SECOND INTERNATIONAL CONFERENCE ON
PORT AND OCEAN ENGINEERING UNDER ARCTIC CONDITIONS
UNIVERSITY OF ICELAND
DEPARTMENT OF ENGINEERING AND SCIENCE

SEA ICE VERSUS ARCTIC OPERATIONS IN THE ALASKAN AREA

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ABSTRACT

The sea ice problem confronting port and ocean engineering in the Arctic; though not insurmountable, must be resolved before the scope of operations can be extended in that harsh environment. This paper presents the sea ice problems that face surface and sub-surface shipping as well as those associated with fixed offshore platform. In addition, verification of several 30 day sea ice forecasts are depicted as examples of the quality control exercised by Fleet Weather Facility, Suitland, Maryland in fulfilling its tasking as the agency responsible for providing sea ice forecasts to the Department of Defense and other activities as approved by the Chief of Naval Operations.*

INTRODUCTION

The United States Navy, Fleet Weather Facility located in Suitland, Maryland is tasked with providing sea ice forecasts to the Department of Defense. The uniqueness of this prediction service and the ability to provide it on a global basis has resulted in numerous requests from other nations to support their polar endeavors. Some of the countries assisted during the past year were Argentina, Brazil, Chile, Denmark, France, Japan, and the Soviet Union.

Currently, reasonably accurate sea ice forecasts, particularly along the ice edge, Figure 1, are being made by the operational sea ice forecaster. As many people know a sea ice forecaster must be a competent meteorologist and oceanographer. It is not so well understood, however, that the sea ice forecaster of today must also be a computer programmer and satellite interpretation expert in order to take maximum advantage of recent technological developments. So while continuing research programs are necessary to fully understand the polar ice pack, the operational sea ice forecaster needs inputs now from the scientific community to effect more

*The ideas in the paper are those of the authors and do not necessarily reflect the views or the policy of the Navy Department or the Department of Defense.

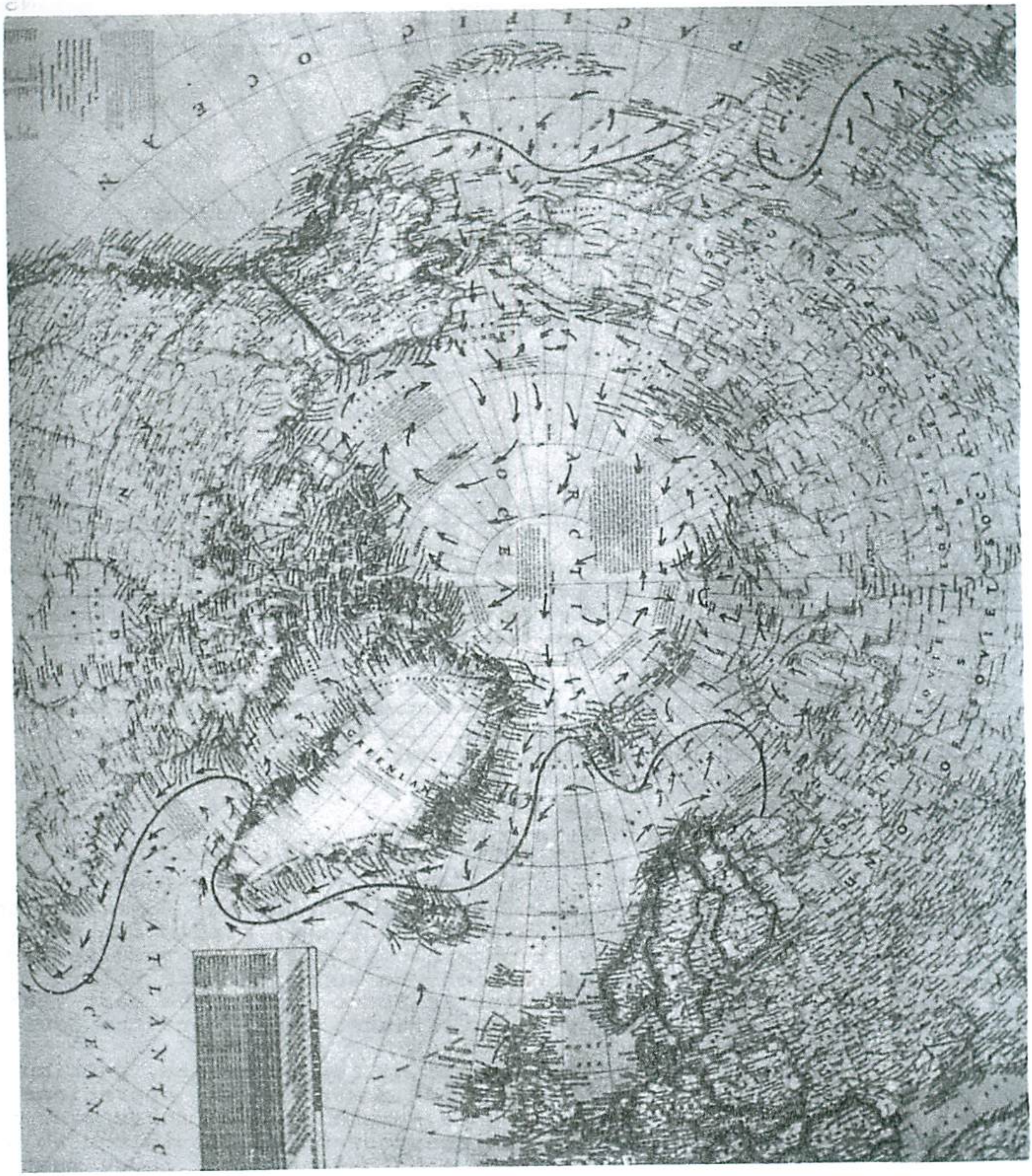

Figure 1.

accurate and longer range predictions.

The Arctic pack, an ever moving, always changing mass of sea ice, Figure 2, is a formidable opponent to Arctic operations. Every floe because of its size and shape has a different sailing characteristic from the next while tremendous natural forces effect its growth and decay. In areas of lesser concentration visual detection of sea ice is severly hampered by white caps, blowing sea spray and fog while high seas preclude detection by radar. In addition, clouds greatly limit the amount of ice information available from satellite and aircraft. These then are some of the problems the sea ice forecaster must overcome and, hence, experience is a very important asset.

SURFACE SHIPPING

Though this paper deals primarily with the problems presented to Arctic operations by the pack ice, it is the associated poor weather in the marginal ice zone that magnifies the hazards, particularly with regard to surface shipping.

The northwest and north coasts of Alaska are perhaps the most dangerous areas in the world where shipping normally occurs. In general, a shore lead develops in July and continues until freeze-up in October. This lead may or may not close at one or more places during the navigation season and it is not unusual for the lead to close again and again from Point Barrow to Cape Simpson. Another area of concern is Camden Bay including Barter Island and the area just east of Barter Island where ice may persist close to the coast. A tongue of ice sometimes extends southward to Point Franklin a result of the small counterclockwise eddy in the southwest to northeast coastal current west of Barrow, Figure 1, and this ice tongue may remain close to the coast the entire summer.

Though some years the pack may retreat many miles offshore, the usual situation is for the pack to remain in a threatening position throughout the navigation season. Surface ships plying the coastal lead may be beset by the pack or even driven aground as a result of the tremendous force of the southward moving pack.

The history of Arctic exploration includes many accounts of ships being beset or crushed by the ice pack. As recently as 1970 and 1971, icebreakers operating in the Chukchi and Bering Seas were beset by winter ice.

In March 1970, the Chukchi Sea pack, subjected to storm force northerly winds, carried an icebreaker 30 nautical miles to the south and held the vessel in a vise-like grip with a 12 degree list for 4 days. The resulting southward movement from the inexorable pressure of the ice brought the vessel to within 7 nautical miles of grounding water. In all the years the authors have observed the Chukchi Sea pack it was at this time the most heavily ridged, Figure 3.

In the Bering Sea during March 1971 another icebreaker was carried by the pressure of the pack some 20 nautical miles to the west. Figures 4 through 8 depict conditions that occurred in the Bering Sea in March 1970 that were more severe than those the icebreaker experienced in March 1971.

The above accounts happened in winter ice and both south of the Arctic circle and pose the question; "How would ships other than icebreakers have fared in similar situations?"

