Lake Monitoring in Wisconsin using Satellite Remote Sensing

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Wisconsin Department of Natural Resources
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LDCM artist's rendering: NASA/Goddard Space Flight Center Conceptual Image Lab

Remote sensing applications for environmental monitoring

Satellite-based water quality monitoring for improved spatial and temporal retrieval of chlorophyll-a in coastal waters

E. Therese Harvey[a,*], Susanne Kratzer[a], Petra Philipson[b]

Improved algorithm for routine monitoring of cyanobacteria and eutrophication in inland and near-coastal waters

Mark William Matthews[a,*], Daniel Odermatt[b,c]

Monitoring selective logging in western Amazonia with repeat lidar flights

Hans-Erik Andersen[a], Stephen E. Reutebuch[a,*], Robert J. McGaughey[a], Marcus V.N. d'Oliveira[b], Michael Keller[c,d]

Multi-resolution time series imagery for forest disturbance and regrowth monitoring in Queensland, Australia

Michael Schmidt[a,b,*], Richard Lucas[c], Peter Bunting[d], Jan Verbesselt[e], John Armston[a,b]

Estimating lake carbon fractions from remote sensing data

Tiit Kutser[a,b,*], Charles Verpoorter[c,b], Birgot Paavel[a], Lars J. Tranvik[b]

Tree cover and forest cover dynamics in the Mekong Basin from 2001 to 2011

Patrick Leinenkugel[a,*], Michel L. Wolters[a], Natascha Oppelt[b], Claudia Kuenzer[a]

Quantification of two decades of shallow-water coral reef habitat decline in the Florida Keys National Marine Sanctuary using Landsat data (1984–2002)

David A. Palandro[a,*], Serge Andréfouët[b], Chuanmin Hu[a], Pamela Hallock[c], Frank E. Müller-Karger[a], Phillip Dustan[d], Michael K. Callahan[e], Christine Kranenburg[a], Carl R. Beaver[e,f]

Ice sheet change detection by satellite image differencing

Robert A. Bindschadler[a,*], Ted A. Scambos[b], Hyeungu Choi[c], Terry M. Haran[b]

Advantages and disadvantages of remote sensing for lake monitoring

Advantages

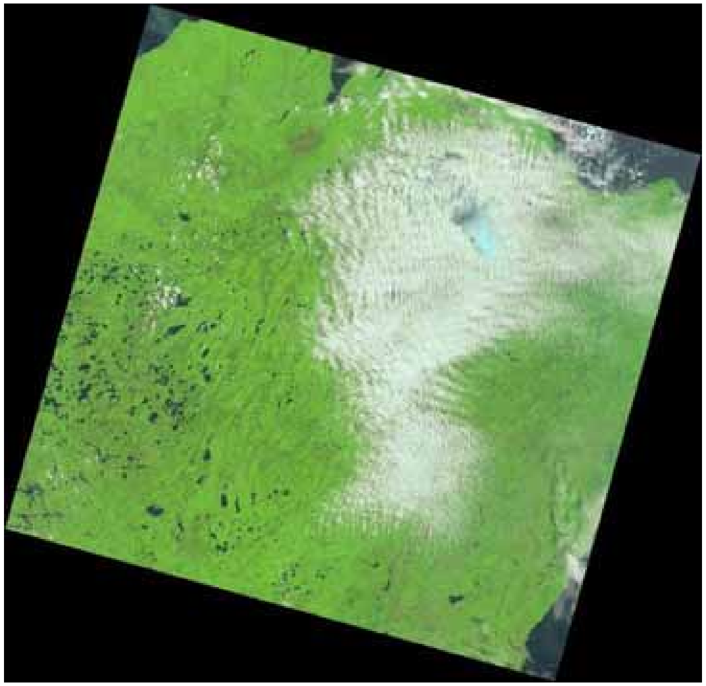
- Water quality data with a high spatial and temporal resolution for thousands of lakes at a time
- Evaluation of environmental problems and potential health risks
- Historical data for studies of trends in water quality
- Real time data for integration into early warning systems to protect the public from harmful algal blooms

Disadvantages

- Optically complex conditions found in lakes
- Potential interference from the lake bottom in shallow lakes
- Dynamic changes in water quality
- Limited number of water quality parameters
- Calibration and validation of models typically requires the collection of ground truth data

Remote sensing activities at the Wisconsin DNR

- Systematic processing of Landsat 7 ETM+ and Landsat 8 OLI data for the retrieval of water clarity
- Studies of the major drivers of lake water clarity, their interactions, and the potential impacts of land use and climate on water clarity
- Increase in Earth observation monitoring capabilities through the optical and biogeochemical characterization of lakes in support of algorithm calibration, refinement, and validation



Landsat 8 OLI image courtesy of the U.S. Geological Survey

Remote sensing activities at the Wisconsin DNR

EO sensors suitable for water quality assessment with public access data policy

	Pixel Size (m)	Bands (400-900 nm)	Revisit cycle	CHL	CYP	TSM	CDOM	SD	K_d
Low res.									
MODIS	1000	9	Daily	Highly suited	Potential	Highly suited	Highly suited	Highly suited	Highly suited
MODIS	500	2	Daily	Not suited	Not suited	Potential	Potential	Potential	Potential
MODIS	250	2	Daily	Not suited	Not suited	Potential	Not suited	Potential	Potential
MERIS & OCM2	300	15	2-3 days	Highly suited	Highly suited	Highly suited	Highly suited	Highly suited	Highly suited
VIIRS	750	7	2x/day	Suited	Potential	Potential	Suited	Suited	Suited
Med res.									
Landsat	30	4	16	Potential	Potential	Suited	Suited	Suited	Suited
Future									
Sentinel-3	300	21	Daily	Highly suited	Highly suited	Highly suited	Highly suited	Highly suited	Highly suited
LDCM	30	5	16	Suited	Potential	Suited	Suited	Suited	Suited
Sentinel-2	10-60	10	3-5 days	Highly suited	Suited	Highly suited	Suited	Highly suited	Highly suited
HySpIRI	60	60	19 days	Highly suited	Highly suited	Highly suited	Highly suited	Highly suited	Highly suited

