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CATEGORIZATION OF NORTHERN GREEN BAY ICE COVER USING LANDSAT 1 DIGITAL DATA - A CASE STUDY

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CATEGORIZATION OF NORTHERN GREEN BAY ICE COVER USING LANDSAT 1 DIGITAL DATA--A CASE STUDY[1]

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Northern Green Bay ice cover on February 13, 1975, was analysed using LANDSAT 1 digital data on the computer facilities at the Environmental Research Institute of Michigan. Training sets, consisting of selected areas in the LANDSAT scene that represent various ice types, were entered based upon the tone, texture, and location of the ice within the bay. The classification algorithm used in the analysis consisted of a modified maximum likelihood procedure using the multivariate Gaussian probability density function. It was found that seven ice types could be differentiated in the ice cover, that new (thin) ice could be distinguished from water, and that ice could be distinguished from relatively thin cloud cover. Training set statistics and area tabulations were generated and a color coded categorized image was produced. Recommendations are made for future studies.

1. INTRODUCTION

Various researchers have conducted investigations to classify or categorize ice types and features (e.g., Marshall, 1966; Chase, 1972; Bryan, 1975), to map ice distribution (e.g., Barnes and Bowley, 1973; Leshkevich, 1976), and to monitor and attempt to forecast ice movement with remotely sensed data (e.g., Strong, 1973; Rumer et *al.*, 1979; Walsh and Johnson, 1979). Much of the research on Great Lakes ice cover has used manual (visual) interpretation of satellite and other remotely sensed data (e.g., Rondy, 1971; Wartha, 1977), of which the LANDSAT satellite data set is only a part. A large portion of this work has used the visible and infrared (IR) bands of weather satellites, such as ITOS, NOAA, and GOES (e.g., Chase, 1972; McGinnis, 1972; Quinn *et* al., 1978) and, more recently, side looking airborne radar (SLAR) imagery (Larrowe et at., 1971; Schertler et *al.*, 1975; and Bryan and Larson, 1975).

The purpose of this study was to investigate whether Landsat digital data can be used for objective classification of various types of Great Lakes ice cover. The major objectives were to determine if in the study area new ice (thin ice) can be differentiated from water, if ice can be differentiated from cloud cover, and if various ice types (categories) can be classified with a maximum likelihood procedure. Secondary objectives included determining the percent coverage of each ice type and calculating the total percentage of water surface covered by ice.

The uses for such information include adding LANDSAT classified data to other sources of Great Lakes ice-cover information for the purpose of historic

[1]GLERL Contribution No. 243

documentation and ice-cover mapping, as input data for ice-cover and ice transport modeling, as input data to help determine the impact of ice cover on photosynthesis, and as a possible aid to navigation during the extended winter navigation season.

This study used a previously recorded LANDSAT 1 scene and was submitted for fulfillment of the requirements of a course in Remote Sensing of Earth Resources conducted at the Environmental Research Institute of Michigan.

2. DATA SOURCE AND DESCRIPTION OF STUDY AREA

2.1 Data Source

Although limited by frequency of repetitive coverage and cloud cover, LANDSAT 1 satellite imagery provides relatively large-scale images in four bands spanning the visible and near-IR wavelengths. A LANDSAT scene covers approximately 185 km x 185 km on the ground at a scale of about 1:1,000,000, with a resolution of about 80 m. Each picture element (pixel) is approximately 56 m x 79 m in size (1.1 acres) and a scene is composed of approximately 7.5816 x 106 pixels. For more information about the LANDSAT system, see Taranik, 1978. The wavelengths sensed in each band are as follows:

Band 4--0.5 - 0.6 μm (visible)

Band 5--0.6 - 0.7 μm (visible)

Band 6--0.7 - 0.8 μm (near-IR)

Band 7--0.8 - 1.1 pm (near-IR)

2.2 Description of Study Area

The study area includes approximately the northern half of Green Bay and the adjacent area of Lake Michigan (figure 1). The LANDSAT 1 scene (1935-15530) that was used for this study was recorded on February 13, 1975 (figure 2). Although there was no ground truth of the ice cover on the bay, this scene was chosen for the study because there appear to be several different ice types on the bay and on adjacent Lake Michigan waters. Clouds obscure the north and northeast portion of the scene, extending over Big Bay de Noc and intermittantly over adjacent Lake Michigan waters, but the central portion of the bay appears to be cloud free.

