9G45 - 31

Use of Nimbus II APT to Determine the Rate of Ice Disintegration and Dispersion in Hudson Bay

Contract No. NAS 5-10343
Technical Report No. 8

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Prepared for

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ABSTRACT

This Report describes the result of an investigation of the Nimbus II, APT data to determine the rate of ice disintegration and dispersion over Hudson Bay. The Nimbus observations over this region during the period of May-July 1966 were carefully analyzed and compared with corresponding conventional synoptic data.

This investigation has analyzed and presented an example of the application of the Nimbus data to the Earth Resources Program.

Section 2 briefly comments on the data, case selection, and procedures.

Section 3 discusses the techniques used for identification of ice distribution.

Section 4 summarizes the rate of ice disintegration and dispersion.

Section 5 presents some conclusions derived from this investigation.

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1. INTRODUCTION

The primary objective of the Nimbus satellites is to provide new and improved meteorological observations from space. This aim has been successfully attained to date. In addition, utilization of the Nimbus data has been realized in areas useful to the Earth Resources Program.

One of the potential applications of the Nimbus data, other than cloud observation, lies in the observation of the ice limit in major lakes, coastal harbors, bays, and estuaries of the Polar and sub-Polar regions. This report analyzes the ice-surveillance applications of Nimbus II APT data for May - July 1966, over the region of Hudson Bay.

Scientists in a variety of disciplines are concerned with ice distribution. For example, the meteorologist is concerned with ice primarily as an indicator of climatic changes; the hydrologist is concerned with the storage of water in the form of ice in lakes, rivers, and reservoirs, as well as formation and its rate of melt; the oceanographer is mostly concerned with the effects of ice as a hazard to shipping and as an indicator of ocean currents.

Today, the primary vehicle for obtaining ice information is aircraft. Aerial ice reconnaissance is used to search for leads or openings in ice large enough and long enough to permit passage of ships. In addition, the aerial ice observer looks for features that indicate ice formation, advance, or break-up, or for characteristics which show that icebreakers could be used to open ice-covered ports or waterways for shipping. Aircraft are used extensively for ice-reconnaissance missions, both over the ocean and in the Great Lakes region. Ship and land station reports complement the aerial-reconnaissance program. The success of many of these aerial missions is limited by logistic and economic factors. Furthermore, the accuracy of the observations is largely contingent upon the training and experience of the observer. The observer is also limited in the size of the area that he can view effectively--usually a distance of about 15 mi. on either side of the aircraft. Added to this is the possibility of location error due to navigation difficulties, particularly in the Arctic and Antarctic regions. Also, aerial reconnaissance is often hampered by extended periods of poor flying weather. (Although poor weather conditions at the airport may not permit aircraft operations, a large part of the area to be surveyed may be clear.)

Early experiments involving interpretation and use of satellite imagery have already demonstrated the feasibility of using space vehicles to complement and supplement the conventional ice reconnaissance and surveillance program.

1.1 Background

Hudson Bay is a shallow, subarctic, inland sea situated in the middle of the Canadian Shield. It is 520,000 Km^2 in area and has an average depth of 100 m. The hydrologic system may be considered to be an enormous estuarine basin into which is poured the drainage water from 5,832,000 Km^2 of the continent.

Little was known of the winter ice conditions of Hudson Bay before Hare and Montgomery (1944) published the results of their research showing that Hudson Bay freezes over completely for several months of the year.

The pack ice in Hudson Bay is made up almost entirely of one-year or winter ice; therefore, the floes are mostly smooth and flat, but with sharp, jagged, young pressure ridges where they have been forced together by wind and water. Some of these ridges are as much as 25 ft. high. The thickness of the ice ranges from 3 to 6 ft., and considerably more where rafting has occurred (Dunbar and Greenaway, 1956).

Traditionally, the pack ice begins to clear from the southeastern portion of the Bay by the latter part of May; however, the Bay is not entirely clear of ice until late July at the earliest.

In general, the circulation of water in Hudson Bay is anticlockwise, with a southward flow on the west side and a northward flow on the east side. There is no information on the rate of this flow. However, evidence has suggested that the general circulation is triggered by spring discharge off the drainage basin (Collin, 1966).

Extreme tidal range within the Bay displays an important influence on the initial ice break-up. The rise of tide is from 0.5 - 0.8 m at Port Harrison on the east coast and from 3.5 - 4.6 m at Churchill on the west coast. However, the major influences on the rate of ice break-up and dispersion in this region of little current flow are the surface-wind flow pattern and temperature increases over the Bay area.

1.2 Summary of Results

The analysis of Nimbus II APT photographs for the period of 16 May - 15 July 1966, when either all or a part of the Hudson Bay region was cloud-free, indicates that the satellite can provide operationally useful information on ice disintegration and eventual dispersion. In this region during spring a totally cloud-free satellite observation can be expected once every four or five days. In most cases, ice cover can be reliably identified and differentiated from cloud cover without referring to conventional data. Also, it appears that the ice distribution can be mapped with reasonable accuracy. Identification of numerous geographic features along the coastline of Hudson Bay enabled extremely accurate one-degree grid overlays to be prepared. Relatively small changes on the ice limit were, therefore, readily detected.

Picture quality limited the gray scale in most cases to three distinct tones: dark, gray, and white. The dark areas are presumed to be open or mostly open water; the grayer areas, broken or thin ice; and the brighter areas represent pack or snow ice. Also, because of picture quality, no significant mesoscale detail could be observed in the ice structure.

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2. DATA

2.1 Satellite Data

2.1.1 Case Selection

The initial Nimbus II APT data sample provided nearly daily coverage of the Hudson Bay region for the period 16 May - 15 July 1966. However, the number of cases in which significant changes in ice distribution could be determined was, as expected, smaller than the overall sample. Relatively few cloud-free observations were made over a significant area of the ice limit and over significant periods of time to observe any change. A large number of observations revealed scattered areas of ice distribution through regions of broken or thin cloud; however, these cases did not provide enough data near the major ice edge to be useful in this study. Also, many of the observations were not usable because of inadequate picture quality or high object nadir angles.

A total of ten cloud-free or nearly cloud-free observations were selected for study over the approximate eight-week period. In most instances, a significant portion of the ice limit could be observed for a one- or two-day period immediately prior to or following each case selection.

2.1.2 Procedures

Upon initial case selection from the working prints, landmark reference points were used in preparing grid overlays at one degree intervals.

Pattern continuity was then used to establish the ice distribution in each case. Once pattern continuity had been established, it was mapped on a one degree gridded base map of Hudson Bay (Fig. 1). Comparisons of these mappings allowed for a reasonable determination of the rate of east to west dissipation of the ice cover.

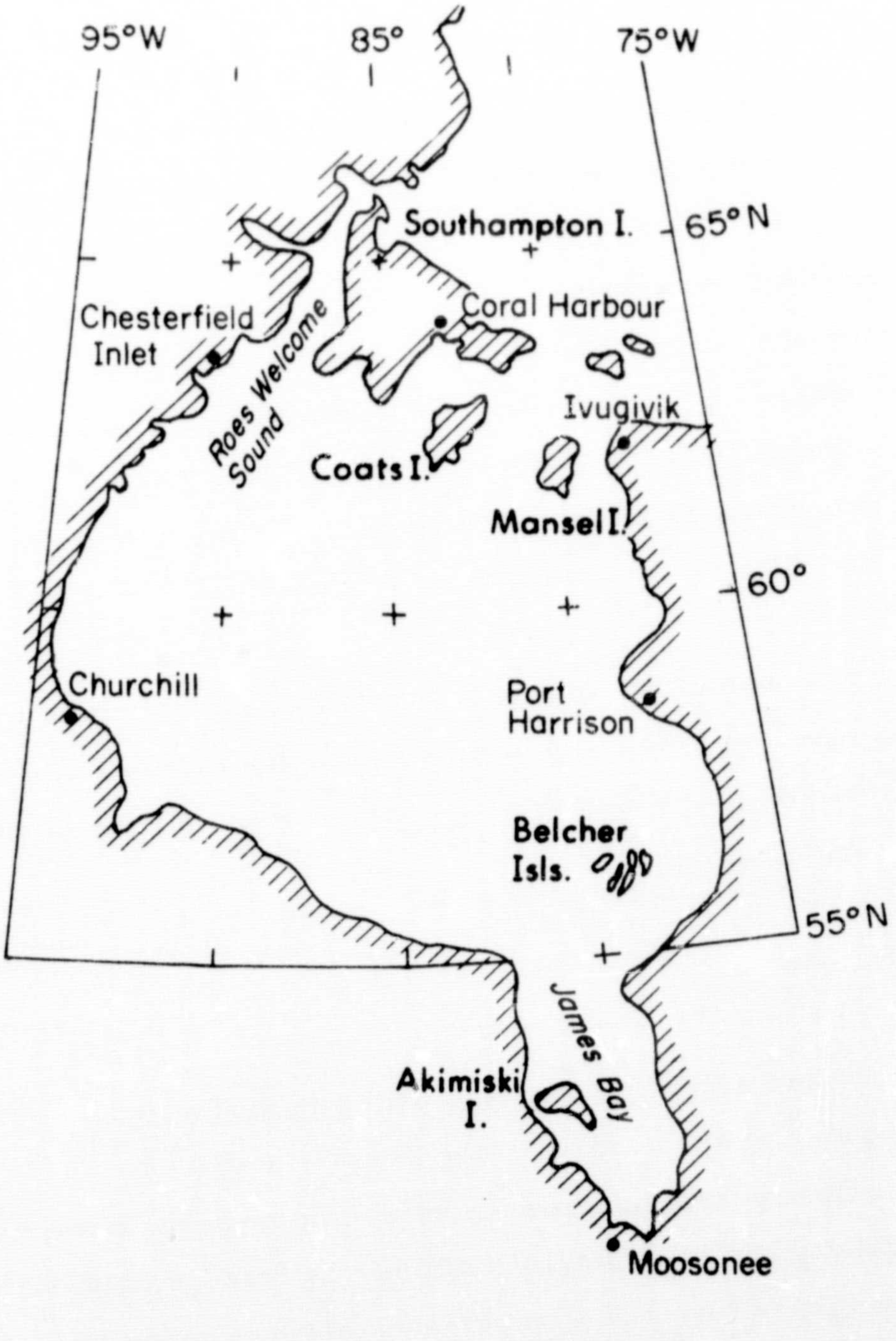

Fig. 1 Hudson Bay Area Base Map.

