**HICO Data User's Proposal**

# Optical Variability and Remote Sensing of Inland Lakes Across the State of Wisconsin

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**Abstract**

The Wisconsin Department of Natural Resources has funded a pilot project to measure optical variability in inland lakes across the State of Wisconsin in the summer of 2011. The optical data will be used to evaluate/refine/develop algorithms for use with multispectral and hyperspectral (if this data use request is approved) imagery to retrieve parameters such chlorophyll concentration, absorption of non-algal particles and colored dissolved organic matter. The multispectral and hyperspectral imagery will be compared for potential product suites and accuracy of the respective retrieved parameters. Additionally the subpixel variability of the 300 m multispectral imager will be compared with the 95 m hyperspectral imager to help inform planning of the NASA GEO-CAPE mission.

**Project Description**

Lakes across the State of Wisconsin have a variety of optical, physical, biological, and chemical variability associated with the lake class and surrounding land use. These lakes play a role in carbon processing across the landscape and have considerable recreational value. The Wisconsin Department of Natural Resources (WDNR) has an interest in monitoring these lakes for management purposes and the University of Wisconsin-Madison has an interest in observing spatial variability and change through time. Previous and on-going, Landsat imagery has been used to quantify clarity in these lakes (Figure 1). While water clarity has been an effective screening tool, it does not provide constituent concentrations that would help to further inform academic research and state agency management. The spectral band placement and bandwidth precludes Landsat from being able to discern optical constituents within aquatic water bodies. Ocean color radiometers such as **Sea**-viewing **Wi**de **F**ield-of-view **S**ensor (SeaWiFS) and **MOD**erate resolution **I**maging **S**pectroradiometer (MODIS) that are used for optical differentiation of chlorophyll, non-algal particles, colored dissolved organic matter (CDOM), and other parameters, have a spatial resolution of 1 km, which is too coarse to characterize spatial variability within the size of lakes found in the State of Wisconsin. The European Space Agency's **ME**dium **R**esolution **I**maging **S**pectrometer (MERIS) full resolution imagery is 300 m and has been used to experimentally to characterize relative variability within Wisconsin inland lakes (Figure 2).

An optical dataset is necessary to be able to evaluate how existing algorithms are performing in these inland lakes. Extensive databases exist for the North Temperate Lakes Long Term Ecological Research sites, which include the Madison Lakes Region and the Trout Lake Region (http://lter.limnology.wisc.edu/). The research at these LTER sites is facilitated by the Center for Limnology at the University of Wisconsin-Madison. The WDNR also has an extensive dataset of ancillary data for many lakes across the state. However, optical data specific to understanding satellite algorithm performance has been lacking. The WDNR has funded a pilot study to characterize optical properties across a variety of lakes within the state during the summer of 2011 to aid in the refinement and development of satellite algorithms. The initial scope of the effort was to utilize MERIS imagery. However, with the advent of the availability of Hyperspectral Imager for the Coastal Ocean (HICO) data, we would like to explore the potential HICO imagery has to help characterize variability within inland lakes in Wisconsin at higher spatial and spectral resolution than any other available imagery set with correct band placement and signal to noise for remote sensing of aquatic targets.

The Upstate Freshwater Institute (UFI, Syracuse, NY) has the necessary instrumentation to perform a full coincident optical survey of the inherent optical properties (IOPs) and apparent optical properties (IOPs) (Table 1). We have contracted with UFI to make the optical observations across a variety of lakes in Wisconsin (Figure 1) between June 14 -21, 2011. In addition to UFI's equipment and laboratory services, UW-Madison and WDNR have dedicated equipment and expertise to most fully sample and interpret the optical and biological variability between lakes. Colleen Mouw will work with the UFI and WDNR datasets collected during the field survey to evaluate a suite of remote sensing algorithms. These will primary include inversion algorithms that coincidently retrieve [Chl], NAP and CDOM. Additionally, algorithms that utilize the red-edge region of the spectrum that have been successful with hyperspectral data will be explored.