3. DATA ANALYSIS

3.1 Equipment

The equipment used for this study is that of the Earth Resources Data Center (ERDC) at the Environmental Research Institute of Michigan (ERIM). The ERDC equipment used includes the multispectral data analysis system (MDAS) consisting of a DEC PDP 11/70 computer, which performs MDAS control and some processing functions; a color moving window display, which presents a color-coded image display of a 320 x 240 picture element (pixel) field of data;

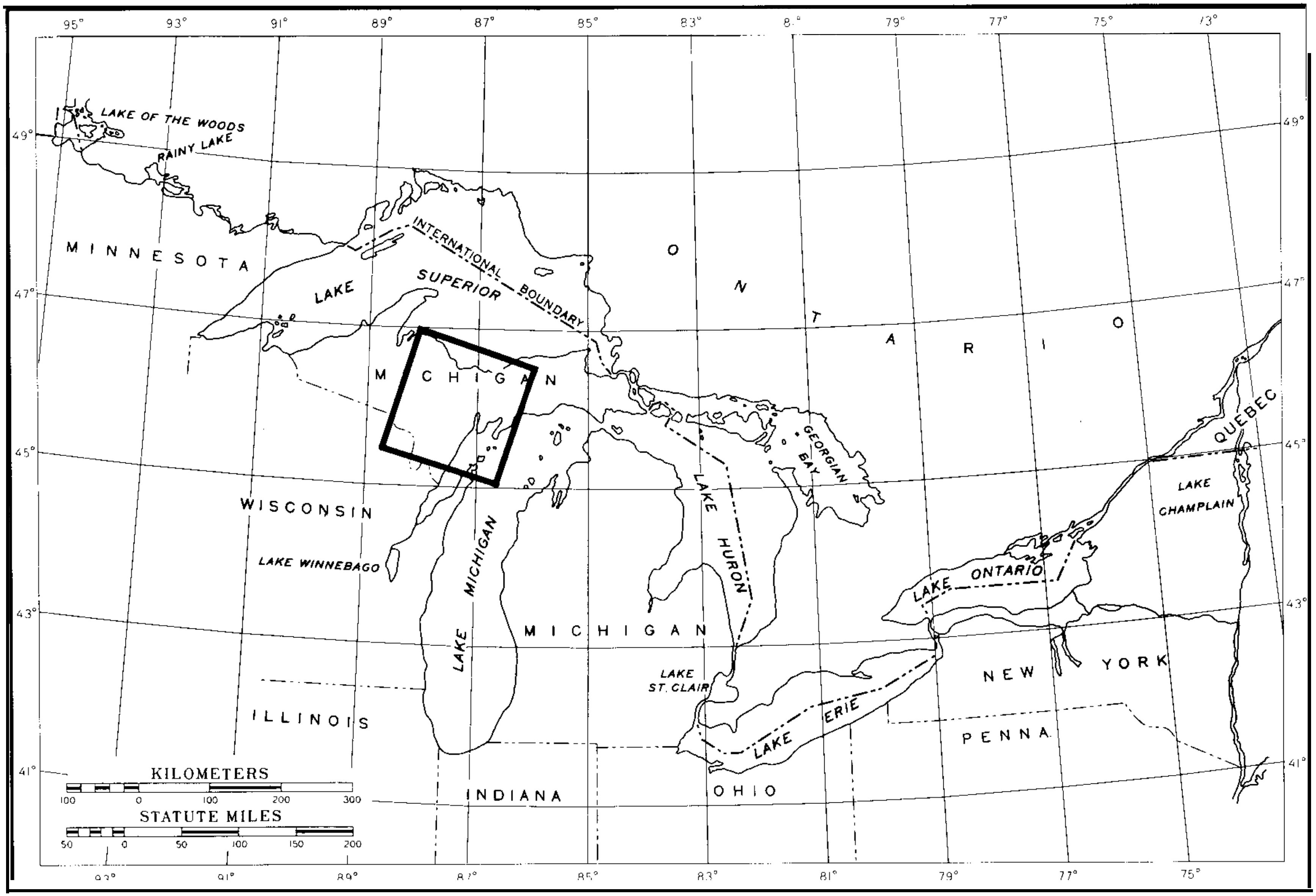

Figure 1.--*Area covered by LANDSAT 1 scene, February 13, 1975.*

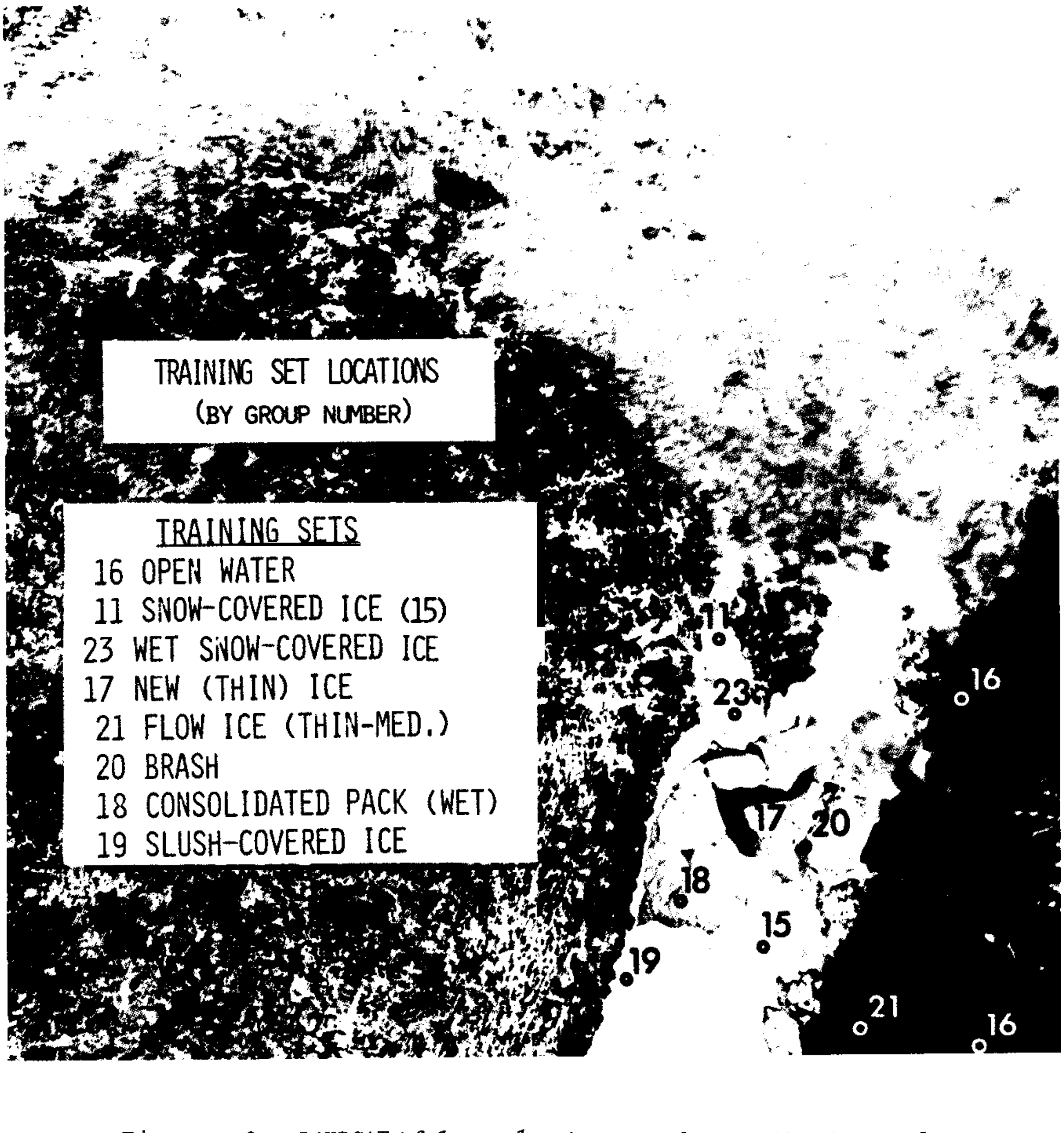

Figure 2.--*LANDSAT 1 false-color image, February 13, 1975, and tmining set locations (by group number).*

an operator interaction panel, which provides operator interaction with the MDAS system by moving the display field, changing the image scale, and positioning and shaping the cursor to select, enter, and modify training set data; a multivariate categorical processor (MCP), which is the hardware implementation of the categorical processing algorithm based on a multivariate Gaussian probability density function (maximum likelihood) and provides high speed multispectral data categorization (Dye and Chen, 1975); high-density digital tape and disc drives from which data can be input directly from LANDSAT computer compatible tapes and which provide storage for categorized data. In addition, a Datagrid digitizer consisting of a work surface, free moving hand held cursor, and a keyboard-cathode ray tube display console provides the capability to enter map coordinates to geometrically correct a LANDSAT scene or to create a "digital mask" that can be used to mask certain portions of a scene. An Optronics P1500 drum film recorder produces annotated, corrected, categorized film output products, and a line printer produces printed output. For more information about MDAS, see Wilson, 1979.

3.2 Approach

The data was processed from two 800 BPI LANDSAT 1 digital tapes. The color moving window display was used to examine the LANDSAT 1 digital files. Training sets, consisting of groups of pixels on the LANDSAT scene thought to be prime examples of the categories being classified, were entered by using the display's cursor. Each training set was arbitrarily assigned a training set number, group number, color code, and a name. A categorical analysis program processed the pixels and generated a set of processing coefficients for each group from the mean signal and standard deviations in each of the four LAWDSAT bands. The hardware multivariate categorical processor categorized the scene based on the training sets entered, and the Optronics film recorder produced three film separates from which the color-coded image was generated.

