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A New View of Coastal Oceans From the Space Station

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Understanding and quantifying the natural processes that occur along coasts are critical components of managing environmental resources and planning and executing coastal operations, from humanitarian relief to military actions. However, the coastal ocean is complicated, with dissolved and suspended matter that hinders water transparency, phytoplankton blooms that can be toxic, and bathymetry and bottom types that vary over spatial scales of tens of meters, all of which affect processes in an area that spans millions of square kilometers.

A hyperspectral imager collects the spectrum of the light received from each pixel in an image. For environmental characterization the wavelength range typically spans the visible and shortwave infrared wavelengths, and the spectrum is collected in contiguous spectral intervals 1–10 nanometers wide. This spectral information is exploited to provide significantly more information about vegetation, minerals, and other components in the scene than can be retrieved from panchromatic or even multispectral imagery, which rely primarily on the shape of the object for detection [*Goetz et al.*, 1985]. Such technology can also work over shallow seas. Over the past 2 decades, experiments with hyperspectral imagers on airborne platforms have demonstrated the ability to characterize the coastal environment [*Davis et al.*, 2002, 2006] and produce maps of coastal bathymetry, in-water constituents, and bottom type.

The Hyperspectral Imager for the Coastal Ocean (HICO™), now operating on the International Space Station (ISS), extends this capability to the diversity of coastal environments worldwide. HICO was built and, along with the previously developed Remote Atmospheric and Ionospheric Detection System (RAIDS), was integrated into the HICO-RAIDS Experiment Payload (HREP) module in 24 months, at a small fraction of the cost of a traditional space instrument. The data now being received are providing an exciting new view of coastal environments around the world.

The HICO Instrument

Data from HICO are beginning to flow to the Earth-observing community. HICO (Figure 1a), designed and built by the Remote Sensing Division of the U.S. Naval Research Laboratory, is the first hyperspectral imager specifically made for environmental characterization of the coastal ocean from space. HICO images one scene per 90-minute orbit, with each scene spanning an area approximately 42 kilometers wide and 190 kilometers long, large enough to capture the scale of coastal ocean dynamics. Each pixel is a 95-meter square, with 88 spectral channels covering the range from 400 to 900 nanometers. This includes visible light (400–700 nanometers), which penetrates the water and provides information on water properties and bottom reflectance, and shortwave infrared radiation (700–900 nanometers), which is used to correct for atmospheric aerosols and surface reflectance.

The development and construction of HICO were sponsored by the U.S. Office of Naval Research (ONR) under its Innovative Naval Prototype (INP) program. A key goal of the INP program is to demonstrate methods to save costs and time in developing instruments for space. HICO accomplished these savings by using commercial components where available, including the spectrometer, a control and data storage computer, the camera, and a rotation mechanism to point the imaging line of sight. Because of low levels of ionizing radiation in the space environment at ISS, the latter three

