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/NRMRL
Naval Research Laboratory-Stennis Space Center

Jessica Aukamp	USEPA/NHEERL/Gulf Ecology Division
Donald Cobb	USEPA/NHEERL/Atlantic Ecology Division
Robyn Conmy	USEPA/National Risk Management Research Laboratory/Land Remediation and Pollution Control
George Craven	USEPA/NHEERL/Gulf Ecology Division
Richard Gould	Naval Research Laboratory/ Bio-optical Physical Processes and Remote Sensing Section
James Hagy	USEPA/NHEERL/Gulf Ecology Division
Darryl Keith*	USEPA/NHEERL/Atlantic Ecology Division
John Lehrter	USEPA/NHEERL/Gulf Ecology Division
Ross Lunetta	USEPA/National Exposure Research Laboratory/Environmental Services Division
Michael Murrell	USEPA/NHEERL/Gulf Ecology Division
Kenneth Rocha	USEPA/NHEERL/Atlantic Ecology Division
Blake Schaeffer	USEPA/NHEERL/Gulf Ecology Division

*email: keith.darryl@epa.gov

EPA United States Environmental Protection Agency

Special Thanks to:

Oregon State University
NASA ISS Program Office
American Astronautical Society
and
EPA Office of Research and Development
EPA Pathfinder Innovation Program (Grant 2011)
EPA Safe and Sustainable Waters Research Program

EPA United States Environmental Protection Agency

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.

EPA United States Environmental Protection Agency

Program Objectives

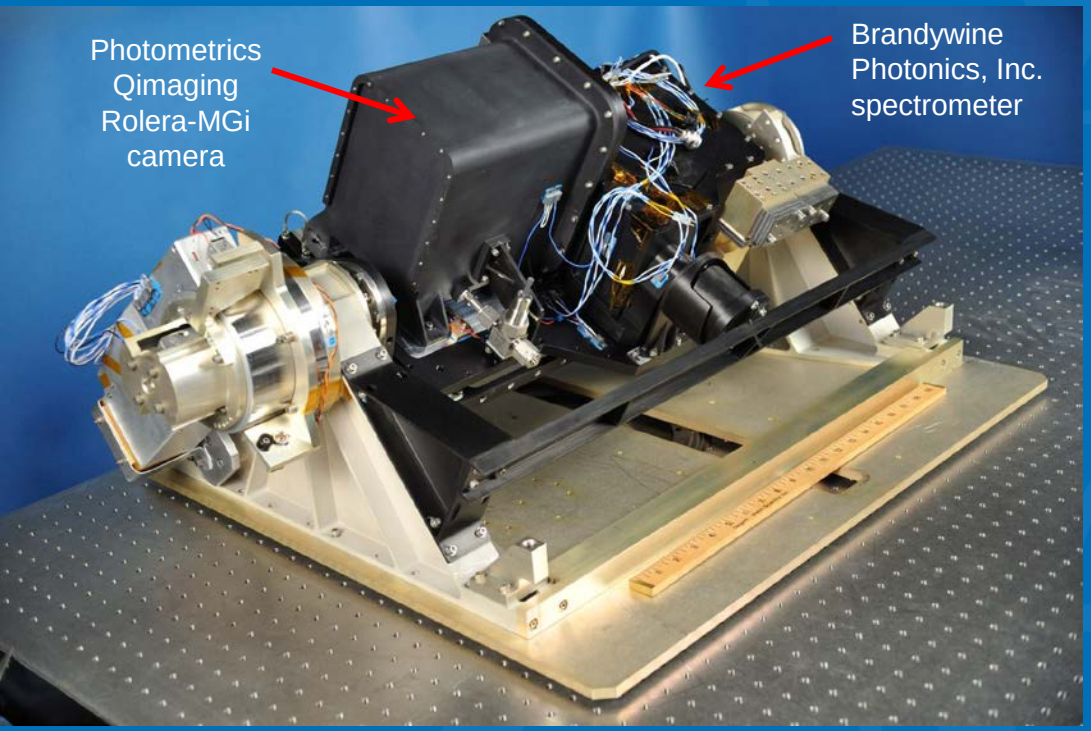
Use HICO imagery to develop a novel space-based environmental monitoring system that provides information for the sustainable management of coastal ecosystems.

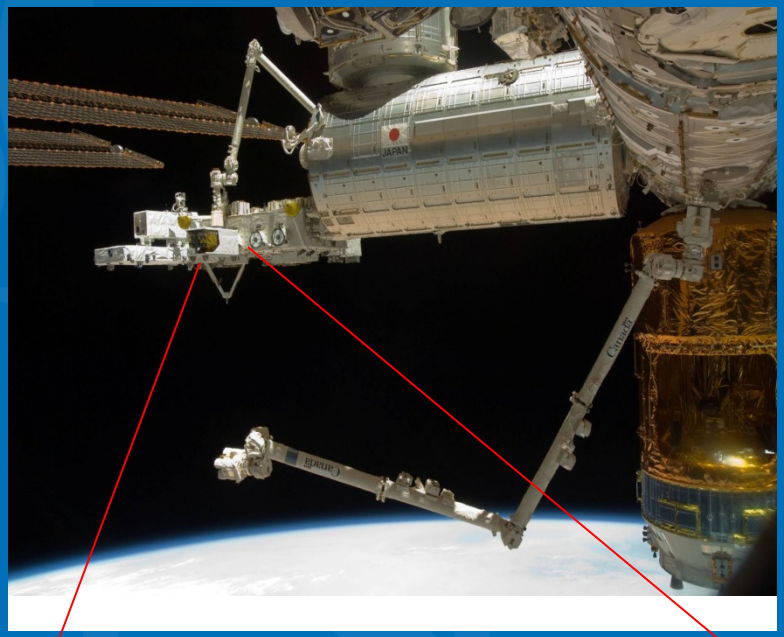
To demonstrate that water quality information derived from HICO could be incorporated into a prototype smart phone application to disseminate data to managers in the EPA Office of Water.

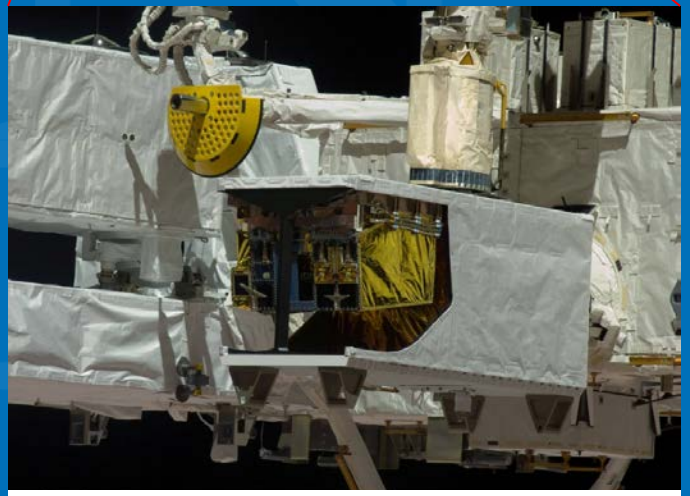
Water quality news reports may change the social and economic dynamics for the Nation to not only be aware of its water quality conditions but support sustainable practices to maintain or improve conditions at their favorite recreational areas.

Hyperspectral Imager for the Coastal Ocean (HICO)

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







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

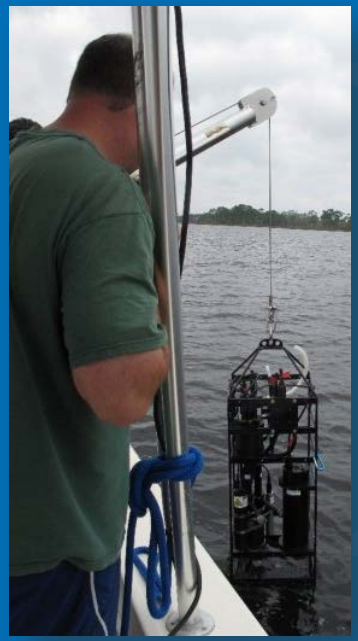
Program Implementation

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.