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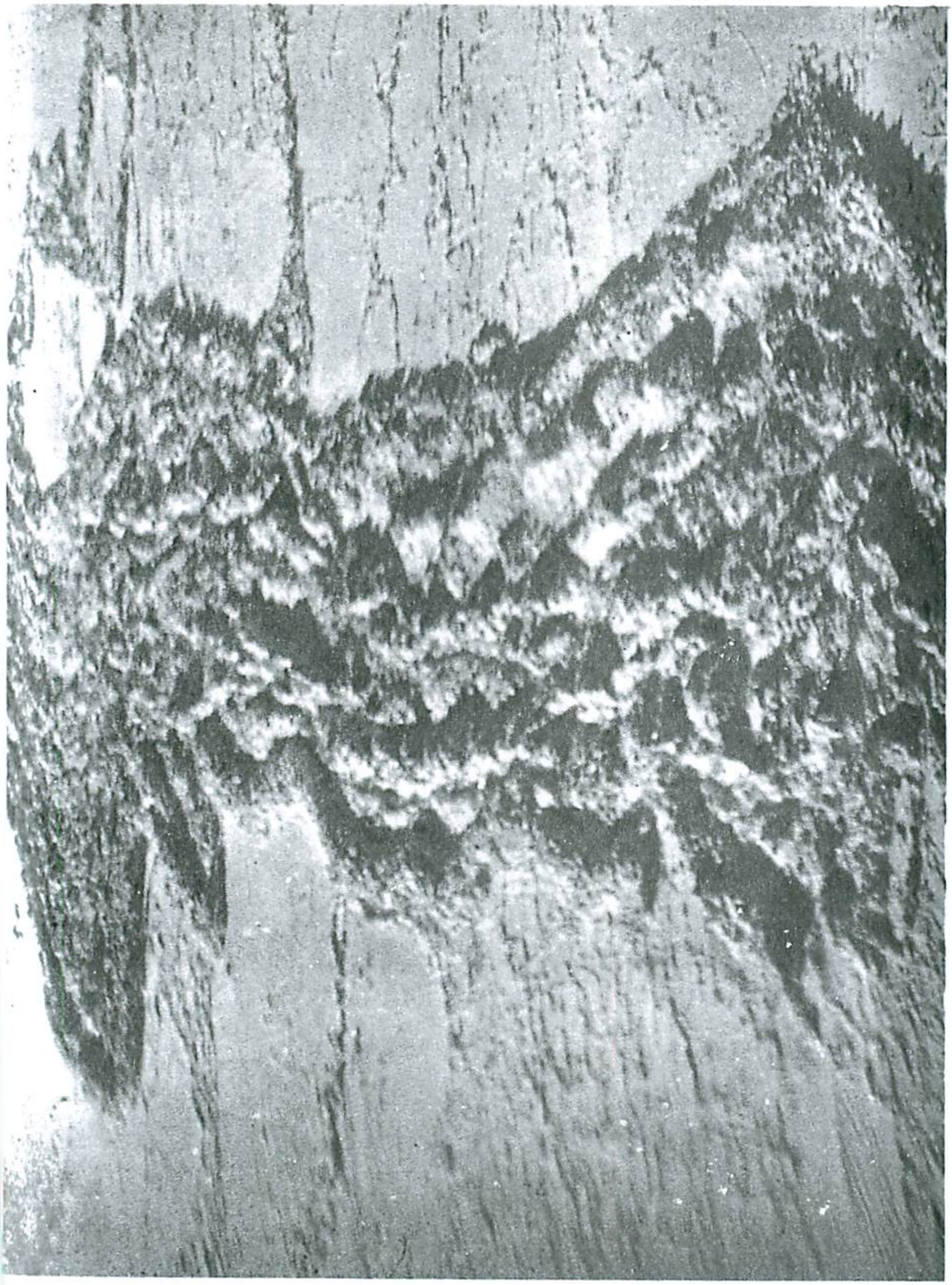


Figure 3.

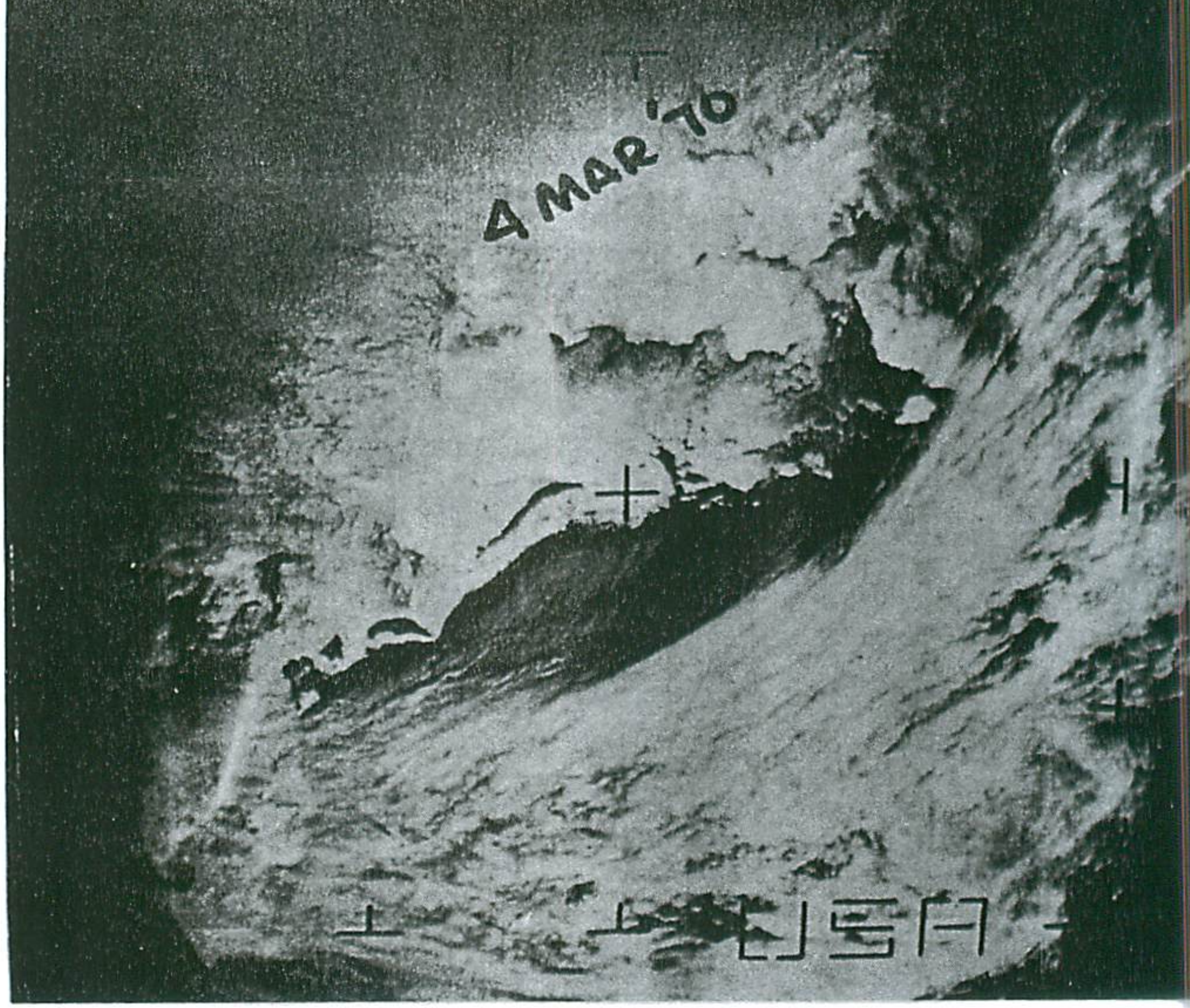


Figure 4. Bering Sea 04 March 1970. Note the ice growth movement of the ice edge in the vicinity of Nunivak Island, Figures 4 through 8.