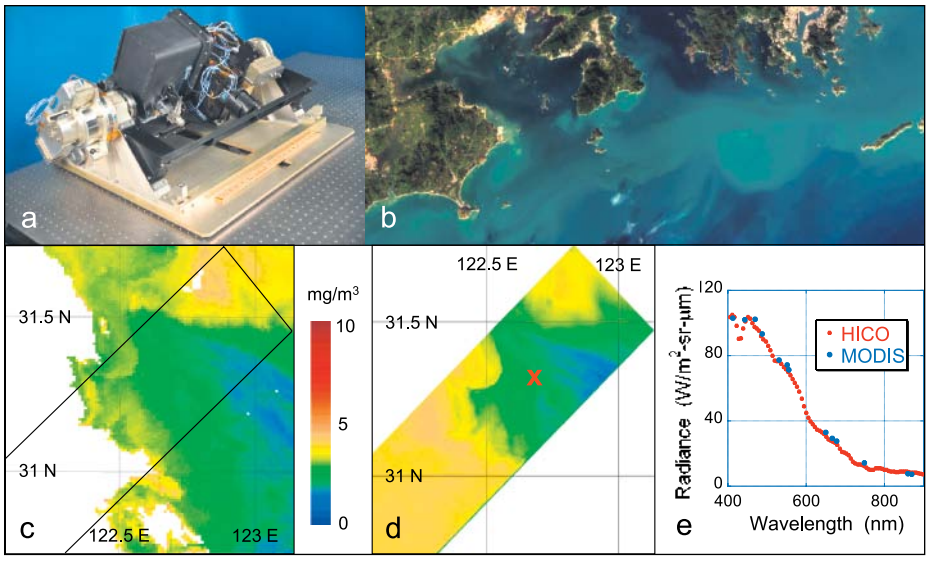

Fig. 1. (a) The Hyperspectral Imager for the Coastal Ocean (HICO™) fully assembled and ready for integration into the HICO and Remote Atmospheric and Ionospheric Detection System (RAIDS) Experimental Payload (HREP) module launched to the International Space Station. (b) Early HICO image of Hong Kong, taken on 2 October 2009. (c and d) Nearly coincident Moderate Resolution Imaging Spectroradiometer (MODIS) and HICO data products from images collected near the Yangtze River, China, 18 January 2010. Figure 1c is a MODIS image (taken at 0500 UT) of chlorophyll a concentration (milligrams per cubic meter). The white areas indicate no retrieval due to saturation of one or more channels of the MODIS sensor. The outlined area indicates the location of the HICO image relative to the MODIS image. Figure 1d is a HICO image (taken at 0440 UT) of chlorophyll a concentration (milligrams per cubic meter) from HICO data using a standard chlorophyll algorithm. Note that HICO does not saturate and provides data at much higher resolution over the entire scene. (e) Spectral radiances measured by HICO and MODIS at the location of the cross in Figure 1d. HICO captures a full spectrum over its wavelength range compared to the specific channels of MODIS.

commercial electronic components could be used without radiation shielding beyond that provided by the experiment structure, with only mechanical reinforcement of the circuit boards. Even with the compressed schedule, HICO underwent characterization and calibration [*Lucke et al.,* 2011] as well as full vibrational and thermal vacuum testing, providing a model for taking an experiment rapidly from the laboratory to space.

Although HICO was built on a tight schedule and with a limited budget, it was built to meet a specific set of performance requirements. The primary HICO performance parameters were vetted by 2 decades of airborne hyperspectral imagery [*Corson et al.,* 2008]. In particular, HICO has a high signal-to-noise ratio when imaging dark coastal ocean scenes (greater than 200:1 over visible wavelengths). Further, it has low polarization sensitivity and spatial resolution sufficient to demonstrate the retrieval of coastal environmental products from space.

Observation Capabilities

HICO was launched on 10 September 2009 and installed on ISS on 17 September. It began collecting imagery 8 days later (Figure 1b). To save costs, HICO does not have an onboard calibrator. Periodic confirmation of the wavelength sampled by each HICO spectral channel is performed in orbit by imaging a bright scene such as clouds and comparing the spectral features in the HICO image with known solar spectral lines. Radiometric calibration, used to quantitatively convert the digital data from the camera to the brightness of the scene, is performed in orbit through well-characterized land sites and comparisons with NASA's spaceborne Moderate Resolution Imaging Spectroradiometer (MODIS; http://modis.gsfc.nasa.gov/) data.

HICO is designed for the coastal ocean and has several advantages for that environment (Figures 1c–1e) compared to MODIS, which is optimized for imaging the vast open ocean. HICO has sufficient spatial resolution to image the complexity of coastal features. Further, it can image over a wide range of scene brightnesses, allowing it to image the dark, open ocean as well as bright features such as river plumes. The additional spectral channels (88 on HICO as compared to nine on MODIS for ocean imaging) can be used to differentiate sediments, colored dissolved organic matter, phytoplankton, and other components in the coastal ocean [e.g., *Lee et al.,* 2007].

Future Directions

HICO has been operating since 25 September 2009 and has collected more than 2500 images of coastal sites worldwide. Work continues on processing and validating products from this unique data set to further scientific understanding of coastal environments.

HICO data are a pathfinder for future sensors. A similar imager with space-qualified components on a small satellite in a low-Earth Sun-synchronous orbit would collect far more data, be more responsive to unfolding natural events such as pollution plumes or severe coastal weather, and meet many specific naval and civilian needs. NASA has identified a need for a similar sensor in geosynchronous orbit, called the Geostationary Coastal and Air Pollution Events (GEO-CAPE) instrument [*Committee on Earth Science and Applications From Space,* 2007] to provide frequent sampling of the coastal ocean. GEO-CAPE would provide hourly sampling of U.S. coastal waters with approximately 300-meter pixels and produce hyperspectral image data. HICO data can be used to simulate those data or data for other potential coastal ocean sensors to help establish science and performance requirements and optimize the design of those instruments.

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—MICHAEL R. CORSON, Remote Sensing Division, Naval Research Laboratory, Washington, D. C.; E-mail: corson@nrl.navy.mil; and CURTISS O. DAVIS, College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis