The Hyperspectral Imager for the Coastal Ocean (HICO): Sensor and data processing overview

Conference Paper · November 2009

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Weilin Hou
United States Naval Research Laboratory
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Marcos J. Montes
United States Naval Research Laboratory
129 PUBLICATIONS **2,052** CITATIONS

REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
20-01-2010	Conference Proceeding	

4. TITLE AND SUBTITLE	
The Hyperspectral Imager for the Coastal Ocean (HICO): Sensor and Data Processing Overview	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER 0602435N

6. AUTHOR(S)	
Mark David Lewis, Richard Gould, R. Arnone, P. Lyon, P. Martinolich, R. Vaughan, A. Lawson, T. Scardino, W. Hou, W. Snyder, R. Lucke, M. Corson, M. Montes, C. Davis	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER 73-6287-A9-5

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
Naval Research Laboratory Oceanography Division Stennis Space Center, MS 39529-5004	NRL/PP/7330-09-9374

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
Office of Naval Research 800 N. Quincy St. Arlington, VA 22217-5660	ONR
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release, distribution is unlimited.

20100126150

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The Hyperspectral Imager for the Coastal Ocean (HICO) is a new hyperspectral sensor that will be housed on the International Space Station (ISS). The low-cost, rapid-development sensor was built by the Naval Research Laboratory (NRL). NRL is also responsible for mission planning and operational data processing for this new sensor. HICO is sponsored and funded by the Office of Naval Research (ONR) within its Innovative Naval Prototype (INP) program. HICO is integrated and flown with support from and under th direction of the Department of Defense Space Test Program. HICO will be the first spaceborne hyperspectral sensor optimized for environmental characterization of both the coastal and open ocean. HICO samples the 350 to 1070 nanometer spectral range in 128 spectral channels and has a spatial ground sampling distance (GSD) of 100 meters. HICO is manifested for launch in September, 2009; once operational it will be used to routinely collect imagery of select coastal regions around the world.

15. SUBJECT TERMS

Hyperspectral Imager for the Coastal Ocean, innovative naval prototype, exposed facility

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Richard Gould
Unclassified	Unclassified	Unclassified	UL	9	19b. TELEPHONE NUMBER *(Include area code)* 228-688-5587

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

NRL SSC HICO Article for Oceans 09 Conference

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M.D. Lewis, R.W. Gould, Jr., R.A. Arnone, P.E. Lyon, P.M. Martinolich, R. Vaughan, A. Lawson, T. Scardino, W. Hou, W. Snyder, R. Lucke, M. Corson, M. Montes, C. Davis

Abstract

The Hyperspectral Imager for the Coastal Ocean (HICO) is a new hyperspectral sensor that will be housed on the International Space Station (ISS). The low-cost, rapid-development sensor was built by the Naval Research Laboratory (NRL). NRL is also responsible for mission planning and operational data processing for this new sensor. HICO is sponsored and funded by the Office of Naval Research (ONR) within its Innovative Naval Prototype (INP) program. HICO is integrated and flown with support from and under the direction of the Department of Defense Space Test Program. HICO will be the first spaceborne hyperspectral sensor optimized for environmental characterization of both the coastal and open ocean. HICO samples the 350 to 1070 nanometer spectral range in 128 spectral channels and has a spatial ground sampling distance (GSD) of 100 meters. HICO is manifested for launch in September, 2009; once operational it will be used to routinely collect imagery of select coastal regions around the world.

In the spirit of the INP program, HICO will be used as a prototype pathfinder sensor to establish sensor management and algorithm requirements for future generations of spaceborne hyperspectral sensors. The HICO project is designed as a one-year mission, with the goal of placing a similar sensor aboard a future free-flying satellite, following demonstration of the sensor capabilities on the ISS. Hyperspectral imaging provides unique capability for coastal monitoring and ocean characterization. Coastal products from HICO such as bathymetry, optical properties, biological properties, and bottom characterization can provide coastal managers and researchers new capabilities for ocean observation from space. HICO derived products requires complex processing procedures from calibration, atmospheric correction, and in water algorithms in order to exploit hyperspectral signatures. This presentation describes the HICO sensor and the operational processing required to convert raw HICO data to ocean bio-optical products.