2.2 Conventional Data

The overall ice dispersion was compared with corresponding mean surface wind-flow patterns and surface air temperature increases throughout the region. Mean 1800 GMT winds and temperatures were derived for several coastal stations over four separate time intervals to determine periodical synoptic changes over the entire data period. It was felt that the 1800 GMT data would more closely approximate the maximum temperatures for each day.

Analyses were prepared for the periods of 16 - 31 May, 1 - 15 June, 16 - 30 June, and 1 - 15 July 1966.

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3. TECHNIQUES FOR IDENTIFICATION OF ICE DISTRIBUTION

Before the rate of ice disintegration and dispersion can be determined from satellite data, the positive identification of the ice distribution must be established. This Section will discuss the differentiation between ice and cloud through the use of conventional cloud reports, pattern stability, appearance and recognition of geographical features.

3.1 Differentiation Between Ice and Cloud

One important problem in the use of satellite observations for ice distribution analyses is differentiating ice from clouds. In satellite photographs, ice cover appears considerably brighter than the normal background tone. This is especially true if the ice is all or partially snow-covered. In Fig. 2, for example, the brightness of the Hudson Bay pack and snow ice cover is in sharp contrast to the open-water areas near the coastline and the coastline itself. Thus, the ice distribution is easily identified when no clouds are present. Ice, particularly when snow-covered, can have reflectivities to that of clouds. The problem, therefore, is not in identifying ice or cloud, but in differentiating between the two. The following techniques were used in this study to reliably identify ice distribution in Hudson Bay:

1. reference to concurrent cloud observations;
2. pattern stability;
3. recognition of geographical features;
4. pattern appearance.

3.1.1 Reference to Concurrent Cloud Observations

Reference to synoptic weather charts was principally used to determine major cloud systems over the region of interest. When the region is only partially cloud covered, some ice can often be distinguished in the Nimbus data. Also, a large

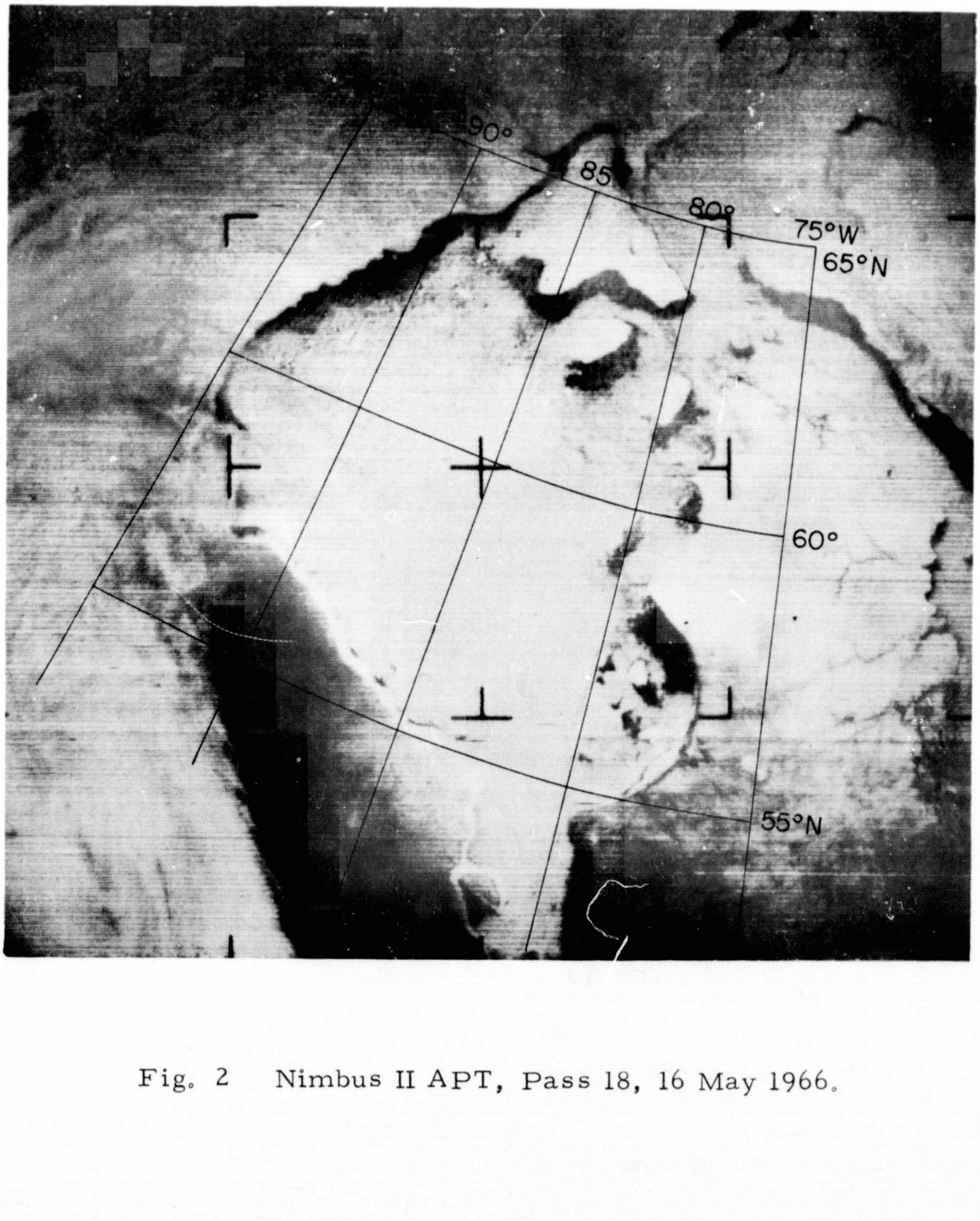

Fig. 2 Nimbus II APT, Pass 18, 16 May 1966.

number of observations revealed scattered areas of ice distribution through regions of broken and thin cloud layers; however, these cases did not provide enough data near the major ice edge to be useful in this study.

3.1.2 Pattern Stability

When concurrent cloud observations indicate clear or only partial cloud cover, ice can be reliably identified by pattern stability. Since clouds seldom retain the same shape for more than a few hours, stable patterns viewed by Nimbus over Hudson Bay are indicative of ice cover. To employ this technique, observations a day or more apart are required. When observations are several days apart, the following must be taken into consideration: (1) possible changes in ice distribution due to sudden melting or freezing; or (2) to wind-driven shifts during a storm passage.

3.1.3 Recognition of Geographical Features

Recognition of geographical features was also a very important technique employed to identify ice, since this technique immediately indicated no clouds were present in the observed area. The miles of coastline and the many islands within Hudson Bay were easily recognized and readily verified on standard maps of the region.

3.1.4 Pattern Appearance

The final technique employed was identification of pattern appearance. Although clouds and pack ice can have nearly the same reflectivities, ice-covered areas are usually smooth textured, while clouds are often rough or lumpy in appearance. For example, although the tones are similar, the ice is considerably smoother than the cloud in Fig. 3.

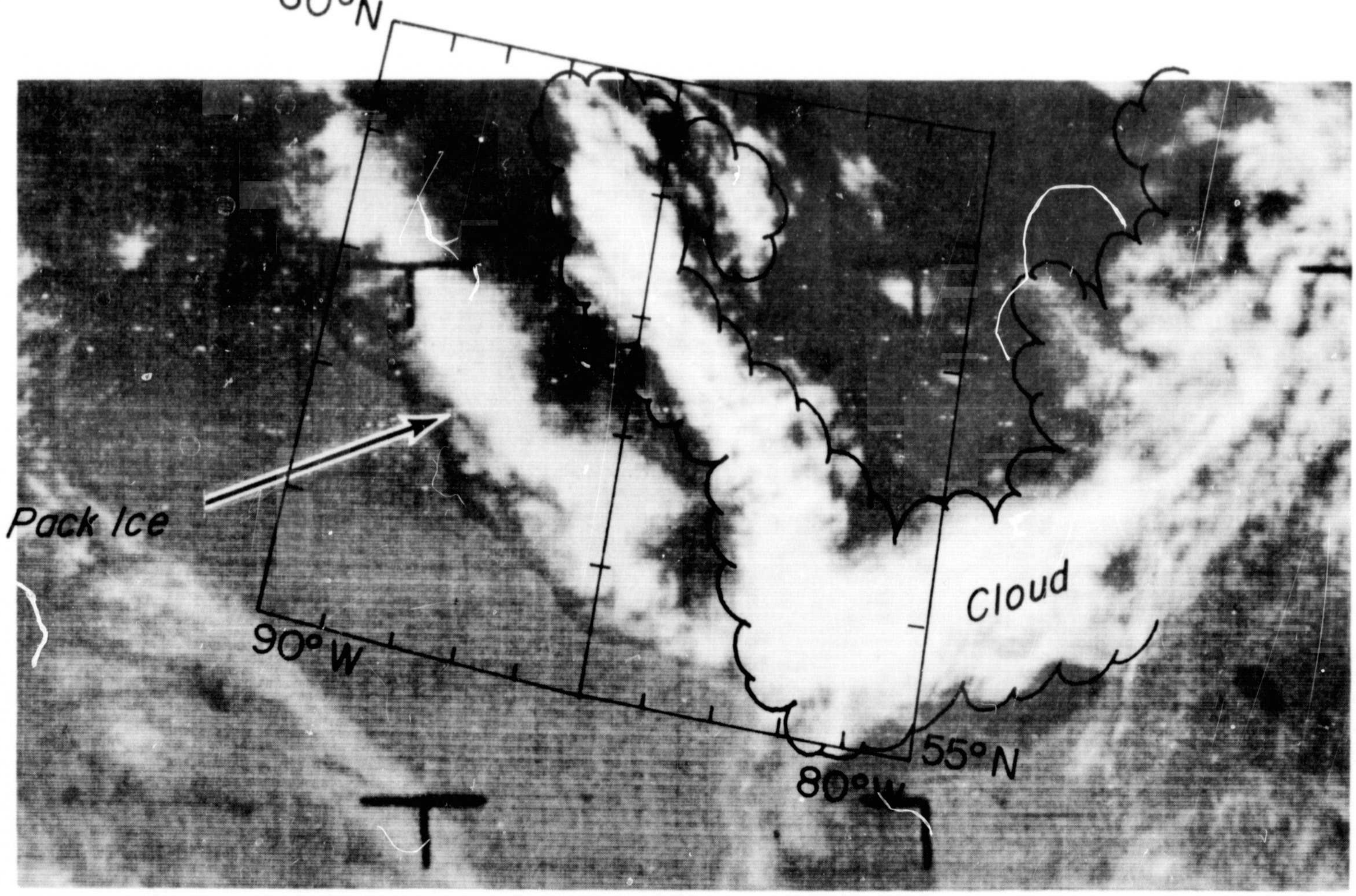

Fig. 3 Nimbus II APT, Pass 817, 15 July 1966.

