Evaluating color producing agents and assessing algal bloom dynamics in the coastal waters of South Carolina, USA, using hyperspectral data.

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ABSTRACT

Since 2004, the shallow coastal ocean environments off of South Carolina, USA have been experiencing repeated events of algal blooms that lead to developments of coastal hypoxia. Current observations indicating the decline in water quality clarity is based on the interpretation of limited *in situ* water quality and meteorological data. While these data provide point measurements of the biogeochemical dynamics that indicate water quality, they are lacking in both the temporal and spatial detail needed to understand the changes taking place at different parts of the waters (such as the near-shore verses offshore-zone), and the linkage between the water quality observations and the input sources. Such information can be crucial in understanding the processes behind the development of blooms to predict future hypoxia event and can be obtained from remotely sensing data. This study will employ a high resolution (GSD ~ 90m) HICO hyperspectral data to a) characterize the major color producing agents (CPAs) in the shallow coastal waters of SC, b) identify the various phytoplankton communities that exist and c) study the regional oceanographic process that constrain the water masses to near shore that potentially prevents the dispersion of terrestrial input. Regional biogeo-optical algorithms will be developed to accurately retrieve concentrations of CPAs. This study will also be used to calibrate and validate atmospheric corrections of HICO and validate HICO Level 2 products.

BACK GROUND

Coastal zones are complex and dynamic ecological systems that represent the most productive areas of the marine environment. They have important functions including primary food supply, recreation, biodiversity and transportation. These important functions and their scenic properties have resulted in the high population density building stress on these environments. To support the sustainability and better manage the resources it requires the understanding of the state of the conditions and enhanced capability of real-time monitoring of the resources. In coastal zones, a key index that can be used to assess the stress on the environment is the water quality. This is heavily influenced by the terrestrially derived inorganic and organic matters and the interaction of chemical, biological and physical components gives rise to the optical complexity, observed in the shallow coastal waters of Long Bay, SC, producing "Case 2" waters. Millions of people visit the beaches of South Carolina every year (MBCC, 2009). The state monitors beach water quality to ensure public health is protected. Conventional method of monitoring coastal waters is by *in situ* biogeochemical measurements and water samples that are taken 24 hours to process. Therefore, advisories may not be issued until the next day and thus today's advisory is based on yesterday's water quality (SECOORA, 2011). The conventional approach a) has limited spatial and temporal resolution and makes it difficult to understand the spatial and temporal dynamics of the water quality components which is a function of color producing agents (CPAs) such as phytoplankton, suspended materials and dissolved organic matter, and b) does not provide real-time beach advisories and/or effective early warning systems which are crucial to ensure public safety. Remote sensing (RS) technologies are being used worldwide to monitor aquatic systems and it provides an instantaneous synoptic overview of these systems once the data is calibrated using *in situ* measurements. This can provide unmatched, cost-effective, quantitative measures of change with spatial resolutions down to the order of meters. In the "Case 2" type coastal waters of SC, particularly in Long Bay, Bull Bay and Charleston optical characterization of the areas is essential for the understanding and the development of algorithms that transform measured spectral reflectance to estimates of CPAs.

PROBLEMS

Recently, repeated cases of algal blooms leading to hypoxic conditions have been observed in the shallow coastal ocean environments such as those along the open-ocean, shallow shelf, coastal region off of South Carolina (Sanger et al. 2010, Libes & Kindelbereger, 2010). Studies such as Conley et al., 2009 have shown that repeated occurrences of hypoxic events promote an increased susceptibility of further prolonged hypoxia and accelerated eutrophication.
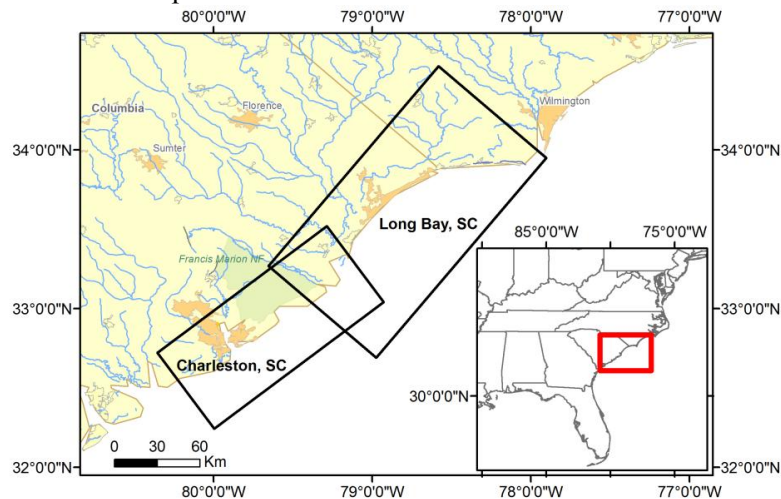

Fig. 1 Long Bay and Charleston, USA – highly urbanized environments with riverine inputs.

