Using Citizen Volunteer Lake Water Quality data to Calibrate and Validate Satellite Imagery for Assessment of 10,000+ Minnesota Lakes

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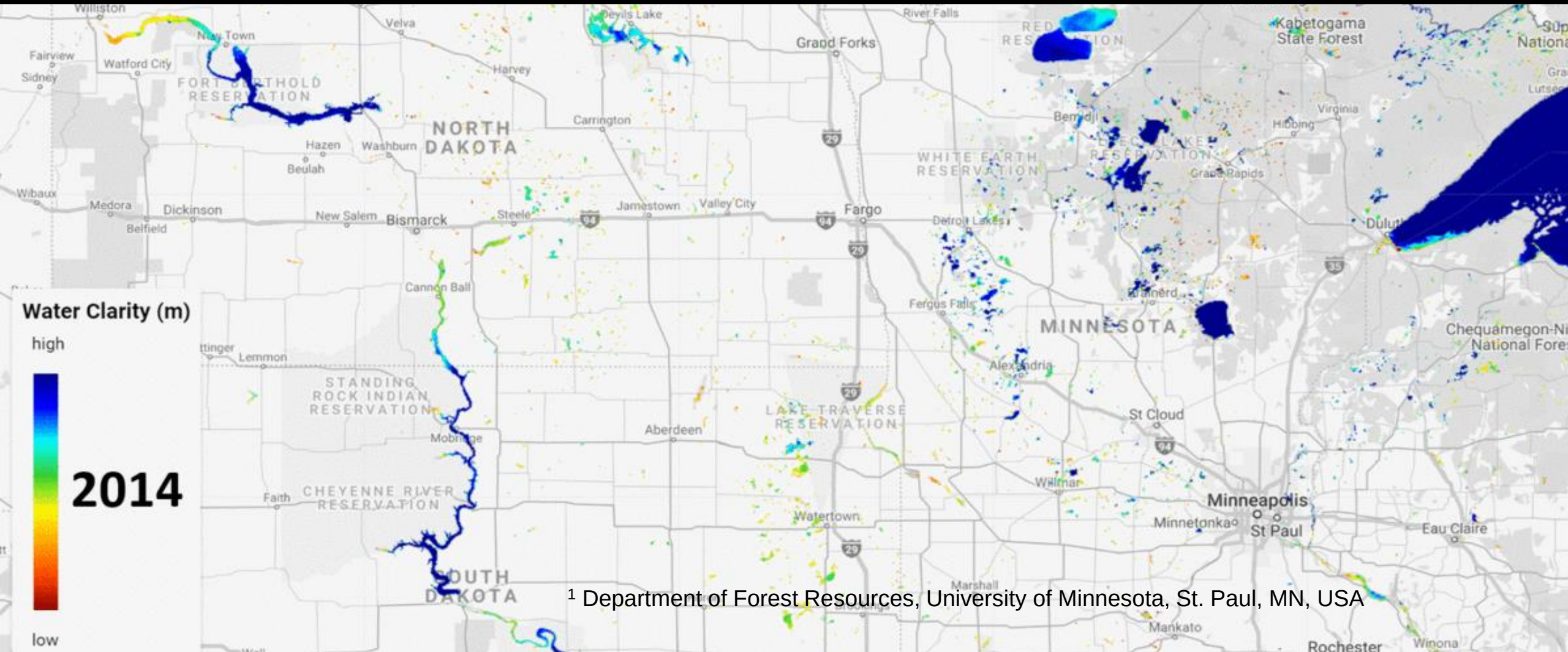
Leif Olmanson Ph.D., olman002@umn.edu



[1] Department of Forest Resources, University of Minnesota, St. Paul, MN, USA

2013 Land Cover

Northern Minnesota Wetlands

Red River Valley

Northern Lakes and Forest

Northern Glaciated Plains

North Central Hardwood Forest

Western Corn Belt Plains

Classes
- Emergent Wetlands
- Forested/Shrub Wetlands
- Open Water
- Extraction
- Coniferous Forest
- Deciduous Forest
- Mixed Forest
- Grassland/Managed Grass
- Hay/Pastures
- Row Crops

1% Impervious 100 %

Minnesota Landsat Water Clarity 2015

RRV
215 lakes

NMW
215 lakes

NLF
5,671 lakes

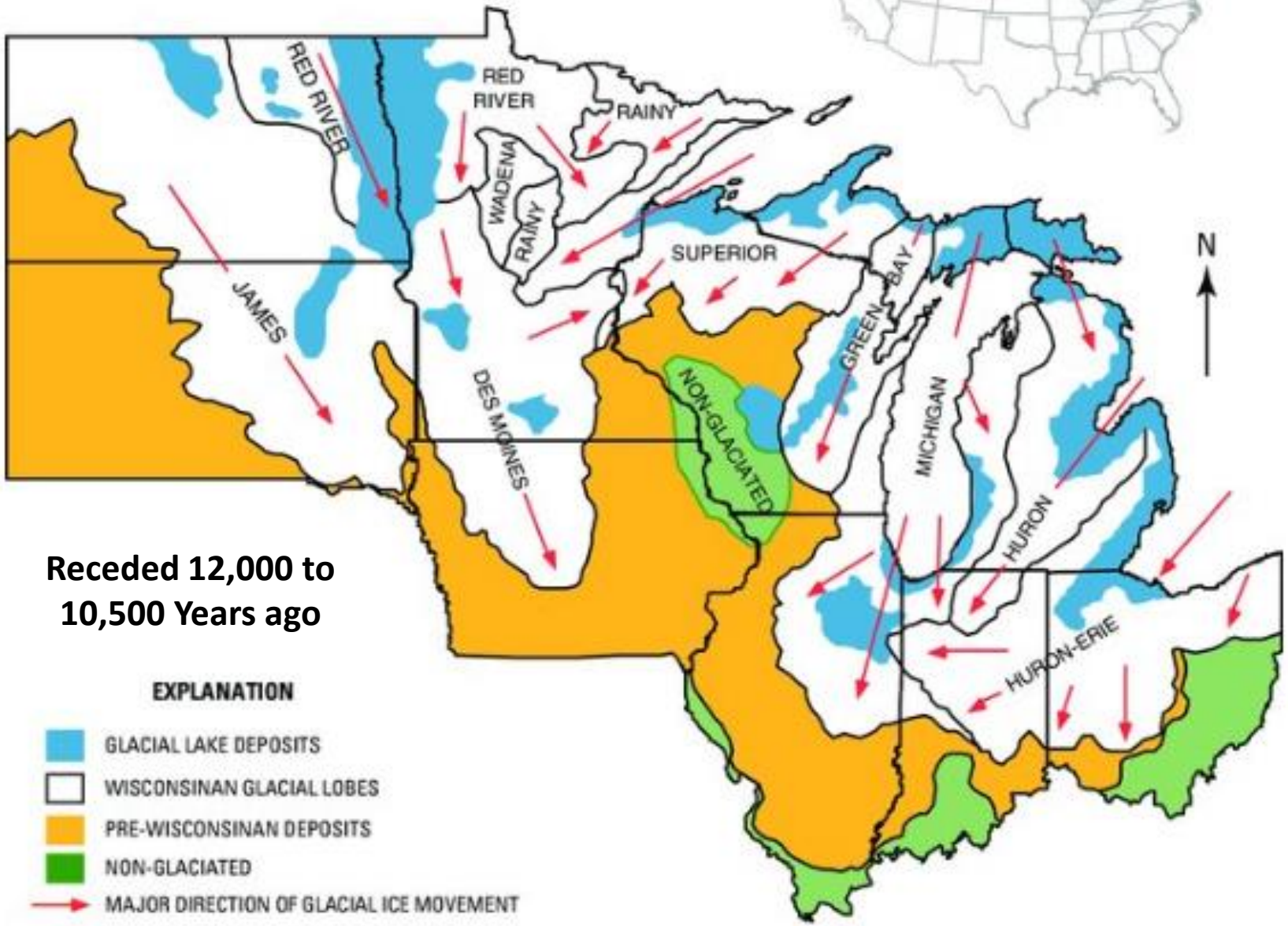
NGP
690 lakes

NCHF
4,466 lakes

WCBP
835 lakes

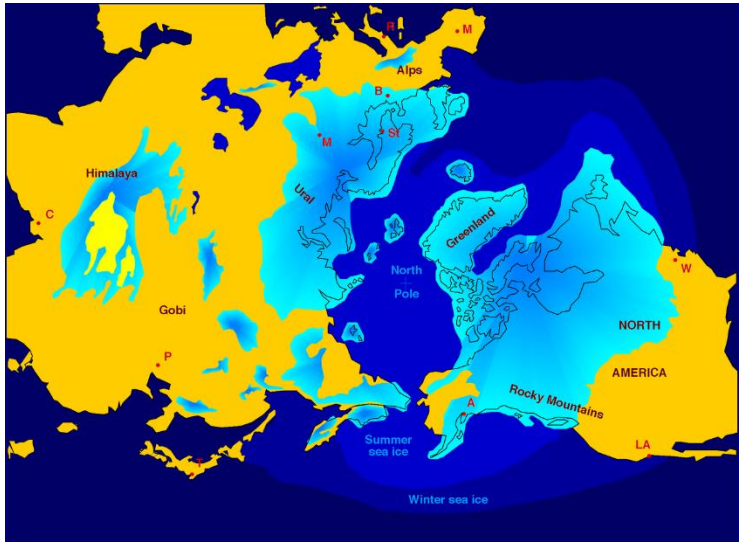
Water Clarity
SD(m)
- >4
- 2-4
- 1-2
- 0.5-1
- <0.5

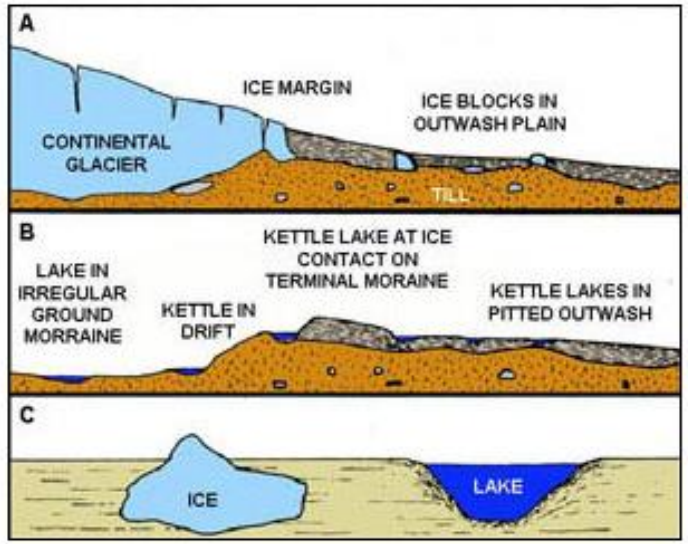
Generalized glacial geologic map of the upper Midwestern USA



Receded 12,000 to 10,500 Years ago

Northern Hemisphere glaciation during the last ice ages.





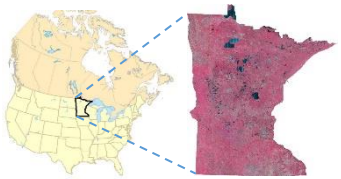
A. A glacier covers all the land in its path.

B. After the glacier recedes the landscape is irrevocably altered.

C. Even small amounts of underground ice can form a lake upon melting.

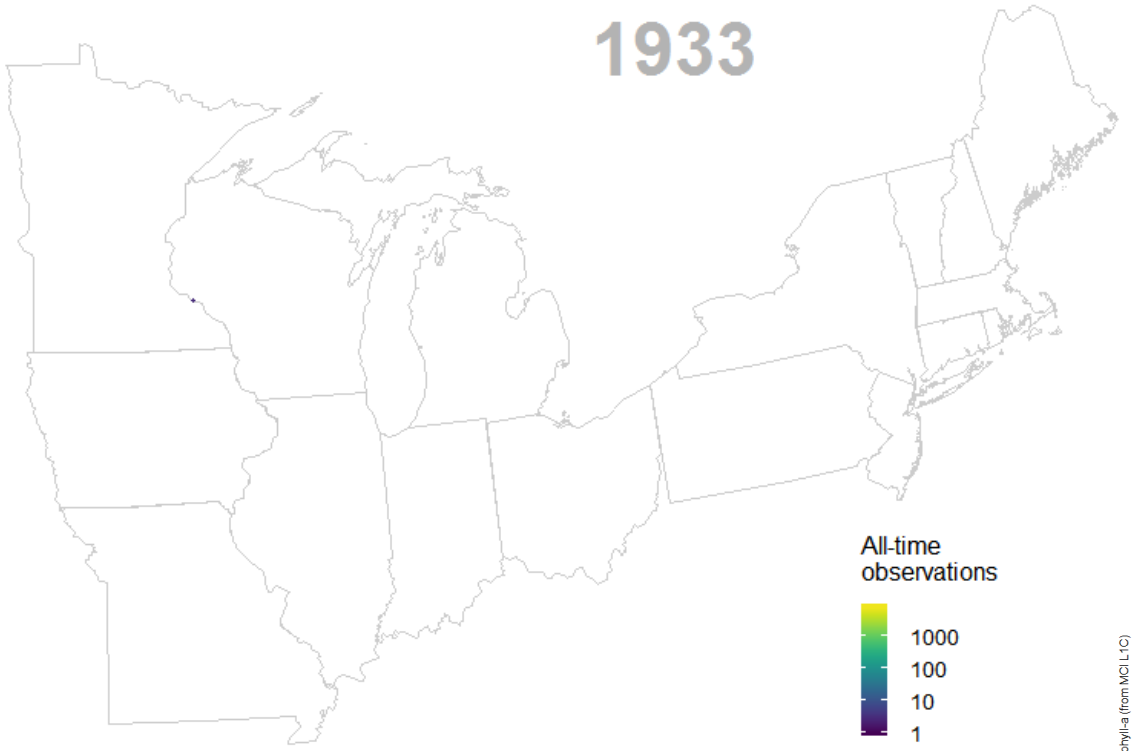
Water Quality Observations Through Time in LAGOS-NE By Nicole Smith

Posted October 27, 2017

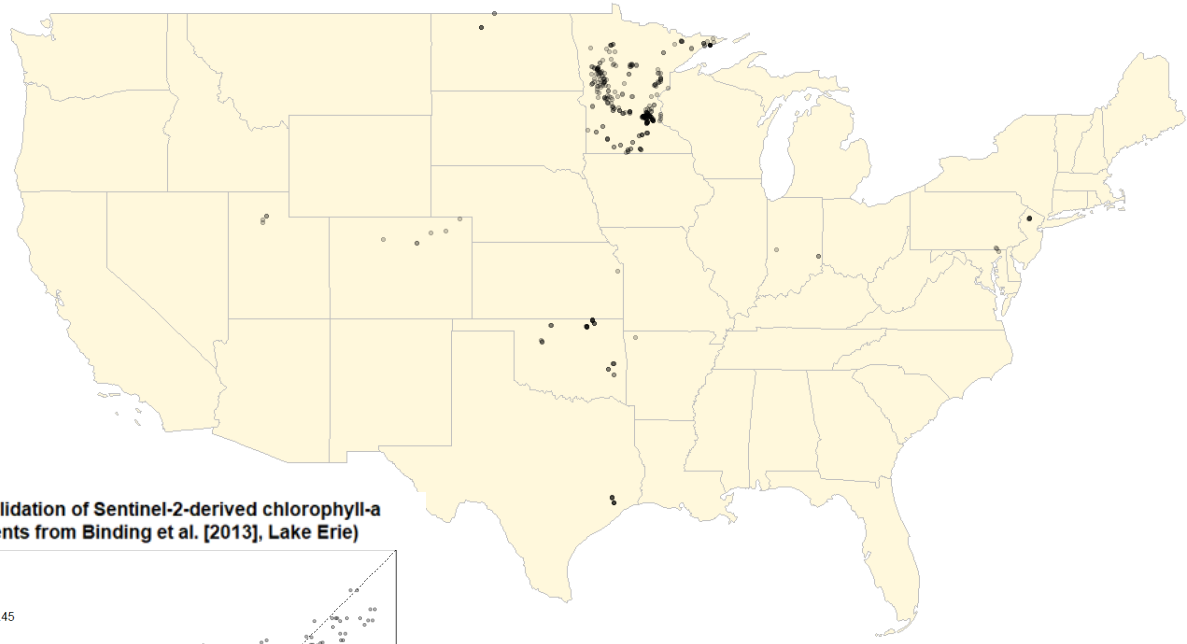


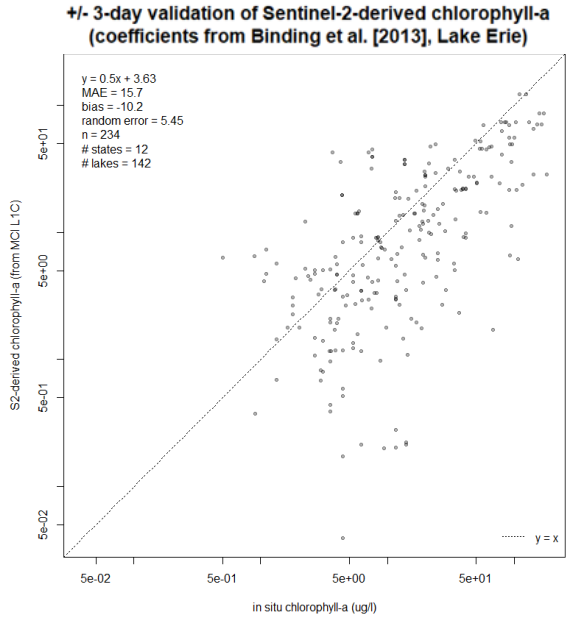
Cyanobacteria Assessment Network

Lake water quality field observations in LAGOS-NE



Available chlorophyll data ± 3 days of Sentinel-2 imagery





Sentinel-2 Maximum Chlorophyll Index (MCI)

Salls, Schaeffer, Keith, Urquhart, Amanatides. *In Prep.* A validation of the Sentinel-2 Maximum Chlorophyll Index in US lakes.

Publicly accessible lake water quality and ecological context data for the US

https://lagoslakes.org/2017/10/27/water-quality-observations-through-time-in-lagos-ne-by-nicole-smith/

We interviewed 111 stakeholders in USA and Canada

The ability to measure and evaluate these water quality repair projects is not where it needs to be!!!!!!!

Pressure to develop lake shore exists to increase property taxes

The right system is to measure, protect, repair and continuously monitor

It is less expensive to protect a lake on the way to impairment then to repair a lake after impairment

Adaptive management is needed to maintain and improve water quality – continuous monitoring is important

Being asked to do more and more with less and less

Don't really have ongoing data to measure performance - big gaps in data

Remote sensing can fill gaps and focus areas to monitor

Need more data to make better decisions-solutions

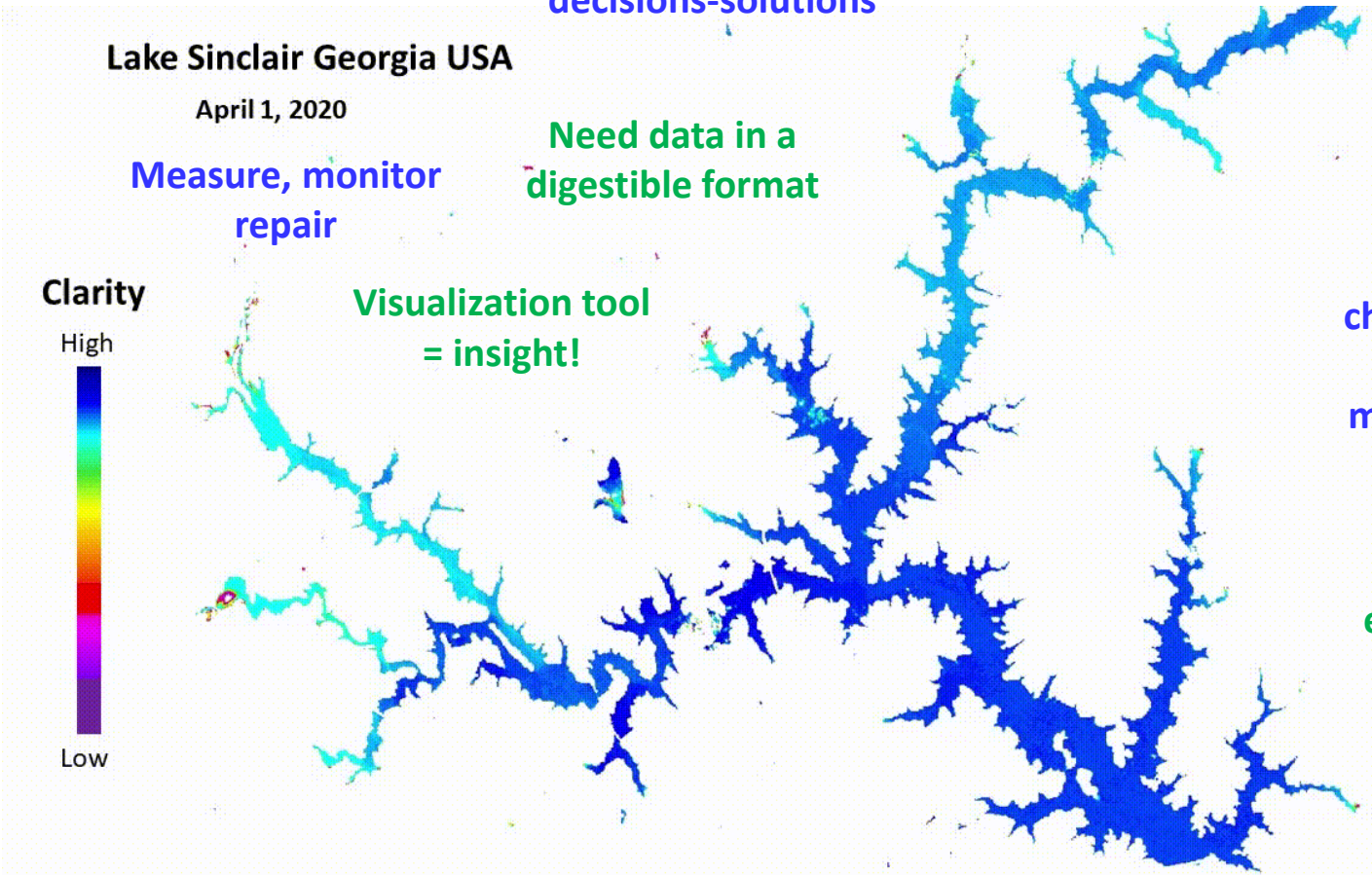
The science is easy, but the people part is hard

Historically un-developable land now developed

Do not have great baseline data

Report how money is spent, not environmental outcomes

Changing climate effects are extremely difficult to manage



Measure, monitor repair

Need data in a digestible format

Visualization tool = insight!

