Landsat Determined Geographic Change

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ABSTRACT: Geomorphic changes in the Yukon River Delta occurring over a thirty-five year span have been detected through comparison of a recent Landsat image with earlier maps compiled from aerial photography. Island formation or growth and channel migration were found to have taken place with a calculated location precision of around 200 m. Geographic control of the Landsat image was established through digitization of surveyed control points used for control of aerial photography for mapping. Tide stage considerations were found to be useful in these low-lying areas, even though the astronomical tide range here is relatively small.

BACKGROUND

THE RESULTS DESCRIBED HERE were derived from a project initiated because field parties performing research for the Outer Continental Shelf Environmental Assessment Program, using LORAN location determinations in the vicinity of the Yukon River Delta (see Figure 1), found themselves making oceanographic measurements at positions the existing United States Geological Survey (USGS) maps indicated as land. The USGS maps are based on aerial photographs and triangulation surveys performed in the 1950s. Because the Yukon Delta is a hydrologically active area, it was thought that perhaps significant coastline changes had taken place between the time the maps were prepared and the present. An alternative explanation was that the LORAN-determined positions were in error because of coastal radio propagation interference problems. This study was undertaken to determine whether recently acquired Landsat imagery could be used to resolve these two possible explanations for the LORAN position measurements.

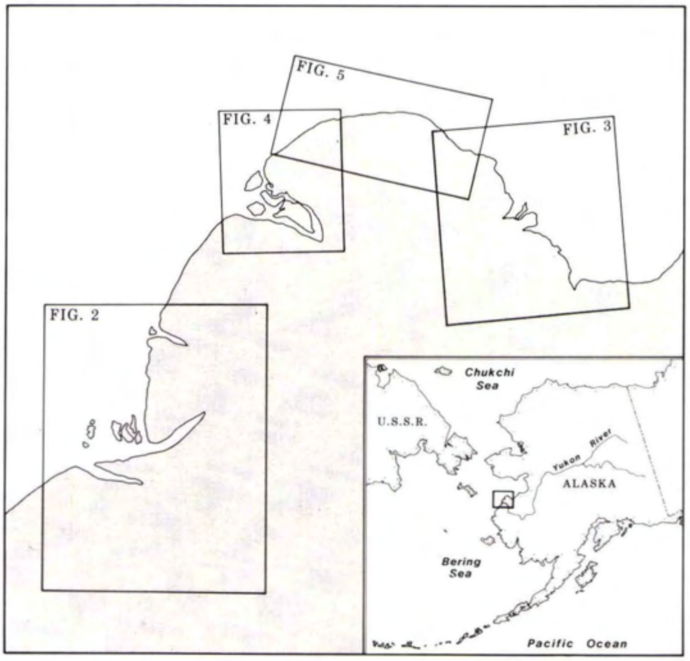

FIG. 1. Shown are (1) the general location of the study area (inset map lower right hand corner), (2) the configuration of the land/water boundary of the study area, and (3) the locations of the areas chosen for intensive study shown in detail on subsequent figures.

APPROACH

The existing maps of the Yukon Delta were prepared through the use of aerial photographs with surveyed triangulation points for geographic control for transfer of information from photographs to map sheets. However, there were apparently considerably fewer control points than photographs. Thus, between triangulation points, it would appear that geographic control was based on continuity established between adjacent photographs. In general, mapped geographic data are placed onto a map projection which represents a particular geometric relationship between locations on the spherical earth and the flat map sheet. The projection generally used by USGS is the Universal Transverse Mercator projection. In this projection meridians are very nearly straight lines, while lines of equal latitude are slightly curved. Thus, latitudes and longitudes are not arranged in a rectangular array.

In order to compare the map and image, both must be transformed to the same projection at the same scale. The most logical way to do this is to first transform data from both formats into a digital base in terms of latitude and longitude, and then display both data sets in any projection and scale desired.

The existing Universal Transverse Mercator projection map of the study area was digitized using a digitizing table. A program was required to transform between the curvilinear latitude-longitude coordinates of the map to the rectilinear coordinate system of the digitizing table. The transforming program used in this type of process must be specific not only to the projection of the map, but also to the portion of the projection represented.

