



# Vicarious Calibration Of The Hyperspectral Imager For Coastal Oceans (HICO) Using MOBY And AERONET-OC Data

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# Acknowledgement

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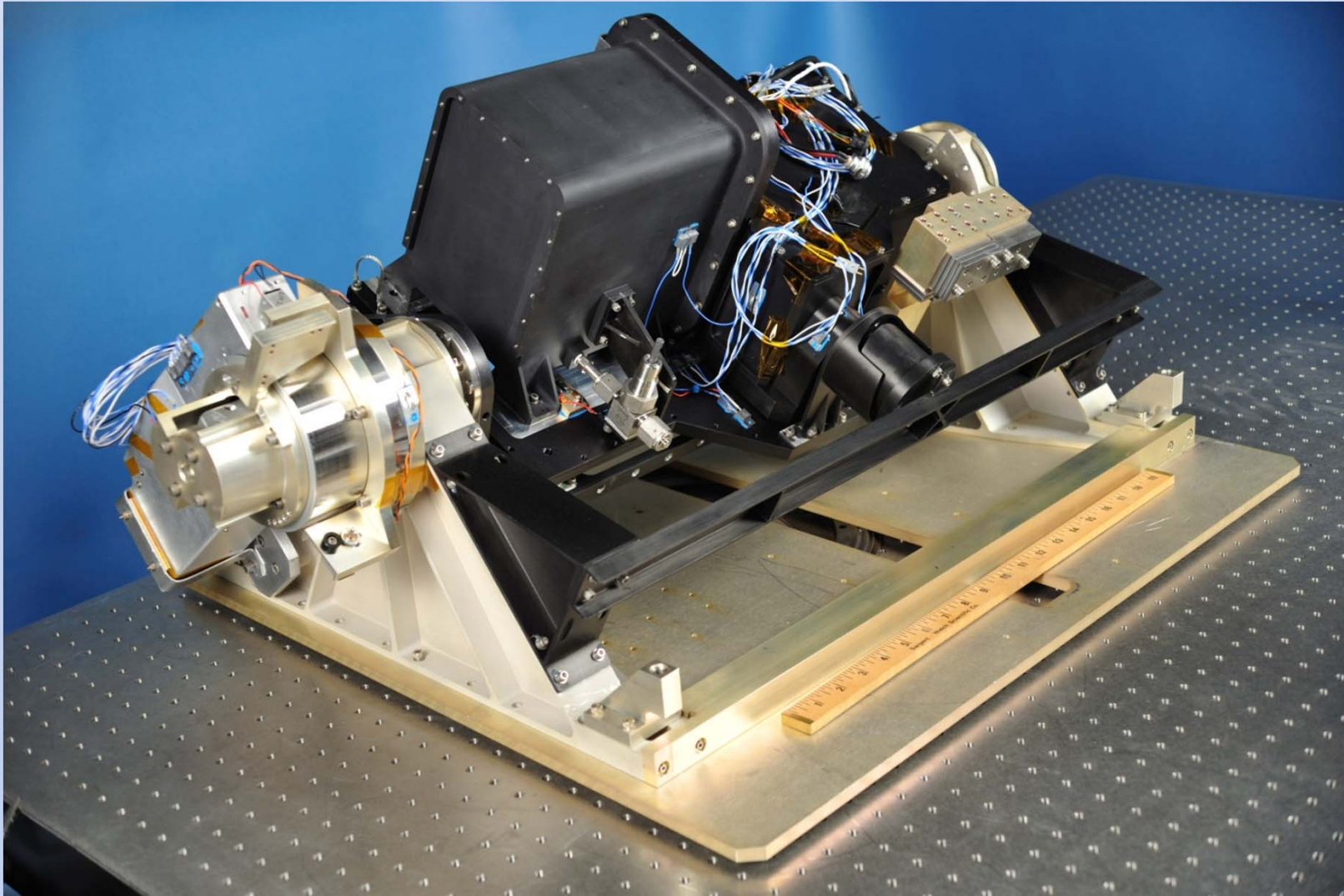
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- “Hyperspectral Sensor Development for TACSAT”  
(Program Element: 0603758N)
- “Improving Blended Multi-sensor Ocean Color Products through Assessment of Sensor Measurement Differences”  
(Program Element: 0602435N)

We also acknowledge and appreciate in situ data available from:

- NOAA Marine Optical Buoy (MOBY)
- Aerosol Robotic NETwork (AERONET) Stations
- US EPA through Blake Schaeffer

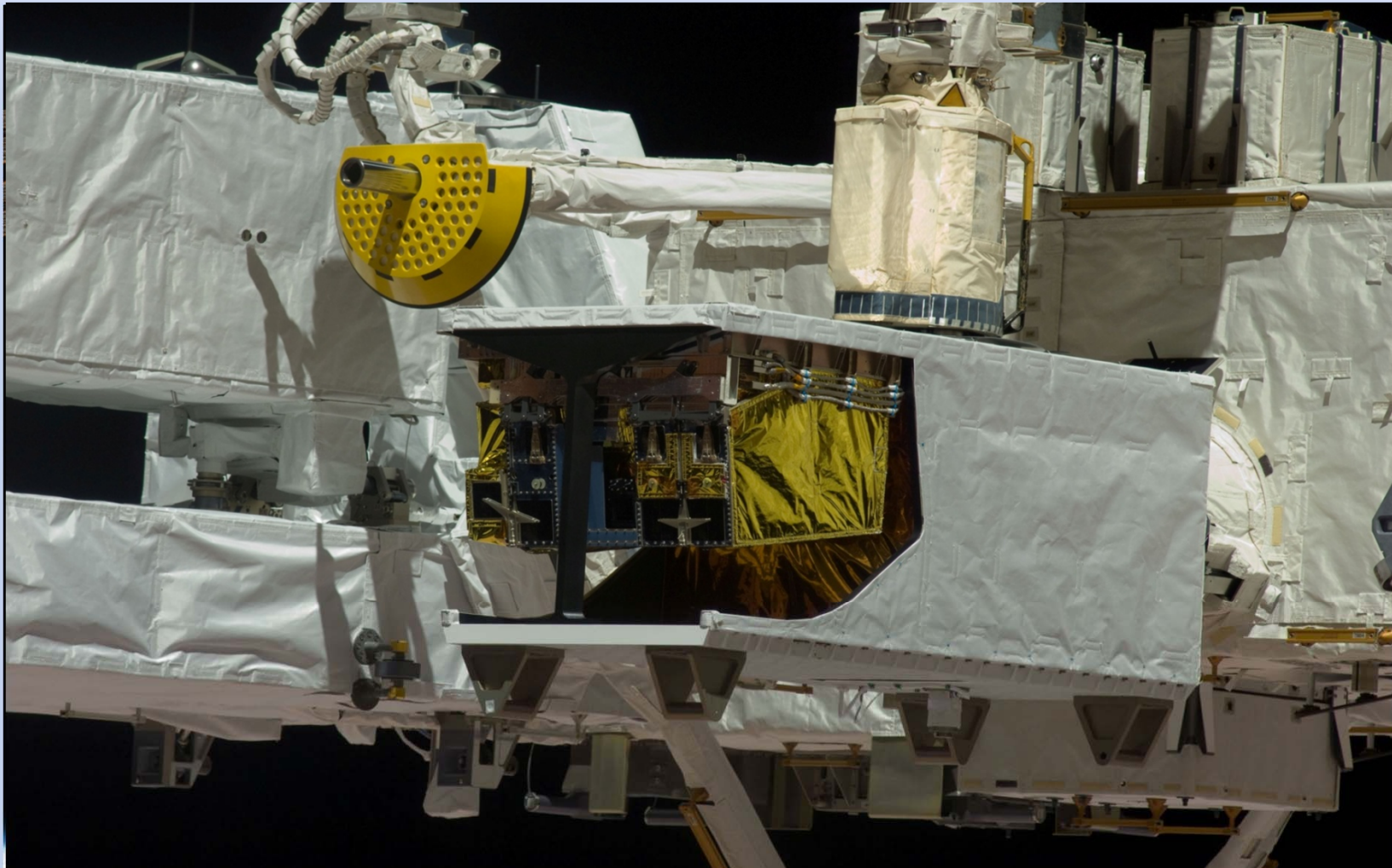
# Hyperspectral Imager for Coastal Oceans (HICO)



