LOW-ALTITUDE AVIRIS DATA FOR MAPPING LANDFORM TYPES ON WEST SHIP ISLAND, MISSISSIPPI

Joseph P. Spruce,[1] Ervin G. Otvos,[2] and Marco J. Giardino[3]

1. INTRODUCTION

Barrier islands help protect the southern and southeastern U.S. shoreline from hurricanes and severe storms. They are important for coastal resource management and geologic research, especially in studies that involve changes in island areas and surface environments, and they display a dynamically changing and diverse mix of landform and vegetative cover habitats. Many Gulf Coast barrier islands have undergone dramatic decreases in areal extent, often due to hurricane and severe storm damage. For example, Louisiana's barrier islands have lost 55 percent of their surface area over the past 100 years (Williams et al., 1992; Louisiana Department of Natural Resources, 1998).

Aerial photography and Landsat data have been used to monitor changes in barrier island areal extent, although neither data source is optimal for making maps of detailed landform types at site-specific scales. High-spatial-resolution hyperspectral imagery, such as that obtained from the high-spatial-resolution Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) sensor, may enable improved mapping of landform types, which would benefit studies of the dynamics of barrier island environments.

During the summers of 2000 and 2001, a study was conducted to assess low-altitude AVIRIS data for mapping the landform types of West Ship Island, a barrier island in Harrison County, Mississippi (Figure 1). Otvos et al. (2001) submitted an internal report on this work to the National Aeronautics and Space Administration (NASA). This study area was selected because of the availability of low-altitude AVIRIS data acquired on July 22, 1999, and because of the area's accessibility to the investigating team. West Ship Island is one of six barrier islands that belong to the Gulf Shores National Seashore, which is managed by the National Park Service. This island contains an impressive range of landform categories. Surface types include beach, dune, and sand flat environments (Otvos, 1995; Otvos et al., 2001). West Ship Island also harbors Fort Massachusetts, a historic fort used during the Civil War. Because it is located near Stennis Space Center, the island is frequently imaged by NASA's airborne and spaceborne sensors.

West Ship Island was formed when Hurricane Camille split the former Ship Island in half on August 17, 1969. Between 1849 to 1974, Ship Island lost 463 acres due to segmentation and shoreline erosion. As of 1991, West Ship Island was about 3.5 miles long by 0.4 miles wide and 555 acres in extent (Otvos et al., 2001). West Ship Island further diminished in size in 1998 when erosion caused by Hurricane Georges decreased the island area to about 468 acres (Schmid, 2001). At the same time, East Ship Island was temporarily split into two segments (Otvos et al., 2001; Schmid, 2001). Otvos (1981; 1995) provides much additional information on island formation processes for Ship Island and related barrier islands along the Mississippi Sound.

2. RATIONALE FOR RESEARCH

Aerial photography is frequently used in geomorphologic mapping, including the mapping of coastal landforms (Way and Everett, 1997). Aerial photography is a standard data source for wetland mapping for the U.S. National Wetland Inventory. Landsat data have been used for monitoring change compared to pre-existing wetland maps (Wilen and Smith, 1996; Tiner, 1997; Koeln and Bissonnette, 2000). Aerial photography is also used for mapping general vegetative cover types of barrier islands (e.g., Army Corp of Engineers, 1981; Tiner, 1997; Torres-Pulliza et al., 2002). In addition, aerial photography is frequently employed to map shoreline change (e.g., Gorman

[1] Lockheed Martin Space Operations – Stennis Programs, John C. Stennis Space Center, Joseph.Spruce@ssc.nasa.gov
[2] University of Southern Mississippi, Gulf Coast Research Laboratory, ervin.otvos@usm.edu
[3] NASA Earth Science Applications Directorate, Marco.Giardino@ssc.nasa.gov

et al., 1998), although some scientists have used Landsat data to assess shoreline and/or wetland change at regional scales (e.g., Dobson et al., 1995; Wilen and Smith, 1996; Tiner, 1997; Shao et al., 1998; Koeln and Bissonnette, 2000).

