Great Lakes Workshop Series on Remote Sensing of Water Quality

Executive Summary and Final Report on 2014 Series

Robert Shuchman, Michigan Tech Research Institute

Larry Liou, NASA Glenn Research Center

Amanda Grimm, Michigan Tech Research Institute

December 2014

Contents

MichiganTech Research Institute

Executive Summary

A series of two workshops on remote sensing of water quality for inland lakes, focusing on the Laurentian Great Lakes, was held in spring 2014. The series was proposed by NASA Glenn Research Center and organized on their behalf by Michigan Tech Research Institute .To engage the widest possible variety of stakeholders and make in-person attendance possible for a larger number of participants, a series of two workshops in two different cities was planned. Workshop 1 was hosted by the Ohio Aerospace Institute in Cleveland, OH on March 12-13, and Workshop 2 by the NOAA Great Lakes Environmental Research Lab (GLERL) on May 7-8.

Workshop Series Steering Committee

Larry Liou, Lead for Freshwater Research, NASA John H. Glenn Research Center
Robert Shuchman, Co-Director, Michigan Tech Research Institute-Michigan Tech University
Steve Greb, Hydrologist, Wisconsin Department of Natural Resources (DNR)
George Leshkevich, Physical Scientist, NOAA Great Lakes Environmental Research Laboratory (GLERL)
John Bratton, Deputy Director, NOAA GLERL
Jennifer Read, Executive Director, Great Lakes Observing System (GLOS)
John Lekki, Optical Systems Research Engineer, NASA John H. Glenn Research Center

The remote sensing of water quality and associated features (wetlands, ice, land cover) has advanced significantly in recent years, including improvements of freshwater-specific optical algorithms; developments in aquatic applications of radar, lidar and hyperspectral data; and the availability of increasingly capable unmanned aerial vehicles (UAVs), autonomous underwater vehicles (AUVs) and other novel platforms. Existing regional institutions (e.g., the Great Lakes Observing System—GLOS, the Great Lakes Commission and NOAA GLERL) are already working to coordinate research and facilitate data sharing; however, the Great Lakes remote sensing community of practice is still in the early stages of development. In this context, the workshop series was convened with the following goals:

- Provide an opportunity for all Great Lakes investigators and end users to build a shared knowledge base and apply that information to develop improved strategies and best practices;
- Identify the state of the science and practice of Great Lakes remote sensing;
- Understand the needs of end users;
- Prioritize the current scientific and technological gaps; and
- Make recommendations related to those gaps by formulating input related to actions for remote sensing of water quality to the 2017 NASA Earth Science Decadal Survey.

Each workshop combined presentations on discipline expertise or synergistic organizations and activities related to the goals of the workshop with breakout sessions designed to crowdsource expert opinions on priorities and knowledge gaps from attendees with a range of different and complementary areas of expertise. Participants in both workshops were also asked to suggest short (10 week) pilot projects that would advance the state of Great Lakes remote sensing and potentially be suitable for NASA DEVELOP or other programs. Workshop participants represented a wide range of organizations from government to academic and non-profit to industry. A list of attendees of each session is included in the final report for the workshop series. All presentations, breakout session results and pilot project ideas from both workshops are posted on the workshop series website (http://mtri.org/workshops/nasagreatlakes2014/).

Workshop 1 Breakout groups

Day 1

1. Update sensor requirements for remote sensing of inland lakes
2. Remote sensing data and derived product gaps
3. Technology gaps (sensors, instruments, & other hardware)

Day 2

4. New potential applications for remote sensing of inland waters
5. Algorithms/modeling current approaches
6. Platform/mission gaps and recommendations

Workshop 2 Breakout groups

Day 1

1. Moving forward with a regional remote sensing strategy
2. Distribution of Great Lakes data
3. Algorithm comparison studies

Day 2

4. Create plan to maintain an active Great Lakes RS community
5. Remote sensing derived products sharing & credit to originators
6. Define time series RS datasets

Overall, the workshop series indicated NASA's strong interest in providing next-gen satellites pertinent to Great Lakes problems as well as enabling demonstration projects. As underlined by the plenary talks in the series, under the Great Lakes Research Initiative, the EPA, NOAA, USGS, USFWS, and NPS have embraced the use of remote sensing to solve problems, e.g., invasive species monitoring, nuisance vegetation growth, harmful algae blooms, water quality monitoring, bathymetric mapping, thermal plumes, river plume studies, and ice monitoring.

The workshop series laid the foundation for open collaboration in developing a regional working strategy for remote sensing, applications and data management methods. The regional community has accomplished a great deal with sensors that were optimized for freshwater, but it was agreed that filling certain gaps (hyperspectral, SAR, a better replacement for MERIS) would enable substantive advances. Strong emphasis was placed on the importance of outreach and user-friendly data portals, as many potential end users are not aware of existing remote sensing resources and capabilities. Another repeating theme was the great potential represented by the integration of remote sensing data and modeling for better estimation of features that cannot be remotely sensed (e.g., nutrients, oxygen, bacteria). The development of this community of practice is ongoing via the website, Google Group, implementation of pilot projects, and planned annual update meetings.

The Great Lakes Workshop Series on Remote Sensing of Water Quality was supported by the Applied Science Program, Earth Science Division, NASA.

Final Report on the Spring 2014 Workshop Series

This report details the activities and outputs of the Spring 2014 workshop series. The list of proposed short-term pilot projects, tables from the breakout discussions, the workshop attendee lists and agendas for the two meetings are included at the end of the document.

Workshop 1: March 12-13, Ohio Aerospace Institute, Cleveland, OH

The focus of Workshop 1 was to come to consensus on a list of remote sensing requirements for the Great Lakes and on the current priorities for data and technology gaps. At this first meeting, the 60 in-person attendees and 18 web participants laid the foundation for open collaboration in developing a regional working strategy for remote sensing, applications, and data management methods.


First Great Lakes Remote Sensing Workshop

Workshop 1 Day 1

A large portion of the first day of Workshop 1 was devoted to information sharing among the attendees. The keynote speaker, Cameron Davis of the US EPA, opened with a review of the important role of remote sensing in the protection and restoration of the Great Lakes. An excellent set of presentations were given on diverse aspects of Great Lakes Remote Sensing, including recaps of three previous workshops related to Great Lakes remote sensing, reviews of remote sensing technologies and Great Lakes remote sensing algorithms, and a talk on the role of the NASA Earth Science Division in monitoring water quality.

Breakout session 1 focused on updating the list of sensor requirements for remote sensing of inland lakes and was led by Dr. Joseph Ortiz from Kent State University. The breakout group came to consensus on the continuing development of the PACE, GeoCape, HyspIRI, Sentinel 3, and OLCI sensors/missions, and suggested the need for hyperspectral capabilities available on a shorter timescale. It was noted that aircraft and UAV platforms that could be tasked on demand would meet this need, and that options for intermediate timescales include venture class (disposable) satellites and microsats. Aircraft could also be used for testing applications of proposed space instrumentation, e.g., plume mapping. Most of the expertise in the room was focused on visible instrumentation, so most of the recommendations related to temporal and spatial resolution and the optimization of spectral resolution came from that perspective. Another important consideration that was addressed is that input data for atmospheric (aerosol) correction need to be coincident with the scene. There are two ways to do that: have ground-based instrumentation or have instrumentation on the same or a close-following platform. The need for wider spectral ranges was discussed, e.g. to differentiate sediment from plankton. Expanding the spectral range out to 3500 nm, for example, would allow us to differentiate siliciclastic particles from carbonates. There is also a need to enhance the dynamic range in the visible range of the EM spectrum. Many of the instruments in orbit are optimized for land rather than aquatic sensing, which is true for band placement and temporal repeat time as well as dynamic range. Finally, the group prioritized the development of multispectral lidar that can collect near-surface profiles (3-4 m) at a higher spatial resolution with the potential to differentiate CPAs, but with the caveat that results would potentially be noisy and not extend beyond the first optical depth. Other specific findings of this group are detailed in Table 1.

Breakout session 2 was aimed at identifying and prioritizing current gaps in remote sensing data and derived products. The session was led by Dr. George Leshkevich from the NOAA Great Lakes Environmental Research Laboratory (GLERL). Important general notes made by the group included the following:

- Many products available for oceans don't yet have Great Lakes correlates (examples: species ID, diatom vs. non-diatom)
- It is important to look at the hydrology of the whole Great Lakes basin – better spatial resolution is needed for many products to be able to resolve the ponds and rivers that feed into the Lakes
- Upcoming foreign data streams will often have higher resolution than currently available sources
- Better synthesis is needed between in situ and satellite data in terms of geographic and temporal availability. Google Earth Engine is moving in the right direction on this issue
- Great Lakes remote sensing represents a potential role for public/private partnerships for both cloud computing and airborne data collection
- Remote sensing data should be utilized more to validate and improve forecasting methods; more generally, remote sensing is better used as a component of an integrated system rather than as standalone tools—modeling and remote sensing should inform each other
- There is strong interest in the potential for fusion of Landsat or other higher-resolution EO imagery and ocean color imagery to characterize within-pixel variability for ocean color products
- Higher spatial and spectral resolution for multispectral and/or hyperspectral data were generally acknowledged as high priorities
- Ramping up GEO-CAPES/GOCE type satellite missions was identified as a priority

Additional points from this session are included as Table 2.

Breakout session 3 was led by Colin Brooks of Michigan Tech Research Institute (MTRI) and identified technology gaps related to the remote sensing of inland lakes. This group organized their discussion points into three major topics:

1. *Specific technologies where our group said there were gaps*
    a. Power-charging docking stations for remote / unmanned mobile devices (underwater, airborne)
    b. Cabled observatories in the Great Lakes – deployment for longer time periods than buoys
    c. Wireless data transmission underwater – more rugged, fewer cables
    d. Crowd-sourcing data collection tools / technologies – making it easier for the citizen scientist to contribute data
    e. Ice thickness sensors – use for shipping, science / impacts of a changing climate
    f. Webcams – digital imaging sensors that are easily deployable – could be many more!
    g. Fish monitors – track where they go, collect ambient data
    h. SAR platforms – no U.S. data source currently exists for radar data for ice monitoring, vegetation mapping, etc.
    i. Chemical sensors – a need for inexpensive, lightweight water & airborne sensors
    j. Aircraft-deployable cameras – can we turn commercial flights into frequent imaging platforms for the Great Lakes? Potential for pilot with NASA aircraft to understand safety & other deployment issues
    k. Cubesats & other small satellites – can these be used more to lower the cost of satellite imagery collection & make it more frequent?
    l. Buoys, gliders, AUVs, UAVs, surface vehicles, balloons – there is a need to take greater advantage of these rapidly developing hardware platforms
2. *Gaps in data and model access & understanding*
    a. Improved data resolution - spatial, temporal, and 3D / profiles
    b. Better understand of what's out there for data, models, platforms, etc.
    c. Better access to platforms – ex: UAVs only used part-time for hurricane monitoring could be deployed in the Great Lakes
    d. Improved visualization – making it easier to for people to understand the data
    e. Types of data – can we make radar and thermal data more readily available (with higher resolution)
    f. Access to modeling code & results – some scientists want to run the code, others would like to tweak the parameters through a web-accessible interface, others are focused on data querying
3. *Gaps in our community*
    a. Broader, stronger Great Lakes Remote Sensing Community - Stronger voice and outreach to advocate for remote sensing ; get NASA into the GLRI process
    b. Always keeping in mind understanding the value of and need for the data, and the cost to create them for technology gaps

Detailed proceedings from breakout session 3 are included as Table 3.

Workshop 1 Day 2

Plenary presentations on Day 2 of the workshop included talks on combining remote sensing with modeling approaches for Great Lakes monitoring; sensors, products and applications related to the remote sensing of inland water quality; a presentation on NASA ESD's water-specific activities, and short presentations on relevant topics. Attendees also proposed an initial list of short pilot projects related to Great Lakes remote sensing. The majority of the afternoon was again devoted to breakout group discussions.

