ISS Hyperspectral Imager for the Coastal Ocean (HICO): Application of Space-based Hyperspectral Imagery for the Protection of the Nation's Coastal Resources

EPA/ORD/NHEERL/NERL

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The U.S. Environmental Protection Agency's mandate to protect human health and the environment requires innovative and sustainable solutions for addressing the Nation's environmental problems.

HICO offers EPA and the environmental monitoring community an unprecedented opportunity to observe changes in coastal and estuarine water quality across a range of spatial scales not possible with field-based monitoring.

What is ocean/estuary color?

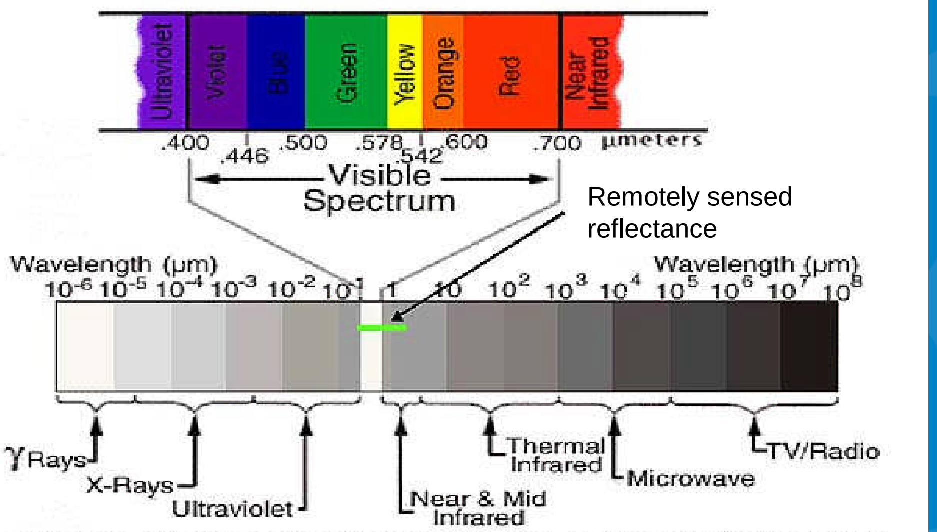

Figure 1. Electromagnetic spectrum and region of reflected light remote sensing.

Definition of Remotely Sensed Reflectance (R_{rs})

$$R_{rs}(0^+,\lambda) = L_w(0^+,\lambda)/ E_s(0^+,\lambda)$$

R_{rs} = remotely sensed reflectance (1/sr)

L_w $(0^+, \lambda)$ = water leaving radiance measured above the air/water interface (W m^{-2} sr^{-1}),

E_s $((0^+, \lambda)$ = downwelling irradiance measured above the air/water interface (W m^{-2} sr^{-1})

Program Objectives

Use HICO imagery to develop a novel space-based environmental monitoring system that provides information for the sustainable management of coastal ecosystems.

To demonstrate that water quality information derived from HICO could be incorporated into a prototype smart phone application to disseminate data to managers in the EPA Office of Water.

Water quality news reports may change the social and economic dynamics for the Nation to not only be aware of its water quality conditions but support sustainable practices to maintain or improve conditions at their favorite recreational areas.

Hyperspectral Imager for the Coastal Ocean (HICO).... Intent and a bit of history

- HICO is intended as a pathfinder for follow-on sensors designed with better resolution and for routine observations of coastal, riverine, and estuarine waters (Lucke et al., 2011).
- Built on the legacy of the NRL Ocean **P**ortable **H**yperspectral **I**mager for **L**ow-**L**ight **S**pectroscopy (Ocean PHILLS) airborne imagers and funded as an Innovative Naval Prototype by the Office of Naval Research
- January, 2007: HICO selected to fly on the International Space Station (ISS)
- November, 2007: Construction began following the Critical Design Review
- September, 2008: Space-qualified instrument delivered to the DOD Space Test Program for integration and spacecraft-level testing
- April, 2009: Shipped to Japan Aerospace Exploration Agency (JAXA) for launch
- September 10, 2009: HICO launched on JAXA H-II Transfer Vehicle (HTV)
- September 24, 2009: HICO installed on ISS Japanese Module Exposed Facility

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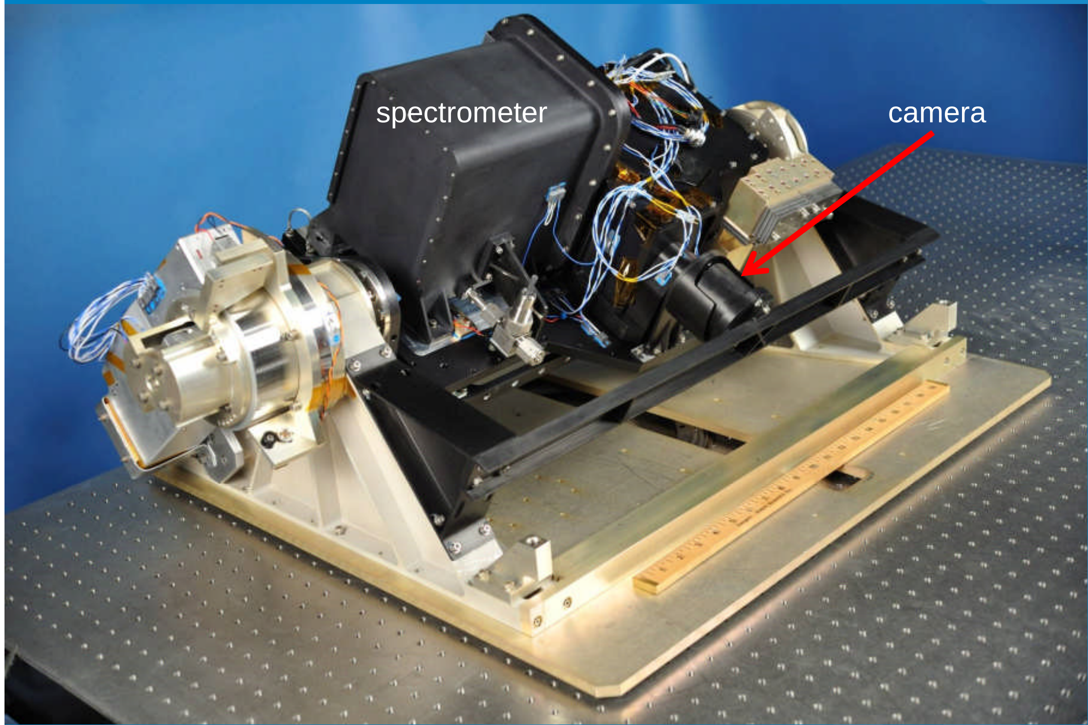
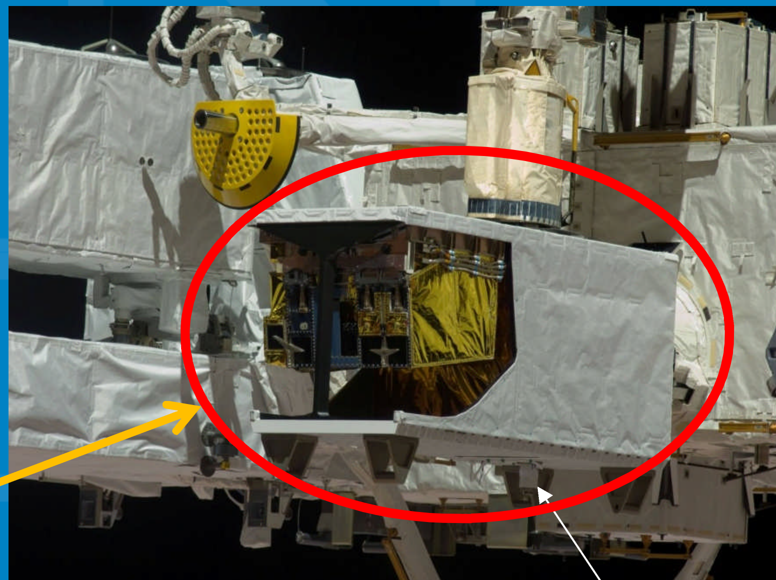
Hyperspectral Imager for the Coastal Ocean (HICO)