After entering test training sets for "snow-covered ice" and "snow-covered land" and running the categorical analysis program, it could be seen on the color display that some of the snow-covered land was categorized as snow-covered ice and vice versa. The transformed variables for '*snow-covered land" (group 13), shown in table 1 and plotted around the group means for "snow-covered ice" (group 15) in figure 3, illustrate the similarity of these groups. Since in this study the water and ice-covered water areas of northern Green Bay and adjacent Lake Michigan are of primary concern and since these areas comprise less than a quarter of the total scene, it seemed justified and advantageous to "mask" out the land area in the scene. Thus, the approach to the study was to geometrically correct the LAWDSAT scene first. To do this, a prominent set of points (nine points were used) found on the LANDSAT scene and entered as "points" with the cursor on the color moving-window display were also digitized from 1:80,000 scale lake charts of Green Bay. These reference points were then used by the appropriate program to correct the scene geometrically. Next, the boundary of the northern portion of Green Bay and adjacent Lake Michigan coinciding with the scene was digitized from a 1:240,000 scale lake chart to produce a "digital mask." The entire scene was classified based on the training sets entered for ice types and open water and the land areas except for islands were later photographically masked. The digitized boundary

Table 1.--Training set statistics comparing snow-covered ice (group 15) and snow-covered land (group 13)

Training Set Statistics					Explanation
GROUP 15	Snow-Covered Ice				-Group Number and Name
INC VAR	1	2	3	4	-Channels (Bands)
MEANS	219.5	212.7	187.6	138.4	-Mean Digital Counts by Band for Pixels in Training Set
STD DEV	7.9	8.2	7.8	8.7	-Standard Deviations
DETERMINANT	1.34E+06				-Dispersion Within Group.
EIGENVALUES					-Average of Sum of Transformed Variables Evaluated at Group Means Squared--The larger the eigenvalue, the easier it is (on the average) to separate the group from other groups.
Transformed Variables 1	355.1				
2	0.9				
3	0.8				
4	0.5				

TRANSFORM VARIABLES

Ch.# (Bands) VN	COEFFICIENTS 1	2	3	4	CONTRIBUTION 1	2	3	4
1	0.05	-0.18	0.05	0.01	0.9	0.0	0.0	0.0
2	0.07	0.07	-0.21	-0.09	1.2	0.0	0.0	0.0
3	0.05	0.10	0.16	-0.05	0.8	0.0	0.0	0.0
4	-0.05	0.01	0.03	0.18	0.9	0.0	0.0	0.0

-Coefficients Used to Calculate Transformed Variables and the Contribution of Each to the Generation of its Respective Transformed Variable (1.0 equals average usefulness.)

TRANSFORM VARIABLES EVALUATED AT GROUP MEANS

GROUP	WEIGHT	1	2	3	4
11	1.0	1.3	0.5	-0.3	-0.1
12	1.0	-26.4	-0.1	-0.1	-0.2
*13	1.0	0.0	1.0	-0.1	0.2
15	0.0	0.0	0.0	0.0	0.0
16	1.0	-26.9	0.1	0.1	0.2

-Distance (Standard Deviations) From the Group Means (of Group 15 in This Case)

*Snow-Covered Land

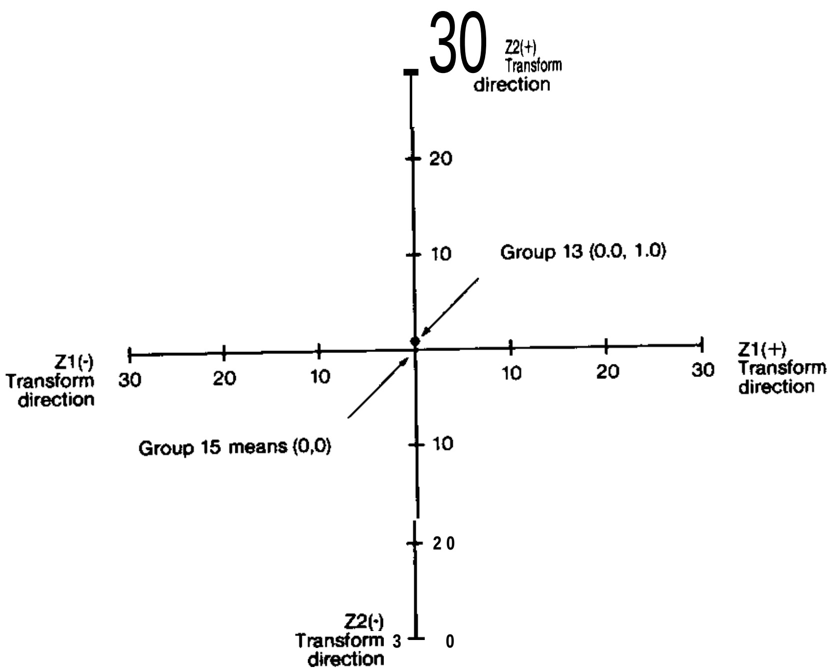

Figure 3.—*Transformed variables (1 and 2) for snow-covered land (group 13) plotted around the group means for snow-covered ice (group 15). (Axes units are Standard Deviations.)*

was needed to generate area statistics as the software deleted land areas from the scene so that the computer algorithm tabulated only pixels in the ice-covered and open-water areas. Moreover, because the whole scene was classified, a number of interesting observations can be made about the classified cloud cover and land areas; these will be discussed later.

