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The Hyperspectral Imager for the Coastal Ocean (HICO™) Provides a new View of the Coastal Ocean

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ABSTRACT

The Hyperspectral Imager for the Coastal Ocean (HICO™) was installed on the International Space Station on September 24, 2009. HICO™ is the first spaceborne hyperspectral imager optimized for environmental characterization of the coastal zone. With a high signal-to-noise ratio for ocean imaging, 90 m GSD and full spectral coverage from 400 to 900 nm and a 42 by 192 km scene size HICO™ provides a unique view of the coastal ocean from space. HICO™ data are collected and processed to produce maps of coastal bathymetry, bottom characteristics, and water column optical properties. To illustrate this versatility we present examples of HICO™ products for a diversity of coastal environments.

INTRODUCTION

The coastal ocean is a very complicated environment containing high levels of phytoplankton, suspended and dissolved organic matter, suspended sediments with various bottom types and depths, all of which can vary significantly on scales of tens to hundreds of meters. While multispectral ocean color imagers with 1 kilometer spatial resolution are excellent for imaging the open ocean the coastal ocean requires higher spatial sampling and multispectral data generally does not contain sufficient information to quantify and characterize the coastal environment (Davis et al. 2007). Over the past two decades, hyperspectral imaging from aircraft platforms has developed as a powerful method of characterizing the coastal environment. A hyperspectral imager records a contiguous spectrum of the light received from each pixel in the scene, and this extra spectral information is exploited to produce the desired maps of bathymetry, bottom type, water constituents, and other coastal properties (Goetz, et al. 1985; Davis et al. 2006).

The Hyperspectral Imager for the Coastal Ocean (HICO™) (Corson, et al. 2005) is the first spaceborne imaging spectrometer designed specifically to sample the coastal ocean. HICO™ samples selected coastal regions at approximately 90 m with full spectral coverage (400 to 900 nm sampled at 5.7 nm) and a 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 optical properties (absorption and scattering coefficients), bottom types, and bathymetry and on-shore vegetation maps. As an INP, HICO™ also demonstrates innovative ways to reduce the cost and schedule of this space mission including using Commercial Off-The-Shelf (COTS) components where possible. HICO™ was built, calibrated and tested in 16 months by the Naval Research Laboratory. HICO™ was completed in July 2008 and integrated into the HICO™ and RAIDS Experimental Payload (HREP) in August 2008. HREP was launched on the Japanese H-2

Transfer Vehicle (HTV) September 10, 2009. The HTV rendezvoused with the ISS on September 17, 2009. HREP was installed on September, 24, 2009 and the first HICO imagery was collected on September 25, 2009. HICO™ is operating normally and Image quality is excellent. A companion paper in this volume by Corson et al. discusses the HICO™ imager and its performance. Here we give an overview of the data handling and processing and we present example results for coastal regions and river mouth areas.

HICO™ DATA PROCESSING

HICO™ is a demonstration sensor and data is collected for particular study areas, from a target list compiled by NRL personnel with input from Navy, university, and international partners. The standard HICO™ scene is 42 x 192 km and a maximum of one scene is collected on each 90 minute orbit. Data requests are compiled by NRL and sent to the ISS by NASA for execution. Data is transmitted from the ISS to NASA Marshall Space Flight Center and then transferred to NRL in Washington DC (NRL-DC) for processing. The initial processing from level 0 (raw data) to level 1b (calibrated radiances with geolocation information) includes dark current subtraction, CCD smear correction, 2nd order correction, spectral calibration and radiance calibration (Fig. 1). The calibrated data are then sent to NRL Stennis Space Center (NRL-SSC) for further processing using the NRL SSC Automated Processing System (APS). APS was developed for processing SeaWiFS, MODIS and other multispectral ocean color data. It ingests level 1b data and produces a wide range of standard products. APS was modified in two fundamental ways to process HICO™ data: the capability to ingest full hyperspectral data cubes was added, along with the capability to apply hyperspectral algorithms to make a variety of products from that data. Thus, APS HICO™ has two processing lines: one for making standard APS products from HICO™ data convolved to multispectral bands and one for exploiting the full hyperspectral data. Using the multispectral line HICO™ data is binned spectrally to simulate MODIS data and then processed to produce all the standard MODIS products but at 90 m ground sample distance (GSD) instead of the MODIS 1 km GSD. This is important in coastal areas were the tides, diurnal winds, river outflow and bottom features create complex patterns in the coastal ocean.

The Hyperspectral processing is more experimental. As HICO™ is the first ocean color hyperspectral sensor in space we have not previously developed automated processing for hyperspectral ocean color data. The hyperspectral processing branch includes several options for atmospheric correction and product production which are being tested at NRL-DC, NRL-SSC and OSU. Additionally, the calibrated hyperspectral image cube is available and that data is being used at NRL, OSU and other universities and laboratories for developing new hyperspectral algorithms.

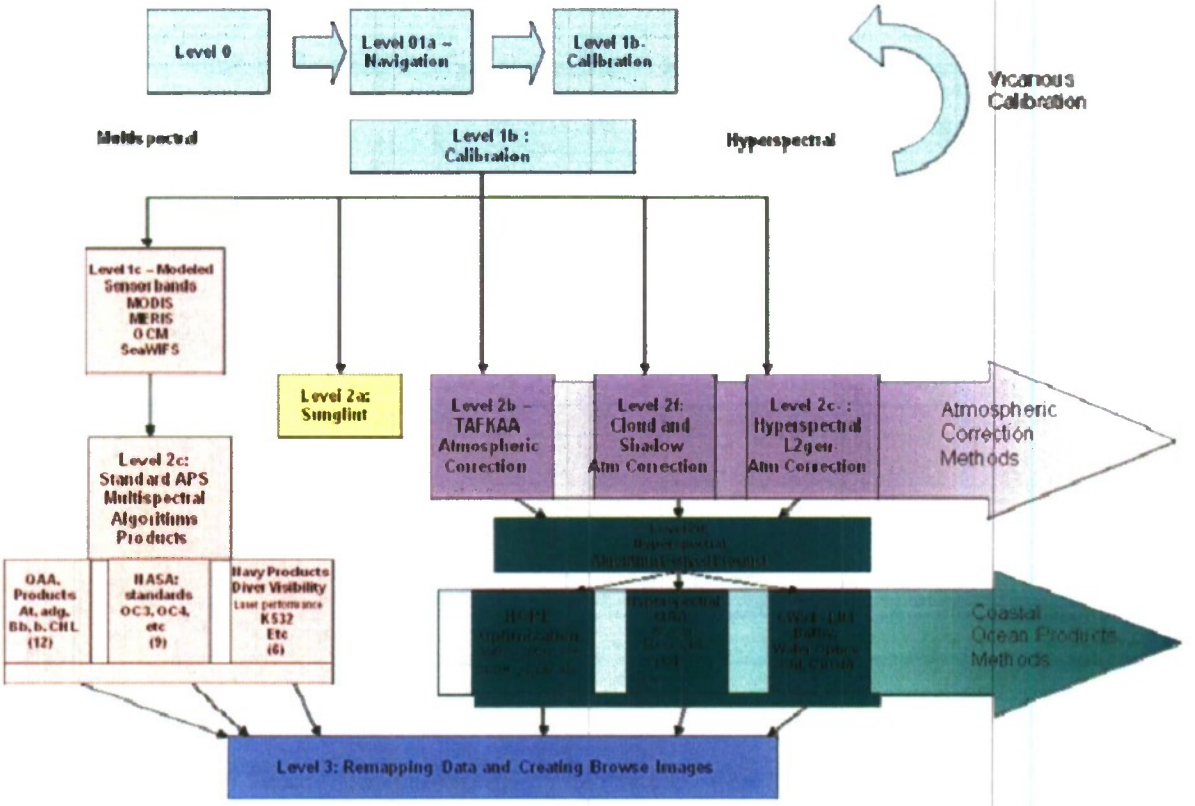

Figure 1. Flow diagram for the HICO™ data processing system. The initial processing from Level 0 to 1b (blue boxes) is done at NRL-DC. The multispectral processing line (pink boxes done in APS at NRL-SSC) is used to produce MODIS like products at 90 m GSD. The Hyperspectral processing line (purple and green boxes) uses multiple approaches for atmospheric correction and product production to test and evaluate new approaches to take advantage of the full spectral data. Level three and higher processing (geolocation, binning, remapping, etc.) is then done to both data types.