1st spaceborne imaging spectrometer specifically made for the environmental characterization of the coastal ocean from space

HICO is installed in the HICO-RAIDS experiment payload (HREP) on the Japanese Experiment Module - Exposed Facility

HICO Viewing Slit

HICO Tech Specs

Parameter	Performance	Rationale
Spectral Range	380 to 960 nm	All water-penetrating wavelengths plus Near Infrared for atmospheric correction
Spectral Channel Width	5.7 nm	Sufficient to resolve spectral features
Number of Spectral Channels	~100	Derived from Spectral Range and Spectral Channel Width
Signal-to-Noise Ratio for water-penetrating wavelengths	> 200 to 1 for 5% albedo scene (10 nm spectral binning)	Provides adequate Signal to Noise Ratio after atmospheric removal
Polarization Sensitivity	< 5%	Sensor response to be insensitive to polarization of light from scene
Ground Sample Distance at Nadir	~100 meters	Adequate for scale of selected coastal ocean features
Scene Size	~50 x 200 km	Large enough to capture the scale of coastal dynamics
Cross-track pointing	+45 to -30 deg	To increase scene access frequency
Scenes per orbit	1 maximum	Data volume and transmission constraints

Arnone et al., (2009) HICO for NASA Gulf Workshop

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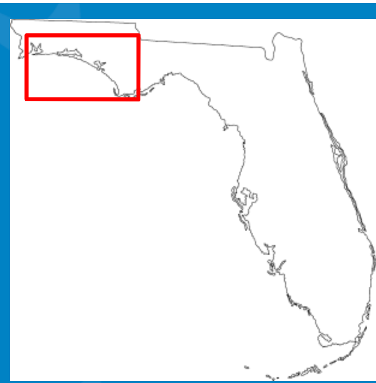
Program Implementation



Collected 49 images from four estuaries along NW Florida during April 2010 to May 2012 during ISS Expeditions 24 - 31

Pensacola, Choctawhatchee, and St. Andrew Bays are shallow (~4.0 m), microtidal (tidal range ~ 1.0 m) brackish water estuaries. St. Joseph Bay is slightly deeper (~8 m) and not influenced by the inflow of fresh water.

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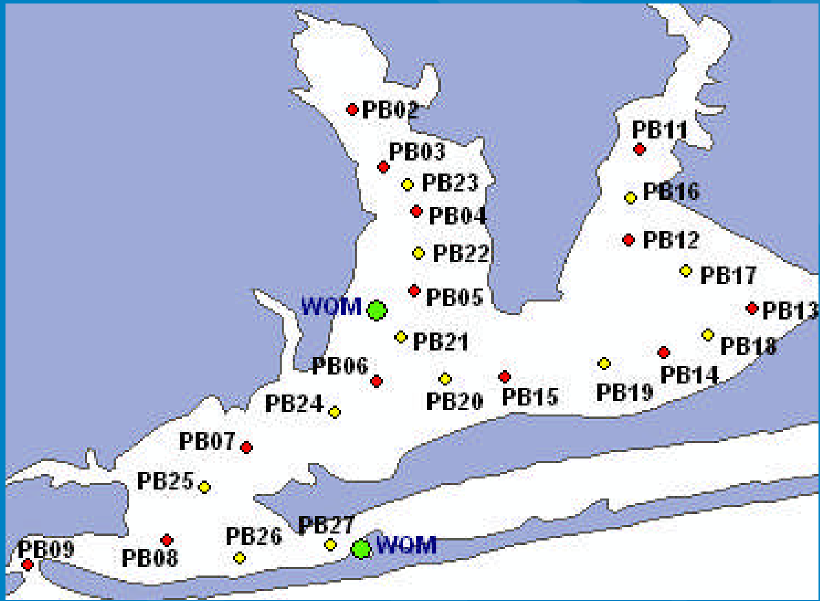
Field Validation Program

Sample stations

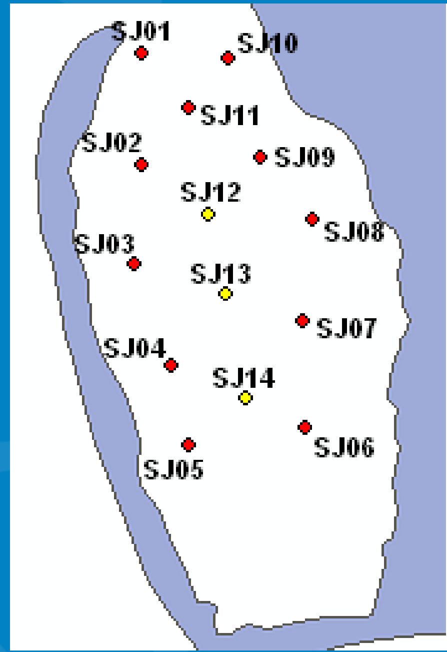
Green = water quality moorings (chl *a*, turbidity, and CDOM)

Yellow = above water radiance, temp, salinity, and optical properties

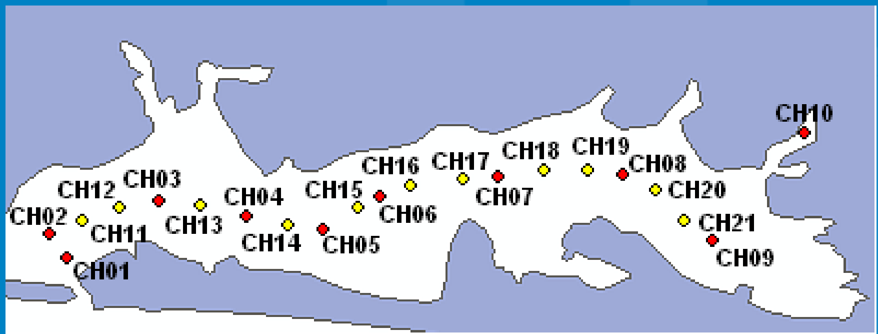
Red = same as yellow + discrete water samples



