1098: Integrating satellite data analysis into a water quality monitoring program

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Abstract

Water quality monitoring is an integral tool in the management of freshwater resources. It identifies trends in water quality and tracks the effects of anthropogenic influences such as shoreline development and eutrophication and the successes of restoration actions. Remote sensing presents a cost efficient complementary approach for a more comprehensive assessment of our freshwater resources. The open access to Earth observation data limits the costs to software maintenance and data processing costs and makes the integration of remote sensing into water quality monitoring programs more attractive for natural resources management agencies. The operational annual satellite retrieval of the water clarity for thousands of lakes across Wisconsin from Landsat 7 ETM+ and Landsat 8 OLI-TIRS data assists the Wisconsin DNR in trophic state assessments for the State of Wisconsin. The results are shared within the Wisconsin DNR for the Wisconsin Water Quality Reports to Congress in compliance with Section 305(b) of the Clean Water Act and with state and local water quality managers, lake organizations, and the public. Summer water clarity maps are shared through the Wisconsin Lakes & Aquatic Invasive Species Mapping Tool and GIS data portal. Current remote sensing activities at the Wisconsin DNR include the transition of image processing efforts from a desktop to cloud environment, the collection of field and satellite match-up data for waterbodies across Wisconsin to support algorithm development and validation efforts by external partners, and the development of strategies for the integration of satellite data products into our water quality monitoring program. This poster provides insights in the different components of the successful integration of satellite data analysis into our water quality monitoring program and can serve as a roadmap for natural resources management agencies.

CP14D-1098: Integrating satellite data analysis into a water quality monitoring program

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Remote sensing of water quality at the Wisconsin DNR

Remote sensing presents a cost-efficient complementary approach for a more comprehensive assessment of our freshwater resources and has been utilized to estimate the water clarity, expressed as Secchi depth, for Wisconsin's large number of lakes for almost two decades. Current remote sensing activities at the Wisconsin DNR include the transition of image processing efforts from a desktop to cloud environment, the collection of field and satellite match-up data for waterbodies across Wisconsin to support algorithm development and validation efforts by external partners, and the development of strategies for the integration of satellite data products into our water quality monitoring program.

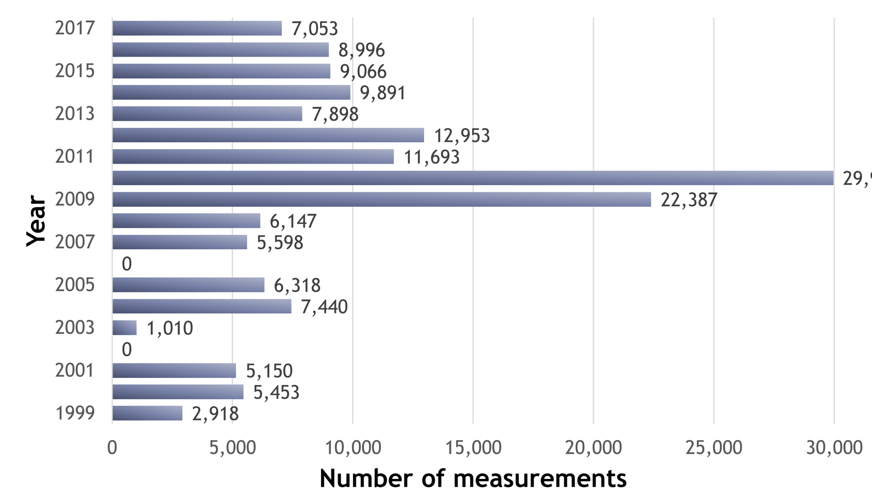

Figure 1. Number of satellite retrieved Secchi depth measurements from 1999 to 2017.