4. ICE DISINTEGRATION AND DISPERSION

A number of observations, using Nimbus II APT satellite data, are discussed in this Section to demonstrate the application of ice-mapping techniques in determining the rate of ice disintegration and dispersion in Hudson Bay. The Nimbus pictures and derived ice distribution maps are presented in pairs.

Nimbus II provided excellent coverage of the region during the period of ice break-up in 1966. During this period, a near normal amount of clear weather over the area allowed sufficient observations of ice distribution to determine an east to west recession of the ice cover. Since these observations proved too numerous for separate discussion, only those observations showing major changes in the ice distribution will be discussed.

Although, as previously stated, the picture quality did not allow any determination of mesoscale ice features, the major ice edge was clearly visible throughout the data period.

4.1 16 May 1966

On this date, the initial ice break-up has already begun. The Nimbus picture and derived ice distribution map are shown in Figs. 4a and 4b. The region is extremely clear on this day, with the entire coastline and major islands easily identified. To the south, in James Bay, the rather dark, triangular-shaped area, south of Akimiski Island, is presumably open water. On the west coast, from about Churchill to Roes Welcome Sound, the very dark area along the coast is the open lead created by prevailing westerly winds along this coast during the winter months. Off the southern coast of Southampton Island, a very narrow region (ranging from about 10-30 mi.) of open water and thin or broken ice is clearly visible. Similar regions are visible to the southeast of Coats Island, and Mansel Island. There is also a larger area of open water visible along the east coast, south of Port Harrison.

Fig. 4a Nimbus II APT, Pass 18, 16 May 1966.

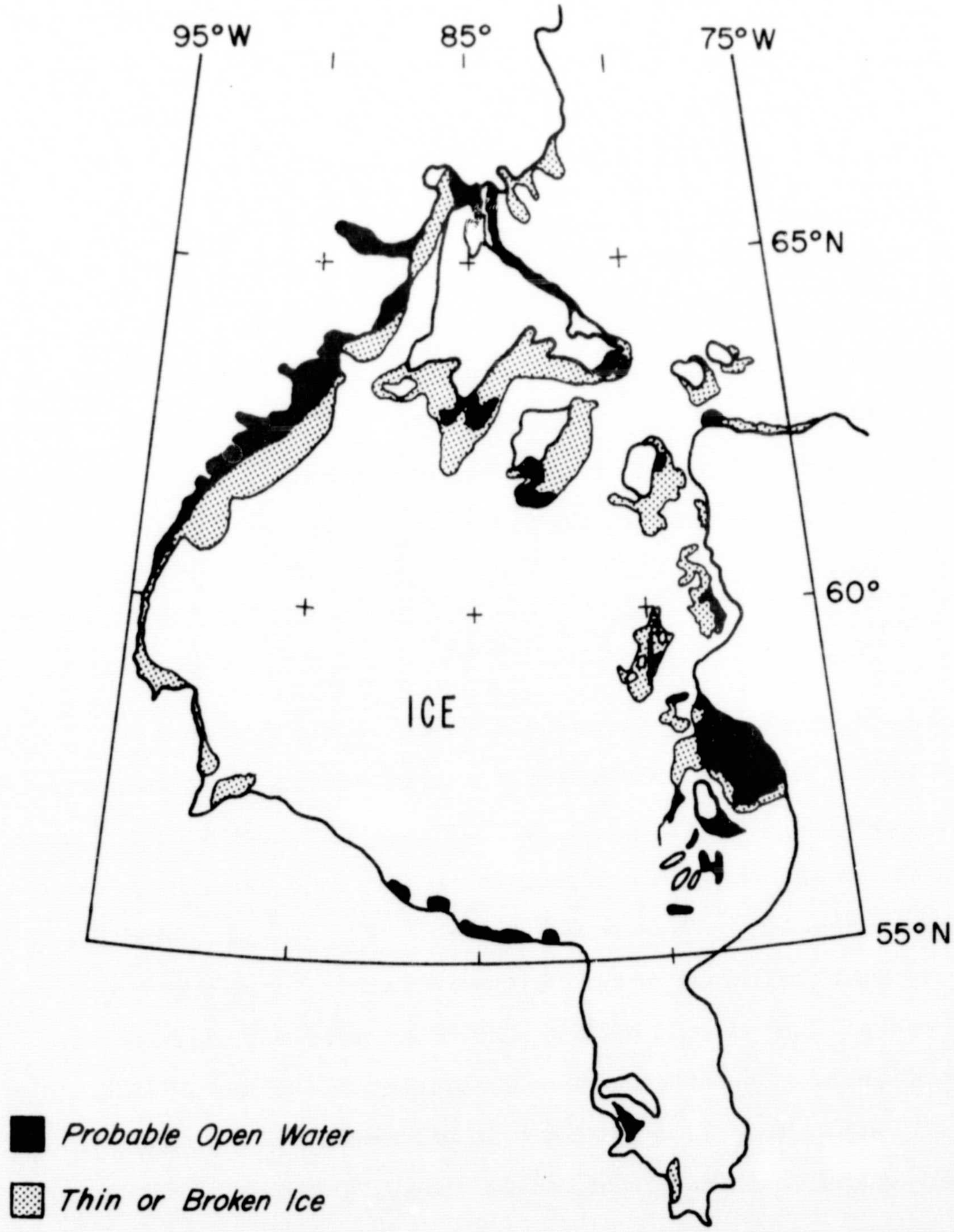

Fig. 4b Mapped Ice Distribution, 16 May 1966.

4.2 28 May 1966

The observation on 28 May shows a marked decrease in picture quality and considerable cloud cover over the western portion of the Bay. However, the major ice edge is distinctly visible in the eastern half of the Bay and clearly shows major recessions in the ice distribution over the past 12 days. Because of the poor quality of this observation, reproduction for illustration did not seem feasible; however, Fig. 5 shows the mapped ice distribution on this date. Comparison with the 16 May observation shows considerable break-up and dispersion just off the east coast. The mean 1800 GMT surface-wind flow and the mean 1800 GMT temperatures were derived for the several coastal stations, over the period of 16-31 May, and are shown in Fig. 6. Two storm systems passed south of James Bay during this period, which allowed for the mean easterly flow across the southern half of the region.

4.3 8 June 1966

Again skies are essentially clear. Although some thin cloud is visible to the south of Mansel Island, it does not restrict the observation of the major ice edge. Figs. 7a and 7b show the distribution 11 days later. The continued recession of the ice edge toward the west during this period is clearly evident. Little or no change is apparent at the ice edge off the west coast since 16 May. Also, the ice edge off the east coast has receded well west of the Belcher Islands, located north and east of James Bay. However, ice is still visible within the narrow waterways separating these elongated islands. The rather narrow, bright area along the east coast north of Port Harrison and also along the west coast is believed to be an icefoot. An icefoot can be composed of any combination of frozen spray, snow accumulations, stranded ice floes, tidal action, or brash or slush thrown up by a storm.

The mean 1800 GMT surface-wind flow and 1800 GMT temperatures over the period of 1-15 June 1966 are shown in Fig. 8.

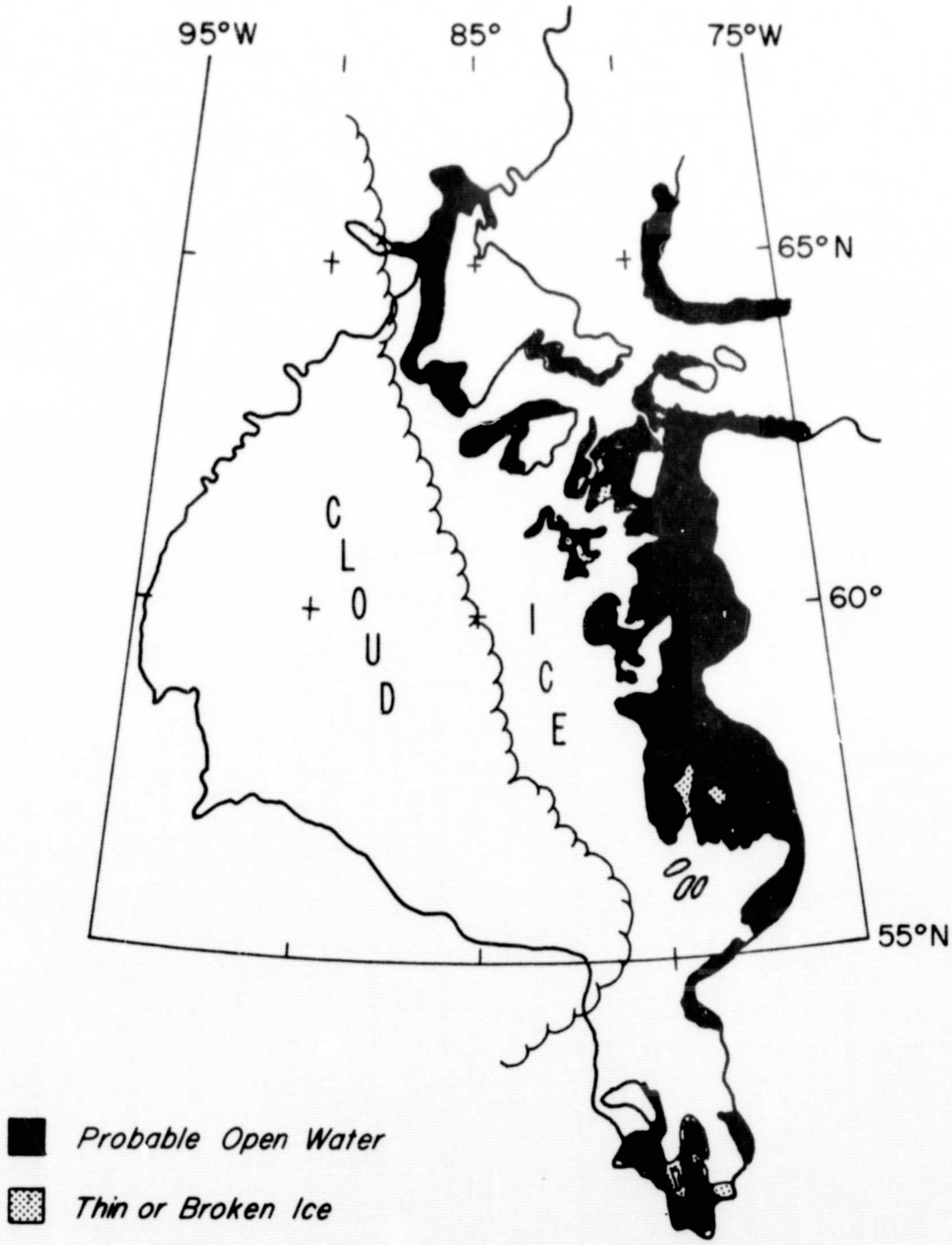

Fig. 5 Mapped Ice Distribution, 28 May 1966.

