HICO Data User's Proposal

Title: HICO acquisition for early detection and monitoring algal blooms in Indian River Lagoon

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

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Abstract/Project Summary

This proposal is being submitted as a continuation/extension of the existing project. We are requesting 12 more monthly images of Indian River Lagoon starting from May 2014. The goal of the continuation project is early detection and monitoring of phytoplankton blooms (aka Super looms) that have been plaguing IRL for the past three years. All regional officials who have been monitoring the lagoon including St. Johns River Water Management District, Kenney Space Center, Volusia County Environmental Management, and Florida Fish and Wildlife Conservation Commission either have detected early signs of the 2014 blooms and predict subsequent blooms in 2014. Early detection of phytoplankton bloom events in any estuarine system can be vital information to have in order to initiate management actions. This project will contribute to the advancement in classification/mapping of types and spatial abundance of algal blooms for very shallow (≤ 2 m) depths where optical modeling using remote sensing is complicated. The 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, the HICO program's focus: providing HICO data for scientific research on coastal zones and other regions around the world sp that the data will be exploited for coastal scientific questions that are otherwise hard to complicated.

I. Statement of Work/Project Description

I.1 Current Status of Ongoing HICO Project

The overall goal of our ongoing HICO project entitled "Model to Separate Water Column Chlorophyll and Benthic Vegetation Signals from HICO Data" was to develop a HICO (Hyperspectral Imager for the Coastal Ocean) based mapping protocol for benthic vegetation mapping in turbid productive waters. We proposed to integrate our existing models and to calibrate the new model using HICO data in order to develop a protocol to map benthic seagrass beds because the previous chlorophyll mapping methods (MEdium Resolution Imaging Spectrometer-MERIS and Landsat TM) that were used for the Indian River Lagoon (IRL) system were not performing accurately to distinguish between phytoplankton and seagrass signals. As part of the project, we received four Lever-2 (L2) images that were acquired in March 2013, October, 19 2013, and February 20, and 28, 2014 from Oregona State University. Concurrent field trips were conducted whenever the weather conditions permitted and boats were available to collect ground-truth data. The March 2013 data were used to develop algorithms to better distinguish macroalgae from vascular seagrass; and a peer-reviewed journal article was published in GIScience and Remote Sensing in March 2014 summarizing the findings.

I.2 Statement of Goal and Project Importance

This proposal is being submitted as a continuation/extension of the existing project. We are requesting 12 more monthly images of Indian River Lagoon (IRL) starting from May 2014. ***The goal of the continuation project*** is early detection and monitoring of phytoplankton blooms (aka Super looms) that have been plaguing IRL for the past three years.

BACKGROUND: The IRL is reported to be one of the most productive and diverse estuaries in North America, largely related to its expansive seagrass coverage (Littler et al. 2008). The IRL's seagrass community boasts the highest species richness in North America (Virnstein and Hall 2009). The species rich, healthy seagrasses and macroalgae areas provide a vital habitat, nursery, and forage ground for several commercially and recreationally important species as well as endangered species such as the Florida manatee (*Trichechus manatus* atirostris), several species of sea turtle, numerous estuarine dependent finfish, and invertebrates such as blue crabs and shrimps. Florida Fish and Wildlife Conservation Commission (2003) estimated that one acre of seagrass beds can support 50 million invertebrates.

During the summer of 2011, an unprecedented algal bloom formed producing chl *a* concentrations over eight times (often exceeding 100 μg/L) the historical mean in some areas, lasting seven months and spanning the entire northern IRL (SJRWMD 2012). The bloom covered approximately 53,000 hectares of open water; the IRL suffered the loss of over 34,000 acres of seagrass (SJRWMD 2012), primarily due to reduced light reaching seagrass beds (Phlips and Badylak 2011). IRL seagrasses suffered further from subsequent brown tides occurring in 2012 in Mosquito Lagoon and north IRL, two of the IRL's sub lagoons. In many areas, the seagrass abundance has not returned to the pre-bloom status as of 2013. As seagrass beds collapsed in IRL, cascading tragic incidents such as *Pyrodinium* blooms in summer 2013, deaths of flagship species such as manatees, dolphins, and pelicans occurred as the trophic balance was broken, which undoubtedly affect the economy, health, and lifestyles of the surrounding community. The three primary phytoplankton species that affects the IRL are *Pedinophyceae* (2011), *Aureoumbra lagunensis* (2012), and *Phyrodinium bajamense* (2013). In addition, there are several other phytoplankton species that appeared to be associated with pelican mortality and fish kills. All regional officials who have been monitoring the lagoon including St. Johns River Water Management District (SJRWMD), Kenney Space Center (KSC), Volusia County Environmental Management, and Florida Fish and Wildlife Conservation Commission (FWC) have detected early signs of the 2014 blooms and predict subsequent blooms in 2014.