Introduction

The Hyperspectral Imager for the Coastal Ocean (HICO) is designed to provide hyperspectral imagery for the study of the coastal ocean and adjacent land. The HICO sensor collects 128 contiguous spectral channels of solar reflectance in the 350 to 1070 nm range. HICO will be installed on the International Space Station (ISS) in September of 2009. The HICO data flow from the ISS will provide a maximum of 15 scenes per day. Standardized data processing is required to provide timely HICO data products and to create coordinated evolution of the processing applications and data products. Several data refinement transformations are required to generate the products that are useful for research. These transformations will be performed by the Remote Sensing and Oceanography Divisions of the Naval Research Laboratory, located in Washington, DC and at the Stennis Space Center in Mississippi, respectively.

HICO will be installed on the Exposed Facility (EF) of Kibo, which is the Japanese Experiment Module

(JEM) on the ISS. The EF section of Kibo was connected to Kibo's Pressurized Module (PM) on July 18, 2009. The HICO sensor will be one of the first experiments to be installed on the JEM-EF shown in Fig. 1.

After the sensor begins to provide a stream of hyperspectral data scenes, NRL will pass the data through a series of processing steps to create a set of data products. A sequence of software modules will transform the raw data packets of HICO data into ocean parameter data products. First, the raw data (Level 0) will be calibrated and geolocated (Level 1b). Then the data will be processed through a series of software modules to yield ocean products, such as chlorophyll concentration, absorption and backscattering coefficients, and others. Several of these software modules will be developed within the Automated Processing System (APS), a data processing system developed at NRL to create ocean products from a variety of satellite sensors [1]. Each data transformation will be tested to ensure data quality. Once the data processing system is finalized, the processed data sets will be distributed to Navy customers and the broader research community.

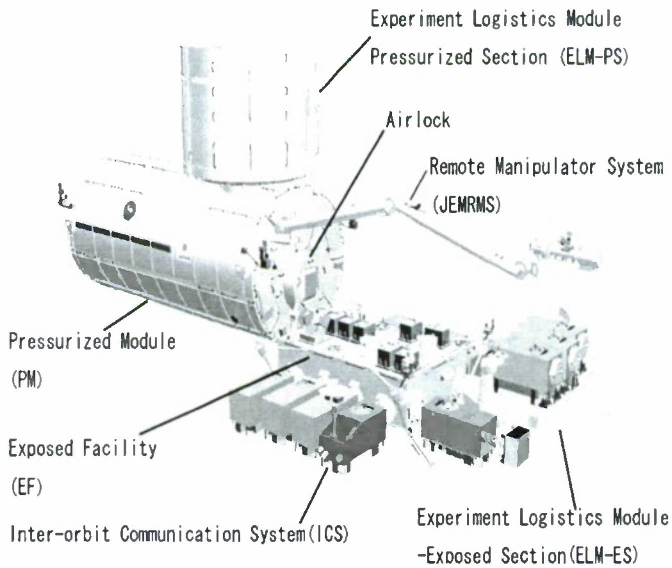

Figure 1. Kibo Module

The HICO sensor (Fig. 2) has been assembled, tested and evaluated by NRL [2]. The evaluation included radiometric, spectral, and geometric calibration, characterization of polarization sensitivity, and vibration and thermal-vacuum testing. Once completed, HICO was integrated into the HICO RAIDS Experiment Payload (HREP) which was subjected to further testing at NRL, NASA and the Japanese Space Agency (JAXA). The HICO sensor is now at JAXA's Tanegashima Island Launch facility ready for integration to the H-II Transfer Vehicle (HTV) and is scheduled to be launched to the ISS on September 11, 2009. HICO data will provide unique hyperspectral data with 100 m ground sample distance (GSD) for selected regions of the coastal ocean around the world. Data will be collected to demonstrate the utility of hyperspectral data for naval applications and for scientific studies of the coastal ocean. Due to the ISS orbit the HICO sensor will sample selected coastal regions at different times of the day and from a range of viewing angles. The unique viewing geometry and orbit of HICO on the ISS is quite different from existing ocean color sensors in sun-synchronous, polar orbit (SeaWiFS, MODIS), providing a variety of data processing challenges, including pixel geolocation, atmospheric correction, and bio-optical inversion to yield useful ocean products. However, the flexibility also makes HICO especially useful as a pathfinder for future ocean color imagers, including those in geostationary orbits.