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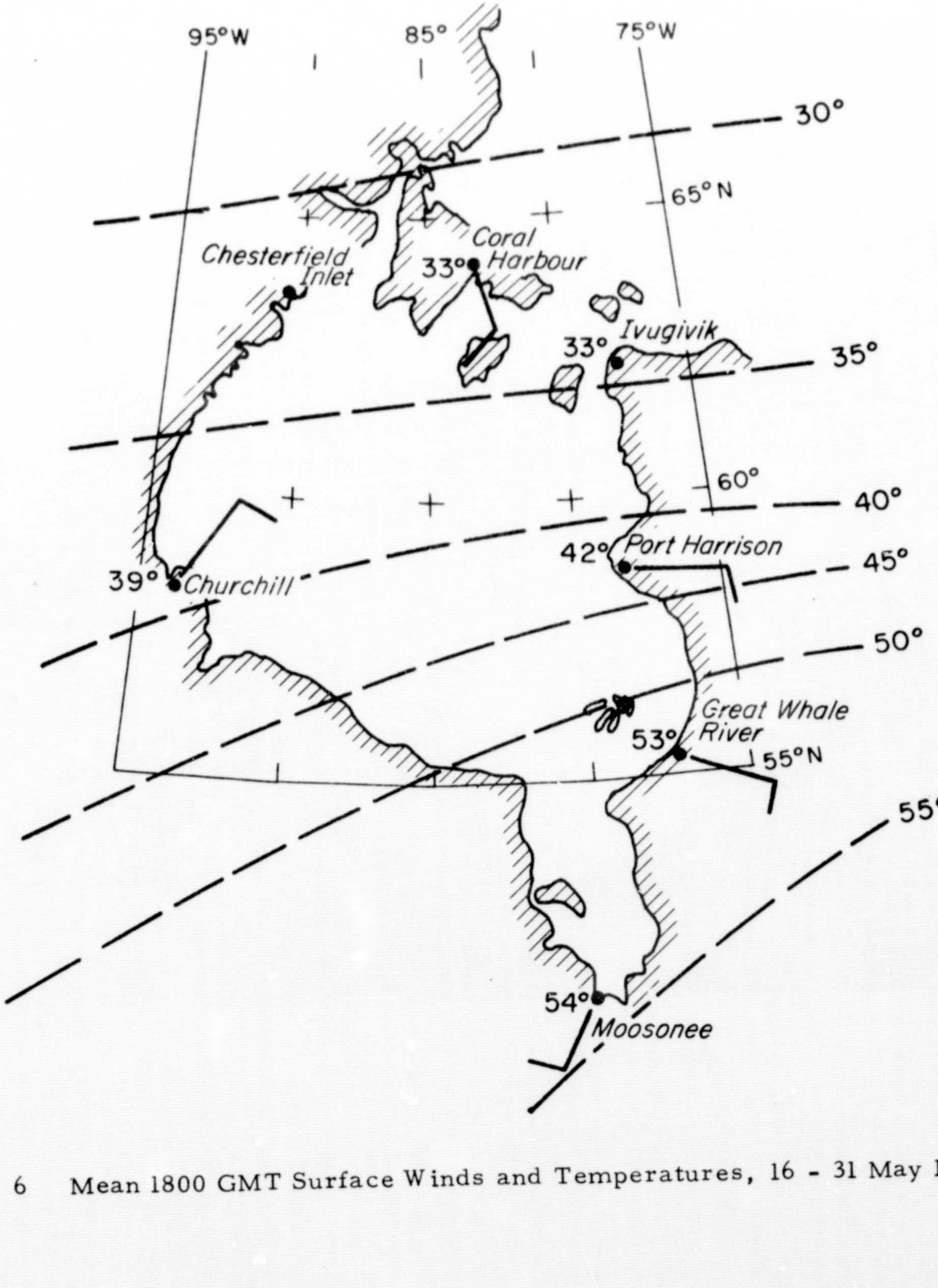

Fig. 6 Mean 1800 GMT Surface Winds and Temperatures, 16 - 31 May 1966.

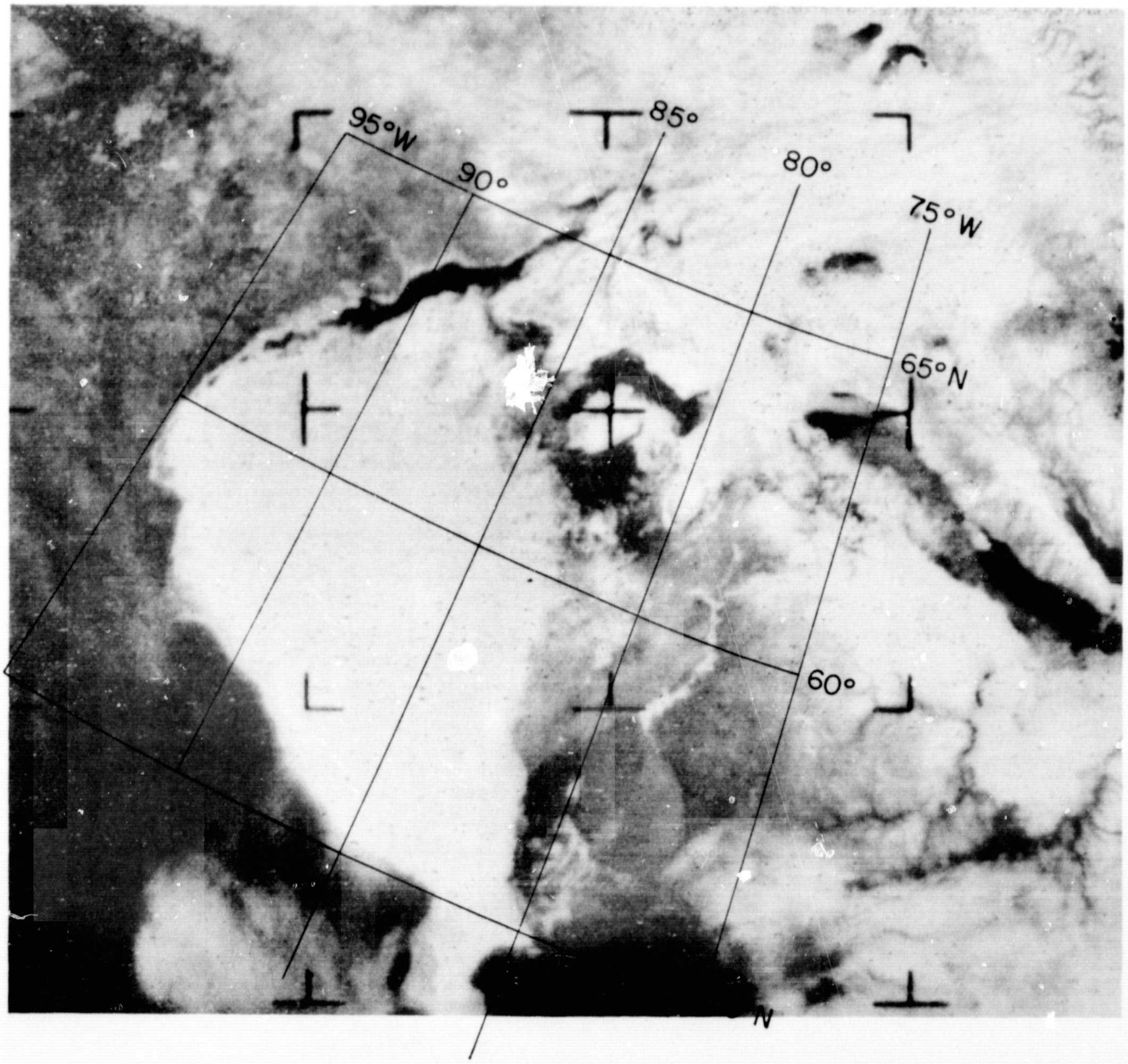

Fig. 7a Nimbus II APT, Pass 324, 8 June 1966.

