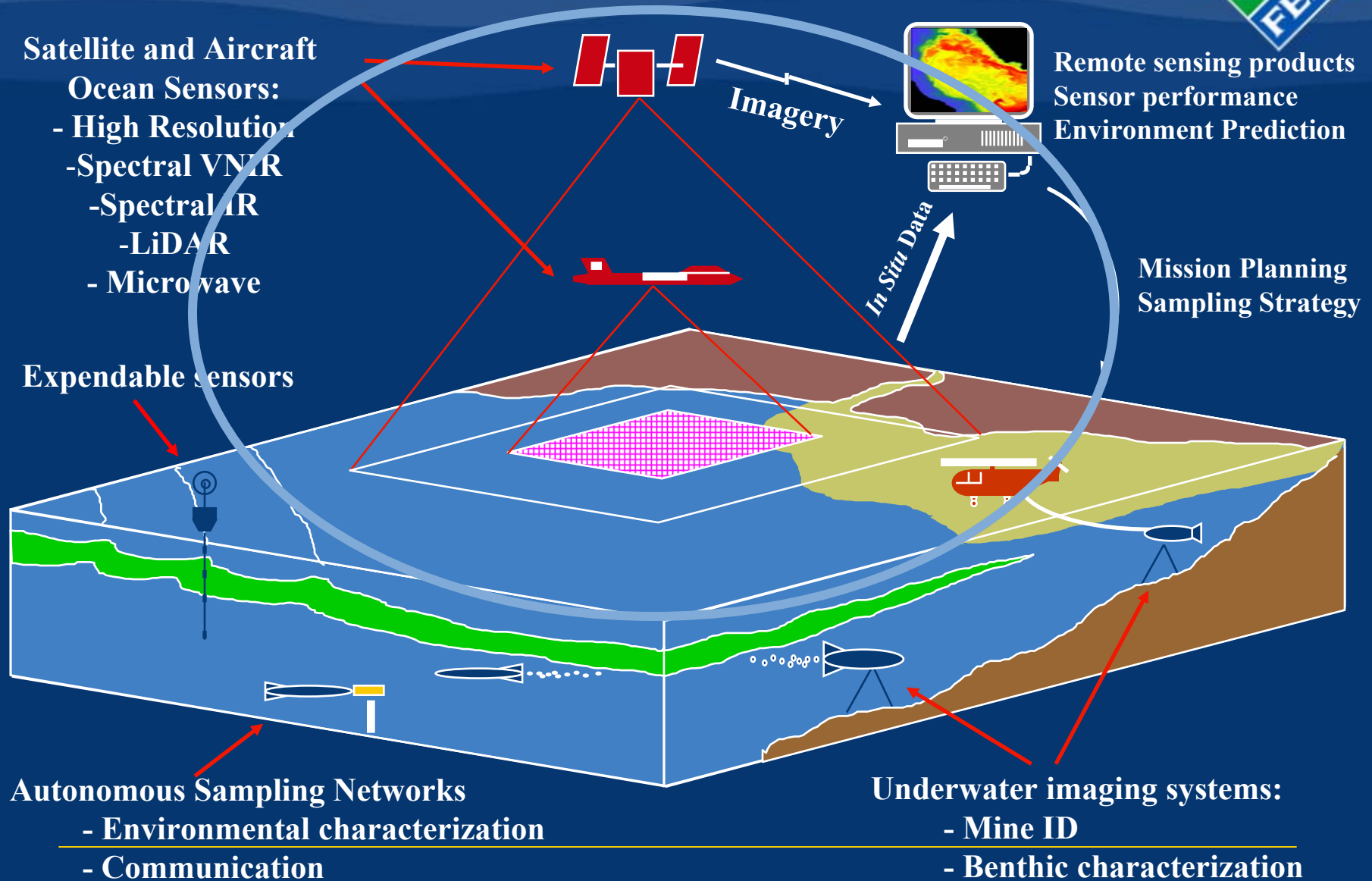




The Development of Airborne Optical Remote Sensing for Coastal Ocean Observatories

Cast of many...

Operational Oceanography

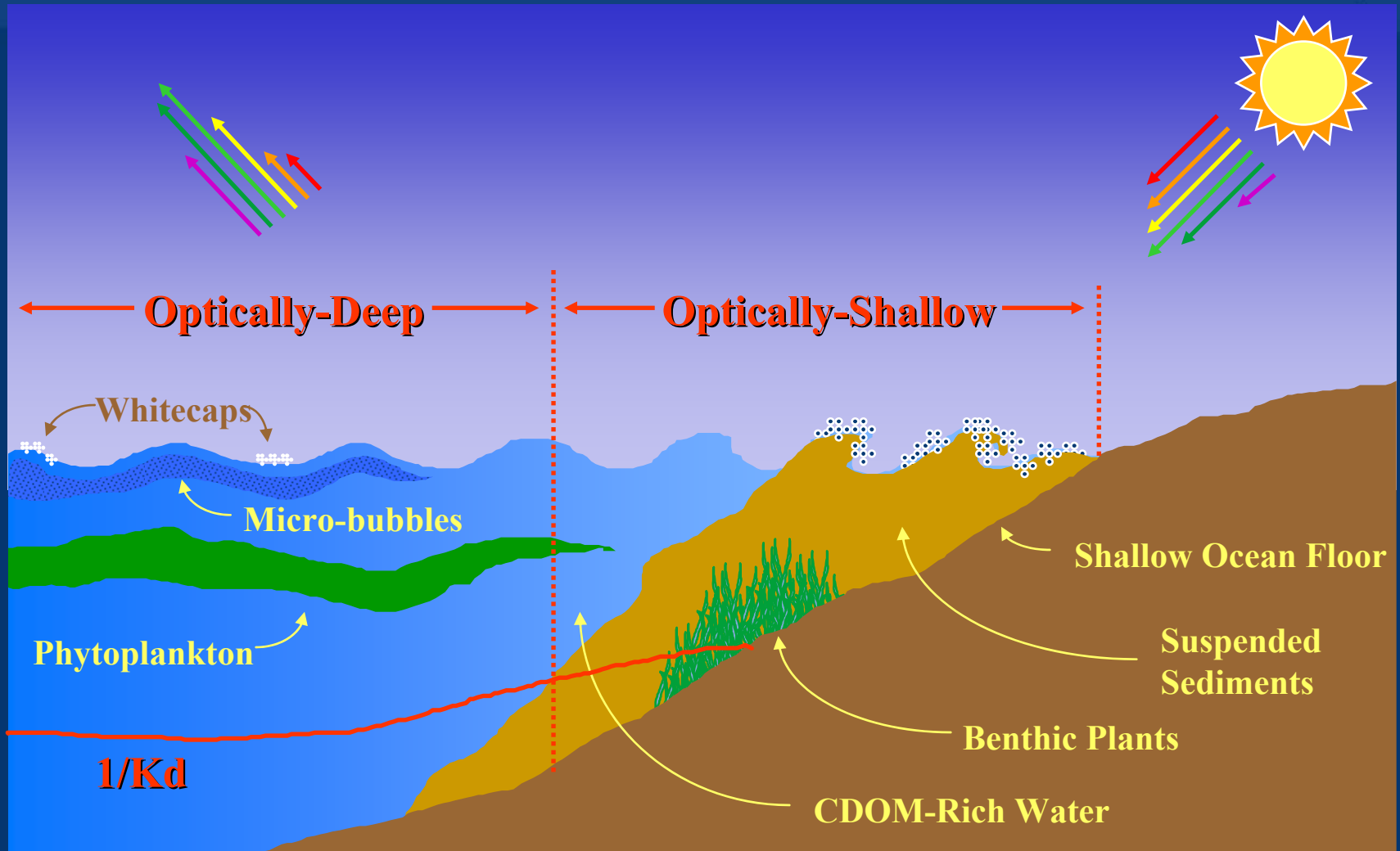


Naval LPA Intelligence, Surveillance, and Reconnaissance (ISR)



- Atmospheric ISR
 - Aerosol optical depth/Slant Path Visibility
 - Water vapor
- Ocean Very Shallow Water (VSW) ISR
 - Mine Counter Measures (MCM)
 - Bathymetry, bottom type and reflectance
 - Water clarity $K_d(490 \text{ nm})$ /Diver Visibility
 - Suspended sediments
 - Vertical structure of scattering properties
 - Phytoplankton chlorophyll
 - Colored Dissolved Organic Matter (CDOM)
- Beach Zone ISR
 - Vegetation and soil types
 - Terrain categorization/Elevation
 - Trafficability (ingress and egress routes)