YES, all kinds of things can be reported without going to a certified lab

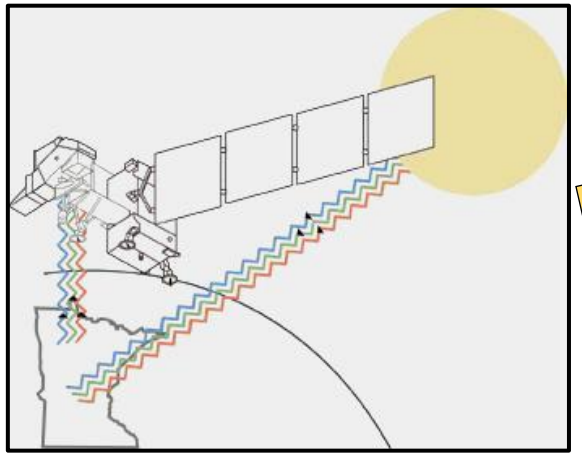
Having real time chlorophyll data would be really helpful for managing lakes, river and streams

Struggling with the expectations of politicians and worried we will not have enough stories of benefits for ongoing funding

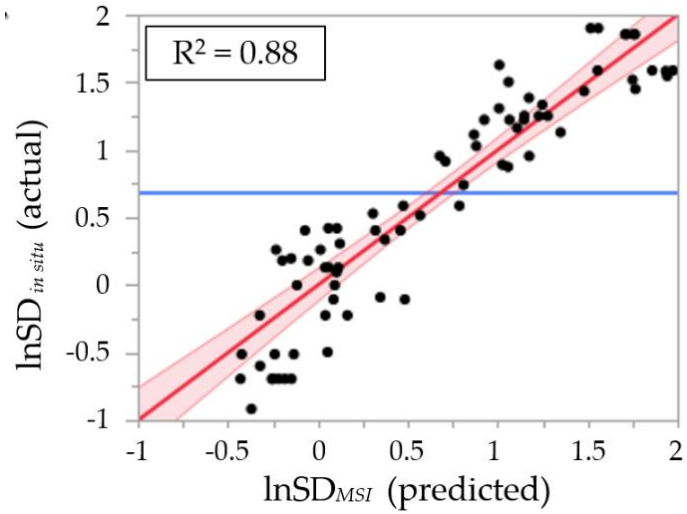
What we did

1. Citizens measure water clarity (Secchi depth)

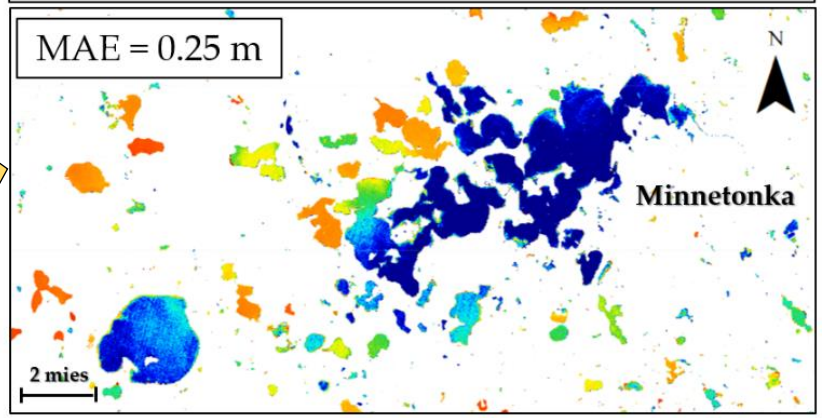
2. Near the same time satellites collect imagery



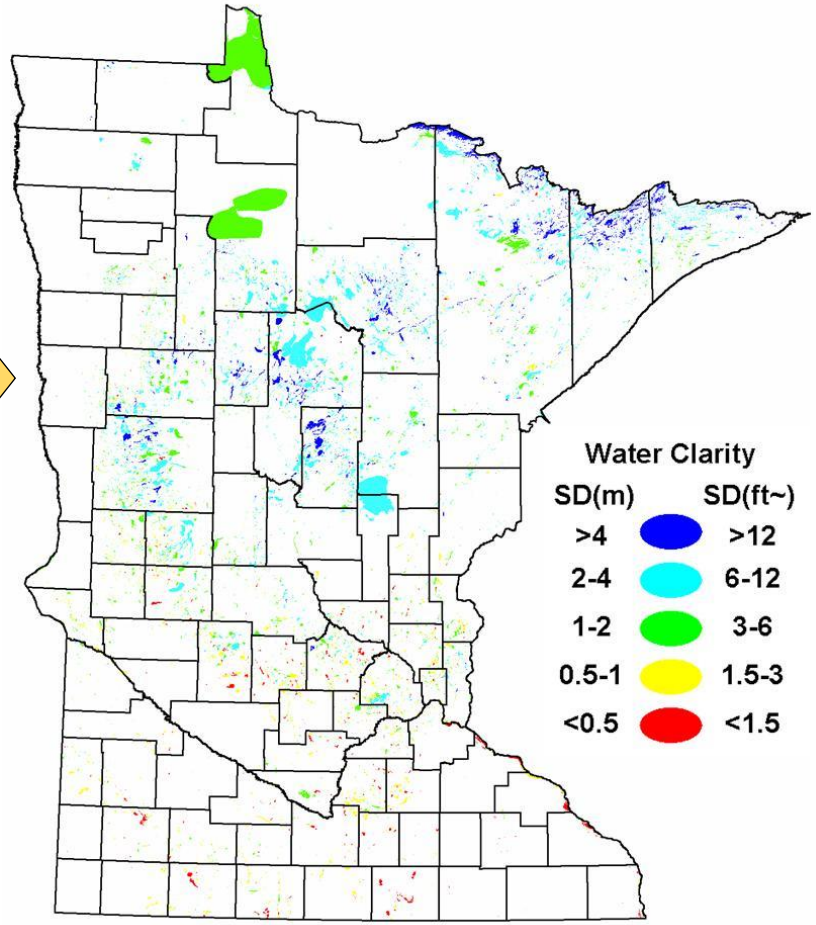
3. Build statistical models



$$SD_{MSI} = \exp(a(R_{rs}(B2) / R_{rs}(B4)) + b(R_{rs}(B5) \times R_{rs}(B4)) + c)$$



4. Generate statewide water clarity maps



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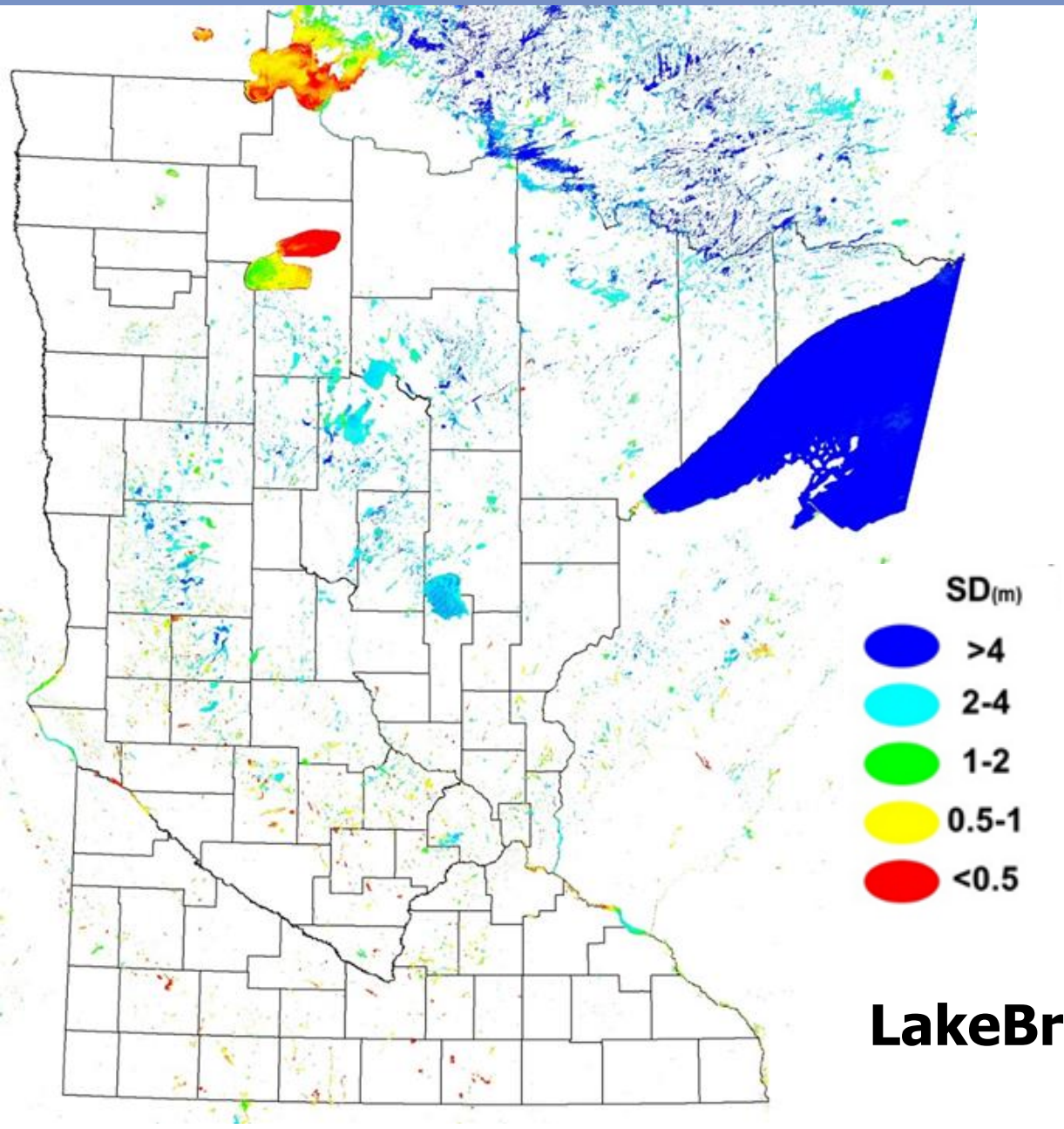


Prior Accomplishments:

HIGHLIGHTS

•9 statewide water clarity assessments 1975 – 2015 for 10,000+ Minnesota lakes ~5-year intervals using empirical methods

• Analysis of spatial and temporal trends and causative factor

•LakeBrowser: Est. 2002 An online resource for thousands of unique monthly visitors

• Now updated to include monthly 2017 through 2022… clarity, chlorophyll and CDOM with an automated system

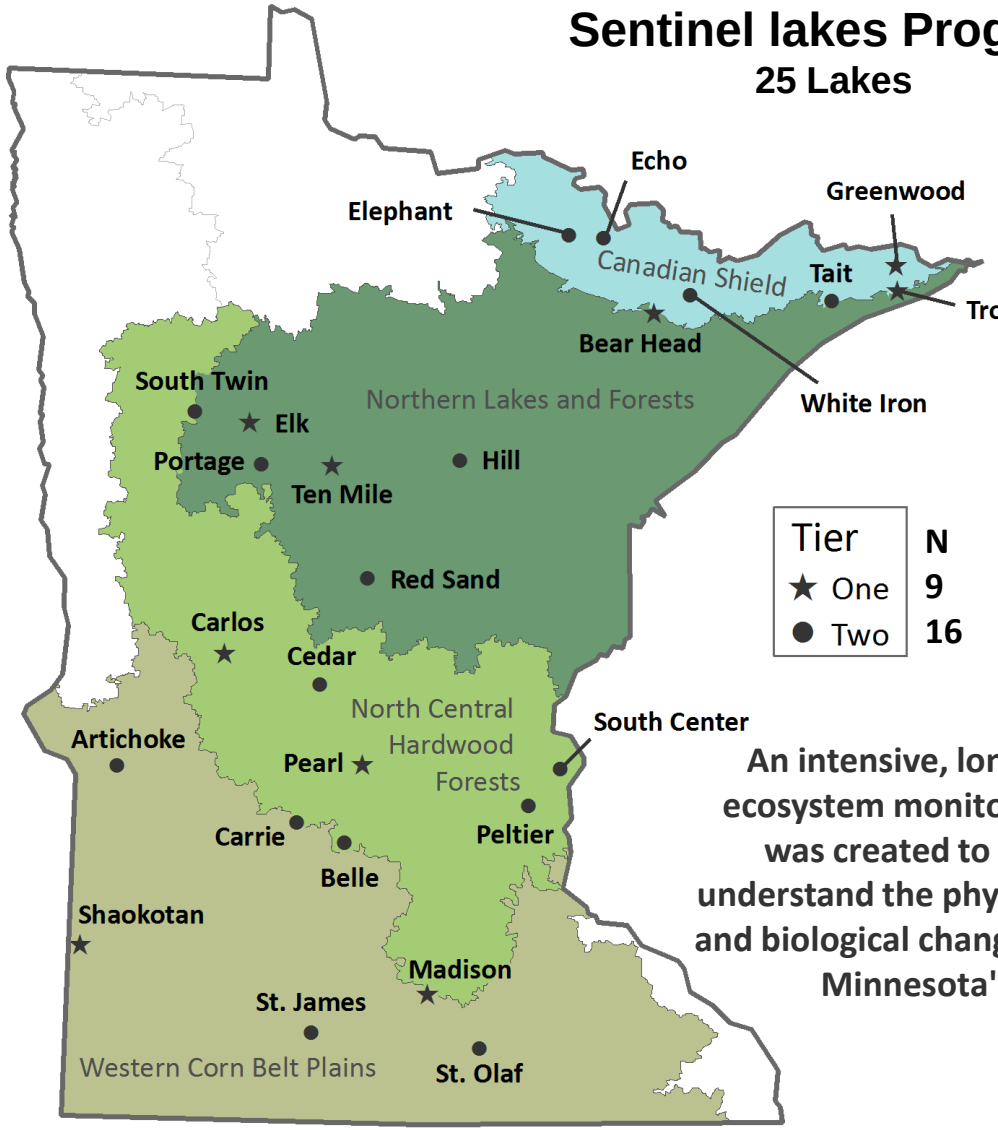
LakeBrowser https://lakes.rs.umn.edu/

MINNESOTA POLLUTION CONTROL AGENCY

DEPARTMENT OF NATURAL RESOURCES

Sentinel lakes Program

25 Lakes



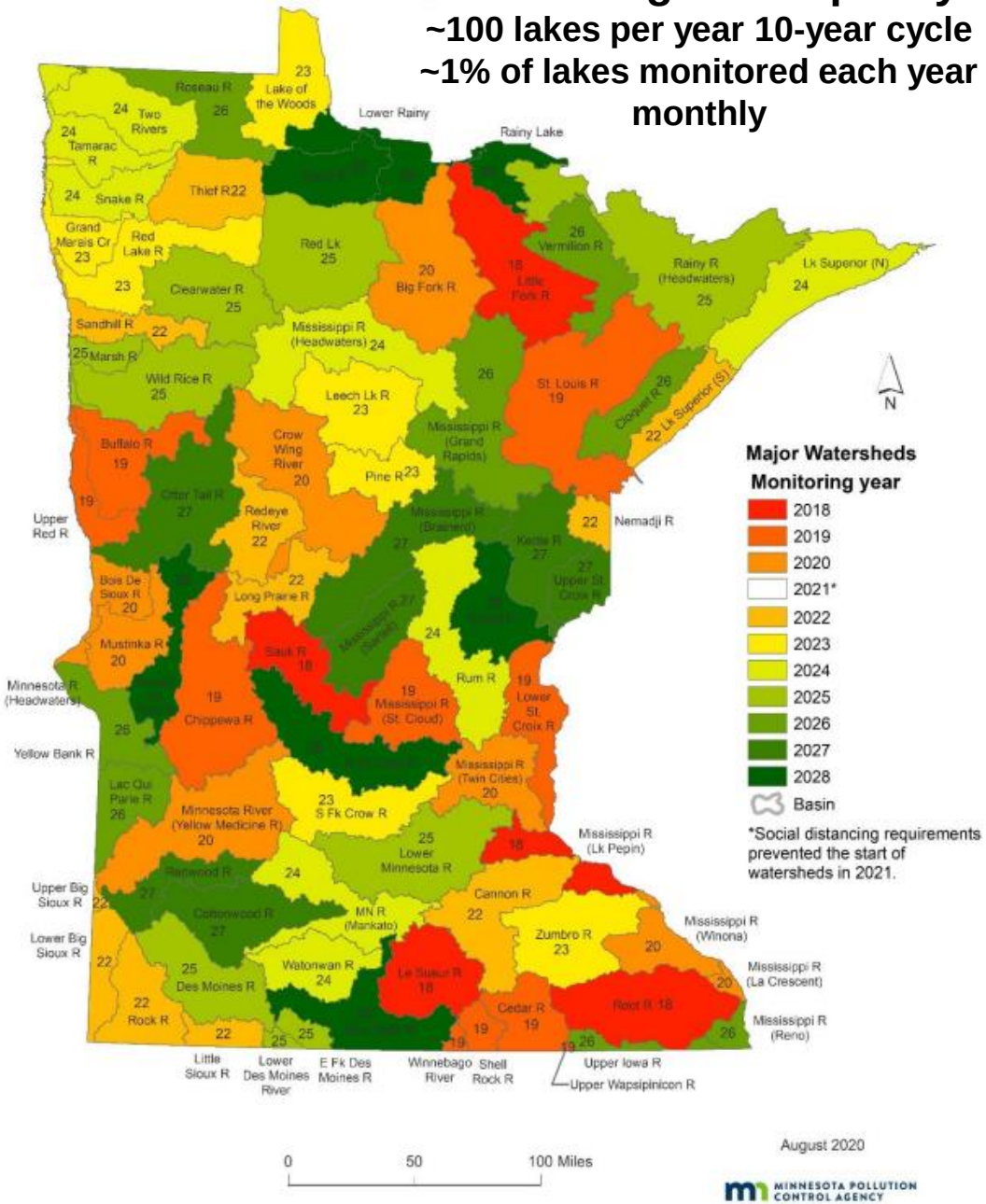
Tier	N
★ One	9
● Two	16

Macroinvertebrates
Plants
Phytoplankton
Water chemistry
Zooplankton

An intensive, long-term lake ecosystem monitoring program was created to detect and understand the physical, chemical, and biological changes occurring in Minnesota's lakes.

Watershed approach to monitoring water quality

~100 lakes per year 10-year cycle
~1% of lakes monitored each year monthly



Volunteer Water Monitoring Program

Minnesota

- **1973** University of Minnesota's Joseph Shapiro started Citizen Lake Monitoring Program (**CLMP**)
- **1978** Transferred to Minnesota Pollution Control Agency (MPCA)
  - Training, picking up and analyzing samples, data management, oversight-validation,

The CLMP is a cooperative program that combines the **technical resources of the MPCA** and the efforts of **citizen volunteers** statewide who collect water quality data on their lakes. The participation of citizen volunteer monitors in the CLMP effectively increases the monitoring capabilities of the MPCA. The CLMP is a **cost-effective** way to obtain good, basic, water quality data on many of Minnesota's lakes. For many of them, CLMP data is the only water quality information available.

Lake, river, and stream associations 1,200 volunteers on over 1,000 lakes

- **Weekly** transparency measurements using a Secchi disk 1000 lakes
- Enhanced Lake Monitoring Program (**monthly**) 2 to 4 lakes
  - Phosphorus
  - Nitrogen
  - Chlorophyll
  - Clarity

- **Metropolitan Council** - Citizen-Assisted Monitoring Program (CAMP)
  - Training, picking up and analyzing samples, data management, oversight-validation, **sponsors pay to be included in the program**

- Metro area is well monitored while outstate is less monitored but **RMB Labs** provides a similar service usually organized through COLAs

Wisconsin Citizen Lake Monitoring Network (CLMN)

The Citizen Lake Monitoring Network (CLMN) 1000+ citizen volunteers statewide

- collect high-quality lake monitoring data, educate and empower our volunteers, and share our data to inform lake management.
- CLMN staff provide the necessary equipment and training to conduct these monitoring activities.
- Volunteers provide their time, expertise, energy
- The information gathered by these monitoring programs is used by Wisconsin Department of Natural Resources and university biologists and researchers, UW-Extension, and other interested individuals.

DNR monitors about 100 lakes and the citizens monitor about 900 lakes Citizen monitoring is mostly Secchi Disk while about 400 to 500 collect water samples.

Wisconsin DNR was able to show that volunteer collected data is as high quality as what DNR collects.

What do CLMN volunteers monitor?

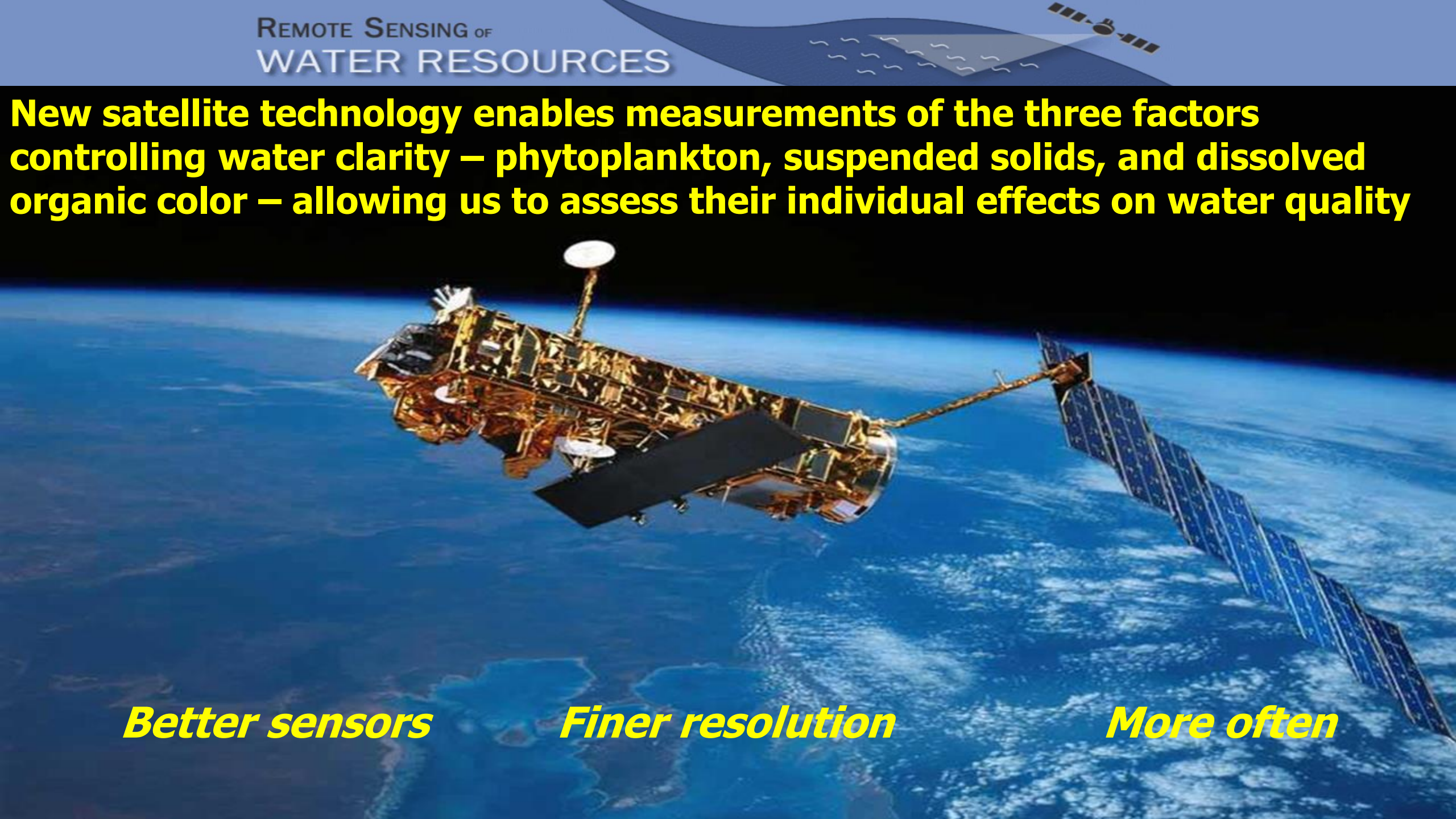
phosphorus levels, chlorophyll-A concentrations, water clarity, and a temperature profile from the top to the bottom of the lake.

