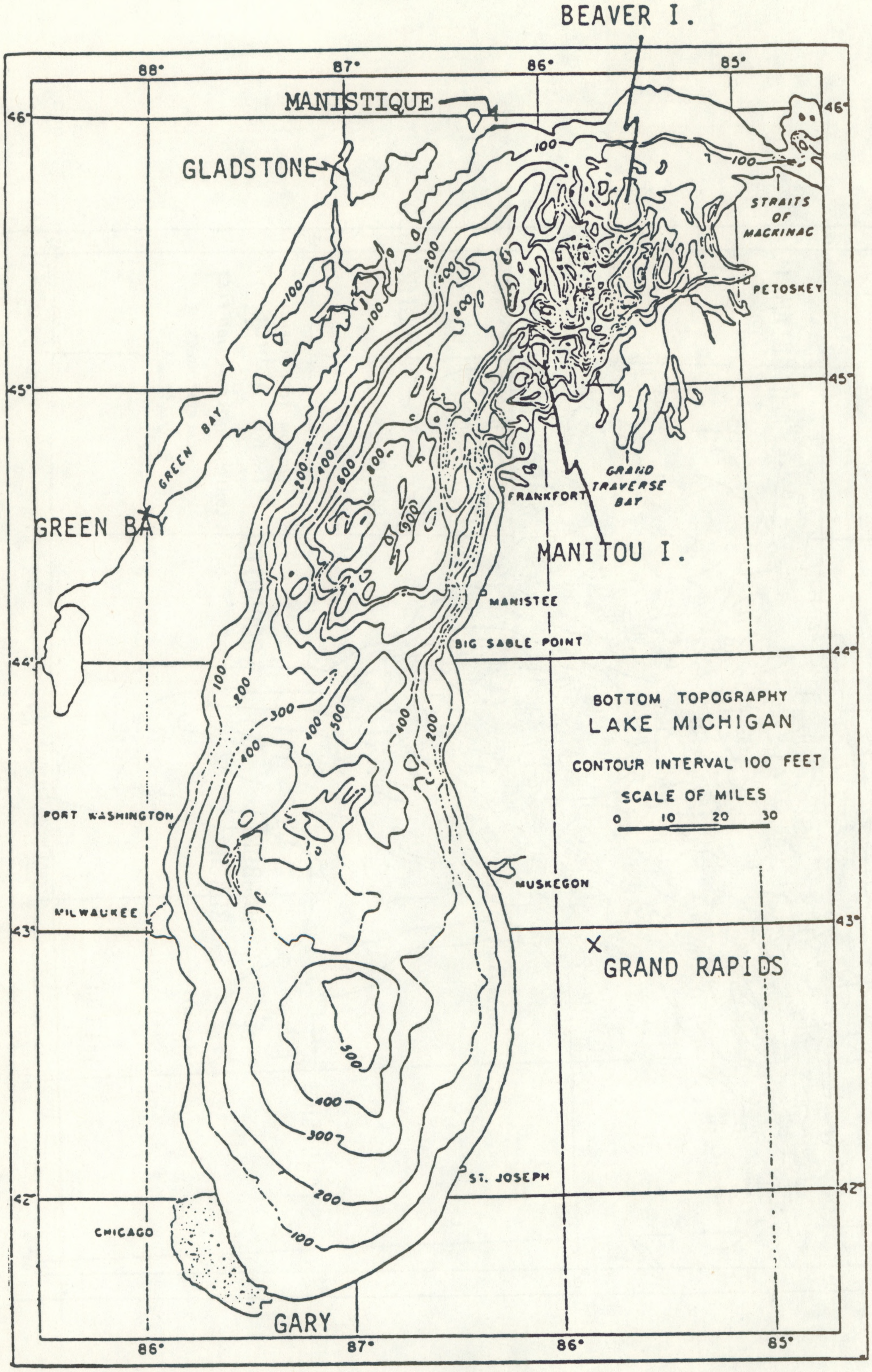


Figure 2. Bathymetric and geographic location chart for Lake Michigan.

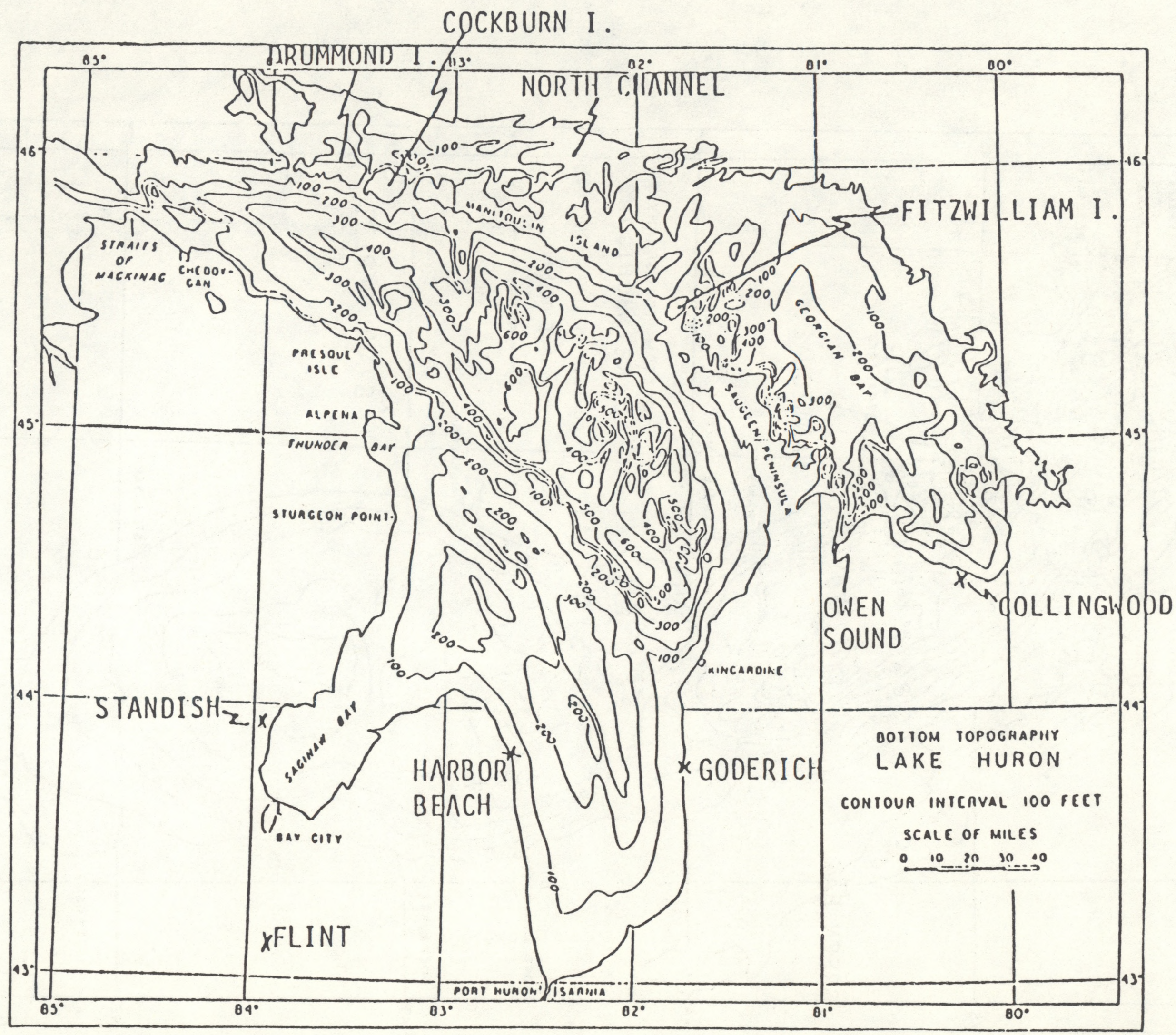


Figure 3. Bathymetric and geographic location chart for Lake Huron.

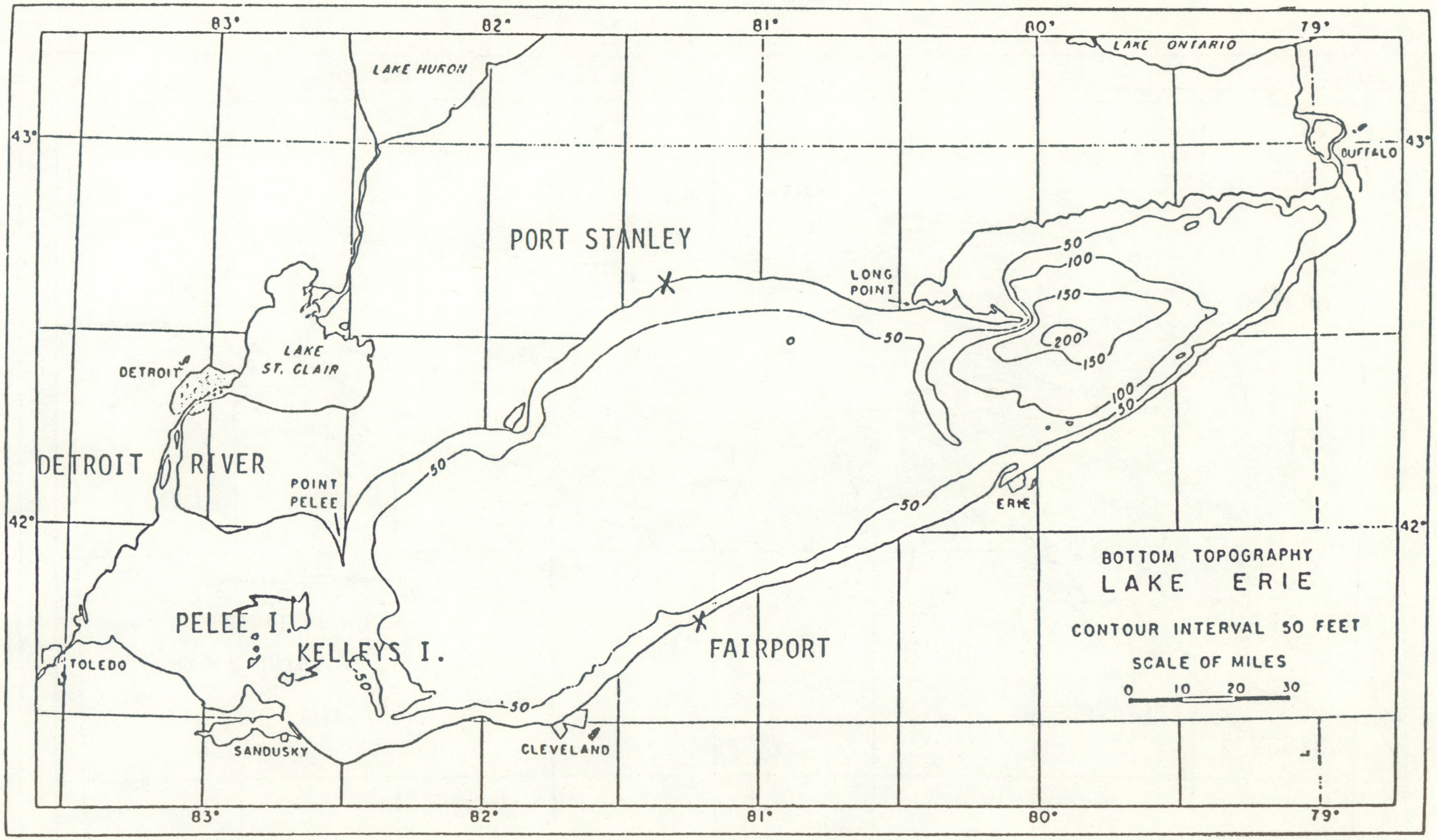


Figure 4. Bathymetric and geographic location chart for Lake Erie and Lake St. Clair.