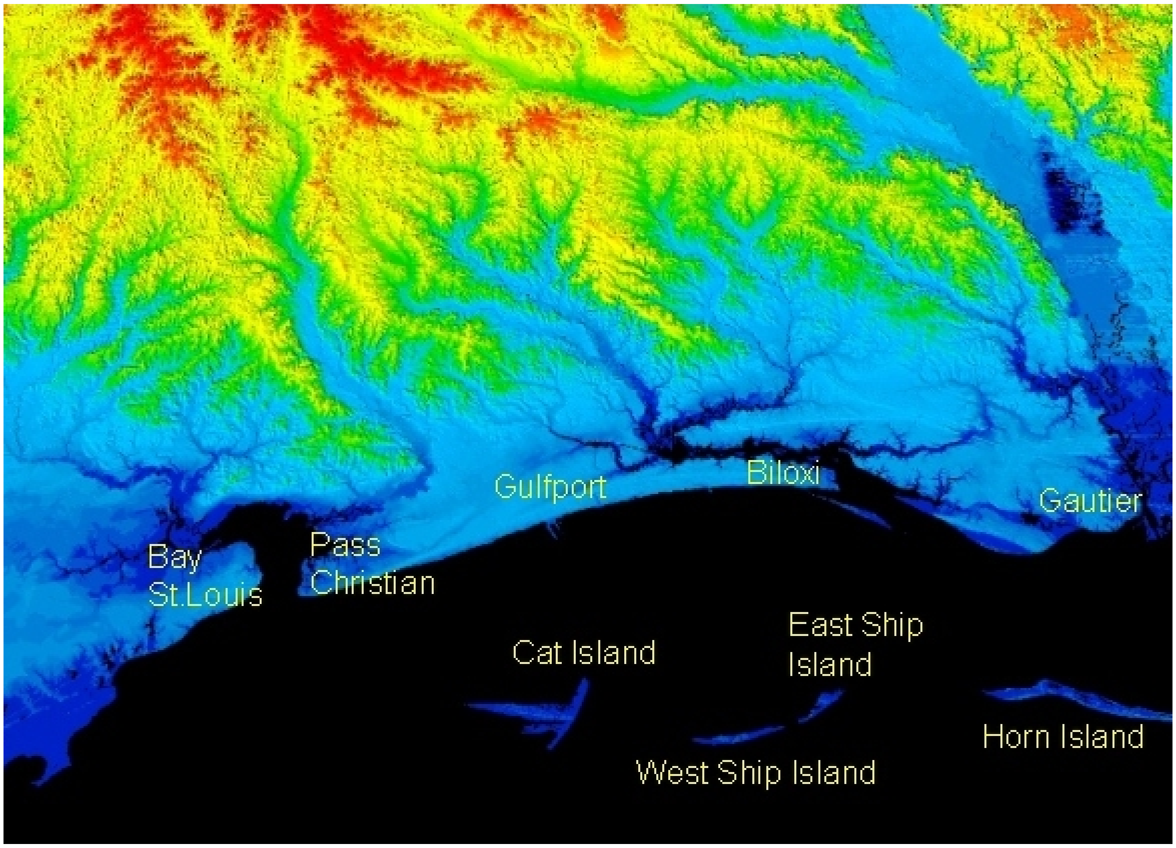


Figure 1. Oblique View of U.S. Geological Survey 30-Meter Digital Elevation Model for Mississippi Gulf Coast Showing Study Area Location

While aerial photography is commonly used in coastal wetland studies, it is not without its shortcomings (Wilen and Smith, 1996; Tiner, 1997). For example, the use of aerial photography for accurate mapping of land cover categories requires a trained analyst to interpret and delineate cover types, usually stereoscopically. This process is highly subjective and time-consuming and can be confounded by poor contrast between spectrally similar features. In many cases, panchromatic, true color, or color infrared aerial photographs provide insufficient contrast for identifying spectrally similar cover types, especially monoscopically, and often even with stereoscopic viewing. Hyperspectral remote sensing offers an alternative method that can be more automated and less subjective in that the analyst does not have to delineate and identify each polygonal surface cover feature.

With numerous narrow contiguous bands recording visible through short-wave reflective infrared energy, airborne hyperspectral imagery, such as AVIRIS, can be useful in separating spectrally similar cover types. However, detection can depend on data quality, on reference training data, and on processing technique. More recently, hyperspectral remote sensing has been tested for improving maps and for assessing coastal habitats (e.g., Bachman et al., 2001; Donato et al., 2001; Garcia and Ustin, 2001; Neuenschwander et al., 1998; Ustin, 2001). Ustin (2001) and Bachman et al. (2001) have mapped invasive plants in coastal environments with some success. Carter and Young (1993) conducted hyperspectral analyses of stressed vegetation on a barrier island.

A few of the hyperspectral studies were in regard to classifications of barrier island environments (Bachman et al., 2001; Donato et al., 2001; Neuenschwander et al., 1998), although none employed low-altitude hyperspectral data for mapping landforms. The study by Neuenschwander et al. (1998) applied high-altitude AVIRIS data with 20-meter spatial resolution to produce highly accurate coastal land cover maps of Kennedy Space Center. Neuenschwander et al. (1998) reported that the best map produced from AVIRIS data used the 13 most signal-rich minimum noise fraction bands, subjected to a supervised neural net classifier. This map contained seven upland and five wetland categories with an overall accuracy of 93.5 percent. The results provided some indication that low-altitude AVIRIS data of 3.4-meter spatial resolution could produce high-quality maps of landform types over West Ship Island.

Depending on the data type, the use of low-altitude, high-spatial-resolution airborne sensor data can enable smaller minimum mapping units as well as more detailed maps of island landforms, vegetative communities, and elevation. This study utilized the high spatial resolution of low-altitude hyperspectral and multispectral imagery for mapping barrier island landform types and also employed digital terrain models for mapping landform elevation.

