Benthic Habitat Mapping of Coral Reefs with High Spatial Resolution Satellite Imagery

High Spatial Resolution Commercial Imagery Workshop
May 19-21, 2003

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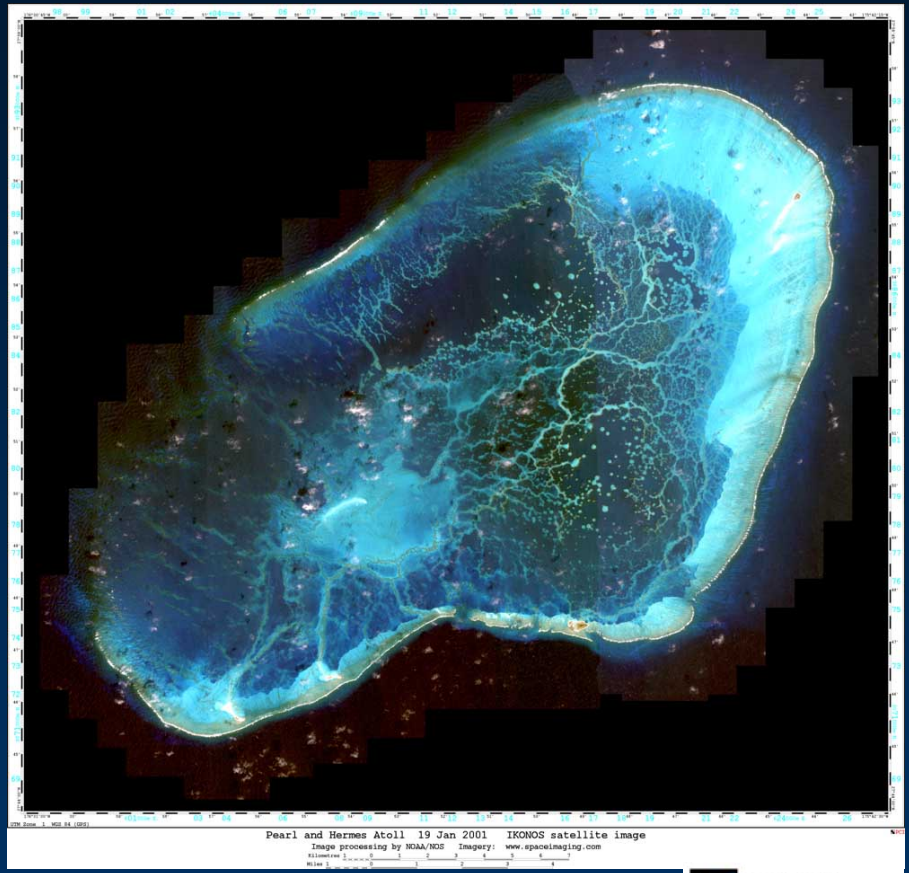
NOAA National Ocean Service
National Centers for Coastal Ocean Science
Center for Coastal Monitoring
and Assessment

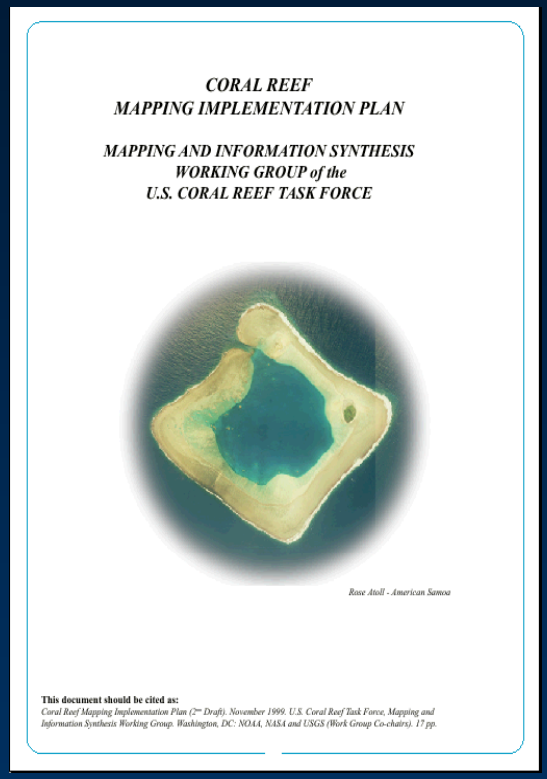
Partners:

US National Geodetic Survey,
US National Marine Fisheries Service – Honolulu Lab
US Fish & Wildlife Service
US National Park Service
Hawaii DLNR
University of Hawaii
Analytical Labs of Hawaii



Pearl & Hermes, NW Hawaii
Mapped true color IKONOS image

U.S. Coral Reef Task Force
Mapping Implementation Plan



CORAL REEF
MAPPING IMPLEMENTATION PLAN

MAPPING AND INFORMATION SYNTHESIS
WORKING GROUP of the
U.S. CORAL REEF TASK FORCE

Rose Atoll - American Samoa

This document should be cited as:
Coral Reef Mapping Implementation Plan (2nd Draft). November 1999. U.S. Coral Reef Task Force, Mapping and Information Synthesis Working Group. Washington, DC: NOAA, NASA and USGS (Work Group Co-chairs). 17 pp.

- **Digital high resolution maps of coral reef ecosystem habitats**
- **Delineate benthic habitats using hierarchical classification system**
- **Map All U.S. States, Territories, Commonwealths & the FAS by 2007**
- **Integrate maps with research & monitoring activities for use by researchers and managers**

Challenge: Map shallow coral reef habitat in remote areas

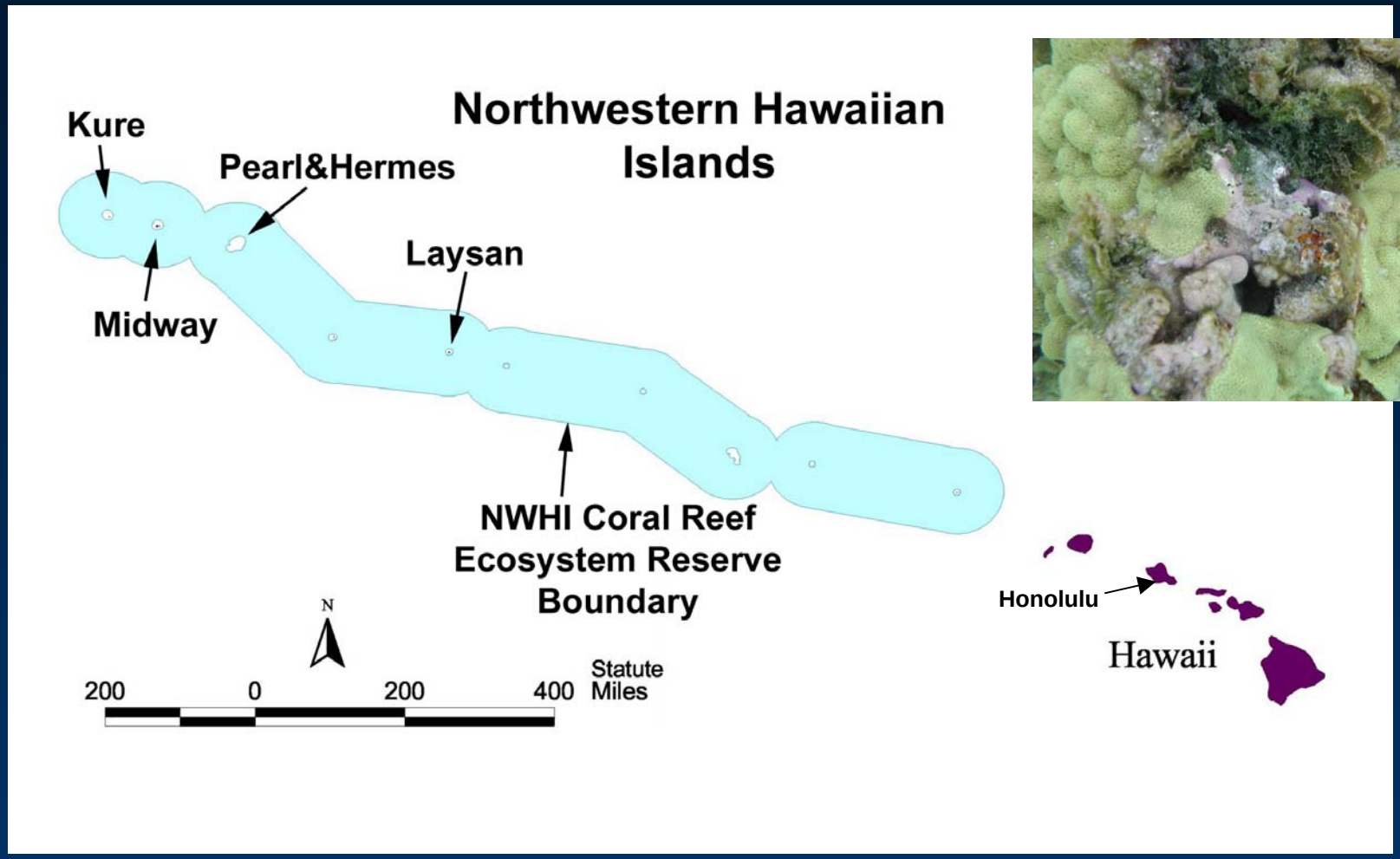
Northwest Hawaii was initial priority:

- NW Hawaii Coral Reef Ecosystem Reserve declared in Dec 2000
  - under consideration for designation as a U.S. National Marine Sanctuary
- Large (100-700 km^2), widely separated shallow water areas
- Island chain extends over ~2200 km, with limited access

Need:

- wide spatial coverage and high spatial resolution
- ability to reach remote geographic locations … at a reasonable cost
- accurate georeferencing
- efficient, cost-effective data processing

Northwest Hawaii – large and remote reefs



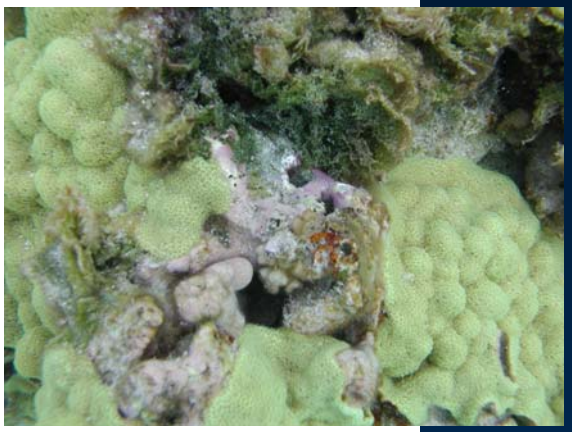


Photo:
K. Holderied

Satellite-based Mapping Approach

- use high spatial resolution satellite imagery - IKONOS
- field data for validation

Figure 7. Individual patch reef at Midway Atoll.

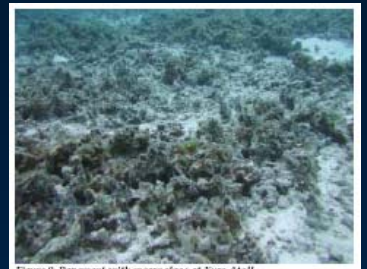


Figure 9. Pavement with macroalgae at Kure Atoll.