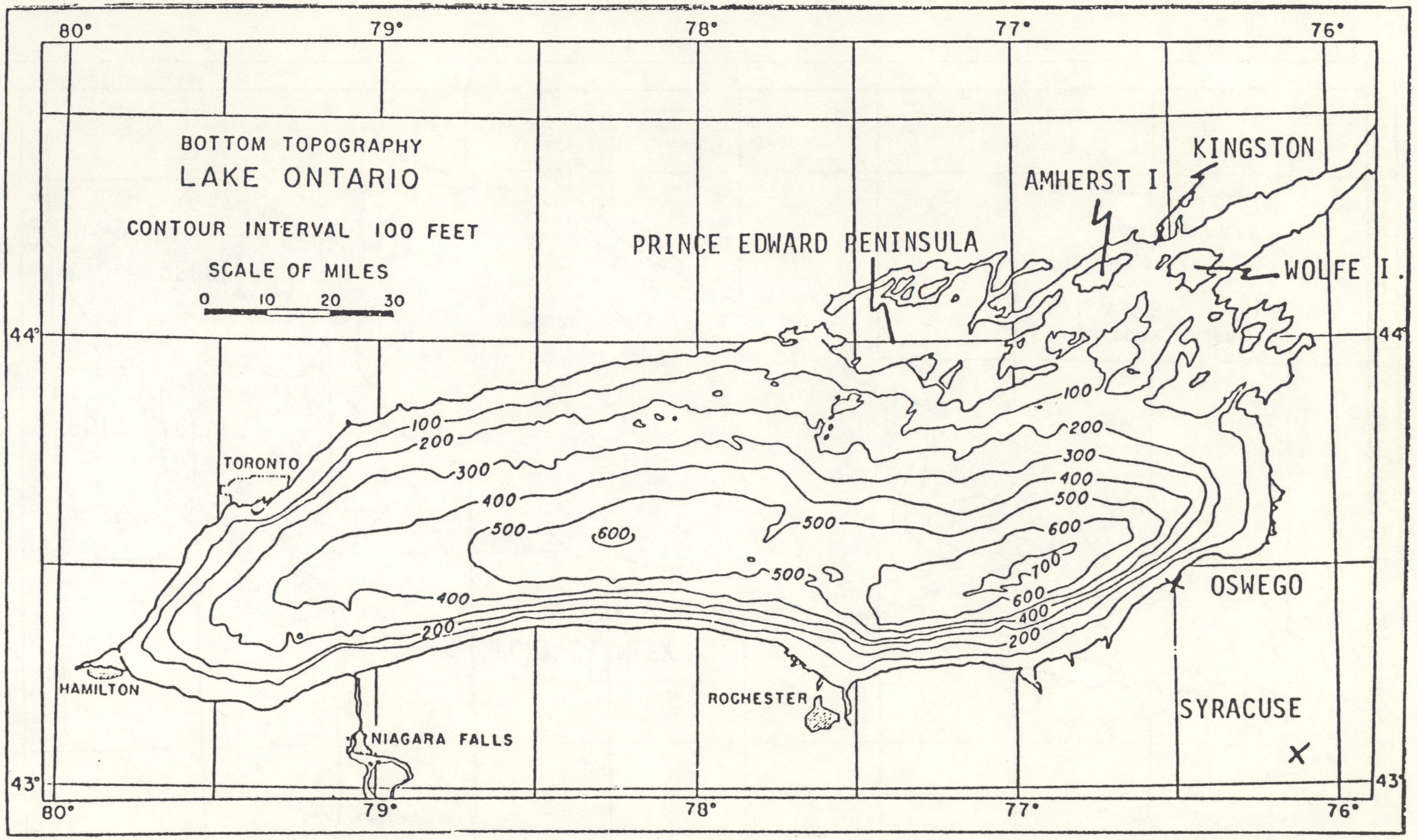
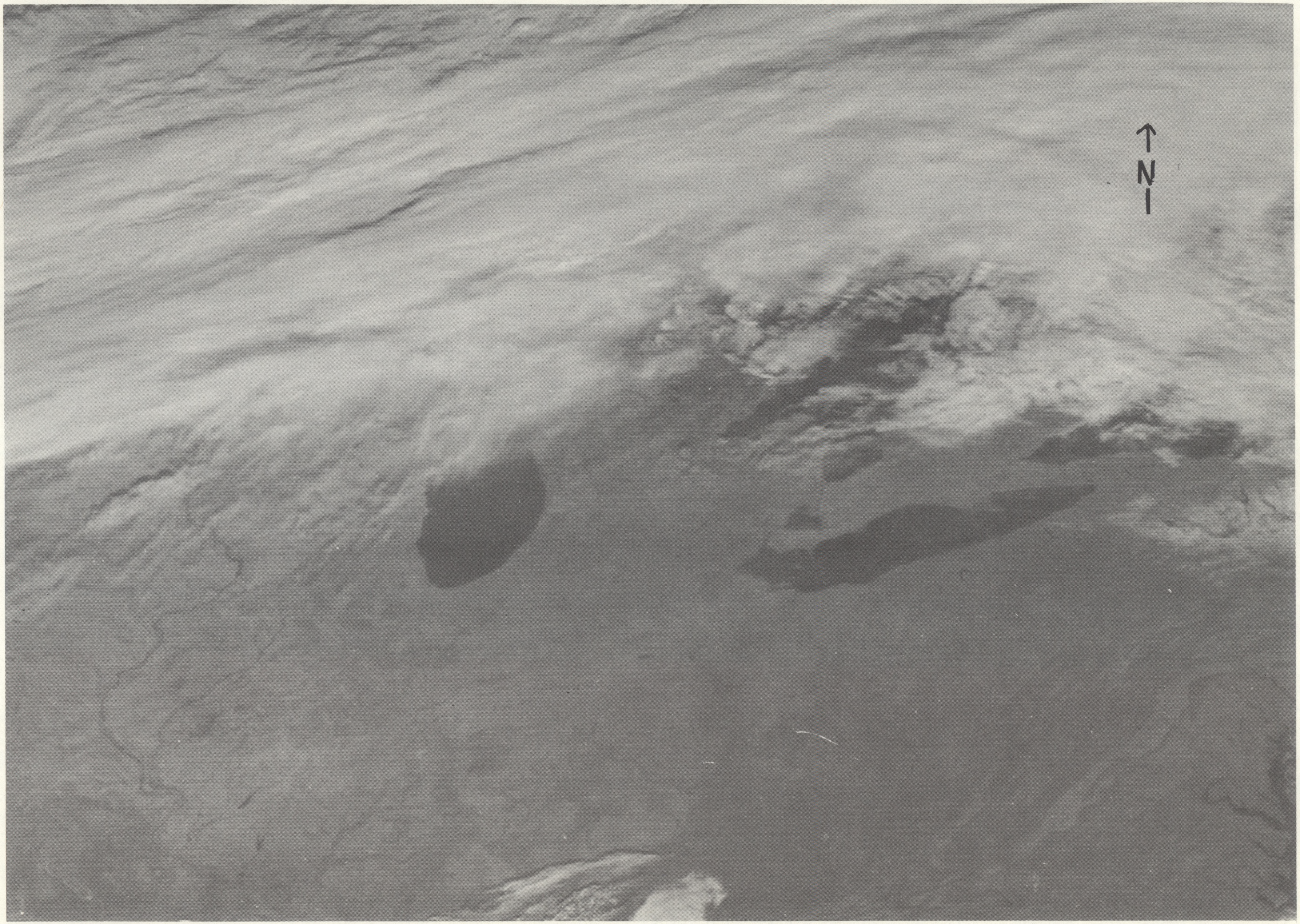


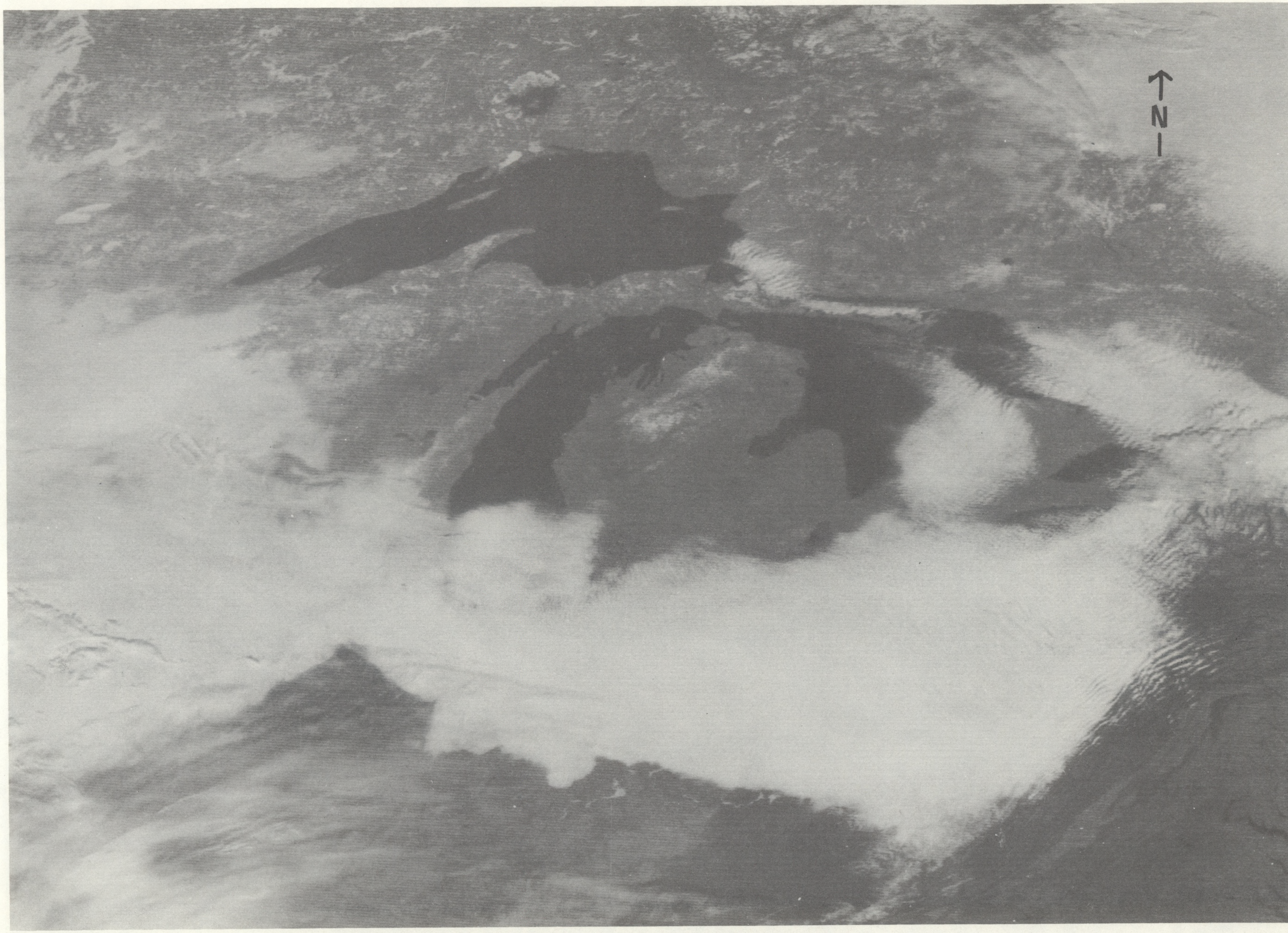
Figure 5. Bathymetric and geographic location chart for Lake Ontario.

Satellite Imagery of Great Lakes Ice

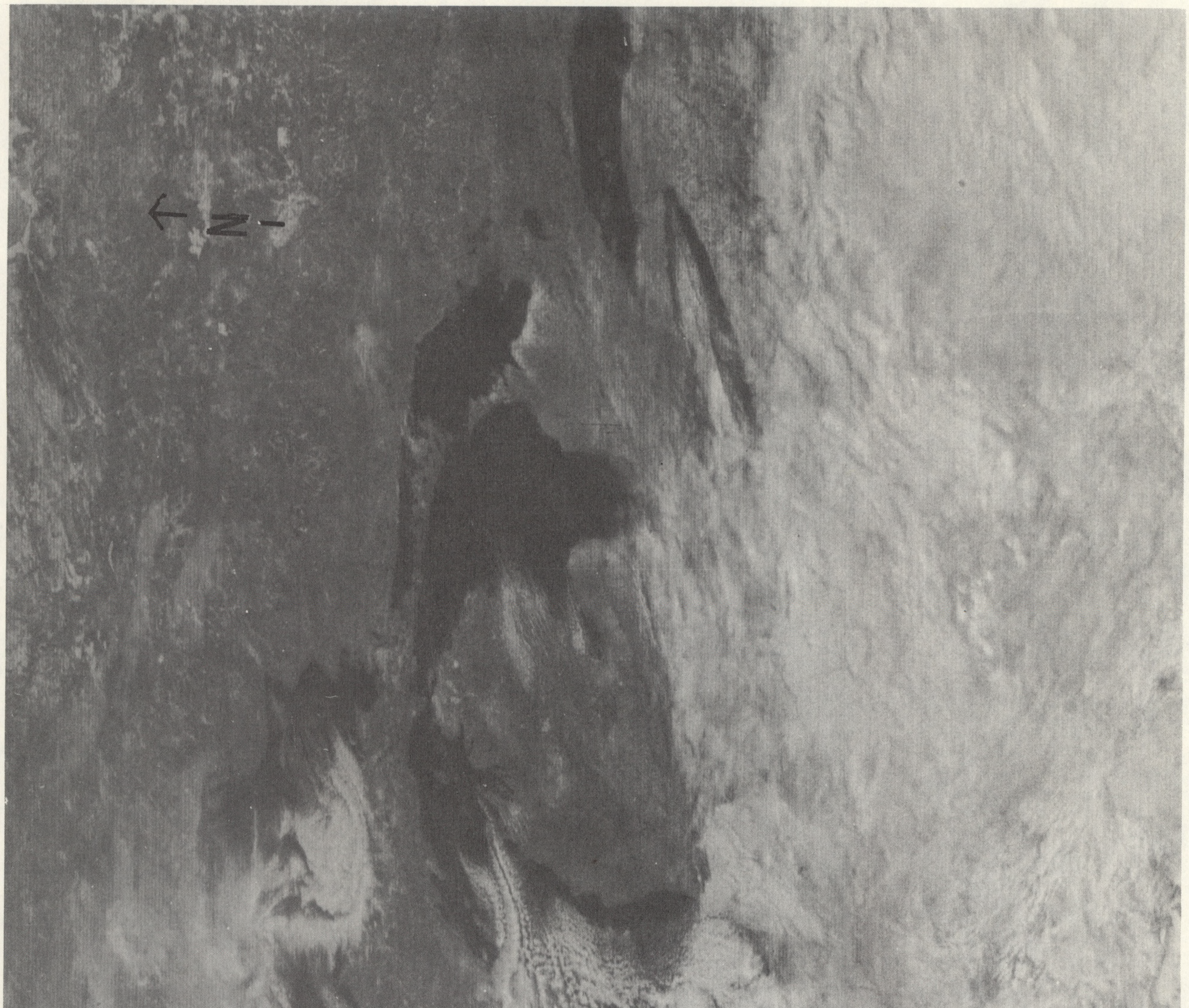
December 15, 1979 through April 27, 1980