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

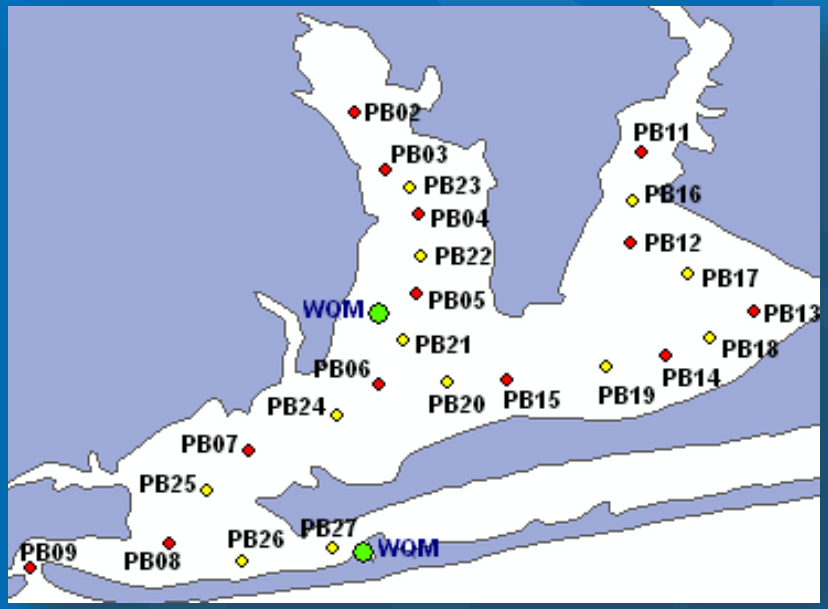
EPA United States Environmental Protection Agency

Sample stations

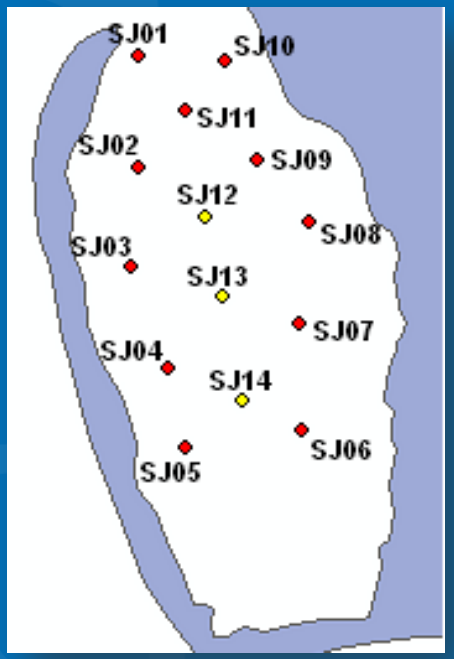
Green = water quality moorings (chl *a*, turbidity, and CDOM)

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

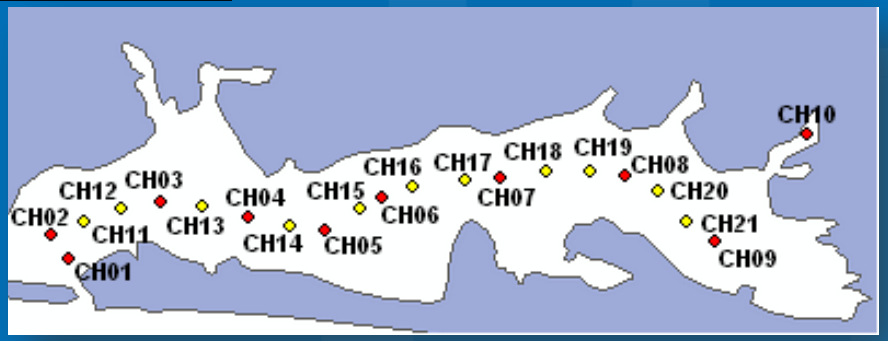
Red = same as yellow + discrete water samples



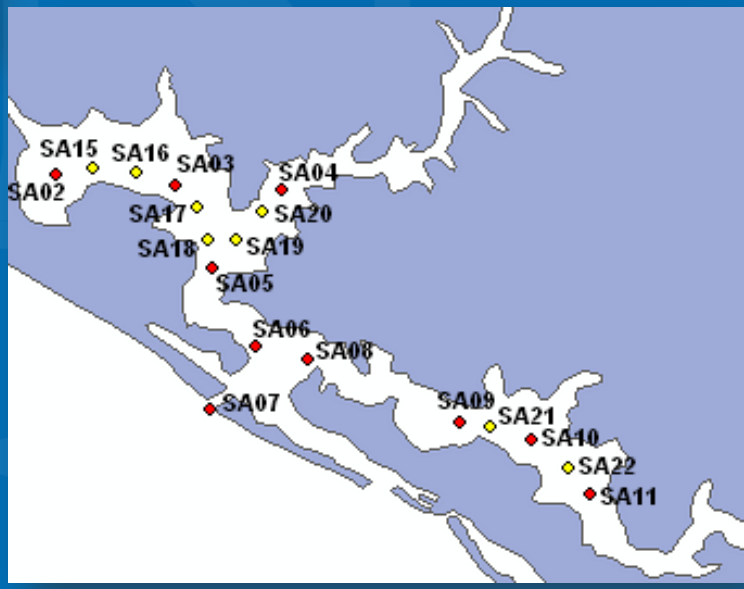
Pensacola Bay



St. Joseph Bay



Choctawhatchee Bay



St. Andrew Bay

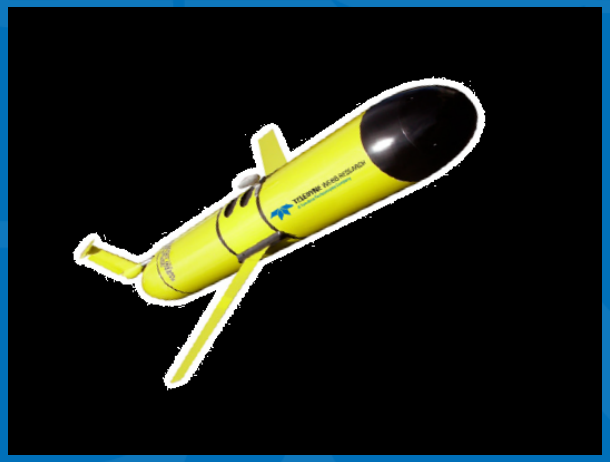
Office of Research and Development
National Health and Environmental Effects Research Laboratory/ Atlantic Ecology Division

