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USE OF ERTS DATA FOR MAPPING ARCTIC SEA ICE

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ABSTRACT

The purpose of this investigation is to evaluate the application of ERTS data for detecting and mapping Arctic sea ice. The specific objectives are to determine the spectral bands most suitable for detecting ice, to measure the scale and types of ice features that can be detected, and to develop interpretive techniques for differentiating ice from clouds and for mapping ice concentrations. The ERTS data are being analyzed primarily for three Arctic areas, the eastern Beaufort Sea, Baffin Bay, and the Greenland Sea.

1. INTRODUCTION

Extensive further study of the Arctic sea ice is essential for both economic and scientific purposes. Of particular national interest is the economic development of Arctic Alaska. Regardless of the course of this development and the eventual decision affecting oil transport, economic exploitation will require increased shipping in Arctic waters, demanding increasingly accurate ice-condition forecasts.

The increasing scientific interest in sea ice is demonstrated by the recent formation of Project AIDJEX, the Arctic Ice Dynamics Joint Experiment, the purpose of which is to gain a quantitative understanding of the interaction between the fields of motion of the atmosphere, the pack ice, and the liquid ocean (Division of Marine Resources, 1970). Several scientists have pointed out that because of the critical effect of sea ice on the heat balance of the Arctic, the amount of ice may be an important and possibly a key factor in the climate of the northern hemisphere (Fletcher, 1966; Maykut and Untersteiner, 1969; and Committee on Polar Research, 1970). In another report, Fletcher (1968) states that the seasonal patterns of surface heat exchange over oceanic regions, which are directly related to ice distribution, are the most important factors to monitor in both the Arctic and Antarctic.

Despite the importance of adequate ice information, the inaccessibility of the polar regions has required the use of slow and costly methods for data acquisition. Now, in Project AIDJEX and in other upcoming scientific endeavors in polar regions, remote sensing will play an increasingly vital role. In fact, as early as 1966, Fletcher stated that the "observational barrier" in the Arctic was crumbling primarily under the impact of satellite observation systems. Clearly, the benefits that will result from the continued development of improved spacecraft ice survey techniques will be substantial.

2. APPLICATION OF ERTS DATA

Although studies such as those reported by McClain and Baliles (1971) and Barnes, Chang and Willand (1972) have demonstrated that useful sea ice information can be acquired from existing meteorological satellite systems, nevertheless, serious limitations in the use of these data do exist. In particular, the spatial resolutions of the sensors are adequate only for detecting gross ice boundaries and do not permit the mapping of small-scale features such as leads and polynyas, which may be especially critical for heat-balance considerations. Furthermore, intermediate ice concentrations cannot be mapped with the reliability desired by scientific and operational personnel, and icebergs, except for the largest Antarctic tabular bergs, cannot be detected. ERTS-1 is now providing the first opportunity to investigate the application of high-resolution, multispectral spacecraft data for ice mapping.

Analysis of ERTS-1 MSS data and a limited sample of RBV data from the Arctic during the period from late July through late October 1972 indicates that sea ice can be identified in all of the spectral bands because of its high reflectance. Moreover, considerable information on ice type and on ice surface characteristics can be derived from the joint analysis of the various spectral bands, particularly the MSS-4 (0.5 to 0.6 μm) and MSS-7 (0.8 to 1.1 μm) data. Identification of ice types and the scales of ice features can be made according to variations in reflectance and spatial patterns. Also, although ice and clouds may have similar reflectances, ice can be distinguished from clouds through the following interpretive keys:

- The brightness of ice fields and large ice floes is often more uniform than that of clouds. Furthermore, ice floes and features such as leads and cracks within an ice field can at times be detected through thin cirriform cloud cover.
- Cloud shadows can often be detected on the underlying ice surface.
- Edges of most ice features, particularly ice floes, are more distinct than edges of clouds.
- Ice cover fits coastlines and islands, permitting land features to be recognized.

