HICO Data User's Proposal

Title: Model to Separate Water Column Chlorophyll and Benthic Vegetation Signals from HICO Data

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Abstract/Project Summary

Level 2 HICO images that cover Indian River Lagoon are requested in order to develop a HICO based mapping protocol for submerged aquatic vegetation (SAV) in turbid productive waters. The specific objectives are to: (1) develop a novel algorithm to decompose the HICO remote sensing reflectance from optically shallow productive coastal waters in order to separate the signals of water column chlorophyll (phytoplankton) and SAV (seagrass and macroalgae); (2) calibrate and validate the algorithm using atmospherically corrected HICO data and *in situ* data; (3) develop and implement mapping protocols to separately map seagrass and phytoplankton using a single HICO dataset. The proposed project location adds a unique coastal region and properties that have not yet explored in the HICO North American network. The Lagoon is known to boast its highest SAV species richness in the U.S, but also with frequent small to medium algal bloom events. There are abundant data on its water quality and seagrass community, consistently monitored for almost 20 years, which will be a valuable advantage in model adjustments to HICO data. This project will contribute to advance the HICO mission for SAV and phytoplankton mapping through a model to separate benthic and water column chlorophyll signals.

I. Statement of Work/Project Description

I.1 Statement of Goal and Project Importance

The overall goal of this project is to develop a HICO (Hyperspectral Imager for the Coastal Ocean) based mapping protocol for benthic vegetation mapping in turbid productive waters. The specific objectives are to: (1) develop a novel algorithm in order to decompose the HICO remote sensing reflectance from optically shallow productive coastal waters in order to separate the signals of water column chlorophyll (phytoplankton) and benthic vegetation (seagrass and macroalgae); (2) calibrate and validate the algorithm using atmospherically corrected HICO data and *in situ* data; (3) develop and implement mapping protocols to separately map seagrass and phytoplankton using a single HICO dataset.

This project will contribute to the advancement in classification/mapping of algal blooms and seagrass beds for very shallow ($\leq$ 2 m) depths where optical modeling using remote sensing is complicated. For example, one of the complications during summer months is that many lagoons in Florida experience severe algal blooms and regular seagrass mapping to monitor their growth and productivity using aerial surveys becomes an extremely difficult task because of the masking of seagrass signal by the bloom. The expected significance of the proposed project is to incorporate the bloom signal in existing algorithms in order to improve their accuracy for shallow coastal benthic mapping using HICO data. Therefore, this project will support the Naval Research Laboratory (NRL)'s goal to distribute HICO data to share the end user products and algorithms in evaluating HICO data.

I.2 HICO Data Requested and Utility to the Proposers

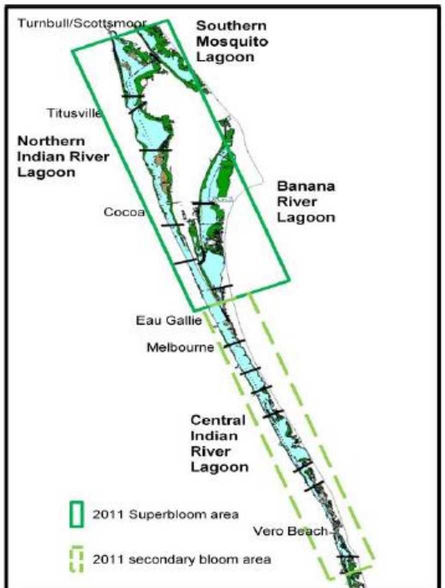

Figure 1-1. Indian River Lagoon system and locations of the 2011 superbloom and secondary bloom

We request Level 2 HICO images that cover southern Mosquito Lagoon, Northern Indian River Lagoon, and Banana River Lagoon, centered at (Lat: 28.568844, Long: -80.757854; Fig. 1) during four different times over a one year period. We propose to combine our existing models and to calibrate the new model to HICO data in order to develop a protocol to map benthic seagrass beds.