- digital processing – classification based on spectral, textural spatial information
- rule-based, hierarchical classification

Figure 5. Aggregated coral heads at Kure Atoll.

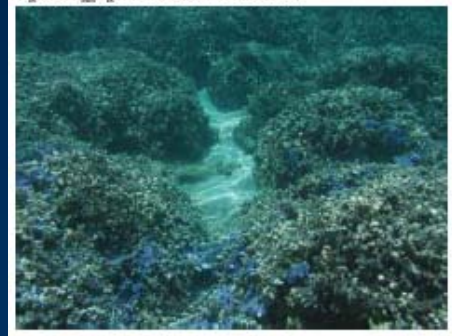


Figure 4. Linear reef at Midway Atoll.

Data Sources

- IKONOS commercial satellite imagery
  - 4-m multispectral (blue/green/red/nearIR); detection to ~30 m depth
  - 1-m panchromatic with detection to ~4 m depth
  - pointable 11 km swath (multiple swaths on a single pass)
  - horizontal positioning <15 m (with orbital parameters alone)
  - constrain acquisition to minimize sunglint and clouds

- NOS NWHI research cruise on SS Midway (Aug-Sep 2001)
  - Benthic habitat validation points (1131 total at 10 sites)
  - Survey-grade GPS ground control collected by NGS teams
  - Bathymetry transects run with survey-grade recording fathometer

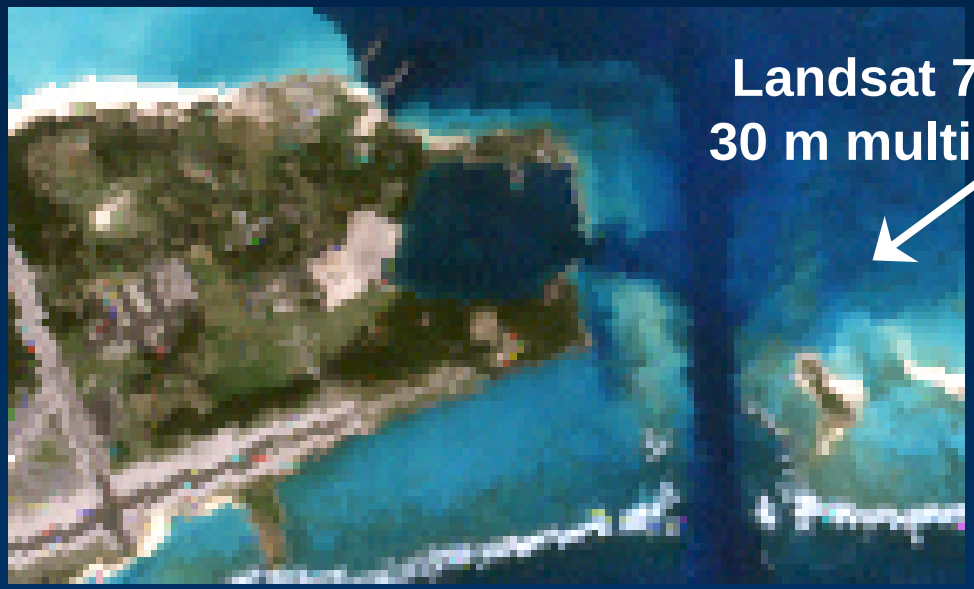
- Lidar bathymetry data
  - collected with LADS Mk II airborne system (4 m resolution)
  - transects flown at Kure, Pearl&Hermes and Midway

Sand Island, Midway Islands, NWHI

Mapping Coral Reef Habitats
Satellite Data Options

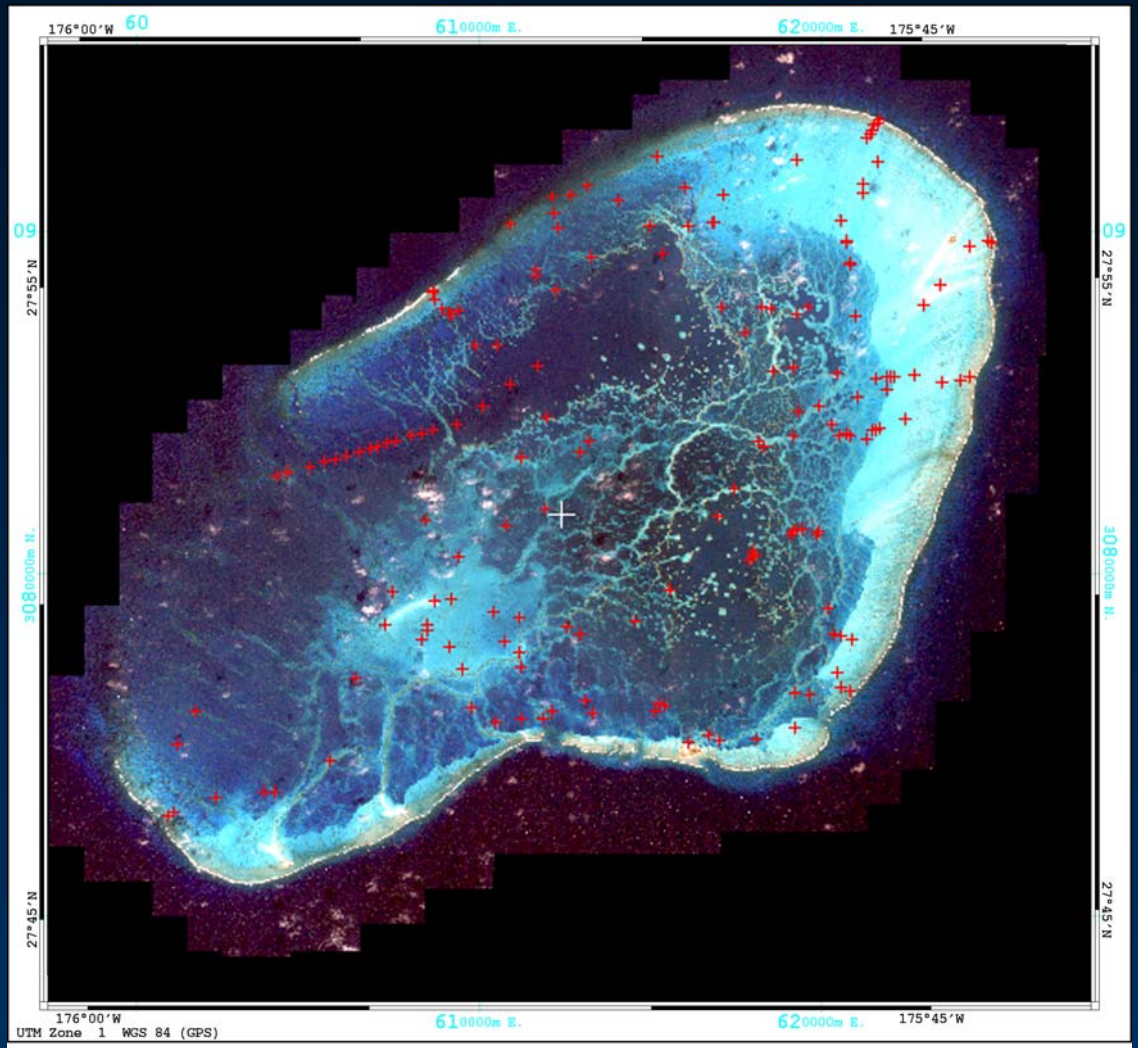
IKONOS - 4 m multispectral

Midway Islands runway



Landsat 7 ETM+
30 m multispectral

IKONOS
1 m pan



Pearl & Hermes Atoll, NWHI IKONOS satellite image

Benthic habitat validation points from NOS 2001 NWHI cruise

Benthic habitat validation points collected for Pearl & Hermes Atoll

- 173 points obtained over 3 days

Photo: M. Anderson

Image Processing Methods

- Position with orbital parameters and refine with ground control.
  - NGS acquired ground control for most of NWHI on NOS cruise
  - final horizontal accuracy < 4 meters in most cases

- Mosaic multiple swaths for study area if necessary.

- Use satellite calibration to get radiance, then calculate remote sensing reflectance. Correct total reflectance for atmospheric and ocean surface effects, obtaining water reflectance.

- Calculate bathymetry from water reflectance – only requires a limited number of soundings for calibration.

- Use derived bathymetry to adjust reflectance for water column attenuation and calculate bottom albedo.

True color image from IKONOS reflectance

Mapped total reflectance for Midway Islands

- mosaic of imagery from January and March 2001

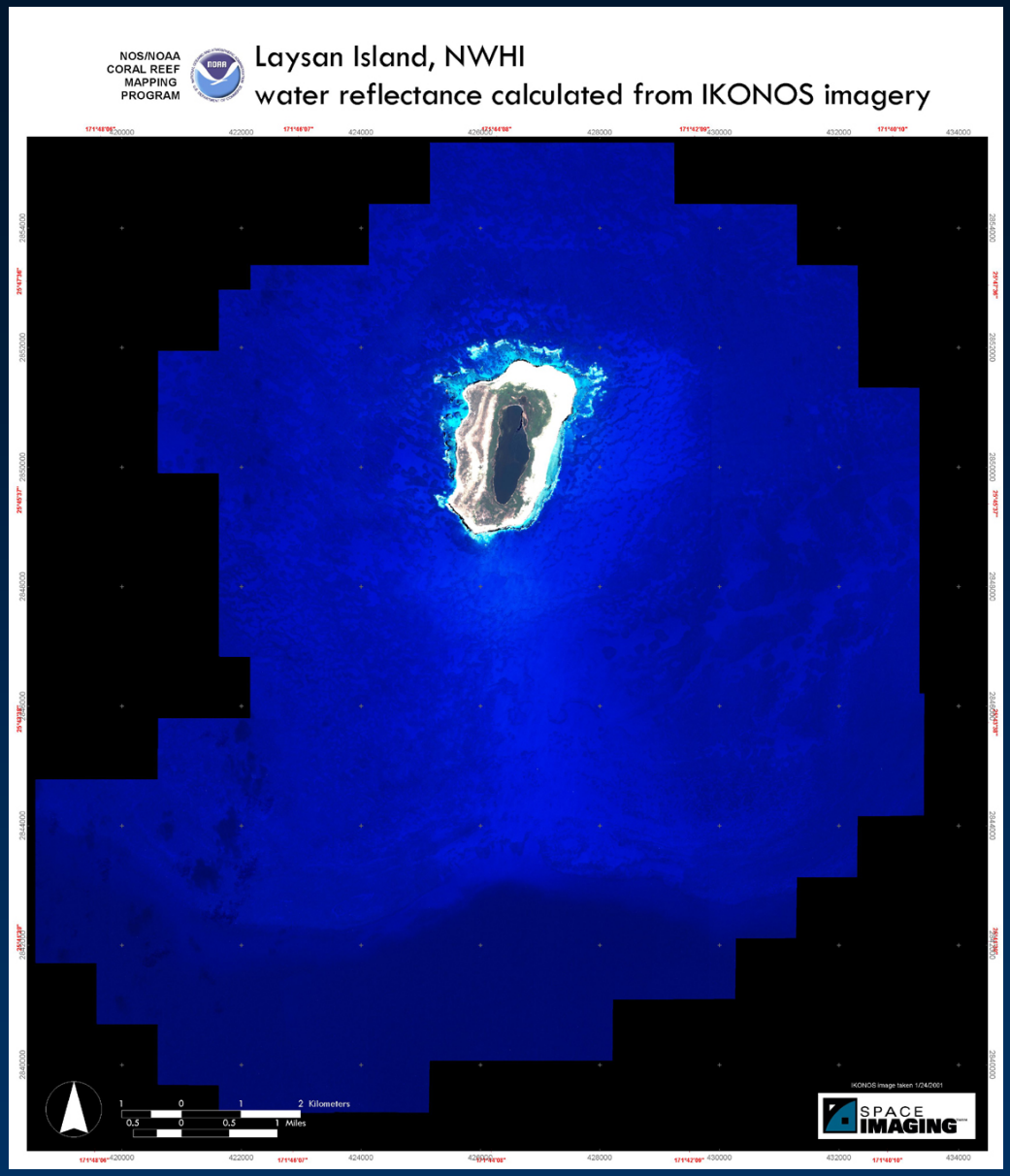
- horizontal accuracy <5 m with satellite positioning alone. Refined to ~2 m with NGS ground control