At this time, hypoxic conditions were found in the near-shore waters (5 to 7 m depth) off an open beach in the central portion of Long Bay, SC (Sanger at al. 2010, Fig 1). The current knowledge of the decline in water clarity at Long Bay, SC is based on the interpretation of data from two continuous monitoring stations and individual research projects which were carried out between 2006 and 2008 (Sanger et al., 2012). The *in situ* measurements made include DO, temperature, conductivity, nutrient concentration (various forms of nitrogen and phosphorus), DOM and chlorophyll concentration. While these data provide point measurements of the biogeochemical dynamics that indicate water quality, they are lacking in both the temporal and spatial detail needed to understand the changes taking place at different parts of the waters (such as the nearshore verses offshore-zone), and the linkage between the water quality observations and the input sources. For example, measurements made at the few sites provide little information about how nutrients and sediments are transported throughout the coastal water by currents. Such information can be crucial in understanding the processes behind the development of algal blooms to predict future hypoxia event and can be obtained from remotely sensing data. Empirical and semi-analytically based remote sensing algorithms that retrieve concentrations of the CPAs are widely available. However the complex interactions of the physical, chemical and biological process at local environments and the lack of knowledge of the bio-optical properties specific to the region results in inaccuracies and poor performance in the standard algorithms. Various studies in coastal waters have demonstrated the need for regional algorithms in order to accurately retrieve concentrations of CPAs. Moreover, satellite data needs to be calibrated and validated due to complexities of satellite observations (e.g. atmospheric interferences or issues pertaining to spatial and temporal sampling). Monitoring of narrow stretch of near-shore coastal waters also requires high GSD sensor data.

Through this study we plan to put in place a system to utilize remotely sensed and field measurement data to determine the bio-optical properties and quantify water clarity measurements over the narrow belts of the coastal waters of Long Bay and Charleston using a high resolution (90 m pixel size) hyperspectral HICO data. These data can be used to create maps of water clarity to within 90 m of the shoreline and to assess the impacts and fate of individual sources such as a highway drain. The changes in near-shore clarity at particular areas of interest, such as near stream inflows, can be observed in time series derived from these clarity maps.

OBJECTIVES

1) To identify the primary "Case 2" water constituents in the coastal waters of SC using various analytical approaches applied to hyperspectral data.
2) To measure and characterize the optical properties of the coastal waters of SC using field and lab-based instruments.
3) To perform multivariate calibration of spectrally derived components using *in situ* data.
4) To develop robust regional algorithms to estimate in-water constituents over the coastal waters of SC from HICO sensor data abroad ISS.
5) To perform calibration and validation of existing atmospheric corrections of HICO and validate HICO products
6) To provide a platform, and opportunity for training undergraduate and Master's students in field/lab techniques using new and advanced technologies of optical/biophysical oceanography.

In order to achieve the above objectives, the project requires HICO data level L1B at the selected target sites (Fig 2) and L2B for validation purpose of the derived products

TARGET SELECTION (2 TARGETS)

