PREDICTING HARMFUL ALGAL BLOOMS IN DETROIT LAKE OR

James Watson, Mat Titus

The Prediction Lab LLC

email: info@thepredictionlab.com

web: www.thepredictionlab.com

Oregon State University

CITY OF Salem AT YOUR SERVICE

Public Works Department

THE PREDICTION LAB

Harmful Algal Blooms (HABs)

Harmful Algal Blooms (HABs)

Environment | Local | Science | News | Water | Health

As Salem Frets About Toxic Algae, Should The Rest Of Oregon?

by **Erin Ross** Follow OPB June 7, 2018 6:30 a.m. | Updated: June 7, 2018 3:27 p.m. | Portland, Ore.

Harmful Algal Blooms (HABs)

Environment | Local | Science | News | Water | Health

As Salem Frets About Toxic Algae, Should The Rest Of Oregon?

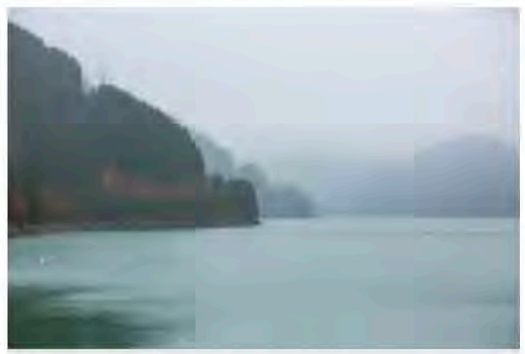
by **Erin Ross** Follow OPB June 7, 2018 6:30 a.m. | Updated: June 7, 2018 3:27 p.m. | Portland, Ore.

Q&A: How Do Algae Blooms Affect Oregon's Water Supply?

01:54 04:16

OPB

Download



Detroit Lake in Detroit, Oregon, Saturday, March 18, 2017. Detroit Lake flows downstream into Salem's drinking water intake.

Bradley W. Parks/OPB

For the second time in two weeks, Salem is under a drinking water advisory, and there's very little the city can do about it.

Test results released Wednesday from water collected four days prior found an algae-produced toxin was present at levels deemed unsafe for certain groups to drink. It's left city and state residents asking how it happened and wondering if it will happen elsewhere.

Harmful Algal Blooms (HABs)

Environment | Local | Science | News | Water | Health

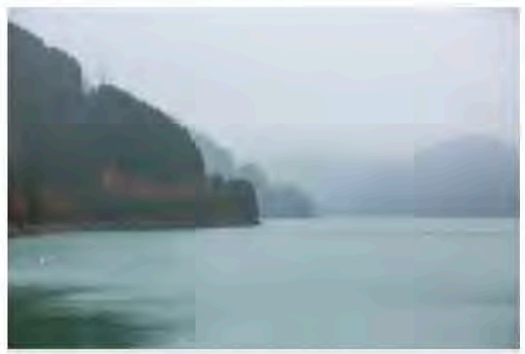
As Salem Frets About Toxic Algae, Should The Rest Of Oregon?

by **Erin Ross** Follow OPB June 7, 2018 6:30 a.m. | Updated: June 7, 2018 3:27 p.m. | Portland, Ore.

Q&A: How Do Algae Blooms Affect Oregon's Water Supply?

01:54 04:16

Download



Detroit Lake in Detroit, Oregon, Saturday, March 18, 2017. Detroit Lake flows downstream into Salem's drinking water intake.

Bradley W. Parks/OPB

For the second time in two weeks, Salem is under a drinking water advisory, and there's very little the city can do about it.

Test results released Wednesday from water collected four days prior found an algae-produced toxin was present at levels deemed unsafe for certain groups to drink. It's left city and state residents asking how it happened and wondering if it will happen elsewhere.

Toxic algae blooms found in parts of Detroit Lake again, Oregon health officials warn

by KATU Staff | Wednesday, June 13th 2018

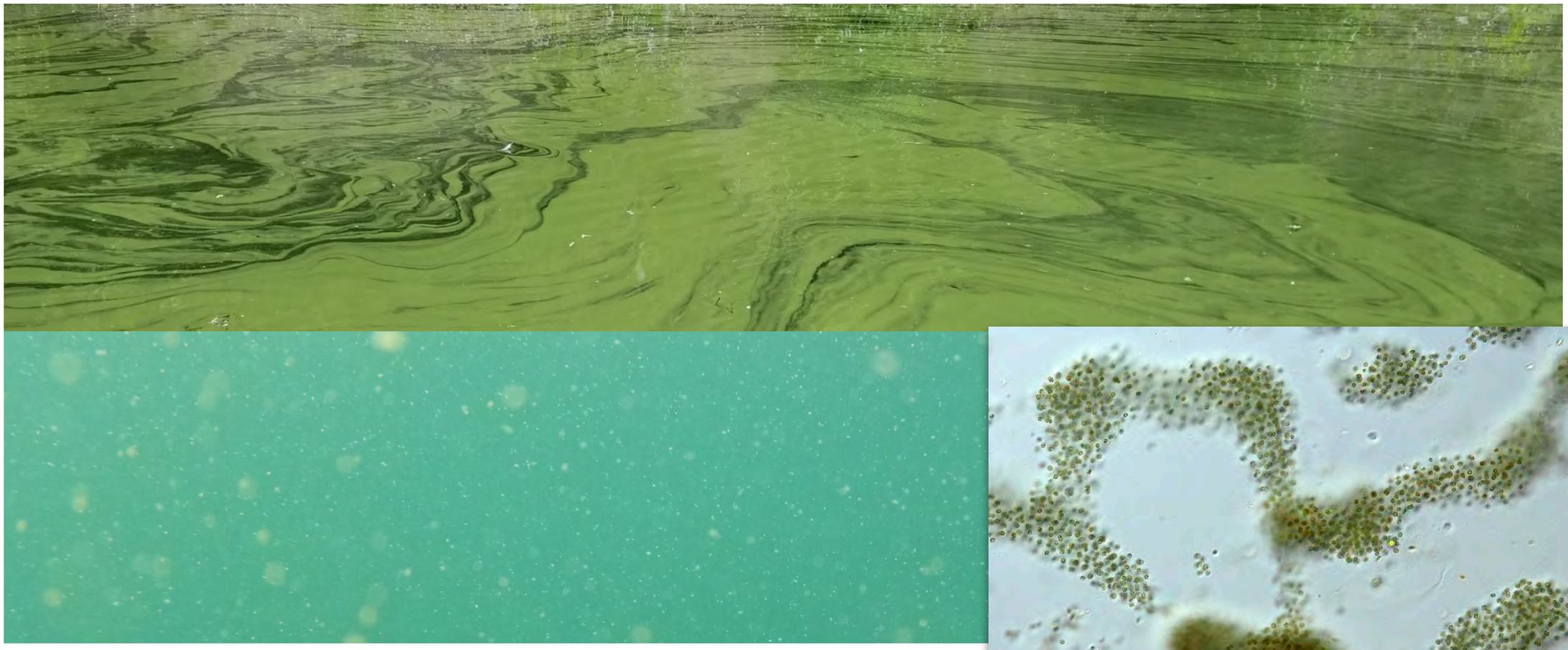
Detroit Lake. (KATU Photo)

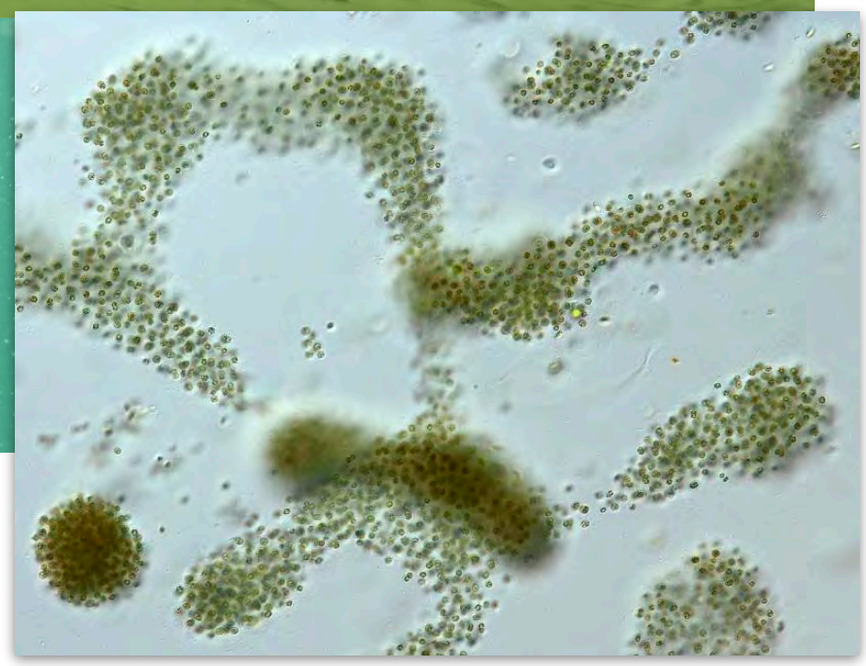
Harmful Algal Blooms (HABs)

- Algal blooms occur naturally in Detroit Lake
- Toxins are sometimes released (creating a HAB)

Harmful Algal Blooms (HABs)

- Algal blooms occur naturally in Detroit Lake
- Toxins are sometimes released (creating a HAB)





Cyanobacteria (a harmful algae)

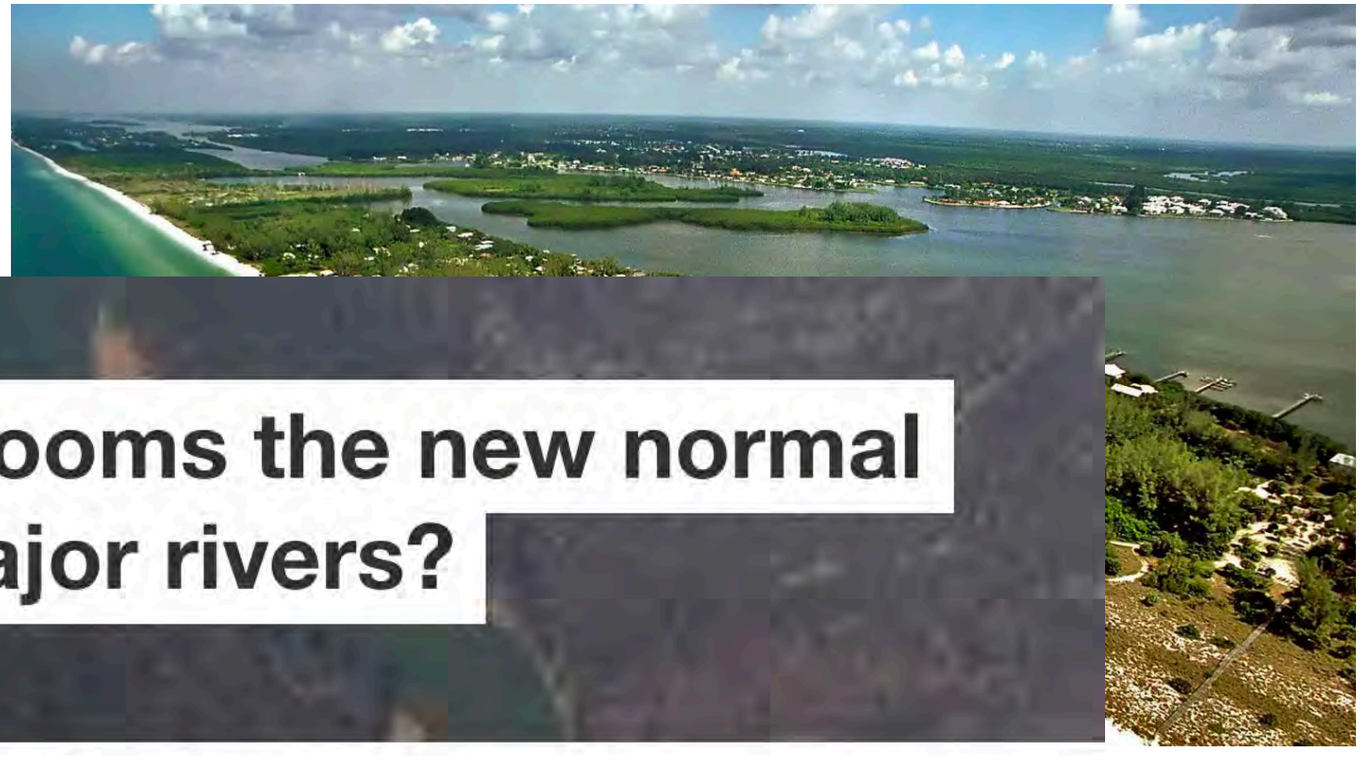
Harmful Algal Blooms (HABs)

Harmful Algal Blooms (HABs)

Harmful Algal Blooms (HABs)

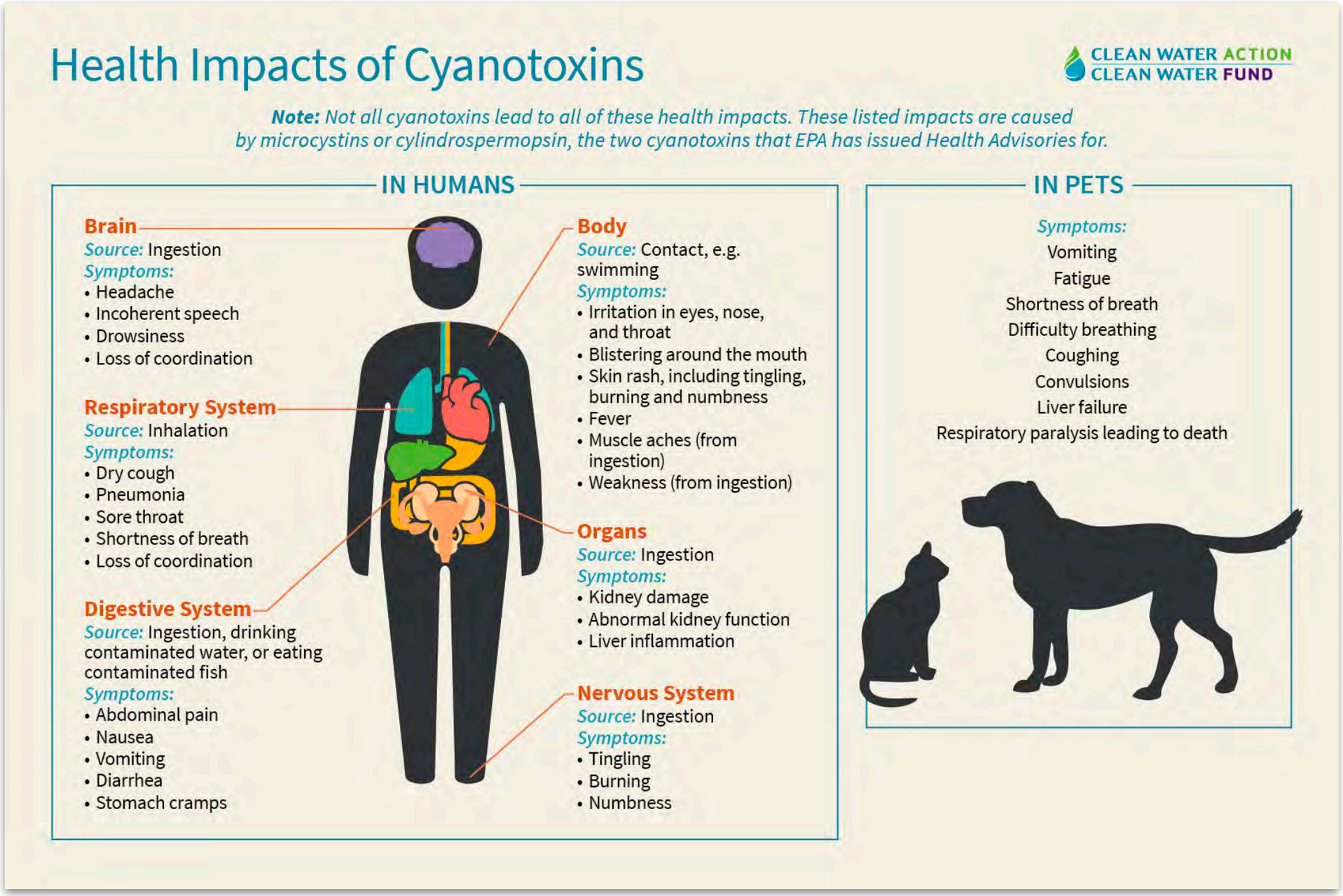
Harmful Algal Blooms (HABs)

Harmful Algal Blooms (HABs)



HABs are a problem

- People, Pets, Fisheries



HABs are a problem

- People, Pets, Fisheries

Health Impacts of Cyanotoxins

CLEAN WATER ACTION
CLEAN WATER FUND

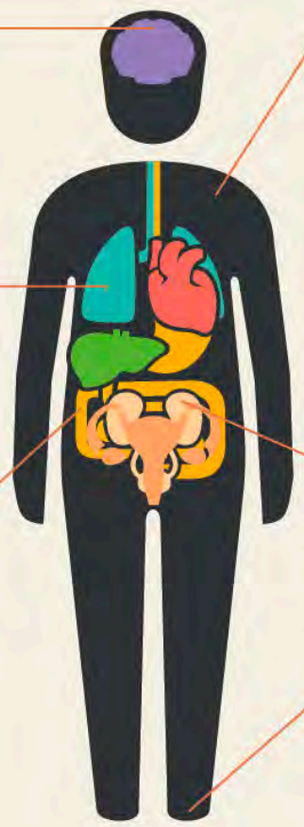
Note: *Not all cyanotoxins lead to all of these health impacts. These listed impacts are caused by microcystins or cylindrospermopsin, the two cyanotoxins that EPA has issued Health Advisories for.*

IN HUMANS

Brain
Source: Ingestion
Symptoms:
- Headache
- Incoherent speech
- Drowsiness
- Loss of coordination

Respiratory System
Source: Inhalation
Symptoms:
- Dry cough
- Pneumonia
- Sore throat
- Shortness of breath
- Loss of coordination

Digestive System
Source: Ingestion, drinking contaminated water, or eating contaminated fish
Symptoms:
- Abdominal pain
- Nausea
- Vomiting
- Diarrhea
- Stomach cramps



Body
Source: Contact, e.g. swimming
Symptoms:
- Irritation in eyes, nose, and throat
- Blistering around the mouth
- Skin rash, including tingling, burning and numbness
- Fever
- Muscle aches (from ingestion)
- Weakness (from ingestion)

Organs
Source: Ingestion
Symptoms:
- Kidney damage
- Abnormal kidney function
- Liver inflammation

Nervous System
Source: Ingestion
Symptoms:
- Tingling
- Burning
- Numbness

IN PETS

Symptoms:
Vomiting
Fatigue
Shortness of breath
Difficulty breathing
Coughing
Convulsions
Liver failure
Respiratory paralysis leading to death

Fish die-off

Algae are plants…

- Like other plants they need just a few things to grow:

James’ garden (everything dead)

Algae are plants…

- Like other plants they need just a few things to grow:

James’ garden (everything dead)

Algae are plants…

- Like other plants they need just a few things to grow:

James’ garden (everything dead)

Algae are plants…

- Like other plants they need just a few things to grow:

James’ garden (everything dead)

Algae are plants…

- Like other plants they need just a few things to grow:

This is a jungle

Algae are plants…

- Like other plants they need just a few things to grow:

This is a jungle

And this…

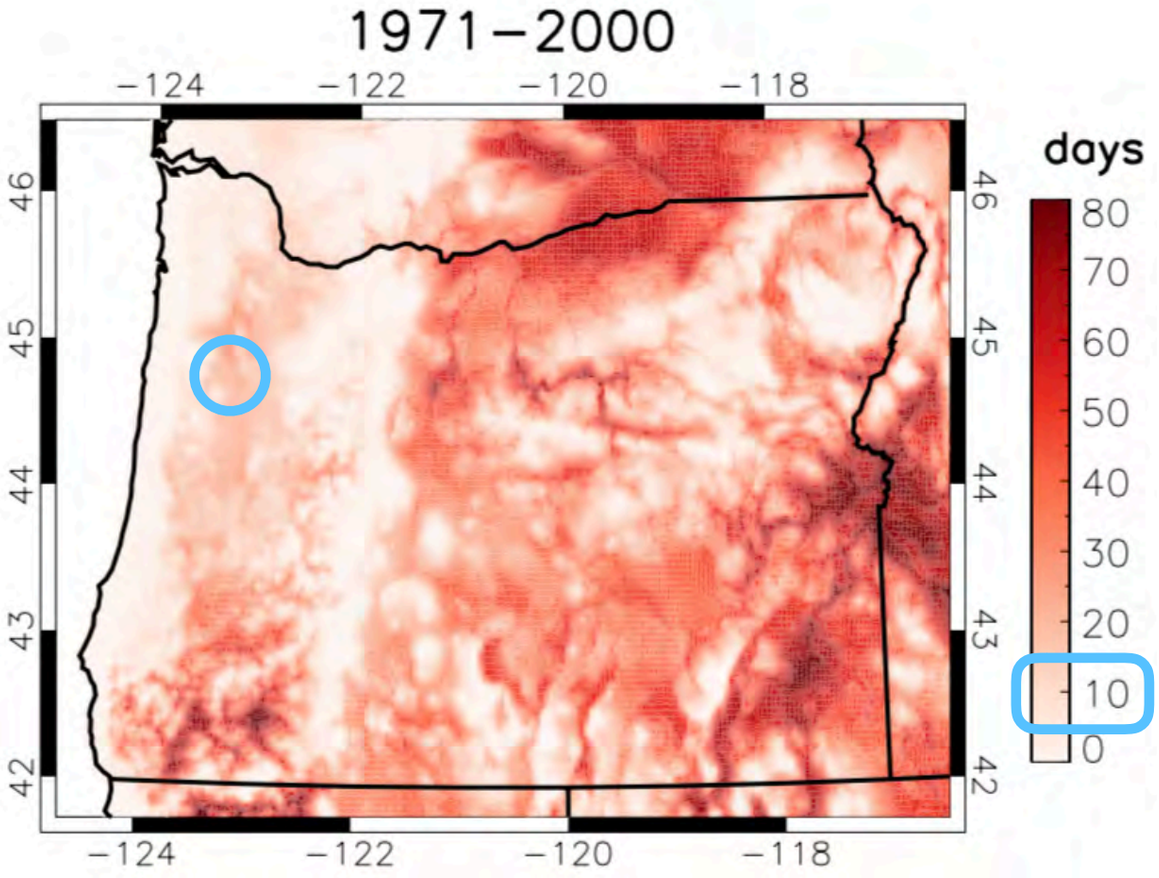
- We will see radical changes in Oregon’s weather in the coming decade(s)…

And this…

- We will see radical changes in Oregon's weather in the coming decade(s)… 2015, 2016, 2017, 2018

And this…

- We will see radical changes in Oregon's weather in the coming decade(s)… 2015, 2016, 2017, 2018

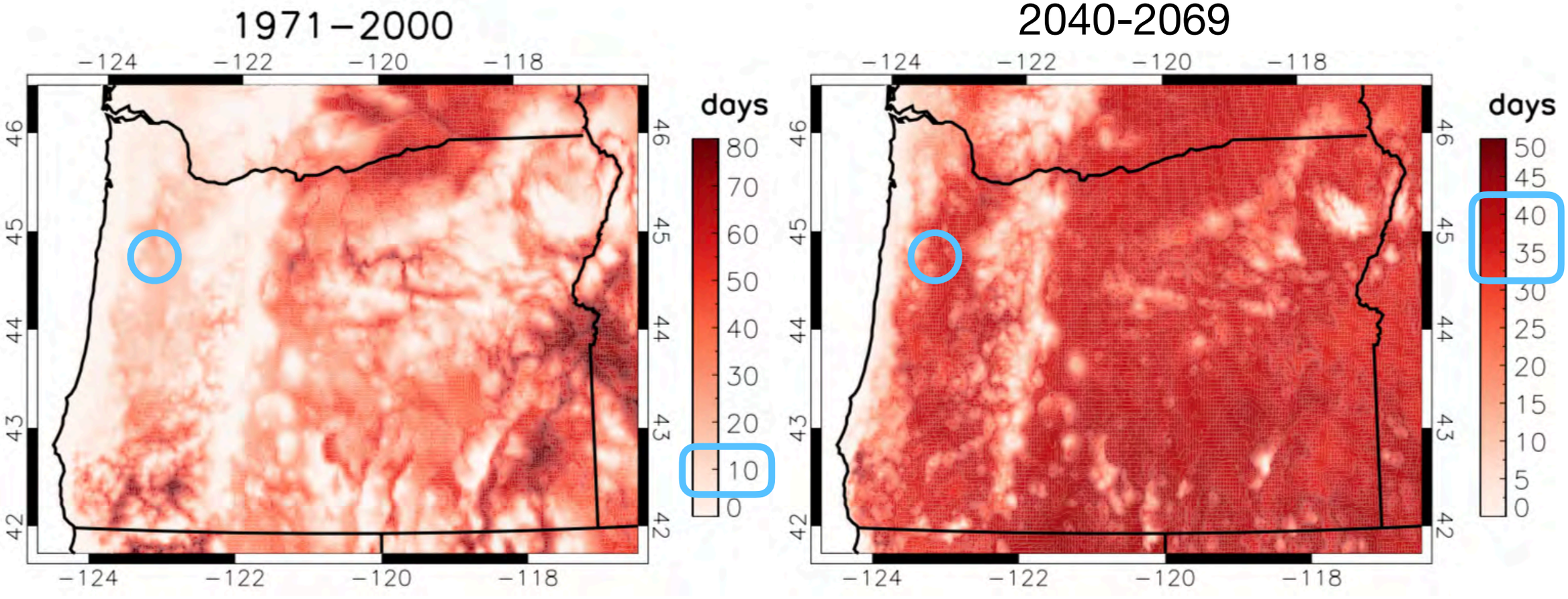


The average number of days per year where temperature >86°F

Fig: OCCRI (Oregon Climate Change Research Institute)

And this…

- We will see radical changes in Oregon's weather in the coming decade(s)… 2015, 2016, 2017, 2018



The average number of days per year where temperature >86°F

Fig: OCCRI (Oregon Climate Change Research Institute)

HABs are the new normal

HABs are the new normal

- Instead of a once in a decade event, HABs will regularly occur each year

HABs are the new normal

- Instead of a once in a decade event, HABs will regularly occur each year
- A HAB early-warning system is critical *now*, and for going into an uncharted future

HABs are the new normal

- Instead of a once in a decade event, HABs will regularly occur each year
- A HAB early-warning system is critical *now*, and for going into an uncharted future
- With challenges there are opportunities:

HABs are the new normal

- Instead of a once in a decade event, HABs will regularly occur each year
- A HAB early-warning system is critical *now*, and for going into an uncharted future
- With challenges there are opportunities:
  - *Take advantage of the data revolution*

HABs are the new normal

- Instead of a once in a decade event, HABs will regularly occur each year
- A HAB early-warning system is critical *now*, and for going into an uncharted future
- With challenges there are opportunities:
  - *Take advantage of the data revolution*
  - *Lead the push for smart & resilient communities*

HABs are the new normal

- Instead of a once in a decade event, HABs will regularly occur each year
- A HAB early-warning system is critical *now*, and for going into an uncharted future
- With challenges there are opportunities:
  - *Take advantage of the data revolution*
  - *Lead the push for smart & resilient communities*
  - *Make use of Internet of Things (IOT) technologies*

Last year

Last year

- OSU meeting last summer: Nitin Joshi and Devin Doring described the situation at Detroit Lake
- I heard "I dare you to solve this problem…"

Devin Doring presenting at OSU (2018)

Our solution:

Our solution:

- Phase 1:

  - Review state of the art in terms of HAB prediction

Our solution:

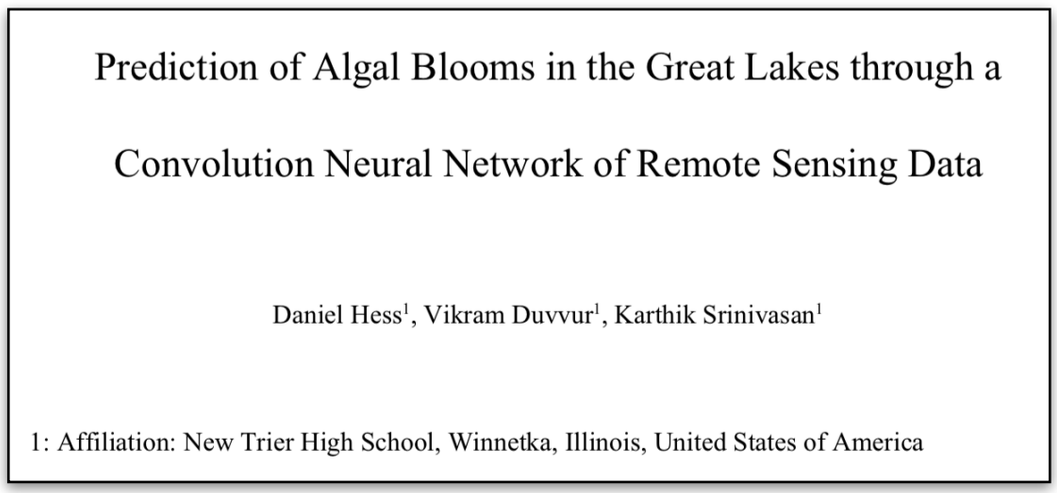
- Phase 1:
  - Review state of the art in terms of HAB prediction
- Phase 2:
  - Choose method for predicting HABs in Detroit Lake (providing measures of uncertainty… this is a risk management problem)
  - Identify important variables
  - Help design future monitoring and prediction of HABs in the lake

Phase 1: State of the art

- >100 research papers
- Numerous operational products…

Phase 1: State of the art

- >100 research papers
- Numerous operational products…



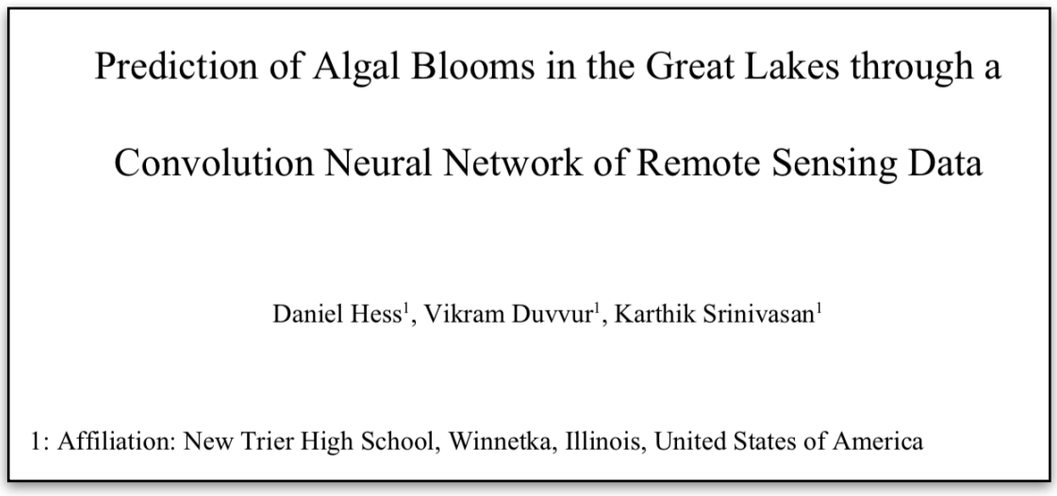
Prediction of Algal Blooms in the Great Lakes through a Convolution Neural Network of Remote Sensing Data

Daniel Hess[1], Vikram Duvvur[1], Karthik Srinivasan[1]

1: Affiliation: New Trier High School, Winnetka, Illinois, United States of America

Phase 1: State of the art

- >100 research papers
- Numerous operational products…



Prediction of Algal Blooms in the Great Lakes through a Convolution Neural Network of Remote Sensing Data

Daniel Hess[1], Vikram Duvvur[1], Karthik Srinivasan[1]

1: Affiliation: New Trier High School, Winnetka, Illinois, United States of America

International Journal of *Environmental Research and Public Health*

MDPI

Article

Improved Prediction of Harmful Algal Blooms in Four Major South Korea's Rivers Using Deep Learning Models

Sangmok Lee and Donghyun Lee *

Department of Business Administration, Korea Polytechnic University, 237, Sangidaehak-ro, Siheung-si, Gyeonggi-do 15073, Korea; tkdahr1331@gmail.com

Phase 1: State of the art

- >100 research papers
- Numerous operational products…

Prediction of Algal Blooms in the Great Lakes through a Convolution Neural Network of Remote Sensing Data