Coastal Ocean Imaging Spectroscopy



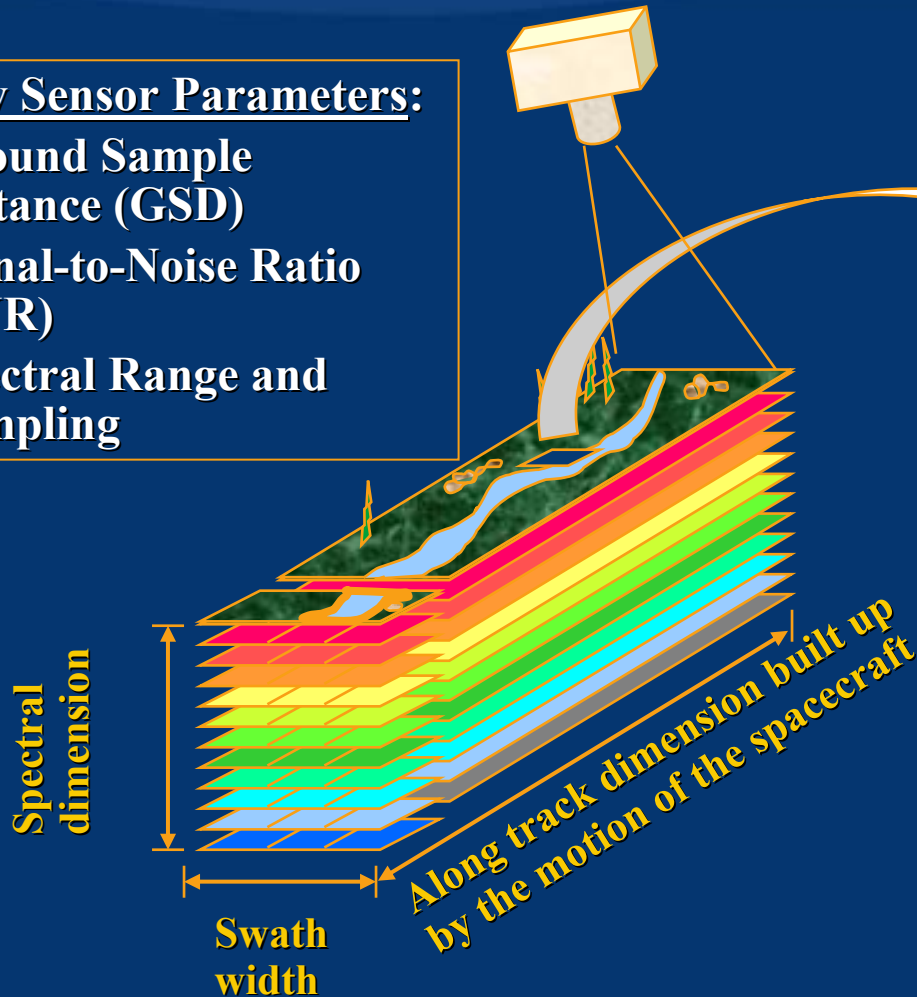
HyperSpectral Imaging (HSI) Concept



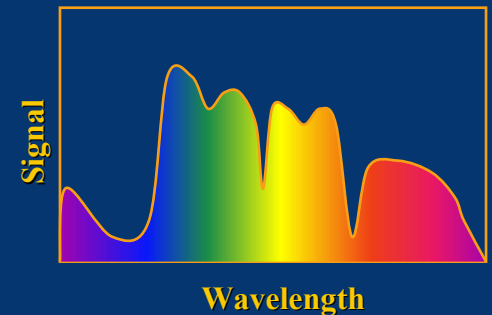
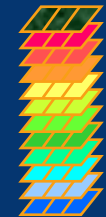
PHILLS hyperspectral sensor

Key Sensor Parameters:

Ground Sample Distance (GSD)
Signal-to-Noise Ratio (SNR)
Spectral Range and Sampling



Each pixel contains a spectrum, composed of many contiguous bands, that is used to identify the materials present in the pixel

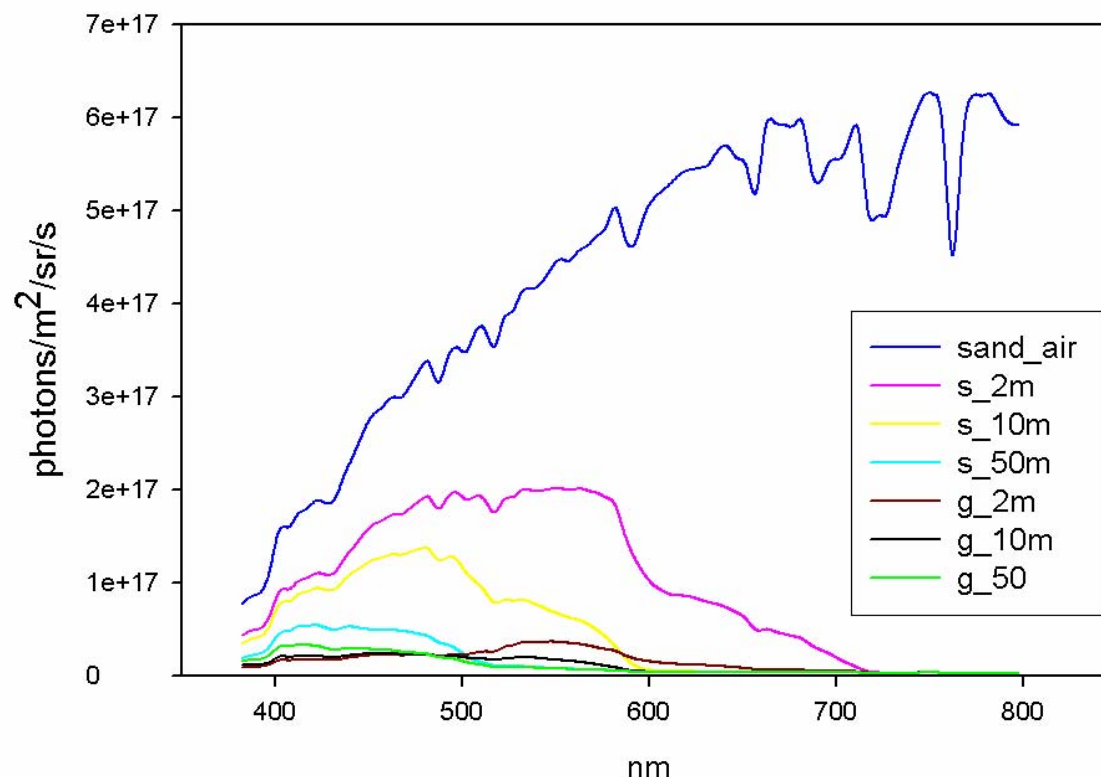


Why is it difficult?

Dark Target Spectroscopy



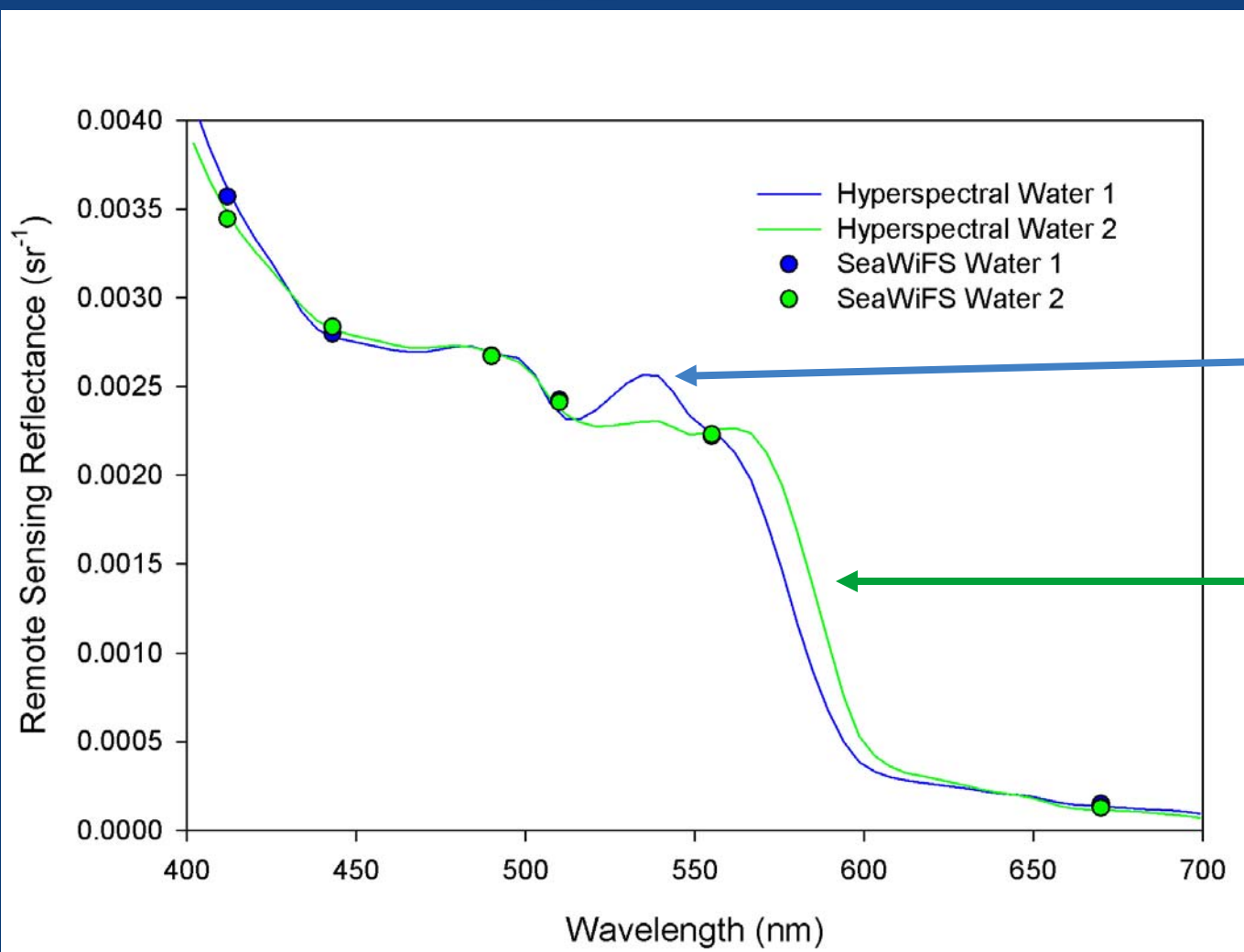
Upwelling Radiance from Sand and Grass
Bottoms in Case 1 Waters



Water is an extremely dark target compared to land targets. In addition, water attenuates signal exponentially with depth, at different rates per wavelength.

Why is it difficult?

