

# HICO Imagery for Geospatial Analysis of Organic Carbon, Phytoplankton, and Tidal Wetlands of the Georgia Coast & SAB

Principal Investigator: John F. Schalles  
Creighton University  
Biology Department  
Omaha, NE 68178-0103 USA  
TEL: 1-402-280-2811  
FAX: 1-402-280-5595  
Email: [JohnSchalles@creighton.edu](mailto:JohnSchalles@creighton.edu)

Co Investigator: William L. Miller, Jr.  
University of Georgia  
Marine Science Department  
Athens, GA 30602-3636 USA  
TEL: 1-706-542-4299  
FAX: 1-706-542-5888  
Email: [bmiller@uga.edu](mailto:bmiller@uga.edu)

PI signature, date

Designated Creighton Univ. official signature, date

---

Dr. John F. Schalles

---

Dr. Patrick J. Borchers, V.P. for Academic Affairs

## Abstract/project summary

The Georgia coast has large expanses of tidal salt marsh, high tidal amplitudes, and coastal rivers and estuaries with individual and variable mixtures of inorganic nutrients, organic carbon, and algal and non-algal particulates (including clays and detritus). The offshore system has net heterotrophy, and is the focus of major carbon cycling and mass balance studies. Collectively, we have an extensive spectral library and ancillary water constituent data for this coastal domain. We propose to use HICO imagery of the Georgia coast to test our Case 2, coastal water algorithms for (1) phytoplankton chlorophyll, (2) total suspended matter, (3) CDOM, (4) photochemical oxidation of carbon substrates, and (4) tidal salt marsh biomass. Our algorithms are parameterized with data from extensive optical and water constituent analyses within the South Atlantic Bight and additional Case 2 coastal water domains. Our site, which includes optically complex waters of estuaries, sounds, and the shelf waters of the South Atlantic Bight, exhibits high spatial and temporal variability and represents a robust test of both our algorithms and HICO imagery data.

## 1. Statement of work/project description

**A. Background:** We are seeking a time series of HICO imagery for the Georgia Coast (estuaries, sounds, coastal wetlands, and nearshore waters). Our two groups (Miller lab at University of Georgia; Schalles lab at Creighton University) have extensive background and baseline data and derived algorithms for CDOM, photochemical oxidations, and algal chlorophyll for the central Georgia coast. Large spatial and temporal variation exists due to differences in watersheds, vegetation phenology, and precipitation patterns. The adjacent South Atlantic Bight (SAB) is a net heterotrophic portion of the NW Atlantic Boundary current region, effluxing about  $2.5 \text{ mol CO}_2 \text{ m}^{-2} \text{ yr}^{-1}$  and laterally transporting about  $4.5 \text{ mol CO}_2 \text{ m}^{-2} \text{ yr}^{-1}$  equivalent carbon to the open ocean (Jahnke, 2010). Coastal wetlands are a significant, but not well quantified source of this extra carbon respired within or exported from SAB waters. The central SAB ( $\sim 31^\circ$  and  $33^\circ$  N latitude) accounts for the majority of all coastal wetlands and river discharges within this region.

**B. State of the Field:** For remote estimation of chlorophyll *a* in turbid, Case 2 waters several approaches using the pigment's red absorption band at 675 nm and the fluorescence and scattering peak of phytoplankton near 700 nm are utilized by our group (Schalles et al., In Press; Schalles, 2006; Gitelson et al., 2007; Zhou et al, 2008). These procedures largely correct for non-algal particle scattering and CDOM light attenuation. Providing there is sufficient backscatter signal, these algorithms greatly improve Chl estimation in Case 2 waters compared to conventional ocean color schemes using bands in the blue to green portion of the visible spectrum. Application of these alternative schemes to coastal systems has thus far been limited by band sets and spatial resolution of ocean color sensors. Hyperspectral AISA and NCALM Lidar data were recently used to map (1 m resolution) vegetation at species level, aboveground plant biomass, and substrate elevation for the Duplin River marshes at Sapelo Island (Hladik et al., In Review).

