Developing Coastal Surface Roughness Maps Using ASTER and QuickBird Data Sources

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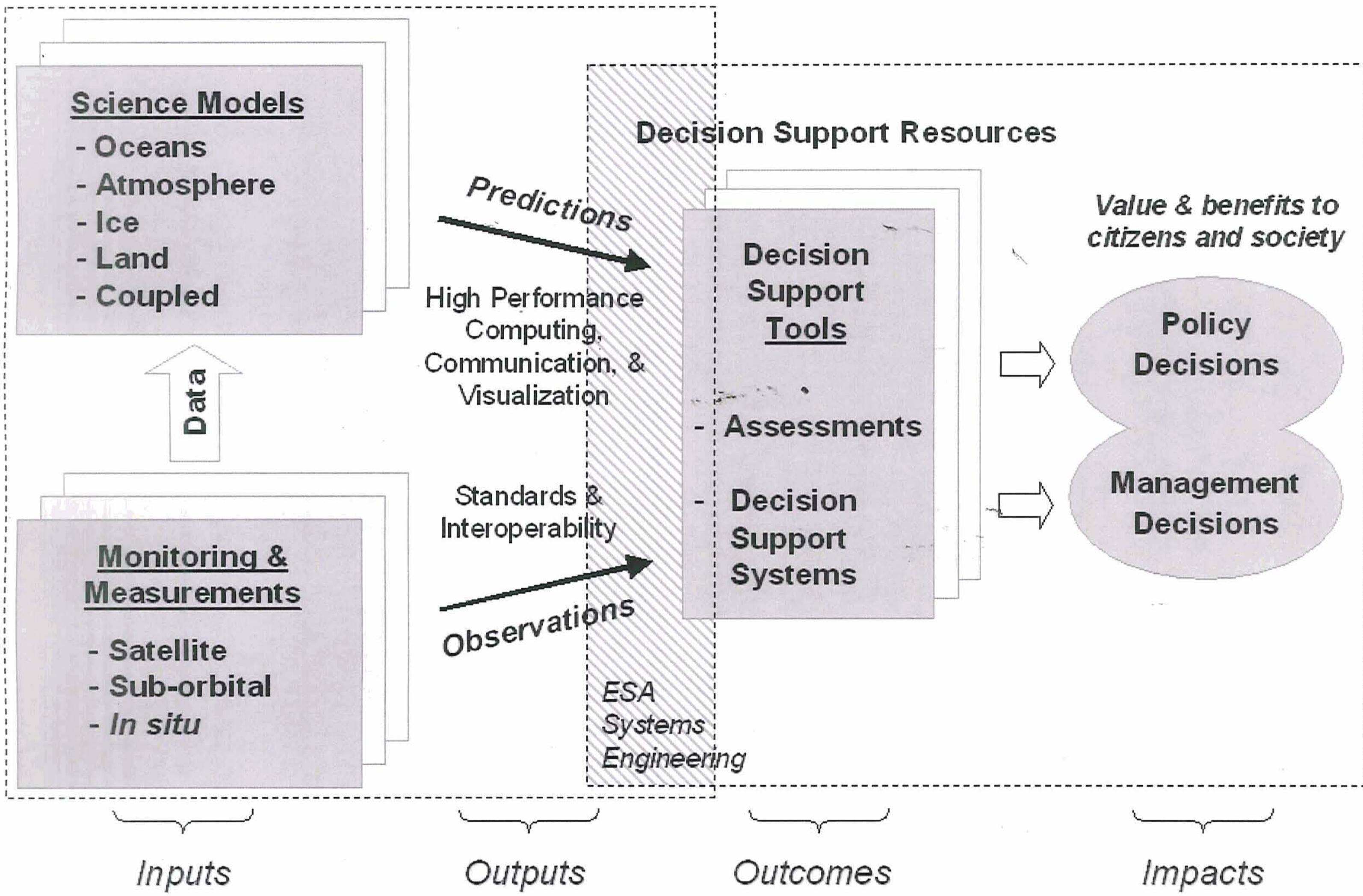
Discussion Items

- Introduction
- Selection of Initial Study Area
- Remote Sensing and GIS Data Used in Initial Study
- Remotely Sensed Data Processing Methods
- Preliminary Results
- Concluding Remarks

Project Background

- This presentation regards one element of a larger project on the integration of NASA science models and data into the Hazards U.S. Multi-Hazard (HAZUS-MH) Hurricane module for hurricane damage and loss risk assessment.
- HAZUS-MH is a decision support tool being developed by the National Institute of Building Sciences for the Federal Emergency Management Agency (FEMA). It includes the Hurricane Module, which employs surface roughness maps made from National Land Cover Data (NLCD) maps to estimate coastal hurricane wind damage and loss. NLCD maps are produced and distributed by the U.S. Geological Survey.
- This presentation discusses an effort to improve upon current HAZUS surface roughness maps by employing ASTER multispectral classifications with QuickBird "ground reference" imagery.

Role of NASA in Enhancing Decision Support Tools Like HAZUS-MH



Aerodynamic Surface Roughness and z_0

- Aerodynamic surface roughness: the variation in an area's terrain and surface cover and its influence on wind flow across its extent.
  - Smooth surface types include open water and fallow bare fields.
  - Rough surface types can include forest and built-up urban areas with more heterogeneous arrangements of surface obstacles.

- Aerodynamic roughness length (z_0): the height above the surface level at which the mean wind speed becomes zero because of characteristics of local surface roughness elements.

- z_0 is a parameter used to measure terrain roughness due to ground surface roughness elements, such as buildings, trees, and other obstructions. HAZUS-MH employs z_0 maps derived from NLCD products and look-up tables (LUTs).

HAZUS-MH Wind Module User Interface

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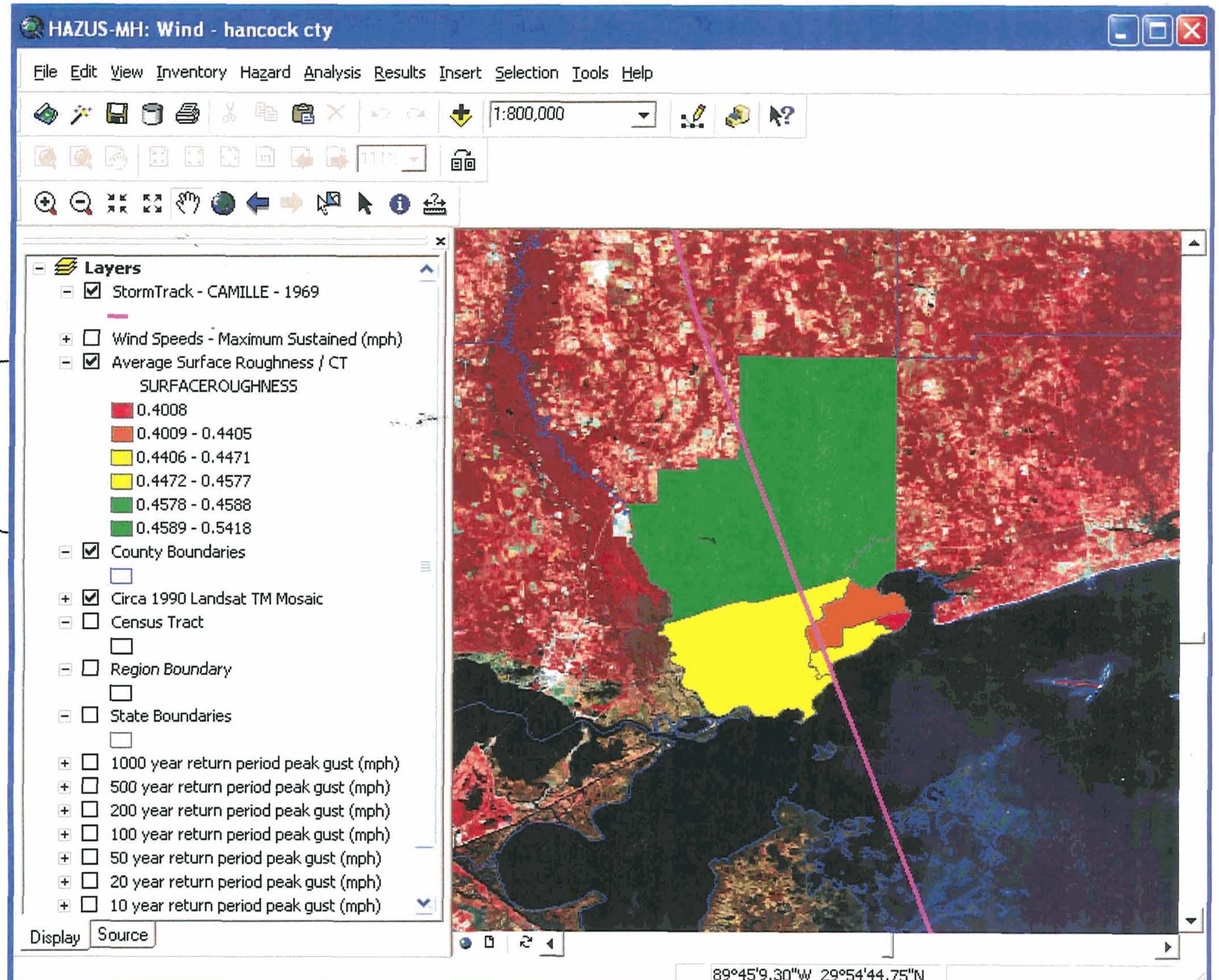
HAZUS-MH / ArcGIS Example for Hancock County, Mississippi

HAZUS-MH Hurricane Module uses NLCD-based surface roughness averaged by census tract