Spectral Resolution in Shallow Water



Depth = 6.5 m
IOP = Case 1
Bottom = soft coral

Depth = 13 m
IOP = Pure H₂O
Bottom = sponge

Mission History/Data Availability



- **Deployments**

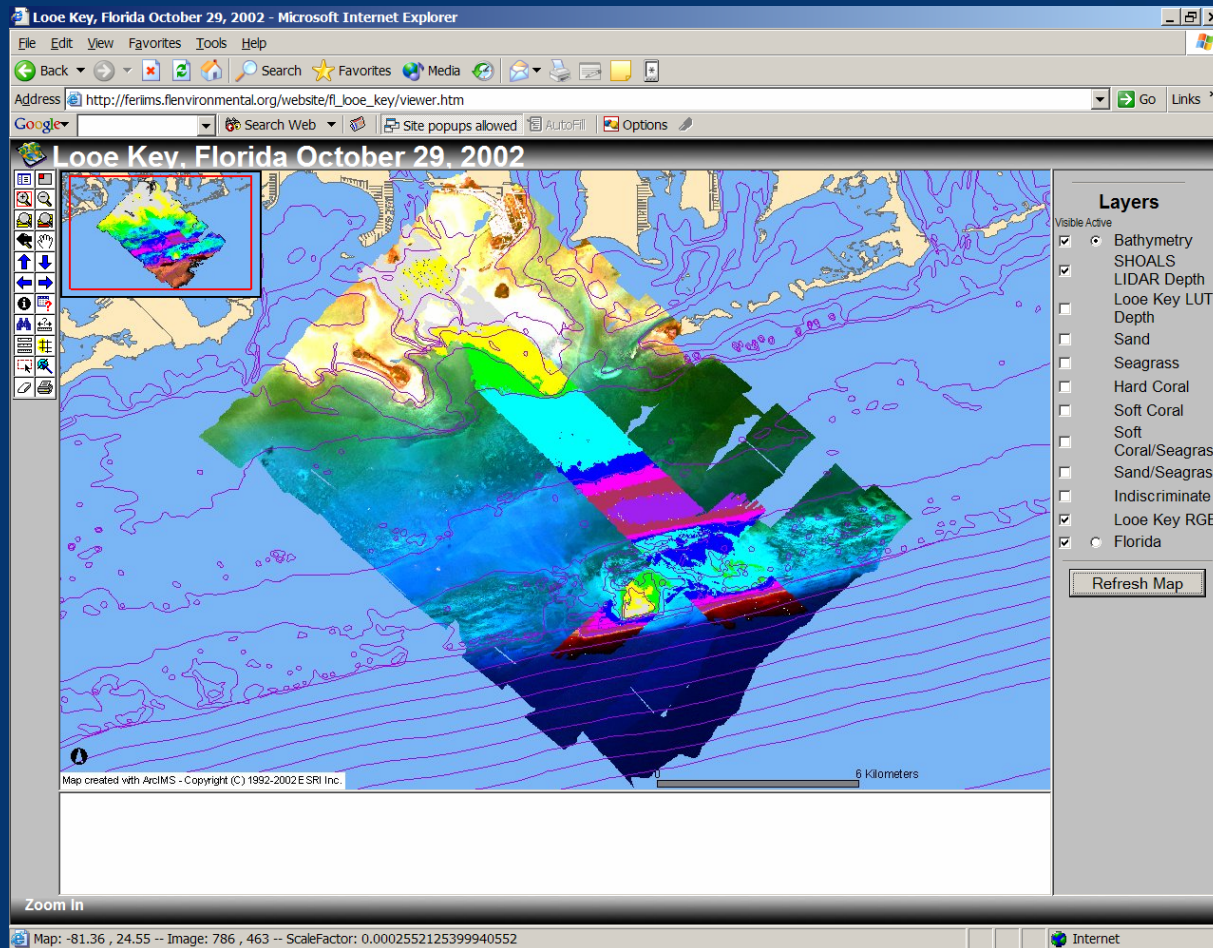
- **2000 – West Florida Shelf**
- **2001 – WFS and New Jersey Coast**
- **2002 – San Diego, Mobile, AL, Monterey, CA, and Looe Key, FL**
- **2003 – Monterey, CA, Fort Lauderdale, FL, and Sarasota, FL**
- **2004 – Humboldt Bay, San Francisco, Monterey, Big Sur, San Luis Bay, Santa Barbara Channel, LA Harbor, San Diego, CA**
- **2006 – Morro Bay, San Luis Bay, Santa Barbara, San Diego, CA; Pearl River, MS**



Is HSI the real product?
No – The real product is geospatial ISR.



Joint Hyperspectral/LIDAR Experiment

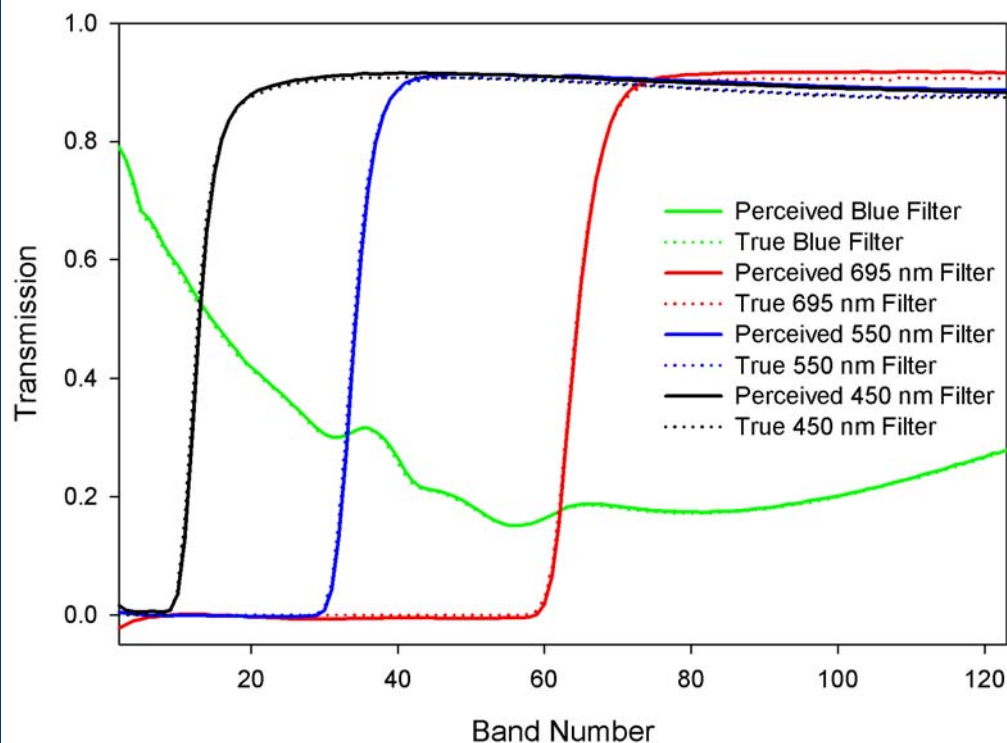


**ArcIMS
Distribution of
HSI/LIDAR
products**

Looe Key, FL

Product Generation

Step 1. – Calibration and Orthorectification



↑ Putting the photons in the right place
Putting the pixel in the right place →

Product Generation

Step 2. - Illumination and Atmosphere Correction



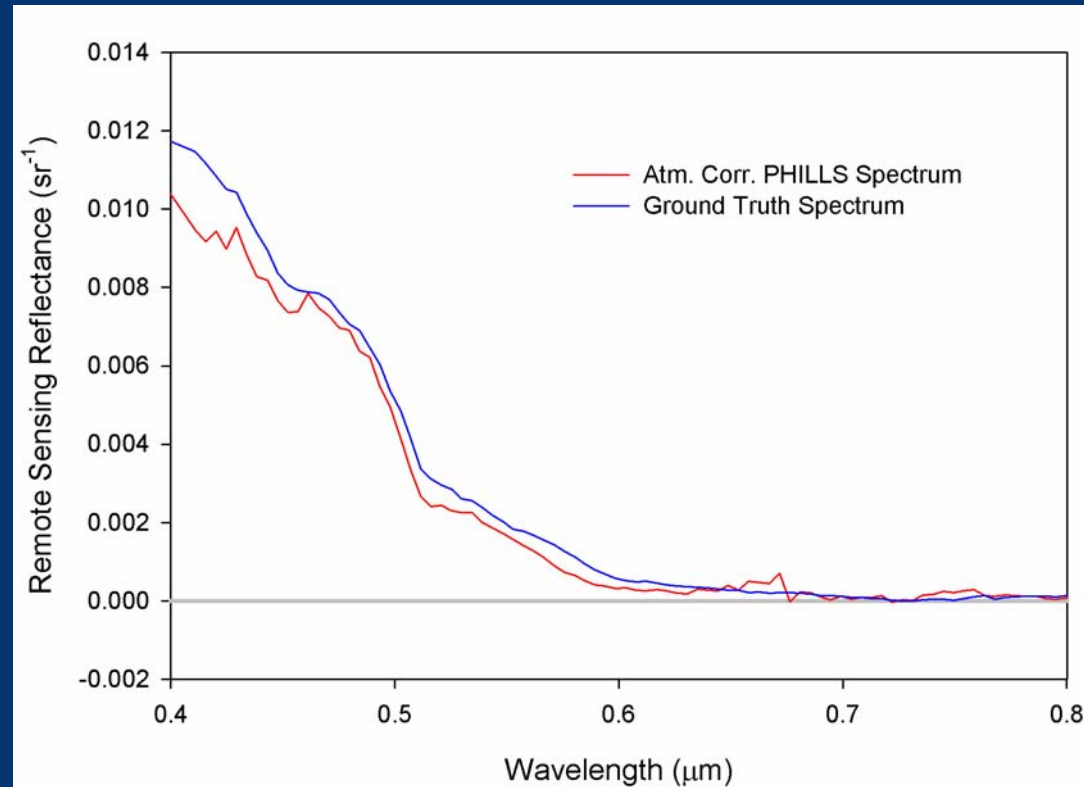
Range in which the GA was bounded

Water Vapor	= [.5, 2.0]
Ozone	= [.30, .38]
Tau 550	= [.05, 1.2]
Wind Speed	= [2, 6, 10]
Relative Humidity	= [50, 70, 80, 90, 98]
Aerosol Model	= ['urban', 'maritime', 'coastal', 'coastal-a', 'tropospheric']

75,000,000 possible solutions!