The next step was to enter training sets for various types of ice cover and open water. Although no actual ground truth was available for this scene, the categories were chosen based on texture, tone (false color), and location of the ice cover within the bay or lake and named according to their visual appearance on the false-color LANDSAT scene and positive transparencies (bands 4, 5, 6, 7) using the nomenclature set forth in the "Ice Glossary" (Lake Survey Center, 1971). There are three main reasons for the difference in tone of the ice cover (personal communication, Dr. G. H. Suits*). One is the loss of air voids in the snow or ice cover. As water fills the voids (yielding wet snow or slush), light is kept from "bouncing" among the voids (facets), which would cause a lower reflectance. The second is specularity or the smoothing of a" ice surface by melting or a thin layer of water, causing it to become more specular. Because the sun never gets overhead at northern Green Bay latitudes, light is reflected off the surface at an angle other than the satellite's look angle. Thus, the surface looks darker from the satellite's direction. The third depends on the amount of liquid water on the ice surface or around the ice cover in the case of floes. If sufficient in volume, the absorption by water of energy in the near-IR wavelengths causes a lower reflectance and thus a darker image, as can be seen when band 4 (visible) and band 7 (near-IR) are compared (figure 4). This factor probably accounts for the relatively dark tone of non-snow covered new (thin) ice (especially in band 7) as light passes through it and is absorbed by the water below. Thus, the more that water interacts with ice type, the darker its tone. For example, wet snow-covered ice should appear darker than snow-covered ice but not as dark as slush-covered ice and so forth.

Defining seven categories of ice and open water, eight training sets were entered (figure 2) by using the cursor on the color moving-window display [groups 11 and 15, "snow-covered ice," were merged to form one group (training set)]. When the mean digital counts were plotted by band, the categories (training sets) chosen were seen to be quite separable, ranging from the bright "snow-covered ice" to the dark "open water" (figure 5). The multivariate categorical processor was then used to categorize the scene. Area tabulations were generated (table 2) and the categorized, color-coded scene was filmed (figure 6).

4. RESULTS

Seven types of ice cover were classified based on the training sets entered (figure 7). When figure 2 is compared with figure 8, a number of observations can be made about the classified scene. As expected, portions of the snow-covered land were classified as "snow-covered ice" and "wet snow-covered ice." The clouds over the land area in the north and northeast portions of the scene were classified as predominantly "wet snow-covered ice," "consolidated pack," and "slush-covered ice." This would indicate that

*Environmental Research Institute of Michigan, Ann Arbor, Michigan.

Band 4 (visible)

Band 7 (near IR)

Figure 4.--*Comparison* of *LANDSAT 1 band* ***4 and band 7 to*** *illustrate* ***the*** *influence of water on* **the tone** of ***ice cover.***

Table 2.--*Area tabulations--Northern Green Bay and adjacent Lake Michigan waters.*

Group Number	category	Percent of Total	Acres	km^2
0	Uncategorized	17.43	212540.19	860.12
11 and 15	Snow-Covered Ice	20.84	254111.33	1028.35
i6	Open Water	17.02	207559.67	839.96
17	New (Thin) Ice	4.60	56042.02	226.79
18	Consolidated Pack	6.66	81156.06	328.43
19	Slush	6.25	76153.28	308.18
20	Brash	3.69	45011.65	182.16
21	Flow	13.12	159965.41	647.36
23	wet Snow-Covered Ice	10.40	126773.03	513.03
TOTALS		100.00	1219312.62	4934.37

