# An Evaluation of the CoastWatch Change Detection Protocol in South Carolina

## Abstract

*The NOAA sponsored CoastWatch Change Analysis Project (C-CAP) will utilize remote sensing technology to monitor changes in coastal wetland habitats and adjacent uplands on a cycle of 1 to 5 years. Two study areas in South Carolina were selected to test various C-CAP change detection protocols using near-anniversary Landsat Thematic Mapper data obtained in 1982 and 1988. Fort Moultrie (dominated by salt and brackish marsh) and Kittredge (40 river miles inland and dominated by bottomland hardwoods and riverine aquatic beds) study areas were used to evaluate a modified C-CAP classification scheme, image classification procedures, change detection algorithm alternatives, and the impact of tidal stage on coastal change detection. The modified CoastWatch Classification Scheme worked well and can be adapted for South Carolina with minor adjustments. Unsupervised "cluster-busting" techniques coupled with "threshold 3 majority filtering" yielded the most accurate individual date classification maps (86.7 to 92.3 percent overall accuracy; Kappa coefficients of 0.85 to 0.90). The best change detection accuracy was obtained when individual classification maps were majority filtered and subjected to "post-classification comparison" change detection (85.2 percent overall accuracy; Kappa coefficient of 0.82). Suggestions are made concerning appropriate change detection matrix logic and the format of change detection legends. The multiple date images selected for coastal change detection should meet stringent tidal stage guidelines which have yet to be fully documented.*

## Introduction

The conterminous United States lost 53 percent of its wetlands to agricultural, residential, and/or commercial land use from the 1780s to 1980s (Dahl, 1990). Oil spills occurring throughout the world continue to devastate coastal wetland (Jensen *et al.*, 1990). More abundant "greenhouse" gases in the atmosphere appear to be increasing the Earth's average temperature (Clarke and Primus, 1990). This may produce a significant rise in global sea level, eventually inundating much of today's coastal wetlands (Kana *et al.*, 1984; Lee *et al.*, 1992). The continued loss of coastal and inland wetlands may lead to the collapse of coastal ecosystems and associated fisheries (Haddad and Ekberg, 1989). Therefore, accurate and timely documentation of wetland gains and losses is critical to their conservation and management. To fulfill this need, the National Oceanic and Atmospheric Administration (NOAA) initiated the CoastWatch Change Analysis Project (C-CAP) which will utilize remote sensing technology to monitor changes in coastal wetland habitats and adjacent uplands on a cycle of 1 to 5 years (Kiraly *et al.*, 1990).

Practical procedures must be established before C-CAP can become an operational program producing a comprehensive, nationally standardized database on coastal habitat change. To achieve this, NOAA sponsored a series of workshops focused on developing regional operational protocols applicable to coastal uplands as well as wetlands (Cross, 1991). The results of these workshops and other interagency meetings are summarized in the revised C-CAP protocol dated 4 December 1992 (Dobson *et al.*, 1992).

This research evaluated several elements of the protocol by applying them to coastal wetland (Fort Moultrie) and inland wetland (Kittredge) study areas in South Carolina (Plate 1). The paper reports on (a) useful multiple date image classification logic, (b) appropriate change detection logic, and (c) preliminary findings concerning the effect of tidal stage when performing coastal change detection using satellite remote sensor data.

## South Carolina CoastWatch Study Areas

### Fort Moultrie, South Carolina

The Fort Moultrie, South Carolina, USGS 7.5-minute quadrangle encompasses several diverse land cover types including built-up beach front, undeveloped beach front, extensive salt and brackish marshes (dominated by smooth cordgrass, *Spartina alterniflora*), mature maritime forest, upland pine, and cultivated land (Plate 1c). Urban features include the towns of Mount Pleasant, Sullivan's Island, and Isle of Palms. The proximity of these communities to the growing metropolitan area of Charleston has led to an increase in the rate of urbanization and infrastructure development in recent years.

### Kittredge, South Carolina

The Kittredge, South Carolina, USGS 7.5-minute quadrangle is located 40 miles inland from Charleston, South Carolina along the Cooper River (Plate 1a). It consists of extensive stands of upland pine, bottomland hardwoods, numerous oxbow lakes, emergent and submergent riverine aquatic beds, and cultivated land. The Cooper River is tidally influenced in this study area. Although several small towns exist within the area, the largest urban feature in the quadrangle is a U.S. Naval Reserve.

## Data Sources and Preprocessing

Six Landsat Thematic Mapper (TM) images were analyzed in this study (Table 1). The 09 November 1982 and 19 Decem-

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Photogrammetric Engineering & Remote Sensing,
Vol. 59, No. 6, June 1993, pp. 1039–1046.