Chosen Model (after ~59K runs)

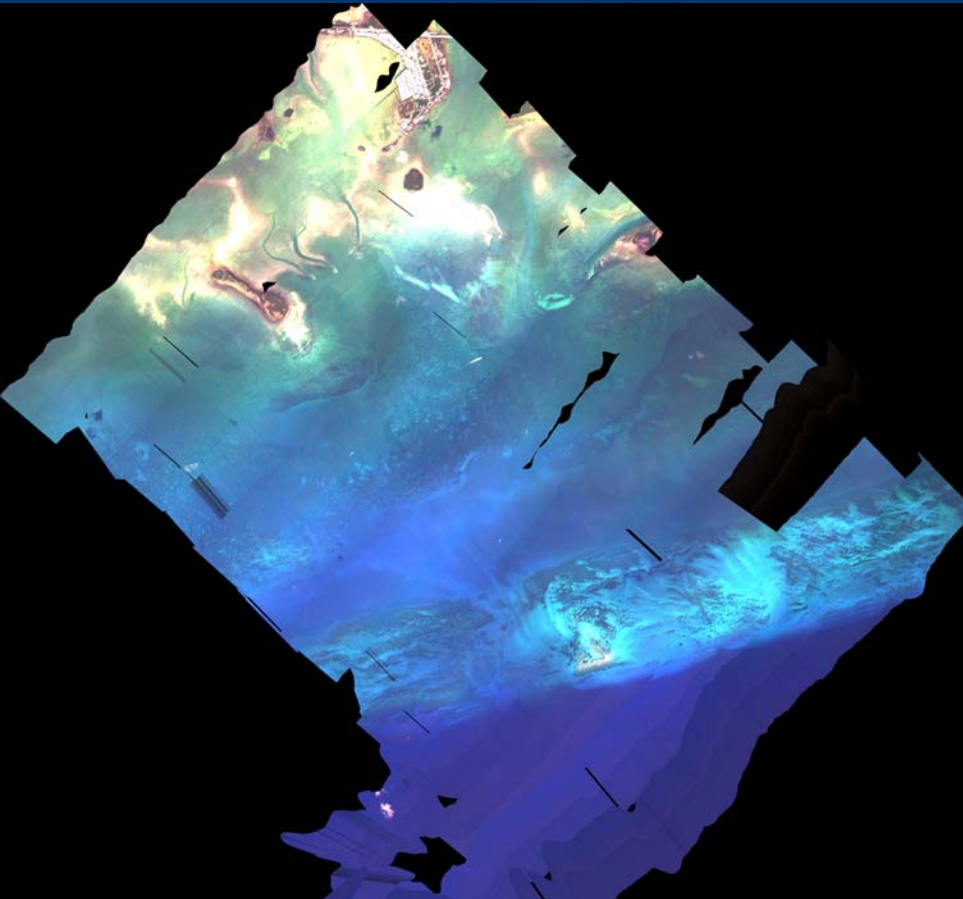
Water Vapor	= 1.895
Ozone	= 0.3792
Tau 550	= 0.050
Wind Speed	= 2
Relative Humidity	= 50
Aerosol Model	= urban



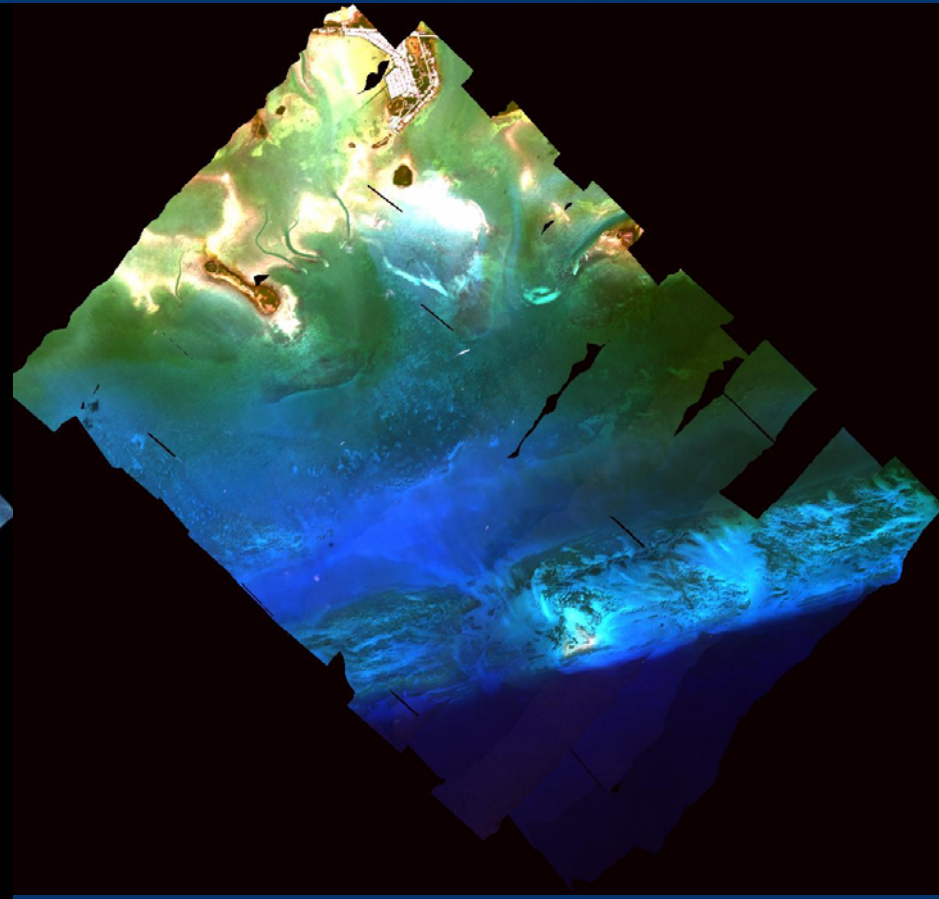
HSI Atmospheric Correction



Pre-Atmospheric Correction



Post-Atmospheric Correction

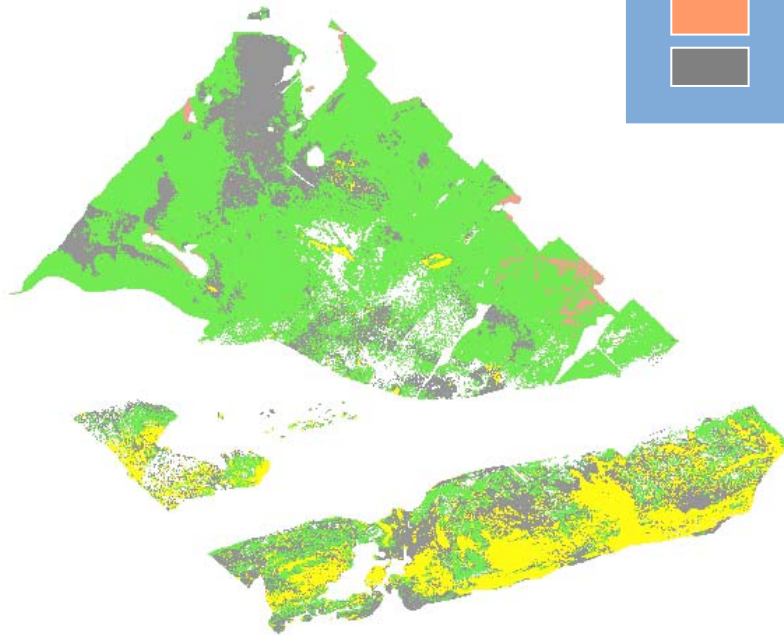


Product Generation

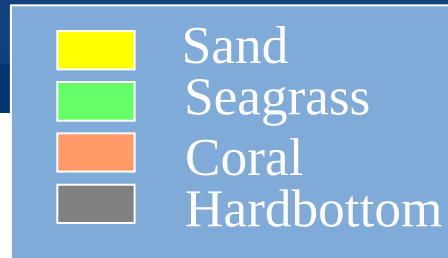
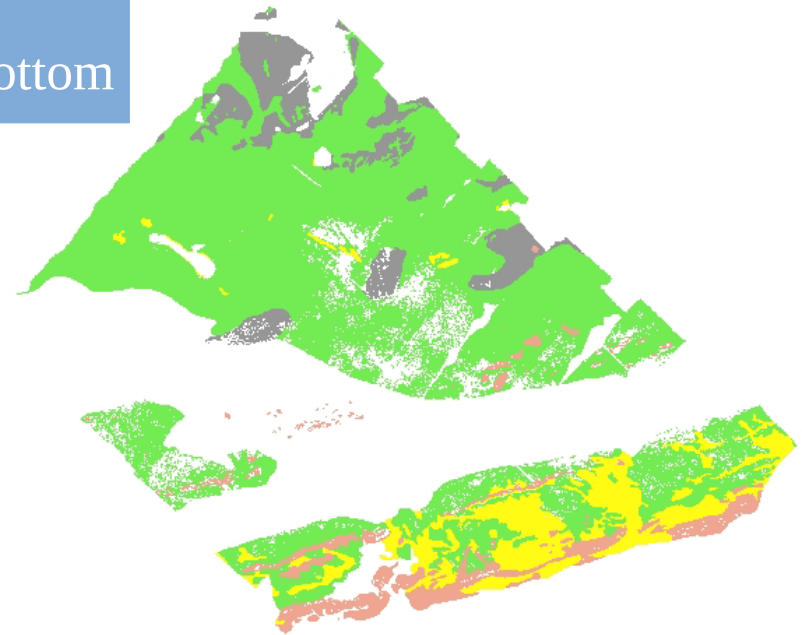
Step 3. – Geospatial Intelligence



FERI LUT 2002



NOAA 1992



- 16 m resolution
- Unknown pixels removed from both data sets.

Evidence of Algal Overgrowth in the Florida Keys



Caulerpa brachypus is a nonnative macroalgae that has invaded Florida's coral reefs.

Photo courtesy of Harbor Branch Oceanographic Institution, Inc.



Typical algal overgrowth on coral rubble in Florida.