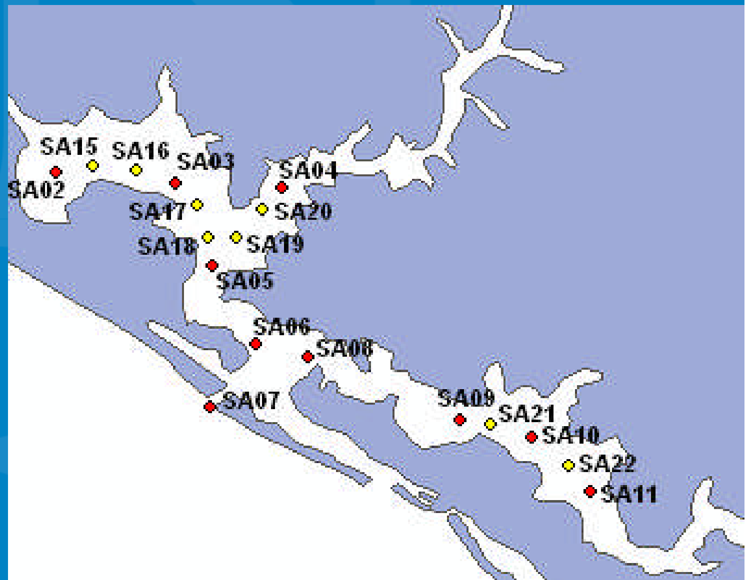
Pensacola Bay



St. Joseph Bay



Choctawhatchee Bay



St. Andrew Bay

Field Validation Program – Part 1

Using small boat surveys within each estuary, collected and processed water column profile and above-water hyperspectral data (R_{rs}) and water quality samples (Chl *a*, TSS, CDOM, salinity)

Water column profiling

Above-water radiometry

Laboratory analysis

Attempted to conduct sampling within 1-3 days of an ISS overflight

Field Validation Program – Part 2

Autonomous underwater vehicles (AUVs) were deployed concurrently with HICO overpasses by the NRL Stennis Space Center Detachment (NRL/SSC) and the USEPA Atlantic Ecology Division (AED)

NRL/SSC deployed a Slocum electric glider off of Pensacola Bay along the 15-30 m bathymetric contours which recorded:

temperature
salinity (conductivity)
chlorophyll and CDOM florescence

Slocum
G2 Glider
Designed and
manufactured
by Webb Research

AED deployed a REMUS (**R**emote **E**nvironmental **M**onitoring **U**nit) AUV in Pensacola and Choctowhatchee Bays which recorded:

temperature
salinity (conductivity)
chlorophyll and turbidity
at approximately one meter depth

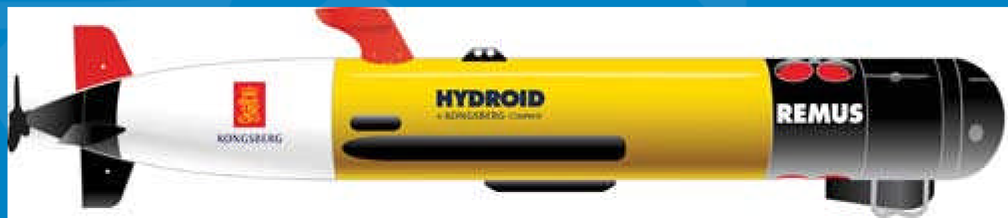
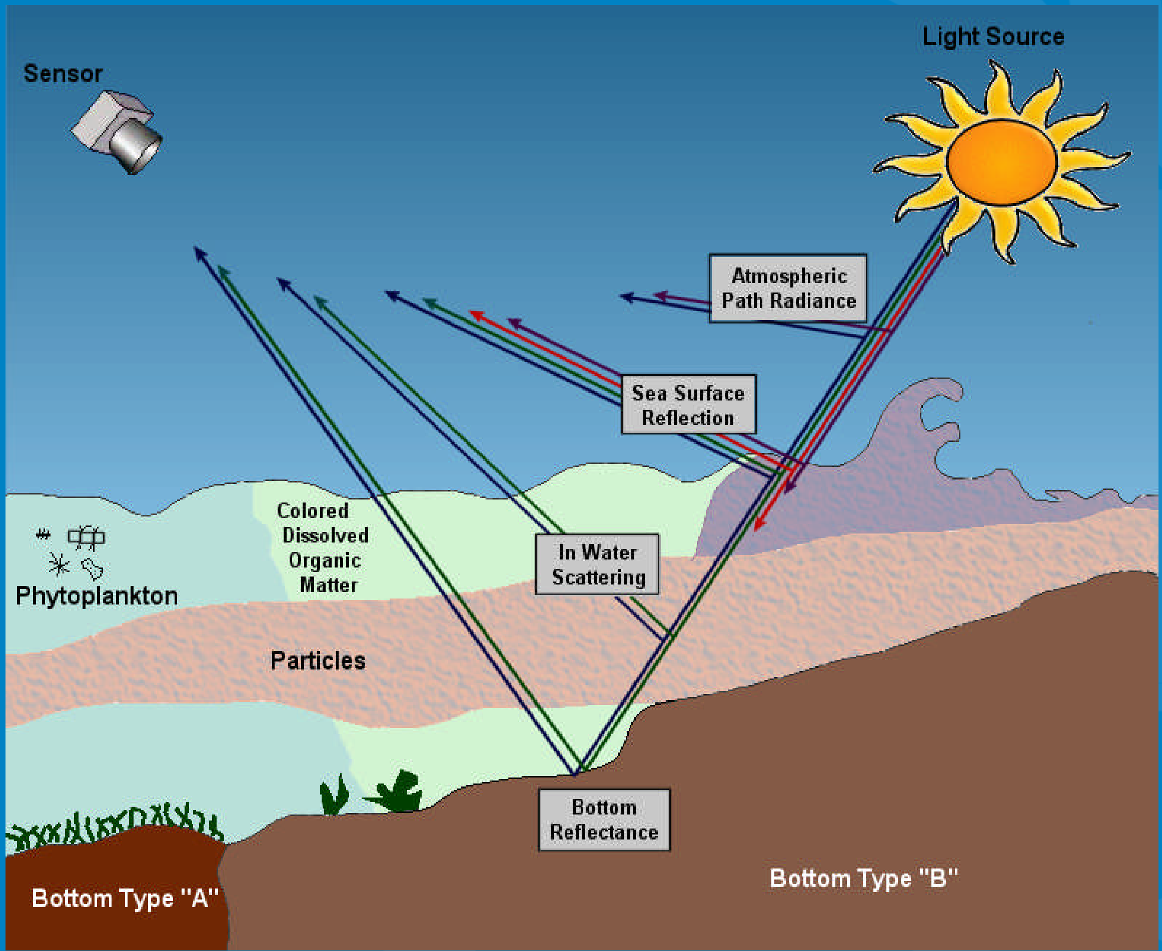


Photo courtesy of Kongsberg Maritime

HICO Image Processing: Optical Components of a Coastal Scene



Multiple light paths

- Scattering due to:
  - atmosphere
  - aerosols
  - water surface
  - suspended particles
  - bottom
- Absorption due to:
  - atmosphere
  - aerosols
  - suspended particles
  - dissolved matter

