MichiganTech Research Institute

Great Lakes Remote Sensing Algorithms

Status, Comparisons, and Future Directions

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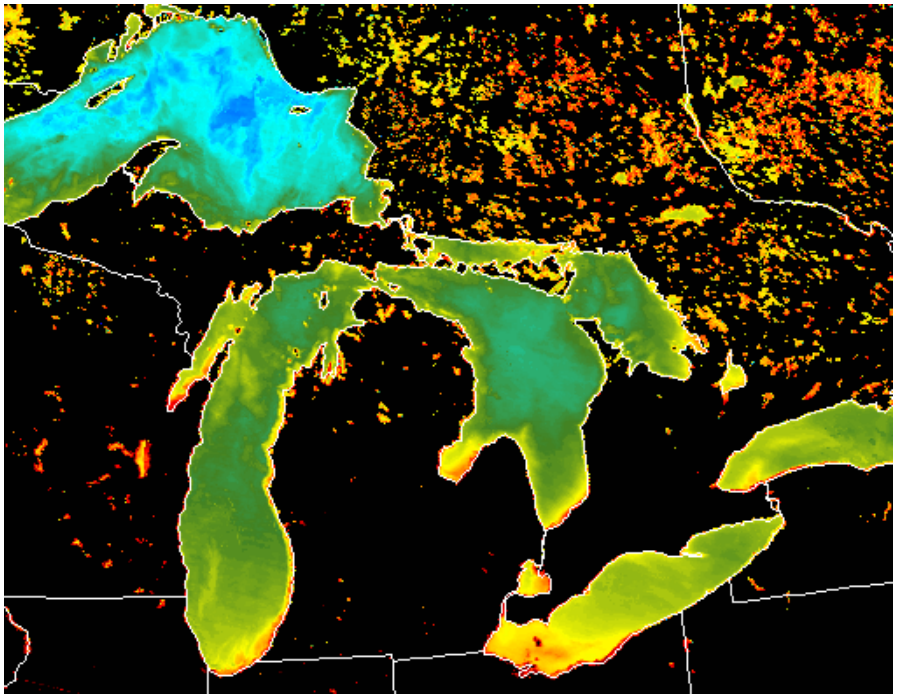
Great Lakes Remote Sensing Algorithms
Status, Comparisons, and Future Direction

- Summarize Remote Sensing Products, Potentially Available for the Great Lakes
  - Example products
- It's all about the Chlorophyll
  - NASA standard band-ratio approach
  - Tuned NASA band ratios (GLF)
  - CPA-A approach
- It's all about the Harmful Algal Blooms (HABs)
  - MTRI approach
  - Stumph approach
  - Environment Canada approach
- Future Directions
  - New algorithm approaches
  - New in situ optical measurements
  - Additional algorithm comparisons

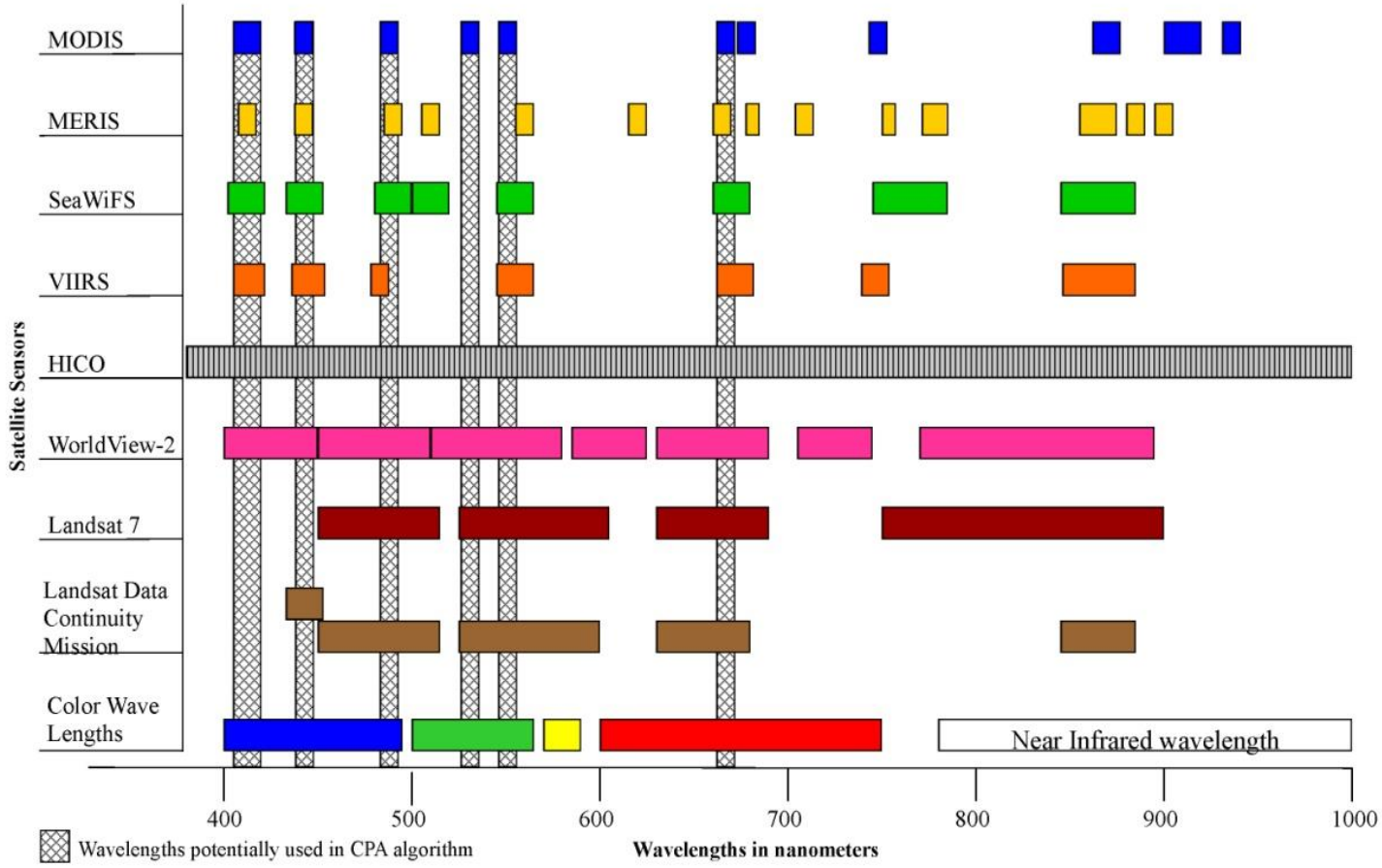


Summary of Satellite Systems for Great Lakes Water Quality Measurements

Water Quality Measure Product	Sensor	Spatial Resolution	Temporal Coverage	Revisit Time
Lake Surface Temperature (LST)	MODIS	1 km	2002–Present	Daily
Color-Producing Agents (chl,doc,sm)	MODIS	250 m–1 km	2002–Present	Daily
	VIIRS	750 m	2012–Present	Daily
	MERIS	330 m	2002–2012	2–3 Days
	CZCS	1 km	1979–1986	Periodic
	SeaWiFS	1 km	1997–2011	Daily
Optical Depth (Kd, PAR, Photic Depth)	Landsat	30 m	1975–Present	16–17 Days
	MODIS	250 m–1 km	2002–Present	Daily
	VIIRS	750 m	2012–Present	
Harmful Algal Blooms (HABs)	MODIS	250 m–1 km	2002–Present	Daily
	VIIRS	750 m	2012–Present	Daily
	MERIS	330 m	2002–2012	2–3 Days
Submerged Aquatic Vegetation (SAV)	Landsat	30 m	1975–Present	16–17 Days
	MODIS	250 m–1 km	2002–Present	Daily
	VIIRS	330 m	2002–2012	2–3 Days
	MERIS	750 m	2012–Present	
Sediment Plume (TSSIGL)	MODIS	250 m–1 km	2002–Present	Daily
	VIIRS	750 m	2012–Present	Daily
	MERIS	330 m	2002–2012	2–3 Days
	CZCS	1 km	1979–1986	Periodic
	SeaWiFS	1 km	1997–2011	Daily
	Landsat	30 m	1975–Present	16–17 Days
Primary Productivity (PP)	MODIS	250 m–1 km	2002–Present	Daily
	VIIRS	750 m	2012–Present	Daily
	MERIS	330 m	2002–2012	2–3 Days
	CZCS	1 km	1979–1986	Periodic
	SeaWiFS	1 km	1997–2011	Daily

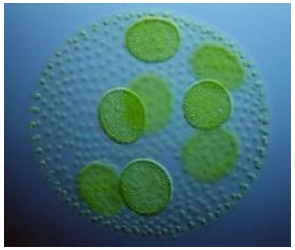
Additional surface wind speed and direction, remote sensing products, wetland maps, lake ice extent and concentration

Ocean Color Satellite Band Comparison



Chlorophyll (CHL) , Dissolved Organic Carbon (DOC), Suspended Mineral (SM) Algorithm

- Water Color in Inland and Coastal Water Results Mainly from Three Different Parameters, Known as Color-Producing Agents (CPAs):
  - **Chlorophyll (CHL):** A green pigment found in plant cells. Algal cells that are suspended in water produce a green-yellow color.
  - **Dissolved Organic Carbon (DOC):** Organic carbons that are produced as part of micro-organism metabolism or are transported from decaying vegetation products via rivers and streams. DOC only absorbs light, it doesn't scatter it. It appears yellow to brown in color (CDOM).
  - **Suspended Minerals (SM):** Inorganic particulate matter. Scatters and absorbs light.

