HICO On-Orbit Performance and Future Directions

Curtiss O. Davis[1], Nicholas Tufillaro[1], Mike Corson[2], Bo-Cai Gao[2], Jeff Bowles[2] and Bob Lucke[2]
[1]*College of Earth, Ocean and Atmospheric Sciences, Oregon State University,*
104 CEOAS Admin. Bldg., Corvallis, OR 97331 USA
[2]*Remote Sensing Division, Naval Research Laboratory, Washington DC 20375 USA*
cdavis@coas.oregonstate.edu

Abstract: The Hyperspectral Imager for the Coastal Ocean (HICO) is flying on the International Space Station. Here we give a brief overview of HICO on-orbit performance and suggest future directions for imaging the coastal ocean.
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1. Introduction

The Hyperspectral Imager for the Coastal Ocean (HICO) is the first spaceborne imaging spectrometer designed to sample the coastal ocean. HICO samples selected coastal regions at 95 m with full spectral coverage (88 channels covering 400 to 900 nm) and a high signal-to-noise ratio to resolve the complexity of the coastal ocean. HICO has been operating on the International Space Station (ISS) since September 17, 2009 and collected over 5000 scenes. HICO was sponsored by the Office of Naval Research and built as an Innovative Naval Prototype to demonstrate a rapid and low cost approach to building space instruments. HICO was built calibrated, characterized, tested for space flight and delivered for integration in 16 months. HICO was integrated into the HICO and RAIDS Experiment Payload (HREP) which was installed on the ISS one year later. As a demonstrator HICO was designed to operate for 1 year; it has currently been operating for 29 months. Additionally HICO was designed to meet specific performance requirements and has met or exceeded all requirements. The data is now being used to demonstrate the utility of 95 m hyperspectral data for the coastal ocean.

HICO passed all the usual reviews and testing for a space instrument and it was well calibrated and characterized in the laboratory. However, due to the very limited budget HICO does not include an on-board calibrator, and because of its location on the ISS it cannot image the full moon monthly for calibration. Because of these limitations HICO has required on-orbit calibration using Fraunhofer lines for spectral calibration and stable land scenes for radiometric calibration. Those corrections are detailed in a submitted publication [1] and outlined briefly below.

2. On-orbit Calibration and Example Data

HICO was spectrally and radiometrically calibrated in the laboratory before launch. After launch and installation on the ISS small shifts in alignment (a few microns) were detected resulting in changes in spectral calibration and field of view. To provide useful data HICO has been recalibrated on orbit.

For the spectral calibration full resolution HICO data (1.7 nm spectral sampling) is collected over bright land or cloud scenes. Spectral matching techniques are used to match absorption features in the HICO spectra to the known Fraunhofer and atmospheric absorption features [1]. This is done on a regular schedule. An initial shift of 1.7 nm was noticed in the spectral calibration as HICO adjusted to the conditions on the ISS. This shift decreased slightly over the first 90 days, and then stabilized at 0.94 nm. The data is corrected using a table of spectral calibration over time to assure the correct spectra for any given data set.

Although HICO is an ocean color instrument, it has a very high dynamic range and does not saturate over high reflectivity scenes including most clouds and desert areas. This permitted the use of a number of stable desert calibration sites previously used by the Landsat Science Team, the NASA EO-1 Science Team, and the NASA JPL AVIRIS Team, for inter-satellite data comparisons. In particular comparisons were made with MODIS land channels (ocean channels saturated) for sites where we collected near simultaneous HICO and MODIS data. Using this data HICO on-orbit calibration was found to be different from the laboratory calibration. Adjustments were made to the dark correction, second order light correction and radiometric calibration [1]. Comparison of HICO to MODIS data from ocean scenes not used in the calibration process (Fig. 1) show excellent agreement, and HICO appears stable and providing good quality data.

Because of the limitations of operating on the ISS and the lack of a full data system HICO data is used strictly for demonstration purposes. Applications that have been demonstrated include shallow water bathymetry, analysis of river plumes and identification of harmful algal blooms. One example is the HICO image taken September 3, 2011 of a massive *Microcystis* bloom in Lake Erie (Fig. 2). The bloom was developing over several weeks and was already a concern to water resource managers and scientists working on the Great lakes. Lake Erie is a major source of drinking water and *Microcystis* is a toxic algae. The HICO image provides a clear spectral signature to track the bloom. It also has the area coverage and spatial sampling to show the full extent of the bloom and the physical mixing processes that are forming eddies transporting the *Microcystis* into the eastern part of the Lake.

