R. A. Weismiller
S. J. Kristof
D. K. Scholz
P. E. Anuta
S. A. Momin
Purdue University
West Lafayette, IN 47906

Change Detection in Coastal Zone Environments*

Four techniques were used to analyze Landsat MSS temporal data in order to detect areas of change of the Matagorda Bay region of Texas.

Introduction

Our nation's coastal zones are locales of unending change. Effective inventorying and monitoring of these changes are required for resource management. Conventionally, monitoring of these areas has been accomplished either by local on-site surveys or photo-interpretation of aerial photographs, and change detection has required the manual comparison of various single date analyses. For large area inventories, both local surveys and photo-interpretative techniques require large data collection efforts and are time-consuming and subjective in nature.

Consequently, it would be desirable to develop and implement a computerized change detection procedure suitable for large area inventories.[1] However, before operational monitoring procedures can be established, satisfactory computer-aided change detection techniques must be developed. In order to meet this need, this study was initiated toward developing and evaluating various change detection techniques based upon computer-aided analysis of Landsat multispectral scanner (MSS) data to monitor coastal zone environments.

Study Site

A portion of the Matagorda Bay estuarine system located along the Texas Coast was selected for this study. This area is characterized by a great diversity in geography, resources, climate, waterways, and estuaries similar to the entire coastal zone of Texas. Also, it is subjected to numerous natural hazards such as shoreline erosion, land surface subsidence, stream flooding, hurricane tidal surges, and active surface faulting. Lower elevations of the coastal area are covered with marshes and swamps, and the stand-plains are chiefly of sandy materials. The coastal upland areas consist mainly of clay and mud materials deposited as sediments during the Pleistocene era. Land use within this study site is divided principally among agriculture, rangeland, urban, industry, recreation, and large marsh-covered tracts.[2]

Approach

Data

Landsat MSS data collected on November 27, 1972 and February 25, 1975 were used as the principal data sources for this study. These data were geometrically corrected (i.e., rotated, deskewed, and rescaled)[3], overlaid, and precision-registered to ground control points selected from appropriate U.S. Geological Survey (USGS) 7½ minute topographic quadrangle maps. This procedure produced a multidate eight-channel data set at a scale of 1:24,000 and registered points in the data to their exact ground position. Reference data utilized to support the analysis of the Landsat data included 1970, 1971, and 1975 color and color-infrared aerial photography, Geologic Atlases compiled by the Texas Bureau of Economic Geology, and

* This work was accomplished under the National Aeronautics and Space Administration Contract No. NAS9-14016. Journal Paper No. 6689, Purdue University, Agricultural Experiment Station.

Photogrammetric Engineering and Remote Sensing,
Vol. 43, No. 12, December 1977, pp. 1533-1539.

Spectral Environmental Classification overlays produced by Lockheed Electronics Corporation.

SINGLE DATA ANALYSIS

A non-supervised approach utilizing the maximum likelihood classifier as implemented by LARSYS[4] was used to produce a classification for each date for areas corresponding to individual USGS 7½ minute quadrangle maps. The resultant classifications included informational categories of agriculture, rangeland, grasslands, wooded areas, swamp timber, fresh and brackish marshes, mud and sand flats, beach and beach ridges, residential areas, and open water classes. This initial study demonstrated that digital analysis of Landsat MSS data could be used to inventory the coastal environment effectively.[5]

ABSTRACT: *Development of satisfactory techniques for detecting change in coastal zone environments is required before operational monitoring procedures can be established. In an effort to meet this need, a study was directed toward developing and evaluating different types of change detection techniques, based upon computer-aided analysis of Landsat multispectral scanner (MSS) data, to monitor these environments.*

The Matagorda Bay estuarine system along the Texas coast was selected as the study area. Land use within this area is divided principally among agriculture, rangeland, urban, industry, recreation, and large marsh-covered tracts.

Four change detection techniques were designed and implemented for evaluation: (1) post-classification comparison change detection, (2) delta data change detection, (3) spectral/temporal change classification, and (4) layered spectral/temporal change classification. Each of the four techniques was used to analyze a Landsat MSS temporal data set in order to detect areas of change of the Matagorda Bay region.