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 fluorescence



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

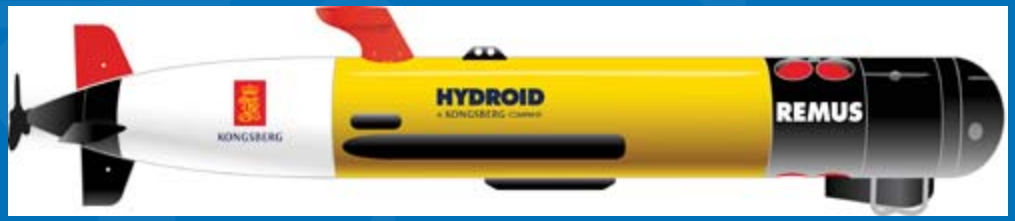
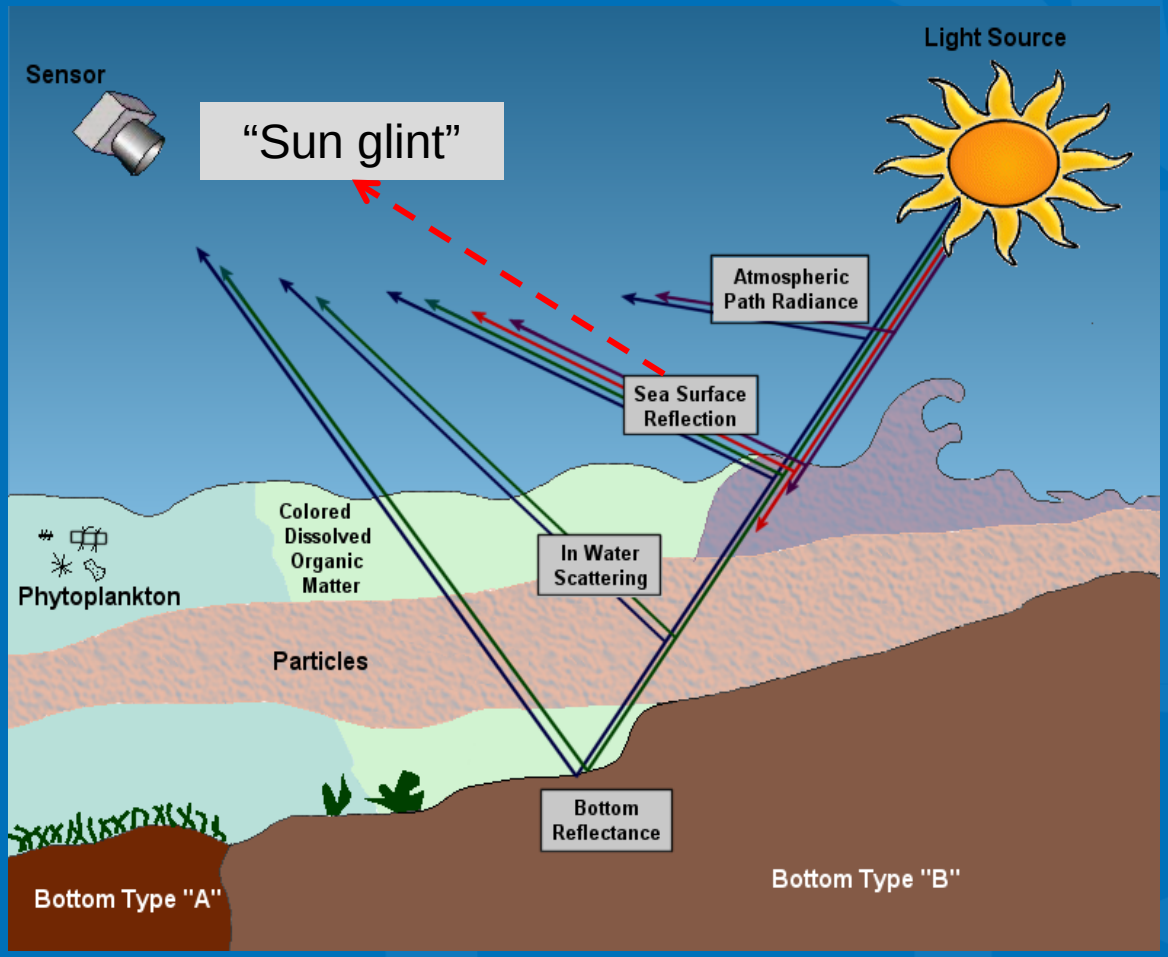


Photo courtesy of Kongsberg Maritime

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

United States Environmental Protection Agency

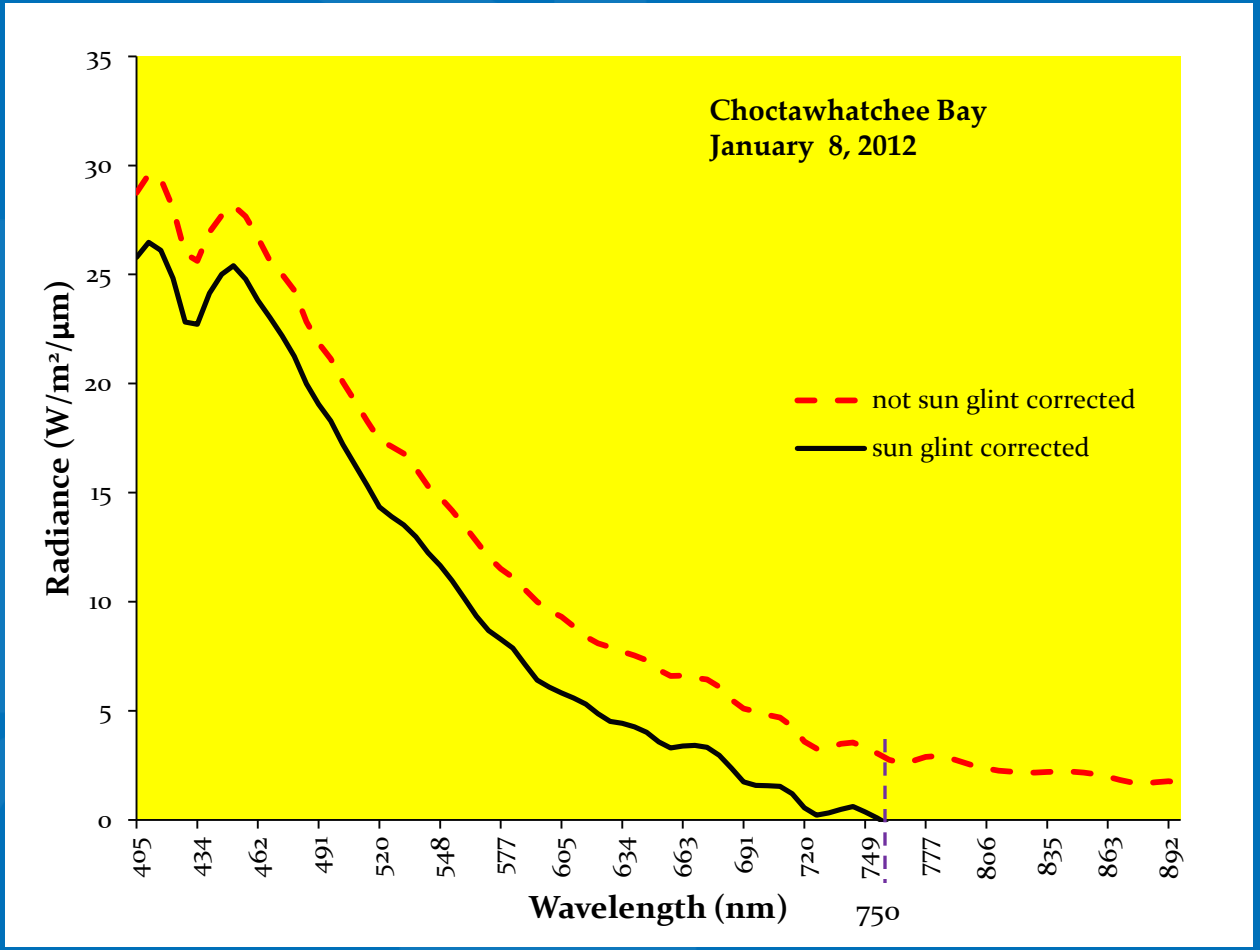
Example of the effect of the sun glint correction routine on HICO Level 1b radiance data (Goodman et al., 2008)

Approach:

Subtract radiance at 750 nm from the radiance at each wavelength in the spectrum.

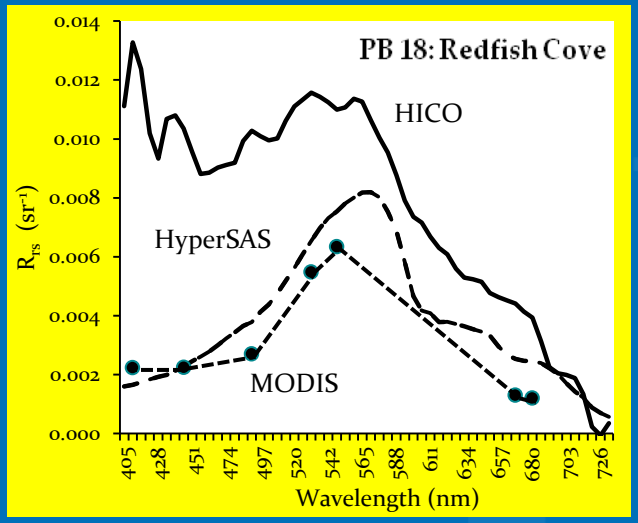
Major assumption:

•NIR light is strongly absorbed by water

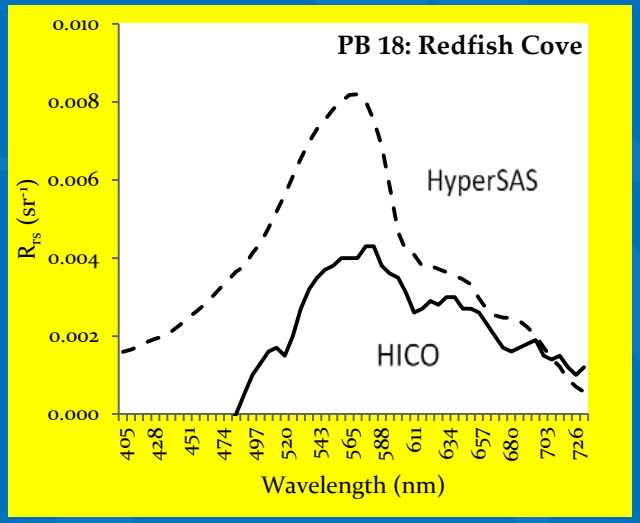


Approaches to atmospherically correct HICO remote sensing data

HICO image - Pensacola Bay June 2, 2011

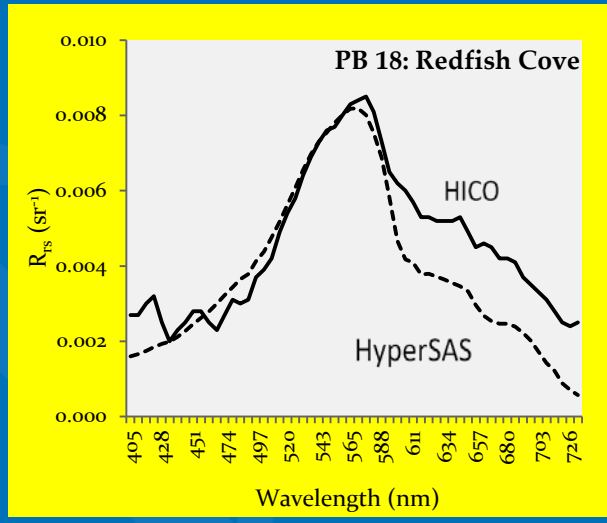


HICO spectral signatures processed using the Naval Res. Lab automated processing system (APS) and compared with HyperSAS above water signature



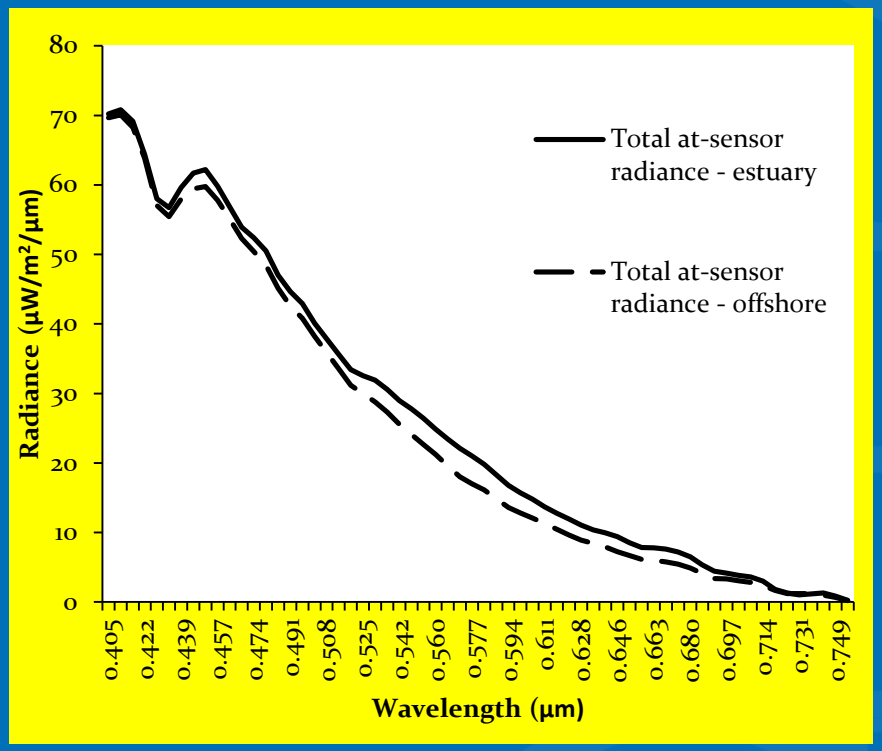
HICO spectral signature processed using the ENVI FLASSH * atm. correction program and compared with HyperSAS above water signature

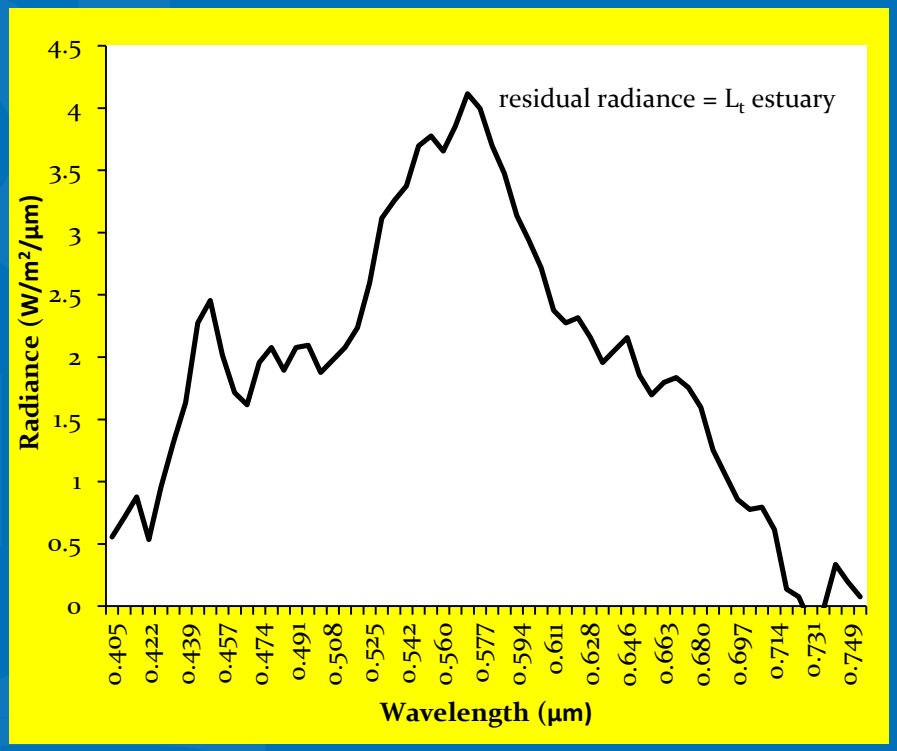
* **F**ast-**L**ine-of-Sight **A**tmospheric **A**nalysis of **S**pectral **H**ypercubes



HICO spectral signature processed using the dark pixel subtraction approach and compared with HyperSAS above water signature

“dark pixel” atmospheric correction





$L_{t\ \text{at-sensor}} = L_{t\ \text{offshore}} + L_{t\ \text{estuary}}$

$L_{t\ \text{at-sensor}} - L_{t\ \text{“dark”offshore}} = L_{t\ \text{estuary}}$

HICO Image Processing Steps

Step 1	Open HICO Level 1b Image with calibrated TOA at-sensor radiances
Step 2	Recover true at-sensor radiance values
Step 3	Sun glint correction
Step 4	Dark pixel subtraction
Step 5	Convert from $W/m^2/um/sr$ to $uW/cm^2/nm/sr$
Step 6	Convert at-sensor Radiance to Reflectance
Step 7	Convert at-sensor Reflectance to Remote sensing Reflectance
Steps 8 - 9	Create GLT + Geolocate + Warp Images
Step 10	Clip estuary shapefile to Warped image
Step 11	Export clipped R_{rs} data to EXCEL

Determine Mean Solar Irradiance (F_0)

Determine diffuse transmittance from sun to pixel (t_0)

Cloud removal (if needed)