HICO™ IMAGES OF THE COASTAL OCEAN

We are currently collecting HICO™ data for over 200 locations worldwide; some are land calibration sites, but most are coastal ocean sites. We have particularly focused on sites with on-going field work and on complex coastal scenes where we think we will get the most benefit from the higher spatial and spectral resolution of HICO™ data. The current emphasis is on doing an on-orbit calibration using comparison with other well calibrated ocean color satellite sensors and land and ocean reference sites and on testing and evaluating several approaches to atmospheric correction.

For optically shallow sites we are testing several algorithms including a lookup table approach (Corson et al. 2010) and the Hyperspectral Optimization Processing Execution (HOPE) algorithm (Lee et al. 2007). The HOPE algorithm uses analytical models of the Rrs spectrum as a function of five independent variables (representing properties of water column and bottom) for optically shallow waters. HOPE algorithm products for a HICO image near Key Largo are shown in Fig. 2. There is generally good agreement with the results of these algorithms and independent data sets (Lee et al.

2007) but further tests are needed specifically for HICO™ data for a wide variety of optically shallow environments.

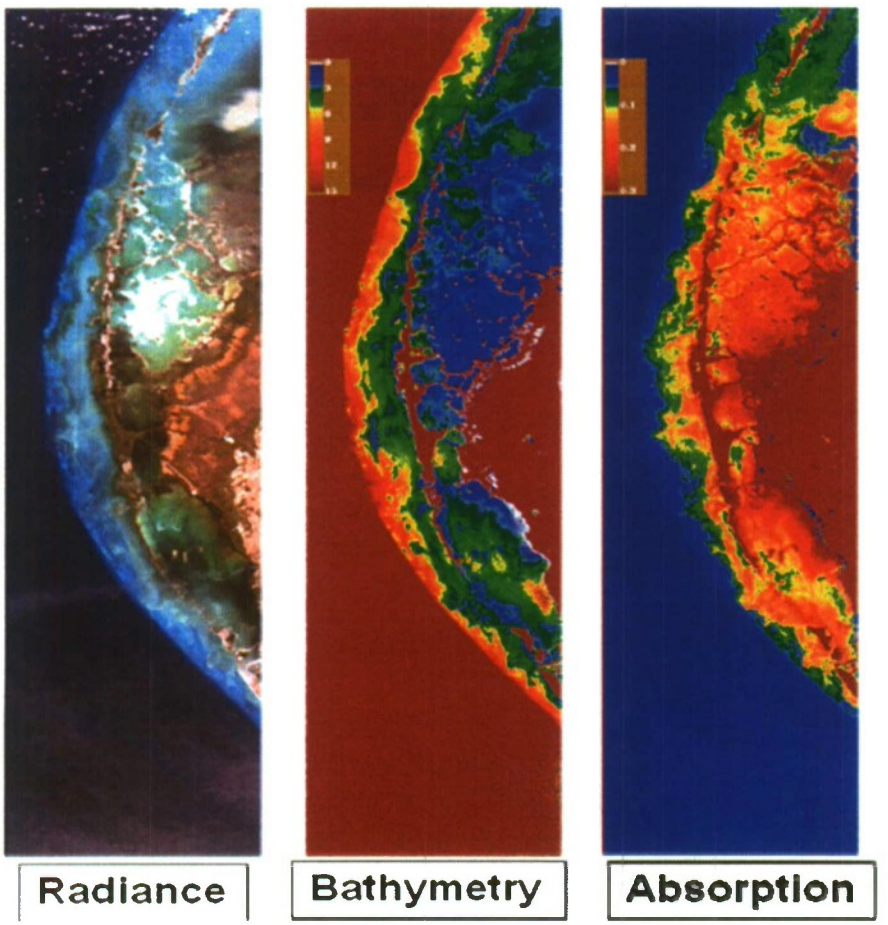

Figure 2. HICO™ image of the Florida Keys and derived products using the HOPE algorithm. The top of the image is southwest and the bottom Northeast; Key largo is the island at the bottom right of the image. Left; a RGB image using 3 HICO™ channels. Middle; Bathymetry (meters) from the HOPE algorithm. Depths greater than 15 m and land areas are shown in dark red. Right; Absorption at 660 nm.

HICO™ is designed to image the coastal ocean. The 90 m GSD is adequate to image rivers and many manmade features giving context to the coastal images. HICO™ images of the month of the Columbia River show break walls, bridges and other features (Fig. 3). The images were taken two days apart and show dramatic changes over that short time period. The March 17, 2010 image shows large waves from a storm on March 16th breaking on the coast, break walls and bars near the river mouth. Two days later the seas are relatively calm and waves are no longer breaking over the break walls.

