The Development of Imaging Spectrometry of the Coastal Ocean

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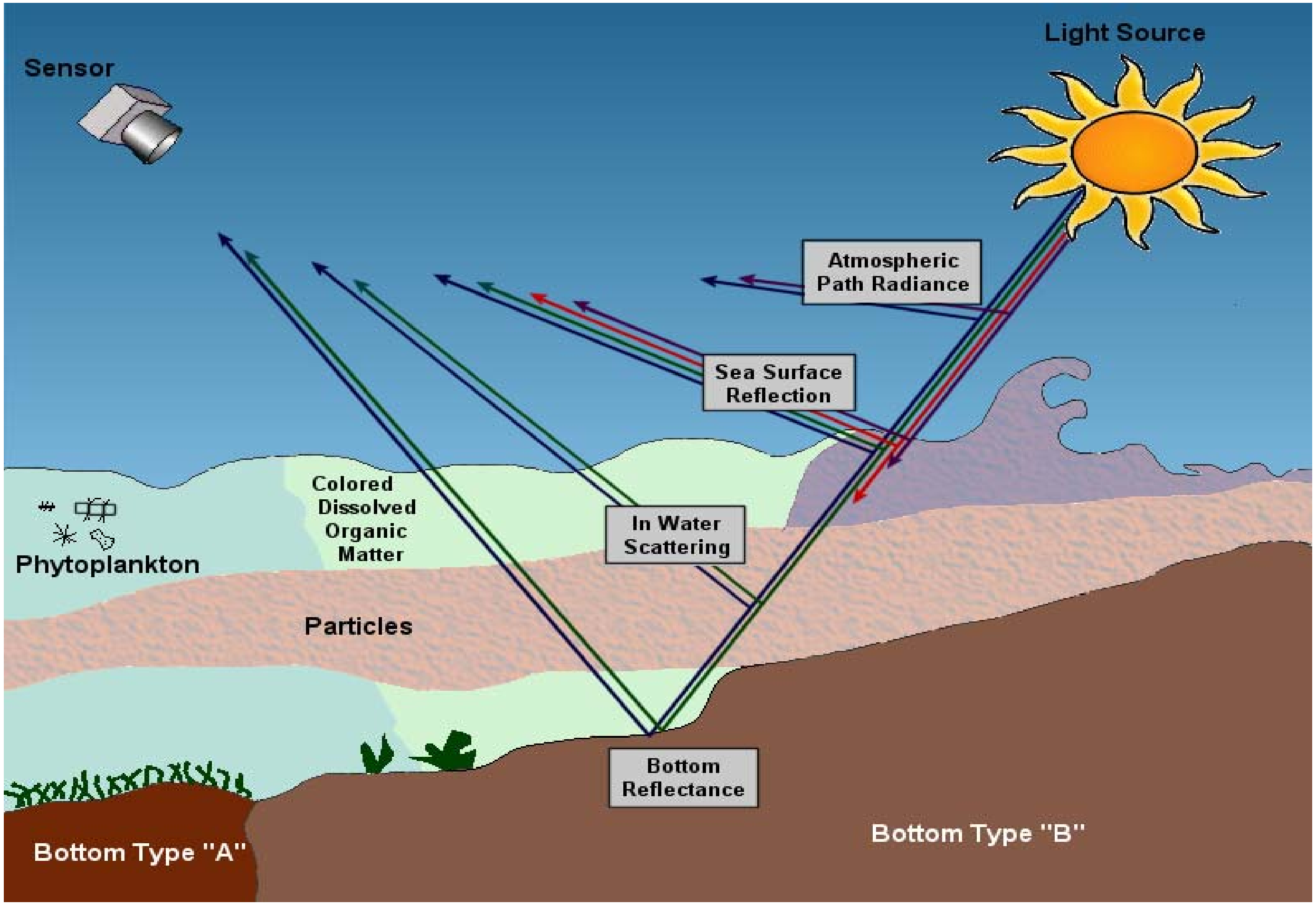
Imaging Spectrometry of the Coastal Ocean: Presentation Outline

- Why Imaging Spectrometry?
- Airborne Experience
  - AVIRIS
  - PHILLS
  - New systems: SAMSON and CASI
- Tafkaa Atmospheric Correction
- Ocean Product Algorithms and Applications
- Spaceborne Imaging Spectrometry
  - Hyperion Results
  - COIS
- Summary: A tribute to Alex Goetz

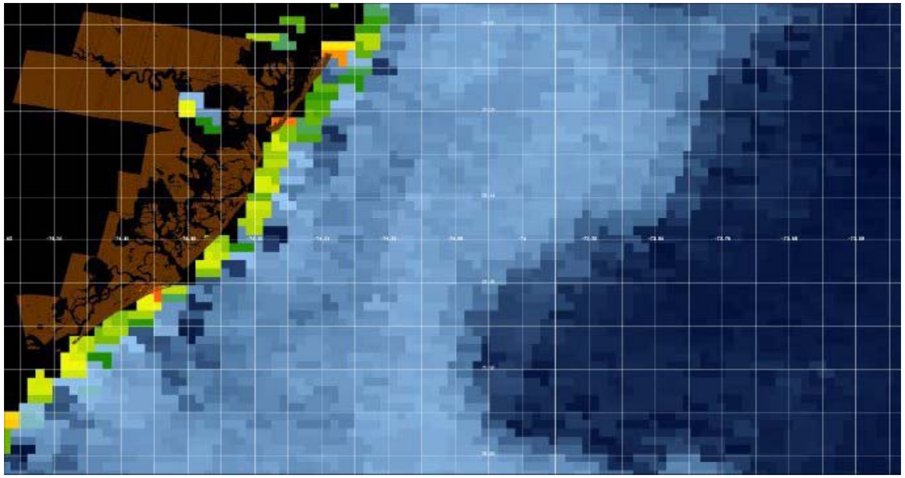
Resolving the Complexity of Coastal Optics Requires Imaging Spectrometry



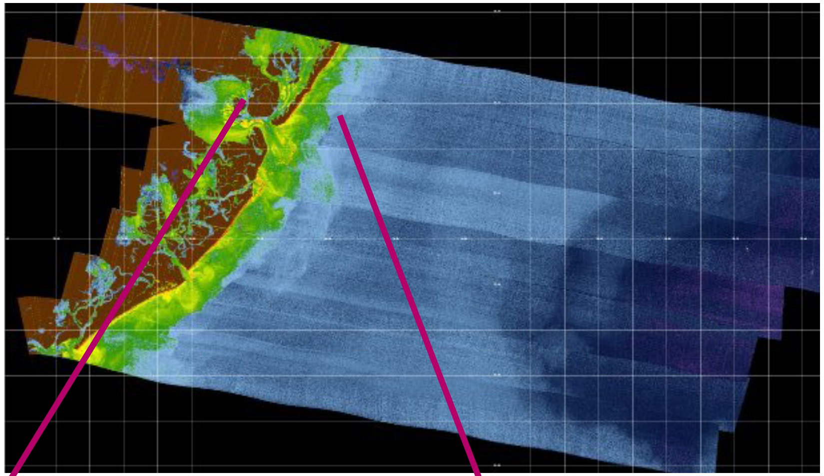
Extensive studies using shipboard measurements and airborne hyperspectral imaging have shown that visible hyperspectral imaging is the only tool available to resolve the complexity of the coastal ocean from space.
(Lee and Carder, *Appl. Opt.*, 41(12), 2191 – 2201, 2002.)