A Landsat image can also be thought of as a map projection. However, it is not, strictly speaking, a projection, and furthermore, Landsat images contain small distortions arising from a number of sources. As a result, a uniformly systematic transformation between locations on the image and their positions in terms of latitude and longitude is not possible. In our case a six-parameter least-squares fit was used to transform from what has been called "space-oblique" to geographic coordinates. For this study, it was determined that the most economical approach was to digitize the coastline from the Landsat image manually rather than attempt to transform the entire image. Using the least-squares transformation, each point digitized from the image can be referenced in terms of latitude and longitude and, following that, be plotted according to any desired map projection and scale.

There is an additional detail in this latter process which should be discussed and may be unique to our approach: establishment of geographic control for data taken from the Landsat image. A commonly used technique is to locate identifiable geographic features on the image and determine their latitude and longitude from a map. These features and their locations are then used to determine the transformation between image points

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and their geographic position. The problem with this is the following: the only locations on a map that can be guaranteed to be accurately located are the surveyed triangulation points. All other locations were determined through some interpolation technique and are thus subject to some error--particularly at locations far removed from control points. Furthermore, if one is to determine the geographic location of a feature on a map, it is necessary to scale the location off the map—another potential source of error. Thus, locations used as image control points which are not original map control points use doubly interpolated values: once when the location was transferred from aerial photographs to the map sheet, and again when the map sheet was scaled for the latitude and longitude of the location.

Triangulation points are usually on hill tops or exposed areas with good visibility (so that they can be seen from other triangulation points). Inspection of our Landsat imagery showed that many of these triangulation points, even in the low-lying and generally tundra covered Yukon Delta region, could be identified in terms of general location relative to nearby lakes and river channels, and more precisely by light toned areas on the color-infrared images associated with drier, well-drained hill top locations. Thus, we were able to digitize the Landsat image locations of the triangulation points themselves, and use their precise locations as determined by survey techniques.

METHODS

Landsat image 4108521393 of the Yukon River Delta area had been obtained on 5 July 1985. This image was acquired at Fairbanks by the University of Alaska, Landsat "Quick-Look" system and was recorded photographically by a MDA FIRE laser beam recorder at 1:1,000,000 scale. The portion of the image to be digitized was enlarged from that scale to approximately 1:250,000 scale by means of a professional photographic enlarger. The coastline is indistinct in this region because of shallow waters offshore and wet conditions onshore. It is difficult to trace such an indistinct boundary with the digitizing cursor. Therefore, the best visual estimate of the major land/water boundaries was traced with ink directly on the image with a line thickness of approximately one Landsat pixel width, thus producing an "idealized" coast.

The digitizer used had the ability to sample at a density of 100 points per inch. However, this sampling rate, applied to Landsat imagery at the enlarged scale utilized here, simply overfills the computer memory unnecessarily. A sampling rate was chosen that oversampled Landsat pixels at a rate of three to one--thereby not introducing intolerable errors due to sampling density, yet remaining economical in terms of computer memory.

Although a few triangulation points are shown on 1:250,000-scale maps, many more are found on the 1:63,360-scale series. Furthermore, the latter scale maps contain many geographic details which enable one to more precisely locate the triangulation point on the Landsat image. After carefully locating the control points on the image, the digitizer was used to provide the computer with the relative positions of these control points for computation of the polynomial relationship between image locations and their geographic coordinates. The digitizer was then used to convert coastlines traced on the Landsat image to a digital data base of latitude/longitude locations.

The digital data base representing mapped shorelines was compiled by digitizing shorelines from the 1:250,000-scale maps of the study area. Control was established through use of the Universal Transverse Mercator (UTM) coordinates printed around the boundaries of the map. A computer program calculated latitude/longitude locations for each digitized point using the UTM coordinates. By this means both shoreline data sets were converted to tables of points referenced in terms of latitude and longitude. It should be emphasized that this methodology allows absolute rather than relative comparison of locations on map and image.

RESULTS

The two data sets were printed at 1:250,000-scale, together, but with different colors. The differences shown were so small that it would be pointless to reproduce the resulting map here at page size. Figures 2, 3, and 4 show the subregions identified on Figure 1 where the differences between the map and image were considered sufficiently significant to warrant analysis and discussion. In these figures the map land/water boundaries are shown as dotted lines and the image land/water boundaries as solid lines.