Daniel Hess[1], Vikram Duvvur[1], Karthik Srinivasan[1]

1: Affiliation: New Trier High School, Winnetka, Illinois, United States of America

International Journal of *Environmental Research and Public Health*

MDPI

Article

Improved Prediction of Harmful Algal Blooms in Four Major South Korea's Rivers Using Deep Learning Models

Sangmok Lee and Donghyun Lee *

Department of Business Administration, Korea Polytechnic University, 237, Sangidaehak-ro, Siheung-si, Gyeonggi-do 15073, Korea; tkdahr1331@gmail.com

Bayesian model averaging for harmful algal bloom prediction

GRANT HAMILTON,[1,4] ROSS MCVINISH,[2] AND KERRIE MENGERSEN[3]

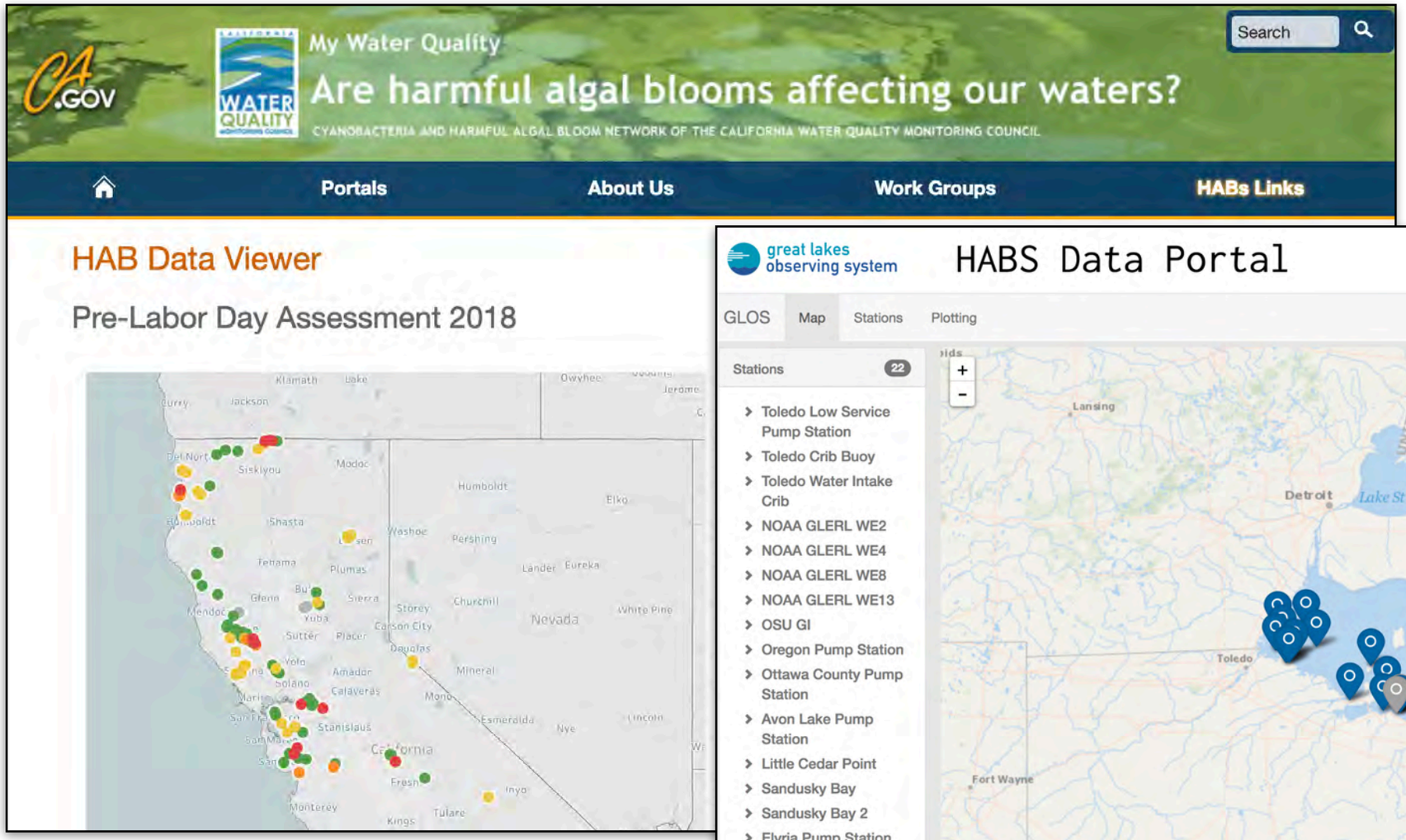
[1]*School of Natural Resource Sciences, Queensland University of Technology, GPO Box 2434, Brisbane, Queensland 4001 Australia*
[2]*Mathematics Department, The University of Queensland, Brisbane, Queensland 4072 Australia*
[3]*School of Mathematical Sciences, Queensland University of Technology, GPO Box 2434, Brisbane, Queensland 4001 Australia*

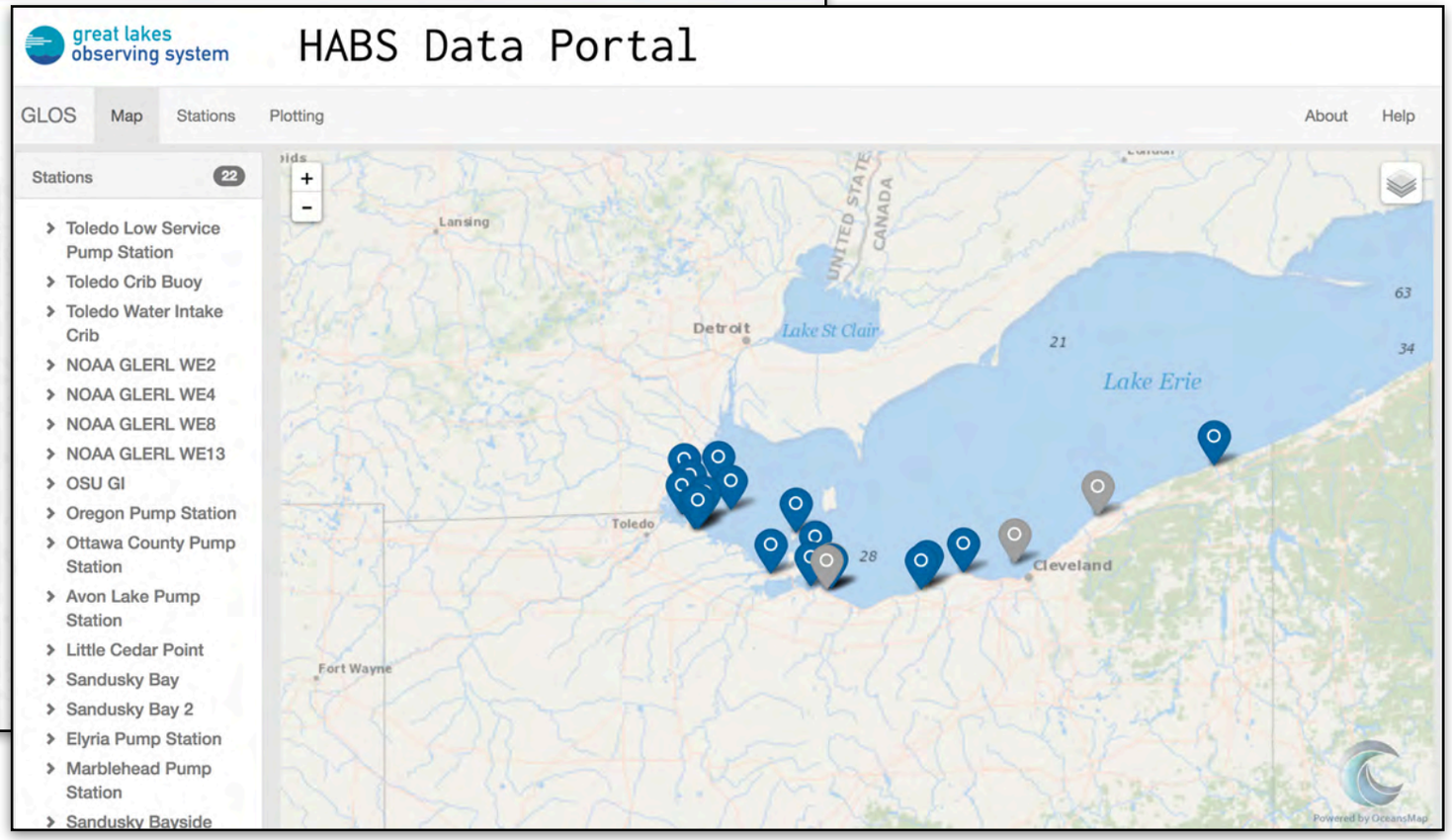
Phase 1: State of the art

- >100 research papers
- Numerous operational products…

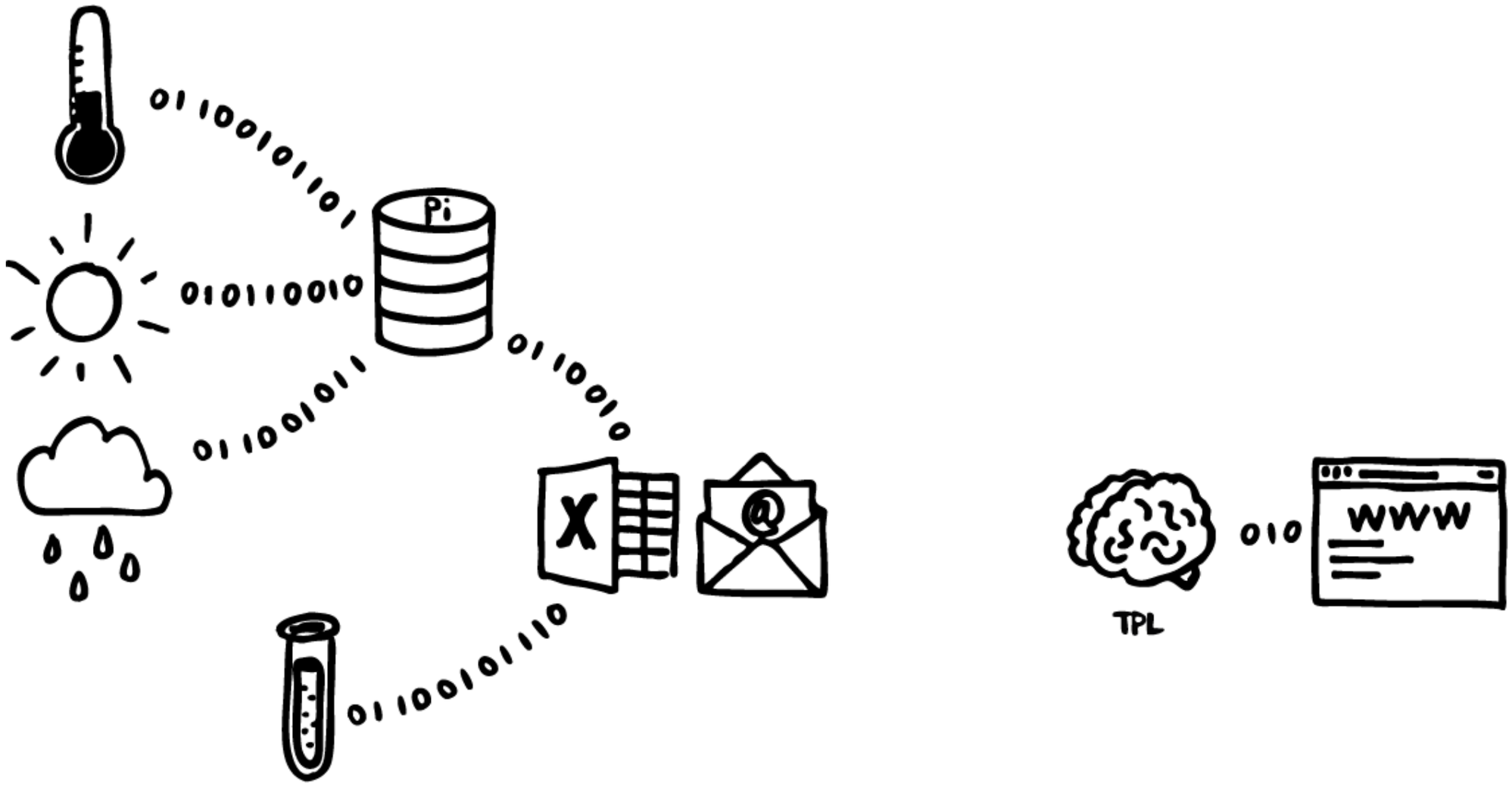
Phase 1: State of the art

- >100 research papers
- Numerous operational products…

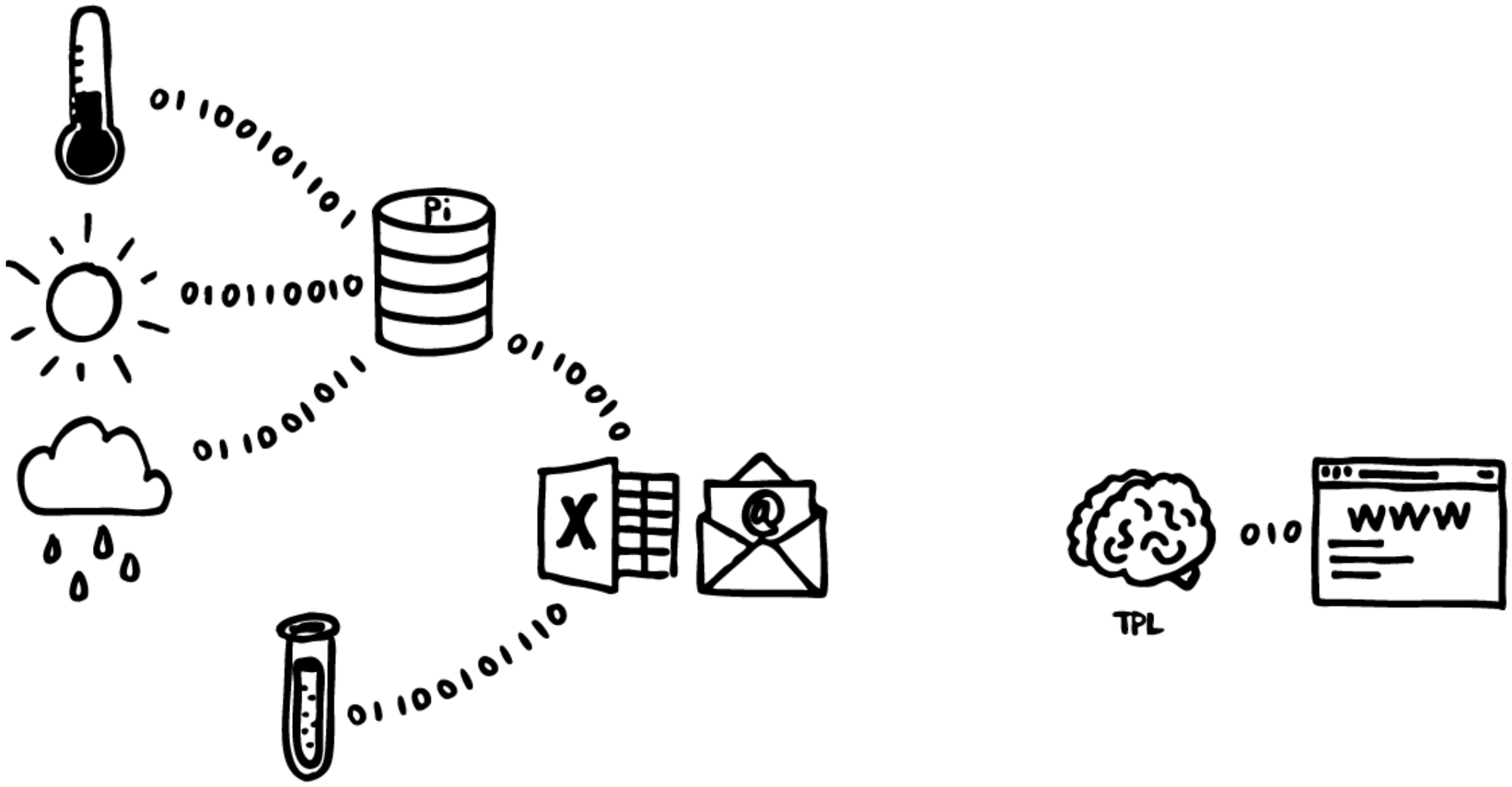




Our solution: work-flow



Our solution: work-flow



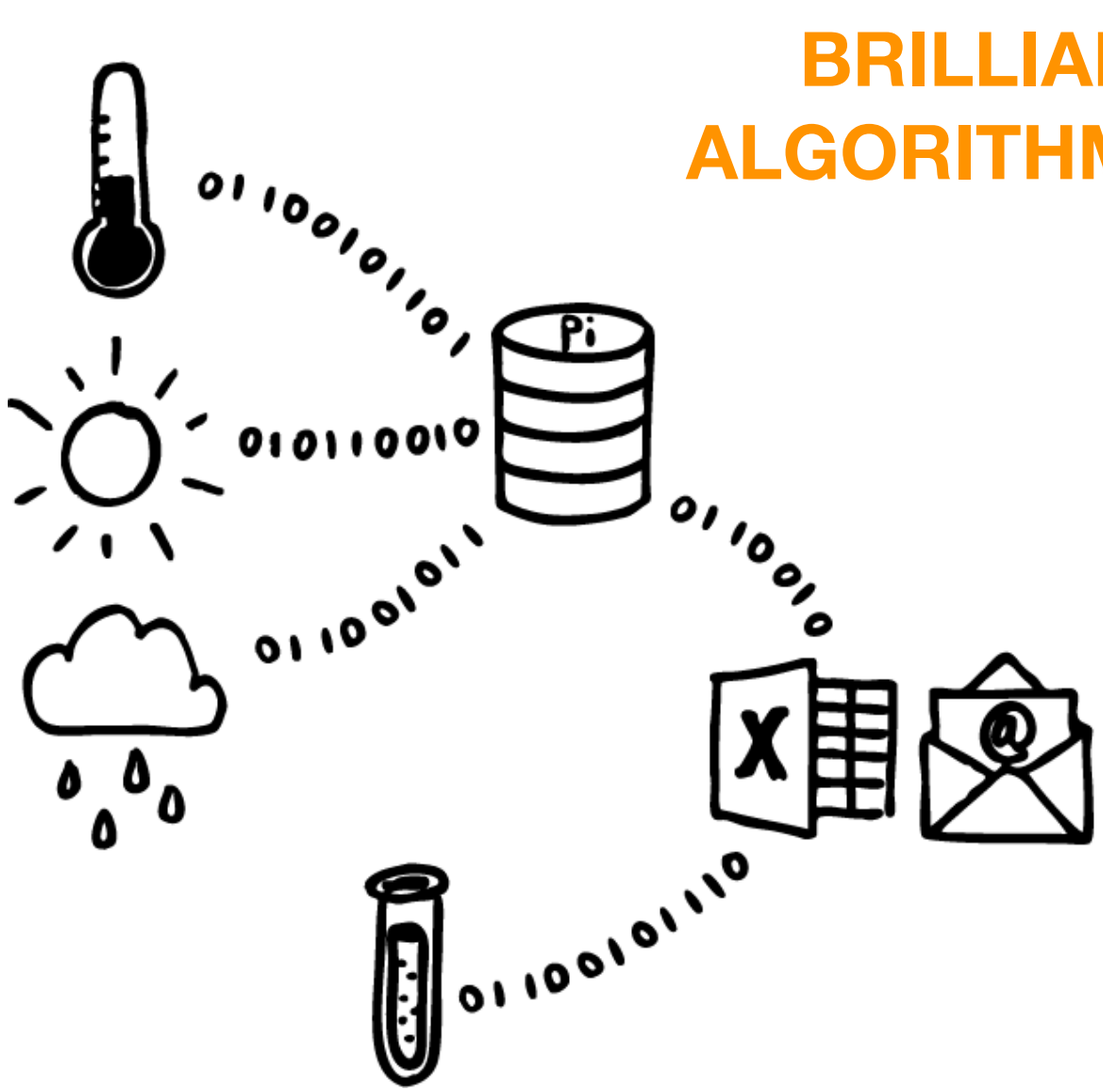
Our solution: work-flow

- historical, near real-time, and real-time monitoring
- lots of variables (from weather to the abundance of specific algal species)
- lots of locations around the lake

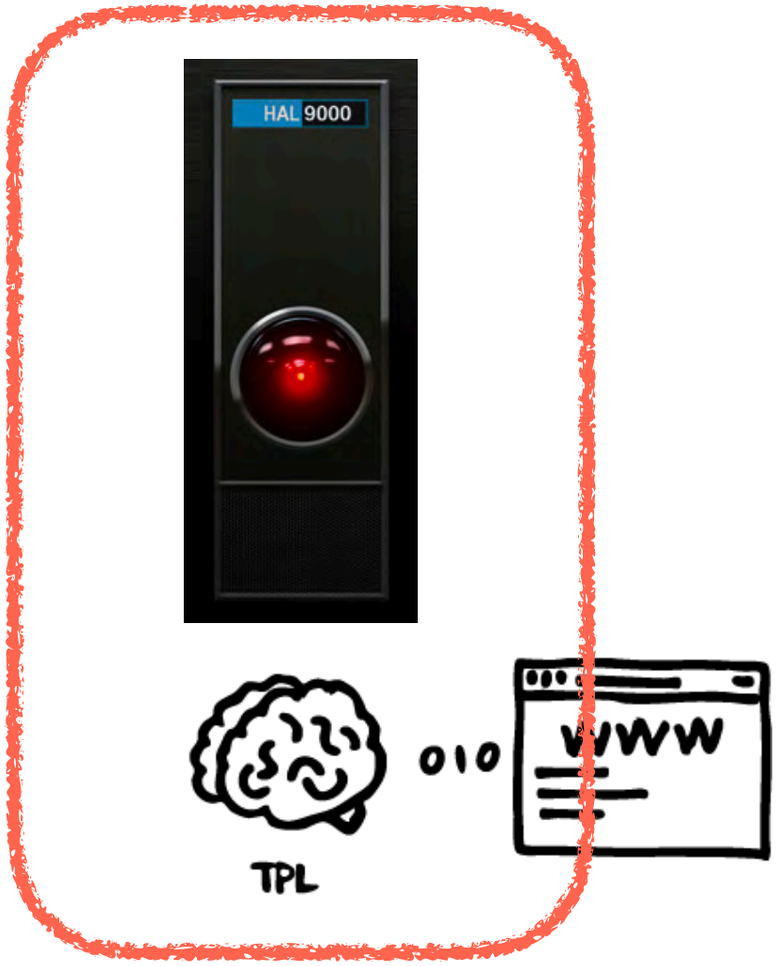
Our solution: work-flow

- historical, near real-time, and real-time monitoring
- lots of variables (from weather to the abundance of specific algal species)
- lots of locations around the lake