This type of monitoring is done four times per year,

https://dnr.wisconsin.gov/topic/lakes/clmn

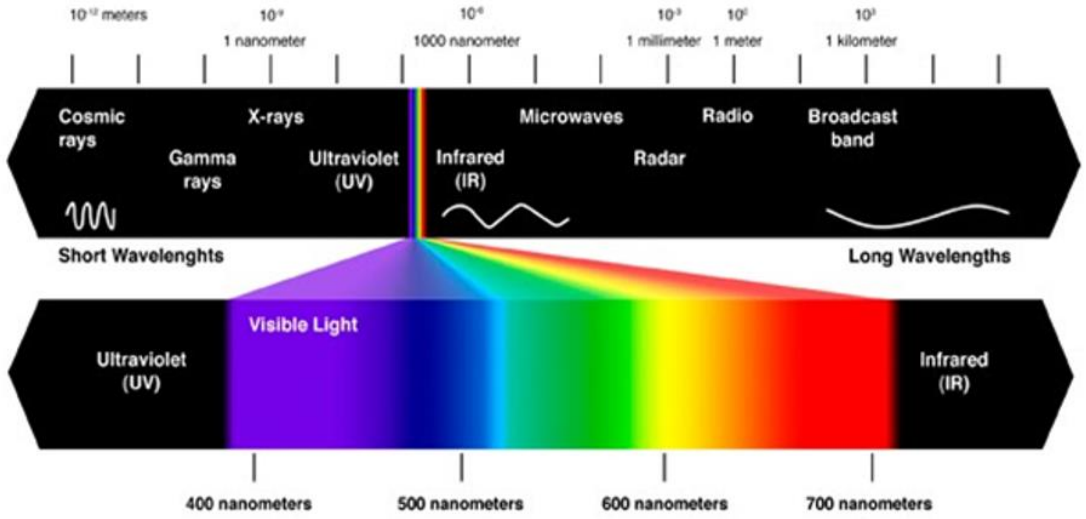
Remote Sensing of Water Resources

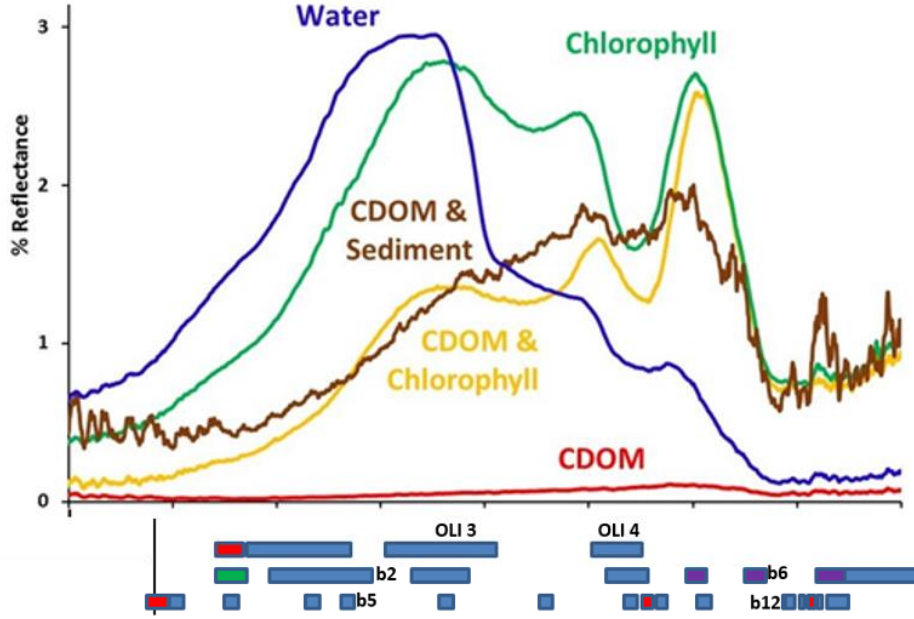
New satellite technology enables measurements of the three factors controlling water clarity – phytoplankton, suspended solids, and dissolved organic color – allowing us to assess their individual effects on water quality

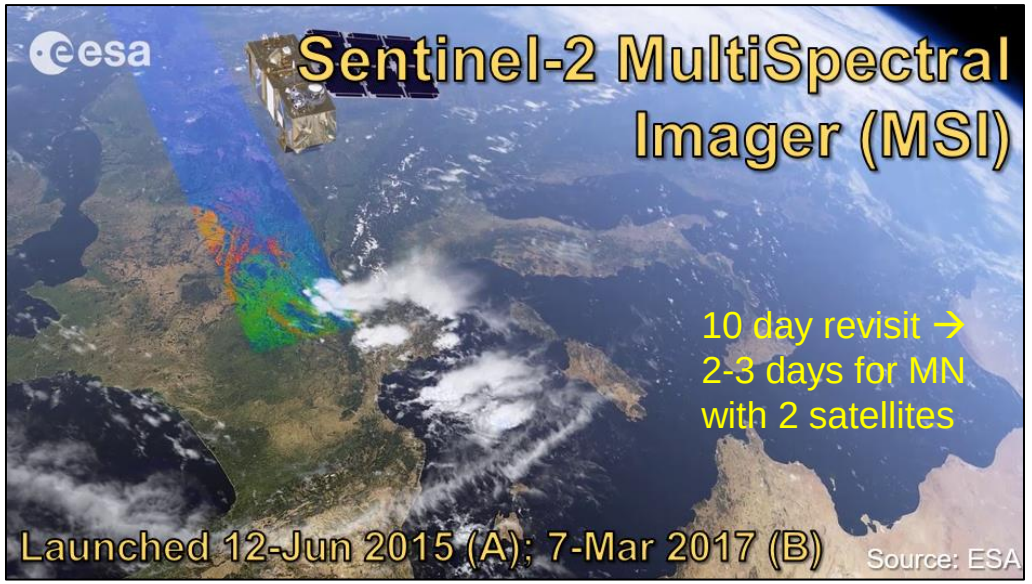


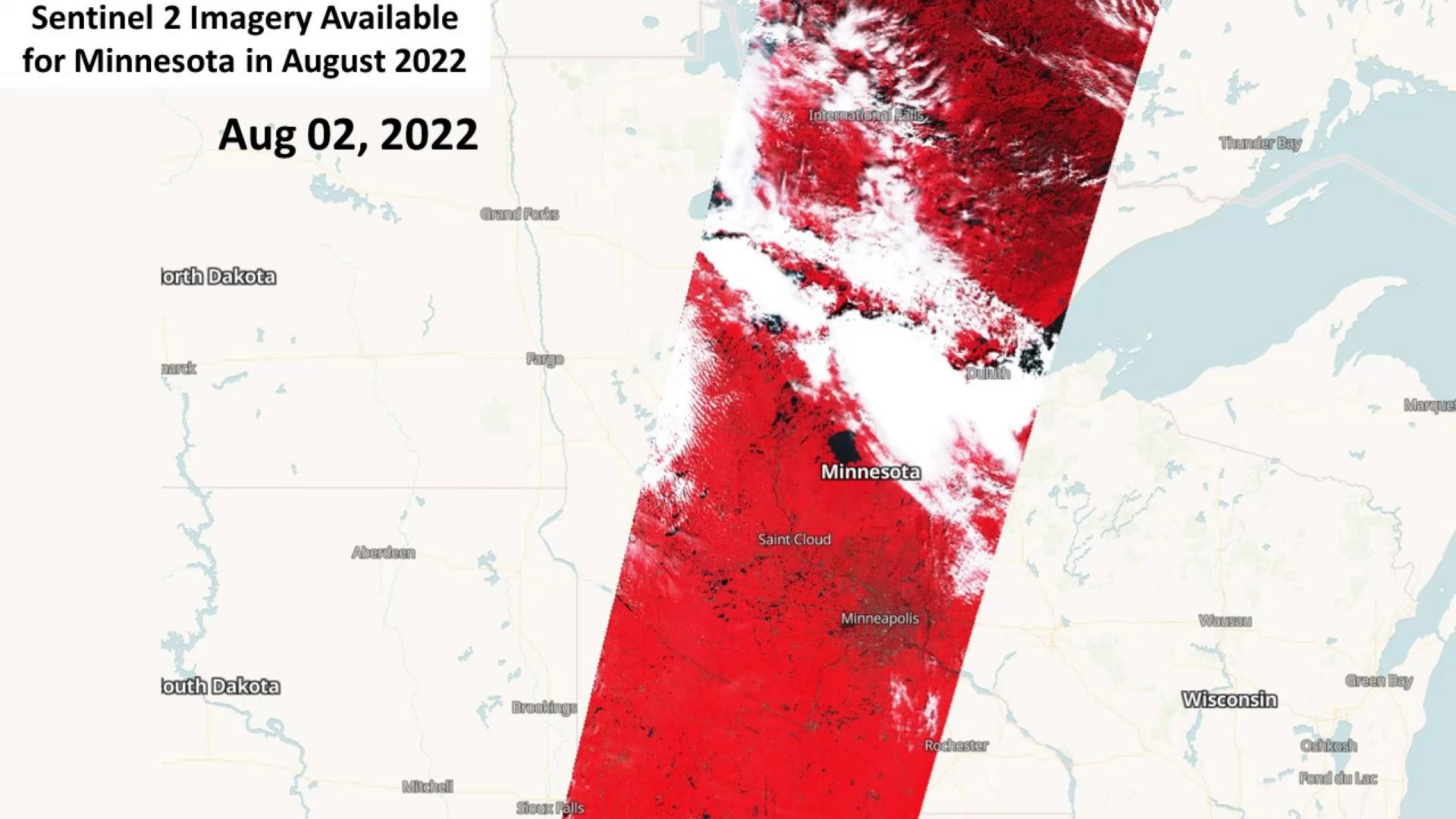
Better sensors ***Finer resolution*** ***More often***

Measurements have been mostly limited to water clarity due to inherent Landsat sensor spectral band configurations





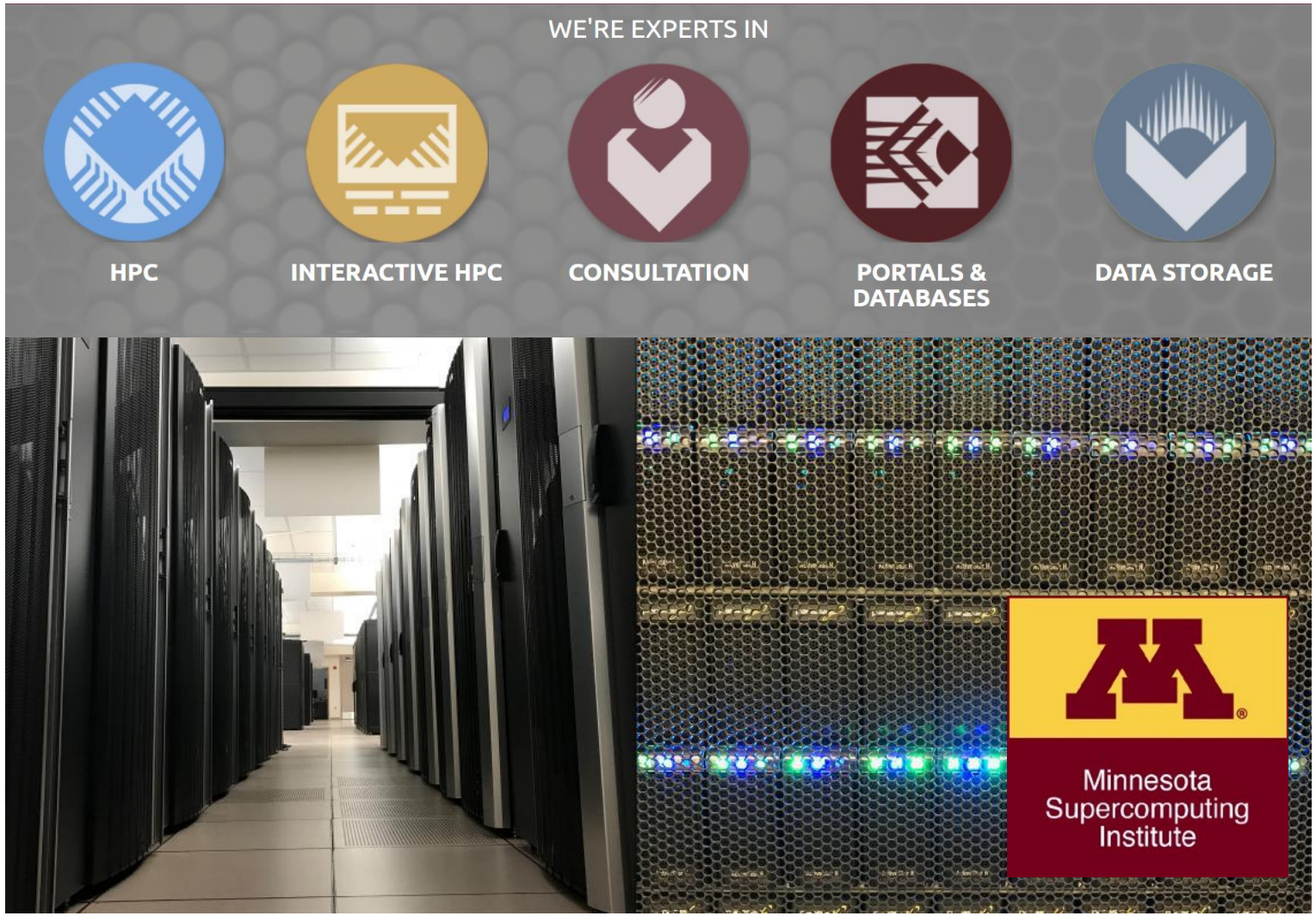



Sentinel 2 Imagery Available
for Minnesota in August 2022
Aug 02, 2022
International Falls
Thunder Bay
Grand Forks
orth Dakota
narck
Fargo
Duluth
Minnesota
Saint Cloud
Aberdeen
Minneapolis
Wausau
outh Dakota
Brookings
Green Bay
Wisconsin
Rochester
Oshkosh
Fond du Lac
Mitchell
Sioux Falls

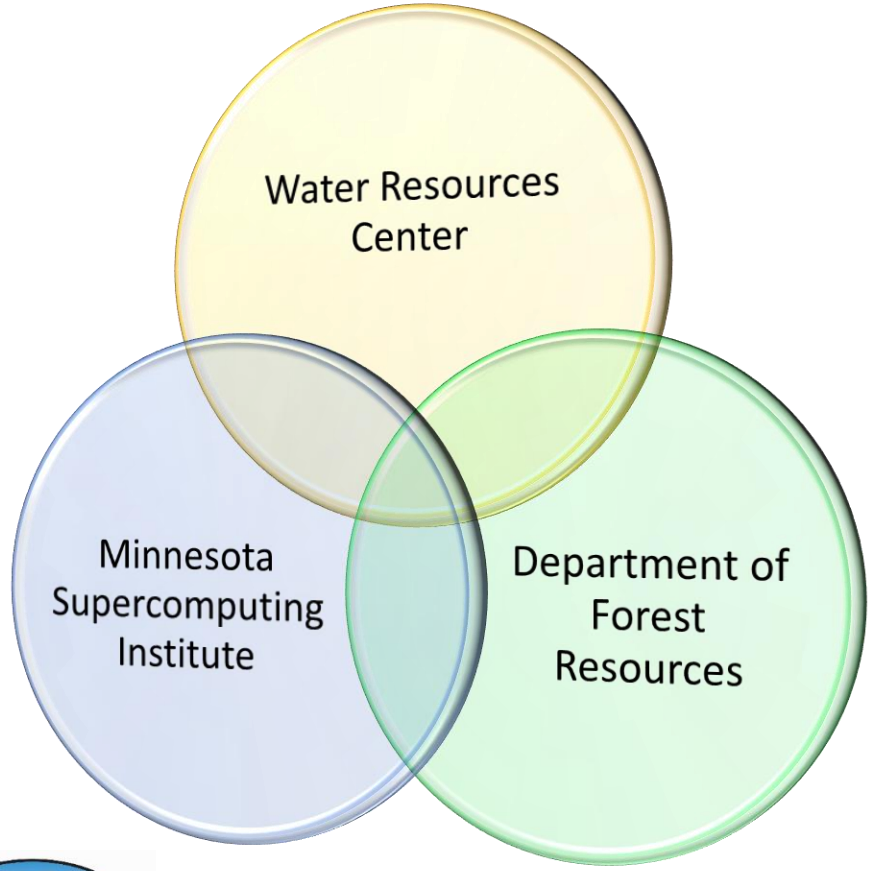
Landsat 8 & 9 Imagery Available for Minnesota in August 2022

Aug 01, 2022

High Performance Computing



Collaborative Effort



ENVIRONMENT AND NATURAL RESOURCES TRUST FUND

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Opportunity: Near real-time water quality monitoring

Landsat 8
Landsat 9 Sep 2021
Sentinel-2
Sentinel-3

esa
European Space Agency

opernicus
Europe's eyes on Earth

Minnesota Supercomputing Institute (MSI) high performance computing systems

Atmospheric Correction

Water Mask

Cloud Mask

Smoke Mask

Prepare images using new automated methods

UNIVERSITY OF MINNESOTA
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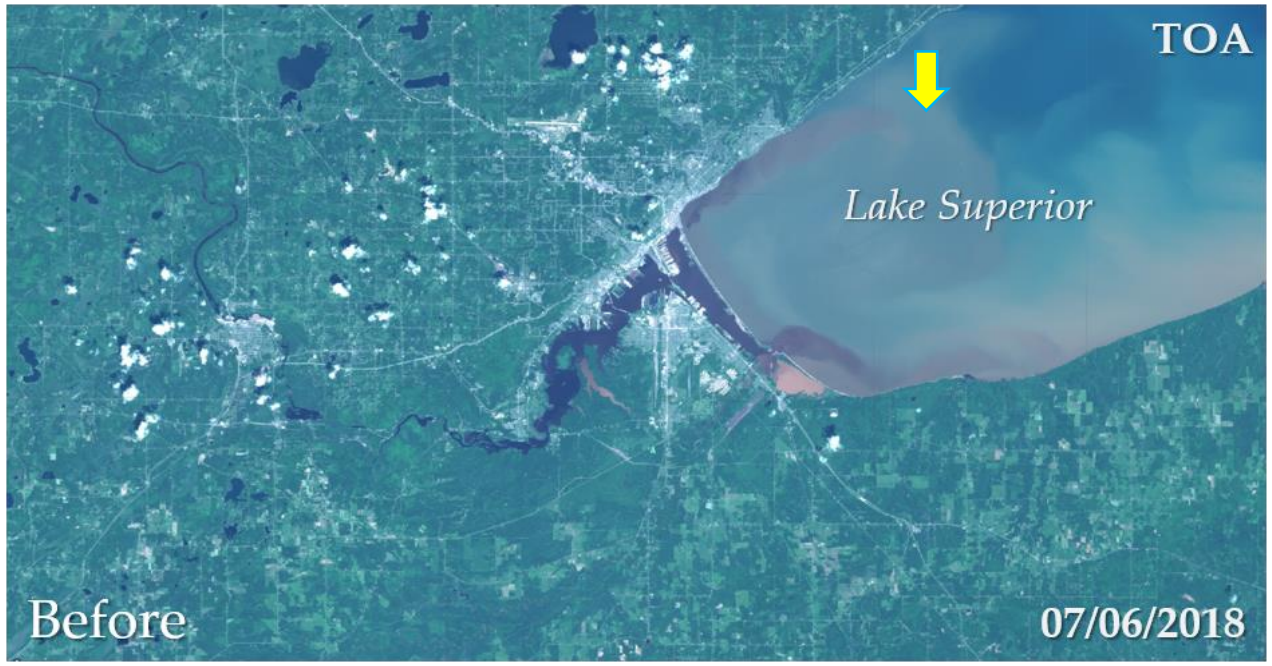
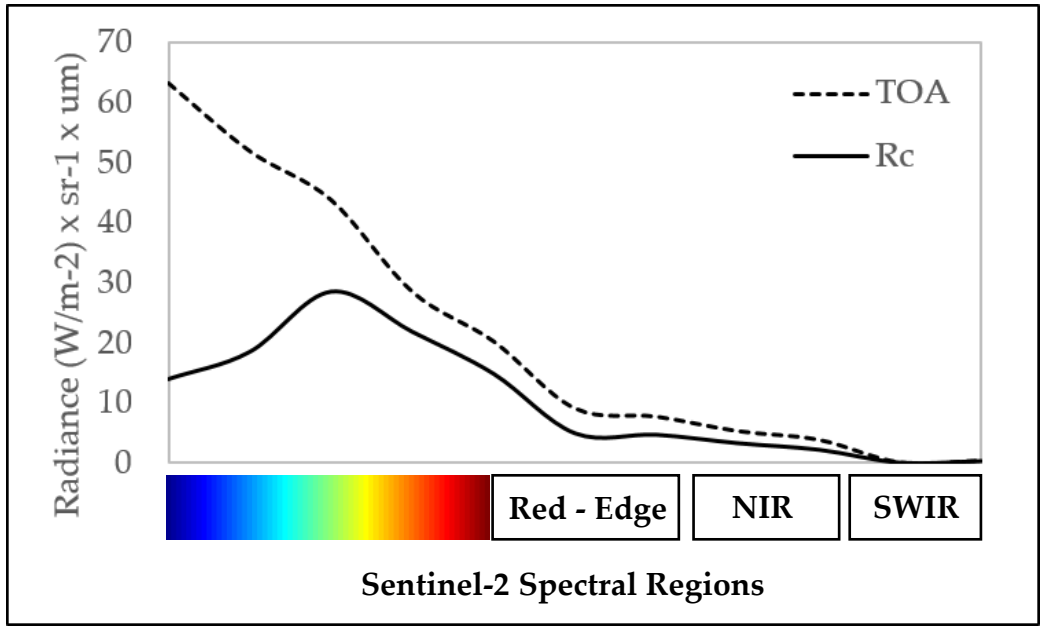
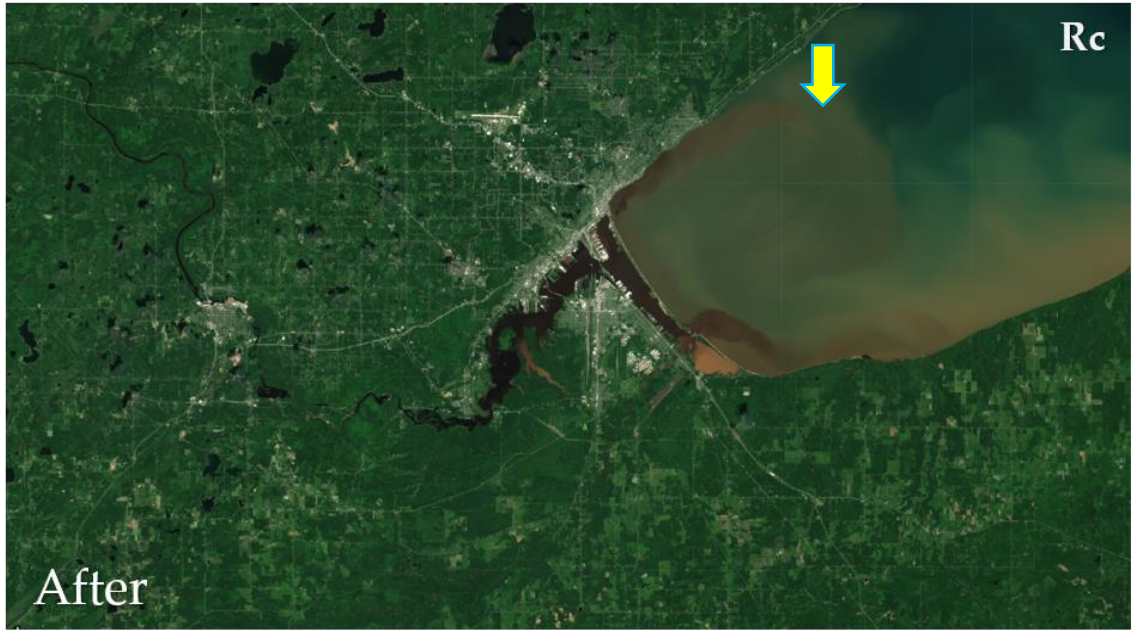
Atmospheric Correction

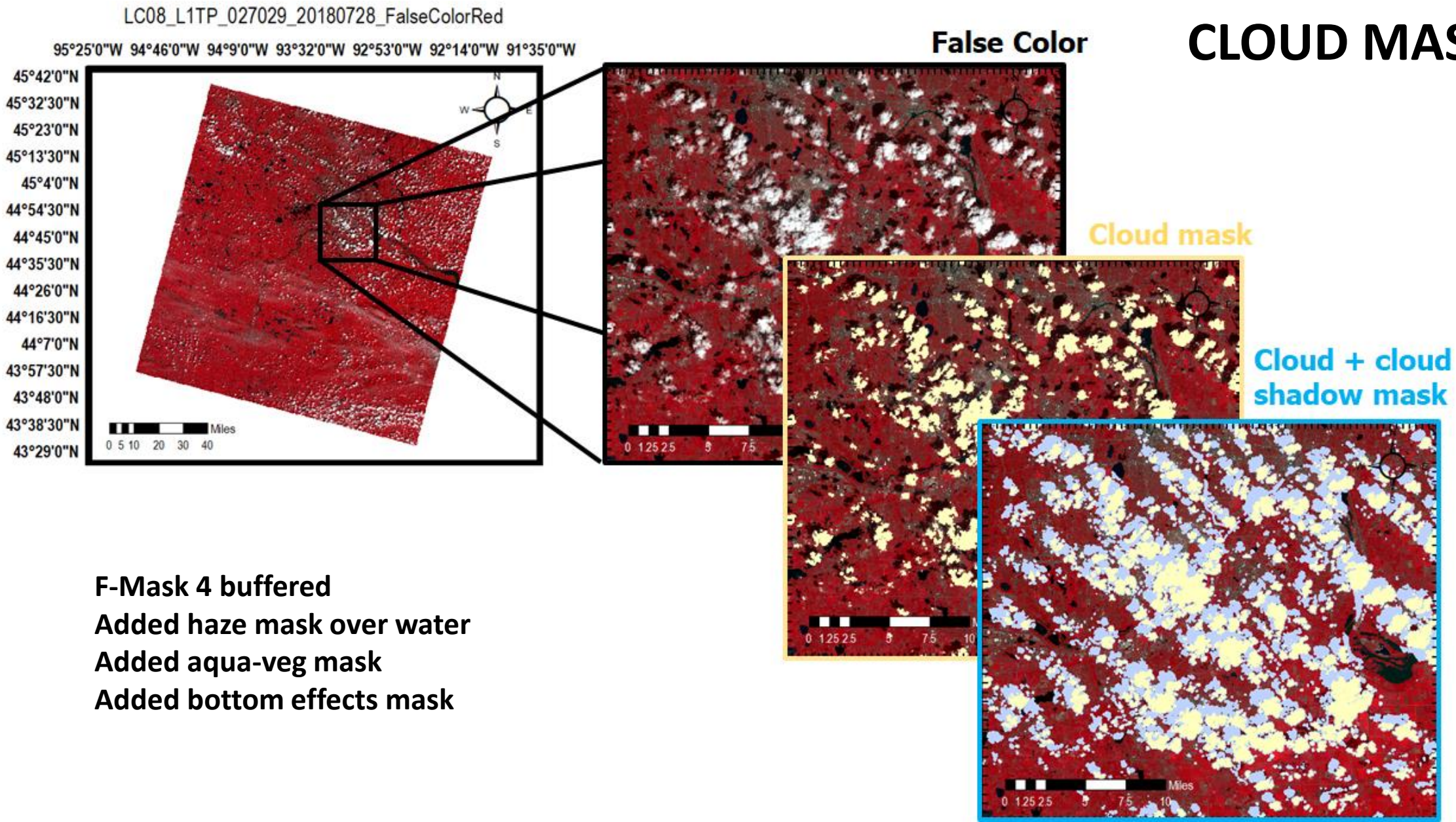






The molecular scattering signal due to ozone and Rayleigh effects in the atmosphere may constitute as much as 90% of the total signal for spectral bands from the blue to red (typically 443 to 670 nm)