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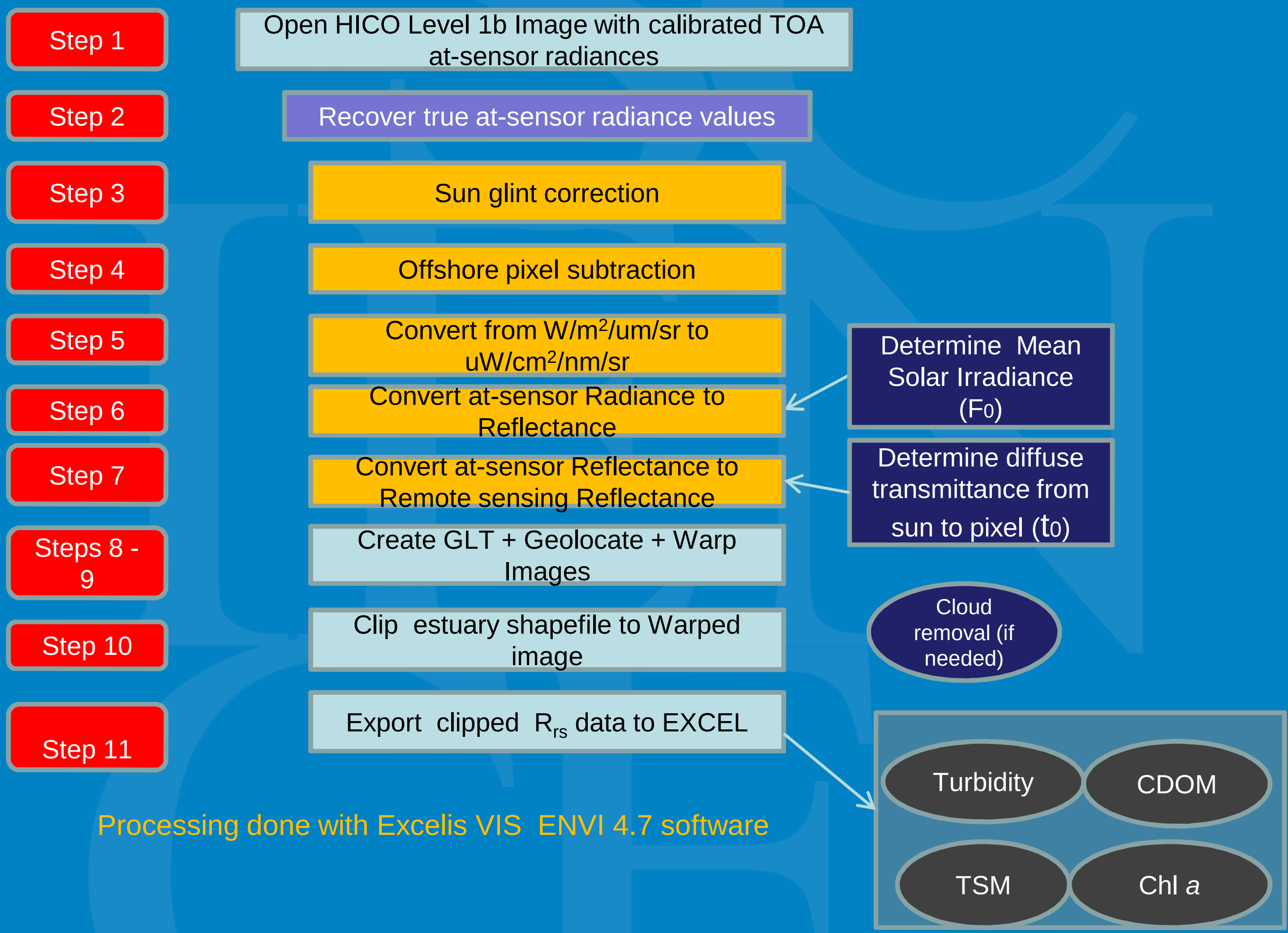
HICO Image Processing Steps



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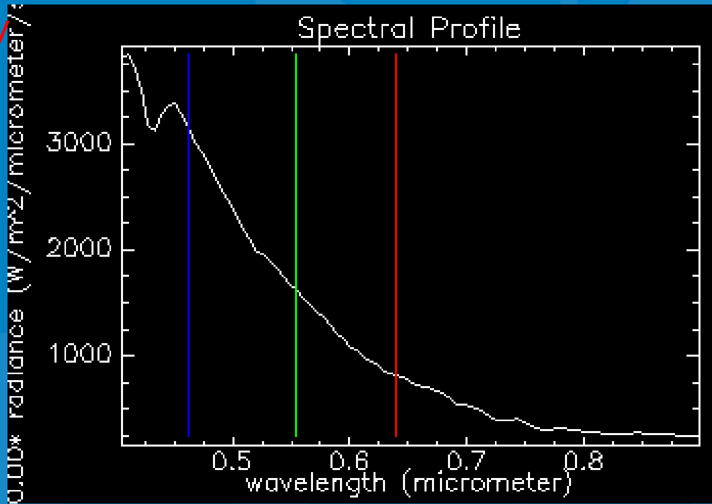
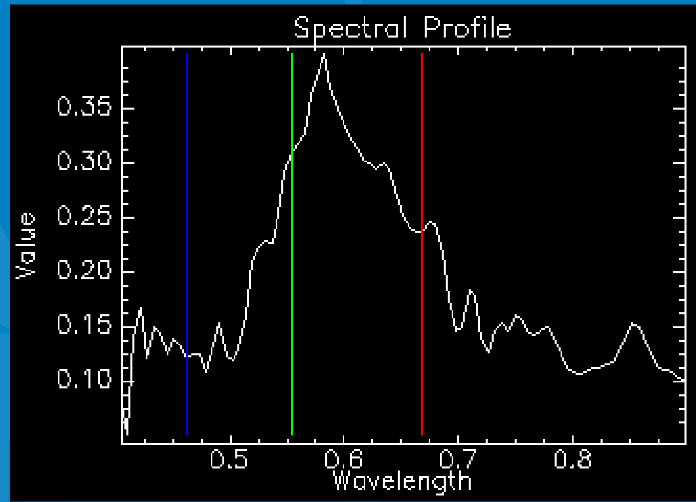
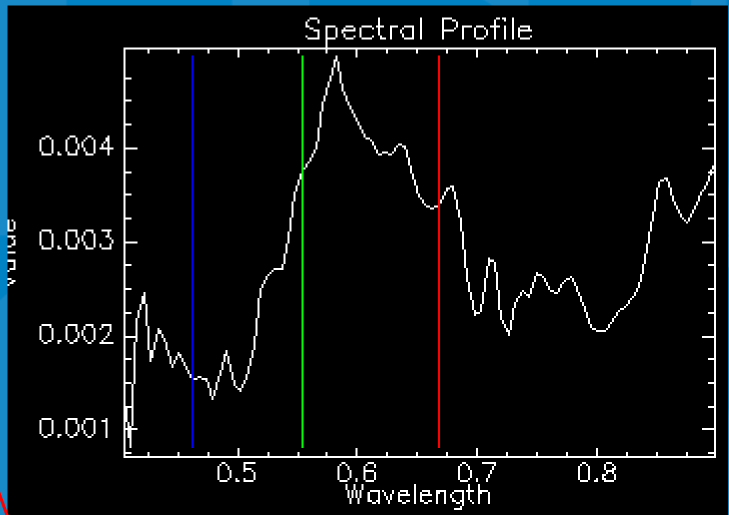
iss2012016.0116.193730.L1B_PensacolaBay_des.v03.9170.20120117211554.100m.hico.bil