The data plan for HICO has three main components: data collection, data processing and data distribution. In addition, processed data will be validated by comparing it to other sensor data and in situ data sources. Prior to launch, NRL assembled a "target deck" of desired ocean targets (geographic locations of interest to the Navy and the scientific community). Data collection includes determining which scenes are to be acquired (based on priorities and sensor ephemeris data), and scheduling those scenes for acquisition. It also includes the actual sensor activation and data storage. A mission plan containing the schedule of data requests will be created every 2 days based on the HICO constraint that no more than one scene can be acquired per orbit.

These mission plans will be uplinked to the ISS. After data collection the HICO data will be downlinked by NASA using standard procedures and communication links for the ISS. Data will then be transferred to NRL for processing from raw data packets (Level 0 data) to calibrated and geolocated images (Level 1b data). Level 1b data will be archived at NRL and processed into ocean data products. Following product generation, NRL will distribute the data products to naval users and Oregon State University (OSU); OSU will further distribute the HICO data products to university researchers and the international science community.

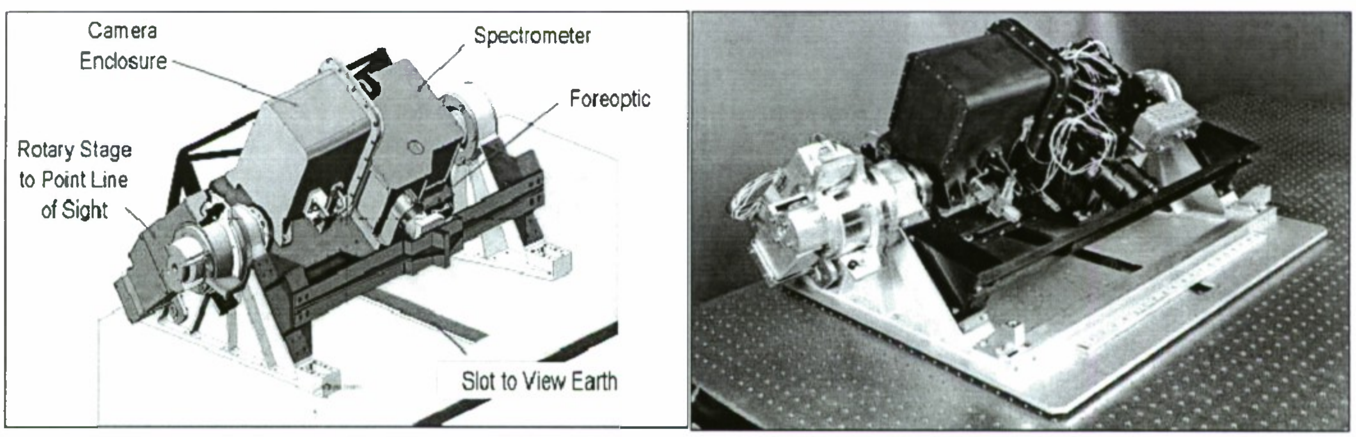

Figure 2. HICO Sensor (Image Credit NRL)

HICO Mission Planning and Data Collection

A methodology for HICO mission planning and data collection has been established. This includes implementing a system for selecting sites for HICO data collection and translating the scene information into a data collection schedule. It also involves transferring that information to NASA for uplink to the ISS, collecting the data and then downlinking the data to ground stations.