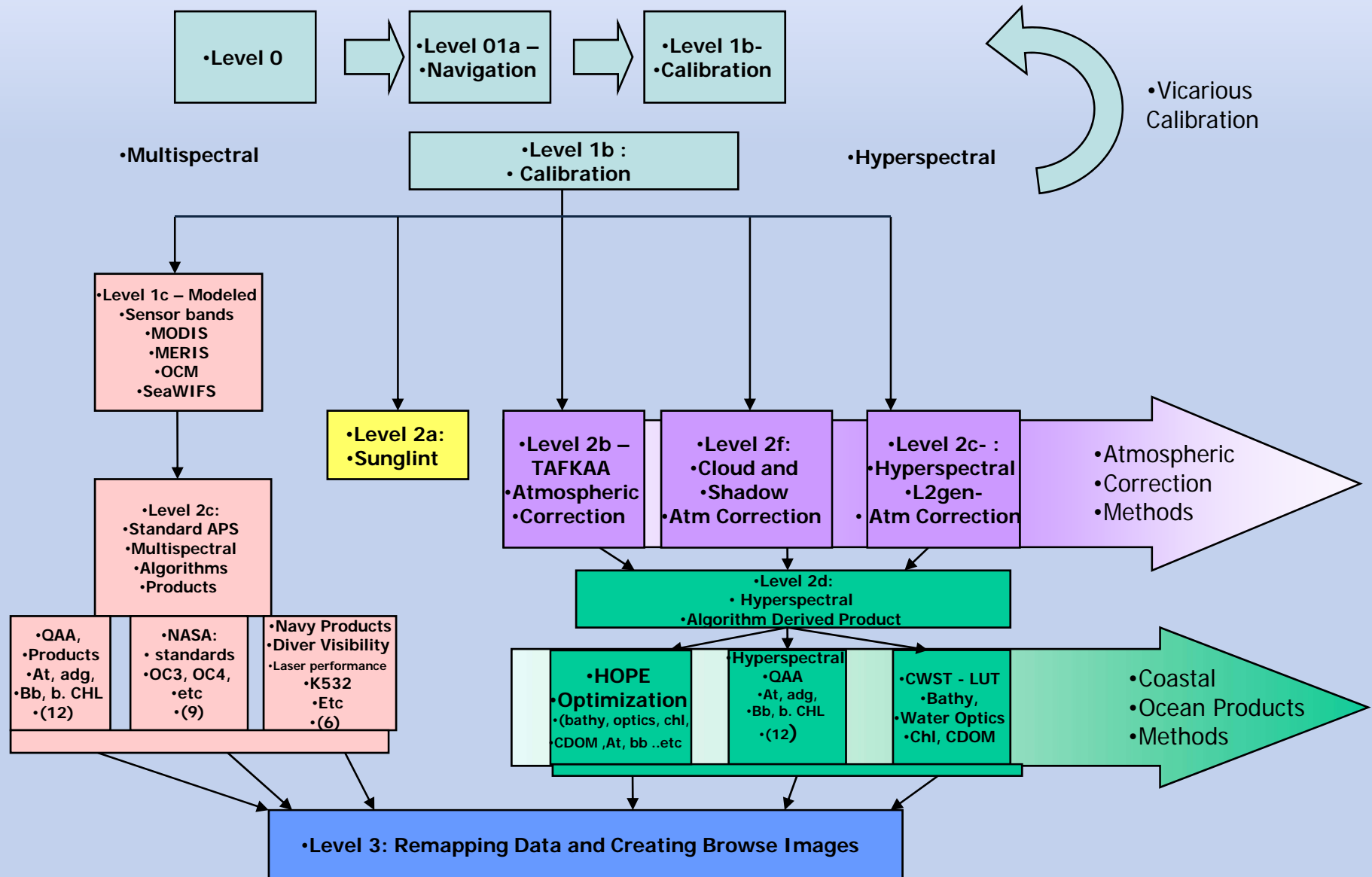
# HICO Sensor Parameters

Parameter	Performance	Rationale
Spectral Range	350 to 1070 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	128	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

# HICO on Japanese Module Exposed Facility



# HICO Processing Activity in APS



# Processing Adjustment

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- Normalized Water Leaving Radiance (nLw) values derived from:
  - sensor measurement
  - radiometric calibration
  - atmospheric correction algorithm
- Changes occurred in HICO sensor between lab characterizations and installation on ISS
- Sensor calibration degrades over time
- Atmospheric Correction used to derive nLw
- Vicarious Calibration provides updated gains to improve accuracy of data recording / radiometric calibration / atmospheric correction system

# Vicarious Calibration Process

## Update sensor gain factors

- Sensor Gain( $\lambda$ ) =  $\frac{\text{Vicarious } L_{\text{toa}}(\lambda)}{\text{Measured } L_{\text{toa}}(\lambda)}$
- Apply sensor gain to raw data and reprocess data products

