ICE CONDITIONS ON THE CHESAPEAKE BAY
AS OBSERVED FROM LANDSAT DURING
THE WINTER OF 1977

James Foster

Systems and Applied Sciences Corporation
Riverdale, Maryland

Dorothy Schultz, William C. Dallam

General Electric Company
Beltsville, Maryland

ABSTRACT

Landsat imagery of the Chesapeake Bay region taken during January and early February demonstrates the extent of the ice coverage that occurred during the unusually cold winter of 1977. Photographic interpretation and digital analysis have been utilized to monitor, map, and measure the ice and snow conditions as observed on eight Landsat scenes. Several different types of ice were identified in the Chesapeake Bay and its tributary system from Landsat, and changes in the ice patterns and ice cover extent were also detectable from the satellite imagery. An interactive computer system (General Electric IMAGE 100) was used to classify the ice into categories based on spectral signatures. Using these spectral signatures in conjunction with a limited amount of ground truth data, the ice thickness was inferred and the area percentages of the ice thickness categories were estimated.

PHOTOINTERPRETIVE ANALYSIS

In most winters ice in the Chesapeake Bay (Figure 1) is confined to the upper bay and its tributaries, but in January and February of 1977 the ice cover was extensive in the lower bay, south of the Chesapeake Bay Bridge, as well as the upper bay. Ice began to form in the northern end of the upper Chesapeake Bay during the last few days of December, 1976 (Figure 2), and by the middle of January, as unusually cold weather persisted, the ice cover had expanded well into the lower bay (Figure 3).

Ice conditions as observed on Figure 3 which is a Landsat scene taken on January 15, 1977, show differences in the extent of the ice coverage in the Chesapeake Bay and the tributary system. From the Susquehanna River at the northern end of the bay to the Bay Bridge (refer to Figure 1) the ice cover is closed (80-100% ice cover), whereas from the Bay Bridge to Cove Point, near the center of the bay, the ice cover is broken (50-80% ice cover), and from Cove Point southward the ice cover is open (0-40% ice cover). Rivers emptying into the bay are generally consolidated with ice (100% ice cover), however, some rivers entering the bay from the west have a broken ice cover. The water in these rivers is faster moving and thus, ice formation is somewhat retarded. Bridges also seem to have an effect in the formation and build-up of ice by acting as barriers to the flow of large ice sheets. This may have expedited the consolidation of the ice cover upstream from the Potomac River Bridge and the Chesapeake Bay Bridge.

Although it is often difficult to distinguish between different types of ice, because different types of ice may have the same appearance or spectral signature, several