Breakout session 4 was asked to brainstorm new potential applications for remote sensing of inland waters. Led by Dr. Steve Greb from the Wisconsin DNR, the group produced the following summary:

1) **Water Quality**
    - **a.** Mapping invasive and/or emergent aquatic plant species
    - **b.** Detection/tracking of water plumes
    - **c.** Algal composition mapping
    - **d.** Plume constituent mapping
    - **e.** Illicit discharges
    - **f.** Oil spills
    - **g.** Water clarity
    - **h.** Microplastic monitoring
    - **i.** Beach monitoring/health
    - **j.** Fish habitat maps
2) **Physical Properties**
    - **a.** Bottom substrate/sediment type mapping
        - **i.** Habitat mapping
        - **ii.** Fisheries
        - **iii.** Modeling
        - **iv.** Substrate
    - **b.** Dangerous (rip) current hazard maps
    - **c.** Real-time dangerous current alerts nearshore winds, waves, and currents
    - **d.** Drainage tile mapping
    - **e.** Mapping Tsunami-like waves created by storms
    - **f.** Fine scale water height and/or flooding
    - **g.** Watershed modeling

Detailed output from the discussion is included as Table 4.

Breakout session 5, led by Dr. David Schwab of the University of Michigan Water Center and Michigan Tech Research Institute, reviewed the current approaches to Great Lakes algorithms and modeling. The group ultimately decided that a more time-consuming review of this topic would be very helpful to the community and proposed such as a pilot project. The following is an outline of some important discussion points:

1. Data needs for algorithm validation
    a. What constitutes "real validation"?

        i. Everyone has their own validation metrics, sometimes hard to interpret
        ii. It would be useful to get the Great Lakes onto the AERONET-OC network
        iii. Strict cal/val would give us confidence and help with algorithm development
    b. Potential to use drifters, gliders + Lagrangian approach to provide more validation data
    c. A standard suite of measurements with strong cal/val would facilitate algorithm development
        i. Protocols needed for collection of calibration data, data storage & processing methods
        ii. NASA protocols developed for ocean work can often be followed
        iii. Much of the data used for validation is originally collected for other purposes
            1. Dataset characteristics often less than ideal
        iv. We are lacking a central community archive for regional remote sensing calibration data
        v. Standard measurements should include standards for the metadata describing how data is collected
        vi. Should we have a standardized operational archive and a separate experimental archive so data collection isn't limited?
        vii. An organized community data gathering cruise would be useful for validating models under development
        viii. NOAA-GLERL's data represents all lakes & across the whole growing season
        ix. In situ data collected at the surface is of use for comparing atmospheric correction & radiative transfer models
    d. IOP variability - backscattering & scattering coefficients of different particle types – is a huge issue
    e. We can make better use of Lake Guardian and UNOLS vessels to collect cal/val data
2. Algorithm development
    a. Community responsibility for algorithms—need to open up algorithm development to be testable by others
        i. Repeatable "apples to apples" comparisons
    b. Multiple algorithms are also useful for the same application—there's no single approach that works best for all datasets
    c. Monte Carlo comparison of algorithms
    d. Similar experiments conducted in different environments – what works in one lake might not in another
    e. Would be beneficial to have something for water quality models similar to the Coupled Model Intercomparison Project (CMIP) for climate models
    f. Recommend standardizing nomenclature (TSS/TSM/SM, Kd/Kt/turbidity/water clarity, epilimnion mixed layer/hypolimnion/thermocline)
    g. Need for a comprehensive assessment of atmospheric correction techniques
        i. Advise users when/where to use different corrections, provide warnings
    h. Have to consider bands included in continuity datasets,
    i. Some products have been validated over land but not water, produce negative values over water
    j. Intercomparison would also be of use for radiative transfer models (e.g. REMI in Europe)

The group began to sketch out a comprehensive spreadsheet of Great Lakes algorithms, which is included as Table 5.

Breakout session 6, led by Larry Liou of NASA Glenn Research Center, produced a list of platform and mission gaps and recommendations. They noted that data sharing should be emphasized on all platforms, as such information could be valuable to the DOD, Homeland Security, etc. They also proposed a pilot project to define needs for UAV research related to water quality. The results of the discussion are included as Table 6.

Workshop 2: May 7-8, NOAA Great Lakes Environmental Research Center, Ann Arbor, MI

The second workshop of the series focused on data distribution methods and websites for the Great Lakes and on planning follow-on measures to maintain an active Great Lakes remote sensing community. Additional focused presentations on a range of aspects of the current science of Great Lakes remote sensing were hosted, and the discussions of data gap and research prioritization from Workshop 1 were continued. Participants again broke out into smaller discussion groups each afternoon, and generated additional pilot project ideas to add to the list from the first workshop, adding contact persons for each project to facilitate their implementation. A Google Group was established to help attendees and other stakeholders remain in contact and continue to collaborate after the completion of the workshop series (https://groups.google.com/forum/#!forum/great-lakes-rs).

Workshop 2 Day 1

Plenary presentations on Day 1 included reviews of the research initiatives of the USGS GLSC and NOAA GLERL that involve remote sensing, overviews of the NASA Applied Science Water Resource Program and the Great Lakes Observing System (GLOS), and a primer on the GLOS Data Management and Communications subsystem.

Breakout session 1 laid the groundwork for the development of a regional remote sensing strategy. The session was led by Dr. John Bratton of the NOAA Great Lakes Environmental Research Laboratory. The group outlined the following components that would need to be developed for an effective strategy:

1. Science strategy: research agenda, development and engagement
    a. Work backwards from larger-scale agendas
    b. Find the place for remote sensing within the regional science strategy
    c. Focus on water quality
    d. Address agriculture and other parts of the system, not just open water
    e. Sort science questions by timespan and temporal feasibility
2. Prioritization criteria
3. Priority Great Lakes issues or topics (based on input from outside sources: GLWQA, GLRI, etc.)
    a. Gap analysis of regional data needs
4. A proposed organization for a more formal Great Lakes remote sensing community of practice
    a. More permanent working group with a chair and board?
    b. Permanent website for regional planning/collaboration
5. Recommendations for a portfolio of existing, modified or future platforms, instruments and products for Great Lakes monitoring, with mechanisms to coordinate feedback
    a. Develop a database of existing regional infrastructure
    b. Protect existing sources of data (satellites have a limited lifespan, which ones are important to us?)
6. A stakeholder engagement strategy utilizing intermediaries (e.g. CGLG, state DNRs, Council of Great Lakes Industries, AmericaView, HOW, Sea Grant extensions) and designer/operator professional societies (WEF, ASCE, AWWA, EPRI)
    a. Develop traceability matrices for satellites
        i. Document what the users want and need
        ii. Use to 'market' the satellite products
7. Community timeline matched to the deadlines of parallel activities

Breakout session 2 focused on the distribution of Great Lakes data, led by Dr. Jen Read of GLOS. Participants noted that the vast majority of data is still inaccessible except very locally, i.e., it's sitting on someone's shelf. A subset of that data is still in handwritten form or otherwise not digitized. Thus, the recovery of older/archived data, which would require significant funding and facilitation, is a major issue and undertaking. Additional aspects of this issue include metadata, hosting, outreach/publicity about the existence of available data, and acknowledgement/credit of data creators.

Also related to the issue of data sharing, remote sensing can be seen as too much of a hurdle by non-remote sensing scientists. Thus, it should be a priority to narrow the gap between remote sensing scientists and "everyone else". This issue is not just data accessibility but how to make data discoverable and "on the radar" of non-remote sensing researchers. Because websites are passive and the usefulness of email is limited, attending user-focused meetings may be a useful approach.

Detailed output from this discussion is included here as Table 7. The group also outlined the following next steps related to this topic:

- Refine/finalize the information in the table
- Gap analysis: Differentiate the data/products we already have from those that are patchy or currently unavailable
- Ask user communities to review/assess the above chart, provide additional feedback, priorities
- Sort data types into priority quartiles
- Incorporate into GLOS preproposals
- Develop a "primer" webpage on remote sensing data for non-RS-savvy potential users

Breakout session 3 followed up on the first workshop's discussion of Great Lakes algorithms and modeling, again led by Dr. David Schwab. The group produced a set of recommendations to scope out a Great Lakes chl-a comparison study, and to develop an Aeronet-like site for the Great Lakes for real-time regional atmospheric correction. The group submitted the following notes on the development of such resources:

- Algorithm comparisons should use the same measurements of success
- Could follow the Alliance for Coastal Technologies (ACT) approach used to compare instrumentation as a template (3 measurements, run algorithms on the same samples at the same time)
- NASA could function like ACT by managing an algorithm intercomparison website and acting as a trustee/broker
- A new algorithm intercomparison would be useful for some scientists in the community, others are happy with what they have
- Need to take types of error into consideration. For example, for a HAB algorithm, under-predicting is worse than over-predicting.
- More data need to be collected during blooms; data collection during blooms is limited in some ways due to surface scum
- Possibly no single best algorithm – different conditions during blooms may be best modeled by different algorithms
- Atmospheric correction is part of an algorithm and should be included in the documentation of the algorithm

Workshop 2 Day 2

Day 2 opened with a talk by Lana Pollack, Chair of the U.S. Section, International Joint Commission, focused on the purpose of the IJC and their needs for monitoring data and expertise. An overview of the NOAA Great Lakes CoastWatch program was presented, and the use of the GLOS DMAC was demonstrated. Following a tour of NOAA GLERL, participants broke into the final set of discussion groups and added to the list of proposed pilot projects from Workshop 1.

Breakout session 4, led by Larry Liou of NASA Glenn Research Center, was tasked with identifying follow-on measures to maintain an active Great Lakes remote sensing community. The group proposed the following actions:

1) Annual group meetings
    a) Perhaps associated with a larger conference
    b) Include a poster session in future meetings
2) Draft a formal statement of purpose
3) Education & public outreach (both focused and general public outreach)
    a) Healing Our Waters
    b) State Aerospace and Technology Committee
    c) Media Day around upcoming summer flight
4) Offer something similar to the NASA Planetary advisory Committee, but for freshwater or inland and coastal
5) Communication
    a) Google Group listserv
    b) Permanent website
        i) Exchanging documents
        ii) Discussion forum
6) Publication
    a) Workshop summary report (with executive summary)
    b) Generate position papers summarizing how remote sensing can address federal, state and local needs related to Great Lakes issues
7) Coordinate collection of ground-based validation data
    a) Community data cruises/expeditions?
    b) Compile a database of on-going water sampling

Breakout session 5 discussed issues of data creator rights and attribution related to data sharing. As the group, led by Tad Slawecki of LimnoTech, reported, data sharing is often limited by the concerns of data originators related to their rights, acknowledgement, and data misuse. The group presented the following list of potential nonexclusive solutions:

- Reward data originators by updating them on who has used and cited their data
- Grade datasets (e.g., using stars like on Amazon)

- Register users and ask how they plan to use data
- Good metadata might help control data misuse
- Identify operational vs. research data – Level of review scale?
- Give data users guidance on how to cite/credit datasets

The group also emphasized the importance of thoughtfully defining and then adhering to a set of data sharing best practices, including guidelines related to documentation (metadata standards, specifying the required data citation for acknowledgement, and inviting others to review your metadata); data storage (addressing accessibility, persistent identifiers, and the use of data formats intended for long-term use, e.g., ASCII rather than Excel 2000); and data discovery (working to make data discoverable, listing the data on appropriate clearinghouse-type websites, and using keywords and tags that will make data more likely to be found using a search engine). The group proposed multiple short pilot projects related to the data sharing problems discussed.

Breakout session 6 generated a prioritized list of useful time series data products, including status/feasibility and applications. The group discussed the fact that the 'baseline' used for time series varies between products, so it is necessary to clearly communicate what baseline is used. Also, smooth vs. exact interpolations are preferred for different applications, making it important to document processing flow. Participants reflected that many end users are not interested in working with the raw data but just want the derived products delivered in an accessible way. The CU GRACE data portal's point-and-click interface for time series charts was cited as a good example of user-friendly functionality (http://geoid.colorado.edu/grace/dataportal.html). The list of time series products produced by the group is included here as Table 8.