Total Loss / Total Value Compared to Peak Gust Wind Speed Per LULC

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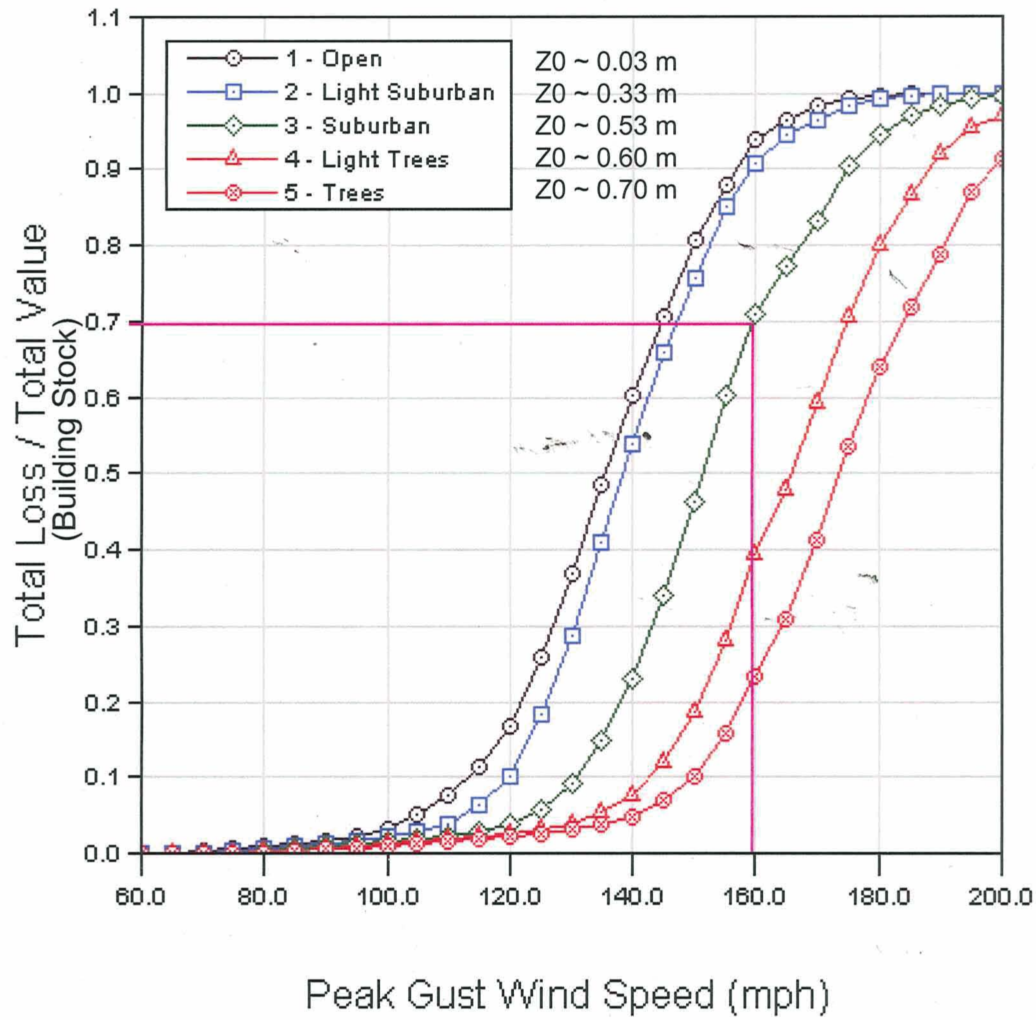
Property in Open Terrain Experience More Loss at Lower Hurricane Wind Speeds



Source: FEMA (2003)

Research Objectives

- Investigate NASA and commercial remote sensing data for improving surface roughness mapping inputs to the HAZUS-MH Hurricane Module.
  - Can NASA remote sensing data (e.g., ASTER) be used to improve regional coastal surface roughness estimation, compared to current maps from 1992 NLCD?
  - Can high-resolution commercial satellite imagery be useful in a reference capacity for improving regional maps of coastal surface roughness?
- Assess data processing techniques for remote sensing based surface roughness estimation, including
  - Indirect measures of surface roughness, such as from LULC maps and look-up tables (LUTs).
  - Estimates of surface roughness elements (e.g., average height, width, density of buildings, trees, or other surface obstacles) that can be used to improve regional surface roughness maps.

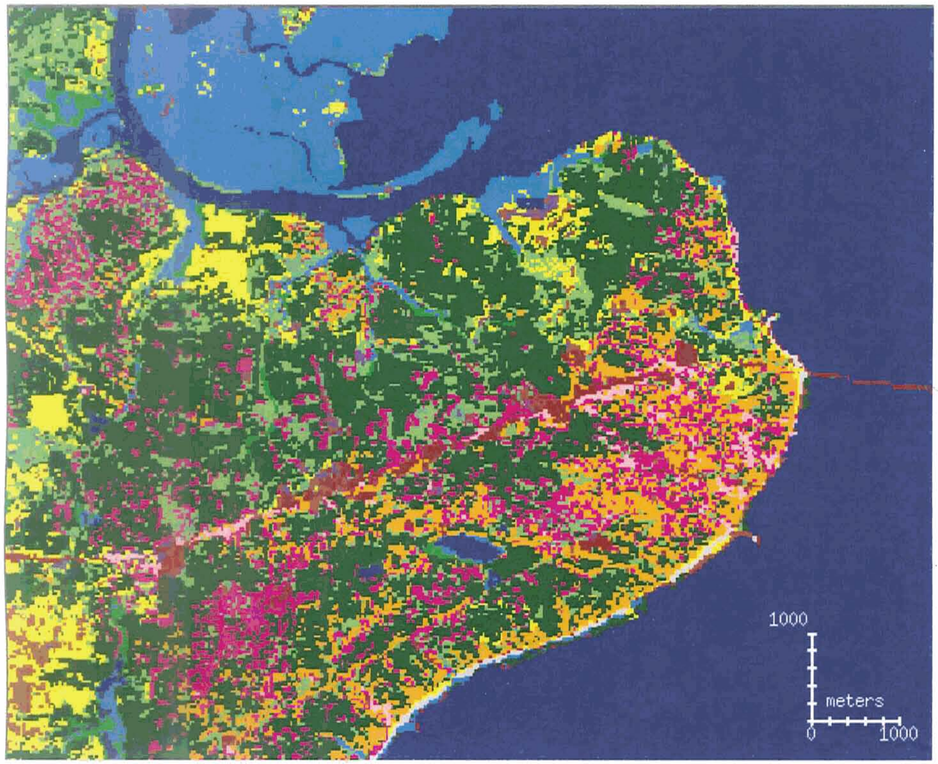
NLCD Map vs. Landsat – Bay St. Louis

TM data acquired 11/1/1990

continued

NLCD Map vs. Landsat – Bay St. Louis

1992 NLCD map overlain onto TM data
acquired 11/1/1990



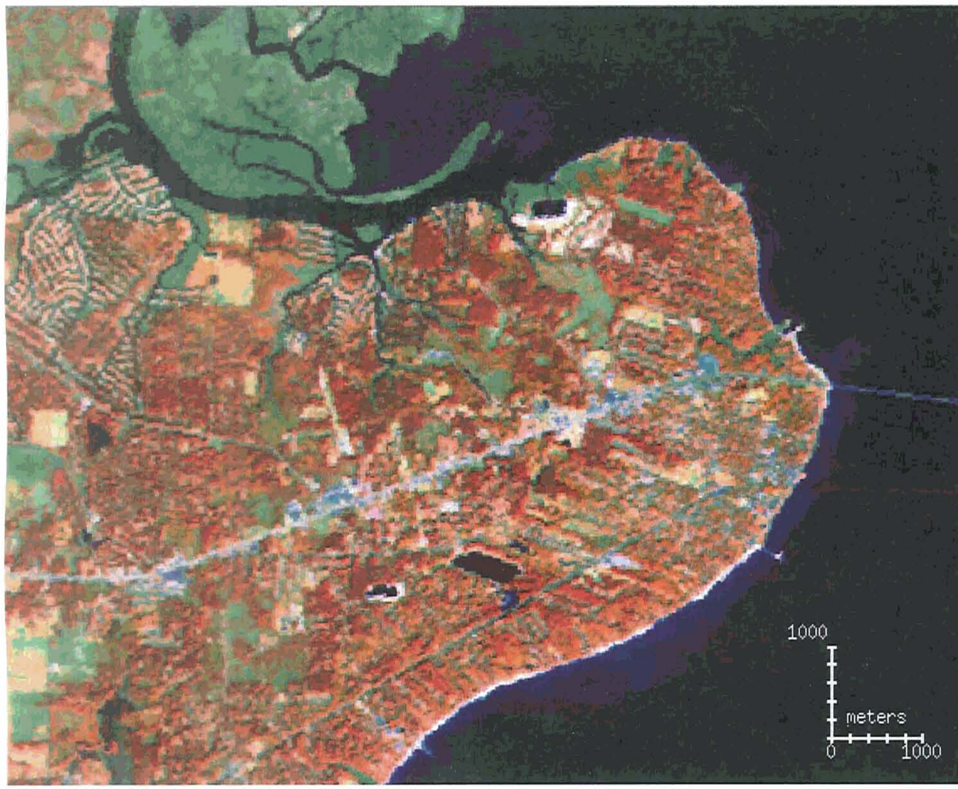
Legend for NLCD Map

Color	Class #	Class Description	HAZUS z_0
	11	Open Water	0.01
	21	Low Intensity Residential	0.33
	22	High Intensity Residential	0.53
	23	Commercial/Industrial/Transportation	0.35
	31	Bare Rock/Sand/Clay	0.09
	32	Quarries/Strip Mines/Gravel Pits	0.18
	33	Transitional (e.g., Clearcut Forest)	0.20
	41	Deciduous Forest	0.68
	42	Evergreen Forest	0.73
	43	Mixed Forest	0.71
	51	Shrubland	0.12
	71	Grassland/Herbaceous	0.04
	81	Pasture/Hay	0.05
	82	Row Crops	0.05
	83	Small Grains	0.06
	84	Fallow	0.04
	85	Urban/Recreational Grasses	0.03
	91	Woody Wetlands	0.58
	92	Emergent Herbaceous Wetlands	0.09