1. Scheduling and Commanding

A list of desired scenes has been developed and prioritized. During the operating life of the HICO sensor a two or three day mission plan will be uploaded to the ISS every Monday, Wednesday and Friday. The mission plans will be developed using the Satellite Tool Kit (STK). STK is a software package available from Analytical Graphics, Inc that allows complex sensor orbital and viewing computations to be performed from airborne or orbital platforms. It will be used to model the HICO sensor viewing geometry from the ISS. Other inputs into STK will be NASA operational data including the planned ISS orbital trajectory and attitude time line. STK will be used to determine what scenes from the prioritized list can be acquired given the planned ISS orbit and attitude information. The schedule is a 2 or 3 day list of scenes within the HICO field of regard, which is +45 deg/-30 deg off-nadir. The HICO sensor will then be programmed to acquire these scenes.

2. Mission and Data Characteristics:

The HICO sensor will acquire at most one observation (scene) per orbit (15 orbits per day). The integration time is 13.7 milli-seconds which translates to 73 frames per second. During data collection the sensor will sequence through several positions and data collection phases. First, the rotating stage will position the sensor at the stowed position and the camera will be turned on. Two hundred dark frames will be collected with the sensor in this position. Then the camera will be turned off and rotated to the scene imaging position. The sensor will be turned on and the frames of the scene will be acquired. After the scene is acquired the camera will be turned off and rotated back to the stowed position. Finally the camera will be turned on and additional dark frames will be acquired before the camera is turned off. The dark frames will be used to calibrate the data by providing information on the inherent electronic noise generated by the system.

This results in a standard HICO scene that consists of:

- Dark frames before scene acquisition = 512 samples x 200 lines x 128 channels
- Standard image = 512 samples x 2000 lines x 128 channels
- Dark frames after scene acquisition = 512 samples x 200 lines x 128 channels
- Scene total = 512 samples x 2400 lines x 128 channels x 2 bytes
- Data file scene size is therefore 314.6 Mbytes
- Geographic scene size is 50 km wide by 200 km long

High spectral resolution observations of 384 spectral channels will occasionally be acquired for wavelength calibration, tracking or special experiments. In this high spectral resolution mode the integration time will be set to 30 milli-seconds which translates to 33 frames per second. In this mode only 500 lines of data and 200 lines of dark frame data will be collected and the total scene size will be 275.3 Mbytes.

3. Data/Information Downloading:

The images will be stored in flash memory in the onboard computer until overwritten. The memory will hold approximately 40 images or a minimum of 2.5 days of data. The images will be placed in the downlink queue immediately after collection. It should take less than one ISS orbit to downlink one HICO scene to a ground station.

Once the HICO data is downlinked to the NASA ground station it is forwarded to NRL to be reassembled from its individual downloaded data packets. NRL will assemble the image data and processes it to Level 1b, which involves calibration of the raw counts to radiance values and appending geolocation information. The imagery will then be stored in the Hierarchical Data Format (HDF) and processed further using APS. HDF is a data file format designed by the National Center for Supercomputing Applications (NCSA) to assist users in the storage and manipulation of scientific data across diverse operating systems and machines. NCSA developed a library of callable routines and a set of utility programs and tools for creating and using HDF files [3].

HICO Data Processing in APS

To meet the research community's needs, HICO data must be processed and distributed in a timely fashion. The data scenes need to be downlinked, ingested and processed into HICO data products, rapidly and with minimal operator intervention. These processing steps include modules for quality assurance, sensor calibration checks, algorithm validation, and product generation. The data products will be distributed to Navy operational users as part of the Innovative Naval Prototype (INP) demonstration and to the broader HICO science team and research community.

1. Automated Processing System (APS)

NRL developed APS, which processes satellite data into ocean color data products. APS is a collection of methods used for ocean color processing which provide the tools for the automated processing of satellite imagery [1]. These tools are in the process of being modified to handle the HICO data stream. APS was developed for multispectral imagery from polar-orbiting satellites, so modifications are required to handle the hyperspectral data stream and the unique viewing geometry. Furthermore, additional atmospheric correction routines will be adapted for HICO imagery and evaluated. This will include an implementation of the TAFKAA atmospheric correction procedure which focuses on atmospherically correcting images over shallow aquatic areas, where complications arise dur to the varying effects from specular reflection, wind blown surface waves, and reflectance from the benthic substrate [4]. Cloud and Shadow and Near Infrared (NIR) armospheric correction algorithms will also be evaluated.