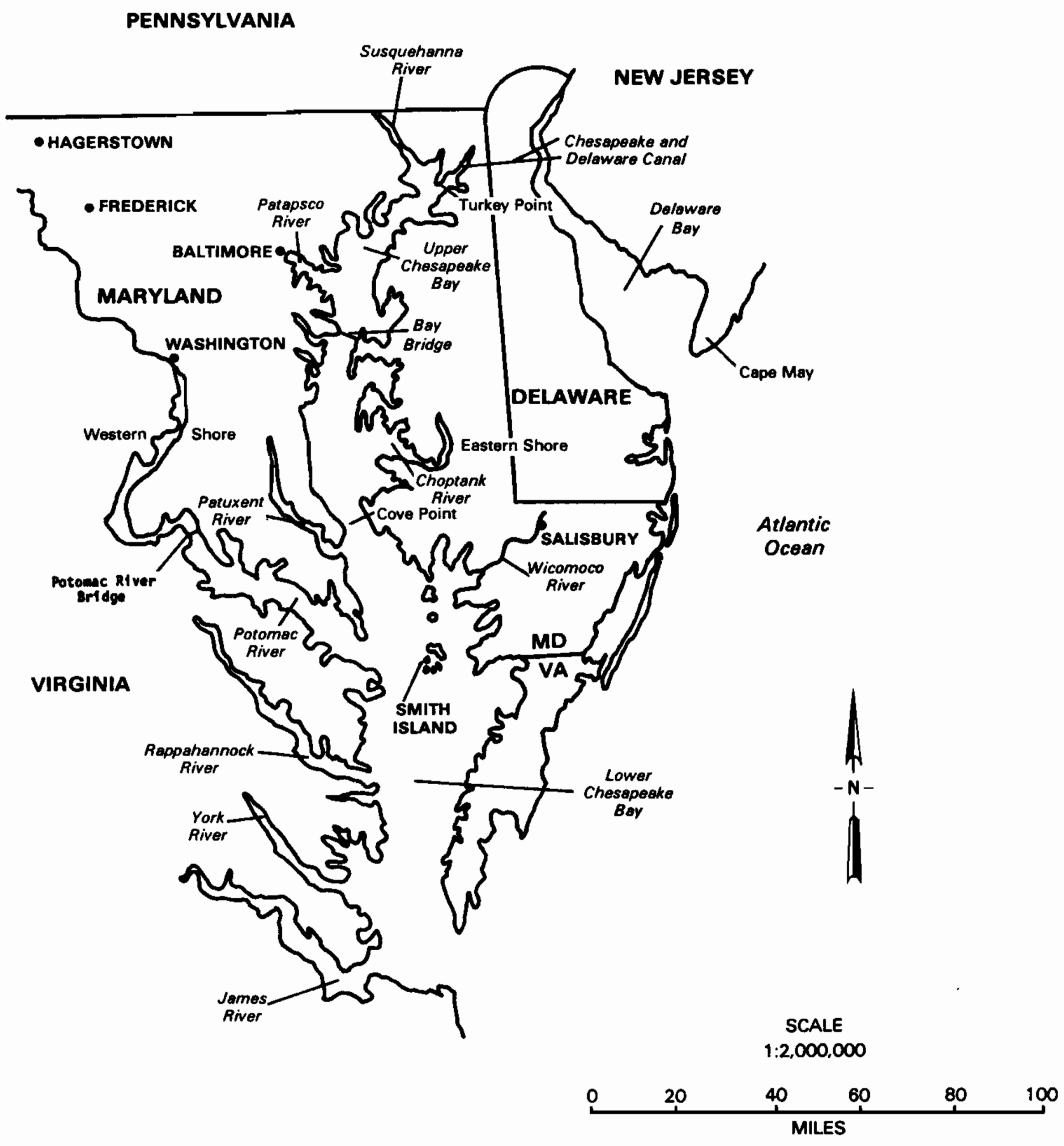

Figure 1
Map of the Chesapeake Bay Region

Figure 2
Landsat Image of December 27, 1976

Figure 3
Landsat Image of January 15, 1977

different types of ice can be identified on this same Landsat scene (Figure 3). Shore ice, which takes the form of longitudinal bands of ice attached to the shore can be seen in the tributaries and estuaries of the bay on both the eastern and western shores. Frazil ice, which is an agglomeration of individual platelets of ice, can be observed in the faster moving waters of the Potomac River. These platelets can be easily compacted by wind or waves and seem to form more readily in open and faster moving waters. Black ice or clear ice, which is newly formed ice that appears darker than other types of ice because of its transparency, is generally confined to the central bay on this image. In the northern part of the upper bay, the ice has a white appearance due to the presence of a light snowcover.

The maximum ice cover extent in the Chesapeake Bay was reached in early February. Landsat images of the bay region taken on February 1 and 2 (Figures 4 and 5) and February 7 and 8 (Figures 6 and 7) show obvious changes in the extent and pattern of the ice cover as compared to the January 15 image (Figure 3). The ice cover as observed in early February north of the Bay Bridge is nearly completely consolidated as is the ice in all of the rivers and inlets entering the bay from the eastern shore of Maryland. Also note that the Potomac and Patuxent Rivers show a greater ice cover in early February than on January 15. In the early February imagery, ice extends well into the southern part of the lower bay (Figures 4 and 6), whereas in the January 15 image, the ice extends only to about Cove Point.

The ice cover as observed in the early February imagery is concentrated in the eastern part of the lower bay. The bay region had been subjected to strong northwest and west winds for several days at the end of January and the beginning of February which forced the ice against the eastern shores of both the Chesapeake and Delaware Bay (Figure 4). Ice patterns in the central Chesapeake Bay show definite patterns of longitudinal cracking and compression from the west to the east as a result of the constant winds.