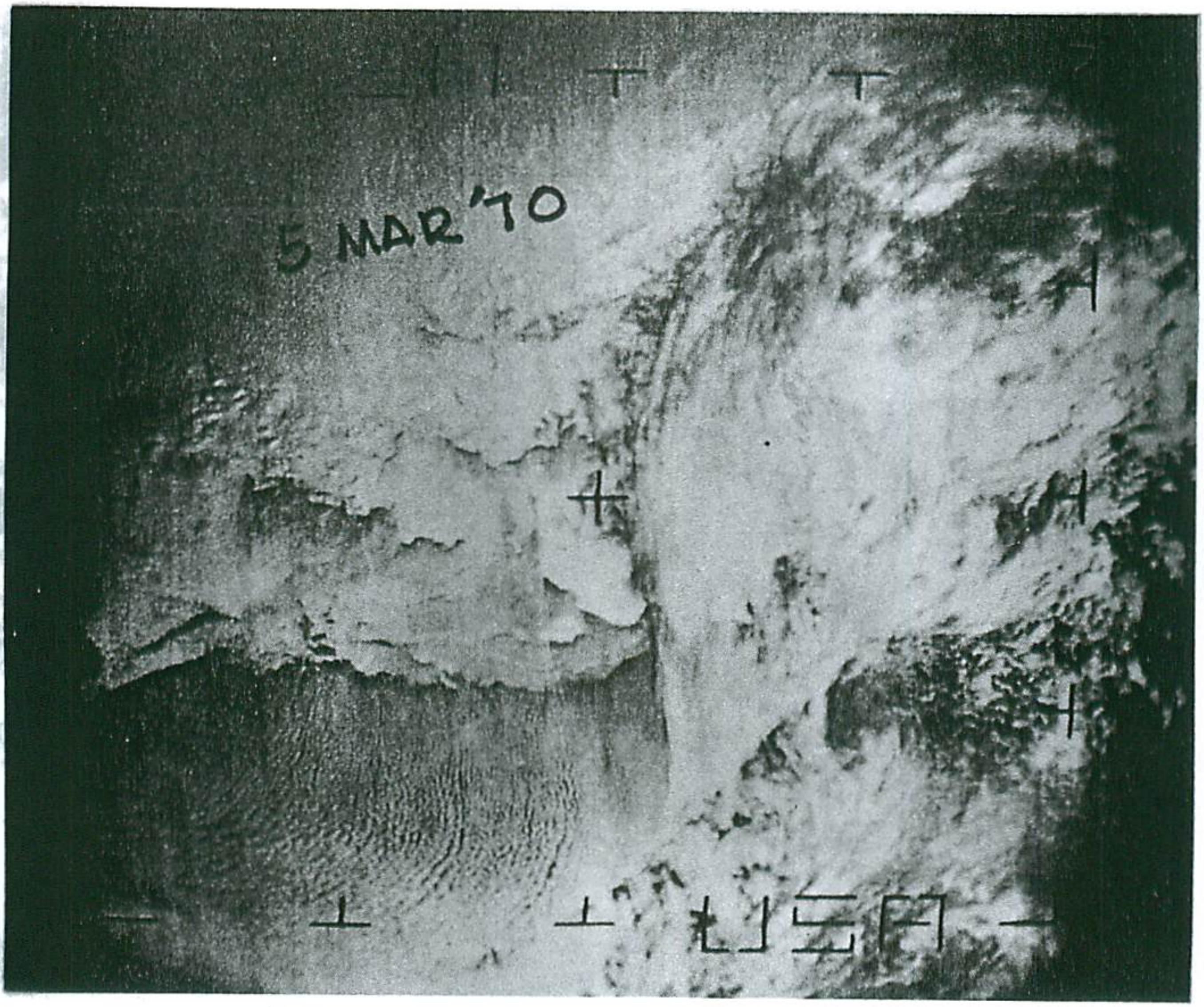


Figure 5. Bering Sea 05 March 1970.

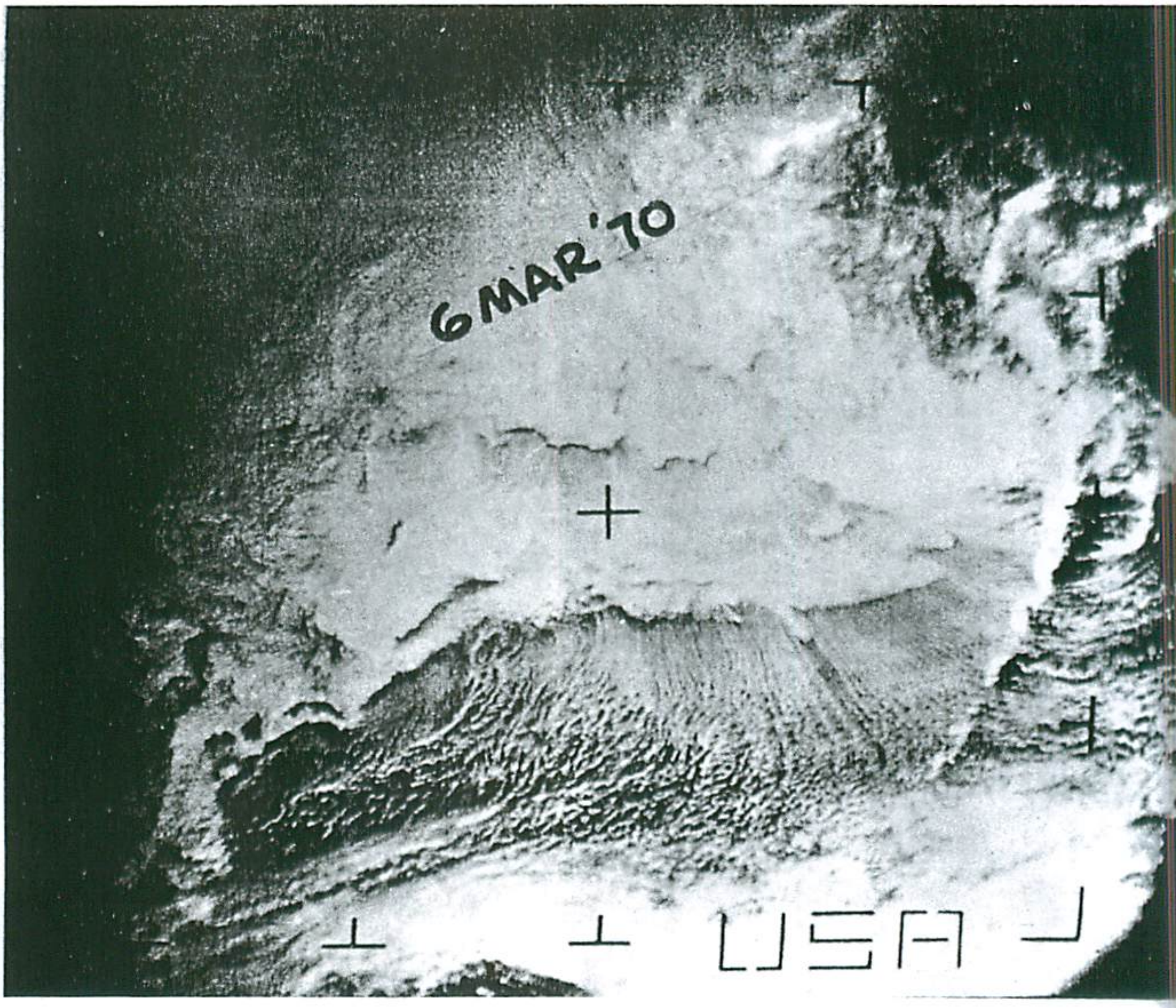


Figure 6. Bering Sea 06 March 1970.

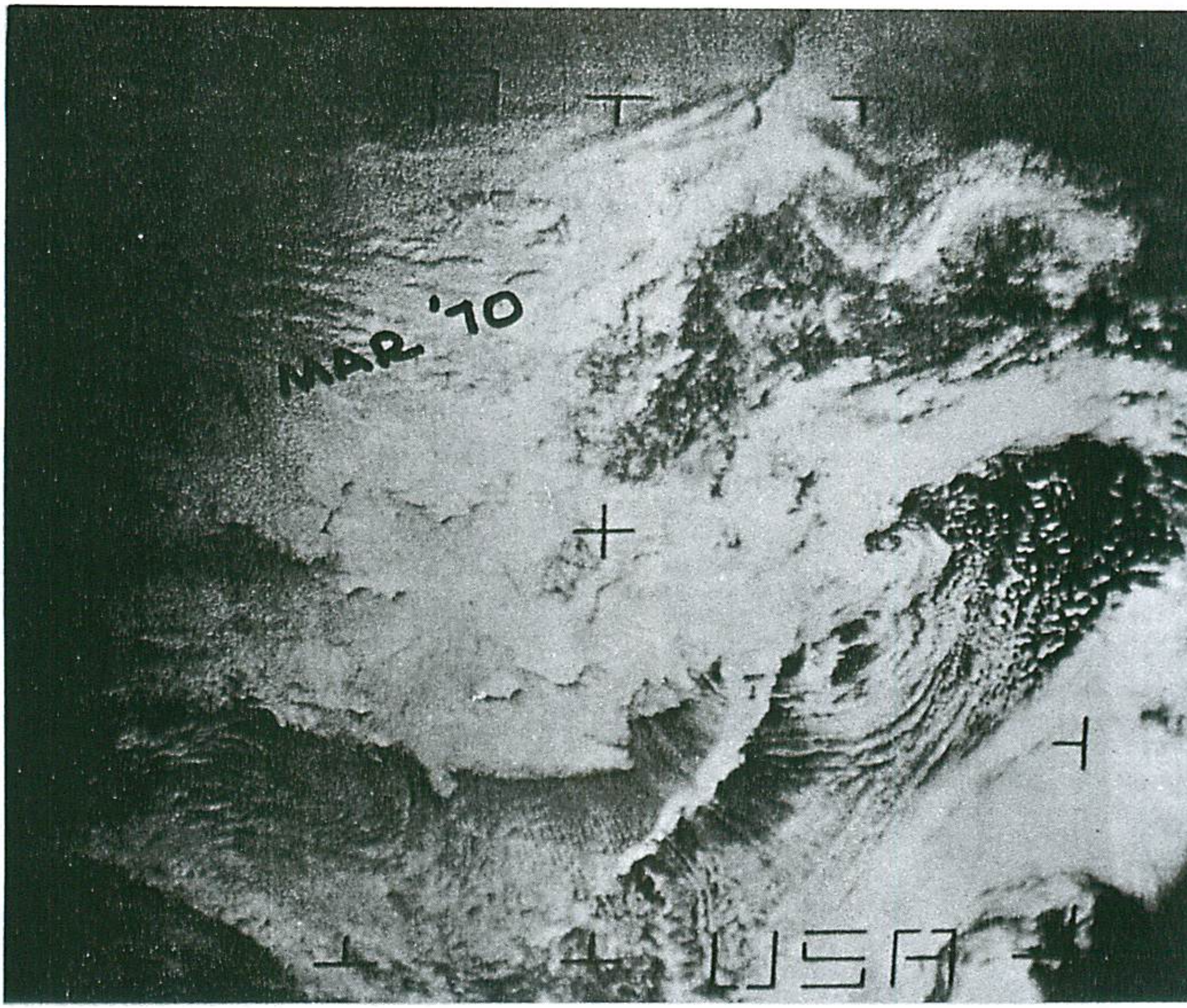


Figure 7. Bering Sea 07 March 1970.

