Multispectral Change Vector Analysis for Monitoring Coastal Marine Environments*

Abstract

Documenting temporal changes to coastal zones is an essential part of understanding and managing these environments. The exclusive use of traditional surveying tools may not be practical for monitoring large, remote, or rapidly changing areas. This paper investigates the utility of multispectral Landsat Thematic Mapper satellite data for documenting changes to a Caribbean coastal zone using the change vector analysis processing technique. The area of study was the coastal region near the village of Buen Hombre on the north coast of the Dominican Republic. The primary habitats of interest were the intertidal mangrove forests, and the shallow water seagrasses, macroalgae, and coral reefs. The change vector analysis technique uses any number of spectral bands from multidate satellite data to produce change images that yield information about both the magnitude and direction of differences in pixel values (which are proportional to radiance). The final products were created by appending color-coded change pixels onto a black-and-white base map. The advantages and limitations of the technique for coastal inventories are discussed.

Introduction

Coastal zones contain some of the most biologically complex and productive ecosystems on Earth. Much of the world's population resides in coastal regions and exploits their abundant resources. Documenting temporal changes to coastal zones is an essential part of understanding and managing these environments. Resource surveys of coastal areas typically use topographic maps, nautical charts, aerial photographs, and direct observations. Maps, charts, and photos are often unavailable for many areas or are out of date and limited in their information content. On-site surveying can be very costly, time consuming, and, thus, inefficient for areas requiring repeated inventories. The exclusive use of these traditional surveying tools may not be practical for monitoring large, remote, or rapidly changing areas (Stoffle, 1991). This paper investigates the utility of multispectral Landsat Thematic Mapper (TM) satellite data and the change vector analysis (CVA) processing technique for documenting changes to a Caribbean coastal zone.

The area of study was the coastal region near the village of Buen Hombre on the north coast of the Dominican Republic. Buen Hombre is a small fishing and farming community of about 900 people located approximately 20 kilometres east of Monte Cristi on the shore of the Atlantic Ocean. The coastal ecosystem here is very diverse, complex, and relatively pristine. The region can be divided into several zones along a distance from shore transect which includes (1) an intertidal mangrove forest, (2) a first lagoon with extensive seagrass meadows and macroalgae, (3) patch coral reefs in the first lagoon, (4) a first barrier coral reef, (5) a second lagoon, and (6) a second barrier coral reef (Luczkovich, 1991). A third reef system also exists in much deeper water. The primary habitats of interest were the mangrove forests, and the shallow water seagrasses, macroalgae, and coral reefs.

This work was completed as part of a CIESIN** pilot project (Stoffle and Halmo, 1991; Luczkovich et al., 1993). The task was established to determine whether satellite data can be used by an interdisciplinary research team to identify small area changes to the coastal zone (Wagner *et al.*, 1991). The project also attempted to explain the processes, both natural and human induced, affecting the ecosystem and how the resulting changes are affecting the local people. The research team included 12 members with a wide range of expertise including cultural anthropology, climate and atmosphere science, marine biology/ecology, soil and crop science, and remote sensing technology. Field work was conducted in the Buen Hombre coastal region to gather base-line data for the project. This on-site surveying included marine observations and sampling employing SCUBA diving at over 50 sites during a three-week period in February and March of 1991.

The change vector analysis technique (Malila, 1980) is an empirical method of detecting radiometric changes between multidate satellite images in any number of spectral bands. This method yields information about both the amounts and types of changes in the data. The changes are characterized by vectors having magnitudes and directions in multispectral change space.

Method

Thematic Mapper data sets of the study area recorded on two seasonally similar dates were used in the processing (path/row: 8/46, 02 February 1985 and 04 January 1989). Prior to

*Presented at the First Thematic Conference on Remote Sensing for Marine and Coastal Environments, New Orleans, Louisiana, 15–17 June 1992.

**Consortium for International Earth Science Information Network, University Center, Michigan.

Jeffrey L. Michalek
Thomas W. Wagner
Environmental Research Institute of Michigan, P.O. Box 134001, Ann Arbor, MI 48113–4001.

Joseph J. Luczkovich
Institute for Coastal and Marine Resources, and Department of Biology, East Carolina University, Greenville, NC 27858–4353.

Richard W. Stoffle
Bureau of Applied Research in Anthropology, Department of Anthropology, University of Arizona, Tucson, AZ 85721.

Photogrammetric Engineering & Remote Sensing,
Vol. 59, No. 3, March 1993, pp. 381–384.

0099-1112/93/5903-381$03.00/0

the CVA processing both images were geocoded, registered, and radiometrically normalized.

