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APPLICATION OF THERMAL IMAGERY TO THE DEVELOPMENT OF A GREAT LAKES ICE INFORMATION SYSTEM

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APPLICATION OF THERMAL IMAGERY TO THE DEVELOPMENT OF A GREAT LAKES ICE INFORMATION SYSTEM

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ABSTRACT

Recent measurements and analysis have shown that thermal infrared imagery (wavelength, 8-14μm) can be employed to delineate the relative thicknesses of various regions of freshwater ice, as well as, differentiate new ice from both open water areas and thicker (young) ice. Thermal imagery was observed to be generally superior to visual (0.4 - 0.7μm) and our SLAR (3.3 cm) imagery for estimating relative ice thicknesses and delineating open water from new ice growth. In a real-time Great Lakes Ice Information System, thermal imagery can not only provide supplementary imagery but also aid in developing interpretative methods for all-weather SLAR imagery, as well as, establishing the areal extent of spot thickness measurements.

INTRODUCTION

Previous studies in the arctic by Ketchum, 1956 and Polin, 1966 have demonstrated the potential of such thermal imagery for determining ice distributions and relative ice thicknesses in adjacent areas. However, the geographic location and expanse of the Great Lakes Basin is such that storms, winds, currents, upwellings, and other hydrometeorological parameters impart important changes in the ice cover in a matter of one day. The Great Lakes ice situation is much different from the Arctic and therefore warrents new considerations in the application of thermal imagery systems for ice information.

Interpretative keys involving the size, shape, tone, and texture associated with the various ice types and ice surface topographic features are generally used in classifying ice types. These various ice types, in turn, are arranged into a hierarchy corresponding to ice age and development, which categories are then associated with ranges of ice thickness. This classification system, developed primarily for Arctic type ice identification, has many shortcomings when applied to the classification of the freshwater ice encountered in the Great Lakes. Notably visual clues are confusing and sometimes totally lacking which would allow new ice, in an early stage of development, to be delineated from open water areas as well as from young ice which ranges between 10 and 30 cm thick. Slush ice layers which form especially as a result of the freezing of water saturated snow help to obliterate many of the visual clues associated with new and young ice formations. Frequently, surface topographic features and patterns associated with finger rafting and pressure ridging are obscured by a clutter of relict slush patterns, snow filled cracks, and wind streaks.

This paper will review some of the preliminary findings associated with the applicability of thermal imagery in providing ice information and discuss its overall role in a Great Lakes Ice Information System.

THERMAL SCANNER

A single channel Bendix airborne line scanner, mounted in the NASA Lewis C-47 aircraft, was used in these investigations. Radiation from the ground was scanned by a single surfaced, flat mirror (IFOV of 2.5 milliradians). The energy within a 120 degree FOV, centered beneath the aircraft, was collected and focused by reflective optics through an optical filter (8-14μm transmission) onto a photovoltaic detector cooled with liquid nitrogen.

An internal blackbody reference source allowed the imagery to be calibrated with respect to absolute temperatures. This system had a capability of detecting scene temperature differences as small as 0.1°C.

VISUAL - THERMAL IMAGERY COMPARISON

Some of these visual ice interpretative problems that were mentioned previously will now be illustrated using visual and thermal imagery. Figure 1 allows the information available from photographic imagery in the visible region of the spectrum to be contrasted with that obtained from the scanner in the thermal infrared region. These images encompass an area of approximately 7 square kilometers in Lake St. Clair. In the visual image, the various photographic tones are determined by variations in reflectivity, while the tones in the thermal image result from variations primarily in surface temperature. The radiation imaged by the thermal scanner is associated with the surface "skin" temperatures of the upper fraction of a millimeter of the ice and water surface due to the large absorption coefficients for both water and ice which range from 500 cm^{-1} at 8μm to over 1000 cm^{-1} at 14μm. The emissivity of water and ice is generally very high (>0.97) in the 8 - 14μm region and for angles of incidence less than approximately 50 degrees.