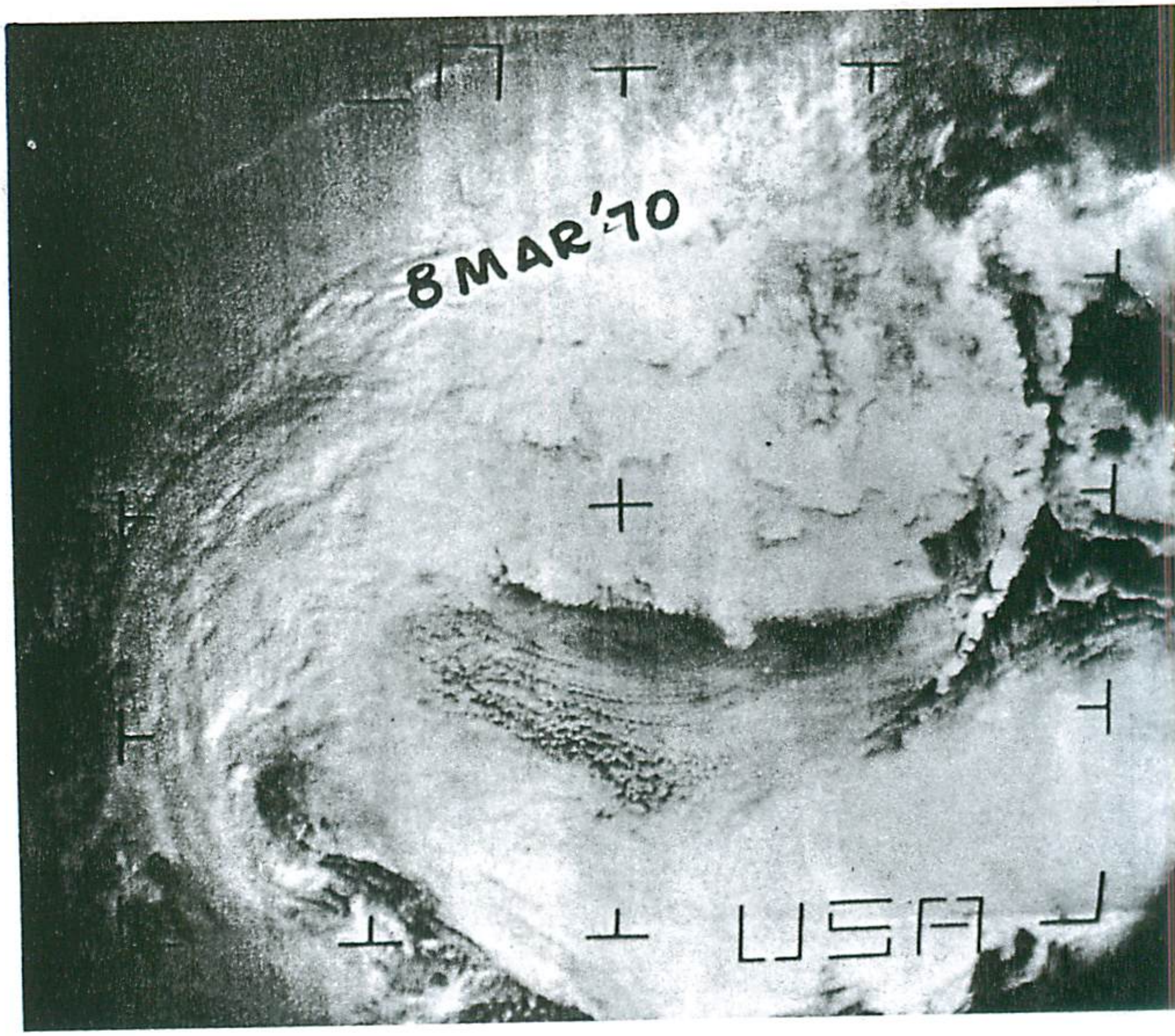


Figure 8. Bering Sea 08 March 1970.

Standard hulldesign of ships of today does not permit ice-breaking or the capability of being lifted out of the crushing ice pack. If winter ice can stop icebreakers, then the much thicker and harder Arctic pack must be even more dangerous. It should also be noted that when pressure from the north is being exerted against a hull the Arctic pack has an almost unlimited source of ice to draw from.

Deep draft vessels, those drawing 30 feet or more, when operating in the narrow coastal lead off Alaska are never any distance from the grounding water nor are they ever far from the threatening pack. In some cases the 10 fathom curve is only 5 nautical miles off the coast. A deep draft vessel in this coastal lead is always in a perilous situation.

Though strong northerly winds do not occur regularly in this area during the navigation season, they do sometimes happen and can be persistent. There are only two alternatives for deep draft vessels when the coastal lead is narrow and northerly winds are forecast; (1) run west and south to open water south of Point Barrow or (2) run east for open water in Mackenzie Bay.

At this stage in ship construction, shipping along the north coast of Alaska is possible for deep draft vessels only during the summer navigation season. Increased power, maneuverability and hull strength will certainly increase the navigation season especially into autumn. Depending on the location of the pack and the capability of the ship in new ice the season could be extended into November and perhaps even longer.

There is obviously a need for:

(1) Reliable and accurate sea ice forecasting services.

(2) A protected deep water harbor close to major activities.

(3) An increase in the navigation season through better ship construction.

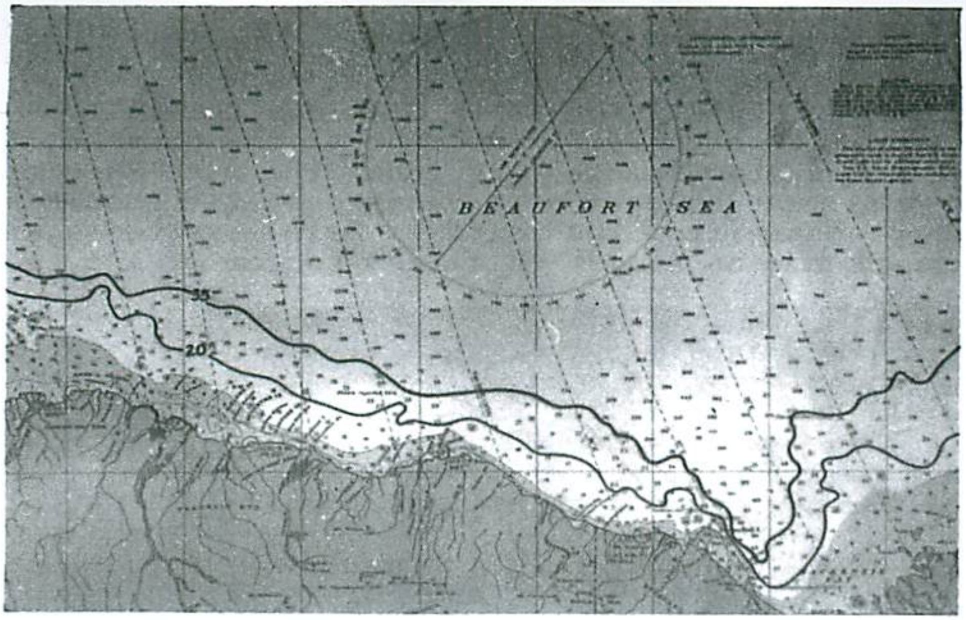
(4) Icebreaker assistance as required.

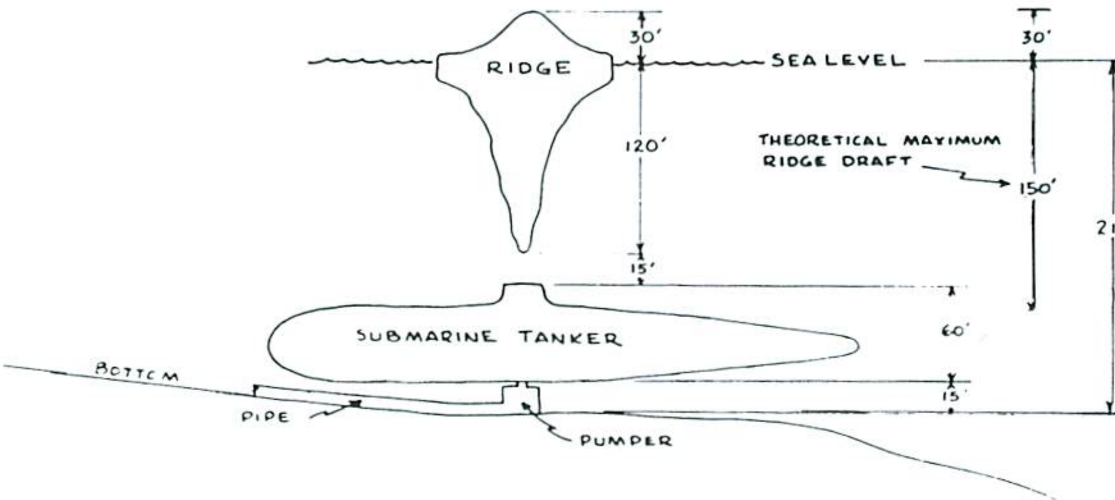
SUBMARINE TANKERS

Submarines can operate anywhere in the Arctic where the water depth is sufficient for safety from the underwater projection of pressure ridges. Without dependable ice forecast services submarines should never operate inshore of the 35 to 40 fathom curve off the north coast of Alaska, Figure 9. The depth of 35 fathoms is arrived at by adding 60 feet for the overall height of a submarine to the theoretical maximum depth of pressure ridge keels which is 150 feet, Figure 10. Off Prudhoe Bay it is necessary for a submarine to be over 50 nautical miles off the coast, or to the edge of the continental shelf to be secure from ridge keels.