New methods for biogeochemical cycles using remotely sensed data now reach well beyond simple estimates of chlorophyll. Using a principal component analysis (PCA) to estimate attenuation of UV radiation from ocean color (Fichot et al., 2008), Fichot and Miller (2010) have outlined methodology for calculating photochemical and photobiological rates in surface waters. This will broaden the study of elemental cycles in the ocean to include DOC photooxidation, redox cycling of biologically important elements, trace gases exchange, and UV effects on primary production. This approach has been proposed for carbon monoxide production and the current model is appropriate for multispectral (SeaWiFS & MODIS) data from blue water and shelf systems. The model needs confirmation and testing in dark coastal waters and must be updated for the high spatial and spectral resolution required for inshore remote sensing.

**C. HICO Data Requested and Utility to the Proposers:** We request coverage for multiple dates (four or more to capture phenology and variations in river discharges) centered on the Georgia coast at:

**latitude 31° 24' 50" N and longitude 81° 11' 0" W**

Provision of Level 2 processing is requested (particularly atmospheric correction to produce a HICO hyperspectral image cube). We are proposing to apply our pigment, organic carbon, and photochemistry algorithms to produce products useful in studying the sources and fates of materials outwelling from a region of extensive tidal marshes and associated inshore waters into the SAB. In addition, the spatial distribution of plumes, fronts, plankton chlorophyll, and CDOM in response to river discharges, tidal dynamics, and shelf circulation patterns is very important to understanding the ecology and carbon balances of this system. A significant issue in refining carbon budgets for the SAB and other heterotrophic shelf waters is the partitioning of organic carbon between rivers as point-sources of inland derived carbon versus non-point source tidal marshes and inshore and near shore phytoplankton. The results of our proposed study are also valuable to the Georgia Coastal Ecosystems LTER project, and the ability to model this complex system, which displays high spatial-temporal variability (GCE-LTER).

**D. Study Site:** Georgia, with about 160 km of coastline, accounts for about 33% of all East Coast salt marshes (Wiegert and Freeman, 1990). The coastal system here is notable for its extensive salt marshes, broad shelf, low wave energy and high tidal energy of nearshore waters, and turbidity plumes extending 10-20 km offshore, bordered seaward by salinity and or turbidity fronts (Hopkinson and Wetzel, 1982). These near shore turbidity plumes and fronts are well depicted in a March, 2010 World View 2 satellite image (Figure 1). Altamaha River discharge on that date was  $1030 \text{ m}^3 \text{ sec}^{-1}$ , which was 12.5% greater than a 78 year average for March flows. Note the brown, clay turbid water of the Altamaha River in its outwelling plume and the lateral transport of this river into tidal passages and the Doboy Sound to the north. Doboy Sound's hydrology is dominated by tidal exchanges, but also by freshwater inputs at higher Altamaha River flows. In contrast, Sapelo Sound, between Sapelo and St. Catherine's Islands, is a tidal system with minimal freshwater influence. Constrained by frontal boundaries, primary productivity and chlorophyll patterns typically decrease by an order of magnitude in the first 10 -15 km offshore, whereas the outer shelf is dynamic and largely driven by upwelling episodes (Bishop et al., 1980).



Figure 1. Central Georgia Coast and nearshore waters (World View 2 image Mar 26, 2010; DigitalGlobe).

The combined river, hydrological, and tidal dynamics of this marsh-dominated coast produce a complex setting for evaluation of carbon cycling, requiring long-term, high resolution observations. Cai (2011) summarized the complexity of this region and notes that in the short distance between the Altamaha River and Sapelo Sound (Figure 1), the contribution of DIC to the ocean shifts dramatically. Altamaha river water contains less DIC than the seawater it joins while Sapelo Sound water is oversaturated with  $\text{CO}_2$  due to respiration of marsh production. Also, the DOC exported by these marshes is estimated to be 54% of their NPP and contributes ~86% of the total DOC exported to the SAB; and combined river export adds the

additional 14%. The dominant interactions between tidal flushing and marsh dynamics create a complex, non-point source system for carbon cycles that is difficult to quantify and spatially depict. Accurate CDOM retrieval provides a window into the spatial and temporal workings of this complex DOC story.

***E. In Situ and Other Data*** - Our two laboratories have conducted systematic measurement programs of the hydrologic optics, bulk optical properties, vertical water column structure, and carbon photochemistry processes within the shelf waters and adjacent inshore sounds, tidal watersheds, and coastal plain rivers of the Georgia coast. These existing data sets, plus our considerable experience in these aquatic systems, are valuable assets for the classification and interpretation of HICO imagery for the Georgia Bight and broader South Atlantic Bight domain. Ancillary data sets also include the monitoring network of the Georgia Coastal Ecosystem LTER, a decade (1999 – 2009) of South Atlantic Bight Synoptic Offshore Observational Network (SABSOON) data, the NOAA Station 41008 Data Buoy, USGS discharge data for Georgia coastal rivers, and 59 years of coastal research conducted at the University of Georgia Marine Institute, which includes hydrology, biogeochemistry, inshore and nearshore phytoplankton and microbial assessments, and marsh productivity and community ecology.