The post-classification comparison technique reliably identified areas of change and was used as the standard for qualitatively evaluating the other three techniques. The layered spectral/temporal change classification and the delta data change detection results generally agreed with the post-classification comparison technique results; however, many small areas of change were not identified. Major discrepancies existed between the post-classification comparison and spectral/temporal change detection results.

CHANGE DETECTION ANALYSIS

Four specific test sites were selected within the Matagorda Bay estuarine system for implementation and evaluation of change detection techniques. These were the areas included in the Austwell, Port Lavaca-E, Port O'Connor, and Pass Cavallo-SW USGS 7½ minute topographic quadrangles.

Four techniques for detecting change were designed and implemented for evaluation[6]: (1) post-classification comparison, (2) delta data change detection, (3) spectral/temporal change classification, and (4) layered spectral/temporal change classification. All four techniques require registration of the data prior to analysis. A brief description of each technique follows.

POST-CLASSIFICATION COMPARISON CHANGE DETECTION[7]

Post-classification change detection is based on the comparison of independently produced spectral classifications. The comparator is simply a processor that "compares" two standard LARSYS classifications by utilizing class pairs specified by the analyst and generates a results tape indicating areas of change. Thus, the change classes derived are defined by the analysts rather than being identified spectrally by using pattern recognition techniques. By properly coding the classification results for time t_1 and t_2, the analyst can produce change maps which show a complete matrix of changes. In addition, selective grouping of classification results allows the analyst to observe any subset of changes which may be of interest.

DELTA DATA CHANGE DETECTION[8]

The delta data change detection technique is based upon the classification of a multispectral difference data set. A delta (subtraction) transformation combines the n-channel multispectral data sets obtained at different times and produces a multispectral delta data set having n-channels. Since the LARSYS system assumes that all data samples used are non-negative, a bias is added to each difference so that the resulting delta data are non-negative. Thus, the complete transformation is simply

$$\delta X^k_{ij} = x^k_{ij}(t_2) - X^k_{ij}(t_1) + b_k$$

where X^k_{ij} = Multispectral value for channel k; $i,j = 1, \ldots, N$ assuming an $N \times N$ image

i = Row
j = Column
k = Channel
b_k = Bias for Channel k
t_1 = First date
t_2 = Second date

This approach assumes that specific changes from one time to another will produce a non-negative result which can be detected either by examining the images directly or by first classifying the delta data, then examining the results displayed in image form. The classification method is similar to that for classification of ordinary multispectral data; however, it emphasizes classification of multispectral change instead of changes in multispectral classification.

SPECTRAL/TEMPORAL CHANGE CLASSIFICATION

The spectral/temporal change classification technique is based upon a single analysis of a multidate data set to identify change. In a two-date Landsat data set, eight channels of data would be analyzed by using standard pattern recognition techniques. By using data sets collected under similar conditions at nearly the same day of the year but from different years, one would expect that classes where change is occurring would have statistics significantly different from where change had not occurred and could be so identified.

LAYERED SPECTRAL/TEMPORAL APPROACH[9-11]

The layered or decision-tree classifier is essentially a maximum-likelihood classifier using multi-stage decision logic. It is characterized by the fact that an unknown sample can be classified into a given class by using one or more decision functions and channels in a successive manner. This classification strategy can be most easily illustrated by a tree diagram consisting of a root node, a number of non-terminal nodes or decision stages (layers), and terminal nodes (i.e., the decision-making procedure terminates with the unknown sample being assigned to the class at a terminal node). A non-terminal node is an intermediate decision, its immediate descendent nodes representing the possible outcomes of that decision.

To specify a decision tree uniquely, two sets of information are necessary: (1) how the terminal and non-terminal nodes are linked and (2) the decision functions and channels of all the non-terminal nodes. The decision tree can be constructed manually or by an automatic optimized logic tree-design procedure. For the purpose of change detection a hybrid of these two procedures was utilized. Decision trees for each of the two dates, t_1 and t_2, were obtained automatically and then manually linked, introducing within the tree a logic for detecting the desired changes.

RESULTS

A quantitative evaluation of the change detection procedures developed would require the collection of a comprehensive set of reference data (ground observations and/or aerial photography) coincident with the Landsat overpass. However, coincident reference data were not available for this particular project (i.e., reference data for the 1972 Landsat data consisted of aerial photography collected in 1970 and 1971). Thus, only a qualitative evaluation of the results of the change detection techniques could be accomplished.