Photo courtesy of U.S. Department of the Interior, U.S. Geological Survey, Center for Coastal Geology

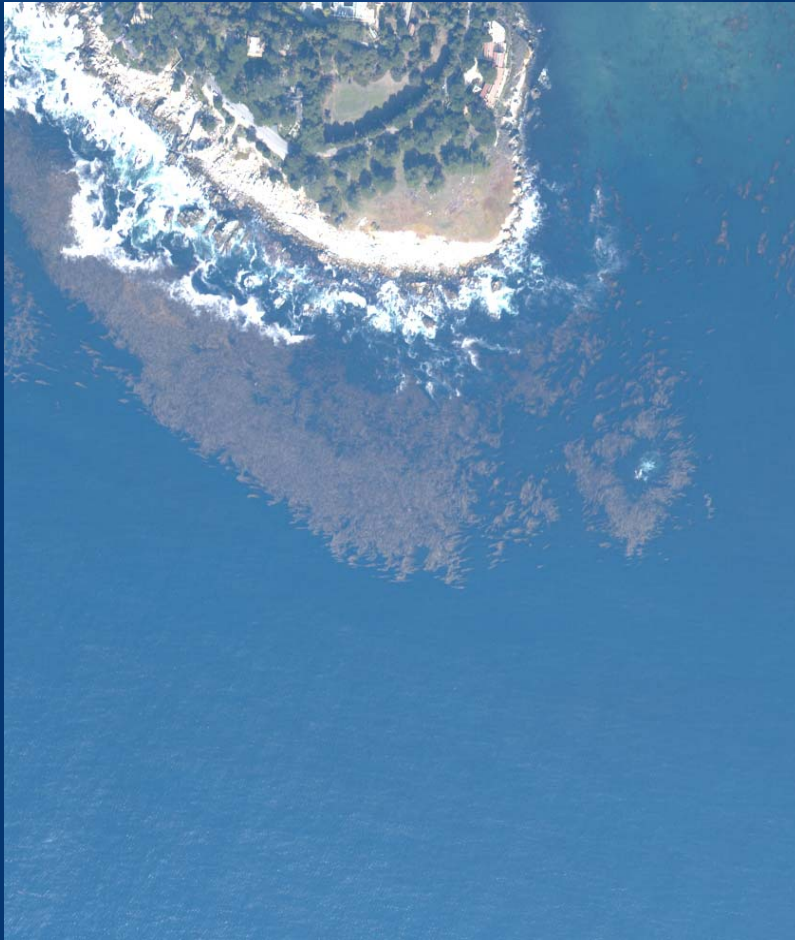


CSU CICORE HSI Program

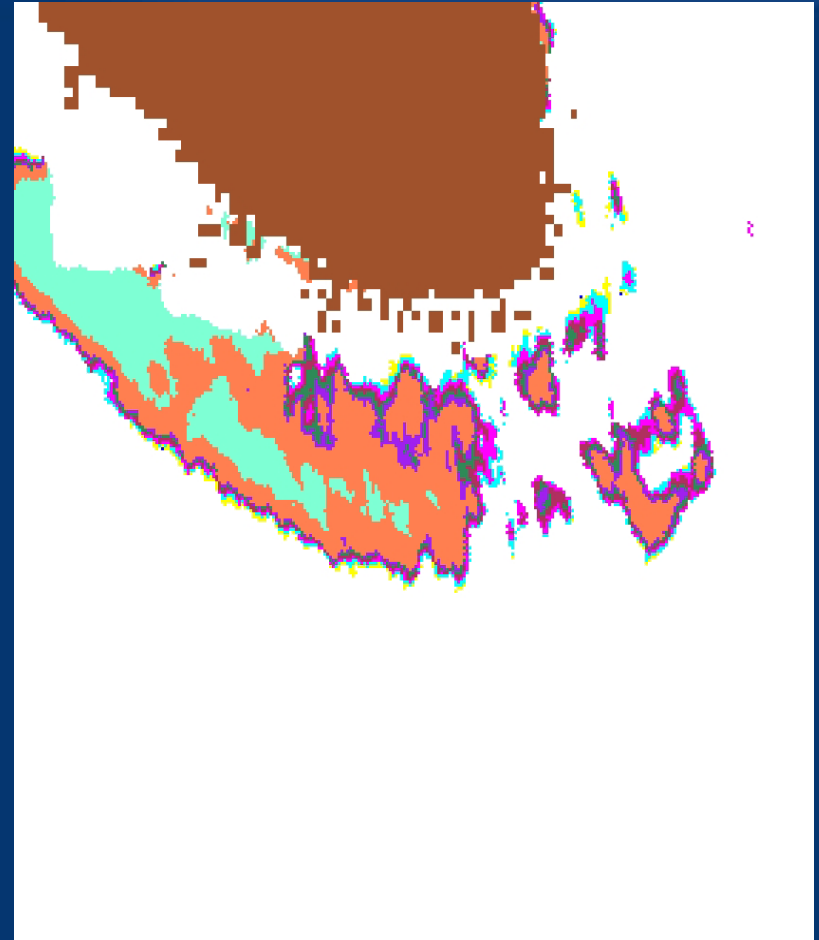
CA Integrated Coastal Observatory for Research and Education



Monterey Peninsula October 2004



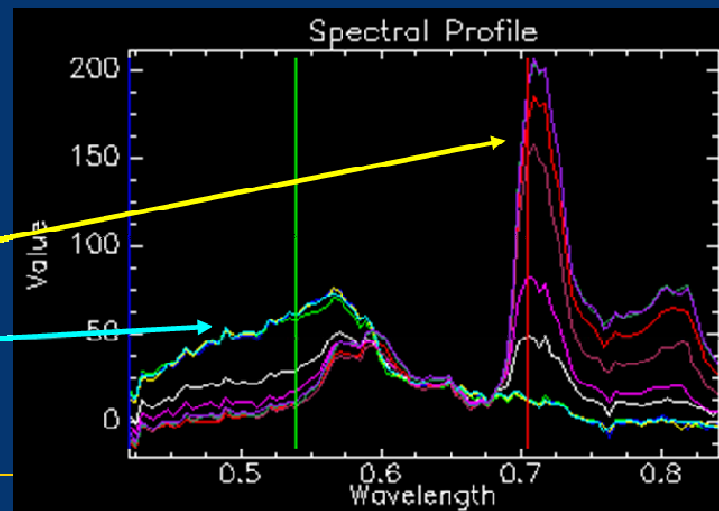
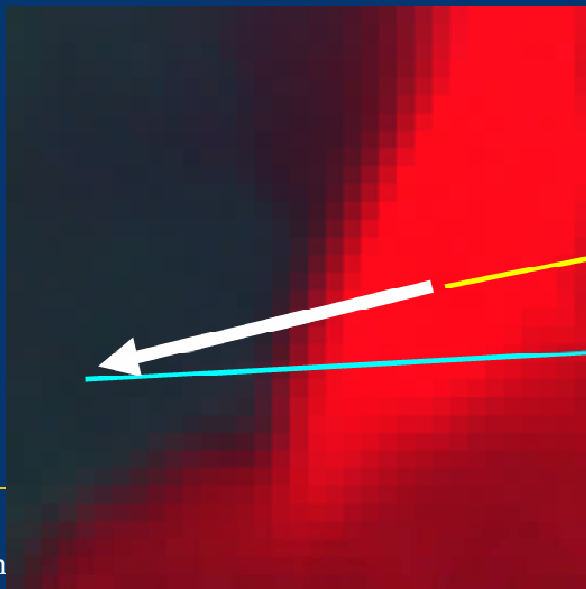
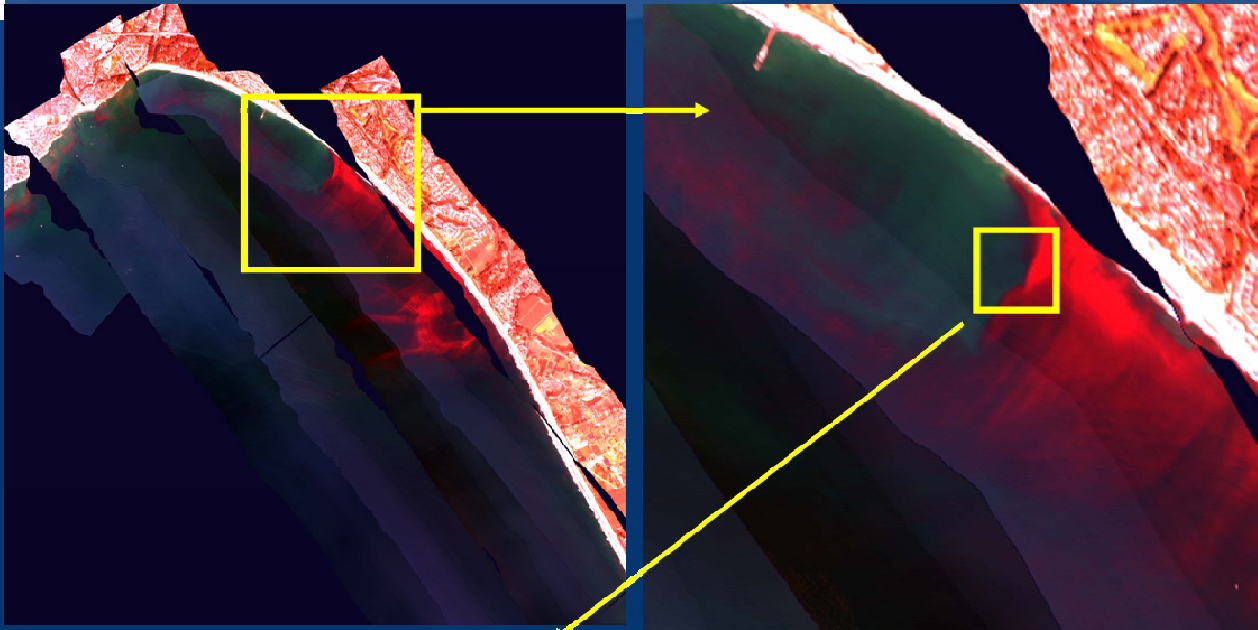
MSI (DSS) OrthoPhoto 0.5 m