The first of these, Figure 2, shows the vicinity of the Yukon Delta's most southerly tributary, Kwikluak Pass. Here the most conspicuous changes appear to be growth of the islands at the channel mouth. The 1:63,360-scale 1950 map shows these islands surrounded by extensive mud flats. The apparent change in size suggests that the islands have expanded through materials accreting upon these adjacent mud flats. It was thought that perhaps this interpretation resulted from misjudgment of the correct location of the shoreline. However, Landsat color infrared imagery clearly shows these areas with a red cast--indicating healthy vegetation. Thus, there is little doubt that these areas are now above sea level a good deal of the time. In addition, a high altitude aerial photograph obtained of the area in 1980 shows the islands with a geometric configuration similar to that digitized from the Landsat image (although there is no control and, therefore, precise scale and location determination is not possible).

Also shown in Figure 2 are apparent changes in the location of the shores of Kwikluak Pass. The north bank appears to have

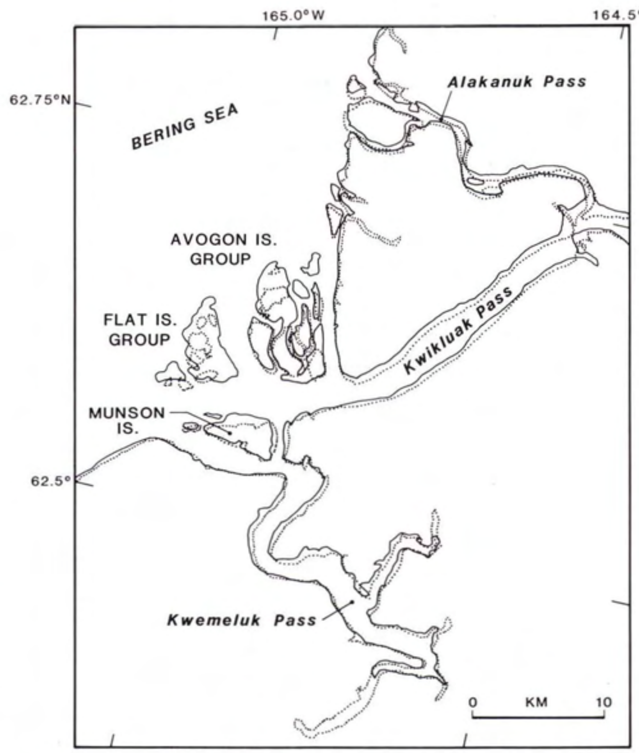

FIG. 2. Shown are shorelines as determined from 1950 series USGS maps (dotted line) and shorelines as determined from 1985 Landsat image (solid line) in the vicinity of Kwikluak Pass - the southwestern distributary - of the Yukon River.

eroded, while the south bank appears to have been built up. As discussed later, our criterion for credible changes was three picture elements. The apparent movement of the north bank satisfied this criterion, while the apparent south bank displacement did not. Thus, the evidence indicates that this tributary is widening as a result of erosion of the north bank, and that perhaps the south bank is filling in somewhat.

Figure 3 shows the vicinity of the Okwega and Apoon passes. There appears to have been major erosion at both the Okwega and Apoon mouths. Close comparison of the image with the 1:63,360-scale topographic maps shows no coastal features on the image that can be identified uniquely with features on the topographic maps. Thus, all the indicated changes apparently occurred, including the widening of the channel between the delta mainland and the large island in the left hand corner of this figure.

Figure 4 shows the vicinity of Kawanak Pass. Here, changes measurable by this technique appear to be small to marginal. Nunaktuk Island appears to be eroding on its landward side and aggrading on the seaward side, while the seaward-facing peninsula on the largest island (not named on USGS maps) in Kawanak Pass has been reduced in size.

Figure 5 shows the broad curved delta region between the Kawanak and Okwega entrances. Two distinct and concentric boundaries can be seen here on all summertime satellite images. The landward boundary is far inshore from the shoreline on the topographic map, while the seaward boundary is somewhat offshore from the topographic map's shoreline. The crescent-shaped area within this region appears to be vegetated but very wet. These results seem to indicate that the delta is aggrading here.