Our solution: work-flow



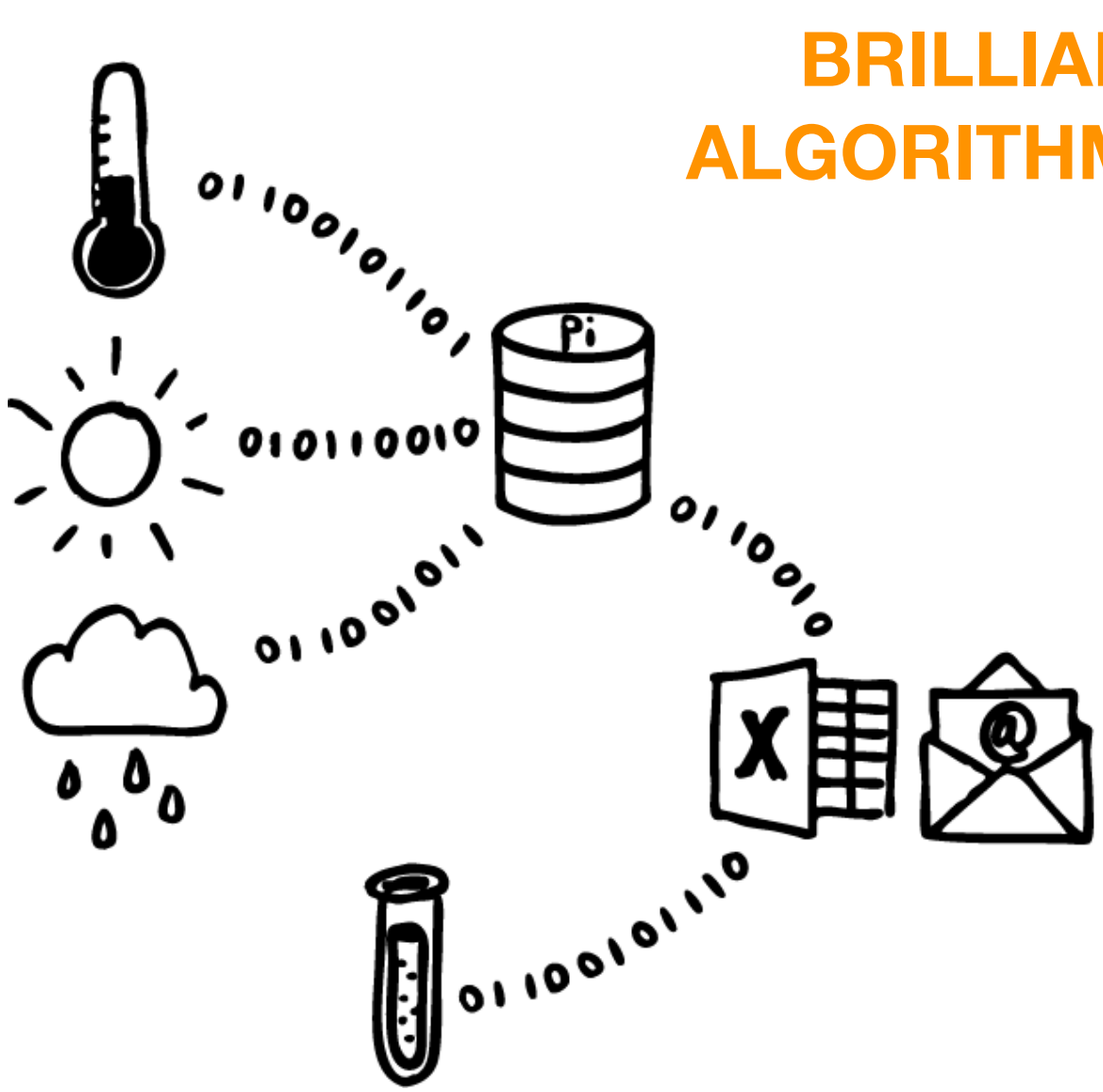
BRILLIANT ALGORITHMS



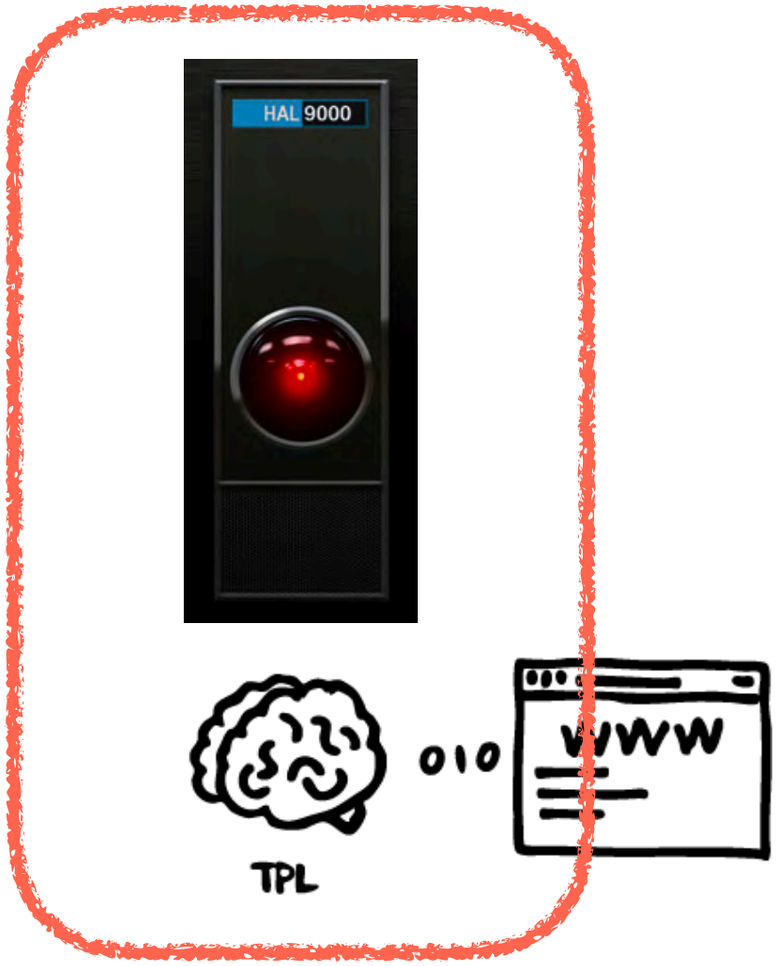
— Employ and advance the cutting-edge

— Statistics, AI and Machine Learning

Our solution: work-flow



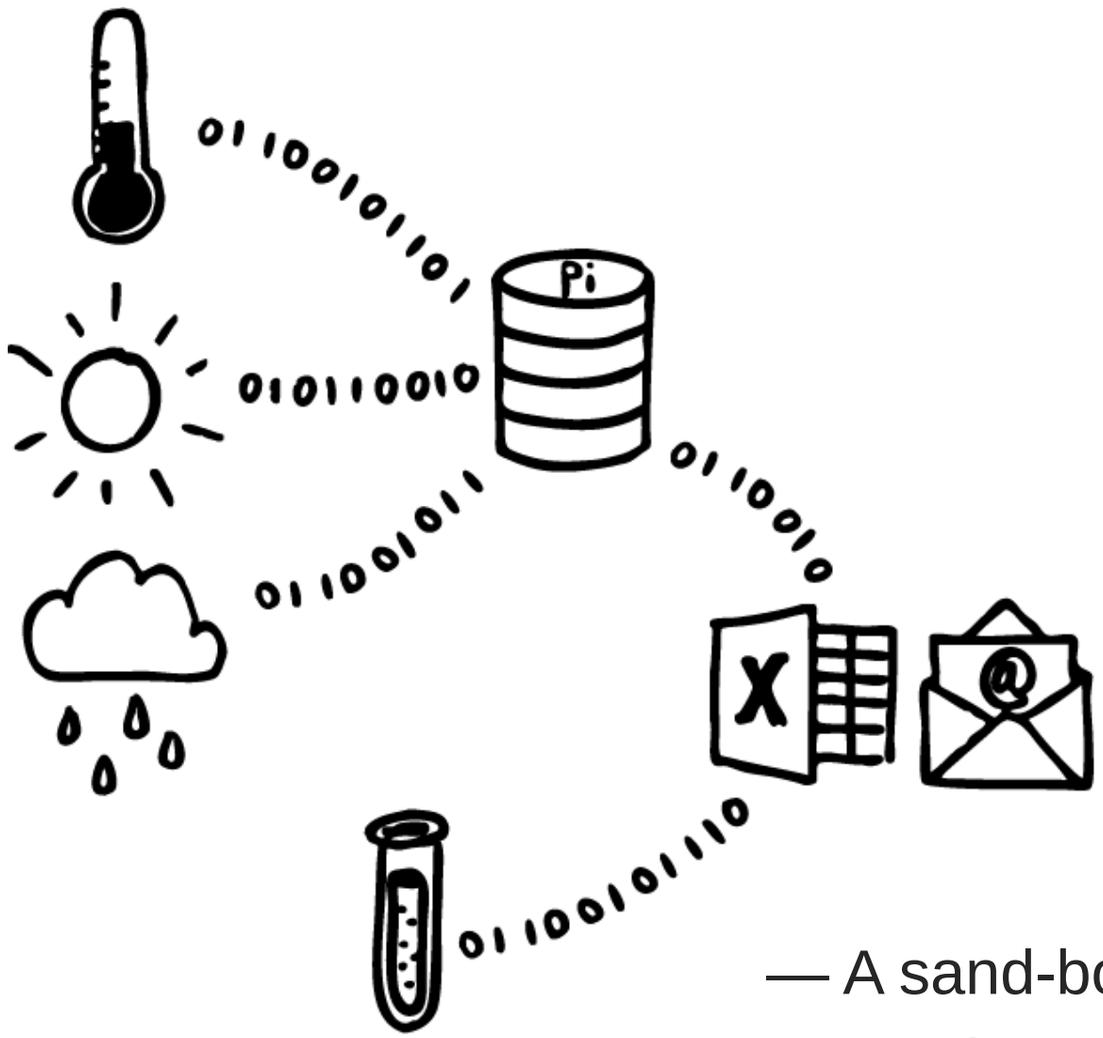
BRILLIANT ALGORITHMS

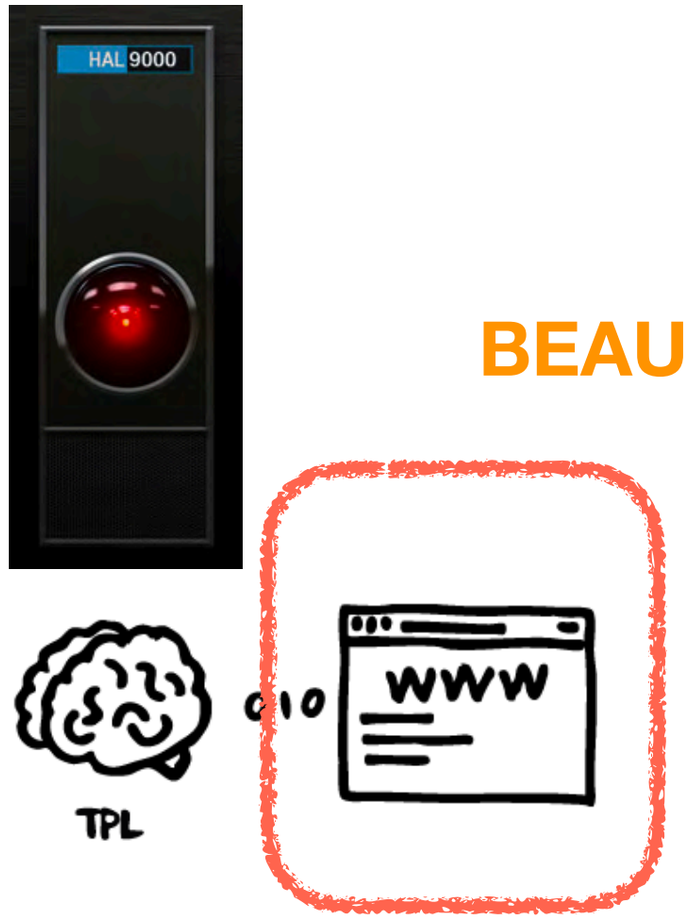


— Employ and advance the cutting-edge

— Statistics, AI and Machine Learning

Our solution: work-flow



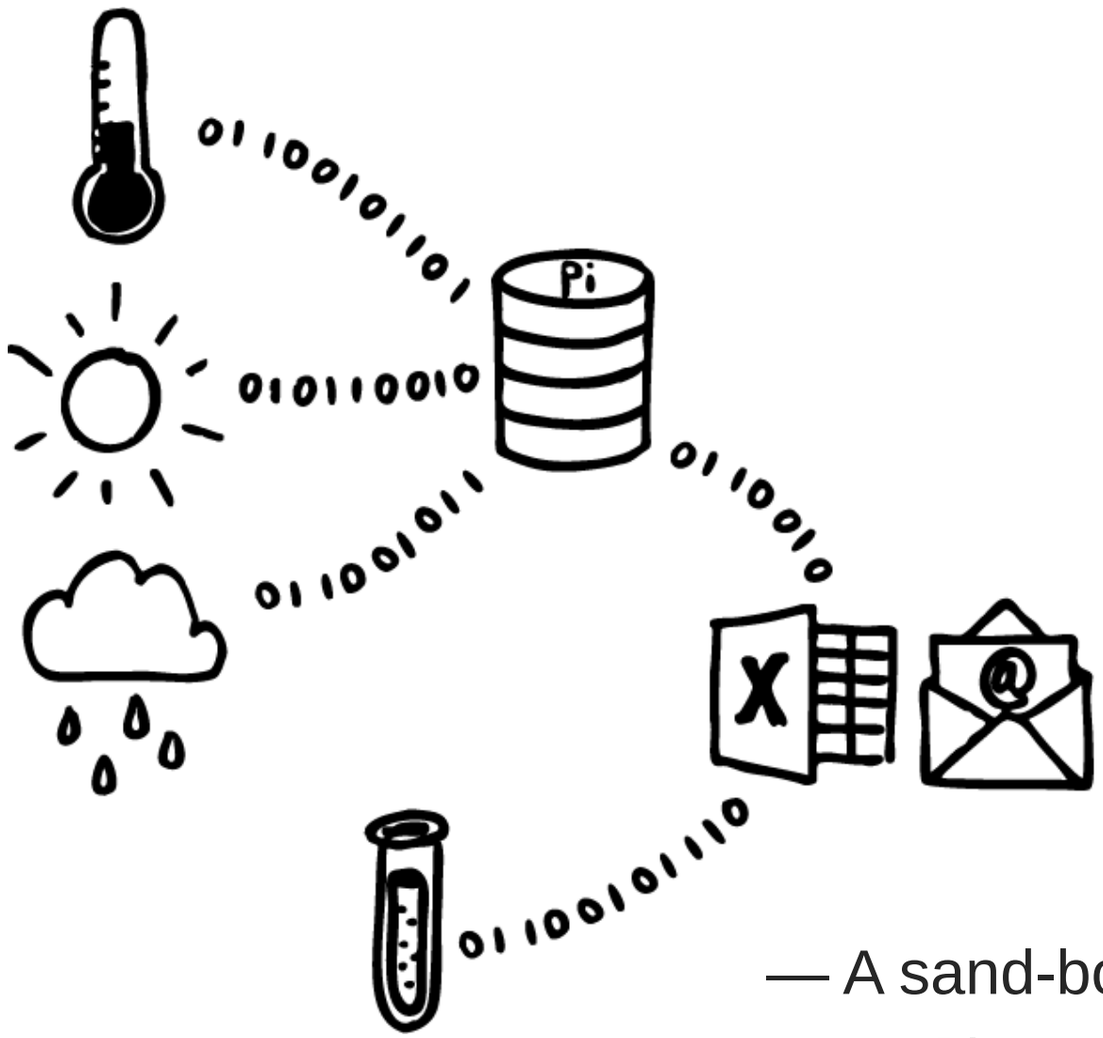


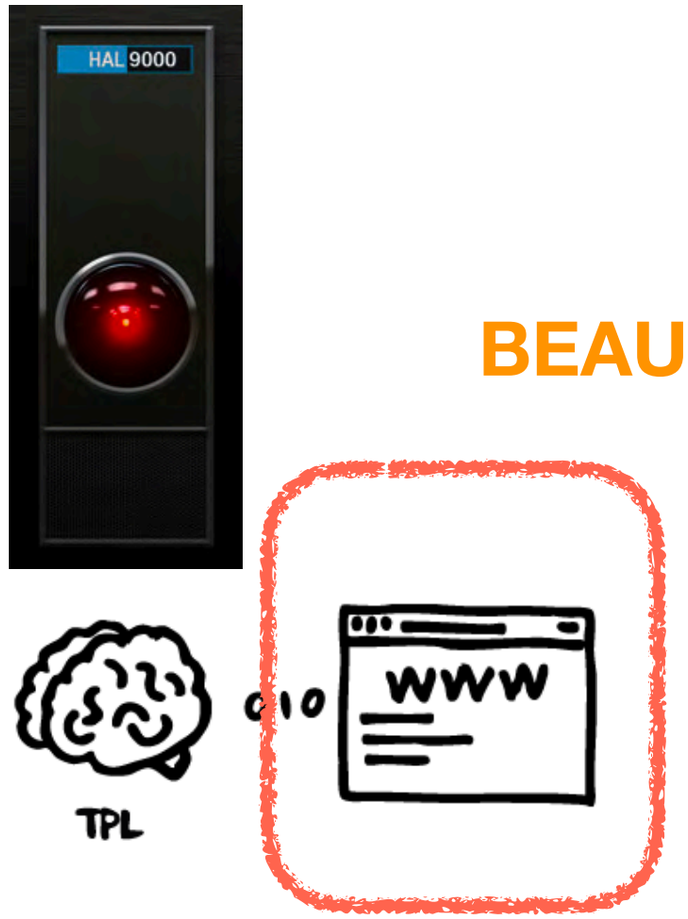
BEAUTIFUL BLOG

— A sand-box for the co-creation of knowledge

— Clear and compelling visualization: public and COS staff

Our solution: work-flow





BEAUTIFUL BLOG

— A sand-box for the co-creation of knowledge

— Clear and compelling visualization: public and COS staff

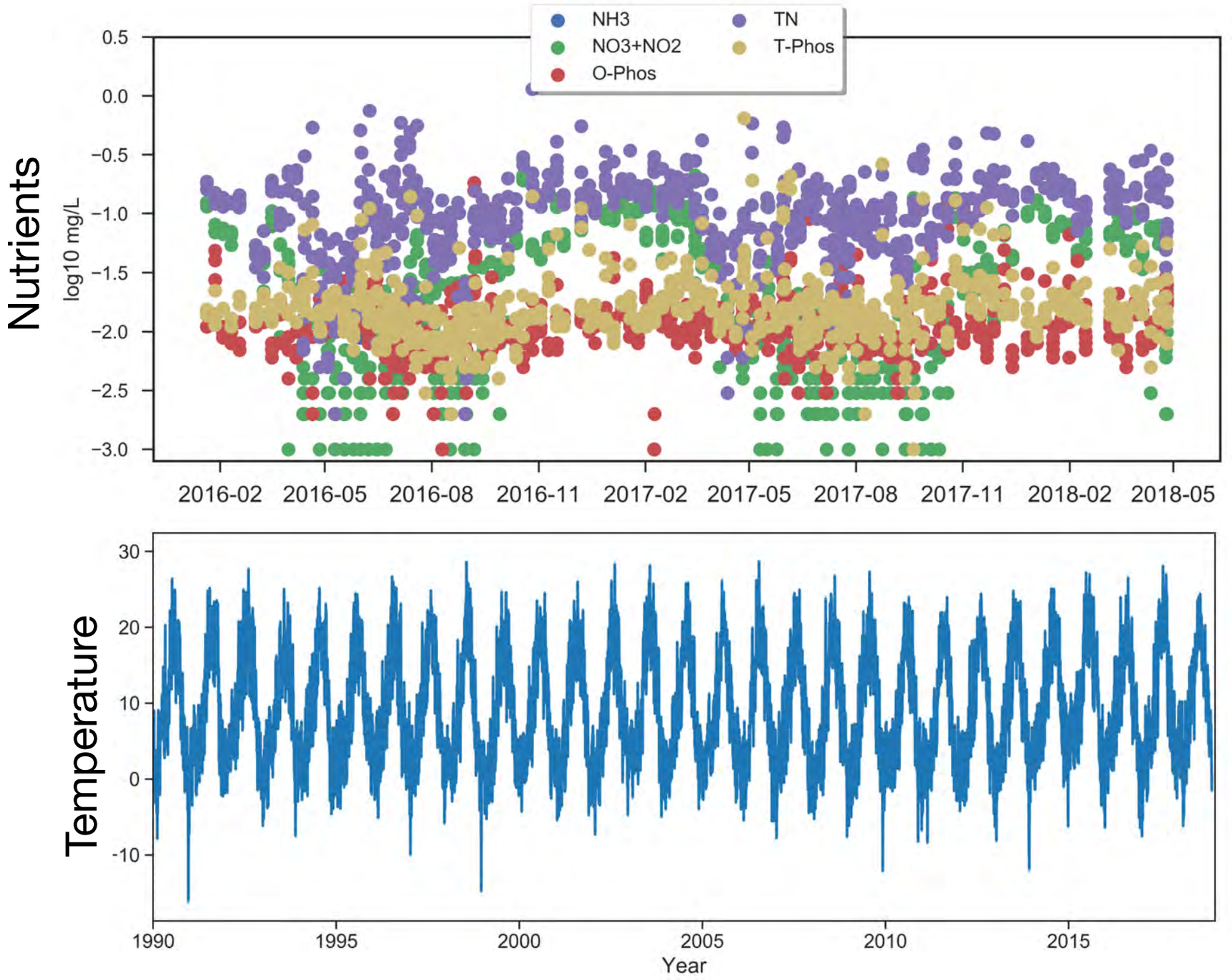
Big Data

Big Data

Current data streams provided by COS:

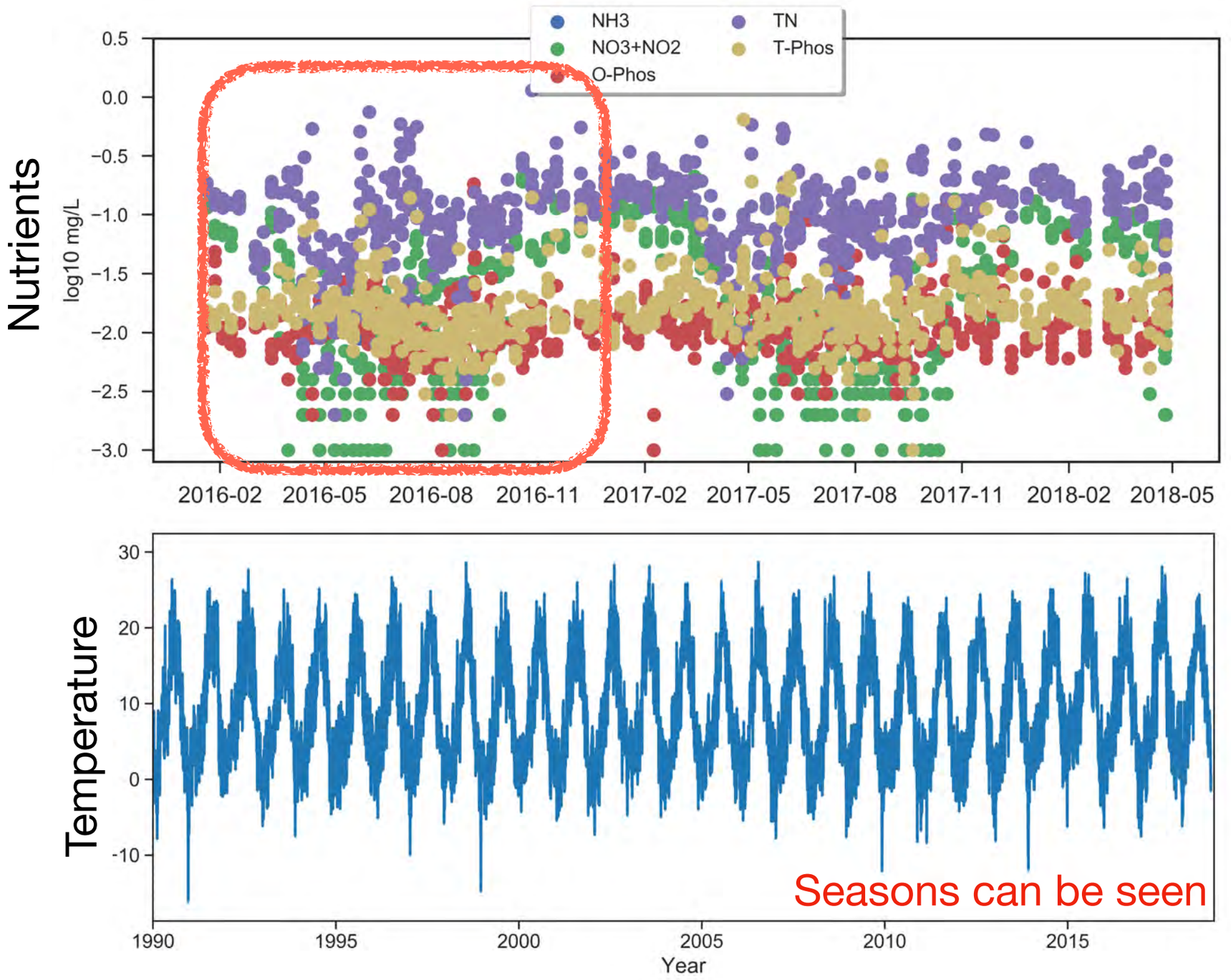
Big Data

Current data streams provided by COS:



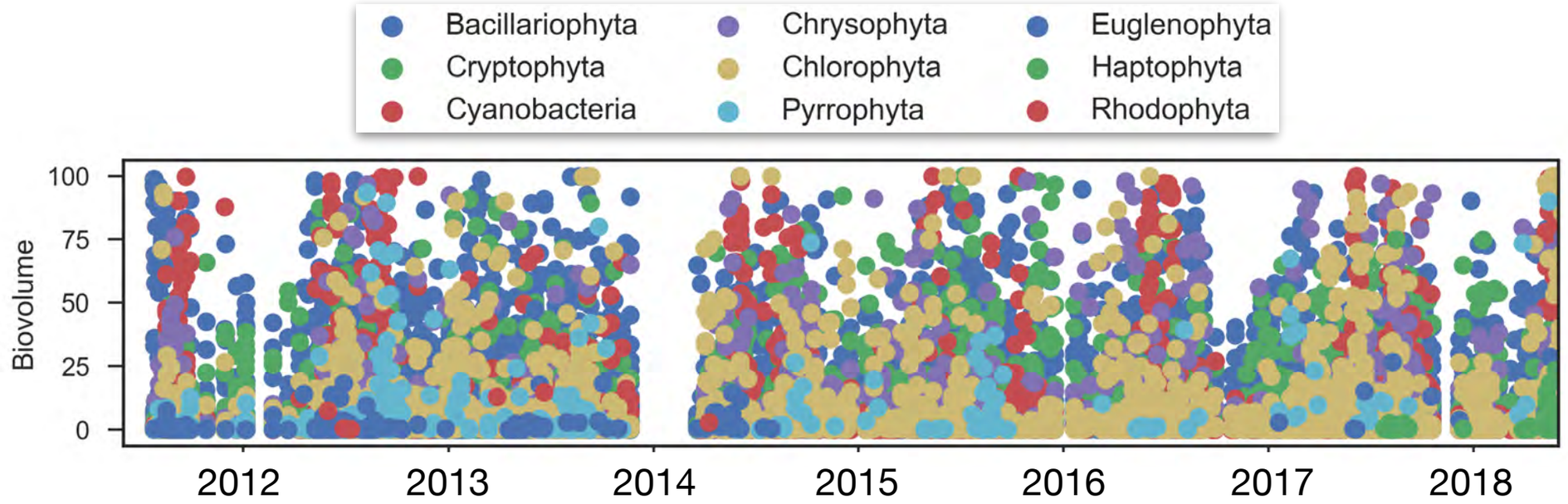
Big Data

Current data streams provided by COS:



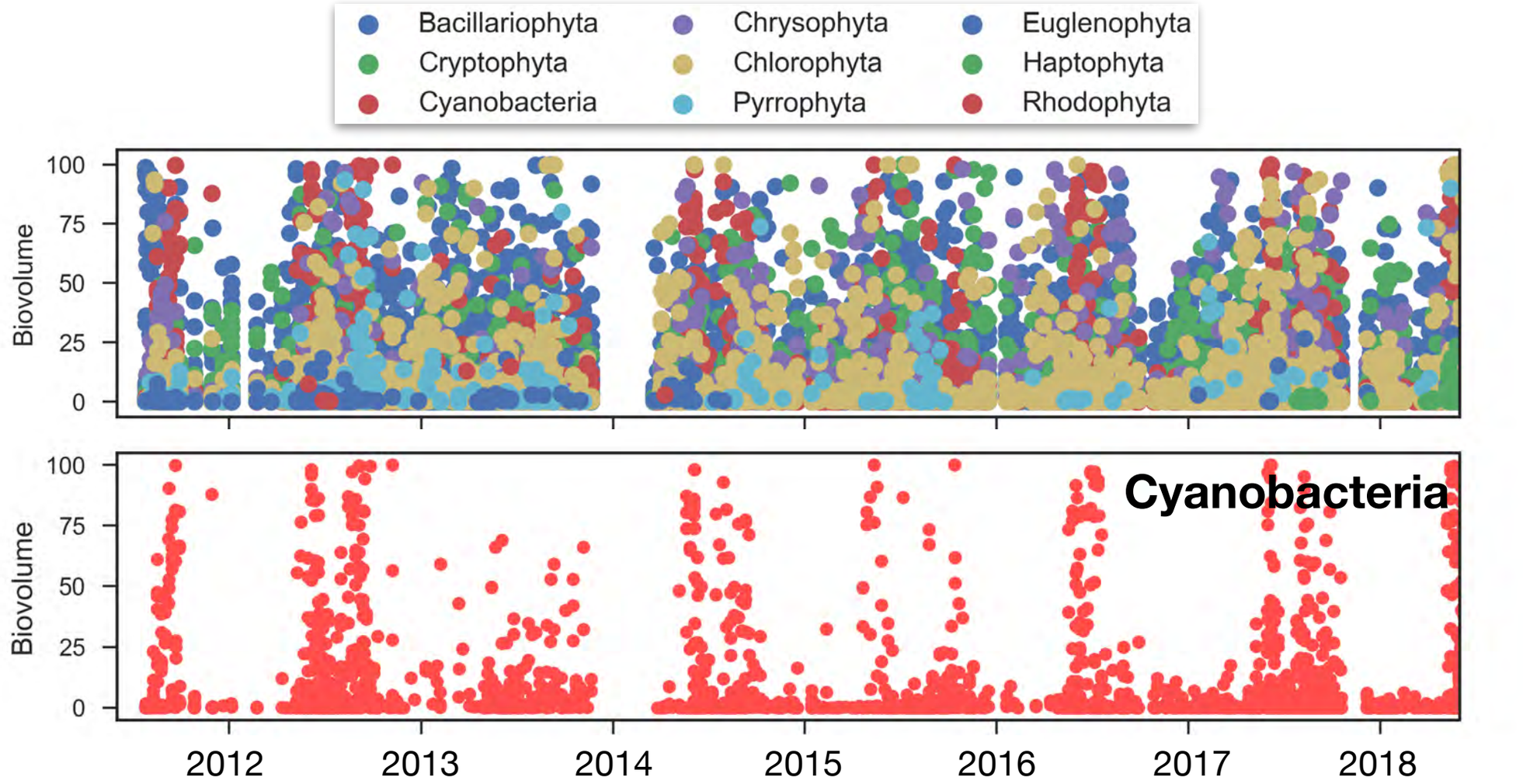
Big Data

Current data streams provided by COS:



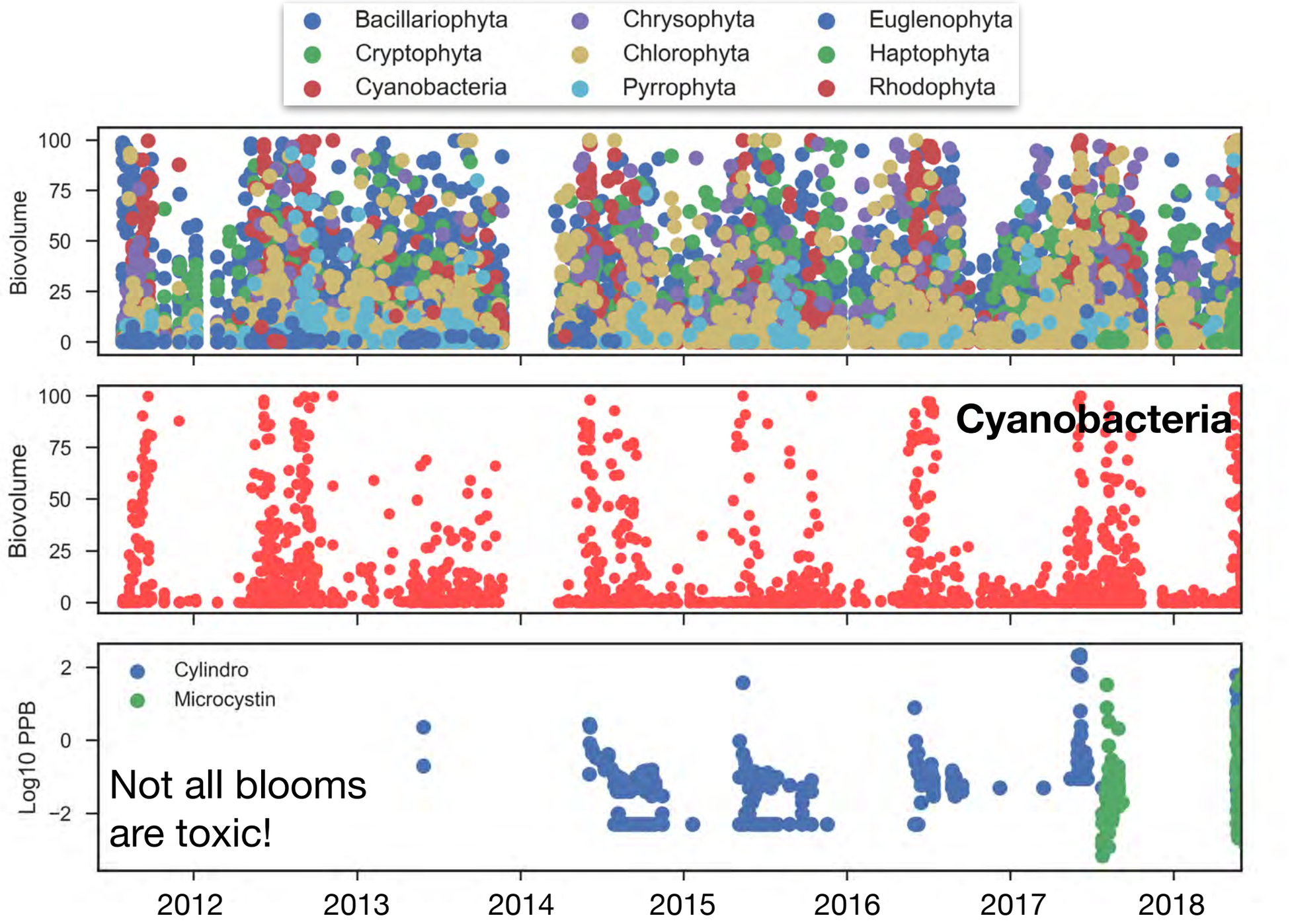
Big Data

Current data streams provided by COS:



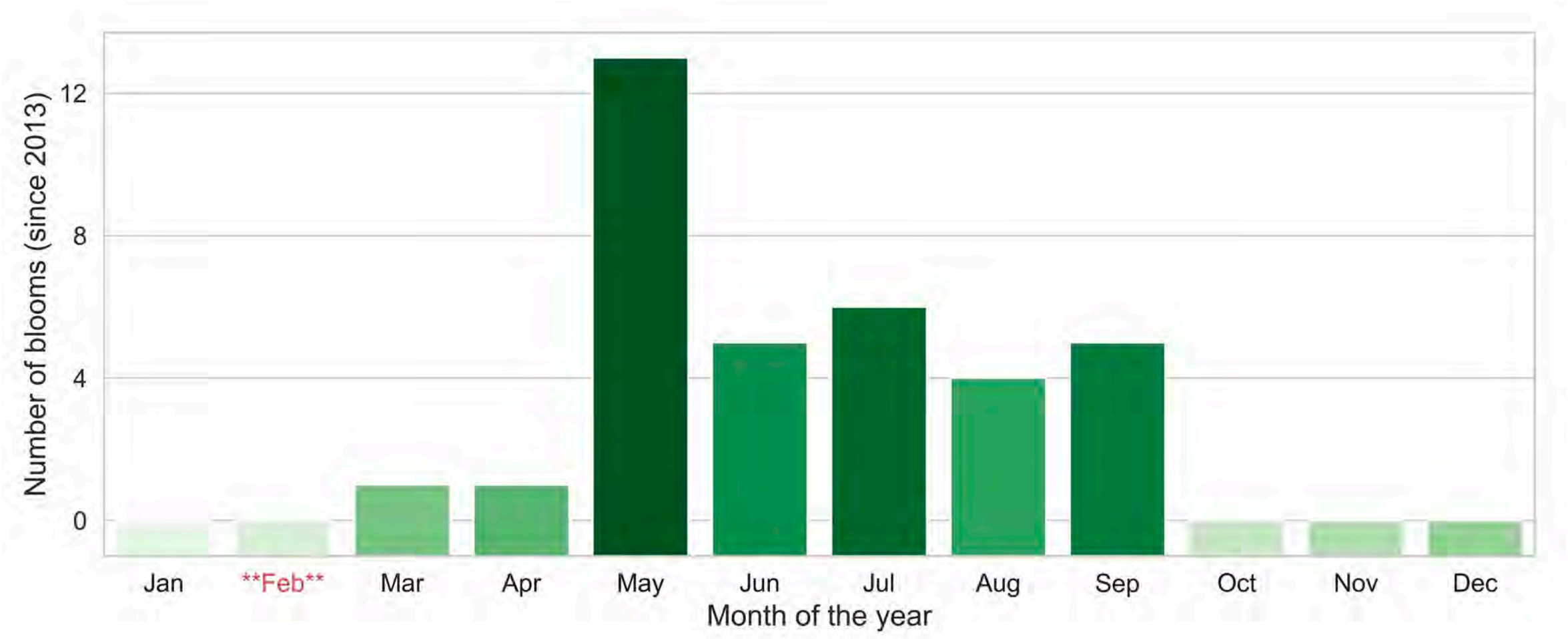
Big Data

Current data streams provided by COS:



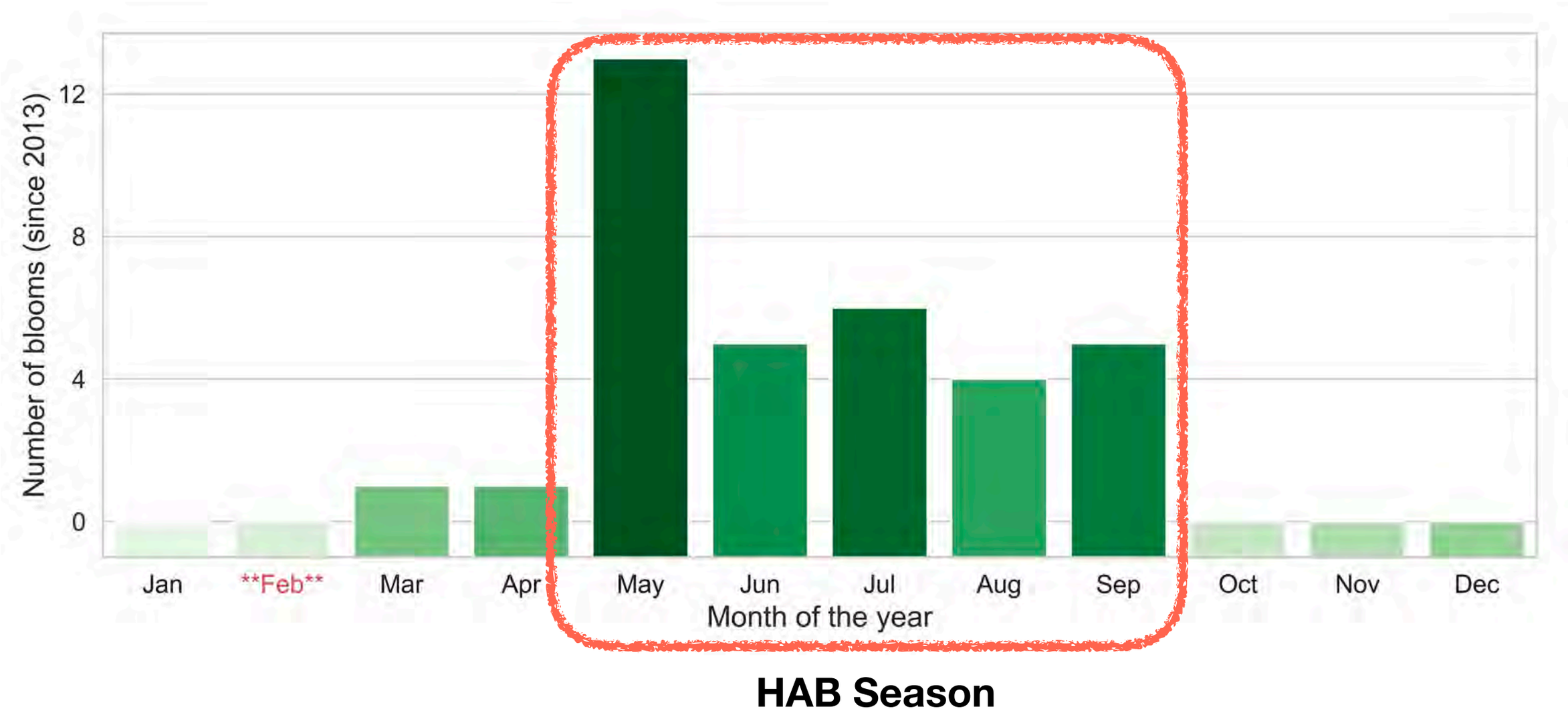
The bloom season

- Clearly define the harmful algal bloom season…



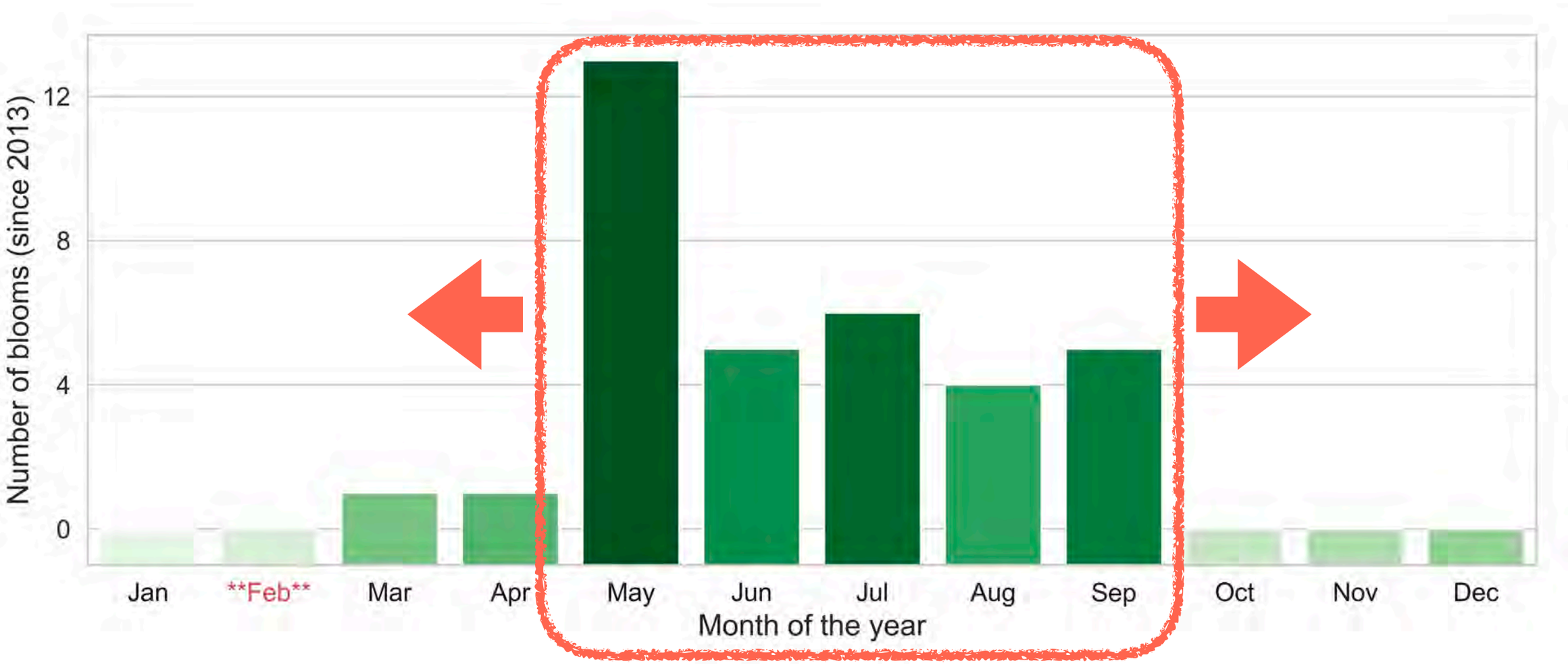
The bloom season

- Clearly define the harmful algal bloom season…



The bloom season

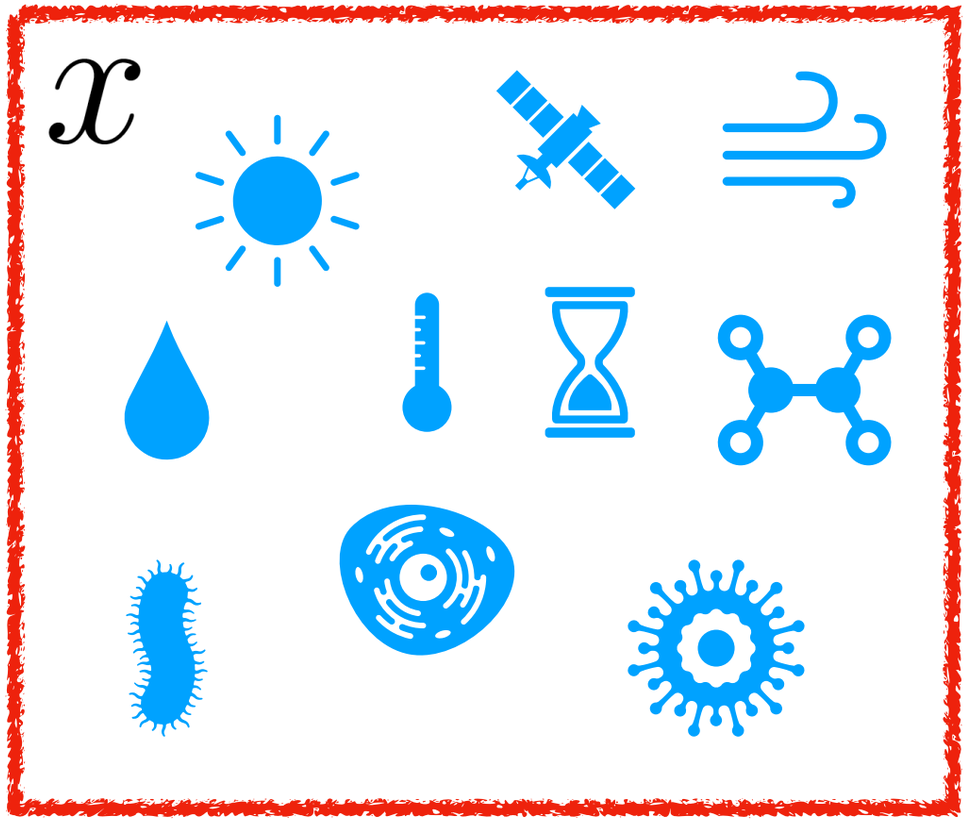
- Clearly define the harmful algal bloom season…



HAB Season
As more data come in, we will track when the season starts and ends

Brilliant algorithms

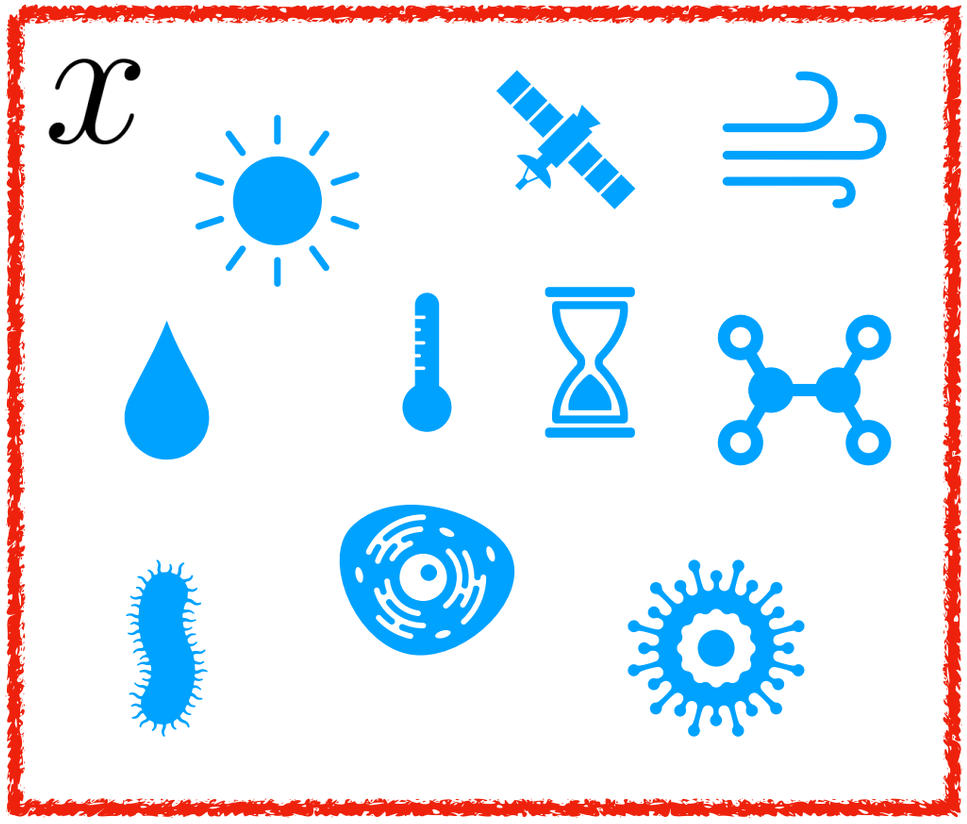
Mathematical Modeling



$f(x)$

Estimated Toxin Level

Mathematical Modeling



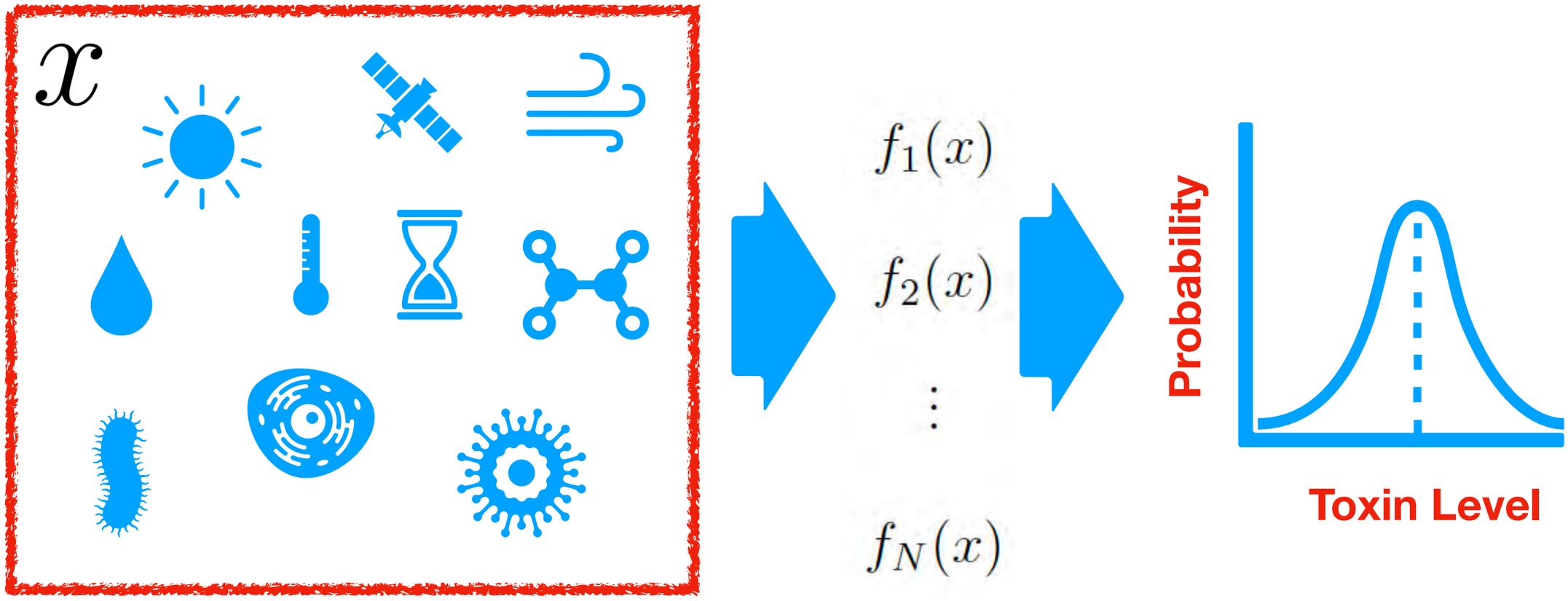
$f(x)$

Estimated Toxin Level

Since all models are wrong the scientist cannot obtain a "correct" one by excessive elaboration. On the contrary following William of Occam he should seek an economical description of natural phenomena.

Since all models are wrong the scientist must be alert to what is importantly wrong. It is inappropriate to be concerned about mice when there are tigers abroad.

Mathematical Modeling

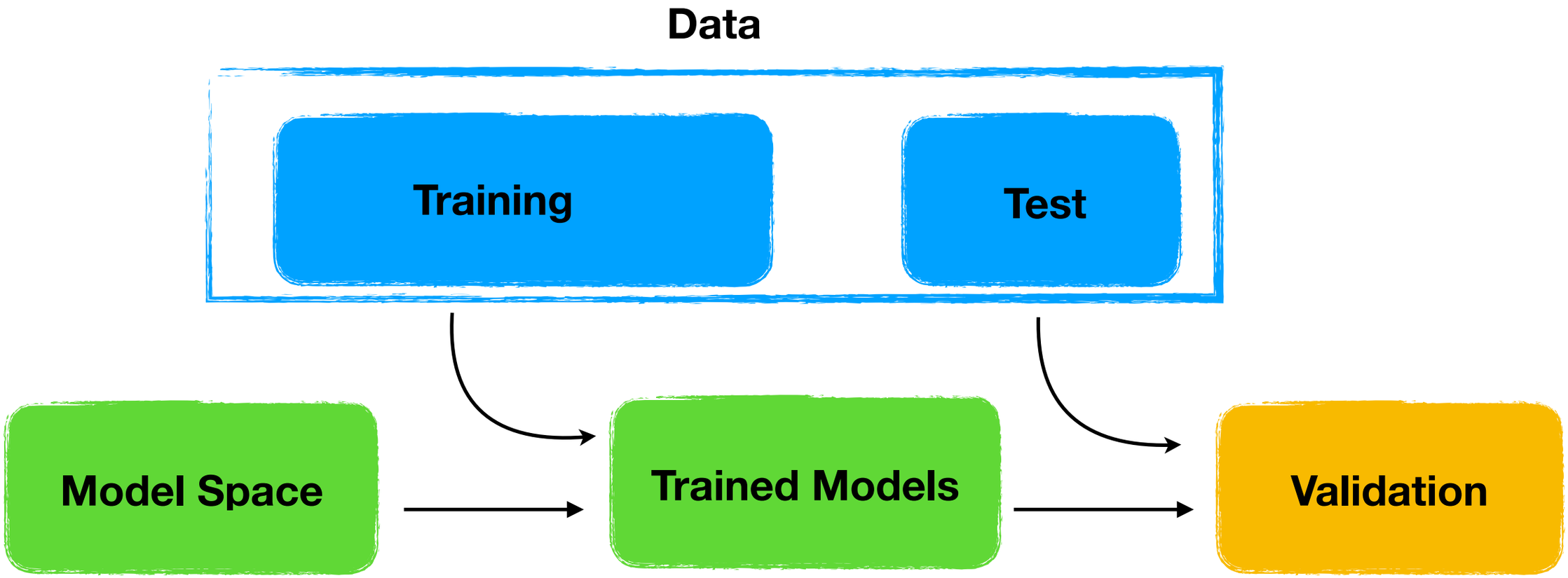


Since all models are wrong the scientist cannot obtain a "correct" one by excessive elaboration. On the contrary following William of Occam he should seek an economical description of natural phenomena.

Since all models are wrong the scientist must be alert to what is importantly wrong. It is inappropriate to be concerned about mice when there are tigers abroad.

Machine Learning:
Finding an effective model

- Model choice from validated data

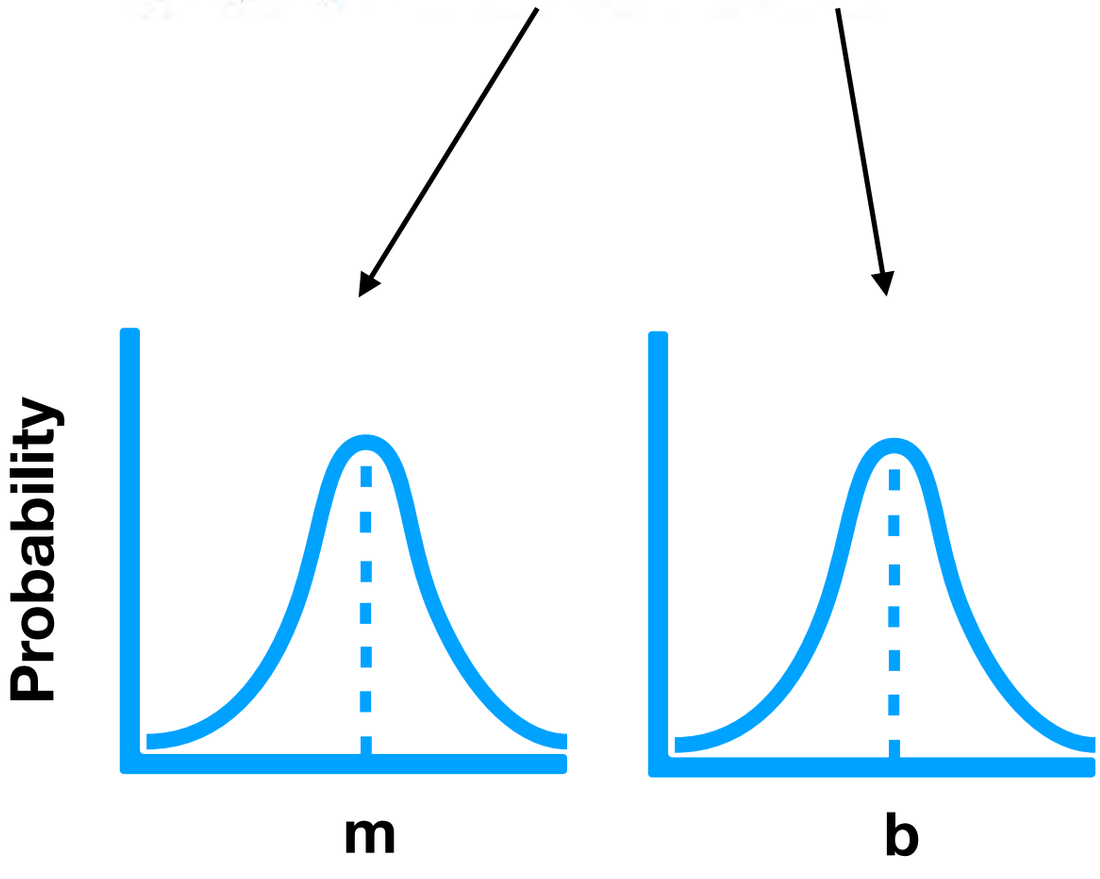


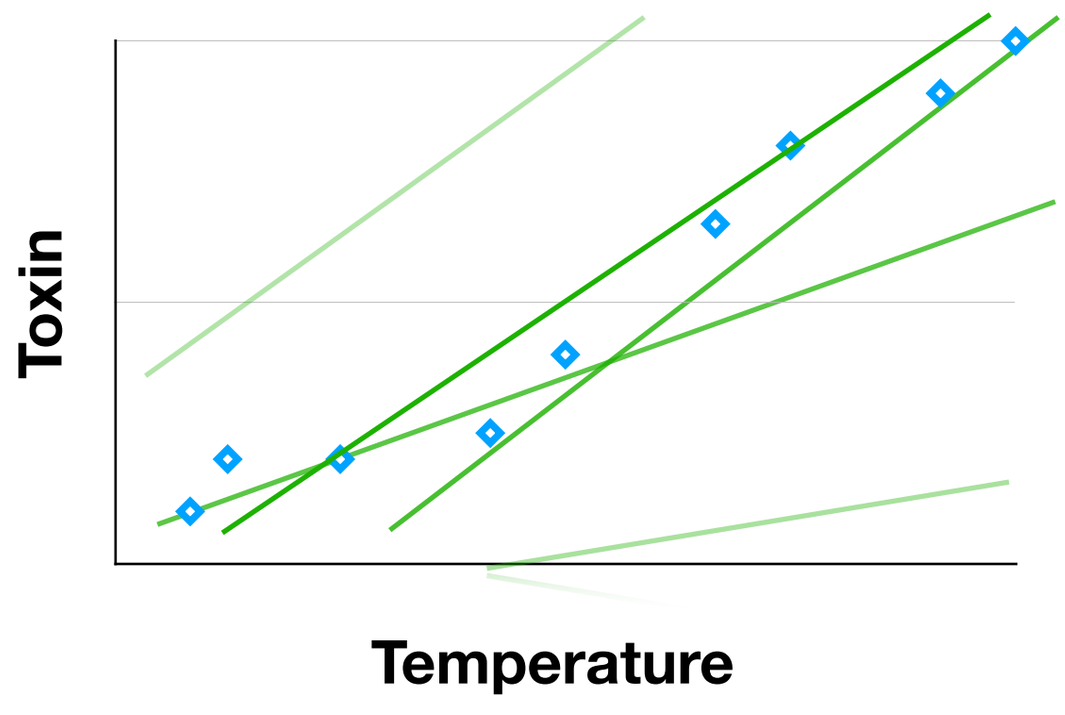
- Data complexity vs. model complexity

Bayesian Model Averaging

- All models are wrong but some are useful

$$f(x) = mx + b$$





Bayesian Model Averaging

- Posterior distribution: $$P(T|x) = \sum_{k=1}^{N} P(T|f_k, x)P(f_k|x)$$

x	**Previously Observed Data**
T	**Tomorrow's Cyanobacteria Level**
f_k	**Model Choice**

Bayesian Model Averaging

- Posterior distribution: $$P(T|x) = \sum_{k=1}^{N} P(T|f_k, x)P(f_k|x)$$

x	**Previously Observed Data**
T	**Tomorrow's Cyanobacteria Level**
f_k	**Model Choice**

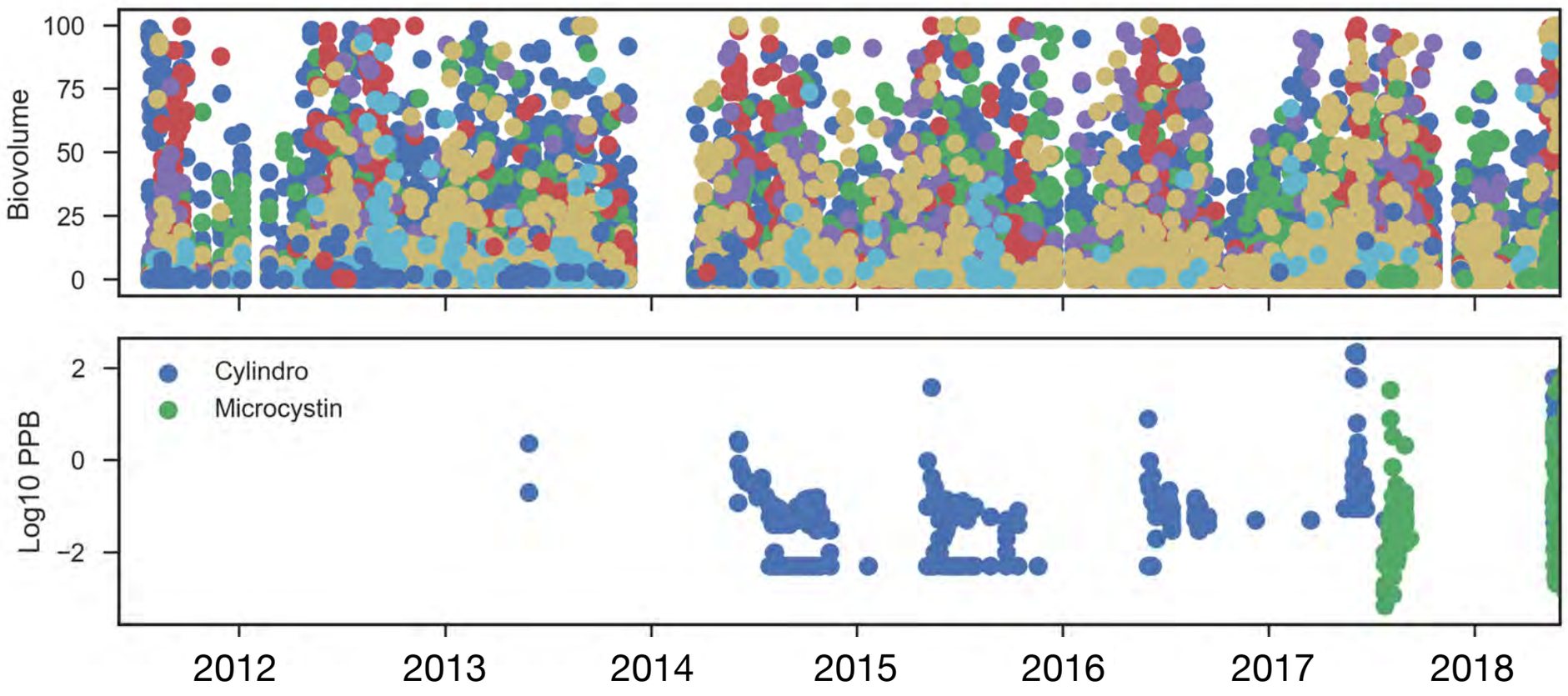
- Bayes Theorem: $$P(f_k|x) = \frac{P(x|f_k)P(f_k)}{\sum_{\ell=1}^{N} P(x|f_\ell)P(f_\ell)}$$

- Balancing assumptions with evidence

2018 back-test

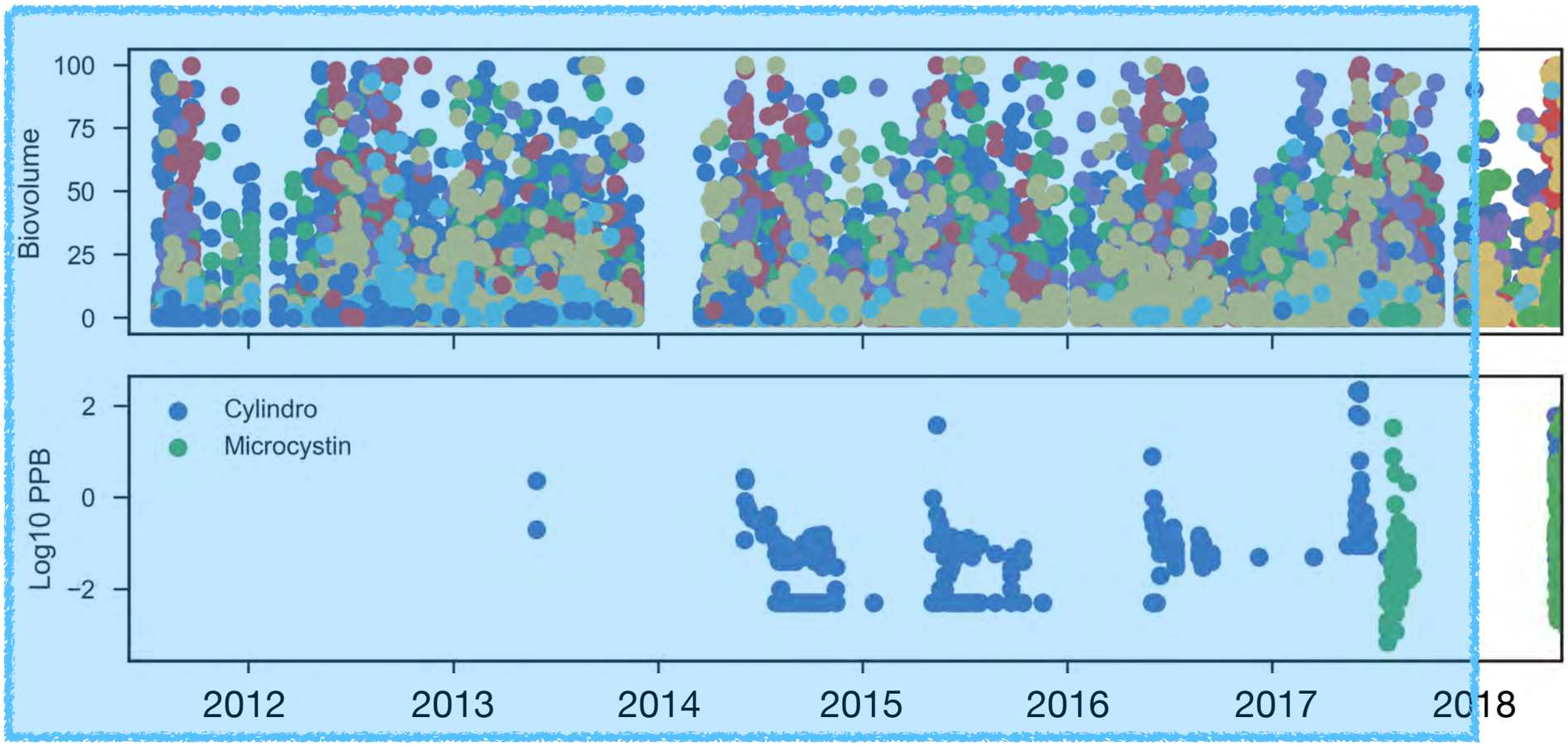
2018 back-test

- Train models on all data excluding 2018
- Test model on 2018… what if this were last year



2018 back-test

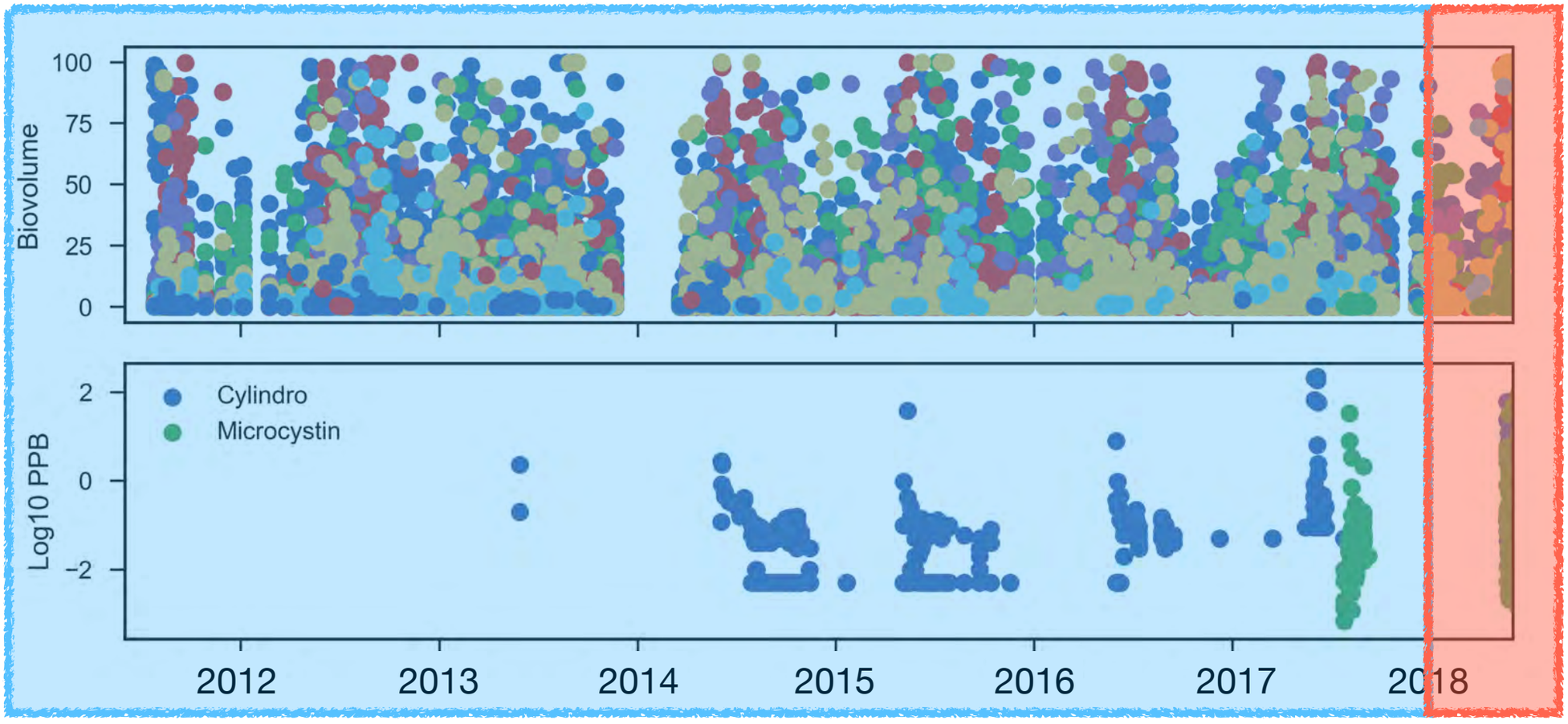
- Train models on all data excluding 2018
- Test model on 2018… what if this were last year



Training data

2018 back-test

- Train models on all data excluding 2018
- Test model on 2018… what if this were last year



Training data

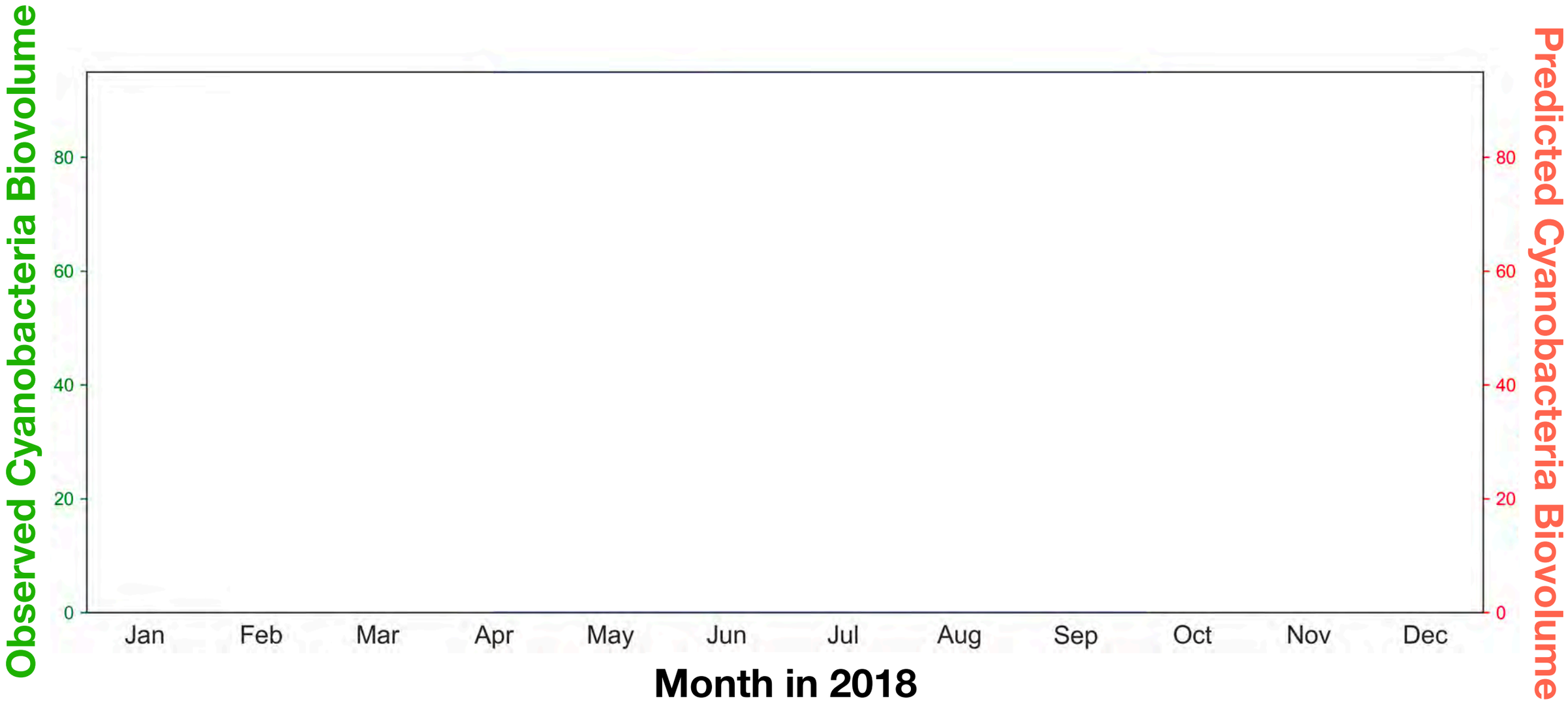
Test data

2018 back-test

- Imagine its 2018….