## **2. Investigator Biographical Sketches and Available Facilities and Equipment**

**Dr. John Schalles** is Professor of Biology and Director of the Environmental Science Program at Creighton University in Omaha, Nebraska. He earned a B.S. in Biology at Grove City College (1971), an M.S. in Zoology at Miami University (1973), and a Ph.D. in Biology at Emory University (1979). He served as chair of the Creighton Biology Department from 1998-2006. Dr. Schalles was lead scientist for the Geospatial Analysis and Data Development thematic group within the NOAA-NCCOS Environmental Cooperative Science Center. As lead scientist, he has directed nine hyperspectral AISA image acquisitions and accompanying field surveys at seven National Estuarine Research Reserves located between Texas and Delaware. He has \$511 K in current awards (NOAA, NASA, and NSF) and had \$786K in additional awards over the past decade (NOAA, NASA, and NSF). Dr. Schalles has or has held visiting appointments with the University of Georgia Marine Institute, USDA-ARS, University of Nebraska-Lincoln, Savannah River Ecology Laboratory, and Iowa State University. He has served as a consultant and panelist for NOAA, NRC, USEPA, USDOE, BLM, and US Department of State. Dr. Schalles has authored or co-authored 39 papers, given more than 160 professional presentations, and has supervised 15 graduate and 87 undergraduate students in research at Creighton. In 2010 he received the Creighton College of Arts and Sciences Award for Professional Excellence in Scholarship and the Nebraska Chapter of the Sierra Club's Environmental Educator Achievement Award.

**Dr. William Miller** is a Professor in the Department of Marine Science at the University of Georgia in Athens, GA and the Director of UGA's Marine Institute on Sapelo Island. He earned a B.A. in Biology at Wake Forest University (1979), a M.Sc. in Marine Science at the University of South Florida (1985), and a Ph.D. in Oceanography at the University of Rhode Island (1990). Dr. Miller was a chemical contractor, then a National Research Council postdoctoral fellow with the U.S. EPA in Athens, GA before joining the faculty in the Department of Oceanography at Dalhousie University in Halifax, Nova Scotia, Canada. While in Canada Dr. Miller served as PI for the Canadian Surface Ocean Lower Atmosphere (SOLAS) program, the largest national oceanography effort at the time, and served on numerous International groups related to the IGBP SOLAS organization. Returning to the US in 2004, Dr. Miller serves as a Full Professor with 50% effort dedicated to research and limited teaching, and 50% to administration. Research funding since 2004 amounts to just over \$1.5M (NASA, ONR, Sea Grant, NSF) and current funding from NSF is \$397K to study photochemistry in the North Pacific. He has more than 50 peer-reviewed publications, over 100 scientific presentations at national and international conferences, has served as committee member for 21 graduate students, external examiner for 5 Ph.D. defenses, advisor for 3 postdoctoral scientists, and is/was major professor for 5 Ph.D. (3 graduated) and 7 M.Sc. (6 graduated) students. He has served on review panels for NASA, NSERC Canada, Dept. Fisheries & Oceans Canada, and as a reviewer for numerous international funding agencies and scientific publications, currently an Associate Editor for Marine Chemistry. Dr. Miller has been a visiting professor at the University of Marseilles, Luminy, France (working with CNRS), and the University of Tokyo, Atmosphere Ocean Research Institute, Kashiwa, Japan.