Turbidity

CDOM

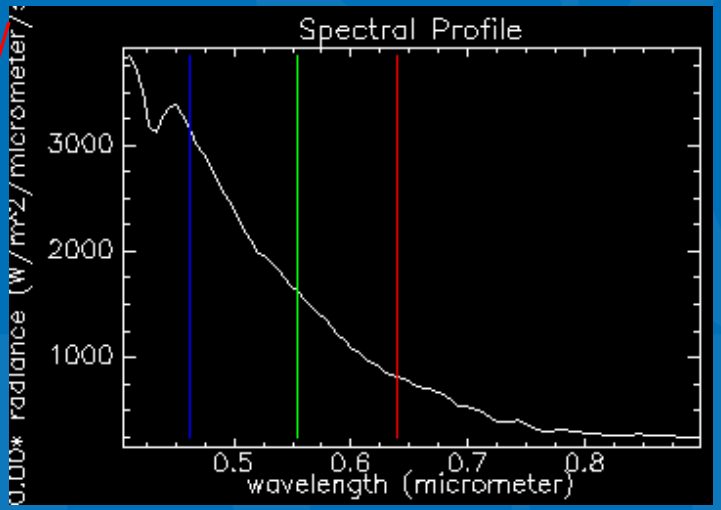
TSM

Chl *a*

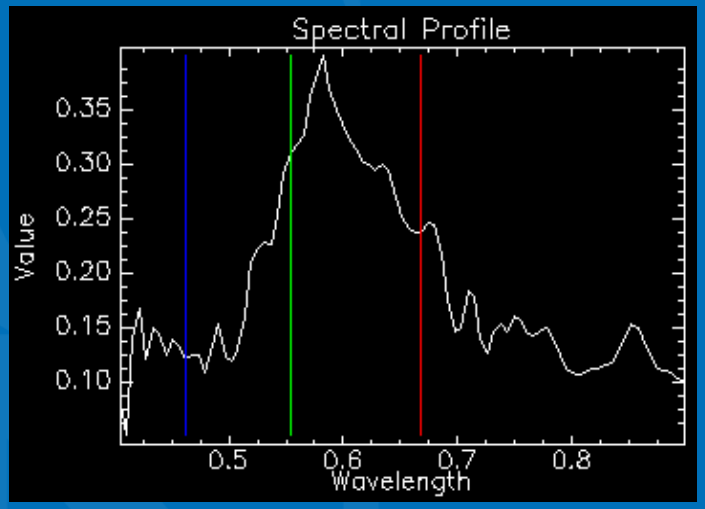
Processing done with Excelis VIS ENVI 4.7 software

EPA
United States
Environmental Protection
Agency

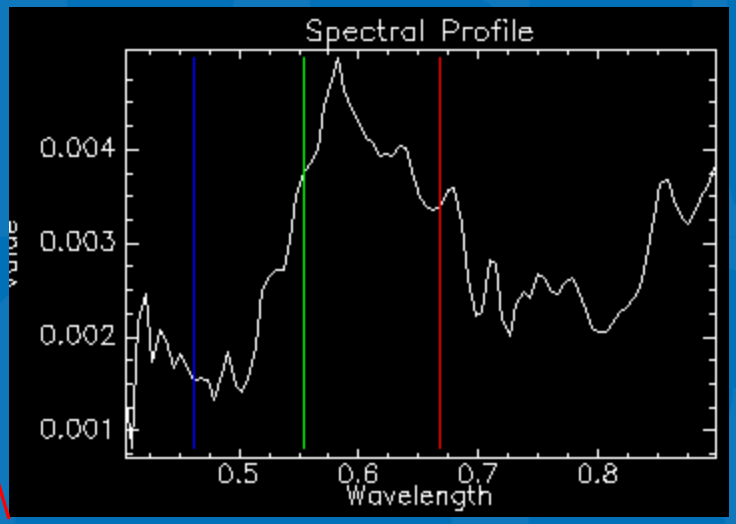
iss2012016.0116.193730.L1B_PensacolaBay_des.v03.9170.20120117211554.100m.hico.bil



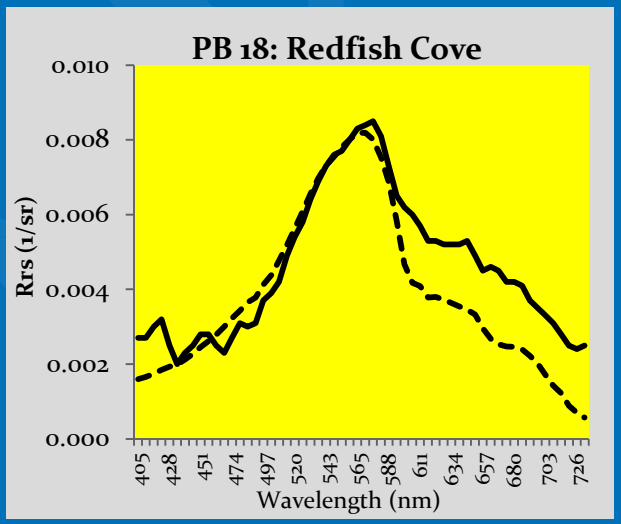
Step 1: Level 1b calibrated radiance



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



Step 7: Remotely sensed Reflectance (1/sr)



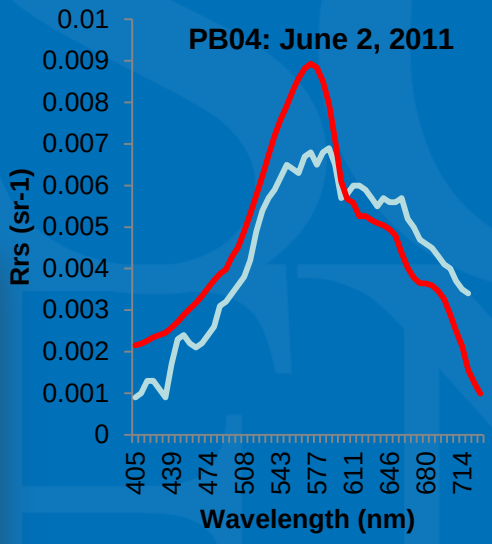
Spectral match-ups between HyperSAS (dotted line) and HICO spectral signature (solid line).

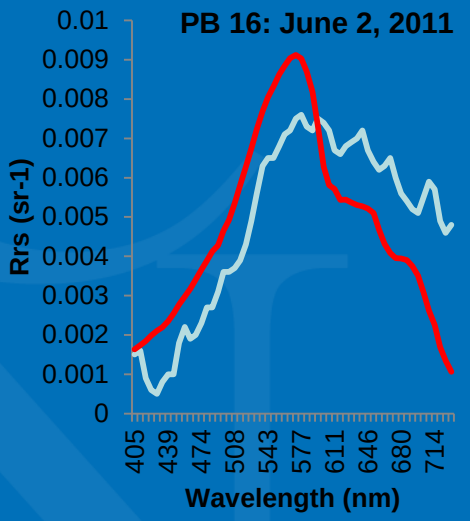
Office of Research and Development
National Health and Environmental Effects Research Laboratory/ Atlantic Ecology Division

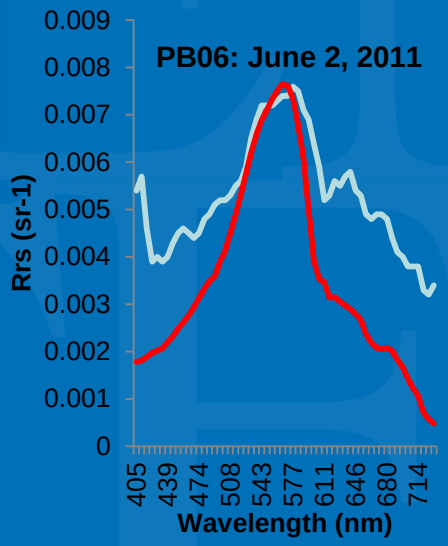
EPA
United States
Environmental Protection
Agency

