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# AN OPERATIONAL ALL-WEATHER GREAT LAKES ICE INFORMATION SYSTEM

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# AN OPERATIONAL ALL-WEATHER GREAT LAKES ICE INFORMATION SYSTEM

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## ABSTRACT

This report describes an all-weather ice information system developed by the NASA Lewis Research Center as part of the twelve federal agency Great Lakes Winter Navigation Program for which the U.S. Army Corps of Engineers is lead agency. The system utilizes an X-band Side-Looking-Airborne-Radar (SLAR) for determining type, location, and areal distribution of the ice cover in the Great Lakes and an air-borne, S-band, down-looking short pulse radar for obtaining ice thickness. The SLAR system is currently mounted aboard an U.S. Coast Guard C-130B aircraft. Digitized SLAR data is relayed in real time via the NOAA-GOES satellite in geosynchronous orbit to the U.S. Coast Guard Ice Center in Cleveland, Ohio. SLAR images along with hand-drawn interpretative ice charts for various winter shipping areas in the Great Lakes are broadcast to facsimile recorders aboard Great Lakes vessels via the MARAD marine VHF-FM radio network to assist such vessels in navigating both through and around the ice.

The results from the 1974-1975 season demonstrated that the system was capable of providing near real-time all-weather ice information which vessels could use to reduce costly delays and hazards associated with winter navigation.

## INTRODUCTION

The Great Lakes-St. Lawrence Seaway system has traditionally been closed to navigation during the winter ice season from mid-December until early April because of possible adverse effects and the resultant added expense due to winter weather and ice. Since 1970, twelve federal agencies led by the U.S. Army Corps of Engineers and the U.S. Coast Guard have participated in a federally sponsored Winter Navigation Program to determine the feasibility of shipping season extension and to provide, if possible, for year-round navigation on the Great Lakes.

In the winter, the Great Lakes are subjected to a variety of weather patterns and to rapid temperature changes. Periods of freezing temperatures are generally not long enough to cause an entire lake-wide ice sheet to form. Consequently, various stages of ice formation and decay often occur at different locations within the Great Lakes. The collection, analysis, and timely dissemination of accurate information concerning the location, areal extent, type, and thickness of the ice has been recognized by the Winter Navigation Program as an essential element in the successful extension of the navigation season.

Side-Looking-Airborne-Radar (SLAR) with its ability to penetrate all but the most severe weather and to map large areas is a sensor system which has the operational capability for monitoring fresh water ice conditions. Larrowe et al. (1971) using an X-band synthetic aperature system and the U.S. Coast Guard (1972) using a Ku-band system, showed the feasibility of using SLAR for this purpose. During the winter of 1972-1973, the NASA Lewis Research Center began a program to develop correlations between SLAR imagery taken by an AN/APS-94C X-band system and ice types in the Great Lakes. The results of this program (Jirberg et al., 1973), showed that SLAR could monitor the extent of the ice cover and discriminate between many ice types but that it could not determine ice thickness. Because ice thickness information is an invaluable aid for winter navigation, NASA Lewis also developed an S-band short-pulse radar system (Vickers et al., 1973, and Cooper et al., 1974), for measuring ice thickness from an aircraft. This short-pulse radar accurately measures the thickness of smooth ice sheets. The short-pulse radar system should also be able to determine ridge heights, and this is a feature we are developing at the present time.

The SLAR and ice thickness radar are the remote sensors used in the NASA ice information system An equally important part of the system is the processing and distribution of the data from these sensors. This operational ice information system for shippers in the Great Lakes is described in this report.

THE 1973-1974 DEMONSTRATION RESULTS

During the 1973-1974 Winter Navigation Season Program, three OV-1 Mohawk aircraft equipped with AN/APS-94 SLAR were regularly flown by the U.S. Army and NASA to obtain criteria for an operational ice information system and to demonstrate the usefulness of the information. The SLAR images were recorded on photographic film during the flights and processed upon landing. A combination SLAR image and hand drawn interpretative ice chart was then transmitted via the Great Lakes Marine VHF network to vessels operating in the Great Lakes.