3. GEOSPATIAL DATA ACQUISITION

A wealth of remote sensing and other geospatial data exists for West Ship Island, mostly originating from Federal and State agency sources. Several remote sensing datasets were downloaded from NASA's data archive for use in the study, including 1) low-altitude AVIRIS hyperspectral imagery acquired July 29, 1999, at 3.4-m ground sampling distance (GSD); 2) Airborne Data Acquisition and Registration (ADAR) multispectral imagery acquired November 9, 1997, at 0.5-m GSD; and 3) Star-3*i* Digital Terrain Map data acquired November 11, 1999, at 10-m GSD. The ADAR and Star-3*i* datasets were acquired by NASA as part of the Scientific Data Purchase program from Positive Systems, Inc., and Intermap, respectively.

Additional geospatial datasets were acquired for use in a reference capacity, including 1) digital orthophoto quarter quadrangle (DOQQ) imagery acquired by the U.S. Geological Survey (USGS) on January 11, 1997, and produced at 1-m spatial resolution; 2) Digital National Wetland Inventory map; 3) 1:24,000 scale USGS digital raster graphic topographic map; and 4) field survey data collected August 2, 2001, in the form of locations determined with a Global Positioning System receiver, with digital handheld photography, and with field-annotated hardcopies of remote sensing imagery and related mapping products.

4. MAPPING METHODS

The AVIRIS and Star-3*i* data came as preregistered segments, whereas the ADAR imagery was in the form of seven nonregistered frames of image data. The AVIRIS, ADAR, and Star-3*i* data were subsequently mosaicked to provide complete coverage of the island. Doing so was straightforward for the AVIRIS and Star-3*i* data but required additional image-to-image coregistration of ADAR data frames prior to mosaicking. Once mosaicked, the path-oriented AVIRIS mosaic was atmospherically corrected with Atmosphere Removal (ATREM) Program software (Gao et al., 1993), which outputs data scaled to apparent ground reflectance. Insufficient information was available for atmospheric correction of the ADAR data. The data were scaled in terms of raw digital numbers. Analysts later georeferenced the AVIRIS and ADAR data to fit the Universal Transverse Mercator map projection (WGS84 spheroid and datum). Doing so required use of USGS DOQQ data as reference data for selecting ground control points (GCPs). The AVIRIS data was georeferenced with a second order polynomial fit, 52 GCPs, and a +/- 3.4-m root mean square error (RMSE). The ADAR data needed additional effort to georeference, requiring a fourth order polynomial fit, 195 GCPs, and +/- 3.7-m RMSE.

The AVIRIS datasets were then classified into cluster classes, using the unsupervised Iterative Self-Organizing Data Analysis Technique (ISODATA) clustering algorithm resident to ERDAS IMAGINE software. This approach was selected because it requires much less information for effective application in comparison to the supervised method. The latter approach puts the burden on the analyst to derive spectral training statistics (i.e., signatures) for segmenting the landscape into discrete land cover types. When the study began, the research team knew of the landforms that occur in the study area but was largely unaware of the spectral variability of these features; consequently, the unsupervised approach was selected. In doing so, each ISODATA classification run was performed by using 50 iterations, 99 percent convergence between iterations, cluster means initialization along the first principal component axis, automatic scaling, and sampling of every pixel.

Classification was performed on a subset of AVIRIS bands rather than on the entire spectrum of 224 bands. In particular, the AVIRIS data cube was subset into a file of 15 select bands (Table 1). The selected bands appeared to offer comparatively high spectral separability between common land and water surface cover types. Analysts assessed spectral signature separability across bands by visualizing and interpreting AVIRIS-based spectral signatures for several upland and wetland forest, shrub, grass, barren, and water surface types using AVIRIS data from a previous study described by Spruce (2001) and Spruce et al. (2001). ISODATA classifications of land cover can be quite effective with quality multispectral datasets of 15 bands or less. The use of 15 select AVIRIS bands was expected to result in a similar if not better classification, especially if the bands had high spectral contrast between land cover types of interest and acceptable signal resolution.

Table 1. Bands of AVIRIS Data Selected for Classification

Subset Channel	AVIRIS Band Number	Band Center (nanometers)	Spectral Reflectance Region
1	15	508.02	Left side of green
2	20	557.14	Green peak
3	32	675	Red absorption well
4	35	673.25	Red absorption well
5	36	682.79	Lower part of red edge
6	45	768.66	Upper part of red edge
7	56	873.67	NIR plateau, left side
8	66	974.58	NIR plateau, right side
9	77	1078.06	NIR, transition to SWIR
10	91	1209.73	NIR, transition to SWIR
11	102	1305.43	NIR, transition to SWIR
12	137	1654.04	SWIR-1 (Landsat TM 5)
13	194	2211.8	SWIR-2 (Landsat TM 7)
14	204	2311.49	SWIR-2
15	212	2391.06	SWIR-2

NIR = near-infrared
SWIR = short-wave infrared

The AVIRIS data were classified initially into 20 clusters, which analysts subsequently recoded into a binary mask containing land and water categories. Additional masking techniques were then employed to isolate the raw data obtained from the land cover. The masked raw data was then reclassified with ISODATA cluster busting (Jensen, 1996) into 30 cluster classes. These classes were described and assigned to apparent landform types by an experienced coastal geomorphologist.