APS currently processes data from the Advanced Very High Resolution Radiometer (AVHRR), the Moderate Resolution Imaging Spectroradiometer (MODIS), the Medium Resolution Imaging Spectometer (MERIS), the Sea-viewing Wide Field-of-view Sensor (SeaWiFS), the Coastal Zone Color Scanner (CZCS), and the Ocean Colour Monitor (OCM) sensors. There are some major differences between the HICO data and the AVHRR, MODIS, MERIS, SeaWiFS, CZCS, OCM data. Specifically, HICO data is hyperspectral providing many more spectral channels than the currently processed data sets, which are all multispectral. However there are substantial software methods and capability already exisiting in APS which makes it a good choice for the automated processing of HICO data. Methods of calibration, atmospheric correction and bio-optical inversion algorithms for HICO data are being integrated into APS. In addition, many NRL customers who plan to use HICO data already use APS and can readily ingest products at different data levels from APS into their processing systems.

APS is a collection of UNIX programs and shell scripts designed to automatically generate map-projected image data bases of satellite derived products from a heavy flow of raw satellite data. Individual scenes are sequentially processed using standard parameters from the raw digital counts (Level-1) to radiometrically and geometrically corrected (Level-3) products within several minutes. APS further processes data into several different temporal (daily, 8-day, monthly, yearly, and latest pixel) composites or averages. These products are stored in the HDF with APS specific attributes. Additionally, it automatically generates quick-look "browse" images in JPEG format and may populate an SQL database using PostgreSQL.

APS was designed, developed, and implemented by the NRL Ocean Sciences Branch (Oceanography Division) to handle continuous streams of satellite data from multiple sensors. Originally, the system was designed to produce sea surface temperature maps from data collected by the Advanced Very High Resolution Radiometer (AVHRR) sensor. Data from the AVHRR is received and processed daily (up to six passes per day). APS has since been upgraded to process ocean color satellite data from the MODIS, MERIS, SeaWiFS, CZCS, and OCM sensors. APS provides near real-time processing with the additional option of reprocessing historical data. This reprocessing capability provides a powerful tool to test algorithm changes; we can easily compare results from previous processing versions with results using new or modified algorithms. For example, we can reprocess the entire 11-year SeaWiFS archive of Gulf of Mexico imagery in a few weeks.

APS uses a simple monitoring technique, which has been found to be reliable. The main driver regularly polls a specified input directory for incoming data and, for each file that is found, executes what are known as areas scripts on the file in a working directory. Multiple area scripts define the geographic regions of interest to the user. If the image swath covers any of the areas of interest, the scene is processed and ocean products are produced for each area covered. After each area script has been run on the file, the resulting data products are moved to an output directory. This method uses the input directory as the queueing system for data to be processed. The areas scripts do the actual construction of the desired data products.

2. APS Data Levels

APS transforms data through a series of processing levels. The data at each level is stored in units of measurements consistent with the associated transformation. In addition, metadata containing information about the scene will be added at specific levels. This metadata includes information such as the number of rows, columns, and channels as well as information such as channel wavelength, geolocation projection, sensor viewing geometry and ephemeris data.

The following discussion gives a brief introduction to the data levels that will be used by APS for HICO data processing. Initially, the raw data are transformed to a calibrated and geolocated format, eventually ending at Level 1b. Higher order data products are created from the Level 1b data.

Level 0 contains at-sensor data information stored as top of atmosphere radiance data in digital numbers. It also contains metadata describing instrument status, ISS location and star finder/tracker data.

Level 1a incorporates navigational information into the top of the atmosphere radiance data set. This includes geolocation information for each pixel in the image and also stores additional status information of the sensor.

Level 1b data is the result of a calibration transformation to top of the atmosphere radiance in units of milli-watts/meter^2/steradian. The geolocation, sensor status and viewing geometry metadata are also updated. NRL is in the process of extending APS to transform the HICO Level 1b data into a variety of ocean data products. The system will be developed to automatically perform the transformations when new HICO data is received. These data levels are described in the following paragraphs.

