Potential Drivers of Harmful Algal Blooms in New York State Lakes

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https://phys.org/news/2016-08-algal-blooms-true.html

The Jefferson Project at Lake George

IBM Research

Outline

- Environmental Drivers
    - Nutrients
    - Temperature
    - Wind
    - Precipitation/ Runoff
- Regional Analysis
- Jefferson Project Skaneateles Deployment

https://phys.org/news/2016-08-algal-blooms-true.html

The Jefferson Project at Lake George

IBM Research

Harmful Algal Blooms

- Seasonal patterns - rise and fall of functional groups

- Cyanobacteria (Blue Green Algae)
  - *Microcystis*
  - *Aphanizomenon*
  - *Anabaena*
  - *Planktothrix*

- Harmful algal blooms represent an unbalance in the planktonic community, in which BGA massively *outcompete* other phytoplankton for limited resources (light and nutrients)

No Bloom: A report has been evaluated by DEC HABs Program or NYSDOH staff, and there is a low likelihood that a cyanobacteria bloom is present. At least one of the following criteria must be met: (1) in the absence of a sample, visual evidence is not consistent with a cyanobacteria bloom; (2) BG chlorophyll levels ≤ 25 µg/L; (3) microscopic confirmation sample is not dominated by cyanobacteria and not present in bloom-like density; or (4) only in absence of the previous criteria being met: microcystin ≤ 4 µg/L.

Suspicious Bloom: DEC HABs Program or NYSDOH staff have determined that a report of a bloom is likely to be cyanobacteria; digital photographs, a descriptive field report from professional staff or trained volunteer or closure of a regulated swimming area all may constitute reports that can be considered Suspicious Blooms. For surveillance reports received from the public, lay monitors, etc., DEC HABs Program staff will determine if a bloom is Suspicious and whether collection of a sample is feasible or warranted.

Confirmed Bloom: The DEC HABs Program receives laboratory analytical results from a sampled bloom that fulfills at least one of the following criteria: (1) BG chlorophyll levels ≥ 25 µg/L; (2) microscopic confirmation that majority of sample is cyanobacteria and present in bloom-like densities; (3) only in absence of the previous criteria being met: microcystin ≥ 4 µg/L but less than high toxin thresholds and accompanied by ancillary evidence of the presence or recent history of a bloom.

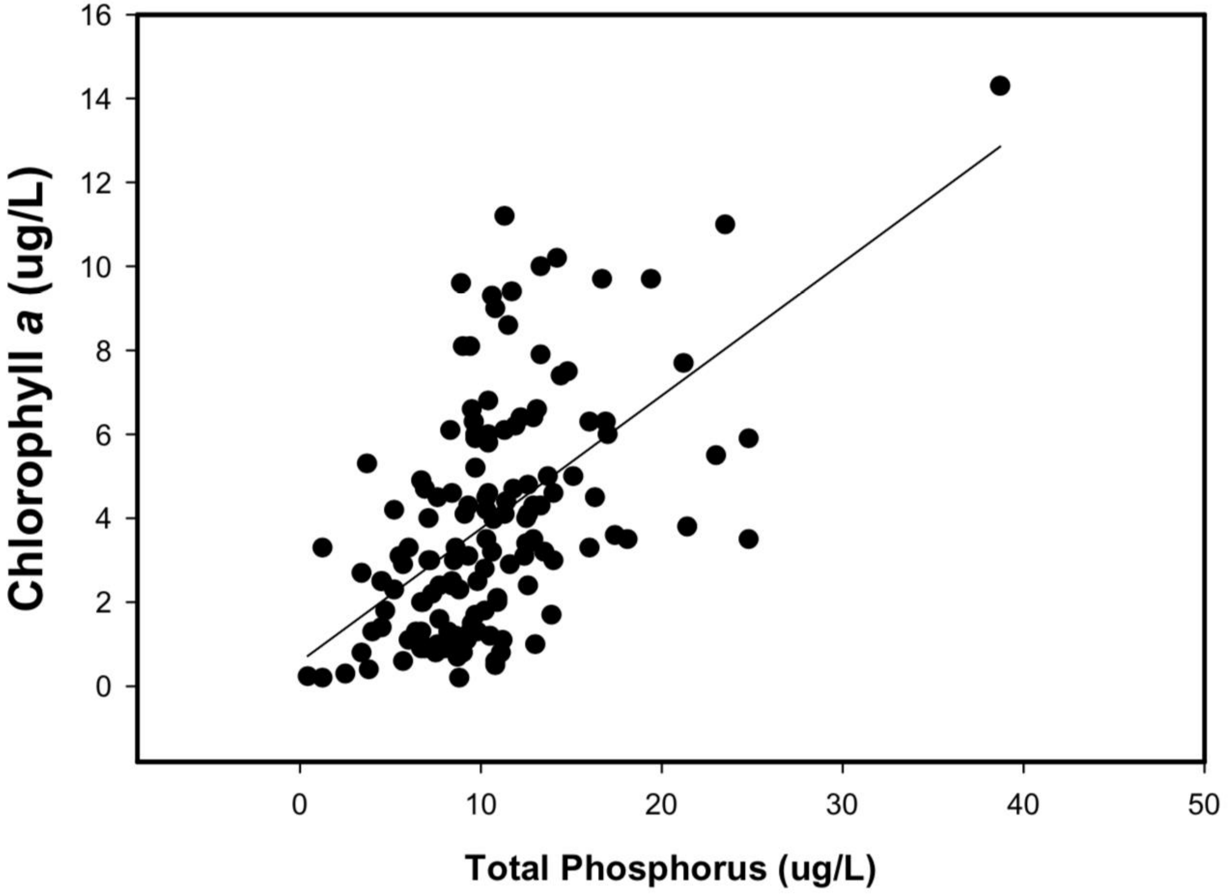
http://www.waterontheweb.org/under/lakeecology/14_algalsuccession.html

Confirmed with High Toxins Bloom: The DEC HABs Program receives laboratory analytical results from a waterbody with a Confirmed Bloom that meets either of the following criteria: (1) microcystin ≥ 20 µg/L (shoreline samples only); (2) microcystin ≥ 10 µg/L (open water samples only); (3) known risk of exposure to anatoxin or another cyanotoxin, based on consult between DEC HABs Program and NYSDOH staff.

https://www.dec.ny.gov/docs/water_pdf/habsprogramguide.pdf

Nutrients

- Basal nutrient load influences mechanisms driving HAB development

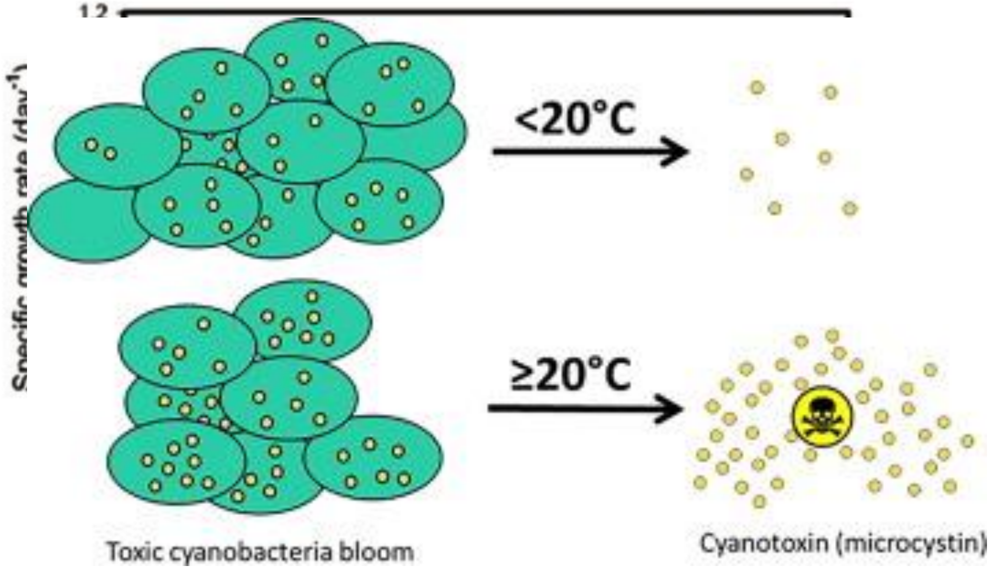


Makarewicz, Joseph & Lewis, Theodore & J. White, Daniel. (2019). Water Quality of the North End of Cayuga Lake: 1991-2006.

Temperature and Solar Irradiance

- *Microcystis* has a high Q_{10} (temperature coefficient)
    - Measure of growth for every 10°C increase in temp (Lehman *et al.,* 2013)

- Elevating ambient surface water temperatures by approximately 4°C led to significantly higher growth rates for mcyD-carrying Microcystis cells than non-toxic cells (Bui *et al*., 2018)



Bui *et al.* 2018

As growth rates of eukaryotic taxa decline, cyanobacterial growth rates reach their optima (Paerl and Huisman 2009)

Microcystis & Planktothrix = BGA
Asterionella = Diatom
Cryptomonas = Eukaryote

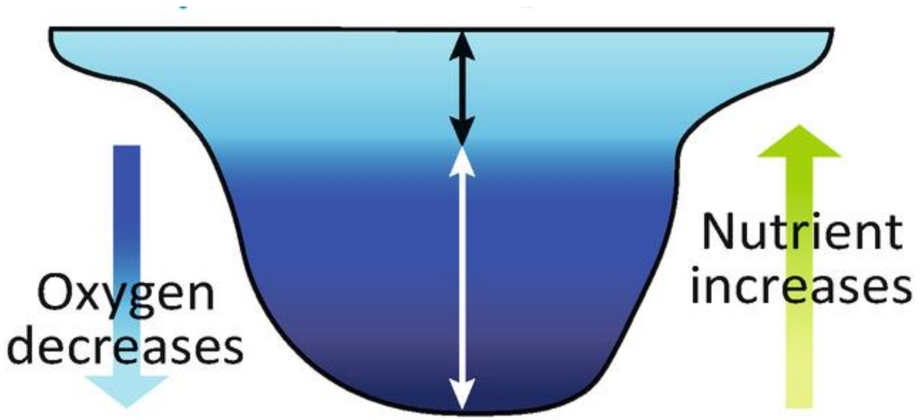
Surface Scum

- Bloom creates suboptimal photosynthetic conditions in underlying water
- Requires sustained periods of *low wind* to prevent mixing (Bartoli *et al*., 2018)

Frozen cross section of HAB

Mobility and Speed

- *Microcystis aeruginosa* migration speed = 140m d-1 (Reynolds & Walsby, 1975)
- Sinking phytoplankon or flagellar motion = 0.4 -1m d-1 (Smayda, 1970)
- Expand/ contract air vacuoles in response to environmental stimulus within minutes
- Thermocline becomes barrier to weak swimmers
- BGA can access *both* increased nutrients (hypolimnion) and increased light (photic zone)
    - Mixing reduces competitive advantage



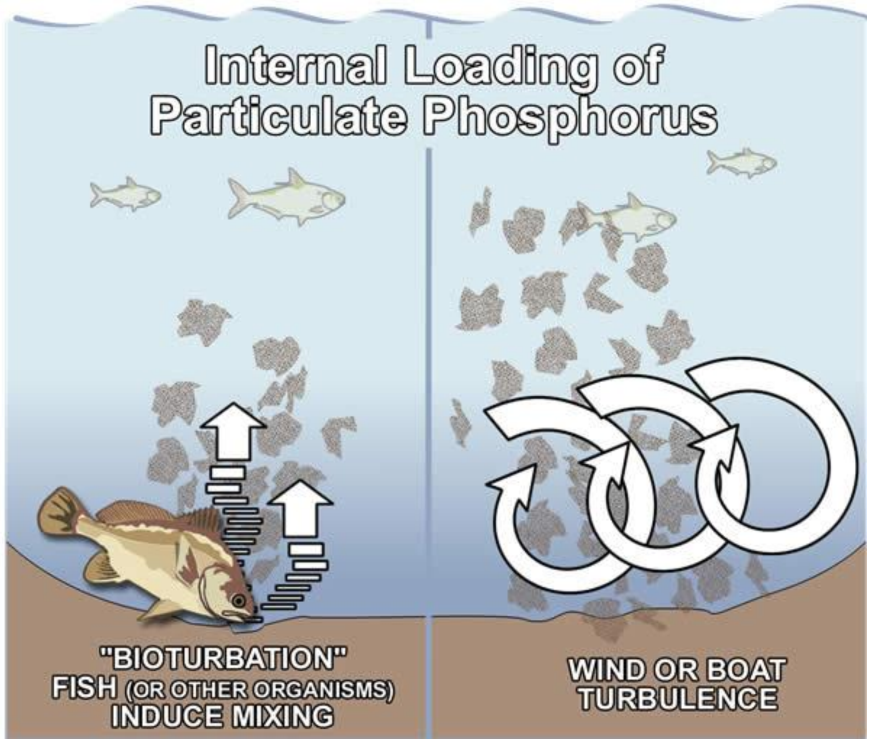
https://link.springer.com/chapter/10.1007/978-3-319-93043-5_6

Internal Loading

- Internal Loading
  - Chemical reduction of Iron-P compounds (hypoxia)

- Interstitial water within benthic sediment

- Physical mixing of benthic sediment transports trapped nepheloid nutrients into water column



http://www.lmvp.org/Waterline/fall2006/pwithin2.html

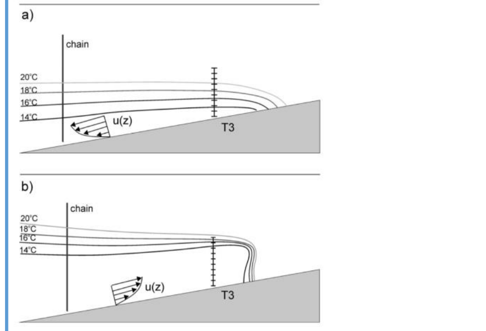
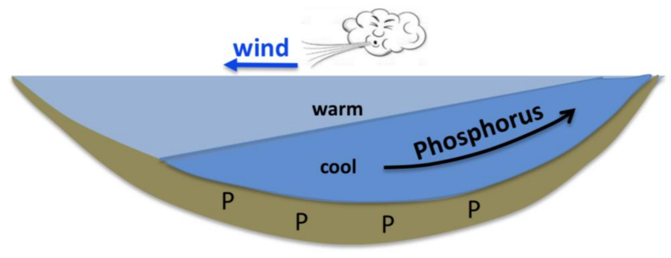
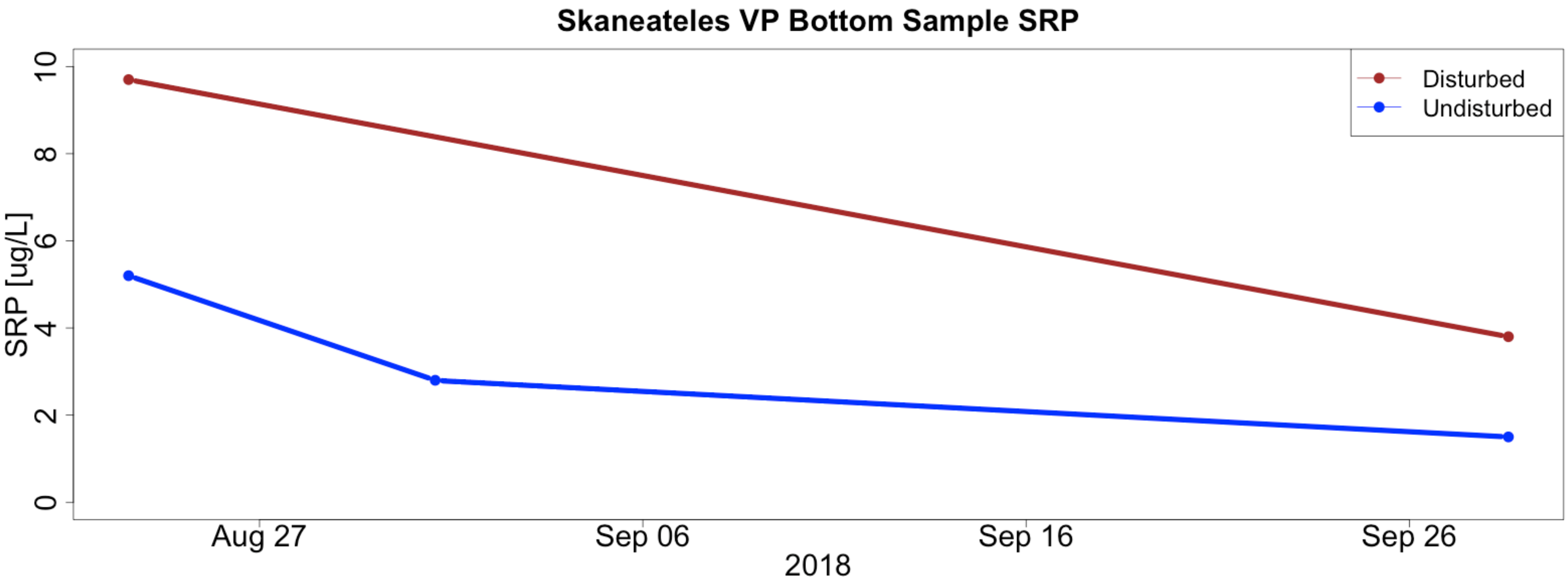