Unsupervised classification proceeded similarly for ADAR multispectral data, except that it was based on four broad multispectral bands in the visible/near-infrared portion of the electromagnetic spectrum. Only one classification was performed on the ADAR data and no attempt was made to reclassify the raw data corresponding to the land features, because the 1997 ADAR data were believed to be out of date because of the land cover change caused by Hurricane Georges in 1998. Fortunately, the AVIRIS data collection occurred after Hurricane Georges and the island had suffered no subsequent hurricane damage. Consequently, more effort went into developing the AVIRIS classifications.

The Star-3*i* digital terrain model was used to create a shaded relief map for the island. This was a trial and error process because of the subtlety of the terrain, over which vertical microtopographic differences of 0.5 feet might result in different landform and/or vegetation type. The local relief was not apparent on the shaded relief map until the elevation height was stretched 25 times in the “Z.” This information was subsequently utilized in refining the AVIRIS and ADAR classifications.

Hardcopies of resulting landform maps and remote sensing imagery were produced for field validation on August 2, 2001. The field survey occurred about two years after AVIRIS data collection. Land cover changes were evident in the lowest lying areas. Approximately 70 percent of the island area was visited during the survey and many points of interest were noted on hardcopy imagery and maps for subsequent entry into a GIS-based coverage. Handheld photography was taken at each point of interest. GPS locations were also collected for areas that were difficult to locate on hardcopy imagery and maps.

The field survey data were then used to refine descriptions of cluster classes on the AVIRIS and ADAR classifications. Publications by Duncan and Duncan (1987) and by Tiner (1993) were consulted in describing vegetation-dominated landforms. Work by Otvos (1995) and Godfrey (1976) were also used in developing class descriptions.

5. PRELIMINARY ANALYSIS OF RESULTS

Figure 2 shows a low-altitude AVIRIS Red, Green, Blue (RGB) composite image that has been enhanced with the raw data for the land stretched independently of the raw data for the water using masking techniques to isolate the raw data for the land cover and water features, respectively. The enhancement enabled clear visualization of the comparatively sparse vegetation in the beach and dune zones of the island perimeter. This enhancement is an important tool in assessing the AVIRIS landform classification shown in Figure 3. This figure also provides a map legend and summarizes the areal extent of each cluster class. This preliminary map displays all of the common landforms on the island. Both the island perimeter and the interior include numerous landform and environment categories.

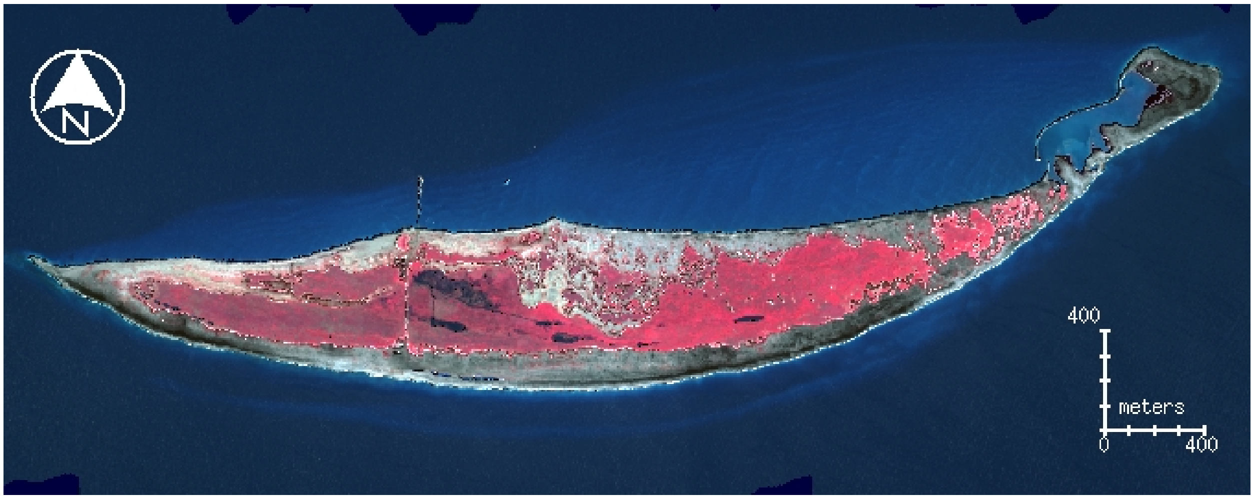
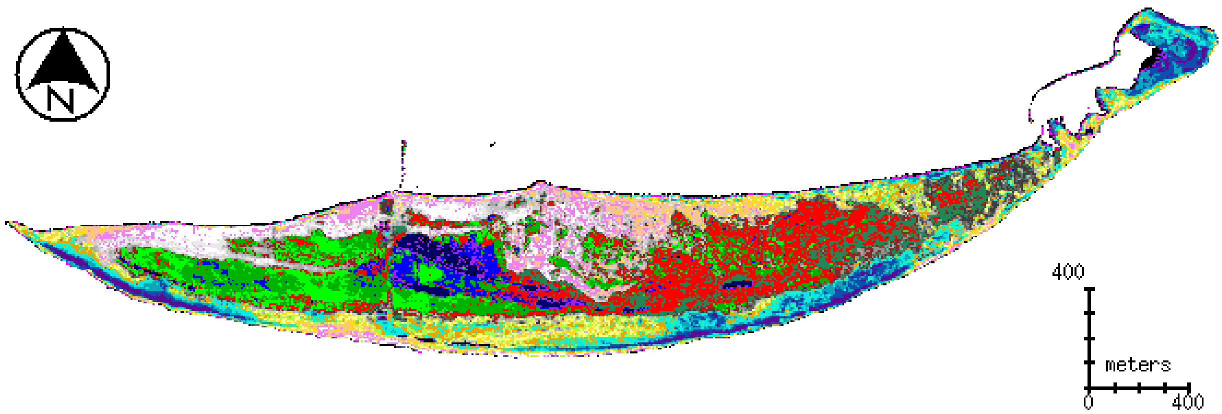