1. Center point for **Long Bay, SC** is 78°58'7.3"W 33°23'34.3" N (Priority Target 1)
2. Center point for **Charleston, SC** is 79°58'11.37"W 32°35'48.6" N (Priority Target 2)
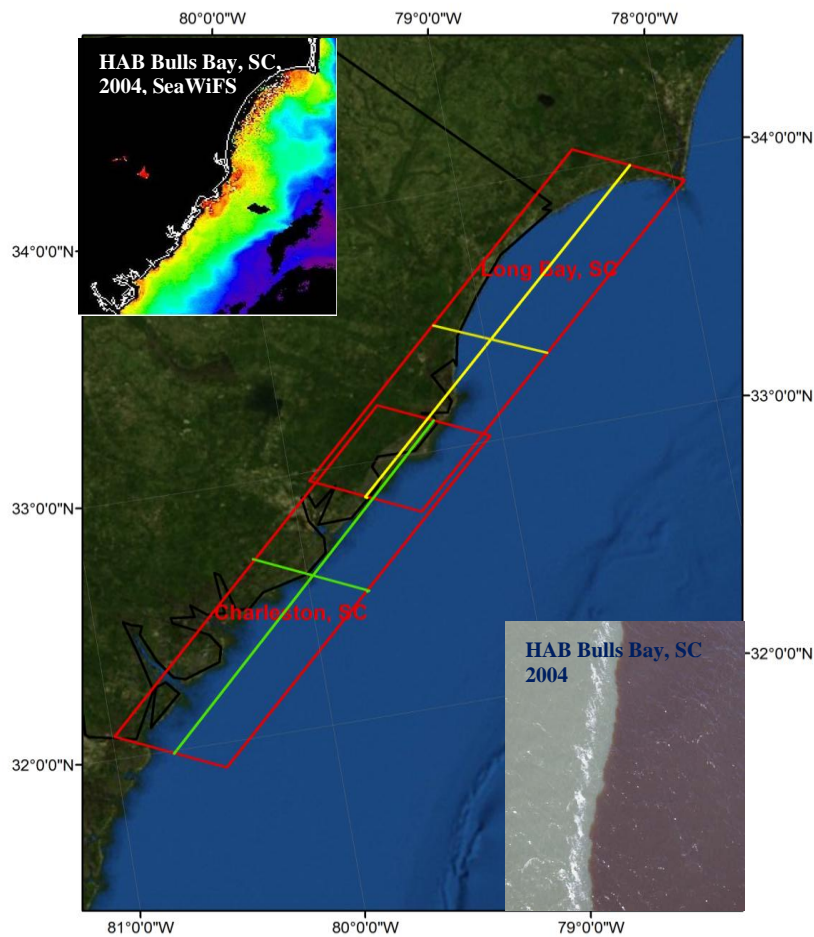

Fig. 2. Selection of two target sites for HICO footprint.

RATIONALE

Our collaborative water quality research group consists of Dr. Adem Ali (Remote sensing and water quality; College of Charleston), Dr. Amin (Remote Sensing; NRL Stennis Space Center), Dr. Ortiz (Oceanography; KSU Geology), and several students (2 graduate and 2 undergraduates at the College of Charleston). The research group has extensive experience in conducting water quality studies. Our efforts will focus on the coastal waters where the presence of multiple color-producing agents (e.g. chlorophyll a, suspended sediments, and CDOM) results in optical complexity, producing "Case 2" water. We plan to conduct sampling cruises during the fall of 2012, spring of 2013 and throughout the summer period of 2013 and continue to assess temporal variability at a 90 pixel resolution provided by HICO. Our research group has excellent record of data dissemination. We have presented previous results at several regional, national and international-level conferences including the American Geophysical Union (AGU), 2011 and the International Association of the Great Lakes Research (IAGLR), 2009, 2010, 2011. Results from 2012 cruises will be presented at the HICO annual meeting and Ocean Science meetings. We have also published a paper on water quality studies in Lake Erie in the Journal of Great Lakes Research, 35(3):361-370.2009, and have two manuscript that has been accepted pending revision in the Journals of Remote Sensing and Journal of Geocarto.

BIOGRAPHICAL SKETCH

Dr. K. Adem Ali, P.I., is an Assistant professor in Remote Sensing and GIS at the College of Charleston, SC, USA. He has been working on developing satellite based algorithms that can accurately retrieve biogeochemical constituents in optically complex aquatic environments. Adem is involved in developing bio-optical models using several methods including, PCA, PLS, wavelets and ANN to retrieve multiple color producing agents in "Case 2" type waters.

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- **Ali, K.A**, Witter, D.L and Ortiz, J.D (2010). An improved method for optical-feature extraction from multi-spectral data. International Association of Great Lakes Research (IAGLR)-53nd Annual conference, Oral, (18-22 May 2010), Toronto, OT, Canada.
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Dr. R. Amin is a research scientist at the Naval Research Laboratory at the Stennis Space Center, Mississippi. He has developed optical algorithms to detect and classify harmful algal blooms from space and also optical cloud shadow detection technique for ocean color sensors. Dr. Amin's current research interests include optical algorithm development, atmospheric corrections, cloud-shadows, fluorescence, and harmful algal blooms.

- **Ruhul Amin**, David Lewis, Richard W. Gould, Weilin Hou, Adam Lawson, Michael Ondrusek, and Robert Arnone, "Assessing the application of cloud shadow atmospheric correction algorithm on HICO," Environ. Res. Lett. (submitted)

- **Ruhul Amin**, Richard W. Gould, Weilin Hou, and Robert A. Arnone, "Optical Algorithm for Cloud Shadow Detection over Water," IEEE Trans. Geosci. Remote Sens. (accepted on June 4, 2012)
- **Ruhul Amin**, Jing Zhou, Alex Gilerson, Barry Gross, Fred Moshary and Samir Ahmed, "Novel Optical Techniques for Detecting and Classifying Toxic Dinoflagellate *Karenia brevis* Blooms Using Satellite Imagery," Optics Express Vol. 17, Iss. 11, pp. 9126-9144 (2009). Selected and republished in the Virtual Journal for Biomedical Optics Vol. 4, Iss. 7, (2009).