The rivers entering the southern portion of the lower bay from the western shore also show the effect of the wind; as the ice in these rivers is pushed against their banks (Figure 4). In addition, note the extension of ice off the tip of Cape May, New Jersey (Figures 4 and 6) which has been driven into the open Atlantic by the force of the wind. Further evidence of a strong westerly wind can be seen by the smoke plumes drifting eastward across the Delaware Bay on the February 1 image (Figure 4).

Changes in the ice cover extent and patterns were also detected between the February 1 and the February 7 images. The most noticeable change is that subsiding winds have permitted the ice to reform in those areas of the Chesapeake and Delaware Bay which were previously ice-free (Figures 4 and 6). The extension of ice off Cape May has changed dramatically between the February 1 and February 7 images. On the February 1 image, the ice extension is only about 5 miles (8 kilometers) off Cape May, but 6 days later the ice has drifted 30 miles (48 kilometers) to the south and east and has also greatly increased in size.

In addition, changes in ice cover conditions were also observable in the overlap areas between the February 1 and 2 Landsat images (Figures 4 and 5) and the February 7 and 8 Landsat images (Figures 6 and 7). The most conspicuous differences have taken place in the lower Potomac River and in the Chesapeake Bay between the Potomac and the Choptank Rivers. The ice in the lower Potomac as seen in the February 1 image, is packed against the north shore of the river, but just 24 hours later the ice has become dislodged and is drifting into the bay. The ice/open water boundary in the bay between the Potomac and Patuxent Rivers is nearly straight as viewed on the February 1 image; however, the next day, a portion of the ice boundary is concave rather than straight. Presumably, these changes are also the result of strong winds. Also, the ice in the central bay as observed on February 7, is fairly well intact, although many cracks are evident, but one day later of February 8, the ice in the middle of the bay has become separated from the ice adjacent to the eastern shore and appears to be breaking up.

Ice conditions were so severe during 1977 that Smith Island, in the south central part of the Chesapeake Bay, was inaccessible by boat from January 17 until early February, and an oil barge carrying much needed fuel oil for heating purposes was unable to make its way up the Wicomoco River to Salisbury, Maryland during the same time period. Figure 8 is a photograph taken in early February showing the ice conditions encountered by ships on the lower bay.