Satellite retrieval of the water clarity in traditional image processing software

The image processing efforts at the Wisconsin DNR concentrate on remote sensing data from the NASA/USGS Landsat Program. Landsat Collections Level-1 data are rescaled to top of atmosphere (TOA) reflectance and used for the development of image acquisition date specific algorithms for the satellite retrieval of the water clarity. Software packages used include ENVI 5.5 +IDL 8.7 and ArcGIS 10.6.1 for Desktop.

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

Equation 1. Model for the satellite retrieval of water clarity from Landsat 8 OLI-TIRS images.

ln(SD) – Natural logarithm of the Secchi depth
OLI_{B2} - Operational Land Imager Band 2
OLI_{B4} – Operational Land Imager Band 4

Data acquisition
Pre-processing and mosaicking of Landsat images
QA/QC of water clarity data
Extraction of field data signatures from Landsat images
Multiple linear regression of field and satellite data
Retrieval of water clarity from Landsat images
QA/QC of satellite retrieved water clarity data

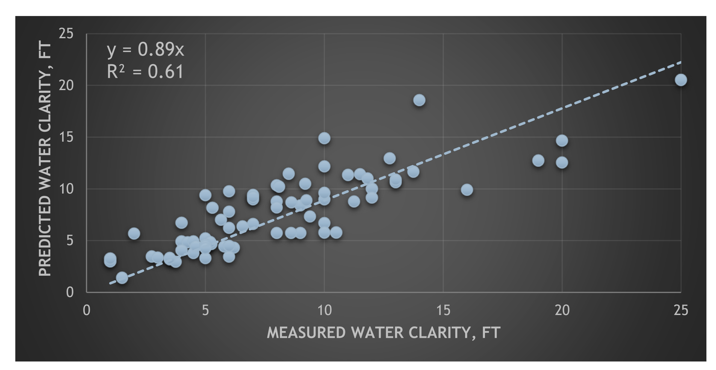

Figure 2. Comparison of field measured and satellite retrieved water clarity data for 2016-07-26 (data processed in ENVI 5.5 + IDL 8.7 and ArcGIS 10.6.1 for Desktop).

Number of samples	74
Mean absolute error	1.90 ft
Mean absolute percentage error	29.2 %

Note: The results include two stations with field measured Secchi depth values of 1.00 ft and satellite retrieved Secchi depth values of 2.99 and 3.27 ft which resulted in percentage errors of 199.3 and 226.8% for these two stations.

Satellite retrieval of the water clarity in Google Earth Engine

In past years, the satellite retrieval of the water clarity in a desktop environment required the download and processing of anywhere from 54 to 86 Landsat 8 OLI-TIRS and Landsat 7 ETM+ images and the storage of 1 TB of data. The transition of these image processing efforts from a desktop to cloud environment is imperative for an increase in Earth observation capabilities for the State of Wisconsin and was explored for a set of Landsat 8 OLI-TIRS images acquired in summer 2016. The image processing chain was successfully transitioned to the cloud-based Google Earth Engine (GEE) platform with the exception of an unsupervised classification step. Software packages used include GEE and QGIS 3.4.1.

Ancillary data acquisition
QA/QC of water clarity data
Set up of Google Earth Engine
Production of a CSV with the extracted field data signatures
Multiple linear regression of field and satellite data
Mosaicking, reprojection, and warping of Landsat images with GDAL
Production of a CSV with the estimated water clarity values
QA/QC of estimated water clarity data

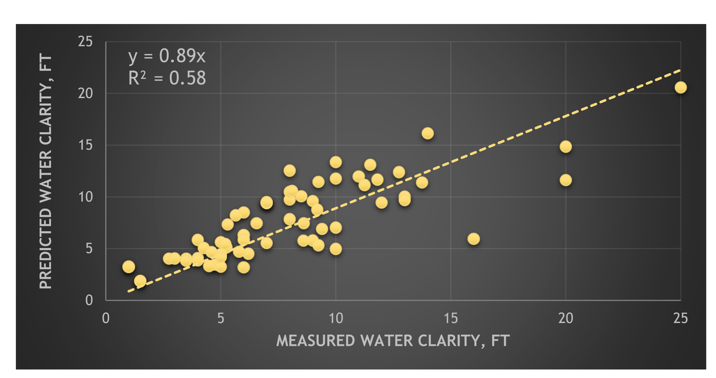

Figure 3. Comparison of field measured and satellite retrieved water clarity data for 2016-07-26 (data processed in GEE).