Overall Workshop Findings

In summary, the workshop series laid the foundation for open collaboration in developing a regional working strategy for remote sensing, applications, and data management methods. There were several recurring comments and themes:

- The regional community has done a lot with sensors that were not optimized for freshwater, but filling certain gaps (hyperspectral, SAR, a better replacement for MERIS) would enable substantive advances
- Many potential users are not aware of existing remote sensing resources and capabilities—data portals need to be user-friendly, perhaps include a remote sensing primer
- Integration of remote sensing data & modeling holds great potential for better estimation of features that cannot be remotely sensed (e.g. nutrients, oxygen, bacteria)
- The workshop series indicated NASA's strong interest in providing next-generation satellites pertinent to Great Lakes problems as well as enabling demonstration projects. As underlined by some of the plenary talks in the series, under the GLRI, the EPA, NOAA, USGS, USFWS, and NPS have embraced the use of remote sensing to solve problems, e.g.,
    - Invasive species monitoring
    - Nuisance vegetation growth
    - HABs
    - Water quality monitoring
    - Bathymetric mapping

    - Thermal plumes
    - River plume studies
    - Ice monitoring
- The community should work backwards from water quality issues and reach out to key people working on each issue to determine potential remote sensing applications
- Reach out to non-remote sensing scientists (e.g., those who do lakewide experiments) about how aerial/fine scale remote sensing could benefit their research
- We need a comprehensive remote sensing data portal/clearinghouse that is friendly to non-remote-sensing-savvy end users

Next steps for the Working Group on Great Lakes Remote Sensing will be to continue to expand and maintain the community website, work to develop a regional remote sensing strategy, reach out to non-remote sensing Great Lakes stakeholders, move forward with selected pilot projects from the list generated by workshop participants, and generate position papers summarizing how remote sensing can address federal, state and local needs related to Great Lakes issues. The NASA Glenn Research Center plans to continue in a leading role in the development of this community of practice.

Workshop 1 Participants

Steve Ackerman, Professor, University of Wisconsin-Madison

Doug Alsdorf, Professor, Ohio State University

Rafat Ansari, Biofluid Sensor Systems Scientist, NASA Glenn Research Center

*Andrew Barnard, VP of R&D, Sea-Bird Scientific

*Eric Baumann, Aerospace Engineer, NASA Glenn Research Center

Ricky Becker, Asst. Professor, University of Toledo

Terri Benko, State Coordinator, OhioView – AmericaView

Caren Binding, Research Scientist, Environment Canada

Andrea Bolks, ORISE Research Fellow, US-EPA R5

John Bratton, Acting Director, NOAA Great Lakes Environmental Research Laboratory

Colin Brooks, Environmental Lab Manager/Research Scientist, Michigan Tech Research Institute

Timothy Bruno, Chief, Office of the Great Lakes, PA Department of Environmental Protection

Dan Button, Physical Scientist, USGS

Javier Concha, PhD Candidate, Rochester Institute of Technology

Warren Currie, Environmental Scientist/Fisheries Biologist, Fisheries and Oceans Canada

Kevin Czajkowski, Professor, University of Toledo

Cameron Davis, Senior Advisor to the US EPA Administrator

Paul DiGiacomo, Chief, Oceanography and Climatology Division, NOAA-NESDIS STAR

Peter Esselman, Nearshore Landscape Ecologist, USGS

Ransook Evanina, Environmental Engineer, NASA

Douglas Feikema, Aerospace Engineer, NASA Glenn Research Center

*Chris Fidler, New York State DEC

Lawrence A. Friedl, Earth Science Division, NASA Headquarters

*Ulf Gafvert, GIS Coordinator, National Park Service

Aaron Gerace, Rochester Institute of Technology

Steve Greb, Wisconsin DNR

Larry Greer, NASA Glenn

Amanda Grimm, Asst Research Scientist, Michigan Tech Research Institute

Daniela Gurlin, Wisconsin DNR

Dorothy Hall, NASA Goddard Space Flight Center

Jeff C. Ho, PhD student, Stanford University

Seth Hothem, Senior Investigator, Northeast Ohio Regional Sewer District

*Brian Huberty, Remote Sensing Lead, FWS

Gary Hunter, Senior Electronics Engineer, NASA Glenn Research Center

Michael F. Jasinski, Research Hydrologist, NASA Goddard Space Flight Center

*Mark Johnston, GIS Manager, The Field Museum

Clarence Jones, Project Coordinator, Educational Programs Office, NASA GRC

Nancy Kilkenny, Web Content Writer, NASA Glenn Research Center

Val Klump, University of Wisconsin-Milwaukee

Michael Krasowski, Senior Research Engineer, NASA Glenn Research Center

Tibor Kremic, NASA Glenn Research Center

Stephanie Kula, USGS

Christine Lee, NASA Earth Science Division

George Leshkevich, Physical Scientist, NOAA Great Lakes Environmental Research Laboratory

Barry Lesht, CSC, Inc.

Shengpan Lin, Michigan State University

Larry Liou, Project Manager, NASA Glenn Research Center

Frank Lopez, Manager, ODNR/Old Woman Creek NERR

Naima Lusane, Project Coordinator, Paragon TEC/NASA Glenn Research Center

Darren McKague, Research Scientist, University of Michigan

Amita Mehta, NASA-UMBC-JCET

Alan J. Micklewright, Chief of Aircraft Operations, NASA Glenn Research Center

Carrie Milward, Biologist, Northeast Ohio Regional Sewer District

William Moore, NASA SEMAA WSU

Colleen Mouw, Asst Professor, Michigan Tech University

David O'Donnell, Senior Engineer, Upstate Freshwater Institute

Daniel Oldham, Computer Engineer, NASA Glenn Research Center

Joseph Ortiz, Kent State University

Ann Over, Chief, Space Science Project Office, NASA Glenn Research Center

Feng Peng, Upstate Freshwater Institute

Doug Rickman, NASA/MSFC

Kenton Ross, NASA DEVELOP

Steve Ruberg, NOAA GLERL

Nicki Shafer, Molecular Microbiologist, NEORSD

David Schwab, Michigan Tech Research Institute/University of Michigan

Robert Shuchman, Co-Director, Michigan Tech Research Institute

*Tad Slawecki, Senior Engineer, LimnoTech

*Beth Stauffer, AAAS Science & Technology Policy Fellow, EPA Office of Research and Development

Roger Tokars, Electrical Engineer, NASA Glenn Research Center

Carol Tolbert, Project Manager, NASA

Ben Vander Jagt, Ohio State University

Andrea Vander Woude, Research Fellow, University of Michigan CILER, NOAA GLERL

*Jerry Voltz, Senior Project Coordinator, Paragon TEC

James Watkins, Research Associate, Cornell University

Matthew Whitley, Michigan Tech Research Institute

Michelle Wienert, Michigan Tech Research Institute

Jomil Wiley, NASA SEMAA Project Lead, Education Programs Office/Paragon TEC

*Foad Yousef, Michigan Technological University

*web attendee

Workshop 2 Participants

Salah Ahmed, NASA

Rafat Ansari, Biofluid Sensor Systems Scientist, NASA Glenn Research Center

Sean Backus, Manager, Great Lakes Water Quality Monitoring, Environment Canada

Ricky Becker, Asst. Professor, University of Toledo

Terri Benko, State Coordinator, OhioView – AmericaView

*Caren Binding, Research Scientist, Environment Canada

Rob Bondurant, Owner, ARS Group

John Bratton, Acting Director, NOAA Great Lakes Environmental Research Laboratory

Colin Brooks, Environmental Lab Manager/Research Scientist, Michigan Tech Research Institute

Timothy Bruno, Chief, Office of the Great Lakes, PA Department of Environmental Protection

Bo Bunnell, Fish Biologist, USGS Great Lakes Research Center

Dan Button, Physical Scientist, USGS

Javier Concha, PhD Candidate, Rochester Institute of Technology

Warren Currie, Environmental Scientist/Fisheries Biologist, Fisheries and Oceans Canada

Kevin Czajkowski, Professor, University of Toledo

Brad Doorn, NASA

Peter Esselman, Nearshore Landscape Ecologist, USGS

Ransook Evanina, Environmental Engineer, NASA

Douglas Feikema, Aerospace Engineer, NASA Glenn Research Center

*Chris Fidler, New York State DEC

*Ulf Gafvert, GIS Coordinator, National Park Service

Aaron Gerace, Rochester Institute of Technology

Steve Greb, Wisconsin DNR

Amanda Grimm, Asst Research Scientist, Michigan Tech Research Institute

*Daniela Gurlin, Wisconsin DNR

Dorothy Hall, NASA Goddard Space Flight Center

Jeff C. Ho, PhD student, Stanford University

*Brian Huberty, Remote Sensing Lead, FWS

Gary Hunter, Senior Electronics Engineer, NASA Glenn Research Center

*Christopher Itori, Simon Fraser University

Val Klump, University of Wisconsin-Milwaukee

Chris Kontoes, Regional Sales Manager, NortekUSA

Tibor Kremic, NASA Glenn Research Center

*Brandon Krumwiede, Great Lakes Geospatial Coordinator, The Baldwin Group at NOAA Coastal Services Center

Christine Lee, NASA Earth Science Division

George Leshkevich, Physical Scientist, NOAA Great Lakes Environmental Research Laboratory

Barry Lesht, CSC, Inc.

Shengpan Lin, Michigan State University

Larry Liou, Project Manager, NASA Glenn Research Center

Darren McKague, Research Scientist, University of Michigan

Linda Novitski, University of Michigan/CILER

Joseph Ortiz, Kent State University

Ann Over, Chief, Space Science Project Office, NASA Glenn Research Center

Kelli Paige, Program Manager, Great Lakes Observing System

Feng Peng, Upstate Freshwater Institute

Lana Pollack, International Joint Commission

Jennifer Read, Great Lakes Observing System

Doug Rickman, NASA/MSFC

Steve Ruberg, NOAA GLERL

Michael Sayers, Michigan Tech Research Institute

David Schwab, Michigan Tech Research Institute/University of Michigan

Robert Shuchman, Co-Director, Michigan Tech Research Institute

Tad Slawecki, Senior Engineer, LimnoTech

*Beth Stauffer, AAAS Science & Technology Policy Fellow, EPA Office of Research and Development

Roger Tokars, Electrical Engineer, NASA Glenn Research Center

Andrea Vander Woude, Research Fellow, University of Michigan CILER, NOAA GLERL

*David Warner, Research Fishery Biologist, USGS

*James Watkins, Research Associate, Cornell University

Matthew Whitley, Michigan Tech Research Institute

Michelle Wienert, Michigan Tech Research Institute

*Foad Yousef, Michigan Technological University

*web attendee

Proposed Short Pilot Projects

No.	Idea Title	Description	Deliverable(s)	Personnel/Role/Phone No.
1	Comprehensive assessment of atmospheric correction routines over the Great Lakes	Still one of the greatest hurdles in GL remote sensing is accurate removal of atmospheric effects & how this affects higher-level products. There hasn't been a comprehensive assessment of the currently available atmospheric correction algorithms. Similar comparisons needed for chl/PP/HABs (Joe Ortiz, Gary Fahnenstiel, Dmitri P interested in chl/HABs)	Recommendation of best atmospheric correction approach for the Great Lakes	Caren Binding, Andrea VanderWoude, Jeff Ho, & others Graduate students?
2	Generation of in situ data truth set using GLNPO observations	Examine GLNPO data holdings & develop robust procedure to condition In situ data for comparisons to remote sensing retrievals	Detailed written procedure on how to condition GLNPO data Different levels of GLNPO products (1/2/3)?	Barry Lesht, Bob Shuchman, Jim Watkins, others
3	Generate a primer on what GLNPO holdings contain	Examine GLNPO data holdings and write a descriptor Incorporate corresponding Canadian datasets	GLNPO Primer	Jim Watkins, Warren Currie, others

No.	Idea Title	Description	Deliverable(s)	Personnel/Role/Phone No.
4	Multispectral lidar	Write white paper to develop concept of active lidar sensor for WQ applications, physics modeling, etc.	Feasibility report Establish the feasibility of airborne and satellite lidar for observing water quality. Testing would include a theoretical model and aircraft data if available.	Steve Greb, Michael Jasinski
5	ARSET – Great Lakes training for resource managers			
6	Feasibility of existing commercial flights as a RS platform	Could begin with the NASA fleet Look for precedents – others may have done similar activities in the past (Darren McKague), including aerosols (Joe Ortiz) and aerial imagery. Could look at both larger and small/private providers Ferries, ships, smaller boats as well as planes as possible platforms	Feasibility report	Joe Ortiz, Larry Liou, Darren McKague, Warren Currie, Colin Brooks
7	Developing applications of UAVs for GL monitoring	Review several applications that could be developed for use in Great Lakes (fixed-wing, heli/hexa/octocopter) Could have similar project focused on AUVs	A defined set of shorter-term applications of UAVs for environmental mapping & monitoring	Colin Brooks, Doug Alsdorf, Ben Vander Jagt, others

No.	Idea Title	Description	Deliverable(s)	Personnel/Role/Phone No.
8	Defining the GL oil spill and WQ monitoring radar mission	Begin to prepare oil spill remote sensing response capabilities in the GL May be able to get WI, MN, and PA involved (Benko) Could substitute other issues (toxicity, for example) for oil spill	Detailed description of requirements for a SAR-based oil spill monitoring system	Bob Shuchman, Brian Huberty, George Leshkevich, Colin Brooks, OhioView/Terry Benko, Steve Ruberg, Douglas Feikema, others
9	GRC/Educational Program Office Great Lakes internship			Clarence, Larry
10	Mapping between available GL RS products and potential end users	Could combine with 9 Bring in non-remote sensing savvy potential users Two-way communication about needs and capabilities		Joseph Ortiz
10	Creating a WQ working group as an approach to address HABs, etc.			Terry Benko, Larry Liou, Nancy French
11	Developing a WQ monitoring app for smartphones			Nancy French, Larry Liou
12	Development of a WQ information app	Provide WQ data for specific locations		Larry Liou

No.	Idea Title	Description	Deliverable(s)	Personnel/Role/Phone No.
13	Expand the nearly 2 decade old Upper Midwest Resac project funded by NASA where inland Lake Water Quality was mapped with Landsat for MN, WI, MI....why not do the entire basin? The infrastructure is still in place.			Brian Huberty
14	Identification of Stakeholders			
15	Review of Policy Documents			
16	Creating a Networking or organizational visual	Create a chart or story map of who/where we are, and what we're doing; include a description of expertise; maybe an opportunity for a video	Chart	
17	UAV determine tile drainage to nutrient loading	Can we use UAVs to determine tile drainage to nutrient loading in a more effective manner		
18	Calendar with closing dates for proposal	Google calendar to organize important events and deadlines		Amanda
19	Inventory of ground truthing groups and activities	Something similar to GLATOS		
20	Assessing hurdles to US-Canada cooperation	Figure out how we can find cooperation	Guidelines	
21	What can we do with a hyperspectral small-sat, or what questions can we answer with a small-sat?	Find questions that we can answer with a hyperspectral small-sat		
22	Develop a Great Lakes Remote Sensing 101 slideshow/video	Create a slideshow of general information on		
23	Identify technology or algorithms to help researchers			

No.	Idea Title	Description	Deliverable(s)	Personnel/Role/Phone No.
	of smaller bodies of water			
24	Compile samples of products for the end users	Create a collection of examples of data so the end user can see the utility of widgets and remotely sensed data		
25	Great Lakes Ice	How does ice extent and duration affect spring/summer water temperaturatures? (this may have implications for HABs)	Graphs of water temperatures and ice extent/duration for one of the lakes. Could be presented somewhere as a poster	Dorothy Hall 301-604-5771 Dorothy.k.hall@nasa.gov Collaborator: George Leshkevich if he is interested

Table 1: Workshop 1, Breakout Session 1: Inland Lakes Remote Sensing Sensor Requirements – review and update the input data required for existing remote sensing water quality products

Breakout leader: **Dr. Joseph Ortiz**, Kent State University

Requirement	Applications/ Derived Products	Spatial Resolution Needed	Temporal Resolution Needed	Priority (1,2,3…)	Current status (met, planned, unmet)	Remarks
Ocean color imagery	Chl/DOC/SM monitoring, HABs mapping, sediment plumes, primary production estimation	Desired 100 m, Minimum 1 km	Daily or preferably Sub-daily	1	Partially met by MODIS and VIIRS	Both MODIS and VIIRS fall short of MERIS's spectral band set; 100-m imagery would allow for much better HAB mapping/modeling
Thermal imagery	Water surface temperature maps Multispectral-geologic applications		Daily	?	Partially met by current multispectral sensors (MODIS, Landsat 8, others)	
Scatterometer data	Wind fields over large inland lakes	~10-15 km	Every 6 hours desired	?	Partially met by QuikSCAT	Higher spatial and temporal resolution needed; The NOAA PORD lists wind direction and speed measurements; ISS-RapidScat is slated to launch this year and will provide better resolution
Synthetic aperture radar (SAR)	Ice cover mapping, wetland classification, lake circulation, mapping lake shorelines, water level?	~100 m or better depending on application	Weekly desired	?	New data needs partially met by Canada's RADARSAT, airborne UAVSAR; no NASA satellite	High cost of RADARSAT data prohibitive
Water altimetry	Monitor changes in water storage and river discharge; improve circulation modeling	100 m horizontal, on the scale of centimeters vertical	Daily	?	Planned: Upcoming Surface Water Ocean Topography (SWOT) mission	SWOT will improve on ICESat/ENVISAT abilities
Hyperspectral imagery	Algal and mineral constituents, watershed land cover, substrate mapping	Desired 10 m, Minimum 100 m	Daily or preferably Sub-daily	1	Partially met by HICO	

Requirement	Applications/ Derived Products	Spatial Resolution Needed	Temporal Resolution Needed	Priority (1,2,3…)	Current status (met, planned, unmet)	Remarks
Lidar	Water level	1 m	Sub-daily	2		Would enable better/more global watershed mapping Water profiler depth limitations unclear, might get too noisy in larger lakes (small lakes less so)
Passive microwave	Soil moisture, ice type	10 km		?		
Others On the ground	Radiometry Standard suite of measurements NASA's standard suite of measurements need evolution, given new technologies			2		

Table 2: Workshop 1, Breakout Session 2: What remote sensing data and derived products are missing for inland lakes, and what would we gain by filling those gaps?

Breakout leader: **Dr. George Leshkevich**, NOAA GLERL

Data Type	Product Gap	Application/ Rationale	End users	Priority (High, Medium, Low)	Spatial Scale Required	Temporal Scale Required	Remarks
Medium-resolution hyperspectral imagery	No hyperspectral-derived products available	Better mapping and monitoring of invasive species, coastal wetlands and benthic habitats	Ecologists, land managers, fisheries	High	<100 m		Aerial hyperspectral imagery is very expensive, HICO is too coarse for many environmental applications HyspIRI is still 10+ years out
Medium-resolution multispectral (Landsat-type) imagery	Temporal coverage limited to 16 day repeat	Daily repeat would improve SAV maps	Regulators, resource managers, researchers	High	30 m	Daily desired	
Active/passive microwave	Improved high-resolution soil moisture and precipitation data	Modeling and predicting surface runoff and stream discharges for nutrient and pollutant transport modeling	Land managers, regulators, modelers	High	1 km for precipitation data, 50-100 m for soil moisture data	Daily	

Data Type	Product Gap	Application/ Rationale	End users	Priority (High, Medium, Low)	Spatial Scale Required	Temporal Scale Required	Remarks
Ocean color imagery	Primary productivity maps	Nutrient modeling, carbon studies, etc.	Researchers, resource managers	High	1-km	Daily desired	Interpolating between cloud-free dates needs improvement; Can we develop a new Kd490 method based on something similar to CPA-A rather than a band ratio? If such a product were available, it would open up research avenues w/hypoxia data Wouldn't capture grazing/effects of zooplankton
Ocean color imagery	Nearshore Chl/SM/DOC estimation	Nearshore water quality monitoring	Resource managers, researchers	High	100 m	Daily desired	
Scatterometer	Wind fields						
SAR	Wind, waves & surface currents						
	Substrate types & texture						
	Dreissena densities						

Data Type	Product Gap	Application/ Rationale	End users	Priority (High, Medium, Low)	Spatial Scale Required	Temporal Scale Required	Remarks
Multispectral imagery	Better shallow water retrievals of water quality parameters (chl, DOC, sediment, etc.)	Improve modeling of nearshore/offshore dynamics		High – nearshore/offshore is a priority in new GLWQA			More research needed into how to accurately remove the signal from bottom reflectance Increasing lake clarity in Great Lakes is resulting in larger area of the lakes with a bottom return
	Phosphorus						No agreed-upon method to produce this, but Blue Water Satellite has a commercial product Is there a proxy or indicator? Could this be developed at least at a regional level? Can we remotely sense other variables that can be used to better model phosphorus? Correlation btwn turbidity and phosphorus
	Salinity						Higher resolution than SMOS needed
	Bubbles						Example of a product more useful for modelers than for end users
	Hypoxia						Might involve modeling+in situ+RS rather than a direct RS product

Data Type	Product Gap	Application/ Rationale	End users	Priority (High, Medium, Low)	Spatial Scale Required	Temporal Scale Required	Remarks
Thermal	Daily SST maps						Already available as a product, could be more accessible to end users
	Microplastic mapping						
	Surfactant mapping						
	Proxy for *E. coli* detection						Wave, turbidity, DOM are remotely sense-able and could be useful for *E. coli* modeling Another example of where the integration of RS/ground data/modeling would be really useful *E. coli* age matters

Data Type	Product Gap	Application/ Rationale	End users	Priority (High, Medium, Low)	Spatial Scale Required	Temporal Scale Required	Remarks
	River plumes						Operational product that represents all/most plumes desired Hydrologic modeling can estimate river inputs well but RS could be really useful for understanding how that disperses into the lake, defining the plume boundaries Different spatial resolutions might be appropriate for local vs. lakewide effects of river loading Small tributaries can be disproportionally important
	Ice surface temperature	Useful in ice modeling, forecasting, research on under-ice diatoms					Desired as a regular product

Table 3: Workshop 1, Breakout Session 3: Technology gaps related to remote sensing of inland lakes (sensors, instruments, & other hardware)

Breakout Leader: **Colin Brooks** (Michigan Tech Research Institute)

Gap	Application/ Rationale	Outcomes	Timeframe	Remarks
Small optical sensors/profilers that can be mounted on a glider or AUV	Provide inputs required for inverse radiative transfer calculations	Improved satellite retrievals	Short term	Funding issue
Improved radiometer instrumentation on moored buoys	Provide input for improved atmospheric correction over water and calibration/validation of derived satellite values	More accurate satellite retrievals	Mid-term	
Improved battery technology for unmanned underwater and aerial systems	Already available aerial and aquatic unmanned systems can extend or multiply the reach of survey and research missions	Improved and more cost-effective data collection	Mid-term	
Improved battery and data communication technology for moored buoy sensor systems	Buoy data are helpful for integrating real-time in situ data and satellite observations; moored buoys can be sited very far from land where laying a fiber optic cable would be prohibitive.	Increased capabilities to supply power to instruments and transmit data to shore	Mid-term	
Docking stations	Recharge, allowing long-term data collection	Flexibility in data collection		

Gap	Application/ Rationale	Outcomes	Timeframe	Remarks
Cabled observatories	Decrease seasonal restrictions	Year round observations		
Underwater wireless data transmission	Effectively transmit data underwater; 10 m range acceptable	Less cabling, more rugged systems	Near/ midterm	Research, but not fully developed
Easily deployable technologies for Crowd sourced or public access data	Increase ease of data sharing, more data	Citizen participation, more data		Cost vs. value
Ice thickness sensors	Better ice thickness measurement	Useful for shipping and scientific purposes		
Webcams and remotely accessed cameras	Ice classification, underwater tracking, weather reporting, visibility, rudimentary Chl estimate, wildlife	Better dataset of what's going on, general intelligence		
Ability to easily deploy autonomous aerial sensors	Plume monitoring, algal bloom, mapping fish spawning, etc.	Better data		
Improved resolution, spatial and temporal	More views of GL region,	Better resolution		
3d water column profiling (vertical column)	Heat budget of lakes, thermal structure important	Better understanding of GL processes		

Gap	Application/ Rationale	Outcomes	Timeframe	Remarks
Improved fish and wildlife monitors	Useful information on organism, but also using the organism as a means of transportations,	Helps wildlife/biological sciences, but also environmental monitoring		
Lack of a domestic U.S. radar platform (SAR) for Cloudy/nighttime /year-round conditions	Ice area analysis, improved vegetation mapping, wind and wave direction	Improved year-round sensing of GL conditions	Longer-term	Advocate to demonstrate usefulness, advocate our voice, microSAR UAV deployment interest
Better understanding of sensor availability and access	GL monitoring	Improved integration of these datasets into science and decision making	Short-term	
Better access to existing UAV platforms	GL monitoring, resources aren't being used when in place, inefficient	More data being collected, better use of existing resources	Short-term	HIRAD, hurricane center Miami