● Highly suited ● Suited ● Potential ● Not suited

CHL=Chlorophyll; CYP=Cyanophycocyanin; TSM=Total Suspended Matter; CDOM=Coloured Dissolved Organic Matter; SD= Secchi Disk Transparency; Kd=Vertical Attenuation of Light

Table from Dekker, A.G. & Hestir, E. L. (2012) *Evaluating the Feasibility of Systematic Inland Water Quality Monitoring with Satellite Remote Sensing*. CSIRO: Water for a Healthy Country National Research Flagship

Landsat 8 OLI and TIRS

(02/11/2013)

OLI

- Eight multispectral bands and one panchromatic band
- Pixel size 30 m for multispectral bands and 15 m for panchromatic band

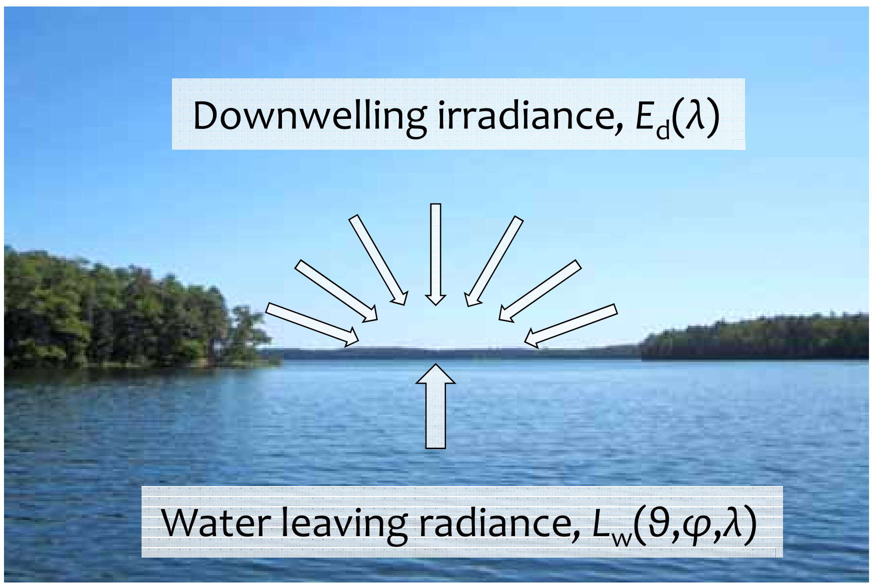
TIRS

- Two thermal bands
- Pixel size 100 m

- Scene size 170 x 180 km
- Repeat cycle 16 days

Remote sensing of water quality

Remote sensing reflectance



Trout Lake

Water leaving radiance

$$R_{rs}(\vartheta, \varphi, \lambda) = \frac{L_w(\vartheta, \varphi, \lambda)}{E_d(\lambda)}$$

Downwelling irradiance

Remote sensing of water quality

Absorption and scattering coefficients

Sensitivity of the reflectance to variations in the solar zenith angle

$$R_{rs}(\vartheta, \varphi, \lambda) = \frac{f(\lambda)}{Q(\lambda)} \frac{b_b(\lambda)}{a(\lambda) + b_b(\lambda)}$$

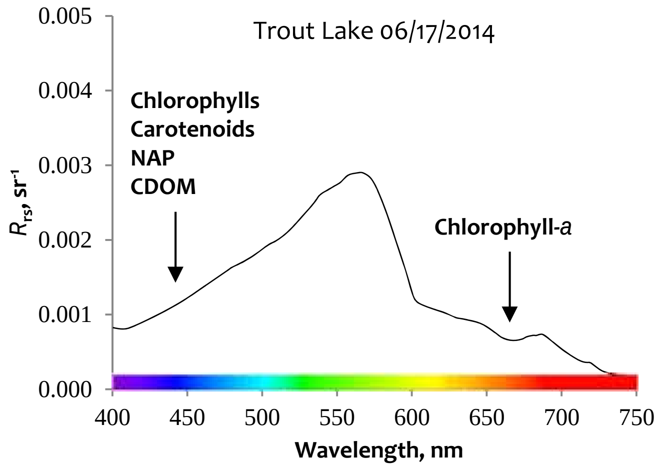
Bidirectional properties of the reflectance