**Goal:** Develop a robust remote sensing approaches to quantify lake optical parameters including chlorophyll concentration, non-algal particles, and colored dissolved organic matter. Explore the product suite and accuracy retrieval potential between multispectral and hyperspectral imagers.

**Objectives**

1) Characterize Wisconsin lake optical properties. Fifteen Wisconsin lakes representing a range of lake water quality conditions have been selected (Table 2). The lakes were identified based on a range of previously determined clarity (from Landsat imagery), class (drainage vs. seepage, depth, and size) surrounding land use variability impacting eutophication and availability of ancillary data. Two staff from Upstate Freshwater Institute (UFI) along with their optical instrumentation will travel to Wisconsin from June 14-21, 2011. WDNR will supply field vehicles, boats, and logistics. Full analysis and characterization of each lake's absorption, scattering, ternary dominance of chlorophyll, non-algal particles, and colored dissolved organic matter, as well as phytoplankton identification and sizing will be carried out.

2) Evaluation, refinement and development of optical algorithms using multispectral (MERIS) and hyperspectral (HICO) imagery. MERIS and potentially HICO imagery coincident with the above field campaign will be acquired. NASA currently achieves MERIS full resolution imagery for North America and imagery of Wisconsin is freely available from January 2009 to the present. Spectral remote sensing reflectance ($R_{rs}(\lambda)$) observed by MERIS and potentially HICO will be compared to *in situ* radiometry measurements to ensure the atmospheric correction scheme is sufficient. A variety of inversion algorithms will be applied to the *in situ* $R_{rs}(\lambda)$ observations at the MERIS and potentially HICO bands. The best performing algorithms will undergo optimization informed by the *in situ* absorption and scatting measurements for a given water body or group of water bodies. The optimized algorithm(s) will be applied to MERIS and potentially HICO imagery producing biogeochemical parameters (chlorophyll concentration, total suspended matter, and CDOM) with water quality implications. The *in situ* biogeochemical parameter set will be used for validation of the MERIS and potentially HICO imagery.

**Available Facilities**

UFI has a proven track record for providing high quality IOP and AOP measurements. They currently own all needed optical instrumentation for hyperspectral in situ characterization (Table 1). The WDNR will provide a boat and captain, transportation and field logistics to successfully carry out the field campaign. WDNR will also provide phytoplankton identification and sizing for ancillary information in understanding the variability in phytoplankton optical properties observed. Mouw at the UW-Madison, Space Science and Engineering Center, has sufficient computing resources and data storage capacity to handle the optical analysis, algorithm evaluation and imagery archive. Background information on PI, Colleen Mouw and co-I, Steven Greb follow.

**Output and Deliverables**

While the first order products ([Chl], NAP, CDOM) are not novel, their retrieval from inland lakes in Wisconsin at a relevant spatial resolution is. These products allow academic research and management investigations into variability and change of inland lakes. The multispectral (MERIS) and hyperspectral (HICO) imagery will be compared for potential product suites and accuracy of the respective retrieved parameters. Subpixel variability of the 300 m multispectral imager will be compared with the 95 m hyperspectral imager to help inform planning of the NASA GEO-CAPE mission. MERIS will be used for routine observations, while HICO imagery when available would be used to supplement our understanding with additional spectral and spatial information.

**Expected deliverables:**

- Attendance of the annual HICO meeting
- Algorithm approach and resulting processed imagery for chlorophyll, and absorption of NAP and CDOM.
- Comparison of multispectral vs. hyperspectral product suites and accuracy to inform the NASA GEO-CAPE mission.