Figure 4
Mosaic of Two Landsat Scenes taken on February 1, 1977

Figure 5
Landsat Image of February 2, 1977

Figure 6
Mosaic of Two Landsat Scenes taken on February 7, 1977

Figure 7
Landsat Image of February 8, 1977

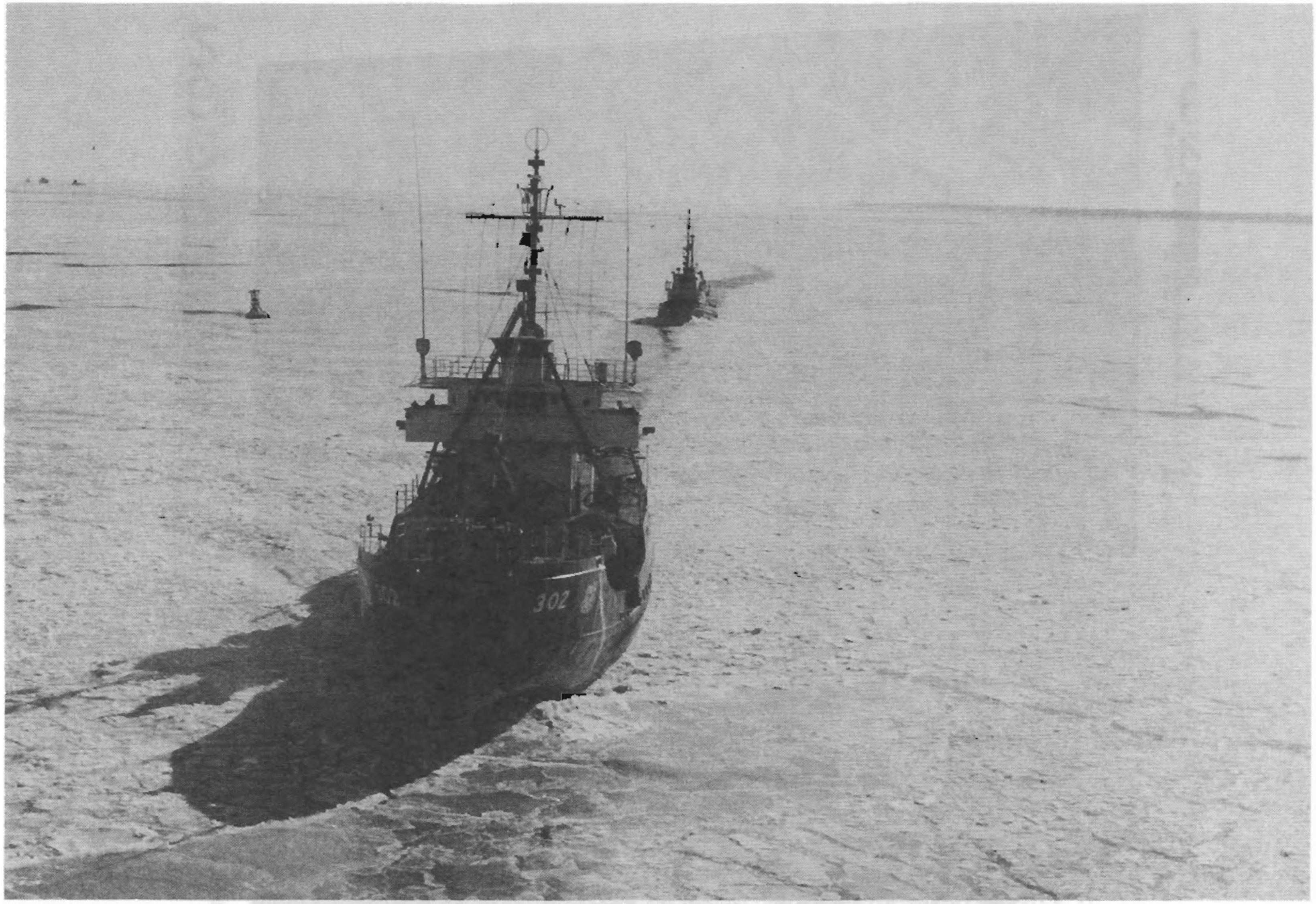

Figure 8
Photograph of the Lower Chesapeake Bay
Courtesy of U.S. Coast Guard

The ice finally began to break up and melt as above normal temperatures worked their way into the bay area during the last half of February. The ice melted from a south to north direction and from the shore towards the middle of the bay. By the end of February, only a few concentrations of rotten ice could be detected in the upper bay (Figure 9). Note that the ice does not appear as bright or white as it does on earlier images. This is because the melting ice has become dirty due to pollution, dust and sludge which has accumulated on its surfaces and edges.

Snow as well as ice is a major feature observable in Landsat imagery during January and February of 1977. Landsat scene 2742-14534 (Figure 5) shows an extensive snow area covering most of the image. The majority of this snow was a result of a January 6 storm that deposited up to 6 inches (15 cm) of snow over northern Virginia and central Maryland. Extremely cold air during the month of January allowed the snow to remain on the ground until early February. In many locales, snow was on the ground for over 40 days, a very unusual occurence in this area. On this image, Baltimore and Washington are generally snow-free because of street clearing activities and the prodigious amount of heat that these cities generate. They appear as dark, almost black, blotches on the Landsat image. The smaller cities of Hagerstown and Frederick, Maryland, do not have as dramatic a heat island effect and thus are not yet free of snow, and so they appear as gray spots on the image. Note also how the snowline changes as the snow cover area decreases on January 15 (Figure 3), February 2 (Figure 5), and February 8 (Figure 7).

DIGITAL ANALYSIS

In an effort to gain more information about the ice cover on the Chesapeake Bay, digital analysis was performed on Landsat scene 2742-14534, taken on February 2, 1977 (Figure 5). Discrimination and classification of the bay ice into categories based on reflectance levels or spectral signatures of the ice was accomplished by using Landsat digital tapes processed on the General Electric IMAGE 100 Multispectral Analysis System. Using these spectral signatures in conjunction with a limited amount of ground truth data, the thickness of the ice could be inferred and the area percentages of the ice thickness categories could be estimated.