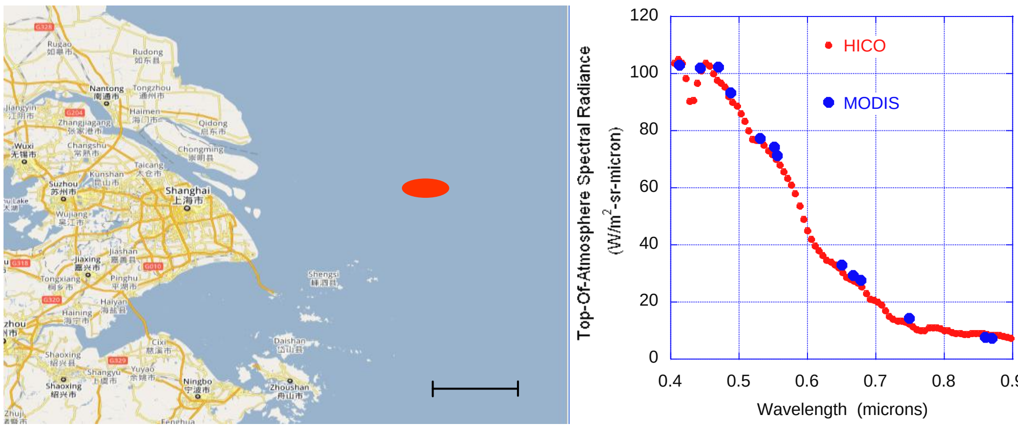

Fig. 1. Comparison of HICO and MODIS at sensor radiances for near coincident images 18 January 2010 (HICO Time: 04:40:35 UTC, MODIS Time: 05:00:00 UTC) of the Yangtze River plume offshore from Shanghai, China. Left, map showing the location of the comparison data (red dot); the scale bar is 50 km. Right the comparison of the top of the atmosphere spectral radiances.