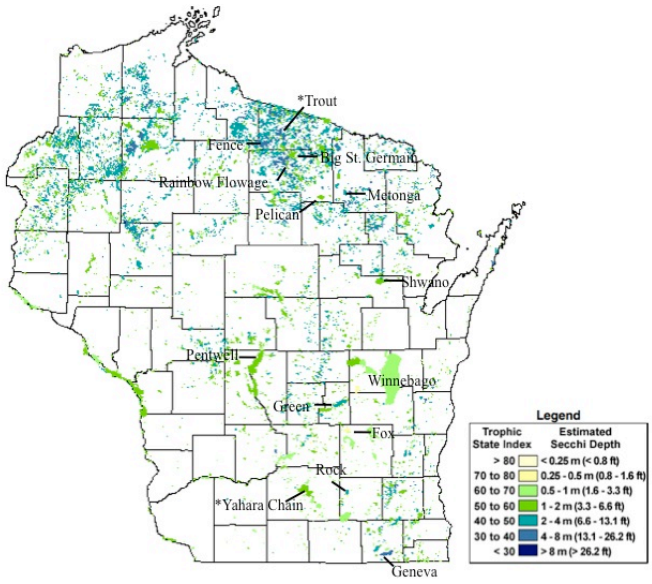


**Figure 1.** Location of the selected lakes for the *in situ* optical survey occurring June 15-21, 2011, overlain on estimated lake clarity from LandSat imagery. The lakes were selected to capture a wide variety of optical conditions. Lakes denoted with an asterisk are NSF LTER sites.

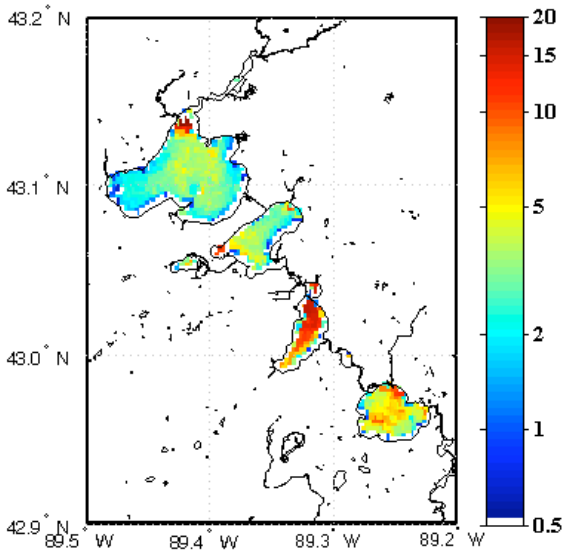


**Figure 2.** An example MERIS full-resolution (300 m) image from the Yahara chain of lakes near Madison, WI on May 7, 2009. The image was processed with BEAM using the case 2 regional processor.

**Table 1:** In-situ optical, biological, and physical parameters that will be measured.

| ***In situ IOPs*** | ***In situ AOPs*** | ***Laboratory*** |
|---|---|---|
| $a_{pg}(\lambda)$, $a_p(\lambda)$, $a_g(\lambda)$ (WETLabs AC-S) | $E_s(\lambda)$, $L_u(\lambda)$, $E_d(\lambda)$ (Satlantic HyperPro) | chlorophyll |
| $c(\lambda)$ (WETLabs AC-S) | $L_s(\lambda)$, $L_t(\lambda)$ (Satlantic) | TSS |
| $b_b(\lambda)$ (WETLabs BB9) | in water $R_{rs}(\lambda)$ (calculated from HyperPro) | total phosphorus |
| fluorometric chlorophyll (WETLabs) | above water $R_{rs}(\lambda)$ (Ocean Optics spectroradiometer) | $a_p(\lambda)$, $a_d(\lambda)$, $a_g(\lambda)$, $a_{ph}(\lambda)$ |
| fluorometric CDOM (WETLabs) | PAR (Biospherical) | microscopic phytoplankton identification & sizing |
| fluorometric phycocyanin (WETLabs) | | |
| | | ***Ancillary*** |
| | | Temperature (SeaBird) |
| | | Specific conductance (SeaBird) |