The 1985 data were geometrically corrected to the Universal Transverse Mercator projection with a 25-metre grid. Several well distributed geographic control points obtained from 1:50,000-scale topographic maps or from Global Positioning System satellites were used to calculate the geometric transform. A subscence of the full TM image containing the study area was resampled using the restoration resampling method (Dye, 1976). Subpixel resampling errors were obtained in both the north-south and east-west directions for the geometric correction. The 1989 image was then registered to the 1985 geocoded image by scene-to-scene resampling.

Significant pixel value differences in satellite data of the same area obtained on different dates occur due to actual scene changes, sun elevation differences, and sensor variations. In order to determine which data set to radiometrically modify, pixel value histograms were produced and analyzed for the visible TM bands of both images. A slightly wider data range existed in the 1985 image, therefore, the 1989 data were selected for modification so that the maximum amount of radiometric detail would be included in the processing.

Pixel clusters from both images which appeared similar in natural color composites were examined using a display device, and digital numbers for a sample of these pixels were recorded from bands 1, 2, and 3. The terrain classes of these clusters included bare soil, mangrove forest, and deep water. The pixel values from each band were plotted against each other to verify linear relationships between the data of both images. Because linear relationships existed in all three channels, regression lines were calculated and the gain (slope) and offset (intercept) coefficients were used with linear radiometric balancing software to modify the 1989 data to more closely match the 1985 data.

The visible TM bands were selected for the CVA processing because some of the habitats of interest were in clear, shallow water and these wavelengths (band 1: blue, band 2:green, band 3:red) are able to penetrate such water columns. It was assumed that disturbances to the existing mangrove forests, seagrass meadows, macroalgae, and coral reefs would result in vector magnitude increases in the data, because the foundations of these habitats are mainly bright sand or other sediments. Damaged or dying corals also become brighter (bleached) when their symbiotic algae are expelled (Glynn, 1991). Conversely, any substantial areas of growth in these habitats should be indicated by vector magnitude decreases.

The CVA method computes the total change magnitude per pixel by determining the Euclidean distance between end points through n-dimensional change space, i.e.,

$$\sum_{i=1}^{n} (X_2 - X_1)^2{}_i$$

where "X_1" and "X_2" are the date 1 and date 2 pixel values and "i" is the TM band. A scale factor can be applied to each band to magnify small changes in the data. A factor of five was used in the processing of each TM band for this work. The change direction for each pixel is specified by whether the change is positive or negative in each channel. Thus, 2^n possible types of changes can be determined per pixel (Virag and Colwell, 1987). Because this processing used three input bands, there were 2^3 or 8 possible types of changes, or sector codes, that could be detected (Table 1). For the rare instances where pixel values did not differ between the two dates, a default direction of "+" was used to ensure that all pixels were assigned a direction.

The initial output image of the CVA processing was a two-byte file where channel 1 indicated the sector code and channel 2 contained the scaled vector magnitudes. Next, the change information was superimposed onto a black-and-white base map with the change pixels color-coded according to their sector code. This multispectral change magnitude (MCM) image incorporates both the change magnitude and direction information from the CVA processing (Virag and Colwell, 1987).

In order to make the final images more interpretable, only scaled magnitudes over a threshold value were appended onto MCM images. This threshold was used to avoid including changes due to sensor noise. The threshold was determined by examining deep water areas, which should be unchanged, and recording their scaled magnitudes from the CVA file. A threshold was selected that included significant changes but avoided those which were obviously due to sensor noise.

Results

Two final MCM images of the study area were produced. One with sectors 7 and 8 changes coded as magenta and red, respectively, and the other with only sector 1 changes coded as yellow.

Changes in sectors 7 and 8 were of interest because they represented pixels where the threshold magnitude level was met due to digital number increases in bands 1 and 2, but not in band 3, or due to increases in all three bands. It was hypothesized that clear, shallow water areas of corals, algae, and seagrasses that may have been damaged or destroyed would change from dark to light in all three bands, or possibly only in bands 1 and 2 because band 3 has a reduced ability to penetrate the water column and is less effective as water depth increases. Any portions of the intertidal mangrove forest that had been cut should also be identified with the sectors 7 and 8 MCM image. Several areas in the MCM image of sectors 7 and 8 showed changes to the study area. Among these was a large, oblong region (>60 pixels) in the first lagoon, plus several smaller areas (1 to 8 pixels) in the first lagoon, first barrier reef, and along the shoreline. Plates 1 and 2 show corresponding subscenes of the 1985 and radiometrically balanced 1989 TM data in natural color composites. Plate 3 shows the MCM subscene with sectors 7 and 8 changes identified.