Gap	Application/ Rationale	Outcomes	Timeframe	Remarks
Broader, stronger, GL remote sensing community	Stronger voice and outreach to advocate for remote sensing	Educate congresspeople, better understanding for the need for these resources	Relatively short-term	Direct participation of NASA in GLRI; outreach to Scientific communities, Management agencies, decisionmakers; Consistency of message and prioritization; inspire kids by bolstering their understanding of tools available
Visualization tools	Improving understanding of the science data,	Improving understanding of the science data		
Chemical sensors and accuracy of sensors (in situ sensors)	pH sensors, HABs toxicity, phosphorous, Nitrogen, CO2, e. coli, sir quality sensors	Less expensive, more precise, more robust, larger coverage		Lab on a chip?; UAVs dipping sensors into water
aircraft of opportunity with pre-existing flights	100s of flights over GL a day, so opportunity for science, same flight paths, high repeat time, outreach to passengers	Much larger set of GL imagery and near-continuous		Safety, mounting, etc. (light cheap inexpensive, self-powered); FAA; potential Glen RC pilot
Spatial and temporal resolution of thermal sensing	Improved thermal monitoring in the GL	Higher resolution, more complete thermal surface imaging of the GL	Long-term(satellite) ; short-term (other alternatives)	Infrared webcams

Gap	Application/ Rationale	Outcomes	Timeframe	Remarks
Access to forecast and modelling code (open-source code)	Customizable runs of the code, find areas with high wind, recreating flooding events,	Improved understanding of the science		Changeable input parameters, not necessarily changing code
Public access to modeling	User-friendly interactive simulation	More value from data,		Point query tool under GLOS; Panoply works with THREDDS
Using models to interpolate RS data	Data assimilation	More value from data		Integration with RS and modelling
CubeSats, smallsats, nanosats	More platforms for sensing GL, fill/compliment need for data	Less expensive, more frequent data collections		

Table 4: Workshop 1, Breakout Session 4: New potential applications for remote sensing of inland waters

Breakout leader: **Dr. Steve Greb**, Wisconsin DNR

Application	**Spatial scale required**	**Temporal scale required**	**Remote sensing input data needed**	**End Users**	**Priority (High, Medium, Low)**	**Remarks**
Mapping invasives and/or emergent aquatic plant species	10-1 m	Annual, seasonality	Hyperspectral and/or high-resolution multispectral data, fusion with radar may improve accuracy, LIDAR, in Situ	Local communities, harbor managers, regulators, state/federal agencies	High	Both emergent (*Phragmites*) and submerged (Eurasian watermilfoil) species, should *Cladophora* be included?
Bottom substrate/sediment type maps for habitat mapping, fisheries, modeling, substrate	30 m - .5 m	Update every ~5 years to reflect changes caused by e.g. sediment redistribution, dreissenid reef expansion	Side-scan sonar, acoustic bottom surveys, hyperspectral imagery, LIDAR	Ecologists, fisheries scientists, geologists	Medium	Last lakewide mapping effort was ~1960s
Dangerous (rip) current hazard maps	10-100 m	Updated every 5 years	Multispectral aerial imagery, bathymetric lidar	NOAA, Coast Guard, beach authorities, coastal engineers,	High	
Real-time dangerous current alerts Nearshore- winds, waves, and currents	10-100 m	Daily	Surface wind speeds from scatterometers, wave height from SAR altimeter	NOAA, beach authorities, emergency response, and landowners.	High if available real-time or within hours	Better SAR and scatterometer temporal and spatial coverage needed for this to be useful

Application	Spatial scale required	Temporal scale required	Remote sensing input data needed	End Users	Priority (High, Medium, Low)	Remarks
Fish spawning habitat maps	~1 m	Spawning dependent	Aerial or UAVs, commercial multispectral imagery, LIDAR	USGS		Substrate mapping is key,
Detection/tracking of water plumes	10m	Daily or <1	SAR, airborne sensors, thermal, hyperspectral	Municipalities, resource managers,	high	Water intake
Drainage tile mapping	1 m	sporadic	UAV based infrared,	farmers		
Algal composition mapping (species,	100 m	High frequency as needed, seasonal (early and late)	Hyperspectral, AUV under ice	Regulators, resource managers	High	HICO has potential; pelagic vs. benthic; chlorophyll a vs b; flagellates vs cyanobacteria vs diatoms
Plume constituent mapping	100 m	Daily	Hyperspectral	Regulators, resource managers, DNR	High	HICO has potential
Mapping Tsunami-like waves created by storms	100m	1-minute	Underwater buoys, radar Doppler	Surfer-dudes, homeowners, insurance companies, swimmers,		Can be caused by coastal landslides
illicit discharges	10m	Daily,	SAR, airborne sensors	Regulatory agencies, Municipalities, Homeland security/FBI/Police	High	

Application	Spatial scale required	Temporal scale required	Remote sensing input data needed	End Users	Priority (High, Medium, Low)	Remarks
Oil spills	100m	daily	SAR, airborne sensors	Regulatory agencies, Municipalities,	high	
Water Clarity	300 m	monthly	color imagery			
Microplastics monitoring				EPA, plankton,		
Fine scale water height and/or flooding	10 m or 1 m	Seasonal, multiple readings/day		Nursery habitats, fish, landowners, boaters		
Watershed modeling	30 m					Crop rotations, impervious surfaces
Water quality						
Beach monitoring/health						Bacteria concentration hotspots related to turbidity,

Table 5: Workshop 1, Breakout Session 5: Current approaches to Great Lakes algorithms/modeling

Breakout leader: **Dr. David Schwab**, University of Michigan/Michigan Tech Research Institute

Product	Algorithm/model	Status	Validation data	Strengths	Deficiencies / Modifications needed	Remarks
HABs	MTRI	Partially validated		Includes scum & pelagic components	Quantification of scum component needed	There is a distinction between algorithms that detect algal blooms vs. discriminate HABs
HABs	Stumpf	Partially validated				Developed for MERIS, has been expanded to MODIS with some loss of sensitivity
HABs	Ortiz Full-spectrum algal classification		Cell counts conducted independently	Can use Landsat to hyperspectral as input with better results at higher spectral resolution; differentiates phytoplankton functional groups		
HABs	Moore UNH/Mouw					

Product	Algorithm/model	Status	Validation data	Strengths	Deficiencies / Modifications needed	Remarks
HABs	Binding					Specific to MERIS/hyperspectral
Chl concentration	NASA OC3/4	Validated		Works well in case I waters	Not applicable to case II waters	Not sensor-dependent; includes Great Lakes fit
Chl/DOC/SM	MTRI CPA-A	Validated		Works well in case I and II waters	Requires HO model to produce robust estimates	Provides estimates of all 3 CPAs, can use any ocean color satellite
Chl	Semi-analytical (Simis)					Looks at chl and phycocyanin separately and corrects chl for phycocyanin and vice versa
Chl	Binding					Red/IR inverse modeling approach, also get SM
Chl	RIT/Mobley					LUT approach; IOPs needed as inputs; estimates all 3 CPAs
Chl	MERIS MCI					More appropriate for high-biomass conditions

Product	Algorithm/model	Status	Validation data	Strengths	Deficiencies / Modifications needed	Remarks
Chl	OC5/Gohin					
Chl	Fluoresence line height					Can use 667/678/748 nm or others depending on sensor
Chl	Gittelson					
Chl	Coast color					Neural network-based
Temperature						
Primary production	GLPPM (MTRI/Shuchman/Fee)					
Primary production	Morin					Correlation-based
Primary production	Eppley					
Primary production	Dmitri P					
Primary production	Lorenz					Gulf of Mexico
Cloud cover						

Product	Algorithm/model	Status	Validation data	Strengths	Deficiencies / Modifications needed	Remarks
Atmospheric correction	SeaDas level 2					See the JGLR remote sensing special issue for 7 more
Atmospheric corr	ELM					
Atmospheric corr	Stumpf					
Kd/Turbidity/Water clarity	Upstate freshwater institute			Differentiates spectra of different particle types		Particle type/optical properties has a large effect on Kd;
Whiting events						
Suspended minerals						Needs to be corrected for biogenic contributions
CDOM/DOC estimated from CDOM						
Surface glint						With increasing spatial resolution, can no longer use a statistical model to deal with glint

Table 6: Workshop 1, Breakout Session 6: Platform/Mission Gaps & Recommendations

Breakout Leader: **Larry Liou**, NASA Glenn Research Center

Gap	Applications	Revisit time	Spatial res. needed	End users	Priority	Remarks
Landsat Continuity Mission Sustained land imaging program	Too many to mention. Water quality Ag mapping Forest cover Climate Etc.	16 days	At least 30m (multi) 15m (pan)	Scientists Decision Makers Farmers Lake managers Meteorologist Fire Disaster Etc.	Highest	-Still refining data release -May only get four scenes a season -If we want changes, we need to let NASA know
SAR	• Ice mapping • Wind field mapping • Vegetation mapping • Soil moisture • Flooding • Oil Spill • Global applications – glacier thickness, etc.				Very High	• It can operate day/night • Need immediate data for some disasters – rapid response capability • There is not an aircraft system in the US that can cover the Great Lakes right now in an emergency situation. • Distinct interaction with oil sheen (all day/night, weather, etc.) • Coast Guard interaction • Lacking this technology right now
Hyperspectral	• Land cover mapping, CPA monitoring, HABs mapping	Daily	30 m	Researchers, resource managers	High	
Dedicated Great Lakes Water Quality and Oil Spill Monitoring Mission (airborne fleet)	• Disaster mapping • Water quality • MANY others	24/7, up to hourly		Disaster relief managers, FEMA, Coast Guard, FWS, Contractors, NOAA, etc.	High	• NASA has the aircraft – S3 • FWS have aircraft as well. • This has to be an operational system (1-3 backups) • C-band used for oil • S-Band (maybe) • K-band (might be too short) • Characteristics under/over ice?

Gap	Applications	Revisit time	Spatial res. needed	End users	Priority	Remarks
AUVs (autonomous underwater vehicles)	• What's under the ice? Visible imagery and sonar could both detect an under-ice oil spill.	Not available on **operational** level yet, need docking station		--Oil Companies --Agencies (NOAA, EPA, etc.)	High	• 12 hr missions, sonar, camera, $250K instrument.has been developed, not available on an operational basis • Preventive inspection
UAV	• HABs, oil spill monitoring, invasive species mapping, fish spawning, marine safety, search and rescue,	Several times a day, on demand Not available on o**perational** level yet,			High	• A SAR sensor can be flown on these • Reuse of an existing UAV • NASA is already investing in used large UAVs with SAR instrumentation (expensive)
Fleet of small UAVs	• HABs, oil spill monitoring, invasive species mapping, fish spawning, marine safety, search and rescue,	Several times a day, on demand	Larger coverage area at one time		High	• Docking stations, Western Lake Erie, Solar power, • FAA regulations prohibitive

Gap	Applications	Revisit time	Spatial res. needed	End users	Priority	Remarks
CYGNSS – fleet of 8 small satellites	• Water quality • Hyperspectral • Earth Science Ecology • Any monitoring needing higher revisits • Same thing you're doing with MODIS now. Detecting HABs, forecasting, seeing events initiate, modeling • Smaller lakes • Global everything, HABs, Ice, etc. • SAR • Hurricane monitoring	High – Better than one satellite Validate theories better	100 m	Modelers Researchers Forecaster Indirect Users Water Managers Waste Water Treatment Plants Farmers Weather forecasting	High	• Low cost • LEO • Large spatial coverage • Better revisit coverage • Even distribution • "fleet" "constellation" • Push the cost down • Low inclination orbiting satellite • Determine what is best for your target • Concept is chip size – 10cm cube • Share a ride • DOD keen on small satellites • Flexibility in case another instrument fail • Life cycle-one year in low orbit… two years is common now, longer in higher orbit. • Launch in 2015 • $180 million
Earth-imaging lidar Platform	• Coastal, benthic and wetland surveying, erosion analysis • Vegetation mapping (better than SAR) • Global applications – Glacier thickness, etc.	Annually Seasonally for Vegetation mapping		Engineers, resource managers Vegetation community	Medium	Multi frequency/multi spectral lidar could expand applications

Gap	Applications	Revisit time	Spatial res. needed	End users	Priority	Remarks
Water-profiling lidar	• Fish stock • Nearshore bathymetry in some lakes (not others, e.g., Western Lake Erie)					
Tandem SAR	DEMs, change detection, current mapping					
Sounding Rocket						Can get a shared ride fairly easily Camp Perry Location Launch?
Kites						Versatile Agile Low cost
Balloons						Versatile Agile Low cost
Small Satellites						• $1 Million • University class mission
Additional Buoys – Network of Buoys	• Water quality monitoring, HABs, Hypoxia, Central Western Lake Erie • Weather monitoring • Air quality monitoring	Seasonal 24/7				• Can be used at strategic points of lake/river • More of them • Need a support infrastructure

Gap	Applications	Revisit time	Spatial res. needed	End users	Priority	Remarks
Additional Fixed Platforms	• Year-round ice observations • Weather monitoring • Air quality monitoring • Water quality monitoring, HABs, Hypoxia, Central Western Lake Erie •	Year-round 24/7				• Maintenance needs? Once a year. • Reliable • More of them • Need a support infrastructure
Additional Onshore Platforms	• Temp monitoring of shoreline water	Year round 24/7				• Thermal • Admiral Perry Monument • Coal plants • Science Center not tall enough • Steam ship
Cabled Observatories	•					• Homeland security issues
Ship-based	• Water quality • Weather					• Charter boat captains is an existing program – expanding on that • Research vessels • Large commercial vessels • Ferry's
Commercial Aircraft	• Imaging					• Delta • Southwest NASA
Private Aircraft	Imaging					•
Sea Plane	Imaging					

Gap	Applications	Revisit time	Spatial res. needed	End users	Priority	Remarks
Fish platform	• Temp, location,					• GLOS program is using this right now for the Great Lakes Acoustic Telemetry Observation System (GLATOS) • Make into a better capability • Microcystin • Citizen science
Crowd Sourcing (smart phone, etc.)	• Water quality • Fish					•

Table 7: Workshop 2, Breakout Session 2: Distribution of Great Lakes data

Breakout Leader: **Dr. Jennifer Read**, GLOS

Data Type	Description	Responsible organization	Access sites	Frequency of observation	Amount of data	Candidate central data repository	Most Useful Product Format	User Groups	Remarks
Buoy	Meteorological and lake observations from buoy sensors	Owner of the buoy (various)	UGLOS, GLOS Explorer, NDBC websites	10-min	Up to 100 values/10 min	NDBC, GLOS-DMAC	Cell phone, website, text messaging, time series/windrows diagrams, figures showing change as a function of water depth	Search and rescue, oil spill and other spill extents, hydrodynamic modeling, coastal intelligence, coastal resiliency → support better decisionmaking, HAB extents	NDBC data have a 20-min interval Current buoy data interfaces aren't user-friendly Improved figures with time series/depth info would be useful for particle movement modeling Stevens Institute website is an example of better graphics
Chl/SM/DOC concentrations	Ocean color-derived products	MTRI, NOAA GLERL, other academic insts.	MTRI, NOAA CoastWatch websites	~Weekly	All 5 lakes @ 1-km resolution	NOAA CoastWatch, GLOS-DMAC	Rasters, JPEGs, text messaging of average values, tables		

Data Type	Description	Responsible organization	Access sites	Frequency of observation	Amount of data	Candidate central data repository	Most Useful Product Format	User Groups	Remarks
Water column profile data	Various types of profiles, e.g., temperature, oxygen, chl, currents						Spatially or temporally combined profiles, geospatially referenced		Not currently centralized
Images/video	Webcam, UAV, AUV, aerial						Still images, streaming video, time lapse images, stitched mosaics – georeferenced	Trip planning (both recreational and research/professional), classification verification, beach managers (e.g. seagull flock → beach closing, human health applications), fish tracking	
Thermal imagery	Satellite, aerial, UAV						Still images, streaming video, time lapse images, stitched mosaics - georeferenced		
Hyperspectral data	Satellite, aerial, UAV						Image datasets, spectral profiles derived from imagery, derived products such as weekly HABs extents used for forecasts		UAVs could provide cloudy-day hyperspectral imagery

Data Type	Description	Responsible organization	Access sites	Frequency of observation	Amount of data	Candidate central data repository	Most Useful Product Format	User Groups	Remarks
Crowdsourced data via apps, etc.	Socioeconomic data; data mining from Twitter, Instagram							Early warnings of episodic events, socioeconomic researchers,	Can be used for RS validation, extending field season, characterizing variability
Citizen science projects									Can help ameliorate funding cuts for projects
Spill extents	Oil and other spills			Regular scans/surveys for skills desired			Early warning with routine sampling, tracking extents – provided as georeferenced maps	Spill response teams	No consistent RS effort yet in the Great Lakes, under development now Other parts of the world have high-frequency spill scanning programs in place Oil is distinct in radar imagery

Data Type	Description	Responsible organization	Access sites	Frequency of observation	Amount of data	Candidate central data repository	Most Useful Product Format	User Groups	Remarks
SAR (synthetic aperture radar) data							Georeferenced images & derived products	Wetlands mapping, ice mapping, spill mapping,	US doesn't have its own satellite; Canada, ESA & Japan have platforms Radar is robust to weather/time of day
HAB extents							Georeferenced maps, derived forecasts		
Plumes	e.g. sediment plumes						Temporal series of maps Plume constituents & concentrations are important outputs		Bob Guza UCSD – example for outputs of this data type
Transect data	Gliders, towed arrays						Continuous georeferenced data; many formats and data types. Raw data is a point series		Distinct from profile data Difficult to deliver due to data characteristics Rutgers is an example of a good display

Data Type	Description	Responsible organization	Access sites	Frequency of observation	Amount of data	Candidate central data repository	Most Useful Product Format	User Groups	Remarks
Water clarity							Georeferenced map of K(PAR) and/or Kd(490) with temporal information	Recreational users – divers, kayakers	Forecasts for boaters etc. Remote sensing of water clarity is matured so this could be developed into a forecast fairly easily Crowdsourcing could be useful here (Secchi depth)
Capped wells	Oil & gas	CHS hydrographic services doesn't have detailed information, States					GIS layer of locations with attributes (status, age, history)	Scientists, emergency response (Coast Guard), improved no-anchor maps	Very little knowledge and some are aging Dense in central and eastern Lake Erie
Fisheries acoustics	Active acoustics / biosonics						Kg/ha of fish – densities of fish & mysids; NetCDF for raw data		

Data Type	Description	Responsible organization	Access sites	Frequency of observation	Amount of data	Candidate central data repository	Most Useful Product Format	User Groups	Remarks
Passive fisheries acoustics	Fish sounds							Scientists	
Benthic, fisheries & zooplankton surveys		EC is gathering fisheries, zooplankton, acoustics data in a database for sharing, using universalized protocols USGS, Ministry of Natural Oceans &					Georeferenced density data at multiple trophic levels	Managers, researchers, management agencies, commercial fisheries, fisheries modeling	Database design for datasets this size will be a challenge
Sidescan & multibeam sonar data							Derived products: Bathymetry raster, substrate hardness/benthic habitat type, xtf for raw data (?)		PACIOOS, Hawaii Geology group (?), NOAA Digital Coast are good example websites

Data Type	Description	Responsible organization	Access sites	Frequency of observation	Amount of data	Candidate central data repository	Most Useful Product Format	User Groups	Remarks
Land cover data	Coastal wetlands & invasive species (Phragmites) are of particular interest						Georeferenced map	Local planning agencies, researchers, agencies, conservation groups,	Various versions with different resolutions & classes available from different sources (US/Canada agencies, states, universities)
Benthic habitat type/substrate type		MTRI has a Landsat-resolution SAV map					Georeferenced map	Management agencies, researchers	Crowdsourced validation could be useful here
Thermistor data							Charts of temperatures at different depths over time for a location,	Researchers, water intake managers, modelers, recreational fishermen, other recreational users,	
Oblique aerial imagery							Georeferenced images	Recreational boaters, management agencies, conservation groups, researchers,	USACE Great Lakes imagery is recent and available online

Data Type	Description	Responsible organization	Access sites	Frequency of observation	Amount of data	Candidate central data repository	Most Useful Product Format	User Groups	Remarks
Lidar	Both terrestrial & bathymetric	Much currently available data is at the county level, national level has been initiated. CHARTS lidar is limited to nearshore, misses larger shoals like at Sleeping Bear					XYZ point cloud, DEMs, DSMs, other derived maps	Local, state, federal agencies, coastal zone managers,	
Ice coverage & thickness							Georeferenced map of ice cover, time series maps	Shipping, Coast Guard, scientists, ice fishermen	Could crowdsource ice thickness from fishermen
Microbial water quality - FIBD							Georeferenced maps, time series	Beach and water quality managers, water utilities, recreational users & boaters, researchers	Could be useful for source tracking

Data Type	Description	Responsible organization	Access sites	Frequency of observation	Amount of data	Candidate central data repository	Most Useful Product Format	User Groups	Remarks
Dangerous nearshore current hotspots							Georeferenced maps of rip-associated features, 'threat level' estimates for shoreline	Beach managers, agencies, Coast Guard, researchers, recreational users	
Current maps							Windrose	Researchers	
Wind & wave data							Nowcasts & forecasts, web-accessible georeferenced maps very important	Researchers	Not all data currently collected is publicly available, some is already shared

Table 8: Workshop 2, Breakout Session 6: Define time series remote sensing datasets

Breakout leader: Dr. George Leshkevich, NOAA GLERL

Product	Sensor	Applications	End users	Priority (High, Medium, Low)	Length of time series	Repeat time	Status/Feasibility	Remarks
HABs	Ocean color (CZCS, SeaWiFS, MODIS, MERIS, VIIRS)	Health advisories, water quality monitoring	Researchers, beach/lake managers, fishermen, water utilities	High	1979-1987, 1998-present	~Weekly	Under development	
Primary productivity	Ocean color (CZCS, SeaWiFS, MODIS, MERIS, VIIRS)	Water quality monitoring, carbon studies, lake ecology research	Ecologists, water resource managers,	High	1979-1987, 1998-present	Monthly	Under development	
Chlorophyll-a	Ocean color (CZCS, SeaWiFS, MODIS, MERIS, VIIRS, Sentinel-3)	Water quality monitoring, carbon studies, lake ecology research	Ecologists, water resource managers, water utilities, fishermen	High	1979-1987, 1998-present	Monthly	Under development	
Water clarity / light attenuation / Kd(490)	SeaWiFS, MODIS, MERIS, VIIRS, Sentinel-3			High			Very feasible	Product exists, no time series yet

Product	Sensor	Applications	End users	Priority (High, Medium, Low)	Length of time series	Repeat time	Status/Feasibility	Remarks
Temperature/SST	AVHRR, Pathfinder	Monitor lake warming, distribution of warming among sub-basins	Researchers, managers, government agencies, fishermen, weather modeling	High	~1982-present (resolution-dependent, 8 km for earliest dates, 1 km beginning late 80s)		Very feasible	Product already exists, no time series yet Day/night or night only? Global Lake Temperatures Consortium is looking at lake warming at the global scale Usefulness of data quality flags varies among sensors
Ice	SAR, swath altimeter, ground-penetrating radar	Ice type, ice surface temperature, ice formation and breakup dates	Coast Guard, shipping industry, other industries, climate modeling, other research	High	1992 (ERS-1) - present		Very feasible	Not much measured ice thickness data, "guesstimated" data back to early 80s IceSat-2 will provide ice freeboard data

Product	**Sensor**	**Applications**	**End users**	**Priority (High, Medium , Low)**	**Length of time series**	**Repeat time**	**Status/Feasibi lity**	**Remarks**
Water level								Already compiled from water level gauges
Wave height and/or wind speed	Scatterometer		Wind farm developers, risk management for marinas & coastal structures, researchers, HABs modeling					
Surface PAR – photosynthetically active radiation					1998-present			MODIS product includes estimates of PAR under clouds Product exists but not time series

Product	Sensor	Applications	End users	Priority (High, Medium , Low)	Length of time series	Repeat time	Status/Feasibi lity	Remarks
Land use/cover		Input loadings, water quality policy,			~1975 (Landsat 1)			CCAP is every 5 years; NASS has annual crop type cover maps Land use is more integrated in the new GLWQA Major differences between US/Canada land cover products
Vegetation					1970s (AVHRR)			
Wetlands		Changes in connectivity						
Submerged aquatic vegetation (Cladophora)	Landsat	Cladophora/ nuisance algae mapping, waterfowl dieoffs, beach managemen t			~1975 (Landsat 1)			Time series completed for focal areas

Product	Sensor	Applications	End users	Priority (High, Medium, Low)	Length of time series	Repeat time	Status/Feasibility	Remarks
Bathymetry		Monitoring sand/dune movement, stamp sand monitoring, rip current mapping						
CO_2							Currently low feasibility	
Microplastics							Currently low feasibility	
Aerosols								
Surfactants							Currently low feasibility	
Hydrocarbons							Currently low feasibility	

Product	Sensor	Applications	End users	Priority (High, Medium, Low)	Length of time series	Repeat time	Status/Feasibility	Remarks
Modeled hypoxia							Currently low feasibility	Surrogate/indicator that's remotely sense-able coupled with a model Hypoxia in the GL is often sub-surface due to stratification, surface measurements may not be relevant
Turbidity					1979-1987, 1998-present		Very feasible	
SSM					1979-1987, 1998-present		Very feasible	
CDOM					1979-1987, 1998-present		Very feasible	
Modeled phosphorus							Currently low feasibility	Turbidity/SSM as surrogates?
Algal groups	Hyperspectral							

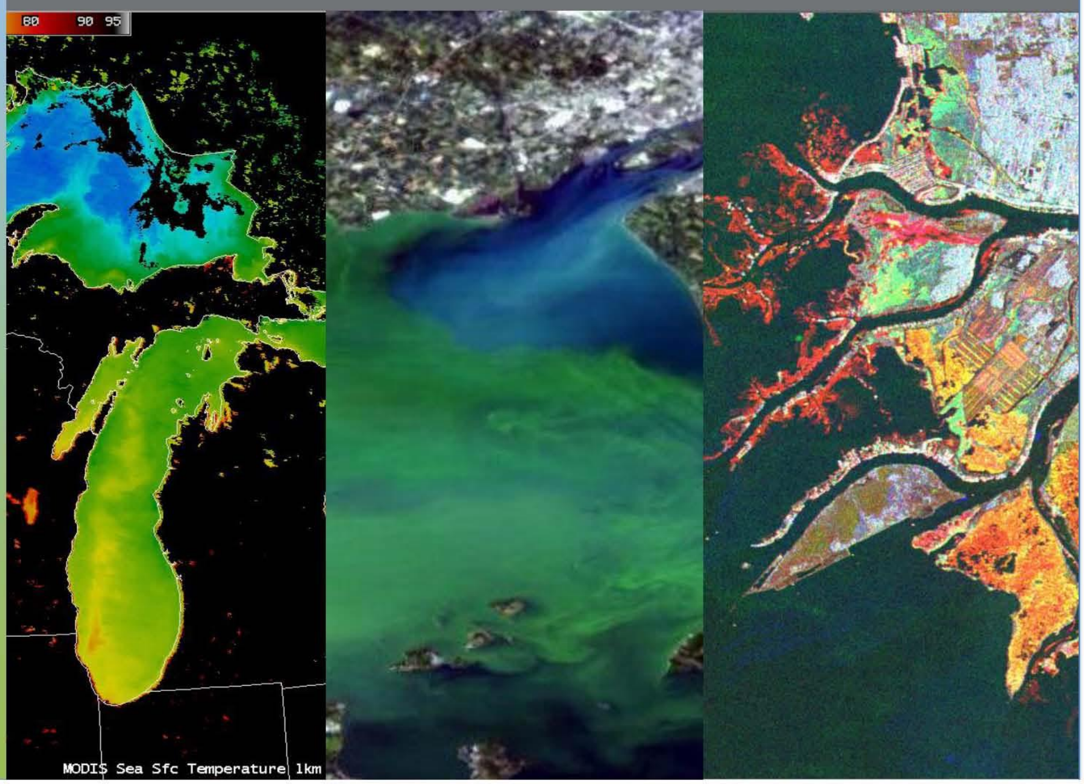
Product	Sensor	Applications	End users	Priority (High, Medium, Low)	Length of time series	Repeat time	Status/Feasibility	Remarks
Modeled E. coli		Public health, beach forecasting, water utilities						Surrogate/indicators needed
Cloud cover								
Meteorology								
Incoming & outgoing longwave/shortwave radiation								

Appendix 1: Agenda from Workshop 1

mtri.org/workshops/nasagreatlakes2014/

Workshop 1: March 12-13, 2014; Ohio Aerospace Institute, Cleveland

Great Lakes Workshop Series on Remote Sensing of Water Quality



Michigan Tech Research Institute

NASA

OAI
Ohio Aerospace Institute

Agenda

Wednesday March 12

8:00-8:30	Arrival and sign-in
8:30-8:35	OAI Welcome (Michael Heil, OAI)
8:35-8:45	NASA GRC Welcome (Janet Watkins, NASA GRC)
8:45-9:25	Keynote Speaker (Cam Davis, EPA)
9:25-9:55	"Updates on NASA ESD, missions, and Decadal Survey" (L. Friedl, NASA)
9:55-10:10	Workshop goals, format, anticipated results (L. Liou, NASA)
10:10-10:30	Break
10:30-10:50	"Remote sensing technologies—status and future directions" (J. Lekki, NASA)
10:50-11:10	"Great Lakes remote sensing algorithms—status, comparisons and future directions" (R. Shuchman, MTRI)
11:10-12:00	"Summary of previous workshops related to Great Lakes Remote Sensing" (J. Bratton, NOAA GLERL; C. Mouw, MTU; D. Alsdorf, OSU)
12:00-1:15	Lunch (provided in Sun Room)
1:15-1:45	Summarize, organize into breakout groups 1-3 & go over breakout directions
1:45-3:30	Breakout groups 1, 2 & 3
3:30-4:00	Break
4:00-4:30	Breakout groups 1, 2 & 3 report out
4:30-5:00	General discussion and group photo
5:00-6:30	Reception at Ohio Aerospace Institute (Sun Room)

Wireless Access
Free wireless internet access is available through OAI's guest network, OAI_VIS. No password is necessary.

Keynote Speaker Cameron Davis, Senior Advisor to the US EPA Administrator

Conference Presentations
Presentation slides from all workshop talks will be posted on the workshop series website at mtri.org/workshops/nasagreatlakes2014/plenary_presentations.html

Enjoy your visit to Cleveland

- The Rock & Roll Hall of Fame and Museum, located 20 minutes from OAI, is open daily from 10 am-5:30 pm.
- Attractions within walking distance of the Hall of Fame include the Great Lakes Science Center, which houses the NASA Glenn Visitor Center, and the International Women's Air & Space Museum
- A short distance from the museums, the Great Lakes Brewing Company in downtown Cleveland is an award-winning and environmentally conscious microbrewery
- Check the workshop website for an area guide map of restaurants close to OAI

De

Thursday March 13

8:30-8:50	Review of Day 1
8:50-9:10	"Combined modeling/RS approaches for the Great Lakes" (D. Schwab, UM/MTRI)
9:10-9:40	"Remote sensing of water quality in inland and other coastal waters: sensors, products and applications" (P. DiGiacomo, NOAA)
9:40-10:00	Break
10:00-10:20	"Water-specific NASA ESD activities, with a focus on the Great Lakes and water quality" (C. Lee, NASA)
10:20-11:05	Special Presentations (NASA DEVELOP Program, NASA GRC Aircraft Capabilities, OSU UAV for Water Quality)
11:05-11:30	Summarize, organize into breakout groups 4, 5 & 6 and go over directions
11:30-12:30	Lunch (provided in Sun Room)
12:30-2:20	Breakout groups 4, 5 & 6
2:20-2:50	Break
2:50-3:20	Breakout groups 4, 5 & 6 report out
3:20-4:00	Group discussion of potential short (10-week implementation) pilot projects that could be used to explore the most feasible and important areas identified by all breakout discussions
4:00-4:30	Concluding Remarks
4:30	Adjourn

Breakout groups

Day 1

1. Update sensor requirements for remote sensing of inland lakes
2. Remote sensing data and derived product gaps
3. Technology gaps (sensors, instruments, & other hardware)

Day 2

4. New potential applications for remote sensing of inland waters
5. Algorithms/modeling current approaches: status/strengths/deficiencies
6. Platform/mission gaps and recommendations

Workshop Series Steering Committee

Larry Liou, Lead for Freshwater Research, NASA John H. Glenn Research Center

Dr. Robert Shuchman, Co-Director, Michigan Tech Research Institute—Michigan Tech University

Dr. Steve Greb, Hydrologist, Wisconsin Department of Natural Resources (DNR)

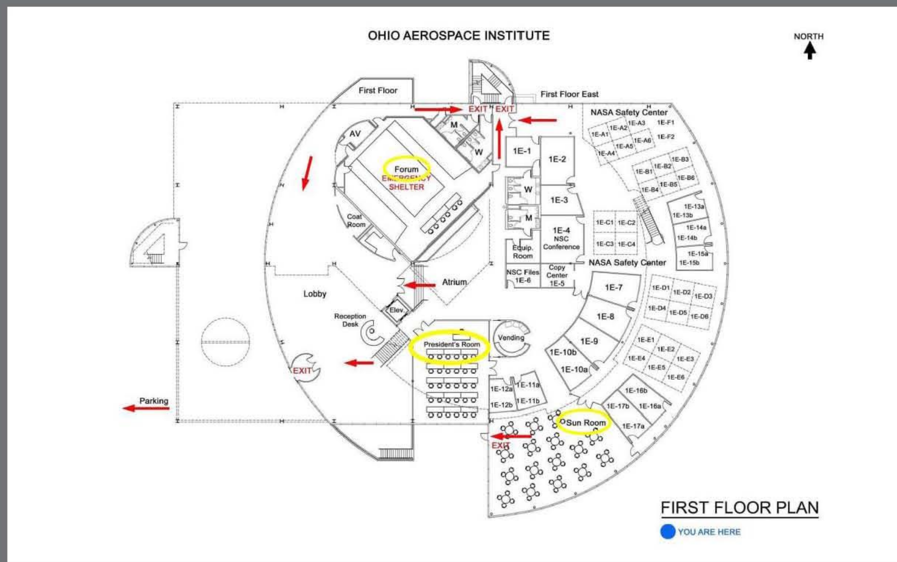
Dr. George Leshkevich, Physical Scientist, NOAA Great Lakes Environmental Research Laboratory (GLERL)

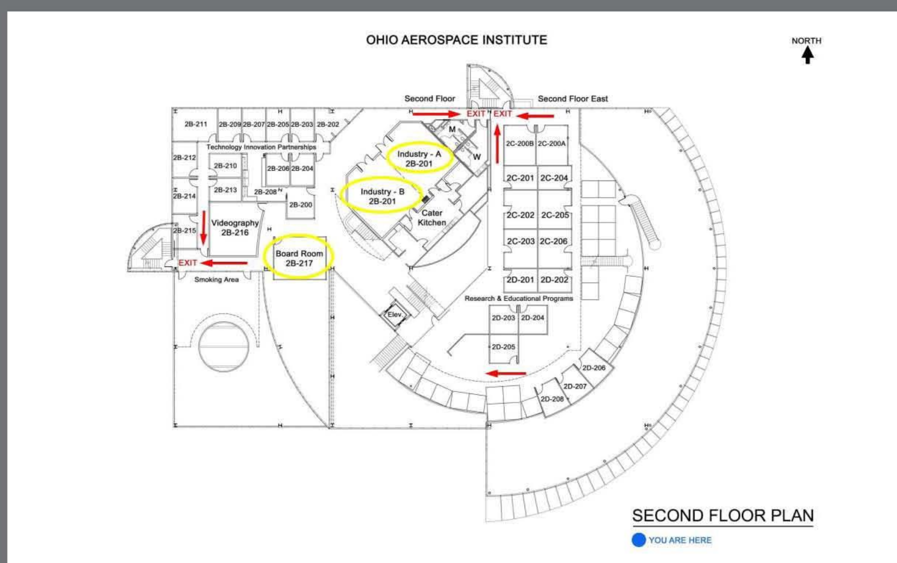
Dr. John Bratton, Deputy Director, NOAA GLERL

Dr. Jennifer Read, Executive Director, Great Lakes Observing System (GLOS)

Dr. John Lekki, Optical Systems Research Engineer, NASA John H. Glenn Research Center

eveloping a Great Lakes remote sensing community of practice





The Great Lakes Workshop Series on Remote Sensing of Water quality is supported by the Applied Science Program, Earth Science Division, NASA.