Nineteen vessels representing four shipping companies participated in the 1973-1974 demonstration program. A total of 137 separate SLAR Image/Ice Chart Products were generated and relayed to the vessels. The areas for which Products were generated are shown in figure 1. The dashed line areas were provided at a much less frequent basis than the other areas. A sample Product for the Lake Superior Area 2 is shown in figure 2. In the SLAR image the center strip along the length of the image represents the aircraft ground track. The SLAR maps the radar return from both sides of the aircraft producing an image whose total width is 100 Km. The shore boundaries and ice types for this part of Lake Superior are shown in the interpretative ice chart above the SLAR image. Light tone (white) areas in the image indicate areas of relative large amounts of backscattered radiation from such ice types as brash, ridges, rafted areas, etc. The dark tone areas represent areas of minimal backscattered radiation from such features as open water and smooth surface ice. For example, the ice near Duluth is composed of solid ice sheets over 30 centimeters thick with relatively few ridges. This area in general appears dark in the image but ridges show clearly. The straight bright lines leading into Two Harbors are ship tracks and the bright return area above Point Detour represents a refrozen brash area. The open water areas indicated by the ice chart represent the path of least resistance for lake vessels. Further information on interpreting SLAR imagery can be found in Schertler et al (1975). The interpretative ice chart shown in figure 2 outlines the various areas of ice as to thickness, relative concentration and percentage of various size pieces using the standard Great Lakes ice nomenclature and plotting symbols.

An example of the utility of the ice imagery is shown in figure 3. The top SLAR image in the figure shows that on April 7, 1974, northerly winds had compacted an ice field along the southern shore, west of Whitefish Point. The inner regions of Whitefish Bay remained 100 percent ice covered. The high return from the established ship track can be seen inside the Bay. The ROGER BLOUGH, a U.S. steel ore vessel, upbound into Lake Superior on April 7, used the SLAR image to navigate north around this ice pack. The BLOUGH's route is indicated by the thick white line. On this same day, the U.S. Coast Guard icebreaker SOUTHWIND attempted to open a new vessel track through the ice pack west of

Whitefish Point. After making only limited progress through this rafted region, the icebreaker decided to also detour north around the ice pack. Three days later on April 10, a south wind had opened this ice pack so that the best route for the BLOUGH to navigate on its return trip was a southerly one through a series of large leads as shown in the figure.

During the latter part of the season, ice thickness flights using the short-pulse radar were flown using the NASA C-47 aircraft. The thickness radar determines the time difference between the pulse returns from the ice-air interface and the ice-water interface (see figure 4). This time difference is proportional to ice thickness. (See Cooper et al., 1974, for a complete description of the aircraft system.) Thickness results from a typical short-pulse radar flight are shown in figure 4. The dashed lines in this figure indicate various flight line traverses. The mean ice sheet thickness generally changes gradually as a function of distance. It was found that thickness of the ice is not a rapidly changing variable with time and it was only necessary to make ice thickness surveys on a once-a-week basis.

As was shown by the SLAR imagery in figure 3 which was used by the ROGER BLOUGH, the dynamic weather conditions in the Great Lakes can affect major changes in ice cover in very short time periods. The shipping captains who participated in the 1973-1974 season were well aware of this fact and they indicated that when the ice was moving they would have very little confidence in 12-24 hour old information. After reviewing these results it was decided that flying OV-1 aircraft with processing of imagery after the flight was not a practical means of providing timely ice information for two principle reasons. First, because of the short range of the OV-1, it was necessary to have two processing centers (one at Sault Sainte Marie, Michigan and one at Cleveland, Ohio) with a duplication of personnel. Second, by the time some of the information was processed and disseminated to the shippers it was sometimes out of date. Nevertheless, shipping companies indicated positive interest in receiving such information. As a result of the 1973-1974 demonstration program, Project ICEWARN was formed to further the development of the ice information system.

PROJECT ICEWARN

Project ICEWARN is a cooperative program between the U.S. Coast Guard, NOAA National Weather Service and NASA to develop and demonstrate an all-weather, near real time ice information system for Great Lakes Winter Navigation. The technical development of the system is carried out by NASA and the system is jointly demonstrated by the Coast Guard, NOAA/NWS and NASA.

The system developed so far under Project ICEWARN is shown in figure 5. A multi-engine U. S. Coast Guard C-130B aircraft equipped with a real aperture X-band SLAR (AN/APS-94) system surveys the areas shown in figure 1. For the SLAR missions this aircraft is flown at an 11,000-foot altitude with an average ground speed of 280 knots.

The SLAR has a pulse repetition rate of 750 pulses/second. The returns from these transmitted pulses are divided into 400 equal right antenna and 400 equal left antenna time segments or range bin intervals. For each range bin, the SLAR video signal is sampled and digitized into a six-bit data word. The digitized SLAR video data from a single radar pulse are accumulated in memory and averaged exponentially with the return from the previous pulses. Auxiliary data including aircraft drift, ground speed and altitude are multiplexed with the averaged radar video data every 806 ms to form a real time serial Bi-$\phi$-L data output of 6032 bits/second.