Figure 6. A schematic diagram describing the asymmetry in stratification between up and downwelling events. The position of isotherms is shown at both the deep mooring and the benthic mooring. a) During downwelling events there is a stable stratification in the water column. b) During upwelling events the isotherms resemble a 'bore-like' structure due to cold water that advances fast from deeper parts of the lake along the shallow slope.
doi:10.1371/journal.pone.0057444.g006

Cossu and Wells, 2013 (Lake Simcoe)



It comes from the Mud! Nutrients, Internal, Loading, Internal Waves, and Infernal Honeoye HABs.
Nelson Hairston, Cornell University

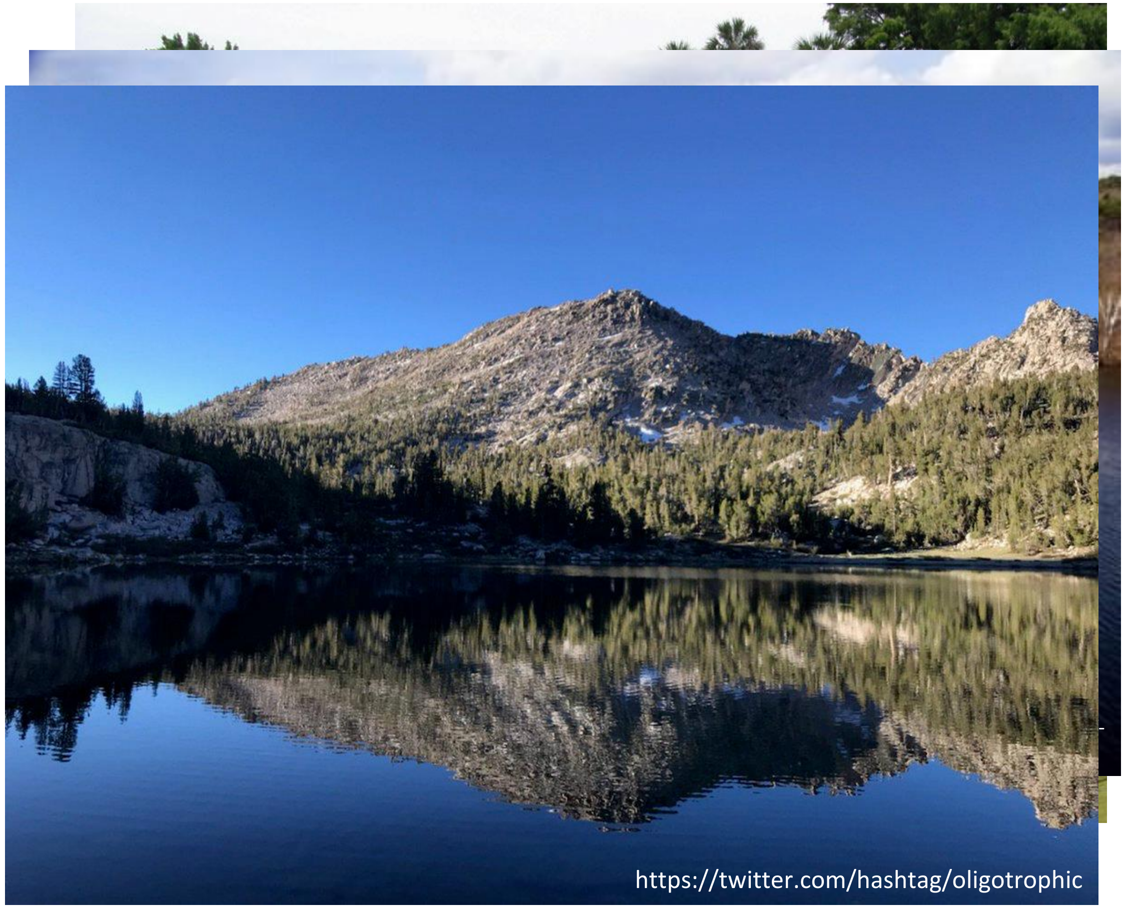


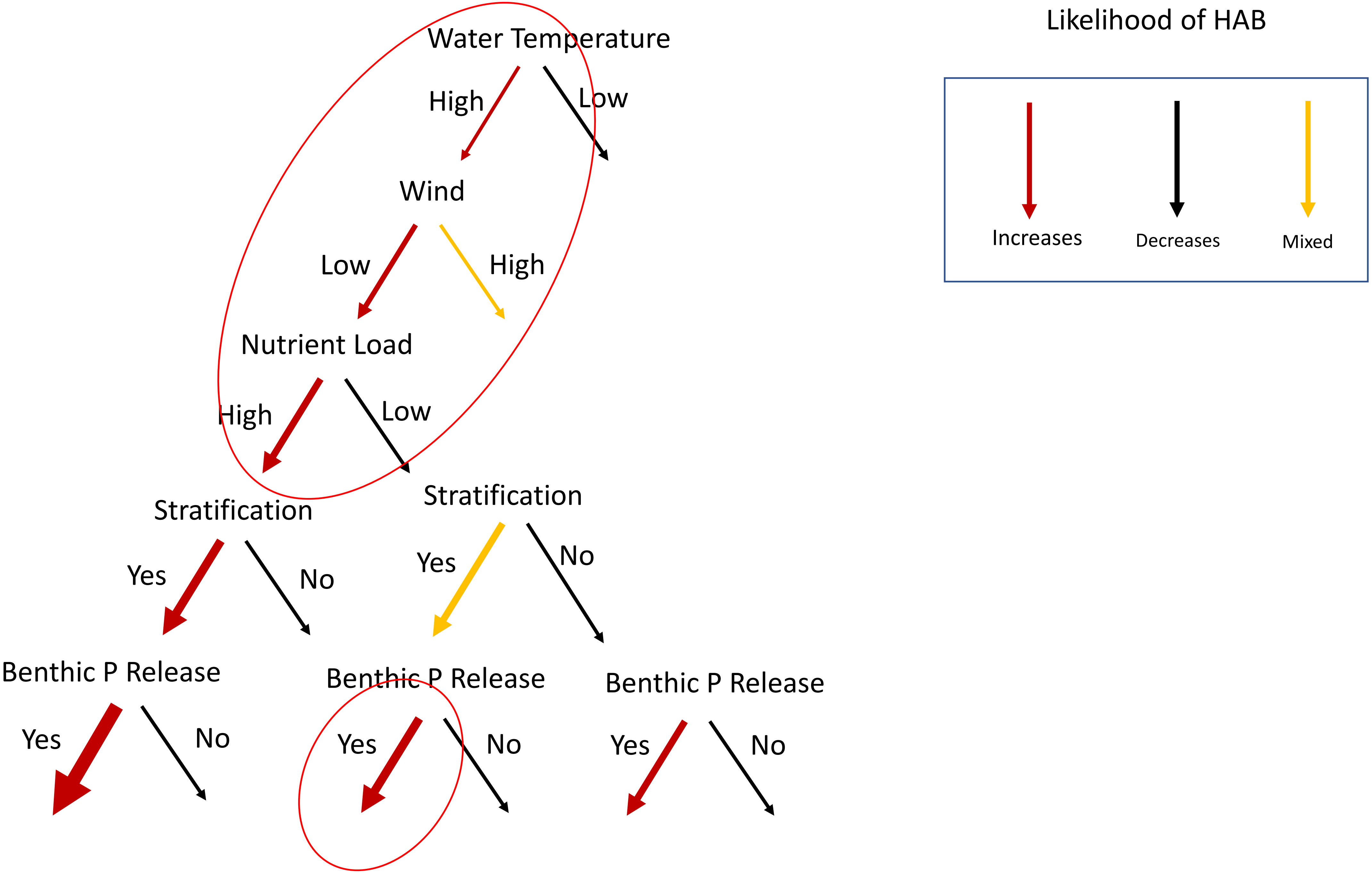
BGA - Competitive Advantage

- Chronic Loading
  - High Temp (Q_{10} and ↑ stratification)
  - Low wind (scum formation)

- Acute Loading
  - Precipitation (external loading)
  - Runoff = nutrients accessible by all functional groups
    - No competitive advantage

- Divergence in vertical nutrient profile
  - Stratification
  - Internal Loading
  - BGA mobility gives competitive advantage through preferential access to nutrients


https://twitter.com/hashtag/oligotrophic



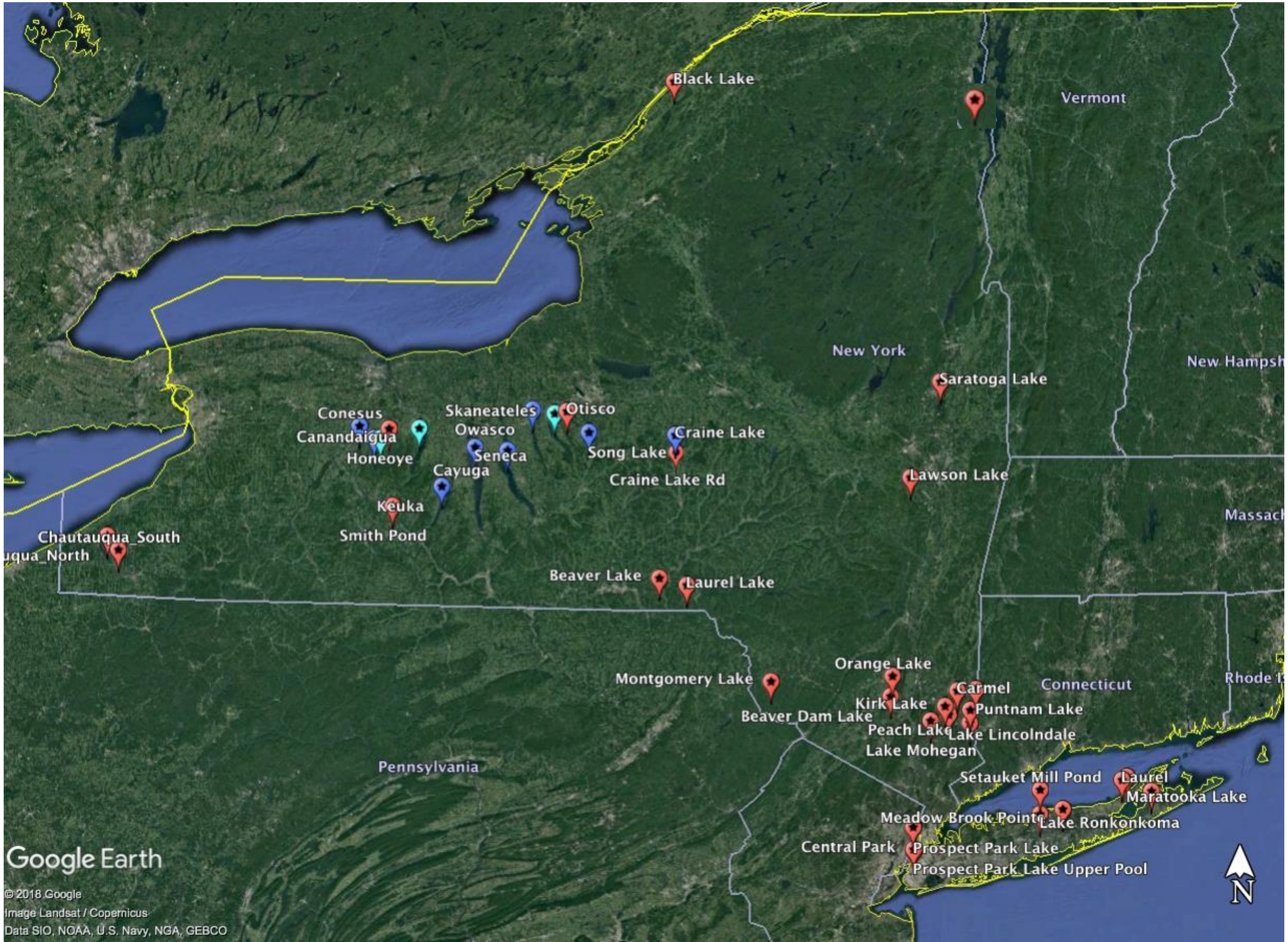
Likelihood of HAB
Increases
Decreases
Mixed
Water Temperature
High
Low
Wind
Low
High
Nutrient Load
High
Low
Stratification
Yes
No
Stratification
Yes
No
Benthic P Release
Yes
No
Benthic P Release
Yes
No
Benthic P Release
Yes
No

Regional Analysis

- HABs Reports
  - 40 Lakes + 12 Basins
  - DEC (Rebecca Gorney)
  - Skaneateles Lake Association
  - Vermont DOH
  - Seneca Lake Pure Waters Association (Frank DiOrio)

- Weather Data
  - Meteorological Assimilation Data Ingest System
  - Hobart William Smith (John Halfman)