Since the comparison of results from two single date classifications is the basis of the post-classification comparison change detection procedure, the results of this technique were used as the standard for evaluating the results from the other three procedures. Correlation of the unsupervised spectral classes derived from single date classifications with informational classes was accomplished by:

(1) associating the spectral classifications with aerial photography when appropriate;
(2) utilizing a ratio, $A = V/IR$, calculated for each spectral class, where V is the relative intensity of the mean spectral values of the visible wavelengths $\{(0.5 \text{ to } 0.6\mu\text{m}) + (0.6 \text{ to } 0.7\mu\text{m})\}$ and IR is the relative intensity of the mean spectral values of the reflective infrared wavelengths $\{(0.7 \text{ to } 0.8\mu\text{m}) + (0.8 \text{ to } 1.1\mu\text{m})\}$; and

TABLE 1. CLASS PAIRS DEFINED FOR THE POST-CLASSIFICATION COMPARISON CHANGE DETECTION TECHNIQUE FOR THE PORT O'CONNOR QUADRANGLE.

Class No.	Informational Classes Nov. 72 — Feb 75
1	urban—urban
2	woody/herbaceous—woody/herbaceous
3	spoil—spoil
4	submerged—submerged
5	water—water
* 6	any non-burn—burn
* 7	any non-spoil—spoil
* 8	any non-woody—woody
* 9	any non-water—water
*10	any non-submerged—submerged
*11	any non-urban—urban
* change classes	

(3) by summing the relative intensity values ("summed response") of all four bands to determine the magnitude of relative spectral responses for each spectral class.

By observing the aerial photography, the ratio A, and the summed response, the analyst delineated major vegetation and land-use categories within the coastal zone area. Results from the Port O'Connor quadrangle, which are representative of the four test areas, are presented for illustrative purposes.

By utilizing the post-classification comparison technique, the November 1972 and February 1975 dates for the Port O'Connor test site were classified into 25 and 23 spectral classes, respectively. These classes were grouped into six ecological categories: (1) urban, (2) woody/herbaceous vegetation, (3) submerged vegetation and tidal flats, (4) spoil areas, (5) water, and (6) burned areas. The logic comparator was constructed in order to identify the class pairs listed in Table 1. The map produced by this comparison (Figure 1) illustrates the areas of change.

Cluster analysis of the delta data set produced 13 delta spectral classes representing seven identifiable informational classes (Table 2). These information classes were not in a 1:1 correspondence with the post classification comparison classes but rather were dispersed over a number of the classes. However, visual inspection of the delta data change results map showed a good general agreement between the post-classification comparison and delta data change results in that the no-change water/land interfaces and the delineation of burn areas were in close agreement. Pixels classified into the mixed and urban change classes were widely dispersed through the land and marsh areas. This situation may be related to the inherent difficulty of using present Landsat resolution and wavelength bands to discriminate reliably among certain surface features and not to the change detection procedure.

In order to evaluate the spectral/temporal approach for detecting change, three areas from the eight-channel data set were clustered to identify potential change classes. These included the agricultural region, intercoastal waterway, and the barrier island, areas where change was expected to be occurring. Statistics developed during clustering were used to identify potential change classes by using the following empirically-derived criteria:

> a change class was probable if the ratio ($A = V/IR$) for each of the two dates differed by more than 0.30 and the summed response differed by more than 25.0.

The 52 spectral classes that were identified resulted in five information classes (Table 3), four of which represented change.

Comparison of the results of the spectral/temporal approach to the post-classification comparison technique indicated major disagreement. Pixels classified into the woody to woody class by the post-classification comparison technique were classified as vegetation to soil, and soil to vegetation change classes (Table 3) by the spectral/temporal change detection technique. Similarly, the pixels classified into the submerged-submerged, any non-submerged-submerged, and water-water classes were classified as a water to soil change class. Only the burn change class agreed well with the post-classification comparison change results.