Water Reflectance

Midway Islands

- use near-IR band to correct total reflectance for atmospheric (absorption, reflection and scattering) and ocean surface (waves) effects

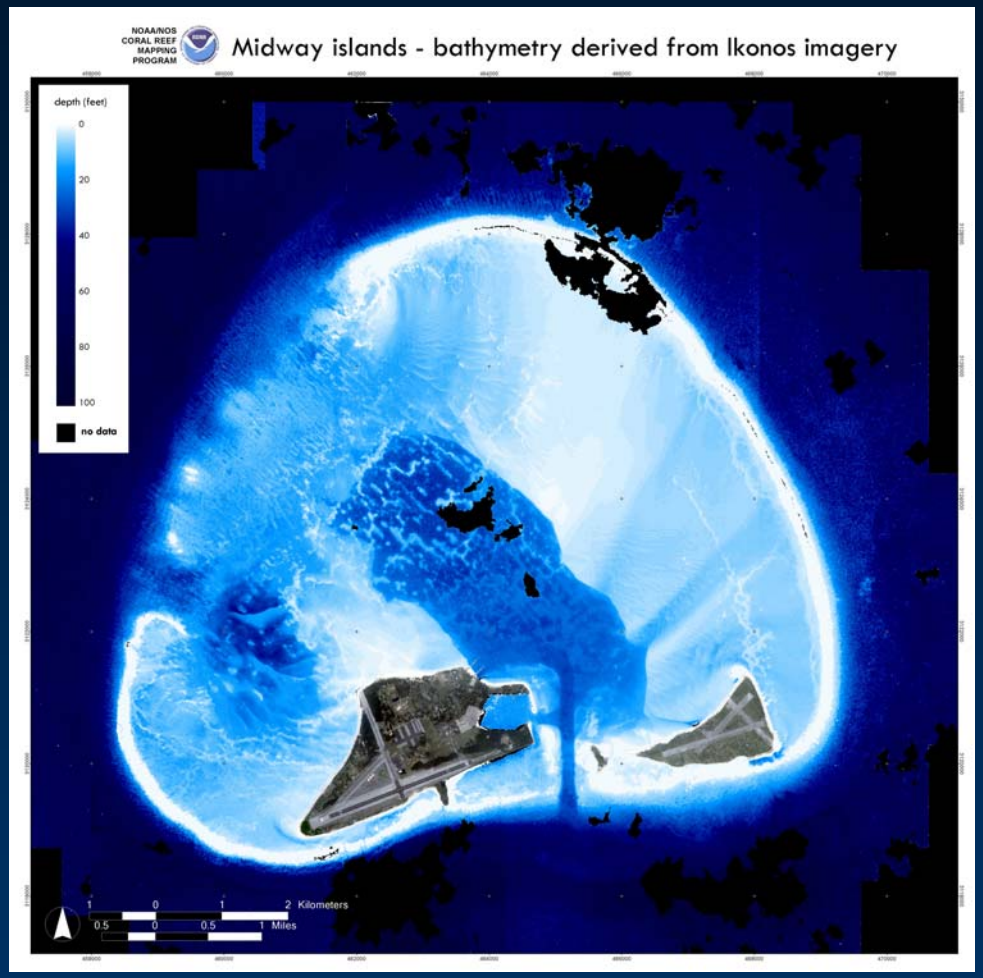
- can incorporate SeaWiFS data to improve the atmospheric correction process



Water reflectance for Laysan Island

- NW Hawaiian atolls characterized by a wide variety of shapes and bathymetries

Bathymetry from IKONOS Satellite Imagery



Midway Islands

- need water depth at same spatial resolution as imagery to calculate bottom albedo

- use nautical chart soundings to calibrate and validate with available independent depth data (small boat bathymetry transects and lidar)

- extracted depths to ~30 m

- useful as stand-alone product

Habitat Classification and Map Production

- Classify benthic habitat
  - use water reflectance, bathymetry and bottom albedo
  - segment using spectral and spatial information
  - rule-based classification
  - minimum mapping unit of 400 m^2 (1/8 acre), with identification of features as small as 100 m^2
  - incorporate independent information as GIS layers
  - use hierarchical classification scheme

- Generate preliminary maps and validate with field data

- Obtain external review and refine maps as necessary

Draft NWHI Benthic Habitat Classification Scheme

1000 Unconsolidated Sediments
- 1100 Sand
- 1200 Carbonate mud
- 1300 Unconsolidated rubble

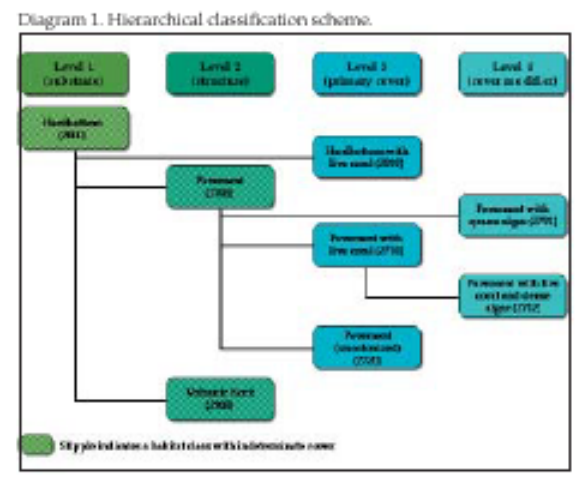
2000 Corals and Hardbottom
- 2100 Linear reef
- 2200 Aggregated coral heads
- 2300 Spur and groove
- 2400 Individual patch reef
- 2500 Aggregated patch reef
- 2600 Scattered coral/rock in sand
- 2700 Pavement
- 2800 Pavement with sand channels
- 2900 Volcanic rock

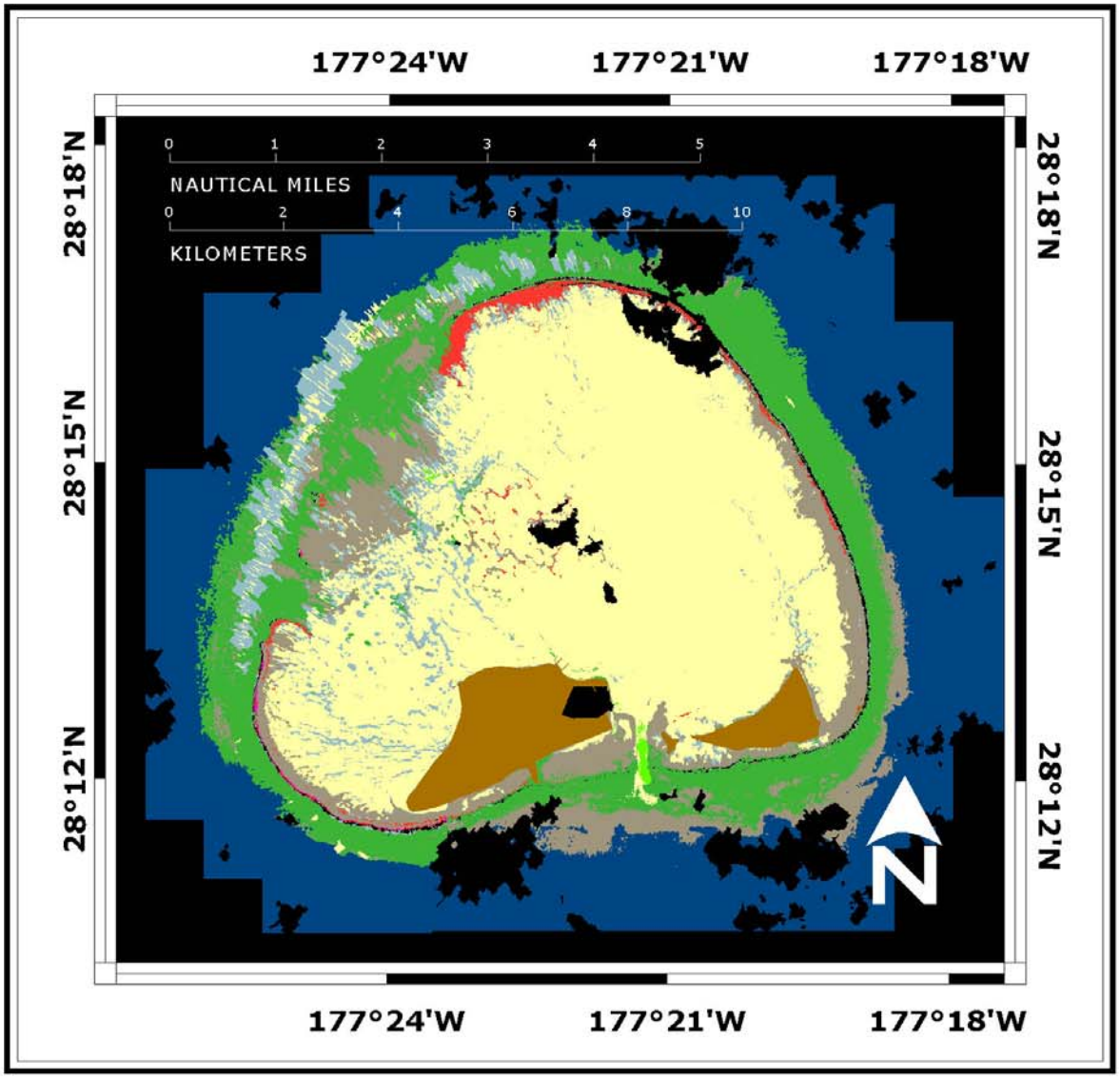
** 3rd level modifier: cover types
- 1 – live coral (>10% coral cover)
- 2 – uncolonized hardbottom
- 3 – encrusting coralline algae

**4th level modifier: algal cover
- 1 – sparse algae
- 2 – dense algae

3000 Submerged Vegetation
- 3100 Seagrass beds
  - 3110 Patchy seagrass (10-50%)
  - 3120 Continuous seagrass (50-100%)
- 3200 Macroalgae (fleshy and turf)
  - 3210 Patchy macroalgae (10-50%)
  - 3220 Continuous macroalgae (50-100%)