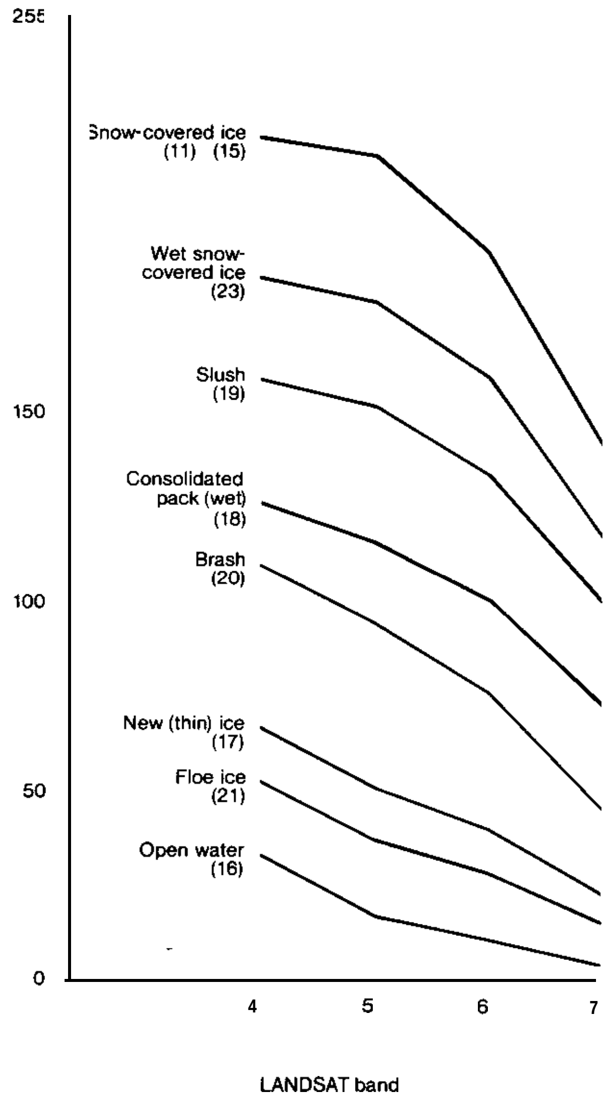

Figure 5.--*Mean* ***digital count8*** *of training sets--bands* ***4, 5, 6, and 7.***