## Record satellite data

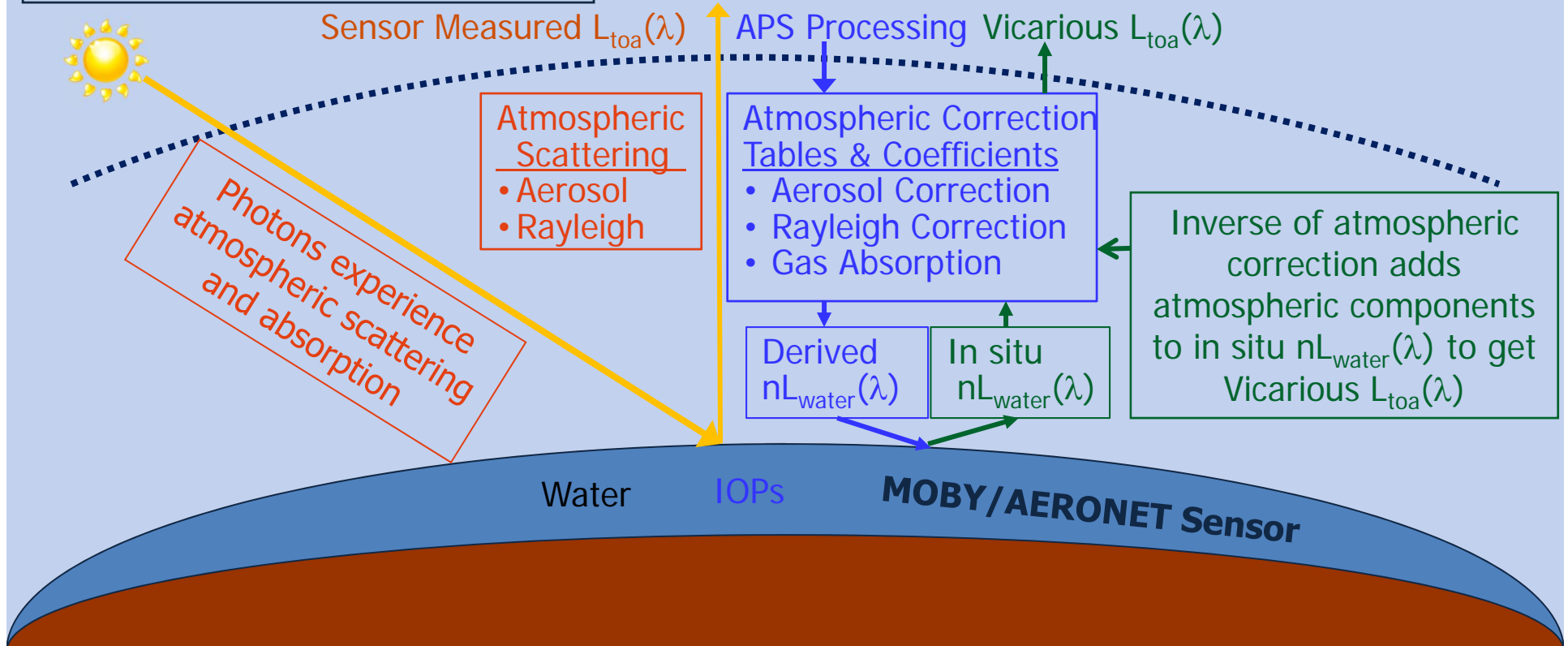
- Measure top of atmosphere radiance, **Measured  $L_{\text{toa}}(\lambda)$**

Satellite Sensor



## Convert water leaving radiances to top-of-atmosphere radiance

- Use in situ  $nL_{\text{water}}(\lambda)$  data to estimate top of atmosphere radiance, **Vicarious  $L_{\text{toa}}(\lambda)$** , by performing inverse of atmospheric correction





# Atmospheric Correction Algorithm

- Goal: To retrieve the normalized water-leaving radiance ( ${}_nL_w$ ) accurately from the spectral measurements of the TOA radiance  $L_t(\lambda)$

- Gordon-Wang atmospheric correction algorithm is used in this study

- TOA atmospheric path radiance:

$$L_t = L_{wc} + L_g + L_w + L_r + L_a + L_{ra}$$

- Terms represent white-cap, glint, water, rayleigh, aerosol and molecular scattering radiances

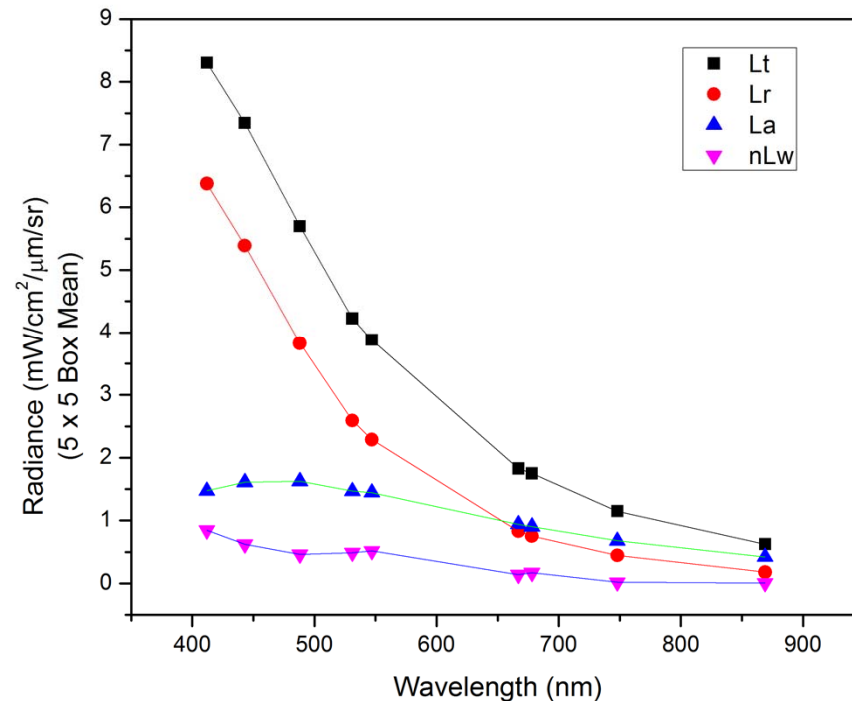
- Inverting previous equation to solve for  $L_w$  leaves:

$$L_w = L_t - (L_{wc} + L_g + L_r + L_a + L_{ra})$$

- Normalized water leaving radiances  ${}_nL_w$  can be computed from  $L_w$  and sensor geometry

# Radiance Components in Atmospheric Correction

- $L_r = f_0 * V_{scatter} * pressure$ 
  - $f_0$  = TOA solar irradiance
  - $V_{scatter}$  = Volume Scattering Function
  - Pressure = function of path radiance
  - $V_{scatter}$  and pressure terms depend on sensor/solar geometry
  - Solar irradiance,  $f_0$ , interpolated to HICO wavelength at HICO bandwidth
- Wavelengths of  $L_r$  tables have to match wavelength center and bandwidth of sensor  $L_t$  data set



- MODIS-retrieved  $L_t$ ,  $L_r$ ,  $L_a$ , and  $nL_w$  for 412, 443, 488, 531, 547, 667, 748, and 869 (nm) wavelengths at the AERONET-OC location for the Gulf of Mexico, May 4, 2010.

