The Hyperspectral Imager for the Coastal Ocean (HICO)

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Introduction and Outline

• Why Measure Ocean Color?
  – The ocean’s role in the carbon cycle - NASA
  – Coastal ocean dynamics - NOAA and Navy
• The Hyperspectral Imager for the Coastal Ocean (HICO)
  – How it came to be
  – The challenge of operating on the International Space Station (ISS)
• What we can see with HICO?
  – Collecting and processing HICO data
  – Comparison to other ocean color data
  – Scenes from around the World
• Access to HICO data via. COAS HICO website
Seven year composite of the global distribution of chlorophyll from SeaWiFS data (blue low and yellow high concentrations). SeaWiFS has been highly successful for addressing NASA goals to better understand the global ocean carbon cycle and climate change.
For Coastal management we need higher Resolution MODIS 1 km water clarity Images of Chesapeake Bay and surrounding area

MODIS 1 km water clarity  MODIS simulated water clarity at 250 m
The Coastal Challenge

- In the open ocean there are two optical components the water and the Phytoplankton (single celled plants that are the base of the ocean food chain)
  - 4-5 spectral channels can resolve this (e.g. SeaWiFS)

- In the coastal ocean we add suspended sediments from rivers or re-suspension from the bottom and colored dissolved organic matter from decaying plants.
  - Need 10 or more channels (e.g. MERIS)

- Near shore we can also image the bottom (to 20 m in clear waters) which can have reflectance from the sediments, rocks, coral reefs, algae, etc. Now we have a very difficult chore to resolve this complexity. Need to sample the full spectrum of light that penetrates the water column.
  - HICO with 90 channels is the first sensor in space designed to do this
A hyperspectral imager records a spectrum of the light from each pixel in the scene. Hyperspectral image analysis exploits this extra spectral information.

For an open land scene, the total spectrum for a pixel is a weighted sum of the spectra of what is in that pixel. The imager and method of exploitation must be tailored to the scene and the desired products.
Physical and biological modeling of the scene is often required to analyze the hyperspectral image.

Accurate radiometric calibration of the imager is necessary to compare data to models.
NRL Airborne Coastal Environmental Hyperspectral Program

- 16 years end-to-end development of airborne coastal environmental hyperspectral imaging

Sensor Performance Modeling

Nonlinear Manifold Analysis

PURSUIT Pattern Recognition / Classification

ORASIS Spectral Identification

Sensor Development

Requirements Evaluation

Product Evaluation

Product Extraction

Spiral Development

Sensor Calibration

Ground / Water Truth

Flight Campaigns

Data Processing

Georectification

TAFKAA Atmospheric Removal Algorithm

PHILLS-1 Ground Truth ASD

Sensor Performance Modeling

Signal to Noise Ratio

Wavelength (nm)

Signal to Noise

f/4

f/2.8

f/2

GSD = 100m

Albedo = 5%

GMC = 1

0

50

100

150

200

250

300

350

400

500

600

700

800

900

1000

Signal to Noise Ratio

10 nm Spectral Bins

Wavelength (nm)
HICO in Space is a Natural Next Step

Space provides repeat access to coastal types worldwide

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Georectification

Mangrove coast

Delta coast

Sensor Performance Modeling

Signal to Noise Ratio

Wavelength (nm)

Signal to Noise

Wavelength (nm)

f/4

f/2.8

f/2

GSD = 100m

Albedo = 5%

GMC = 1

PHILLS-1

Ground Truth ASD
What is the Hyperspectral Imager for the Coastal Ocean (HICO)?

- HICO is an experiment to see what we gain by imaging the coastal ocean at higher resolution from space.
- The HICO sensor:
  - first spaceborne imaging spectrometer designed to sample coastal oceans
  - samples coastal regions at <100 m (380 to 1000 nm: at 5.7 nm bandwidth)
  - has high signal-to-noise ratio to resolve the complexity of the coastal ocean
- Sponsored as an Innovative Naval Prototype (INP) of Office of Naval Research to see if we can do this at reduced cost and a greatly shortened schedule.
- Supported by the Space Test Program for Integration and Launch
- Additional support from NASA and JAXA for launch and integration onto the Japanese Experiment Module Exposed Facility on the International Space Station (ISS)
HICO Mission Requirements

• Launch and operate the first spaceborne coastal Maritime Hyperspectral Imager (MHSI) with high signal-to-noise ratio for dark coastal scenes
  – large scene size and moderate spatial resolution appropriate for the coastal ocean
  – high sensitivity in the blue and full coverage of water-penetrating wavelengths

• Demonstrate scientific and naval utility of maritime hyperspectral imaging from space
  – bathymetry
  – water optical properties
  – bottom type
  – terrain and vegetation maps