DISCUSSION

Proper evaluation of the significance of these results requires understanding of the limits of resolution of the digitization process. These limits arise in the following ways:

(1) The pixel size of the Landsat image determines the ultimate limit of control point precision. The Landsat pixel footprint is 60 by 80 metres. On the 1:250,000-scale Landsat enlargement, the pixel dimension is roughly 0.4mm. A unit of this size can easily be located on the image. However, this should not be taken as an implication that a pixel containing a triangulation point can necessarily be uniquely identified. The point we wish to make here is that, in principle, the pixel can be resolved by the digitizing cursor and, therefore, the process of digitization should not be a source of imprecision.

(2) All data are converted to geographic coordinates by means of a least-squares polynomial fit of surveyed latitudes and longitudes to plotter x and y values. Clearly, no image data converted to geographic coordinates through the plotter can be expected to possess greater accuracy than the precision of this best fit as measured through the fit residuals. Not only does the precision of the fit depend upon accurately locating the triangulation points, but the fit model should contain sufficiently high order terms that the residual values reflect errors in locating triangulation points, not the inability of the model to close.

Triangulation point values were input to the fit model and residual values noted. If the residual value for one or two particular triangulation points was large, the points were re-digitized taking particular care with the location of the bad triangulation points and the model was run again. The new re-

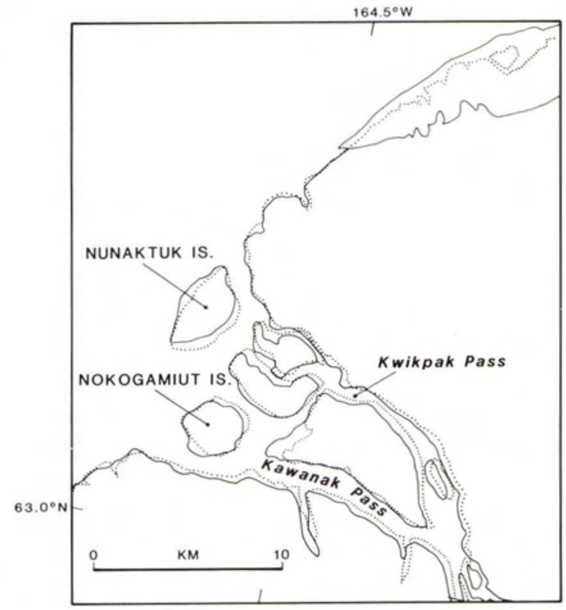

FIG. 4. Shown are shorelines as determined from 1950 series USGS maps (dotted line) and shorelines as determined from 1985 Landsat image (solid line) in the vicinity of Kawanak Pass - the northwestern distributary - of the Yukon River.

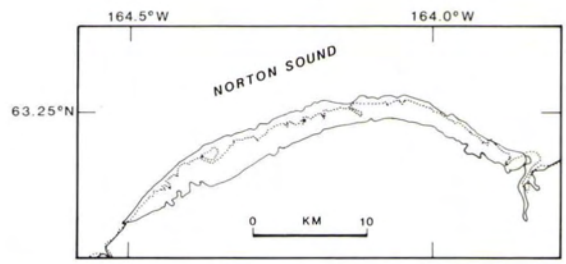

FIG. 5. Shown are the shorelines as determined from 1950 series USGS maps (dotted line) and the boundaries of a wet zone as determined from 1985 Landsat image. The shoreline of the wet zone is close to (but offshore from) the 1950 shoreline. The area appears to be aggrading.