# Vicarious Calibration 2 Step Process

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## Aerosol Scattering Radiance, $L_a$

- Emissivity derived from signal response at 748 and 868 nmeter
- Emissivity used to select aerosol model
- Aerosol model used to establish  $L_a$  for processing pixel
- Aerosol model selection process discussed in H.R. Gordon, M. Wang, "Retrieval of water-leaving radiance and aerosol optical thickness over the oceans with SeaWiFS: a preliminary algorithm", Applied Optics January 1994, Vol 33, No 3, Pg 443

## Vicarious Calibration requires a 2 step process

- First step generates gains for NIR wavelength bands
- This stabilizes the gains influencing the emissivity derivation
- Second step generates gains for visible wavelength bands

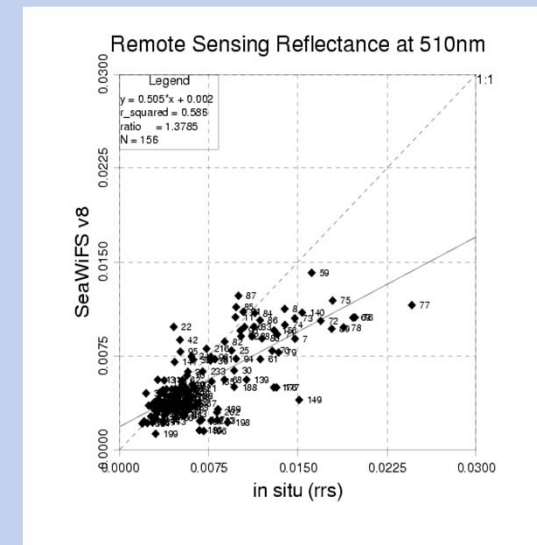
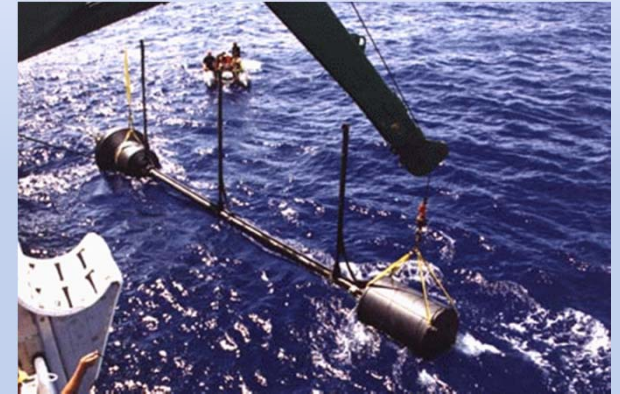
# Gain and Offset Computation

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- Objective of vicarious calibration is to compute gains and offsets which transform  $L_t$  to  $vL_t$  values that compute insitu  $nL_w$  values after atmospheric correction is performed
- Gains and offsets can be computed
  - Single date case: ratio of vicarious  $L_t$  and measured  $L_t$  using notation of “gain =  $vL_t / L_t$ ” where “offset = 0”
  - Multiple date case
    - Use multiple dates to create  $L_t$  and  $vL_t$  pairings
    - Perform linear regression to generate equation ( $y = mx + b$ )
    - Let gain =  $m$  and offset =  $b$ , yields
    - $vL_t = (\text{gain}) L_t + \text{offset}$
- After gain/offsets are computed scenes are reprocessed using new gain and offset for each band

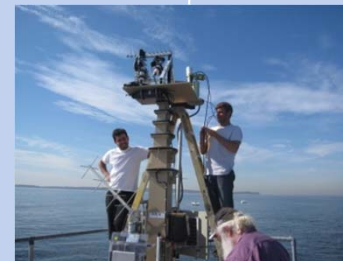
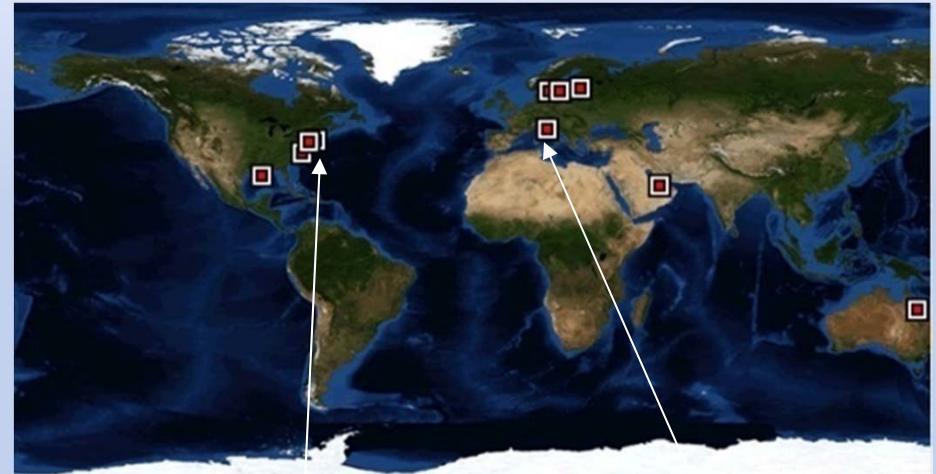
# Current In Situ Data Used for Vicarious Calibration

- Marine Optical Buoy (MOBY) is managed by NOAA
- Moored in uniform water volume near Lanai, Hawaii
- Performs several atmospheric measurements
- Also measures Inherent Optical Properties (IOPs) and Normalized Water-leaving Radiance ( $nL_w$ )
- MOBY provides in situ data to perform vicarious calibration for several NASA / NOAA sensors
- MOBY data stored in Ca/Val database for vicarious calibration of hyperspectral data stream



# Aerosol Robotic NETwork - Ocean Color (AERONET-OC)

- Managed by NASA Goddard Space Flight Center (GSFC)
- Over 500 locations that record atmospheric data with 14 locations recording in-water data which include:
  - Long Island Sound Coastal Observatory (LISCO)
  - Venice Acqua Alta Oceanographic Tower (AAOT)
- New Gulf of Mexico WaveCIS location managed by NRL
- AERONET data stored in Cal/Val database for vicarious calibration of multispectral HICO\_MODIS data stream



Long Island Sound Coastal Observatory (LISCO)



Venice, Italy (AAOT)