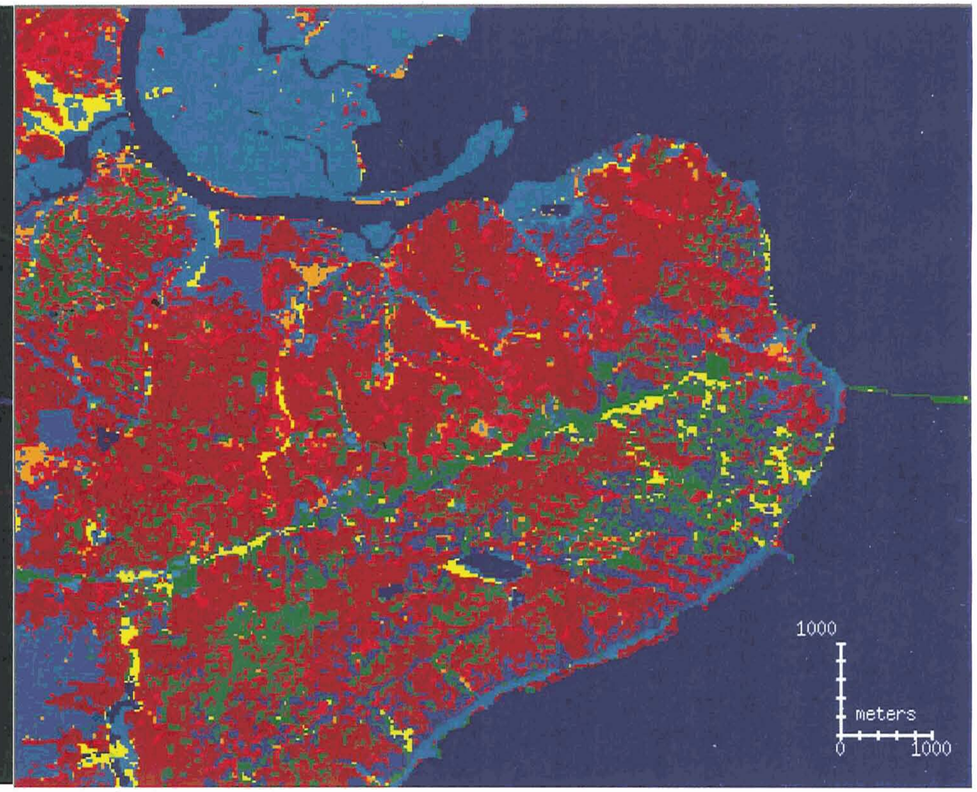
The 1992 NLCD over Bay St. Louis provides an example of mapping performance for small coastal cities. Residential housing densities are mapped using Landsat, TIGER Census Block, and digital line graph road GIS data.

Surface Roughness Map From NLCD

1990 Landsat Data Compared to Surface Roughness Map
from 1992 National Land Cover Data
Location: Bay Saint Louis, Mississippi Gulf Coast



Landsat RGB from Bands 4,5,3



Surface Roughness (in meters)

Why ASTER Data for Mapping z_0?

- HAZUS software currently uses LUTs and NLCD LULC maps (from Landsat), plus Tiger GIS data to map average surface roughness (z_0) per census tract.
- From the NASA Terra satellite, ASTER VNIR multispectral imagery has 15 meter resolution, higher than Landsat TM and ETM+ data. ASTER LULC classifications may improve mapping of coastal residential areas.
- Improved surface roughness mapping inputs to HAZUS-MH should help estimates of hurricane wind property damage and loss because model shows high sensitivity to surface roughness variation (FEMA, 2003; Lavelle et al., 2003).
  - z_0 change of ~5-10% for county scale runs caused discernable changes in model output for a 100 mph storm over Broward County, Florida (see next slide).

z_0 Sensitivity Effects on HAZUS-MH Output

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Summary of HAZUS-MH Sensitivity Analysis Done for Broward County, Florida

z0 Setting Per Run (Category 2 Hurricane)	Brick & Wood Debris (% change)	Concrete & Steel Debris (% change)	Residences Destroyed (% change)	BRELE[1] (% change)	BRELE (change in $1000 units)
z0 (default)	655,640 tons	3,509 tons	620 residences	$4,279,190	$4,279,190
z0 - 100% (smoothest)	130%	1135%	967%	185%	$7,898,797
z0 - 75%	89%	738%	613%	133%	$5,692,410
z0 - 50%	41%	260%	215%	68%	$2,920,481
z0 - 25%	18%	103%	88%	29%	$1,237,484
z0 - 10%	6%	28%	27%	9%	$384,015
z0 - 5%	3%	13%	13%	4%	$187,907
z0 + 5%	-2%	-14%	-11%	-4%	-$163,204
z0 + 10%	-4%	-20%	-19%	-7%	-$288,905
z0 + 25%	-10%	-39%	-38%	-14%	-$610,218
z0 + 50%	-17%	-60%	-57%	-24%	-$1,012,895
z0 + 75%	-23%	-75%	-72%	-31%	-$1,346,009
z0 + 100%	-26%	-84%	-81%	-36%	-$1,543,640
z0 + 200% (roughest)	-30%	-94%	-92%	-41%	-$1,757,180

[1]BRELE = Total Building Related Economic Loss Estimate

ASTER Imagery of Stennis Space Center

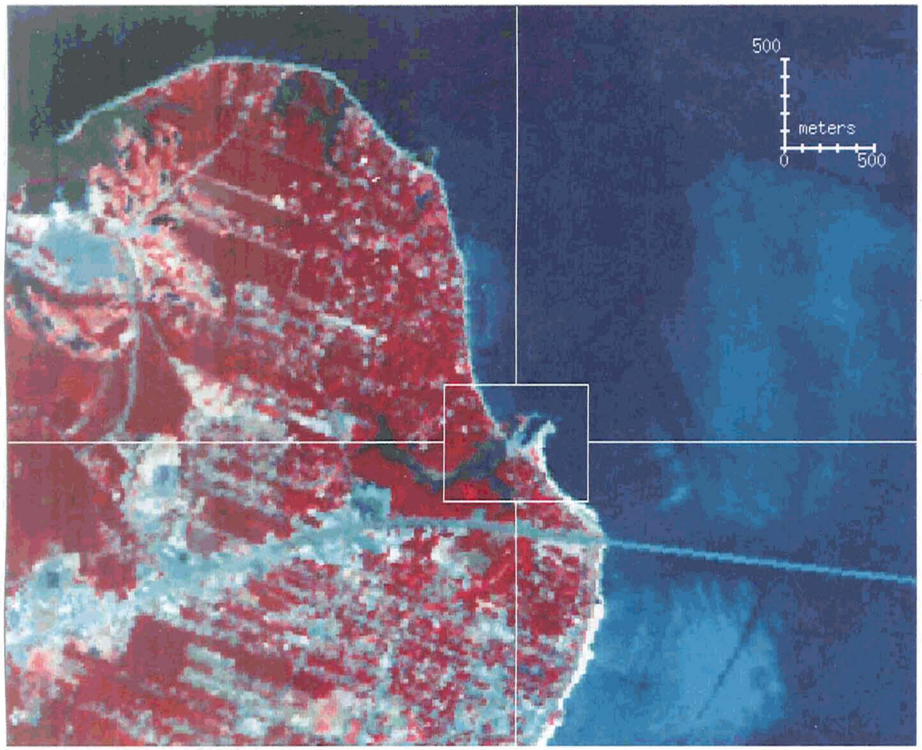
ASTER Bands 3,2,1 RGB
Acquired 8/16/2000

Landsat ETM+ Bands 4,3,2 RGB
Acquired 9/17/2000

ASTER imagery depicts linear features better than Landsat ETM+; however, pan-sharpened Landsat ETM+ tends to produce comparable displays.

ASTER Compared to QuickBird Imagery

ASTER VNIR RGB
15-Meter Resolution



Pan-Sharpened QuickBird RGB
0.7-Meter Resolution

Location of Imagery: Bay Saint Louis, Mississippi

NLCD LULC Mapping Accuracy – Southeast USA

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Overall Accuracy of 1992 NLCD Map: 0.81 (on scale of 0 to 1)
Based on Aerial Photo Comparison by USGS

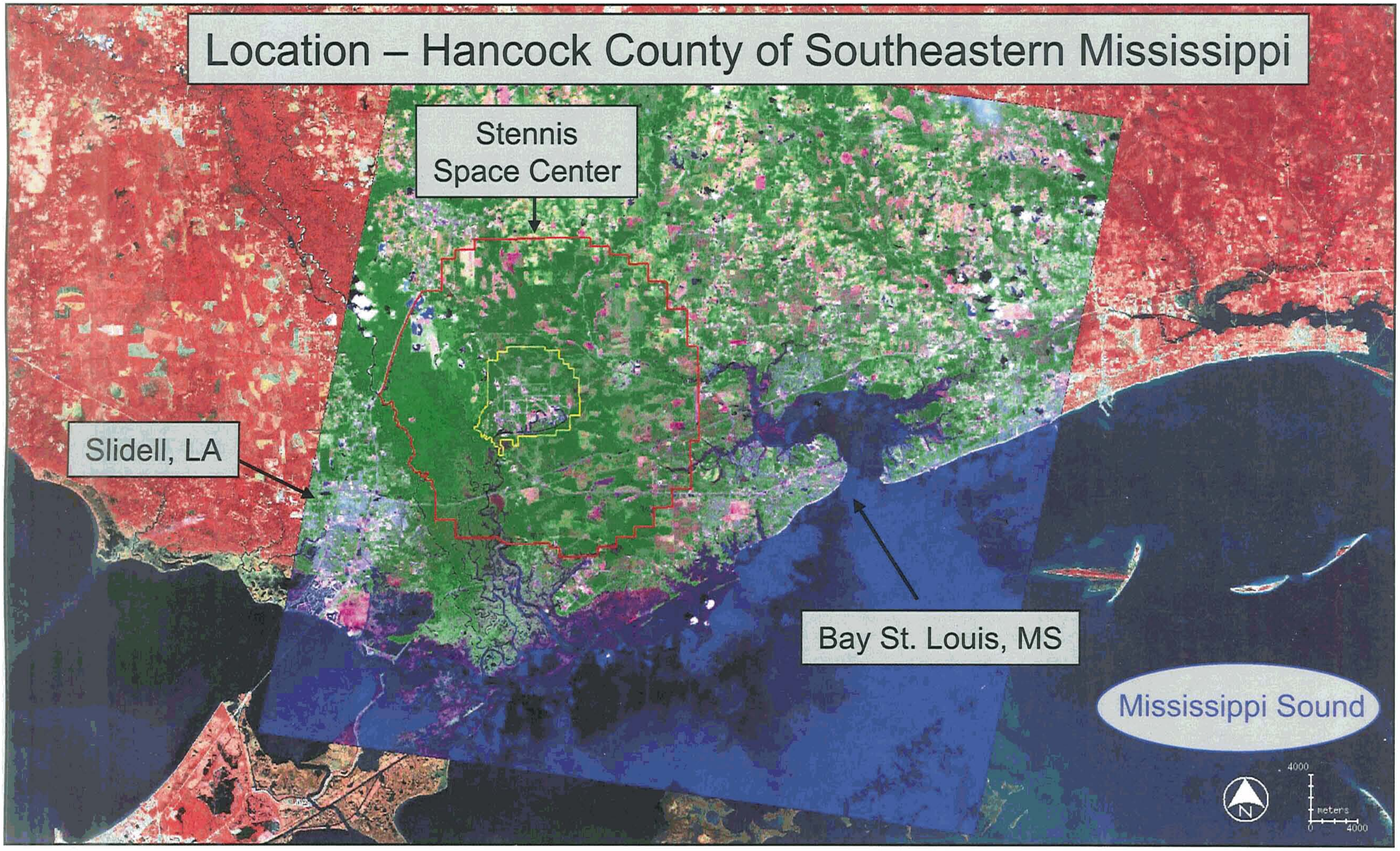
Accuracy of Common NLCD Types for Southeast USA