0099-1112/93/5906–1039$03.00/0

TABLE 1. STUDY AREA AND DATA SOURCES.

| Study Areas | Satellite Remote Sensor Digital Data | Aerial Photography | Digital National Wetlands Inventory |
|---|---|---|---|
| Fort Moultrie, S.C. | TM 09 Nov 82 | NHAP 10 Mar 83 | |
| ■ coastal wetland | 04 Mar 87 | (1:58,000) | |
| | 14 Oct 87 | | |
| | 19 Dec 88 | | Yes |
| Kittredge, S.C. | 06 Oct 90 | NAPP 10 Feb 89 | |
| ■ inland wetland | 09 Dec 90 | (1:40,000) | |

TABLE 2. TENTATIVE COASTWATCH CLASSIFICATION SCHEME (KLEMAS *ET AL.*, 1992).

| Class Number | Class Name |
|---|---|
| 1.0/5.0 | Developed/Exposed Land |
| 2.0 | Cultivated Land (agriculture) |
| 3.0 | Herbaceous Grassland |
| 4.1 | Woody Deciduous[1] |
| 4.2 | Woody Evergreen[1] |
| 4.3 | Woody Mixed[1] |
| 7.26 | Estuarine Emergent Wetland |
| 7.34 | Riverine Aquatic Beds[2] |
| 7.98 | Palustrine Forested Wetland |
| 8.0 | Water |
| 8.22 | Estuarine Unconsolidated Bottom |

[1] Merged to "Upland Forest" for display purposes
[2] Found only in the Kittredge study area

ber 1988 TM images were used in the evaluation of the change detection methodologies. All six TM scenes were used to investigate the effect of tidal stage on image classification and change detection.

1:58,000-scale National High Altitude Photography (NHAP) was acquired on 10 March 1983 and more recent 1:40,000-scale National Aerial Photography Program (NAPP) data were obtained on 10 February 1989 (Table 1). The leaf-off, color-infrared photography corresponds closely with the 9 November 1982 and 19 December 1988 TM images and was used to evaluate classification and change detection error.

### Image Rectification

CoastWatch deliverables are, first and foremost, change detection products, the accuracy of which is largely dependent on the precise geometric registration of multi-temporal remote sensor data sets. For this reason, image-to-map and image-to-image rectification error must be minimized.

A subset of the 9 November 1982 TM data containing both the Fort Moultrie and Kittredge study areas was rectified to a Universal Transverse Mercator (UTM) projection using 81 ground control points, nearest-neighbor resampling logic, and a root-mean-square error (RMSE) of less than ± 1.0 pixel (± 30 m). The remaining TM scenes were registered to this geometrically corrected image with an average RMSE of < 0.75 pixel. This "image-to-map" then "image-to-image" procedure allowed many more usable ground control points to be identified in the multiple dates of TM data and greatly improved the multiple date image-to-image registration which is so important when performing change detection.

## Classification of Multiple Dates of Imagery

A portion of the tentative CoastWatch Classification Scheme is summarized in Table 2 (Klemas *et al.*, 1992). The C-CAP protocol requires maps of the coastal zone which identify "from-to" changes in land cover based on this scheme. It is not sufficient to simply identify "change" versus "no-change" pixels in the map. Rather, specific elements of a change detection matrix such as the one shown in Figure 1 must be able to be selected and portrayed in map format, e.g., a pixel changed from water to estuarine emergent wetland. "Post-classification comparison" change detection logic is one of the most appropriate methods for providing such specific cartographic and statistical information (Jensen, 1986). Therefore, this research evaluated methods of mini-

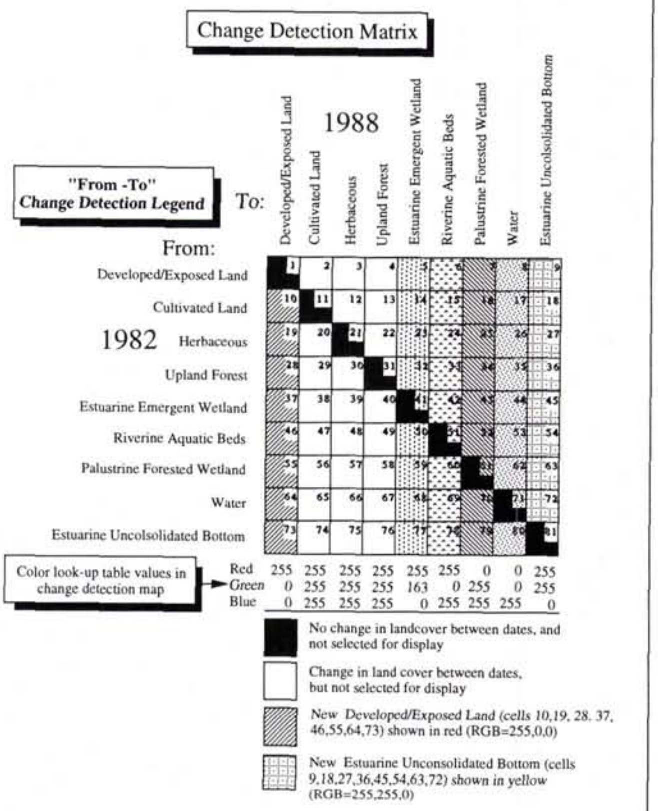

Figure 1. This diagram summarizes the basic elements of a change detection matrix which can be used to select specific "from-to" classes for display in a change detection map. There are *($n^2$ - n)* off-diagonal possible change classes which may be displayed in the change detection map (72 in this example) although some may be highly unlikely. The off-diagonal cells shaded in this diagram were used to produce the Kittredge and Fort Moultrie, South Carolina change maps in Plates 3a and 3b. For example, any pixel in the 1982 map that changed to Developed/Exposed Land in 1988 is red (RGB = 255, 0, 0). Any pixel that changed into Estuarine Emergent Wetland in 1988 is orange (RGB = 245, 163, 0). Individual cells can be color coded in the change map to identify very specific "from - to" changes. A color version of the matrix can be used as a change detection legend.