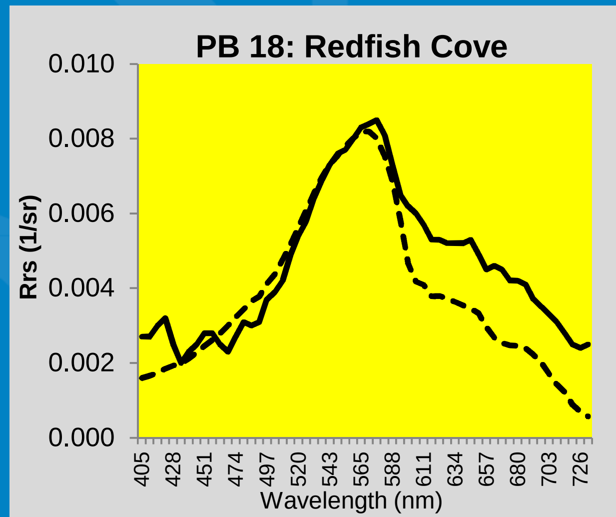
Step 1: Level 1b calibrated radiance



Step 4:Offshore pixel subtraction (W/m²/um/sr)



Step 7: Remotely sensed Reflectance (1/sr)



Spectral match-ups between HyperSAS (dotted line) and HICO spectral signature (solid line).

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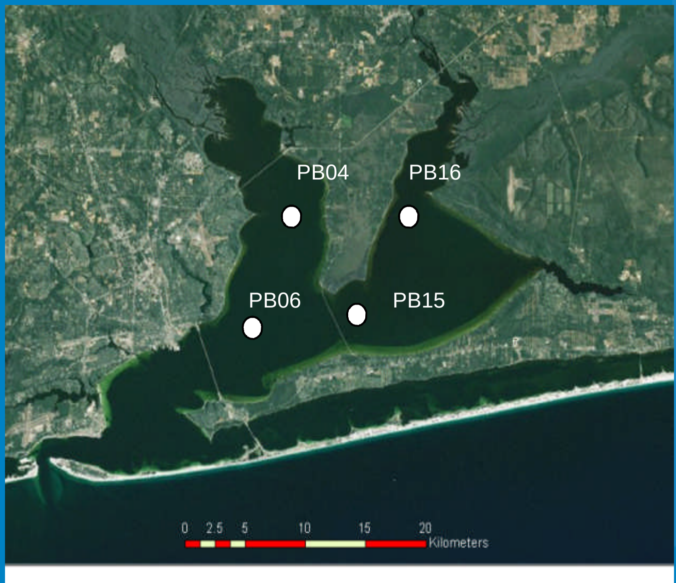
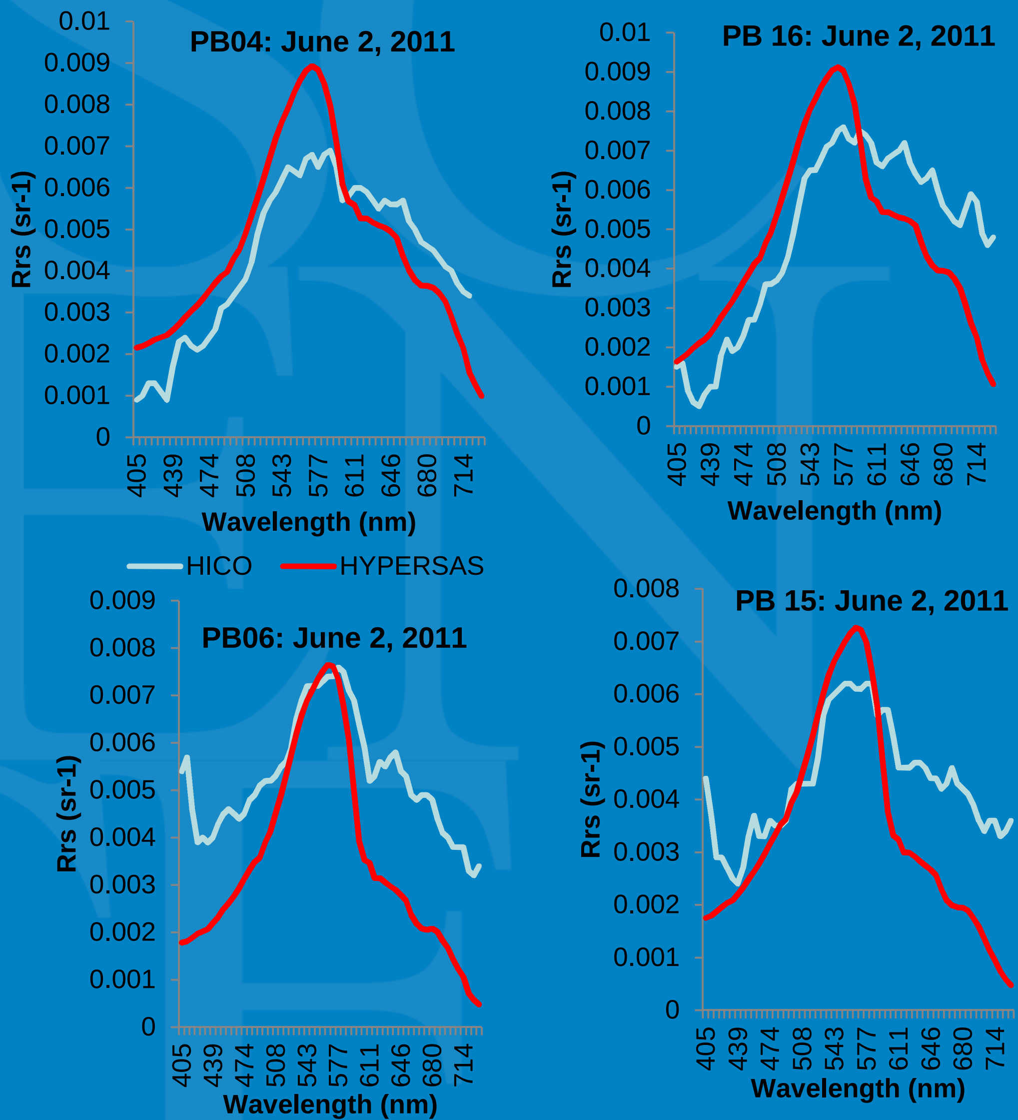
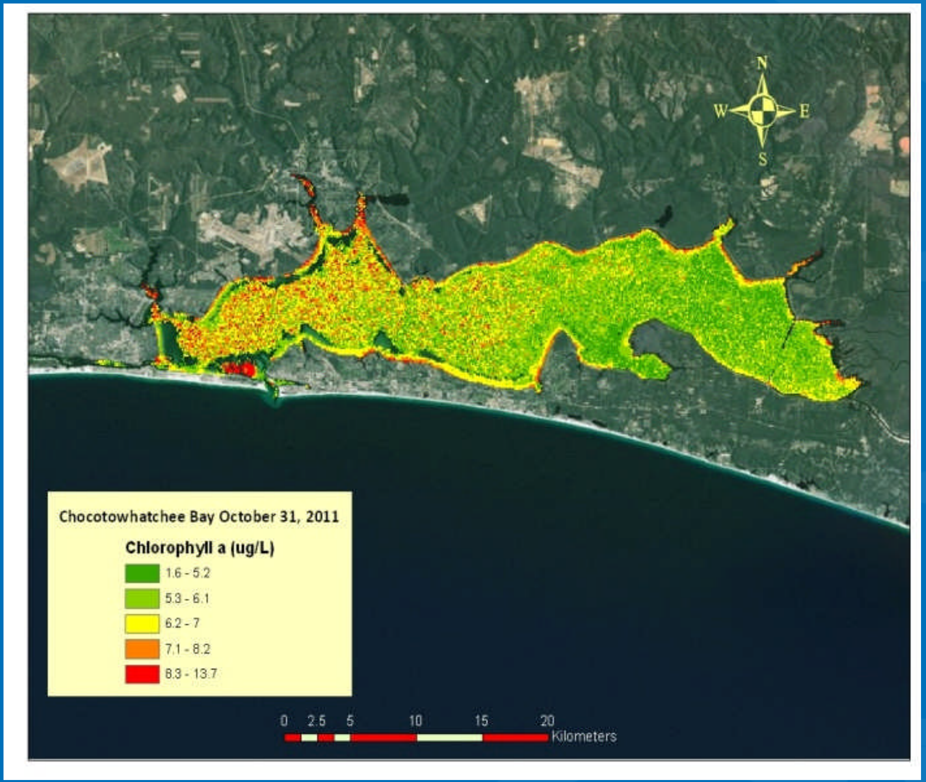
Spectral Match-ups