NLCD Class	NLCD Class Description (Modified Anderson Level 2)	User's Accuracy	Producer's Accuracy	Z0 LUT (meters)
11	Water	1.00	0.96	0.010
21	Low density residential	0.38	0.55	0.330
22	High density residential	0.23	0.29	0.530
23	Commercial/industrial/transportation.	0.65	0.54	0.350
31	Bare rock/sand/clay	0.57	0.95	0.090
32	Mining	0.48	1.0	0.180
33	Transitional	0.40	0.5	0.200
41	Deciduous forest	0.86	0.93	0.680
42	Evergreen forest	0.8	0.97	0.730
43	Mixed forest	1.0	0.24	0.710
81	Shrubland	0.69	0.03	0.120
82	Hay and pasture	0.82	0.11	0.050
85	Urban grass	0.5	0.23	0.030
91	Woody wetlands	0.77	0.94	0.580
92	Emergent herbaceous wetland	0.95	0.94	0.090

- The accuracies reported at left are based on majority agreement across 3x3 pixel sampling areas.
- User accuracy regards commission error; producer accuracy regards omission error.
- Reference: Stehman et al. (2003)
- The z_0 LUTs are those used by the HAZUS software for coastal Mississippi (source: Applied Research Associates).

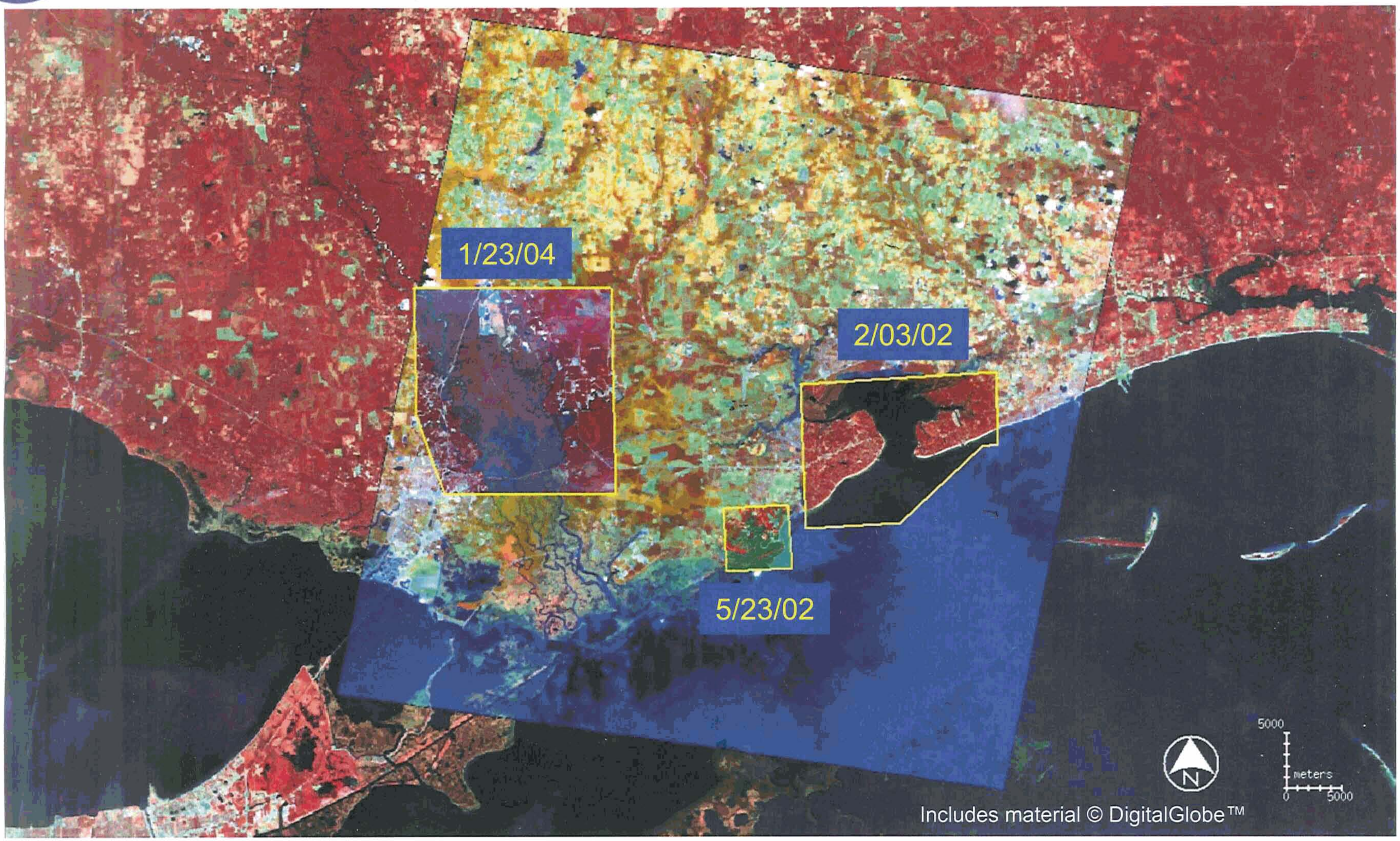
In terms of z_0 estimation, Landsat 1992 NLCD does not map urban development types as well as desired, partially due to spectrally mixed pixels occurring at the Landsat spatial resolution.

ASTER Multispectral Data Used in Study



ASTER Image in Foreground was Acquired August 16, 2000
(Circa 1990 Landsat TM Mosaic is Shown in Background)

QuickBird Scenes Used in Study



QuickBird Data Overlain onto Circa 2000 ASTER Scene
(Circa 1990 Landsat TM Mosaic in Extreme Background)

Preparing ASTER Data for Image Classification

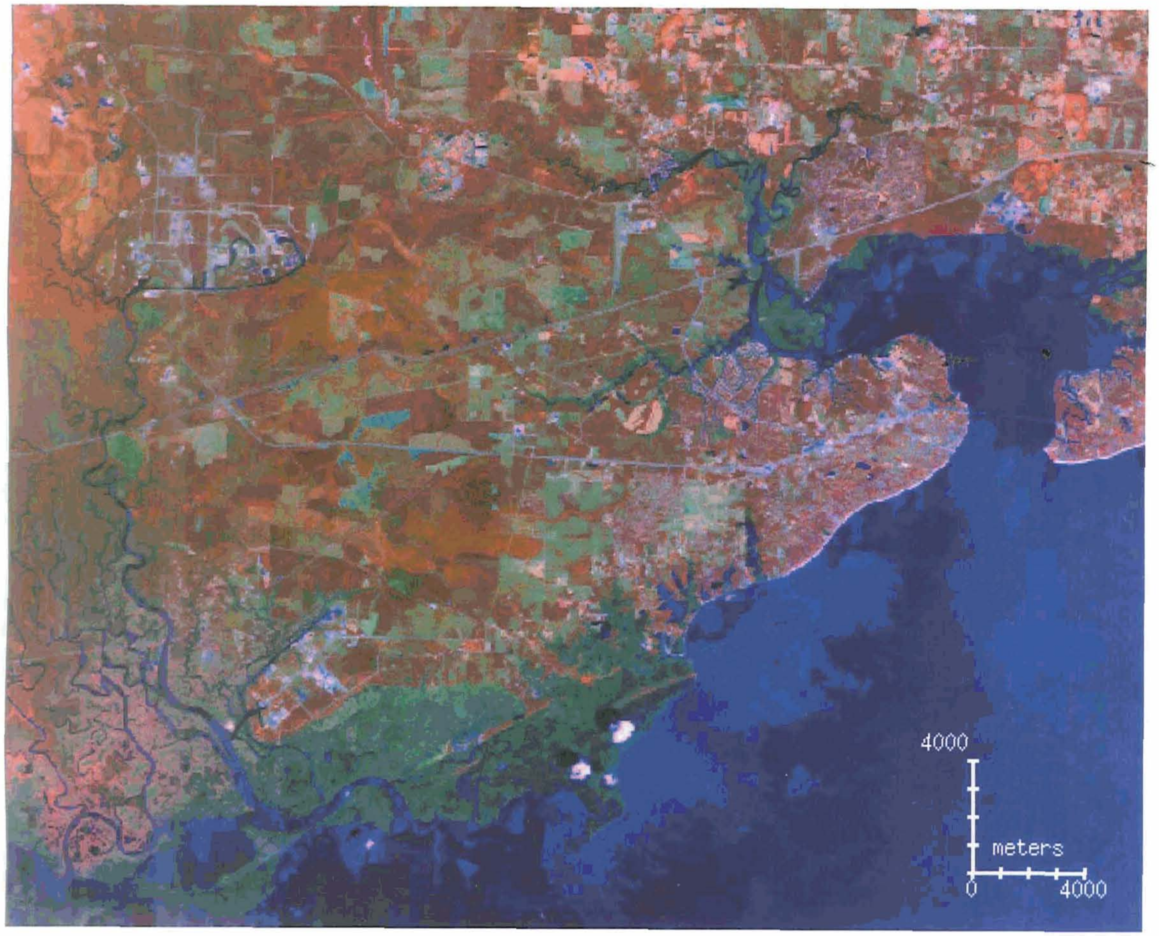
1. Import ASTER VNIR and SWIR data into ERDAS IMAGINE format.
2. Co-register SWIR to VNIR bands.
3. Pan-sharpen SWIR to VNIR bands.
   - Employed Local Mean and Variance Matching (LMVM) filtering technique described by de Béthune et al. (1998).
4. Georegister ASTER data to Landsat TM orthorectified data.
5. Compute band ratios (NDVI and NDMI).
   - NDMI (moisture index) = (SWIR1-NIR1) / (SWIR1+NIR1) – based on TM band 5/4 moisture stress index by Hunt and Rock (1989)
   - Band ratios were computed to improve classification performance
6. Create composite data stack of VNIR and SWIR bands plus band ratios (11 total bands).