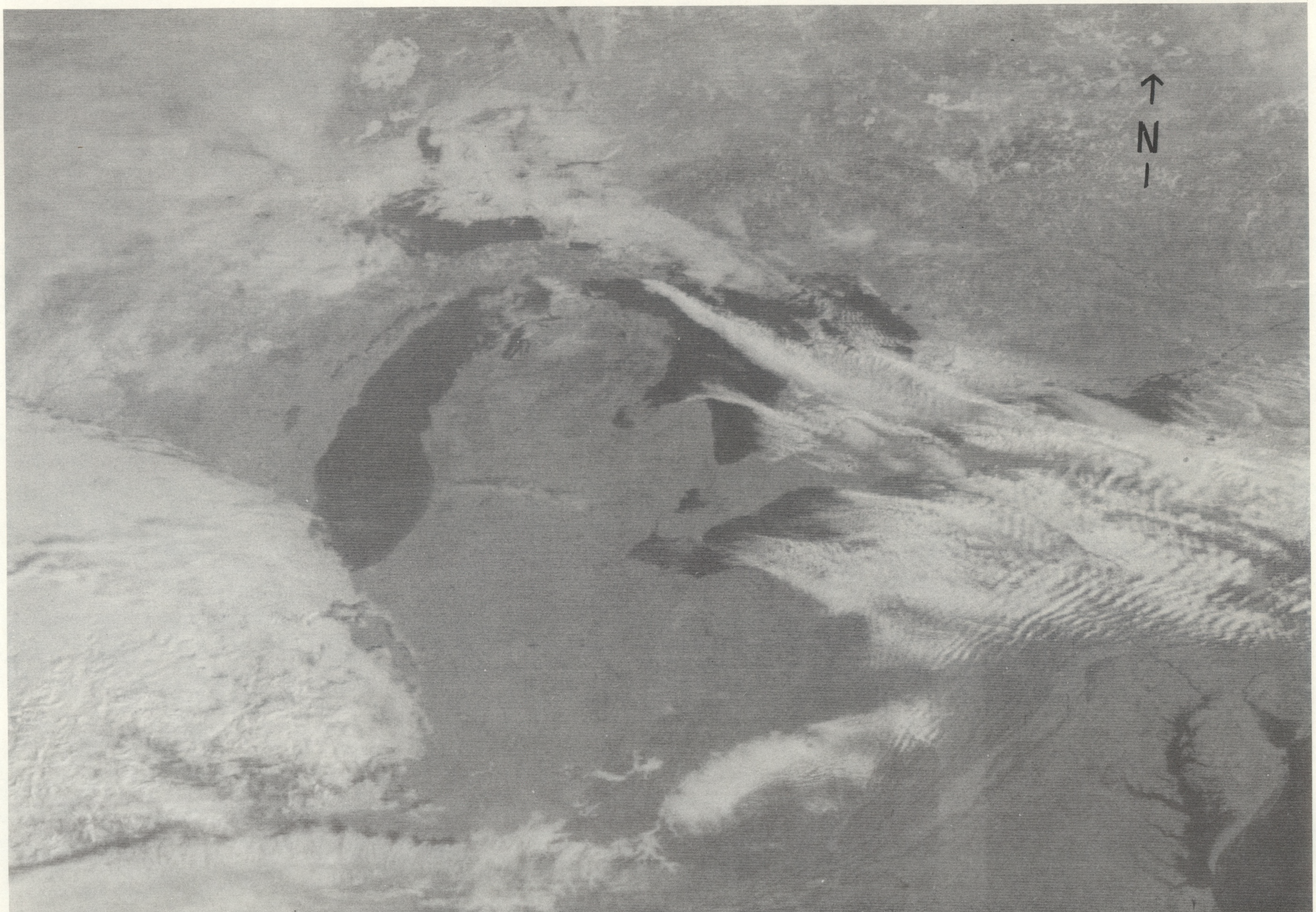
A.1. GOES VISSR image for December 15, 1979