Figure 2. AVIRIS Color Composite Image of Study Area with Bands 56 (873 nm), 32 (675 nm), and 20 (557 nm) Assigned to RGB

Based on comparisons to AVIRIS imagery and field checks, the AVIRIS map of the island exterior clearly separates the foreshore and backshore environments. The island perimeter includes several landform classes with bare sand and with sand covered by various types of sparse vegetation. Among the foreshore sand cover categories, the AVIRIS map distinguishes between bright siliceous, slightly calcareous sand that occurs mainly on the Mississippi Sound side and dark sand concentrates of heavy minerals found commonly on the Gulf beaches. For the backshore, the AVIRIS map shows barren sand flats as well as partially vegetated dunes containing pioneering herbaceous vegetation, low shrubs, or xeric grasses. Although sand cover types usually occur predominantly on the beach, sand sheets created by storm overwash and eolian blow out extend from the north shore southward to the island interior in some areas. Major eolian sand accumulations can also be found near Fort Massachusetts.



Color	Cluster #	Acres	Landform	Land Cover
	1	7.4	beach on Sound side	moist sand
	2	3.7	foreshore on Sound side	wet sand
	3	5.0	interior flat	lowest marsh
	4	13.5	interior flat	high marsh
	5	45.1	interior sheet	moist grassland
	6	1.6	beach	moist sand
	7	29.1	interior sheet, ridge	marsh
	8	63.1	interior flat	shrub/scrub
	9	28.5	interior flat	marsh
	10	15.8	interior flat	disturbed edge vegetation
	11	11.8	backshore flat on Gulf side	sand
	12	16.1	backshore flat	sand
	13	17.3	exterior flat, spit	sand
	14	1.6	exterior flat	sand
	15	10.8	interior patch	disturbed edge vegetation
	16	16.0	backshore flat	sand
	17	11.1	dune patch	sparse, disturbed vegetation
	18	9.3	interdune or dune flat	sparse vegetation and sand
	19	16.4	exterior flat, spit	sand
	20	18.5	backshore flat	wet sand
	21	12.6	dune flats	sparse vegetation and sand
	22	19.1	beach flat, some on cuspate spit	sand
	23	11.6	dune flats	sparse vegetation and sand
	24	15.9	backshore flat, dune ridge - on Gulf side	sand
	25	13.7	exterior flat, minor amounts on spit	sand
	26	10.9	dune patch - small areas	sparse vegetation and sand
	27	17.0	backshore sheet - interridge location	sand
	28	12.1	dune patch - small areas	sparse vegetation and sand
	29	20.6	high backshore sheet, parabolic dunes	sand
	30	17.5	backshore sheet - moderately high	sand

Figure 3. AVIRIS Classification of Landform Type

The AVIRIS classification of the island interior identifies many land cover types. Several vegetation categories were identified mainly on the interior sand flats, including various types of marsh dominated by sedges and rushes. Grassland, shrub/scrub, very low-forested swamp, shallow ponds occurring in swales between old beach ridges, and a few small patches of slash pine forest were among the surface cover categories. The interior also included beach ridges, indicative of ancient island shoreline positions and the dynamic nature of barrier island changes. Such landforms of the island interior can be viewed on the Star-3*i* shaded relief map (Figure 4). The shrub/scrub type often grows on the higher ground, including relict beach ridges and the higher sand sheet surfaces. In this case, land cover type is not necessarily the same as landform. Land cover on the island is in part affected by the site conditions: wetness, salinity, tidal influence, and level of disturbance. However, at least for the island interior, the same vegetation type can occur on multiple landforms that are of interest to coastal geomorphologists.