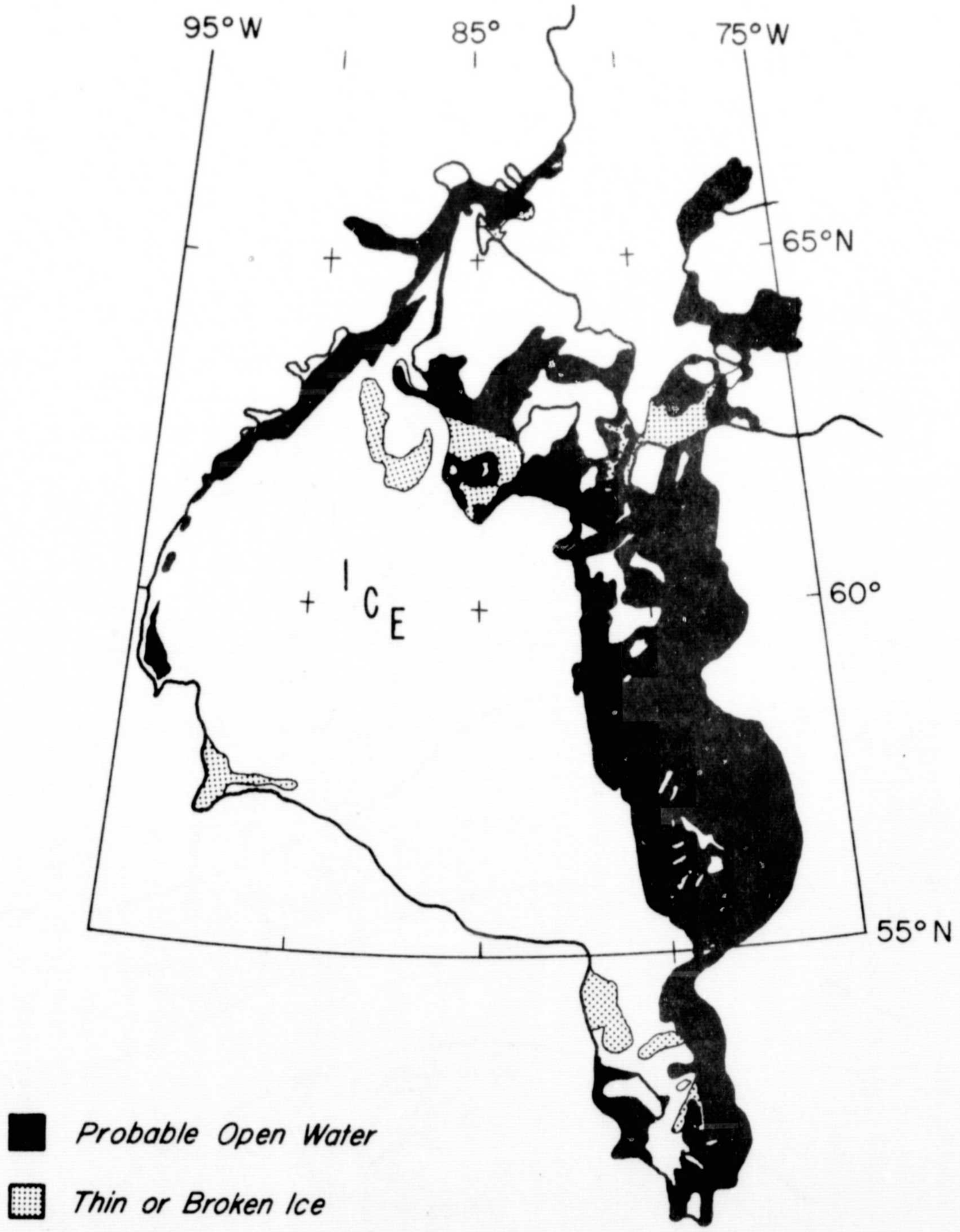

Fig. 7b Mapped Ice Distribution, 8 June 1966.

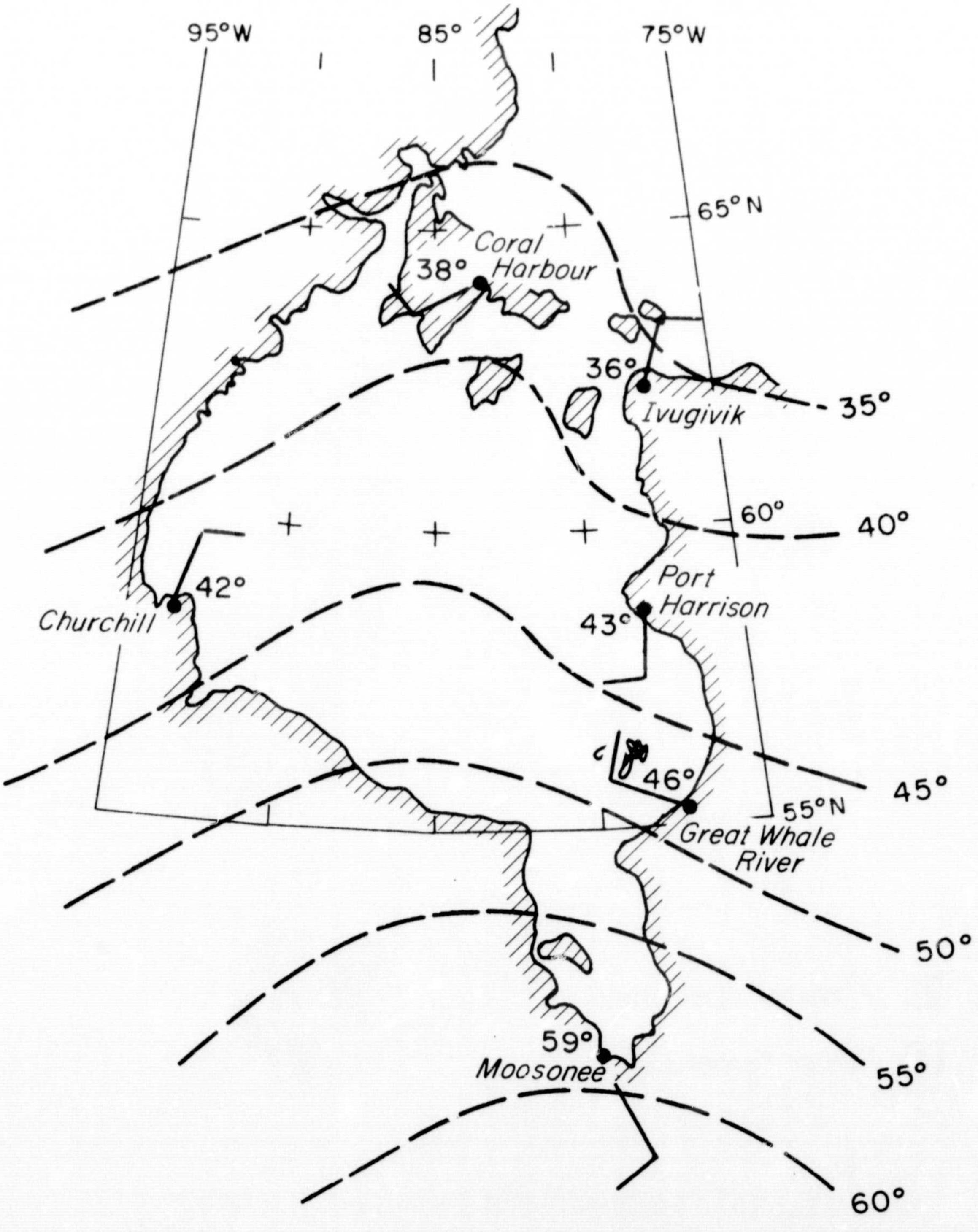

Fig. 8 Mean 1800 GMT Surface Winds and Temperatures, 1 - 15 June 1966.

4.4 19 June 1966

The observation on 19 June, 11 days later, shows some change in the major ice edge; however, a marked reduction in the amount of recession over this period is clearly evident. Some thin cloud bands are in evidence over eastern Hudson Bay, but the ice edge is clearly discernible. Figures 9a and 9b show the Nimbus picture and mapped ice distribution, and Fig. 10 shows the mean 1800 GMT surface wind flow and mean 1800 GMT temperatures over the period of 16-30 June 1966.

4.5 3 July 1966

By this time, major changes have taken place in the size and structure of the ice cover. Although a narrow cloud band is observed over the James Bay area and an isolated cloud patch appears at the southern end of Roes Welcome Sound, the remaining portion appears extremely clear. The Nimbus picture and derived ice distribution map are shown in Figs. 11a and 11b.

The northern portion of the remaining ice has become much grayer and darker, which would indicate that the pack ice in this region has become considerably thinner and more broken. The edge of the solid pack ice is, therefore, rather ill-defined in this case.

The mean 1800 GMT surface wind and mean temperatures affecting this observation would best be represented by Fig. 10.

4.6 15 July 1966

On this final observation, only the southern half of Hudson Bay is observed in the Nimbus picture. However, the major portion of the remaining narrow ice field is clearly visible along the area to the southwest. The Nimbus picture and ice distribution map for this case are shown in Figs. 12a and 12b. Considerable melt has occurred over this 12-day period along the eastern and northern ice edge. This melt resulted once more in a very well-defined ice limit. The mean 1800 GMT surface wind flow and temperatures over the period of 1-15 July are shown in Fig. 13.

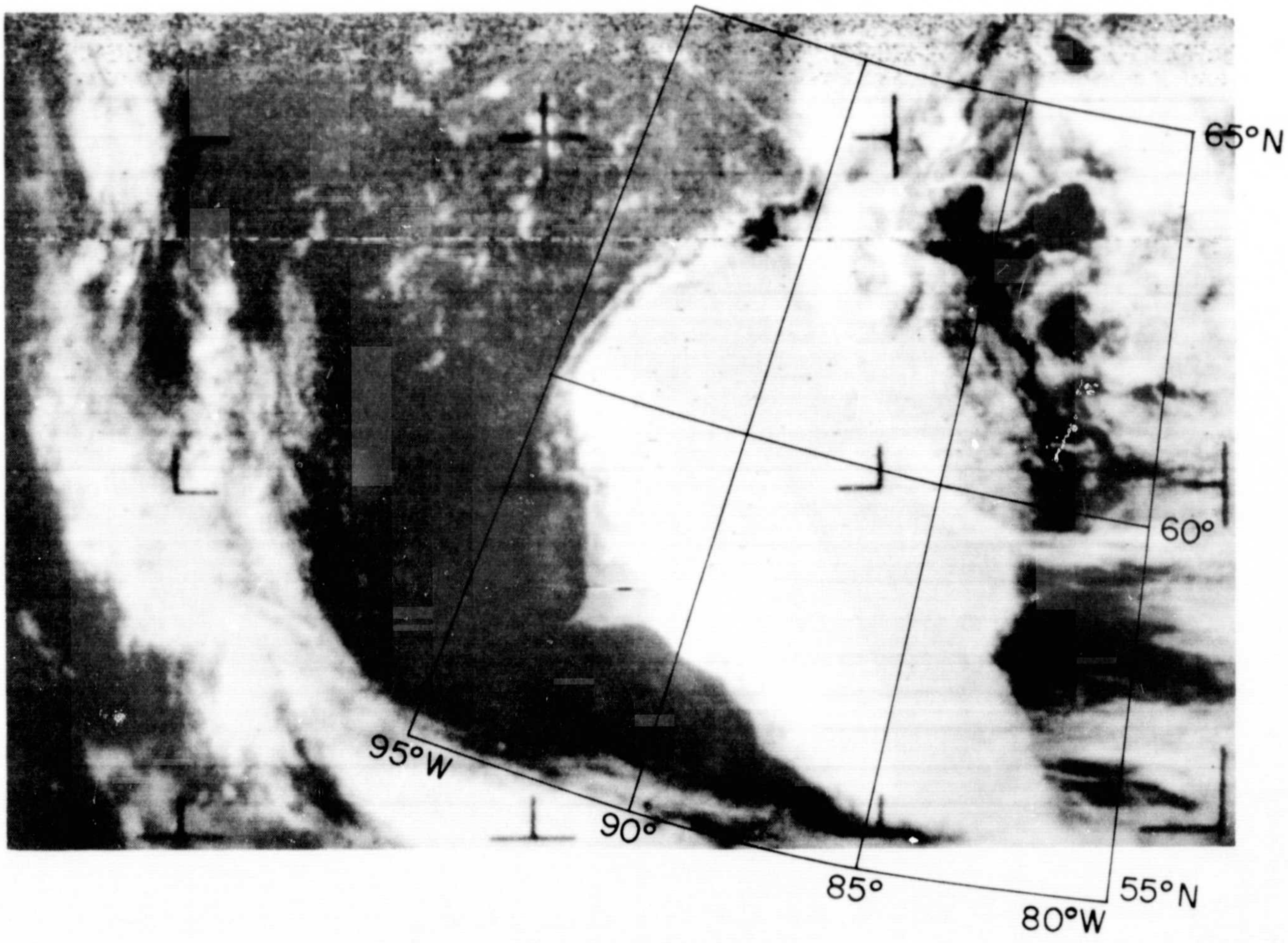

Fig. 9a Nimbus II APT, Pass 471, 19 June 1966.