**Table 2.** Names and locations of Wisconsin lakes that will be observed during the optical and biological survey that will take place June 14-21, 2011.

| ***Lake*** | ***Location*** | ***Lake*** | ***Location*** |
|---|---|---|---|
| Yahara Chain | 43.0437, -89.3738 | Shwano | 44.7945, -88.5662 |
| Geneva | 45.5916, -88.4360 | Metonga | 45.5209, -88.9050 |
| Rock | 43.0790, -88.9159 | Big St. Germain | 45.9223, -89.5369 |
| Green | 43.8460, -88.9587 | Fence | 45.9512, -89.8672 |
| Pentwell | 44.0591, -90.0179 | Trout | 46.0374, -89.7032 |
| Winnebago | 44.1992, -88.4268 | Rainbow Flowage | 45.8343, -89.5471 |
| Fox | 43.5588, -88.9190 | Pelican | 45.5281, -89.2081 |

**Biographical Sketches**


## COLLEEN B. MOUW

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### PROFESSIONAL PREPARATION

| | | | |
|---|---|---|---|
| Western Michigan University | Biology (*cum laude*) | B.S | 2000 |
| University of Rhode Island | Oceanography | M.S. | 2003 |
| University of Rhode Island | Oceanography | Ph.D. | 2009 |

### APPOINTMENTS

| | |
|---|---|
| 2010-present | Associate Researcher, University of Wisconsin-Madison |
| 2009-2010 | Postdoctoral Research Associate, University of Wisconsin-Madison |
| 2001-2009 | Graduate Research Assistant, University of Rhode Island |
| 2008 | Adjunct Instructor, Valparaiso University |
| 2004-2006 | Technical Associate, University of Massachusetts-Dartmouth |
| 2000-2001 | Field Scientist, Kieser & Associates |
| 2000 | Instructor, Grand Valley State University |
| 1996-1999 | Research Assistant, NOAA, GLERL |

**RESEARCH INTERESTS:** Remote sensing of visible spectral reflectance in ocean and lakes; algorithm development; bio-optics; phytoplankton ecology and physiology; carbon cycling; ecosystem structure response to environmental and anthropogenic change.

### PUBLICATIONS


Mouw, C.B., J.A. Yoder, and S.C. Doney, Impact of phytoplankton community size on a linked global ocean optical and ecosystem model. *J. Marine Systems, in review*.

Naik, P., E.J. D'Sa, H. Gomes, J.I. Goés, and C.B. Mouw, Absorption properties in southeastern Bering Sea during July 2008: analysis, parameterization and absorption budget*, J. Geophys. Res., in review*.

Mouw, C.B. and J.A. Yoder (2010) Optical determination of phytoplankton size distribution from global SeaWiFS imagery. *J. Geophys. Res.,* 115(C12018), doi:10.1029/2010JC006337.

Martini, K., E. Frajka-Williams, and C.B. Mouw, (2009) The Pattullo Conference: Building Community Through Mentoring. *Oceanography* 22(1): 180-183.

Mouw, C.B. and J.A. Yoder (2005) Primary production calculations in the Mid-Atlantic Bight, including effects of phytoplankton community size structure. *Limnol. Oceanog.* 50(4): 1232-1243.

Fahnenstiel, G. L., C. Beckmann, S. E. Lohrenz, D. F. Millie, O. M. E. Schofield, and M. J. McCormick (2002) Standard Niskin and Van Dorn bottles inhibit phytoplankton photosynthesis in Lake Michigan. *Verh. Internat. Verein. Limnol*., 28(1): 376-380.


