Lake Monitoring in Wisconsin using Satellite Remote Sensing

D. Gurlin and S. Greb
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

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Monitoring selective logging in western Amazonia with repeat lidar flights

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

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Estimating lake carbon fractions from remote sensing data

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

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Ice sheet change detection by satellite image differencing

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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

**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

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

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Pixel Size (m)</th>
<th>Bands (400-600 nm)</th>
<th>Revisit Cycle</th>
<th>CHL</th>
<th>CYP</th>
<th>TSM</th>
<th>CDOM</th>
<th>SD</th>
<th>Kd</th>
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<tr>
<td>MODIS</td>
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<td>Sentinel-2</td>
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<td>19 days</td>
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</tbody>
</table>

- 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

Remote sensing of water quality

Remote sensing reflectance

\[
R_{rs}(\theta, \varphi, \lambda) = \frac{L_w(\theta, \varphi, \lambda)}{E_d(\lambda)}
\]

Downwelling irradiance, \(E_d(\lambda)\)

Water leaving radiance, \(L_w(\theta, \varphi, \lambda)\)

Trout Lake
Remote sensing of water quality

Absorption and scattering coefficients

Sensitivity of the reflectance to variations in the solar zenith angle

\[ R_{rs}(\theta, \varphi, \lambda) = \frac{f(\lambda)}{Q(\lambda)} \frac{b_b(\lambda)}{a(\lambda) + b_b(\lambda)} \]

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 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
Systematic processing of satellite data for water clarity

Algorithm calibration

\[
\ln(SD) = a + b \times \frac{\text{OLI}_{B2}}{\text{OLI}_{B4}} + c \times \text{OLI}_{B2}
\]
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/
Algorithm calibration

\[
\ln(C) = a + b \times \frac{\text{OLI}_{B3}}{\text{OLI}_{B4}} + c \times \text{OLI}_{B2}
\]
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

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
Water clarity is regulated by many different drivers.

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

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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