THE HYPERSPECTRAL IMAGER FOR THE COASTAL OCEAN (HICO) ON THE INTERNATIONAL SPACE STATION

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ABSTRACT

The HICO (Hyperspectral Imager for the Coastal Ocean) program is the first demonstration of environmental characterization of the coastal zone using a spaceborne maritime hyperspectral imager. 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 will also demonstrate innovative ways to reduce the cost and schedule of this space mission by adapting proven aircraft imager architecture and using Commercial Off-The-Shelf (COTS) components where possible.

Index Terms— hyperspectral, imaging spectrometry, ocean optics, littoral, coastal

1. INTRODUCTION

Visible and near infrared wavelengths in the approximate range 0.4 to 0.8 microns constitute the only portion of the electromagnetic spectrum that penetrates water and directly probes the water column. In the coastal environment where the water contains significant dissolved and suspended matter and the bottom may be visible, the scene image is spectrally complicated requiring well-calibrated hyperspectral imaging to retrieve bathymetry, bottom type, chlorophyll content, and water inherent optical properties [1]. Furthermore the coastal ocean scene is dark, with an albedo of only a few percent, and from space it is viewed through the atmosphere which is significantly brighter in the visible wavelengths than the water surface, due to scattered sunlight. These conditions impose stringent requirements for a Maritime HyperSpectral Imaging (MHSI) system which are in general not met by systems designed for land applications.

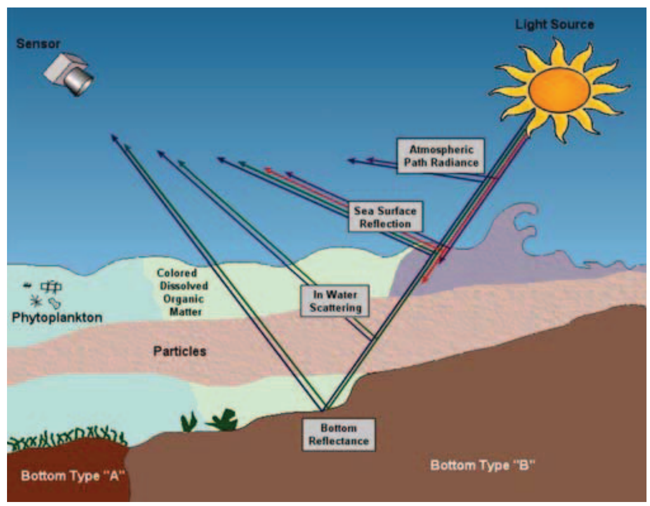

Figure 1. Illustration showing the optical complexity found in the coastal ocean, particularly when imaging the bottom. Imaging spectrometer data are required to resolve bathymetry, bottom type and water column optical properties at the same time [1].

Hyperspectral imaging of the littoral zone from space offers repeat, all-season coverage of coastal zones worldwide to produce environmental products including bathymetry, water clarity, suspended and dissolved matter, bottom type, classification of on-shore vegetation, and the opportunity to build time series of images to initialize and validate predictive coastal models. However, hyperspectral imaging of the littoral environment involves specific challenges not found in hyperspectral imaging of the land. While land generally presents a bright, high albedo scene, the coastal ocean has a low albedo and is dark. In fact, when a maritime scene is viewed from a high-altitude aircraft or space, the scattered light from the atmosphere is significantly brighter than the underlying water scene over most of the visible spectrum (Figure 2), and careful removal of the effects of the atmosphere is required to obtain accurate water-leaving radiances. Water surface reflections of both direct sunlight and sky background are also significant and must be accounted for. The special challenges of atmospheric correction over the ocean required a new approach using a full vector radiative transfer model and designed specifically to deal with skylight reflecting off of the sea surface. This atmospheric correction algorithm was initially published in 2000 [2] and versions have been developed for imaging spectrometers flying at any altitude including space.

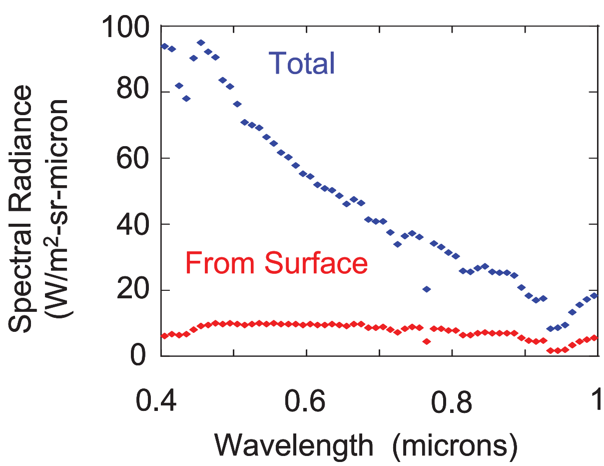

Figure 2. Spectral radiance modeled (using MODTRAN) spectral radiance above the atmosphere for 5% surface albedo and 45 degree solar zenith angle. In the blue wavelengths, the atmosphere (total minus surface) is significantly brighter than the surface.