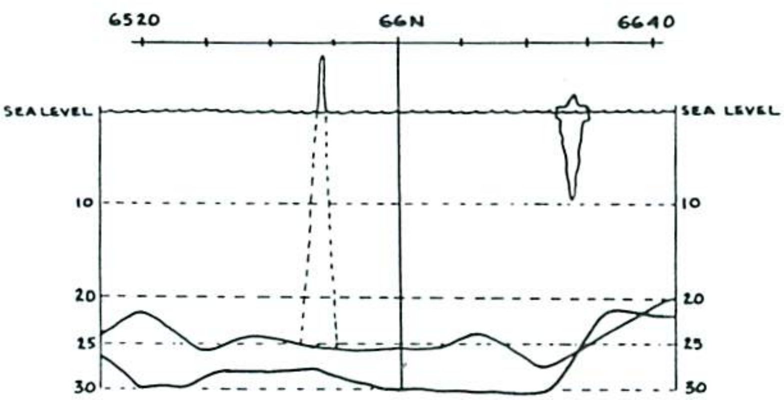
Water openings or newly refrozen water openings are a frequent occurrence in drifting pack ice. They occur less often, however, wherever a geographic restriction is imposed such as the north coast of Alaska. Water openings are required by submarines as a place to surface in an emergency. At those times when onshore drift prevails the openings will occur farther offshore.

Submarine tankers transiting the Bering Sea, Bering Strait, and Chukchi Sea will have problems with pressure ridge keels. Ridges towering 18 feet have been recorded in drift ice in the Bering Sea and one at the edge of the fast ice off Port Clarence, Alaska was measured at 28 feet above sea level. In the Bering Sea these ridge heights are unusual and in the case of the 28 foot ridge it was grounded in 42 feet of water. Since ridge sails to ridge keels are in the ratio of 1/3 to 1/5 then the 18 foot ridge





DANGER FROM PRESSURE RIDGES
EVEN AT 35 FATHOMS



BERING STRAIT

1. RIDGES OVER 70' FROM TOP OF SAIL TO BOTTOM OF KEEL HAVE BEEN MEASURED JUST NORTH OF STRAIT

2. MAXIMUM DRAFT WOULD BE 56' PLUS. THAT DOESN'T NEGATE SUBMARINE WINTER OPERATIONS, BUT CERTAINLY MAKES IT DIFFICULT FOLLOWING A STORM.

could have a keel extending 90 feet below sea level.

Pressure ridges have grounded in the Chukchi Sea many times. In particular, at approximately 72N, 162W where a sea mount exists at a depth of some 70 feet a ridge first detected there in the Spring of 1971 remains in the same position as of the date of this paper indicating that is has survived at least two summer melt seasons and some high sea conditions. This ridge was observed by aircraft on 21 September 1972 and can be detected from satellite photographs especially in the winter time when a polynya occasionally becomes associated with it.

Just north of the Bering Strait in an area of slightly shallower water more extensive (east/west) ridges are encountered signifying that submarine tankers would have to exert caution and circumnavigate at times to reach the Alaskan north coast from the south, Figure 11. There is a possibility that in rare instances the only way a submarine tanker could safely reach the north coast would be by an approach under the pack from the north.

The only real reason for submarine tankers in lieu of or as a complement to surface tankers is for year round operations. If oil, for example, is to be transferred from wells to a submarine tanker then either two, of several possible alternatives, must be considered. Either bury a pipeline to the edge of the continental shelf or dig a deep channel to the north coast.

FIXED OFFSHORE PLATFORMS

A mobile platform eliminates many problems that sea ice poses for a fixed platform and will experience difficulties similar to those of surface shipping.

Fixed offshore platforms fall in either one of two categories; platforms in fast ice or platforms in drift ice. Of the two, the platform in fast ice is more likely to survive.

By definition, fast ice is fairly level ice that grows relatively undisturbed from the land seaward and remains attached to the shore. This definition does not account for pressure ridges found at its seaward boundary nor does it include the physical properties of thermal expansion and contraction of the ice. Thermal expansion and contraction are likely the biggest problems a fixed platform must overcome since sea ice expands until it reaches a temperature of approximately minus twelve degrees Celsius and then it contracts, with the expansion being about twice the lateral distance of the contraction.

A second problem occurs when the fast ice breaks and commences to drift. The magnitude of this problem is determined, of course, by the rate of drift and the amount of ice brought against the platform. When the fast ice has broken and has drifted seaward or melted, then, except where the platform is protected by outer islands, the platform becomes exposed to the drifting pack.

Fixed platforms in pack ice could be carried away by the pack. The survival of a fixed platform in pack ice, particularly off the north coast of Alaska, will simply depend on the strength of the rig. The survival of the fixed platform in Cook Inlet leading to the port of Anchorage, Alaska gives some indication of the chance for survival of a fixed platform in pack ice. However, compared to Cook Inlet ice the Arctic pack is much thicker, harder, larger and greater in concentration for the most part. Though some floes in Cook Inlet, formed under unusual circumstances, may exceed 8 feet in thickness, in general, the pack is about 3 feet thick, does not have a large surface area and is not inclined to lodge against a platform. This suggests a need for trial platforms in both fast and drift ice or the use of mobile platforms only.

SEA ICE FORECASTING

If Arctic operations continue to expand then sea ice forecasts must become more reliable and accurate. And if the forecasts are to become more reliable and accurate then more input data must become available and a better processing of this data must become a reality.

Visual aerial observations by a trained ice observer are still the best source of sea ice data, however, aircraft availability, aircraft range and obscuring fog and low stratus are limiting factors to visual observations.

At present, imagery from sensors aboard satellites constitute the only source of reliable data, particularly for remote areas. Visual, infra-red and now micro-wave photographs are filling the huge data gaps left by the lack of more conventional observations. The ground truth necessary to qualify or disqualify the information gained by interpreting the satellite imagery is obtained from visual observations.

The micro-wave imagery, capable of penetrating all but the more active frontal systems is now being used operationally and despite its relatively low resolution of 25km and extremely small scale it is the most promising source of ice data to date, Figures 12 and 13. By use of this imagery a constant watch can be maintained on the movement, growth and disintegration of the polar packs during periods of darkness and cloud cover.

Since the microwave data is quantitative and available on a global basis a project is underway to automatically map the ice edge and plot some inner pack information on a day by day basis. This will relieve the forecaster of this tedious task. Once this automated ice edge program is completed the ice edge can be advected using forecast wind, current and temperature information. The forecaster would then massage this automated analysis and forecast ice edge based on his experience and other information.

SEA ICE FORECAST VERIFICATION

The sea ice forecasts 5 day, 7 day and 30 day are made by hand massaging sea ice movement vectors at the grid points depicted in Figure 14 and computed using the automated scheme listed in Figure 15. In particular, 30 day sea ice movement vectors are calculated from geostrophic surface winds derived from a 30 day mean sea level prognosis, Figure 16. In addition to the 30 day sea ice vectors sea surface temperature, forecast surface temperature anomaly, climatology and forecaster experience are employed in the preparation of the 30 day sea ice forecast chart which is issued twice a month for the Northern Hemisphere.

Figure 17, is the initial 30 day sea ice forecast chart issued by the Fleet Weather Facility Suitland. The dashed line indicates the latest sea ice analysis available at the time the forecast is prepared. The sea ice forecast itself depicts a general expansion of the ice field and except in the vicinity of 165E verified quite well.