# Representative True Color HICO Scenes



MOBY: 09/24/11



AAOT: 07/11/10



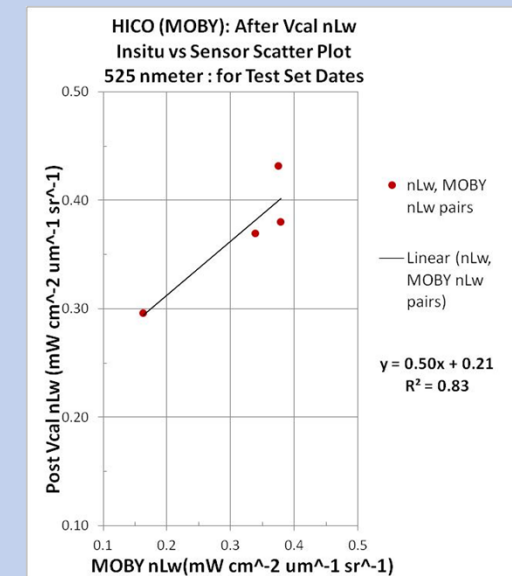
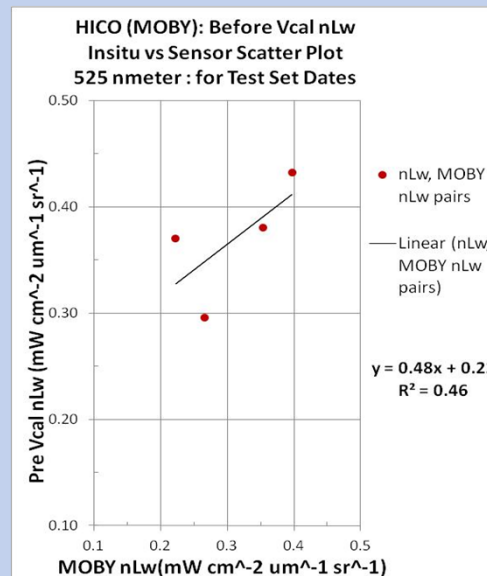
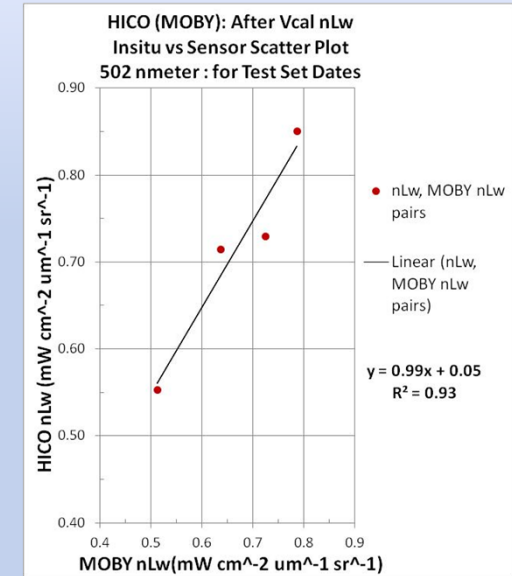
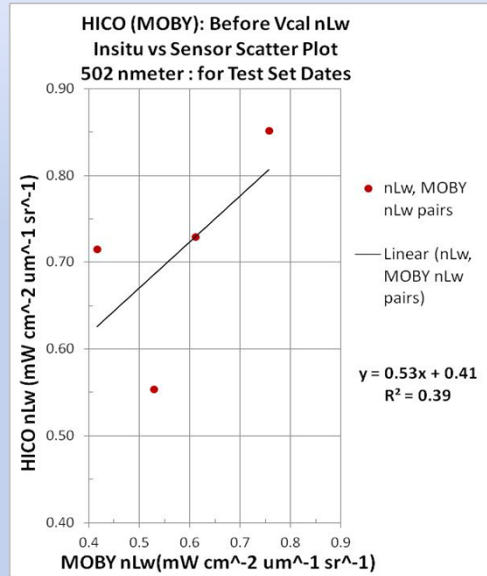
LISCO: 07/11/10



Pensacola: 06/02/11

# Vicarious Calibration Hyperspectral Verification

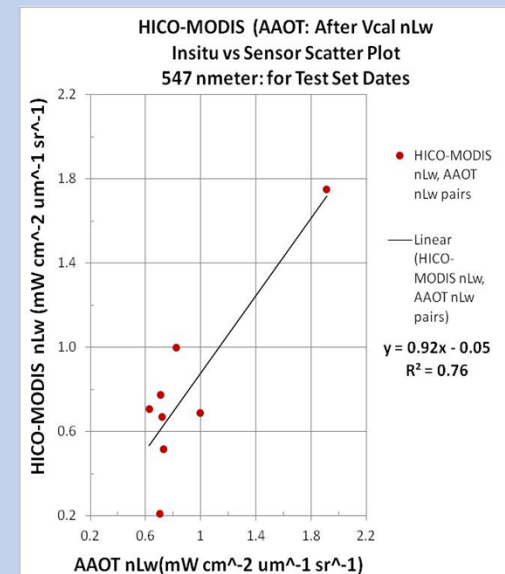
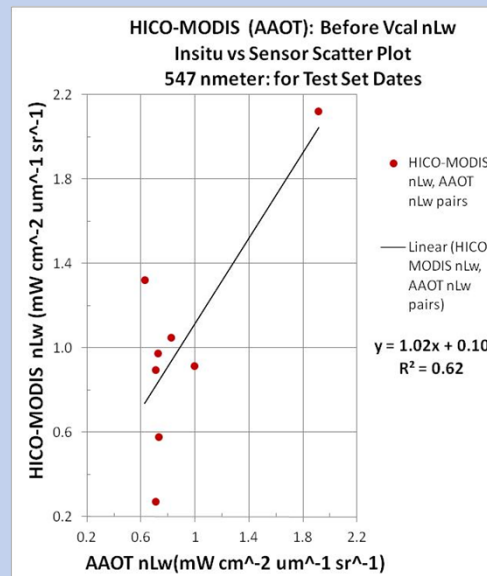
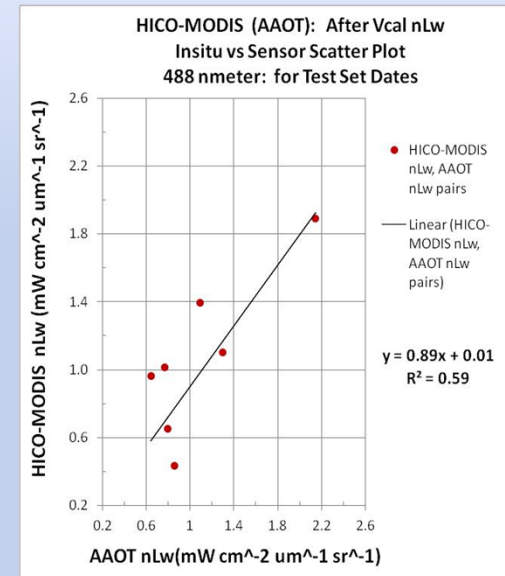
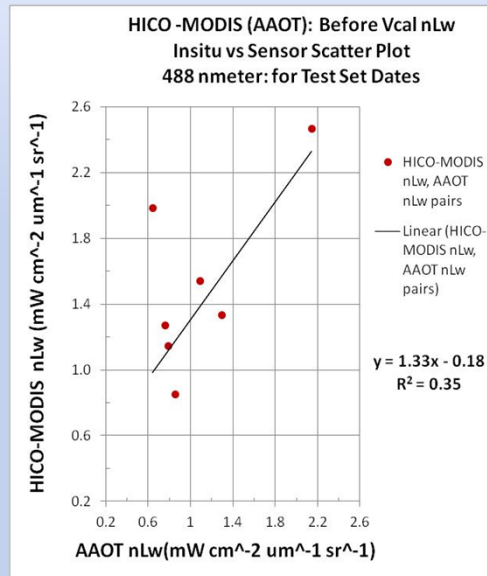
- 4 MOBY samples used to train vicarious calibration
- Scatter plot of 4 separate MOBY samples used to test MOBY in situ and HICO nLw values
- Before and after vicarious calibration
- Wavelength locations: 502 and 525 nm





# Vicarious Calibration Multispectral Verification

- 8 AAOT samples used to train vicarious calibration
- Scatter plot of 7 separate AAOT samples used to test AAOT in situ and HICO\_MODIS nLw values
- Before and after vicarious calibration
- Wavelength locations: 488 and 547 nm



# Vicarious Calibration In Situ Data

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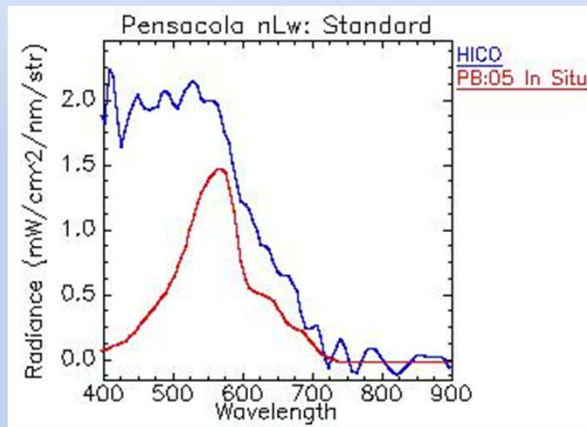
- Vicarious Calibration process shown for MOBY data has also been performed with AERONET data
  - Gains/offset can be generated for each AERONET station
  - Gains/offsets can be generated for entire set of AERONET stations grouped together
- Insitu data for vicarious calibration can also be provided by collected multi or single date field data