The digital SLAR data are relayed from the aircraft to the Coast Guard Ice Navigation Center in Cleveland via two possible communication networks. The primary mode is a continuous real-time transmission to the NOAA GOES satellite with subsequent microwave downlink to the NOAA Command and Data

Acquisition Station at Wallops Island, Virginia, and on to the Ice Center over a conditioned phone line. The transmitter to the GOES operates at a center frequency of 402 MHz with a RF power output of 150 watts. The relay from GOES to the ground receiver occurs at an S-band frequency of 1.6 GHz. The secondary or back-up data relay mode from the aircraft consists of a direct S-band transmission at 2.26 GHz to a ground receiver either at Sault Sainte Marie, Michigan, or at the Cleveland Ice Center. In this mode the data are fast-dumped from the aircraft at 48,256 bits/sec by tape recorder playback after a data run is completed. After the data are transmitted to the receiver at Sault Sainte Marie, Michigan, it is relayed on to the Ice Center over a conditioned phone line.

Once the data arrive at the Cleveland Ice Center, a 200 line/inch black and white SLAR image print is generated on dry silver paper using a CRT-Fiber Optics Recorder. The print made from the dry silver paper is of photographic quality with 9-12 gray scale levels. The advantage of the dry silver paper is that it is developed by a heater in the recorder avoiding time consuming wet processing. After the SLAR image is made in the Ice Center, it is interpreted by trained personnel and the combination SLAR Image/Ice Chart Product discussed previously is generated. This combination Product is then transmitted by radio facsimile to the vessels on the Great Lakes.

The shipboard facsimile equipment is an Alden recorder. Essential features of this equipment are its ability to provide a radar image of eight gray levels and to operate automatically. The facsimile products received aboard the ships are at a scale of 1:762,000. A transparent overlay of the Great Lakes Navigation Charts at the same scale is used to overlay the SLAR image for course plotting. With the Project ICEWARN system, it is possible to supply ships with ice information within a couple of hours after it is acquired by the aircraft.

During the 1974-1975 winter navigation season, 25 vessels representing five shipping companies and two Coast Guard icebreakers received SLAR Image/Ice Chart Products. A total of 158 separate products were generated from 56 flights between January 16 and April 6, 1975. The Coast Guard C-130B aircraft which conducted the flights was based at the NASA Lewis Research Center in Cleveland. All SLAR missions over the product areas shown in figure 1 could be accomplished with the C-130 aircraft returning to Lewis without refueling. The flights were conducted on an average of once every two days with daily coverage during times of rapidly changing weather conditions. During this same time period, nine short pulse ice thickness radar flights were conducted by the NASA C-47 aircraft.

An example of the frequent coverage obtained during the 1974-1975 season is shown in figure 6. SLAR images from the Straits of Mackinac for the 27th, 29th, and 31st of March 1975 are presented. On the 27th of March the area of the Straits between Beaver Island and Bois Blanc Island remains primarily ice covered with thickness between 15 and 50 centimeters. The dark toned area along the northern shore between St. Ignace and Port Island is 70 percent covered with thin ice. The area east of Bois Blanc is primarily ice free. Between Beaver Island and Green Bay, bright tone patches of brash ice can be seen in primarily open water areas. Winds from the east then drove the ice out of the inner area of the Straits around Mackinac City. The imagery of the 29th reveals that belts of brash are all that is left in this area. As a result of a wind shift around to the west on the 30th, the inner part of the Straits was again ice filled by the 31st with areas of rafting and ridging. This type of ice information which permits efficient icebreaker planning and ship routing eliminates costly delays.

CONCLUDING REMARKS

The results from the 1974-1975 season demonstrated that the Project ICEWARN System was capable of providing near real-time all-weather ice information to vessels in the

Great Lakes in a truly operational mode. During the 1975-1976 winter season, the U.S. Coast Guard, NOAA/NWS and NASA will continue to demonstrate the Project ICEWARN system in support of winter shipping activities.

It is planned that the ice thickness radar will be installed aboard the C-130B aircraft and the thickness data along the aircraft's ground track will be transmitted simultaneously with the SLAR data to the Coast Guard Ice Center. In addition an ice thickness radar will be installed aboard a U.S.C.G. Sikorsky H-53 helicopter operating out of Traverse City, Michigan.

Another addition for the 1975-1976 season will be the installation aboard the U.S.C.G. Icebreaker WESTWIND of the necessary equipment for receiving and recording SLAR imagery directly from the C-130 aircraft. A real time image capability will enable the WESTWIND to react to the very rapidly changing ice conditions in the Straits of Mackinac.