CLOUD MASKING

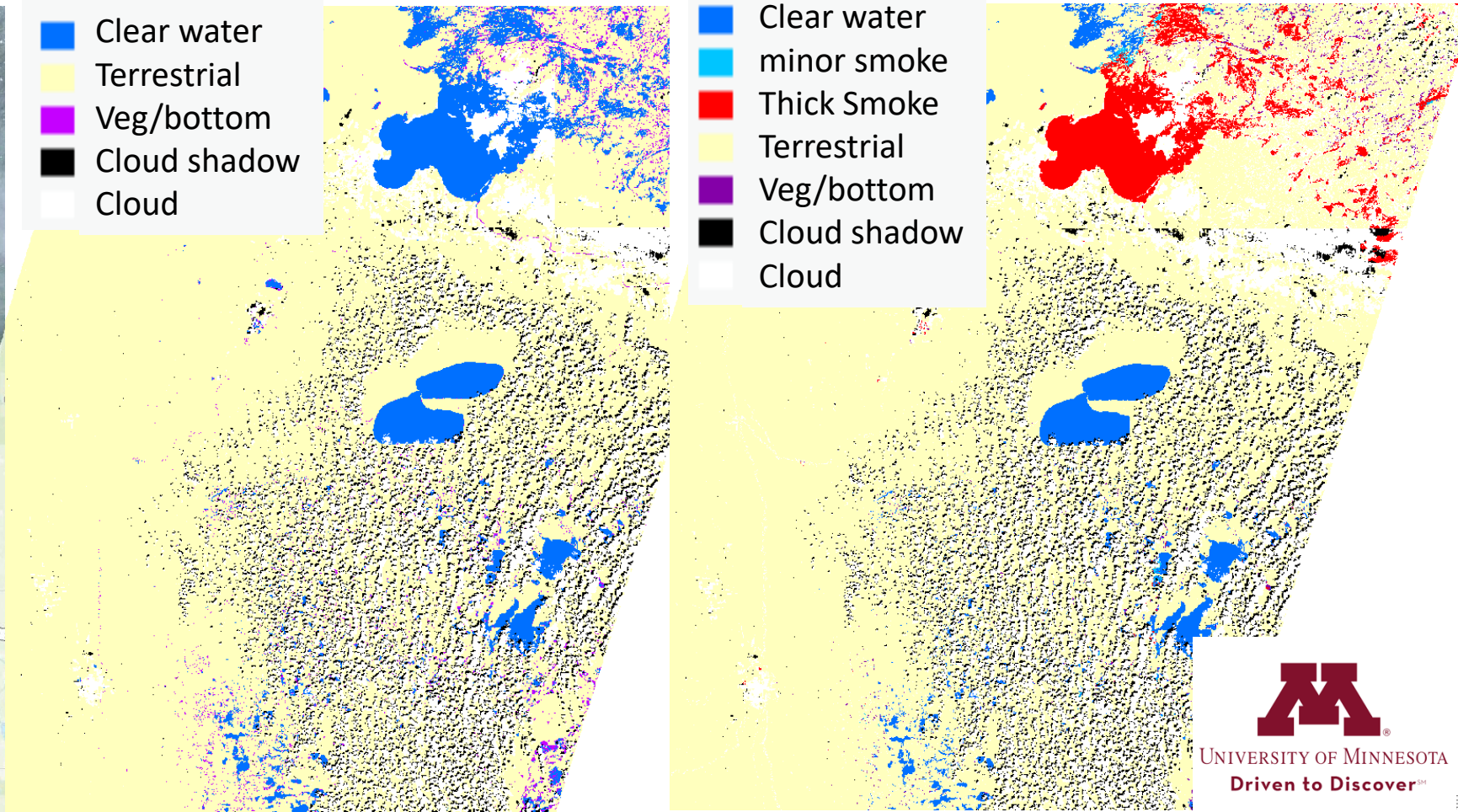


F-Mask 4 buffered
Added haze mask over water
Added aqua-veg mask
Added bottom effects mask

SMOKE MASKING

True color imagery

Cloud/shadow/haze/aqua_veg mask



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Landsat 8
Landsat 9 Sep 2021
Sentinel-2
Sentinel-3

esa
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Smoke Mask

Prepare images using new automated methods

Chlorophyll

Water clarity

CDOM

Suspended Solids

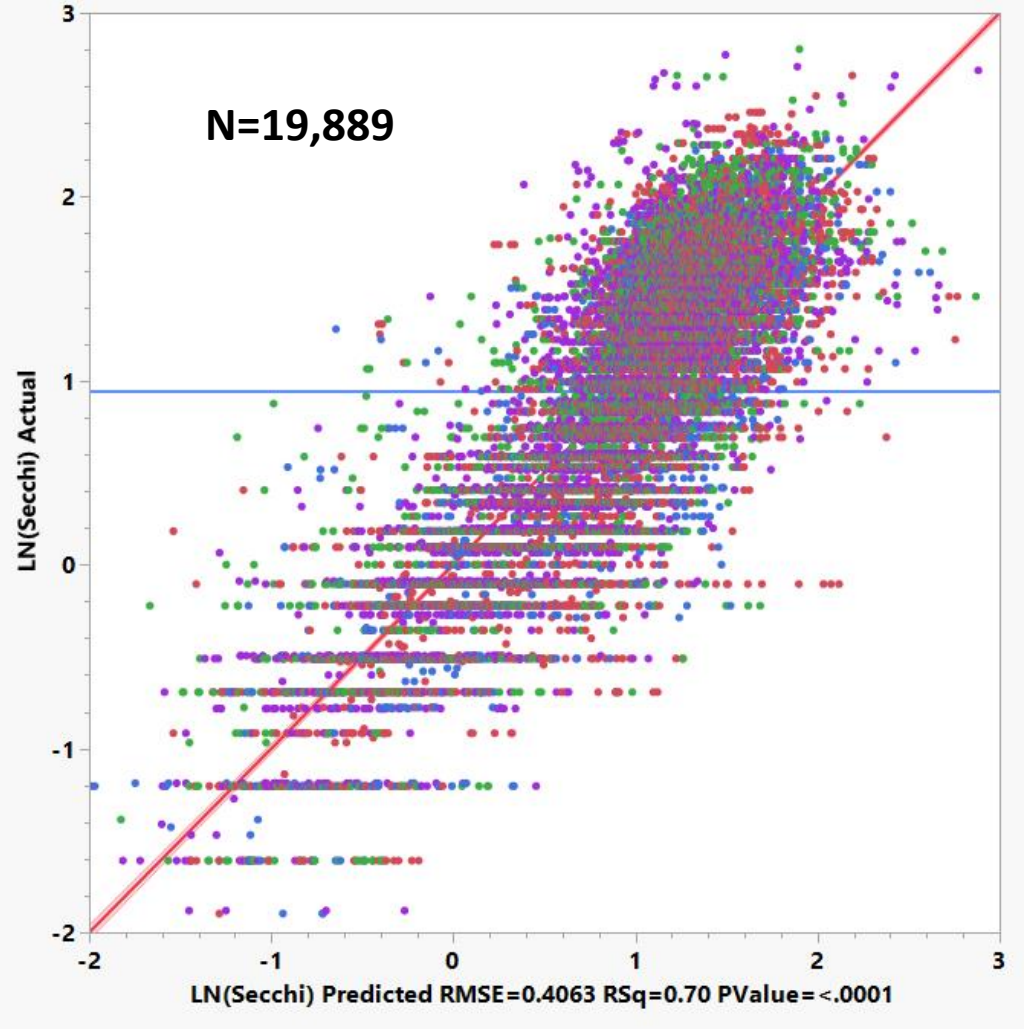
Apply water quality models

Water Quality Models

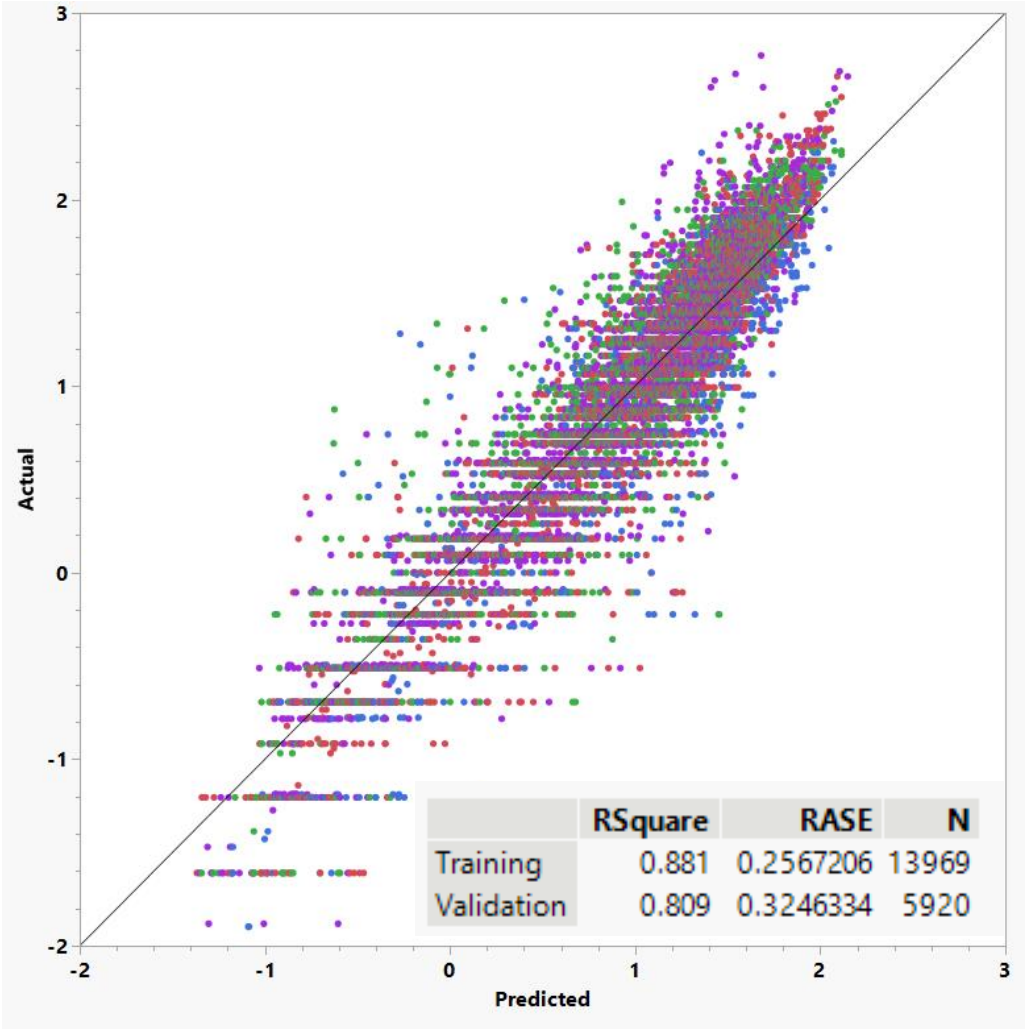
Secchi Disk Transparency

2017 - 2020 in situ match-ups within one day

Multilinear Regression



Machine Learning

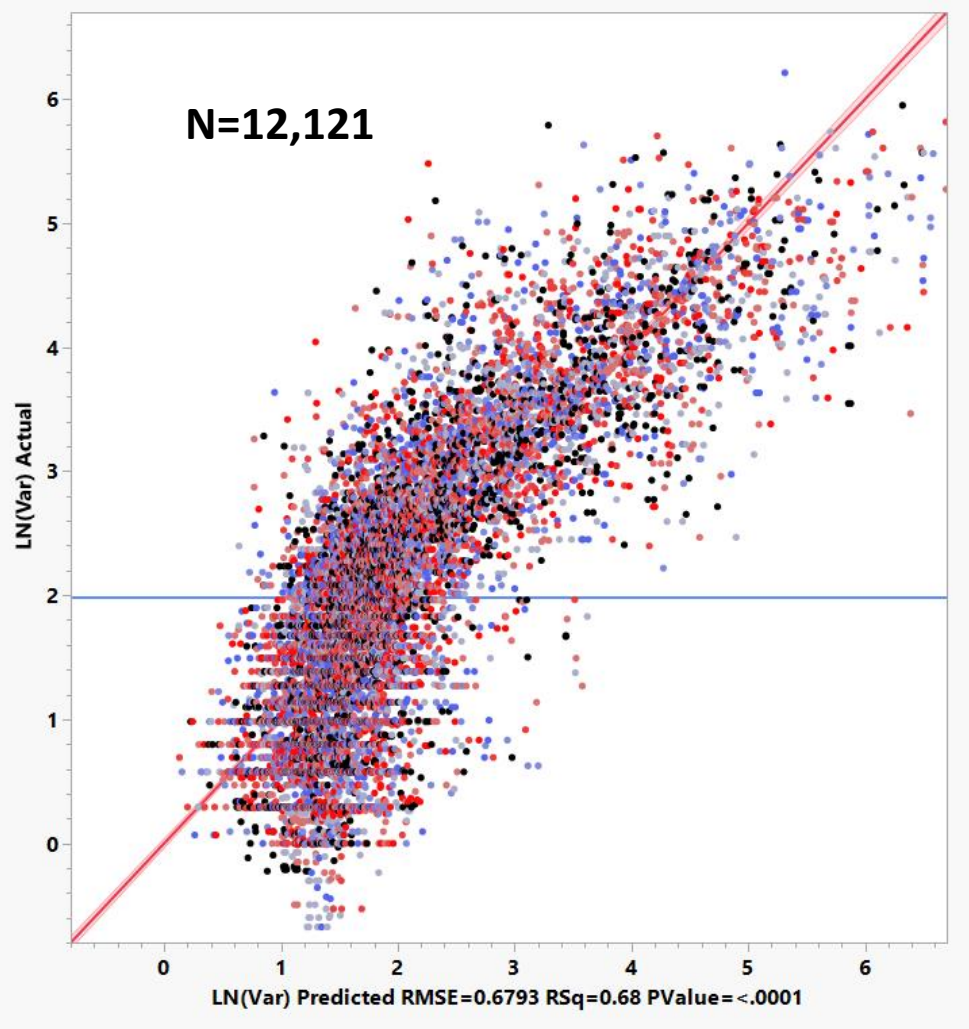


Chlorophyll

Water Quality Models

2017 - 2020 in situ match-ups within three days

Multilinear Regression



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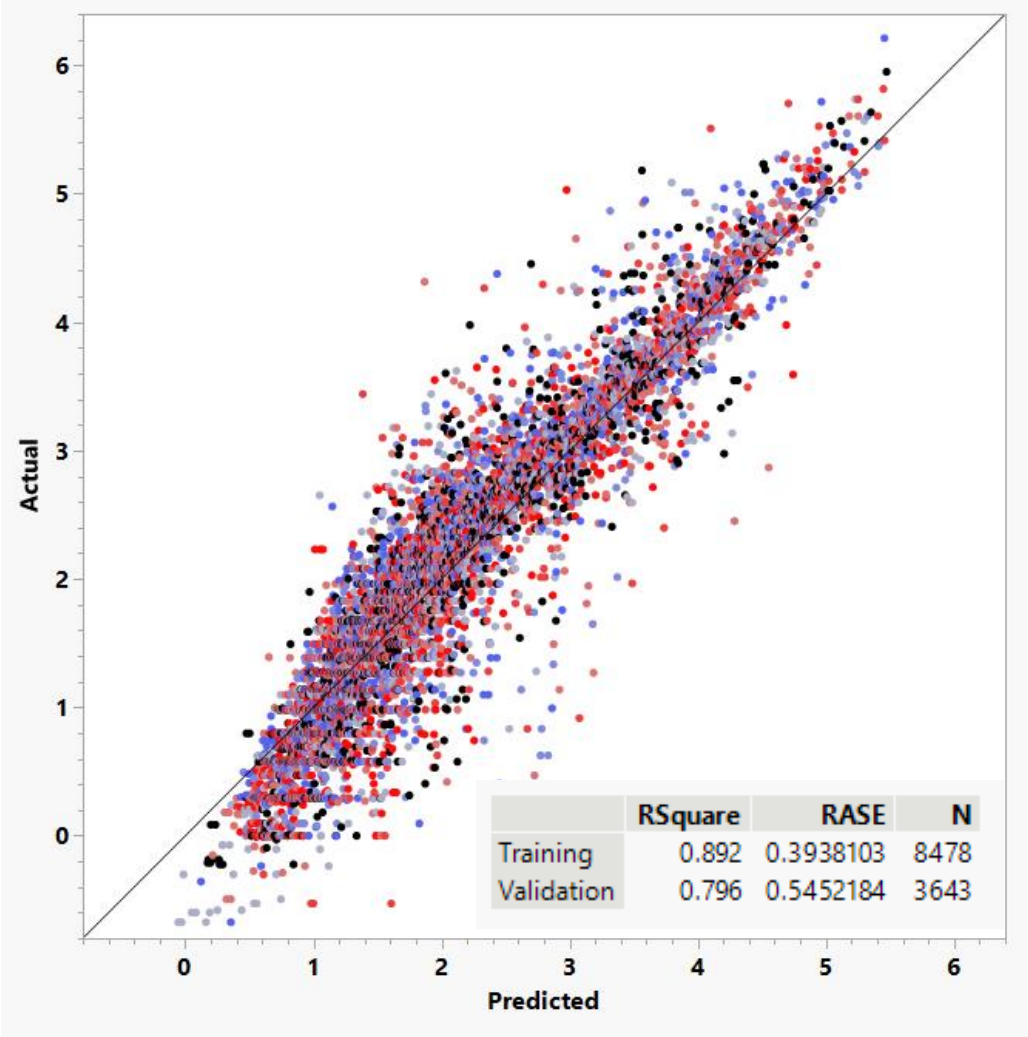

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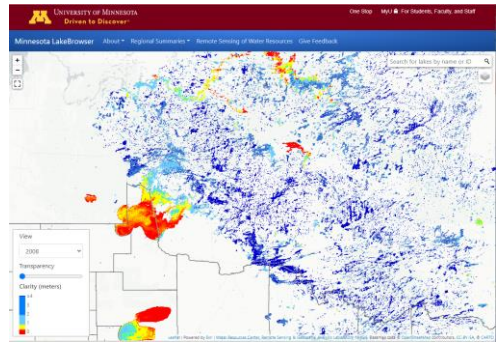
EROS USGS

esa European Space Agency

opernicus Europe's eyes on Earth

Landsat 8
Landsat 9 Sep 2021
Sentinel-2
Sentinel-3

LakeBrowser



Maps, data, statistical summaries, time-trend plots and animations

Minnesota Supercomputing Institute (MSI) high performance computing systems

Atmospheric Correction

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Cloud Mask

Smoke Mask

Prepare images using new automated methods

Chlorophyll

Water clarity

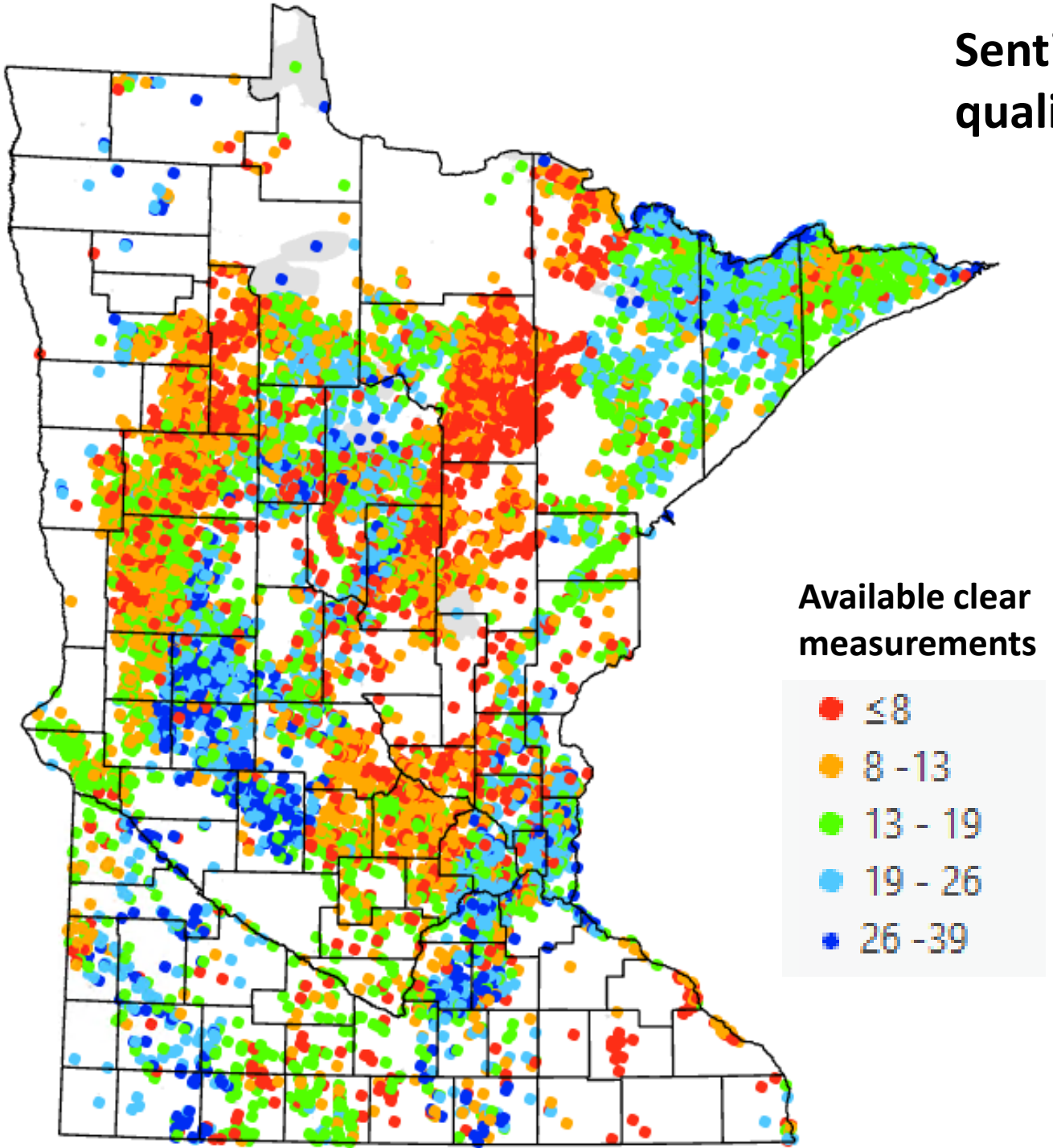
CDOM

Suspended Solids

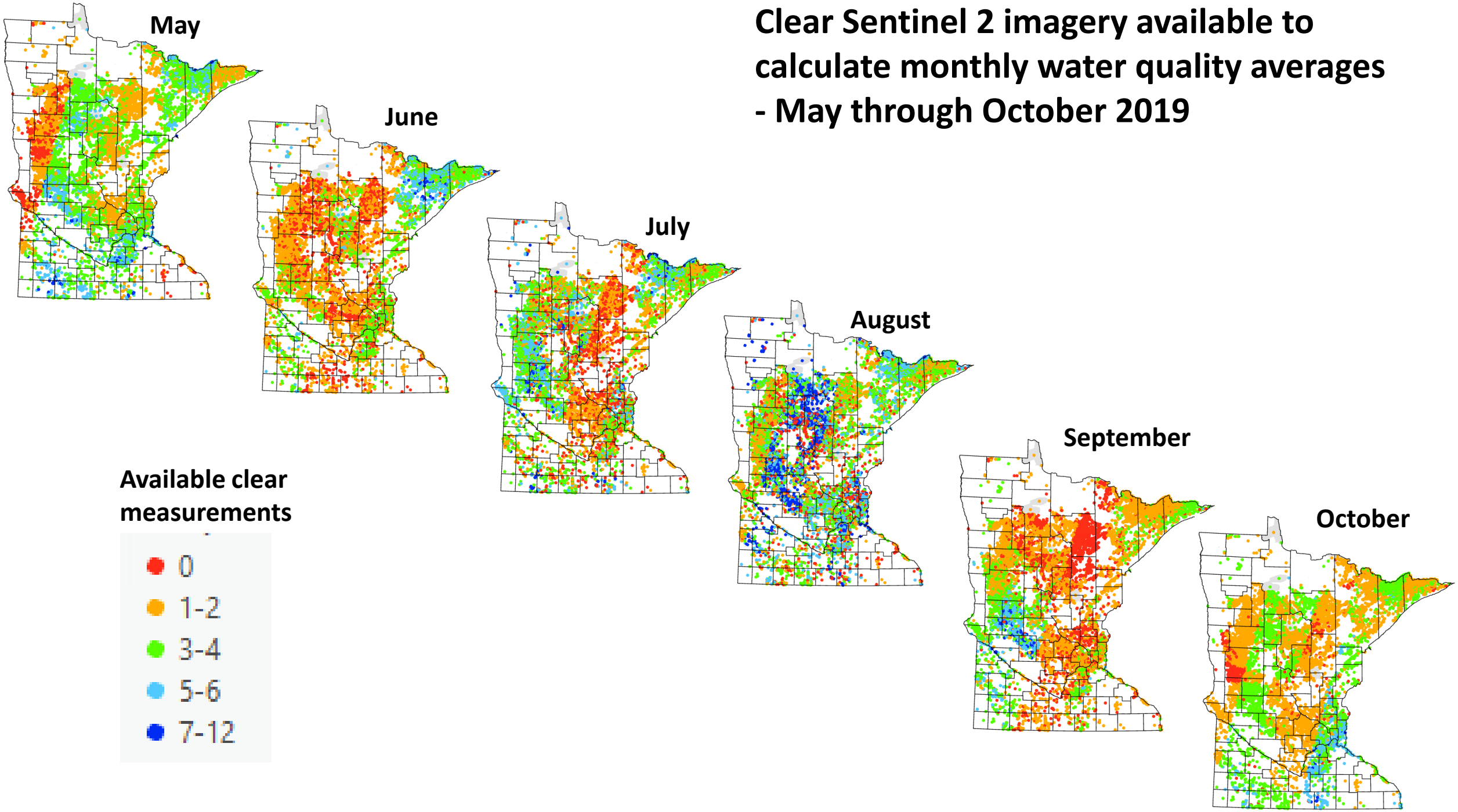
Apply water quality models

Provide customized information to agencies, researchers, and citizens.