A.2. GOES VISSR image for December 28, 1979

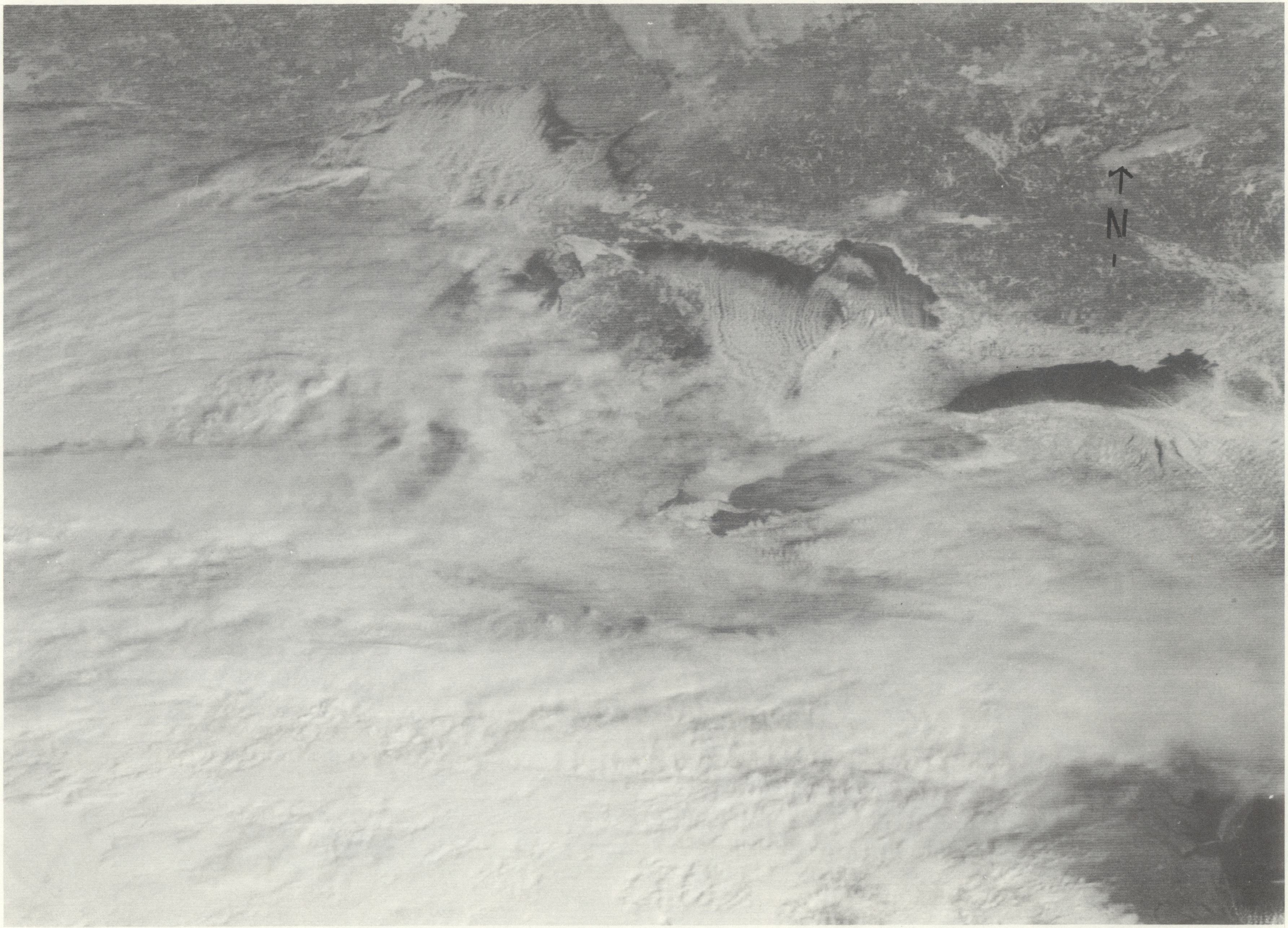


A.3. GOES VISSR image for January 5, 1980

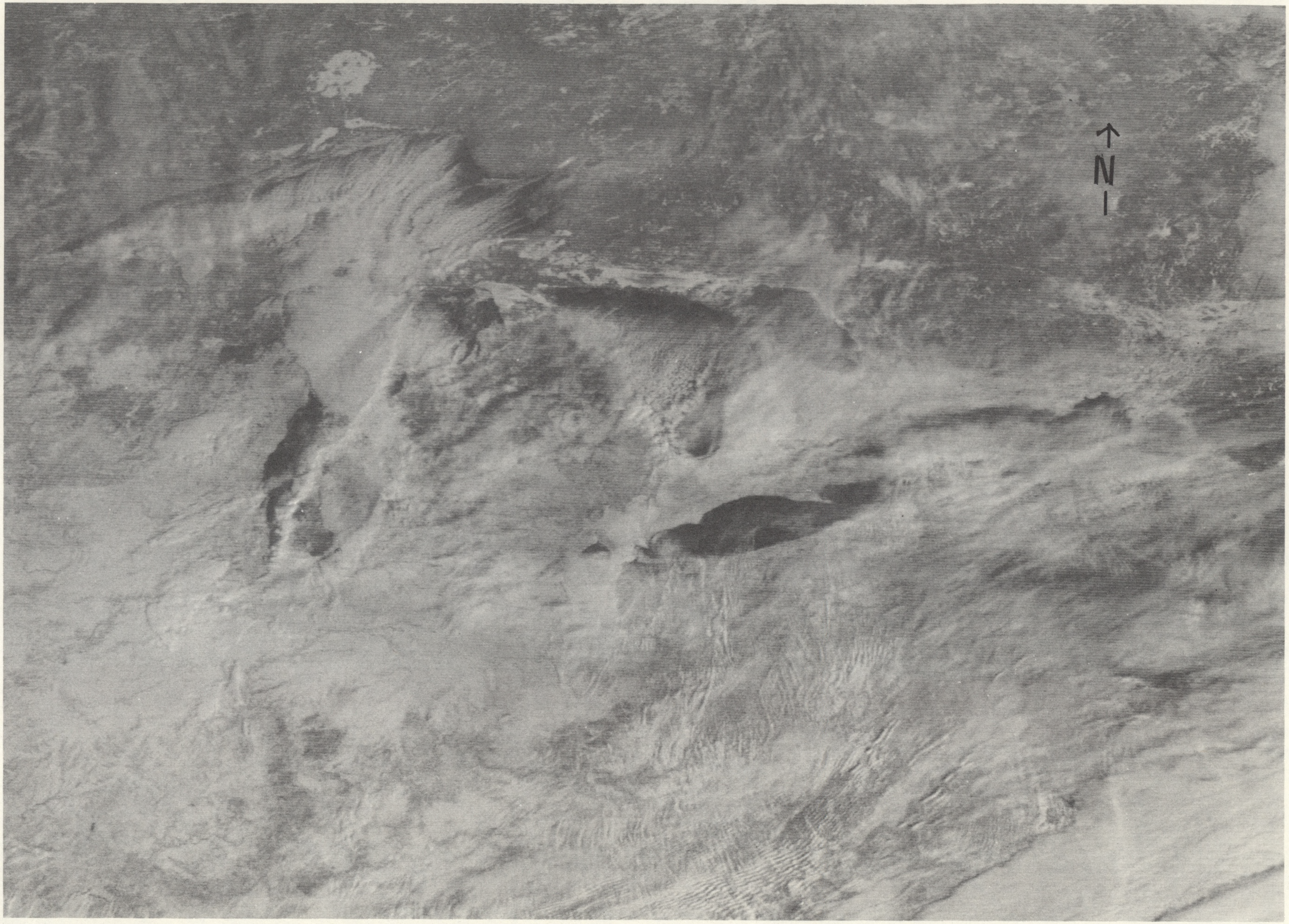


A.4. GOES VISSR Image for January 21, 1980

A.5. GOESS VISSR Image for January 26, 1980

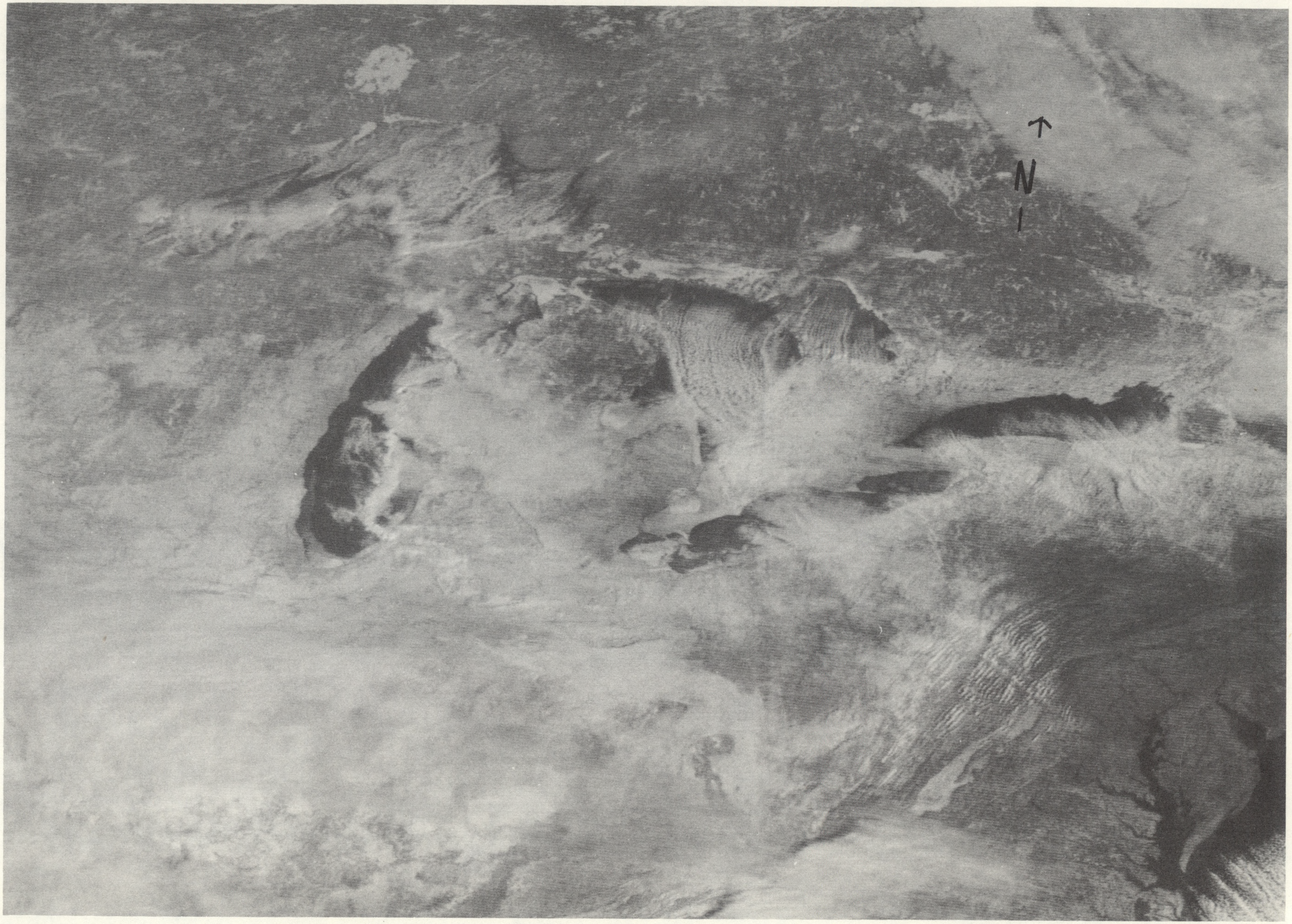


A.6. GOESS VISSR Image for January 30, 1980

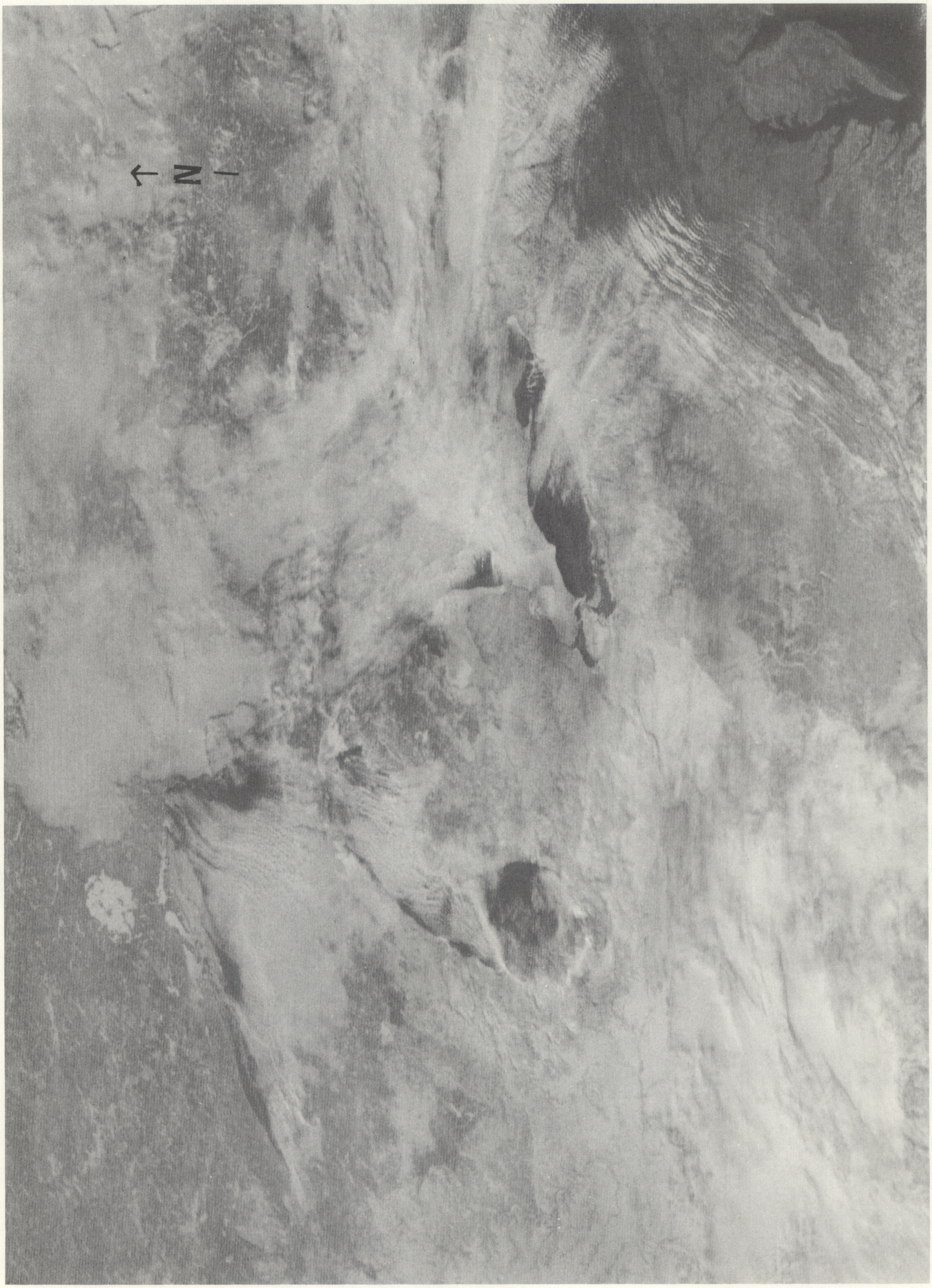


A.7. GOESS VISSR image for January 31, 1980

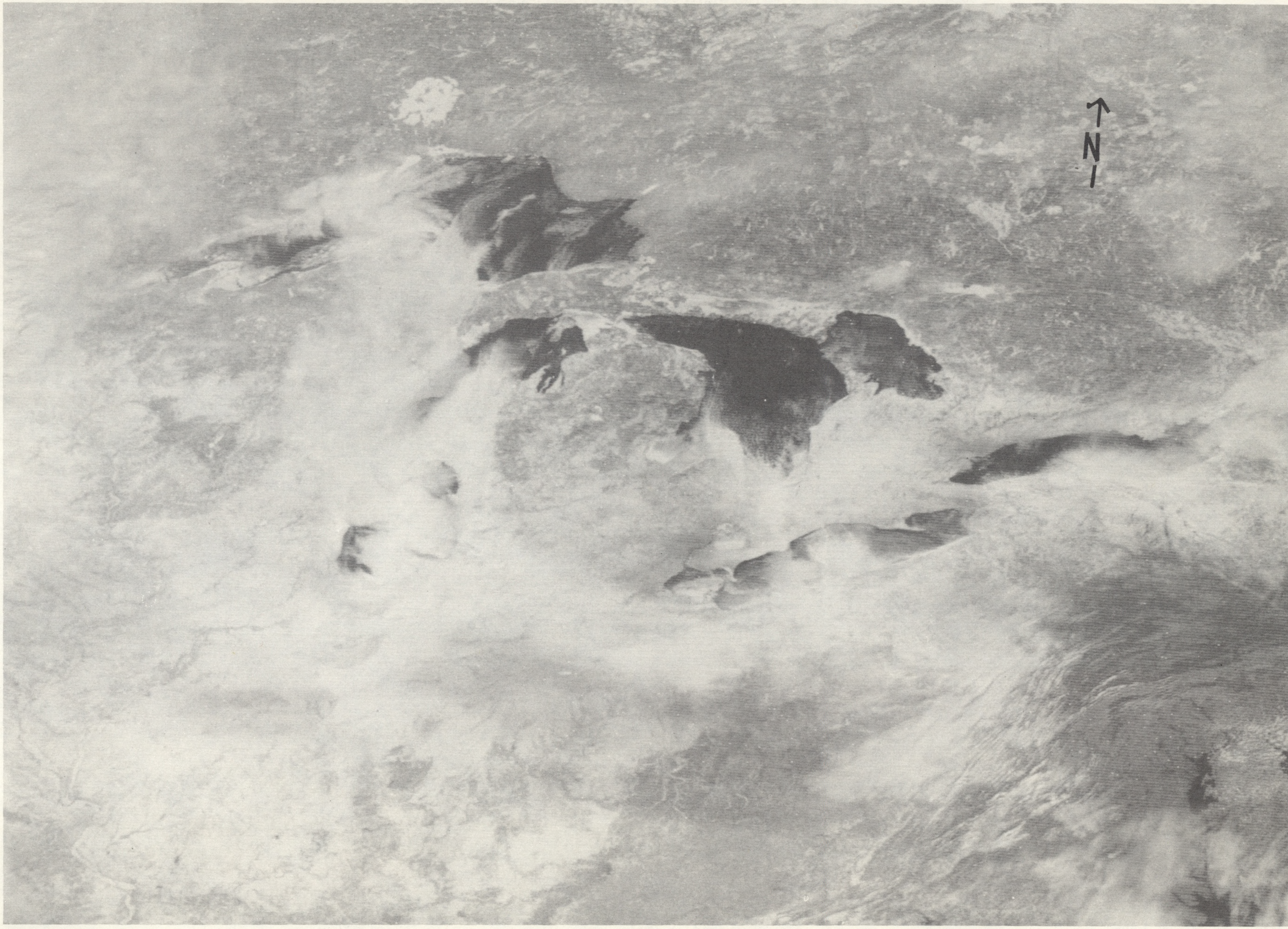
A.8. GOES VISSR image for February 1, 1980



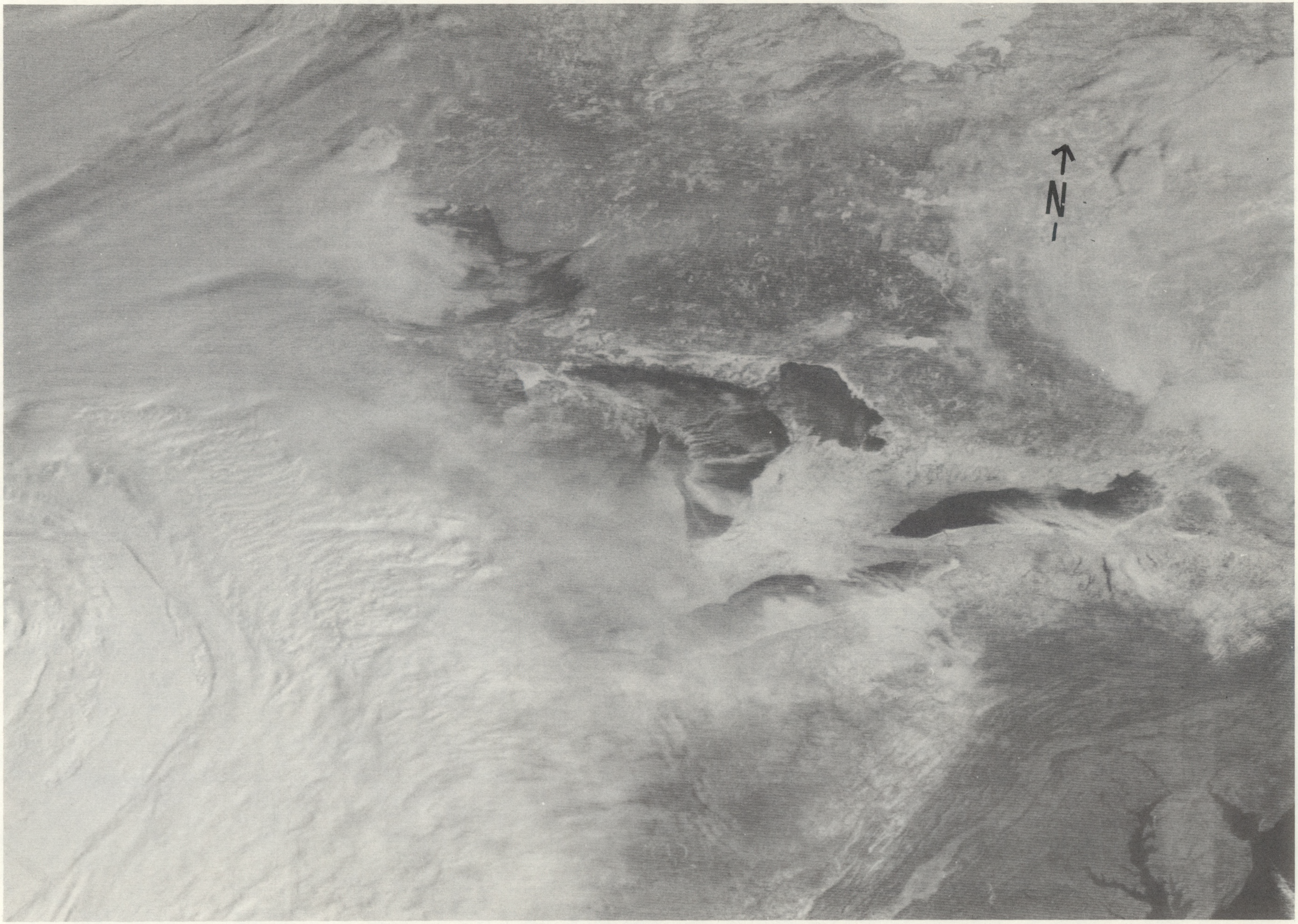
A.9. GOES VISSR Image for February 2, 1980