HSI Kelp Density (10% intervals)

Harmful Algal Bloom (Red Tide)

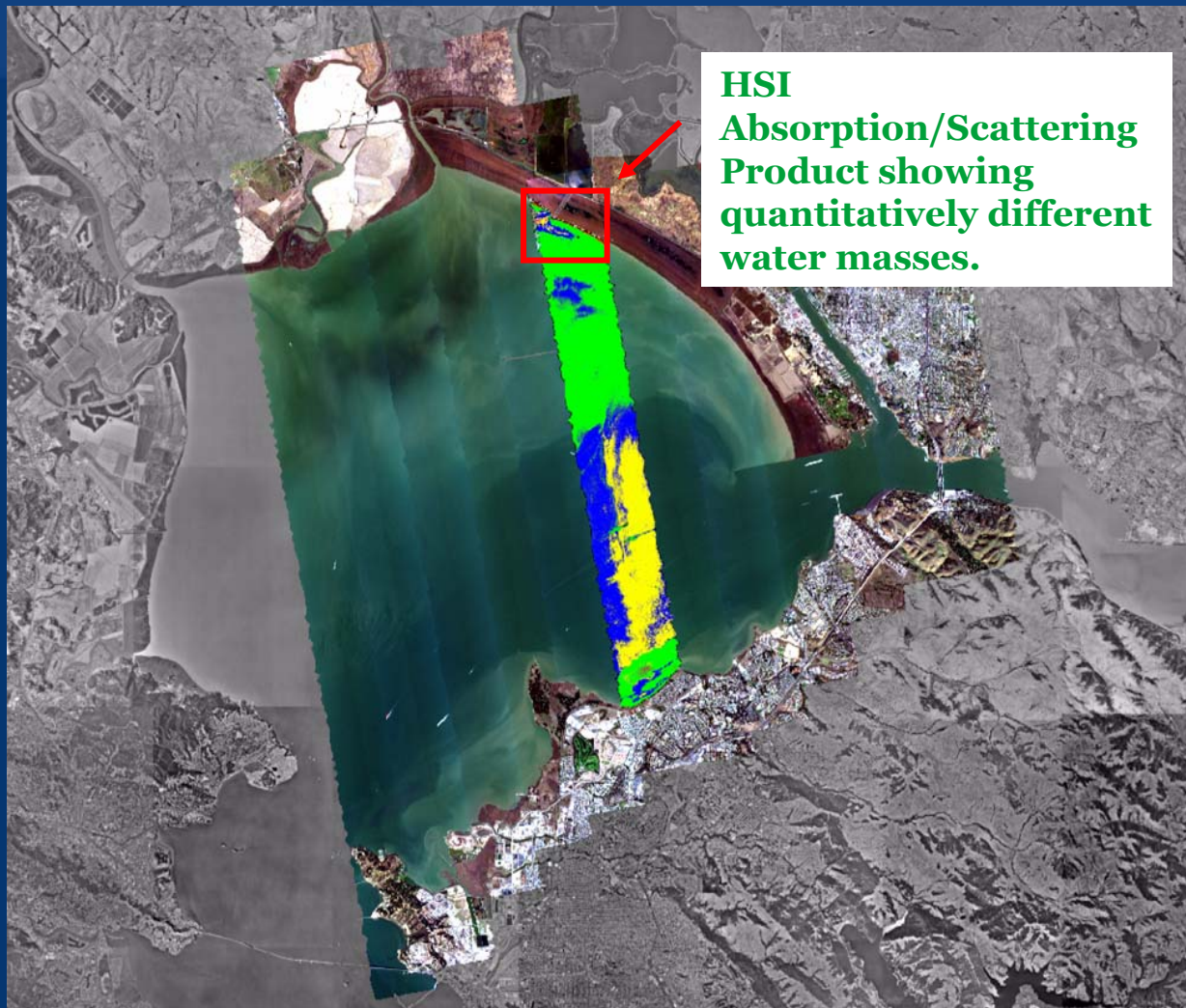
Monterey Bay, October 2002



Water Clarity/Quality

Inherent Optical Properties

San Francisco Bay 2004



Water Clarity/Quality Inherent Optical Properties *San Francisco Bay 2004*





Product Generation

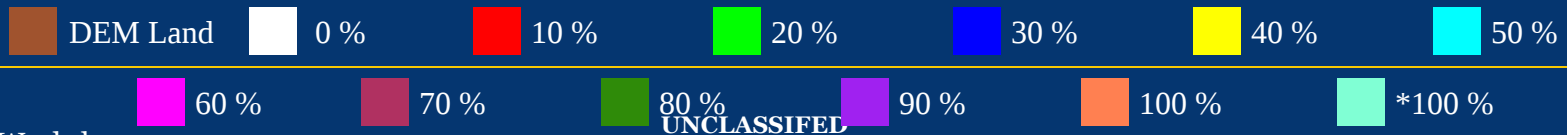
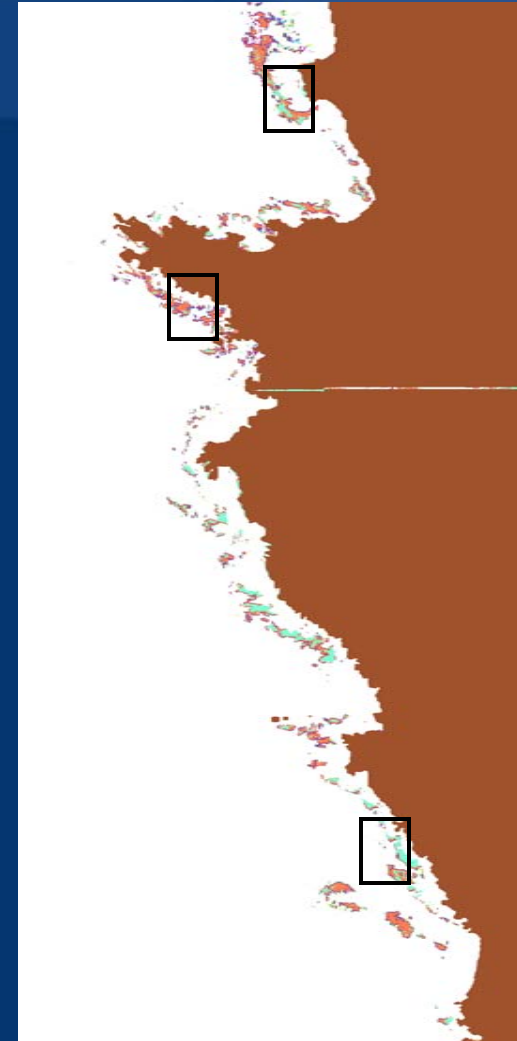
Kelp Coverage Comparison



2002



2004





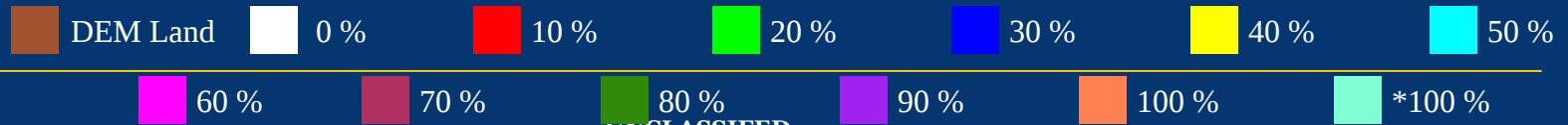
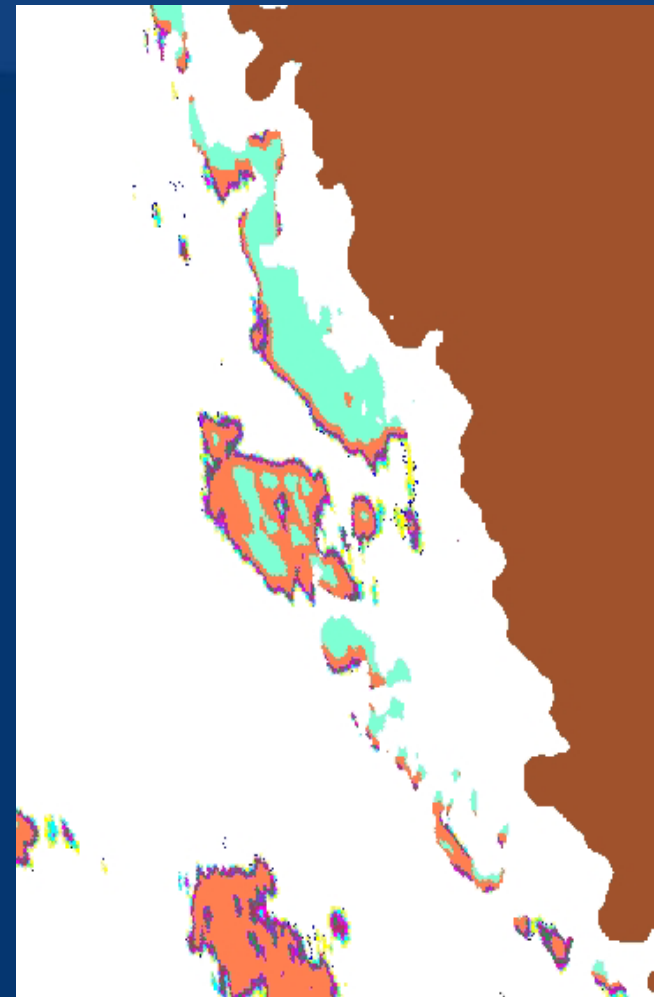
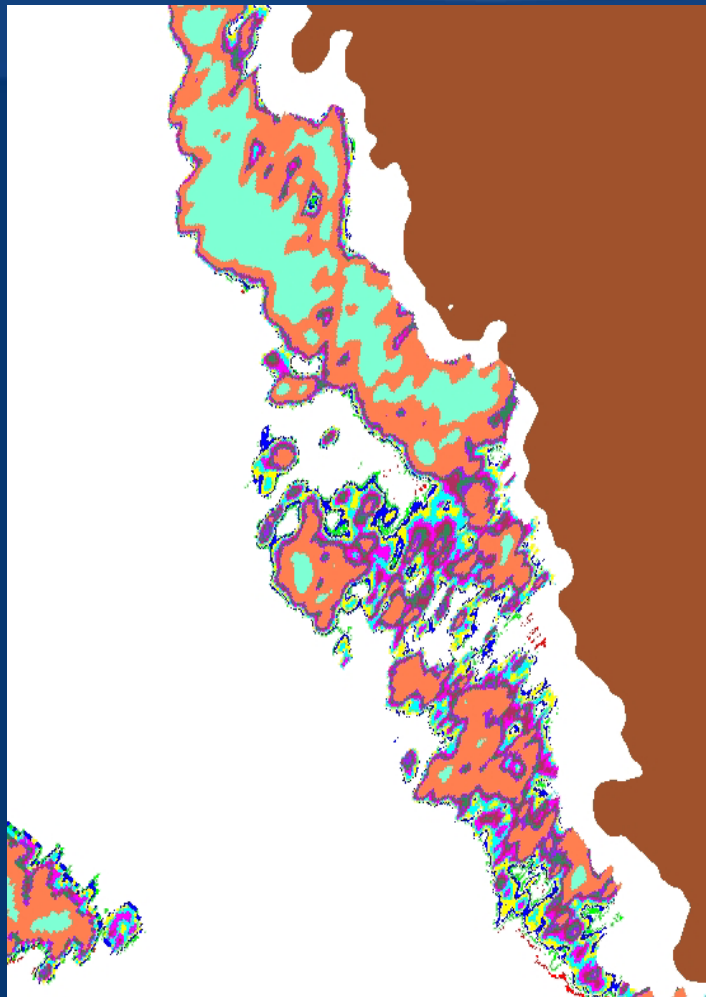
Product Generation