The spatial scale of littoral hyperspectral imaging is also significantly different from that often required for land applications. Hyperspectral imaging over land often requires a Ground Sample Distance (GSD) on the order of meters, comparable to the size of man-made objects. For practical spaceborne hyperspectral imagers, this small GSD leads to limitations on the size of the scene that can be imaged. In contrast, a significantly larger GSD of tens of meters, comparable to the spatial resolution of harbor charts, is often satisfactory for environmental characterization of the coastal zone because of the larger spatial scale of environmental features. This larger GSD makes possible scene sizes of thousands of square kilometers required to capture the scale of coastal dynamics.

2. COASTAL IMAGER DESIGN REQUIREMENTS

The considerations discussed in section 1 lead to specific performance requirements for a MHSI, including requirements for high signal-to-noise ratio for the low albedo water scene, and accurate spectral and radiometric calibration [3].

Visible radiation is the only part of the electromagnetic spectrum that penetrates water to significant depths. The 400 - 700 nm spectral range is used to extract information about the in-water constituents and bathymetry and bottom properties. Wavelengths from 760 to 860 nm are used to estimate the aerosol properties over the water for atmospheric correction. Expanding the spectral range to 380 – 1000 nm will provide additional channels to improve atmospheric correction.

Spectral absorption features of liquids and solids are on the order of 30 to 50 nm wide in the visible and near infrared. Extensive experience with AVIRIS data and with 2 nm hand held spectrometer data has shown that 10 nm spectral sampling is adequate to sample and resolve these coastal features [1].

The ocean is a dark target and a very high SNR is required for ocean imaging. Over 90 % of the at-sensor signal for an ocean scene is from the atmosphere. Based on two decades of experience with airborne imaging spectrometers [4] a SNR of >200:1 for a 5% reflectance target is needed for ocean scenes so that sufficient SNR is left after atmospheric correction to resolve ocean features.

The sky is highly polarized, and the polarization is dependent on the sun elevation and azimuthal angle, the viewing geometry, wind speed and the amount of aerosols. Although ocean measurements are made at angles to avoid direct sun glint, some skylight is always reflected off the sea surface into the sensor. To avoid errors from polarized skylight polarization sensitivity should be < 5% [5].

The required Ground Sample Distance (GSD) depends on the application. Extensive requirement studies including Navy, NOAA and other users has determined that 100 m GSD is required for many coastal applications including:

- 2.5a Regional High Resolution Weather Impacted Imagery
- 2.8 Shallow Water Bathymetry
- 2.9b Coastal Ocean Color
- 2.10b Coastal Ocean Chlorophyll
- 2.11b Coastal Ocean Optical Properties
- 2.12 Bioluminescence Potential
- 2.13 Littoral Sediment Transport (supporting)

[6,7]. When the bottom is imaged the 100 m data will provide a useful product, but for many applications, such as bathymetry, a higher resolution on the order of the 30 m used for harbor charts is required.

To provide high quality data there is an additional set of performance parameters that will be measured to evaluate system performance. These parameters including MTF, stray light, saturation levels, and long term stability will be measured and the performance accepted as measured. Any problems that are identified will be corrected to the extent possible in the processing software. This is the approach used with the airborne prototype for HICO the Portable Hyperspectral Imager for Low-Light Spectroscopy (PHILLS) [8] which has resulted in high quality data.

3. THE HICO PROGRAM

The goal of the HICO program is to launch and operate the first spaceborne coastal Maritime Hyperspectral Imager (MHSI). An MSHI is designed to have the high Signal-to-Noise Ratio (SNR) required for dark coastal scenes. It captures large scenes at moderate spatial resolution appropriate for the coastal ocean. HICO is designed to have high sensitivity in the blue and full coverage of water-penetrating and near IR wavelengths

A major goal of the HICO Program is to demonstrate the scientific and naval utility of MHSI data from space. HICO data will be used to derive bathymetry, water optical properties, bottom type, and terrain and vegetation maps for coastal areas of interest around the world. HICO is planned to operate for at least a year to provide an annual time series of these products for the development of coastal models for selected sites.

HICO is also an Innovative Naval Prototype. As discussed below in section 3.2 HICO will demonstrate new and innovative ways to develop and build the imaging payload to reduce cost and shorten the time to launch. The goal is to serve as an innovative pathfinder for future spaceborne hyperspectral imagers

3.1 HICO on-orbit imaging system performance

HICO was designed to meet the requirements as outlined in section 2. These are the key HICO measured and planned performance:

- Ground Sample Distance: 100 m at nadir
  - Sufficient for many coastal environmental features
- Spectral coverage: 0.38 to 1.0 microns
  - Includes all water-penetrating wavelengths
- Spectral binning: 0.0057 microns spectral bin width
  - Sufficient to resolve spectral features in coastal scenes
- Signal-to-Noise Ratio: greater than 200 to 1 for water-penetrating wavelengths, assuming 5 percent effective surface albedo and 0.011 micron spectral bins
  - Required for sufficient residual signal to noise after atmospheric correction
- Radiometric accuracy: 5% or better
  - Required to fit image data to physical models to retrieve environmental data products
- Polarization sensitivity: 5% or less
  - To preserve radiometric accuracy when observing polarized scene
- Scene size: 50 x 200 km (nominal)
  - Appropriate for coastal scene sizes
- On-orbit lifetime: one year minimum
  - Required to collect data over all seasons

There are many possible products from imaging spectrometry data. For HICO we plan to demonstrate water inherent optical properties, colored dissolved organic matter, Chlorophyll, suspended sediments, and bathymetry and bottom-type mapping. These products will be incorporated into seasonal dynamical models for representative coastal types worldwide.