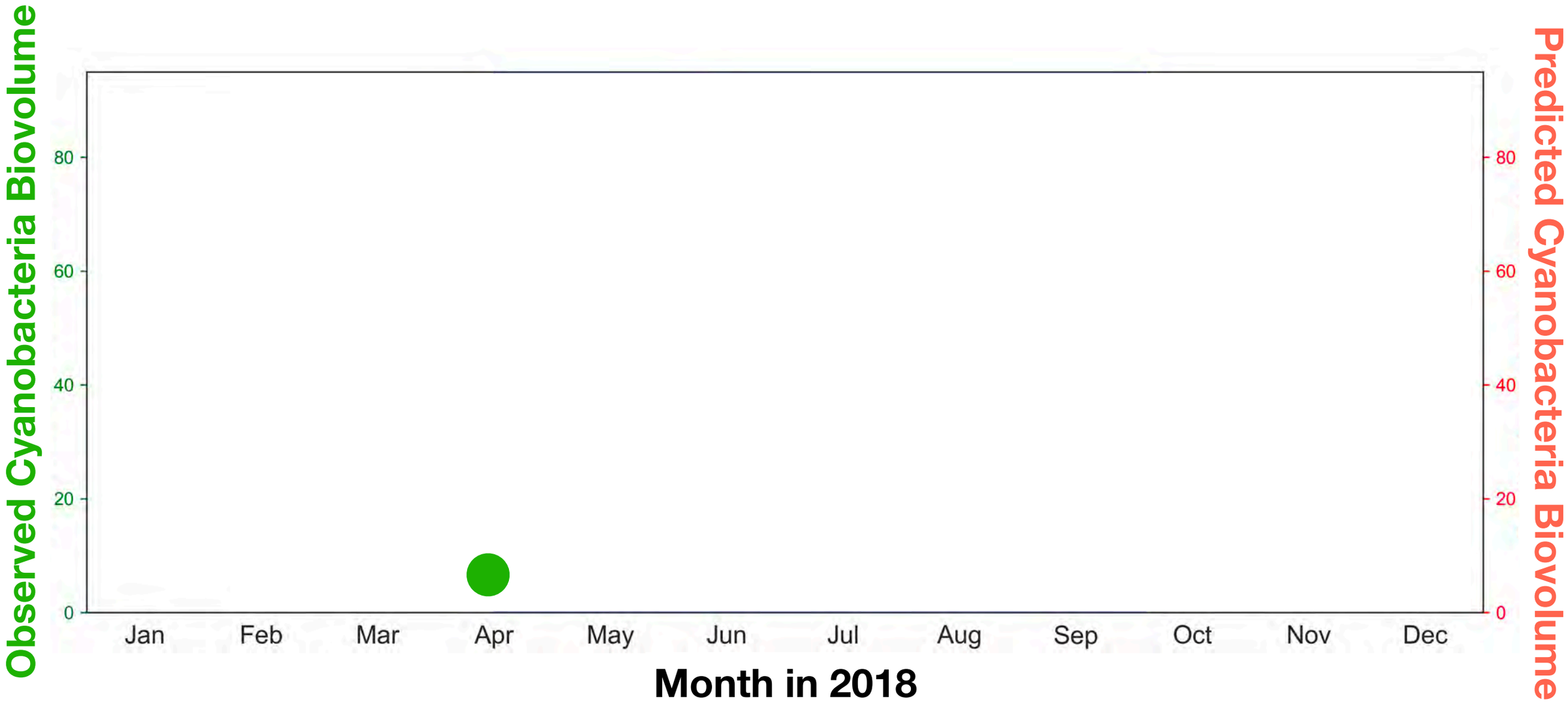
2018 back-test

- Imagine its 2018….



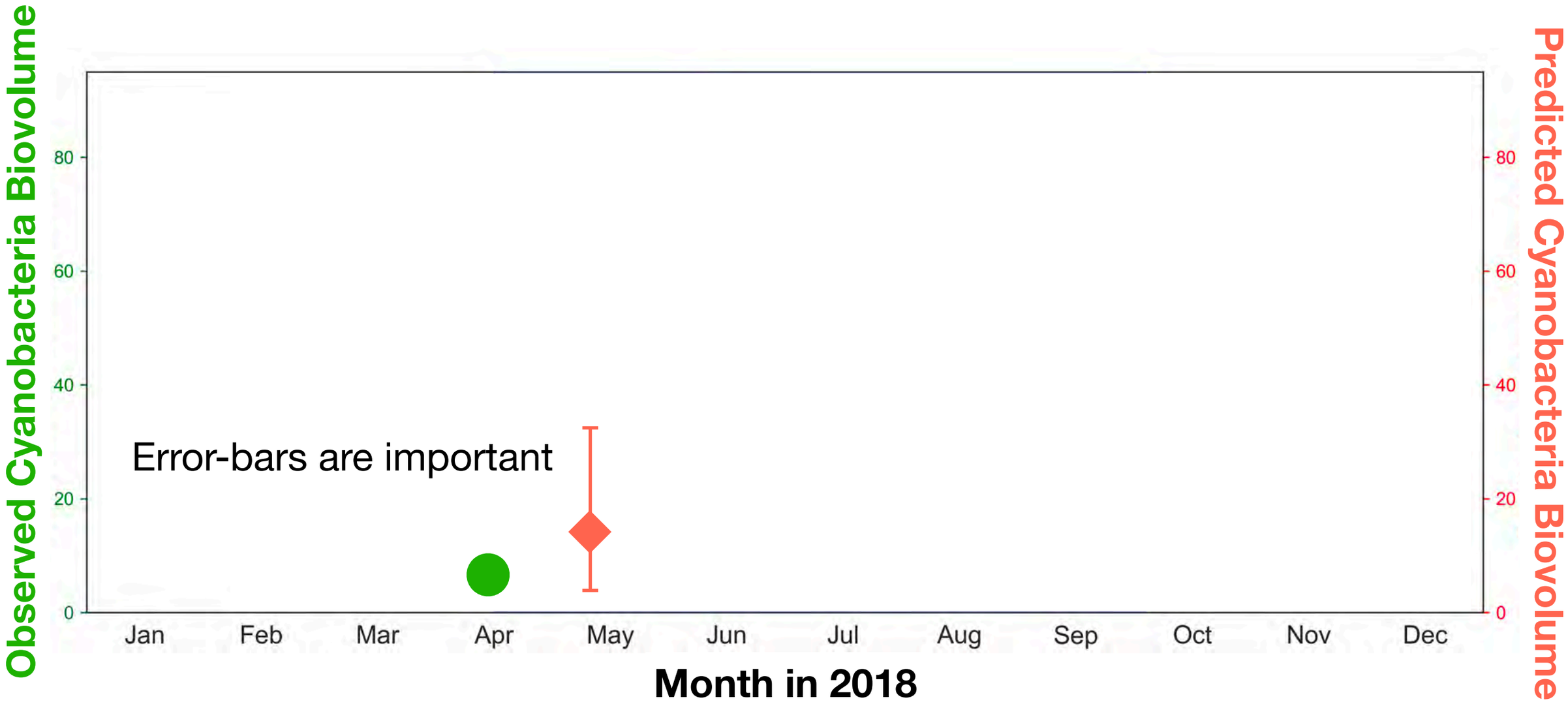
2018 back-test

- Imagine its 2018….



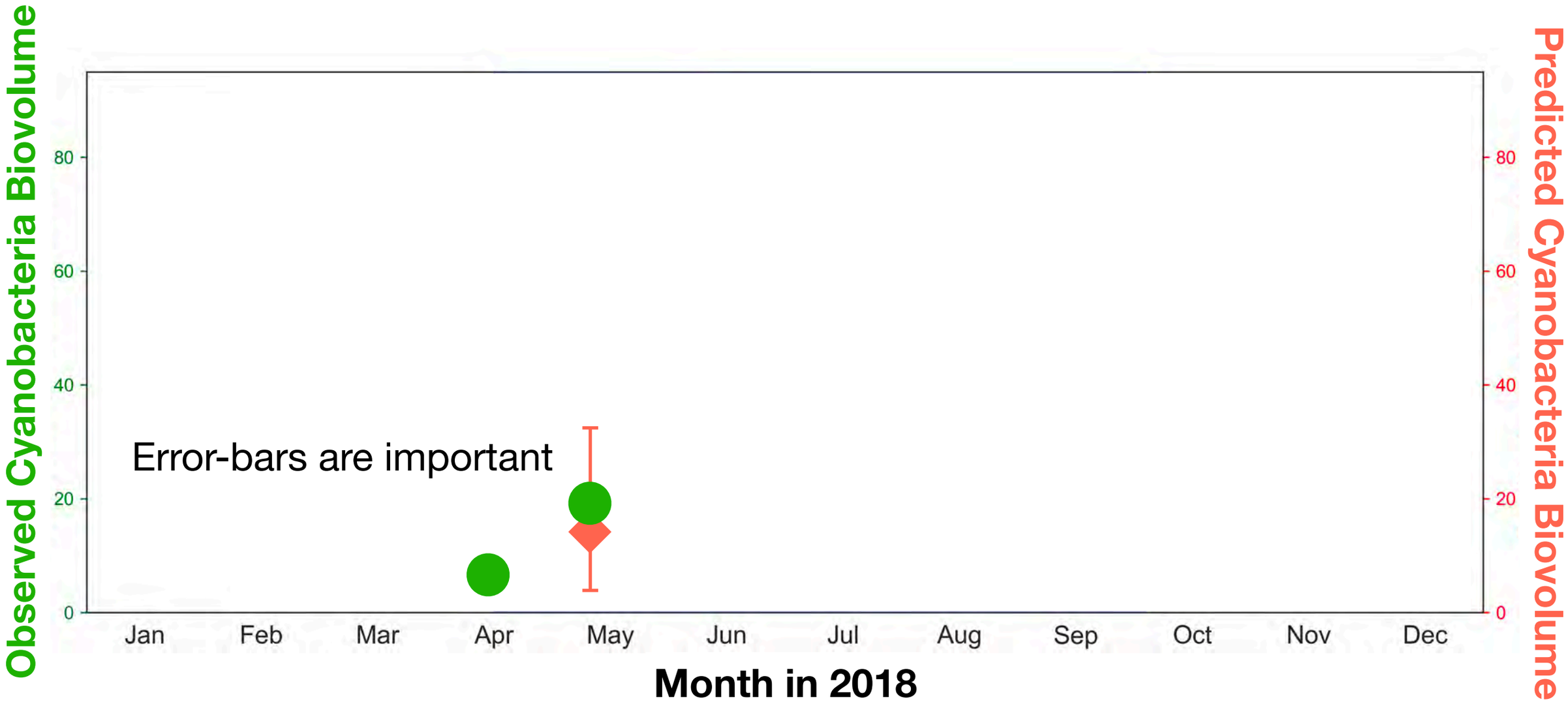
2018 back-test

- Imagine its 2018….



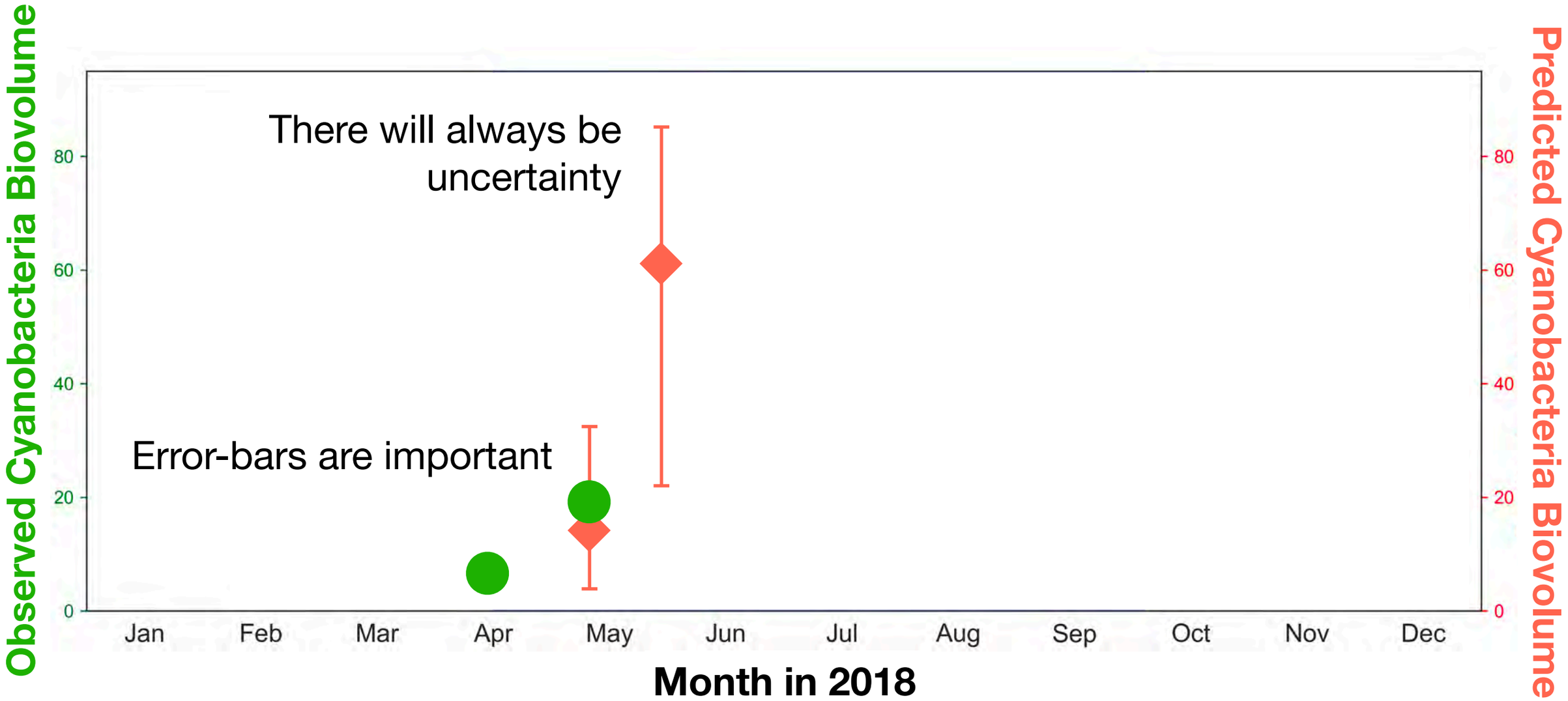
2018 back-test

- Imagine its 2018….



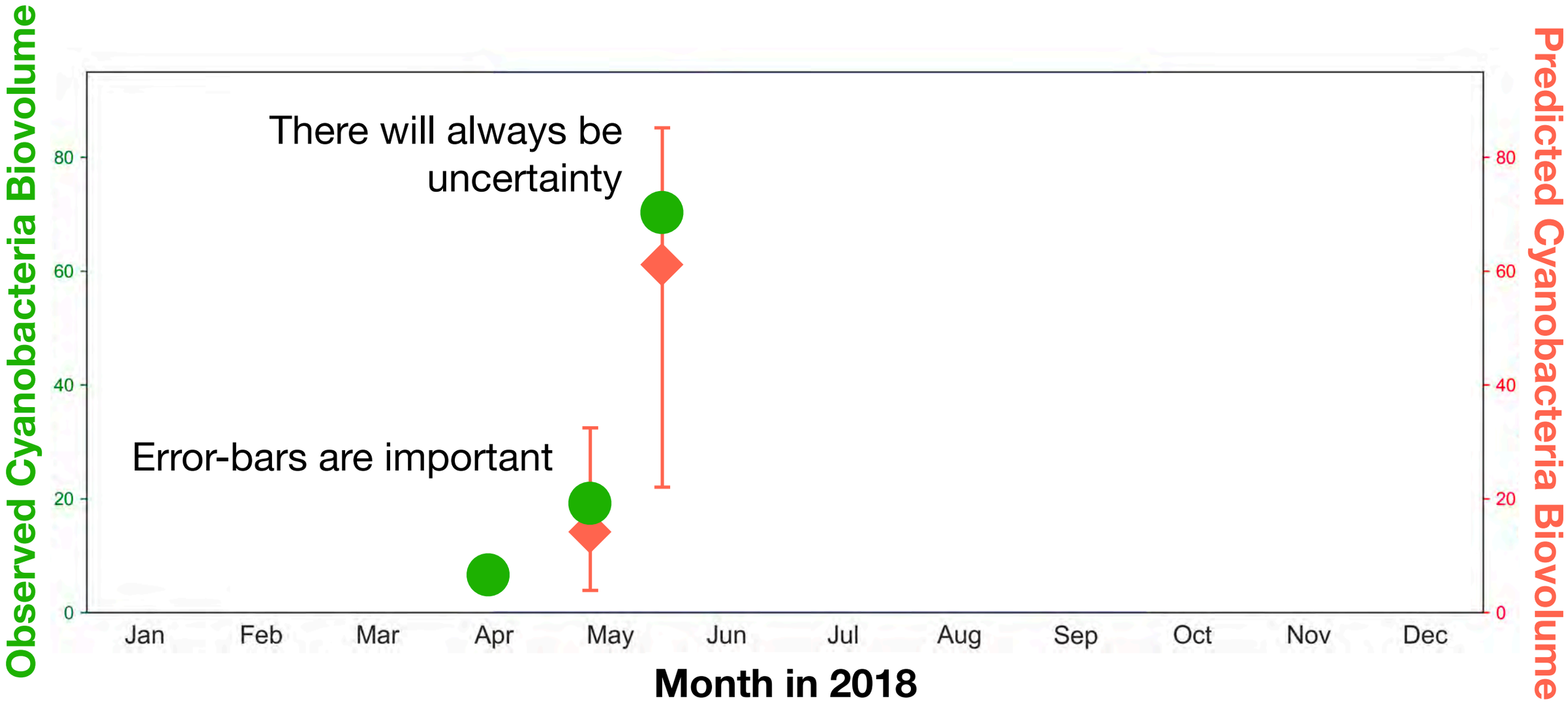
2018 back-test

- Imagine its 2018….



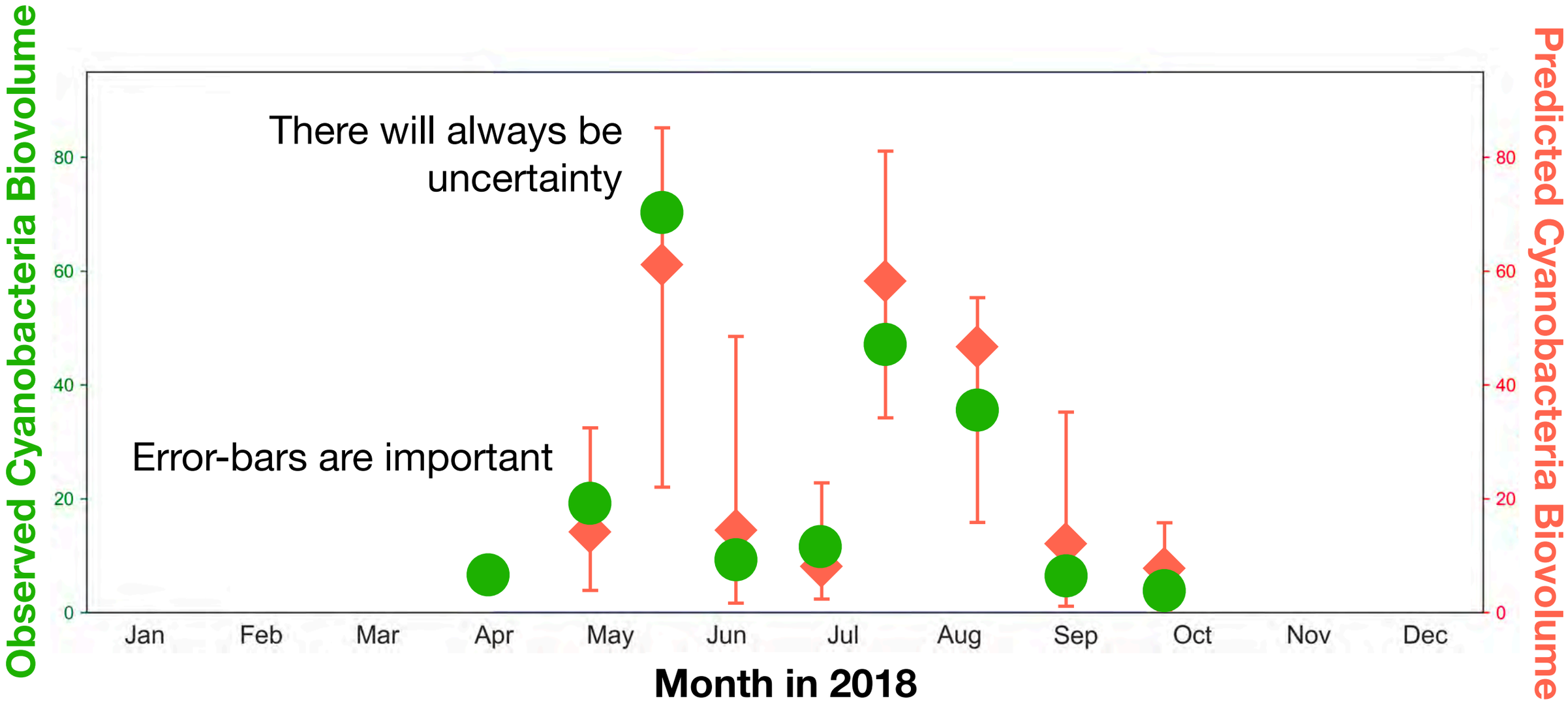
2018 back-test

- Imagine its 2018….



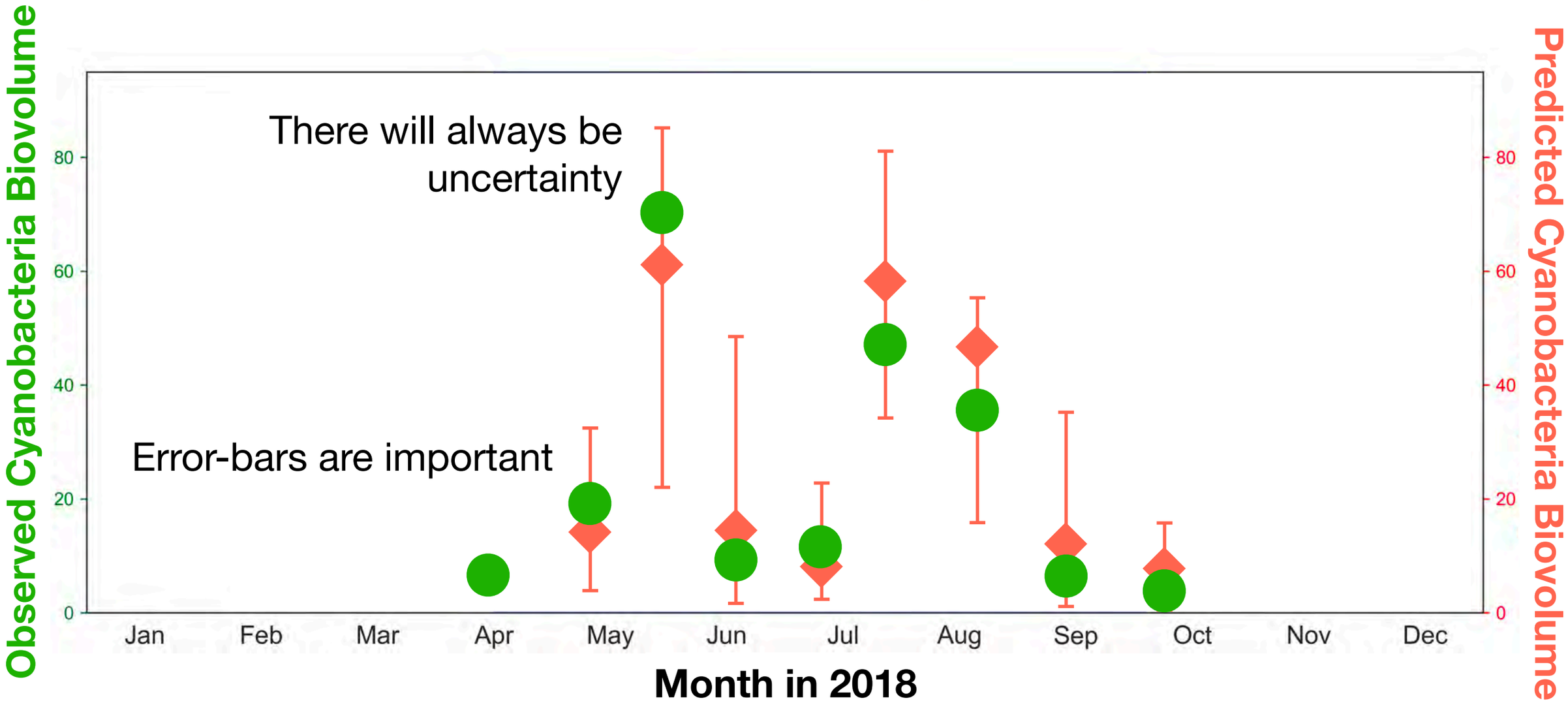
2018 back-test

- Imagine its 2018….



2018 back-test

- Imagine its 2018….for algal concentrations our accuracy was 80-92%*



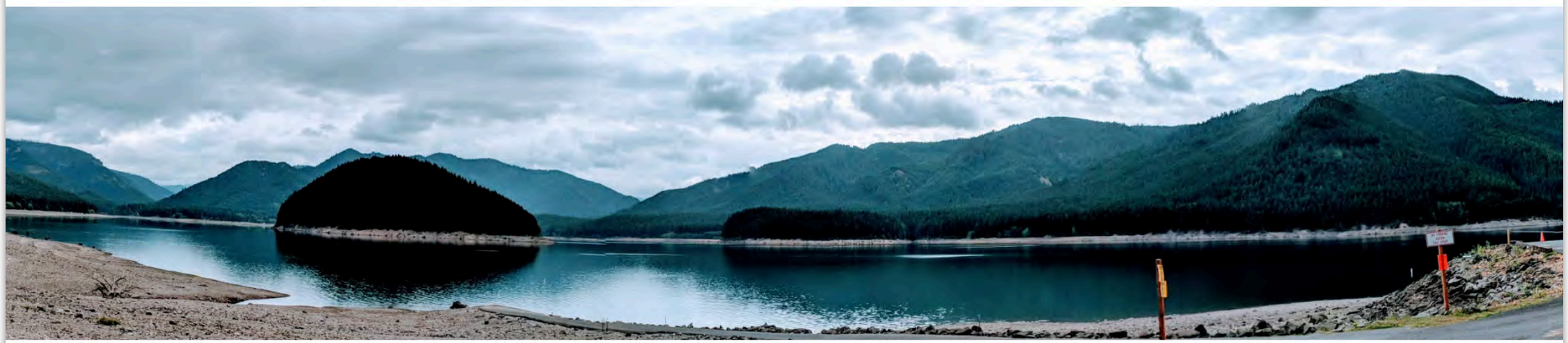
*depending upon the definition of a “bloom”

Beautiful blog

- We wanted something more visually compelling than other HAB data portals
- Balance usability and knowledge transfer (for the public and City of Salem staff)
- https://thepredictionlabllc.github.io/detroit-lake-predictions/

We are ready! big data, algorithms, blog

The Prediction Lab & The City of Salem



Detroit Lake Predictions

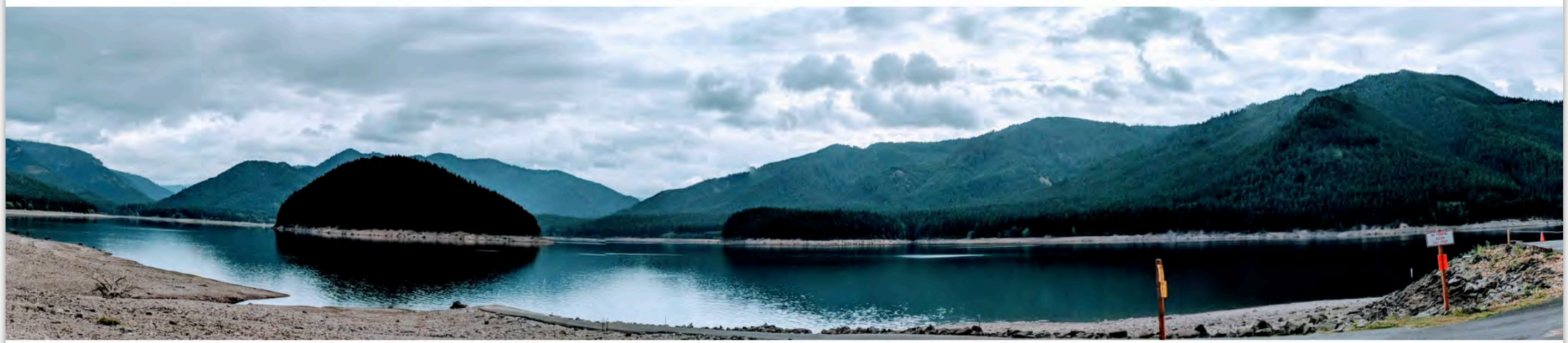
An initiative to care for our water source

Bloom Forecast Mar 15-22

Our models suggest that in the next week lake conditions will most likely stay clear of harmful algae.

We are ready! big data, algorithms, blog

The Prediction Lab & The City of Salem



Detroit Lake Predictions

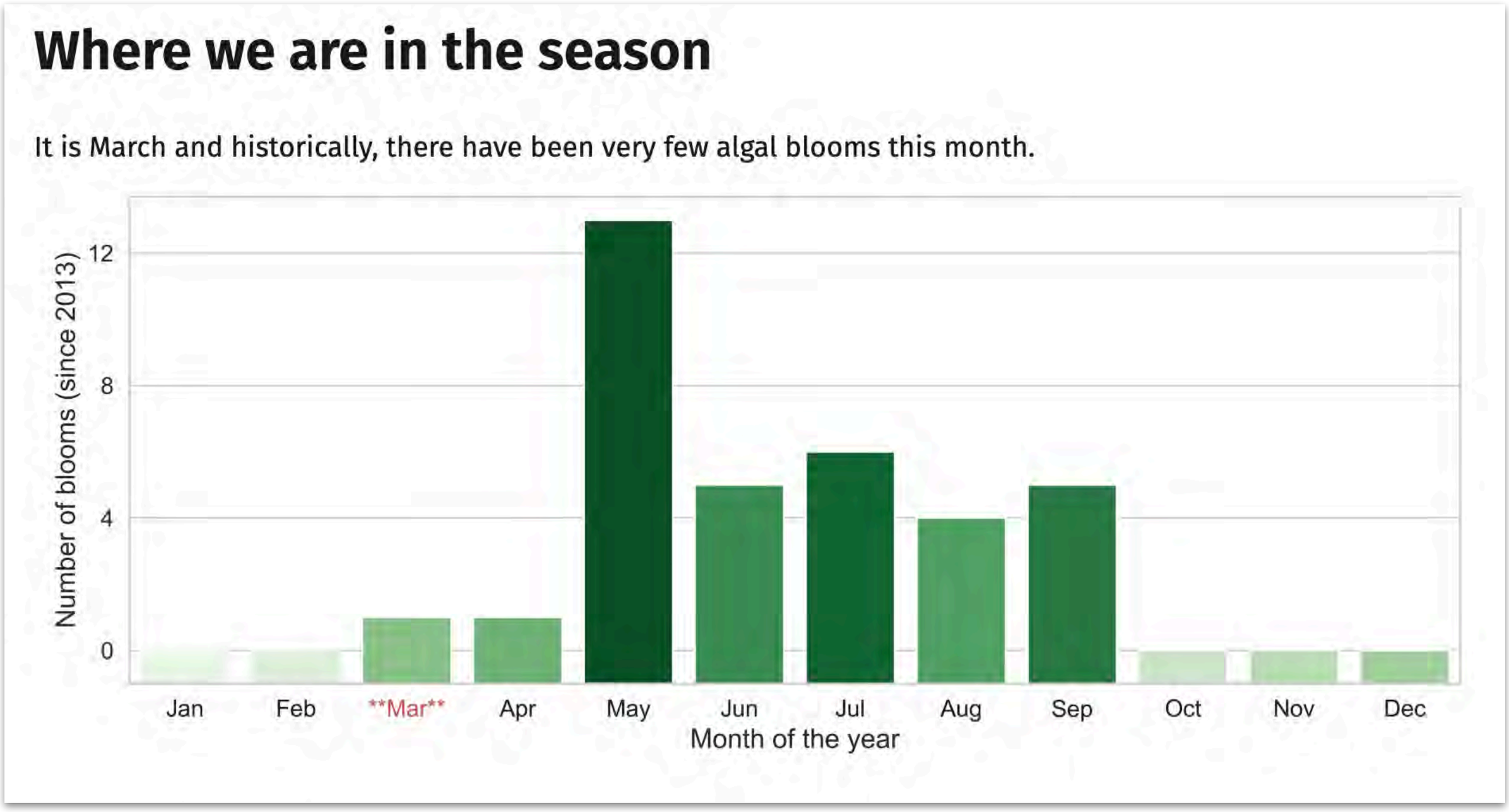
An initiative to care for our water source

Bloom Forecast Mar 15-22

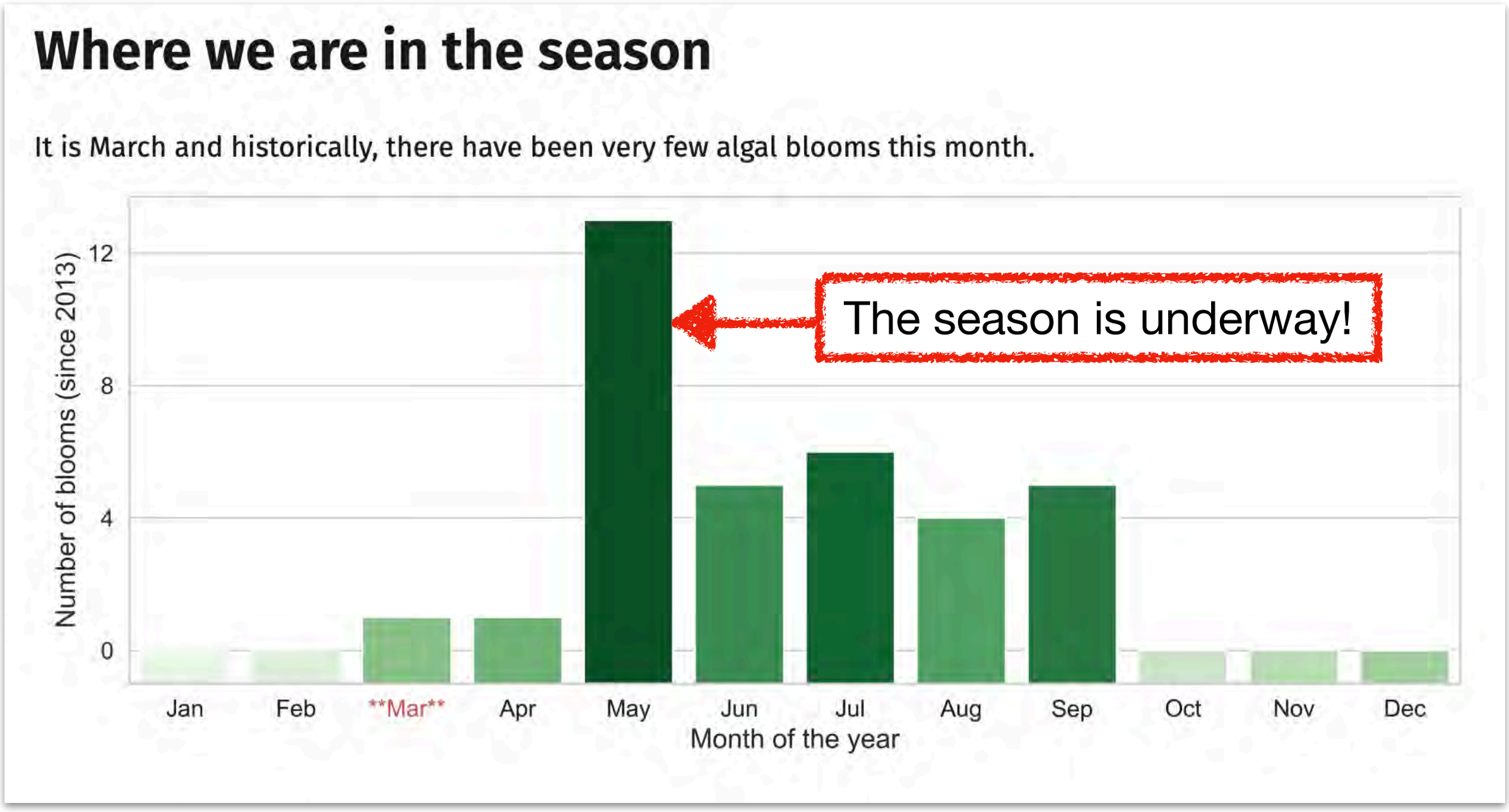
Weekly forecasts of algal conditions in the lake

Our models suggest that in the next week lake conditions will most likely stay clear of harmful algae.

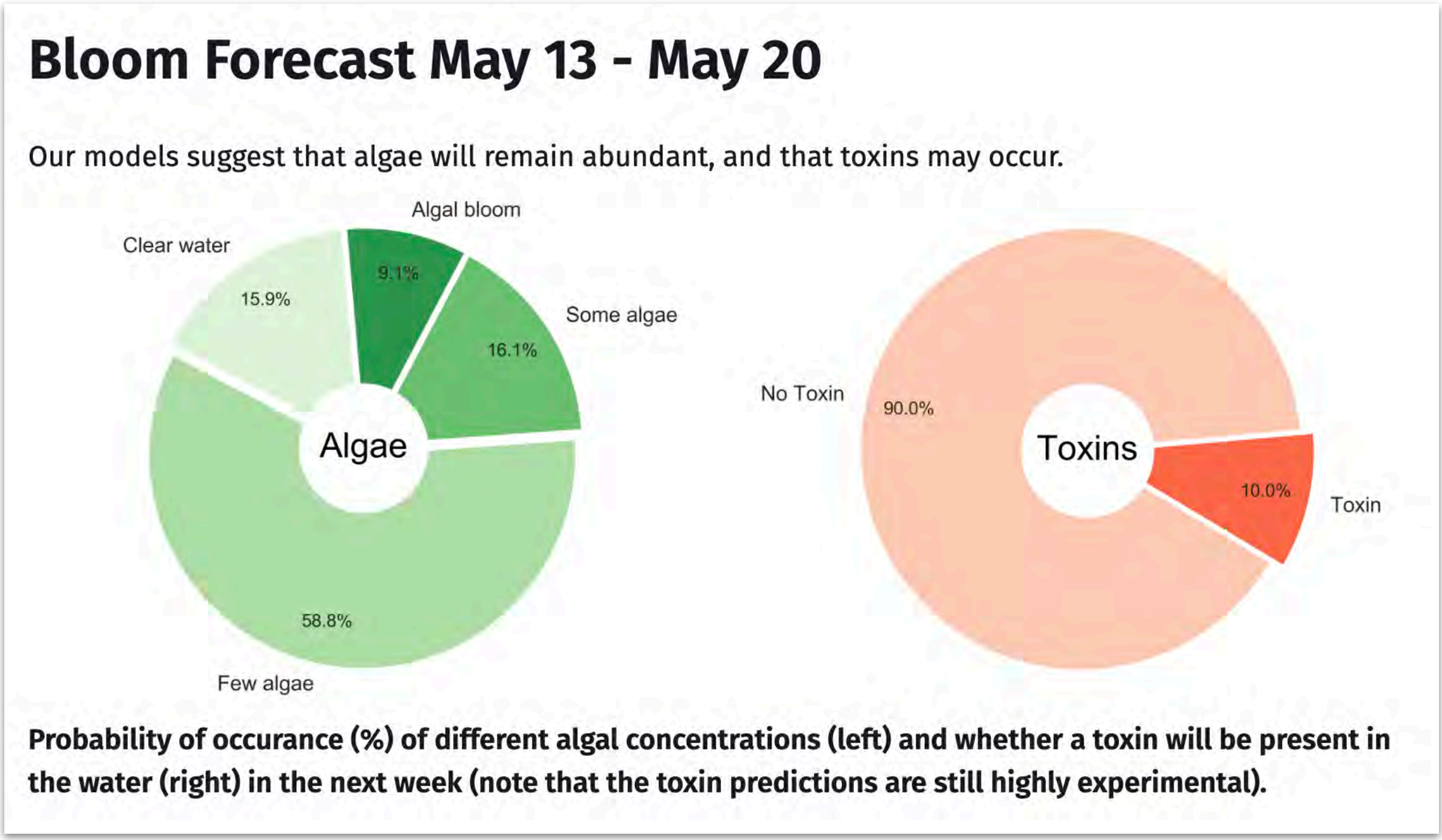
We are ready! big data, algorithms, blog



We are ready! big data, algorithms, blog



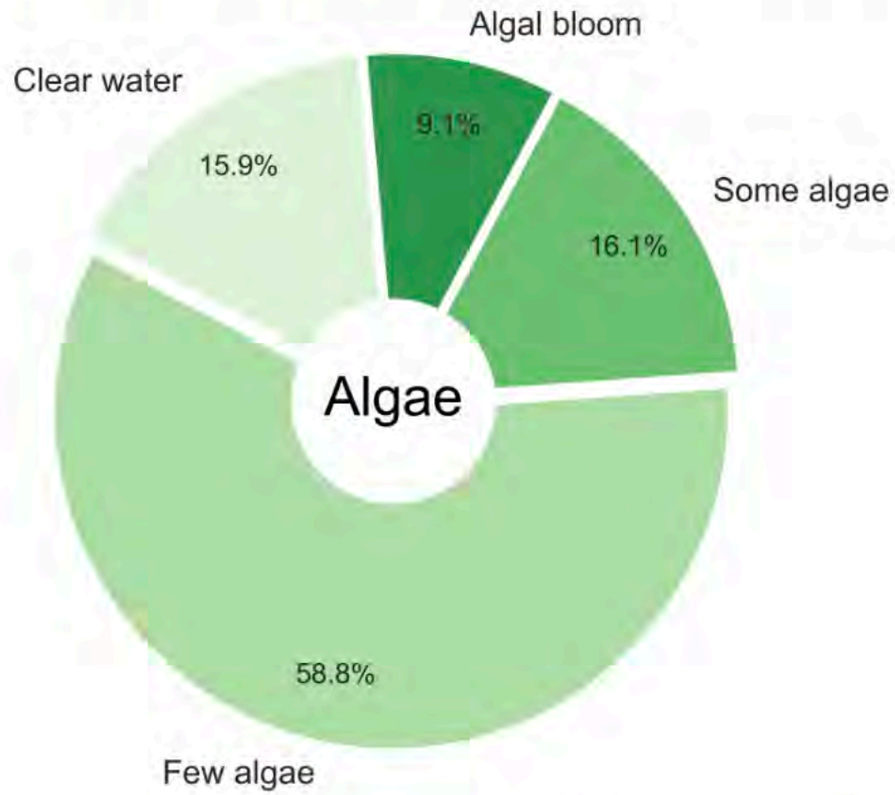
We are ready! big data, algorithms, blog

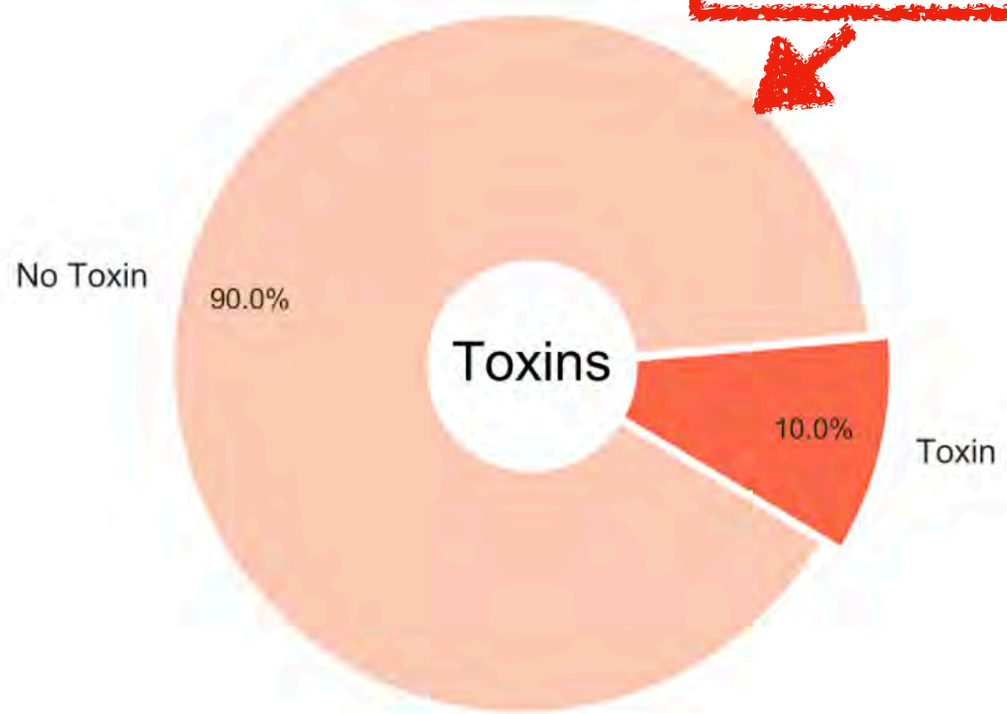


We are ready! big data, algorithms, blog

Bloom Forecast May 13 - May 20

Our models suggest that algae will remain abundant, and that toxins may occur.





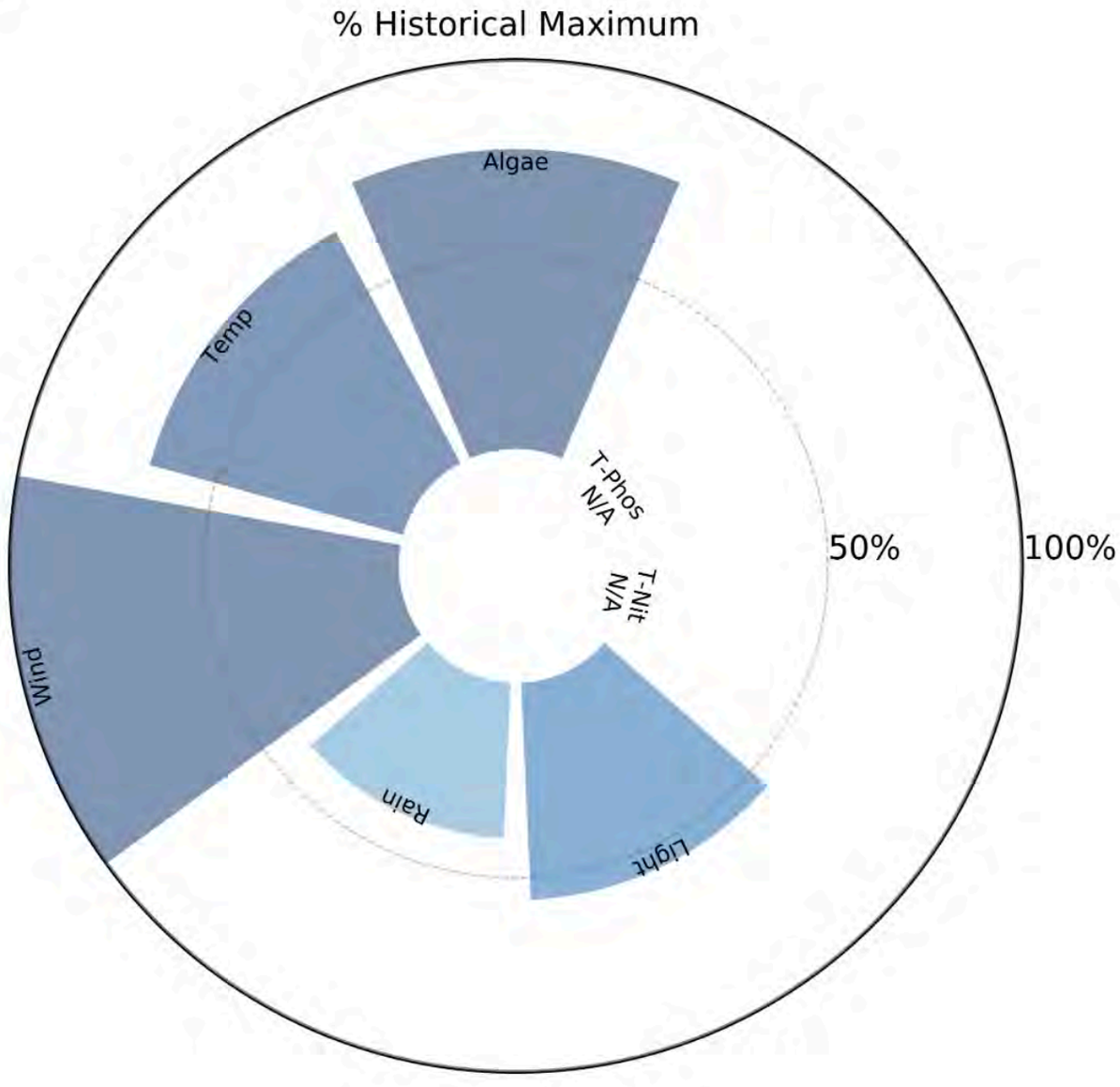
Still highly experimental

Probability of occurance (%) of different algal concentrations (left) and whether a toxin will be present in the water (right) in the next week (note that the toxin predictions are still highly experimental).

We are ready! big data, algorithms, blog

Latest lake conditions

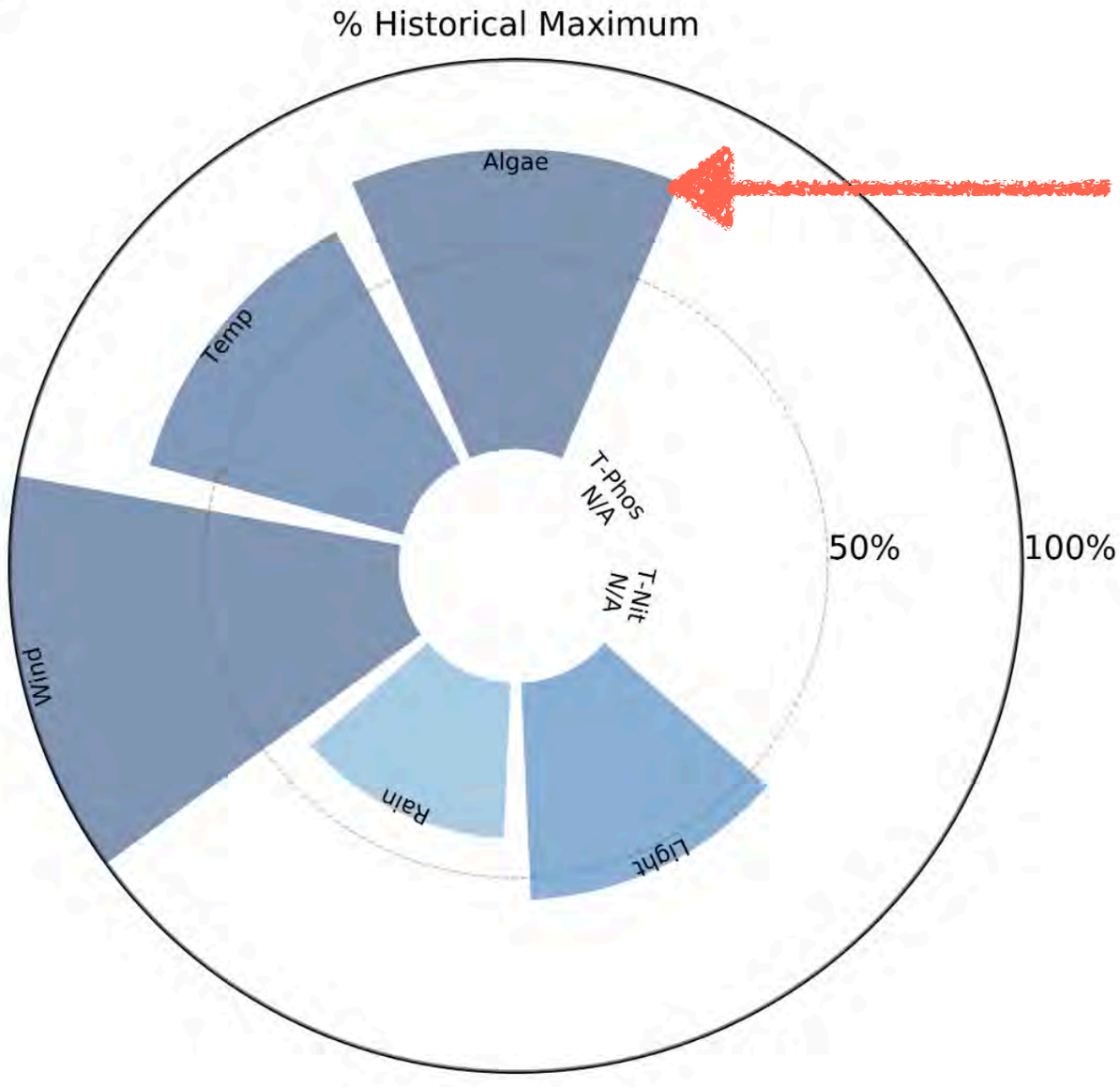
Water samples from the lake were analyzed last week for nutrients and algal concentrations. In addition, information on the weather was collected. These data are presented below as a percentage of their historical maximum.



We are ready! big data, algorithms, blog

Latest lake conditions

Water samples from the lake were analyzed last week for nutrients and algal concentrations. In addition, information on the weather was collected. These data are presented below as a percentage of their historical maximum.

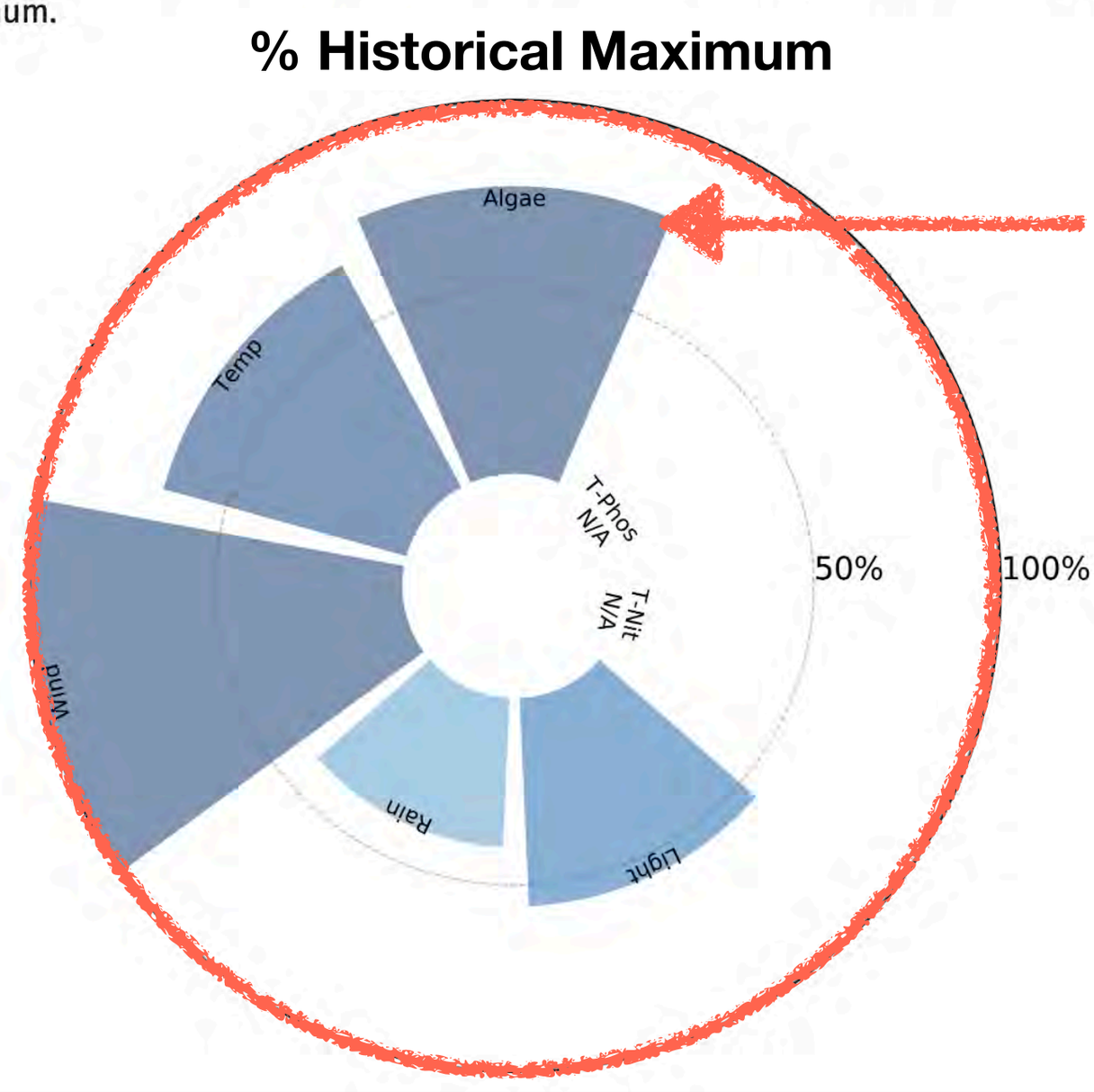


Are algae present?

We are ready! big data, algorithms, blog

Latest lake conditions

Water samples from the lake were analyzed last week for nutrients and algal concentrations. In addition, information on the weather was collected. These data are presented below as a percentage of their historical maximum.

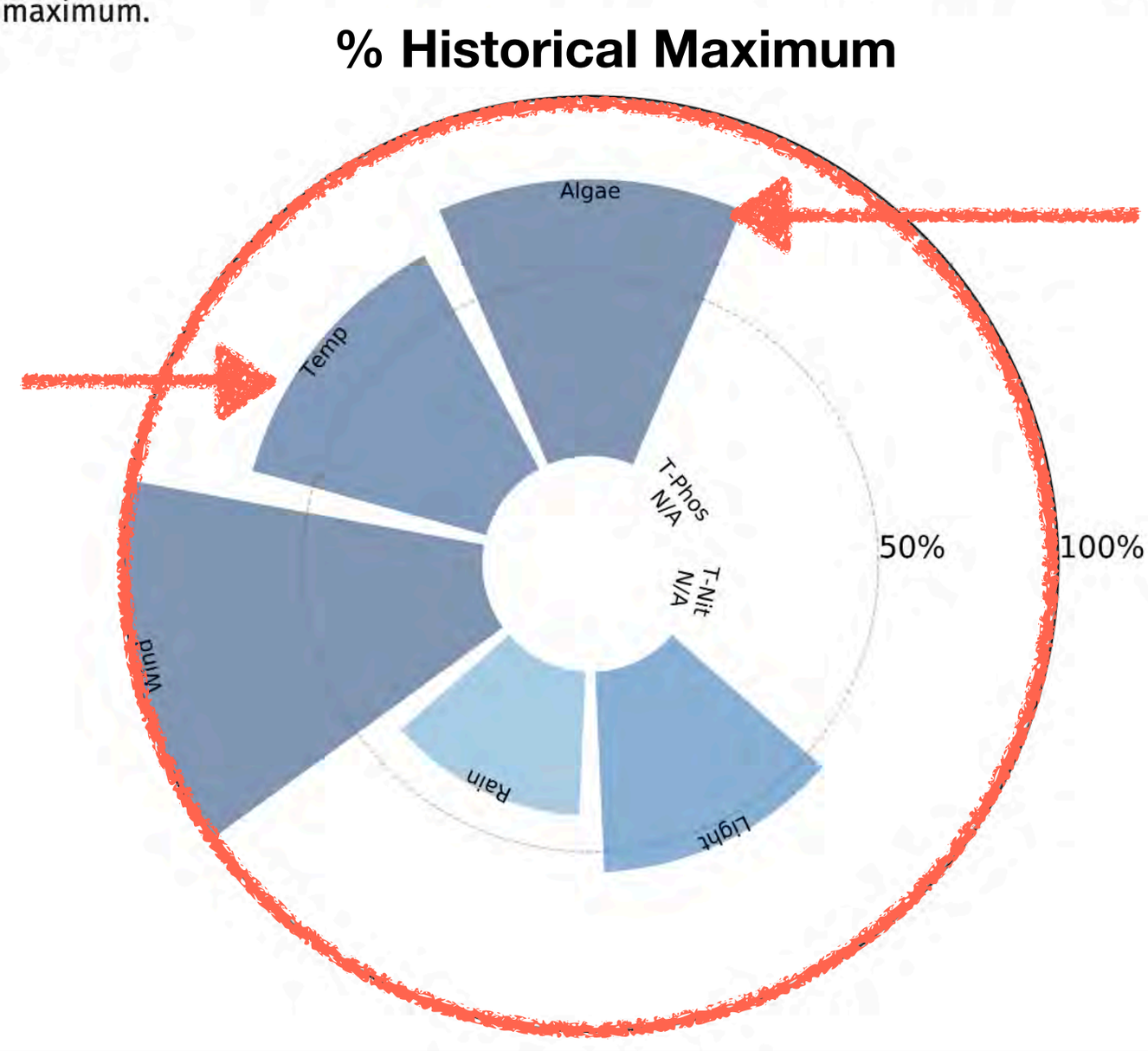


Are algae present?

We are ready! big data, algorithms, blog

Latest lake conditions

Water samples from the lake were analyzed last week for nutrients and algal concentrations. In addition, information on the weather was collected. These data are presented below as a percentage of their historical maximum.