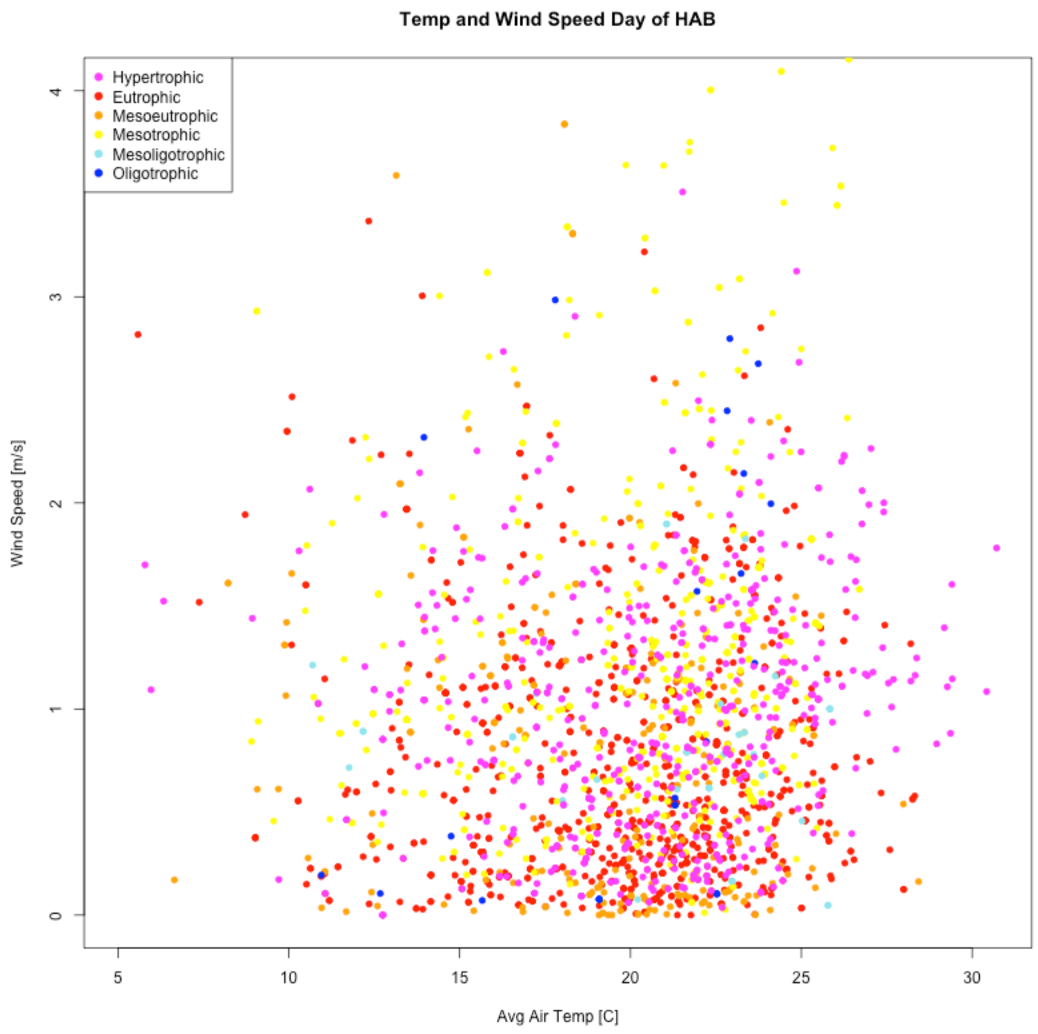
Geographic Coverage



Regional Analysis

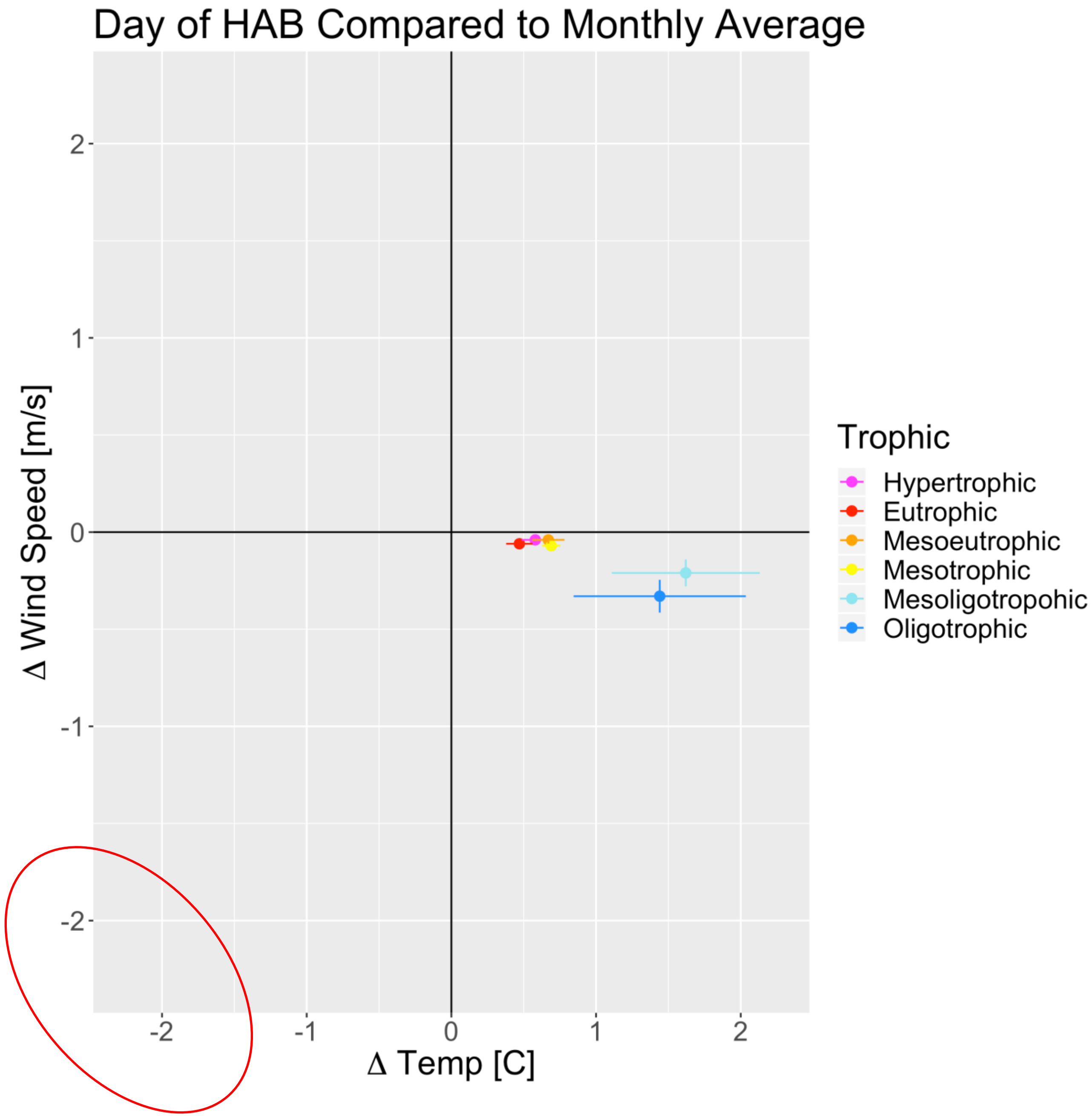
- Air temperature & wind speed
- Trophic status as indicator of chronic nutrient load

- Shotgun pattern
  - Variance indicates complex/ multiple interrelated drivers for HABs
  - Meteorological data is not the *whole story*
    - Lake specific conditions
    - Species specific physiology
    - N:P ratio
    - Grazer effect
    - Invasive species

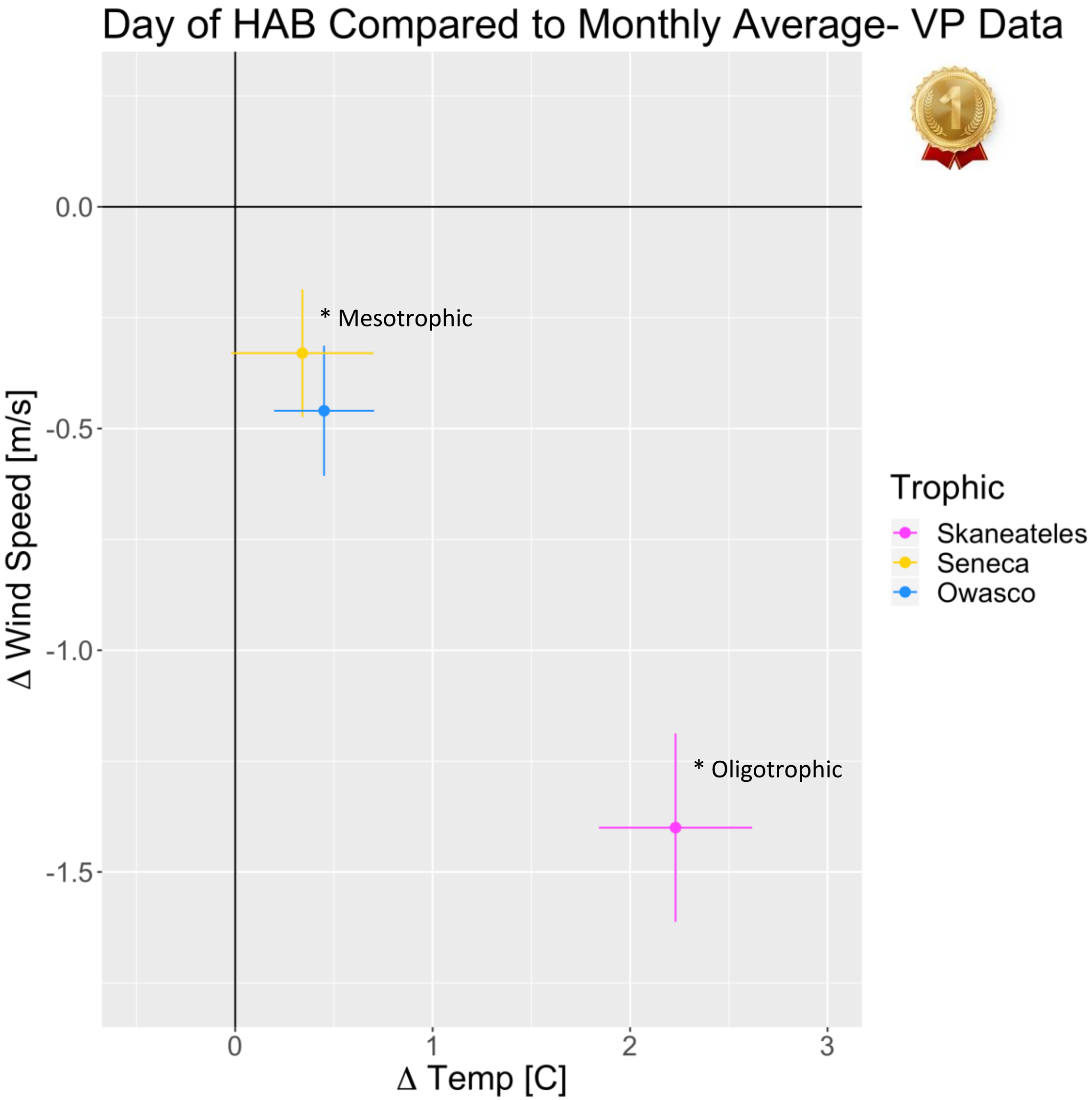


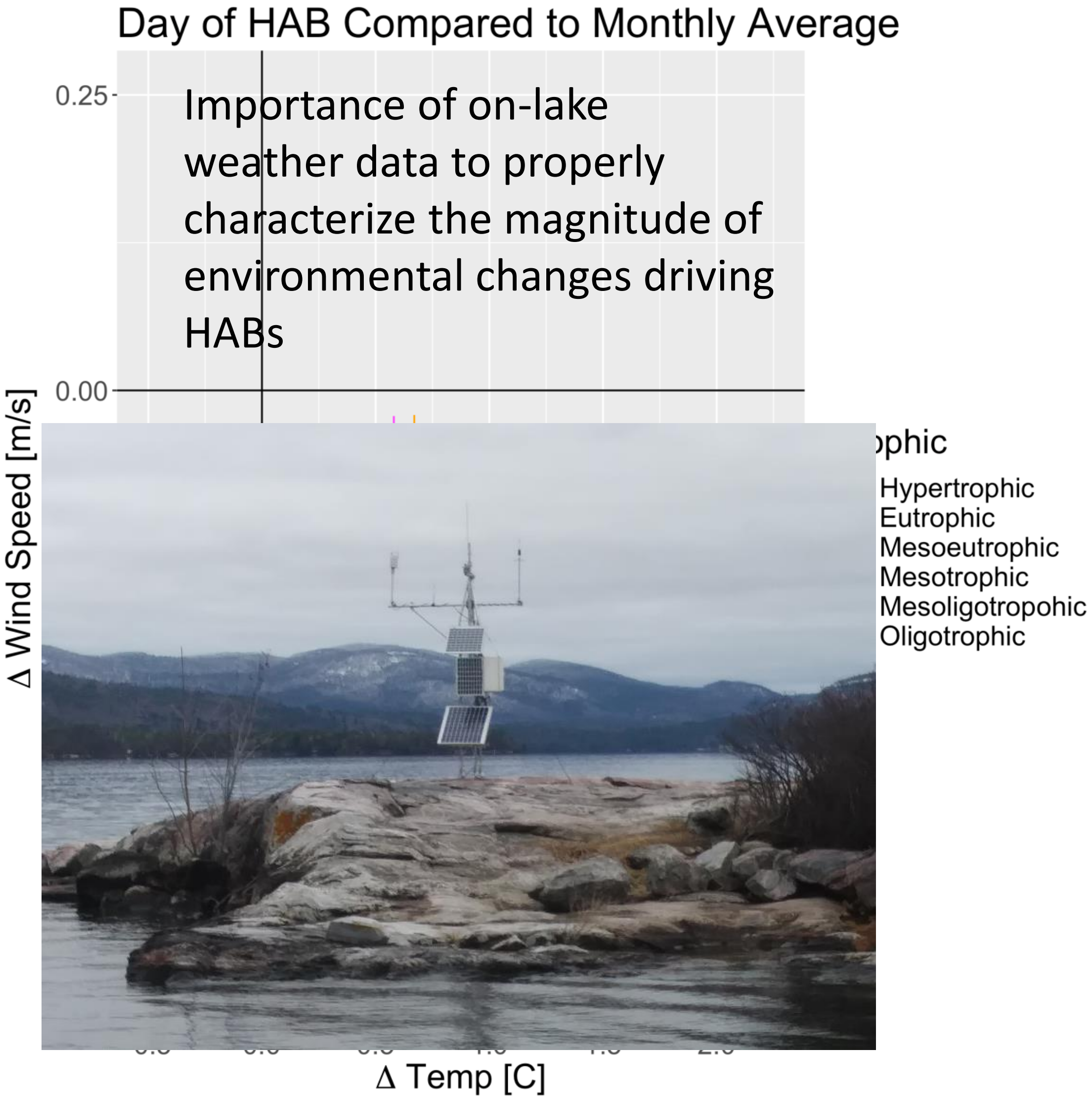
Regional Analysis

- All trophic levels have a lower than average wind speed, and higher temps on the day of a HAB
- Higher trophic lakes cluster together
  - Above nutrient threshold - lakes are *primed* for HABs
  - May only take a small change in either temp or wind to trigger a HAB
- Oligotrophic lakes require a much bigger environmental *push* to trigger a HAB

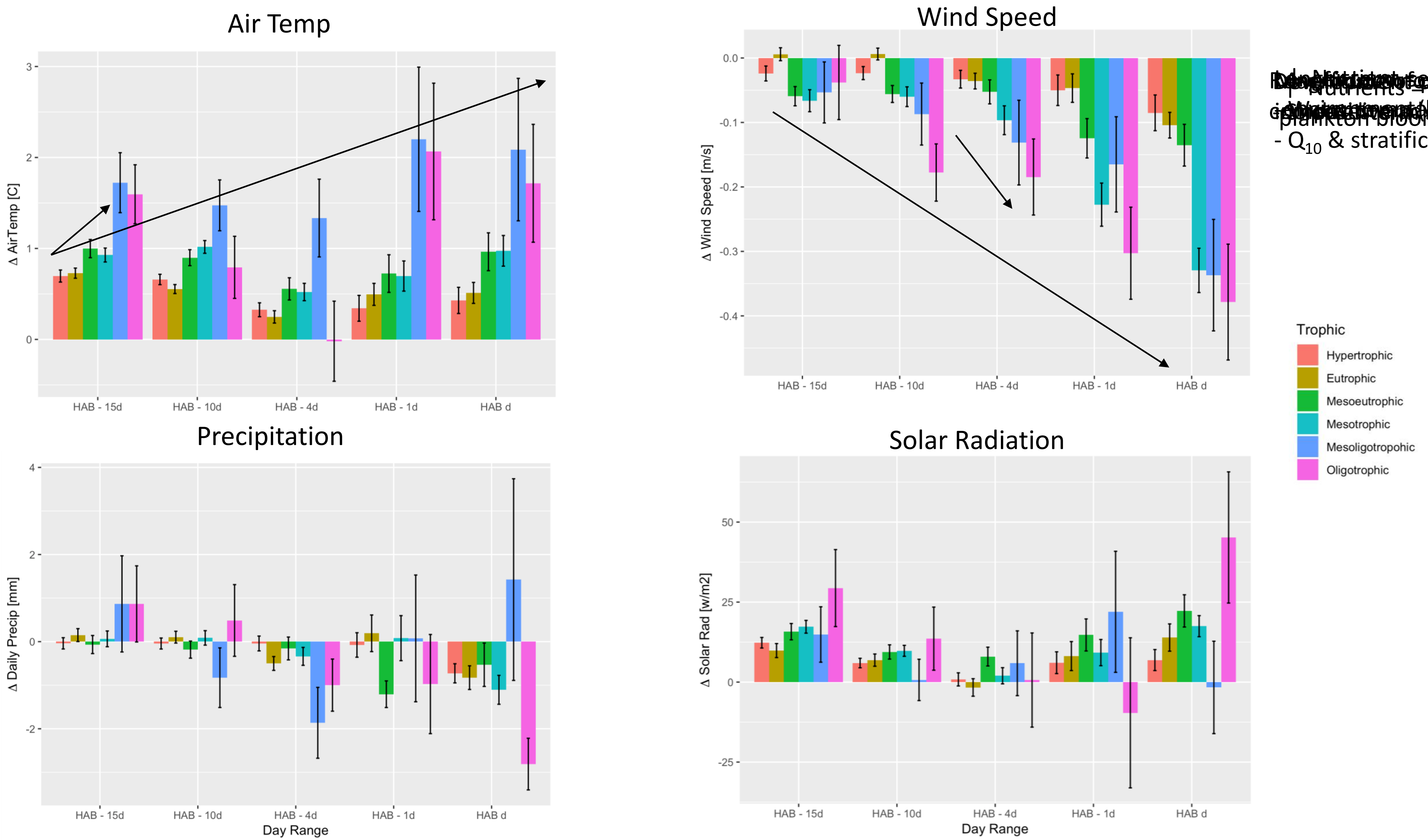


Mesonet vs On-Lake stations show similar pattern (~ 2x Δ)





Importance of on-lake weather data to properly characterize the magnitude of environmental changes driving HABs



- Q_{10} & stratification

Finger Lakes as Living Laboratory

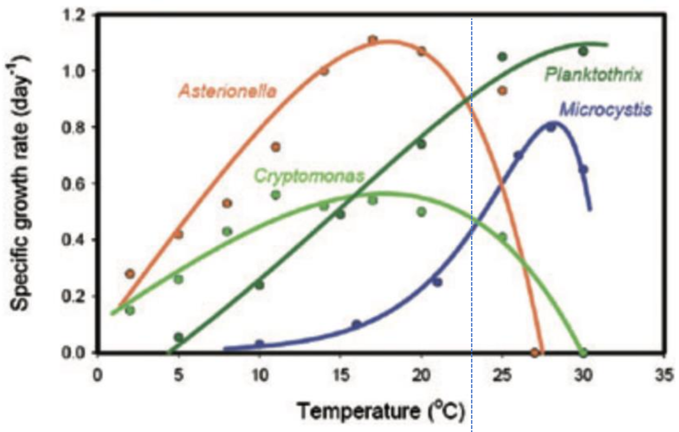
- Finger Lakes have similar:
  - Climate
  - Orientation
  - Geologic history
- Range of trophic levels