Sector 1 changes (threshold magnitude decreases in all three bands) were of interest because they could identify any areas of significant growth at the edges of the habitats characterized by a bright to dark change. The sector 1 MCM image did not indicate any substantial areas of vector magnitude decreases in the mangrove forests, shallow lagoons, or coral reefs. It is likely that this type of change did occur in the study area, but was either not spatially large enough to be

TABLE 1. SECTOR CODE DEFINITIONS FOR CHANGE VECTOR ANALYSIS PROCESSING WITH TM BANDS 1, 2, AND 3.

Sector Code	TM Change Direction		
	Band 1	Band 2	Band 3
1	−	−	−
2	−	−	+
3	−	+	−
4	−	+	+
5	+	−	−
6	+	−	+
7	+	+	−
8	+	+	+

+ indicates pixel value increase from date 1 to date 2.
− indicates pixel value decrease from date 1 to date 2.

Plate 1. 1985 TM natural color composite (band 3: red; band 2: green; and band 1: blue) subscene of the coastal area near Punta Rucia, Dominican Republic.
TM path/row: 8/46 Projection: UTM with 25-metre grid
Date: 02 February 1985 Approximate Scale: 1:75,000

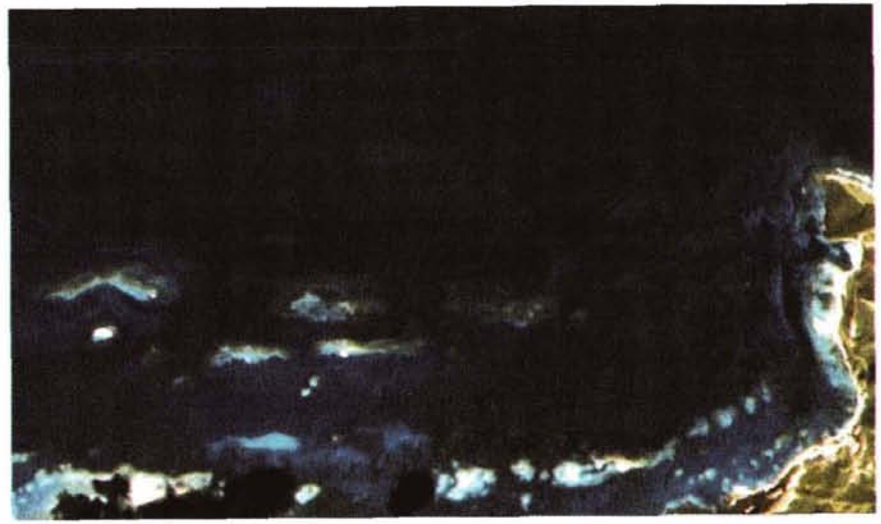

Plate 2. 1989 TM natural color composite subscene of the coastal area near Punta Rucia, Dominican Republic.
TM path/row: 8/46 Projection: UTM with 25-metre grid
Date: 04 January 1989 Approximate Scale: 1:75,000

Plate 3. 1985–1989 TM Multispectral Change Magnitude image of sectors 7 and 8 with change information superimposed onto the 1985 band 1 data. Red indicates threshold magnitude increases in bands 1, 2, and 3 (sector 8). Magenta indicates threshold magnitude increases in bands 1 and 2 (sector 7).
Date 1: 02 February 1985 Projection: UTM with 25-metre grid
Date 2: 04 January 1989 Approximate Scale: 1:75,000

captured by the 25-metre pixel size or did not exceed the threshold magnitude selected.

Discussion

Change vector analysis processing of the visible TM bands identified several areas where sectors 7 and 8 changes appeared to occur to the mangrove forests, shallow lagoons, and coral reefs in the study area. Many areas of change were recorded, but further on-site observations are required for verification of specific habitat changes. Although the water in the study area is very clear, it is possible that some of the observed changes were due to water clarity and quality differences. It is interesting to note that a large majority of the observed changes were to the shoreline, the first lagoon, and the inshore coral reefs. These near shore sites appear to be changing more rapidly and over a wider area than sites further offshore. The abundance of changes to near shore sites could be due to the increased amount of activity (fishing and SCUBA diving) in nearby shallow waters compared to offshore sites. The offshore sites are more difficult to access because only small boats are available and the sea state in these areas is typically rough and more dangerous.

A particular advantage of the CVA method is the ability to process any number of spectral bands desired. This is important because not all changes are easily identified in any single band or spectral feature. The processing can be completed to detect all radiometric changes in the data or only those greater than a selected threshold. For use in coastal marine inventories, the CVA technique may be most valuable as a tool for locating suspected areas of habitat changes prior to more intensive field surveying. This could save time and money available for on-site work, thereby enabling more efficient use of project resources. In addition to coastal habitat monitoring, the technique may be valuable for water quality and clarity studies. Also, the CVA method should be more cost efficient and effective for large areas than other techniques for recording changes such as multispectral classification.