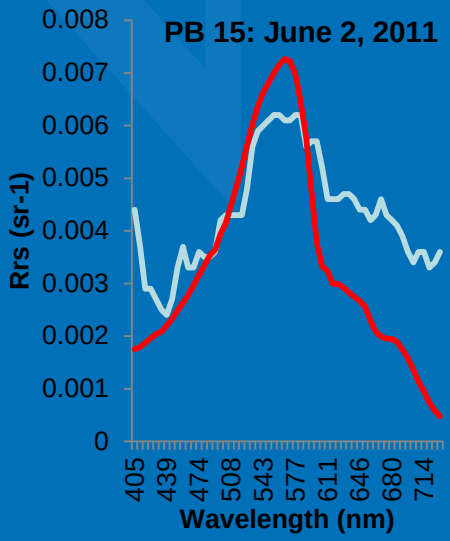
Spectral Match-ups

Pensacola Bay, FL

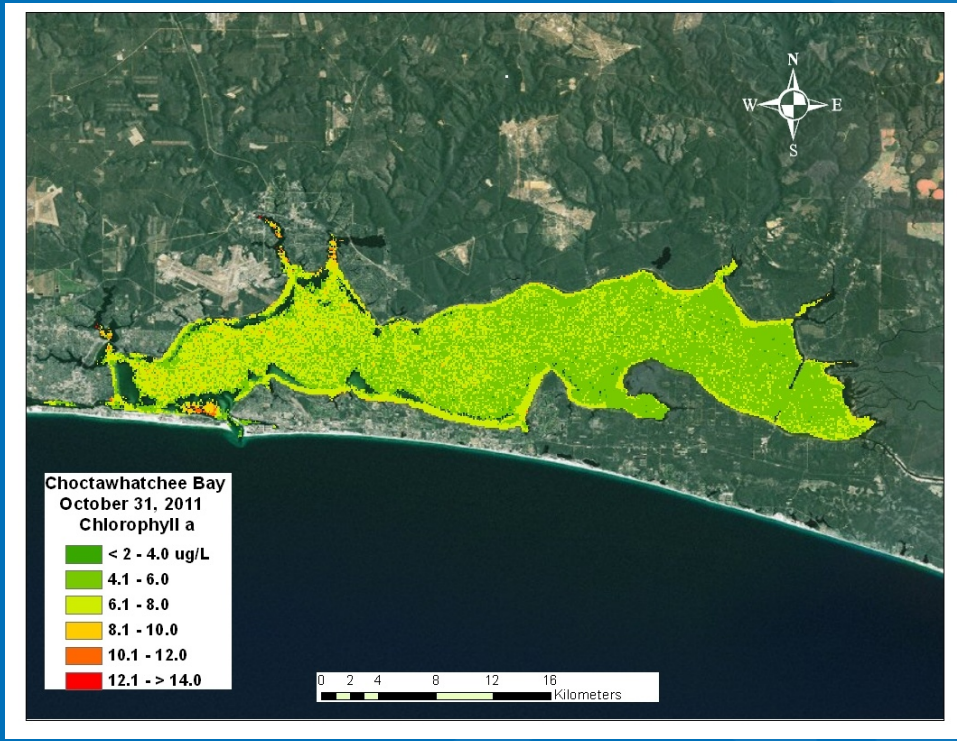


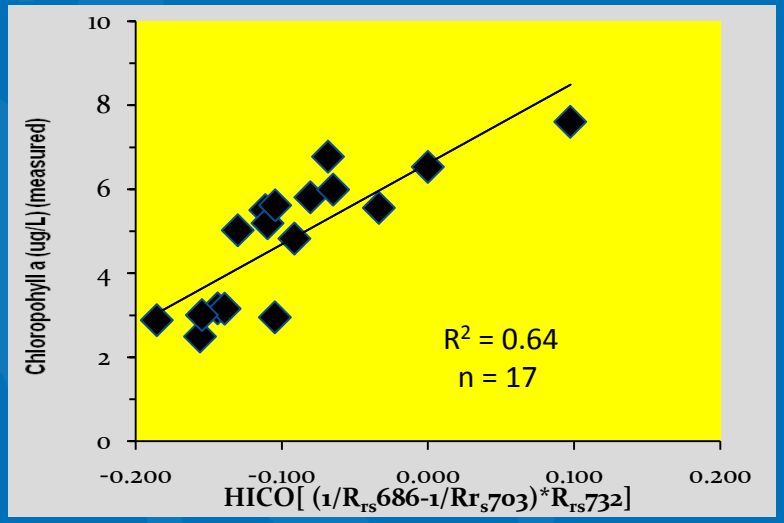




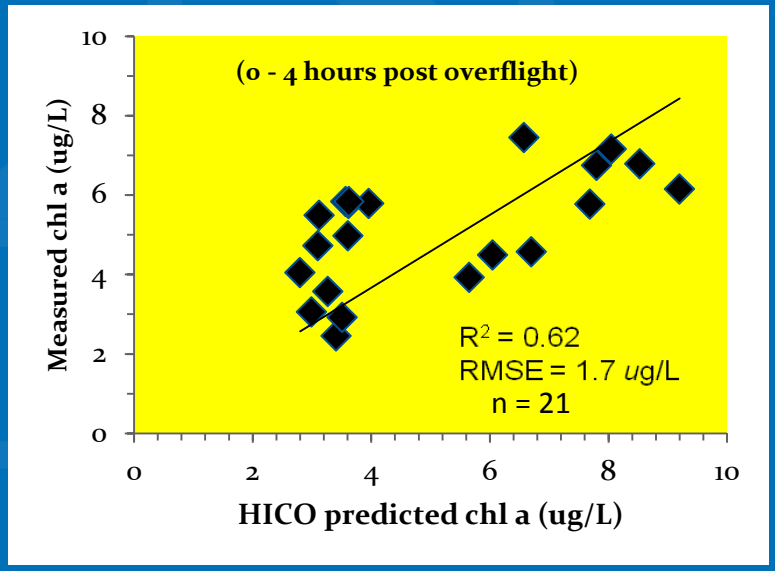


Chl *a*: indicator of phytoplankton abundance and eutrophication





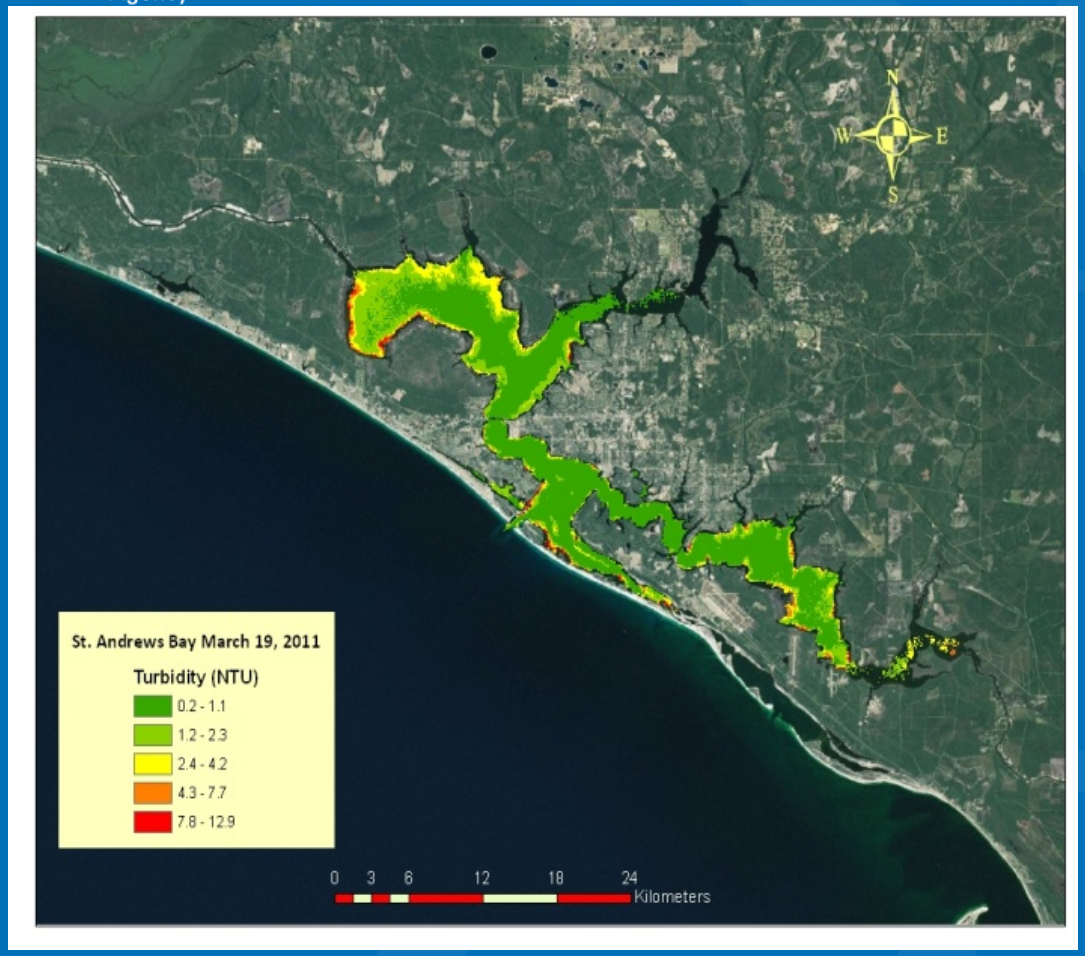
approach of Gitelson et al., 2011

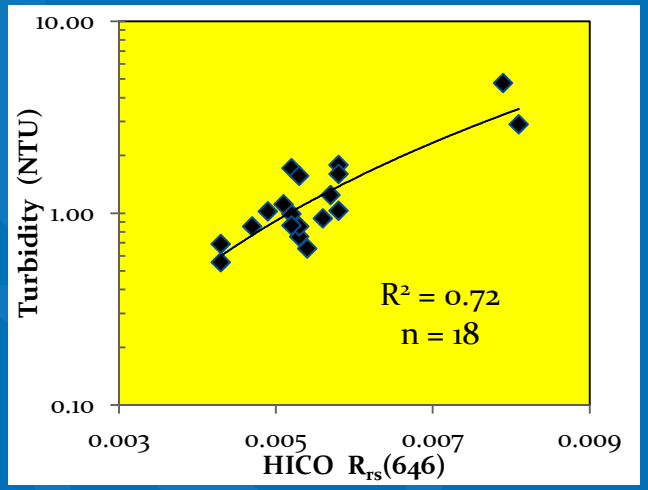