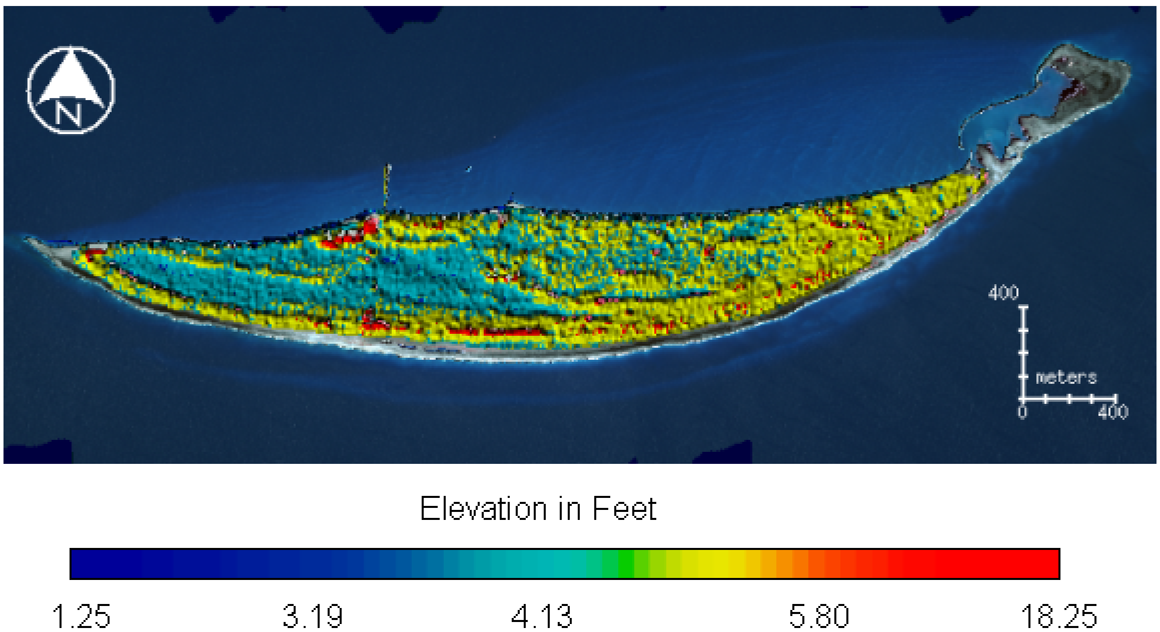


Figure 4. Hillshaded Digital Terrain Model Derived from Star-3*i* Radar Data and Draped Over AVIRIS RGB Shown in Figure 2

The field survey enabled common landforms and cover types evident on the AVIRIS classification to be visited and documented for further research. These field checks indicated that the AVIRIS color composite imagery displays island landforms: foreshore, backshore, vegetated dunes, and island interior zones. The AVIRIS classification does not distinguish between backshore and dune landforms when covered by dry bright sand and does not show interior vegetated beach ridges as a distinct landform type. The AVIRIS map is a consistent and reliable predictor of common cover types as compared to field checks. However, rare cover types, such as the relict pine forest, were not uniquely identified. Some of the sparsely vegetated dunes appeared to be misclassified as barren sand types. Such problems can be addressed through additional cluster busting techniques as described by Jensen (1996) and Spruce (2001). The field survey also confirmed the finding of Schmid (2001) that Hurricane Georges resulted in significant land cover change. These changes made it difficult to evaluate the landform classification produced from the 1997 ADAR multispectral dataset. However, certain areas showed only minor land cover change. In those areas one could use hardcopies of ADAR color composite imagery in the field. These image maps were especially useful in locating the few small patches of remnant pine forest that were difficult to see on the AVIRIS color composites because of the coarser spatial resolution.

The research focused on the mapping of landforms in the intertidal zone and higher terrestrial landform environments of the island. It was difficult to map land cover in more specific terms because of the lack of timely *in* *situ* data on vegetation community distributions, especially in the marshlands. The dynamic nature of barrier island environments made it impractical to map specific plant communities, particularly in the marshy island interior. Marsh cover type distributions did not correspond well with the field survey, largely because of the 2-year time difference between the AVIRIS data collection and the field survey. No attempt was made to map subtidal geomorphologic environments using the AVIRIS data. A quantitative accuracy assessment of the AVIRIS landform classification is underway and will be reported at a later date.

6. CONCLUDING REMARKS

Preliminary results suggest that low-altitude AVIRIS data can be effective for mapping landform-specific environments of both the island's exterior and interior. In particular, the AVIRIS classification enabled multiple cover types to be identified on the beaches and dunes on the island's exterior. AVIRIS classification also enabled mapping of multiple environments (i.e., cover types) in the island's interior, including vegetated land cover types occupying relict beach ridges, inter-ridge swales, and sand flats. The AVIRIS classification did not always clearly identify all landforms in specific terms. However, this classification supplied a great deal of information on land cover associated with barrier island landforms.