PATENT: *Optical Cloud Shadow Detection Technique Over Water*, reported to Naval Research Laboratory, Washington, DC, 3/14/2011, NAVY # 101062

Dr. Joseph, D. Ortiz is a Professor in the Department of Geology at Kent State University. He is an expert in VNIR derivative spectroscopy, remote sensing, and physical properties (grain size and elemental analysis). His current research is focused on the decomposition of derivative spectroscopic data sets to extract information about algal pigment classes, clay minerals, iron oxyhydroxides, carbonates, and siliciclastics. He has applied these methods to various classes of earth materials including: filtered water samples, and lacustrine and marine sediment.

- See publication and presentations above with K.A. Ali
- **Ortiz, J.D.,** Nof, D., Polyak, L., St. Onge, G., Lise-Pronovost, A., Naidu, S., Darby, D., and Brachfeld, S. 2012: The Late Quaternary flow through the Bering Strait has been forced by the Southern Ocean Winds. JPO, Early online release: 7/19/2012, (doi: 10.1175/JPO-D-11-0167.1).
- **Ortiz, J.D.,** Application of Visible/near Infrared derivative spectroscopy to Arctic paleoceanography, IOP Conf. Series: Earth and Environmental Science 14, 2011, 012011 doi:10.1088/1755-1315/14/1/012011, (http://iopscience.iop.org/1755-1315/14/1/012011/pdf/1755-1315_14_1_012011.pdf)
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PATENT: KSU.348: US Utility Patent Application for "Core measurement stand for use with a portable XRF scanner", Ser. No.: 12/769,892; 2010

AVAILABLE FACILITIES

The Geology department at the College of Charleston has the necessary facilities and instruments (1-10 listed below) to run a program of sampling and observations along the coastal and Bay waters in South Carolina. Moreover, additional instruments (11-16, listed below) will also be available from Naval Research Laboratory (NRL), Stennis Space Center (SSC). Under previous NASA funding, NRL has developed atmospheric correction and new satellite ocean color inversion algorithms that have been implemented in NRL's Automated Processing System (APS). APS produces daily near real time ocean color products from various ocean color sensors including HICO. NRL/SSC has written APS, which is capable of processing real-time and archived AVHRR, SeaWiFS, MODIS, MERIS, VIIRS, and HICO satellite imagery. APS is a powerful, extendable, image-processing tool. It is a complete end-to-end system that includes sensor calibration, atmospheric correction, and bio-optical inversion. APS incorporates, and is consistent with, the latest NASA MODIS code and enables us to produce the NASA standard MODIS products, as well as Navy-specific products using NRL algorithms [7]. This allows us to test and validate new products and algorithms, and to reprocess many data files (dozens of scenes/day). Furthermore, we can automatically extract image data from regions-of-interest to facilitate time-series analyses and from specific locations for match-ups with in situ data. NRL/SSC is one of only a few institutions that has digested and implemented the complete MODIS processing code, and also have implemented VIIRS processing. NRL maintain the code for compatibility with NASA/Goddard.

1. GER 1500 spectroradiometer to measure water leaving radiance and above surface down welling irradiance
2. ASD Field Spec 4 Hi-Res spectroradiometer
3. Submersible water quality data logger YSI 6600V2 (15 water quality parameter including optical sensors for chlorophyll a, phycoerythrin and CDOM
4. Flow through spectrophotometer for CDOM
5. TD-700 Fluorometer for pigments, and CDOM
6. HPLC for pigment analysis
7. Scanning electron microscope for compositional analysis of inorganic sediments
8. High powered Linux systems equipped with IDL / ENVI 4.8 (ITT VIS), SeaDAS 6.4 (NASA) and ArcInfo 10.1 (ESRI)
9. 10 workstations for image processing and data analysis.
10. Dedicated RV- 30" (assuming it's a 30' feet boat) boat for access to the field
11. IOP profiling package
12. Optical Phytoplankton Discriminator (OPD)
13. Gliders
14. HyperPro
15. LISST
16. Flow Cytometer

OUTPUT DELIVERABLES

Publications in peer review journals
Presentation of Results at the HICO annual meeting
Validation and calibration of HICO atmospheric correction modules and L2B products

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