The need for High Spatial Resolution in the Near Coastal Ocean

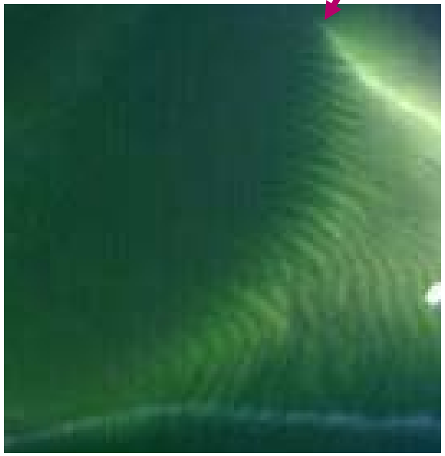
SeaWiFS 1 km data



PHILLS-2 9 m data mosaic



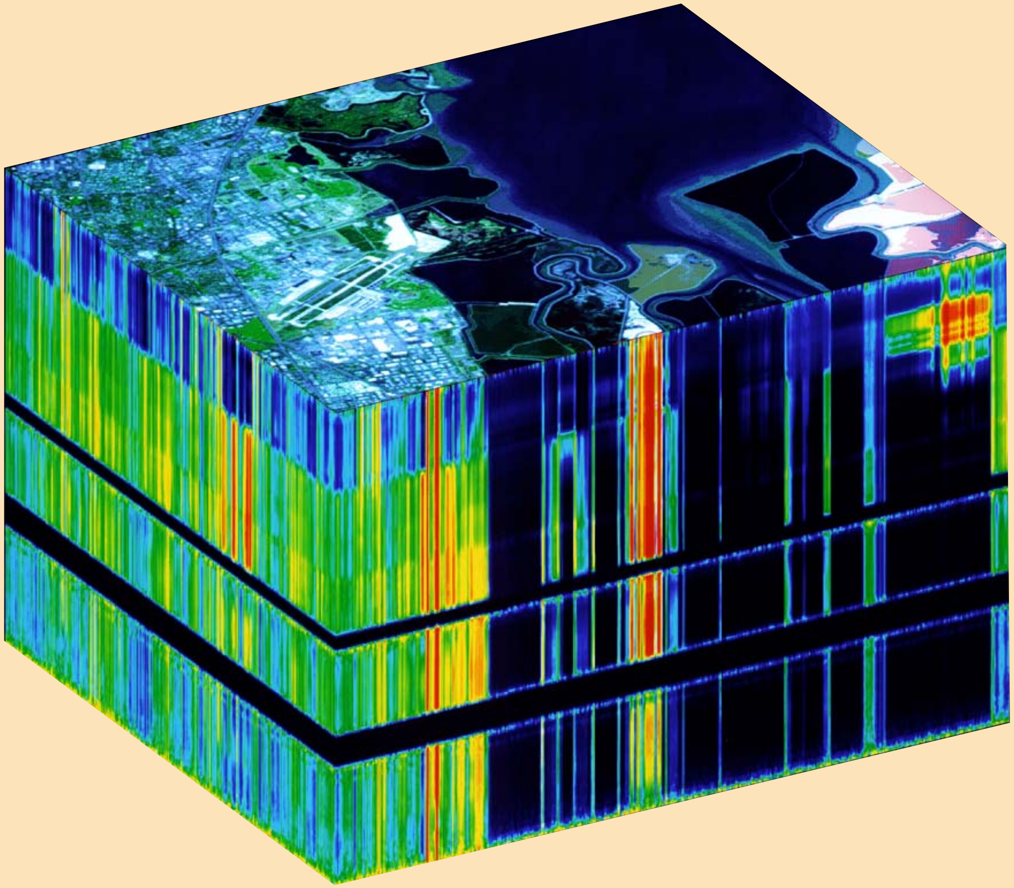
Near-simultaneous data from 5 ships, two moorings, three Aircraft and two satellites collected to address issues of scaling in the coastal zone. (HyCODE LEO-15 Experiment July 31, 2001.)



Sand waves in PHILLS-1 1.8 m data

Fronts in AVIRIS 20 m data

Airborne Visible/Infrared Imaging Spectrometer (AVIRIS)



- NASA Instrument Built and Operated by JPL
- Flown on NASA's ER-2 at 20km Altitude 20m Ground Sample Distance (GSD), or on a Twin Otter for 4 m GSD
  - 220 (10nm) Spectral Bands
  - 0.4 to 2.5 µm
- AVIRIS Image Cube
  - Moffet Field, CA
  - Top of Image RGB From 3 Spectral Bands
  - Sides - Spectral Dimension of the Edge Pixels
    - Red ⇒ High Signal
    - Purple ⇒ Low Signal

Solving the Shallow Ocean Remote Sensing Problem using Hyperspectral Data

Remote-sensing reflectance (R_{rs}) is a function of properties of the water column and the bottom,

$$R_{rs}(\lambda) = f[a(\lambda), b_b(\lambda), \rho(\lambda), H], \qquad (1)$$

where $a(\lambda)$ is the absorption coefficient, $b_b(\lambda)$ is the backscattering coefficient, $\rho(\lambda)$ is the bottom albedo, H is the bottom depth.