Steps for Initial ASTER Classification

1. Produce preliminary ISODATA unsupervised classification to mask out cloud- and shadow-covered areas from preprocessed ASTER scene.
   - Each run = 50 maximum iterations or until there was 99% agreement between successive iterations
   - Edit output as needed using GIS editing techniques
2. Run ISODATA classification on cloud- and shadow-removed preprocessed ASTER scene, producing first-cut classification (~Anderson Level 1).
   - Assign cluster classes into general land-cover categories based on comparison to ASTER, DOQQ, and QuickBird RGBs.

Result of First-Cut ASTER Classification

ASTER First-Cut Classification
versus ASTER RGB Color Composite



- Classification of 6 general classes, excluding clouds and cloud shadows.
- Noteworthy confusion occurs between marsh, river water, forest, and forested residential areas.
- Raw data for each of these general classes were later reclassified into NLCD classes using ISODATA clustering techniques.

continued

Result of First-Cut ASTER Classification

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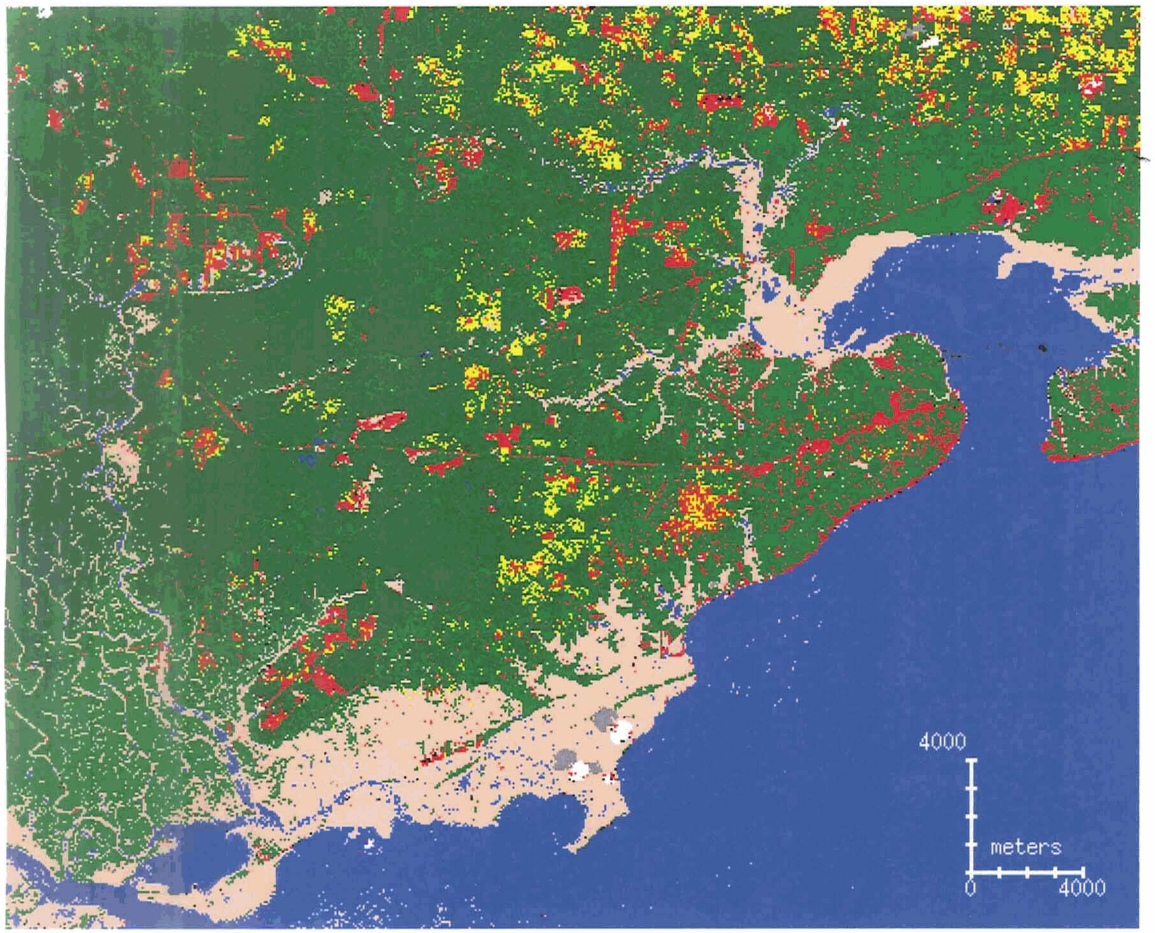
ASTER First-Cut Classification versus ASTER RGB Color Composite



- Classification of 6 general classes, excluding clouds and cloud shadows.
- Noteworthy confusion occurs between marsh, river water, forest, and forested residential areas.
- Raw data for each of these general classes were later reclassified into NLCD classes using ISODATA clustering techniques.

Row	Color	Class_Names
0		
1		water
2		bare inert surfaces
3		herb dominated clearing
4		brown marsh+ (includes water)
5		green marsh+ (includes forest)
6		forest and scrub
7		clouds
8		cloud shadows

Steps for Refining ASTER Classification

1. Employ ISODATA cluster busting techniques (Jensen et al.,1987) to independently reclassify each general category of land use/land cover.
   - Done for 6 broad LULC categories
2. For each reclassification, assign each cluster class to the predominant NLCD land use/land cover category, based on comparison to high-resolution remote sensing and field survey data.
   - For each reclassification, the number of clusters was set to twice the number of tones evident on masked raw data RGBs
3. As needed, refine reclassifications using GIS techniques on conditional basis.
   - Done either interactively or through automated spatial model

Refined ASTER Classifications – "Bare Inert"

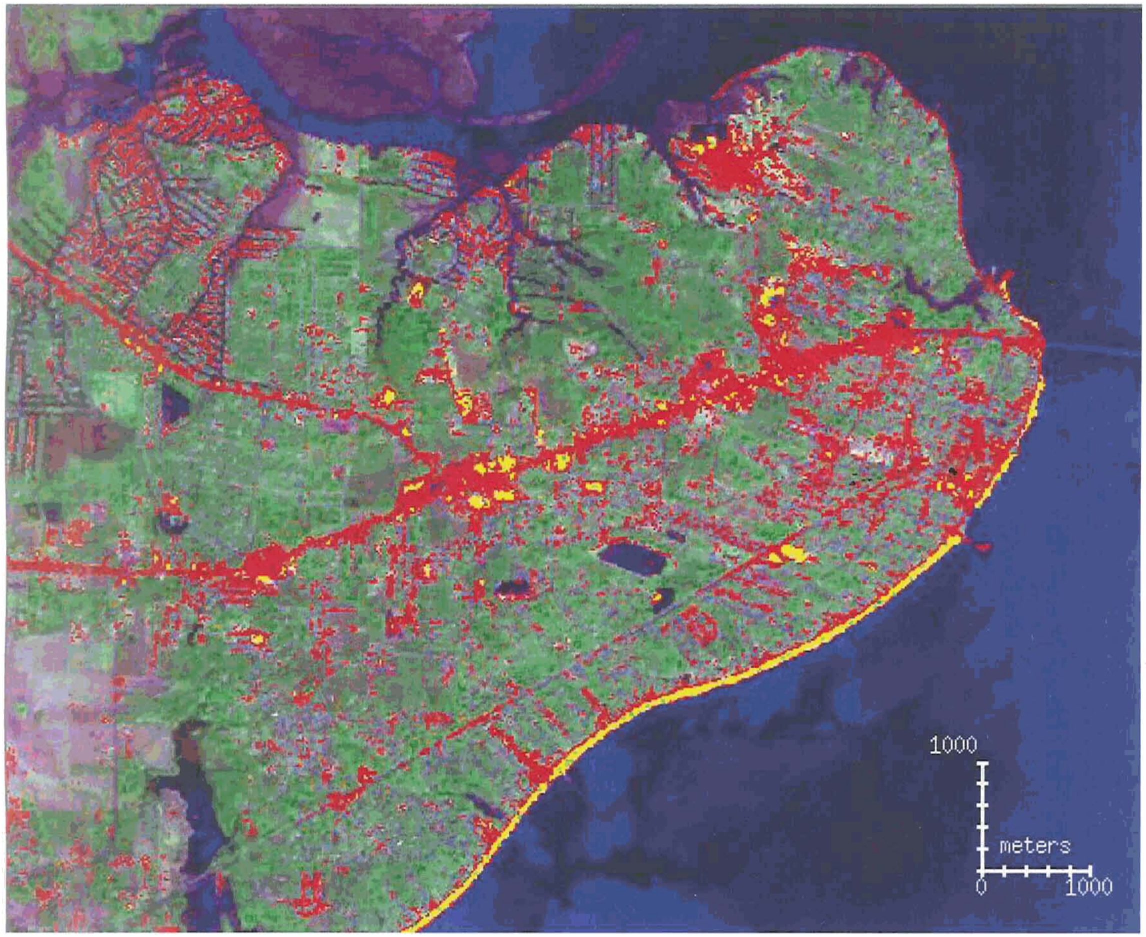
ASTER Reclassification of Urban Surfaces Compared to ASTER RGB

Backdrop – ASTER RGB
Location – Bay St. Louis, MS

continued

Refined ASTER Classifications – "Bare Inert"

ASTER Reclassification of Urban Surfaces Compared to ASTER RGB



Red = Commercial, Industrial, and Transportation (NLCD Class 23) with some Residential Housing (NLCD Classes 21-22)