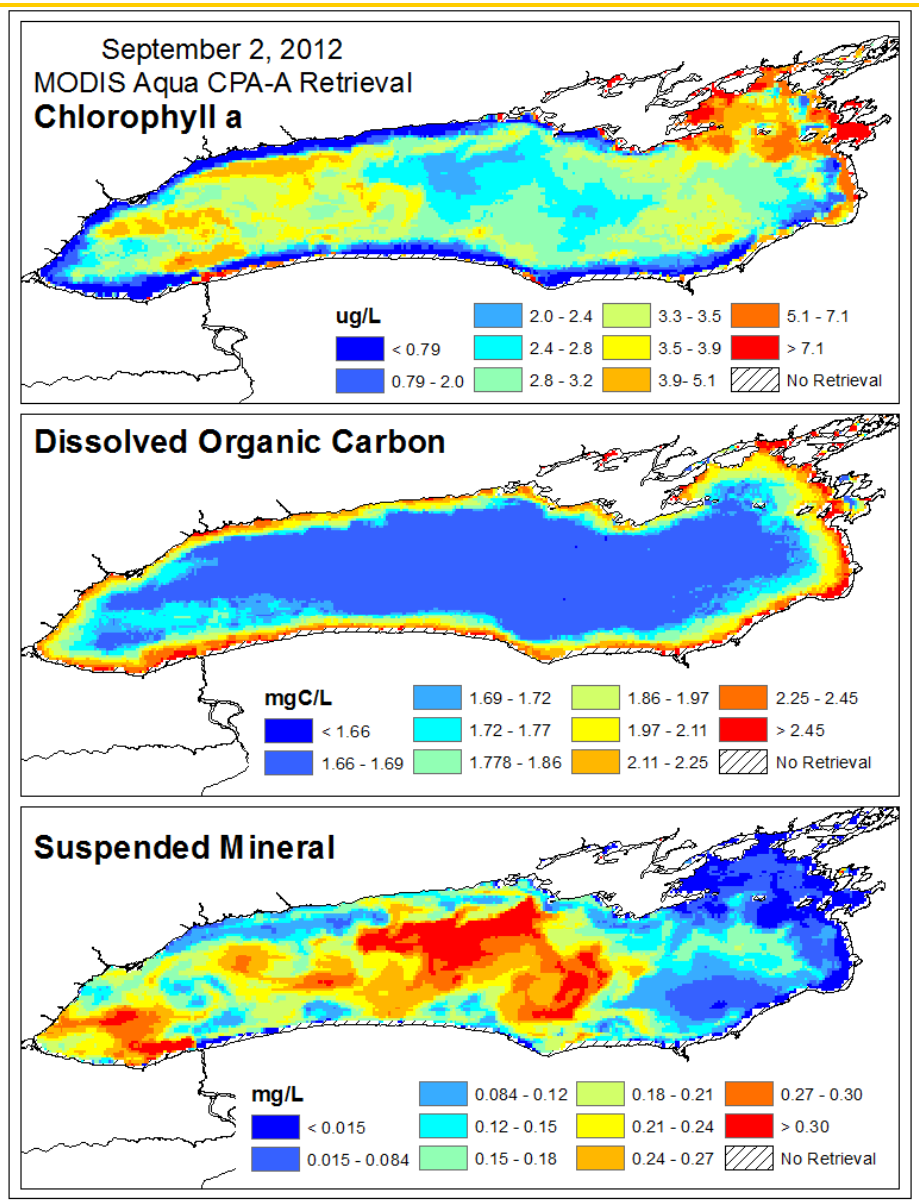


CHL

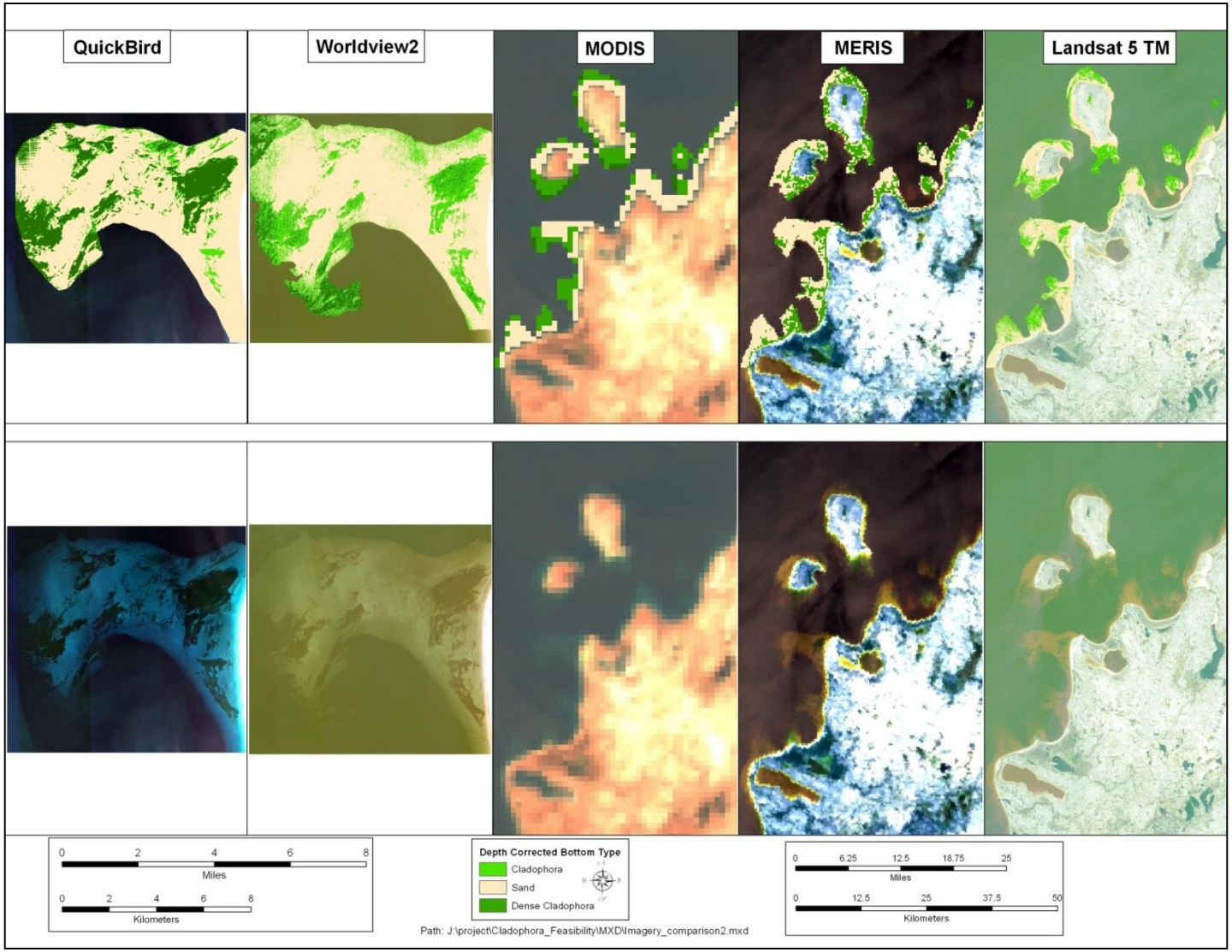
DOC

SM

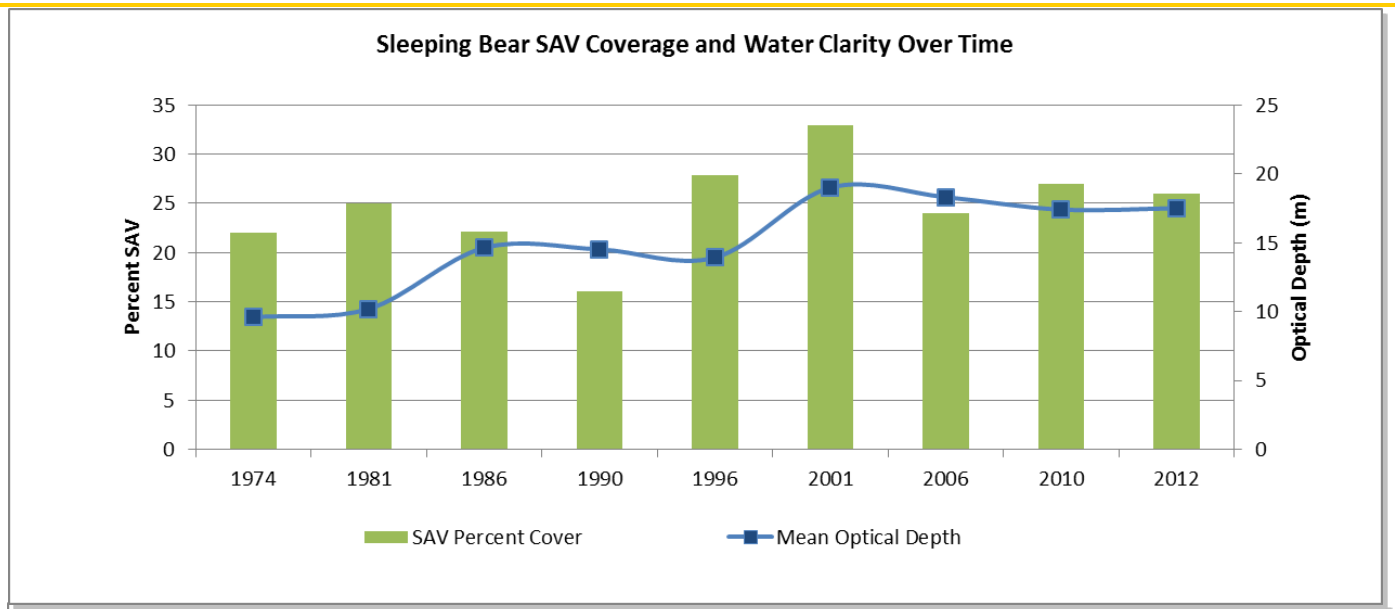
September 2, 2012 MODIS Aqua CPA-A Retrieval for Lake Ontario

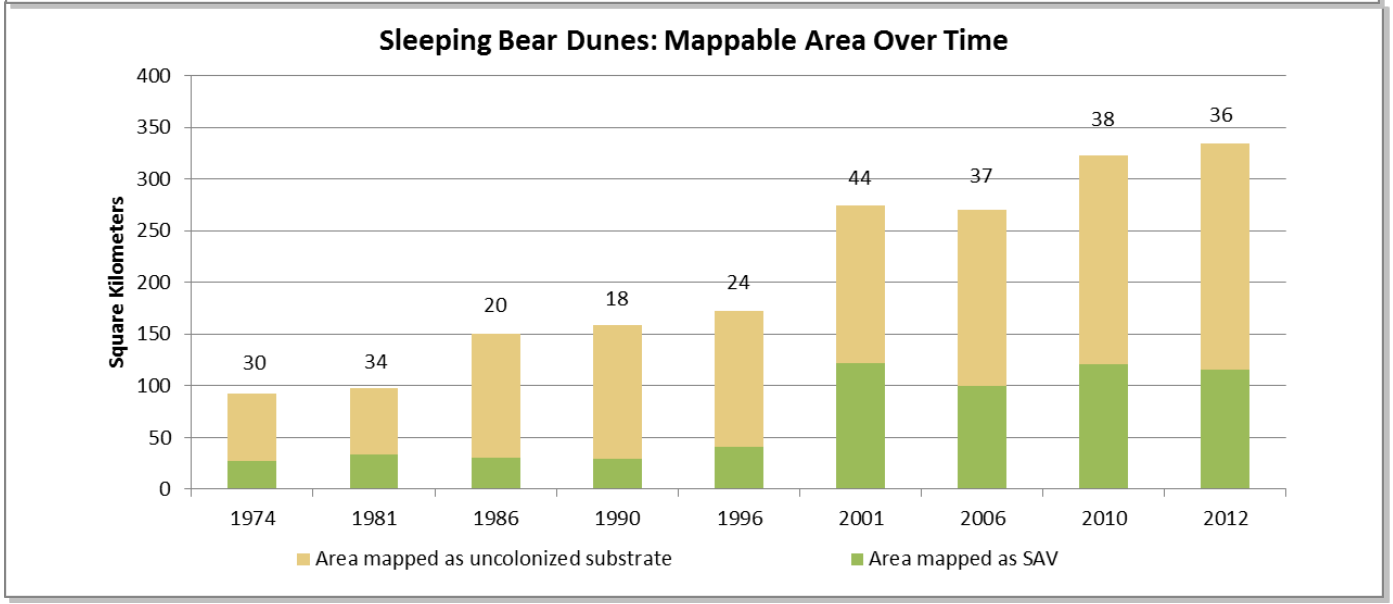


Multi-scale SAV/*Cladophora* Mapping Capability

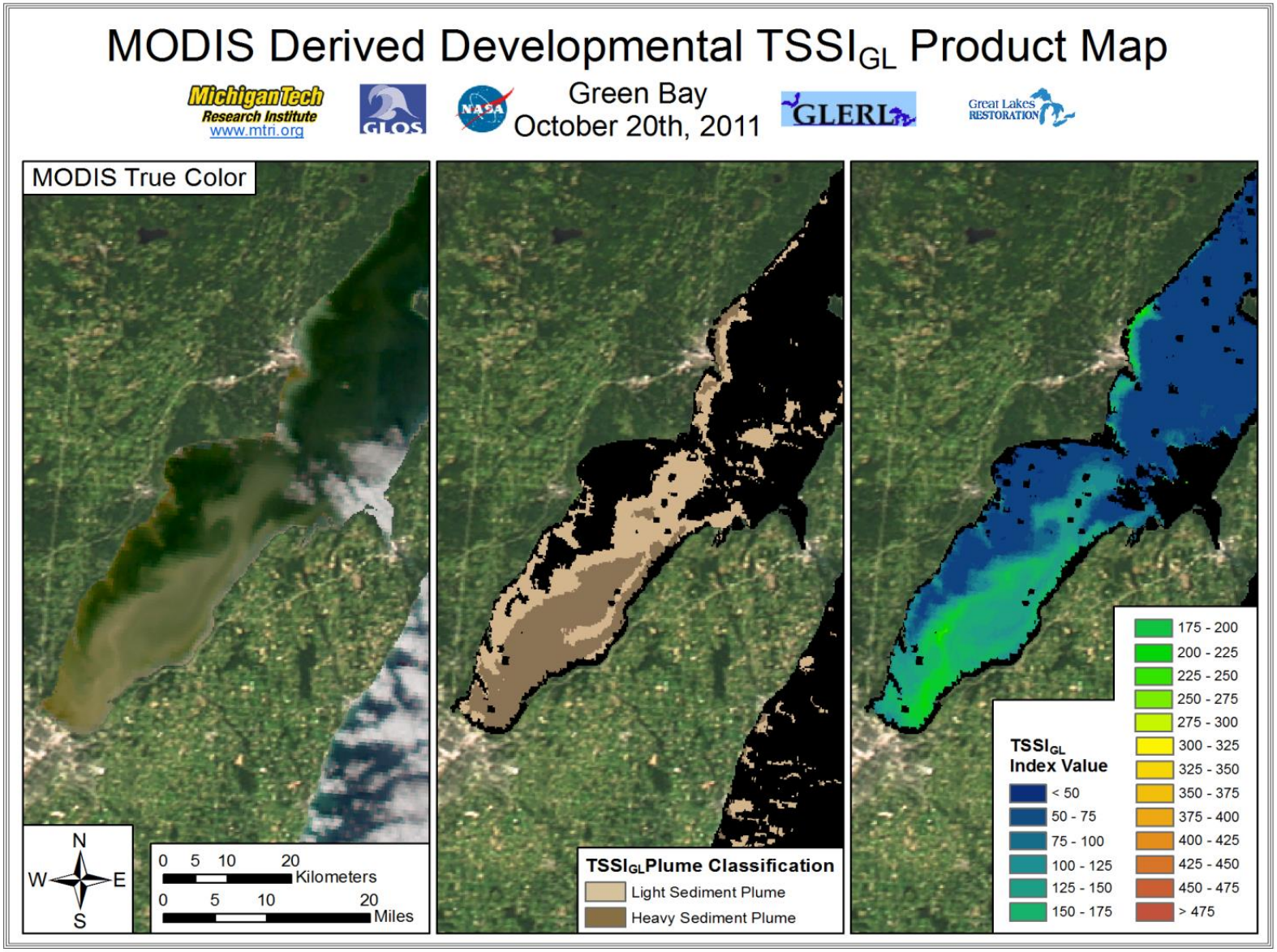


Sleeping Bear Dunes National Lakeshore
Lake Michigan



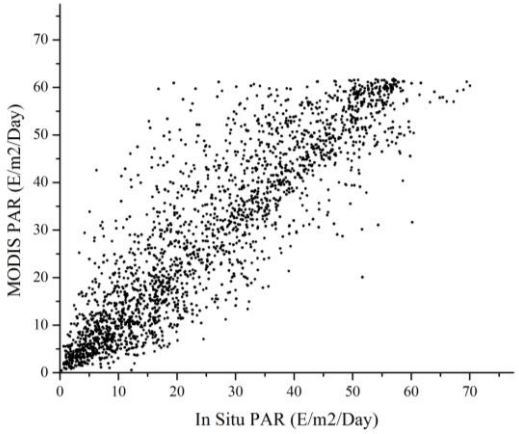


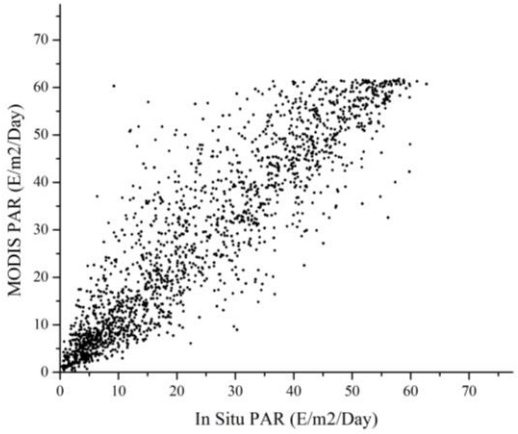
Green Bay AOC Sediment Plume Example: TSSI – Great Lakes Algorithm