Level 1c data contains HICO data that has been used to model specific multispectral sensor data. The modeled data will primarily be MODIS data, but can also represent data from other sensors which are currently processed by APS. The modeled MODIS data will have 9 spectral channels generated by integrating the HICO channels across the spectral response function of the MODIS channels in the 350 nm to 1070 nm range. This will enable the HICO data to be processed as though it were MODIS data, with existing multispectral algorithms in APS, for direct comparison with and validation against MODIS imagery.

Level 2a is the result of a transformation designed to remove sea surface glint. The sun glint correction algorithms will incorporate methodology from Hedley, et al. [5] and/or Hochberg et al. [6]. These algorithms were developed for 10 meter data and may need to be modified to accommodate the 100 meter HICO data sets. The output of the glint correction may not be in units of remote sensing reflectance. Depending on how and when this transformation is performed, the results could be glint-corrected radiance or glint-corrected at-sensor reflectance or glint-corrected remote-sensing reflectance.

Level 2b data is the result of an atmospheric correction using the automated TAFKAA atmospheric correction algorithm. This process will use date, time, latitude, longitude, as well as the input radiance file and scale factors to generate atmospherically corrected reflectance or R_{rs} files.

Level 2c data is the result of standard APS multispectral algorithms. These transformations will be only performed on the Level 1c multispectral data modeled from HICO data. These data products will include the QAA optical products, the Gould water mass classification, and the radiance ratio derived chlorophyll concentration. Standard Level 2 pixel quality flags will be set for a variety of data quality conditions.

Level 2d data contains processed hyperspectral ocean water and bathymetry products. These data products include data products of the water's inherent optical properties (IOP), optimization of absorption and scattering coefficients as well as bottom depth and bottom reflectance products. Metadata flags for conditions such as turbid water, high and negative radiance values will be added.

Level 2e data contains land products such as the results of the Bachmann algorithms for vegetation/terrain mapping.

Level 2f data contains hyperspectral remote sensing surface reflectance R_{rs} data products. It will also update the metadata for flags showing land areas and water areas and also pixels covered by clouds and those which failed the atmospheric correction process.

Level 3 data contains previously described Level 1a data products that have been remapped to standard projection systems such as UTM.

Fig. 3 shows the relationship and transformation flow of the data as it passes through the various levels of data transformation. The arrows show the data flow from level to level. All of the output will be archived in the HDF5 format.