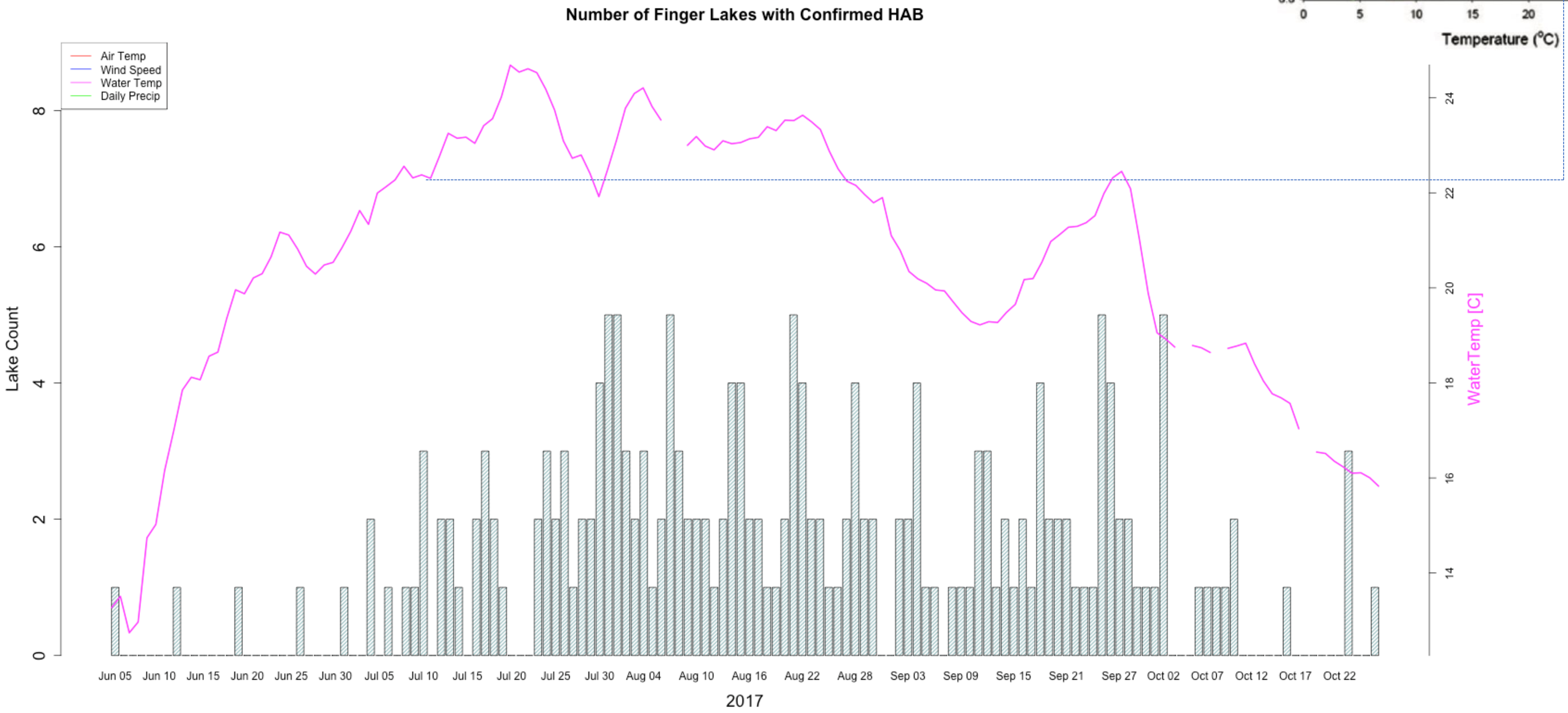
- Confirmed HABs on multiple Finger Lakes in a single day
  - Suggests favorable weather conditions for bloom formation

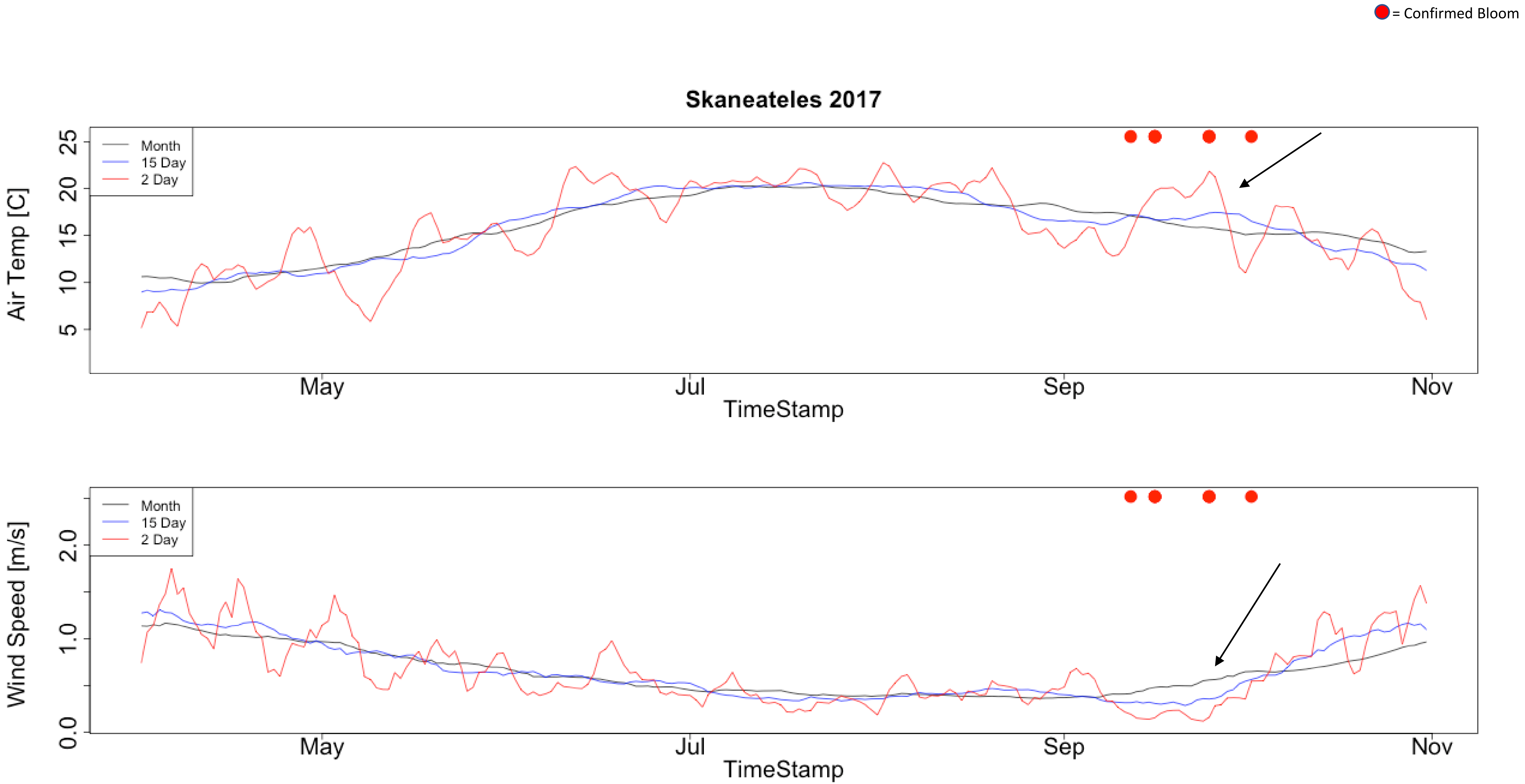
https://www.nasa.gov/multimedia/imagegallery/image_feature_276.html

Finger Lakes as Living Laboratory

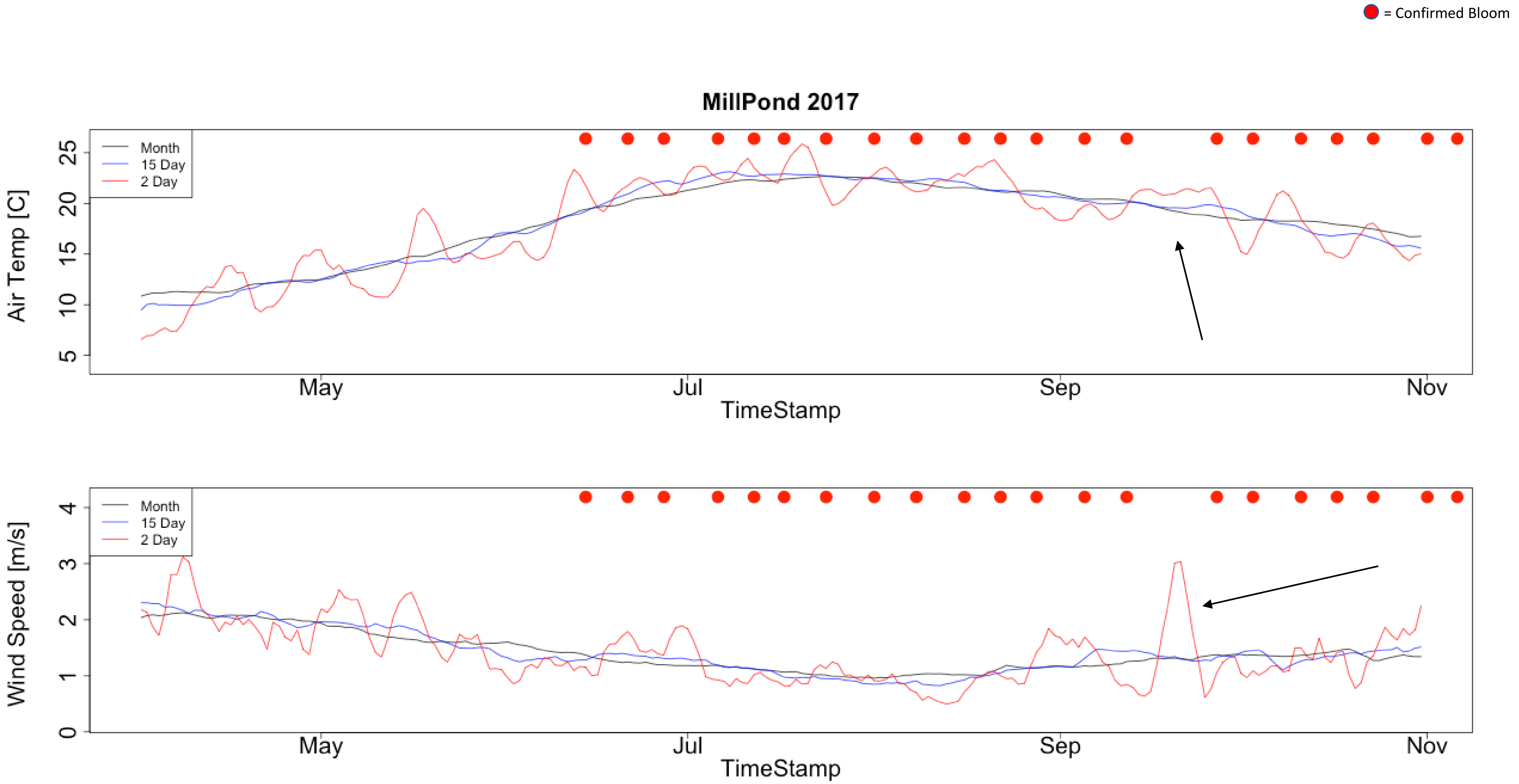
Water Temperature

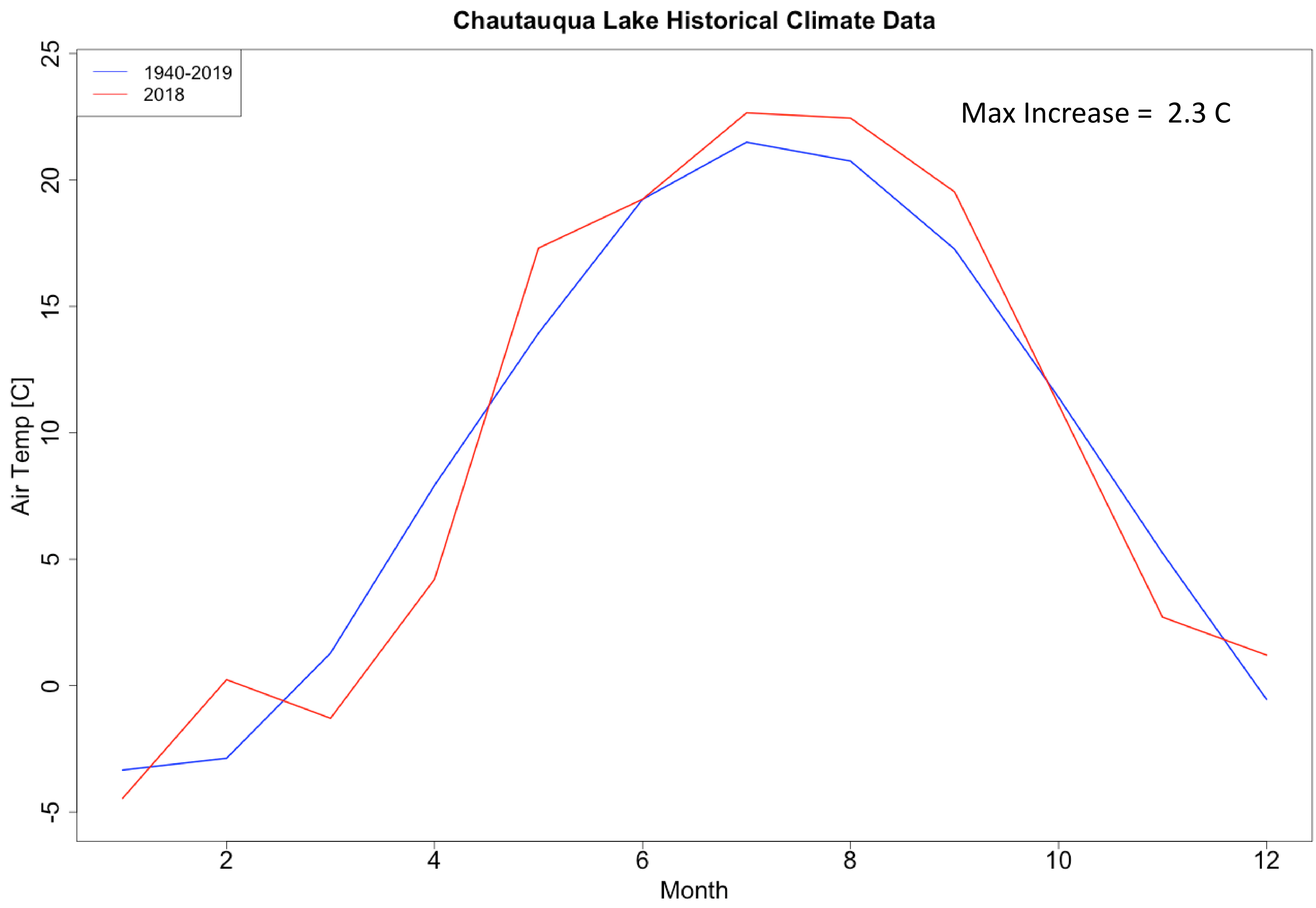






= Confirmed Bloom
Skaneateles 2017
Air Temp [C]
25
20
15
10
5
Month
15 Day
2 Day
May
Jul
Sep
Nov
TimeStamp
Wind Speed [m/s]
2.0
1.0
0.0
Month
15 Day
2 Day
May
Jul
Sep
Nov
TimeStamp


= Confirmed Bloom
MillPond 2017
Month
15 Day
2 Day
Air Temp [C]
5
10
15
20
25
May
Jul
Sep
Nov
TimeStamp
Wind Speed [m/s]
0
1
2
3
4
May
Jul
Sep
Nov
TimeStamp



Chautauqua Lake Historical Climate Data
1940-2019
2018
Max Increase = 2.3 C
Air Temp [C]
Month
-5
0
5
10
15
20
25
2
4
6
8
10
12