Detection of change using the layered spectral/temporal approach involved developing a layered decision tree based upon

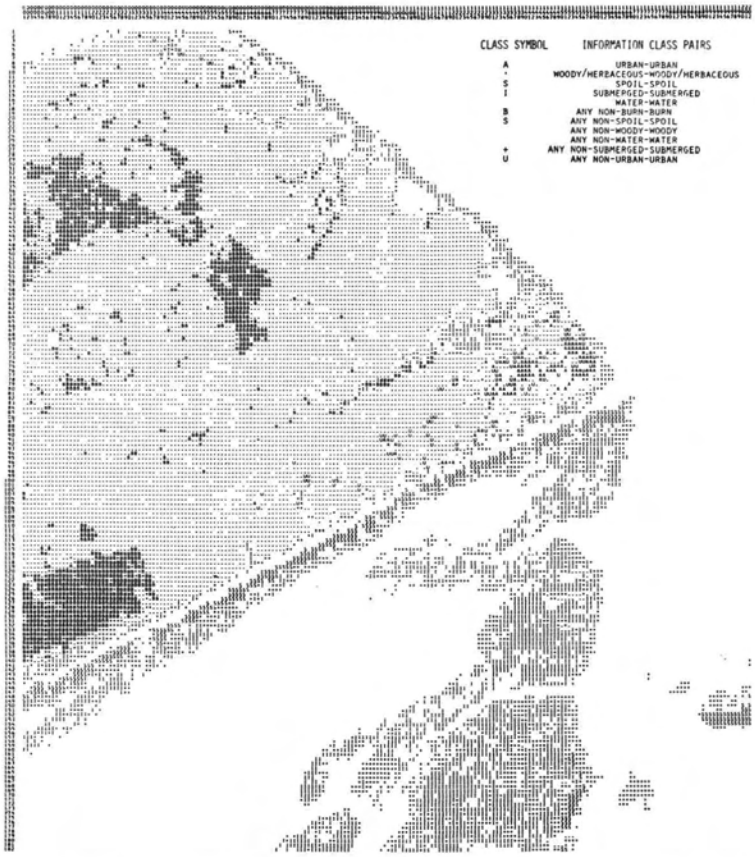

FIG. 1. Results of the post-classification comparison change detection technique for the Port O'Connor quadrangle.

TABLE 2. CLASSES DELINEATED BY DELTA DATA CHANGE DETECTION METHOD AND THEIR CORRESPONDING POST-CLASSIFICATION COMPARISON INFORMATIONAL CLASSES FOR THE PORT O'CONNOR QUADRANGLE.

Class No.	Informational Classes
* 1	any non-spoil to spoil
* 2	any non-spoil to spoil
* 3	mixed and any non-submerged to submerged
* 4	mixed and any non-urban to urban
* 5	woody to woody and any non-submerged to submerged and any non-urban to urban
6	woody to woody
7	woody to woody and water to water
8	woody to woody
9	water to water
10	water to water
11	water to water
*12	any non-burn to burn
13	water to water

* change classes

TABLE 3. CLASSES DELINEATED BY SPECTRAL/TEMPORAL CHANGE DETECTION METHOD FOR PORT O'CONNOR QUADRANGLE.

Class No.	Informational Classes
*1	Vegetation to soil
*2	Soil to vegetation
*3	Vegetation to burn
4	No change land class
*5	Water soil
6	No change water class

* change class

$time_1$ statistics for $time_1$ (November 1972) and attaching a layer decision tree based upon $time_2$ statistics for $time_2$ (February 1975) to the appropriate terminal nodes of $time_1$, producing a "change decision tree." Results of this procedure produced 47 spectral classes and 18 information classes, 10 of which were change classes (Table 4).

Results of the layered spectral/temporal approach were in good agreement with those obtained by the post-classification comparison procedure. Burn areas and the no-change land/water interfaces were very similar. Urban areas were well identified; however, occasionally the dredged spoil areas along the intracoastal waterway were placed into the urban class due to the similarities in spectral response. Some of the confusion between classes was attributed to the trimming of the decision trees (which was necessary to accommodate the tree in computer memory).

TABLE 4. CLASSES DELINEATED BY LAYERED SPECTRAL/TEMPORAL CHANGE DETECTION METHOD FOR THE PORT O'CONNOR QUADRANGLE.