In the positive thermal image the lighter toned areas correspond to warmer temperatures while the darker toned areas indicate colder temperatures. Very light toned, open water areas are readily delineated from the darker tones of the newly frozen ice in the thermal image while such distinctions are very difficult, if not impossible, to discern in the visual image. Close examination of the visual image will reveal hairline type, white streaks in some of the seemingly open water areas which are characteristic of water and snow filled cracks in new ice formations. Generally such hairline crack features are difficult to detect because their very narrow width falls below the detectable resolution element in such wide angle, high altitude imagery. The relative temperature variations associated with the various tonal contrasts within the thermal image are indicated on the figure. The very dark toned, ribbon like regions in the thermal image, a characteristic of areas of colder, thicker ice, correlate with the light toned regions in the visual image. These mound-like features often result when cracks and leads in the ice become saturated with snow and refreeze forming a thick interface between adjacent pieces of ice. The overall, uniform tonal shading of the thermal image indicates that the ice cover is at the same surface temperature and therefore is of generally the same relative thickness.

It is evident from these above comparisons that thermal imagery can provide a much stronger capability in delineating various regions of ice, especially those associated with new ice development, than visual imagery.

ICE THICKNESS

The surface temperature of freshwater ice, bounded by relatively warm and constant temperature water beneath and colder surface air temperatures above, reflects an equilibrium between the heat conducted from the water through the ice to the surface, the heat absorbed by the ice from the incident solar radiation, the heat radiated from the surface, and the heat convected from the surface by the surrounding air. Since ice is a fairly good insulator, the thicker the ice the less observable is the warming influence of the underlying water and the closer the upper surface temperature of the ice will approach the outside air temperature. To adequately model the thermal environment of the ice, parameters such as thermal conductivities, heat transfer coefficients, water and air temperature, local wind velocity, average surface, roughness, type of ice, amount of snow cover, incoming solar radiation, percentage of cloud cover, and other hydrometeorological factors must be considered. These complexities make it difficult to obtain thickness measurements on an absolute bases; however, relative temperature measurements and their corresponding correlation to ice thicknesses can be provided.

Using tonal contrasts associated with open water areas, finger rafting patterns, and shore ice formations in thermal imagery, a range of actual ice thicknesses, correlated with relative surface temperatures, may be established. Open water areas could establish the upper temperature, zero thickness, limit; while shore ice formations could provide a low temperature, thick ice, lower limit.

Thrust structure patterns, frequently observed in ice sheets on the Great Lakes and characteristic of an intermediate range of ice thicknesses, could become the key interpretative clues in relating surface temperature to ice thickness using thermal imagery.

Figure 2 is used to illustrate this technique. An example of the fairly well-defined pattern associated with a finger rafting type thrust structure in young ice is shown in this figure.

Finger rafting consists of an alternating series of parallel rectilinear overthrusts and similar shaped underthrusts, producing a square-wave type pattern. This pattern easily identified in the visual image is seen as a ribbon like dark toned, colder temperature feature in the thermal image. An enlargement of a thermal image of this same pattern, taken two days earlier and as a lower altitude is also shown in this figure. Newly formed thin ice will produce a jagged pattern with irregular and poorly defined edges due to the inability of the ice to transmit the structural forces. As the ice becomes thicker, such patterns are characterized by more clearly defined rectilinear edges. Well defined square wave patterns are associated with young ice approximately 15 - 18 cm thick. Ice thicker than approximately 20 cm will tend to form pressure ridges. Finger rafting patterns are also frequently detectable even under a snow cover because of the tendancy of water within the snowpack to soak into and delineate the edge patterns.

The rounded edges, shown in these images, are characteristic of young ice approximately 10- 12cm thick. The darker tones, colder temperatures, are associated with the over- and under-thrusted ice sheet which is twice as thick as the adjacent ice sheet. By measuring the relative surface temperatures of the shore ice rafted regions, and open water area and obtaining information regarding the ice thickness along the shore line it is possible to establish a relationship between relative surface temperature and ice thickness for this ice region and its adjacent area.