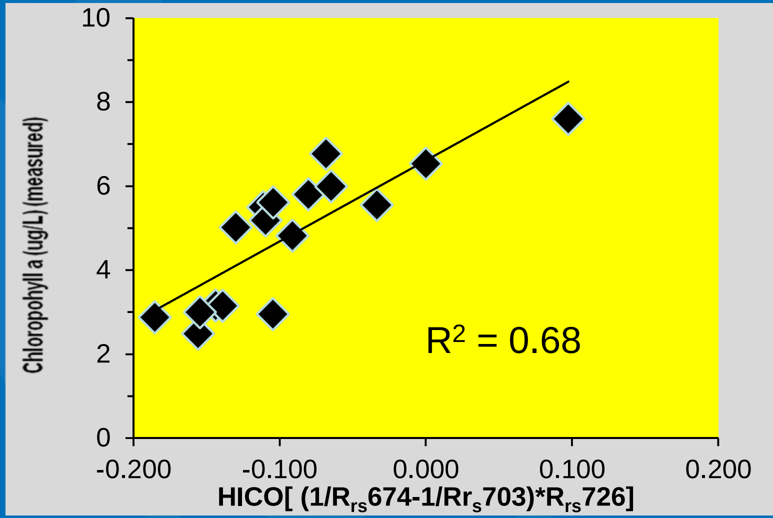


Pensacola Bay, FL

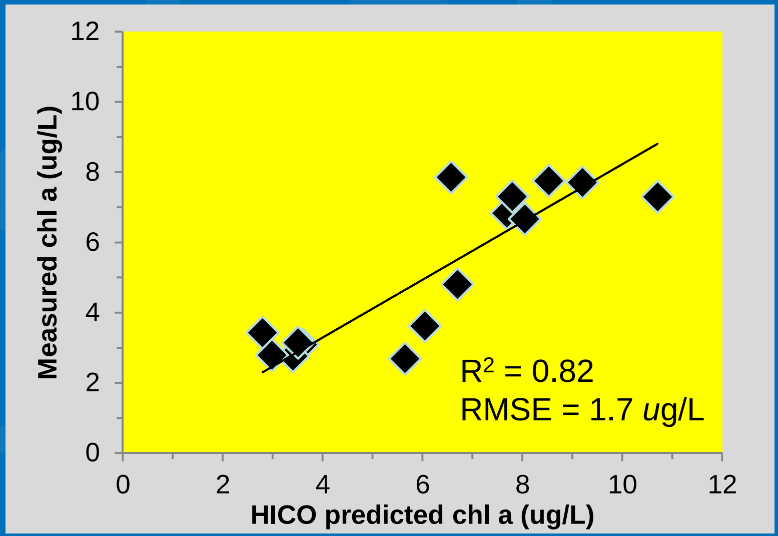


Chl *a*: indicator of phytoplankton abundance and eutrophication





approach of Gitelson et al., 2011



$$\text{Chl } a = 19.264 \times [a] + 6.614$$

$$a = [1/R_{rs(674)} - 1/R_{rs(703)}] \times R_{rs(726)}$$

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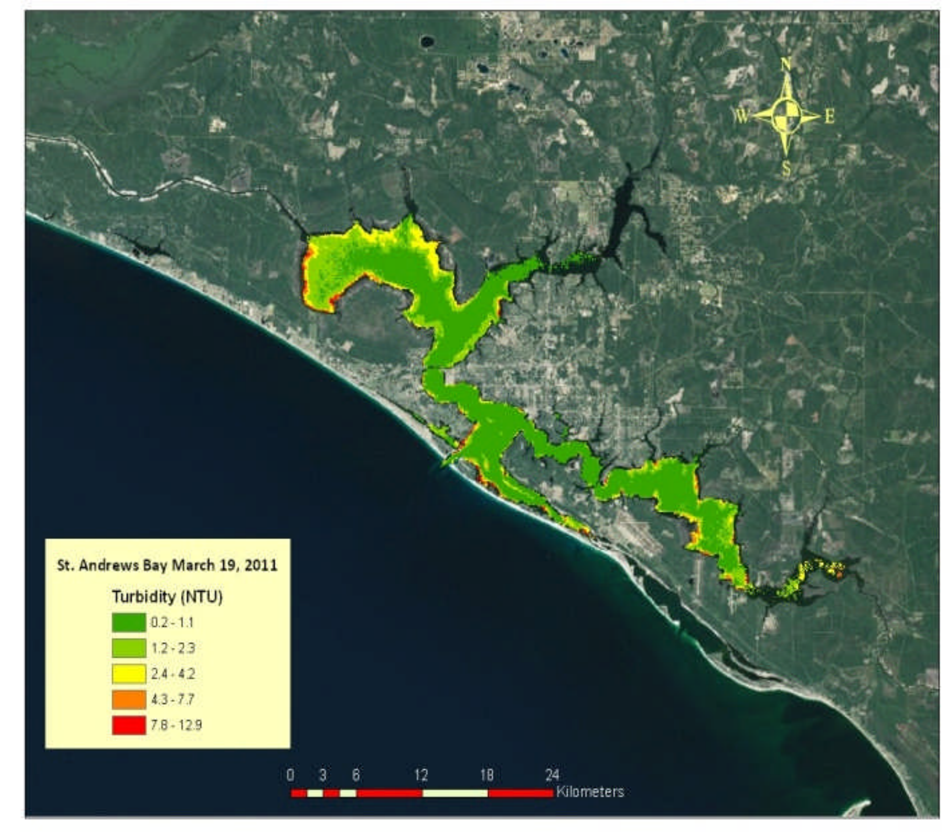
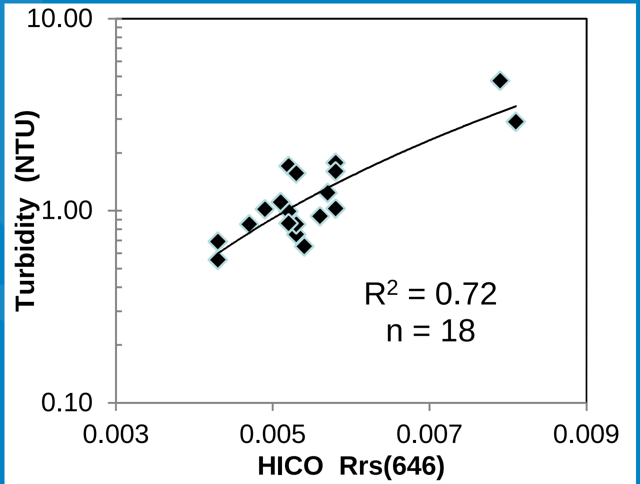
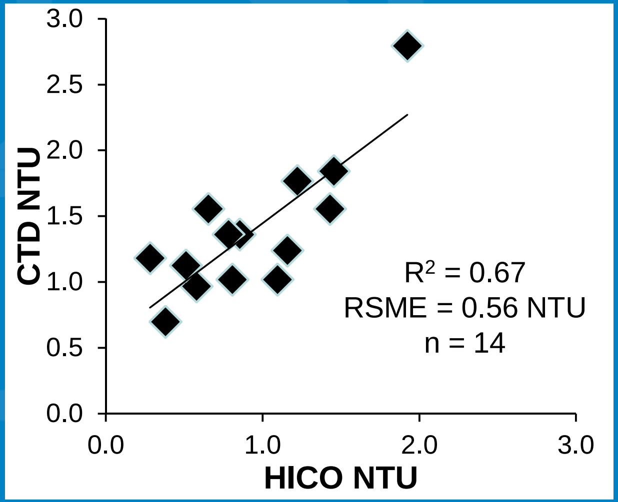
Turbidity is an indicator of the distribution of total suspended matter in estuaries