Class No.	Information Classes	
* 1	woody	urban
2	urban	urban
3	woody	woody
* 4	urban	woody
* 5	woody	burn
* 6	urban	burn
7	water	water
* 8	spoil	water
* 9	submerged	water
*10	water	spoil
11	spoil	spoil
*12	submerged	spoil
*13	water	submerged
*14	spoil	submerged
15	submerged	submerged
16	water	confusion
17	spoil	confusion
18	submerged	confusion

* change classes

CONCLUSIONS

In devising a change detection procedure, one property to consider is the relative complexity of the method; all other things being equal, a simpler approach would be more desirable for implementation reasons. However, more complex methods may have more performance potential in the long run. On a scale of increasing complexity, the four methods investigated may be ordered:

(1) *Delta data change detection.* This method requires only a simple subtraction followed by a single classification.
(2) *Post-classification comparison change detection.* This method requires two separate classifications followed by a logical comparison.
(3) *Spectral/temporal change classification.* While this method requires only a single classification, it is a vastly more complex one, requiring more classes and probably more features.
(4) *Layered spectral/temporal change classification.* This method involves not only a complex classification but also *a priori* knowledge of the logical interrelationship of the classes as well.

In a change detection analysis, change detection error can arise from classification errors at date one, date two, or both times. To evaluate precisely the results of various change detection procedures, comprehensive ground information must be available to identify any error condition.

Since adequate reference data for a thorough evaluation was not available, the post-classification comparison change detection results were used as the standard for qualitative evaluation of the results from the other three procedures. Areas of major change were reliably identified by the post-classification comparison technique. This is due in part to the fact that the analysis procedures required are routine and quite well understood.

Evaluation of the other three change detection techniques indicates that:

- The delta data change detection method may be too simple to deal adequately with all the factors involved in detecting change in a natural scene. Too much information may be discarded from the data in the subtraction process whereby only the four band difference data remains from the two sets of original four bands. Images created from the delta data may be quite useful, however, in qualitatively assessing change by image interpretation.
- The spectral/temporal and layered spectral/temporal change detection methods cannot be ruled out at this point

because each appears to have undeveloped potential. The layered spectral/temporal change detection results in particular showed best agreement with the post-classification comparison results. More complex methods usually require more carefully drawn data inputs together with greater user understanding in order to achieve their potential.

References

1. R. L. Lillestrand. June 1972. Techniques for change detection. *IEEE Transactions on Computers*. Vol. C-21, No. 7.
2. Bureau of Economic Geology. 1975. *Environmental Geologic Atlas of the Texas Coastal Zone*. University of Texas, Austin, Texas.
3. Anuta, P. E. 1973. *Geometric correction of ERTS-1 digital MSS data*. Laboratory for Applications of Remote Sensing. Information Note 103073. Purdue University, West Lafayette, Indiana.
4. Phillips, T. L. (editor). June 1973. *LARSYS User's Manual*, Vol. 1, 2. Laboratory for Applications of Remote Sensing. Purdue University, West Lafayette, Indiana.
5. *Final Report*. June 1, 1974-May 31, 1975. NASA Contract NAS9-14016. Laboratory for Applications of Remote Sensing. Purdue University, West Lafayette, Indiana.
6. *Final Report*. June 1, 1975-May 31, 1976. NASA Contract NAS9-14016. Laboratory for Applications of Remote Sensing. Purdue University, West Lafayette, Indiana.
7. Swain, P. H. 1976. *Land use classification and mapping by machine-assisted analysis of Landsat multispectral scanner data*. Laboratory for Applications of Remote Sensing. Information Note 112776. Purdue University, West Lafayette, Indiana.
8. Anuta, P. E. 1973. *An analysis of temporal data for crop species classification and urban change detection*. Laboratory for Applications of Remote Sensing. Information Note 110873. Purdue University, West Lafayette, Indiana.
9. Swain, P. H., C. L. Wu, D. A. Landgrebe, and H. Hauska. 1975. Layered classification techniques for remote sensing applications. *Proceedings* of the Earth Resources Survey Symposium. Houston, Texas.
10. Wu, C. L., D. A. Landgrebe, and P. H. Swain. 1974. *The decision tree approach to classification*. Laboratory for Applications of Remote Sensing. Information Note 090174. Purdue University, West Lafayette, Indiana.
11. Hauska, H., and P. H. Swain. 1975. The decision tree classifier: Design and potential. *Proceedings* Purdue Symposium on Machine Processing of Remotely Sensed Data. Purdue University, West Lafayette, Indiana.