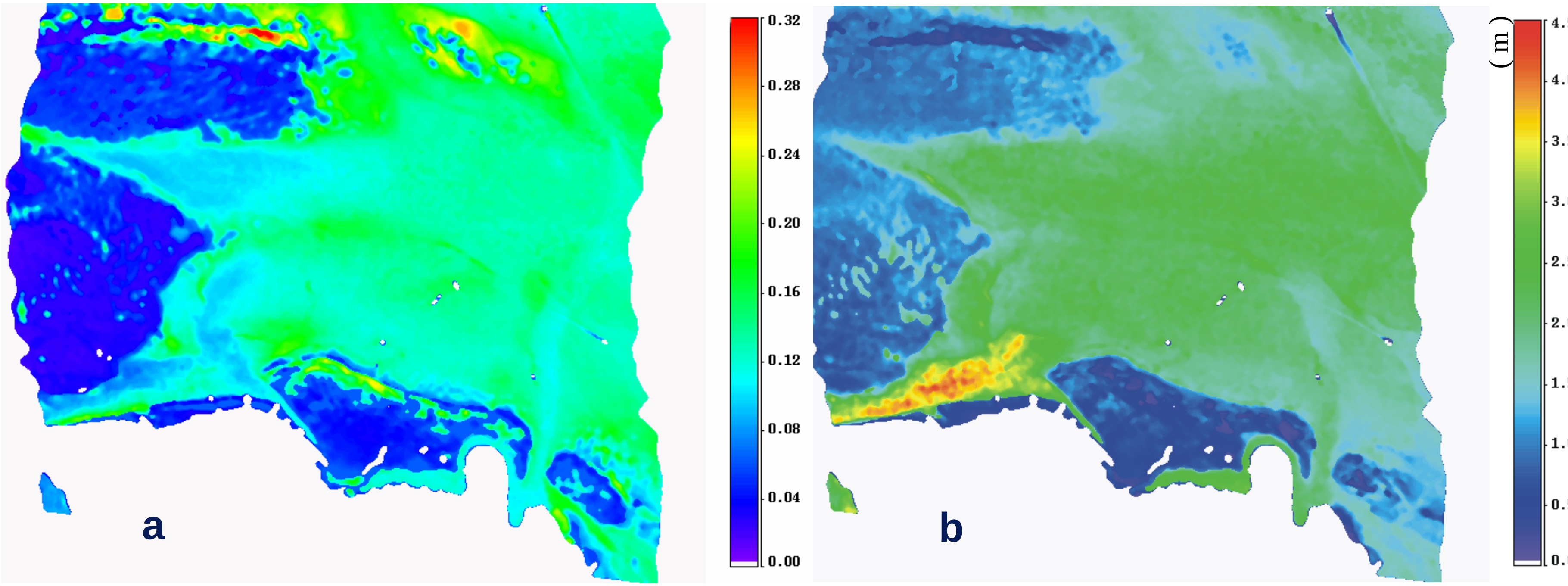
It is desired to *simultaneously* derive bottom depth and albedo and the optical properties of the water column.

Lee et al. (*Appl. Opt.*, 38: 3831-3843, 1999) proposed a new model which can be used with hyperspectral data without the need for ancillary data. They used a semi-analytic model (Lee et al., *Appl. Opt.*, 37: 6329-6338, 1998) for remote sensing reflectance as a function of absorption, scattering, bottom albedo and depth. Then they used a predictor - corrector approach and optimized the result by minimizing an error function.

The Tampa Experiment

- **AVIRIS data Was collected over Tampa Bay, FL November 18, 1998 at 1200.**
  - **AVIRIS was flown on a Twin Otter aircraft at 3810 m giving 4 x 4 m pixels on the ground.**
- **Remote sensing reflectance, and water properties (chlorophyll *a*, and water absorption coefficients) were measured at a deep-water reference site with uniform water properties that was imaged on the same flight line.**
- **The result of calibration and atmospheric correction (using MODTRAN 4) of the AVIRIS data was validated by comparing to the reverence site data.**
  - **The calibration was refined slightly to match the reference data.**
- **Bathymetry results were compared to ship track measurements and the latest Bathymetric Charts (>20 yrs old).**
- **A complete description can be found in Lee et al., *J. Geophysical. Research*, 106(C6), 11,639-11,651, 2001.**

Bathymetry and Bottom type from AVIRIS Image of Tampa Bay



a) Bottom albedo at 550 nm and b) bathymetry derived from AVIRIS data for Tampa Bay, FL. Accurate values were retrieved in spite of the fact that water clarity is poor and varies greatly over the scene.

(Lee, et al., *J. Geophys. Research*, 106(C6), 11,639-11,651, 2001.)

The NRL Portable Hyperspectral Imager for Low-light Spectroscopy (PHILLS)

AN-2 Aircraft

PHILLS image of shallow water features near Lee Stocking Island, Bahamas used to develop and validate hyperspectral algorithms for bathymetry, bottom type and water clarity.

Ocean PHILLS is a push-broom imager.

f 1.4 high quality lens, color corrected and AR coated for 380 –1000nm.

all reflective spectrograph with a convex grating in an Offner configuration to produce a distortion free image (Headwall, Fitchburg, MA).

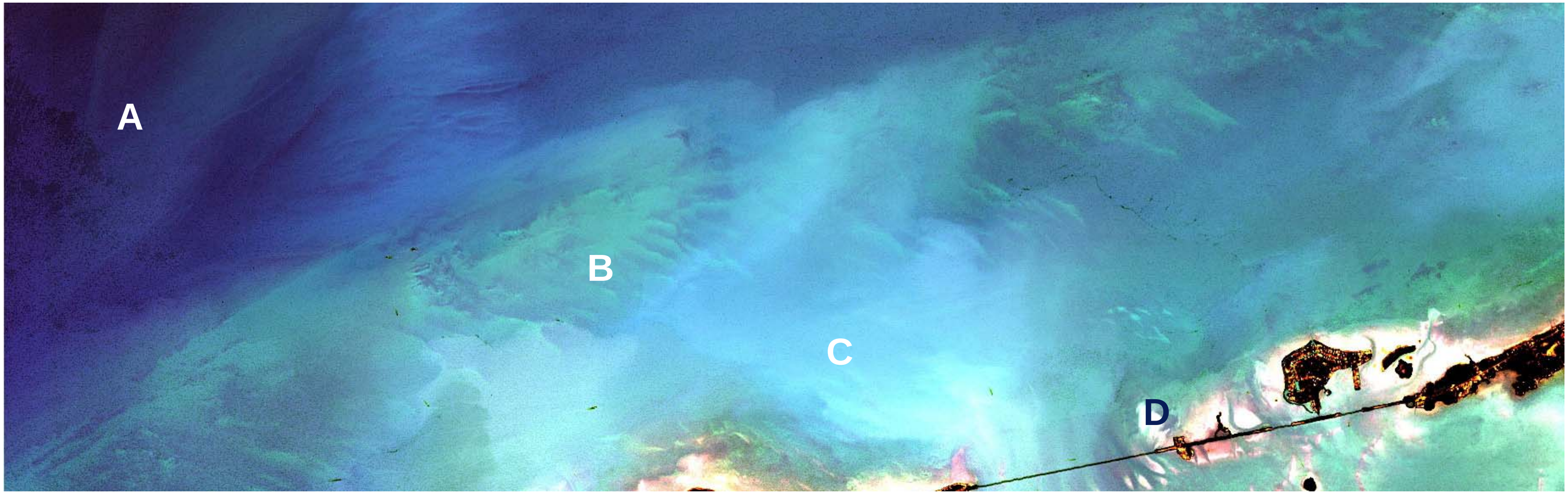
1024 x 1024 thinned backside illuminated CCD camera (Pixel Vision, Inc, Beaverton, OR).