Early detection of phytoplankton bloom events in any estuarine system can be vital information to have in order to initiate management actions. One of SJRWMD current monitoring programs collects monthly water samples for phytoplankton analysis. However, there are a limited number of sampling sites distributed over the length of the IRL. Additionally, a monthly sampling frequency could easily miss the beginning phases of algal bloom growth, or fail to detect its first appearance altogether. The use of satellite images can fill the spatial and temporal "gaps" identified above, to allow for enhanced aerial extent and higher spatial continuity. Patterns of bloom expansion and migration over large areas of the estuary could also be better resolved with the aid of HICO imagery.

This project will contribute to the advancement in classification/mapping of types and spatial abundance of algal blooms for very shallow (≤ 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 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, the HICO program's focus: providing HICO data for scientific research on coastal zones and other regions around the world so that the data will be maximally utilized for coastal scientific questions that are otherwise complicated.

I.3 HICO Data Requested and Utility to the Proposers

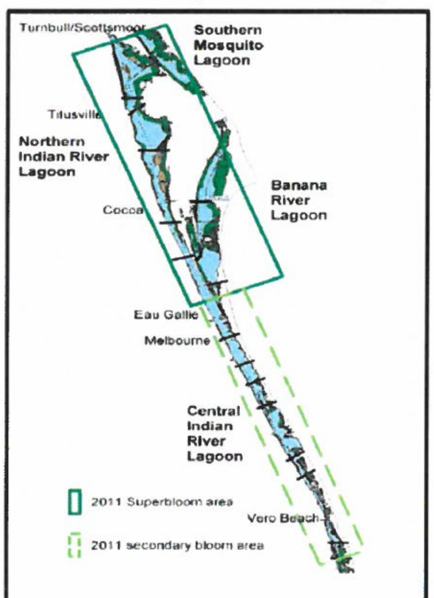

Figure 1-1. Indian River Lagoon system and locations of the 2011 superbloom and secondary bloom

We request L2 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) 12 different times over a one year period starting May 2014 (ideally, roughly once every month). We propose to combine our existing models and to calibrate the new model using HICO data in order to develop a protocol to map benthic seagrass beds even during an ongoing bloom.

I.4 Advantages of Using HICO Data

Harmful Algal Bloom (HAB) is a major water quality and public health issue in the inland waters and estuarine environments as it can hamper recreational activities, degrade aquatic habitats (fish kills), and potentially affect human health (toxin impact). Regional environmental government organizations, scientists and mangers have identified

"Improve Harmful Algal Bloom detection and forecasting in the Indian River Lagoon" as one of its top priorities. Unfortunately measuring concentrations of phytoplankton using conventional methods (discrete sampling) is laborious, expensive, and time consuming. Remote sensing technologies have been proposed to map the spatial distribution of HAB over large areas at regular time intervals. However, not enough research has been done regarding quantifying their spatio-temporal distributions using satellite data. Therefore, there is a need to create a prediction tool in the form of a semi-analytical model which can use hyperspectral satellite images to detect, and map the spatio-temporal distributions of harmful algal blooms in IRL. The model can act as a first of its kind tool that will allow the identification of 'hotspots' of varying types of phytoplankton blooms during early stages of a bloom and will have a significant impact on ongoing water quality-ecological- fisheries research.

I.5 Statement of Work

Algal bloom detection, quantification, type identification, and mapping: The investigators have performed significant research in deconstructing the remote sensing signal to differentiate between more typical and toxic phytoplankton so that spatio-temporal distribution of specific algal blooms can be studied (Mishra and Mishra 2012; Mishra et al. 2013, Ogaswahara et al. 2013). At B-CU, we have been using satellite data in monitoring algal blooms in IRL since 2011 (Kamerosky 2012; Cho et al. 2014). We will use and improve existing models for estimating algal mass for periodic mapping of algal blooms using HICO data at the study locations.