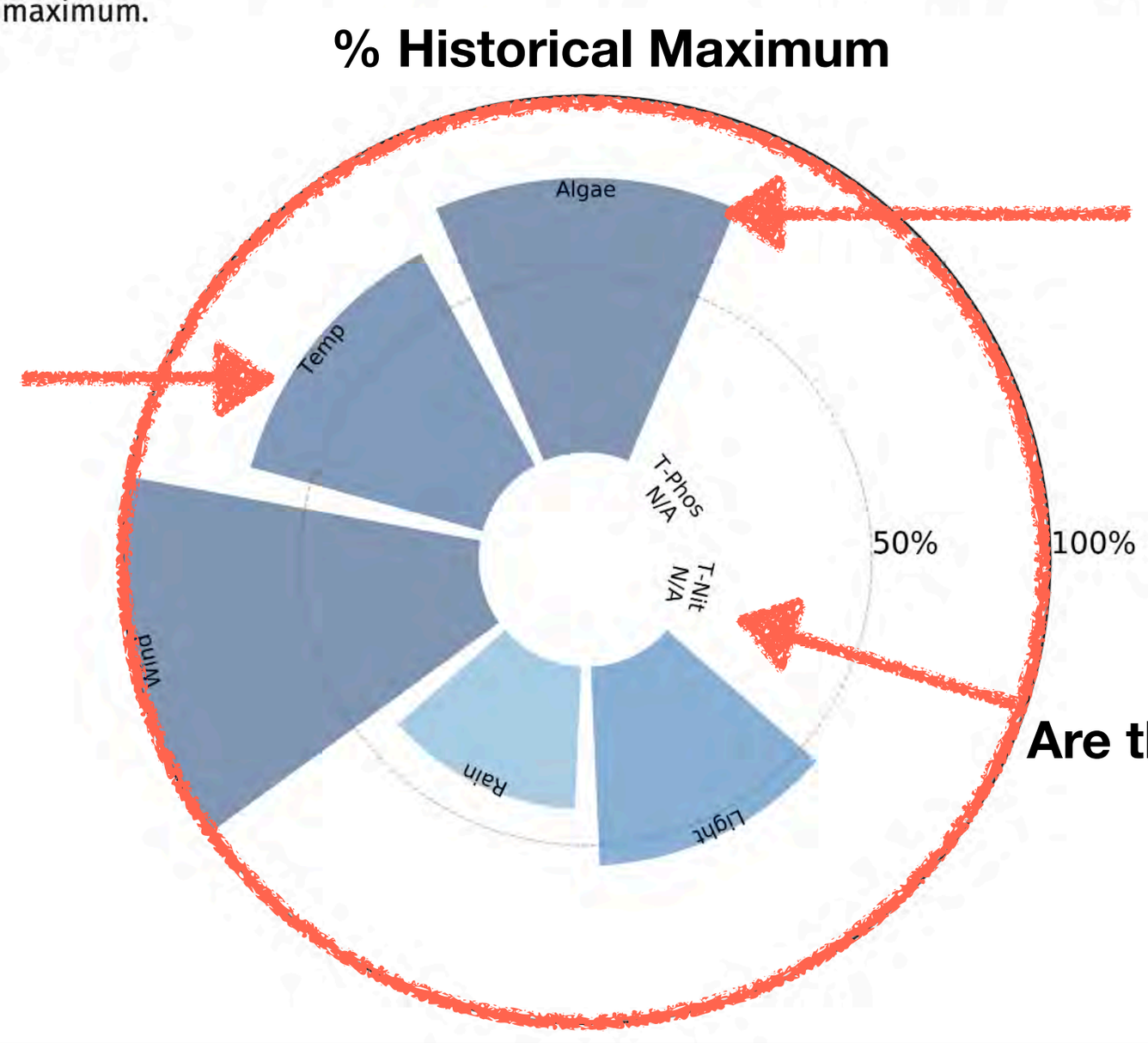
Are algae present?

Is it hot?

We are ready! big data, algorithms, blog

Latest lake conditions

Water samples from the lake were analyzed last week for nutrients and algal concentrations. In addition, information on the weather was collected. These data are presented below as a percentage of their historical maximum.



We are ready! big data, algorithms, blog

Home

Who we are

– Data

Predicting

Looking at 2018

Next Steps

Forecast archive

Email

GitHub

The Prediction Lab & The City of Salem

Detroit Lake Pre

An initiative to care for our water source

Bloom Forecast Mar 15-22

Our models suggest that in the next week lake conditions will most like

The future

The future

- Phase 1: review state of the art

The future

- Phase 1: review state of the art
- Phase 2: make predictions with data in hand

The future

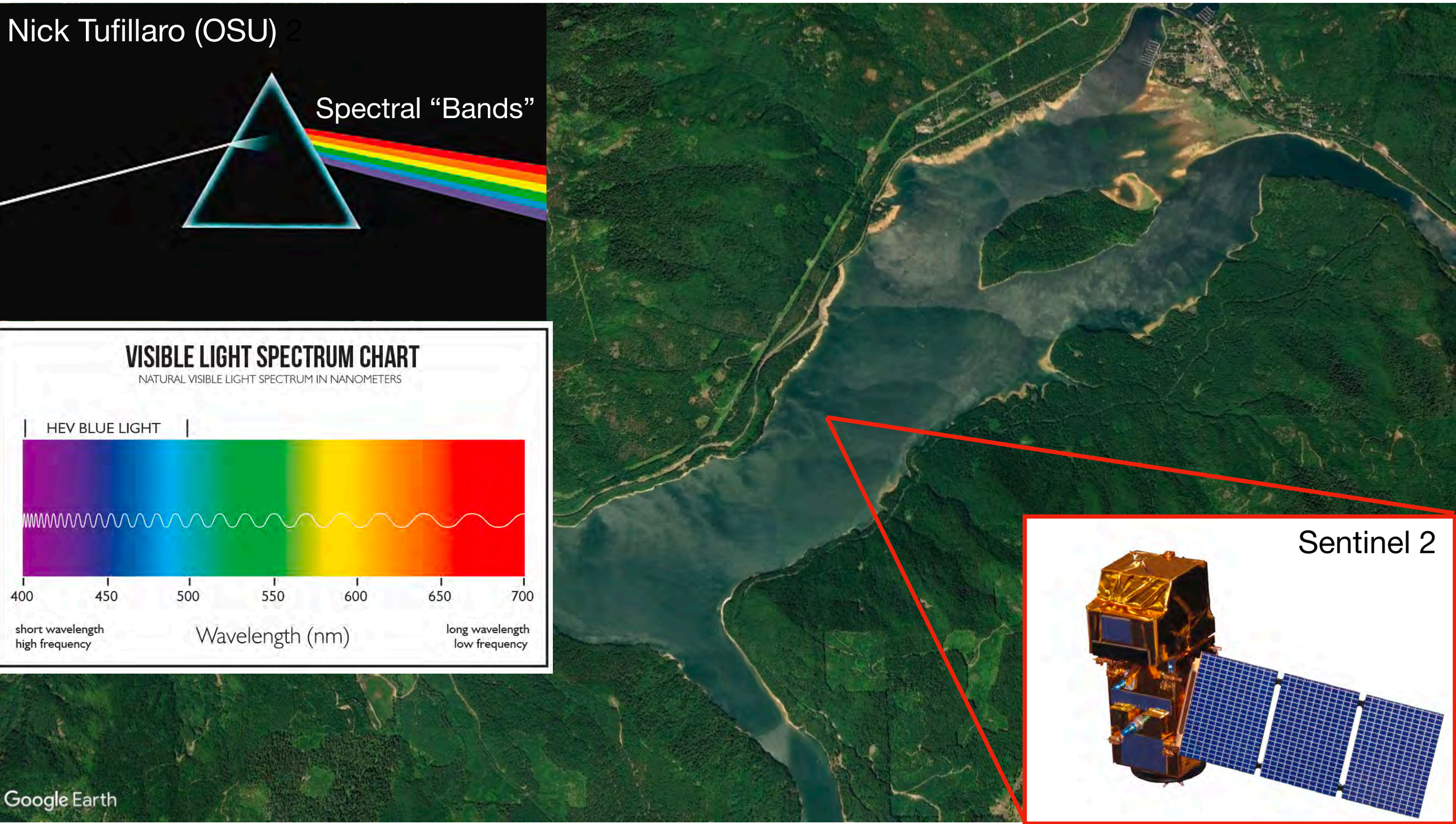
- Phase 1: review state of the art
- Phase 2: make predictions with data in hand
- Phase 3:
  - Maintain prediction system (our algorithms will continue to learn and improve)
  - Create new (vital) data streams
  - Create new machine learning models
  - Enhance geovizualization
  - Near real-time predictions

The future: satellite data

The future: satellite data

The future: satellite data

Nick Tufillaro (OSU) 2

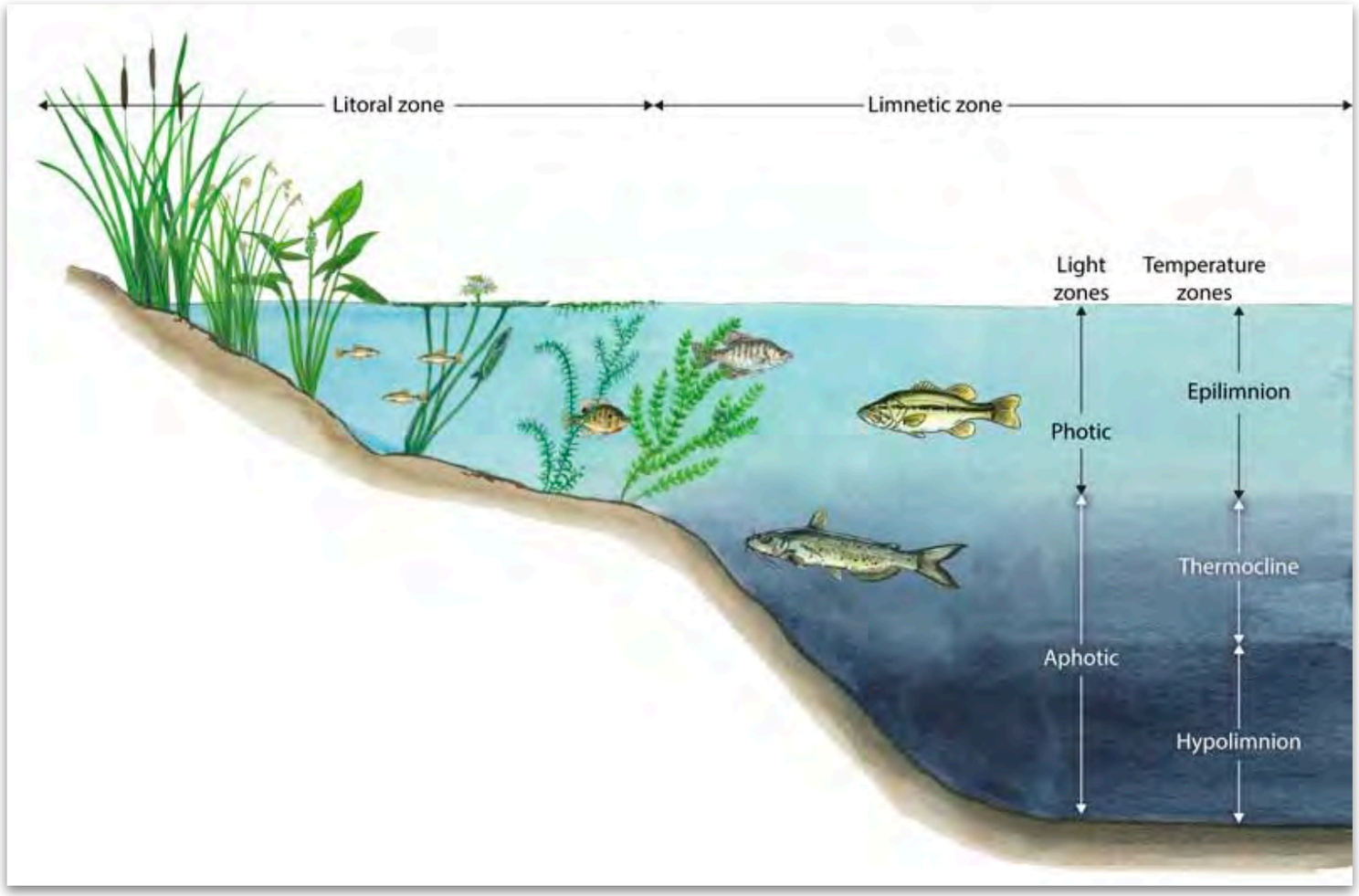


The future: continuous recorder

- Satellite data only scratch the surface…

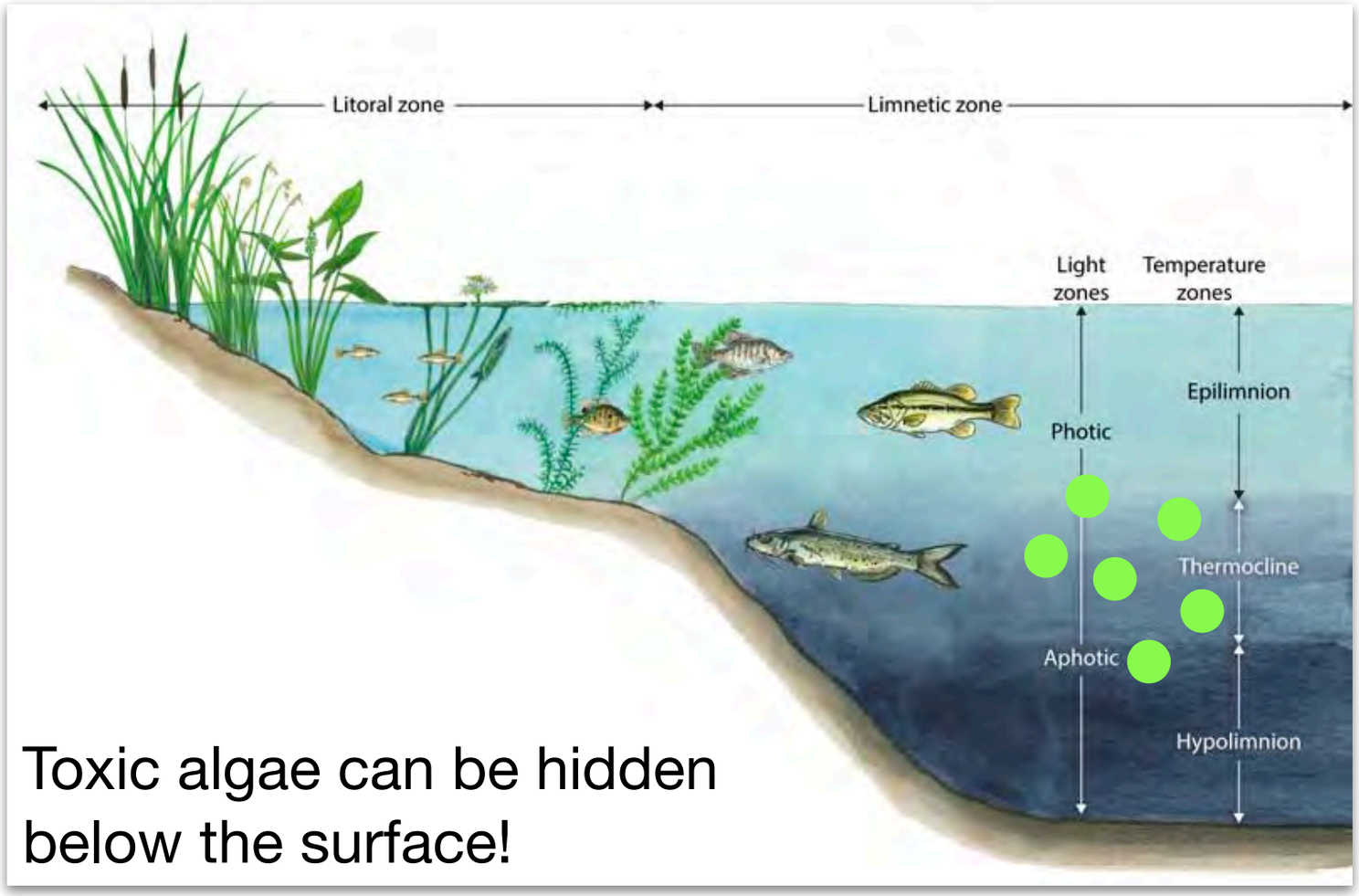
The future: continuous recorder

- Satellite data only scratch the surface…



The future: continuous recorder

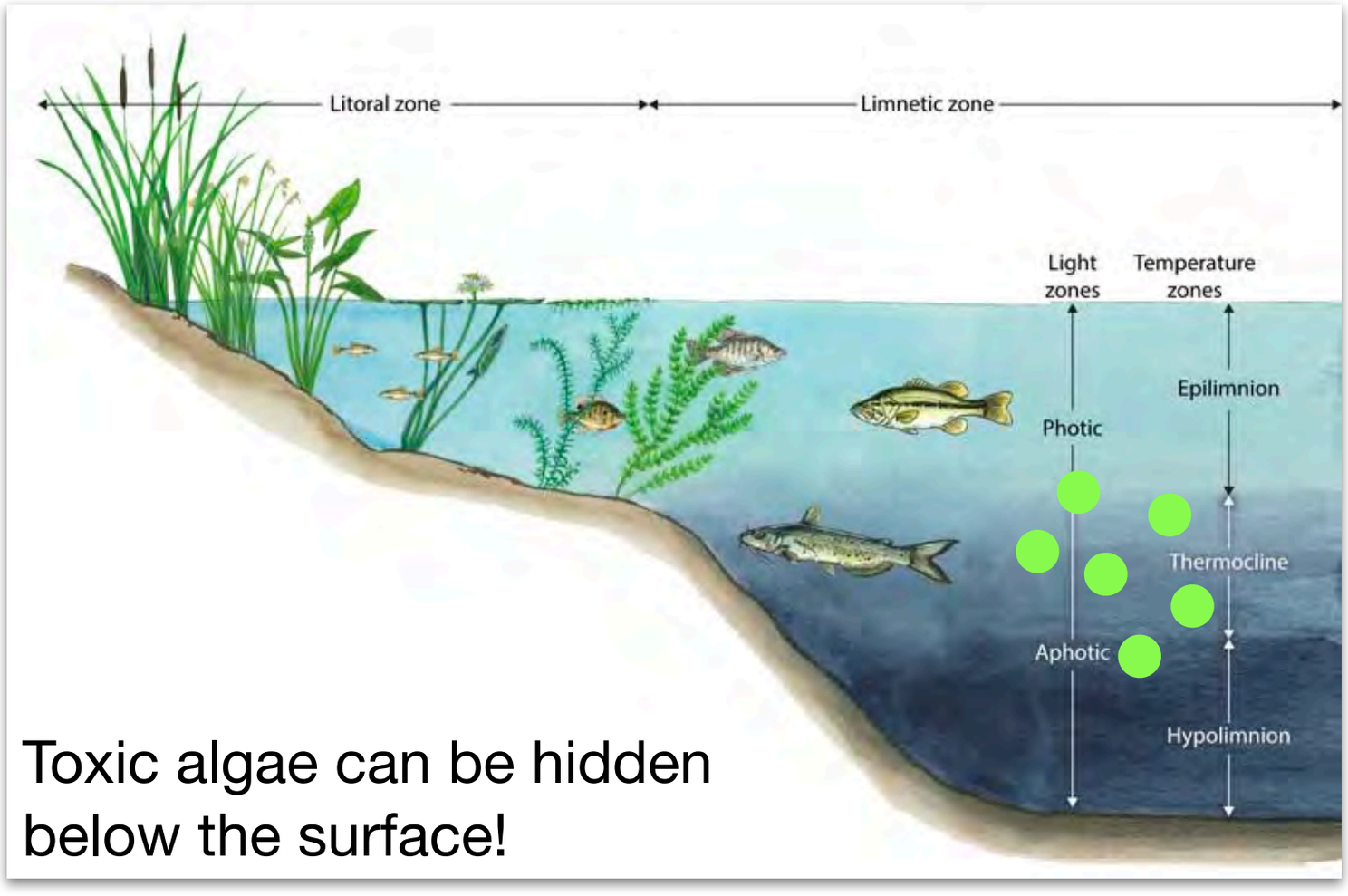
- Satellite data only scratch the surface…



Toxic algae can be hidden below the surface!

The future: continuous recorder

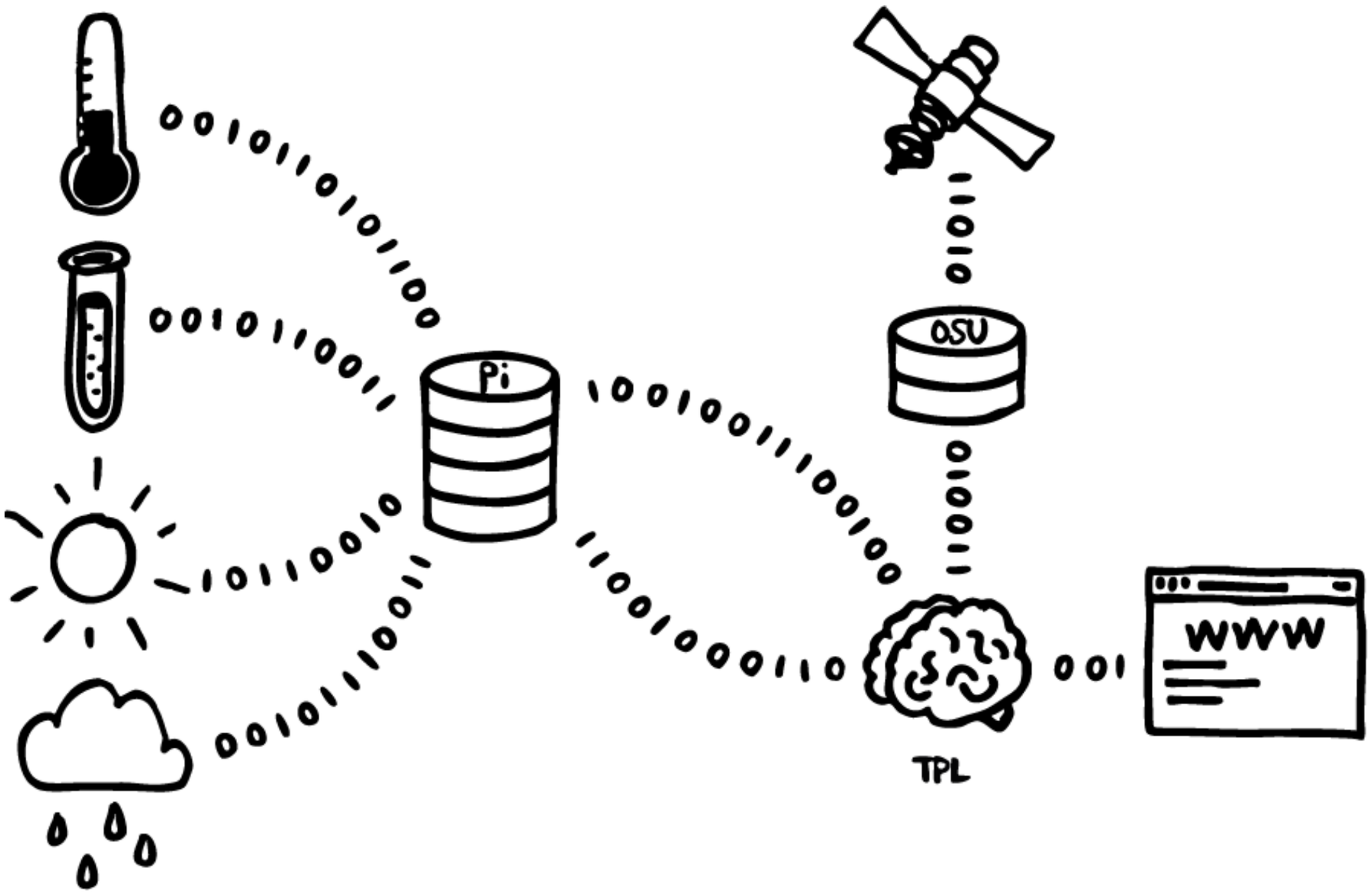
- Satellite data only scratch the surface…



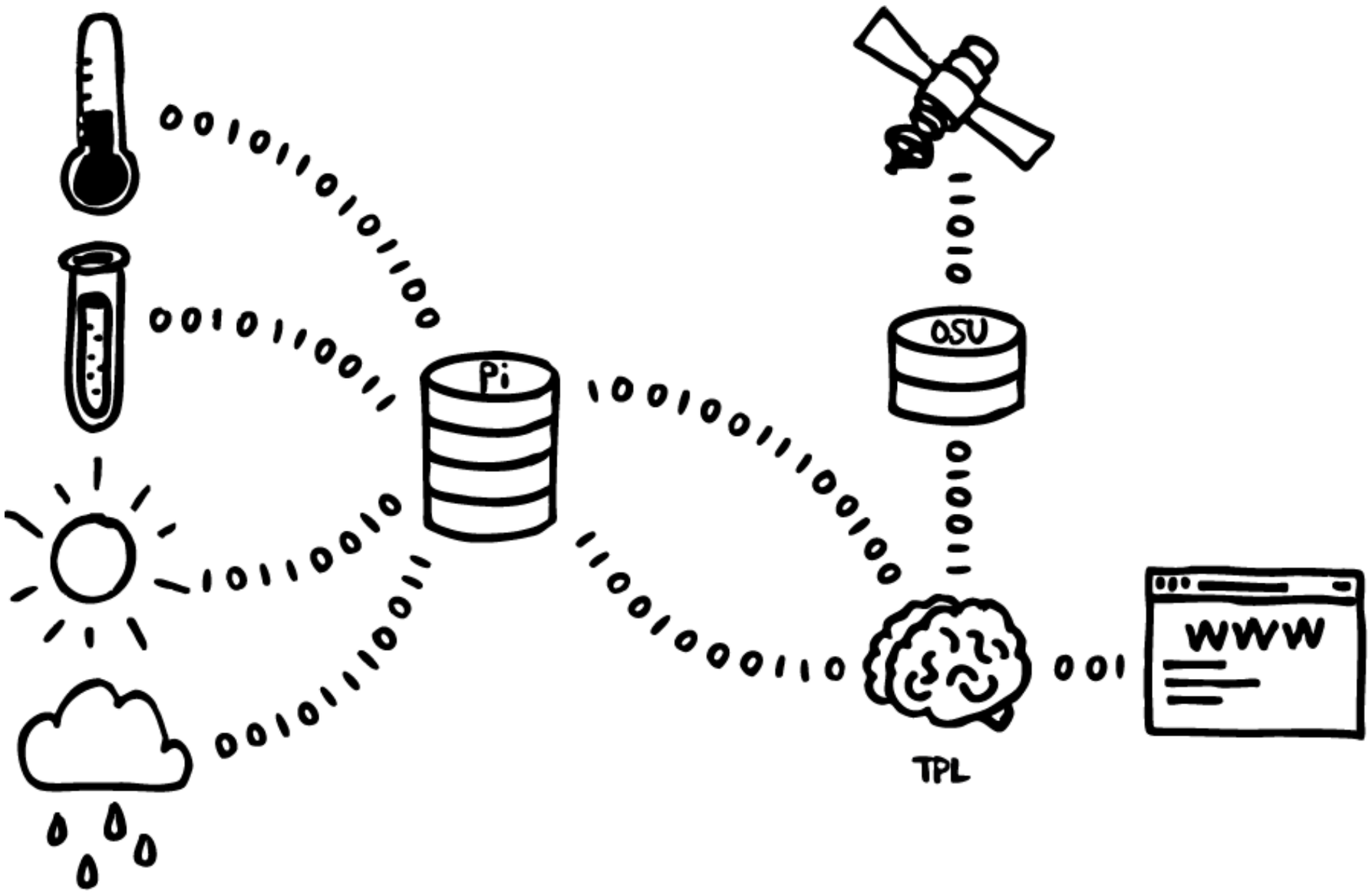
Toxic algae can be hidden below the surface!