A.10. GOES VISSR image for February 3, 1980

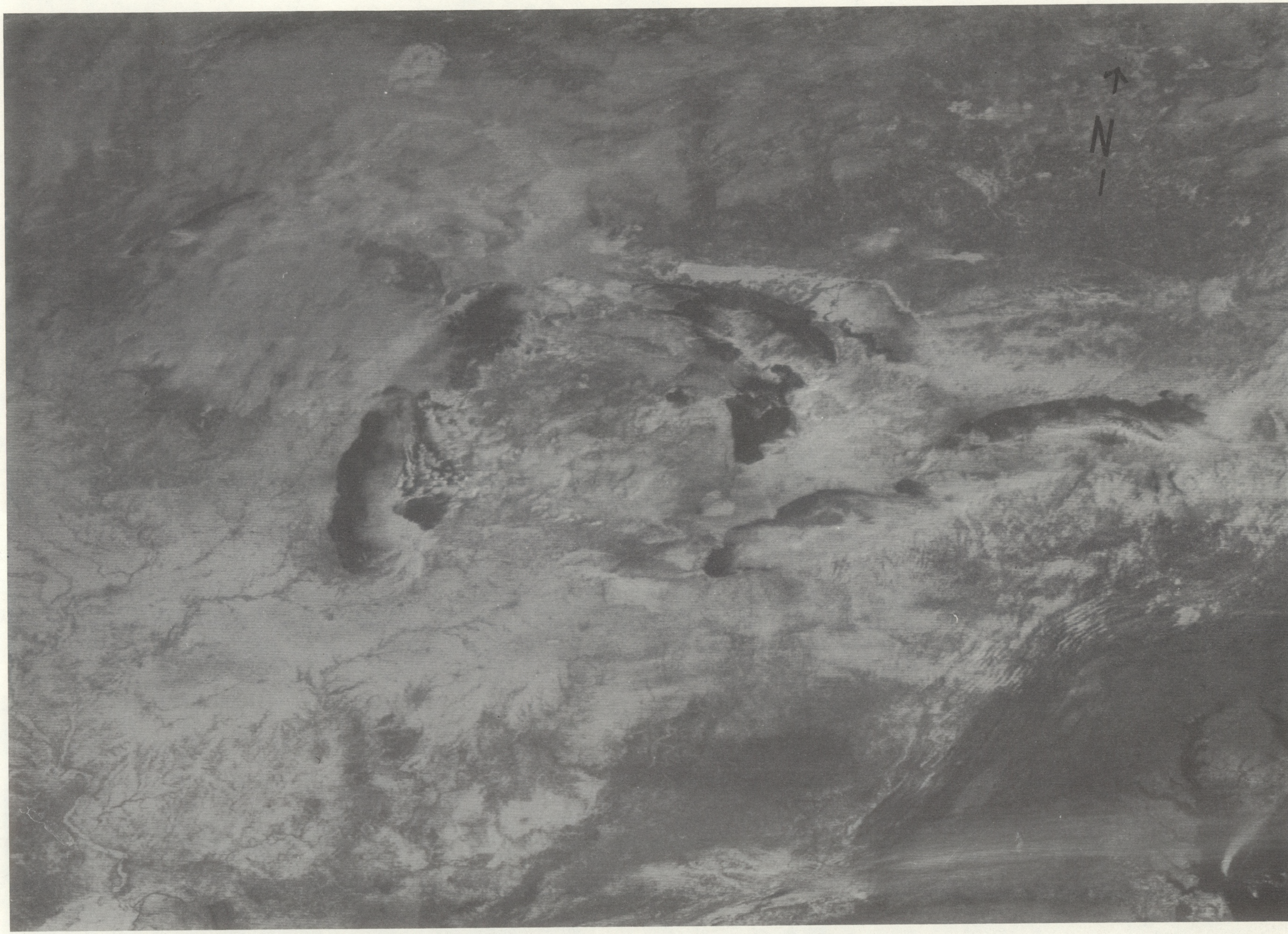


A.11. GOES VISSR image for February 4, 1980

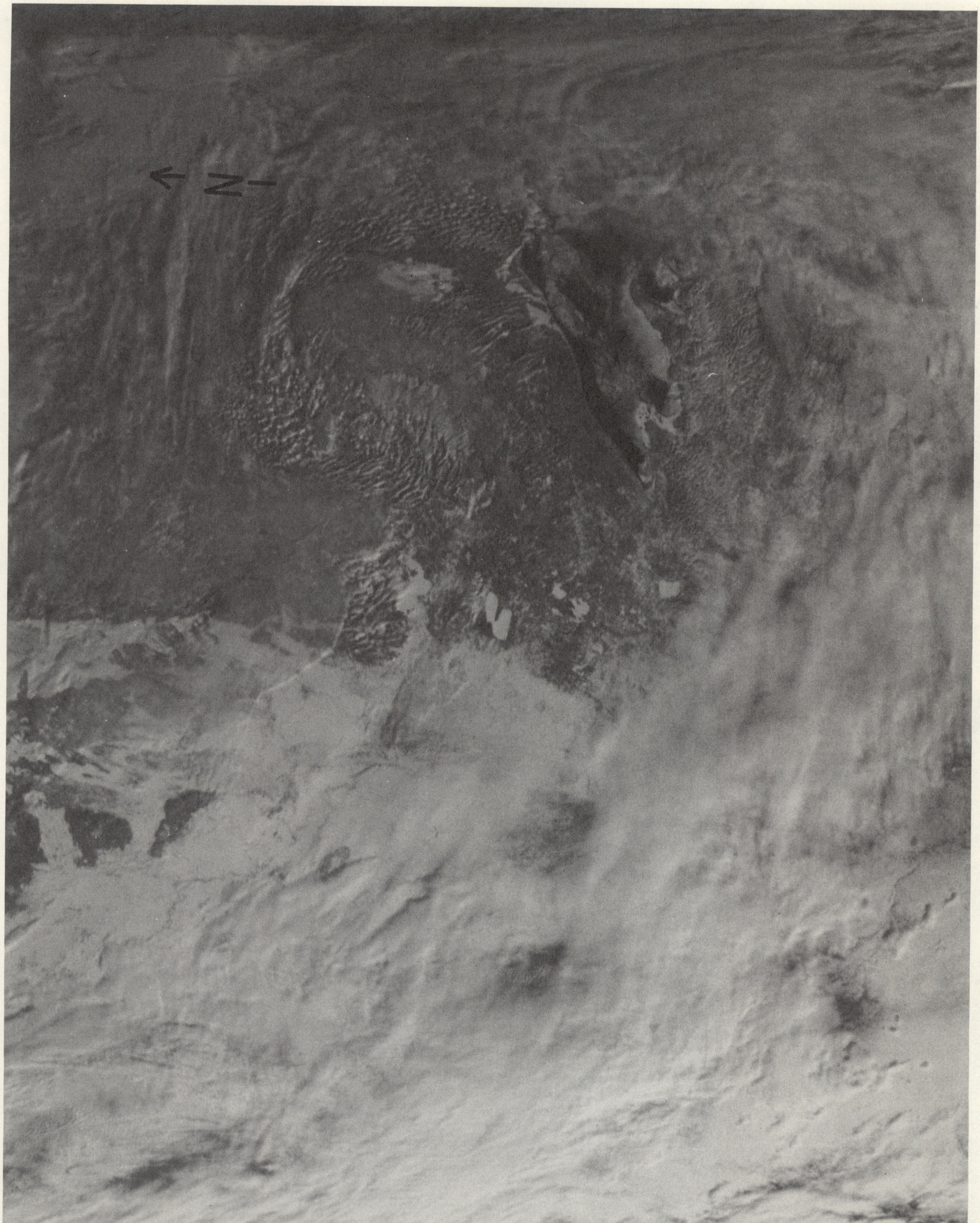


A. 12. GOES VISSR image for February 5, 1980

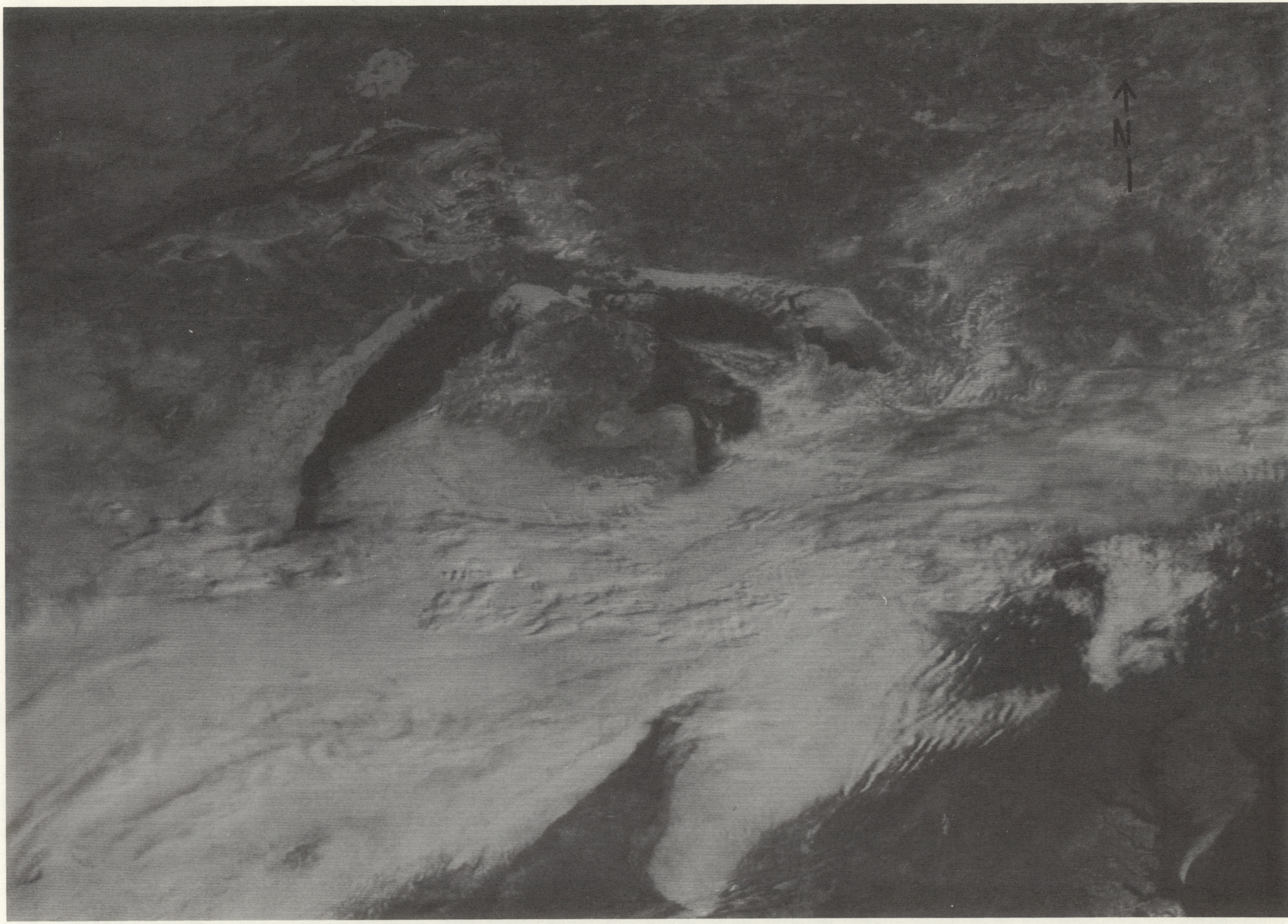
A.13. GOES VISSR image for February 8, 1980



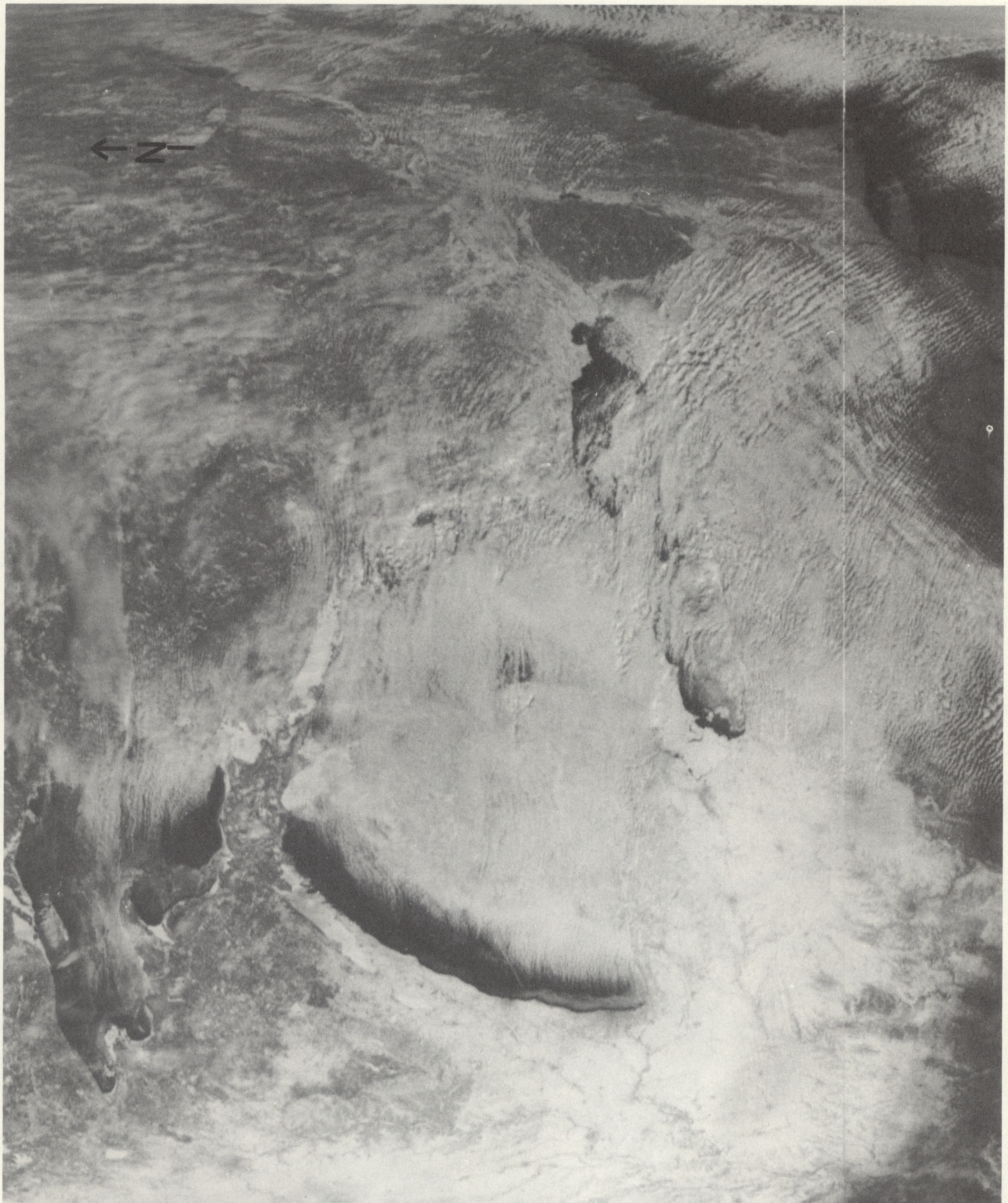
A.14. GOES VISSR image for February 12, 1980