Yangtze River in China is a major source of sediments and nutrients to the China Sea and Straits of Taiwan. In a comparison of chlorophyll products from MODIS and HICO™ (Fig. 4) we see the big picture in the MODIS data, but far more detail in the HICO™ data. Also, note that the MODIS algorithms fail over waters with high sediments, but the HICO™ data is not saturated and the HICO™ algorithm returns useful data even in these high sediment waters. Were the MODIS data is not saturated the match of chlorophyll values is very good.

Figure 3. HICO™ RGB images of the Columbia River mouth. Left; March 17, 2010. Right, March 19, 2010. The tide is essentially the same in both images. In the March 17th image large waves from a storm on March 16th are seen breaking on the coast, shoals and break walls. Astoria, Oregon is in the bottom center of the image with bridges visible crossing the Columbia and the bay to the west of Astoria.

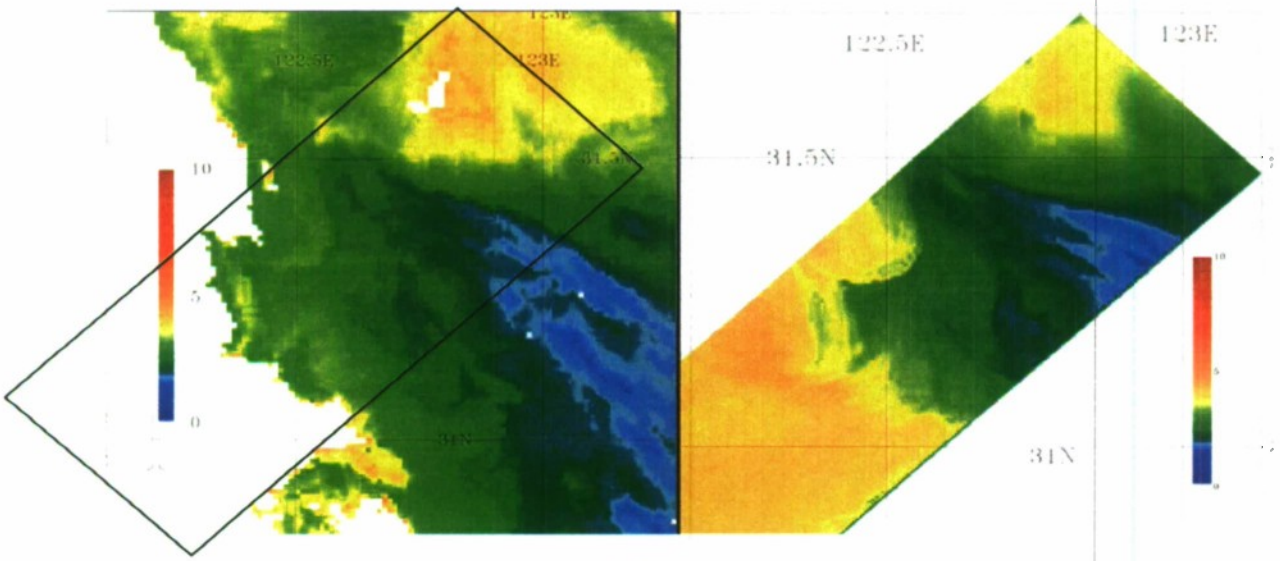

Figure 4. Nearly coincident MODIS and HICO™ images of the Yangtze River, China taken on January 18, 2010. Left, MODIS image (0500 GMT) of Chlorophyll-a Concentration (mg/m³) standard product from GSFC. The box indicates the location of the HICO image relative to the MODIS image. Right, HICO™ image (0440 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.)

CONCLUSION

HICO™ is a demonstration project. The first goal was to build an ocean color imager to meet naval requirements for the coastal ocean in less than 18 months and demonstrate that it works on orbit. This was successfully completed in October 2009. We are now focused on the second goal to demonstrate the utility of HICO™ data for characterization of the coastal ocean for selected sites around the world. This is an on-going effort. After 9 months we have completed an initial on-orbit calibration and we are evaluating algorithms for atmospheric correction and various coastal ocean products. We anticipate operating HICO™ for three years and to provide data for a wide variety of uses in the coming years.

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