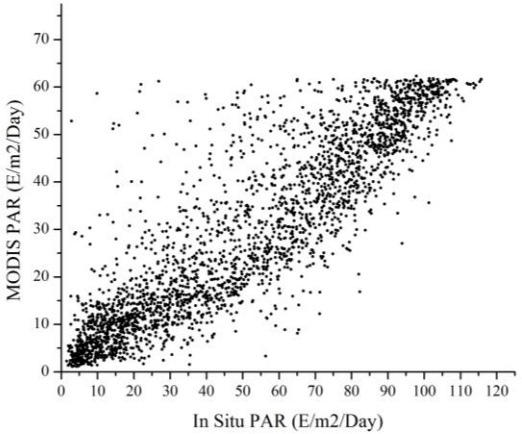


Great Lakes PAR Trends

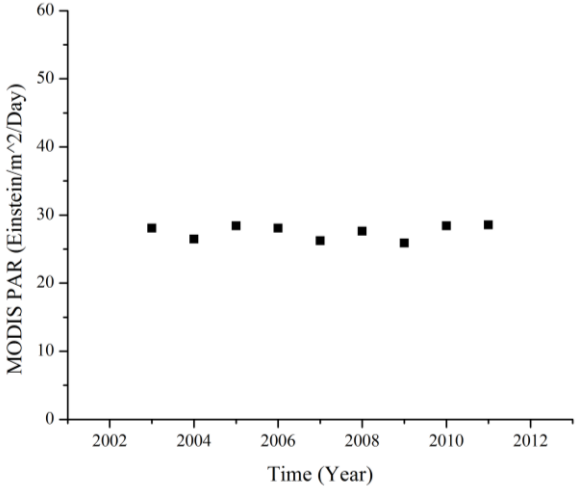
MODIS vs. *in situ*

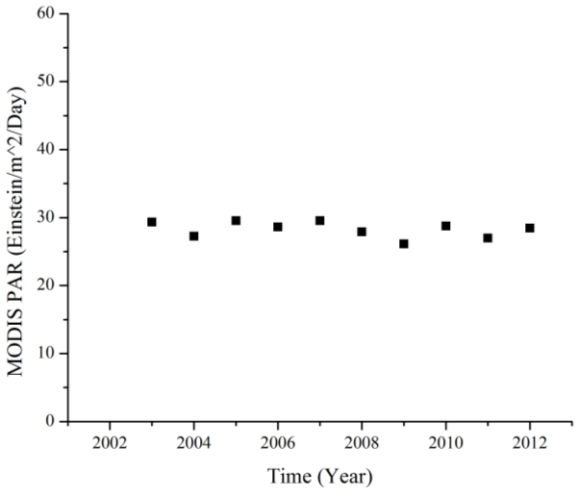


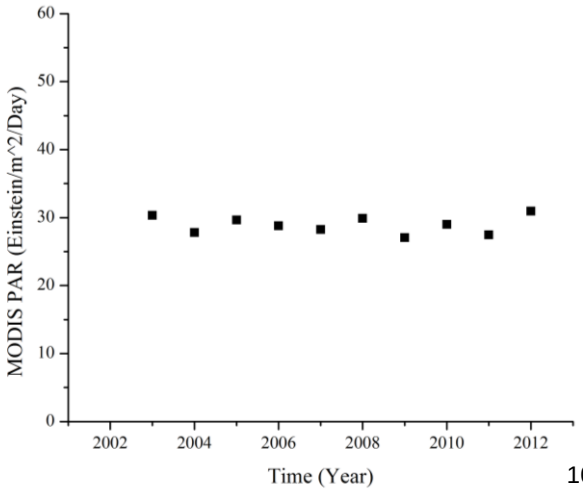




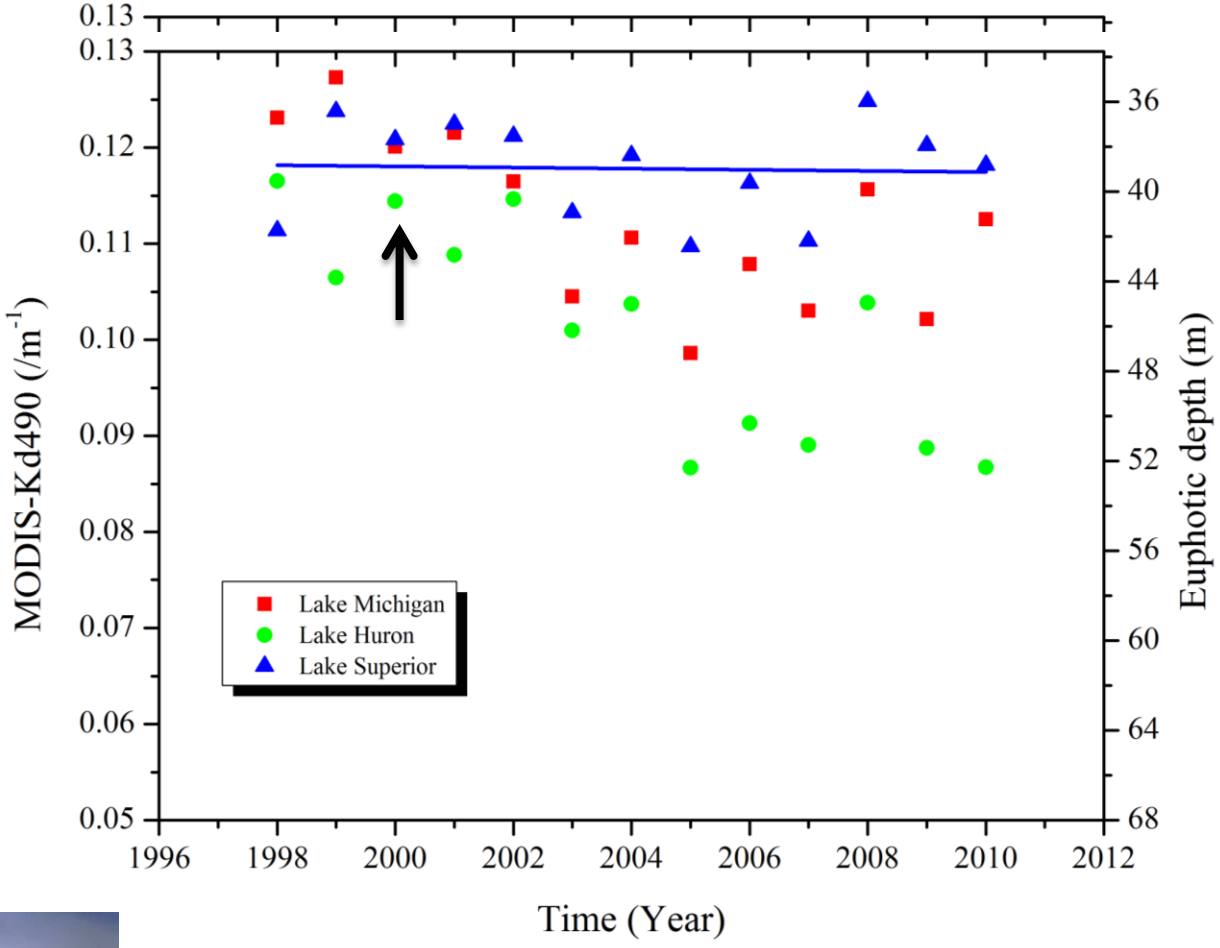
Historical trends-MODIS whole lake Annual Average