- The spatial frequencies of ice features are not characteristic of cloud patterns. These features include ice floes surrounded by broken ice, narrow ice bands, and spiral patterns induced by ocean currents.

- When repetitive coverage is available, some ice features remain stable over the 24-hour interval between observations. Even at the longer periods between ERTS cycles, some large floes can still be identified.

3. MAPPING OF ICE FEATURES

The analysis of 9.5" positive prints for two passes crossing Hudson Bay in the area south of Coats and Southampton Islands during late July (Pass 41, 26 July; Pass 55, 27 July) shows a well-defined ice boundary southwest of Coats Island, with several bights and tongues apparently caused by a westerly surface wind flow. The ice along the immediate ice edge appears to consist mostly of brash or rotten ice, whereas the ice east of the edge consists of varying concentrations of vast, big, or medium category ice floes. An ice belt is visible off the south coast of Southampton Island, and fast ice together with some vast ice floes are located along and just off the north coast of Coats Island. (NOTE: Ice floes are defined in the WMO Sea Ice Nomenclature (WMO Pub. No. 259, TP. 145) as follows: Giant Floe - over 10 km (6.3 n.mi.) across; Vast Floe - 2 to 10 km across; Big Floe - 500 to 2000 m across; Medium Floe - 100 to 500 m across; Small Floe - 20 to 100 m across).

The ice features mapped from the ERTS data are in good agreement with the conditions reported in ice charts (supplied by the Canadian Ice Forecasting Central) for the last week in July. These charts indicate a sharp, irregular (bights) ice edge extending southwest of Coats Island with ice-free water to the west, and an ice belt south of Southampton Island composed of 3/10's of first year ice of which 1/10 is medium or larger size floes. The area northwest of Coats Island in Fisher Strait is shown to be comprised of 5/10's of first year ice of which 2/10's is medium or larger size floes.

Banks Island

Four ERTS passes crossing the Banks Island, Amundsen Gulf, and Franklin Bay area during late July have also been analyzed (Pass 43, 26 July; Pass 71, 28 July; Pass 85, 29 July; Pass 98, 30 July). Although much of Amundsen Gulf is open water in these passes, several isolated vast ice floes are located off the west coast of Banks Island, south of a giant ice floe (about 12 km x 50 km). A field of very close (7-8 oktas) and close (6-7 oktas) pack ice is located to the southeast of Banks Island, and areas of close, open (3-6 oktas) and very open (1-3 oktas) pack ice exist in Amundsen Gulf. Ice in Franklin Bay is composed of close, open and very open pack ice; although one giant floe and several vast ice floes are observed in the bay, the majority of the ice consists of big, medium and small floes.

Aerial survey ice charts for the period 25-30 July indicate that a giant ice floe does exist off the southwest coast of Banks Island. A small area south of this giant ice floe is indicated as 4/10's of first year ice of which 2/10's is comprised of medium or larger size floes. The area of Amundsen Gulf south of Banks Island to about 70.5°N is indicated as open water with some loose ice strips, and several small areas of first year ice are indicated south of 71°N into Franklin Bay.

With the repetitive coverage of the Amundsen Gulf area, measurements of ice motion have also been made. Measurements of the positions of ice floes off the west coast of Banks Island during the 24-hour periods indicates a mean direction of motion toward the west-southwest at about 8 knots. Little or no movement is observed in the giant floe to the north, although some deterioration (breaking off of smaller floes) has apparently occurred. Measurements of the 24-hour motions of ice floes in western Franklin Bay off the coast of Cape Bathurst show a mean direction toward the northwest at 7 to 15 knots into Amundsen Gulf and the Beaufort Sea.