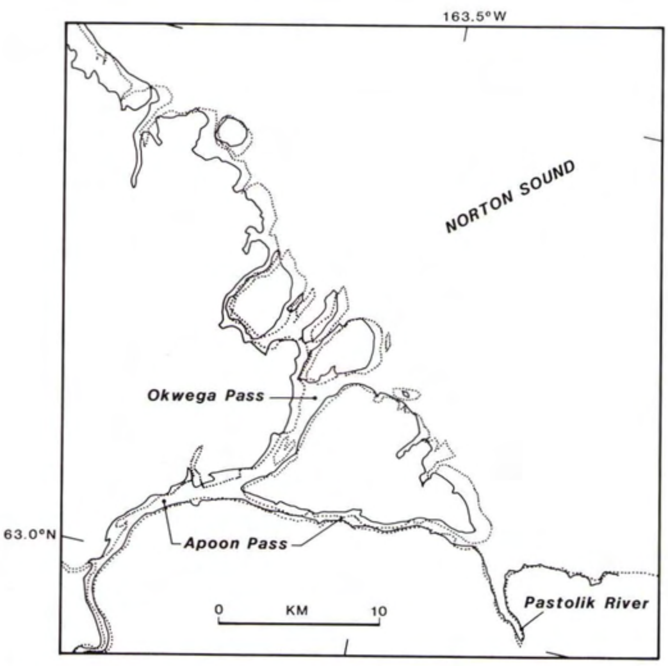

FIG. 3. Shown are shorelines as determined from 1950 series USGS maps (dotted line) and shorelines as determined from 1985 Landsat image (solid line) in the vicinity of Okwega and Apoon passes - the northeastern distributaries - of the Yukon River.

sidual was evaluated and, if necessary, the triangulation points were re-digitized. This iterative process was performed until the residuals for the triangulation points were at the largest on the order of 200 metres--about 2 1/2 pixel dimensions. By this method, the most likely "locations" of the triangulation points were found.

The RMS residual values obtained by this method were usually somewhat less than 200 metres. However, 200 metres was taken as the largest acceptable residual. On the basis of this, it was assumed that no data could be transferred from the Landsat image with greater accuracy than this value. However, as will be described in the following paragraphs, there were other sources of uncertainty of slightly greater magnitude.

(3) The enlarged Landsat image was so large that it required two computer data files. Control for each file was established using the same set of control points. The variation of the calculated locations of the control points arising from points digitized with each file influences how well the portions of the digitized Landsat image will match at file boundaries.

This variation was determined through the best fit latitude and longitude values calculated for the eight control points obtained each time a new portion of the image was digitized. The variation average was of the order of 100 metres, while the maximum variation was 200 metres.

(4) The uncertainty resulting from the ability to reproducibly trace out the idealized coastline during digitization affects the quality of the digitized data. While the ultimate reliability of this process cannot be evaluated, the repeatability of the process was measured.

As a test, a portion of the idealized coast was digitized twice. When the resulting plotted coastlines were placed over one another at 1:250,000 scale, the agreement varied from virtually identical (for a line width of 0.4mm) to a variation of approximately three line widths or 1.2mm. This 1.2mm variation is equivalent to approximately 240 metres, or three Landsat pixel dimensions. This is equivalent to the maximum variability of the digitized control point locations. Thus, the largest errors arising from the coastal boundary digitization process were somewhat larger than those arising from the best fit to the control point locations.

(5) The number of points per inch recorded by the digitizer and reproduced by the printer affect the precision of the final product.

The digitizer records between 100 and 140 points to the inch, depending on the speed of the digitization. This means that each pixel, or 0.4mm of image (at 1:250,000 scale), will be registered by two or three points. This oversampling is required to assure sampling precision is greater than the data precision resulting from the Landsat pixel size.

(6) Additional factors such as the phase of the tide at various points on the Yukon Delta when it was imaged, and the difficulty of determining the water/land interface of the Landsat image, influence interpretation of the final product. These factors are discussed in subsequent sections.

COMMENTS REGARDING PROCEDURES

(1) The digitizer used was sufficiently precise to register individual pixels on a Landsat image enlarged to a scale of 1:250,000. Surprisingly, it was found to be more difficult to identify the pixel containing the control point than to digitize it accurately once it was identified. However, the closeness of the fit suggests this is not as significant a problem as might be imagined.

(2) The iterative method used to locate most likely locations of control points is a bit tedious but (we think) rewarding. Although we did not attempt to achieve an RMS fit closer than 200 metres, it is possible that, using a computer, the set of pixels with least residuals could be found automatically (i.e., the set of pixels, each representing one triangulation point). However, the question of uniqueness would require some attention and, in fact, that was potentially a problem here. Our approach, although certainly less than rigorous, was to assume that some triangulation points, because of their distinctive locations, would be identified reasonably well and, if only a few points were badly located, the residuals for the "good" locations would be small and only the "bad" points would have to be re-located. This seemed to be the case. However, there is always the possibility that a set of digitizer locations had been found with a geometric relationship resulting in a small RMS residual, yet the locations would actually be displaced in some systematic fashion from the triangulation points.