Sentinel 2 imagery available to calculate water quality values - May through October 2019

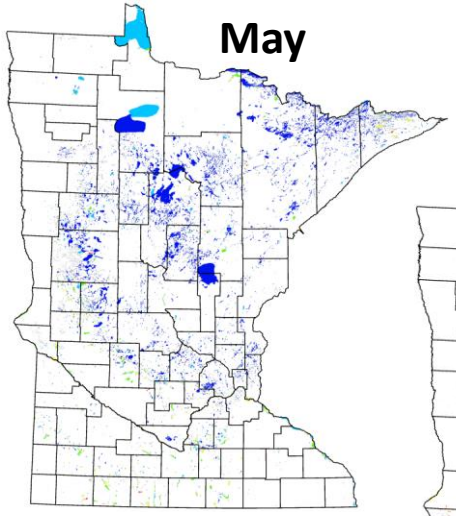


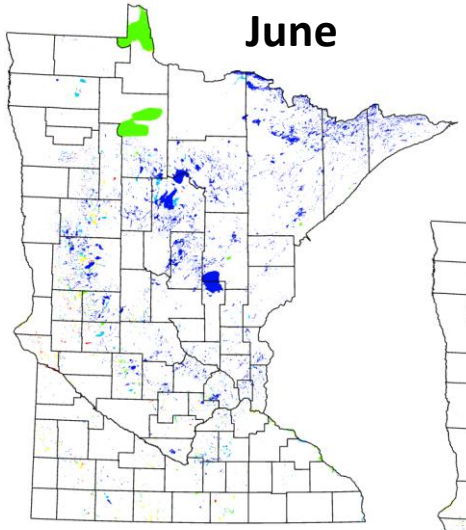
Clear Sentinel 2 imagery available to calculate monthly water quality averages - May through October 2019

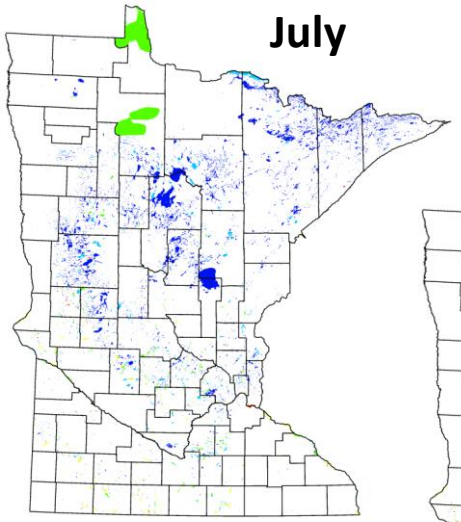


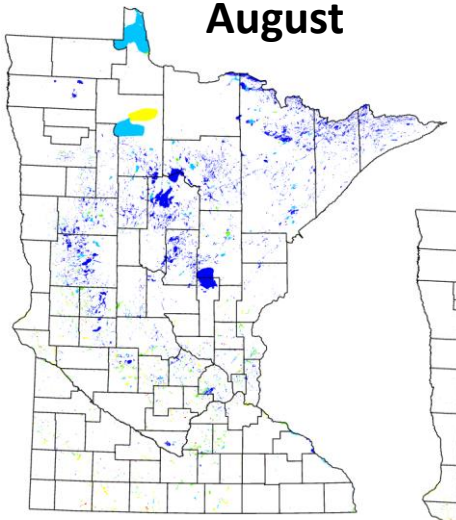
Example Sentinel 2 imagery water quality products monthly averages for May through October 2019

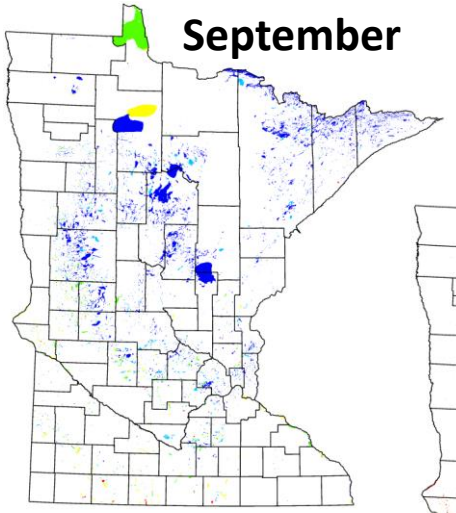
Chlorophyll, clarity and CDOM

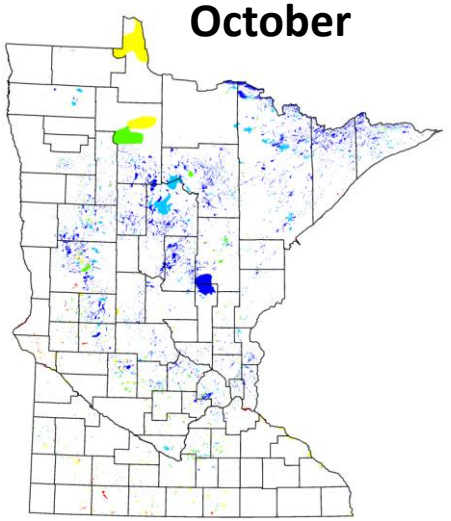








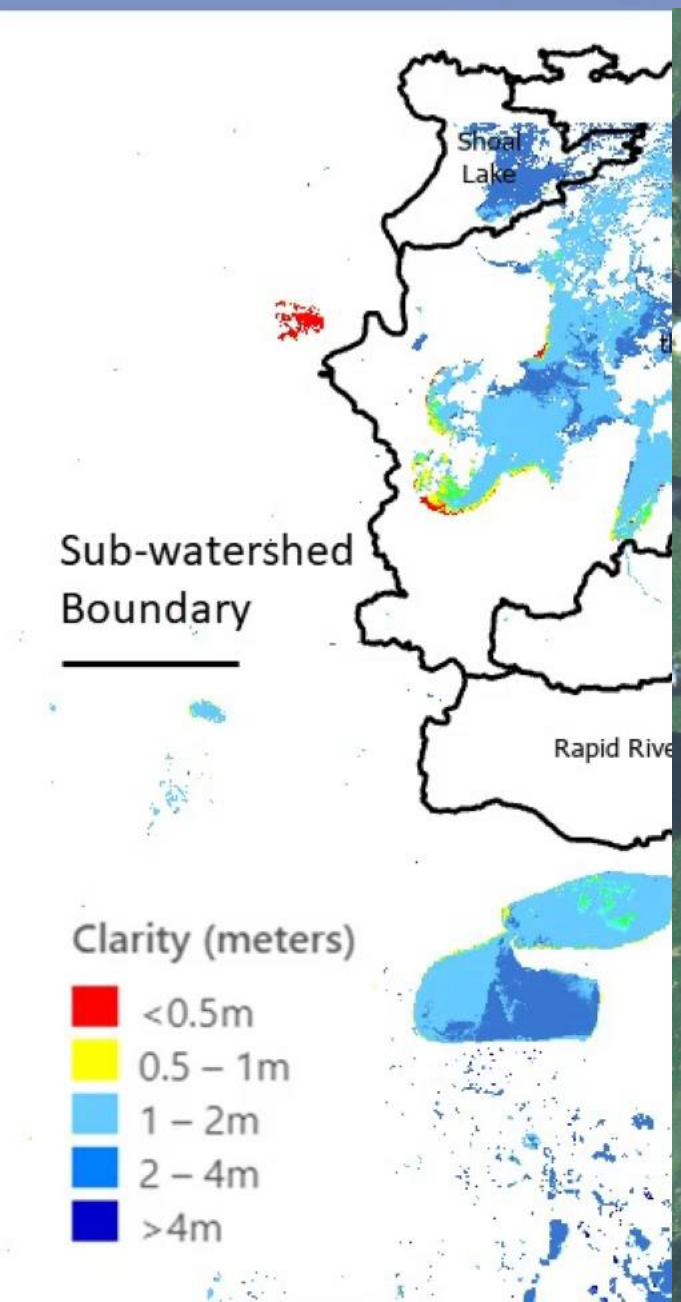


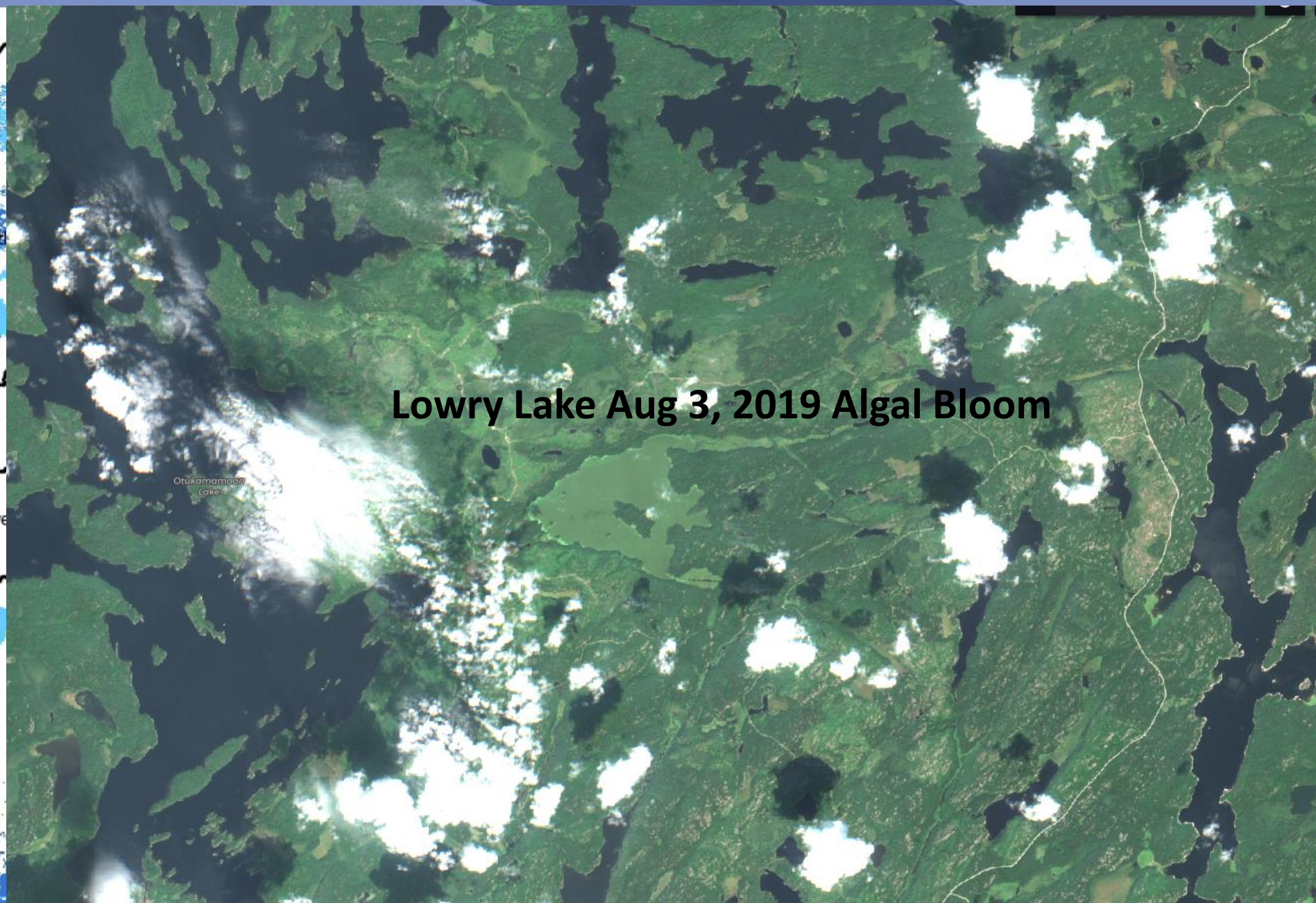


Map Legend

	TSI	SD m
	<40	>4
	40-50	2-4
	50-60	1-2
	60-70	0.5-1
	>70	<0.5

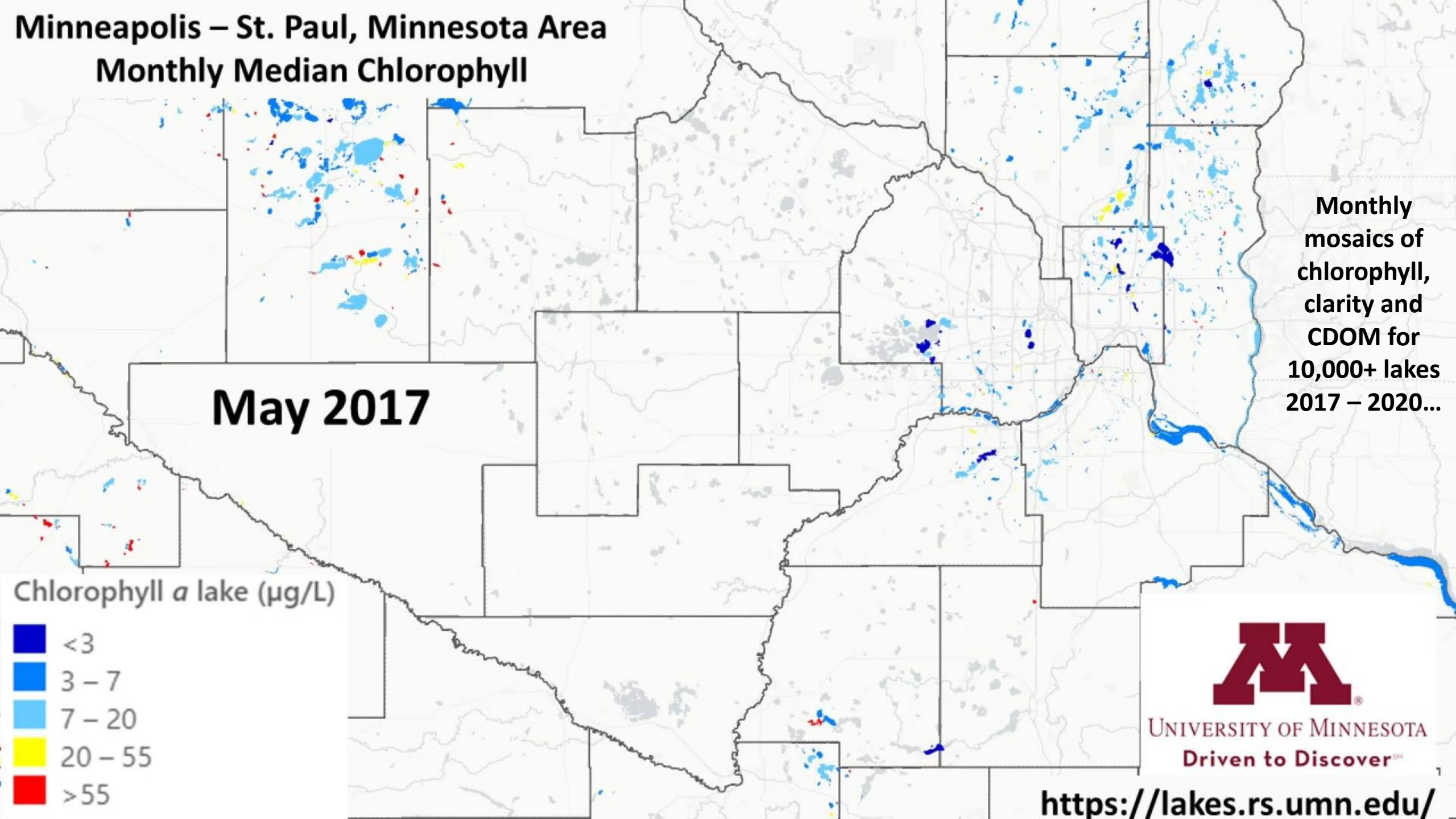
https://lakes.rs.umn.edu/





Lowry Lake Aug 3, 2019 Algal Bloom

Minneapolis – St. Paul, Minnesota Area
Monthly Median Chlorophyll



Monthly mosaics of chlorophyll, clarity and CDOM for 10,000+ lakes 2017 – 2020…

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Southern Minnesota daily chlorophyll for mesotrophic, eutrophic and hypereutrophic lakes

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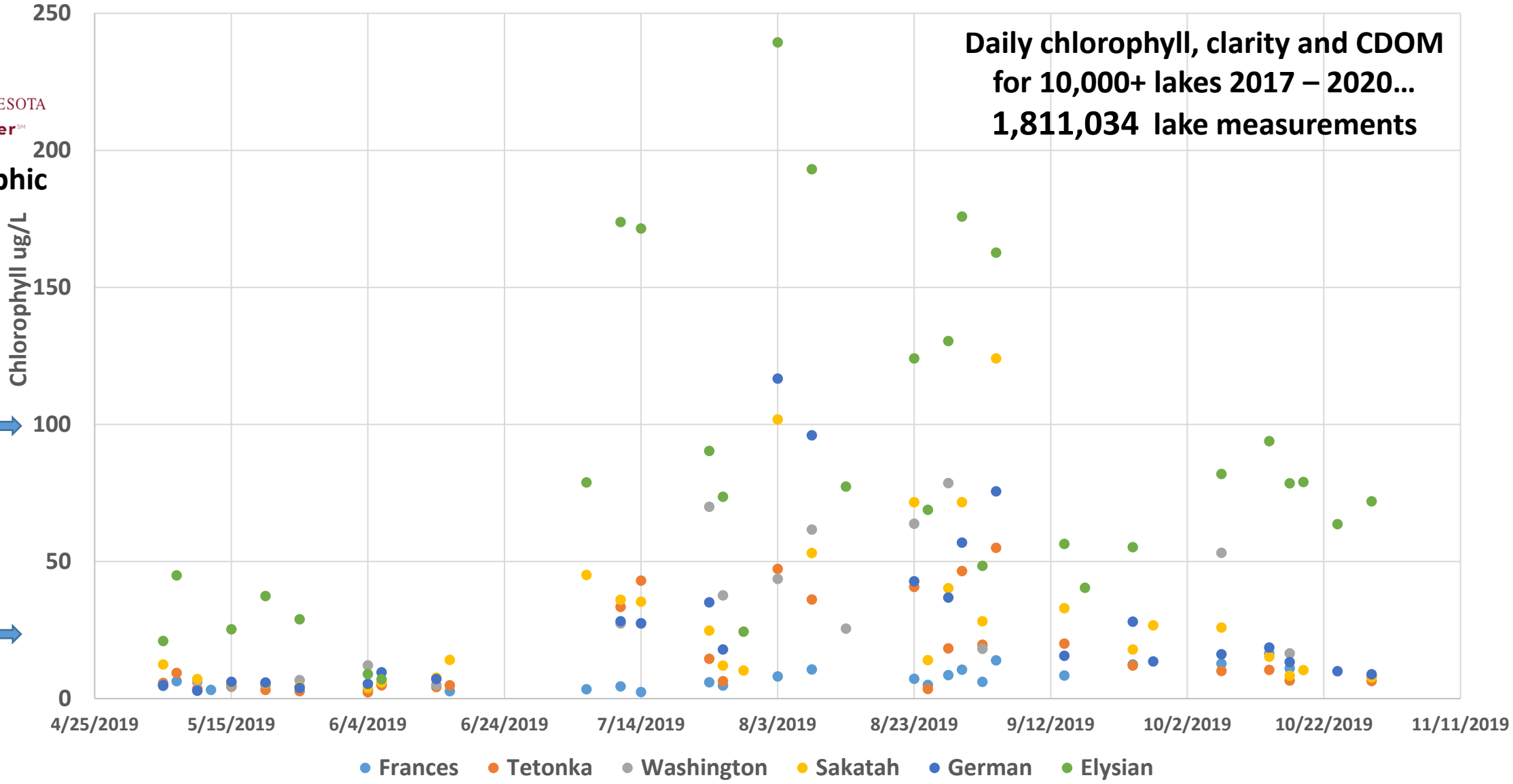
Hyper-eutrophic

Eutrophic

Mesotrophic



Southern Minnesota daily chlorophyll for mesotrophic, eutrophic and hypereutrophic lakes