# Vicarious Gain/Offset Validation

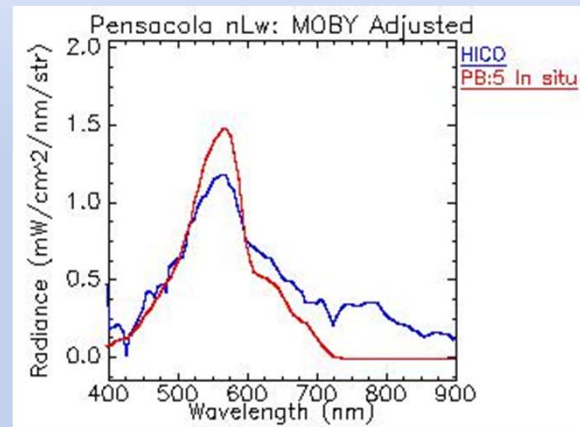


Pensacola Beach In Situ Data Stations

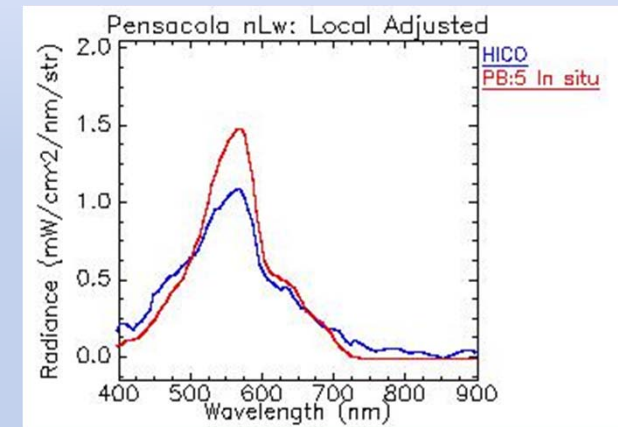
# Vicarious Adjustment: 06/02/11 Pensacola Beach: PB05



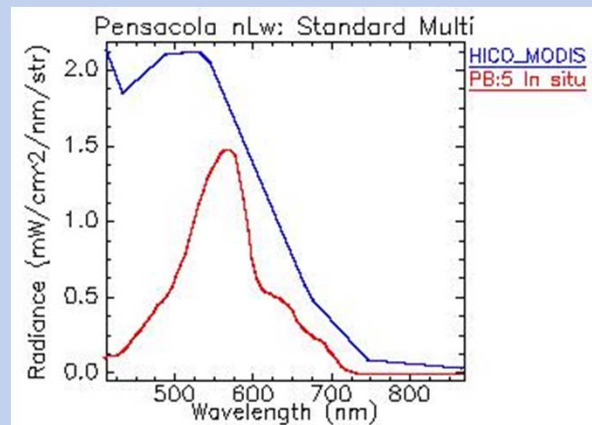
No Adjustment: Hyperspectral



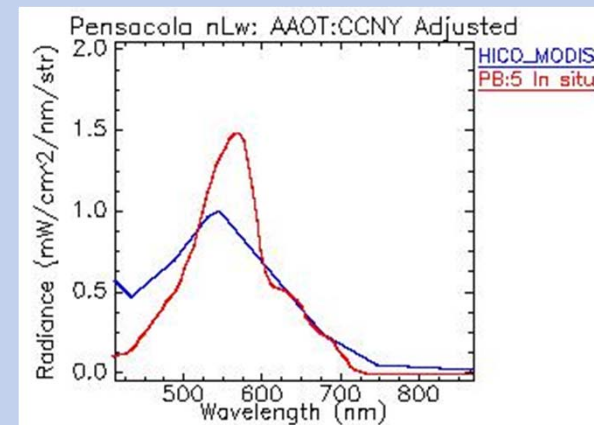
Vcal MOBY Adjustment



Vcal Pensacola Adjustment

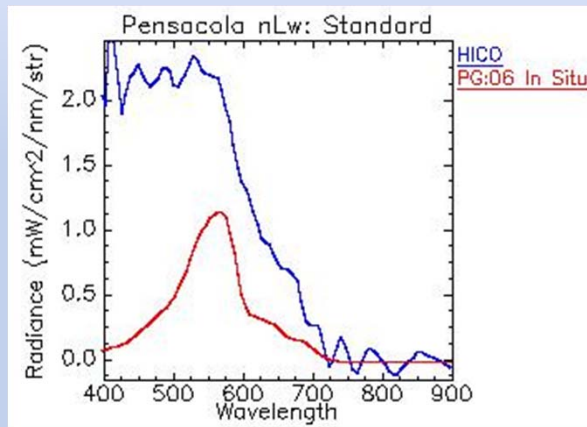


No Adjustment: Multispectral

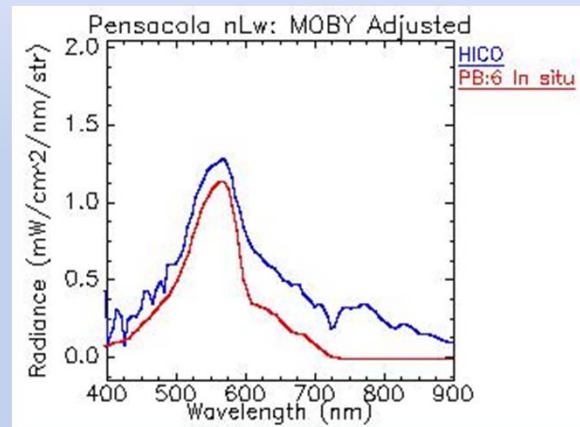


Vcal AAOT LISCO Adjustment

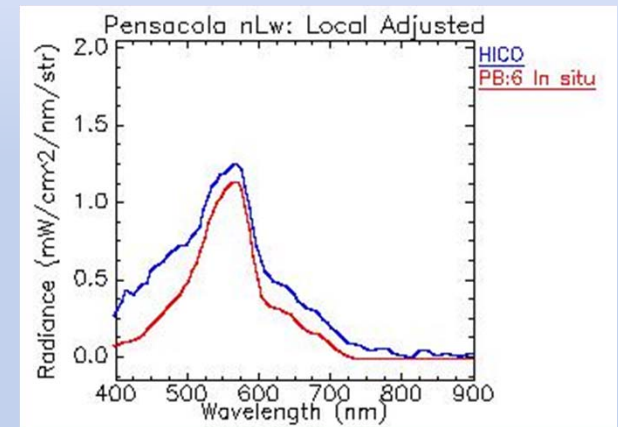
# Vicarious Adjustment: 06/02/11 Pensacola Beach: PB06