(3) In our case the limiting factor, when digitizing data for comparison purposes, was the ability to accurately locate boundaries being digitized. This corresponded to three Landsat pixels or 240 metres. This is still larger than the accuracy which can be achieved using a best fit to an array of control points. Therefore, comparisons of greater precision than performed here could be made, providing that boundaries could be clearly identified on the Landsat image. In this particular example this was a problem because shorelines in the Yukon Delta region are indistinct due to wet conditions onshore and shallow regions offshore. As described earlier, the approach to this problem was to idealize the land/water boundary by drawing it in ink. However, this only solved the problem in terms of the decision of where to locate the digitizing cursor; the boundary was sufficiently indistinct that it might possibly have been located as much as one or two line widths away. Thus, greater precision may not be achievable in this particular case. Shoreline identification by means of a digital algorithm operating on moisture-sensitive wavelength data (i.e., Landsat bands 3 and 4) could possibly be applied to this problem. However, while in principle one pixel precision would appear to be possible by this method, in practice the actual shoreline location accuracy may be poorer than that.

CONCLUSIONS REGARDING GEOMORPHIC CHANGES

Clearly measurable changes have taken place at Kwikluak Pass and Okwega/Apoon Pass · Kwikluak Pass is shown in Figure 2; Okwega/Apoon Pass is shown in Figure 3. There are numerous areas with lesser changes both on the coastline and in the river system. First among these is the Yukon Delta between 164.0°W and 164.5°W. Other areas are Kawanak Pass and the north bank of the Yukon River. Kawanak Pass is shown in Figure 4. The portion of the Yukon River noted appears in Figure 2.

Kwikluak Pass (Figure 2) includes the pass itself, three island groups, and the most southerly branch of the Yukon River. The most conspicuous changes appear to have occurred on the three island groups; Avogon Island group, Munson Island, and the Flat Island group. All the island groups appear to have enlarged considerably. Inspection of the 1:63,360-scale topographic maps reveals that, in 1950, all the island groups were surrounded by significant mud flats. The enlarged islands on the image appear to reflect the incorporation of portions of these mud flats into these islands.

Landsat imagery may not adequately distinguish between heavily silt-laden water, very shallow water, and land at the shoreline. However, it is worth noting that the Landsat image does not display the extensive mud flats indicated on the 1:63,360-scale topographic maps, but shows them as vegetated areas. Thus, it is a valid assumption that much of the area existing as mud flats 30 years ago has been incorporated into the island systems as they exist today. Aerial photography from July 1980 and a Landsat image from July 1975 confirm this; these show the three island groups as they appear on the digitized Landsat image.

The branch of the Yukon River in Figure 2 appears to have eroded on its north bank and built up its southern bank. Major changes in the Yukon River appear to have taken place at 62.75°N, 164.50°W. The erosion of the north bank satisfies the 3-pixel width criteria necessary to reveal a valid change, but the changes

TABLE 1. TIDE STAGE AT THREE PASSES IN THE YUKON DELTA

	Kwikluak Pass	Kawanak Pass	Apoon Pass
Landsat image (5 July 1985), 2139 GMT	+0.5 ft	+0.5 ft	+3.7 ft
Aerial Photography (23 July 1980), 2030 GMT	+0.5 ft	+0.6 ft	+2.1 ft
Landsat image (22 July 1975), 2136 GMT	+0.1 ft	0.0 ft	+2.4 ft

on the southern bank do not. Thus, we may conclude that the northern bank of the river has eroded and that this branch of the river is widening.