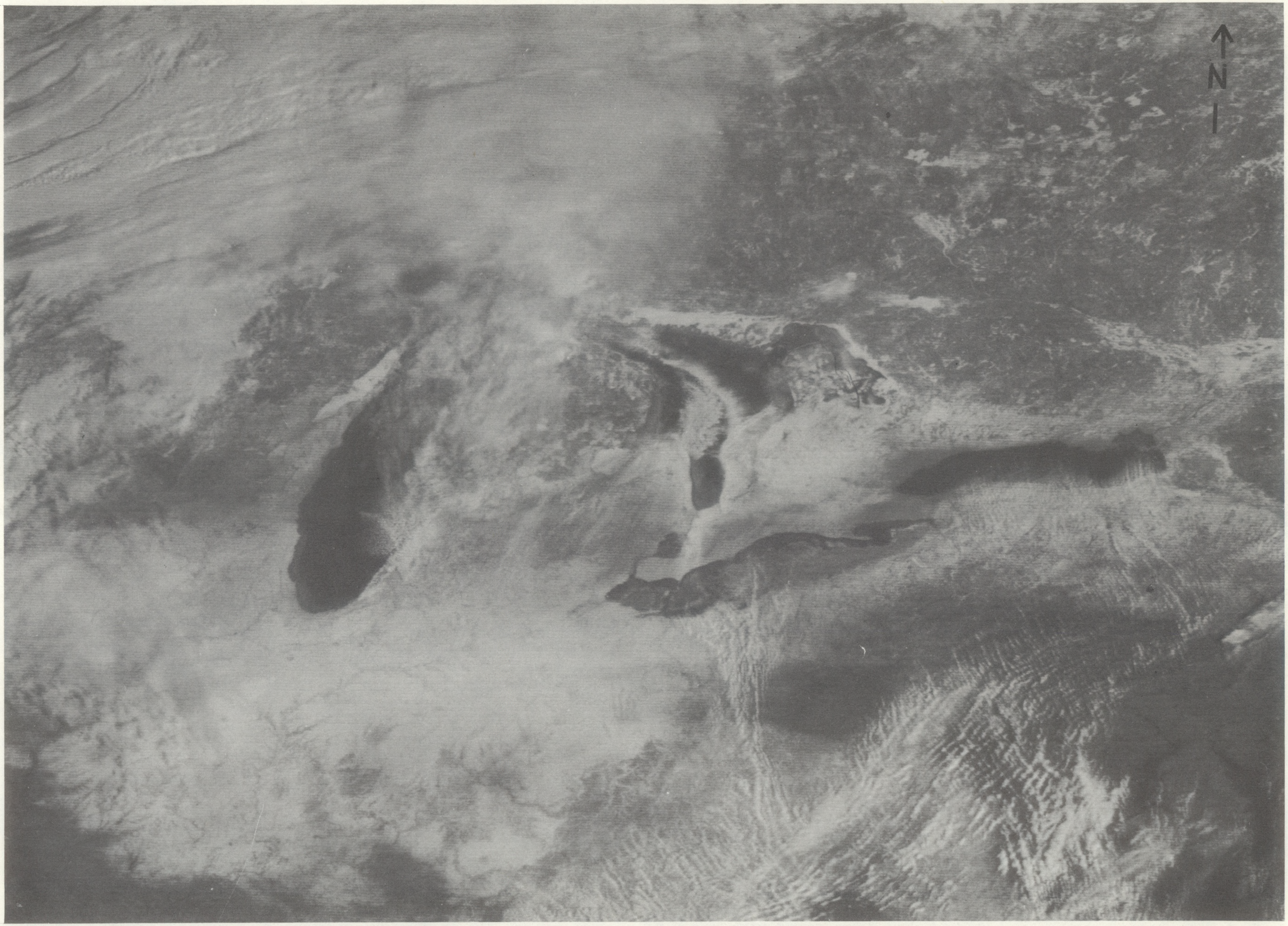
A.15. TIROS-N AVHRR image for February 13, 1980



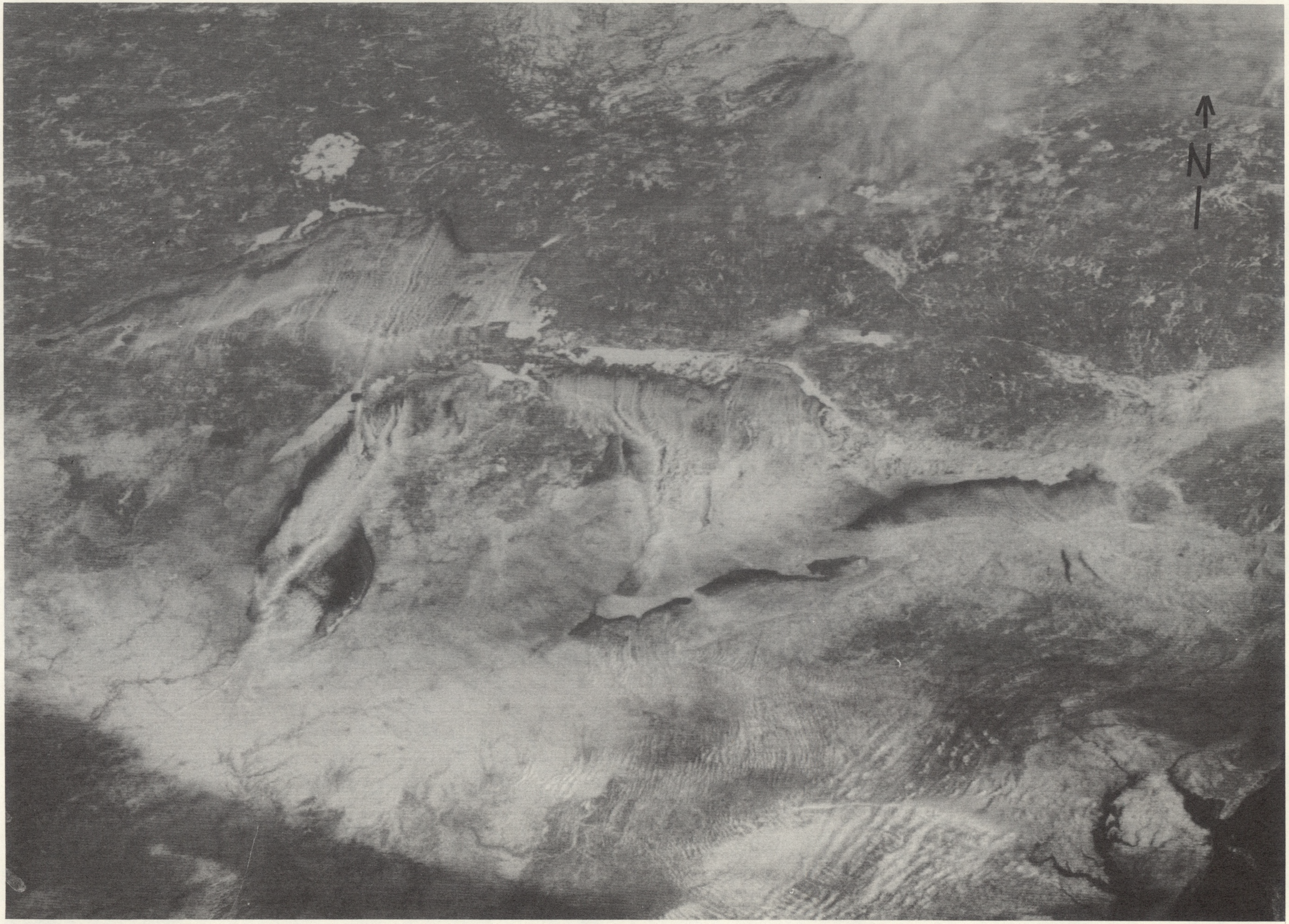
A.16. GOES VISSR image for February 14, 1980



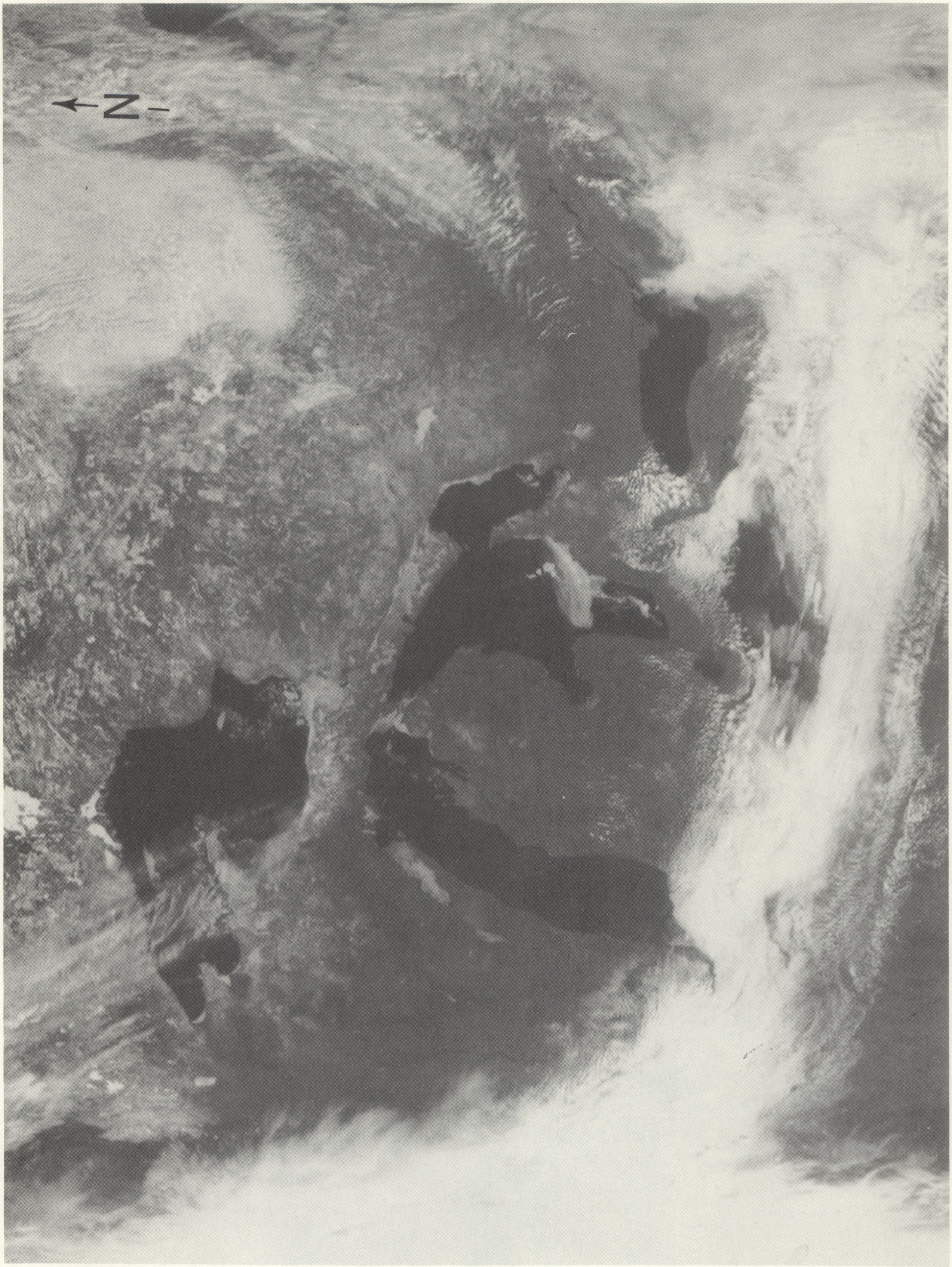
A.17. TIROS-N AVHRR image for February 17, 1980