Workshop Contacts:

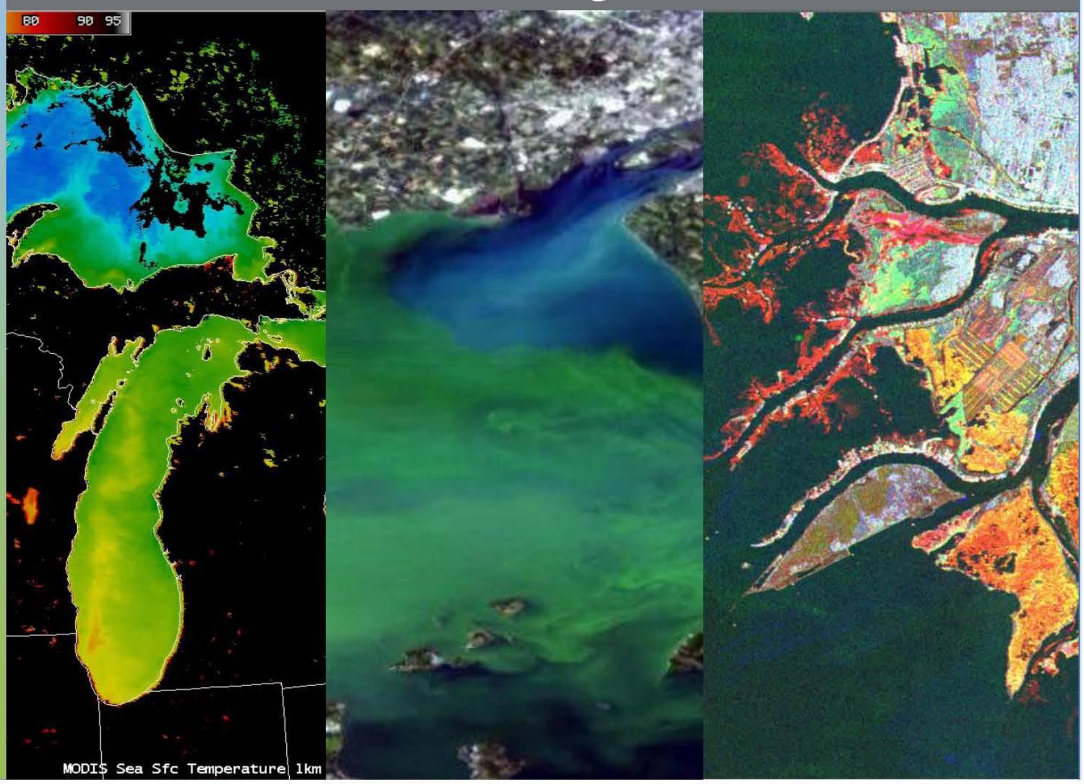
Larry Liou, NASA GRC
(216) 650-4696, Larry.C.Liou@nasa.gov

Amanda Grimm, MTRI
(734) 985-5151, aggrimm@mtu.edu

mtri.org/workshops/nasagreatlakes2014/

Workshop 2: May 7-8, 2014;
NOAA GLERL, 4840 S. State Rd., Ann Arbor, MI

Great Lakes Workshop Series on Remote Sensing of Water Quality



Michigan Tech Research Institute

NASA

GLERL
Great Lakes Environmental Research Laboratory

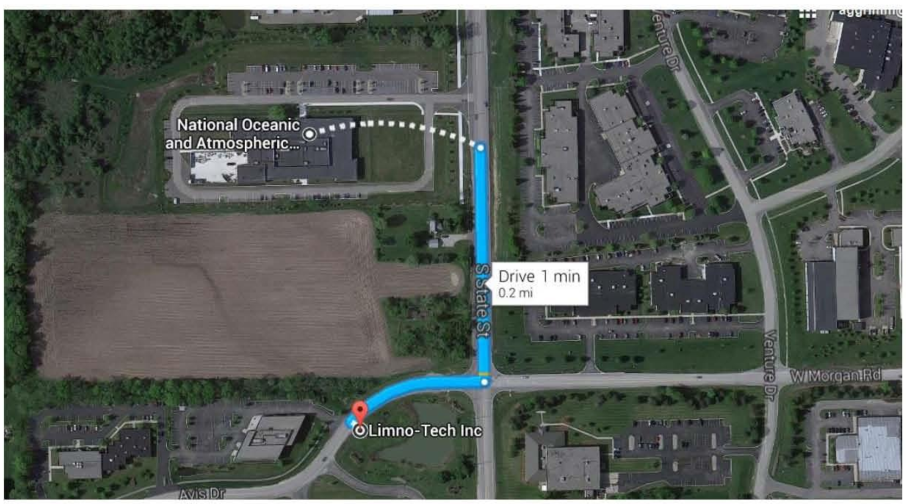
Agenda

Wireless Access
Free wireless internet access is available through NOAA-GLERL's network. No password is necessary.

Wednesday May 7

8:00-8:30	Arrival and sign-in
8:30-8:45	NOAA GLERL Welcome (John Bratton, NOAA GLERL)
8:45-9:15	USGS Great Lakes science initiatives & the role of remote sensing (Bo Bunnell, USGS-GLSC)
9:15-9:45	Brief review of Workshop 1 (Robert Shuchman, MTRI/Larry Liou, NASA)
9:45-10:00	Workshop 2 goals, format, anticipated results (Larry Liou, NASA)
10:00-10:20	NASA Applied Science Water Resource Program Overview (Brad Doorn, NASA)
10:20-10:40	Break
10:40-11:00	Great Lakes Observing System: Measuring for Management (Jen Read, GLOS)
11:00-11:20	GLOS Data Management And Communications (DMAC) overview (Tad Slawecki, LimnoTech)
11:20-12:00	NOAA remote sensing research in the Great Lakes (John Bratton, NOAA GLERL)
12:00-1:15	Lunch
1:15-1:45	Organize into breakout groups 1-3 & go over breakout directions
1:45-3:30	Breakout groups 1, 2 & 3
3:30-4:00	Break
4:00-4:30	Breakout groups 1, 2 & 3 report out
4:30-5:00	General discussion
5:00-6:30	Reception at LimnoTech, 501 Avis Dr., Ann Arbor, MI

Conference Presentations
Presentation slides from all workshop talks will be posted on the workshop series website at mtri.org/workshops/nasagreatlakes2014/plenary_presentations.html



To make the short trip to LimnoTech from NOAA GLERL for the Wednesday evening reception, turn right onto State St. and take the first right onto Avis Dr.

Thursday May 8

8:30-9:00	Review of Day 1 (Liou/Shuchman)
9:00-9:30	Great Lakes research & the role of the International Joint Commission (Lana Pollack, IJC)
9:30-9:50	GLOS DMAC demonstration (Tad Slawecki, LimnoTech)
9:50-10:10	Break
10:10-10:30	NOAA Great Lakes CoastWatch Program (George Leshkevich, NOAA GLERL)
10:30-11:45	NOAA GLERL tour
11:45-12:00	Organize into breakout groups 4, 5 & 6 and go over directions
12:00-1:00	Lunch
1:00-2:30	Breakout groups 4, 5 & 6
2:30-2:45	Break
2:45-3:10	Breakout groups 4, 5 & 6 report out
3:10-4:30	Group discussion of potential short (10-week implementation) pilot projects that could be used to explore the most feasible and important areas identified by all breakout discussions
4:30	Adjourn

Breakout groups

Day 1

1. Moving forward with a regional remote sensing strategy – John Bratton
2. Data distribution of Great Lakes remote sensing data – Jennifer Read
3. Algorithm comparison studies – David Schwab

Day 2

4. Create plan to maintain an active Great Lakes RS community – Larry Liou
5. Remote sensing derived products sharing & credit to originators - Tad Slawecki
6. Define time series RS datasets (i.e. HABs, primary productivity) – George Leshkevich

Workshop Series Steering Committee

Larry Liou, Lead for Freshwater Research, NASA John H. Glenn Research Center

Dr. Robert Shuchman, Co-Director, Michigan Tech Research Institute—Michigan Tech University

Dr. Steve Greb, Hydrologist, Wisconsin Department of Natural Resources (DNR)

Dr. George Leshkevich, Physical Scientist, NOAA Great Lakes Environmental Research Laboratory (GLERL)

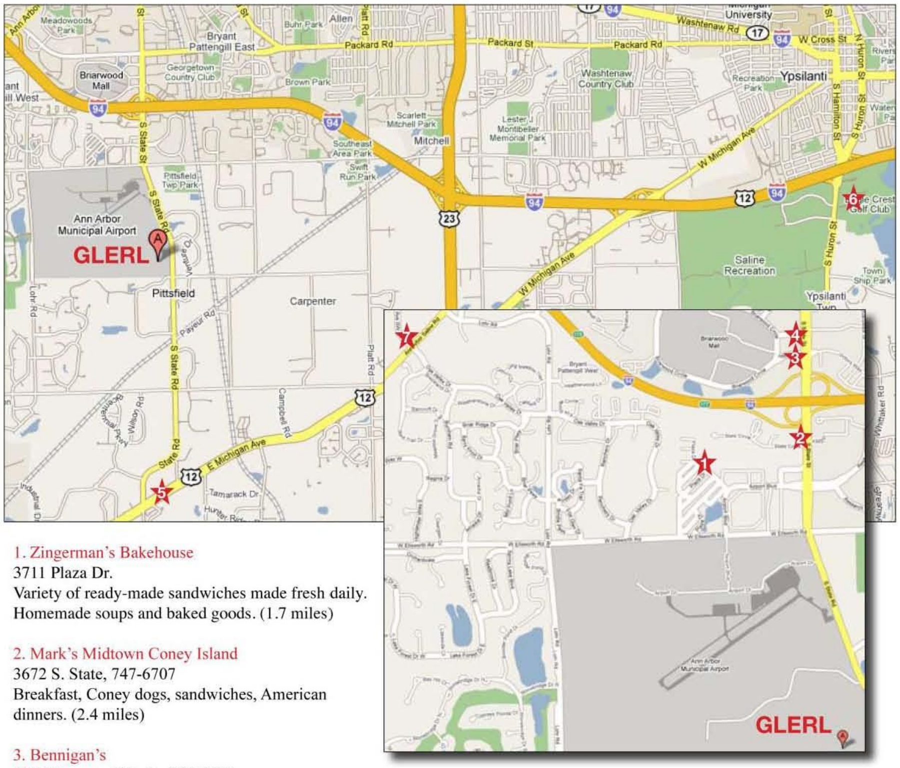
Dr. John Bratton, Deputy Director, NOAA GLERL

Dr. Jennifer Read, Executive Director, Great Lakes Observing System (GLOS)

Dr. John Lekki, Optical Systems Research Engineer, NASA John H. Glenn Research Center

eveloping a Great Lakes remote sensing community of practice

Restaurants near GLERL



1. Zingerman's Bakehouse
3711 Plaza Dr.
Variety of ready-made sandwiches made fresh daily. Homemade soups and baked goods. (1.7 miles)

2. Mark's Midtown Coney Island
3672 S. State, 747-6707
Breakfast, Coney dogs, sandwiches, American dinners. (2.4 miles)

3. Bennigan's
575 Briarwood Circle, 996-0996
Sandwiches, seafood, pasta, chicken, steak, burgers, salads. (1.8 miles)

4. Romano's Macaroni Grill
3010 S. State, 663-4433
Pasta and other Italian favorites, plus wood-fired pizzas, calzones, steak, and seafood. (2.2 miles)

5. Caffe Dolce
6961 E. Michigan Ave., Saline
Coffeehouse specializing in housemade baked goods, soups, sandwiches, espresso drinks, and excellent customer service. (2.5 miles)

6. Eagle Crest Clubhouse
1275 Huron St., Ypsilanti
Sandwiches, burgers, salads. (8 miles)

7. Godaiko
3115 Oak Valley (Village Centre)
930-2880
Traditional Japanese cuisine, including sushi and sashimi. (3.2 miles)

The Great Lakes Workshop Series on Remote Sensing of Water quality is supported by the Applied Science Program, Earth Science Division, NASA.

Workshop Contacts:
Larry Liou, NASA GRC
(216) 650-4696, Larry.C.Liou@nasa.gov

Amanda Grimm, MTRI
(734) 985-5151, aggrimm@mtu.edu