4000 Other delineations
- 4100 Land
- 4200 Emergent vegetation (mangrove)
- 4300 Artificial
- 4400 Unknown

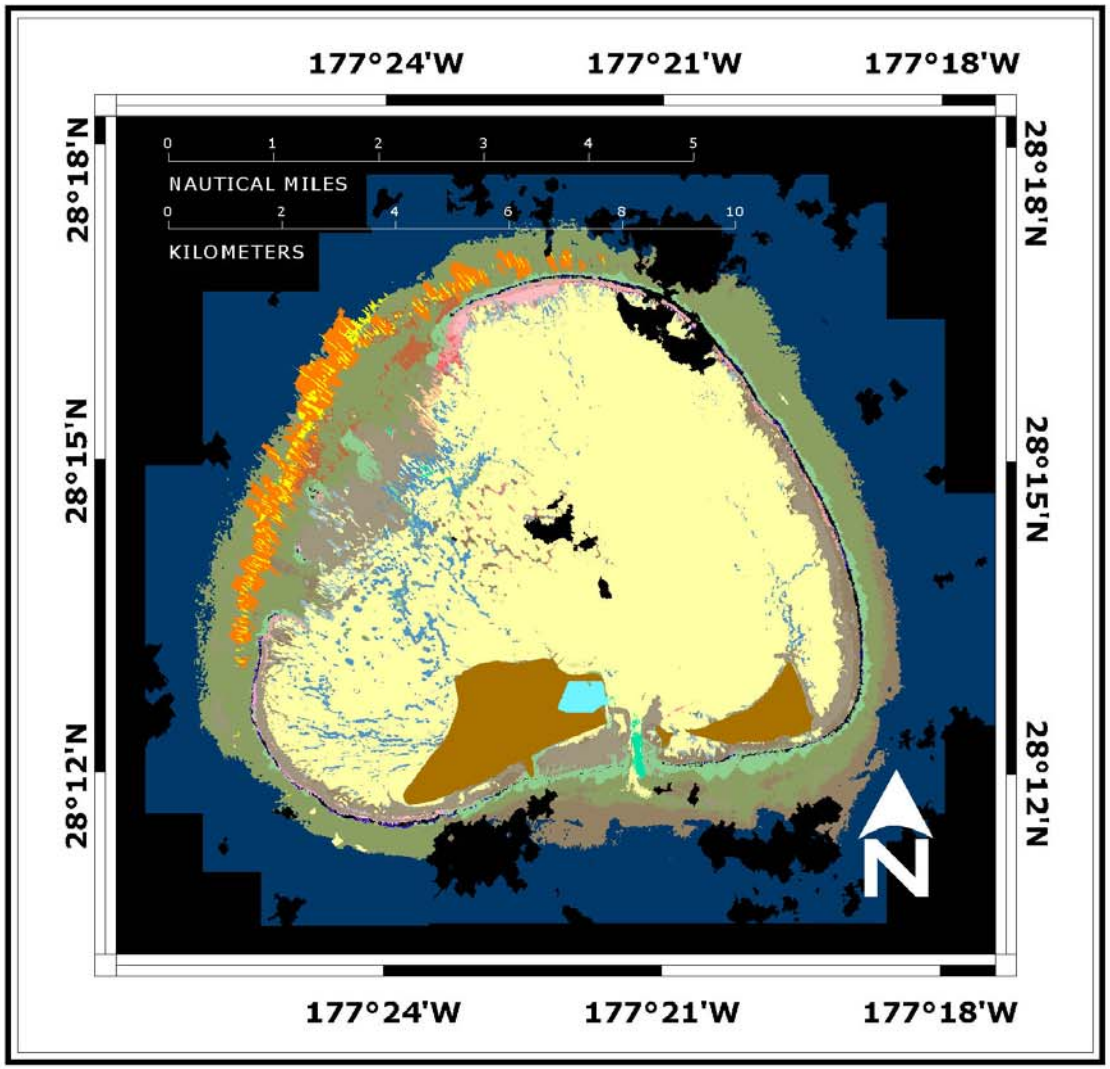




- Unconsolidated
- Unconsolidated, >10% macroalgae
- Hardbottom, indeterminate cover
- Hardbottom, >10% macroalgae
- Hardbottom, >10% live coral
- Hardbottom, uncolonized
- Hardbottom, >10% crustose coralline algae
- Deep water
- Land
- Cloud/shadow/surf/no data

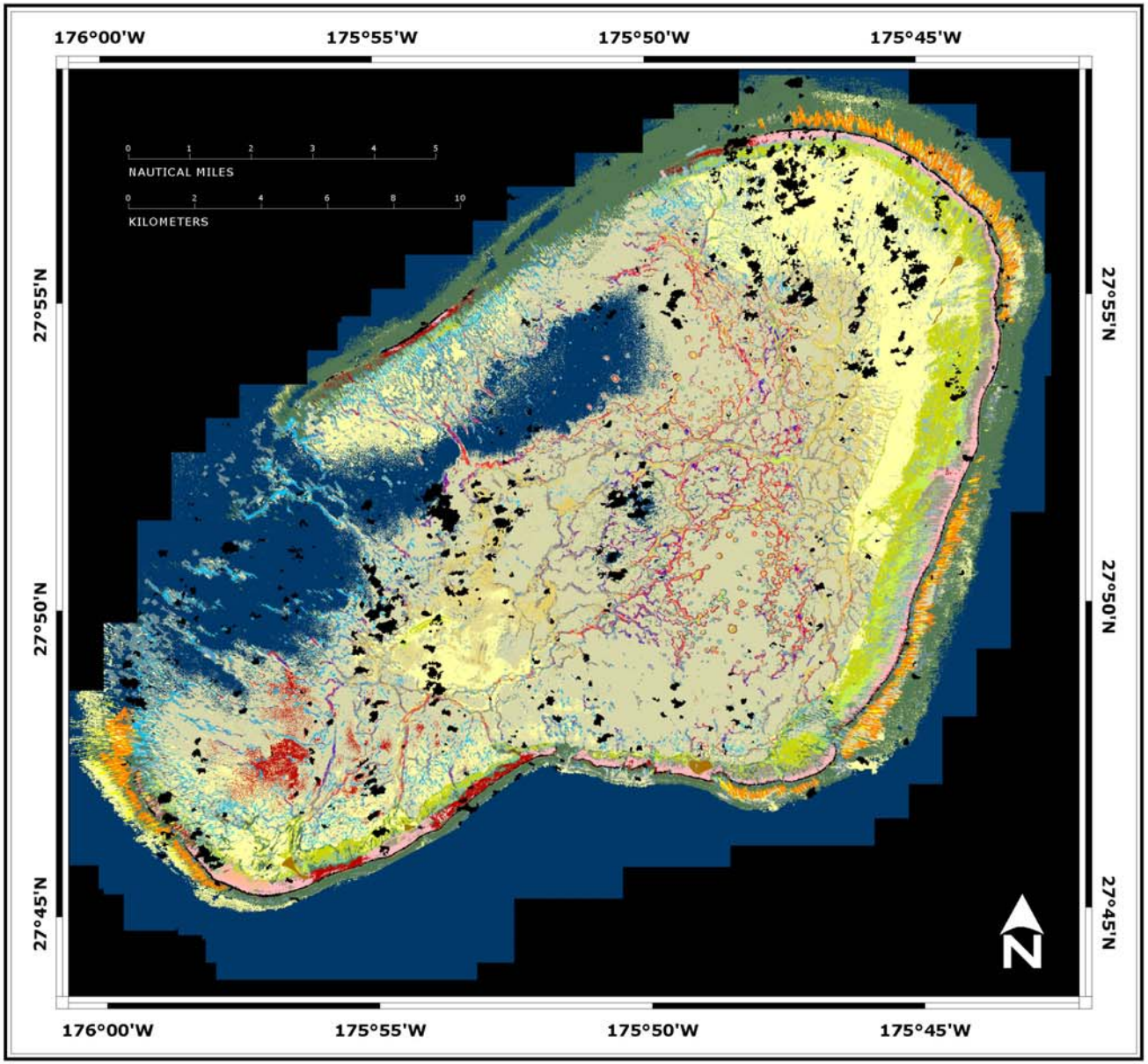
Midway Islands, NW Hawaii

Benthic Habitat Cover Map



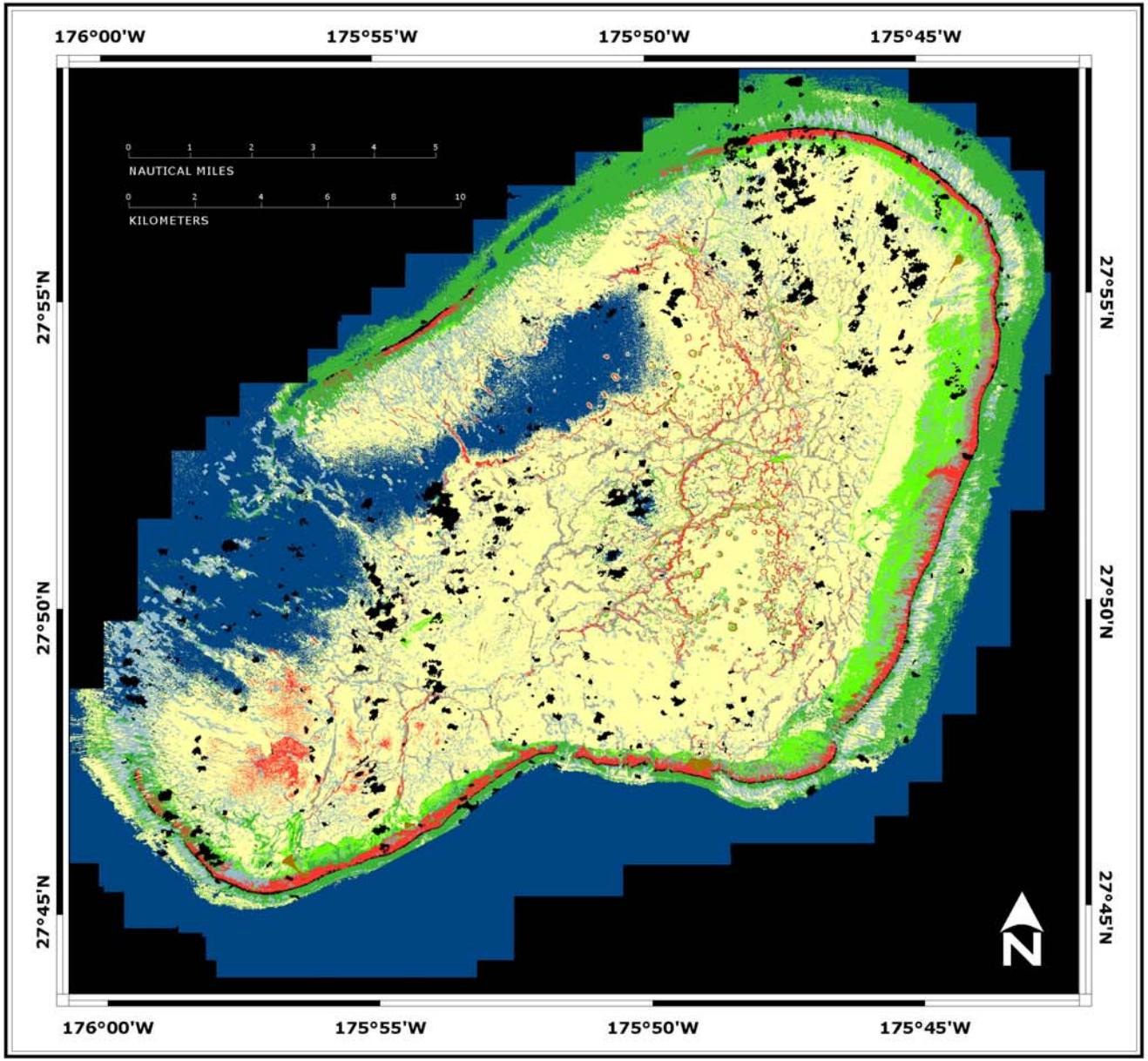
Midway Islands,
NW Hawaii

Benthic Habitat Map



Pearl & Hermes Atoll

Benthic Habitat Map



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Pearl & Hermes Atoll, NW Hawaii