VISUAL - RADAR - THERMAL IMAGERY COMPARED

The distinctively different responses of ice in widely separated regions of the spectrum and the importance of thermal imagery for accurate interpretation are illustrated in Figure 3. Note that only in the thermal IR image is the open water area near the tip of Pelee Point clearly discriminated. The basic difference that sets the thermal IR apart from both the visual and the SLAR is that it responds to emitted rather than scattered radiation by the ice. In the case of the SLAR microwave radiation it is primarily the backscatter off the edges of the ice at ice-water corner interfaces which produces the image as described by Jirberg, et. al. (1973). Since the new unfractured ice along the west shore of Pelee Point does not contain sufficient scatters, it is not differentiated from the adjacent open water area. Similarly in the visible, the lack of defects in the new ice sheet that scatter the solar illumination precludes it being separated from the dark open water area.

Further comparison of thermal IR to visual, in this case ERTS-1 satellite imagery, is made in Figure 4.

At the time of the satellite pass, the area was under a high (above 6 Km) cirrus cloud layer. In an enlarged portion the ERTS imagery near the southern shore of Lake Erie off Lorain, Ohio, a rather large distinctive light tone feature is observed with a dark toned background. The thermal image, as well as, simutaneous acquired oblique angle visual imagery, reveals that this entire area is covered with a layer of skin ice which has been broken up by wind and wave action. The distinctive pattern highlighted in every channel of the visual and near infrared imagery, is not discernable in the thermal imagery, apparently possessing no distinctive thermal contrast with the adjacent areas. The mottled light gray pattern of the thermal imagery evidences the honeycombed pattern of the wind broken, skin ice. Fast ice development along the shore can also be distinguished in both ERTS and thermal imagery. In another area of the ERTS image, near

Cleveland, tonal features in the broken ice floes correlate in both the visual and thermal spectral regions. The light tones of the satellite imagery corresponds to the dark tones, colder temperature of the thermal imagery indicating relatively thicker ice.

GROUND-TRUTH DATE SUPPORT

Thermal imagery obtained in conjunction with either ground truth thickness measurements or with data from a non-imaging, pulsed radar ice thickness system being developed at Lewis (Vickers, et.al.,1973) can aid in determining the areal extent of these spot thickness measurements to the surrounding ice sheet by delineating regions of relative uniform thickness adjacent to such spot measurement locations. An analyses of thermal imagery in advance of planning ground truth measurements will aid in determining locations where ground truth will be most valuable in supplying a comprehensive sampling of the present stage of ice development.

CONCLUDING REMARKS

Preliminary analysis has shown that tone contrasts in thermal infrared imagery (8-14μm) allows various regions of similar ice thickness to be established thereby permitting new ice to be readily delineated from open water areas and thicker young ice found within the Great Lakes. The complexities involved in establishing a realistic thermal radiation model for the ice surface may preclude the use of thermal imagery for establishing absolute ice thicknesses. However, by making use of the tonal characteristics of open water areas, shore ice formations, and surface topographic features such as finger rafting, a range of ice thicknesses can be established for adjacent areas from thermal imagery. Future experience in interpreting such imagery should allow even more definitive characteristic to be established for various ice features and types which in turn may provide additional clues for determining ice thicknesses. Thermal imagery was generally superior to both visual and SLAR imagery for estimating relative ice thicknesses and differentiating regions of new ice in open water areas. Thermal imagery with its rather limited areal coverage and dependence on cloud-free conditions will play only a secondary role in a total Ice Information System for the Great Lakes. By providing interpretative keys for SLAR imagery evaluation and delineating the areal extent of pulsed microwave spot thickness measurements, thermal imagery will occupy a vital supplementary role in ice reconnaissance.