approach of Chen et al., 2007



Turbidity = $2*10^6$ X $[R_{rs}(646)^{2.7848}]$

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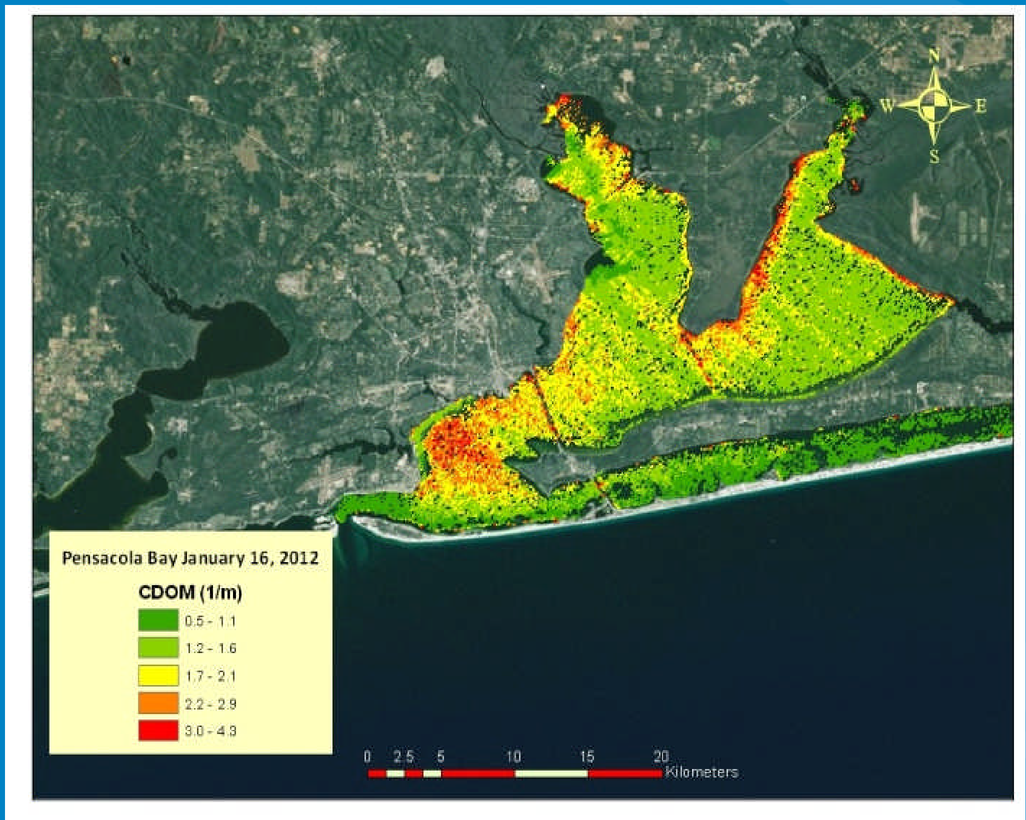
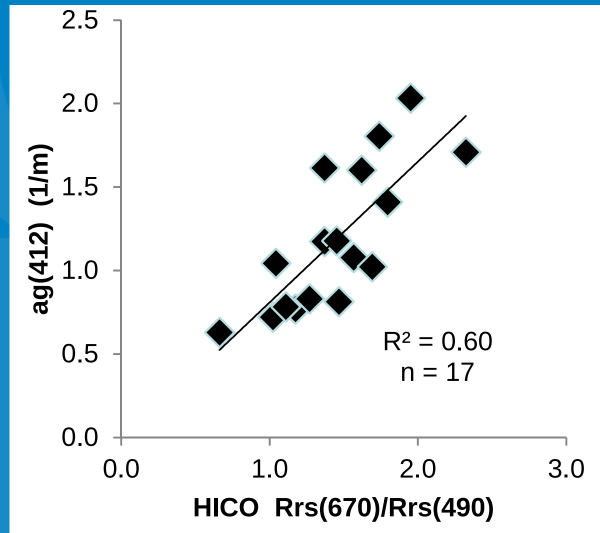
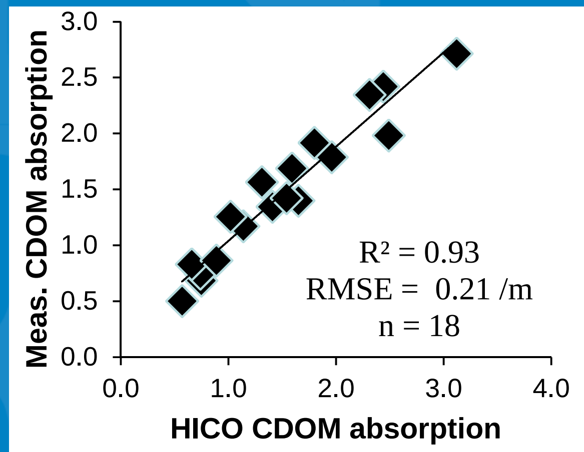
Colored Dissolved Organic Matter Absorption: indicator of light attenuation in estuaries