Figure 18, illustrates the problem of forecasting general recession of the pack ice. Extensive recession was forecast for the Sea of Okhotsk while the Bering Sea west of Bristol Bay was expected to change very little. The verifying ice edge is shown to

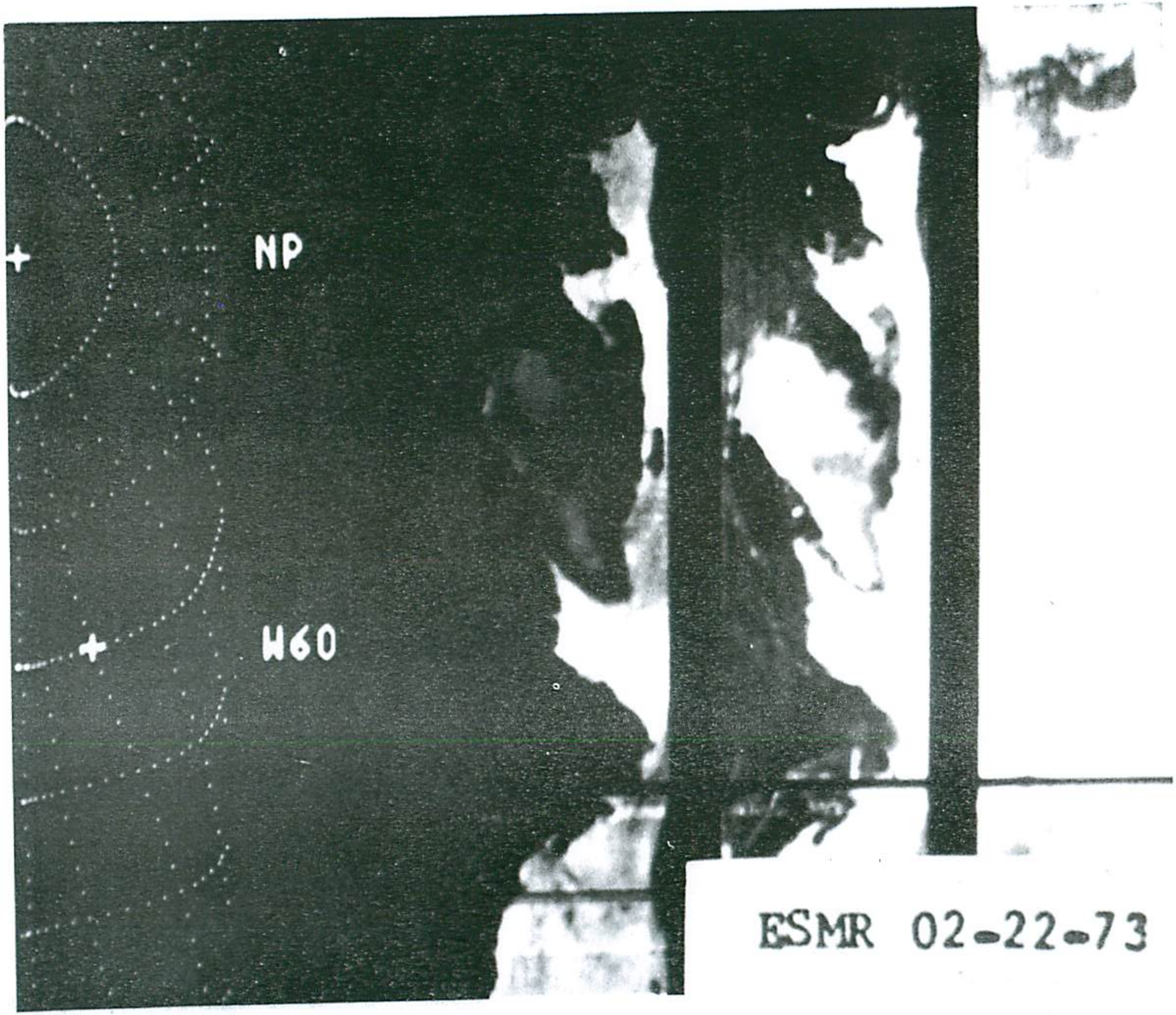


Figure 12. Note the Odden east of Greenland

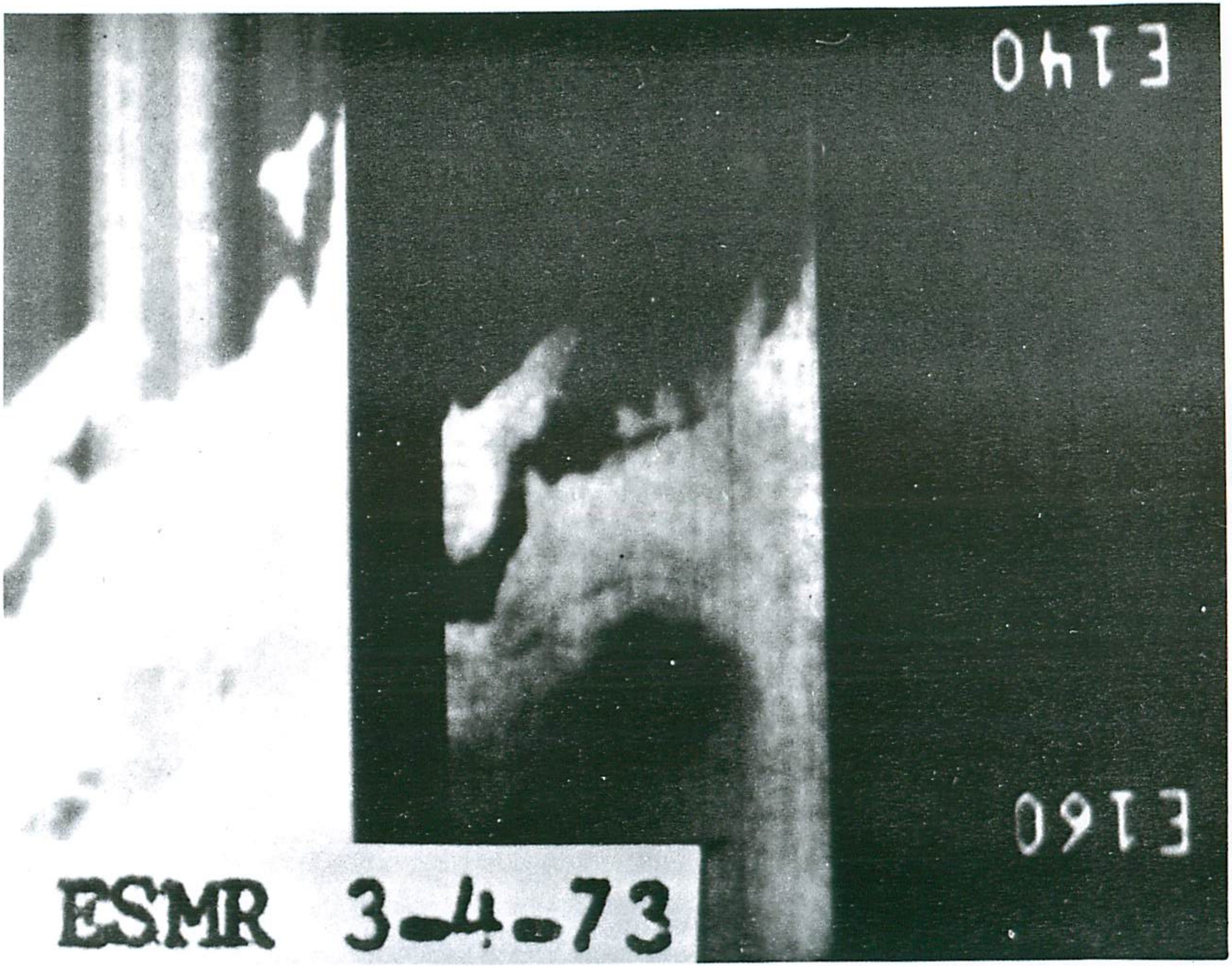


Figure 13. Note the ice tongues extending southward to the kuril Islands which were not detectable by other means.

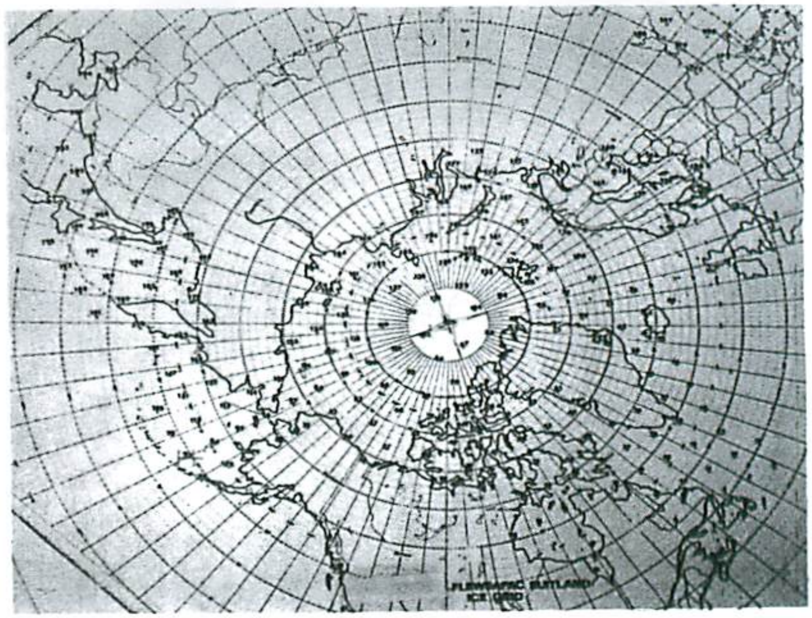


Figure 14.