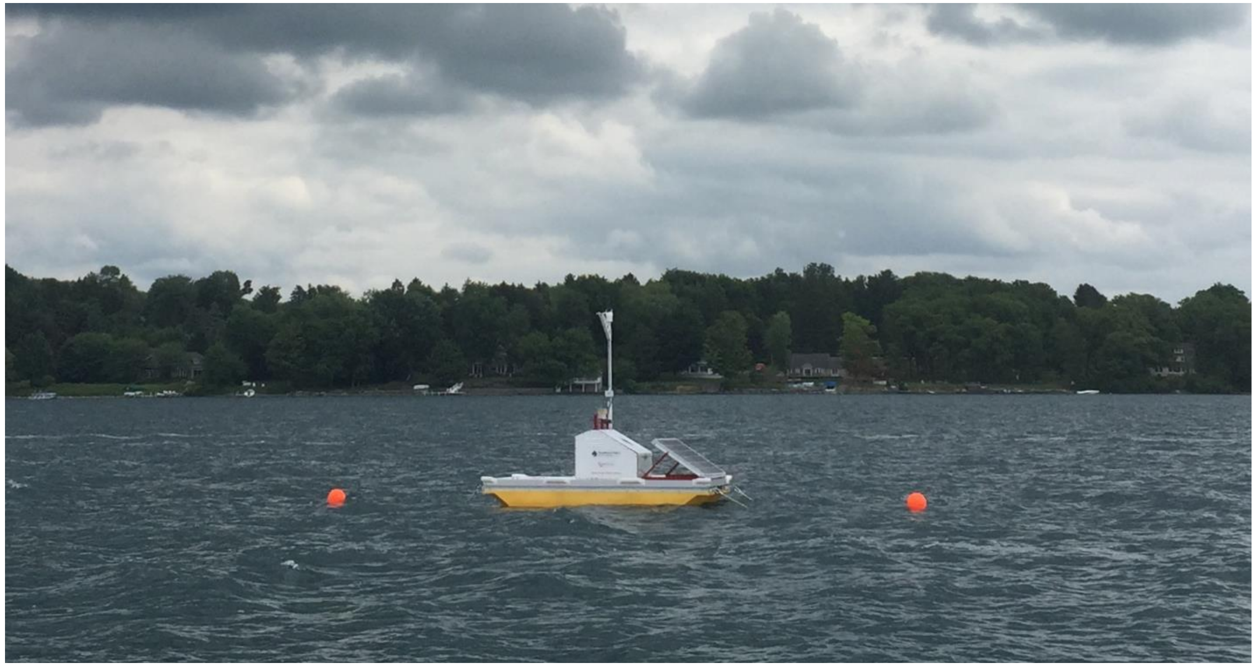
Machine Learning Model

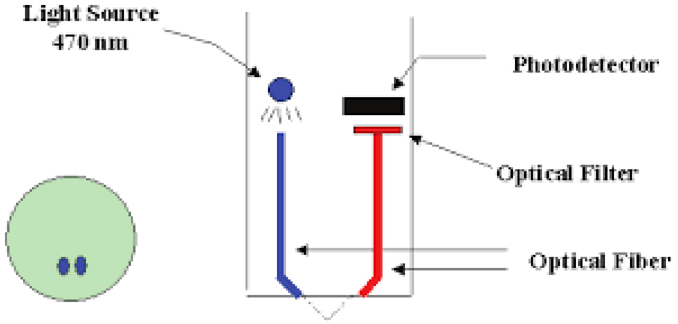
- Random Forest
- Measures of importance
    - Air temp (long & short range)
    - Wind speed (short range)
    - Solar radiation (short range)
    - Precipitation (mid & long range)

https://www.analyticsvidhya.com/blog/2016/04/complete-tutorial-tree-based-modeling-scratch-in-python/

Skaneateles Deployment

- Technology from the Jefferson Project at Lake George
- Hydrodynamic and weather modeling
- Vertical profiler collected over 23 GB of data
- Analysis is ongoing
- Monitoring – Importance of HF data for HABs monitoring
    - EXO2 sonde set at 4 Hz sampling rate (UHF)
    - High sampling rate allows for detailed characterization of complex and ephemeral events
    - Overcome inherent limitations of sensors

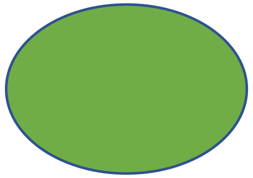




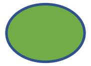
685 +/- 20 nm

20 mg/L

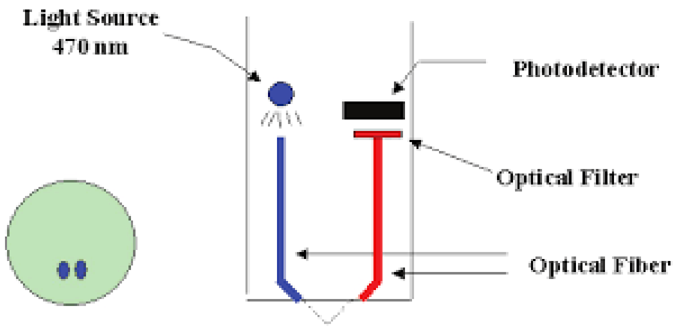
5 mg/L

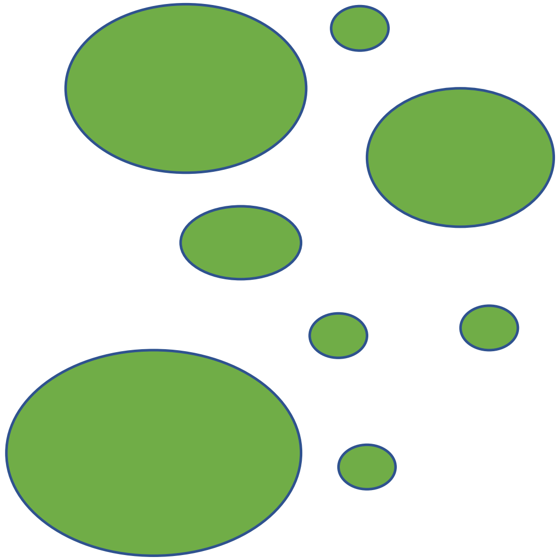


10 mg/L



5 mg/L

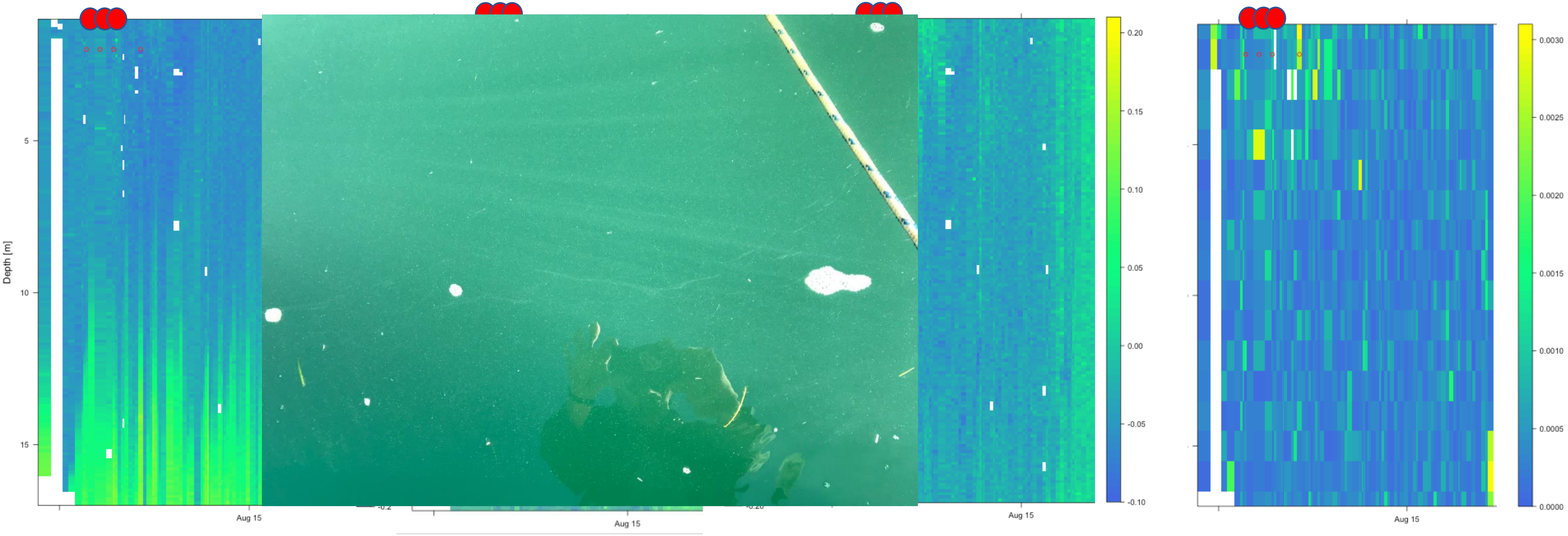




If sampling rate is low, run the risk of underestimating variability in system and are more likely to run afoul of shortcomings in sensor technology

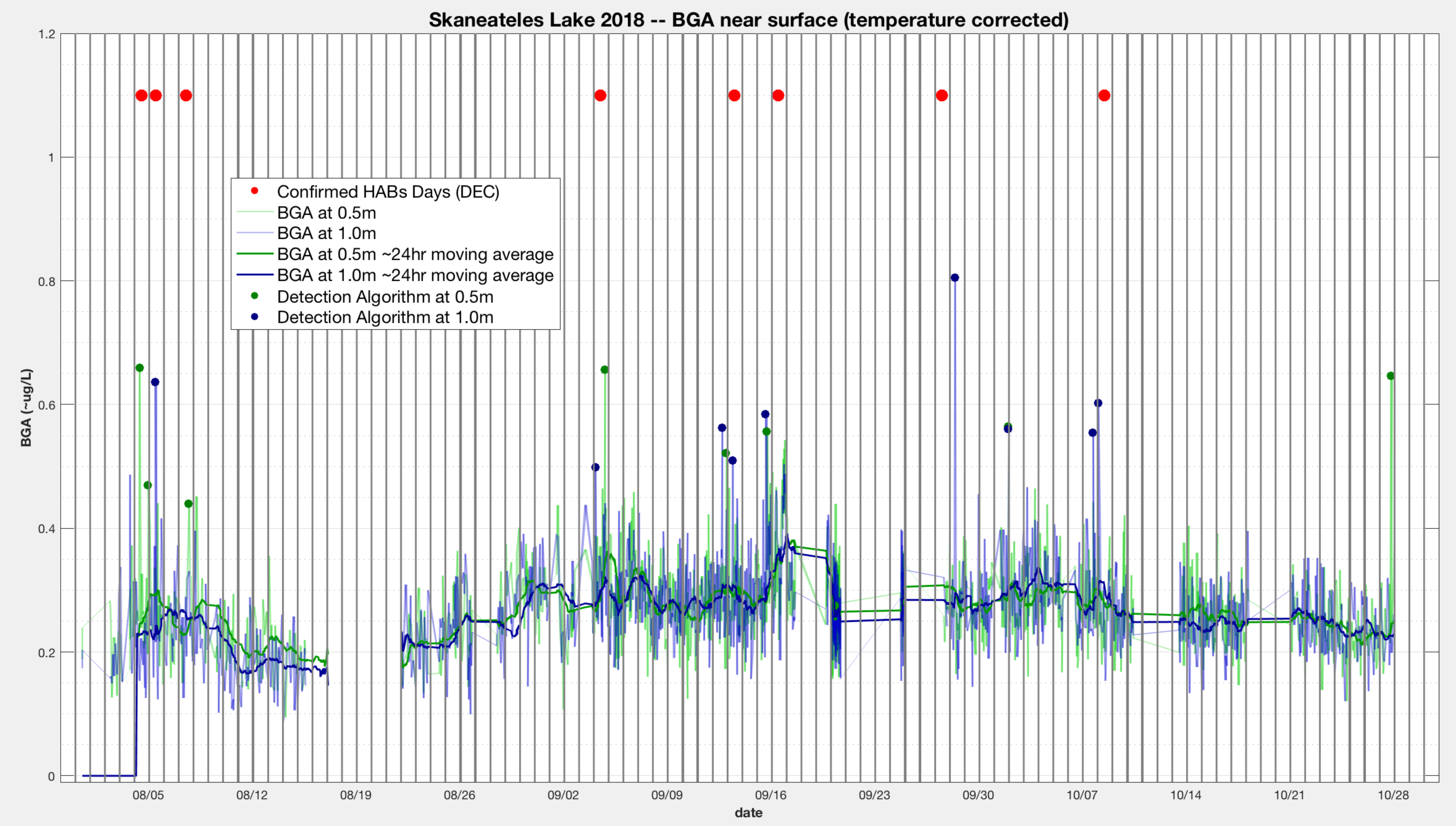
4 Hz Sampling Rate
Mid-Lake VP

BGA (Raw) | BGA (Temp Corrected) | Ratio BGA/ Chl a | BGA Variance per Meter

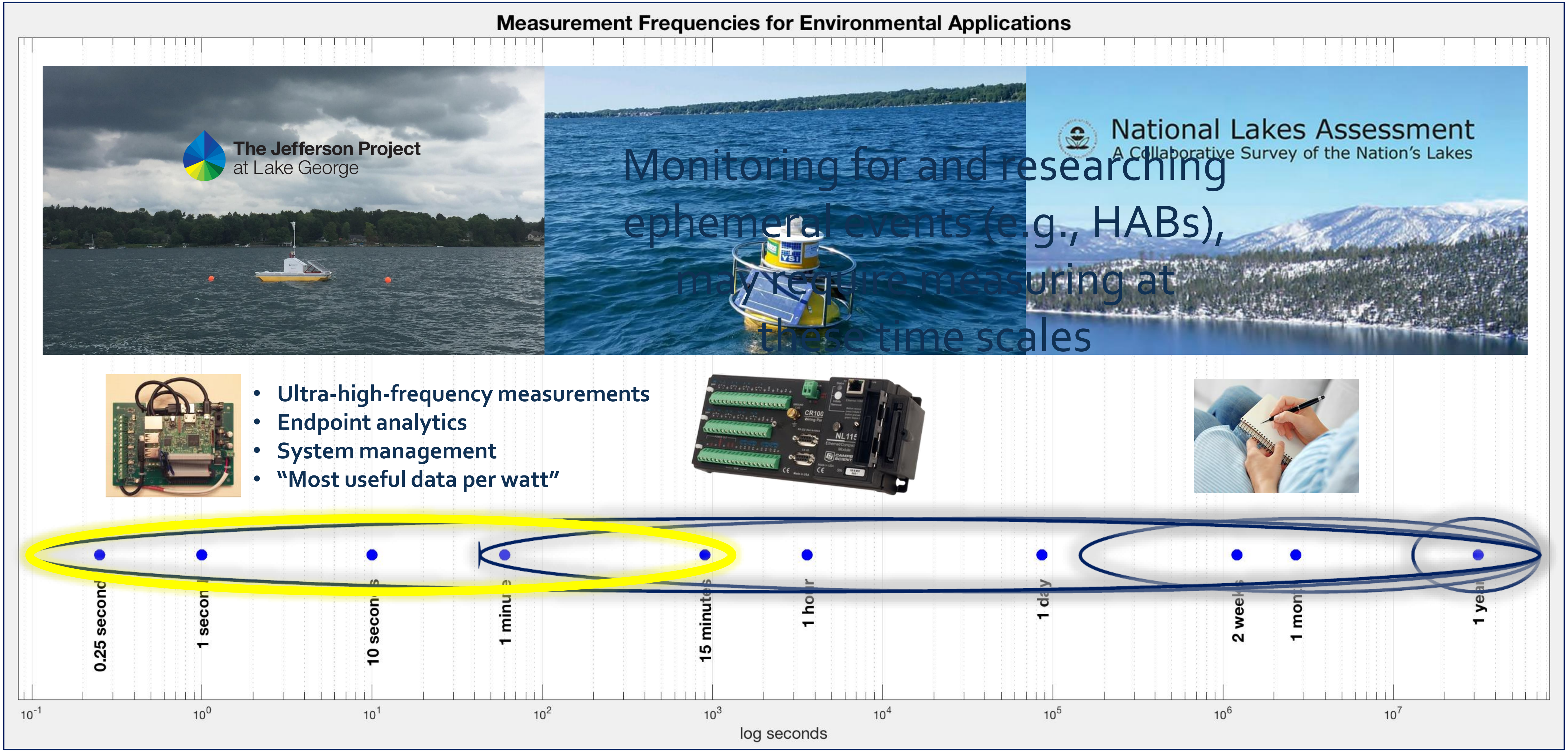


= Confirmed Bloom

2018 Aug 04, 05, 07



Skaneateles Lake 2018 -- BGA near surface (temperature corrected)
Confirmed HABs Days (DEC)
BGA at 0.5m
BGA at 1.0m
BGA at 0.5m ~24hr moving average
BGA at 1.0m ~24hr moving average
Detection Algorithm at 0.5m
Detection Algorithm at 1.0m
BGA (~ug/L)
date
1.2
1
0.8
0.6
0.4
0.2
0
08/05
08/12
08/19
08/26
09/02
09/09
09/16
09/23
09/30
10/07
10/14
10/21
10/28