Benthic Habitat Cover Map

Accuracy Assessment for Benthic Habitat Classification

Field data - reference

Image classification

N=61	Unconsolidated sediments	Coral Colonized Hardbottom	Uncolonized Hardbottom	Macroalgae	TOTAL	USER ACCURACY
Unconsolidated sediments	**14**		2	2	18	**78%**
Coral Colonized Hardbottom		**8**			8	**100%**
Uncolonized Hardbottom		1	**10**	4		
Macroalgae		1	9	**1**		
TOTAL	14	10	21	1		
PRODUCER ACCURACY	**100%**	**80%**	**48%**	**62**		

Overall Accuracy Assessment of Aggregated Habitat Cover for all NWHI Islands

Mapped Habitat Type	Actual Habitat Type: Hardbottom with >10% live coral	Hardbottom with >10% crustose coralline algae	Hardbottom (uncolonized)	Hardbottom with >10% macroalgae	Unconsolidated with 10% or less macroalgae or seagrass	Unconsolidated with >10% macroalgae or seagrass	Row Total	User Accuracy
Hardbottom with >10% live coral	**50**	3	5	5	0	0	63	79%
Hardbottom with >10% crustose coralline algae	0	**11**	0	0	1	0	12	92%
Hardbottom (uncolonized)	6	0	**33**	2	3	0	44	75%
Hardbottom with >10% macroalgae	1	2	11	**16**	3	6	39	41%
Unconsolidated with 10% or less macroalgae or seagrass	9	1	18	11	**161**	6	209	77%
Unconsolidated with >10% macroalgae or seagrass	3	0	1	1	3	**1**	9	11%
Column Total	69	17	68	38	171	13	376	
Producer Accuracy	72%	65%	48%	42%	94%	9%		

Overall Accuracy	**72%**
Kappa Statistic	**0.59**
Tau Coefficient	**0.62**

Actual Structure Type

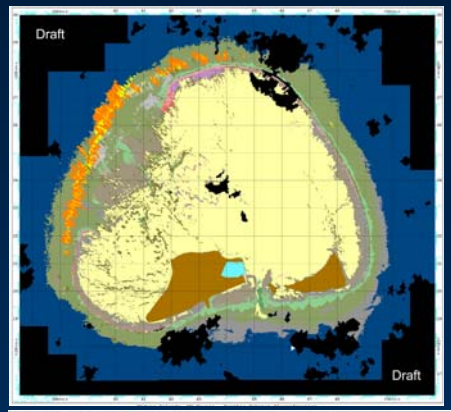
Mapped Structure Type	hardbottom	unconsolidated	Row Total	User Accuracy
hardbottom	**221**	16	237	93%
unconsolidated	47	**171**	218	78%
Column Total	268	189	457	
Producer Accuracy	82%	90%		

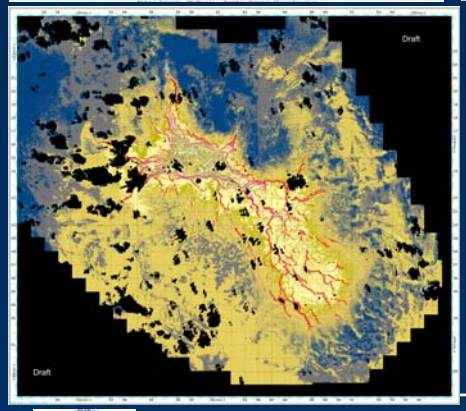
NW Hawaii Coral Reef Mapping Results

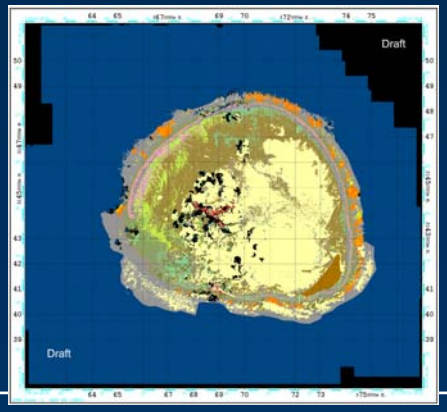
Area Mapped (km²)

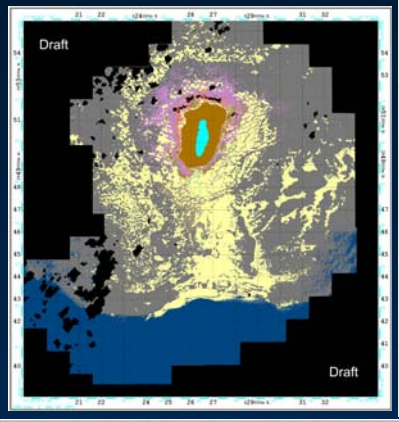
Kure Atoll - 70	French Frigate Shoals - 418
Midway Islands - 96	Maro Reef – 519
Pearl & Hermes Atoll – 389	Necker Island - 228
Lisianski Island – 439	Nihoa Island - 74
Laysan Island - 127	