Fig. 9b Mapped Ice Distribution, 19 and 20 June 1966.

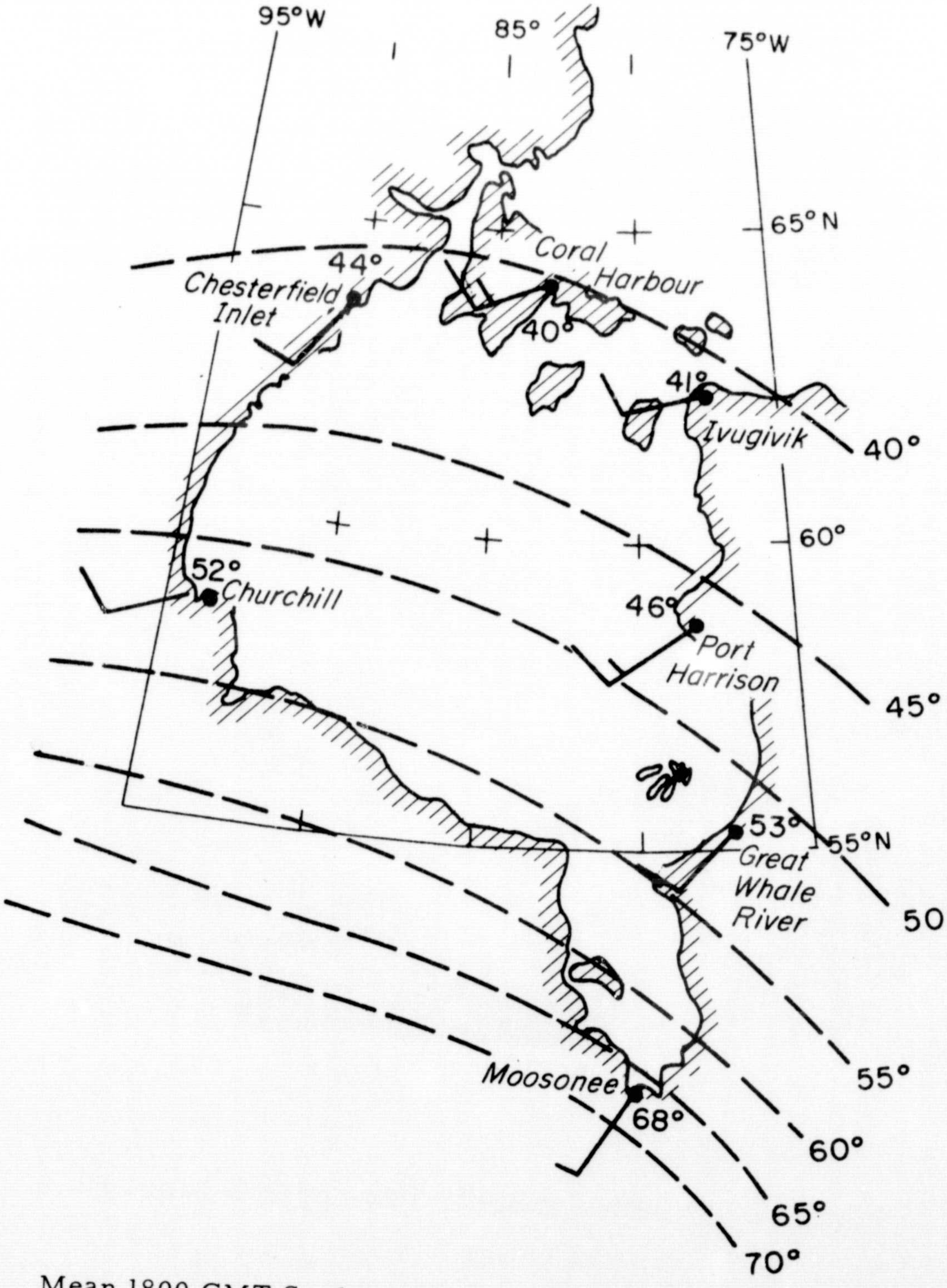

Fig. 10 Mean 1800 GMT Surface Winds and Temperatures, 16 - 30 June 1966.

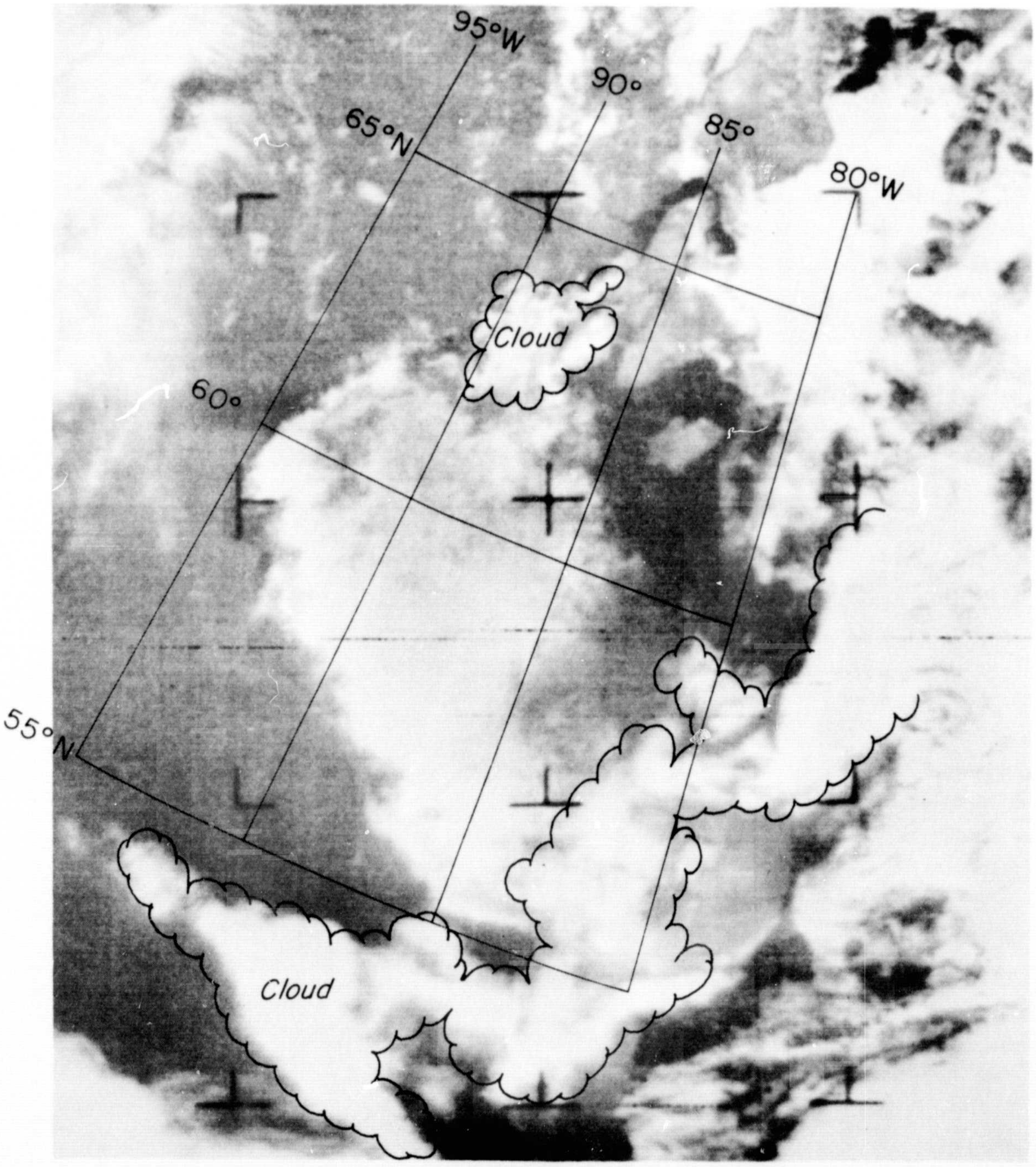

Fig. 11a Nimbus II APT, Pass 657, 3 July 1966.