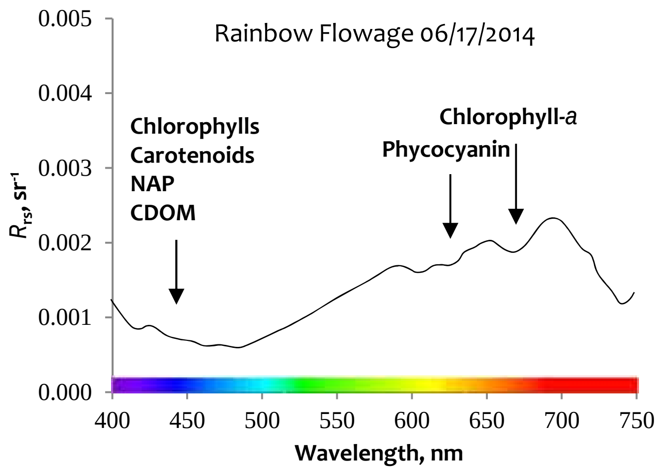
Absorption coefficient

Backscattering coefficient

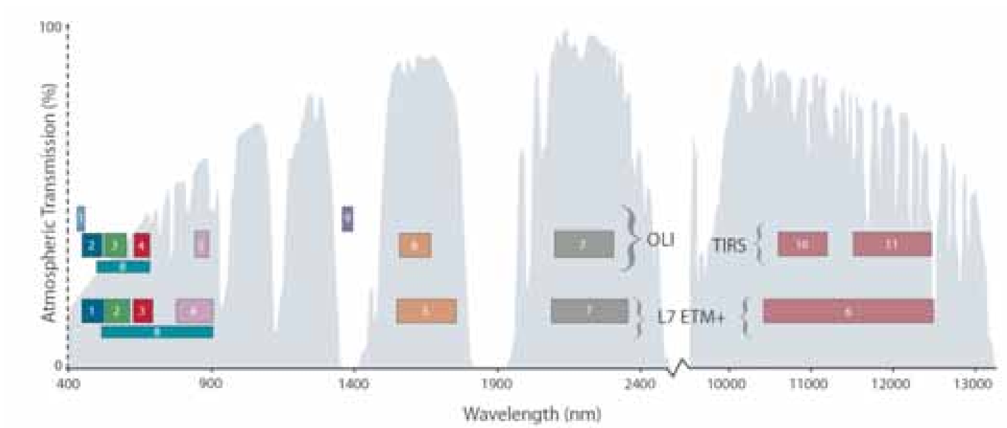
$$a(\lambda) = a_{\varphi}(\lambda) + a_{NAP}(\lambda) + a_{CDOM}(\lambda) + a_{w}(\lambda)$$

Remote sensing of water quality





Landsat 8 spectral bands

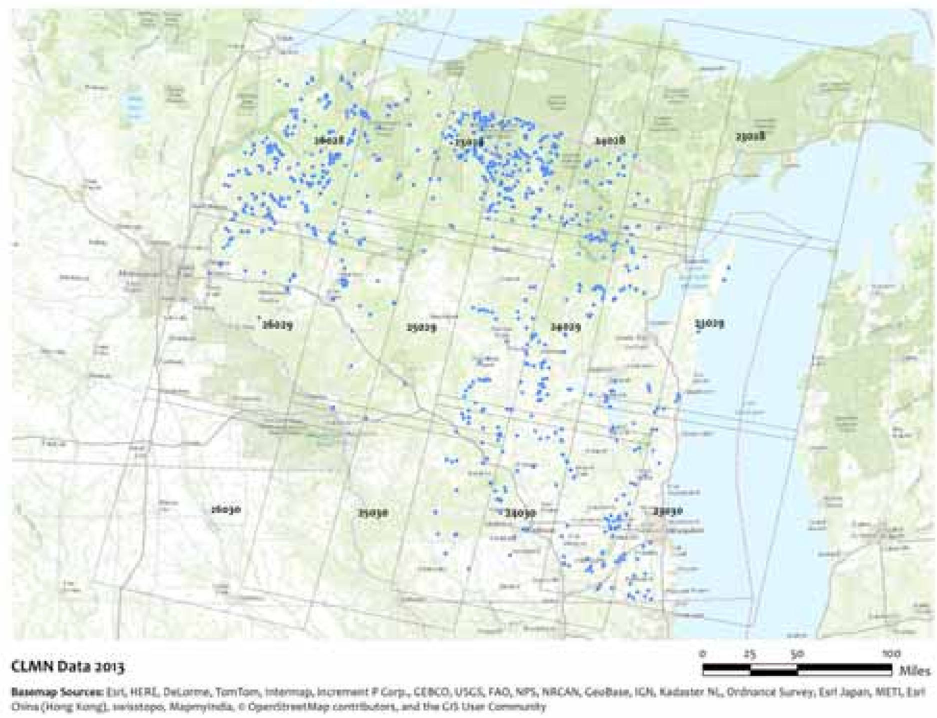


Landsat 8 spectral bands graph from http://landsat.gsfc.nasa.gov

Systematic processing of satellite data for water clarity

2013 water clarity estimation

- 54 satellite images
- 3992 ground truth measurements
- 32 data processing steps
- 9 image mosaics for algorithm development
- 475 ground truth measurements for algorithm development
- 8561 water clarity estimates
- 3788 files
- 0.94 TB of data



Systematic processing of satellite data for water clarity

Image processing steps

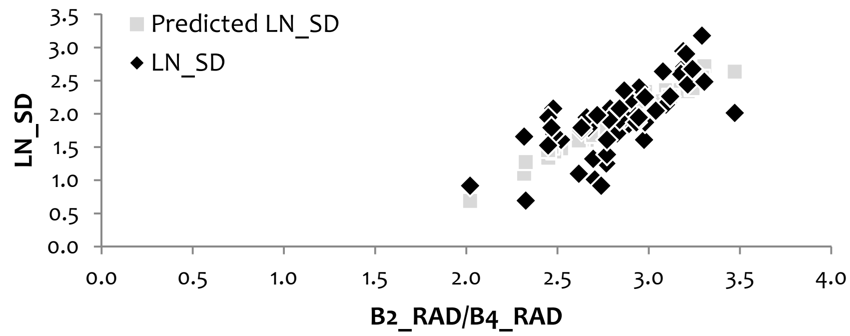
- Conversion of data to TOA spectral radiance
- Reprojection of images to WTM
- Removal of cirrus clouds
- Removal of land
- Removal of shallow waters and aquatic vegetation
- Mosaicking
- Extraction of radiance values for CLMN stations with data collected within one week from image acquisition date

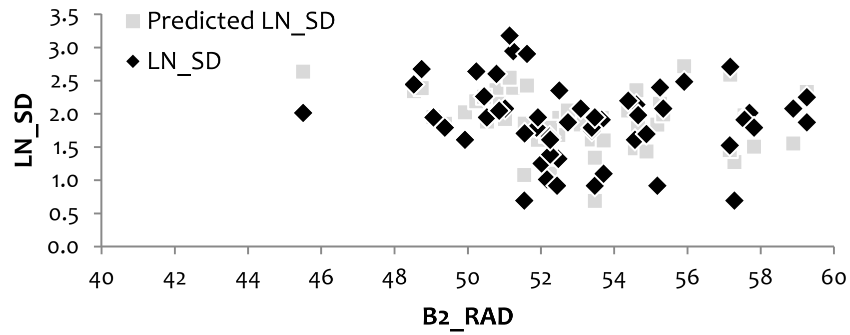
Landsat 8 OLI image of Lake Winnebago
07/18/2013

Systematic processing of satellite data for water clarity

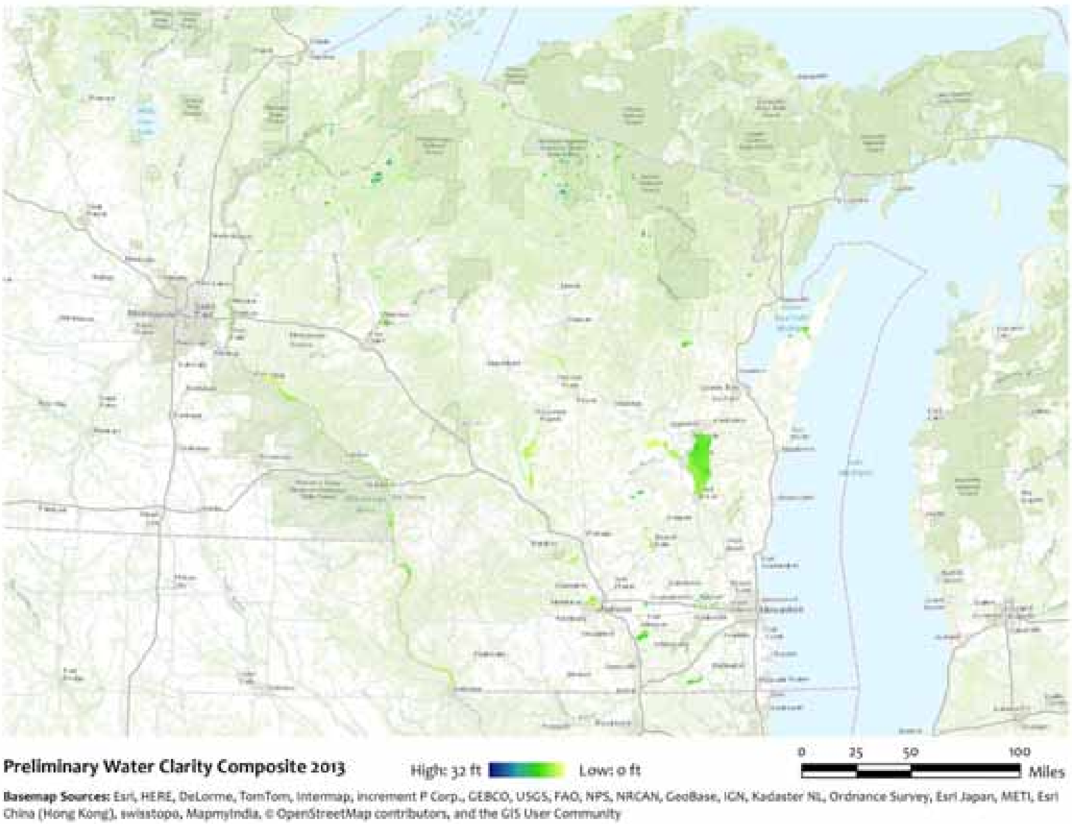
Algorithm calibration

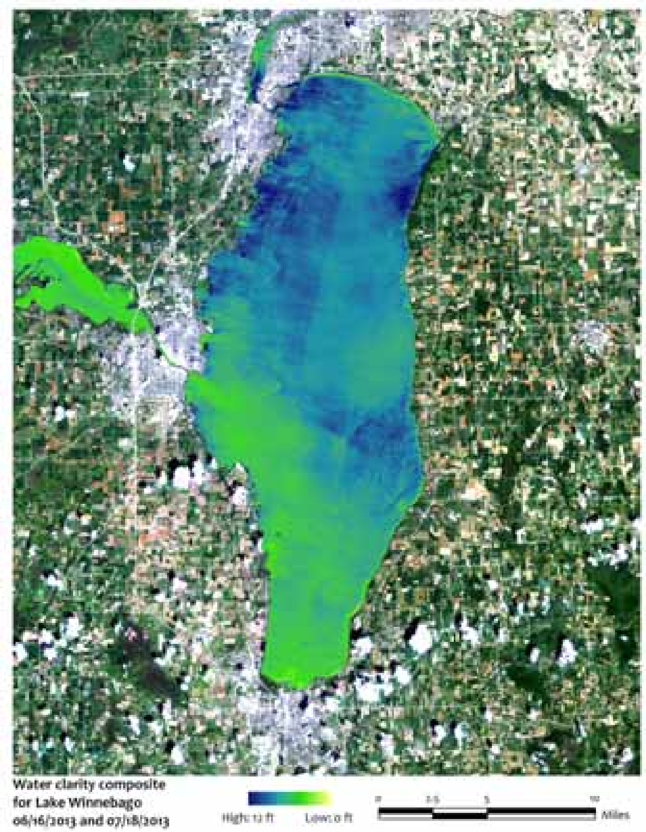
$$\ln(SD) = a + b \times \frac{OLI_{B2}}{OLI_{B4}} + c \times OLI_{B2}$$