Number of samples	67
Mean absolute error	1.86 ft
Mean absolute percentage error	29.0 %

Note: The results include two stations with field measured Secchi depth values of 1.00 ft and satellite retrieved Secchi depth values of 3.26 and 3.22 ft which resulted in percentage errors of 226.5 and 222.0% for these two stations.

Data use for integrated reporting

The operational annual satellite retrieval of the water clarity for thousands of lakes across Wisconsin from Landsat 7 ETM+ and Landsat 8 OLI-TIRS data assists the Wisconsin DNR in trophic state assessments for the State of Wisconsin. The results are shared within the Wisconsin DNR for the Wisconsin Water Quality Reports to Congress in compliance with Section 305(b) of the Clean Water Act and with state and local water quality managers, lake organizations, and the public.

$$TSI_{SD} = 60 - 14.41 \ln(SD)$$

TSI - Trophic State Index
SD - Secchi depth, m
ln - Natural logarithm

Equation 2. Calculation of Carlson's TSI from Secchi depth data (Carlson, 1977).

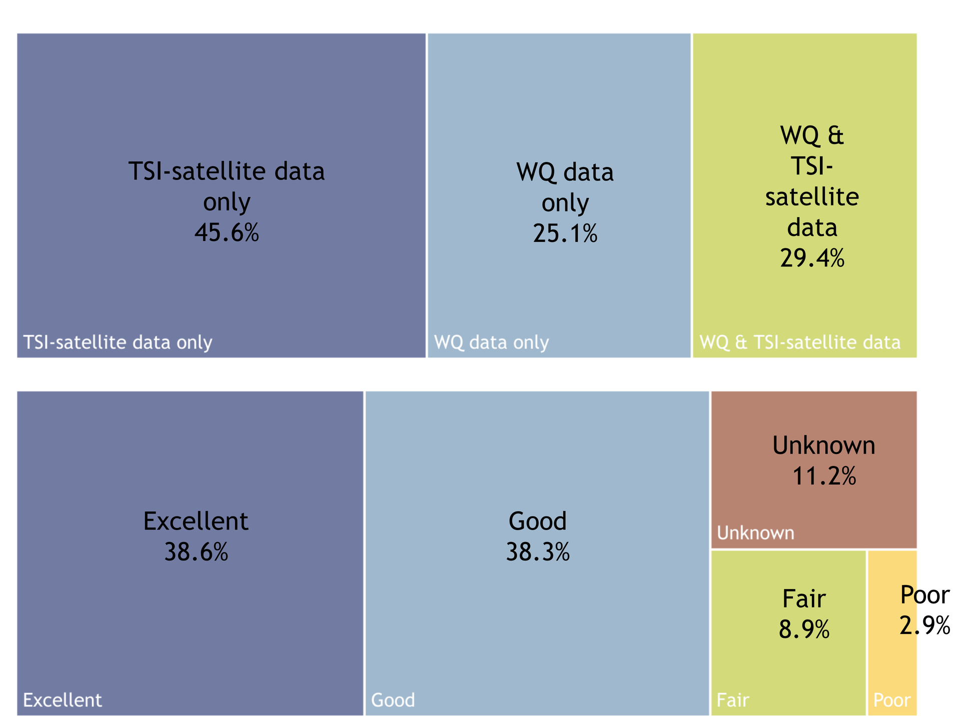

Fig. 4 Lake assessment methods, top, and lake water quality according to lake trophic status, bottom (Data shared by A. Beranek, Wisconsin DNR)

Collection of field and satellite match-up data

The collection of field and satellite match-up data for waterbodies across Wisconsin to support algorithm development and validation efforts by external partners prevents the duplication of these efforts at the Wisconsin DNR and addresses the challenge of a complete representation of the optically complex conditions found in Wisconsin's large number of lakes. These activities include comparisons of atmospheric correction techniques and algorithms for the satellite retrieval of constituent concentrations in collaboration with the Wisconsin DNR.