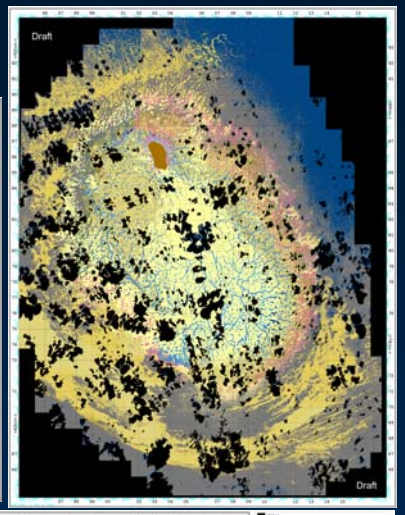
Total - 2,363

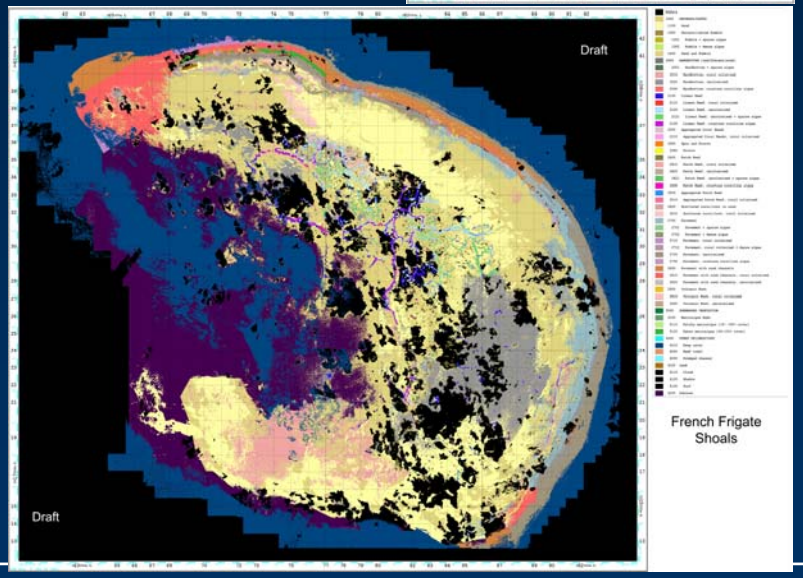




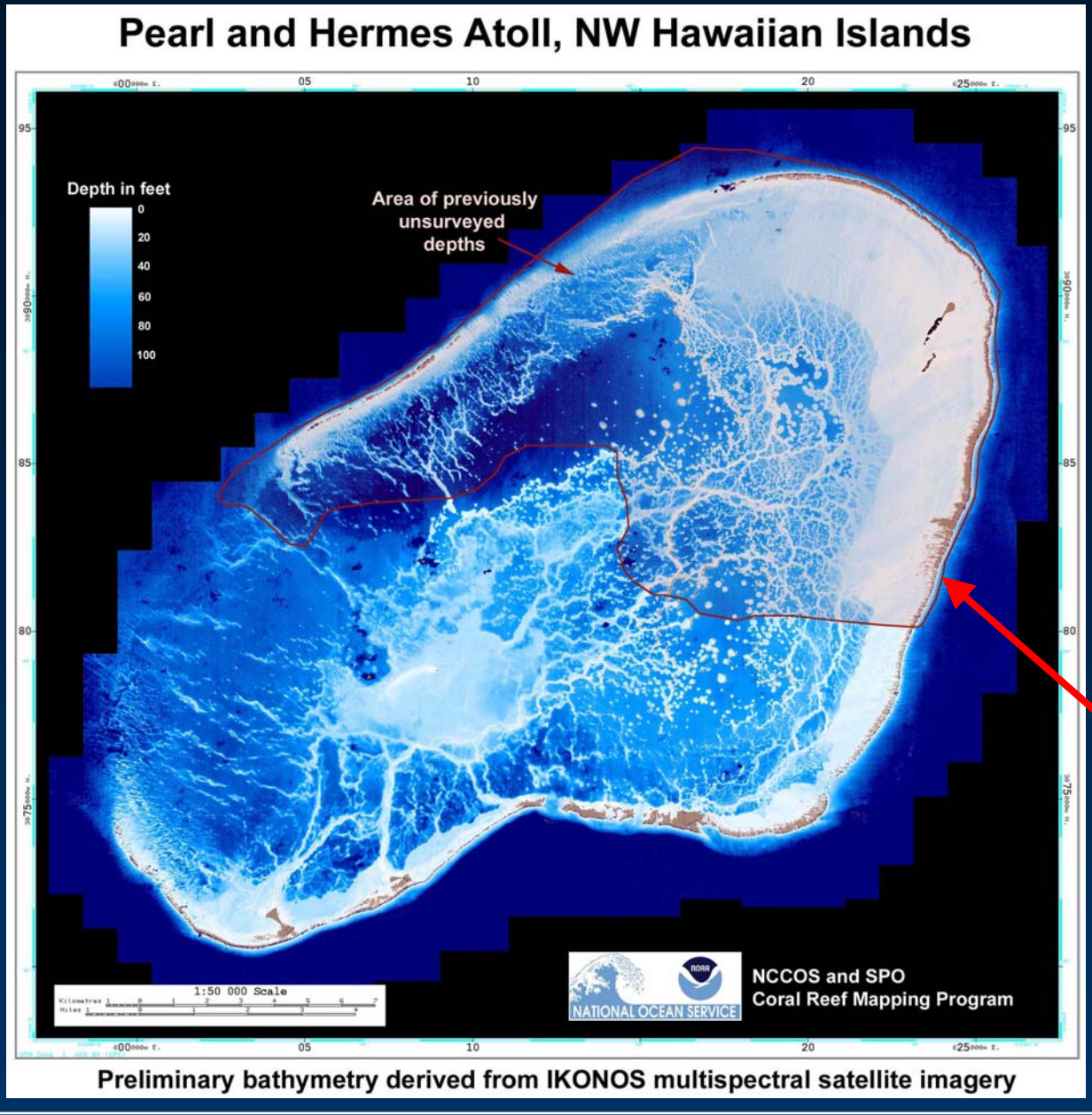








Navigation Applications of Satellite Imagery



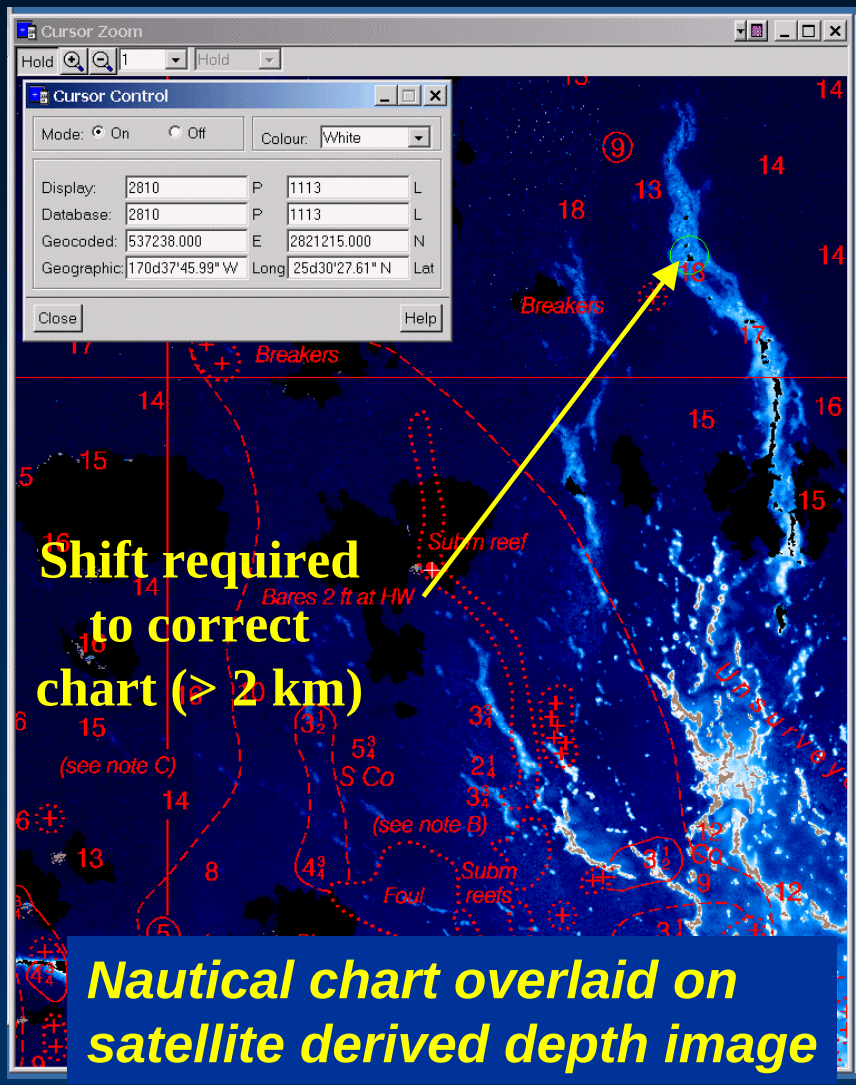
Water depth map derived from IKONOS satellite imagery

Stumpf, Holderied and Sinclair, 2003
Limnol. Oceanogr., 48 (1) , 547-556

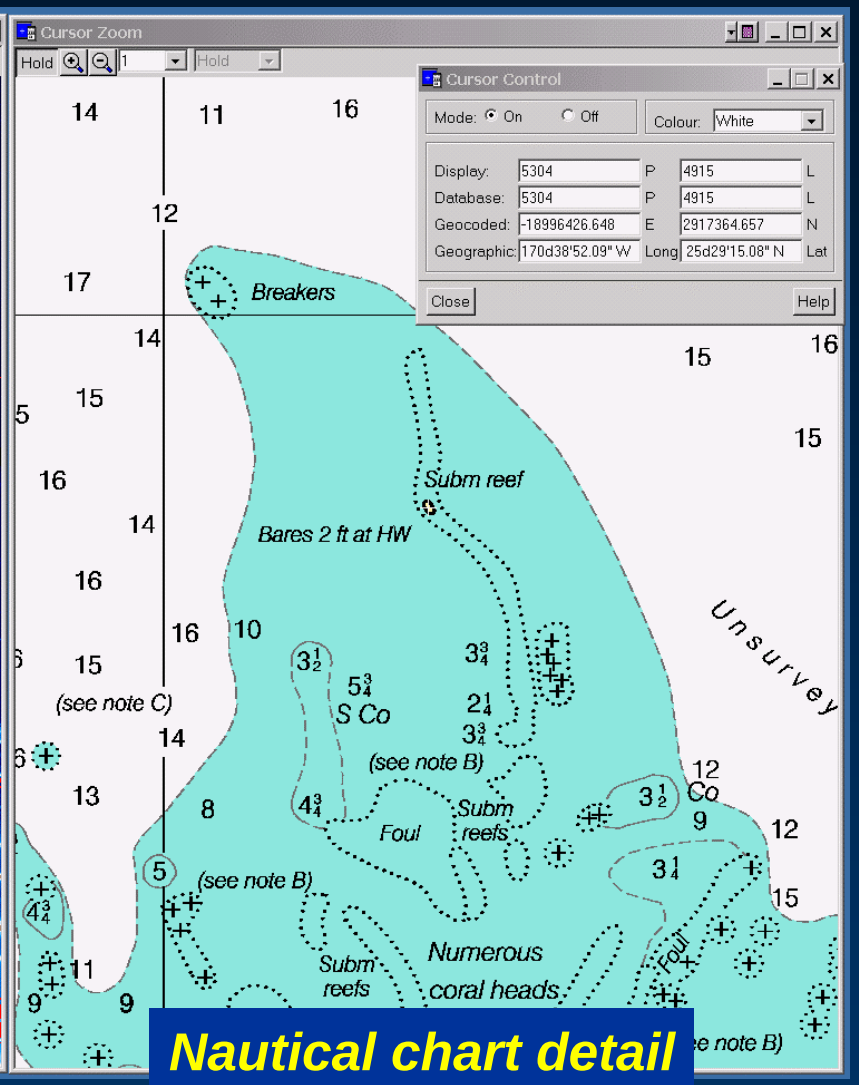
Shaded area indicates region without any depth soundings on the nautical chart

Nautical Chart Update for Maro Reef, NW Hawaii

- using bathymetry derived by NOS from IKONOS data



Nautical chart overlaid on satellite derived depth image

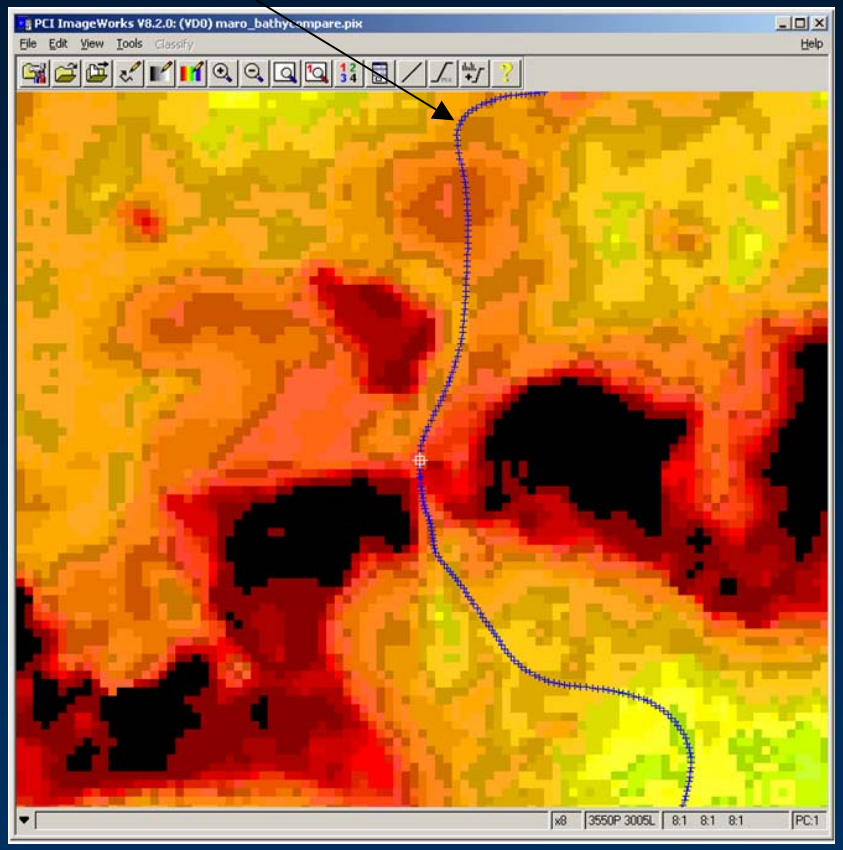


Nautical chart detail

Nautical Chart Positioning, Maro Reef NW Hawaii

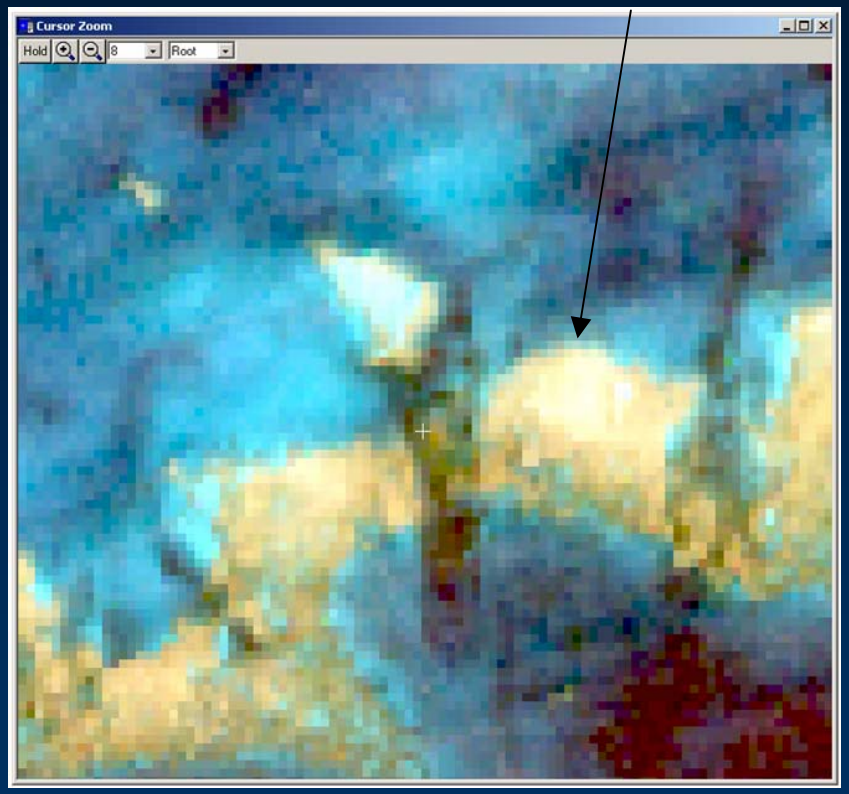
- Validate satellite image position against NGS field fathometer measurements