Remarkable Changes in Water Clarity Due to Quagga Mussels

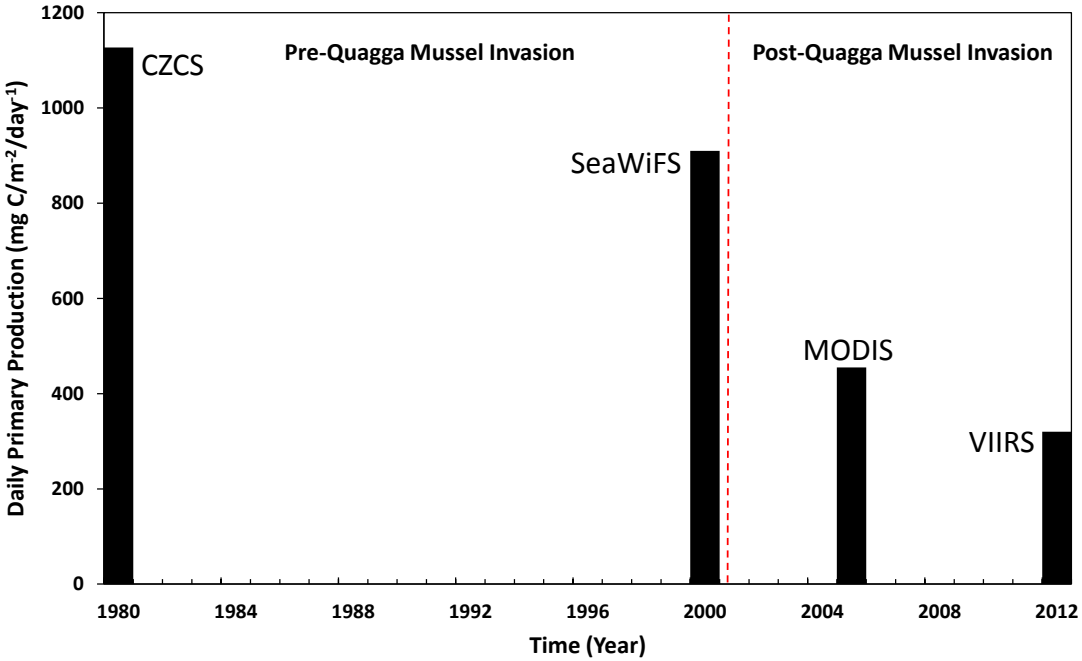


> 900 Trillion Dreissenid Mussels in Lake Michigan

Secchi Disks > 30 m LM & LH after 2010

MODIS-GLPPM Annual

- Extended Historical Lake Michigan Analysis



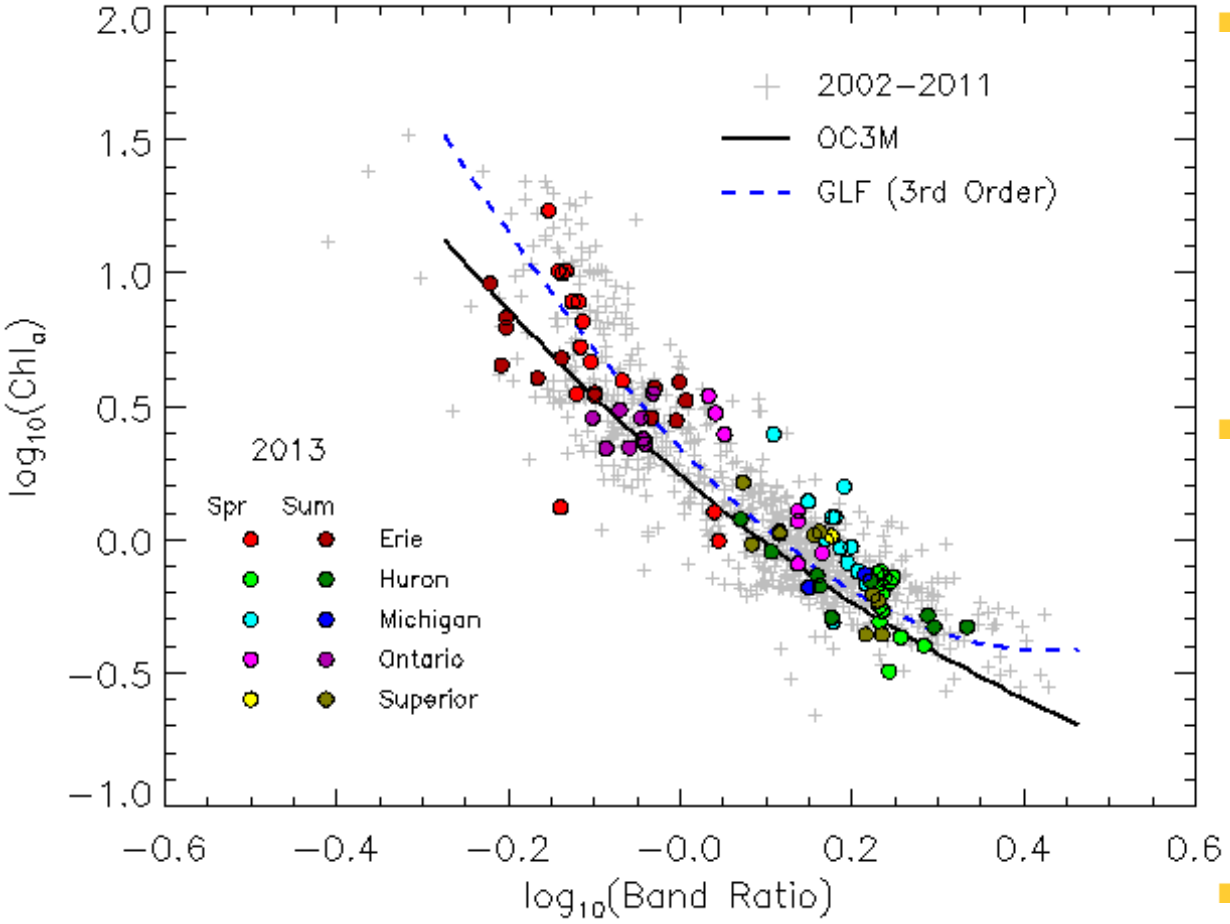
~72% Decrease in PP

- Preliminary Total Carbon Fixation for all the Great Lakes ~31 Tg C/year (2008)

Satellite Chlorophyll Retrieval Algorithms for the Great Lakes

- NASA Standard Band Ratio OC3/OC4 - O'Reilly et al. 1998
- Modified/tuned Band Ratio Great Lakes Fit (GLF) Model – Lesht et al. 2013
- Color Producing Agent Algorithm (CPA-A) – Shuchman et al. 2013
- Binding Red/NIR Method – Binding et al. 2012
- Lake Superior CDOM Correction approach – Mouw et al. 2013