Measurement Frequencies for Environmental Applications
The Jefferson Project at Lake George
National Lakes Assessment
A Collaborative Survey of the Nation's Lakes
Monitoring for and researching ephemeral events (e.g., HABs), may require measuring at these time scales
• Ultra-high-frequency measurements
• Endpoint analytics
• System management
• "Most useful data per watt"
0.25 second
1 secon
10 secon
1 minu
15 minute
1 hou
1 da
2 wee
1 mon
1 yea
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}
10^{6}
10^{7}
log seconds

The Jefferson Project
at Lake George

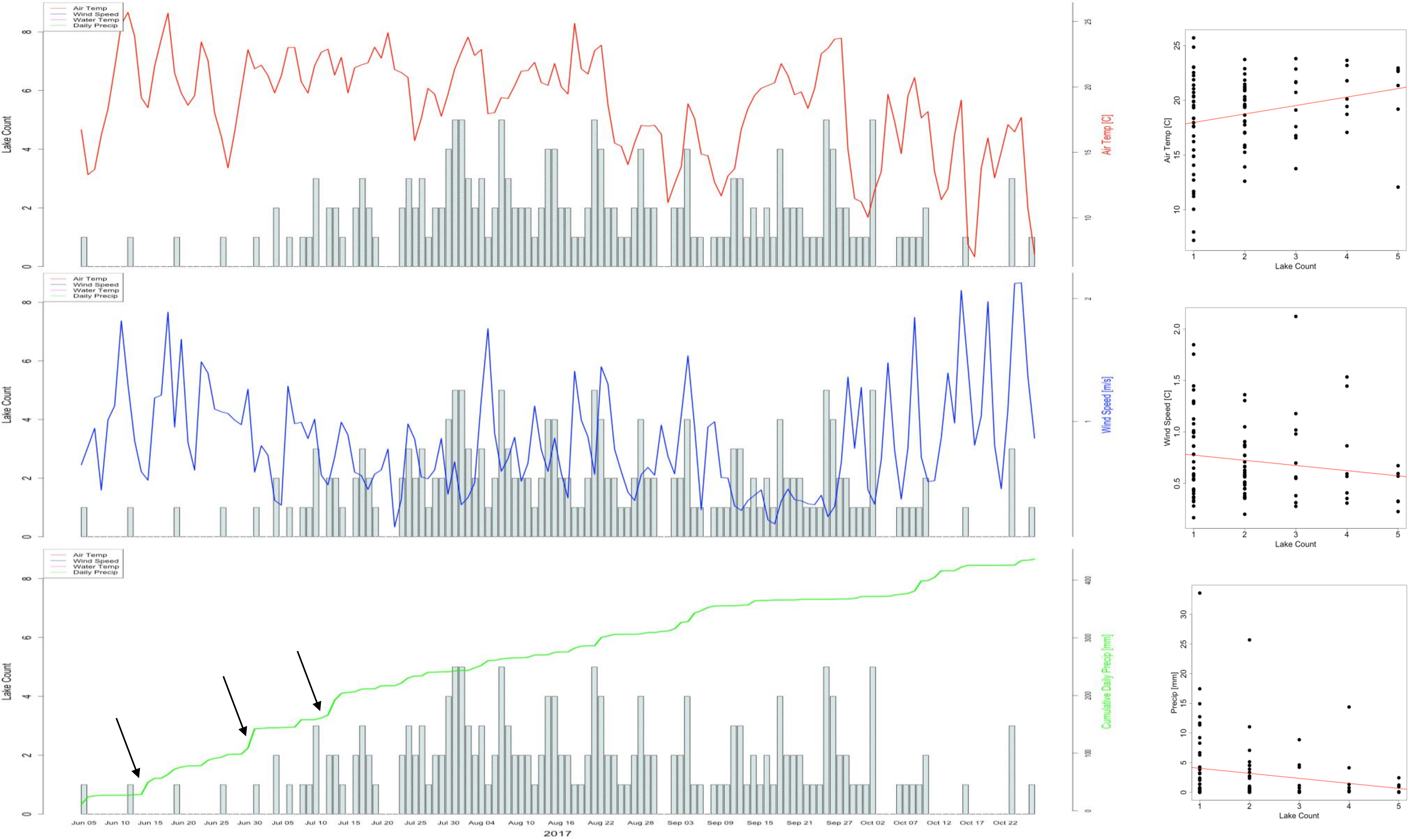
Michael Kelly
Harry Kolar
Campbell Watson
Guillaume Auger
Michael Henderson
Lloyd Treinish
Eli Dow

Rebecca Gorney
Frank DiOrio
John Halfman
Meghan Brown
Eric Siy
Jim Sutherland

Kevin Rose
Jeremy Farrell
Mark Lucious
Rachael DeWitt
Paul Torrisi
John Menapace

Larry Eichler
Mark Swinton
Rick Relyea
Laurie Ahren
David Diehl
Ken Johnson

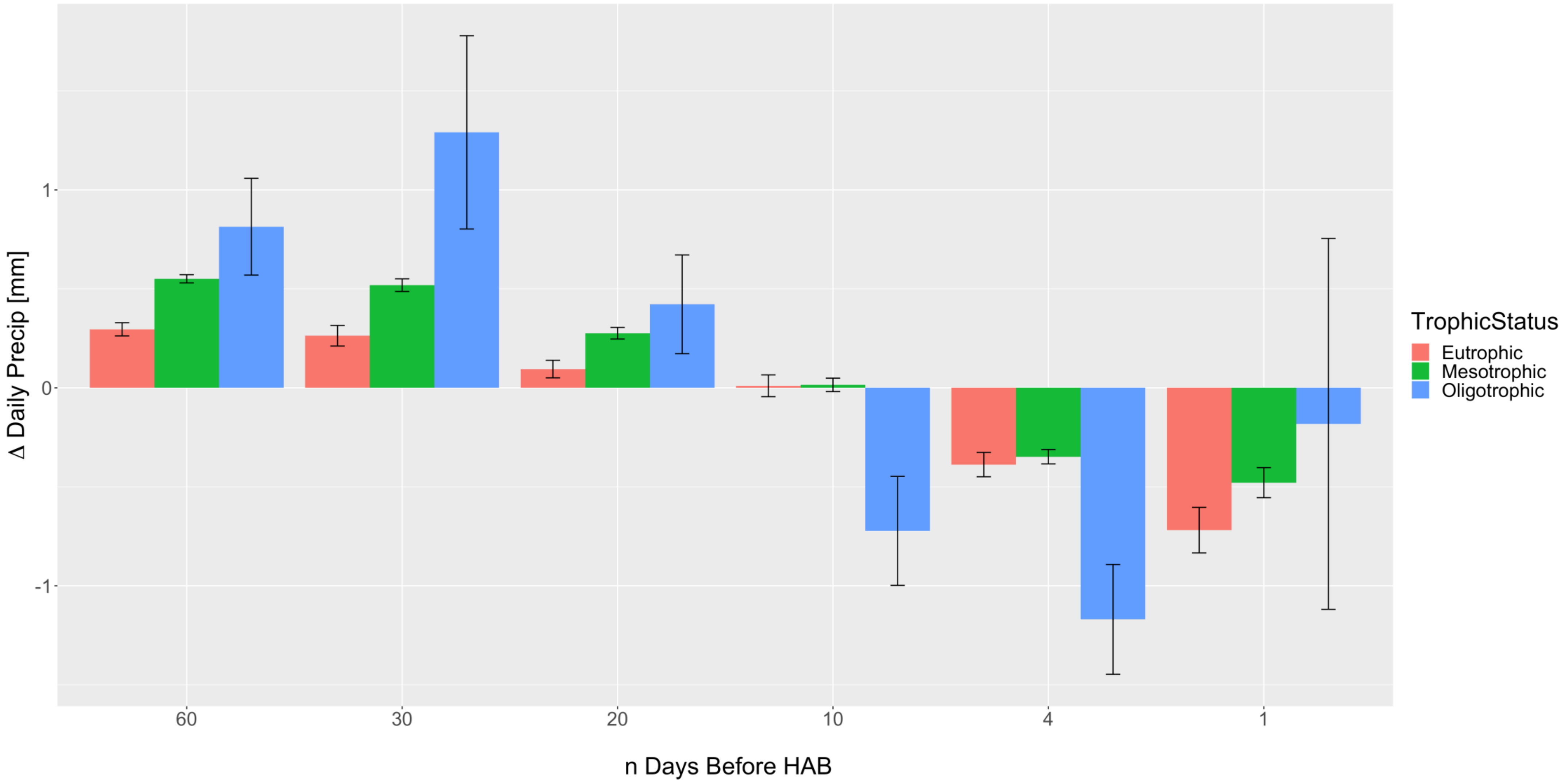
Back Up Slides



Air Temp
Wind Speed
Water Temp
Daily Precip
Lake Count
Air Temp [C]
Wind Speed [m/s]
Cumulative Daily Precip [mm]
Jun 05
Jun 10
Jun 15
Jun 20
Jun 25
Jun 30
Jul 05
Jul 10
Jul 15
Jul 20
Jul 25
Jul 30
Aug 04
Aug 10
Aug 16
Aug 22
Aug 28
Sep 03
Sep 09
Sep 15
Sep 21
Sep 27
Oct 02
Oct 07
Oct 12
Oct 17
Oct 22
2017
Wind Speed [C]
Precip [mm]

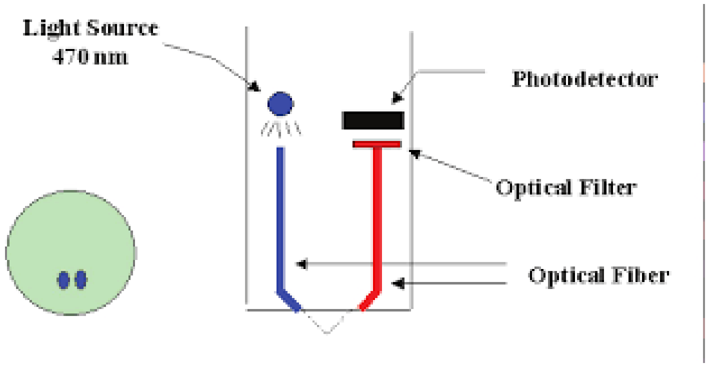
Longer Term Drivers

Precipitation/ Runoff

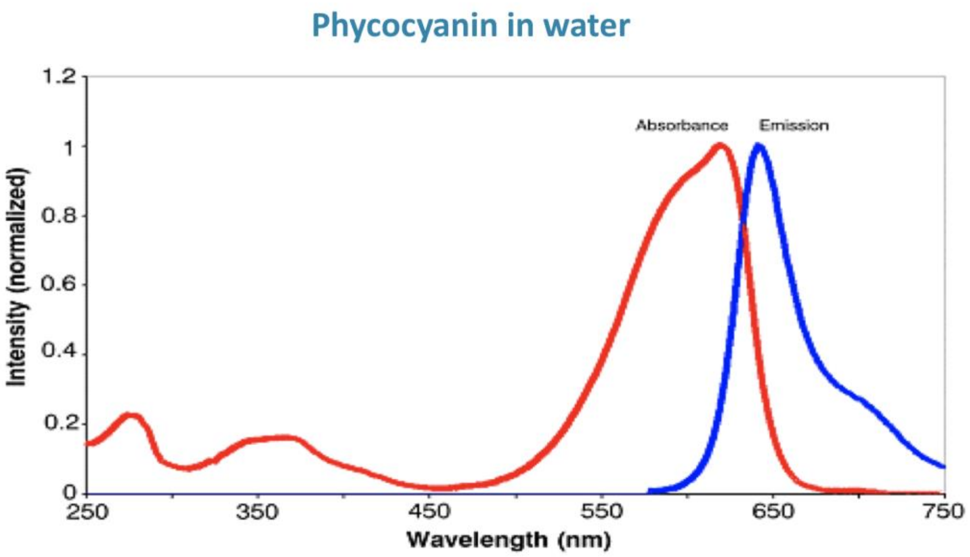


Bloom Characterization

BGA Sensor



Parameter	Phycocyanin	Chlorophyll
Ex ʎ	590 ± 15 nm	470 ± 15 nm
Em ʎ (meas.)	685 ± 20 nm	685 ± 20 nm
Range	0 to 100 RFU; 0 to 100 µg/L PC	0 to 100 RFU; 0 to 400 µg/L Chl
Resolution	0.01 RFU; 0.01 µg/L PC	0.01 RFU; 0.01 µg/L Chl
Detection Limit	0.01 µg/L PC	0.01 µg/L Chl



https://www.ysi.com/File%20Library/Documents/Technical%20Notes/T606-The-Basics-of-Chlorophyll-Measurement.pdf

Water Research Foundation

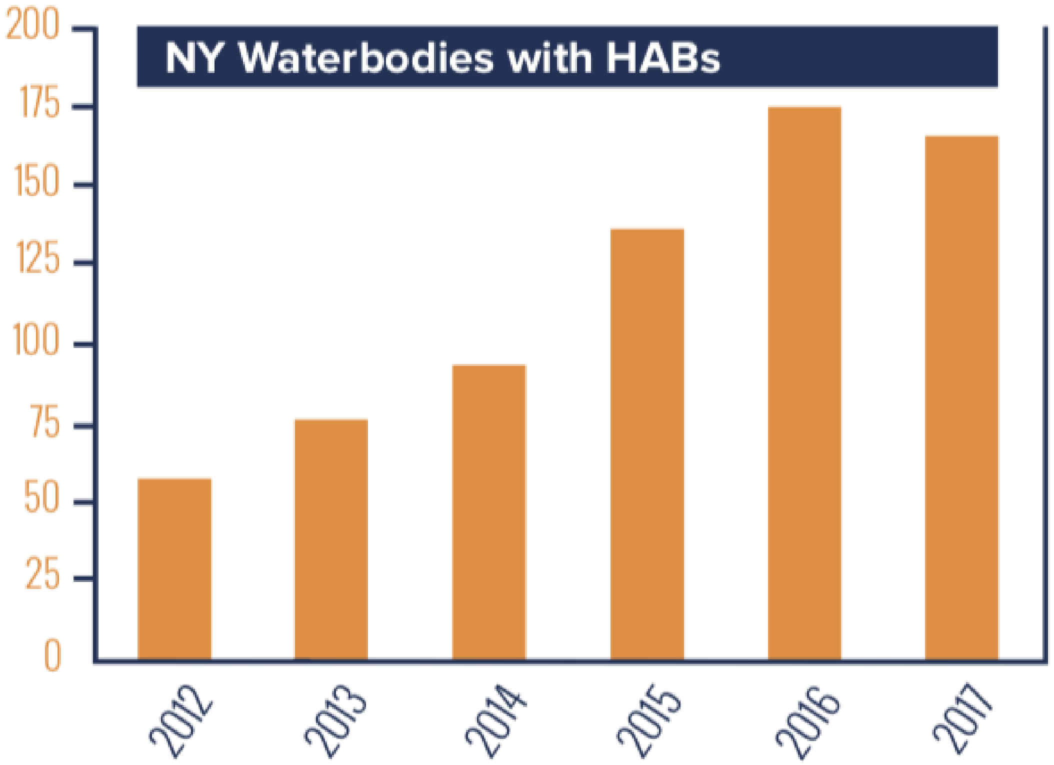
Impact of Climate Change on the Ecology of Algal Blooms [Project #4382]

It is evident that although cyanobacterial blooms can be enhanced by increasing temperature, there must be sufficient phosphorus and nitrogen to sustain high populations…….. The analysis of a 1,000-lake database revealed that the interaction between temperature and nutrients was not synergistic and that cyanobacterial biovolume was predominantly controlled by nutrients. Nutrients were the most important factor in oligotrophic lakes, temperature was most important in mesotrophic lakes, while the interaction between nutrients and temperature was highly significant in eutrophic lakes.