Although little work has been done in attempting to determine ice thickness from satellite imagery, the use of reflectance levels derived from satellite picture elements in the visible and near infrared wavelengths to determine snow depths has been explored by McGinnis et al. (1975) and others. Although some success has been achieved, in general, it is difficult to determine a snow depth of greater than about 6 inches (15 centimeters) from satellite data using wavelengths between .4-1.1 μ. This is because snow has such a high albedo that the signatures become saturated and an accurate gradation of snow depths is not possible. However, since the reflectance levels for ice are not as high as snow, because ice is more dense than snow and scatters radiation less effectively, the ice signatures are not saturated and, thus, more spectral information can be acquired. This additional spectral information may allow an assessment of ice thickness to be made. Variations in the reflectance levels of ice, however, may be a result not only of differences in ice thickness but also ice type and quality. In this case though, it seems that the reflectance levels of ice in the Chesapeake Bay are closely related to differences in ice thickness.

Using a unique program of the IMAGE 100 system called "feature space projection," five different classes of ice were distinguished. In feature space projection, a two axis display showing the relative distribution of the reflectance levels of Landsat picture elements (pixels) is presented on a graphic terminal (Figure 10). The two axes selected for the analysis were the nearly uncorrelated Landsat bands 5 and 7. Pixels in band 5 (.5-.6 μ) have a dynamic range of 127 values, and pixels in band 7 (.8-1.1 μ) have a dynamic range of 64 values. The density of data displayed illustrates the relative population of pixels in the scene having a certain reflectance level in the two Landsat bands. This display allows the user to define rectangles (partitions) isolating concentrations or clusters in the projection. A category may be designated by a single partition or the user may choose to define the category as the sum of several partitions. The rectangles in Figure 10 delineate the partitions of the feature space projection that conform to certain ice categories. The partition boundaries were selected so that a meaningful classification for the bay ice was obtained. The feature space projection method of classification was used rather than the