Boat track - recording fathometer/GPS



Satellite derived bathymetry: black/red=shallow

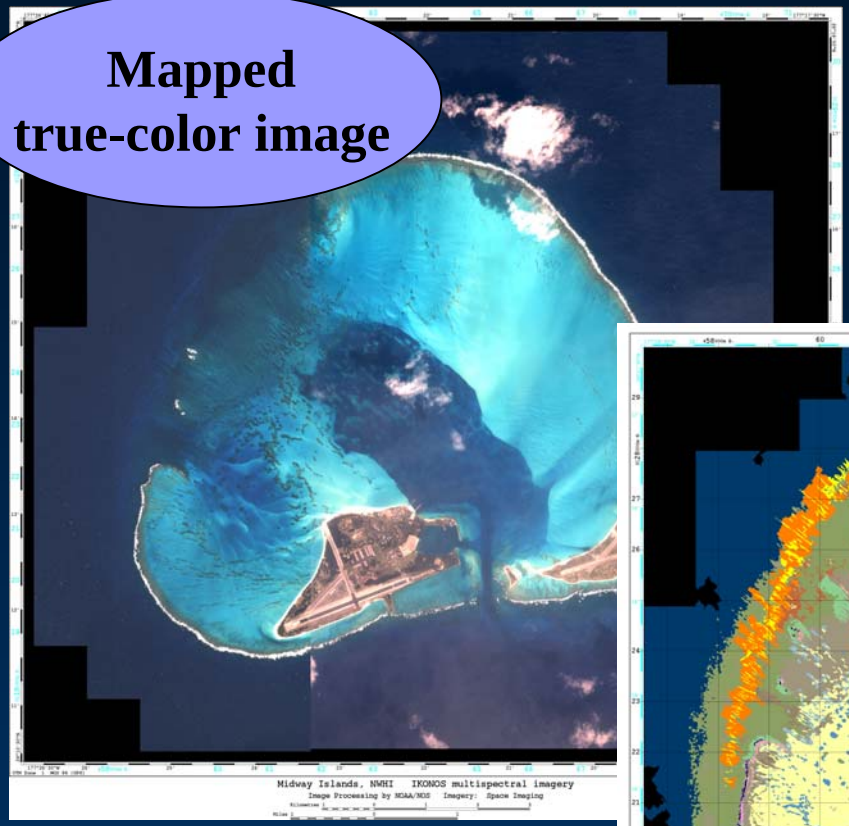
Near-surface coral reef



True-color image derived from IKONOS

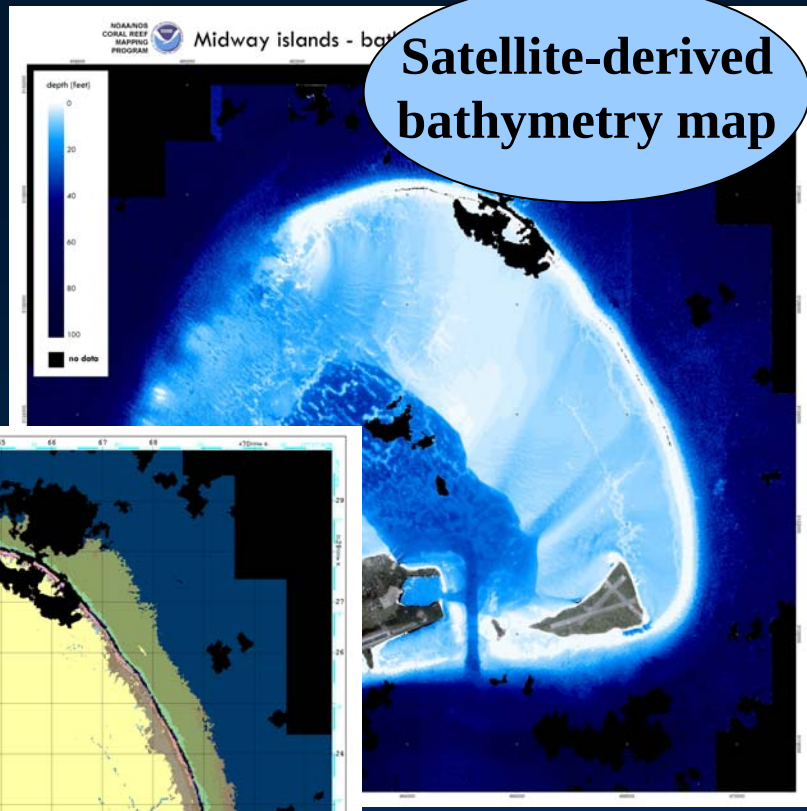
Satellite-based benthic habitat map products

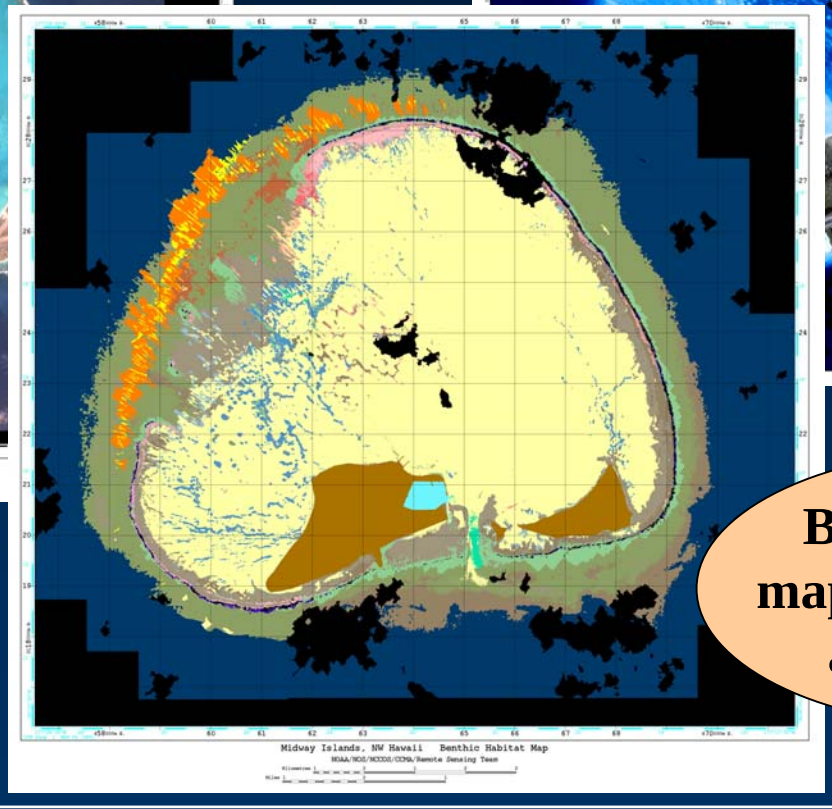
Mapped true-color image



Midway Islands

Satellite-derived bathymetry map





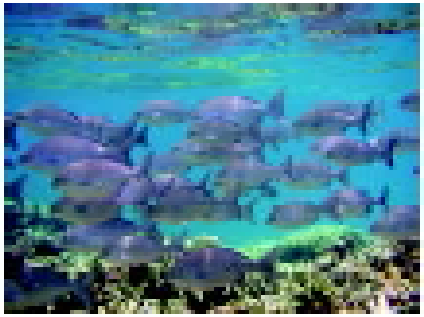
Benthic habitat map - from imagery and field data

Multiple map products derived from IKONOS satellite imagery

Satellite-derived products - Atlas

Atlas of the Shallow-Water Benthic Habitats of the Northwestern Hawaiian Islands

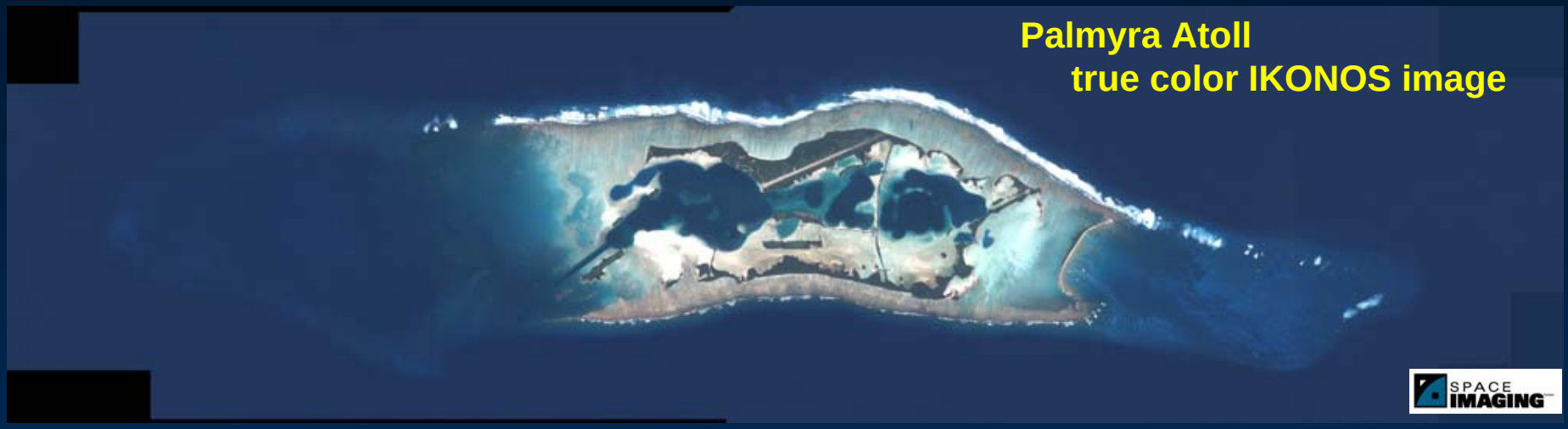
DRAFT



U.S. Department of Commerce

March 2003

Future work



- Assist Pacific partners in mapping other U.S. Pacific reefs
  - visual interpretation, digital processing or combination

- Apply techniques to other environments (seagrass, wetlands) and use other sensors (QuickBird, Landsat, airborne)