A.18. GOES VISSR image for February 26,1980

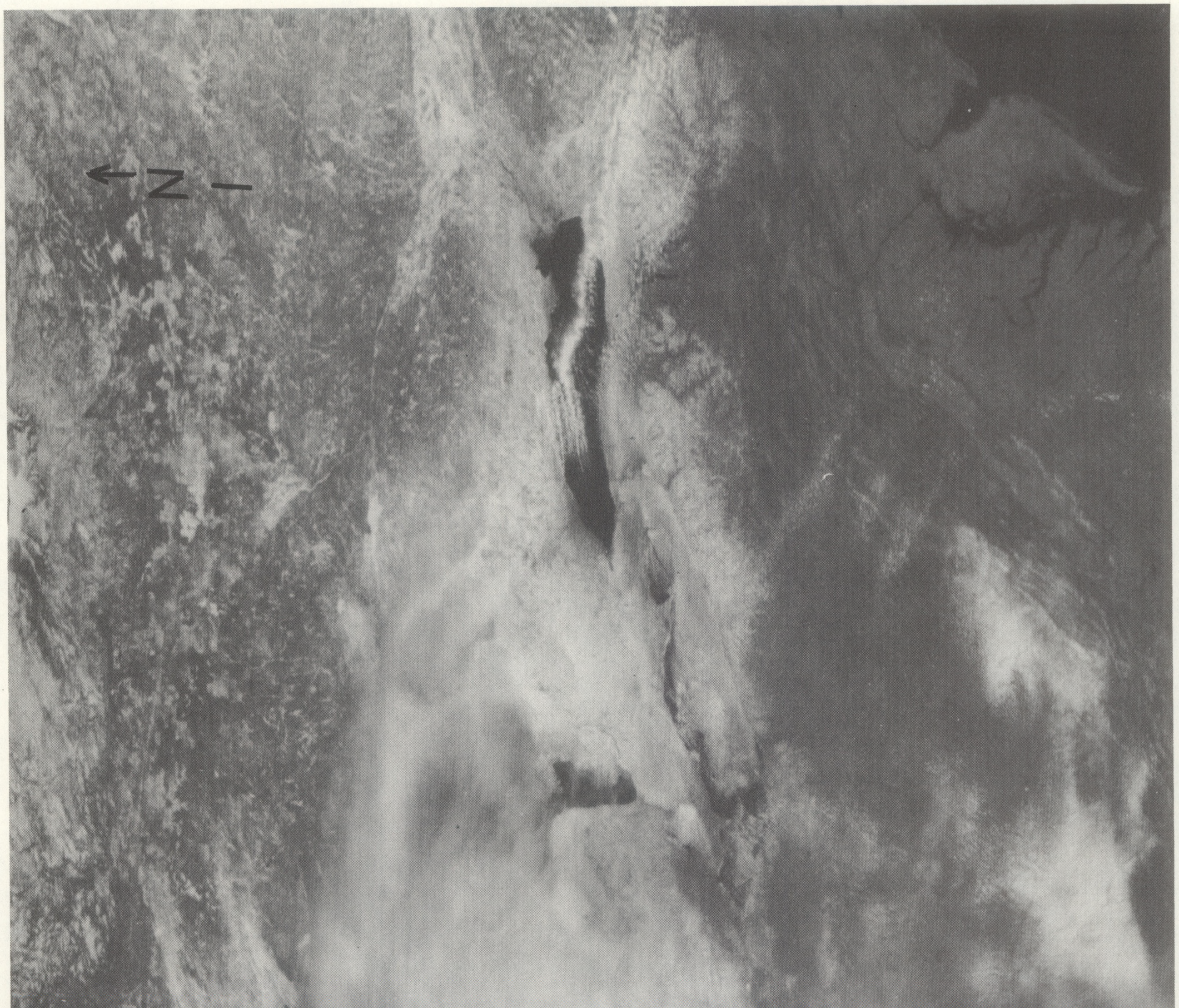


A.19. GOES VISSR image for February 29, 1980

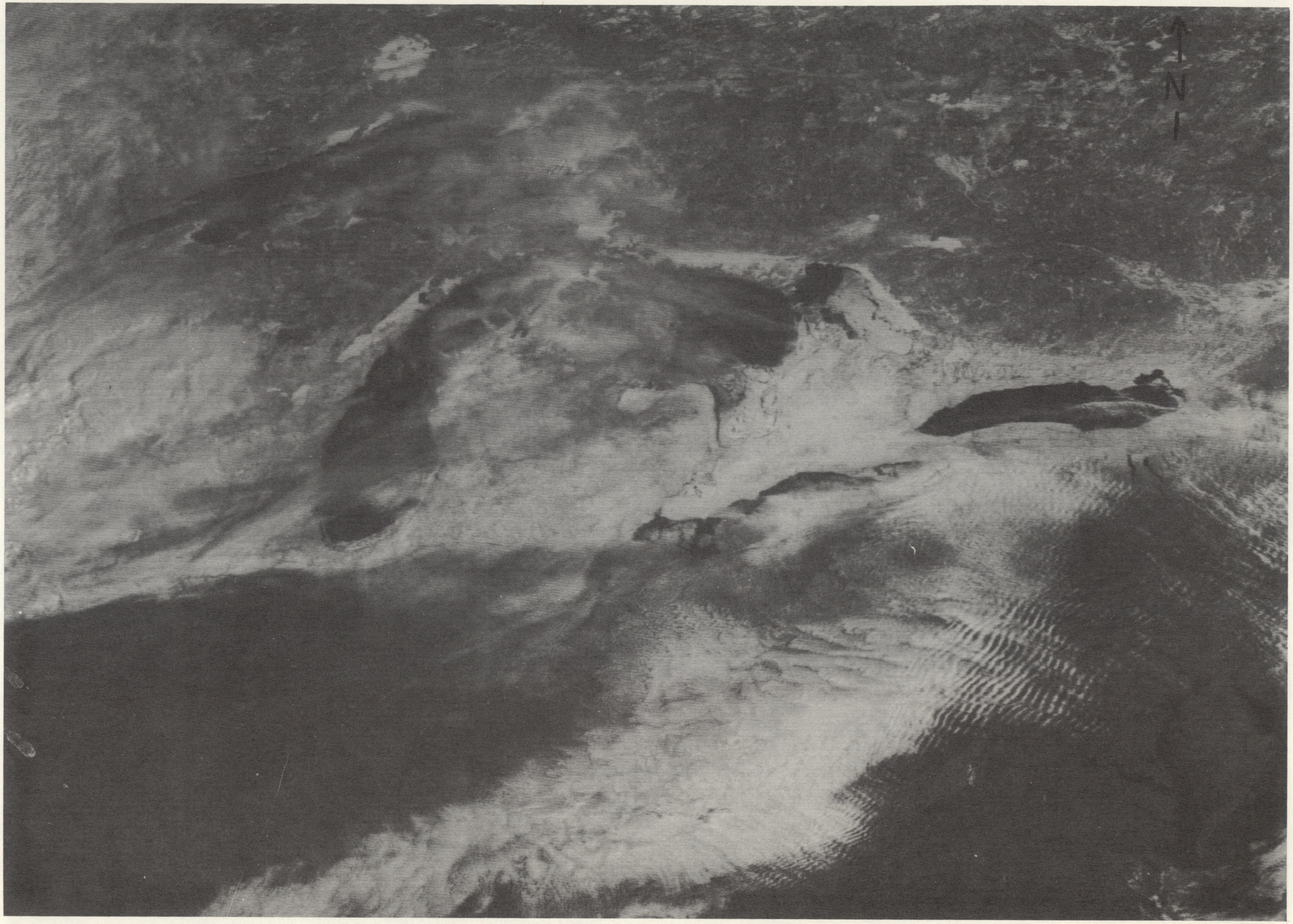


A.20. TIROS-N AVHRR image for March 2, 1980

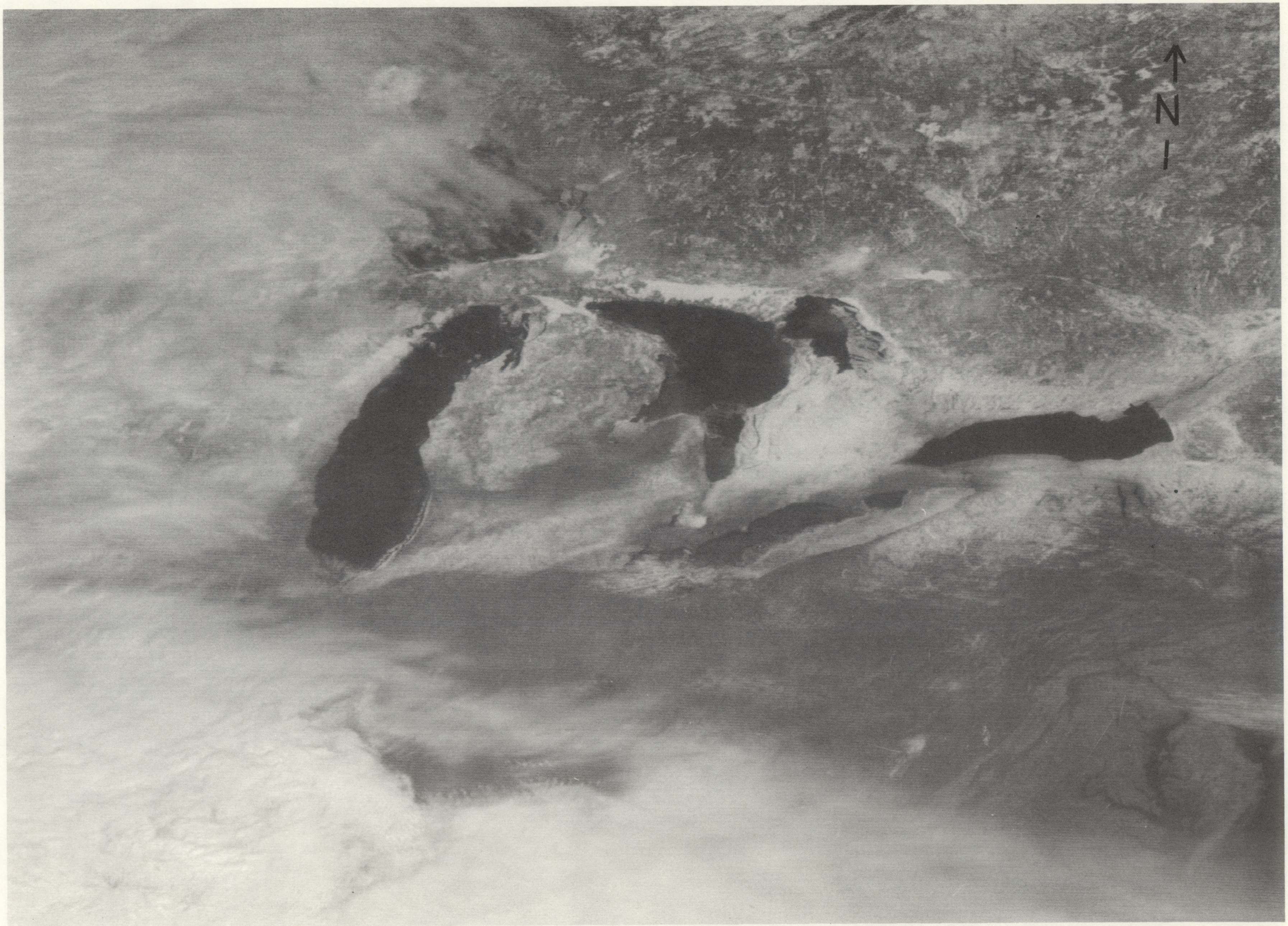
A.21. GOES VISSR image for March 3, 1980