Images 1000 pixels cross track and is typically flown at 3000 m altitude yielding 1.5 m GSD and a 1500 m wide sample swath.

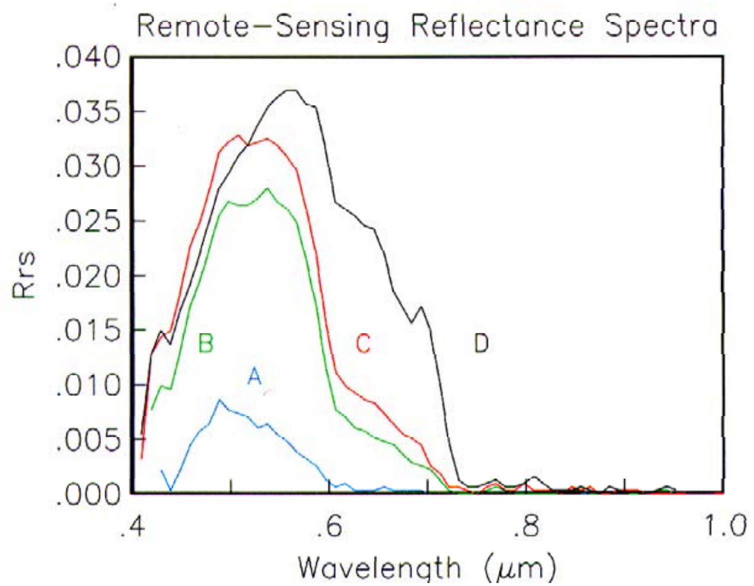
(C. O. Davis, et al., (2002), Optics Express 10:4, 210--221.)

PHILLS Sensor

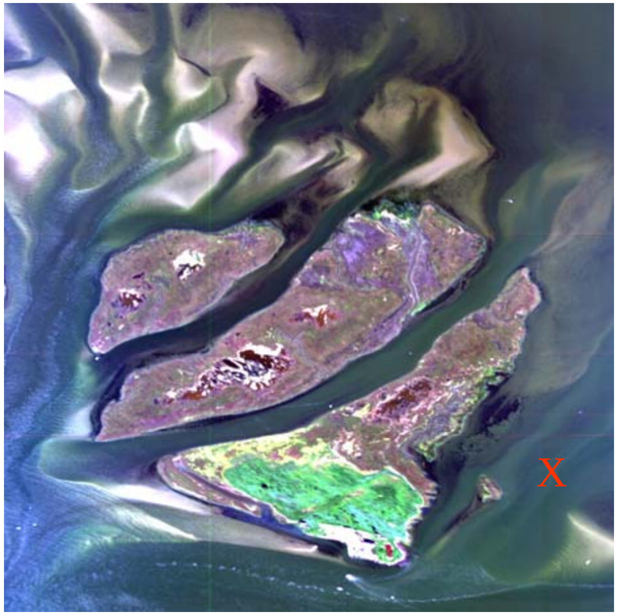
Tafkaa Atmospheric Correction Including Surface Glint Correction for Ocean Scenes

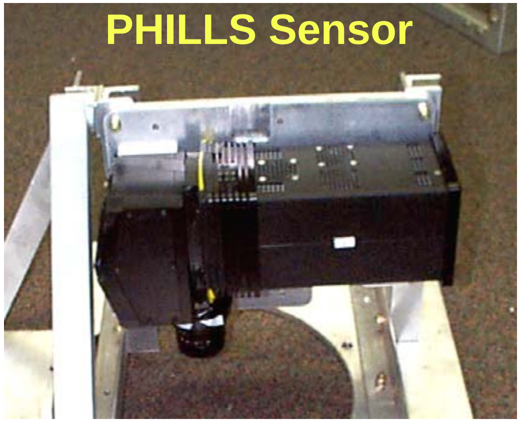


AVIRIS data were atmospherically corrected using the Tafkaa algorithm for ocean scenes. The data are corrected for skylight reflected off the sea surface and then it is assumed that the water leaving radiance is 0 for wavelengths greater than 1.0 micron. (Gao, et al., *Appl. Opt.* 39, 887-896, 2000)