Use of Multiple Remote Sensing Technologies

IKONOS – true-color; 4 m pixel

AERIAL PHOTOGRAPHY – true-color; 1.2 m pixel

HYPERSPECTRAL – 72 bands between 350 and 1000 nm; 3 m pixel

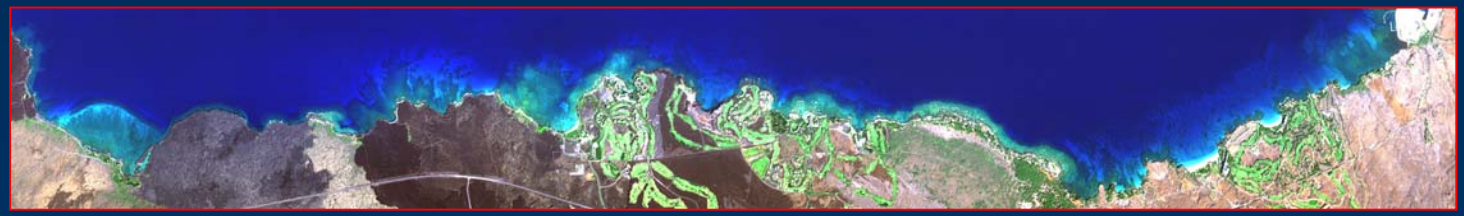
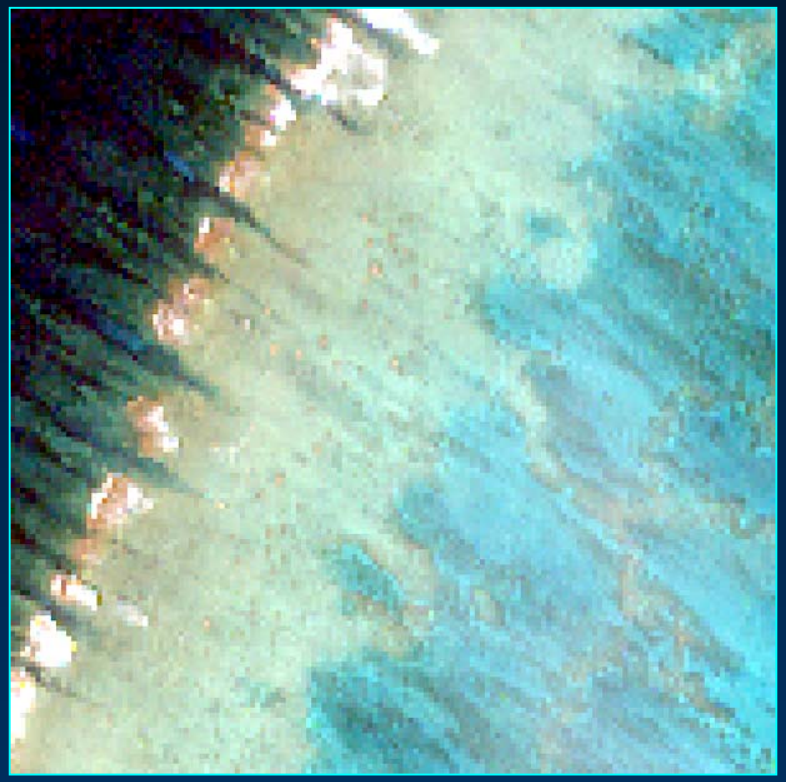


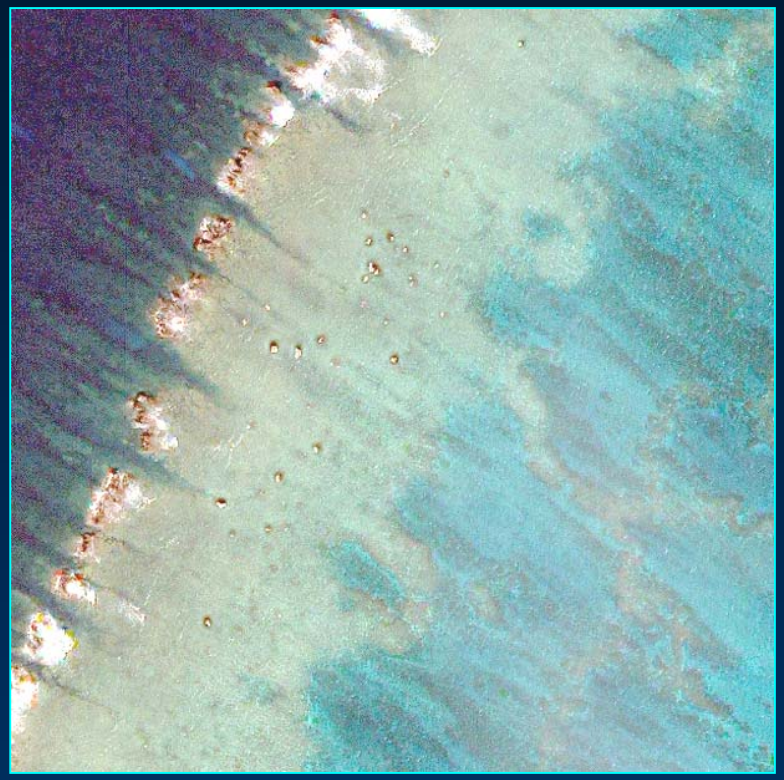
Image source: T. Battista

Facilitating visual interpretation of coral reef habitat

IKONOS image of a portion of Kure Atoll, NW Hawaii

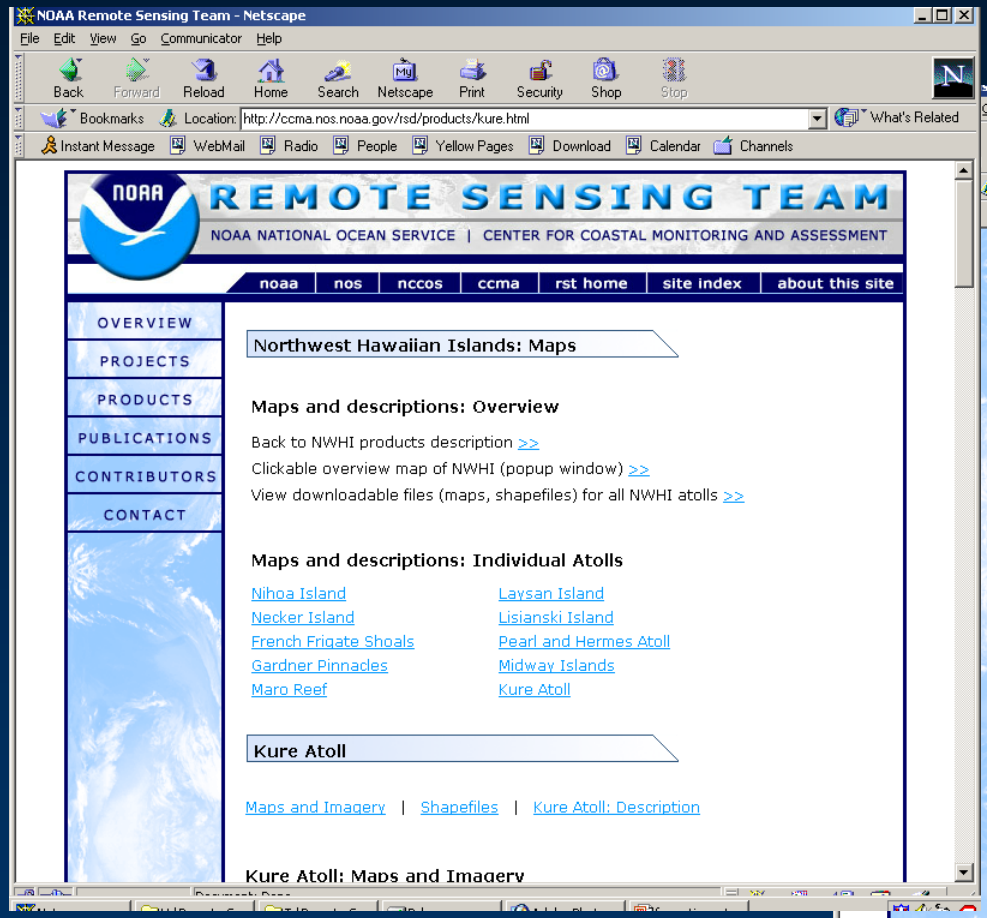
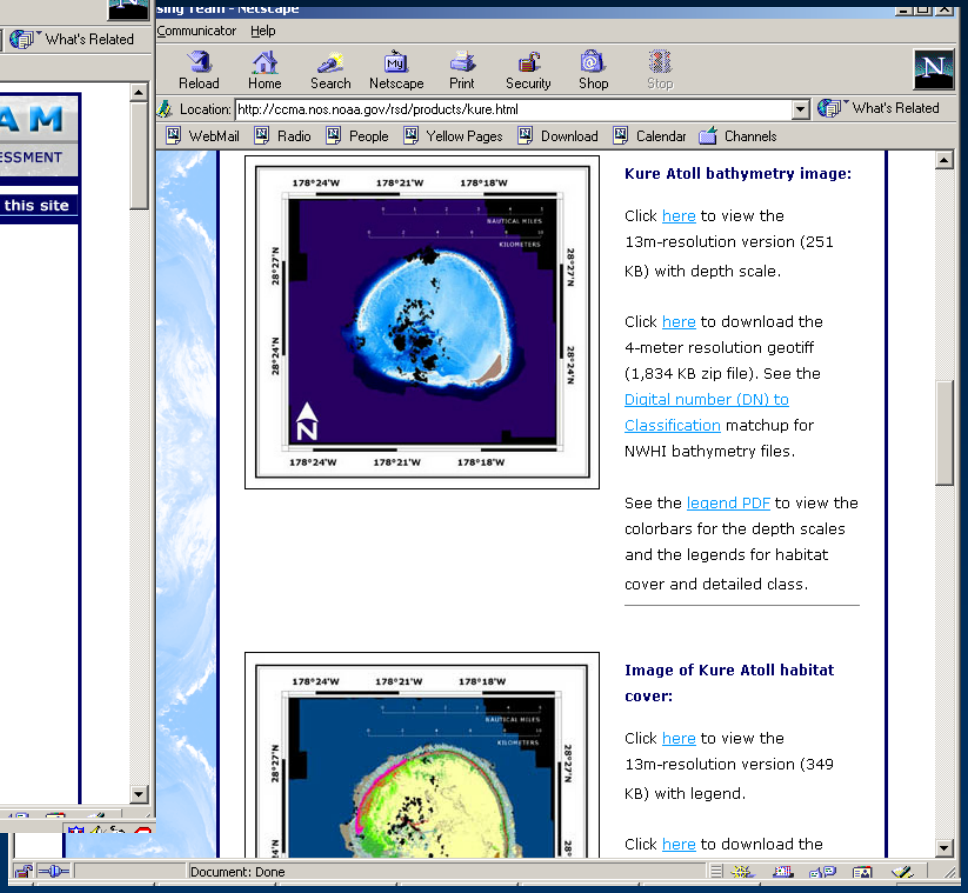


4-m true-color image



Pan sharpened true-color image
(PCI Geomatics pan sharpening module)

Satellite-derived products available on NOS website

National Centers for Coastal Ocean Science
Center for Coastal Monitoring and Assessment
Remote Sensing Team

http://ccma.nos.noaa.gov/rsd