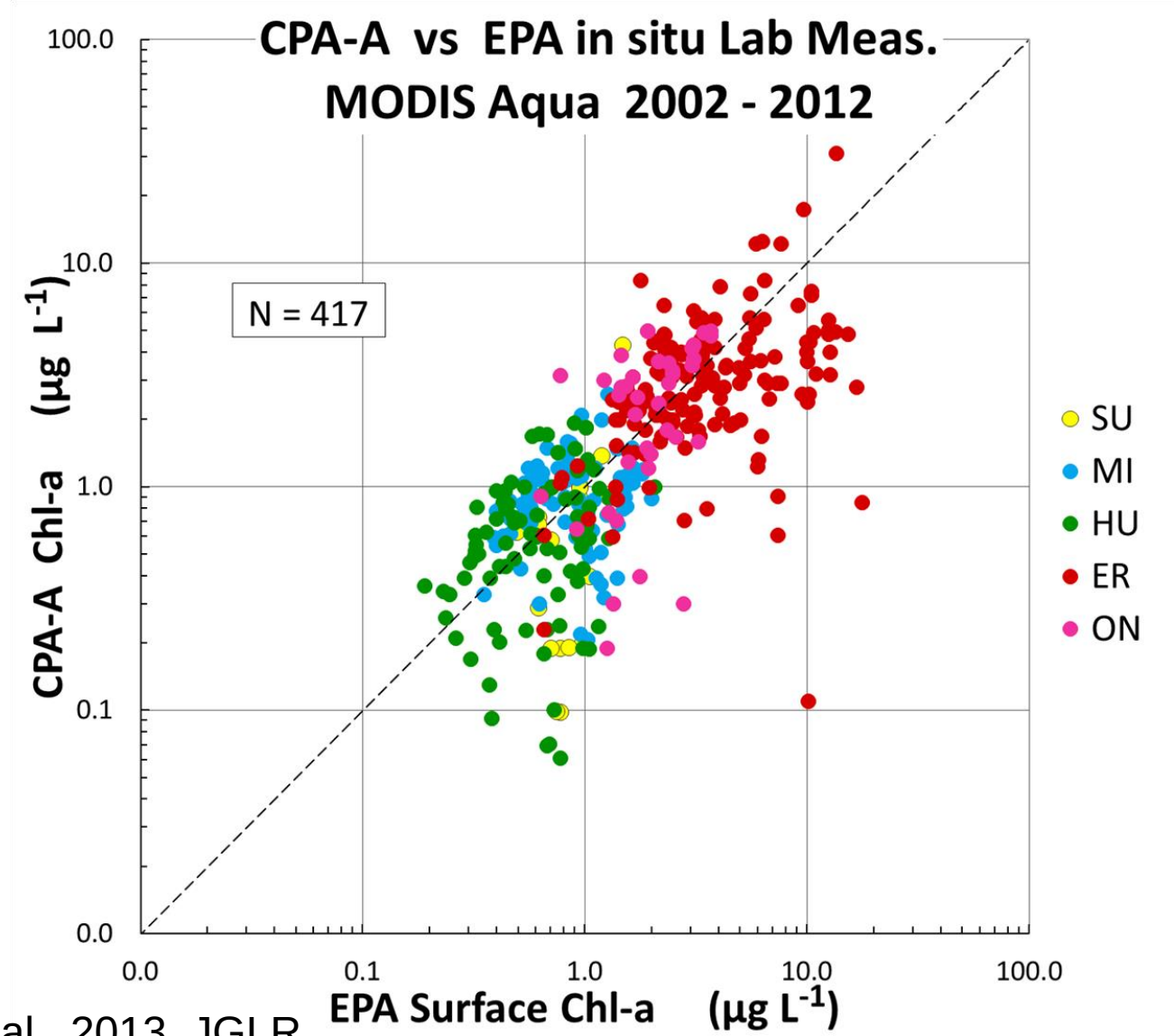
GLF Comparison with New (2013) Data



Lesht et al., 2013, JGLR

- Chlorophyll in the Great Lakes waters sampled by GLNPO is definitely related to the blue/green band ratio measured by satellite.
- The chlorophyll estimates obtained from a band ratio retrieval algorithm fit to the Great Lakes data are sufficiently accurate for quantitative research.
- New, independent, data confirm the stability and accuracy of the algorithm.

CPA-A

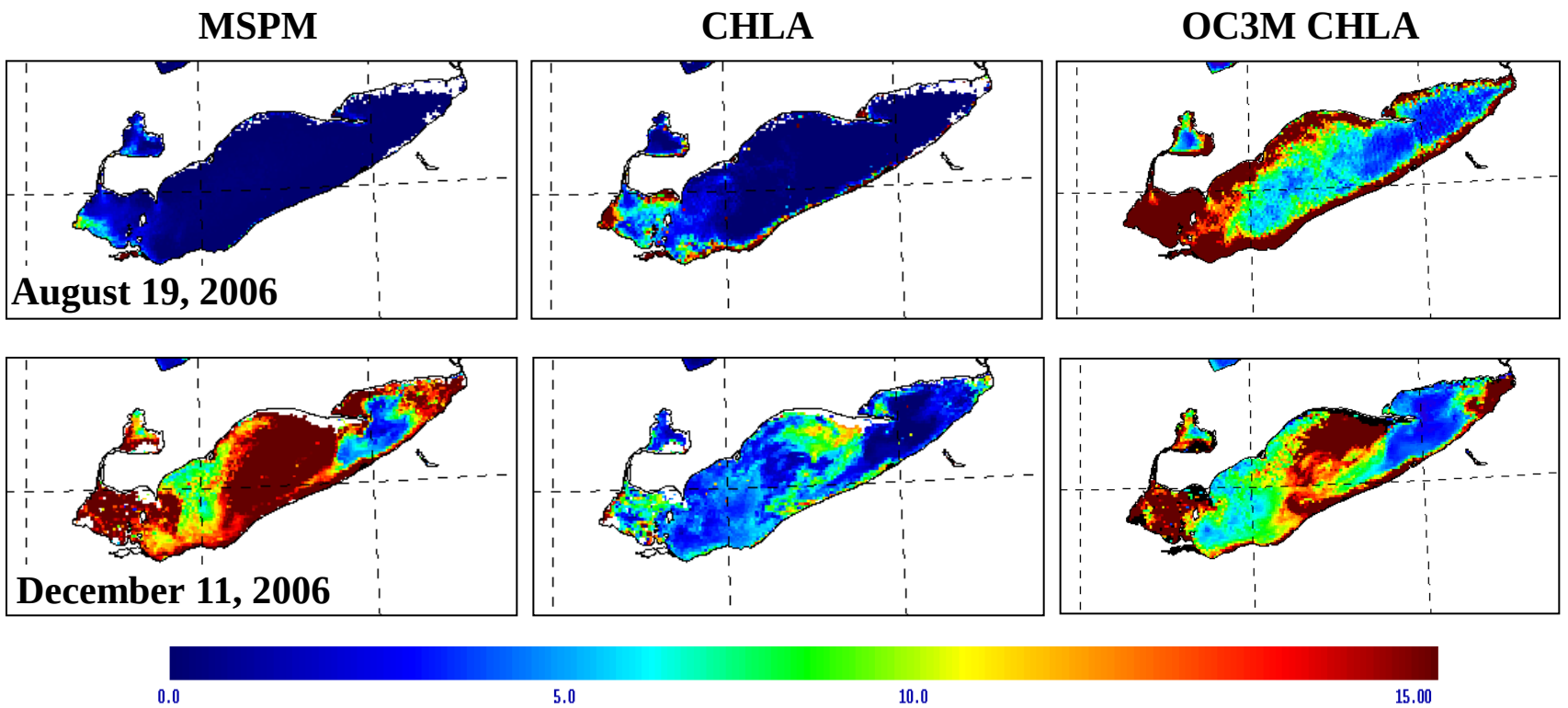


Shuchman et al., 2013, JGLR

Environment Canada

Inverse Modelling of Red/NIR Bands to Discriminate Algal/mineral Material

Modelling in the Red-NIR: Validation



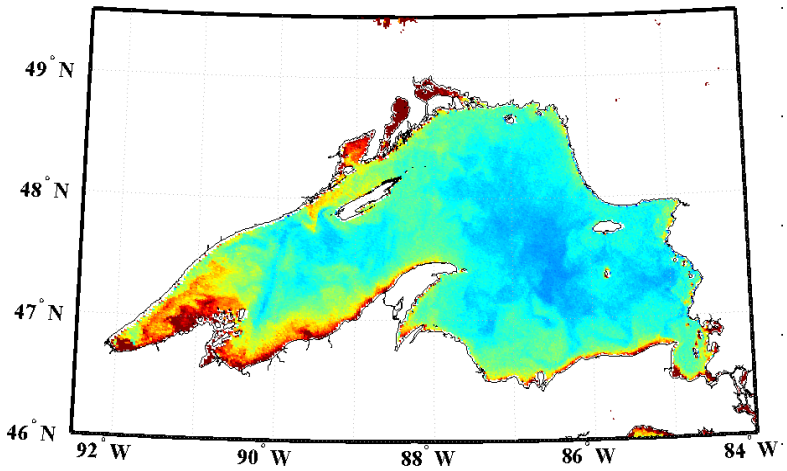
MSPM	CHLA	OC3M CHLA
RMSE = 0.85 g m^{-3}	RMSE = 2.06 mg m^{-3}	RMSE = 6.08 mg m^{-3}
R^2 = 0.94, N = 82	R^2 = 0.96, N = 82	R^2 = 0.87, N = 82

Environment Canada

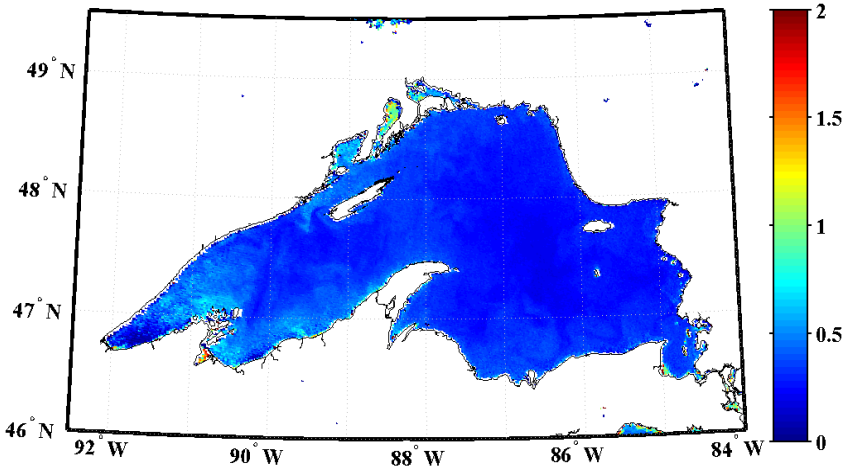
Binding et al., 2012, JGLR

Lake Superior CDOM Correction for Chlorophyll Retrievals

OC4 [Chl]