The unsupervised classification method employed in this study appeared to be effective, although refinement and perhaps other techniques would be needed to identify land cover types in more specific terms. While the band selection approach worked, in retrospect it would have been better to include a blue band for classification and for AVIRIS color composite screen displays.

The Star-3*i* digital terrain model was useful for aiding the assessment of the AVIRIS classification as it enabled viewing of the subtle island interior landforms (e.g., ancient beach ridges) that were difficult to see on the AVIRIS imagery. Its 10-meter spatial resolution was not optimal for this task, although it was much better than the alternative 30-meter USGS Digital Elevation Model. The current landform map of West Ship Island could perhaps be improved by using a much higher-spatial-resolution digital elevation map than the Star-3*i* product in conjunction with the AVIRIS classification discussed here. However, the combined use of the AVIRIS and Star-3*i* data could also enable a better landform map to be produced.

Hardcopies of the 0.5-meter ADAR multispectral imagery were effective in aiding the field survey. However, the classification of the ADAR data was difficult to evaluate because of hurricane-induced land cover changes that had impacted the island after the ADAR data were acquired. Despite this shortcoming, the ADAR data did provide general information on land cover types and a useful estimate of the areal extent of the island prior to Hurricane Georges.

This study enabled assessment of low-altitude AVIRIS data for mapping landform environments of barrier islands in the Gulf Coast region of the United States. Based on initial results, high-spatial-resolution hyperspectral imagery, such as AVIRIS, appears to be a useful tool for mapping the landform and land cover of barrier island and other coastal environments. Additional work is underway to confirm these preliminary observations.

7. ACKNOWLEDGEMENTS

This work was supported by the NASA Earth Science Applications Directorate under contract number NAS 13-650 at the John C. Stennis Space Center, Mississippi.

8. REFERENCES

Army Corp of Engineers, 1981, Recommended Scales of Aerial Photography for Mapping Barrier Island Vegetation, Coastal Engineering Technical Note, USACE Technical Report TN-V-8, January 1981, 2 pp. Also online [accessed 27 August 2002]: http://chl.wes.army.mil/library/publications/chetn/pdf/cetn-v8.pdf.

Bachman, C. M., T. F. Donato, K. Dubois, R. A. Fusina, M. Bettenhausen, J. H. Porter, and B. R. Truitt, 2001, "Automatic Detection of Invasive Plant Species on a Barrier Island in the Virginia Coastal Reserve Using HYMAP and IKONOS Data," Proceedings for IGARSS 2001, CD-ROM, 3 pp.

Carter, G. A., and D. R. Young, 1993, “Foliar Spectral Reflectance and Plant Stress on a Barrier Island,” Int. J. Plant Sci., vol. 154, pp. 298-305.

Dobson, J., E. A. Bright, R. L. Ferguson, D. W. Field, L. L. Wood, K. D. Haddad, H. Iredale III, J. R. Jensen, V. V. Klemas, R. J. Orth, and J. P. Thomas, 1995, NOAA Coastal Change Analysis Program (C-CAP): Guidance for Regional Implementation, NOAA Technical Report NMFS 123, U.S. Department of Commerce, April 1995. Also online [accessed 14 September 2002]: http://www.csc.noaa.gov/crs/lca/protocol.html.

Donato, T. M., C. M. Bachman, and R. A. Fusina, 2001, “High Resolution Remote Sensing Observations at the Virginia Coastal Reserve Long-Term Ecological Site,” Proceedings for IGARSS 2001, CD-ROM, 3 pp.

Duncan, W. H., and M. B. Duncan, 1987, The Smithsonian Guide Seaside Plants of the Gulf and Atlantic Coasts from Louisiana to Massachusetts, Exclusive of Lower Peninsula Florida, Smithsonian Institution Press, 409 pp.

Gao, B., K. Heidebrecht, and A. Goetz, 1993, “Derivation of Scale Surface Reflectances from AVIRIS Data,” Remote Sens. Environ., vol. 44, pp. 165-178.

Garcia, M., and S. L. Ustin, 2001, “Detection of Interannual Vegetation Responses to Climatic Variability Using AVIRIS Data in a Coastal Savanna in California,” IEEE Transactions of Geoscience and Remote Sensing, vol. 39, no. 7., pp. 1480-1490.

Godfrey, P. J., 1976, “Barrier Island of the East Coast,” Oceanus, vol. 19, no. 5, pp. 27-40.

Gorman, L., A. Morang, and R. Larson, 1998, “Monitoring the Coastal Environment; Part IV: Mapping, Shoreline Changes, and Bathymetric Analysis,” J. Coastal Res., vol. 14, no. 1, pp. 61–92.

Jensen, J. R., 1996, Introductory Digital Image Processing: A Remote Sensing Perspective, Prentice-Hall, Inc., 231 pp.