TABLE 3. CLASSIFICATION ACCURACY OF INDIVIDUAL DATES OF LANDSAT TM DATA USING UNSUPERVISED CLASSIFICATION LOGIC AND VARIOUS POST-CLASSIFICATION MAJORITY FILTERS - FORT MOULTRIE STUDY AREA -

| | 09 Nov 82 Classification | | 19 Dec 88 Classification | |
|---|---|---|---|---|
| Treatment | Kappa | Overall (%) | Kappa | Overall (%) |
| **Original** | **0.803** | **82.91** | **0.822** | **84.78** |
| Filter - Threshold 6 | 0.821 | 84.45 | 0.834 | 85.80 |
| Filter - Threshold 5 | 0.839 | 86.03 | 0.857 | 87.85 |
| Filter - Threshold 4 | 0.843 | 86.45 | 0.881 | 89.39 |
| **Filter - Threshold 3** | **0.846** | **86.67** | **0.881** | **89.90** |
| *'Merged Upland Forest'* | 0.834 | 86.29 | 0.850 | 87.94 |

mizing the errors associated with "post-classification comparison" change detection techniques. The methods included (1) the classification of individual dates of remote sensor data, (2) the application of various post-classification spatial filters to improve classification accuracies, and (3) the use of image differencing techniques to create a "change/no-change" binary mask to exclude areas identified as "unchanged" from further analysis.

The independent classification of the 9 November 1982 and 19 December 1988 TM datasets were produced using iterative, "cluster busting" unsupervised classification logic (Jensen *et al.*, 1987). Five spectral bands were used to classify the 1982 image (bands 1 to 5) and six (bands 1 to 5 and band 7) were used for the 1988 scene.

### Classification of the Fort Moultrie Study Area

The rectified TM data were classified using a maximum-likelihood sequential clustering algorithm to derive 150 spectral clusters which were plotted in two-dimensional (red versus near-infrared) feature space (Jensen, 1986; Hodgson and Plews, 1989). Pixels represented by these clusters were labeled based on (a) their position in feature space, and (b) their spatial location when overlaid onto a color composite of the rectified imagery. Those clusters that could not be readily classified (usually mixed pixels) were used to create a mask to extract the corresponding areas of confusion in the original, rectified remote sensor data. The clustering algorithm was then applied to only the confused pixels to obtain additional clusters. A total of 186 clusters were used to produce final classification of the 9 November 1982 image. This "cluster-busting" procedure was iterated three times to classify the 1988 image into 176 clusters. The final clusters for each date were recoded using the Tentative CoastWatch Classification Scheme (Table 2) to produce the Fort Moultrie classification maps shown in Plates 2c and 2d. The three "woody" forest classes listed in Table 2 were mapped, but were recoded into a single "Upland Forest" class for presentation purposes (and because the specific types of intra-forest change are not that important to C-CAP objectives). All error evaluations presented were based on the disaggregate forest classes.

There were some problems associated with the classification of the Fort Moultrie study area on both dates. First, it was necessary to combine developed and exposed land (bare soil) into a single class. This was primarily due to the high sand content of soils in this area, which results in bare soil having approximately the same reflectance characteristis as urban concrete. Second, cultivated land was not always separable from other classes. The draft protocol suggests that the dates of imagery be selected to optimize the separability of wetland vegetation which, for the southeastern United States, corresponds to the winter and early spring months (Jensen *et al.*, 1987). Therefore, the dates selected were not ideal for classifying cultivated land because the fields may be fallow or overgrown with short grass during this time of the year. Ideally, a third date of imagery acquired in the summer months could be used to identify all cultivated land. When this is not possible, on-screen digitizing of "consistent" cultivated land might be appropriate such as described in Jensen *et al.* (1992).

A method based on the work of Martin (1989) was selected to evaluate the accuracy of the individual thematic maps. Samples from the high resolution NHAP and NAPP color-infrared aerial photographs were selected through the use of a grid overlay and the generation of random i,j coordinates. A class was assigned to each sample based on photointerpretation and a limited amount of field work. These random samples were then located in the digital classification map only if there was a homogeneous 3 by 3 block of pixels at that location. This methodology resulted in 86 "ground reference" samples for the 1982 classification and 84 for the 1988 classification. The application of randomly selected samples for accuracy assessment is a useful methodology as long as the samples are no larger than ten pixels in size (Congalton, 1988). The 1982 classification had an overall accuracy of 82.91 percent (Kappa of 0.803) while the 1988 classification had an overall accuracy of 84.78 percent (Kappa of 0.822). When the three "woody" forest classes were merged into a single "upland forest" class, the classification accuracy of the individual dates increased to 86.29 percent (Kappa of 0.834) in 1982 and 87.94 percent (Kappa of 0.85) in 1988.