• As a Naval Innovative Prototype (INP) demonstrate new and innovative ways to develop and build the imaging payload
  – reduce cost
  – reduce schedule

• Serve as a pathfinder for future spaceborne hyperspectral imagers
HICO Development Timeline

- Summer 2006: Space Test Program asked if HICO could be ready for September 2009 launch to the Japanese Experiment Module – Exposed Facility (JEM-EF) on the ISS
- Winter 2006-2007: HICO accommodation study for JEM-EF
- March 2007: HICO manifested on Space Station JEM-EF

**Beginning of HICO Space Station project**

- June 2007: Preliminary Design Review
- November 2007: Critical Design Review
- May 2008: HICO imager delivery
- July 2008: HICO Test Readiness Review
- September 2008: HICO delivery to the HICO RAIDS Experimental Payload (HREP)

**Project start to sensor delivery in 16 months**

- September 10, 2009: Launch to Space Station
- September 24, 2009: HREP installed on Japanese Experiment Module and activated

HICO image of Hong Kong, October 2, 2009. Scene approximately 42 x 192 km
HICO Flight Sensor - Stowed position

- Camera
- Spectrometer
- Lens
- View port
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Performance</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral Range</td>
<td>380 to 960 nm</td>
<td>All water-penetrating wavelengths plus Near Infrared for atmospheric correction</td>
</tr>
<tr>
<td>Spectral Channel Width</td>
<td>5.7 nm</td>
<td>Sufficient to resolve spectral features</td>
</tr>
<tr>
<td>Number of Spectral Channels</td>
<td>102</td>
<td>Derived from Spectral Range and Spectral Channel Width</td>
</tr>
<tr>
<td>Signal-to-Noise Ratio for water-penetrating wavelengths</td>
<td>&gt; 200 to 1 for 5% albedo scene (10 nm spectral binning)</td>
<td>Provides adequate Signal to Noise Ratio after atmospheric removal</td>
</tr>
<tr>
<td>Polarization Sensitivity</td>
<td>&lt; 5% (430-1000 nm)</td>
<td>Sensor response to be insensitive to polarization of light from scene</td>
</tr>
<tr>
<td>Ground Sample Distance at Nadir</td>
<td>92 meters</td>
<td>Adequate for scale of selected coastal ocean features</td>
</tr>
<tr>
<td>Scene Size</td>
<td>42 x 192 km</td>
<td>Large enough to capture the scale of coastal dynamics</td>
</tr>
<tr>
<td>Cross-track pointing</td>
<td>+45 to -30 deg</td>
<td>To increase scene access frequency</td>
</tr>
<tr>
<td>Scenes per orbit</td>
<td>1 maximum</td>
<td>Data volume and transmission constraints</td>
</tr>
</tbody>
</table>
Radiometry

- Use Model to Predict SNR for Ocean Scene from Orbit

Modeled HICO Signal to Noise Ratio for 5% and 30% Surface Albedo and 11.4 nm Spectral Bins

![Graph showing modeled HICO signal to noise ratio for different surface albedos and wavelengths.](image-url)
Integrating HICO into HREP

HICO flight imager in the Laboratory

HICO with thermal blankets in HREP
HICO Launched to the ISS September 10, 2009

Launched from Tanegashima Island Space Center, Japan
HICO Installed on the ISS on September 24, 2009
HICO docked at ISS – Now What?
Data Collection, Processing and Results

- Commanding HICO data collections
- HICO Image Locations
- Data Processing flow
- Example Images and Data
- HICO Web site and data distribution
Mission Planning with Satellite Tool Kit (STK)

Combines scene locations, ISS attitude, ISS ephemeris, HICO pointing and constraints to produce list of all possible observations in particular time period.

Constraints include:
- Targets in direct sun
- Angle from ISS z-axis to Sun $\leq 140^\circ$
- Sun specular point exclusion angle $= 30^\circ$
- Sun ground elevation angle $\geq 25^\circ$
Locations chosen based on:
1. Location – within latitude limits of ISS orbit
2. Type – ocean, coast, land
3. Use – CalVal, Science, Navy, etc

- Currently ~300 locations identified
- New sites can be added which may mean fewer observations of each site due to “competition” between sites
L0 to L1B File Generation

- L0 Files
  - SOH and science data
  - Attitude data
  - Position, velocity data
  - Science timing data

- Science data
  - Attitude, position, velocity, time
  - Dark subtraction, 2nd order, stray light, spectral and radiance calibration

- SOH Data
- Geolocation
- Calibrated data

L1B as ENVI image cube or in HDF-5
**Spectral Properties**

**Left:** Spectra extracted from pixels along the east-west transect shown in yellow. Approximate locations of the spectra are indicated by same color Xs on the image. Spectra are scaled calibrated at-sensor radiances.

**Right:** Mean and standard deviation of 1295 pixels in the red Region of Interest. The SNR (\(\mu/\sigma\) including all sensor and environmental variations) is >300:1 for much of the spectra. Spectra are scaled calibrated at-sensor radiances.
HICO-MERIS Matchup (Lt)
Newport, OR 2 December 2009

HICO
(90 m GSD, 100 channels, 380-960 nm)

MERIS
(300 m GSD, 15 channels)

Radiance (W/m² sr micrometers) vs Wavelength (nanometers)
Relative Bathymetry of Han River Area Mud Flats

HICO Image off Korean Peninsula

Scene ~ 42 km x 192 km
Imaged October 21, 2009

Relative Bathymetry Map
Retrieved from HICO Image

Submerged Mud Flat
Water Channel

Shallow Water
Approx. 1 meter Depth

Deep Water

bathymetry algorithm
Internal waves at the Straits of Gibraltar

Generation of the Internal Wave

Camarinal Sill And the Tidal Boar.

Internal Wave packets

Straits of Gibraltar
HICO Image Dec 5, 2009
(R. Arnone analysis)
HICO Image of the Columbia River, March 19, 2010
HICO Images of the Columbia River

March 17, 2010

March 19, 2010
Derivative Spectroscopy with HICO

Columbia River 13 July 2010

Spectrum at-sensor
(pixel locations shown in RGB)

N. B. Tufillaro, preliminary results
Radiometric Comparison of HICO to MODIS (Aqua)

Nearly coincident HICO and MODIS images of turbid ocean off Shanghai, China demonstrates that HICO is well-calibrated.

**HICO**
- Date: 18 January 2010
- Time: 04:40:35 UTC
- Solar zenith angle: 53°
- Pixel size: 95 m

**MODIS (Aqua)**
- Date: 18 January 2010
- Time: 05:00:00 UTC
- Solar zenith angle: 52°
- Pixel size: 1000 m

**Top-Of-Atmosphere Spectral Radiance**

R.-R. Li, NRL
Nearly coincident MODIS and HICO™ images of the Yangtze River, China taken on January 18, 2010. Left, MODIS image (0500 GMT) of Chlorophyll-a Concentration (mg/m³) standard product from GSFC. The box indicates the location of the HICO image relative to the MODIS image. Right, HICO™ image (0440 GMT) of Chlorophyll-a Concentration (mg/m³) from HICO™ data using ATREM atmospheric correction and a standard chlorophyll algorithm. (Preliminary Results by R-R Li and B-C Gao.)
Comparison of HICO and MERIS

At Sensor Spectra Comparison

Lake Okeechobee
Comparison of HICO and MERIS

Lake Okeechobee

Reflectance Spectra Comparison

Ping Lee Cloud/Shadow and HOPE algorithms
HICO Image
Bahamas: 10/22/09

Radiance
Bathymetry
Absorption

Ping Lee
HOPE Algorithm
HICO Image
Key Largo, Florida: 11/13/09

Radiance

Bathymetry

Absorption

Ping Lee
HOPE Algorithm
Selected HICO APS Data Products
Key Largo, Florida

Radiance

chl_02

Kd_490

bb_551
Planned HICO Data Distribution at OSU

- Developed HICO Public Website at OSU using published and approved for distribution data, publications and presentations.
  - Currently Password protected working with a test group of users
- Will include some example HICO data (e.g. Columbia River) that is approved for distribution.
- OSU HICO Web site will be portal for data requests and distribution
  - Data requests require proposal and data agreement signed by the requestor and their institution and approved by NRL.
- Example data and data requested by that user will be available to them.
- [http://hico.coas.oregonstate.edu/login/login.shtml](http://hico.coas.oregonstate.edu/login/login.shtml)
OSU HICO Website: Select from Archive
ISS Orbit

ISS orbit predictions during local daylight (solar elevation above 15 degrees) are shown below (Google Earth plugin required). Note that *orbit prediction accuracy decreases considerably with time*. Please see below the figure for more information.

**Future Date Range**
start date (YYYY-MM-DD)
2010-09-30

- 1 day
- 3 days

**Target Areas**
- show ascending targets
- show descending targets
- show names

[Prev day] [Update] [Next day]
# NRL – HICO Team

## NRL – DC
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- Curt Vandetta, OSU
- Ricardo Letelier, OSU
- Zhong-Ping Lee, MSU

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Summary (HICO Docked on the Space Station)

- Built and launched in 28 months
- Over 1700 scenes in first year
- Two more years of operations
- Data from OSU HICO website