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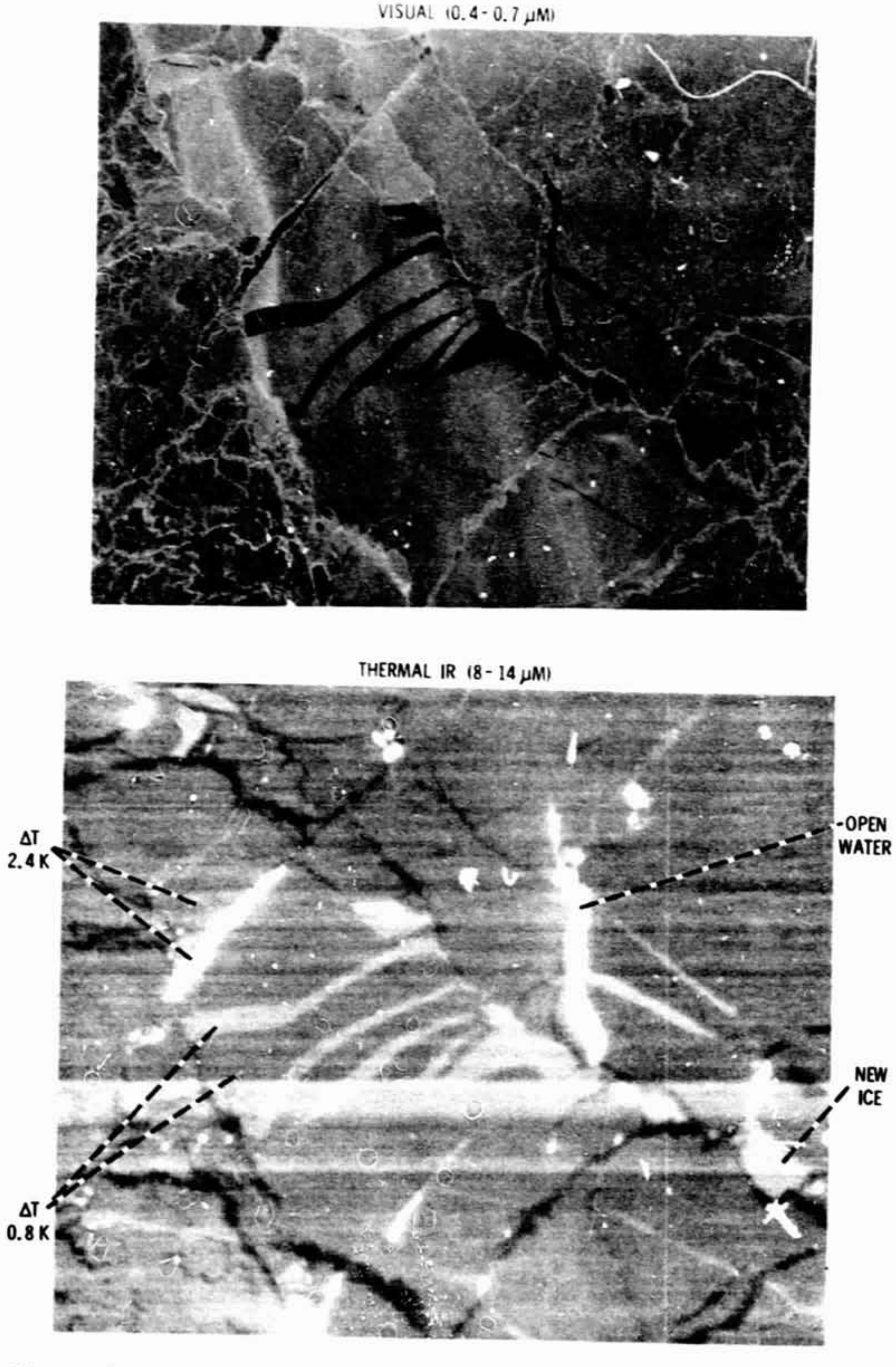

Figure 1. An example of ice conditions in Lake St. Clair as seen in the visible (upper) and thermal IR (lower).