CDOM corrected [Chl]



IAGLR 2011 Presentation, Mouw et al., 2013, JGR Oceans

Harmful Algal Blooms (HABs) Algorithms for the Great Lakes

- Cyanobacteria Index (CI) - Wynne et al. 2008, Stumpf et al. 2011
- Maximum Chlorophyll Index (MCI) – Gower et al. 2004, evaluated in Lake Erie by Binding et al. 2013
- MODIS Least Squares – Becker et al. 2009
- MODIS MTRI Multi-faceted Approach – EPA Report
- Phycocyanin Detection with Landsat – Vincent et al. 2004

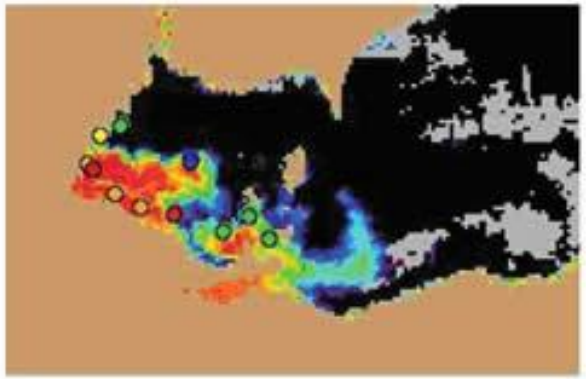
Cyanobacterial Index (CI)

EXPERIMENTAL
Lake Erie Harmful Algal Bloom Bulletin
4 September 2008
National Ocean Service
Great Lakes Environmental Research Laboratory
Last bulletin:

Conditions: A *Microcystis aeruginosa* bloom has been identified in western Lake Erie from the Maumee River mouth eastward, along the south shore.

Analysis: A *Microcystis aeruginosa* bloom was identified on August 26, 2008 through the use of MERIS imagery. The bloom was confirmed through sampling on August 28, 2008 and extends from the Maumee Bay eastward and along the southern shore of western Lake Erie. Concentrations range from very high to low, with the greatest concentration at the Maumee Bay in the far SW corner of the basin (41.7919N, -83.3925W) along the southern shoreline almost to the Bass Islands (41.6602N, -83.0780W). Satellite chlorophyll levels have exceeded 40 ug/L. A cyanobacteria bloom is also present in Sandusky Bay, however the majority of the bloom was primarily comprised of *Planktothrix spp.* and some *Anabaena spp.* *M. aeruginosa*, *Anabaena spp.* and *Planktothrix spp.* are known to produce toxins. Strong winds and thunderstorms are expected through Friday, which may cause the bloom to disperse, become mixed within the water column or possibly concentrate along the southern shore of Lake Erie. Further sampling is recommended.

-Tomlinson, Wynne



Imagery shows the spectral shape at 681 nm from September 2, 2008, where colored pixels indicate the likelihood of *Microcystis* (with red being most likely). *Microcystis* concentration sampling data from August 28, 2008 are shown as red circles (very high), orange circles (high), yellow circles (medium) green circles (low) and blue circles (very low) and purple circles (not present).

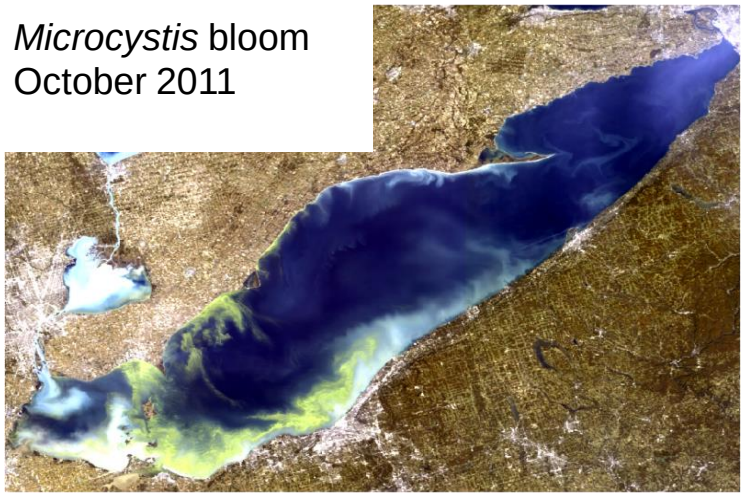
Wind conditions from South Bass Island, OH

Lake Erie: Strong northeasterly winds (10-20 knots) are expected through tonight, and are expected to shift southwesterly on Friday. Northwesterly winds of 5-15 knots are expected Saturday and Sunday, with a decrease in storm activity.

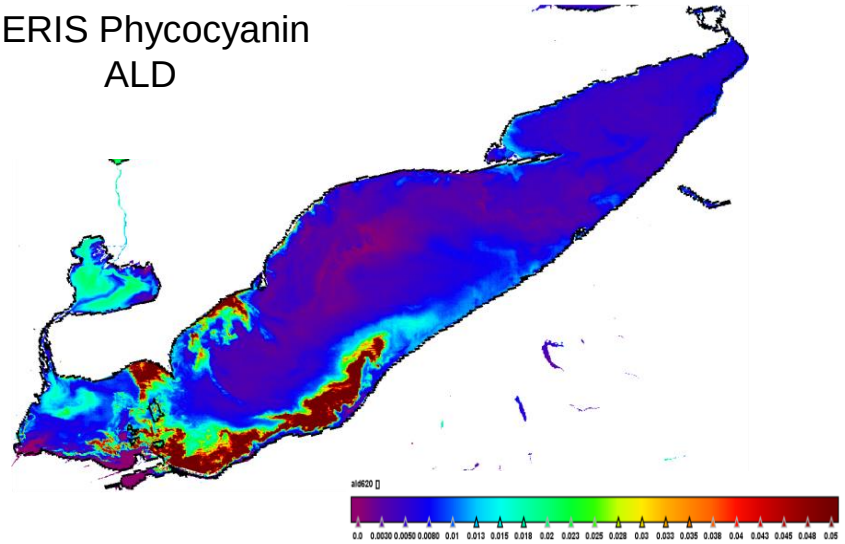
Please note:
1. MERIS Imagery was distributed by the NOAA Coastwatch Program and provided by the European Space Agency
2. Cell counts were collected by the Great Lakes Environmental Research Laboratory
3. The wind data is available throught the National Data Buoy Center

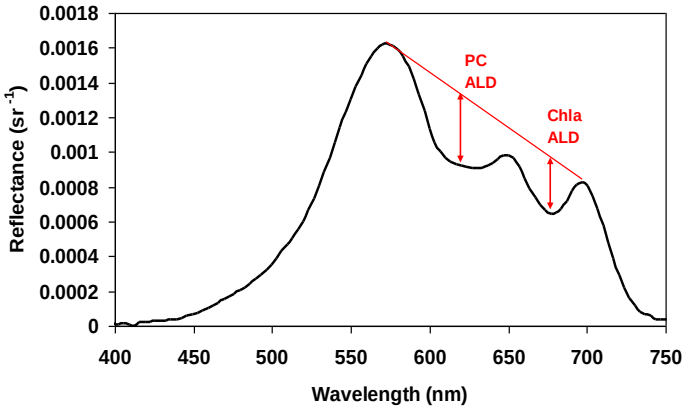
Maximum Chlorophyll Index (MCI)