**Facilities** - The University of Georgia Marine Institute (UGAMI) on Sapelo Island is the operational base for our coastal field programs. UGAMI has a fleet of small boats, field vehicles, running seawater labs, analytical labs, office space, and on-island housing. New fiber optic campus connections to a high-bandwidth microwave (NSF funded) provides good internet connection to the mainland. As Director, Dr. Miller will coordinate support for both field and laboratory operations based at UGAMI. Miller's group maintains laboratory facilities at both the UGA Marine Science Department (Athens, GA) and at UGAMI (Sapelo Island, GA) relevant to this project. Both labs contain facilities for wet chemistry, sterile and clean techniques with vented hoods, autoclaves, controlled environment incubators, filtration equipment, water baths and the usual laboratory equipment. Miller's field equipment includes the following: - A Satlantic MicroSAS for above water radiometric measurements w/ (1) sensor for above-surface multispectral UV downwelling irradiance: 305, 325, 340 and 380nm, (1) sensor for above-surface multispectral Visible downwelling irradiance: 412, 443, 490, 510, 555, 670 and 683nm, (2) sensors for below-surface multispectral Visible upwelling radiance: 412, 443, 490, 510, 555, 670 and 683nm, w/ data acquisition & logging system (Stor-X), a Satlantic MicroPRO for vertical attenuation profiling w/ (1) sensor for above-surface multispectral UV downwelling irradiance: 305, 325, 340 and 380nm, (1) sensor for above-surface multispectral Visible downwelling irradiance: 412, 443, 490 and 555nm, (1) sensor for below-surface multispectral UV downwelling irradiance: 305, 325, 340 and 380nm, (1) sensor for below-surface multispectral Visible downwelling irradiance: 412, 443, 490 and 555nm, and built-in depth sensor, and a Satlantic ISUS for beam attenuation and nitrate (details of these Satlantic instruments can be found at <http://www.satlantic.com/>).

Laboratory equipment available at UGAMI and UGA includes the following: A 1.5 kilowatt DSET Suntest CPS solar simulator, an OL Series 756 portable UV-VIS spectroradiometer with an OL 752-10 plug-in spectral irradiance NIST standard lamp for calibration, a Perkin-Elmer UV/Visible Lambda 40 spectrophotometer, a Perkin Elmer LS50B spectrofluorometer, a World Precision Instruments 1-m pathlength liquid waveguide capillary cell, a Shimadzu TOC-V CPN analyzer w/ autosampler (IC mode for CO<sub>2</sub> determinations), and (2) Millipore Milli-Q UV high purity water systems w/ Elix supply. Computational capacity for image analysis, spectral calculations, matrix operations, photochemical statistical calculations, etc. is more than sufficient for the proposed work (multiple Apple Intel Core Duo computers). The Marine Science Department at UGA pays a dedicated computer technician available to support all faculty projects. Access to NASA ocean color products is ongoing and has been used in previous projects. We maintain IDL and Matlab licenses to generate mapped products similar to those anticipated as deliverables for this project. The University of Georgia provides excellent infrastructure for access to outside data and supplies, and dedicated support staff for technical and computer intensive research.

The Schalles Lab at Creighton has the following relevant capabilities: dual Ocean Optics USB2000 Spectroradiometers for simultaneous measurement of solar downwelling irradiance and target radiance/reflectance, CDAP operating software (Univ. Nebraska CALMIT) with real time spectral data display, fiber optic cables and foreoptics, YSI 6600 multi-instrument profiling sonde which includes a turbidimeter and chlorophyll fluorometer, and high resolution GPS. This equipment, and standard sampling gear, is deployed on the University's customized 5.5 m Sundance Skiff with Raymarine navigation instruments and charts. The laboratory routinely performs algal pigment (including HPLC), phytoplankton taxonomy, CDOM, and suspended matter analyses. Spectroradiometer data are processed with CDAP and MS Excel. The lab has 4 ENVI and ArcGIS workstations, and a dedicated Netgear ReadyNAS Pro server with 8 TB storage. His group uses the WASI water optics model and has access to Hydrolight software.

### **3. Output and Deliverables**

**A. Products** - We will apply and evaluate our own chlorophyll and organic carbon retrieval algorithms (see Section B) with HICO data. We will also evaluate current algorithms for total suspended matter (TSM) using our existing spectral library and TSM estimates, and select, parameterize, and apply the best model. We will produce the following from our analyses: (1) spatially explicit maps of chlorophyll, TSM, CDOM, and UV attenuation for the estuaries, sounds and coastal waters in each HICO scene; (2) evaluation of the

PCA approach of Fichot and Miller (2010) for calculating and mapping photochemical and photobiological processes (for example, DOC photo-oxidation rate, and carbon monoxide and CO<sub>2</sub> production); and (3) evaluation of HICO for synoptic mapping of salt marsh vegetation indices and above-ground biomass, as part of ongoing work for the Georgia Coastal Ecosystems LTER.