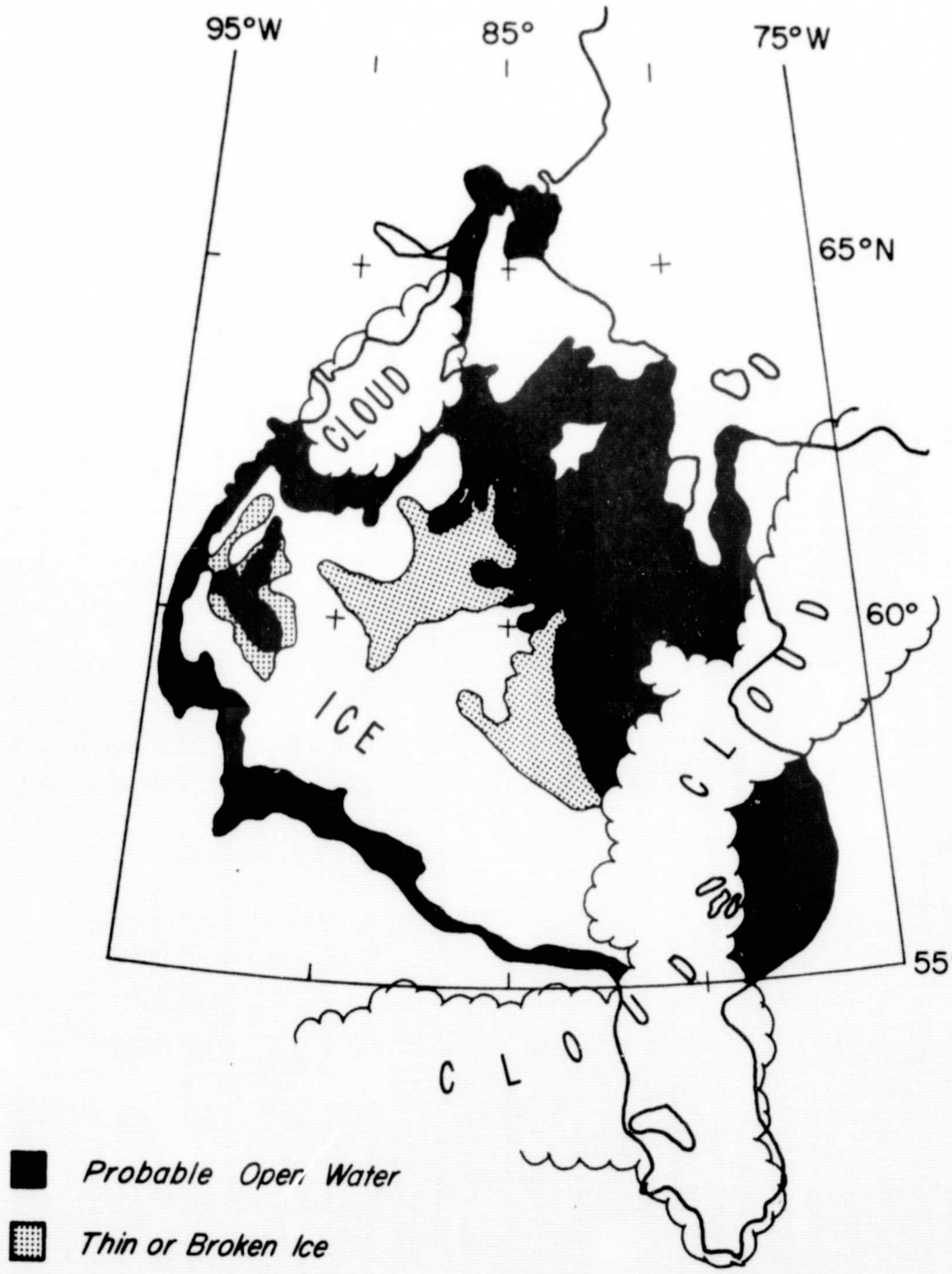

Fig. 11b Mapped Ice Distribution, 3 July 1966.

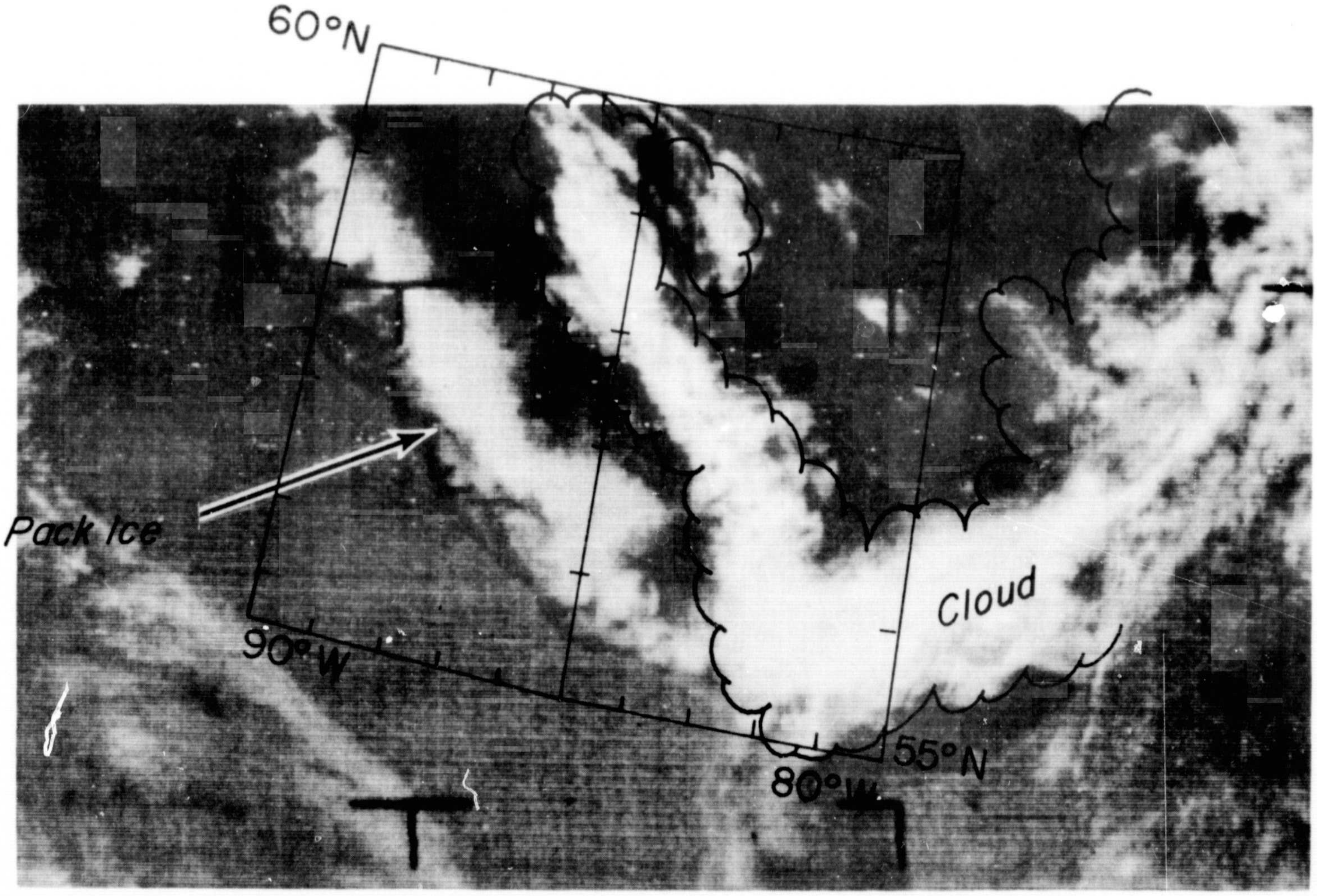

Fig. 12a Nimbus II APT, Pass 817, 15 July 1966.

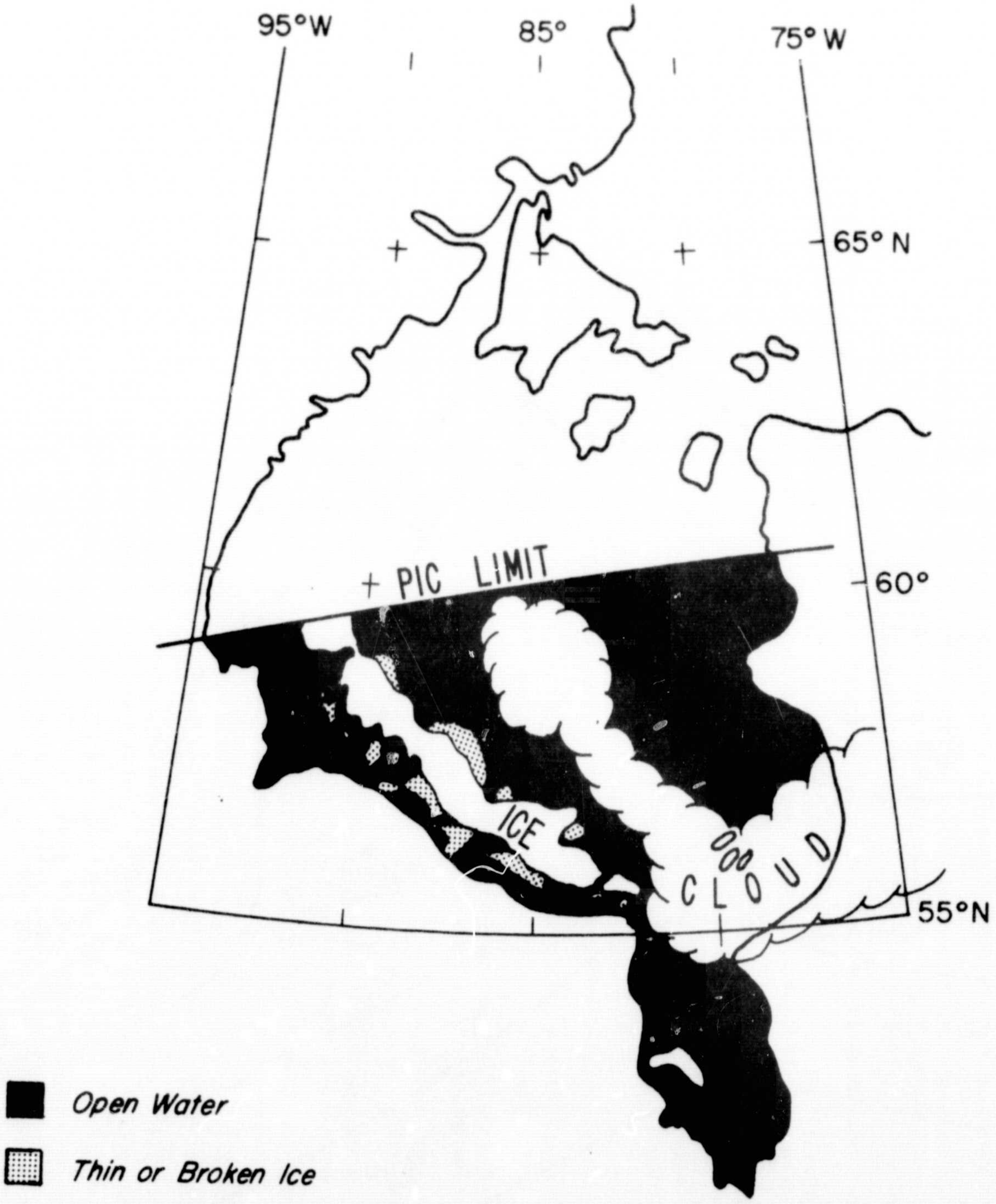

Fig. 12b Mapped Ice Distribution, 15 July 1966.