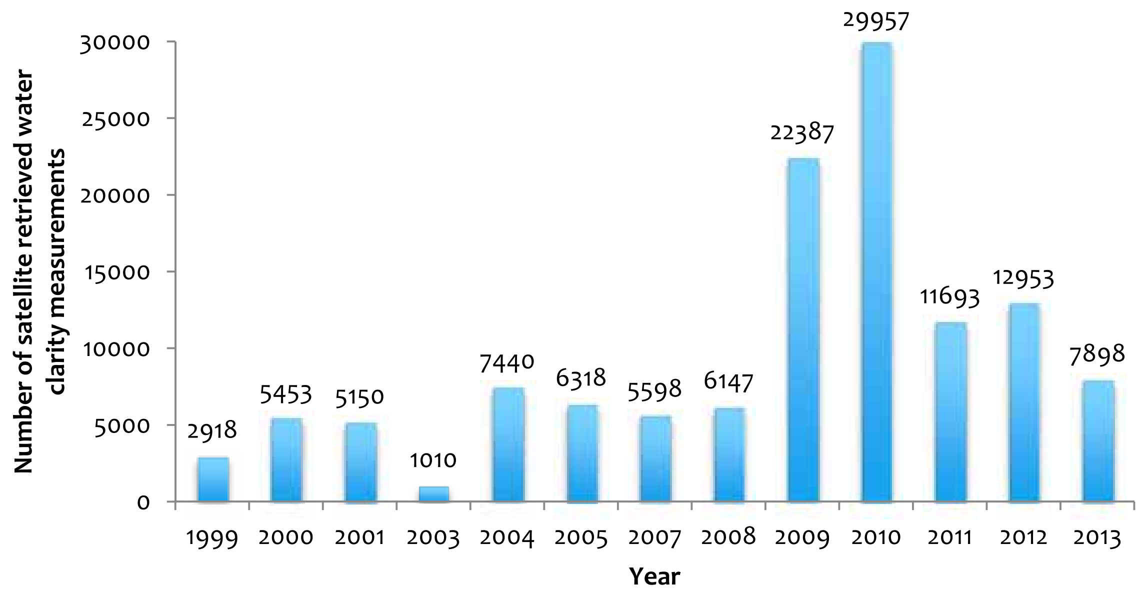


2013 preliminary water clarity composite



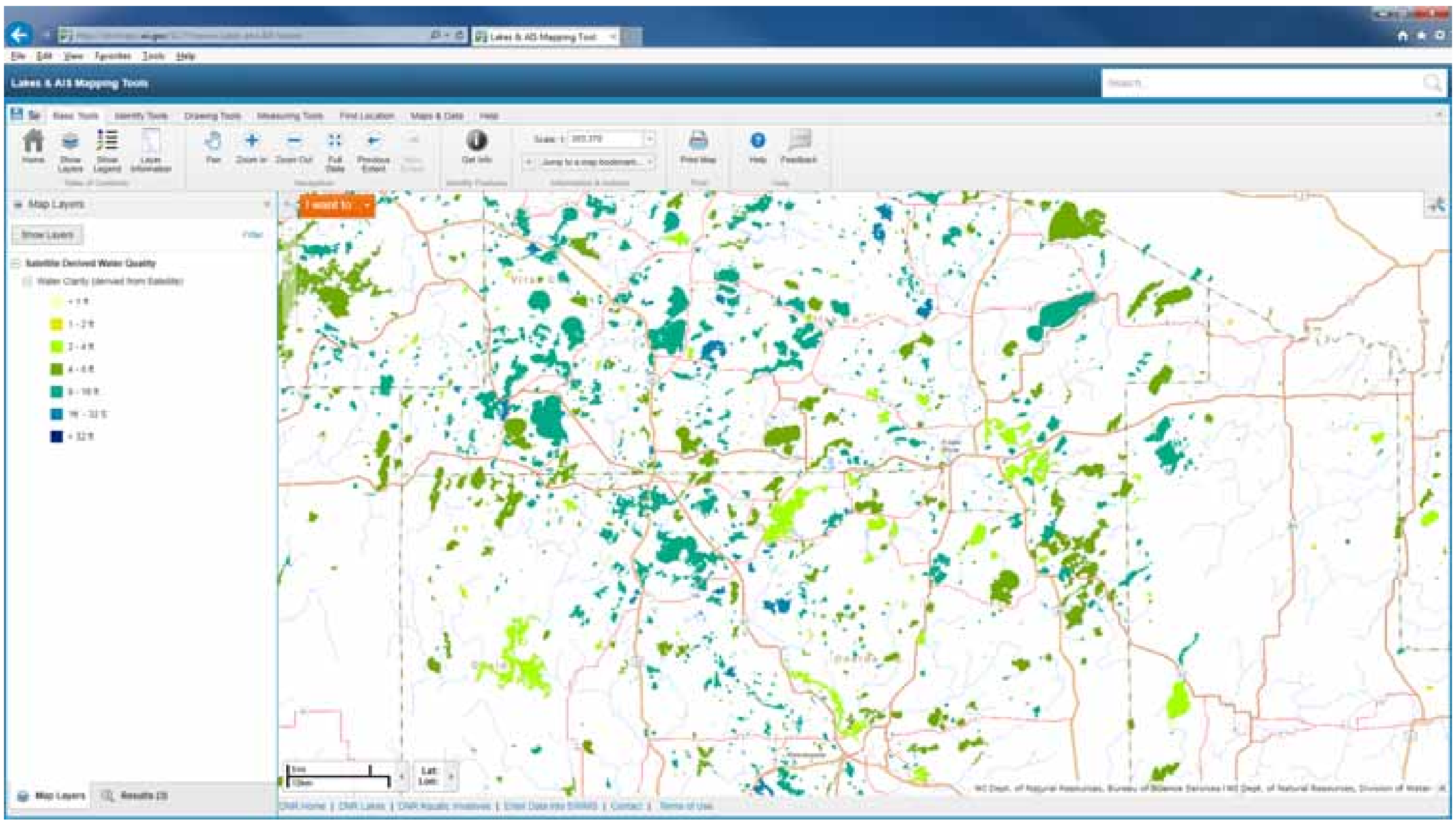


Systematic processing of satellite data for water clarity



Lakes and Aquatic Invasive Species (AIS) Mapping Tool

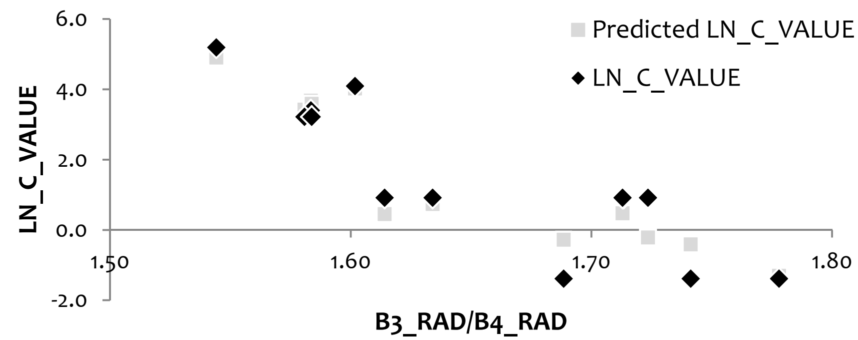
http://dnr.wi.gov/lakes/viewer/

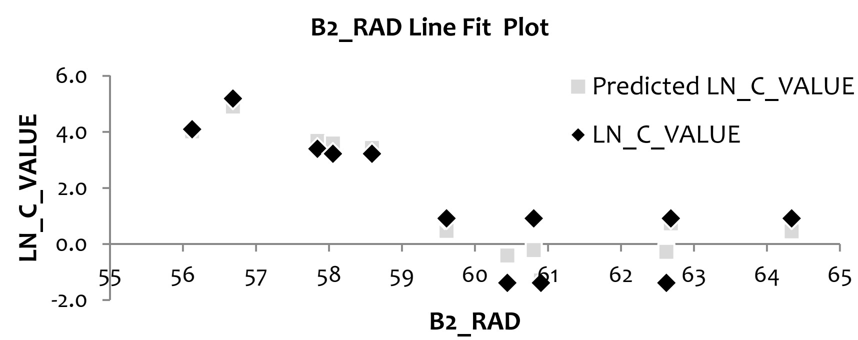


Systematic processing of satellite data for water color

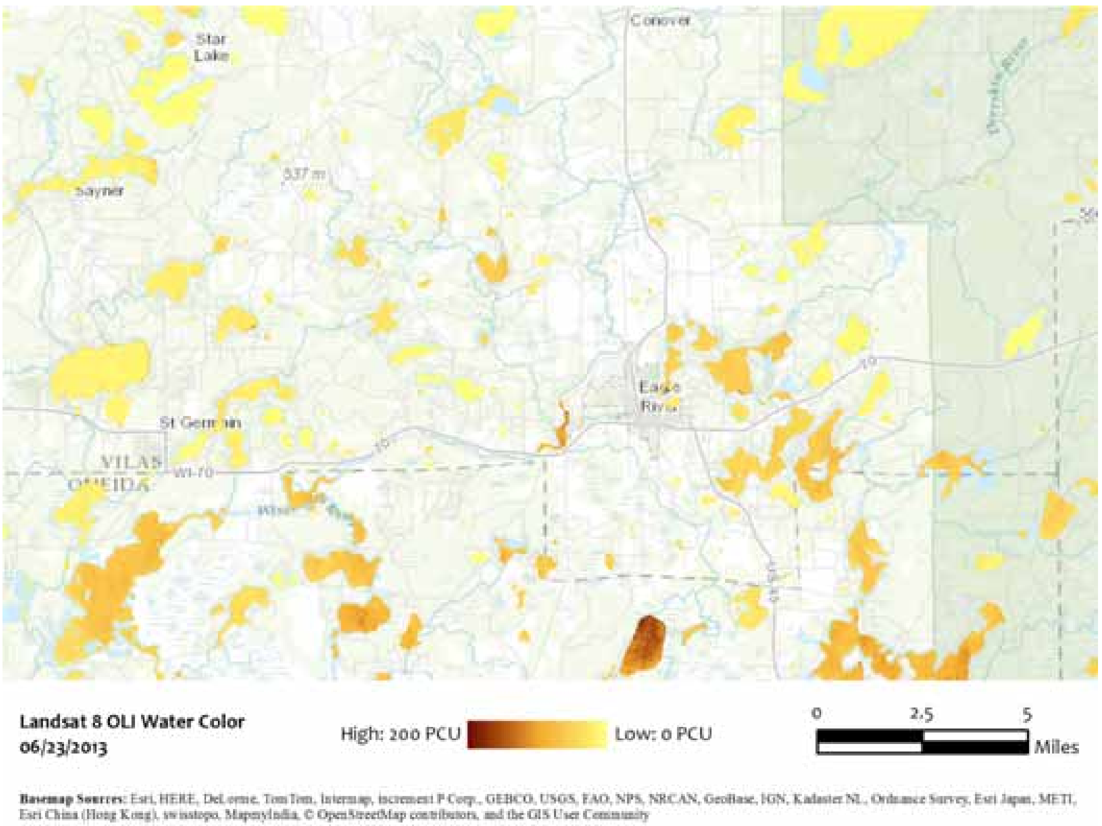
Algorithm calibration