YSI vertical profiler collects information at all depths

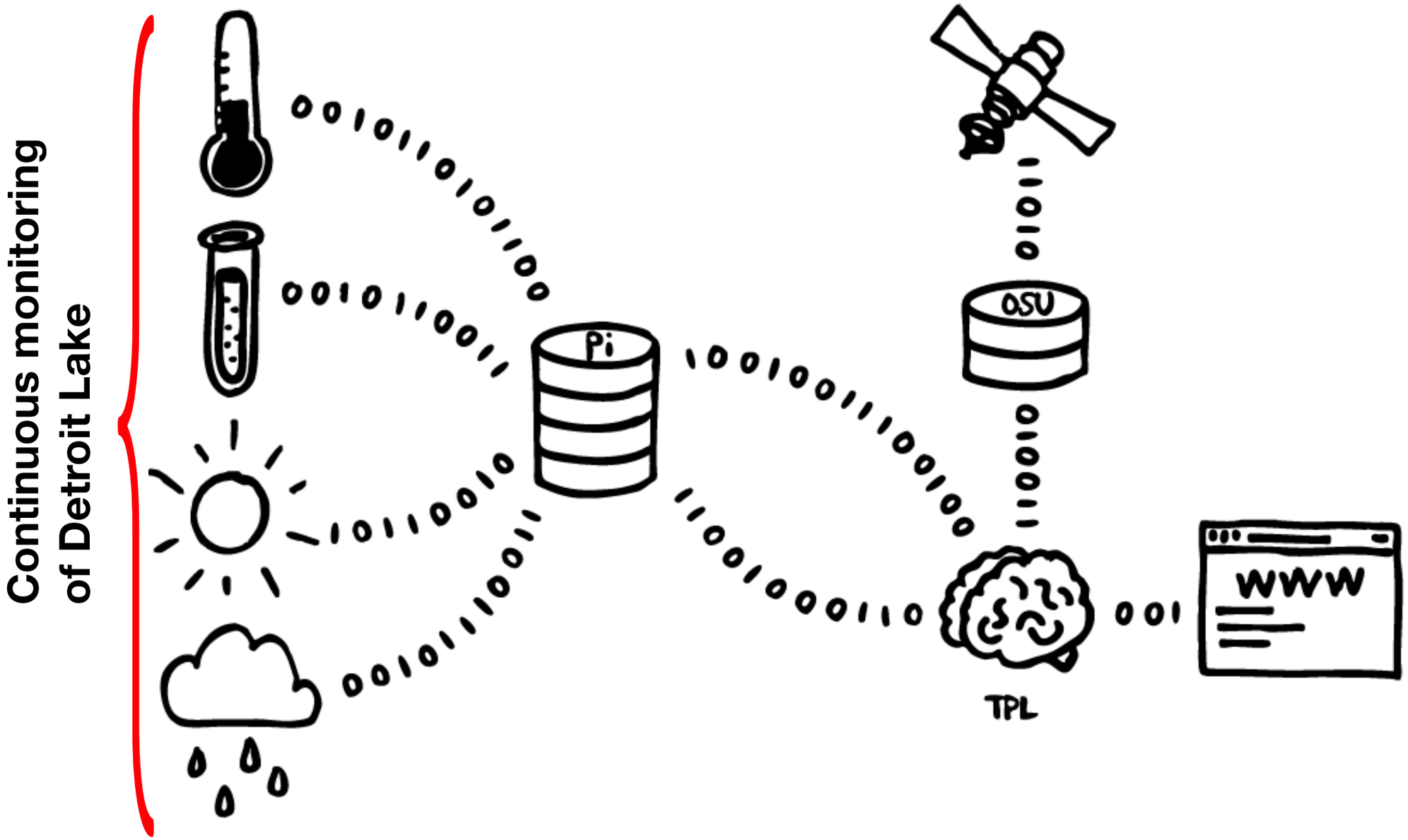
The next step: real-time predictions



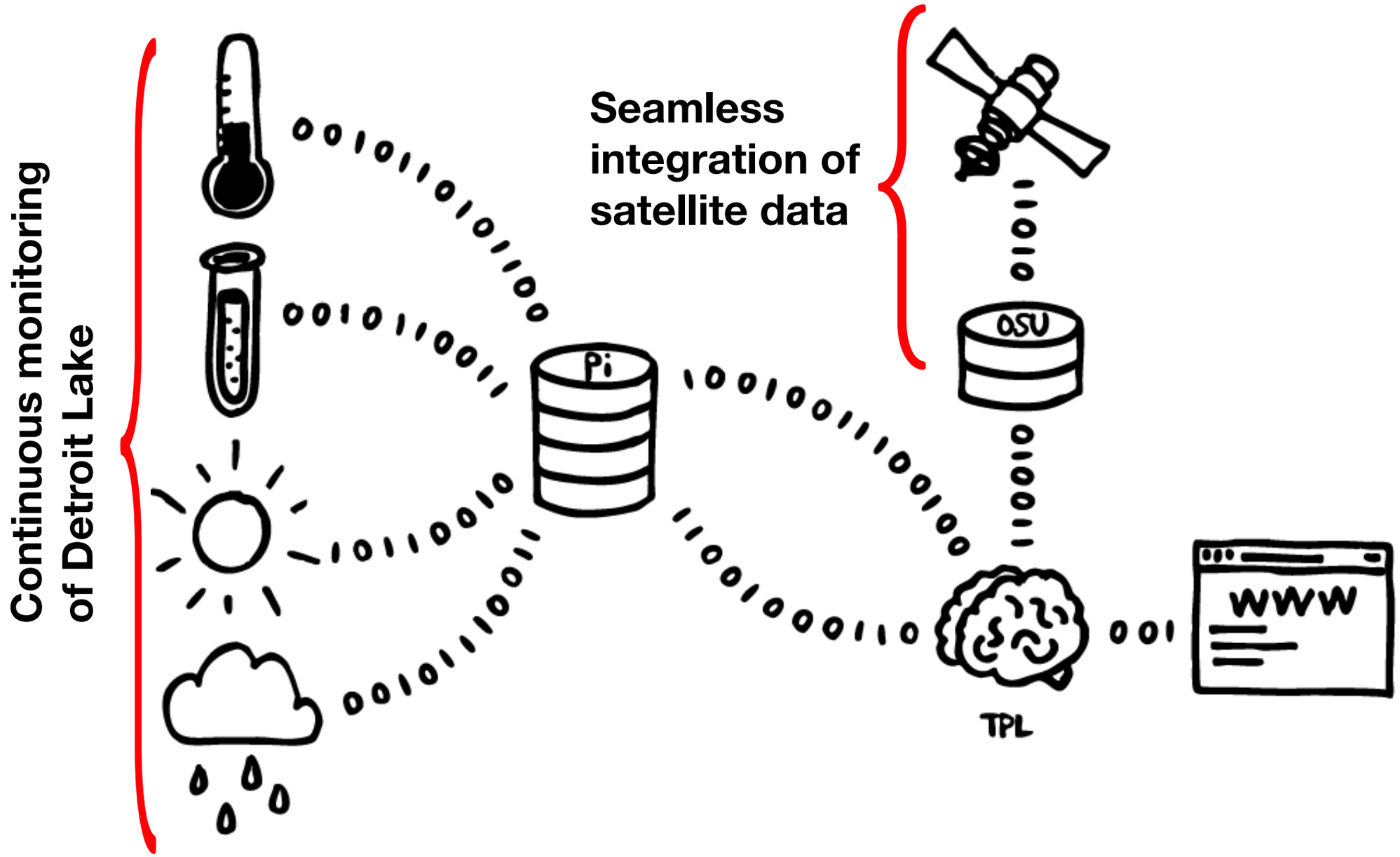
The next step: real-time predictions



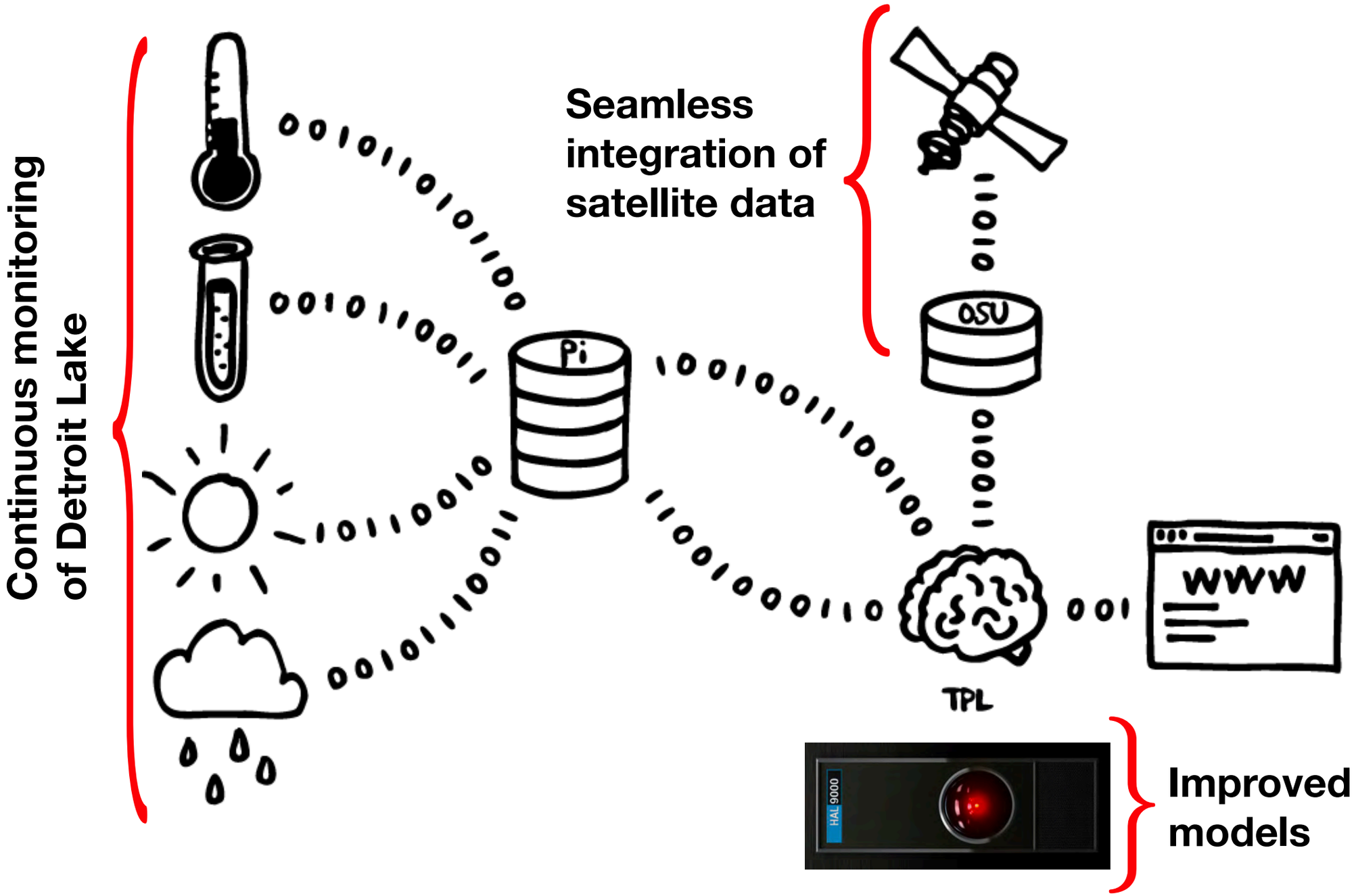
The next step: real-time predictions



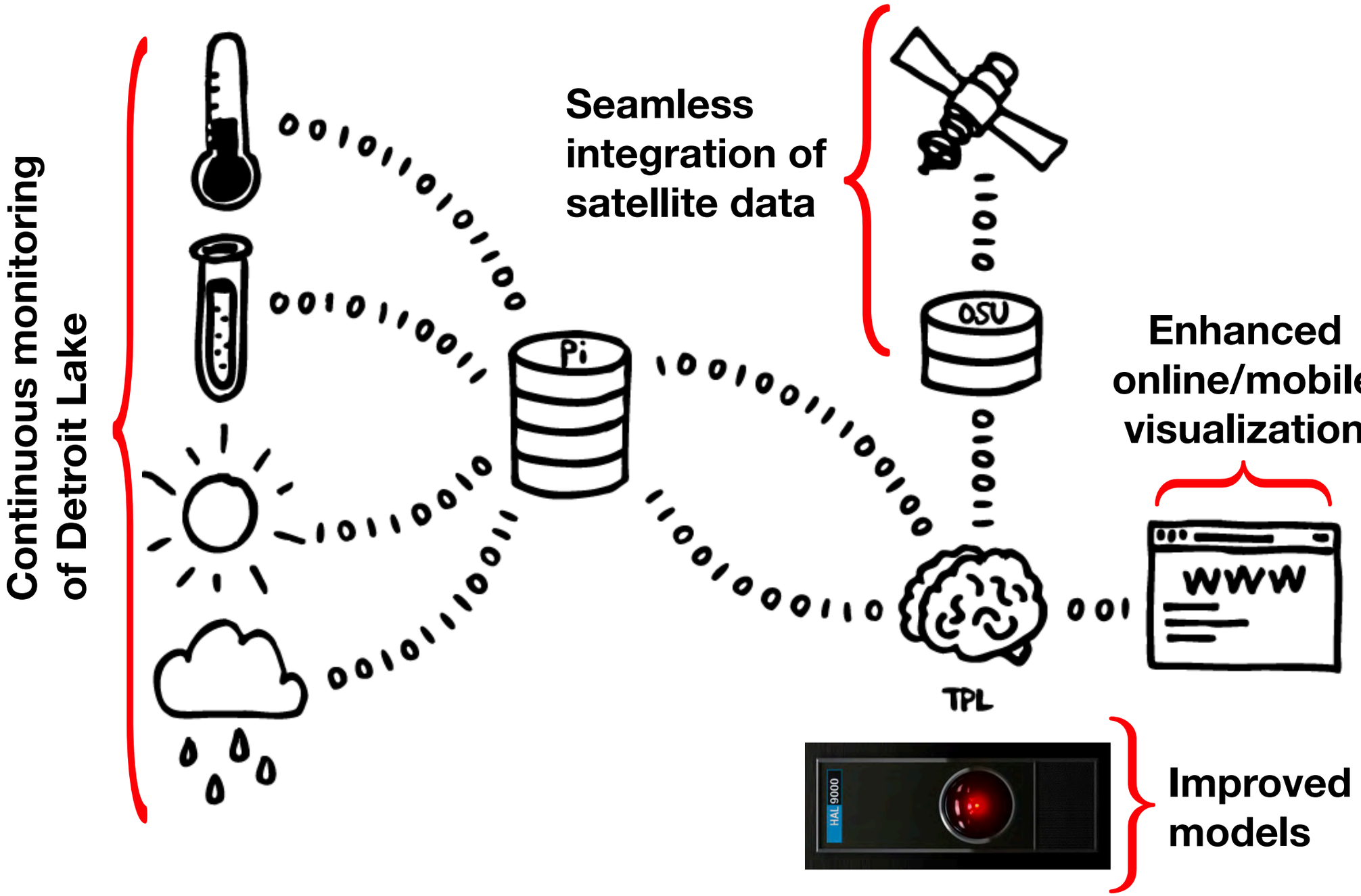
The next step: real-time predictions



The next step: real-time predictions



The next step: real-time predictions



Phase 3+ : other water systems

Photo: Brandin Hilbrandt, Detroit Lake, 03/19

THE END

James Watson, Mat Titus

email: info@thepredictionlab.com

web: www.thepredictionlab.com

HAB blog: https://thepredictionlabllc.github.io/detroit-lake-predictions/

Oregon State University

CITY OF Salem AT YOUR SERVICE

Public Works Department

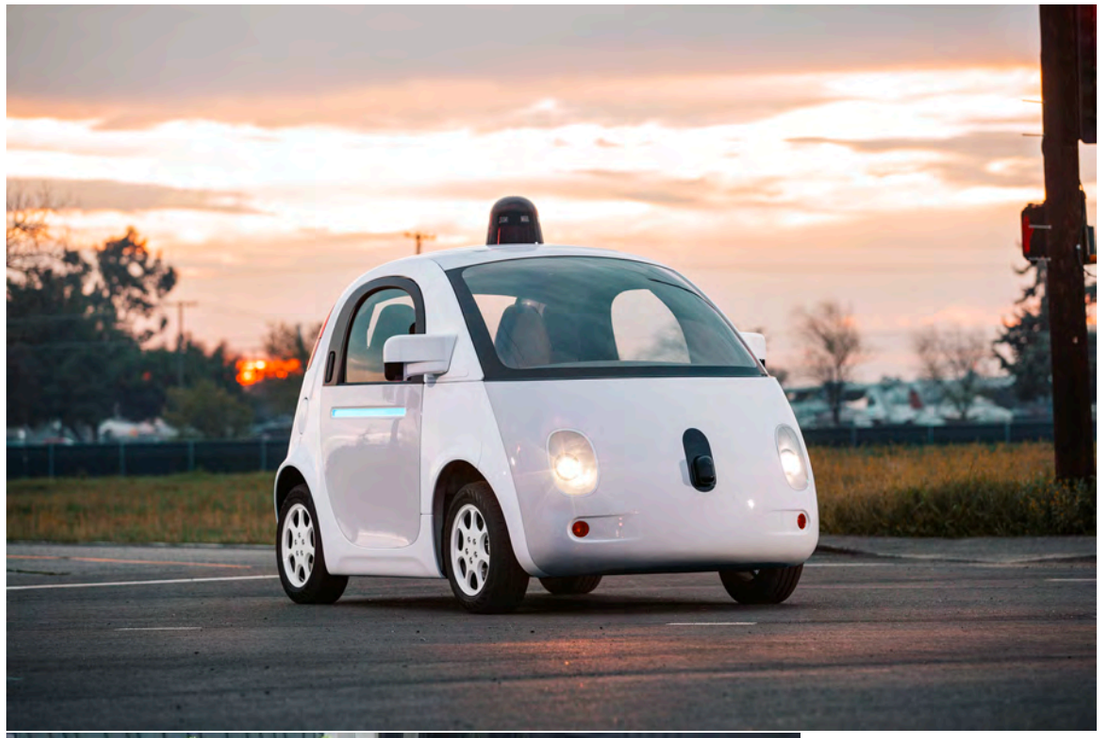
THE PREDICTION LAB

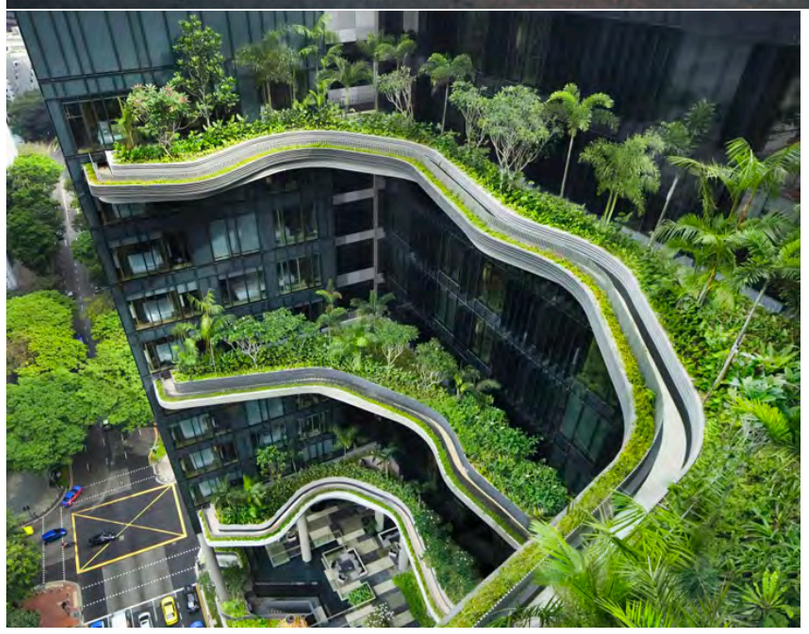
Last thoughts: an amazing future

Last thoughts: an amazing future

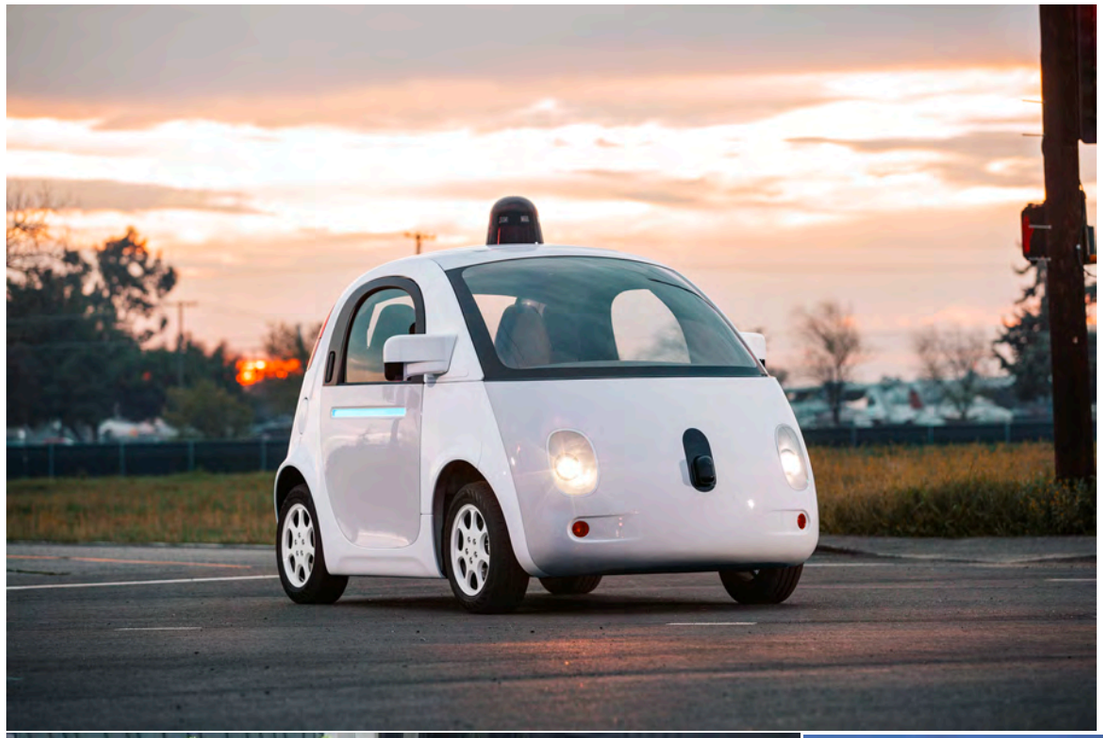
Last thoughts: an amazing future

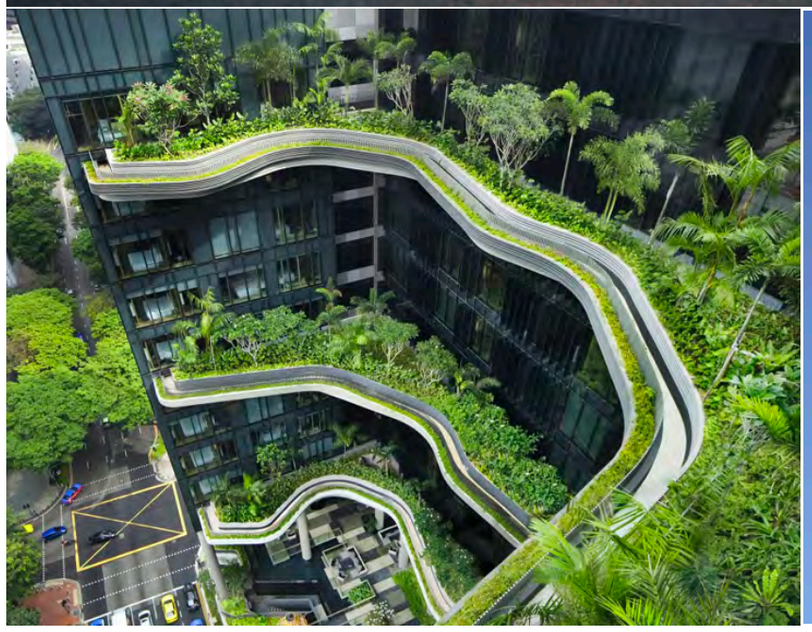
Last thoughts: an amazing future

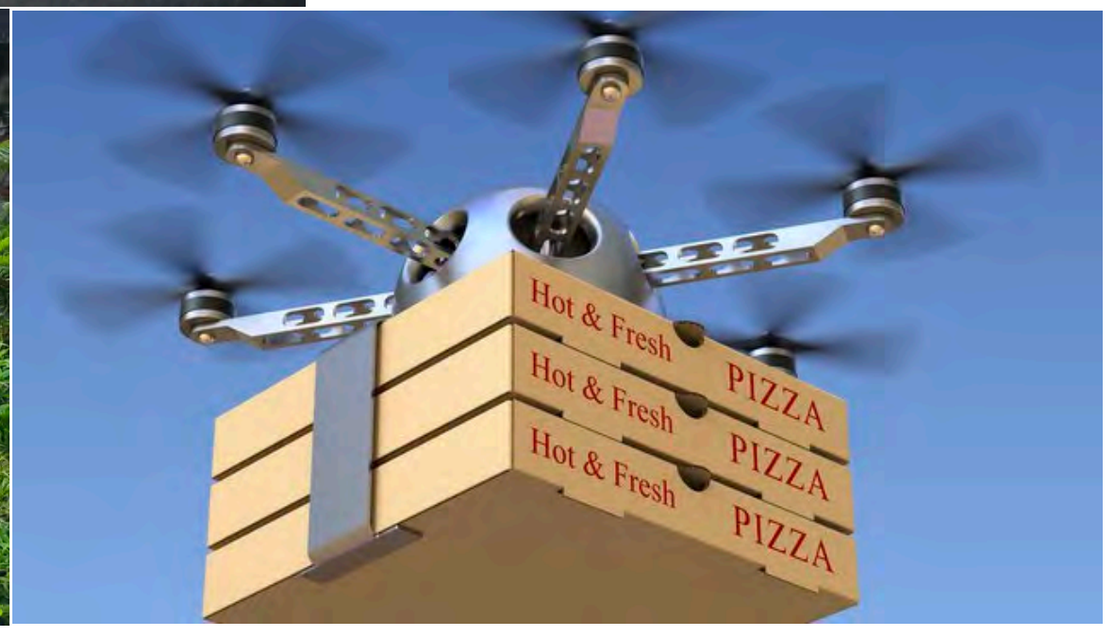




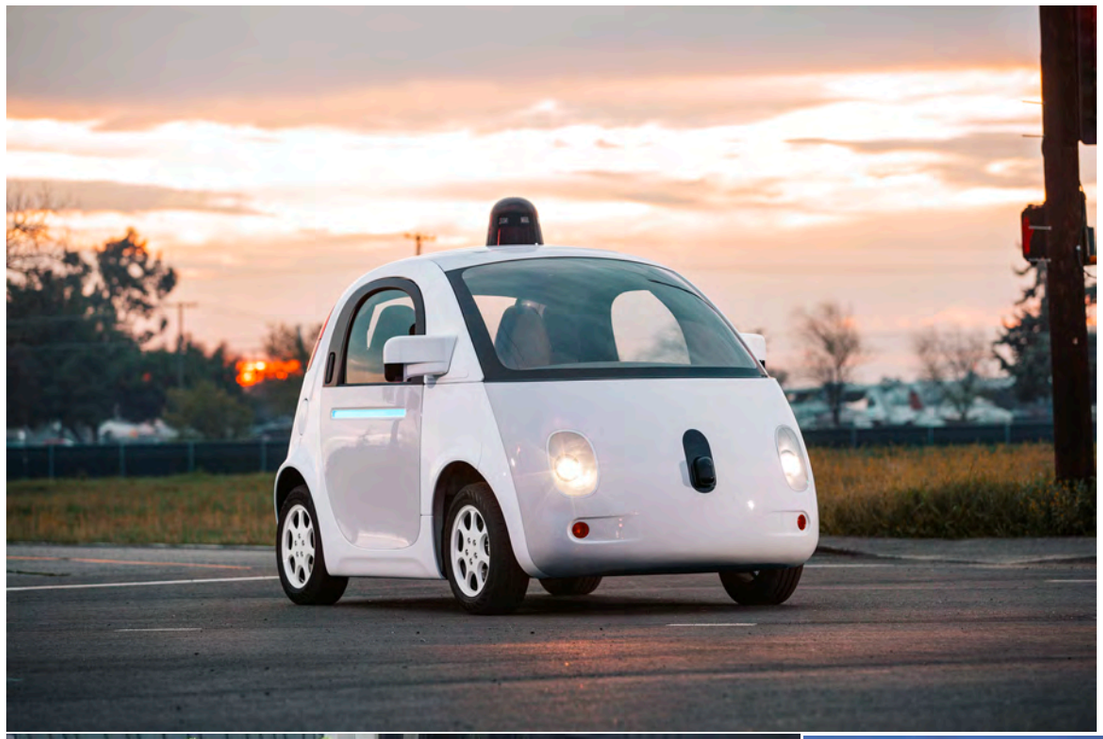
Last thoughts: an amazing future





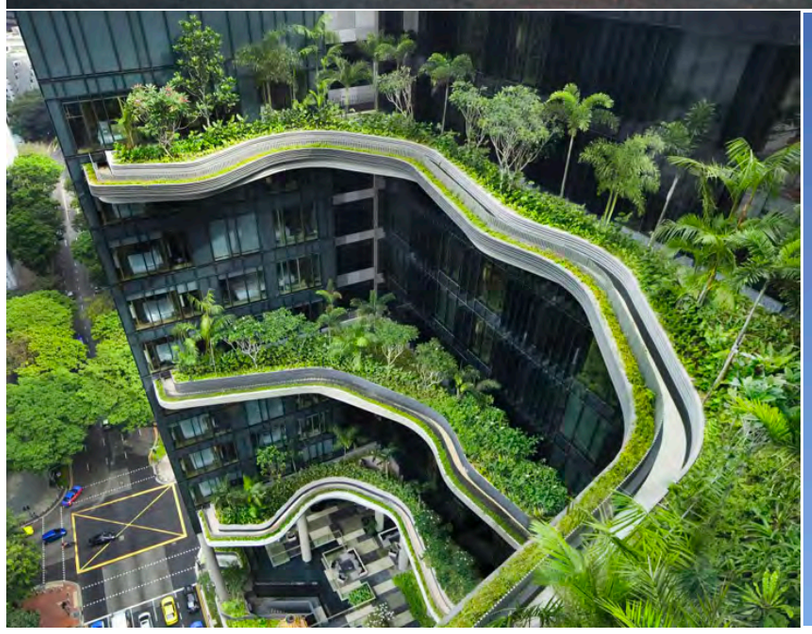


Last thoughts: an amazing future

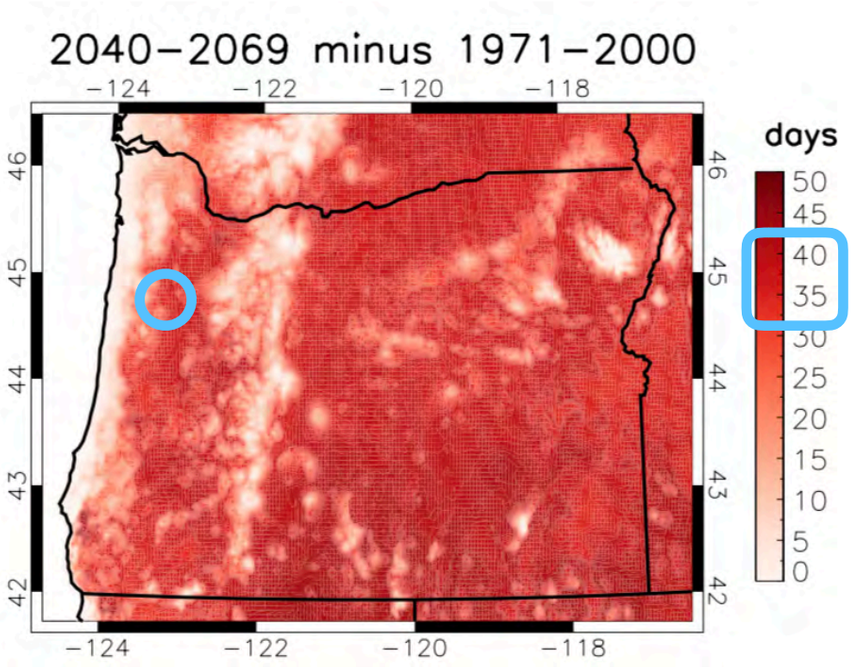


The future is now (these photos are all real)

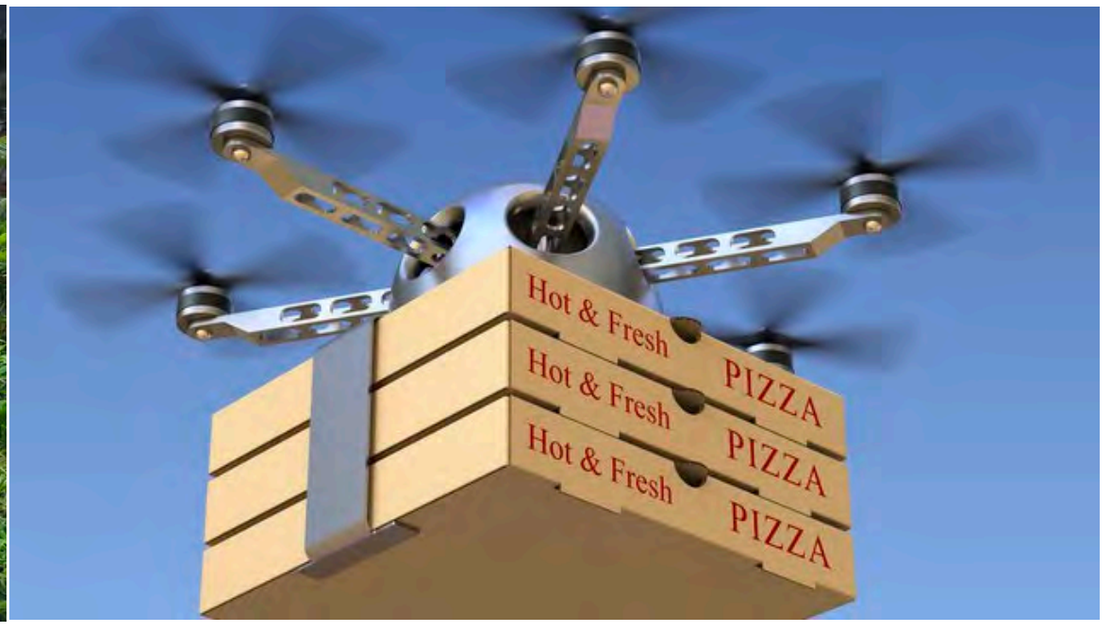
There are amazing new services



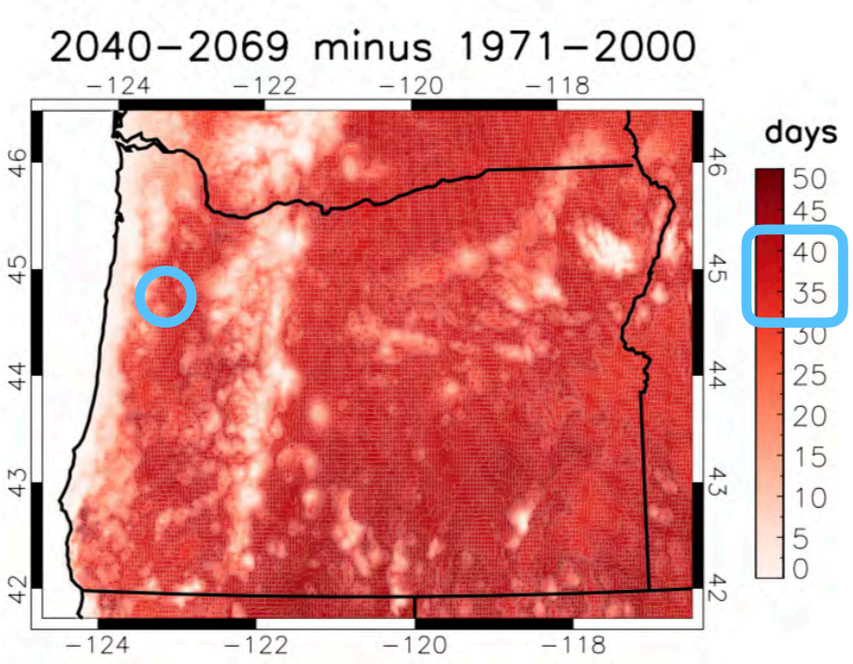
Last thoughts: an amazing future



Can we maintain essential services like clean water?



Last thoughts: an amazing future



Can we maintain essential services like clean water?

Yes: with big data and brilliant algorithms

Photo: Brandin Hilbrandt, Detroit Lake two weeks ago

Adaptability and Potential

- Next-gen data
  - YSI profiler
  - Satellite hyperspectral imagery
  - In-house assays

- Next-gen tools
  - Dimension Reduction Techniques
  - Bayesian Neural Networks
  - Convolutional Neural Networks
  - Variational Autoencoders