A.22. GOES VISSR image for March 6, 1980

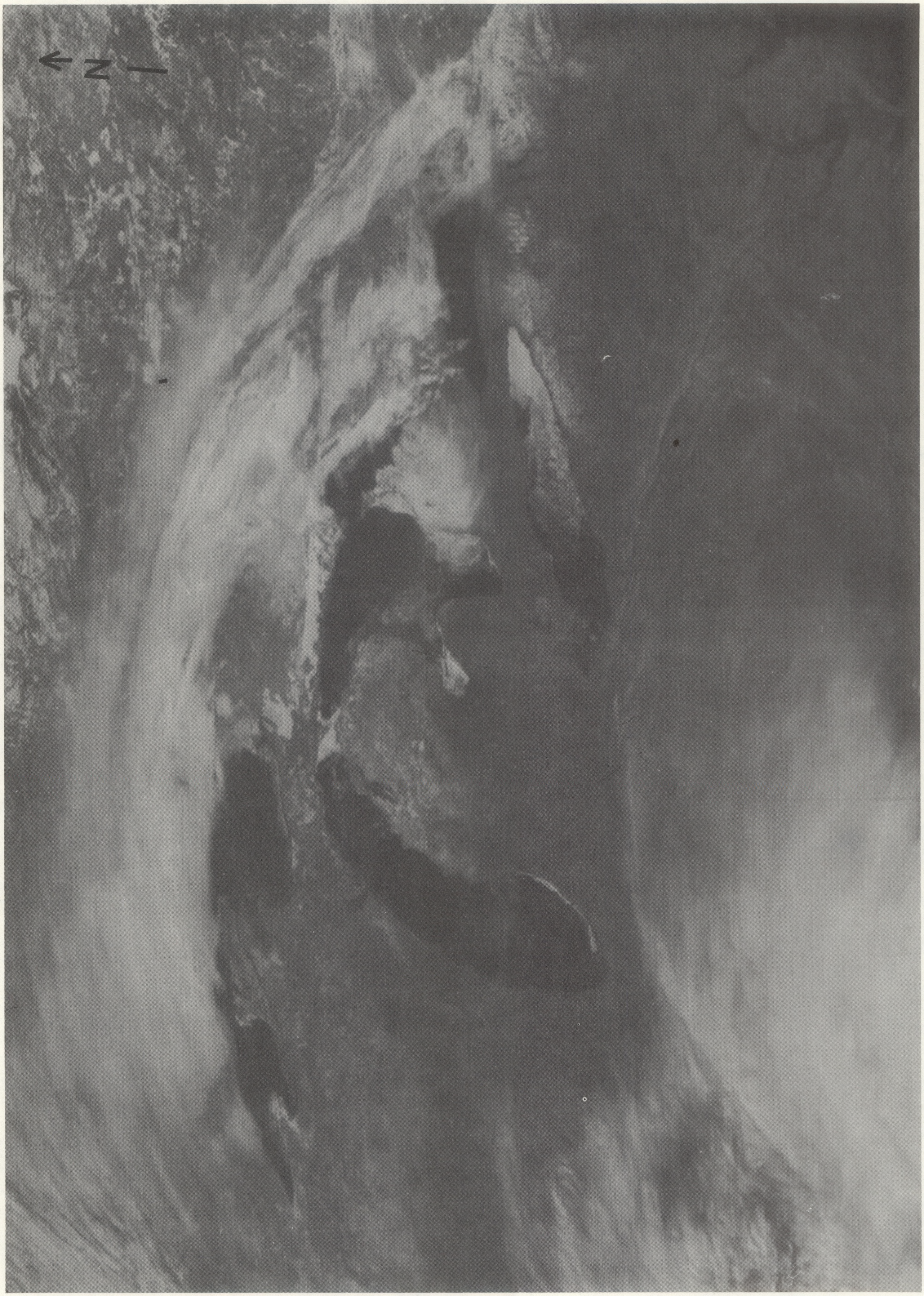


A.23. GOES VISSR image for March 9, 1980

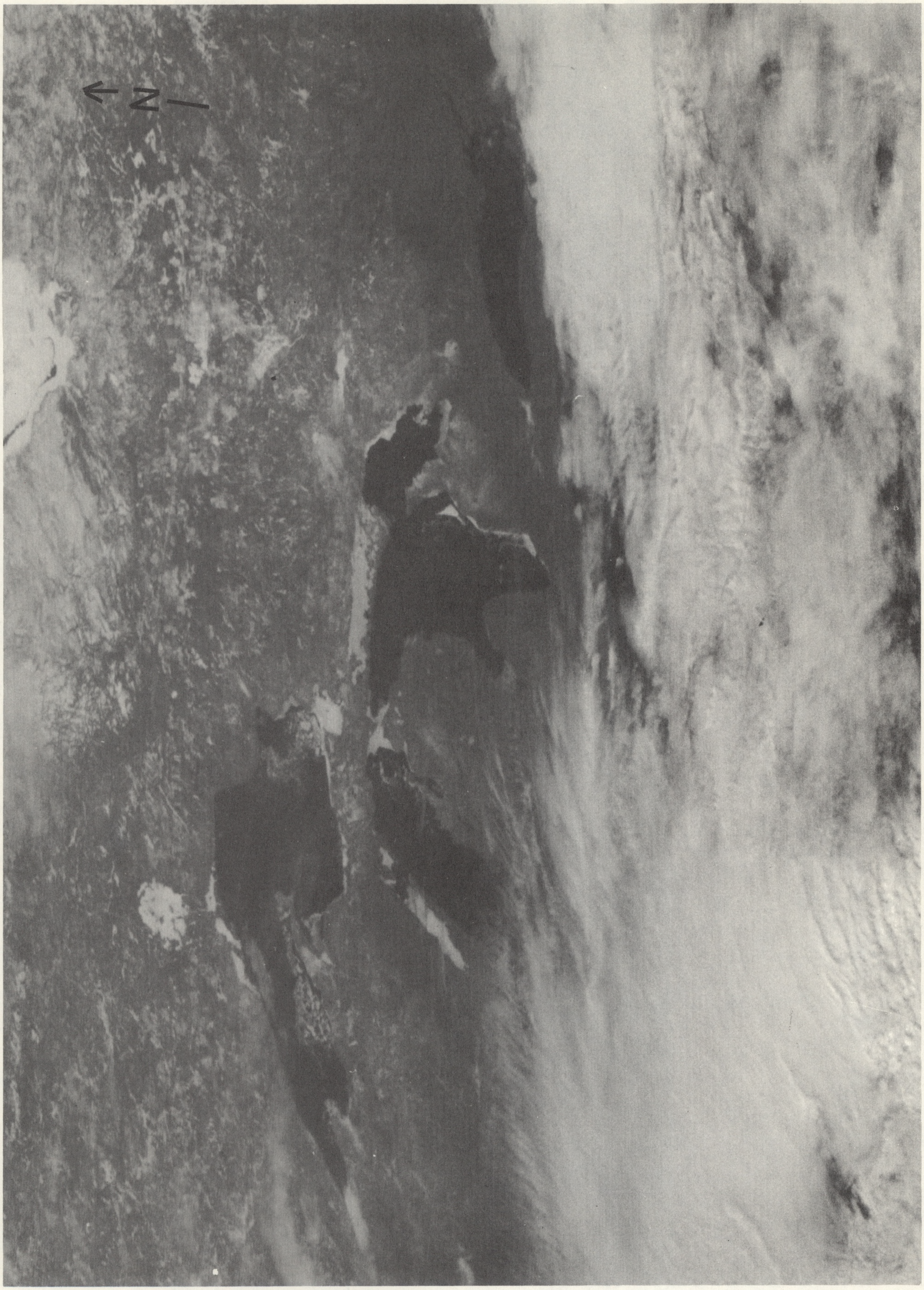


A.24. GOES VISSR image for March 12, 1980

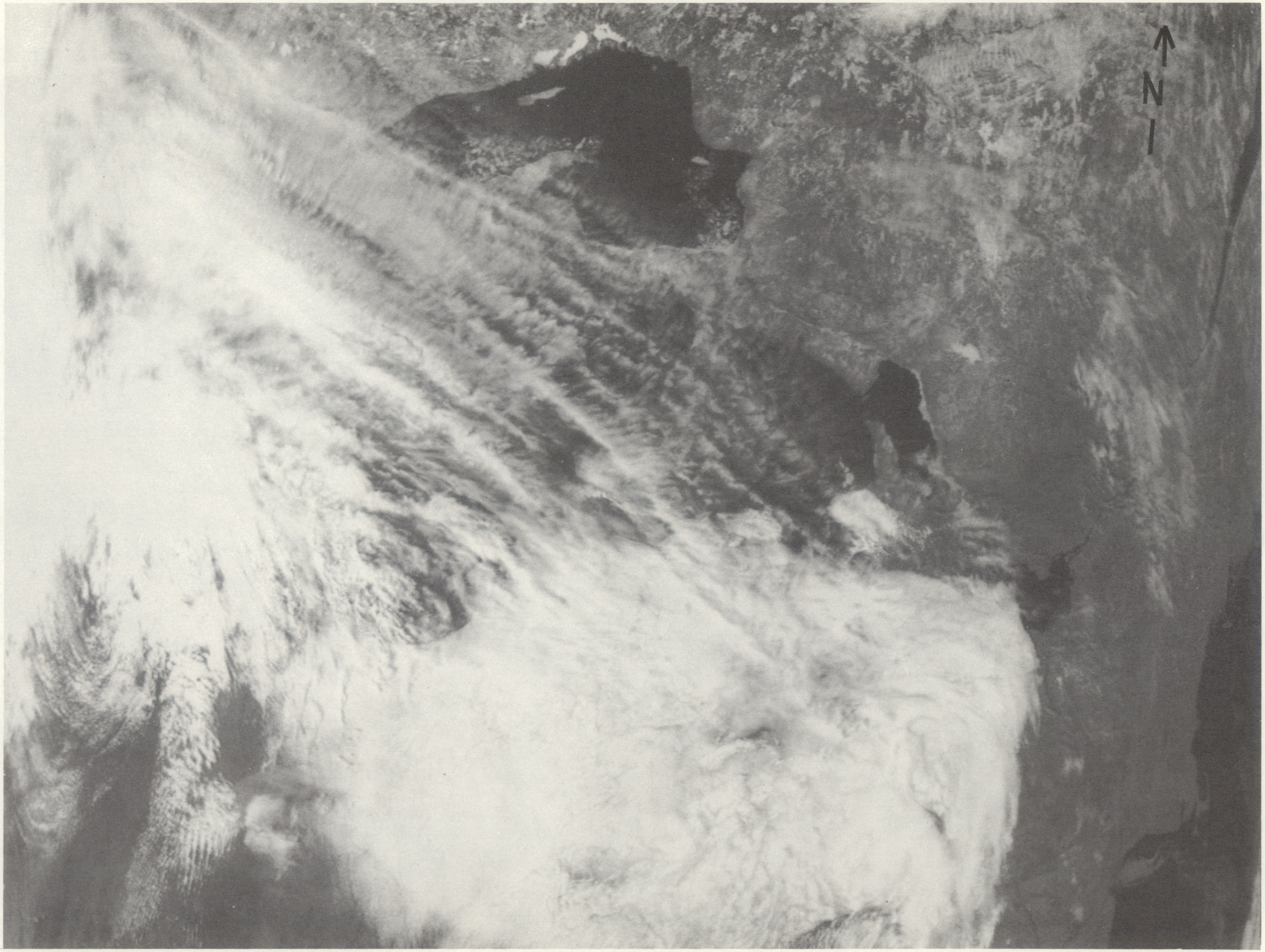
A.25. TIROS-N AVHRR image for March 15, 1980



A.26. GOES VISSR image for March 19,1980

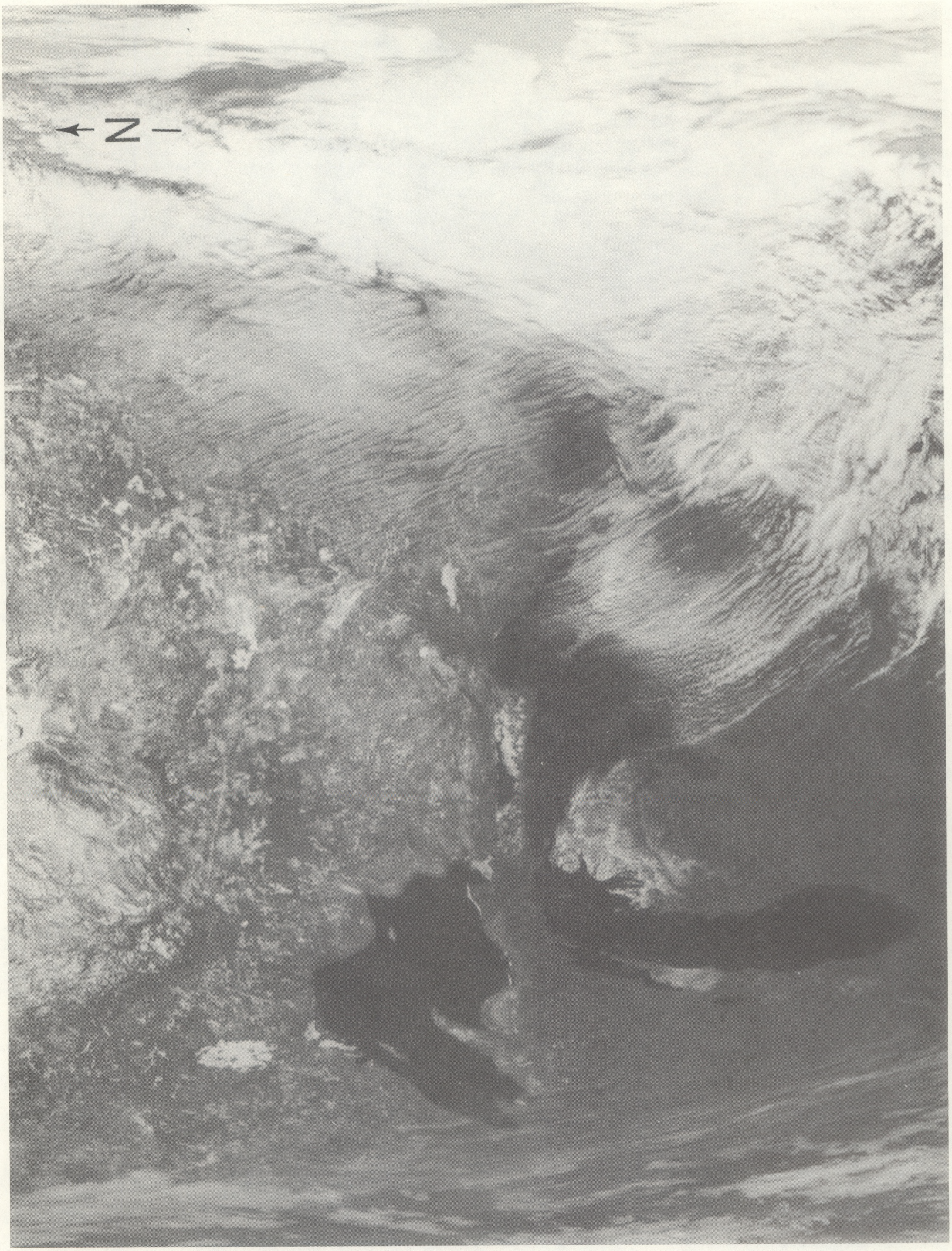


A.27. GOES VISSR image for March 30,1980



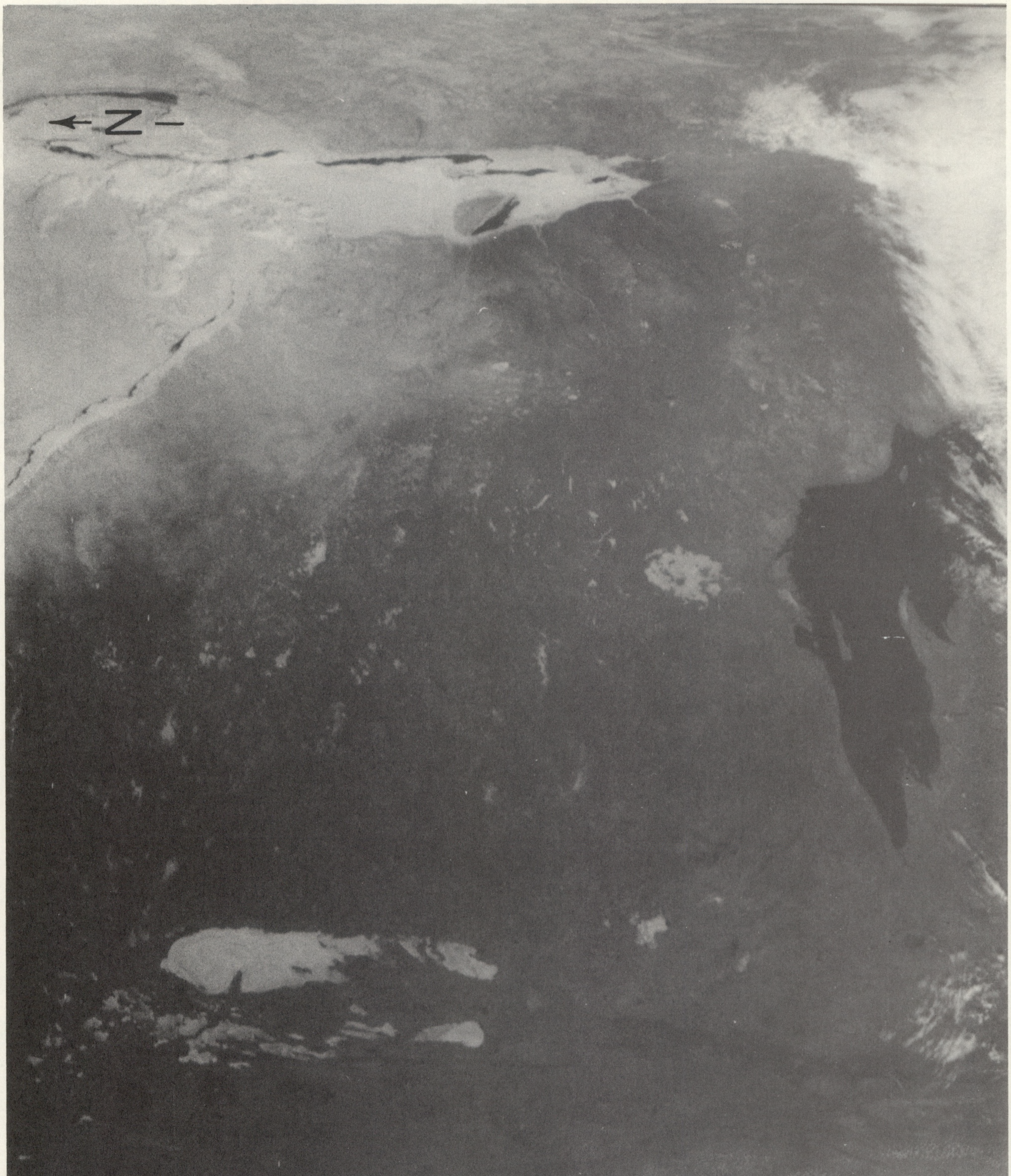
A.28. TIROS-N AVHRR image for April 1, 1980

A.29. GOES VISSR image for April 5, 1980



A.30. TIROS-N AVHRR image for April 16, 1980

A.31. GOES VISSR image for April 21, 1980



A.32. TIROS-N AVHRR image for April 27, 1980

(Continued from inside front cover)

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