It is expected by the 1976-1977 winter navigation season, the Project ICEWARN All-Weather Ice Information System will be transferred, for operational use, to the U.S. Coast Guard and NOAA/National Weather Service.

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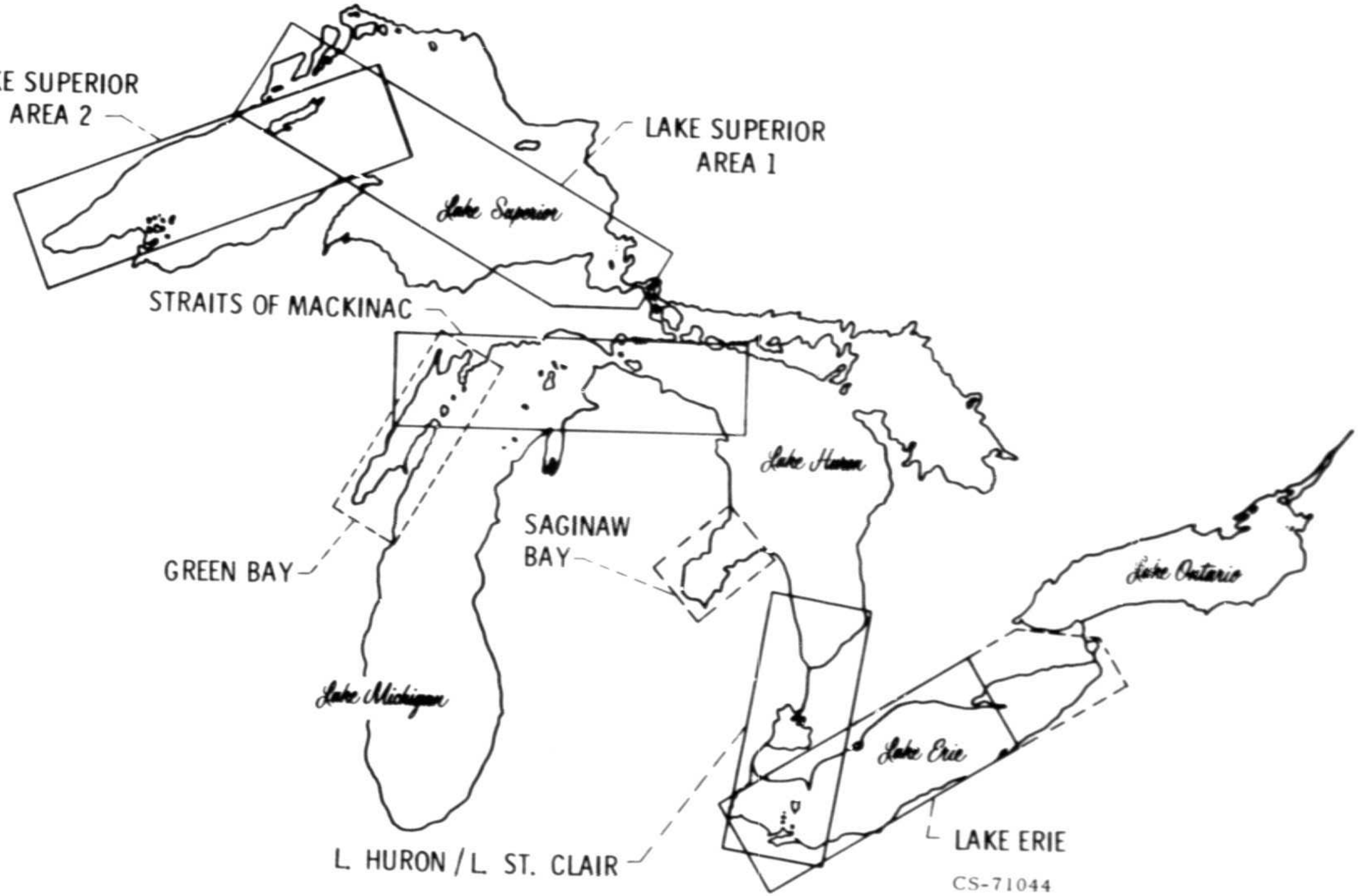