The field data collected in 2016 included measurements of the inherent and apparent optical properties and constituent concentrations for 30 stations in nine lakes across Wisconsin. Satellite remote sensing reflectance spectra were simulated from radiometric measurements collected with two customized Ocean Optics USB2000+ VIS-NIR spectrometers. The satellite data for potential match-up analyses included Landsat 8 OLI-TIRS and Sentinel-2A MSI images for three different dates.

Particulate and total backscattering coefficients were derived from volume scattering coefficient measurements collected with a WET Labs ECO BB9 scattering meter and absorption coefficients were derived from laboratory measurements. Water samples for the analysis of the water color, turbidity, and constituent concentrations were collected at a depth of 0.5 m and stored in the dark on ice for subsequent analysis at a Wisconsin DNR laboratory and the Wisconsin State Laboratory of Hygiene.

Table 1. Descriptive statistics of the constituent concentrations measured at 30 locations in nine lakes across the state in 2016.

Constituent	N	Min	Max	Median	Mean	Standard deviation	CV (%)
Secchi Depth, m	30	0.6	8.2	1.4	2.0	2.1	102.5
True Color, PCU	30	2.0	20	5.0	8.82	6.24	70.7
Turbidity, NTU	30	0.335	18.5	4.44	5.16	4.37	84.7
DOC, ppm C	30	3.98	10.3	7.75	7.63	1.92	25.1
Chl*a*, µg L^{-1}	30	1.14	68.4	14.0	19.0	16.3	85.5
Total Phosphorus, mg L^{-1}	30	0.0184	0.127	0.0351	0.0478	0.0335	70.0
TSS, mg L^{-1}	30	0.549	19.5	7.42	7.99	4.97	62.1
OSS, mg L^{-1}	30	0.471	15.0	5.21	5.69	3.58	62.8
ISS, mg L^{-1}	30	0.0784	6.25	1.50	2.30	1.86	81.0

Chl*a* – chlorophyll-*a* concentration, DOC – dissolved organic carbon concentration, TSS – total suspended solids concentration, OSS – organic suspended solids concentration, ISS – inorganic suspended solids concentration, N – number of samples, CV – coefficient of variation

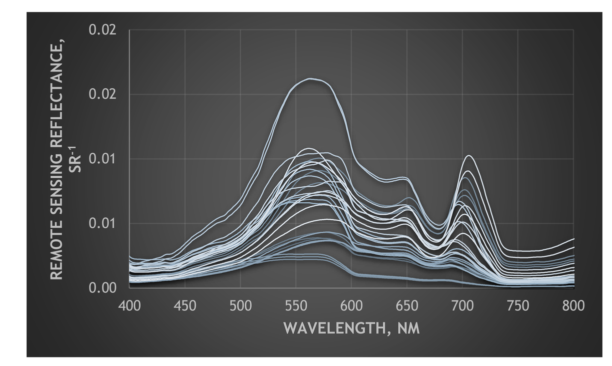

Figure 5. Remote sensing reflectance spectra from 30 locations measured in 2016.