The application of post-classification "majority" filtering techniques have increased the accuracy of land-cover mapping in certain instances (Kenk *et al.*, 1988). To test the ability of majority spatial filtering to improve the TM classifications, four 3 by 3 majority filters with different threshold values (ranging from 3 to 6) were applied to both classifications. Accuracy statistics (Kappa coefficient of agreement and overall) for all treatments were calculated and summarized in Table 3. In every case, the accuracy of the 1982 and 1988 classification mproved through the application of majority filtering techniques. The greatest improvements were achieved using a 3 by 3 matrix filter with a majority threshold of 3 (Table 3).

### Classification of the Kittredge Study Area

The original, rectified TM data of the Kittredge study area were classified using the same methodology. The "cluster busting" procedure was iterated three times for the classification of both dates and resulted in 284 clusters for the 1982 scene and 241 for the 1988 scene. The final classification maps are shown in Plates 2a and 2b.

Problems similar to those encountered during the classification of the Fort Moultrie TM imagery occurred when attempting to classify the two Kittredge TM images. There was difficulty distinguishing between developed and exposed land (e.g., bare soil). Cultivated land was confused with palustrine forest in certain instances. Different dates of imagery or "on-screen" digitizing of consistent cultivated land may be required to successfully distinguish between these phenomena.

Ninety-three and 84 ground reference samples, respectively, were used to determine the accuracy of the 1982 and 1988 Kittredge classification maps. Accuracy statistics

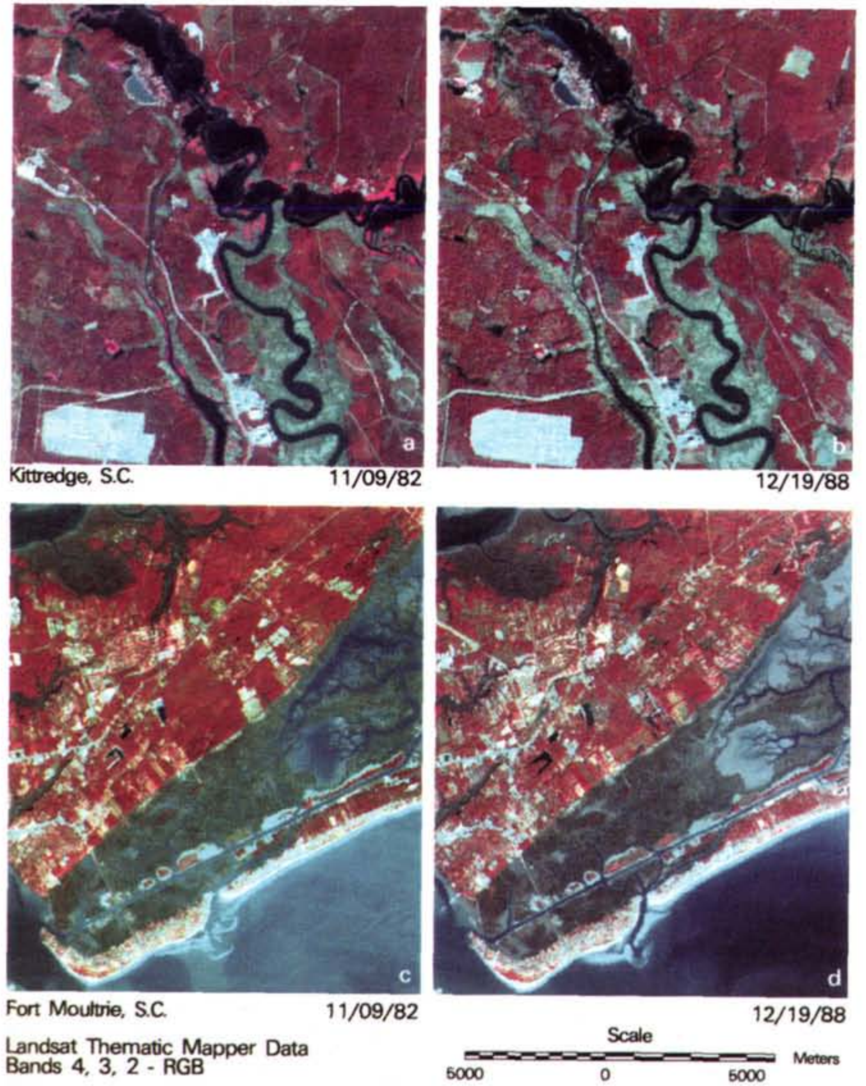

Plate 1. Color-infrared color composites of the Landsat Thematic Mapper data (bands 4, 3, 2 = RGB) of the Fort Moultrie, South Carolina and Kittredge, South Carolina study areas selected to test CoastWatch change detection protocols. Fort Moultrie and Kittredge contain extensive estuarine emergent wetland. Kittredge also exhibits palustrine forested wetland and riverine aquatic beds.