1. CALCULATE THE AVERAGE GEOSTROPHIC WIND DIRECTION AND SPEED AT EACH GRID POINT (dd ff)

2. MODIFY dd FOR ff. $dd' = 31.3e^{-.168ff} + dd$

3. MODIFY ff FOR SEASON AND dd'. $ff' = ff + 2\sqrt{ff} \times A$ WHERE A IS A FACTOR DEPENDENT ON WIND DIRECTION AND MONTH OF THE YEAR.

4. CALCULATE THE ICE DRIFT SPEED FOR ff'. $\alpha = .025 + .00772ff'$

5. MOVE ICE WITH dd', α

   a. ICE DIRECTION = dd'
   b. ICE DISTANCE = α x 24 HRS/DAY x Y DAYS

6. PRINTOUT ICE MOVEMENT VECTORS

7. MOVE ICE WITH CURRENT DIRECTION AND SPEED DDFF

   a. ICE DIRECTION = DD
   b. ICE DISTANCE = FF x .01 x 24 HRS/DAY x Y DAYS

8. MOVE ICE WITH WIND AND CURRENT

   a. ICE DIRECTION = DD + dd' } VECTOR ADDITION
   b. ICE DISTANCE = 5b + 7b }

9. PRINTOUT ICE MOVEMENT VECTORS

Figure 15.

Figure 16.

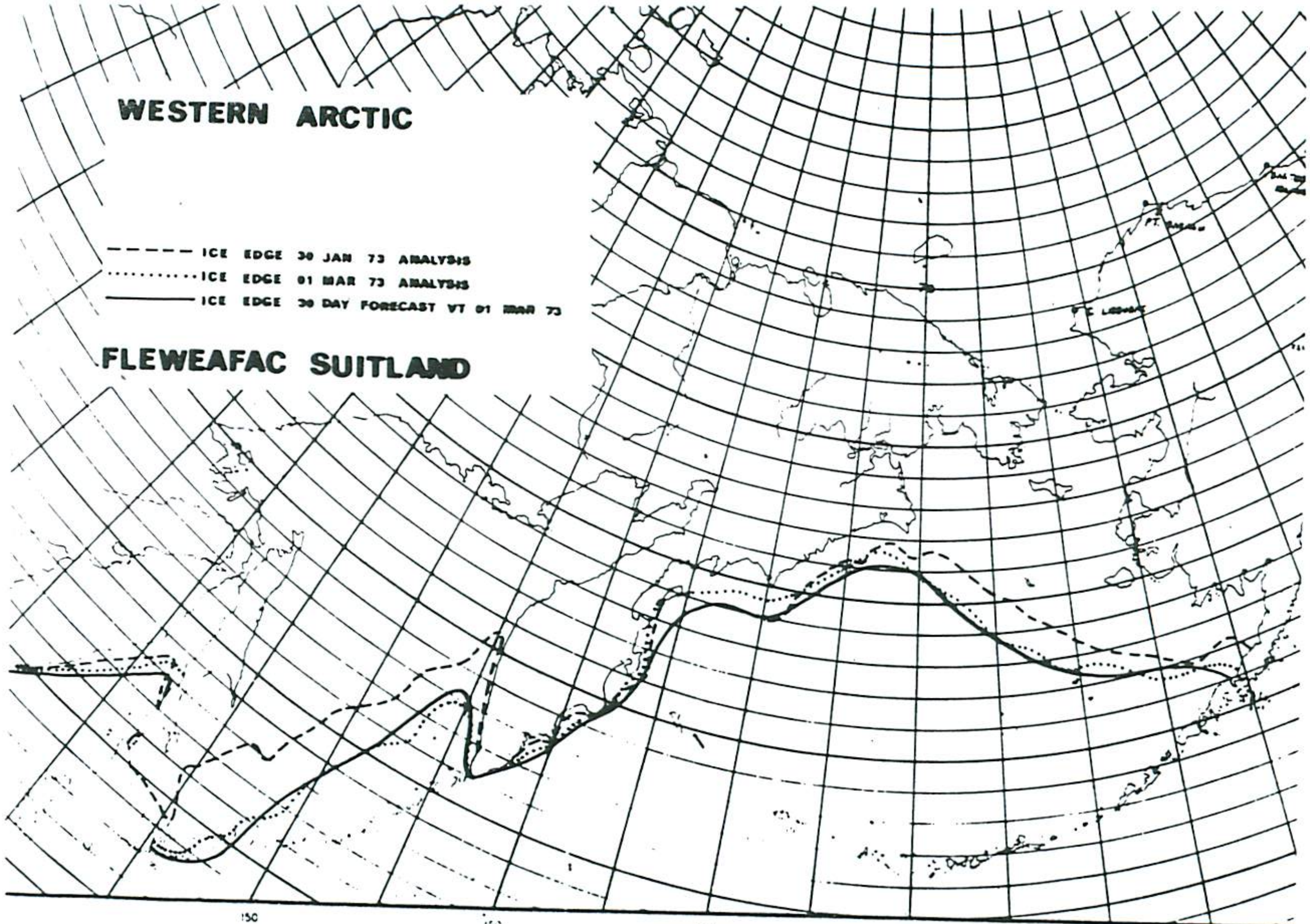

WESTERN ARCTIC
ICE EDGE 30 JAN 73 ANALYSIS
ICE EDGE 01 MAR 73 ANALYSIS
ICE EDGE 30 DAY FORECAST VT 01 MAR 73
FLEWEAFAC SUITLAND
150
160
170

Figure 17.

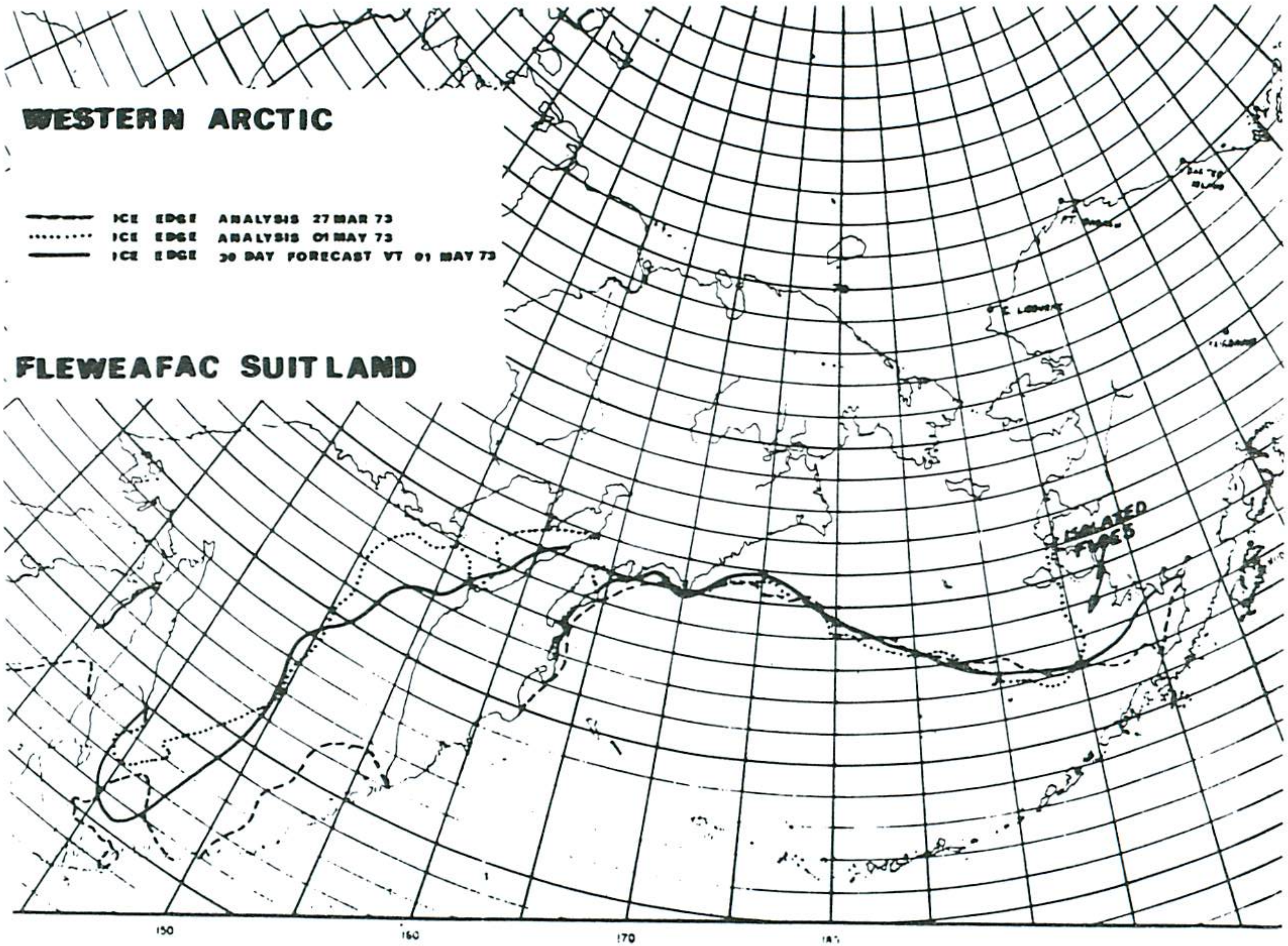

WESTERN ARCTIC
ICE EDGE ANALYSIS 27 MAR 73
ICE EDGE ANALYSIS 01 MAY 73
ICE EDGE 30 DAY FORECAST VT 01 MAY 73
FLEWEAFAC SUITLAND
150
160
170
ISOLATED FLOES

Figure 18.

be far to the northwest of the forecast ice edge in Kuskokwim Bay, however, Kuskokwim Bay did contain isolated remnant pressure ridges which are a hazard to navigation.