In eutrophic lakes where there is enough P to go around, it becomes an issue of temp, and other ecological issues (community compositions and coemption between phytoplankton groups)

Increase in HABs Across New York State

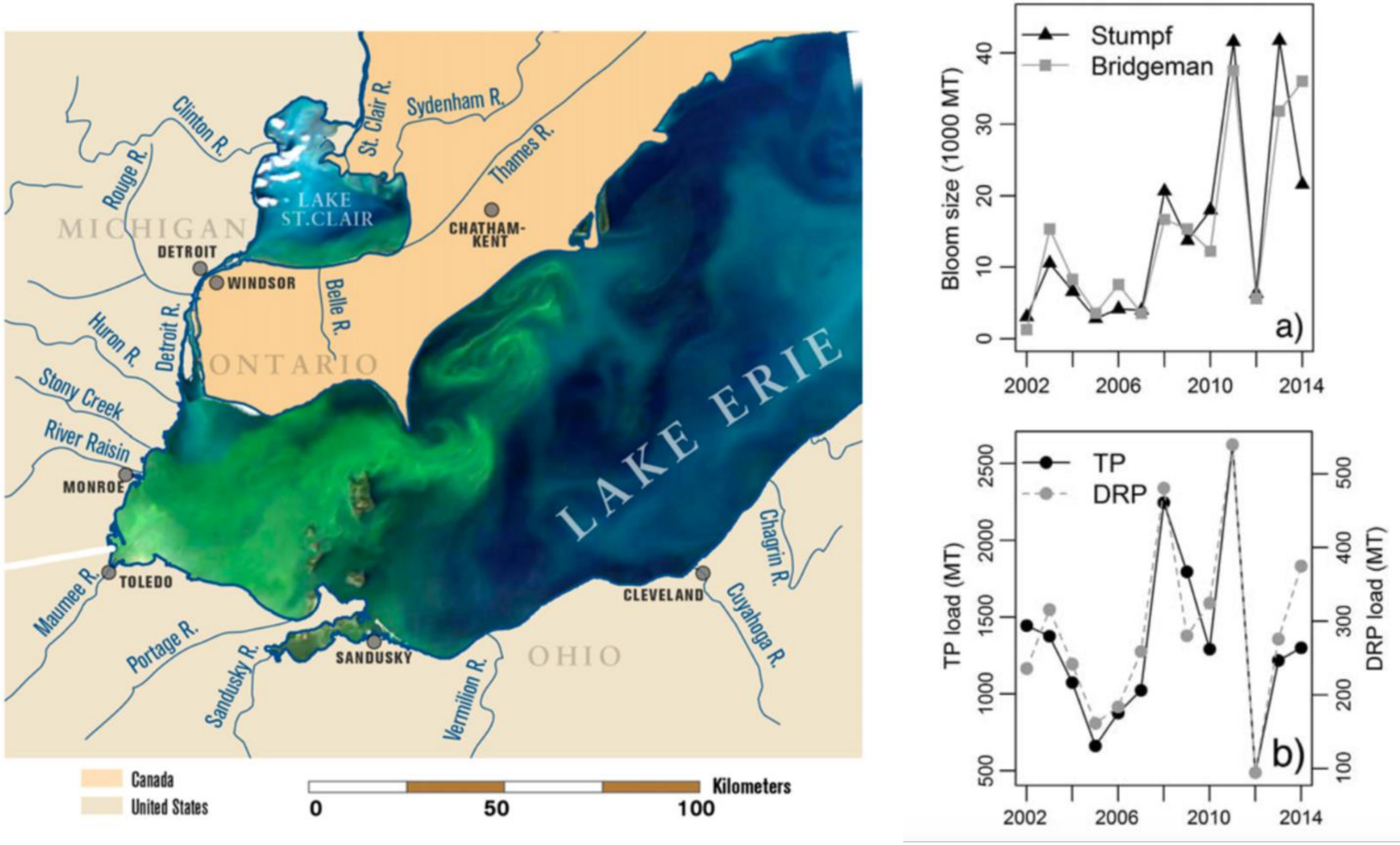
- Climate change
  - Increased water temperature
  - Increase in storm severity (runoff)
- Invasive species
  - Selective feeding leads to decrease in both grazers and competitors of BGA
  - Increase in nutrient recycling



NY DEC HAB Action Plan Executive Summary (2017)

Nutrients

I. Bertani et al. / Journal of Great Lakes Research xxx (2016) xxx–xxx

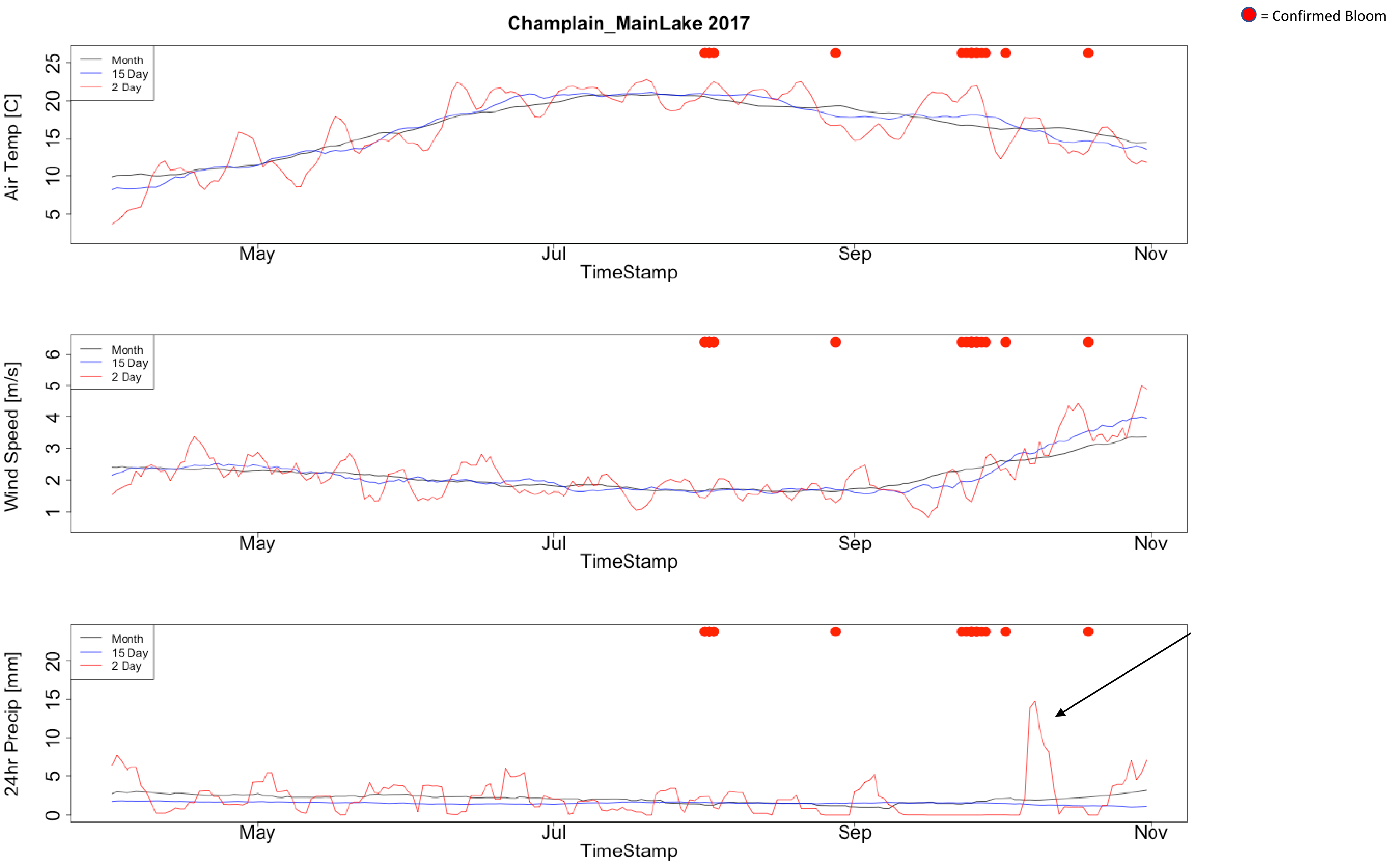


Grazing

- *Daphnia* - a major grazer of phytoplankton in lakes
  - Presence of *Daphnia* reduced filamentous cyanobacterial biomass (Paterson et al. 2002)

- Zebra mussels (*Dreissena polymorpha*)
  - Invasive Dreissenid mussel
  - Selectively feed on competitors and grazers of BGA
  - Increase the basal level of biologically available P through excretion and disturbance of sediments (Vanderploeg, 2001)

https://fineartamerica.com/featured/8-water-flea-daphnia-magna-ted-kinsman.html?product=greeting-card



Champlain_MainLake 2017
= Confirmed Bloom
Month
15 Day
2 Day
Air Temp [C]
Wind Speed [m/s]
24hr Precip [mm]
May
Jul
Sep
Nov
TimeStamp

Legacy Phosphorus (Internal Loading)

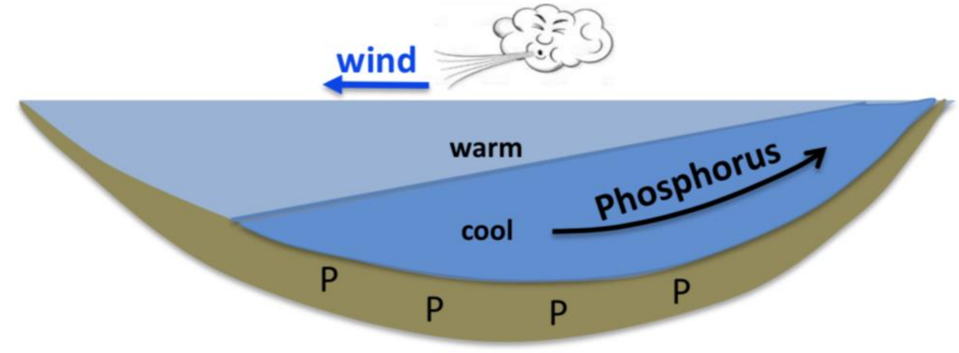
Nutrients liberated from benthos by multiple means:

- Chronic
    - Decomposition of organisms on benthos
    - Excretion by bottom dwellers (zebra mussels)

- Acute
    - Chemical reduction of Iron-P compounds (hypoxia)
    - Mechanical induced disturbance of sediments
        - Hairston- Honeoye Lake
        - Cossu and Wells – Lake Simcoe

    - Mixing events transport nepheloid nutrients into water column

    - <u>BGA competitive advantage in oligotrophic lakes</u>



It comes from the Mud! Nutrients, Internal, Loading, Internal Waves, and Infernal Honeoye HABs.
Nelson Hairston, Cornell University

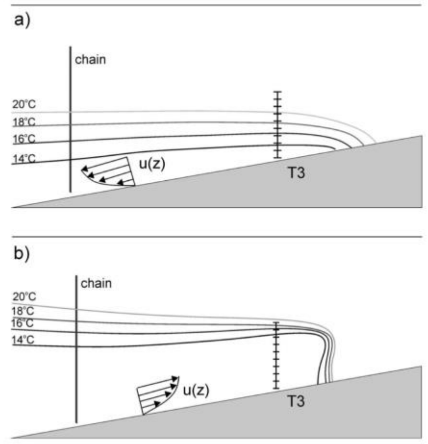


Figure 6. A schematic diagram describing the asymmetry in stratification between up and downwelling events. The position of isotherms is shown at both the deep mooring and the benthic mooring. a) During downwelling events there is a stable stratification in the water column. b) During upwelling events the isotherms resemble a 'bore-like' structure due to cold water that advances fast from deeper parts of the lake along the shallow slope.
doi:10.1371/journal.pone.0057444.g006

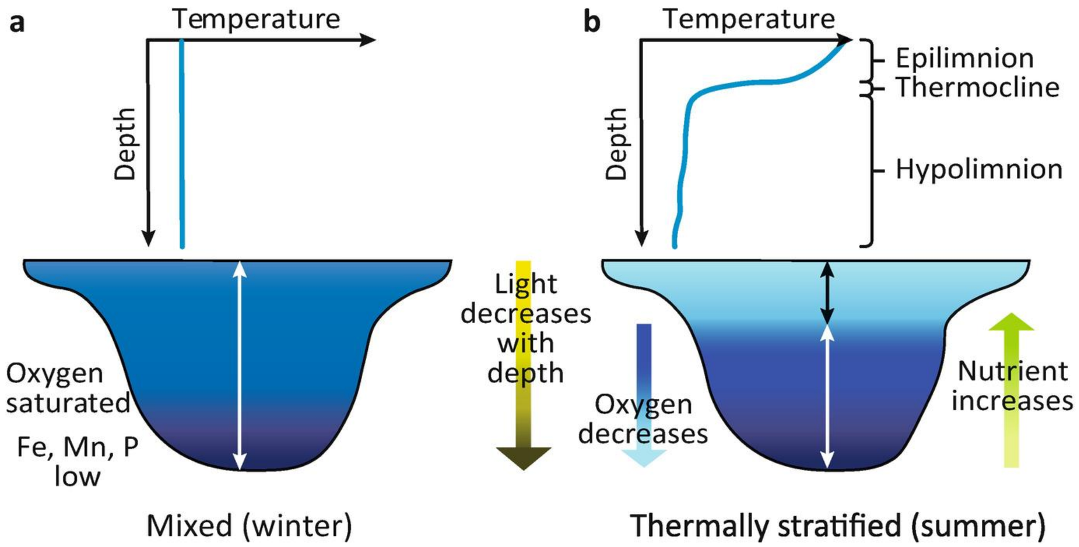
Cossu and Wells, 2013

Lake Stratification

- Higher water temps = increased thermal stratification
  - Reduced vertical mixing
  - Nutrient limitation in epilimnion
  - Thermocline becomes barrier to weak swimmers

- BGA can access both increased nutrients (hypolimnion) and increased PAR (photic zone)

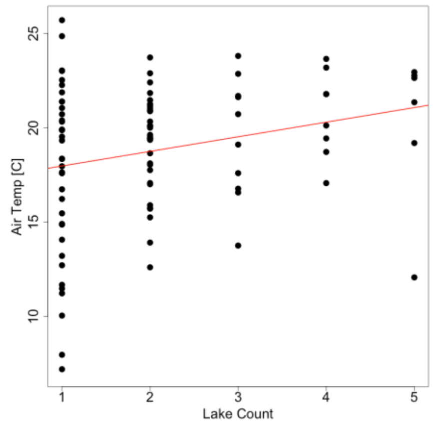
- Well mixed waters less prone to HAB (Bartoli *et al*., 2018)