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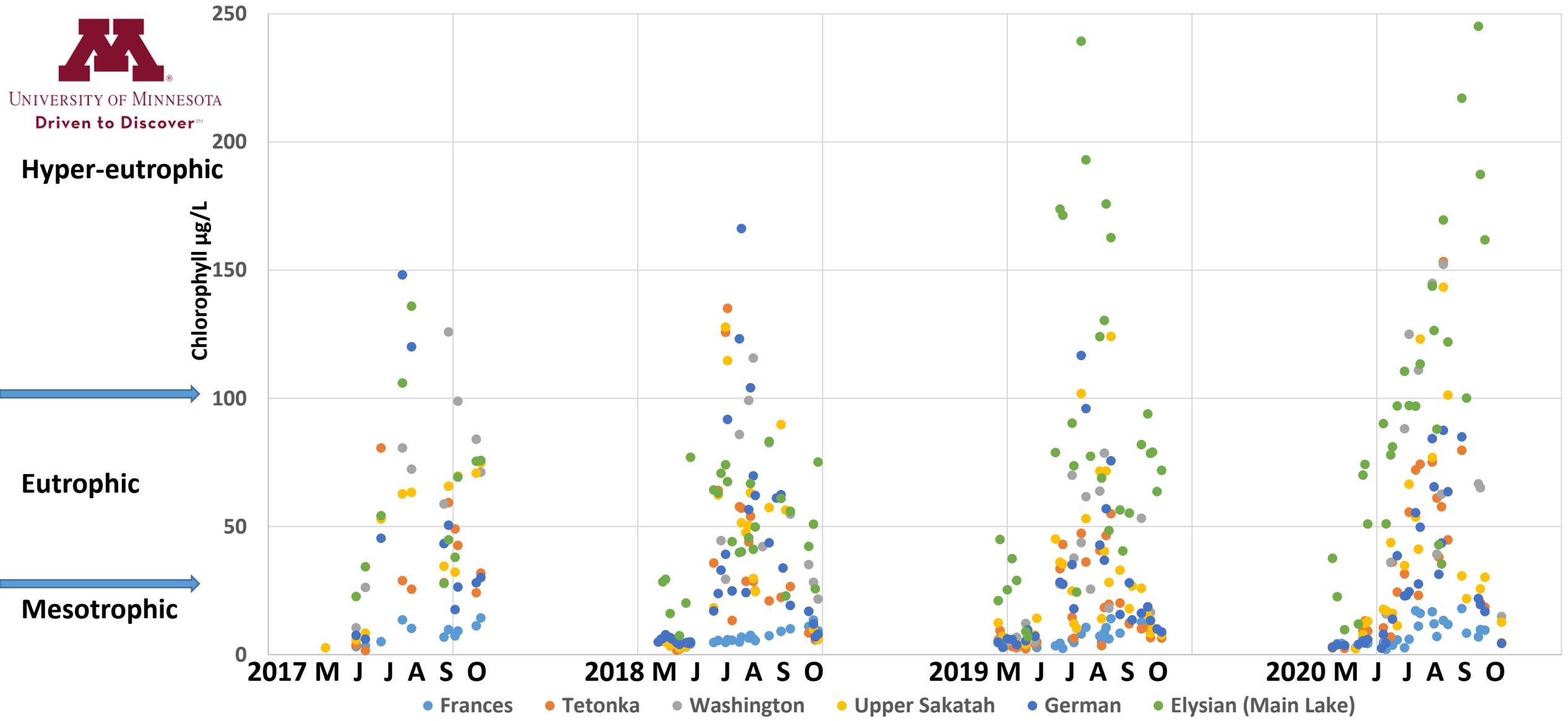

Southern Minnesota monthly median chlorophyll for mesotrophic, eutrophic and hypereutrophic lake phenology

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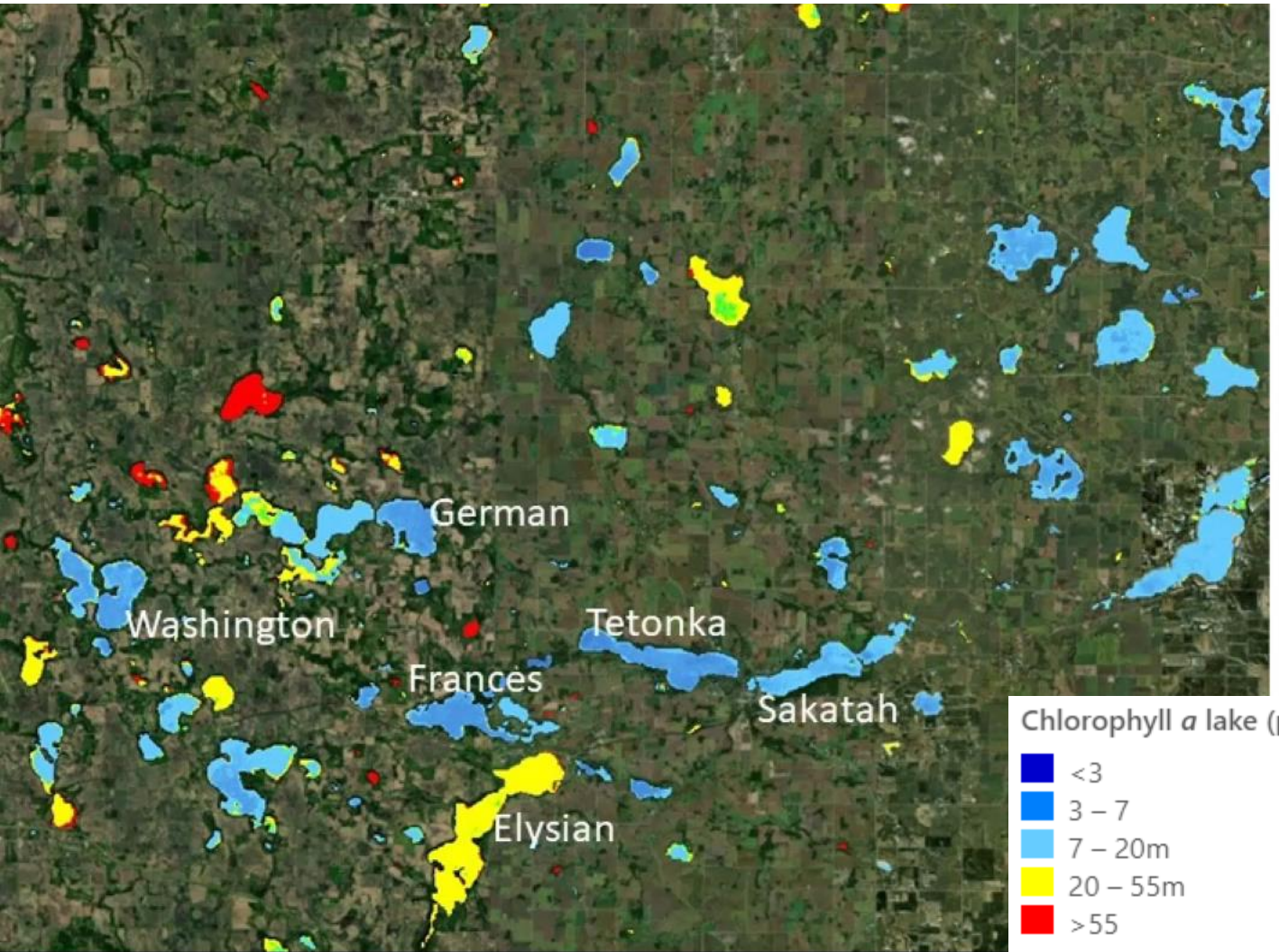
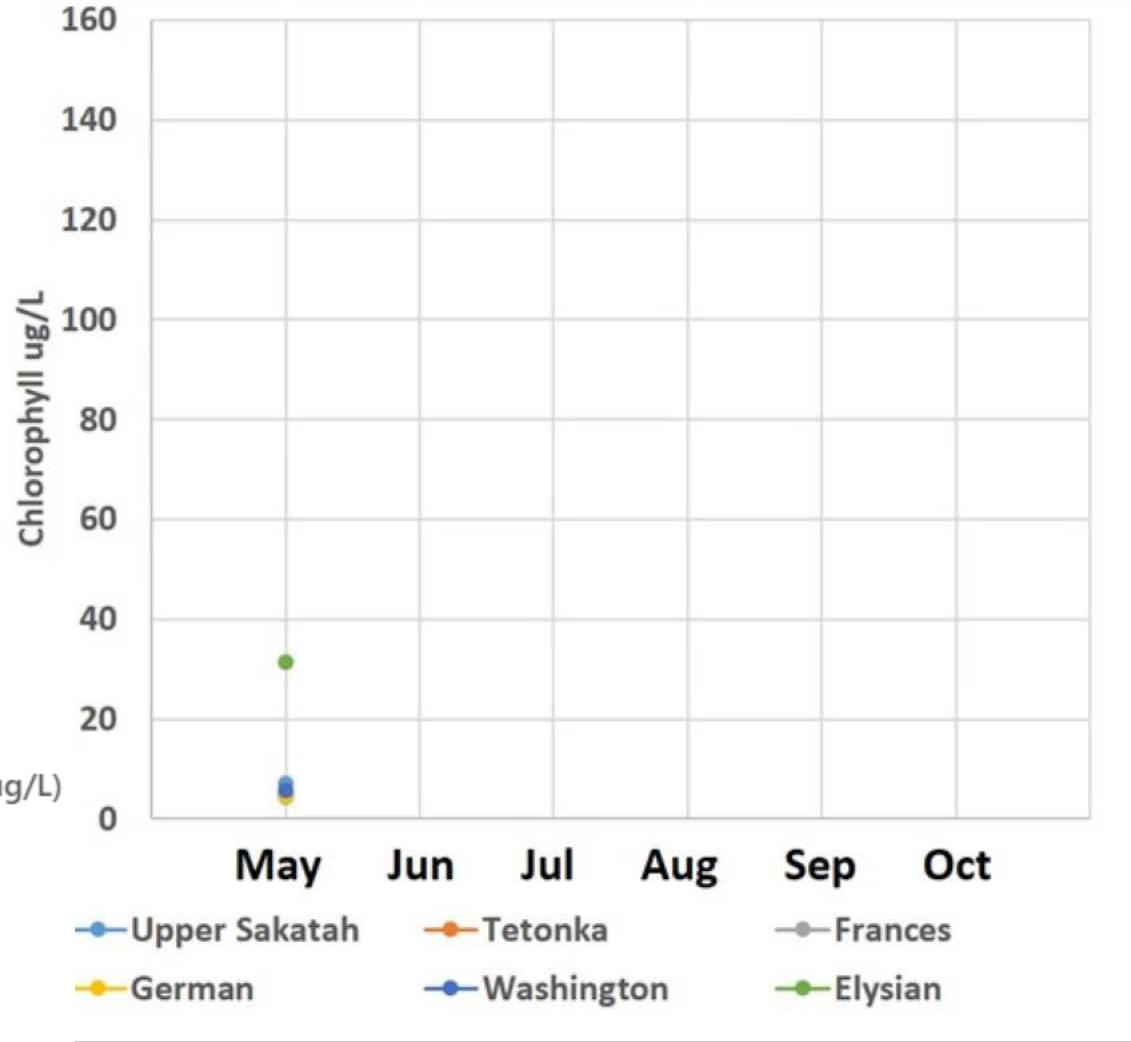
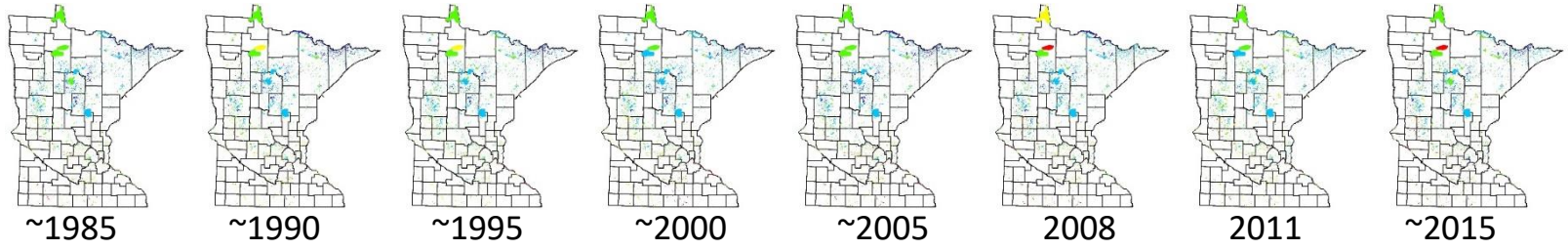
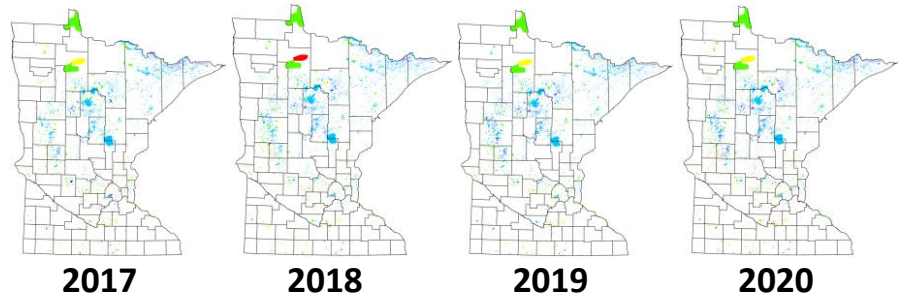
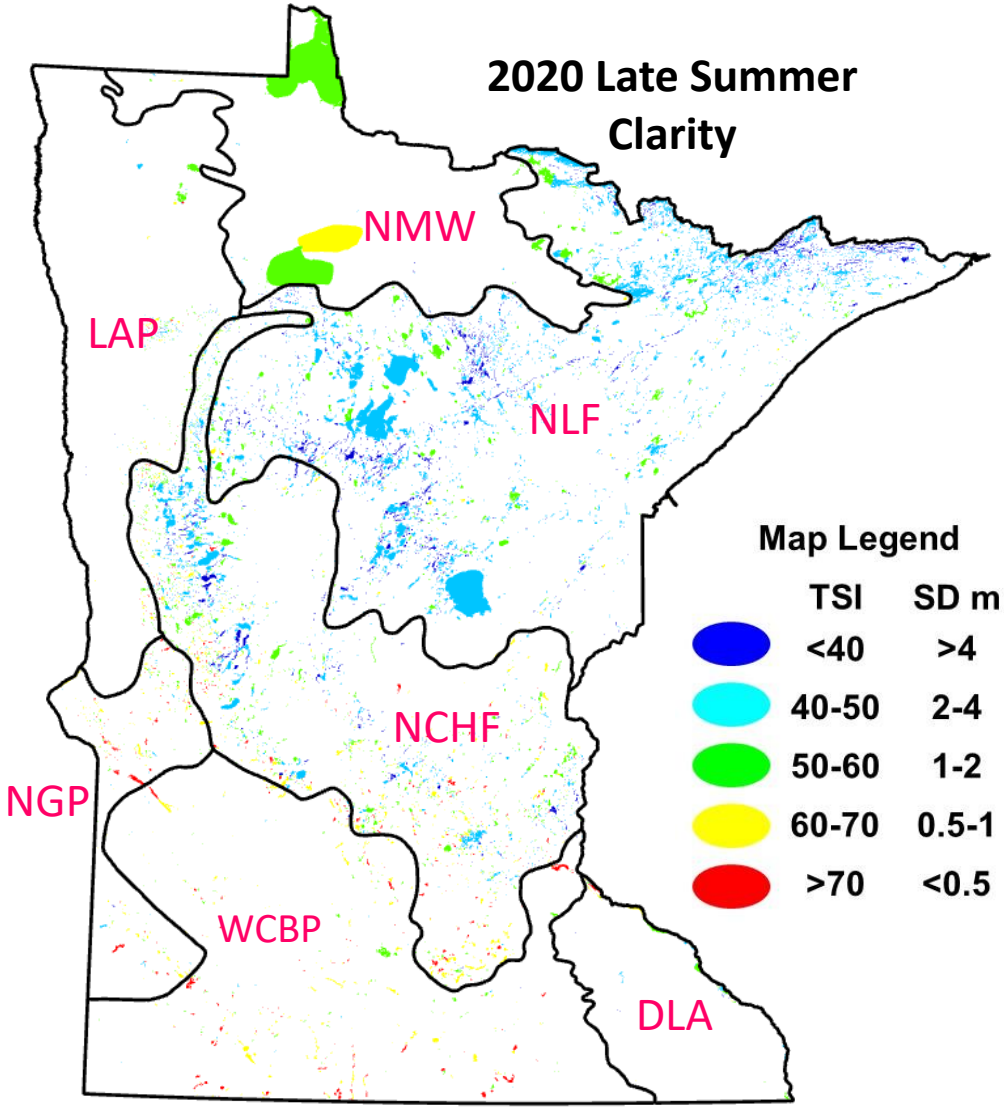


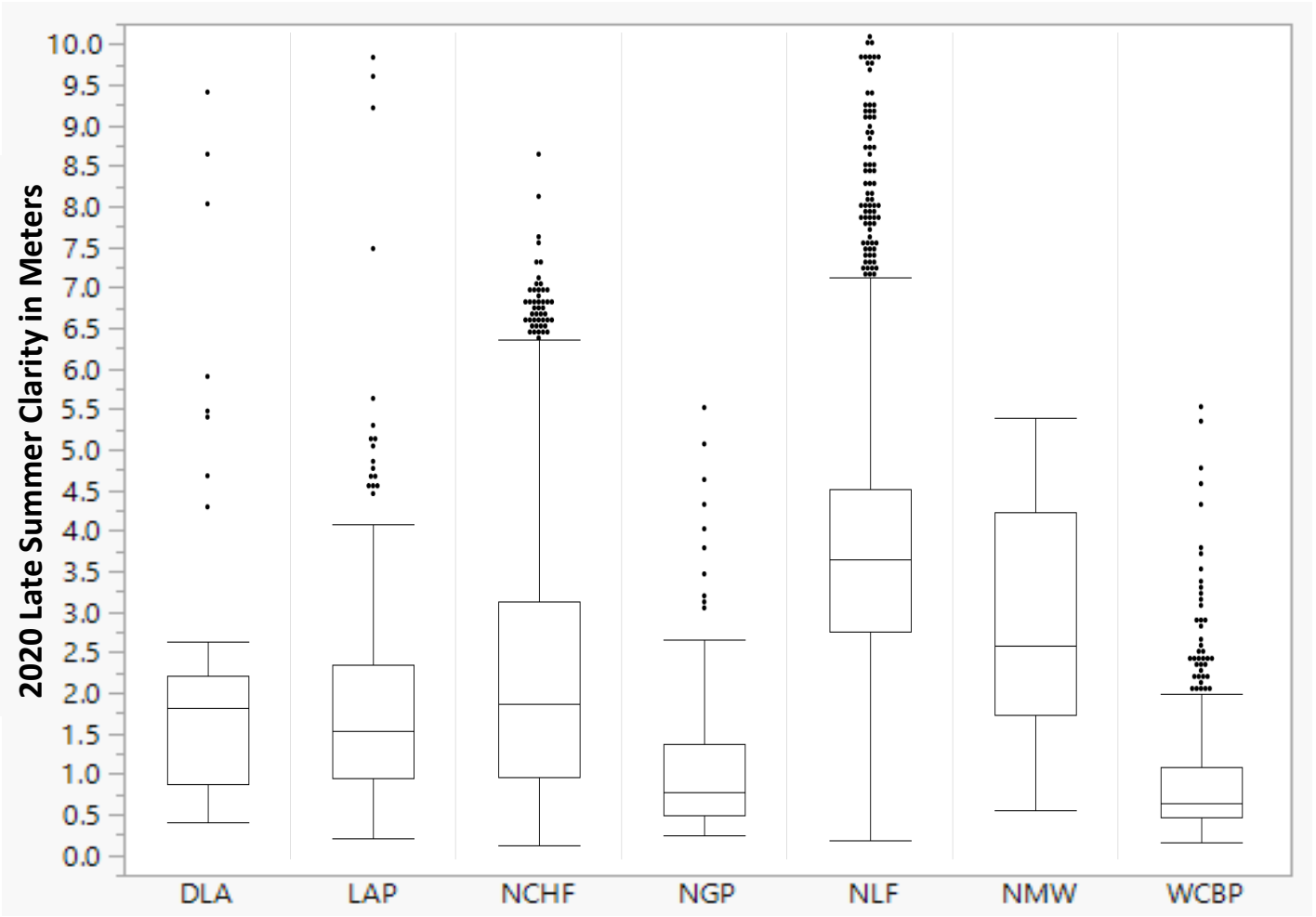




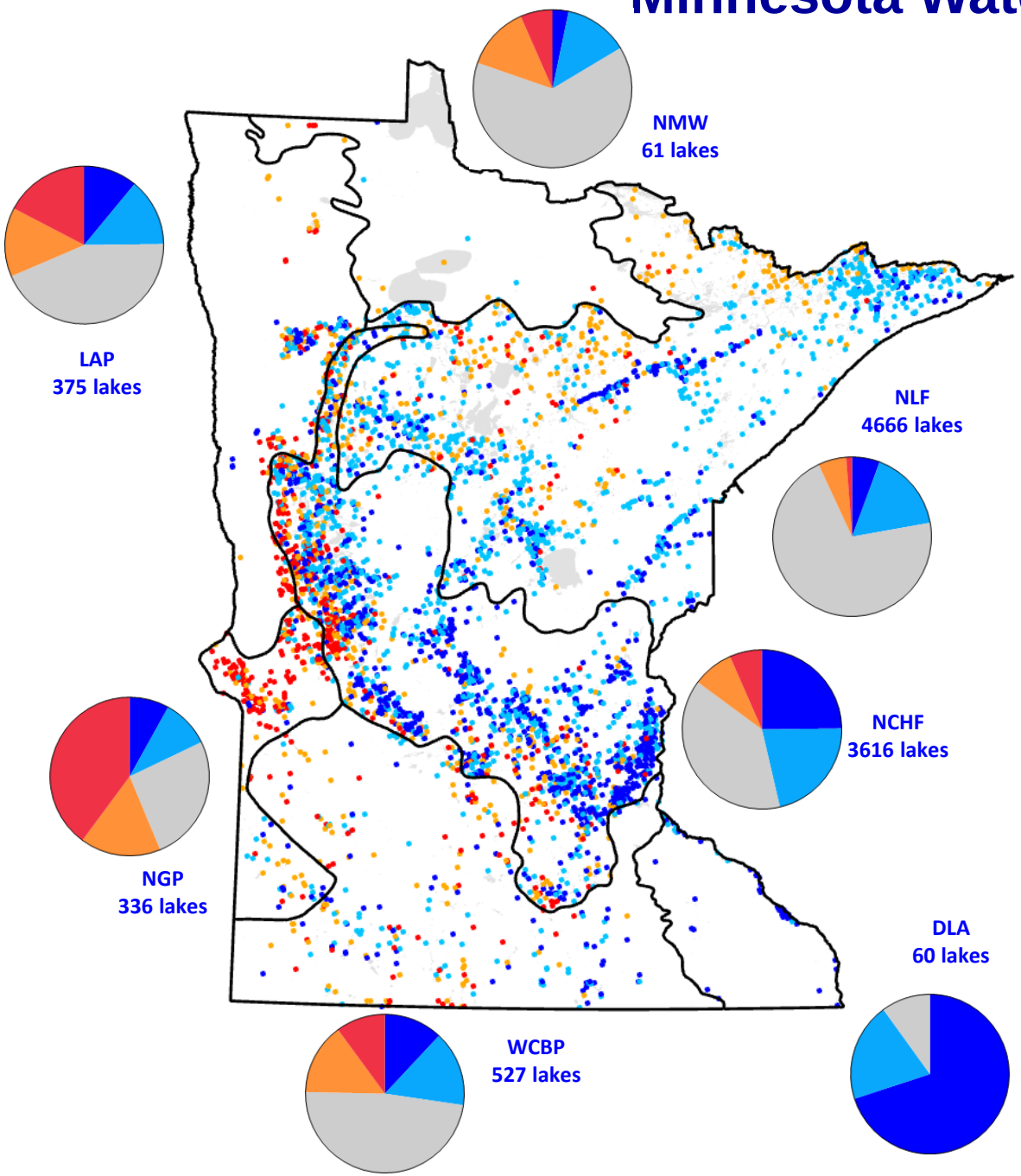


Spatial and Temporal Analysis of Water Clarity

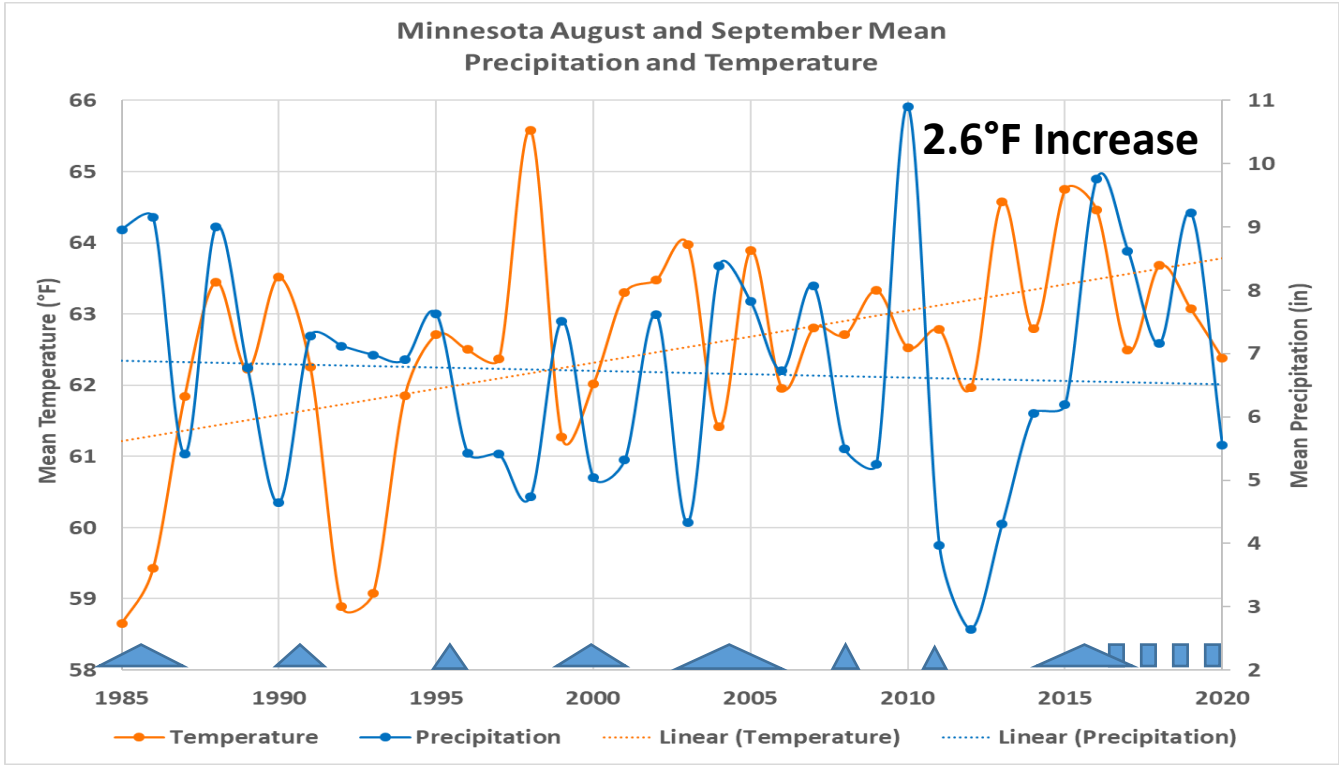




Minnesota Water Clarity Trends by Ecoregion, 1985 – 2020

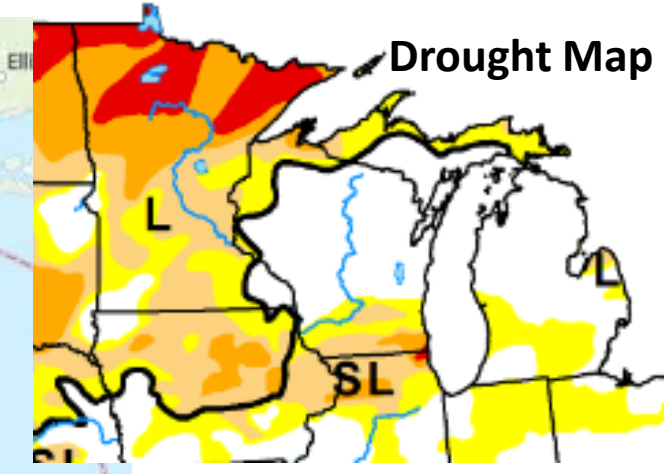


- 9,641 Lakes assessed in 1985, 1990, 1995, 2000, 2005, 2008, 2011, 2015, 2017, 2018, 2019 & 2020
- 1884 Lakes (19.5%) linear trend line change ≥ 10 TSI units (2x or ½ algal biomass)
  - 1335 Lakes (13.8%) water clarity increased >10 TSI units
  - 549 Lakes (5.7%) water clarity decreased >10 TSI units
- 2125 Lakes (25.9%) linear trend line change 5 to 10 TSI units
  - 1738 Lakes (18.0%) water clarity increased 5 to 10 TSI units
  - 762 Lakes (7.9%) water clarity decreased 5 to 10 TSI units