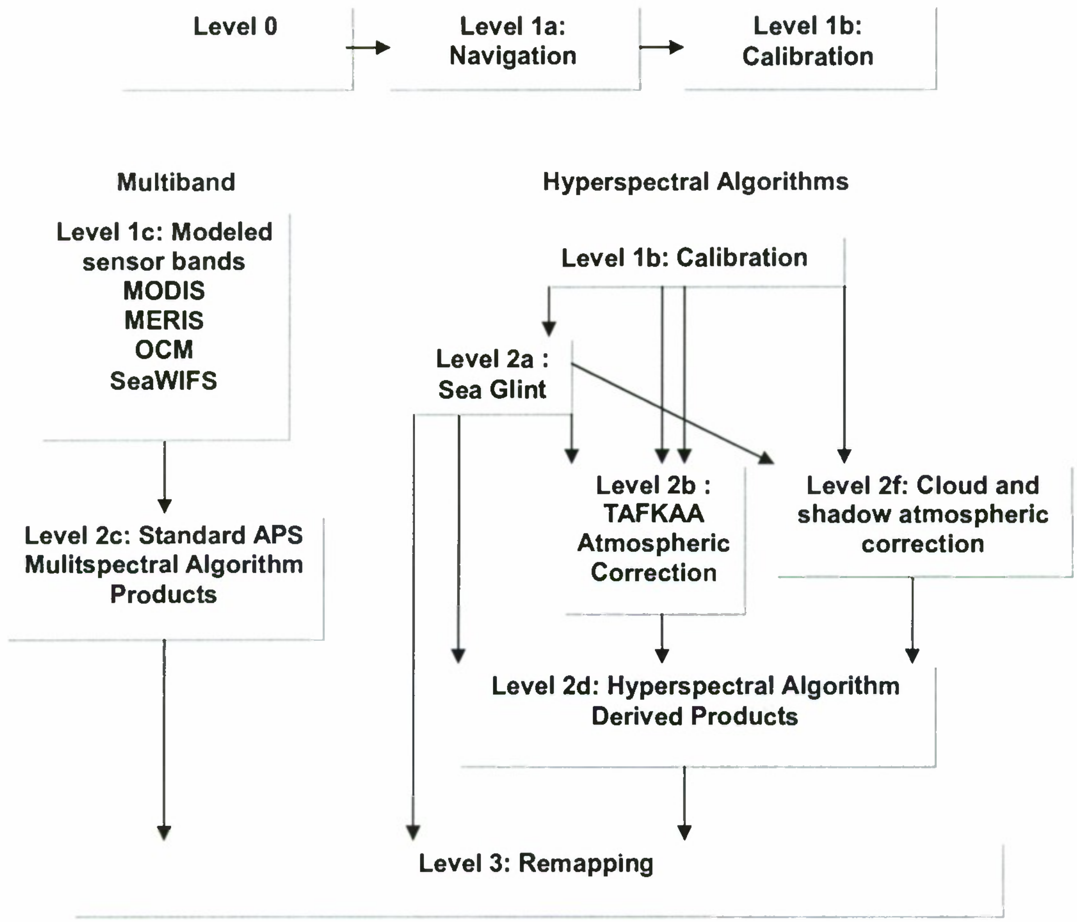

Figure 3: HICO Data Levels

HICO Data Distribution

Once the data products have been processed through APS they will be made available to the research community. Domestic users of the data will be able to acquire dataset through NRL. International users of the data will be able to acquire data sets through OSU.

Data Product Validation and Usage

HICO data will provide a rich set of data products for coastal ocean research. Multispectral data sets will be modeled by HICO. For example, HICO channels will be integrated across the MODIS spectral response function. This will provide proxy data at 9 MODIS wavelength channels. However, the MODIS proxy data derived from HICO will have the 100 meter HICO GSD. Comparison of the proxy multispectral data products to the true multispectral data products will give some indication of improvement in data products due to the increased spatial resolution. Data products generated by multispectral sensors include standard NASA products as well as navy-specific products: chlorophyll concentration, partitioned absorption coefficients (colored dissolved organic matter (CDOM), phytoplankton and detritus), backscattering coefficients, diver visibility, bottom depth, bottom reflectance, optical water mass characterization, and total/organic/inorganic suspended particulate loads. The HICO bio-optical products will be compared to in situ ground truth data. This will enable assessment of HICO data product quality.

In situ data stored at the Martha's Vineyard Coastal Observatory (MVCO) in Massachusetts will be used to validate HICO data. MVCO has a wealth of ocean data from the coastal waters of Massachusetts. Among other data types this data sets includes wave fields, turbidity, chlorophyll and temperature. Data products derived from HICO data will be compared with the MVCO in situ data to quantify the accuracy of the remotely sensed data products.

Other sites, such as White Sands, New Mexico, may be used in the validation process. The area around White Sands has large homogeneous psuedo-invariant bright reflective characteristics. Spectra from HICO can be compared to spectral reflectance taken from the ground to also characterize the spectral response of the sensor and also atmospheric phenomenon.

Conclusions

The HICO sensor was built and tested by NRL, and NRL will manage the collection, processing, archival, and distribution of the data. A wide variety of bio-optical products will be generated to support both Navy and scientific missions in open-ocean and coastal waters. Furthermore, the 100 meter spatial resolution of HICO will enable investigations of riverine and estuarine environments. With the wealth of contiguous spectral wavelength information, HICO will facilitate development of new hyperspectral algorithms and ocean products, and will advance our understanding of phenomena that are better identified in more narrow wavelengths than current multispectral satellite sensors.

Acknowledgment

This program is supported by NRL 6.2 base program PE- 6000123, Autonomous "Processing for Producing Hyperspectral Products on Tactically Relevant Time scales" and "Realizing the Naval Scientific return of HICO"

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