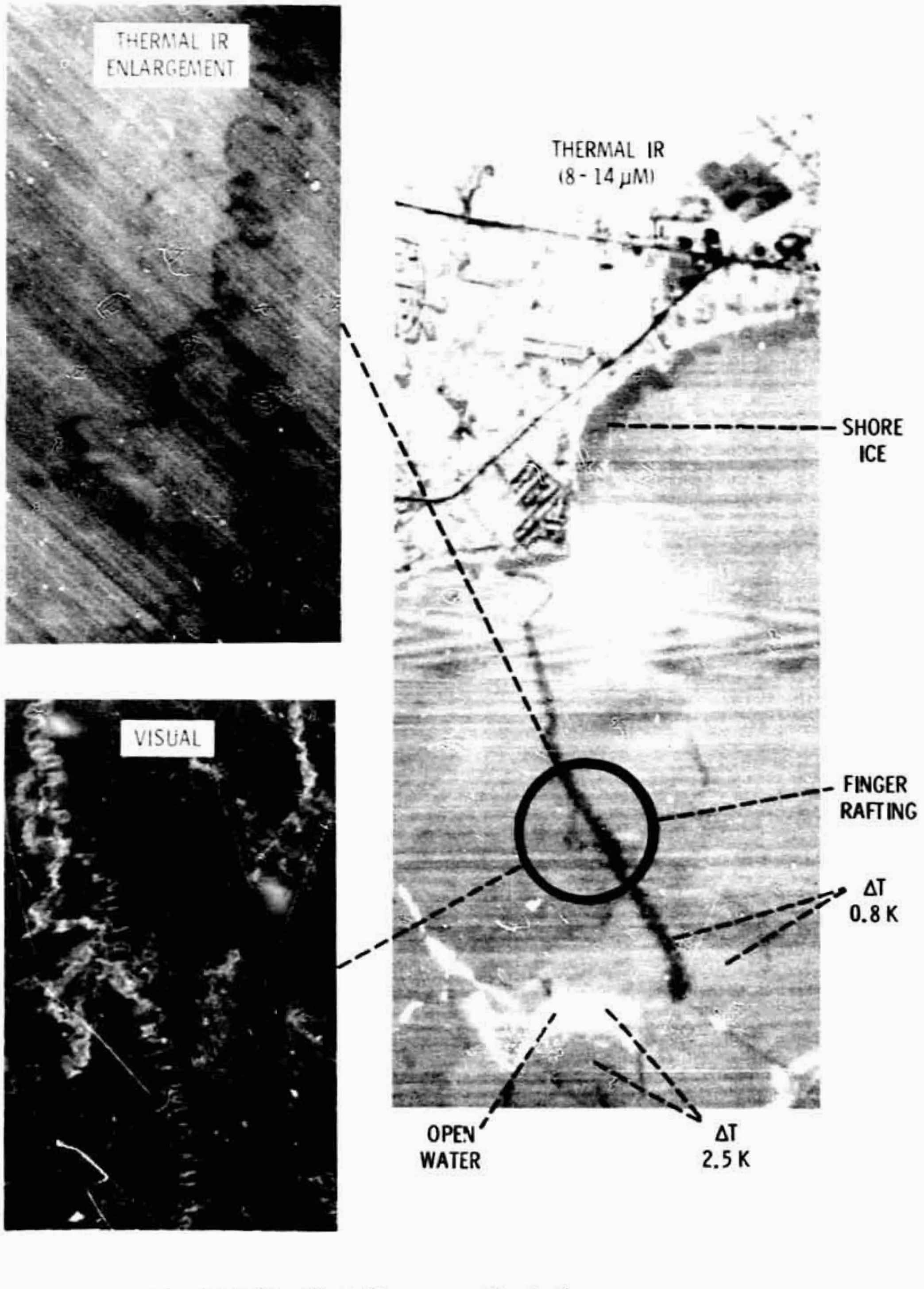

Figure 2. An example of a finger rafted thrust structure in the ice cover on Lake St. Clair.