I.3 Background to the Proposed Work

Shallow coastal areas are one of the most productive habitats, yet the most sensitive landscape to human-induced environmental alteration and natural disasters. Modeling of optical water properties for the coastal zone is more complicated due to high amounts of suspended particles (phytoplankton, seston, and inorganic particles) and variable water depths compared to the deeper portions of oceans. In addition, bottom backscattering in the shallow areas can be significant, which makes the near infrared (NIR) signals more important, especially in the areas that contain substantial amount of seagrasses, benthic algae, and any other submerged aquatic vegetation (SAV). In these shallow and optically complicated areas, the conventional Beer-Lambert's exponential light attenuation with depth is not applicable. Most of the currently available benthic and chlorophyll mapping models do not adequately distinguish benthic vegetation signals from water column chlorophyll signals.

PI's team has been developing new approaches to extract backscattering signals by reducing depth effects and minimizing impact of turbidity by properly modeling the scattering and absorption components in these dynamic, productive, and shallow coastal littoral areas. Co-I's research team has developed and tested various algal pigment mapping algorithms for turbid coastal environments. These algorithms were successfully applied to various coastal waters using airborne hyperspectral data (i.e. AISA Eagle) and multispectral satellite data (i.e. MERIS) (Mishra and Mishra, 2012). We have also been involved in algal bloom mapping using MERIS in Indian River Lagoon, FL since 2011.

The Indian River Lagoon (IRL) is a 252 km long estuarine system on the Atlantic Ocean side of central Florida, USA (Fig. 1) with an average depth of 2 m and widths varying from 0.5 to 5 km. The species rich, healthy SAV community IRL, including seagrasses and macroalgae, provides a vital habitat, nursery, and forage ground for several commercially and recreationally important species and endangered species such as the Florida manatee (*Trichechus manatus latirostris*). The area surrounding the IRL has been undergoing rapid development resulting in degradation of the ecological services the lagoon provides. In response, the St. Johns River Water Management District (SJRWMD) has been monitoring water quality and SAV at 18 sites since 1996 to support general ecosystem health analysis (SJRWMD 2012).

From early spring through late fall of 2011, a massive bloom of phytoplankton and the resultant loss of seagrass occurred throughout most of the IRL system, extending from southern Mosquito Lagoon to just north of Ft. Pierce Inlet (Fig. 1; SJRWMD 2012). This bloom and seagrass decline far exceeded any past events remembered or documented in terms of geographic scale, bloom intensity (Chlorophyll *a* concentrations often exceeding 100 μg/L) and duration, and rate and magnitude of seagrass loss. The other bloom reached immense proportions, deserving its own label or category "superbloom" (SJRWMD 2012). The 2011 superbloom covered approximately 53,000 hectares of open water including Banana River Lagoon, northern IRL, and southern Mosquito Lagoon. In addition, there have brown blooms that have had severe impact on seagrass beds in Mosquito Lagoon in 2012.

A group of scientists and managers from regional governments and universities formed a consortium to analyze the currently available data for a consensus-driven thesis on the 2011 superbloom, its impacts on SAV, any observations regarding post-2011 recovery of SAV and water quality, and management recommendations. There are also two secondary objectives. One is to identify, prioritize, and fill critical gaps in our understanding of the Lagoon, particularly its nutrient-trophic relationships with an emphasis on a balanced macrophyte community. The other objective is to continue collaboration among the Consortium institutions beyond this investigation to sustain and improve long-term research and management of the IRL system.

I.4 Advantages of Using HICO Data

The current chlorophyll mapping methods (MERIS and Landsat TM) that are used for IRL are not appropriate to distinguish phytoplankton signals from those of benthic seagrass beds'. One of the reasons is the limited spectral resolution of the satellite data, which makes it impossible to depict the fine differences in varying pigments' reflectance peaks and absorption. HICO provides the necessary hyperspectral bands that are particularly designed for coastal mapping. If the current water correction and chlorophyll mapping algorithms are calibrated to the HICO data, it will be possible to extract the benthic vegetation and water column phytoplankton signals separately from the same dataset. We specifically plan to separate the 705 nm reflectance peak due to chlorophyll reflectance (algal bloom) from the broad NIR band reflectance due to seagrass reflectance. The high spectral resolution of HICO will enable us to distinguish the dominant pigment types of the bloom events from the seagrss signal.