approach of Bowers et al., 2004



$$ag_{412}\,(m^{-1}) = 0.8426 \times [R_{rs}(670)/R_{rs}(490)] - 0.032$$

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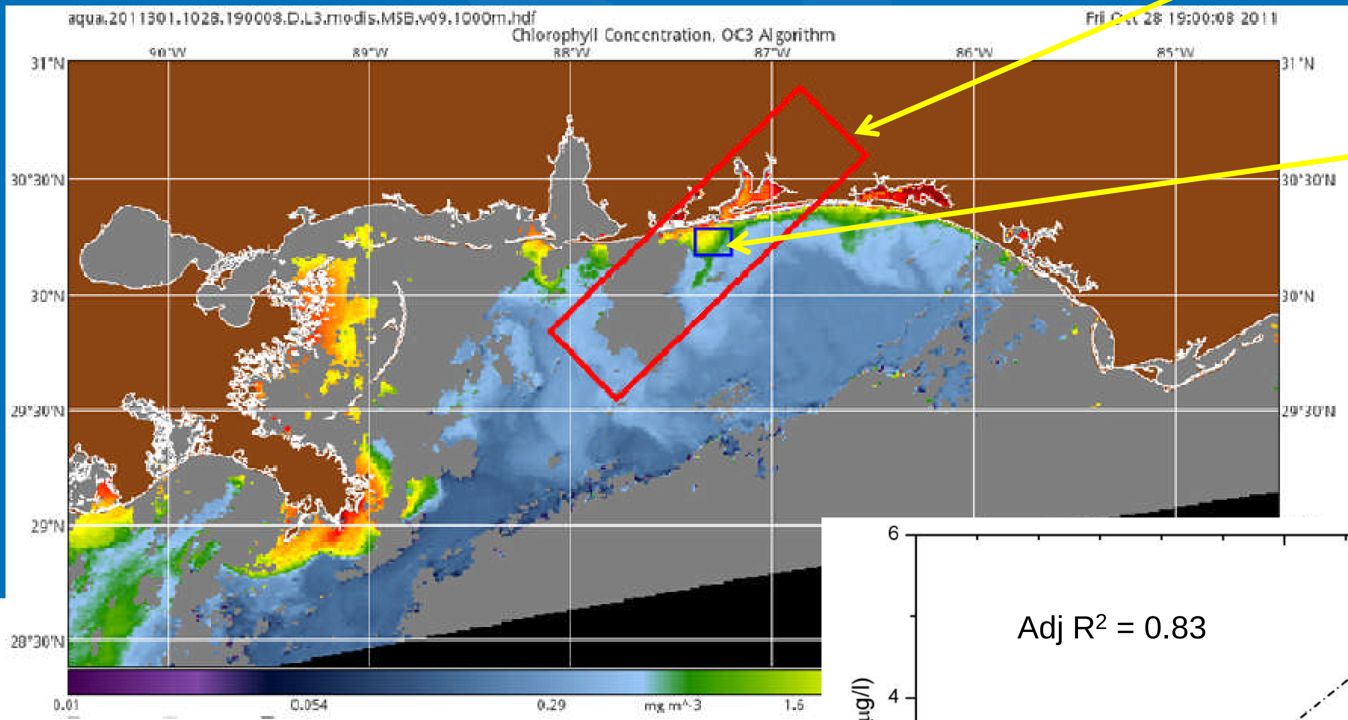
HICO/MODIS Comparison

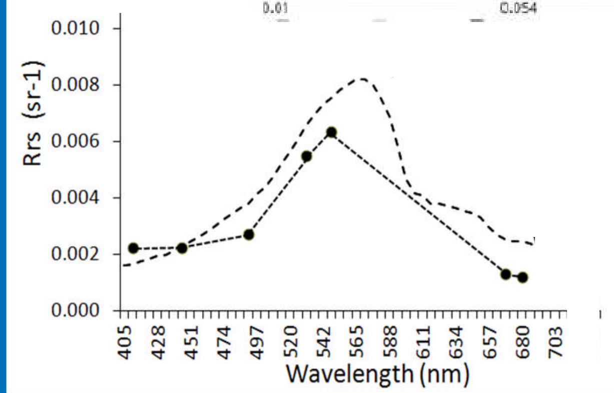
MODIS scene 19:00 GMT, 7 minutes before HICO

October 28, 2011 HICO and MODIS image date

HICO scene

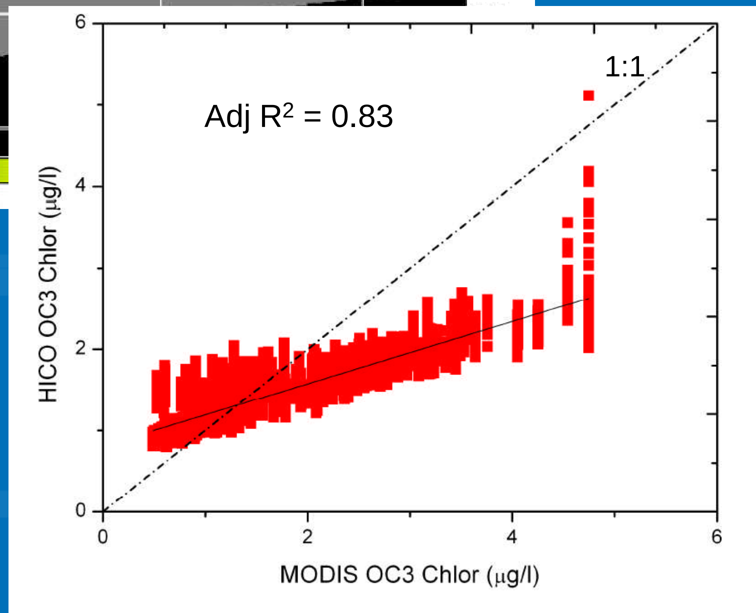
Pixels common to both images and used in the match-up





Dashed line = HyperSAS R_{rs}

Dotted line = HICO R_{rs} at MODIS bandwidths



Program Summary

Using atmospherically corrected HICO imagery and a comprehensive field validation program, regionally-tuned algorithms were developed to estimate the spatial distribution of chlorophyll *a*, colored dissolved organic matter, and turbidity for four estuaries along the northwest coast of Florida from April 2010 – May 2012.

The HICO-derived water quality data from this project have been uploaded to a internal EPA HICO website for review and use by the EPA Office of Water and a prototype mobile application has been completed.

Conclusions

HICO helped us to show that it is possible for a hyperspectral space-based sensor to produce products that meet the needs of EPA.

While the potential benefits are many, there are several issues that must be resolved before HICO images and data can be incorporated into routine monitoring programs of EPA

- ***HICO is currently limited to only <u>one</u> image per orbit.***

- ***ISS overpass times are difficult to precisely predict. These uncertainties led to the rescheduling of planned image acquisitions which at times impacted the effective deployment of crews for field validation activities.***

HICO has the potential to be a valuable monitoring tool, if transitioned to a constellation of sensors.

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Special Thanks to:

Crews on ISS Expeditions 24 - 31
Naval Research Laboratory Remote Sensing Division
Oregon State University
NASA ISS Program
American Astronautical Society
and
EPA Office of Research and Development
EPA Pathfinder Innovation Program (Grant 2011)
EPA Safe and Sustainable Waters Research Program