FIGURE 1.-STANDARD SLAR IMAGE/ICE CHART PRODUCT AREAS

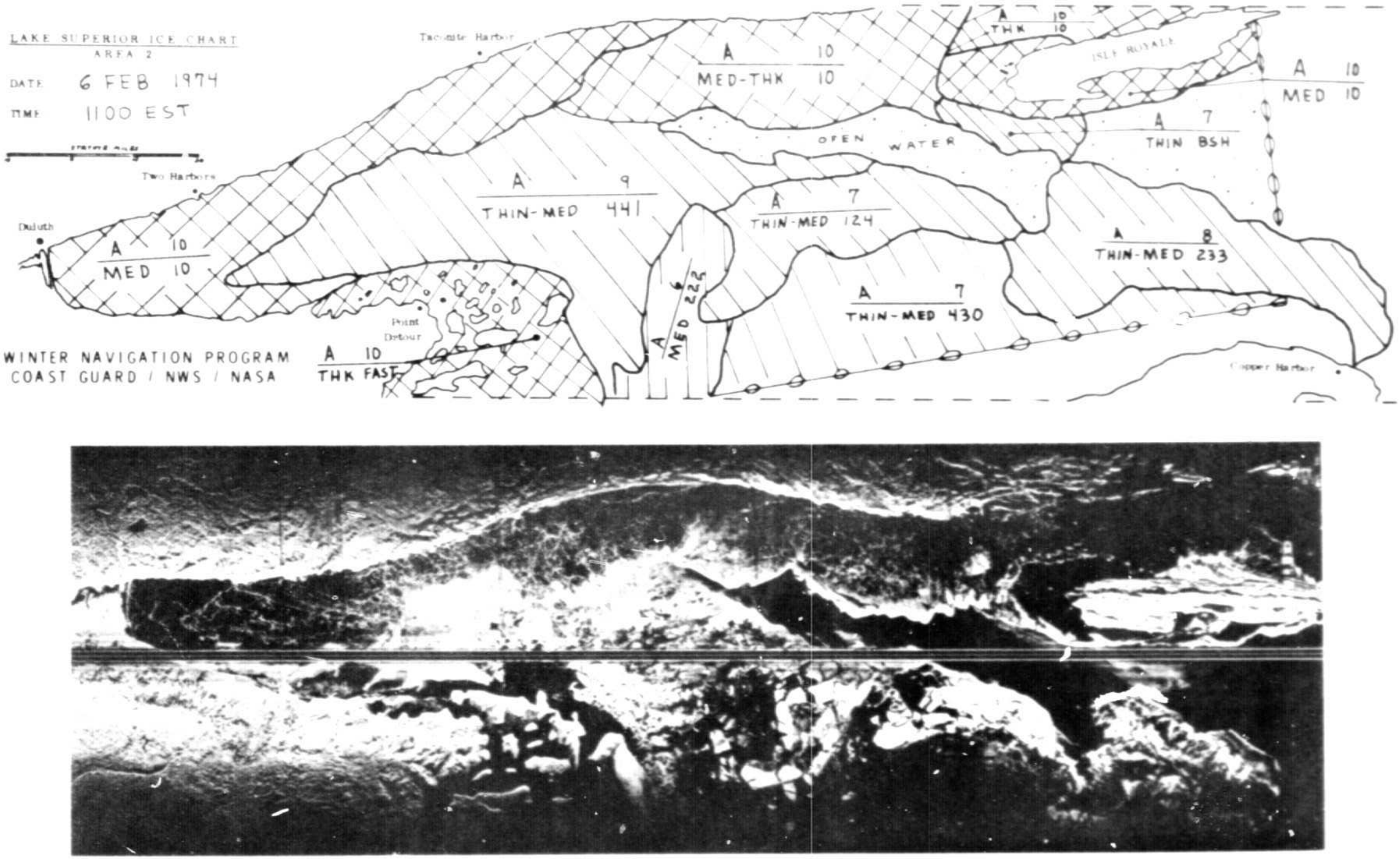



FIGURE 2.-SLAR IMAGE/ICE CHART PRODUCT FOR