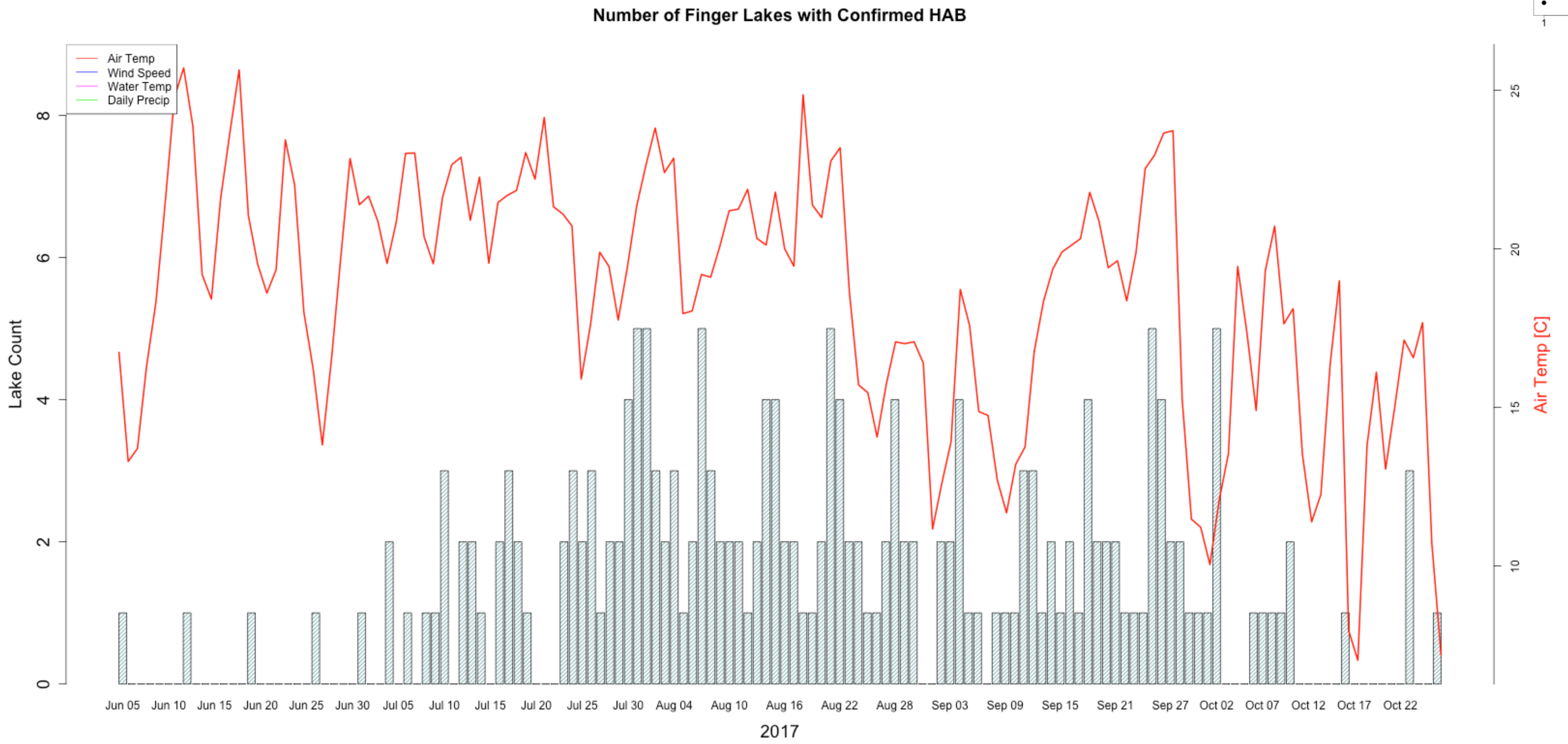


https://link.springer.com/chapter/10.1007/978-3-319-93043-5_6

Finger Lakes as Living Laboratory

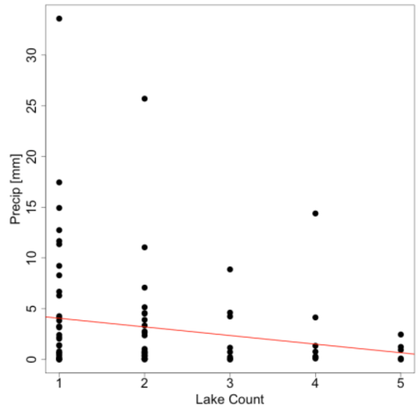
Air Temperature

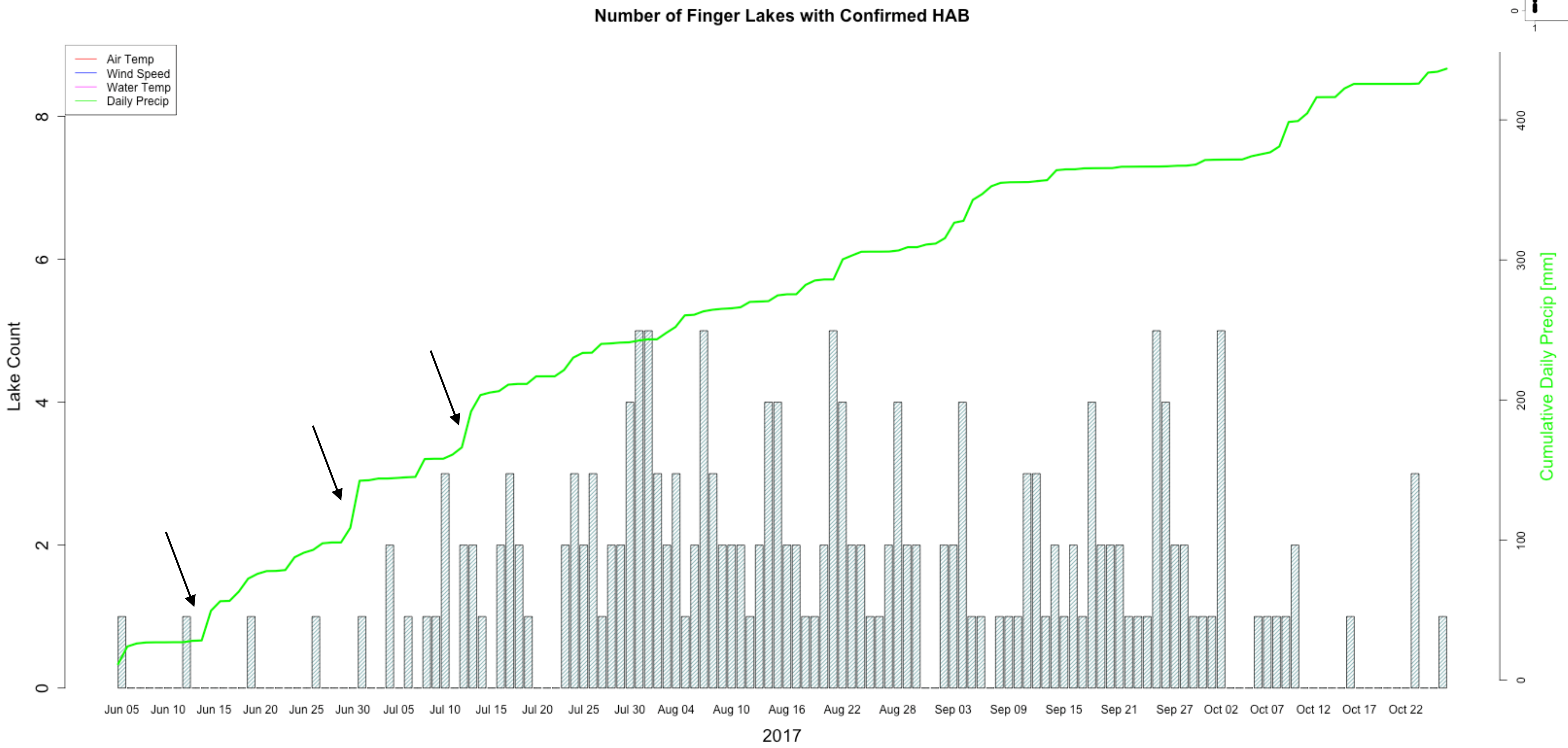




Finger Lakes as Living Laboratory

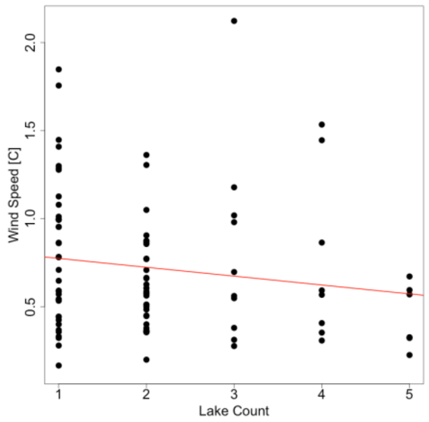
Cumulative Precipitation

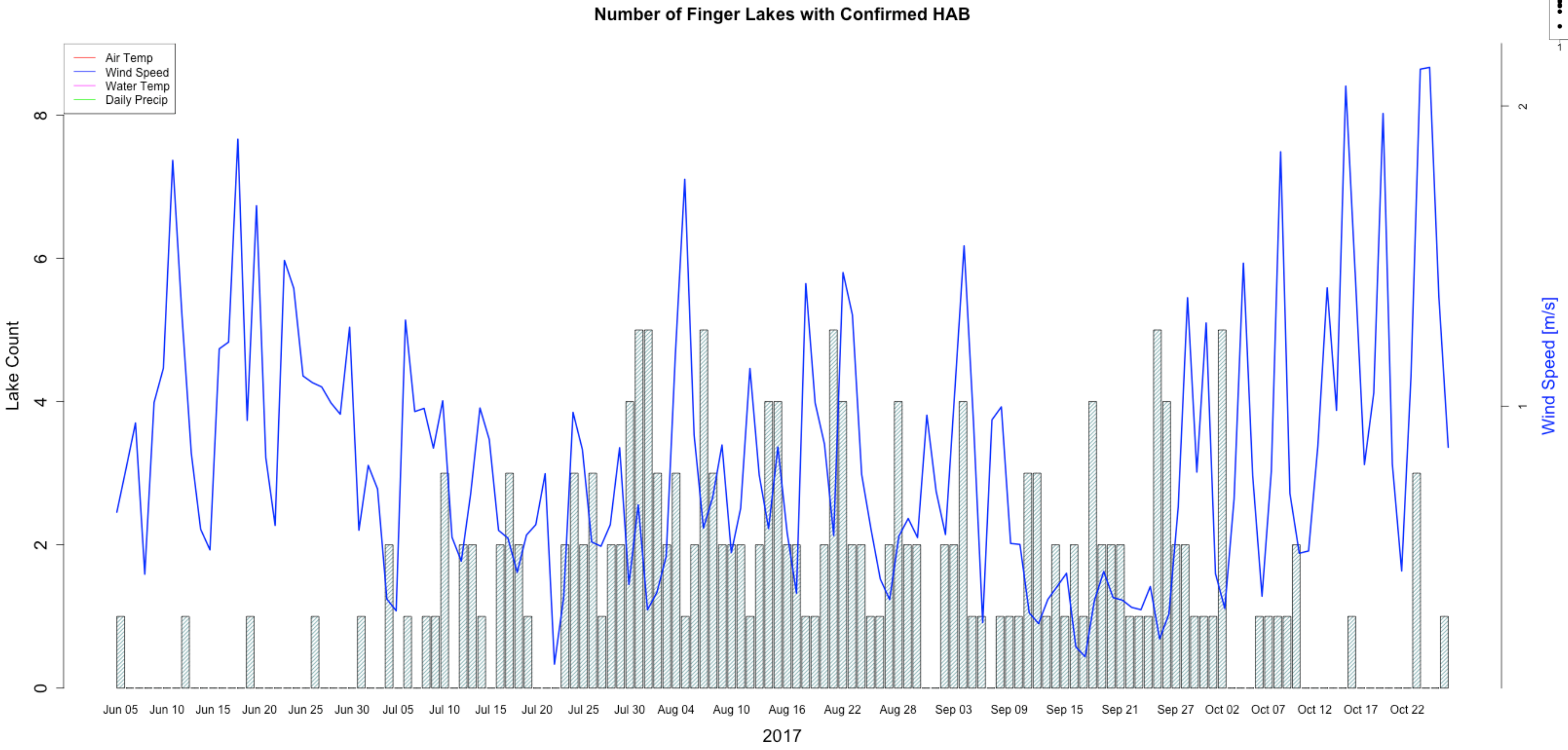




Finger Lakes as Living Laboratory

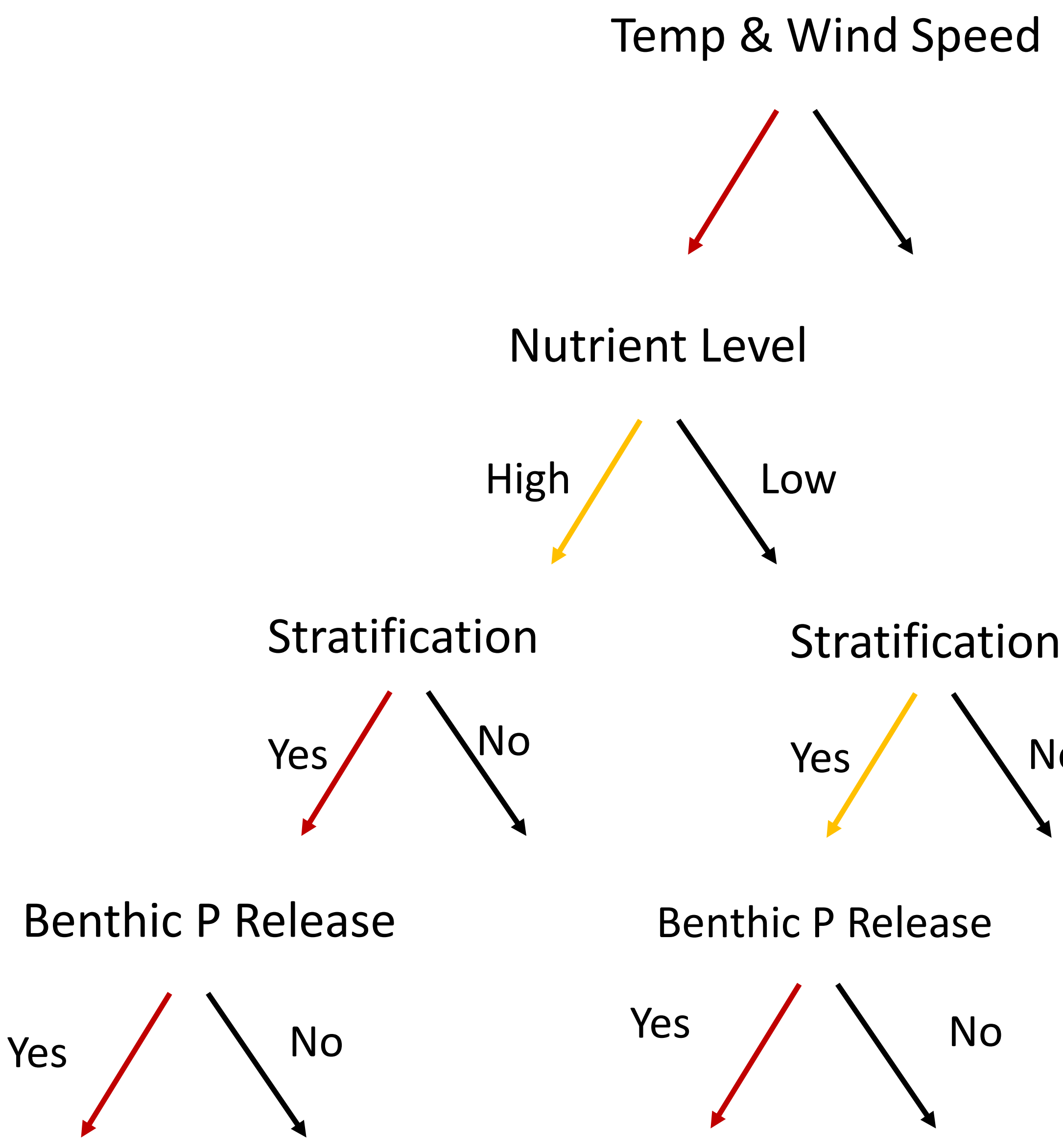
Wind Speed

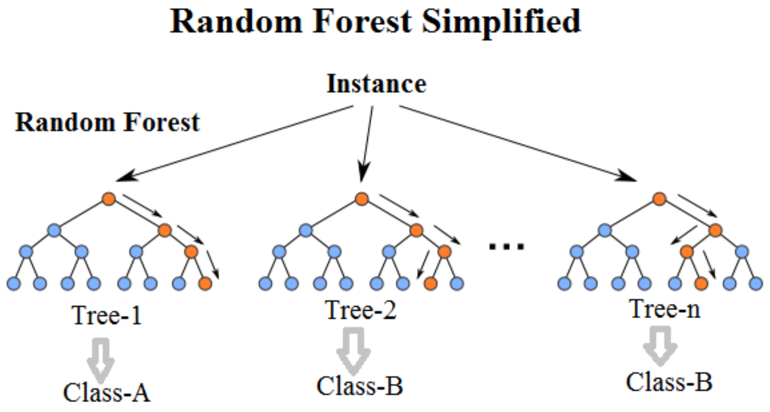




BGA - Competitive Advantage

- External loading derived nutrients (runoff) are equally available to planktonic community
- Both stratification (thermocline) and benthic release mechanisms represent barriers to nutrient access for non-motile phytoplankton (HEAT x2)
- Mobility gives BGA competitive advantage through exclusive access to nutrients





https://sefiks.com/2017/11/19/how-random-forests-can-keep-you-from-decision-tree/

- P with temp > 25°C
  - Growth rates for toxic strains of Microcystis increased in Lake Champlain (170%), Mill Pond (125%), and Lake Agawam (20%) (Parrish, 2014)

- Stokes Law
  - Vertical velocity of phytoplankton is inversely proportional to viscosity (Reynolds, 2006)

40 Lakes + 12 Basins

Lake	TrophicState
Canadice	Oligotrophic
Canandaigua	Mesoligotropohic
Carmel	Eutrophic
Cayuga	Mesoeutrophic
Conesus	Mesoeutrophic
George	Oligotrophic
Hemlock	Mesoligotropohic
Honeoye	Eutrophic
Keuka	Mesoligotropohic
Otisco	Mesoeutrophic
Owasco	Mesotrophic
Palmer	Mesoeutrophic
Putnam	Eutrophic
Seneca	Mesotrophic
Skaneateles	Oligotrophic
Champlain_IsleLaMotte	Mesotrophic
Champlain_PortHenry	Mesotrophic
Champlain_MainLake	Mesotrophic
Champlain_SouthLake	Hypertrophic
Champlain_MissisquoiBay	Hypertrophic
Champlain_StAlbansBay	Eutrophic
Champlain_MallettsBay	Mesotrophic
Champlain_InlandSea	Mesoeutrophic
Champlain_ShelburneBay	Mesotrophic
Champlain_BurlingtonBay	Mesotrophic
Champlaion_OtterCreek	Mesoeutrophic
Beaver	Mesoeutrophic
BeaverDam	Eutrophic
Black	Eutrophic
CentralPark	Hypertrophic
Craine	Mesotrophic
Kirk	Mesoeutrophic
Laurel	Mesoeutrophic
Lawson	Eutrophic
Lincolndale	Eutrophic
Maratooka	Hypertrophic
MeadowBrook	NoData
MillPond	Eutrophic
Mohegan	Eutrophic
Montgomery	Mesoeutrophic
Orange	Eutrophic
Peach	Eutrophic
ProspectPark	Hypertrophic
ProspectPark2	Hypertrophic
Ronkonkoma	Eutrophic
Saratoga	Mesoeutrophic
SetauketMill	NoData
Smith	Eutrophic
Song	Mesotrophic
Waccabuc	Mesoeutrophic
Chautauqua_North	Eutrophic
Chautauqua_South	Hypertrophic