**B. Advancing the HICO Mission** - The location of our project adds a coastal region with properties not yet represented in the HICO North American network; i.e. one with semidiurnal tides with high amplitudes, extensive and productive coastal wetlands, rivers and estuaries with large intra and intersite variabilities, and a broad shelf region with a heterotrophic water column. Our substantial experiences with hydrological optics and measurements in this region, coupled with algorithms tuned to waters dominated by highly turbid, case 2 waters, provide an opportunity to compare and contrast algorithm approaches in a highly robust and challenging optical environment.

**C. HICO Team Meeting** - At least one investigator, and possibly both Schalles and Miller will attend an annual meeting, present project results, and join in discussions about uses and applications of HICO data.

#### 4. References

- Bishop, S.S., J.A. Yoder, and G.-A. Paffenhofer. 1980. Phytoplankton and nutrient availability along a cross-shelf transect off Savannah, Georgia, U.S.A. *Estuar. Coastal Mar. Sci.* 11: 359-368.
- Cai, W.-J., Wang, Z.A., Wang, Y., 2003. The role of marsh-dominated heterotrophic continental margins in transport of CO<sub>2</sub> between the atmosphere, the land-sea interface and the ocean. *Geophys. Res. Lett.* 30, 1849.
- Cai, Wei-Jun (2011) Carbon Paradox: CO<sub>2</sub> Sinks or Sites of Terrestrial Carbon Incineration? *Annu. Rev. Mar. Sci.* 2011. 3:123-45. doi: 10.1146/annurev-marine-120709-142723
- Fichot C. G., S. Sathyendranath, and W. L. Miller (2008) SeaUV and SeaUVC: Algorithms for the retrieval of UV/Visible diffuse attenuation coefficients from ocean color. *Remote Sens. Environ.* 112:1584-1602.
- Fichot C. G., and W. L. Miller (2010) Quantifying marine photochemical fluxes using remote sensing: a monthly, global, depth-resolved climatology of carbon monoxide (CO) photoproduction. *Remote Sens. Environ.* 114; 1363-1377.
- Hladik, C.M., M. Albers, and J.F. Schalles. Data fusion of hyperspectral and LIDAR imagery for salt marsh mapping. *Remote Sens. Environ.* (In Review).
- Hopkinson, C.S., and R.L. Wetzel. 1982. In situ measurements of nutrient and oxygen fluxes in a coastal marine benthic community. *Mar. Ecol.-Prog. Ser.* 10: 29-35.
- Georgia Coastal Ecosystems LTER. GCE Research Program. Retrieved July 26, 2011 from <http://gce-lter.marisci.uga.edu/public/research/research.htm>
- Gitelson, A.A., J.F. Schalles, and C.M. Hladik. 2007. Remote chlorophyll-a retrieval in turbid, productive estuarine waters: Chesapeake Bay Case Study. *Remote Sens. Environ.* 109(4): 464-472
- Gitelson, A.A., B-C Gao, R-R Li, S. Bernikov, and V. Sapygin. 2011. Estimation of chlorophyll-a concentration in productive turbid waters using a Hyperspectral Imager for the Coastal Ocean—the Azov Sea case study. *Environ. Res. Lett.* 6: 024023 (6 pp).
- Schalles, J.F., and C.M. Hladik. Mapping phytoplankton chlorophyll in turbid, Case 2 estuarine and coastal waters. *Israel J. Plant Sci.* (Invited Paper; In Press)
- Schalles, J. F. 2006. Optical remote sensing techniques to estimate phytoplankton chlorophyll *a* concentrations in coastal waters with varying suspended matter and CDOM concentrations. In: (L. Richardson and E. Ledrew, editors) *Remote Sensing of Aquatic Coastal Ecosystem Processes: Science and Management Applications*. Springer. pp. 27-79.
- Wiegert, R.G. and B.J. Freeman. 1990. Tidal salt marshes of the Southeast Atlantic coast: a community profile. U.S. Fish and Wildlife Service. *Biol. Rep.* 85 p.
- Zhou, J., A. Gilerson, I. Ioannou, S. Hlaing, J. Schalles, B. Gross, F. Moshary, and S. Ahmed. 2008. Retrieving quantum yield of sun-induced chlorophyll fluorescence near surface from hyperspectral *in-situ* measurement in productive water. *Opt. Express* 16(22), 17468-17483.