Figure 9
Landsat Image of February 26, 1977

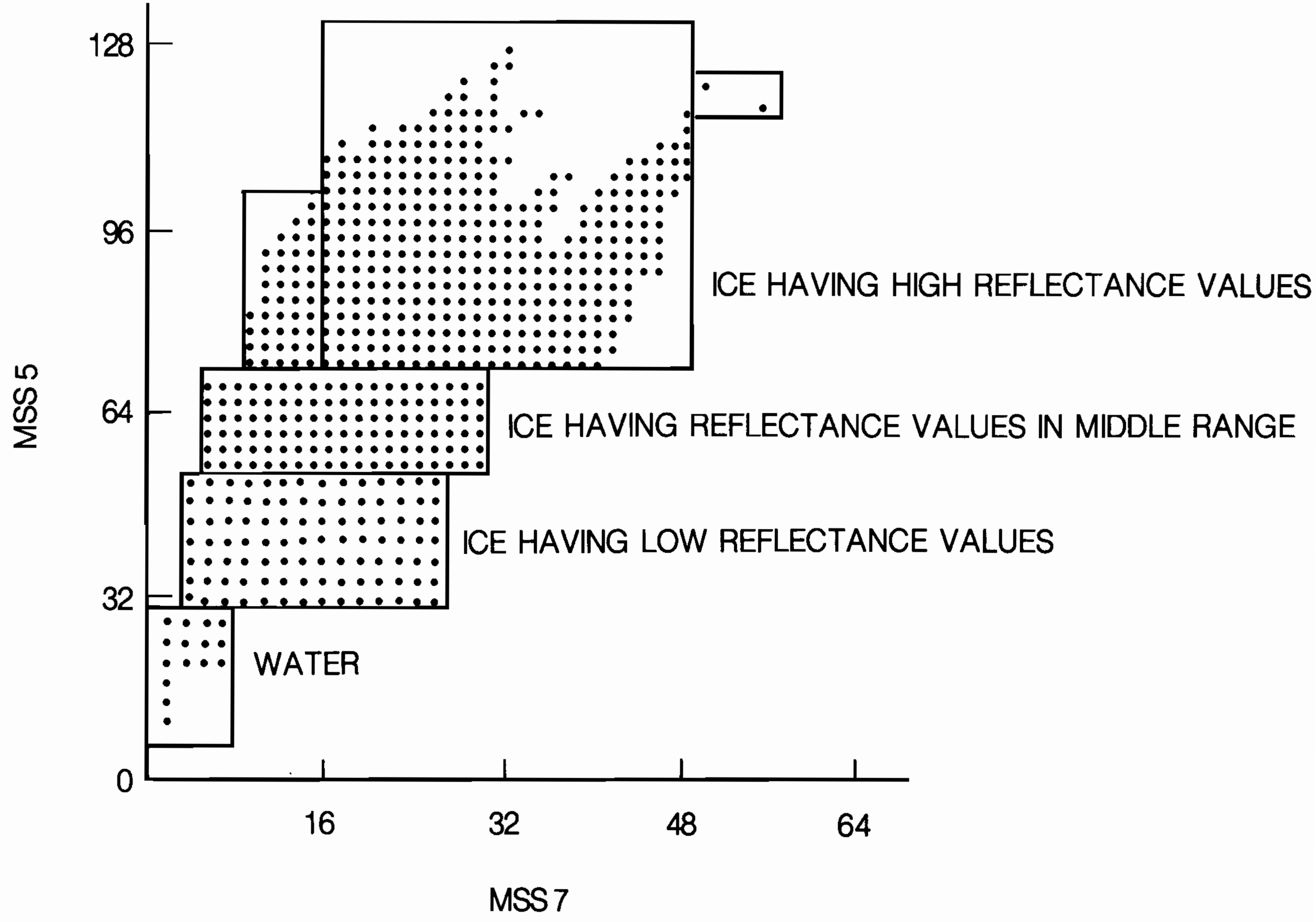

Figure 10
Feature Space Projection of Ice from the February 2, 1977 Landsat Image

more conventional training site method, because it is faster, more versatile and it does not require a pure, homogeneous site in order to obtain an accurate classification, as does the training site method. For a more detailed explanation of feature space projection see the IMAGE 100 Users Manual.

Feature space projection was performed on a representative set of subscenes in the Chesapeake Bay, on the February 2 image. The classification of as large an area as the Chesapeake Bay requires that the user select several areas to be sure that all of the various spectral signatures of ice are included in the classification. Four subscenes, each approximately 9 x 9 miles (15 x 15 kilometers), were displayed simultaneously on the IMAGE 100 cathode ray tube. They include the area from the mouth of the Patapsco River to the Chesapeake Bay Bridge, the upper bay from the mouth of the Susquehanna River to Turkey Point, the open bay near the mouth of the Choptank River, and the mouth of the Potomac River (refer to Figure 1). The spectral signatures or reflectances recorded in these areas were used to classify all of the ice in the Chesapeake Bay on the February 2 image. The resulting classified digital data of this image is shown in Figure 11.

Once the ice was classified into categories based on spectral signatures then ice thicknesses were determined with the assistance of the Maryland State Department of Natural Resources, since they periodically measured the ice during January and February. Ice thickness measurements obtained from the Maryland State Department of Natural Resources corresponded to the ice categories derived from the Landsat digital classification. The ice categories were then assigned thickness values based on the Department of Natural Resources measurements. This Landsat classification process allows the extrapolation of ice thicknesses to be extended over the entire bay even though the in-situ measurements were limited. The resulting ice thickness data are shown in Table 1. Area measurements of the ice thickness categories were calculated using the electronic planimeter program available on the IMAGE 100 System. Approximate area percentages of the ice categories for the Chesapeake Bay and its tributary system as observed on the February 2 image, Landsat scene 2742-14534, are also shown in Table 1.

TABLE 1

	Ice Thickness		% of Bay Area as observed on Landsat scene 2742-14534
	Open Water		35
	Less than 4"	(< 10cm)	18
	4-8"	(10-20cm)	14
	6-10"	(15-25cm)	12
	10-24"	(25-61cm)	20
	More than 24"	(> 61cm)	1

CONCLUSIONS

Landsat scenes taken during December, 1976 and January and February of 1977 were used to monitor, map, and measure the ice conditions of the Chesapeake Bay. Photointerpretive analysis was used to map and monitor the ice cover extent and to distinguish between different types of ice. Classification of the bay ice into categories based on spectral signatures of the ice was accomplished using the General Electric IMAGE 100 Multispectral Analysis System. Using these spectral signatures in conjunction with a limited amount of ground truth data, the thickness of the ice was inferred and the area percentages of the ice thickness categories were estimated.