As with other change detection techniques, ephemeral changes in the data like those due to different atmospheric states and sea surface conditions are also recorded and can make interpretation difficult. Another possible limitation of the CVA method used with TM data is that very substantial changes must occur before being detected by the resampled 25-metre pixels. The method will become more effective for monitoring shallow marine environments as new sensors specifically designed for ocean science observations with improved spatial resolutions and spectral band locations become available.

Summary

The change vector analysis (CVA) processing technique was tested using the three visible wavelength bands of Landsat Thematic Mapper data for detecting changes to a coastal zone in the Dominican Republic. The habitats of interest included the intertidal mangrove forests and shallow water seagrasses, macroalgae, and coral reefs. The CVA approach characterizes changes in the data by computing vectors with both pixel magnitude and direction information. Change information is then appended onto a black-and-white base map with the change pixels color-coded according to their directions. Any number of spectral bands desired can be used in the processing; therefore, 2^n possible change directions can be determined. All radiometric changes to the data can be recorded or only those greater than a selected threshold.

Several small pixel clusters (1 to 8 pixels) representing radiance increases to the first lagoon, first barrier reef, and the shoreline were identified. A large area change (>60 pixels) of the same type was also recorded in the first lagoon. Most of the observed changes occurred in the near shore portions of the study area which are used more frequently for fishing and SCUBA diving by residents and tourists. The CVA method can be a valuable tool for coastal resource surveys and monitoring, especially for identifying suspected areas of changes prior to more detailed on-site observations.

Acknowledgments

Other contributing scholars to this project included David B. Halmo (Bureau of Applied Research in Anthropology, University of Arizona); Andrew Williams (Department of Anthropology, University of Michigan); Donald Portman, William Kuhn, and David Willson (Department of Atmospheric, Oceanic, and Space Sciences, University of Michigan); C. Gaye Burpee (Department of Crop and Soil Sciences, Michigan State University); Ray Laurin (Environmental Research Institute of Michigan); and Brent Stoffle (Department of Sociology and Anthropology, East Carolina University). A special thanks also goes out to all of the people in the Dominican Republic communities of Buen Hombre and Punta Rucia for their friendship and support of this work.

References

Dye, R.H., 1976. Restoration of Landsat Images by Discrete Two-Dimensional Deconvolution, *Proceedings of the Tenth International Symposium on Remote Sensing of Environment*, Ann Arbor, Michigan, pp. 725–729.

Glynn, P.W., 1991. Coral Reef Bleaching in the 1980's and Possible Connections with Global Warming, *Trends in Ecology and Evolution*, 6:175–179.

Luczkovich, J.J., 1991. Marine Ecology of the Buen Hombre Coast, *Satellite Monitoring of Coastal Marine Ecosystems: A Case from the Dominican Republic*, (R.W. Stoffle and D.B. Halmo, editors) Consortium for International Earth Science Information Network report, University Center, Michigan, pp. 93–140.

Luczkovich, J.J., T.W. Wagner, J.L. Michalek and R.W. Stoffle, 1993. Discrimination of Coral Reefs, Seagrass Meadows and Sand Bottom Types from Space: A Dominican Republic Case Study, *Photogrammetric Engineering & Remote Sensing* 59(3):385-389.

Malila, W.A., 1980. Change Vector Analysis: An Approach for Detecting Forest Changes with Landsat, *Proceedings of the LARS Machine Processing of Remotely Sensed Data Symposium*, West Lafayette, Indiana, pp. 326–336.

Stoffle, R.W., 1991. Executive Summary, *Satellite Monitoring of Coastal Marine Ecosystems: A Case from the Dominican Republic*, (R.W. Stoffle and D.B. Halmo, editors), Consortium for International Earth Science Information Network report, University Center, Michigan, pp. 1–8.

Stoffle, R.W., and D.B. Halmo, 1991. *Satellite Monitoring of Coastal Marine Ecosystems: A Case From the Dominican Republic*, Consortium for International Earth Science Information Network report, University Center, Michigan.

Virag, L.A., and J.E. Colwell, 1987. An Improved Procedure for Analysis of Change in Thematic Mapper Image-Pairs, *Proceedings of the Twenty-First International Symposium on Remote Sensing Environment*, Ann Arbor, Michigan, pp. 1101–1110.

Wagner, T.W., J.L. Michalek, and R. Laurin, 1991. Remote Sensing Applications in the Coastal Zone, *Satellite Monitoring of Coastal Marine Ecosystems: A Case from the Dominican Republic*, (R.W. Stoffle and D.B. Halmo, editors), Consortium for International Earth Science Information Network report, University Center, Michigan, pp. 17–56.