$$\ln(C) = a + b \times \frac{OLI_{B3}}{OLI_{B4}} + c \times OLI_{B2}$$





2013 preliminary water color product



Average

Water Color

Big Saint Germain Lake

- 5.5 PCU

Rainbow Flowage

- 33.0 PCU

Pickerel Lake

- 13.3 PCU

Major drivers of lake water clarity

Focus on

- Explained variance
- Response distributions

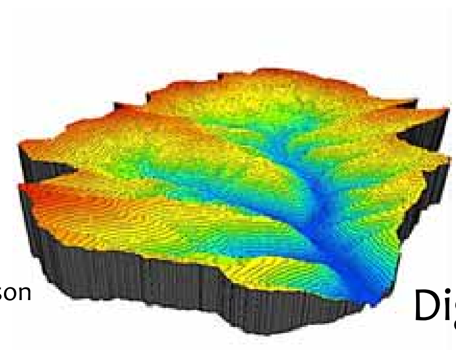
Predictor categories

- Climate
- Land use/land cover
- Surficial geology
- Water chemistry
- Lake morphology & position
- Runoff potential

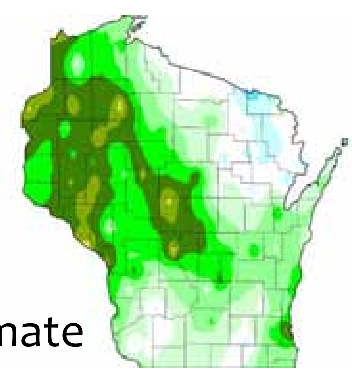