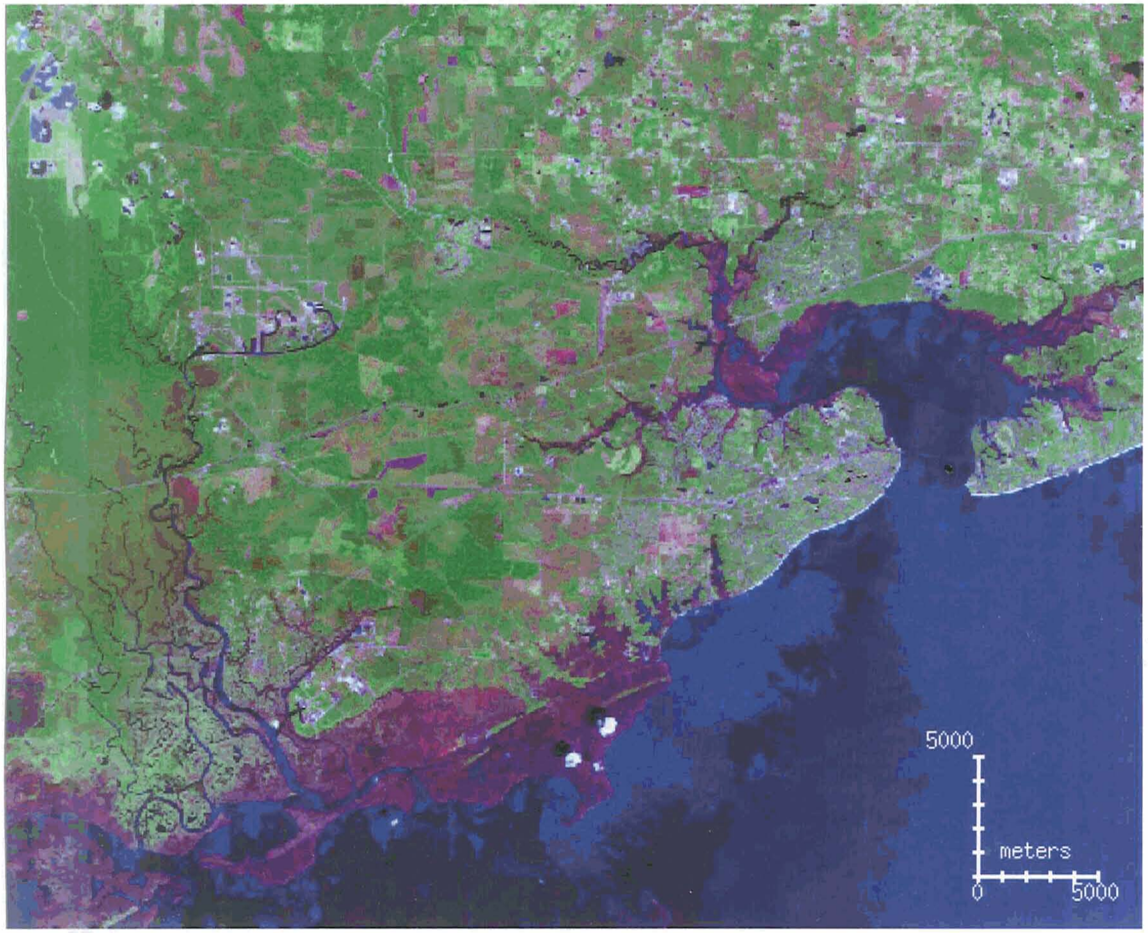
Yellow = Bare Rock, Sand, and Clay (NLCD Class 31) with some Commercial (NLCD Class 23)

Backdrop – ASTER RGB
Location – Bay St. Louis, MS

Urban LULC types are reclassified correctly at the local scale, though often confused regionally. To clarify, interactive GIS editing was used to separate spectrally similar LULC types into more discrete categories.

ASTER Classifications – "Green Marsh"

ASTER Reclassification of "Green Marsh" – Prior to GIS Editing

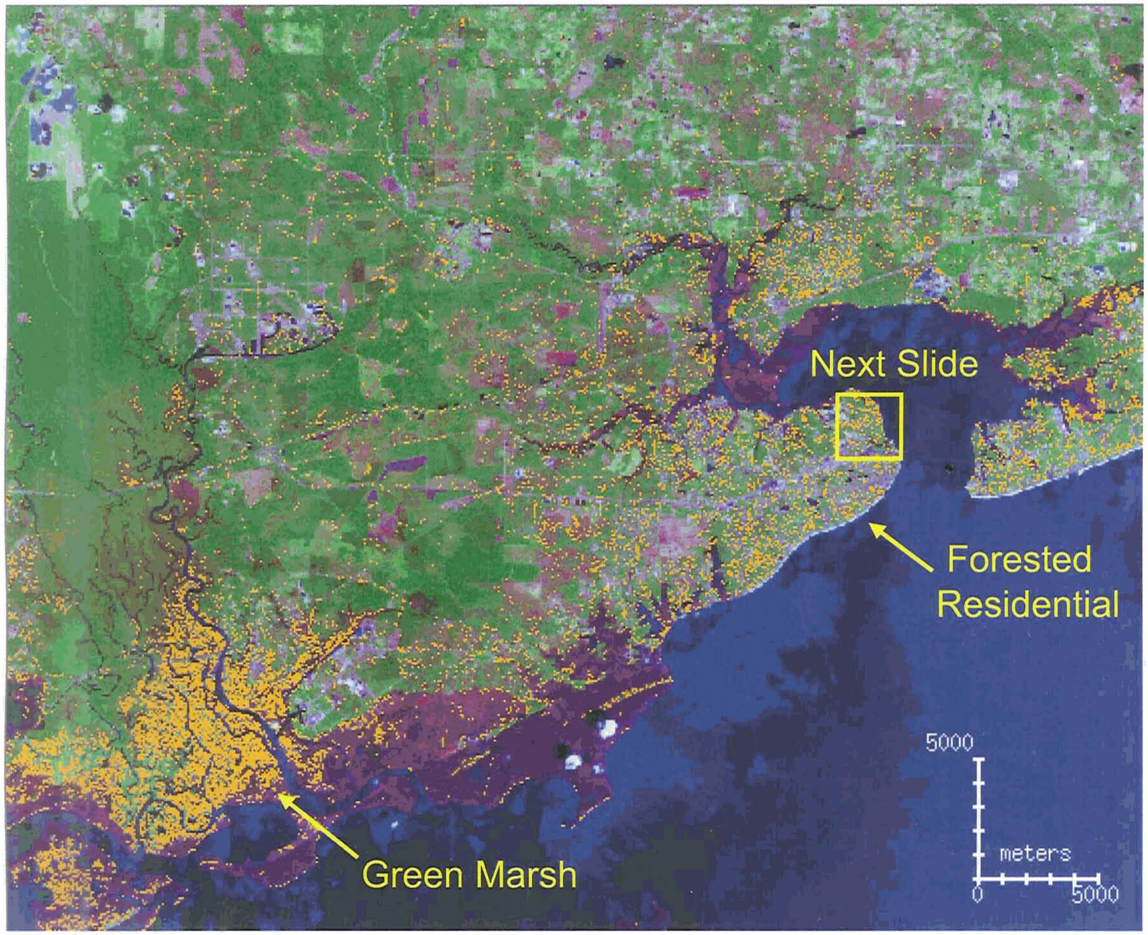


Backdrop – ASTER RGB
Location – South Hancock County, MS

continued

ASTER Classifications – "Green Marsh"

ASTER Reclassification of "Green Marsh" – Prior to GIS Editing



Orange = Emergent Herbaceous Wetlands, Residential Areas, Transportation, and Transitional Areas

Backdrop – ASTER RGB
Location – South Hancock County, MS

Reclassified green marsh remained confused, often with forested, low-density residential areas. To clarify, GIS-based interactive editing needed to be applied.

ASTER Classifications – Residential Areas

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Zoom of Reclassified ASTER “Green Marsh+” Versus QuickBird Data

Backdrop – Pan-Sharpened QuickBird RGB
Location – Bay St. Louis, MS

Includes material © DigitalGlobe™

Five cluster classes from the reclassified “Green Marsh” have a strong association with residential areas. GIS editing is feasible because the confused marsh and residential areas occur in different locations.

continued

ASTER Classifications – Residential Areas

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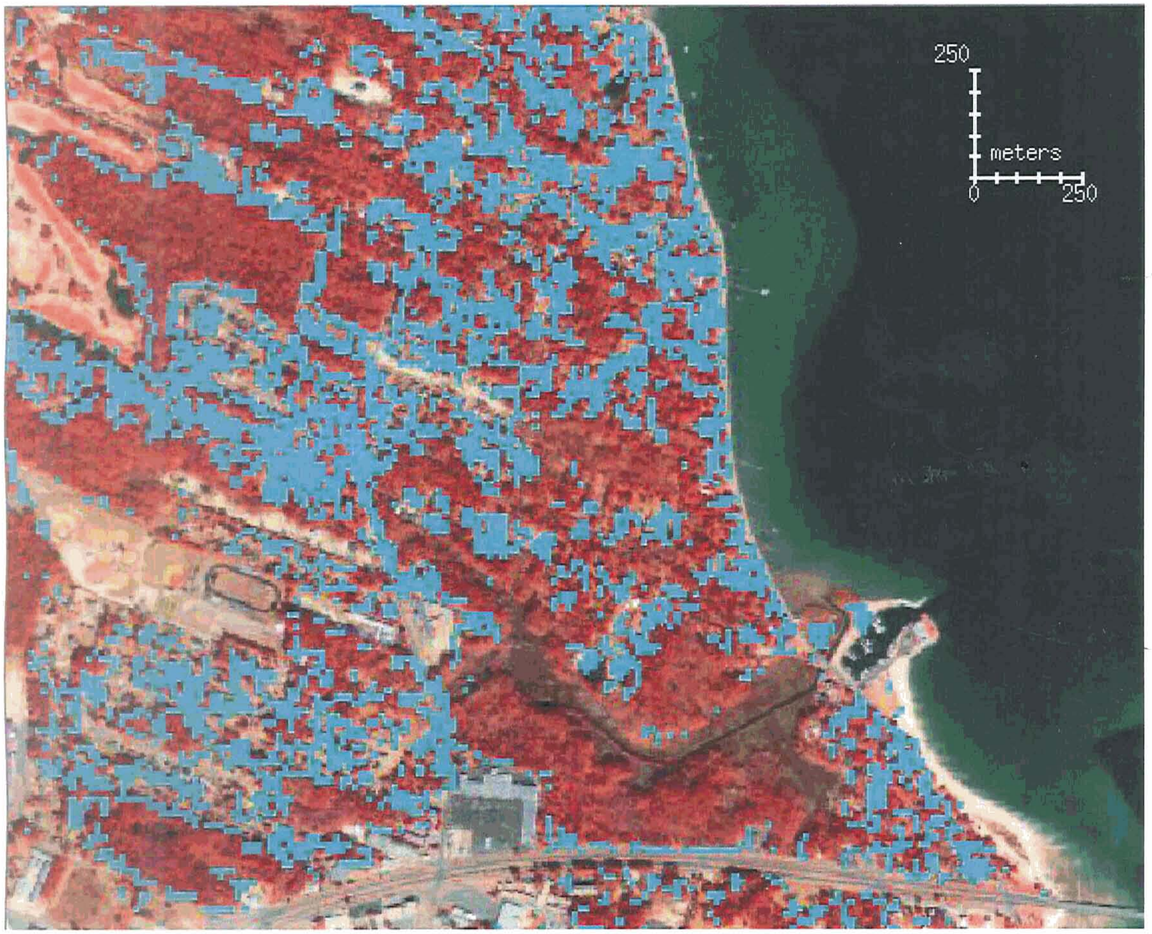
Zoom of Reclassified ASTER "Green Marsh+" Versus QuickBird Data



Includes material © DigitalGlobe™

Cyan = Emergent Herbaceous Wetlands and Residential Areas with some Transportation and Transitional Areas

Backdrop – Pan-Sharpened QuickBird RGB
Location – Bay St. Louis, MS

Once GIS editing is applied, general location of residential areas can be depicted with ASTER data, although some confusion with forest still occurs.