Eastern Beaufort Sea

In two ERTS passes crossing the eastern Beaufort Sea southwest of Prince Patrick Island (Pass 141, 2 August; Pass 420, 22 August) a well defined irregular ice boundary can be identified in the Beaufort Sea. For the earlier pass, the MSS-5 and MSS-7 bands were used in the analysis because ice features in the MSS-4 band appeared nearly saturated; for the later pass, the MSS-4 and MSS-7 bands were used. On 2 August, a total of 13 very large "giant floes" (10 to 35 n.mi. across) can be identified within the area from about 72° to 75°N and 132° to 138°W. These floes are surrounded by ice concentrations consisting primarily of open pack and close pack with many various sized smaller floes. Twenty days later, on 22 August, the same 13 giant floes can be identified because of their shapes and surface features. Significant deterioration has occurred in only two of the floes, where large areas (about 1/4 of the original floe size) have apparently broken off their southern edges and broken into smaller floes. As positive identification of these giant floes was possible over the 20-day period, their motions could be measured. These measurements indicate a mean direction of motion toward the southwest, with a clockwise shift in the direction of motion from north to south; in addition to moving in a more westerly direction, the southernmost floes also moved more slowly.

Visible surface features in the floes in this area include apparent leads, fractures, thaw holes, and puddles. Surface features that are brighter than the surrounding areas (in contrast to the dark fractures and leads) may be ridges or hummocks. A comparison of the surface features of individual floes over the 20-day period, primarily using the MSS-7 band, shows that noticeable changes do occur. Both puddles (depressions in the ice filled with melt water) and thaw holes (vertical holes in the ice formed when puddles melt through to the underlying sea water) appear as small dark spots on the ice surface, making it difficult to distinguish between the two. However, since many of the smaller dark spots observed on 2 August are not visible on 22 August, it suggests that they are puddles which have refrozen. The larger dark spots which are visible on both dates are undoubtedly thaw holes. Also, the multispectral analysis of the MSS-4 (or MSS-5) and MSS-7 bands provides additional information to distinguish between puddles and thaw holes, since at the shorter wavelengths, puddles do not appear as dark as do thaw holes.

Greenland Sea (along East Coast of Greenland)

ERTS imagery covering the eastern coastal area of Greenland (Pass 890, 25 September; Pass 1057, 7 October) shows wide variations in ice types and concentrations. Several features of interest in the ice field can be detected, including compacted belts and eddies that apparently result from the combined effect of surface wind and current flow. Also, in enlargements of one scene from the 25 September pass, fast ice can be identified along the north coast of Shannon Island (located just north of 75°N at 18°W). A darker pattern within one area of the fast ice is believed to be the result of flooded ice, since a river with numerous small tributaries empties into the bay at this location. This pattern in the MSS-7 data is not as black as open water, and is light-gray in the MSS-4 band, suggesting that the melt water may have become refrozen.

Enlargements of selected areas of the MSS-4 and MSS-7 frames for 7 October show distinct ice features that are not readily detectable in the original 9.5" positive prints. In this case, the original prints, which presumably were processed through standard photographic procedures applied to all images and directed toward enhancement of land features, are too dark to depict much of the sea ice. The experimentation in producing the enlarged prints shows, however, that special processing of the 70 mm negatives to obtain desired brightness and contrast allows ice features to be brought out, although the snow-covered land areas are saturated.

In one enlargement, what appears to be bands of ice southeast of Kap Brewster in the original print (MSS-4), is seen to be actually the denser portions of a cirrus cloud band. In another enlargement of Scoresby Sund, areas of rotten or brash ice and possible icebergs not visible in the original 9.5" positive prints can be detected. For example, in the original MSS-4 print, several areas of compacted brash ice appear in a dark gray tone, while large floes or icebergs are barely visible; in the corresponding MSS-7 band, no ice is visible. In the MSS-4 enlargement, however, distinct northern and southern limits of rotten or brash ice can be detected, and the limits of the areas of compacted brash ice are clearly visible as well as additional areas of compacting with lesser concentrations. In addition, the major floes or bergs appear much brighter and are at a scale that allows measurement of their sizes.