THE WESTERN PART OF LAKE SUPERIOR ON FEBRUARY 6, 1974

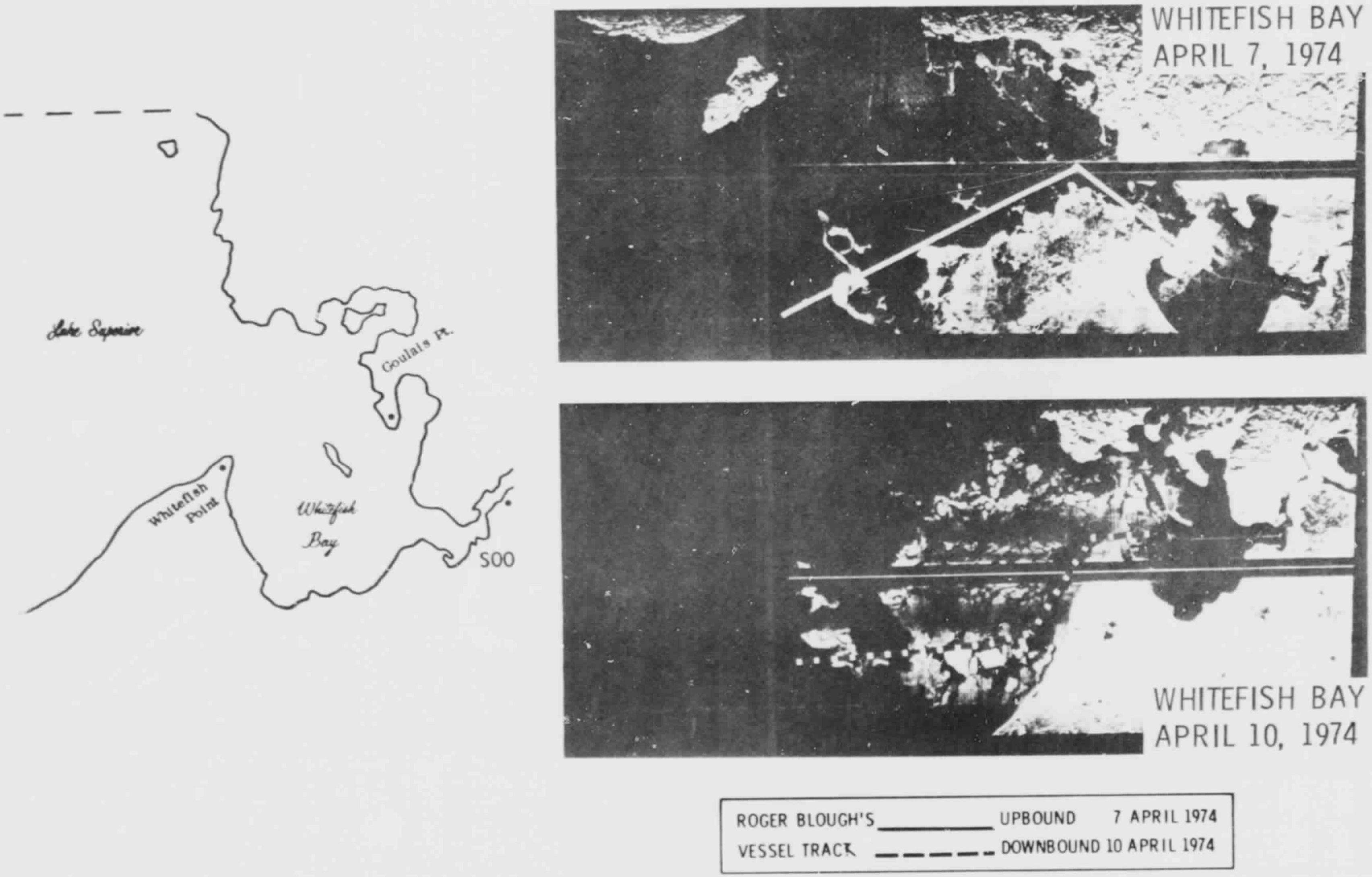
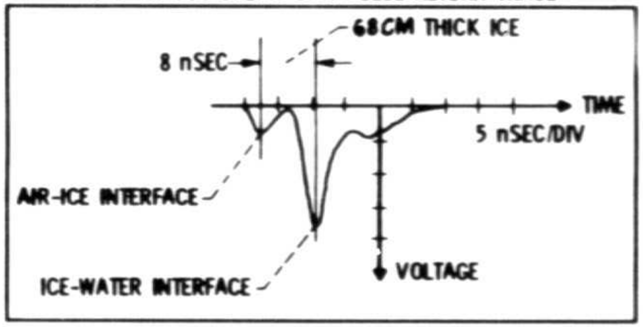