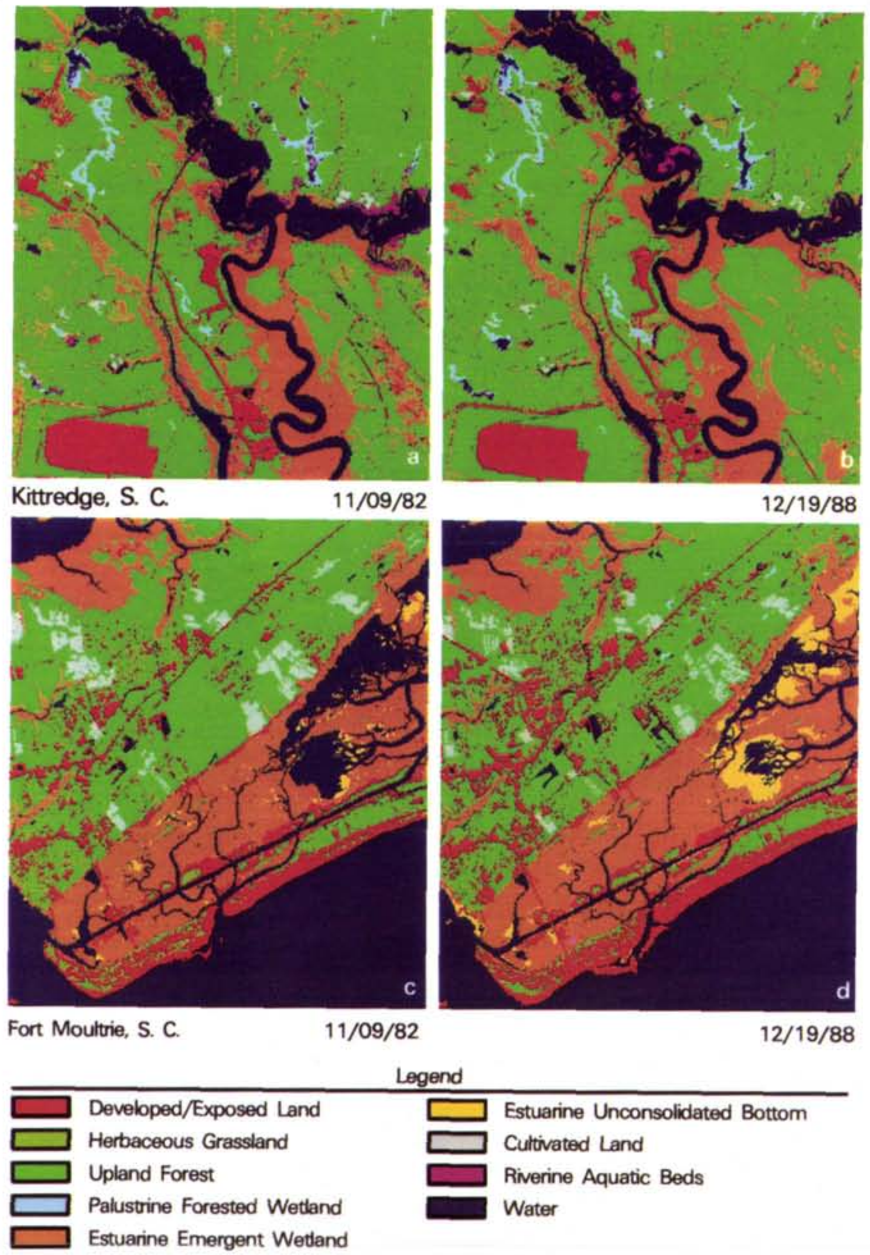

Plate 2. Individual classification maps of the Fort Moultrie and Kittredge, South Carolina study areas in 1982 and 1988 based on the analysis of Landsat Thematic Mapper data. Classes are from the Tentative CoastWatch Classification Scheme.