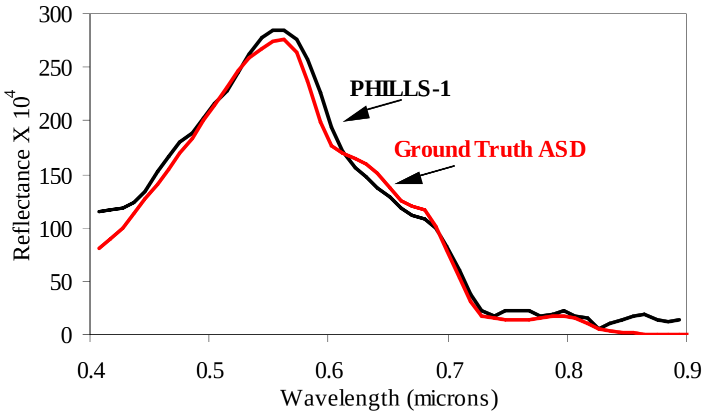


Extensive In-situ data for product validation at LEO-15 site, New Jersey, USA

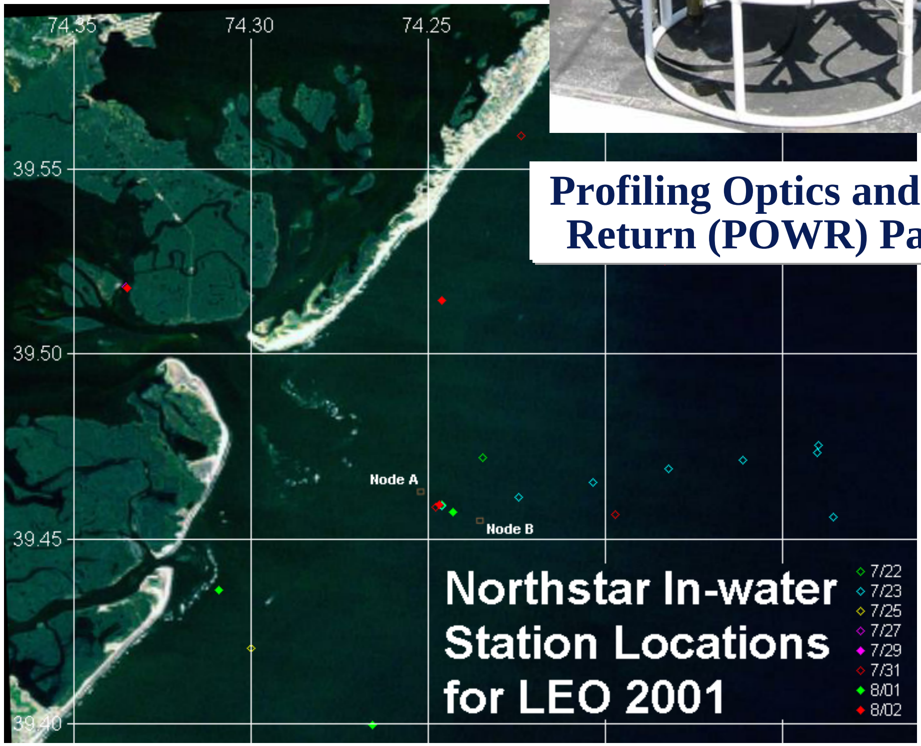




Profiling Optics and Water Return (POWR) Package

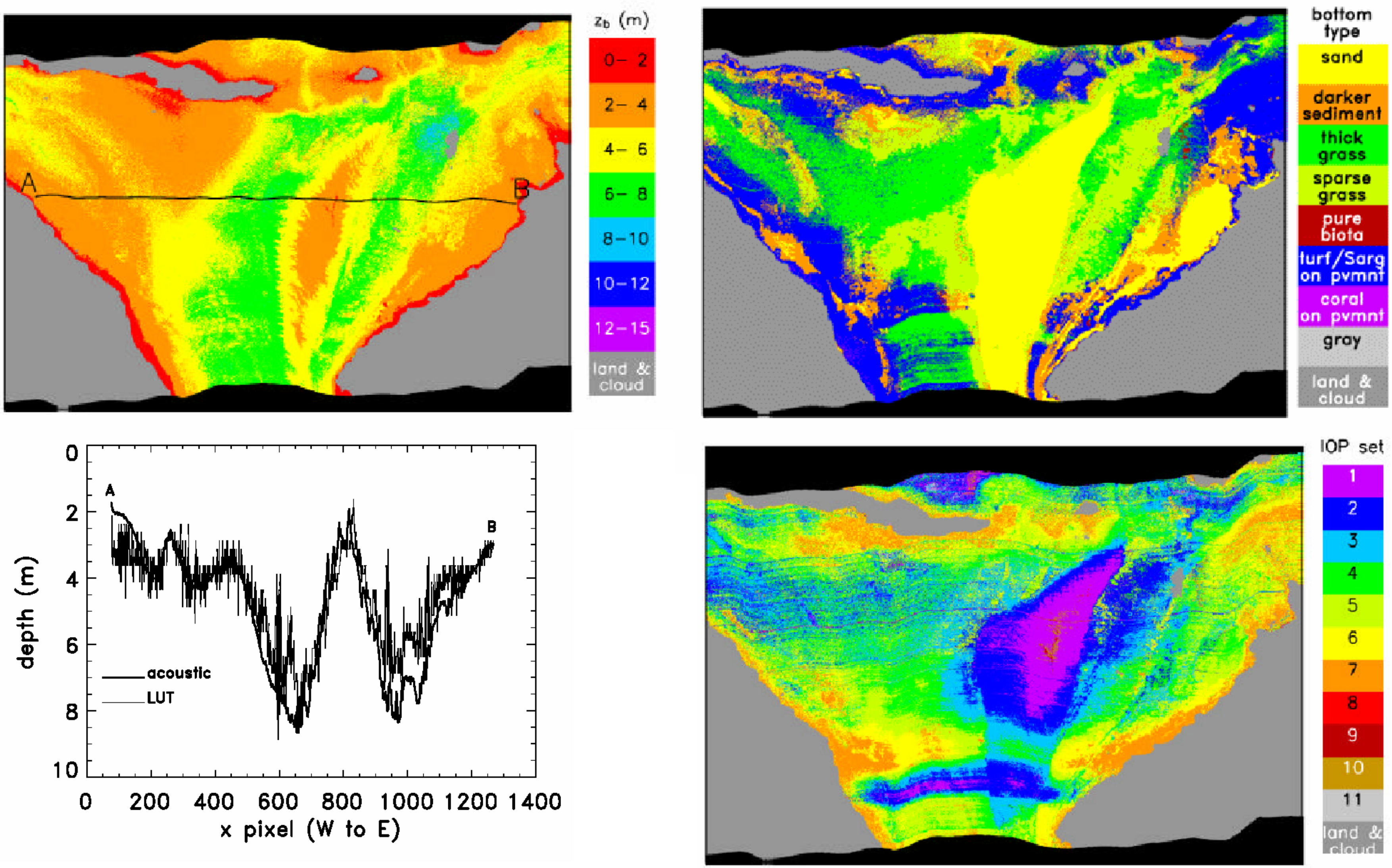


Comparison at the X. (C. O. Davis, et al., (2002), Optics Express 10:4, 210--221.)