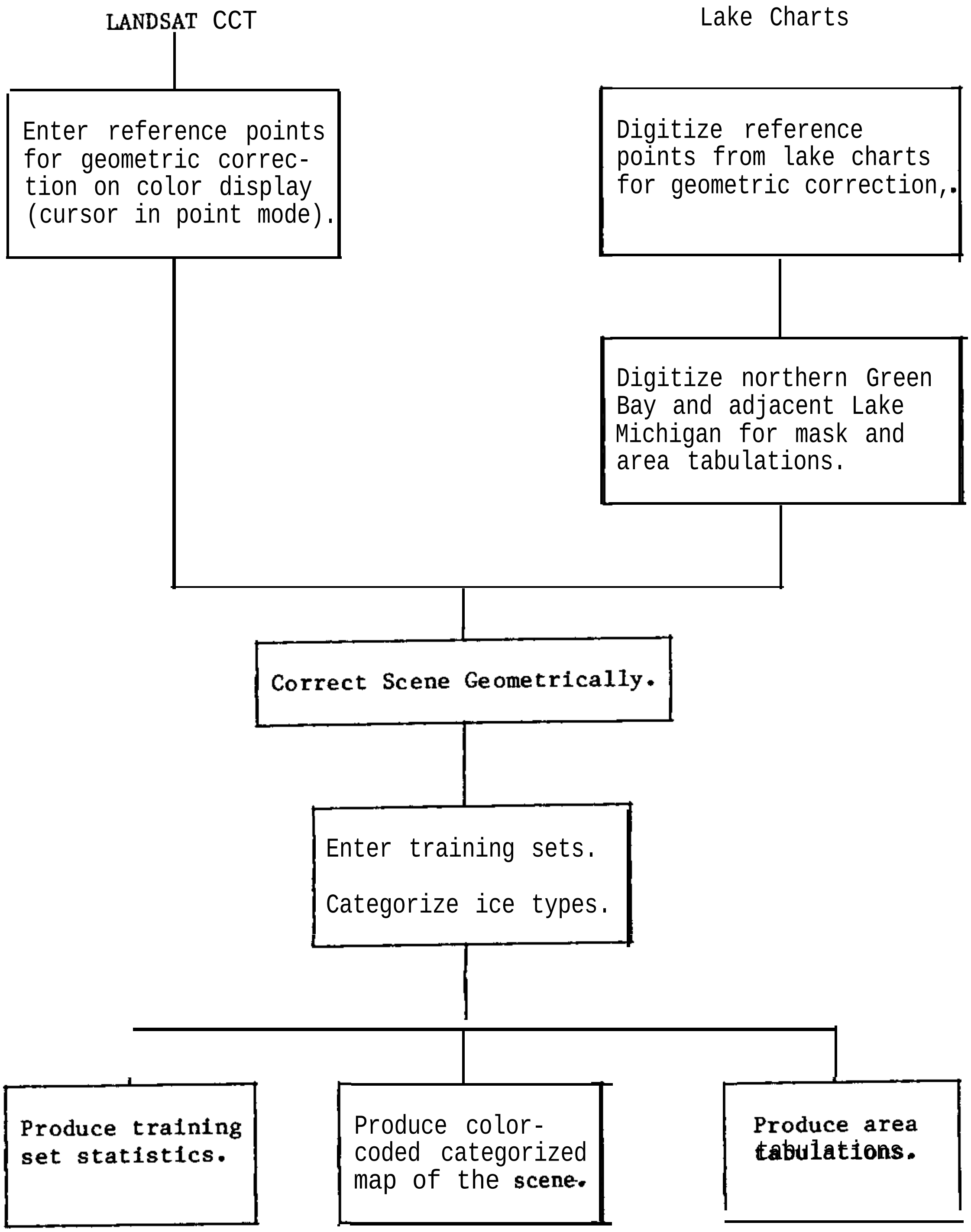

Figure 6.--*Summary of processing steps.*

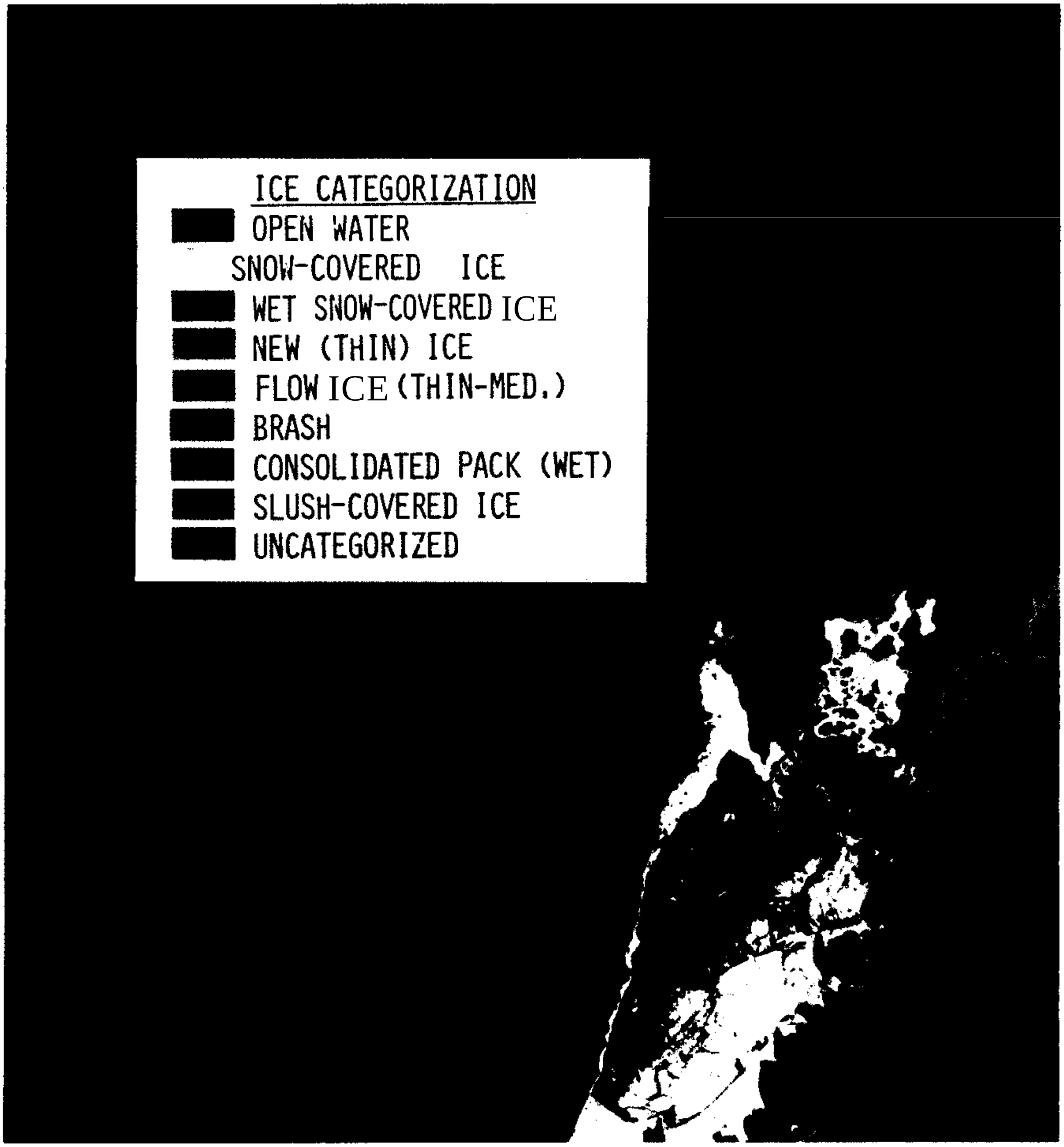

Figure 7.--*Ice categorization* of *LANDSAT 1 scene, February 13, 1975 (masked).*

Figure *8.--Ice categorization* of *LANDSAT* 1 scene, *February 13,1975(unmasked)*.

the top of the cloud cover has the same reflectance and, therefore, records the same digital counts as those categories. It is interesting to note that, although the cloud cover over land seems thick and continuous in figure 2, small uncategorized areas (black) and small patches of snow-covered land classified as "snow covered ice" (white) can be seen through breaks in the cloud cover. Furthermore, "new ice" (yellow) and "open water" (blue) can also be detected in the extreme northwest area of the scene (figure 8) covering a portion of Lake Superior (figure 1). This is significant for mapping ice cover.