$$\text{Chl } a = 17.477 \times [a] + 6.152$$

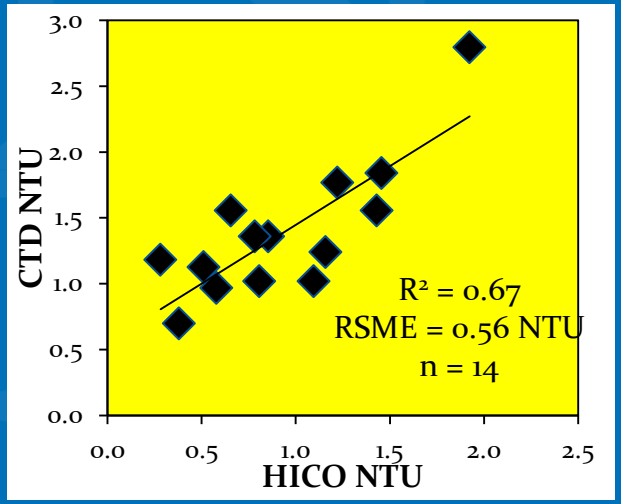
$$a = [1/R_{rs(686)} - 1/R_{rs(703)}] \times R_{rs(732)}$$

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



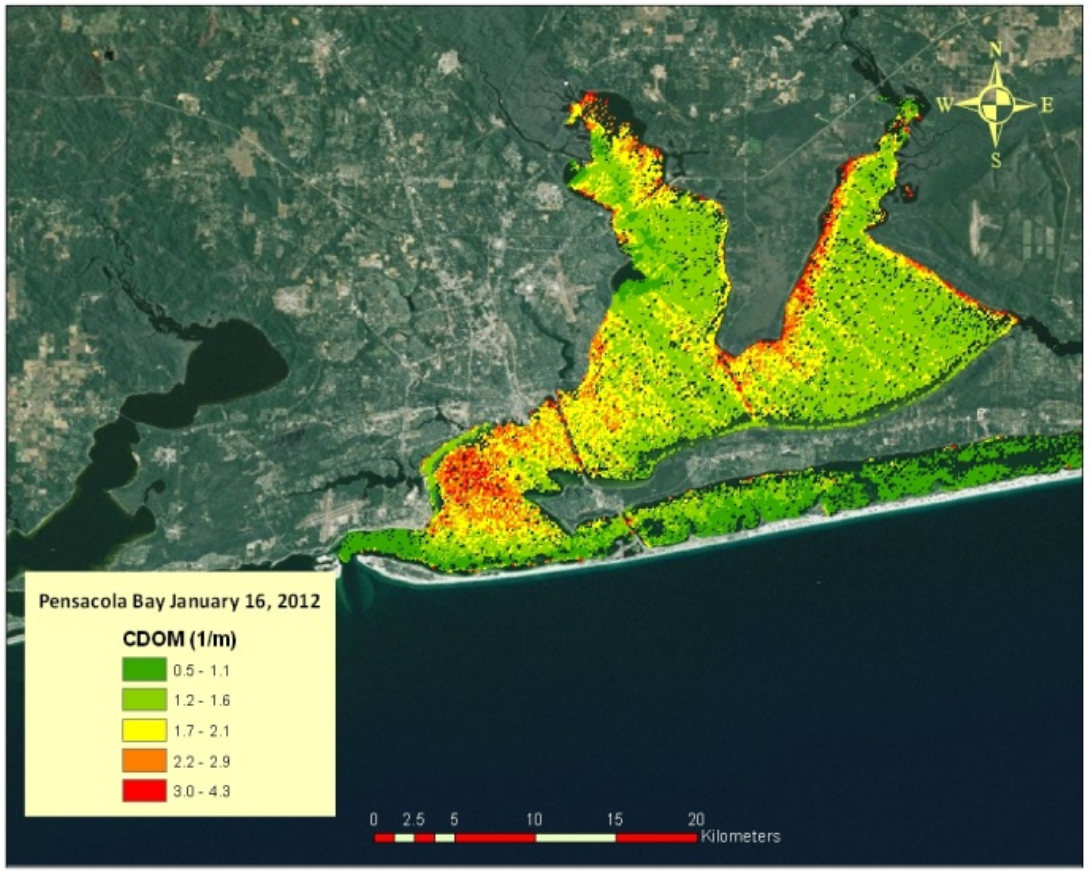


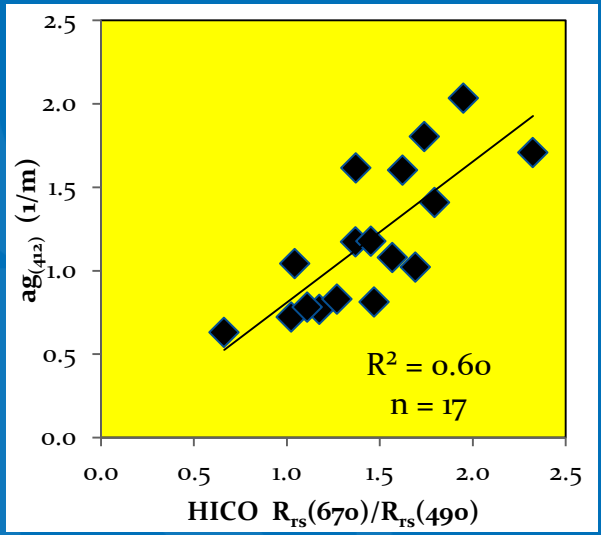
approach of Chen et al., 2007



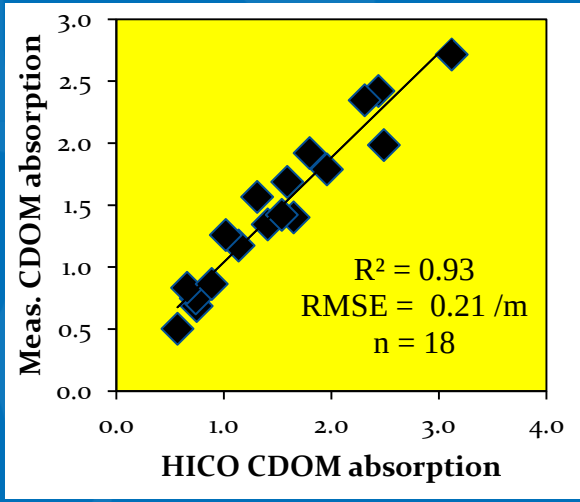
$$\text{Turbidity} = 2*10^6 \text{ X } [R_{rs}(646)^{2.7848}]$$