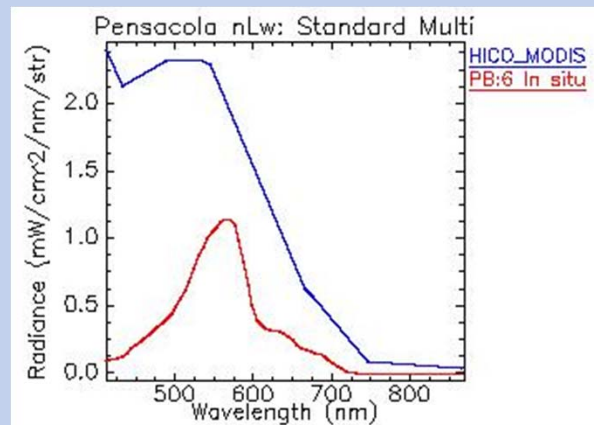
No Adjustment: Hyperspectral



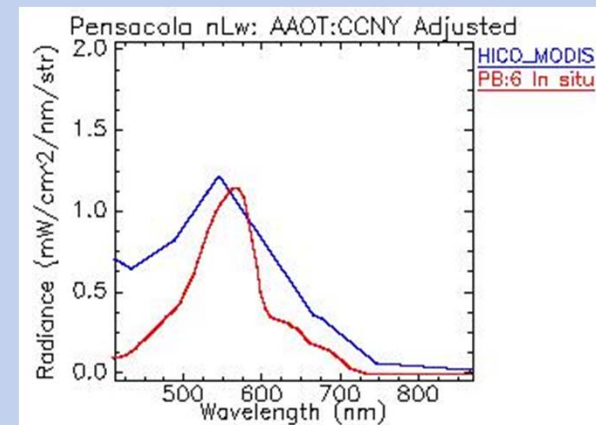
Vcal MOBY Adjustment



Vcal Pensacola Adjustment

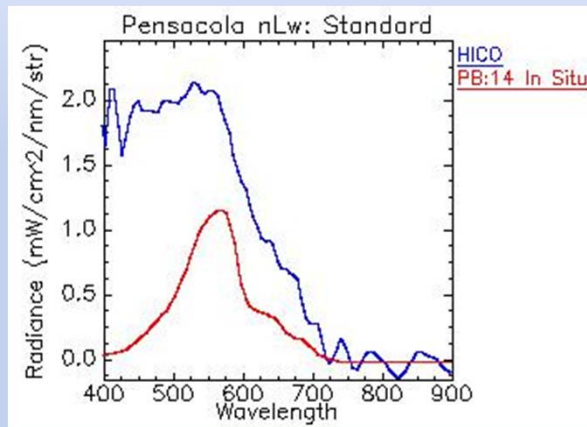


No Adjustment: Multispectral

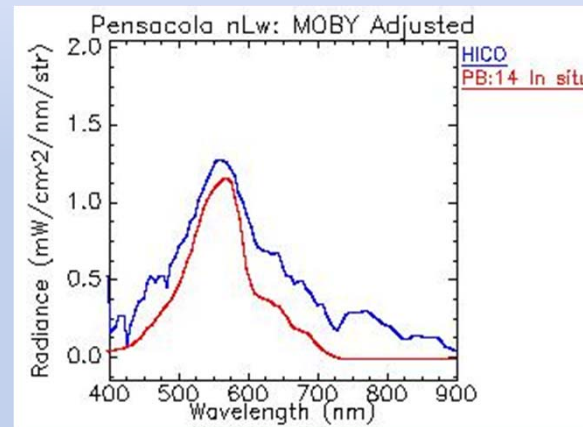


Vcal AAOT LISCO Adjustment

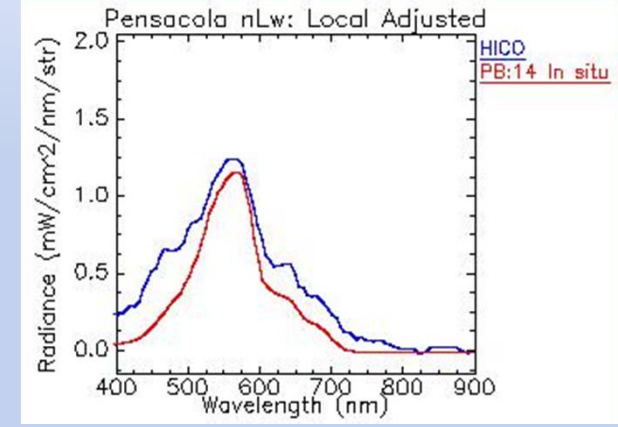
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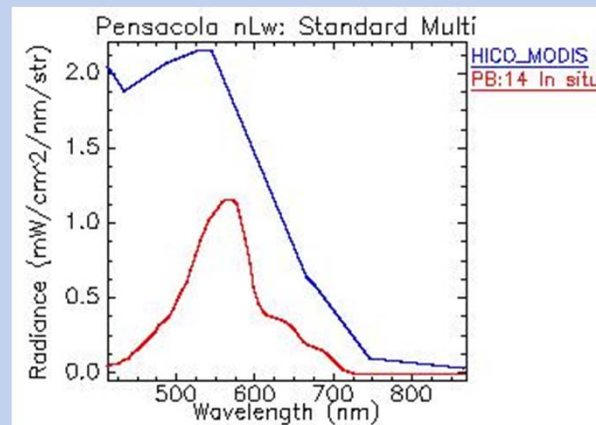
No Adjustment: Hyperspectral