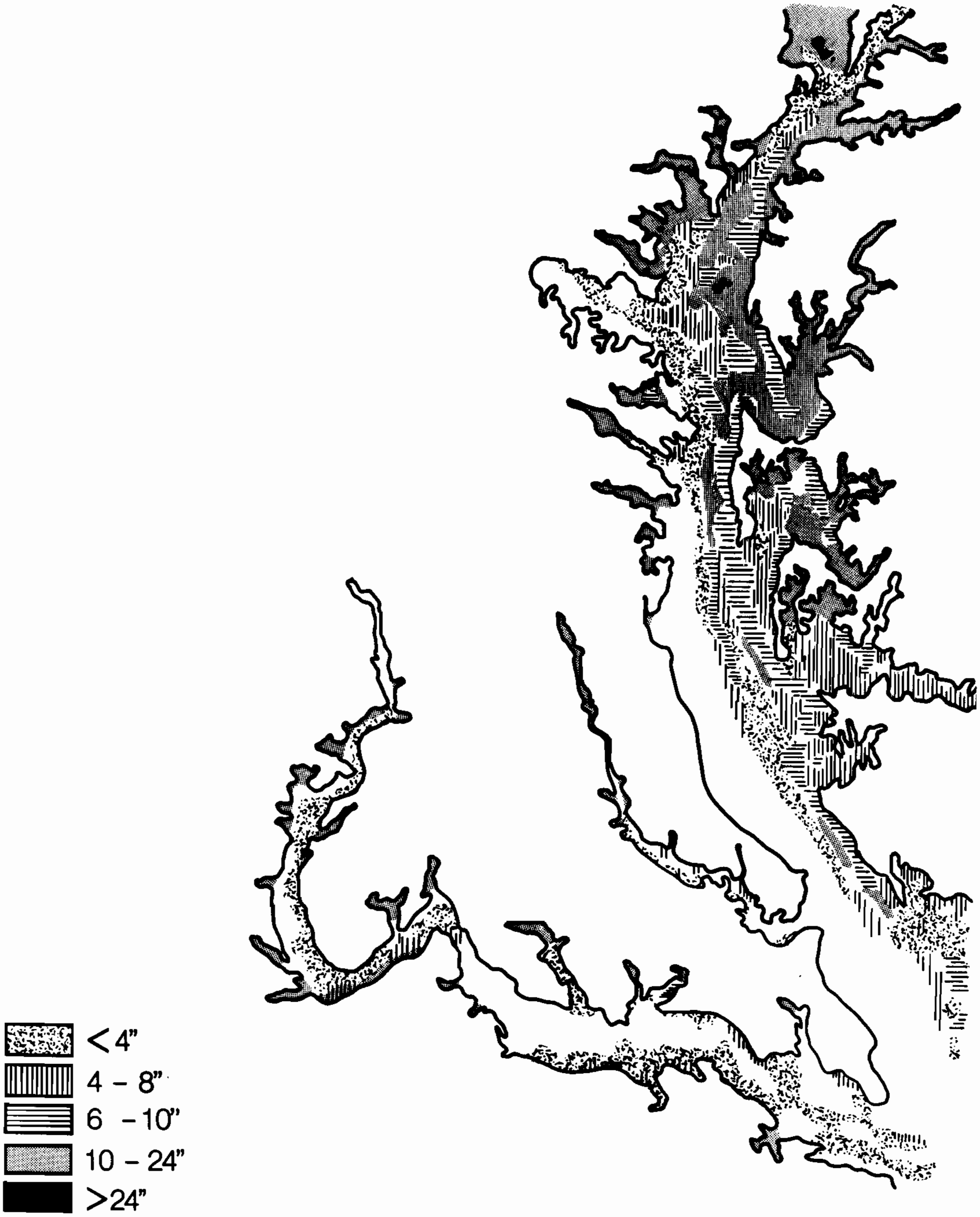

Figure 11
Landsat Map of February 2, 1977 Showing Classified Ice Data

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