Koeln, G., and J. Bissonnette, 2000, “Cross-Correlation Analysis: Mapping Land Cover Change with a Historic Land Cover Database and a Recent, Single-Date Multispectral Image,” Proc. 2000 ASPRS Annual Convention, Washington, D.C. Also online [accessed 18 June 2002]: http://www.glc.org/monitoring/wetlands/subcommittees/CCA_Paper.doc.

Louisiana Department of Natural Resources, 1998, Coast 2050: Toward a Sustainable Coastal Louisiana, Louisiana Coastal Wetlands Conservation and Restoration Task Force and the Wetlands Conservation and Restoration Authority, Baton Rouge, Louisiana, 161 pp. Also online [accessed 27 August 2002]: http://www.coast2050.gov/report.pdf.

Neuenschwander, A. L., M. M. Crawford, and M. J. Provancha, 1998, “Mapping of Coastal Wetlands via Hyperspectral AVIRIS Data,” Proceedings of the 1998 International Geoscience and Remote Sensing Symposium, Seattle, Washington, July 6-10, 1998, pp. 189-191.

Otvos, E. G., 1981, “Barrier Island Evolution and History of Migration, North Central Gulf,” Mar. Geol., vol. 43, pp. 195-243.

Otvos, E. G., 1995, “Coastal Field Trip: New Orleans, Louisiana to Pensacola Beach, Florida,” Geological Society of America Annual Meeting, Field Trip Guidebook No. 4, pp. 95-128.

Otvos, E. G., J. P. Spruce, and M. J. Giardino, 2001, Remote-Sensing Mapping of West Ship Island Surface Environments, Coastal Mississippi, Final Report Submitted to NASA Summer Faculty Program, Stennis Space Center, Mississippi, 19 pp.

Schmid, K., 2001, West Ship Island Evolution, Morphology, and Hurricane Response – 1995 to 2000, Mississippi Department of Environmental Quality, Office of Geology, Open File Report 133, 36 pp.

Shao, G., D. R. Young, J. H. Porter, and B. P. Hayden, 1998, "An Integration of Remote Sensing and GIS to Examine the Responses of Shrub Thicket Distributions to Shoreline Changes on Barrier Islands," J. Coastal Res., vol. 14, pp. 299-307.

Spruce, J. P., 2001, "Low-Altitude AVIRIS Data for Mapping Land Cover in Yellowstone National Park: Use of ISODATA Clustering Techniques," Proceedings of the Tenth JPL Airborne Earth Science Workshop, February 27-March 2, Jet Propulsion Laboratory, Pasadena, California, pp. 387-396. Also online [accessed 2 September 2002]: http://popo.jpl.nasa.gov/docs/workshops/01_docs/2001Spruce_web.pdf.

Spruce, J. P., A. S. Warner, and G. Terrie, 2001, "Development of Ground Reference GIS for Assessing Land Cover Maps of Northeast Yellowstone National Park," Poster, 2001 ESRI Conference, San Diego, California.

Tiner, R. W., 1993, Field Guide to Coastal Wetland Plants of the Southeastern United States, University of Massachusetts Press, 329 pp.

Tiner, R., 1997, Identifying and Monitoring Wetlands, In: Manual of Photographic Interpretation, second edition, W. R. Phillipson (ed.), ASPRS, Bethesda, Maryland, pp. 475-494.

Torres-Pulliza, D., J. Brock, C. Lea, and M. Duffy, 2002, "Classification of Barrier Island Land Cover Using Aerial Photography and Lidar Airborne Remote Sensing," Proceedings of the 5th International Airborne Remote Sensing Conference and Exhibition, Miami, Florida, Ann Arbor, Michigan, CD-ROM, 8 pp.

Ustin, S., 2001, "Hyperspectral Techniques for Identification of Invasive Weeds," Poster, Proceedings of 2001 Strategic Environmental Research and Development Program Symposium. Also online [accessed 2 September 2002]: poster at http://www.serdp.org/symposiums/2001/presentations/2C-Ustin.pdf and abstract at http://www.serdp.org/symposiums/2001/PosterAbstracts.pdf.

Way, D. S., and J. R. Everett, 1997, Landforms and Geology, In: Manual of Photographic Interpretation, second edition, W. R. Phillipson (ed.), ASPRS, Bethesda, Maryland, pp. 117-165.

Wilen, W., and G. Smith, 1996, "Assessment of Remote Sensing/GIS Technologies to Improve National Wetlands Inventory Maps," Proceedings of the Sixth Biennial Remote Sensing Conference, April 29-May 3, Denver, Colorado, pp. 50-64.

Williams, S. J., S. Penland, and A. H. Sallenger, Jr. (eds.), 1992, Louisiana Barrier Island Erosion Study: Atlas of Shoreline Changes in Louisiana from 1853 to 1989, U.S. Geological Survey and Louisiana Geological Survey, 103 pp.