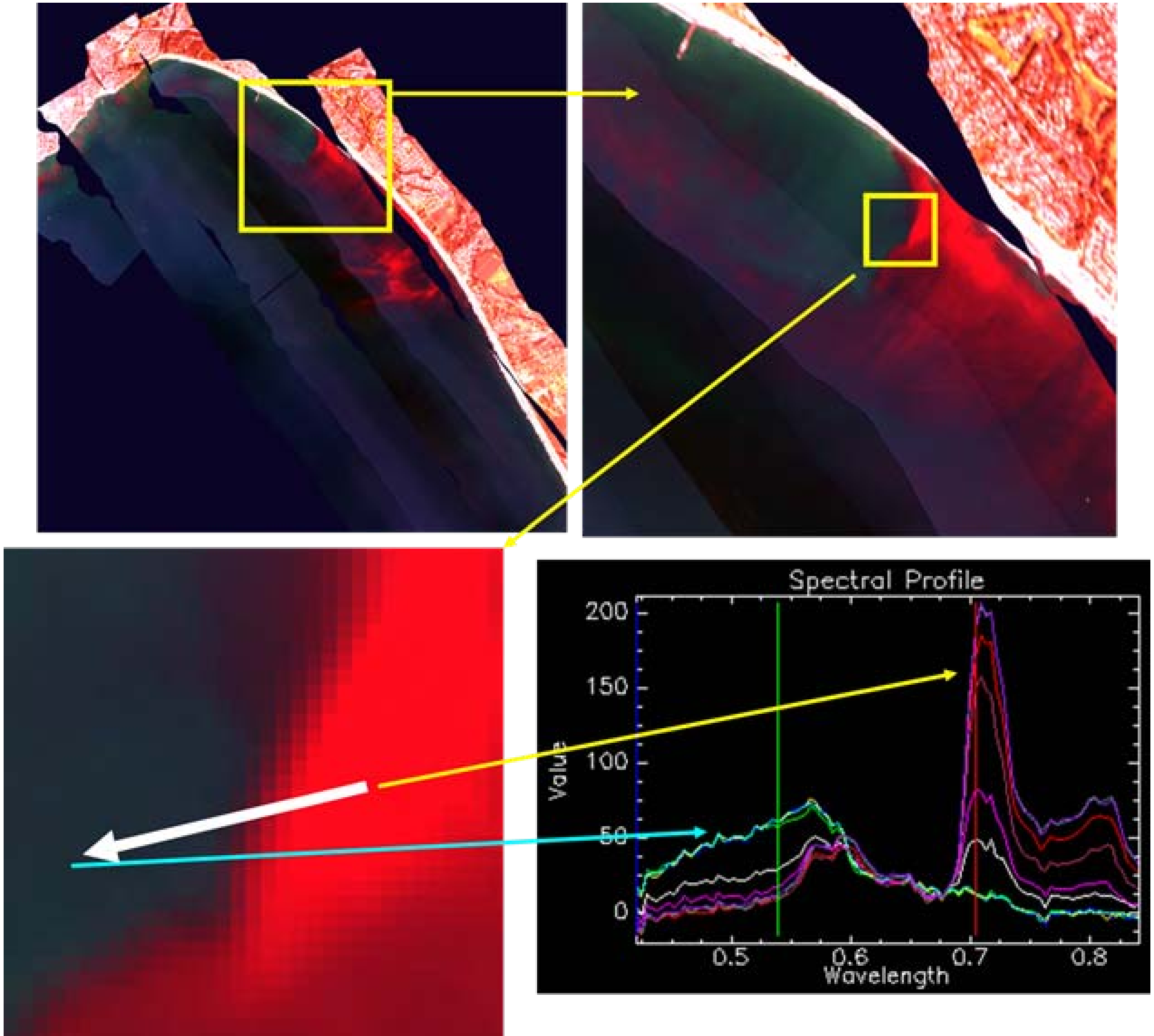


Bathymetry, Bottom Type and Optical Properties
Example Approach: Look-up Tables

Interpretation of hyperspectral remote-sensing imagery via spectrum matching and look-up tables, Mobley, C. D., et al., 2005, Applied Optics, 44(17):3576-3592.



Example Application - Harmful Algal Bloom



Harmful Algal Bloom in Monterey Bay, CA threatens beach areas.

- **Bloom near coast and on the order of 2 x 5 km would not be resolved in 1 km MODIS data.**
- **Spectral data key for bloom identification.**

PHILLS-2 airborne hyperspectral data from Paul Bissett, Florida Environmental Research Institute. (October 2002 *Ceratium spp. bloom*)

SAMSON
Spectroscopic Aerial Mapping System with On-board Navigation

- **The Florida Environmental Research Institute (FERI) has 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.**
- **Automated geolocation to 1 Pixel**
- **Co-registered Digital Framing Camera**

Hyperion – Spaceborne Hyperspectral Imagery

Analyzed 6 DATA SETS - HYPERION DATA:

Chesapeake Bay	(19 Feb ’02)	
Chesapeake Bay	(6 Sep ’02)	
Gulf of Maine	(27 Aug ’02)	
Gulf of Mexico	(15 Aug ‘02)	(Apalachicola Bay, FL)
Bahrain	(27 Aug ’02)	
Looe Key, FL	(26 Oct ‘02)	

ANALYSIS INCLUDES:

Matching With SeaWIFS Imagery

Comparison With In-situ Data From Cruises And Moorings In The Area

Qualitative Identification Of Possible Features

Application Of Remote Sensing Processing Techniques

Quantitative Extraction Of Features And Bathymetry

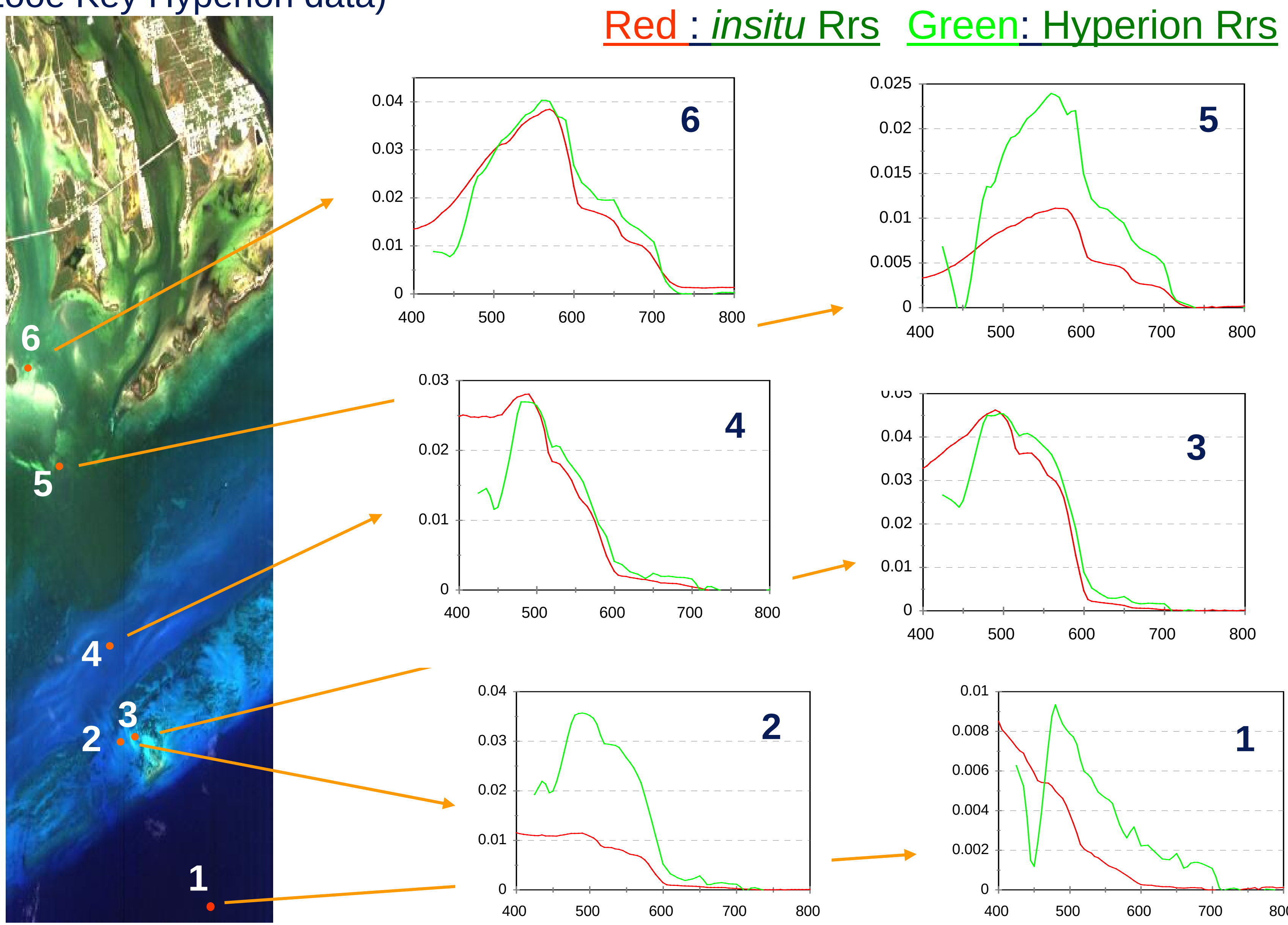
Identification Of Hyperion Issues

THE NRL TEAM:

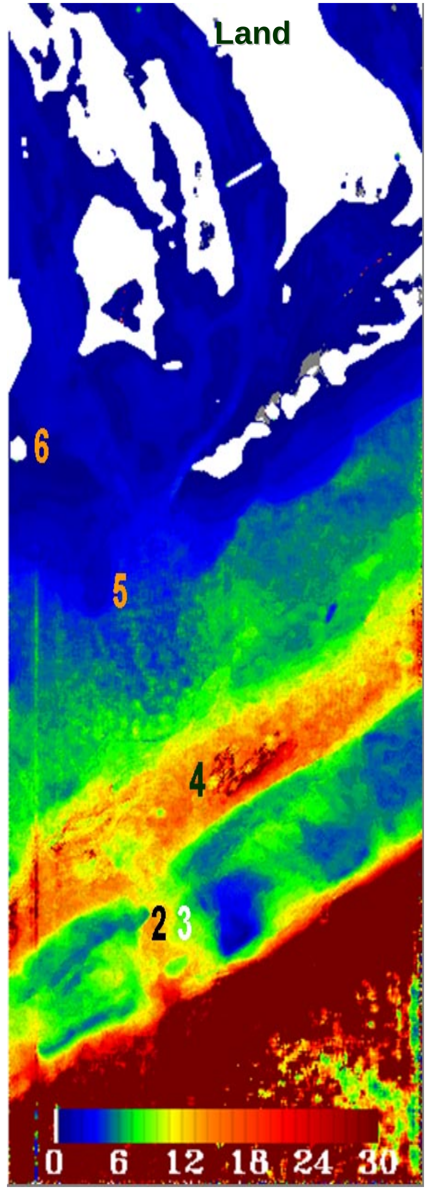
Bo-Cai Gao, Marcos Montes, Curt Davis, Bob Arnone and Ping Lee (NRLSSC)

Rrs comparison (after Tafkaa)

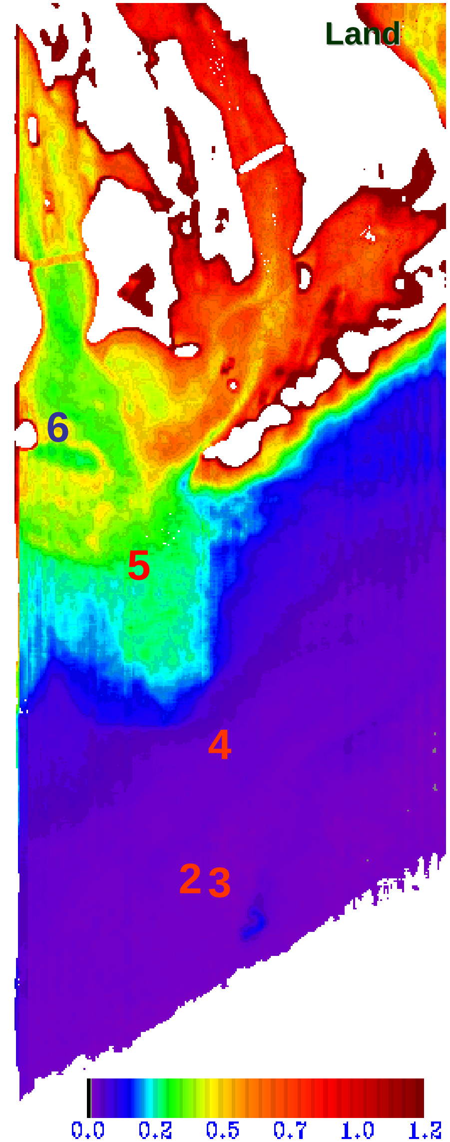
(Looe Key Hyperion data)



Looe Key Hyperion



Bottom depth (m)



Water absorption at 440 nm (m^{-1})

Summary – Hyperion

1) Able to estimate in-water spectra from Hyperion spectra!

- This was better than expected with SNR of 10-50!

2) Applied Optimization methods to water spectra to extract water properties, water depth and bottom reflectance

- Validation is required.

3) Vicarious calibration techniques were required for to overcome SNR and Sun glint (used coincident SeaWIFS data for cross-calibration)

4) Current Hyperion calibration is inadequate for quantitative ocean applications.

5) Atmospheric Correction methods are critical for quantitative analyses

- Several methods used; difficult because of low SNR and calibration issues.

6) The ability to extract ocean products from HYPERION data exceeded expectations indicating the value of having hyperspectral data for the coastal ocean.

Coastal Ocean Imaging Spectrometer (COIS)

Objective: Naval Research Laboratory (NRL) program to Develop and Demonstrate the Application of Space-based Hyperspectral Imagery (HSI) for Characterization of the shallow coastal ocean.

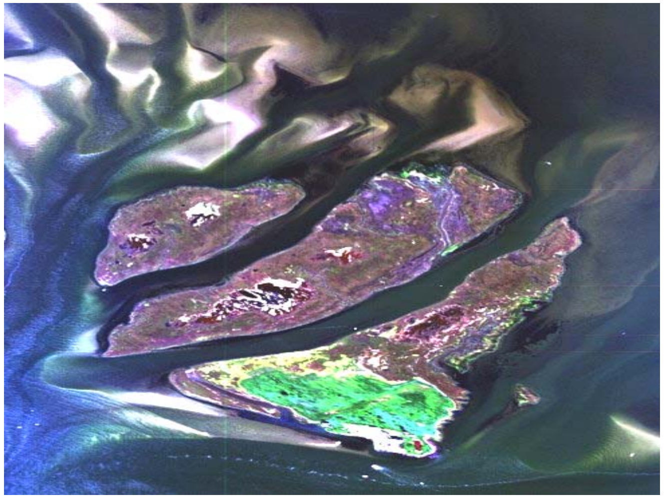
- Collect Visible Near-Infrared (VNIR) Hyperspectral Data.
- Process and compress the data on board.
- Compile Multi-year Seasonal Hyperspectral Database for 50 (global) Littoral sites for seasonal analysis and geophysical model development.