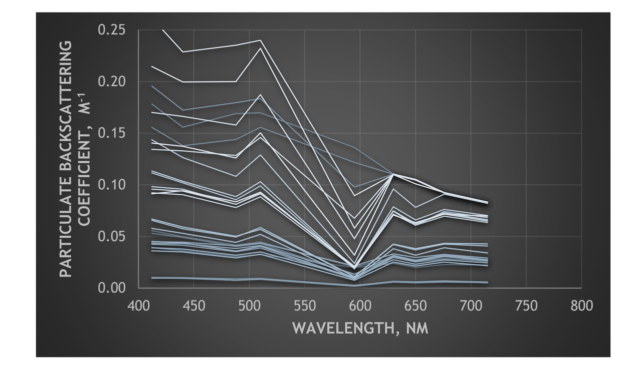

Figure 6. Particulate backscattering coefficients from 30 locations measured in 2016.

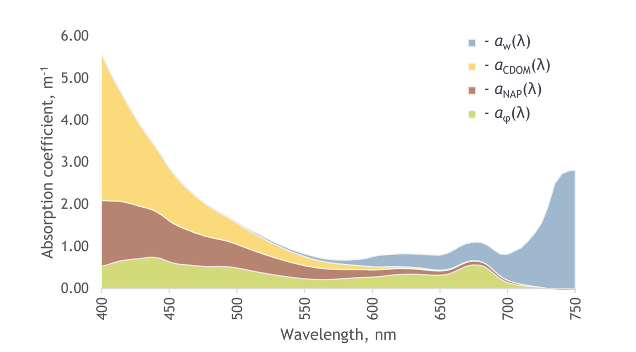

Figure 7. Absorption coefficients measured at station WN2 in Lake Winnebago on 2016-09-02 .

$a_w(\lambda)$ – absorption coefficient of pure water (Pope and Fry, 1997)
$a_{CDOM}(\lambda)$ – absorption coefficient of Chromophoric dissolved organic matter
$a_{NAP}(\lambda)$ – absorption coefficient of non-algal particles
$a_\varphi(\lambda)$ – absorption coefficient of phytoplankton pigments

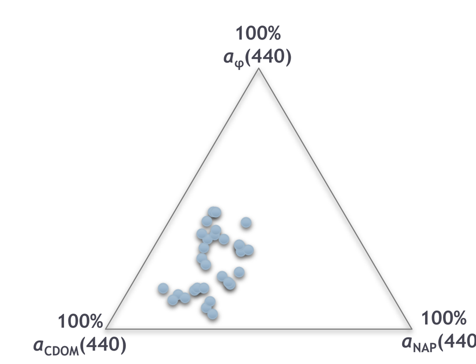

Figure 8. Absorption coefficients from 30 locations measured in 2016.

Expansion of image processing efforts

The image processing efforts at the Wisconsin DNR include the exploration of standard image processing software packages for the satellite retrieval of the total suspended solids (TSS) and chlorophyll-*a* (Chl*a*) concentrations. Landsat 8 OLI-TIRS and Sentinel-2A MSI images acquired on 2016-09-03 were processed in ESA SNAP 7.0.0 with the C2RCC processor for a field and satellite match-up data analysis. The default processing parameters were adjusted to estimated freshwater salinity and water temperature values, AURAOMI and NCEP retrieved ozone and air pressure at sea level values, and the mean elevation of the State of Wisconsin.

The initial comparison of field measured and C2RCC retrieved TSS and Chl*a* concentrations in Lake Winnebago for the Sentinel-2A MSI image indicates a slight overestimation of the TSS concentration and a substantial underestimation of the Chl*a* concentration. The TSS results were within the expected range while the Chl*a* results were outside the expected range and will require the additional exploration of the C2RCC retrieved inherent optical properties. The spatial distribution of TSS in the southern part of the lake is attributed to a southern wind on the image acquisition date.