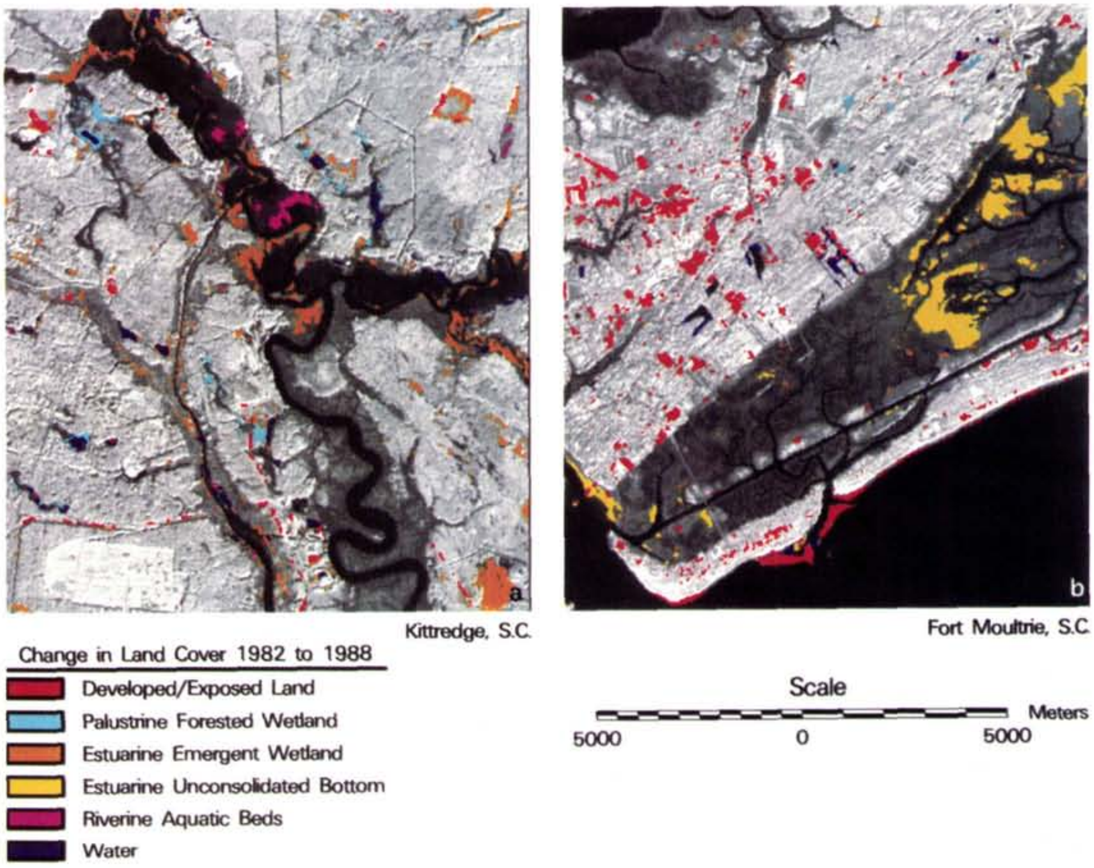

Plate 3. Change detection maps of the Fort Moultrie and Kittredge, South Carolina study areas derived from analysis of 9 November 1982 and 19 December 1988 Landsat Thematic Mapper data. The nature of the change classes selected for display are summarized in Figure 1. The change information is overlaid onto the Landsat TM band 4 image of each date for orientation purposes.

TABLE 4. CLASSIFICATION ACCURACY OF INDIVIDUAL DATES OF LANDSAT TM DATA USING UNSUPERVISED CLASSIFICATION LOGIC AND A 3 BY 3 POST-CLASSIFICATION MAJORITY FILTER
- KITTREDGE STUDY AREA -

| | 09 Nov 82 Classification | | 19 Dec 88 Classification | |
|---|---|---|---|---|
| Treatment | Kappa | Overall (%) | Kappa | Overall (%) |
| Original | 0.858 | 88.30 | 0.840 | 86.80 |
| Filter - Threshold 3 | 0.901 | 92.30 | 0.884 | 91.40 |

(Kappa and overall) for the original classification and a 3 by 3 majority filtered map (threshold of 3) were calculated and summarized in Table 4. As expected, the application of a majority filter yielded superior results on both dates. In fact, the filtered map data on both dates were > 90 percent accurate.

## Change Detection

### Treatments

Four variations of "post-classification comparison" change detection were evaluated for the Fort Moultrie study area (Table 5): (1) a traditional method which compared the original classifications directly, (2) the comparison of two classifications which had undergone majority filtering with a 3 by 3 pixel filter and a threshold value of 3, (3) the use of a "change/no change" mask applied to the original classifications prior to any comparison, and (4) the application of the same mask to the majority filtered classifications. Traditional classification and majority filtering have already been dis-

TABLE 5. RESULTS OF THE FORT MOULTRIE POST-CLASSIFICATION CHANGE DETECTION COMPARISONS USING 1982 AND 1988 LANDSAT THEMATIC MAPPER IMAGERY: KAPPA COEFFICIENTS AND OVERALL CLASSIFICATION ACCURACY.

| Treatments | Original unsupervised "cluster busting" classification | Majority filter applied to individual classification maps |
|---|---|---|
| Original Unsupervised "cluster busting" classification | Kappa = 0.65<br>Overall % = 69.51 | Kappa = 0.82<br>Overall % = 85.17 |
| 1982 vs. 1988 "Change/no change" mask applied | Kappa = 0.55<br>Overall % = 61.43 | Kappa = 0.72<br>Overall % = 75.55 |

cussed. It is instructive to describe the nature of the "change/no-change" mask treatment.

The accuracy of any post-classification change detection is strongly influenced by the accuracies of the independent classifications (Jensen, 1986). Classification error in either of the dates will result in an erroneous indication of change. The draft protocol suggests that one possible method of minimizing such errors is to use the spectral information of the raw images to differentiate between areas of change and no change. Therefore, a "change/no-change" mask was created and applied using the following logic.