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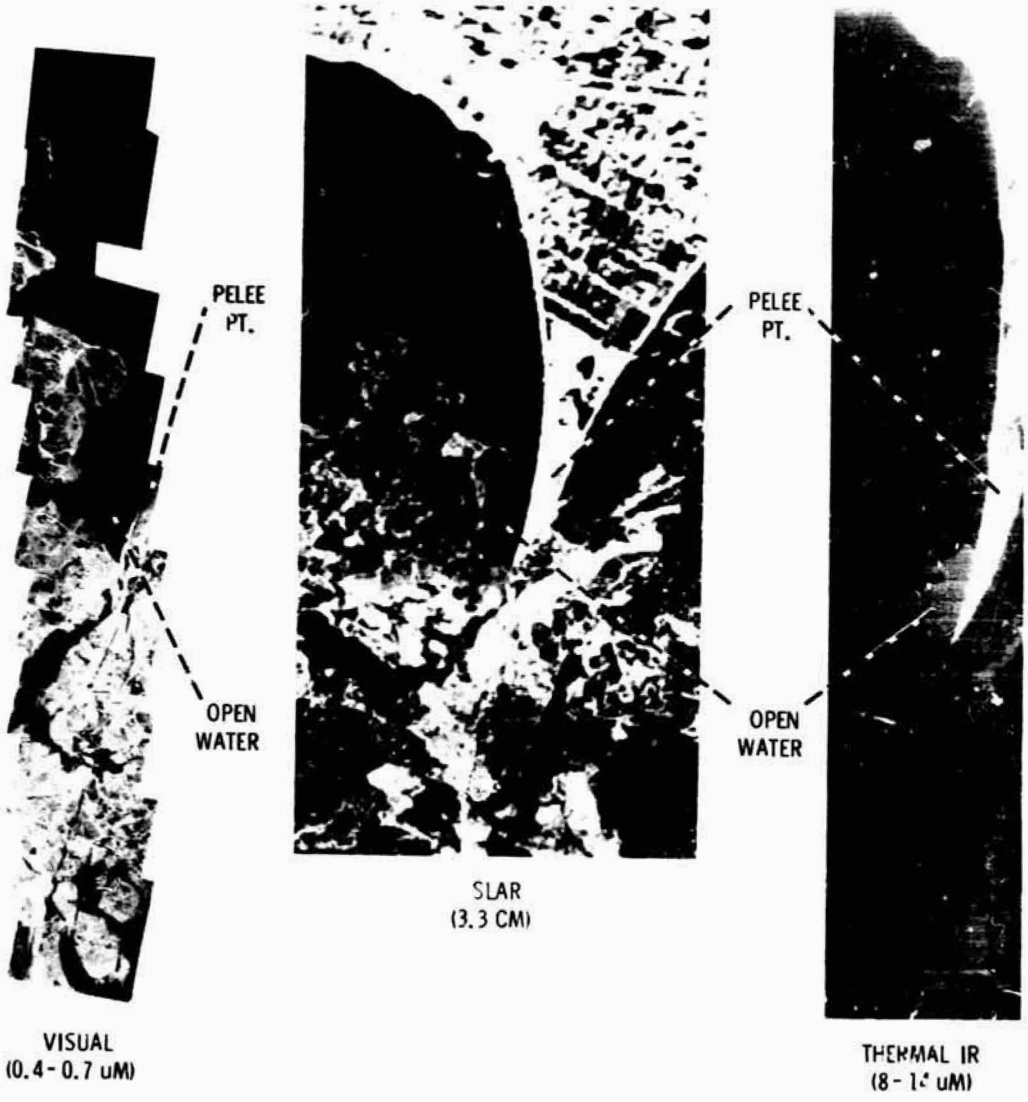

Figure 3. Thermal IR, radar, and visual imagery of ice conditions in Lake Erie near Pelee Point.