Description: COIS is a hyperspectral imaging payload designed to image, process and store 40 km x 100 km images of VNIR (0.4-1.0 µm, 60 bands) HSI data at 40 m GSD from the NPOESS spacecraft. Collect and downlink an average of two scenes per orbit.

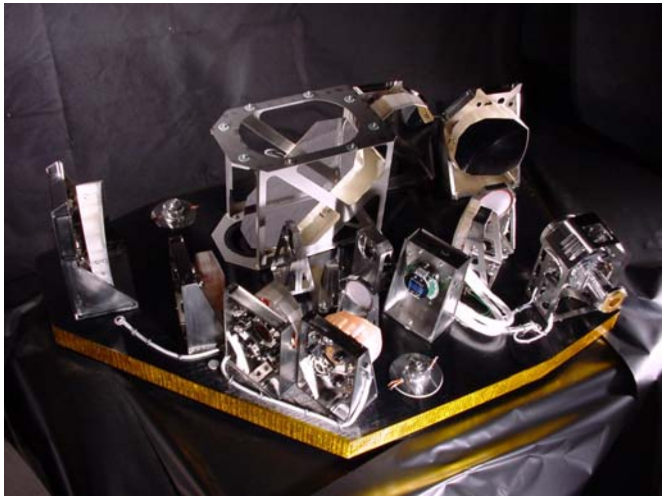
- Gimbaled imager with15 cm aperture TMA telescope, and Offner design grating spectrometer.
- Processing performed onboard using NRL's ORASIS algorithm on a fast parallel processor.

Status: Selected for flight on second NPOESS spacecraft (2011) Pending successful outcome of engineering accommodation study and NPOESS Restructuring.

Sponsors: Office of Naval Research (ONR) to fund completion of sensor and Space Test Program (STP) to fund accommodation to spacecraft.

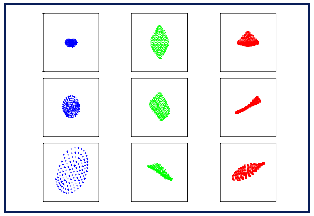


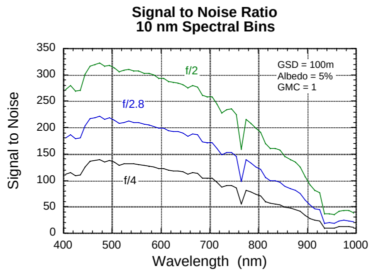
Shallow water optical properties, bathymetry and bottom types



Engineering model of COIS at NRL

NRL Spiral Development of Products from Hyperspectral Imagery





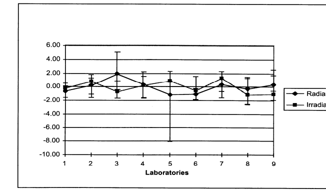
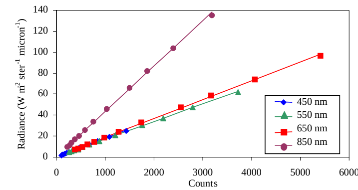
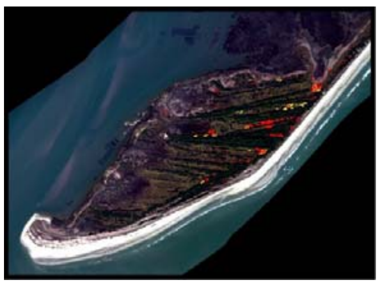
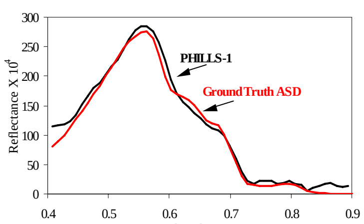
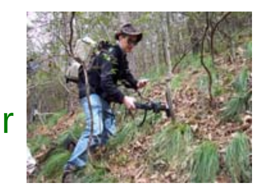


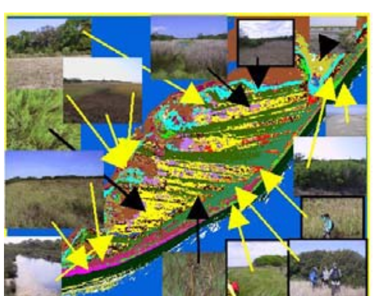
Figure 6. Percent Difference From Mean, Radiance and Irradiance

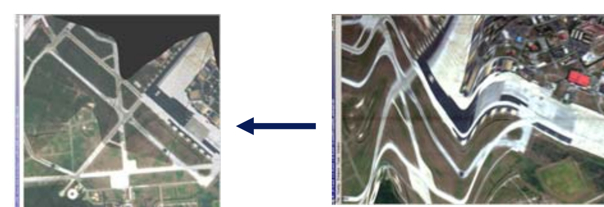












Sensor Development

Sensor Calibration

Flight Campaigns

Ground / Water Truth

Data Processing

Product Extraction

Product Evaluation

Requirements Evaluation

Product Algorithm Development

ORASIS Spectral Identification

PURSUIT Pattern Recognition/ Classification

TAFKAA Atmospheric Removal Algorithm

How we got started - A Tribute to Alex Goetz

- Ocean imaging spectrometry started by Ken Carder and Curt Davis proposing to use AVIRIS data for coastal applications in 1987.
- The High Resolution Imaging Spectrometer (HIRIS) was selected in 1989 as part of the EOS program with Alex Goetz as the team leader.
  - Curt Davis and Ken Carder selected as ocean team members; Curt subsequently became the JPL Program Scientist
  - Though the launch would be a decade away Alex urged the team to move forward quickly to achieve the developments needed to make use of the HIRIS data. Under Alex's leadership the team developed:
    - ATREM
    - SIPS the forerunner of ENVI
    - Alex saw the need for compact, well-calibrated field spectrometers and founded ASD.
    - A host of applications for geology, ecology and oceanography were initially developed for HIRIS.
  - HIRIS was cancelled during a round of major cost cutting for the EOS program but the legacy of HIRIS lives on thanks in large part to Alex's leadership.
- We are still waiting for a HIRIS quality imaging spectrometer in Space.