Kelp Coverage Comparison - Zoom3 - RGB



2002

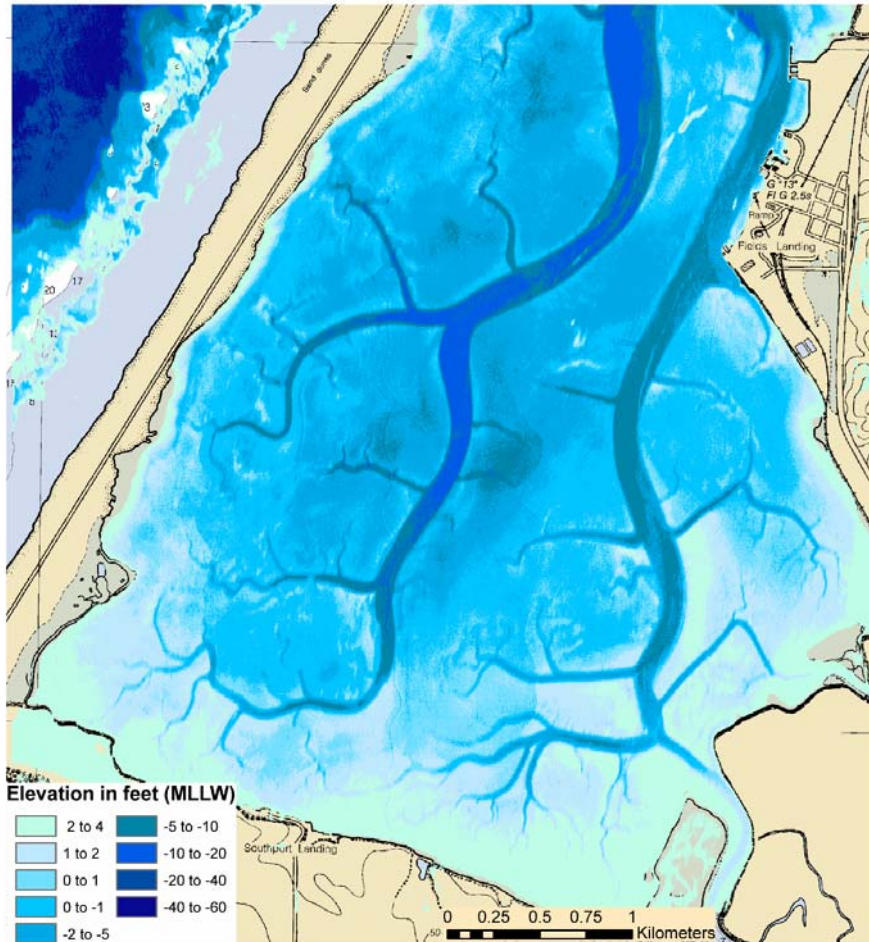
2004





Humboldt Bay Eel Grass Identification

Chaeli Judd, MS Thesis, Judd et al., 2006 (in prep)



LIDAR/HSI Fused Bathymetric Product



HSI determined eel grass distributions, previously unknown.

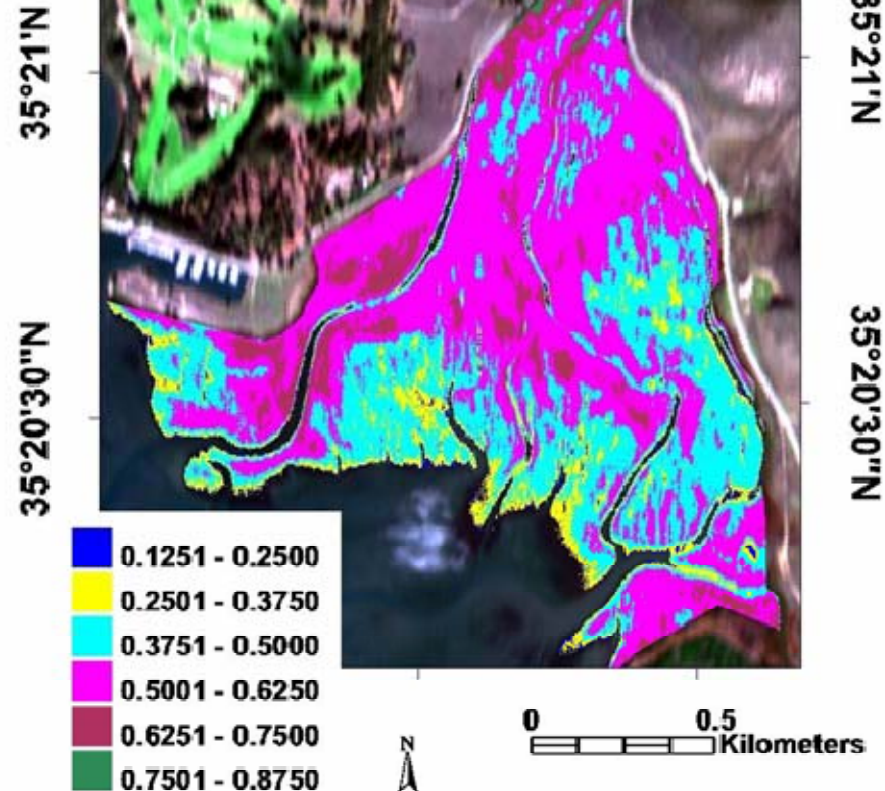


Morro Bay HSI Vegetation Classification

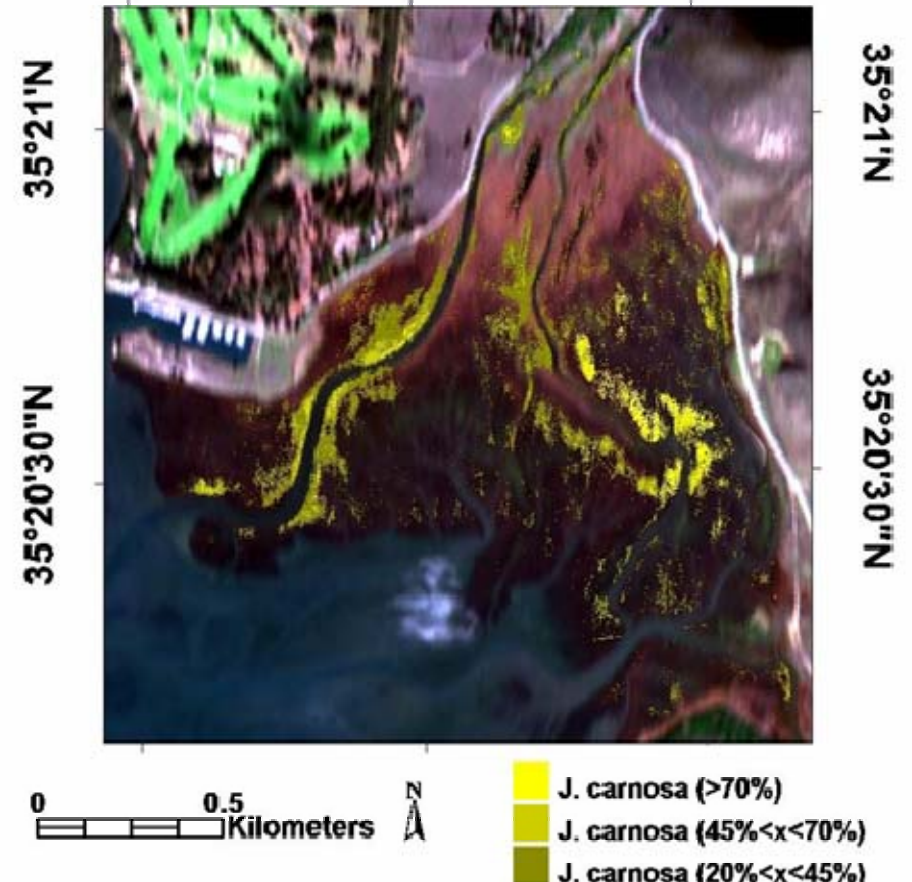
Mike Sauer, CalPoly MS Thesis
Sauer et al., 2006 (Submitted)



120°50'30"W 120°50'W 120°49'30"W



120°50'30"W 120°50'W 120°49'30"W



MSI NDVI Vegetation Index

HSI Competitive interaction zones
between *Jaumea carnosa* and *Salicornia virginica*

Operational Image Resolution

What People Want





Operational Image Resolution

What People Got – PHILLS 3 x 12 m



SAMSON

Spectroscopic Aerial Mapping System with On-board Navigation



- We have developed a low-cost, robust HyperSpectral Imager, the Spectroscopic Aerial Mapper with On-board Navigation (SAMSON).
- SAMSON provides for a full HSI dataset 256 bands in the VNIR (3.5 nm resolution) at 75 frames per second, with a SNR, stability, dynamic range, and calibration sufficient for dark target spectroscopy.