https://arcgis.dnr.state.mn.us/ewr/climatetrends/

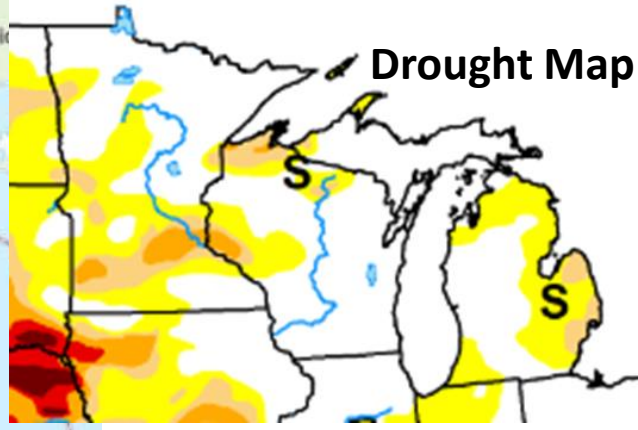
Upper Midwest USA
Late Summer Clarity
Lake Level 2021
23,000+ Lakes



Map Legend

TSI	SD m
<40	>4
40-50	2-4
50-60	1-2
60-70	0.5-1
>70	<0.5

Upper Midwest USA
Late Summer Clarity
Lake Level 2022
23,000+ Lakes



Map Legend

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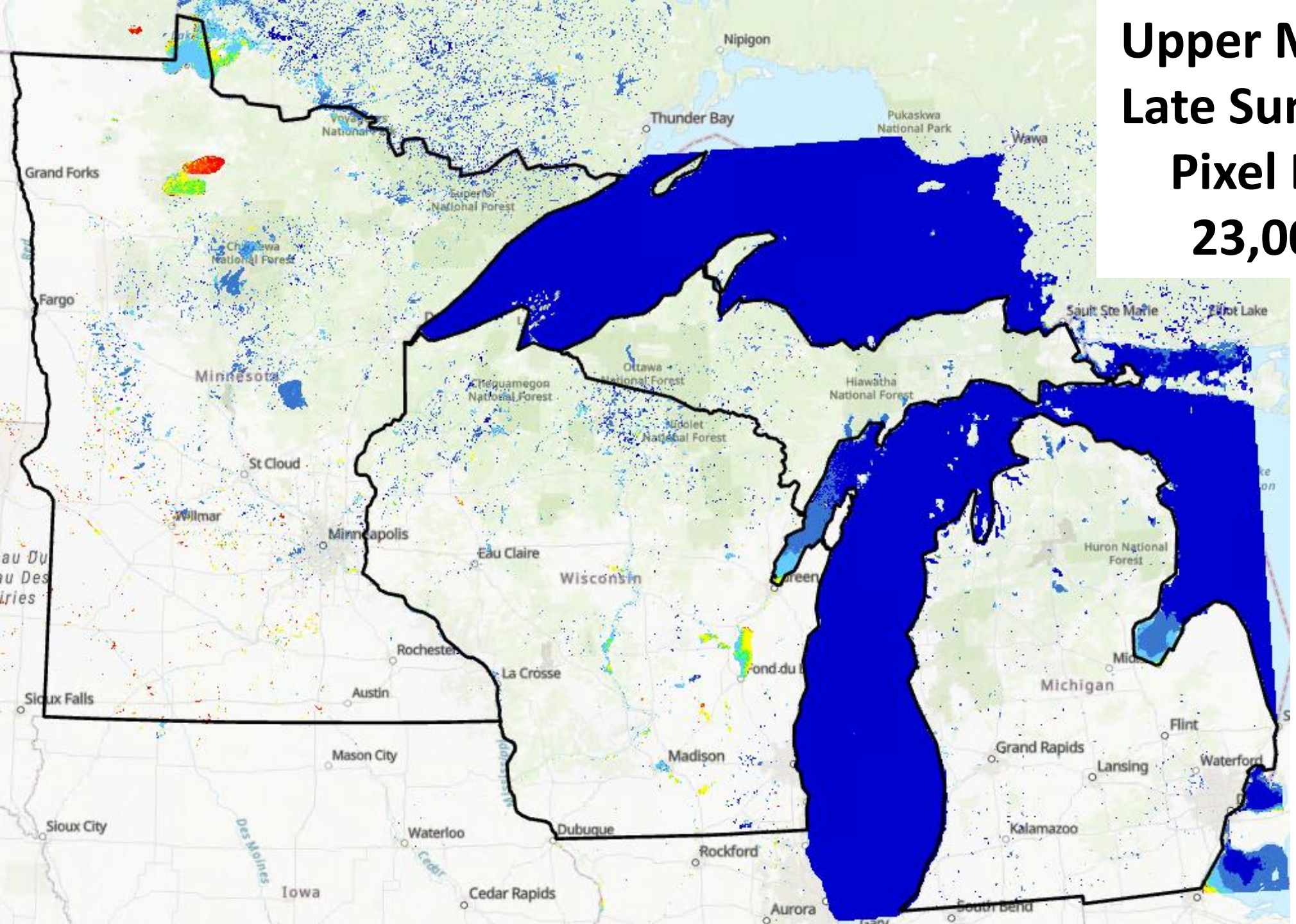
Upper Midwest USA
Late Summer Clarity
Pixel Level 2021
23,000+ Lakes

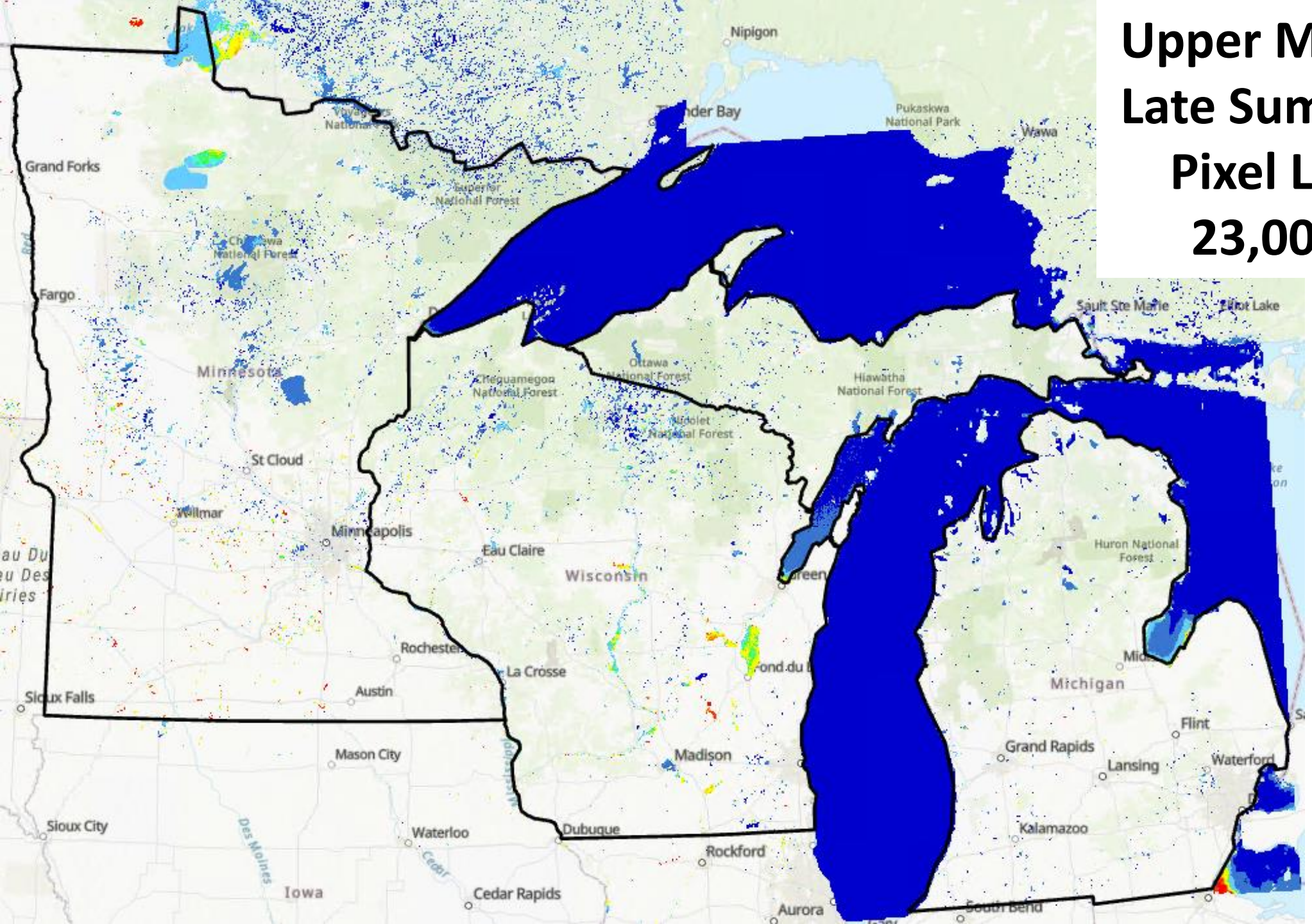


Legend

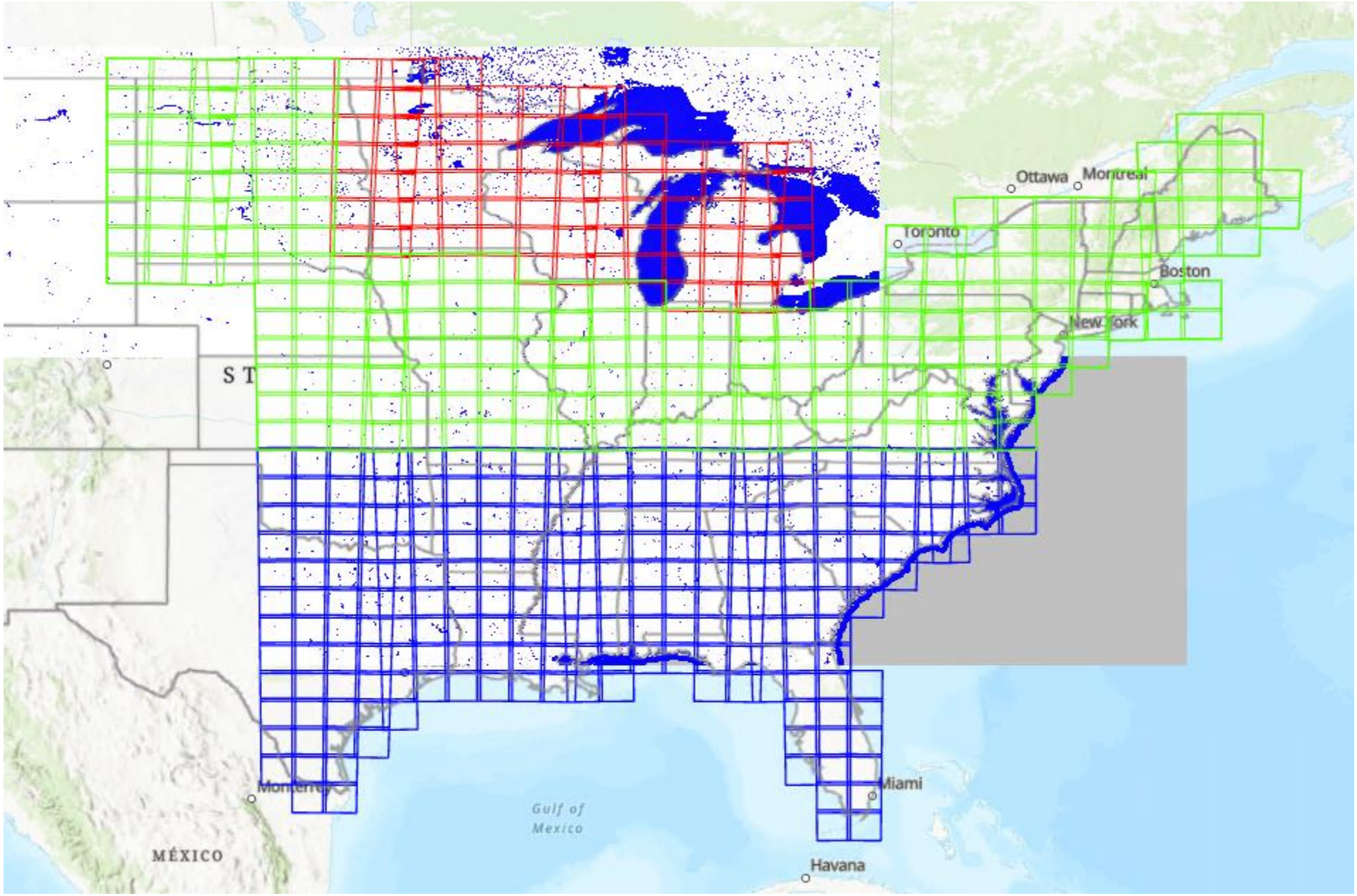
Clarity

≥13 ft	≥4 m
10	3
7	2
3	1
0	0

Upper Midwest USA
Late Summer Clarity
Pixel Level 2022
23,000+ Lakes



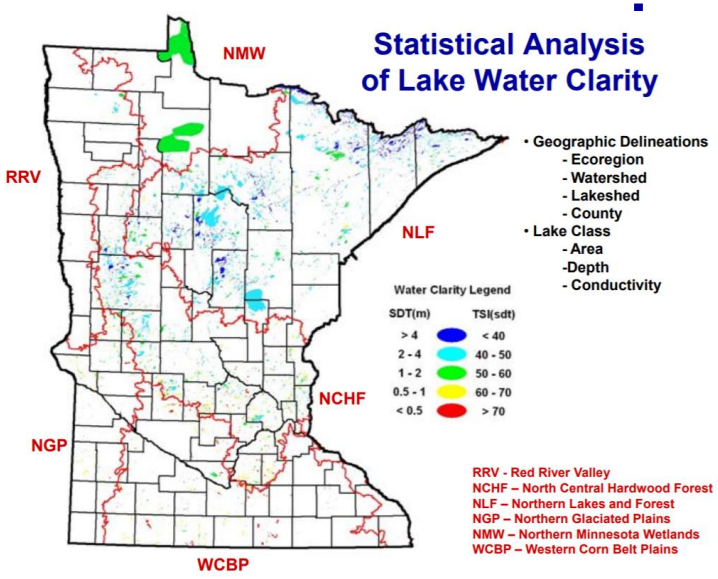
Downloading Sentinel 2 data for the eastern USA for regional testing of WQ algorithms



Enhanced Minnesota LakeBrowser: Is Here!

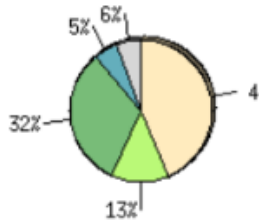
:

Providing a comprehensive historical record of water quality parameters in Minnesota lakes



Statewide Analysis

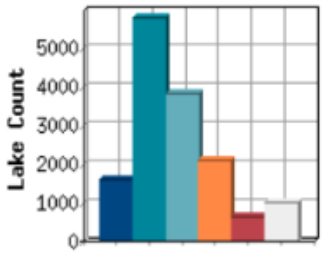
Statewide Land Cover



Land Cover	Acres
Agriculture	23,543,485
Grass/Shrub/Wetland	7,252,474
Forest	17,149,220
Water	2,878,544
Urban	3,166,216

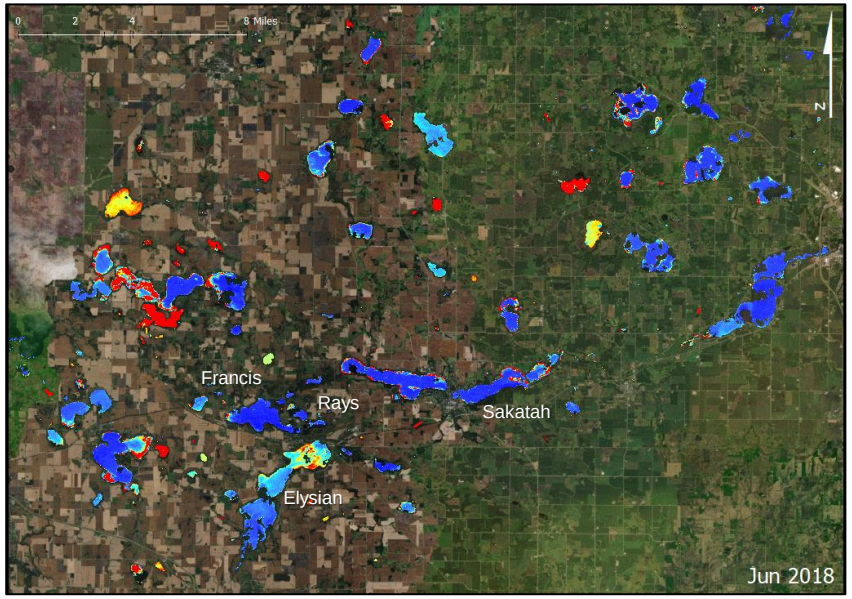
Statewide Land Area	53,997,846 acres
Statewide Impervious Area	960,465 acres
Percent Impervious Area	1.88 %

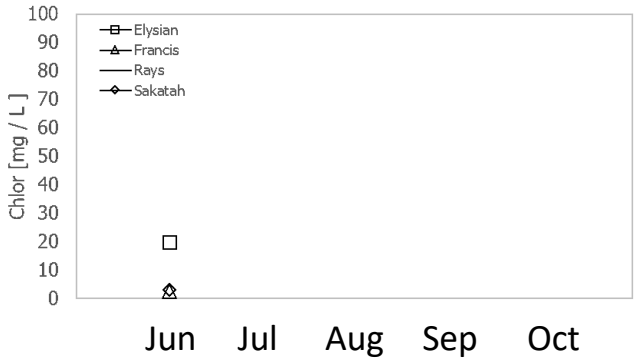
Statewide Lake Clarity



Lake Clarity	Lake Count
4m and up	1558
2-4m	5804
1-2m	3822
.5-1m	2098
0-.5m	624
no data	997
Statewide Total Lakes	14,903

Study per-lake water quality trends over time





http://lakes.rs.umn.edu

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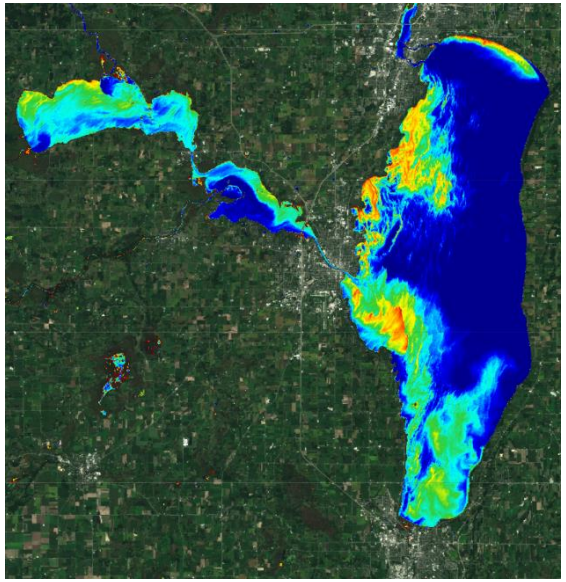
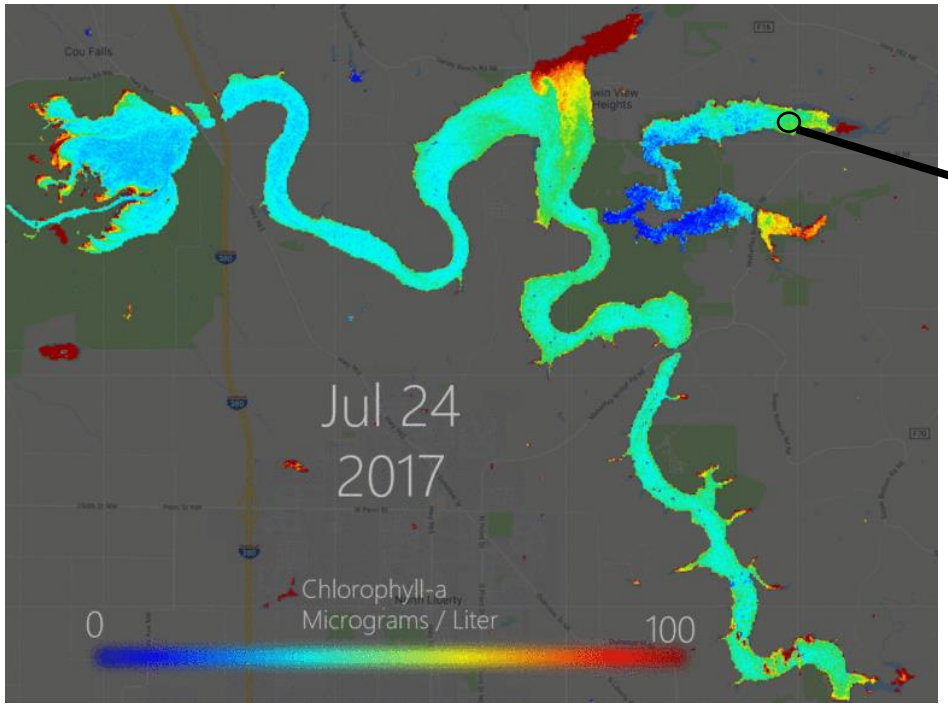
Moving towards regional level model validation