The thin clouds over Lake Michigan (lower right portion of figure 2) that are often confused with new or thin ice when visually interpreting a LANDSAT scene become uncategorized (black) in figure 7. This is probably because they are thin and have been modified in their reflectance by the dark toned water below, which causes them to record a digital count unlike any of the ice types. Moreover, the "flow ice" (tan) and "new (thin) ice" (yellow) in Lake Michigan stand out in the classified scene (figure 7) whereas they are difficult to detect in the false-color scene (figure 2).

The crescent shaped area in the middle of the bay, although difficult to identify as new ice or open water on the false-color scene (figure 2), has been classified as open water (figure 7) based on the training set for "open water" (group 16) taken in Lake Michigan (figure 2). However, the "new (thin) ice," which can be seen in the false-color image in the lower leg of the crescent (group 17 in figure 2), also appears in the categorized scene (figure 7) in the upper leg of the crescent, only part of which can be detected in the false-color image. "New (thin) ice" (yellow) also appears in the classified image in the area of open water just north of the crescent (figure 7), but cannot be readily detected in the false-color image.

Area tabulations were computer generated, and are summarized in table 2. The digitized lake-land boundary was used to mask out land areas. Approximately 65.56 percent of the 4,934.37 km^2 of water area was classified as ice covered and only 17.43 percent of the area was unclassified (cloud or unclassified ice).

5. CONCLUSIONS AND RECOMMENDATIONS

It was found in the LANDSAT 1 scene studied that, based upon the training sets, different ice types (categories) could be differentiated in the ice cover; that new (thin) ice can be differentiated from open water; and that, although thick cloud cover can be classified as types of ice, in this scene, ice can be differentiated from relatively thin cloud cover. This seems to be especially true for thin and newly formed ice in areas of open water. In addition, if some indication can be found that there is ice present below a cloud cover, especially in a coastal or bay area, ice mapping can be made more accurate. This could also be of some value to navigation if it were the only information available.

However, certain questions arise that warrant further study. For example, will relatively thick cloud cover be classified as one or a combination of the three ice types ("wet snow-covered ice," "consolidated pack," or "slush-covered ice") in other scenes. In other words, will relatively thick clouds always have the same reflectance and result in the same digital counts as one or more of those three ice types, at least at Green Bay latitudes? How "thin" do clouds have to be to avoid being classified as an ice type and can ice be differentiated from thin clouds in other scenes covering different areas on the Great Lakes and at different times during the ice season? Moreover, can reflectance measurements, such as those made by Leonard Bryan in a 1973 study (figure 9) (Bryan, 1975), be converted to digital counts and, accounting for atmospheric attenuation and Sun azimuth and elevation, be used for training sets (ground truth) to classify freshwater ice cover? If so, ice cover might be classified into broad categories from scene to scene.

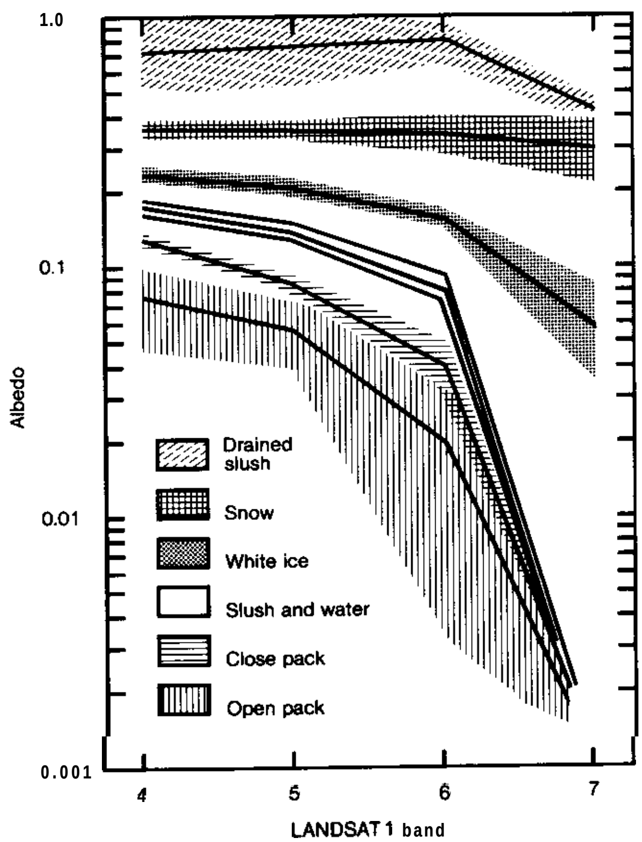

Figure 9.--*Spectral* response from ice and snow surfaces.

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