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





approach of Bowers et al., 2004



$$a_{CDOM412}\,(m^{-1}) = 0.8426 \times [R_{rs}(670)/R_{rs}(490)] - 0.032$$

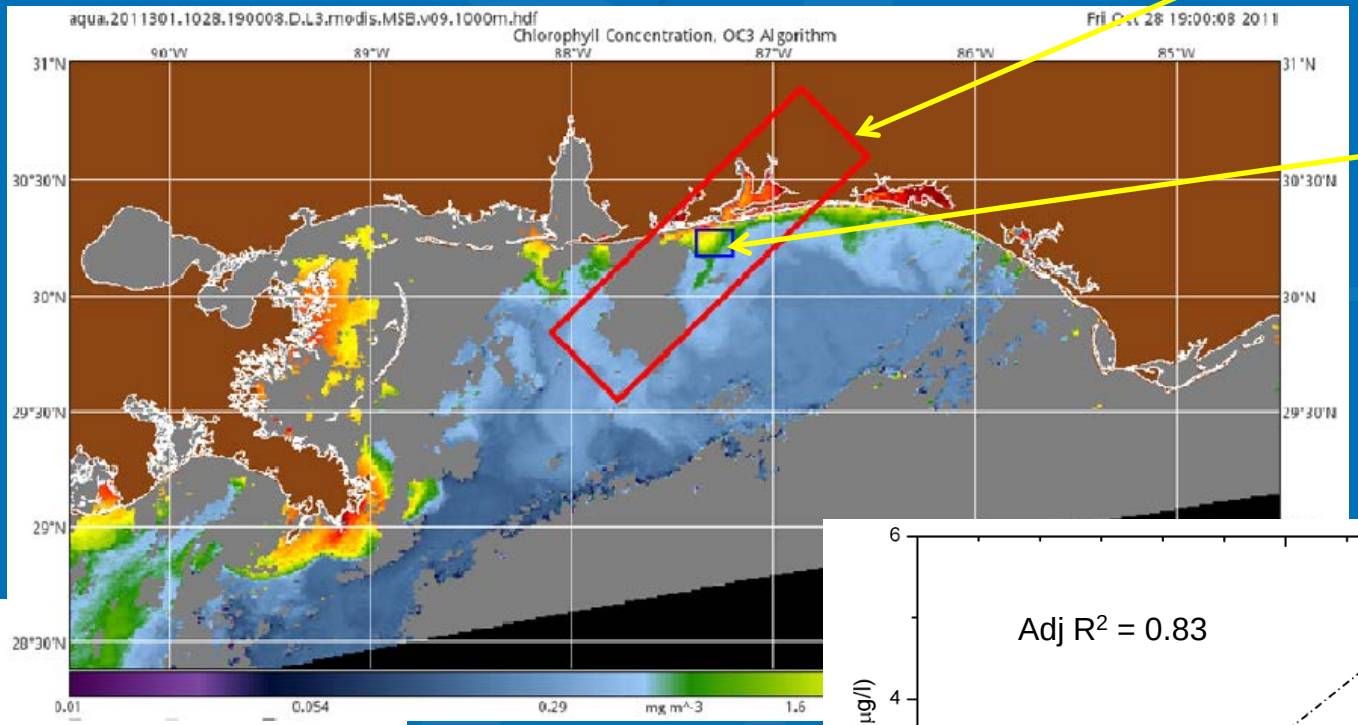
HICO/MODIS Comparison

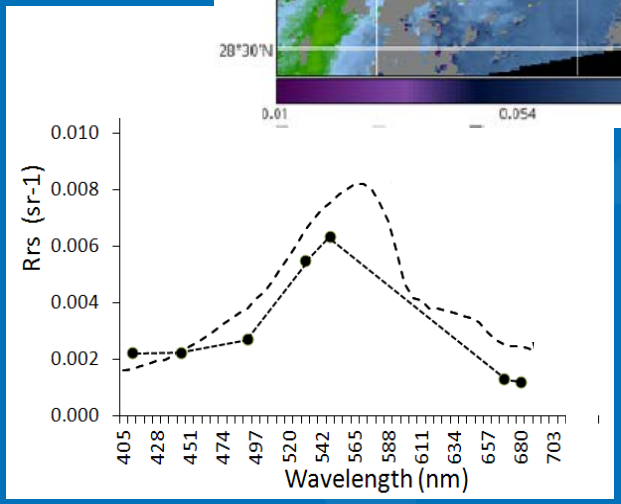
MODIS scene 19:00 GMT, 7 minutes before HICO

HICO scene

October 28, 2011 HICO and MODIS image date

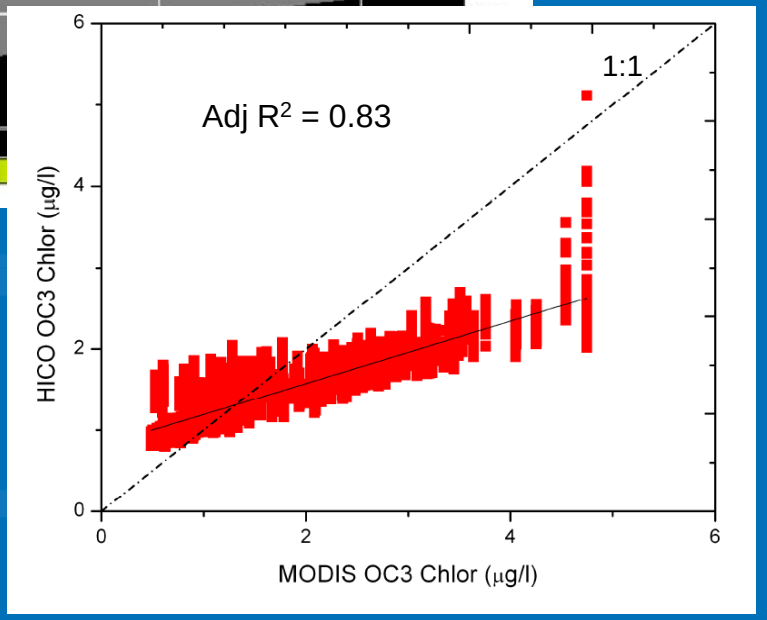
Pixels common to both images and used in the match-up





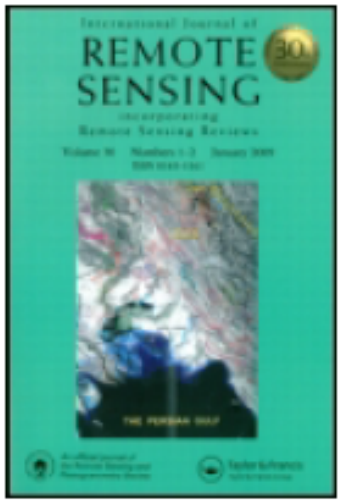
Dashed line = HyperSAS R_{rs}

Dotted line = HICO R_{rs} at MODIS bandwidths



Office of Research and Development
National Health and Environmental Effects Research Laboratory/ Atlantic Ecology Division

United States Environmental Protection Agency



International Journal of Remote Sensing

Remote sensing of selected water-quality indicators with the hyperspectral imager for the coastal ocean (HICO) sensor

Darryl J. Keith[a], Blake A. Schaeffer[b], Ross S. Lunetta[c], Richard W. Gould Jr.[d], Kenneth Rocha[a] & Donald J. Cobb[a]

[a] US EPA National Health and Environmental Effects Research Laboratory, Atlantic Ecology Division, Narragansett, Rhode Island 02882, USA

[b] US EPA National Health and Environmental Effects Research Laboratory, Gulf Ecology Division, Gulf Breeze, Florida 32561, USA

[c] US EPA National Exposure Research Laboratory, Research Triangle Park, North Carolina 27709, USA

[d] Bio-Optical Physical Processes and Remote Sensing Section, Naval Research Laboratory, Stennis Space Center, Mississippi 39529, USA

Published online: 25 Mar 2014.

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 were 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 to two</u> images 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 continues to serve as a valuable resource for algorithm development for water quality indicators in estuaries and the coastal ocean and as a test bed for the development /testing of protocols for data to be collected by hyperspectral sensors on HyspIRI, Geo-CAPE, and PACE (?).