4. MULTISPECTRAL CHARACTERISTICS OF SEA ICE

The investigation of the multispectral characteristics of sea ice has concentrated on a comparison between the MSS-4 (0.5 to 0.6 μm) and MSS-7 (0.8 to 1.1 μm) bands. The results of the initial analysis of these spectral bands are summarized below:

- Overall contrast is greater at MSS-7. Open water areas and mountain shadows appear blacker than at MSS-4.

- Some areas of sea ice that appear uniformly bright at MSS-4 are very dark at MSS-7; these are believed to be areas of melt-water on top of the ice surface. Other features that appear dark in both bands are believed to be cracks or thaw holes through the ice. Thus, through use of both spectral bands, puddles can be distinguished from cracks and thaw holes.

- Areas of apparent brash ice appear darker than areas of thicker ice at MSS-4, but can still be easily detected; these areas are difficult to distinguish from open water at MSS-7. However, ice floes that are difficult to distinguish from surrounding ice at MSS-4 because of similar reflectances, appear distinctly brighter than the surrounding ice at MSS-7.

- In areas of nearly solid ice cover, greater detail is evident at MSS-7. This is primarily because tonal differences between ice floes, brash ice, and cracks and openings are greater at MSS-7 than at MSS-4. Also, tonal variations within some ice floes are evident at MSS-7; these variations may be associated with hummocks, ridges, or refrozen leads.

- Broken cloud fields over ice are more easily distinguishable at MSS-7 because of more distinct shadows, both on the ice surface and within the cloud field itself. However, the most reliable method to distinguish between clouds and ice is to use both the MSS-4 and MSS-7; at MSS-7, cracks in the ice and cloud shadows have similar reflectances, whereas at MSS-4, the cracks appear significantly darker than do the cloud shadows.

- Glaciers on the coasts of Greenland generally have a uniform reflectance throughout their extents at the MSS-4 spectral band. The lower extents of several of these glaciers, however, appear much darker at the MSS-7 band. This difference is likely due to melt water covering the lower portion of the glacier as opposed to snow covering the higher elevation part.

5. CONCLUSIONS

Sea ice is detectable in all of the ERTS MSS spectral bands and can be distinguished from clouds through a number of interpretive keys. The photographic processing of prints from the original 70 mm negatives can be important for ice detection, however, since exposures selected to retain detail in land areas may result in the loss of significant ice features. Overall, the MSS-4 (0.5 to 0.6 μm) and MSS-5 (0.6 to 0.7 μm) bands appear to be better for mapping ice boundaries, whereas the MSS-7 (0.8 to 1.1 μm) band provides greater detail in the ice features.

Considerable information on ice type can be derived from the ERTS data. Ice types that appear to be identifiable include: ice floes of various categories, pack ice of various concentrations, ice belts, brash ice, rotten ice, fast ice, leads, fractures, cracks, puddles, thaw holes and flooded ice. Although larger icebergs can be seen, it is difficult to distinguish them from ice floes. Ice features as small as the "small floe" (20 to 100 m across) can be detected, and the sizes of features somewhat smaller than 100 m across can be measured from enlarged ERTS prints. Ice concentrations can be mapped, and the resulting concentrations are in good agreement with the limited amount of correlative data available to date. Ice features can be identified over 24-hour periods enabling their movements to be measured; some large floes can even be recognized over intervals of as long as 20 days, enabling mean ice movements over longer periods to be determined.

The multispectral analysis of the ERTS MSS-4 and MSS-7 bands provides much information on ice type and ice surface features that cannot be derived from a single spectral band. For example, thaw holes can often be distinguished from puddles because of their different appearances in the two bands. These surface features can be indicative of ice age. Furthermore, snow lines on glaciers can be reliably mapped through the joint use of the MSS-4 and MSS-7 data.

6. REFERENCES

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