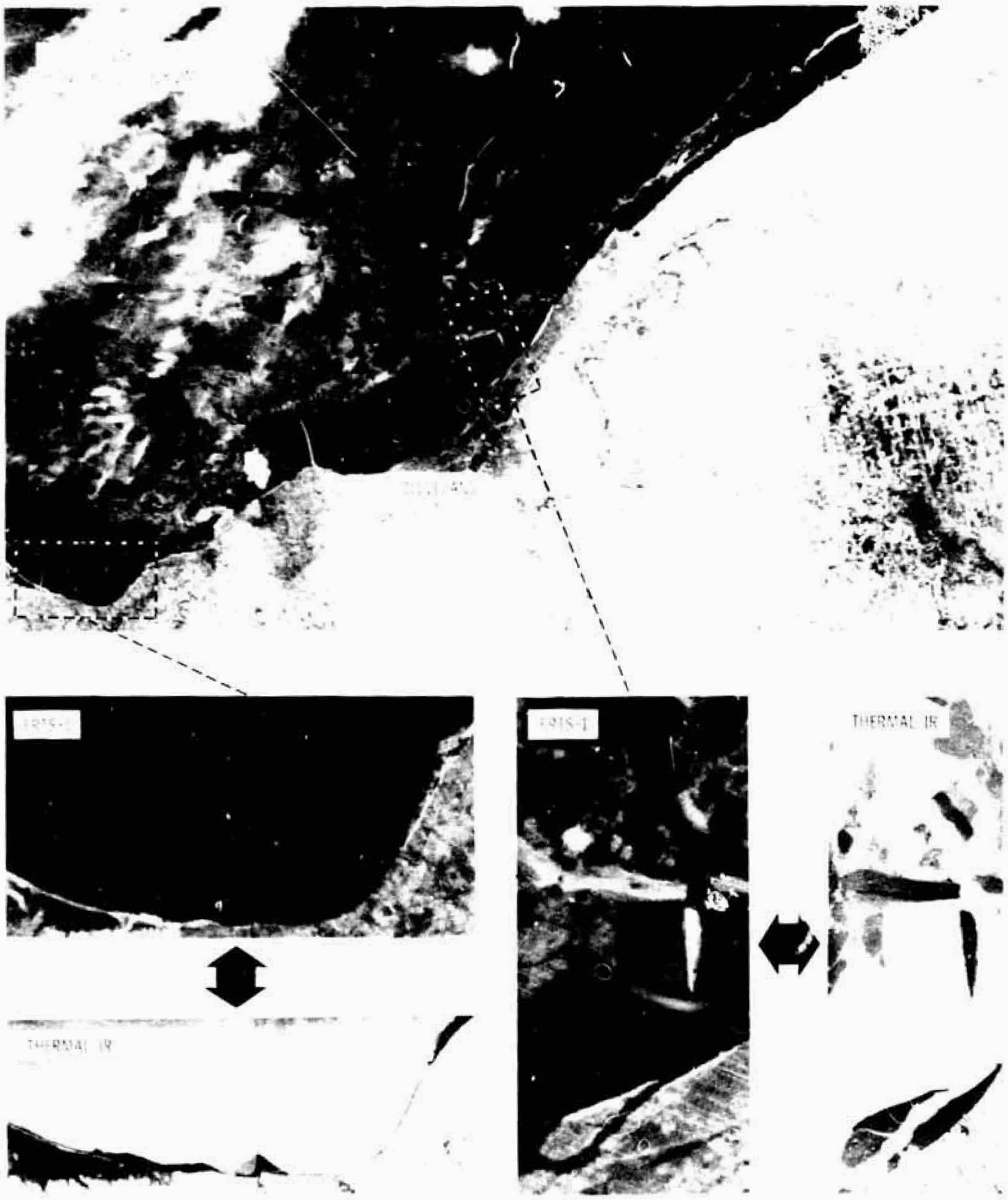

Figure 4. Thermal IR and ERTS-1 Satellite Imagery of Ice conditions in Lake Erie on January 13, 1973.