Component 1: Field data collection and analysis:

Field data will be used for model tuning and validation and is a crucial part of the project. Field data collection will take place throughout the IRL. At each sampling location, the suite of field data at each sampling point will include: 1) Above water remote sensing reflectance (R_{rs}) measurements using Ocean Optics (Ocean Optics JAZ) hyperspectral radiometer ; 2) Measurement of physical parameters (temperature; pH; dissolved oxygen); 3) Water samples for laboratory analysis of Phycocyanin (PC), chlorophyll-a (chl-*a*), Colored Dissolved Organic Matter (CDOM), and total suspended solids (TSS); 4) Differential Global Positioning System (DGPS) locations; and 5) Digital photographs. Most of the data are available through the partners SJRWMD, KSC, County Environmental Management, and FWC; on some occasions the cell counts and types of phytoplankton are also available.

1) Remote sensing reflectance (R_{rs}) data collection- R_{rs} data will be used along with water sample data in fine tuning the already developed laboratory-based PC and other phytoplankton reflectance detection model, and also to validate the accuracy of the field-based model. We will use two calibrated Ocean Optics spectroradiometer for collecting hyperspectral R_{rs} data. The dual-fiber system, with two inter-calibrated radiometers, mounted on a platform will acquire reflectance data in the range 400-900 nm with a sampling interval of 0.3 nm. Radiometer #1, equipped with a 25° field-of-view optical fiber will be pointed downward to measure the surface upwelling radiance, $L_u\ (0^-,\lambda)$, whereas, Radiometer #2, equipped with an optical fiber and cosine diffuser (yielding a hemispherical field of view), will be pointed upward to acquire down welling irradiance, $E_d\,(0^-,\lambda)$. The two radiometers will be inter-calibrated immediately before and after measurements in each field site. After the data acquisition, R_{rs} will be calculated as follows:

$$R_{rs} = L_u\,(0^-, \lambda)/\ E_d\,(0^-, \lambda) \quad (1)$$

2) Measurement of physical parameters- The data suite will include temperature, pH, and dissolved oxygen conc. at each sampling location using YSI probes (Yellow Spring Instruments Inc., Ohio). These data will serve as collateral data while analyzing the seasonal dynamics of phytoplankton in the water.

Component 2: Satellite data acquisition and atmospheric correction:
Our previous research experience indicated that a successful PC detection model using satellite data requires a careful selection of spectral bands. Therefore, we intend to test our model on L2 HICO data. The HICO sensor collects hyperspectral image data over the continuous spectrum from 380 to 960 nm, sampled at 5.7 nm at a spatial resolution of 90 meters, with a very high signal-to noise ratio. Images will be acquired and georeferenced (± 0.2 pixel; nearest neighbor) by the application of well-characterized ground control points to remove any positional distortions. The field sampling date and time will be synchronized with satellite cross over timings to avoid the uncertainties in satellite observation and *in situ* measurements.
Component 3: Model output:
The model output will be maps indicating the spatial distribution of various types of phytoplankton concentrations in the study sites. All the maps will be validated for accuracy by analyzing the predicted versus the measured chlorophyll *a* concentrations and cell counts at each location. Successful validation will result in the production of series of surface algal blooms showing the quantitative distribution of toxic algae in IRL using hyperspectral

satellite data. Finally, a protocol document will be prepared detailing the step-by-step process starting from downloading satellite data to applying the detection model and generating toxic algae distribution maps. The algal bloom detection model along with the protocol document can be a powerful tool for local and state agencies for real-time monitoring of phytoplankton blooms in IRL.

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. 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 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 45 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 2011-2013 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 and now along the FL Atlantic coast 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 35 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 $22 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. His research always include combinations of field and satellite data to answer environmental questions. He also has access to facilities and equipment necessary to complete this project. For more on Co-PI's qualifications to conduct this research project, please refer to "biographical sketch" below.*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 SJRWMD, KSC, Volusia County, and FWC for their collaboration and assistance with obtaining 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 the partners including SJRWMD.

Output and Deliverables

III.1 Products

The immediate products of the project will be as follows: The immediate outcome of the project will be fourfold, (1) development of a semi-analytical model for detecting and mapping HAB using remote sensing, (2) application of the model to HICO data to produce maps of HAB distributions in IRL, (3) identification of critical hotspots and probable causes of HAB occurrence in IRL, and (4) a report recommending the most suitable HICO algorithms and protocols to be used to produce accurate quantitative maps of toxic algae distribution in coastal waters. At least one peer-reviewed publication is expected by the end of the project

III.2 Advancing the HICO mission

The proposed project location IRL, is a unique coastal region that have gone through several years of disasters associated with phytoplankton blooms of several species. 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 seagrass community, but also with 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 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 harmful phytoplankton mapping.

III. References

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