Microcystis bloom
October 2011



MERIS Phycocyanin
ALD

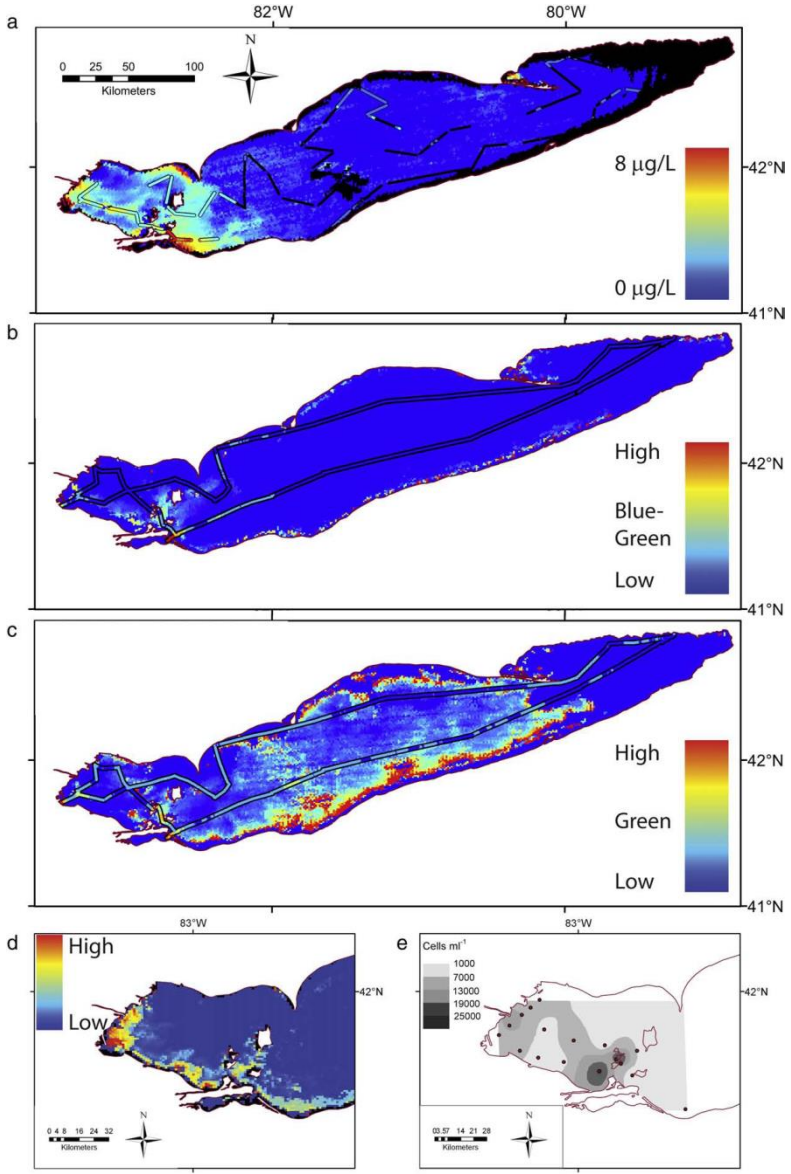


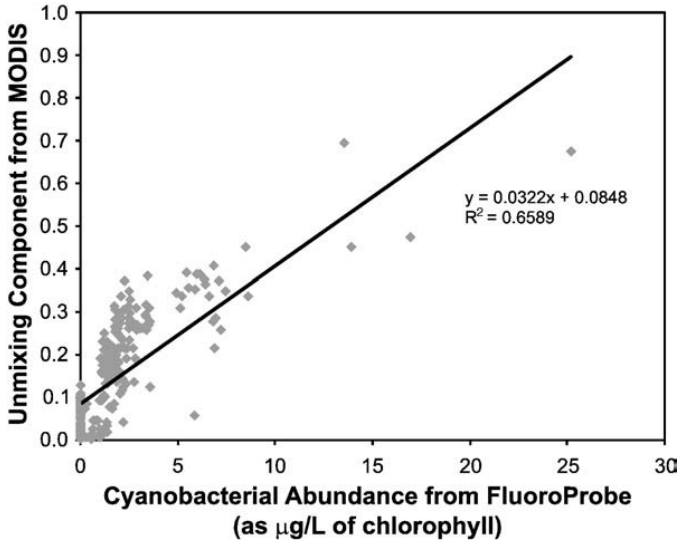


Environment Canada

Binding et al. 2013

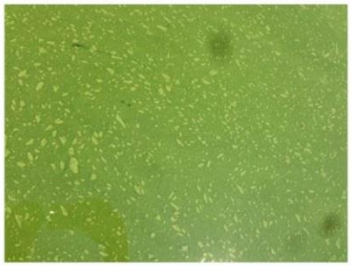
MODIS Least Squares

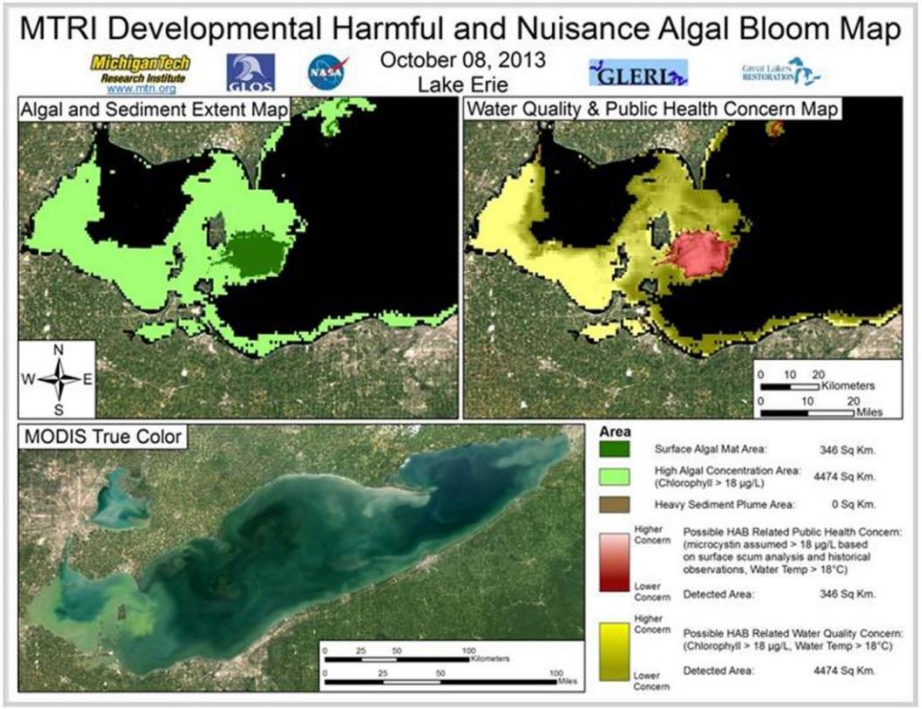


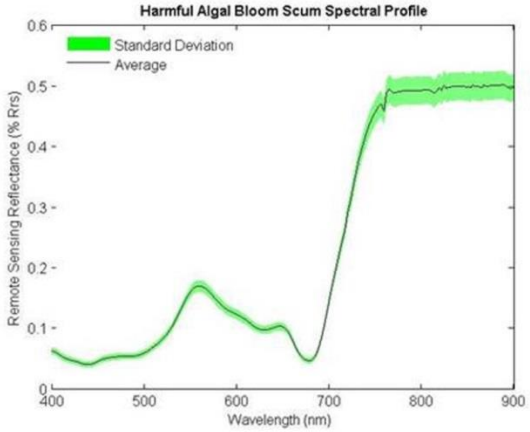


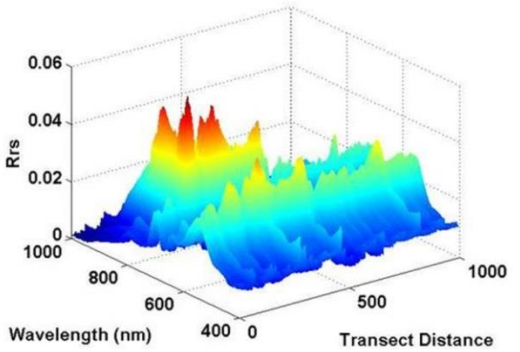
Becker et al., 2009

MODIS MTRI Multi-Faceted Approach









Satellite Derived Data	In Situ Data			
	HAB Present	No HAB Present	**Totals**	User's Accuracy
HAB Present	**44**	6	50	88%
No HAB Present	3	**15**	18	83%
Totals	47	21	68	
Produce's Accuracy	94%	71%		
Overall Accuracy = 87%				

Weekly HAB product has been validated at 87% accuracy

Future Directions
Existing Suite of Algorithms

- Additional Algorithm Verification
- Comparisons of Derived Products
- Generation of Comparison Matrix Indicating Applicability (“Sweet Spot”) of Each Algorithm

Future Directions

Additional Great Lakes Specific Remote Sensing Algorithms

- Improved Chl, HABs, cdom, sm, Retrieval Algorithm
- Surface Scum Index for HABs
- Sediment Plume Extent and Constituent Type and Concentration
- Algal Species Determination
- Shallow Water Depth Correction
- Shallow Water Bathymetry
- Lake Bottom Mapping
- Others

Future Directions
Combined Remote Sensing Models

- Combine Remote Sensing Observations with Geophysical Models
- HABs Model is Good Example

Summary Remarks on Great Lakes Algorithms

- Many Chlorophyll Retrieval Algorithms Exist for Great Lakes
  - Most have “sweet spot”
  - Band ratio techniques work well in open lakes
  - Nearhore, embayments, Lake Erie/Ontario require more sophisticated approaches
  - Primary productivity calculations require robust chl as input
- HABs Algorithms have been Developed and Successfully Evaluated
  - U.S. satellites (MODIS/VIIRS) lack optimum band for blue/green algae detection
  - NOAA approach utilizes a CI
  - MTRI utilizes Chl → HABs empirical relationship and identification of surface scum
  - New approach under development will utilize hydro-optical properties of HABs to achieve retrieval success

Summary Remarks on Great Lakes Algorithms (cont)

- Significant Amount of Ongoing Investigations by U.S. and Canadian Agencies, Academia, Industry, and NGOs on Better Algorithms for chl, doc, sm, Kd, PP, Sediment Plumes, and HABs
  - New algorithm for lake-wide evaporation