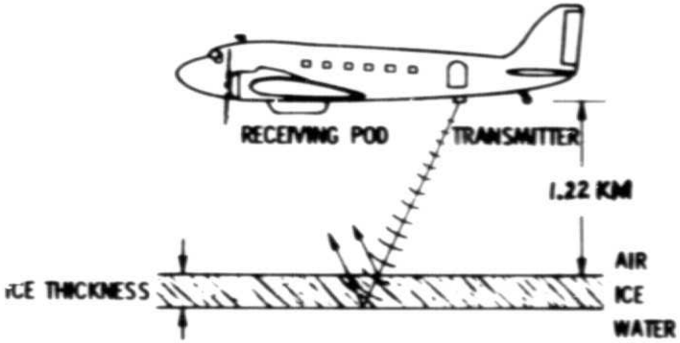

FIGURE 3.-USE OF SLAR IMAGERY FOR VESSEL ROUTING UNDER GREAT LAKES ICE CONDITIONS

## ICE THICKNESS RADAR

S-BAND (2.8 GHz) RADAR PULSE RETURN TRACE




SCHEMATIC OF AIRCRAFT OSCILLOSCOPE DISPLAY




SCHEMATIC OF PULSE RADAR OPERATION


LAKE SUPERIOR SUMMARY ICE CHART
DATE: 28 MAR 74 - - - - - - - - -
29 MAR 74 —·—·—·—

WINTER NAVIGATION SEASON PROGRAM
COAST GUARD / NWS / NASA / ARMY

FIGURE 4.-RESULTS FROM AN S-BAND SHORT PULSE ICE THICKNESS FLIGHT

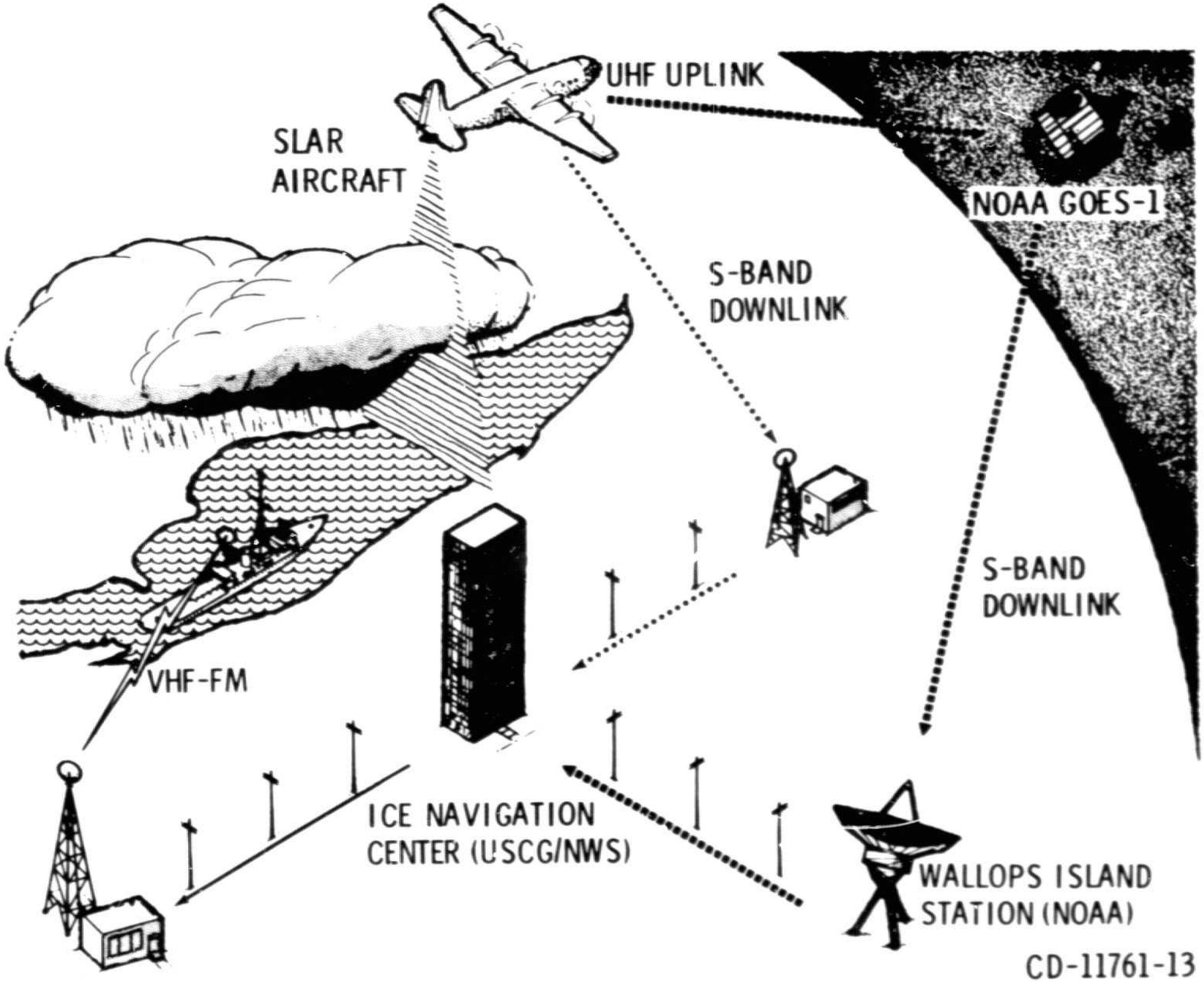



FIGURE 5 -SCHEMATIC OF THE GREAT LAKES MICROWAVE ICE INFORMATION PROGRAM (PROJECT ICEWARN)