Figure 19, is noteworthy because of the extensive recession forecast off the coast of Newfoundland despite the fact that that area experienced severe ice conditions at and prior to the time the forecast was made, Figure 20. The forecast was based on the strength of the warm temperature anomaly expected to develop and persist in the Newfoundland area and accurately led to the conclusion that the approach to Goose Bay, Labrador would open earlier than normal.

In general the Eastern Arctic (95W eastward to 105E) presents a greater forecast problem than the Western Arctic (105E to 95W) primarily because of the stronger ocean currents in that area.

ACKNOWLEDGEMENTS

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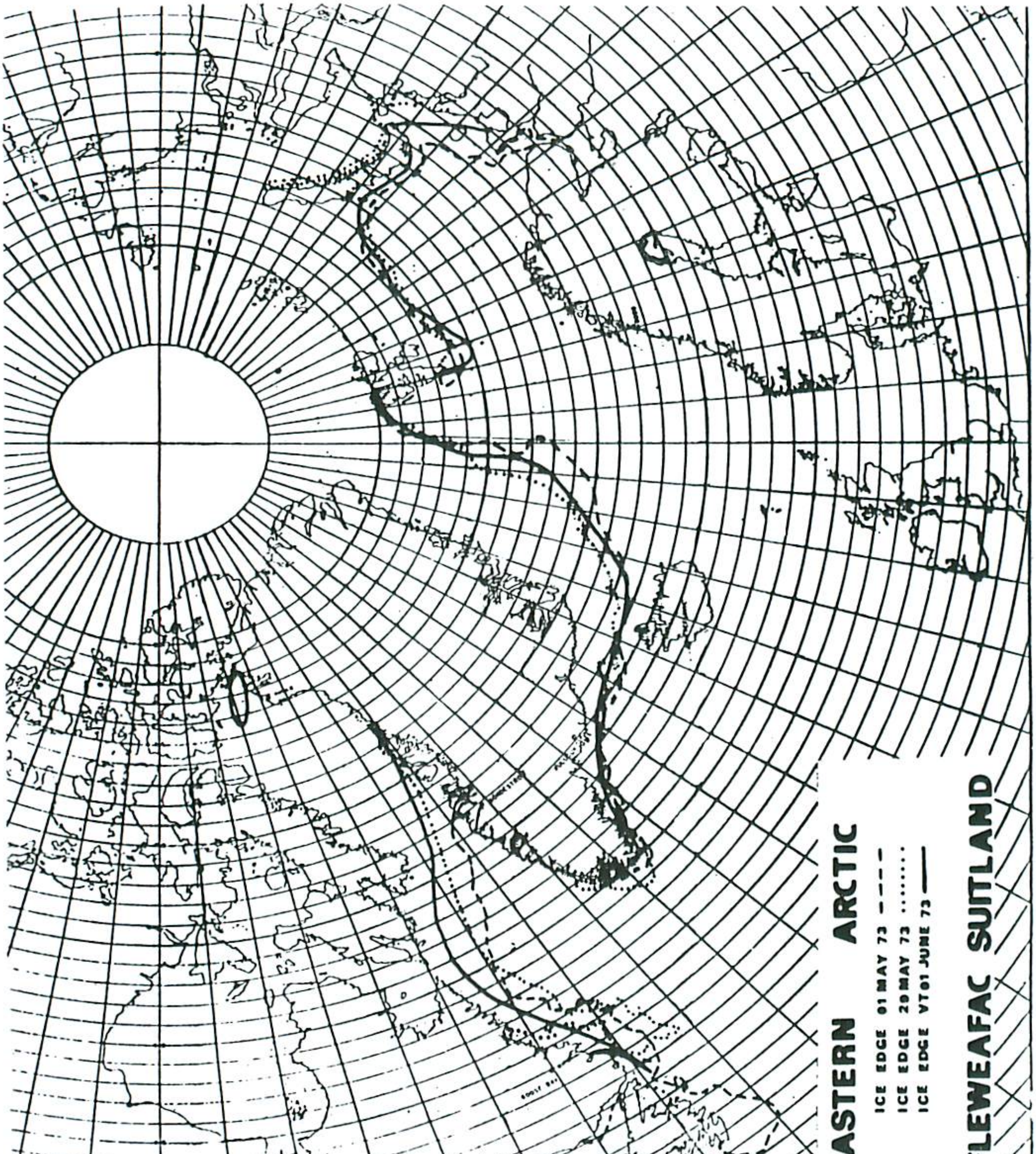
EASTERN ARCTIC
ICE EDGE 01 MAY 73
ICE EDGE 29 MAY 73
ICE EDGE VT01 JUNE 73
FLEWEAFAC SUITLAND

Figure 19.

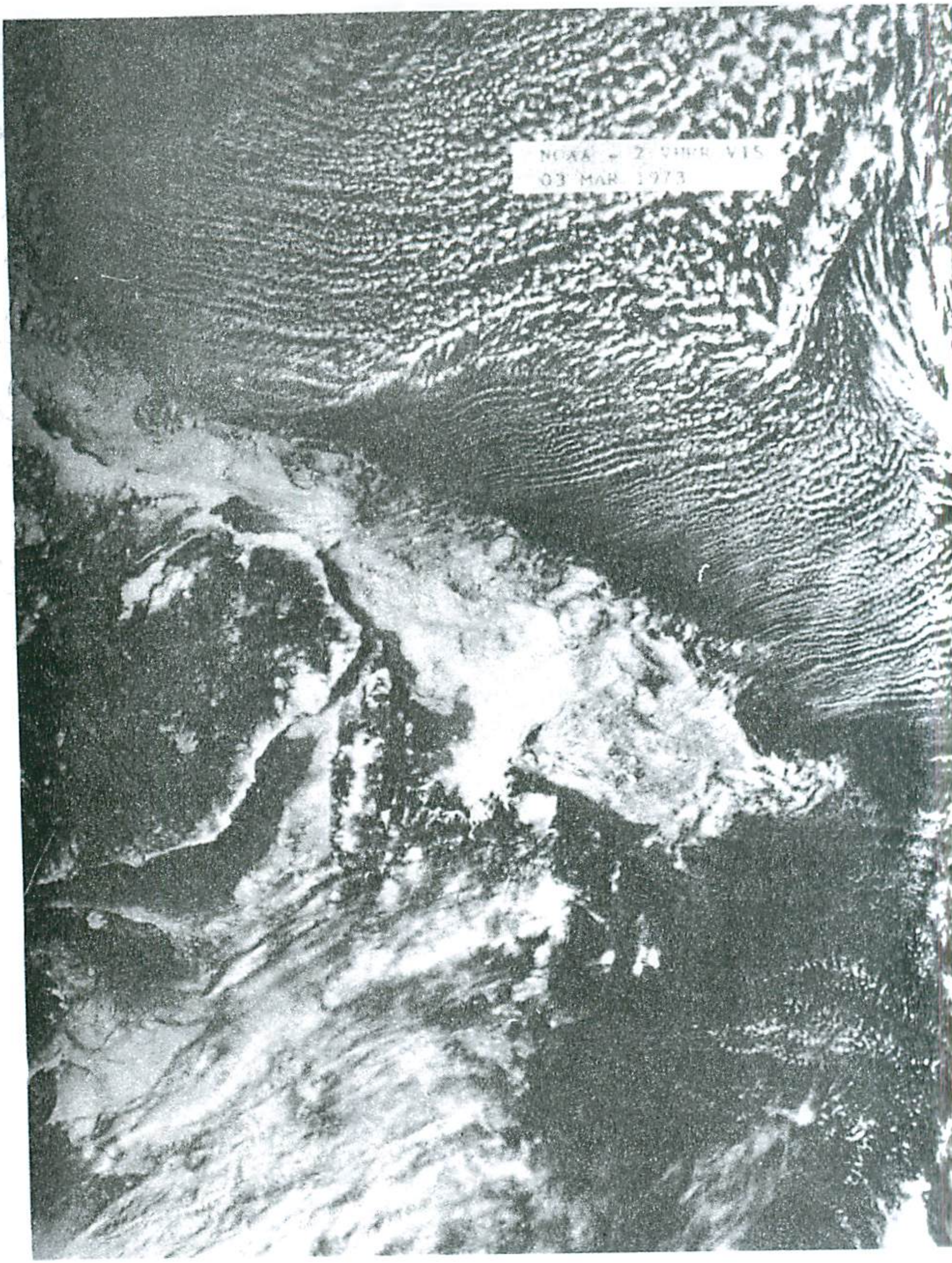

Figure 20.