Band 5, 9 November 1982 data for the entire subset (encompassing both study areas) were algebraically differenced with band 5 data obtained on 19 December 1988 to identify those pixels in the scene which changed. The same procedure was applied using TM band 3 data. Using classical GIS overlay logic, the TM band 5 "change/no-change" pixels were allowed to "dominate" all upland pixels found within the 1982 classification map while the TM band 3 derived "change/no-change" pixels were allowed to dominate for the tidally influenced areas. The union of these two operations was a single change/no-change binary mask which was applied to the 19 December 1988 classification map prior to the post-classification change detection procedure. This resulted in the theoretical removal of all pixels in the 19 December 1988 classified map which had not changed since 9 November 1982 according to the change/no-change mask. It was hypothesized that the removal of such information would reduce errors of commission in the change detection as suggested by Pilon *et al.* (1988). An alternative is to apply the mask to the raw 1988 data prior to classifying it. Theoretically, the results of the final change detection would be the same.

### Fort Moultrie Study Area Change Detection

A change detection map of the Fort Moultrie study area derived from 1982 and 1988 Landsat TM data is shown in Plate 3b. The 1982 and 1988 classification maps were compared on a pixel by pixel basis using an *n* by *n* GIS "matrix" algorithm whose logic is shown in Figure 1. This resulted in the creation of a "change image (map)" consisting of brightness values from 1 to 81. The analyst then selected specific "from - to" classes for emphasis. Only a select number of the 72 ($n^2 - n$) possible off-diagonal "from - to" land-cover change classes summarized in Figure 1 were selected to produce the change detection map. For example, all pixels which changed from any land cover in 1982 to "Developed/Exposed Land in 1988 were color coded red (RGB = 255, 0, 0) by selecting the appropriate "from - to" cells in the change detection matrix (10, 19, 28, 37, 46, 55, 64, and 73). If desired, the analyst could highlight very specific changes such as all pixels which changed from "Developed/Exposed Land" to "Estuarine Emergent Wetland" (cell "5" in the matrix) by assigning a unique color look-up table value (not shown). The color coded change detection map revealed significant growth in developed/exposed land, palustrine forested wetland, and estuarine unconsolidated bottom.

Assessing the accuracy of a change detection map is no simple task. In fact, there is relatively little literature on the topic (Jensen and Narumalani, 1992). This study used the error evaluation methodology previously described except that the random samples selected in the NHAP and NAPP data had to coincide with "from-to" categories which could be located in *both* the 1982 and the 1988 digital classification maps. Despite the generation of hundreds of random *i,j* coordinates, only 25 homogeneous, 3 by 3 pixel samples were obtained for the Fort Moultrie quadrangle. These reference data were used to calculate the overall and Kappa coefficient change detection map accuracy (Table 5). The highest change detection accuracy for the Fort Moultrie study area was obtained by the direct comparison of the filtered classifications (Kappa statistic of 0.82; overall accuracy of 85.17 percent). The lower accuracy of the "change/no-change" mask treatment was due to the underestimation of classes of change versus unchanged. In other words, the "change/no-change" mask previously discussed was too conservative. Despite this shortcoming, the application of this method to the filtered classifications had a higher accuracy than the traditional comparison of the original classification (Kappa of 0.72; overall accuracy of 75.55 percent). An additional analysis was performed with the three "woody" classes merged into a single "upland forest" class. This resulted in a change detection Kappa coefficient of 0.852 and an overall accuracy of 90.59 percent (not shown in table).

### Kittredge Study Area Change Detection

A map of selected classes of change in the Kittredge study area is shown in Plate 3a and is based on the change detection matrix logic presented in Figure 1. Of particular interest are the extensive areas of new estuarine emergent wetlands and riverine aquatic beds. Change detection maps should be interpreted cautiously, however, because the maps are absolutely a function of which classes in the change detection matrix are selected for display. For example, in order to identify both the losses and gains of riverine aquatic beds from 1982 to 1988, additional classes in the matrix would have to be selected (compare Plates 2a and 2b to see where the beds were gained and lost). Therefore, great care must be exercised when selecting which change classes to display from the change detection matrix.

The selection of hundreds of random *i,j* coordinates within the NHAP and NAPP aerial photography resulted in 23 homogeneous 3 by 3 pixel samples that could be used to evaluate the change detection error in the Kittredge study area. The overall accuracy was 76.6 percent with a Kappa of 0.721.

## The Effect of Tidal Stage on Wetland Classification in the Fort Moultrie Study Area

The tentative C-CAP tidal protocol for selecting satellite remote sensor data is (a) "mean low tide" preferred, (b) 30 to 60 cm (1 to 2 feet) acceptable, and (c) 90 cm (3 feet) or more unacceptable. Unfortunately, only tangential empirical research has been conducted to determine the significance of tidal stage variation (or flooding) when detecting change in coastal wetlands (Madec, 1991; Williams and Lyon, 1991). Ideally, tidal stage would be held constant between dates, but this would greatly undermine the utility of satellite imagery by severely limiting the amount of available data.