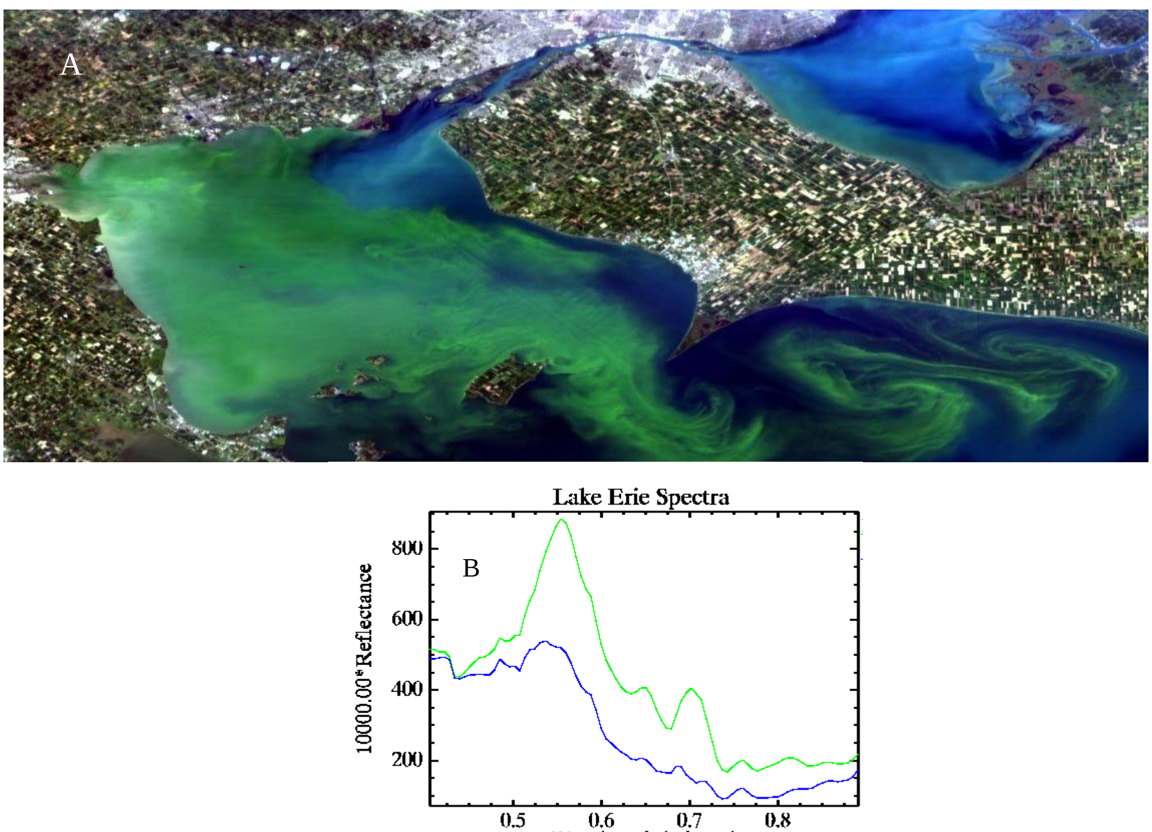

Fig. 2. A) HICO Image of a massive *Microcystis* bloom in western Lake Erie, September 3, 2011 as confirmed by spectral analysis. B) Example spectra from the Image. The bottom spectrum (blue) is from the open waters, the top spectrum (green) is from the *Microcystis* bloom. Peaks at 560, 660 and 710 nm are characteristic of the bloom. In particular, the peak at 660 nm is from pycoerythrin which is diagnostic for *Microcystis* and other blue-green algae.

3. Summary and Future Directions

HICO has met and exceeded all ONR Innovative Naval Prototype (INP) goals: It was built and delivered in 16 months (goal 18 months), it has operated for over a year in space (currently 29 months), sensor performance and data quality is as expected from models and lab measurements, and the sensor is stable and providing useful science quality data for over 50 users worldwide. A detailed description of the HICO instrument has been published [2] and a project overview was published in AGU EOS [3]. Detailed description of the on-orbit performance and calibration is completed and submitted for publication [1] and the operation of HICO has been extended to three years. HICO data are available at http://hico.coas.oregonstate.edu and the site includes publications, data access, example data and directions on how to use the data.

However, since HICO was built in 16 months and very limited budget many corners had to be cut. HICO used commercial off-the-shelf parts wherever possible and the computers and pointing motor are not space qualified, and both experience occasional malfunctions believed to be the result of radiation exposure and must be reset. The ISS orbit (+/- 52 deg. and slowly progressing) limit daylight viewing opportunities and Space Station activities can further limit imaging opportunities. Also HICO's 95 m GSD is adequate for the coastal ocean but not adequate when imaging the bottom or adjacent marshes and land areas where 30 m GSD is required. HICO does not have on-orbit calibration capabilities, and there is no data beyond 900 nm for atmospheric correction and land data. Because of the limited budget HICO data is calibrated but not atmospherically corrected or geolocated except on request for individual scenes. There is no funding for routine reprocessing and producing a Climate Data set, or long term archiving of the data.

To address these limitations we recommend a new Coastal Hyperspectral Imager (CHI) on a small free-flying spacecraft which would have a number of key advantages over HICO:

1. Broader spectral bandwidth. CHI would collect data from 380 to 1650 nm. The longer infrared wavelengths would improve atmospheric correction and make it possible to characterize beaches and plants along the shoreline and snow and ice in alpine regions and in the Arctic.
2. Finer spatial resolution. CHI will collect data with 30-m GSD, which will be able to re-solve ocean bottom, coastal, glacier and arctic features.
3. Optimized orbit. CHI would fly on a small dedicated satellite in a near-noon equatorial crossing time polar orbit. It will be able to image locations in high latitudes every day and locations in mid to low latitudes every 2nd or 3rd day.
4. Wide field of regard. Agile spacecraft would be able to rotate CHI through 60 degrees, from -30˚ to +30˚ from nadir, to allow rapid revisit (1-3 days) to study sites. It could also point fore or aft 20˚ to avoid sunglint.
5. Optimized radiometric calibration. The agile spacecraft could allow moon imaging; CHI radiometric calibration maintained on-orbit by scanning the full moon once a month.
6. Optimized spectral calibration. CHI will calibrate signal wavelengths on-orbit to within 0.2 nm by comparing observed and known spectral features including Fraunhofer absorption lines and atmospheric absorption features.
7. Complete data processing system. HICO data processed to level 1B; CHI would have a full data system, with all data processed to geolocated end products. This would include reprocessing as needed and archiving in a climate data center.

4. References

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