Five cluster classes from the reclassified "Green Marsh" have a strong association with residential areas. GIS editing is feasible because the confused marsh and residential areas occur in different locations.

NLCD Classification – Residential Areas

Zoom of 1992 NLCD Residential Area Compared to QuickBird RGB

Backdrop – QuickBird RGB
Location – Bay St. Louis, MS
(North of Highway 90)

continued

NLCD Classification – Residential Areas

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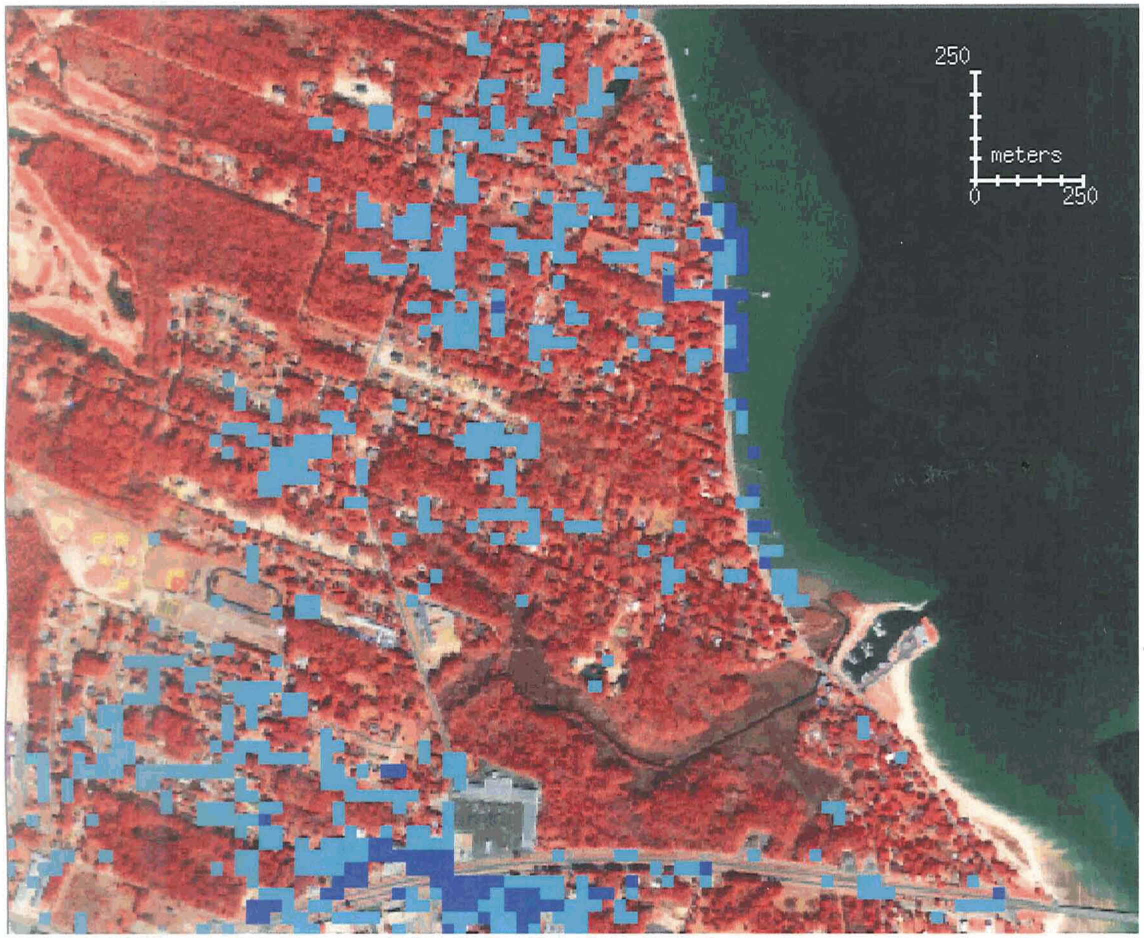
Zoom of 1992 NLCD Residential Area Compared to QuickBird RGB



Cyan = Low Density Residential
Blue = High Density Residential

Backdrop – QuickBird RGB
Location – Bay St. Louis, MS
(North of Highway 90)

The 1992 NLCD appears to under-classify forested, low-density residential areas in Bay St. Louis, MS (partially because of environmental change since 1992).

Example of Edited ASTER Classification

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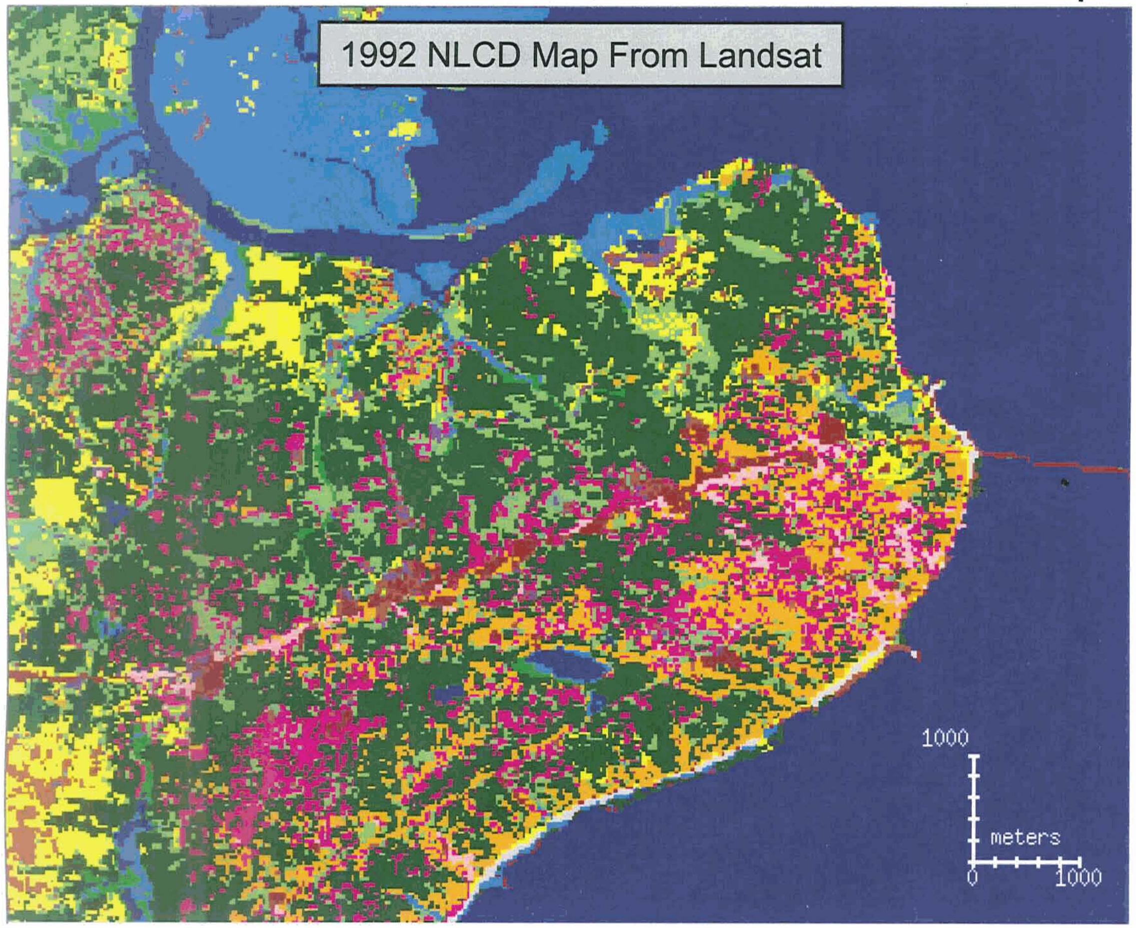
Edited ASTER NLCD Classification Compared to 1992 NLCD Map



Color	Class #	Class Description
	11	Open Water
	21	Low Intensity Residential
	22	High Intensity Residential
	23	Commercial/Industrial/Transportation
	31	Bare Rock/Sand/Clay
	32	Quarries/Strip Mines/Gravel Pits
	33	Transitional (e.g., Clearcut Forest)
	41	Deciduous Forest
	42	Evergreen Forest
	43	Mixed Forest
	51	Shrubland
	71	Grassland/Herbaceous
	81	Pasture/Hay
	82	Row Crops
	83	Small Grains
	84	Fallow
	85	Urban/Recreational Grasses
	91	Woody Wetlands
	92	Emergent Herbaceous Wetlands

continued

Example of Edited ASTER Classification

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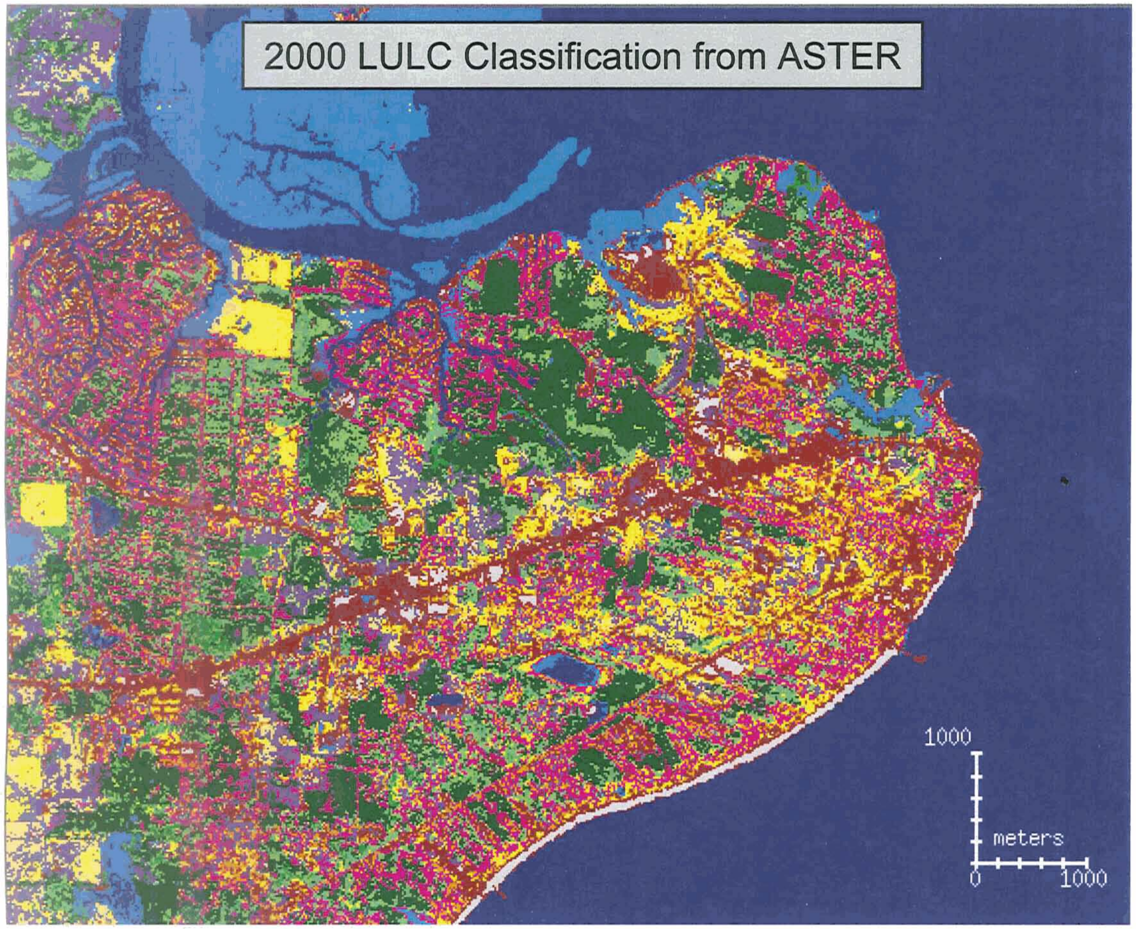
Edited ASTER NLCD Classification Compared to 1992 NLCD Map



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The ASTER LULC classification appears to map roads, residential areas, and waterways in greater detail. Such data may be useful for mapping specific coastal residential areas of interest to HAZUS-MH end users.

Surface Roughness Maps From 1990 NLCD and ASTER LULC Classification

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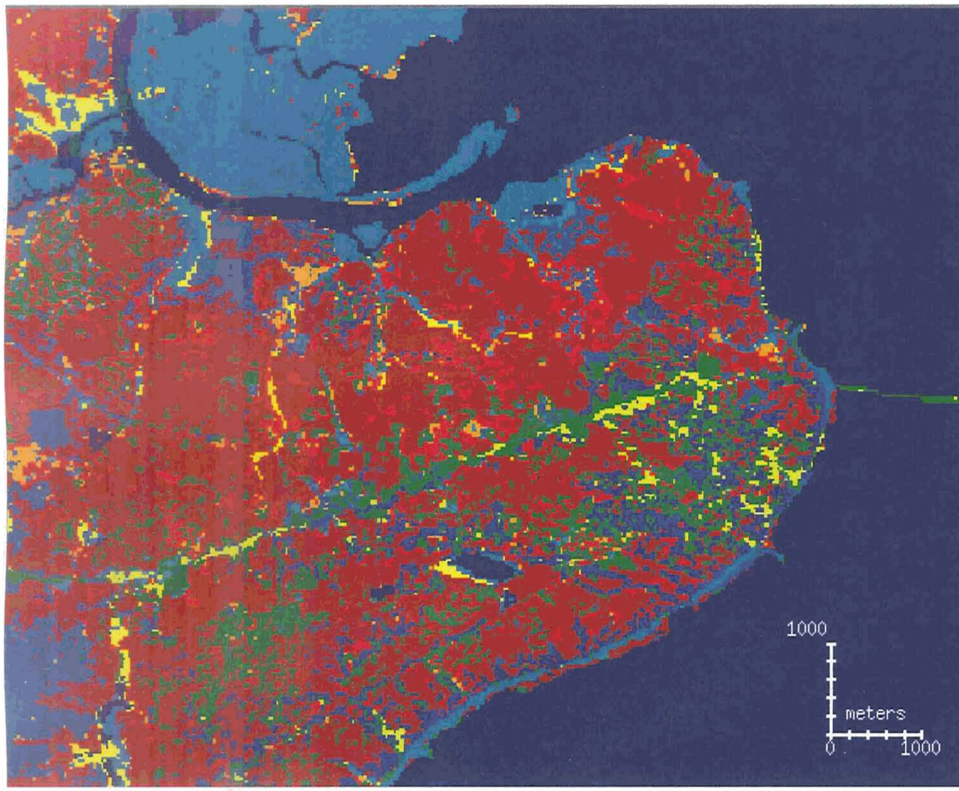
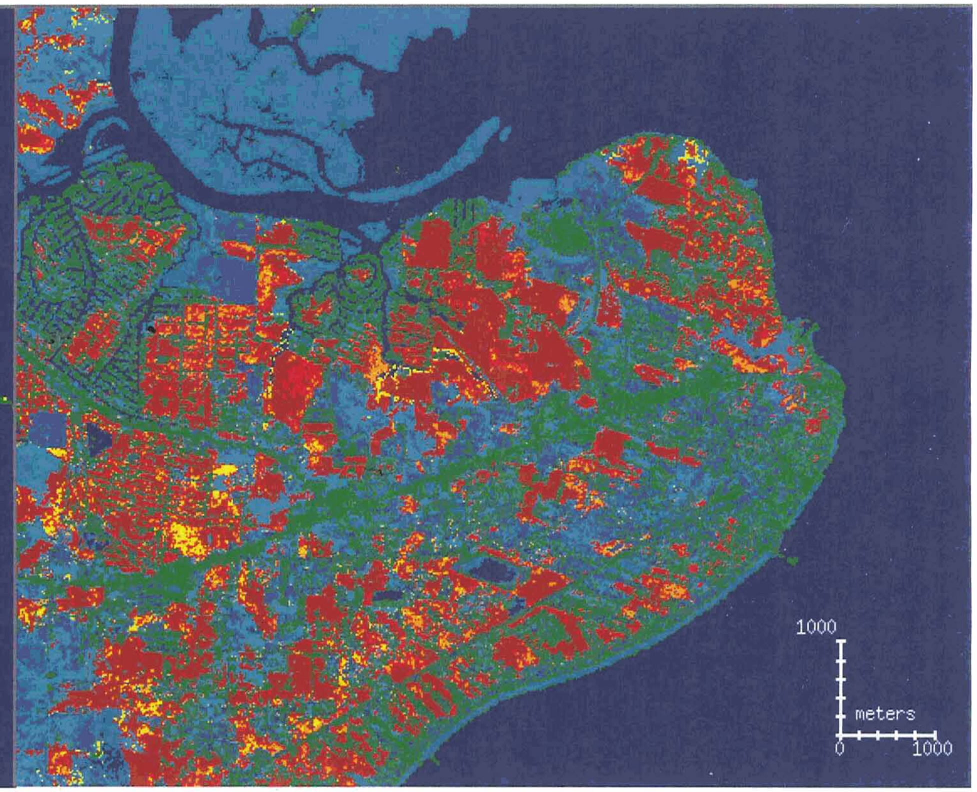
Location: Bay Saint Louis, Mississippi Gulf Coast

Surface Roughness From 1992 NLCD



Surface Roughness From 2000 ASTER LULC



Surface Roughness (in meters)

0.01 Water | 0.35 | 0.73 SW Forest

ASTER Classifications – Initial Observations

- While ASTER data was processed into surface roughness maps, it was not trivial to produce, largely because of the spectral similarity between many land use/land cover types in the NLCD scheme and the fact that only one date (i.e., season) of data was used.
- Reclassification of ASTER raw data for spectrally similar land cover associations helped to reduce but not to eliminate classification error. As with Landsat NLCD, ASTER data clustering did not automatically equate to LULC maps.
- Separation of the urban development classes required interactive editing using GIS techniques, various ancillary data, and decision rules. The making of Landsat NLCD products also requires similar but more automated processes.
- The refined ASTER LULC classification showed residential areas, waterways, and roads better than the 1992 Landsat NLCD, compared to QuickBird and DOQQ screen displays. Comparisons between the ASTER and Landsat NLCD were confounded by environmental change between 1992 and 2000.

Role of High-Resolution QuickBird Data

- Pan-sharpened QuickBird imagery aided ASTER LULC classification analysis, especially in cluster class to NLCD type assignments.
- It is expected that QuickBird data will also be invaluable for upcoming quantitative accuracy assessment.
- QuickBird imagery showed better spectral contrast between LULC types compared to CIR DOQQs, especially for subtle forest conditions depicted on the ASTER imagery.
- The QuickBird imagery was of similar vintage as the ASTER data, especially compared to the DOQQ imagery. However, the DOQQs were more similar in date to the 1992 NLCD.
- The QuickBird imagery showed potential for classification of surface roughness elements (e.g., buildings), but the one test scene contained excessive shadows because of a winter acquisition date.

Final Remarks

- The ASTER NLCD classification shows promise for improving coastal surface roughness mapping inputs to HAZUS-MH on an area-specific basis. However, doing so required considerable effort and advanced imaging expertise. ASTER surface roughness maps may be a viable option for HAZUS end users in need of more spatially resolved, up-to-date surface roughness maps than via the 1992 NLCD maps.
- Future work should include quantitative map accuracy assessment on the ASTER LULC map of southeastern Mississippi. A comparable effort is also needed to quantify the 1992 (or 2000, if available) Landsat NLCD product.
- ASTER surface roughness maps are also being produced and tested for additional HAZUS project study areas, including Broward County, FL, and Pender/Onslow Counties, NC.
- Other NASA data sources are being explored as well, including SRTM elevation data and pan-sharpened Landsat ETM+ data.
- High-resolution satellite and aerial imagery will continue to be used in developing and evaluating coastal surface roughness maps derived from NASA data sources.

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