### SYNERGISTIC ACTIVITIES

- NASA GEO-CAPE Ocean science working group member
- NASA MODIS science team member
- Graduate student science advisor - Atmospheric and Oceanic Sciences Dept., U. Wisconsin-Madison
- Reviewer: Deep Sea Res., Mar. Ecol. Prog. Ser., J. Mar. Syst., Rem. Sens. Environ., Global Biogeochem. Cycles, J. Appl. Met. Clim., Estuaries and Coasts, NSF Biological Oceanog., NASA Ocean Biology and Biogeo
- NOAA Science-on-the-Sphere – imagery provider
- Active in MPOWIR (Mentoring Physical Oceanography Women to Increase Retention) and ESWN (Earth Science Women's Network)

**STEVEN R. GREB**
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**Education**

| | | | |
|---|---|---|---|
| University of Wisconsin-Stevens Point, | B.S | Chemistry & Water Res. Manag. | 1978 |
| Utah State University | M.S. | Hydrology | 1986 |

**Employment**

| | |
|---|---|
| 2004-2006 | Consultant to the United Nations International Hydrologic Programme |
| 1992-present | Research Hydrologist/Limnologist- Wisconsin Department of Natural Resources |
| 1986-1992 | Water Resources Project Position- Wisconsin Department of Natural Resources |
| 1984-1986 | Teaching Assistant- Utah State University |
| 1978-1984 | Head Chemist- State of Wyoming Water Quality Laboratory |

**Research and Professional Interests:** Remote sensing applications for inland and coastal water quality ecosystem management, riparian nutrient loss, thermal pollution in the urban environment, effects of forestry best management practices on stream water quality, impact of climate change on hydrologic regimes

**Synergitic Activities**

- Integrated Global Observing Strategy (IGOS) (member of the scientific steering committee)
- International Ocean Color Coordinating Group (IOCCG) committee member
- Group on Earth Observations (GEO) chair of water quality working group
- Integrated Global Water Cycle Observation (IGWCO) Science Advisory Committee
- Reviewer: Water Resources Res., J. American Water Res. Bull., Remote Sens. Environ., Watershed Sci. Bull., NASA Energy and Water Cycle Study Program Review
- Wisconsin Climate Change Initiative (hydrologic working group)

**Recent Research Activities (past 5 years)**

- Lake Clarity Measurements from Satellite Remote Sensing
- Multisensor Spaceborne Monitoring of Global Large Lakes: Assessment Water Quantity and Quality
- Potential Thermal Pollution from Runoff Water in Urban Areas
- Lake Nutrient Inputs from Shoreline Development
- Relationship of Ecological Landscapes and Land Use to Small Stream Nutrient Loads
- Occurrence of Pathogens in Urban Stream

**Selected publications**

Greb, S.R., A. Herveti and P. DiGiacomo (2007) Global Water Quality Monitoring. In, *The Full Picture*, Chapter 3. Tudor Rose Press, London.

S.R.Greb (2005) Freshwater Water Quality Monitoring by Remote Sensing; Current and Potential Applications and Needs Assessment. A report to the Integrated Global Observing Strategy (IGOS) Water Cycle Committee, United Nations Environmental Programme. 22pp.

Graczyk, D.W., R.J. Hunt, S.R. Greb, C.A. Buchwald, and J.T. Krohelski (2003) Hydrology, Water Quality, and Yields from Near-Shore Flows to Four Lakes in Northern Wisconsin, 1999-2001. US Geological Survey. Water-Resource Investigations Report 03-17.

Greb, S.R. and R.T. Bannerman (1997) Influence of Particle Size on Wet Pond Effectiveness. Water. Env. Research 69(6): 1134-1138.

Archer, J.R., J.R. Ball, J.H. Standridge, S.R. Greb, P.W. Rasmussen, J.P. Masterson, L. Boushon. Cryptosporidium spp. Oocyst and Giardia spp. Cyst Occurrence, Concentrations and Distribution in Wisconsin Waters. Wisconsin Dept. of Natural Res. Pub. No. WR43-420-95.

Greb, S.R. and D.J. Graczyk (1995) Frequency-Duration Analysis of Dissolved Oxygen Concentrations in Two Southwestern Wisconsin Streams. *Water Res. Bull.* 31(3): 431-438.