A preliminary study sponsored by NOAA was initiated to determine the potential significance of tidal stage on wetland classification using multiple dates of Landsat TM data acquired along a continuum of tides (Table 6). These data were classified using the "cluster busting" technique described earlier into just four classes of information (maps not shown): estuarine emergent marsh, estuarine unconsolidated bottom, water, and upland. A National Wetlands Inventory (NWI) map of the region (not confined just to the Fort Moultrie quadrangle) was recoded to create a mask containing only these tidally influenced classes. This mask was applied to each classification map, guaranteeing a consistent geographic area for comparison. The total hectares of estuarine emergent wetland in each image were computed. The tide at

TABLE 6. TIDAL STAGE AND TOTAL WETLANDS CLASSIFIED USING LANDSAT TM DATA OF FORT MOULTRIE, S.C.

| Date | Tidal Stage (cm)* | Estuarine Emergent Wetland |
|---|---|---|
| 19 Dec 88 | 1 | 3,514.59 |
| 09 Nov 82 | 44 | 3,359.70 |
| 09 Dec 90 | 72 | 3,061.08 |
| 14 Oct 87 | 83 | 3,026.61 |
| 04 Mar 87 | 133 | 2,728.44 |
| 06 Oct 90 | 211 | 2,075.40 |

* Centimeters above Mean Low Tide (MLT) derived from NOAA tide tables

the time of Landsat TM data acquisition was obtained from NOAA tide tables (Table 6).

The data were subjected to a regression model to determine the strength of the relationship between tidal stage and estuarine emergent wetland present. The resulting equation:

$$y = -6.953x + 3591.41$$

yielded an $r^2$ of 0.983 significant at the 0.001 level. We know that very little estuarine emergent marsh has changed in this region because of extensive biological research by Bradley *et al.* (1990) and the change detection research presented in this paper. Therefore, as the tide comes in, it produces more mixed pixels which may be misclassified as water. The result may be a decrease in the amount of emergent wetlands reported and an inaccurate map. Spurious change would be depicted in change detection maps if these data were used. Additional research is being conducted to verify the consistency of the relationship and to suggest more rigorous C-CAP tidal protocol.

## Recommendations

Below are recommendations based on an evaluation of C-CAP protocols in two South Carolina coastal environments.

### CoastWatch Image Data Selection

- Landsat TM data were used to map the land cover of wetlands and adjacent upland areas. One image per change detection year may not be adequate to discriminate between certain classes, especially those confused with cultivated land.
- The middle infrared TM bands were particularly useful and accounted for much of the separability between wetland types.
- C-CAP tidal stage protocol appears to be too lenient and must be made more rigorous through additional investigation of the tidal influence on wetland classification.

### Image Classification

- The Tentative CoastWatch Classification Scheme was generally useful. However, attempts to completely distinguish between some classes (e.g., developed/bare soil, cultivated land, herbaceous) were not feasible using Landsat TM data. The land-cover classes should be prioritized according to their importance to C-CAP program objectives. This would eliminate the need to obtain information on certain classes and standardize the scheme used between regions and states.
- The spectral remote sensing data cannot differentiate between estuarine, riverine, or marine wetlands as identified in the complete CoastWatch Classification Scheme. "Saline" stratification must be made using ancillary GIS data sources.
- Unsupervised "cluster busting" techniques coupled with "post-classification majority filtering" yielded the most accurate individual date classification maps.
- The C-CAP classification accuracy protocol is 90 percent for all categories. This accuracy was not obtainable using Landsat TM data. The protocol should probably be reduced to 85 percent accuracy, similar to the USGS land cover mapping protocol.

### Change Detection

- "Post-classification comparison" change detection logic is suitable for the C-CAP program if the individual dates of imagery are classified as accurately as possible. Such logic is essential if diverse 'from-to' classes of interest are to be displayed.
- The use of a "change/no-change" mask based on multiple date image differencing of specific bands may be a useful preprocessing function if an appropriate "threshold" is selected. The mask can then be used to classify only those pixels which have changed on the latest date of imagery.

### CoastWatch Products

- The change detection "from-to" classes of interest must be standardized so that those classes identified in South Carolina are equivalent to change detection classes for other states. The change detection legend must be standardized.
- Compressed data files provided to the user must be standardized and include (a) rectified remote sensor data for each date, (b) the raw final clusters obtained during the classification of each date, (c) the recoded final classes for each date as specified in the CoastWatch Classification Scheme, and (d) the post-classification comparison change detection file with integers representing the "from-to" classes.
- A history of the procedures used to create the C-CAP change detection map should be carefully documented in a "lineage" file as described by Jensen and Narumalani (1992).

## Acknowledgments

This project was funded by the National Oceanic and Atmospheric Administration through the S. C. Sea Grant Consortium. Richard Lacy (S.C. Land Resource Conservation Commission), Bjorn Kjerfve and Pradeep Talwani (Dept. of Geology, USC) made valuable contributions to this research. All image processing was performed using ERDAS software.

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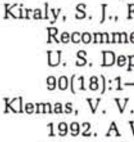
(Received 14 December 1992; accepted 24 January 1993)



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