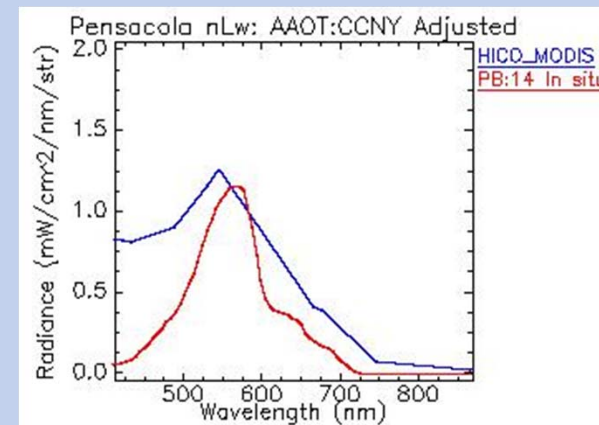
Vcal MOBY Adjustment



Vcal Pensacola Adjustment

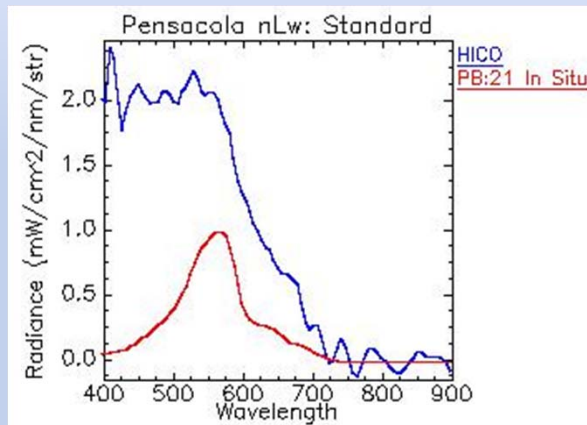


No Adjustment: Multispectral

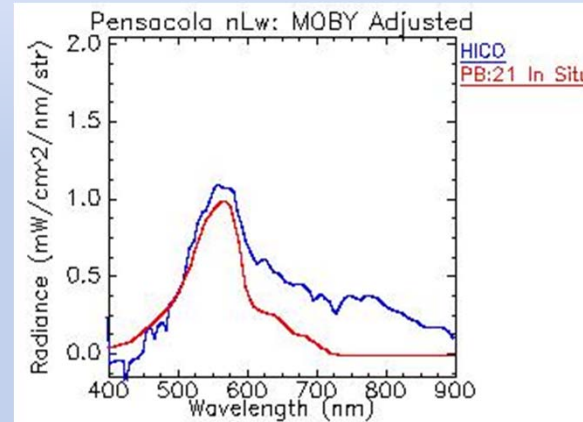


Vcal AAOT LISCO Adjustment

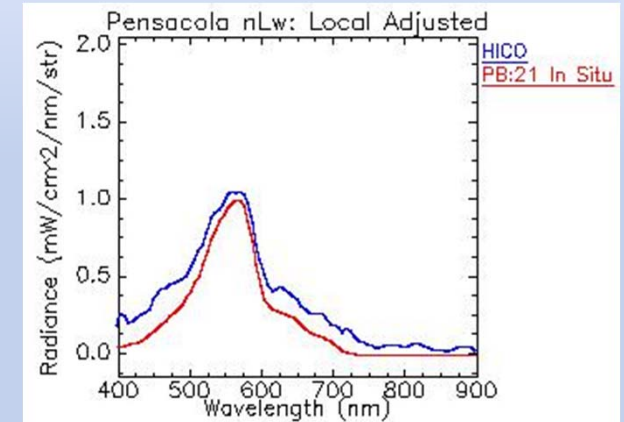
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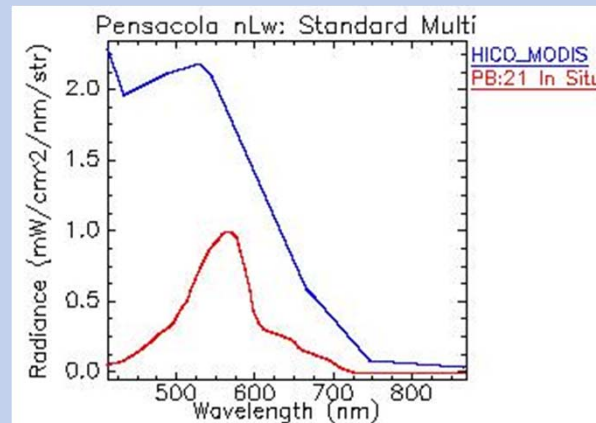
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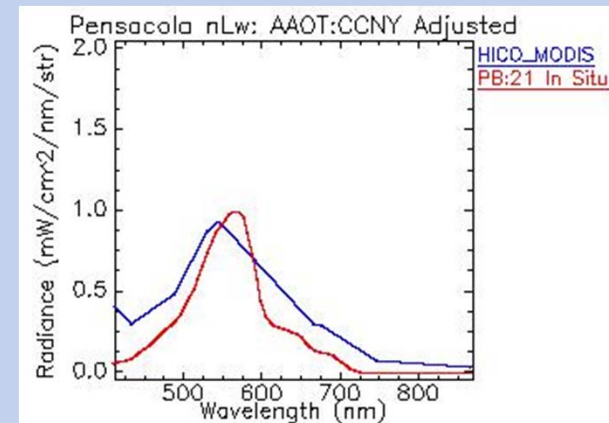
Vcal MOBY Adjustment



Vcal Pensacola Adjustment



No Adjustment: Multispectral



Vcal AAOT LISCO Adjustment

# Future Research Directions

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- Improve gain/offset calculation for blue and NIR regions
  - Update solar irradiance to derive  $L_r$  more closely with HICO wavelengths
  - Investigate causes for  $nL_w$  rise in the NIR region
  - Identify aerosol model is selected by vicarious calibration code
- Apply new gain/offset to more scenes and compare with more in situ data
- Apply new gain/offset within automated processing of HICO data



# Summary

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- Performed vicarious calibration for HICO and HICO-MODIS data using training set of MOBY and AERONET data, respectively
- Verified results of updated gains from vicarious calibration using training set by applying them to test set of HICO and HICO-MODIS data
- Validated results of vicariously calibrated gains by matching them with Pensacola Beach in situ data
- Determined additional tasks needed to refine results

# Contact Information

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View NRLProcessed HICO data  
www7331.nrlssc.navy.mil  
Links

- 1) Browse Imagery
- 2) Mobile Image Viewer App
- 3) HICO Archive Target Search (HATS)

Subscribe for HICO Research  
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Tool developed to find and display current satellite imagery on a mobile device (See Mobile Image Tool link)

**Bio-Optical/Physical Processes and Remote Sensing Section Code 7331  
Stennis Space Center, Mississippi 39529**

As a team, members of the Bio-Optical/Physical Processes and Remote Sensing Section have broad experience and expertise in many aspects of remote sensing and coupled physical/ecological modeling. We conduct research to better understand oceanographic processes in coastal and open-ocean environments. Our overarching goal is to exploit this knowledge of the marine environment to address a wide variety of navy needs related to optical variability, underwater light penetration, and physical/optical forecasting. However, we also work closely with external agencies and universities to address a wide variety of oceanographic science questions. Our state-of-the-art facilities include satellite receiving and image processing/analysis systems, in situ and laboratory optical instrumentation, advanced physical and ecological models, and access to high-performance super computers. Recent instrumentation acquisitions include gliders (one with an Optical Plankton Discriminator), trawl-resistant physical/optical moorings, and a flow cytometer. Research interests within the section include ocean color

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**What is HICO?**

The Hyperspectral Imager for the Coastal Ocean (HICO<sup>SM</sup>) is an imaging spectrometer based on the PHILLS airborne imaging spectrometers. HICO is the first spaceborne imaging spectrometer designed to sample the coastal ocean. HICO will sample selected coastal regions at 90 m with full spectral coverage (350 to 900 nm sampled at 5.7 nm) and a very high signal-to-noise ratio to resolve the complexity of the coastal ocean. HICO is sponsored by the [Office of Naval Research](#) as an Innovative Naval Prototype (INP), and will demonstrate coastal products including water clarity, bottom types, bathymetry and on-shore vegetation maps. As an INP, HICO also demonstrates innovative ways to reduce the cost and schedule of this space mission by adapting proven PHILLS aircraft imager architecture and using Commercial Off-The-Shelf (COTS) components where possible.

**HICO Status**

The HICO program was initiated in February 2004. In January 2007 HICO was selected to fly on the Japanese Experiment Module Exposed Facility (JEM-EF) on the International Space Station. Construction began following the Critical Design Review on November 16, 2007. HICO was completed in July 2008 and it was integrated into the HICO and RAIDS Experimental Payload (HREP) in August 2008. HICO is integrated into HREP and flown with support and direction from DOD's Space Test Program. HREP has also received support from NASA and JAXA as the first US experiment payload on the JEM-EF. HREP was launched on the H-2 Transfer Vehicle (HTV) September 10,

# Questions

Thank you for your interest in this project