Lake Mitchell, South Dakota

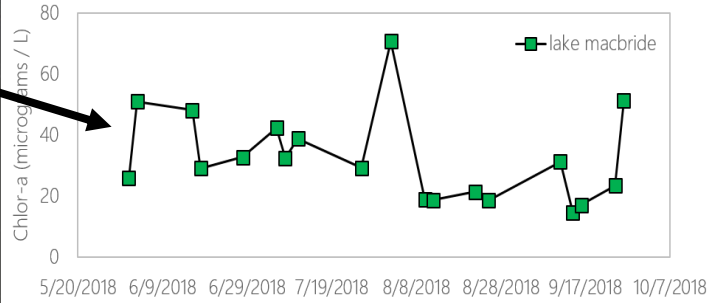
Lake Winnebago, WI



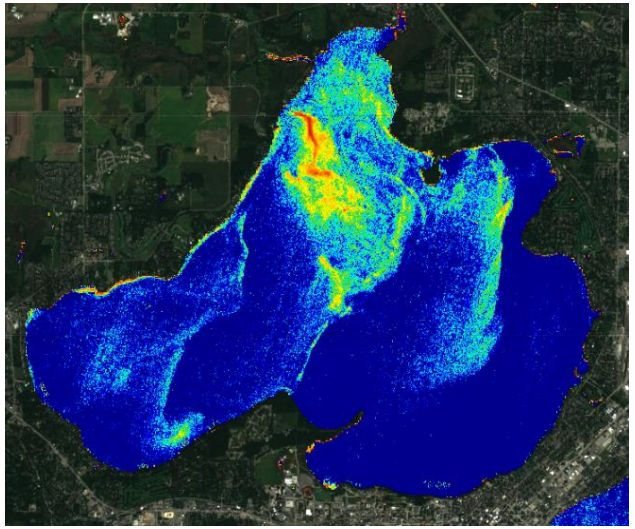
Lake McBride, South Dakota



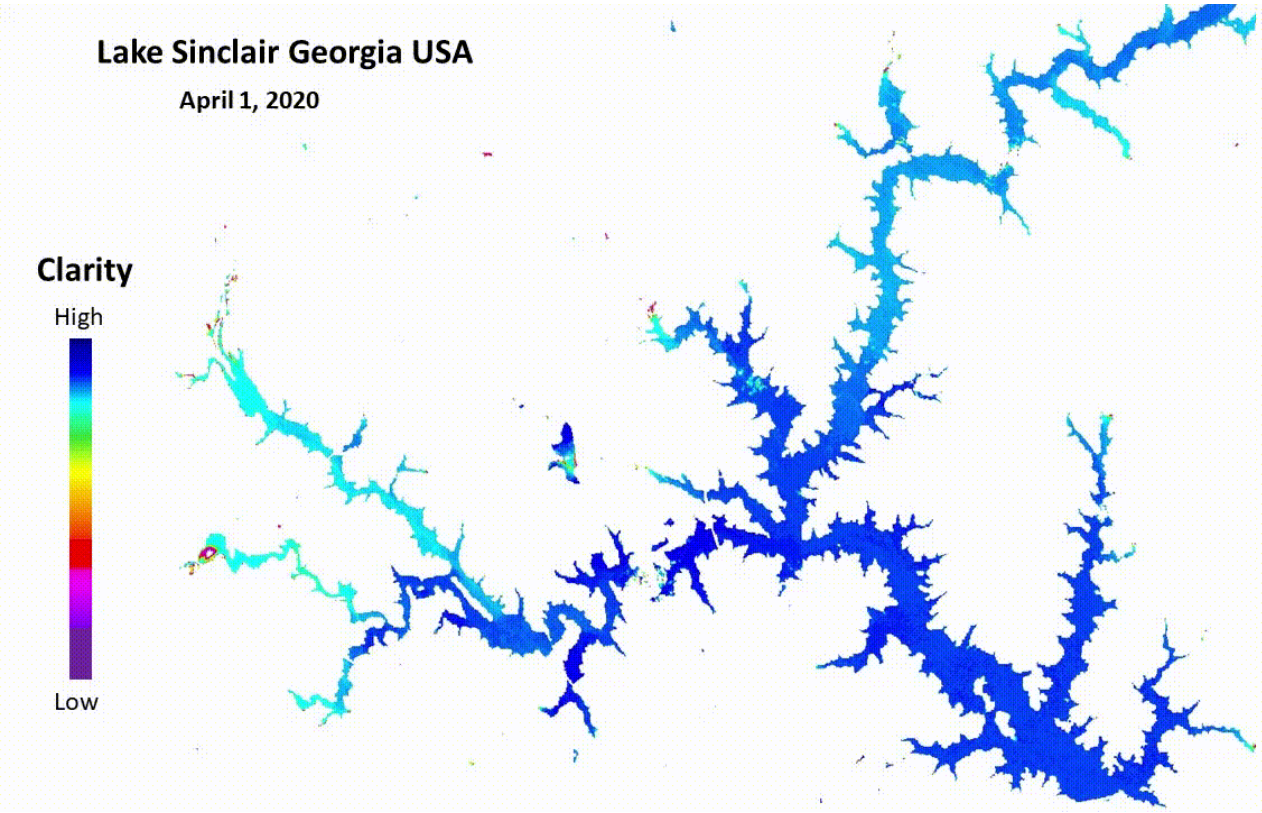
Lake Level Pixel Information

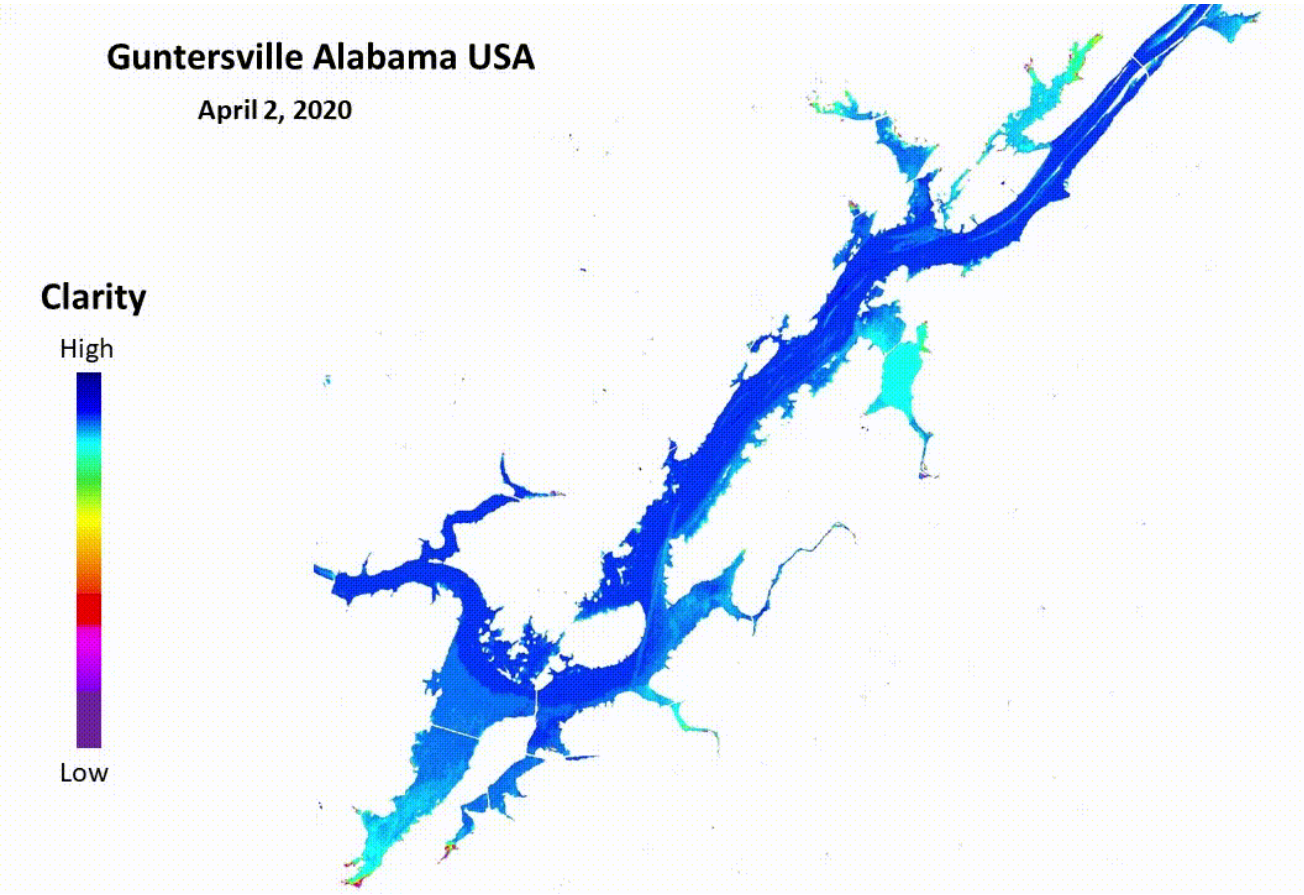


Lake Mentdota



Moving towards CONUS level model validation





Acknowledgments

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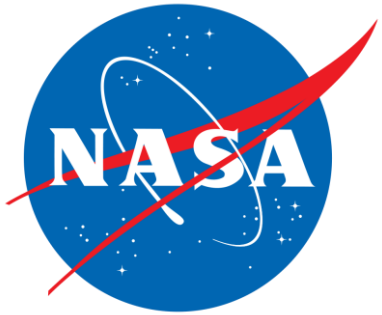
MINNESOTA POLLUTION CONTROL AGENCY

USGS
science for a changing world



esa
European Space Agency

olman002@umn.edu

@LakeBrowser

Paradigm Shift in Lake and Fisheries Management?

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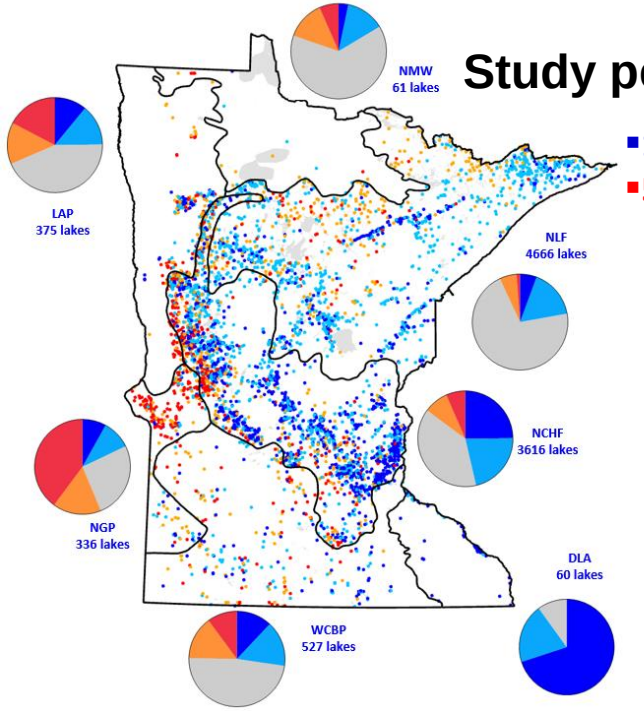
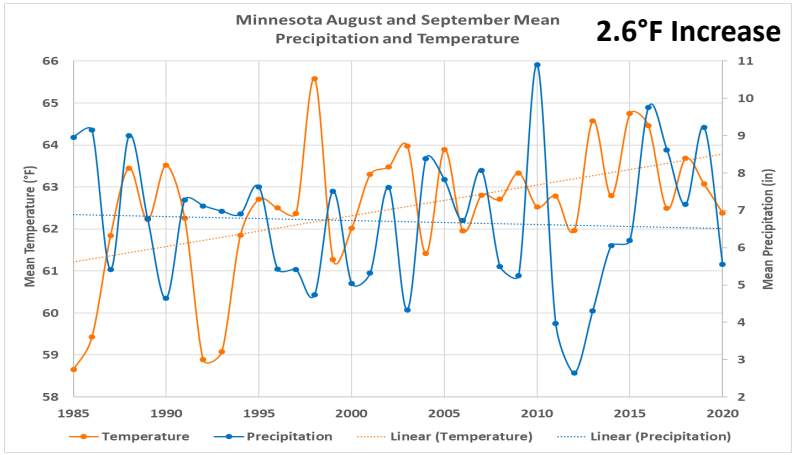
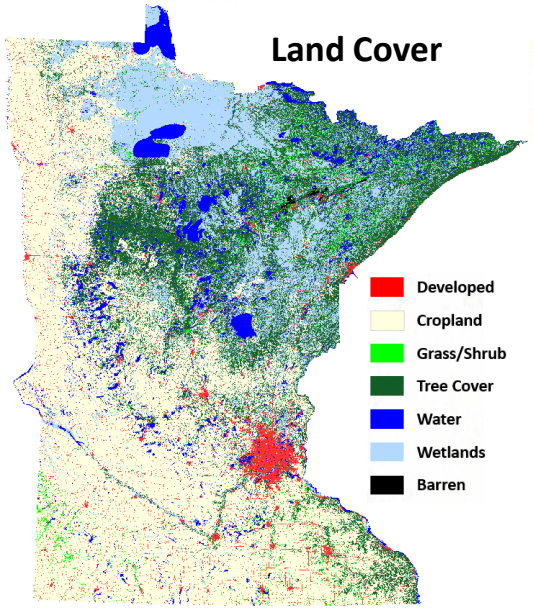
Study per-lake water quality trends 1985 – 2020

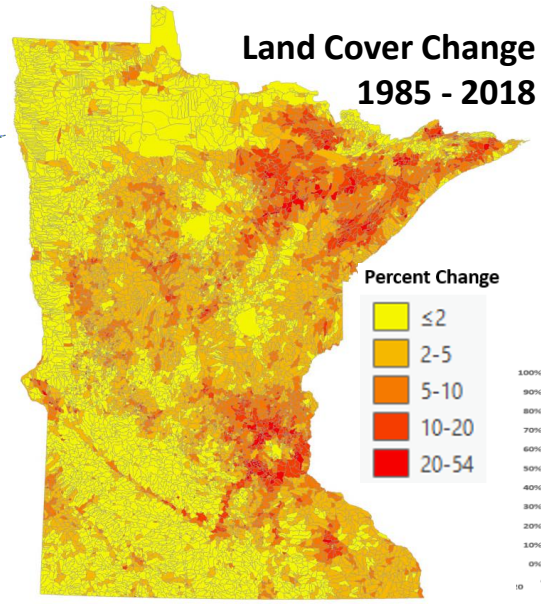
- 1335 Lakes (13.8%) water clarity increased >10 TSI units
- 549 Lakes (5.7%) water clarity decreased >10 TSI units

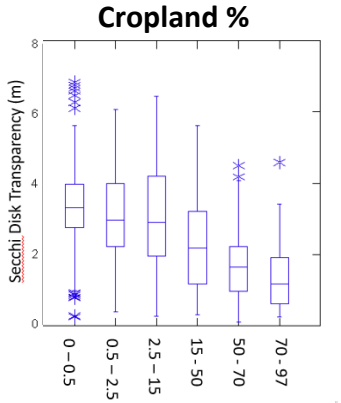


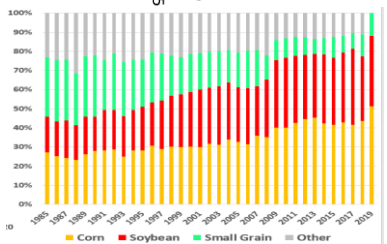


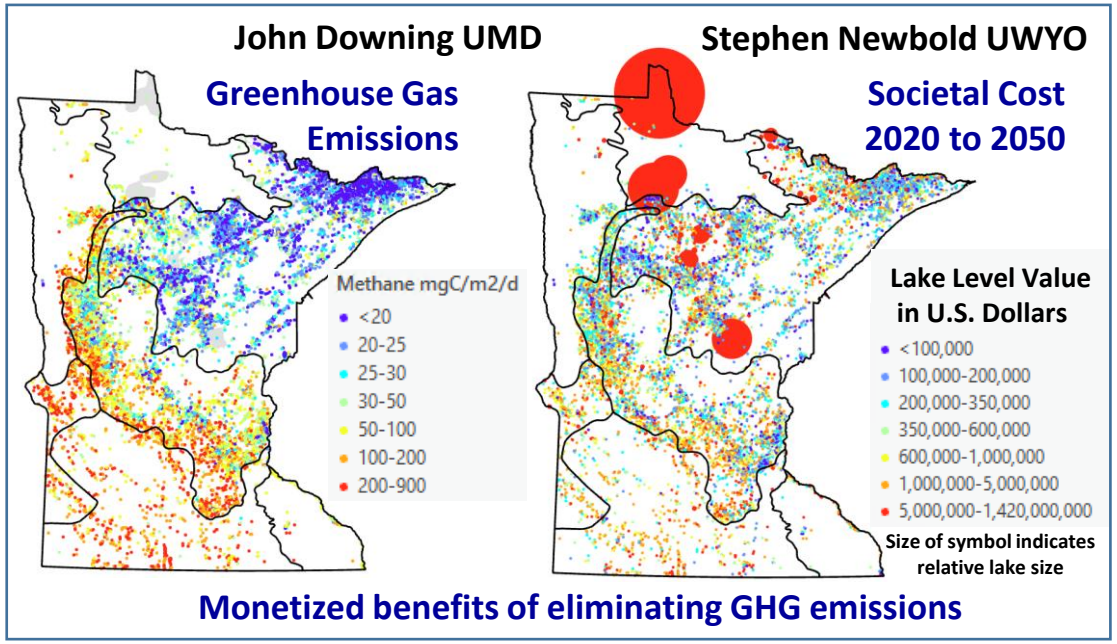
How can near real-time monitoring of all lakes be used to target resources to mitigate climate change and improve water quality and fisheries management?







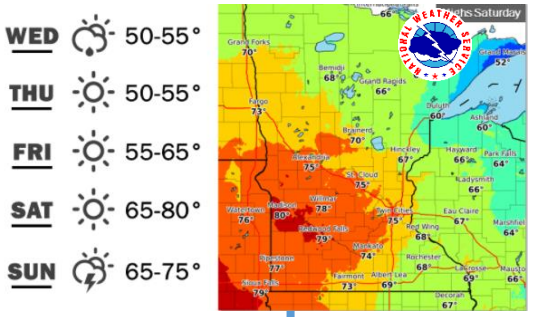




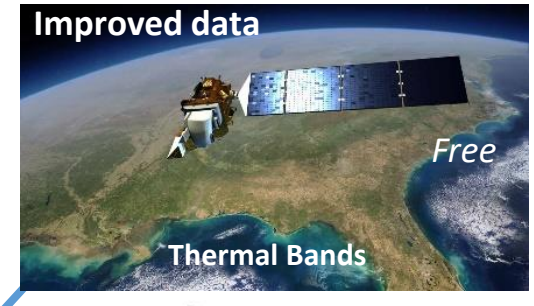
~20 Billion U.S. dollars – Incentive to protect lakes

Modeling Approach to Forecast Temperature, Chlorophyll and HAB Potential

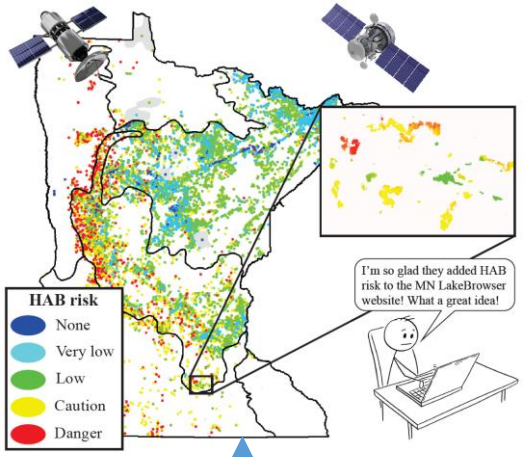
Real-time and forecast weather data



Recent & upcoming satellites: *Landsat 8 & 9*

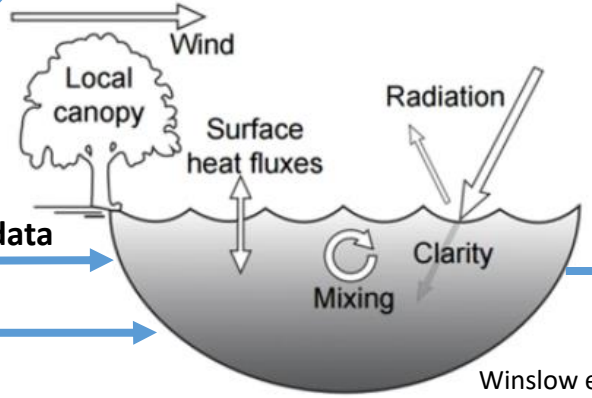


Add temperature, chlorophyll and HABs risk to LakeBrowser



UMN high performance computing systems

weather data



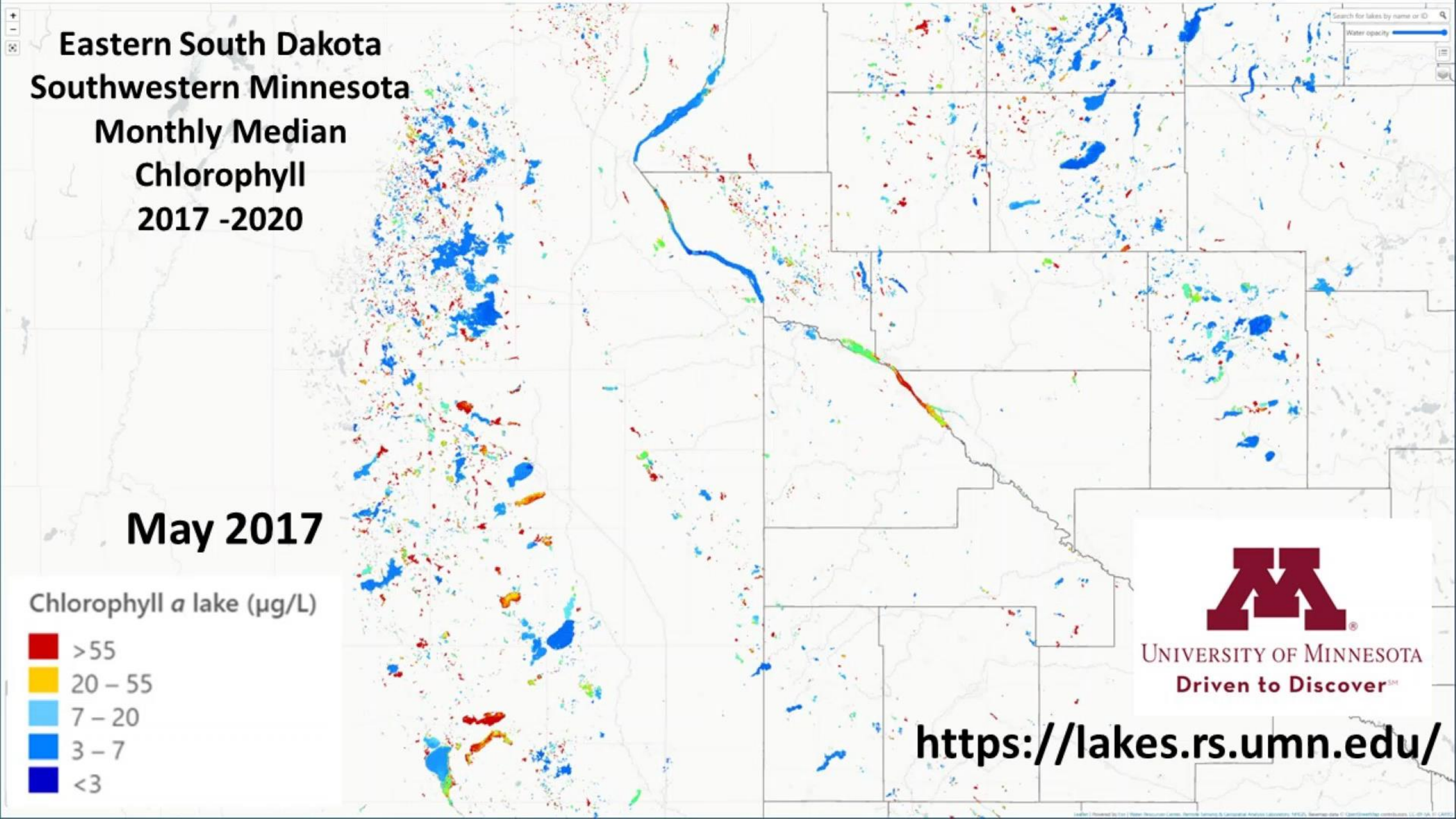
Winslow et al. 2017

Water Temperature Models

Existing Automated Water Quality Monitoring System + Satellite Derived Temperature

develop models to forecast chlorophyll/HABs

Eastern South Dakota
Southwestern Minnesota
Monthly Median
Chlorophyll
2017 -2020



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