I.5 Statement of Work

We have developed a water-depth correction algorithm to improve detection of underwater vegetation spectra signals. We modeled the effects of the overlying water column on upwelling hyperspectral signals by empirically separating the energy absorbed and scattered by the water using data collected through a series of controlled experiments (Cho and Lu 2010; Lu and Cho 2011; Washington et al. 2012). The study results demonstrate that the empirically driven hyperspectral algorithm significantly restore the NIR signals originated from seagrass dominated sea floors when applied to airborne hyperspectral data. NIR reflectance serves as the primary cue for discriminating benthic/water column vegetation/algae type. The algorithm has been successfully validated and applied to airborne AISA Eagle hyperspectral images. Under the current module, users are able to select water depth (0 – 1.0 m) and turbidity (0-20 NTU) using slide bars, for which (a) given hyperspectral band(s) can be corrected. The corrected reflectance can be generated and compared to the original one at either a given pixel, within a small subset. In addition, the original and corrected images can be displayed.

Mishra et al. (2005, 2006, 2007) have done a significant amount of work on benthic habitat mapping and chlorophyll mapping (Mishra and Mishra, 2012) using field-, airborne-, spaceborne-multi/hyperspectral data. Their research focused on the development of a suite of algorithms using remotely sensed data and radiative transfer models for shallow marine bathymetry estimation and bottom recognition of benthic habitats (corals, seagrass, microalgae) off the coast of Roatan Island, Honduras. Their research provided solution for minimizing the confounding influences of atmospheric attenuation, water depth, and water column attenuation on the reflectance properties of the benthic habitats. Together, we have the necessary experience, expertise, and equipment to carry out this project for shallow littoral environment.

Further field measurements of benthic and above water spectral data, water column concentrations of Chlorophyll *a*, CDOM, total suspended solids, and water depth will be acquired for our study area (The IRL seagrass beds) close to HICO data acquisition period. The model-derived bottom reflectance, water column chlorophyll, and the field measured bottom albedo will be compared to validate the algorithm. Benthic classification results using the original and water corrected images and the field ground truth data will be used in accuracy assessment, at reference points collected during the field research. After spectral adjustments and validation using corresponding HICO data, the algorithms will be implemented into satellite data such as HICO.

II. Biographical Sketch and Available Facilities

II.1 Biosketch of Investigators

Cho (PI) is Associate Professor of Environmental Science at Bethune-Cookman University (B-CU), Daytona Beach, FL. Cho is a coastal scientist who specializes in application of remote sensing data to the underwater/aquatic environment and coastal habitats. She published over 40 peer reviewed and invited articles, book chapters, field guide books on remote sensing of seagrass mapping and water correction algorithms, and coastal environment. Her current research interests include use of remote sensing for studies on the 2010-2011 super algal blooms that affected the Indian River Lagoon, FL. She has extensive research experience on coastal waters and underwater habitats in the Gulf of Mexico (> 13 years) garnered through numerous completed and on-going projects funded by NASA, the Geospatial Intelligence Agency, the National Oceanic and Atmospheric Administration, Sea Grant, the Department of Marine Resources, and the Gulf of Mexico Alliance. She has conducted research and published extensively in both disciplines of coastal biology, ecology, and remote sensing.

Mishra (Co-I): Over the past few years most of his research efforts have been devoted to the development of semi-analytical models and geospatial techniques for monitoring coastal and shallow marine ecosystems. He has published more than 30 articles in that area alone. During his academic career, he has submitted grants as either a PI or co-PI for external funding in excess of $12 million, successfully receiving close to $7 million from federal agencies such as NASA, NSF, and NOAA. The techniques he has developed to assess and understand the health and constitution of fragile marshes at large spatial scales using Landsat and MODIS data directly impacts restoration and conservation efforts. He has received multiple grants totaling $686,000 to monitor the immediate impact of the spill on the coastal wetlands, including a NSF RAPID and the Gulf Research Initiative Phase III grant to acquire field data in 2010 2011 and calibrate Landsat based models. One of our papers detailing the preliminary assessment of the post-spill state of the marsh was published this year in a high impact journal (impact factor 4.6), which is the first quantitative oil spill wetland impact assessment paper after the Gulf disaster. Our preliminary results on the BP oil spill study have been widely reported by national media (NY Times, Washington Post) and other state/local media outlet.