3.2 HICO as an Innovative Naval Prototype

HICO is an Innovative Naval Prototype (INP) sponsored by the Office of Naval Research. In 2005, the Office of Naval Research (ONR) and the Naval Research laboratory (NRL) began a program to design, build, and operate the first spaceborne hyperspectral imagers optimized for the coastal ocean. This transition to space platforms is founded on more than a decade of airborne hyperspectral imaging experience at NRL and other laboratories, which provides the basis for imager performance requirements and algorithms for atmospheric removal and littoral product retrievals [4,5].

Wherever possible HICO uses Commercial Off-The-Shelf (COTS) components (Figure 4) this includes the camera, computer and rotation stage. To facilitate this approach hermetic enclosures are used for the camera, computers and electronics (Figure 3). This enables the use

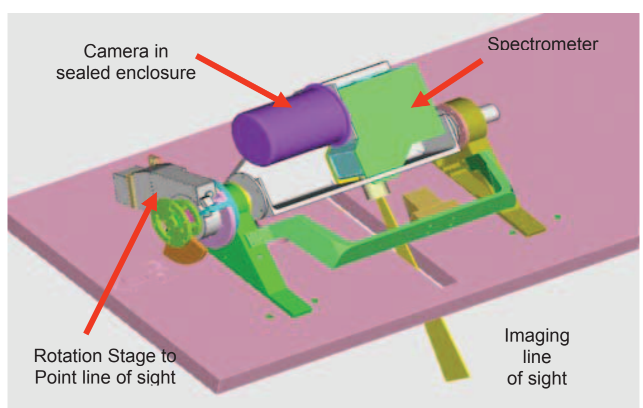

Figure 3. An engineering model of HICO. HICO is shown in the imaging position.

of ruggedized aircraft components and modern computers that might not be space qualified for years greatly reducing the cost and time to complete the instrument package.

3.3 HICO on the International Space Station

HICO is integrated and flown under the direction of DoD's Space Test Program. HICO is combined with a second NRL experimental payload the Remote Atmospheric and Ionospheric Detection System (RAIDS) [9] to form the HICO RAIDS Experiment Package (HREP). HREP will be attached to the Japanese Experiment Module-Exposed Facility (JEM-EF) in the International Space Station (ISS) where it will operate independently of the astronaut activity inside the station.

HICO is manifested for July 2009 launch on the H2 Transfer Vehicle (HTV) from Tanegashima, Japan. The HTV docks with the JEM and then a mechanical arm will transfer HREP and attach it to the JEM-EF (Figure 4).

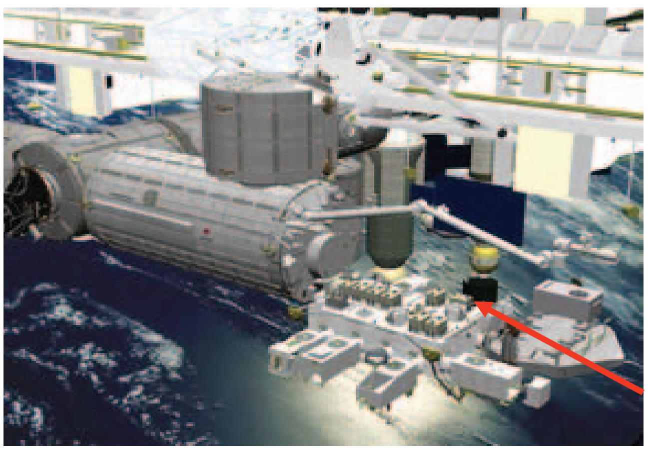

Figure 4. The Japanese Experiment Module (JEM) on the International Space Station. The arrow indicates where the HICO and RAIDS Experiment Package (HREP) will be attached to the JEM External Facility.

HICO is on schedule for the July 2009 launch to the International Space Station. The program began in early 2006 and is progressing on a very rapid schedule as listed below.

Completed Milestones:

Mission Requirements Review - February 28, 2006
Mission Requirements Document - March 16, 2006
HICO manifested on Space Station - March 2007
Preliminary Design Review - June 18, 2007
Critical Design Review - November 8, 2007
HICO imager delivery - May 30, 2008

Scheduled Milestones:

HICO test readiness review - June 16, 2008
HICO delivery to combined payload September 1, 2008
Payload delivery to JAXA - February 16, 2009
Launch to International Space Station - July 9, 2009
On-orbit checkout complete - September 25, 2009

ACKNOWLEDGEMENTS

HICO is made possible by a talented and dedicated team. We gratefully acknowledge funding from ONR and funding and technical support from the Space Test Program. Without their support and the cooperation and support from NASA and the Japanese Space Agency JAXA this program would not be possible.

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