The Hyperspectral Imager for the Coastal Ocean (HICO): Sensor and Data Processing Overview

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Sponsored as an Innovative Naval Prototype (INP) of 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
August, 2008: sensor integration completed
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
HICO sensor
• is 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
HICO Goal and Objectives

- Goal: build and operate the first spaceborne hyperspectral imager designed for coastal oceans
- Data processing by NRL 7200 (Remote Sensing Division) and 7300 (Oceanography Division)
- Other space HSI: ARTEMIS (launched this summer), Hyperion on NASA EO-1
- HICO sponsored by ONR as an Innovative Naval Prototype
- Coordinated by DOD Space Test Program with NASA (Houston)
- Instrument: high signal to noise, moderate spatial resolution, large area coverage
- Mission planning objectives and products:
  - support of demonstrations of Naval utility of environmental products (ONR mission)
  - repeat imaging of selected coastal sites worldwide over all seasons (extended mission)
  - exploration of the wide range of solar illumination and viewing angles “provided” by the ISS (extended mission)
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.
HICO Sensor - Stowed position

spectrometer & camera

Slit
### Most Requirements Derived from Aircraft Experience

<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>~100</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%</td>
<td>Sensor response to be insensitive to polarization of light from scene</td>
</tr>
<tr>
<td>Ground Sample Distance at Nadir</td>
<td>~100 meters</td>
<td>Adequate for scale of selected coastal ocean features</td>
</tr>
<tr>
<td>Scene Size</td>
<td>~50 x 200 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>
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</table>
HICO on Japanese Module Exposed Facility
HICO docked at ISS
Mission Planning with Satellite Tool Kit (STK)

Combines targets, ISS attitude, ISS ephemeris, HICO FOR 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 $\geq 25^\circ$
L0 to L1B File Generation

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

**Science data**
- Dark subtraction 2nd order calibration

**SOH Data**
- Geolocation
- Calibrated data

**L1B HDF**
Individual scenes are sequentially processed from the raw digital counts (Level-1) using standard parameters to a radiometrically, atmospherically, and geometrically corrected (Level-3) product within several minutes.

It further processes the data into several different temporal (daily, 8-day, monthly, and yearly) composites or averages (Level-4).
- HICO repeat may preclude this normal processing

Additionally, it automatically generates quick-look "browse" images in JPEG format which are stored on a web.
- PNG, TIFF/GeoTIFF, World File side-car file

Populates an SQL database using PostgreSQL.

It stores the Level-3 and Level-4 data in a directory-based data base in HDF format. The data base resides on a 20TB RAID array.
- APS format in netCDF (v3, v4), HDF (v4, v5).
HICO Processing Activity in APS

Level 0

Multispectral

Level 1b - Navigation

Level 1b - Calibration

Level 1c - Modeled Sensor bands
MODIS
MERIS
OCM
SeaWiFS

Level 2a: Sunglint

Level 2b - TAFKAA Atmospheric Correction

Level 2f: Cloud and Shadow Atm Correction

Level 2c: Hyperspectral L2gen-Atm Correction

Atmospheric Correction Methods

QAA, Products
At, adg, Bb, b, CHL
(12)

NASA: standards
OC3, OC4, etc
(9)

Navy Products
Diver Visibility
Laser performance
K532
Etc
(6)

Level 3: Remapping Data and Creating Browse Images

Hyperspectral

Level 2d: Hyperspectral Algorithm Derived Product

HOPE Optimization
(bathy, optics, chl,
CDOM, At, bb etc)

Hyperspectral QAA
At, adg, Bb, b, CHL
(12)

CWST - LUT
Bathy, Water Optics
Chi, CDOM

Coastal Ocean Products Methods

Vicarious Calibration
HICO Image
Hong Kong : 10/02/09
HICO Image
Bahrain: 10/02/09
HICO Image
Chesapeake Bay: 10/09/09
Comparison of HICO and MERIS

Spectra Comparison

• Pattern of HICO spectra overlaid on MERIS spectra
• Comparison has good visual fit

Lake Okeechobee
Comparison of HICO and MERIS

Reflectance Spectra Comparison

- Cloud / Shadow Atmospheric Correction Performed
- Pattern of HICO spectra overlaid on MERIS spectra
- Comparison has good visual fit

Lake Okeechobee
HICO
Sunglint Correction Module

- Original ENVI Module written in IDL; modified, converted to C.
- Based on the Hochberg et al. (2003) algorithm developed using 4m Ikonos imagery; Modified by Hedley et al. (2005); now modified to be automated.
- NIR band used to determine amount of glint in each band (limitation: NIR $\lambda$ should be between 700 and 910 nm)
- Called as separate module from APS.
- Complete hyperspectral processing.

- Uses deep-water pixels only to develop regression equation
- Prior to atmospheric correction
- Uses NIR to derive relative spatial glint distribution
- Scaled by absolute glint contribution from VIS bands
HICO
Sunglint Correction Module

Tested on AVIRIS HICO-proxy
20m resolution image.

Input file name:
aviris_20010731_r04_sc03to06.bil
(short integer, BIL, 2000 lines, 512 pixels per line)

- data converted to 32-bit floating point to test
the deglint program.
- deglint program can accept either type of data
as input).

display lines: 600 to 1399 (image height 800)
display pixels: 0 to 511 (image width 512)
Display bands: R - 57 (672.9 nm)
G - 31 (523.4 nm)
B - 18 (448.8 nm)

NIR band: 90 (862.2 nm)
Classification to identify water pixels (based on NDVI computation):

\[
\text{NDVI} = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}}
\]

**Land pixel**: computed NDVI > NDVI threshold (-0.2).

**Water pixel**: computed NDVI <= NDVI threshold (-0.2) and RED band value <= water threshold (1000).

**Deep-Water pixel (red)**: computed NDVI <= NDVI threshold (-0.2) and RED band value <= deep-water threshold (600).

**Shallow-Water pixel (green)**: NDVI threshold (-0.2) and RED band value >= deep-water threshold (600).

*Uses statistics from deep-water pixels for glint correction (correction applied to all bands).*

(the question is how to set the proper shallow-water threshold values - more tests may be needed…..)
$R_i' = R_i - b_i \times (R_{\text{NIR}} - \text{Min}_{\text{NIR}})$

$R_i$ is visible band pixel value
$R_i'$ is “deglinted” value

Outliers (shallow pixels?) that should not be included in regression – *needs refinement*
HICO Sunglint Correction Module

Before Glint Removal

After Glint Removal
HICO
Sunglint Correction Module

Wave Facet

Before Glint Removal

After Glint Removal

TOA Radiance

Wavelength

original
final
HICO
Sunglint Correction Module

Deep Water
HICO
Sunglint Correction Module

Turbid Plume
HICO
Sunglint Correction Module

Land values do not change
HICO Image
Bahamas: 10/22/09

Radiance
Bathymetry
Absorption
HICO Image
Key Largo, Florida: 11/13/09

Radiance
Bathymetry
Absorption
Selected HICO APS Data Products
Key Largo, Florida

Radiance

chl_02

Kd_490

bb_551
Near-Infrared Slope Algorithm

Assumptions

- **At 715-735 nm, total absorption is controlled by pure-water absorption** (i.e., absorption by phytoplankton pigments, detritus, and CDOM are negligible and the spectral curve shapes are relatively flat).

- **The spectral shapes of b and b_b are also relatively flat over this narrow wavelength range** (only a 2.8% difference between b(715) and b(735), using the spectral model of Gould et al., 1999).

- **The C term is a constant**
  \[ C = \frac{t^2 f}{n^2 Q} = 0.047 \]

\[ \lambda_1 = 715 \text{ nm}, \quad \lambda_2 = 735 \text{ nm} \]
\[ a_{w1}, \text{ pure water absorption at } 715 \text{ nm} = 1.007 \]
\[ a_{w2}, \text{ pure water absorption at } 735 \text{ nm} = 2.39 \]
\[ b_{b2} = 0.97234 \quad b_{b1} \]
**Lake Okeechobee**

**Rrs**

following Cloud & Shadow atmospheric correction

R: Band 62 (701.1 nm)
G: Band 36 (552.2 nm)
B: Band 21 (466.3 nm)

Some negative reflectances in clear water
Lake Okeechobee

Absorption Coefficient (m⁻¹)

Scattering Coefficient (m⁻¹)
# NRL – HICO Team

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HICO Docked on the Space Station

Questions?