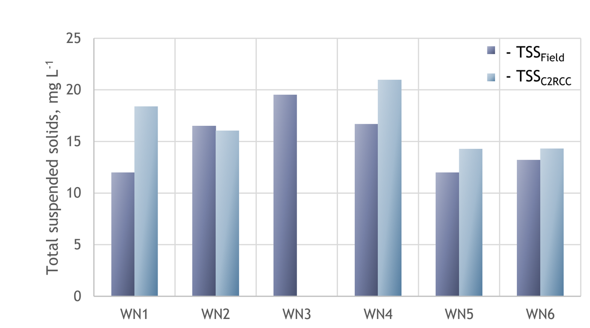

Figure 9. Comparison of field measured and C2RCC retrieved TSS concentrations in Lake Winnebago for the Sentinel-2A MSI image acquired on 2016-09-03.

Number of samples	5
Mean absolute error	2.90 mg L^{-1}
Mean absolute percentage error	21.8 %

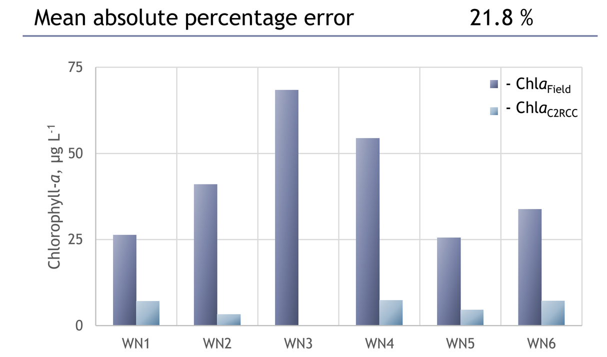

Figure 10. Comparison of field measured and C2RCC retrieved Chl*a* concentrations in Lake Winnebago for the Sentinel-2A MSI image acquired on 2016-09-03.

Number of samples	5
Mean absolute error	30.2 µg L^{-1}
Mean absolute percentage error	82.4 %

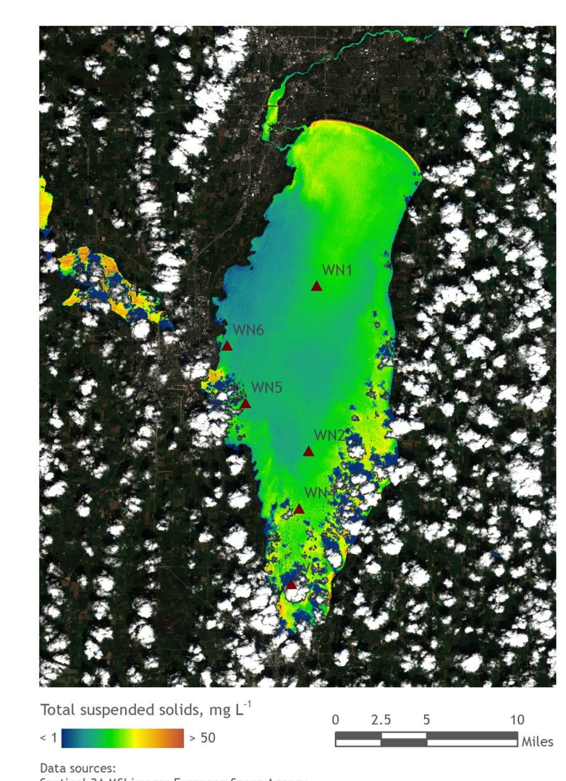

Figure 11. Sentinel-2A MSI TOA reflectance overlaid with the C2RCC retrieved TSS concentrations for Lake Winnebago on 2016-09-03. The locations of stations WN1 to WN6 used in the field and satellite match-up data analysis are shown in red.

Note: The field data were collected one day in advance of the satellite images which is expected to affect the results of the field and satellite data match-up data analysis in large and shallow wind driven systems such as Lake Winnebago.

References

Carlson. R.E. (1977). A trophic state index for lakes. *Limnology and Oceanography, 22(2)*, 361-369

Pope, R.M. & Fry, E.S. (1997). Absorption spectrum (380–700 nm) of pure water. II. Integrating cavity measurements. *Applied Optics. 36(33)*, 8710-8723