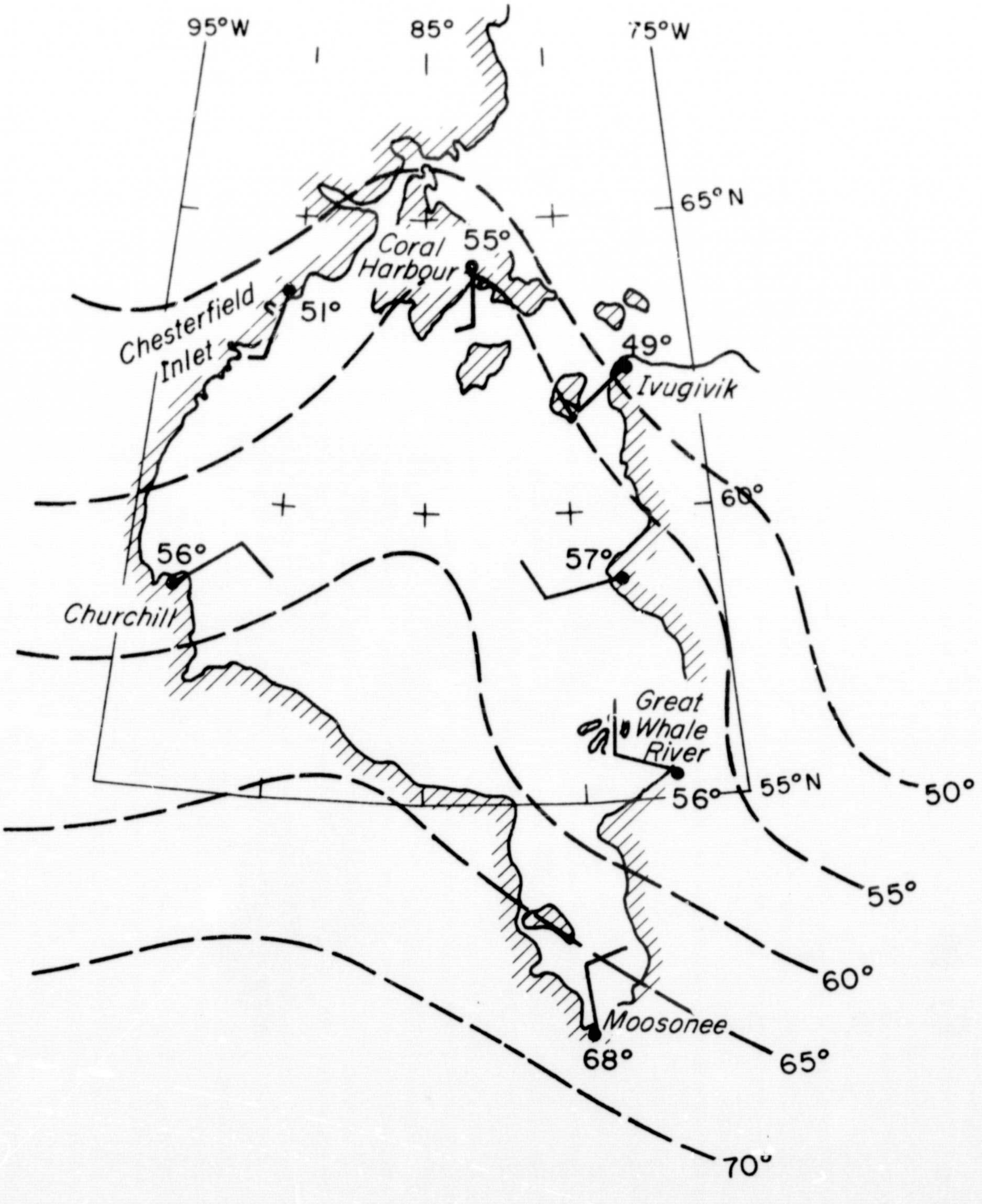

Fig. 13 Mean 1800 GMT Surface Winds and Temperatures, 1 - 15 July 1966.

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4.7 Discussion

The overall recession rate of the Hudson Bay ice for the spring of 1966 is clearly shown in Fig. 14. Estimates of the rate of recession taken from this illustration show a fairly steady rate of about 4 to 5 mi. per day westward through 8 June. From this date until about 19 June, a marked reduction is apparent in this rate. During this period, the rate was reduced to about 2 mi. per day. After 19 June, the recession of the edge of the solid pack ice appears to have increased to roughly the original rate of about 4 to 5 mi. per day. Then in early July an increase to about 6 to 7 mi. per day became apparent.

The initial ice break-up along the eastern coastal area during the latter part of May can most probably be attributed to the mean easterly wind flow and the overall warming trend which it created (see Fig. 6). This persistent easterly flow resulted primarily from a large, nearly stationary high-pressure system located to the north over Baffin Island; the flow was aided by the passage of two low-pressure systems passing just to the south of Hudson Bay. The warming trend accompanying this surface wind flow brought mean temperatures along the east coast to between 35° and 53°F -- well above freezing. The ice recession over the period can, therefore, be mostly attributed to wave and water action created by this easterly flow, rapid melt due to warming, and break-up due to tidal action. We believe that the extremely slow rate of current flow would not have been an important factor in the rate of ice dispersion.

The noticeable change in the recession rate in early to mid-June could, in part, be the result of the random, mean wind flow over the region during the first half of June (see Fig. 8). During this period, since weather systems were moving fairly rapidly, the pack ice was not subjected to persistent wind flow. Also, as observed in Fig. 8, no marked increase in mean temperature range had occurred over the area.

During the latter half of June however, the recession rate had increased to roughly what it had been during the initial break-up. The passage of two, deep, low-pressure systems over the northern region of Hudson Bay during this period established a fairly strong southwesterly flow, which resulted once again in a considerable warming trend over the entire area. The latter of the two systems remained nearly stationary over a period of about five days, and greatly affected the remaining ice cover (see

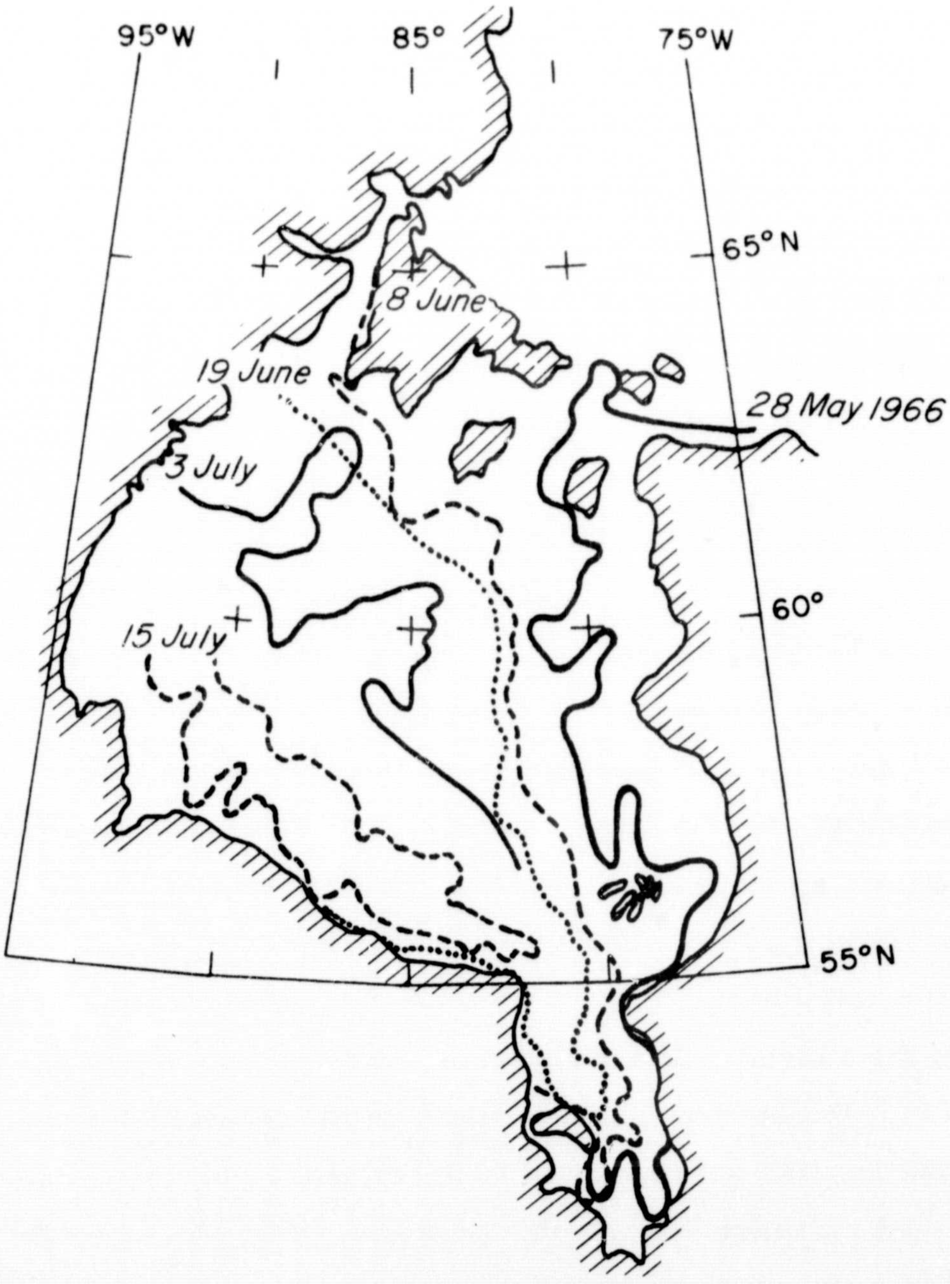

Fig. 14 Recession of Major Ice Edge, 28 May - 15 July 1966.

Fig. 11b). This storm developed a rather broad area of warm rain that contributed greatly to a change in gray scale along the northern limit of the more solid pack ice. This rainfall, together with the rather warm, southwesterly wind flow, had the greatest effect observed in the overall appearance and distribution of the ice during the entire data period.

The increased recession rate during the first half of July is probably a result of the marked mean temperature increase (see Fig. 13) over the region. Mean 1800 GMT wind flow is shown to be onshore at each of the coastal stations. This wind flow is presumably a sea breeze effect due to an increased warming of the surrounding land mass.

5. SUMMARY AND CONCLUSIONS

The results of this study clearly indicate that the rate of ice dispersion in the Hudson Bay region can be determined with reasonable accuracy from Nimbus satellite photography. Ice distribution can, in almost all cases, be distinguished from cloud cover on the basis of concurrent synoptic reports, pattern continuity, landmarks and texture.

Although lack of sufficient gray scale, due to picture quality, did not allow mesoscale ice features to be observed, the data did supply reasonably good observations of the overall limit of the pack ice throughout the data period.

A usable, essentially cloud-free, satellite observation of Hudson Bay can generally be expected at least once every four or five days. Useful observations on two or more consecutive days are not uncommon, thereby permitting the frequent use of pattern continuity for ice identification. With this frequency of observation, it appears that the Nimbus satellite can provide operationally useful data on the rate of ice dispersion.

A comparison of this data with corresponding synoptic data is needed to determine the mechanisms for sudden changes in the overall ice appearance and distribution. Persistent wind flow, increased temperatures, and rainfall combine to play an important role in the ice break-up and dispersion. These factors, as well as tidal action and current flow, essentially determine the rate of the dispersion process.

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