National Land Cover Database

USDA National Soil Survey

Water chemistry



Digital elevation models

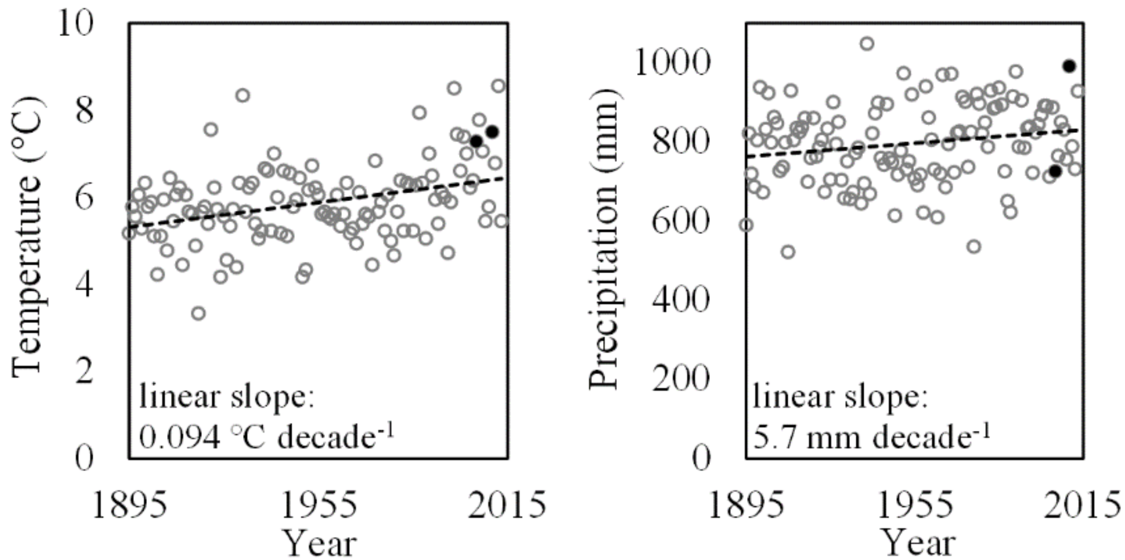


Gridded climate

Data courtesy of Kevin Rose, University of Wisconsin-Madison

Major drivers of lake water clarity

What are the implications of long term trends in temperature and precipitation?



Data courtesy of Kevin Rose, University of Wisconsin-Madison

Major drivers of lake water clarity

Water clarity is regulated by many different drivers.