II.2 Facilities

Integrated Environmental Science at Bethune-Cookman University has an aquatic/wetland habitat quality laboratory, a dark room for spectral measurements, and a GIS/Remote Sensing computer laboratory. Laboratory and field equipment/instruments include Turner Design fluorometers, Hach turbidimeters, and colorimeters, two Ocean Optics USB 2000+ units, JAZ spectroradiometer, a Nikon D80camera, YSI DO and salinity meters, pH meters, a LiCor PAR meter, water samplers, and an Aquaflo hand-held fluorometer. Ten Trimble GPS units with TerraSync software also are available for GPS work. The GIS/Remote Sensing computer laboratory has site licenses for ESRI GIS ArcMap, Matlab, Spatial Analyst, Microsoft Office 2003/2007, Microsoft Vista, SPSS, ENVI + IDL, ENVI FLAASH, Hydrolight-Ecolight 5.0, and SpectraSuite for Ocean Optics.

At the Department of Geography at University of Georgia, Mishra manages and operates the Geospatial Lab and the Spectroscopy Lab. Geospatial Lab is equipped with high speed workstations, image processing and GIS software, and high resolution scanner and plotter for map production. Spectrscopy Lab is equipped with all the instrumentation needed to carry out the field data collection for the project including, Ocean Optics Hyperspectral Sensors (USB 4000), Calibration Panels (Labsphere 95% and 5%), Fiber Optic Cables (30 m; 10m, 5m), LAI 200 meter, AccuPAR LP-80 LAI meter, drying oven, Differentially Corrected GPS Pro XRS (GARMIN) system, LI-COR Quantum Sensor (LI-190SA), LI-COR Underwater Quantum Sensor (LI-192SA), LI-COR Pyranometer Sensor (LI-200SA), CR3000 Data loggers (Campbell Scientific), Pressure Sensor (In-Situ: PXD-261), Video Camera, Digital SLR Camera, and Laptop w/5 serial ports (for use with equipment).

PIs have contacted the seagrass and water quality scientists at St. Johns River Water Management District's for their collaboration and assistance with boats and personnel for ground field data collection.

II.3 Ancillary Datasets Used in the Proposed Work

We have access to over a decade of water quality data, including light attenuation, concentrations of Chlorophyll *a*, TSS, and CDOM in the Indian River Lagoon system collected, quality-controlled, managed, and available through St. Johns River Water Management District (SJRWMD). In addition, there are optical models (Gallegos and Kenworthy 1996; Gallegos 2005) that predict light penetration for the system, long-term data on phytoplankton assemblage composition, records of the SAV (seagrass, macroalgage) distribution, and models predicting the response of SAV to varying light regimes.

The proposers also have a substantial amount of hyperspectral data of various seagrass, SAV species, and water column constituents from Gulf States and from controlled dark rooms at varying water depths (0-2.0 m at 5 cm intervals for turbidity values of 0-20 NTU) from previous projects. We will continue to add quality controlled spectral measurements of water constituents and SAV data to the spectral library that can be used for model calibration.

III. Output and Deliverables

III.1 Products

The immediate products of the project will be as follows:
(1) Development of a model for separating bloom signal from seagrass signal using remotely sensed data
(2) Model application to HICO data to produce maps of chlorophyll *a* and seagrass distributions in IRL
(3) A final report detailing the methodology and models applied to the image data, and project results
(4) A set of recommendations regarding the potential band configurations on future coastal sensors for seagrass and chlorophyll *a* mapping

(5) Any relevant spatial data layers (both raster and vector) (soft copy)
(6) Presentations at the annual meeting, local, and national meetings
(7) Published results in a peer reviewed journal

III.2 Advancing the HICO mission

The proposed project location adds a unique coastal region and properties that have not yet explored in the HICO North American network. The Indian River Lagoon system is known to boast its highest SAV species richness in the U.S. It is a shallow lagoonal system with an extensive and productive SAV community, but also with frequent small to medium algal bloom events. There are abundant data on its water quality and seagrass, consistently monitored by St. Johns River Water Management District for almost 20 years, which will provide a valuable advantage in model adjustments to HICO data. This project will contribute to advance the HICO mission for SAV (seagrass and macroalgae) and phytoplankton mapping through a novel model to separate benthic and water column chlorophyll signals.

III.3 Annual HICO Team Meeting

One of the investigators will attend the required annual meeting to present the project results and discuss HICO data and their uses and applications in coastal seagrass and phytoplankton mapping.

IV. References

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