SAMSON HSI/MSI installation *on 3-axis stabilized mount*



High Resolution MSI

0.5 m RGB - Morro Bay 2006

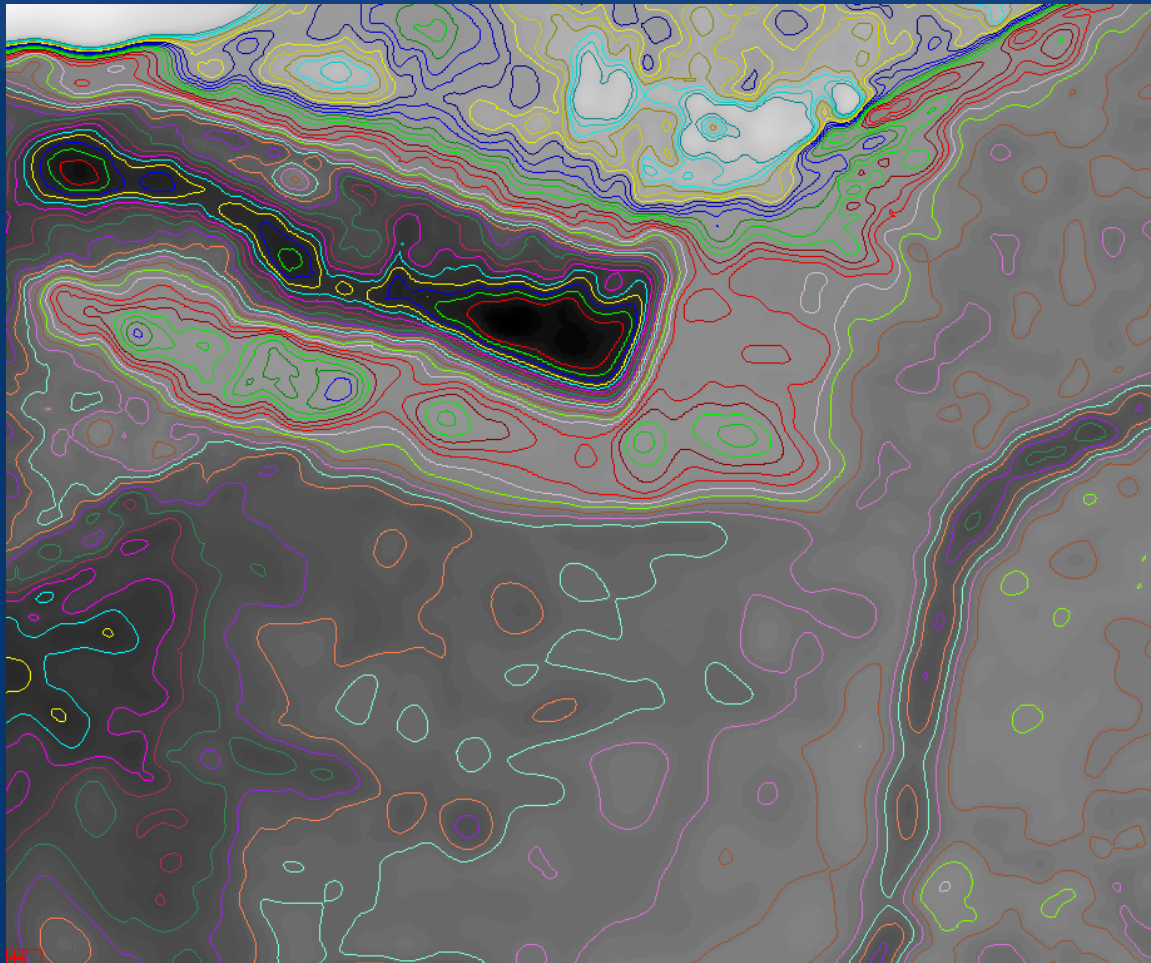


Is there more here for coastal geo-intelligence ...?



High Resolution Digital Elevation Map

1.5 m - Morro Bay 2006



0.25 m
contours

Elevation critical in both Sauer et al., and Judd et al., studies.

Fused RGB/Digital Elevation Map

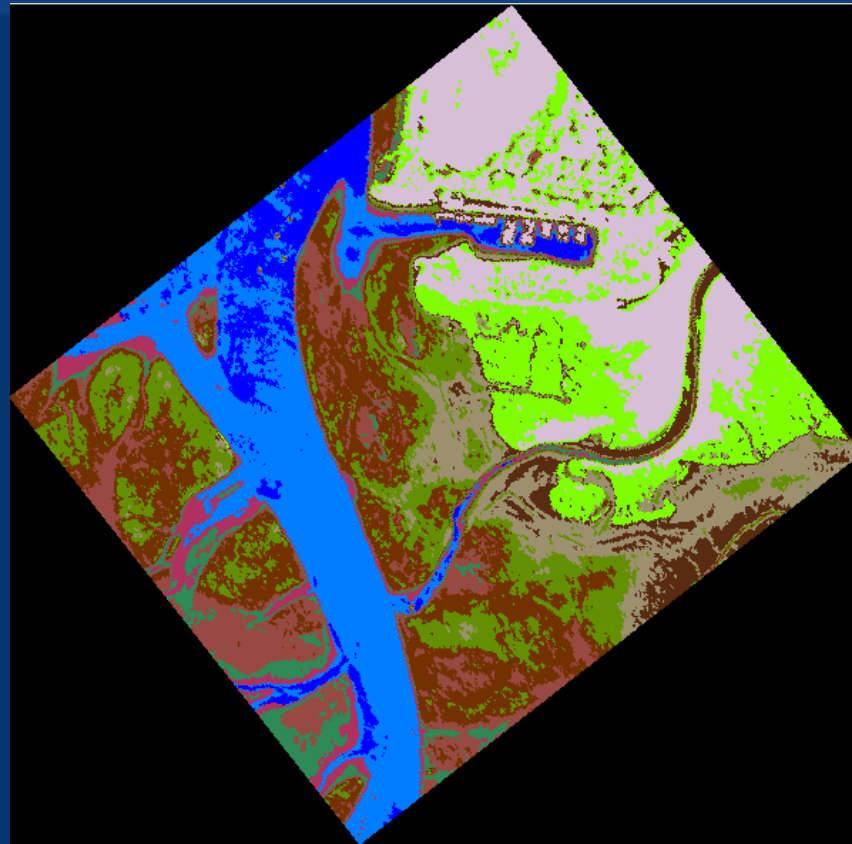
0.5/1.5 m - Morro Bay 2006



Elevation and its rate of change are ecological determinants in riparian communities.

HSI Classification

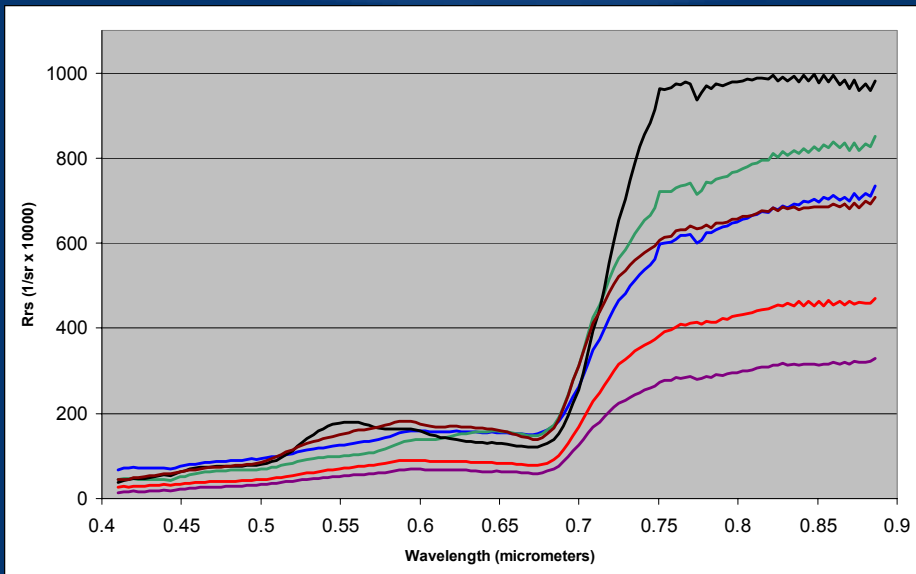
3.0 m HSI - Morro Bay 2006



Unsupervised classification – 16 classes

HSI Spectra

3.0 m HSI - Morro Bay 2006



Higher SNR than previous PHILLS, particularly in NIR.



Much better spatial resolution –
But is it good enough?

Spatial Resolution Studies

Morro Bay 2006



Low Res HSI – 3 m

High Res HSI – 1 m



Higher Res MSI – 0.5 m
also have 0.15 m

Some Summary Thoughts



- Geospatial technologies are ultimately about intelligence. Coastal ocean observatories should give operational geo-intelligence for effective decision making.
- Airborne optical remote sensing is a tool that is ready for operational deployment.
- Operation deployment is at least an order of magnitude more difficult (and expensive) than research and education.
 - TBs of data
 - Rapid turn around of relevant products
 - Contractor mentality
- Deployment optimization may be product and site specific.
 - Spatial and spectral resolution requirements will drive deployment requirements (and costs).