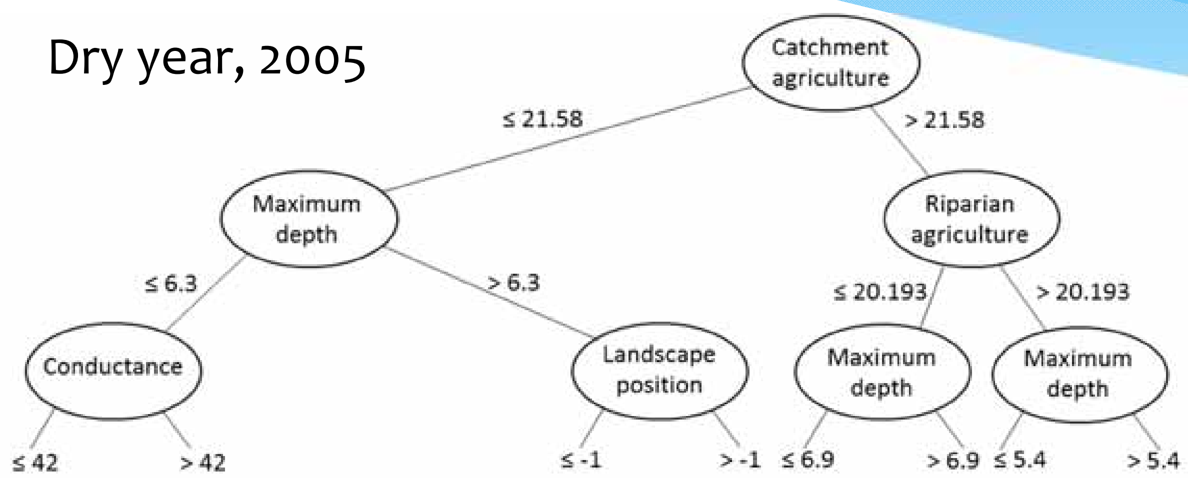
Dry year, 2005
Wet year, 2010

Predictor category	Predictors (#)	2005 variance explained	2010 variance explained
Climate	13	30.0	23.1
Land use/land cover	26	28.5	21.3
Lake morphometry	4	27.5	23.7
Run-off potential	5	18.8	11.7
Catchment morphometry	11	17.9	12.0
Water chemistry	3	12.8	2.1
Geology	18	4.3	3.6
Total	80	64.4	52.4

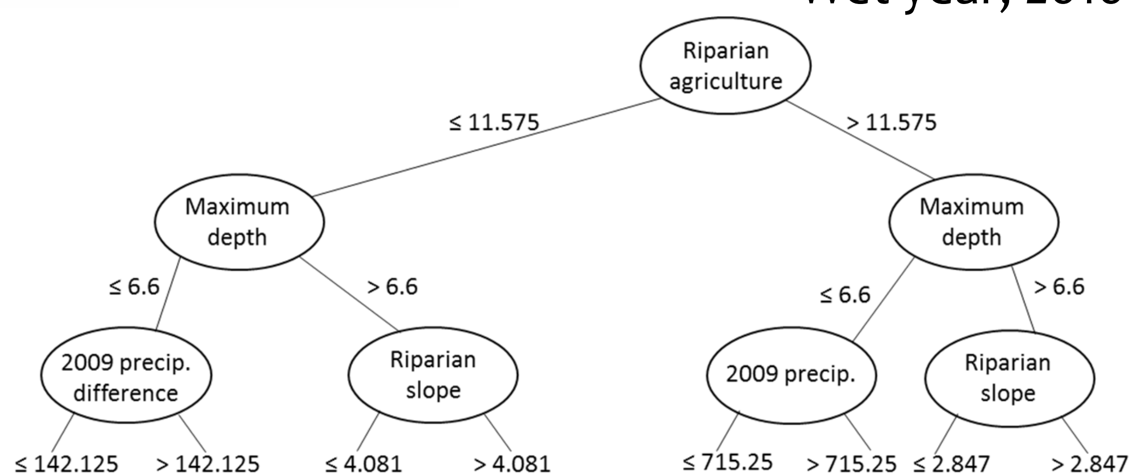
Data courtesy of Kevin Rose, University of Wisconsin-Madison

Major drivers of lake water clarity

Dry year, 2005



Wet year, 2010

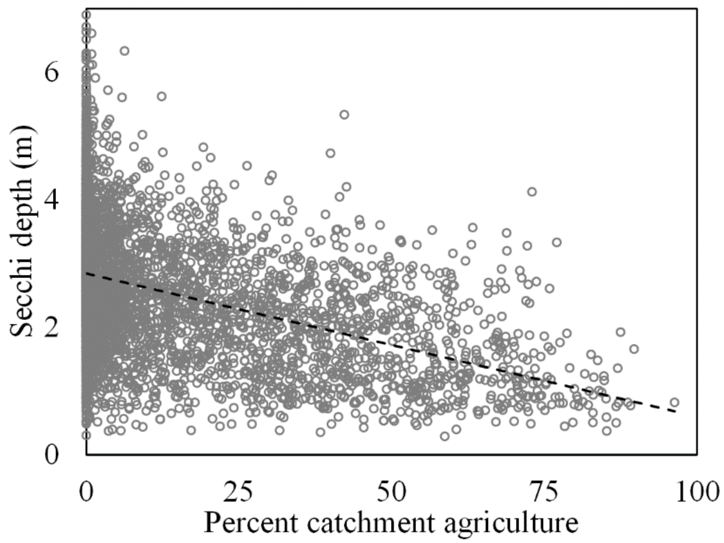


Data courtesy of Kevin Rose, University of Wisconsin-Madison

Major drivers of lake water clarity

Regulators of lake water clarity

- Deep lakes high in the landscape tend to be the clearest
- Agricultural land use is the best land use predictor of water clarity
- High precipitation is associated with lower water clarity



Data courtesy of Kevin Rose, University of Wisconsin-Madison

Increase in Earth observation monitoring capabilities

Optical and biogeochemical characterization of lakes

- Field data collection in summer and fall 2014 for algorithm development
- 24 lakes in Wisconsin

Field and laboratory measurements

- Water temperature, dissolved oxygen, conductivity, and Secchi depth
- Reflectance
- Water color and turbidity
- TSS, ISS, and OSS
- Absorption and backscattering coefficients

Return from field data collection at Lake Geneva

Thank you!

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