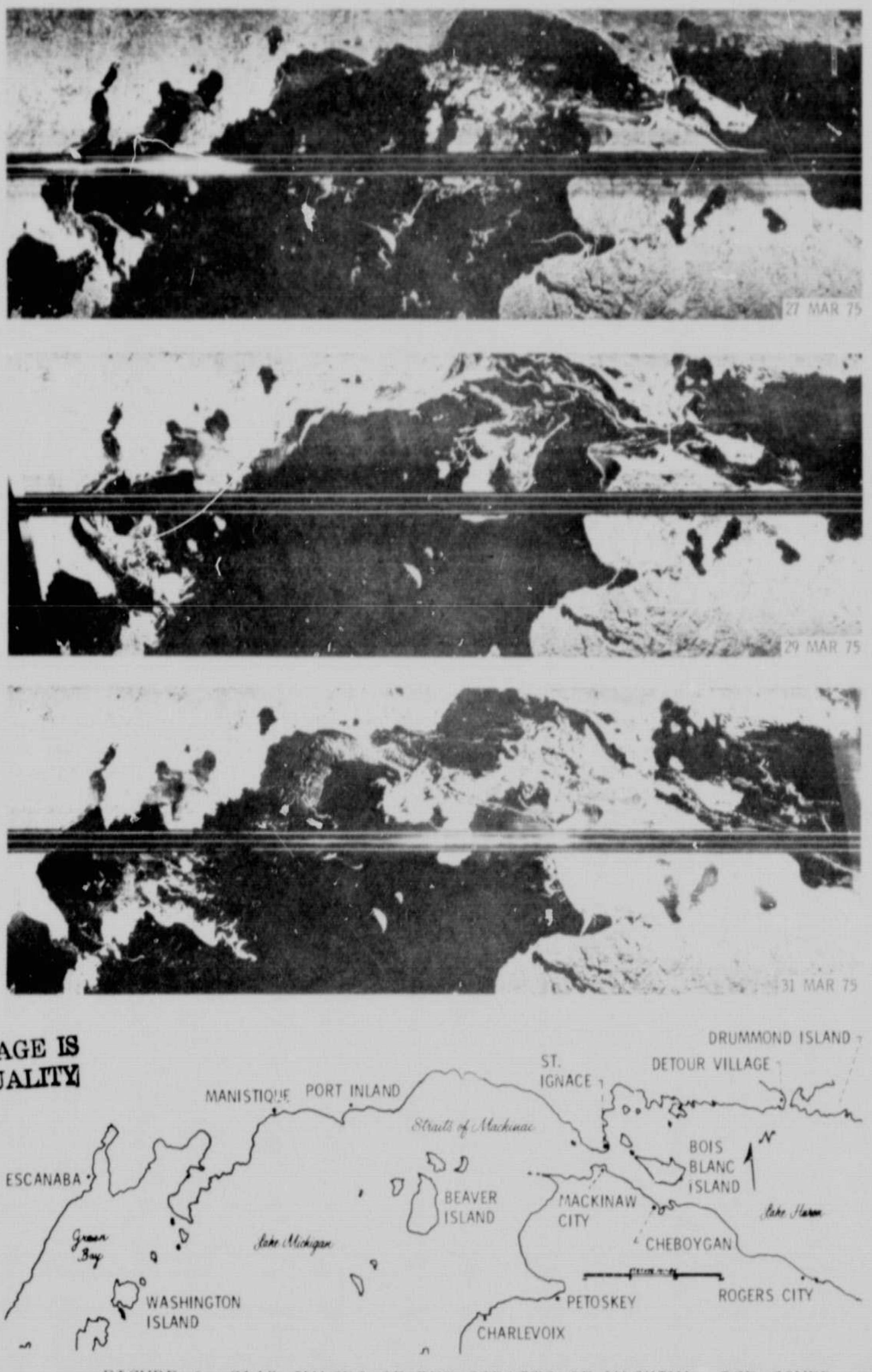



FIGURE 6.-SLAR IMAGES OF THE STRAITS OF MACKINAC ICE COVER ON MARCH 27, 29, and 31, 1975