Okwega/Apoon Pass (Figure 3) appears to have undergone major erosion at both the Okwega mouth and the Apoon mouth. The "V" shaped island in Okwega Pass on the topographic map is also on the image, but it was not digitized because the major objective of our study was to identify changes on the coastline. Close comparison of this portion of the image with the 1:63,360-scale topographic maps reveals few small-scale details on the image that could be identified with corresponding details on the topographic maps, although the general pattern remained the same. Thus, all the indicated changes, including the rather significant widening of a channel between the mainland and an island in the upper left hand corner of Figure 3, potentially occurred. A Landsat image from 22 July 1975 shows this shoreline to be much the same as on the topographic map. Aerial photography from July 1980 does not cover the entire Okwega/Apoon Delta, but a frame exists for the island which has apparently separated from the mainland. This frame shows the island as it is represented on the topographic map.

One of the areas where less conspicuous changes have occurred is the Yukon Delta between 164.0°W and 164.5°W (Figure 5). On the image this area appears as a dark band between the open water and the land. The boundaries of the dark band were digitized for comparison with the shoreline from the topographic map. It appears that deposition is occurring in this region. The shoreline on the USGS map of 1950 is just landward of the shoreline of this band. Hence, most of this band was present in 1950 and was identified as land. Furthermore, this land is clearly vegetated on the aerial photography. Thus, deposition occurring here is slow relative to the thirty-five year sampling frequency. Interestingly enough, aerial photographs of this region show a less distinct demarcation than does the Landsat image between the land within the dark band and the land further onshore. Presumably, the near infrared bands of Landsat are responding to wetness even more than does the color infrared photography.

Some identifiable changes may have occurred in Kawanak Pass (Figure 4). There appears to be some evidence that Nunaktuk Island is eroding on its landward side and building up on its seaward side. The largest island in the figure appears to have lost a peninsula on its western side. Inspection of aerial photography reveals that the Landsat image differentiates vegetated land from non-vegetated areas very well at this location. In an effort to understand why this was occurring, a variety of possible reasons were investigated. The most likely explanation seems to be that Okwega/Apoon Pass and Kawanak Pass (to a lesser extent) were at very nearly highest tide conditions at the time the Landsat image was acquired, and, as a result, seawater completely covered the mud flats. Thus, the water/vegetation boundary was distinct.

The tide in Apoon Pass is more or less diurnal, and the diurnal range is 4 feet at the mouth as reported in the United States Coastal Pilot. The tides at the pass entrance are greatly affected by winds which may be sufficiently strong to cause local sea level changes overshadowing the astronomical tides. North and east winds lower water level, and south and southwest winds raise it. A large area to the west of the mouth of Apoon Pass is described by the Coastal Pilot to be entirely an open marsh. It appears that this marsh was covered by water at the time of the Landsat image.

The tide ranges at Kwikluak Pass and Kawanak Pass are 2.3 feet and 2.7 feet, respectively. Tide tables were consulted to determine the tide stage for the 5 July 1985 Landsat image, the 23 July 1980 aerial photography, and for the 22 July 1975 Landsat image. The calculated tide stages are presented in Table 1.

This suggests that a high tide state present at the time of the 1985 Landsat image could account for the appearance of this portion of the Landsat image. It need not imply erosion of the shoreline, resulting in abrupt transition landforms such as bluffs.

Inspection of weather maps for this period reveals that winds were present from the south and west. As described in the Coastal Pilot, these may have amplified the coastal flooding in the Apoon Delta to levels greater than would have been predicted by tide influences alone. The statement in the Coastal Pilot that this delta has extensive marsh land likewise supports tide flooding as the reason for the appearance of this image.

Within the Yukon River System many changes appear to have occurred. Many of these are valid changes. However, as the principle object in digitizing the river system was to indicate the main channel of the Yukon for orientation purposes, many small islands and sloughs (though visible on the image) were not digitized. One should not draw conclusions about changes in the river system without reference to the Landsat image.

This project demonstrates that it is possible to locate surveyed triangulation points on a Landsat image and use them to create a very current map for comparison with older maps to identify recent changes in coastlines. However, one must consider tide states when doing this kind of comparison. We also suggest that, based on this approach, a more rigorous methodology might be developed.

REFERENCES

U.S. Dept. of Commerce, 19XX. *Tide Tables, High and Low Water Predictions, 1975, West Coast of North and South America*, NOAA, Washington, D.C.

———, 1985. *United States Coastal Pilot, Pacific and Arctic Coasts: Cape Spencer to Beaufort Sea.*: #9m, NOAA, Washington, D.C.